

THE WORK AT THE MINOR PLANET CENTER

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The Minor Planet Center at the Cincinnati Observatory is engaged in three kinds of activities: (1) the publication and distribution of the Minor Planet Circulars (MPC's), (2) the collection and maintenance of a complete file of minor planet observations, and (3) the computation of orbital elements and ephemerides.

The MPC's are single, looseleaf sheets, printed on both sides, containing (1) all observations of minor planets as reported to us by the various observatories, (2) orbital elements and residuals of differential corrections, and (3) ephemerides of minor planets not included in the annual ephemeris volume published by the Institute of Theoretical Astronomy in Leningrad. The MPC's were started in 1947; their number reached 1000 by November 20, 1953; 2000 by May 9, 1960; and 3000 by October 1, 1969. The mailing distribution list contains about 125 foreign and 65 domestic addresses, mostly astronomical observatories and libraries. A small supply is preserved for future uses. At present the material is prepared on punched cards and proofread in advance. Multilith master sheets are then printed directly from a magnetic tape on the IBM 1401.

The minor planet observation file is now maintained on magnetic tape, and there is also a complete file of punched cards in storage. It is intended to be complete since 1939, and it also contains all previous observations that we have had occasion to keypunch and use, mostly in carrying out well-determined differential corrections over an arc of many years. Each observation contains the planet's number or provisional designation; the time of observation in U.T.; $\alpha(1950.0)$; $\delta(1950.0)$; a three-digit observatory code; and provision for magnitude, residuals, 10-day motion, and a reference. On the magnetic tape these data are sorted in order of planet number and date. The total now exceeds 130 000. We have standard programs that permit us to print and/or punch all the observations between any given pair of limits, to print and/or delete any specific observation, and to add new or corrected observations. Because the more than 12 000 observations of the *Palomar-Leiden Survey of Faint Minor Planets* (van Houten et al., 1970) consist mostly of faint objects that may never be observed again, they have not been included in this file unless they have been identified with some otherwise known object. We then

use the provisional designation, NNNN P-L, where NNNN is the four-digit number (greater than 2000) that has been assigned in the Palomar-Leiden survey. All the observations of the survey are in storage and available on punched cards.

Preliminary orbits of newly discovered objects, extending over a heliocentric arc of not more than 90° , are computed by the variation of geocentric distances (Herget, 1965). This method has the advantage of incorporating all the available observations simultaneously; and if there is a sufficient number of observations, it is not subject to any critical cases. In the event that the observations as given are dynamically inconsistent for any reason, the solution quickly iterates to zero.

The differential correction of an orbit based on observations extending over a long arc requires the computation of a trajectory that includes accurate perturbations by all the major planets. During the years 1955 to 1967 these computations were performed on the calculator at the Naval Ordnance Research Center, Dahlgren, Va., by the method of variation of arbitrary vectorial constants (Musen, 1954). The resulting orbit for each completed planet was then carried forward so as to produce on microfilm all the ephemerides until A.D. 2000. These ephemerides have an interval of 10 days; they include the heliocentric and geocentric distances and the phase angle; and they extend to 8 hr elongation on either side of the Sun. This work was completed for 465 minor planets, and we have approximately 12 000 future ephemerides on file. For a few years we also had the computations organized for the IBM 1410, using the method described in Herget (1962). This proved to be more effective, because the program had no singularity for very small eccentricities. At present we compute on the IBM 360 by means of Cowell's method, using J. Schubart's *N*-body program, and the latter has been augmented to include the integration of the variational equation for the six usual starting values and two optional variable planetary masses. The output of this program is coordinated directly with the differential correction program.

We continue to examine all observations for possible identifications, as witness Bardwell's recent success in identifying 155 Scylla. Currently we are engaged in providing various special ephemerides for the physical observation of selected minor planets and for using some minor planets in lieu of standard stars in stellar spectroscopic observations.

