Around 1500 Near Earth Asteroid Orbits Improved via EURONEAR

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What is EURONEAR?

The **EURO**pean **N**ear **E**arth **A**steroid **R**esearch

> A project to increase the European contribution in NEA research;

> Born in 2006 at IMCCE Paris (by O. Vaduvescu and M. Birlan);

> Proposing to study orbital and physical properties of NEAs;

> The dream to establish one or two dedicated telescopes in both Hemispheres was not fulfilled yet;

> A collaborative project contributing to education and public outreach, having amateurs and students as collaborators and co-authors.

The EURONEAR Nodes and Collaborators

> Currently, 19 nodes including more than 60 astronomers from 8 EU countries and Chile are included in the EURONEAR (informal) consortium:

- Spain: ING (O. Vaduvescu), IAC (J. Licandro), IAA (J. L. Ortiz), CSIC-IEEC (J. M. Trigo), Alicante (A. C. Bagatin), SVO (E. Solano), Huelva (J. M. Madiedo);
- France: IMCCE (M. Birlan), OCA (P. Tanga), ;
- Italy: Padova (M. Lazzarin), Torino (A. Cellino);
- UK: Armagh (D. Asher), Open Univ (S. Green), Liverpool (J. Marchant);
- Czech Republic: Ondrejov (P. Pravec);
- Germany: TLS Tautenburg (B. Stecklum);
- Finland: Tuorla (R. Rekola);
- Slovakia: Bratislava/Modra (A. Galad);
- Chile: UAUA Antofagasta (E. Unda-Sanzana);

> BUT: only very few of these are active, thus the list will be revised soon;

> Nevertheless, some 20 dedicated amateurs and student collaborators (mostly Romanian, ING, etc) have contributed more!

EURONEAR – Two Major Science Goals

A: Orbital amelioration via astrometry (since 2006)

1) Secure the orbits of newly discovered PHAs and VIs;
2) Follow-up and recovery of NEAs, PHAs and VIs in most need of data (more uncertain, small arc, one opposition objects);
3) Data mining existing imaging archives available online;
4) Incidental discovery of many MBAs and some NEAs.

B: Physical properties via photometry, spectroscopy and polarimetry: rotation, size, binarity, albedo, mass, taxonomy (since 2014)
See our ACM2014 NEA physical characterization poster;

Both goals require lots of observing time (difficult to obtain via normal time applications) or regular observing time preferably using dedicated 1-2m or larger telescopes (which Europe does not hold)!

Observing runs within the EURONEAR network

1000 NEAs observed (astrometry) from 5 countries with 15 telescopes:

> Cerro Tololo, Chile - Blanco 4m (2n 2011);
> Isaac Newton Group, La Palma - WHT 4.2m (2011-2013 few hrs D-time);
> Isaac Newton Group, La Palma - INT 2.5m (15n 2009-2014 + 50h ToO time);
> La Silla, Chile - ESO/MPG 2.2m with WFI camera (3n 2008);
> TLS Tautenburg, Germany - Schmidt 2m with CCD (30n 2012-2014);
> Las Campanas Observatory, Chile - Swope 1m (15n 2008);
> Cerro Tololo, Chile - Yale 1m telescope (5n 2008);
> La Silla Observatory, Chile - ESO 1m (2n 2007, included in the FP7 proposal);
> Cerro Armazones Observatory, Chile - 0.84m (1n 2007);
> Haute Provence Observatory, France - 1.2m (15n 2007-2011);
> Pic du Midi Observatory, France - T1m 1m (20n 2006-2011);
> Argelander Institute for Astronomy, Bonn, Germany - 0.5m (10n 2011-2013);
> Galati public outreach Observatory, Romania - 0.40m (100n 2011-2014);
> Bucharest Urseanu public outreach Observatory, Romania – 0.25m and 0.3m telescopes (30n 2006-2014).

Observing runs and network (2)

Six papers including 20+ EURONEAR observing runs: 1000 observed NEAs, PHAs and VIs, few thousand incidental known MBAs and new objects, 18 best new NEA candidates.

1-2. Observing NEAs with a small telescope
> Major surveys overview, planning observations, data reduction, catalogs, etc
> Sample run using the York Univ 0.6m telescope (Toronto)
> Romanian Astronomical Journal, Vaduvescu 2004 and 2005;

3. EURONEAR First Results
> Two runs 1m telescopes, (Pic T1m and OHP 1.2m)
> 17 observed NEAs, planning tools, reduction pipeline,
> Astrometry, O-C calculator, etc
> Planetary and Space Science, Vaduvescu et al. 2008;

Observing runs and network (3)

4. Paper presenting 162 NEAs observed during regular runs 2006-2009
   > 55 nights total (1500 reported positions)
   > Using eight 1-2m telescopes (INT 2.5m, ESO 2.2m, OHP 1.2m, Swope 1m, CTIO 1m, Pic 1m, ESO 1m, OCA 0.85m)
   > Astronomy & Astrophysics, Birlan et al. 2010, incl 9 students/amateurs

5. Recovery, follow-up and discovery of NEAs and MBAs using 3 large field 1-2m telescopes (Swope 1m, ESO 2.2m & INT 2.5m) 2008-2010
   > 100 NEAs, 558 known MBAs, 628 unknown objects (including 58/500 MBA discoveries and 4-16 NEA candidates)
   > MBA and NEA observability statistics using 1-2m telescopes
   > Planetary and Space Science, Vaduvescu et al. 2011, 13 students/amateurs

> More than 100 MPC and MPEC publications including NEAs & MBAs;
> 15+ communications in conferences including students & amateurs;

More observing runs and network (4)

6. 741 NEAs observed by the EURONEAR network (2006-2012);

   > Counting reached about 1000 observed NEAs today (July 2014);

   > Including 10 new runs observed with 9 telescopes: Blanco 4m MOSAIC-2, WHT 4.2m, INT 2.5m WFC, TLS Tautenburg 2m, OHP 1.2m, Pic du Midi T1m, plus 3 educational/amateur scopes: Bonn 0.5m, Galati 0.4m and Urseanu Bucharest 0.3m.

   > Planetary and Space Science, Vaduvescu et al 2013, includes 24 students and amateurs from Romania, Chile, Germany, France, UK, Iran;

7. In 2014A the Spanish TAC accepted our 30h INT ToO proposal to recover about 100 one-opposition NEAs by V~23.5 (one quarter of all known one-opposition NEAs!) a program to continue 20h in 2014B;

   > To become a paper in 2015 and include about 10 students/amateurs;

Data mining of imaging archives

Four NEA data-mining projects and papers in collaboration mostly with students and amateurs: 500 NEAs and PHAs p/recovered.

