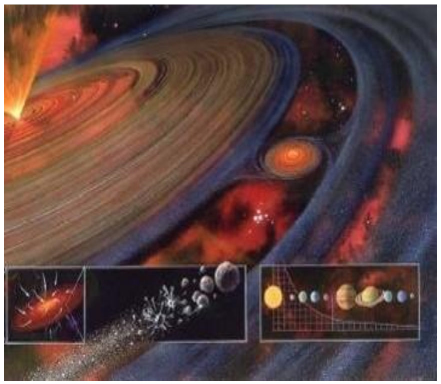
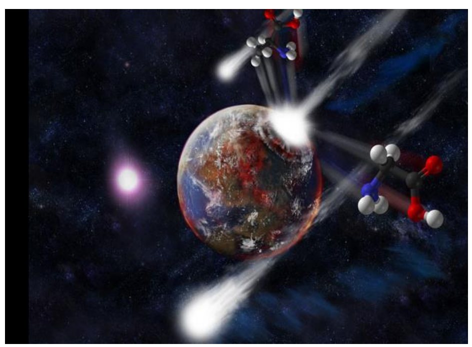
Davide Perna

INAF – Osservatorio Astronomico di Roma



Near-Earth Asteroids: Risks and Opportunities

LIneA Webinar – 15 July 2021

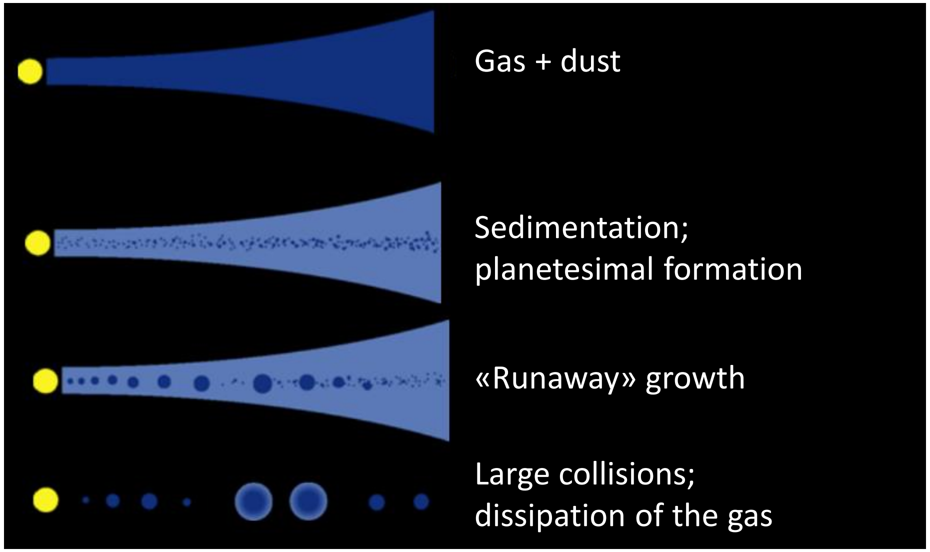
Small bodies: witnesses of the primordial solar system

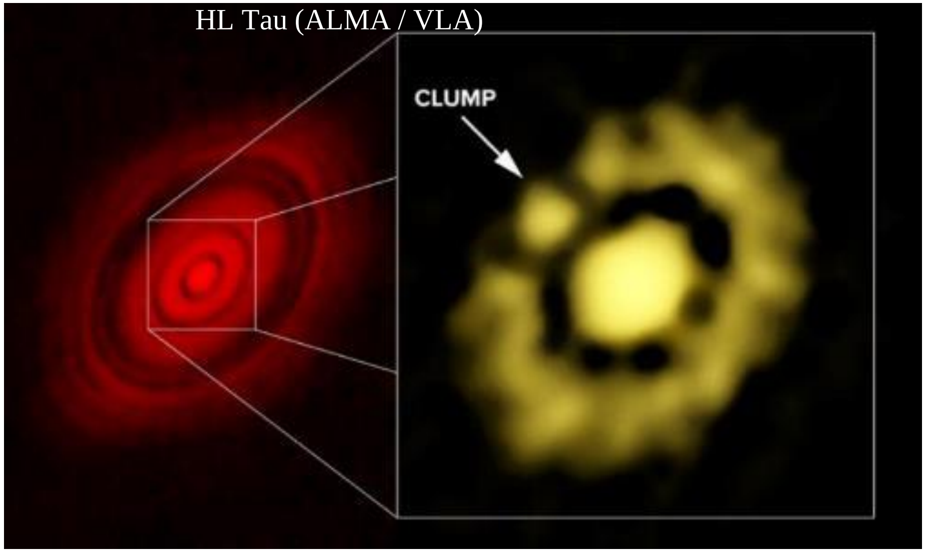
Which processes governed the formation and evolution of the primordial solar system?

Which information we can get for the study of exoplanetary disks?

Solar system small bodies represent the last vestiges of planetesimals and protoplanets

