Journal of Astronomical History and Heritage, 2(2):81-86, 1999

A century of drivers of astronomical progress

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Abstract
The main focus of the session of papers reported here was on the interaction between new technology and astronomical discoveries in the 20th century in the areas of optical, radio, X-ray, and computational astronomy. The advent of new ideas and new people (and kinds of people) in the discipline have also been major drivers of progress. Some of these are discussed briefly here, along with a few technological items from other parts of astronomy. It is intended that the four main presentations appear in later issues of JAH^2.

Key words: steady state cosmology, gamma ray astronomy, twentieth century astrophysics, spectroscopy, particle physics

1 INTRODUCTION

The American Physical Society Centennial session on technological drivers of astronomical progress had its origins in the realization by Astrophysics Division chair (Trevor Weekes) and chair-elect (Virginia Trimble) that the American Astronomical Society would complete its first century (DeVorkin, 1999) in the same year and in the feeling that the sister societies ought to celebrate together somehow. (Indeed the AAS centennial meeting also had an APS centenary talk by Harry Lustig on its programme.) Within the allotted half day, one could not possibly explore all the ways astronomy has changed in the 20th century. Hence the decision was made to focus on technological drivers, relegating issues of theory and person-power to a brief introduction, of which this is the written version.

The four main talks dealt with optical, including infrared and ultraviolet, astronomy (Judith G. Cohen, California Institute of Technology), radio astronomy (Kenneth Kellermann, National Radio Astronomy Observatory), X-ray astronomy (Herbert Gursky, Naval Research Laboratory), and computational astronomy (David Arnett, University of Arizona). All four have made major contributions to the widgetry and its use in their own territories. Some additional wavebands and non-electromagnetic astronomy were also relegated to the outer darkness of the introduction.

2 STEADY-STATE COSMOLOGY: THE CLASSIC EXAMPLE

An astronomer asked to illustrate the concept that a new idea does not have to be right to make important contributions to a field will invariably come up with the example of steady-state cosmology. First enunciated in 1948 as an alternative to a general-relativistic evolutionary (big bang) universe, it remained a viable, though never enormously popular, model for a decade or more. During this period, a great deal of work in observational cosmology, at both radio and optical wavelengths, was to some extent motivated by the desire to 'test' (that is, disprove) steady state, and by the mid 1960s, one could describe a test (like angular diameters or apparent magnitudes of galaxies vs. redshift) as not very powerful by saying that "It doesn't even disprove steady state."

The three propounders, Hermann Bondi, Thomas Gold, and Fred Hoyle were 29, 27, and 32 years old when their initial steady-state papers were written (Bondi and Gold, 1948; Hoyle, 1948) and had recently completed several years of war-related radar work together. All had shown early promise in mathematics and science in general, though none had intended to become an astronomer at the time he arrived in Cambridge. All were to a certain extent outsiders in Cambridge as well as cosmology (Bondi and Gold being Austrian-born Jews, and Hoyle firmly maintaining his strong Yorkshire accent throughout). Hoyle had published several astronomical papers (but none on cosmology) during the war years, and all three brought relatively-unsullied minds to the issues of whether creation might be amenable to scientific study and, if so, whether this might improve our understanding of the large-scale behaviour of the universe in other ways, for instance in accounting for objects, including Earth, with ages larger than the reciprocal of the Hubble constant. Kragh (1996) includes a number of details about their education and early work as well as the definitive study of the subsequent fate of the steady-state idea and its spin-offs.

There are undoubtedly a great many lessons to be learned from the history of the steady-state cosmological model and its continuing defence, in modified form, by a handful of early supporters, but they do not undermine the point that a wrong idea can be enormously powerful in driving scientific research.

Another earlier and less well-known example is the giant-and-dwarf theory of stellar evolution, put forward by Henry Norris Russell (Russell 1913; Russell *et al.*, 1926), which guided, or sometimes misguided, stellar astronomy for more than a decade, until nuclear reactions came into their own.

