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COVER IMAGE

A painting by Aboriginal artist Wendy Jackamarra representing Aboriginal Elders and radio astronomers sharing sky stories by a campfire. See the paper by John Goldsmith on pages 205–215 in this issue of the journal.

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EDITORIALS

The study of Australian ethnoastronomy (commonly called 'Indigenous astronomy') has experienced a surge of interest in recent years as researchers focus on exploring the astronomical knowledge and traditions of Aboriginal and Torres Strait Islander cultures. This focus resulted in a significant number of refereed papers that have appeared in the literature (particularly in this journal), as well as postgraduate theses and educational programs. The *Journal of Astronomical History and Heritage* (*JAHH*) has been a major outlet for research on indigenous astronomy since 2009, with the publication of five papers on Aboriginal Australian astronomy, six papers on indigenous astronomy in India, and one paper on Maori astronomy in New Zealand.

The first conference dedicated to Australian Indigenous astronomy was held at the Australian Institute for Aboriginal and Torres Strait Islander Studies (AIATSIS) in Canberra on 27 November 2009. The meeting featured astronomically-themed artworks from Yamatji artists near Geraldton, Western Australia, as part of the bid to build the Square Kilometer Array (a large array of radio telescopes) on the traditional lands of the Yamatji people. This meeting, titled "*Ilgaridjiri: Things Belonging to the Sky*", brought together Aboriginal Elders, academics, educators and researchers to share their work and knowledge of Indigenous Australian astronomy. This set a precedent for hosting annual events and meetings on Indigenous astronomy. One of the featured speakers at the AIATSIS meeting was Dr Dianne Johnson, who spoke about various Aboriginal traditions of the Pleiades. She is well known for her book *Night Skies of Aboriginal Australia: A Noctuary* (Sydney University Press, 1998), which was the first comprehensive book to be published on Australian Indigenous astronomy. Sadly, Dr Johnson passed away in 2012, but her influence in the field of Australian Indigenous astronomy remains strong.

However, it was not until the Australian Space Sciences Society hosted their 2012 annual meeting in Melbourne that researchers and Elders were again brought together to discuss Indigenous astronomy. In 2013, the Society held its annual meeting at the University of New South Wales, which coincided with the inaugural meeting of the Australian Society for Indigenous Astronomy, held at the University's Nura Gili Indigenous Centre. The ASSC session, Chaired by Alice Gorman and myself, included a number of quality presentations on Indigenous sky knowledge. Dharawal Elder, Les Bursill, opened the session and speakers included Hugh Cairns, Robert Fuller, Trevor Leaman, Ragbir Bhathal, David Pross, Geoffrey Wyatt, Alice Gorman and myself. John Goldsmith also gave a plenary talk on his work with Aboriginal communities in Western Australia. His paper won the award for Best Student Presentation and it appears in this issue of *JAHH*.

The conference organisers, Wayne Short and Iver Cairns, kindly granted me permission to invite the speakers to submit their papers for inclusion in this special conference issue of *JAHH*. This resulted in a number of high quality submissions on various aspects of Australian Indigenous astronomy, including more recent submissions. I would like to thank Professor Wayne Orchiston, the Editor of *JAHH*, for dedicating this issue to Australian Indigenous astronomy and for giving me the opportunity to develop my editorial skills by taking charge of the ethnoastronomy papers in this issue. The experience has been positive and I hope to continue this relationship in the future.

Dr Duane Hamacher, *Guest Editor*

I am grateful to Duane Hamacher for overseeing the preparation of the papers on Indigenous Australian astronomy that appear in this issue of *JAHH*. Duane faced the challenge of getting all the submitted papers refereed, and then editing those accepted for publication.

Over the past year or so the size of each issue of *JAHH* has increased from the original 88-90 pages (when we mailed out hard copies and postage limited the size) to between 110 and 140 pages. When it came time for me to format the papers Duane supplied and assemble the July-August issue of *JAHH* I quickly discovered we had room for additional papers, so I have selected two that were to appear in the November-December issue. Whilst neither relates to Australia, each is on archaeoastronomy, which means we are able to devote this entire issue to ethnoastronomy and archaeoastronomy.

Professor Wayne Orchiston, *Editor*

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SONGLINES AND NAVIGATION IN WARDAMAN AND OTHER AUSTRALIAN ABORIGINAL CULTURES

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Abstract: We discuss the songlines and navigation of the Wardaman people, and place them in context by comparing them with corresponding practices in other Aboriginal Australian language groups, using previously-unpublished information and also information drawn from the literature. Songlines are effectively oral maps of the landscape, enabling the transmission of oral navigational skills in cultures that do not have a written language. In many cases, songlines on the Earth are mirrored by songlines in the sky, enabling the sky to be used as a navigational tool, both by using it as a compass and by using it as a mnemonic.

Notice to Aboriginal and Torres Strait Islander Readers: This paper contains the names of people who have passed away.

Keywords: ethnoastronomy, cultural astronomy, Aboriginal Australians, navigation, songlines.

1 INTRODUCTION

1.1 Aboriginal Australian Astronomy

It is now well established that many traditional Aboriginal cultures incorporate significant references to the sky and to astronomical phenomena (e.g. Cairns and Harney, 2004; Fuller et al., 2014a; Haynes, 1992; Johnson, 1998; Mountford, 1956, 1976; Norris and Hamacher, 2009, 2011; Norris and Norris, 2009; Stanbridge, 1857, 1861). For example, many different Aboriginal cultures across Australia refer to the 'Emu in the Sky' (Cairns and Harney, 2004; Fuller et al., 2014b; Massola, 1963; Norris and Norris, 2009), formed from the arrangement of dark clouds within the Milky Way. Equally important in many Aboriginal cultures across Australia are the Orion constellation, which usually symbolises a young man or group of young men, and the Pleiades (Seven Sisters) cluster, which usually symbolises a group of girls pursued by Orion. Star stories can also encapsulate ceremony, law and culture for transmission to the next generation (Harney and Norris, 2009).

This traditional knowledge extends well beyond mere symbolism, and many Aboriginal cultures contain evidence of a detailed understanding of the sky. For example, within traditional songs can be found explanations of tides, eclipses and the motion of the celestial bodies (Hamacher and Norris, 2012; Norris, 2007; Norris and Norris, 2009). Practical applications of this knowledge include the ability to predict tides, as well as navigation, time keeping and the maintenance of a calendar (Cairns and Harney, 2004; Clarke, 2009).

Evidence for these astronomical traditions is found not only in oral traditions, but also in art and artifacts. Some groups of stone arrangements are aligned to cardinal points with an accuracy attainable only by astronomical measurement (Hamacher et al., 2013). The Wurdi Youang stone ring in Victoria contains alignments to the position of the setting Sun at the equinox and the solstices (Norris et al., 2013). Statistical tests show that these alignments are unlikely to have arisen by chance, and instead the builders of this stone arrangement appear to have deliberately aligned the site to astronomically-significant positions.

Although evidence of astronomical knowledge has been found in many Aboriginal cultures, the best-documented example is undoubtedly that of the Wardaman people, largely because of co-author Harney's enthusiasm to share his traditional knowledge with the wider world. In particular, the book *Dark Sparklers* (Cairns and Harney, 2004: henceforth DS) documents in exquisite detail the astronomical lore of the Wardaman people.

1.2 Directionality

The concept of cardinal directions is common amongst Aboriginal language groups in Australia (Hamacher et al., 2013, and references therein). The Warlpiri people in central Australia are especially prominent in this respect, as much of their culture is based on the four cardinal directions that correspond closely to the four cardinal points (north, south, east and west) of modern western culture (Laughren, 1978, 1992; Nash, 1980, Pawu-Kurlpurlurnu et al., 2008). In

the Warlpiri culture, north corresponds to 'law', south to 'ceremony', west to 'language' and east to 'skin'. 'Country' lies at the intersection of these directions, at the centre of the compass—i.e. 'here' (Pawu-Kurlpurlurnu et al., 2008; also per-sonal communication from Pawu-Kurlpurl-urnu to Norris, 2008).

Cardinal directions are also important in Ward-aman culture, and were created in the Dreaming by the Blue-tongued Lizard (DS: 60):

> Blue-tongue Lungarra now he showing all these boomerang, calling out all the names: east, west, north, south, all these sort of type.

Other language groups have cardinal directions that may vary from the modern western con-vention, although east and west are often assoc-iated with the rising and setting positions of the Sun, and the words for east and west are often based on the word for the Sun (Hamacher et al., 2013, and references therein). However, in some cases, the cardinal positions are loosely defined and may vary markedly from place to place (Breen, 1993).

Directionality is also important in the sleeping position, as described by Harney (DS: 61):

> We gotta sleep east, not downhill. We can sleep crossway, but we're not allowed to sleep towards the Sun going down. Sleep down the bottom, it's bad luck for you because you're against the Sun. If you sleep on the eastern way and going that away, that's fine. Facing west, you gotta change your bed. Head up on the east when you sleep … each person where they die, in our Law, we always face them to their country. Graveyard always face to their country, they can look straight to their country.

Burials in other traditional Aboriginal cultures were often aligned to cardinal directions. For example, the deceased in New South Wales (henceforth NSW) were buried facing east, in a sitting position (Dunbar, 1943; Mathews, 1904: 274).

In contrast to the east-west alignments of burials, initiation sites in NSW were often align-ed roughly north-south. In a study of *bora* (init-iation) sites in NSW, Fuller et al. (2013) found that *bora* sites have a statistically significant preferred orientation to the south and south-west, which is consistent with circumstantial evidence that *bora* grounds are aligned with the position of the Milky Way in the night sky in August, which is roughly vertical in the evening sky to the south-southwest. This connection between *bora* sites and the Milky Way was sub-sequently confirmed in ethnographic studies by Fuller et al. (2014b), who found that the head and body of the 'Emu in the Sky' correspond to the small and large *bora* rings respectively on the ground.

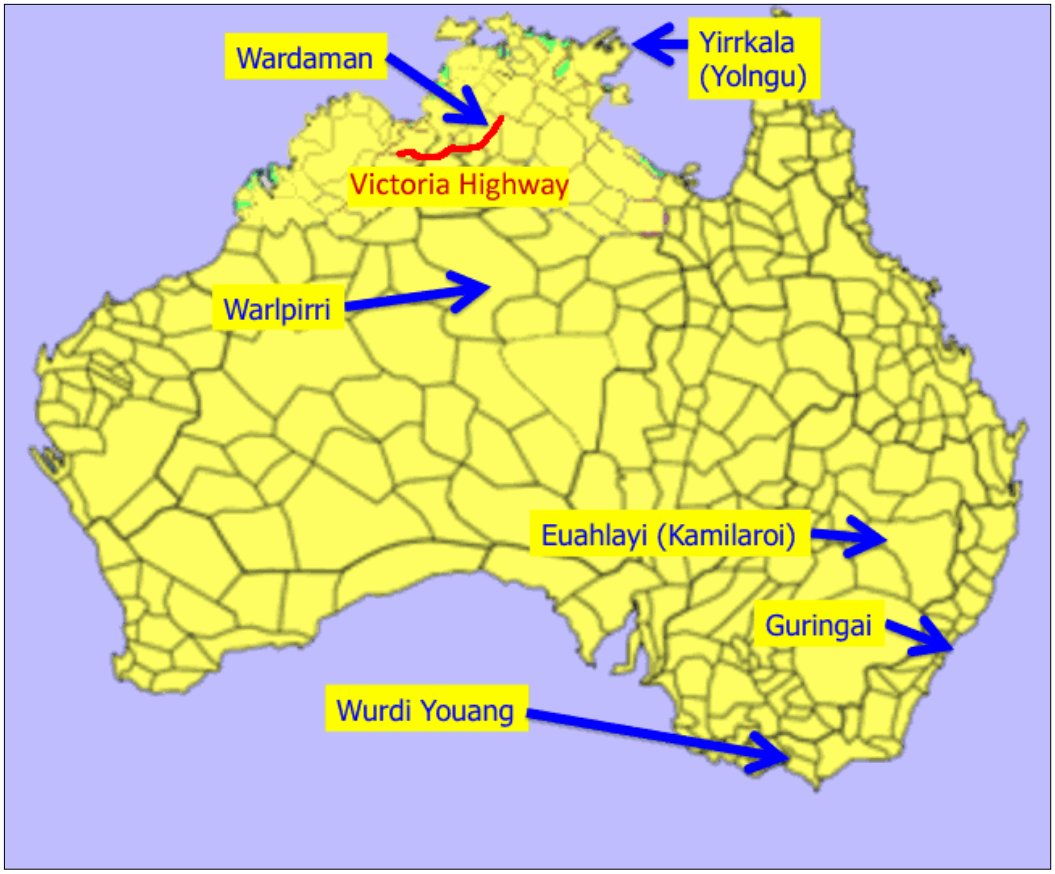

Figure 1: Map showing some of the places and the locations of language groups discussed in the text (adapted from a map licensed under the Creative Commons Attribution-Share Alike 3.0).

1.3 Wardaman Astronomy

The land of the Wardaman people is about 200 km southwest of Katherine in the Northern Territory (see Figure 1). We are fortunate that co-author Harney grew up and was educated and initiated at a time when the Wardaman people still followed a largely traditional lifestyle (see Figures 2 and 3). The language and culture of the Wardaman people has a particularly strong astronomical component, and are well documented in DS. The three major creation figures (Froglady Earthmother and her two husbands, Rainbow and Sky Boss) are all signified by dark clouds in the Milky Way, and stars and nebulae document other figures and other events. The Southern Cross is particularly important, and its orientation defines the Wardaman calendar and marks the cycle of dreaming stories throughout the year.

In the words of Harney (2009):

> In the country the landscape, the walking and dark on foot all around the country in the long grass, spearing, hunting, gathering with our Mum and all this but each night where we were going to travel back to the camp otherwise you don't get lost and all the only tell was about a star. How to travel? Follow the star along … While we were growing up. We only lay on our back and talk about the stars. We talk about emus and kangaroos, the whole and the stars, the turkeys and the willy wagtail, the whole lot, everything up in the star we named them all with Aboriginal names. Any way we talked about a lot of that … but we didn't have a watch in those days. We always followed the star for the watch … Emu, Crocodile, Cat Fish, Eagle Hawk, and all in the sky in one of the stars. The stars and the Milky Way have been moving all around. If you lay on your back in the middle of the night you can see the stars all blinking. They're all talking.

1.4 This Paper

Aboriginal songlines and navigation are not well documented, and the primary goal of this paper is to summarise the available information, including some previously-unpublished information. This paper is doubtless incomplete, and hopefully will be supplemented or superseded by more detailed studies.

Figure 2: A previously-unpublished photograph of Bill Yidumduma Harney (right) in about 1940, together with his friend and a large barramundi they caught in a waterhole on Willeroo Station (photograph courtesy B.Y. Harney).

This paper focuses on the songlines and navigation of the Wardaman people, for which the best documentation is available, while making comparisons with corresponding practices in other Aboriginal Australian language groups. This paper departs from conventional scholarly practice because one of the authors (Harney) is the senior Wardaman Elder with a great reserve of traditional knowledge, much of which has not yet been documented. It is therefore appropriate to include quotes from Harney in his own words. One aim of this paper is to document some of this traditional knowledge. Where possible, we do so by using the verbatim transcripts of Harney's verbal descriptions, accompanied by a reference with dates and other details. No attempt has been made to reword these descriptions. This is to retain the original flavour and avoid unintentional misinterpretation.

We recognise that the many different Aboriginal language groups have different practices and cultures, and by describing the practices of different cultures in this paper we recognise the risk of imposing a 'one size fits all' stereotype to all these cultures. That is not our intention. Instead, this paper should be regarded as a sample of the available information on the navigational practices of Aboriginal Australians.

2 SONGLINES

The English word 'songline' was coined by Chatwin (1987), but the concept is ancient and embedded in traditional Aboriginal cultures. They are often referred to as 'Dreaming Tracks', and can also be called 'strings' (Clarke, 2003: 19) in the sense that they connect different people and sacred sites. According to Harney (2009):

> Between the star and the landscape and the rock painting and all that, they're more or less connected together around the country.

Mulvaney and Kamminga (1999: 95) argue that they also represent the trading routes that criss-cross Australia. Gammage (2011: 24) says:

> A songline or storyline is the path or corridor along which a creator ancestor moved to bring country into being. It is also the way of the ancestor's totem, the geographical expression of their songs, dances and paintings animating its country, and ecological proof of the unity of things.

According to Wositsky and Harney (1999: 301):

> Songlines are epic creation songs passed to present generations by a line of singers continuous since the dreamtime. These songs, or song-cycles, have various names according to which language group they belong to, and tell the story of the creation of the land, provide maps for the country, and hand down law as decreed by the creation heroes of the

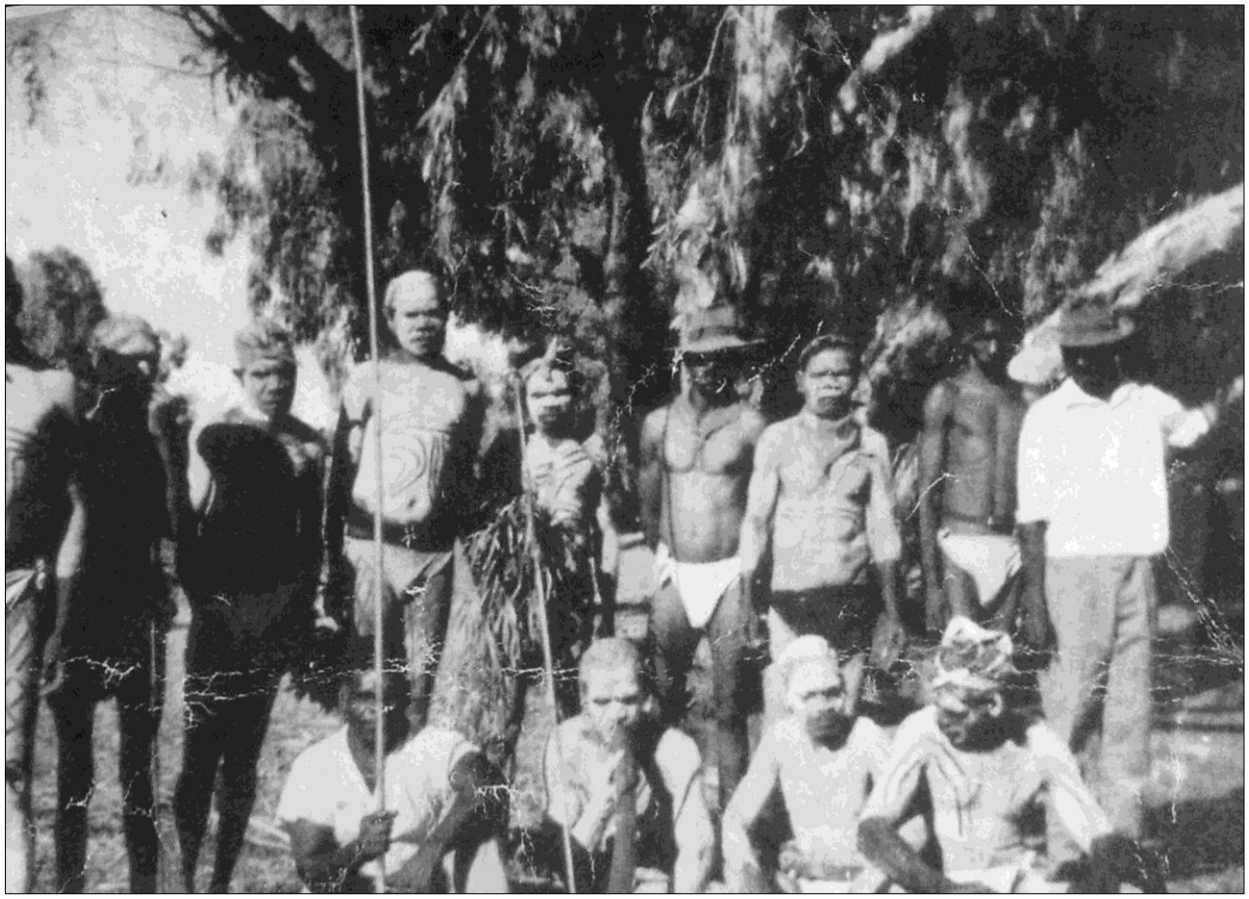

Figure 3: A previously-unpublished photograph of Bill Yidumduma Harney's family in 1929 (photograph courtesy B.Y. Harney).

> dreamtime. Some songlines describe a path crossing the entire Australian continent.

As well as marking routes on the ground, songlines were also paths in the sky, several examples of which are described in detail in DS. Harney (2009, personal communication to Norris) described how the songlines on Earth were mirrored by the songlines in the sky, so that knowledge of the sky formed a mnemonic for tracing a route on Earth. This mirroring was created when the Creator Spirits moved to the sky (DS: 99):

> One day it was all different, when they come down and make up the Creation line songs, because they travelling. When everything become still. They all split up, land, become all the stars ...

For example, one songline starts at Yirrkala in Arnhem Land, where the Yolngu believe *Barnumbirr* (Venus) crossed the coast as she brought the first humans to Australia from the east (Allen, 1975; Norris and Norris, 2009). Her song, contained within the Yolngu Morning Star ceremony, describes her path across the land, including the location of mountains, waterholes, landmarks and boundaries. The song therefore constitutes an oral map, enabling the traveller to navigate across the land while finding food and water. It is said by Yolngu Elders at Yirrkala that the same song is recognisable in a number of different languages along the path from east to west, crossing the entire 'top end' of Australia. The song changes along the route, being longer and more 'singsong' in the east, and shorter, and broken into short sharp segments, in the west (personal communication by Elders at Yirrkala to Norris, 2007).

Many other songlines are known across Australia (e.g. Kerwin, 2010). Fuller et al. (2014c) report several songlines known to the Euahlayi people, including the eaglehawk songline that extends from Heavitree Gap at Alice Springs to Byron Bay on the East Coast, connecting the Arrernte people with the Euahlayi people, and also connecting the stars Achernar, Canopus and Sirius. The Euahlayi people also know the Black Snake/Bogong Moth songline connecting Normanton on the Gulf of Carpentaria with the Snowy Mountains near Canberra, which also follows the Milky Way.

Another example is the two songlines that are said by Darug Elders to extend west from Sydney, through Sackville, and then roughly follow the paths of the Great Western Highway and the Bells Line of Road respectively, until they join again at Little Hartley (personal communication by Des Dyer and Gordon Workman of the Darug Tribal Aboriginal Corporation to Norris, 2007). Supporting evidence includes the Darug rock engravings found close to the path of the Great Western Highway through the Blue Mountains.

The creation of the songlines is described by Harney and Lee (2010: 11):

> They put all them together, then with that, they made all the Songlines, right across the country. And that Creation Song now, we still got it today. Nothing been changed, we still got that old one. Original one. Because we gotta have that for all this rock painting, all the different sites, and rock.

Such long distance paths were important because of the important trading routes (e.g. Gammage, 2011; Kerwin, 2010, and references therein) traversing Australia for the trading and exchange of goods, such as the export of ochre from Wardaman country. Lee and Harney (2009) explain that

> Red and yellow from this area are considered very powerful and were traded for long distances for use in ceremonies.

A journey, sometimes taking months, would have several functions, including attending ceremonies, as well as trading. The trading itself might include the trading of intellectual property, such as songs and dances, as well as material objects.

Later, many of these ancient trade routes, which were often based on songlines, laid the basis for some of the current networks of highways across Australia (Wositsky and Harney, 1999: 14):

> They showed him the way right through from Willeroo to Victoria River Downs Station. My grandfather used to go in the lead, and blaze the trees all the way, following the old Aboriginal walking pad, and old Bill would come along behind him making the road. They call it the Victoria Highway now, but it was never the Victoria Highway at all – it was just the original Aboriginal walking trail right through Arnhem Land and Katherine Gorge and past Willeroo, right down to Western Australia. They used that walking trail to trade their boomerangs and spears and many different ochres and when they did the trade they had ceremonial meetings. That had been a walking trail for a hell of a long time … all the way from Cape York right through Borroloola and straight across the country. They hit Roper River and followed the Roper River all the way past Mataranka and they came right past Willeroo.

3 NAVIGATION

Tindale (1974: 75) was aware of ancient Aboriginal tracks across large parts of Australia, but considered that their use was mainly for travelling short distances. However he noted of the trading routes (Tindale, 1974: 81) that

> ... the great distances covered and also the difficulties encountered, considering the precarious line of communication across formidable dry areas, are striking.

It is curious that there is almost no discussion of the navigational practices of Aboriginal people by those who studied their culture extensively during the last century, such as Elkin, the Berndts and Mountford. With hindsight, many of the songs and stories that they describe involve a route on Earth, or in the sky, followed by creator-spirits, but were not discussed at the time in terms of navigation. For example, Elkin (1938: 304) appears to have heard at least one songline without noting its significance:

> ... each … sings all night its cycle of the hero's experiences as he journeyed from the north coast south and then back again north … a headman sitting nearby commented that the Ngurlmak, according to the text, was now in that country, then in another place, and so on, ever coming nearer until at last it was just where we were making the recording.

Mountford (1976: 50) discussed the extensive trading networks without asking how people navigated these vast distances, and discussed Aboriginal astronomy without asking if the stars were used for navigation. He apparently encountered song-line descriptions, but did not remark on their navigational significance. For example, he recounts (Mountford, 1976: 462):

> The series of twelve drawings … indicate that the route of Orion and the Pleiades extends from the Warburton range in Western Australia through the Rawlison, Petermann, Mann, and Musgrave ranges, reaching Glen Helen, in the country of the Western Aranda. At some point between the Petermann and Mann mythical route, the name of the man of Orion was changed from Jula to Nirunja …

It is unclear whether this lack of discussion reflects the assumptions and interests of the anthropologists at the time, or because this knowledge was regarded by the Aboriginal participants as secret. Nevertheless, the available evidence (e.g. Kerwin, 2010) shows unambiguously that the ability to navigate long distances was widespread.

Amongst the Wardaman people in northern Australia, most travelling was done at night, when the air was cool and the stars were visible as guides. Furthermore, there was a belief that distances were smaller at night (DS: 65):

> The old people, the old man walking during the day saying the distance get far away from you. Walk in the night in the darkness, the distance shrinking up. Somehow it's shrinking up! The Earth's pulling away from you pretty fast! Shrinking up, that's what they told us. But … during the daytime, the Earth's still standing still. Aborigine call it in a word, the Shame – he shamed to move.

Elsewhere in Australia, night-time travel was less common. Maegraith (1932) and Lewis (1976) found that Central Desert people did not use the stars for navigation, and did not travel at night, and Fuller et al. (2014c) found that Euahlayi people did not travel at night.

Where possible, and for long-distance navigation, a songline would be followed (DS: 63):

> Not just songline trail, walking trail, trade routes. You sing a song, then you follow your song, in that track you go along singing the song, like a blazed mark.

Traditional Aboriginal Elders (such as Harney) have an intimate knowledge of the night sky, far better than that of most modern-day Western astronomers (such as Norris), and can name many stars in any given patch of sky, and explain their role in the Dreaming stories. Mountford (1976: 449) considered that

> ... many Aborigines of the desert are aware of every star in their firmament, down to at least the fourth magnitude, and most, if not all, of those stars would have myths associated with them.

These Aboriginal Elders also understood how the whole pattern rotated over their heads from east to west during the night, and how it shifted over the course of a year (DS: 61):

> Each time you look at the stars it's in a different inch by half an inch, or quarter of an inch by quarter of an inch, or whatever. That's where the old Aborigines, all the Elders, see that travelling. Then later on it's over there earlier in the year.

For shorter journeys, or when a songline was not available, the direction of the Moon or patterns of the stars were used for navigation (DS: 63):

> You judge how far it is to Willeroo, you say about 3km, you aim for that 3 km in your mind. That's all! You've got to go cross ways? That's Emu Foot tells you, he's south. If you want to go southwest, you go on the right hand side of the emu …

Navigating by the stars is still considered by Harney (2009) to be preferable to following the modern road:

> You know road might be going to the water a bit, road might be going out of the waterhole and you like to get perished too that's what he's about. But the star the mainly the one really guide you straight to the waterhole and all this.

The path of the planets in the sky, the ecliptic, had special significance (DS: 65):

> The Dreaming Track in the sky! Planets mak-

> ing the pathway! Travelling routes, a pathway you could call it, like a highway! Travelling pathway joins to all different areas, to base place, to camping place, to ceremony place, where the trade routes come in; all this sort of things. The Dreaming Track in the sky, the planets come straight across … walking trail becomes a pad, then becomes a wagon road, two wheel tracks, then become a highway. That's how they started off, four of them.

While star maps do exist in Aboriginal paintings and possibly in rock engravings, no Aboriginal star maps intended for navigation have been recorded. Instead, all the knowledge is committed to memory in the form of songlines, which may therefore be regarded as 'oral maps'. In a culture with no written language, but with a strong tradition of memorising oral knowledge, this is probably the optimum way of recording and transmitting navigational information.

4 CONCLUDING REMARKS

We have presented new information, and also material drawn from the literature, to show that:

(1) Songlines are effectively oral maps of the landscape, enabling the transmission of oral navigational skills in cultures that do not have a written language;
(2) Songlines extend for large distances across Australia, and are often identical to the trading routes, and were presumably used for navigating these trading routes;
(3) Some modern Australian highways follow the paths of Aboriginal songlines;
(4) In many cases, songlines on the Earth are mirrored by songlines in the sky; and
(5) The sky is used as a navigational tool, both by using it as a compass, and by using it as a mnemonic to remember the songlines on the ground.

5 ACKNOWLEDGEMENT

We acknowledge and pay our respects to the traditional owners and Elders, both past and present, of the Wardaman people and of all the other language groups mentioned in this paper. We also thank Hugh Cairns for permission to reproduce selected passages from *Dark Sparklers*.

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STAR MAPS AND TRAVELLING TO CEREMONIES: THE EUAHLAYI PEOPLE AND THEIR USE OF THE NIGHT SKY

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Abstract: The Euahlayi people are an Aboriginal Australian language group located in north-central New South Wales and south-central Queensland. They have a rich culture of astronomy and use of the night sky in resource management. Like several other Aboriginal peoples, they did not travel extensively at night, and so were assumed not to use the night sky for navigation. This study has confirmed that they, like most other Aboriginal groups, travelled extensively outside their own country for purposes of trade and ceremonies. We also found previously unpublished evidence that they used 'star maps' in the night sky for learning and remembering waypoints along their routes of travel, but not for actual navigation.

Notice to Aboriginal and Torres Strait Islander Readers: This paper contains the names of people who have passed away.

Keywords: Australian ethnoastronomy, Euahlayi people, star maps

1 INTRODUCTION

Cultural astronomy is defined as the study of the effect of astronomical knowledge or theories on ideologies or human behaviour (Campion, 2004: xv). Fuller et al. (2014a: 3–4) report that while there is a rich knowledge of Aboriginal astronomy, the literature on Kamilaroi and Euahlayi astronomy, based on ethnography from the ninteenth century, is limited and contains many contradictions. They collected knowledge of the sky from current Kamilaroi, Euahlayi, and neighbouring communities, including many interviews and recordings of stories during 2013 from eight participants from those communities. Those participants, referred to in the texts as P1 to P8, are noted in the Acknowledgements. One participant, Michael Anderson, with both Euahlayi and Kamilaroi heritage, provided such a complete description of star maps as it related to his culture that he is included as an author of this paper.

Fuller et al. (2014a) confirmed the hypothesis that the knowledge gained could add to the current body of knowledge of Aboriginal Australian sky culture. Most of the data were released under the terms of Ethics Approval 5201200462 by Macquarie University. This paper presents previously-unpublished data from the study used to determine whether the knowledge about star maps collected through the larger project adds a deeper level of understanding into the sky culture of the Kamilaroi and the Euahlayi peoples.

The stories collected by Fuller et al. (ibid.) do not just entertain and describe some physical object in the sky. Aboriginal culture is oral in nature, and oral transmission of knowledge is extremely important, particularly in regards to

law. As Aboriginal law governs all aspects of Aboriginal life, it establishes a person's rights and responsibilities to others, the land and natural resources (Law Reform Commission of Western Australia, 2006: 64). Cultural stories transmit law, and in this respect may have different levels of meaning. Sveiby and Skuthorpe (2006: 45–51) described four levels; one being for children (to explain nature), others being for relationships between people, relationships between the community and country, and ceremonial practices. A participant in the project said that some stories could have up to "30 levels" of meaning. While we have avoided reference to the ceremonial levels of meaning in this study, in the case of the use of the sky for travelling to ceremonies, we may reference ceremonial matters where permission has been received from the owners of such ceremonial knowledge.

2 THE EUAHLAYI PEOPLE

The Euahlayi people are an Aboriginal Australian cultural group located in the northwest of New South Wales (NSW). Ash et al. (2003: 1) have described the Euahlayi language as 'Yuwaalayaay', but Euahlayi participants in the project maintain that 'Yuwaalayaay' is a clan language of the neighbouring Kamilaroi people, and that Euahlayi is a separate language (P2). Mathews (1902: 137) described the 'Yualeai' language as:

> The natives speaking this language are located upon a tract of country in southern Queensland, including the Bokhara, Birrie, Narran, Ballonne and Moonie Rivers, and extend some distance within the New South Wales frontier, where they are met by the Kamilaroi nation.

When this area was described by Sim and Giacon (1998: vii, xii), Sim described the language in the area as 'Yualeiai', while Giacon (the Editor) changed this to Yuwaalayaay, so there have been a number of interpretations of the name over the years. Figure 1 shows the area of the Euahlayi language group (labelled 'Juaaleiai').

The population of the Kamilaroi and Euahlayi cultural grouping was estimated at 15,000 in 1788, although participants point out that the resources available could maintain a population as large as 60,000. This may have dropped to as low as 1000 in 1842 (Sveiby and Skuthorpe, 2006: 25–26). As a result of pressure from European colonisers, there was a movement of Aboriginal people in this group towards the northwest. The current population of people identifying as having Kamilaroi and/or Euahlayi ancestry is approximately 29,000 (estimates from Kamilaroi Nation Applicant Board). The same source estimates the current number of people with Euahlayi ancestry as being "around 3000", implying that the population at the time of European invasion was small.

3 ABORIGINAL TRAVEL AND NAVIGATION USING THE STARS

3.1 Navigation at Night

Haynes and Haynes (1996: 7–8) described the difference between Aboriginal and European astronomy:

> Astronomy, in the sense of a comprehensive and coherent body of knowledge about the stars, was an integral component of Aboriginal culture. Like the Newtonian-based system of Western science, it represented an attempt to construct a view of the Universe as an ordered and unified system, but in most ways it was fundamentally different. It was relational rather than mathematically-based, and it was concerned with similarity rather than with difference, with synthesis rather than analysis, with symbiosis rather than separation … For the Aborigines, the stars not only evoked wonder, they predicted and explained natural occurrences and provided celestial parallels with tribal experiences and behavioural codes.

A common question is: Do Aboriginal people use the stars for navigation at night? Norris and Harney (2014) show that Wardaman people prefer to travel at night, and use the stars for navigation. Maegraith (1932: 25) stated that Aboriginal people of the Central Desert were unable to navigate at night, notwithstanding their detailed knowledge of the night sky. Lewis (1976: 273–274), as a part of a project on Aboriginal route-finding with Walbiri and Pintupi people in the Simpson Desert, found that his participants did not use the stars for navigation, and were disoriented at night when unable to see landscape features. The answer to this question therefore seems to vary from one language group to another.

One of the participants in the present study (P2) stated that while Aboriginal people had a clear understanding of the sky at night, and could use stars and other objects for directions, they had no interest or purpose in travelling at night.

Kerwin (2010: 68–69) lists anecdotal stories from participants in his research showing Aboriginal peoples' ability to navigate in their country using the stars at night. Cairns and Harney (2003: 9) describe the Dreaming Track in the sky that helps navigation on the ground, and Norris and Harney (2014) give other examples.

There is much evidence in the literature about the Aboriginal use of the night sky for predicting when resources would be available. Fuller et al. (2014b) have shown how the Emu in the Sky, an important object outlined by the

dust clouds in the Milky Way, governed the Euahlayi peoples timing of the use of the emu egg resource on the ground. Almost all the literature on Aboriginal astronomy refers to the central role of the night sky in Aboriginal cultural stories. Sveiby and Skuthorpe (2006: 41) describe Aboriginal storytelling as 'dramatic art', and one can imagine that many of the stories collected since colonisation were told at night, using the key cultural figures and animals of the Dreaming that were connected to objects in the sky. These stories had many levels (Sveiby and Skuthorpe, 2006: 42–50), from children's stories to entertain or describe natural phenomena, to levels describing spiritual action and ceremonies.

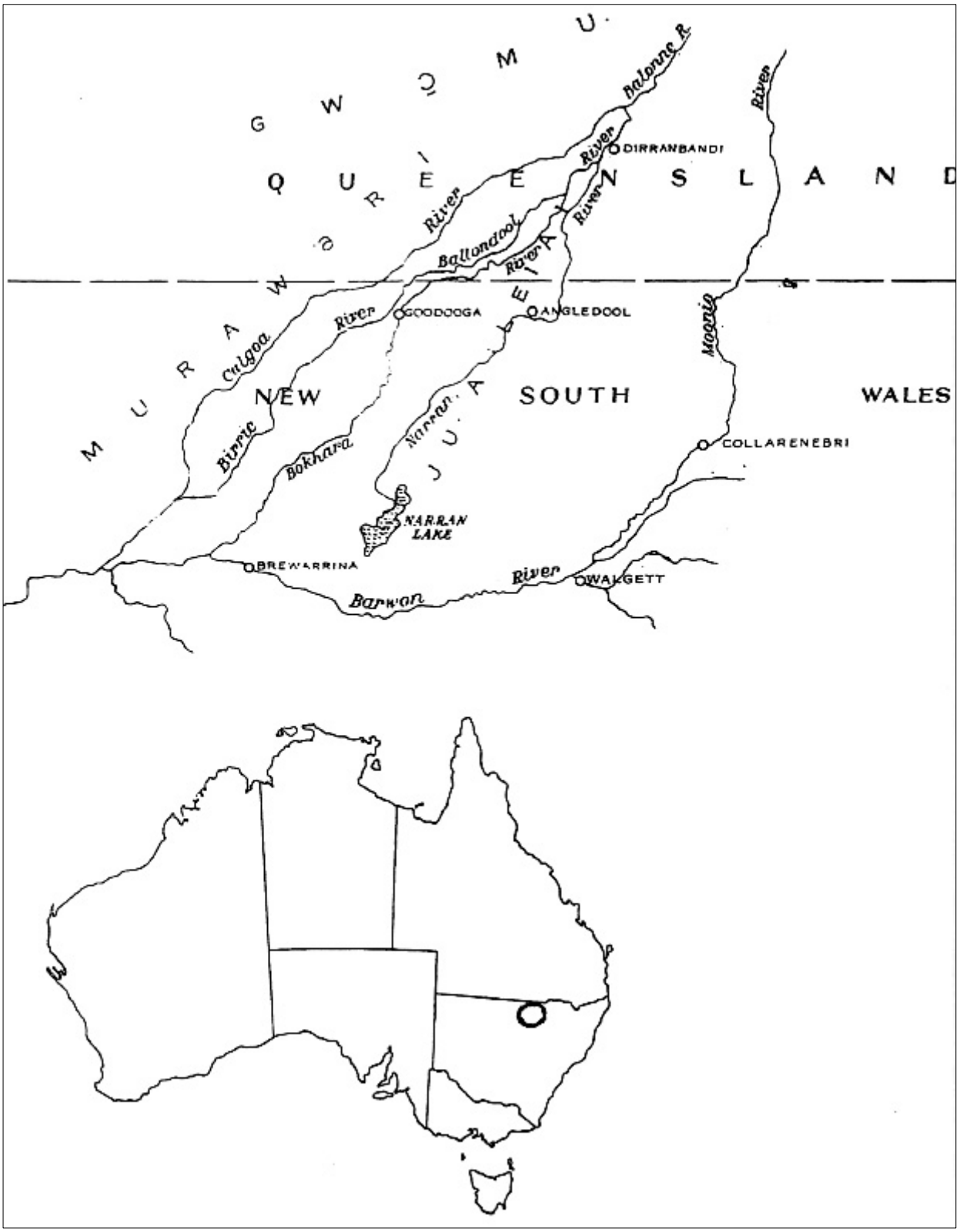

Figure 1: Location of the Euahlayi language group (after Sim and Giacon, 1998).

3.2 Travel

Research on Aboriginal culture in the last two centuries has brought a change in the original view by colonists that Aboriginal peoples were nomadic hunter-gatherers eking out a subsistence existence. As early as the 1840's Curr speculated that Aboriginal people in Victoria (VIC) had an excess of leisure time after fulfilling their needs (Sahlins, 1972: 24). Sahlins (1972: 9–32) coined the description 'The Original Affluent Society' for hunters and gatherers, including Aboriginal Australian peoples, and used data from early ethnographic studies in Australia to show that they were able to meet their needs with adequate time to spare for leisure, and that travel was limited to a need to access resources. Kerwin (2010) made a strong case that Aborigines travelled mainly for trade and ceremony, but that otherwise, most Aboriginal people living in the better-resourced parts of Australia lived sedentary lives in clearly-defined territories. He and earlier writers, such as McBryde (2000: 157–164), Mulvaney and Kamminga (1999: 95), and Flood (1983: 235–36), described a vast network of trade routes throughout Australia, trading in goods, ceremonies and stories. These included well-established trade routes connecting the inland with coastal Queensland (QLD), and down the Great Dividing Range to the Snowy Mountains. Commodities traded included bunya nuts, pituri (a nicotine-based narcotic), stone axes, ochre and wooden implements. Stories and ceremonies were also traded along the same routes, and people from different language groups attended and participated in ceremonies, such as the *bora* initiation ceremony of the southeast of Australia. Reynolds (1981: 11–12) described the "... large ceremonial gatherings (that) provided the venue for gossip, trade and cultural inter-change."

3.3 Songlines and Dreaming Tracks

Stories and ceremonies were traded along particular routes across Australia. Kerwin (2010: 113–120) and McBryde (2000: 157–164) showed that trade routes were as important as songlines and Dreaming tracks. In some cases, stories were also traded along trade routes, and eventually that trade route became a songline or Dreaming track, and the route was incorporated into the story. For example, the Two Dog Dreaming story (Kerwin 2010: 37, 90) describes how the ancestral emu, *Kuringii*, was chased by two ancestral dingoes along a trade route from Cape York to South Australia (SA) through the Queensland Channel Country. *Kuringii* was eventually killed at the foot of the Flinders Ranges, and his blood is the source of the prized red ochre from Parachilna in SA. In this way, the ochre traded on this route became part of the story in such a way that the route is now a songline for the song that relates the story. A Dreaming track is another way to express the meaning of a story that is a part of a traditional Dreaming story that travels down a trade route. Kerwin (2010: 113–114) says that a Dreaming story or songline can change from one end of the track to the other, but still has the same basic theme. The language of the story will also change as it moves through different language groups along the track, but as the story is sung, the 'melody' remains the same; only the language changes. A person can recognise the story without understanding the language (P2). Kerwin (2010) also says that as the story travels over the landscape it will have changes relating to the local country of those singing the story, but the original theme remains the same.

Songlines can also be seen in the sky at night. Euahlayi people (P2) know of a songline stretching from Heavitree Gap at Alice Springs to Byron Bay on the East Coast. This is the songline of *Mulliyan-ga* (the eaglehawk), and runs from the star Achernar in the West overhead to Canopus, to Sirius, and then to the East. *Mulliyan-ga* fought, and was defeated by the caterpillar, *Yipirinya,* at Alice Springs after travelling from the East, and his spirit remains in Achernar. This is a songline that connects the Arrernte people of Alice Springs with the Euahlayi people of northwest NSW, and it is possible the Arrernte have a story that connects to *Mulliyan-ga*. The Euahlayi (ibid.) also know of the Black Snake/Bogong Moth songline, which connects Normanton on the Gulf of Carpentaria with the Snowy Mountains near Canberra. This songline in the sky follows the Milky Way and intersects with the *Mulliyan-ga* songline over Euahlayi country.

4 STAR MAPS AND TRAVELLING TO CEREMONIES

Cairns (1996, 2005) speculated that small depresssions in the sandstone, known as cupules, at the Elvina Track site north of Sydney might represent maps of the stars in the sky. However, Bednarik (2008), an expert in rock art, has been very sceptical that cupules are anything other than natural phenomena in all but very limited cases.

