

CCD PHOTOMETRY OF ASTEROIDS AT THE U.S. AIR FORCE ACADEMY OBSERVATORY DURING 1996

Charles J. Wetterer
Department of Physics
United States Air Force Academy
USAF Academy, CO 80840

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CCD photometry measurements of three asteroids (96 Aegle, 752 Sulamitis, and 4284 Kaho) obtained during 1996 at the US Air Force Academy observatory are reported. These asteroids were observed as part of cadet and faculty research. Only 4284 Kaho had a sufficient lightcurve to determine its rotational period (4.065 ± 0.015 hours) and amplitude of variation (0.63 magnitudes in V).

All observations were made at the U.S. Air Force Academy observatory. A Photometrics (PM512) CCD camera attached to a 61-cm Cassegrain telescope was used to take five to ten minute exposures of the asteroids through a standard Johnson V-band filter. All images were processed using NOAO's IRAF package and differential photometry of the asteroids with nearby stars was performed. Differential photometry between stars was also accomplished to ensure the comparison stars were not variable. All three asteroids have no previous determination of a rotation period as listed in the 1996 August Uppsala Astronomical Observatory's list of rotation periods.

96 Aegle was observed 15 times over a 3.5 hour period (5.5 to 9.0 hours UT) on UT 96 January 25. The amplitude of variation was found to be less than about 0.03 magnitudes, with no apparent trend (see Figure 1).

752 Sulamitis was observed thirty times over a 3.7 hour period (3.4 to 7.1 hours UT) on UT 96 December 13. The amplitude of variation was found to be about 0.04 magnitudes, possibly observed from maximum to minimum light during the first 2.5 hours (see Figure 2). Assuming a symmetric double minima lightcurve and if indeed one fourth of the period was observed in this time, Sulamitis' period is about 10 hours.

4284 Kaho was observed eight times over a 2.1 hour period (5.7 to 7.8 hours UT) on UT 96 June 13 and nineteen times over a 4.9 hour period (4.2 to 9.1 hours UT) on UT 96 June 14. To construct a composite lightcurve, a rough calibration of the

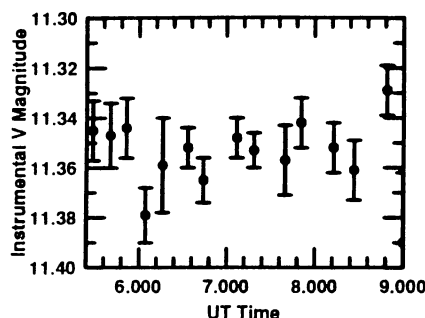


Figure 1. Lightcurve for 96 Aegle on UT 96 January 25.

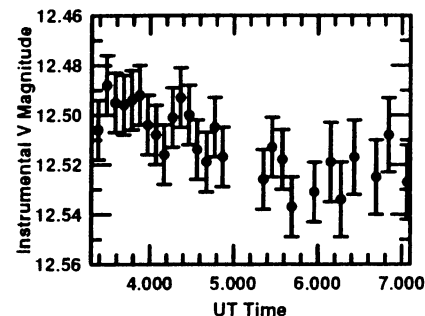


Figure 2. Lightcurve for 752 Sulamitis on UT 96 December 13.

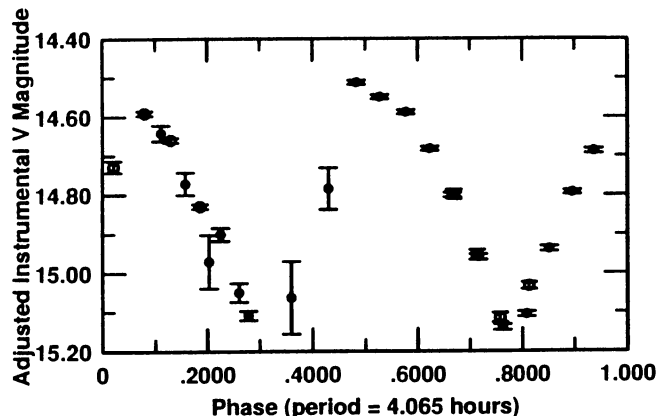


Figure 3. Composite lightcurve for 4284 Kaho based on a 4.065 hour synodic period. UT 96 Jun 13 - open circles, UT 96 Jun 14 - closed circles. Zero phase = UT 96 Jun 13, 07:00:00. Lightcurve corrected for light travel time.

magnitude offset for each night was determined by using the Hubble Guide Star Catalog magnitudes (Russell et al. 1990) of at least two of the comparison stars. These magnitudes were adjusted to common Earth-Kaho and Sun-Kaho distances (1 A.U. for both), although an additional magnitude offset (due to systematic errors in the GSC magnitudes and phase effects) was also necessary. The synodic period was determined by visually matching the composite lightcurve and was found to be 4.065 ± 0.015 hours. No other periods produced an acceptable lightcurve. The observed V amplitude of variation was 0.63 magnitudes. The composite lightcurve is shown in Figure 3.

References:

Russell, J.L., Lasker, B.M., McLean, B.J., Sturch, C.R., & Jenkner, H. (1990). "The Guide Star Catalog. II - Photometric and astrometric models and solutions". *AJ* **99**, 2059-2081.

