CANADIAN METEOR SCIENCE: THE FIRST PHASE, 1933-1990

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Abstract: Canadian meteor science, encompassing visual, photographic, spectrographic and radar studies of meteors, along with research on impact structures and the retrieval of meteorites, was widely respected during the second half of the twentieth century. There is no question that the leadership of Peter M. Millman made the research field possible. Yet a combination of changes to government institutions, budgetary constrictions, university department priorities and shifting research interests led to the field's near demise in Canada not long after Millman's death.

Keywords: Canada, meteor astronomy, meteorites, radar, Peter Millman, D.W.R. McKinley, Ian Halliday

1 INTRODUCTION

During most of the twentieth century, Canadian astronomy was dominated by stellar spectroscopy and radio astronomy (Jarrell, 1988). More peripheral areas, such as extra-galactic research and cosmology, came late. Least cultivated of all was planetary astronomy, with one significant exception: meteor science. For nearly a half-century, Canadian work in this area was innovative and highly respected. Then, it nearly faded away. Scientific fields are typically built by a network of key players, but small fields, or scientific fields in relatively small national contexts, can owe their origin and energy to a single person. Such was the case for Canadian meteor science. The original Canadian research programmes, initiated wholly or in part by Peter Millman, had largely run their courses before his death in 1990. We can consider the research programmes of this period, 1933 to the late 1980s, as the first phase of Canadian meteor science. It was almost entirely prosecuted by government scientists until changing priorities, along with the departures and deaths of the principals, brought the programmes to an end. A second phase, still in progression, began in earnest in the 1990s, prosecuted largely by university-based astronomers and geologists with few or no connections to the researchers of the first phase.

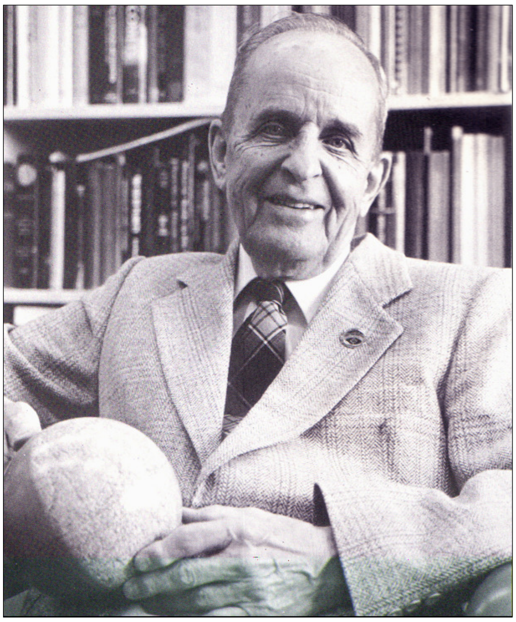

Figure 1: Peter Millman (1906−1990), in retirement (after Halliday, 1991b: 180).

Before the 1930s, meteors and meteorites elicited little interest in Canada. The pages of the *Journal of the Royal Astronomical Society of Canada*, and its predecessor journals, published from 1890, carried news items on meteor showers or meteorite falls but no research papers. Its founding Editor, University of Toronto Professor Clarence Augustus Chant, was aware of meteor research published in contemporary journals. He simply inserted news or articles from other journals. Many of these were by the renowned English meteor expert, William F. Denning. This changed, briefly, in 1913. A train of bright, daylight fireballs was visible in much of Canada that year, and Chant (1913) collected as many accounts as he could and summarized the observations in the *Journal.* In the first twenty-seven years of the *Journal* (1907-1934), before Millman became a regular contributor, just 25 articles on meteors or meteorites appeared, while in the next twenty-seven years (1934-1961), 147 articles appeared, the majority by Millman and his co-workers.

Peter Mackenzie Millman (Figure 1) was born in Toronto on 10 August 1906, but grew up in Japan, the son of Canadian missionaries (Halliday, 1991a, 1991b, 1994; Jarrell, 2007). His interest in astronomy grew during his secondary education at the Canadian Academy in Kobe, leading him to return to the University of Toronto in 1925. He joined the Royal Astronomical Society of Canada (RASC) that same year. Four years later, he graduated in astronomy with the Society's Gold Medal. He was fortunate during his undergraduate years to serve for three summers as a student assistant at the Dominion Astrophysical Observatory (DAO).

Most Canadian astronomers in the first quarter of the century were trained by Chant, but as astronomy was taught by only two people, he was unable to develop a graduate programme. His best students were directed to either Harvard, where he took his own Ph.D. (in physics) or to California, where he had spent a summer at Lick Observatory in order to learn new techniques. In 1929, Millman moved to Harvard, where Harlow Shapley was building up a Ph.D. programme; Millman obtained an A.M. in 1931 and a Ph.D. in 1932. Shapley had a handful of meteor spectra, taken some years earlier as part of the Harvard patrol, but never analysed, and he proposed that Millman study them for his dissertation (see Tors and Orchiston, 2009). Clearly captivated by meteor science, Millman remained a further year as Agassiz Scholar.

While Millman was at Harvard, Chant and his associate, R.K. Young, were creating the David Dunlap Observatory (Figure 2). With a major, new telescope—it would be the second-largest reflector in the world—Chant began to expand the Department of Astronomy. In 1933, Millman was called to Toronto to join the staff. In the following year, Frank and Helen Sawyer Hogg joined the Department. Frank Hogg was a fellow Canadian and Shapley's first Harvard Ph.D. graduate. Millman had known both Hoggs at Harvard. Because of Young's and Frank Hogg's interests, the Observatory's research programme centred on stellar radial velocities and Millman, like all members of staff, was expected to participate regularly, but he also was able to develop his own specialty. At the time, he was the only Canadian astronomer studying meteors.

2 ORGANIZING AMATEURS

The amateur holds a unique position in astronomy, unlike any other science except perhaps biology, where naturalists play a supporting role. The discovery of comets and novae, the monitoring of variable stars and observations of meteors and fireballs have long been grist for the amateur's mill (e.g. see Dunlop and Gerbaldi, 1988; Edberg, 1992; Percy and Wilson, 2000). In meteor astronomy, amateurs played a key supporting role in North America from the late 1920s. How this partnership worked in the United States differed from how it evolved in Canada. A single professional, Millman, stands at the centre of the Canadian story.

