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The Meteoroid Orbit Facility AMOR: Recent Developments

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Abstract. Some 3×10^5 radar meteoroid orbits have been secured to date by the AMOR project since its inception in 1990. For many types of study it is important to realize a high angular resolution; for example to probe more incisively meteoroid stream orbital structure in order better to determine the rôle of the various processes controlling stream dynamics. The orbital precision of AMOR has been enhanced by developing a new dual spacing interferometer using single channel phase detection. In addition, a Doppler-sensing facility has been incorporated to record simultaneously data concerning middle atmospheric dynamics allowing better interpretation of the individual echo signals.

1. Introduction

The Advanced Meteor Orbit Radar (AMOR) facility has been in operation since February 1990 recording the atmospheric trajectories, pre-atmospheric velocities and hence heliocentric orbits of meteoroids down to a limiting diameter of $\sim 100\mu$m. The 26.3 MHz radar system (Baggaley *et al.* 1994) employs three sites, spaced 8 km apart, each of which employs antennas having narrow azimuthal fan-shaped radiation patterns. The patterns have azimuthal responses restricted (within $\sim 1^\circ.5$) of directions (north and south) in the local meridian and yet broad in elevation.

The meteor echo orthogonality condition permits the delineation of both the meteor trajectory and the radiant in the topocentric sphere from the echo elevation and range. Time differences between echoes registered at the three sites provide orthogonal velocity components. In addition a small proportion of echoes yielding high-grade signal/noise ratio exhibit Fresnel diffraction oscillatory behaviour from which independent atmospheric speeds are available. A proportion of those meteors provide sufficient record at the three sites to yield deceleration measurements and hence pre-atmospheric speed. With the necessary corrections for the Earth's gravity, zenith attraction, diurnal aberration and the Earth's orbital motion, together with appropriate coordinate transformations, the heliocentric orbital elements are deduced. The raw multiple echo signal data archived prior to 1995 were secured employing a single elevation-finding interferometer. This paper reports the enhanced operation achieved by including a second interferometer installed to improve the precision of elevation and hence echo height measurements, which are unambiguous from 70 to 120 km.

2. The dual interferometer

Each of the facility's five receiving antennas and the central site transmitting antenna consists of a collinear dipole array having a radiation pattern directed in the prime meridian. The azimuthal patterns are manicured by providing gabled feeding to produce side-lobe reduction. Three receiving antennas are situated at three 8 km spaced sites with two additional arrays at the central site to form dual spacing interferometers. Spacings of 3.0 λ and 11.5 λ were chosen to provide high precision unambiguous echo elevations over the range of angles $0 - 180°$. The antenna arrays are matched to coaxial cables of equal electrical length which are housed in underground sealed ducting to feed separate receivers (Fig. 1). Using conventional HF phase detectors it is necessary to record both the in-phase and quadrature-phase signals. To utilize storage channels better we have developed as an alternative a uni-channel phase detector. Intermediate frequency signals pass to the two phase detectors which use phase-locked loops to provide square waves corresponding to the signals at the 1.6 MHz IF. A logic sequence phase comparator produces an output which is monotonic over a 4π range so that there is no unstable phase region and consequential uncertainty. Two analogue output signals correspond to the IF phase differences between signals Phase1-Phase4 and Phase1-Phase5.

Calibration of the phase detectors was carried out by employing calibrated cables of known phase delay in conjunction with a signal generator feeding a matching network with buffered outputs and also by using a common antenna with the matching network. The phase analogue signals are digitized and multiplexed with the multi-site (not shown) meteor echo amplitude profiles, date etc. Data are placed directly into the RAM of a dedicated computer by DMA and all operations are controlled by high level language programs.

3. Doppler information

The interpretation of meteor echo characteristics can be complicated by atmospheric dynamical effects - the mean, zonal and meridional solar driven wind components and turbulence produced by gravity wave action. Uniform winds produce echo range shifts while vertical shears in the horizontal winds can produce height changes during the echo.

