# Lightcurves of Icy “Dwarf Planets” (Plutoids)


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## Abstract

We present lightcurve results of 11 Trans-Neptunian Objects (TNOs) obtained in 3 observation runs at El Leoncito (CASLEO), 2.15 m telescope and Cerro Tololo Inter-American Observatory (CTIO), 1.0 m Yalo telescope. Lightcurve results will help the classification of this Icy “Dwarf Planets” as possible Plutoid objects. 9 targets were selected from an original 39 candidate list, and observed in a total amount of 12 nights spread in September 2007, August and December 2008. We obtained photometric data for (120178) 2003OP32, (145453) 2005RR43, (145452) 2005RN43, (145451) 2005RM43, (47171) 1999TC36, (55637) 2002UX25, (145452) 2005RN43, (120178) 2003OP32, 2002MS4, 2007UK126 and (55565) 2002AW197. Most of the objects present a quasi-flat lightcurve (amplitude less than 0.1 mag), denoting a quasi-spherical or oblate shape. We calibrated data with NOAO IRAF and performed differential photometry. In some observation runs, Landolt standard fields L92, L113 and L95 were observed and V-R color index was computed for some objects.


## 1. Introduction

The International Astronomical Union has introduced a new category of objects in the Solar System: the "dwarf planets". The icy "dwarf planets" in the Trans-Neptunian region have been lately designated as "Plutoids". From the geophysical point of view, the "dwarf planets" are objects in hydrostatic equilibrium. Therefore, the shape and the rotational state can be used to put constraints in some physical properties such as density. Tancredi & Favre (2008) have proposed classification criteria for "dwarf planet" based on their shape and size, mainlyconsidered as the estimates of the shapes from the lightcurves.

**Criteria to classify a body as a “dwarf planet”**

**1.** The diameter of the body should be $D$>450 km for icy objects and $D$>800km for rocky ones. These limits are not precisely determined and they depend on factors such us the composition of the material and the ambient temperature.

**2.** If there is a direct measurement of the relative roughness with values < 1% and the shape correspond to a figure of equilibrium, the candidate is accepted (*Case I*).

**3.** If not, we analyze the observed lightcurve amplitude ($\Delta m$).

**4.** If $\Delta m<0.15$ *mag*, the candidate is accepted as a small departure from a sphere or MacLaurin spheroid with small albedo spots (*Case II*).

**5.** If $\Delta m\geq 0.15$ *mag*, the lightcurve (the intensity square) is fitted to a Fourier series of order two and the ratio (β) between the quadratic sums of the coefficients of order 1 and 2 is computed.

**6.** If $\Delta$m<0.25, the lightcurve can be fitted to a triaxial ellipsoid. We then analyze if this ellipsoid corresponds to the Jacobi family. We compute the range of possible densities as a function of the assumed aspect angle of the observed lightcurve.

**7.** If there are solutions with $\rho\geq 1$ gr.cm$^{-3}$, the candidate is accepted as a Jacobi ellipsoid (*Case III*).

**8.** If all the solutions correspond to $\rho<1$ gr.cm$^{-3}$, the candidate is not accepted. The size might be overestimated due to an assumption of a low albedo ($p_V$>>0.1) (*Case IV*).

**9.** If $\Delta m>0.25$, the candidate is not accepted, the lightcurve departs from an ellipsoidal figure possibly due to important contributions of albedo spots or there is an overestimation of the size due to an assumption of a low albedo ($p_V$>>0.1) (*Case V*).

No lightcurves have been published for about half of the possible 39 candidates, which makes it impossible to decide on their status. We have conducted an observational program to obtain lightcurves in the visible spectrum for a set of these candidates. Combined with published spectra and estimates of the size, we can classify these objects according to the proposed scheme, and we can put constraints on their physical properties and geophysical history.

## 2. Observations

Direct CCD imaging in the visual spectrum was performed in all observing runs and 5 – 7 minute exposures were taken in order to achieve SNR ~ 30 or higher.

