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The EURONEAR Lightcurve Survey of Near Earth Asteroids - Teide Observatory, Tenerife, 2015

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Abstract One meter class telescopes could bring important contributions in the acquisition of lightcurves of near Earth asteroids (NEAs), based on which rotations and other physical properties could be derived or constrained. Part of a collaboration between IAC, ESA and the EURONEAR during the semester 2015A, the IAC80 and OGS telescopes at Teide Observatory in Tenerife were allocated for such a photometric project during 64 nights spread in a few observing runs. The main funding for this long observing mission was raised by the student observer Radu Cornea supported by the local newspaper *Sibiu 100%* which identified sponsorship offered by 9 private companies from his natal city Sibiu in Romania (included in the Acknowledgements). We observed 33 lightcurves of NEAs not published before, including 10 potentially hazardous asteroids (PHAs). Based on the quality of the Fourier period fits, we sorted the results in four groups which include 7 secured periods, 9 candidate periods, 10 tentative periods and 7 objects not solved. We resolved periods or suggested constraints for 13 NEAs having no other rotation knowledge (including 3 PHAs), confirming periods for other 6 targets published by other authors (mainly by Brian Warner). We suggested tumbling or binary nature for 6 targets (probing one of them) recommended for future dedicated campaigns. For the first time, we derived ellipsoid shape ratios for 21 NEAs (including 4 PHAs).

Keywords Near Earth Asteroids · Lightcurves · Rotation Periods · Physical Properties

1 Introduction

Near Earth Asteroids (NEAs) represent laboratories to study the formation and evolution of our Solar system, the apparition of water and life on Earth, providing also cheap opportunities for nearby space exploration and possible future mining industries. In the meantime, near Earth objects (NEOs) and potentially hazardous asteroids (PHAs) have been traced to be responsible for known past extinctions of some species [2] and they could pose longer future risk of impact with our planet, so their early discovery, orbital amelioration and physical characterisation are essential for the future of mankind.

Besides spectroscopy which requires larger telescopes endowed with visible and near infrared spectrographs, the observation of lightcurves of NEAs represent a great opportunity for small telescopes (sometime undersubscribed or closed) and also for amateur telescopes endowed with CCD cameras. These cheap instruments and especially the great amount of time available to amateur instruments can contribute to the physical characterization of NEAs during flybys of our planet. These studies can improve the knowledge of the faint end of the small asteroid

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populations which are otherwise difficult to observe in the main belt accessible only to larger telescopes (typically oversubscribed with other domains of astrophysics). Moreover, longer timespan and multi-site observational campaigns could improve the knowledge about binary asteroids [13,19], tumbling asteroids [11], and about some subtle effects such as the YORP/Yarkovsky [22], space weatering [7], thermal fatigue and fragmentation [10] which could change the orbits of smaller asteroids and create hazardous objects.

There are 19,122 NEAs known at 26 Nov 2018 (NASA/JPL [1]), from which only 1470 objects have any attempted lightcurves (less than 8%). Only 894 NEAs have any derived periods (meaning only 4.5%), and only 601 NEAs have solid periods (quality codes $Q = 3-$ or 3, meaning 3%). Only a few amateur astronomers contribute worldwide more substantially (lead by Brian Warner in USA who has observed more than one thousand NEAs), while very few professional programs dedicate time for lightcurve of NEAs using professional telescopes. In this context, since 2014 the EURONEAR [2] project is contributing in NEA lightcurves using mostly 1 m class telescopes available to the members of this network in Europe and Chile. Aznar et al. [3] published the first results using two small amateur telescopes to observe 17 NEAs, then Vaduvescu et al. [20] published the second data paper summing other 101 NEAs. Few other Minor Planet Bulletin publications include few more NEAs or binary NEAs observed by two of us [5,21] and including some collaborators led by B. Warner [30–32].

This is the third survey data paper in the EURONEAR photometric series. It resumes the long observational campaign performed in semester 2015A at Tenerife Observatory by the young Romanian amateur astronomer Radu Cornea who observed lightcurves of 33 NEAs using two 1 m class telescopes. Another (the fourth) data paper will resume this survey effort to sum together about 200 NEA lightcurves observed within EURONEAR between 2014 and 2018, which means 14% of all NEA lightcurves published today. Next, we will join this large photometric dataset with another spectral dataset of 76 NEAs observed in 2014-2015 part of a related EURONEAR project by Popescu et al. [18]. Amalgamating this entire dataset with other photometric and spectroscopic data available in the literature, we plan to conclude with a science paper aiming to link physical to orbital properties of NEAs and main belt asteroids (MBAs). Section 2 will present the observing facilities, and Section 3 the planning and data reduction software. The main Section 4 includes the observed NEAs and results, then the final Section 5 summarises the conclusions.

2 The Observing Facilities

Thanks to the collaboration between the IAC, ESA and EURONEAR, a total of 64 nights (mostly bright and gray time) spread during the 2015A semester were allocated for lightcurve observations with two telescopes at Teide Observatory in Tenerife, Canary Islands, Spain. Thanks to private sponsorship raised by the student Radu Cornea in his natal city of Sibiu, Romania (included in the Acknowledgement section), he could gather the necessary funding to support himself during 6 months to observe this entire campaign, which actually has become the longest ever EURONEAR observing mission. We briefly present next the two involved observing facilities, including their main characteristics in Table 1.

2.1 The IAC80 0.8 m Telescope (IAC80)

The 0.82 m $F/11.3$ IAC80 telescope was entirely built in Spain and installed in 1991 at Teide Observatory (OT) at 2390 m altitude in Tenerife. At its direct Cassegrain focus the CAMELOT camera with 2048×2048 13.5 µm pixels in installed, providing 0.304″/pixel and a square 10.6′ field. Up to 9 broad band or narrow band filters could be mounted in the filter wheel. The median OT site seeing is 0.8″, while the IAC80 typical seeing is 1.0″. We used IAC80 during 7 observing blocks (4-6 nights each) summing 37 nights.

2.2 The ESA OGS 1.0 m Telescope (OGS)

The 1.0 m ESA Optical Ground Station (ESA-OGS) was inaugurated in 1995 at Teide Observatory, being built by Carl Zeiss for tests of laser link communications with the Artemis satellite and also for observations of space debris. The telescope is also used by ESA for some NEO follow-up and survey work part of the Space Situational Awareness (SSA) programme, and by the IAC for other astronomical observations. At its Ritchey-Chrétien wide field $F/4.4$ focus, the OGS is equipped with a e2V CCD camera with 4096×4096 15.0 µm pixels of 0.70″/pixel covering a square 44.3′ field. For most our observations we windowed half this field (FOV $22' \times 22'$), imaging only the central square field, in order to read faster. We used the OGS during 5 observing blocks (5-7 nights each) summing 27 nights.

[1] https://ssd.jpl.nasa.gov/sbdb_query.cgi
[2] www.euronear.org

Table 1: Technical characteristics of the telescopes and total observed time (ObsT column).

Observatory	Country	Telescope	Acronym	D (m)	F/D	Camera	Pixel ($''$)	FOV ($'$)	Seeing ($''$)	ObsT (h)
Izaña Teide (OT)	TF Spain	IAC80	IAC80	0.82	11.3	CAMELOT	0.30	10.6	1.0	130
Izaña Teide (OT)	TF Spain	ESA-OGS	OGS	1.00	4.4	CCD	0.70	22 (44)	1.0	121

2.3 Tracking and Filters

Both IAC80 and OGS telescopes are capable to track Solar system objects using differential tracking rates, and we used this mode to observe most of our targets at half proper motion. Following the targets at half speed has three advantages: it allows to double the exposure time for fainter objects (and the S/N ratio) without trailing reference stars; both targets and reference stars have similar (half trailed) shapes allowing eventually to use PSF photometry to achive similar uncertainties; and the shifted field of view of the entire observing session is smaller (half the one obtained by tracking at full μ), allowing more standard stars to remain longer in the field, possible to be used for the entire session. Only for a few faint and very slow moving targets we used tracking at full proper motion, to increase the S/N on target.

To minimize the Moonlight and calibrate photometry in the same band used before in EURONEAR, for most targets we used the Sloan r filter (in IAC80) or the Harris R filter (in the OGS), observing only few very faint and slowly moving targets in white band (no filter) with the OGS.

3 Planning Tools and Data Reduction Software

Before each observing block, we used the EURONEAR *Long Planning* web-based tool [3] to search for observable NEAs having no lightcurve data known before, placing a typical limiting magnitude $V \sim 18$, proper motion slower than $\mu < 5''$/min, and minimum visibility 3 hours above 30 degrees altitude.

Following every observing night, the observer used the *Lightcurve Determination for Asteroids* (LiDAS) pipeline (Vaduvescu et al., [20]) to reduce the preliminary lightcurves (relative to some arbitrary zeropoints), in order to plan the targets and exposure times for the next observing nights.

Later on, we reduced the photometry using the *MPO Canopus* [4] Windows based software written by Brian D. Warner, importing the images previosuly reduced by bias and flat field using some IRAF [5] scripts. Canopus identifies the fields and allows matching up to 5 photometric stars whose r-band magnitudes were later updated for each session based on their VizieR [6] precise magnitudes from the SDSS 12 [1], Pan-STARRS DR1 [9] or the APASS catalog [12]. Using Canopus, we finally merged all multi-night data and fit the asteroid lightcurves, deriving the rotation periods or only some constrains for some poorly observed objects.

4 The Observed NEAs and Results

Table 2 includes 33 NEAs observed during our Tenerife 2015 campaign. We prefer to keep the targets designations originally used in 2015, adding the asteroid number wherever it became available in the meantime. We list the NEA number or designation (marking in bold PHAs), the orbital class (APollo, AMor or ATen), absolute magnitude H, the observing date or interval (in format DD/MM/YY), telescope, apparent magnitude V, proper motion μ (in $''$/min), exposure time (in seconds), total observed time (rounded up in hours), reduced magnitude $H(\alpha)$ at observed phase angle α (in degrees), derived semi-major axis ratio a/b, measured amplitude, derived rotation period P (in hours) and the Fourier fit error σ in the second last column.