1. EURONEAR: Data mining of asteroids and NEAs:

   > Introducing PRECOVERY server (2008);
   > Application on the Astronomical Observatory Bucharest Plate Archive - 13,000 plates 0.4m refractor (1930-2005);
   > Astronomische Nachrichten, Vaduvescu et al. 2009, 2 students/amateurs

2. CFHT Legacy Survey Archive (CFTHLS) MegaCam survey:

   > 25,000 MegaCam mosaic CCD images 3.6m, 2003-2009;
   > 143 NEAs and PHAs found and reported from 508 images;
   > Astronomische Nachrichten, Vaduvescu et al. 2011, 6 students/amateurs

Data mining of imaging archives (2)

3. Mining the ESO WFI and INT WFC archives. Mega-Precovery (2010):

> 330,000 mosaic CCD images taken with ESO/MPG 2.2m WFI and the ING/INT 2.5m WFC 1998-2009;
> 152 NEAs and PHAs found in 761 images reported to MPC;
> Prolonged orbits for 18 precovered objects and 10 new opposition recoveries;

> In 2010 we introduced Mega-Precovery server and Mega-Archive: 39 instrument archives (ESO, NOAO, CADC, etc) including 4.3 million images available to query for NEAs, asteroids and comets via Mega-Precovery!

> Astronomische Nachrichten, Vaduvescu et al. 2013, includes 13 students and amateurs;

> Check also our Mega-Precovery ACM2014 poster.

More data mining of imaging archives (3)

4. Data Mining the SuprimeCam Archive for NEAs

> 70,000 SuprimeCam mosaic CCD images taken with Subaru telescope (1999-2012);

> About 1000 known NEAs were searched on 5000+ candidate images!

> About 100 known NEAs were found/measured on 500+ images;

> Additionally, we are scanning few hundreds selected SuprimeCam fields for new NEAs to improve the NEA statistics at the faint end;

> Poster presented at ACM2012 meeting in Japan;

> To become a paper in 2014, collaboration with 14 students/amateurs.

Other topics and papers related to EURONEAR

Six papers related to asteroids, comets and MBCs lead by some EURONEAR collaborators:

1. Asteroid pairs: Formation of pairs by rotational fission (Pravec, et al. 2010, Nature)

2. Binary asteroids: Distribution of orbit poles of small, inner main-belt binaries (Pravec et al. 2011, Icarus)

3. Chemical evolution of comets: Spectroscopic observations of new Oort cloud comet 2006 VZ13 and four other comets (Gilbert et al, 2011, Monthly Notices RAS)

Other topics and papers related to EURONEAR (2)

Papers related to Main Belt Comets (MBCs) lead by EURONEAR collaborators:

4. Water-ice-driven Activity on Main-Belt Comet P/2010 A2 (LINEAR)? (Moreno et al. 2010, Astrophysical Journal)

5. (596) Scheila in outburst: A probable collision event in the Main Asteroid Belt (Moreno et al. 2011, Astrophysical Journal)

6. The dust environment of Main-Belt Comet P/2012 T1 (PANSTARRS) (Moreno et al. 2013, Astrophysical Journal)

EURONER asteroid discoveries and naming

1. 500 MBAs discovered and 58 official based on the ESO/MPG 2.2m 3-night run in 2008 (reduced by 6 students and amateurs);

2. First Romanian discoverers of asteroids (2008) lead by two Romanian astronomers from Diaspora in a team of 9 mostly students and amateurs reducing data remotely in near real time;

3. Some 1000 MBAs discoveries and 100 to become official based on the short INT opposition 3-night survey run in 2012 observed and reduced By 5 Romanian students and amateurs;

4. First 5 asteroids discovered by Romanians named after passed away Romanian astronomers: (263516) Alexescu, (257005) ArpadPal, (320790) Anestin, (330634) Boico and (346261) Alexandrescu;

5. First secured NEA discovery of a NEA from La Palma/INT: 2014 LU14

Data reduction and astrometry

Software for image processing, field correction and source recognition:

> THELI (Erben, Schrimer, Dietrich et al, 2005):

- Applied to correct the field to improve the astrometry;
- Mandatory for large field and PF cameras (INT-WFC, Blanco MOSAIC, etc);

> SDFRED for Subaru SuprimeCam (Ouchi, Yagi, 2002, 2004);

> Our own IRAF pipeline for image reduction some tasks;

> FIND_ORB (Gray, 2014) and ORBFIT (Millani et al, 2014) for orbital fit;

> Astrometrica (Raab, 2014):

- Easy to learn and use remotely by students and amateurs;
- Detect, clasify, measure and report all moving objects within few hours (up to 2-3 days) by dedicated students & amateurs!

Improved astrometry

(Birlan et al, 2010)

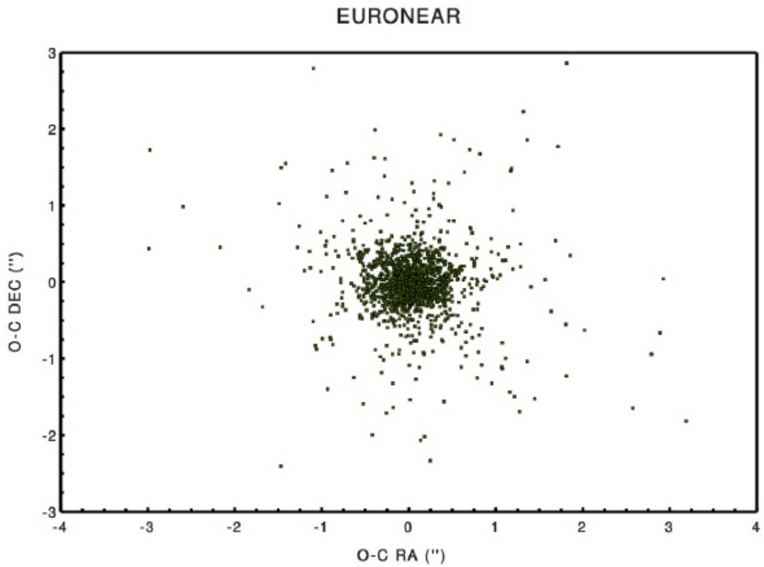


Fig. 2. (o-c) residuals for 1538 positions of 162 NEAs observed in the EURONEAR network. Most of the points are confined within 1″, probing the observational capabilities for all facilities and the accurate data reduction.