The first observing run was performed in CASLEO with the 2.15 m telescope during 13, 14, 18 and 19 September 2007. Problems regarding non-uniform parasite illumination in Ropper 1300B detector made adequate calibration impossible. Ropper CCD is 1310 x 1300 px @ plate scale of 0.23“/px and Field Of View (FOV) around 5' square. Objects observed were (120178) 2003OP32, (145453) 2005RR43, (145452) 2005RN43 and (145451) 2005RM43. The average seeing was 2”.

The second observing run was performed at CTIO with the 1.0 m Yalo telescope during 14, 25, 26 and 27 (half night) August 2008. 5 minute exposure time was applied in direct CCD mode with Y4K camera 4064 x 4064 px in 2x2 binning mode @ 0.578”/px and a FOV around 20' square. Landolt Fields L92, L95 and L113 were used to standard calibration with IRAF. The objects observed were (47171) 1999TC36, (55637) 2002UX25, (145452) 2005RN43, (120178) 2003OP32 and 2002MS4. The last one was placed in a very crowded field and star extraction is being implemented with DAOPHOT package. The average seeing was about 1.6”.

The third observation run was performed in CASLEO using the same instrument configuration as explained above during 26, 27, 28 and 29 December 2008, however, images were taken in 2x2 binning mode @ 0.46“/px. The observed objects were 2007UK126 and (55565) 2002AW197. The average seeing was approximately 2,2”.

## 3. Data Reduction

In all observing nights, calibrations images were taken. This includes Flat Fields (Dome Flats and Sky Flats around 10 each type per filter used). We also exposed around 10 dark frames each night to corroborate the negligible electron current present in both Y4K and Ropper CCD detectors Nitrogen-cooled at a -120 C temperature. For Bias processing, overscan fitting was performed in both detectors. In particular, the Y4K camera has 4 overscan regions, one for each amplifier which required sophisticated IRAF script by Massey and modified by us to run over 2x2 binned images. Anyway, Bias frames were recorded to make sure no 2-dimensional noise pattern was present.

One regarding comment worth for the first run in CASLEO was a non-uniform parasite illumination that appeared in direct CCD Ropper 1300B and affected most of the images. Background subtraction was implemented in IRAF with ILLUMSKYCORR task and also implemented in MaxIm DL 5 software with Background Subtraction operation, and very negligible lightcurve distortion is noticed because the gradient remained stable and static over the run.

A growth curve for faint objects was computed and the optimal aperture for photometry resulted in 3 arcsec. Typical photometric errors obtained were below 0.05 mag for CASLEO runs and almost 0.01 mag for CTIO run. Several images were rejected as photometric ones because of the presence of stars near the object. That is the case of TNO 2002MS4 that presented a very crowded star field and more advanced data reduction is being applied in order to eliminate surrounding stars by PSF modeling with DAOPHOT package. Photometry was performed with PHOT package under NOAO/IRAF v2.14 and SAO DS9 display engine.

