This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 870377.

Near Earth Object Modelling And Payloads for Protection

The European Commission funded NEO-MAPP project in support of the ESA Hera mission

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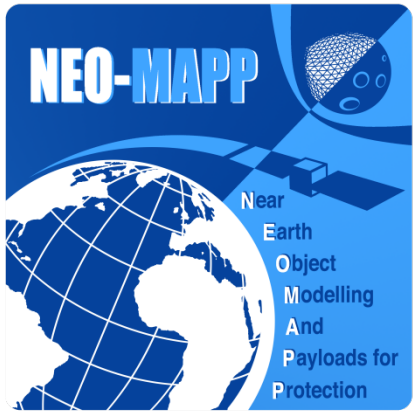
On behalf of the NEO-MAPP Consortium

7th IAA Planetary Defense Conference 2021



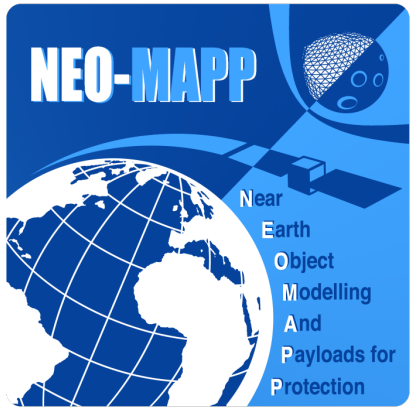
15 partners

3 years

Kick-off on Feb. 6, 2020

Participant no.	Participant organisation name	Participant short name	Country
1 (CO)	Centre National de la Recherche Scientifique	CNRS	France
2	Asteroid Foundation	AF	Luxembourg
3	Airbus Defence and Space GmbH	Airbus	Germany
4	Aristotelio Panepistimio Thessalonikis	AUTH	Greece
5	Deutsches Zentrum für Luft- und Raumfahrt e.V.	DLR	Germany
6	FCiencias.ID – Associacao para a Investigacao e Desenvolvimento de Ciencias	FC.ID	Portugal
7	GMVIS SKYSOFT, S.A.	GMVPT	Portugal
8	Instituto de Astrofisica de Canarias	IAC	Spain
9	Institut Supérieur de l'Aéronautique et de l'Espace (ISAE-SUPAERO)	ISAE	France
10	Museum für Naturkunde Berlin	MfN	Germany
11	Royal Observatory of Belgium	ROB	Belgium
12	Universidad de Alicante	UA	Spain
13	University of Bern	UBERN	Switzerland
14	ALMA MATER STUDIORUM - Università di Bologna	UBO	Italy
15	Université Grenoble Alpes	UGA	France

P.I. Patrick Michel (CNRS)



The main goal of NEO-MAPP is to provide:

Significant advances in both:

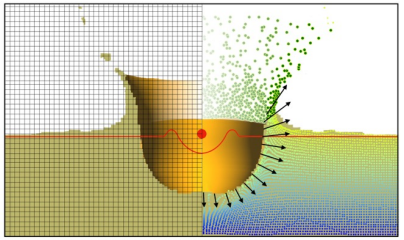
- Our understanding of the dynamics and response of NEOs to external forces (in particular a kinetic impact or a close planetary approach), and

- The associated measurements by a spacecraft (including those necessary for the physical and dynamical characterization in general).

The Hera mission (ESA, Space Safety Program) is the reference mission.

NEO-MAPP activities focus on the support of the development of the Hera mission, and beyond

In the framework of the Hera mission, defined as the reference mission



- **Pushing the limits of numerical modelling** of the response of NEOs to a kinetic impact, as well as of their physical and dynamical properties

- **Increasing the maturity of multiple spaceborn and landed European instruments** directly related to planetary defence, focusing on measurements of surface, shallow sub-surface and interior properties of NEOs.

- **Developing algorithms and simulators** to prepare for close-proximity operations and payload data analyses and exploitation.

- **Developing innovative and synergetic measurement and data-analysis strategies** that combine multiple payloads, to ensure optimal data exploitation for NEO missions.

- **Developing and validating robust GNC strategies and technologies** enabling surface interaction and direct response measurements performed by Cubesat or small/micro-lander (µLander) architectures.