The solar system as a “case model” that we can study in detail, and even in-situ

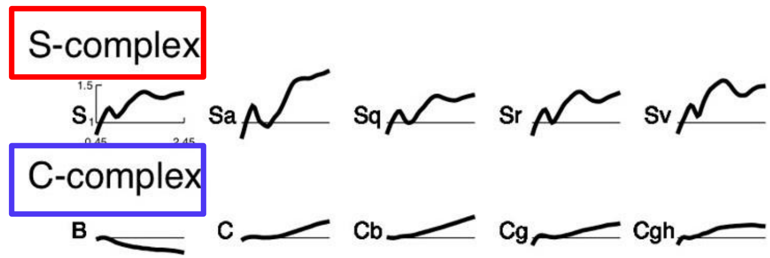


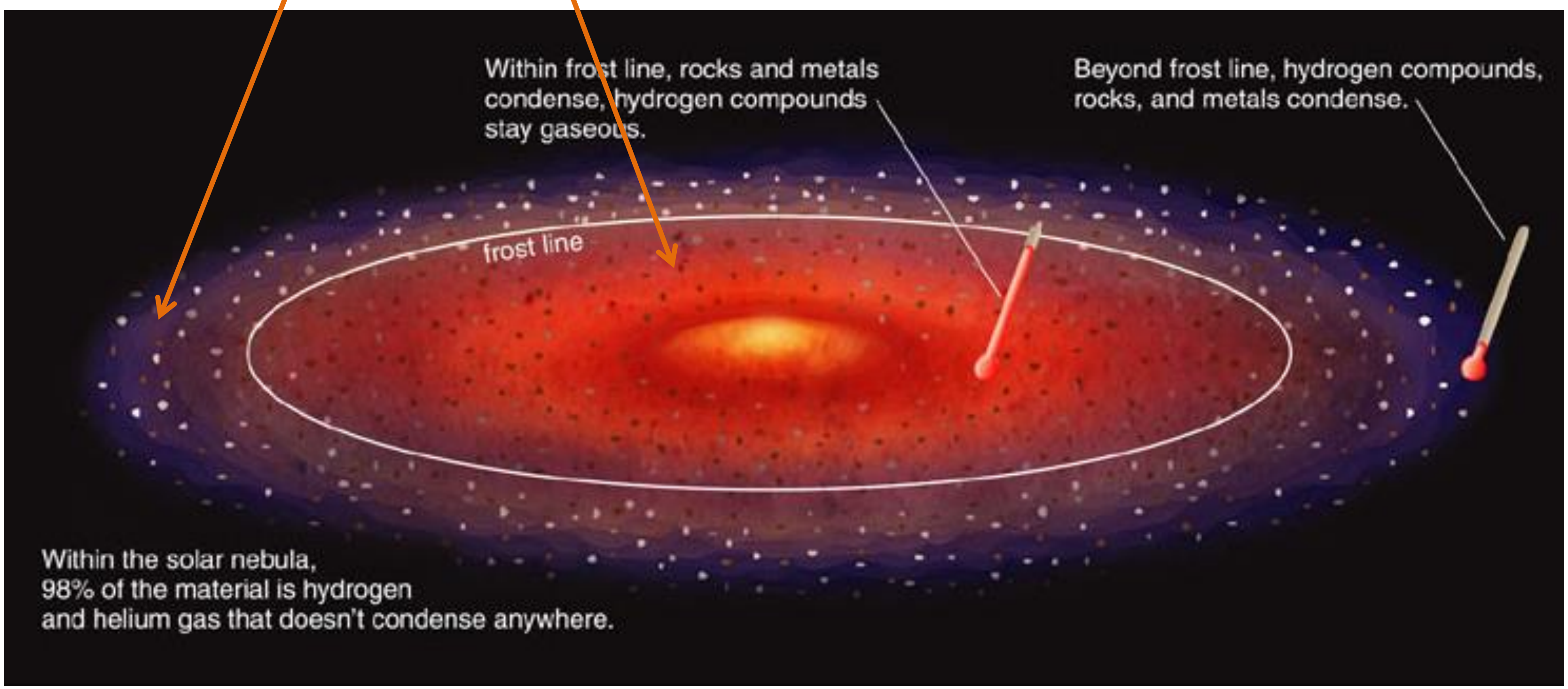


Small bodies: witnesses of the primordial solar system

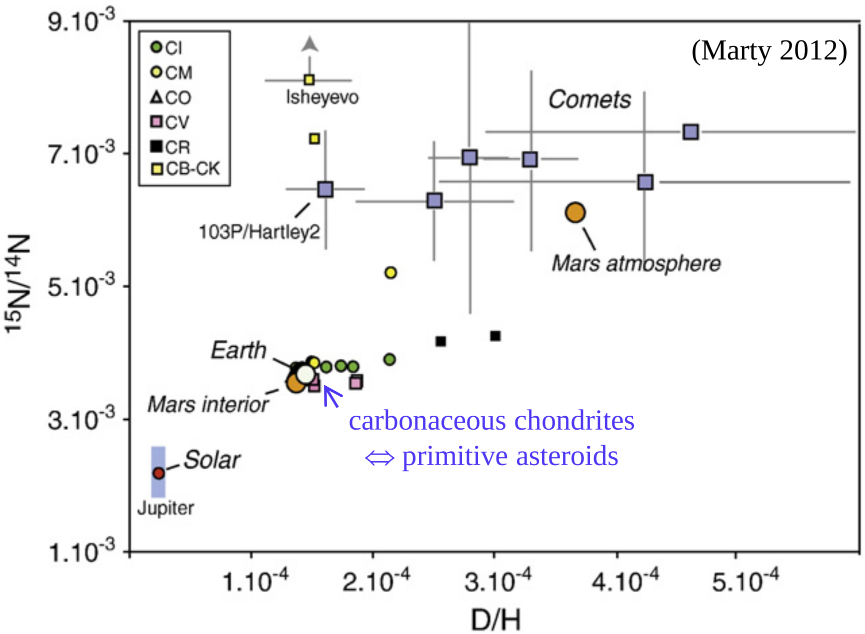
«Evolved» small bodies

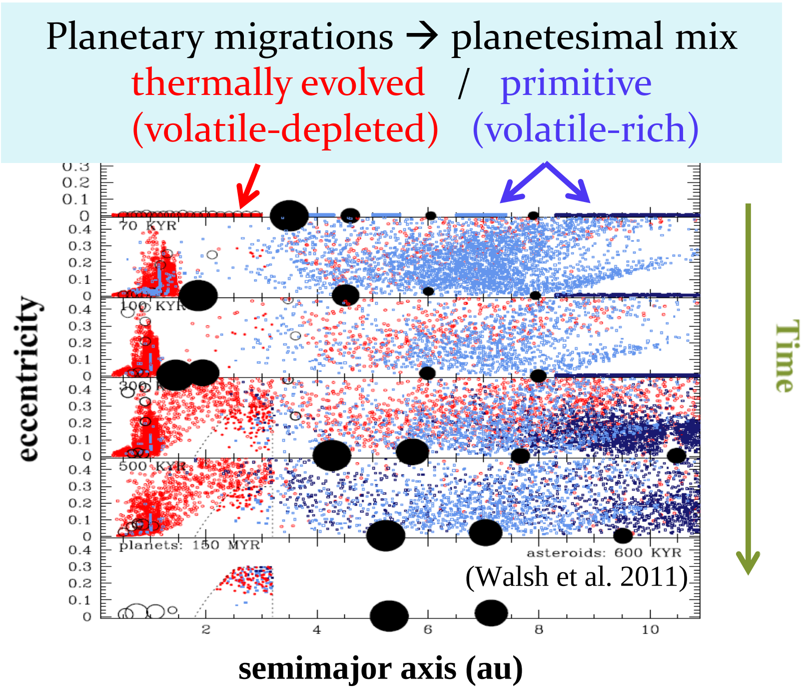
«Primitive» small bodies





Primitive asteroids:
the most probable source of prebiotic material



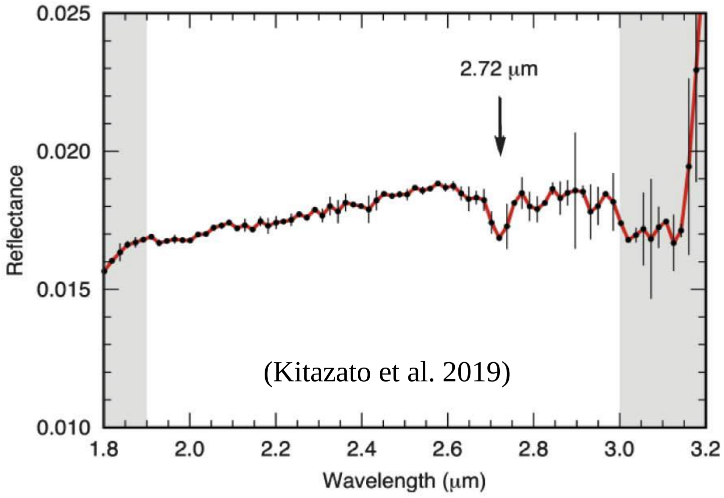


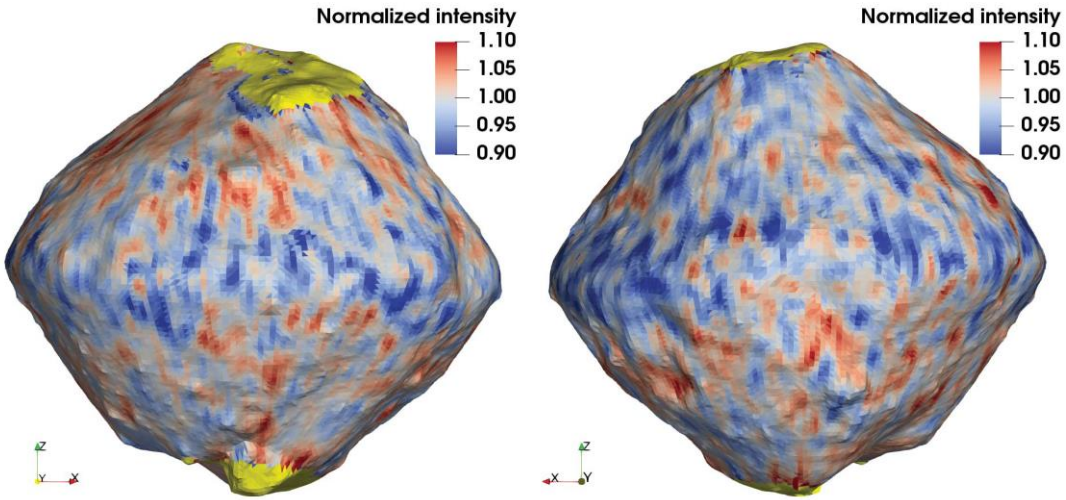
Both:

- **isotopic ratio measurements**
- **dynamical simulations**

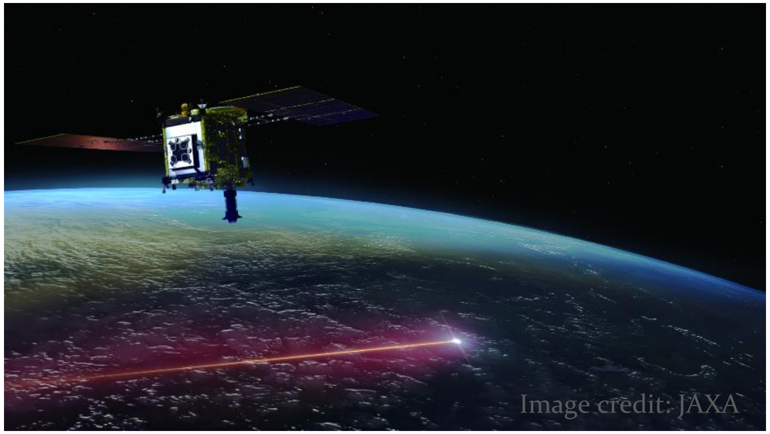
point towards a major delivery by water- and organic-rich primitive asteroids

Hayabusa 2 @ Ryugu





OH–bearing minerals (most likely Mg-rich phyllosilicates) are ubiquitous on Ryugu



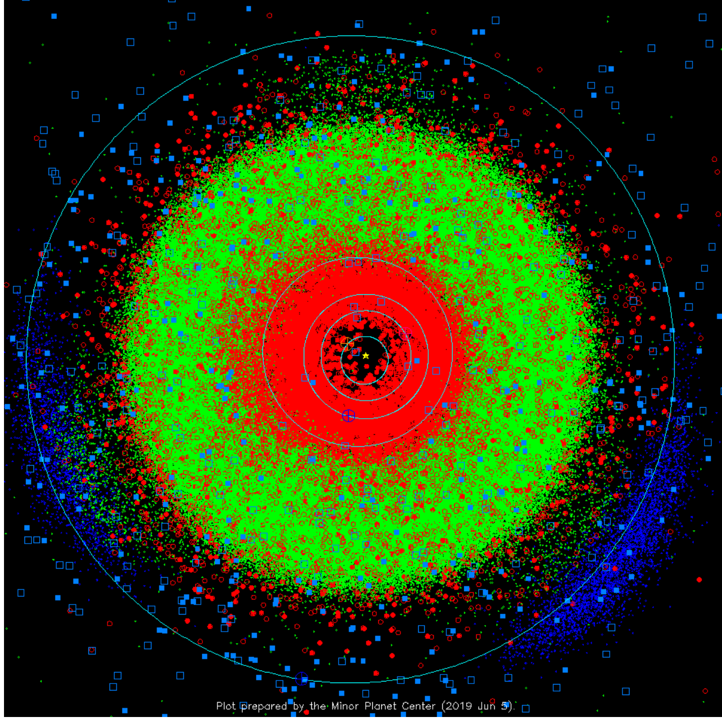
Solar System Small Body census

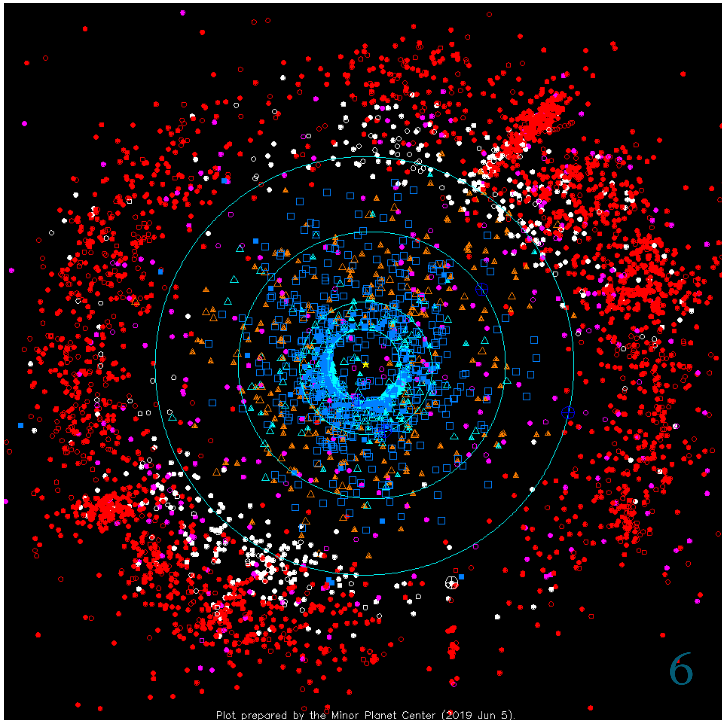
- Existing: ≈ 10^{12} - 10^{14}
- Discovered: ~10^6 (~10^7 with LSST)
- Space mission targets: ~30

→

space missions to study in unprecedented detail selected targets and their returned samples...

... ground-based studies to characterise the global population and better quantify how much of prebiotic material these objects could have brought to the primordial Earth

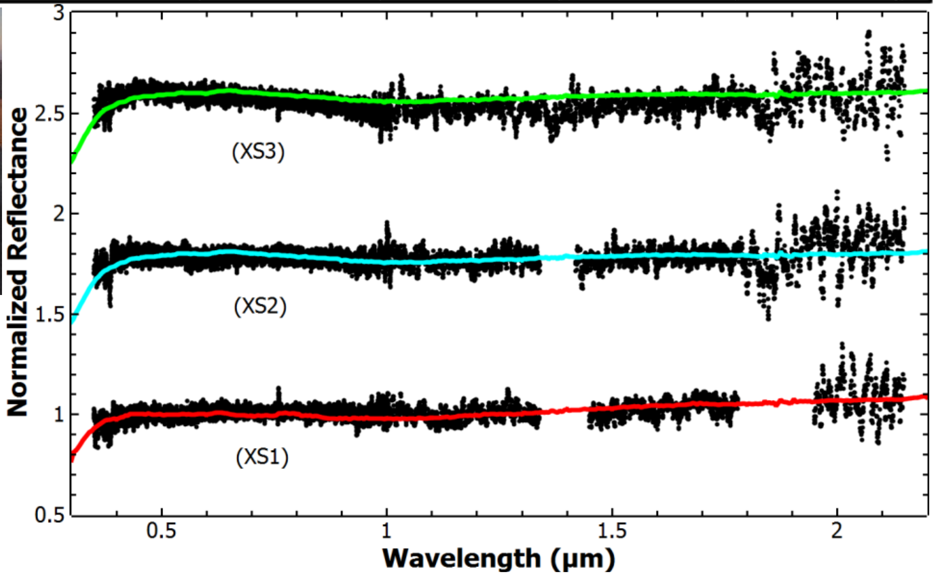


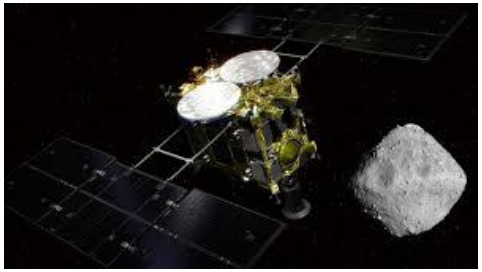


Ryugu composition: the "ground truth"

Perna et al. (2017), based on ESO-VLT data:

- "...small heterogeneities on the surface"
- "...best fitting meteorites are unusual/heated CM and CI carbonaceous chondrites"

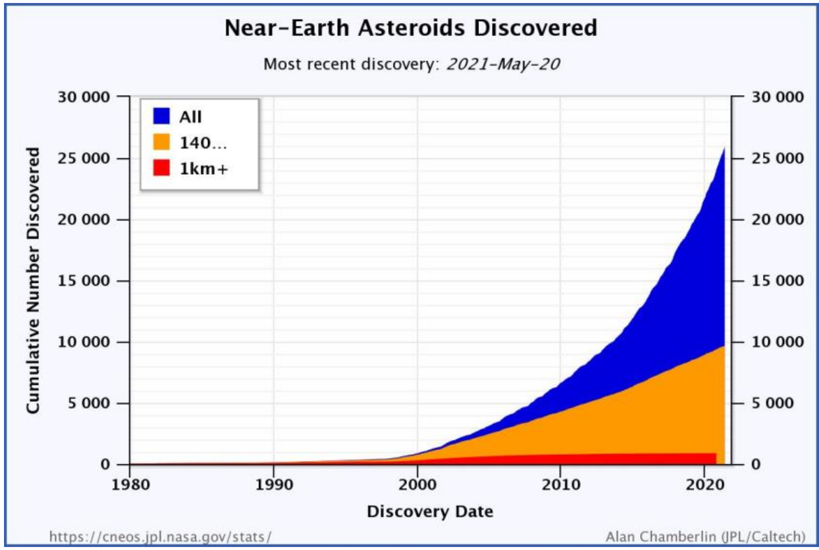




Kitazato et al. (2019), based on NIRS3/Hayabusa 2 data:

- "...relatively homogeneous composition"
- "...spectra of thermally metamorphosed CI chondrites and shocked CM chondrites are similar to those of Ryugu"