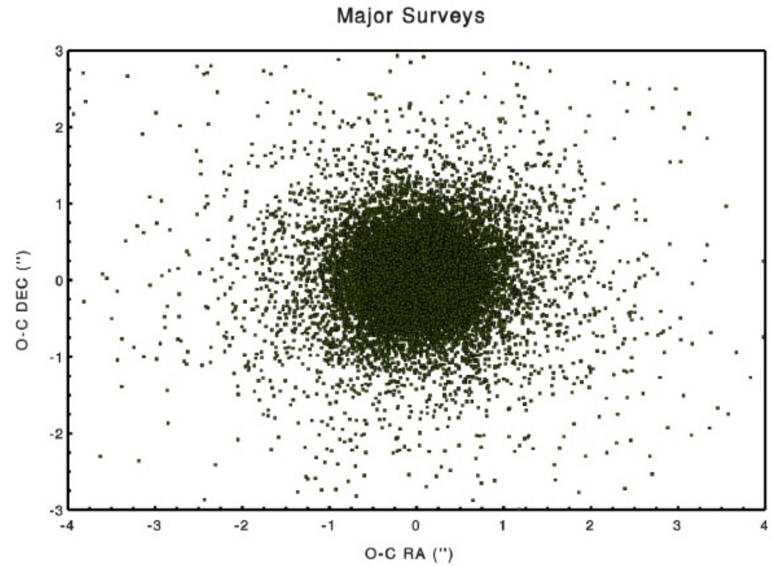
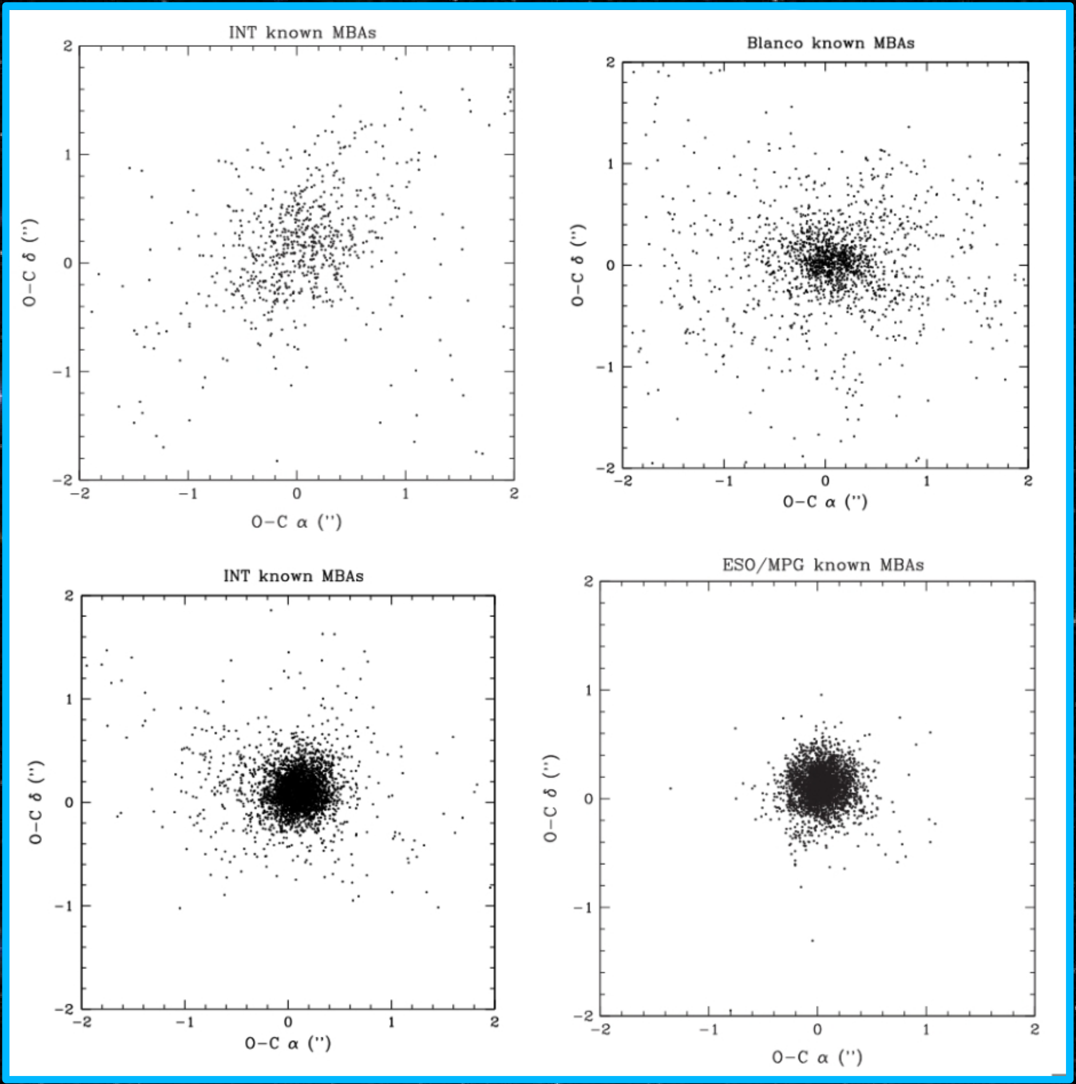


Fig. 3. Over 23 000 (o-c) residuals related with observations performed by all other surveys which observed in the past the same asteroids with EURONEAR. Comparing this plot with the one of Fig. 2, one can observe that EURONEAR observations appear better confined around zero, and this fact is also supported by statistics.

O-C Residuals: Smaller O-Cs => Improved orbits
EURONEAR FWHM 0.4″ versus 0.6″ major surveys

Comparing large field 2-4m facilities



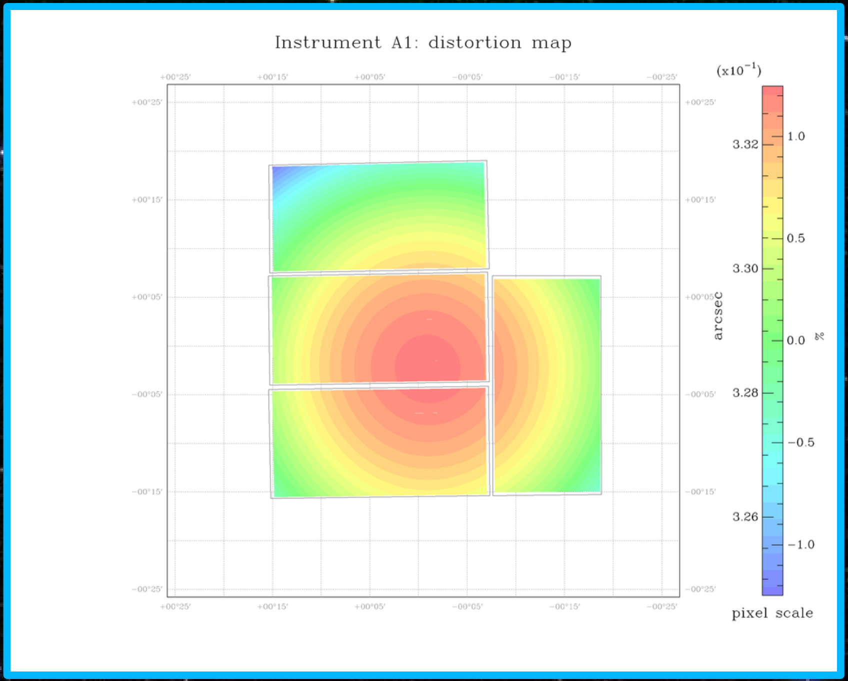
Upper-left: Known MBAs PF INT WFC field not corrected (2010): RMS = 0.97″

