# METEOROID ORBITS DETERMINED BY SOUTHERN HEMISPHERE RADAR

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ABSTRACT. A radar meteor orbit facility of novel design has been developed at the University of Canterbury. Synchronous digital noise averaging, impulse suppression and meteor echo recognition using a microprocessor system, along with high gain antennas, allow a limiting radar magnitude of about +13 to be achieved, making this the most sensitive meteor orbit radar to date. An exhaustive survey of faint sporadic meteors will be carried out, along with an investigation of the little-known Southern showers. Since the observatory is ideally located with respect to the Eta Aquarid radiant, a programme of observations during the Comet Halley perihelion epoch is planned.

## 4. INTRODUCTION

Direct spacecraft measurements of meteoroidal impacts have the advantage of being unaffected by the vagaries of the Earth's atmosphere, and can also investigate the interplanetary environment away from 1 A.U. However, the detectors only give crude measures of meteoroidal velocity and orbit, and since the flux of the dust is low the small detector area in a spacecraft experiment leads to a tiny sample of the inter-planetary dust complex.

Meteor observations, which use the atmosphere as a collecting area, do not suffer from these limitations. A variety of optical methods have been used to measure orbits down to +7.5 magnitude (Hawkes et al. 1984) and fluxes down to +12 (Cook et al. 1980). With the radar technique, in which the samples may number thousands of meteors per hour, a few orbits down to +12 magnitude and many to +10 have been measured by the Harvard survey (Cook et al. 1972), and fluxes to a limiting magnitude of +15 (Eshleman and Gallagher, 1962).

The presently described radar apparatus will determine the orbital parameters of meteors mostly in the magnitude range +8 to +13. The limiting meteoroid diameter is about 50 microns: this will therefore be the first orbital survey to have a significant overlap with those particles causing the zodiacal light and gegenschein, and will hence allow the dynamics of the zodiacal cloud to be directly investigated.

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## 2. PREVIOUS RADAR TECHNIQUES

A variety of radar techniques have been used to determine meteor orbits since the first demonstration by McKinley and Millman (1949). The group at Jodrell Bank, England, used three spaced receivers to determine the meteor trajectory with the velocity being calculated from the instantaneous oscillation frequency of the Fresnel diffraction echo at any one of them (Davies and Gill, 1960). This method is limited by the small fraction of meteors which render usable diffraction echoes.

Most subsequent experiments have been broadly based upon the spaced receiver method. The Harvard group in the United States used eight separate sites (Cook et al. 1972), whilst a rotatable antenna was used at Kazan in the Soviet Union to reach magnitude +8 (Andrianov et al. 1970). Previous meteor orbital surveys in the Southern hemisphere have been those at Adelaide, South Australia (Nilsson, 1964; Gartrell and Elford, 1975), reaching magnitudes +6 and +8 respectively. There is little known of the meteoric complex fainter than magnitude +8 in the Southern hemisphere.

## 3. THE CANTERBURY METHOD

The spaced-receiver technique employed to date suffers from the severe drawback that few meteors give measurable diffraction oscillations. This is especially important in that it is a biased selection effect, with certain velocities being partially excluded. The resultant orbital distribution of sporadic meteors would not, therefore, be a true measure of the interplanetary population.

In the Canterbury method three stations, each separated by about 3km, are again used. However, the two components of the velocity (North-South and East-West) are determined from the relative timings of meteor echoes at the three sites, rather than by the Fresnal oscillation method. Indeed, the oscillations are lost from the recorded echoes due to temporal averaging of the echoes, employed to reduce the effect of random cosmic noise.

The specular reflection causing a radar echo from the meteor trail (see e.g. McKinley, 1961) means that the time-lag between two stations is exactly half of the meteor travel time for that direction and separation. Typical time-lags would be of the order of 0.05s; since the radar operates at a pulse repetition frequency of 450 Hz, this corresponds to about 20 pulses. By using digital cross-correlation analysis, relative delays precise to a quarter of a pulse period are possible, and the velocity can be found in the vast majority of cases to better than 5%. The radiant coordinates are limited by the antenna beam width and elevation data (as discussed below) to an accuracy of about $\pm 2^{\circ}$.

The velocity components in two orthogonal directions are now known. To determine the complete trajectory, the specular reflection constraint is again applied. The phase coherent radar transmitter operates at 26.36 MHz, delivering 25 kW peak pulse power. The antenna gains are high: about 26 dB for the transmitter and 18.6 dB for the receiver, compared to an isotropic radiator. These correspond to linear antenna dimensions of about 300 metres. The beam widths are narrow in azimuth (±1°.6 for the transmitter, ±2°.4 for the receiver arrays, centered on due South) but fairly wide in elevation (or zenith) angle (elevation maximum at 30°±15°). The relative beam widths in azimuth for the transmitter and receiver mean that secondary lobes are suppressed.