The Near-Earth Asteroid population



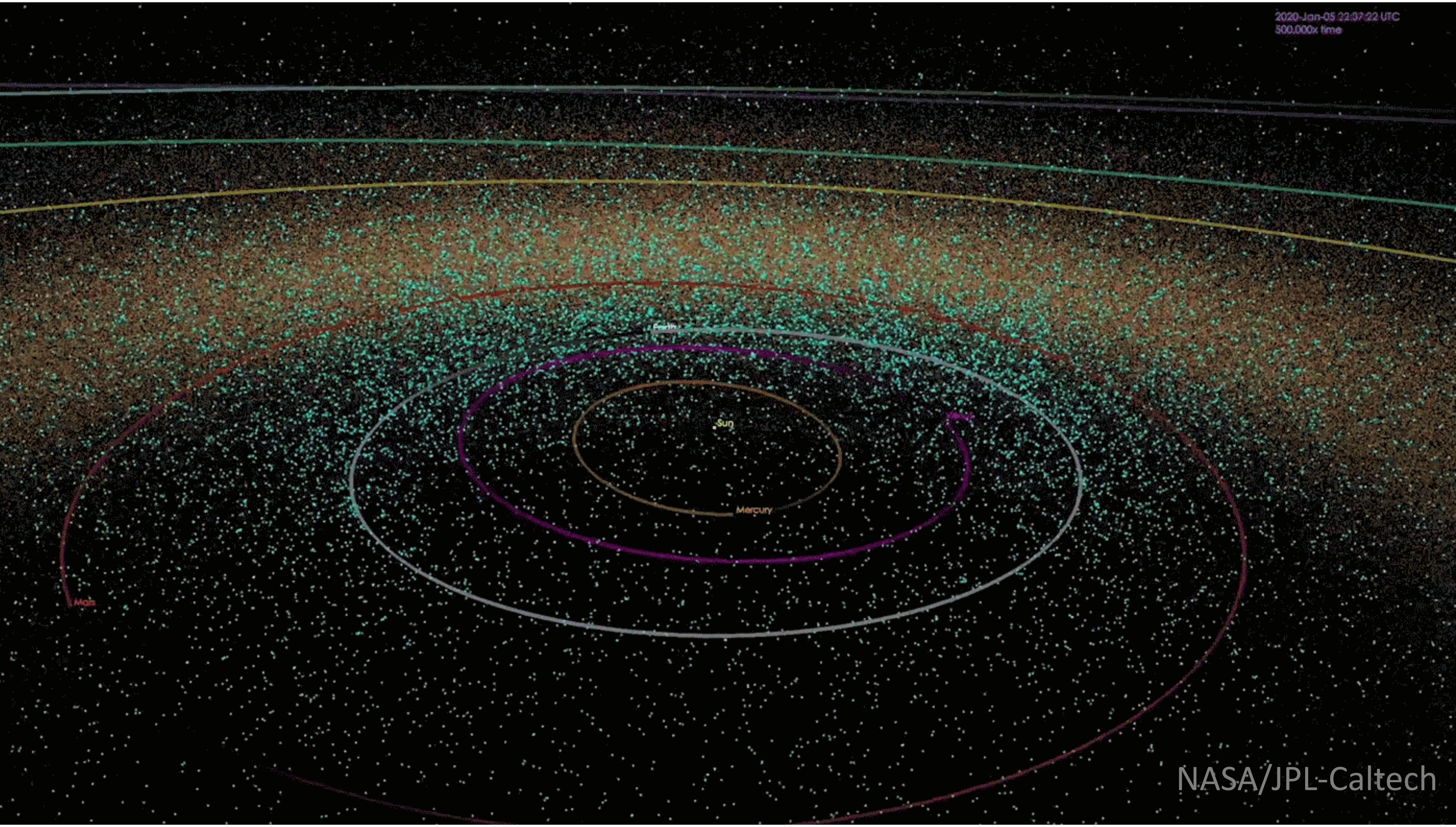
A Ride With The Earth

An animation centered on Earth showing the known objects that have approached to within 20 million km between July 2007 and June 2008. See the Animations Page on the MPC website for a description of the symbols used in this animation.

Population discovered was >5 times smaller than today

https://minorplanetcenter.net/

The Near-Earth Asteroid population



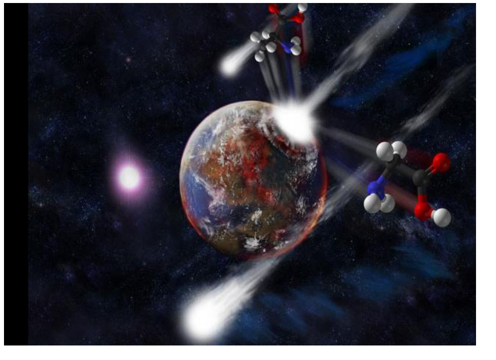
Why Near-Earth Asteroids do matter

- The closest building blocks of the solar system
  - ✓ Relevant for the origin of prebiotic material on the early Earth
  - ✓ Study of small-sized asteroids

- Accessible targets for space missions
  - ✓ Science
  - ✓ Water/mineral resources

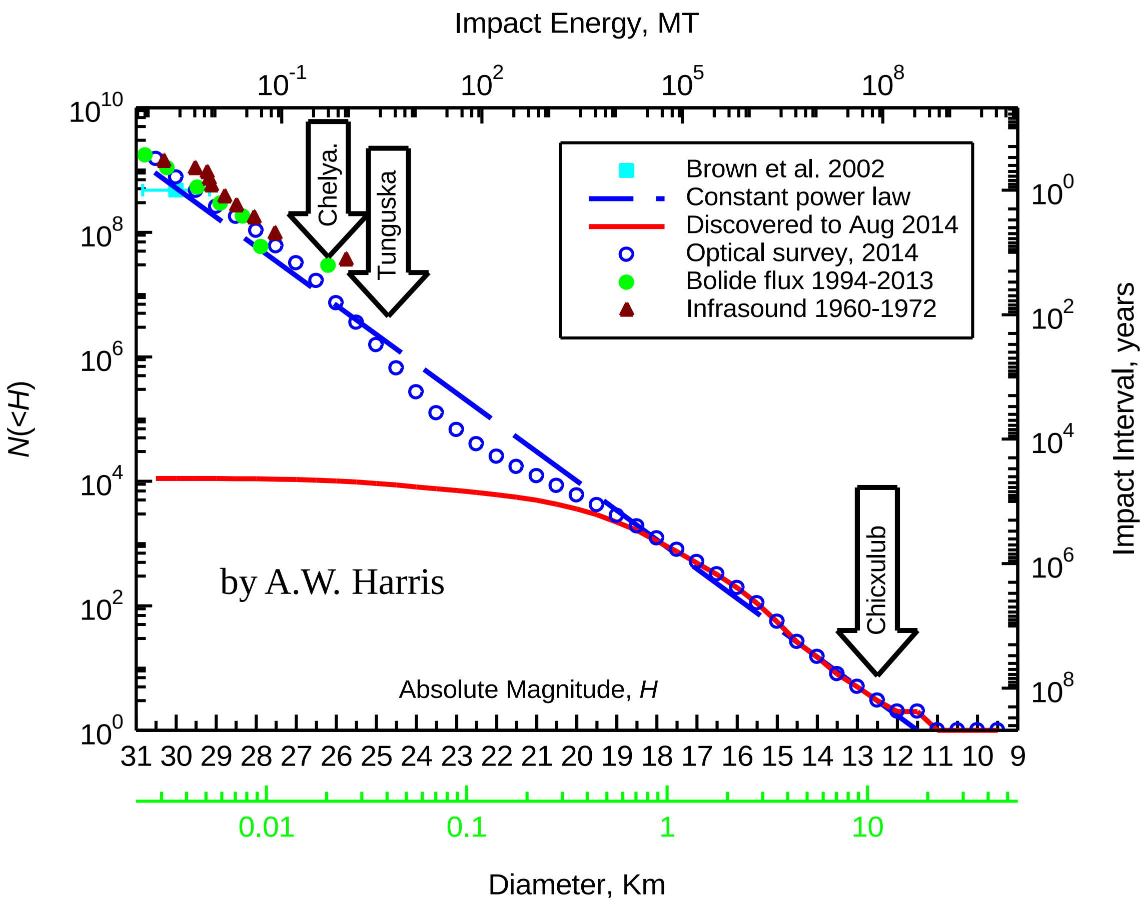
- Planetary defense



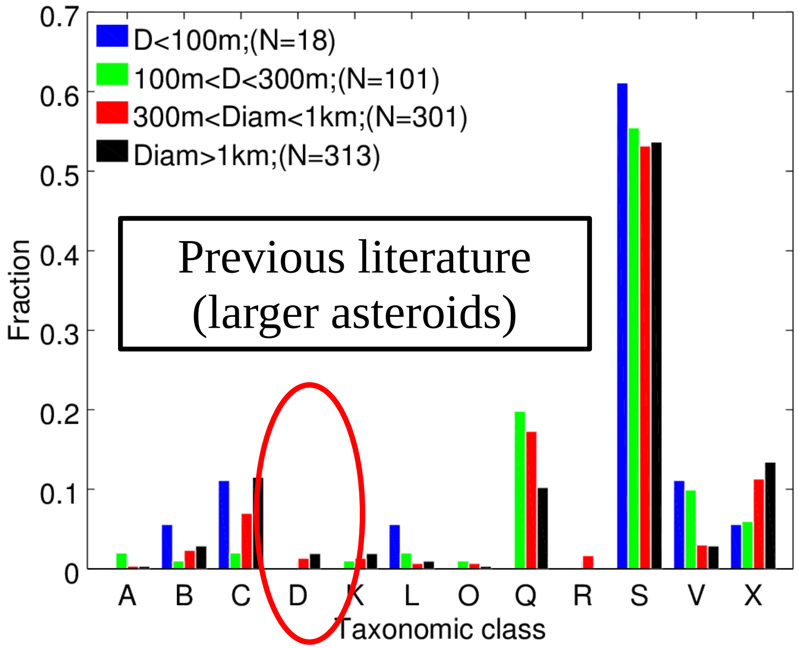
Why to study the "small" near-Earth asteroid population?

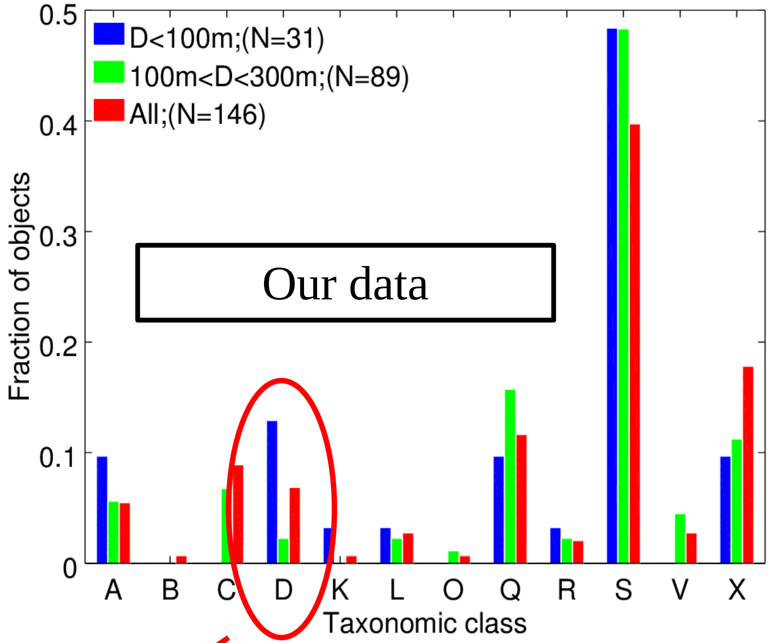
- **Most frequent impactors**
- **Opportunity to study size-dependent physical properties (composition, Yarkovsky effect, rotation, shape, material strength, …)**
- **Extremely poorly known (observable only at close approaches)**

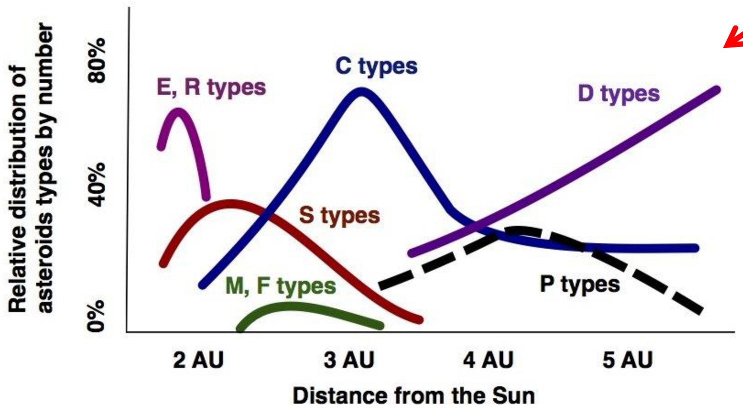


Small NEAs: ESO-NTT visible spectroscopy

(Perna et al. 2018)



