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Ready for EURONEAR NEA surveys using the NEARBY moving source detection platform

O. Vaduvescu[a,b,c], D. Gorgan[d], D. Copandean[d], V. Bacu[d], T. Stefanut[d], A. Sabou[d], C. Nandra[d], C. Boldea[c], V. Pinter[c], M. Popescu[b,e], E. Petrescu[f], D. Bertesteanu[f], T. Davison[a,g], F. M. Pérez Toledo[e], A. Boldea[c,h], M. Predatu[c], T. Zegmott[a,i], T. G. Wilson[a,j], L. Hudin[k], M. Stanescu[f], A. Stanica[c], A. Buhulea[c], A. Stoica[f], A. Timpea[f], S. Anghel[f,l,m], D. Ciobanu[r], R. Toma[m], V. Casanova[n], B. Stecklum[o], N. Choque-Challapa[p], P. Short[a,q], A. Tudorica[r]

[a]*Isaac Newton Group (ING), Apt. de correos 321, E-38700, Santa Cruz de La Palma, Canary Islands, Spain*
[b]*Instituto de Astrofisica de Canarias (IAC), Via Lactea, 38205 La Laguna, Tenerife, Spain*
[c]*University of Craiova, Str. A. I. Cuza nr. 13, 200585, Craiova, Romania*
[d]*Technical University of Cluj-Napoca, Str. Memorandumului 28, 400114, Cluj-Napoca, Romania*
[e]*Universidad de La Laguna, 38205 La Laguna, Tenerife, Spain*
[f]*Bucharest Astroclub, Str. Cutitul de Argint 5, sector 4, Bucharest, Romania*
[g]*University of Central Lancashire, Preston, Lancashire, PR1 2HE, UK*
[h]*National Institute for Nuclear Physics and Engineering, P.O. Box MG6 077125 Bucharest-Magurele, Romania*
[i]*Centre for Astrophysics and Planetary Science, School of Physical Sciences, University of Kent, Canterbury CT2 7NH, UK*
[j]*Department of Physics and Astronomy, University College London, Gower Street, London WC1E 6BT, UK*
[k]*Amateur Astronomer, ROASTERR-1 Observatory, 400645, Cluj Napoca, Romania*
[l]*Faculty of Physics, University of Bucharest, 405 Atomistilor, Magurele, Ilfov, Romania*
[m]*Astronomical Institute of the Romanian Academy, Str. Cutitul de Argint 5, sector 4, Bucharest, Romania*
[n]*Instituto de Astrofisica de Andalucia, CSIC, Apdo. 3004, 18080 Granada, Spain*
[o]*Thüringer Landessternwarte Tautenburg, Sternwarte 5, D-07778 Tautenburg, Germany*
[p]*Kapteyn Astronomical Institute, University of Groningen, Postbus 800, 9700 AV Groningen, Netherlands*
[q]*Department of Physics and Astronomy, University of Sheffield, Sheffield, UK*
[r]*Amateur Astronomer, Romania*

Abstract

In 2015 we started a PhD thesis aiming to write a moving objects processing system (MOPS) aimed to detect near Earth asteroids (NEAs) in astronomical surveys planned within the EURONEAR project. Based on this MOPS experience, in 2017 we proposed the NEARBY project to the *Romanian Space Agency*, which awarded funding to the *Technical University of Cluj-Napoca* (UTCN) and the *University of Craiova* for building a cloud-based online platform to reduce survey images, detect, validate and report in near real time asteroid detections and NEA candidates. The NEARBY platform was built and is available at UTCN since Feb 2018, being tested during 5 pilot surveys observed in 2017-2018 with the *Isaac Newton Telescope* in La Palma. Two NEAs were discovered in Nov 2018 (2018 VQ1 and 2018 VN3), being recovered and reported to MPC within 2 hours. Other 4 discovered NEAs were found from a few dozen possible NEA candidates promptly being followed, allowing us to discover 22 Hungarias and 7 Mars crossing asteroids using the NEARBY platform. Compared with other few available software, NEARBY could detect more asteroids (by 8-41%), but scores less than human detection (by about 10%). Using resulted data, the astrometric accurancy, photometric limits and an INT NEA survey case study are presented as guidelines for planning future surveys.

1. Introduction

The survey of the nearby space and continuous monitoring of the near Earth objects (NEOs) and especially near Earth asteroids (NEAs) are essential for the future of our planet. Therefore, their discovery and monitoring should represent priorities in the solar system research and our nearby space exploration.

Since 1980, six US-led NEO sky surveys (Spacewatch, LONEOS, NEAT, LINEAR, CSS and Pan-STARRS) have been using upgraded old or modern 1-2 meter class telescopes which discovered more than 99% from the entire known NEO population (passing 20,000 objects in May 2019). Since 2015 the ATLAS project of the University of Hawaii conducts a survey using two 0.5m telescopes, which have discovered about 300 NEAs, proving that surveys on small telescopes still have a future. In about 5 years, the US-led LSST survey should start to operate for at least one decade in Chile, using a 6.5 m diam equivalent mirror with the aim to cover the entire visible Southern sky every few nights using short exposures to detect and secure NEOs, besides other science aims.

In the meantime, the first two pioneering surveys in Europe were ODAS at OCA-DLR in France and Germany (1996-1999 which discovered 4 NEAs using a 0.9 m telescope) and CINEOS in Italy (2001-2004 which discovered 7 NEAs using a 0.6 m telescope). Actually, the European NEO surveys are still being led by two amateur and public outreach facilities, namely PIKA at *Crni Vrh Observatory* in Slovenia (which discovered 27 NEAs since 2003 using one 0.6 m telescope) and LSSS at *La Sagra Observatory* in Spain (which discovered about 100 NEAs between 2008 and 2014 using three 0.45 m telescopes). Since 2010, ESA uses their 1 m ESA-OGS telescope in Tenerife during a few dark nights every month for the TOTAS survey which discovered 23 NEAs, most of the time being used for tracking and finding space debris [1, 2, 3]. Soon, ESA should deploy the "fly-eye" 1 m prototype telescope in Sicily, aiming to increase their NEO and space debris contributions and install other such facilities elsewhere.

Since 2006, the *European Near Earth Asteroids Research* (EURONEAR) project aims to increase the European contribution in the NEO field using existing telescopes available in both hemispheres to the members of this network. In particular, it ameliorated orbits of about 1,500 known NEAs based on observations using mostly 1-2 m class telescopes [4, 5, 6] and [7] and another 500 NEAs based on data mining of existing image archives of 2-8 m class telescopes [8, 9, 10, 11]. EURONEAR has involved many students and amateur astronomers who reduced the images and used *Astrometrica* software to visually search, measure and report all moving objects appearing in all frames, which included few dozen thousands main belt asteroids (MBAs). Nine NEAs were discovered serendipitously using the 2.5 m *Isaac Newton Telescope* (INT) during about 50 nights total [12], while five other NEAs were lost due to lack of telescope time for recovery or late reduction. During two runs (ESO/MPG 2.2 m used for 3 nights in 2008 and the INT during 3 nights in 2012) we carried out small surveys in the ecliptic (only about 10 sq. deg in total) to visually search for new MBAs and NEAs, following and discovering a few hundred MBAs.

2. NEARBY Platform

In Sep 2015 we have embarked in a PhD thesis aiming to deploy an automated moving object processing system (MOPS) able to detect asteroids and NEAs in small astronomical surveys observed with the INT within the EURONEAR project [13].

Thanks to a grant from the Romanian Space Agency (ROSA) part of the ESA-SSA segment, in Oct 2017 we inherited this MOPS and have embarked in the NEARBY project (Visual Analysis of Multidimensional Astrophysics Data for Moving Objects Detection)[1] aiming to build a cloud-based online platform for automatic image reduction, detection, assisted human validation and recognition of NEA candidates in larger astronomical surveys observed with any telescope and large field camera.

[1] http://cgis.utcluj.ro/nearby

2.1. Modules

The MOPS pipeline uses the following three modules presented in detail our previous papers [14, 15]:

1. The image correction module processes the raw astronomical images (uploaded from the telescope in FITS format) by typical CCD artifacts (bias and flat field - available as two sets of raw FITS images taken every night) and bad pixels (defined as bad pixel files charaterising any instrument - available in PL format). This module is written in Python and uses IRAF.

2. The field correction module maps with field distortions and resamples the raw images using a given (constant) pixel scale across the whole field. Several steps are involved in this process:
   - Uniformises raw FITS keyword headers (instrument dependent, using IRAF);
   - Extracts a catalog of sources detected in the processed images (using SExtractor);
   - Computes the sky-plate transformation used to correct field distortion (known to especially affect large prime focus cameras, using SCAMP);
   - Resamples FITS images based on the transformation functions (using SWarp);
   - Extracts a new catalog of sources in the resampled images (using SExtractor).

3. The asteroid detection module identifies the asteroid trajectories by pairing source catalogs assumed to move linearily in time and space (based on their topocentric J2000 equatorial coordinates α, δ) in series of images, rejecting fixed objects (stars, galaxies), any remaining noise or cosmic rays detected in the resampled images. This module has been presented in extension in another paper [16].

2.2. Architecture

An efficient scalable computing infrastructure is essential to achieve near real time data reduction and validation of the detected sources in large astronomical surveys needed to support near real time workflow flux between the telescope and the MPC database. The solution presented by NEARBY takes into account the following requirements:

- Automatic processing of multidimensional data taken with mosaic cameras consisting by many CCDs in order to detect and identify moving objects in astronomical images using at least 3 typical field repetitions;
- Visual analysis of the processed fields, involving human validation of the moving sources, assisted by web-based static and dynamical presentations;
- Flexible description of the processing pipeline;
- Adaptive processing and detection over high-performance, cloud-based, computation infrastructures.

To allow flexible client installation within different operation system environments, the NEARBY modules were deployed as containerized applications [15]. The infrastructure supporting this architecture is based on Kubernetes and Docker containers. It encapsulates every tier inside different containers, allowing flexible changes and easy adaptation of the configuration to any particular user case scenario .

2.3. Data management

The NEARBY platform architecture uses a three-tier model, consisting in a presentation level, a service level and a data level, all providing flexible and reusable components [15]. The NEARBY database level was implemented using a MySQL server. Here we list the database tables in which the survey (images and data) is stored:

- *Experiment* (survey) - defines all the observations taken with the same telescope and instrument during one given observing run (few neighboring nights);
- *Night* - groups all the observations taken during one given observing night of the given experiment;
- *Field* - a particular sky area (defined by the same telescope pointings) observed in a sequence (repeated at least 3 times within maximum few dozen minutes) during one given night;

- *Project* - one given NEARBY execution (characterised by a few given configuration files) of the same field observed during one night part of an experiment;
- *AstObject* (candidate asteroid detection) - one potential asteroid identified in one field;
- *Report* - groups all potential asteroids identified in one field, which need to be validated by human reducers.