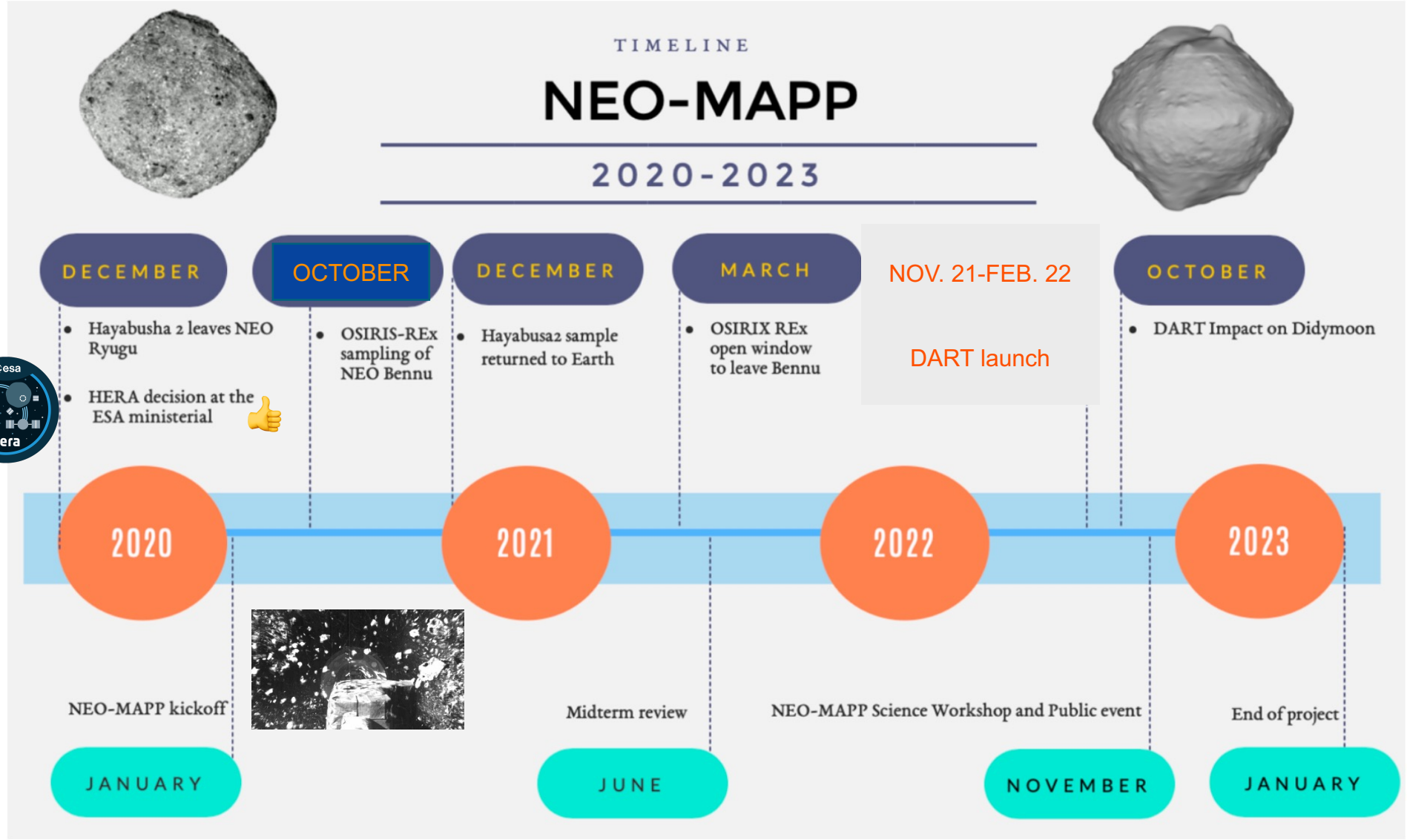
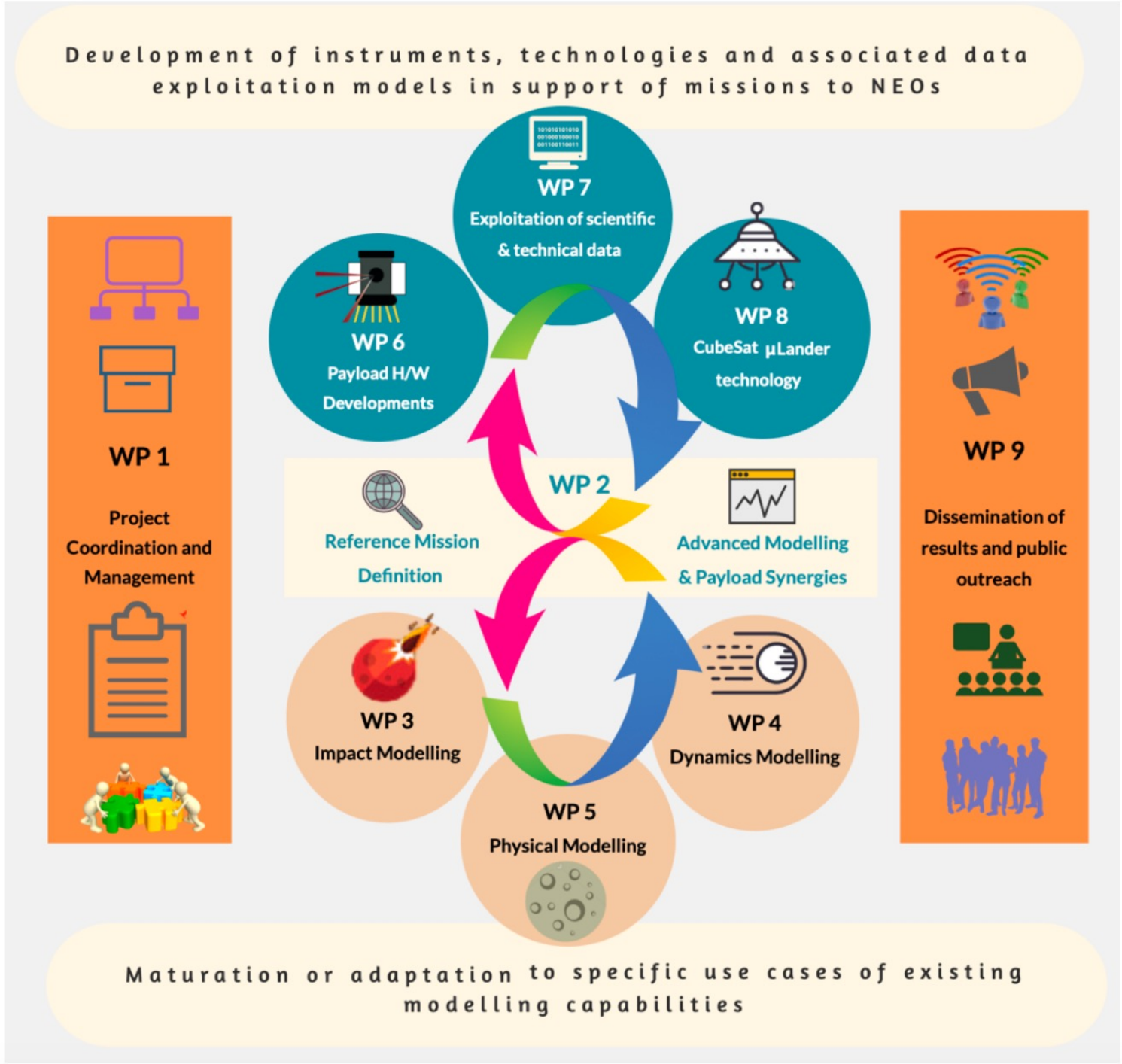
