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

O. Vaduvescu · R. Cornea · A. Aznar Macias ·
A. Sonka · M. Predatu · M. Serra-Ricart

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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 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 from private sponsors based in his natal city of Sibiu, Romania, mentioned 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. We derived ellipsoid shape ratios for 21 NEAs (including 4 PHAs) not known before.

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 or near infrared spectrographs, the observation of lightcurves of NEAs represents 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 populations which are otherwise difficult to observe by larger telescopes (typically oversubscribed with other domains

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O. Vaduvescu
Isaac Newton Group of Telescopes (ING), Apto. 321, E-38700, Santa Cruz de la Palma, Canary Islands, Spain
Instituto de Astrofísica de Canarias (IAC), E-38205 La Laguna, Tenerife, Spain
E-mail: ovidiu.vaduvescu@gmail.com

R. Cornea
Romanian Society for Meteors and Astronomy (SARM), CP 14 OP 1, 130170 Targoviste, Romania

A. Aznar Macias
Isaac Aznar Observatory, Aras de los Olmos, Valencia, Spain

A. Sonka
Astronomical Institute of the Romanian Academy, 5 Cutitul de Argint, 040557 Bucharest, Romania

M. Predatu
University of Craiova, Faculty of Sciences, A. I. Cuza 13, Craiova, RO-200585, Romania

M. Serra-Ricart
Instituto de Astrofísica de Canarias (IAC), E-38205 La Laguna, Tenerife, Spain
Universidad de La Laguna, Dpto. Astrofísica, E-38206 La Laguna, Tenerife, Spain

of astrophysics). Moreover, longer timespan and multi-site observational campaigns could improve the knowledge about binary asteroids [13,20], tumbling asteroids [11], and about some subtle effects such as the YORP/Yarkovsky [23], space weatering [7], thermal fatigue and fragmentation [10] which could change the orbits of smaller asteroids and create hazardous objects.

There are 20,944 NEAs known as of 16 Sep 2019 (NASA/JPL [1]), from which only 1668 objects have any attempted lightcurves (about 8%) and solid periods have been derived for only 721 NEAs (quality codes $Q = 3-$ or 3, meaning 3.4%). Only a few amateur astronomers contribute worldwide more substantially and the current leader is Brian Warner in the USA who has observed more than one thousand NEAs. In the meantime, very few programs dedicate time for lightcurve of NEAs using professional telescopes. In this context, since 2014 the EURONEAR project [2] 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. [21] 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 [5,22] and including some collaborators led by B. Warner [31–33].

This is the third data paper in the EURONEAR NEA lightcurve survey. It presents the longer 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 include observations taken between 2017 and 2020 with other telescopes. We will resume in 2021 the entire survey effort by summing together about 200 NEA lightcurves observed within this EURONEAR project between 2014 and 2020, which means about 10% of all NEA lightcurves published. Next, we will join this large photometric dataset with another spectral dataset of 76 NEAs observed in 2014-2015 [19] and with other photometric and other spectro-photometric and spectroscopic results carried by M. Popescu (private communications). Amalgamating this entire dataset with other photometric, spectroscopic and spectro-photometric data available in the literature, we plan to conclude in 2021 with a science paper aiming to compare physical and 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), 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.

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[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 able to track Solar system objects using differential tracking rates, and we used this mode to observe most of our targets at half proper motion (μ). Following the targets at half speed has three advantages: it allows to double the exposure time for fainter objects (and the S/N ratio) before trails of reference stars become significant; 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 [21] 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 previously reduced by bias and flat field using some IRAF[5] scripts. *MPO 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 *MPO 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.

To avoid ambiguities in the *MPO Canopus* plots generated by a session which starts before midnight followed by another session which starts before next midnight, we edited the legend of the plots by adding the decimal date at the start of each session, whose numbers are also included before in the legend. In some cases, we needed to split one target observed during one night in two or more sessions due to the rapid proper motion of some targets which forced us to observe two nearby fields and split the night in a few sessions whose start time was added as decimal days in the legends of the plots.

4 The Observed NEAs and Results

Table 2 includes 33 NEAs observed during our Tenerife 2015 campaign. Runs separated by at least one week observed with the same or both telescopes are given in separated lines. 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), mean reduced magnitude $H(\alpha)$, phase angle interval α (in degrees), derived semi-major axis ratio a/b, measured amplitude, derived rotation periods P (in hours) and

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[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

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].

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

First, with bold fonts 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 fonts 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) 2003 LC5, (216523) 2001 HY7, (241662) 2000 KO44, (285331) 1999 FN53, (285625) 2000 RD34 (TP2 suggested by us [21]), (306462) 1999 RC32, (416032) 2002 EX11, 2002 EX8, 2008 KV2, (432655) 2010 XL69, (453707) 2010 XY72 and 2015 HO116. We confirmed periods for other 6 targets, namely: (141527) 2002 FG7, (427684) 2004 DH2, 2007 ED125, (436775) 2012 LC1, (459872) 2014 EK24 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). The multi-night photometric fit is affected mainly by the change in phase angle of targets. The phase relation slope for asteroids ranges between about 0.025 and 0.035 mag/degree, thus if the phase relation is unknown, then a change in phase angle of only 1 degree can introduce an uncertainty of 0.01 magnitudes, and changes by a few degrees could be observed for about 8 targets in the column α. 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 ellipsoid 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. [24]. 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 ellipsoid 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. In the legend of each figure we label the Canopus session number and the date (month/day) with decimals corresponding to the first image of the session.

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

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[7] http://www.alcdef.org

[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 (**PHA**)	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	18.3-19.0	—	>0.5	TP>5	—	—
(90367) 2003 LC5	AP	17.7	10-13/03/15	OGS	18.1-18.2	2.4-2.2	90,100,120	14	19.60	53.5-52.0	1.19	0.32	TP1=2.75	—	—
...	...	...	...	...	...	...	...	...	...	...	...	...	TP2=19.4(38.8)	—	—
(112985) 2002 RS28	AM	15.7	20/04/15	IAC80	19.2	4.2	120	2	16.20	10.8-10.8	—	—	—	—	mult
(140288) 2001 SN289	AP	16.6	10/03/15	OGS	17.6	3.2	60	2	18.95	56.9-56.9	—	>0.2	—	—	...
...	...	...	25/03/15	IAC80	17.2	5.6	40	3	19.30	68.3-68.4	—	>0.4	TP>4	—	6.58
(141527) 2002 FG7	AP	18.9	25/03/15	IAC80	15.7	3.3	40	4	18.95	11.2-11.3	...	1.00	—	1e-2	...
...	...	...	18-19/04/15	IAC80	19.0-19.1	0.4	150,200	11	19.95	25.8-26.3	1.92	1.00	**6.31**	1e-2	6.306
(152679) 1998 KU2	AP	16.6	14-15/06/15	IAC80	16.1-16.0	4.6-4.7	50	5	18.20	53.0-54.0	—	>0.2	TP>5	—	125
(159504) 2000 WO67	AP	17.0	16-22/06/15	IAC80	18.2	1.1-1.0	150,200	15	17.95	24.1-29.0	1.06	0.09	1.96	1e-2	7.84
(216523) 2001 HY7	AM	20.6	22/04/15	IAC80	19.2	2.7	40	2	21.70	21.7-21.6	...	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	18.5-12.4	1.15	0.18	(P2=0.041)	1e-3	—
(235756) 2004 VC	AP	18.7	26-28/04/15	OGS	18.7-18.8	3.0-2.4	60,80	9	21.15	85.0-86.3	—	>0.6	—	—	7.18
(241662) 2000 KO44	AM	17.6	16-19/06/15	IAC80	18.8-18.7	2.8-3.0	80,60,70	9	19.43	49.2-49.8	1.05	0.12	**2.42**	1e-2	—
(285331) 1999 FN53	AP	18.3	25/03/15	IAC80	18.4	0.9	120	2	...	55.7-55.7	...	...	...	...	—
...	...	...	21-23/04/15	IAC80	17.6-17.5	2.1-2.4	80	7	21.20	82.1-85.1	2.61	1.07	**4.42**	1e-2	...
...	...	...	24/04/15	OGS	17.5	2.6	60	6	...	86.7-87.0	...	...	...	...	...
(285625) 2000 RD34	AM	17.8	16/03/15	OGS	19.0	0.6	30	2	18.07	9.9-9.9	1.11	0.14	P2=0.0304	1e-4	TP2=0.065
(306462) 1999 RC32	AM	18.5	10-14/03/15	OGS	18.4-18.7	2.4-2.1	100,120,45,60	18	18.73	3.0-4.5	1.34	0.34	P1=37.57	2e-1	—
(345646) 2006 TN	AM	19.9	20/04/15	IAC80	17.8	5.5	50	2	21.20	40.6-40.5	—	>0.1	—	—	3.05
...	...	...	25/04/15	OGS	18.0	4.5	40	1	21.30	39.4-39.4	—	>0.1	—	—	...
(410088) 2007 EJ	AP	18.1	22-23/02/15	IAC80	18.3-18.4	2.0-1.9	120	7	19.55	34.4-34.1	1.10	0.18	TP=7.77	1e-2	4.781
...	...	...	26/02/17	OGS	18.6	1.8	60	4	...	33.6-33.6	...	...	...	...	...
(416032) 2002 EX11	AM	20.8	14-16/03/15	OGS	18.7	0.7-0.6	120,70,30	5	21.75	20.7-18.9	1.51	0.66	5.36	1e-2	—
(425450) 2010 EV45	AM	19.6	18/04/15	IAC80	18.5	1.1	120	3	21.30	31.0-31.0	1.90	1.18	(TP=4.65)	1e-2	3.520
...	...	...	25+27/04/15	OGS	18.4	1.0-0.9	60	3	...	33.5-34.3	...	...	...	...	...
...	...	...	19-22/05/15	IAC80	18.1	1.0-1.2	120	11	21.05	38.3-39.4	...	0.35	TP=9.15	1e-2	...
(427684) 2004 DH2	AT	20.2	24/02/15	IAC80	17.3	6.0	50	1	...	6.2-6.2	—	...	...	...	...