Upper-right: PF Blanco Mosaic-II not corrected (2011): RMS = 0.90″

Bottom-left: PF INT WFC field corrected (2012): RMS = 0.41″

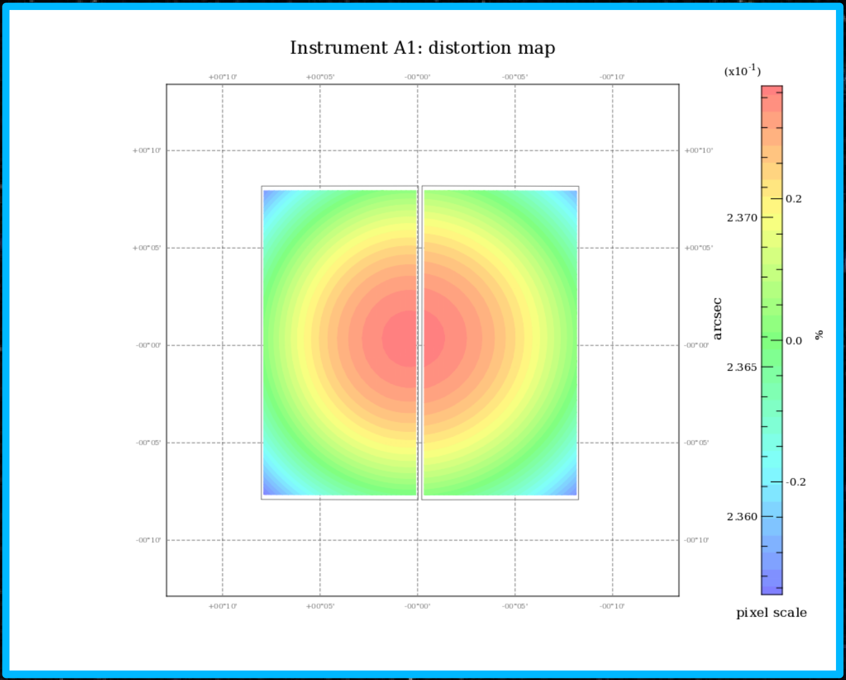
Bottom-right: WFI Cass field not corrected (2008): RMS = 0.28″

Solving the PF large field distortions

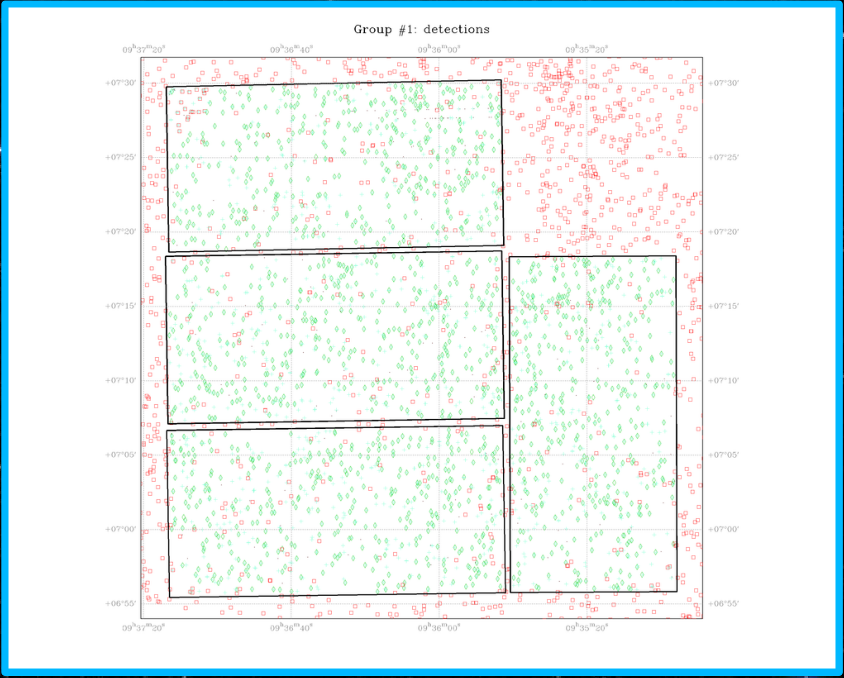


Left: INT WFC distortion map shows pixel scale changes from 0.325”/pix to 0.333"/pix from center to margins which propagate to 10" astrometric errors should a simple linear model be applied!

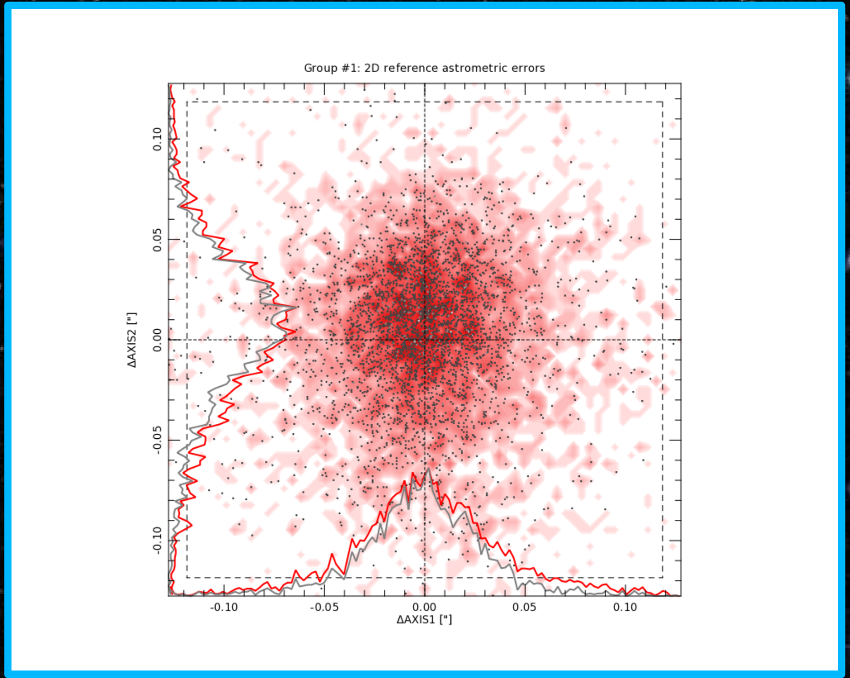
Right: WHT PFIP map shows optical distortions from 0.2358 to 0.2374"/pix from center to margins, resulting in 2" errors without field correction (THELI/SCAMP plots)



Solving the PF large field distortions (2)



Left: INT WFC matched stars (green symbols) used for field correction and not matched red catalog stars (outside the field
or surpassing the used astrometric tolerance accuracy)



Right: WHT PFIP map showing O-C astrometric residuals following field correction (THELI/SCAMP plots)