The following seven configuration files keep initialisation data including few essential paremeters needed for NEARBY processing:

- `camera-properties.ini` - The instrument configuration file for the given experiment defining the mosaic camera (essential keywords, gains, readout noise, CCD sizes and their sky positions relative to the centre);
- `configFile.sex` - SExtractor configuration file for the given instrument setting the detection threshold, magnitude zero-point;
- `paramFile.param` - SExtractor output parameter (columns) file (same for all NEARBY runs);
- `configFile.scamp` - SCAMP configuration file holding the star reference catalog to be downloaded from VizieR;
- `configFile.swarp` - SWarp configuration file setting the pixel scale for resampled images;
- `configFile.missfits` - MissFits configuration file (same for all NEARBY runs);
- `config.txt` - NEARBY *CrossObj* parameters (needed for asteroid detections, whose values should be carefully set for a given instrument, weather conditions and observing cadence).

Typically, given one instrument and exposure time, the same configuration files could be used during all nights and experiments, and they could be uploaded only once for the given experiment. In case of variable weather conditions, some parameters could need fine tuning in bad weather conditions, and these configuration files need uploaded for some given nights or fields, overwriting the experiment default values.

2.4. Web interface

The presentation layer exposes to the users all the NEARBY platform functionalities in an intuitive and flexible manner. The NEARBY interface was developed under HTML5 and *Bootstrap*, being accessible through web browsers, which provides a great advantage of our online plaform compared with any other desktop applications. The platform supports distribution of work to multiple users who simultaneously reduce different nights and fields and who could collaborate or consult the team leader before validating some difficult detections (e.g. asteroids very faint, moving very slowly, located in crowdy fields or close to bright stars or galaxies which could create confusions).

The NEARBY web interface allows the observers to sort the nights and fields and to upload the raw survey and calibration images. The reducers can independently define projects for their allocated fields and start their execution, then validate online the asteroid detections after summary visualisation (typically sufficient) of the animations of the automate detections of the moving sources, assisted by some additional data (FWHM, ellipticity and position angle for each detection, trajectory direction and proper motion), and eventually helped by few quality control plots (individual CCD and entire mosaic field distortion plots) and finally the reduced images packed in a ZIP file downloadable and importable in third party software (such as *Astrometrica*). We present in Figure 1 the NEARBY MPC Report visualisation interface which assists the reducers to validate the detections.

3. First NEARBY NEA Pilot Mini-Surveys

The MOPS and later NEARBY have been tested on images acquired with the 2.5 m diameter *Isaac Newton Telescope* (INT) installed at 2300 m altitude in *Observatorio Roque de los Muchachos* (ORM) in La Palma, Canary Islands, Spain. At its $F/3.3$ prime focus, the INT is equipped with the Wide Field Camera (WFC), a mosaic consisting in four $2k \times 4k$ pixels CCDs with size $0.33''$/pixel covering 0.27 sq.deg. arranged in a $34' \times 34'$ L-shape design with about $1'$ gaps between CCDs. During all runs we used the Sloan r filter.

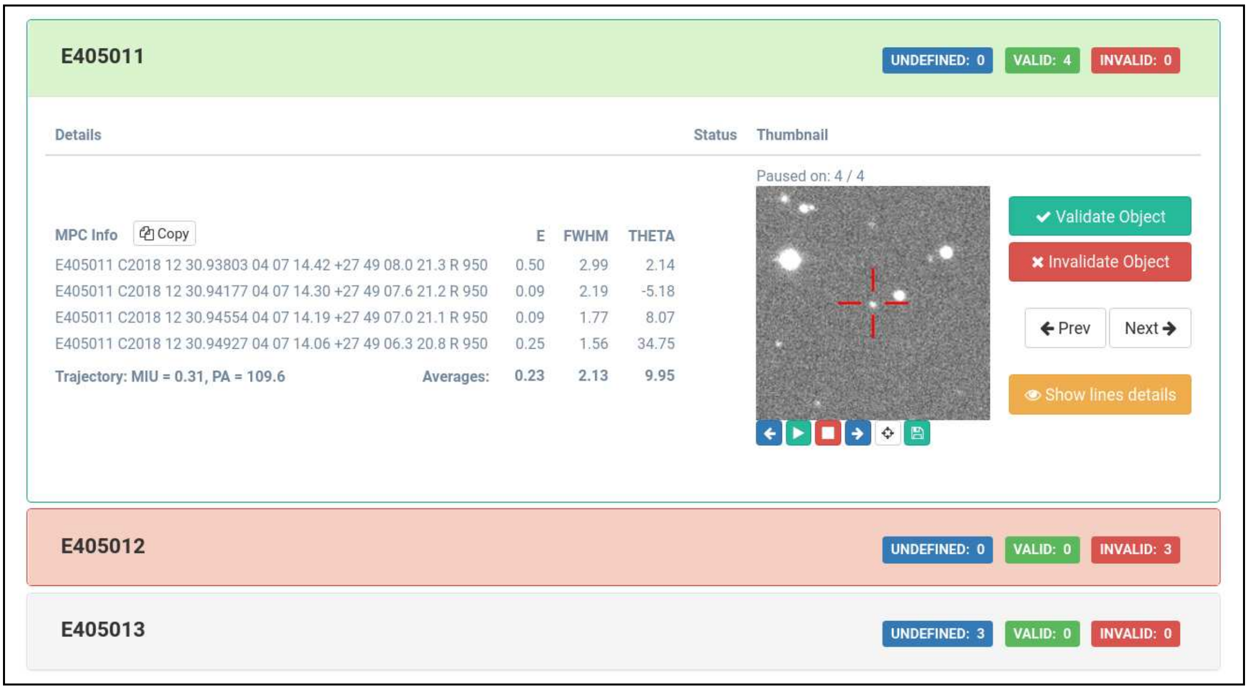


Figure 1: *NEARBY MPC Report interface assisting the reducers to validate moving sources.*

Table 1 includes the first tests of the NEARBY platform during few hours dark time available in a few nights (first three runs in 2017 and 2018) and two actual mini-surveys (last two runs in 2018). The five runs are demarked, and for each we include the observing dates (start of night), rounded number of observed hours, number of WFC observed fields, Solar elongation along the ecliptic (all observed ecliptic latitudes bellow $\sim 2°$), the exposure time (in seconds), seeing (stellar FWHM measured in images in arc seconds), number of valid detections, unknown detections (with percentages of all detections), average number of detections per field, and number of possible NEA candidates.

Based on the reduced reports for each field, the NEA candidates were flagged using the MPC NEO Rating[2] [17] and our simple EURONEAR $\epsilon-\mu$ tool [5] implemented online in 2018 as the *NEA Checker*[3] in order to allow recovery and follow-up using the INT or other telescopes from the EURONEAR network. Given the very limited areas of our mini-survey tests, a relatively low NEO Rating limit (about 10%) was allowed whenever the $\epsilon-\mu$ tool showed objects having proper motions μ located above the NEA border in order to spot potential NEAs, Hungarias (HUN) and Mars crossing (MC) asteroids.

We define a *possible NEA candidate* any unkown objects (validated by reducers following automatic detection by NEARBY or found by visual blinking in *Astrometrica*) not identified with any known asteroid (using available searching tools and the updated MPC database) located above the border in the $\epsilon - \mu$ model or moving in inverse direction than all other asteroids in the same field or region. Typically any such object has a MPC NEO score above 10%. We define a *NEA candidate* any unknown object whose MPC NEO score is above 50%. During most of our pilot mini-runs, we have been reported possible NEA candidates and NEA candidates to MPC as soon as possible (sending a single report email), except for some possible artefacts which we first hold to attempt first recovery observations (if positive, sending both discovery and recovery data in one report).

[2]https://minorplanetcenter.net/iau/NEO/PossNEO.html
[3]http://www.euronear.org/tools/NEACheck.php

Table 2 includes 50 such possible NEA candidates identified during all runs. We include the detection acronym, observed field name, observing date (corresponding to the apparition of the object on the first image), number of observed nights N (where r suffix represents recovery during the same first night), apparent magnitude R during first night (average of all measurements), MPC NEO Rate, Solar elongation ϵ, proper motion during first night (μ in arcsec/min), the NEA demarcation border (magenta line in the $\epsilon - \mu$ model), the reducer acronym, software used for detection, and some observations regarding the detection or the object. We used the following acronyms for the reducers: AB Afrodita Boldea, AS Adrian Stanica, CB Costin Boldea, DB Daniel Bertesteanu, DC Daria Ciobanu, EP Elisabeta Petrescu, LH Lucian Hudin, MP Marcel Popescu, MS Malin Stanescu, OV Ovidiu Vaduvescu, PM Marian Predatu, RT Ruxandra Toma, SA Simon Anghel, ST Andra Stoica, VP Viktoria Pinter.

Table 3 gives the possible NEA candidates followed-up with the INT or other two telescopes during or right after the NEARBY mini-surveys. We list the object acronym, MPC official designation (whenever this is available, searched in April 2019), the orbital class, orbital elements (calculated using the $Find\_Orb$ software[4] for the unknown objects or listed by MPC for the known objects), the perihelion distance q (in a.u.), minimal orbital intersection distance (MOID, in a.u.), residuals mean square root for all nights fit (σ in arcsec), the number of observations and observed nights, and finally the absolute magnitude (H) according to $Find_Orb$.

3.1. First pilot test images - March 2017

Three hours were devoted during the D-night 28/29 March 2017 for the acquisition of 16 INT-WFC ecliptic fields needed for the first testing of MOPS and later NEARBY. We used 60 s exposures and 4 repetitions observing 4 nearby fields (ABCD-... sequences) in relatively good seeing conditions (stellar FWHM $1.3 - 2.0''$ as measured in images). In Section 4.5 we will use these fields to compare the NEARBY detections with human reduction and other software.

Regular human reduction using *Astrometrica* blinking was performed by two very experienced reducers during the next day in order to report asteroids and to ensure crediting of new objects and eventual NEA discoveries. 383 valid moving sources (69% known and 31% unknown asteroids) were reported based on human detection (in average 24 asteroids in each WFC field or 89 per sq.deg). One relatively bright apparent trail (about $7''$ long) was detected by L. Hudin in the unique image of the last observed field during twilight, but the following night recovery attempt aimed to the two possible directions could not confirm this detection which was not reported to MPC.

Our first INT run granted for NEARBY testing (C29/2018A PI: O. Vaduvescu, 9-13 Feb 2018) was unfortunatelly ruined due to snow and ice, thus we eagerly waited for other opportunities to arise until the next semester.

3.2. First pilot real-time tests - May 2018

Six hours dark during the first part of three consecutive nights could be dedicated to the first real-time NEARBY tests during 2-4 May 2018 (INT run C85/2018A devoted to NEA lightcurves, PI: O. Vaduvescu, observer ING student T. Zegmott). A total of 56 INT-WFC fields were observed in the ecliptic in relatively bad seeing conditions (FWHM $1.5 - 3.0''$) using 60 s exposures and ABCD sequences. 540 asteroids (between 10% and 25% unknown) were validated and submitted within few hours to MPC (only about 10 per WFC field or 36 per sq.deg, due to bad seeing). Among these, two possible NEA candidates were found, the first with very low NEO score but located above the $\epsilon - \mu$ magenta limit (not followed), and the second rated 100% by a new reducer but not found during the following night, thus possibly being an artefact (not reported to MPC).

The proper motion for the MBAs located in the fields targeted during this run (Solar elongations $106 - 126°$) was quite low (typical $\mu = 0.2 - 0.3''$/min). Combined with the bad seeing, this made NEARBY to fail to detect about half MBAs, confusing slower moving objects with fixed stars. We realised this fact upon comparing NEARBY versus visual detection in *Astrometrica*, drawing some important lesson learned for future runs. Namely, for the sky regions where the expected proper motion of MBAs is small ($\mu < 0.3''$/min) and/or especially when the weather is bad (seeing $> 2''$), then the observing cadence should be enlarged, and eventually taking more repetitions for each field.

