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Recent Asteroid Lightcurve Studies at the Palmer Divide Observatory

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Abstract

Finding the period and amplitude of asteroid lightcurves has been the main objective at the Palmer Divide Observatory since 1999. Since that time, more than 230 lightcurves have been measured, the majority of them having been produced in the last three years. In the last two years, special consideration has been given to the Hungaria group as well as potential binary asteroids. The latter effort has been in cooperation with the Binary Asteroids Survey conducted by Petr Pravec of Ondrejov Observatory. This report details recent results and their implications in terms of solar system evolution.

1. Introduction

The reasons for determining asteroid lightcurve parameters have been covered in several places, for one in my book, “A Practical Guide to Lightcurve Photometry and Analysis” (Warner 2006). In brief, the periods derived from the lightcurves can be correlated against size, family or group, location within the solar system, taxonomic class, or a combination of these and other attributes. The can lead to the development of theories regarding the evolution of the asteroid system or their structure and density. The latter are important when attempting to determine the extent of the threat of certain asteroids should they collide with Earth.

When several lightcurves are obtained over a sufficient range of *viewing aspects*, the shape and orientation of the spin axis of the asteroid can be determined. With the large surveys coming on line, the work of shape and spin axis modeling can proceed at even greater rates, assuming that data is supported by lightcurves, which are more and more obtained by amateurs.

Spin axis orientation becomes important in determining if certain asteroids might have a common origin and to what degree the *YORP effect* (Yarkovsky-O'Keefe-Radzievskii-Paddack) has on rotation rates and spin axis orientation (see Vokrouhlický 2003). This in turn can lead to further developments in theories concerning asteroid evolution and dynamics.

All of the above and much more can be determined in no small part by simply finding the period and amplitude of a lightcurve. It is relatively easy work for an amateur equipped with a telescope, CCD camera, and software for measuring images and finding the lightcurve parameters.

2. The Palmer Divide Observatory

The Palmer Divide Observatory has been in operation at its current location since 1999, which is about 25 miles north of Colorado Springs, CO, and 8 miles east of Monument, CO. The elevation is 2300 meters. The observatory consists of two building housing three telescopes (Figure 1).

Figure 1. The Palmer Divide Observatory. The left-hand building houses the 0.5m R-C telescope while the right-hand one houses two 0.35m SCT telescopes.

The main building contains a 0.5m Ricthey-Chretien telescope built by ScopeCraft in Kanab, UT

(Figure 2). The camera is a Finger Lakes Instrumentation IMG camera with Kodak 1001E chip (1Kx1Kx24µm). The field of view is approximately 22x22 arcminutes. The camera includes an FLI filter wheel with BVRC filters.

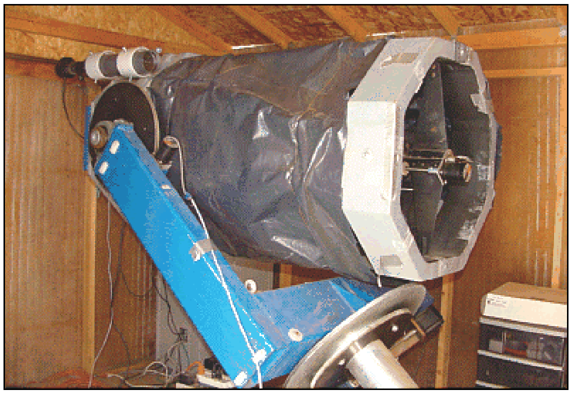


Figure 2. The 0.5m Ritchey-Chretien.

The second building contains two 0.35m Meade LX-200GPS telescopes (Figure 3). One telescope is equipped with the same FLI-1001E camera as the 0.5m telescope while the second telescope has an SBIG ST-9E camera with Kodak 206E chip (512x512x20µm). The second 0.35m scope also uses a f/5 focal reducer to increase the field of view and provide a better pixel scale match.

Figure 3. The two 0.35m LX-200GPS telescopes.

All three telescopes have a pixel scale of about 2.5 arcseconds per pixel, which suits the average seeing at PDO. Most imaging is done unguided with exposures ranging from 60 to 240 seconds. The longer exposures do suffer from some trailing, especially on the 0.5m. However, it is not severe enough to hamper accurate photometry. A guide scope and independent guider are being fitted on the 0.5m to allow for even long exposures when working fainter targets, be they closer but smaller or larger and more distant.

