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Remnants from the past, building blocks for the future: the near-Earth asteroids

Marcel M. Popescu

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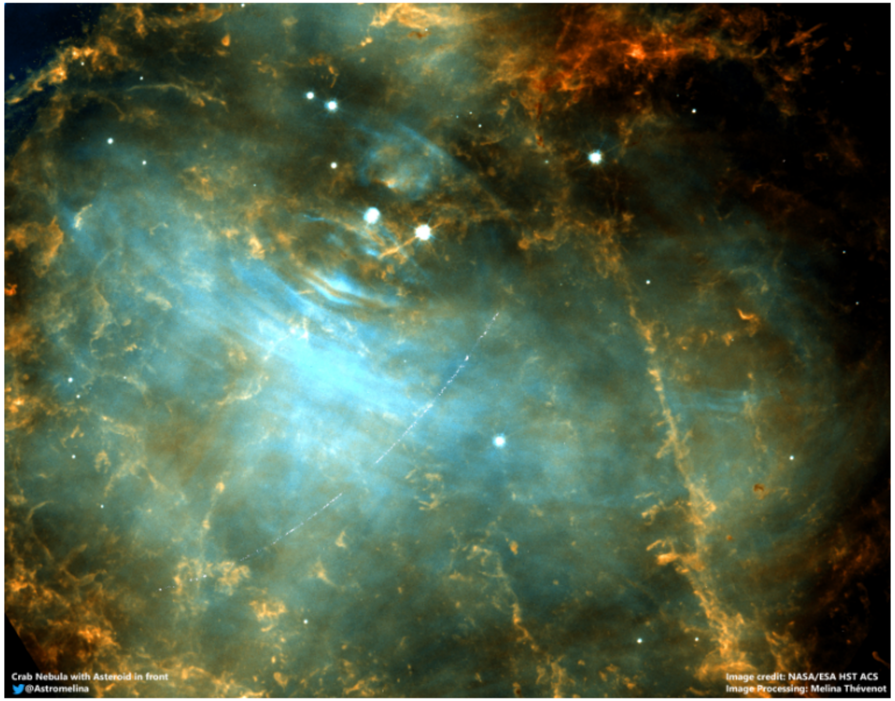
popescu.marcel1983@gmail.com

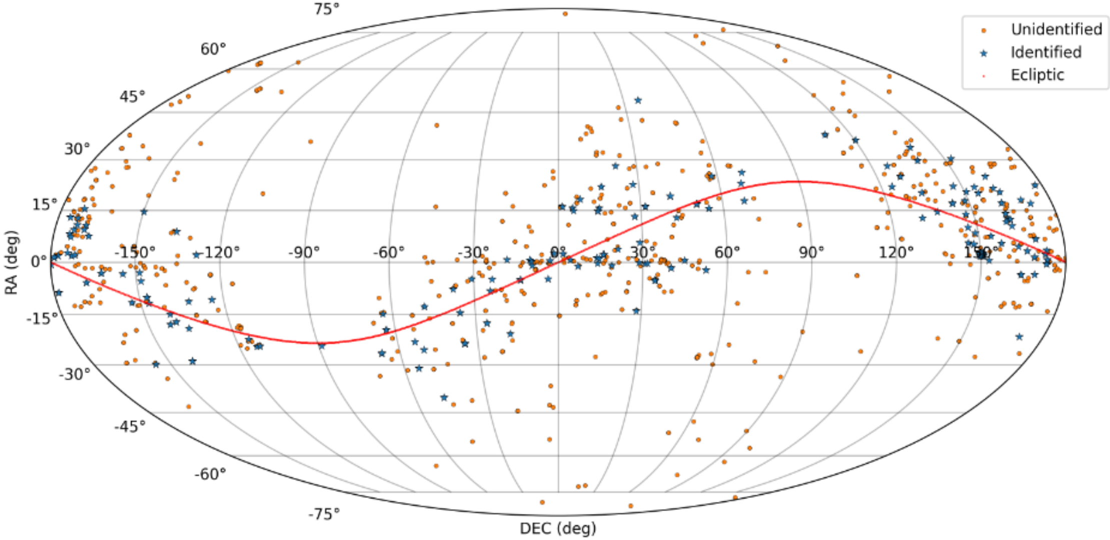
Moving sources in astronomical images

The near Earth asteroid (153591) 2001 SN263 19 January 2022 15:58-20:00 UTC. Observations performed with T025 - BD4SB telescope (MPC code 073). Blinking 3 images taken at an interval of 2 hrs. The asteroid had a sky motion of 0.97 arcsec/min

All over the sky



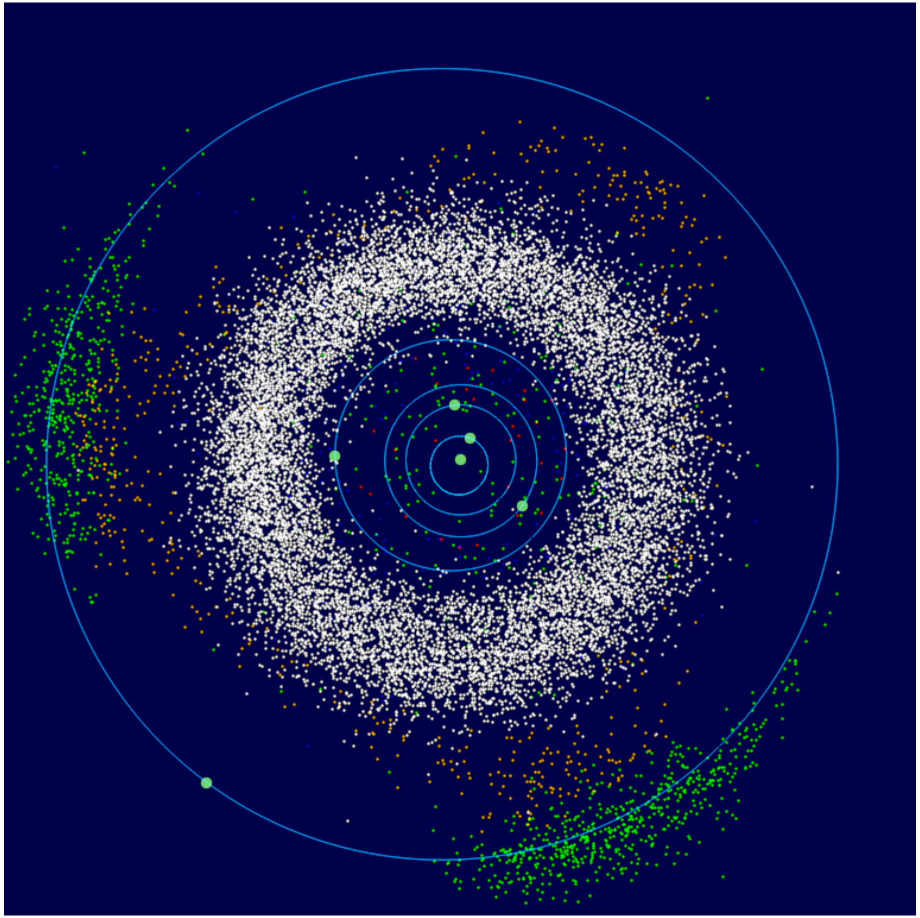
Asteroid (190838) 2001 SE101 passing in front of the Crab Nebula (M1) in observation with ACS/WFC F550M band (observation j9fx11010), taken on 5 December 2005. Pseudocolour composition with F606W and F550M filters by citizen scientist Melina Thévenot.



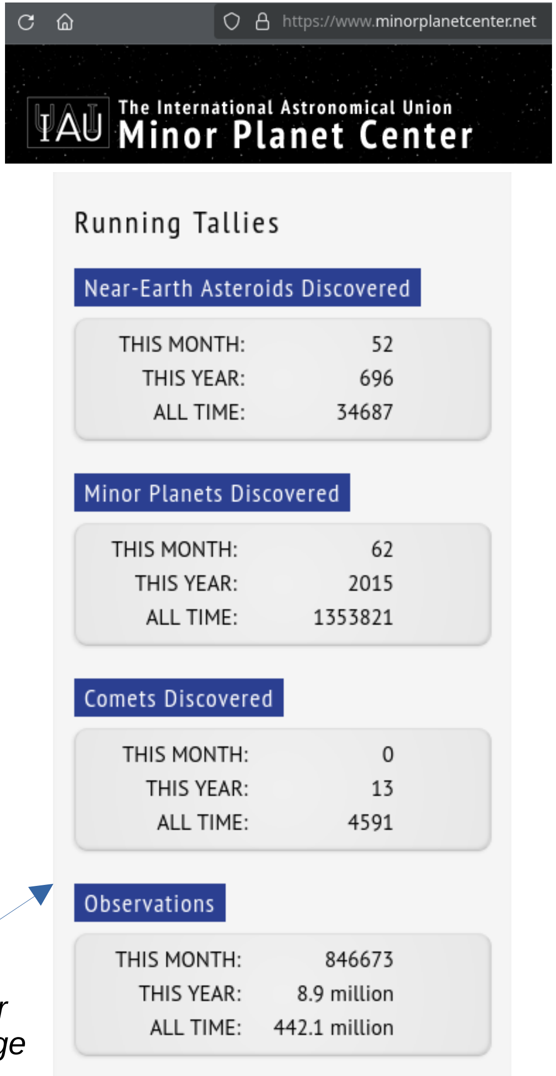
The distribution on the sky of the SSO observed in Hubble Space Telescope images. The blue points show the identified, known asteroids. The orange points show the location of objects for which we did not find any associations with known SSO. The ecliptic is shown in red.

Kruk, García Martín, Popescu et al. 2022 A&A

Asteroids



Map of the inner Solar System (schematic).
Source: https://commons.wikimedia.org/



Print-screen of Minor Planet Center webpage April 10, 2024

<u>Near Earth Objects (NEOs)</u>

A near-Earth object (NEO) is any small solar system body whose orbit brings it into proximity with Earth. By definition, a solar system body is a NEO if its closest approach to the Sun (perihelion) is less than 1.3 astronomical units (au).

Artistic view of primordial Solar System. Source: Internet

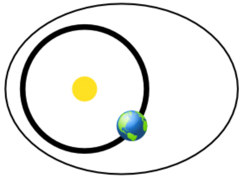
- *<u>The population is dynamic</u>* in terms of its ongoing resupply from both main-belt asteroid and comet sources.
- *<u>Undergo a diverse range of physical processes</u>* involving their response to external factors such as solar flux and impacts
- Objects that are *<u>capable of impacting Earth</u>*, delivering meteorites, and civilization-threating impacts (centuries to geologic timescales).
- *<u>The most accessible spaceflight destinations</u>*
- Their proximity to Earth observers allows a variety of observational techniques.
- Currently NEOs include more than 32000 near-Earth asteroids (NEAs) and more than one hundred near-Earth comets.

OSIRIS-REx touchdown of (101955) Bennu. Credit NASA / OSIRIS-REx

NEAs orbits

Amors

Earth-approaching NEAs with orbits exterior to Earth's but interior to Mars' (named after asteroid (1221) Amor)



$$a > 1.0 \text{ AU}$$
$$1.017 \text{ AU} < q < 1.3 \text{ AU}$$

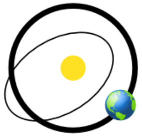
Apollos

Earth-crossing NEAs with semi-major axes larger than Earth's (named after asteroid (1862) Apollo)

$$a > 1.0 \text{ AU}$$
$$q < 1.017 \text{ AU}$$

Atens

Earth-crossing NEAs with semi-major axes smaller than Earth's (named after asteroid (2062) Aten)



$$a < 1.0 \text{ AU}$$
$$Q > 0.983 \text{ AU}$$

Atiras

NEAs whose orbits are contained entirely within the orbit of the Earth (named after asteroid (163693) Atira)

$$a < 1.0 \text{ AU}$$
$$Q < 0.983 \text{ AU}$$

(q = perihelion distance, Q = aphelion distance, a = semi-major axis)

Source: https://cneos.jpl.nasa.gov/about/neo_groups.html

… and a very special one

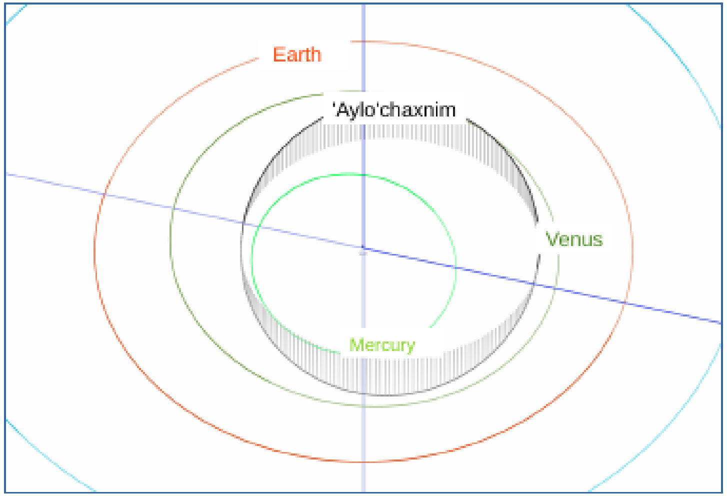


Fig. 1 Orbit of 2020 AV2 (black) compared with the orbit of inner planets.