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
...	...	...	25-26/02/15	OGS	17.3-17.2	5.9-5.6	50,20,25,30	3	20.50	4.5-2.9	1.25	>0.4	8.97	1e-2	8.962
...	...	...	28/02/15	INT	17.6	5.0	25	3	20.52	5.1-5.2	—	0.27	(3.75)	1e-2	...
(429584) 2011 EU29	AP	19.9	25/02-01/03/15	OGS	18.5-18.6	1.8-1.6	120,60	5	18.15	8.9-7.4	—	>0.5	—	—	43.5
(430439) 2000 LF6	AM	19.8	22/05/15	IAC80	18.9	2.5	120	1	21.10	38.0-38.0	—	>0.1	—	—	14.92
(432655) 2010 XL69	AM	19.7	23/05/15	IAC80	18.6	1.8	100	5	20.92	25.3-25.2	...	0.31	(2.52)	9e-2	—
...	...	...	14-15/06/15	IAC80	18.7-18.8	1.9	120	4	20.78	19.4-19.7	1.17	0.24	**2.79**	1e-2	...
(433992) 2000 HD74	AM	18.0	21/04/15	IAC80	19.2	1.2	80	2	19.15	30.6-30.6	—	>0.3	TP>3	—	9.36
(436324) 2010 GZ6	AM	19.5	20-22/04/15	IAC80	18.8-19.0	4.9-4.6	50,30,20	6	18.73	24.6-28.3	—	0.05	—	—	—
...	...	...	24/04/15	OGS	19.2	4.2	30	1	...	31.6-31.6	—	...	—	...	...
(436775) 2012 LC1	AP	16.5	23/05/15	IAC80	17.0	2.3	70	3	17.80	26.3-26.3	...	>0.5	—	—	...
...	...	...	16-17/06/15	IAC80	18.9-19.0	0.8-0.7	180	4	18.20	30.5-30.7	1.41	0.63	5.64	2e-2	5.687
(453707) 2010 XY72	AP	18.6	19-21/04/15	IAC80	17.2-17.1	4.4-4.9	60,20	6	19.65	21.9-19.9	—	>0.1	—	—	—
...	...	...	25-26/04/15	OGS	16.8-16.7	5.7-5.8	20,10	3	19.60	17.7-17.8	—	>0.3	TP>5	—	—
(454100) 2013 BO73	AP	20.0	26-27/04/15	OGS	19.1	2.1-2.2	90,40	1	19.00	18.6-20.2	—	>1.0	—	—	—
(459872) 2014 EK24	AP	23.3	22-23/02/15	IAC80	17.7-17.6	5.8	60,20	7	24.55	28.7-25.7	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	14.5-16.6	...	0.59	0.0988	1e-4	...
2002 EX8	AP	20.8	14-16/03/15	OGS	18.6-18.3	5.2-6.3	70,25,15	6	21.86	26.5-28.1	1.09	0.15	5.32	3e-2	—
2007 ED125	AP	21.0	13-15/03/15	OGS	17.0-17.2	5.2-3.8	30,50	12	22.23	27.7-22.2	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	27.5-27.4	...	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	23.8-20.1	1.08	0.12	(P2=0.040)	1e-3	...
2015 CA1	AM	20.6	11-13/03/15	OGS	17.7-17.8	6.4	30,40,45	10	21.80	30.4-32.2	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	32.5-35.3	1.08	>0.3	TP>5	—	47.2
2015 HO116	AP	25.5	26/04/15	OGS	15.6-15.5	219-225	3	1	26.80	32.4-31.1	1.41	>0.6	TP=0.90	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) 2002 FG7 was observed with IAC80 during one night in March ($V = 15.7$) and two nights in April 2015 ($V = 19.0$). During first run in March the target was moving faster ($\mu = 3.3''/\text{sec}$) passing 3 nearby fields, so we needed to split the reduction in 3 sessions (labeled 425, 426 and 427 on the plot). During the second run in April the target moved slower ($\mu = 0.6''/\text{sec}$) and we could accommodate each night in one session (labeled 428 and 429). Despite of the change of 15 degrees in phase angle, the two runs could be used to derive a secured period $P = 6.31 \pm 0.01$ h, thanks to the large amplitude $A = 1.0$ mag. This period matches well the findings of B. Warner [27] who observed the target during two nights ($PL = 6.306$ h, U=3) and J. Oey [18] who collected a very good sampled during 3 nights ($PL = 6.3140$ h, U=3).

(241662) 2000 KO44 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) 1999 FN53 was observed during four nights with IAC80 (in March and April at $V = 17.6$ - sessions 431, 432 and 434) plus another night with the OGS (in April, session 433). Fitting the April sessions give 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.

(432655) 2010 XL69 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 based on the June two nights fit with amplitude $A = 0.24$ mag, not confirmed by anybody else yet.

(459872) 2014 EK24 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 first night and second night fits. Then we include the second night phase plot which compared the adopted period with its half and double possible solutions. Finally, we include the IAC80 and OGS fits, fitting all nights available for each telescope. The OGS plot clearly shows larger uncertainties than the IAC80 ones.

PHA 2007 ED125 was observed with the OGS during 3 nights in March (at $V = 17.0 - 17.2$). Thanks to the relatively large amplitude $A = 0.51$ mag, the bimodal solution gives $P = 5.618 \pm 0.002$ h which matches the result of B. Warner [28] ($PL = 5.620$ h, U=3-) who observed the target during four nights few days after us. The monomodal (around 2.8 h) and the trimodal (at 7.5 h) solutions are not plausible, also suggested by the period spectrum (see Figure 1).

