Mining the ESO WFI and INT WFC archives for known Near Earth Asteroids. Mega-Precovery software *

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Abstract: The ESO/MPG WFI and the INT WFC wide field archives comprising 330,000 images were mined to search for serendipitous encounters of known Near Earth Asteroids (NEAs) and Potentially Hazardous Asteroids (PHAs). A total of 152 asteroids (44 PHAs and 108 other NEAs) were identified using the PRECOVERY software, their astrometry being measured on 761 images and sent to the Minor Planet Centre. Both recoveries and precoveries were reported, including prolonged orbital arcs for 18 precovered objects and 10 recoveries. We analyze all new opposition data by comparing the orbits fitted before and after including our contributions. We conclude the paper presenting *Mega-Precovery*, a new online service focused on data mining of many instrument archives simultaneously for one or a few given asteroids. A total of 28 instrument archives have been made available for mining using this tool, adding together about 2.5 million images forming the *Mega-Archive*.

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1 Introduction

Telescopes endowed with large field mosaic cameras having their images archived and stored for public online access are becoming very appealing nowadays to data mining work for many science aims. One of such aim involves the improvement of the orbital knowledge of the Near Earth Asteroids (NEAs) and Potentially Hazardous Asteroids (PHAs) which is one of the aims of the *European Near Earth Asteroid Research* (EURONEAR) project since 2006.

To achieve this goal, few years ago we introduced the PRECOVERY software devoted to search *all* known asteroids to date in *any* archive uploaded as

a simple observing log recorded in a standard format (Vaduvescu et al., 2009). This tool uses the SkyBoT web service (Berthier et al., 2006) to predict accurate positions for all known asteroids. Using PRECOVERY, all known asteroids could be searched in any archive for serenditipitous recoveries and precoveries (apparitions before discovery) including all known NEAs, PHAs, as well as all other numbered and provisionally named asteroids catalogued to date. Using this server, we searched the CFHTLS archive finding 143 encounters of known NEAs and PHAs (Vaduvescu et al., 2011a).

A recent similar initiative coordinated with the EU-RONEAR efforts includes a citizen-science project led by E. Solano from the Spanish Virtual Observatory (SVO, 2011; Solano et al., 2011). Following its press announcement (Tristan, 2011), this Spanish service has registered more than 3,000 users who measured and reported



^{*} Using ESO/MPG WFI images served by the ESO Science Archive Facility and INT WFC images served by the CASU Astronomical Data Centre.

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more than 600 positions of some 150 NEAs (Solano, 2011). Besides its public outreach value, this work has a meritorious contribution to report moving sources not detected by the SDSS automated detection algorithm and not published in the SDSS moving source catalogues (Ivezic, 2008). The above number of detections could be compared with another SDSS NEO project which found 104 NEAs in the SDSS archive (Kent et al., 2009).

A similar focused tool of NASA was announced recently (Yau et al., 2011). The *Moving Object Search Tool for NEOWISE and IRSA* (MOST) is a new web-based server that enables researchers to look for serendipiously observed solar system objects (NEAs, asteroids and comets) contained in the images held by the NASA/IPAC Infrared Science Archive (IRSA), including single epoch exposures from WISE. MOST takes as input an object name or set of orbital parameters.

Part of a student bachelor project, the ESO/MPG WFI archive (1999 to 2003) was data mined for photometry of known asteroids using the Astro-WISE and SkyBoT servers (Bout, 2007). Taking into account three selection parameters, the author measured mostly two colour photometry from 354 occurrences of 144 asteroids (primarily Main Belt Asteroids - MBAs) on 1380 WFI images.

Another asteroid data mining tool was announced recently (Gwyn et al., 2011). The *Solar System Object Search* (SSOS) of the Canadian Astronomical Data Center (CADC) allows users to search for images from a variety of archives for *single* moving objects, accepting as input either an object designation, a list of observations, a set of orbital elements or a user-generated ephemeris for an object.

During the last years we applied our PRECOV-ERY work to other large field archives, also applying our work to other data mining facilities (Vaduvescu et al., 2009; Vaduvescu et al., 2011a). In the same frame of the EURONEAR project, introduced Mega-Precovery project (Popescu et al., 2010; Popescu and Vaduvescu, 2010; Popescu and Vaduvescu, 2011), a web service dedicated to data mining of image archives for some given asteroids. Using this tool, one could search one or more existing archives for any given asteroid or a list of few asteroids (numbered or provisionally numbered).

In the present paper we present new data mining contributions carried out in the frame of EURONEAR project. Firstly, the ESO/MPG WFI and INT WFC archives observed between 1998 and 2009 are mined for all known NEAs and PHAs. We distributed this workload to a team of 13 Romanian students and amateur astronomers, thus the project has some educational aim, besides its main EURONEAR development role. Secondly, we present our public new EURONEAR data mining service *Mega-Precovery*, together with its associated *Mega-Archive*. Throughout this paper and conform with our two previous papers, we define "precoveries" as apparitions before discovery date (Steel, 1997).

The paper is structured in 5 sections. Section 2 presents the ESO/MPG WFI and INT WFC archives, giving an overview of their basic characteristics. Section 3 presents the data mining results, counting the encounters of NEAs and PHAs, listing the precoveries and recoveries at a new or the last opposition whose orbital improvement is analyzed. Section 4 presents *Mega-Precovery* software and its associated *Mega-Archive*. Section 5 lists the conclusions and a few related projects.

