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First EURONEAR NEA discoveries from La Palma using the INT[⋆]

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ABSTRACT

Since 2006, the EURONEAR project has been contributing to the research of near Earth asteroids (NEAs) within an European network. One of the main aims is the amelioration of the orbits of NEAs, and starting in February 2014 we focus on the recovery of one-opposition NEAs using the Isaac Newton Telescope (INT) in La Palma in override mode. Part of this NEA recovery project, since June 2014 EURONEAR serendipitously started to discover and secure the first NEAs from La Palma and using the INT, thanks to the team-work including amateurs and students who promptly reduce the data, report discoveries and secure new objects recovered with the INT and few other telescopes from the EURONEAR network. Five NEAs were discovered with the INT, including 2014 LU14, 2014 NL52 (one very fast rotator), 2014 OL339 (the fourth known Earth quasi-satellite), 2014 SG143 (a quite large NEA) and 2014 VP. Another very fast moving NEA was discovered but was unfortunately lost due to lack of follow-up time. Additionally, another 14 NEA candidates were identified based on two models, all being rapidly followed-up using the INT and another 11 telescopes within the EURONEAR network. They include one object discovered by Pan-STARRS, two Mars crossers, two Hungarias, one Jupiter trojan, and other few inner MBAs. Using the INT and Sierra Nevada 1.5 m for photometry, then the Gran Telescopio de Canarias (GTC) for spectroscopy, we derived the very rapid rotation of 2014 NL52, then its albedo, magnitude, size, and its spectral class. Based on the total sky coverage in dark conditions, we evaluate the actual survey discovery rate using 2-m class telescopes. One NEA is possible to be discovered randomly within minimum 2.8 square degrees and maximum 5.5 square degrees. These findings update our past statistics, being based on double sky coverage and taking into account the recent increase in discovery.

Key words: astrometry; minor planets; near Earth asteroids; surveys; photometry; spectroscopy

1   INTRODUCTION

Near Earth Asteroids (NEAs) are defined as minor planets with a perihelion distance (q) less than 1.3 au (JPL 2015; Morbidelli 2002). Currently, the NEA population includes four major classes, namely Amors, Apollos, Atens and Atiras. Potentially Hazardous Asteroids (PHAs) are defined as NEAs having a Minimum Orbital Intersection Distance (MOID) less than 0.05 au and the absolute magnitudes (H) less than 22 mag, which corresponds to objects larger than about 150 m. This limit in size represents the asteroids large enough to potentially cause a global climate disaster and threaten the continuation of human civilization.

We know today (Jan 2015) more than 12 000 NEAs (MPC 2015), mostly discovered by a few dedicated surveys funded in the U.S. using 1m class telescopes (Catalina, LINEAR, Spacewatch, NEAT, LONEOS) and more recently by Pan-STARRS 1.8m (Jedicke et al. 2007) and the WISE/NEOWISE 0.6m infrared space surveys (Wright et al. 2010; Mainzer et al. 2011). Some other 10,000 NEAs larger than 100m were estimated to exist Mainzer et al. (2012), most of them falling within 2-m class discovery capabilities (Vaduvescu et al. 2013a).

Part of the known NEA population, about 400 objects have poor orbital data, being unobserved for years and having orbits calculated based on small arcs spanning a few weeks or days following discovery, resulting in more uncertain recoveries and in some cases in marginal or bad matches and lost objects. The ameliora-

tion of such NEA orbits is an opportunity for 2-m class telescopes equipped with relatively large field imaging cameras, including the Isaac Netwon Telescope (INT) operated on the island of La Palma by the Isaac Newton Group (ING) in the Spanish *Observatorio del Roque de los Muchachos* (ORM) of the *Instituto de Astrofísica de Canarias* (IAC).

Since 2006, the *European Near Earth Asteroids Research* (EURONEAR) has contributed mainly to the orbital amelioration of NEAs within a European network (Vaduvescu et al. 2008) which includes now 20 European and one Chilean nodes. For this project we used mostly 1-4m telescopes and a few other smaller facilities available to our network (Birlan et al. 2010a,b; Vaduvescu et al. 2011a, 2013a) plus archival imaging taken by 2-4m telescopes (Vaduvescu et al. 2009, 2011b, 2013b). During the last 8 years we have succeeded in improving about 1,500 NEA orbits (Vaduvescu et al. 2014) thanks to the collaboration with about 30 students and amateur astronomers from Romania, Spain, UK, Chile, Germany and France, who have been actively involved in data reduction, observations, discoveries, data mining, software and database development, working together mostly remotely via the internet. Beside the above papers, this work produced around 100 MPC/MPEC publications (Vaduvescu et al. 2008-2014) and more than 10 contributions in international conferences.

Since February 2014 part of the ING Spanish and UK regular calls, EURONEAR has been granted time for three observing proposals (the Spanish C136/2014A, C88/2014B and the UK P2/2014B) to use the INT telescope endowed with the Wide Field Camera (WFC) for the program "Recovering NEAs and Eliminating VIs: A Pilot ToO Program with the INT-WFC" (Vaduvescu et al. 2015). By securing a few dozen short triggers (max 1h/night) throughout two semesters, our team is aiming to recover about 200 one-opposition faint (mostly $22 < V < 23$) and uncertain

($\sigma < 20'$) NEAs, and also to discover and secure promptly a few NEAs serendipitously observed in the program fields. Although in the past years EURONEAR serendipitously discovered but could not secure a few NEAs (Vaduvescu et al. 2013a), since February 2014 we started to secure our NEA discoveries thanks to the conjunction of three essential factors: the very fast data reduction in a team comprising about 10 amateur astronomers and students (including some ING students), the INT override opportunity and the involvement of a few EURONEAR nodes and collaborators able to access other mostly 1m class telescopes for rapid follow-up. By meeting these conditions, since June 2014 EURONEAR discovered and secured the first five NEAs ever discovered from La Palma and using the INT.

In Section 2 we introduce the INT observations and data reduction. In Section 3 we present the circumstances of our NEA discoveries, while in Sections 4 and Section 5 we discuss two special objects, namely the very fast rotator 2014 NL52 and the Earth quasi-satellite 2014 OL339. In Section 6 we re-assess the unknown NEA sky density accessible to 2-m surveys nowadays, and in Section 7 we discuss future strategy and work in progress.