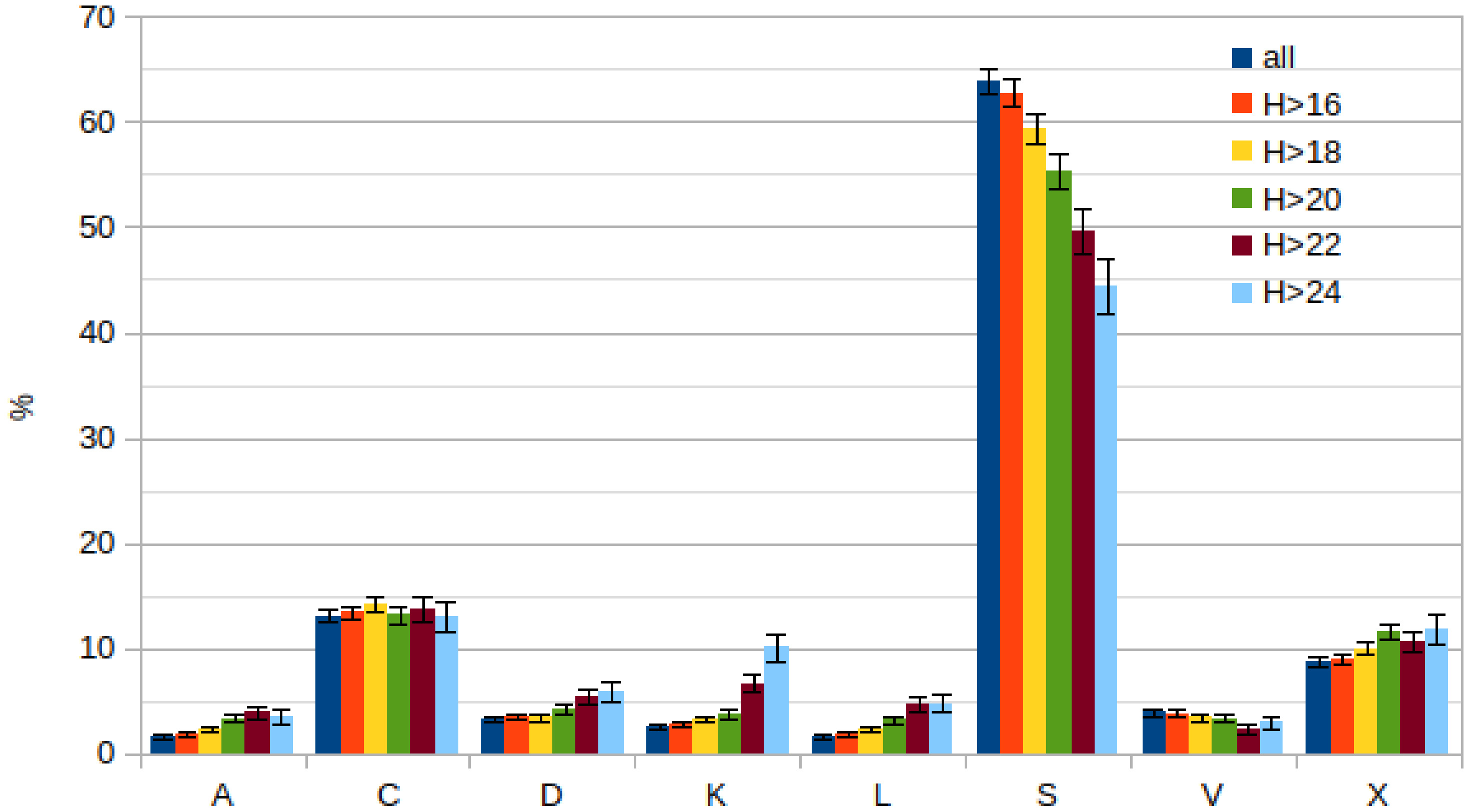




Asteroidal contribution to the terrestrial prebiotic material could be even more important than previously foreseen

Small NEAs: extended survey

(Ieva et al. 2020)



- **Our data (ESO-NTT + TNG) + MITHNEOS/MANOS surveys: 1081 NEAs**
- **Primitive (dark) asteroids: more abundant at small sizes (larger H), despite observational bias**
- **Still limited statistics (few tens of NEAs) for most classes: more data needed!**

NEO ROCKS

Near Earth Object Rapid Observation, Characterization and Key Simulations

- **Kick-off & nominal duration**: Jan 2020, 3.5 years
- **Funding by the EC**: 2.1 M€

Most of current NEA discoveries: small-sized objects at close approaches (many are lost due to lack of follow-up observations)

→ A main goal of NEOROCKS: rapid-response dynamical and physical characterization of newly-discovered NEAs

→ Significant increase of the statistics on small NEAs!

Participant organisation	Country
Istituto Nazionale di Astrofisica (INAF) – *coordinating partner*	Italy
Agenzia Spaziale Italiana	Italy
University of Padova	Italy
LESIA – Obs. de Paris	France
Obs. de la Cote d'Azur	France
University of Edinburgh	UK
Astronomical Institute of the Czech Academy of Sciences	Czech Republic
Instituto de Astrofisica de Canarias	Spain
SpaceDyS s.r.l.	Italy
DEIMOS Space s.l.u.	Spain
DEIMOS Space s.r.l.	Romania
DEIMOS Castilla La Mancha	Spain
NeoSpace sp z.o.o	Poland
Resolvo Srl	Italy

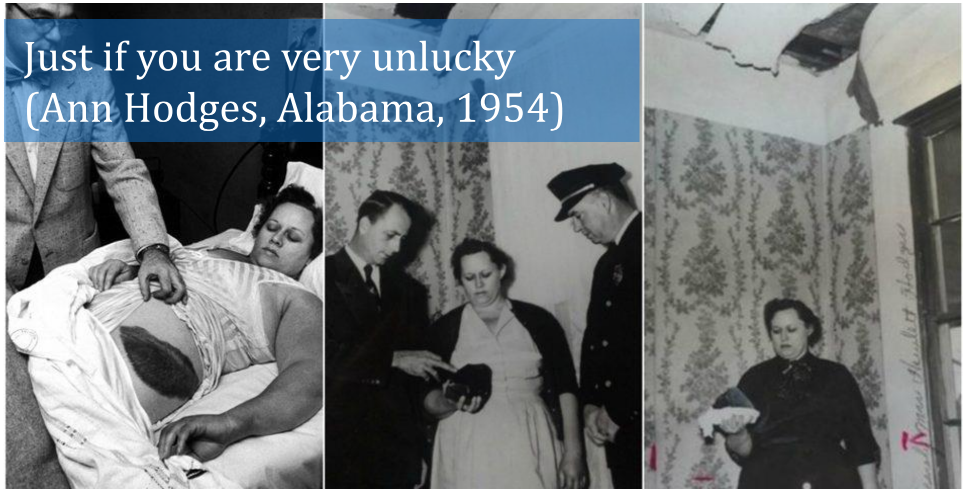
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 870403.

Horizon 2020
European Union funding
for Research & Innovation

The NEA proximity: a risk...

Every ≈10^4 years
Energy: ≈10^3 Hiroshima bombs

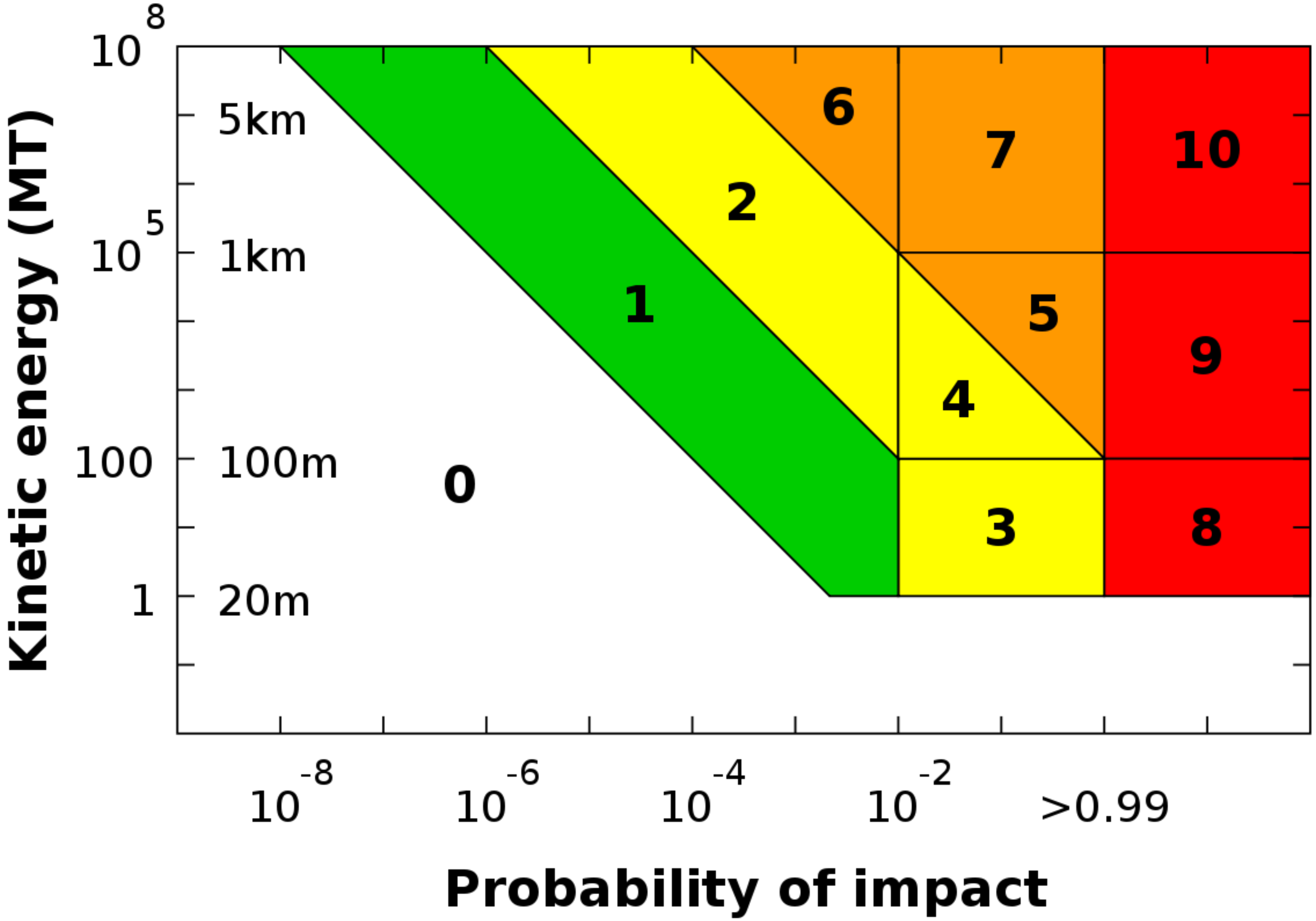
Every ≈10^8 years
Energy: ≈10^{11} Hiroshima bombs



Just if you are very unlucky
(Ann Hodges, Alabama, 1954)