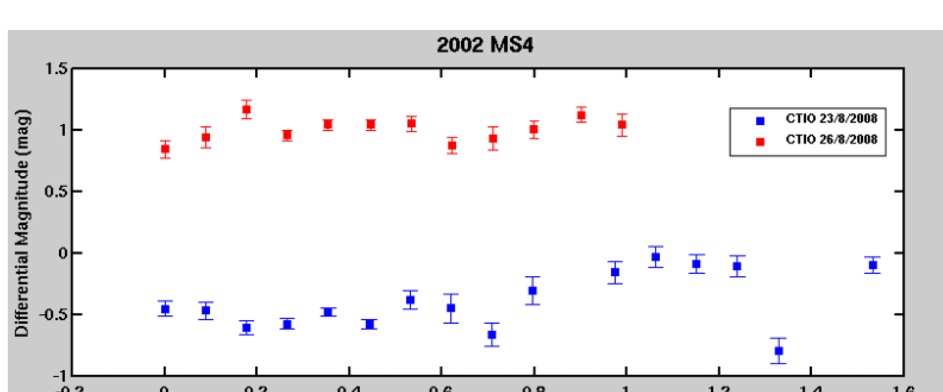
**Observation Summary**

| Object | Date | #Images | r(AU) | Δ(AU) | α(deg) | Telescope |
|---|---|---|---|---|---|---|
| 2002MS4 | 23/08/08 | 12 | 47.3 | 46.8 | 1.1 | CTIO |
| | 26/08/08 | 16 | 47.3 | 46.8 | 1.1 | CTIO |
| (120178) | 13/09/07 | 16 | 41.3 | 40.4 | 0.7 | CASLEO |
| | 14/09/07 | 16 | 41.3 | 40.4 | 0.7 | CASLEO |
| | 18/09/07 | 39 | 41.3 | 40.4 | 0.8 | CASLEO |
| | 25/08/08 | 22 | 41.4 | 40.4 | 0.4 | CTIO |
| | 26/08/08 | 25 | 41.4 | 40.4 | 0.4 | CTIO |
| (55565) | 26/12/08 | 30 | 46.6 | 45.9 | 0.9 | CASLEO |
| | 27/12/08 | 32 | 46.6 | 45.9 | 0.9 | CASLEO |
| | 28/12/07 | 23 | 46.6 | 45.9 | 0.9 | CASLEO |
| | 29/12/08 | 32 | 46.6 | 45.9 | 0.9 | CASLEO |
| (145451) | 13/09/07 | 16 | 35.2 | 34.8 | 1.5 | CASLEO |
| | 14/09/07 | 12 | 35.2 | 34.8 | 1.5 | CASLEO |
| | 18/09/07 | 41 | 35.2 | 34.8 | 1.5 | CASLEO |
| (145452) | 13/09/07 | 19 | 40.7 | 39.8 | 0.6 | CASLEO |
| | 19/09/07 | 30 | 40.7 | 39.8 | 0.6 | CASLEO |
| | 24/08/08 | 24 | 40.7 | 39.7 | 0.3 | CTIO |
| | 27/08/08 | 37 | 40.7 | 39.7 | 0.3 | CTIO |
| (145453) | 13/09/07 | 16 | 38.5 | 38.0 | 1.3 | CASLEO |
| | 14/09/07 | 11 | 38.5 | 38.0 | 1.3 | CASLEO |
| | 19/09/07 | 42 | 38.5 | 38.0 | 1.3 | CASLEO |
| (47171) | 23/08/08 | 37 | 30.8 | 38.1 | 1.4 | CTIO |
| | 25/08/08 | 25 | 38.8 | 38.1 | 1.4 | CTIO |
| 2007UK126 | 26/12/08 | 34 | 45.5 | 44.8 | 0.9 | CASLEO |
| | 27/12/08 | 25 | 45.5 | 44.8 | 0.9 | CASLEO |
| (55637) | 24/08/08 | 32 | 41.9 | 41.4 | 1.2 | CTIO |