[4] https://www.projectpluto.com/find_orb.htm

3.3. Second pilot real-time tests - September 2018

Four hours dark during the end of two consecutive nights 15-16 Sep 2018 were devoted to the second NEARBY real-time tests (run P6/2018B, PI: S. Lowry, observer T. Zegmott). 36 INT-WFC fields were observed in average and bad seeing conditions (FWHM $1.5 - 3.5''$) using 60 s exposures at elongation similar with previous run, thus we used 5 repetitions per field and longer 9-point sequences (ABCDEFGHI-...).

A total of 212 asteroids were detected (between 10% and 32% unknown), making in average only 6 objects per WFC field (22 asteroids per sq.deg), due to bad seeing. Three possible NEA candidates were spotted, one having NEO rating 98% and location above the $\epsilon - \mu$ border and apparently not known by *Astrometrica* and FITSBLINK[5], but later identified as NEA 2018 KF3 (discovered by Pan-STARRS at 20180526).

3.4. First NEARBY pilot mini-survey - November 2018

The first NEARBY pilot mini-survey took place at the INT during 5 nights between 31 Oct and 5 Nov 2018 (including one break night 3/4 Nov awarded to other program). The sky was mostly dark (with some 13h total grey time following last quarter Moon during the end of first nights), and the seeing was average or bad (FWHM $1.5 - 3.5''$), with 3 hours lost in the third night due to humidity. To maximize the survey area and avoid trailing (not accommodated in NEARBY), we decided to use exposures of 30 s, taking into account that most NEAs move faster than $2 - 3''$/min.

Four observers took part of this run, namely O. Vaduvescu and M. Popescu, assisted by ING students T. Davison and T. G. Wilson (only the first two nights). A team of 13 remote reducers (located in a few places in Romania) validated the findings, the fields being distributed by the project leader O. Vaduvescu via a Google Drive spreadsheet able to edit by the whole team. We present in Figure 2 a screenshot showing some of the work distribution during the first night. Each line represents one field, then we include its status, basic observing comments, quick-scan reducer (using *Astrometrica*), the number and name of possible NEA candidates, objects for follow-up, name of the NEARBY reducer, number of all valid detections, comments from project leader and the reducer. Similar spreadsheets follow during each night of the run are created and supervised by the project leader, being accessible by the whole team via the bottom tabs (n1, n2, etc).

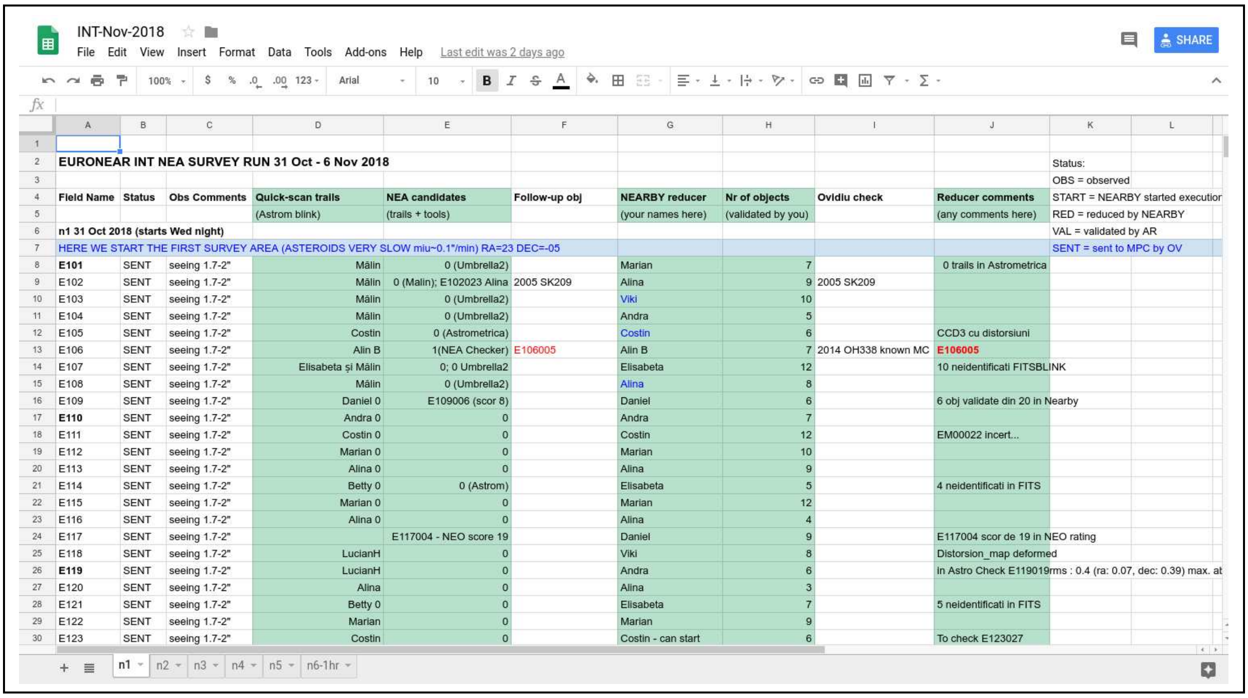
Additionally to the main validation work in NEARBY which is not able to detect trailing asteroids yet, the reducers visually blinked NEARBY reduced images in *Astrometrica* to avoid loss of faster NEA, searching only for streaks and eventually fainter and faster objects which could escape the automate NEARBY detection. Each night, two or three survey regions were chosen at low ecliptic latitudes ($|\beta| < 3°$) using a spreadsheet which generated the starting pointing for each 4-point or 9-point sequence along the ecliptic, while the telescope position for each ABCD pointing was commanded by a Python script which cycle the nearby sequences. All survey regions were chosen to avoid major surveys (taking into account each night the MPC Sky Coverage plots[6]), to avoid Milky Way, and to be higher in the sky during the observing interval.

During the five nights, a total of 2,597 valid moving sources were detected in 321 WFC fields (87 sq.deg), making in average 8 objects per field (30 asteroids per sq.deg). Besides the actual survey time, a total of 10 hours during the run plus another hour during the next D-night were devoted to recovery and follow-up (using typical exposures of 60 s and 4-6 subsequent repetitions per field), with the aim to acquire 2-3 night arcs for each potential NEA candidate for deriving preliminary orbits and their clasification during the same run.

3.4.1. First NEARBY NEA Discoveries

During the whole run we identified 25 possible NEA candidates for recovery, 18 of which were detected by NEARBY (72%). Four objects were clear NEA candidates (having NEO scores between 76, 100, 99 and 98), from

[5]http://www.fitsblink.net/residuals
[6]https://www.minorplanetcenter.net/iau/SkyCoverage.html



	A	B	C	D	E	F	G	H	I	J	K	L
1												
2	EURONEAR INT NEA SURVEY RUN 31 Oct - 6 Nov 2018										Status:	
3											OBS = observed	
4	Field Name	Status	Obs Comments	Quick-scan trails	NEA candidates	Follow-up obj	NEARBY reducer	Nr of objects	Ovidiu check	Reducer comments	START = NEARBY started executior	
5				(Astrom blink)	(trails + tools)		(your names here)	(validated by you)		(any comments here)	RED = reduced by NEARBY	
6	n1 31 Oct 2018 (starts Wed night)										VAL = validated by AR	
7	HERE WE START THE FIRST SURVEY AREA (ASTEROIDS VERY SLOW miu~0.1"/min) RA=23 DEC=-05										SENT = sent to MPC by OV	
8	E101	SENT	seeing 1.7-2"	Mălin	0 (Umbrella2)		Marian	7		0 trails in Astrometrica		
9	E102	SENT	seeing 1.7-2"	Mălin	0 (Malin); E102023 Alina	2005 SK209	Alina	9	2005 SK209			
10	E103	SENT	seeing 1.7-2"	Mălin	0 (Umbrella2)		Viki	10				
11	E104	SENT	seeing 1.7-2"	Mălin	0 (Umbrella2)		Andra	5				
12	E105	SENT	seeing 1.7-2"	Costin	0 (Astrometrica)		Costin	6		CCD3 cu distorsiuni		
13	E106	SENT	seeing 1.7-2"	Alin B	1(NEA Checker)	E106005	Alin B	7	2014 OH338 known MC	E106005		
14	E107	SENT	seeing 1.7-2"	Elisabeta și Mălin	0; 0 Umbrella2		Elisabeta	12		10 neidentificati FITSBLINK		
15	E108	SENT	seeing 1.7-2"	Mălin	0 (Umbrella2)		Alina	8				
16	E109	SENT	seeing 1.7-2"	Daniel 0	E109006 (scor 8)		Daniel	6		6 obj validate din 20 in Nearby		
17	E110	SENT	seeing 1.7-2"	Andra 0	0		Andra	7				
18	E111	SENT	seeing 1.7-2"	Costin 0	0		Costin	12		EM00022 incert...		
19	E112	SENT	seeing 1.7-2"	Marian 0	0		Marian	10				
20	E113	SENT	seeing 1.7-2"	Alina 0	0		Alina	9				
21	E114	SENT	seeing 1.7-2"	Betty 0	0 (Astrom)		Elisabeta	5		4 neidentificati in FITS		
22	E115	SENT	seeing 1.7-2"	Marian 0	0		Marian	12				
23	E116	SENT	seeing 1.7-2"	Alina 0	0		Alina	4				
24	E117	SENT	seeing 1.7-2"		E117004 - NEO score 19		Daniel	9		E117004 scor de 19 in NEO rating		
25	E118	SENT	seeing 1.7-2"	LucianH	0		Viki	8		Distorsion_map deformed		
26	E119	SENT	seeing 1.7-2"	LucianH	0		Andra	6		in Astro Check E119019rms : 0.4 (ra: 0.07, dec: 0.39) max. at		
27	E120	SENT	seeing 1.7-2"	Alina	0		Alina	3				
28	E121	SENT	seeing 1.7-2"	Betty 0	0		Elisabeta	7		5 neidentificati in FITS		
29	E122	SENT	seeing 1.7-2"	Marian	0		Marian	9				
30	E123	SENT	seeing 1.7-2"	Costin	0		Costin - can start	6		To check E123027		

Figure 2: *Sample of the NEARBY Google Drive document keeping the whole team workload distribution.*

which two objects were credited as our discoveries (one brighter detected by NEARBY and one fainter trail detected by human blink in *Astrometrica*). We will present next these objects, including our two discoveries in Figure 3.

2018 UO (E131103) was detected during the first night in the field E131 analysed in *Astrometrica* by the experienced reducer L. Hudin, as a medium bright object moving relatively slow ($\mu = 0.6''$/min well bellow the $\epsilon-\mu$ border) but with a high NEO score 76. Consequently, we reported it as an NEA candidate, but the MPC identified it as being first time observed by Pan-STARRS 2 about two weeks before us.

