MEERKAT ASTEROID GUARD – ESA'S IMMINENT IMPACTOR WARNING SERVICE

F. Gianotto(1,4), **M. Frühauf**(3), **J.-L. Cano**(1), **L. Conversi**(1), **L. Faggioli**(1,4), **M. Fenucci**(1,5), **D. Föhring**(1,4), **D. Koschny**(2,3), **R. Kresken**(6,7), **M. Micheli**(1,4), **R. Moissl**(1), **D. Oliviero**(1,5), **A. Porru**(1), **P. Ramirez Moreta**(9,10), and **R. Rudawska**(2,11)

(1)ESA ESRIN / PDO / NEO Coordination Centre, Via Galileo Galilei, 00044 Frascati (RM), Italy, Email: neocc@esa.int
(2)ESA ESTEC / PDO, Keplerlaan 1, 2201 AZ Noordwijk, The Netherlands
(3)LRT / TU Munich, Boltzmannstraße 15, 85748 Garching bei München, Germany
(4)RHEA Systems, Via di Grotte Portella, 28, 00044 Frascati (RM), Italy
(5)Elecnor Deimos, Via Giuseppe Verdi, 6, 28060 San Pietro Mosezzo (NO), Italy
(6)ESA ESOC / PDO, Robert-Bosch-Straße 5, 64293 Darmstadt, Germany
(7)CGI Deutschland B.V. & Ko. KG, Rheinstrasse 95, 64295 Darmstadt, Germany
(8)Alia Space System Srl, Via San Giuseppe Calasanzio 15, 00044 Frascati (RM), Italy
(9)ESA ESAC / PDO, Cno. Bajo del Castillo s/n, 28692 Villafranca del Castillo, Madrid, Spain
(10)GMV, Isaac Newton 11, Tres Cantos, 28760 Madrid, Spain
(11)RHEA Systems, Jonckerweg 18, 2201 DZ Noordwijk, The Netherlands

ABSTRACT

Telescope surveys continuously scan the night sky in search for undiscovered asteroids and comets. New detections need to be immediately analyzed for their orbits, even before they receive an official designation. This is necessary to promptly perform follow-up observations in case of potential hazards, or to start mitigation actions. Here we introduce Meerkat, an automated imminent impactor warning service developed and operated by the ESA NEO Coordination Centre.

Keywords: near-Earth asteroids; imminent impactors; Space Safety; ESA Operations.

1. INTRODUCTION

Until today, only six asteroids were discovered before their impact, and all of them were first observed less than 24 hours before the impact. This underlines the need for a rapid orbit determination and threat assessment. Besides impactors, artificial objects and other interesting natural objects are regularly discovered, which need to be identified among conventional near-Earth objects (NEOs) and followed-up, before their ephemerides get too uncertain and they get lost.

The ESA Planetary Defence Office (PDO) developed and operates an independent imminent impactor warning service, called Meerkat Asteroid Guard (Meerkat for short). The fully automated system is running 24/7 and analyses newly discovered NEOs, published on the NEO Confirmation Page (NEOCP) of the Minor Planet Center (MPC). Meerkat uses the systematic ranging technique to compute a preliminary orbit and to detect potential impacts. In addition, the system is searching for close approaching objects, interior-Earth objects and potential interstellar objects. If a notable object is found, Meerkat automatically informs subscribers via e-mail and the NEOCC through messages on the mobile phone. In addition, all computation results can be accessed via a web-portal, that is currently available only internally to the ESA NEOCC.

Since its introduction [1], Meerkat successfully detected the last two impactors, 2022 EB5 and 2022 WJ1, and it has been improved in terms of stability, reliability, and performances. In December 2022, Meerkat started sending its results through a mailing list opened only to people actively involved in NEO field. The subscription can be requested at the address `neocc@esa.int`.

2. MEERKAT ASTEROID GUARD

2.1. Systematic ranging

When the observational arc is too short, the classical techniques of orbit determination, such as the least-square method, are typically not effective. The systematic ranging relies on the fact that the right ascension α and the declination δ, and their rates $\dot{\alpha}$ and $\dot{\delta}$, constrain the position of the observed object in the sky. On the other hand, the range ρ and the range-rate $\dot{\rho}$, that are the other two quantities needed to estimate an orbit, are either unknown or very poorly determined. The systematic ranging computes a set of least-square orbits over a grid in $(\rho, \dot{\rho})$, that contains the so called admissible region [2]. The admissible region is a set of points in the $(\rho, \dot{\rho})$ plane corresponding to orbits bounded to the Solar System, and that