2015 CA1 was observed with the OGS during 3 succesive nights in March 2015 (9 hours total time) at fast motion $\mu = 6.4''/\text{min}$, resulting in a secured period $P = 3.146 \pm 0.001$ h whose spectrum we include in Figure 1. Our period is similar to the published value of F. Monteiro et al. [14,15] ($PL = 2.949$ h, U=3-) who observed this target during 3 sparser nights (5 hours in total) using a smaller telescope. We could obtain this dataset (Monteiro, private communication), but unfortunately we could not fit our two data sets together. Treated separately, both data sets can be fitted acceptably by either period, the two periods being in ratio 15:16, corresponding to 16 cycles versus 15 cycles during 47.2 hours (almost two nights). Given the more pronounced deep in the our spectrum and our slightly longer timespan, we believe that our period is favored.

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) 2000 WO67 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 the 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 can't be spotted in our periodogram. We recommend future observations, preferably using a larger telescope during longer continuous timespan.

PHA (216523) 2001 HY7 (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. The IAC80 fit and the fourth night OGS fit agree well and both use better sample than the other nights, 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.

(285625) 2000 RD34 is a large 1-2 km NEA, first targeted by us during two nights 13-14 Mar 2015 with the Mercator 1.3 m telescope [21]. This data showed clear fast rotation in two filters (g and r - see Figure 14 in [21]) 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 whose curve could be visible superposed on the main curve of the primary. 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 [21]). Definitely, one longer campaign using preferably a larger (at least 2-m telescope) is needed to confirm the nature of this interesting large object.

(306462) 1999 RC32 is a large NEA (0.5-1.0 km) which was observed during 5 successive OGS nights. Most nights show clear trends in the raw plots but the amplitudes are small $A < 0.1$ mag and the OGS data seems dominated by noise. Nevertheless, 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) 2002 EX11 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 $A = 0.66$ mag.

(427684) 2004 DH2 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 [21]). 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 $P = 8.97 \pm 0.01$ (holding using orders 2, 3 or 4) but incompletely covered (second plot) and only a limit for the amplitude of $A > 0.3$ mag). This period matches the result of B. Warner who covered the target better during 3 nights and who derived $P = 8.962$ h U=3- [28].

(436775) 2012 LC1 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 [27] 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). The attempt to fit all the three datasets was impossible probably due to the large variation of phase angle during the two months, nevertheless we could join our data to Warner's data and part of Benishek's data, probing Warner's period $P = 5.688$ h.

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 $A = 0.15$ mag which suggest the candidate period $P = 5.32 \pm 0.01$ h (using order 3) which should be regarded with caution due to lack of complete coverage. No other period data has been published for this object.

PHA 2008 KV2 was targeted with IAC80 during one night in April, 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.

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, including their tentative periods in Table 2 (TP) and plotting their curves in 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) 2003 LC5 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), thus we adopt the average $TP2 = 2.75 \pm 0.08$ h. 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. [16] derived maximum amplitudes of 0.54 and 0.48 mag, but no period.

(140288) 2001 SN289 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. This matches the findings of B. Warner [27] who observed the same target during 6 nights in March and April, deriving the period $P = 6.58$ h (U=2) with amplitude 0.34 mag.

(152679) 1998 KU2 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 [29] in Oct+Nov 2015 (14 nights) who derived a period $P = 125$ h (U=2).

(410088) 2007 EJ 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 [21]. 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 because of the change of 10 degrees in the phase angle. B. Warner observed the object during 4 nights in January 2015 [28], deriving $P = 4.781$ h (U=2) which looks better than our tentative periods, possible thanks to the larger amplitude observed in January. We believe that this object needs longer coverage at a future apparition, preferably using at least a 2-m class telescope.

(425450) 2010 EV45 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 in April), we could suggest possible binarity and multiplicity. This target was observed by B. Warner during 4 nights in May [27], who proposed a different period $P = 3.520$ h (U=2+, $A = 0.27$ mag). Clearly, this object requires follow-up to remove the ambiguity.

(433992) 2000 HD74 was observed during only 2 hours left in one April night. The short curve shows a clear trend with at least one maximum (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) [27].

PHA (453707) 2010 XY72 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 period fit could be derived, but the OGS plots displaying larger amplitude can provide at least some lower tentative period ($TP > 5$ h).

2015 HA1 was observed during two nights in May with IAC80 (less than 3 hours total), both affected by bad weather. We present the raw data for both nights in Figure 3. The amplitudes are very small during both nights (~ 0.1 mag) and during the second night the reduced magnitude is brighter by ~ 0.2 mag due to the increase of phase angle, suggesting a long tentative period of at least five hours, with amplitude larger than ~ 0.3 mag. Any fitting attempt of separate nights is risky due to the small coverage. This object was observed by B. Warner during 5 nights in 2015, who suggested Earth-day commensurate period $P = 47.2$ h (U=2-) [27].

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 $\mu = 3.7'/\mathrm{min}$) 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) 2002 RS28 was observed first by us using the Mercator 1.3 m telescope in 11 Mar 2015 [21], apparently showing rapid oscillations possibly fitted by $TP2 = 0.151$ 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 ($P = 5.94$ [27], $P = 3.82$ [30] and most likely $P = 4.787$ [29], all using U=2), and also by Carbognani [8] in April who suggested a period $P = 3.436$ h (U=1).

PHA (235756) 2004 VC was observed during 3 nights with the OGS in April 2015 (9 hours total). We could not fit all nights together, and in Figure 4 we publish the raw plots, which show some minima. Three weeks before, the object was observed during 3 nights by B. Warner [27] who derived a reliable $P = 7.18$ h (U=2+). Neither this period, nor $P = 10.6$ h also mentioned by this author could be fitted by our complete dataset.

(345646) 2006 TN 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 [27].

PHA (429584) 2011 EU29 was observed with OGS during two nights at the end of Feb 2015 (sessions 532 and 533, 5 hours total). 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 during two nights (sessions 41 and 42), obtaining another very flat curve in the first night and a slowly decreasing curve during the second [21]. 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 [28].

(430439) 2000 LF6 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 [27], proposing $P = 14.92$ h (U=2).

(436324) 2010 GZ6 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 (454100) 2013 BO73 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 [21]: (90367) 2003 LC5 (tentative periods $TP1 = 19.4 \pm 0.2$ h and $TP2 = 2.77 \pm 0.08$ h), (216523) 2001 HY7 (PHA, candidate secondary period $P2 = 0.042 \pm 0.001$ h), (285625) 2000 RD34 (candidate secondary period $P2 = 0.0304 \pm 0.0001$ h, confirming Mercator findings), (306462) 1999 RC32 (candidate primary period $P1 = 37.57 \pm 0.01$ h and suggested secondary period $0.1 < P2 < 0.7$ h), (425450) 2010 EV45 (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 summarize 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 mostly bright and grey nights allocated in a few runs during 2015A 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 25 NEAs (including 7 PHAs) with periods not known before our campaign.

- We solved or constrained periods of 13 NEAs (including 3 PHAs) having no other rotation knowledge known yet, namely: (4947) Ninkasi, (90367) 2003 LC5, PHA (216523) 2001 HY7, (241662) 2000 KO44, (285331) 1999 FN53, (285625) 2000 RD34, (306462) 1999 RC32, (416032) 2002 EX11, (432655) 2010 XL69, PHA (453707) 2010 XY72, 2002 EX8, PHA 2008 KV2, and 2015 HO116.

- We confirmed periods for other 6 targets published by other authors, namely: PHA (141527) 2002 FG7, (427684) 2004 DH2, (436775) 2012 LC1, (459872) 2014 EK24, PHA 2007 ED125, and 2015 CA1.

- We suggested tumbling or binary nature for 6 targets (probing one of them), namely: (90367) 2003 LC5, PHA (216523) 2001 HY7, (285625) 2000 RD34, (306462) 1999 RC32, (425450) 2010 EV45 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).

