A BRIEF HISTORY OF THE MINOR PLANET CENTER

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I was deeply sorry when I knew Conrad's death on IAUC 9148. Also I felt that it was my proud that I was just living in the time of his activity together in Cambridge. *Syuichi Nakano*

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I. Two eras

Since the work done at the Minor Planet Center and at its predecessor, the Rechen-Institut at Berlin-Dahlem, has been involved almost exclusively with the solving of numerical problems, a history has to be divided into two eras. Before the invention of the electronic computer, all of the work done on minor-planet orbits was done by hand. Some astronomers such as Gustav Stracke computed with logarithms, and others such as Paul Herget used mechanical calculators. In either case the computation of orbits was very difficult, and only a few people in the world could do this work with the speed and accuracy required. After computers became available, the field was open to anyone who had access to a computer and to the necessary programs.

During the first era, the main problem in minor-planet astronomy was how to calculate orbits that would keep the planets from being lost. In the second era, this is no problem. The problem now is how to disseminate a very large amount of information quickly and efficiently to those who need it.

II. 19th Century Work

During the 19th century, some of the finest mathematicians in the world worked on the application of Newtonian mechanics to the problem of orbit determination. In 1801, C. F. Gauss was able to develop a method to determine the orbit of Ceres, the first minor planet to be discovered. This made it possible for astronomers to recover this minor planet after its conjunction with the sun. Others, such as P. A. Hansen and J. F. Encke, devised methods of computing the perturbing effects of the major planets upon the the minor-planet orbits. The emphasis was on finding methods which minimized the number of calculations while attaining the desired accuracy.

Even before the first photograph was taken of a minor planet, the computational problems presented serious difficulties. After 1891 — when Max Wolf made the first photographic discovery of a minor planet, (323) Brucia — the difficulties became much greater. The best that astronomers could hope to do was to keep minor planets that had been numbered from

being lost. Even this conservative goal could not always be met.

III. The Rechen-Institut

By 1910 minor-planet astronomy was organized in a more formal way at the Rechen-Institut in Berlin-Dahlem. At that time, F. Cohn announced that their aim was to provide minor-planet ephemerides accurate to 30′–60′. In 1917 the publication of ephemerides was separated from the Rechen-Institut's *Jahrbuch* and put into the publication *Kleine Planeten.* In 1926 the Rechen-Institut began the publication of the *RI Circulars*, which are the direct forerunner of the *Minor Planet Circulars.*

Although the Rechen-Institut was a very-well-run organization with an excellent staff, they had to deal with a group of photographic observers who were relentless in their efforts to discover more minor planets for numbering. This was particularly true of Wolf and Karl Reinmuth, who both observed at Heidelberg. As of Jan. 1, 1989 — more than 50 years since Wolf made his last observation and more than 30 years since Reinmuth made his — Reinmuth leads in the discovery of numbered minor planets with 355, and Wolf is second with 243.

After World War I, Germany was not a member of the International Astronomical Union. But even though Commission 20 of the IAU tried to encourage international cooperation in minor-planet astronomy, the Rechen-Institut under Stracke continued to be the center for the receiving and dispensing of information on minor planets.

In 1935 Stracke summarized the work done at the Rechen-Institut in the previous 25 years. There were then 1301 numbered minor planets. Of these, 83 had still (as far as was known) been observed at only one opposition. Approximate perturbations by Jupiter were calculated for most of the planets, but for others only empirical corrections to the mean motion or mean anomaly were applied.

Then came World War II, and work on minor planets was almost brought to a standstill. By the end of the war, activity at the Rechen-Institut had been completely disrupted. The majority of the staff had moved from Berlin to Heidelberg. After 1944 almost no ephemerides of numbered minor planets could be distributed to observers. By 1947, with so little observing having been done in the previous two years, more than 20 percent of the 1564 numbered minor planets were on the critical list — either because they had not been observed for ten years or because they had been observed at fewer than four oppositions.

IV. The Minor Planet Center's Beginnings

It was at this time that a new era in minor-planet astronomy had its beginning. It appeared in 1947 that the Rechen-Institut could no longer handle the responsibility of taking care of the minor-planet orbits. To fill the void, Dirk Brouwer, acting president of Commission 20 of the IAU, asked Herget to start the Minor Planet Center at the Observatory of the University of Cincinnati. Herget agreed to do this and, at the 1948 meeting of the IAU, the following announcement was made by IAU president H. Spencer Jones in his opening address:

"A center for information has been established at the University of Cincinnati under the direction of Prof. Paul Herget; the minor planet circulars from Cincinnati give announcement of new discoveries, positions of minor planets, computed orbits and other relevent information."

Herget was a natural choice for the job even though he came from an institution with no reputation in this branch of astronomy. He had attended the University of Cincinnati, majoring in mathematics. He went to work as an assistant at the Cincinnati Observatory, working on the reduction of meridian circle observations. While he worked at the observatory, he planned to do graduate work at the university (still majoring in mathematics). However, after a short while he began to read articles in research publications such as the *Astronomical Journal* and became interested in orbit theory. As a result he began to consider himself a student in astronomy rather than mathematics.

Since no one at the university specialized in the computation of orbits, Herget was largely self-taught in the field. Although he took courses in physics and mathematics at the university and was taught about observational methods at the observatory, he learned how to compute orbits on his own. He wrote his doctoral thesis on the computation of orbits, stressing the use of vectors and of computational schemes suited for mechanical calculators rather than logarithms.

