History of the Adelaide Radar Meteor work 1950-1990

by

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This is a history of Radar Studies of Meteors carried out at the University of Adelaide during the period December 1949 – December 2000. For over 50 years this work was under my general direction and I am pleased to see that the work is still continuing under Professors Reid and Vincent and that Adelaide is still a centre of excellence in Meteor Astronomy and in meteor studies of the dynamics of the upper atmosphere.

First, what are meteors and where do they come from?

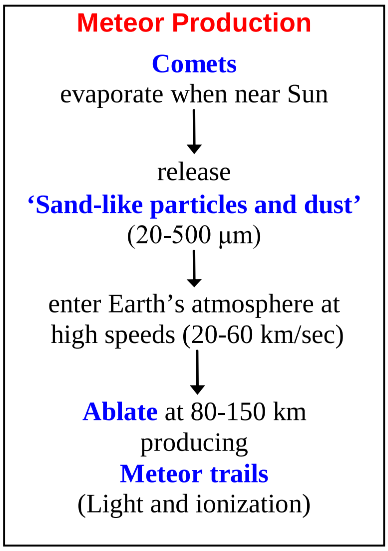

Figure 1. Meteor production

Figure (1) describes the source and production of meteors. Meteors are caused by the ablation, burning up, of small particles that travel around the Sun and impact on the Earth's atmosphere. The particles themselves are part of the last vestiges of the formation of the Solar System having spent most of their life trapped in comets. They are sometimes called the 'crumbs of creation'. They are released into independent orbits when the ices in a comet evaporate during a close passage by the Sun. The entry of the particle into the Earth's atmosphere produces light and ionization at heights between about 80 and 150 km. The particles are predominantly silicates. The size of the particles is close to beach sand so that this handful of sand is a good reminder of a sample of meteoroids that ablate to form meteors.

Toward the end of the war, radars in England endeavouring to detect ballistic missiles, observed a large number of non-missile echoes that turned out to be echoes from meteor trails. An example is shown at the right in Figure 2.

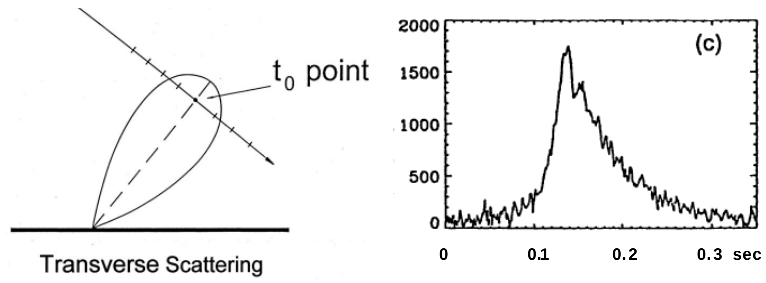

Figure 2. Typical radar echo from a meteor trail

From about mid-1945 a small research group at Manchester University, began studying meteors using ex-war-time radars at a university field station at Jodrell Bank about 30 km south of Manchester. The leader of the group was a 30 year old senior lecturer, named Dr Bernard Lovell.

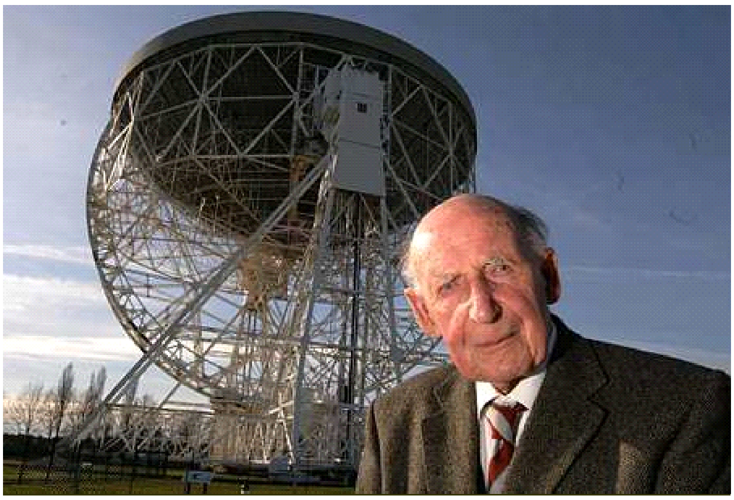

Figure 3 Sir Bernard Lovell on his 90th birthday

Here he is (Figure 3), now Sir Bernard Lovell, photographed on his 90th birthday in front of the large radio telescope that bears his name.

In mid-1948 the University of Adelaide appointed Dr. L.G. H. Huxley, a Reader in Physics at Birmingham, to the Elder Chair of Physics at Adelaide. Prior to leaving the UK, Huxley had a conversation with Lovell at Jodrell Bank seeking advice on any potential radio astronomy research that might be started at Adelaide. Lovell strongly advocated that Huxley initiate radar studies of meteors as the whole southern hemisphere was an open field for such work.

Huxley accepted Lovell's advice and soon after his arrival at Adelaide in January 1949, he suggested three possible lines of research, one of which was radar studies of meteors. This was appealing to me and I commenced my PhD work in January 1950, four years after the commencement of meteor work at Jodrell Bank in the UK.

In retrospect it is to Bernard Lovell that the credit should go for persuading Huxley 64 years ago to establish at Adelaide a research group on the radar studies of meteors. Lovell died 3 weeks ago – he would have had his 99th birthday yesterday (31 August).