Diagram generated with JPL Small-Body Database Browser

Orbital parameter		value±1σ uncertainty
Semimajor axis, a (au)	=	0.55541670±5.7E-8
Eccentricity, e	=	0.17707297±9.0E-7
Inclination, i (°)	=	15.86857312±6.1E-5
Longitude of the ascending node, Ω (°)	=	6.7024±0.00026
Argument of perihelion, ω (°)	=	187.3290±0.00031
Mean anomaly, M (°)	=	327.2155±0.00045
Perihelion, q (au)	=	0.45706742±5.1E-7
Aphelion, Q (au)	=	0.65376597±6.7E-8
Absolute magnitude, H (mag)	=	16.21±0.775

Table 1. Heliocentric Keplerian orbital elements of 2020 AV2 and their 1σ uncertainties. The orbit determination is referred to epoch Epoch 2459800.5 (2022-Aug-09.0) TDB (Barycentric Dynamical Time, J2000.0 ecliptic and equinox). Source: JPL Small-Body Database (solution date, 2022-Feb-14 04:50:02).

Numerical simulations predicted the existence of a population of small bodies that is orbiting entirely inside Venus orbit. These asteroids are called Vatiras (in analogy with Atira-class NEAs) or Interior to Venus Orbit Objects. The only one known up to now was discovered on January 4, 2020 at Zwicky Transient Facility (Bolin et al. MPEC 2020) and it was called (594913) 'Aylo'chaxnim.

Popescu et al. 2020 MNRAS

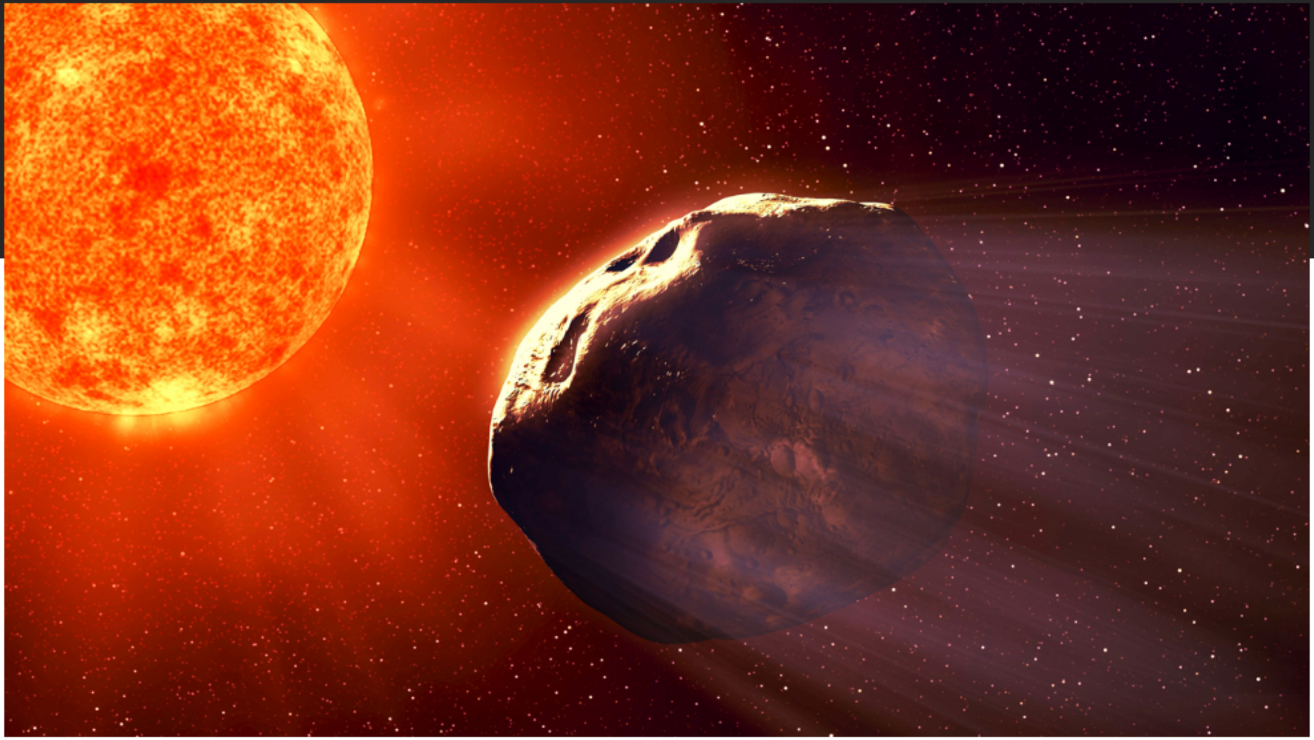
Science

NEWS | SPACE

First asteroid found within Venus's orbit could be a clue to missing 'mantle' asteroids

2020 AV2 has a composition similar to Earth's mantle

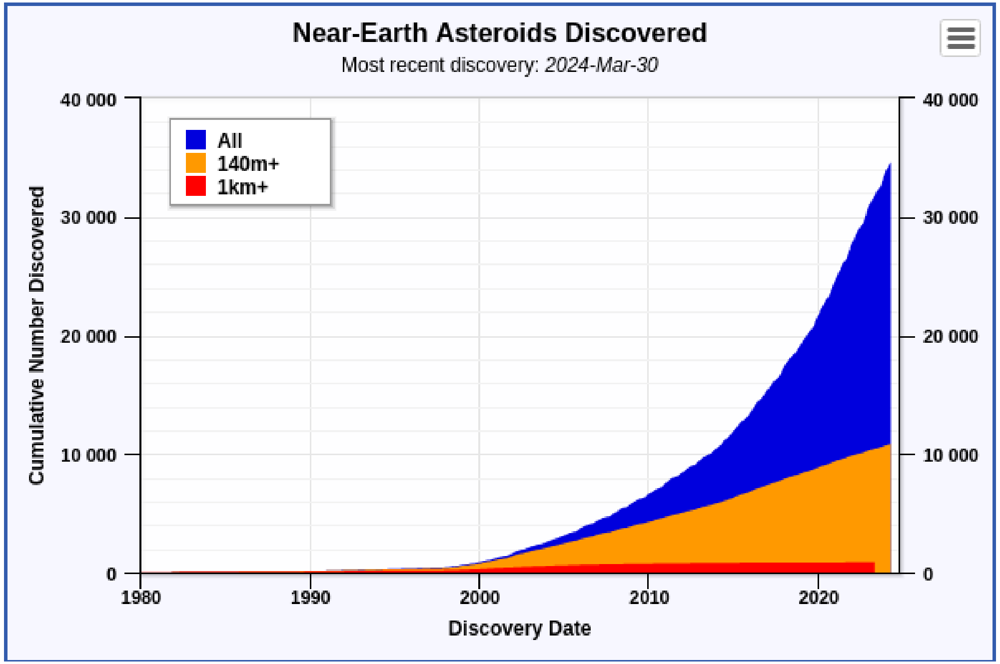
1 JUL 2020 · BY NOLA REDD



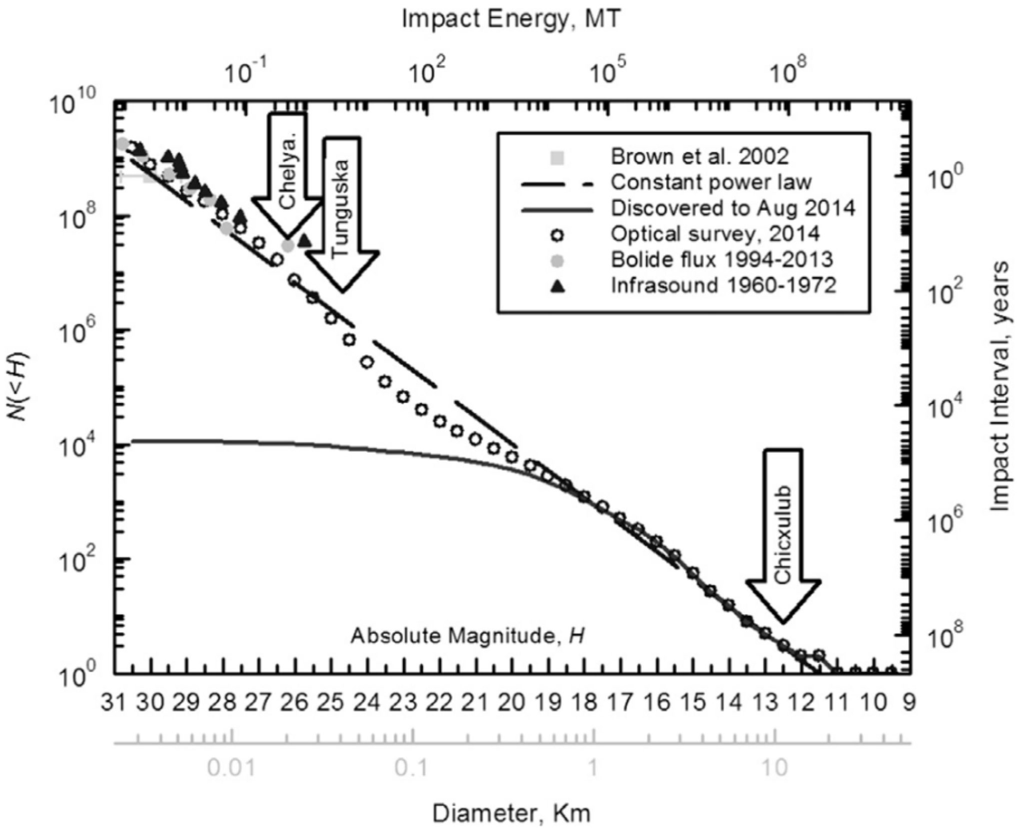
The first Vatira, 2020 AV2, may point to asteroids resembling Earth's mantle. EQUINOX GRAPHICS/SCIENCE SOURCE

Source: https://www.science.org/content/article/first-asteroid-found-within-venus-s-orbit-could-be-clue-missing-mantle-asteroids

How many NEOs are known and how many they are?

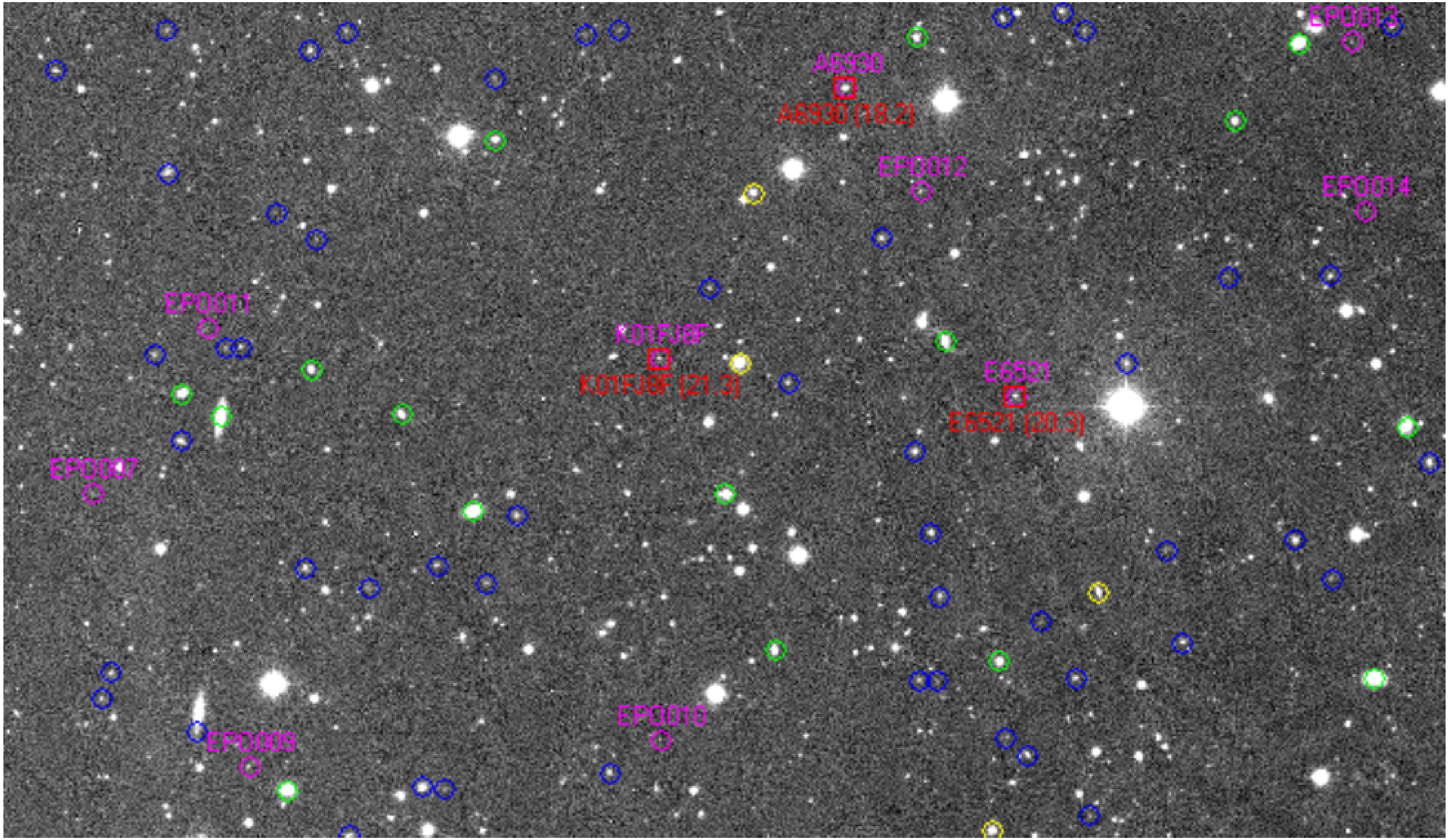


The cumulative number of known Near-Earth Asteroids (NEAs) versus time. Totals are shown for NEAs of all sizes, those NEAs larger than ~140m in size, and those larger than ~1km in size. Credit: CNEOS / NASA - JPL



Estimate of cumulative population of NEOs based on survey discovery statistics from 2012 to 2014. We note that H magnitudes have been translated into size assuming the mean NEO albedo of 0.14 (Mainzer et al., 2011). Compositional diversity is also neglected in impact energy computation. See Harris and D'Abramo (2015) for more details.