One of his first activities on his return to Canada was to recruit, train and coordinate his amateur 'army' of visual observers. While his graduate studies had concentrated upon photographic and spectrographic work, he was also interested in visual observations. He had organised visual observers at Harvard in 1932. When he began teaching at Toronto in the fall of 1933, he immediately sought volunteers to observe the Leonids in November and the Geminids in December (Millman, 1934a). Student volunteers were available and, because of his connection with the RASC, and the proximity of the country's largest branch of that Society, he could tap amateur assistance. The first recruits to his army were few: only five observed the Geminids, but one night of the Leonids brought out thirty-two observers. Millman's preferred method was to set out five or six observers facing outwards in a circle, with a timekeeper/recorder in the centre. This ensured all-sky coverage. His base of operations was the uncompleted David Dunlap Observatory, which was then sufficiently far from Toronto to have reasonably dark skies.

At this time, Charles Olivier's American Meteor Society was reorganising itself into regions, with Directors planning observing sessions and coordinating data collection across the USA, a scheme that Millman thought efficient. He remarked:

> It should be mentioned in this connection that Canada is about untouched territory as far as systematic meteor observations are concerned and that a real aid to astronomical research may be rendered by amateurs in various parts of Canada who would be willing to act as local representatives of the Royal Astronomical Society of Canada in the collecting of meteor observations and in the planning of observational programmes. (Millman, 1934b: 330).

Millman's plea was answered with observations of the 1934 Perseids. In addition to the David Dunlap group, RASC centres in Montreal, Ottawa, Toronto, Hamilton and Winnipeg assisted, with a total of forty-five observing groups with 132 individuals making nearly 6,300 observations. In Ottawa, Dominion Observatory staff members Miriam Burland and Malcolm Thomson directed the second largest group of observers. Usually occupying two, sometimes three, sites, in the Ottawa area, they could be counted upon to observe the major showers. Volunteers came from the Ottawa centre of the RASC, the country's second largest. Over the next five years, major showers would be observed from eight to ten locations, mostly in Ontario, but with sites as far flung as British Columbia and Newfoundland. Data were then sent to Millman for analysis. In January 1934, he began a regular column, "Meteor News", in the *Journal of the Royal Astronomical Society of Canada* to report on Canadian observations and on other items of interest in this growing field.

Figure 2: The David Dunlap Observatory in the 1930s (Jarrell Collection).

Science students were Millman's mainstay at the David Dunlap Observatory, and the list includes a number of people who subsequently became prominent in science, including Arthur Schawlow, later to share a Nobel Prize for his work on laser spectroscopy. Women made up about one-third of the observers at Toronto, and sometimes more than half in Ottawa. Where sufficient numbers were available, teams of six were used, but there were a few scattered observers working alone or in pairs.

Millman published the data on hourly counts in "Meteor News," usually trying to calculate averages based upon the average for the six-person group. These, he believed, were more accurate than counts provided by individual observers. This contrasted with the American Meteor Society's reliance upon individual counts. In addition to counts, Millman insisted upon as accurate an estimate of magnitude as possible. This assumed, of course, relatively experienced amateurs, although Millman could not always expect to obtain them. As he noted:

> The organization of visual meteor observing generally depended on the recruitment of a large number of heterogeneous, but enthusiastic volunteers. The police sometimes added to the sky-watchers' problems, as they were inclined to question the propriety, and even the sanity of mixed groups which spent all night in freezing temperatures in unsheltered fields, emitting frequent cries of "Time"! (Millman and McKinley, 1967: 280-281).

Each observer was given a map with a stereographic projection of the sky. Millman's emphasis was upon getting the path plotted and estimating the brightness within half a magnitude if possible.

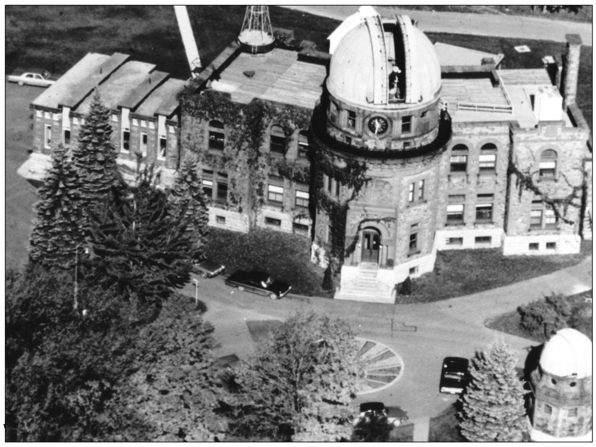

Figure 3: The Dominion Observatory, Ottawa, in the early 1950s (Jarrell Collection).

Once Canada entered the Second World War in 1939, it was no longer 'business as usual' for the Astronomy Department. "Meteor News" appeared in the *Journal* through 1940, then lapsed, with the last instalment in February 1941. In that year, Millman enlisted in the Royal Canadian Air Force (RCAF), initially teaching aerial navigation, but later working in Operational Research in London, England. He ended the War as Scientific Adviser to the Chief of Air Staff.

Reluctant to return to the University of Toronto due to the low salaries there, he considered remaining in the RCAF but received an invitation from the Dominion Astronomer, R.M. Stewart, to take a post at the Dominion Observatory (Figure 3). He resigned his commission and took up the Ottawa post as Head of the Stellar Physics Division in July 1946 knowing that Carlyle Beals was soon to lead the Observatory. Millman had earlier worked with Beals at the DAO and respected him highly. During the 1930s and 1940s, the Stellar Physics Division had produced solar and stellar spectra with obsolete equipment. Given retirements in the Division, Millman had a free hand to promote his own research programme.

3 NEW TECHNOLOGIES AND NEW DIRECTIONS: THE SUPER-SCHMIDT TELESCOPES

Before joining the Dominion Observatory, Millman was involved in discussions with Harvard, MIT and the US Navy about the possibilities of meteor photography with pairs of Super-Schmidt cameras. Once Beals became Director in Ottawa, Millman persuaded him to join the programme and in due course, two small observatories were built in Alberta. In March 1946, Millman was in Cambridge, Massachusetts, to talk with other specialists, notably Harvard's Professor Fred L. Whipple, who had just arrived at Harvard when Millman was in residence. In 1943, Whipple published a paper arguing that by photographing meteors entering the Earth's atmosphere and determining their velocities and altitudes, one could analyse the density of the upper atmosphere. Such data, although useful scientifically, might also have military applications. Harvard would develop special cameras for a research programme, MIT agreed to analyse the data, and Millman offered Canadian assistance in meteor spectroscopy. US Navy representatives at the meeting promised to underwrite the costs of the American portion of the project. The scheme involved using pairs of high-quality cameras, spaced over a baseline of several kilometres, which could photograph meteor trails simultaneously. The measurement and reduction of the data from the photographic plates could then provide information on the meteors' paths.