None of the targeted NEAs was observed before and had no published periods by the date of our observations. During our survey, mostly Brian Warner targeted about half the list and later published his results in Minor Planet Bulletin. For comparison with our results, we include the published literature periods (PL) in the last column of our Table 2, according to the ALCDEF database [7].

[3] http://www.euronear.org/tools/longplan.php
[4] http://www.minorplanetobserver.com/MPOSoftware/MPOCanopus.htm
[5] IRAF is distributed by the National Optical Astronomy Observatory, which is operated by the Association of Universities for Research in Astronomy (AURA) under a cooperative agreement with the National Science Foundation
[6] http://vizier.u-strasbg.fr/viz-bin/VizieR
[7] http://www.alcdef.org

We provide in the P column of Table 2 the periods in four notations, depending on the uncertainty of our results.

First, with bold characters in column P we give the *secured periods* for the best observed objects (most of them which agree well with published periods), proposed to be flagged with quality codes $U \sim 3$ (acc to ALCDEF codes [8].

Second, we list with normal characters the *candidate periods* for incompletely covered targets, possibly dual periods (typically half or double our preferred or previously published value) or some suggested short periods (labeled with P2) for candidate tumblers or possible binary asteroids. We propose most of the candidate periods to be flagged with quality codes $U \sim 2$.

Third, we mark by TP the *tentative periods* of some insufficiently observed targets (most producing only a lower period limit) and some suggested periods for objects showing multiple (more than two) solutions. These tentative periods should probably correspond to quality codes $U \sim 1$ and should be regarded with caution.

Fourth, we skip assesing any periods for some *poorly observed objects* during only one or two nights and for a short available interval, or targets observed during some nights affected by weather. Most of these objects show flat and/or noisy curves, possibly due to round shapes or pole orientation during our observations.

We proposed new periods or constraints for 13 targets, namely: 4947 Ninkasi, 90367, 216523, 241662, 285331, 285625 (TP2 suggested by us [20]), 306462, 416032, 2002 EX8, 2008 KV2, 2010 XL69 (432655), 2010 XY72 (453707) and 2015 HO116. We confirmed periods for other 6 targets, namely: 141527, 2004 DH2 (427684), 2007 ED125, 2012 LC1 (436775), 2014 EK24 (459872) and 2015 CA1.

The magnitude error bars are dominated by the target photometric uncertainties. The field zero points are quite secure, being derived from a few (up to 5) SDSS or Pan-STARRS catalog stars in the field typically being bellow 0.01 mag (a bit larger for APASS stars whenever the other catalogs did not cover the region). Although the OGS apperture is larger than IAC80, the larger pixel size of the OGS result in fewer pixels available to solve the fainter source fluxes, which could actually decrease the OGS photometric precision. The period uncertainties are adopted from Canopus, and they should be regarded with caution for targets having shorter time coverage.

We calculated the shape ratios a/b for 21 NEAs (including 4 PHAs), assuming a simple triaxial body model with semimajor axes $a > b > c$ and the object rotation around the c axis, following the method of Zappala et al. [23]. First, we derived the light curve amplitude at zero phase angle using the expression $A(0) = A(\alpha)/(1 + m\alpha)$, where A is the amplitude and $m = 0.0225$ (the average of known slope parameters to date). The shape ratios a/b are included in Table 2.

We present the photometry plots in two main groups. The first group includes the resolved objects having derived *secured periods* or *candidate periods* whose phase Fourier fits are included in Figure 1 and Figure 2, respectively. The second group includes in the Appendix the poorly observed objects, having derived *tentative periods* or *no periods* including tentative fits or raw JD plots in Figure 3 and Figure 4, respectively. In both groups the figures follow the asteroid designations given in Table 2.

We resume in Table 2 the observing circumstances and results of our campaign. Next, we will discuss the findings for each target.

[8] http://www.minorplanet.info/datazips/LCDB_readme.txt

Table 2: 33 NEAs observed during the EURONEAR Tenerife 2015 lighcurve survey. Please see Section 4 for the explanation of the columns.

NEA	Cls	H	Obs.nights	Telescope	V	μ	Exp	T	$H(\alpha)$	α	a/b	A	P	σ	PL
4947 Ninkasi	AM	18.0	22/04/15	IAC80	19.1	1.1	150	3	19.15	18.3	—	>0.5	TP	—	—
90367	AP	17.7	10-13/03/15	OGS	18.1-18.2	2.4-2.2	90,100,120	14	19.60	52.5	1.19	0.32	TP1, TP2	—	—
112985	AM	15.7	20/04/15	IAC80	19.2	4.2	120	2	16.20	10.8	—	—	—	—	mult
140288	AP	16.6	10/03/15	OGS	17.6	3.2	60	2	18.95	57.0	—	>0.2	—	—	...
...	...	...	25/03/15	IAC80	17.2	5.6	40	3	19.30	68.3	—	>0.4	TP	—	6.58
141527	AP	18.9	25/03/15	IAC80	15.7	3.3	40	4	18.95	10.8	...	1.00	—	1e-2	...
...	...	...	18-19/04/15	IAC80	19.0-19.1	0.4	150,200	11	19.95	10.8	1.92	1.00	**6.31**	1e-2	6.306
152679	AP	16.6	14-15/06/15	IAC80	16.1-16.0	4.6-4.7	50	5	18.20	53.0	—	>0.2	TP	—	125
159504	AP	17.0	16-22/06/15	IAC80	18.2	1.1-1.0	150,200	15	17.95	24.1	1.06	0.09	1.96	1e-2	7.84
216523	AM	20.6	22/04/15	IAC80	19.2	2.7	40	2	21.70	21.7	...	0.17	P2=0.042	1e-3	—
...	...	...	24-28/04/15	OGS	19.1-18.9	2.9-3.0	40,20,60	9	22.10	33.6	1.15	0.18	(P2=0.041)	1e-3	—
235756	AP	18.7	26-28/04/15	OGS	18.7-18.8	3.0-2.4	60,80	9	21.15	85.0	—	>0.6	—	—	7.18
241662	AM	17.6	16-19/06/15	IAC80	18.8-18.7	2.8-3.0	80,60,70	9	19.43	49.2	1.05	0.12	**2.42**	1e-2	—
285331	AP	18.3	25/03/15	IAC80	18.4	0.9	120	2	...	...	...	...	...	...	—
...	...	...	21-23/04/15	IAC80	17.6-17.5	2.1-2.4	80	7	21.20	81.3	2.61	1.07	**4.42**	1e-2	...
...	...	...	24/04/15	OGS	17.5	2.6	60	6	...	...	...	...	...	...	...
285625	AM	17.8	16/03/15	OGS	19.0	0.6	30	2	18.07	9.9	1.11	0.14	P2=0.0304	1e-4	TP2=0.065
306462	AM	18.5	10-14/03/15	OGS	18.4-18.7	2.4-2.1	100,120,45,60	18	18.73	3.0	1.34	0.34	P1=37.57	2e-1	—
345646	AM	19.9	21/04/15	IAC80	17.8	5.5	50	2	21.20	40.5	—	>0.1	—	—	3.05
...	...	...	25/04/15	OGS	18.0	4.5	40	1	21.30	39.5	—	>0.1	—	—	...
410088	AP	18.1	22-23/02/15	IAC80	18.3-18.4	2.0-1.9	120	7	19.55	34.5	1.10	0.18	TP	1e-2	4.781
...	...	...	26/02/17	OGS	18.6	1.8	60	4	...	...	...	...	...	...	...
416032	AM	20.8	14-16/03/15	OGS	18.7	0.7-0.6	120,70,30	5	21.75	20.7	1.51	0.66	5.36	1e-2	—
425450	AM	19.6	18/04/15	IAC80	18.5	1.1	120	3	21.30	31.0	1.90	1.18	TP	1e-2	3.520
...	...	...	25+27/04/15	OGS	18.4	1.0-0.9	60	3	...	...	...	...	...	...	...
...	...	...	19-22/05/15	IAC80	18.1	1.0-1.2	120	11	21.05	38.3	...	0.35	TP	1e-2	...
2000 HD74 (433992)	AM	18.0	21/04/15	IAC80	19.2	1.2	80	2	19.15	30.6	—	>0.3	TP	—	9.36
2000 LF6 (430439)	AM	19.8	22/05/15	IAC80	18.9	2.5	120	1	21.10	38.0	—	>0.1	—	—	14.92

Table 2 (continued from previous page)