3. General Program Description

The general program involves selecting targets, taking the images, measuring the images, and then analyzing the resulting data.

3. 1. Searching for Targets

The general approach to a night's work involves several considerations. All of these combined result in an initial set of three to five asteroids to be worked.

3. 1. 1 Altitude and Magnitude

A first-pass search using a search utility in MPO Canopus finds all asteroids at least 30° above the eastern horizon at the planned start of observations. The search is further confined to those asteroids within reach of the instruments available. One or more of the telescopes may already be committed to certain targets and so the magnitude range may be set to accommodate only those that can be set on new targets.

3. 1. 2 Hungarias

A separate and stand-alone search utility finds all those Hungarias that are brighter than a given magnitude and have a solar elongation greater than 90° (sometimes 120°). The search includes the RA and Declination of each asteroid and so it can be easily determined which Hungarias, if any, can be considered.

3. 1. 3 Binary Asteroid Candidates

Whether found as part of the Hungaria or regular target searches or by members of the Binary Asteroids group run by Petr Pravec, priority is given to these known candidates over all others, save the Hungarias.

3. 1. 4 Proximity

If possible, more than one asteroid is assigned to each of the 0.35m telescopes. As long as the distance between two targets is not great, the slew time and accuracy is sufficient to maintain a good sampling of both curves and not lose the target because of an inaccurate slew. Periodic Auto-Synchronization is performed with the controlling MPO Connections scripts to assure the scope remains close to target and in focus throughout the run.

3. 1. 5 Multiple Target Blocks

On occasion, usually long winter nights, even a pair of asteroids will set long before the onset of twilight. In this case, a script may be set up to move the telescope to work yet another asteroid (or pair) for a few hours. On some nights, up to eight asteroids have been worked for at least a few hours.

The problem with working these additional asteroids is that they are often a month or two from opposition and so they take some time to be where they can be worked for longer periods. During this time, long gaps can occur due to weather or the moon, making it difficult to tie multiple nights together. For some reason, the probability that these additional asteroids will have long periods seems to be high. Given that long period asteroids need to be followed for prolonged stretches of time and that large gaps in coverage makes period analysis even more difficult, it would seem that Murphy is working overtime when it comes to selecting these additional targets.

3. 1. 6 Visual Double Stars

In response to the all-too common bad luck of picking targets for a second set on a given night, I have recently taken to observing visual double stars via CCD. There are more than 100,000 doubles in the Washington Double Star Catalog (Mason 2006), many of which have not been measured in years. It's a simple matter to use the search routine in MPO Connections to find a list of 50 or so doubles and create a script to image them in both V and R at least four times. Double stars also make an excellent diversion during full moon when the moon is obscuring all worthwhile asteroids. Of course, there are many bright asteroids needing follow up work for shape and spin axis work as well.

3. 2. A Typical Night

Setup begins about sunset when the roofs of the buildings are rolled off and telescopes and the computers in the observatories turned on. All operations are run from in my house, located about 25 meters from the observatories. I use RAdmin ("virtual desktop") software to control the observatory telescopes remotely (http://www.famatech.com/). Figure 3 shows a schematic of the networking layout. This system has proved to be very efficient and has meant not being out on cold winter nights more than necessary.