2018 VE (E165100) was detected during the first night (observed first at 1 Nov at 01:57 UT) in the field E165 by the same experienced reducer L. Hudin who detected it during next morning via blinking in *Astrometrica* as a very faint trail (R 20.4) moving very fast ($\mu = 11.7''$/min) and resulting in a relatively long trail (18 pixels) which escaped NEARBY detection. During the second part of that night, the NEARBY server was down a few hours, which prevented us to reduce this field faster. Following Lucian's findings, we reported this clear NEA candidate about 7 hours after the observation. The same field was imaged 5 hours after us by Catalina survey (around 7 UT), being reported by their pipeline earlier than us, thus unfortunately we lost the discovery credit (MPEC 2018-Y44).

2018 VQ1 (E223100) was discovered during second night in the field E223 by the observer and reducer M. Popescu (MPEC 2018-X85) who spotted it in *Astrometrica* as a quite faint ($R = 21.2$) and relatively fast ($\mu = 4.1''$/min) small trail (Figure 3) which escaped NEARBY detection. Thanks to the near real time NEARBY reduction of the field and visual quick-scan of the reducer, we submitted the MPC report in less than two hours after observing, which also allowed us to recover the object two hours later, which was essential for second night recovery in very bad seeing conditions and then securing the discovery credit.

2018 VN3 (E522022) was discovered during the fifth night in the field E522 by NEARBY, being validated by the reducer C. Boldea (MPEC 2018-Y90) as a relatively bright ($R = 19.7$) and relatively slow ($\mu = 2.1''$/min) star-like apparition (Figure 3). The object was reported only one and half hour after discovery, allowing us immediate recovery

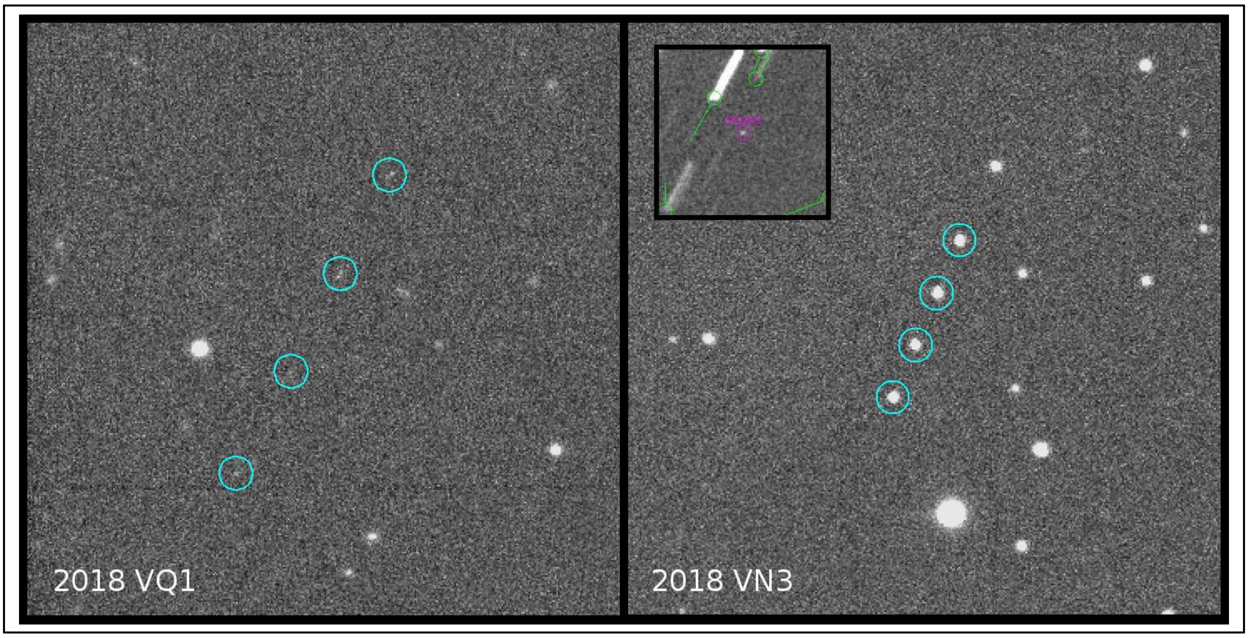


Figure 3: *The first two NEARBY NEA discoveries during the Nov 2018 pilot mini-survey using the Isaac Newton Telescope (INT). The figures match the normal sky orientation, and each field is about* $4' \times 4'$*. Left: 2018 VQ1 discovered by M. Popescu (1 Nov 2018) based on NEARBY reduced images and visual blink in Astrometrica; Right: 2018 VN3 discovered by C. Boldea (6 Nov 2018) based on NEARBY detection, recovered by L. Hudin using his small 30-cm diam amateur telescope in Cluj-Napoca, Romania (small inset combined track and stack image).*

during the same night, which enlarged the arc to two hours. During the next night, it was recovered by L. Hudin using his own 30-cm amateur telescope from the city of Cluj-Napoca, Romania, marking a premiere for EURONEAR (see his inset detection in Figure 3 of 28 images by 45 s exposures using track and stack in *Astrometrica*).

Based on recovery and follow-up of the other possible NEA candidates, the following 5 objects resulted to be Hungaria asteroids: E138015 (unknown to MPC) found by C. Boldea, E142027 (2018 VH18) and E156038 (2018 VJ18) both found by E. Petrescu, E181106 (still unknown, found by R. Toma) and E439011 (2018 VF30, found by M. Predatu). Additionally, another object could be a Mars crosser (more observations are needed to establish its exact orbital status), namely E130023 (not known yet to MPC) found by A. Boldea. All these 6 Hungarias and Mars crossing asteroids should be also credited as NEARBY discoveries.

3.5. Second pilot mini-survey - December 2018

A total of about 19 hours dark could be accessed during the first part of 4 nights 27-30 Dec 2018 granted to another related EURONEAR run (C9/2018B PI: O. Vaduvescu, joined by the student co-observer F. Pérez-Toledo). 197 WFC fields (53 sq.deg) located in two directions in the ecliptic were surveyed mostly in good conditions (FWHM $1.0-1.5''$) using 30 s exposures and ABCD sequences, except for the second night when the seeing deteriorated (FWHM $2-3''$) and we used 40 s exposures.

2,129 asteroids were detected and validated, making in average 11 per field (40 objects per sq.deg). 19 possible NEA candidates were detected. Between these, one apparently unknown NEA candidate (E305a01) was found by C. Boldea (rating 84 and located above $\epsilon - \mu$ border), identified later as 2017 KE35 (discovered by Pan-STARRS 1 in 2017). Other possible NEA candidates resulted in discovery of 10 Hungaria asteroids (all being still unknown to MPC), namely: E307010 and E427009 found by D. Ciobanu, E340013 by D. Bertesteanu, E345017 by R. Toma, E359042 by V. Pinter, E372M42 by M. Predatu, E374023 and E451027 by E. Petrescu, E432a01 and E436060 by S. Anghel. Moreover, up to 5 Mars crossing asteroids were validated: E314a01 found by M. Stanescu, E354032 by E. Petrescu and E362033 by D. Ciobanu (all in need of orbital confirmation), plus E409041 found by C. Boldea and E439016 by D. Bertesteanu. All these 15 Hungarias and Mars crossers should be credited as NEARBY discoveries.

4. NEARBY Data Analysis

In this section we assess the astrometric accuracy and the photometry limits of the NEARBY based on some data resulted during our INT-WFC mini-surveys.

4.1. Field correction

Most larger field prime focus cameras (including WFC) suffer of image distortion effects which need to be corrected in order to achieve accurate astrometry across the whole observed field. In our past EURONEAR INT-WFC experience, in many cases *Astrometrica* could not accommodate the WFC distortion (even using larger order polynomial fittings), and the entire field recognition failed, especially in CCD3 which is more distant to the optical centre and affected by more bad columns. Therefore in our previous EURONEAR work, we had to use THELI (in manual GUI mode) for image reduction and field correction, before *Astrometrica*.

Upon automate image treatment in IRAF (bias, flat field and bad pixels), the NEARBY pipeline calls SExtractor, Scamp, and Swarp, which sucessfully correct the field distortion using any given reference catalog (set in the Scamp configuration file). Upon some testing using different catalogs, for our INT runs we decided to use 2MASS [18] which is homogenous across all sky and deep enough to provide a few dozens or hundred reference stars across each WFC CCD. For each field, the field recognition and image correction could be checked by the assistant reducer who can access the distortion field maps from the upper side of the field interface (Figure 4).

4.2. Astrometric accuracy

We assessed the NEARBY INT-WFC astrometric accuracy by plotting the observed minus calculated (O-C) positions of the known numbered asteroids, which have very good orbits and ephemerides (better than $0.1''$). In Figure 5 we present an example using data for 60 WFC fields observed in 5/6 Nov night in average seeing $1.5 - 2.5''$. More than 1,200 measurements for about 300 numbered known asteroids as faint as $V \sim 22$ are plotted, showing average total residuals $O - C = 0.21''$ ($0.06''$ in α and $0.01''$ in δ).

4.3. INT-WFC photometry limits

In Figure 6 we plot the histogram for valid moving objects function of their apparent magnitude, based on all our INT 2/3 Nov 2018 data representing more than 3,300 measurements for 800 asteroids observed in 70 fields with 30 s exposure time in average seeing conditions ($1.5 - 2.5''$). An apparent maximum around $R = 21.5$ is visible, with few hundred asteroids detected to $R = 23$ mag and few dozen up to $R = 23.5$ limiting magnitude.

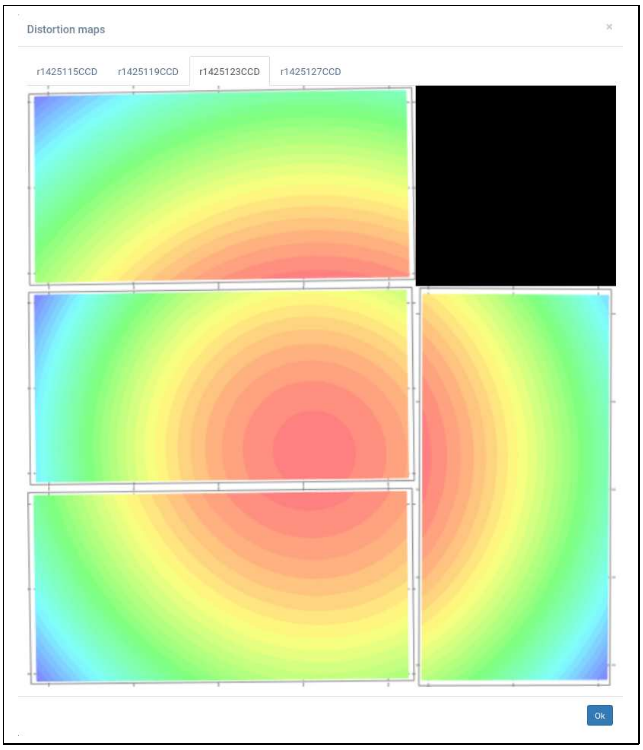


Figure 4: *Typical Scamp distortion map showing the NEARBY reduction of the third image* (`r1425123.fit`) *of the field E557 observed at 5/6 Nov 2018 with the INT/WFC, with the color map mapping slightly different pixel scales.*

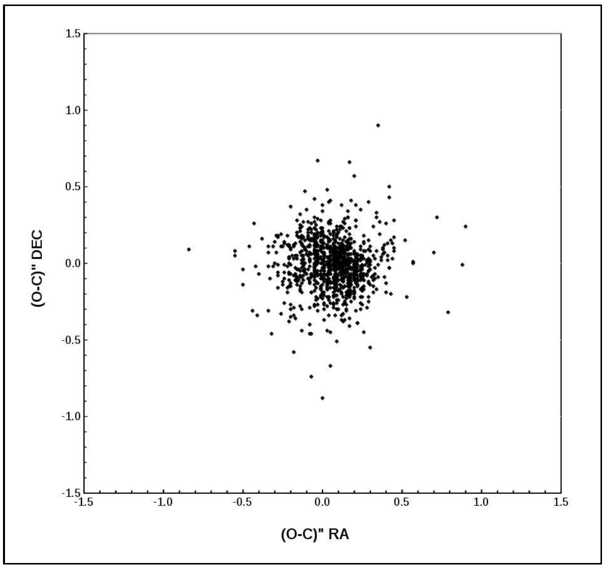


Figure 5: *Observed minus calculated (O-C) residuals for about 300 known numbered asteroids observed during 5/6 Nov 2018. The O-Cs were calculated using the FITSBLINK server*[7].