In early 1950 I was joined by two Honours students Des Liddy and Alan Weiss and the three of us formed the first Radiophysics Group.

And then in 1951 we were joined by David Robertson, a Research Scientist at Weapons Research Establishment and a gifted radio engineer who had enrolled as a PhD student. It was at this stage that we made a very significant decision and changed our emphasis from meteor astronomy to measuring the drift of the short-lived meteor trails in order to study the winds in the upper atmosphere.

2. The Radiophysics Group

We acquired a surplus wartime radio transmitter, adapted it to generate 1kW of continuous wave transmissions and installed it in a small room on the second floor of the Physics Department. As the building has a tiled roof a simple antenna was placed in the ceiling space above the transmitter.

Receivers and recording equipment were installed in a building near Salisbury. After a few months with us, Robertson pointed out that we could determine the direction of arrival of echoes from meteor trails by recording signals on three spaced antennas as is shown in Figure 4. Here is the layout, and on the right a photograph of three of the antennas. Mount Lofty can be seen in the far distance.

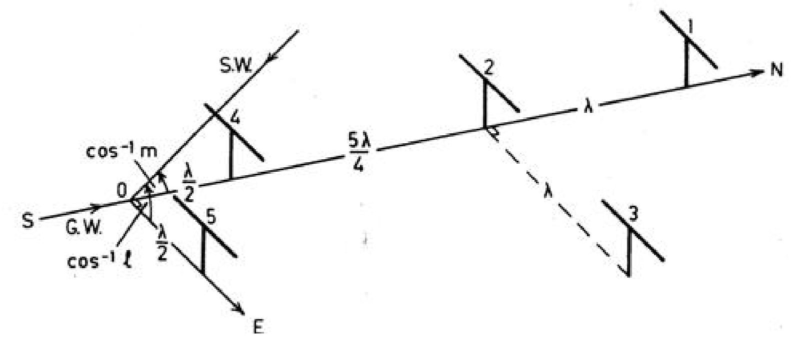

Figure 4. The meteor direction finding system. The forerunner for such systems now installed worldwide.

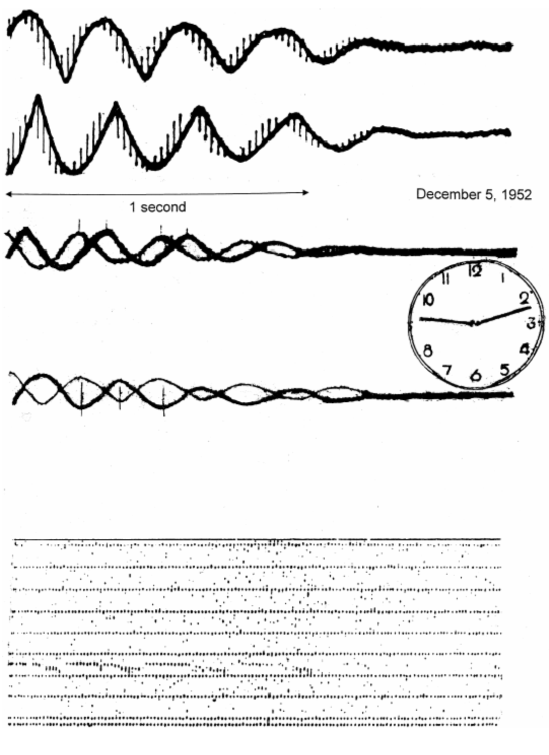

Figure 5 A typical wind record photographed onto moving 70mm wide recording paper in 1952.

I will not go into any details here, other than to point out that the records had to be read manually and the relative shift of one trace compared to another required marking peaks on the records as shown.

It was many years before digitisation of the data allowed this operation to be made automatic.

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3. The Meteor Radiant System, and the work of A. A. Weiss

Early in 1952 Lovell offered to assist us in setting up an independent radar system specifically designed to measure the properties of meteor showers, and Huxley suggested that Weiss go to Manchester and bring back some equipment for this purpose. Toward the end of 1952 Weiss returned with two receivers and recording equipment. He then built a transmitter and the antenna system based on designs from Manchester, and observations commenced in mid-1953.

Six years later Weiss moved to Sydney to join the CSIR Solar Radio Group. By the time he left Adelaide, Weiss had discovered 7 new meteor streams and produced a steady stream of publications. Weiss's lone astronomical work at Adelaide stands as a beacon in radar meteor astronomy in Australia.

5. Meteors and Upper Atmosphere Winds - Adelaide and Mawson

Observations of atmospheric winds from radio measurements of the motion of meteor trails commenced in June 1952 and continued for about five years. Robertson and I completed our PhD work in the late 1950s..

In early 1954 the Antarctic Division of the Department of External Affairs was seeking proposals for upper atmosphere studies in Antarctica, and I suggested that we build a meteor-wind radar for installation at Mawson.. The Antarctic Division agreed to fund the project.

One of our B.Sc. graduates, Carl Nilsson, took the equipment to Mawson in December 1956 and operated it there for a year. Due to problems with interference between the meteor radar and the communication equipment at the base, the Mawson observations were somewhat limited.

6. Measurement of meteoroid speeds using the continuous wave radar.

At the beginning of 1955 I decided that we should commence measuring meteoroid speeds, that is the speed of the incoming particle, using a radio method pioneered by a group at Ottawa in Canada in 1951.

