Now located at the Observatorio del Roque de los Muchachos, on the Canary Island of La Palma, the historic Isaac Newton Telescope was the focus of the Author’s visit—seen here, looking north, at sunset.
As a reducer and collaborator of the European scientific project EURONEAR, I am part of the VIMP project under the coordination of Dr. astronomer Ovidiu Văduvescu, from Isaac Newton Telescope - Isaac Newton Group - La Palma, Canary Islands, Spain, and the guidance of Mr. amateur astronomer and programmer Lucian Curelaru and Dr. astronomer Marcel Popescu from the Astronomical Institute of the Romanian Academy.

VIMP project description:

As part of the EURONEAR project, the VIMP tool (Virtual Impactors Using Mega-Precovery) was developed to search for virtual impactor asteroids included in the Sentry and Neodys lists, using the images from the Mega-Precovery archives. VIMP identifies images of potential virtual impactors, which are then prioritized and examined by human reducers.

A Virtual Impactor is an asteroid whose motion in one of the possible orbits could hit Earth. The plane of the asteroid’s orbit intersects that of the Earth, thus, due to the position of the asteroid at a given moment, it generates a possible impact. Impact positions, calculated for the next 100 years, are published in the Sentry and Neodys lists.

FindCCD plot showing the Blanco-DECam overlay of the image and the uncertainty position as of Jan 2019 of the poorly observed NEA 2015 BS516 (bordered in red) covering many CCDs that needed careful searching by a team of three people.
VIMP uses the NEOdys server to extract ephemeris and uncertainty ellipses of the searched objects, then intersects these regions with the coordinates of all images in the Mega-Archive. The ephemeris is a spreadsheet, composed in advance by an astronomical observer, which indicates the positions of celestial bodies or astronomical phenomena. The uncertainty ellipse is the area determined by calculation in which the asteroid should be observed.

Each intersection generates an image, which is tabulated and prioritized based on the telescope's limit magnitude and the location of the ellipse of uncertainty within the image. Then, the images are downloaded and examined by reducers trained in the VIMP project, helped by software to overlap the searched area and the region of uncertainty with the actual images generated.

The research method:

For the asteroid record, the virtual impactors were divided into several worksheets created in Google Drive, depending on the time of observation and the updated version of the software used. Virtual impactors have been identified by a proper name, as it appears in official records, e.g. 2017UQ6. There are some worksheets containing the data obtained in the previous observations, pages from which the search parameters could be accessed and the images downloaded and processed. The reducers are assigned several objects that they have to research, next to the investigated VIs being noted the name of the reducer and his observations resulting from the research.

An image from the archive is assigned to each asteroid. After downloading it, the photo must be converted to another image type in order to be recognized by the search software. Because the downloaded image is very large, it was divided into smaller images. The reducers use the FindCCD and NEOdys sites to find out the estimated position of the asteroid and to download the correct image to locate the object.
After extracting the images, the reducer uses the Astrometrica software to overlap the asteroid’s images and to generate the apparent motion of the asteroid in the images for a good determination of its location, being possible that other objects other than the object of interest could appear in the researched area.

DS9 display search of the DECam CCD 60 image, overlaying the NEODyS uncertainty region (bordered in red) of the trailed VI 2014 HN199 (marked in green).
In some cases, image overlap is not possible due to the long period of time between the observations, which led to a large difference in coordinates between the centers of the observed images. This is not a problem, as most of the researched objects are close to the predicted coordinates of the ephemeris.

Because virtual impactors have a fairly high speed, most of them form a trail, similar to a comet tail, that makes them easier to identify and it distinguishes them from other asteroids. The tail is only visible in the images, because of the high-exposure of the camera. The trail is not perfectly visible in all cases, sometimes one of its ends being outside the ellipse of uncertainty.

The orbit of the asteroid is its trajectory through outer space, under the action of gravity. In the case of asteroids, the orbit is elliptical with the Sun at the focus of the ellipse.

There was a case in which the orbit turned out to be hyperbolic, which required a long re-observation in order to establish with certainty whether this asteroid belongs to our solar system or whether it is an interstellar object. According to the results of our current research, it can be considered to be an interstellar object, but the team reserves the
right to re-observe it in the future when the area of objects investigated and the software used will be improved. So far, following our research, the object has been reconfirmed as a special VI object that is at risk of hitting the Earth. We specify in this context that so far only two interstellar objects are officially recognized, the famous' Oumuamua and the comet Borisov.

After determining the coordinates of the object (position in the sky in equatorial coordinate system), the report is sent to the project coordinator to confirm whether the object is the one sought. If so, it goes through several checks and further research to improve the orbit as well as the data needed to determine the risk/degree of impact (in Palermo scale and Torino scale) and possible moments of impact. Afterwards the final results are sent to Minor Planet Center, at the Neodys Risk List and Sentry Impact Table where this data is published and updated.

Minor Planet Center is an institution collects astronomical observations and orbits of dwarf planets, asteroids and comets, and it operates operates under the auspices of the International Union of Astronomers.