NEA (**PHA**)	Cls	H	Obs.nights	Telescope	V	μ	Exp	T	$H(\alpha)$	α	a/b	A	P	σ	PL
2002 EX8	AP	20.8	14-16/03/15	OGS	18.6-18.3	5.2-6.3	70,25,15	6	21.86	26.5	1.09	0.15	5.32	2e-2	—
2004 DH2 (427684)	AT	20.2	24/02/15	IAC80	17.3	6.0	50	1	...	...	—	...	...	...	...
...	...	...	25-26/02/15	OGS	17.3-17.2	5.9-5.6	50,20,25,30	3	20.50	5.0	1.25	>0.4	8.97	1e-2	8.962
...	...	...	28/02/15	INT	17.6	5.0	25	3	20.52	5.0	—	0.27	(3.75)	1e-2	...
2007 ED125	AP	21.0	13-15/03/15	OGS	17.0-17.2	5.2-3.8	30,50	12	22.23	27.6	1.34	0.51	**5.617**	1e-3	5.620
2008 KV2	AT	21.3	22/04/15	IAC80	19.1	3.9	40	2	22.40	27.5	...	0.11	P2=0.039	1e-3	—
...	...	...	24-26/04/15	OGS	19.0-18.9	4.0-4.1	40,60,20	4	21.95	21.9	1.08	0.12	(P2=0.040)	1e-3	...
2010 XL69 (432655)	AM	19.7	23/05/15	IAC80	18.6	1.8	100	5	20.92	25.3	...	0.31	(2.52)	9e-2	—
...	...	...	14-15/06/15	IAC80	18.7-18.8	1.9	120	4	20.78	19.4	1.17	0.24	**2.79**	1e-2	...
2010 XY72 (453707)	AP	18.6	19-21/04/15	IAC80	17.2-17.1	4.4-4.9	60,20	6	19.65	20.9	—	>0.1	—	—	—
...	...	...	25-26/04/15	OGS	16.8-16.7	5.7-5.8	20,10	3	19.60	17.7	—	>0.3	TP	—	—
2010 GZ6 (436324)	AM	19.5	20-22/04/15	IAC80	18.8-19.0	4.9-4.6	50,30,20	6	18.73	26.4	—	0.05	—	—	—
...	...	...	24/04/15	OGS	19.2	4.2	30	1	...	...	—	...	—	...	...
2011 EU29 (429584)	AP	19.9	25/02-01/03/15	OGS	18.5-18.6	1.8-1.6	120,60	5	18.15	7.4	—	>0.5	—	—	43.5
2012 LC1 (436775)	AP	16.5	23/05/15	IAC80	17.0	2.3	70	3	17.80	26.3	...	>0.5	—	—	...
...	...	...	16-17/06/15	IAC80	18.9-19.0	0.8-0.7	180	4	18.20	30.5	1.41	0.63	5.64	2e-2	5.687
2013 BO73 (454100)	AP	20.0	26-27/04/15	OGS	19.1	2.1-2.2	90,40	1	19.00	18.7	—	>1.0	—	—	—
2014 EK24 (459872)	AP	23.3	22-23/02/15	IAC80	17.7-17.6	5.8	60,20	7	24.55	28.6	1.92	0.73	**0.0998**	3e-4	0.09976
...	...	...	10-11/03/15	OGS	17.7-17.9	3.8-3.6	20	2	24.00	14.5	...	0.59	0.0988	1e-4	...
2015 CA1	AM	20.6	11-13/03/15	OGS	17.7-17.8	6.4	30,40,45	10	21.80	30.4	1.27	0.43	**3.146**	1e-3	2.949
2015 HA1	AT	21.2	19-20/05/15	IAC80	17.3-17.4	11.1	30	3	17.18	32.5	1.08	0.15	TP	3e-2	47.2
2015 HO116	AP	25.5	26/04/15	OGS	15.6-15.5	219-225	3	1	26.80	32.4	1.41	>0.6	TP	3e-2	—

4.1 Secured Periods

We accurately resolved rotation periods for 7 NEAs (including 2 PHAs) listed as *secured periods* labeled in bold in Table 2, with plots given in Figure 1. Four results agree well with the data available in the literature (to compare with PL column in Table 2), while other three include new findings. We secured the periods for the following targets:

PHA 141527 was observed during 3 nights with IAC80 in March ($V = 15.7$) and April 2015 ($V = 19.0$), resulting in a secured period $P = 6.31 \pm 0.01$ h (thanks to the large amplitude $A = 1.0$ mag) which matches well the findings of B. Warner [26] who observed the target during two nights ($PL = 6.306$ h, U=3) and J. Oey [17] who collected a very good sampled during 3 nights ($PL = 6.3140$ h, U=3).

241662 was followed during four nights with IAC80 in June 2015 ($V = 18.8$), producing a secured period $P = 2.42 \pm 0.01$ h (dominated by small amplitude $A = 0.12$ mag) which apparently remained unobserved by others.

285331 was observed during four nights with IAC80 (in March and April at $V = 17.6$) plus another night with the OGS (in April), giving a secured period $P = 4.42 \pm 0.01$ h with a high amplitude $A = 1.07$ mag, which is a pioneer result for this target.

PHA 2007 ED125 was observed with the OGS during 3 nights in March (at $V = 17.0 - 17.2$) resulting in $P = 5.618 \pm 0.002$ h and amplitude $A = 0.51$ mag which matches the result of B. Warner [27] ($PL = 5.620$ h, U=3-) who observed the target during four nights few days after us. Although the period spectrum suggests also possible half value ($P \sim 2.8$ in Figure 1), we adopt the double value due to the slight different shapes of the two growing curves and their maxima.

2010 XL69 (432655) was observed quite faint ($V = 18.6 - 19.0$ mag) using the IAC80 during 3 nights in May and June, resulting in two very similar periods from which we adopt $P = 2.79 \pm 0.01$ h with amplitude $A = 0.24$ mag, not confirmed by anybody else yet.

2014 EK24 (459872) is a small NEA (65 m, acc to ALCDEF) observed with IAC80 during two nights in Feb 2015, then with the OGS during two other nights in March (at similar $V = 17.7$ mag). Thanks to its high amplitude ($A = 0.84$ mag), we determined its very fast rotation with $P = 0.09975 \pm 0.00002$ h (about 6 minutes). This matches well the result of P. Pravec ($PL = 0.09976$ h, U=3-) and improves other few results included in the ALCDEF database. In Figure 1 we plot the first IAC80 raw data (which prompted us to reduce the exposure time in order to sample the fast rotation), then the IAC80 one-night and two-night phase plots, then finally the OGS plot which clearly shows larger uncertainties than the IAC80 ones.

2015 CA1 was observed with the OGS during 3 nights in March 2015 at fast motion $\mu = 6.4''/\text{min}$, resulting in a secured period $P = 3.146 \pm 0.001$ h similar to the published value of F. Monteiro et al. [14] ($PL = 2.949$ h, U=3-) who observed this target during 3 nights.

4.2 Candidate Periods

We obtained good fits, considered as *candidate periods*, for 9 targets (including 3 PHAs), whose plots included in Figure 2 and periods P are given in normal notation in Table 2:

PHA 159504 was observed with the IAC80 during 5 nights in June 2015. The amplitude was small ($A = 0.09$ mag) and the individual nights gave potential fits between $1.4 < P < 2.2$ h, while first four nights converged to $P = 1.96 \pm 0.01$ h which we propose as the candidate period for this object. B. Warner observed this target during 8 nights in May and June at larger amplitude ($A = 0.20$ mag), proposing a longer period $P = 7.84$ h (U=2) whose higher second maximum was quite poorly sampled, and which makes exactly four times our candidate period.

285625 is a large 1-2 km NEA, first observed by Vaduvescu et al. [20] during two nights 13-14 Mar 2015 with the Mercator 1.3 m telescope. This data showed clear fast rotation in two filters (g and r - see Figure 14 in [20]) suggesting a tentative secondary period $TP2 = 0.065$ h, possible due to the tumbling or binary nature of this object (one possible small fast spinning moon). On 16 March we follwed-up this target with the OGS during only two hours (partially affected by clouds), proposing some candidate period $P2 = 0.0304 \pm 0.0001$ h (1.8 minutes, although quite noisy), which is about half our Mercator result but matches the Mercator color lightcurve fit ($P = 0.033$ h - see Figure 11 in [20]). Definitely, one longer campaign using preferably a larger (at least 2-m telescope) is needed to confirm the nature of this interesting large object.

The quite large PHA 216523 (0.2-0.4 km) was observed during one night with IAC80, then during four nights with the OGS. The individual curves taken during 3 nights (one IAC80 and two OGS) could be fited with fast periods between $0.04 < P2 < 0.06$ h and the IAC80 and fourth night OGS agree well, so we prefer this candidate solution $P2 = 0.042 \pm 0.001$ h (2.5 minutes) which suggest tumbling or binary status to be carefully analysed in the future.

306462 is a large NEA (0.5-1.0 km) which was observed during 5 OGS nights. Most nights show clear trends in the raw plots, while individual nights could be fit with small periods $0.1 < P2 < 0.7$ h and small amplitudes $A < 0.1$ mag. The entire 5 night dataset could be fit with a long candidate period $P1 = 37.57 \pm 0.17$ h, suggesting tumbling status which needs to be confirmed in a future campaign.

416032 was observed with the OGS during 3 nights in March 2015, apparently having sampled two minima and one maximum. The candidate period is $P = 5.36 \pm 0.01$ h (not completely covered) with amplitude of about $A = 0.66$ mag.

2002 EX8 was observed with the OGS during 3 nights in March, for only 6 hours total. The curves look flat and are barely covered, showing an amplitude $A = 0.14$ mag which suggest the candidate period $P = 2.41 \pm 0.01$ h (using order 5). No other period data has been published for this object.

2004 DH2 (427684) was observed in Feb 2015 with the IAC80 during one night, then for two more nights with the OGS telescope. We followed it during another night the INT 2.5 m during only 3 hours (see [20]). By joining the INT and OGS data, a possible period $TP = 3.75 \pm 0.01$ h could be suggested (first plot in Figure 2). By adding all three datasets (INT, OGS and IAC80), we could suggest a better candidate period $TP = 8.97 \pm 0.01$ (holding using orders 2, 3 or 4) but incompletely covered (second plot) and only a trusty limit for the amplitude ($A > 0.4$ mag). This period matches the result of B. Warner who observed the target during 3 nights and who derived $P = 8.962$ h U=3- [27].

PHA 2008 KV2 was targeted in April during one night with IAC80, then during 3 more nights with the OGS for a total of 6 hours. The individual nights are quite flat with the fourth showing the largest amplitude, and the overall four nights suggest some very long period (first in Figure 2). The IAC80 fit agrees with the second OGS night fit (second and third plots in Figure 2), suggesting a very fast candidate secondary period $P2 = 0.039 \pm 0.001$ h (2.3 minutes) with small amplitude $A = 0.11$ mag. The object size is between 0.1-0.3 km, thus the fast rotation could be due to tumbling or binary nature.

2012 LC1 (436775) was observed with the IAC80 during one night in May 2015, then two more nights during another block in June. Both these nights result in a candidate period $P = 5.64 \pm 0.01$ h (although incompletely covered) with a large amplitude $A = 0.63$ mag. The target was observed by B. Warner in April [26] who derived a period $P = 5.687$ h (U=3) and by V. Benishek in May [6] who derived $P = 5.687$ h (U=3).