Discoveries using dedicated observations

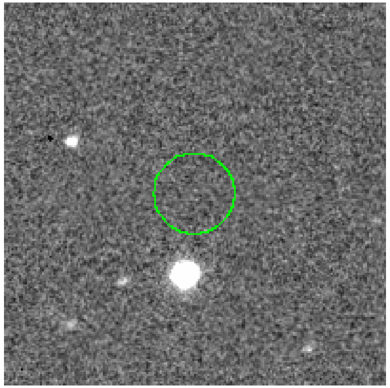


A field obtained with 2. 54m INT-WFC on February 28, 2012. Ten asteroids were identified (marked with pink), from which only three were known at the moment of the observation. The size of the field is (15 arcmin x 15 arcmin).

Popescu 2012, Ph. D. thesis

The ParaSOL project comes into play

What if we don't see the NEO in a single exposure?



Single exposure obtained using the 2.54 m Isaac Newton Telescope

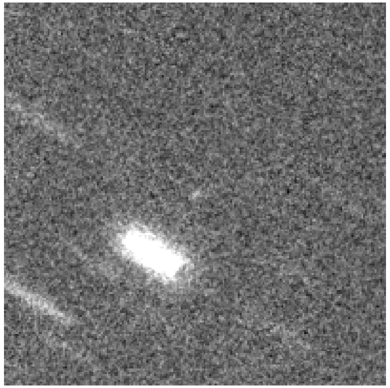


Image obtained using track and stack technique from 12 exposure.

Data-parallel detection of Solar System objects and space debris (acronym ParaSOL)

- Origins in the professional – amateur collaboration
- Financed by Romanian National Authority for Scientific Research and Innovation, CNCS – UEFISCD
- The overall goal of our team is to create a dedicated platform and to apply it for the ***near-real time*** discovery, recovery and monitoring of NEAs, space debris, an other small bodies of the Solar System.
- The main software modules handled by this project are STU, shorthand for Synthetic Tracking on Umbrella, IPP, our image pre-processing pipeline, and Webrella, the web interface for these.

Synthetic Tracking before us

- The synthetic Tracking Algorithm (e.g. Gladman et al. 1997) improves the signal to noise ratio by stacking across all possible apparent motion vectors
- Trades off smaller telescopes for longer integration times and computational power
- Used to be slow, but modern computers are faster, with major gains in "accelerator" hardware (GPUs)

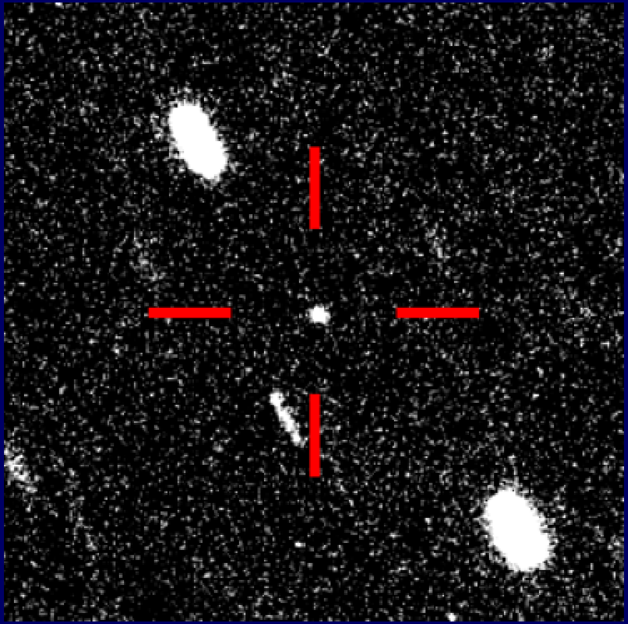
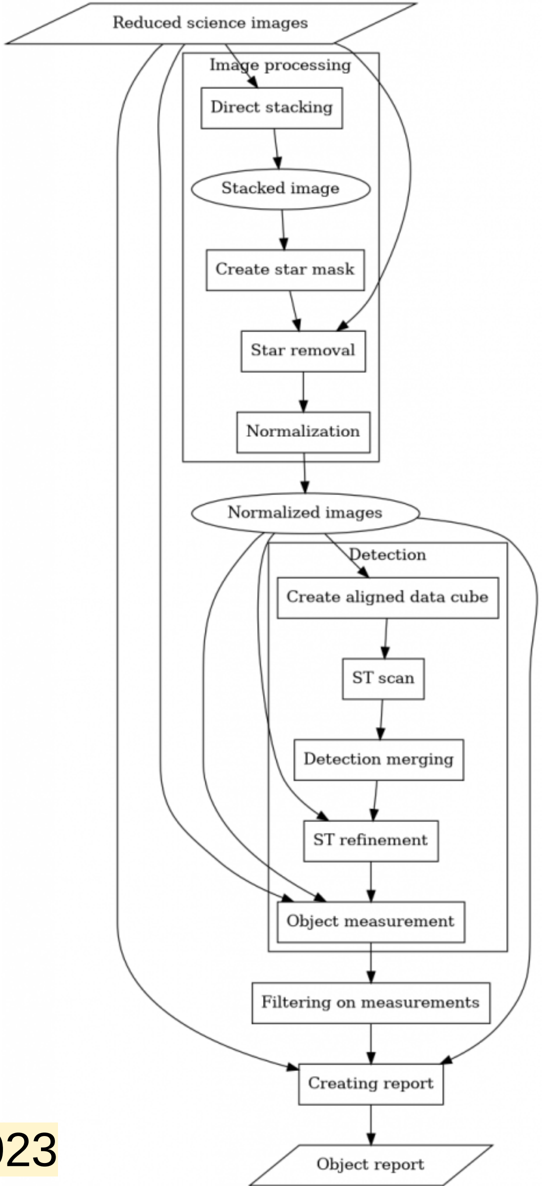


Figure: **1999 TH94**, observed with INT under bright time, integration time $12 \times 30\,s$. At magnitude 21, it is at the blink limit. Detection obtained using our STU.

Stănescu et al. ACM 2023

Synthetic Tracking with our STU

- Hypothesis rejection design (very cheap initial scan, increasingly powerful filters following)
  - Level inputs & remove fixed sources
  - Fast shift-and-(add & median)
  - Combine & refine motion vectors
  - Measure detections
- Efficient implementation on graphics processing unit (GPU)
- Written in .NET Framework + OpenCL → highly portable
- Tested on Linux and Windows with AMD and nVidia GPUs, as well as CPUs (but much slower)



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NEO detection, where to?

What would our fast Synthetic Tracking mean for the future of NEO discovery?

Short term

- ST will "eat the world"
- Shallow deployments widely used, especially in existing surveys
- Knowhow disseminated, differences in behavior known widely
- First dedicated survey proposals

Long term

- Efficient deep synthetic tracking
- All large-scale surveys will be ST
- Niche approaches: ballon-borne and small space telescopes, etc.
- Fast computational techniques will spread to improve image processing
- ST will open up SSBs to industry (think NHATS)

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The discovery of 2023 DZ_2

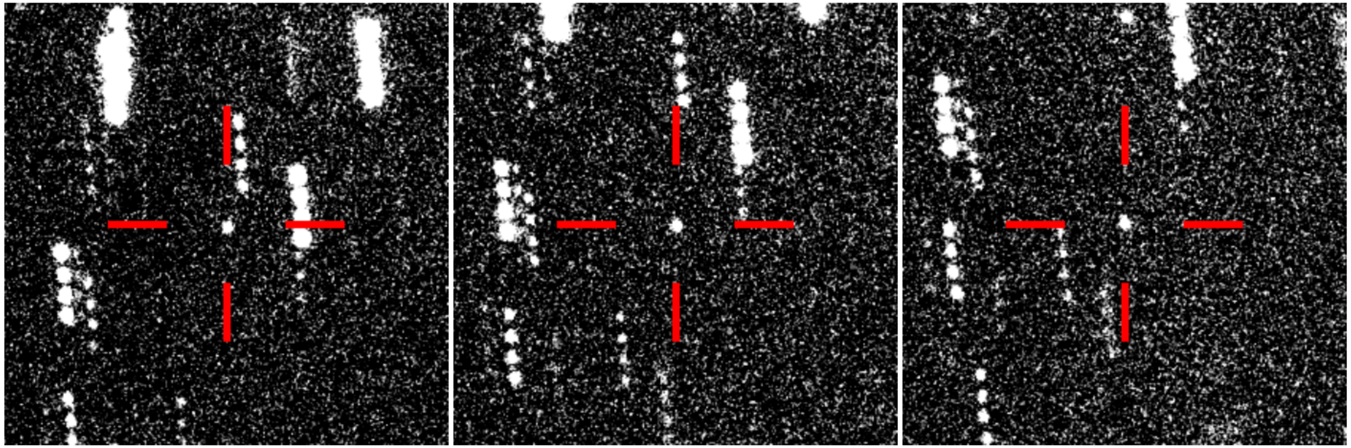
Observations

The 2.54 m Isaac Newton Telescope

The Wide Field Camera instrument mounted in the prime focus of INT

Field name	Date	UT start	UT end	Nexp	AM	Seeing
n1o1	27-Feb-2023	22:21	23:31	12	1.02	1.5
E309252	28-Feb-2023	22:14	22:28	12	1.01	1
E309252	01-Mar-2023	22:46	22:00	12	1.02	1.1

The date and Universal Time (UT) for the beginning and for the end of the observing set, the number of exposures (NExp), the mid-observation airmass (AM), and the median seeing (Seeing) in arcseconds are shown.



The “re-scaled mean" combined images used to detect 2023 DZ_2 by the STU algorithm. Three subsets of four images each were stacked for detecting this new object.

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2023 DZ_2 as Virtual Impactor

Object Designation	Year Range	Potential Impacts	Impact Probability (cumulative)	$V_{infinity}$ (km/s)	H (mag)	Estimated Diameter (km)	Palermo Scale (cum.)	Palermo Scale (max.)	Torino Scale (max.)
(2023 DZ2)	2026-2121	123	2.3e-3	7.35	23.9	0.056	-1.16	-1.17	1
101955 Bennu (1999 RQ36)	2178-2290	157	5.7e-4	5.99	20.6	0.490	-1.41	-1.59	
29075 (1950 DA)	2880-2880	1	2.9e-5	14.10	17.9	1.300	-2.05	-2.05	

Print screen from JPL Sentry System website

Orbital parameter		value±1σ uncertainty
Semimajor axis, a (au)	=	2.1555715±0.0000002
Eccentricity, e	=	0.53892721±0.00000005
Inclination, i (°)	=	0.0814345±0.0000012
Longitude of the ascending node, Ω (°)	=	187.91380±0.00006
Argument of perihelion, ω (°)	=	5.95978±0.00006
Mean anomaly, M (°)	=	348.674236±0.000002
Perihelion distance, q (au)	=	0.993875393±0.000000007
Aphelion distance, Q (au)	=	3.3172677±0.0000003
Absolute magnitude, H (mag)	=	24.3±0.4