Another use of the term 'star map' describes the use of patterns of stars to represent routes of travel on land. During the summer months, Aboriginal people travelled through their own country, and often the country of other clans and language groups, to trade in goods and stories, and in particular, to attend and participate in ceremonies. These ceremonies often took place at special sites, such as *bora* grounds, that had been used for such purposes

for long periods of time, and usually marked a story or event of spiritual significance that took place at that location during the Dreaming. Early ethnographers documented these ceremonies in sufficient detail that we are able to find examples of ceremonies where it was clear that people from a wide area attended. Mathews (1894: 106–109) describes a *bora* ceremony at Gundabloui (near Collarenebri NSW) in 1894 where the attendees travelled up to 160 km on foot to attend. The camp was broken down into three sections, one being people from the Mogil Mogil, Collarenebri and Walgett areas (most likely the Euahlayi language group), another from the Kunopia, Mungindi, and Welltown areas, and the last from the Moonie and St. George (QLD) areas. The latter two groups were possibly Kamilaroi and Bigambul language groups. According to Mathews, messengers were sent out after the *bora* ceremony at Kunopia (near Mungindi NSW) two years prior to invite people to the Gundabloui *bora*. As the time for the *bora* approached, the people attending commenced travelling, with one of the messengers as a guide. They travelled by day and camped at night. In this case (Mathews, 1894: 124), the ceremonies were held between 12 February and 10 March, but attendees began arriving a month before. *Bora* ceremonies took place over a wide range of months (Fuller et al., 2013: 31), but it appears that they were normally held during the summer months.

Fuller et al. (2013) studied *bora* grounds in the northwest and north central area of NSW and over the border in south central QLD, which consisted of a large circle of cleared earth or stone, connected by a cleared pathway to a smaller circle of cleared earth or stone. The larger circle was considered to be the 'public' circle, where all participants could attend, and the smaller circle was the 'sacred' circle, where only the initiates and Elders were allowed. Mathews (1894: 106–109) suggested that Euahlayi people travelled long distances to attend *bora* ceremonies, so that people from individual clan groups would have had a need to know how to navigate through a very large area, possibly using the Dreaming tracks described above. We are not aware of any actual portable 'maps' having been found in Australia, and the only suggestions of way-finding devices have been stone or clay *'cyclons'* in NSW, *'toas'* (decorative objects in various materials from Central Australia), and message sticks, but the functions of these objects for travel is not clear (Kerwin, 2010: 74–78).

A different use of the sky is provided by a co-author (Anderson), and confirmed in part by the participants P4, P7, and P8. For the Euahlayi, and for the Kamilaroi and neighbouring language groups, there was another way to use the stars for travelling which was not a form of navigation by the stars. This was the use of patterns of stars ('star maps') to teach people how to travel in and outside of their country. Knowledge in Aboriginal culture is transmitted orally, so this technique could be considered a memory aid to assist in teaching and as a reminder for future travel. Initiated men, including the messengers mentioned by Mathews, would be the holders of this knowledge. It is possible women were also included, as knowledge of travel was not necessarily ceremonial in nature. In Euahlayi country, the winter months of May, June, and July would be used for planning the travel to ceremonies during the summer months, starting as early as September. The people planning to travel would already know where they had been invited, as the messengers would have arrived with the invitations. A part of the early winter activities would be the travel plan, and at this time, young men (and perhaps women) would be taught how to travel using the songlines or Dreaming tracks described by the star maps. The knowledge holder would use a clear night at the right time of the year and point out the directions for travel, using the patterns of stars in the star map in the sky to guide the intended traveller from place-to-place on the ground using the stars as what we now call 'waypoints' in terrestrial navigation. To the Aboriginal person, these waypoints could be a bend in a river, a waterhole, a marked tree or a stone arrangement. Eventually the star map would lead to the destination, which would be the ceremonial ground.

An example, based on mid-May in the late evening, would be a star map leading to Carnarvon Gorge in QLD, which is a known ceremonial centre. This is a trip of over 600km. Looking at the southeast sky, the winter camp in Euahlayi country where the planners are located is represented as an area in the constellation Sagittarius bounded by the stars Epsilon Sagittarii, Beta Sagittarii, W Sagittarii, Delta Sagittarii, and the star cluster M7. This area would have also incorporated Kamilaroi and Murrawarri peoples. The star map to Carnarvon Gorge would proceed from the winter camp to the stars Gamma Scorpii (representing Dirranbandi, QLD), Kappa Scorpii (St. George, QLD), Theta Scorpii (Surat, QLD), Eta Scorpii (Roma, QLD), and Zeta Scorpii (Carnarvon Gorge). This is represented in Figure 2.

If the travel was to the Bunya Mountains (which was the source of the prized bunya nuts), the traveller would turn at Theta Scorpii (Surat, QLD), to Sigma Arae (Chinchilla, QLD), to Alpha Arae (Dalby, QLD), then to Beta and Gamma Arae (Bunya Mountains). This is represented in Figure 3. The travel to share in bunya nuts with the language groups whose

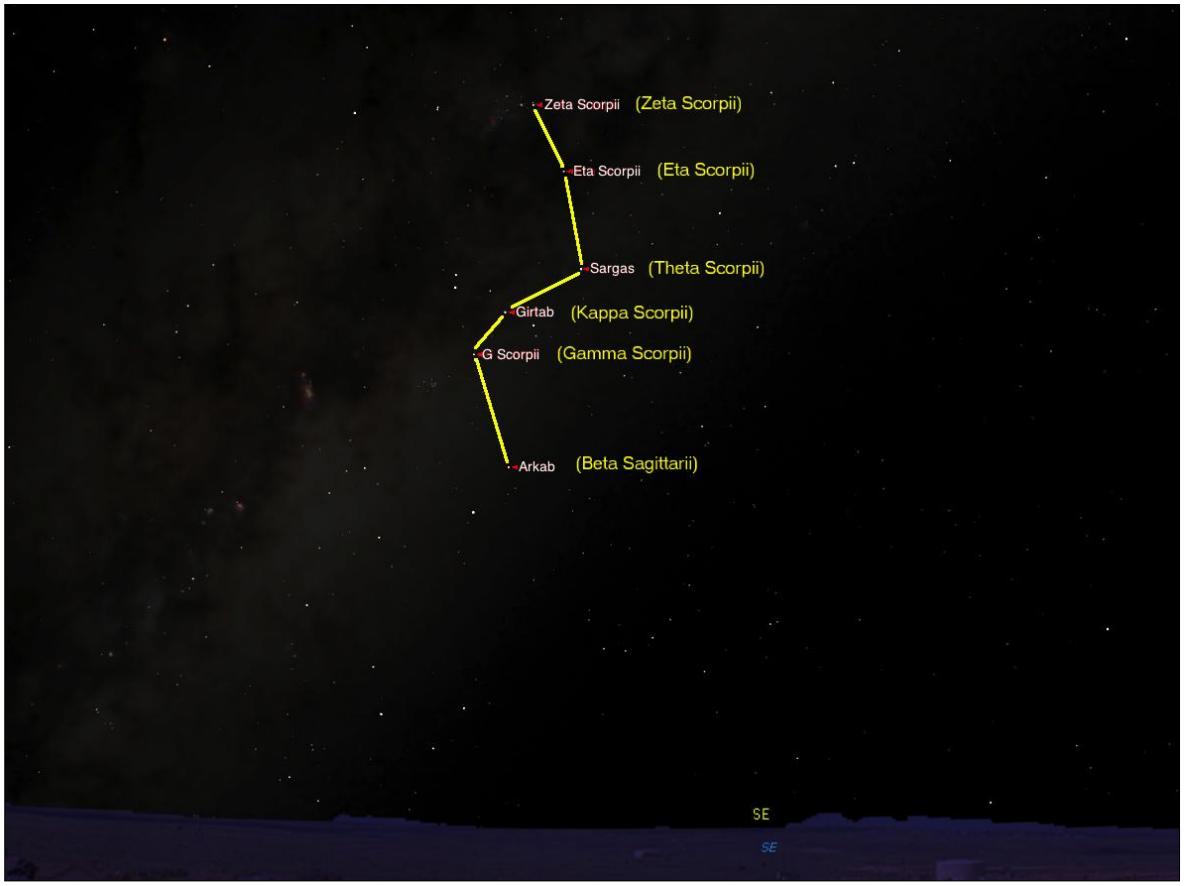

Figure 2: Goodooga to Carnarvon Gorge star map (image: courtesy Starry Night Education).

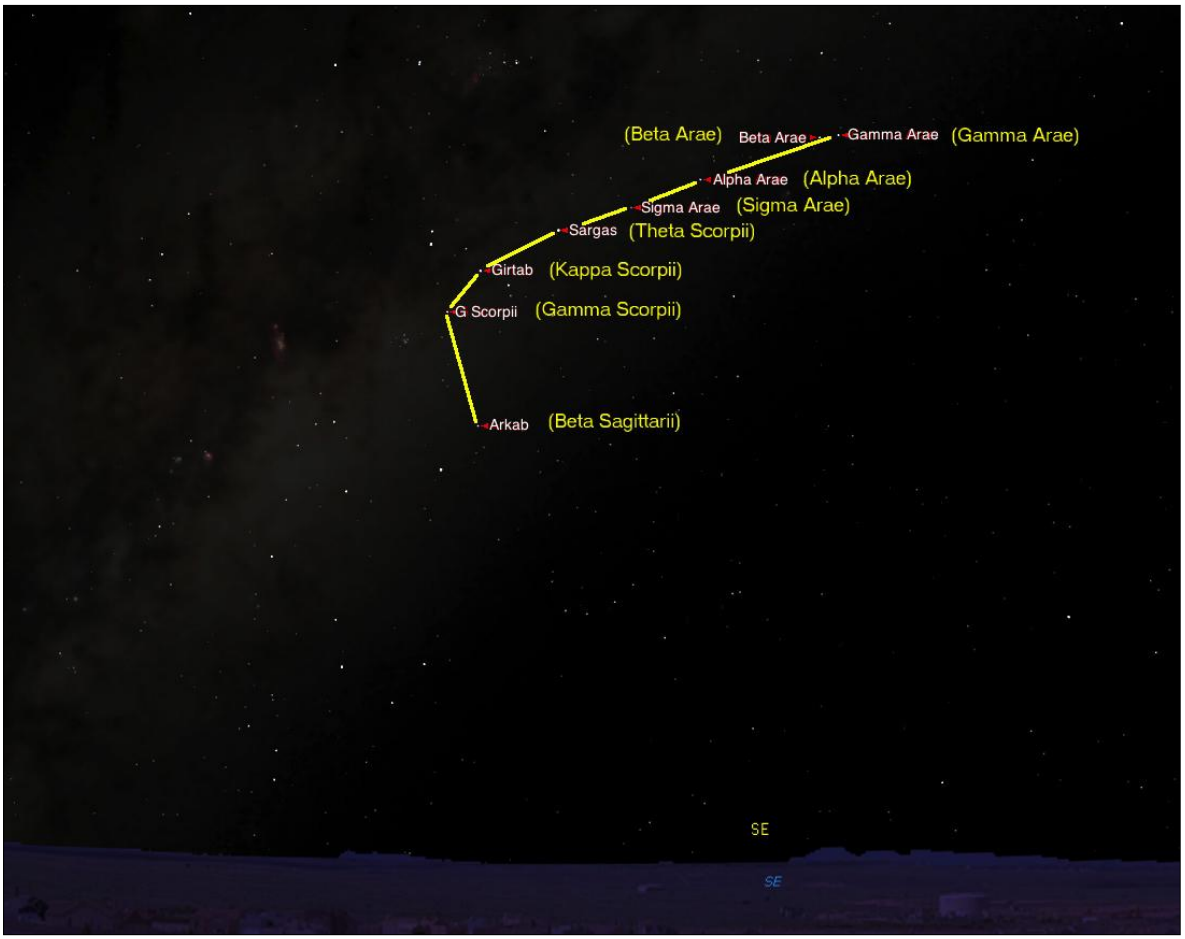

Figure 3: Goodooga to Bunya Mts. star map (image: courtesy Starry Night Education).

Figure 4: Ground travel routes to Carnarvon Gorge and Bunya Mts. (image: Google Earth).

country was the Bunya Mountains is well documented by Ridley (1875: 159) and Pietre (1904: 11).

The same travel is represented on the ground by red lines in Figure 4. The actual ground routes are only loosely similar in direction to the star maps because the star maps do not represent a navigation aid in terms of direction and distance, but just a memory aid to the waypoints. In September, when the travel might commence, the same stars can be seen (higher in the sky and to the southwest), but they have rotated to the point where they would be difficult to use as a navigation aid. It is interesting to note that many main roads (yellow lines in Figure 4) appear to align with the Aboriginal travel routes and some towns appear at the Aboriginal waypoints. According to Kerwin (2010: 159–163) and Norris and Harney (2014), many Aboriginal trading routes became routes of travel for Europeans and stock routes for the movement of animals. These routes later became main roads, and where they turned or split, towns often appeared.

The concept that these Aboriginal routes were also storylines or Dreaming tracks is reinforced by one of the waypoints on Figure 4, Dirranbandi (Noondoo). This point is actually 25 km east of the town of Dirranbandi, at a point called Noondoo Ridge, which is the highest point in the area, and provides a clear view to the south. Anderson has confirmed that the storylines had their beginning at this point because the Southern Cross (Crux) could be clearly seen from this point, and the stories themselves had their origin in the night sky around Crux.

There were other star mapped routes used by the Euahlayi, including one which travelled to the northwest to a waterhole near Quilpie, QLD which was a ceremonial centre for Aboriginal people from a wide area, including the Arrernte people from the Central Desert (a distance of over 900 km). The star map started from the winter camp (Beta Sagittarii/Goodooga) to X Sagittarii (Hebel, QLD), to 51 Ophiuchi (Ballon, QLD), to Eta Ophiuchi (Cunnamulla, QLD), to Zeta Ophiuchi (Yowah, QLD) then to Epsilon Ophiuchi (waterhole northwest of Quilpie, QLD). Figure 5 shows the star map, and Figure 6 shows the ground route. The fact that other Aboriginal groups came to such ceremonial meeting points suggests that they also used star maps for teaching travel, but that their star maps were different to those used by the Euahlayi, other than reaching the same

point on land. It may also be that the songlines of the Euahlayi routes connected to the songlines of the other groups at the ceremonial places.

There were a number of ceremonial sites in QLD and NSW where the Euahlayi people travelled, and the final star map in this study must have been used to educate people about them and their general location. This star map

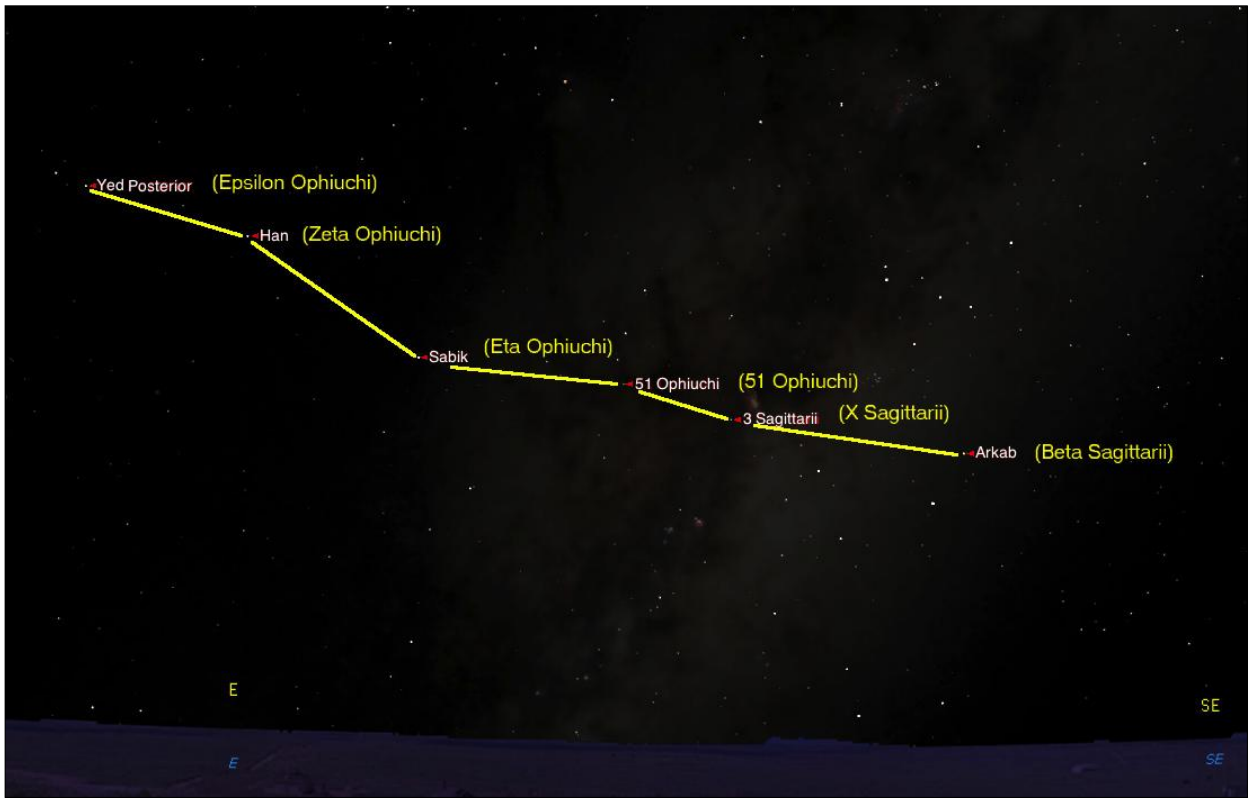

Figure 5: Goodooga to Quilpie waterhole star map (image: courtesy Starry Night Education).

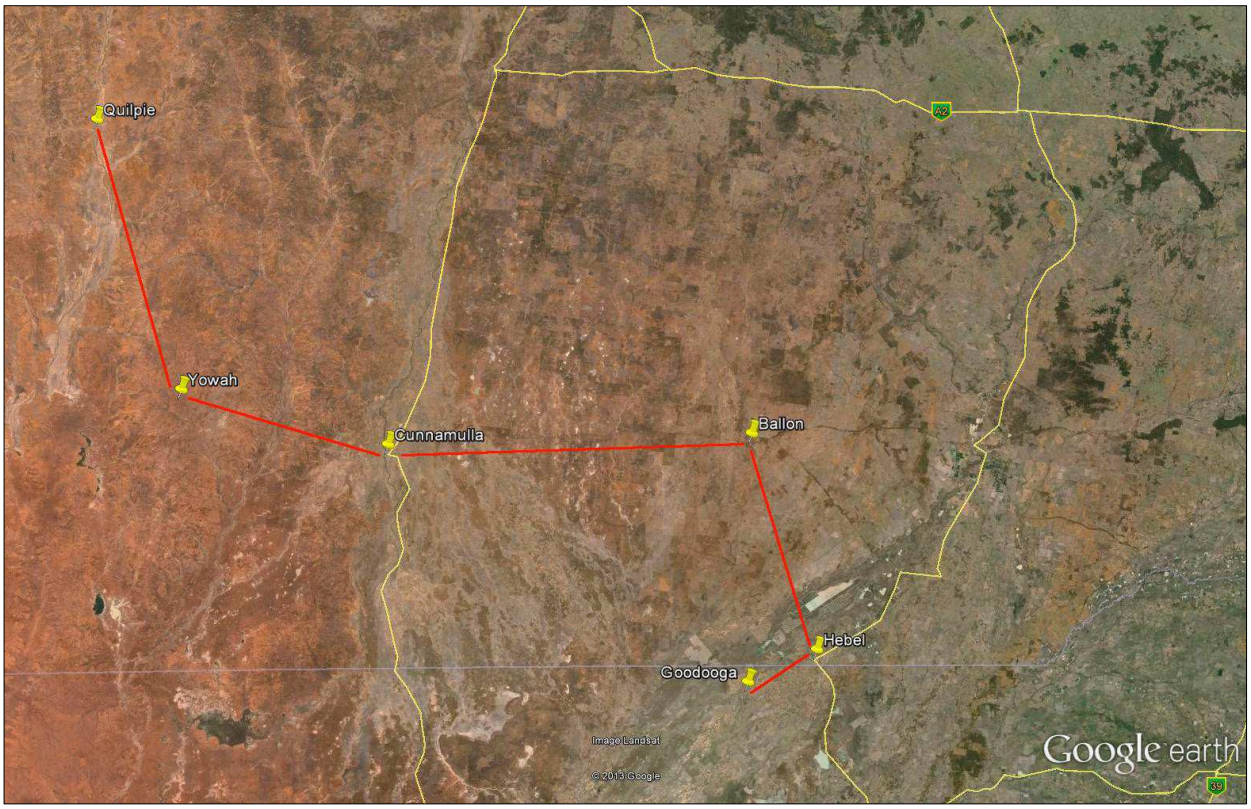

Figure 6: Ground travel route Goodooga to Quilpie waterhole (image: Google Earth).

is not a map of waypoints and travel, but simply a representative map of mainly *bora* grounds. Figure 7 shows the star map, and Figure 8 shows the equivalent ground map.

Figure 7: Regional *bora* star map (image: courtesy Starry Night Education).

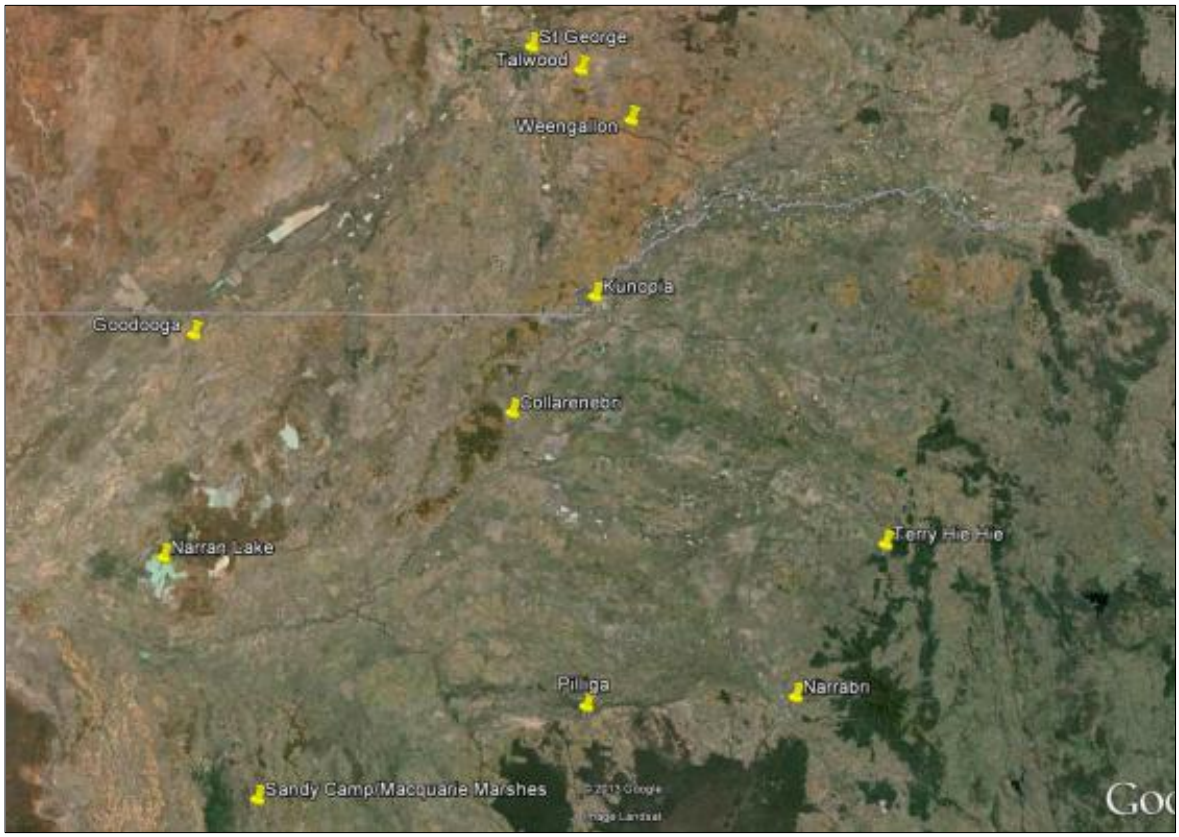

Figure 8: Regional *bora* ground map (image: Google Earth).

The Euahlayi, Kamilaroi and Bigambul people used the *bora* grounds in this map, but at Sandy Camp a number of language groups joined for ceremonies, including the Euahlayi, Kamilaroi, Murrawarri, Ngemba, Wiradjuri, Wongaibon and Wailwon.

There is some symmetry between the star map and the ground map if you turn the star map image about 45° to the right, but it was probably not intended to be used as an exact representation, and certain locations, such as Narran Lake, are clearly out of place.

All the stars identified for the star maps described in this study have been checked to see if (1) they are visible in mid-August from north central NSW, and (2) if they are sufficiently bright that they can be seen with the naked eye. In both cases, this was correct. In the second case, from a dark sky location as no doubt existed prior to the light pollution brought by Europeans, the visual limiting magnitude (dimness able to be perceived) is 7.5–8.0 (Bortle, 2001: 126–127). All the stars in the star maps are significantly brighter than the visual limiting magnitude.

5 CONCLUSIONS

Aboriginal people in Australia have a rich and well-developed knowledge of the night sky, which they use in their culture of oral transmission of knowledge, and as a means of assisting in their management of resources. The Euahlayi language group is a relatively small language group located in north-central NSW and south-central QLD, and shares many cultural aspects with the Kamilaroi and other surrounding language groups.

We have shown that while many Aboriginal cultural groups have a rich knowledge of the night sky, this does not necessarily mean that they all use the stars and night sky for actual navigation in the sense of European celestial navigation. This could be because they have no need to travel at night, or could be related to cultural reasons, such as the difference in the use of astronomy between Aboriginal and European peoples.

There is clear evidence that before the European invasion (and after), there was a very well-established and extensive network of trade routes in Australia, used extensively by Aboriginal people for trading in goods, ceremonies and stories, and that these trade routes were aligned with songlines and Dreaming stories, many of which covered vast distances across the Australian continent. These songlines sometimes had their equivalents in the night sky, also crossing great distances, while the connections between the songlines on the ground and in the night sky are yet to be confirmed.

There is no evidence that Aboriginal people possessed portable maps of the night sky, other than some way-finding devices, the purposes of which remain unclear. However, the Euahlayi people used a known pattern of stars in the night sky to teach and remember a number of waypoints on a route to a destination, often a ceremonial gathering place. This star map was used in winter during the planning for the summer travel, and we have identified at least three routes from Euahlayi country to ceremonial or resource destinations. A further star map identified the general location of many of the *bora* ceremonial grounds in north-central NSW and south-central QLD, but was not used for actual travel. These *bora* grounds linked at least three language groups in that area, but one ceremonial site was identified as a place for gatherings of up to seven language groups.

Further research on the use of star maps for travel by other language groups, particularly those who might have met the Euahlayi peoples at common ceremonial locations, may lead to a clearer understanding of the Aboriginal use of the night sky for travel.

6 ACKNOWLEDGEMENTS

We acknowledge and pay our respects to the traditional owners and Elders, both past and present, of the Kamilaroi, Euahlayi, Ngemba and Murrawarri peoples. We thank the participants of the Kamilaroi project, Michael Anderson, Rhonda Ashby, Lachie Dennis, Paul Gordon, Greg Griffiths, Brenda McBride, Jason Wilson, and one anonymous person, for their stories and those of their families. We particularly thank Michael Anderson for his detailed story on the star maps, which is central to this study. Michael has acknowledged *Gheedjar* (Walter Sand) and Jack McCrae as his sources for this knowledge, who told him they were taught by *Boobar* (Fred Reece) and Jack Murphy. Anderson was also told that Jack Murphy was taught by a descendant of King Rory from Walgett, who taught Ridley his knowledge of the sky in 1872 (Ridley, 1873: 273–275).

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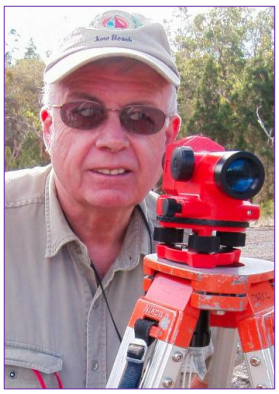

He was educated as an anthropologist (B.A., Gettysburg College, USA), but never practiced as one. After retiring from careers as a military pilot then businessman, with a long interest in astronomy, he took up the challenge to combine his interests in anthropology and astronomy by studying Australian cultural astronomy. Mr Fuller is now studying Kamilaroi astronomy for a Master of Philosophy in Indigenous Studies at Macquarie University in Sydney, Australia.

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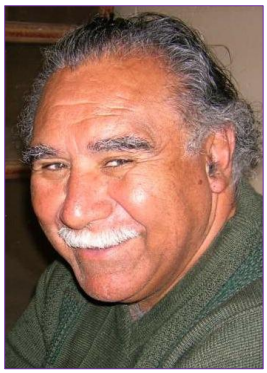

Michael Anderson (Nyoongar Ghurradjong Murri Ghillar) is an Aboriginal rights activist, leader of the Euahlayi tribe of 3,000 people living in northwestern New South Wales, and Native Title claimant to their traditional lands on their behalf. He was taught Euahlayi customs and traditions through his people's sacred ceremonies. Mr Anderson has lectured in Aboriginal studies and Aboriginal politics at several Australian universities, where he wrote and taught units in Aboriginal studies that were inclusive of traditional Aboriginal society.

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ARE SUPERNOVAE RECORDED IN INDIGENOUS ASTRONOMICAL TRADITIONS?

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Abstract: Novae and supernovae are rare astronomical events that would have had an influence on the sky-watching peoples who witnessed them. Although several bright novae/supernovae have been visible during recorded human history, there are many proposed but no confirmed accounts of supernovae in indigenous oral traditions or material culture. Criteria are established for confirming novae/supernovae in oral traditions and material culture, and claims from around the world are discussed to determine if they meet these criteria. Aboriginal Australian traditions are explored for possible descriptions of novae/supernovae. Although representations of supernovae may exist in Aboriginal traditions, there are currently no confirmed accounts of supernovae in Indigenous Australian oral or material traditions.

Keywords: Historical astronomy, ethnoastronomy, cultural astronomy, Aboriginal Australians, novae, supernovae.

1 INTRODUCTION

Like many indigenous cultures around the world, Aboriginal Australians possess detailed knowledge of the night sky, using it for navigation, calendars and time-keeping, food economics, ceremonies and social structure (e.g. Cairns and Harney, 2003; Fredrick, 2008; Hamacher and Norris, 2011a; Johnson, 1998). This sky knowledge involves an understanding and explanation of planetary motions, relative stellar positions, lunar phases and tides, and the position of the rising and setting Sun throughout the year with respect to the landscape (Hamacher and Norris, 2011a; Norris and Hamacher, 2009; Norris et al., 2013). This knowledge includes explanations of transient phenomena, such as meteors, comets, eclipses and aurorae (Hamacher and Norris, 2010; 2011b; 2011c; and Hamacher, 2013, respectively). This sky knowledge has been passed down through successive generations in the form of oral traditions and material culture (Clunies-Ross, 1986).

Indigenous astronomical traditions contain scientific information that explains the natural world in terms of cause-effect. This scientific information was based on observation and deduction and was used for predictive purposes. Indigenous Australians linked lunar phases to tides and used this information as a guide for deciding when to fish, and their traditions contained an explanation as to how and why the Moon was connected to tides (e.g. Johnson, 1998: 27, 37). The heliacal rising of the Pleiades signalled the arrival of winter in the Central Desert (Tindale, 2005: 374), while the rising of the celestial emu after dusk informed Aboriginal people that emu eggs were ready to be collected (e.g. Fuller et al., 2014). Similarly, transient phenomena, whether rare or common, are often linked to special events on the Earth. For example, the sudden flash of a meteor may coincide with a death in the community, or the appearance of a comet or eclipse might coincide with a famine, drought or battle (Johnson, 1998: 86–89).

2 NOVAE AND SUPERNOVAE

Novae are stellar explosions that occur in white dwarf stars that are members of binary systems. When the companion star (generally a main sequence star or a red giant) expands, ejected gas fills its Roche Lobe and overflows into the Roche Lobe of the white dwarf, forms an accretion disk and settles on the surface of the white dwarf. Eventually conditions (e.g. pressure and temperature) are right to ignite a thermonuclear explosion in the accumulated surface layer, causing a nova outburst. This event may be visible to us and seen with the naked eye for periods ranging from days to weeks.

A supernova is the explosion of a star, and is one of the most violent events in the Universe. The energy released during a supernova explosion is up to 10 billion times the star's normal energy output. These events can occur in one of two primary ways: (1) A compact star, such as a white dwarf, accretes enough material to exceed the Chandrasekhar limit (~1.4 $M_{\odot}$). Its core temperature then reignites nuclear fusion, causing a runaway reaction that leads to a supernova; and (2) If a massive star (>8 $M_{\odot}$) undergoes core collapse, it will release a tremendous amount of potential gravitational energy, blowing the outer layers of the star into space at speeds approaching 10% the speed of light. A supernova can release as much energy in a month as our Sun does in 10 billion years. Supernovae can outshine entire galaxies and may be visible to the naked eye for a period ranging from weeks to years.

Both novae and supernovae form shells of heated material that are ejected into space.

Those formed from novae are much less massive and have a lifetime of a few hundred years. Supernova remnants have much longer lifetimes and will expand into the surrounding medium for hundreds to thousands of years before slowing to local speeds. The interested reader is directed to Arnett (1996) for an in-depth discussion of supernovae physics.

Bright novae and supernovae would have had an impact on the people and cultures that witnessed them. Several have been visible to the naked eye over the last few thousand years, some of which appeared brighter than the brightest stars. Yet accounts of these events in oral (non-literate) cultures around the world remain scant in the literature.

3 HISTORICAL NOVAE AND SUPERNOVAE

Seven bright novae (m_V = +2 or brighter) have been visible from Earth since 1890.[1] Only one —V603 Aquilae—rivalled Sirius (Alpha Canis Majoris, m_V = –1.46) in brightness, reaching a visual magnitude (m_V) of –1.4 in 1918 (Harrison et al., 2013). Nine supernovae are known to have been visible to the naked eye in the last 2,000 years (Green, 2002), seven of which had an apparent magnitude of 0 or brighter (see Table 1).

Supernovae are generally named after the year in which they were visible (or believed to have been visible). For example, a supernova that appeared in the year 1054 CE is named 'SN 1054'. Recorded supernovae visible to the naked eye appear roughly once every 250 years on average. Historical supernovae have been recorded by literate cultures such as the Chinese, Koreans and Romans (Chu, 1968; Clark and Stephenson, 1982; Shen, 1969; Stothers, 1977). A list of currently-known bright supernovae recorded over the last 2,000 years, plus a few bright supernovae that are believed to have been visible before this time, is given in Table 1 in order of age (oldest to youngest).

Most of these records were taken from cultures in the northern hemisphere. Since a significant portion of the galactic plane, and the Large and Small Magellanic Clouds, are only visible at more southerly latitudes, some bright supernovae were not recorded by literate cultures.

Since indigenous cultures around the world were keen observers of the night sky (Ruggles, 2011), we expect to find descriptions of novae/supernovae in indigenous oral or material culture. Many claims of these records have been made. The next section establishes criteria for confirming these accounts, and is followed by a brief survey of novae/supernovae claims from around the world. Finally, we analyse an oral tradition from Australia that describes the appearance of a bright new star in the sky.

4 IDENTIFYING NOVAE AND SUPERNOVAE IN INDIGENOUS CULTURAL TRADITIONS

Since transient celestial phenomena, such as comets, meteors and eclipses, are recorded in oral and material traditions by cultures around the world, it is likely that supernovae were also recorded. But identifying a clear example is difficult, as two main problems impede our ability to directly associate an oral tradition or art form with a particular supernova event: (1) descriptions in oral traditions are generally ambiguous; and (2) motifs in material culture are sometimes open to interpretation. Because of this, misidentifications and misinterpretations of supernovae-in-culture are common. This necessitates a list of criteria required to confirm a nova/supernova in oral traditions (O), material culture (M) or both (OM):

Table 1: Known bright (minimum m_V = 2.0) supernovae since 1 CE, plus five supernovae known to have been visible during human (pre)history.

Name	Location	RA	Dec	m_V	D (ly)	Type	Age
Vela	Vela	08h 34m	−45° 50′	−10 ?	815±98	-	11000-12300 BP
Veil	Cygnus	20h 45m	+30° 42′		1470	-	~5000 BP
HB9	Auriga	05h 01m	+46° 40'		2608±1304		4000-7000 BP
Puppis A	Puppis	08h 24m	−42° 59'	−1.4 ?	7000	-	~3700 BP
E0102-72	Tucana	01h 04m	−72° 01′	+2	190000	-	1000–2650 BP
RX J0852.0-4622	Vela	08h 52m	−46° 22'		700?	-	680-1100 BP
SN 185	Circinus	14h 43m	−62° 30′	< −8 ?	8200	Ia(?)	185 CE
SN 386	Sagittarius	18h 14m	−19° 46′	+1	14700	II	386 CE
SN 393	Scorpius	17h 14m	−39° 48′	−1	34000	-	393 CE
SN 1006	Lupus	15h 02m	−42° 06′	−7.5	7200	Ia	1006 CE
SN 1054	Taurus	05h 35m	+22° 01′	−4	6500	II	1054 CE
SN 1181	Cassiopeia	02h 06m	+64° 50′	−1	8500	-	1181 CE
SN 1572	Cassiopeia	00h 25m	+64° 09′	−4	8000	Ia	1572 CE
SN 1604	Ophiuchus	17h 30m	−21° 29′	−2.5	14000	Ia	1604 CE

Notes: The peak magnitude of RX is not known, as its distance is controversial. The data are shown in order of age, citing their designation, age or year discovered (CE = Common Era, BP = Before Present), current home constellation, celestial coordinates (right ascension and declination in J2000 from SIMBAD: http://simbad.u-strasbg.fr), and the peak visual magnitude, if known (there is some uncertainty in these estimates—the values provided are estimates only). Data for SN 185 to SN 1604 are from Stephenson and Green, 2002; RX J0852.0-4622 from Aschenbach et al., 1999; E0102-72 from Hughes et al., 2000; Puppis-A from Winkler et al., 1988; HB9 from Leahy and Tian, 2007; Veil from Blair et al., 2009; and Vela from Cha et al., 1999. The m_v of Puppis-A was calculated using current estimates of its distance.[2]

(1) O: There is a description of a 'new star' appearing in the sky;
(2) OM: The location on Earth from which the 'new star' was seen;
(3) OM: The period in time when the 'new star' appeared;
(4) OM: The location of the 'new star' in the sky.
(5) M: Evidence that the motif represents a star.
(6) OM: A nova/supernova remnant is located where a 'new star' was visible.

In many Indigenous Australian cultures, as with other global cultures, spirits of the deceased take the form of stars (Johnson, 1998: 16-19). Therefore, stories that describe the appearance of a bright new star in the sky may be a reflection of this belief and not an account of a nova or supernova. Establishing a date of origin for an oral tradition is also problematic since many Indigenous traditions are not set in linear time. Frequently, they refer to a creation period 'long ago'. For novae/supernovae representations in material culture, archaeometric-dating methods could potentially be used to identify a time period from which the account may have taken place, assuming the artefact or artwork was made when the supernova was visible. But without ethnographic or historical evidence, connecting material culture to these astronomical events is speculative. Regarding criterion #6, the supernova record is incomplete, so a cultural description of a supernova event could assist astronomers in locating a supernova remnant, particularly in the southern latitude skies where records are fewer than in the north. Nova remnants also have much shorter lives than supernova remnants. This could make identifying a nova difficult (even though this is necessary for its confirmation). Although not a set criterion, it would be helpful (where this is possible) if an oral tradition specifically acknowledges that the 'new star' is no longer visible to the naked eye.

Each criterion has a potential 'gray area', such as the time the new star was visible (does the time estimated need to be within a day, a year, a century?) or the star's location in the sky (within a degree or two of the supernova remnant or just in that general part of the sky?). Even providing evidence that a motif represents a star can be challenging. These criteria serve only as a guide, and any possible supernova account that is weighed against these criteria will need to be assessed individually.

These criteria will now be applied to proposed supernovae accounts from around the world, followed by a survey of possible accounts from Australia.

5 PROPOSED NOVAE AND SUPERNOVAE ACCOUNTS IN CULTURE

5.1 Bolivia: Vela SN

George Michanowsky proposed that a supernova was witnessed by indigenous Bolivians and recorded in their rock art (Anonymous, 1973). A petroglyph on a flat rock is believed to be associated with an annual festival. The petroglyph shows four small circles, flanked by two larger circles. Michanowsky believes the four smaller circles represent the stars of the 'false cross' on the border of Carinae and Vela, and the two larger circles represent Canopus (Alpha Carinae) and the Vela supernova. He cites the name of this part of the sky (the region of the Gum Nebula) by local indigenous people as *Lakha Manta*, apparently meaning *The Gateway to Hell*, and mentions some local astronomical traditions describing two celestial dogs that chased a rhea across the sky, which they killed in the constellation of Vela. Michanowsky's interpretation is speculative and there is no ethnographic evidence to support this hypothesis. The indigenous people of the area claim no knowledge regarding the petroglyph's meaning or any connection to their astronomical traditions.

5.2 Iraq (Mesopotamia): Vela SN

George Michanowsky (1977) also claimed that the Vela supernova was witnessed by the Mesopotamians and recorded on their artefacts. He claims the Vela supernova was recorded as the "… giant star of the god Ea in the constellation of Vela of the god Ea …" on a clay tablet. Michanowsky's reasoning for interpreting this symbol (according to his translations) is that the "… constellation to the north is the 'Exalted Lady': the constellation Puppis." This would have put the "giant star" on the border of the constellations Vela and Puppis, where the Vela supernova remnant is located. Michanowsky cited an age of ~6,000 years for the Vela supernova, despite the age estimated at the time being between 6,000 and 11,000 years. Besides the number of assumptions and interpretations necessary for this hypothesis to be true, modern astrophysical observations show that the Vela supernova was visible in the sky >10,000 years ago (Cha et al., 1999), not at the lower limit of 6,000 years cited by Michanowsky.[3]

5.3 Burzahom, India: SN HB9

According to Iqbal et al. (2009) and Joglekar et al. (2011), Neolithic art at Burzahom (near Srinagar, India) depicts two celestial objects above a pair of hunters (Figure 1E). They cite the date of the art as 3,000–1,500 BCE and Joglekar et al. suggest that the motifs represent a full (or near full) Moon and a supernova. Searching for

supernova remnants dating to within this time period and near the ecliptic, Joglekar et al. propose the candidate is supernova HB9, which dates to ~5,000–2,000 BCE (Leahy and Tian, 2007). The meaning of the rock art is open to interpretation and the hypothesis that this represents a supernova is based on loose assumptions.

5.4 New Zealand: SN 185

Green and Orchiston (2004) propose that *Mahutonga*, a star with no modern counterpart that is described in the astronomical traditions of the Maori of Aotearoa (New Zealand), may be a description of a supernova. *Mahutonga* means "… a star of the south that remains invisible." The relationship between the term *Mahu* and the constellation Crux suggests it is related to this part of the sky. Green and Orchiston search for candidate supernovae near Crux that would have been visible over the last millennium when the Maori arrived in New Zealand. Due to its location near Alpha Centauri, the authors suggest SN 185 is the best candidate. This would mean that the *Mahutonga* reference is proto-Polynesian in origin, as this supernova was visible nearly 1,000 years before the Maori colonised New Zealand around 1,280 CE (Lowe, 2008). It is also possible the historical supernovae record is incomplete and *Mahutonga* may refer to a currently-unknown supernova in that region of the sky.

5.5 Arizona, USA: SN 1006

Barentine (2006) suggests that a Hohokam petroglyph outside of Phoenix, Arizona (Figure 1A) represents SN 1006. The area was occupied from 500–1100 CE and Barentine claims the event is depicted "… in context with recognizeable asterisms …" such as Scorpius. The claim was challenged by archaeoastronomers Anthony Aveni and Edwin Krupp as a misinterpretation of a common motif (Cull, 2006). This reference is a conference abstract, and nothing else has been published in the literature. Until further evidence is presented, this interpretation is speculative.

