RECOVERIES, FOLLOW-UP OBSERVATIONS AND NUMBERING OF MINOR PLANETS

Paul G. Comba
1411 Galaxy Lane
Prescott AZ, 86303
e-mail: comba@northlink.com

(Received: 9 July Revised: 11 August)

This paper discusses follow-up observations of previously discovered asteroids, and the development of strategies to enhance the effectiveness of observations from discovery to numbering.

A previous paper (Comba 1997) described the author's minor planet observing activities at Prescott Observatory during the first fully-instrumented year of operation. Starting in March, 1996, observations were made with a 46-cm f/4.5 reflector and an ST-8 CCD camera, and analyzed with the Astrometrica program. The net results were the discovery of 207 minor planets, plus several hundred astrometric observations of other asteroids. (The referenced paper gave 210 as the number of discoveries, but it was later found that 3 of them were duplicates.)

This paper discusses the recoveries and re-observations of a subset of the first year's discoveries, and presents some strategies intended to improve the effectiveness of observations, from discovery to the numbering of the asteroids.

Review of discovery process

1. An observer obtains astrometric observations of a moving object on two nearby nights and sends them to the Minor Planet Center (MPC). The MPC tries to determine whether the observations pertain to a known object. If no such identification can be made, the object is given a provisional designation, such as 1996 FP3. In either case, the observer is informed of the result. The receipt of a provisional designation may be considered a discovery in the extended sense.

2. If further observation of the object are submitted to the MPC in the following weeks, the MPC computes a more precise orbit. It may then happen that, upon further checking, the new object is found to be identical to a previously discovered one that was given a different designation. The MPC then declares one of the designations to be the principal one, and the corresponding observer gets credit for the discovery. The principal designation is awarded not necessarily to the first discoverer, but to the one who first supplies the observations from which a "reasonable" orbit is determined.

3. When a minor planet has been observed repeatedly at several oppositions, so that a very precise orbit can be computed, it gets numbered. In the strict sense, a discovery is recognized only when the planet's number and the discoverer's name are published in the Minor Planet Circulars. The requirements for numbering are discussed further below.

Follow-up on first year discoveries

Table I classifies the discoveries made in the first year and their subsequent history. The class labels are briefly described in the body of the table. L+ and L- refer to objects that were identified (linked) with earlier discoveries, and were credited to the author or to another discoverer respectively. The numeric class labels refer to the number of days from the first to the last observation during the discovery opposition. In general, the objects in the classes L+, L- and 50+ were brighter than visual magnitude 18.5 at discovery, while the others were fainter. Among the class L+ objects, 11 had been observed at one previous opposition, 8 at two, and 2 at three.

One column shows the number of objects that were recovered (the term applies to objects that have been observed at a single opposition) or re-observed at a later opposition; this number does not include those that were subsequently numbered. The "missed" objects were searched for repeatedly over a fairly wide area, hence their residuals (observed minus calculated) were probably 15 arc minutes or more. The "too faint" could not be reobserved because of their being too faint, too low in the sky, or in the Milky Way.

The single "too faint" object in the 50+ class was 1996 UJ, a Mars crosser that was at opposition in May 1998 at magnitude 21, declination -43, and in the Milky Way--a triple whammy. The 3 rediscoveries of class 30- were unplanned and made accidentally by other observers.

Figure 1 is a plot of the recovery R. A. residuals as a function of the observation arc length. The R. A. residuals were in all cases much greater than the Dec. residuals. It should be noted that many recoveries occurred well before opposition, when the objects had a smaller apparent motion and less time had elapsed since the previous opposition observations. The median residual for class 50+ objects is 1.3 arc minutes, and it is clear from Figure 1 that almost all these objects could have been recovered even with a camera/telescope having a rather small field, say 10 arc minutes.

In light of the first year's experience, an effort was made in the second year to increase the number of discoveries of brighter objects (magnitude less than or equal to 18.5). This was achieved in part by doing some searches with a smaller telescope, 25-cm f/4, which yields a field of 47x31 arc minutes. Brighter objects are more likely to have been observed before, or of being observable for 50 days or more. As a result, while the total number of discoveries declined to 175, the number of class L+ or 50+ objects increased to 51.