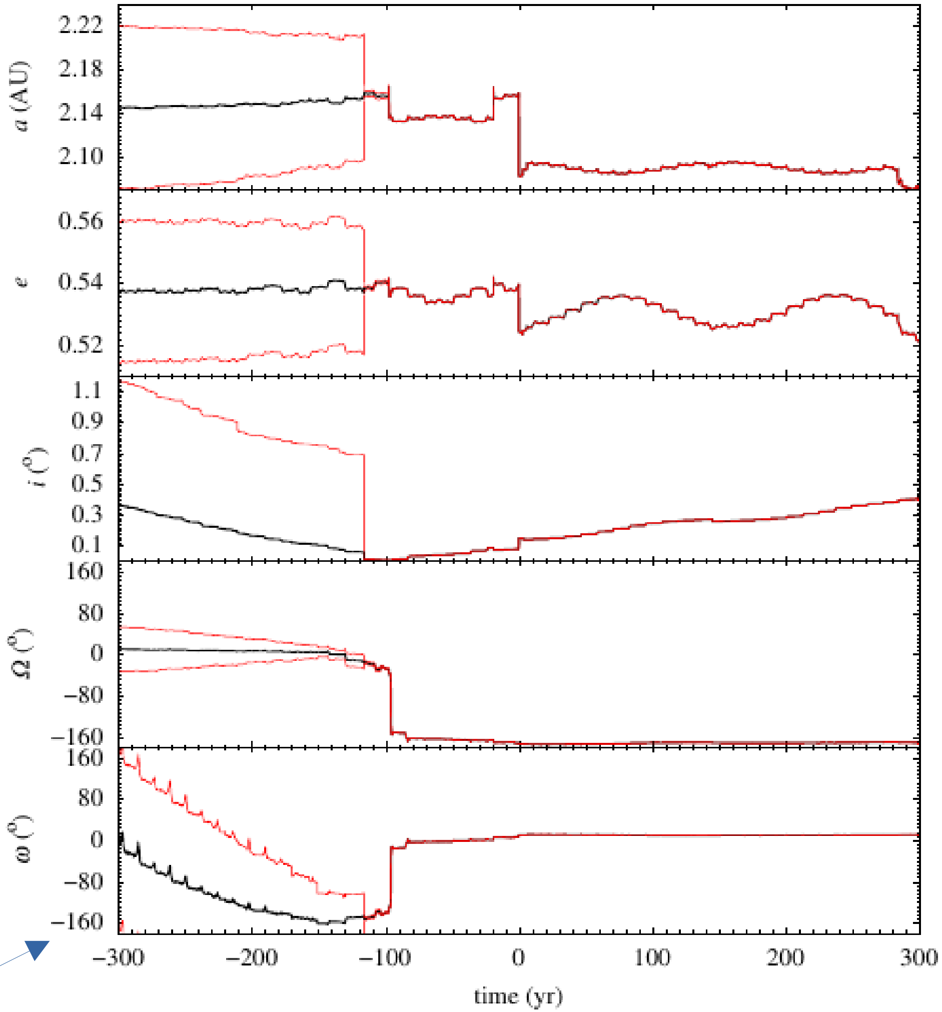
Values of the heliocentric Keplerian orbital elements and their respective 1σ uncertainties of 2023 DZ2. The orbit determination of 2023 DZ2 is referred to epoch JD 2460000.5 (25-Feb-2023) TDB (Barycentric Dynamical Time, J2000.0 ecliptic and equinox) and it is based on 635 observations with a data- arc span of 72 days (solution date, 24-April-2023, 08:41:00 PDT). The input data also include radar observations (4 delay and 1 Doppler). Source: JPL's SBDB.

- It was catalogued as a VI by Jet Propulsion Laboratory's (JPL) Sentry System for Earth impact monitoring, by the NEODyS CLOMON2 Risk page list, and also by ESA Risk List.
- As additional observations were reported to the MPC by multiple observers around the world, the cumulative impact probability increased by several orders of magnitude (up to a cumulative impact probability of 0.0023 on March 18).
- The analysis of the improved orbits led to the eventual removal of 2023 DZ_2 from the Sentry System.

Orbital dynamics of 2023 DZ_2

- Asteroid 2023 DZ2 has a MOID with Earth of 0.00005 au.
- The dynamics of 2023 DZ_2 is controlled by Earth and Jupiter, with Earth currently being a direct perturber.
- The orbital evolution shows multiple discontinuities linked to past and future close encounters with the Earth–Moon system.
- We confirm that 2023 DZ_2 will not impact Earth in the foreseeable future as a result of secular near-resonant behavior

Evolution of the values of the semimajor axis (a, top panel), eccentricity (e, second to top panel), inclination (i, third to bottom panel), ascending node (Ω, second to bottom panel), and argument of perihelion (ω, bottom panel) of 2023 DZ2.
The panels display results of the integrations of 1000 control orbits with initial positions and velocities generated using the Monte Carlo. In black, we display the average evolution of the orbital element and in red we show the range linked to the 1-σ uncertainty. The output time-step size is 0.1 yr. The source of the input data is JPL's SBDB and they are referred to epoch 2460023.5 (20-Mar-2023) TDB that is the origin of times.



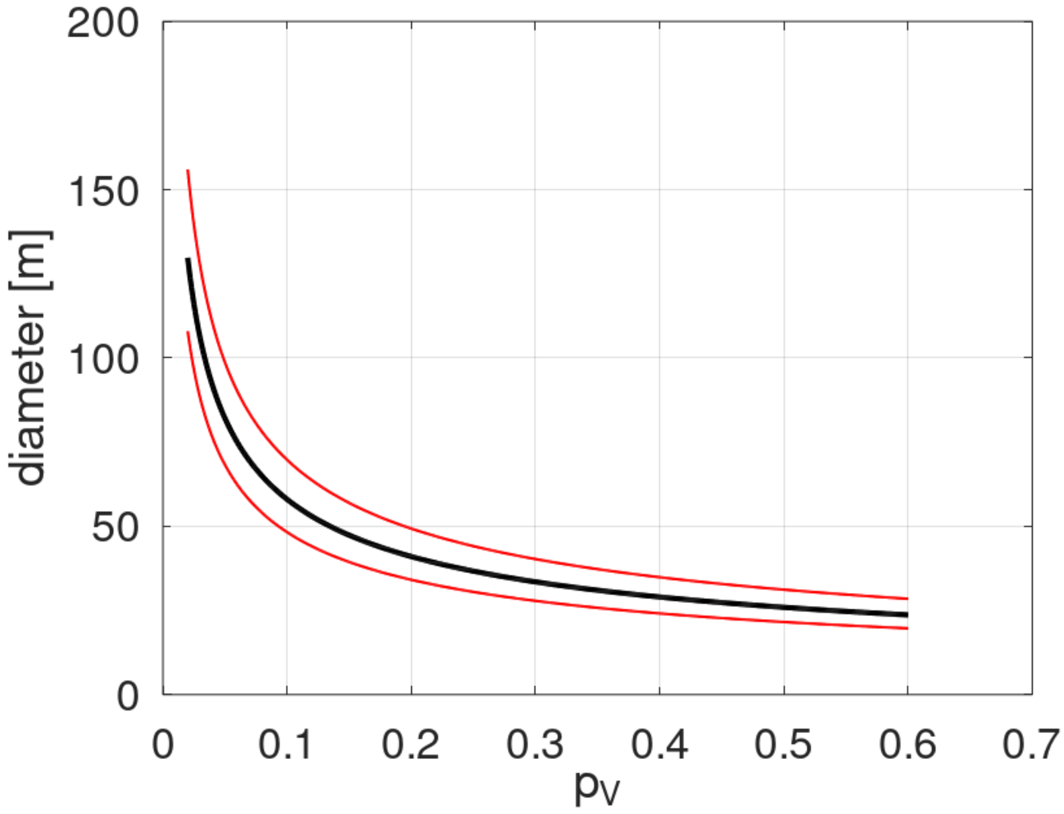
How big is this body?

$$D = \frac{1329}{\sqrt{p_V}} 10^{-H/5},$$

*where **D is the diameter** in kilometers and **p_V and H** are the geometric albedo and absolute V-band magnitude, respectively, on the so-called H, G magnitude system (see Bowell et al. 1989). Source: Harris & Harris & Harris 1997, and reference there in*

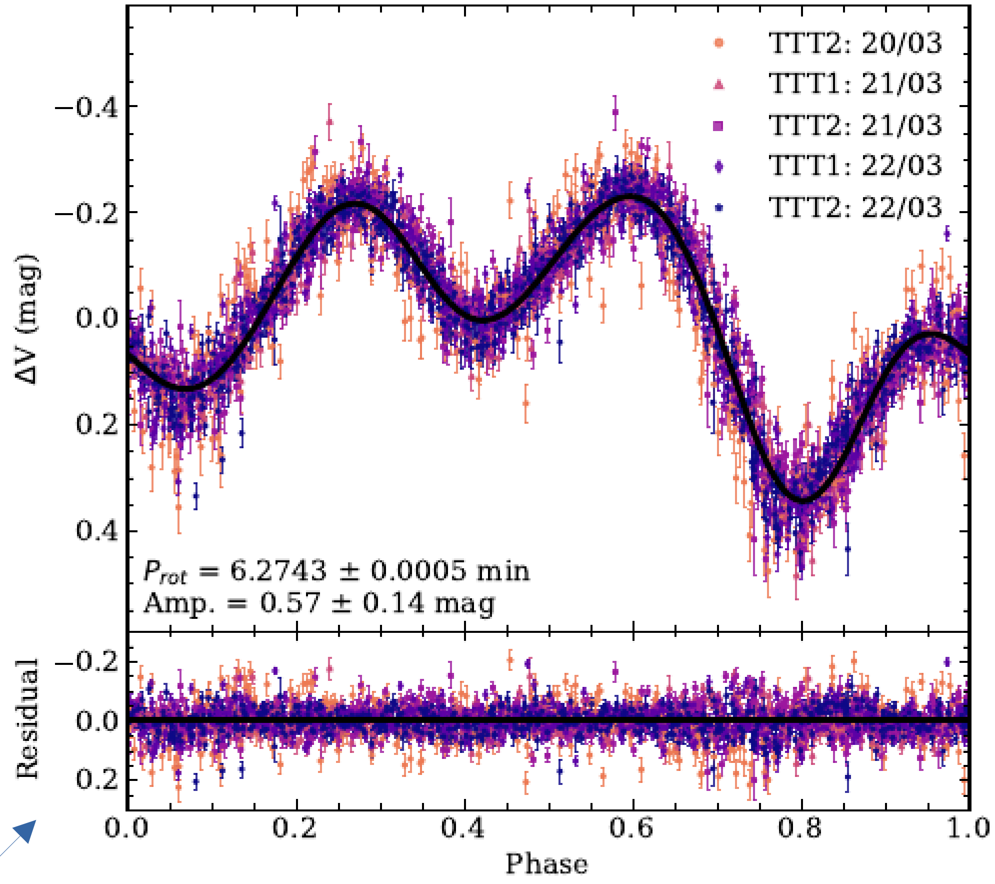
H = 24.3 +/- 0.4 mag

p_V = ? (0.02 -- 0.6)



