HARVARD COLLEGE OBSERVATORY

SMITHSONIAN ASTROPHYSICAL OBSERVATORY

Final Scientific Report

February 1, 1963 to December 31, 1965

RADIO METEOR PROJECT

APRIL 15, 1966

PREPARED UNDER NASA CONTRACT NASr—158

HARVARD COLLEGE OBSERVATORY
SMITHSONIAN ASTROPHYSICAL OBSERVATORY
RADIO METEOR PROJECT

Contract NASr-158

Director: Dr. Fred L. Whipple

Coordinator: Dr. Gerald S. Hawkins

Final Scientific Report
February 1, 1963-December 31, 1965

April 15, 1966

Cambridge, Massachusetts 02138

3-66-46

HARVARD COLLEGE OBSERVATORY

Harvard Radio Meteor Project
Contract NASr-158

FINAL SCIENTIFIC REPORT
February 1, 1963-December 31, 1965

In February 1958 the Harvard Radio Meteor Project embarked on a 3-year program, under Contract NASr-158, involving the improvement of the Havana, Illinois, radio meteor data-gathering and -reduction facilities, and scientific studies to analyze the data.

The improvements in the facilities included the installation of new receiving antennas to increase the system sensitivity to permit the observation of meteors to magnitude +12; the installation of phase-measuring equipment to produce a measure of meteor height; and the introduction of digital data-recording and -processing equipment to increase the data-handling capacity of the system.

The scientific findings, based on the analysis of data produced by the improved system, have been given in a series of Research Reports.

Research Report No. 1, June 1963, The Velocity of Faint Meteors by Gerald S. Hawkins, Bertil-Anders Lindblad, and Richard B. Southworth. This report describes preliminary measurements of meteor velocity to a limiting magnitude of +10 that have been obtained with a multistation radar system. The authors find systematic change in the average velocity of meteors that depends upon the magnitude and hence the size. Between magnitude +6 and +9 the velocity decreases

by 5 km sec^{-1}. Indications are that the effect becomes more marked for meteors fainter than +9. The authors attribute this effect to the difference in orbits within the various meteor populations.

Research Report No. 2, July 1963, The Physical Characteristics of Meteors by Gerald S. Hawkins and Richard B. Southworth. The authors find that the heights of meteors at magnitude +9 are significantly lower than the theoretical predictions. They interpret this difference in terms of different physical characteristics of these small objects. The faintest meteors show signs of total fragmentation; i.e., the radar echoes indicate a shower of independent particles for each meteoroid. The number of fragments observed is of the order of several thousand per meteoroid. The cluster of particles is contained in a fairly narrow cylinder around the original trajectory of the meteoroid.

Research Report No. 3, August 1963, The Meteor Population by Gerald S. Hawkins. This report discusses meteor flux to a limiting magnitude of +12, meteor sources, composition and physical characteristics, and the impact rates on a satellite in the environment of the earth.

Research Report No. 4, December 1963, Additional Data on the Velocity of Faint Meteors by Kenneth Baker. A study of meteor velocities (Hawkins, Lindblad, and Southworth, 1963), obtained from observations made by the Harvard Radio Meteor Project, indicated a systematic decrease of 5.3 km sec^{-1} in the average velocity for an increase in magnitude from +6 to +8.5. Report No. 4 presents additional data reduced more recently at magnitude +8.5 that give an average velocity 3.9 km sec^{-1} higher than that obtained previously. The difference is attributed to a seasonal selection effect caused by the position of the apex in the sector of the sky to which the antenna is sensitive and to a

systematic variation in the semimajor axes of the orbits of meteors encountered by the earth during a year. The data still indicate a decrease in average meteor velocity with increasing magnitude.

Research Report No. 5, February 1964, On the Ionizing Efficiency of Meteors by Franco Verniani and Gerald S. Hawkins. This report is an analysis of the available data concerning the probability of ionization of meteors as determined by radar and visual observations. The authors find that the probability of ionization varies as v^4, and by comparison with the optical efficiency it is possible to estimate an absolute value for the ionizing efficiency. This work is of critical importance in establishing a preliminary mass scale for the radio meteors. Preliminary estimates show that the masses are an order of magnitude smaller than those given in Research Report No. 2. Final determination of the ionizing efficiency will, of course, await a successful experiment at Wallops Island.

Research Report No. 6, June 1964, The Influx of Geminid Meteors Relative to the Sporadic Background at Magnitudes +4 and +8 by Kenneth Baker. In this report, the ratio of the influx rates of Geminid to sporadic meteors has been determined by radio observations made at two different magnitudes. After approximate corrections for selection effects, the author estimates that between magnitudes +4.2 and +8.7 the influx of Geminid meteors relative to the sporadic background decreases with increasing magnitude and that the peak activity occurs slightly earlier.