Uppsala Astronomical Observatory's "Rotation Periods of Asteroids" (1996

August update). http://www.astro.uu.se/planet/rotast_eng.html

MINOR PLANET SOFTWARE ON THE WEB

Sergio Foglia
Serafino Zani Observatory
F. Bisleri 11
I-20148 Milano
Italy
[md3576@mcLink.it]

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The Minor Planet Software computer programs described by Foglia (1997, *MPB* 24, 8) are also available on Web at the URL: "http://www.mclink.it/mclink/astro/uai/sez_ast". The 1997 version of orbital elements of minor planets are also on line.

DISCOVERING MINOR PLANETS

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

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This paper describes the discovery process and reviews the author's experience in this area. The purpose is to encourage other amateurs to undertake the very rewarding pursuits of minor planet astrometry and discovery.

Introduction

In one year's time, starting 1996 March 26, the author has discovered 210 minor planets that were given provisional designations by the Minor Planet Center (MPC). In the same span of time, over 2500 astrometric observations were submitted to the MPC and published in the Minor Planet Circulars. The author himself is quite astonished at these results, which far exceed any hope that one may have entertained at the outset. The enabling events were the attachment of an ST-8 CCD camera to an 18" f/4.5 reflector, and the use of the Astrometrica program for blinking and processing images.

It must be acknowledged that the author has several advantages not enjoyed by every amateur. Being retired, one can devote most of one's energies to the pursuit of minor planets. The weather in Prescott, Arizona produces many clear nights and very few unbearably cold ones. And the ST-8 camera is very large by amateur standards.

From Collecting to Astrometry to Discovery

Like other asteroid aficionados, the author spent many years visually observing ever more minor planets with a series of increasingly large telescopes. The next logical step was to take up astrophotography, which increased the limiting magnitude by about 2.5. The hope of discovering a new asteroid was often in the back of one's mind, but the likelihood seemed very remote.

Photography also opened the door to astrometry. A procedure was developed (Comba 1995) for measuring photographs on a computer screen after scanning them on a flat bed scanner. The procedure gave satisfactory results and was used for a year and a half. In that period of time one asteroid was discovered, 1995 ON, at V magnitude 16.5, which was close to the photographic limit.

Unfortunately the procedure was very slow, and it became clear that much better results

could be obtained with a CCD camera. Equally important, by 1995 excellent astrometric software was available that interfaced with both the CCD image files and the Guide Star Catalog.

The very first pair of CCD images that the author blinked using the Astrometrica program, intending to do astrometry on a known asteroid, showed two objects jumping back and forth side by side, where only one had been expected. It seemed that a new asteroid was being discovered, and this was confirmed the next night. This event brought home the realization that in the CCD world, astrometry inevitably leads to discovery. In fact for many months all discoveries were made while doing astrometry on known minor planets or on previously discovered ones. Later on, a few searches were made specifically for the purpose of discovery.

What's a Discovery?

The Minor Planet Center (MPC) in Cambridge, MA is the clearing-house for all astrometric observations of asteroids and all discoveries. With rare exceptions, the MPC does not welcome reports of discoveries based on a single night's observations.

If, while blinking a pair of CCD images, you find an object that you cannot identify, the next step is to try to find out if it is a known object. This can be done by subscribing to the MPC Computer Service, which is accessed through the Internet. From the Computer Service you can get a listing of all known asteroids which at a specified time lie within a circle of one degree radius centered at a given point in the sky. If the position of your find (which you should have determined at least approximately) does not match with any of the objects on the listing, you have passed the first hurdle.

In this connection it is useful to know the a priori odds. Very few asteroids that ever become brighter than magnitude 16 remain to be discovered. Between 16 and 17 the odds are also against a new discovery. Between 17 and 18 the odds are quite good, and beyond 18 they are overwhelmingly in favor of a new discovery.

The positions of the newly found object should now be determined with astrometric precision (if this has not already been done). From two good observations one can predict the position of the object for the next several days by linear extrapolation, possibly making slight corrections to take into account the fact that an asteroid appears to accelerate before reaching opposition and to slow down thereafter; or, by interacting with the Computer Service, one can get an approximate ephemeris. In any case, it is

best to try to confirm the discovery as soon as possible, preferably the next night.

You should now send the two nights' observations to the MPC by e-mail. They will again check them against the positions of known objects and notify you of the results. If your object appears to be new, you will also be told its provisional designation.

At this point you may want to keep observing your object every few days or weeks, submitting your observations to the MPC, so that its orbit may be computed with increasing accuracy. This will lead to one of several possibilities:

- (1) It may happen that, after further checking on the part of the MPC staff or some other orbit computer, it is found that the same object has already been discovered; and that the other discoverer's observations were used to prove the identity of the two discoveries. In that case, the other discoverer's provisional designation is retained as the principal designation, and when the asteroid is ultimately numbered he/she will be listed as the discoverer. At this point you may understandably lose interest in further observing the object.
- (2) Conversely, it may happen that the identity between your object and a previously observed one is established on the basis of your observations, and your designation then becomes the principal one. This is the most desirable outcome, in that the earlier observations make it possible to compute a more accurate orbit, which makes it easier to recover the asteroid at the next opposition.
- (3) No earlier observations of your object can be found. This is the most challenging situation: it is now up to you to accumulate enough observations to make the recovery possible.

After a minor planet has been observed at a second opposition, it is unlikely to become lost. However, the MPC requires that it be observed on at least four oppositions before it can be numbered, so one must be prepared to make additional observations over the next few years. After the planet is numbered, the discoverer's name becomes part of the public record and he/she has the privilege of proposing a name for the planet.

One Year's Experience

The author's experience is summarized in the tables below. Table 1 indicates the magnitudes at the time of discovery. These are visual magnitudes, which are 0.4 fainter than the R magnitudes measured directly