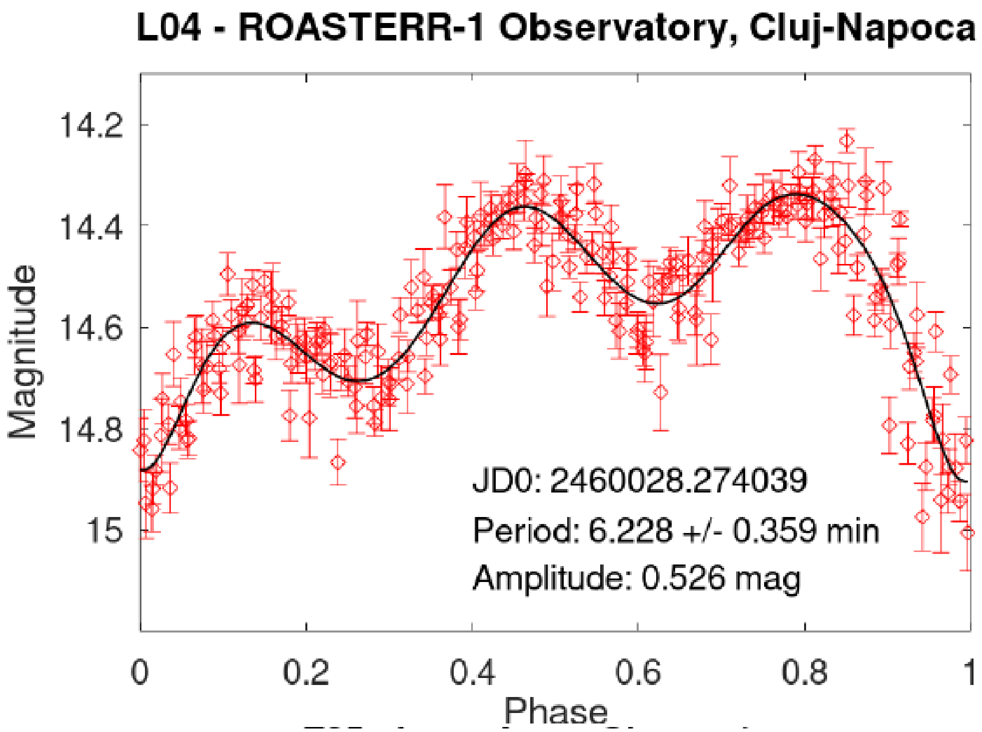
Lightcurves

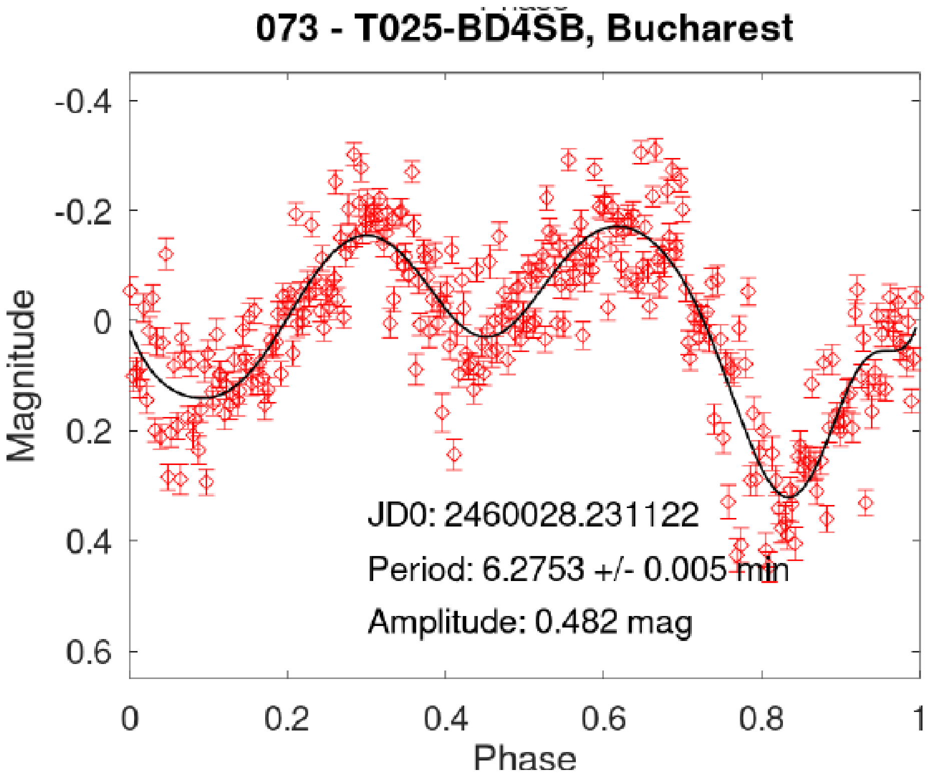
- Photometric data were obtained during three consecutive nights at the "Telescopios Gemelos de Dos Metros" (Two Meter Twin Telescopes — TTT) facility.
- The exposure time was dynamically set between 10 and 20 s to ensure a signal to noise ratio (SNR) larger than 50.
- A total of five observing runs were performed, one with TTT2 on March 20 and two simultaneous runs with each telescope on the nights of March 21 and 22.
- Photometric measurements were extracted and corrected for distance and light–time.



Phased light curve of 2023 DZ_2 computed from photometric measurements obtained by the TTT1-2 telescopes. The rotation period and amplitude of the curve are shown at the lower left corner of the top panel. The total coverage is 9.8 h, distributed over three consecutive nights. Residuals are shown in the bottom panel.

Pro – Am collaboration for lightcurves





Example of phased light curve of 2023 DZ_2 computed using photometric measurements obtained within the professional–amateurs collaboration.

What we learned from the lightcurves?

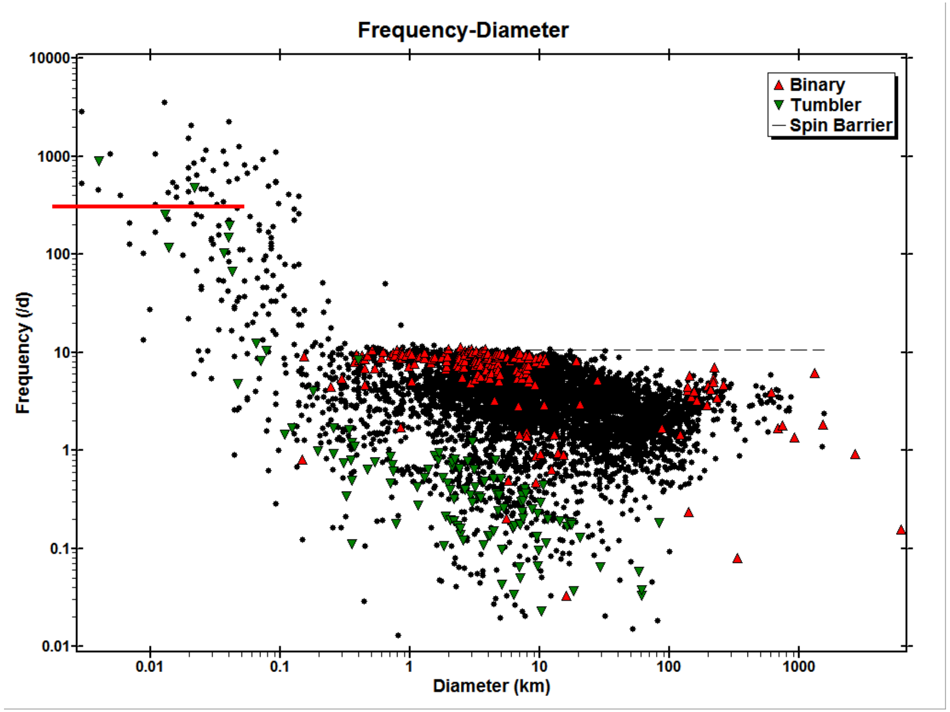
- P_{rot} = 6.274 min is indicative of **intrinsic strength to resist centrifugal disruption**, otherwise 2023 DZ2 would break apart.

- It could be a **coherent body or monolith** (e.g. Monteiro et al. 2020; Sánchez & Scheeres 2014).

- The data existing in Asteroid Lightcurve Database (LCDB, Warner et al. 2009),20 updated on February 2023 shows that **no faster rotator correspond to a low (i.e. ≤ 0.10) albedo asteroid** (Licandro et al. 2023b).

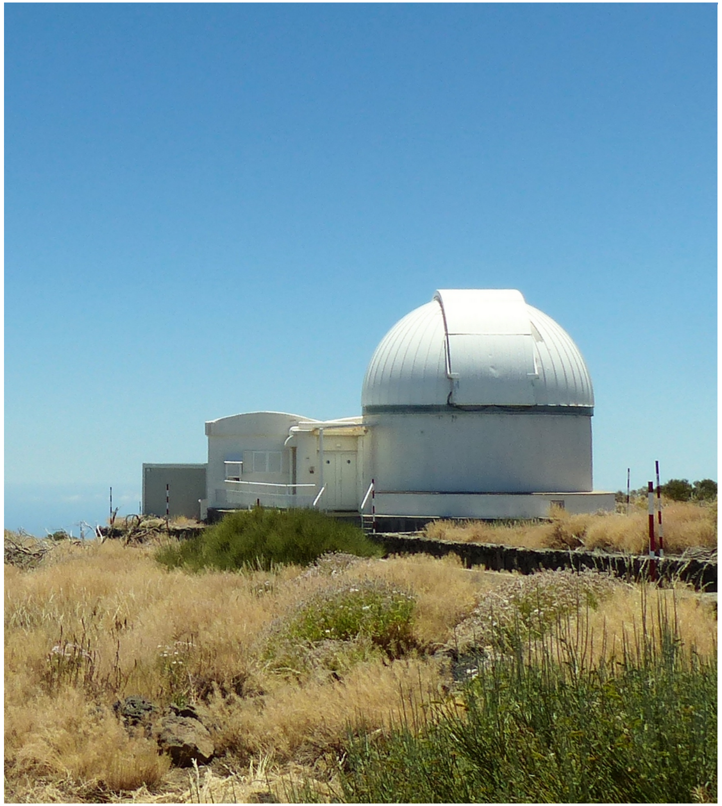
- At an absolute magnitude H ≈ 24 mag and an albedo of p_V ≤ 0.1, this asteroid will have a size larger than 60 m which for a rotation period of Prot = 6.2743 ± 0.0005 min is outside the spin barrier determined by (Rondón et al. 2020) for low albedo asteroids

- The three peaks of the light curve show an **irregular shape** which favours the hypothesis of a monolithic body.



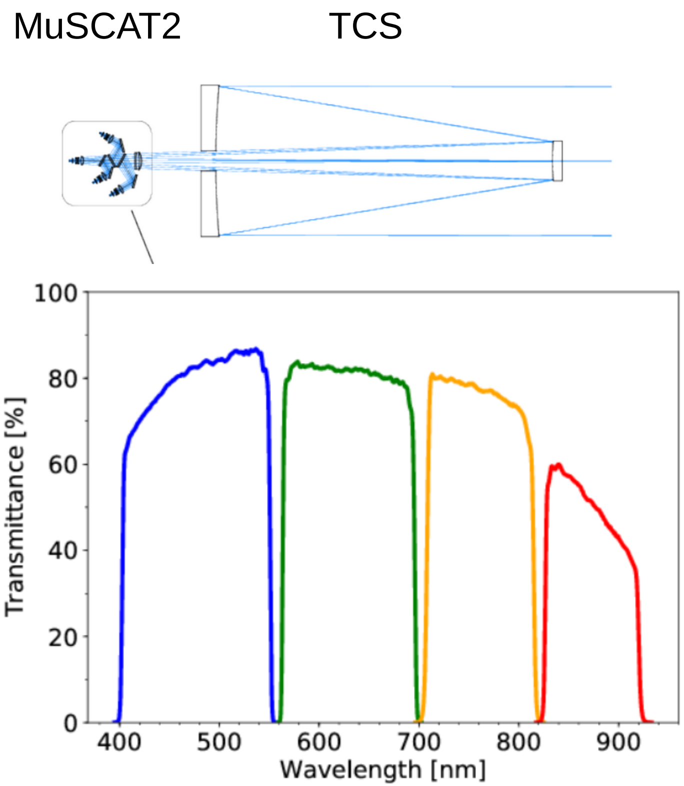
The periods of more than 8300 minor planets plotted as frequency (cycles/day) vs. size (km). Source ALCDEF -- Asteroid Lightcurve Photometry Database.

Spectro-photometry: the instrument



Telescopio Carlos Sánchez (TCS) is a 1.52 m telescope located on Teide Observatory, Izaña (Tenerife, Canary Islands, Spain) at 2390 m altitude.

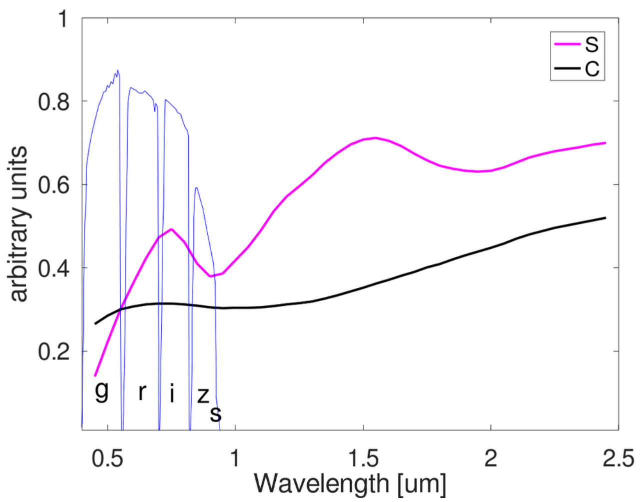
MuSCAT2 instrument mounted on TCS. The four cameras provide images obtained simultaneously with four different filters.



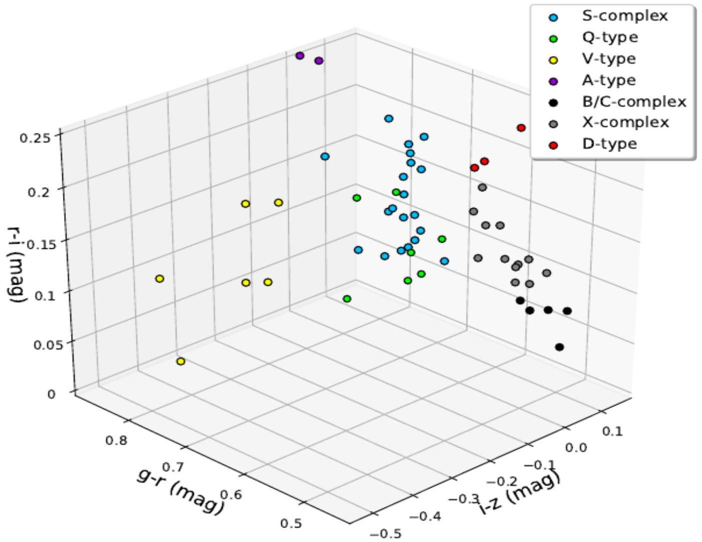
Total transmittance of the MuSCAT2 instrument in g (400–550nm), r (550–700 nm), i(700–820 nm), and zs (820–920nm) bands (Narita et al. 2019).

Classification

- The filters sample relevant spectral features for asteroids.
- For 86 asteroids observed by us there is published spectral data (e.g. Lazzarin et al. 2005, 2008; de León et al.2010; Perna et al. 2018; Popescu et al. 2019; Binzel et al. 2019 …)
- The taxonomic types defined in DeMeo et al. (2009) system have been divided in three major groups, namely the Q / S-complex (green and blue dots), C-complex (black dots) and X-complex (grey dots). Besides them, the end-member types A-, D- and V-types.