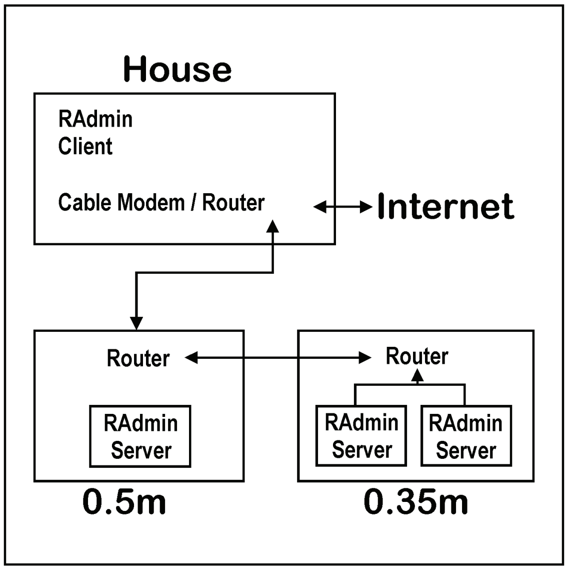


Figure 4. Network layout at PDO

Once inside, I run the search routines described in the previous section and determine which asteroids or other targets are to be observed. Scripts for MPO Connections are written on each controlling computer (via RAdmin). If the same targets are being worked as the previous run, the existing script is updated to save the files to a different directory and reset the time for morning twilight. If a new script is required, I usually just modify an existing one and so save some time by not having to create a new one from scratch.

3. 2. 1 Initial Scope Positioning

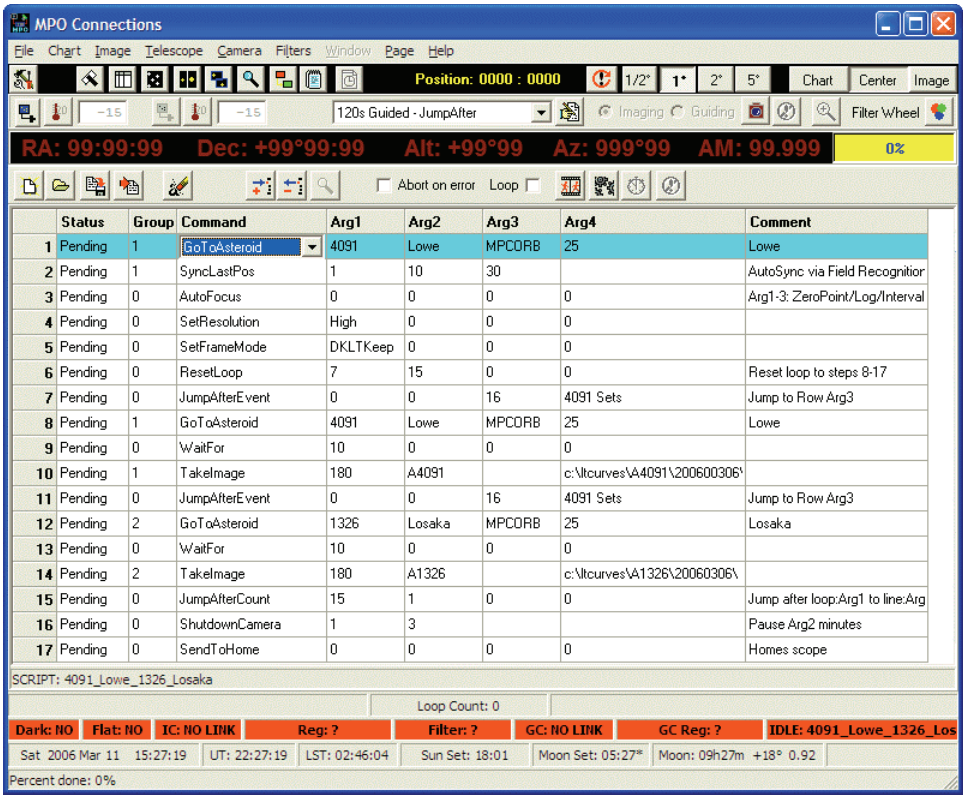
After the scripts are loaded, I send the scopes to a bright star near the meridian. All three scopes start from a known home position and so a slew to that initial star almost always puts that star within the field of the CCD camera. The true position of the scope is found by comparing the image against a chart centered on the star's position and the scope's pointing is updated, if necessary.

After this initial sync, the scopes are each sent either directly to their first target field or, if the field is not quite high enough, to a bright star relatively near the asteroid field. An autofocus routine is run just prior to the start of actual observing.

3. 2. 2 The Observing Run

The scripts are started 30 minutes before the end of astronomical twilight or when the field is at least 25-30° high. While working below 30° is not generally recommended, the extra 10-30 minutes of observing time can be important.