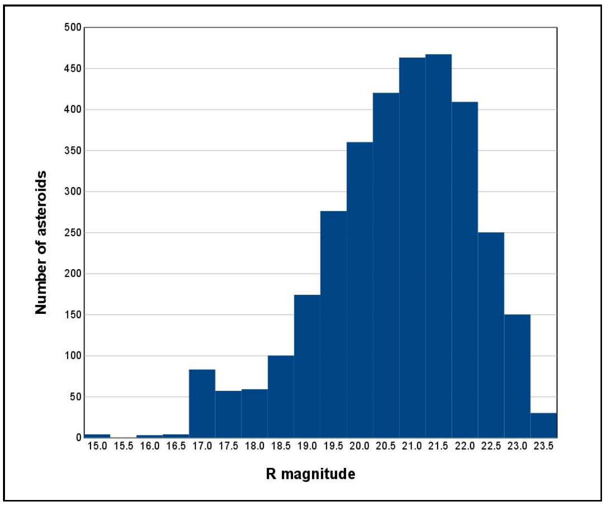


Figure 6: *Sample of histogram plotting the INT photometric survey limits for valid asteroid NEARBY detections (70 WFC fields observed during 2/3 Nov 2018 night).*

4.4. NEO rating tool and the $\epsilon - \mu$ model

In Section 3 we mentioned the two selection criteria for potential NEA candidates which triggered recovery and follow-up observations during our NEARBY mini-surveys. Serving community for almost 15 years, the MPC NEO rating tool (`digest2`) can accurately distinguish near Earth objects (NEOs) and other interesting populations from MBAs based on short-time observations. The algorithm uses two population models and it was presented in detail [17], the code being made available later. The NEO rating tool outputs a score, D_2, representing a pseudo-probability that an observed tracklet belongs to a given Solar System orbit type. This score allows MPC to set a threshold for posting NEO candidates on the MPC NEOCP list in order to allow rapid confirmation and follow-up by other stations. Since 2012, this threshold D_2 was raised to 65% from 50%, due to the increase in NEO discoveries and the many false alarms from objects which resulted to be non-NEOs. Although it has been improved continuously, `digest2` and the $D_2 = 65$ threshold are not perfect predictors for NEOs, and [17] shows cases of NEOs scoring bellow the threshold in some circumstances and recommends some possible code improvements.

To have an alternative tool for checking possible NEA candidates in our INT observations, in 2010 we developed a simple model which assumes circular and coplanar motion with the Earth orbit and uses only two observational parameters, namely the Solar elongation ϵ and the proper motion μ [5]. Using this model, the border marking potential NEO candidates was defined in the $\epsilon - \mu$ plane as a curve (marked in magenta color) of a hypotethical orbit having semimajor axis $a = 1.3$ a.u. If any observed object is located in the $\epsilon - \mu$ plane above the magenta line, then it could be considered a possible NEA candidate and followed to establish its precise status. In 9 Nov 2015 we could actually check the value of our $\epsilon - \mu$ model which resulted in the discovery of the NEA 2015 VG66. Although our INT observations of this unknown object were scored by `digest2` to only 42%, its location above the magenta line trigered our alert for follow-up observations, because the INT became unavailable. In this process, P. Veres searched and could visually precover the object in the Pan-STARRS image archive (observed before our INT observations), confirming that their dataset received a lower NEO score 25% which prevented it to be followed and be posted on NEOCP.

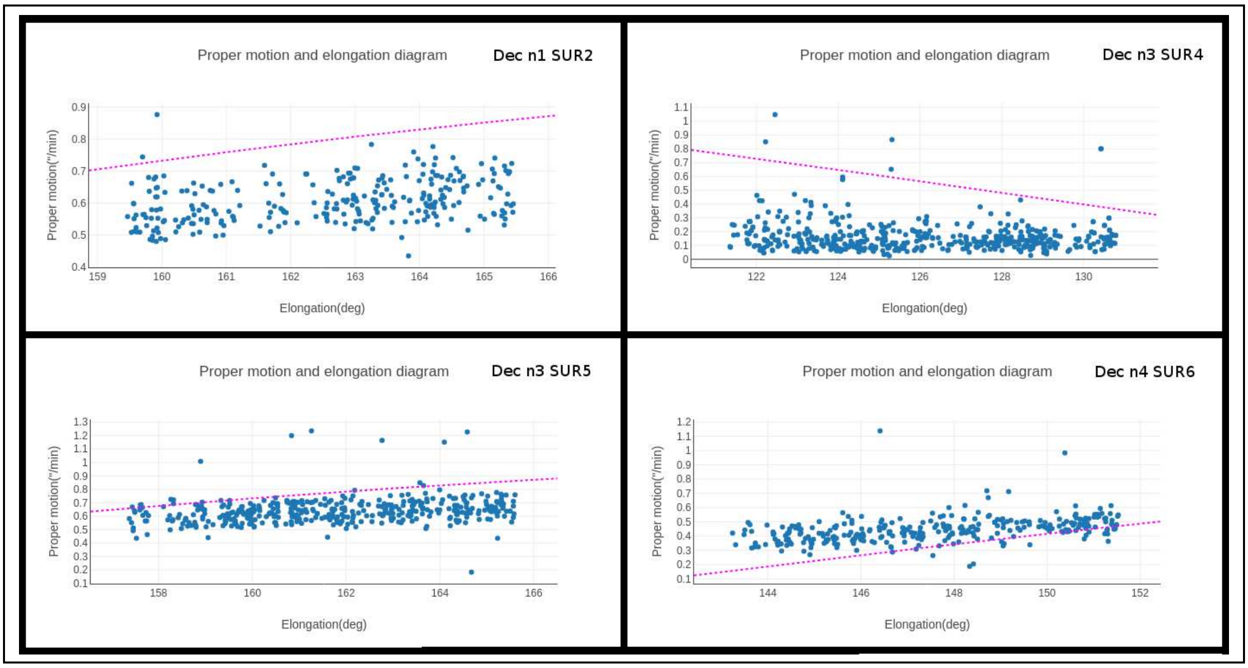


Figure 7: *Samples of the $\epsilon - \mu$ plots classifying possible NEA candidates in entire survey fields observed with the INT during our Dec 2018 NEARBY mini-survey.*

In Figure 7 we include a sample of $\epsilon-\mu$ plots including objects detected by NEARBY in entire survey fields (dozen INT-WFC fields each observed in the ecliptic in a small elongation range). While most possible NEA candidates are classified correctly in the first three plots and they could be identified with Mars crossing or Hungaria asteroids in Table 3, clearly the model is faulty in the fourth plot due to singularity caused by proximity to radial proper motions which make the magenta line to fall bellow most observed objects (which are MBAs).

We compared NEO rating with the $\epsilon - \mu$ tool taking into account all 50 possible NEO candidates detected during our 5 test mini-surveys. According to Table 2, $\epsilon - \mu$ failed to classify correctly two out of six cases of actual NEAs (marked in bold or italics), while in the other cases the MPC rating tool classified correctly non-NEOs (all scores being bellow 65%) while the $\epsilon - \mu$ considered the detections as possible NEA candidates. Nevertheless, in 50% cases (22 objects from 44 NEA candidates after dropping the 6 confirmed NEAs), the $\epsilon - \mu$ classification resulted in discovery of 22 Mars crossing or Hungaria asteroids, while in some cases the NEO Rating did not predict any such interesting orbits.

4.5. Comparison with other softwares

Well established surveys such as Pan-STARRS [19] or CSS have developed their own moving object processing systems (MOPS) to reduce images, detect moving sources, flag NEO candidates, identify known objects, pair one-night detections in tracklets and multi-night tracklets in unknown objects, calculate new orbits and predict follow-up alerts for newly discovered NEOs.

Alternatively, other in-house software aimed to asteroid surveys are relatively easier to develop today, thanks to the freeware or open source standard astronomical image environments available under Linux such as IRAF [20], PyRAF[8], SExtractor/Astromatic [21, 22], *Astrometry.net* [23] and others. Other commercial codes for field recognition, moving object detection and astrometric reduction have been written by dedicated amateur astronomers or small

[8]https://pypi.org/project/pyraf

companies under Windows, for example *Astrometrica*[9] (Herbert Raab), *Hyperion Prism*[10] (Gregory Giuliani), *PinPoint*[11] (Robert B. Denny), or under Linux, for example [24] and *Asteroid Detector*[12] (open source written by David Rankin). Using data from our Mar 2017 INT-WFC pilot mini-survey, we compared source detections in 15 fields reduced with NEARBY and a few other software. In Figure 8 we present the histogram with the number of valid asteroid detections in each field.