Herget then received a fellowship and spent a post-doctoral year at the University of California. There he worked under A. O. Leuschner, who was head of the astronomy department and a noted expert on orbit computation. Herget did not agree with Leuschner on the best method of computing preliminary orbits, favoring the method developed by Gauss — while Leuschner had developed his own method based on work done by Laplace. Herget did get from Leuschner an interest in computing general perturbations for minor planets.

General perturbations involve the expression of the perturbing effects of the major planets as a function of time. These expressions are very complicated and usually contain lengthy trigonometric series. Special perturbations involve the numerical integration of the equations of motion. If you know the position and velocity of a minor planet at a time t_1 and you want to find the position at another time t_2, you must integrate over the entire interval between t_1 and t_2. Because numerical integrations are easily done on electronic computers, special perturbations are now used for most work on orbits of minor planets.

When Herget returned to Cincinnati after his year in California, he began to work on the general perturbations of several minor planets. Encouraged by Leuschner, he computed perturbations for (132) Aethra, one of the minor planets discovered by J. C. Watson. Watson had left money in his will to support work on the orbits of the minor planets which he had discovered. Because of its large eccentricity, the orbit of (132) Aethra was the most difficult of Watson's discoveries to calculate with general perturbations, but Herget was able to do it commendably.

During world War II, Herget had worked at the U. S. Naval Observatory with W. J. Eckert, one of the leading advocates of the use of automatic punched-card equipment in solving problems in navigation and astronomy. This experience made Herget realize that if the Minor Planet Center — with a very small staff — was going to do the work that had been done at the Rechen-Institut, automated punched-card methods would have to be used.

The first priority at the Minor Planet Center obviously was to begin to publish the *Minor Planet Circulars (MPCs)*. This was done in the fall of 1947. The first issue explained the purpose of the *Circulars* and offered free shipping by surface mail to all recognized institutions and observers.

Very soon after the Minor Planet Center was started, Herget added Eugene Rabe (of the Rechen-Institut) to his staff. Rabe played a very important role in the organizing and publishing of the MPCs. He had nearly full responsibility for them during the period from 1952 to 1959. He also did his own astronomical research working particularly with the theory of the Trojan orbits. In 1950, Peter Musen, who also had worked at the Rechen-Institut, joined the staff at Cincinnati. He developed a method of variation of vectorial elements which Herget programmed to calculate special perturbations by electronic computer.

V. The ITA

In the beginning a major concern of the Minor Planet Center was to find a way to

replace *Kleine Planeten*, the annual volume of ephemerides for numbered minor planets. In 1947 ephemerides had been computed by various groups throughout the world, but the distribution was disorganized. The Institute for Theoretical Astronomy (ITA) in Leningrad had published a complete volume of ephemerides in 1947, so it was decided by the IAU that this institute would be responsible for the 1948 volume.

However the 1948 volume was very slow to be distributed in the western countries. So from 1949 to 1952 the Minor Planet Center published a volume of ephemerides with the responsibility for their computation being parcelled out to cooperating institutions. In 1949 all of the ephemerides were computed at Heidelberg. At the same time, annual ephemeris volumes were still being published by the ITA in Leningrad. In 1952 it was decided to end this duplication of effort: responsibility for publishing the ephemerides was returned to the ITA. They, in turn, agreed to provide the Minor Planet Center with a number of copies to be distributed in the west.

For a few years the Minor Planet Center distributed corrections to some of the ephemerides, but — as the cooperation between the ITA and the Minor Planet Center improved — this was soon discontinued. The ITA agreed to use some ephemerides provided by other institutions and to print the names of the minor planets in Latin letters. Later they also began to print an English translation to the text at the beginning of the volume.

This cooperation has continued now for nearly 40 years and seems to improve with age. The Russian astronomers now provide elements with current epochs for all the numbered minor planets. This makes it possible for observers to calculate their own ephemerides, but ephemerides are also published. The Minor Planet Center is responsible for numbering minor planets and for publishing ephemerides of these new planets and also unnumbered minor planets.

VI. Perturbations computed by machine

From a long-term standpoint, the greatest problem facing the new Minor Planet Center in 1947 was how to calculate perturbations for the orbits of the 1500+ numbered minor planets. Following Eckert's leadership, Herget developed his own method of doing numerical integrations with punched-card machines that were usually used for business purposes such as accounting. These machines performed only one operation at a time as cards were fed through, and the problem was to arrange the operations in a sequence in such a way that complicated tasks could be performed. In 1947 Herget started to calculate first-order Jupiter

perturbations, at first using an IBM 601 Calculating Punch at the observatory.

His idea at first was to calculate Jupiter perturbations for numbered minor planets in need of orbit corrections. He then planned to furnish these perturbations to collaborators who would be responsible for doing the differential corrections of the orbits. A critical list of minor planets compiled by Herget and Brouwer was published on *MPC* 191. On this list were a number of planets for which it was indicated that perturbations would be computed.

This collaboration seems to have worked fairly well. Orbits were corrected by astronomers from a number of countries, including Japan. On *MPC* 1423-31 a summary of the results up to that time is given. It shows that first-order-Jupiter perturbations were computed for 323 numbered minor planets. From these, 97 orbit corrections were performed; twenty-four of these orbits were corrected by Japanese astronomers, most of them by H. Hirose and B. Takase. The main reason that more was not done with these perturbations is that better methods had been developed to do this work in the years between 1948 and 1956. During these years electronic computers became available which made calculating with punched-card machines obsolete.