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This research has made use of the VizieR catalog access tool at CDS, Strasbourg, France [17], 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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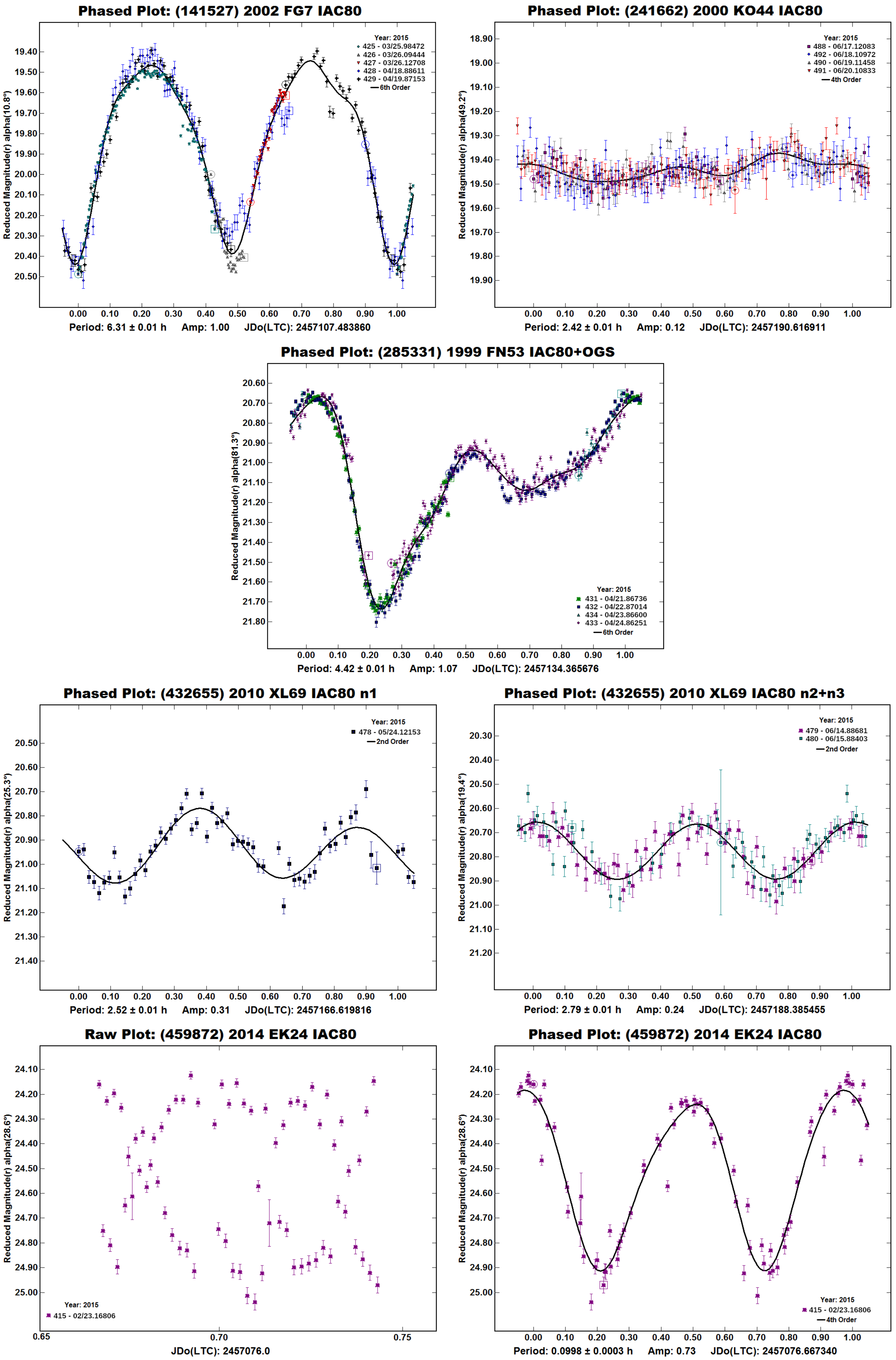

Figure 1: Lightcurves of NEAs resolved with secured periods.

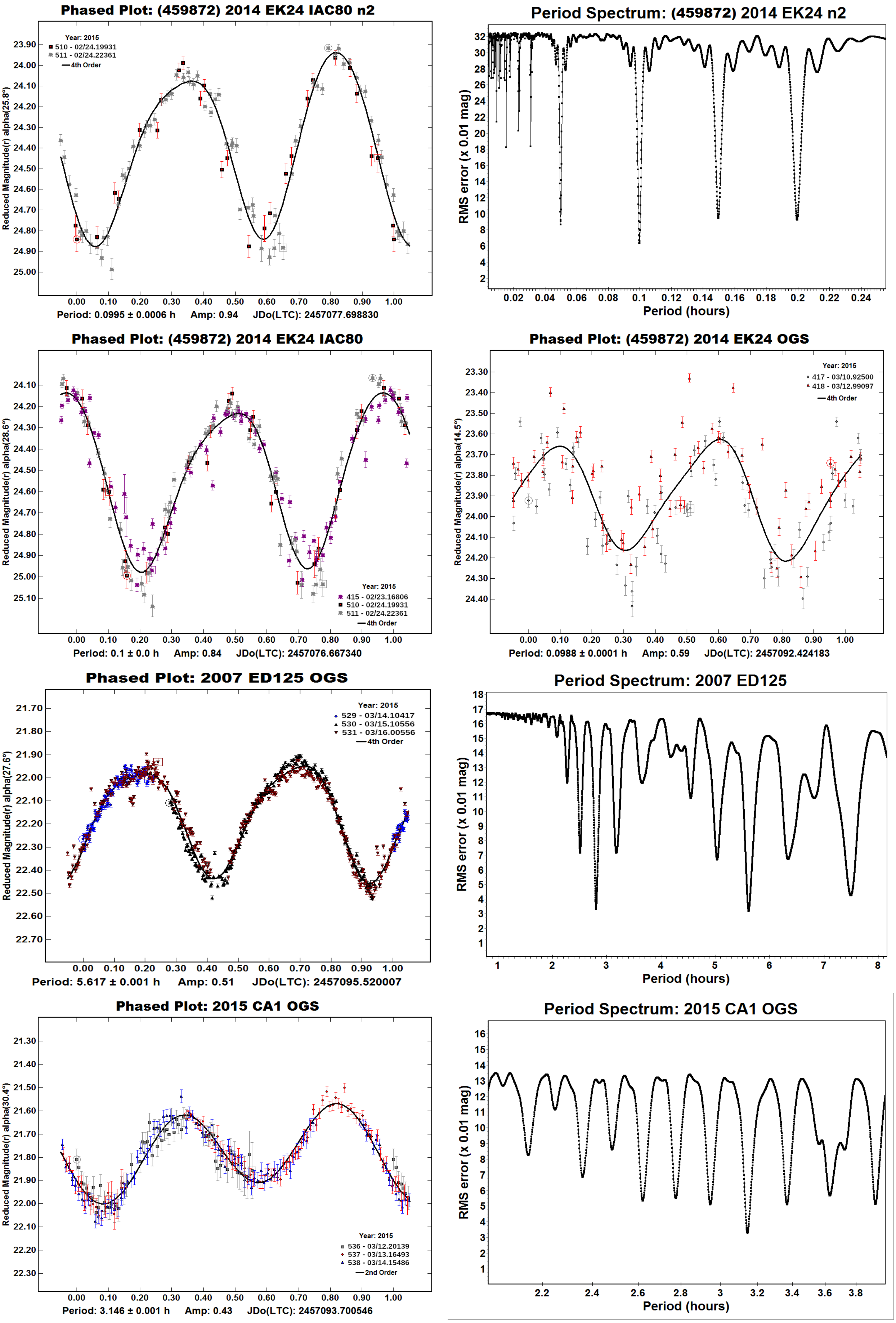

Figure 1 (continued): Lightcurves of NEAs resolved with secured periods.