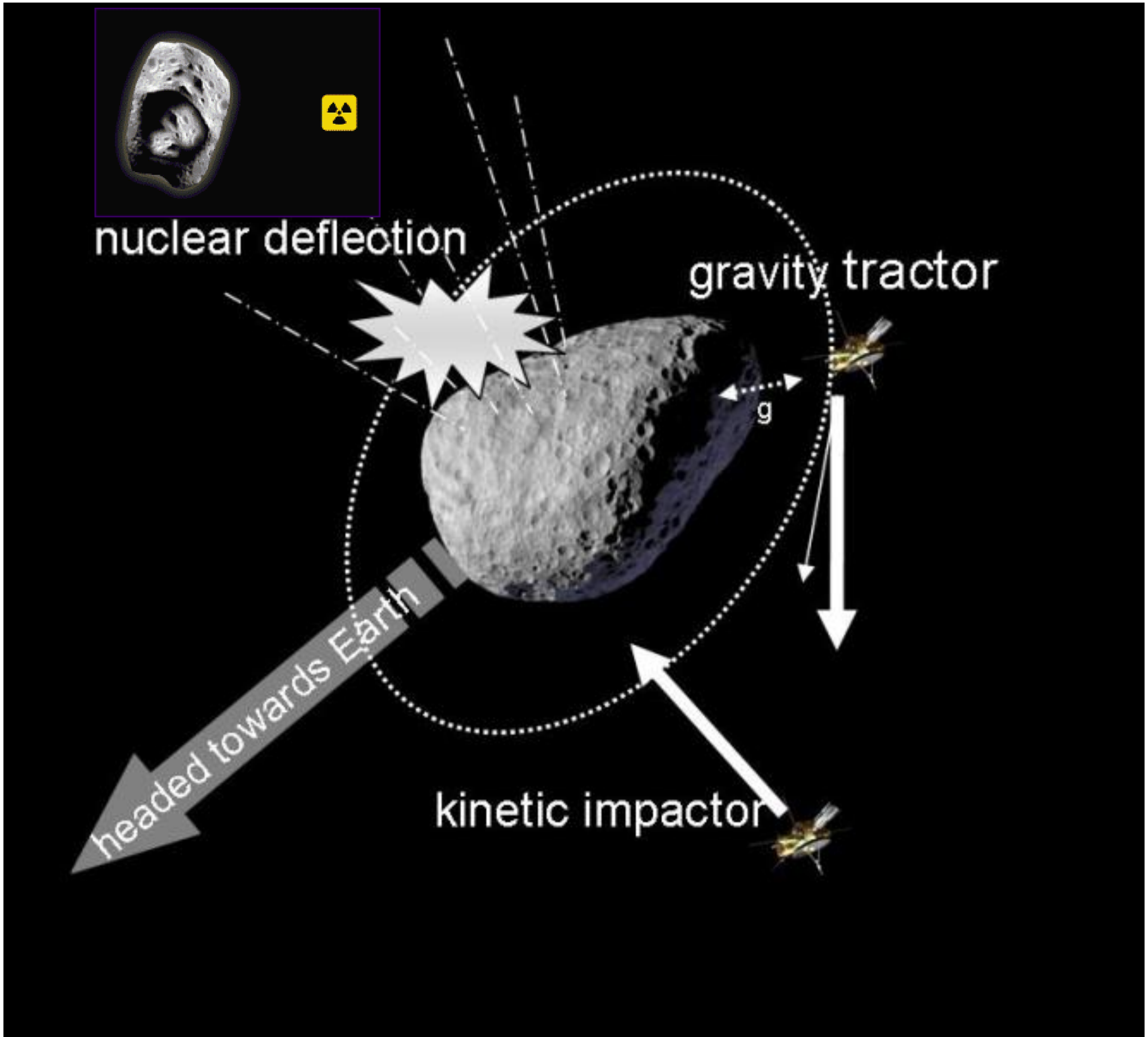
Every ~10^2 years
Energy: ~30 Hiroshima bombs

The Torino scale

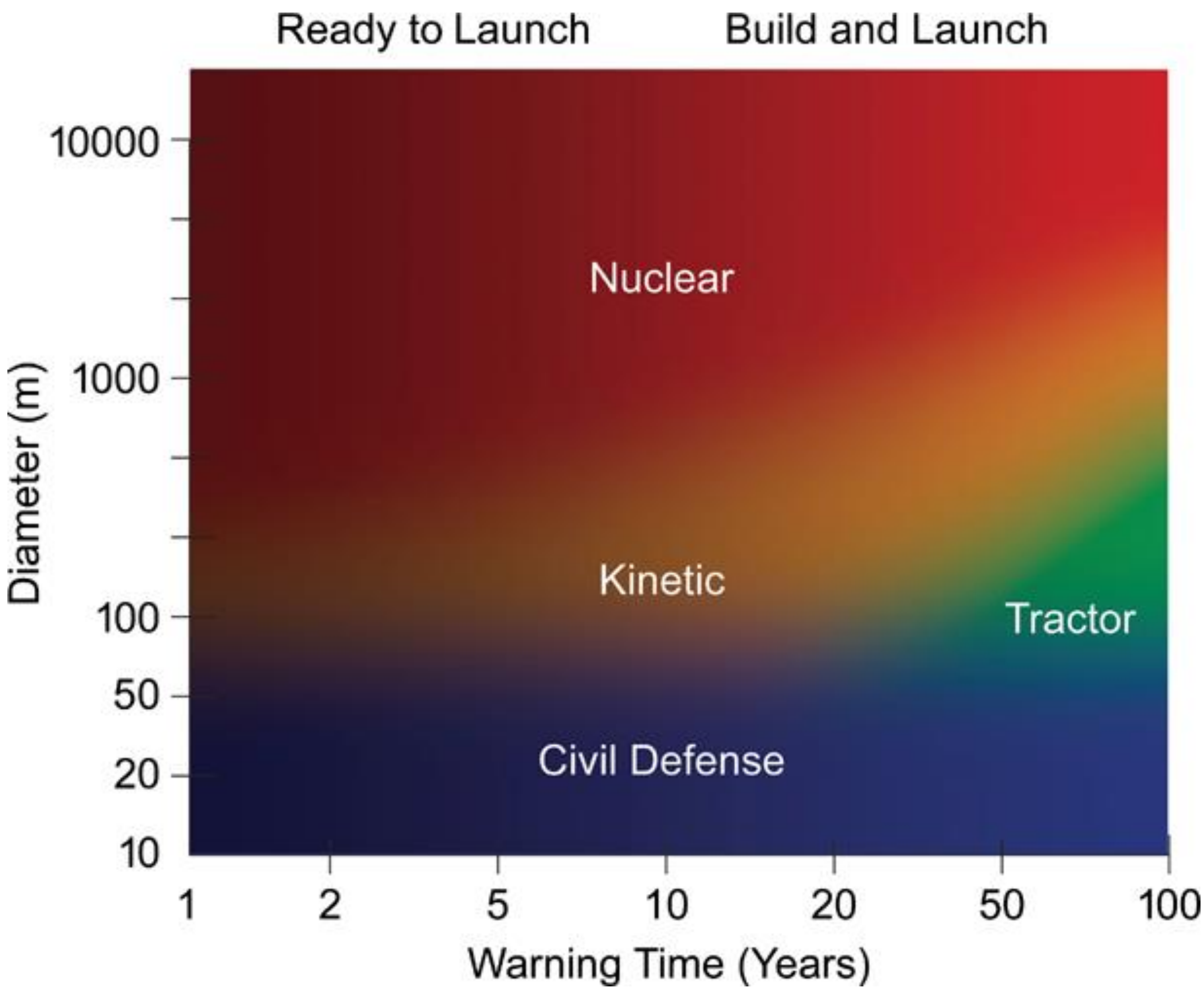



DON'T PANIC!
GBV
XVI EXODINOLOGY CO
the frequency of a dinosaur killer impact is about 1 every 100 million years...
so... why should we worry ?

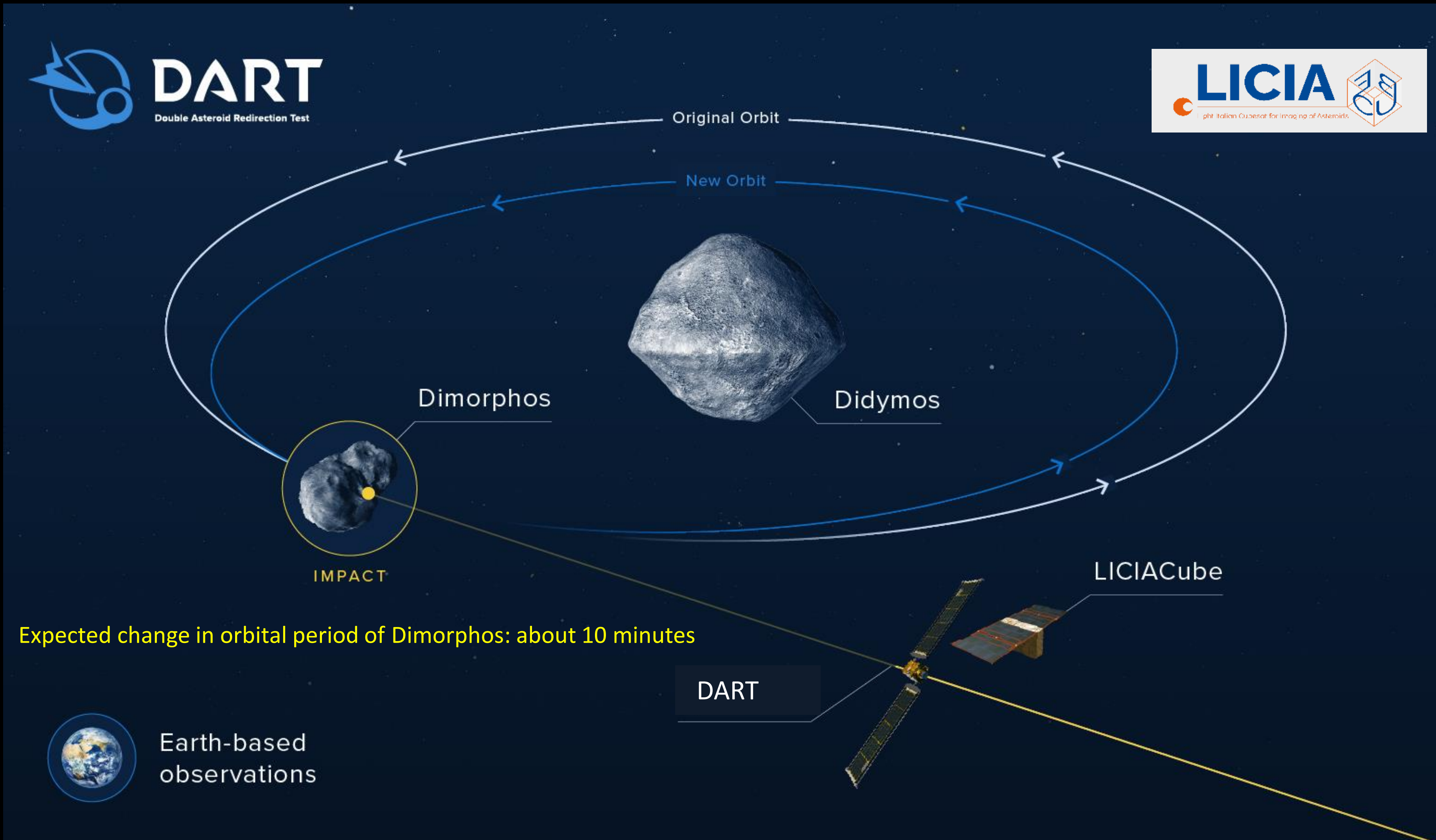
Mitigation measures



Mitigation measures



NASA - DART
Double Asteroid Redirection Test


DART
Double Asteroid Redirection Test
LICIA
Original Orbit
New Orbit
Dimorphos
Didymos
IMPACT
LICIACube
Expected change in orbital period of Dimorphos: about 10 minutes
DART
Earth-based observations

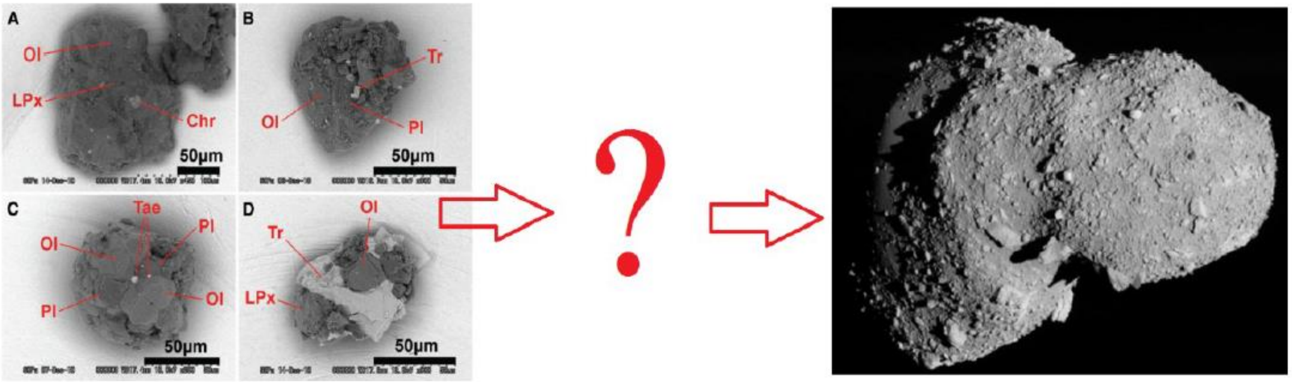
NASA - DART
Double Asteroid Redirection Test

