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Asteroid Precovery. A citizen-science project using the Virtual Observatory.

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Abstract

Precovery is the process of finding an astronomical object in archive data taken before the discovery of the object. The Virtual Observatory project makes it much easier to access large collection of images in astronomical archives and, thus, opens the possibility to explore them to find more information about certain objects, for instance, Near Earth Asteroids. We have started a citizen-science project that combines some automatic algorithms, Virtual Observatory techniques and the participation of many people that, not being professional astronomers, help to find professional results and make a significant contribution to the accurate knowledge of the orbits of NEAs. The project started in July 2011 and during its first year more than 3000 registered users have collaborated to make more than 164.000 measurements corresponding to around 7600 archive images and 1000 different NEAs. As a result of this work, around 2300 new data, for more than 500 objects, have been submitted to the Minor Planet Center for publication. The great reception of the system as well as the results obtained makes it a valuable and reliable tool for improving the orbital parameters of Near Earth Asteroids.

1 Introduction

Near Earth Asteroids (NEAs) are small bodies whose orbits bring them into close proximity with the Earth. In particular, Potentially Hazardous Asteroids (PHAs) are defined based on parameters that measure the object's potential to make threatening close approaches to the Earth.

The resolution approved in the IAU General Assembly held in Beijing on August 2012 to *"coordinate and collaborate on the establishment of an International Near-Earth Objects (NEO) early warning system, relying on the scientific and technical advice of the relevant* *astronomical community, whose main purpose is the reliable identification of potential NEO collisions with the Earth, and the communication of the relevant parameters to suitable decisions makers of the nation(s) involved"* reflects the increasing awareness of the importance of improving the knowledge about the number, size and trajectory of Near Earth Asteroids and their potential danger for the Earth.

Only the discovery is not enough to quantify the thread level of a NEA. The most important work is to calculate accurate orbits using observations that cover a time period as long as possible. In order to do this, there are two main strategies: performing follow-up observations after discovery or mining astronomical archives with information (images, catalogues) prior to the discovery date. Precovery (short for "pre-discovery recovery") is the term that describes the process of identifying an object in archive data whose presence was not detected at the time the observation was made.

Several projects are dedicated to discovery and follow up observations of NEA objects (see Vaduvescu et al. (2011)) but not so many are devoted to look for asteroids in astronomical archives. These efforts started in the nineties using photographic plates (for instance, AANEAS[1], AANEOPP[2] or DANEOPS[3]), but the necessary visual inspection of every plate represents a very time-consuming task that requires an enormous amount of work. The most modern digitized archives allow for computer algorithms to analyze the images but the lack of homogeneity and interoperability between them made it difficult to combine data from different sources and requires different developments to work with each archive (see Boattini et al. 2001, Vaduvescu 2011 and references therein for some examples of projects dedicated to mine digital archives).

The Virtual Observatory[4] is an international initiative designed to provide the astronomical community with the standardization, data access and research tools necessary to enable the exploration of the digital, multiwavelength universe, resident in the astronomical data archives. Using this approach makes it much easier and efficient to look for NEAs in archival images.

Although computer algorithms help to identify those archive images where a given object can be present, the visual inspection of those images is still one of the best ways to get accurate information. Although the huge amount of data available in astronomical archives and services make visual analysis by a single individual or reduced group of collaborators impossible, this problem can be overcome if a crowdsourcing scenario is considered. This is the basis of the citizen-science projects whose most popular examples in Astrophysics are Galaxy Zoo[5] and its extension to Zooniverse[6]. The discovery of extra solar planet candidates using the Kepler Public Archive (Fischer et al. 2012) or the identification of a new class of compact star-forming galaxies (*The Green Peas*) (Cardamone et al. 2009) are good examples of the results obtained in these projects.

[1] http://msowww.anu.edu.au/ rmn/aaneas.htm
[2] http://www.arcetri.astro.it/science/aneopp/
[3] http://earn.dlr.de/daneops/
[4] http://www.ivoa.net
[5] http://www.galaxyzoo.org
[6] http://www.zooniverse.org

Here we describe a citizen-science project designed by the Spanish Virtual Observatory[7] to precover NEAs in the Data Release 8 of the Sloan Digital Sky Survey (Hiroaki et al. 2011). Through visual inspection of sequences of images, the user is requested to identify the asteroid and measure its coordinates. After some post-analysis and quality checks, the asteroid positions are sent to the Minor Planet Center[8] to improve the associated orbital parameters.

The project gives the public the opportunity to participate in an attractive initiative going through the same steps as professional astronomers (data acquisition, data analysis and publication of results) and making useful contributions to a better knowledge of potential threads of collision with the Earth. The public release of the system took place on July 2011, and after one year, more than 3000 users have made use of it.

In Section 2 we describe briefly the project layout and in Section 3 we give a summary of the results obtained during this first year.

2 The system.

Up to now, there is only one archive publicly available in the system: the 8th release of the Sloan Digitized Sky Survey (SDSS, York et al. 2000). This survey has obtained, over twelve years of operations, over 4 million images in five optical bands: r, i, u, z, and g (Fukugita et al. 1996). One of the characteristics of the survey, that is specially interesting for our purposes, is that, for each pointing in the sky, five images are taken consecutively through the five filters, with a small time difference. This helps to identify small solar system objects by comparing the images taken in the different bands because, being much closer, they should be seen as moving objects compared to the background stars.

The whole project comprises two main independent elements:

- The automatized search for images where known NEAs are expected to be detectable.
- The citizen science web page where the visual inspection and precise coordinate gathering is performed by the users.

