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A SOUTHERN HEMISPHERE RADAR METEOR ORBIT SURVEY

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Abstract: A meteor radar system has been operated on a routine basis near Christchurch, New Zealand, to determine the orbits of Earth-impacting interplanetary dust and meteoroids. The system sensitivity is +13 visual magnitude, corresponding to ~100 μm sized meteoroids. With an orbital precision of 2° in angular elements and 10% in orbital energy (1/a), the operation yields an average of 1500 orbits daily with a total to date in excess of 10⁵.

The use of pc's and automated data reduction permit the large orbital data sets we collect to be routinely reduced. Some illustrative examples are presented of the signal formats/processing and the results of data reduction, giving the individual orbital elements and hence the overall distributions. Current studies include the distribution of dust in the inner solar system; the influx of meteoroids associated with near-Earth asteroids; and the orbital structure existing in comet-produced streams.

THE RADAR SYSTEM AND DATA COLLECTION

After some years of construction a meteor orbit radar (AMOR) was commissioned for routine determination of the heliocentric orbits of Earth-impacting dust in 1990 February (Steel and Baggaley, 1985; Taylor, 1991). The facility (acronym AMOR being one type of near-Earth asteroid of interest in dust studies) is situated at geographic coordinates 172°41' East, 43°49' South near Christchurch, New Zealand. The transmitter provides 20 kW peak pulse power at 26.2 MHz, with a pulse interval of 2.64 ms (giving a sampling frequency of 379 s⁻¹), fed into a horizontal stack of eight rhombic antennas providing a south-directed beam about 30° above the horizon: this means that most detected meteors have radiants close to and south of the equator. Meteor echoes are received by an array of three antennas with spacing N-S and E-W of ~8 km, each antenna being a collinear array of length 12λ. FM radio links transmit signals from each outstation to the central site. Echo elevation is measured using a radio interferometer consisting of two antennas having a ground separation of 5λ providing signals in phase quadrature. Echo timing between the three antenna arrays provides N-S and E-W meteoroid velocity components which together with the echo elevation located within the narrow (~2° azimuth) transmitter beam permits each meteor radiant point and its velocity to be determined; for more details of this and previous radar meteor orbit determination techniques see Steel and Baggaley (1985) and references therein. This technique has an advantage over previous orbit radars using Fresnel diffraction patterns to determine velocities in that the resulting number of successful orbit determinations is about an order of magnitude greater (because of the paucity of recorded diffraction patterns). The system limiting sensitivity corresponds to radio meteor magnitudes of about +13 [approximately 100 μm-sized dust particles; this is similar to the limiting magnitude of the Harvard Radar Meteor Project (Cook *et al.*, 1972), although most meteors detected therein were rather brighter (larger meteoroids)].

To facilitate interfacing to a portable pc the facility uses a five channel meteor logger, consisting of timing control, signal duplexing using transfer via direct memory access to the computer, and linear 8-bit conversion to digitize the incoming analogue radar signals. The interface to the pc permits the logging of three amplitude channels (from the spaced antenna locations named Home, Nutt and Spit) and two phase channels (triangular sine and cosine: Tin and Tos), all with 40μs

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sampling, which renders 66 range bins each of width 6 km in every radar sweep. The echo recognition program records a half-second of data straddling each meteor, identifies enduring echoes, and discriminates against interfering signals.

Raw echo data from the 30 Mbyte pc disk are transferred to the institution's VAX mainframe where programs operate on the data using various digital signal processing routines in order to reject echoes affected by ionospheric scatter and broadcast interference and those yielding ambiguous parameters; suppression of random transient signals *etc.* is also carried out. Time intervals

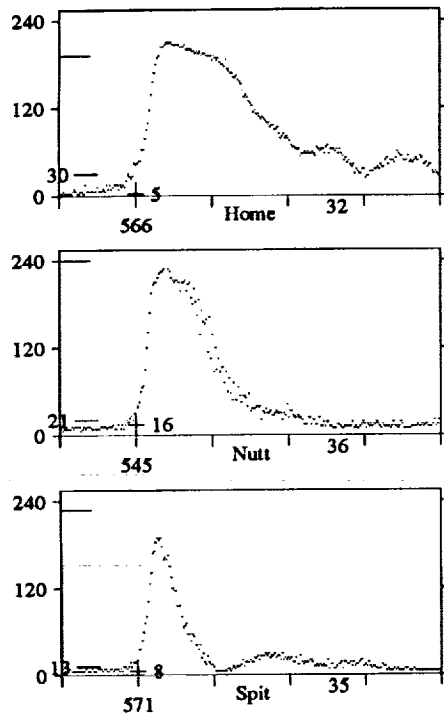


Figure 1: An example of a raw meteor observation record where no Fresnel oscillations are detected, as is most often the case.