I suggested the project to John Mainstone, a Honours Physics graduate, and we agreed that he would develop a magnetic tape system to record and replay the early and vital part of the radar meteor signals with a delay of about 2 seconds. John is here today and I wish to pay tribute to his contribution to this special area of meteor astronomy

The first distribution of the speeds of meteoroids observed by Mainstone in 1959 is shown in Figure 6.

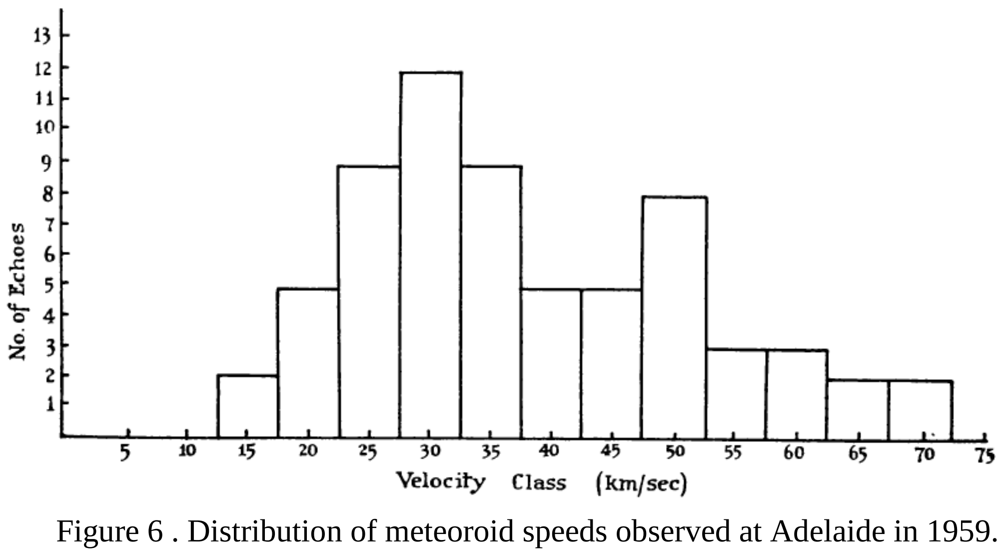

Figure 6 . Distribution of meteoroid speeds observed at Adelaide in 1959.

Not only were these the first such observations in the Southern hemisphere, they were also superior in accuracy to any such observations in the Northern hemisphere. Adelaide was now pre-eminent in the precise measurement of meteoroid speeds using radar, a position that has continued to the present day.

6. Meteor orbits and atmospheric turbulence at meteor heights

In January 1957 I decided that we should set up a multi-station receiving system to measure meteor orbits. In September 1958 the system was installed at a new site at St. Kilda, about 22 km north of Adelaide. The St Kilda field station continued to be used for about 20 years..

The multi-station system, shown in Figure 7, had two supplementary receiving sites about 5 km East and North of the main field station at St Kilda and the data was sent to the main station via FM links.

