MONITORING THE NEAR-SPACE METEOROID POPULATION USING THE AMOR RADAR FACILITY

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ABSTRACT

The heliocentric orbital distribution of Earth-impacting meteoroids is provided via routine surveillance using the radar monitoring system Advanced Meteor Orbit Radar (AMOR). This orbital description of the Solar System dust population provides the speed and directional characteristics of the influx of this external dust into the Earth's environment. Details of this high-speed background dust component are important inputs for assessing the multiple contributions to the space debris population.

Key words: Meteors; Meteoroids; Radar Meteors.

1. INTRODUCTION

In order to determine the background to the artificial Earth-orbiting debris population, it is important to measure the geophysical parameters of observation and the heliocentric orbits of meteoroids originating from cometary and asteroidal sources as they appear close to the Earth.

Several techniques are used to probe the interplanetary meteoroid. In-situ dust detection has been performed by interplanetary probes such as Ulysses and Galileo [6; 7]. Meteoroids measured by this method are $\lesssim 1\ \mu$m in size. Non-gravitational forces are important in this regime with solar radiation and electrostatic effects being the most important. Experiments involving the counting and characterization of surfaces exposed to the interplanetary dust cloud [10] also may be used to give coarse orbital distributions. Lunar crater frequency and size distributions may also be used for these experiments [9]. Study of the zodiacal light intensity [11] provides estimates of spatial density of dust.

Observation of meteoric dust ablation in the atmosphere provides a particularly valuable study technique. Optical methods (TV intensifier, super-schmidt, and small-camera) yield very accurate orbits for observed meteors. Radar methods, while less accurate for individual orbits, are able to sample dust throughout the day and night continuously during the year with several orders of magnitude increase in the data rate compared with that obtained optically easily possible. Radar, as with other methods, has inherent biases—however by correcting for these known effects one may obtain high resolution and statistically accurate orbital distributions.

2. THE AMOR FACILITY

The AMOR facility (geographical coordinates $172^\circ 39'$ E, $43^\circ 34'$ S) is the only radar system routinely cataloging the orbits of meteoroids [1; 2; 3]. The system has been in operation since 1990 in an increasingly time-continuous mode: currently $\sim 9 \times 10^5$ high quality meteoroid orbits with a limiting size of 40 μm (mass $\sim 3 \times 10^{-10}$ kg) have been secured.

AMOR uses azimuthally narrow antenna beams to locate the meteor ionization train implicitly—such a narrow beam has the added advantage of permitting an increase in radar gain allowing the detection of very small particles. In order to obtain the pre-impact heliocentric orbit of the particle its observed directional velocity must first be measured. This is accomplished by the comparison of returned echo profiles from the central site and from two remote sites located ~ 8 km west and north of that (see figure 1). The signals from the remote sites are relayed by UHF telemetry. Analysis of the Fresnel diffraction pattern observed on $\sim 30\%$ of meteor profiles allows an independent measure of the in-atmosphere speed for validation purposes. A dual-spacing interferometer is formed from three receiving antennas at the central site providing unambiguous elevation angle measurements. An azimuthal interferometer is unnecessary due to the narrow (1.6° full width half power) azimuthal extent of the transmitted beam. The meteoroid orbital uncertainties arising from the slight ambiguity in the position of the meteor within the beam are of a similar size to the $\sim 0.5^\circ$ uncertainty inherent in the elevation measurement. Uncertainties in the velocity components are typically $\sim 3\%$.

A recent addition to the system has been a set of East-West orientated antennas. As shown in figure 1 these antennas have look directions perpendicular to the original North-South antennas and supplement the sky coverage available. The system automatically switches between the two array directions every 10 minutes in order to sample both directions. GPS synchronization is used to ensure that all components are switched simultaneously.

The process of data reduction is completely computerized with automated algorithms providing objective quality control, and reduced orbits and topocentric parameters, for each meteor detection. The radar facility has $\sim 95\%$ operational time with continual surveillance by modem communication enabling prompt action to avert technical