Ordinate: Radar pulse number (spacing 2.64 ms).
Abscissa: Relative amplitudes (8-bit digital).

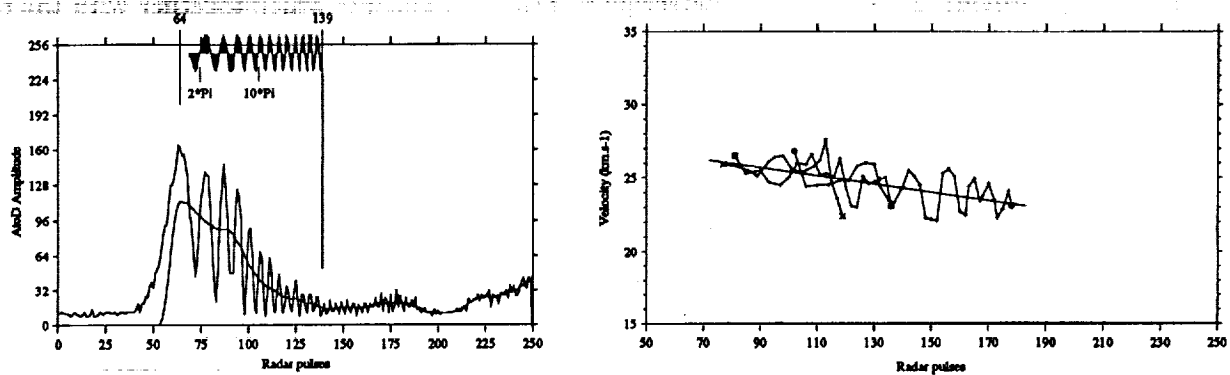


Figure 2: An example of a meteor echo showing a Fresnel pattern and the deduced deceleration. Left: Diagnostic output from routines establishing the relative phase of pulse amplitudes: the deceleration can thus be determined from this record only, in principal.

Right: Velocity data from simultaneous Fresnel patterns at the three receiving sites allow a cross-check; in addition the deceleration may vary at different points in the meteoroid trajectory (different altitudes). The measured atmospheric deceleration was 10.6 km sec^{-2} .

between echoes are defined by the instant of the maximum gradient in the rising edge of the signal (corresponding to the specular reflection condition in the leading edge of the Fresnel diffraction pattern of the echo). Those echoes with well-defined diffraction patterns in at least one channel, about 10% of the total, provide an independent velocity calibration: algorithms to extract the sinusoidal component and hence derive a velocity are applied, whilst the analysis of subsections of either one oscillating profile or overlapping subsections from multiple stations yield meteoroid decelerations. Such information permits accurate estimates of pre-atmospheric velocities for these dust particles. Example of meteor echo records are shown in Figures 1 and 2.

Reduction programs calculate the heliocentric orbital elements after standard corrections for diurnal aberration, zenith attraction and the Earth's orbital motion with several coordinate transformations. The overall system resolution is about 2° in angular elements (due mainly to the antenna beam widths) and 10% in $1/a$ (due mainly to the echo timing uncertainties).

METEOR ORBIT SURVEY DATA

There are two unique features of the AMOR facility. One is the rapid reduction of on-site radar signal recordings to provide orbital element data sets amounting to approximately 1500 meteor orbits daily: this allows in principle an almost continuous survey, the limitation being the stamina of the staff. Secondly, the data processing software and graphics permit the comprehensive display of all desired orbital information. The provision of such facilities allows the full exploitation of the incoming data in near-real time, whereas the volume of data tended to strangle the surveys carried out in the 1960's. For example, the equipment of the Harvard Radar Meteor Project (Cook *et al.*, 1972) was run generally for only the first five minutes in each hour; the available technology has advanced sufficiently to allow powerful radars such as AMOR to now provide in a manageable form very extensive data sets pertaining to the distribution of meteoroids and dust in the inner solar system, and thus the origin (NEA's? SP Comets? LP Comets?) and evolution of these particles to be better understood (*cf.* Baggaley and Taylor, these proceedings).

The computer software and hardware mentioned above allow the efficient presentation of many characteristics of the data; for example radiant plots (RA *vs.* Dec), orbital element distributions, ecliptic velocity projections (yielding direction of arrival in geocentric or heliocentric frames), or two-dimensional plots (*e.g.* semi-major axis *vs.* eccentricity). Examples are presented in Figure 3 for the whole data set collected between 1990 April and 1991 June; these are unweighted data, with no allowance having been made for the meteoroid collision probability with the Earth, detection probability in the atmosphere, and other selection effects which distort the detected distributions from the true distributions in space.