Signals from antenna 1 (extracted from the IF of the receiver) are processed by two phase detectors using a free running local oscillator as reference. Output signals corresponding both to the transmitter ground pulse and the returned echo are measured and stored in a second computer. This data set is Fourier analyzed giving apparent frequencies of both transmitter and echo, the difference between which corresponds to the Doppler shift of the trail echo. The in-phase and quadrature data are treated separately and results are accepted only if they are consistent.

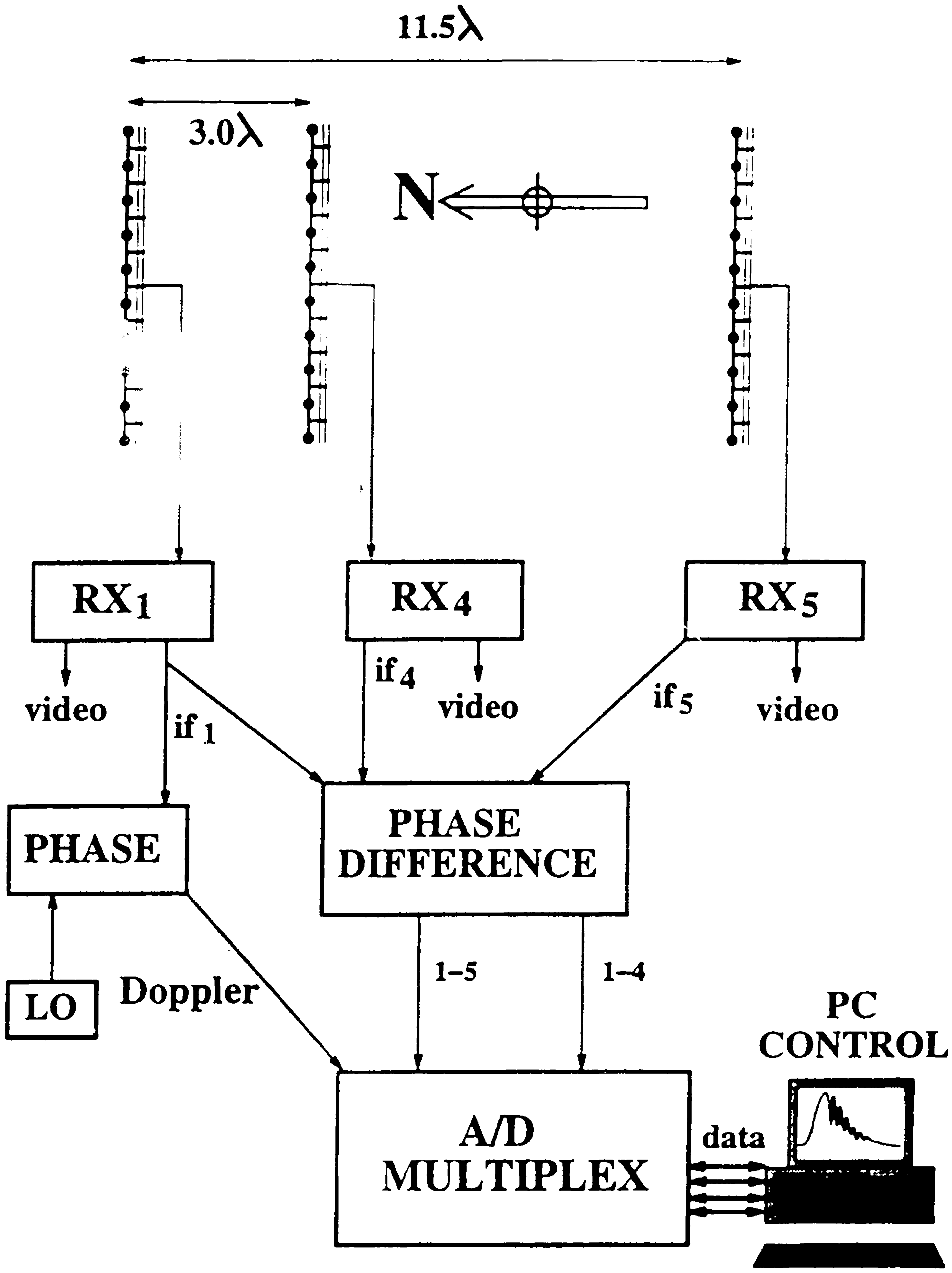

Figure 1. The dual interferometer, receiver and Doppler arrangement

4. Performance

A minority of echoes exhibit clear diffraction patterns and processing of the echo profiles in terms of Fresnel function fitting yields an independent measure of atmospheric speed. Use of the reduction method proposed by Pecina (1996) may prove to be useful for high speeds.