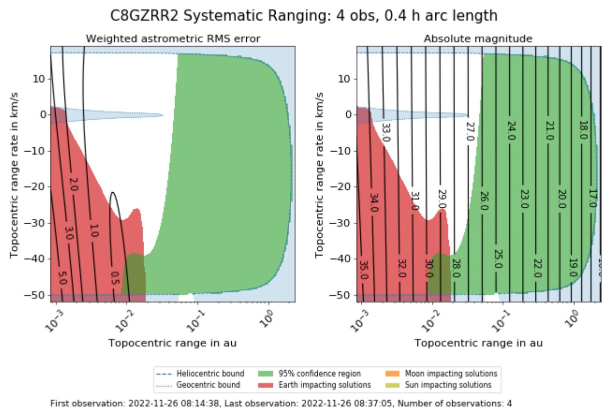

Figure 1. RMS of the observational residuals (left panel), and absolute magnitude (right panel) obtained with systematic ranging, for the object C8GZRR2.

are not satellites of the Earth. After the fits, the residuals provide a probability on the $(\rho, \dot{\rho})$ plane. More details about the systematic ranging technique can be found in [3, 4].

Figure 1 shows the RMS of the observational residuals (left panel), and the absolute magnitude (right panel) maps computed with the systematic ranging of object C8GZRR2. The green area represents the 95% confidence region of the orbit, that is bounded by the admissible region. The border of the admissible region for the object trajectory is delimited by the heliocentric bound (dashed blue curve), and by the geocentric bound (dotted blue curve), while the area outside the admissible region is depicted in light blue. The red area represents orbits on a collision trajectory with the Earth. The RMS of the residuals in the left panel, and the absolute magnitude on the right panel, are shown as level curves, superimposed to the previously described quantities appearing in the figure.

2.2. Automated plots

Meerkat was designed in close collaboration with observers to fit their needs. Therefore, specialized plots help observers to estimate the real threat of a potential impactor and reduce the effort of finding well-fitting observatories for follow-up observations.

The *Dashboard* plot (Figure 2) gives a clear overview for threat assessment by visualizing the relevant information as pie charts. Among others, an impact score and an impact time estimate are shown. Another feature is the orbital class dependent size estimate. This distinction is important, since impacting solutions of the systematic ranging tend to have larger absolute magnitudes and hence smaller object sizes. Without this classification, mitigation and follow-up actions might be based on too large impactor size estimates.

The *Station Selection* plot (Figure 3) helps choosing the right observatory for follow-up observations. It shows a time and field-of-view (FoV) dependent detection score

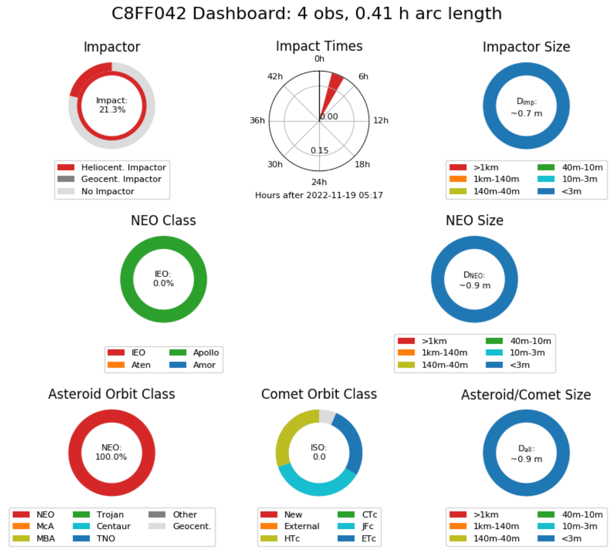

Figure 2. Dashboard plot of object C8FF042.

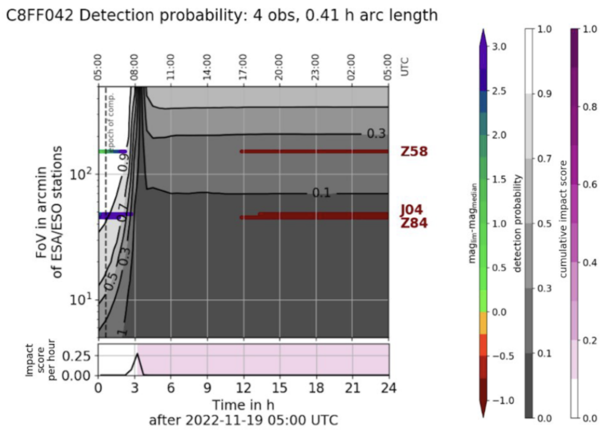

Figure 3. Stations plot of object C8FF042.

contour. A number of selected observatories, displayed as lines with fixed FoV values and a line length depending on the ephemeris visibility, are plotted above the contour. The observatory lines are colored in a scheme indicating the visibility by the visual magnitude, depending on the stations' limiting magnitudes. Hence, the user can immediately see which of the stations can observe the object in terms of visual magnitude and ephemeris, and which stations have high chances of detecting the object.