2 Data Mining the WFI and WFC Archives

Until the apparition of the SDSS 2.5m survey in 2000 and later the dedication of Pan-STARRS 1.8m survey telescope in 2007, the ESO/MPG 2.2m telescope equipped with the WFI mosaic camera and the INT 2.5m telescope endowed with the WFC mosaic camera have been two of the most powerful 2m class large field facilities in the world. Available since 1999 and 1998, respectively, and still operating and partially devoted to survey work, these two facilities have given to European astronomers access to both hemispheres using mosaic cameras more than half degree field each.

2.1 ESO/MPG WFI Archive

The Max Planck Garching (MPG) 2.2m telescope is owned by the European Southern Observatory (ESO) in La Silla, Chile. In 1999 the Wide Field Imager (WFI) was mounted at the Cassegrain F/5.9 focus of the ESO/MPG (Baade et al., 1999). WFI is a mosaic camera consisting of a 2×4 CCDs $2K\times 4K$ pixels each, covering a total field of view of $34'\times 33'$ (0.30 square degrees) with a pixel scale of 0.24 "/pix.

In this paper we studied the ESO/MPG WFI archive during the period 25-10-1999 (first light) to 27-08-2009 (when we started this ESO project), although WFI has continued to be offered by ESO and MPG beyond this date. During this period, the WFI acquired 96,913 science images. In Figure 1 (top) we plot in cyan (fainter dots) the WFI sky coverage during the above period. This shows random pointings between $\delta \sim -90^\circ$ and $\delta \sim +30^\circ$ driven by various science interests with some small patches covered by few extragalactic programs. We draw in magenta (fainter curve) the ecliptic, which has been followed by at least two NEA survey and follow-up programs led by Boattini et al., 2004; Vaduvescu et al., 2011b and other Solar System work led by other PIs.

2.2 INT WFC Archive

Owned by the Isaac Newton Group (ING), the 2.5m Isaac Newton Telescope (INT) is installed in the Northern European Observatory of Roque de los Muchachos (ORM) in La Palma, Canary Islands. Since 1998 the prime focus of the INT houses the Wide Field Camera (WFC) which

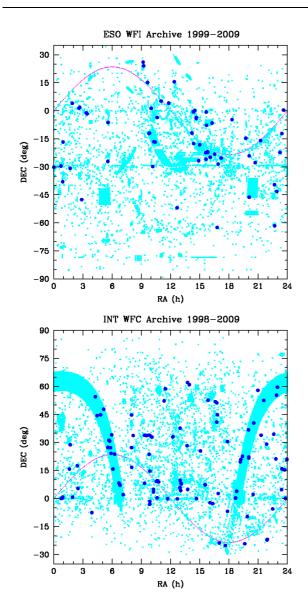


Fig. 1 The sky coverage of the ESO WFI and INT WFC archives whose observed fields are plotted as cyan (fainter) dots. Both hemipheres are covered randomly, including few sky patches and the galactic plane covered by a few surveys. We overlay with blue (larger) dots the NEAs and PHAs encountered in this work and with magenta (fainter curve) the ecliptic.

consists of 4 CCDs $2K\times 4K$ pixels each, covering an L-shape $34'\times 34'$ (0.28 square degrees) with a pixel scale of 0.33 "/pix.

In this paper we studied the INT WFC during the period 20-06-1998 (first light) to 10-07-2009 (when we started the INT project), although WFC is continuing to be offered by the ING beyond this date. During the above period, the WFC acquired 237,768 science images. Figure 1 (bottom) plots the sky coverage of the WFC archive during this period. The plot shows random distribution between

 $\delta \sim -30^\circ$ and $\delta \sim +90^\circ$ and clearly some 10° wide band around the galactic plane which represents the two major galactic INT surveys, namely *The INT/WFC Photometric H \alpha Survey of the Northern Galactic Plane* (IPHAS, Drew et al., 2005) and *The UV-Excess Survey of the Northern Galactic Plane* (UVEX, Groot et al., 2009) to be completed soon. We draw with magenta the ecliptic, which has been followed sporadically by few Solar system runs led by A. Fitzsimmons (NEAs and comets), J. L. Ortiz (TNOs), J. Licandro (MBCs), O. Vaduvescu (NEAs) and possibly other PIs.

2.3 Exposure Time and Filters

Figure 2 plots the histogram of the exposure times used in the ESO WFI archive (above) and the INT WFC (bellow). Most images were taken with exposures shorter than 200s in both archives, therefore they are suitable for findings of NEAs affected by a small trail effect caused by their fast proper motion ($\mu > 1''/\text{min}$). Few other maxima in exposure times are visible on both histograms for longer exposures, up to 2500s in both archives.

We also studied the usage of filters in the two archives. The ESO WFI archive counts 44 filters, while INT WFC counts 20 filters (both broad and narrow band). For the ESO WFI archive, 93% represent 13 broad band filters (led by Rc, I, B, V and no filter), while 30 other filters representing narrow band and others count for only 7%. For the INT WFC archive, 73% represent 14 broad band filters (led by r, i, g, V and no filter) while 6 narrow band filters count for 27%. In conclusion, both ESO WFI and INT WFC archives are appropriate for asteroid detection in most of their broad band images.