5.6 Guam: SN 1054

Villaverde (2000a) claims that an oral tradition from the Micronesian island of Guam may describe the appearance of a new star in the sky that rivalled Venus in brightness. Villaverde believes this new star is SN 1054. Researcher Frank Guerrero claims that pictograms at Rit-idian Cave on the northern end of Guam (Figure 1B) represent events that occurred in the constellation Auriga, which is adjacent to Taurus where SN 1054 was visible (Villaverde, 2000b). The cave contains pictograms showing a lunar calendar estimated to have been made some 4,000 years ago (Iping, 1999). This research is still in progress and has not yet been subject to peer review.

5.7 New Mexico, USA: SN 1054

The most famous—and controversial—claim of a supernova being represented in material culture is that of Anasazi rock art in Chaco Canyon, New Mexico (e.g. Brandt and Williamson, 1979; Brecher et al., 1983) (Figure 1C). Some researchers claim that a motif near a hand stencil and a crescent Moon represents SN 1054, which was visible in the sky from the site during the period of Anasazi Culture and would have appeared below the crescent Moon on the date it was first visible, as noted by Chinese historical records. Despite being wildly popular with the public, many researchers within the anthropological and archaeological communities do not support this interpretation, refuting these claims as a misrepresentation of the crescent Moon and Venus (e.g. see Collins et al., 1999; Koenig, 1979; and Schaefer, 2006, among many).

5.8 Srinagar, India: SN 1604

Sule et al. (2011) claim to have identified SN 1604 in a mural on a doorway arch (Figure 1D) in the mosque of Madani, in Srinagar, India. According to Sule et al., the mural shows the alleged supernova as a dragon's head on the tail of the constellation Sagittarius. This interpretation has been challenged as a misidentification of Islamic astrological iconography (van Gent, 2013).

5.9 Victoria, Australia: 1843 Eruption of Eta Carinae

In the 1840s, the hyper-massive luminous blue variable (LBV) star Eta Carinae went through a period of instability and ejected 20 solar masses of stellar material into space, brightening to such an extent that it appeared as the second brightest star in the night sky before fading to invisibility (Smith and Frew, 2011). Hamacher and Frew (2010) demonstrated that the event was incorporated into the oral traditions of the Boorong Aboriginal people in northwestern Victoria, near Lake Tyrrell. This account was confirmed because an Englishman named William E. Stanbridge recorded a detailed description about Boorong astronomy from two Boorong men in the 1840s. The description includes the brightness, colour, position and catalogue number of the star (Stanbridge, 1858, 1861). It must be noted that this star does not classify as either a nova or a supernova. It was an eruptive variable that did not destroy the star. This is commonly called a 'supernova impostor' event.

5.10 Australia: Unidentified

Murdin (1981) speculates that a circular 'bicycle wheel' motif in Aboriginal rock art in Sturts Meadows, western New South Wales, Australia, represents a supernova (Figure 1F). These motifs, as well as others sometimes called 'sun-burst' designs, are found in rock art across Australia (e.g. McCarthy, 1983: 163; Flood, 1997: 183, 185, 208, 241). Two Aboriginal petroglyphs in Lane Cove National Park in the northern suburbs of Sydney (known to the author) show a crescent and a 'sunburst' design, reminiscent of the Chaco Canyon rock art. The meaning of these 'sunburst' motifs varies, and in many places (such as Lane Cove) their meaning is unknown. None is known to depict supernovae.

5.11 Summary

Only one of the accounts described in this section confirms the sudden brightening of a star in oral traditions: the 'supernova-impostor' eruption of Eta Carinae in 1843. This event was witnessed by the Boorong people of western Victoria, Australia and incorporated into their oral traditions. This is confirmed because Stanbridge recorded the required data, such as the star's physical appearance, position in the sky and catalogue number during the star's outburst. However, the Great Eruption of Eta Carinae was not a real nova or supernova. All other cases described above are inconclusive and require further evidence before they could be confirmed as nova/supernova accounts.

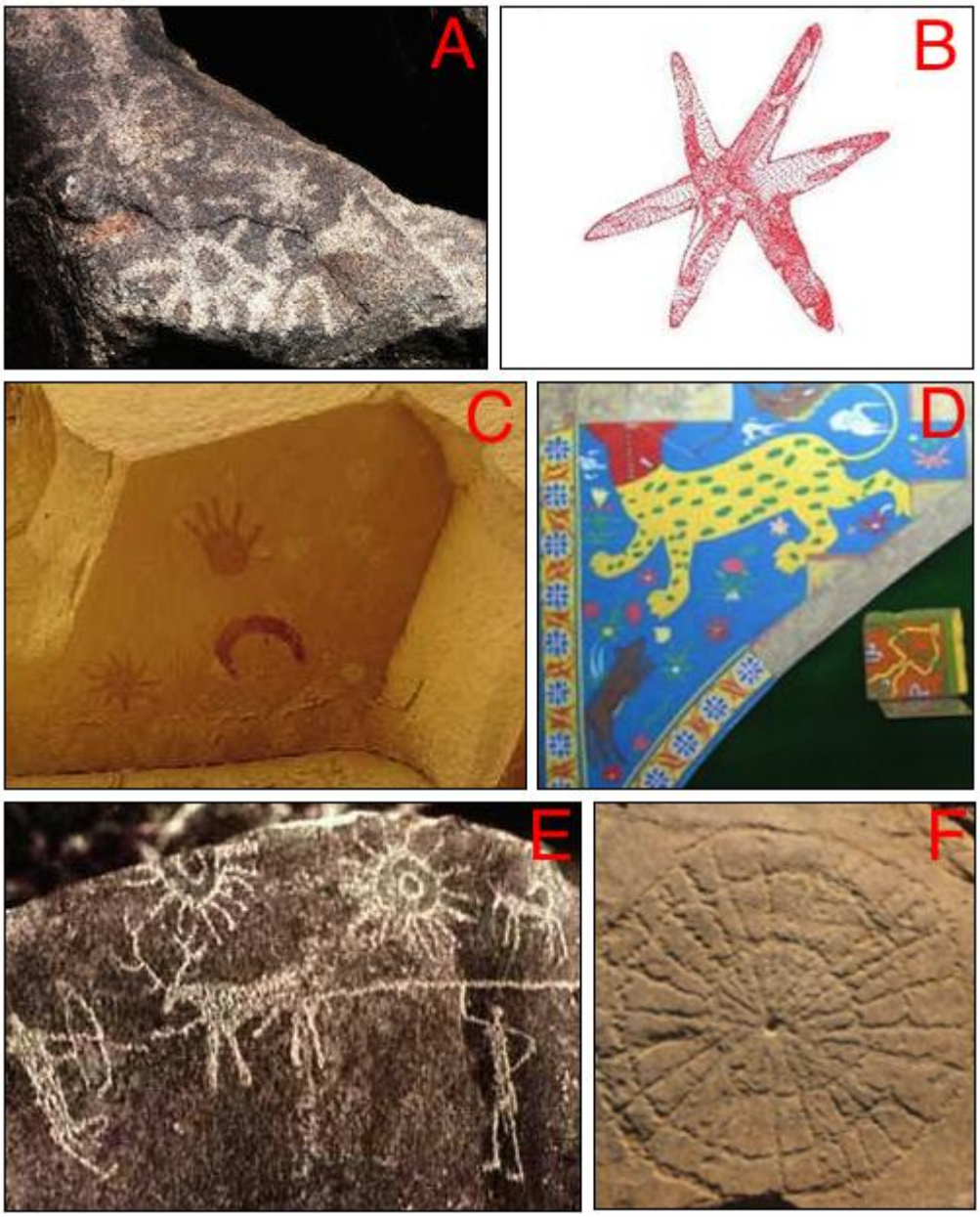

Figure 1: **A**: Hohokam rock art, Arizona, USA (photograph: J. Barentine); **B**: Ritidian Cave rock art, Guam (illustration by Michael S. Argenal); **C**: Chaco Canyon rock art, New Mexico, USA (photograph: R. Lussier); **D**: Mural in the Mosque of Madani, Srinagar, India (after Sule et al., 2011); **E**: Neolithic rock art, Burzahom, India (photograph: http://ignca.nic.in/images/rock/big/brock_03.jpg), **F**: Aboriginal rock art, New South Wales Australia (after Murdin, 1981: 477).

The following section analyses a possible supernova account from Australia. As with the accounts in the previous section, the story is analysed to demonstrate the challenges and difficulties in linking oral traditions and historical supernovae.

6 A SUPERNOVA ACCOUNT FROM AUSTRALIA?

Literature regarding Australian Indigenous oral traditions was surveyed for references to possible supernovae. One story was identified that indicated the appearance of a bright new star in the sky. The story, entitled "The Fisherman Brothers", is from the Yolngu people of Arnhem Land in the Northern Territory of Australia (Wells, 1973: 31–36). In the story, two brothers, *Nuruguya-mirri* (the older) and *Napiranbiru* (the younger), were fishing in a canoe when a storm hit, destroying their boat. *Nuruguya-mirri* was stronger and helped *Napiranbiru* reach the shore, but drowned while saving him. To honour *Nuruguya-mirri's* courage, the community held a ceremony. That night, the people saw "... a bright star shining, new and sparkling ..." in the sky. The people said the new star was *Nuruguya-mirri*. When *Napiranbiru* was an old man and passed away, he asked the spirits to place him in the sky with his brother. The brothers are now two bright stars close together on the bank of the sky-river, called *Milnguya* (Milky Way). A nearby faint star is the brothers' little campfire. These stars have been shining in the sky "... for longer than anyone can remember ..." (Wells, 1973: 31).

Variations of the story are found across Arnhem Land. Mountford (1956: 496-499) cites a similar identical story from Blue Mud Bay, Arnhem Land. In this account, two brothers are fishing in a bark canoe near Woodah Island, northwest of Groote Eylandt off the south-eastern coast of Arnhem Land. On their way home, a storm hit and the waves capsized the brothers' canoe. In this account, the younger brother (*Jikawana*) dies first, followed by the older brother (*Nungumiri*). The story of the brothers' demise is reflected in the sky. The brothers, the fish and their canoe are seen as dark absorption nebulae ('starless spaces') in the Milky Way. According to Mountford (1956: 498), the younger brother is a dark nebula in the Milky Way within the constellation Serpens, and the elder brother is a dark nebula near Sagittarius. The rock on which the elder brother collapsed is seen as a portion of the Milky Way near Theta Serpens, and their canoe is represented by a line of four small stars near Antares (Alpha Scorpii). This story is represented in Aboriginal bark paintings from Arnhem Land (see Figure 2).

Figure 2: A Yolngu bark painting of the Fisherman Brothers in the Milky Way (after Mountford, 1956: 499, Plate 157-A (cropped); see, also, Plate 157-C).

Additional sources were examined for variations of this story (e.g. Allen, 1976; Berndt and Berndt, 1989; Chaseling, 1957; Harney and Elkin, 1968; Mountford, 1956; Warner, 1937). Wells' account is the only version that mentions the appearance of a bright new star, although Allen mentions a bright flash of light in the sky. It is unclear if this account was recorded exactly as the Aboriginal custodians told it or if Wells used a degree of 'poetic license' in retelling the story, inserting the description of a 'new star' herself.

According to Wells, the bright new star is still visible as one of two stars close together along the sky river (Milnguya), with a fainter star nearby representing the brothers' celestial campfire (Wells, 1973: 31). The identity of the two stars representing the brothers is not given, but is most likely the optical double stars Shaula and Lesath (λ and υ Scorpii, m_v = +1.6 and +2.7, respectively), which are both commonplace in Yolngu and other Aboriginal astronomical traditions (Fredrick, 2008: 118; Johnson, 1998: 71, 74; Mountford, 1956: 481, 501; Mountford, 1976: 459-460; Stanbridge, 1858: 139). Shaula is the second brightest star in Scorpius and Lesath is separated from Shaula by ~0.6°. They both lie within the galactic bulge near the border of a dark dust lane. To the Aboriginal people of Groote Eylandt, the acronychal rising of Shaula and Lesath (at the end of May) signals the end of the wet season and the start of *mamariga*—a dry season marked by southeasterly winds (Mountford, 1956: 481). These stars are seen as the children of the planets Venus (*Barnimbida*, father) and Jupiter (*Duwardwara*, mother). Mountford does not specify that these are the boys in the Fishermen Brothers story, but variations of stories, or stories of the same stars, exist within the same language groups. If the identity of the two brothers is Shaula and Lesath, the faint star (the brothers' little campfire in the sky) could be HR 6583 (Spectral Type K0/K1III, m_v = +5.53), Q Scorpii (G8/K0III, +4.27) or HR 6501 (K0III, +5.99).

The story indicates that all three stars are still visible today. The criteria set above are not met, meaning this is an unconfirmed supernova claim. It is worth noting that a bright supernova was visible within 4° of Shaula and Lesath in the year 393 CE. SN 393 occurred in a dark patch within the tail of Scorpius (Figure 3). SN 393 was recorded by Chinese astronomers in the asterism of Wei (the tail of Scorpius) in the second lunar month (between 27 February and 28 March) and was reportedly visible for about seven months before fading from visibility (Clark and Stephenson, 1975; Wang, 2006). It appeared as a bright star with an estimated m_v of −1 at its peak, making it the second brightest star in the sky after Sirius before it faded from visibility. It is unknown whether this supernova relates to the Fisherman Brothers story, but the connection seems improbable.

7 DISCUSSION AND CONCLUDING REMARKS

We are certain that ancient and indigenous people witnessed novae and supernovae, and we strongly believe that these events were incorporated into their oral traditions and possibly material culture. There is only solid evidence that the Boorong people of western Victoria noted the Eta Carinae supernova-impostor event in the 1840s and incorporated it into their astronomical traditions (Hamacher and Frew, 2010). Without the written information pro-

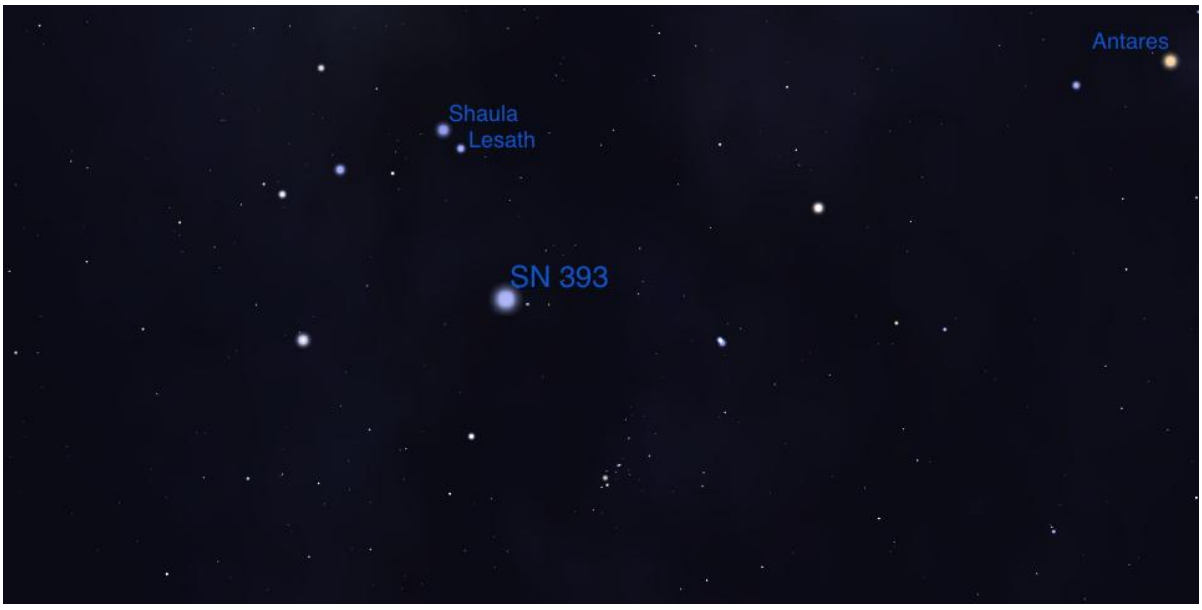

Figure 3: SN 393 as seen in the tail of Scorpius near the stars Shaula and Lesath (image from Stellarium, with labels added by the author).

vided by W.E. Stanbridge, confirming this record would be impossible. None of the remaining claims presented in this paper are confirmed and many are either not accepted by the academic community or have not yet been subject to peer review (e.g. Anonymous, 1973; Barentine, 2006; Michanowsky, 1977; Villaverde, 2000a; 2000b).

The Fishermen Brothers story from Australia indicates the appearance of a bright new star in the sky. The location from which the story was taken is known, but the location of the 'new star' in the sky is inferred. The time period in which the star appeared is unknown, and only one story describes the appearance of a bright new star. From the criteria set in Section 4, it is considered unconfirmed.

This paper establishes criteria necessary to identify novae/supernovae in oral traditions or material culture. It should be emphasised that attempts to link oral traditions or material culture to novae/supernovae are worthwhile. The identification of these phenomena in oral accounts or material culture will benefit our understanding of cultural astronomy and indigenous knowledge traditions. These accounts could also potentially lead astronomers to unrecorded supernova remnants.

8 NOTES

1. IAU Central Bureau for Astronomical Telegrams, CBAT List of Novae: http://www.cbat.eps.harvard.edu/nova_list.html
2. Using the standard equation $m = -5 + 5*\log_{10}(d) + M + A$, where m is the star's apparent magnitude, d is the star's distance in parsecs (2,147 pc), M is the star's absolute magnitude (−17 for a Type II SN), and A is galactic extinction (1.8 magnitudes per kpc for stars in the Galactic Plane within a few kpc of Earth). This only serves as a rough estimate.
3. If Michanowsky's translation of the position of the 'giant star' is accurate, and assuming the 'giant star' was a supernova, another possibility could be the Puppis-A supernova, which was visible in the same part of the sky ~3,700 years ago. At 8.5 times the distance of the Vela remnant, Puppis-A would have been much fainter than Vela, but still bright ($m_v = -1.4$, approximately as bright as Sirius). It should be noted that Michanowsky's claims are not widely accepted and have been criticized by the academic community (e.g. see Huyghe, 1981).

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THE EMU SKY KNOWLEDGE OF THE KAMILAROI AND EUAHLAYI PEOPLES

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Abstract: This paper presents a detailed study of the knowledge of the Kamilaroi and Euahlayi peoples about the 'Emu in the Sky'. This study was done with ethnographic data that was not previously reported in detail. We surveyed the literature to find that there are widespread reports of an 'Emu in the Sky' across Aboriginal Australian language groups, but little detailed knowledge available in the literature. This paper reports and describes a comprehensive Kamilaroi and Euahlayi knowledge of the Emu in the Sky and its cultural context.

Notice to Aboriginal and Torres Strait Islander Readers: This paper contains the names of people who have passed away.

Keywords: Australian ethnoastronomy, Kamilaroi people, Euahlayi people, Emu in the Sky

1 INTRODUCTION

Cultural astronomy is the interdisciplinary study of how various cultures have understood and used astronomical phenomena, and the mechanisms by which this understanding is generated (Iwaniszewski, 2009; Sinclair, 2006). It is generally divided into archaeoastronomy (past cultures) and ethnoastronomy (contemporary cultures). Because cultural astronomy is a social science informed by the physical sciences (Ruggles, 2011), the field has been dubbed the "anthropology of astronomy" (Platt, 1991: S76).

Fuller et al. (2014: 3–4) reviewed the history of cultural astronomy in an Aboriginal Australian context. They report that while there is a rich knowledge of Aboriginal astronomy, the literature on Kamilaroi and Euahlayi astronomy, based on ethnography from the nineteenth century, was often very limited in detail and contained many contradictions between the stories reported. For that reason, this project (involving a collaboration between Robert Fuller, Ray Norris, and Michelle Trudgett) included an ethnographic phase to collect knowledge of the sky from current Kamilaroi, Euahlayi and neighbouring communities. The ethnography comprised multiple interviews and recordings of stories during 2013 from eight participants with mostly mixed heritage from the Kamilaroi, Euahlayi, Ngemba and Murrawarri communities. These participants are mentioned in the Acknowledgements. One participant, Michael Anderson, with both Euahlayi and Kamilaroi heritage, provided such a complete description of the 'Emu in the Sky' as it related to his culture that he has been included as a co-author of this paper. The 'Kamilaroi Project' (as we will continue to describe the study conducted by Fuller, Norris and Trudgett) confirmed the hypothesis that the knowledge gained could add to the current body of knowledge of Aboriginal Australian sky culture. Most of the data were released under the terms of the Ethics Approval by Macquarie University. This paper presents previously-unpublished data from the Kamilaroi Project used to

determine whether the knowledge about the 'Emu in the Sky' collected through the larger project adds a deeper level of understanding to the sky culture of the Kamilaroi and the Euahlayi peoples.

Like most Aboriginal stories, those collected in the Kamilaroi Project do not just entertain and describe some physical object in the sky. Aboriginal culture is oral in nature, and oral transmission of knowledge is extremely important, particularly in regards to Law. Aboriginal Law governs all aspects of Aboriginal life, establishing a person's rights and responsibilities to others, the land, and natural resources (Law Reform Commission of Western Australia, 2006: 64). Cultural stories transmit Law, and in this respect can have different levels of meaning. Sveiby and Skuthorpe (2006: 45–51) describe four levels: one being for children (to explain nature), others being for relationships between people, relationships between the community and country, and ceremonial practices. A participant in the Kamilaroi project said that some stories could have up to "30 levels" of meaning, suggesting that most of those levels were secretive and ceremonial in nature. Here we avoid references to secret levels.

2 THE KAMILAROI AND EUAHLAYI PEOPLES

The Kamilaroi and Euahlayi peoples are an Aboriginal Australian cultural grouping located in the north and northwest of New South Wales (NSW). The Kamilaroi language groups are described as 'Gamilaraay' and 'Yuwaalaraay/ Yuwaalayaay' (Ash, et al., 2003: 1), while the Euahlayi have a similar but distinct language.

The geographical boundaries of the area defined for this study of the Kamilaroi and the Euahlayi are based on the language group boundaries reported by Austin (2008: 2), which is very similar to that proposed by Sveiby and Skuthorpe (2006: 25). Figure 1 shows the approximate area of the cultural group and languages. Participants in the Kamilaroi project have stated that the map is incorrect, in that Yuwaalayaay and Yuwaalaraay are gradations of the same Kamilaroi clan dialect, that this clan grouping, indicated by the area '6', is actually further north, and that the Euahlayi language group covers the area '7', the southern part of area '6', and westwards towards the Culgoa River. Discussion with several linguists has confirmed that a debate continues about the locations and names of some of the language groups in this area.

The population of this cultural grouping was estimated at 15,000 in 1788, and as low as 1,000

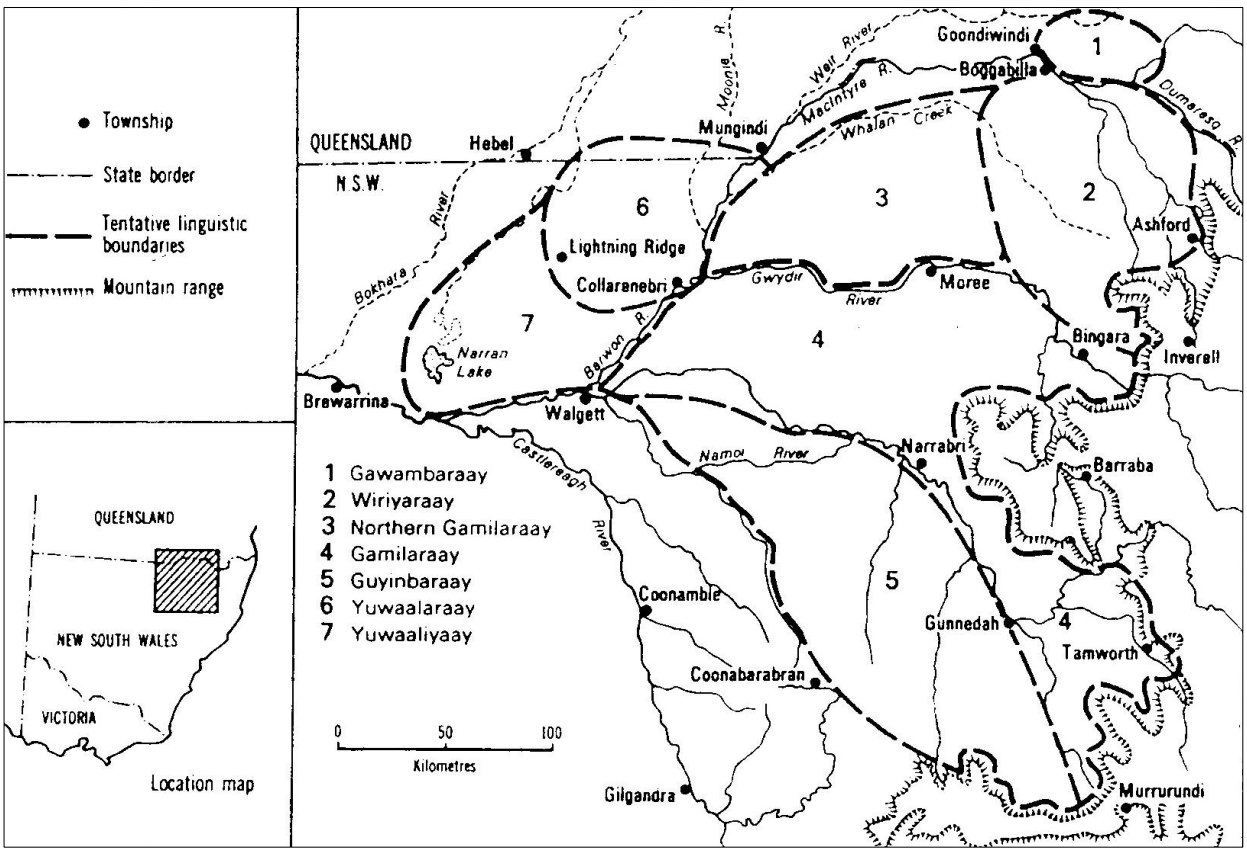


Figure 1: Language location in northern New South Wales. Note that 1–7 are Kamilaroi dialects (after Austin, 2008).

in 1842 (Sveiby and Skuthorpe, 2006: 25–26). A participant in the Kamilaroi project has speculated this could have been as large as 60,000 with the resources available in the area of the study. As a result of pressure from European settlers, there was a displacement of Aboriginal people in this group towards the northwest. The current population of people identifying as Kamilaroi and/or Euahlayi ancestry is approximately 29,000 (Kamilaroi Nation Applicant Board, 2013, pers. comm. Board Chairman).

3 THE EMU IN THE SKY ACROSS AUSTRALIA

We searched for references to an Emu in the Sky (Emu) across Aboriginal Australian literature, and found them in the literature from cultures in South Australia (SA) (Nullarbor and central desert), West Australia (WA) (Kimberley, Tanami, and Murchison regions), Northern Territory (NT), Victoria (VIC), Queensland (QLD) (Gulf country and southeast) and NSW (Sydney basin).[1]

The earliest reference to the Emu was by Stanbridge (1857: 139), who reported that the Boorong people of west central VIC said that an emu (Tchingal) resided in the dark patch (the Coalsack nebula) under the constellation Crux (commonly known as the Southern Cross). The next mention in the literature was by Ridley (1873: 273–274), who spent an evening under the sky with an Aboriginal man called King Rory from near Walgett, NSW. King Rory informed Ridley that there was an Emu (*gao-ergi*) in "... the dark space under the tree ..." meaning the Coalsack ("the tree" being the Southern Cross). King Rory, who was most likely Euahlayi, used the term *gao-ergi*, which is phonetically very similar to the current Kamilaroi/Euahlayi words *Gawarrgay/Gawarghoo* (Ash, et al., 2003: 82). We have confirmed that *Gawarrgay/Gawarghoo* is the correct word for the Emu, as *dhinawan* is used for the emu on Earth. Fuller et al. (2014: 29) argued that King Rory had been taught this knowledge by his grandfather when he was about 15, and Ridley estimated him to be about 60 in 1871, so his description of the Emu was learned well before any European explorers or settlers had reached the Walgett area, giving strong support to the idea that the Emu concept pre-dates European contact in this region. Ridley also gave King Rory's tribal name as *Ippai Dinoun*, *Ippai* being one of the Euahlayi marriage classes, and *Dinoun* being Ridley's spelling of the current *dhinawan*, which is the emu's name in Kamilaroi/Euahlayi, and was his totem, so he should have been knowledgeable about the Emu.

Later references to the Emu include Palmer (1885: 174) who has a reference from the Gulf country in QLD, Bates and Wilson (1972: 59–60), and Bates (n.d.: 13) who said that the emu in the "... Yamminga times of long ago ..." went up into the sky and "... became Wej Mor – the dark patch in the Milky Way." Bates is believed to have collected this story at Ooldea, SA, around 1904 from the Ngalea language group (Great Victoria Desert).

Basedow (1925: 315, 332–334) has several references to the Emu from northern Australia. Some unknown Aboriginal groups from the Musgrave Ranges of the Tanami Desert (WA) spoke of a "... resting emu ..." (*kaleya pubanye)* in the Coalsack. The Larrakia from near Darwin (NT) had a very complete view of the Emu which is remarkably like that of more recent investigations, and told Basedow that "... the Coalsack was the head of a gigantic emu ..." which was made up of dark patches in the Milky Way as far as Scorpius, with the legs extending even further.

In his field notes of an expedition to the Warburton Ranges, Tindale (1935: 457–459) refers to a story from the Pitjantjatjarra (Central Desert) about an Emu called *Kalaia*. Worms (1940: 271) has a reference to the Emu from his work with a Kimberley (WA) group.

Love (1987: 4) refers to his correspondence with V. Ford in 1985, in which Ford describes the Emu as follows: "... to the Aboriginal this dark constellation was the Emu, its head being the Coalsack, its body being in Scorpius and its legs in Ophiuchus." In Hafner et al. (1995: 34) Ngitji Ngitji told of stories of the Emu and the Milky Way from northern SA. More recently, Cairns (1996: 9–10) suggested that a rock engraving of an emu at the Elvina Track site in Kuringai National Park (NSW) could represent the Emu. Norris and Norris (2009: 6–7) have shown that the engraving mirrors the Emu, in both shape and azimuth, in April, which is the time of the year when emus lay their eggs (Figure 2).

Cairns and Harney (2003) describe the 'Cosmic Emu' of the Wardaman people and their neighbours in the area bounded by the Victoria and Daly Rivers of the NT, based on the knowledge of Bill Yidumduma Harney, a Wardaman Elder. They connect the Emu to songlines and rock art, and to descriptions by previous writers.

4 THE EMU OF THE KAMILAROI AND EUAHLAYI

There are a limited number of written sources about the culture of the Kamilaroi and Euahlayi, mostly from the latter half of the nineteenth cen-

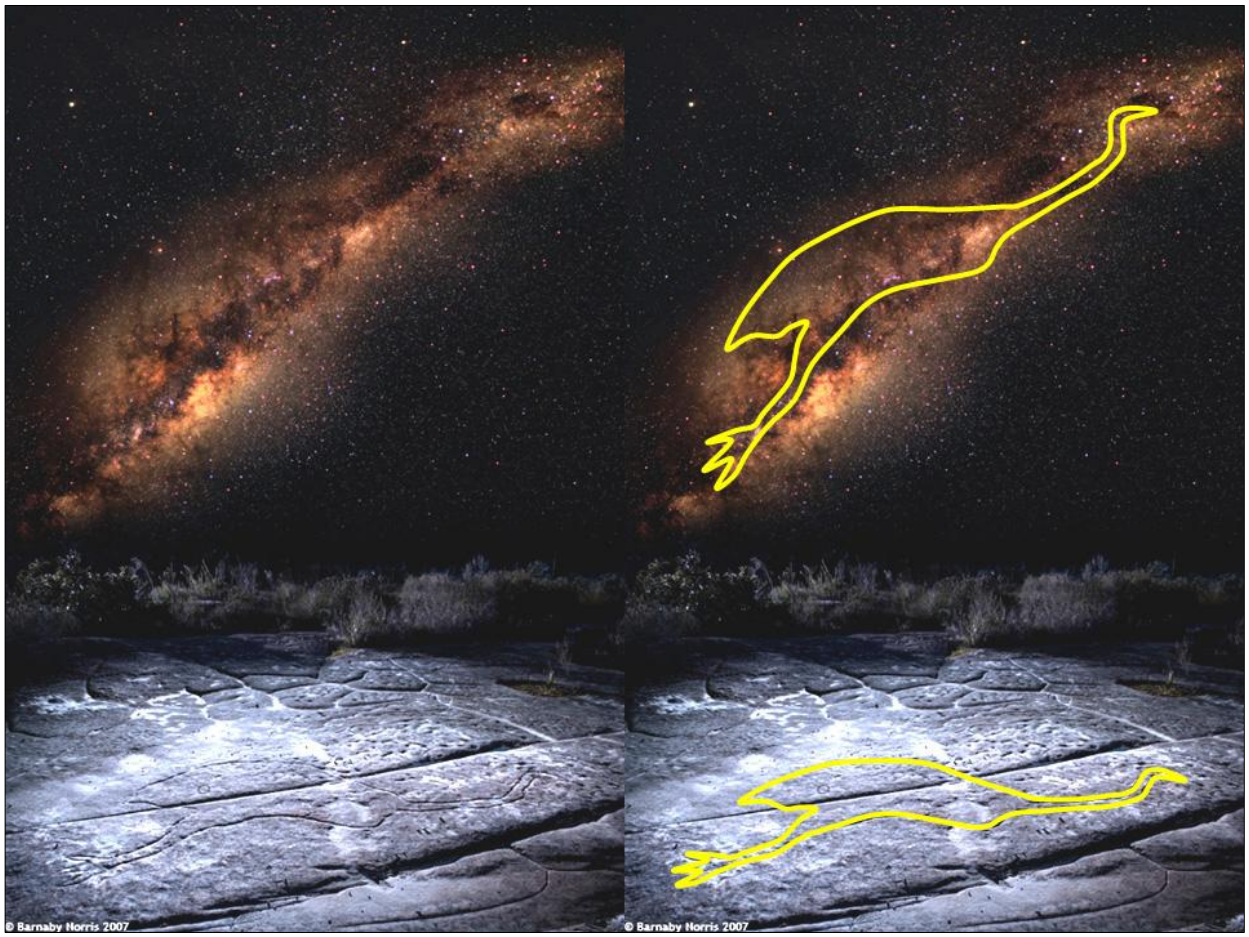


Figure 2: Kuringai Emu in the Sky (images courtesy Barnaby Norris and Ray Norris).

tury. These were Ridley (1856; 1873; 1875), Fraser (1888), Greenway et al. (1878), Greenway (1901) and Fison and Howitt (1880). R.H. Mathews (1900; 1904) are relevant to this study, as are papers by K. Langloh Parker, a contemporary of Mathews who lived on the Narran River in the late 1800's and collected a large body of folklore about the Euahlayi (Parker, 1896; 1898; 1914; Parker and Lang, 1905). Sveiby and Skuthorpe (2006) have more recently described the culture of the Nhunggabarra band of the Kamilaroi/ Euahlayi language group.

It has been established that the idea of an Emu, as a cultural object used in stories, rather than the emu bird, existed across Australia at the time of the European invasion. Basedow's in-formation from the Larrakia, Ford's descriptt-tion, and the more recent investigation of the Kuringai people's stone engraving of an emu near Sydney (Figure 2), all point to at least some Aboriginal groups seeing the Emu as a long, stretched out figure in the dust clouds of the Milky Way from the Coalsack to beyond Scorpius. Six of the eight participants in the ethno-graphic phase of the Kamilaroi project referred to the Emu as an emu figure stretching from the Coalsack to Scorpius, and most could describe its appearance. However, the story from Anderson, as used in this study, is the only complete story collected, including linkage to the Kamilaroi/Euahlayi culture and resource management.

The Emu, as seen by the Kamilaroi and Euahlayi, changed in position from season to season, as the Milky Way containing the Emu changed position in the night sky. As the Emu changes position, it alters in appearance, and that appearance has connections to cultural and resource matters. All of the images of the Emu's appearance in this study are seen mid-evening, around 21:00 hrs local time, in the area of the study. The head of the Emu (the Coalsack) can be seen all year, as the Southern Cross is circumpolar when viewed from this latitude, but the neck and the body of the Emu may or may not be visible at different times of the year, due to the rotation of the sky (which is the result of the tilt of the Earth from summer to winter, and the position of the Earth in its revolution around the Sun). We have used the computer planetarium program, Starry Night Pro,[2] adjusted to provide a non-light-polluted sky to determine the various views of the Emu used in this study. Anderson describes the cultural appearance of the Emu in the Milky Way as seen using Starry Night Pro. Through this, the authors were able to confirm that the appearance of the Emu began at the Coalsack under

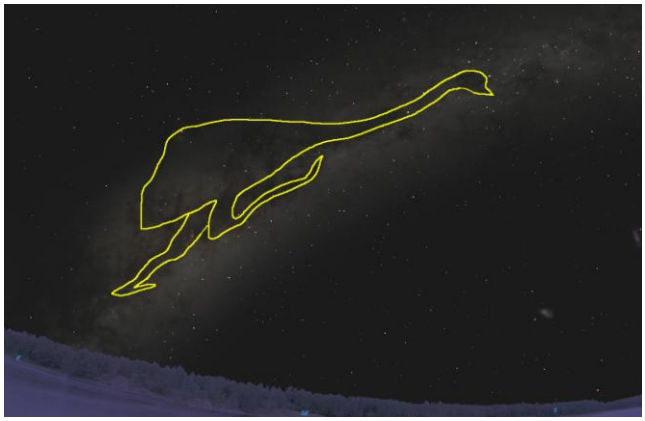


Figure 3 (above): The Emu in autumn (April-May), running after a mate (image from Starry Night Education).

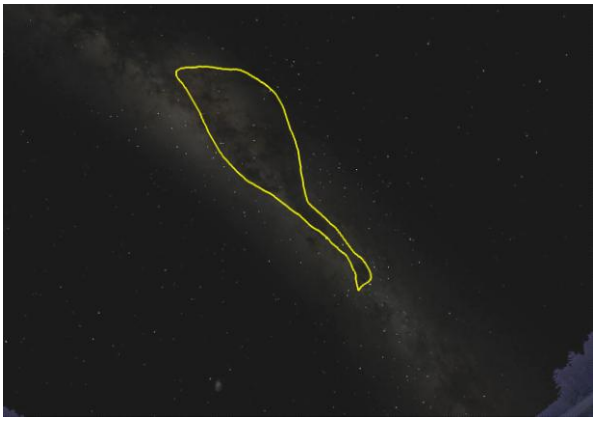


Figure 4 (top right): The Emu in winter (June-July), sitting on its nest (image courtesy of Starry Night Education).

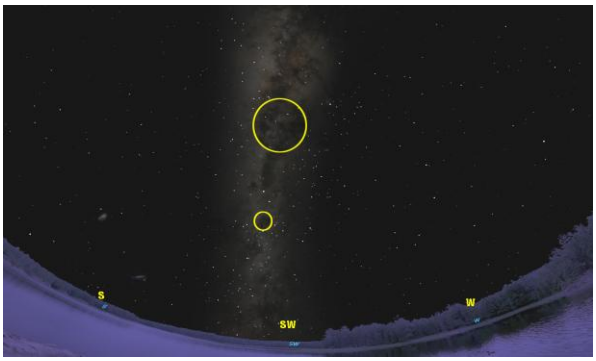


Figure 5 (bottom right): Emu in late winter (August-September) over the South-southwest (image from Starry Night Education).

the star α Crucis, which formed the Emu's head, then β and α Centauri, which form the start of the neck, down the dust lanes of the Milky Way to η Lupus and γ^2 Norma, at which point the dust lanes expand with the body of the Emu, reaching the maximum thickness with ε and λ Scorpii, and tapering towards 36-Ophiuchi and 3-Sagittarii, eventually ending near μ Sagittarii.

While the head and neck of the Emu can be seen in the sky as early as March, it reaches its first appearance in full length after sunset in April and May, when it is seen stretching from the South to the southeast (Figure 3). At this time, the Kamilaroi and Euahlayi say the Emu has legs, and appears to be running. This reflects the behaviour of female emus, who chase the males during the mating season.[3] Because emus are laying their eggs at this time, the appearance of the celestial Emu is a strong reminder to the Kamilaroi and Euahlayi people that eggs are available.

In June and July, the appearance of the Emu changes. The legs disappear, and the Emu, which is now seen as male, is sitting on its nest, hatching the new chicks (Figure 4). After female emus lay the eggs, it is the male that broods the eggs (ibid.). At this time, the eggs are still an available resource, and can be taken from the nest.

The Kamilaroi and Euahlayi have in common their male initiation ceremony, the *bora*. Many language groups in southeast Australia used a similar ceremony, sometimes using the borrowed Kamilaroi word, *bora*. For the Kamilaroi and Euahlayi, the preferred months for their *boras* are after August, according to participants in the Kamilaroi project, because the Milky Way was vertical in the sky to the southwest in August and early September.

The connection between the Milky Way and the *bora* could be linked to the culture hero, *Baiame*, who was common to many language groups in southeast Australia (Fraser, 1888; 10). *Baiame's* son, *Daramulan,* was given to the people and it is through *Daramulan* that *Baiame* "... sees all." (Fraser 1882: 208, Howitt 1884: 458). *Baiame* is worshipped at the *bora* ceremony (Ridley, 1873: 269) and *Daramulan* is believed to come back to the Earth by a pathway from the sky (Fraser, 1882: 212). and Sheed (1996: 41) reports that *Baiame* "... dwells in the sky, beside a great stream of water (Milky Way)."

In late winter (August to September), the neck of the Emu becomes indistinct in the sky, leaving the body to represent an emu egg (Figure 5). This was taken, according to Anderson, as a sign that the emu chicks were hatching, and that the egg resource was no longer available. Because the male emus look after the chicks (Eastman, 1969), this has led to some speculation (Love, 1987: 3) that this connects the Emu to the *bora* ceremony. As the male emu hatches and raises the chicks, so the Aboriginal Elders nurture the male initiates. There is little literature on this subject, other than Winterbotham (1957: 3–4), who reported on information from a southeast QLD Aboriginal Elder, Gaiarbau, who indicated the link between the *bora* and sky. This reinforces Love's speculation.

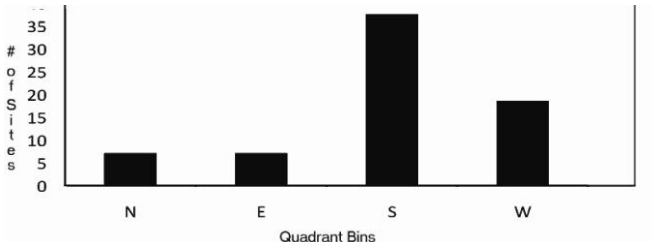


Figure 6: Frequency of alignment of *bora* sites to cardinal quadrants (defined as a quarter of a circle; an arc of 90°, N being 0°, S being 180°); c.f. Fuller et al. (2013).

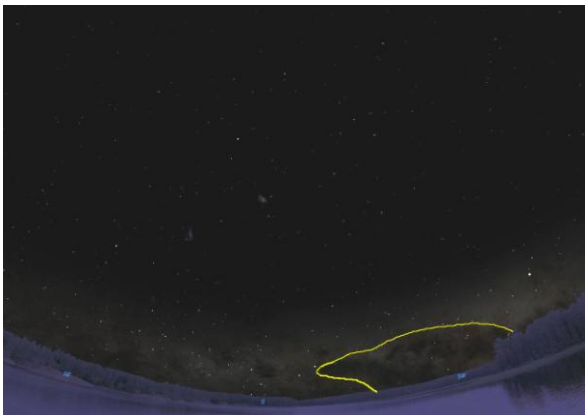
Fuller et al. (2013: 36) tested the hypothesis that the orientations of *bora* ceremonial circles are aligned to the position of the Milky Way, which is vertical in the sky after sunset to the south-southwest in August and early September. Figure 6 shows the preference in orientation of 68 *bora* sites in NSW and southeast QLD where the orientation was known. The results show that the preference is strong in the southern quadrant, where the Milky Way is located in August and early September. To determine if this was a chance clumping of a random distribution of orientations, Fuller et al. conducted a Monte Carlo simulation, in which 68 orientations were distributed randomly in each of the bins shown in Figure 6. They repeated this process 100 million times. In only 303 of the 100 million runs did the number in any one bin equal or exceed 35, from which they concluded that the likelihood of the peak in Figure 6 occurring by chance is about 3×10^{-6} or 0.0003%. They concluded that this distribution was clearly not the result of chance, and that the builders of the *bora* rings intentionally aligned most of them to the southern quadrant. This lends support to the claims that *bora* ceremonies are linked to the Milky Way

The head of the Emu is still visible in the sky in late winter, and together with the body, they appear to form a large and small ring in the Milky Way, which may be representative of the small and large *bora* rings that are laid out on the ground (Figure 5). The head represents the smaller, sacred, *bora* ring, and body the larger, public ring, and looking at the rings in the sky, they mirror the layout of the *bora* rings on the ground. If Fuller et al. (2013) are correct in their alignment hypothesis, this may be the reason that *bora* sites are aligned to the southern quadrant. At this time of year, Aboriginal people in the area of the study would be leaving their winter camps to travel to ceremonial sites for ceremonies including the *bora*.