2 OBSERVATIONS AND DATA REDUCTION

All discovery observations were acquired in La Palma using the 2.5m INT telescope during two regular visiting nights plus three of INT D-nights. The follow-up work (consisting of a few follow-up nights for astrometry and photometry) was carried out using the 2.5m INT telescope (all objects) and some fields were followed-up using another 11 telescopes of the EURONEAR network or other collaborators: the 1.5 m in Sierra Nevada Observatory (OSN), Tautenburg 2 m (TLS) in Germany, the 2 m Livepool Telescope (LT), the 4.2 m William Herschel Telescope (WHT) and Mercator 1.2 m in La Palma, the 1 m ESA Optical Ground Station (ESA-OGS) and IAC80 0.8 m in Tenerife, C2PU 1 m in France, Modra 0.6 m in Slovakia, Poznan 0.7 m (PST2) in Arizona and GLORIA D50 0.5 m in Ondrejov (remotely controlled). **In Table 1 we include the main characteristics of these facilities.** We are indebted and we offered co-authorship to all these involved collaborators.

At the prime focus of the INT we used the Wide Field Camera (WFC) which consists of four CCDs $2k \times 4k$ pixels, covering an L-shaped $34' \times 34'$ field with a pixel scale of 0.33 ″/pix. All WFC frames were observed with no binning and using slow readout (48s). During all runs we used the Sloan r filter to avoid fringing and minimise twilight and any possible moonlight. For all fields we tracked all our main targets (the known one-opposition NEAs) at their half proper motion. We used in all cases sequences of 6 to 8 times 120s exposures, needed to detect most of our faint targets typically around $22 < V < 23$. Most of the nights were dark with good seeing (typical average 1.2″ for the INT) and low airmass for all fields (better than 1.4).

For data reduction, first we used THELI (Erben et al. 2005; Schirmer 2013) to subtract the bias and twilight flat and to correct the known field distortion at the prime focus of the INT. Second, we used Astrometrica software (Raab 2015) with a fit order 1-2 and PPMXL or UCAC4 catalogs, to detect all moving sources via human blink (typically a few dozen known or unknown main belt asteroids in each field). As the third quality control step, we used the FITSBLINK (Skvarc 2015) and the EURONEAR O-C (observed minus calculated) servers, also the Minor Planet Center (MPC) NEO rating tool and finally the Find_Orb software (Gray 2015) to check the astrometry and confirm the target NEA based on orbital fits. Reducing all data in a team of about 10 experienced students and amateurs, we could classify, measure and report all the INT detections from all the fields to MPC, within one day.

3 DISCOVERED NEAS AND OTHER NEA CANDIDATES

In Figure 1 we include the discovery images (composite of all frames) and in Table 1 we include the log and discovery circumstance data for our six discovered NEAs and other 14 follow-up NEA candidates discussed in Section 3.7. We include the observers, data reducers and actual discoverer (in bold), the official designation, EURONEAR nickname, discovery date (UT of the first image), observed field (typically known one-opposition NEAs), **the apparent** proper motion μ (in arcsec/min), Solar elongation (in degrees), MPC NEO Int score (between 0-100), the exposure time (in seconds) and number of images, measured R-band magnitude, orbital elements (estimated by Find_Orb for very short orbits) semi-major axis a (in astronomical units au), eccentricity e, inclination i (degrees), MOID (au), absolute magnitude H, orbit type, number of EURONEAR follow-up nights FN and actual orbital arc (days or minutes).

In Figure 2 we plot the discovered objects in the $\epsilon - \mu$ model (Vaduvescu et al. 2011a) which allowed us to distinguish and follow-up all NEA candidates, together with their MPC NEO rating score. In Figure 3 and Figure 4 we plot in solid circles the orbital elements of our five discovered NEAs and with crosses the other NEA candidates, drawing with green, blue and red dots the entire known Amors, Apollos, and Atens, respectively. We discuss briefly here the discovery circumstances and orbital parameters in the entire known NEA population context.

3.1 2014 LU14, the first NEA discovered from La Palma

Designated as EUHT171 by the actual discoverer Lucian Hudin who analysed images with Astrometrica, this NEA candidate was imaged first on 2 June 2014 at 04:17 UT in the field of the one-opposition NEA 2012 MR7 observed by the ING student V. Tudor during our C136 trigger of the regular INT program C106 (PI: L. Verdes-Montenegro).

With a MPC NEO score Int=100 and situated close to the border of the $\epsilon - \mu$ model (Vaduvescu et al. 2011a) (which is less efficient at lower Solar elongations), this NEA candidate was secured and followed on four nights with the INT by the observers O. Vaduvescu during the C106 run, A. Kong and R. Jin during the next C50 run (PI: D. Torres) and O. Vaduvescu and M. Popescu during the N8 run (PI: O. Vaduvescu). Finally this Apollo object received permanent designation 2014 LU14 (MPS 518060 and 518856) and became the first EURONEAR NEA discovered and secured from La Palma and using the INT telescope (ING, 2014).

3.2 2014 NL52, a very fast rotator

The actual discoverer Lucian Hudin reported an unknown long trail in one of the fields of our main target PHA 2010 SH13 observed in the morning of 10 July 2014 at 04:36 UT during the Spanish CAT service night attended by O. Zamora. Designated EUHT288, this fast NEA candidate was moving with a proper motion of $\mu = 6.1''$/s at relatively low Solar elongation $\epsilon = 93°$, resulting in a MPC NEO score 100 and being placed well above the NEO limit on the $\epsilon - \mu$ model.

Due to the scheduled INT instrument change, next day we lost

access to the telescope, so we alerted the EURONEAR nodes and other collaborators to secure this fast moving NEA. Fortunately, the *Instituto de Astrofísica de Andalucía* (IAA, one of the EURONEAR nodes) responded promptly, and they used the 1.5 m telescope at Sierra Nevada Observatory (OSN), based on DDT time granted at very short notice by S. Ruiz and R. Duffard, thus the observer A. Sota successfully recovered the object in one of the fields, securing our discovery.