3 Results

3.1 Found Objects

Run with the two archives and assuming a safe limiting magnitude V=23, PRECOVERY reported a total of 7,123 candidate images (1,535 for the ESO WFI archive and 5,588 for the INT WFC archive). These images were inspected, then astrometrically resolved and measured by our team in a distributed but homogenous manner. After inspection and search, only 761 images from the initial candidates resulted in reported positions, which represents only 11%. This dramatic decrease could be explained by some factors, led by the optimistic limiting safer magnitude V=23, the exposure time, proper motion, Moon phase, weather conditions, airmass, uncertainty in some ephemerides and magnitudes, used filters, etc.

In Figure 1 we overlay with blue (larger) dots the NEA and PHA fields measured in the two archives (ESO WFC above and INT WFC bellow). In both archives the NEA findings are spread randomly with respect to the ecliptic up to high ecliptic latitudes ($\beta \sim 40^{\circ}$), in agreement

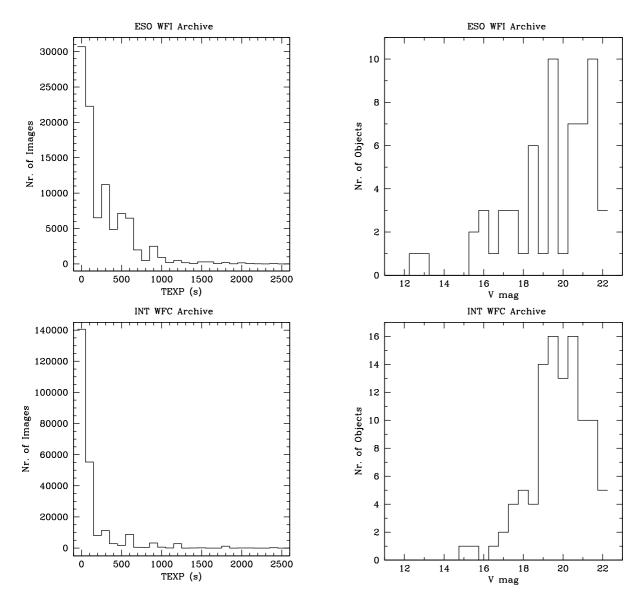


Fig. 2 Histograms showing the exposure time used in the ESO/MPG WFI archive (above) and the INT WFC archive (bellow). Relatively short exposures (less than 1-2 minutes) were mostly used, making the two archives suitable for searching NEAs affected by the trail loss effect.

Fig. 3 Histograms showing the predicted V magnitude of the encountered NEAs and PHAs in the two surveys (ESO WFC top and INT WFC bottom). A limit around $V\sim 22$ was reached in both archives, consistent with 2m facilities.

with the known distribution of the inclinations of the NEA population. In total, 152 objects were measured and reported, namely 44 PHAs (15 in the ESO and 29 in the INT archive) and 108 other NEAs (40 in the ESO and 68 in the INT archive). 124 objects have datasets included within the timespan of their existing arcs. For a total of 28 objects we were able to prolong the existing arcs by new or last opposition datasets. From these, 18 objects represent precoveries (8 in the ESO archive and 10 objects in the INT one) and 10 objects represent recoveries at a new opposition or prolonged arcs at the last opposition (6 in the ESO and 4 in the INT archive).

Figure 3 shows the histogram of the predicted V magnitude for the encountered objects in the two archives (ESO WFI above and INT WFC bellow). Both datasets show fainter objects around $V \sim 22$, according to the limiting magnitude of 2m-class telescopes imaging moving asteroids with relatively short exposures (less than \sim one minute).

Using PRECOVERY and *Mega-Precovery* (presented in Section 4), one could search the two archives for apparitions of any other given asteroid(s), including precoveries of new NEAs and PHAs catalogued after August 2009 (the end of our work). We plan to update soon these archives beyound 2009.

3.2 Astrometry

Like in our previous distributed work involving students and amateurs, we used the *Astrometrica* software (Raab, 2012) to resolve the astrometry of the fields. After resolving and aligning the multiple images of the same field, we searched for the asteroids in the *candidate images* by blinking the images, finally measuring manually the asteroid positions. We used quadratic sky-plate transformation and the USNO-B1 catalog that allowed in average identification of about 50-100 reference stars in each CCD which was resolved individually.

Figure 4 plots the O-C residuals (observed minus calculated positions) of the objects measured by us in the ESO WFI archive (above) and the INT WFC archive (bellow). Residuals are mostly clustered around origin for the ESO WFI archive (standard deviation $0.56^{\prime\prime}$ and average deviation $0.34^{\prime\prime}$), these being mostly dominated by catalog errors and measurements. The INT WFC residuals (right) show a larger spread (standard deviation $0.72^{\prime\prime}$ and average deviation $0.53^{\prime\prime}$) mostly due to the larger known WFC field distortion in the prime focus of the INT which is larger than that of the ESO WFI Cassegrain camera.

Because most exposure times were quite short (less than one-two minutes) most asteroid apparitions show stellar or small elliptical aspect easily fitted by Astrometrica which measures their centres in respect to mid-exposure time. We encountered also few longer trails caused by longer exposures for which we measured in the same manner the two ends, then we measured the average position corresponding to the mid-time exposure.