To the time of writing 132,996 individual meteor orbits have been determined with AMOR, compared to the total of about 68,000 determined by radar, photographic and TV techniques from the U.S.A., the U.S.S.R., Somalia, Australia and Canada and stored at the IAU Meteor Data Center in Lund, Sweden. Thus not only have we almost doubled mankind's inventory of meteor orbits with AMOR, but we have also increased the number of southern hemisphere meteor orbits by an even larger factor. The only previous radar orbit set-up south of the equator was operated from Adelaide, South Australia, in the 1960's, and produced less than 4,000 orbits to sizes of ~ 1 mm (see Olsson-Steel, 1988, and original references therein); the Soviets built a radar near Mogadisho in Somalia in the 1960's giving orbits for southern radiants but these are of dubious quality. As this program enters the detailed analysis stage, with much stream-searching and so on to be carried out amongst the currently-available data set, we plan to continue operations so as to increase the available archive of meteor orbits from the southern hemisphere further still, with particular emphasis upon deep southern radiants.

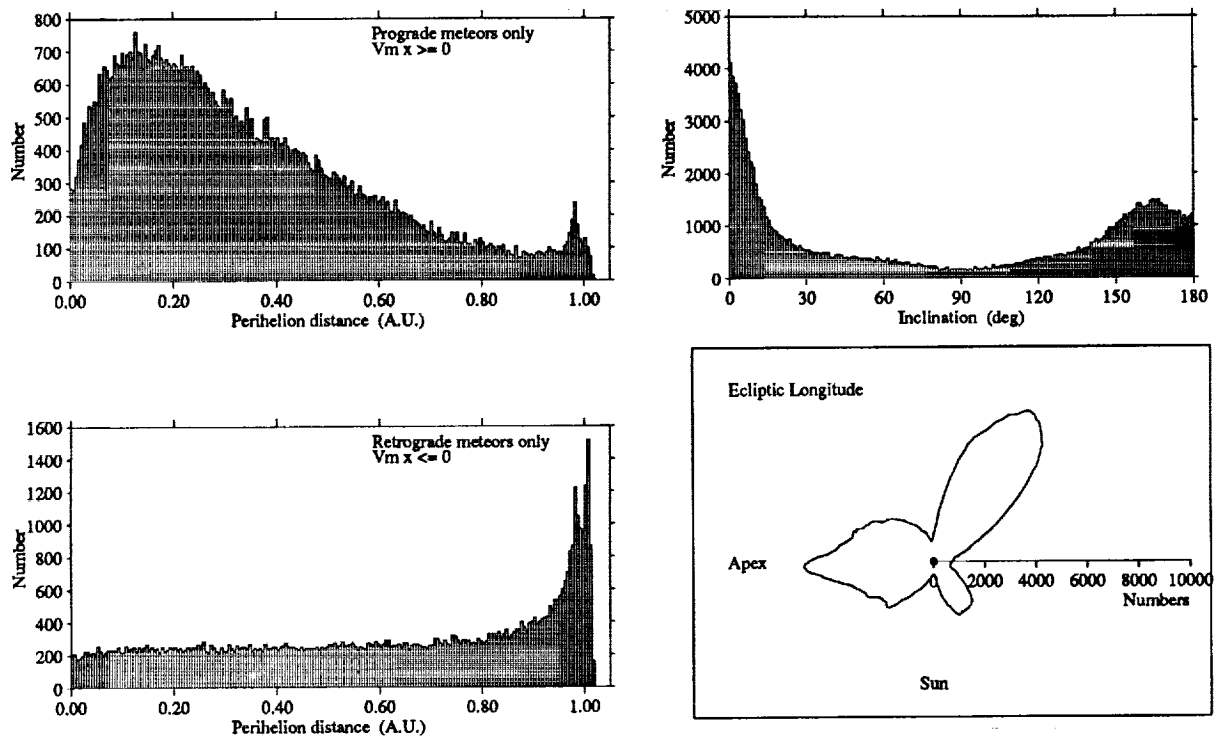


Figure 3: Examples of orbital element distributions for 132,996 meteors detected between 1990 March and 1991 June. At top right the inclination distribution indicates that there are many meteoroids of low inclination and an increase in the number at $i > 120^\circ$, although this is mainly due to the higher collision probabilities (low and high i) and higher incoming velocities (high i) of such orbits. At left are shown the distributions of perihelion distances separately for the prograde and retrograde meteoroids, showing that most prograde meteoroids are detected well-away from perihelion, most retrograde meteoroids close to perihelion; again impact probability considerations mean that these should not be viewed as being true distributions in space. (Note that the twin peaks near $q = 1$ AU in the plots allow an independent assessment of the eccentricity of the Earth's orbit to be made!). The polar plot of the corrected (Earth's motion removed) ecliptic radiants shows the three-lobed shape characteristic of the same distributions from other surveys. For comparative plots see, for example, Olsson-Steel (1988).

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