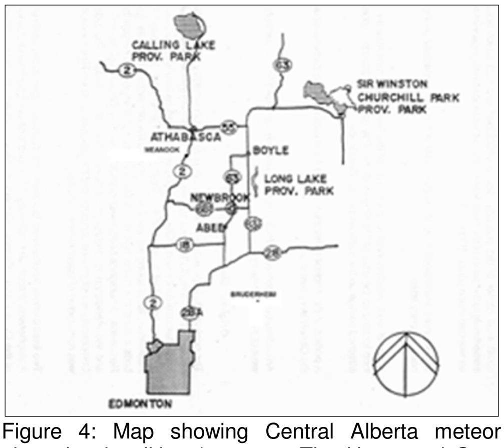

Figure 4: Map showing Central Alberta meteor observing localities (courtesy: The Hammond Consulting Group Ltd.).

In May 1946, the Chief of the US Navy's Bureau of Ordnance invited the Canadian Government to participate. Canada agreed to commit the Dominion Observatory to the project as a partner with Harvard. Millman came on staff two months later and planning began. Harvard intended to locate two pairs of cameras in New Mexico, while Canada agreed to purchase one pair. Millman then needed a site. He required uncluttered horizons and clear nights, but he also wanted to be far enough north of the American sites to have a good spread of latitude. On the other hand, he did not want to have too much interference from the aurora borealis. The prairies seemed ideal, and after some searching, he chose as his first site, Meanook, near Athabasca, Alberta (Figure 4). A federal geomagnetic station had been located there since 1916 and offered a secure base. For a second camera location, Millman chose the hamlet of Newbrook, forty-two kilometres to the southeast (Figure 4). The sites must have been selected by late 1947. In the following year, Beals (1948) reported that:

> This investigation is being carried out in co-operation with the R.C.A.F., the U.S. Bureau of Naval Ordinance [sic] and Harvard University. It is undertaken primarily as a joint defence project and has as its object the study of the upper atmosphere in its relation to the velocities of high speed projectiles. It is also expected that it will lead to much useful general information concerning the nature of meteors … [part of sentence missing] the structure of the atmosphere supplementing the work at Ottawa with more extensive data obtained with more powerful equipment.

Because of the defence implications, the RCAF was to provide $3,000 for the construction of the two Alberta stations. However, $18,000 for the two new cameras would come out of the Observatory's funds.

By the spring of 1948, Beals believed that construction of the two stations was imminent. Millman would travel west and work with Meanook's officer-in-charge, H.E. Cook, in supervising the erection of simple frame buildings to house the new telescopes. At the same time, the Observatory purchased 0.8 hectares of land in Newbrook. Unfortunately, the prime contractor, the Perkin-Elmer Corporation, experienced difficulties in producing the cameras, so the project went on hold. The five-year experimental 'Defence Project' was to have begun in 1946, but by the time the Observatory's estimates for 1949/1950 went to the Minister there was still no progress in sight. The cameras in question, known as Super-Schmidts, were designed by Harvard's J.G. Baker as its contribution. The units were very sophisticated for the time. They were massive wide-angle telescopes, each with a spherical primary mirror and a hemispherical, transparent corrector shell. Ideally, they could record meteors much fainter and more quickly than the cameras then in use, theoretically up to 200 times more efficiently. But no optical firm could supply the hemispherical shells. With Navy prodding, the US Bureau of Standards undertook development of the lenses. Finally, by the summer of 1951, the first Harvard unit was shipped to New Mexico. Canada's pair was not ready until the spring of 1952. After Millman inspected them in Connecticut, the cameras—each weighing 2.2 tonnes—were flown to Alberta by the RCAF. Millman made the first exposure at Newbrook in August (Millman, 1959; Hodgson, 1994).

In choosing sites in Alberta for the meteor stations, Millman was primarily interested in having observations made as far north as practically possible, in this case, about 54º. By having a wide latitude spread, more sky could be covered. The Harvard sites in New Mexico were at approximate latitude 32º North. It soon became apparent that the Canadian locations were much less suitable than the American ones. Being so far north, the extended summer twilight meant that much of June and July was useless for observation. In fact, the Alberta observers took their holidays during this period or devoted their time to routine maintenance. While longer winter nights might have compensated, the cloudiness of north-central Alberta, combined with extreme cold, routinely dropping to –30º C or lower, curtailed the work. Alberta also experienced far more auroral activity than New Mexico. Although aurorae interfered with meteor studies, they did favour the National Research Council of Canada's (NRC) auroral studies. During the International Geophysical Year (IGY) in 1957-1958, Millman's staff placed an all-sky auroral camera at Meanook and made visual aurora observations at Newbrook (Meek, 1959). By the time the IGY ended, the American meteor photography programme was essentially complete and its cameras turned to artificial satellite tracking.

The Harvard programme had had a good head start. Regular work with the Super-Schmidts did not commence in Alberta until 1954, but astronomical and meteorological limitations meant that the Canadians could not compete in observational efficiency. Statistics at the end of 1957 tell the tale: the New Mexican observers averaged 130 good photographic nights a year compared with the Canadians' 40. From 1954 to 1957, the Alberta observers managed 1,800 pairs of exposures, from which 165 pairs recorded meteor trails. This was approximately 20% of the American rate.

The work could be frustrating, and the conditions required that those in charge be resourceful and tough. Harvard hired non-scientific staff to undertake the photography, but the Dominion Observatory insisted upon men with scientific training, usually single men paid relatively low salaries. As it happened, two of the first three initial observers were married.

The first Newbrook observer, Arthur A. Griffin (Figure 5), was a Belleville, Ontario, native who graduated from Toronto in 1951 with an honours B.A. in astronomy. Millman had spotted him a year earlier when Griffin was a student assistant at the David Dunlap Observatory. When Griffin and his new bride arrived in Newbrook there was no residence, and they spent some months in a hotel before refitting an uninsulated shack with no plumbing. A small residence was ready in late 1952. Depending on weather conditions and time of year, the unpaved roads to Edmonton and to Meanook were either dust, mud or ice. Still, the Griffins were able to raise a family in the small, welcoming community. Meanook was even more remote, and the observers' isolation was also scientific. They were a long way from other astronomers, although visitors—like Millman, or his associate, Ian Halliday—occasionally passed through. Even Beals made an appearance. To break the monotony, the observers visited one another, drove into Edmonton as often as possible, and were in direct contact via two-way FM radios.