Following the discovery night, our team gathered orbital and physical follow-up data on 12 nights, including the OSN 1.5 m telescope (observer A. Sota during 5 nights), the 2 m Liverpool Telescope (LT, proposal CQ14B01 during one night managed by J. Marchant also member of EURONEAR), the INT (during two D-nights observed by O. Vaduvescu, V. Tudor and T. Mocnik), and the Tautenburg 2 m TLS telescope at the Karl Schwarzschild Observatory (during 4 nights observed by B. Stecklum, another member of EURONEAR). This object was also observed spectroscopically with the 10.4m *Gran Telescopio Canarias* (GTC, PI: J. de Leon, observer: C. Alvarez, reducer: A. Cabrera-Lavers). We will discuss the physical data in Section 4. In the meantime, this Apollo object received designation 2014 NL52, becoming the second EURONEAR NEA discovery (MPS 522840, 523438, 524006, 531624, 533418).

3.3   2014 OL339, the fourth known Earth quasi-satellite

Designated as EURC061 by its actual discoverer Farid Char, this NEA candidate was observed at 29 July 2014 02:51 UT during an INT D-night attended by O. Vaduvescu and V. Tudor, in the main target field NEA 2013 VQ4. The detection of this unknown object was quite difficult (the most difficult from all our discoveries) due to its faintness ($R \sim 21.9$) and relatively fast proper motion ($\mu = 2.1''/s$) which resulted in small trails in the vicinity of two stars, probably escaping detection an automated pipeline. Observed at relatively low Solar elongation ($\epsilon = 117°$), the object immediately became a NEA candidate with a MPC NEO score 100 and located well above the NEA limit on the $\epsilon - \mu$ model.

During next night we could secure our discovery using the INT, triggering some time during our own NEA photometry program N8 (PI: O. Vaduvescu), then we could follow-up two more nights, thanks to our C136 ToO program (during one D-night observed by T. Mocnik) and also during our new P2 ToO program triggered during the regular U.K. P1 program (PI: V. Dhillon joined by observer D. Sahman). While fitting the data using the Find_Orb software (Gray 2015), O. Vaduvescu noticed an orbit very close to the Earth ($a \sim 0.999$ au). Finally, this Aten object was published as 2014 OL339 (MPS 525771) and became our third EURONEAR discovered and secured NEA which indeed turned out to be a very rare NEA to be discussed in Section 5.

3.4   2014 SG143, our largest discovered NEA

Designated EUHT461, this brighter NEA candidate ($R = 20.5$) was discovered by Lucian Hudin in the field of the main target NEA 2011 XE1 observed in the morning of 18 September 2014 at 03:51 UT, during a D-night attended by O. Vaduvescu, T. Mocnik and M. Popescu. Moving relatively slowly ($\mu = 1.0''/s$) but relatively far from opposition ($\epsilon = 145°$), the object became an obvious NEA candidate with a score of 98 and being located above the $\epsilon - \mu$ plot.

Thanks to our new 2014B U.K. P2 program, the following night we were able to override the P10 program (PI: B. T. Gänsicke,

observer M. Hollands) to secure this NEA candidate. Then, the collaborators M. Micheli and D. Koschny scheduled some follow-up observations using the 1m Optical Ground Station of the European Space Agency (ESA-OGS, observer M. Busch, reducers A. Knofel and E. Schwab) which confirmed its NEA status. Finally, this Amor object was oficially named 2014 SG143 (MPS 533750) and became our fourth NEA discovered from La Palma and using the INT. This is actually a large object and our largest NEA discovery, estimated between 0.6-1.4 km (NEODyS and EARN database) based on its absolute magnitude $H = 18.4$.

3.5   2014 VP, the brightest NEA discovery

Designated as EUHR001 by its actual discoverers Lucian Hudin and Radu Cornea, this NEA candidate was seen on 4 November 2014 05:20 UT during an INT D-night, being observed by the ING students T. Mocnik, M. Díaz Alfaro, I. Ordonez-Etxeberria and F. Lopez-Martinez in the field of the target NEA 2004 CL1. This relatively bright object ($R \sim 19.3$ and our brighest discovered NEA) was trailing due to its fast proper motion ($\mu = 5.3''/s$), the two ends of the trail being averaged and reported within hours to the MPC. Observed at $\epsilon = 143°$ Solar elongation, this object became an obvious NEA candidate with a MPC NEO score 100 and clearly located well above the NEA limit on the $\epsilon - \mu$ model.

Despite the targeted recovery observation of the Spacewatch survey which recovered our NEA six hours later, the predicted positional uncertainty for the second night reached about 0.5°, while the weather at ORM and Moon conditions remained very poor. Once again, the EURONEAR network was alerted to recover this object, and fortunately our Poznan EURONEAR node (observers T. Kwiatkowski and K. Kaminski) was able to recover the object using their 0.7 m PST2 remote telescope located at the Winer Observatory in Arizona. The following night, a battery of 3 telescopes (OSN 1.5 m with observer V. Casanova, IAC80 with observer M. Gomez-Jimenez and INT with observers T. Mocnik service observer of a run PI: I. Negueruela), followed by O. Vaduvescu and collaborators using the 1.2 m Mercator and B. Stecklum using the TLS 2 m telescopes enlarged the arc and firmed the orbit of this Apollo NEA which officially became 2014 VP and our fifth EURONEAR NEA discovered using the INT from La Palma.

3.6   EUHT400, a small object lost due to lack of follow-up time and very rapid motion

The reducer Lucian Hudin reported a very long trail caused by the unknown object designated EUHT400 at 4 August 2014 01:40 UT, in the corner of a frame taken by V. Dhillon (PI of P1 program) and co-observer D. Sahman, triggered by our P2 NEA override program. Moving very fast ($\mu = 11.2''/s$) and very close to opposition ($\epsilon = 176°$), this was our most obvious NEA candidate with a MPC score 97 and located very high on the $\epsilon - \mu$ model.