Using FITSBLINK asteroid residual server calculator (Skvarc, 2012) we checked the astrometry for possible errors which could include bad measurement of few faint targets, faint objects affected by nearby bright stars, possible confusion caused by larger sky uncertainties, etc. Then we reported the two datasets (one for each archive) to Minor Planet Center (MPC). These include 316 positions of 55 objects found in the ESO archive and 445 positions for 97 objects found in the INT archive. After minor revision from the MPC (Spahr & Williams, 2011) and our careful re-measurement of five objects (3% of the total), MPC accepted and published the astrometry (Elst et al., 2011 for the ESO archive and Fitzsimmons et al., 2011 for the INT archive).

3.3 Orbital Improvement

The mined data for the 152 found objects was used to ameliorate orbits of the encountered NEAs and PHAs. Most of the data improved the density within the existing arcs, the observing date being contained in the existing orbital arc timeframe. For 28 objects we prolonged the existing orbital arcs by new oppositions or last opposition datasets, adding 18 precoveries and 10 recoveries. In the Apendix Table A1 we list these 28 cases of NEA and PHA encounters representing precoveries and recoveries at a new or the last op-

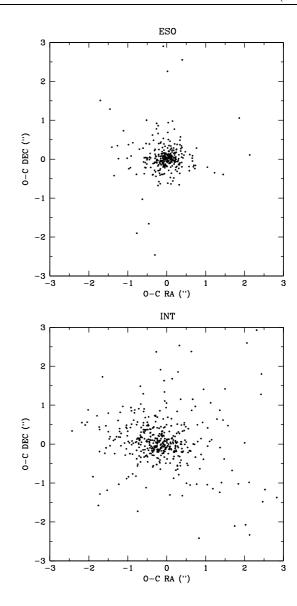


Fig. 4 O-C residuals (observed minus calculated) for the NEAs and PHAs found in the the ESO/MPG WFI (above) and INT WFC archives (bellow). For the ESO WFI, the standard deviation is $0.56^{\prime\prime}$ and the average deviation $0.34^{\prime\prime}$, mostly due by catalog errors. For the INT WFC, the standard deviation is $0.72^{\prime\prime}$ and the average deviation $0.53^{\prime\prime}$, mostly dominated by astrometric errors due to the uncorrected field of the camera mounted in the prime focus of the INT.

position. Four of these objects (2005 CG41, 1996 XX14, 2003 MK4 and 2002 DH2) were previously reported to MPC in 2005, being observed by other PIs. We mark these objects with an asterix in Table A1 and Table A2. In the third column we list the orbital arc length before and after our datamining work. A few cases represent major encounters, namely:

- precoveries at the first opposition: 2005 TU45 (arc prolonged by 5 years), 2005 MB (extended by 2 years), 2009 TG10 (extended by 6 years), 2009 NA (from 5 months to 9 years), 2006 PW (from 1 year to 5 years), 2009 HW2 (from 3 days to 2 months), 2009 SP171 (from 2 months to 2 years), 2009 FU23 (a very desirable PHA whose arc was prolonged from 2 months to 7 years) and 2006 KA (from 2 years to 6 years);
- recoveries at the last opposition: 1996 XX14 (arc prolonged from 2 months to 8 years), 2003 MK4 (PHA very desirable, extended arc from 2 months to 2 years), 2002 DH2 (from 4 months to 3 years) and 1994 JX (arc increased by 5 years).

We compare the orbits of the precovered and recovered objects fitted with FIND_ORB software (Gray, 2012) using their published positions (full orbital arc) available via MPC. In the Appendix Table A2 we list the orbital elements obtained excluding our data (first line) and including our data (second line). Orbits of most asteroids were improved using our mined data, namely the σ residuals in last column decreased for most. In only 3 cases σ residuals increased, namely: 2009 HW2 (from the INT archive, from $\sigma = 0.43''$ to $\sigma = 0.48''$), extended arc from 3 days to 2 months), 2001 XK105 (ESO archive, from $\sigma = 0.61''$ to $\sigma = 0.63''$, for which only two images were encountered), and 2006 KA (ESO archive, from $\sigma = 0.49''$ to $\sigma = 0.53''$, for which only one image was available showing a long trail for which we reported the middle and the two ends taking into account the predicted proper motion).

4 Mega-Precovery

Despite some recent data mining efforts, the vast collection of CCD images and photographic plate archives still remains insufficiently exploited. PRECOVERY covers all catalogued asteroids (including all known NEAs and PHAs), but the search of an entire archive could take quite a long time, typically about 10 hours for some 10,000 square degrees sky coverage of a single archive. Therefore, some dedicated tool to target one or very few selected objects is necessary to speed up data mining of asteroids, including important NEAs and PHAs.

In this sense we designed *Mega-Precovery*, with the aim to fasten and target the search of one or some few important objects, such as PHAs or Virtual Impactors (VIs). Given this, we propose to search very large *collections of archives* for images which include one or a few selected known asteroids in their field. There are two components of this project:

- the database (named Mega-Archive) which includes the individual instrument archives, namely the observing logs for their science CCD images or plates available from a collection of instruments and telescope around the globe. The Mega-Archive is an open project allowing other instrument archives to be added later for exploration by anybody who would like to contribute; the Mega-Precovery software for data mining the Mega-Archive for the images containing one or a more desired catalogued objects (NEAs, PHAs or other asteroids) included in a local daily updated MPC database;

The input of *Mega-Precovery* consists of: 1. a selection of the *instrument archives* to be searched (including the option to search either one or all the existing archives in the same time) and 2. the specified asteroid or list of few asteroids given by their names, numbers or provisional designations. The output of *Mega-Precovery* consists of a list of *candidate images* in which the searched object is expected to be visible based on two main thresholds, namely the expected limiting magnitude of the archive and the expected positional uncertainty of the searched object (provided by the user based on the currently known orbit).