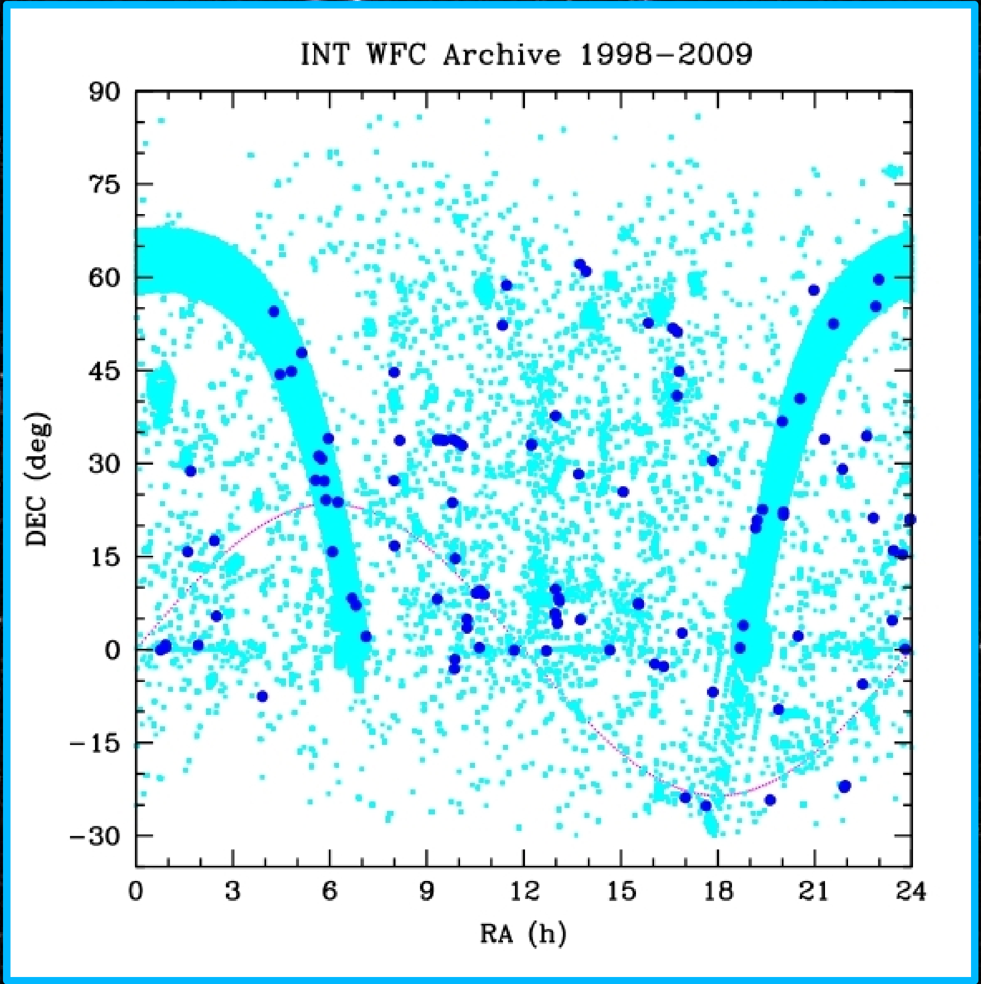
Extending orbital arcs using image archives

(Vaduvescu et al, 2011a)

Table A1 Five special classes including 58 NEA and PHA asteroids data mined in the CFHTLS. Besides the asteroid name we give its MPC classification, the number of CFHTLS observations, the orbital arc and the number of covered oppositions before and after adding our data, and some comments showing how our work improved the orbits.

Asteroid	Classification	Obs.	Arc	Opp.	Comments
			Extended Arcs at First Opposition (Precoveries):		
2008 ED69	NEA very desirable	6	9m/4y	2/3	Arc prolonged by 3 yrs
2005 CJ	PHA very desirable	3	5/8m	2	Arc prolonged by 3 mths
2006 PA1	PHA very desirable	1	4y	3	Arc prolonged by one mth
2008 OX2	PHA	4	2y	2	Arc prolonged by 1.5 mths
2003 WO151	NEA very desirable	3	2y	2	Arc prolonged by 1.5 mths
2005 LW	NEA very desirable	2	4/5y	3/4	Arc prolonged by 8 mths
2005 OW	NEA extremely desirable	3	4/5m	1	Short arc prolonged by 1 mth
2005 QN11	NEA extremely desirable	3	4/5m	1	Short arc prolonged by 1 mth
2005 QS10	NEA very desirable	3	4y	2	Arc prolonged by 1.5 mths
2005 SS4	NEA very desirable	4	3y	3	Arc prolonged by 2 weeks
2004 BE86	NEA very desirable	4	5y	2	Arc prolonged by one mth
2007 RM133	NEA	8	3y	2	Arc prolonged by one week
2008 SQ1	NEA	5	5y	2	Arc prolonged by one mth
2008 AF4	PHA very desirable	1	4m/6y	2/3	We only at 2nd opp, Goldstone radar target
2007 FS35	NEA very desirable	4	3m/8y	2/3	We only at 2nd opp
2008 CR118	PHA	1	8m/5y	2/3	We only at 2nd opp
2006 SV19	NEA	3	6y	3/4	We only at 2nd opp, numbered (212546)
2006 SU49	PHA very desirable	3	7y	3/4	We only at 2nd opp
2005 RN33	NEA very desirable	6	4y	2	We first at 2nd opp
2008 XE3	NEA	4	4y	2	We 2nd set at 1st opp
2005 UU3	NEA very desirable	4	2y	2	We 2nd set, only just 4 hrs after discovery
			Extended Arcs at Last Opposition (Recoveries):		
1998 VD35	PHA desirable	1	2/7y	3/4	Arc prolonged by 5 yrs, numbered (20425)
1993 BX3	PHA desirable	6	11/13y	3/4	Arc prolonged by 5 yrs, numbered (65717)
1999 GS6	PHA desirable	3	7/8y	4/5	Arc prolonged by 1 yr, numbered (152754)
2005 RR6	PHA very desirable	4	2y	2	Arc prolonged by 2 weeks
2005 WA1	PHA extremely desirable	3	1/7m	1	Initial 3 week arc prolonged by 6 mths
2003 TG2	NEA for survey recovery	3	18/24d	1	Very small arc prolonged by one week, old object
2004 XG29	NEA extremely desirable	1	25/35d	1	Very small arc prolonged by 10 days
1998 XA5	NEA very desirable	3	4/8y	3/4	Arc prolonged by 4 yrs

Data mining of NEAs in existing imaging archives



Cyan fine dots: 230,000
INT-WFC pointings
1998-2009

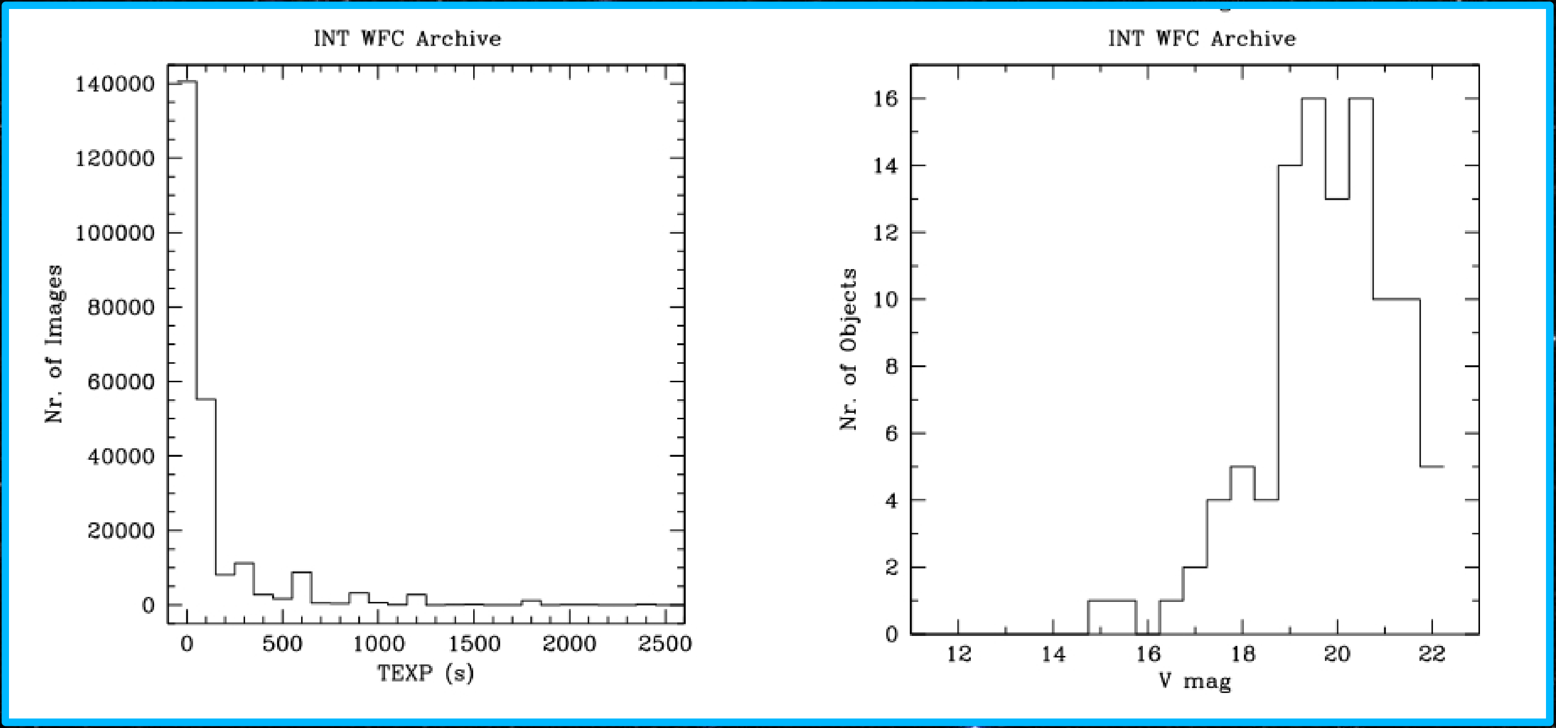
Blue larger dots:
97 NEA findings measured and reported (445 positions)