Echoes originating at a given elevation yield two phase difference values; Phase14 and Phase15. The antenna ground factor together with the directional properties of meteor trajectories, echo range factor restrict the echo elevations to about 12° – 60° and 120° – 168°. Figure 2 shows the relation between these two phase differences for all orbits secured on May 4, 1995: the cluster of echoes with elevation $\sim 41°$ is due to the η Aquarid stream. The important feature is the small scatter exhibited by the multiple phase branches consistent with the known phase measurement uncertainties ($< 10°$).

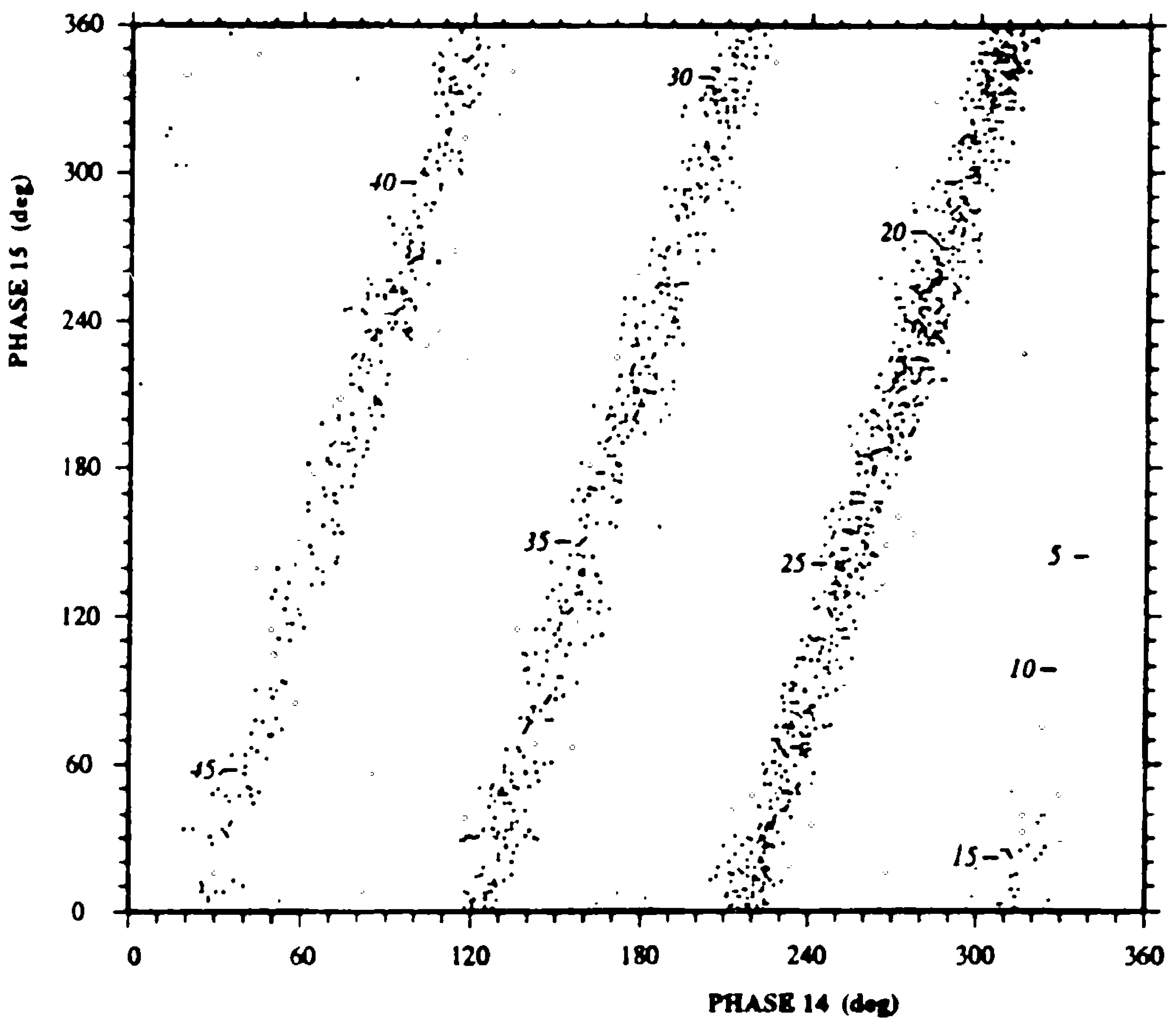

Figure 2. Dual interferometer phase plot for individual echoes for one day (May 4, 1995) with elevations labelled at 5° intervals

Figure 3 for the same data displays the difference between elevations measured using each interferometer pair and the mean elevation. The spread increases with decreasing elevation and is consistent with the expected behaviour in which the difference in cosines of elevation is invariant. Using the echo amplitude distribution in adjacent range bins enables a range uncertainty of ~ 1 km to be realized. The uncertainty in Elev15 is $\sim 0°.3$ at about 30°. Notice that this corresponds to a length along the trajectory of close to 1 km which is very similar to the length of the principal Fresnel Zone at distance R, $(R\lambda/2)^{1/2}$: this represents therefore a limit to the angular accuracy achievable with a radar system.

5. Geocentric radiants

The enhanced capability has been in place since April 1995. As an illustration of the power of the system, the daily progression in the geocentric radiants of streams resulting from the Earth's orbital motion is presented here. In selecting meteors from the archived orbit set as being members of particular streams, the non-dimensional weighted orbital discriminant (D') of Drummond (1981) was employed. Using the data set a serial search was performed using the orbital elements, a, e, i and ω (with Ω free because of the Earth's motion) resulting in a set of orbits each of which was closer than D' = 0.04 to all others in the set. Figure 4 shows with superimposed ecliptic, the geocentric radiants (epoch 2000.0) for data over solar longitudes 35° to 55°, (April 26 to May 16, 334 members) for the η Aquarids. The eastwards daily radiant progression over the 21 days is a clear feature of the meteor radiants and Figure 5 shows the mean daily radiant for changing day-of-the-year. Similar behaviour occurs for other southern hemisphere, May-June streams - the α Scorpiids and the χ Scorpiids.