Research Report No. 7, August 1964, Preliminary Analysis of Meteor Radiants and Orbits by Gerald S. Hawkins, Richard B. Southworth, and Shoshana K. Rosenthal. This report is an analysis of meteor orbits given for the period January through August 1962 from radar measurements obtained at Havana, Illinois. Corrections have been applied to make the radar observations compatible with photographic data, and a

comparison of the two sets of results has been made. Approximately 25 percent of the radar meteors were in the category of minor streams. The remainder of the meteors are discussed on a statistical basis. The distribution of meteor radiants seems to be fairly constant from month to month and is, therefore, a predictable quantity. The concentrations of radiants at the apex, and at the sun and antisun points are confirmed. In addition, a new concentration is found between the apex and the north ecliptic pole. The polar concentration is unique to the radar observations and corresponds to the toroidal group of meteors. The limiting mass of the survey was 10^{-5} g, and the limiting magnitude approximately +10 on the visual scale.

Research Report No. 8, October 1964, Calculation of the Response Function of the Harvard Radio Meteor Project Radar System by W. Graham Elford. In this report, the relationship between the flux of meteors incident on the earth and the observed rate of radio meteors is determined in terms of (1) the number distribution of meteors as a function of magnitude, (2) the density of meteor radiants over the celestial sphere, (3) the parameters of the radio equipment, and (4) a simple form for the ionized trail. The theory has been applied to the system at Havana, and an estimate made of the average flux over the earth of meteors of magnitude +12. A provisional value of 80 $km^{-2} hr^{-1}$ has been obtained. The relative density of radio meteor radiants over the celestial sphere has been determined for the 8 months January to August, 1962. The analysis is being extended to determine the spatial distribution of meteoric particles for these months.

Research Report No. 9, November 1964, Meteor Echo Rates and the Flux of Sporadic Meteors by W. Graham Elford and Gerald S. Hawkins. In this report theoretical diurnal variations in the meteor echo rate have been computed for the Harvard Radio Meteor Project radar system at Havana, Illinois. Meteor showers with radiant

declinations < +50° are detected for about 3 hours per day, while showers with radiant declinations > +70° are continuously detected. The dependence of total echo rate on declination has been established, showing that the maximum numbers of meteors are detected from radiants at declinations of +70° to +75°. The weighted distribution of observed meteors as a function of declination is symmetrical about zero declination.

The diurnal variation in the sporadic echo rate during March 1963 has been shown to be consistent with five concentrations of meteor radiants: one near the apex; two centers on the ecliptic and about 70° from the apex; and two centers, one about 60° north and the other about 60° south, of the apex. A comparison of the observed and theoretical rates for March indicates that the average flux over the earth of sporadic meteors that produce trails with zenith line densities in excess of 4.5×10^{10} electrons m^{-1} is 40 km^{-2} hr^{-1}.

Research Report No. 10, December 1964, On the Ablation Coefficient of Meteors by Gerald S. Hawkins, Richard B. Southworth, and Franco Verniani. The authors have found that the ablation coefficient of meteoroids depends on the velocity, brightness, and mass of the object, and is practically independent of the zenith angle.

Research Report No. 11, December 1964, The Distribution of Sporadic Meteor Radiants by W. Graham Elford, Gerald S. Hawkins, and Richard B. Southworth. In this report the distributions of the radiants of sporadic meteors observed during the period January through August 1962 have been corrected for various selection effects, and the results for each month are presented as contour diagrams of radiant density over the celestial sphere. For meteors detected above a certain limiting line density, concentrations of radiants occur near

the apex, at the sun and antisun positions, and at high latitudes between the apex and north ecliptic pole.

The average radiant distribution has also been corrected for velocity selection in order to find a preliminary version of the radiant distribution to a given limiting mass. The resultant distribution shows three concentrations of radiants, at the sun and antisun positions and at high latitudes north of the apex.

It is estimated that the average flux over the earth of sporadic meteors whose mass exceeds 1.3×10^{-6} g is $\simeq 40$ km^{-2} hr^{-1} or 10^{-8} m^{-2} sec^{-1}.

Research Report No. 12, March 1965, Masses, Magnitudes, and Densities of 320 Radio Meteors by Franco Verniani and Gerald S. Hawkins. This report, a continuation of the statistical analysis in Research Report No. 2, concerns the same observational material. A recent revision of the mass scale (Verniani and Hawkins, 1964) is taken into account, and the present values for masses and densities supersede the values quoted in Research Report No. 2.

In August 1965 the Smithsonian Astrophysical Observatory in cooperation with NASA Headquarters sponsored an International Symposium on "Meteor Orbits and Dust" at Cambridge, Mass. This was a significant conference and the details of the proceedings have been edited at the Smithsonian Astrophysical Observatory and will be published in the near future in the Smithsonian Contributions to Astrophysics.

Throughout the period of this contract scientists on the project have made themselves available for advice and consultation with scientists within NASA.

Simultaneous ground observations have been made with the radar equipment during periods of special interest for satellite observations.