4.3 Tentative Periods

We suggest some fits, considered as *tentative periods* for 10 targets (including one PHA). Most objects were insufficiently observed, or they had very small amplitude, lower signal to noise ratios or they were affected by bad weather. Some of these targets could be slow rotators, tumblers or binaries. We discuss next their fits or constraints, labeling their period in Table 2 with TP (tentative period) and including their plots Figure 3 of the Appendix.

4947 Ninkasi is a large NEA (0.6 km) which was observed during one night (only 2.5 hours) in April 2015 with the IAC80 telescope, its curve showing clear increasing trend with amplitude 0.5 mag, suggesting only a tentative period lower limit $TP > 5$ h.

90367 is a large NEA, estimated 1.6 km. We observed it during four consecutive nights in March 2015 for about 3-4 hours every night (16 hours total) using the OGS telescope. The third and the fourth night fits agree ($TP2 = 2.77 \pm 0.08$ h and $TP2 = 2.72 \pm 0.07$ h fitted with order=4). All nights show deep V-shape profiles (Figure 3) and could be fit with the tentative monomodal period $TP1 = 19.4 \pm 0.2$ h ($A = 0.66$ mag) or bimodal $TP1 = 38.8$ h. This object is suspected to be binary or tumbling and needs dedicated study. Based on NEOWISE sparse data, C. R. Nugent et al. [15] derived maximum amplitudes of 0.54 and 0.48 mag, but no period.

140288 is a large NEA (1.4 km) which was observed in March for 5 hours total during two nights (two weeks apart) using the OGS and IAC80 telescopes. The OGS curve is very scattered, but the IAC80 data (plotted in Figure 3) shows a clear trend and two apparent maxima which allows us to draw a tentative period $TP > 4$ h and amplitude of about $A \sim 0.4$ mag. The object was observed by B. Warner [26] during 6 nights in March and April, who derived the period $P = 6.58$ h (U=2) with amplitude 0.34 mag.

152679 was followed with the IAC80 during two nights in June (5 hours total). The very sparse data suggests a very long trend, with tentative lower limit $TP > 5$ h based on the longer second night dataset (3 hours). This object is likely tumbler, based on the intensive observations of B. Warner in Oct+Nov 2015 (14 nights) who derived a period $P = 125$ h (U=2).

410088 was observed by us first with the INT during two nights 2-3 Feb 2015 which suggested a tentative period $TP = 2.377$ h published in our previos paper [20]. It was followed-up about 3 weeks later during two nights with IAC80 and another night with the OGS. The best tentative periods seems to be $TP = 7.77 \pm 0.01$ (hold with orders 2 to 6, $A = 0.18$ mag). The INT does not fit with the Tenerife data, probably due to the change of 10 degrees in the phase angle. B. Warner observed the object during 4 nights in January 2015 [27], deriving $P = 4.781$ h (U=2).

425450 was observed in April during 3 nights (6 hours) with both telescopes, then after one month in May during 3 nights (12 hours) with IAC80. We include in Figure 3 phased plots from the two runs which show few maxima which need order 5 to fit two tentative periods: $TP = 4.65$ h ($A = 1.18$ mag) and respectively $TP = 9.15$ ($A = 0.35$ mag) which we tentatively adopt. Both these results should be regarded with caution, as one can see in the two period spectra included in Figure 3. Due to the multiple drops (including the sudden deep one in April), we could suggest possible binarity and multiplicity. This target was observed by B. Warner during 4 nights in May [26], who proposed a different period $P = 3.520$ h (U=2+, $A = 0.27$ mag).

2000 HD74 (433992) was observed during only 2 hours left in one April night. The short curve shows a clear trend with at least one maxima (amplitude $A > 0.2$ mag), constraining some tentative period $TP > 3$ h. This object was observed during 6 nights by B. Warner in May who derived $P = 9.36$ h (U=2) [26].

PHA 2010 XY72 (453707) was observed in April during 3 nights with IAC80 (6 hours), then two more nights with the OGS (3 hours total), both in relatively dense star fields. The first 3 nights look very flat ($A < 0.1$ mag), while the last two show clear minima (see Figure 3 for all raw plots). No decent fit could be derived, but the curvy OGS plots can provide at least some lower tentative period ($TP > 5$ h).

2015 HA1 was observed during two nights in May with IAC80 (only 3 hours total). Two similar tentative periods are suggested in Figure 3, from which we prefer the second fit, $TP = 0.87 \pm 0.03$ h. The object was observed by B. Warner during 5 nights in 2015, who suggested Earth-day commensurate period $P = 47.2$ h (U=2-) [26].

2015 HO116 was observed right after its discovery by Catalina survey, being surprised at very close encounter with Earth (0.015 a.u.; $V = 15.6$), while it was crossing the sky extremely fast (proper motion $\mu = 3.7'$/min) which forced us to use very short exposures (3 sec) and cover 5 neighbouring fields, using the OGS. A clear maximum and apparent minimum appear visible (with small uncertainties, despite the very short exposures), suggesting $TP = 0.45 \pm 0.04$ h ($A = 0.64$ mag) based on which we suggest the bimodal tentative period $TP = 0.90 \pm 0.04$ h. Apparently, nobody else attempted any lightcurve for this small 20-40 m object, which will actually be difficult to recover based on its very short two day orbit.

4.4 Poorly Observed Objects

No periods could be obtained for the following 7 objects (including 3 PHAs), whose raw plots are given in Figure 4 in the Appendix:

112985 was observed first by us using the Mercator 1.3 m telescope in 11 Mar 2015 [20], apparently showing rapid oscillations which could be fit with $TP2 = 0.151$ h or $TP2 = 0.353$ h, which are unusualy fast for this very large 2-4 km NEA. We could devote only 2 hours with IAC80 in 20 April, proving a flat curve which matches our Mercator findings and confirms either a round object, pole orientation or a longer principal period specific for tumbling objects. It was observed by B. Warner in April, June and November 2015, who proposed three different periods (5.94 [26], 3.82 [29] and 4.787 [28], all with U=2), and also by Carbognani [8] in April who suggested a period of 3.436 (U=1).

PHA 235756 was observed during 3 nights with the OGS in April 2015 (9 hours total). We could not fit all nights together, so in Figure 4 we publish the raw plots, which show some deeps. Three weeks before, the object was observed during 3 nights by B. Warner [26] who derived $P = 7.18$ h (U=2+).

345646 was observed during one night with IAC80 and another with the OGS (only 3 hours total). Both sessions show very flat curves ($A \sim 0.1$ mag) which can not fit any period, and in Figure 4 we include the raw data. Two weeks before the object was observed by B. Warner during 4 nights who derived $P = 3.05$ h (U=2+), proving our small amplitude [26].

2000 LF6 (430439) was observed during only one hour in May, showing a relatively flat trend, thus no period could be even constrained. B. Warner covered this object during 7 nights in June [26], proposing $P = 14.92$ h (U=2).

2010 GZ6 (436324) was observed during 3 nights with IAC80 (6 hours total) and another night with the OGS (one hour). All nights showed quite flat curves with no clear trend, and no period could be fit to the available data. In Figure 4 we include the IAC80 raw sample (all 3 nights and second night).

PHA 2011 EU29 (429584) was observed with OGS during two nights (5 hours total) at the end of Feb 2015. Both nights show a similar very small decreasing trend ($A < 0.15$ mag) with no periodicity. We followed this object with the INT in full Moon conditions, obtaining another very flat curve in the first night and a slowly decreasing curve during the second [20]. The INT data appears to show small oscillations which can't be proved in the OGS data. We include in Figure 4 our entire dataset (INT and OGS). Independently, the object was observed intensively during 8 nights by B. Warner who derived a very long period $P = 43.5$ h ($A = 0.65$ mag, U=2-) suggesting tumbling status [27].

PHA 2013 BO73 (454100) was observed with the OGS during two nights in April (only 2 hours total). The first night shows a slowly decreasing trend, while the second shows a minimum bit is affected by a saturated star in the asteroid path impossible to remove by Canopus (possible responsible for the second jump in the curve. No fit can be suggested based on this little data, and we include the raw plots in Figure 4.

4.5 Suggested Tumbling or Binary Objects

As evidenced above, the following 6 NEAs (which include 2 PHAs) show possible tumbling or binary nature, based on their relatively large size and rapid oscillations (few minutes) observed with IAC80, OGS, Mercator and INT [20]: 90367 (tentative periods $TP1 = 19.4 \pm 0.2$ h and $TP2 = 2.77 \pm 0.08$ h), 216523 (PHA, candidate secondary period $P2 = 0.042 \pm 0.001$ h), 285625 (candidate secondary period $P2 = 0.0304 \pm 0.0001$ h, confirming Mercator findings), 306462 (candidate primary period $P1 = 37.57 \pm 0.01$ h and suggested secondary period $0.1 < P2 < 0.7$ h), 425450 (possible binary or multiple due to multiple drops, including the deep one in April), and 2008 KV2 (PHA, candidate secondary period $P2 = 0.039 \pm 0.001$ h). These definitely need more nights in dedicated campaigns, preferably involving more sites spread in longitude, to study in detail their physical properties.

5 Conclusions

We resume here the main results of this survey:

- One meter class telescopes available for longer observation campaigns are great opportunities (including in bright time) for physical characterization of NEAs, specifically lightcurves.
- During 64 nights allocated in a few runs during the 2015A semester we used the IAC80 and OGS telescopes to acquire lightcurves of 33 NEAs (including 10 PHAs).
- All targets had no published lightcurves before our observations, but about half were independently observed by Brian Warner and few other authors and published in MPML, most of these findings being confirmed by us.
- We solved periods or suggested constraints for 13 targets (including 3 PHAs) having no other rotation knowledge before, namely: 4947 Ninkasi, 90367, PHA 216523, 241662, 285331, 285625, 306462, 416032, 2002 EX8, PHA 2008 KV2, 2010 XL69 (432655), PHA 2010 XY72 (453707) and 2015 HO116.
- We confirmed periods for other 6 targets published by other authors, namely: PHA 141527, 2004 DH2 (427684), PHA 2007 ED125, 2012 LC1 (436775), 2014 EK24 (459872) and 2015 CA1.
- We suggested tumbling or binary nature for 6 targets (probing one of them), namely: 90367, PHA 216523, 285625, 306462, 425450 and PHA 2008 KV2.
- No rotation periods or constraints could be solved for 7 targets, due to lack of time or bad weather.
- We derived ellipsoid shape ratios a/b for 21 NEAs (including 4 PHAs).