Although we immediately alerted our EURONEAR nodes and collaborators, unfortunately none was able to follow-up the object during the next night. Not being allowed to trigger additional time at the INT, we asked the INT observer R. Génova-Santos (ITP13-8 program, PI: Rubino-Martin) who kindly accepted a very short window in the hope of recovering EUHT400 pointing the telescope to three neighbouring fields spanning across the very elongated sky uncertainty ellipse ($\sim 2°$ major axis). Unfortunately, the object did not show up in any of these images, although at least one other fast moving object (denoted as EUVI016 which does not match

the EUHT400 orbit) was found after very careful analyse a few months later by Victor Inceu. During the next night, the recovery of EUHT400 became impossible due to sky-rocketting uncertainty (estimated by MPC to at least $10°$), so we lost this discovered NEA, unfortunately.

3.7 Other NEA candidates

Besides the above six obvious NEA discoveries, between Feb-Nov 2014 as part of our INT ToO programs, our team followed up 14 unknown objects considered NEA candidates based on their MPC NEO Int score (chosing a lower 20% threshold for safety) and also the $\epsilon - \mu$ model (Vaduvescu et al. 2011a). We include these objects in Table 2, plotting them with crosses in Figure 2, Figure 3 and Figure 4, and we discuss next some of these objects.

Although located around the $\epsilon - \mu$ NEA limit (plotted as a magenta dotted line in Figure 2) and observed close to opposition, up to six NEA candidates turned out to be regular main belt asteroids, namely the objects EUHTT05 (designated as 2014 FY32, MPS 506887), EUMO086 (2014 OG361, MPS 525793), EUHT275 (MPC score 23 and moving perpendicular on the direction of other MBAs in the field), EUHT251 (score 25), EUMO207 (score 51) and EUMO208 (score 33, followed-up from Modra 0.6m and GLORIA D50 0.5m Ondrejov telescopes).

The very fast object EUHT308 ($\mu = 6.3''$/min) resulted in a long trail and became an obvious NEA candidate (score 100), being reported immediately to MPC. Nevertheless, this object was discovered by Pan-STARRS two days before, our INT recovery observations confirming its Amor orbit (MPS 524257).

Two NEA candidates, namely EUHT164 (designated as 2014 LP9, MPS 518055, 518856, $\mu = 1.4''$/min observed at very low Solar elongation $\epsilon = 50°$, MPC Int score 91) and EURC055 (score 27) have found to be Mars crossers.

Our faintest NEA candidate EURM074 ($R = 21.8$) was observed to move relatively fast ($\mu = 2.3''$/min) at relatively low Solar elongation ($\epsilon = 87°$), consistent with its MPC score 100. Unfortunately the object could not be recovered during the second night (up to a deeper $r \sim 22.5$ limit), so these findings should be regarded with caution. Its very short arc (7 min) could be fit by Find_Orb in a near circular Earth-like orbit of Arjuna class.

Two more objects, namely EUHT309 (designated 2014 OH198, MPS 526663, 528326, discovered by Pan-STARRS) and EUHT462 (designated 2014 SP62, MPS 533673, discovered by INT and followed-up by ESA-OGS 1m) were found to be Hungarias.

The object EUMO201 (designated as 2014 RC13, MPS 531887, discovered by INT) could be recovered in twilight with the WHT 4.2 m telescope (observer: F. C. Riddick) and OSN 1.5 m twice (observer: V. Casanova) but could not be seen few days later, using neither the C2PU 1m, nor the LT 2 m. Its 3-day arc orbit corresponds to a Jupiter trojan.

Finally, while scrutinising recently the three recovery fields of the lost EUHT400, Victor Inceu discovered another fast moving object (denoted EUVI016, $\mu = 6.1''$/min, Int score 100), although this NEA does not match the previous night EUHT400 orbit.

4 THE VERY FAST ROTATOR 2014 NL52

Based on the INT discovery images showing our long trail object EUHT288 and also based on the OSN follow-up images, L. Hudin visually noticed rapid variation in brightness, suggesting first that the new object could be a fast rotator. To study rotation, O. Vaduvescu secured 2h in the Liverpool 2 m telescope (LT) and later 2h with the INT, part of his Dutch N8 program for lightcurves of NEAs.

4.1 Rotation period

The asteroid was observed photometricaly on 20/21 July 2014 with the 1.5 m telescope at the OSN observatory. Due to the object's faintness ($V \sim 20$ mag), the EEV 42-40 CCD mounted at the telescope was used without any filters. The exposure time was 60 s with a 2 s readout. The data was reduced using the LIDAS package (Lightcurve Derivation for Asteroids) written in Python by the ING student Vlad Tudor. The lightcurve obtained from the 0.62 h run revealed a possible rotation period of $P_1 = 4.43 \pm 0.03$ min but its significance was questionable, due to high noise.

A confirmation of the asteroid short period was obtained on 29/30 July 2014 when 2014 NL52 was observed with the INT. The object was observed for 1.86 h using the SDSS r filter. The exposure time was 20 s, with a duty cycle of 25 s using a $5' \times 5'$ window in CCD4. The data were reduced using the same LIDAS package. The lightcurve was analysed by iteratively fitting a Fourier series using different trial periods (Kwiatkowski et al. 2009). The best fit was obtained for two synodic periods: $P_2 = 4.459 \pm 0.003$ min and $P_3 = 8.917 \pm 0.004$ min which is quite common in case of noisy lightcurves. It is important to note that the lightcurve peak-to-peak amplitude was $A \approx 0.6$ mag, and the solar phase angle was ($\alpha = 58°$). To analyse such ambiguities, we used simulations of Butkiewicz et al. (2014) in which lightcurves were obtained for different model shapes, spin axes and illuminations. All lightcurves simulated at $\alpha = 58°$ and $A = 0.6$ mag had two maxima and two minima per period. This let us believe the P_2 solution represents the true period of 2014 NL52 so that we assign it a reliability code $U = 2+$ (Warner et al. 2009). We did not attempt to fold the 20 and 29 July data because the 3σ uncertainty in the derived synodic period, after 9 days, would lead to the uncertainty in the rotation phase as large as 6 rotations.