Figure 4 shows a typical script for two targets in MPO Connections. This script obtained about 150 images of each asteroid during the night. The position of the scope was periodically updated and the focus reset, all without any human intervention. At the end of the night, when 4091 Lowe reached 30° in the west or Nautical Twilight began, whichever came first, the camera cooling was turned off and the telescope sent to its home position. Most of this was done while I was sleeping. All that was required in the morning was to upload the images to the analysis computer, remotely shutdown the observatory computers, and close the roofs. If I could just figure out a way to put garage door openers on those roofs, I wouldn't have to go outside at all – except to use the binoculars or 5" refractor!



	Status	Group	Command	Arg1	Arg2	Arg3	Arg4	Comment
1	Pending	1	GoToAsteroid	4091	Lowe	MPCORB	25	Lowe
2	Pending	1	SyncLastPos	1	10	30		AutoSync via Field Recognitior
3	Pending	0	AutoFocus	0	0	0	0	Arg1-3: ZeroPoint/Log/Interval
4	Pending	0	SetResolution	High	0	0	0	
5	Pending	0	SetFrameMode	DKLTKeep	0	0	0	
6	Pending	0	ResetLoop	7	15	0	0	Reset loop to steps 8-17
7	Pending	0	JumpAfterEvent	0	0	16	4091 Sets	Jump to Row Arg3
8	Pending	1	GoToAsteroid	4091	Lowe	MPCORB	25	Lowe
9	Pending	0	WaitFor	10	0	0	0	
10	Pending	1	TakeImage	180	A4091		c:\ltcurves\A4091\200600306	
11	Pending	0	JumpAfterEvent	0	0	16	4091 Sets	Jump to Row Arg3
12	Pending	2	GoToAsteroid	1326	Losaka	MPCORB	25	Losaka
13	Pending	0	WaitFor	10	0	0	0	
14	Pending	2	TakeImage	180	A1326		c:\ltcurves\A1326\20060306\	
15	Pending	0	JumpAfterCount	15	1	0	0	Jump after loop:Arg1 to line:Arg
16	Pending	0	ShutdownCamera	1	3			Pause Arg2 minutes
17	Pending	0	SendToHome	0	0	0	0	Homes scope

SCRIPT: 4091_Lowe_1326_Losaka

Loop Count: 0

Dark: NO | Flat: NO | IC: NO LINK | Reg: ? | Filter: ? | GC: NO LINK | GC Reg: ? | IDLE: 4091_Lowe_1326_Los

Sat 2006 Mar 11 15:27:19 | UT: 22:27:19 | LST: 02:46:04 | Sun Set: 18:01 | Moon Set: 05:27* | Moon: 09h27m +18° 0.92

Percent done: 0%

Figure 4. The screen shot above shows a typical MPO Connections script that is used to work two asteroids continuously through the night and then shutdown the camera and telescope at the end of the run.

3. 3. Standardizing Observations

In the sample script above, no provision is made for filtered observations. Typically, most of the lightcurve work has been conducted using a clear filter and, more recently, no filter – which provides a 0.3m gain over the clear filter. For shorter period asteroids, filtered observations are not required since it's possible to catch enough of a cycle in a single night and so matching runs from several nights is fairly straightforward.

However, this practice needs to change. First, it's much harder to match sessions for an asteroid if the period is long and/or the sessions are spread out over several weeks and even months. Second, baseline lightcurves to be used by Mikko Kaasalainen and others in combination with data from large surveys must be calibrated to a standard system. Last, but not necessarily finally, merging data sets used in the binary asteroids program run by Petr Pravec is much simpler and introduces fewer random variables if all data are on a standard system.

A recent article in the *Minor Planet Bulletin* by Richard Binzel (2005) and outlined in greater detail in my book (Warner 2006) makes reducing to approximate standard magnitudes relatively quick and easy. With only a little refinement, using two filters for a limited number of observations, even more accurate results can be obtained.

3. 4. Data Reduction and Period Analysis

Once the images are uploaded to the analysis computer, the one in the house that controls the observatory computers, the images are measured in MPO Canopus. This program uses aperture photometry to determine the raw instrumental magnitudes of the target and up to five comparison stars.

The differential value between the target and average of the comparisons is used for period analysis.