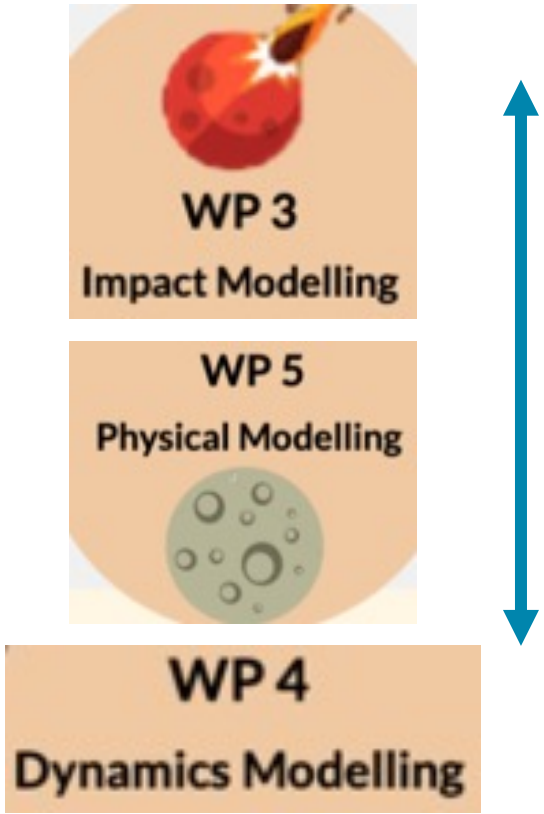