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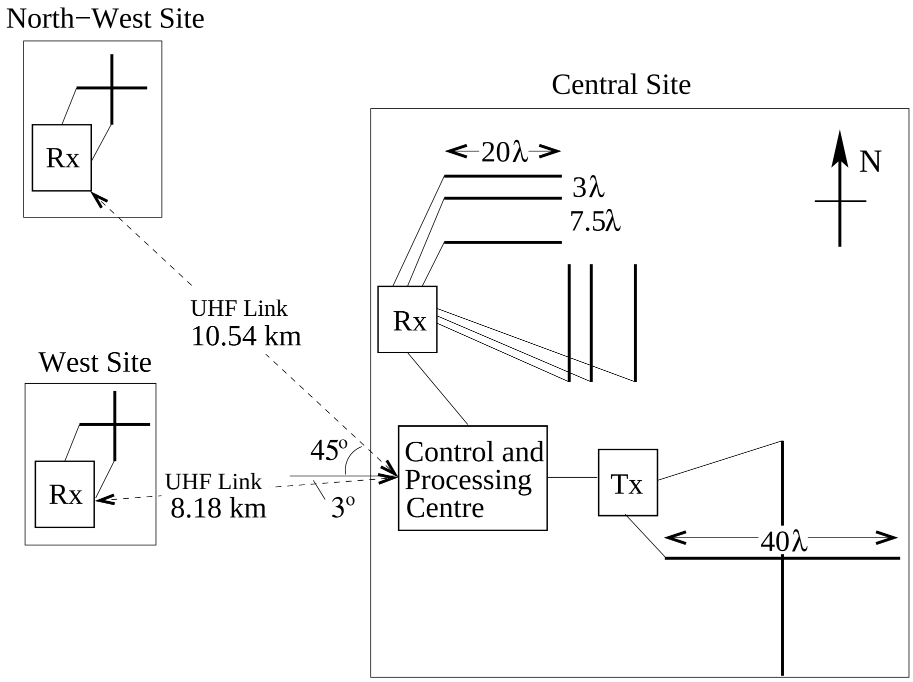


Figure 1. Schematic of the AMOR facility. The central site comprises the transmitters; orthogonal transmitting arrays; elevation finding dual-spacing interferometer receiving antennas for each direction and operations control.

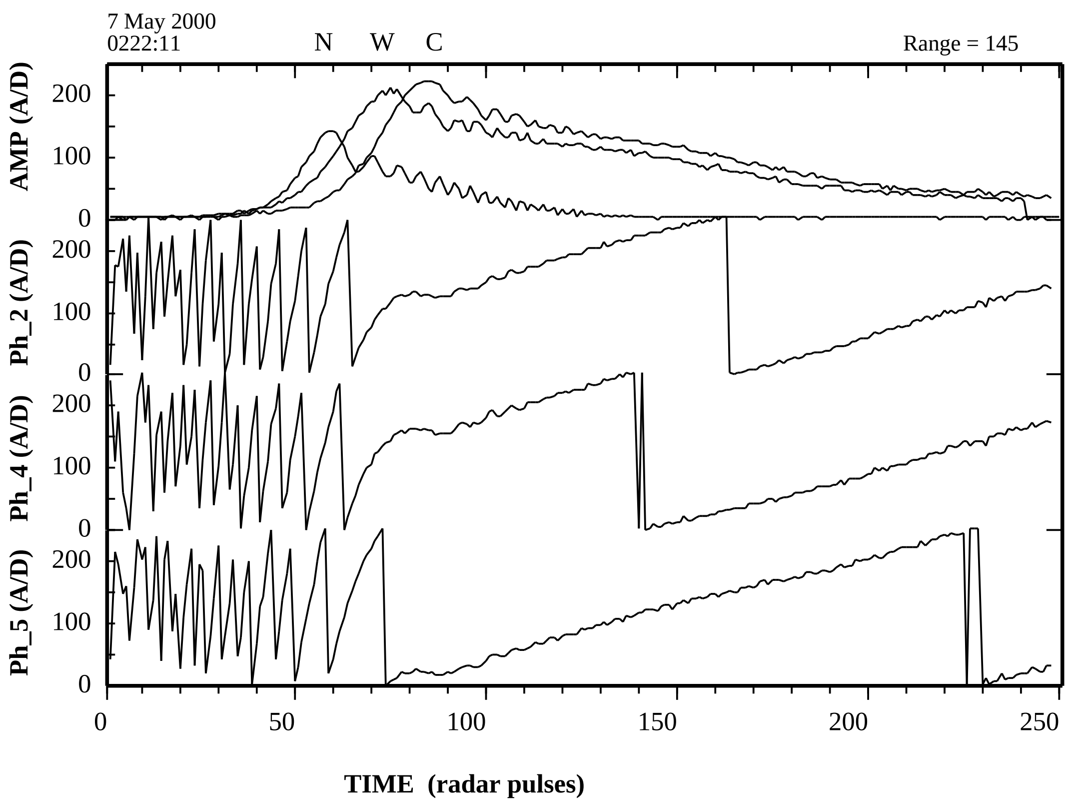


Figure 2. A typical AMOR *observation. The upper 3 traces correspond to received echo amplitude from the North (N), West (W), and Central (C), receiver sites. The 3 lower traces are the three independent phases measured by the interferometer. All of the signals shown are digitized with values ranging from 0–255 which corresponds to a* $0 - 2\pi$ *range for phase.*

problems. Data is also transferred from the field station by modem link daily for prompt reduction and storage.