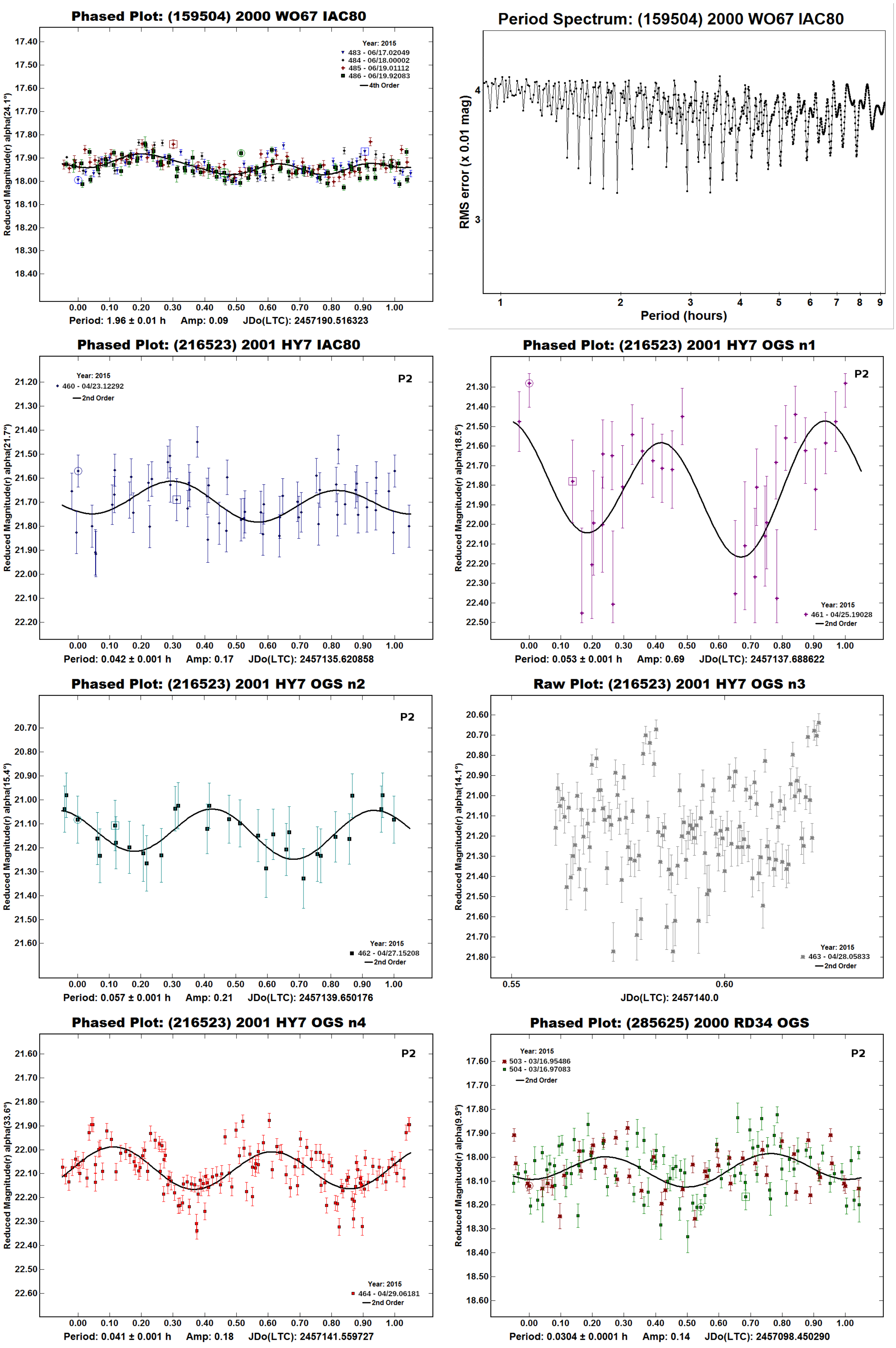

Figure 2: Lightcurves of NEAs resolved with candidate periods.

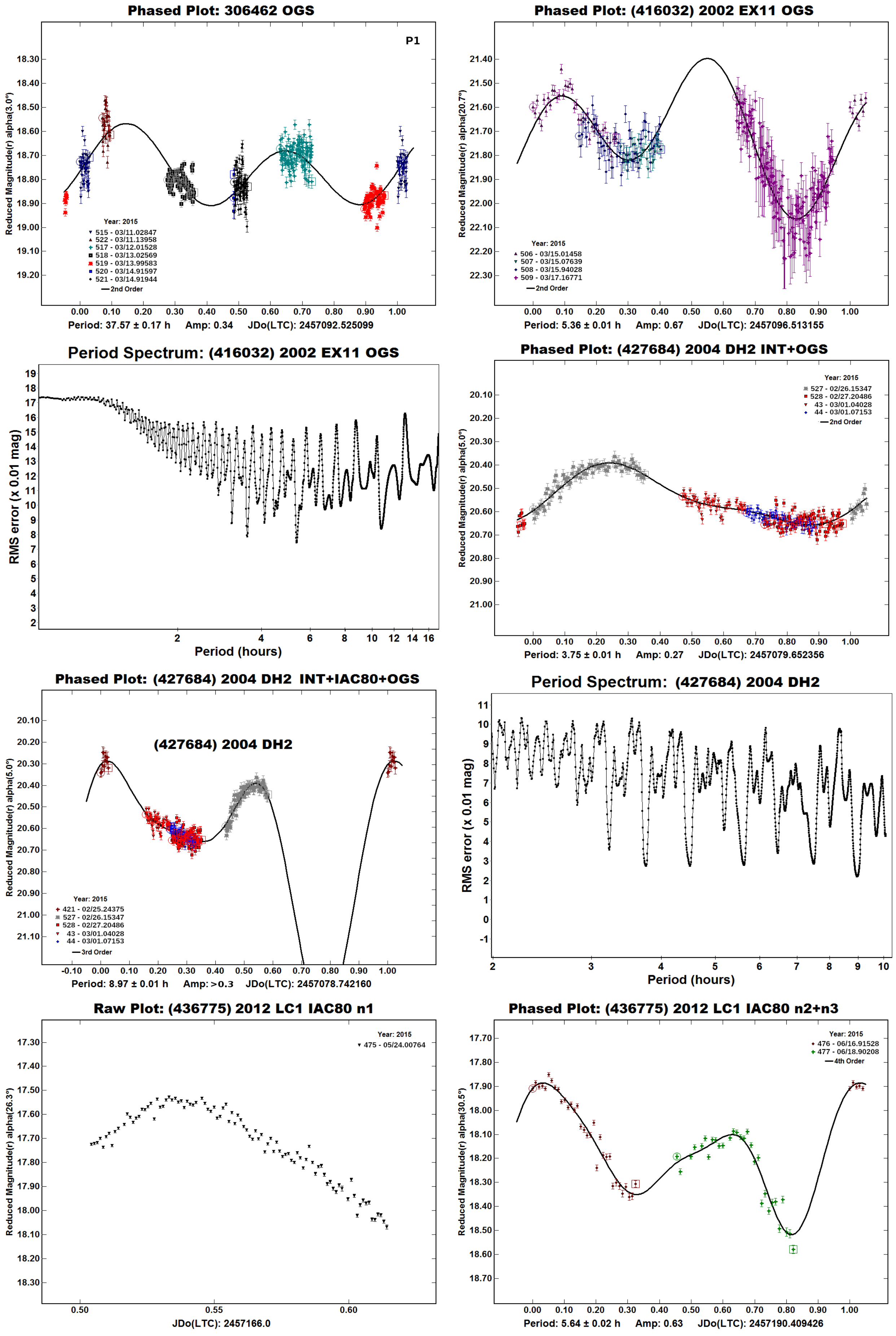

Figure 2 (continued): Lightcurves of NEAs resolved with candidate periods.