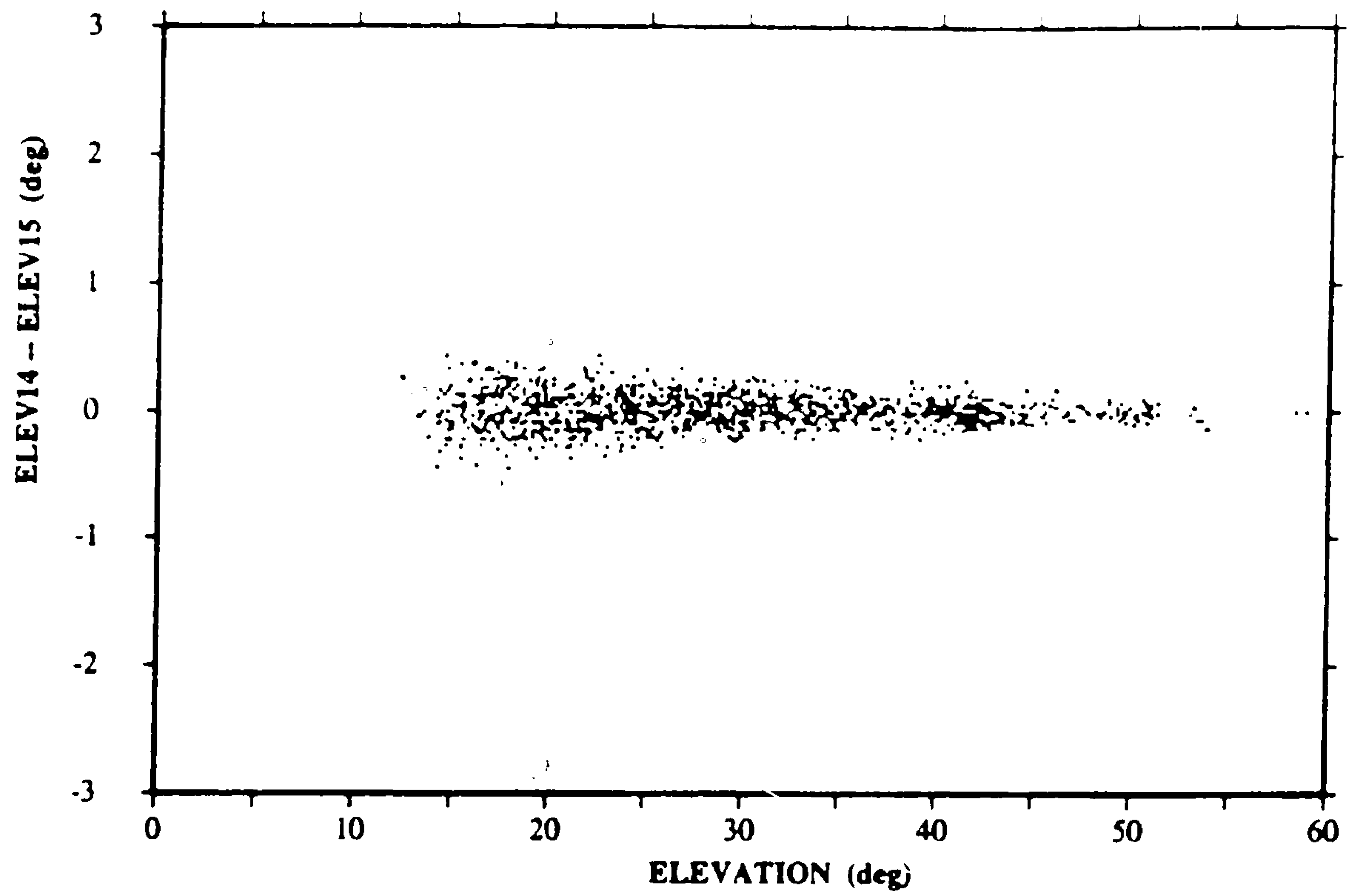

Figure 3. The difference in elevations as measured by each interferometer. Note the η Aquarids at elevation ~ 41°