Acknowledgements Thanks are due to Brian Warner for making available *MPO Canopus* [9] and ALCDEF database [10], the main tools used today in asteroid lightcurve work by many amateurs and professional astronomers.

This research has made use of the VizieR catalog access tool at CDS, Strasbourg, France [16], used to query the SDSS [1], Pan-STARRS [9] and APASS [12] surveys to establish accurate calibration zero points for each field. We also used SAOImage DS9 developed by Smithsonian Astrophysical Observatory.

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[10] http://www.alcdef.org
[11] http://www.euronear.org/sponsors.php

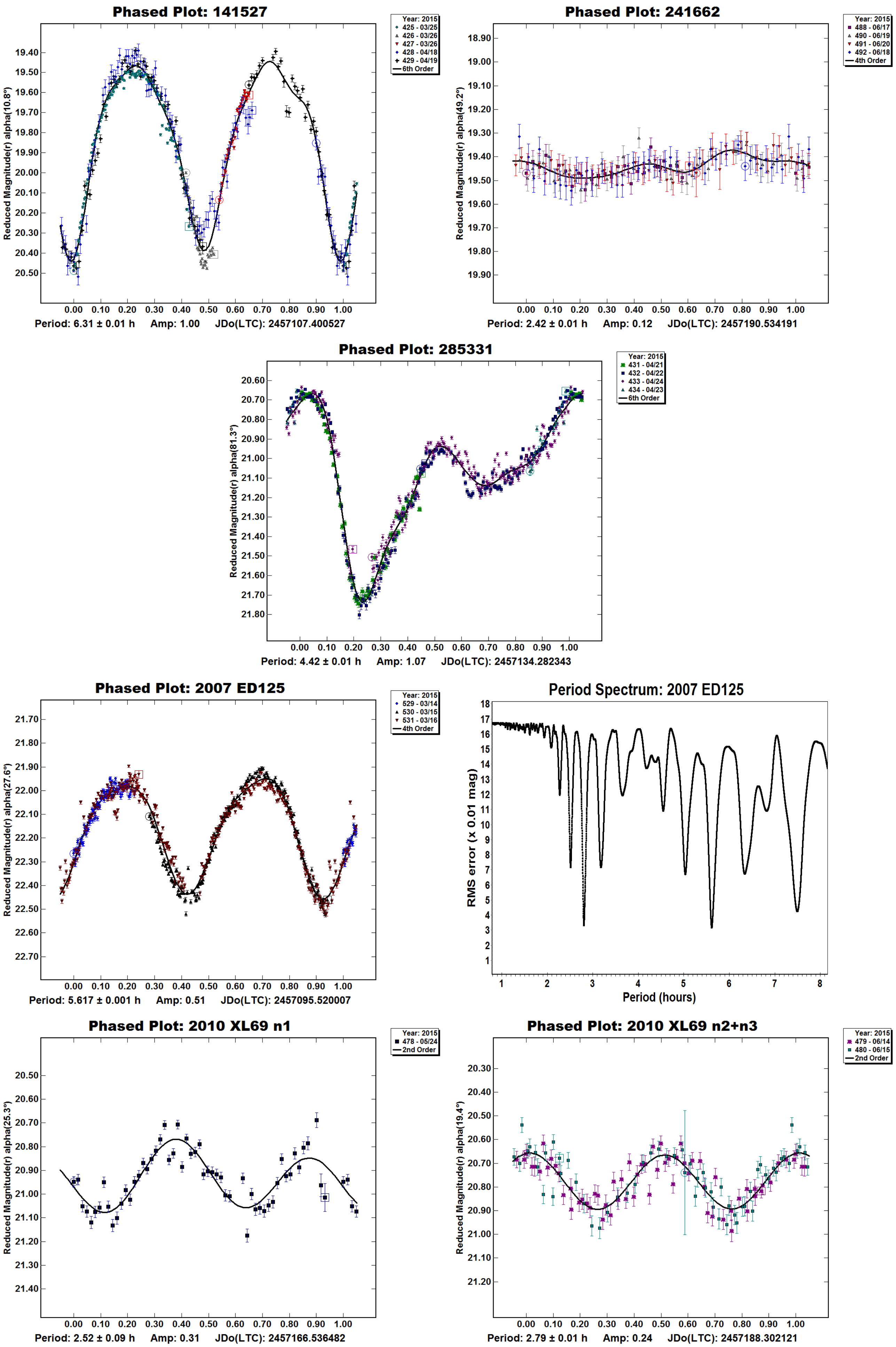


Figure 1: Lightcurves of NEAs resolved with secured periods.

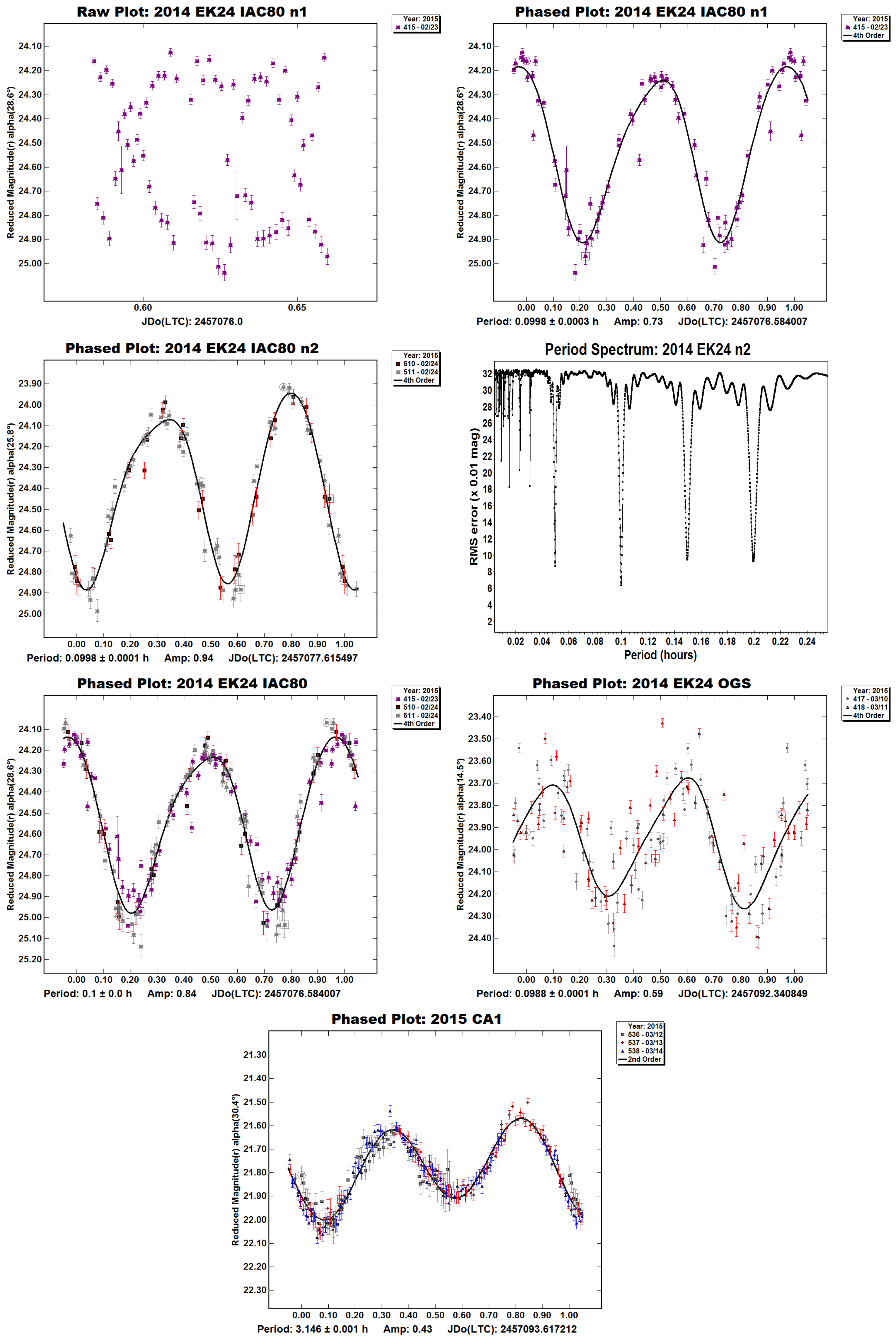


Figure 1 (continued): Lightcurves of NEAs resolved with secured periods.