Sentry Impact Table is the risk page of NASA, CNEOS, JPL, [https://cneos.jpl.nasa.gov/sentry/](https://cneos.jpl.nasa.gov/sentry/)

*The importance of discovering asteroids close to Earth:*

International archives of astronomical images represent huge opportunities for time-honored astronomy sciences and other important topics, such as space defense.
Astronomical observatories should enhance this wealth and make it more accessible in the age of big data. In 2010, the EURONEAR project introduced the Mega-Archive database and the Mega-Precovery image server, in order to extract data containing celestial bodies from the solar system, focusing on asteroids close to Earth.

Astronomical image archives provide valuable means for improving the physical properties of bodies in the Solar System and, in particular, of Near Earth Asteroids (NEAs), which remain observable for a short period of time. Asteroids close to Earth are the laboratories for studying the formation and evolution of dwarf planets and their physical interactions with the Sun and the planets. Some of the asteroids close to Earth, potentially dangerous asteroids and virtual impactors, could present a certain risk due to the possibility of impact, but also represent an opportunity for cheaper space missions and possibly for future mining industries.

In addition to discovery of asteroids, their recovery and tracking are essential for providing the initial orbital solution and for finding connections to other known objects. In most cases, small asteroids fade quickly and become invisible even to the largest telescopes, which are expensive to access and usually do not have time for urgent reactions. However, existing image archives are a free opportunity to improve orbit knowledge, based on serendipitous counters of searched targets, using tools dedicated to data extraction.
On a cosmic scale, asteroids close to Earth pose a real threat to humanity, and there are cases where virtual impactors, which move very fast, or imminent, cannot be recovered by even the largest telescopes. In such cases, tools capable of extracting data from very recent archives can become crucial for the discovery of such objects, so that they can improve their orbit, assess risks and, ultimately, eliminate threats of impact.

Identifying and measuring fixed objects that appear in archives is relatively simple, but searching for objects that move in the solar system becomes more complicated, requiring the intersection of spacetime trajectories with the help of archives containing hundreds of thousands of images. Asteroids close to Earth and virtual impactors are mainly very important for search, because of the dangerous potential they have.

Within the EURONEAR project, major image archives have been introduced to improve known NEA orbits, involving many amateurs and students in public information and education projects.

The Mega-Archive includes over 15 million images taken from the scientific archives of the Canadian Astronomical Data Center (CADC), later the Canada France Hawaii Telescope (CFHT); Southern European Observatory (ESO), Las Cumbres Global Observatory Telescope (LCOGT), Isaac Newton Group (ING), US National Optical Astronomy Observatory (NOAO), Subaru-Mitaka-Okayama-Kiso Archive (SMOKA), The Wide Field Imager (WFI), Anglo-Australian Telescope (AAT), Sloan Digital Sky Survey (SDSS-III DS9 version).

The Mega-Precovery project aims to allow public searches of asteroids, NEAs, in a large collection of image archives.

Currently, apart from the one hosted by EURONEAR, there is only one other web tool that allows asteroid searches in a large collection of archive images, namely "Solar System Object Image Search" (SSOIS) 6, hosted at CADC in Canada. Only a few major NEA observation missions, such as NEAT and Spacewatch or Pan-STARRS allow precovery searches of known asteroids and NEAs in their own archives.
In recent years, other tools have been designed to take advantage of the Mega-Archive for sciences other than NEAs, such as fixed objects, binary stars, which can be used in the following research niches: Mega-Precovery in orbit, Mega-Archive Precovery from observations, MASFO for fixed objects, MASDS for double stars, FindCCD for moving and fixing objects.

Within VIMP, several of the research methods specific to Mega-Precovery niches were used.

**Conclusions:**

We have already entered the era of big data, in which present and future observations will provide a huge amount of valuable imaging data for astronomical data processing. In this regard, the EURONEAR project recommends the IAU to adopt a common format and recommends that all researchers use it for indexing and storing scientific images, making the images available for programmable queries.

Near-Earth asteroids and virtual impactors are very important to be found because of their dangerous potential. To the best of our knowledge, there are only two public web servers that can search for asteroids in huge archive collections, which index millions of images, namely Mega-Precovery (hosted by EURONEAR) and SSOIS (hosted by CADC).

The application of VIMP to the archive has so far resulted in 1286 VIs investigated, 54 VIs being recovered, 16 of which have been removed from Neodys, 16 from Sentry and 17 from both lists, 23 have been listed with lower risk, and 12 with higher risk, 3 potential fast rotators and 1 with anomalies. Dozens of other objects are still being researched, and other archives are planned to be searched in the near future.
We specify that the author of this paper was assigned a number of 31 VI asteroids, of which 11 VIs were recovered and included in the 54 VIs described above.

The VIMP project was the only Romanian scientific project presented at the Geneva Congress, European Planet Science Congress-Division for Planetary Science Joint Meeting 2019.

Since 2006, the EURONEAR project has been part of the European contribution to near-Earth asteroid research. In addition to the new observations, it has identified data extraction from image archives as an excellent tool for improving orbits, and it's implementing educational and scientific projects that are affordable and open even to middle and high school students.

Composite images of the six serendipitous NEA discoveries by EURONEAR using the INT in 2015.
A meteor glowing as it enters the Earth's atmosphere

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