Optimal patterns of observations

Beginning observers and discoverers tend to make unnecessarily many observations. To define a sufficient but non-redundant pattern of observations, one must consider several issues. First, how many observations of the same field should be made on a given night? If the purpose is to discover new objects, the answer is two, and the images should preferably be

Table I. Disposition of first year discoveries

Class	Description	Total	Reobs/ recov	Reobs & numbered	Missed	Too faint
L+	Linked, credited to author	21	10	8		3
50+	Arc of 50 days or more	21	20			1
30-49	Arc of 30 to 49 days	9	3		3	3
30-	Less than 30 days, 3+ nights	76	3			
2N	2 nights	73				
L-	Linked, credited to others	7				

taken over several fields in rotation, (e. g., 1 2 3 1 2 3). This insures a longer time interval between images of the same field, hence a better estimate of the proper motion of any object that may be discovered.

If the purpose is to observe a known object, the opinion of the experts (Bowell et al., 1989) is that "The measurement of three (or more) positions of a main-belt asteroid on the same night is usually a waste of time". The author examined a small sample (N=25) of triplets of his own observations, and found that in 80 percent of the cases they were so perfectly consistent that the third observation was indeed redundant. In the other 20 percent of the cases there may be a very small advantage in having three data points instead of two.

If one can blink a pair of images at the telescope, and finds two clear asteroid images, that should certainly settle the matter. However, if the images can be blinked only later, there are several reasons why a third image may be desirable:

1. It may happen, specially in a crowded star field, that one or even two asteroid images are too close to a star to be measurable. The third exposure is a form of insurance against this eventuality, specially desirable if the Moon or weather may interfere with re-observing the object in the near future.

2. CCD images tend to be noisy from cosmic-ray hits and other artifacts. In rare cases, it may take 3 images to unequivocably identify a moving object.

3. The marginal cost of obtaining and measuring the third image is rather small, if one figures the overhead involved in planning the observations, acquiring and centering the field at the telescope, and setting up the astrometry program.

In the unlikely event that one discovers a fast moving object and recognizes it at the telescope, it is important to make more observations, preferably spread out over several hours, and to measure and communicate them to the MPC as soon as possible.

With two observations of a newly discovered asteroid, one can compute its apparent daily motion by dividing the difference of of the coordinates at the two positions by the time difference, expressed as a fraction of a day. If the motion is retrograde, as is the case near opposition, this calculation overestimates the R.A. motion by about 2 or 3 time seconds, depending on the (unknown) distance of the asteroid, because of the parallax effect due to the Earth's rotation. This correction is independent of the time interval between the observations.

From the daily motion, one can get an estimate of the object's positions for the next several days. If the object is before opposition, where it appears to accelerate, the actual motion is likely to be slightly greater than the estimate; and viceversa after opposition.

After the two nights' observations are sent to the MPC, they compute a Vaisala orbit. This is an approximate orbit from which an ephemeris can be computed that gives reasonably good predictions for the next 10 to 15 days. The ephemeris can be obtained by subscribing to the MPC Computer Service or by connecting with the MPC web site at

http://cfa-www.harvard.edu/iau/MPEph/MPEph.html

To plan the next set of observations, two considerations apply. First, orbit computers find it very advantageous to have observations in pairs of nearby nights: this makes it possible to establish the reliability of the observations. Second, while an arc of 50 days has proved quite adequate to achieve a recovery, it is just as easy, with some planning, to stretch the same observations over 60 days. In that case, the MPC usually classifies the orbit as "long arc", computes ephemerides using perturbations (making them more precise), and publishes its U parameter (discussed below).

This prompts us to propose the following as the ideal observation schedule, counting the days from the day of discovery: (0 1 7 8 30 31 60 61). Of course the weather may interfere with the schedule, and the pair (7 8) may have to be moved forward on account of the Moon. If an asteroid has been previouly observed, the identification can often be made after the first 4 nights, making it then a multi-opposition object.