In the spring, around November, the Emu once again is transformed (Figure 7). For the Kamilaroi and Euahlayi, the Emu is also *Gawar-rgay/Gawarghoo*, a featherless emu who travels to waterholes and looks after everything that lives there. Come November, the Emu is now (along with the Milky Way it inhabits) low on the horizon in the evening. Due to atmospheric extinction, the neck and the head are difficult to see, so the body of the Emu seems to be 'sitting' on the horizon. According to Anderson, this is because the Emu is now believed to be sitting in a waterhole, and as a consequence, the waterholes in the country are believed to be full (which would normally be the case in southeast Australia after the winter rains). The Kamilaroi have another name for the emu bird: *ngurran. gali* (*Euahlayi: dthnarwon.gulli*). This translates to "an emu sitting" or "emu in the water", which may well relate to this view of the celestial Emu.

Later in the summer, the Milky Way and the Emu have dipped even lower, and the Emu has become almost invisible on the horizon (Figure 8). At this time, the Emu is believed to have left the waterholes, and because of this, the waterholes in the country are dry, which may well be the case in the summer. The Emu will not be visible again until its head peeps above the horizon in February, followed by the body in March.

Some of the major themes of the Kamilaroi Project, such as 'what's up there is down here', are reflected in the Kamilaroi/Euahlayi stories of the Emu. A few participants, including Anderson,



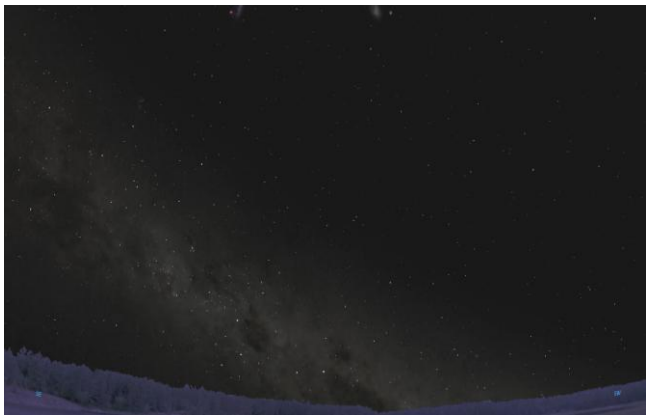


Figure 7 (left): The Emu sitting in a waterhole in spring (November)(image from Starry Night Education).
Figure 8 (right): Summer, when most of the emu is below the horizon (image from Starry Night Education).

commented on their belief that, at one time, the sky and everything in it was 'down here', and what is now 'down here' was in the sky. For that reason, what is seen in the sky now is also on the ground, and the varying views of the Emu also have close connections with things on the ground, in particular the emu bird, which was an important resource. The view of the Emu was closely connected to the resource management of the emu, possibly the ceremonial aspects of the male initiation ceremony, and in regards to waterholes, the management of country.

5 CONCLUSION

We have shown that the Emu in the Sky is an important cultural figure in many different parts of Aboriginal Australia. While many of the literature reports have only the barest details, where traditional knowledge still exists, there is the possibility of working with the knowledge-holders to restore a more complete understanding to the public record. The support of the participants in the Kamilaroi Project has provided a very detailed picture of how the Emu in the Sky fitted into the sky knowledge and culture of the Kamilaroi, Euahlayi, and possibly their Murrawarri and Ngemba neighbours. This would appear to be the first Aboriginal cultural grouping in Australia where this knowledge was brought together into a unified description. We believe the knowledge gained in this one aspect of culture meets the aims of the hypothesis of the Kamilaroi Project to add to the overall understanding of the sky knowledge of the Kamilaroi and Euahlayi peoples. This information may also be used in future research to strengthen the understanding of how Aboriginal Australian culture linked the behaviour of cultural objects in the sky with animals and resources on the land.

6 NOTES

1. It is no surprise that the emu is seen as a cultural figure in the sky throughout Australia, given the importance of the emu as a resource for food, egg shells, feathers and bones.
2. http://astronomy.starrynight.com
3. http://www.environmental.nsw.gov.au/animals/TheEmu.htm

7 ACKNOWLEDGEMENTS

We acknowledge and pay our respects to the traditional owners and Elders, both past and present, of the Kamilaroi, Euahlayi, Ngemba, and Murrawarri peoples. We thank the participants of the Kamilaroi project, Michael Anderson, Rhonda Ashby, Lachie Dennis, Paul Gordon, Greg Griffiths, Brenda McBride, Jason Wilson and one anonymous person, for their stories and those of their families. We particularly thank Michael Anderson for his detailed story on the Emu, which is central to this study. This paper was originally presented at the 2013 Australian Space Sciences Conference at the University of New South Wales. We also thank the two anonymous referees and the guest editor, Duane Hamacher, for their feedback.

This research was approved by the Macquarie University Human Ethics Committee (5201200462). The ethnographic data from the Kamilaroi Project will be retained by Robert Fuller for five years, and then transferred for secure storage by Macquarie University in accordance with the terms of the Ethics Approval. Access to the data, subject to the terms of the Ethics Approval, can be requested through the author.

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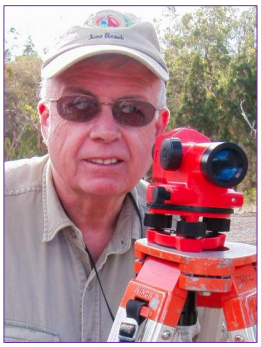
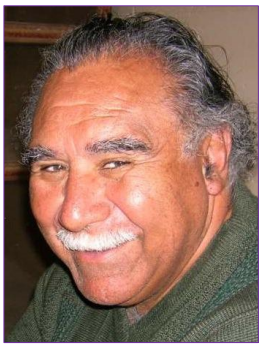
Robert (Bob) Fuller is a late-life returnee to academia.



He was educated as an anthropologist (B.A., Gettysburg College, USA), but never practiced as one. After retiring from careers as a military pilot then businessman, with a long interest in astronomy, he took up the challenge to combine his interests in anthropology and astronomy by studying Australian cultural astronomy. Mr Fuller is now studying Kamilaroi astronomy for a Master of Philosophy in Indigenous Studies at Macquarie University in Sydney, Australia.

Michael Anderson (Nyoongar Ghurradjong Murri Ghillar) is an Aboriginal rights activist, leader of the Euahlayi tribe of 3,000 people living in northwestern New South Wales, and Native Title claimant to their traditional lands on their behalf. He was taught Euahlayi customs and traditions through his people's sacred ceremonies. Mr Anderson has lectured in Aboriginal studies and Aboriginal politics at several Australian universities, where he wrote and taught units in Aboriginal studies that were inclusive of traditional Aboriginal society.



Professor Ray Norris is an astrophysicist with CSIRO Astronomy & Space Science and an Adjunct Professor at Warawara - Department of Indigenous Studies at Macquarie University. He has published about 300 peer-reviewed papers, including 15 on Aboriginal Astronomy, and wrote the book "*Emu Dreaming: an Introduction to Australian Aboriginal Astronomy*".

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ABORIGINAL ASTRONOMICAL TRADITIONS FROM OOLDEA, SOUTH AUSTRALIA. PART 1: NYEERUNA AND 'THE ORION STORY'

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Abstract: Whilst camped at Ooldea, South Australia, between 1919 and 1935, the amateur anthropologist Daisy Bates CBE recorded the daily lives, lore and oral traditions of the Aboriginal people of the Great Victoria Desert region surrounding Ooldea. Among her archived notes are stories regarding the Aboriginal astronomical traditions of this region. One story in particular, involving the stars making up the modern western constellations of Orion and Taurus, and thus referred to here as 'The Orion Story', stands out for its level of detail and possible references to transient astronomical phenomena. Here, we critically analyse several important elements of 'The Orion Story', including its relationship to an important secret-sacred male initiation rite. This paper is the first in a series attempting to reconstruct a more complete picture of the sky knowledge and star lore of the Aboriginal people of the Great Victoria Desert.

Notice to Aboriginal and Torres Strait Islander people: This paper contains brief references to Aboriginal Australian male initiation rites and its links to the sky. The full knowledge of these rights is not discussed, as it is restricted. This paper also gives the names and images of people who are deceased.

Keywords: Ethnoastronomy, cultural astronomy, Aboriginal Australians, Orion

> "Here in the bright, still evenings, I studied the skies, astronomy being an old love of mine, and compiled my aboriginal mythologies, many of them as poetic and beautiful as are the starry mythologies of the Greeks." Daisy Bates (1936: 23).

1 INTRODUCTION

The first in-depth study of Australian Aboriginal astronomy began with William E. Stanbridge, who wrote on the ethnoastronomy of the Boorong people of western Victoria (Stanbridge, 1858; 1861). Other early pioneers in the field include Brian Maegraith (1932), Charles Mountford (1939; 1958; 1976) and Norman Tindale (1959; 2005). To this list we can add Daisy Bates CBE (1859–1951) who, whilst camped at Ooldea on the southern fringes of the Great Victoria Desert, South Australia, between 1919 and 1935, recorded the language, customs and oral traditions of the local Aboriginal people, including their astronomical knowledge and traditions.

This paper is the first of a series that comprehensively studies and analyses Aboriginal astronomical traditions in the Great Victoria Desert in western South Australia and south-eastern Western Australia. In this paper, our aim is to use data recorded by Daisy Bates to analyse one of the more detailed astronomical traditions from Ooldea, South Australia—that of 'The Orion Story' (discussed in Sections 4 and 5). In this paper, we provide a brief biography of Daisy Bates and explore her astronomical interests and pursuits at Ooldea. We then briefly outline our search of the Daisy Bates Collection, held in the archives of the National Library of Australia (NLA) in Canberra. This is followed up by a more detailed analysis of an oral tradition involving the stars surrounding the constellations of Orion and Taurus, and which appears to contain references to several transient astronomical events. We then briefly look at how this story is incorporated into the male initiation rites at Ooldea, and how this may offer clues to a sophisticated understanding of the daily and annual movements of the celestial sphere.

2 DAISY BATES CBE (1859–1951)

Daisy Bates (Figure 1) is an enigmatic, complex and somewhat controversial figure in Australian history. Her popular biographies (e.g. Blackburn, 1994; Hill, 1973; Salter, 1971; Wright 1979) contain a fictitious and fanciful version of Bates' early life, with claims that she was of 'aristocratic' Anglo-Irish Protestant heritage. Later investigations show that she was actually born into poverty to Irish-Catholic parents and orphaned at a young age (De Vries, 2008; Reece, 2007). Despite her poverty, she was educated in languages, literature, history and science, all playing an important role in her later life in England and Australia (De Vries, 2008: 46–51).

During a voyage to Australia in 1899, Bates befriended Father Dean Martelli, an elderly Catholic priest returning to an Aboriginal mission at Beagle Bay near Broome. Over several

conversations, Bates soon learned the plight of the Aboriginal people, who were then dying in large numbers from "... white man's diseases and despair ...", along with their culture (De Vries, 2008: 114). Showing great interest in recording and preserving their culture, Bates accepted an invitation to visit the mission, where one Abbott Nicholas was compiling a language dictionary. Apart from being Bates' first physical contact with Aboriginal people (De Vries, 2008: 115), the experience also taught her the basic skills of a field anthropologist (Reece, 2007: 36). Temporarily rejoining her husband at Roebuck Plains in 1901, she used these skills to observe and record the vocabularies and rituals of the Aboriginal people camped at their cattle station (De Vries, 2008: Chapters 9 and 10; Reece, 2007: 39; Salter, 1971).

After moving to Perth in 1904, Bates worked as a junior clerk for the Western Australian Government, collecting and compiling vocabularies from several Aboriginal language groups. As well as enabling Bates to build up a more complete picture of Aboriginal life (De Vries, 2008: Chapter 11; Reece, 2007: Chapter 2), this work also brought her into contact with the anthropological fraternity, through which she gained some level of academic credibility, becoming the Western Australian correspondent for the Anthropological Institute of Great Britain, a Fellow of the Royal Anthropological Society of Australasia, and a Member of the Royal Geographical Society of Melbourne (Bartlett, 1997; De Vries, 2008: 149; Reece, 2007: 49–50).

By 1910, and after an extensive eight-month field survey of the Aboriginal peoples of Western Australia, including interviewing the last survivors of the Bibbulmun culture, Bates had amassed a huge amount of data on language, oral traditions, religion and kinship. It was finally published posthumously in 1985 as *The Native Tribes of Western Australia*, thanks to the extensive editorial work provided by White (1985). The ethnographic information contained within it has assisted in supporting recent native title claims (Burke, 2011; Reece, 2007: 9–10; Sullivan, 1995).

After being bestowed the title of 'Honorary Protector of Aborigines' in 1912 (De Vries, 2008: 165; Reece, 2007: 67), Bates spent the next 20 years among the Aboriginal people of South Australia, firstly with the Mirning people at Eucla and Yalata, then moving to Ooldea ('Yooldilya Gabbi') in 1919 (Bates, 1938: Chapters 15 and 17; Colley et al., 1989; De Vries, 2008; Reece, 2007). For some South Australian localities mentioned in this paper see Figure 2.

Bates was appointed CBE (Commander of the Order of the British Empire) in 1934, more in recognition of her Aboriginal welfare work than for her anthropological research (De Vries, 2008: 215–217; Reece, 2007: 112–113). In the following year, she left Ooldea for Adelaide to work on her autobiography (De Vries, 2008: Chapter 18; Reece, 2007: Chapter 4). Published in 1938, *The Passing of the Aborigines* became a best-seller, praised by the general public but harshly criticised by the anthropological community, mostly for the outmoded portrayal of Aboriginal people as a 'dying race' and her increasing obsession with unsubstantiated and sensationalistic stories of cannibalism (De Vries, 2008: 243–246; Reece, 2007: 124–125). In 1945, deteriorating health and poor eyesight eventually forced Bates to move to Adelaide, and she passed away at Prospect, South Australia, on 19 April 1951 at the age of 91 (De Vries, 2008: 262; Reece, 2007: 154–155).

Figure 1: Daisy Bates in Adelaide circa 1936, aged 76 (courtesy: State Library of South Australia).

3 ASTRONOMY AT OOLDEA

Located on the southern fringe of the Great Victoria Desert, Ooldea served as an outpost ('Ooldea Siding') for the Trans-Australian Railway (Bates, 1938: Chapters 15 and 17; Brockwell et al., 1989; Colley et al., 1989; Reece, 2007: 79). It was also the location of one of the few permanent sources of freshwater ('Ooldea Soak'), which made it an important drought refuge for many Aboriginal peoples (Tindale, 1974: 69) and an ideal starting point for several inland expeditions by colonial explorers (Brockwell et al., 1989; Gara, 1989). It also played an important role as a meeting place for Aboriginal ceremony and trade, with cultural items traded from many locations across the continent (Bates, 1938; Berndt, 1941; Brockwell et al., 1989; Colley et al., 1989).

The eastern part of the Great Victoria Desert surrounding Ooldea was the traditional land of the Kokatha people. West of the Kokatha lands

Figure 2: Locations where Bates lived and worked alongside the Aboriginal peoples, including Eucla, Yalata, and finally Ooldea. Also indicated are the locations of Wandanya (Waldana Well), the area from which 'The Orion Story' originated according to Bates, and Oodnadatta, where anthropologists Ronald and Catherine Berndt witnessed the *Minari* and *Baba* Inma in 1944 (image credit: user Astrokey44 (Wikimedia Commons)).

were the Ngalea lands, the principle water refuge being at Waldana Well (Bates, 1921a; Gara, 1989). Together, with other groups to the north and west, including the 'Spinifex People' (*Pila Nguru*), they made up part of the 'Western Desert culture' sharing a similar social structure and religious beliefs, and speaking closely-related dialects (Berndt, 1959: 93–95; Cane, 2002; Gara, 1989). The Aboriginal people of Ooldea and surrounding areas were forcibly removed to Yalata in the 1950s to make way for atomic tests (Cane, 2002).

Whilst at Ooldea, Bates again recorded a substantial amount of material on her observations of Aboriginal daily life (Bates, 1904–1935). In time, she gained sufficient trust and respect of her Aboriginal neighbours, which not only allowed her to witness sacred ceremonies, but to be entrusted with the safe-keeping of Inma objects (sacred boards) after the death of their custodians (Bates, 1938; Reece, 2007: 95).

In her book, Bates also mentions her passion for astronomy and the manner in which she observed the Ooldea night sky (Bates, 1938: Chapter 17):

> ... a smaller bough shed on the crest of the hill, with a ladder leading to its leafy roof, that was my observatory. Here in the bright, still evenings, I studied the skies, astronomy being an old love of mine, and compiled my aboriginal mythologies, many of them as poetic and beautiful as are the starry mythologies of the Greeks.

Based on her archived notes, it seems her astronomical interests did not go much beyond that of an amateur. She seemed more interested in the star stories than in the astrophysical and cosmological concepts of the time. We know she did not possess a telescope at Ooldea (Reece, 2007: 95), but the use of printed star

charts and ephemerides cannot be ruled out.

At Ooldea, Bates sat with Elders as they drew maps of the constellations, stars and totemic signs in the sand with sticks, which she later translated into their Western equivalents using her own knowledge of astronomy (Hill, 1973). Some of the astronomical knowledge and traditions collected by Bates was restricted to males (i.e. 'Men's business'). Although the exact reason why this information was passed on to Bates is unclear, it was most likely the result of her long tenure with the community, building up trust and respect with the Elders, combined with the fact that she was not Aboriginal. It was not uncommon at the time for Elders to share sacred or secret knowledge with outsiders provided they did not reveal it to non-initiated members of the community. Doing so could have serious repercussions, as attested by the legal case that followed the publication of Charles Mountford's (1976) book *Nomads of the Australian Desert*, which contained knowledge of some secret Pitjanjatjara ceremonies. This outcome resulted in the book being banned in the Northern Territory of Australia, and a heightened level of caution and distrust has since been shown towards researchers (Neate, 1982).

Much of Bates' work on Aboriginal astronomical knowledge was published, either as syndicated newspaper articles (e.g. see Bates, 1921b; 1921c; 1924a; 1924b; 1933) or in books authored by others (e.g. Ker Wilson, 1972). Some of it also remains in the form of unpublished field notes in the National Library of Australia. It is from these notes that the original accounts of Aboriginal astronomy from the Great Victoria Desert, centred on Ooldea, are found. These are dispersed within Section VII of Manuscript 365 of the Daisy Bates Collection (Bates, 1904–1935) as a series of numbered folios. These folios are undated, making it difficult to place these in a chronological order. Complicating the issue is the fact that some folios appear to contain fragments of astronomical knowledge from Ooldea that were incorporated with those from other language groups or regions that Bates studied previously, such as those from the Mirning people of Eucla, or the Bibbulmun and Noongar people of southern Western Australia (Folios 25/308; 26/78; 26/81-84). Other folios (Folios 26/47; 26/106-7; 26/113) appear to be attributed solely to the Ooldea region and contain lists of astronomical objects with their corresponding Aboriginal names or traditions.

Combining these objects with contributions from other researchers (e.g. Hill, 1973; Berndt, 1941), a full list of astronomical objects, their Aboriginal names/meanings, and their Western counterparts, are listed in Table 1. These data are being used for a larger project to reconstruct the Ooldea night sky. A full analysis of these astronomical traditions, including their relationship to seasonal change, food economics and social structure, is the focus of future work.

4 'THE ORION STORY'

'The Orion Story' stands out for its detail and its intriguing references to possible observations of several transient astronomical events. This story is first encountered in an article published in *The Australasian* (Bates, 1921b). Whilst giving an account of bird life in the region around Ooldea, she digresses into the story:

> ... Jurr-jurr, a species of night owl,[1] whose hoarse cry is thus rendered by the natives, has a distinction of being translated into a star, and is now Canopus, watching over ming-arri (mountain devil), now the Pleiades, who is being pursued by Nyiruna (Orion) 'round and round the sky'. The little mountain devil, inaptly named (as it is absolutely the most harmless of all living creatures) occupies a unique position in native legend. Ming-arri were all women in long ago times who never wished to mate with men. They lived by themselves and kept a tribe of dingoes to keep all men away, the dogs killing and eating all the men they caught. Ming-arri brought forth and reared their babies, but laid the injunction on each one as it grew up that "it must never talk or whistle" or the men would catch it. Nyiruna was a great hunter in those days, and he wanted ming-arri very badly for his wives, and left food for them and tried to catch them, but the dingoes ate the food and chased Nyiruna away, and by and by, when ming-arri went into the sky, Nyiruna followed them, and there he is, still chasing them round and round, while the dogs, who are all around ming-arri, still keep him away. Ming-arri have now no voice at all, because their mothers never let them speak in the old days.

This article seemed to have attracted the interest of one of her readers as the next time the story is mentioned by Bates it is in the form of a response to "Canopus" in the editorial section of *The Australasian* (Bates, 1904–1935: Folio 25/441-442; Bates, 1921c):

> The myth referred to, in my article on "The Great Plain's Edge" does not belong to the Nullarbor Plain natives, for there are no natives living on the plain except a few "strays" from Eucla or the north, who work now and then at White Well and Nullarbor Plains stations, near the head of the Bight. The myth concerning Orion and the Pleiades belongs to a tribe living near Wandunya and other waters, about 128 miles north 200 miles northwest of Ooldea Siding. The myth is known to the Mingarri totem people, to whom it belongs, so to speak; and as the myth is a totem one, and its totemists have only recently come into civilised areas, your correspondent "Canopus" may rest assured that it is purely an aboriginal myth, with no "dressing" whatever from outside.

Table 1: The Ooldea night sky as reconstructed from the field notes of Daisy Bates (1904–1935), with contributions from Hill (1973) and Berndt (1941). Spelling variations most likely reflect the different language groups from which the stories originated.

Object Type	Western Name	Aboriginal Name or Attribution	Aboriginal Interpretation
Galactic	Milky Way	*Dhoogoor Yuara*[1]	River that never dries/road of dreaming
	Coal Sack	*Kallaia, Kalia*	Emu Head (body is dust lanes in Milky Way)
	Magellanic Clouds	*Boolbarradu, Balbaradu*	Brothers (collectively)
	Large Magellanic Cloud	*Murgaru, Badhu-Wudha*	Right-handed Brother
	Small Magellanic Cloud	*Oimbu, Kurulba*	Left-handed Brother
Constellation, Cluster, or Asterism	Crux	*Waljajinna*	The Track of Eaglehawk
	Pointers	*Jurding, Dhurding*[2]	Club of Eaglehawk
	Delphinus	*Nyumbu, Mamu,*	Crow Children
	Aquarius	*Bailgu*	Brush Fence
	Gemini	*Wati Kutjera*[3]	Two Men (ancestral beings)
	Orion	*Nyeeruna, Nyiruna*	Hunter of the Seven *Mingari* Sisters
	Hyades	*Kambugudha*	Eldest of the *Mingari* (Thorny Devil) Sisters
	Pleiades	*Yugarilya, Kunggara*	Seven Young *Mingari* Sisters
	Pisces	*Warramula*[1]	*Kadaicha* (Sorcerer) Men on the Trail
	Line of stars between Beta Tauri (Elnath) and Achernar	*Mingari's Dogs*	Row of dingo puppies placed before *Nyeeruna* to stop his advances on the Seven *Mingari* Sisters (Pleiades)
Star	Stars (generic noun)	*Kattana*	"Heads"
	Alpha Centauri	*Maalu*	
	Beta Centauri	*Kanyala*	
	Alpha Geminorium	*Mumba*[2]	The lazy one of the *Wati Kutjera*
	Beta Geminorium	*Kuruka'di*[2]	The wise, skilful one of the *Wati Kutjera*
	Altair	*Kangga Ngoonji*	Crow Mother
	Vega	*Gibbera*	Bush Turkey
	Antares	*Warrooboordina*[1]	Black Cockatoo (Fire Carrier)
	Rigel	*?*	*Badwuja's* Brother (?)
	Canopus	*Joor-Joor, Jurr-jurr*	The Owlet Nightjar
	Beta Tauri (Elnath) or Zeta Tauri (?)	*Babba*	Dingo Father
	Aldebaran		Left Foot of *Kambugudha*
	Betelgeuse		*Nyeeruna's* Right Arm
	Achernar	*Ngurunya (?)*	Dingo Mother
	Spica	*Karduna*	?
Solar System	Morning Star	*Maalu*[4]	Red Kangaroo
	Evening Star	*Kulbir*[4]	Grey Kangaroo
	Venus	*Genba (Guldu) Katta*	*Genba's* (*Guldu's*) Head
	Mars	*Kogolongo, Koggalangu*	Black Cockatoo with red feather in its tail
	Jupiter	*Karrail Katta*	*Karrail's* Head
	Moon	*Beera*	*Beera Goarrija* (Waxing), *Beera Bulgana* (Full), *Beera ilung* (Waning)
	Lunar Eclipse	*Beera Dharbongu*	
	Meteor	*Mama*	

Notes: 1. From Hill (1973) and may or may not refer to that same group. Other star names are similar. 2. Cane (2002: 94) claims these men are the Pointers, Alpha and Beta Centauri. 3. From Berndt (1941). The *Wati Kudjera* story originated from the Warberton Range, Western Australia, but had drifted down to Ooldea through tribal migration. These stars and story are not mentioned in any detail in Bates' notes. 4. Bates incorrectly identifies and describes Jupiter as the morning star and Venus as the evening star, when in fact both 'stars' are Venus.

> The country from which the Mingarri totem people come is not yet taken up, and those who have come to my camp from that area are absolutely uncivilised. Up to the present I have obtained only a portion of the myth, but with every fresh arrival I obtain a little more. No new narrator has contradicted the portion of the myth obtained. Orion is Nyiruna chasing the Pleiades, but I am not yet able to name the particular stars which are Mingarri's dogs, though Achernar has been pointed to more than once, as one of Mingarri's dogs. The natives' personal description of Orion and the Pleiades is not suitable reading for other than purely scientific magazines, but it is extremely interesting and quite "native". I have not the whole connected myth as yet, for it takes a long time to get a complete legend or myth from the uncivilised natives. I may mention that in all native star myths, from the Kimberley district in Northern Western Australia to the Mingarri totem group in South Australia, the Pleiades are "a lot of women"; but as far as I remember without my notes it is only in the group that Orion comes in as Nyiruna hunting them. The Mingarri myth is known to neighboring tribes of other totems."

The oral tradition in question is a story of the *Mingarri* totem from an Aboriginal community near Wandunya (also known as Waldana Well, ~322 km northwest of Ooldea, Figure 2). According to Bates, this oral tradition is known from a wide area of Central Australia, beyond the border into Western Australia to Diamantina River and Cooper River regions of northeastern South

Australia-southwestern Queensland to the eastern edge of the Great Nullarbor Plain of western South Australia. *Mingarri* is the totem of Thorny Lizard (*Moloch horridus*), also known as the 'thorny dragon', 'thorny devil' or 'mountain devil' (Figure 3). This small lizard (up to 20 cm in length) is covered in conical spikes and inhabits the desert and scrub over most of central Australia (Browne-Cooper et al., 2007).

From the tone of Bates' response we can infer that her correspondent "Canopus" has raised doubts to the genuineness of the story, possibly as it resembles the Greek version of the Orion myth too closely to be purely 'native'. Bates goes to great lengths to assure that the story is genuine but fragmentary, and that she is still in the process of collecting more parts of the complete story from different sources. This may explain the twelve-year gap between her first, incomplete version of "The Orion Story" (above) and the final, more complete version that she later published in *The Sydney Morning Herald* newspaper (Bates, 1933). This version can also be found in Bates' manuscript records as Folio 25/85-88. A second, almost identical folio (Folio 26/13-16) also exists in the records, but it cannot be dated in relation to the other. Their similarity suggests they were both written about the same time, and one may have been a 'back-up copy' for the other. As both are similar, only one is reproduced in full in the Appendix.

In these accounts, the stars that constitute the Western constellation of Orion (Figure 4) are seen as a hunter, named *Nyeeruna* (spelled *Niyruna* in Bates' earlier account).[2] He is a vain pursuer of women, with a feathered headdress, ochred body, string belt (Belt of Orion) and whitened tassel (the scabbard of Orion's sword). Each night he pursues the sisters of the Pleiades (*Yugarilya*), who are of the *Mingari* (also spelled *Min-garri*, *Ming-arri* or *Mingarri*) totem.

Nyeeruna is forever prevented from reaching *Yugarilya* by *Kambugudha*, their eldest sister, represented by the Hyades, who guards her younger sisters. *Kambugudha* taunts *Nyeeruna* by standing before him (represented by the V-shape of bright stars in the Hyades, the 'head' of Taurus the bull). The club in *Nyeeruna's* right hand (Betelgeuse) fills with 'fire magic' ready to throw at *Kambugudha*. However, she defensively lifts her left foot (Aldebaran), which is also full of 'fire magic', which causes him great humiliation and puts out the fire magic of his arm. In her contempt of his vanity, *Kambugudha* places a line of dingo puppies[3] between her and *Nyeeruna*, represented by an arc of stars between Orion and the Hyades.[4]

Eventually, *Nyeeruna's* magic returns with force and his hand (Betelgeuse) increases in brightness. *Kambugudha* calls to *Babba* the father dingo, who rushes over to *Nyeeruna* and "… shakes and swings him east and west by his middle …" while *Kambugudha* points and laughs at him. However, her timid sisters are frightened and hide their heads until *Babba* loosens his hold and returns to his place. As this happens, many other beings such as *Joorrjoorr* the owlet-nightjar (Canopus), *Beera* (Moon), and *Kara* the red-back spider (Rigel), mock and laugh at *Nyeeruna*, who again loses his red fire and 'no sparks' come from his body in his shame and humiliation.

Figure 3: According to Bates' story, the Seven *Yugarilya* Sisters of the Pleiades were all *Mingarri* (Thorny Devil, or lizard) totem. The Thorny Devil (*Moloch horridus*) is found throughout the central desert regions of Australia and feeds exclusively on ants (*Minga*). The 'hump' on the back of its neck is the 'false-head', used as a defense mechanism (image credit: user KeresH Wikimedia Commons).

Mountford (1948: 167–168) records a variation of the *Nyeeruna* story: the stars of Orion are *Nirunya*, a man pursuing the group of women called *Kunkarunkara* (Pleiades). Mountford does not give many details, but claims that the women usually outsmarted *Nirunya*. On occasion, one of the women "… would fall victim to his desires." (page 167). The Mountford version (which came from an Aboriginal woman named *Numidi*), from the Central Desert, describes a place where *Nirunya* attempted to capture two women as they were digging for yams. The women saw him coming from the sky and went underground briefly before bursting out and escaping to the sky. Physical traces of the incident are evident on the ground, including the place from which the women emerged and a hole dug in the rock where they were searching for yams. Unfortunately, the Mountford version does not provide any details of other stars that may shed light on the story recorded by Bates. Maegraith (1932), who wrote about the astronomy of the Aranda (Arrernte) and Luritja peoples of the Central Desert, did not collect stories about Orion or the Pleiades, as they were not visible in the early August night during his fieldwork in Hermannsburg (*Ntaria*). Tindale (1959) recorded a story from the Western Desert

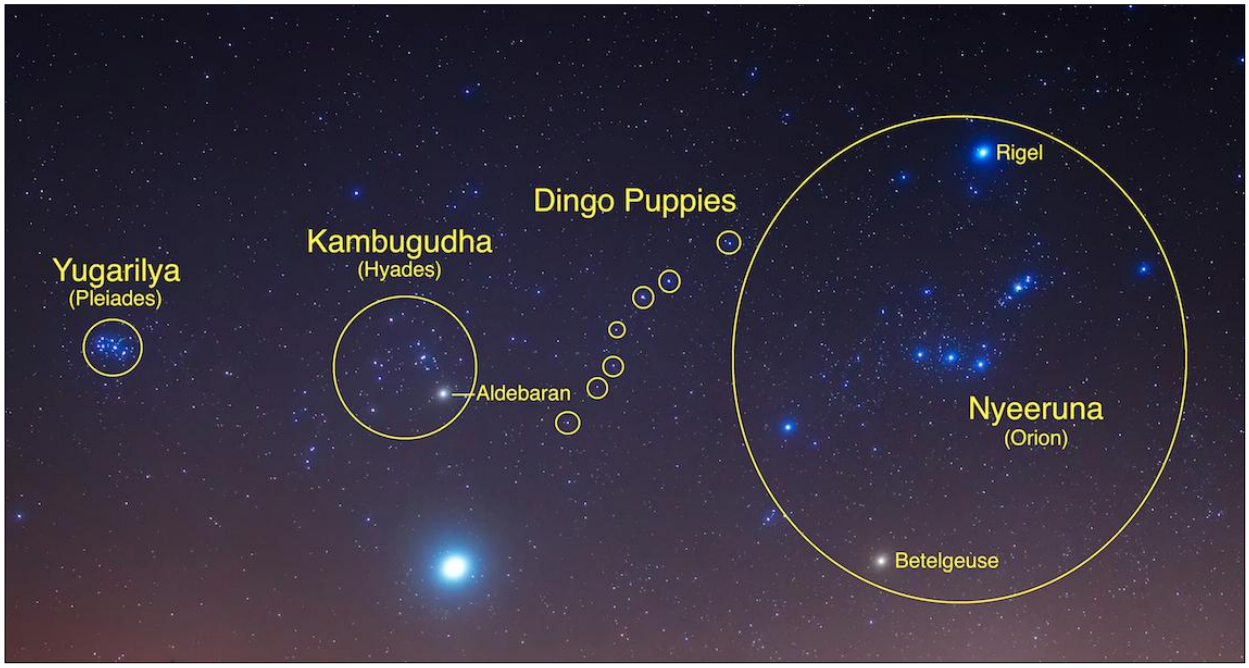

Figure 4: A correct Southern Hemisphere perspective of the night sky containing most of the key players in 'The Orion Story', including (from left to right) the Pleiades (*Yugarilya*, the seven *Mingari* Sisters), the Hyades (*Kambugudha's* legs), the 'horns of the bull' (*Babba* the father dingo), Orion's 'shield' (Dingo puppies) and Orion (*Nyeeruna*). The bright object below the Hyades is the planet Jupiter (image credit: free stock image from www.favewalls.com).

that describes the Pleiades as *Kungkarungkara* and Orion (stars of the belt) as *Njiru*.

5 INTERPRETING 'THE ORION STORY'

Of the various Aboriginal traditions across Australia regarding the stars in Orion and the Pleiades, nearly 90% associate the stars of Orion with a man or group of men and the stars of the Pleiades with a woman or group of women—a trend found across the world (Fredrick, 2008: 57). Although there are similarities between the Greek myth of Orion and Bates' record of the Orion Story, there is no evidence of post-colonial Western cultural influence. In fact, the story forms the basis of an important male initiation rite (Berndt and Berndt, 1943; 1945, see Section 6). Under closer scrutiny, the story unveils several very interesting elements.

Firstly, the description of *Nyeeruna's* arm (Betelgeuse) is that it fills with fire magic, his hand becoming periodically brighter, and then fainter before brightening again. This suggests, as first proposed by Fredrick (2008: 59), that the Aboriginal observers may have noticed the variability in brightness of the star Betelgeuse. Betelgeuse is a semi-regular variable star with a period of ~400 days (Dupree et al., 1987; 1990; Gray, 2000; 2008; Kiss et al., 2006; Smith et al., 1989; Stothers, 2010). Although the magnitude range, from maximum to minimum brightness and back again, is easily noticeable by eye ($m_{v(max)}$ = 0.1, $m_{v(min)}$ = 1.1, therefore, $_{\Delta}m_v$ ~1.0, see Table 2), Betelgeuse would need to be observed over many cycles spanning several years for its variable nature to be noticed. However, such a feat is not outside the realms of possibility for keen Aboriginal observers. The close proximity of Rigel and Aldebaran to Betelgeuse enables both to be used as reference stars, which aid in determining Betelgeuse's brightness excursions visually. This technique

Table 2: Bates' original attribution of astronomical characters to principle stars in the Aboriginal story of Nyeeruna and Kambugudha, listing their Aboriginal and Western name, Bayer designation, spectral type, visual magnitude (m_v), variability (Yes or No), their magnitude range (Δm_v). Of the stars described in this oral tradition, only the variability of Betelgeuse would be noticeable to the naked eye.

Aboriginal	Western	Designation	Spectral	m_v	var	Δm_v
Yugarilya (seven *Mingari* Sisters)	Pleiades	M45	...	...	...	...
Left Foot of *Kambugudha*	Aldebaran	α Tauri	K5 III	0.87	Y	0.03
Nyeeruna's Right Arm	Betelgeuse	α Orionis	M2 Iab	0.60	Y	~1.0
Joorrjoorr the Owlet Nightjar	Canopus	α Carinae	F0 1b-II	–0.74	N	...
Kara the Redback Spider	Rigel	β Orionis	B8 Ia	0.13	Y	0.05
Babba the Father Dingo	Elnath?	β Tauri	B7 III	1.68	N	...
	Zeta Tauri?	ζ Tauri	B4 III ep	2.99	Y	0.10
Mother Dingo	Achernar	α Eridani	B3 IV ep	0.45	Y	0.03
?	Procyon	α Canis Minor	F5 IV	0.38	N	...

is still employed by modern variable star observers (e.g. Sigismondi, 2000) and was the method employed by Herschel that led to his discovery of Betelgeuse's variability in 1836 (Herschel, 1840a; 1840b). Interestingly, Bates indicates that this increase in "... fire and lust ..." may be due to the effects of "... radiations from nebulae ... " (Appendix) suggesting that she is unaware of the variable nature of Betelgeuse and its possible connection to the story.

Secondly, *Kambugudha's* foot (Aldebaran), like *Nyeeruna's* right hand (Betelgeuse) also fills with 'fire-magic', suggesting that it, too, was observed to be variable. While Aldebaran is indeed a small-amplitude variable star (Henry et al., 2000; Wasatonic and Guinan, 1997), the brightness variations are much too small to be noticed by naked eye observers ($m_{v(max)}$ = 0.85, $m_{v(min)}$ = 0.88, therefore Δm_v ~0.03). This suggests that the 'fire magic' description may not relate to observed stellar variability. Instead, it may refer to the intrinsic reddish-orange (i.e. 'fire-like') colour of both stars, and the effects of atmospheric scintillation at low elevations. Alternatively, it is reasonably plausible that Betelgeuse's intrinsic brightness variations *were* indeed noticed, but the same 'qualities' were also bestowed on Aldebaran by the storytellers to add a sense of drama to this part of the story. Without further substantiating evidence we cannot prove either hypothesis. We are currently searching the anthropological records for other Indigenous references to the observed variability in Betelgeuse.

Thirdly, the story contains a reference to *Nyeeruna* not having 'sparks' issuing from his body after being humiliated by *Kambugudha*, which, by inference, suggests that 'sparks' may issue occasionally, perhaps when he is "... filled with lust ..." for the seven *Mingari* sisters. Bates again attributes this phenomenon to "nebulae" (Appendix). The 'sparks' are a possible reference to the nearby Orionid meteor shower, caused by the Earth passing through the dust stream of Comet 1P/Halley. The radiant of the Orionids is very close to Betelgeuse and Orion's 'club' (Figure 5) and typically peaks over the last two weeks of October each year (McIntosh and Hajduk, 1983). During this time, Orion rises around midnight and is high in the sky before dawn. Peak intensities can vary from year to year due to clumping of meteoroid material in orbital resonant regions (Rendtel, 2007; Štohl and Porubčan, 1981; Trigo-Rodrigez et al., 2007) and large showers have been recorded historically from many cultures (Ahn, 2003). Meteors feature prominently in Aboriginal traditions (Hamacher and Norris, 2010) and are generally given negative associations, including portents of death and punishment for breaking laws and traditions (Hamacher and Norris, 2010; Hamacher, 2011).

Next, the attribution of *Kara*, the red-back spider, with the blue star Rigel (β Orionis, spectral type B8 Ia, m_v ~0.13) is puzzling. In her field notes, Bates describes Rigel as "redly shining" (Appendix), despite its clearly blue appearance. Bates suggested that Rigel ("… the bright star in the nor' west corner of Orion …") was one of the *Baduwuja* brothers who killed a woman named *Yagga*, who is represented by stars north of Centaurus. She is the wife of *Jiringa*, a star "… northeast of Orion." This could be a reference to Procyon, which is mentioned but not discussed or identified. Bates only gives a vague identity for *Jiringas Yagga*, leaving a positive association uncertain. This leaves one to question the reliability of the story as a whole.

After further investigation of the archival documents, two other folios were uncovered (Folios 26/78 and 26/81-82, dates unknown), both containing a haphazard list of Aboriginal names and their attributions to stars, asterisms and constellations. It is possible that these represent Bates' earliest attempts at piecing together Aboriginal astronomical traditions from the small fragments of information given to her from her Aboriginal informants. Near the end of Folio 26/78, titled "Mythical Names of Stars", the following passage appears:

> … Ngurunya is a star which sets at 9pm in March (Achernar). Kara (spider) is northeast and is the winter evening star. He comes close up to Ngurainya (Vega).

At Ooldea, the star Achernar sets at ~21:00 in mid-May, not in March as Bates indicates. In March, Achernar sets at ~02:00. This discrepancy could be blamed on inaccurate timekeeping (did Bates use a timepiece, or did she just estimate the time of day/night?) or the result of a simple typographical error.

The rest of the passage seems to identify an alternative candidate star for *Kara*. The star that best matches her statements "... star in the northwest … [and] winter evening star…" is Arcturus (α Boötis), which rises before Vega. The phrase "He comes close up to *Ngurainya* …" is most likely a verbatim description given to Bates from her informant/s. The attribution of *Kara* with Arcturus is a much better match than for Rigel, and solves the ambiguity in Bates' recording of the Orion Story. Arcturus is both conspicuously bright (m_v = −0.04), and of the right colour (spectral type K1.5 IIIp, making it appear distinctly orange). Arcturus also plays an important role in the astronomical traditions of other Aboriginal groups throughout Australia,[5] thereby strengthening its candidacy here. Table 2 has been amended accordingly to incorporate this new interpretation (see Table 3).