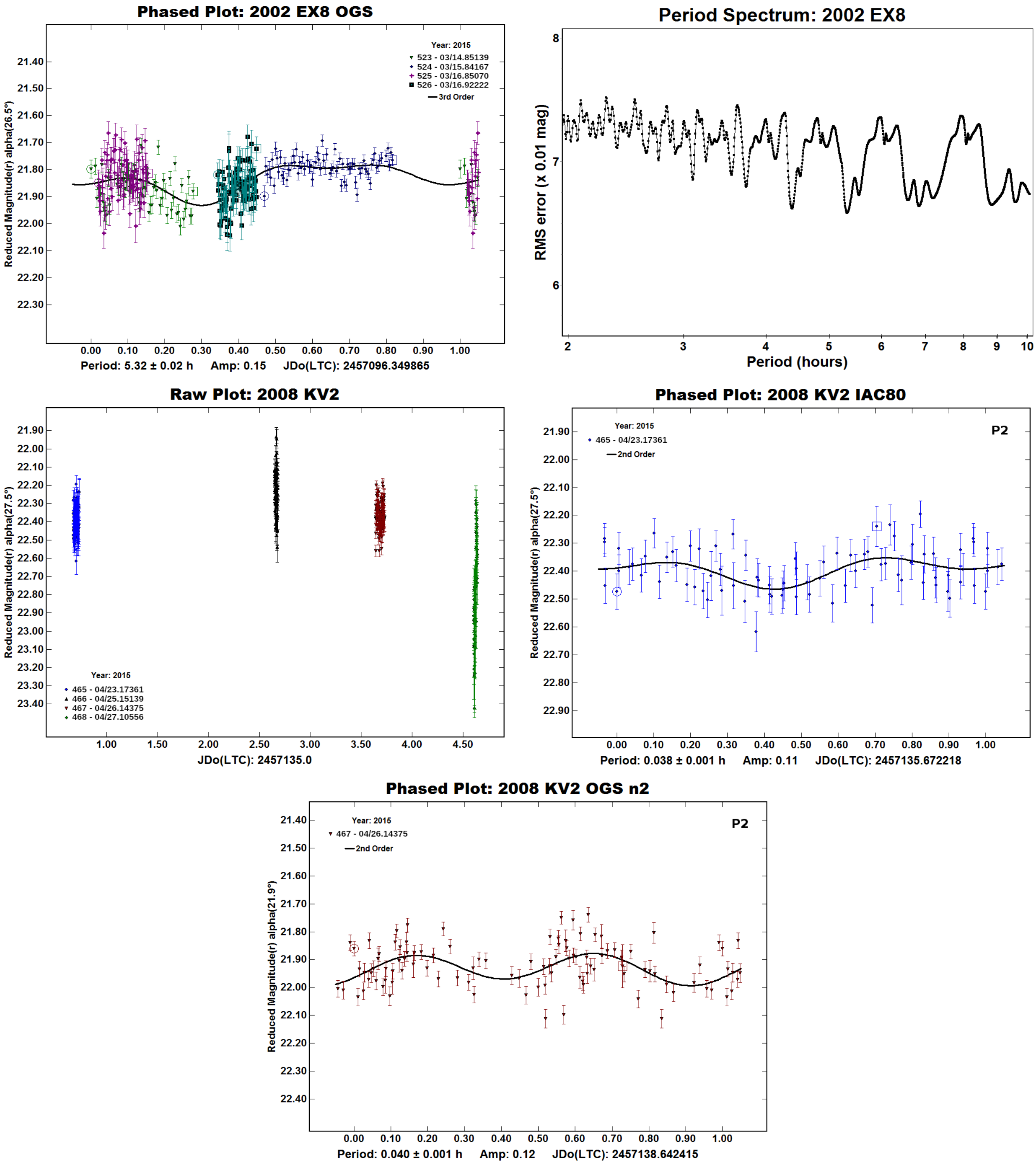

Figure 2 (continued): Lightcurves of NEAs resolved with candidate periods.

6 APPENDIX - Plots of Poorly Observed Objects

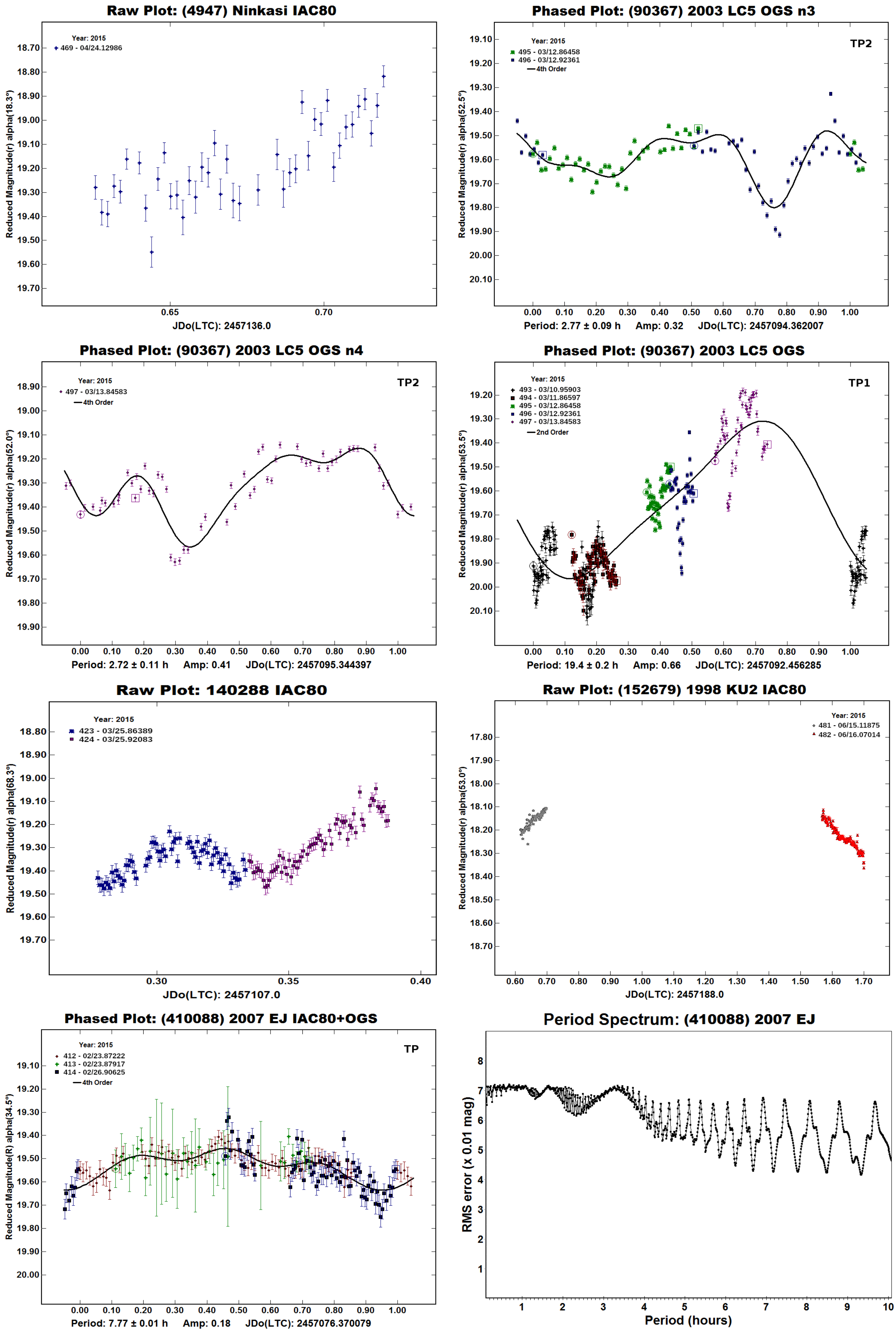

Figure 3: Lightcurves of NEAs poorly observed with tentative periods.