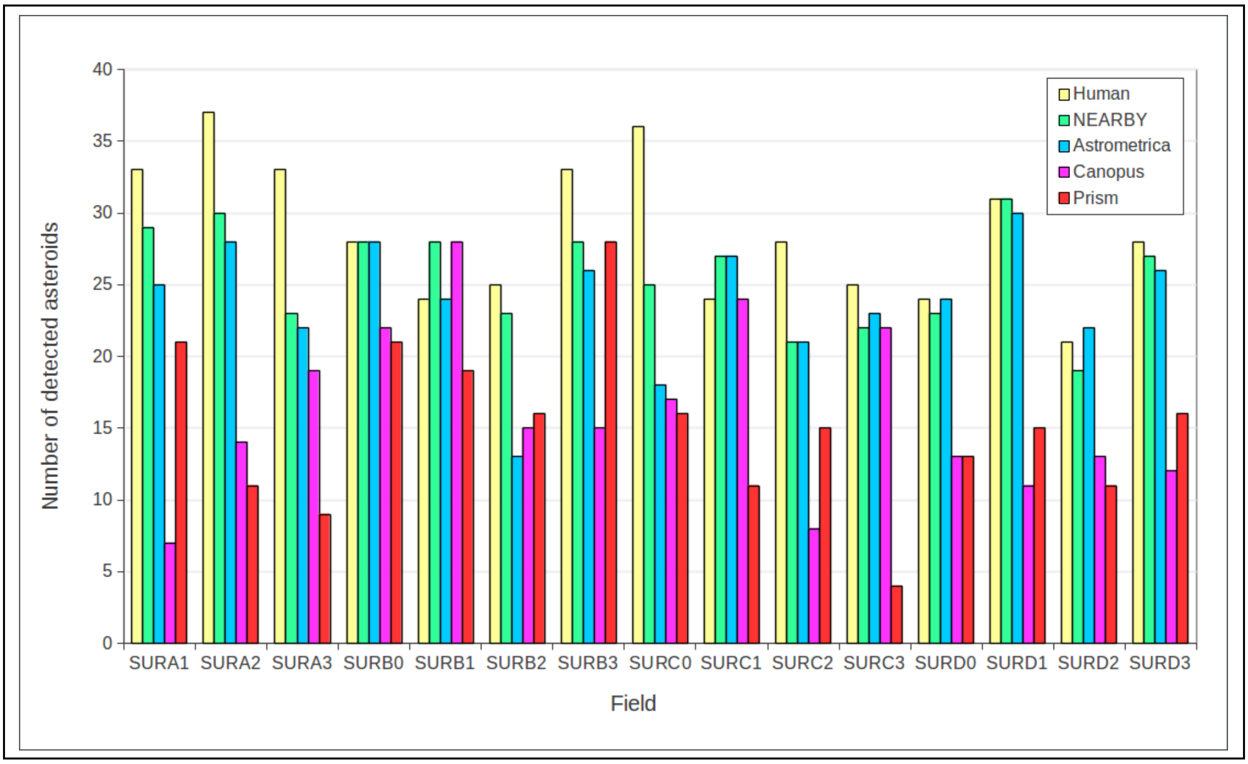


Figure 8: *Comparison between valid NEARBY asteroid detections in the Mar 2017 mini-survey, with results reduced by other similar software and human blink detection.*

First, we compared the number of NEARBY detections with human detections in *Astrometrica* visual blinking mode. Considering all 15 WFC survey fields, NEARBY adds 384 valid detections, while visual work adds 430 asteroids, which is about 11% more than NEARBY. Probably the human detection is still superior to computers, but this holds only in very restrained surveys able to be scanned by humans. Nevertheless, in a few cases, some asteroids lost by human scanning could be recovered by NEARBY.

Second, we compared NEARBY with *Astrometrica* in automatic detection mode, deriving 357 in *Astrometrica* (93% from NEARBY detections). We imported in *Astrometrica* the NEARBY reduced images, which otherwise fails to resolve some raw INT-WFC images due to WFC field distortion.

Third, we compared NEARBY with *Canopus*[13], a software devoted to photometry and lightcurves of asteroids, which also includes a small detection routine. Only sets of 3 repetitions could be loaded in Canopus, which resulted

[9]http://www.astrometrica.at
[10]https://www.hyperion-astronomy.com
[11]http://pinpoint.dc3.com
[12]https://github.com/rankinstudio/Asteroid_Detector
[13]http://www.minorplanetobserver.com/MPOSoftware/MPOCanopus.htm

in 240 asteroids detected by Canopus (63% of NEARBY detections).

Fourth, we compared NEARBY with the *Hyperion Prism* and *PinPoint* software, but none could recognize all CCDs in all fields; while the first could not load at all CCD3, the second could not load about half (different) CCDs, freezing the computer in many cases. Assuming uniform density of asteroids for all CCDs in the 15 tested fields and taking into account 4 CCDs per WFC field, we could assess for *Hyperion Prism* 226 detected asteroids (47% from NEARBY) and for *PinPoint* 171 detections (45% from NEARBY).

5. INT NEA Survey Case Study

Based on our INT pilot survey experience using NEARBY, in this section we derive some expectations and draw some recommendations for future NEA surveys using the INT-WFC or other facilities accessible to EURONEAR network. These could serve first during the 2019B and 2020A semesters when we proposed a NEA survey (30 nights) to cover up to 1000 sq.deg using the INT-WFC.

5.1. Exposure time

Under dark time conditions and typical INT seeing 1.2″ (historic average), exposures of 20-30s could detect magnitude $V \sim 22.5$ at signal to noise $S/N = 4-5$, which is the limit for discovery of faint NEAs using NEARBY. The INT tracking produces good images up to 2-3 minute exposures, while guiding star acquisition is quite slow and improper for surveys, so tracking is appropriate for surveys. Shorter exposures are better for minimizing the trail loss effect of faster NEAs ($\mu > 5''$/min and also for increasing the survey sky area, but the limmiting magnitude will become lower ($V \sim 22$ for 10 s exposures). Small trails (up to about 3 times the average seeing, thus 4″ long) could be detected and paired by NEARBY (not equipped yet with any trail detection algorithm), thus 30 s exposures could detect NEAs as fast as 8″/min, while 20 s exposures could detect brighter NEAs moving as fast as 12″/min.

5.2. Readout and binning

The WFC camera is quite old (first light April 1998) and has very slow readout, which makes it less efficient for fast cadence surveys which in practice keeps the telescope dormant for about half time during the night. Therefore, a careful balance between the exposure time, readout time and binning should be taken into account while planning any NEA survey.

Fast WFC readout works with similar results as slow readout (as tested during our former EURONEAR NEA recovery and follow-up work), and the fast readout reads the whole mosaic in 29 s (versus 48 s the slow mode), so we always prefered fast readout during our entire survey work which is recommended for larger surveys.

The WFC pixel scale is 0.33″, relatively small for NEA surveys but providing accurate astrometry and photometry (around 0.2″ and ~ 0.2 mag for fainter objects), and during our entire work we used default binning 1×1. Binning 2×2 mode is also available (with 25s readout in slow and 15s in fast) and doubles the pixel to 0.66″ (better for NEA surveys), but the noise is higher (by about 1.5 times), and especially much higher in CCD2 which introduces a strong interference pattern which makes CCD2 actually inappropriate for any detection. Eventually, binning 2×2 and fast readout could be used to decrease the readout to 15 s, at the price of dropping the total sky coverage by one quarter due to the loss of CCD2 (which is less preferable).

5.3. Number of repetitions

Minimum three repetitions per field are needed to apply the classic blink MOPS algoritm for pairing moving objects moving linearily during short time (few dozen minutes), but only three repetitions are vulnerable to loss of faint objects (which might not be detected in all 3 images) and also possible miss-pairing due to noise (especially arising in poor seeing conditions) which result in more time spent by human reducers to reject artifacts during validation.

More than four repetitions increase the pairing confidence but consume more time, while more than five become loss of time for a slow reading camera, thus we decided to use and we recommend four repetitions in our pilot surveys. We could confirm this recommendation upon testing few dozen fields observed during our Sep 2018 pilot mini-survey, concluding also that 3 repetitions work fine only in good weather conditions.

Assuming only 4 repetitions per field, exposures of 30 s in fast mode, 29 s readout time and about 20 s telescope slew time from one field to the next neighbour, the 4-point sequence (ABCD) will result in a cadence of 5.3 min between two consecutive images of the same field, 16 minutes orbital arc and will take 21 min to execute. The 9-point sequence (ABCDEFGHI, used for slower moving objects) will result in 12 min between two consecutive images of the same field, 36 min orbital arc and will take 48 min total to execute. This seems more appropriate for survey work but increases the risk of losing faster NEAs which could exit the relatively small WFC field during the entire sequence (e.g. a NEA with $\mu = 10''$/min will shift by $6'$ during the 9-point sequence.

5.4. Sky coverage and discovery rate

Using the WFC fast readout in binning 1×1 and assuming 30 s exposure time, the INT-WFC could cover 100 fields (about 25 sq. deg) to depth V=22.5 in dark time during the average 9 hour long night. In comparison, the well established Pan-STARRS 1 survey covers 7 sq. deg. each field and 1000 sq. deg each night (142 fields), producing up to ~ 20 NEA discoveries every night. Scaling down these PS1 numbers (because of the similar apertures and sites), using 30 s exposures and 4 repetitions, the INT-WFC should be able to discover one NEA every two nights, and this rate actually matches exactly the results of our Nov 2018 observing run. Droping the exposures to 20 s could increase the discovery rate by only 1.14 times, because each exposure is dominated by the sum of readout time and telescope slewing time (about 50 s in total).

6. Conclusions and Future Work

We will summarise here the outcome of the NEARBY project, related tests and future plans.

- NEA survey work have been longer sought within the EURONEAR project, and some experience was gathered via few related programs which suceeded to recover and follow-up about 1,500 known NEAs and also to serendipitously discover first 9 NEAs in the fields blinked visually by students and amateur astronomers;
- In Sep 2015 three of us have embarked in a PhD thesis aiming to write a MOPS pipeline able to reduce and detect moving sources (asteroids and NEAs) in astronomical images using the classical blink method of repeated images of the same fields. The MOPS algorithm and pipeline were presented in two conference papers;
- Related to this, in 2016 we submitted the NEARBY project which in 2017 was funded by the *Romanian Space Agency* part of the ESA-SSA segment, aiming to produce a cloud-based online platform which engaged a team from two Romanian universities, namely *Technical University of Cluj-Napoca* (UTCN) and the *University of Craiova* (UCV). The NEARBY platform was presented in detail in four conference papers;
- Since Oct 2017 the NEARBY platform started to be developed at UTCN, being first tested on 15 archival fields taken during 3 hours in Mar 2017 with the *Isaac Newton Telescope* (INT) in La Palma, then being improved to detect fainter sources while minimising human validation work;
- In Feb 2018 the first NEARBY version was available online for testing during the first pilot observing run which was completely ruined by ice and bad weather, so we were searching other chances for testing;
- Two such short opportunities were identified in May 2018 (6 hours during 3 nights), then in Sep 2018 (4 hours during two nights), when we could conduct the first pilot tests using the NEARBY platform which performed quite well, offering also some learned lessons for improvement;

- The first actual NEARBY pilot survey (321 fields or 87 sq.deg) was conducted with the INT during five nights at beginning of Nov 2018, by four observers assisted by a remote team of 13 reducers (the NEARBY/UCV team plus other volunteering amateurs trained by the PI before the run) who reported all data in near real time (most within few hours since observing), which allowed the reporting (within 2 hours), recovery during the same night (EURONEAR premiere), and the discovery of the first two NEARBY NEAs (which summed the EURONEAR NEA discoveries to 11), also finding other two NEAs discovered by dedicated surveys and discovering 6 Hungaria or Mars crossing asteroids;
- The second smaller NEARBY pilot survey (197 fields or 53 sq.deg) was observed with the INT during four half-nights at the end of Dec 2018, resulting in the recognition of one known NEA and the discovery of 15 Hungaria or Mars crossing asteroids;
- We compared NEARBY with a few similar available software and human detection using the 15 INT fields observed in Mar 2017 in good seeing and dark conditions. Overall, NEARBY detects about 7% more asteroids than *Astrometrica* (which is also slower and unable to correct field distortion of some INT raw images), being also better by about 37% than *MPO Canopus* (which works only with 3 repetitions). NEARBY seems better than *Hyperion Prism* and *PinPoint* by at least twice. Nevertheless, experienced reducers could detect about 11% asteroids more than NEARBY (which we aim to improve soon) but only in a few fields (typically maximum 20 in near real time, based on our experience);
- Although all NEARBY tests were completed using archive and real time images taken with the INT (using the 4 CCD WFC mosaic camera), we are in posession of some Warshaw OGLE-IV images (32 CCDs mosaic camera) which are being tested, with the aim to make NEARBY able to input any other telescope and camera images defined in a given camera configuration file;
- Few other items to implement in NEARBY are under finalisation by the NEARBY contract (oficially ending in May 2019) and two NEARBY mirrors are being installed at UCV and the EURONEAR servers to be able to cope with possible future technical problems which happened in Nov 2018, resulting in loosing the discovery credits of one NEA;
- A recent INT proposal asking all 3 TACs for 100 sq.deg NEA survey (30 nights spread during two semesters) is expecting resolution soon, while other facilities accessible to all EURONEAR members are being identified for other NEA and maybe other surveys in the future;
- We hope to improve NEARBY further and seek other contracts to make it available to third-party dedicated surveys and also to use for new educational and citizen science projects.