The composite lightcurve obtained with $P_2 = 4.459 \pm 0.003$ is presented in Figure 5. Its peak-to-peak amplitude of $A \approx 0.6$ mag can be used to estimate the asteroid minimum elongation $\frac{a}{b}$, where a and b are the semiaxes of the triaxial shape approximation. Using the relation from Kwiatkowski et al. (2010)

$$\frac{a}{b} \geqslant 10^{0.4A(\alpha)/(1+0.03\,\alpha)}, \tag{1}$$

where $A(\alpha)$ is a peak-to-peak amplitude, observed at a phase angle α, we obtain for 2014 NL52 $\frac{a}{b} \geqslant 1.2$.

4.2 Spectra and suggested composition

A low-resolution spectrum of 2014 NL52 was obtained on 15 August 2014 using the Optical System for Imaging and Low Resolution Integrated Spectroscopy (OSIRIS) camera-spectrograph (Cepa et al. 2000, 2010)) at the 10.4m Gran Telescopio Canarias (GTC) located at the ORM observatory. The OSIRIS instrument consists of a mosaic of two Marconi CCD detectors, each with 2048×4096 pixels and a total unvignetted field of view of $7.8' \times 7.8'$, giving a plate scale of $0.127''$/pixel. To increase the signal-to-noise ratio for our observations, the data were 2×2 binned, corresponding to the standard operation mode of the instrument. We used the R300R grism (dispersion of 3.87 Å/pixel) and a $5''$ slit, oriented at the parallactic angle to minimize slit losses due to atmospheric dispersion.

We obtained three spectra with an exposure time of 600 seconds each.

Images were bias- and flat-field corrected, using lamp flats. The two-dimensional spectra were wavelength calibrated using Xe+Ne+HgAr lamps. After the wavelength calibration, the sky background was subtracted and a one-dimensional spectrum was obtained. To correct for telluric absorption and to obtain the relative reflectance, the solar-analog stars SA110-361 and SA112-1333 (Landolt 1992) were observed using the same spectral configuration at an airmass nearly identical to that of the object. Each individual spectrum of the object was then divided by the corresponding spectra of the solar analogs. The resulting spectra were finally averaged and normalized to unity at 0.55 μm. The resulting final reflectance spectrum is shown in Figure 6. We used the M4AST online tool (Popescu et al. 2012) to classify our visible spectrum of NL52, finding that the asteroid is an S-type object.

4.3   Phase curve and size

One service proposal was granted to O. Vaduvescu to use the 4.2 m William Herschel Telescope (WHT), but the bright Moon and the rapidly fading asteroid prevented accurate photometric observations of 2014 NL52, unfortunately.

To derive the asteroid phase curve, we first used the data reported by the NEODyS service. We selected only the observations done in either R or V filters. Using an average colour of the S type NEAs of $V - R = 0.49$ mag (Shevchenko & Lupishko 1998), we transformed the R band magnitudes to V, then we derived the H and G parameters of the phase curve by a least-square fit (Figure 7). The obtained values are $H = 23.84$ mag, and $G = 0.2$. To check this result we calculated the asteroid magnitudes (averaged over its rotation) from the 20 July OSN and 29 July INT data, calibrating them to the standard V magnitudes using the CMC15 and APASS stars found in the CCD images close to the asteroid. The OSN observations were made unfiltered, so to derive object's V magnitude we used two stars with the APASS SDSS $g - r$ colours of 0.91 mag and 0.32 mag. They were redder and bluer than the average colour of an S-type asteroid ($g - r = 0.62 \pm 0.02$, Fig. 10 in Ivezic et al. (2001). The differential photometry of the asteroid using those two stars gave its average r magnitude of 20.91 and 21.01 mag, respectively, thus we accepted the mean of those two values: $r = 20.96$ mag. For the INT data obtained through the SDSS r filter, we determined the asteroid average r magnitude by comparing its brightness with two nearby stars, whose r magnitudes were reported by both CMC15 and APASS catalogs.

The asteroid r magnitudes were then converted to the V band using the standard equations given by Fukugita et al. (1996) with an average colour of S-type ($g - r = 0.62$).

Adding together the two OSN and INT brightness measurements on the phase curve plot (Figure 7), one can see that they are located well below the $H - G$ fit. This is a common situation usually caused by the bias in magnitudes reported to the Minor Planet Center with the astrometric measurements. Obviously, more accurate positions are derived from the CCD frames on which the asteroid is brighter, which favours lightcurve maxima. For this reason we belive the phase curve should be shifted downwards by about 0.45 mag, so that it coincides with our photometric measurements, thus a new value for the absolute magnitude is $H = 24.29$ mag. We note that the $G = 0.2$ obtained from our fit is close to the average value of 0.24 derived for S-type asteroids (Warner et al. 2009). It is difficult to estimate the accuracy of the H value, so we assume

the maximum systematic uncertainty of H to be 0.5 mag, thus the absolute magnitude for 2014 NL52 becomes $H = 24.3 \pm 0.5$ mag.

To derive the effective diameter of 2014 NL52 we use a standard procedure from (Fowler & Chillemi 1992). Knowing that 2014 NL52 is an S-type object, we can assume its geometric albedo in V is $p_V = 0.26^{+0.04}_{-0.03}$ (Thomas et al. 2011). Since we have only a systematic uncertainty for the H value, for the comparable uncertainty of the geometric albedo we adopt a 3σ value, so that $0.17 < p_V < 0.38$. With such values for H and p_V we obtain the effective diameter $D = 36^{+20}_{-12}$ m where the uncertainties indicate an interval in which the true value can be found rather than standard deviations.

5   THE FOURTH DISCOVERED AND FIRST ATEN EARTH QUASI-SATELLITE 2014 OL339

A few weeks after our discovery of 2014 OL339, Carlos de la Fuente Marcos (Universidad Complutense de Madrid) contacted O. Vaduvescu to announce our team an interesing orbital discovery. According to their numerical models based on the currently known orbit, this object turned out to be the fourth ever known NEA to revolve in a quasi-satellite and quite unstable orbit with respect to the Earth, which started at least about 775 years ago and will end 165 years from now (de la Fuente Marcos 2014a).