2.1 Automatic search for candidates.

The first step in the project is checking if any of the around 9000 known NEA objects can be seen in any of the SDSS survey images.

In order to do this, we obtain the list of NEAs from the Minor Planet Center, together with some basic properties, and the list of images, and their metadata, from the SDSS survey.

For each image in the survey, we use NEODyS[9] to get the expected position of each asteroid at the precise time that the image was taken. Comparing this with the image

[7] http://svo.cab.inta-csic.es
[8] http://minorplanetcenter.net
[9] http://newton.dm.unipi.it/neodys2/

metadata, and taking into account the expected magnitude for the object and the survey sensitivity, we get a list of pairs object-image that are fed later to the citizen science web.

This process is repeated automatically on a daily basis. Everyday we recheck the list of NEAR objects in the Minor Planet Center for new objects or objects with updated orbital parameters. For each of them we check again all the survey images for new potential detections.

As a result of this process, we obtained around 56.000 pairs object-image. The visual inspection of this huge amount of information would be an almost impossible task for a single person. But it is doable as a citizen science project.

2.2 Citizen science web page.

The public system[10] is a PHP-based application whose primary function is to provide SDSS images to the users and to gather the astrometric measurements made by them.

People willing to participate in the project must register first and provide some information about them. In particular, they are requested to give their real name, because when we send new data to the Minor Planet Center we must include the names of the collaborators that have participated in obtaining those data.

A list of images is produced for each asteroid. The images are grouped so that those corresponding to the same pointing are shown together (See Fig. 1). Each group of images can be visualized using Aladin[11] (Bonnarel et al. 2000). Aladin is a VO-compliant interactive software sky atlas allowing to visualize digitized astronomical images, superimpose entries from astronomical catalogues or databases, and interactively access related data and information from VO services.

The criterion to identify NEAs relies on the fact that they are Solar System objects and, thus, show proper motions much larger than background stars and galaxies. Given that all the images that are seen in Aladin are taken with a small time difference, most objects will appear as static, that is, in the same position in all the images, but asteroid position should be slightly different in each image. See Fig. 1 for an example.

When the users are able to identify the moving object (in a position close to where it is expected), they must get the precise coordinates for the object in each image using Aladin, and copy them in the web form (See Fig. 1). In some cases the object is too faint to be identified or it lies outside the image limits. In those cases users should state only that in the form.

When the position of one object in a group of images has been measured by, at least, 15 different users with a small standard deviation between measures, it is removed from the public list and moved to a private web site for a final visual inspection before submitting the information to the Minor Planet Center. On the other hand, if the position of a given object in a group of images has been measured by at least 45 users without a good agreement, this pair asteroid-image is also removed from the public site for a careful inspection by the SVO

[10]http://www.laeff.cab.inta-csic.es/projects/near/
[11]http://aladin.u-strasbg.fr/

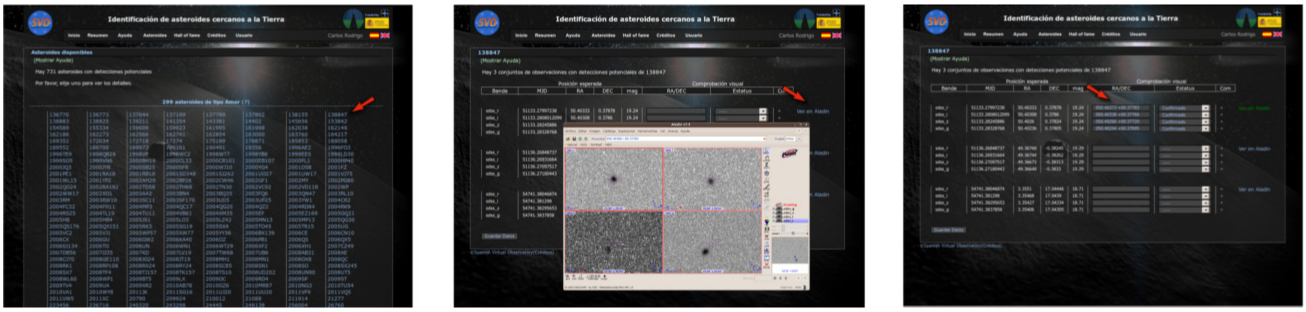

Figure 1: Some captures of the citizen science project showing (1) a list of available asteroids, (2) Aladin visualization of a group of images (note the different position of the asteroid in each image) and (3) the final form where the user introduces the object coordinates.

group.

3 Results.

On July 2012, after one year of starting the project, 3139 users had registered into the system and provided:

- 164.440 different measurements.
- 7591 images analyzed.
- 1008 NEA objects studied.
- 2294 measurements published in the Minor Planet Center for the orbits of 540 different objects.
- Precovery data (prior to the first observation reported in the MPC database) for 60 different objects, 23 of them PHAs.

Some of these measurements have been specially interesting because they have provided an important extension of the known orbit.

4 Conclusions

The increasing amount of data in digital astronomical archives is a huge potential source for information that can be extremely useful in many fields. Using the tools that the Virtual Observatory offers, this information is even easier to access and mine in an efficient way.

In this educational program we have enlisted members of the general public to visually identify Near Earth Asteroids in archive images, doing a work that, being similar in many aspects to what would have been done by professional astronomers, would have been impossible to handle by a single person or an small group.

The results of the project during its first year are successful, both showing the great interest of the general public in this kind of work and the validity, complementarity and powerfulness of our citizen-science project.

The main goal in the near future will be to expand the capabilities of the system by including data from other large area surveys.

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