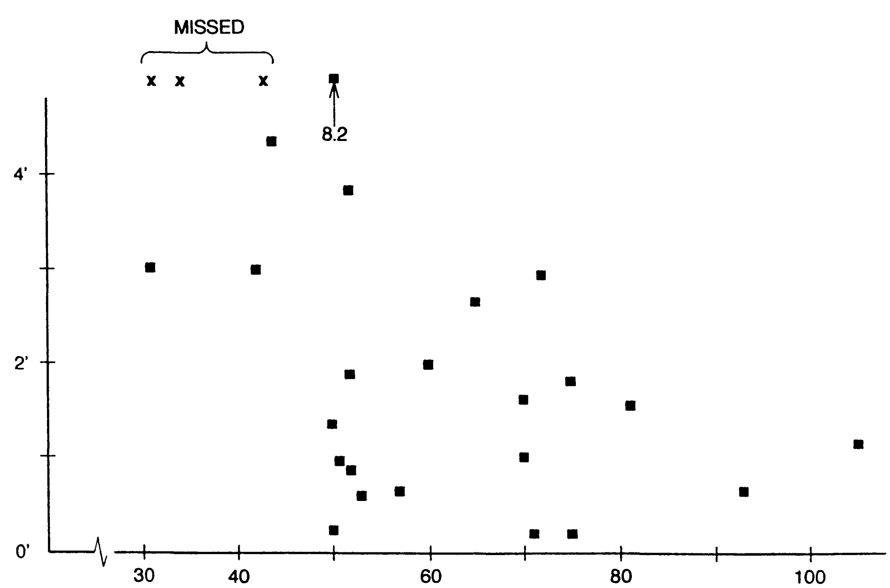

FIGURE 1. RECOVERY R. A. RESIDUALS (ARC MIN) vs OBSERVATION ARC (DAYS)

Multi-opposition objects and numbering

We assume that the goal of an asteroid observing program is to accumulate enough observations on individual asteroids so they can ultimately be numbered. To this end, it is useful to know the numbering rules. These rules, devised for the purpose of insuring that no numbered asteroid would ever be lost (as had happened in the past), have become stricter over the years. At the present time, they are essentially embodies into two parameters, U and J, derived from an asteroid's observations and orbital elements.

U (uncertainty) is explained in detail at the MPC website at

http://cfa-www.harvard.edu/iau/info/UValue.html

U measures, on a logarithmic scale, the estimated position error per decade along the orbit, with U=0 indicating an error of 1 arc second and U=9 of half an orbit. The requirement for numbering is U<=2. Most long-arc asteroids have U=4 or 5 or occasionally 6. Most two-opposition objects have U=3 or 4. In practice, objects with U<=5 can be recovered without difficulty at the next opposition.

The parameter J is only partially explained in (Marsden 1996). It is a sum of several terms intended to weigh the number of oppositions at which an asteroid has been observed, the number of elapsed years, the number of observations at each opposition, and the spread of the observations. A score >=23 typically leads to numbering. The ideal pattern of observations at any opposition appears to be one pairs of nights in each of three lunations, which contributes 8 points to the sum J. In most cases, it takes observations at 4 or more oppositions before the requirements on U and J are met.

While this information is useful for planning an observing schedule, it is the author's opinion that a full description of the computation of J, and the publication of J alongside U in the Minor Planet Circulars, would be of interest to observers and would contribute to the avoidance of redundant observations.

A changing environment

The number of reported observations of minor planets has increased dramatically in recent months, as several programs have intensified the search for potentially hazardous near-earth objects. In May and June 1998 the Lincoln Laboratory Experimental Test Station in New Mexico reported twice as many observations as all the other observatories combined. Meanwhile, Lowell Observatory is gearing up for a very ambitious program (The Lowell Observer, 1998) whereby the entire accessible dark sky would be imaged three times per month to a limiting magnitude of 19.