The period analysis uses the Fourier analysis algorithm developed by Alan Harris (1989). This is the “industry standard” for asteroid lightcurve work, though it works quite well on other types of objects as well, e.g., eclipsing variable stars.

If more than one night’s data is involved, the average magnitude of the comparisons for the first night is taken as the zero point and all the other session zero points are adjusted to make their data match the curve for the first night. Unless the magnitudes are reduced to a standard system, even an internal one, these shifts are purely arbitrary. However, if the data for each night cover a significant portion of the cycle, the error is usually <0.01m.

Figure 5 shows a typical lightcurve obtained at PDO where the data from each session met the requirements for a straightforward matching. Here, the curve has at least double coverage over almost 75% of the cycle, providing a very “solid” solution.

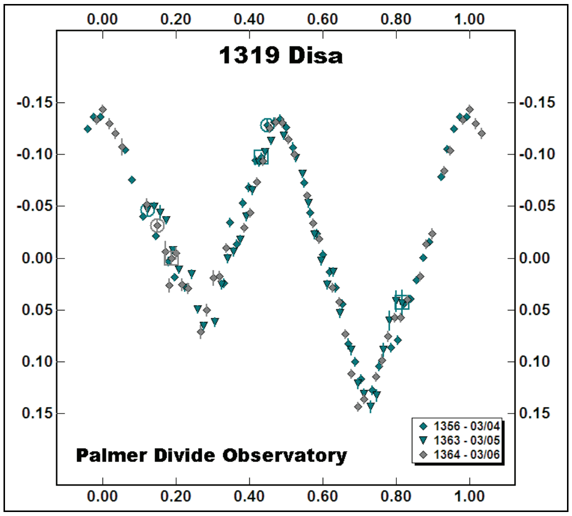


Figure 5. The lightcurve of 1319 Disa obtained at the PDO in March 2006. The synodic period of the curve is 7.080±0.003h. The amplitude of the curve is 0.26±0.02mag.

Figure 6 shows a slightly different situation, one where each session did not cover a significant portion of the curve. In this case, a reasonable solution was possible because the data covered large segments of the assumed cycle and a minimum and two maximums were captured. While the period of 42.16h is likely correct, it is not as certain as the one for 1319 Disa.

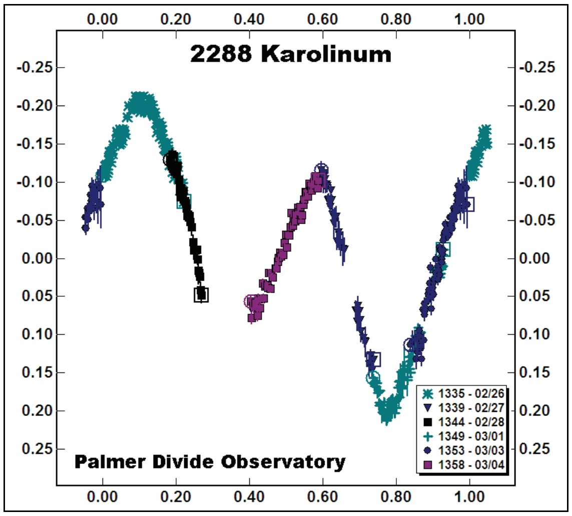


Figure 6. The lightcurve of 2288 Karolinum. The synodic period was reported to be 42.16±0.04h. Catching the minimum and maximums was critical to finding a solution.

3. 4. 1 Avoiding Aliases

The most important thing to keep in mind when doing period analysis is “never trust a computer.” No matter how well written the analysis routine, it can be fooled into finding the wrong solution when the data groups are spaced just right with respect to the period. These incorrect periods are known as aliases and they are a bane to those doing lightcurve work regardless of the type of object.

Periods found with sparse sampling spaced days apart should be considered highly suspect. The best way to eliminate the problem of aliases is to get two good nights back-to-back, meaning as long of runs as darkness allows. It’s not always possible but – if nothing else – minimize the time between sessions and be aware of alternate solutions. My book provides more details and examples of this issue.

As to when you can call it quits even though you don’t have complete coverage of a curve, there’s not a simple answer. It might be said to be when you have enough data such that no other solution makes sense, which makes it a pure judgement call. Given that period analysis has often called a mix of science, experience, and black magic, there may be no definitive answer.