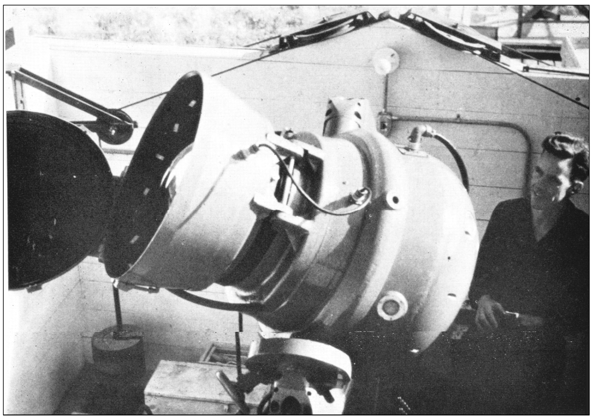

Figure 5: Arthur Griffin and the Super Schmidt at Newbrook (after Millman and McKinley, 1963: Plate 2).

As Griffin recalls (personal communication, 1992), the observers dealt with isolation by keeping busy. There was always activity. New instruments arrived, photographic plates had to be fetched and shipped out, cameras adjusted and repairs made. Observing could be arduous. A typical night began about 11.00 pm and lasted until dawn. The Super-Schmidt cameras were not easy to handle and their shelters had roll-off roofs, giving observers almost no protection against wind and cold. Several cameras were out-of-doors, and observers had to hustle back and forth between the observatory and the yard. The men had to work rapidly. Different parts of the sky were targeted for each night. Before 11.00 pm, depending upon sky conditions the Meanook and Newbrook observers had to decide whether or not to work, exchanging notes by radio. If they did decide to observe, they then made a succession of 12-minute exposures of the agreed-upon patches of sky every 15 minutes. The large cameras had to be opened in the middle to change plates for each exposure. Clouds, a bright Moon or a temperature below –35º C would halt the night's work. However, during an important meteor shower, even clouds had to be tolerated and the observers might remain at their posts all night to 'shoot' through breaks in the

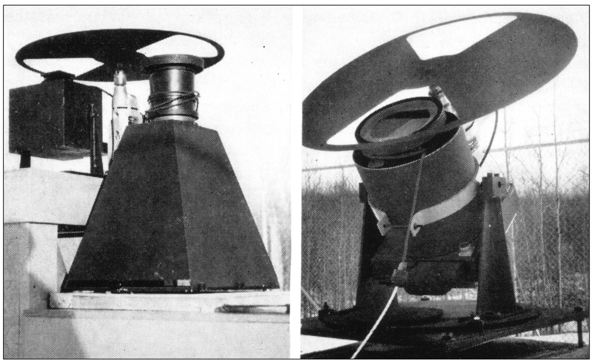

Figure 6: Rotating shutter spectrographs (after *Journal of the Royal Astronomical Society of Canada*, 52, 174, August 1958).

cloud cover. In addition to photographic work, they also made visual observations and noted meteor trails on maps provided by Ottawa. At least for visual work, they could observe through a glass skylight from inside the unheated observatory.

The film was processed at Meanook. Because of the unique design of the Super-Schmidt cameras, the circular film had to be curved. It was formed by heat in a special moulding machine at Meanook. The curved-film exposures were then projected onto flat, glass photographic plates. During the 1950s, these were shipped to Harvard (via Ottawa) for measurement and analysis.

The original impulse for building the stations was to obtain data on the Earth's upper atmosphere, but by the mid-1950s it was apparent that rockets could provide superior information. But Millman's programme was more ambitious: he wanted the fullest data possible on meteors, whether from direct photography, radar or spectroscopy (which was his own specialty). The radar and visual work, initiated at the NRC's Radio Field Station in Ottawa in 1947, moved south of the city in 1956 to the new Springhill Observatory, which acted as the centre for IGY operations. However, much of the photographic and spectrographic work remained in Alberta. The Dominion Observatory and the NRC supplied a wide range of cameras to Newbrook and Meanook. During the 1950s, the two stations used some seventeen different spectrographic cameras with transmission gratings and rotating shutters (e.g. see Figure 6). These, not the Super-Schmidts, were the real heart of the scientific work. This was no easy matter: it could require 100 hours' observing to obtain one good meteor spectrum. Halliday utilized the data in Ottawa for a series of important papers in which he identified chemical lines in meteor spectra, including the auroral green line (see Halliday, 1960).

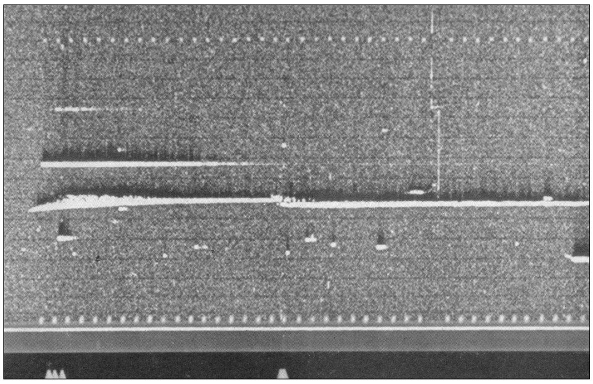

Figure 7: Radar echoes photographed from a cathode ray tube (after *Sky and Telescope* 8, 5, March 1949).

By the time of the IGY, Newbrook and Meanook likely had the world's greatest concentration of meteor cameras. A 1956 survey of world activity (Halliday, 1956) showed that 45% of all meteor spectra known were due to Canadian observers. During the IGY, and the follow-up International Geophysical Cooperation (1958-1959), the routine in Alberta continued, with additional duties to record meteorological data and observe aurorae—photographically at Meanook and visually at Newbrook. One break in routine occurred on 4 October 1957, when the Soviet Union launched the world's first artificial satellite, Sputnik 1. Its initial orbit was too far north for American observatories to photograph its passage, so after telephone calls from American officials to Ottawa, and from Ottawa to Newbrook, Griffin was able to obtain the first photograph of Sputnik from North America on 9 October. From June 1958, satellite tracking of the first two Soviet satellites was hastily added to the Alberta programme, and was initiated at six other stations. Measured positions were passed to the three World Data Centers for satellite observations established during the IGY. At Meanook and Newbrook, the work lasted for several months, normally requiring early evening photography when the satellites caught the reflection of the setting Sun. Nearly daily, Soviet space officials telegraphed orbital data to Newbrook; after plates were measured, the data were passed back. In an area with a concentration of Ukrainian families, this direct contact with Soviet science created a stir. Satellite tracking was an annoyance, however, and the Dominion Observatory soon dropped it.