How will these developments affect the amateur? One can expect, over a period of years, that the number of discoverable asteroids will diminish. With the plethora of expected observations, the concern for redundant observations will vanish, and the follow-up problem will be automatically solved--in most cases.

Two niches where amateur will continue to make valuable contributions are the follow-up of (a) fast moving near-earth objects, and (b) objects that move out of the range of the automated observatories, e.g., to the deep southern sky.

For the near future, however, asteroid hunting remains a viable occupation.

References

Comba, P. G. (1997), "Discovering Minor Planets", Minor Planet Bulletin 24, 33-34.

Bowell, E., Chernykh, N. S., and Marsden, B. G. (1989), "Discovery and Follow-up of Asteroids", in *Asteroids II*, R. P. Binzel et al. (eds), University of Arizona Press.

Marsden, B. G. (1996),. "From Telescope to MPC: Organizing the Minor Planets", in *Dynamics, Ephemerides and Astrometry of the Solar System*, S. Ferraz-Mello et al. (eds), IAU.

The Lowell Observer (Winter 1998). "First Light at LONEOS".

ASTEROID NEWS NOTES

David J. Tholen
Institute for Astronomy
University of Hawaii
Honolulu, HI 96822

Eight Hundred Twenty Three Newly Numbered Asteroids

Since the last installment of News Notes, 823 asteroids have been numbered to crash through the 9000 level and bring the numbered total to 9142. Non-main-belt objects among these include:

(8348)	1988 BX	Hungaria
(8355)	1989 RQ1	Mars crosser
(8373)	1992 AB	Mars crosser
(8376)	1992 OZ9	Hilda
(8404)	1995 AN	Hungaria
(8405)	1995 GO	Centaur
(8444)	1969 TR1	Mars crosser
(8482)	1988 RA11	Cybele
(8507)	1991 CB1	Apollo
(8550)	1994 PV24	Hilda
(8551)	1994 VC7	Hilda
(8566)	1996 EN	Apollo
(8567)	1996 HW1	Amor
(8651)	1989 YU5	Mars crosser
(8709)	Kadlu	Mars crosser
(8721)	AMOS	Hilda
(8743)	1998 EH12	Hilda
(8825)	1988 MF	Hungaria
(8913)	1995 YB2	Hilda
(8915)	1995 YK3	Hilda
(8917)	1996 EU2	Cybele
(8988)	1979 MA4	Cybele
(9023)	1988 RG1	L5 Jupiter Trojan
(9030)	1989 UX5	L5 Jupiter Trojan
(9058)	1992 JB	Apollo
(9068)	1993 OD	Mars crosser
(9069)	1993 OV	Hungaria
(9082)	1994 VR6	Mars crosser
(9084)	1995 CS1	Hungaria
(9121)	1998 DJ11	Hilda
(9142)	5191 T-3	L5 Jupiter Trojan

New Asteroid Names

The highest numbered asteroid that is also named is currently (8725) Keiko, while the lowest numbered asteroid that remains unnamed is (3109) 1974 DC. The previous holder of this distinction, (3081) 1971 UP, was finally named Martinuboh. The total of numbered but unnamed asteroids jumped from 2469 to 3122, so there are now 6020 named asteroids (not counting the unnumbered near-Earth object Hermes), which means there have been only 170 new names attached to numbered asteroids since the last installment of News Notes. I suspect that most of those names are not familiar to MPB readers, though I recognize some names of former or current scientists associated with my graduate institution, The University of Arizona's Lunar and Planetary Laboratory.

(6141)	Durda	Arizona
(7225)	Huntress	NASA Associate Adminis-trator for Space Science
(7231)	Porco	Arizona
(7355)	Bottke	Arizona
(7749)	Jackschmitt	last person to walk on the Moon

Planet Crossing Asteroid Update

The list below includes 132 discoveries since the last installment of News Notes. The trans-Neptunian population is now up to 68. The Lincoln Labs Experimental Test Site in New Mexico is now bearing the fruit of considerable development effort on fast-readout CCDs. They are covering enormous chunks of sky and finding more Earth-approaching objects than anyone else.