Figure 3: *NEO-MAPP timeline in the context of ongoing NEO missions and DART impact.*


Development of instruments, technologies and associated data exploitation models in support of missions to NEOs
WP 7
Exploitation of scientific & technical data
WP 6
Payload H/W Developments
WP 8
CubeSat µLander technology
WP 1
Project Coordination and Management
WP 2
Reference Mission Definition
Advanced Modelling & Payload Synergies
WP 9
Dissemination of results and public outreach
WP 3
Impact Modelling
WP 4
Dynamics Modelling
WP 5
Physical Modelling
Maturation or adaptation to specific use cases of existing modelling capabilities

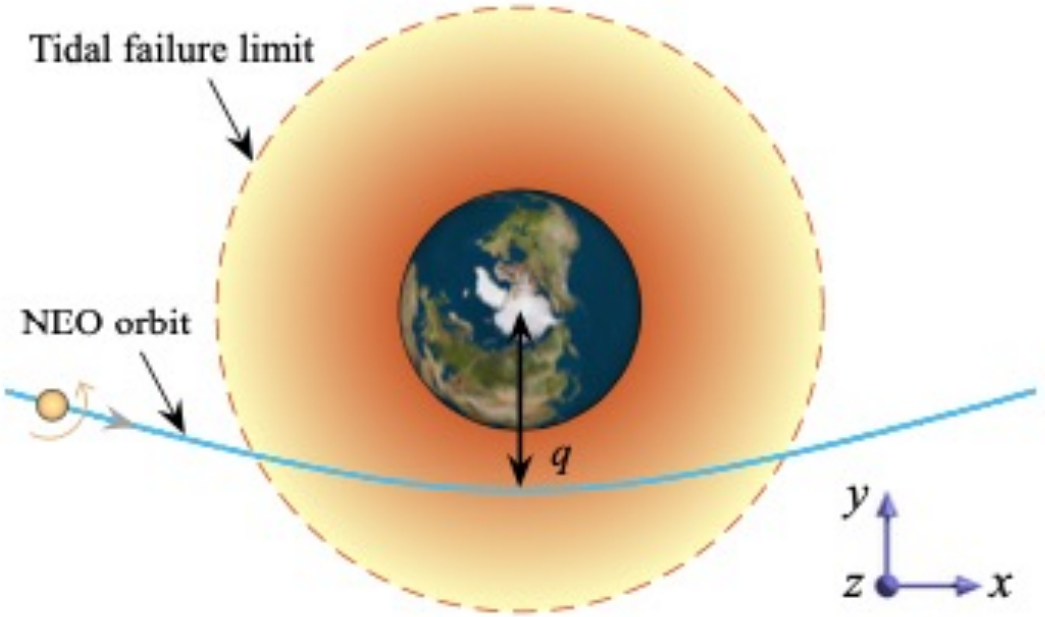
WP2: Advanced Modelling Synergies

- The **impact process** depends on:
  - The **physical properties** of the target
- The **physical properties** of the target are:
  - Modified by the **impact process**
- The **dynamical state** of the target is:
  - Modified by the **impact process**s
- The **physical properties** of the target influence:
  - The **dynamical state**
- Etc … All 3 topics are **clearly interrelated**

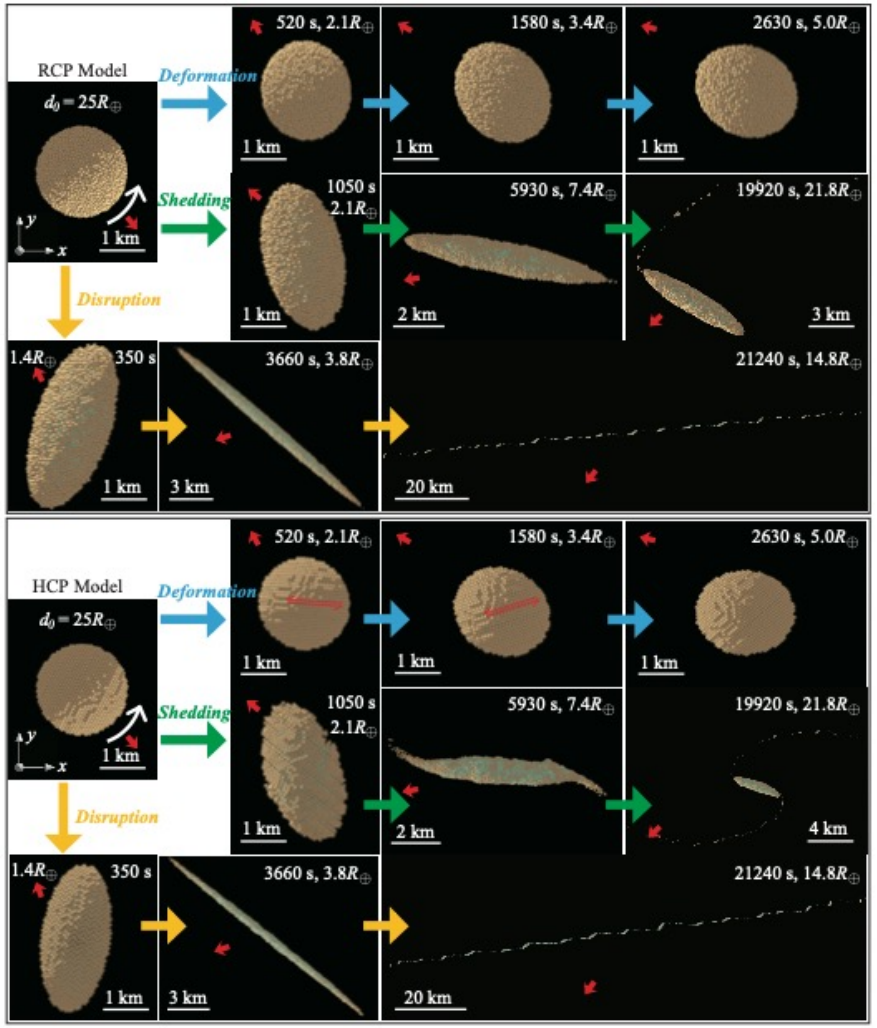


Example of Advanced Modelling Synergies

- **Synergy between WP4-WP5**
  - Tidal encounters: how the dynamics (WP4) and internal properties (WP5) work together!



Zhang & Michel 2020, A&A



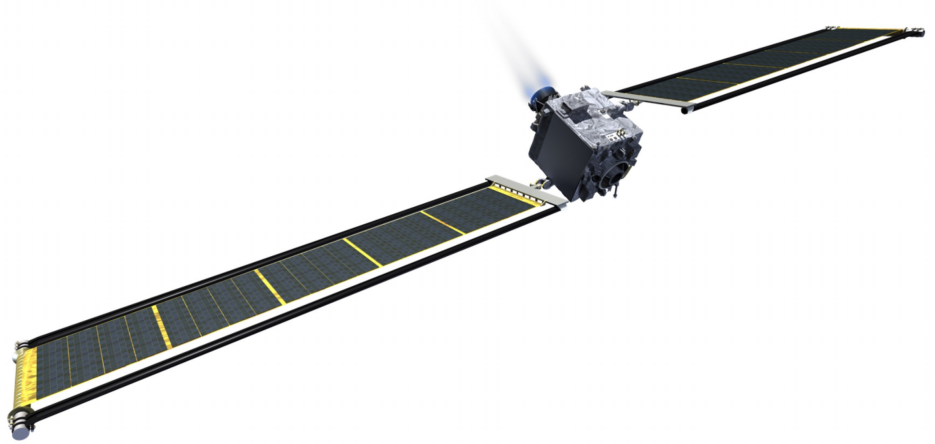
Rubble piles with a Random Closed Packing (RCP) structure start feeling tidal forces at larger distances than Hexagonal Closed Packing (HCP) ones