For the past 10 yr we have provided a plate reduction service for all who may wish to use it. We have 300 000 comparison stars on magnetic tape, taken from the Yale Zones, the AGK2, Cape Photographic Durchmusterung, etc., as provided in machine-readable form by the U.S. Naval Observatory. We have reduced hundreds of plates taken and measured at Indiana, Tokyo, and Nice, and lesser numbers at other observatories. This program includes various checks, it exhibits the root-mean-square error of the comparison stars and thereby affords an estimate of the accuracy of the position of the minor planet.

The orbits of nearly all of the ordinary, numbered minor planets are now of good quality. At the Cincinnati Observatory we have an operational capability to handle all the classical situations that might arise, and we propose to continue this posture in the future.

In the following appendix, the work at the Institute of Theoretical Astronomy at Leningrad and the cooperative program with the Cincinnati Observatory is described.

APPENDIX—THE WORK AT THE INSTITUTE OF THEORETICAL ASTRONOMY AT LENINGRAD

In the absence of Dr. Chebotarev who was unable to attend this meeting, I shall attempt to present a summary based upon our long and fruitful collaboration over the last quarter century, beginning with Professor Subbotin and continuing with N. S. Yakhontova, Dr. Makover, and now Dr. Chebotarev. Shortly after the end of World War II, the Institute of Theoretical Astronomy (ITA) undertook the publication of an annual ephemeris volume of all numbered minor planets to provide for the function formerly served by G. Stracke's (1942) *Kleine Planeten*. To avoid duplication of effort, Dr. Dirk Brouwer arranged an agreement in 1952 whereby ITA undertook to accept and incorporate all ephemerides transmitted by the Cincinnati Observatory and to provide for the computation of all the remaining ephemerides. In return, the Cincinnati Observatory receives 150 copies of the ephemeris volume annually. This has proved to be the beginning of an excellent cooperative program.

About 1961 Yakhontova provided a list arranged into four groups of all the numbered minor planets: (1) those for which ITA could provide reliable, accurate ephemerides; (2) those for which the ephemerides were based upon approximate perturbations by Jupiter only; (3) those for which the ephemerides were based only upon elliptic elements without perturbations; and (4) those for which no ephemerides were being computed. The computations that were undertaken at the Cincinnati Observatory were therefore selected from the last two groups. This division of labor has resulted in the computation of orbits and ephemerides for somewhat more than two-thirds of all the numbered minor planets being undertaken by the ITA.

As better electronic computing machines were developed over the last decade, more and more differential corrections were performed, first including only approximate perturbations by Jupiter, and more recently including accurate perturbations by all the major planets. These improved elements provide more reliable ephemeris predictions. Also, in recent years extended ephemerides have been published for a selected list of the brighter minor planets. Beginning last year, the interval covered by each regular ephemeris has been extended from 50 to 70 days in length.

In August 1970, ITA celebrated the dedication of its own BESM 4 electronic computer by being host to the IAU Colloquium on the Origin and Nature of Comets. More than 30 international guests were in attendance. In

recent years, ITA has directed a minor planet observing program on the 40 cm astrograph at the Crimean Astrophysical Observatory. All the computations of the plate reductions are performed at ITA. More than 1000 observations per year are provided by this program. The theoretical studies on general perturbation methods, improved orbit computing methods, investigations of cometary orbits, etc., are referenced in the triennial report of Commission 20 in the *Transactions of the IAU*.

REFERENCES

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Stracke, G. 1942, Über die geometrischen Grössen und die Masse der Kleinen Planeten. *Astron. Nachr.* 273, 24-28.

DISCUSSION

BANDERMANN: The observed magnitude of the asteroid at discovery may be different at a time of later search for that asteroid due to rotation, etc. Is that considered?

HERGET: The magnitude is used only as an approximate identification criterion.

DUBIN: How well do we know the asteroids for which there are orbital elements?

HERGET: Of those that are numbered, none of them are going to be lost any more; but there are some old numbered ones that cannot be recovered.