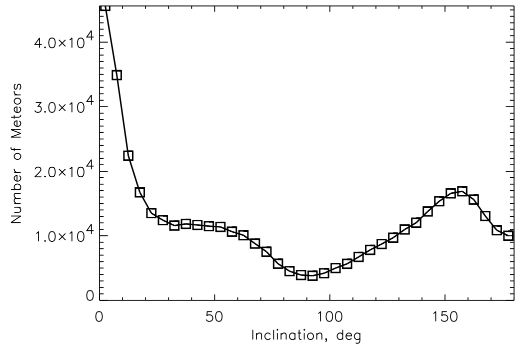
Figure 2 shows a typical echo with Fresnel oscillations clearly visible on the received echo amplitudes and a clear time-lag in arrival of the signals at the different sites allowing accurate velocity measurement. The (wrapped) phase signals used to determine elevation are also shown. Scalar speed is available from the early phase record of each interferometer channel and elevation is determined from interferometer phase differences.

2.1. Calibration of AMOR

It is essential to establish the correct calibration of AMOR for the reduction of heliocentric meteoroid orbits. The speed is calibrated by comparison of the signal time-delay derived speeds against that obtained from Fresnel patterns. The antenna beam pattern is established by equipment calibration as are the various time-lags which occur in the hardware. The directional behaviour of the system is further calibrated by astronomical means. Several known showers (η Aquarids, Sth. δ Aquarids, α Scorpiids, and χ Scorpiids) were used to provide this calibration [1; 2]. These showers have well established orbital parameters provided by other observational methods, e.g. photographic surveys. Uncertainties in the AMOR orbital elements are $\sim 2^\circ$ in angular parameters and $\sim 5\%$ in size parameters [1].

3. SURVEY OF THE EARTH-IMPACTING METEOROID POPULATION

AMOR is the most sensitive orbit determining radar yet build. It has also accumulated an order of magnitude more meteor orbits than had all of the previous surveys [2]. Galligan [5] has shown that the AMOR data set contains very few discernible streams (arising because of the smaller mass distribution index for cometary released grains): it is dominated by the non-stream background. This characteristic when coupled with its near-continuous operation makes it ideal for probing the large-scale structure of the near-Earth dust background. Measurement of the dust flux background is necessary in order to determine the contribution to the total flux measured from particles in Earth orbit. Most of the meteoroids measured by AMOR are on non-Earth orbits. However a small component of the AMOR archives derives from debris orbiting the Earth which in-fall at $\sim 7\ \mathrm{km\,s^{-1}}$. The probability of detecting particles impacting with slow geocentric speeds is lower than that of those at higher speeds due to the dependence of ionization efficiency on the meteoroid's speed [4; 8] hence low speed impacting debris will be underestimated by AMOR.



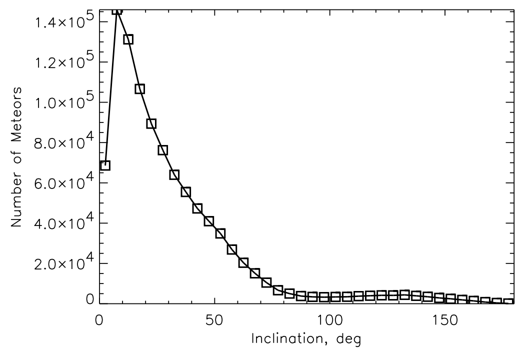


Figure 3. The inclination distribution as observed directly (above) and after correction for the strongest detection bias effects (below).

3.1. Orbital Distributions

An ongoing aspect of work on the AMOR data set is the correction of various bias effect inherent in radar detected data sets. Primarily these corrections relate to the response function of the radar to meteors appearing from particular directions, the ionization efficiency of the meteor, and the probability of collision of a meteor on a given orbit with the Earth. Corrected distributions of selected orbital parameters are shown here to illustrate the level to which the directly observed distributions are biased. The data used for these graphs consists of 5×10^5 meteors detected between 1995 and 1999 by AMOR from which the showers identified in Galligan [5] have been removed. The work on these distributions is in progress and therefore they may change as the result of further bias correction applications.