WP3: Momentum transfer efficiency, β, is sensitive to target properties and impact conditions

Target properties

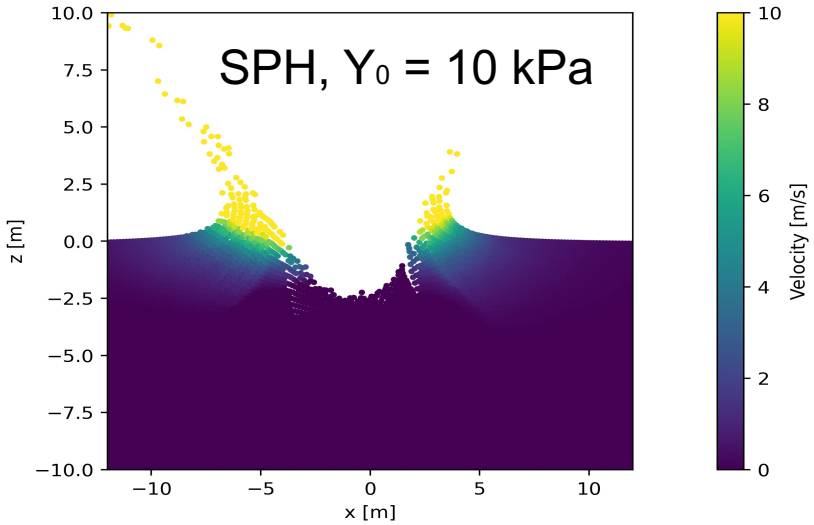
- Cohesive strength - not known
- Bulk density/porosity - not known
- Internal structure - not known

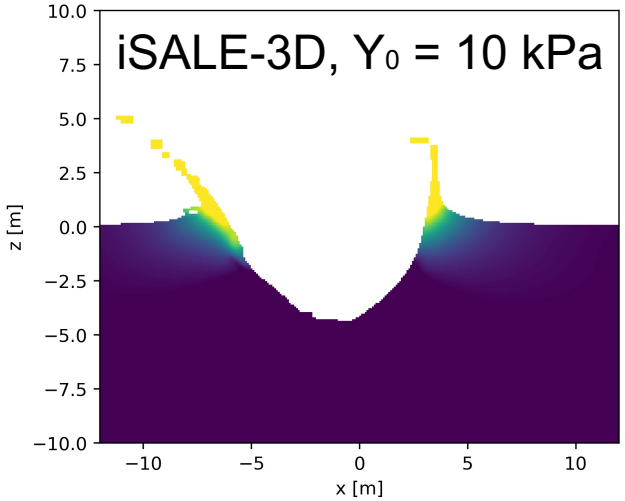
Impact conditions



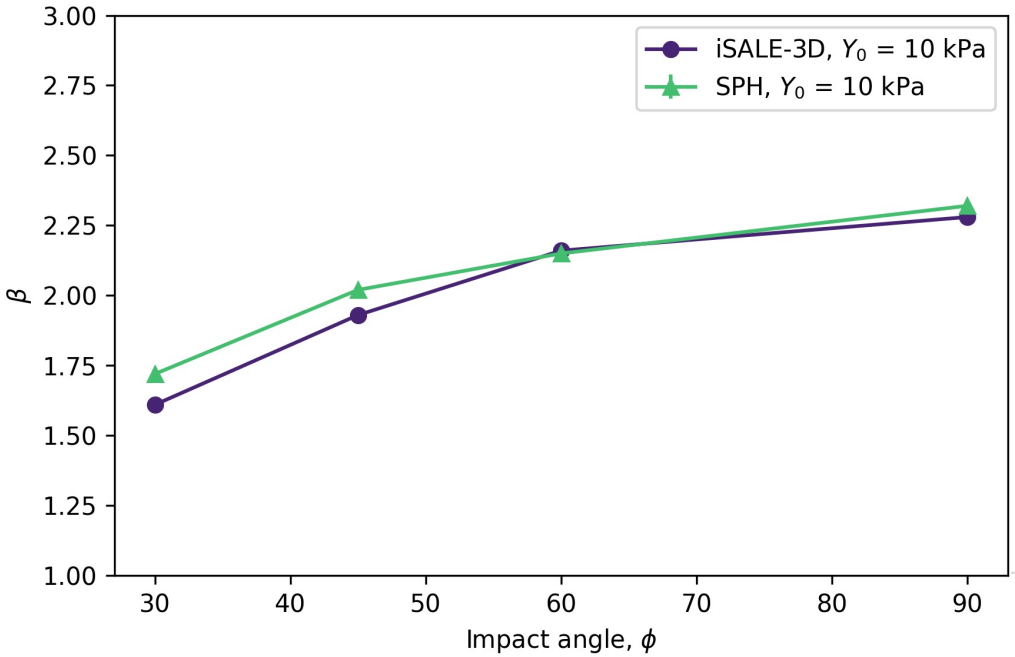
- Impact velocity - known
- Impact angle - not known
- Impactor mass/shape - known