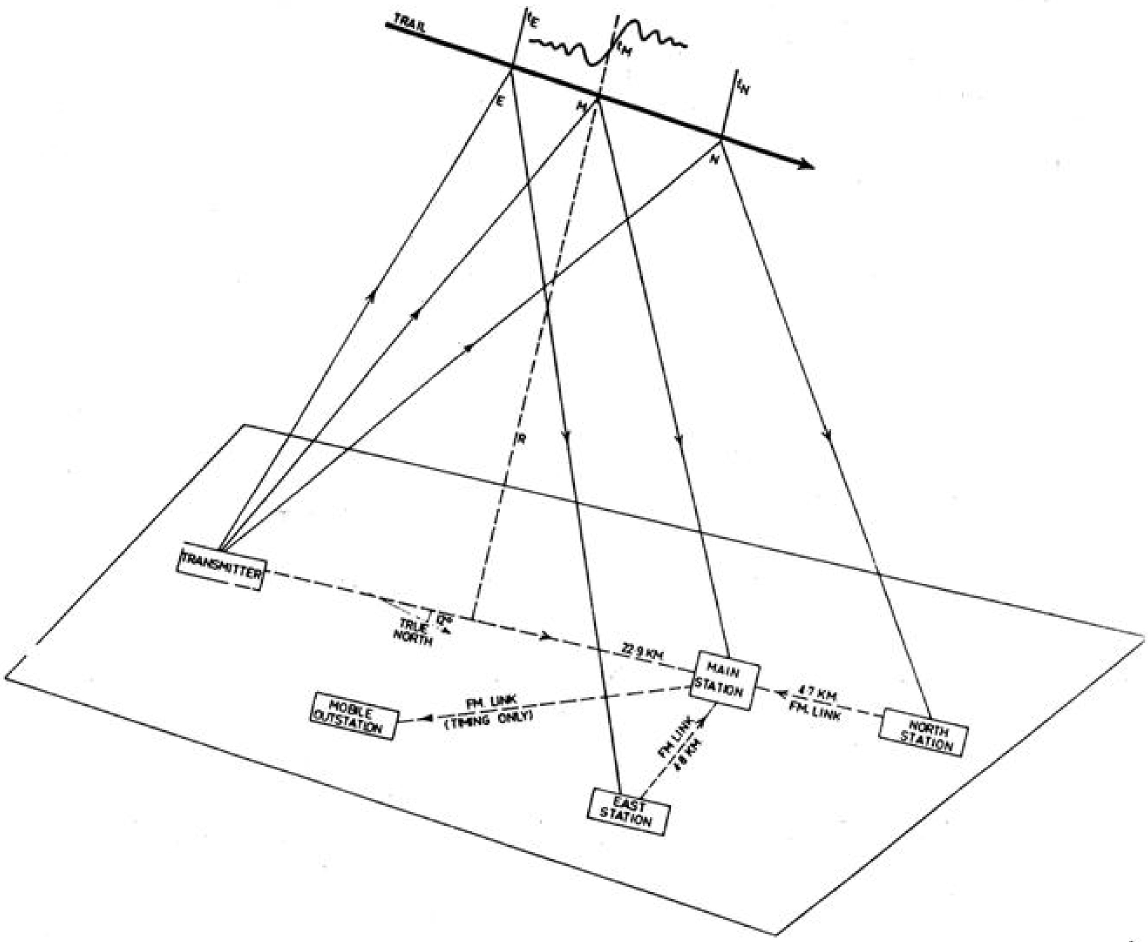

Figure 7. The multi station system used to determine meteor orbits and study atmospheric turbulence in 1961.

In order to record the commencement of the first part of the meteor echoes which contain the orbit information, we used the technique developed by Mainstone. All the data were recorded on magnetic tape and then read off with a delay of about 2 seconds. In the light of present day digital techniques and ease of storing data, it is difficult to appreciate the effort required to build, operate and maintain this electro-mechanical analogue delay system.

Nilsson measured over 2000 orbits, the first such observations in the Southern Hemisphere . He found that many could be grouped to form meteor streams close to the plane of the ecliptic as shown in Figure 8.

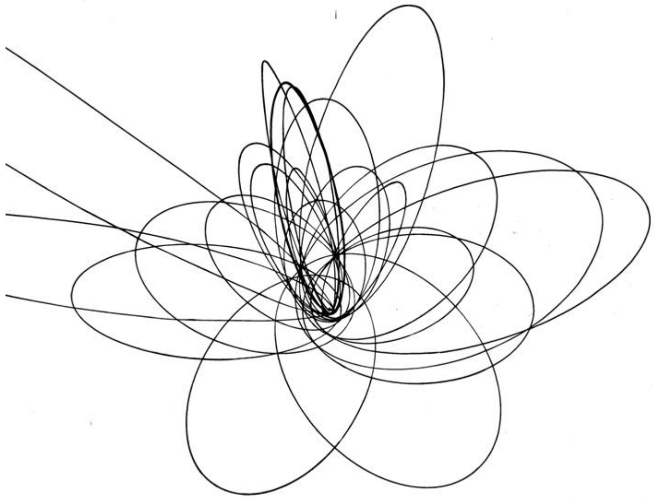

Figure 8. Meteor streams determined from orbit data by Nilsson in 1961. All streams lie close to the plane of the ecliptic.

Figure 7 also shows that there are three points on the trail (E, M, N) where we can measure wind components. Roper used these observations to measure small scale atmospheric turbulence at meteor heights. His measurement of the annual variation of the turbulent dissipation rate at 93 km is shown in Figure 9.

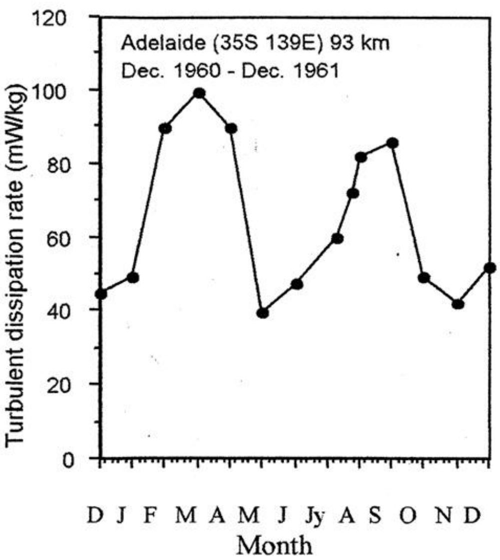

Figure 9. The small scale atmospheric turbulence at 93 km is a maximum in Spring and Autumn and a minimum in Summer and Winter

The 2-day wave

The story of any long research program will, in retrospect, show moments of lost opportunity. In 1965 Elizabeth Doyle commenced a Ph.D. program on the observations of winds at 80 and 90 km. In January 1967 she observed a curious reversal in the winds from North to South, and vice versa on alternate days, as shown in Figure 10.. However, this behaviour was not clearly evident a few days later and it became lost in other work. Doyle had in fact been the first to detect what we now call the 2-day wave - 5 years before its regular presence in summer was recognised by others.