4. Results

4. 1. Combined Asteroid Lightcurves

The number of asteroid lightcurves has risen dramatically in the last few years, as can be see in Figure 7.

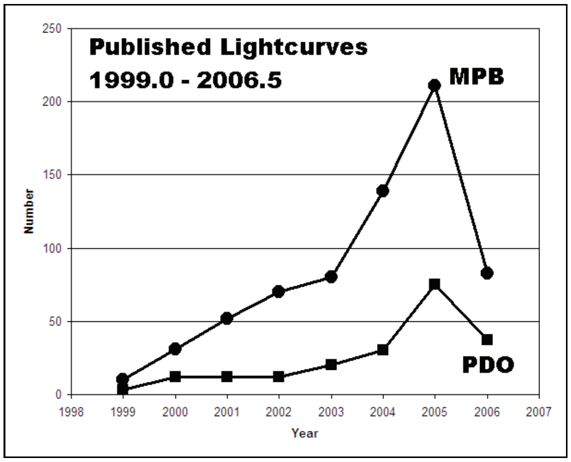


Figure 7. Total lightcurves published in the *Minor Planet Bulletin* between 1990 and mid-2006. MPB is the total number published each year. PDO is the number curves submitted by the Palmer Divide Observatory, with some of those being in collaboration with other observatories.

From only 10 lightcurves published in the *Minor Planet Bulletin* in 1999, the number rose to 211 curves in 2005. With half of 2006 on record, there may be a slight decrease but it still looks to exceed 150 since the 2006 statistics do not include the 40 PDO lightcurves submitted or awaiting write-up at the time of this writing.

This paints only part of the picture, the one dominated by formally published amateur contributions. The lightcurve list maintained by Harris (2006) gives data on approximately 2100 asteroids with about 1650 of those having reliable periods listed. Included in that list are data from professionals and – among others – the group of observers under the direction of Raoul Behrend. This group, of which many are amateurs, has produced a very large number of curves. However, most of the results remain unpublished save on the Behrend web site (2006).

4. 2. Hungaria Asteroids

The Hungarias are high albedo objects that have semi-major axes just outside that of Mars (~1.8-2.0 AU), high inclination, but relatively small eccentricity. Because of the higher albedos (0.3-0.4) shown by about half the group and their proximity to Earth, the Hungarias are among the smallest main belt asteroids that can be covered regularly by amateur sized equipment.

The Hungarias are important because they provide a sampling of non-planet crossing bodies about the same size as NEAs, which do have planet-crossing orbits. Since some theories regarding NEA rotation and binary development rely on planetary influences, a comparison of the Hungaria and NEA populations can demonstrate the validity or refute the validity of these theories. If the two groups have similar spin axis properties and binary population densities, then other factors besides those of planetary influence must be considered.

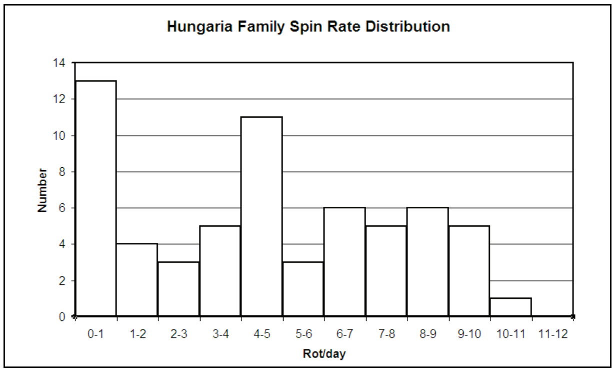


Figure 8. Hungaria Spin Rate Distribution. The X-axis is in rotations per day, or Period(h)/ 24.0.

Figure 8 shows the spin rate distribution of the 62 Hungaria asteroids included in the Harris list (PDO contributed data for 44, or 71%, of those,). A quick look shows that two groups dominate, those with rotation periods >18h and those with periods between 4.8 and 6.0 hours. This distribution is similar to the NEA population (Harris and Pravec 2006), which indicate strong similarities in the forces that control spin axis rates for the two populations and so they are mostly independent of planetary forces.