4 NEW TECHNOLOGIES AND NEW DIRECTIONS: METEOR RADAR

Meteor work might well have concentrated entirely on photographic and spectroscopic studies but for a meeting between Millman and D.W.R. McKinley of the NRC. McKinley was a member of the NRC's radar research programme during the War. He had earlier, as a physics graduate student at Toronto, lived close to the David Dunlap Observatory, where he and his sister participated in Millman's observational sessions. He and Millman had met again, during the War, when Millman sought out radar information for the Royal Canadian Air Force. In the late fall of 1946, Edward Appleton lectured at the NRC on recent British radar astronomy work, noting J.S. Hey's and G.S. Stewart's observations of meteor echoes (Hey, 1973, 19-23). Millman had, in fact, visited them at Richmond Park in the spring of 1945, corroborating their belief that they were detecting meteors. Both Millman and McKinley attended Appleton's Ottawa lecture and afterwards, Millman suggested to McKinley that the Dominion Observatory and the NRC collaborate on a three-way programme of radar, visual and photographic meteor observations. McKinley would handle the radar work, and Millman the photographic observations. For the visual work, Millman brought in his Observatory colleague, Miriam Burland, a veteran of the pre-War observing parties. Work began with the Perseid shower in August 1947 at the NRC's Radio Field Station, just south of Ottawa. Radar recorded more than three times as many meteors as the visual observers, but Millman and McKinley found a correlation between the longer-lived radar echoes and the brightest visual meteors (see Figure 7). The first published data appeared in *Nature* in 1948 (Millman et al., 1948). Radar operations employed war surplus pulse radar units operating at 32.7 MHz with home-movie cameras to record the video output. Millman and McKinley were one of three teams studying meteors with radar: C.D. Ellyett and J.G. Davies (1948) observed with pulse radar at Manchester, while at Stanford, L.A. Manning, O.G. Villard and A.M. Peterson (1952) experimented with continuous wave transmission.

A photograph taken in the summer of 1948 at the NRC's Radio Field Station shows a typical visual observing group (Figure 8). At the top are McKinley and Millman. A fabric enclosure protected the observers somewhat from the wind, but they were still exposed, lying on cots. In 1948, Millman and McKinley decided to estimate altitudes of brighter meteors by combining radar with visual observations, utilising the Radio Field Station and two new outstations near Ottawa (Figure 9). Altitudes were then calculated by combining three radar ranges, or one radar range with one visual plot, or two or three visual plots. The next step came in 1949, with the introduction of continuous wave radar to study meteor velocities. By 1950, nearly 12,000 meteor velocities had been recorded and McKinley (1951) was able to show statistically that most meteors were of Solar System, not interstellar, origin.

After an eleven-year hiatus, Millman's column, "Meteor News", recommenced in the *Journal* of the RASC in 1952. With the success of the Ottawa programme, and McKinley's move up the ranks in the NRC's Radio and Electrical Engineering Division, he suggested that Millman transfer from the Dominion Observatory to the NRC as Head of the Upper Atmosphere Research Section within his Division. This Millman did in January 1955, just as planning for the International Geophysical Year was beginning. As the NRC expected to undertake a major effort for the IGY, and the Radio Field Station was being engulfed by development, Millman and McKinley argued for a new site for visual, photographic and radar observations.

Their plea was answered in the construction of the Springhill Meteor Observatory (Figure 10), 32km south of Ottawa (Millman, 1957). Operations began in the summer of 1957, in time for the beginning of the IGY meteor programme. Although the Observatory was an NRC site, the visual work continued to be coordinated with the Dominion Observatory.

Visual observing at Springhill was a far cry from the open fields at the Dunlap Observatory in the late 1930s. Observers worked on the roof of a small building to give them a good view of the horizon. Eight observers, rather than six, were employed at a time, with the timekeeper in the centre (Figure 11). For protection from the elements, observers were encased in wooden 'coffins' so that only their heads and shoulders were outside. Heat from an oil furnace below was piped into the coffins and timekeeper's station in cold weather. Observers lay upon platforms with a raised back and a foam mattress and each was equipped with a map and a pen that held a flashlight, a rheostat to control the illumination and a button that

Figure 8: Meteor observing group at the Radio Field Station ca. 1950. Standing at the rear (left to right) are McKinley and Millman (courtesy: National Research Council of Canada).

connected to the radar recording device. When a meteor was observed, the button was pressed and a match could be made of a visual and radar record. During the IGY, joint visual and radar observations were made during the seventy-one World Days plus ten days at the peaks of showers.

During the late 1940s and early 1950s, RASC observers continued to send meteor observations to Millman. The Montreal Centre was particularly active

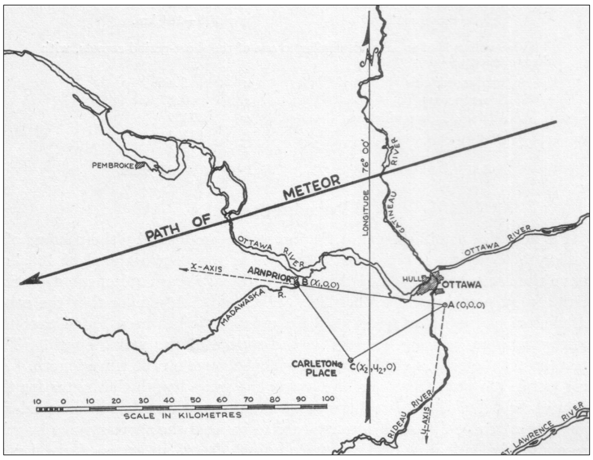

Figure 9: Map of meteor observing sites in the Ottawa area (after *Canadian Journal of Research*, A27, 54, May 1949).

Figure 10: Springhill Meteor Observatory (after *Bulletin of the Radio and Electrical Engineering Division*, National Research Council of Canada, 7(4), Plate 1, 1957).