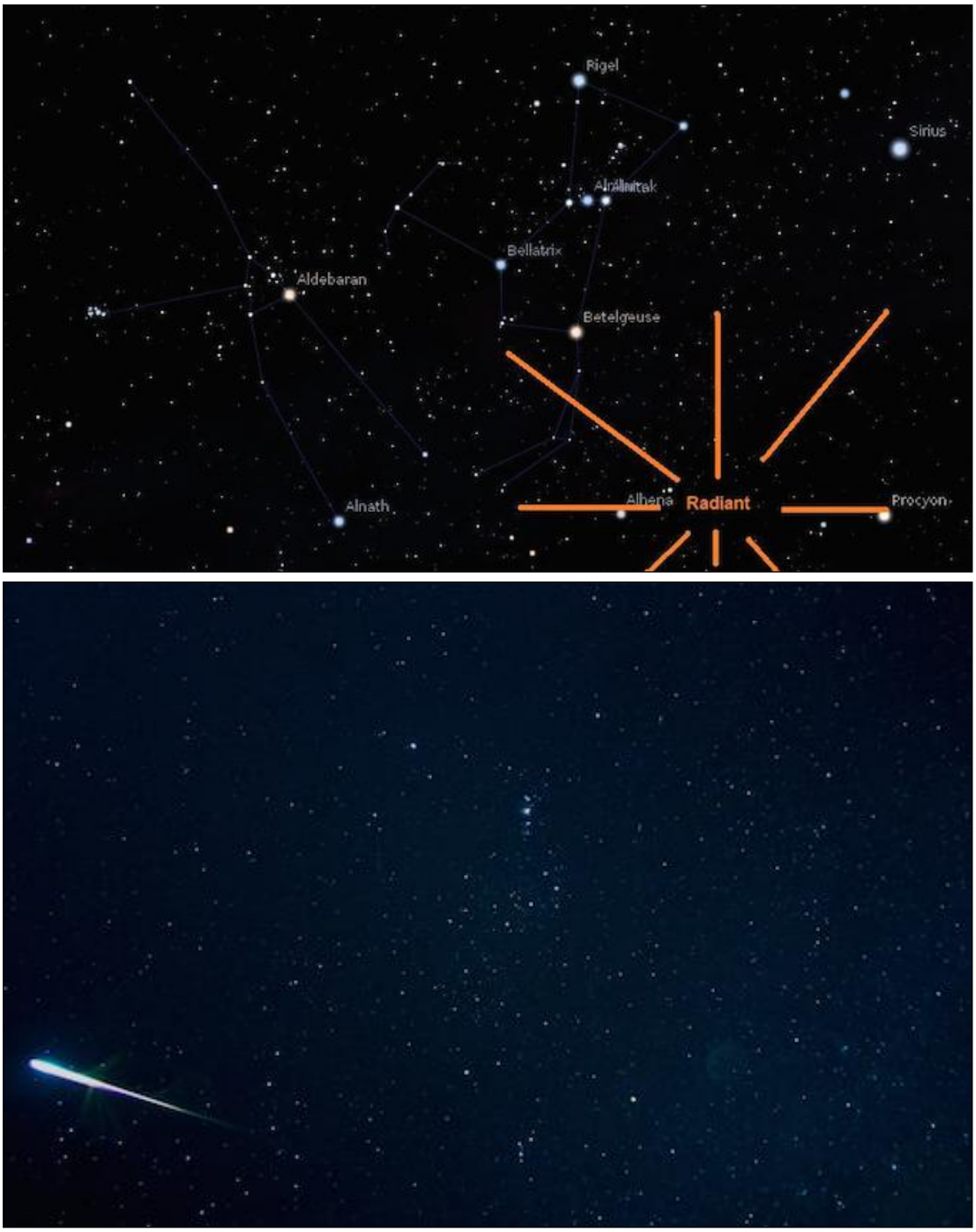

Figure 5(a): The radiant of the Orionids in relation to Betelgeuse in Orion (*Nyeeruna*) and Aldebaran in Taurus (*Kambugudha*). Figure 5(b): A 'spark' from *Nyeeruna's* arm shooting across to *Kambugudha* (an Orionid caught mid-flight). Note: both images have a southern hemisphere perspective (image credits: Figure 5(a) image generated using Stellarium (www.stellarium.org); Figure 5(b) photograph by Rich Swanson, Sierra Vista, Arizona).

Table 3: Same as Table 2, but with re-attribution of Kara the Redback spider with Arcturus, an orange-red giant star, based on Bates' unpublished notes contained in Folio 26/78. The same Folio also gives a possible name to the Mother Dingo. Procyon's Aboriginal name and role still remains unclear.

Aboriginal	Western	Designation	Spectral	m_v	var	Δm_v
Yugarilya (seven *Mingari* Sisters)	Pleiades	M45	...	...	...	...
Left Foot of *Kambugudha*	Aldebaran	α Tauri	K5 III	0.87	Y	0.03
Nyeeruna's Right Arm	Betelgeuse	α Orionis	M2 Iab	0.60	Y	~1.0
Joorrjoorr the Owlet Nightjar	Canopus	α Carinae	F0 1b-II	–0.74	N	...
Kara the Redback Spider	Arcturus	α Boötis	K1.5 IIIpe	–0.04	N	...
Babba the Father Dingo	Elnath?	β Tauri	B7 III	1.68	N	...
	Zeta Tauri?	ζ Tauri	B4 III ep	2.99	Y	0.10
Ngurunya (?) the Mother Dingo	Achernar	α Eridani	B3 IV ep	0.45	Y	0.03
?	Procyon	α Canis Minor	F5 IV	0.38	N	...

But why the error? According to De Vries (2008: 168–169), in the years since arriving at Ooldea, Bates was gradually succumbing to the condition known as vascular dementia, most likely brought on from many years of poor nutrition and advancing age. Vascular dementia is a debilitating disease resulting in gradual memory loss and other cognitive dysfunctions (Tomimoto, 2011). It is possible that during the process of re-writing "The Orion Story" for her newspaper article, she was unable to recall all the facts of the story and, misreading her notes, inadvertently substituted Rigel for Arcturus, not realising the colour disparity between stars. Lending some weight to this hypothesis is a small passage from Folio 26/81-82 (undated), which reads:

> Kara (spider) was 'mate' for M'maingurru (Orion). (He is opposite Bijil.).

This appears to be an earlier fragment of "The Orion Story", and perhaps contemporary with Bates' first article. If we assume that "Bijil" is a mis-spelling of "Rigel", and "*M'maingurru*" is another phonetic variant of "*Mingari*" (and therefore relating to the Pleiades, not Orion), then we can see where the substitution may have taken place. In her confused state of mind, Bates may have transposed these words to read:

> Kara was mate for Mingari (opposite Orion). (He is Rigel).

The first statement is most likely correct,[6] but the second is in error. Also, the original statement "He is opposite Bijil (Rigel)." is ambiguous. Two possible interpretations are that it either means *Kara* is opposite Rigel in Orion, making it Betelgeuse (right colour, but wrong attribution, as the star is already identified as the right arm of *Nyeeruna*) or that it means *Kara* is opposite Rigel in the sky, which makes sense if *Kara* is Arcturus, as it starts to rise in the eastern sky as Rigel sets in the west.

The only linguistic link we can find between *Kara* and a spider is in the Noongar language of southwest Western Australia (Bindon and Chadwick, 2011: 428), a language familiar to Bates. This suggests that one of her informants at Ooldea was either originally from that part of Australia, or was at least familiar with that language. Reed (1993: 127–29) mentions a story of the "Spider Woman of the Great Victoria Desert ...", who amorously pursues and captures a young non-initiated boy, and takes him into the sky where they both become stars (cf. *Kungkapanpa*, see Note 6). Although the woman is unnamed, only mentioning that she is of the "Spider Clan" (i.e. is totemically linked to spiders), there is every possibility that this story is the basis behind Bates' account of *Kara* the Redback Spider in 'The Orion Story'. We are investigating this aspect further.

Lastly, according to Bates, *Babba* the Father Dingo plays an important role in the story. Apart from mentioning that he is associated with the "… horn of the bull …", she does not actually name or indicate a particular star. Two possible candidates are Elnath (β Tauri, $m_v = 1.68$) or the less prominent Zeta (ζ) Tauri ($m_v = 2.99$), both stars marking the tips of the horns of Taurus the bull (Tables 2 and 3). A more intriguing (albeit speculative) possibility is that it may also relate to an eyewitness account of SN 1054, a bright supernova that was prominent in this part of the sky in the year 1054 CE (Collins et.al., 1999; Mayall, 1937; Mayall and Oort, 1942; Polcaro and Martocchia, 2006). The description of *Babba* "... rushing over to *Nyeeruna* ... [and] returning to his place ..." (Appendix) could be in reference to the brightening and dimming of the supernova. This may be explored in later research, though Hamacher (2014) demonstrates the extreme difficulty in linking indigenous astronomical traditions with historical supernovae.

6 'THE ORION STORY' AND MALE INITIATION RITES

In the closing paragraphs of 'The Orion Story' (Appendix), Bates makes reference to witnessing a re-enactment of the story in a ceremony by Aboriginal men of the Ooldea region. Although short on detail and punctuated with some personal bias, there is enough information to suggest that Bates is in fact witnessing the *Minari* and *Baba Inma* ('*Inma*' being the word for 'ceremonial ritual' or 'ceremonial paraphernalia' among this Aboriginal language group) that was later observed and recorded by anthropologists Ronald and Catherine Berndt at Ooldea (Berndt and Berndt, 1943) and Macumba Station near Oodnadatta, South Australia (Berndt and Berndt, 1945; Figure 2). This ceremony involves male Elders enacting the roles of *Nyeeruna* (phonetically spelled *Nji:rana* by the Berndts), the seven *Mingari* (*Minari*) sisters, and *Babba* (*Baba*) the Dingo Father, who attacks and dismembers *Nyeeruna*. The ritual concludes with the subincision of new initiates, signifying their entry into manhood (Berndt and Berndt, 1943). The subincision itself most likely represents the act of *Nyeeruna's* dismemberment by *Babba*, and therefore by inference the initiate 'becomes' *Nyeeruna* (Berndt and Berndt, 1943; 1945; 1977).

Elements of the extended ceremony observed at Macumba Station were performed day and night over the week of 11-17 June 1944, and coincided with a New Moon on the evening of the 11 June (Berndt and Berndt, 1945: 239–240). The subincision rite was performed sometime between sunrise and midday on the last day (Berndt and Berndt, 1945: 249–50).

Noting the strong link between this important ceremony and the constellation of Orion, this tim-

ing is interesting for two reasons. Firstly, due to the close proximity of the Sun to Orion at this time of year (the ecliptic runs close to Orion's 'club'), Orion would not be visible in the sky at any time of the night, including at sunrise or sunset. And secondly, the timing of the rite coincides with Orion being above the horizon in the daytime sky. In the story, Bates states that:

> This performance is usually held at a period when Nyeeruna is absent from the night sky, and it may last until Nyeeruna becomes visible again. Night or day, every native to the groups owning the myth can point out the exact position of Nyeeruna and the attendant stars.

This suggests a sophisticated level of understanding of the daily and annual movements of the celestial sphere, and good positional awareness of important stars and constellations, including those unseen in the sky during daylight hours. The reason for this timing could be purely esoteric; Elders possessing secret sky knowledge may know when the unseen Orion (*Nyee-runa*) was above the horizon, where this cultural hero could secretly 'look down' on and 'participate' in the rite, whereas new initiates lacking this knowledge are unaware and oblivious of this fact until this sky knowledge is passed on.

7 SUMMARY

This is the first paper in a series analysing Aboriginal astronomical traditions in the Great Victoria Desert. Here, we analysed several elements making up 'The Orion Story', the most detailed of Bates' stories of the Ooldea night sky.

Our analysis indicates that the waxing and waning 'fire magic' of *Nyeeruna's* (Orion's) right arm is suggestive of the observed variability in Betelgeuse. However the fact that Aldebaran is also described in these terms makes this interpretation difficult without further supporting evidence. The alternative hypothesis is that it relates to the observed effects of atmospheric scintillation at low elevations.

The 'sparks' being issued from *Nyeeruna* in his lust for the seven *Mingari* sisters (Pleiades) is most likely based on observation of the Orionid meteor shower, the radiant of which is close to the right arm (Betelgeuse) and 'club' of Orion. The fact that the Orionids peak in mid- to late-October, when Orion is low on the Eastern horizon for most of the night prior to sunrise, also lends some weight to the 'fire magic'-atmospheric scintillation hypothesis mentioned above.

The relationship between *Babba* the father Dingo and the 'horn of the bull' requires further analysis. Although we offer two possible candidate stars, Elnath (β Tauri) and Zeta (ζ) Tauri, the fact that Bates does not actually name either star in her story leaves this open to interpretation. One possible reason for this is that she may not have known the name of the star being pointed out to her by her informant/s, only knowing its relationship to the rest of the constellation of Taurus. Because of the location we offer a third alternative, that *Babba* may have been the bright supernova of 1054 CE. However, without substantiating evidence this hypothesis remains speculative, and we are searching the literature for other references to this event.

The orange star Arcturus better matches the colour description and position of *Kara* the Redback Spider, as given in Folios 26/78 and 26/81-82, than the blue-white star Rigel, mentioned in Bates' original account of the story (Appendix). We suggest that this ambiguity in the story may have been due to Bates' poor health and mental state at the time 'The Orion Story' was transcribed.

Based on a detailed account of the *Minari* and *Baba Inma* recorded near Oodnadatta, the male initiation rite may have been timed to coincide with the few days of the year when, due to the Sun's proximity to Orion (*Nyeeruna*), it is unseen throughout the night, but is always in the sky during the daytime. If this is the case, it demonstrates a working knowledge of the annual and daily movements of the celestial sphere and positional awareness of stars and constellations in the daytime sky. We are currently looking for further supporting evidence of this.

8 NOTES

1. Although Bates identifies the bird as a 'night owl' in her earlier news article (Bates, 1921b), she later identifies it as an 'owlet nightjar', a bird totally unrelated to owls. This is most likely the Australian Owlet Nightjar (*Aegotheles cristatus*), found throughout the Australian Outback and known for its nocturnal call.
2. Spelling variations between accounts may be due to the slightly different pronunciations of the names by informants from different language groups and/or an attempt by Bates to get the phonetics right.
3. Among many Central Desert Aboriginal communities, dingoes were domesticated and used for warmth at night, while dingo pups were used as both pets and a food source.
4. Bates describes these as being a line of stars stretching from the horns of Taurus to Achernar. Based on this description, these are most likely the 'shield' stars, $\pi^{1,2,3,4,5,6}$ Orionis and $o^{1,2}$ Orionis, and possibly some stars in Eridanus, e.g. Cursa (β Eridani).
5. For instance, the Boorong of northwest Victoria call Arcturus *Marpeankurrk*, a wise woman who showed her people how to har-

vest the edible larvae (*bittur*) from ants' nests (Stanbridge, 1858; 1861), and when Arcturus crosses the meridian in August it is time to harvest the *bittur*.

6. In the Pitjantjatjara language (Tindale, 1959), the Seven Sisters are the *Kungkarungkara* (*Kunga* = young woman). This linguistically links the *Mingari* sisters to *Kara*. Interestingly, the word *Kara* is the Pitjantjatjara name for Curly Wire Grass (*Aristida contorta*). Similarly, the Anangu version of the Seven Sisters (*Kungkurangkalpa*) contains the word *Kalpa*, which may refer to Rat's Tail (*Dysphania kalpari*), a herb whose seeds are ground up and mixed with honey (from honey ants, *Tjala*) to make cakes. Phillip Clarke (personal communication) suggests that a more likely derivation is from the Yankunytjatjara word *Kungkapanpa*, a 'female cannibal' or 'bogey-woman' that steals babies and children (Goddard, 1996: 42; Goddard and Wierzbicka, 1994: 232).

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11 APPENDIX

References to the story discussed in this paper can be found in two folios (Folios 25/85-88 and 26/13-16) within the archives of the Daisy Bates collection (Bates, 1904–1912) at the National Library of Australia (NLA). As one appears to be a duplicate of the other, only one of these (Folio 26/13-16) is reproduced here, verbatim and in full:

Central Australian Astronomy: The Constellation Orion ('The Orion Story'):

> The constellation Orion is known to the Central Australian natives as Nyeeruna, a name which would seem to have some linguistic affinity with Orion.
>
> Nyeeruna is a hunter, but of women only, a baffled and humiliated hunter, kept for ever at bay by Kambugudha (the "V" in Taurus bull's head), the elder sister of' Yugarilya, the Pleiades, whom Nyeeruna is ever trying to capture and possess, but they are so well-guarded by their elder sister that Nyeeruna has never been able to reach them.
>
> Kambugudha always stands naked before him, feet and legs wide apart, her left foot (Aldebaran) filled with fire magic, which She threateningly-lifts each time she sees Nyeeruna's right hand (Betelgeuse) endeavoring to put red fire magic into his club, to hurl at her and so gain possession of her younger sisters. Kambugudha dares Nyeeruna with her whole body, and is so contemptuous of him and his vain personal display of feathered headdress and ochred body, string belt and whitened tassel that she has placed a line of puppies only between her and Nyeeruna (a faint waving line of stars between Orion and V in Taurus).
>
> The puppies' fathers and mothers -- all relations of Kambugudha -- and her young sisters stand apart on roundabout tracks watching the game. The younger sisters (Pleiades) are very timid and when they see Nyeeruna's body reddened with fire and lust (radiations from nebulae?), fear comes upon them and they change into Mingari (Moloch horridus [the "Thorny Devil" lizard]) while rage lasts; but Kambugudha never changes her defiant attitude and she too can emit fire from her body, so that the red fire of her anger and her magic is so strong that it can subdue the fire magic Nyeeruna throws out, and when she advances towards him, lifting her left foot, she frightens him so greatly that the fire magic of his arm becomes faint and dies out for a while.
>
> Again Nyeeruna's magic comes back in great force and brightness, and when Kambugudha sees the strong magic in arm and body, she calls to a father dingo (horn of the Bull) to come and humiliate Nyeeruna and the Dingo rushes over to Nyeeruna and shakes and swings him east and west by his middle and Kambugudha points at him and laughs but her frightened little sisters hide their heads under their little mountain devil neck humps until Babba loosens his hold and returns to his place again.
>
> A great portion of the constellations and stars Surrounding Orion form part of this great Central Australian myth, Procyon, Achernar, Taurus and others are all ready to help Kambugudha. They resent Nyeeruna's humiliating position and they laugh and are friendly with Kambugudha because of her care for her younger sisters, the Pleiades.
>
> Even Joorrjoorr (Canopus) the owlet-nightjar, though only an onlooker, laughs his Joorrjoorr laugh as he watches Kambugudha blazoning all her charms before the baffled Nyeeruna, daring him forever. Kara the red back spider (Rigel) is also redly shining, ready to bite Nyeeruna. All the animals and birds round and about jeer loudly when they see Babba the Dingo debasing Nyeeruna's manhood. Beera the moon also mocks at him whenever he sits down beside Kambugudha and her young sisters during his journeys to the west, and Nyeeruna loses his red fire and no sparks come from his body (nebulae) in his shame and humiliation.
>
> On fine bright starlight nights, the old men of the Central groups watch the game between Kambugudha and Nyeeruna; the little line of star puppies between them brightens and laughs, and Achernar, the mother dingo, standing at the end of her long row of puppies, joins in the laugh, and the old men re-tell old story, and wink at Beera the moon whenever they see him beside Kambugudha and her young sisters and leering and jeering at Nyeeruna's impotence.
>
> Thus the myth has come down through the ages, but its special interest to ethnologists lies in its adaptation and re-adjustment to the real lives of the groups "owning" the myth.
>
> It has been "dramatized" as a performance for men only, and is acted as a comedy or satire before every young initiate. The myth is first recited to them with many unpublishable details and every night during their novitiate the "play" is performed. They see the Nyeeruna actor trying to reach Kambugudha and her young sisters and they watch Babba the

dingo disgracing Nyeeruna's manhood before the sisters, and see him crawl away in shame and ignominy. No woman can see or take part in the performance but within an enclosure, just about the distance away in which Nyeeruna and Kambugudha and her sisters "sit down" in the sky, a bush enclosure is made before the play begins and within this enclosure women and girls are hidden and raided at will by all the performers, including Nyeeruna. The women represent Kambugudha and her young sisters and the young novices are taught that they can raid young women at will when they have become men. A Nyeeruna is shown throughout in the drama as a "shocking example" to all men.

During the performance songs are sung by the groups owning the special myth, the songs being accompanied by the beating of short heavy clubs on a prepared sand mound (mankind's first "drum") the drum beating and singing being quick and loud or slow and soft as the drama proceeds, the frequent "raiding" of Kambugudha and her sisters being hailed with triumphant drumming and singing.

This performance usually begins when the young boys are considered ready for initiation, and at a period when Nyeeruna is absent from the night sky, and it may last until Nyeeruna becomes visible again.

Night or day every native of the group owning the myth can point out the exact position of Nyeeruna and the other stars and constellations. The young initiates are thoroughly taught Nyeeruna's story, which they must never reveal to women. The moral of the story is meticulously explained by the brothers or guardians of each young novice.

The boys must look upon all women as their slaves, to do their will at all times and in all places, to "fetch and carry" for them throughout their lives.

A certain ruthless and savage power is thus instilled into the young novices as they fully grasp -- through a wearisome reiteration the acted story of the constellation, and see it turned topsy-turvy in meaning and application, and when they realize their appalling power over all their women-kind and think of Kambugudha's successful defiance of Nyeeruna's advances, whatever cruelty is inherent in them in given full bent.

The myth and performance (both grossly phallic) cover a wide area of Central Australia and the western border, south towards the Great Plain's northern edge and east and Southeast towards the Diamantina, Cooper and other rivers.

There is a religious instinct, though in a debased form, in this myth, as their only religious sentiments centre round phallicism. Totems, legends, initiation, all rites and ceremonies are representations of phallic worship.

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DREAMTIME ASTRONOMY: DEVELOPMENT OF A NEW INDIGENOUS PROGRAM AT SYDNEY OBSERVATORY

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Abstract: The Australian National Curriculum promotes Indigenous culture in school education programs. To foster a broader appreciation of cultural astronomy, to utilise the unique astronomical heritage of the site, and to develop an educational program within the framework of the National Curriculum, Sydney Observatory launched *Dreamtime Astronomy*—a program incorporating Australian Indigenous culture, astronomy, and Sydney's astronomical history and heritage. This paper reviews the development and implementation of this program and discusses modifications following an evaluation that was conducted by schools.

Keywords: astronomy education, cultural astronomy, Aboriginal Australians, astronomical history, astronomical heritage.

1 INTRODUCTION AND BACKGROUND

Sydney Observatory is Australia's oldest surviving astronomical observatory and was constructed in various stages, starting in 1858 (Orchiston, 1998; Wood, 1958; 1983). In 1982 the Observatory ceased to function as an autonomous research and educational institution and was incorporated into the Museum of Applied Arts and Sciences (Kerr, 1991; Orchiston, 1988). Whilst education has long been a role of the Observatory (Lomb, 1998; Wood, 1958), science education and the heritage of astronomy are now the primary focus. As a public observatory and museum, Sydney Observatory offers unique and site-specific educational programs in astronomy, meteorology, archaeology, and most recently on the astronomical knowledge of Aboriginal Australians, a topic dubbed 'Aboriginal Astronomy'.

Since 1997 Aboriginal Astronomy has been part of the exhibition and all education tours have included some Aboriginal content, mainly in the planetarium component. Within the domed, darkened room, stars are digitally projected to create a virtual night sky. Aboriginal constellations, such as the Emu in the Sky, are projected on the dome and the astronomy guides recount stories from communities such as Yolngu (Northern Territory) and Murri (Queensland).

Over the past decade there has been a significant increase in research into the astronomical knowledge of the Aboriginal Australians (e.g. see Cairns and Harney, 2004; Fredrick, 2008; Hamacher, 2012; Norris and Norris, 2008). This has coincided with changes in the school curriculum and a desire to increase the number of student visitors to Sydney Observatory. Day school visitation increased nearly 45% to 16,000 between 1998 and 2010, but has plateaued since 2010 (Figure 1). Student numbers for night programs have remained static at around 2,000 per annum.

A decision was made to embrace the new research in Aboriginal astronomy and develop an education program around the subject. This goal was to increase education visits and further enhance the appreciation of Indigenous Australians as arguably the world's oldest astronomers (Norris, 2008).

2 PREVIOUS ABORIGINAL ASTRONOMY PROGRAMS

In 1997 a new exhibition marked the start of the Observatory's presentation of Indigenous astronomy. The small theatre exhibit, named *Cadi Eora Birrung* (meaning "Beneath the Southern Sky" in the language of the Cadigal people of Sydney Cove), includes an immersive space where videos of astronomy-themed 'Dreaming' stories are projected using a 'fishers-ghost' technique. The animations were developed by Aboriginal artists and recorded by Aboriginal actors.[1] Nearby, an interactive computer display allows the user to choose between Aboriginal and Western constellations visible during different seasons of the year.[2]

In 2012, we developed an exhibit that featured meteorites from New South Wales, the Northern Territory (NT) and Western Australia (WA). The exhibit[3] includes both scientific and Aboriginal accounts of the Henbury crater field

(NT) and Wolfe Creek crater (WA). The display also features a painting of the Wolfe Creek crater (which is called *Kandimalal* in the Jaru language) by a noted Jaru artist. We have received positive feedback about the display from visitors.

The installation of extensive Western heritage and Aboriginal exhibits in 1997 marked the beginning of a trend of increasing visitor attendance to Sydney Observatory (Figure 2). This increase has, for the most part, been steadily continuing ever since. There is no evidence to suggest one part of the Sydney Observatory experience is more visited than another. As it is a small building, visitors tend to see a majority of the exhibits. The *Cadi Eora Birrung* exhibit is referenced in tourism guides (Atkinson, 2012) and on the City of Sydney's self-guided walking tour and website (Aboriginal Cultural Attractions, 2014). On average, tourists account for 42% of the visitors to Sydney Observatory.

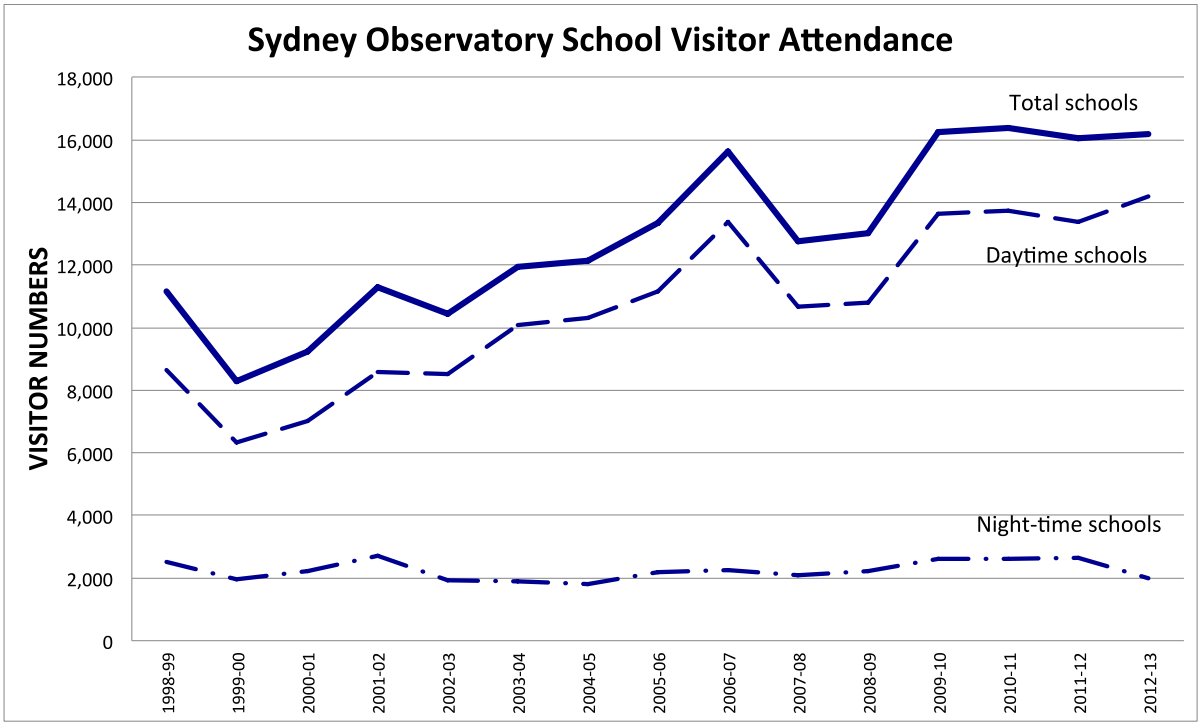

Figure 1: Education visits to Sydney Observatory between 1998 and 2013.

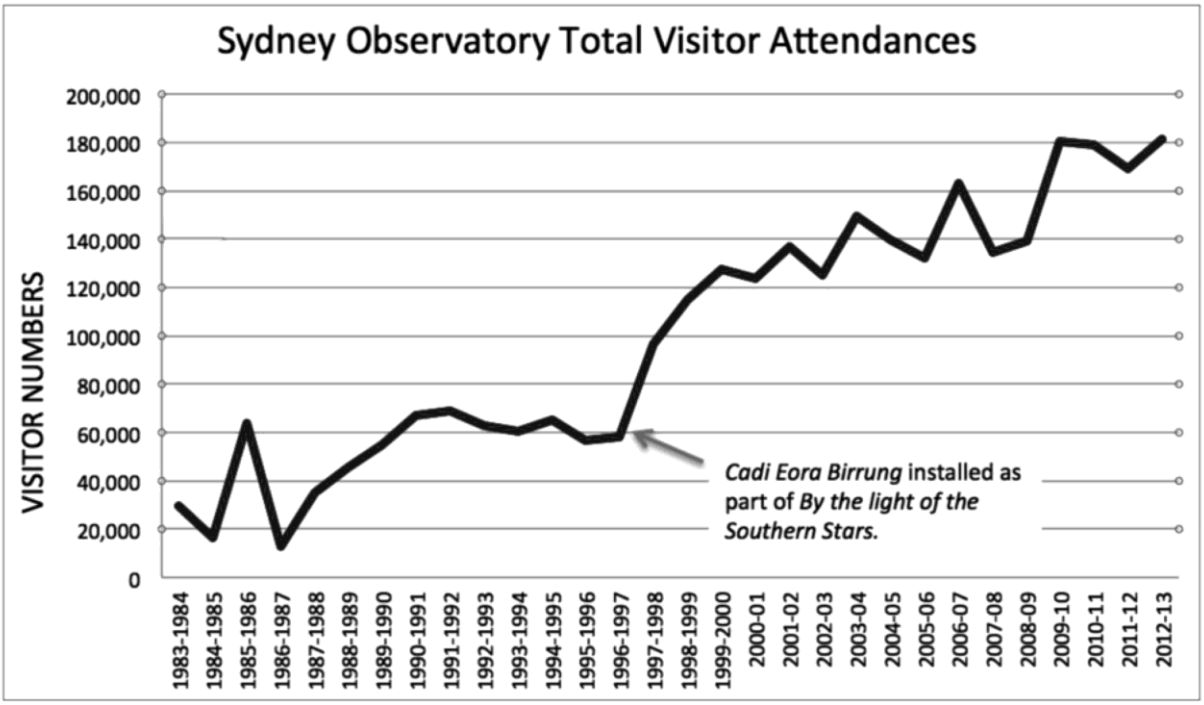

Figure 2: Thirty years of visitor attendances at Sydney Observatory showing the impact of the 'By the Light of the Southern Stars' exhibition and 'Cadi Eora Birrung'.

3 PROGRAM DEVELOPMENT

The development of the new Australian Curriculum (ACARA, 2013), guided by the Melbourne Declaration on Educational Goals for Young Australians in 2008,[4] stressed the importance of a cross-curriculum priority on Aboriginal histories and culture. This is the primary motivation for developing an Aboriginal astronomy program, along with educating the general public about the complexity of Australian Indigenous astronomical knowledge systems.

The *Interactive Experience Model* (Falk and Dierking, 1992), where the personal, social and physical intersect, is a dynamic way for museums to achieve successful learning experiences for school children using their unique attributes outside the school environment. Sydney Observatory has adopted this hands-on approach as central to all of its education programs (Lomb and Stevenson, 2008). With an Indigenous astronomy program, our aim is to achieve what Canadian astronomy educator, John Percy, calls 'minds-on' education.

Percy (2008: 20) considers methods used by ancient cultures as an ideal way of engaging students in the 'big picture' concepts of astronomy:

> The first people to 'do astronomy' were the pre-technological cultures who were able to determine time, date, and direction from the sky. They made and recorded observations, archived and used them … one could argue that these simple observations are the most relevant kinds for most students to make.

This way of thinking made it possible to tie the cultural aspects of Aboriginal astronomy and the scientific approach of astrophysics and cosmology together with a common thread of observation, recording and analysis.

Originally titled *Shared Sky*, and later renamed *Dreamtime Astronomy,* the program highlights the diverse astronomies of Aboriginal people and explores the ways in which they used the stars for navigation, seasonal calendars, food economics, ceremonies and social structure. The framework of Aboriginal cultures, including their beliefs, spirituality, laws and oral traditions is called the *Dreaming,* or *Dreamtime*. It can be viewed as a period in the distant past when ancestors created the land, sky, animals and plants. It can also represent a present or a future reality in which people interact with ancestor spirits (Isaacs, 1980). The *Dreamtime* contains information regarding the daily practices, social structure and knowledge of the community. The *Dreamtime* is synonymous with 'Traditional Knowledge' but is unique to Australian Aboriginal cultures. This is the reasoning behind naming the program *Dreamtime Astronomy*.

A majority of the Aboriginal content for this program was based upon the ethnographic work of William E. Stanbridge, who published a paper on the astronomical traditions he learnt from the Boorong clan of the Wergaia language group in northwestern Victoria in the mid-eighteenth century (Stanbridge, 1861). This was chosen because it represents the earliest comprehensive description of Aboriginal astronomy and is one of the most studied Aboriginal views of the night sky (Hamacher and Frew, 2010; Morieson, 1996).

To implement the program, we needed to determine how to make Aboriginal content relevant and memorable to students who typically had never been exposed to Aboriginal astronomy prior to their visit to Sydney Observatory. We designed three activities to accomplish this.

4 PROGRAM IMPLIMENTATION

The *Dreamtime Astronomy* program, like most tours at the Observatory, lasts for 1.5 hours and involves three activities, each taking 30 minutes.

4.1 Activity 1: Using *Stellarium*

In this activity, students use modern technologies familiar to them, including computers, tablets and smart phones, to use interactive astronomy apps and software packages such as *Stellarium.*[5] *Stellarium* allows the user to simulate the sky on their device. This is particularly important as students can set the view to the night of their visit to the Observatory.

The positions of the planets and Moon along the ecliptic are used to highlight students' existing 'latent' knowledge of constellations, which is typically limited to those of the Zodiac. The software allows students to learn to use the stars to tell time and find direction. This will provide them with a fundamental understanding of how the sky works and give them a chance to play with the software, by seeing for example what objects were in the sky the night they were born.

4.2 Activity 2: Making a Planisphere

The second activity has students make a planisphere[6] (Figure 3) that they can take home. The planisphere includes two discs: the first shows Western names of celestial objects. It is used to help the students determine what stars are in the sky throughout the night at various times of the year; find directions; and tell time. Having explored their knowledge of constellations that relate to Greek mythology, the students replace the inner star-wheel with the second disc, which shows Boorong names of celestial objects. This is accompanied by a small pamphlet containing information about Boorong astronomy, and is red, black and yellow to reflect the colours of the Aboriginal flag.

With the aid of an Indigenous language map of Australia, students are made aware of the diverse range of Aboriginal cultures and astronomies across the continent, with emphasis on the lack of a single Aboriginal 'astronomy' or viewpoint.

Faint half-tone representations of the Southern Cross, Scorpius and Orion are included on the Boorong star-wheel as a reference (Figure 4). These familiar constellations permit students to draw observational correlations between what they already know and what they are learning. Boorong stories that go with the stars are recited and projected on an interactive whiteboard. Problem-solving activities are presented to the students, such as identifying which Boorong stars

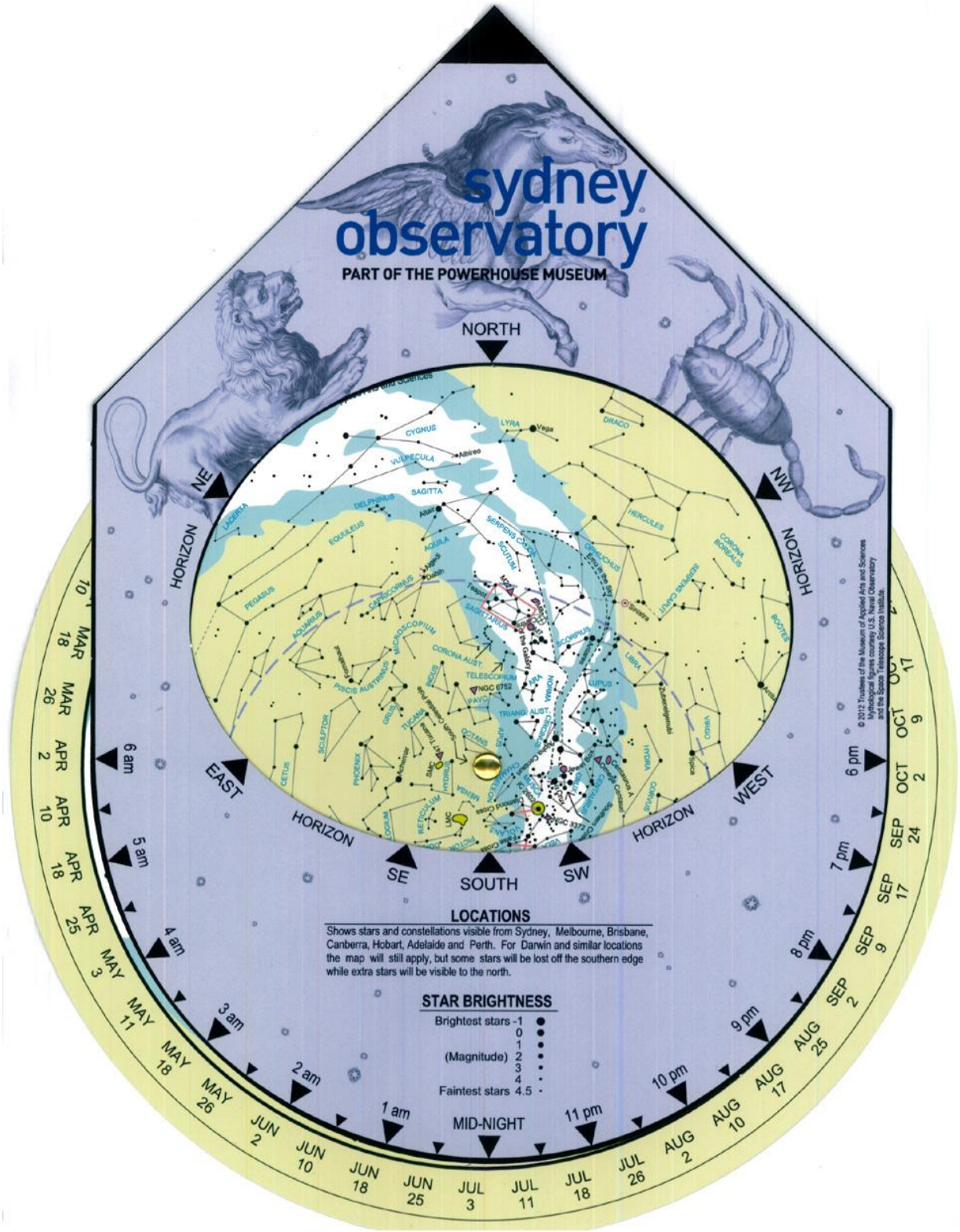

Figure 3: A 'Western' planisphere, developed by Dr Martin Anderson.

are visible at particular times of year and their significance to the people. Examples include the appearance of Arcturus (*Marpeankurrk*) high in the northern sky at dusk when the Boorong people would collect wood-ant larvae, or the rising of Vega (*Neilloan*) at dusk when the mallee-fowl birds began building their nests (Stanbridge, 1861). The accompanying pamphlet provides these details, explaining what these stars meant to the Boorong people.

4.3 Activity 3: Making a Signal Stick

The third component of the program addressed forms of non-verbal communication used by Aboriginal communities that also highlighted the Observatory's role in the young colony of New South Wales. Message sticks were used by Aboriginal people to send information to communities great distances away (Howitt, 1904). This information might include the time and place for a corroboree (ceremony), with the time denoted by lunar phases (Hamacher and Norris, 2011).

From about 1814 onwards, long before Sydney Observatory was even thought of, Fort Phillip on the Observatory Hill site played an important role in signalling (although this quickly faded in modern times). A newly-erected mast[7] at the Observatory now flies flags that not only replicate old signals, but also communicate Sydney's expected maximum temperature, the phase of the Moon, constellations visible, planets visible, and special astronomical objects or events, such as comets, meteor showers, equinoxes and solstices (Figure 5). In the words of George Oxenbridge, the leader of the team that made the flag mast, it became "… a giant message stick for Sydney."

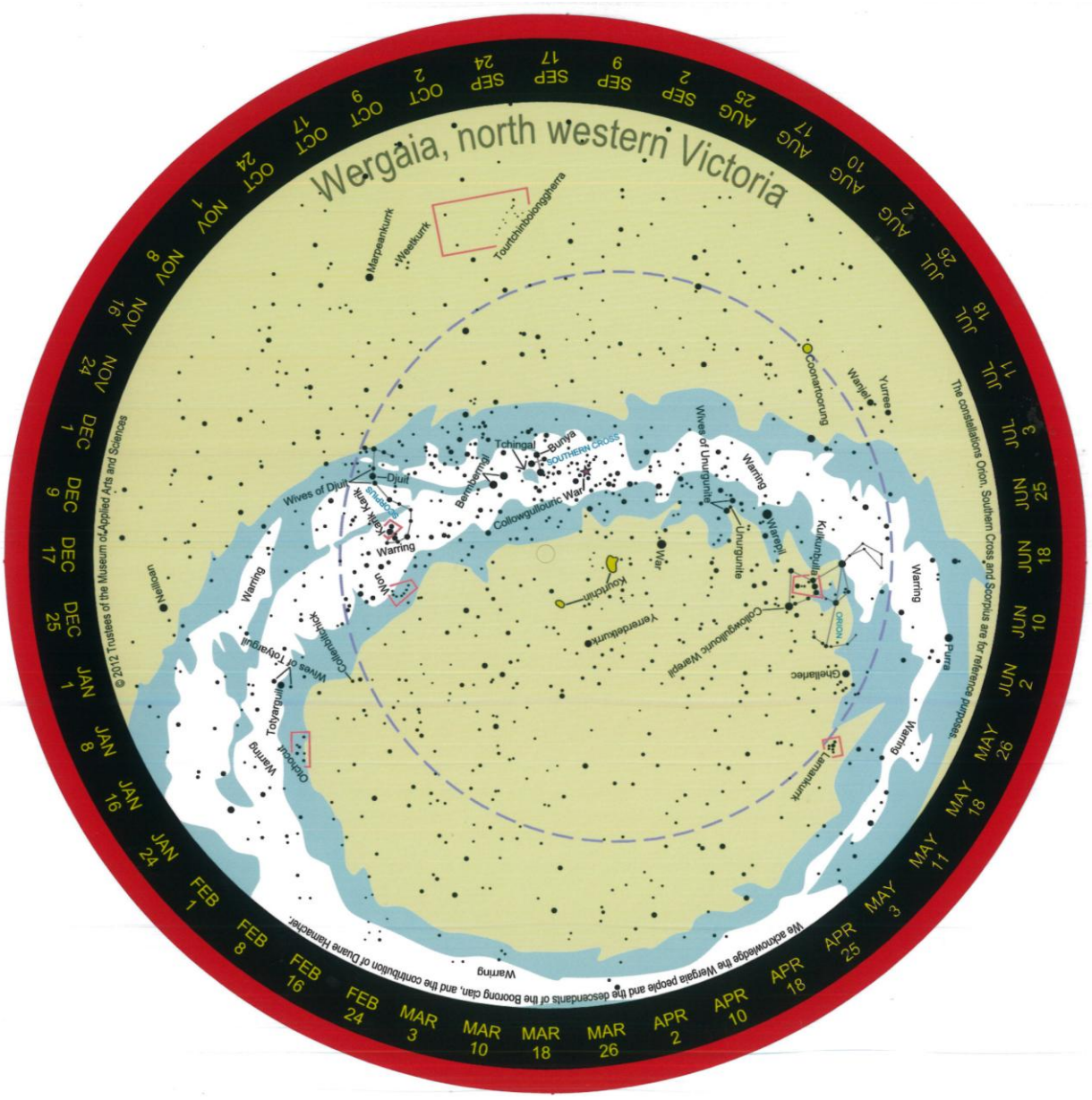

Figure 4: Boorong planisphere inner-wheel by Dr Martin Anderson.

Figure 5: The 2008 flag mast recreation by the Bruce and Joy Reid Foundation (photograph: Geoffrey Wyatt).

It was this idea about signals and message sticks that was used to develop the third (although not entirely astronomical) component of the program. After consultation with staff at the Australian Museum in 2011, the more neutral term 'signal stick' was used, as message sticks sometimes contained information that was gender sensitive (e.g. 'Men's business' or 'Women's business', such as initiation ceremonies). A brief history of signal sticks is presented to the students, with a two-fold intention:

(1) To show their analogous connection to modern passports; and
(2) To show that they represent a complex form of non-verbal communication, comparable to Fort Phillip's flag mast.

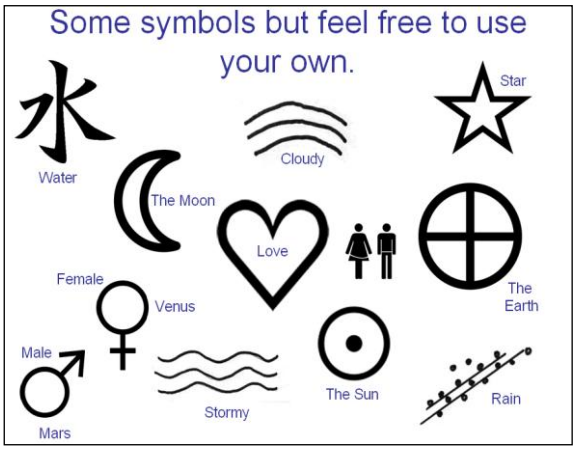

Figure 6: Sample of multi-cultural symbols (image: Geoffrey Wyatt).