There is one difference of note, however. The small number of very fast rotators would seem to indicate that the “spin barrier” does not exist in the Hungarias. The spin barrier dictates when an asteroid must be monolithic in order to survive its fast rotation. Slower rotating asteroids are likely “rubble piles”, or loose conglomerations of material held together as much by, if not more than, gravity and not physical structure.

The often-heard refrain of “More Data!” applies very much to the study of the Hungarias. The sample has grown significantly in the last two years but a much larger number of lightcurves from this group is needed before speculation regarding similarities and differences with NEAs and Main Belt asteroids can be turned into solid theory or fact.

4. 3. Binary Asteroids

Asteroids with satellites were once only speculation with a few tantalizing bits of evidence from occultation observations and sparse lightcurves. As of March 4, 2006, there were 89 asteroids with at least one satellite with a distribution among groups given by Johnston (2006) as:

26	Near-Earth asteroids
5	Mars crossing asteroids
34	main-belt asteroids (one w/ two satellites)
1	Jupiter Trojan asteroid
23	Trans-Neptunian objects (one w/ two satellites).

From 2004 October to 2006 February, the Palmer Divide Observatory made the initial discovery of six binary asteroids (in chronological order):

9069	Hovland
5405	Johnson
76818	2000 RG79
3309	Brorefeld
5477	1989 UH2
34706	2001 OP83

Confirmation and final determination of these discoveries would not have been possible without the contributions of the Binary Asteroids Group under the direction of Petr Pravec, Ondrejov Observatory (Pravec 2005).

The BinAst group has been responsible for the discovery of several other binaries in the past two years – mostly within the NEA and Hungaria populations, leading to a paper by Pravec that included more than 50 co-authors, many of them amateurs (Pravec 2006). The work requires higher precision, 0.02m or less in most cases, and often following the same target for days if not a week or more. However, the scientific rewards are enormous. More observers are needed, especially those in South America, Europe, and AsiaPac.

5. Diversions

During the course of observing asteroids, which means sitting on the same field all night, it's not uncommon to pick a comparison star that is variable. The variable star search routine in MPO Canopus (see Stephens and Koff) is also used to examine stars in the field for previously unknown or unclassified variables.

Admittedly, no emphasis is placed on finding or following up variable stars. Those that have been found tend to be >14m and so unless it is an eclipsing variable with total eclipses, a definitive model using Binary Maker 3 (Bradstreet) is not possible. However, this is a worthy pursuit that yields even more data from the same amount of observing time. Those who can and want to put some variety in their work should devote a little time to this field.

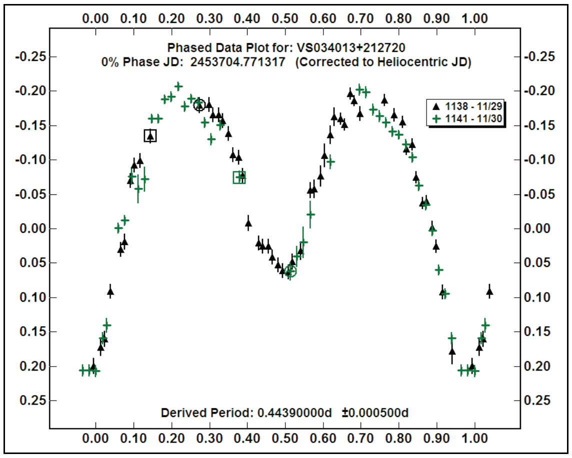


Figure 9. The lightcurve of a variable star "discovered" at PDO. There was no follow up since that took time away from the primary work on asteroids.

A diversion that does not require as much time at the telescope, usually only two to four hours a month, is visual double stars. Work on these at the PDO started in early January 2006, with the result being more than 300 observations submitted to the Webb Society's Double Star Section Circulars for publication. Bob Argyle has written an excellent book on the subject (Argyle 2004) that serves as a good jumping point. This is an excellent "full moon" project when our own natural satellite obscures the asteroids.

6. Acknowledgements

My thanks to Alan W. Harris of the Space Science Institute and Petr Pravec of the Astronomical Institute, Ondrejov Observatory, Czech Republic, for their continued guidance.

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