The definition file containing the instrument archives includes the following data: the filename keeping the telescope observing logs, the observatory code, the width and height of the field (both in degrees, in the direction of α and δ , respectively), the start and end Julian Date defining the timespan of the archive and the limiting magnitude V expected from the given telescope and instrument.

4.1 Mega-Precovery Archive

For easier identification of the images, the *Mega-Archive* is split into more *instrument archives*, each corresponding to a given telescope and camera. Table A3 lists the available *instrument archives* and their basic characteristics. Besides these standard archives, *Mega-Precovery* leaves the user the flexibility to add his/her own instrument archive given in the same standard format, by loading the file to be run by the server. As of August 2012, the *Mega-Archive* counts about 2.5 million images from 28 instrument archives available for search via *Mega-Precovery*. This collection includes all archived ESO imaging instruments¹, most archived NVO imaging instruments (National Virtual Observatory of the United States²), the INT WFC³, CFHTLS⁴, Subaru SuprimeCam⁵ and the AAT WFI⁶ archives.

4.2 Mega-Precovery Software

The Mega-Precovery software is written in PHP, being embedded on the EURONEAR website (EURONEAR, 2012) as a public access application under the Observing Tools section. Figure 5 presents the flowchart of this software. To run Mega-Precovery application, the user needs to load the webpage using any internet browser (block User input interface in Figure 5). In order to create the query, one needs to provide the following information to the web interface:

- http://archive.eso.org/eso/eso_archive_main.html
- ² http://portal-nvo.noao.edu
- $^3\,$ http://casu.ast.cam.ac.uk/casuadc/archives/ingarch/@@query.html
- 4 http://www3.cadc-ccda.hia-iha.nrc-cnrc.gc.ca/cadcbin/cfht/wdbi.cgi/cfht/quick/form
- ⁵ http://smoka.nao.ac.jp/search.jsp
- ⁶ http://apm5.ast.cam.ac.uk/arc-bin/wdb/aat_database/observation_log/make

- A list of names, numbers or provisional designations of the asteroid(s) to search;
- The selection of the *instrument archives* to be searched for (the first default option *ALL* allowing to search the entire *Mega-Archive*);
- The field *Uncertainty* used to accommodate for the uncertainty in telescope pointing plus the uncertainty in position of the searched object due to its (sometime more unsecure) orbit. Based on extended tests, for this parameter we recommend the default value 0.02° but this should be increased in case of poorly known objects or less accurate pointing. Increasing too much this parameter (more than $\sim 1^{\circ}$) would result in selection of false candidate images (false detections);
- The email address where Mega-Precovery could announce the user about the end of long runs and the FTP space where the user should download the data; this includes the same information given in the web browser after the end of the run.

After the user submits the query, this is processed by *Mega-Precovery* in the block *Processor of the input*, then the accurate ephemerides for each archive dates and the given body (bodies) are calculated in the *Ephemerides query block*. This step uses the IMCCE's ephemeris service *Miriade* (Berthier et al., 2009; IMCCE, 2012a) which is queried for some discrete times covering the entire queried telescope archive(s), then accurately interpolated the positions for the observing dates given in the archive (the block *Interpolator*).

We used a five order Bessel interpolation model (IMCCE, 2012b), choosing for the *Miriade* ephemerides a step based on the asteroid proper motion, namely 1 day for objects moving slower than 2 degrees daily and 1 hr for objects faster than this limit. Using this fine time step we ensure sufficient accuracy (< 1') for most NEAs and PHAs passing close to Earth affected by very fast proper motion. For NEAs and PHAs away from close encounters with the Earth, and also for MBAs, the interpolator precision is very accurate (about 1"). The parameters for the interpolation where established as a tradeoff between processing time and predicted position accuraccy and were validated by extensive tests.

Each image of the archive is defined by a rectangular box given by the telescope pointing, the width and height field of view stored with each instrument archive entry. If the predicted position falls within the field of the current image bounded by the *Uncertainty* area, then the current entry is selected as a *candidate image* to hold the queried asteroid. This step is done in the *Selector* block.

Like in PRECOVERY, the format of each instrument archives follows the same *standard format* listing one observation (telescope pointing) on each line which includes the image ID (name of the image file), the Julian date (start of observation), exposure time (sec), telescope pointing (α and δ at J2000 epoch), width and height of the field of view (towards α and δ axis frame, both in degrees), and a eventually

comment (which could include the filter, etc), all separated by "|".

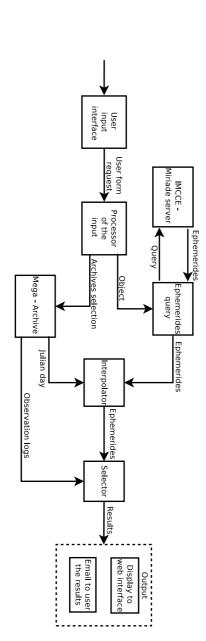
The output of *Mega-Precovery* consists in a list including the images and the corresponding CCD number predicted to contain the queried object(s). The results are displayed both in the web interface (visible only at the end of the run) and sent via e-mail to the user (in case this option was selected). The user can search the images in the online instrumental archive, then download, inspect and measure the data related to this asteroid based on his/her own scientific interest (astrometry, photometry, etc).