Besides 2014 OL339, in Figure 3 and Figure 4 we plot with open circles the other three known quasi-Earth satellites, namely the PHA (164207) 2004 GU9 discovered by LINEAR in 2004, the NEA (277810) 2006 FV35 discovered by Spacewatch in 2006, and the NEA 2013 LX28 discovered by Pan-STARRS in 2013, all three moving in Apollo orbits. In this context, EURONEAR discovered the fourth known Earth quasi-satellite 2014 OL339, which became actually the first such object moving in an Aten orbit, and besides (164207) being the most unstable of the known Earth quasi-satellites (de la Fuente Marcos 2014a).

Using larger field 2-m class surveys to discover fainter NEAs (such as 2014 OL339 at $R = 21.9$) is essential for increasing the known population of Earth quasi-satellites and characterising the closest NEA sub-classes, such as PHAs or the newly defined Arjuna-type asteroids in Earth-like orbits (de la Fuente Marcos 2014b). Moreover, the discovery of such fainter objects is important for identifying targets for future space missions, so in this sense 2-m class surveys (such as Pan-STARRS or Spacewatch) and even smaller NEA projects (such as EURONEAR using the INT-WFC) could bring major contributions to the NEA research.

6   UPDATED UNKNOWN NEA SKY DENSITY ACCESSIBLE TO 2-M SURVEYS

Based on our past INT-WFC dataset collected by mid-2012 in a total 24 square degree survey, Vaduvescu et al. (2013a) estimated the unknown NEA sky density accessible to 2-m surveys, predicting in good conditions (clear and dark sky with seeing below $\sim 1.5''$) a discovery rate of one NEA per two square degrees. We are checking now this statistics using our new 2014 dataset.

Considering all the INT-WFC fields observed in the period Feb-Nov 2014, we count a total of 158 fields observed in dark conditions, similar to those considered our previous work. Taking into account the WFC field of 0.28 square degrees, our 2014 data increases our actual total survey area to about 44 square degrees (almost double compared with our past work). Considering our dis-

covered NEAs, we can count between a minimum of 8 NEAs (the 5 secured objects, the NEA EUHT308 discovered by Pan-STARRS, the lost EUHT400, plus the unknown rapid object EUVI016) and a maximum of 16 NEAs (considering the 8 other NEA candidates located above or very close to the NEA limit on the $\epsilon - \mu$ plot in Figure 2). This gives an actual 2-m survey statistics of one NEA discovered in every 2.8 to 5.5 square degrees (namely between 10 and 20 INT-WFC fields).

The above statistics should be regarded with caution due to our relatively small sky coverage, remaining to be probed by dedicated surveys. We are not aiming to address here the apparent NEA sky distribution based on our modest NEA recovery program which could be affected by some selection and observational effects (Jedicke et al. 2002). Nevertheless, we can briefly compare now our 2014 statistics with the mid-2012 INT statistics (Vaduvescu et al. 2013a) which took into account all NEA candidates (none actually secured) which predicted one NEA discovery in every scanned 2 square degrees. During the past 2.5 years, about 2,500 NEAs have been discovered mostly by 2-m class surveys (growing the number of known NEAs from $\sim 9\,000$ to $\sim 11,500$), actually droping now our old discovery rate prediction to one NEA in every 2.7 square degrees. This expected NEA density matches very well our above discovery estimation rate (one NEA in each 2.8 square degrees) calculated after counting all 16 NEA candidates located above or very close to the NEA magenta limit dotted in the $\epsilon - \mu$ plot in Figure 2.

7 LESSONS LEARNED AND WORK IN PROGRESS

Three essential factors enabled us to discover and secure NEAs, namely:

(i) Our INT override programs which allowed short rapid access during available WFC nights;

(ii) The prompt data reduction in a team of students and amateurs available to reduce all fields and report NEA candidates within a few hours; and

(iii) The EURONEAR network able to contribute by accessing on short notice other telescopes in order to secure some discoveries.

Nevertheless, one very rapid NEA (EUHT400) escaped recovery during the next night and it was subsequently lost due to major sky growing uncertainty and lack of time on other 2-m class or larger telescope. To prevent such losses in the future, we implemented two measures:

(i) One data reduction staff will be available for first quick-look inspection of all images checking for longer trails (resulting in largest uncertainties following nights);

(ii) To save very fast objects including PHAs and Virtual Impactors (VIs), it is essential to secure some follow-up time using other facilities, so we secured LCOGT, IAC80, ESA-OGS and would ideally need the CFHT-MegaCam (best option in the North).

Our main NEA orbital improvement program continues in 2014B and 2015A based on multiple TAC allocation time, with the aim of recovering with the INT more than half the entire known one-opposition NEA population in 2015, and serendipitously discovering a few more NEAs.

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Table 1. The main characteristics of the telescopes involved in NEA discoveries: observatory, telescope diameter (meters), camera name, pixel scale (arcsec/pix), field of view (in arcmin), non-sidereal rate, typical instrumental seeing (arcsec) and limiting magnitude V at S/N=5 detection in dark time one minute exposure at Zenith.