By 1955 Herget had access to the NORC (Naval Ordinance Research Calculator), a large electronic computer. With this machine he could compute accurate special perturbations by all of the planets from Venus to Neptune. Using Musen's method, Herget wrote a program for the NORC that operated at a 20-day interval and would calculate perturbations at a rate of more than 500 minor-planet-years per hour of computer time.

Herget had a great affection for the NORC. At his suggestion, minor planet (1625) was named in honor of the computer. It was the most powerful computer of its time, and because of the influence of Eckert, it was also very easy to program and to use. Herget always wrote his computer programs in machine or assembly language. He had tried an early version of FORTRAN which was not very good, and he never had much faith in higher-level computer languages after that.

The NORC was Herget's favorite computer, but the IBM-650 also had a great influence on the way things developed at the Minor Planet Center. The IBM-650 was the first electronic computer to be produced in large quanities. It was a machine that utilized vacuum tubes and it had a memory of 2,000 words — which would be equivalent to a 20,000 byte memory today. The memory was contained on a rotating drum (40 words at each of 50 locations) so that a particular address could only be accessed one time on each rotation. By today's standards it was a very slow machine, but it was a tremendous improvement over calculating

with a mechanical desk calculator.

In 1956 Herget programmed the IBM-650 to compute perturbations by Earth, Saturn, and Jupiter using Musen's method. This program ran 50 times as slowly as the program on the NORC, but now it was possible for Herget to calculate perturbations without traveling to Dahlgren, Virginia, where the NORC was located. There was an IBM-650 at the Cincinnati Gas and Electric Company at that time, and the people there were happy to have Herget do astronomical calculations in exchange for helping them learn to use the machine. In June of 1958, the University of Cincinnati obtained an IBM-650 which Herget was able to use in an almost-unlimited way.

With the computer at the university, Herget was able to write programs to do many of the jobs that had formerly been done by his collaborators. He soon was automatically doing differential corrections using the method of Eckert and Brouwer. When I first came to the Minor Plant Center in January of 1958, residuals were still being computed by hand, as had been requested by Herget on *MPC* 1506. In fact, that was the first task to which I was assigned. By 1959 it became apparent that it would be much more efficient to do everything by machine. Finally on *MPC* 1830 Herget announced that all that was needed from collaborators were a list of observations and some initial elements. The differential correction would then be completely done on the IBM-650.

VII. Minor planet index

At the same time that the work was being done to improve the method of correcting orbits, another project was started which would eventually make it possible for collaborators again to do significant work on orbits and identifications of minor planets. For many years an index of references to minor planet observations was published by the Rechen-Institut in their *Astronomicher Jahresbericht.* This index was temporarily discontinued in the years 1939 to 1945, although the index for those years was published in a later publication.

Partly to replace this index, Herget decided to start a file of minor planet observations on punched cards. On *MPC* 191 it was announced that such an index would be started and maintained at the Minor Planet Center. It was hoped to have the index complete from the beginning of the year 1939 onwards. For each observation a card was punched with the time, right ascension, declination, equinox to which observation was referred, magnitude (if available), location of observer, and publication reference.

For many years this index was kept on punched cards and was only available to people

who were in Cincinnati. It was such a big job to sort and print this index that it was done only a few times in the years that it was kept on cards. Until December of 1960, the file cards for the index were punched after the *MPCs* were published. Each observation had to be typed in twice, once on a typewriter for the publication and a second time on punched cards for the index.

In December of 1960, Herget decided that instead of typing the *MPC* master sheets, they should be generated from punched cards. *MPC* 2034-2040 were the first to be printed using punched cards. For most of you who are familiar with modern desk-top publishing capabilities, these efforts must seem very crude. However it took all of Herget's considerable expertise at plug-board wiring to get the IBM-407 Tabulator to do as good a job of printing the *MPCs* as it did.

From that time forward, only one card was punched — to be used both for the publishing of *MPCs* and for the file. This led to change in the format of the observations. Only observations that referred to the equinox 1950.0 could be published. Actually, this led to the maintaining of two card files for a number of years. Finally, with the aid of H. J. Carr, Herget converted all of the observations in the old file to the equinox 1950.0, and the complete file was put on magnetic tape. One copy of the tape was sent to the Rechen-Institut and another to the Institute for Theoretical Astonomy in Leningrad, but the tape was not made generally available. From his work on improving orbits, Herget knew that there were many errors on the tape. They were caused mostly by mistakes made by observers; but also to a lesser extent, mistakes had been made in putting the data on the tape. He had hoped to be able to correct most of these mistakes before making a general distribution of the tape, but it was not possible to do that before the Minor Planet Center was moved away from Cincinnati.

VIII. The move to Cambridge.

The Minor Planet Center remained at the Cincinnati Observatory for more than thirty years, which I will discuss in more detail later, but in 1978 Herget retired. His presence at Cincinnati had been the reason for the Minor Planet Center being there. Unfortunately upon his retirement, there was no one at the University to take his place and it became apparent that the Minor Planet Center would have to be moved.

