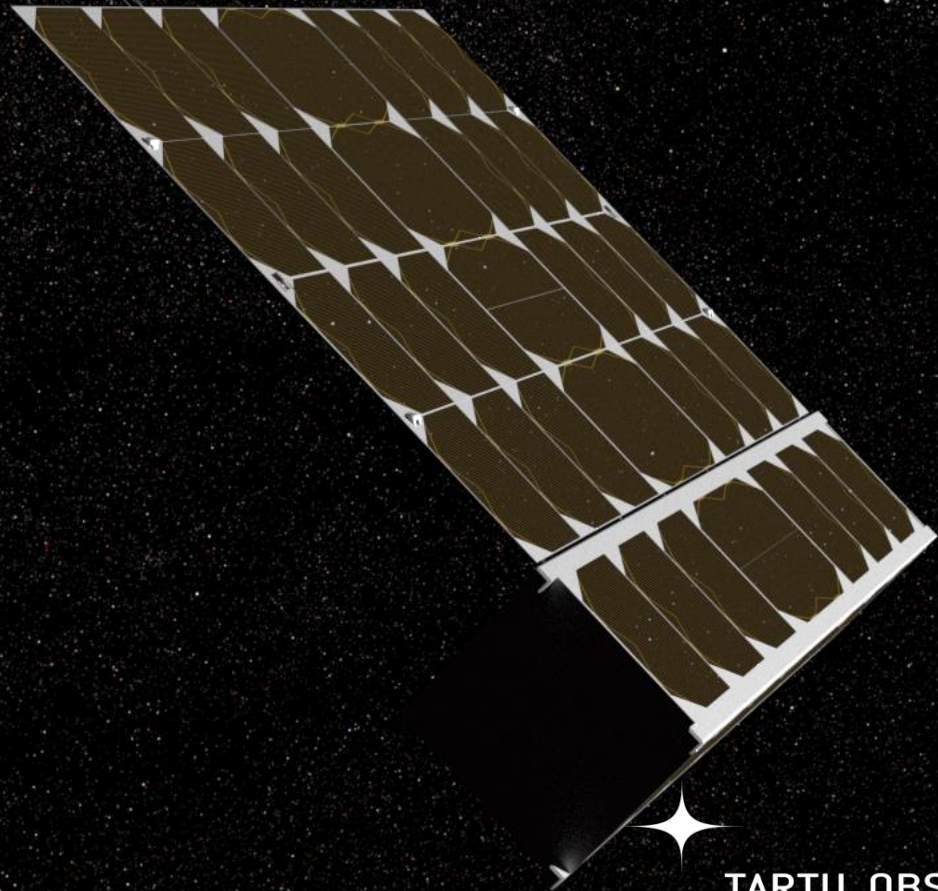


Riders on the Solar Wind: Multi-Asteroid Touring



January 12, 2018

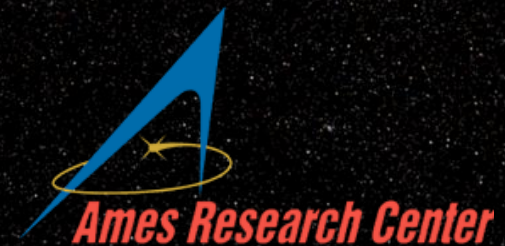
Tallinn School No 21

Andris Slavinskis, Mihkel Pajusalu, Pekka Janhunen et al.

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Why oh why?

- How long we have left on Earth?
- How to maximise habitability of the Earth and go beyond its limits?
- Some challenges: changing environment, overconsumption of resources, overpopulation, large asteroid impact, solar evolution