To inspire the students and serve as a visual prompt, a sample of symbols from various cultures is projected during this section of the tour. The symbols used were taken from Aboriginal, Asian and Middle Eastern cultures, but also included commonly-used symbols such as those for stars, the heart, males and females, and the astronomical symbols for Mars and Venus (see Figure 6).

Students were then given the opportunity to create a signal stick to take home (Figure 7). Each student could decorate their signal stick with symbols that would mean something to them or their immediate circle of friends and family. It could be of any design, and it would not need to be intelligible to anyone other than the intended recipient(s).

5 PROGRAM EVALUATION

In 2013 the program was tested with a sample of four schools with students ranging from Year 2 to Year 4 (aged 7 to 10). Teachers were asked to provide feedback, and it was predominantly positive. The use of modern technologies, such as computers, tablets and smart phones, was well received and the students enjoyed learning with *Stellarium*.

There were, however, a few major points of criticism from the teachers, the students and the guides:

(1) The planisphere could be improved by using local Aboriginal astronomical content (for the Sydney region) rather than content from western Victoria or other parts of Australia.

(2) Students were disappointed that they did not get to use the planetarium.

(3) The signal sticks were an enjoyable activity, but were the least relevant to an experience at Sydney Observatory.

(4) The students were extremely disappointed that they did not get to look through a telescope.

(5) Indigenous guides delivering the content would improve the program.

This feedback enabled us to modify and improve *Dreamtime Astronomy*.

6 PROGRAM MODIFICATIONS

6.1 Modified Activity 1

Students and teachers found Activity 1 (using *Stellarium*) to be educational, enjoyable and engaging. But we decided to combine it with Activity 2 (making a planisphere), as they complemented each other. We also decided to replace the Boorong astronomy content in the

planispheres with Sydney Aboriginal astronomy content. Unfortunately, little has been published on Aboriginal astronomy in the Sydney region, so we developed a partnership between the Observatory and the Nura Gili Indigenous Programs Unit at the University of New South Wales (UNSW) to address this issue.

The UNSW partnership involves a co-author of this paper (Hamacher), who is an academic at Nura Gili and works casually at the Observatory as an astronomy educator. Hamacher teaches an undergraduate unit called *ATSI 3006: Astronomy of Indigenous Australians*. A major assessment for students enrolled in the course is to research an area of Australian Indigenous astronomical knowledge and develop educational materials utilising that research. Students in *ATSI 3006* will research Aboriginal astronomical traditions in the Sydney region and develop a planisphere based on these findings. Preliminary findings have already revealed a number of Aboriginal stories of the sky from the Sydney region, including those of the Dharug, Dharawal, Gundungurra, and Kuringai peoples This content will be incorporated into the *Dreamtime Astronomy* program in mid-2014.

We also realised the pamphlet containing Aboriginal astronomical information was not ideal for the students, as most were left behind. But the students valued the planispheres and kept these. When each student completes the planisphere, the guides show them how to use it. The guides then demonstrate the connection between the rising or setting times of stars and their connection to seasonal cycles using *Stellarium*. The students are given a short demonstration and shown how to download the program to their devices. The pamphlet was discontinued and instead the information will be presented on a webpage from mid-2014.

6.2 Modified Activity 2

We determined that the low astronomical significance of the signal stick activity did not reflect an ideal approach to teaching the students about Aboriginal astronomy. Additionally, the sticks did not serve a useful purpose once the students left the Observatory. In fact, many were left behind. The students' biggest expectation was to look through the telescopes at the Observatory, and they were extremely disappointed that the program did not include this. This came as no surprise as Observatory staff are anecdotally aware that all visitors, regardless of the program, have a strong desire to look through the telescopes in the domes.

We therefore replaced the signal stick activity with telescope viewing in one of the domes. Day-time programs involve students viewing the Sun through a solar telescope. This enables staff to draw attention to the astronomical significance of the solar symbol in the Aboriginal flag while the students observe sunspots and prominences and learn about the physical structure of the Sun.

For night-time programs, students view astronomical objects of significance to Aboriginal people. These may include the Moon, planets, stars and star clusters. This gives the guides a chance to discuss the Aboriginal and scientific significance of these objects. One aspect relates to the colour of stars. The colour of a star can tell astronomers about its surface temperature and age, but in many Aboriginal cultures colours of stars might signify an association with a particular animal or plant. For example, in the Western Desert the red star Antares in Scorpius was associated with the red-tailed black cockatoo. When Antares rises at dusk in May it

Figure 7: Making signal sticks (photograph: Geoffrey Wyatt).

reminds Aboriginal people that the first clutches of eggs will begin hatching (Hamacher and Leaman, 2014). On cloudy nights (and days), when telescope-viewing is not possible, the planetarium session is extended and students are guided through the Aboriginal astronomy exhibits in the Observatory.

6.3 Modified Activity 3

In response to the student's disappointment that they did not get to use the planetarium, we developed a new activity that incorporates use of the planetarium and emphasizes some of the relevant local history.

The earliest information we have about Aboriginal astronomy was recorded by Lieutenant William Dawes, the astronomer on the First Fleet that arrived in Sydney in 1788. He founded the first observatory in Australia on the shores of the harbour at the place now called Dawes Point, which lies at the southern base of the Sydney Harbour Bridge (see Laurie, 1988; Orchiston, 1989). During the short time he lived

in the colony, he befriended a young Aboriginal woman named Patyegarang who taught him the local language and customs. He kept detailed journals, which contain local Dharug names for the Sun, Moon, Milky Way and Magellanic Clouds (Dawes, 1788-1791).

The new activity involves giving each student a worksheet that incorporates Sydney Aboriginal astronomy and the interactions between Dawes and Patyegarang. Aboriginal names of astronomical objects are written on the worksheet for the students to learn and use. They are then taken into the planetarium, where they experience Sydney's twenty-first century light-polluted sky. As the guides share Aboriginal stories of the sky, the planetarium is set to 1788 conditions, enabling the Milky Way to be seen clearly as Dawes and Patyegarang would have seen it. This gives the students an opportunity to learn by experience, just as Dawes did. Additionally, the simulated night sky on the planetarium dome displays other visual cues, including images of animals, plants and Aboriginal ancestors important to the story.

6.4 Other Implementations and Feedback

It was deemed important for the Observatory to have the program delivered by Aboriginal guides so that the students get a more appropriate experience. This also promotes Indigenous involvement in the program. Consequently, in January 2014 the Observatory hired Aboriginal guides to present the *Dreamtime Astronomy* program.[8]

Australia contains two different Indigenous peoples: the Aborigines and the (Melanesian) Torres Strait Islanders. Our current programs only focus on Aboriginal astronomy. There has been little research on the astronomy of the Torres Strait Islanders, but related research does show that Islander culture contains a significant degree of astronomical knowledge (e.g. see Sharp, 2003). A major grant to study Torres Strait Islander astronomy was recently awarded by the Australian Research Council (Hamacher, 2014), and in the future information about Islander astronomy will be incorporated into the *Dreamtime Astronomy* program at Sydney Observatory in order to present a more comprehensive account of Indigenous Australian astronomy.

The modified program, which will not include Sydney Aboriginal content until mid-2014, has recently been trialled during evening public tours, and feedback in the form of ratings on a social media website (Trip Advisor, 01 April 2014)[9] indicate its success. The following is typical of the comments recorded:

> Got there early and toured museum. Very well done. Willy gave us stories from his people about the stars. Interesting, educational and fun. Recommend it.

Ever since it developed an Aboriginal astronomy program, Sydney Observatory has been listed on the 'Portal to the Heritage of Astronomy' website developed by UNESCO and the International Astronomical Union as part of the Astronomy and World Heritage Initiative (Ruggles and Cotte, 2010). This listing provides staff at the Observatory with further incentive to project astronomy as a science with cultural and heritage dimensions.

7 CONCLUDING REMARKS

Astronomy education at Sydney Observatory has enjoyed growth and strong visitation over many years whilst operating as an astronomical museum and adopting an Interactive Experience Model for its learning programs. New cross-curriculum opportunities have inspired activity-rich experiences in Aboriginal astronomy. The *Dreamtime Astronomy* program will provide students and their teachers with an opportunity to visit and engage in the history and heritage of Sydney Observatory and Sydney Aboriginal astronomy. The ambition is to achieve a 'minds-on' experience for students, which engages them in astronomy through a cultural experience. Further evaluation will continue to guide the development and modification of the program and its delivery.

For more than 150 years Sydney Observatory acted as a portal for European-based science, but it now also provides visitors, and especially school students, with an opportunity learn about and experience the astronomical knowledge and traditions of Australia's Indigenous peoples.

8 NOTES

1. Aboriginal Nations created the Dreamtime cartoons, and the Powerhouse Museum especially filmed Aboriginal actors to introduce these in a 'fireside' setting. http://www.thedreamingstories.com.au/.
   The display was curated by Nick Lomb and James Wilson-Miller.
2. The display was developed by Kathy La Fontaine.
3. The exhibit was curated by Duane Hamacher and Katrina Sealy.
4. Ministerial Council on Education Employment Training and Youth Affairs: http://www.curriculum.edu.au/verve/_resources/National_Declaration_on_the_Educational_Goals_for_Young_Australians.pdf
5. http://stellarium.org/
6. The planisphere was designed by Martin Anderson.
7. A re-creation of the flag masts was devel-

oped in 2008 through the generosity of the Bruce and Joy Reid Foundation.

8. William 'Willy' Stevens is the first Aboriginal guide to present *Dreamtime Astronomy*.
9. Pdm267, posted 1 April 2014, 'Dream makers tour', Trip Adviser, http://www.tripadvisor.com.au/ShowUserReviews-g255060-d256722-r199493592-Sydney_Observatory-Sydney_New_South_Wales.html#UR199493592

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THE *ILGARIJIRI* PROJECT: A COLLABORATION BETWEEN ABORIGINAL COMMUNITIES AND RADIO ASTRONOMERS IN THE MURCHISON REGION OF WESTERN AUSTRALIA

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Abstract: The international radio astronomy initiative known as the Square Kilometre Array is a cutting-edge science project, aimed at dramatically expanding our vision and understanding of the Universe. The $2billion+ international project is being shared between Southern Africa and Australia. The Australian component, centred in the Murchison region of Western Australia, is based upon collaboration with Aboriginal communities. A collaborative project called "*Ilgarijiri - Things Belonging to the Sky*" shared scientific and Aboriginal knowledge of the night sky. Through a series of collaborative meetings and knowledge sharing, the *Ilgarijiri* project developed and showcased Aboriginal knowledge of the night sky, via an international touring Aboriginal art exhibition, in Australia, South Africa, the USA and Europe. The Aboriginal art exhibition presents Aboriginal stories relating to the night sky, which prominently feature the 'Seven Sisters' and the 'Emu', as well as the collaborative experience with radio astronomers. The success of the *Ilgarijiri* collaborative project is based upon several principles, which can help to inform and guide future cultural collaborative projects.

Note to the reader: Readers are respectfully advised that the following contains the image and name of an Aboriginal person who has passed away.

Keywords: *Ilgarijiri*, cultural astronomy, Aboriginal art, Aboriginal astronomy, radio astronomy, ASKAP, SKA, Yamatji, Murchison region, Western Australia

1 INTRODUCTION

Ilgarijiri is the Wajarri Yamatji Aboriginal word meaning "Things Belonging to the Sky". With the development and operation of major radio astronomy facilities in the Murchison region of Western Australia (WA), an opportunity was recognised to collaborate with the local Wajarri and Yamatji people and share scientific astronomical knowledge and Aboriginal knowledge of the night sky. This proactive approach has benefitted Aboriginal communities associated with the radio astronomy facilities. This collaboration resulted in an international touring Aboriginal art exhibition that inspired and informed the 'Cosmos, Culture and Landscape Project' (CCLP), which examines the sharing and communication of Aboriginal astronomical knowledge. This paper presents findings in relation to the *Ilgarijiri* collaboration.

1.1 Radio Astronomy in the Murchison Region

The major radio astronomy facilities in the Murchison region of WA are the Murchison Widefield Array (MWA) (Figure 1) and the Australian Square Kilometre Array Pathfinder (ASKAP) pro-

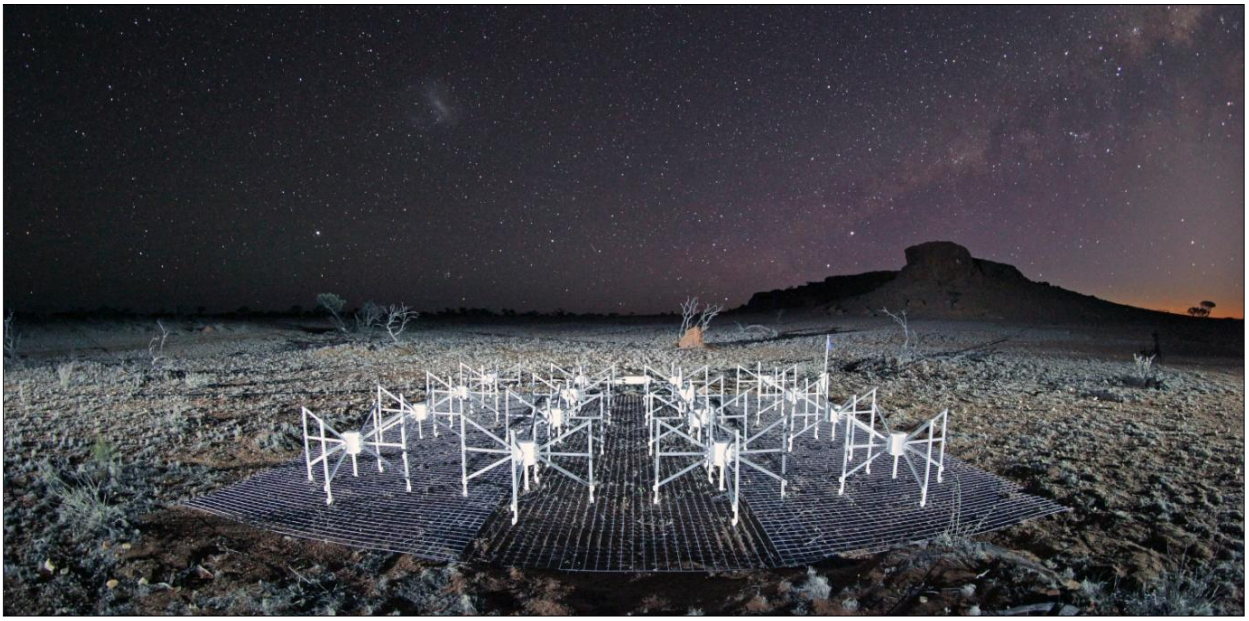

Figure 1: The Murchison Widefield Array and Southern Sky (photograph: John Goldsmith).

ject, both of which are technology demonstrators for the Square Kilometre Array (SKA) radio telescope. The entire project is shared between Southern Africa and Australia/New Zealand. The MWA, ASKAP and SKA are described by Lonsdale et al. (2009), Johnston et al. (2007) and Dewdney et al. (2009), respectively. In WA, the Murchison region was selected after an extensive international search for a location where artificial radio noise interference was minimal. In addition, the region exhibits dark skies.

2 HYPOTHESIS AND OBJECTIVE

This paper examines the hypothesis that collaborative, cross-cultural projects can act as an important catalyst in encouraging the appreciation and respect of Aboriginal and scientific astronomical knowledge. This hypothesis is supported by a research objective, which is to collaborate with Aboriginal people to document and communicate, in a culturally-appropriate manner, contemporary Indigenous astronomical knowledge.

Figure 2: Professor Steven Tingay and Wajarri Elder Teddo Ryan (photograph: Dr Megan Argo, ICRAR).

3 METHODOLOGIES

Research methodologies for the CCLP used a variety of data-collection methods, including site visits, video-based interviews and 360° digital site photography. The selection of interviewees and general coordination was facilitated by Yamaji Art in Geraldton, WA, and members from Marra Arts in Mullewa, WA. The face-to-face interviews were video recorded, with the permission of the interviewees. Interviewees include Yamaji artists Barbara Merritt, Margaret Whitehurst, Olive Boddington (deceased), Kevin Merritt and the then Yamaji Art Coordinator Charmaine Green. Mullewa artists included Wendy Jackamarra, Christine Collard, Debra Maher, Susan Merry and Barbara Comeagain. Radio astronomer Dr Megan Argo (then based at the International Centre for Radio Astronomy Research—ICRAR—in Perth) was also interviewed. Interviews were transcribed, and selected quotes are presented in Section 6.1 below. In addition to the video interviews, site photography was conducted at the Murchison Widefield Array radio telescope, based on 360° imaging techniques, as described in Goldsmith (2011). These images were then processed using Autopano Giga software to create 360° images of the radio telescope site.

4 THE *ILGARIJIRI* COLLABORATION AND KNOWLEDGE SHARING

Ilgarijiri is a collaborative project between radio astronomers and Aboriginal communities, aimed at sharing scientific and Aboriginal knowledge of the night sky. The project was facilitated by interactions between radio astronomers and Aboriginal communities in the Murchison, and developed concurrently with Australia's bid for the Square Kilometre Array (SKA). In this bid, the SKA was envisaged as a radio telescope consisting of thousands of small antennas spread across Australia and New Zealand with a combined collecting area of one square kilometre. This innovative array would be used by astrophysicists to try to better understand the fundamental structure and evolution of the Universe (Tingay et al., 2013).

The Commonwealth Scientific and Industrial Research organisation (CSIRO) developed a public outreach project called "Wildflowers in the Sky" (Drok, 2009/2010), which helped to place optical telescopes in various schools in the Murchison Region, including some remote schools. This public outreach work was complemented by the work of CSIRO Liaison Officer Robin Boddington, who facilitated discussions between Aboriginal communities and radio astronomers.

Recognising opportunities for collaboration, Professor Steven Tingay (ICRAR) began discussions with Yamaji Art to share scientific and Aboriginal perspectives of the night sky (Tingay, 2011). Aboriginal Elder Teddo Ryan and Professor Tingay visited sites in the Murchison Region, including Boolardy Station (Figure 2). As the concept of the *Ilgarijiri* project developed, Yamaji Art took a leading role in working with Aboriginal artists, in collaboration with Marra Arts, Mullewa. The project was conducted under Aboriginal leadership and direction, by Yamaji Art, which facilitated the day-to-day management of artists involved in the collaboration, provided logistical support for site visits, supported artists during the development of artwork, and managed aspects of the exhibition, including the sale of artworks. Artwork sales directly benefitted the artists financially. Thirty Aboriginal Elders and artists were involved in the collaboration, with members from both Yamaji Art and Marra Arts.

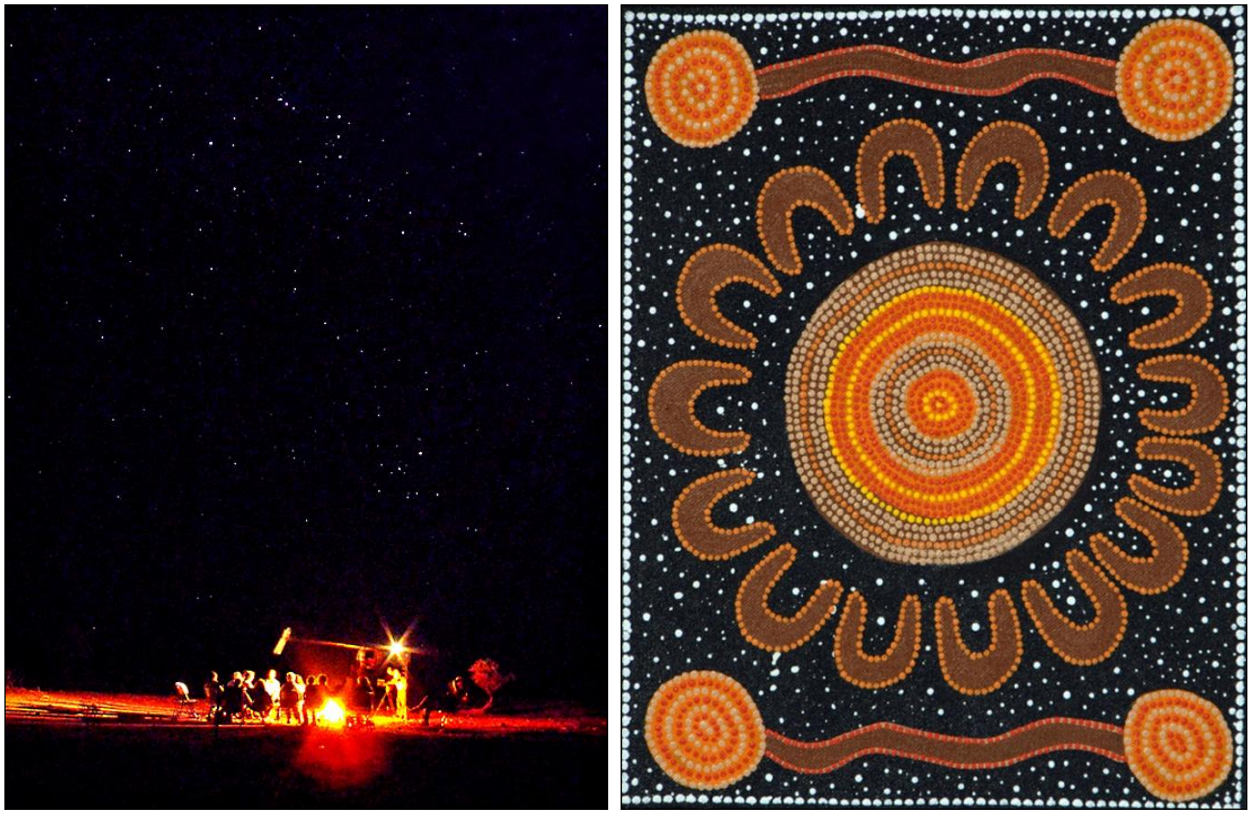

Figure 3: Two views of Ilgarijiri campfire discussions in the Murchison (photograph: Dr Megan Argo (ICRAR); painting: Wendy Jackamarra (Yamaji Art)).

ICRAR radio astronomers involved in the Murchison Widefield Array were brought in as part of the collaboration (Brophy, 2009; Drok, 2009/2010).

Elders, artists and radio astronomers met at Boolardy Station to share their knowledge. After talking around a campfire at night, the group then used telescopes to view a variety of celestial objects, including Saturn and the Jewel Box star cluster, both of which made a considerable impression on the artists. This 'on Country' meeting proved to be a very successful way of opening and developing discussions about the night sky between people who had very different astronomical backgrounds and experiences. The campfire encounter and discussion was filmed as part of the ABC TV's 'Message Stick' series in an episode called "Before Galileo" (ABC, 2009). Two different representations of this meeting are shown in Figure 3.

Inspired by the 'on Country' meeting, *Ilgarijiri* artists then proceeded to create artworks, based on their experiences with the radio astronomers, their impressions of the 'deep space' objects seen through the telescopes, and the shared stories about the night sky. Approximately 30 artists created more than 80 works, and the exhibition has developed over time, with new works created to replace artworks sold during exhibitions. The catalogue of the *Ilgarijiri* exhibition is available online.[1]

5 *ILGARIJIRI* EXHIBITIONS

Coinciding with the International Year of Astronomy in 2009 (Russo and Lindberg, 2010), the first *Ilgarijiri* exhibition was at Geraldton, followed by Curtin University in Perth (Figure 4). *Ilgarijiri* featured prominently at the first national symposium on Aboriginal astronomy, which was held at the Australian Institute of Aboriginal and Torres Strait Islander Studies in Canberra in November 2009 (AIATSIS, 2011; Norris, 2010; Tingay, 2011). The exhibition had its first international showing in Cape Town, South Africa, where it featured at the Communicating Astronomy with the Public conference in 2010 (Figure 5). The next tour was to the USA, to Washington, D.C., in 2011, followed by a tour through the Netherlands, Belgium and Germany in early 2012.

Figure 4: Teddo Ryan (left) and Kevin Merritt (right) at the 2009 Curtin University *Ilgarijiri* exhibition (photograph: John Goldsmith).

Figure 5: *Ilgarijiri* at Cape Town, with Communicating Astronomy with the Public 2010 (photograph: John Goldsmith).

6 RESULTS AND OUTCOMES

The results of the research are presented here, including the interviews with *Ilgarijiri* participants, astronomical themes expressed in the *Ilgarijiri* project, and the creation of new resources, including an exhibition video and virtual tour.

6.1 Interviews With *Ilgarijiri* Artists and Elders

The video-based interviews with the *Ilgarijiri* artists (Figure 6) provided considerable insight into the experience of the various participants in the *Ilgarijiri* collaboration.

The process of developing the *Ilgarijiri* project occurred over an extended period of time so that a number of issues could be carefully considered by Yamaji Art and the participants. Charmaine Green comments:

> Well, anything with the sky is sort of culturally problematic and it took the committee at least eight months to even say yeh, we will go there. It took them a long time sitting in with the board, throwing it back and forth. Shall we do this? Are we doing the right thing? Are we going to get in trouble? What sort of stories? But then the positive side of it out-weighed that because there is not enough a lot of opportunities to tell stories to the wider public, and not enough opportunities to tell stories to our kids or our community ... People knew their boundaries. They knew that there is stories connected to the sky that they can't tell, and they won't tell.

CSIRO Aboriginal Liaison Officer Robin Boddington noted gender restrictions in relation to some Aboriginal sky knowledge:

> … from a woman's point of view, we can't talk about the stars and all that. I could give you the Aboriginal names, but I can't, because it's all related to men's law. Seven Sisters dreaming story and the Milky Way and the Emu, we could tell you that one, but I don't know how much the men could tell you. I can't speak for that ...

The initial responses by Aboriginal artists to the *Ilgarijiri* project were in general enthusiastic and very positive, as Kevin Merritt recounts:

> ... when I first heard about it, I thought it was a really great thing for the artists in this region to be able to put on canvas stories that they've learnt and heard from the old people ... while we are growing. To be able to display to the world as it is, you know, the stories of the stars, I thought that was really great.

However, one artist, Margaret Whitehurst, initially expressed scepticism and doubt, which subsequently developed into a very positive and affirming attitude:

> ... well, when I first started I thought, oh, well nah ... it was going to be boring. Nah ... I haven't got much stories of the sky. When they first approached us and said that we are going to do these stories about the sky, look I don't know much about stories in the sky. All I knew was about this Emu in the sky and (the Yamaji Art Centre staff) said: "You go out and you look at the sky and will see." So we did, and we went out and I just couldn't believe all the things that we saw in the sky, you know. I didn't even know even half of the things that was in the sky, because we didn't look for them things. All we did was look for the Seven Sisters, and the pot in the sky, what they used to tell us. The Seven Sisters, the Emu in sky, that was it. I didn't know any more, till I saw the ones in the sky.

Figure 6: *Ilgarijiri* interviewees (montage image: John Goldsmith).

During the development of the *Ilgarijiri* project, radio astronomer Dr Megan Argo (then based at ICRAR in Perth), participated in site visits to the Murchison region and Boolardy Station. Her astronomy outreach activities provided information about the SKA project to communities in the Murchison region, including remote Aboriginal communities. As she explained:

> ... it's important to go out there and talk to the communities that are there, so that they have an understanding what is happening (in relation to the Square Kilometre Array).
>
> So the first trip I took up there was with Steven Tingay and Rob Hollow and Mary Mulcave from CSIRO, and it was part of the 'Wildflowers in the Sky' project which was a CSIRO initiative, that provided a whole bunch of … schools in the region with their own telescopes. They had 8-inch Dobsonian telescopes that they could use to look at the sky.
>
> ... and we've visited quite a lot of schools in the region, including the remote schools such as … Pia Wajarri which is the closest one to Boolardy Station, where ASKAP is ... So we've done quite a few visits to Pia Wajarri. Actually, we've done viewing nights; we've done class room activities; we've done model Solar Systems; we've had kids running around the school yard pretending to be planets and

> comets, crashing in to each other; we've done water rockets, and things like that as well. There's quite a variety of things that we've done in the region with the schools.

As the *Ilgarijiri* project developed further, a visit back to country was organised for Aboriginal artists, Elders and radio astronomers (including Professor Tingay) at Boolardy Station. This visit included an opportunity to view the night sky together with radio astronomers, to share stories, to listen to scientific views about the night sky and to use telescopes to observe 'deep space' objects. The appreciation of knowledge shared by radio astronomers is evident in the following quotes from Margaret Whitehurst, Wendy Jackamarra and Barbara Merritt respectively:

> … and Mr Tingay showed us a lot of other things that he saw, that we can see up in the sky and what we never seen before. That's where I saw a lot in the sky that night. I can't remember all the names but, because they were, some of them weren't Australian, so. But really enjoyed Boolardy. A good trip. It was wonderful out there, yeh.

> … (sitting) by the camp fire ... and Steve (Tingay) showed us with his laser, pointed all the different things in the sky to us, things that we didn't know were there.

> ... so, we had that opportunity for like, specialists, scientists, to give us more information on it. It was really good ...

Several of the artists commented on the Boolardy Station visit, and particularly the experience of interacting with the radio astronomers and sharing knowledge about the sky. For example, Kevin Merritt said:

> I thought that was very positive, because we were able to relate our stories ... They were able to show close-up views of the constellations that we looked at over our life. We could see that even though we thought it was just a star, it was another constellation, you know. It just blows your mind away ...

> To be able to have their (the astronomers) expertise tell us about all these things, and I think some of the older people learnt a great deal more than what they knew before, about the stars and the constellations, about where we fit in, our own little world, where we fit in this great cosmos we live in.

The experience of pointing out and recognising the Emu sky pattern drew Aboriginal and non-Aboriginal people together, and the impact of sharing this knowledge is clearly evident in the following comments by Margaret Whitehurst:

> ... and that night when we went home, back to the station, sat around a big campfire and we told stories, and we even pointed out the sky. They saw the emu in the sky that night. We pointed it out up in the sky, and the non-indigenous people ... got so excited when they saw the emu in the sky. Yeh, they really ... couldn't believe it ... We'll show you the emu in the sky when it gets dark and we showed it to them ... they just couldn't believe it because we saw it plain as thing out there at Boolardy.

The use of telescopes to examine and observe 'deep space' objects was greatly valued, and for some, it was their first time looking through a telescope. Some objects, such as the Jewel Box star cluster, attracted a great deal of attention in terms of the colours of the stars, as described below by Barbara Merritt:

> That's just amazing thing, sparkling pretty colours, so that's the first painting I drew, was the Jewellery Box [sic.], and that got sold very quickly ... it made a big impression alright … As women, like, these are the things that we talk about, and do. Well, I do beading and things in my spare time and jewellery is in our lives, every day and then to see the Jewellery Box, ahh ...

The experience of observing the night sky using telescopes, and the sharing of Aboriginal and scientific knowledge of the night sky led to a shared experience that strongly inspired the participants. This experience provided a strong basis for the subsequent work by *Ilgarijiri* artists, such as the enthusiastic representation of the Jewel Box star cluster in the exhibition.

The artists also commented on the experience of creating artworks for the *Ilgarijiri* exhibition. As Barbara Merritt emphasized, the retelling of stories was a strong positive experience:

> I think that they really felt like that they were in that painting because of the stories. And like, they were really glad that these stories have come out and so that everyone can learn about these stories about, you know, from our own culture, and the people, and that. Because we still have really cultural people, they're close, and we meet up with them, and talk with them, and they are really glad and happy about it and like to tell you more stories about it.

The artists experienced a wide range of positive benefits arising from the *Ilgarijiri* project, including intergenerational sharing of knowledge. Charmaine Green had this to day:

> ... there's the encouragement of artists, getting artists to come out of their shell and tell stories. It could be stories connected to the sky, or could be stories that are actually in the sky, or leaping from the sky onto the ground so that the activities we do because of something that happens in the sky. The artists just become really more confident, in saying yeh ... well I do have a story to tell, and I want to tell it via painting … So there is those benefits ... You know, building our culture and getting the stories out there, and also that intergenerational type flow there as well with maybe Barbara and Margaret including their grand-

Figure 7: Two representations of the 'Emu' in the sky (painting: Margaret Whitehurst (Yamaji Art); .photograph: John Goldsmith).

> children in looking at the sky, talking about the sky, and then painting and the grandchildren and the children painting with them, so that's been really fantastic.

Artists like Margaret Whitehurst also indicated that *Ilgarijiri* played a role in creating new opportunities for future stories and knowledge sharing:

> Now I think I could do more stories of it, you know, tell more stories about it. Just looking ... through the telescope, into the sky, yeh. It's really given me a lot of things that I can go back, and well, I went back and told my kids and my Grandkids all about it, but they didn't believe me. They didn't believe there were that many things in the sky. Yeh ...

General impressions about the whole *Ilgarijiri* project were provided by the then Manager of Yamaji Art, Charmaine Green:

> It's been a really fantastic project and it's part of us wanting to reclaim the right to tell stories from my perspective anyway, and this project's allowed this ...

An unexpected conceptual difference between scientific and Aboriginal views of the sky was encountered during one of the interviews, which only became evident because of the interview question. When asked about his views of 'deep space', Kevin Merritt explained that this concept is not one that he generally holds:

> And you say 'deep space'. We don't have that con[cept] ... we don't see 'deep space'. As Aboriginal people, we just see what is around us, what's above us and 'deep space' is beyond anyone's comprehension. We just can't understand, you know, how all these things have been created, you know.

Kevin went on to explain that it is the visible cosmos that is most strongly related to:

> ... just what we see with our naked eye ... like the nearest stars that we see, the Moon, the Sun, some of the closest stars, that we see shining so bright in the sky, and we are a part of that. But beyond that we don't have any connection to that.

6.2 Astronomical Themes Featured in *Ilgarijiri*

Major astronomical themes evident in the *Ilgarijiri* exhibition include the Seven Sisters (the Pleiades) and the 'Emu' in the sky. The Emu is a widely-recognised Aboriginal sky pattern in Australia, which is formed by the dark areas in the Milky Way, between Crux (the Southern Cross) and Scorpius (see Fuller et al., 2014; Goldsmith, 1999; Norris and Norris, 2009). The head of the Emu is the Coal Sack nebula, located adjacent to the Southern Cross. The *Ilgarijiri* painting of the Emu sky pattern (Figure 7) is shown next to a panoramic astronomical photograph of the southern Milky Way, with approximately the same orientation, to show the distinctive prominence of the dark areas in the Milky Way when viewed in dark-sky conditions.

The *Ilgarijiri* exhibition featured several paintings of the Seven Sisters (Pleiades), which was a very popular subject (see Figure 8). Despite the relative faintness and small size of this open cluster, the Seven Sisters features very prominently in many Aboriginal stories of the night sky. Stories and knowledge associated with this star cluster often refer to the hunter (man) pursuing the Seven Sisters, and the exploits of one of the sisters, who trails behind the group. In various

Figure 8: Two representations of the Seven Sisters (Pleiades) (painting: Christine Collard (Yamaji Art); photograph: John Goldsmith).

accounts, the male 'hunter' is variously identified as Orion, or the star Aldebaran (*Alpha Taurii*). The pursuit of the Seven Sisters by the hunter, in the story, matches the actual apparent movement of these astronomical objects as they move from east to west across the night sky.

6.3 Creating New Resources: The Exhibition Video and Virtual Tour

The video interviews with *Ilgarijiri* artists and the on-site 360° photography provided new material for the development of two new resources to support the *Ilgarijiri* project: an exhibition video (Figure 9) and a virtual tour (Figures 10 and 11). The exhibition video was developed in collaboration with Yamaji Art and accompanied the 2012 European tour of *Ilgarijiri*. The video features a series of 17 interview excerpts (total run time of 12.5 minutes), in which the *Ilgarijiri* artists introduce the project and share their experiences and anecdotes.

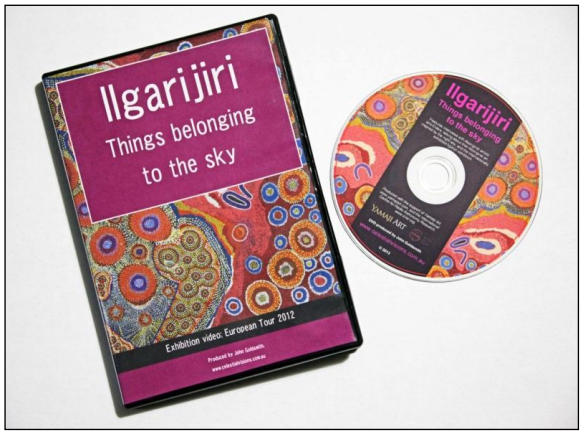

Figure 9: The *Ilgarijiri* exhibition video (photograph: John Goldsmith).

The virtual tour was developed from the photographic site documentation at the Murchison Widefield Array site and the 2009 *Ilgarijiri* exhibition at Curtin University. The virtual tour also included various other Western Australian sites (as part of the broader scope of the Cosmos, Culture, and Landscape Project), such as Wolfe Creek Crater, Wave Rock, Mulka's Cave, the Cosmology Gallery and Horizon Planetarium. In collaboration with Yamaji Art, the virtual tour incorporates images from the *Ilgarijiri* exhibition and shows *Ilgarijiri* artwork that is directly related to the Murchison Radio Astronomy Observatory. The virtual tour was produced on DVD, but there is potential for the virtual tour to be available online at a later stage.

7 DISCUSSION AND SUMMARY

The *Ilgarijiri* collaboration brought together radio astronomers and Wajarri Yamatji people of Western Australia to share scientific and Aboriginal knowledge of the night sky. The project helped develop an understanding and appreciation of the night sky, and respect between radio astronomers, Aboriginal Elders and artists, and the wider Aboriginal community. The collaboration showcased the *Ilgarijiri* exhibition to local, national and international audiences.

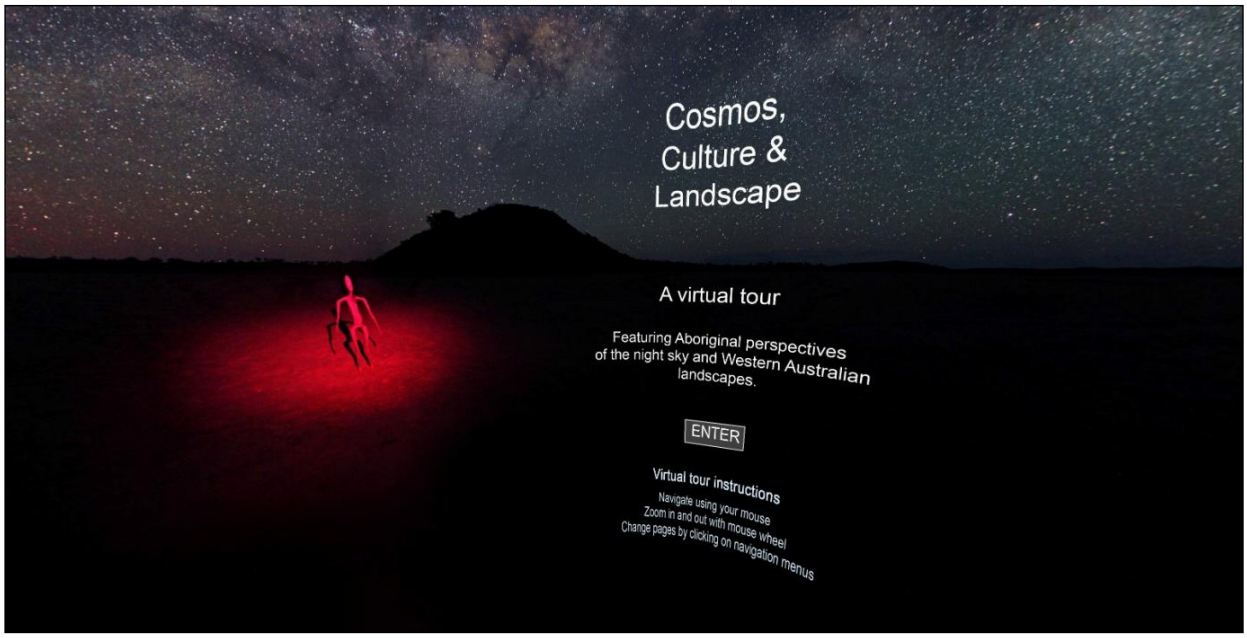

Figure 10: The Cosmos, Culture and Landscape virtual tour (image: John Goldsmith).

Figure 11: Virtual tour image of the Murchison Widefield Array and montaged painting by Wendy Jackamarra and Edward Ryan (image: John Goldsmith).

Indications of the success of *Ilgarijiri* are evidenced by the number of Aboriginal artists who participated in the project; the number of artworks created; the number of exhibitions held, both in Australia and overseas; the number of artworks sold; and the accounts, experiences and opinions of the artists. Yamaji Art led the management of *Ilgarijiri* artists and addressed a variety of issues, ranging from the management of intellectual property to practical logistical and travel issues.

The use of video-based interviews with *Ilgarijiri* participants proved to be particularly effective, enabling an in-depth exploration of topics. These interviews also provided considerable insight into the experience of the various participants in the collaboration. The videos indicate initial perceptions by participants regarding the project, how the project was valued as a means of learning about the night sky, interaction with the radio astronomers, and the importance of creating new artistic representations of stories via the exhibition. Issues and matters of sensitivity were recognised, carefully considered and addressed by Yamaji Art and the participants of the *Ilgarijiri* collaboration.

The *Ilgarijiri* collaboration clearly demonstrated that the night sky can help to bring Aboriginal and non-Aboriginal people together. The artists indicated a positive sense of renewal of stories arising from the creation of the *Ilgarijiri* artworks, based on their shared experience of the night

sky, and maintaining and passing on valued knowledge through their artworks. Their interaction with radio astronomers was viewed very positively, and in particular the use of telescopes generated a lot of enthusiasm and inspiration. This led to the creation of artworks featuring 'deep space' objects, such as the Jewel Box star cluster. This particular cluster attracted a great deal of attention with Aboriginal artists, in part due to the colour of the stars and the cluster's name. Discussions regarding 'deep space' revealed a different conceptual understanding, with an emphasis on what is directly observable with the naked eye in the night sky.

Key principles derived from the experience of the *Ilgarijiri* project have the potential to help shape future collaborations that explore Aboriginal cultural knowledge, art and science. These principles include:

- *Leadership and motivation:* Leadership provides the direction and overall guidance and support for collaborative projects, ideally led by Aboriginal organisations.
- *Consultation and collaboration:* These create an inclusive and shared experience of the night sky that can inspire both artists and scientists.
- *Interdisciplinary skills amongst the project team*: Projects that combine art and science are necessarily multidisciplinary, so they have considerable scope and flexibility to use a wide range of scientific, creative and technology-based skills.
- *Recognition and appropriate addressing of management issues*: Some examples include intellectual property management, cultural issues, research ethics, and sensitivities regarding Aboriginal persons who have passed away. Adequate resourcing and practical support is of primary importance.
- *Project scale:* Projects that engage multiple participants (e.g. artists) are more likely to benefit from such diversity.
- *Orientation towards education:* Whether formal or informal, an orientation towards education can engage a wide range of people.
- *Alignment with big issues:* Aligning projects with high-profile issues such as the Square Kilometre Array and the International Year of Astronomy, etc., can leverage results and benefits.
- *Harnessing emerging technologies:* Digital imaging provides an important way to visually document sites and landscapes, while 360° imaging provides opportunities for virtual tour development.
- *Producing multi-format productions:* Exhibitions, web sites, catalogues, films and virtual tours facilitate different ways of engaging with audiences.

The accounts recorded by the video interviews of *Ilgarijiri* artists support the hypothesis that collaborative, cross-cultural projects can act as an important catalyst in encouraging the appreciation and respect of Aboriginal and scientific astronomical knowledge. The *Ilgarijiri* video interviews have been successfully applied to document and communicate contemporary astronomical knowledge arising from the *Ilgarijiri* collaboration in a culturally-appropriate manner. The use of 360° site photography demonstrated its application as a virtual tour. Key principles assist in guiding future projects involving Aboriginal cultural knowledge, art and science.

8 NOTES

1. http://astronomy.curtin.edu.au/ilgarijiri/

9 ACKNOWLEDGEMENTS

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THE POSSIBLE ASTRONOMICAL FUNCTION OF THE EL MOLLE STONE CIRCLE AT THE ESO OBSERVATORY, LA SILLA. II: THE UPDATED MEASUREMENT CAMPAIGN

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Abstract: This paper reviews and updates the accounts of a previous article discussing the possible astronomical significance of a peculiar, man-made circular stone structure, located close to the European Southern Observatory in La Silla, Chile, and attributed to the El Molle culture. Thanks to further, higher-accuracy measurements *in situ*, we can confirm some of the original hypotheses and dismiss others, upholding the main tenets of the original work.