worth like 5 (very spread) observing nights or
min 10,000 EUR!

(Vaduvescu et al, 2011a)

WFC archive statistics and NEAs

(Vaduvescu et al, 2011a)



Left: Most WFC images were taken with short (<2 min) exposure times, making them suitable for mining for fast moving NEAs
Right: V (apparent magnitude) of encountered NEAs shows the INT efficient up to V=22, surpassing the existing 1-2m surveys

Other results

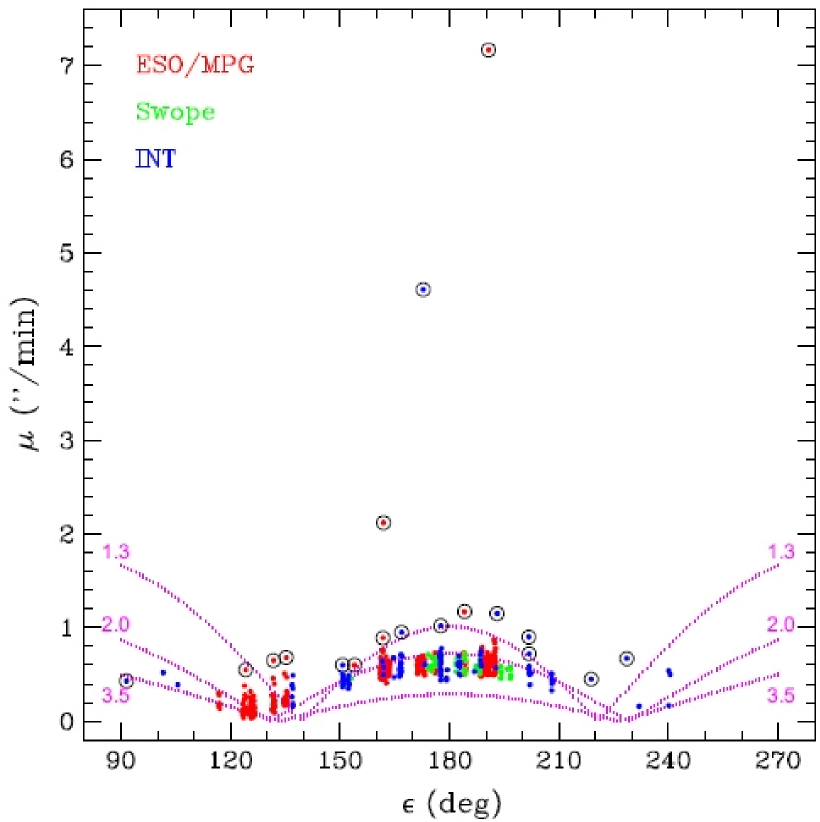


Fig. 5. Basic orbital model using the asteroid observed proper motion μ and the solar elongation ε. We plot all unknown objects observed at ESO/MPG (red), Swope (green) and INT (blue). The three overlaid dotted magenta curves correspond to asteroids orbiting between $a=2.0$ and $a=3.5$ AU (Main Belt) and $a=1.3$ (Near Earth Objects limit). The model allows us to easily flag NEO candidates in a survey. We mark with circles our NEO candidates and we include their properties in Table 4. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Simple orbital model to disclose between MBAs and NEA candidates around opposition based on their proper motion and Solar elongation

(Vaduvescu et al, 2011b)

1-2m survey statistics in magnitude distribution

(Vaduvescu et al, 2011b)