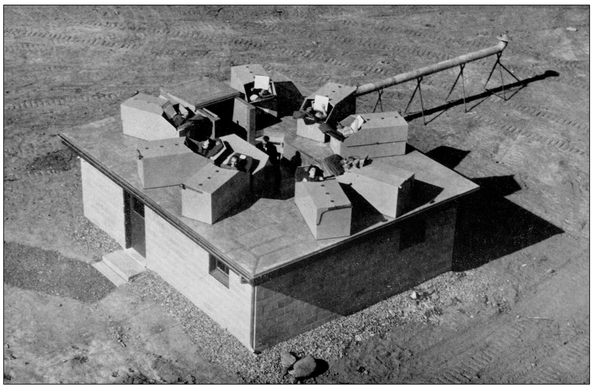

Figure 11: Meteor observers at Springhill in their 'coffins' (after *Bulletin of the Radio and Electrical Engineering Division*, National Research Council of Canada, 7(4), Plate 2, 1957).

from 1946 onwards, joined in the early 1950s by the Regina Astronomical Society, which coordinated observers across Saskatchewan. By the mid-1950s, other groups in Winnipeg, Fredericton, Deep River and Ottawa could be counted upon. For the 1956 Perseids, for example, the Regina group organised eighty-two observers across the Province. Millman did not direct any of these groups, but acted as the clearing house for observations, which he published in "Meteor News". Amateur participation was to be an important part of the NRC's IGY programme. Millman announced in the *Journal* that he would send out instructions and pads of maps to amateurs anywhere who would send data back to the NRC. Response was excellent and he soon had new recruits for his 'army'. As usual, he emphasised group averages and careful magnitude estimates over ten-minute intervals during shower periods and on World Days. Many of the RASC observers joined in, but the response from the United States was even greater. By February 1958, he reported data from 367 observers located in Canada, USA, Puerto Rico, Jamaica, England and Switzerland. Within a few months, reports came in from Italy, Brazil, Japan, India, New Zealand, the Philippines and South Africa. By the time the IGY ended, he reported that some 93,000 meteor observations had been entered onto IBM punch cards.

Some institutions decided to carry on the collection of data after the IGY, and the NRC visual meteor programme was one of these. From 1957 until the end of the programme in 1967, Millman received observations of some 277,000 meteors, mostly from Canadian and American observers. After the IGY, operations slowed at Springhill. Teams of twelve observers were normally used for visual and camera operations, and

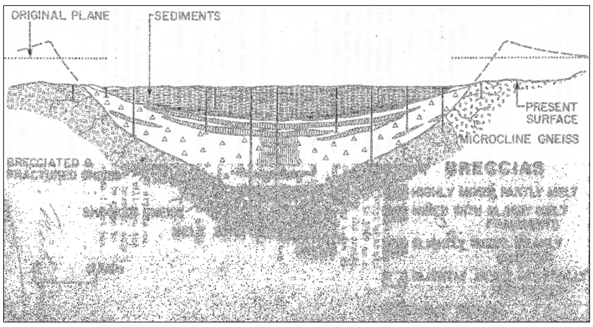

Figure 12: Cross-section of the Brent Crater made by the Geological Survey of Canada (courtesy: Geological Survey of Canada).

since they had to drive out from the city and then observe all night, it only proved efficient to work at times of meteor showers. Still, the data were impresssive: between 1947 and 1969, the NRC's volunteers observed 41,000 meteors at the Radio Field Station and at Springhill.

5 FROM METEORS TO METEORITES

Millman and his colleagues had always concentrated upon meteors, recording them visually, spectrographically and by radar. One consequence of Millman's move to the Dominion Observatory was his influence upon Beals, who was a spectroscopist, trained by Alfred Fowler in London, and a leading specialist on Wolf-Rayet stars. A successful twenty-year career at the Dominion Astrophysical Observatory made him a good candidate for Dominion Astronomer when R.M. Stewart retired in 1946. He was expected to shake up the staid Observatory, which he did, but not without ruffling feathers in Ottawa. Supporting Millman's work—which was quite unlike anything done previously at the Observatory—was one instance of his innovation. After accepting the Directorship, Beals ceased to observe and spent his time through into the early 1950s cleaning up work from his Victoria days and writing research papers.

The work of Beals and his colleagues on impact structures focussed upon the consequences of meteorite falls not on the meteorites *per se*, but their interest in the area was serendipitous. A few terrestrial craters, including the Barringer Crater in Arizona, were known or suspected, but until the late 1940s, most geologists assumed they—just like their lunar analogues—were of volcanic origin. Work by Robert Dietz, Ralph Baldwin, Harold Urey and Gerard Kuiper from 1946 to 1954 strengthened the alternative view that such structures were caused by impacts (see Hoyt, 1987). Baldwin (1949) found that if the diameters and depths of lunar, terrestrial and bomb craters were graphed logarithmically, a smooth curve (the so-called 'Baldwin curve') resulted. Millman brought Baldwin's book to Beals' attention. By chance, two suspicious circular features were noted on aerial photographs in 1950 (New Quebec Crater, in northern Quebec) and 1951 (Brent Crater, in central Ontario). In the former instance, Royal Ontario Museum geologist V.B. Meen examined the site. Millman obtained detailed aerial photographs from the Royal Canadian Air Force in 1953 and analysed the structure to see if it fitted the Baldwin curve. In the same period, J.M. Harrison from the Geological Survey of Canada, undertook a more detailed study of the geology. The Brent crater (Figure 12) had been spotted by a private aerial photography company. Millman and two scientists from the Geological Survey explored the site in July 1951.

In 1955, Beals inaugurated a systematic study of aerial photographs. Systematic research on suspected impact structures required accurate mapping along with geological, magnetic, gravity and seismological studies, followed up by diamond drilling. The Dominion Observatory's involvement, with Beals' blessing, had several advantages: it had a long history and expertise in gravity, magnetic and seismological research and it was a Division of the Department of Mines and Technical Surveys (which also controlled the Geological Survey of Canada). Over the following twenty-five years, most of the impact structures discovered and studied lay in the Canadian Shield, about which the Survey had firm knowledge. Millman's studies of the Brent Crater became a model for the later work by Beals, M.J.S. Innes (from the Gravity and Seismology Division) and others. In 1962, Beals created a petrology laboratory and hired Australian petrologist Michael Dence. Although Beals retired in 1964, he continued to work in the field, and the Dominion Observatory's studies continued until it was closed in 1970; the NRC staff, particularly Halliday and Griffin, continued the work into the 1980s. After his initial work on the Brent Crater, Millman left the field work to others, but followed the research with interest (he was even a President of the Meteoritical Society and of IAU Commission 22).

Almost all the work in Alberta during the 1950s and 1960s had centred on meteor observations. On 9 June 1952, an intensely bright fireball struck the Earth at Abee, thirteen kilometres south of Newbrook. Being early June, with bright twilight, no visual observations had been taken, but Griffin heard the sonic boom. A week later, a meteorite weighing 107 kilogrammes was discovered in a farmer's field (Figure 13). Millman came out from Ottawa and joined Griffin and the Meanook observer, J.M. Grant, in interviewing eyewitnesses to the fireball's descent. Later this information provided the basis for a calculation of an approximate orbit for the fireball (Griffin et al., 1992).