After some inquiries by the IAU Executive Committee, it was agreed that a logical successor to Herget would be Brian Marsden. It was also agreed that the Minor Planet Center would be moved to the Smithsonian Astrophysical Observatory (SAO) in Cambridge,

Masachusetts. As the only staff member working in Cincinnati at that time, I was invited to go along.

Marsden had come to the SAO in 1965, just in time to work on the orbit of the newly-discovered sun-gazing comet, Ikeya-Seki. He has had very little time to relax since then. He started immediately to assist Owen Gingerich in editing the *IAU Circulars* that were issued by the Central Bureau for Astronomical Telegrams. The Bureau had been moved to the SAO at the beginning of that same year. Marsden, who had just finished his doctoral studies at Yale University, was even then one of the world's leading authorities on comet orbits. His interest began when he was still in secondary school, as he worked with other amateur astronomers in his native England doing computations for the BAA.

He succeeded Gingerich as director of the Bureau for Astronomical Telegrams at the beginning of 1968. At about the same time he began to collaborate with the Minor Planet Center. Working with computer software that he and Kaare Aksnes had developed primarily for comet research, Marsden began to investigate orbits of unusual minor planets — epecially those considered to be lost. After a visit to Cincinnati in 1973, Marsden began a closer collaboration. He became interested in separating the hopelessly-lost numbered minor planets from those that could benefit from an orbit correction.

As director of the Central Bureau for Astronomical Telegrams, he worked closely with observers. He especially encouraged the observers such as Elizabeth Roemer, who would make follow-up observations of new, interesting objects.

The move to Cambridge was official on April 1, 1978. It was announced that all observations made after that date should be sent to the new location. Herget continued to issue *MPCs* at Cincinnati until June 30. *MPC* 4391, the first one issued from Cambridge, is dated 1978 August 1. Dan Green joined the staff as a summer intern in June of 1978 and became a full-time staff member two years later. Green is primarily interested in comets, but as the years have gone by, he has become much more involved with the work on minor planets. Syuichi Nakano came to visit the Minor Planet Center in 1986 and has been here since then. He is a great help, especially in coordinating the work done by the Japanese amatuer astronomers.

By the time the Minor Planet Center came to Cambridge, there were nearly 180,000 observations in the archive of minor planet observations. One of the highest priorities of the new director was to make this archive generally available. There was some delay in converting the tape to a new more user-friendly format, and things were complicated further because

of a change in computers at the Smithsonian Astrophysical Observatory while the job was being done. Finally, on *MPC* 5799 it was announced that the tape could be purchased from the Minor Planet Center. Four more editions of the tape have since been released. The last one, issued in June 1986, contained 376,815 observations of minor planets — and, in addition, 25,533 comet observations.

IX. Identifications

In the time before computers, finding identifications was a difficult, very time-consuming task. Finding that observations made in widely-separated years belong to the same minor planet involves a great deal of trial and error. Each trial can involve a substantial number of calculations. It then is not surprising that only a few people had much success when calculations had to be done by hand.

Two names that stand out in the pre-computer search for identifications are A. Patry and O. Kippes. Patry, who worked at the Nice Observatory, developed an ingenious method to compute circular orbits in an efficient way: He compiled a catalogue of these orbits and used them to find identifications. Patry not only found many identifications of unnumbered planets, but he also found two cases where the same minor planet had erroneously been assigned two different numbers. He found that the numbered minor planet (525) Adelaide was the same object as (1171) Rusthawelia, and that (864) Aase and (1078) Mentha were also identical. The numbers and names of (525) and (864) were later reassigned to other minor planets.

Kippes is a Catholic priest who has spent his spare time for many years searching for identifications. With his own very extensive file of observations and orbits, he has made his searches without the use of computing machines. Even in his older years, he has been able to compete with others who use the most modern equipment. As recently as 1980, he found identifications for the lost minor planet (1037) Davidweilla, which led to the recovery of that planet.

At the time I came to the Minor Planet Center in 1958, we were very dependent upon Patry, Kippes, and a few others to search for identifications. We would start with one of their identifications and try to fit the observations with a perturbed orbit. If this succeeded (as it usually did), the planet could very often be numbered — or at least an ephemeris could be computed which would make its recovery possible. Actually, at that time there were enough identifications being made to keep us busy.

After Patry's unexpected and premature death in 1960, the situation changed. L. Boyer at Nice organized and published the remaining circular orbits that Patry had computed, but decided not to continue his identification work. At the same time, the methods of calculating orbits at Cincinnati had become more efficient, so that identifications could be investigated more easily. The result was obviously that we were going to have to begin to search for our own identifications. Herget was not very enthusiatic about this at first, because he did not want the Minor Planet Center to become involved unless he was sure that it could do a good job.

It was really not until 1964 that serious searches for identifications began at Cincinnati. At about that time, Herget wrote a new computer program to calculate preliminary orbits. With this program we begin to make additions to the file of orbits that at been published in 1961 by the Minor Planet Center. Using these orbits, we were able to look for identifications based on similar orbits. We then wrote a program to compute ephemerides without perturbations. Using this program, we would look for favorable oppositions, and with that information we would look for possible identifications. Then again using the computer, we would try to fit our identification candidates by correcting the mean anomaly of the orbit.

After identifications had been made, we would calculate orbits from two oppositions — and then using the improved elements we would compute improved ephemerides. We then would again look through the observation file for additional identifications. These methods were much easier than the pre-computer searches, but we still were making the comparison of the ephemerides and the observation file with our eyes, rather than doing it with the computer.