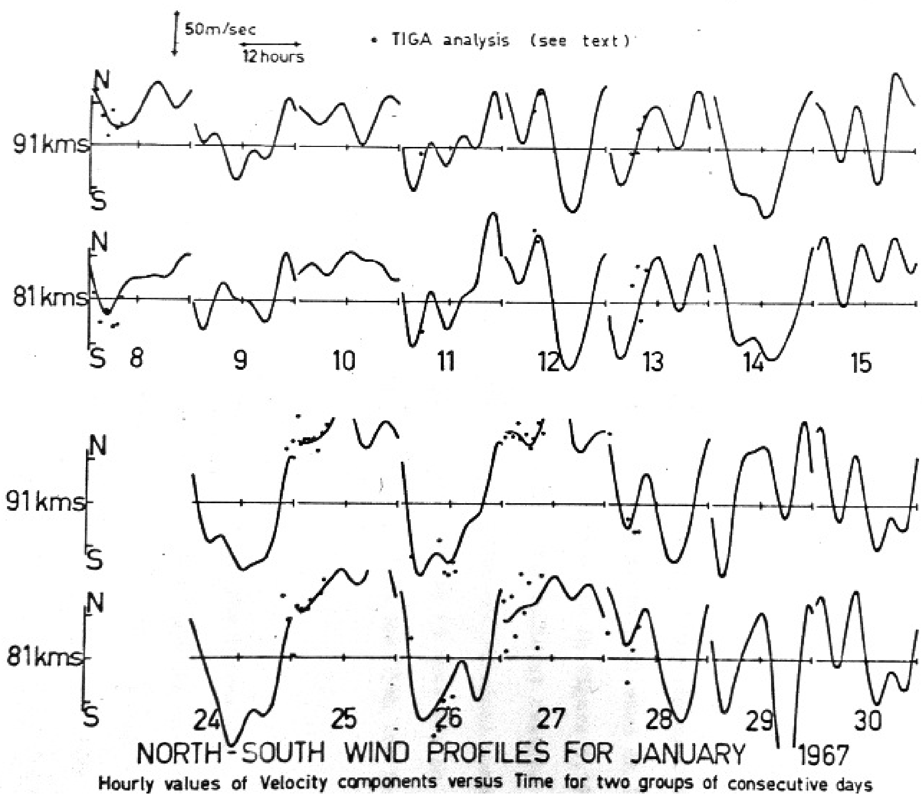

Figure 10. Evidence of the 2-day wave during 24-28 February, 1967.

The last observations with the wind system occurred in the January 1975 and then the whole system was moth-balled - it had operated for over 15 years.

12. Meteoroid speed measurement with the narrow beam VHF radar

In the early 1980s, a new upward pointing narrow beam radar was constructed at the Buckland Park field station for studies of the ionosphere and the atmosphere.

I realised that this new system could also operate as a meteor radar for measuring meteoroid speeds. A typical observation is shown in Figure 11.

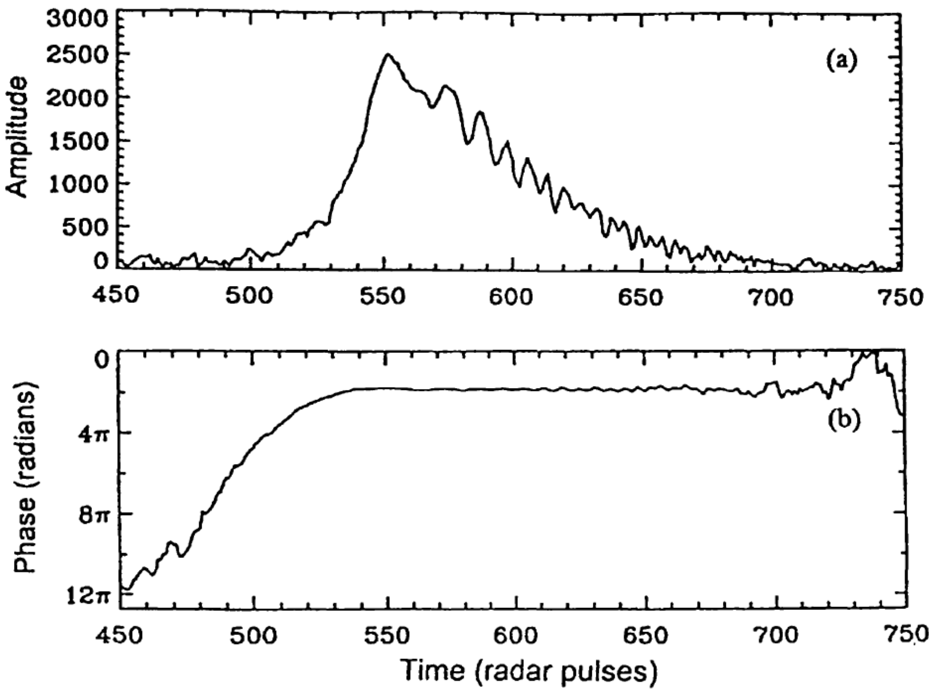

Figure 11. Amplitude and phase of a meteor echo observed with the narrow beam 54 MHz radar.

Up until this time the speed of the meteoroid was determined from oscillatory features as shown in the upper plot. However the early part of the associated phase record in the lower plot can be interpreted as distance of the meteoroid along its path and when that is done the outcome is as shown in Figure 12.