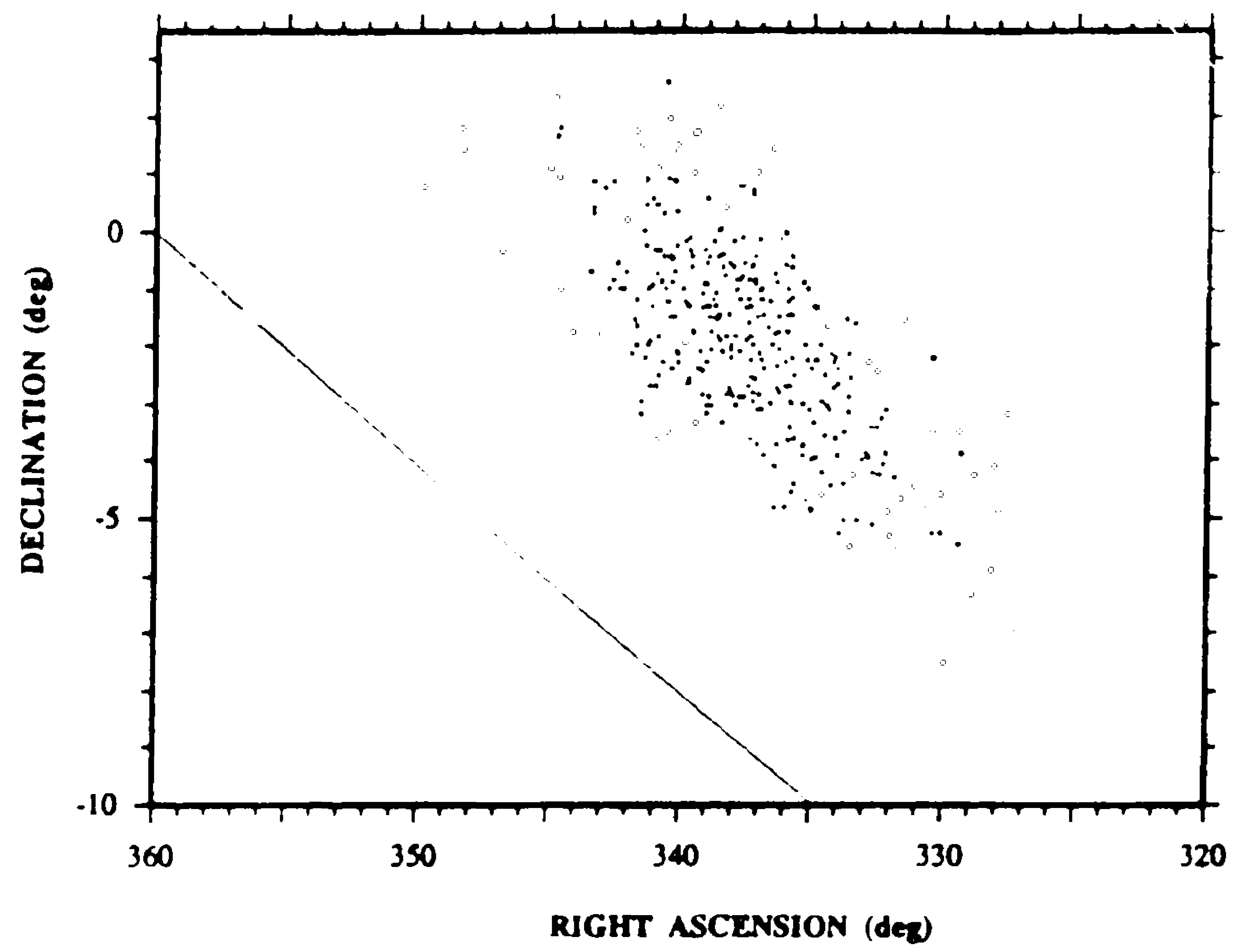

Figure 4. Geocentric radiants of η Aquarid stream members April 26 - May 16, 1995. Ecliptic superimposed.