The echo plane (in which the meteor trail must form if it is to give an echo) is hence constrained in azimuth but not in elevation; by measuring the elevation with a phase pair of antennas (separation 4.75 wavelengths) the meteor velocity and trajectory are found. Any possible ambiguity in the elevation angle due to the multiple lobes of the phase pair is removed by inspection of the echo decay time which depends upon the ambient diffusion coefficient and hence the height of the meteor above sea-level. The antenna pattern of the transmitter should result in very few meteors being detected outside of the main phase-pair lobe centered at 30° elevation.

### 3.1 Synchronous data handling

Data is transmitted back from the two remote receiver sites via frequency-modulated HF links to the main site, where the transmitter and phase pair antennas are located. Daisy chains of microprocessors then synchronously analyse the digital data from five separate channels: three amplitudes (the two remote sites and one of the two phase antennas) and two trigonometric functions (the sine and cosine of the phase pair). The firing of the transmitter is also administered by the main microprocessor control system so that the range, in 5 kilometre bins, is known from the echo timing.

Separate microprocessor algorithms suppress impulses due to extraneous sources, smooth the signal in each range bin from sweep to sweep, average adjacent range bins for additional noise damping, and then discriminate meteor echoes from the background noise. Recognition of an echo in any one of the three amplitude channels results in the data from all five channels being stored on magnetic tape. Since meteors occur about once every five seconds at peak influx, and their duration is up to 0.5s for the purposes of this experiment, the tape is storing data for about 10% of the time. At 450 p.r.f., and with 5 kilometre range bins going out to 333 km, the processing rate is 30 kHz.

The digital tapes are removed for later analysis on a main-frame computer although real-time analysis is technologically feasible: it is hoped to implement such a system in the future.

### 3.2 Data analysis

The meteoric velocity and trajectory differ from the original heliocentric values due to: (i) Deceleration in the atmosphere; (ii) Acceleration by the Earth's gravitational field; (iii) The rotation of the Earth; (iv) The Earth's orbital motion.

In this experiment no direct measurement of atmospheric deceleration is made, unlike the Harvard survey (Verniani,1973). A uniform correction of about 2% is made to the measured velocities, based upon previous data for the deceleration, the ablation coefficient, and meteoritic densities. This gives the pre-atmospheric geocentric velocity which is then corrected for the other effects (Earth attraction, rotation, motion) so that the meteoroid's heliocentric velocity and true radiant are determined. From these the orbital elements can be found, given the time of observation.

Particularly important in finding the distribution of the interplanetary dust are the semi-major axis, eccentricity and inclination. Although individual meteor orbits are not of high precision, the large number of meteors measured during a limited observation period (say, 24 hours per month) permit measurements of the gross orbital parameters, and how these vary with the size of the meteoroid.

It is well known that meteor radars are selective in certain respects. Firstly the 'echo-ceiling' operative at short radio wavelengths limits the probability of detection for meteors ablating at higher altitudes, these being fast meteors (McKinley, 1961). The amount of ionization produced is also a strong function of the meteor velocity, so that the probability of actually detecting a meteor depends upon a number of factors, including the antenna patterns at the ablation height of each meteor.

Secondly, the effective collector area, taking into account gravitational focussing, will also involve the antenna patterns. In general the meteor's velocity is not perpendicular to the collector area so that the radiant is required to implement this calculation.

Thirdly, the probability of a particular meteoroid colliding with the Earth depends upon its orbital parameters, with low inclination orbits being favoured.

These three factors together lead to a 'cosmic weighting' for each detected meteor, and thus an estimate of the number of Earth-crossing meteoroids in particular types of orbits.

## 4. RESEARCH PROGRAMME

The programme of observations is directed towards four major topics: the orbital characteristics of sporadic meteors and how these vary with mass, so that the processes affecting the evolution of cometary debris may be more completely understood; the identification of the many Southern Hemisphere showers indicated by the high fluxes in January and February, and also in June and July; the relationship between orbit type and ablation characteristics (Baggaley, 1981); and a survey over the rest of this decade of the Eta Aquarid shower to see how it changes as the parent comet, Halley, passes perihelion. This shower (May 4-6) has already been used in preliminary checks of the system and sensitivity calibrations. The full orbital programme is expected to begin in late 1984.

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