WG3: Impact modelling - Momentum transfer is influenced by the impact angle





- Preliminary study: Momentum transfer from iSALE and SPH benchmark studies show good agreement at moderate cohesion and porosity
- Impact angle can reduce β by up to 50%



Beta from iSALE-3D simulations compared to SPH simulations. Raducan et al. 2020 (EPSC), Raducan et al. (in preparation)

WG4: Dynamics and physical properties: Creep stability of Didymos: the role of cohesion

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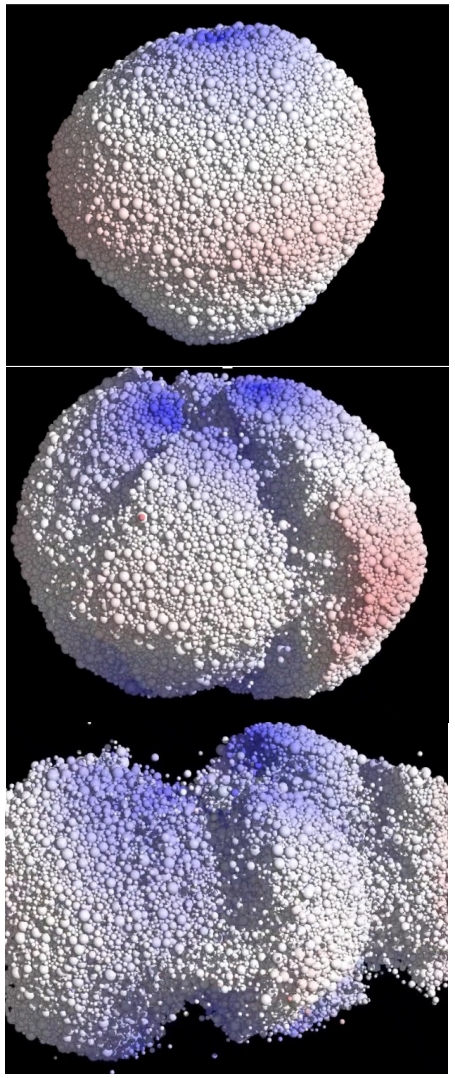
Creep stability of the DART/Hera mission target 65803 Didymos: II. The role of cohesion

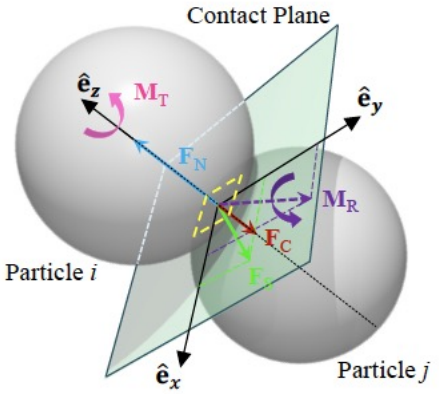
Yun Zhang [a,*], Patrick Michel [a], Derek C. Richardson [b], Olivier S. Barnouin [c], Harrison F. Agrusa [b], Kleomenis Tsiganis [d], Claudia Manzoni [e], Brian H. May [e]

[a] Université Côte d'Azur, Observatoire de la Côte d'Azur, CNRS, Laboratoire Lagrange, Nice 06304, France
[b] Department of Astronomy, University of Maryland, College Park, MD 20742, United States
[c] The Johns Hopkins University, Applied Physics Laboratory, United States
[d] Department of Physics, Aristotle University of Thessaloniki, Thessaloniki, Greece
[e] London Stereoscopic Company, London, United Kingdom