| Observatory	Telescope	Diam	Camera	FOV	Scale	Track	Seeing	Lim.mag
ORM La Palma	INT	2.5	WFC	34×34	0.33	yes	1.2	23.0
ORM La Palma	WHT	4.2	ACAM	8 (diam)	0.25	yes	0.8	24.0
ORM La Palma	LT	2.0	RISE	9×9	0.54	yes	2.0	21.5
ORM La Palma	Mercator	1.2	MAIA	9×14	0.28	yes	1.0	21.5
OSN Spain	T150	1.5	VersArray	8×8	0.20	yes	1.5	21.0
TLS Germany	Schmidt	1.3	Prime	42×42	1.20	yes	2.0	20.5
Calern France	C2PU	1.0	SBIG STX16803	38×38	0.56	yes	2.0	20.5
OT Tenerife	ESA-OGS	1.0	custom	48×48	0.70	yes	1.5	20.5
OT Tenerife	IAC80	0.8	CAMELOT	10×10	0.30	no	1.2	20.5
Winer Arizona	PST2/Poznan	0.7	iXon888	10×10	0.58	yes	2.0	20.0
Modra Slovakia		0.6	Apogee AP-8	25×25	1.47	yes	2.5	20.0
GLORIA Ondrejov	D50	0.5	FLI IMG 4710	20×20	1.20	no	2.0	19.0
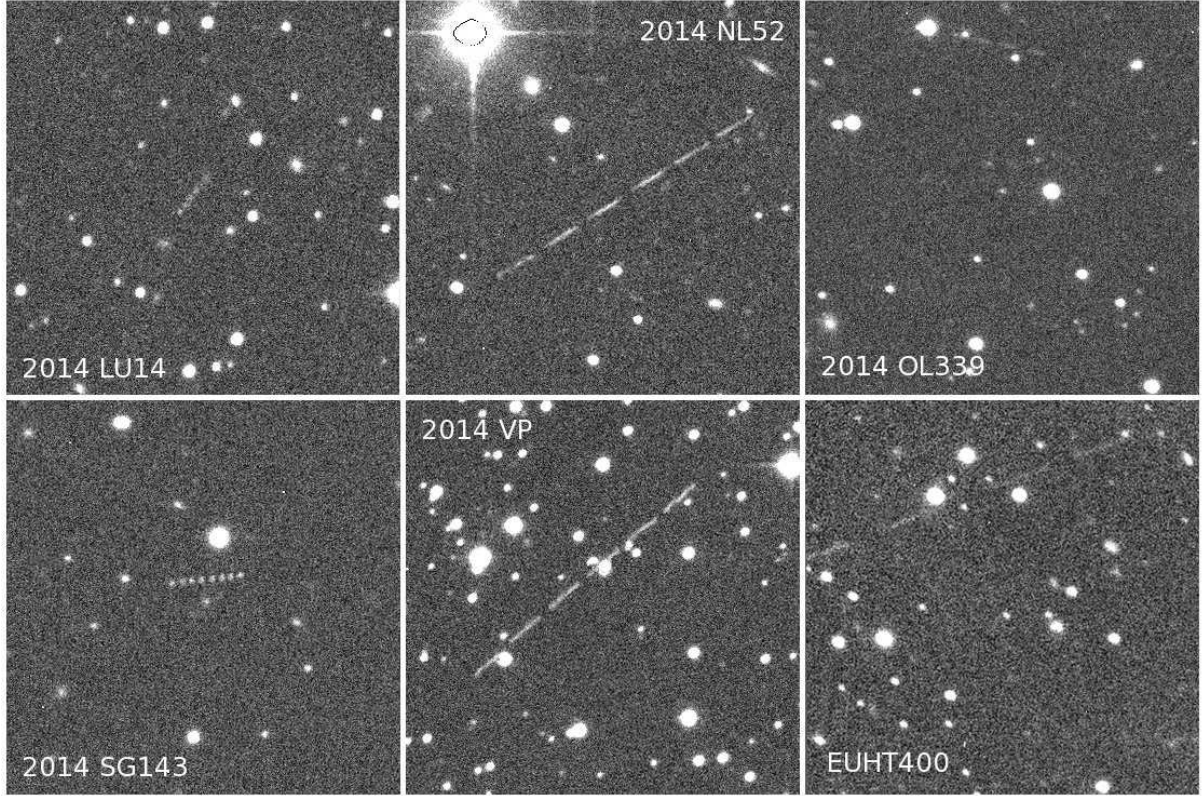
Figure 1. NEA discovery stack images. The field of view (FOV) is $2' \times 2'$ in normal sky orientation. 2014 OL339 could be barely seen in the upper side, while for EUHT400 we include only the last four of the available six images.
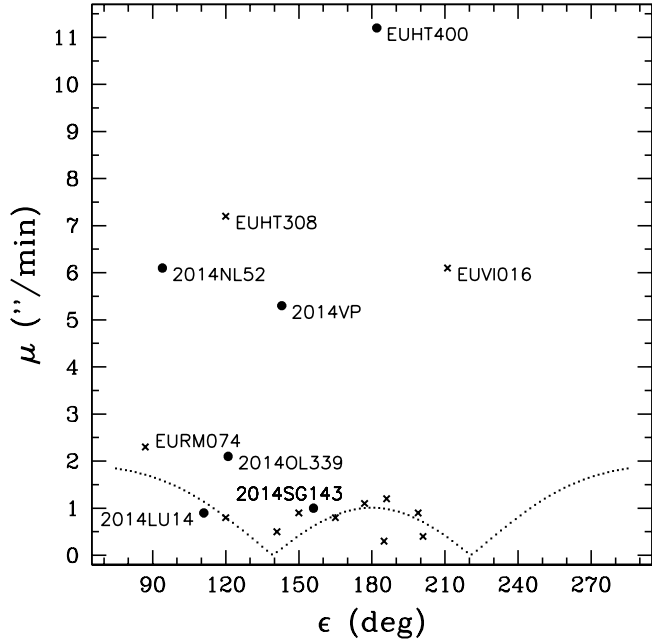
Figure 2. The $\epsilon - \mu$ model (Vaduvescu et al. 2013b) plotting the **apparent** proper motion μ versus Solar elongation ϵ used to distinguish rapidly between MBAs and NEA candidates located above the magenta dotted line roughly defining the NEA limit. We plot in solid circles our 5 secured NEAs plus EUHT400, and with crosses the other 12 NEA candidates.
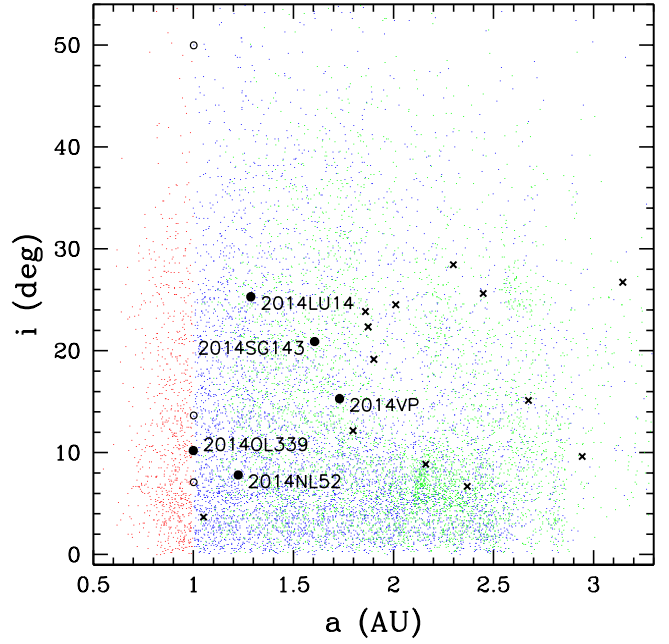