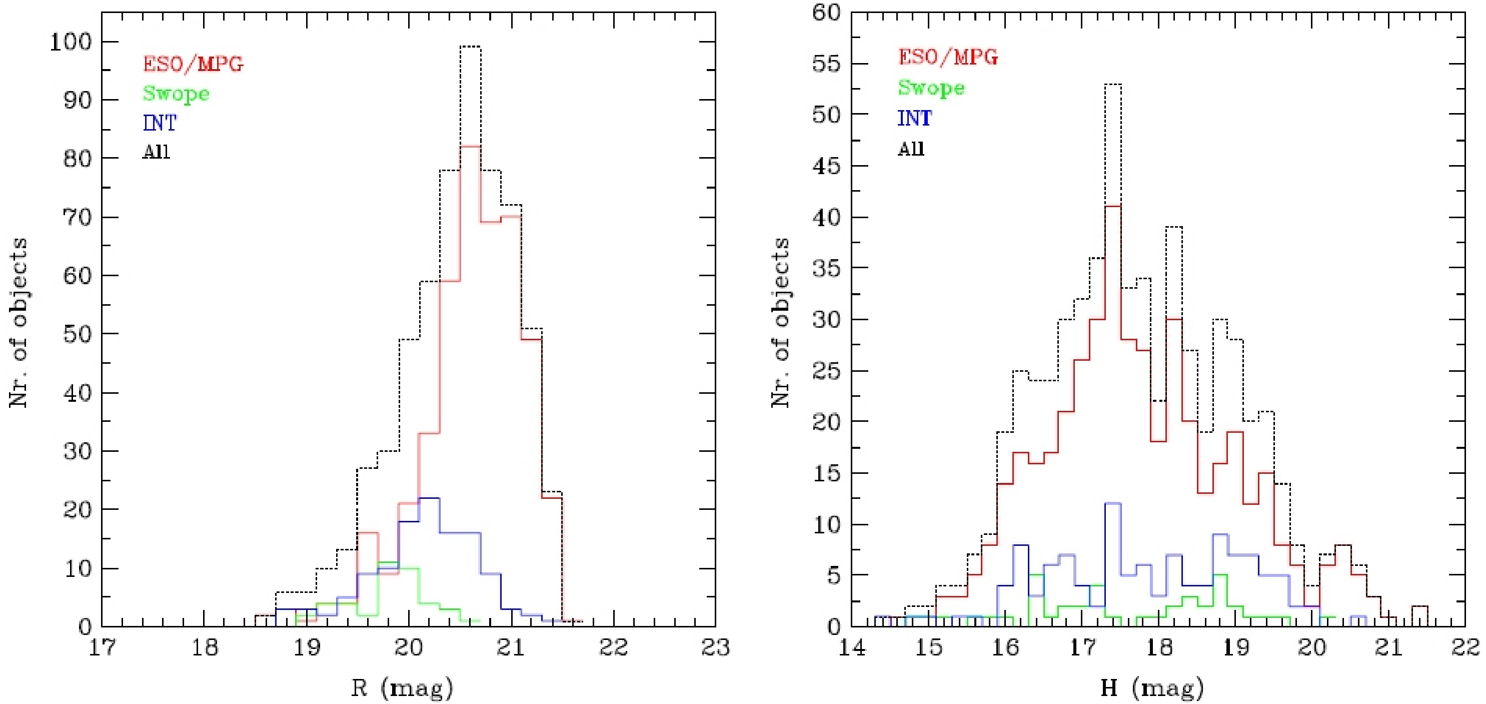


Fig. 9. Histograms showing number of unknown objects as function of observed apparent *R* magnitude (left) and calculated absolute magnitude *H* (right) for the ESO/MPG dataset (red), Swope (green), INT (blue) and the total number of objects (black dots). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

1-2m survey statistics in orbital distribution of discovered MBAs

(Vaduvescu et al, 2011b)

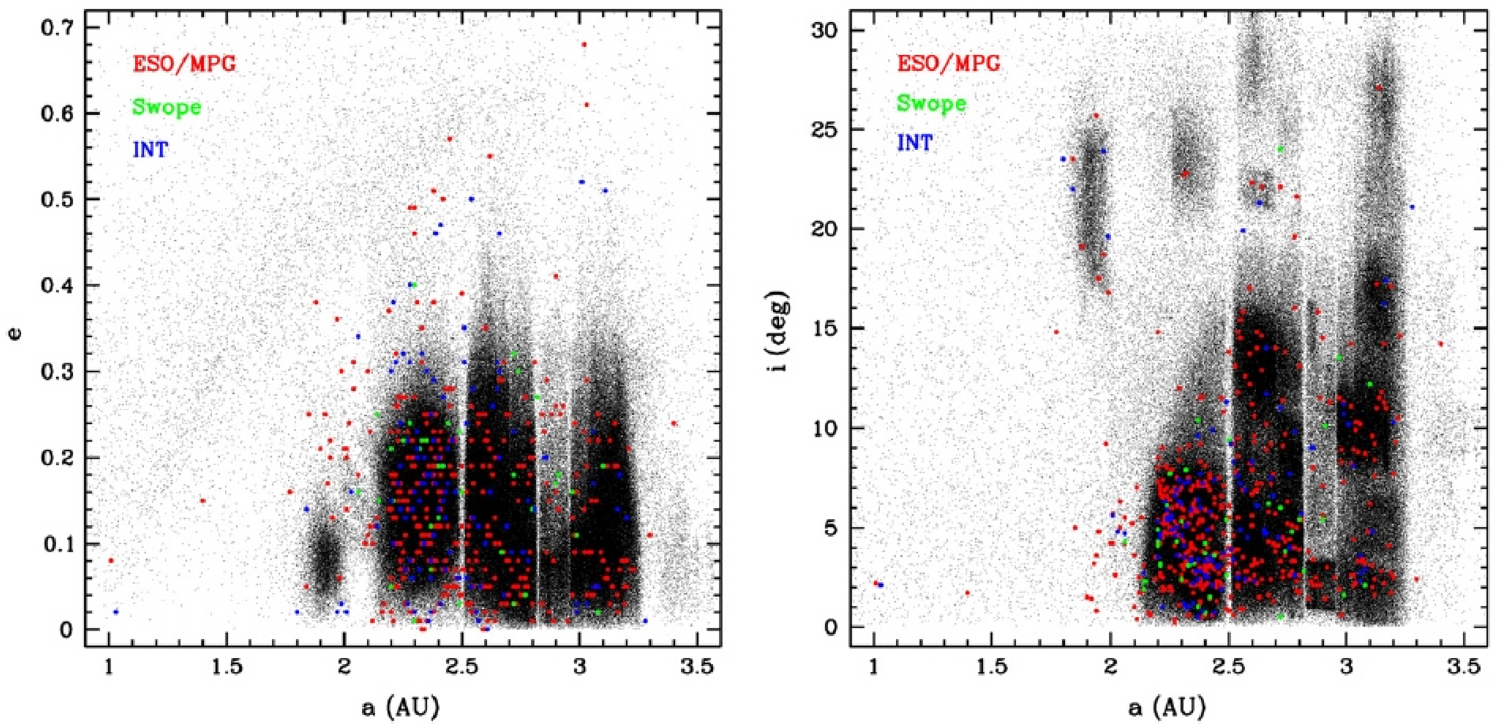


Fig. 7. Orbital distributions of 628 unknown objects observed at ESO/MPG (red points), Swope (green) and INT (blue) compared with the entire known asteroid population (ASTORB - 541,260 fine black points). Although our preliminary orbits were derived using mostly short arcs, the distributions are consistent with the known MBA population, showing the usefulness of the FIND_ORB orbital fit in *a*, *e* and *i*. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

"Mega-Archive" includes 4.3 million images

(Vaduvescu et al, 2012; see also our ACM2014 poster) and will grow soon!

Table A3 28 instrument archives available in August 2012 in the *Mega-Archive* used by *Mega-Precovery* adding together about 2.5 million images. We list the telescope, instrument, number of images (thousands rounded), archive start and end date, field of view (in arcmin), number of CCDs (for mosaics) and estimated V limiting magnitude suitable to detect NEAs.