E. Bowell at Flagstaff in 1977 took the next big step to further automate the search for identifications. He built up his own data base of elements of unnumbered minor planets. He then would test observations on two nights against the whole set of elements. He would get residuals on the first night and, if they were below a specified tolerance, he would apply a correction to the mean anomaly of the orbit to see if the observation was on the line of variation. If that test was passed, the second observation would be tested. If similar small residuals resulted on both nights, there was a good chance that an identification had been found.

The greatest break-through in the automation of identifications came soon after the observation tape was distributed in 1981. Simultaneously several programs were written to compare perturbed orbits with the complete file of observations. Herget, whose interest in

identifications actually increased after his retirement, wrote one of these program and was able to use it successfully before his death in August 1981. L. D. Schmadel wrote a similar program and used it to search for observations that were identical with numbered minor planets. He found nearly 1900 identifications involving the first 2300 numbered planets.

Similar programs have been written by a number of others and very few identifications are now missed, if the initial elements used are anywhere near the truth. At the Minor Planet Center, we often use a program written by Nakano. This program runs on a MicroVAX-II and will test observations of all of the unnumbered objects in our file against a particular set of orbital elements in a little over three minutes.

Another method has been developed for finding additional observations of a minor planet after a fairly good orbit has been obtained: Instead of testing a file of observations, this program tests a file of plate centers. This technique was recently used by both R. H. McNaught and R. M. West to find observations of the formerly-lost minor planet (724) Hapag. Using an improved orbit based on an identification by Nakano, observations at five more oppositions were found and measured on Schmidt plates taken at Palomar and Siding Spring. McNaught has used this method to search successfully for prediscovery positions of near-Earth minor planets. Recently he found positions of the Apollo object 1979 VA, which more than doubled the observed arc for this minor planet.

X. Numbering of minor planets

Before minor planet observations were made photographically, most minor planets were numbered very soon after they were discovered. These visual discoveries were usually fairly-well followed up. Only a few were lost for an extensive period of time, and with the recovery of (155) Scylla in 1970, all of the numbered minor planets discovered before 1891 had been accounted for.

After photographic observations began, it was a different story. In 1892 it was decided to assign provisional designations to new discoveries. Permanent numbers were then subsequently assigned to planets for which sufficient observations were available to satifactorily determine an orbit.

It was not until the Minor Planet Center started that the requirements for numbering were officially made more stringent. On *MPC* 837 it was announced that planets would be numbered only after they had been observed at two oppositions and a perturbed orbit had been calculated that produced satifactory residuals for the known observations. An

exception was made if the perihelion distance was less than 1.67 AU.

The current practice at the Minor Planet Center is much tighter than that given on *MPC* 837. Generally, for a main-belt asteroid, observations at four oppositions are required, with a perturbed orbit closely fitting the observations. In a few cases, minor planets that have been well observed at three oppositions are numbered. Only in the case of very unusual orbits will a minor planet be numbered after being observed at only two oppositions.

The following table shows the number of minor planets that received permanent numbers (in each of five periods of eight years length) from 1949 through 1988:

Years covered	*Planets numbered*	*Average per year*
1949-1956	58	7.2
1957-1964	39	4.9
1965-1972	137	17.1
1973-1980	526	67.8
1981-1988	1636	204.5

The first 16 years represent a period when no automated techniques were used to look for identifications. Also, the emphasis in those years was on already numbered minor planets, many of which were lost. In the years between 1965 and 1972, some automated searching was done for identifications, and the Crimean Astrophysical Observatory began its observing program, which provided many accurate positions of unnumbered minor planets. In the period from 1973 to 1980, more automated searching for identifications was done, and several programs of minor-planet observing were started using large Schmidt telescopes. Among these observers were C. Kowal at Palomar; West and H.-E. Schuster at the European Southern Observatory; H. Kosai, K. Hurukawa, and others at Kiso; and L. Kohoutek at Hamburg.

The huge increase in the next eight years can be attributed to several things. Most important probably was the availability of completely-automatic searches for identifications. In 1982, the first complete year that these methods were used, 294 minor planets were numbered. This represented an application of the automatic searching of the asteroid tape to a large backlog of unnumbered objects. This total has not been reached again, but the average rate of numbering per year has remained around 200 for the years from 1983 to 1988. Another important factor in the increase of numberings has been the significant increase in the number of observations received. Especially important in the period 1981-88 has been

the observing program at the Lowell Observatory under the direction of Bowell.

XI. Minor planet observers

It is obvious that work on minor-planet orbits could go nowhere without observations. When he was directing the minor planet work at the Rechen-Institut, Stracke encouraged observers from all parts of the world to observe minor planets, but he especially depended on Wolf and Reinmuth at Heidelberg. When the Minor Planet Center started most of the observing was being done in Europe at observatories such as Nice, Uccle, and Turku that had been active before the war. However, after the first few years Herget began to depend very heavily upon a new observing program at the Goethe Link Observatory of Indiana University.

The Goethe Link program began in 1947 at the request of the American committee under Brouwer which was trying to organize a program of minor-planet research. Under the direction of Frank Edmondson, the observing was done with a 25-cm Cooke triplet lent to them by the Cincinnati Observatory. Though the telescope had a small aperture, long exposures made it possible to push the limiting magnitude to fainter than 17 on good observing nights.