3 OTHER NEW IDEAS AND PEOPLE

Astronomy has changed large fractions of its spots a number of times; none of the changes was wholly driven from within. The last quarter of the 19th century was marked by increasing friction between proponents of 'the old astronomy' (meaning celestial mechanics and astrometry) and 'the new astronomy' (meaning spectroscopy and astrophysics). The core idea, that absorption features in the solar spectrum could be attributed to sodium, iron, and other specific elements known on Earth, came from Robert Bunsen (a chemist) and Gustav Kirchhoff (a physicist) in 1859. In the half century before all the shouting was over, astrophysics and solar physics had recruited many of their most vigorous practitioners from outside traditional astronomy (Hufbauer, 1991; Lankford, 1997), a new journal was needed (Abt, 1999), and the American community nearly failed to form a single professional society before compromising as the Astronomical and Astrophysical Society of America (Osterbrock, 1999)

That the source of energy for the Sun and stars was a problem was recognized by Eddington, Russell, and others within the astronomical community early in the 20th century when it became clear that Earth was very much older than the potential lifetime of the Sun if contraction were its only resource. Since the answer turned out to be nuclear (once called 'subatomic') energy, it is not surprising that much of it came from people whose background was in nuclear physics. Hans Bethe is, of course, the most famous example, at least to American readers (Bethe, 1939). Also frequently cited (especially in Europe) is the work by von Weizsäcker (1937), whose most influential previous paper was a semi-empirical formula for the mass or binding energy of nuclei (von Weizsäcker 1935). Least well known is the contribution of Atkinson and Houtermans (1929) who considered proton captures (interspersed with electrons, since the neutron was not yet part of the available inventory) that might either build up heavy elements from light ones or add up to helium nuclei that would drop off in a recycling, catalytic process. Atkinson was recruited to the American astronomical community, remaining an AAS member until his death in the mid 1980s, after a long career at Indiana University.

The most recent interaction between standard astronomy and physics has been in the area of particle physics and cosmology, and whether you call it a partnership or an invasion is a matter of taste. Curiously, the 'invasion' point of view is taken by the last defenders of a quasi-steady-state universe (Hoyle *et al.*, 1997). They draw an analogy between the 'fragmentation' of effort in observational and theoretical cosmology caused by the QSS model and a supposedly similar fragmentation caused by particle physics providing new problems (like monopoles) and proposing new solutions to them (like inflation). They seem to have forgotten how unpopular spectroscopy was with many astronomers a century ago, saying, "If the invasion had the precision and the certainty of earlier invasions of astrophysics by atomic theory and nuclear physics, the consequences would obviously be positive. However ... "

Other important parts of 20th century astronomy have also been new ideas in their time. Two that can be traced directly to young astronomers and that were initially fairly unpopular with the older generation were (1) star formation as an on-going process as proposed by Martin Schwarzschild and Lyman Spitzer, when they were brand new assistant professors at Princeton (Trimble, 1997) and (2) evolution in the luminosity of elliptical galaxies as an important and calculable process, as presented in the thesis of Beatrice M Tinsley, with opposition coming from cosmologists who wanted the galaxies to be standard candles and metre sticks so that observations of them could be used to rule out steady state. Conversely, as it were, opposition to the extreme energetics and violence of quasars and related objects that were implied by radio and X-ray data (if the sources were at the distances indicated by their redshifts) came largely from the lingering steady-state sympathizers.

4 THE PEOPLE-TECHNOLOGY CONNECTION

That radio astronomy grew out of the dishes of World War II radar installations is well known (Sullivan, 1984). The dishes and yagi stacks sometimes came with people attached, and (especially in England and Australia) the founders of the field were radar experts, often without advanced university degrees. A probably apocryphal story has E G (Taffy) Bowen (the dean of post-war Australian scientific research) saying to John Bolton (one of the founders of radio astronomy there), "That's an S-band radar dish. You can have it, if you can figure out what to do with it. That's Mr X Y. You can have him, if you can figure out what to do with him." Dutch radio astronomy was sponsored by a traditional astronomer, Jan Oort; the Russian programme by theorists (Josef Shklovsky first and foremost); and Americans were left at the starting gate for some years. Decades down stream, Arno Penzias and Robert Wilson, the Bell Telephone Laboratories discoverers of the cosmic microwave background radiation were not primarily astronomers either.