7. Acknowledgements

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The data used to test the NEARBY platform was available by observations made with the *Isaac Newton 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 Astrofisica de Canarias* (IAC). The authors acknowledge the Spanish and IAC time allocation committee which granted the INT-WFC observing time (programs C85/2018A, C9/2018B and C10/2018B, some service D-time and other past programs) which allowed to test the NEARBY platform.

Three of our EURONEAR members helped to secure some INT discoveries, namely B. Stecklum (*Tautenburg Observatory*), V. Casanova (*Sierra Nevada Observatory*) and J. Licandro (*Teide Observatory*). The collaborators PI R. Peletier, the student observer R. Choque (using some INT time), M. Micheli (using the ESA-OGS telescope in it Teide Observatory) and L. Hudin (using his own 30 cm scope) promptly followed some possible NEA candidates discovered with the INT during our Nov and Dec 2018 pilot surveys. Thanks are also due to E. Poretti for his offer to apply to use the TNG telescope in La Palma for the same aim.

Table 1: The observing log of the INT NEA pilot mini-surveys.

Date	Hours	Fields	Elongation	TExp	Seeing	ValDet	Unknown	Det/Fld	NEAcand
20170328	3	15	141-144	60	1.3-2.0	383	118 (31%)	26	1
20180502	1	12	106-108	60	1.5-2.5	217	21 (10%)	18	1
20180503	2	20	112-117	60	2.0-3.0	136	18 (13%)	7	1
20180504	3	24	120-126	60	2.0-3.0	187	47 (25%)	8	0
20180915	2	18	120-122	60	2.0-3.5	73	7 (10%)	4	2
20180916	2	18	118-120	60	1.5-2.0	139	45 (32%)	8	1
20181031	3	18	126-131	30	2.0-2.5	201	9 (4%)	11	1
...	5	36	171-176	30	2.0-2.5	461	130 (28%)	13	12
...	3	20	156-151	30	2.0-3.0	179	23 (13%)	9	4
20181101	3	18	109-113	30	1.5-2.0	158	32 (20%)	11	0
...	3	16	144-148	30	2.0-2.5	236	86 (36%)	15	1
...	5	44	116-104	30	1.5-3.0	285	31 (11%)	6	0
20181102	3	27	100-105	30	2.0-3.5	77	19 (25%)	3	0
...	2	12	166-164	30	2.0-2.5	31	9 (29%)	3	1
20181104	3	18	97-101	30	1.5-2.5	174	76 (44%)	10	1
...	5	52	167-161	30	1.5-2.5	283	125 (44%)	5	4
20181105	6	60	158-142	30	1.5-2.5	512	183 (36%)	9	1
20181227	2	24	116-123	30	1.0-1.5	200	35 (18%)	8	0
...	2	20	160-165	30	1.0-1.5	275	89 (32%)	14	1
20181228	2	20	108-113	40	2.0-3.0	76	6 (8%)	4	0
20181229	4	47	122-131	30	1.0-1.5	505	129 (26%)	11	6
...	3	28	158-165	30	1.0-2.0	427	203 (48%)	15	6
20181230	3	28	143-151	30	1.0-1.3	301	107 (36%)	11	2
...	3	30	175-169	30	1.0-1.2	345	138 (40%)	12	4

Table 2: Possible NEA candidates and their observing circumstances.

Acronym	Field	Obs. Date	N	R	Rate	ϵ	μ	Border	Red	Software	Observations
EUSH999	SURD4	20170327	1	~ 22	100	144	~ 7	> 0.2	LH	Astrom	trail not reported, not found in n2
EP00082	E108	20180502	1	20.5	8	108	1.0	< 1.2	EP	Astrom	reported, not followed-up
EM00039	E205	20180503	1	20.3	100	115	0.5	< 1.0	ST	NEARBY	not reported, not found in n2, artefact?
ET28013	ET28	20180917	3	22.3	16	121	1.0	> 0.8	CB	NEARBY	preliminary orbit in Table 3
ET37001	ET37	20180917	2	20.2	98	119	0.7	< 0.9	OV	NEARBY	*NEA first obs by PS-1 in 20180526*
EUCP007	ET28013	20180918	3	22.0	22	122	0.8	$= 0.8$	EP	NEARBY	preliminary orbit in Table 3
E124100	E124	20181031	3	20.0	22	128	0.4	< 0.5	EP	Astrom	moves reversely in RA than all others
E130023	E130	20181031	r3	21.2	20	171	1.4	> 1.0	AB	NEARBY	preliminary orbit in Table 3
E131027	E131	20181031	3	20.3	13	173	1.3	> 1.0	ST	NEARBY	first obs by INT
E131103	E131	20181031	1	20.2	76	172	0.6	< 1.0	LH	Astrom	*NEA first obs by PS2 in 20181016*
E138015	E138	20181031	r3	20.6	17	174	1.1	> 1.0	CB	NEARBY	preliminary orbit in Table 3
E142027	E142	20181031	3	21.6	18	176	1.3	> 1.0	EP	NEARBY	only obs by INT
E147031	E147	20181101	2	20.8	13	177	1.2	> 1.0	PM	NEARBY	preliminary orbit in Table 3
E149024	E149	20181101	1	22.4	13	177	1.3	> 1.0	AS	NEARBY	quite fuzzy, 3 positions, not sure
E154031	E154	20181101	1	22.9	10	179	1.3	> 1.0	PM	NEARBY	quite fuzzy, 4 positions
E154100	E154	20181101	1	20.6	98	179	0.9	< 1.0	LH	Astrom	only 3 pos, not found in n2, possib artefact
E156038	E156	20181101	4	20.3	12	179	1.2	> 1.0	EP	NEARBY	first obs by INT
E161030	E161	20181101	3	19.9	14	179	1.3	> 1.0	SA	NEARBY	first obs by G96 in 20180921
E165100	E165	20181101	1	~ 20	100	179	~ 12	> 1.0	LH	Astrom	*NEA faint trail first reported by G96*
E170007	E170	20181101	3	20.8	9	157	0.8	> 0.7	SA	NEARBY	preliminary orbit in Table 3
E171012	E171	20181101	3	22.4	2	156	0.7	> 0.6	SA	NEARBY	preliminary orbit in Table 3
E181007	E181	20181101	3	21.1	6	155	0.9	> 0.6	RT	NEARBY	preliminary orbit in Table 3
E181106	E181	20181102	3	19.2	11	156	1.0	> 0.6	RT	Astrom	preliminary orbit in Table 3
E223100	E223	20181101	r6	21.2	99	143	4.1	> 0.2	MP	Astrom	**NEA faint small trail first obs by INT**
E333011	E333	20181102	2	20.3	30	166	1.2	> 0.9	AB	NEARBY	preliminary orbit in Table 3
E409101	E409	20181104	1	20.2	64	97	1.1	< 1.5	EP	Astrom	known (missed by AsterID)
E422021	E422	20181105	2	20.6	19	167	1.2	> 0.9	EP	NEARBY	unknown
E439011	E439	20181105	2	22.2	17	167	1.1	> 0.9	PM	NEARBY	first obs by INT
E448008	E448	20181105	2	19.7	30	167	1.1	> 0.9	AS	NEARBY	preliminary orbit in Table 3
E470008	E470	20181105	2	20.0	16	163	1.0	> 0.8	SA	NEARBY	preliminary orbit in Table 3
E522022	E522	20181106	r4	19.7	98	154	2.1	> 0.5	CB	NEARBY	**NEA first obs by INT**
E124043	E124	20181227	3	20.9	3	160	0.9	> 0.7	VP	NEARBY	preliminary orbit in Table 3

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Table 2: continued.

Acronym	Field	Obs. Date	N	*R*	Rate	ϵ	μ	Border	Red	Software	Observations
E305a01	E305	20181229	1	20.2	84	122	1.0	> 0.7	CB	NEARBY	*NEA first obs by PS1 at 20170506*
E307010	E307	20181229	r3	20.8	16	122	0.8	> 0.7	DC	NEARBY	preliminary orbit in Table 3
E314a01	E314	20181229	3	20.9	7	124	0.6	< 0.7	MS	Astrom	preliminary orbit in Table 3
E336007	E336	20181229	3	21.4	12	128	0.4	< 0.5	AB	NEARBY	well known MBA (missed by AsterID)
E340013	E340	20181229	3	22.5	16	130	0.8	> 0.5	DB	NEARBY	preliminary orbit in Table 3
E345017	E345	20181229	2	20.6	17	130	0.8	> 0.5	RT	NEARBY	preliminary orbit in Table 3
E354032	E354	20181230	3	21.5	16	159	1.0	> 0.7	EP	NEARBY	preliminary orbit in Table 3
E359042	E359	20181230	3	21.4	16	161	1.2	> 0.8	VP	NEARBY	preliminary orbit in Table 3
E362033	E362	20181230	3	22.2	14	161	1.2	> 0.8	DC	NEARBY	preliminary orbit in Table 3
E368048	E368	20181230	3	20.9	13	163	1.2	> 0.8	DB	NEARBY	preliminary orbit in Table 3
E372M42	E372	20181230	3	20.8	17	164	1.1	> 0.8	PM	NEARBY	preliminary orbit in Table 3
E374023	E364	20181230	3	22.3	14	165	1.2	> 0.8	EP	NEARBY	preliminary orbit in Table 3
E409041	E409	20181230	3	21.9	21	146	1.1	> 0.3	CB	NEARBY	preliminary orbit in Table 3
E427009	E427	20181231	3	21.5	11	150	1.0	> 0.4	DC	NEARBY	preliminary orbit in Table 3
E432a01	E432	20181231	3	21.5	20	175	1.6	> 1.0	SA	Astrom	preliminary orbit in Table 3
E436060	E436	20181231	3	20.3	20	174	1.1	> 1.0	SA	NEARBY	preliminary orbit in Table 3
E439016	E439	20181231	3	21.1	46	173	0.7	< 1.0	DB	NEARBY	preliminary orbit in Table 3
E451027	E451	20181231	1	20.5	17	169	1.3	> 0.9	EP	NEARBY	preliminary orbit in Table 3

Table 3: Possible NEA candidates, orbits and identifications.