Figure 4. The classical $a - i$ orbital distribution (inclination versus semi-major axis) including our discoveries (solid circles) and other NEA candidates (crosses) with respect to the entire known (green dots), Apollos (blue), and Atens populations (red dots). With open circles we plot the other three known Earth quasi-satellites, in comparison with 2014 OL339. The Jupiter trojan 2014 RC13 is located outside the plot (a = 5.2 au).
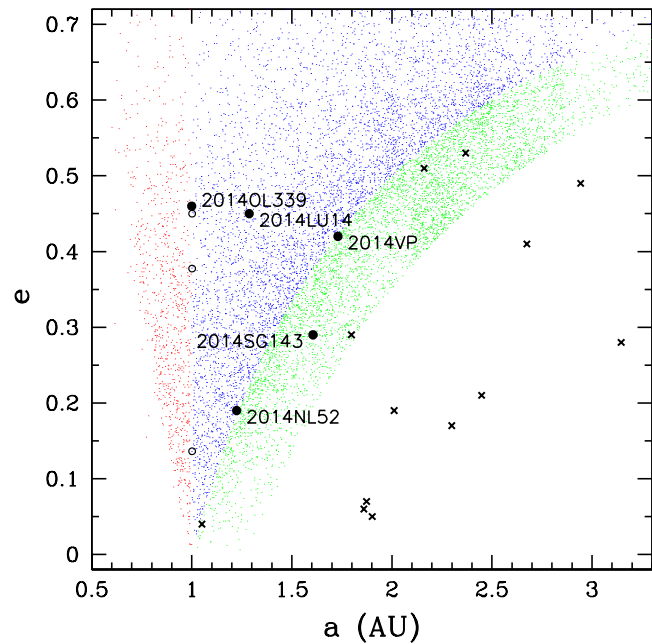

Figure 3. The classical $a - e$ orbital distribution (eccentricity versus semi-major axis) including our discoveries (solid circles) and other NEA candidates (crosses) with respect to the entire known Amors (green dots), Apollos (blue), and Atens populations (red dots). With open circles we plot the other three known Earth quasi-satellites, in comparison with 2014 OL339. The Jupiter trojan 2014 RC13 is located outside the plot (a = 5.2 au).
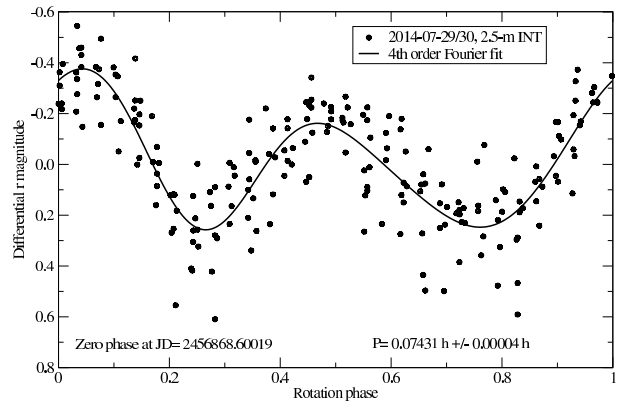

Figure 5. A composite lightcurve of 2014 NL52, observed on 29/30 July 2014 with the INT. It was obtained with the rotation period of P_2 = 4.459 min. A 4-th order Fourier series fit, used to derive the period, has been superimposed on the data.
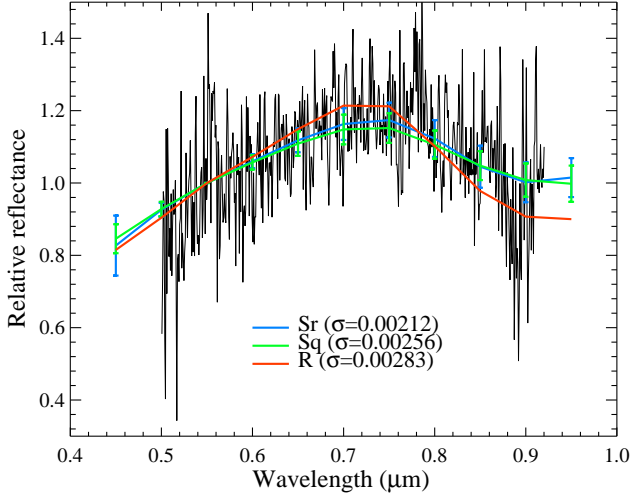
Figure 6. The visible spectrum of 2014 NL52 obtained with OSIRIS at GTC. The mean spectrum of Sr, Sq, and R-type asteroids from DeMeo et al. (2009) are shown in blue, green, and red, respectively. Values in parenthesis indicate the standard deviation of the χ^2 fit for each taxonomic type.
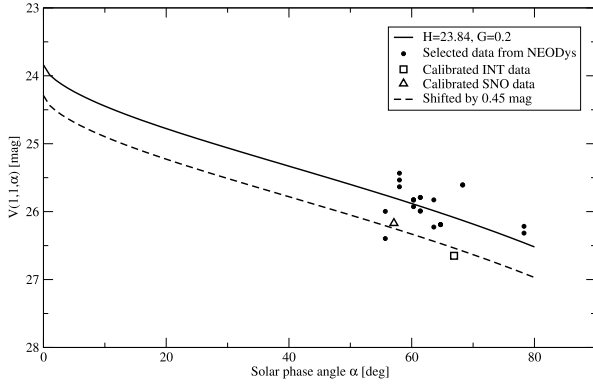

Figure 7. Phase curve of 2014 NL52. Black circles are approximative magnitudes, selected from the NEODyS server, transformed to the V band. Open triangles and squares are average asteroid magnitudes in *V* band, obtained from the lightcurves observed with the 1.5-m OSN telescope and 2.5-m INT. The H-G curve, fitted to the black circles, has been shifted downwards so that it goes close to the photometric measurements.