An even more spectacular fall occurred on 4 March 1960 at Bruderheim, near Edmonton, and some 300 kilogrammes of meteoritic particles were collected (Figure 14). The collection and analysis of this L6 chondrite became a co-operative venture between the Dominion Observatory and the Edmonton Centre of the RASC, along with geologists from the University of Alberta (particularly R.E. Folinsbee) and the Alberta Research Council (Baadsgaard et al., 1961; Millman, 1960). As one consequence of the event, the NRC established an Associate Committee on Meteorites that same year. The Committee brought together experts from the Council, the Observatory and universities across the country. Given the relatively flat terrain, open horizons and sufficient population of the prairies, Western Canada seemed an ideal location for a network of cameras to record bright meteors in hopes of locating any that might fall to Earth. Czechoslovakia and the USA had such networks in place by the mid-1960s; the Smithsonian Astrophysical Observatory's programme, the Prairie Network, operated from the early 1960s to 1995 and recovered one meteorite fall (Plotkin, 1997). With the Associate Committee's endorsement, Halliday and his staff began planning a Canadian network in the latter 1960s, with the first site searches in 1966. The Meteor Observation and Recovery Program (MORP) was a network of twelve automated camera stations across the three prairie provinces, with headquarters at Saskatoon (see the map in Figure 15). In Alberta, three stations, in Vegreville, Lousana and Brooks, anchored the western end. These would keep a constant watch on the sky and, by triangulation, might make it possible not only to determine bright meteors' paths, but also to locate those which survived to hit the ground as meteorites.

The first cameras were installed in 1968, and the network was fully operational by 1971, a year after the closing of Meanook and Newbrook stations (Halliday et al., 1978).

Figure 13: The Abee Meteorite, which fell in a field belonging to Mr and Mrs Harry Buryn who are shown posing in this photograph (after *Journal of the Royal Astronomical Society of Canada*, 86: 8, 1992).

Each station held five cameras and other equipment serviced by local, non-professional operators specially trained for the work. Several weeks' worth of film would be forwarded to Saskatoon at intervals. If at least two stations could record the passage of a bright meteor or fireball, the path could be calculated by computer from the triangulated positions. By the time the programme ended on 31 March 1985, the network had recorded some 900 fireballs, providing detailed data on more than 200. MORP allowed for the recovery of the meteorite fall in Innisfree, east of Vegreville, on 5 February 1977 (Figure 16). Two Alberta stations photographed the fireball and a small search area could be identified. On the 14th, a search on the ground by snowmobile turned up a 2 kg piece in the snow. In subsequent weeks, other pieces of this LL5 chondrite were recovered, allowing for detailed mineralogical analysis. Thanks to MORP, a very large mass of data was obtained, some of which is still being published.

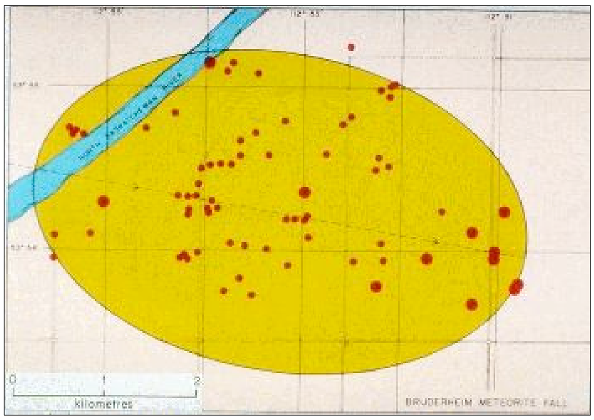

Figure 14: Geographical distribution of the main recovered fragments of the Bruderheim Meteorite, which fell on 4 March 1960. The diameter of each circle indicates the relative weight of the fragment (after www.miac.uqac.ca/MIAC/meteorit.html).

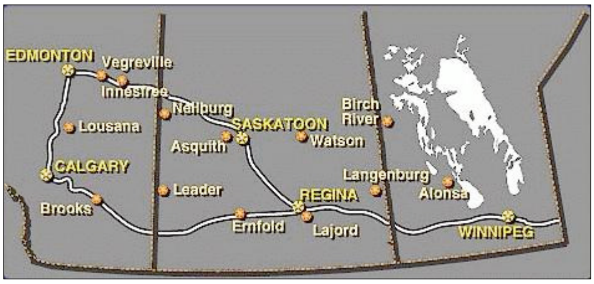

Figure 15: Map showing the locations of the twelve MORP meteor stations between Edmonton, Calgary and Winnipeg (after www.miac.uqac.ca/MIAC/morp.html).

6 INSTITUTIONAL CHANGE AND A CHANGE IN FOCUS

The Alberta operation was relatively inexpensive, was producing useful results and might have continued for many more years. But in 1965, the first rumblings of the possible closing of the two stations were heard. A year earlier, the Government announced it would finance a large, new Canadian telescope, the Queen Elizabeth II Telescope, and the planning team began searching for a site. Early in the search, the Victoria staff believed that Mount Kobau, near Osoyoos, BC, was a superior site and the Department of Mines and Technical Surveys announced, in October 1964, that it had been chosen. While the original proposal was for a single, large telescope, the project soon blossomed into a full-scale national observatory where all federal astronomy could be centralized. This meant the probable closing of both Meanook and Newbrook stations and their removal to Mount Kobau and to a nearby site in the Okanagan Valley. In the prime consultant's preliminary report in 1967, Halliday provided a section on meteor astronomy, noting that the Alberta stations had become "… a leading centre for meteor spectroscopy which, together with the Springhill Observatory, have maintained Canada's leading position in this field." (A.B. Sanderson and Co., 1967, 2.25). Still, Kobau would be a preferable site, with fewer aurorae, less summer twilight, milder winters and fewer clouds. The move would cost some $249,000.