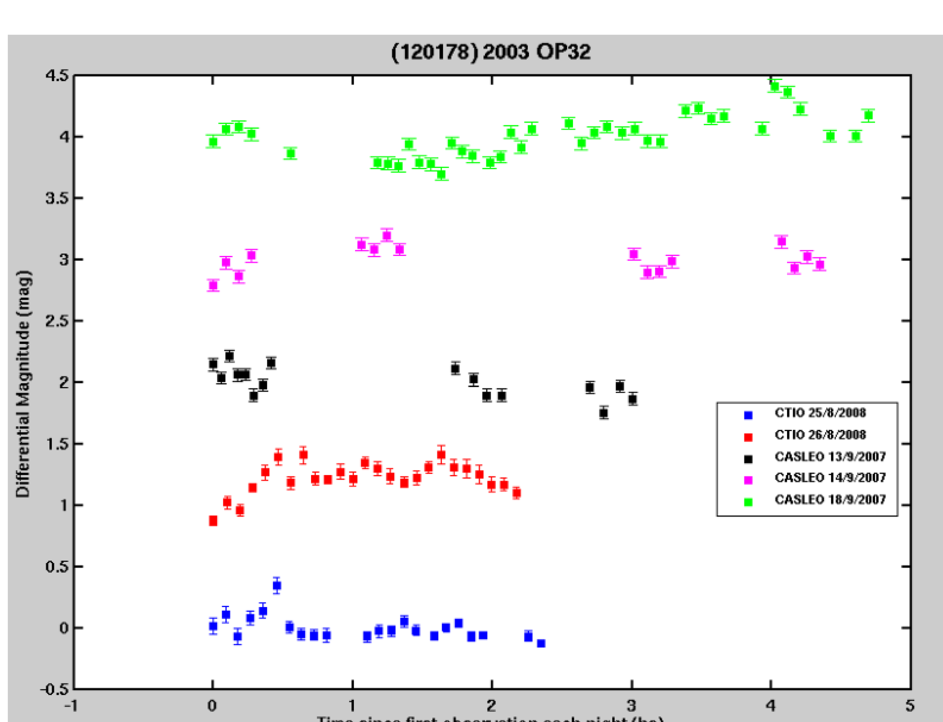
## 3. Results

Overall lightcurves show relative small amplitude and quite scattered data. Here we show lightcurves for each object observed. The observing run is indicated and each night of observation is artificially displaced 1 magnitude up and overlapped in time for ease of visualization.

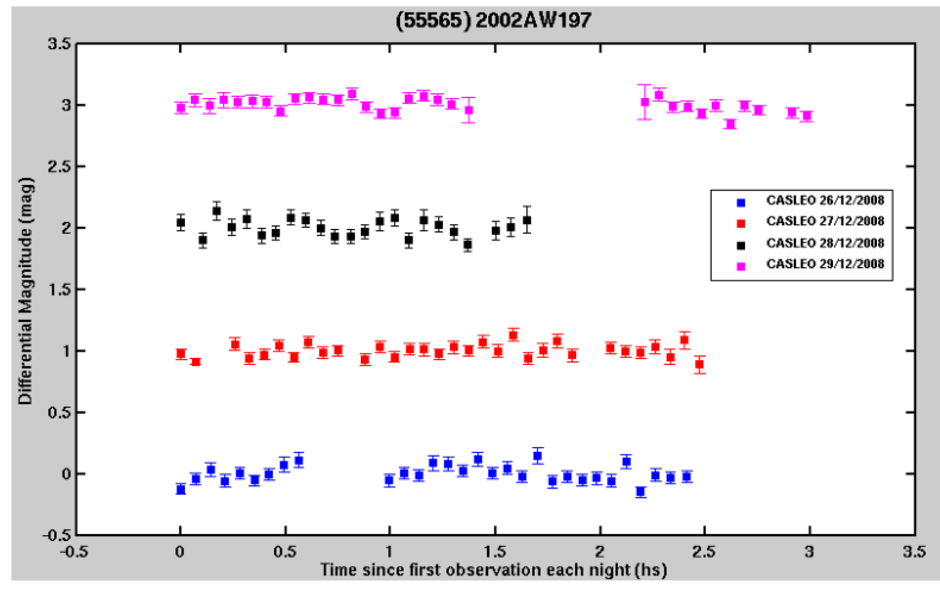
**2002 MS4** – Lightcurve series for each night. Total observed time ~ 2.6 hs