Moving away from electromagnetic radiation, we find neutrino astronomy, with at least two sources to its credit. The pioneering detector for solar neutrinos (the famous chlorine experiment at Homestake Mines in Lead, South Dakota) was developed by a chemist, Ray Davis, Jr.; and the experiments that saw neutrinos from supernova 1987A were main-stream particle physics installations. originally intended to look for decaying protons. Indeed the word 'experiment' rather than observation, telescope, or observatory is a signature of 'not invented here' (where here is astronomy). The developers of LIGO (again mostly physicists, and funded from physics pockets) seem to have caught on to the distinction, since the "O" in the acronym stands for 'observatory.' The pioneer of the field, Joseph Weber, had a background in electronic counter-measures and microwave spectroscopy (as well, interestingly, as in amateur astronomy) and has always called his widgets 'antennas'.

5 THE CURIOUS INCIDENT OF THE GAMMA RAYS IN THE SKY

The founder of optical astronomy was presumably a Zinjanthropus named Og. The infrared and ultraviolet regions opened gradually out from the visible, using slightly modified photographic plates and looking where Herschel and Ritter had shown in 1800-01 that there was solar flux.

The first astronomical sources of radio waves were a complete surprise (Sullivan, 1984; Christiansen, 1963) and eventually required a complete new radiation mechanism (synchrotron) for their explication. X-rays from the Sun had been predicted at more or less the level seen (Friedman, 1962), but the rocket flight that found Sco X-1 (Giacconi *et al.*, 1962) had to be sold as a search for X-ray fluorescence from the Moon (a phenomenon eventually detected by ROSAT about 30 years later). Notice also that many of the first X-ray astronomy papers appeared in physics journals, a marker of new people in the field as well as new technology.

Extra-solar gamma-ray astronomy, in contrast, was a subject with a considerable literature but no photons for nearly a decade. This period shows all the signatures of new ideas and new kinds of people, as well as new widgets. The most optimistic theoretical predictions of gamma ray fluxes came from the steady-state camp, based upon the beliefs that radio-galaxies were powered by annihilation when a galaxy met an anti-galaxy (Burbidge and Hoyle, 1956), and that supernova light-curves reflected the decay of Californium-254 (Burbidge *et al.*, 1957). Both active galaxies and the Crab Nebula were among the first dozen gamma-ray sources, but at flux levels smaller than these predictions by factors of 100 to 1000.

Two major early theory papers appeared in *Nuovo Cimento* (Morrison, 1958) and *Progress of Theoretical Physics* (Hayakawa *et al.*, 1958), with authors from the cosmic ray and nuclear physics communities. And when Alessandro Bracessi flew the first balloon experiment (note the word!) motivated by these predictions, the detector was a nuclear emulsion stack that he had originally meant to use for collecting cosmic ray tracks, and the results were published in *Nuovo Cimento* (Bracessi *et al.*, 1960). The next few upper limits, false alarms, and results of modest statistical significance also appeared in *Physical Review Letters* and other places one does not necessarily expect to find observational astronomy (Cline, 1961; Kraushaar and Clark, 1962; Arnold *et al.*, 1962; Duthie, 1966).

Only in 1968, with the first two positive reports that are still generally credited and cited (Clark *et al.*, (1968) on the galactic background and Haymes *et al.*, (1968) on the Crab) does the literature break into the *Astrophysical Journal*. This is also the time frame in which the X-, gamma-, and cosmic-ray physicists and astronomers found a home in the American Astronomical Society, via the formation of a High Energy Astrophysics Division.

Just in case the title of this section rang an incomplete bell, the allusion is to Sherlock Holmes' "the curious incident of the dog in the night-time." The dog did nothing in the night-time, and for a while it looked as if there were no gamma rays in the sky.

6 ACKNOWLEDGEMENTS

I am deeply indebted to Barbara Welther of the Center for Astrophysics (Harvard) for chairing the astrophysics and technology session and delivering the talk on the basis of my totally-inadequate notes, when circumstances prevented my getting to Atlanta for the APS centenary meeting.

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