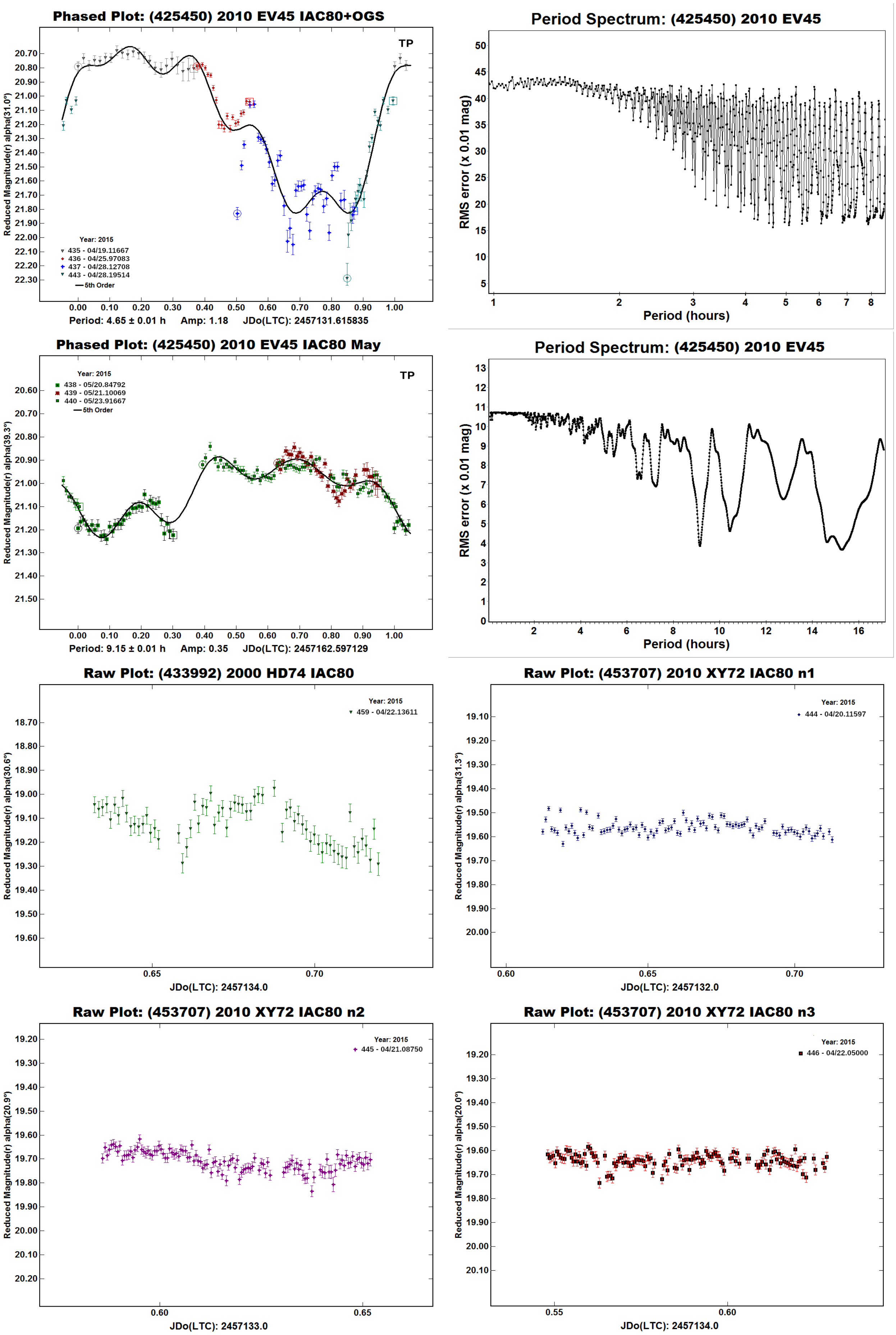

Figure 3 (continued): Lightcurves of NEAs poorly observed with tentative periods.

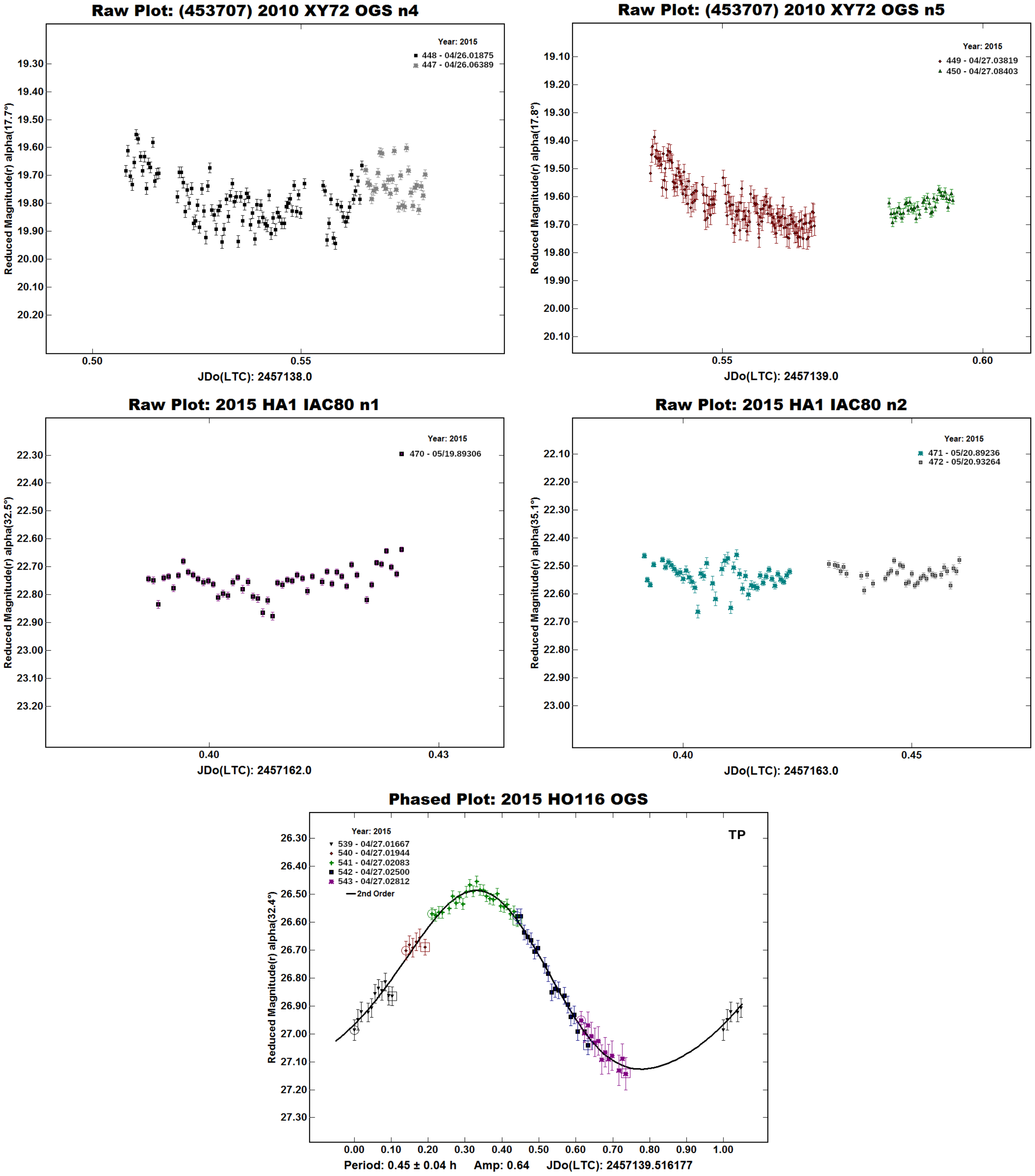

Figure 3 (continued): Lightcurves of NEAs poorly observed with tentative periods.