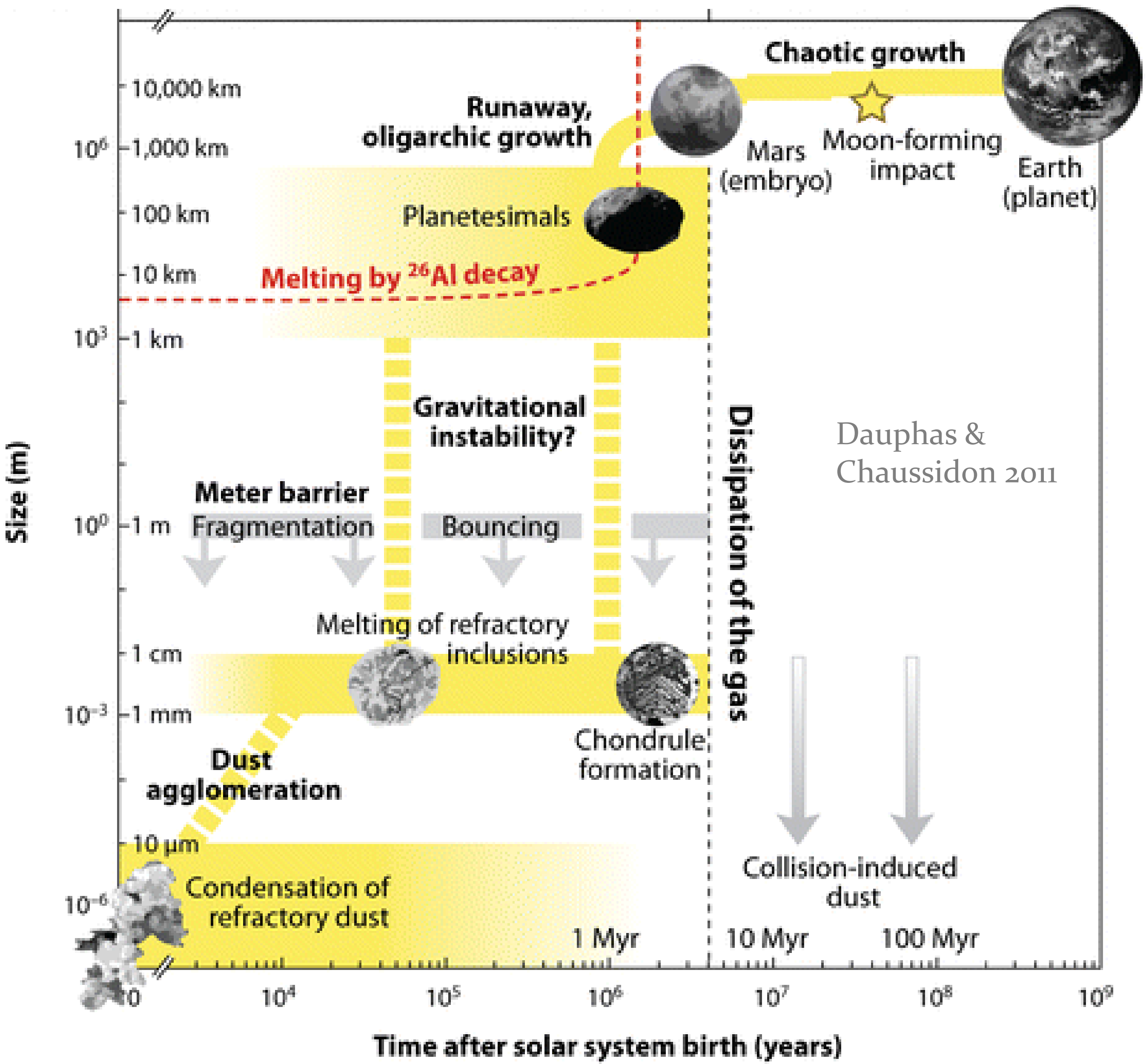
The NEA proximity: a risk…

… & an opportunity

- *Multi-target space missions*
  - ✓ To constrain huge physical diversity

- *Discovery & investigation of ultra-small asteroids*
  - ✓ Unexplored!
  - ✓ To constrain aggregation structure (monolithic vs. cohesive vs. rubble pile)





Dauphas & Chaussidon 2011

NEST

2018 ESA "Fast" mission call

"Near-Earth Space Trekker" selected (6 out of 23 Phase-1 proposals) for Phase-2 after the technical and scientific screening by ESA

Core Team members	
Davide PERNA (Lead Proposer)	INAF – Osservatorio Astronomico di Roma, Italy
Alberto ADRIANI	INAF – IAPS, Italy
Maria Antonietta BARUCCI	LESIA – Observatoire de Paris, France
Lorenzo CASALINO	Politecnico di Torino, Italy
Vania DA DEPPO	CNR – IFN, Italy
Vincenzo DELLA CORTE	INAF – IAPS, Italy
Elisabetta DOTTO	INAF – Osservatorio Astronomico di Roma, Italy
Sonia FORNASIER	LESIA – Observatoire de Paris, France
Alain HERIQUE	IPAG – Université Grenoble Alpes, France
Daniel HESTROFFER	IMCCE – Observatoire de Paris, France
Stavro IVANOVSKI	INAF – Osservatorio Astronomico di Trieste, Italy
Robert JEDICKE	Institute for Astronomy, University of Hawaii, USA
Jean-Luc JOSSET	Space Exploration Institute, Switzerland
Wlodek KOFMAN	IPAG – Université Grenoble Alpes, France
Michèle LAVAGNA	Politecnico di Milano, Italy
Elena MAZZOTTA EPIFANI	INAF – Osservatorio Astronomico di Roma, Italy
Patrick MICHEL	CNRS – OCA, France
Alessandro MURA	INAF – IAPS, Italy
Pasquale PALUMBO	Università di Napoli Parthenope, Italy
Dirk PLETTEMEIER	Technische Universität Dresden, Germany
Jean-Michel REESS	LESIA – Observatoire de Paris, France
Yves ROGEZ	IPAG – Université Grenoble Alpes, France
Alessandro ROSSI	IFAC – CNR, Italy
Giovanni B. VALSECCHI	INAF – IAPS, Italy
Marco ZANNONI	Università di Bologna, Italy

Consiglio Nazionale delle Ricerche

l'Observatoire de Paris

TECHNISCHE UNIVERSITÄT DRESDEN

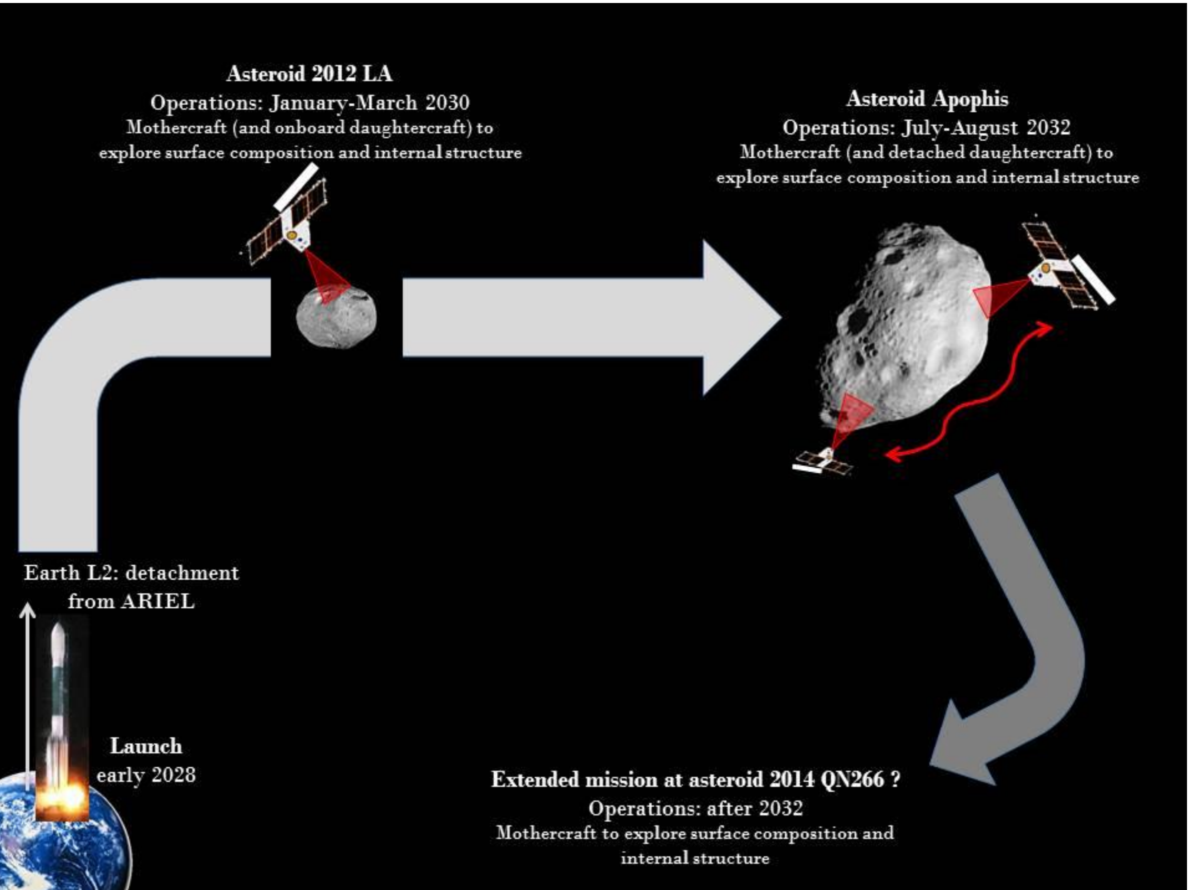
IPAG Institut de Planétologie et d'Astrophysique de Grenoble

Observatoire de la CÔTE d'AZUR

SPACE - X Space Exploration Institute

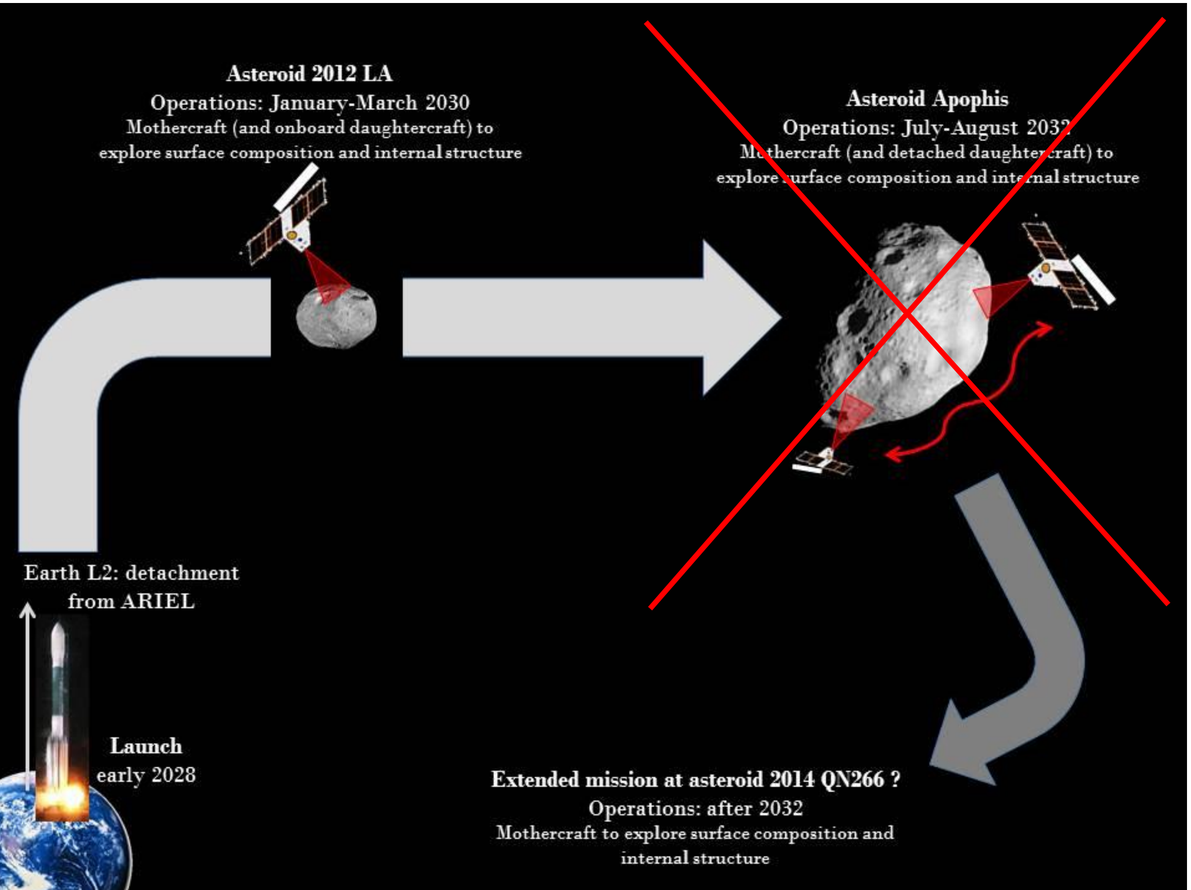
Institute for Astronomy University of Hawai'i