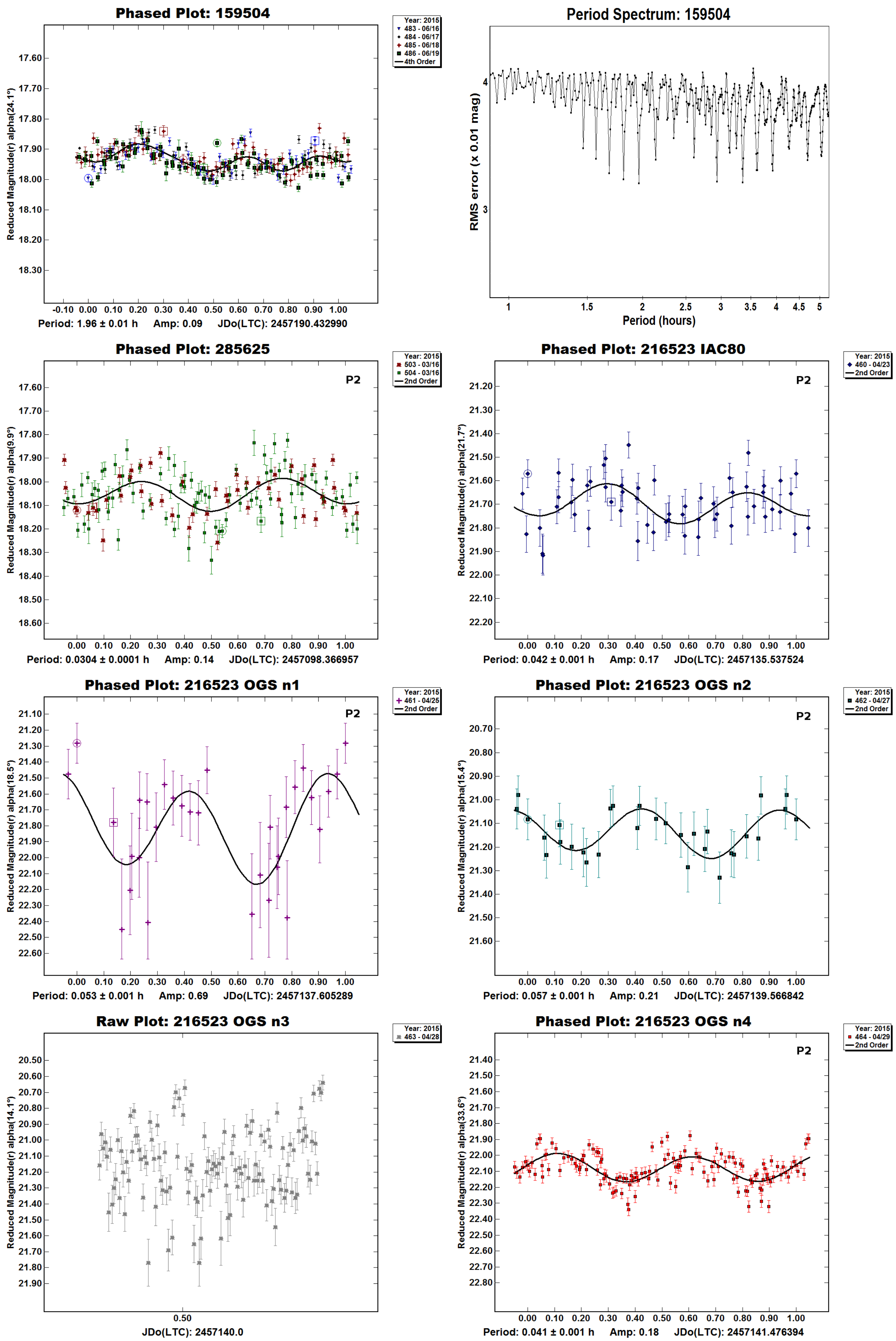
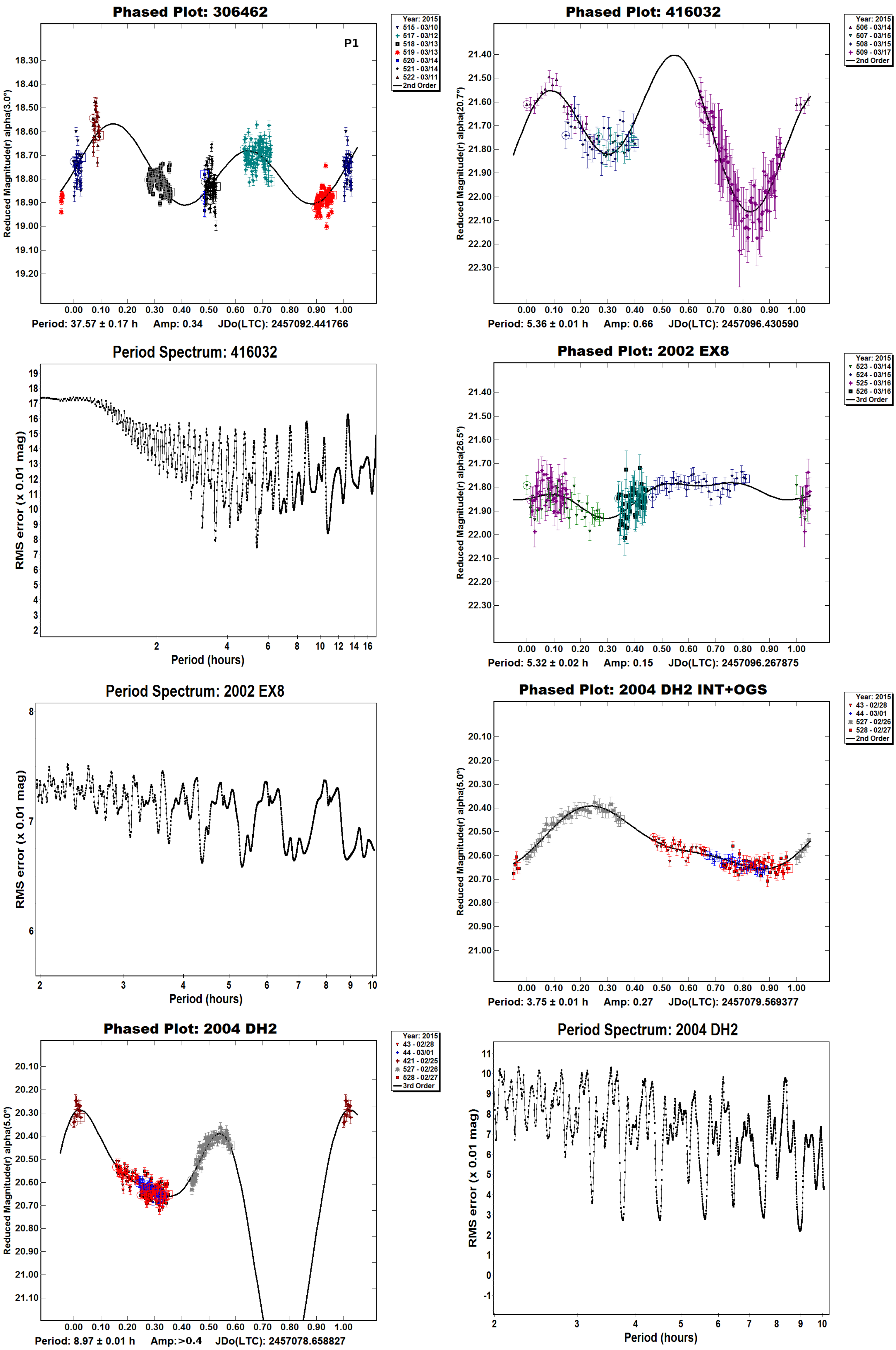


Figure 2: Lightcurves of NEAs resolved with candidate periods.



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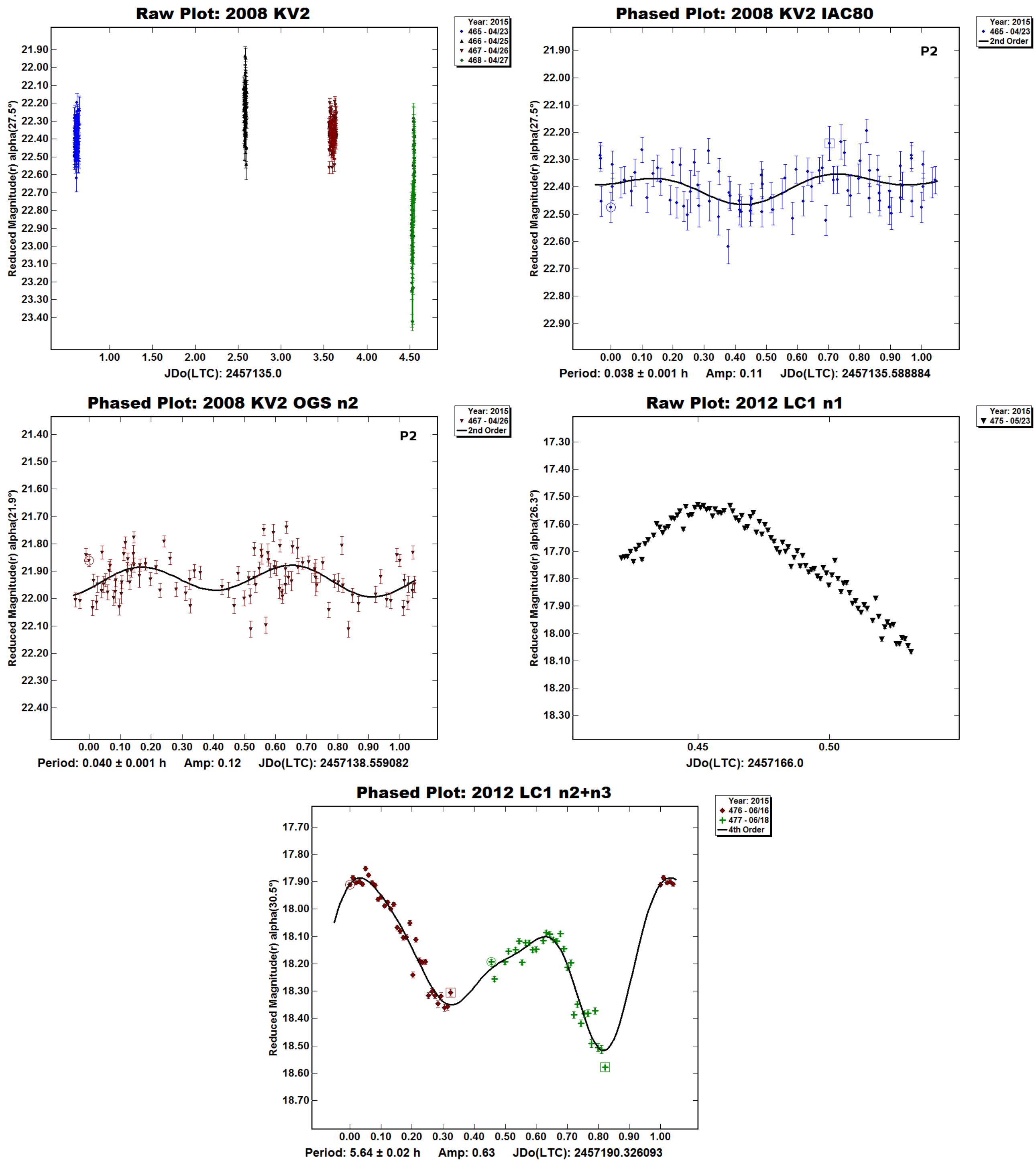

Figure 2 (continued): Lightcurves of NEAs resolved with candidate periods.