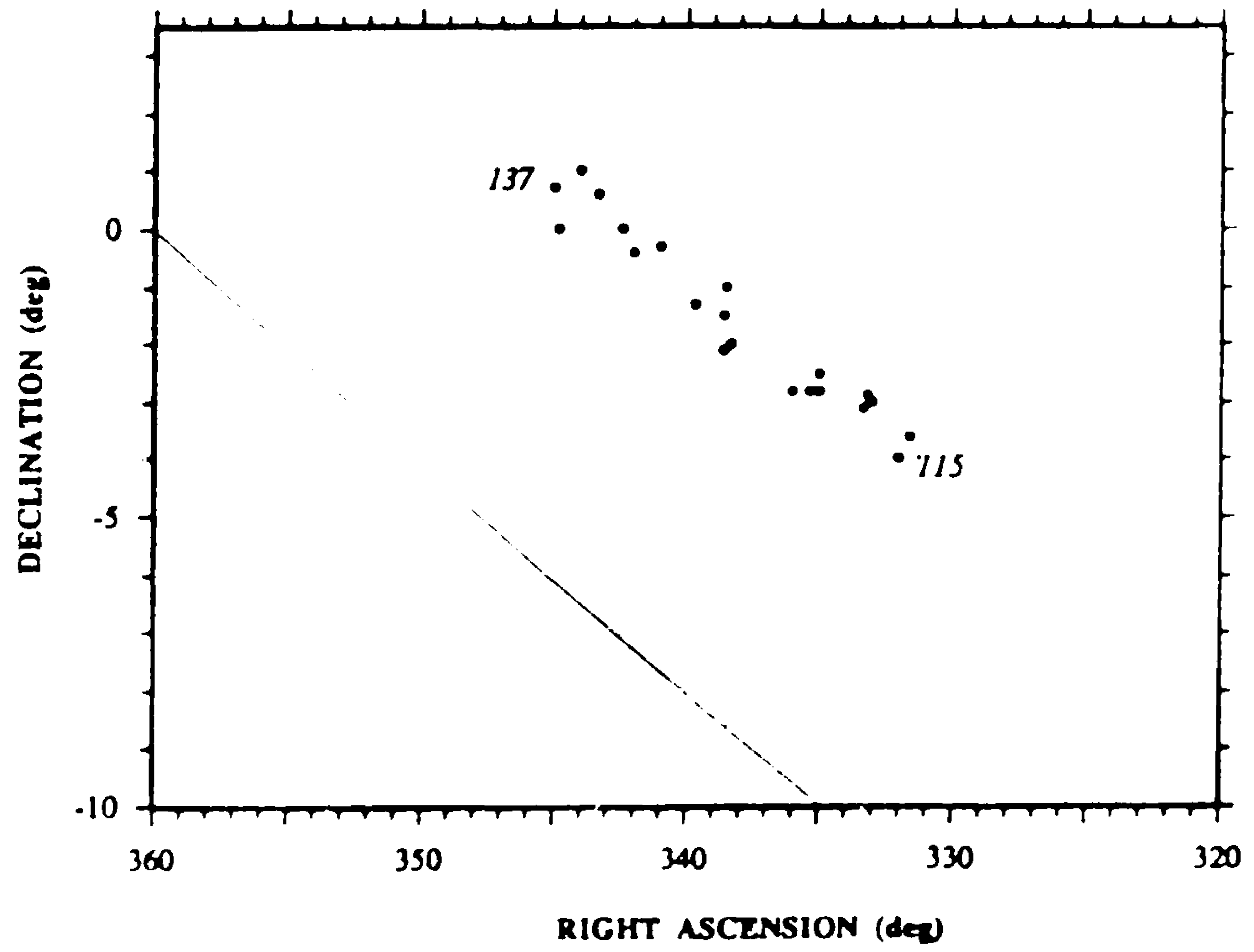

Figure 5. Mean daily (day of year) geocentric radiants of η Aquarids from Fig. 4.

6. The Programme

The AMOR operation as a radar probe of the meteoroid orbit complex has the advantages of sensitivity (particle masses $> 10^{-6}$ g), large acquisition rates ($\sim 10^3$ daily), essentially continuous operation with complete diurnal coverage and rapid processing of radar signal data and reduction to heliocentric orbits. In comparison photographic and image intensifier techniques have somewhat greater orbital precision but much lower data rates. The *in situ* impact detectors (*Galileo* and *Ulysses*), though providing direct measures of meteoroid fluxes and spatial densities for micron and sub-micron dust have very limited directional (and hence orbital) discrimination. Additionally the small area of the dust collection aperture (for example the Munich dust detector, Grün *et al.* 1993) results in probing only the very small sized material. In contrast AMOR utilizing the large collection area of the Earth's atmosphere, can provide statistically large data rates for a range of particle sizes. The precision elevation measurements achievable with the dual interferometer technique provide not only accurate meteor radiant coordinates but also small elevation changes occurring during an echo's lifetime. These changes arise from both the downward shift in the echo point (as the meteor train is created) and from the rotation of the train resulting from vertical shears in the neutral atmospheric wind field. Such a capability providing information on the turbulent nature of the atmosphere, is also valuable for a correct interpretation of the multi-site meteor echo characteristics.

One limitation especially applicable to radar determinations of meteoroid orbits is the uncertainty in atmospheric velocity caused by the multiple site echo timing accuracy. This uncertainty (a similar problem exists using photographic techniques) is carried through to the heliocentric speed determination and can appear as a substantial uncertainty in the orbital semimajor axis, a. In addition to the implementation of the dual interferometer and Doppler system, a new transmitter having double the sampling rate (to 800 Hz) and greater peak pulse power giving a sensitivity improvement equivalent to one stellar magnitude is scheduled to come into operation early 1996.

References

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