- Rendez-vous with multiple NEAs *(few months at each target)*
  - ✓ Baseline targets: **2012 LA** (10-m) and **Apophis** (350-m)
  - ✓ Extended mission target: **2014 QN266** (20-m)
- **Science goals** *(to constrain latest theories about planetary formation)*
  - ✓ Smallest asteroids ever visited
  - ✓ First radar investigation of asteroid interiors



- Electric propulsion (e.g., Arianegroup RIT 2X or Qinetiq T6)
- Daughtercraft to be released at Apophis (close-up investigation and bistatic radar measurements)
- Total ΔV
  - ✓ ~4.8 km/s (baseline)
  - ✓ ~8 km/s (extended)

- NEST proposal didn't pass Phase-2 technical screening:
  - ✓ "Risky" radar technology (TRL 4)
  - ✓ Low ΔV margin to reach Apophis



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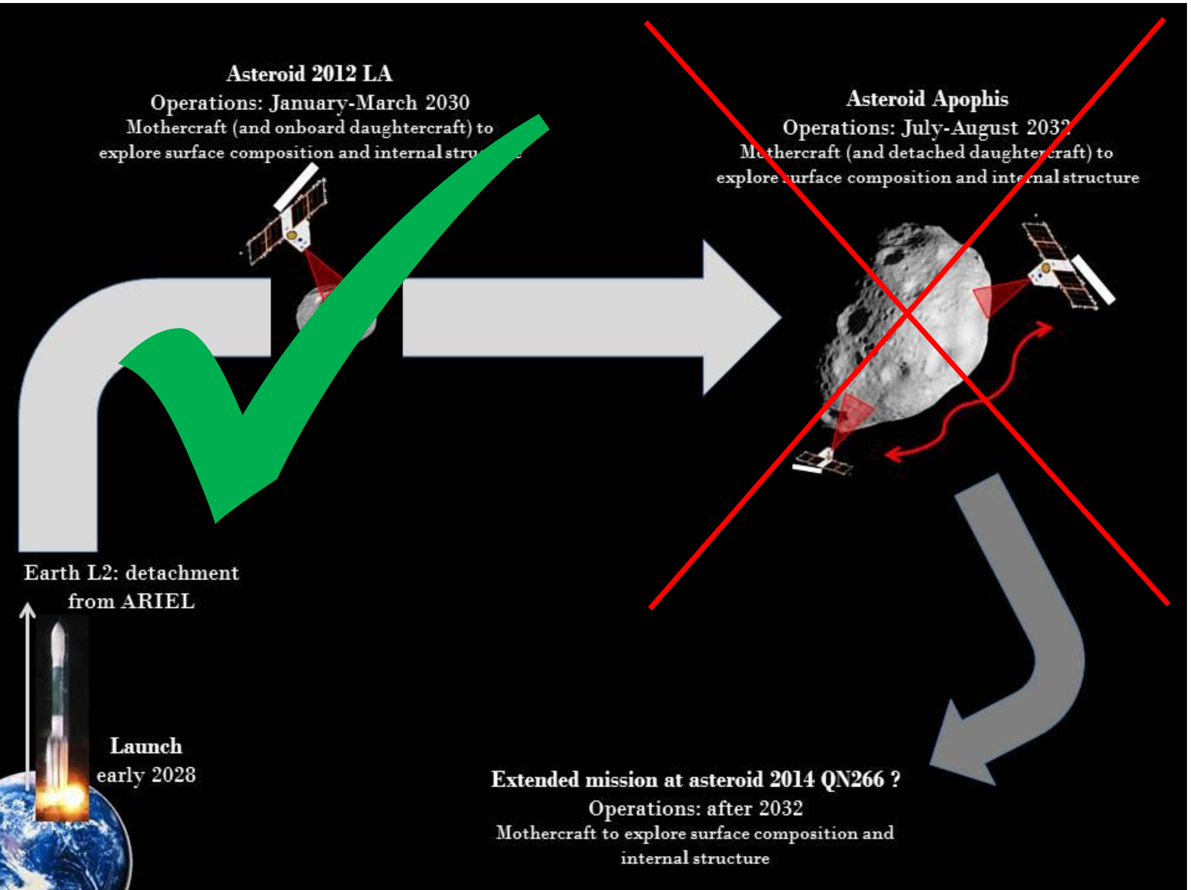


- *Extremely positive Phase-1 scientific assessment!*

→ **Explore next mission opportunities!**

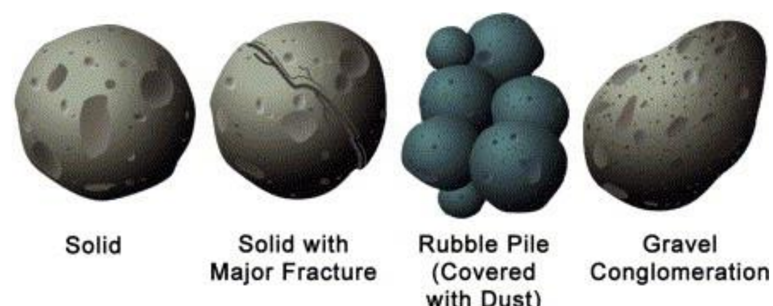
- ✓ Larger mission class
- ✓ Small/cheap missions (no radar)

ANIME
Asteroid Nodal Intersection Multiple Encounters

In a nutshell

- *<u>Concept developed for the 2020 ASI call for "future CubeSat missions"</u>*
  - ✓ ESA GSTP framework
  - ✓ 50-month (phases A-to-D) development plan
  - ✓ 24-month post-launch operations

- *<u>Rendezvous with "high-risk, decametre-size" NEA + 2 PHA fly-bys</u>*
  - ✓ Unexplored physical regimes
  - ✓ Science + Planetary protection



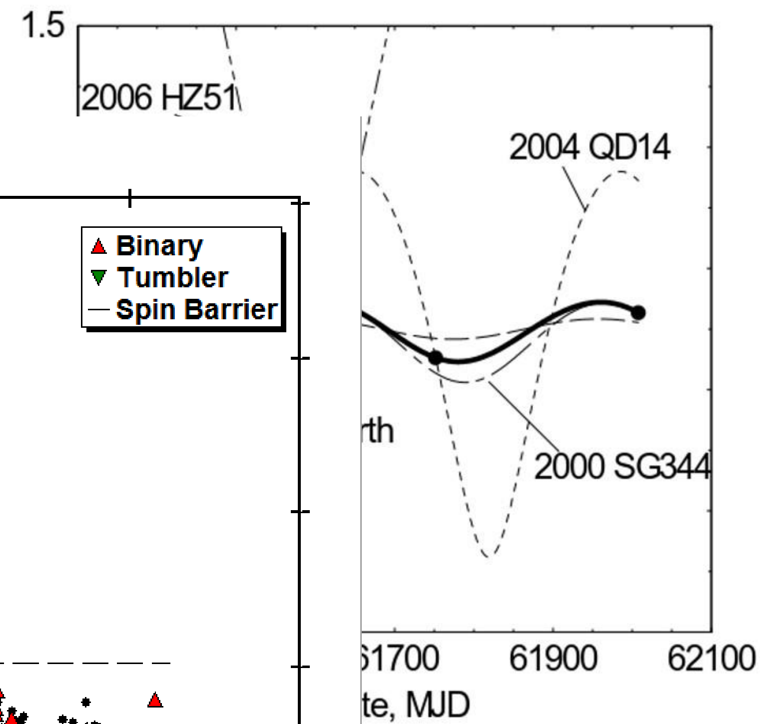
Walkers et al. 2006

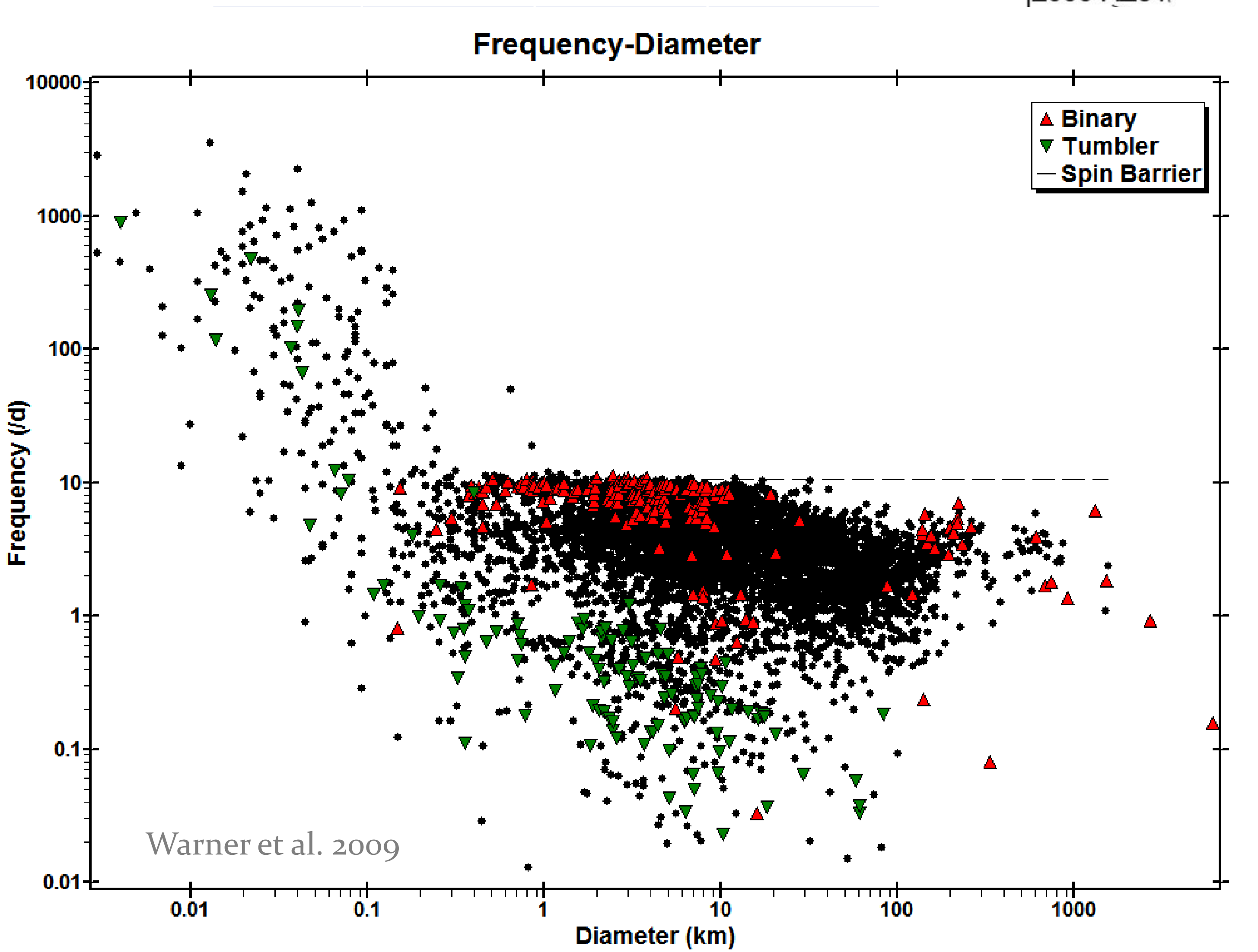
- *<u>COTS, flight-proven components</u>*
  - ✓ Low-cost
  - ✓ Low-risk
  - ✓ High-return!