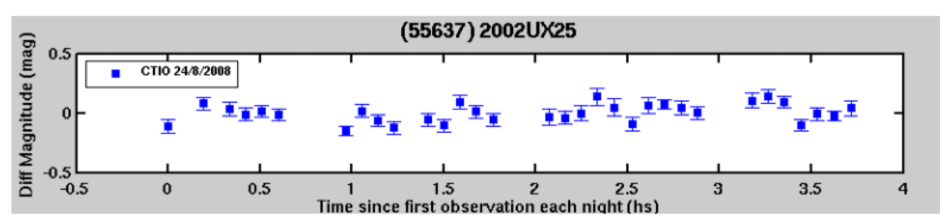

**(120178) 2003 OP32 –** Lightcurve series for each night. Total observed time ~ 17 hs



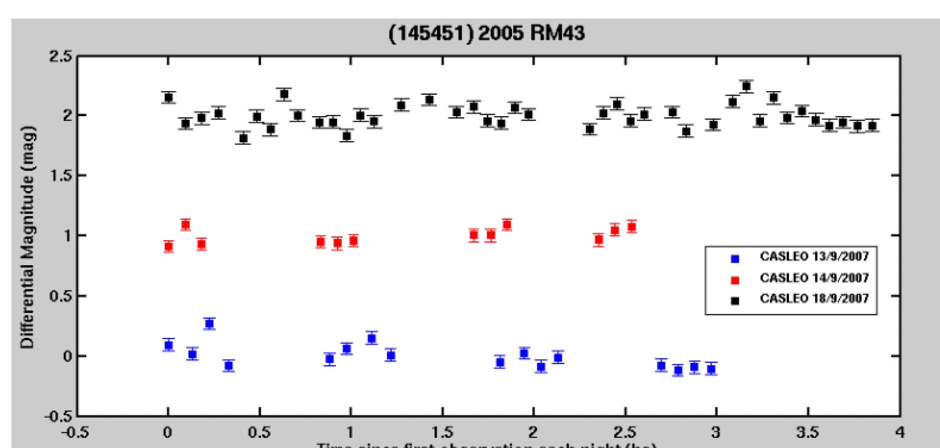

**(55565) 2002 AW197 -** Lightcurve series for each night. Total observed time ~ 9.5 hs



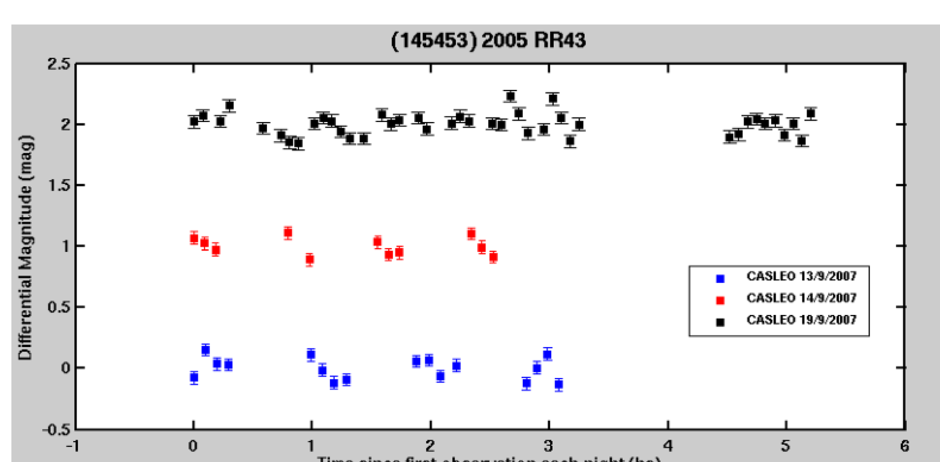

**(55637) 2002 UX25 -** Lightcurve series for the night. Total observed time ~ 4 hs



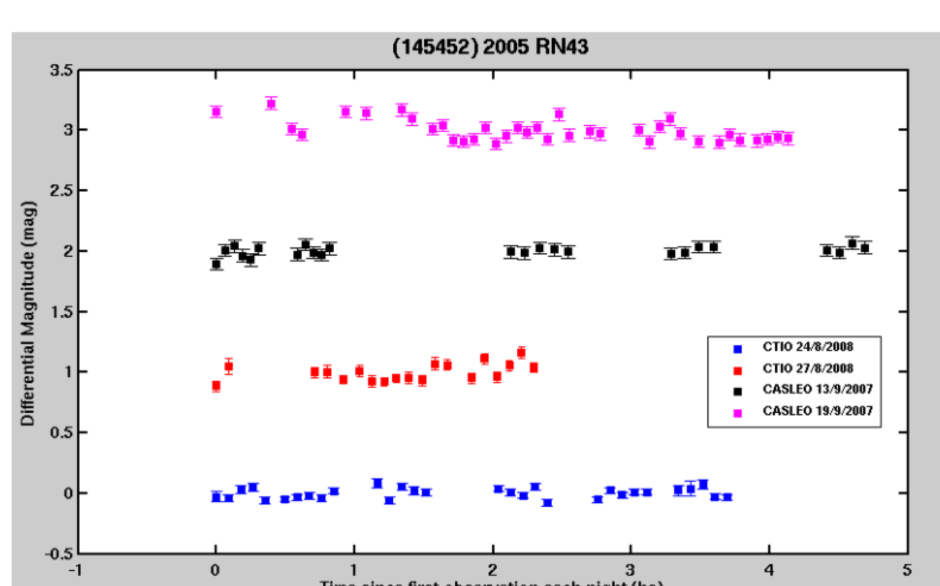

**(145451) 2005 RM43 -** Lightcurve series for each night. Total observed time ~ 10 hs



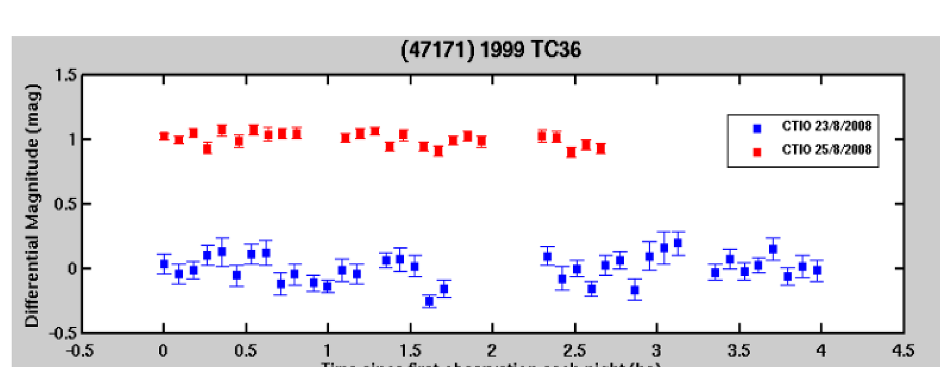

**(145453) 2005 RR43 -** Lightcurve series for each night. Total observed time ~ 11 hs



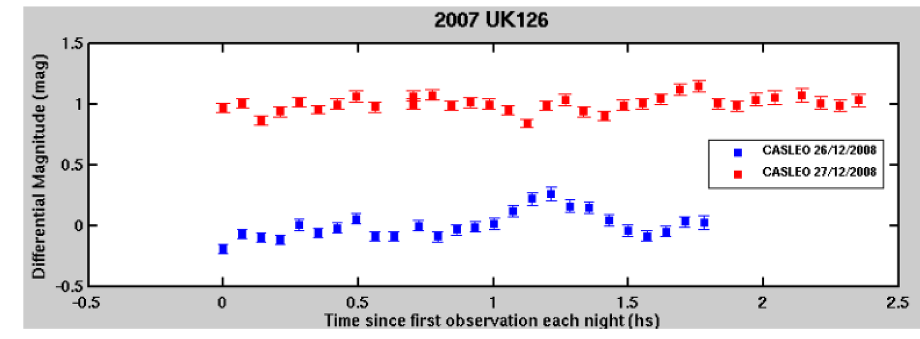

**(145452) 2005 RN43 -** Lightcurve series for each night. Total observed time ~ 15 hs




**(47171) 1999 TC36 -** Lightcurve series for each night. Total observed time ~ 7 hs




**2007 UK126 -** Lightcurve series for each night. Total observed time ~ 4.5 hs




## 4. Discussion

Now we are able to compute amplitudes for objects following this method. We generated lightcurves of Tri-Axial Ellipsoids according to the equations given by Barucci et al (1989). The ellipsoids have axial ratios and pole orientation chosen randomly.

We computed the standard deviation (σ) and the maximum amplitude (A) of lightcurve data points. A linear relation between σ and A is obtained in the range 0<σ<0.3 with a slope of 2.86 as shown in the figure below. Matlab was used to perform calculations.