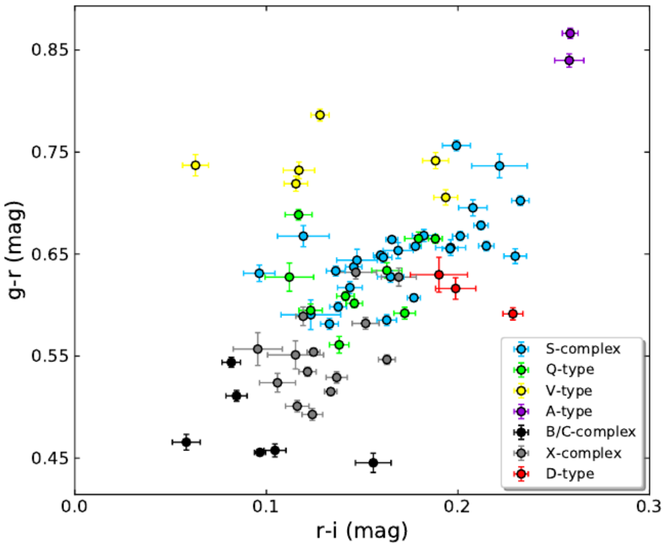
The filters profile compared with the main taxonomic classes (S-complex, C-complex) from Bus-DeMeo taxonomy.



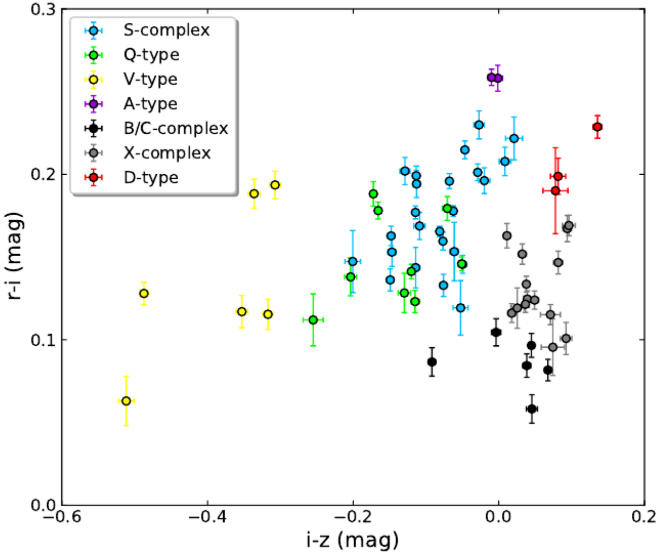
The 3D color diagram of asteroids observed by our program and for which the taxonomic type was previously known based on spectral data

Classification

- Each taxonomic group (C-complex, D, Q, S-complex, V, X) occupies a specific region in the color-color space, as a consequence of their different spectral properties.
- The RF (random decision forests) and the KNN (k-nearest neighbors) algorithms attribute a class for a new object, based on a reference set.
- We assigned a probability for each classification in order to quantify the effect of color errors.



(a)



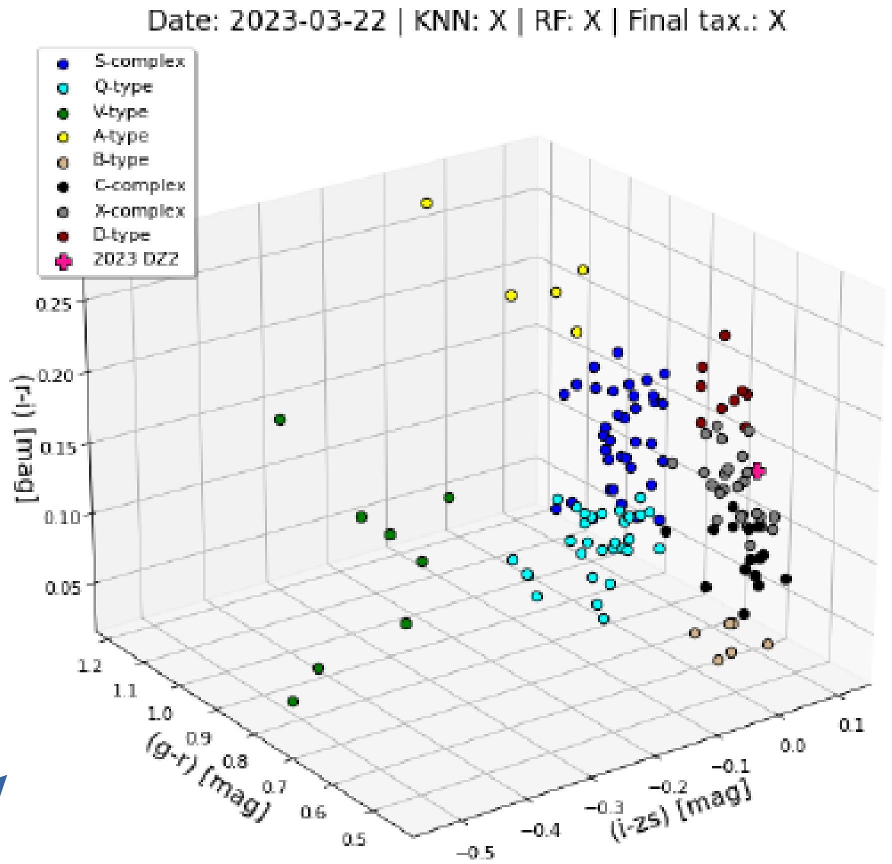
(b)

Reference set: *color-color diagrams of asteroids with already assigned taxonomic type based on the existing spectral data (e.g. Lazzarin et al. 2005, 2008; de León et al.2010; Perna et al. 2018; Popescu et al. 2019; Binzel et al. 2019 ...)*

Spectro-photometry: the results

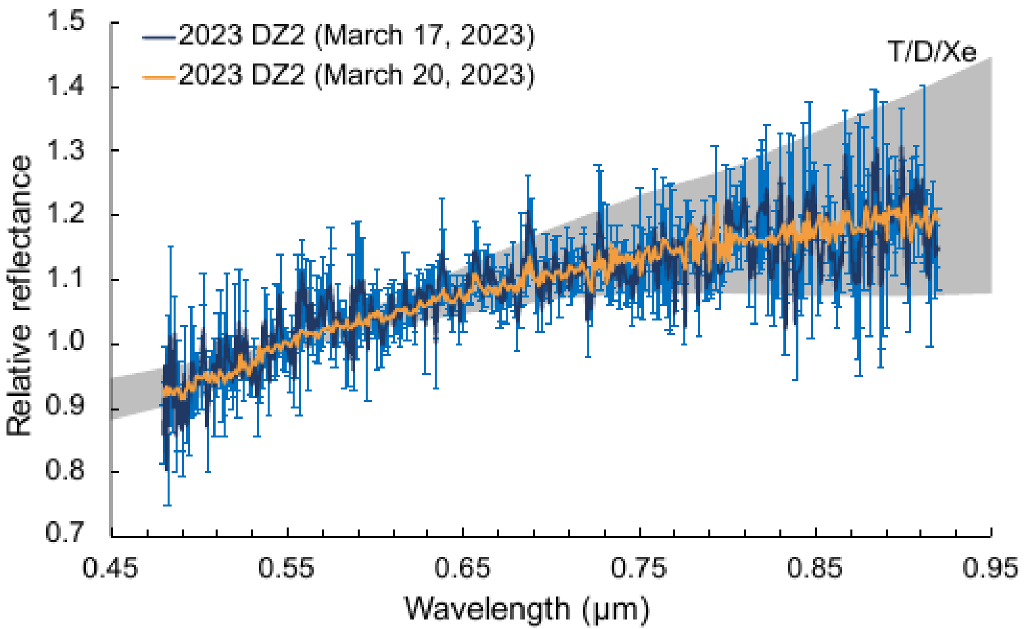
- Based on the colour values of *(g − r) = 0.555 ± 0.055 mag*, *(r − i) = 0.154 ± 0.055 mag*, and *(i − z_s) = 0.064 ± 0.059* mag both algorithms classify **2023 DZ$_2$ as an X-complex member** with 100% probability

The (g-r) vs. (r-i) vs. (i-zs) colour-colour diagrams of the 154 objects with known spectral classification, used to classify 2023 DZ2 based on the TCS/MusSCAT2 data. The taxonomic types defined in DeMeo et al. (2009) system have been divided in three major composition groups, namely the Q / S-complex (green and blue dots), C-complex (black dots) and X-complex (grey dots). Besides them, three end-member types are considered, A-, D- and V-type.



Spectroscopy

The 10.4 m Gran Telescopio Canarias allows to obtain low resolution spectra over the visible wavelengths for objects up to ***<u>~23 magnitude.</u>***



Visible spectra of asteroid 2023 DZ2 obtained with the 10.4 m Gran Telescopio Canarias (GTC) on the night of 17-March-2023 (dark blue) and on the night of 20-March-2023 (orange). Error bars correspond to the standard deviation of the mean for the March 17 data. The error bars for the March 20 data are much smaller and are contained within the larger ones. The grey hatched region accounts for the three best taxonomic fits, in order of increasing $\chi 2$: T, D, and ***<u>Xe-types.</u>***

In summary

Obs. Type	Date Obs. (UTC)	m_V	α (°)	Δ (au)	r (au)
Phot.	2023 03 20.9143	18.0	60.5	0.021	1.006
	2023 03 21.9284	17.5	60.9	0.017	1.004
	2023 03 22.9467	16.8	60.8	0.013	1.003
Colo.	2023 03 22.8725	17.0	60.7	0.013	1.003
Spec.	2023 03 17.8739	19.0	57.9	0.034	1.013
	2023 03 20.9161	18.0	60.5	0.021	1.006

Observation type includes time-series photometry (Phot.), colour photometry (Colo.) and visible spectra (Spec.). The UTC time corresponding to the start of the observations, the predicted apparent V magnitude (mV), the phase angle (α), the geocentric(Δ) and heliocentric (r) distances are shown (these were obtained using the MPC ephemeris service accessed on 30-March-2023).

- ✔ **We discovered** this Apollo-class NEA using the 2.54 m Isaac Newton Telescope.
- ✔ In less than a week since the announcement of the discovery and initial classification as VI of 2023 DZ2, **we determined**
  - *its spin rate and the light curve amplitude,*
  - *its visible colours,*
  - *and its visible spectrum.*
- ✔ Based on these observational data, **we constrained its size and estimate its composition.**
- ✔ **We predicted reliably its dynamical evolution** in the time interval (−47, +142) yr.

Popescu et al. A&A 2023

Objective accomplished!

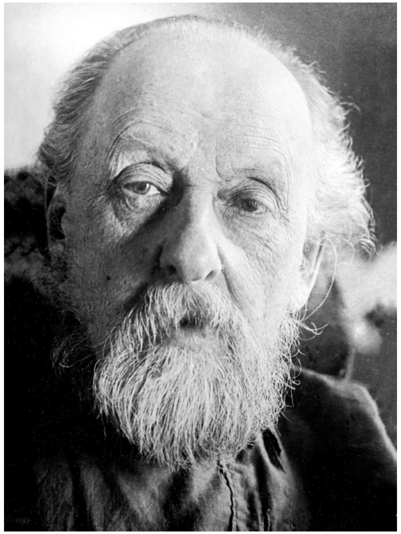
Highlight the critical observational capabilities, both in terms of instruments and data analysis resources, required to implement mitigation strategies to face the potential disasters coming from a cosmic hazard such as an asteroid impact.