ANIME

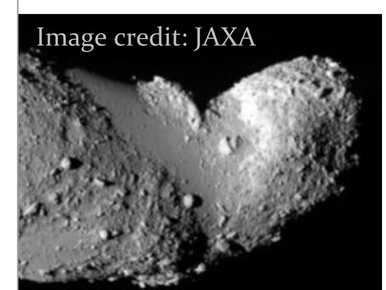
Asteroid Nodal Intersection Multiple Encounters

Targets & mission profile





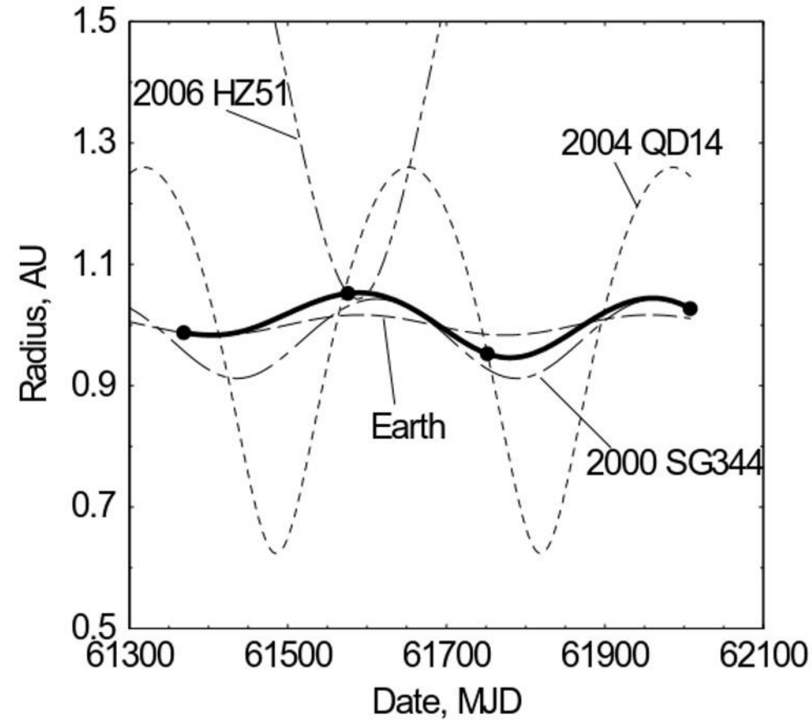
teroid visited to date:
awa (~350 m)



ANIME
Asteroid Nodal Intersection Multiple Encounters

Targets & mission profile

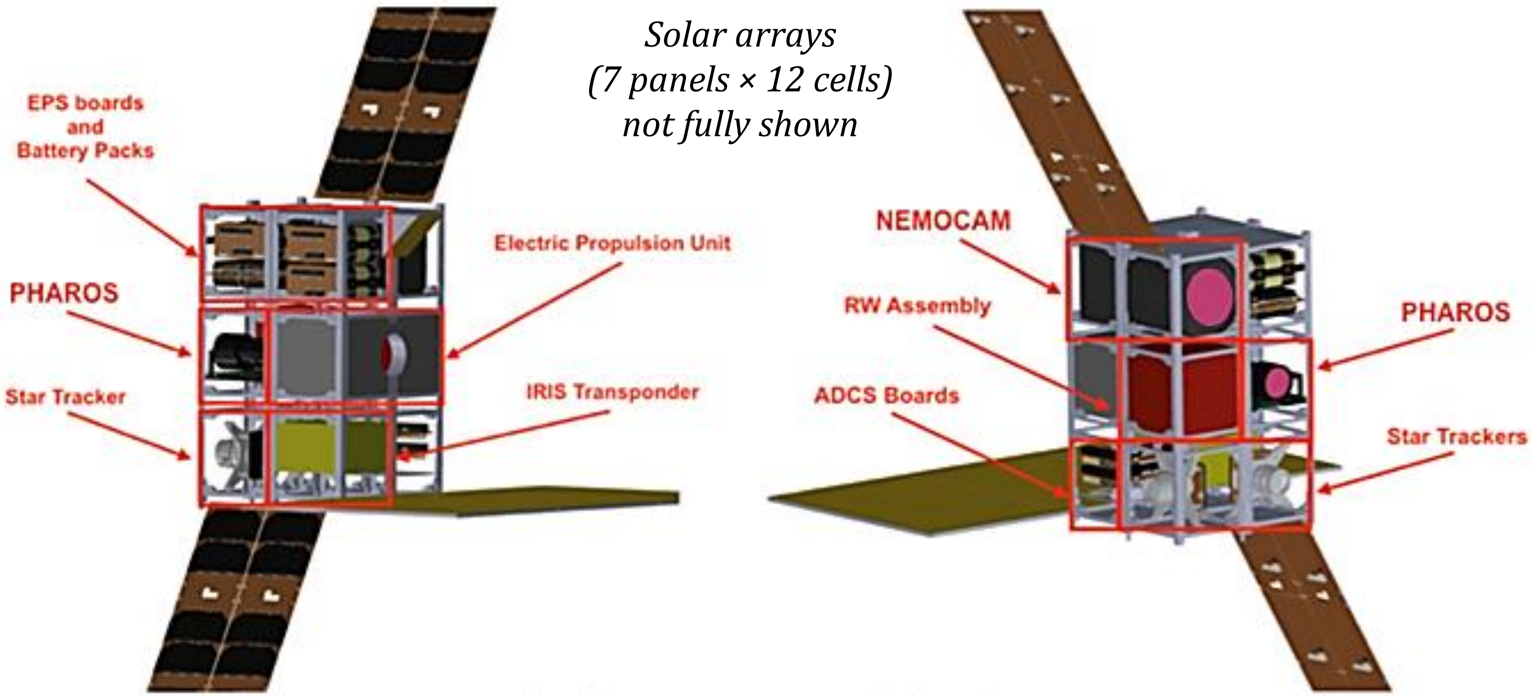
	Earth	2006 HZ51	2004 QD14	2000 SG344
Date	11/2026	6/2027	12/2027	8/2028
V_{rel} (km/s)	0	9.72	10.31	0



- *Baseline scenario*
  - ✓ Launch window ~ Sep.-Dec. 2026
  - ✓ Total ΔV ~ 1.0 km/s
  - ✓ Ample propellant margin (~30%)

- *Huge flexibility*
  - ✓ Launch dates to 2000 SG344 (late 2025 – early 2028)
  - ✓ Alternative fly-by (PHA) and rendezvous (“small-size”) targets
  - ✓ …

Spacecraft design



- *12U CubeSat*
- *COTS components, mostly with TRL 9 acquired in LEO*
- *RF ion thruster (thrust ~1 mN, Isp ~2100 s)*
- *Two RGB off-the-shelf cameras (renamed NEMOCAM & PHAROS)*
- *Margined wet mass ~20 kg*

ANIME

Asteroid Nodal Intersection Multiple Encounters

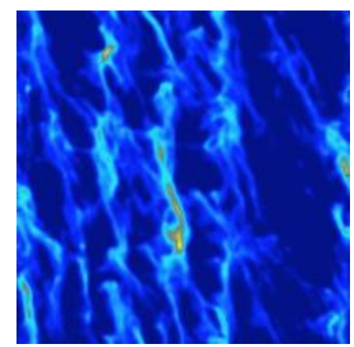
Operations & scientific return

	FoV (across track)	Spatial Resolution (@ 100 km)	Focus
NEMOCAM	2.22°	0.95 m	> 10 km
PHAROS	5.0°	7.8 m	> 400 m

- *Both fly-bys*
  - ✓ V_{rel} ~10 km/s @ ~50 km distance
  - ✓ Decimetre-scale images — Crater SFD, boulder SFD, …

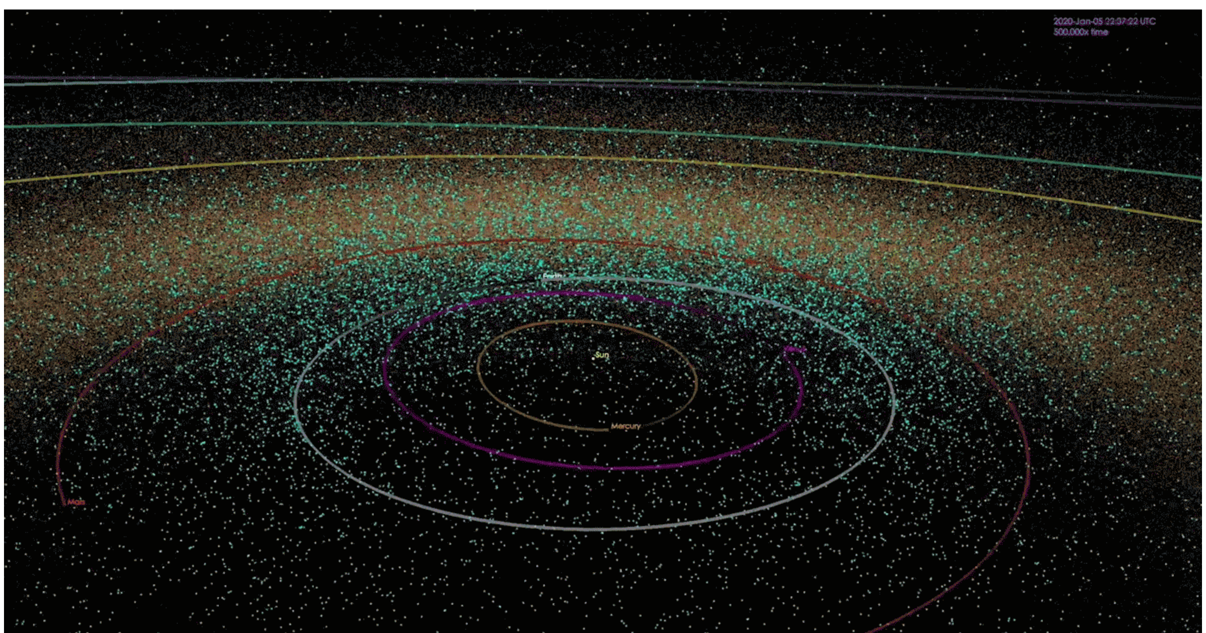
- *Rendezvous with 2000 SG344*
  - ✓ 2-month nominal campaign
  - ✓ Cm-scale images
  - ✓ Radio science
  - ✓ Constraints to orbit/Yarkovsky/YORP
    - ➢ Refinement of Earth impact solutions

Cm-scale images and radio science — Input for streaming instability + N-body numerical simulations

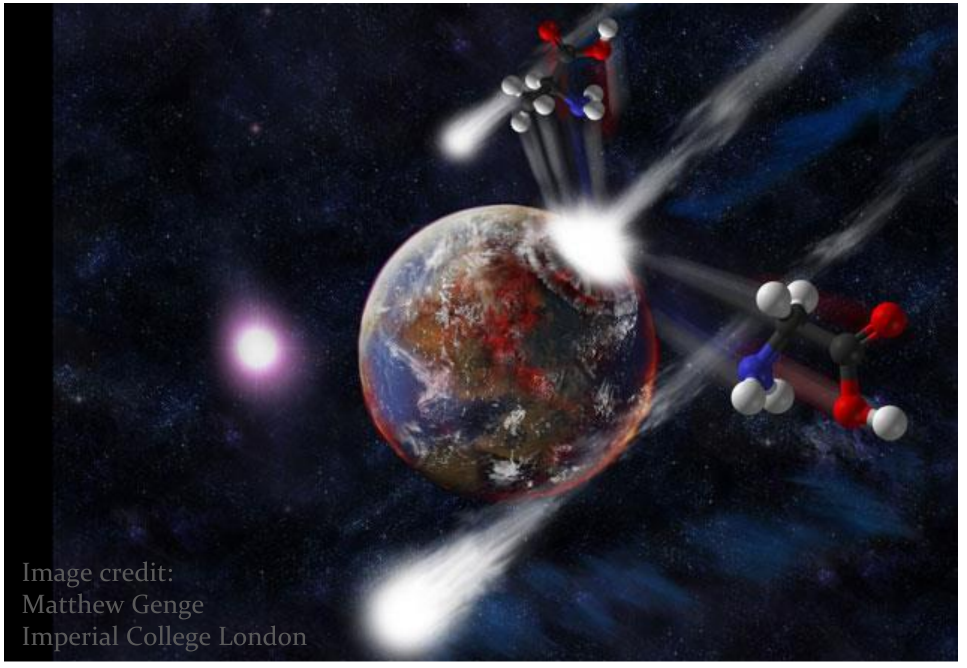


Status

- *ASI call for "future CubeSat missions"*
  - ✓ Among proposals that successfully passed the technical and scientific screening (April 2021)
  - ✓ Financial evaluation currently ongoing
- *Flexible, low-risk, high-return mission concept for both planetary science & planetary protection*
- *Opportunity for technological solutions (deep space validation)*



Muito obrigado pela atenção!



For more information:
davide.perna@inaf.it