Working from "urgent lists" prepared by the Minor Planet Center, the Indiana observers concentrated on numbered minor planets that needed to have orbit improvements. They were particularly interested in removing planets from the critical list. However, because the plates were taken in pairs and blinked, a large number of discoveries were made. In fact, in the years from 1949 through 1965, nearly forty percent of the minor-planet discoveries were made at the Goethe Link Observatory. Ironically although they took nearly 6,300 plates they discovered no comets and only one near-Earth minor planet — 1963 UA, which was later numbered (2059).

Beryl Potter was not a trained astronomer, but she had a great deal of responsibility in the Indiana minor-planet observing program. She blinked most of the plates and obtained approximate scaled positions for all of the observed objects. In the later years of the program she also supervised the measuring of accurate positions when they were needed. She retired in 1966 and the active observing program was terminated, although it was still possible to have accurate positions measured for objects that had been observed in the past.

When the Indiana observing program ended in 1966, it appeared that there might be a crisis in minor-planet astronomy. Observing had reached a low ebb in the early 1960s, as

many of the old minor-planet observers were no longer active. Without the Indiana program, it appeared that very little minor-planet observing would be done. Fortunately this did not turn out to to be true. About the same time, new observing programs were started at the Crimean Astrophysical Observatory and at the Purple Mountain Observatory. Both of these programs used newly-installed Zeiss 40-cm double astrographs. The Purple Mountain program was very active in 1964 and 1965, but then was closed down for a number of years because of the Cultural Revolution in China.

Working closely with the ITA, the Crimean observers under the direction of N. S. Chernykh have for the past 25 years sustained one of the most effective minor-planet-observing programs ever undertaken. During this period they have observed most of the numbered minor planets at more than one opposition and in most of the years have made the majority of new discoveries. The greatest strength of the Crimean program has been the thoroughness with which plates have been blinked and the subsequent measuring of accurate positions for all of the images found. Its weakness has been the delay of several years before positions are reported to the Minor Planet Center.

After 1970 the observing situation improved a great deal. E. Helin and E. M. Shoemaker began the Planet Crossing Asteroid Survey to search for near-Earth asteroids with Schmidt telescopes at Palomar. Other large Schmidts began to be used to observe minor planets, and Bowell revived the observing program at the Lowell Observatory.

Since the Minor Planet Center moved to Cambridge in 1978, this improvement has accelerated. Part of this can be attributed to an increased interest in minor planets. Another factor is the better communication that now exists between the Minor Planet Center and observers. The *MPCs* are now published on a regular schedule and observers can see the results of their efforts much sooner than was true in Cincinnati where batches of *MPCs* were published only two or three times a year. The new computer technology makes reduction of observations much easier and this has also been a factor.

The latest development, of course, has been the tremendous increase in activities of the Japanese amateur astronomers. During the past six months, this group has been the most important source for observations of main-belt minor planets. They have not only made most of the new discoveries, but their follow-up observations have led to identifications being found for many of these new objects.

XII. Unusual Minor Planets

Probably the most exciting work at the Minor Planet Center involves minor planets with unusual orbits. This is especially true of near-Earth objects because of their rapid angular motion. The first asteroid of this type to be discovered was (433) Eros, which caused a great deal of excitement when it was discovered by G. Witt in 1898. Its perihelion distance of 1.133 AU brings it within 0.15 AU of the orbit of the Earth. Because of that, astronomers immediately recognized the possibility of using Eros to make a better determination of the solar parallax. Work on this project was carried on for more than 50 years. What was thought to be the definitive result was published by Rabe in 1950. Ironically, Rabe had made a conceptual error in his work which was not recognized until the results obtained by bouncing radar pulses off of Venus were shown to be in disagreement with the Eros-determined value.

Eros is actually the first example of what are now called Amor minor planets. The name comes from (1221) Amor, the fifth one of this type to be discovered. Amor asteroids are rather arbitrarily defined as those with perihelion distance less than 1.3 AU and greater than 1.017 AU. By the end of 1932, six Amors had been found and five of them had been given numbers. All of these were well observed at their discovery opposition, with the exception of (719) Albert. Albert, as you all probably know, is one of the two numbered minor planets that remain lost. Because it is very faint except when close to the Earth, and because the period of its orbit is very poorly determined, it will only be recovered by chance.

In 1932 the first minor planet that can cross inside the Earth's orbit was discovered by Reinmuth at Heidelberg. It was given the name Apollo even though it had not yet received a number. It was also given the provisional designation 1932 HA. This planet was observed for less than three weeks and was not recovered until 1973. The recovery was rather miraculous, as it was found on the first plate taken in what was to have been an extended search with the 1.55-m reflector at the Agassiz Station of the Harvard College Observatory. Apollo is now numbered (1862) and the name is official.

Apollo-type minor planets are now defined as those with perihelion distance less than 1.017 AU and semimajor axis greater than 1.0 AU. A few years later two more Apollos were discovered. Asteroid 1936 CA was discoved by E. Delporte at Uccle and was given the name Adonis. Adonis was lost until 1977 when it was recovered by Kowal with the 1.2-m Schmidt at Palomar and it is now numbered (2101). Another Apollo-type object, 1937 UB, was discovered by Reinmuth. It approached within 800,000 km of the Earth and its orbit comes

within half that distance from the orbit of the Earth. It has been given the name Hermes, but unfortunately, was observed for only four days and probably will remain lost for a long time into the future.