6 APPENDIX - Plots of Poorly Observed Objects

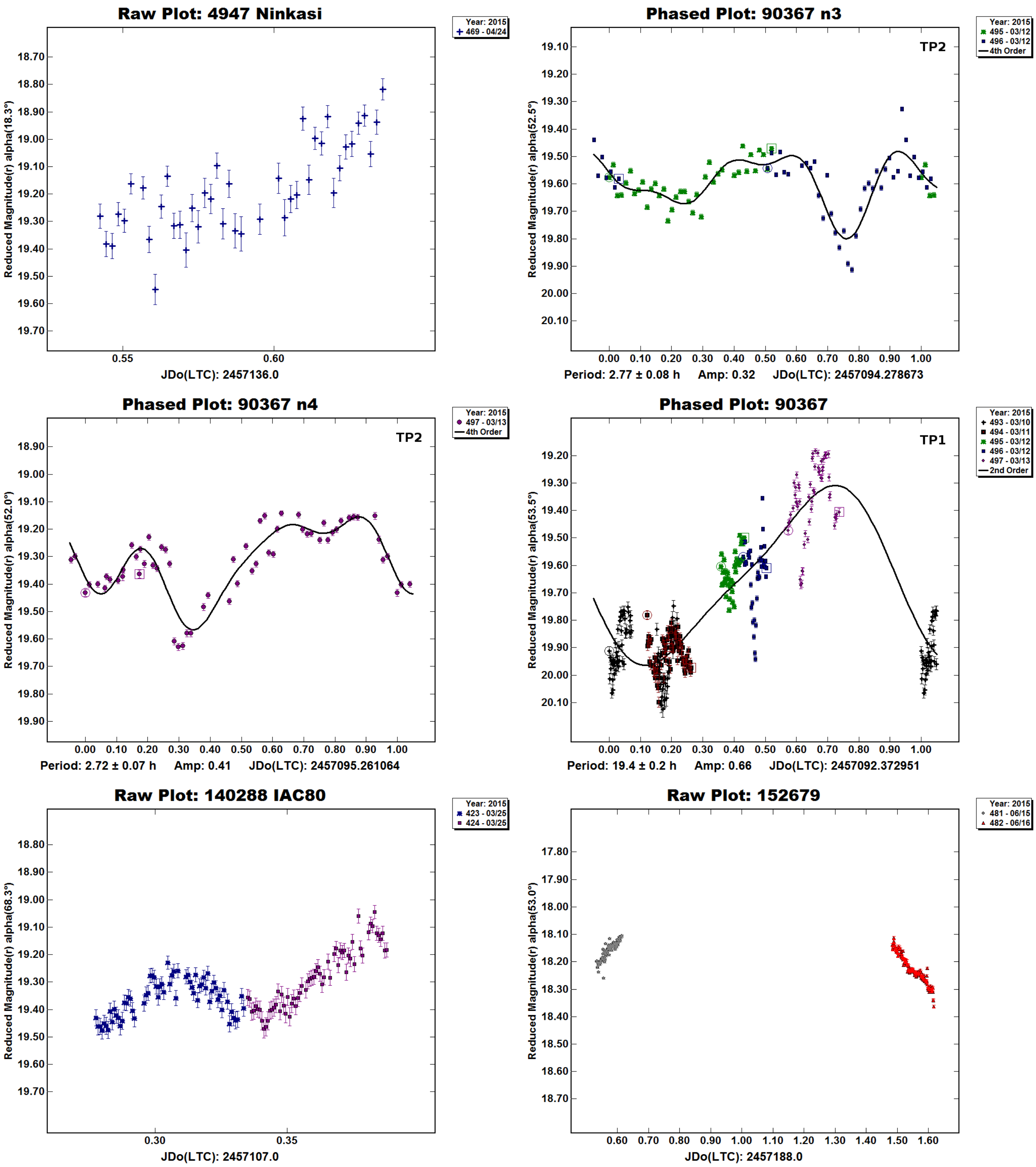

Figure 3: Lightcurves of NEAs poorly observed with tentative periods.

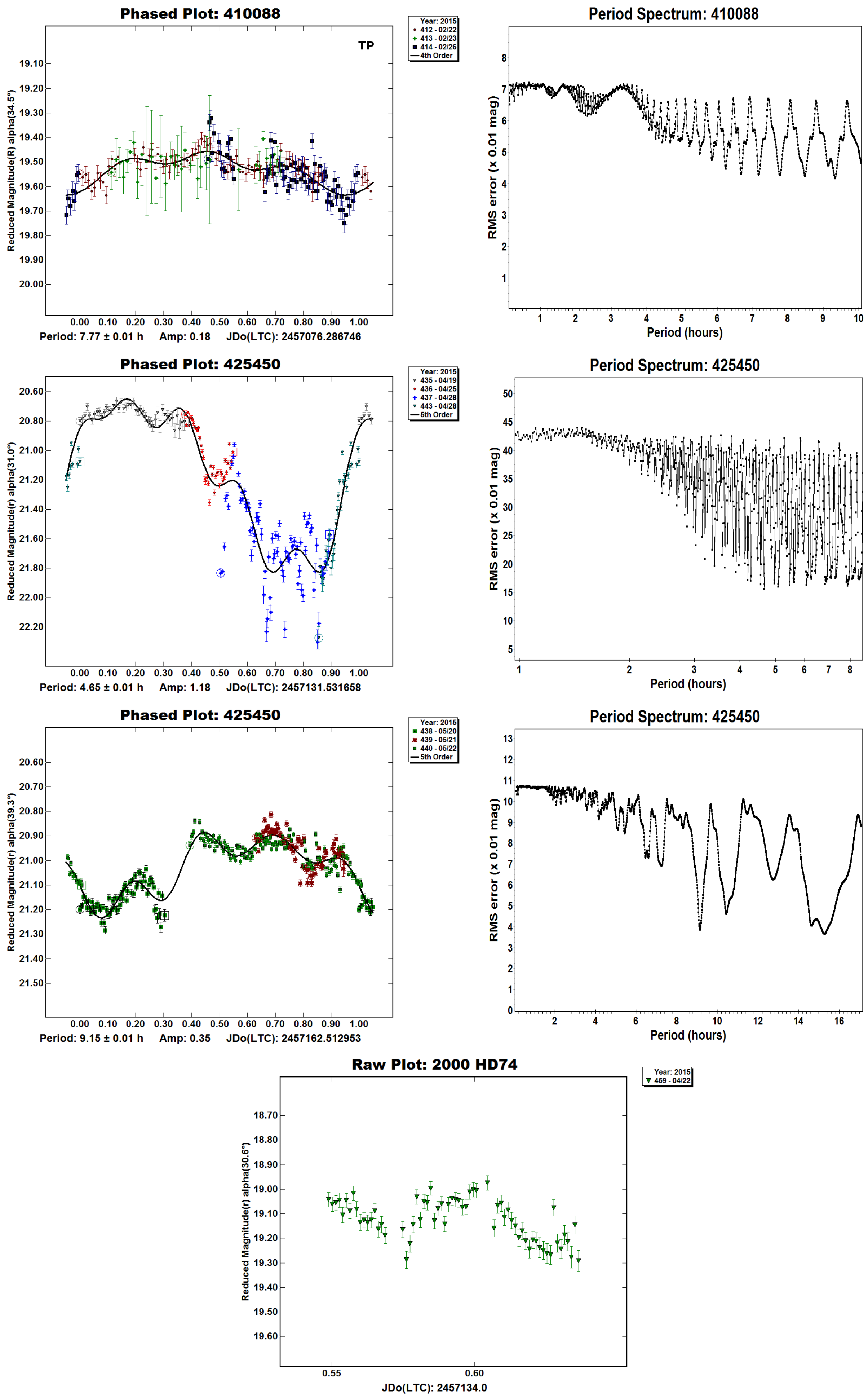

Figure 3 (continued): Lightcurves of NEAs poorly observed with tentative periods.