5 Conclusions and Future Work

Two wide field 2m class telescope archives, ESO/MPG WFI and INT WFC, comprising about 330,000 images were mined to search for serendipitous encounters of known NEAs and PHAs. Two master archives were built based on the observing logs of the two facilities. Using the PRECOV-ERY software, a total of 152 asteroids (44 PHAs and 108 other NEAs) were identified and measured on 761 images and their astrometry was reported to Minor Planet Centre (MPC). Both recoveries and precoveries were reported, including prolonged orbital arcs for 18 precovered asteroids and 10 recoveries, plus other 124 recoveries. We analyze all precoveries and recoveries at a new or last opposition by comparing the orbits fitted before and after including our datasets. Following the PRECOVERY project, we present Mega-Precovery, a new search engine focused on data mining of many instrument archives simultaneously for one or few given asteroids. A total of 28 instrument archives have been made available for mining, adding together about 2.5 million images forming the Mega-Archive.

Few other projects are in plan within the frame of EU-RONEAR data mining of NEAs. Few months ago we started datamining of the Subaru SuprimeCam archive using PRE-COVERY. Another important project will be to extend the mining capabilities of the *Mega-Precovery*. Another project plans to apply *Mega-Precovery* to search the entire *Mega-Archive* in order to recover and improve orbits of some important VIs, PHAs and NEAs. Finally, we plan to continue to enlarge the *Mega-Archive*, adding new *instrument archives*, including CCD cameras and photographic plates. In this sense, any observatories, especially those endowed with large field imaging instruments, are welcomed to contribute to this open source project.

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developed at IMCCE and accessed by PRECOVERY and *Mega-Precovery*, respectively. Acknowledgements are also due to Bill Gray, the author of FIND_ORB software, for his very prompt assistance in order to upgrade his very robust and user friendly code for fitting orbits. Mega-Precovery archive is based on data obtained from the ESO Science Archive Facility, the NOAO Science Archive served by the National Virtual Observatory of the United States, Subaru-Mitaka-Okayama-Kiso Archive (SMOKA), the Canadian Astronomy Data Centre (CADC) and CASU Astronomical Data Centre (United Kingdom). This work has made use of SAOImage DS9 developed by Smithsonian Astrophysical Observatory. We are thankful to Minor Planet Centre, specifically to Tim Spahr who pointed out a few errors in the reported positions. Final acknowledgements are due to the referee David Asher for careful reading and advice to improve our paper.

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A Appendix: Data Tables

Table A1 28 objects found in the ESO and INT archives include 18 precovered asteroids and 10 recovered objects whose arcs were prolonged by a new opposition or at the last opposition. Besides the asteroid name we give its MPC classification (acc. to Jan 2012 database), the number of positions, the length of the orbital arc (before and after our astrometry) and the archive. Four objects marked with an asterix were reported also by other PIs in 2005.

Asteroid	steroid Classification		Arc (before/after)	Archive				
Extended Arcs at First Opposition (Precoveries):								
2005 CG41 *	NEA desirable	12	3d/4d	ESO				
2005 TU45 (231134)	NEA desirable	4	3y/8y	ESO				
2005 MB	NEA very desirable	3	3y/5y	ESO				
2004 XP164 (216707)	NEA desirable	3 5 6 3 2 2	4y/5y	ESO				
2009 TG10	NEA very desirable	6	3y/9y	ESO				
2009 NA	NEA very desirable	3	5m/9y	ESO				
2002 HQ11 (159677)	NEA desirable	2	5y/6y	ESO				
2001 XK105	NEA extremely desirable	2	2m+10d	ESO				
2006 WT1	PHA very desirable	6	4m/5m	INT				
2002 TY57 (250162)	NEA desirable	7	5y+2m	INT				
2006 PW	NEA very desirable	2	1y/5y	INT				
2009 HW2	NEA extremely desirable	8	3d/2m	INT				
2009 SP171	NEA very desirable	2	2m/2y	INT				
2005 BY1	NEA very desirable	12	10m/11m	INT				
2009 FU23	PHA very desirable	2 5 3 3	2m/7y	INT				
2005 VC2	NEA very desirable	5	3m/4m	INT				
2006 KA	NEA very desirable	3	2y/6y	INT				
2000 FL10 (86666)	NEA desirable	3	8y/9y	INT				
	Extended Arcs at Last Oppos	ition (Reco	veries):					
1996 XX14 *	NEA very desirable	7	2m/8y	ESO				
2003 MK4 *	PHA very desirable	7	2m/2y	ESO				
2002 DH2 *	NEA very desirable	8	4m/3y	ESO				
1994 JX	NEA very desirable	8	9y/14y	ESO				
2004 RS25	NEA very desirable	2	3y+1m	ESO				
1999 WK11 (102873)	NEA desirable	6	28y+1m	ESO				
2005 GN59 (164400)	PHA desirable	2	31y+3m	INT				
2002 EQ9 (163191)	NEA very desirable	2	5y+10d	INT				
2007 DK	NEA very desirable	4	5y+7m	INT				
2005 CA (189263)	NEA desirable	4	30y+4d	INT				

Table A2 Extended arcs of NEAs and PHAs at first opposition (precoveries) and last opposition (recoveries). Comparison of the orbits fitted without our data (first line) and including our data (second line). Orbital elements fitted with FIND_ORB at epoch JD = 2456000.5 listing the asteroid name, semimajor axis a, eccentricity e, inclination i, longitude of the ascending node Ω , argument of pericenter ω , and mean anomaly M, followed by the minimal orbital intersection distance MOID, number of fitted observations Obs and the root mean square residual of the fit σ . Four objects marked with an asterix were reported also by other PIs in 2005.