Keywords: archaeoastronomy, prehistoric stone circle, El Molle Culture, La Silla

1 INTRODUCTION

In a previous paper (Bernardi et al., 2012) we described a peculiar, man-made circular stone structure sited in La Silla, Chile, near the European Southern Observatory, which can be attributed to the El Molle Culture. We proposed that these archaeological relics be read in an astronomical sense. Our interpretation stood on a certain number of facts and measurements, as summarized below.

- Three of these stones looked clearly different from all the others, and could arguably pinpoint the horizontal alignment of three bright stars (Canopus, Miaplacidus, and Rigil Kent or Hadar) close to the horizon, as seen from a specific vantage point inside the structure.
- This astronomical alignment seemed to be most relevant during the El Molle period (i.e. approximately between AD 300 and 800) to which the structure can be attributed, as inferred from the ancient engravings spread all around the place; in particular, this alignment did not occur in earlier epochs due to precessional effects, and is less evident at the present time because the elevation from the horizon of the 3-star alignment is higher than it was in the El Molle period.
- We discovered that it was only during this prehistoric epoch that this astronomical event happened in connection with a significant time of the year; in particular, the stars' alignment was visible at dawn during the end of the austral autumn season, when the warmer months were starting to give way to a colder period.
- We interpreted this temporal coincidence by noticing that: (i) El Molle society was based mainly on farming and herding; (ii) during their epoch this region was less arid than now and therefore probably was able to support pasture grazed by livestock during the summer months. With these hypotheses, the alignment could be important for signalling to the herders that it was time to drive their livestock from high ground down to the plains.

The main weak point of this interpretation was the low accuracy of our measurements, which did not allow us to strengthen our theses, even though a certain number of different independent coincidences seemed to support it. Recently, more accurate measurements at the stone circle site have provided further evidence to this end.

2 THE NEW MEASUREMENTS

During a recent observing run at La Silla we were able to make an additional series of measurements, which we specifically planned in order to achieve better accuracy. Our main goal was to re-measure the principal data on which we based our thesis: (1) the direction of the stones with respect to the south; (2) their relative angular distance; and (3) the height of the horizon.

The best instrument for these kinds of measurements is a theodolite, but we could not bring one with us, so we had to resort to two alternative techniques, using the tools at our disposal: a 20-meter tape, a plumb line, a compass, a goniometer of 20-centimeter radius and a ball of thin string. None of these instruments was particularly sophisticated or expensive but, as will be explained in the text, with the exception of the compass and the determination of the direction of south, the accuracy of the measurements was not limited by the instruments but rather by an intrinsic uncertainty in the definition of the quantities to be measured. The tape had a precision of 1 cm, and that of the goniometer can be con-

servatively assumed to be 1°. Finally, although the precision of the compass also was nominally 1°, we judged that this could not be actually reached because of the difficulty of making the measurements and the thickness of the needle. An independent calibration provided a more conservative value of 4° for the accuracy of the compass.

If a theodolite had been at our disposal, our measures still would have only been accurate to a few degrees because of the size of the landmarks (i.e. the stones forming the structure). It is also reasonable to assume that the people who constructed the stone structure did not need or wish to obtain better accuracy, given their supposed purpose and, possibly, their skill. However, our previous measurements were in error by about 10° with regard to the direction of south and >5° for angular distances; therefore, we had a reasonable margin for improvement.

Firstly, and most importantly, we wanted to determine the direction of south through the use of the compass. As expected, south is positioned approximately in the middle between stones A and C (see Figure 1), with an uncertainty of about four degrees. Such an error is due to the measurement procedure rather than to the intrinsic accuracy of the instrumentation at hand. In fact, in order to use the goniometer to determine the angular direction of the reference points, it was first necessary to align the former with the direction of south using the compass. The difference in the dimensions of the two devices—the compass was much smaller than the goniometer—and the difficulty of keeping a stable orienttation were actually the main sources of error.

Once the direction of the south was established and the goniometer was aligned accordingly, we proceeded to determine the angular distances of the stones of the structure from the south. While doing this, we realized that the stone in the middle, the one called B in the previous paper (and see Figure 1 below), is not as significant as originally thought because there are similar ones nearby. This misjudgement was caused by a wrong interpretation of the previous campaign's photographs, which were taken from different vantage points with respect to the central boulder. Consequently, we determined the angular distance of the two principal stones from the south by stretching the string between the center of the goniometer and each pillar.

In this regard, it was immediately evident that the accuracy of the goniometer, which can be estimated to 1°, was higher than the uncertainty due to the dimensions of the stones, which therefore constituted a natural limitation in the definition of the alignment. This was especially true for

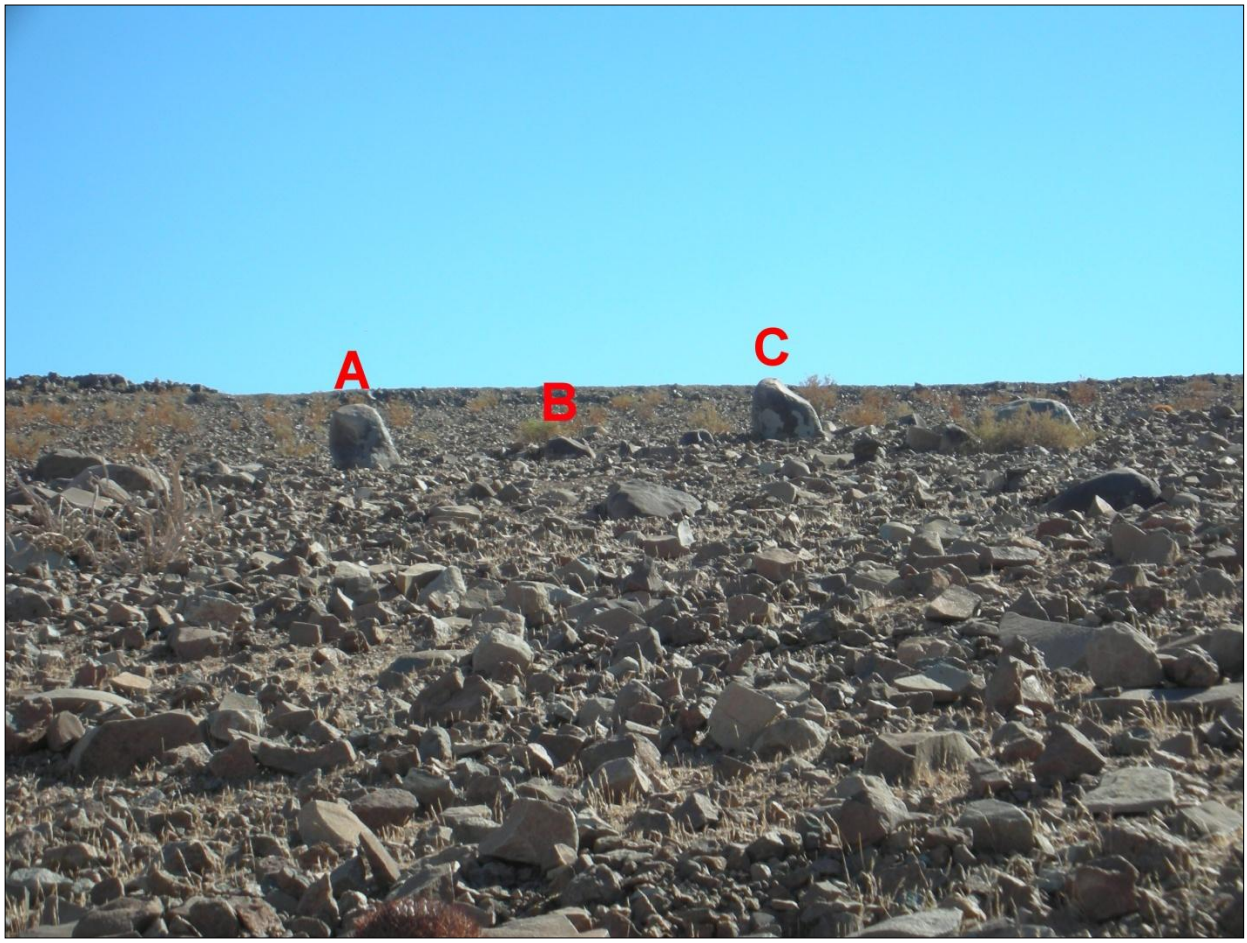

Figure 1: The two pillars (A and C) as seen from inside the circle, and the third lower stone in between (B).

stone A, whose most eastern side (the 'external' one) was 33 ± 1° from the estimated direction of south, while the eastern side (the 'internal' one) was 30 ± 1°.[1] Therefore, the absolute orientation of the pillars encompasses a range of values that account for the physical dimension of the stones plus the instrumental errors.

The additional uncertainty due to the determination of south has to be added to this estimation with the same considerations made in Bernardi et al. (2012), i.e., by keeping in mind that the uncertainties in the absolute orientation of the two pillars are not independent, but are exactly anti-correlated with respect to this error. In other words, if south would be, for example, 2° towards stone A with respect to our estimation, then the absolute direction of A would be 2° smaller, while that of C would be 2° larger.

With these indications in mind, the reader can now understand what is meant by reporting angles in the range [30 ± 1, 33 ± 1] ± 4° east for stone A and [21 ± 1, 22 ± 1] ± 4° west for stone C.

The uncertainty in the absolute direction of south does not affect the estimation of the angular separation between the two stones, which therefore can be given in the range [51 ± 1.4, 55 ± 1.4]°.

The same angular distance is confirmed by another check we carried out which was to use the tape to measure the distance of the two stones from the central one (O) and the distance from A to C. Once again, the largest contribution to the measurement errors came from the difficulty of establishing a single, well-defined, reference endpoint for the connecting segments because of the physical dimensions of the stones. Similarly to the case of the angular measurements, we resorted to determining a 'viability range', by considering two triangles: one with the internal sides of pillars A and C that gave the lowest limit of the range, and the other one with the external sides for the highest limit. All of the distances from O were taken from a single point, the central stone. In other words, we neglected the dimensions of the central stone in our evaluation of the uncertainties of the distances, just like we did for the angular measurements. This was not because this stone is small, but because it is reasonable to assume that the reference point is more or less at the center of this stone and not along one of its sides. In other words, different from the other pillars, in the case of O it was easy to single out a reference point with an uncertainty much smaller than the dimensions of the stone itself.

Regarding the uncertainties of the length measurements, the tape had a nominal accuracy of 1 cm, but this was much better than the accuracy that was actually reasonable to assume. Once again, in fact, we had to face the problem of determining the actual edges of stones A and C, whose shapes are not very regular, and for this reason the accuracy had to be considered ten times larger than the nominal one, that is about 10 cm.

The triangle formed with the external borders had sides AO = 9.40 ± 0.10 m, CO = 9.00 ± 0.10 m and AC = 8.40 ± 0.20 m, and, by means of Carnot's formula for triangles and error propagation, this gives an angular separation of 54.3 ± 1.5°. By comparison, the triangle formed with the internal border had AO = 9.80 ± 0.10 m, CO = 8.50 ± 0.10 m and AC = 7.90 ± 0.20 m, for an angular separation of 50.5 ± 1.5°.

Summarizing, the range we obtained from the length measurements was [50.5 ± 1.5, 54.5 ± 1.5]°, which is perfectly compatible with that obtained from the angular measurements. It should be noted that, while in principle we could get better results with the length measurements because of the potentially higher accuracy of the measurement instrument, in the end the two procedures are at the same level because the real and largest source of uncertainty, as already stated, comes from the dimensions of the stones and from the difficulty of identifying a single, precise reference point, as in the case of the borders.[2]

3 COMPARISON WITH PREVIOUS ESTIMATIONS

Let us see how these results compare with the previous ones and whether they support the hypotheses presented in the earlier paper.

In Bernardi et al. (2012) the angular distance between the two pillars was computed using a rough estimation of the distances, and assuming that they formed an isosceles triangle with the central boulder. The estimation was 47.6 ± 5.3°, which, because of the approximate assumptions we used, is significantly smaller than our current result, although still compatible with it. The most significant comparison, in fact, is with the angular distances between Canopus (the star which should be aligned with stone A) and Hadar or Rigil Kent (stone C), as computed in the same paper.

The angular distance between Canopus and Hadar remained stable at 55° 35′ in the years AD 300–800, i.e. that indicated by historians as the most probable period of persistence of the El Molle culture (see Ballereau and Niemeyer, 1990), while that between Canopus and Rigil Kent varied from 57° 9′ in AD 300 to 57° 24′ in AD 800. These angular distances compare quite well with our new estimations. In particular, the former is perfectly compatible with the largest value of the range, while the latter is compatible at the 2σ level. It is of no use to consider the errors of these astronomically-computed quantit-

ies since their error is at least at the arcsecond level, which is orders of magnitude smaller than that of the in-field measurements.

Meanwhile, the situation regarding the absolute directions of the two stones appears at first sight to be less favourable. As can be noted from Table 1, where a summary of the values given in Bernardi et al. (2012) is presented, the estimated ranges of [30°, 33°] E and [21°, 22°] W for stones A and C do not compare very well with our expectations. For example, we can see from this table that the absolute orientation of Canopus (i.e. that of stone A) as computed with the SLA LIB software, would range from 27° E to 29° E if stone C is identified with Hadar, and from 28° E to 30.5° E if stone C is identified instead with Rigil Kent, both of which are quite different from the expected values of [30 ± 1°, 33 ± 1° E]. Similar, or even worse, considerations hold when comparing the ranges of Hadar and Rigil Kent with the [21 ± 1°, 22 ± 1°] W range estimated for stone C.

Nevertheless, as in the previous paper, the error in determining south has to be considered. This is quite important in principle as it can shift the reference frame, so a misalignment of south reflects in opposite ways on the directions of the two stones.

In this regard, the error due to the magnetic declination should be taken into account. In the previous paper this was about 15 times smaller than the estimated error of the compass, so it was cited but had no relevance. In this case, however, the ratio is much smaller (i.e. about 4) so it is worth a more detailed examination. The magnetic declination is the angle formed by the direction of north indicated by a magnetic compass and that of the geographical north. The coordinates of the stars refer to the latter, so that the directions of the pillars found with respect to the magnetic south should be corrected by this quantity.

Obviously the magnetic declination can be determined by observations, but since it varies both in space and in time, several geophysical models have been developed, from which an estimation of this angle can be obtained where no explicit measurements are available. There are different websites that provide the outcome of such models for an arbitrary location on the Earth and for a limited time span. We chose to use the service provided by the NOAA National Geophysical Data Center (http://www.ngdc.noaa/geomag-web/#declination) whose WMM 2010 model gives 0° 55′ E for the coordinates of La Silla at the time of our measurements (24 December 2012), while the IGRF model gives 0° 57′ E, both with an estimated accuracy of about 30′. The meaning of these values is that the direction of geographical north is about 1° to the left (i.e. westward) with respect to that shown by the compass. This also means that the direction of the geographical (and astronomical) south is about 1° to the left (i.e. eastward), and therefore that the estimated ranges corrected for the magnetic declination are then [29 ± 1°, 32 ± 1°] E and [22 ± 1°, 23 ± 1°] W.

Table 1: The orientation of the candidate stars at the beginning and end of the historical period of interest (after Bernadi et al., 2012). Since both Hadar and Rigil Kent are good candidates for the alignment with stone C, columns 2 and 3 give the orientations if Canopus is aligned with Hadar, while columns 4 and 5 refer to the case of Canopus and Rigil Kent.

Year	Canopus	Hadar	Canopus	Rigil Kent
AD300	27° E	28.5° W	28° E	29° W
AD800	29° E	26.5° W	30.5° E	27° W

This literally goes ‘in the right direction’, but still one has to consider the largest source of error, which is the accuracy of the compass. Although this has improved with respect to the 10° of the previous measurements, it is still quite large, i.e. about 4°, as discussed in the previous Section.

Taking into account this error, it is easy to see that if the actual south were some degrees westwards with respect to our estimations, then the absolute directions of the pillars also would be compatible with the computed stellar positions (see the first row in Table 2). Obviously, if the south had been misaligned by the same amount but in the opposite direction, that would probably have been a decisive indication against our hypotheses (see the second row in Table 2).

The last measurement to be performed was the height of the sensible horizon. Once again we used the goniometer and the rope to determine the visible horizon from the observation point. We then used a plumb line in order to align the goniometer to the vertical of the place and find the astronomical horizon, thus allowing us to use it as a rudimentary clinometer, again by ‘pointing’ at the visible horizon with a piece of string stretched from the center of the instrument. With this technique, the height of the sensible horizon was 5 ± 3°. The measurement accuracy was mainly limited by the difficulties of aligning the goniometer with a plumb line and establishing visually the horizon. In this case, once again a theodolite would have provided a more accurate measure; nevertheless, our re-

Table 2: Estimated absolute directions of the two stones, A and C. The values in Section 2 have been first corrected for the magnetic declination. We then consider that the uncertainty on the determination of the South was about 4° (see again Section 2). The two lines then represent the resulting values when this error is applied in the two extreme and opposite cases.

South (°E)	A (°E)	C (°E)
−4	[25 ± 1, 28 ± 1]	[26 ± 1, 27 ± 1]
+4	[33 ± 1, 36 ± 1]	[18 ± 1, 19 ± 1]

sults confirm those already presented in the previous paper, but now with greater accuracy.

4 CONCLUSIONS

In this paper we present further measurements made at La Silla on the stone structure mentioned in Bernardi et al. (2012). With respect to the conclusions drawn in that paper, after this latest campaign some statements have to be rejected, but the main result regarding the possible astronomical significance of the stone structure is confirmed with a much higher level of confidence.

In particular, what is likely to be rejected is the alignment with three stars, because the relevance of the central stone (which pinpointed Miaplacidus) was probably misjudged on the basis of the pictures taken at the time when the first measurements were made.

On the other hand, the new measurements confirmed, with an accuracy of 1–2°, that the angular separation of stones A and C as seen from the center of the stone circle coincided with that of Canopus and Hadar during the historical period of interest. Meanwhile, the angular separation of Canopus and Rigil Kent is somewhat disfavoured, but is still compatible at the 2σ level of confidence.

It is more difficult to give a final answer about the absolute directions of the stones because of the accuracy of our magnetic compass. We can confirm the absolute alignment of the stones with Canopus and Hadar, but with an accuracy of ~4°, a factor of two improvement with respect to our previous estimation. An accuracy level similar to the one reached for the angular separation might be obtained only with the help of a theodolite. In our opinion, such a precise measurement could provide the final word in favor of or against our astronomical hypothesis, and therefore it should be the main purpose of any additional verification. However, it is worth remarking that even with a theodolite the accuracy of the angular measurements probably will not be improved, for reasons that have nothing to do with the instruments used but rather relate mainly to the physical dimensions of the stones. It is also worth noting that if the purpose of the stone circle was indeed to observe the stars we have identified then the ancient observers did not need—and therefore did not seek—a higher level of accuracy.

The height of the sensible horizon was found to be 5 ± 3°, which is compatible with the requirement that the alignment occurred just above the horizon, which was obviously needed for our hypothesis to hold. Once again, a theodolite would have allowed us to reach a higher level of accuracy.

As a final consideration, aside from the measurement errors, we would like to restate the aspect that struck our minds from the very beginning of this research: countless rocks are spread all around the site, which extends for several hundreds of meters in all directions; these rocks are of varied dimensions and shapes; amongst all of them, two stand out because of their distinctive shapes and placement in a vertical position, making it hard to believe that they ended up practically side-by-side just by chance; they not only lie close to each other, and their tops are close to the visible horizon represented by the uphill mountain ridge. The formulation of our thesis stemmed from two additional observations: 1) a third stone seemed to indicate a significant vantage point, and when the two vertical ones were looked at from this place at least two bright stars (one of which was indeed the brightest in the Southern sky) were seen in the direction of the vertical stones; and 2) the heliacal rising and setting of these two stars happened during a seasonal change which can be reasonably considered of some importance for a population living there during the relevant historical period. Our suggested explanation makes all these ‘coincidences’ fall consistently into place, and although not demonstrable to an accuracy of better than 1–2°, it is certainly more convincing than a mere ‘by-chance interpretation’, and at the same time it provides an intriguing speculative argument.

5 NOTES

1. Such uncertainty cannot be regarded as a normal Gaussian error, because the problem of making an estimate in this case is not caused by the difficulty of associating a precise value with a well-defined direction because of the accuracy of the instrument, but rather by the difficulty of defining the direction itself.
2. This kind of uncertainty cannot be further improved, and the results support our previous statement that having a more precise instrument, such as a theodolite, would not have been of much help, with the exception of determining the absolute directions from south, as we pointed out above, or that of the height of the sensible horizon (see Section 3).

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THE SARDINIAN TYPE UNDERGROUND WELL TEMPLE AT GARLO, BULGARIA: AN ARCHITECTURAL AND ASTRONOMICAL SURVEY

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Abstract: In this paper we describe a rare but relatively well-preserved Sardinian type underground well temple located at the village of Garlo, in Bulgaria. This dates to the fourteenth or thirteenth century BCE, and contains some unique architectural features. We postulate that the Garlo temple was used during the winter solstice for rituals associated with the 'newly-born Sun', underground water and the start of the new annual cycle of life. Solar and water cults are known from ancient Thrace, but previously they have never been combined in this way.

Keywords: archaeoastronomy, Bulgaria, Garlo, underground well temple, solar cults, water cults, winter solstice

1 INTRODUCTION

In the second and third millennium BCE specific examples of ancient sacred architecture appeared in the Mediterranean region: well temples devoted to the cult of underground water. Basic data about the most popular and carefully-studied of these restored well temples are summarized in Table 1, but many have yet to be investigated in detail so important questions about them remain to be answered.

The cult of underground water has its origins in Mesopotamia, with the Sumerian god *Enki*, who was the god of underground water, the god of fertility and the keeper of the world order.

Table1: Data on some of the best preserved and intensively-studied sacred springs and well temples in Europe.

No	OBJECT AND LOCALIZATION: Name // Nearest town // Province // STATE	GOOGLE-EARTH COORDINATES	OBJECT TYPE	DATING	DROMOS AZIMUTH "A", OUTWARDS	STAIRCASE SLOPE "h"	OBJECT DISPOSITION ON THE TERRAIN
1	Underground well temple at Garlo village // W from Breznik // prov. Pernik // BULGARIA	N=42° 47' 14.80" E=22° 50' 52.62"	Undergr. well + tholos	Middle Bronze Age XIV-XIII cent. BC.	170°	Originally h=40°; after restor. h=30°	Tangentially semi-dug at a steep hill slope
2	Pozzo di Enki in Cuccuru Nuraxi // Settimo San Pietro // prov. Cagliari, SARDINIA, ITALY	N=39° 17' 10.25" E=09° 10' 36.58"	Undergr. well + tholos	Middle Bronze Age XIV-XIII cent. BC.	335°	Damaged. h=60°	On horizontal rock plateau
3	Pozzo sacro di Funtana Coberta // N from Ballao // prov. Cagliari // SARDINIA, ITALY	N=39° 34' 51.76" E=09° 21' 06.17"	Undergr. well + tholos	Late Bronze Age X-IX cent. BC.	250°	h=40°	On horizontal terrain
4	Pozzo sacro di Sa Testa // Olbia // prov. Olbia-Tempio // SARDINIA, ITALY	N=40° 56' 04.47" E=09° 32' 45.86"	Undergr. spring + tholos	Late Bronze Age XII-IX cent. BC.	265°	h=40°	On horizontal terrain
5	Pozzo sacro di Sant' Anastasia // Sardara // prov. Medio Campidano // SARDINIA, ITALY	N=39° 37' 00.49" E=08° 49' 11.33"	Undergr. spring + tholos	Late Bronze Age XII-IX cent. BC.	165°	h=40°	On horizontal terrain
6	Pozzo sacro di Matzanni // W from Vallermosa // prov. Cagliari; (S from Villacidro // prov. Medio Campidano) // SARDINIA, ITALY	N=39° 22' 33.10" E=08° 42' 05.19"	Undergr. spring + tholos	Late Bronze Age XII-IX cent. BC.		h=30°	On horizontal terrain
7	Pozzo sacro Santa Cristina // SW from Paulilatino // prov. Oristano // SARDINIA, ITALY	N=40° 03' 41" E=08° 43' 57"	Undergr. spring + tholos	Early Iron Age IX-V cent. BC.	155°	h=40°	On horizontal terrain
8	Pozzo sacro Perfugas // Predio Canopoli // prov. Sasari // SARDINIA, ITALY	N=40° 49' 43.21" E=08° 53' 09.54"	Undergr. spring	Early Iron Age IX-V cent. BC.	250°	h=40°	On horizontal terrain
9	Pozzo sacro Santa Vittoria // W from Serri // prov. Cagliari // SARDINIA, ITALY	N=39° 42' 42.61" E=09° 06' 09.02"	Undergr. spring	Early Iron Age IX-V cent. BC.	210°	h=40°	On horizontal terrain
10	Pozzo sacro di Noddule // between Nuoro & Orune // prov. Nuoro // SARDINIA, ITALY	N=40° 23' 06.88" E=09° 16' 58.36"	Overgr. spring + tholos	Early Iron Age IX-V cent. BC.	?		
11	Pozzo sacro Si Tempiesu // E from Orune, NE from Nuoro // prov. Nuoro // SARDINIA, ITALY	N=40° 24' 39.39" E=09° 24' 46.77"	Overgr. spring + tholos	Early Iron Age IX-V cent. BC.	?		
12	Asclepeion in ancient town of Panticapeion // the N district Adzhimushkay of the modern town of Kerch // Crimean peninsula // UKRAINE	N=45° 23' 50-59" E=36° 32' ±10"	Undergr. well + tholos	Middle Iron Age V-IV cent. BC. (Other references I cent. AD)	?	h=40°	On horizontal terrain

References:
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Митова-Джонова Д. „Произход и същност на протосардинските сакрални кладенци III-I хил.пр.Хр.", София 2007 // Mitova-Dzonova D. "Origine e natura dei pozzi sacri protosardi III-I mill. A.C.", Cagliari 2007 (Bulgarian and Italian edition)

Most of these underground water temples are localised to the island of Sardinia (Figure 1) where between 30 and 40 are known. Beyond this island there are only two isolated examples: one is at Panticapaeum (modern-day Kerch) on the Crimean Peninsula, and the other is at the village of Garlo in Western Bulgaria. It is this latter well temple that is the focus of this paper.

Two basic types of Sardinian water temples exist. At smaller sites, comprising sacred pits or *pozzi sacri*, modest above-ground shrines are found around the springs. Contrasting with these are the complex, sophisticated and very impressive sacred well temples, which include several obligatory components: (1) an underground staircase [dromos]; (2) an underground tholos roofed with a spherical or parabolic axially-symmetrical vault; and (3) a suitably-designed underground water source. The water source itself can take the form of a shallow spring, or a deep well that is lined with masonry. In most cases, the tholos has an *opaeon*, a circular opening at the vault's apex which allows light from the Sun, the Moon and the stars to enter the tholos. Archaeologists believe that some of the well temples originally included above-ground architectural elements. It would appear that all of the underground Sardinian wells had religious functions.

The technical development of the Sardinian well temples continued for more than a millennium. The most ancient examples were supposedly created in the Middle Bronze Age, in the fourteenth and thirteenth centuries BCE. They are constructed using crude cyclopian dry masonry, in a technique that is reminiscent of the fortress walls at Mycenae, Tiryns (continental Greece) and Hattusa (the capital of the Hittite Empire in Asia Minor). The Bulgarian well temple dates to this period and its masonry is like that found in the earliest Sardinian well temples. The most sophisticated well temples in Sardinia appeared in the Late Bronze Age and in the Iron Age, between the ninth and the fifth centuries BCE. They were built of high-quality quadrangular blocks, and contained false vaults. The Crimean underground well temple dates to the very end of this period (Atzeni, 1980; 1987; Gaydukevich, 1949; Guido 1963; Lilliu, 1958; 1967; 1980; 1982; Lilliu and Schubart, 1967, 1979; Melis, 2003; Mitova-Dzonova, 2007; Moravetti, 2005; Webster, 1996; Zervos, 1954).

As Table 1 indicates, the sizes and the proportions of the various well temples varied within certain limits, but the length of the dromos was not strongly prescribed by the cult and the depth of the well varied over a wide range of values. However, the dromos was often oriented in a general southerly direction. It is also worth noting the inclination of the dromos staircase. Published data indicate that the inclination angle of the dromos was ~40° in all of the Sardinian well temples. Since the reconstructed well temple at Garlo in Bulgaria has a staircase inclined at 30° it seems to differ from the general rule, but according to Dermendzhiev (2007), the original pre-restored staircase was steeper and had an inclination of 40°. The staircase in the Crimean temple also warrants a mention. The discoverer, E.E. Lyutsenko, lists a value of 45° in his original text, but depicts an inclination of 40° in the plan of the well temple. Unfortunately the dromos at this site was destroyed long ago and the exact value can no longer be checked (Gol'msten, 1941). So, the inclination of the dromos staircase proves to be a curious contructional invariant in all of the Sardinian type water temples.

2 THE MAIN ARCHITECTURAL FEATURES OF THE GARLO WELL TEMPLE

The underground well temple near the village of Garlo in Bulgaria (Figure 2) is 40km northwest of the capital, Sofia, at a latitude of 42° 47′ 14.80″ N, and a longitude of 22° 50′ 52.62″ E. It is probably the most ancient monument of a sacred architectural nature in Bulgaria, and was discovered in 1971 by Dimitrina Mitova-Dzhonova (1983; 1984a; 1984b; Mitova-Dzonova, 2007). The site was investigated and partially restored in 1972, and in 1983 a large protective building with a special shelter and an exhibition platform for the public was constructed around the well temple. At the same time further, but not entirely correct, restoration was carried out. Unfortunately, in 2007 the special shelter collapsed, but at the end of 2010 the well temple was cleared out again. A decision was taken in 2012 to rebuild the shelter and to restore the tholos floor which had been damaged by treasure hunters. Since 2009, the Garlo well temple has been officially recognised as a Bulgarian 'Archaeological Object of National Importance'.

The construction of the protective building and the restoration disturbed the authenticity of the original structure, thereby complicating our analysis and our measurements, so here we will mention briefly some of the changes that were made during the restoration process in order to describe more exactly the situation:

(a) The diameter of the reconstructed *opaeon* is larger than the original one.
(b) The west wall of the dromos has been completely rebuilt and the original curb stone in the foundation of the wall has been removed.
(c) The staircase which was excavated by the archaeologists was rectilinear, consisted of only 13 steps (counting from the tholos upwards), and ended below the ground surface, whereas the restored staircase has 24 steps (the 11

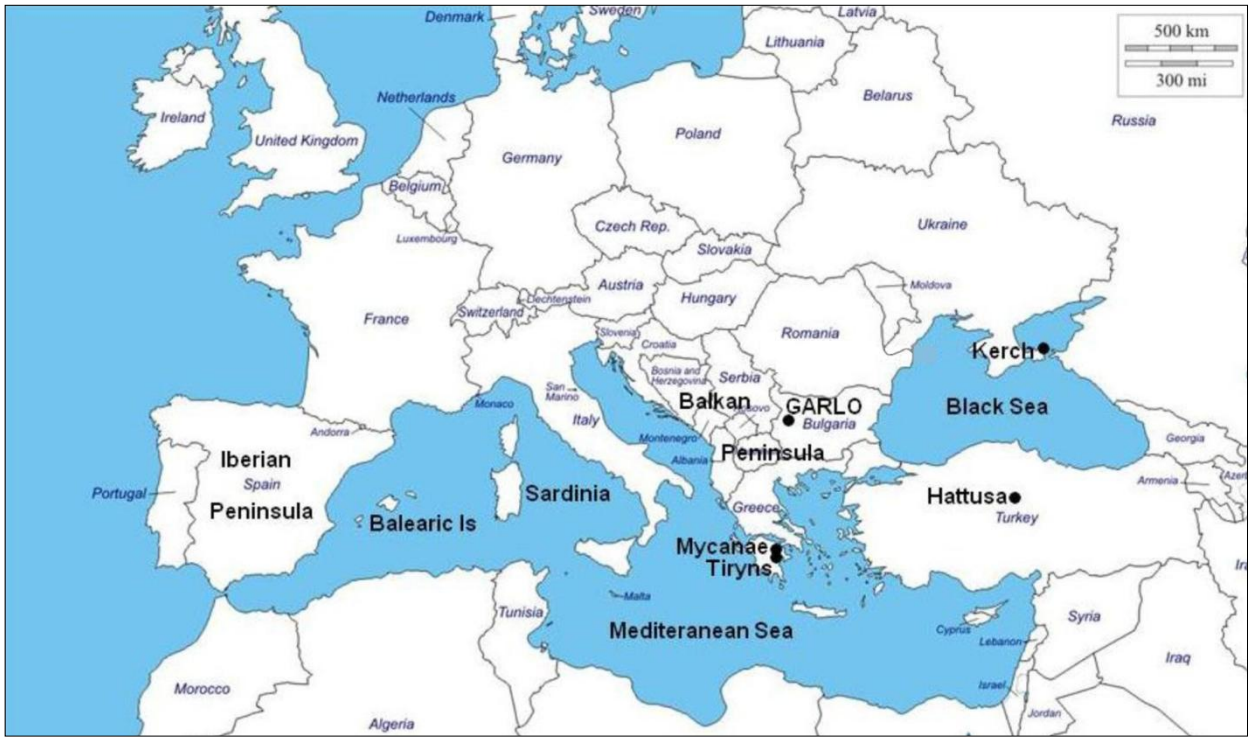


Figure 1: The Mediterranean region and the Black Sea showing localities mentioned in the text, and the Bulgarian underground well temple at Garlo. Other Bulgarian sites mentioned in this paper are shown in Figure 2.

Figure 2: Bulgarian localities mentioned in the text.

newly-added steps forming a 90° turn) leading up to the ground surface.

(d) The original 13 steps were inclined at 40° with respect to the horizon (Dermendzhiev, 2007) whereas—as we have already noted—the restored staircase has a slope of 30°.

(e) The original corridor contained two niches of quite different depths located opposite one another in the walls, but the restored corridor has two equally-shallow niches.

We will now describe the most important architectural features of the Garlo underground

water temple, noting first its extremely-complicated geographical location, on a steep hillside (see Figures 3 and 4). All of the Sardinian well temples were built on flat land, as was the Crimean well temple, but the Garlo well temple is partially dug into a hillside.

Visitors enter the well temple through a covered staircase (the dromos). In the upper section of the staircase it begins as an open-air construction, but its lower part is covered in a quasi-megalithic manner with large rough stone slabs, giving the corridor a trapezoidal cross-section. When the corridor goes deeper into the ground the load on the ceiling increases and the width of the covering stone slabs decreases accordingly (see Figures 5–8). At the lower end the corridor has a triangular cross-section and is crowned with a tapered cotter. The architectural character of the dromos changes significantly from a flat ceiling to a keystone arch along a distance of only 4m in order to adapt to the changing pressure of the stone mass overlay. After its anomalous hillside location, this is the second extraordinary architectural feature of the Garlo well temple.

The core of the structure is the vaulted cylindrical tholos, which has a height and a diameter of about 4m. This vault is the third extraordinary architectural feature of the Garlo well temple. This is not a false vault (constructed with layered square-shaped stone slabs, with the upper layer sticking out a little further inside), but a real vault, where rough stones are ordered in a wedge-like manner. In Figures 9 and 10 we have plotted the precisely-measured tholos profiles in their present-day configurations. The restoration has affected only 0.5m, in the very upper part of the vault. The walls from the tholos floor up to a height of 3m are still preserved in their original state (see Figure 11).

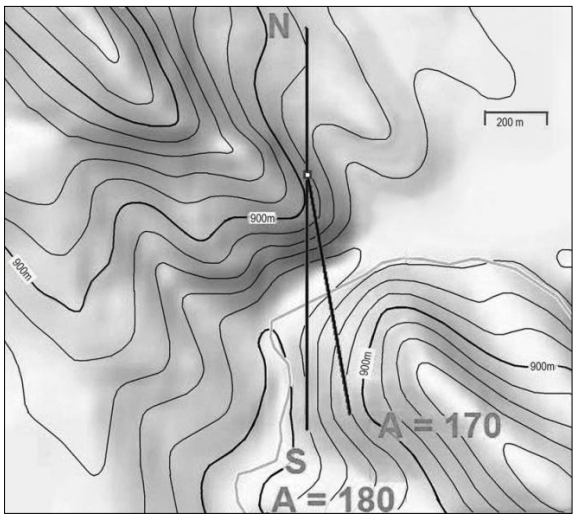


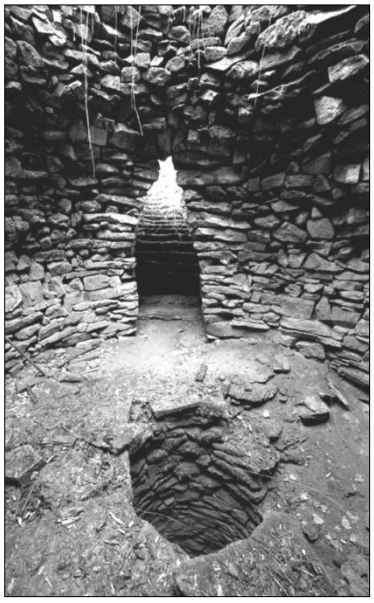
Figure 4: A relief map of the region around the Garlo well temple. NS marks the meridian 180°, and 'A' marks the dromos direction 170° (Google Maps).

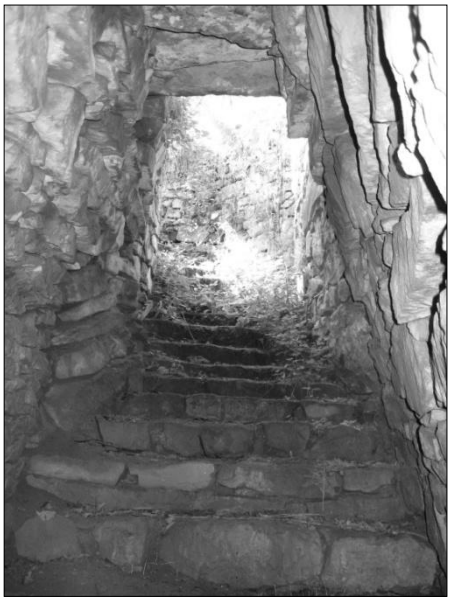
Some important conclusions can be drawn from these results:

1) The cross sections in north, south, east and west directions differ from one another. Therefore the question about the general form of the vault (whether it was spherical or a parabolic/ beehive type) cannot be determined.

2) The N-S cross section is almost symmetrical, while the E-W cross section is strongly asymmetrical. Probably the asymmetry was intentional and was connected with the different pressures on different parts of the tholos and vault due to the complex location of the building.

Figure 3: A panoramic view of the Garlo area from the northwest, showing the location of the village and the underground well temple (indicated by the white circle).





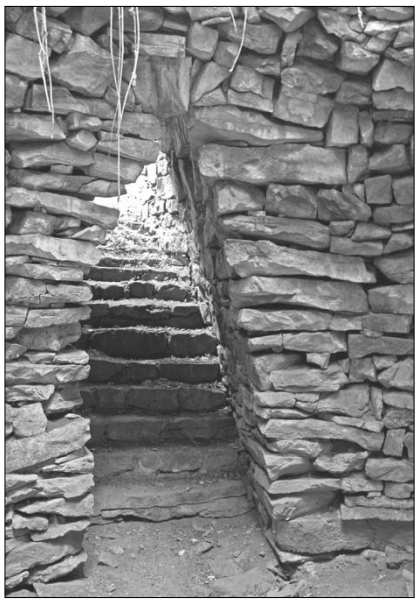
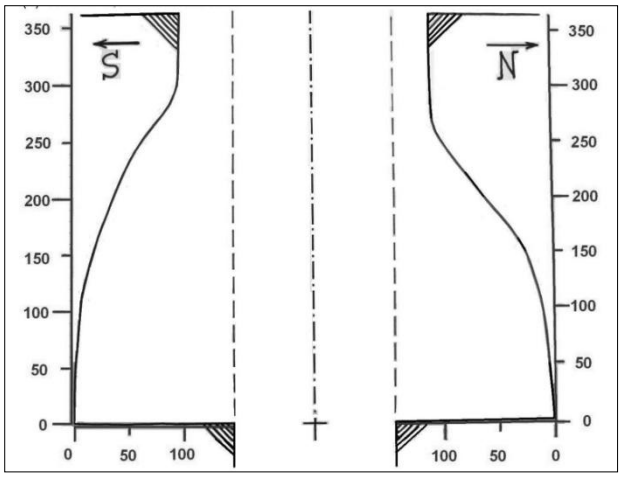


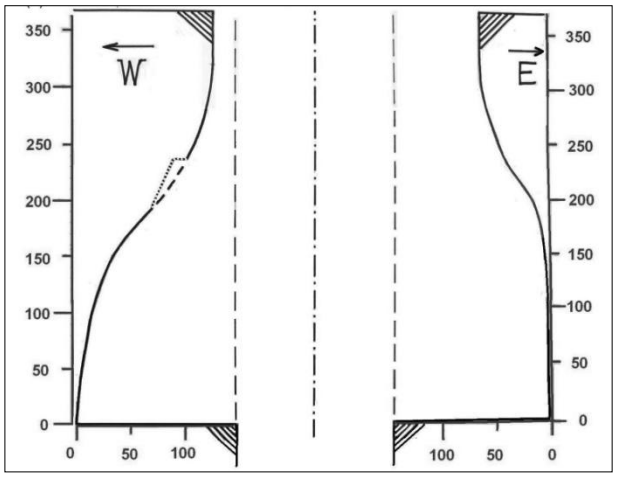
Figure 5 (top, left): A general view of the Garlo well temple from inside the tholos (photograph: L.Tsonev).

Figure 6 (top, centre): The upper trapezoidal part of the dromos, with the lintel (photograph: L.Tsonev).

Figure 7 (top, right): The lower end of the dromos with the keystone arch (photograph: L.Tsonev).

Figure 8 (above): The dromos ceiling seen from below, looking upwards. On the left is the exit to the ground surface (the quasi-megalithic roof, and the lintel), and on the right is the transition of the dromos to the tholos (with the keystone arch) (photograph: L.Tsonev).





Figures 9 (left) and 10 (right): Exact profiles of the tholos walls in four perpendicular directions (diagrams: L. Tsonev).

At the vault apex there is a circular opening (*opaeon*), and after restoration it has a diameter of 2.30m. According to D. Mitova-Dzhonova, the original opening was damaged by treasure hunters before the temple was investigated by archaeologists. She supposes that the original *opaeon* had a diameter close to the diameter of the well (i.e. about 1.30m)—similar to most of the temples of this kind.

The sacred well is situated in the center of the tholos floor, and has a diameter of 1.3m and a depth of approximately 5m.

The concept of a real vault is only supposed to have been invented during Roman times. Therefore, the dating of the Garlo well temple to the fourteenth or thirteenth century BCE by its discoverer, D. Mitova-Dzhonova, on the basis only of some stone and clay artifacts does not seem very convincing from an architectural point

Figure 11: The west (left) and east (right) walls of the tholos (photograph: L.Tsonev).

of view. This unique structure therefore needs to be dated by some more objective physical method, such as by optically stimulated luminescence (OSL). In order to check on the possibility of carrying out OSL dating we have to get a realistic picture of the original terrain before the restoration and before the creation of the protective building around the temple. For this reason we measured for the first time the vertical profile of the mountain slope at the following three different places, which are shown in Figure 12:

1) Profile 'B' crosses the well temple exactly through the center of the *opaeon* where the change in the original terrain was most considerable, not only in the remote past but also in the years 1972–1983;
2) Profile 'A' crosses the hill 50m south of the temple, where the terrain has retained its original slope for more than three thousand years;
3) Profile 'C' crosses the hillside 50m north of the temple, where the road necessary for the restoration of the temple in 1983 was formed.