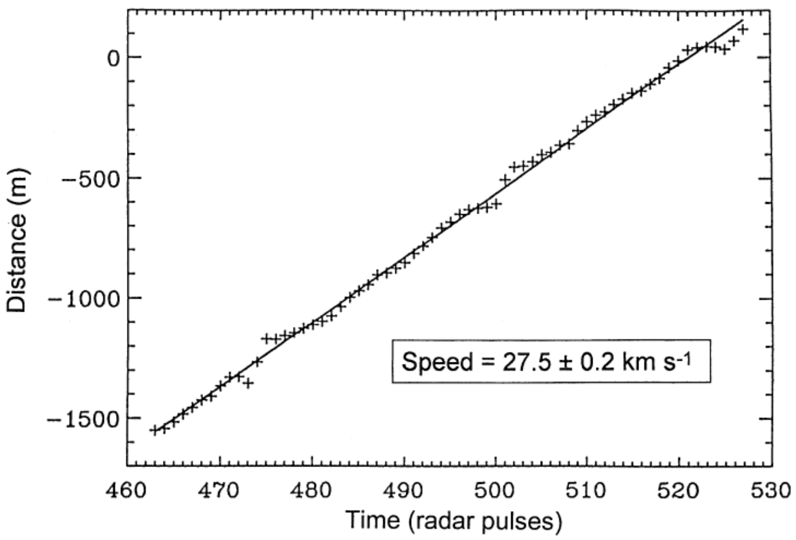

Figure 12. Distance back along the trail from the t_0 point (see figure 2)

The linear relation between the distance and the time gave the speed of the meteoroid as shown. This speed value was 5 times more accurate than previous measurements and the technique could be applied to about 8 times the number of meteoroids.

A comprehensive study of the main outcomes of this method of speed determination was carried out by Manuel Cervera, and once his work was published the phase method of measuring meteor speeds was adopted by most radar meteor groups world wide.

13. The low frequency meteor radar and the inspirational work of Dr Basil Briggs.

I must now go back almost 20 years to 1962 when Dr Basil H. Briggs was appointed to the staff. I am sure Professor Reid will give a full account of Dr Briggs's contribution to the work of the Radiophysics Group. My interest here is to point out that within 12 months Briggs proposed that a completely new research program be set up to study the structure and dynamics of the lower ionosphere with a giant radio telescope 1 km in diameter operating on a radio frequency of 2 MHz.

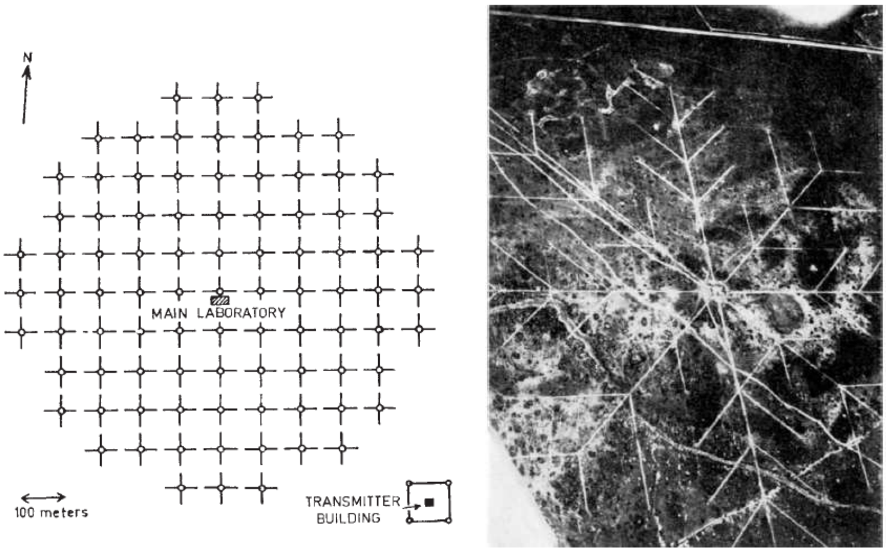

Figure 13.
Aerial photograph of the 2MHz antenna.
Left diagram shows layout of the 89 dipoles.

From the beginning I realised that it would have potential as a low frequency meteor radar. Some preliminary work in the early 1970s showed that the majority of meteors were occurring above a height of 100 km. Meteors at these heights are inaccessible to most meteor radars that operate on frequencies above 20 MHz.

The results of this new study were published in 1975. However it was over a decade later before I was able to fund a post-doctoral position directed specifically at the problem of high altitude meteors. Dr Duncan Steel was appointed to the position and within a few months had measured the height distribution of meteors observed at 2 Mhz.
The results of Steels work are shown in Figure 14.

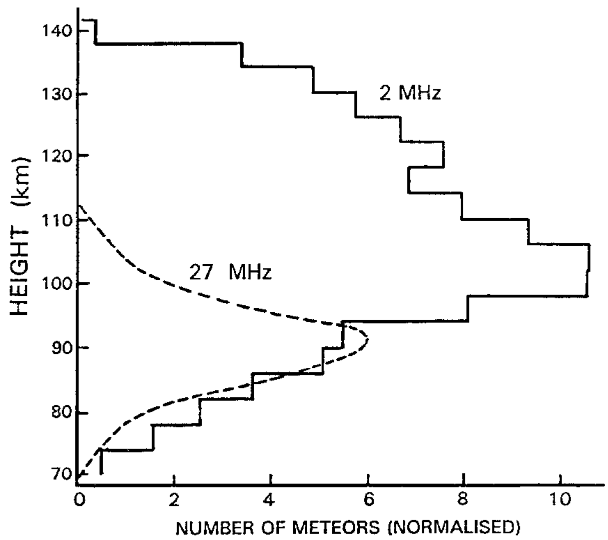

Figure 14. Meteor height distributions measured with a 27 and a 2 MHz radar.

There are about four times as many meteors observed at 2 MHz compared to the number detected with conventional meteor radars. And this discovery was confirmed by some work I had been doing with the people at DSTO that related to the interpretation of observations with the Jindalee over-the-horizon surveillance radar near Alice Springs. Jindalee operates on several frequencies, the lowest being 5 MHz.