Asteroid	a (AU)	e	i (deg)	Ω (deg)	ω (deg)	M (deg)	MOID (AU)	Obs	σ (")
		Ext	ended Arcs a	nt First Opposi	tion (Precover	ries):			
2005 CG41 *	1.0007879	0.2846587	19.09737	137.74366	233.38300	89.72675	0.0902	8	0.98
	1.0589380	0.3535199	25.29019	137.82014	238.16912	75.88581	0.1170	20	0.68
2005 TU45	1.9737518 1.9737518	0.4959559 0.4959559	28.53919 28.53919	120.24291 120.24291	76.86254 76.86254	149.07339 149.07339	0.2669 0.2669	808 812	0.31
2005 MB	0.9852658	0.7927082	41.39802	88.66029	42.80966	53.23488	0.0840	80	0.40
2004 WD164	0.9852658	0.7927081	41.39805	88.66032	42.80964	53.23494	0.0840	83	0.40
2004 XP164	2.1784898 2.1784898	0.4125130 0.4125130	22.64397 22.64397	127.01048 127.01048	310.26942 310.26940	109.80532 109.80534	0.3836 0.3836	104 109	0.52 0.51
2009 TG10	1.9737117 1.9737149	0.4239201 0.4239234	40.88903 40.88867	210.71935 210.71941	12.08752 12.08990	87.39857 87.39260	0.1389 0.1389	47 53	0.39
2009 NA	2.6600451	0.5529338	10.08911	269.50371	98.88855	206.85431	0.1369	498	0.3
	2.6600088	0.5529283	10.08907	269.50366	98.88858	206.85853	0.2669	501	0.4
2002 HQ11	1.8504197 1.8504197	0.5955217 0.5955216	6.04556 6.04556	153.36013 153.36013	322.08227 322.08227	4.04716 4.04716	0.0555 0.0555	139 141	0.43
2001 XK105	2.1303469	0.5004268	7.63156	79.92045	6.99267	104.77324	0.0811	25	0.6
2006 WT1	2.1304028 2.4717312	0.5004399 0.6011840	7.63171 13.68475	79.92043 244.92276	6.99257 170.58186	104.72642 131.36247	0.0811 0.0039	27 79	0.63 0.40
2000 W 11	2.4717312	0.6011840	13.68474	244.92276	170.58186	131.36247	0.0039	85	0.4
2002 TY57	1.9221114 1.9221114	0.3273811 0.3273805	3.45506 3.45507	119.03691 119.03677	259.77000 259.77024	194.64386 194.64380	0.3018 0.3018	134 141	0.4 0.4
2006 PW	1.3813093	0.5275805	35.87687	132.98690	325.07629	88.37690	0.3654	56	0.4
	1.3813093	0.6516801	35.87686	132.98690	325.07629	88.37691	0.3654	58	0.4
2009 HW2	2.2061742 2.1826121	0.5266663 0.5214024	2.90017 2.87655	211.42013 211.42082	350.74180 350.69936	320.03523 325.37582	0.0419 0.0422	24 32	0.4 0.4
2009 SP171	1.3557430	0.3559500	25.62158	223.14972	285.17007	87.36382	0.0613	54	0.4
2005 BY1	1.3557449 3.1548620	0.3559509 0.6909590	25.62172 17.02151	223.14955 298.02275	285.17012 282.16258	87.36292 73.64347	0.0613 0.1962	56 36	0.4
2003 D11	3.1548619	0.6909590	17.02151	298.02271	282.16260	73.64349	0.1962	48	0.5
2009 FU23	0.8371147 0.8371171	0.2820307 0.2820245	13.89992 13.89955	57.82262 57.82290	315.14072 315.14067	121.64228 121.63625	0.0344 0.0344	106 108	0.4 0.4
2005 VC2	2.7670888	0.5871642	36.78132	222.08193	166.90560	136.56584	0.1599	95	0.4
2006 17 4	2.7670893	0.5871642	36.78130	222.08193	166.90566	136.56569	0.1599	100	0.4
2006 KA	1.6331499 1.6331500	0.5614647 0.5614619	31.02218 31.02231	236.08104 236.08099	244.60796 244.60830	323.01311 323.01310	0.0693 0.0693	69 72	0.4 0.5
2000 FL10	1.4629016	0.4268866	29.01712	186.99620	258.80260	319.18251	0.0815	218	0.5
	1.4629011	0.4268877	29.01714	186.99619	258.80242	319.18377	0.0815	221	0.5
100 < 1777 1 4 4	2 5 4 500 24			at Last Opposi			0.1025		0.5
1996 XX14 *	2.5469021 2.5493643	0.6518068 0.6501978	10.58772 10.56587	195.71905 195.57444	184.95389 185.06938	289.92264 281.52481	0.1036 0.0997	52 59	0.6 0.6
2003 MK4 *	1.0803203	0.1811634	22.30645	282.63278	109.56148	181.78607	0.0017	218	0.5
2002 DH2 *	1.0804562 2.0507005	0.1812333 0.5417798	22.31694 20.97315	282.63460 345.75458	109.53443 231.59884	181.29420 134.88238	0.0018 0.0686	225 160	0.5 0.5
2002 DH2 "	2.0506639	0.5417798	20.97313	345.75456	231.59892	134.88238	0.0686	165	0.5
1994 JX	2.7631468 2.7631468	0.5726370 0.5726371	32.16385 32.16383	52.49705 52.49705	193.44617 193.44625	319.74146 319.74147	0.1798 0.1798	92	0.5 0.5
2004 RS25	2.1268859	0.3726371	6.64886	179.03636	195.44625	160.50845	0.1798	100 133	0.3
	2.1268858	0.4795879	6.64886	179.03636	145.29543	160.50849	0.1140	135	0.4
1999 WK11	2.1342937 2.1342937	0.4652704 0.4652704	7.46410 7.46409	72.67897 72.67897	220.35355 220.35355	57.77729 57.77729	0.1482 0.1482	187 193	0.5 0.5
2005 GN59	1.6565831	0.4678204	6.62763	219.03615	202.90753	203.39329	0.0501	570	0.4
2002 EQ9	1.6565831 1.8356544	0.4678204 0.4651654	6.62763 16.30670	219.03615 179.23417	202.90753 44.14087	203.39329 347.65988	0.0501 0.0626	572 362	0.4 0.4
2002 EQ7	1.8356544	0.4651654	16.30670	179.23417	44.14087	347.65988	0.0626	364	0.4
2007 DK	1.3961987 1.3961987	0.5503815 0.5503811	5.17549 5.17550	290.95892 290.95910	354.89948 354.89925	311.16457	0.0894 0.0894	85 89	0.5 0.5
2005 CA	2.7290438	0.5890431	5.17550 16.75355	290.93910	203.97095	311.16454 242.81789	0.0894	89 82	0.5
							0.1495		0.5