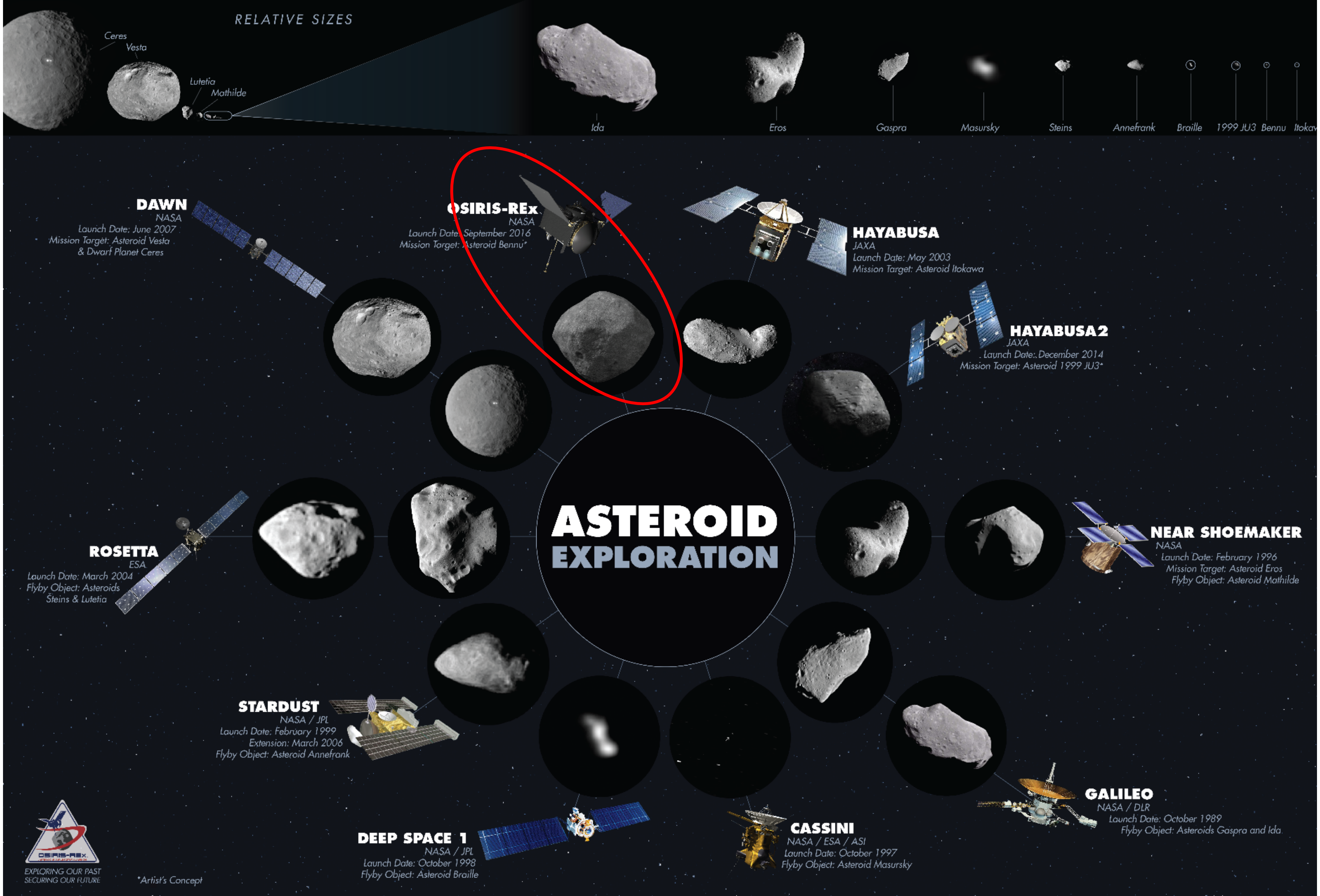
Epilogue

- 2023 DZ2 safely passed at a distance of 175 030 km from Earth, on March 25 at 19:51 TDB (time-scale conversion difference TDB − UT 69.185285 s), when it reached an apparent visual magnitude of 10.3 (for a minimum of ≈10 mag reached about two hours prior to perigee).
- Thanks to its brightness it offered a unique opportunity for characterization with various observational techniques: photometry, spectro-photometry, spectroscopy of various spectral intervals (visible, near-infrared, mid-infrared), polarimetry, and radar.
- The International Asteroid Warning Network (IAWN) organized a world wide campaign with the aim of involving as many observing facilities as possible, in a coordinated manner, to obtain the most accurate physical information about this object.
- The close approach of 2023 DZ_2 offered a great opportunity for a world-wide collaboration to study a potential NEA impactor discovered one month prior to its close approach.

Earth is the cradle of humanity, but one cannot live in a cradle forever.

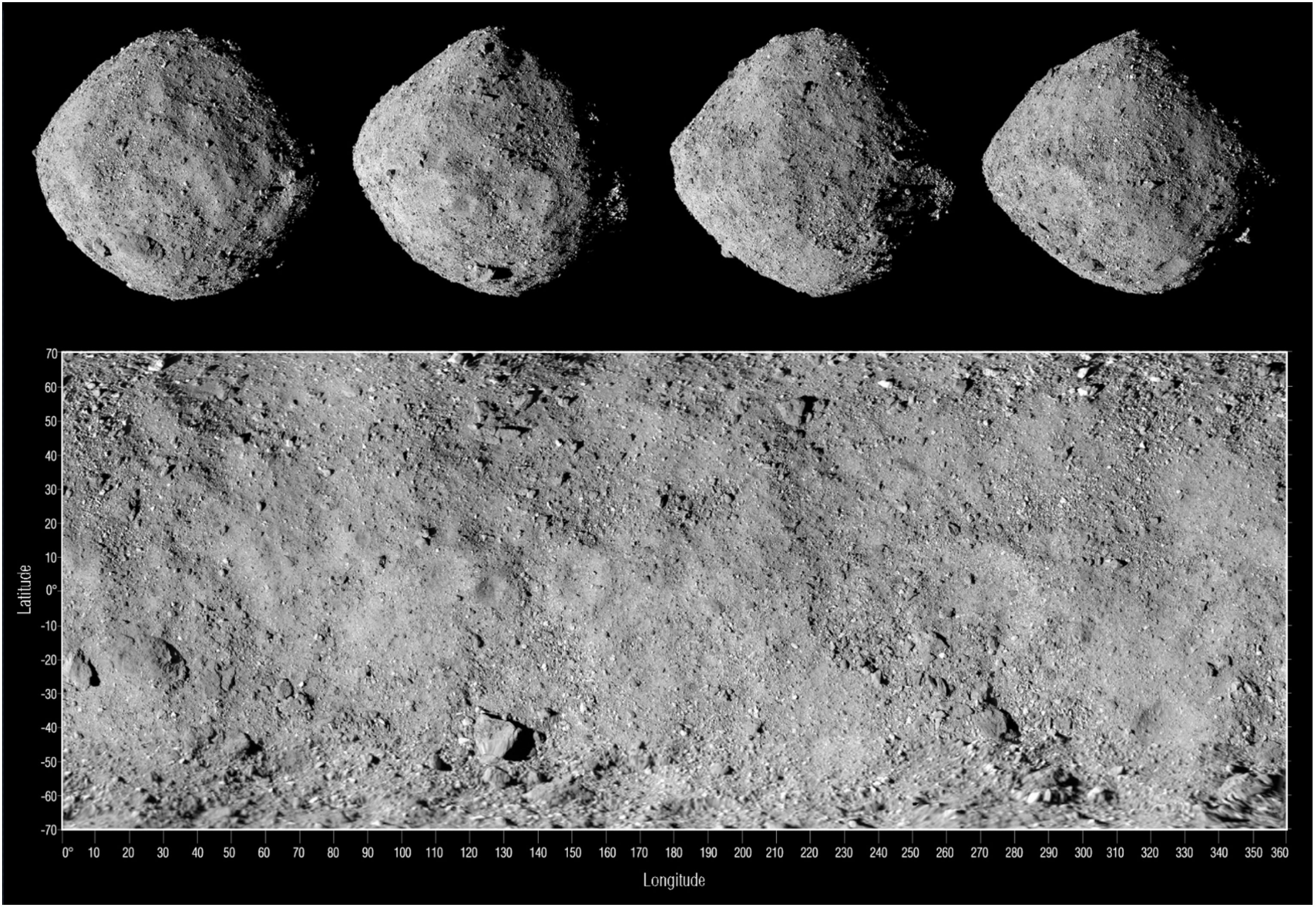
Konstantin Eduardovich Tsiolkovsky





RELATIVE SIZES
Ceres
Vesta
Lutetia
Mathilde
Ida
Eros
Gaspra
Masursky
Steins
Annefrank
Braille
1999 JU3
Bennu
ASTEROID
EXPLORATION
DAWN
NASA
Launch Date: June 2007
Mission Target: Asteroid Vesta
& Dwarf Planet Ceres
OSIRIS-REx
NASA
Launch Date: September 2016
Mission Target: Asteroid Bennu*
HAYABUSA
JAXA
Launch Date: May 2003
Mission Target: Asteroid Itokawa
HAYABUSA2
JAXA
Launch Date: December 2014
Mission Target: Asteroid 1999 JU3*
NEAR SHOEMAKER
NASA
Launch Date: February 1996
Mission Target: Asteroid Eros
Flyby Object: Asteroid Mathilde
GALILEO
NASA / DLR
Launch Date: October 1989
Flyby Object: Asteroids Gaspra and Ida
CASSINI
NASA / ESA / ASI
Launch Date: October 1997
Flyby Object: Asteroid Masursky
DEEP SPACE 1
NASA / JPL
Launch Date: October 1998
Flyby Object: Asteroid Braille
STARDUST
NASA / JPL
Launch Date: February 1999
Extension: March 2006
Flyby Object: Asteroid Annefrank
ROSETTA
ESA
Launch Date: March 2004
Flyby Object: Asteroids
Steins & Lutetia
EXPLORING OUR PAST
SECURING OUR FUTURE
*Artist's Concept

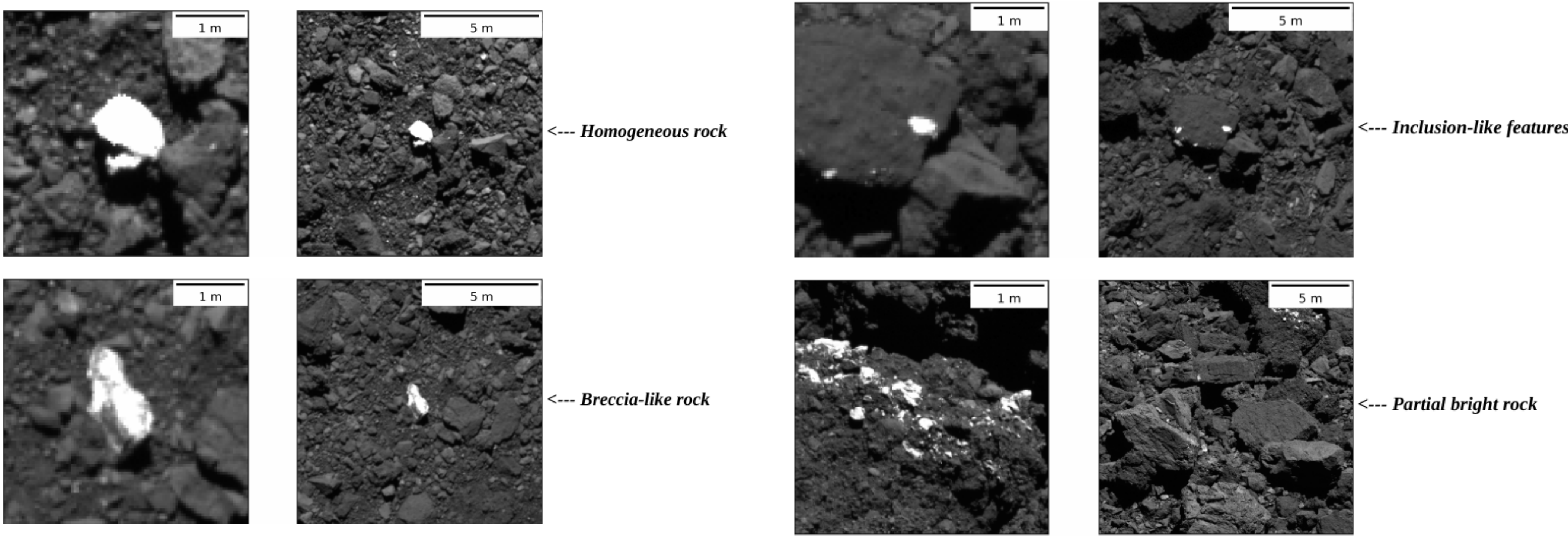
A world in miniature: asteroid Bennu



Asteroid Bennu imaged by the OSIRIS-REx Camera Suite (Credit NASA/JPL - OSIRIS-REx). a) Whole-disk mosaics of Bennu. PolyCam images from 2 December 2018 are combined to show four sides of Bennu. When viewed from left to right these data illustrate one rotation of the asteroid. Phase angles of the images are between 47.72° and 51.91°, and pixel scales are between 0.509 and 2.926 m/pixel b) Global equirectangular map of Bennu. PolyCam images acquired on 1 December 2018 (phase angle range of 33.22° and 35.76° and pixel scales between 0.743 and 3.866 m/pixel) are combined with MapCam images from 13 December 2018, (phase angle range of 38.15° to 52.01° and pixel scales between 1.331 to 1.885 m/pixel) and mosaicked into this equirectangular map of Bennu. North is defined as the +Z pole and points to the top of the image.

DellaGiustina et al. 2019, Nature Astronomy

Widely Distributed Exogenic Materials of Varying Compositions on Asteroid (101955) Bennu



Examples of OSIRIS-REx PolyCam images which outlines the morphological classification of various candidate exogenous material.

Rubble-pile asteroids formed as a result of the catastrophic disruption of a parent body and re-accumulation of the resulting fragments. This process could incorporate materials from both the parent body and its catastrophic impactor.We reported 77 boulders containing possible exogenic material widely distributed across Bennu's surface.