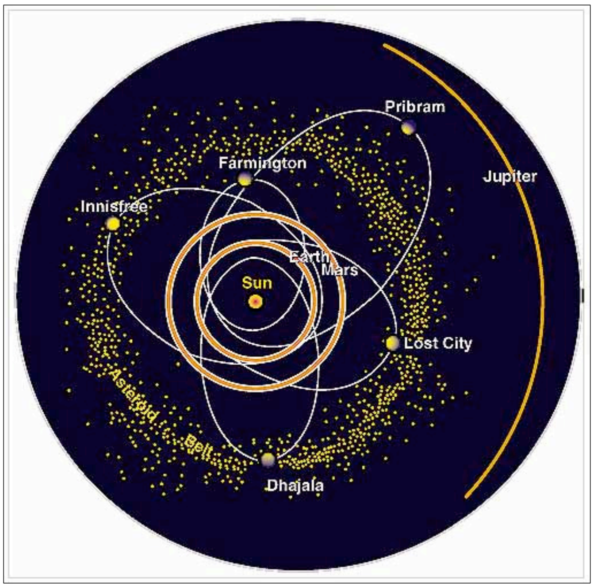

Figure 16: Diagram showing the orbits of the Innisfree meteoroid and other Earth-crossing meteoroids (after www.miac.uqac.ca/MIAC/ morp.html).

Opposition to the Kobau scheme had been building for some time in the eastern universities and broke out later in 1967. Some felt a site in Chile made much more sense than in British Columbia. There were other problems, too. The Head of Toronto's Astronomy Department, Professor Donald MacRae, thought the plans for meteor studies, among others, at Kobau to be "… unimpressive." (MacRae, 1967). The Director of the Observatories Branch in Ottawa, John Hodgson (1967), had to admit by June that Kobau was not likely to be suitable for meteor work. With no unanimity among the astronomers, the Government seized the chance—ostensibly on budgetary grounds—to cancel the entire project in August 1968.

As it turned out, the Alberta stations were doomed for another reason. In 1963, the Glassco Commission on Government reorganization had questioned why astronomy should be divided between two departments, the Dominion Observatory and the NRC, recommending amalgamation within the latter institution. The Trudeau Government, in its Science Policy overhaul, saw the wisdom of the argument and in early 1970 placed all of astronomy under the NRC. The Dominion Observatory in Ottawa was then closed down. This might not have had an impact upon Meanook and Newbrook, as Halliday and his staff transferred to the NRC's Upper Atmosphere Research Section. However, budgetary restrictions meant some programmes would need cutting. Although the stations had produced high-quality data, the expense of piling up even more was not justifiable. The Alberta stations closed that year. Meanook's Super-Schmidt was remounted at Springhill, south of Ottawa; Newbrook's went to the National Museum of Science and Technology. McKinley was by now a full-time administrator and Millman was due for retirement; Halliday was able to keep meteor astronomy alive, though it moved into different areas. By the 1980s, continuing cuts to the NRC budget began to take their toll on the programme; Springhill Meteor Observatory, by then used only occasionally, was closed in the late 1980s. When Halliday and his senior staff were retired by the early 1990s, the meteor programme ceased altogether.

7 TRANSITION TO THE SECOND PHASE

With the winding down of Government-based meteor and meteoritic research, it appeared that Canada's contribution to that area of astronomy would cease. In fact, phoenix-like, meteor science reappeared in the university arena where a few isolated researchers had been working. With the NRC out of planetary science, its Associate Committee on Meteors became redundant. The Committee reorganized itself as the Meteorites and Impacts Advisory Committee of the Canadian Space Agency, and is now a volunteer coordinating body.

There are two links to the Millman era today: his catalogue of fireball observations is now curated by Martin Beech at the University of Regina (Beech, 2003) and the MORP records are housed in the University of Calgary's Geology Department and are still being analyzed (Campbell-Brown and Hildebrand, 2004).

Another meteor group emerged at the University of Western Ontario in London where Peter Brown now directs the Meteor Physics Group, which employs radar, electro-optical devices, telescopes and infrasound. This group now operates a five-station all-sky camera network in southwestern Ontario.

Meteorite recovery, through the Prairie Meteorite Search, was launched by Alan Hildebrand at Calgary and is now a cooperative venture between Calgary, Regina and Western Ontario Universities. Brown, Hildebrand and their groups were central to the study of the Tagish Lake fall in 2000 (Brown et al., 2000).

With a good flow of graduate students into the area, it appears that Canadian meteor science will survive and thrive.

8 CONCLUSION

Canadian meteor science went from nothing to international stature and back to virtual non-existence in sixty years. Before the 1930s, it was not a prominent area of professional astronomy anywhere, with only a few isolated workers, although meteor observing appealed to many amateur astronomers. Peter Millman was attracted to the area because of an unsolved problem: the nature of meteoric spectra. His unflagging leadership naturally attracted others, most notably Ian Halliday and C.S. Beals. During the 1940s and 1950s, several research problems in meteor science became tractable thanks to new technologies: better cameras, films, spectrographs and radar. Millman and McKinley and their Dominion Observatory colleagues turned visual observing into an art. A mountain of data was collected, especially during the IGY, from dedicated observing sites in Alberta and at the Springhill Observatory. The value of the Canadian work was noted, in one sense, by the inclusion of review papers by Millman and McKinley (1963) and Beals et al. (1963) in the five-volume series, *The Solar System*, edited by Barbara M. Middlehurst and Gerard P. Kuiper.

Yet, the research programme had its limits. Many of the interesting questions about meteor streams, shower radiants, speeds, heights, ionization, etc., were answered. When Millman retired, he could no longer defend the maintenance of existing programmes. Shifts in interest came with new researchers in the NRC and budgetary crises. While Springhill, Meanook and Newbrook could have continued to operate, the probability that important new data would be produced was very low. Even the expansion of astronomy programmes in Canadian universities during the 1960s and 1970s brought almost no new blood into this area—the research action was elsewhere.

Canadian meteoritics, in the form of studies of impact structures, came a decade after Millman's first work. This was a natural area for Canadians, with a long tradition of geology and mapping. Even here, the broad-brush work was essentially complete by the 1980s, and interest shifted to the recovery and analysis of meteorites. Again, Canadian advantages—a vast prairies region with unhindered horizons and snow cover much of the year—and expertise in photographic technology, led to the successful MORP programme. By the 1990s, astronomers had an increasingly clear idea of the origins of meteorites, both in terms of their birth places in the Solar System and their compositions. But astronomy at the NRC increasingly focused upon radio astronomy and upon expensive, cooperative optical programmes offshore. With no champion and no new staff, meteor science was cut. Ironically, it was one of the cheapest operations.

Peter Millman saw the winding down of meteor studies with some sadness, but as he related to me in 1989, science always moves on. His first publication on meteors appeared when he was twenty-four; his last was penned when he was eighty-four. He had the satisfaction of knowing that some important questions about the nature and origins of meteors had been answered, and that his work had been an important factor.

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NAC = National Archives of Canada

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