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 VLT 8.2m VLT 8.2m VLT 8.2m VLT 8.2m VLT 8.2m VLT 8.2m VISTA 4.1m VST 2.6m NTT 3.5m NTT 3.5m NTT 3.5m ESO 3.6m ESO 3.6m ESO/MPG 2.2m	FORS1 FORS2 HAWKI ISAAC NACO VIMOS VISIR VIRCAM OmegaCam EMMI SOFI SUSI2 EFOSC2 TIMMI2 WFC	36,000 111,000 69.000 199,000 275,000 66,000 67,000 230,000 19,000 18,000 17,000 47,000 64,000 124,000	23-01-1999 30-10-1999 01-08-2007 01-03-1999 02-12-2001 30-10-2002 11-05-2004 16-10-2009 01-04-2011 17-03-2004 30-03-2006 02-04-2004 03-07-2004 08-05-2004 20-06-1998	26-03-2009 25-02-2012 24-02-2012 25-02-2012 29-02-2012 28-02-2012 26-02-2012 22-06-2011 15-03-2012 01-04-2008 15-02-2012 29-12-2008 16-03-2012 28-06-2006 25-02-2012	$\begin{array}{c} 6.8 \times 6.8 \\ 6.8 \times 6.8 \\ 7.5 \times 7.5 \\ 2.5 \times 2.5 \\ 1.0 \times 1.0 \\ 12.8 \times 16.0 \\ 0.5 \times 0.5 \\ 46.3 \times 46.3 \\ 58.4 \times 58.4 \\ 9.1 \times 9.1 \\ 4.9 \times 4.9 \\ 5.5 \times 5.5 \\ 4.1 \times 4.1 \\ 1.6 \times 1.2 \\ 33.6 \times 32.7 \end{array}$	2 2 4 1 1 4 1 16 32 2 1 2 1 1 8	26 26 26 26 26 26 25 24 25 25 25 25 25 25 25 25		
AURA NVO Instruments:									
KPNO 4m KPNO 4m WIYN 3.5m WIYN 3.5m WIYN 0.9m CTIO 4m CTIO 4m CTIO 0.9m SOAR 4m	MOSAIC NEWFIRM Mini Mosaic WHIRC MOSAIC MOSAIC-2 NEWFIRM Cass Img OSIRIS	33,000 130,000 6,000 89,000 9,000 67,000 74,000 228,000 60,000	01-09-2004 30-06-2007 17-03-2009 04-04-2009 27-05-2009 11-08-2004 18-05-2010 27-03-2009 17-03-2009	27-06-2012 10-07-2012 19-07-2012 11-04-2012 03-05-2012 20-02-2012 17-10-2011 24-07-2012 20-07-2012	$\begin{array}{c} 36 \times 36 \\ 28 \times 28 \\ 10 \times 10 \\ 3.3 \times 3.3 \\ 59 \times 59 \\ 37.0 \times 37.5 \\ 28 \times 28 \\ 13.5 \times 13.5 \\ 3.3 \times 3.3 \end{array}$	8 4 2 1 8 8 4 1 2	25 25 25 25 21 25 25 21 25 25 25		
CFHT 3.6m INT 2.5m Subaru 8.3m AAT 3.9m	CFHTLS WFC SuprimeCam WFC	Othe 25,000 230,000 60,000 5,000	er Instruments: 22-03-2003 20-06-1998 05-01-1999 21-08-2000	02-02-2009 10-07-2009 31-12-2010 05-02-2006	57.6×56.4 34.1×34.5 35.1×27.6 31.4×31.4	36 4 10 8	25 23 26 25		