Telescope	Instrument	Nr. images	Start Date	End Date	FOV ′	CCDs	V
			ESO Instruments:				
VLT 8.2m	FORS1	36,000	23-01-1999	26-03-2009	6.8 × 6.8	2	26
VLT 8.2m	FORS2	111,000	30-10-1999	25-02-2012	6.8 × 6.8	2	26
VLT 8.2m	HAWKI	69,000	01-08-2007	24-02-2012	7.5 × 7.5	4	26
VLT 8.2m	ISAAC	199,000	01-03-1999	25-02-2012	2.5 × 2.5	1	26
VLT 8.2m	NACO	275,000	02-12-2001	29-02-2012	1.0 × 1.0	1	26
VLT 8.2m	VIMOS	66,000	30-10-2002	28-02-2012	12.8 × 16.0	4	26
VLT 8.2m	VISIR	67,000	11-05-2004	26-02-2012	0.5 × 0.5	1	26
VISTA 4.1m	VIRCAM	230,000	16-10-2009	22-06-2011	46.3 × 46.3	16	25
VST 2.6m	OmegaCam	19,000	01-04-2011	15-03-2012	58.4 × 58.4	32	24
NTT 3.5m	EMMI	18,000	17-03-2004	01-04-2008	9.1 × 9.1	2	25
NTT 3.5m	SOFI	126,000	30-03-2006	15-02-2012	4.9 × 4.9	1	25
NTT 3.5m	SUSI2	17,000	02-04-2004	29-12-2008	5.5 × 5.5	2	25
ESO 3.6m	EFOSC2	47,000	03-07-2004	16-03-2012	4.1 × 4.1	1	25
ESO 3.6m	TIMMI2	64,000	08-05-2004	28-06-2006	1.6 × 1.2	1	25
ESO/MPG 2.2m	WFC	124,000	20-06-1998	25-02-2012	33.6 × 32.7	8	23
			AURA NVO Instruments:				
KPNO 4m	MOSAIC	33,000	01-09-2004	27-06-2012	36 × 36	8	25
KPNO 4m	NEWFIRM	130,000	30-06-2007	10-07-2012	28 × 28	4	25
WIYN 3.5m	Mini Mosaic	6,000	17-03-2009	19-07-2012	10 × 10	2	25
WIYN 3.5m	WHIRC	89,000	04-04-2009	11-04-2012	3.3 × 3.3	1	25
WIYN 0.9m	MOSAIC	9,000	27-05-2009	03-05-2012	59 × 59	8	21
CTIO 4m	MOSAIC-2	67,000	11-08-2004	20-02-2012	37.0 × 37.5	8	25
CTIO 4m	NEWFIRM	74,000	18-05-2010	17-10-2011	28 × 28	4	25
CTIO 0.9m	Cass Img	228,000	27-03-2009	24-07-2012	13.5 × 13.5	1	21
SOAR 4m	OSIRIS	60,000	17-03-2009	20-07-2012	3.3 × 3.3	2	25
			Other Instruments:				
CFHT 3.6m	CFHTLS	25,000	22-03-2003	02-02-2009	57.6 × 56.4	36	25
INT 2.5m	WFC	230,000	20-06-1998	10-07-2009	34.1 × 34.5	4	23
Subaru 8.3m	SuprimeCam	60,000	05-01-1999	31-12-2010	35.1 × 27.6	10	26
AAT 3.9m	WFC	5,000	21-08-2000	05-02-2006	31.4 × 31.4	8	25

Conclusions and future work

> The EURONEAR results and publications were achieved with very little funding, using some volunteer students and amateurs based mostly on regular observing time applications and data mining of few important imaging archives;

> In our opinion, 1m telescopes remain quite limited today for NEA work (survey and astrometric follow-up);

> Mostly 2-4m telescopes (and 1m with many nights access needed for lightcurves) are required for physical properties of asteroids and NEAs;

> The 2.5m INT (equipped with the actual WFC or preferably with a Better PF imaging camera ~300 KE) remains a great facility for NEAs;

> A dedicated large field 2m for astrometric and physical work on NEAs based in Canary could complement nicely Pan-STARRS and CSS 1.8m.

Conclusions and future work – Needs:

> Better involvement of EURONEAR nodes: more time applications and observations!

> Observatories, IAU, VO: need for new archives (especially larger FOV) to become accessible online!

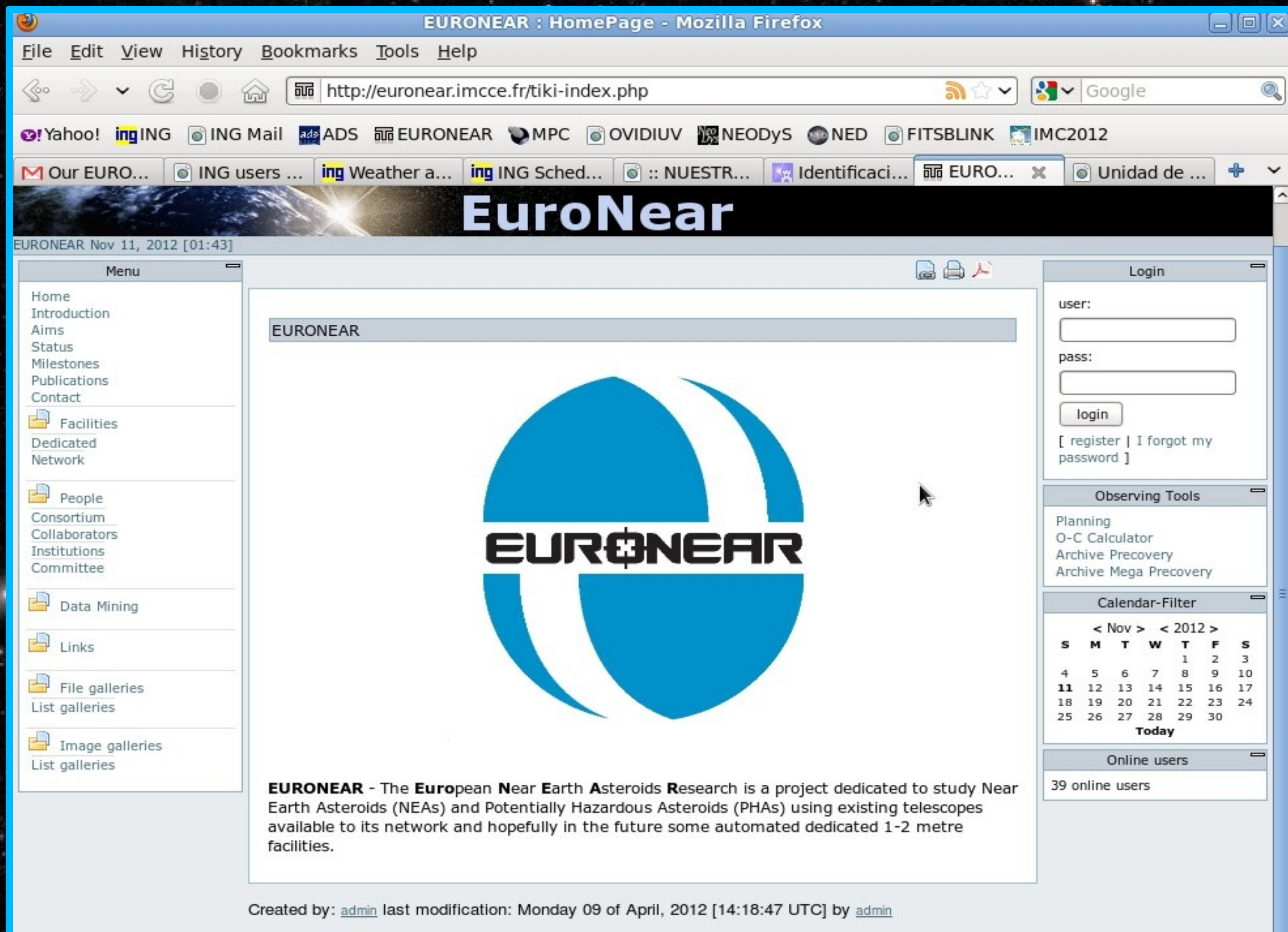
> Increase the human resources (observations, data reduction, software development, data mining, etc):

- Nurture the free collaboration with amateurs and students;
- Funding needed to hire new PhD students and postdocs;

> Few EURONEAR nodes – secure at least one dedicated telescope (via EU funding, collaboration with ESA, etc).

> An alternative would be improving the instrumentation for available 2m class telescopes and buying dozen nights (INT, CAHA, MPG, etc).

References



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Thank you!