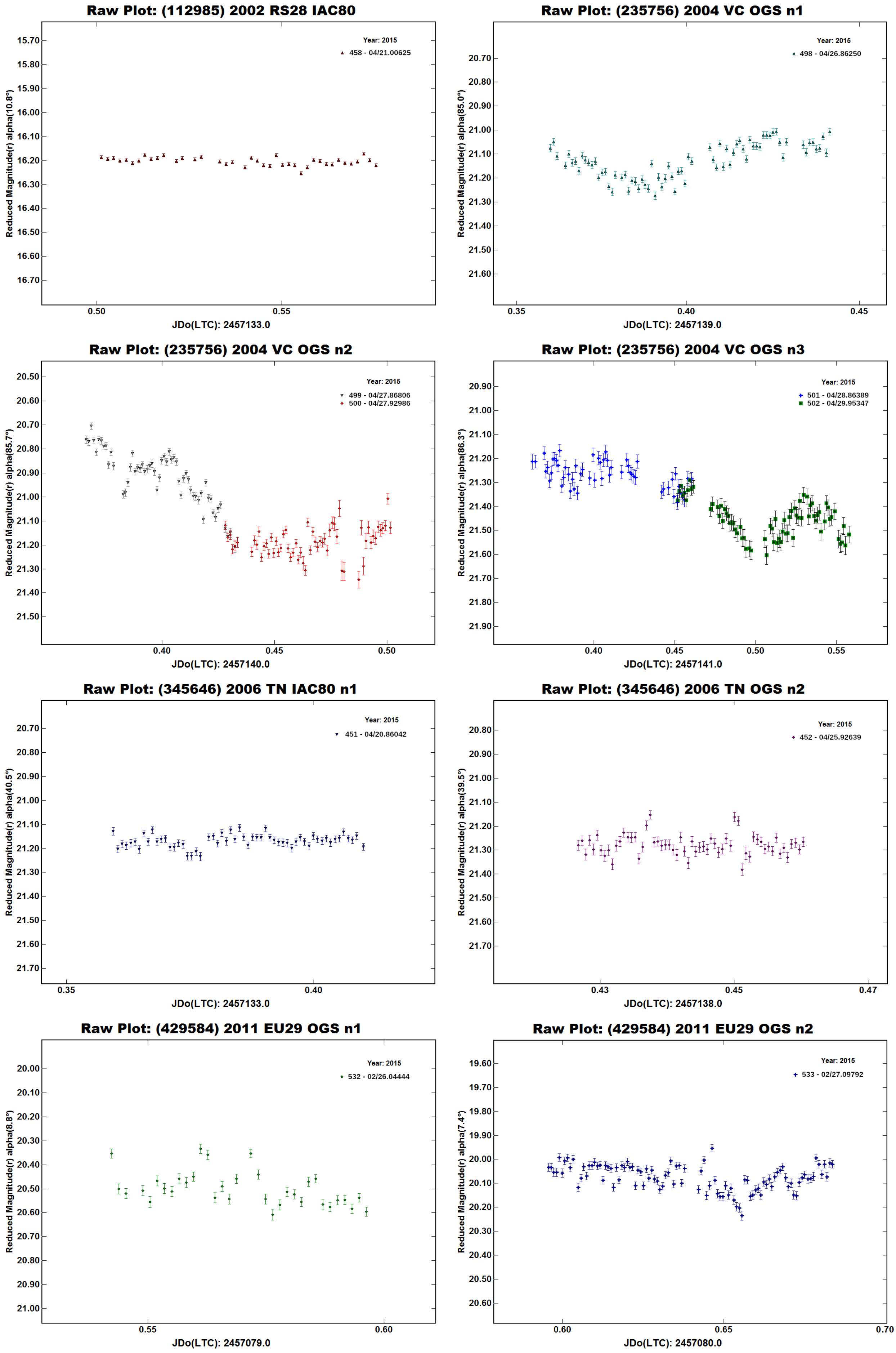

Figure 4: Lightcurves of NEAs poorly observed without periods.

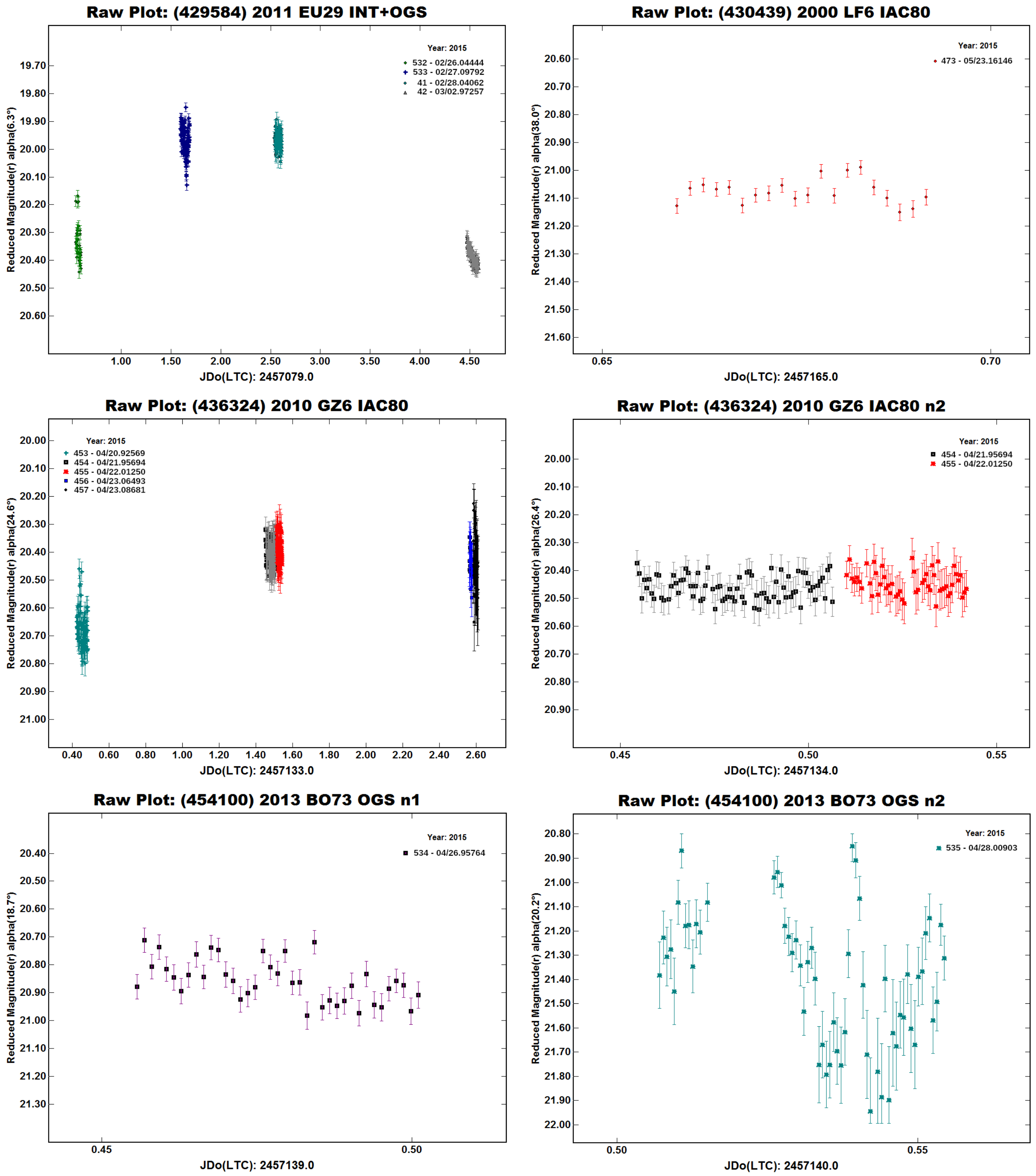

Figure 4 (continued): Lightcurves of NEAs poorly observed without periods.