An unexpectedly-large number of near-Earth minor planets were discovered in the time from 1948 to 1953. The reason for that was mainly that two surveys were being made that covered a large part of the sky. The Lick Proper Motion Survey was conducted with a 51-cm astrograph, and the Palomar Sky Survey I with the 1.2-m Schmidt at Palomar. The first Apollo to be numbered is (1566) Icarus which was discovered with the 1.2-m Schmidt. At the time of its discovery, it had the smallest semi-major axis and the largest eccentricity of any known minor planet. It no longer holds first place in either of these categories.

When I went to work for the Minor Planet Center at the beginning of 1958, activity with regard to close-approach minor planets was low. There were four near-Earth asteroids found in the 1960 Palomar-Leiden Survey, but three of them were observed for only 4 days. Otherwise during the ten years from the beginning of 1958 to the end of 1967, only two Amors and one Apollo were discovered.

(1566) Icarus had a highly-publicized close approach to the Earth in 1968, and became the first minor planet to be observed with radar. In 1969 Marsden calculated orbits for ten of the unnumbered close-approach minor planets, and these were published in the *MPCs*. In the next ten years, eight of the ten were recovered — four by Roemer, one by Kowal, and three by observers at the Agassiz Station of the Harvard College Observatory.

After 1970 there was great a increase in the rate at which these objects were discovered. Partly this is due to an increase in the use of large Schmidt telescopes for observing minor planets. But another important factor is the dedication of a few observers in making searches. Kowal at Palomar used the 1.2-m Schmidt to search for distant objects in the Solar System, but also was able to discover a number of near-Earth asteroids. Starting in 1973, Shoemaker and Helin have made successful searches for close-approach minor planets using the 46-cm Schmidt at Palomar.

In 1976 Helin discovered (2160) Aten, the third type of near-Earth minor planet to be discovered. An Aten minor planet is defined as one having a semi-major axis less than 1.0 AU. The searches with 46-cm Schmidt at Palomar have proven to be the most effective way to search for near-Earth objects, because such a large amount of sky can be observed each month. The searches are still continuing, except that there are now two separate programs, one directed by Helin and the other conducted by Shoemaker and his wife, Carolyn. Be-

sides finding a number of interesting minor planets, the Shoemakers have also discovered 16 comets.

Another reason for the great increase in the discovery rate of minor planets with interesting orbits has been the joining of the Minor Planet Center with the IAU Central Bureau for Astronomical Telegrams at the SAO. In Cambridge the Minor Planet Center is much better able to repond to new discoveries than was the case in Cincinnati. Particularly in the past few years, communications have become almost instantaneous with the use of networked computers. An example is the discovery of the Apollo asteroid 1988 XB by Y. Oshima: Within two days, accurate positions on two nights and an orbit by Nakano had been put on an *IAU Circular* that was distributed by electronic mail. Of course a large part of the credit goes to Oshima for measuring his positions so quickly.

XIII. The Future

Whether the Minor Planet Center can continue to operate in the same way into the future is doubtful. Already there have been some restrictions placed on observers, such as the requirement that current discoveries must be observed on at least two nights before they are recognized. On the whole, this seems to be working well. To some, the naming of minor planets seems frivolous and unnecessary, but over the years we have found it a very good way at least partially to recognize the great contribution made by minor-planet observers — epecially the amateurs. Nearly 10,000 *MPCs* have been published since the Minor Planet Center moved to Cambridge. The number per year has increased to well over a thousand and some limit may have to be placed on what is published.

Based on past experience, there is good reason to expect that the upsurge in minor-planet astronomy will continue. The limitations of the past have largely been overcome. Based on financial support comparable to what is now available, it would seem very possible that there could be as many as 8,000 numbered minor planets at the beginning of the next century. At least until that time we hope that Japanese amateur astronomers will play an important role.

The program of the Japanese amateurs for the most part is being conducted in exactly the way we would suggest. In most cases, discoveries are followed until a preliminary orbit can be determined. At this stage one of the orbit calculators in your group searches for identifications. If none is found, additional observations are made to ensure that the orbit is good enough to make future recovery possible. Another important part of your program

is the recovery of minor planets that have been observed at more than one opposition, but have not been numbered. Because of the great increase in the efficiency of identification searches, we are increasing the number of minor planets in this catagory much faster than minor planets are being numbered.

If there is a bottle neck in the work done in observing minor planets and computing their orbits, it seems now to be in plate measuring, which is for the most part not automated. It is very likely that automated scanning techniques that are being developed will very much improve this situation in the future. In the meantime, there are some observing programs that are only able to measure a limited number of objects on the films or plates taken.

The use of CCDs has become very important in the recovery of minor planets with unusual orbits. First, they allow these objects to be followed much longer than was true in the past and provide very accurate positions. Secondly, if good orbits exist, CCDs make recovery possible at much fainter magnitudes than in the past. Asteroids with ephemeris V magnitudes fainter than 21 can now be searched for with hope for success. The use of CCDs to search for new discoveries has not been very effective because of the small field covered by CCD chips, but new, much-larger chips are now becoming available, and this situation will very likely change.