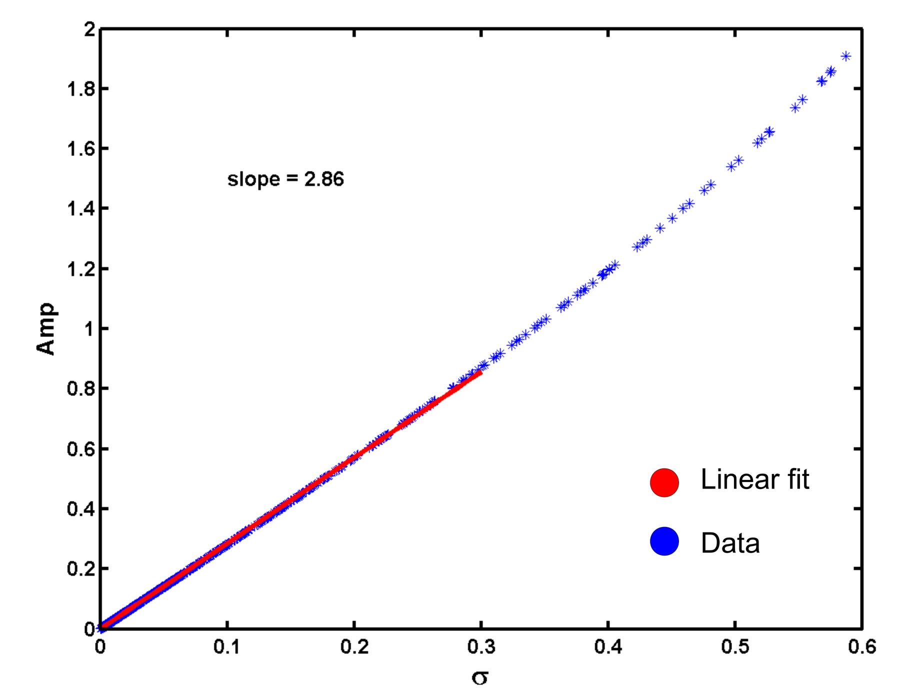



Figure. Visualization of linear relation between Amplitude and Standard Deviation

Now we can establish a simple equation (1) to compute TNOs amplitudes as a function of their observed standard deviation σ.

$$A=2.86\sigma \quad (1)$$

For a reasonable calculation of σ, we implemented a 2σ point rejection criteria and made an iteration until no point was rejected.

In the following table we present standard deviations and amplitudes computed with equation 1.

| Object | #total points | #final points | initial STD | final STD | Est. Amp. (mag) |
|---|---|---|---|---|---|
| 2002MS4 | 28 | 17 | 0.2706 | 0.09544 | 0.2730 |
| (120178) | 118 | 103 | 0.1610 | 0.12428 | 0.3554 |
| (145451) | 69 | 60 | 0.0915 | 0.06389 | 0.1827 |
| (145452) | 110 | 93 | 0.0657 | 0.04331 | 0.1239 |
| (145453) | 69 | 63 | 0.0860 | 0.07062 | 0.2020 |
| (47171) | 62 | 49 | 0.0858 | 0.05249 | 0.1501 |
| 2007UK126 | 60 | 43 | 0.0846 | 0.03865 | 0.1105 |
| (55637) | 32 | 32 | 0.0765 | 0.07648 | 0.2187 |
| (55565) | 117 | 105 | 0.0623 | 0.04917 | 0.1406 |

A selection of objects with amplitudes ≤ 0.15 mag are listed below and can be classified as Dwarf Planets according to item #4 of the exposed criteria.

| Object # and Designation | | Estimated Amplitude (mag) |
|---|---|---|
| (145452) | 2005 RN43 | 0.124 |
| (47171) | 1999 TC36 | 0.150 |
| - | 2007 UK126 | 0.111 |
| (55565) | 2002 AW197 | 0.141 |

## 5. References


**1.** Tancredi, G., Favre, S. 2008. Which are the dwarfs in the Solar System? Icarus, Volume 195, Issue 2, p. 851-862

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**3.** Barucci, M., Capria, M., Harris, A., Fulchignoni, M., 1989. On the shape and albedo variegation of asteroids—Results from Fourier analysis of synthetic and observed asteroid lightcurves. Icarus 78, 311–322.