Figure 3 shows the directly observed and corrected distributions of inclination (note that the corrected distribution shows a relative, not an absolute meteor count, in each histogram bin. The corrected histograms in each case in this paper have been arbitrarily scaled to contain a total of 10^6 meteors). The retrograde meteoroid population ($i > 90^\circ$) is seen to be severely curtailed. This is due to the higher geocentric speeds of meteoroids on such orbits which are over-emphasized due to their high ionization efficiencies. The correction in fact produces a curve ex-

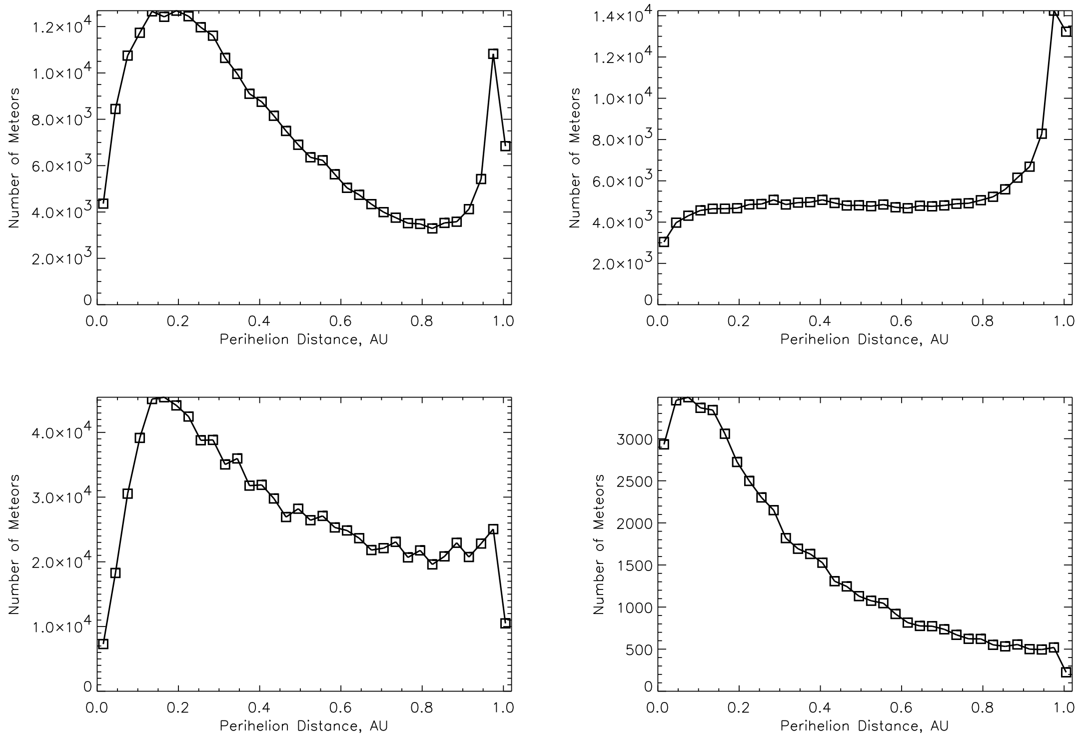


Figure 4. The perihelion distance distribution as observed directly (top) and after correction for the strongest detection bias effects (below). The data set is partitioned into prograde orbits (left) and retrograde (right).