As I rapidly approach my retirement, I can hardly believe how much more efficiently work is being done in minor-planet astronomy than when I started at the Minor Planet Center more than thirty years ago. I expect that this improvement will continue in the future, but there is so much to do that I do not think any of you will have to look for a new hobby.

From 2010 May MPCs:

It is with great regret that we have to report the death, on 2010 May 14, of *Conrad Myron Bardwell*. Although officially associated with the Minor Planet Center only from 1958 to 1989, he continued to compute orbits for another decade or more, and he maintained a strong interest in what the MPC was doing until the end of his life.

Born in Waco, Texas, on 1926 Aug. 11, *Conrad* moved to St. Louis around 1930 and to Denver in 1935. After a brief stint in the U.S. Navy at the very end of World War II he studied education and mathematics at the University of Colorado, where he also lettered in the track team, at one point running 440 yards (402 meters) in just 50 seconds. After spending a year teaching eighth-grade mathematics, he worked for a while for United Airlines and studied business at night school, before transferring to the mathematics department at the University of Wisconsin in Madison, where he came to the attention of astronomer *Charles M. Huffer*. In 1957, when *Paul Herget*, then director of both the Minor Planet Center and the Cincinnati Observatory, was looking for an assistant, he accepted *Huffer's* recommendation that *Conrad* would be an excellent candidate. So *Conrad* joined the MPC staff in Cincinnati in Jan. 1958 and was soon contributing to the day-to-day work. Although automated computers were then being used to calculate planetary perturbations, the orbital differential corrections were still being done by hand, and the first task assigned to *Conrad* was the hand computation of residuals. Automation of this was still a year away.

In the early 1960s *Conrad* was becoming particularly interested in methods for finding minor-planet identifications. Until that time, the recognition of observations of a minor planet at a second opposition was often a rather haphazard process. Ideally, as happened beginning with (1) Ceres, enough observations were made at the discovery opposition that only a limited search was needed to recover the object at the next. As more and fainter objects were discovered, the reality was that the subsequent observations were often entirely accidental and required a process of identification, then generally from the similarity of the orbits computed at the two oppositions, even when there were observations on only two nights at one of them, and the orbit was represented by either a circular or a Vaisala computation. Given that the MPC was collecting both observations and orbits in computer form, *Conrad* felt that the procedures could be automated, and he was singlehandedly responsible for a substantial increase in the recognition of identifications. His identifications, regularly published in the *Minor Planet Circulars* beginning in Aug. 1964, earned him a master's degree from the University of Cincinnati and the title Research Associate at the MPC. This work had a significant effect on the rate at which minor planets were being numbered, and although the MPC had numbered fewer than 100 minor planets---including (1615) Bardwell---during the first half of its 1947-1978 existence in Cincinnati, that number quadrupled during the second half. Furthermore, of the 1564 minor planets that had been numbered prior to 1947, the fraction that was considered lost decreased from some 12% to little more than 1% during the Cincinnati years. *Conrad's* most spectacular identification, published on *MPC* 2678 in 1966, was that the objects numbered (1095) and (1449) were in fact one and the same object; as a consequence, the latter number was retained, and the number and name (1095) Tulipa were assigned to a different object.

Herget's forced retirement at 70 in 1978 meant that the MPC would have to leave Cincinnati. The year before, when I was invited to assume the directorship and move the MPC to Cambridge, I accepted on the condition that *Conrad* would be moving with it and would take the position of Assistant Director. So in Apr.1978 we began a productive collaboration in which *Conrad* upgraded computer programs and improved the identification process further. We also began the practice of publishing the *Minor Planet Circulars* on a monthly basis. Largely due to *Conrad's* efforts, the

year 1980 saw what was then a record 133 new numberings, bringing the total up to 2321, of which just 12 were still lost. He was promoted to Associate Director in 1981, and the following year we collaborated on the publication of a *Catalogue of Orbits of Unnumbered Minor Planets* (2471 entries) and a *Catalogue of Discoveries and Identifications of Minor Planets* (29~157 entries), the first such publications in 20 years. In addition to his work on the preparation of the *Minor Planet Circulars*, *Conrad* participated in the production of further editions of these catalogues during subsequent years, and when he retired at the end of 1989, numberings of minor planets were up to 4295, with only two of them lost. Also in 1989, *Conrad* took up an invitation to visit Japan, and a talk he gave there about the history of the MPC was published in the popular Japanese astronomical magazine *Tenmon Guide*. An English version of his presentation is available at *http://www.oaa.gr.jp/~oaacs/mp/BriefHistoryofMPCbyConradBardwell.pdf*.

Conrad continued to work at the MPC long after his formal retirement, particularly on the preparation of the *Minor Planet Circulars* and coordination with the observing program at the Oak Ridge Observatory. He was still computing orbits in 2001, in which year he also made his final identification, 1950 DA = 2000 YK_{66}, which led to the well-known calculation that this object, now numbered (29075), has a 1-in-300 chance of hitting the earth in the year 2880.

Conrad was a quiet and unassuming man, who continued to pay visits to the MPC on most Saturday afternoons until shortly before his sudden and unexpected death from leukemia. He leaves his wife of almost 51 years, *Joan Wesson Bardwell*, for whom he named (2017), another minor planet for which he made the identifications. They had three sons, *Michael*, *Glenn* and *David*, the first of whom was born at just the time I first met *Conrad*, in Cincinnati in Mar. 1960.

Brian G. Marsden