Acronym	Designation	Class	a	e	i	ω	Ω	M	Epoch	q	MOID	σ	*Obs*	H
ET28013	unknown	MBA	2.26	0.20	24	29	14	350	2458380.5	1.81	0.8305	0.07	16/3n	19.3
EUCP007	unknown	MC	2.67	0.41	29	119	215	22	2458383.5	1.59	0.7254	0.19	16/4n	19.8
E124100	unknown	MBA	2.49	0.31	3	140	206	14	2458424.5	1.73	0.7194	0.15	10/3n	19.0
E130023	unknown	MC?	1.88	0.10	21	350	36	9	2458426.5	1.68	0.6846	0.12	17/3n	20.6
E131027	2018 UG8	MBA	2.64	0.28	31	134	215	29	2458435.5	1.89	0.9665	0.10	16/3n	18.7
E138015	unknown	HUN	1.93	0.06	20	287	216	262	2458426.5	1.80	0.8621	0.08	17/3n	18.7
E142027	2018 VH18	HUN	1.93	0.10	20	133	216	40	2458426.5	1.73	0.7664	0.18	15/3n	20.3
E156038	2018 VJ18	HUN	1.91	0.10	20	120	218	50	2458420.5	1.72	0.7714	0.09	17/3n	19.6
E161030	2018 UH18	MBA	2.59	0.20	33	195	220	349	2458420.5	2.07	0.9088	0.22	14/3n	18.4
E170007	2018 VD75	MBA	2.55	0.33	14	334	49	29	2458490.5	1.72	0.7389	0.18	11/3n	18.6
E171012	unknown	MBA	2.56	0.26	15	323	50	23	2458426.5	1.90	0.9240	0.16	11/3n	20.1
E181007	unknown	MBA	2.78	0.30	28	61	52	328	2458427.5	1.94	1.0762	0.10	12/3n	17.9
E181106	unknown	HUN	1.94	0.10	19	132	233	40	2458428.5	1.74	0.7820	0.05	10/3n	17.4
E223100	**2018 VQ1**	NEA	1.08	0.03	11	262	36	247	2458600.5	1.05	0.0718	0.32	46/8n	24.5
E439011	2018 VF30	HUN	1.89	0.03	20	254	241	277	2458440.5	1.84	0.8862	0.10	8/2n	19.6
E522022	**2018 VN3**	NEA	1.71	0.32	13	209	235	58	2458600.5	1.16	0.1968	0.11	24/5n	21.3
E124043	unknown	MBA	2.70	0.15	25	32	84	337	2458481.5	2.28	1.3274	0.15	12/3n	18.1
E307010	unknown	HUN	1.97	0.14	22	158	251	17	2458485.5	1.70	0.7245	0.20	17/3n	18.6
E314a01	unknown	MC?	1.88	0.11	19	102	250	67	2458485.5	1.67	0.7673	0.15	12/3n	18.9
E340013	unknown	HUN	1.92	0.09	23	27	74	339	2458485.5	1.74	0.7697	0.17	13/3n	20.5
E345017	unknown	HUN	1.85	0.04	24	11	73	352	2458485.5	1.78	0.7954	0.10	14/3n	19.0
E354032	unknown	MC?	2.43	0.31	23	98	80	305	2458485.5	1.67	0.8307	0.11	14/3n	18.5
E359042	unknown	HUN	1.84	0.02	20	145	276	27	2458485.5	1.80	0.8217	0.06	14/3n	19.5
E362033	unknown	MC?	1.86	0.10	18	214	277	327	2458485.5	1.67	0.7010	0.15	13/3n	21.0
E368048	unknown	MBA	2.29	0.16	24	162	276	9	2458485.5	1.91	0.9348	0.11	13/3n	19.5
E372M42	unknown	HUN	1.95	0.06	24	221	84	146	2458492.5	1.84	0.8409	0.10	11/3n	19.2
E374023	unknown	HUN	1.94	0.09	20	142	278	28	2458486.5	1.77	0.8043	0.29	15/3n	20.6
E409041	unknown	MC	3.14	0.49	25	57	76	346	2458492.5	1.61	0.7357	0.06	14/3n	19.8
E427009	unknown	HUN	1.94	0.08	23	102	76	277	2458487.5	1.79	0.8625	0.15	13/3n	19.3
E432a01	unknown	HUN	1.90	0.08	28	18	101	347	2458487.5	1.75	0.7716	0.11	10/3n	20.4
E436060	unknown	HUN	1.86	0.08	18	19	283	158	2458487.5	1.70	0.6909	0.09	18/3n	18.4
E439016	unknown	MC	2.59	0.40	8	22	101	353	2458487.5	1.55	0.5676	0.10	20/3n	20.9
E451027	unknown	HUN	1.93	0.08	21	192	285	351	2458487.5	1.78	0.7955	0.11	21/3n	19.4

References

[1] D. Koschny, M. Busch, The Teide Observatory Tenerife Asteroid Survey, in: K. Muinonen, A. Penttilä, M. Granvik, A. Virkki, G. Fedorets, O. Wilkman, T. Kohout (Eds.), Asteroids, Comets, Meteors 2014, 2014 (Jul. 2014).

[2] D. Koschny, M. Busch, The Teide Observatory Tenerife Asteroid Survey, Planetary and Space Science 118 (2015) 305–310 (Dec. 2015). doi:10.1016/j.pss.2015.08.007.

[3] D. Koschny, G. Drolshagen, Activities in Europe related to the mitigation of the threat from near-Earth objects, Advances in Space Research 56 (2015) 549–556 (Aug. 2015). doi:10.1016/j.asr.2015.03.027.

[4] O. Vaduvescu, et al., EURONEAR: First results, Planetary and Space Science 56 (2008) 1913 (Nov. 2008). doi:10.1016/j.pss.2008.02.025.

[5] O. Vaduvescu, et al., EURONEAR - Recovery, follow-up and discovery of NEAs and MBAs using large field 1-2 m telescopes, Planetary and Space Science 59 (2011) 1632–1646 (Oct. 2011). arXiv:1108.5780, doi:10.1016/j.pss.2011.07.014.

[6] O. Vaduvescu, et al., 739 observed NEAs and new 2-4 m survey statistics within the EURONEAR network, Planetary and Space Science 85 (2013) 299–311 (Sep. 2013). arXiv:1308.5594, doi:10.1016/j.pss.2013.06.026.

[7] M. Birlan, O. Vaduvescu, et al., More than 160 near Earth asteroids observed in the EURONEAR network, Astronomy and Astrophysics 511 (2010) A40 (Feb. 2010). doi:10.1051/0004-6361/200912865.

[8] O. Vaduvescu, et al., EURONEAR: Data mining of asteroids and Near Earth Asteroids, Astronomische Nachrichten 330 (2009) 698 (Jul. 2009). arXiv:0906.5030, doi:10.1002/asna.200811198.

[9] O. Vaduvescu, et al., Mining the CFHT Legacy Survey for known Near Earth Asteroids, Astronomische Nachrichten 332 (2011) 580–589 (Jul. 2011). arXiv:1107.2249, doi:10.1002/asna.201011550.

[10] O. Vaduvescu, et al., Mining the ESO WFI and INT WFC archives for known Near Earth Asteroids. Mega-Precovery software, Astronomische Nachrichten 334 (2013) 718–728 (Aug. 2013). arXiv:1301.6902, doi:10.1002/asna.201211720.

[11] O. Vaduvescu, et al., 280 one-opposition near-Earth asteroids recovered by the EURONEAR with the Isaac Newton Telescope, Astronomy and Astrophysics 609 (2018) A105 (Jan. 2018). arXiv:1711.00709, doi:10.1051/0004-6361/201731844.

[12] O. Vaduvescu, et al., First EURONEAR NEA discoveries from La Palma using the INT, Monthly Notices of the Royal Astronomical Society 449 (2015) 1614–1624 (May 2015). doi:10.1093/mnras/stv266.

[13] D. Copandean, O. Vaduvescu, D. Gorgan, Automated Prototype for Asteroids Detection, in: Proceedings of the 13th IEEE International Conference on Intelligent Computer Communication and Processing (ICCP), pp. 377-382, 2017 (Jan. 2017). arXiv:1901.10469.

[14] D. Copandean, C. Nandra, D. Gorgan, O. Vaduvescu, Asteroids Detection Technique: Classic “Blink” An Automated Approch, in: Proceedings of the IEEE International Conference on Automation, Quality and Testing, Robotics, AQTR 2018 - THETA 21st Edition, pp. 1-6, 2018 (Jan. 2018). arXiv:1901.02542.

[15] V. Bacu, A. Sabou, T. Stefanut, D. Gorgan, O. Vaduvescu, NEARBY Platform for Detecting Asteroids in Astronomical Images Using Cloud-based Containerized Applications, arXiv e-prints (Jan. 2019). arXiv:1901.04248.

[16] T. Stefanut, V. Bacu, C. Nandra, D. Balasz, D. Gorgan, O. Vaduvescu, NEARBY Platform: Algorithm for Automated Asteroids Detection in Astronomical Images, arXiv e-prints (Jan. 2019). arXiv:1901.02545.

[17] S. Keys, P. Vereš, M. J. Payne, M. J. Holman, R. Jedicke, G. V. Williams, T. Spahr, D. J. Asher, C. Hergenrother, The digest2 NEO Classification Code, Publications of the Astronomical Society of the Pacific 131 (6) (2019) 064501 (Jun. 2019). arXiv:1904.09188, doi:10.1088/1538-3873/ab1157.

[18] M. F. Skrutskie, R. M. Cutri, R. Stiening, M. D. Weinberg, S. Schneider, J. M. Carpenter, C. Beichman, R. Capps, T. Chester, J. Elias, J. Huchra, J. Liebert, C. Lonsdale, D. G. Monet, S. Price, P. Seitzer, T. Jarrett, J. D. Kirkpatrick, J. E. Gizis, E. Howard, T. Evans, J. Fowler, L. Fullmer, R. Hurt, R. Light, E. L. Kopan, K. A. Marsh, H. L. McCallon, R. Tam, S. Van Dyk, S. Wheelock, The Two Micron All Sky Survey (2MASS), Astronomical Journal 131 (2006) 1163–1183 (Feb. 2006). doi:10.1086/498708.

[19] L. Denneau, et al., The Pan-STARRS Moving Object Processing System, Publications of the Astronomical Society of the Pacific 125 (2013) 357 (Apr. 2013). arXiv:1302.7281, doi:10.1086/670337.

[20] D. Tody, The IRAF Data Reduction and Analysis System, in: D. L. Crawford (Ed.), Instrumentation in astronomy VI, Vol. 627 of In Instrumentation in astronomy VI; Proceedings of the SPIE Meeting, 1986, p. 733 (Jan. 1986). doi:10.1117/12.968154.

[21] E. Bertin, S. Arnouts, SExtractor: Software for source extraction., Astronomy and Astrophysics 117 (1996) 393–404 (Jun. 1996). doi:10.1051/aas:1996164.

[22] E. Bertin, Automatic Astrometric and Photometric Calibration with SCAMP, in: C. Gabriel, C. Arviset, D. Ponz, S. Enrique (Eds.), Astronomical Data Analysis Software and Systems XV, Vol. 351 of Astronomical Society of the Pacific Conference Series, 2006, p. 112 (Jul. 2006).

[23] D. Lang, D. W. Hogg, K. Mierle, M. Blanton, S. Roweis, Astrometry.net: Blind Astrometric Calibration of Arbitrary Astronomical Images, Astronomical Journal 139 (2010) 1782–1800 (May 2010). arXiv:0910.2233, doi:10.1088/0004-6256/139/5/1782.

[24] K. Allekotte, et al., Astronomical image data reduction for moving object detection, in: Progress in Pattern Recognition, Image Analysis, Computer Vision, and Applications, Berlin, Heidelberg, 2013, p. 116 (2013).