Figure 15 shows the rate of impact on the Earth's surface of meteoroids of a wide range of masses, using data from satellites, the Jindalee radar, and optical systems. Only radar observations at low radio frequencies are consistent with satellite impacts and optical studies.

The question of the type of particles that produce meteor trails above a height of 110 km is still open.

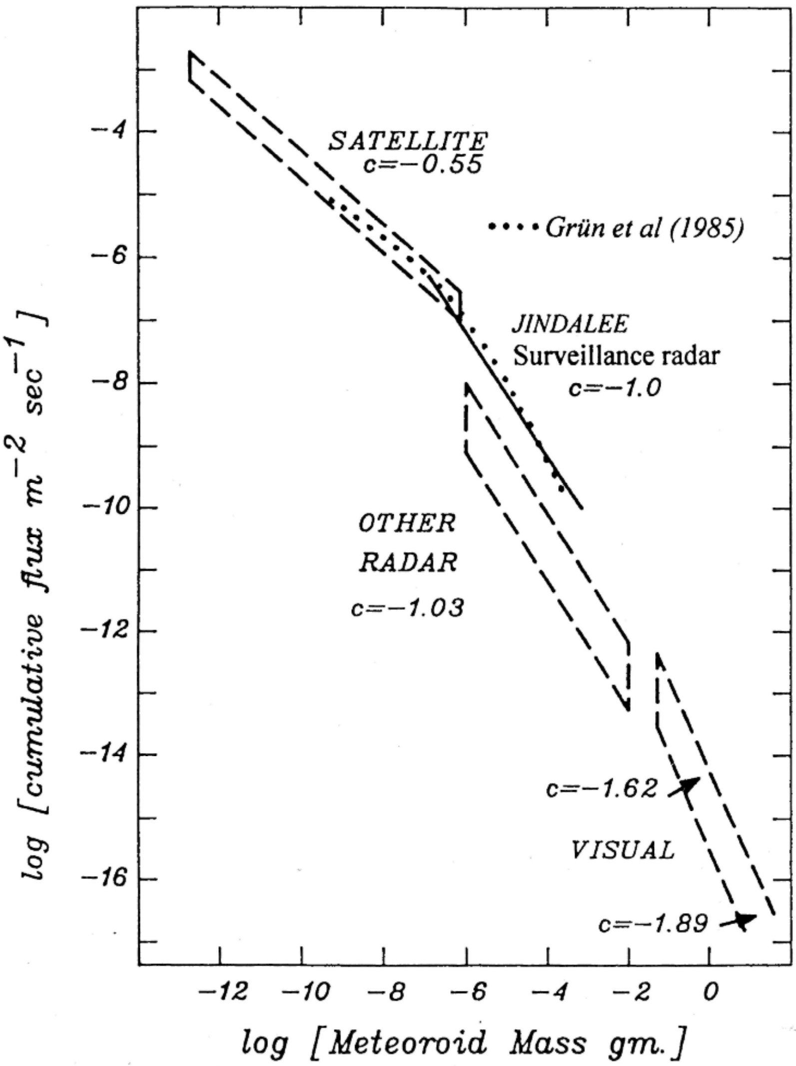

Figure 15. Flux of particles incident on the Earth for a large range of masses. Only radar observations at 6 MHz frequencies or less are consistent with satellite and optical observations

Down the beam meteor radars.

I now turn to another method of studying meteors that we pioneered at Adelaide in the mid-1990s. It is best illustrated by Figure 16.

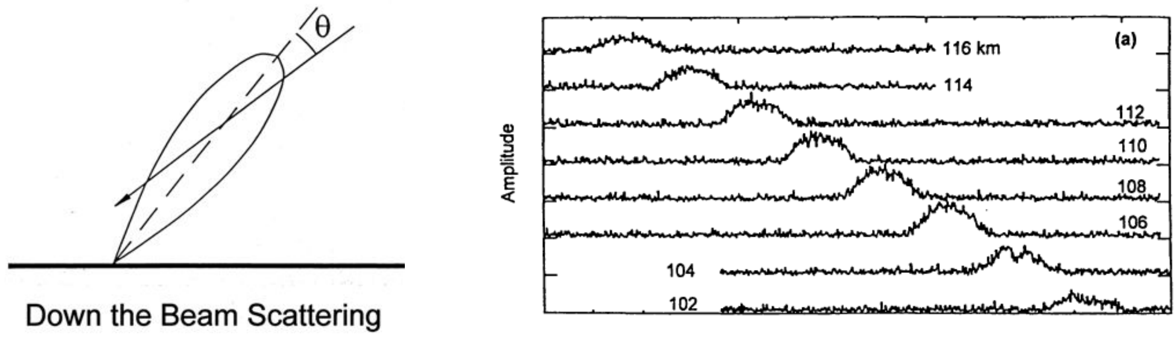

Figure 16. The ionisation from a particle moving down the beam detected in successive range bins.

A meteoroid that moves down the beam of a narrow beam radar will be detected in successive range bins as shown at the right. In this case the radio scatter comes from a small region of ionization about the ablating meteoroid. In 1996, Dr Andrew Taylor, a post-doctoral fellow, observed and recorded the pattern on the right. With additional information about the phase of the signals he showed that he could measure the speed of the meteoroid along its path to a few tenths of a km/s. Taylor showed that invariably the speed of the meteoroid decreased toward the lower end of the meteoroids motion as is shown in Figure 17.