2.3. Meerkat web-portal

As mentioned in the introduction, the computations performed by Meerkat are sent to a mailing list. In addition, the results are present also on a web-portal (see Figure 4) that is currently under test and validation and therefore available only internally to the ESA NEOCC. The main page of the web-portal shows the list of all the NEOCP objects, and the list of objects with the highest impact

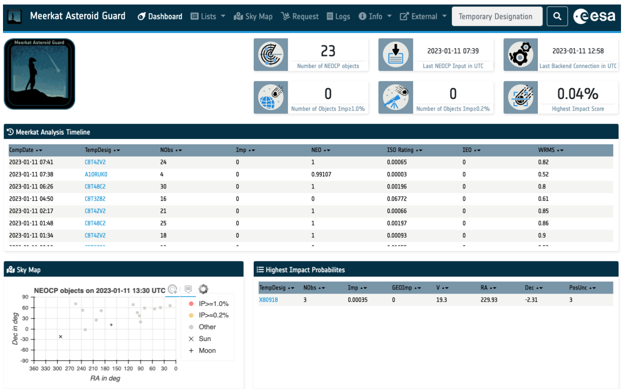

Figure 4. Screenshot of the ESA Meerkat Asteroid Guard web-portal.

probability. Each NEOCP object has a dedicated web-page, showing a summary of all the data available, the results obtained with systematic ranging, and the plots mentioned in Sec. 2.2. In addition, the web-portal provides an ephemeris service with the option of considering only impacting solutions.

3. IMPACTORS DETECTIONS

Since the beginning of its operational lifetime, Meerkat detected two imminent impactors. These events were also recorded by the other two warning services, the Scout system by NASA and the NEOScan system by NEODyS, but in both cases Meerkat was the first one to trigger and send the alert. The first alert was about the object Sar2593 on 11 March 2022 at 20:23 UTC, that was later designated as 2022 EB5. At this time, the impact location was already constrained to about a thousand kilometers with an impact time between 21:21 and 21:25 UTC, so only one hour after the first alert. Due to follow-up observations, the time and location of the impact could be better constrained in the next hours. 2022 EB5 entered the atmosphere at approximately 21:23 UTC at the predicted area, located a few hundred kilometres North of Iceland. The top panel of Fig. 5 shows the impact corridor computed by Meerkat using the first 14 observations.

The second alert was about the object C8FF042 on 19 November 2022 at 05:36 UTC, that was later designated as 2022 WJ1. With only the first 4 observations reported by the NEOCP page, Meerkat determined an impact probability of about 20%. The impact corridor computed with these data is shown in the bottom panel of Fig. 5, with a most-likely hitting point located in North America. Within minutes of the notifications, observers started obtaining follow-up observations of the new asteroid. In less than 30 minutes from the initial trigger, the impact became confirmed thanks to newly reported observations. The impact time and location could also be refined: 2022 WJ1 was going to impact somewhere between Lake Erie and Lake Ontario, near the US-Canada border, around 08:27 UTC. At exactly the predicted time,

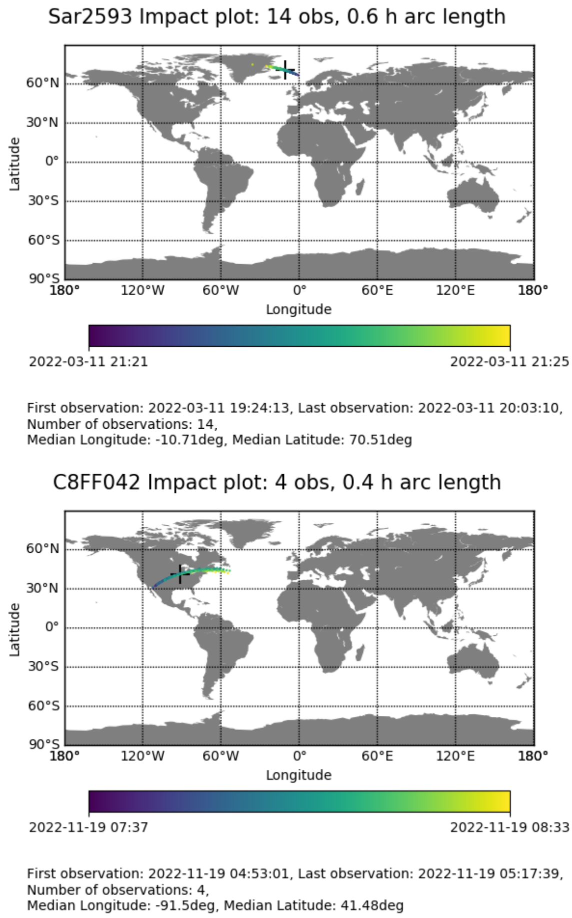

Figure 5. Impact corridor of 2022 EB5 (top panel), and of 2022 WJ1 (bottom panel) as computed by Meerkat.

a fireball event happened at the expected location.

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