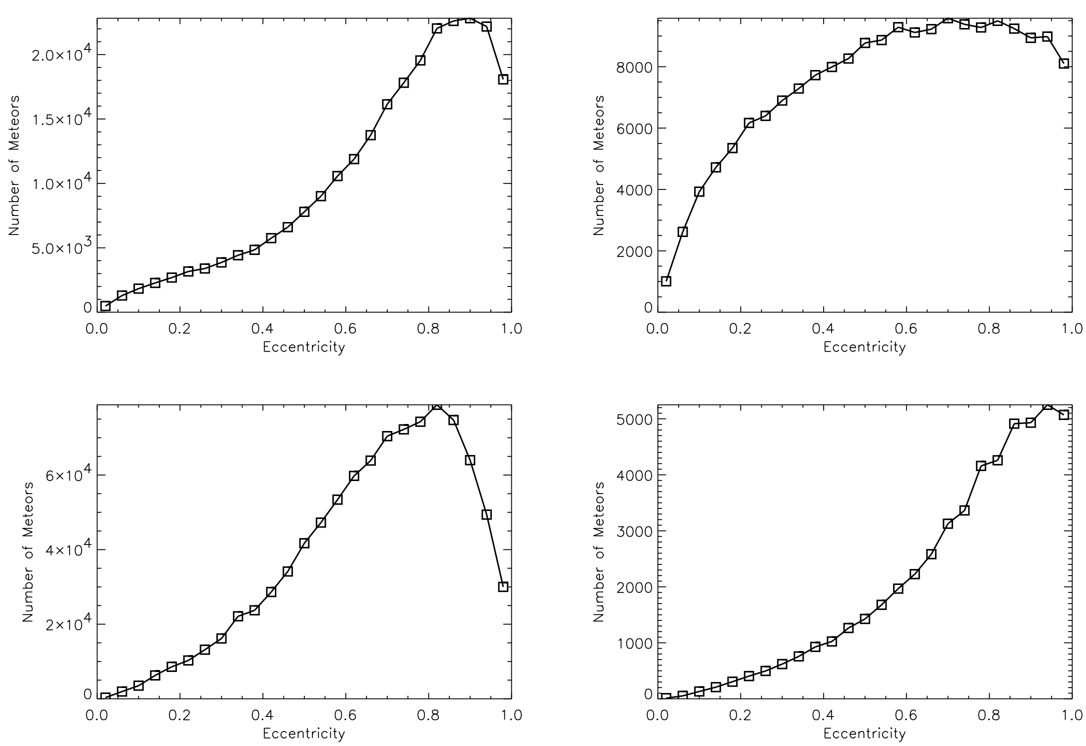


Figure 5. The eccentricity distribution as observed directly (top) and after correction for the strongest detection bias effects (below). The data set is partitioned into prograde orbits (left) and retrograde (right).

ponentially decaying from $\sim 7^\circ$ towards 90°. An interesting feature is the removal of the observed population of near-ecliptic meteors which had previously been the most dominant. The correction for the collision probability with the Earth removes the significance of this population due to the high probability of detection of particles having orbits lying on the ecliptic ($P \sim (\sin i)^{-1}$).

The observed perihelion distance (q) and eccentricity (e) distributions are shown in figures 4 and 5. It is interesting to study the difference between an essentially completely bias driven distribution (retrograde meteors) and one which contains some underlying structure (prograde meteors). Therefore the data set has been partitioned according to orbital direction in these figures.

Direct observation of the q-distribution reveals a strong peak at $q \simeq 1$ AU for both prograde and retrograde meteors. This stems from the increased probability of collision of orbiting dust at the exact orbital radius of the Earth—meteoroids on steeply inclined orbits are likely to achieve perihelion at their orbital nodes as their inclination will increase the distance to the Sun markedly as they proceed from this point; the radial speed component at Earth intersection is also nil if perihelion or aphelion are achieved at that time hence the probability of detection is also increased. The corrected distributions for both partitions therefore remove these peaks on collisional probability grounds. A decline in meteor numbers in both the original and corrected distributions corresponds to that expected due to a predominantly cometary origin of meteoroids—the closer a comet is to the Sun the more dust is released. In further corroboration of this linkage the peaks at relatively eccentric orbits is also similar to that expected from cometary progenitors.

Figure 5 shows the observed and corrected distributions of eccentricity with partitions again according to prograde or retrograde direction. The near-circular retrograde orbits are removed according to the collision probability correction—the more elliptic the orbit the less likely we are to detect it. Near parabolic orbits in a prograde sense are removed due to their high orbital speed at detection which is corrected by the ionization efficiency factor. A corrected distribution remains where most orbits have $e \in [0.5, 0.95]$. It should be noted that both the corrected and original distributions appear to show a sudden truncation of the distribution at the parabolic limit. The majority of hyperbolic orbits appear with eccentricities close to 1 and in many cases these orbits are truly elliptic but have been measured as hyperbolics purely due to measurement uncertainty.

These orbital corrections illustrate the strength of the underlying bias conditions in a radar data set which must be understood and removed. The detected flux is also biased by effects including those due to the diffusion characteristics of the plasma in the atmosphere, the effect of the meteoric plasma column radius on the radar scattering cross-section, and daytime radio interference. Ongoing work involves accounting for such biases and determining the flux of interplanetary dust at distances between 0.98 and 1.02 AU from the Sun.

ACKNOWLEDGMENTS

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