Zhang, Michel et al. 2021



spin-up

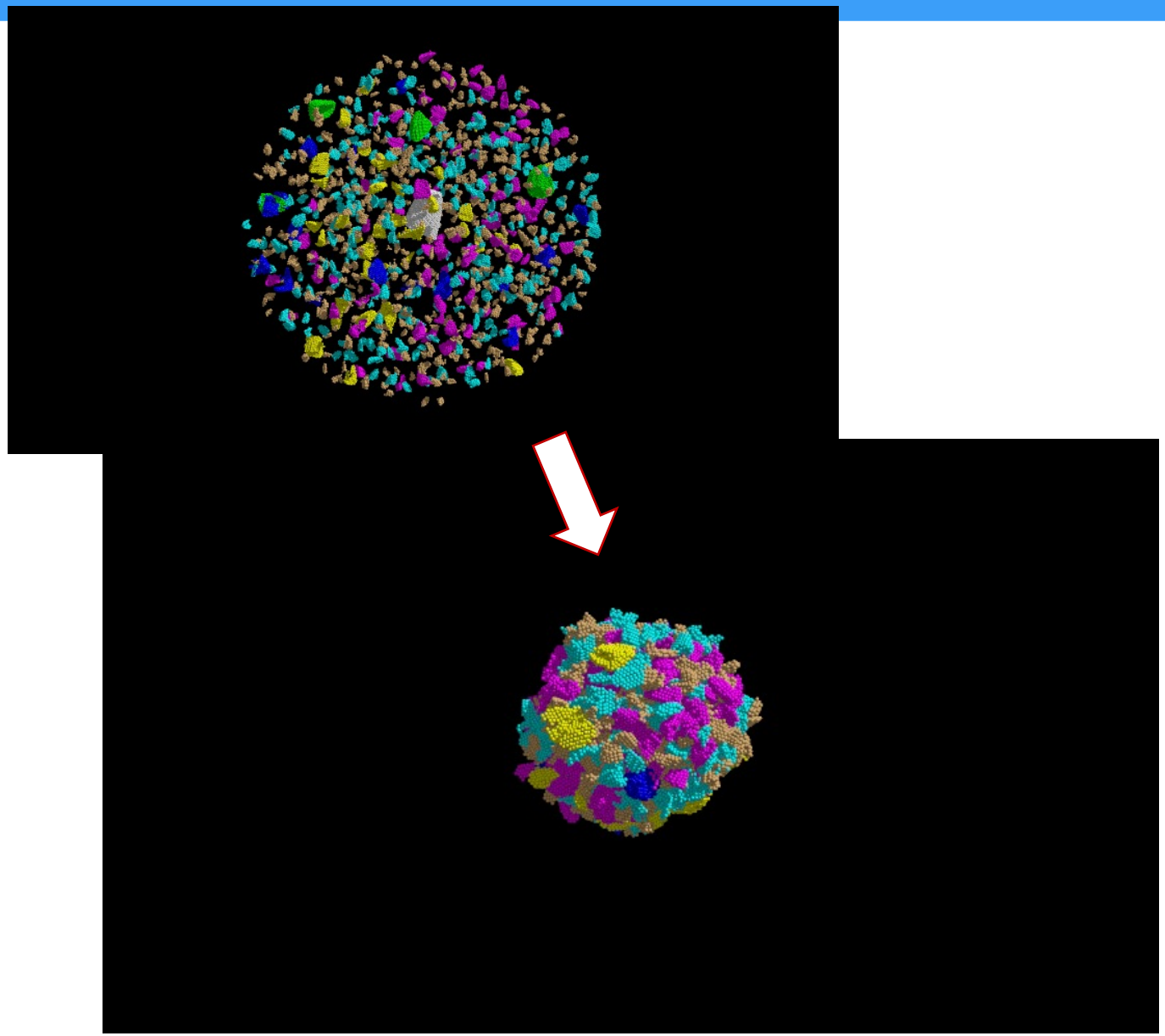


Contact forces and torques between particles in Didymos

Example of a numerical simulation of Didymos' spin-up and failure using the Soft-Sphere Discrete Element Method (SSDEM)

WG5: Internal structure modelling

- Algorithm ready to generate:
  - Irregular shapes of components of accreting gravitational aggregates (rubble-piles).
    - Super-ellipsoids,
    - cellinoids,
    - ‘super-cellinoids’,
    - ‘hyper-cellinoids’.
  - Arbitrary size (mass) distributions.
  - Unlimited number of components.
  - Distribution in space at random ICs.



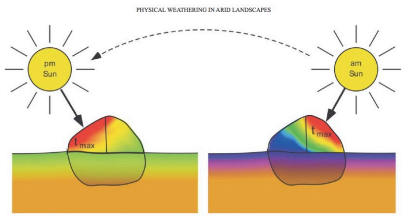
Universitat d’Alacant
Universidad de Alicante

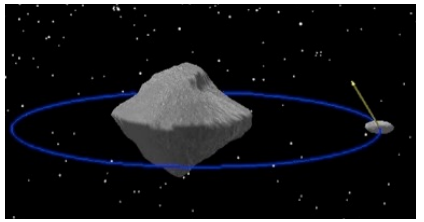
WG6: Payload Example: Seismometer development

- **Rationale:** The objective of the geophone (seismometer) assembly is to measure the ground displacement due to seismic activity on the surface of asteroids. Putting a seismic station on an asteroid could vastly improve our knowledge about the seismic environment and sub-surface structure of an asteroid.

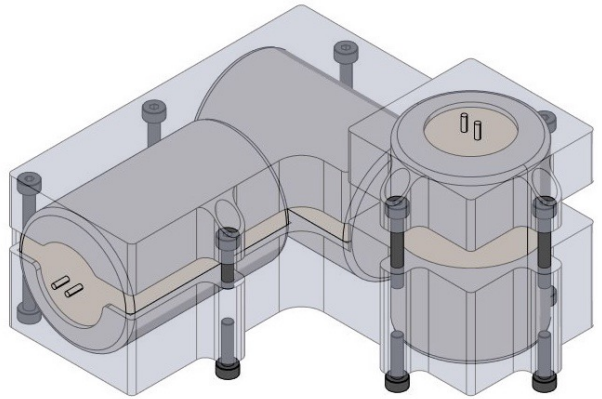
- **Ambition:** The NEO-MAPP development will focus on the testing and prototyping of the geophone assembly in order to increase the TRL of the ISAE geophone from TRL 3 to TRL 4/5. This will include critical instrument design, manufacturing and testing of different models.