This slowing of the meteoroid is the result of collisions with air molecules.

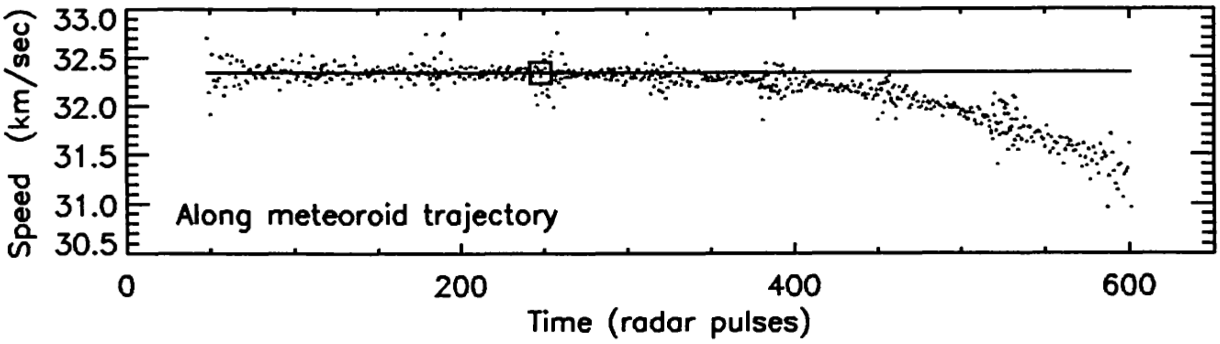

Figure 17. Speed of particle moving down the beam.

The Fresnel Transform analysis.

In the late 1990s I realised that the transverse radar signals from meteor trails could be subjected to a mathematical analysis called a Fresnel Transform that should show up the structure of the meteor trail just behind the ablating meteoroid. It was surprisingly successful and is illustrated in Figure 18.

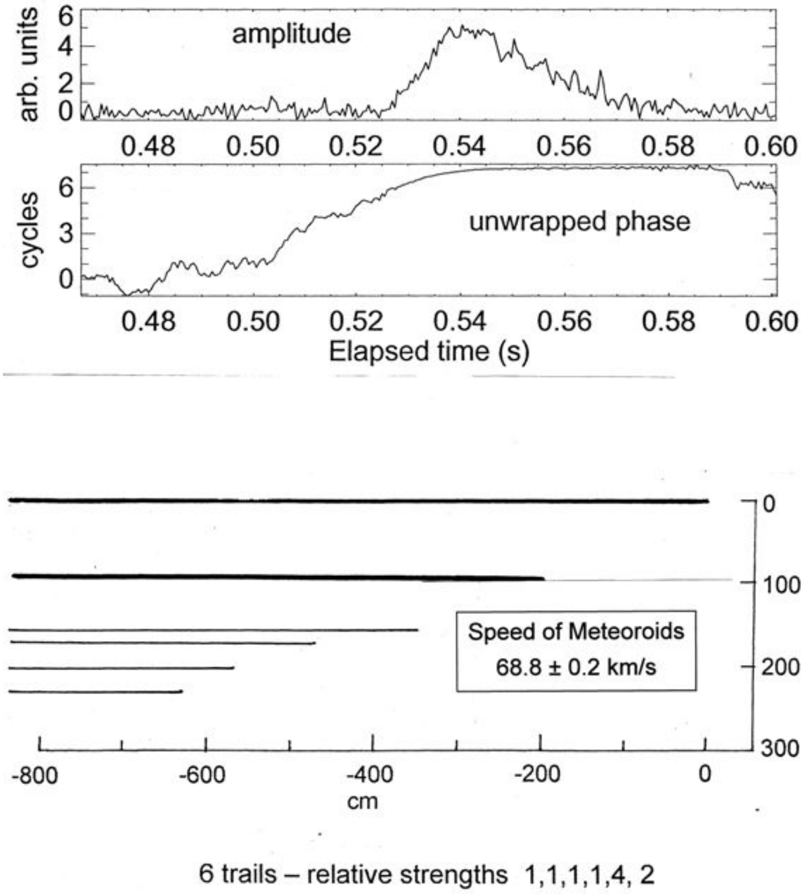

Figure 18. Observed radar record and the Fresnel Transform.

The upper part of the Figure shows the actual radar record from, apparently, one trail. The record looks very noisy. It is not. In fact it contains an extraordinary amount of detail about the meteor trail as is shown in the outcome of the Fresnel Transform in the lower diagram.

The interpretation of the transform is that we are looking at 6 individual trails. The heads of the trails are separated by a few hundred centimetres along the paths, while the trails themselves are separated laterally by less than 250cm. Moreover the outcome gives the relative strengths of each trail. And further, the speed of the meteoroids could be measured with great precision.

Apparently, soon after the ablation of a single meteoroid commenced, it fragmented into 6 components whose relative positions and speeds changed as the trail developed.

This remarkable result is an appropriate place to reflect on the work of the Adelaide Radar Meteor Group. We started in 1950, became world leaders by the 1960s, and now 52 years later, the present members of the Group can justly claim that they have retained that position.

And after a 62 year love affair with the Crumbs of Creation , I still look back with a sense of nostalgia.