Tatsumi & Popescu et al. MNRAS 2022

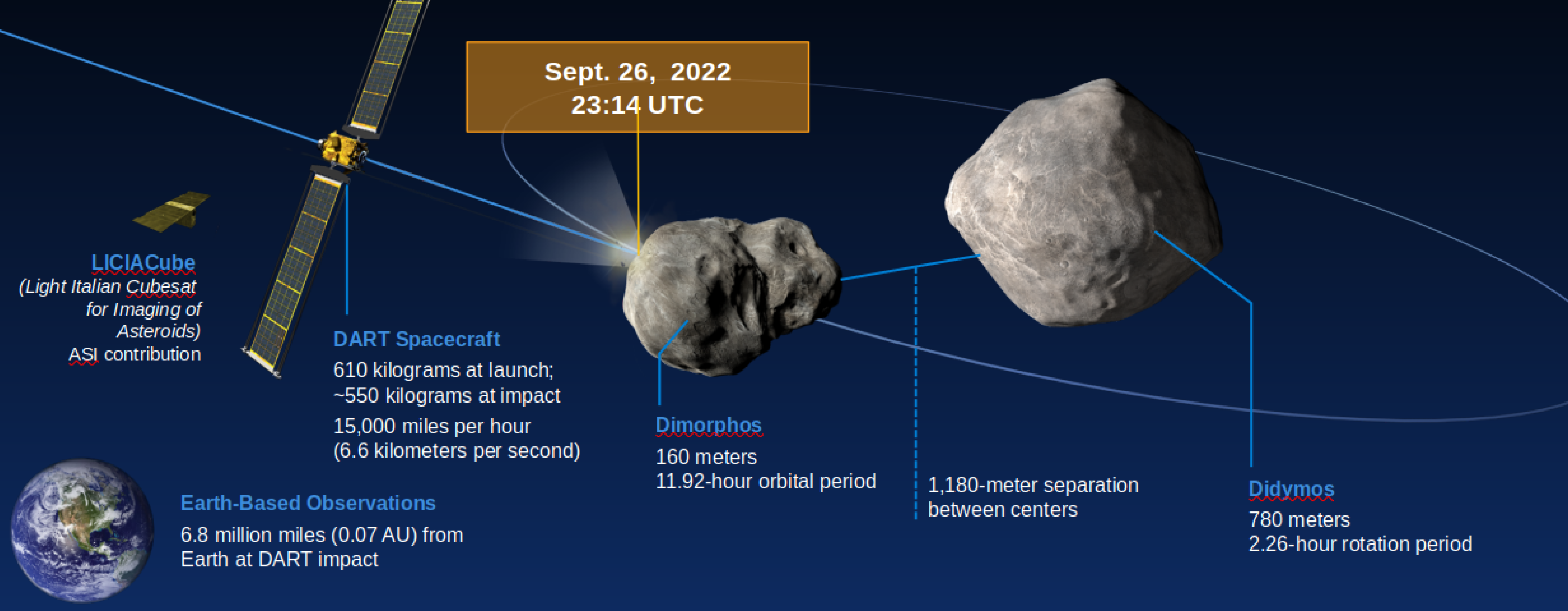
Asteroid Impact and Deflection Assessment (AIDA)

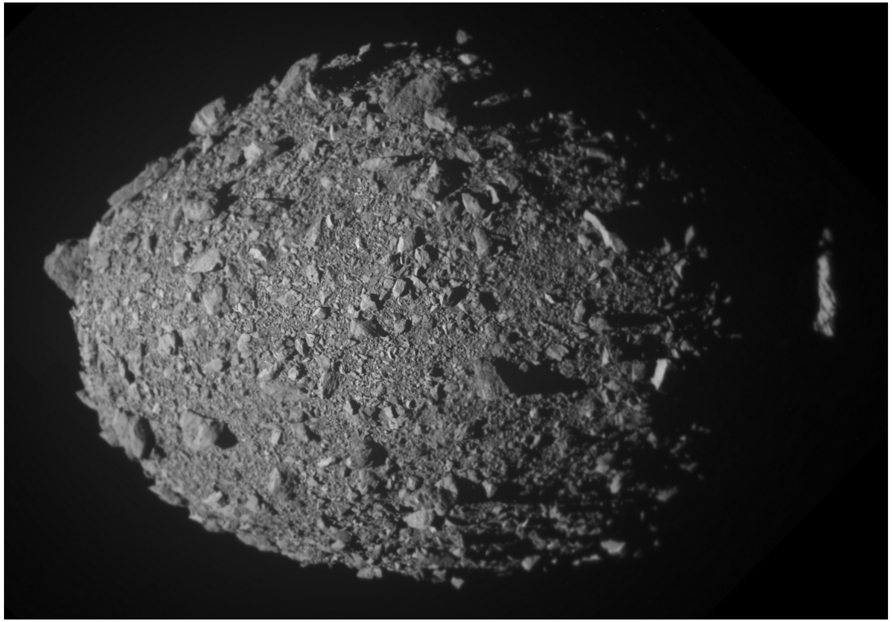
Launch

Nov. 24, 2021

SpaceX Falcon 9
Vandenberg Space Force Base, CA

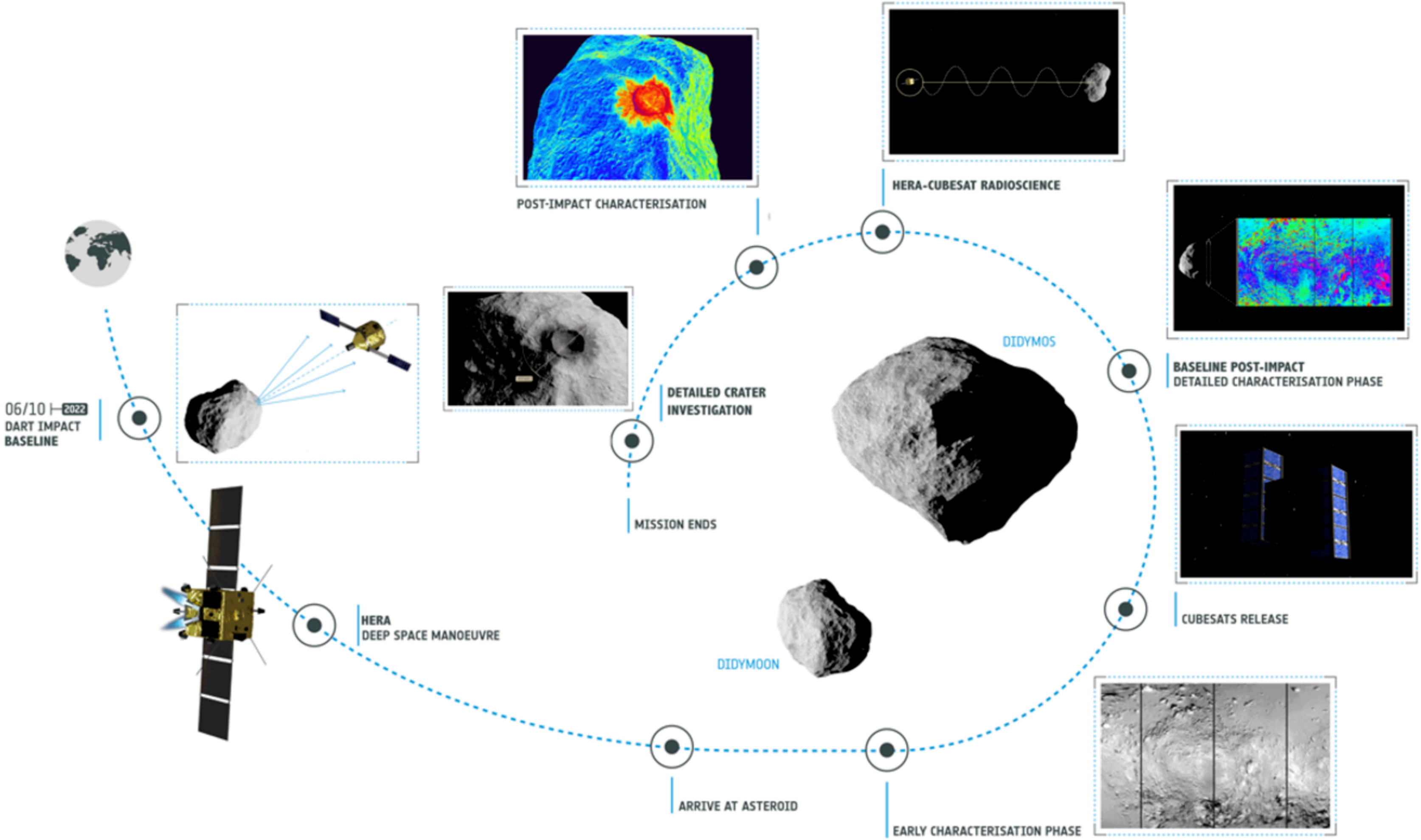
- Target: the binary asteroid Didymos system
- Impact Dimorphos and change its orbital period
- Measure the period change from Earth





Dimorphos - Image obtained by NASA/DART mission with ***11 sec before the impact****. Credit: NASA/JPL, DART mission*

*Image obtained with the 1.52 m Carlos Sánchez telescope (Teide Observatory, Tenerife, Spain) on September 30, 2022 (****3 days after the DART impact****), 04 - 05 UTC. The Sloan g, r, i filters were used.*



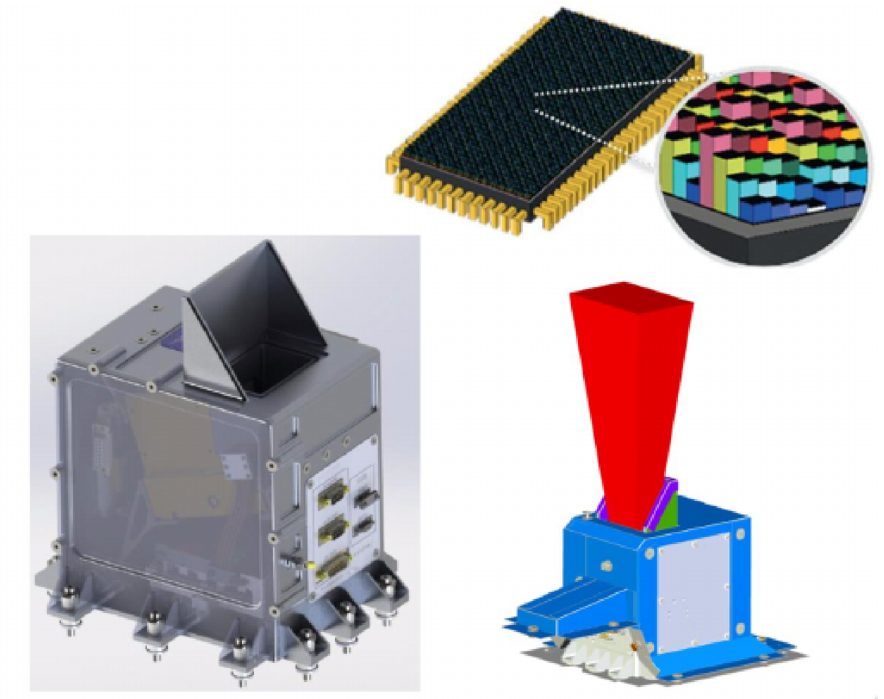
ESA/HERA mission plan

Source: https://www.heramission.space/, https://www.esa.int/Space_Safety/Hera

Further work: hyperspectral imaging

cosine measurement systems

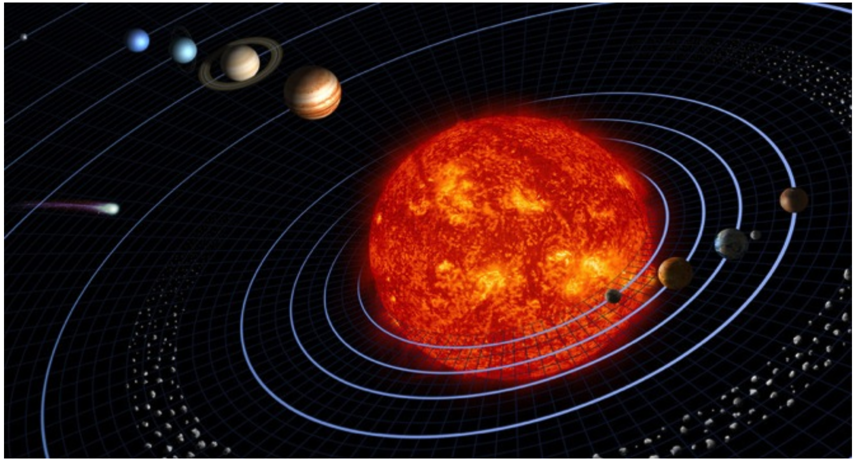
- HyperScout – H (HS-H) is a miniaturized hyperspectral instrument dedicate to planetary missions.
- It is equipped with a 2D sensor and a filtering element for spectral separation.
- The HyperScout line of instruments is developed by *cosine* (*https://www.cosine.nl/*) and partners with support from the European Space Agency and the Netherlands Space Office.
- It has first been developed as an Earth Observation payload by a European consortium led by Cosine Measurement Systems.



The Hyperscout-H, provided by Cosine (NL)

NEOs: exploring our past, securing our future

Revealing Solar System History



Mitigating Impact Hazards

Enabling Human Exploration

Developing a Space Economy

And more: the NEOMIR mission