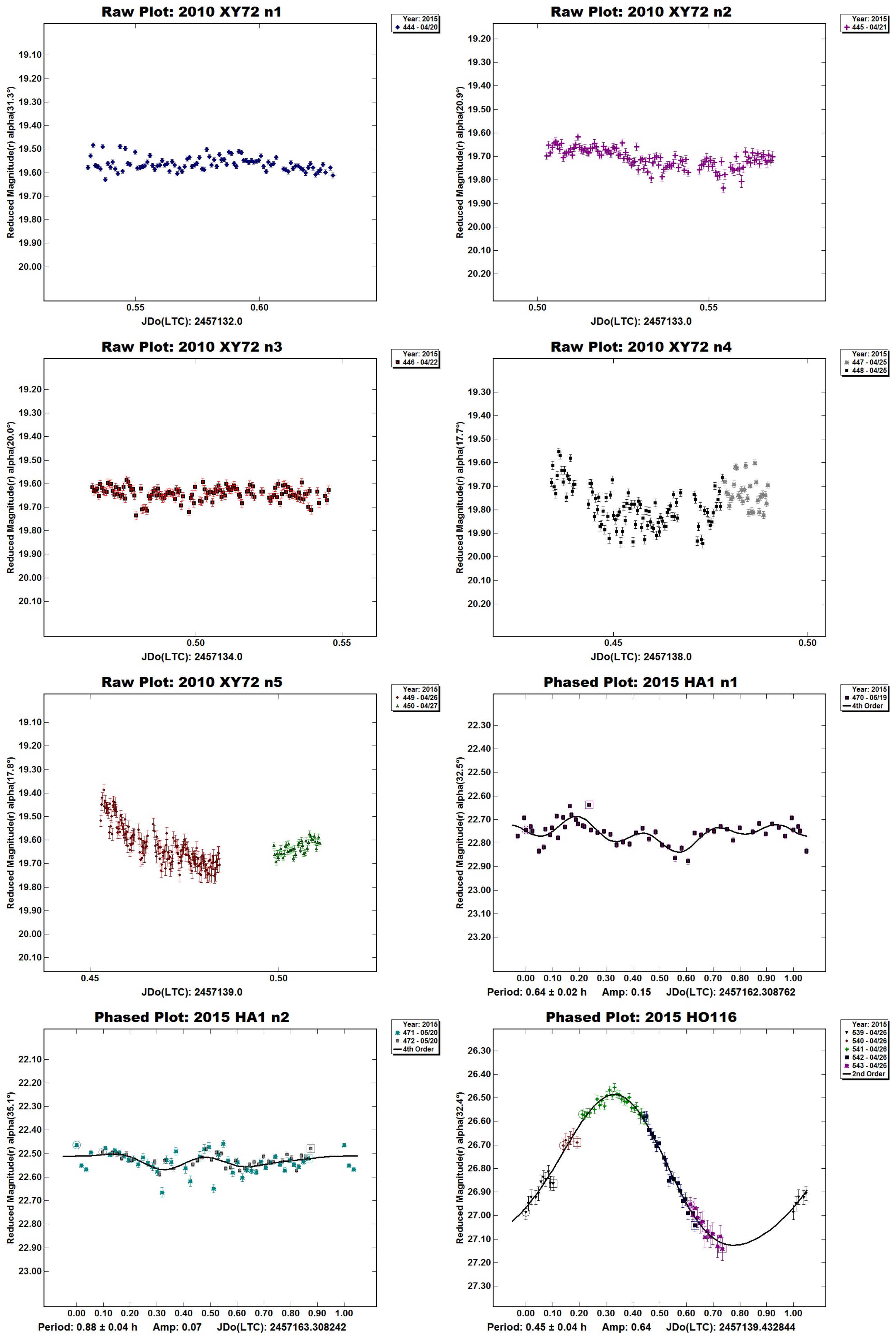

Figure 3 (continued): Lightcurves of NEAs poorly observed with tentative periods.

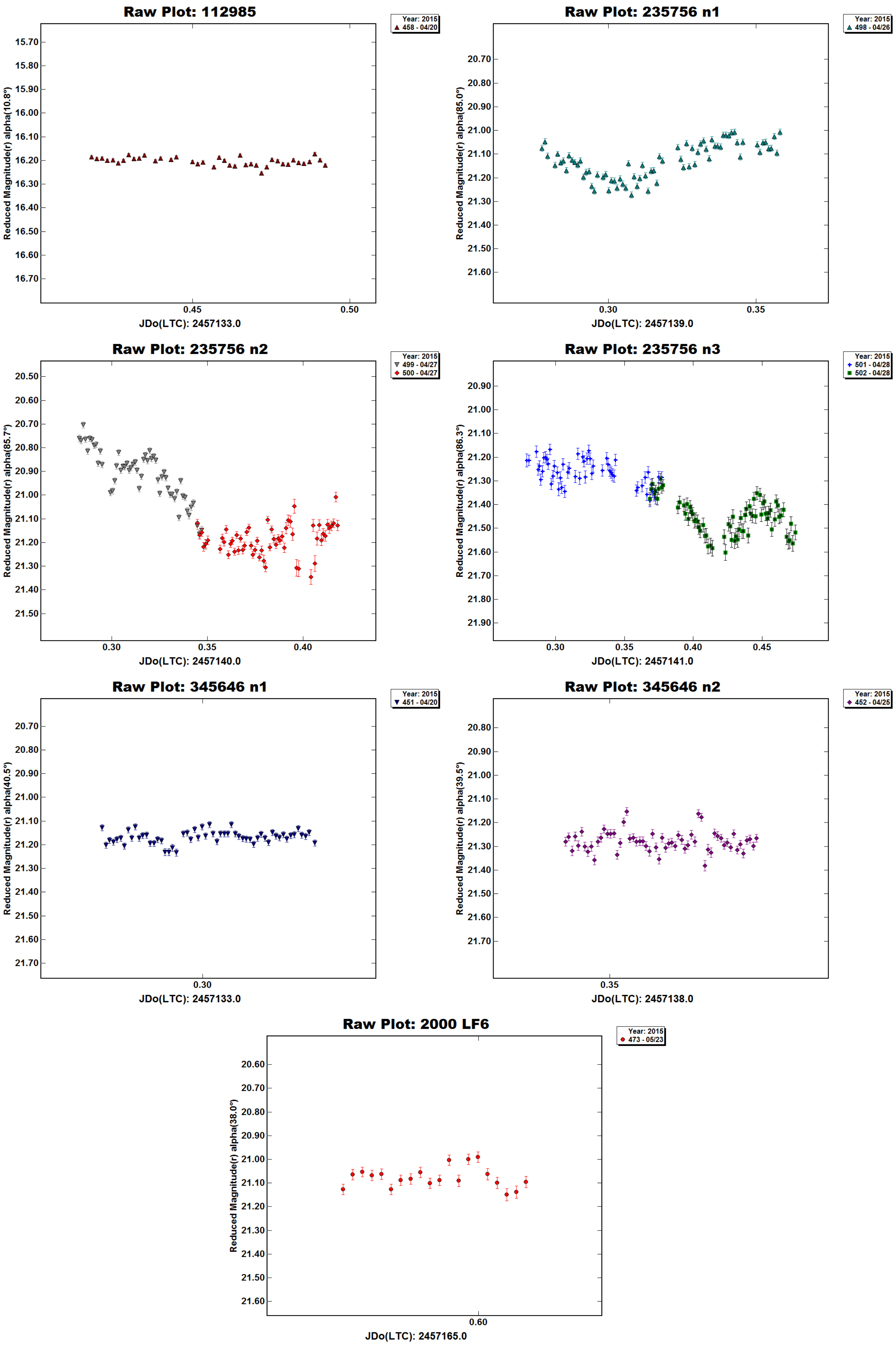

Figure 4: Lightcurves of NEAs poorly observed without periods.

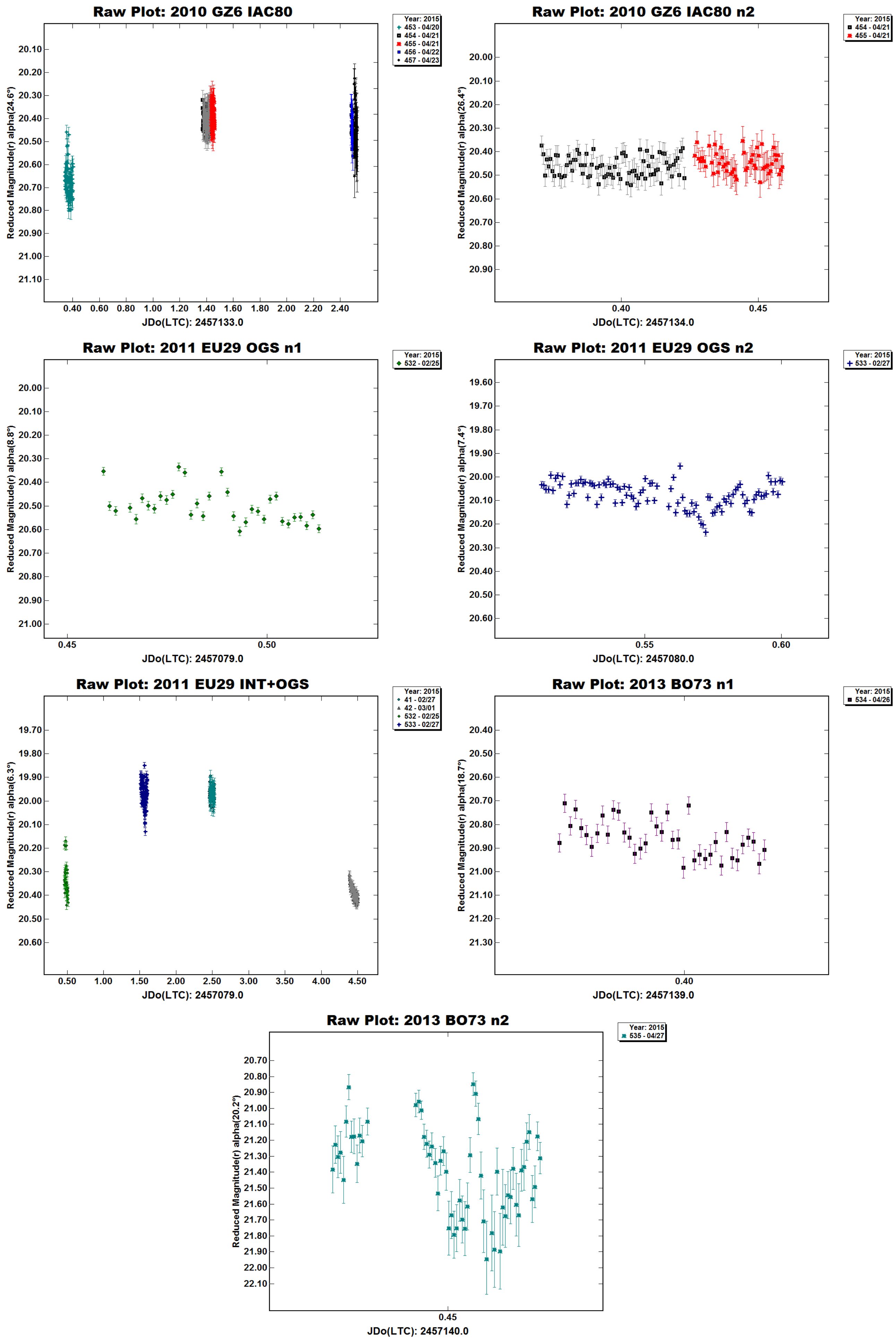

Figure 4 (continued): Lightcurves of NEAs poorly observed without periods.