- The **seismic sensors are commercial sensors** with no active electronics (specifically designed for borehole extreme environments). We are **developing the acquisition electronics at ISAE-SUPAERO**.





Meteoroid impacts, thermal cracking and tidal forces are expected to generate seismic activity on asteroids (Murdoch et al., PSS 2017)



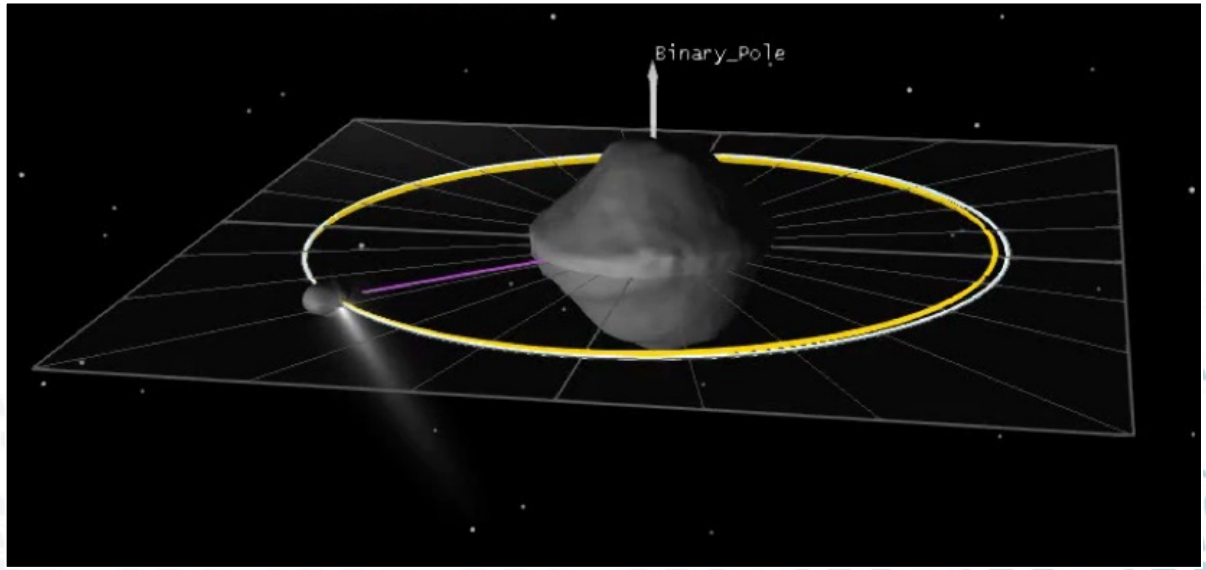
Preliminary design of the ISAE-SUPAERO geophone for the AGEX (ESA COPINS - AIM) study

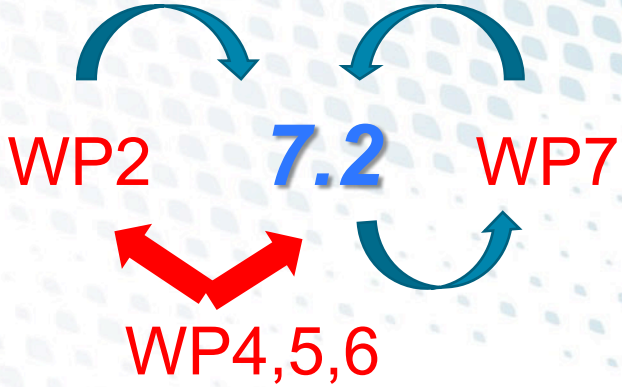
WP7: Multi-Instrument Analysis Example: Dynamical State

– Characterize the (post-KI) *dynamical state* of a NEO system (binary, *Didymos*, *?etc?*) at mission-defined accuracy level (WP2)

→ mass(es), gravity field, shapes, …
→ Perturbed mutual orbit
→ Rotational/librational states

Using:
– Imaging
– Radio Science
– Lidar
– Gravimeter
– …





Advisory Board

Ian Carnelli (ESA)

Michael Küppers (ESA)

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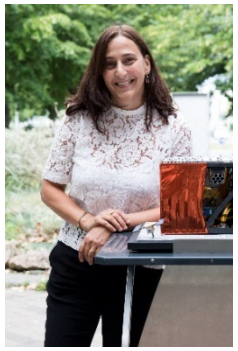

Andy Cheng (APL)

Paul Abell (NASA)

Brian May (Stereo imaging and Queen guitarist!)

Makoto Yoshikawa (JAXA)

NEO-MAPP will:

Near Earth Object Modelling And Payloads for Protection

- **Support modelling and technical studies** needed for the development of the ESA **Hera** mission
- **Develop a modular 'toolbox'** consisting of modelling tools, instruments, data analyses techniques and spacecraft operations, all specifically designed **for planetary defense applications and adaptable for all future NEO space missions**
- Build upon and **sustainably increase expertise** of European scientists and engineers in both **planetary defense efforts and small-body exploration**.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 870377.

NEO-MAPP

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https://neomapp.eu

Thank you.