The result of the profile measurements is exceptionally interesting as it recreates an authentic picture of the slope of the hillside prior to the construction of the underground well temple. In the course of the building process a large 15m deep pit shaped like an inverted cone was excavated in the hillside. Stone masonry was used from the deepest point up to the ground surface: first the well was formed, then the tholos and finally the vault with the *opaeon*. The entire mass of excavated stones and earth removed from the artificial cavity was then piled up on the slope below the level of the well temple's *opaeon* (on what then was the original ground surface). The excavated material was then irradiated by solar UV radiation over a long enough period for the geological luminescence signal accumulated by the quartz grains on the stone surface to be totally bleached away. Then the last layer of rock and soil covered the bleached material and the accumulation of the new archaeological luminescence started. So it would seem that we have here the necessary and sufficient conditions for the application of the OSL dating technique, which has been described by Aitken (1998), Liritzis et al. (1997), Liritzis (2000; 2011) and Theocaris et al. (1997). An independent means of dating the Garlo well temple is critical, and at this stage OSL seems to offer the best possibility.

3 AN ARCHAEOASTRONOMICAL SURVEY OF THE GARLO WELL TEMPLE

3.1 Introductory Remarks

Archaeoastronomical research began in Bulgaria in the second half of the twentieth century by which time it had already been known that a solar cult was widely represented by sacred monuments across the territory of ancient Thrace (i.e. the northern and central part of the Balkan Peninsula).[1] Archaeological sites mentioned below are shown in Figures 1 and 2.

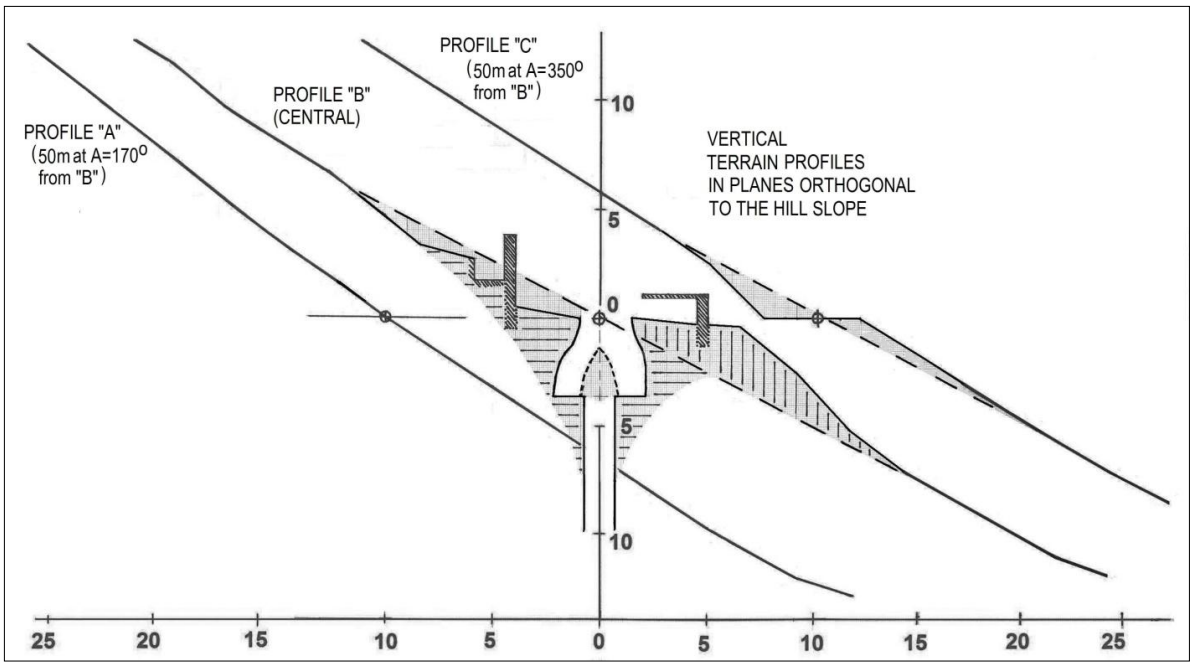


Figure 12: 'A','B', 'C' are exact vertical cross-section profiles at the Garlo well temple site. Horizontal hatching indicates the pit excavated into the hillside at the beginning of the temple-building phase. The vertical hatching shows the excavated material piled up on the slope below the temple *opaeon*. The walls of the protective structure erected around the temple are also partially shown. Coordinates are in meters (diagram: L. Tsonev).

Artifacts dating to the fifth and fourth millenia BCE that have been interpreted as showing the use of solar and lunar calendars at this time are the decorated clay figurines from the village of Ovcharovo near Targovishte in northeastern Bulgaria (Koleva, 1991; Nikolov, 1991), and the gold plates with symbolic scenes from the village of Letnitsa near Lovech in central northern Bulgaria (Dermendzhiev, 2007).

Traces of practicising solar cults have been detected in rock-cut shrines dating to the second millenium BCE at Belintash (Stoev et al., 1991); Harman-kaya (Stoev et al, 2003) and Angel voyvoda (Ivanova, Koleva, and Kolev, 2013) in the Rhodope Mountains, and the ritual complex in the Sliven region in the Balkan Mountains (Banov and Demirev, 1991).

Sites associated with solar cult activities dating from the first millemium BCE until Roman times in the fourth century CE include the Thracian cult buildings described by Gocheva (1991), rock-carvings near Burgas on the southern Black Sea coast (Georgiev, 1991) and rock tombs near Kavarna on the northern Black Sea coast (Toptanov, 1991).

Dolmens in Thrace date from the twelfth to the fourth centuries BCE and have recently been studied from an archaeoastronomical perspective by González-García et al. (2009), Kolev et al. (2008) and Tsonev and Kolev (2012). Although they do not demonstrate a strongly-defined orientation preference, they are directed predominantly towards the south, where the Sun god reached his maximum power (see the left hand histogram in Figure 13). Classic Thracian temples found under tumuli and dating to the period from the fifth century BCE to the third century CE demonstrate the same predominantly southerly orientation of the dromos (Russeva, 2000; 2002), as shown in the right hand histogram in Figure 13.

Lunar and/or stellar observations are not noticeably represented in ancient cult monuments found in Thrace, with the curious exception of the Baylovo Cave near Sofia (Stoev and Stoychev, 1991).

A good review of the astronomical knowledge found in classical Thracian society from the middle of the first millenium BCE up until Roman time, as described by ancient authors, is presented by Gerassimova-Tomova (1991).

A water cult also is known to have existed in Thrace in pre-Roman times, but it was never found in association with sacred underground pits or wells. This cult was expressed by honoring numerous small ground-level springs in their natural state, and without any significant accompanying architecture (Nekhrizov, 2005).

Two Bulgarian shrines associated with sacred springs that do have impressive architectural features, but dating to Roman times only, are the sanctuary of the three nymphs at the village of Kasnakovo near Haskovo (Aladzhov, 1997; Nekhrizov, 2005; Venedikov, 1950) and the sanctuary devoted to Asclepius at the village of Batkun/Patalenitsa near Pazardzhik (Tsontchev, 1941; Zontschew, 1940).

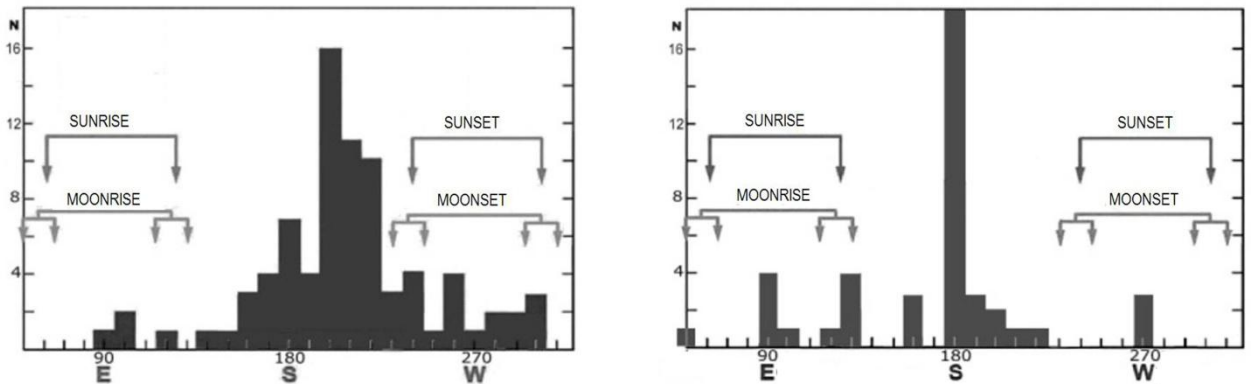


Figure 13: The orientation of 80 dolmens (left) compared with 47 classic Thracian temples under tumuli (right) found in Bulgaria (diagrams: L.Tsonev).

It is clear from the foregoing review that the overall design and the architecture of the Garlo well temple is atypical of the Thracian Culture that developed on the Balkan Peninsula between the fifteenth century BCE and the fifth century CE. The Garlo well temple is unique to this region. At the same time its similarity to some of the Sardinian well temples is obvious and it is because of this that D. Mitova-Dzhonova interpreted the site as a temple of the underground waters, deriving its tradition from the Sumerian god *Enki*. She suggests that the Garlo well temple was created when a group of Sumerians ventured westwards looking for raw materials suitable for development of high-quality bronze metallurgy. After crossing the Black Sea and the Balkan Peninsula this group settled permanently in Sardinia, and on the Balearic Islands and in the Iberian Peninsula. In this area the migrants created the Nuraghi Culture, including the underground well temples (see Mitova-Dzhonova, 1983; 1984a; 1984b; 2012; Mitova-Dzonova, 2007). Some scholars believe that this migration occurred in the opposite direction (towards the east) and was denoted in ancient written sources as the invasion of the 'sea peoples' into the East Mediterranean (Sheppard Baird, 2011).

From the twelfth to the sixth centuries BCE in the eastern part of the Balkan Peninsula a relatively large and multiform megalithic culture appeared, which included several hundred dolmens and menhirs, and five cromlechs (see Tsonev, 2010; Venedikov and Fol, 1976, 1982).

In the same period a rich and multiform megalithic culture also was developed in Sardinia. It included nuraghi towers, dolmens, tombs of the types 'domus de janas' and 'tombe dei giganti', menhirs and cromlechs. However, in contrast to the Balkan Culture of this era the building of well temples in Sardinia did not stop, but instead they attained a remarkable technical level. The late well temples were constructed in dry masonry using very well-formed cubic stones.

In the period from the fifth to the second century BCE the megalithic technique in Thrace was replaced by the use of cubic masonry and fired bricks. The typical sacred sites created in Thrace at this time were monumental tombs and/or temples under tumuli which combine the horizontal plans of the most developed two-chamber dolmens with a dromos (the local Thracian tradition) with the older pattern of Aegean vaulted constructions (the Mycenaean tradition) and with the tumular cover which is of Scythian origin (Kitov and Agre, 2002; Russeva, 2000; 2002).

3.2 A New Interpretation of Garlo Well Temple

Mitova-Dzhonova (1984b) associates the Garlo underground well temple with lunar cults. According to her, there exist specific situations when moonlight enters the tholos vertically through the *opaeon* and is reflected by the water at the bottom of the well. According to Mitova-Dzhonova, these situations allowed the local priests to predict lunar eclipses. However, this interpretation has not been proved by any measurements taken at the temple or by replicated astronomical observations and is mere speculation.

Of course, the Garlo well temple may have been associated with lunar and/or stellar cults, but we prefer to start our interdisciplinary investigation with the most popular cult in ancient Thrace, the solar cult. However, we intend to interpret the Garlo well temple as a structure that combining two basic cults, those of the Sun and of fresh water. We therefore will examine features of the Garlo well temple (its size, scale, construction and location) which could relate to solar observations made for ritual purposes. Three noticeable facts about the Garlo well temple that cannot be explained rationally attracted our attention, and each has a religious aspect.

First is the special interest of the temple-builders in the south direction, which is the orientation of the dromos. Building a genuine dromos

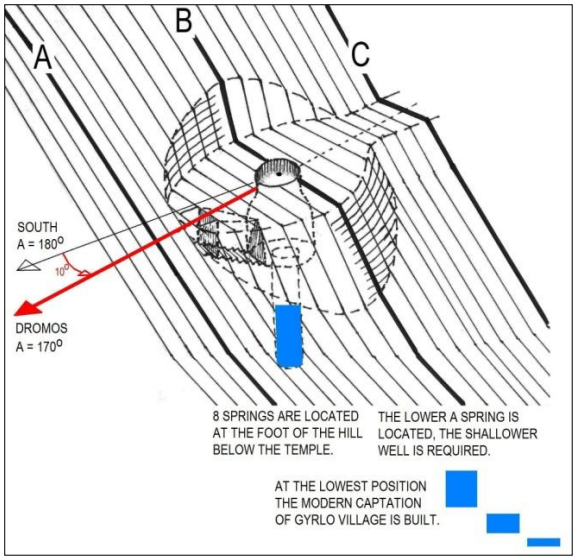


Figure 14: Peculiarities of the Garlo well temple. (a) Numerous springs exist below the temple, at the foot of the hill which would have involved a much simpler and easier temple construction. (b) The dromos deviates slightly from due south (diagram: L.Tsonev).

at the Garlo site in an approximately southerly direction, tangential to the mountain slope (as described here in Section 2), created very complex technical problems. If the dromos was intended as an entrance to the tholos only, the builders could easily have chosen a much simpler approach. The eastern side of the temple is not dug into the hillside but is built freely over the terrain. The entrance could have been placed there using a simple arch, without any corridors or staircases and this would have greatly simplified the construction! It is evident from Table 1 that in Sardinian well temples the orientation of the dromos is not a fixed parameter, i.e. the cult-building tradition permits various dromos orientations. Obviously, the builders of the Garlo well temple intentionally chose the south direction, thereby honoring the culmination of the Sun.

Although Mitova-Dzhonova did not carry out a special archaeoastronomical analysis, what she did, however, was emphasize the second strange feature of the Garlo well temple, which is its striking location high on a steep hillside. There are nine different springs in the surrounding area, most of them at the foot of the hill, yet the highest spring was chosen for the construction of the temple (see Figure 14). Obviously this choice markedly increased the technical complexity of the construction, requiring as it did a deep well in order to reach the spring water. According to Mitova-Dzhonova, only cult requirements could explain such a 'strange' decision. The Minoan specialist, Dr Sheppard Baird (2011), is even more categorical:

> The Nuraghic tholos well temples on Sardinia had no practical function at all. While they could have been used as a source of fresh water there's absolutely no reason to expensively cover the well with a subterranean tholos vault approached by a descending dromos stairway. Throughout this period they were the only purely symbolic tholos structures ever constructed and they can be found exclusively on Sardinia with one very notable exception – the Garlo well temple west of Sofia in Bulgaria.

N. Dermendzhiev (2007) has undertaken the only serious attempt till now to analyze the Garlo well temple from an archaeoastronomical viewpoint (see Figures 15 and 16).

According to Dermendzhiev (2007), ancient people used the temple as a solar calendar measuring instrument throughout the year. They examined closely how the sunlight penetrated the temple through the dromos-corridor and marked the position of the lintel shadow on the floor. In Figure 16 this is denoted by OBSERVER SITUATION No.1. At the winter solstice the sunlight penetrated the temple in a most inclined manner and projected the lintel on the northern wall of the tholos. As time passed

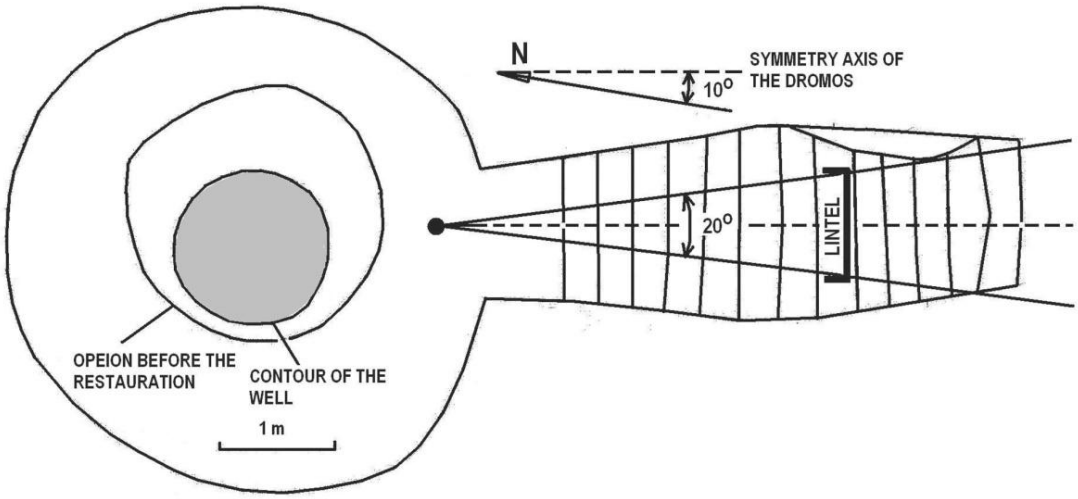


Figure 15: Plan of the Garlo well temple (after Dermendzhiev, 2007).

the lintel shadow moved over the well opening towards the lower end of the dromos. At the summer solstice the sunlight penetrated the temple most abruptly, did not enter the tholos at all, and projected the lintel on the mid-point of the staircase. Then the movement of the lintel shadow was in the opposite direction. Dermendzhiev intended to obtain an exact dating of the temple by examining the process described here, but unfortunately the low professional level of the restoration did not allow him to do this.

Dermendzhiev also published data about the temple parameters before the restoration took place which enable us to draw two important conclusions. Firstly: the observer in situation No.1 in Figure 16 has an azimuthal window of ±10° in respect of the vertical symmetry plane of the dromos. Secondly: the original staircase (with an inclination of 40°) was significantly disturbed during the restoration process and the present staircase has an inclination of only 30°.

Dermendzhiev also accurately measured the azimuthal orientation of the dromos as 170°, but he did not comment on the small deviation from due south. And in our opinion this is the third strange feature of the Garlo well temple.

We will now develop our analysis in the direction taken by N. Dermendzhiev, but we will simplify his hypothesis and also introduce some religious interpretative elements. We are looking for a solar connection in the construction of the well temple, and there are two observational possibilities: (1) the Sun illuminates the well vertically through the *opaeon*; and (2) the Sun illuminates the tholos through the inclined corridor (dromos). Vertical illumination through the *opaeon* is practically impossible: since the latitude variation of Sardinia (40°), Bulgaria (43°) and Crimea (45°) is so large that neither the Sun nor the Moon can be expected to stay vertically above all of the temples.

So we shall comment here only on the penetration of sunlight into the Garlo well temple through the dromos, and in doing so we will propose a new hypothesis. We consider the penetration of sunlight into the tholos at the moment of solar culmination during the winter solstice as a ritual action. This assumption is in accordance with the prevailing orientation of the dolmens and classical temples under tumuli in Thrace. The priest in the tholos observes the sunlight (OBSERVER SITUATION No. 2 in Figure 17) and combines this symbolically with a ceremony associated with the underground water. This combination is believed to produce life-giving power, and to celebrate the start of the new life cycle of nature. From this viewpoint the Garlo well temple plays the role of a marker of the winter solstice only and not the role of a precise calendar-observing instrument. Therefore, our hypothesis does not depend so critically on the low restoration quality and does not require precise knowledge of the original geometrical parameters. Our hypothesis gives a simple explanation for the southerly orientation of the dromos.

In OBSERVER SITUATION No. 2 in Figure 17 the priest has an 'observation window', which is limited above by the lintel, below by the highest staircase step and laterally by both dromos walls. Through this window the priest sees the V-like overlap of the contours of two hillsides, the hill where the temple is built A-A' and the neighboring hill B-B' (see Figures 17 and 18). According to our hypothesis, through this window the observer could not see the solar culmination during the summer solstice and during the vernal and autumnal equinoxes, only during the winter solstice.

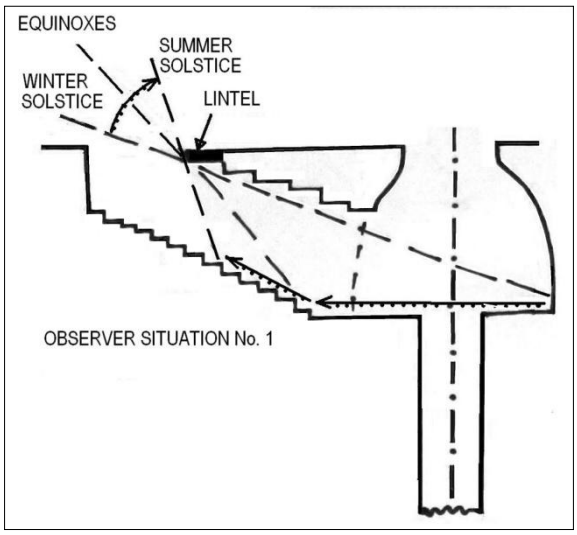


Figure 16: Observer situation No. 1 examined by Dermendzhiev (2007).

The higher the temple is situated the deeper must be the well and the more complex will be the building process. If the temple were situated lower than its actual position, the priest could not observe the solar culmination at the winter solstice from position No. 2 because the Sun would be hidden by the contours of hills A-A' and B-B', and the temple would be in a shady position throughout the whole day. The temple-builders were forced by this situation to place the temple over the highest spring at the hill slope and to build the deepest possible well there (Figure 18). So, our hypothesis explains the apparently anomalous location of the well temple.

We have to add an important remark here. In principle, the possibility of observing the solar culminations in spring, summer and autumn could be achieved from OBSERVER SITUATION No. 2 if the staircase had been steeper.

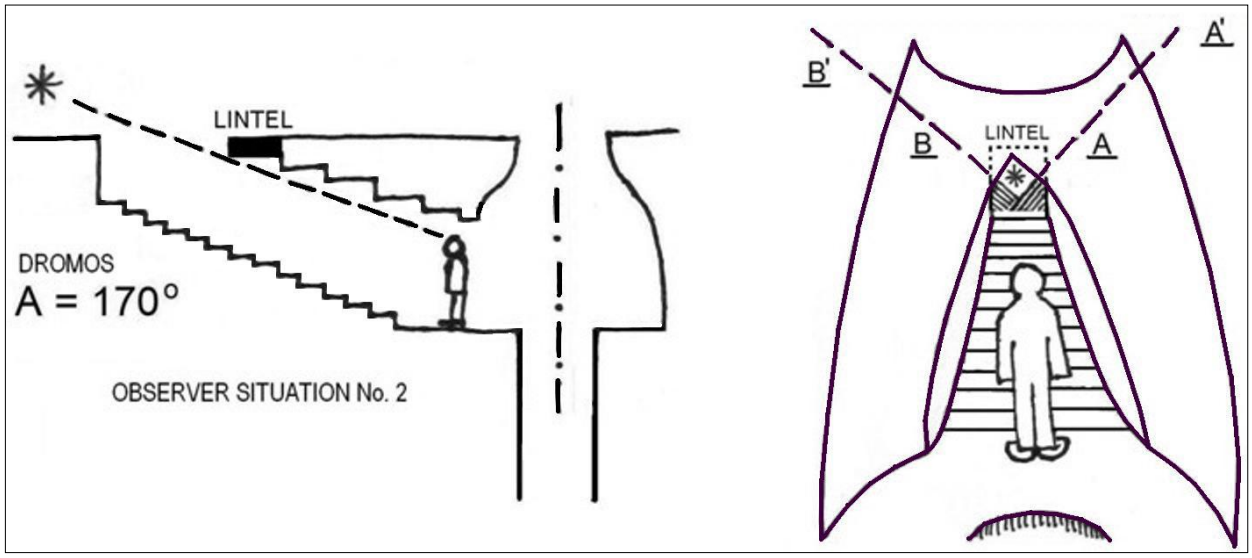


Figure 17: Observer Situation No.2 as viewed from the east (left) and the north (right) (diagrams: L.Tsonev).

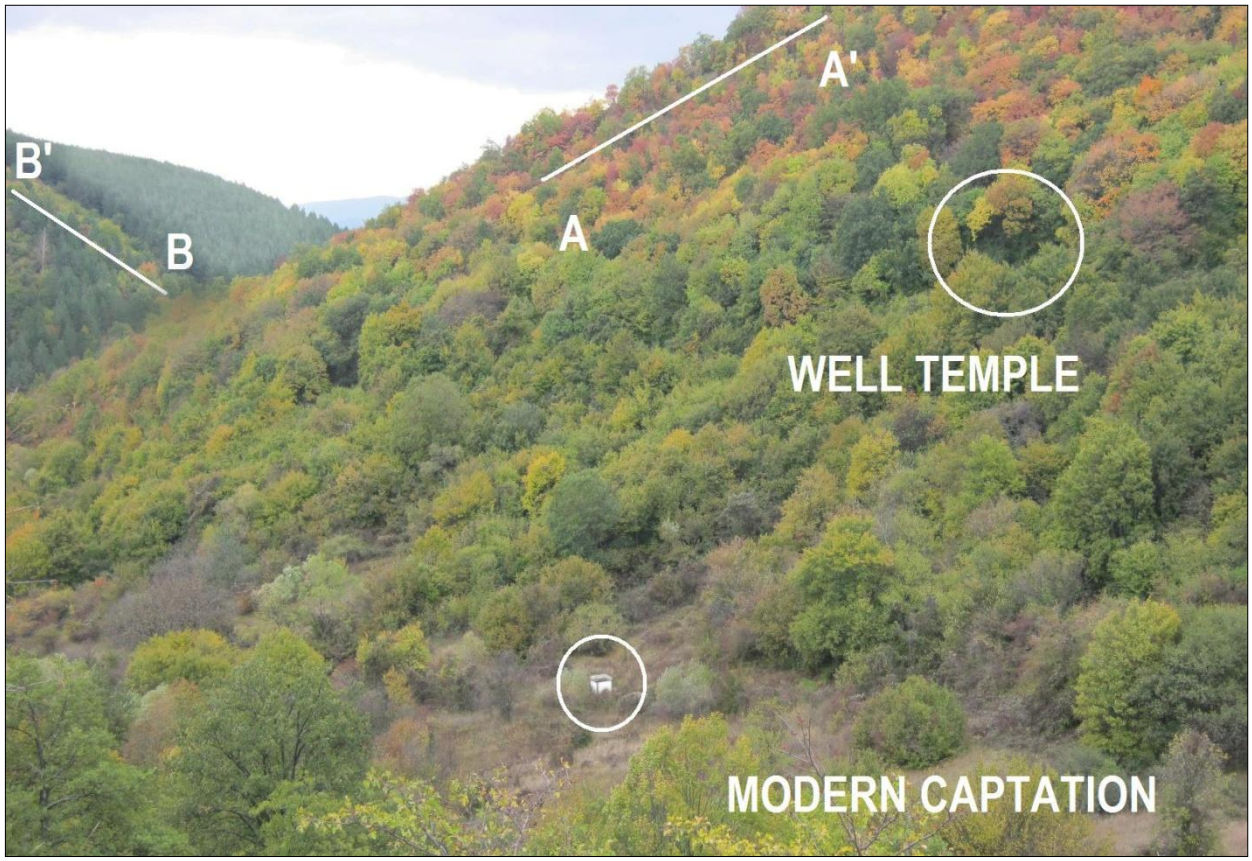


Figure 18: The landscape around the Garlo well temple, showing the contours of mountainsides A-A′ and B-B′ that were visible from the well temple (photograph: L.Tsonev).

However, Table 1 shows that a dromos inclination of 40° seems to have been very important for the cult and for the temple-builders, and therefore it was never violated.

Let us assume that the builders have already chosen the exact place for the tholos, directly above the highest spring. In this situation it turned out that the local relief hindered the observation of the solar culmination directly to the south, so there were two possible solutions to this dilemma:

(1) Make the well deeper, and place the tholos higher up the hill slope (relative to its actual position), which would drastically increase the technical complexity of the building process; or

(2) Rotate the dromos slightly by 10° towards the east in order to direct it towards the saddle between the contours of neighboring hills A-A′ and B-B′. An azimuth of 170° would not allow a *precise* observation of the solar culmination at the winter solstice, but the observation would be close enough for ritual and/or agricultural purp-

oses.

The temple-builders decided on the second alternative, which allowed them to utilize the specific characteristics of the local landscape. This solution is in very good agreement with the actual relief in the temple area (see Figure 19). Our hypothesis, then, also explains the slight deviation of the dromos from due south, as was also mentioned by N. Dermendzhiev.

3.3 Verification of the Solar Hypothesis for the Garlo Well Temple

The verification of the hypothesis by means of direct measurements cannot be done due to two obstacles: (1) the protective building around the site hides the southern horizon; and (2) the dense forest around the protective building also prevents direct observations and measurements through the dromos (e.g. see Figure 20).

Therefore, we were forced to use a complicated two-stage experimental procedure in the summer of 2013. At first, we found from observation position No. 2 that point where the dromos axis hits the wall of the protective building from inside. At the second stage we made our measurements from the additional observer point No. 3, located outside the building in the vertical symmetry plane of the temple defined by the imaginary prolongation of the dromos axis with an azimuth of 170° (see Figure 21). So we determined the horizontal direction (h = 0°), the visual height of the contour of the hill A-A′ (15°) and the upper limit of the observer window in situation No. 2 (23.5°) realized by the lintel of the dromos.

The observation window was reconstructed according to our measurements and is represented by the rectangle in the photograph taken from observer position No. 3 (Figure 22). The result is in very good agreement with our hypothesis. We need to add the following remark here: at the latitude of the Garlo well temple (≈43°) the height of the Sun at its culmination at the winter solstice is equal to h_{ws} = 23.5°; this value coincides with the upper limit of the observer window imposed by the lintel.

If we ignore the inconvenience caused by the unsuccessful restoration it is very likely that the Garlo underground well temple in its original form was used for ritual activities when light from the Sun at the winter solstice penetrated the tholos through the dromos. When this was linked to the underground water, it symbolically marked the start of the new life cycle for the year. The symbolic connection was accomplished if the priest stood in the tholos at observation position No. 2. At this time, the Garlo well temple probably was regarded as a ritual marker of the solar culmination at the winter solstice.

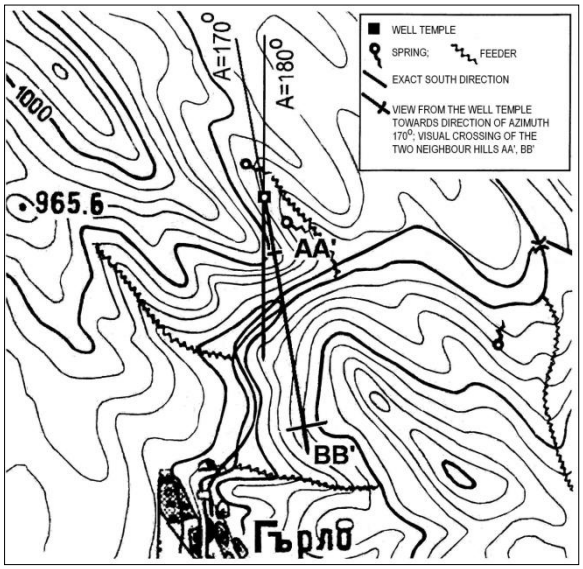


Figure 19: Topographic map of the region around the Garlo well temple.

4 CONCLUDING RFEMARKS

The underground well temple at the village of Garlo in Bulgaria is very similar to well temples on the island of Sardinia, but at the same time it has a unique terrain location and a very specific azimuthal dromos orientation, both of which have very important architectural and astronomical implications. Solar and water cults are well known in ancient Thrace, but they were never combined and expressed in so impressive a manner as occurred at Garlo. The Garlo well temple incorporates both cults in a way that is atypical of ancient Thracian society and its architectural traditions.

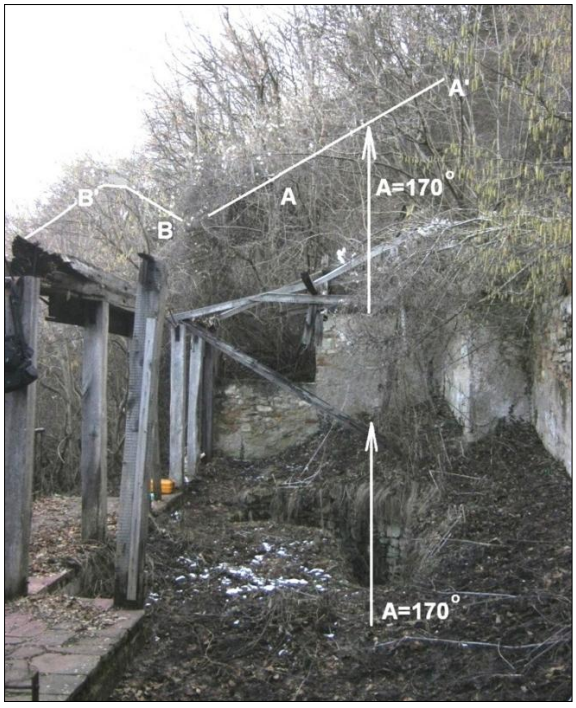


Figure 20: View from a point located inside the protective building along direction with an azimuth of 170°. The shelter collapsed in 2007 (photograph: L.Tsonev).

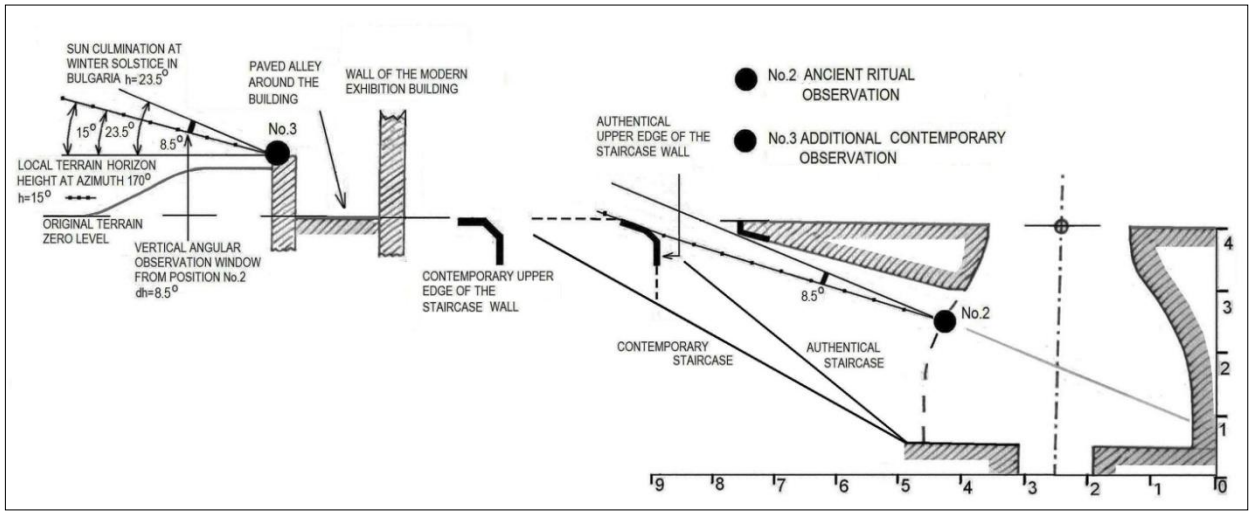


Figure 21: The two-step measuring procedure (points 2 and 3) at the Garlo well temple used to test the possibility for observing the solar culmination at the winter solstice through the dromos (diagrams: L.Tsonev).

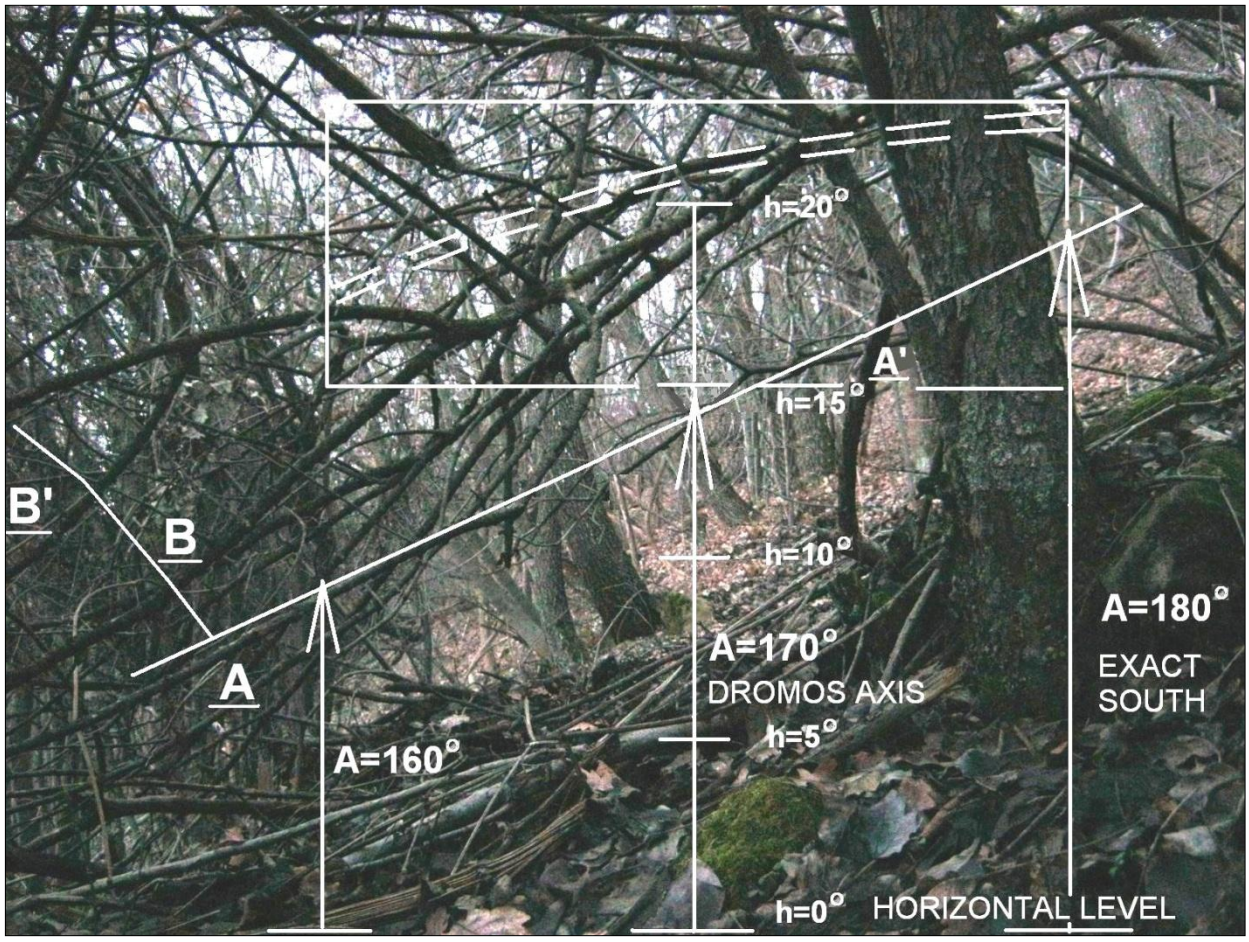


Figure 22: A view from observation point No. 3 in Figure 19, outside the protective building and along azimuth direction 170°. The rectangle represents the observation window for position No. 2 in Figure 19. The double-dashed curve indicates the supposed solar trajectory near the time of the solar culmination at winter solstice (≈23°) (photograph and modifications: L.Tsonev).

Our measurements show that the structure and the location of the temple agree well with this supposition.

Using the framework of the ritual solar hypothesis presented here we obtain for the first time a reasonable explanation for three peculiarities of the temple's construction which have long been noticed but have not been adequately explained by other investigators:

(1) The orientation of the dromos in a southerly direction;
(2) The strange location of the well temple high on a steep hillside; and
(3) The small (10°) deviation of the dromos from due south.

The possibility of explaining all three of these peculiarities can be considered as an argument in support of our hypothesis.

While we do not claim that the interpretation of the Garlo well temple presented here can be applied to all prehistoric underground well temples, it does provide some keys for the future investigation of these structures.

The connection of the Garlo well temple with lunar and/or stellar cults is still an option, but these possibilities require additional research.

Finally, the local vertical relief profiles that we measured at the Garlo well temple site suggest that it may be possible to use optically stimulated luminescence (OSL) for more precise dating of this important archaeoastronomical site.

5 NOTES

1. The Balkan Peninsula, also known as 'the Balkans', is the easternmost of Europe's three great southern peninsulas. However, there is not universal agreement on the region's components. Some define the region in cultural and historical terms and others geographically, though there are even different interpretations among historians and geographers. In an historical sense it includes all of present-day Bulgaria, Greece, Macedonia, Albania, Kosovo, Montenegro, and Bosnia and Herzegovina, and the more southerly parts of Serbia, Croatia, Slovenia and Romania, as well as the European part of Turkey known as Eastern Thrace.

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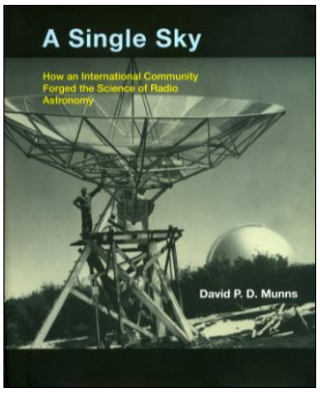
BOOK REVIEWS

***A Single Sky: How an International Community Forged the Science of Radio Astronomy*, by David P.D. Munns (Cambridge, MA, The MIT Press, 2013), pp. 247, 12 illustrations. ISBN 978-0-262-01833-3 (hard cover), 235 × 180 mm, US$34.00.**



A Single Sky traces the emergence of rado astronomy after WW II. It examines the relationships among the various radio astronomy groups and, in turn, their relationship with the established community of optical astronomers. The author, David Munns, is an Australian scholar, and he teaches history at the City University of New York.

Munns states his thesis in the Introduction:

> *A Single Sky* takes issue with the idea that recent science has been driven by competition. The radio astronomers understood science as an open, inclusive, international, interdisciplinary process, and their community succeeded because of cooperation … Instead of a fractious world of science, the radio astronomers saw a single sky, unifying both nations and disciplines.

Radio waves from space were discovered by the American physicist Karl Jansky in 1931, but the new branch of radio astronomy did not develop significantly until after WW II, largely as a result of major wartime advances in radio and radar technology. Much of Munns' analysis focuses on the three major groups that emerged in the immediate post-war years: the CSIRO group in Sydney led by Joe Pawsey (the largest of the three), the group at the Cavendish Laboratory in Cambridge led by Martin Ryle and the group at the University of Manchester led by Bernard Lovell. It is interesting to note that all three group leaders were involved in wartime radar research, as indeed were many of the other early pioneers in radio astronomy.

By the early 1950s new groups had emerged in countries such as France, Germany and the Netherlands, while after a slow start the United States soon became a major player. According to Munns, the fact that radio and optical astronomy relied on completely different technologies encouraged a culture of interdisciplinary and international integration and cooperation. The book has been thoroughly researched, with Munns drawing on extensive archival material in Australia, England and the US. There is also a detailed bibliography which will be of value to other researchers working in this field.

Although I largely agree with Munns' thesis, he has swept at least one inconvenient truth under the rug. It is well documented that Martin Ryle was obsessively secretive about his research, reluctant to visit other groups, and guarded as to who could visit the Cavendish Laboratory. So rather than the collegiate style of radio astronomy groups claimed by Munns, the cooperative model won out *despite* Ryle's combative and competitive nature.

Although there is a wealth of available material, the book has only a handful of photographs, and some are rather dull shots of radio telescopes. Perhaps the most interesting photograph of all is the one on the cover (see above), showing the Australian radio astronomer John Bolton and a 32-ft dish on Palomar Mountain. In 1955 Bolton and his close CSIRO colleague Gordon Stanley were hired by the California Institute of Technology (Caltech) to start a radio astronomy program. The 200-inch Hale Telescope at that time was the largest optical telescope in the world, and its dome can be seen in the background. Munns argues that the photograph is strongly symbolic of the spirit of cooperation that arose between traditional optical astronomers and the new generation of radio astronomers (many of whom had radio and/or radar backgrounds and little initial knowledge of astronomy).

This book follows in the footsteps of the well-known book by David Edge and Michael Mulkay, *Astronomy Transformed*, which was published in 1976. Both books are primarily studies in the sociology of science where the development of radio astronomy is essentially a case study, one used to argue a particular point of view on the nature of science. As a result there is a fair amount of sociology jargon in the Munns book. As one example, Munns constantly refers to new recruits to the growing field of radio astronomy as 'disciples', a term that I'm sure will grate with some readers. Although the book is well written, there is some unnecessary repetition which could have been avoided with tighter editing by the publisher.

No doubt *A Single Sky* will be of interest to sociologists of science, but I suspect that the readership of those interested in the history of radio astronomy may be somewhat limited, despite its very modest price.

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