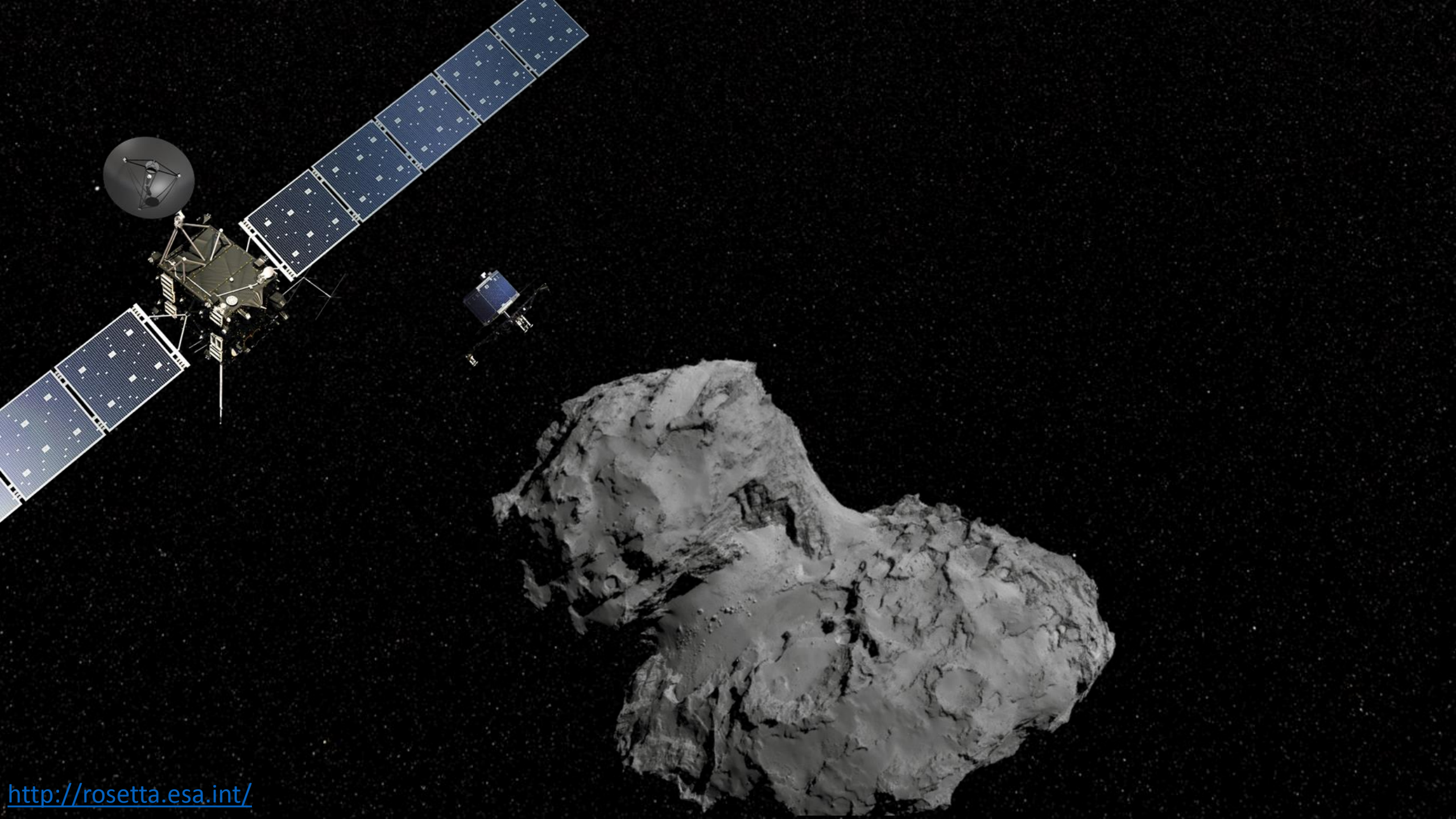
- **Life is rare**
- **Life is precious**

The master plan

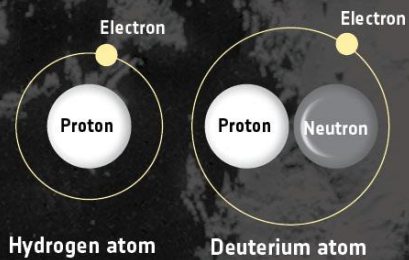
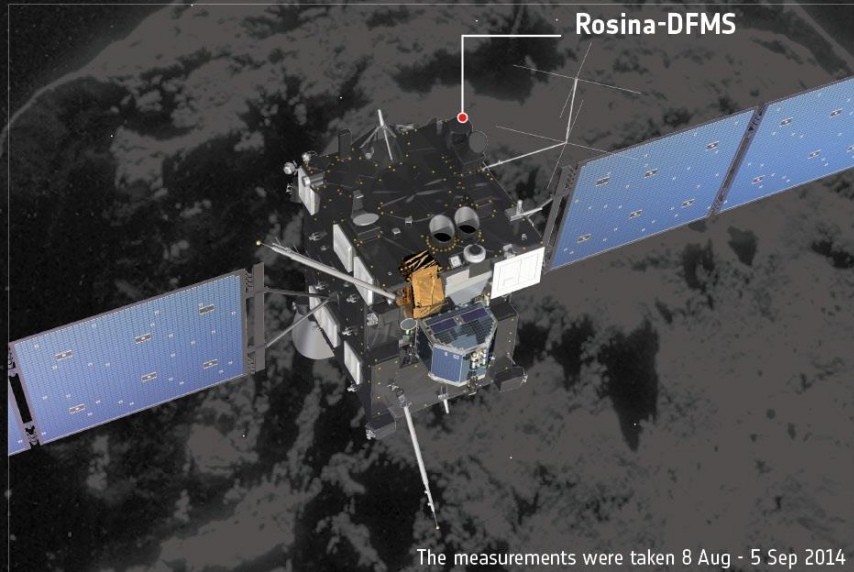
- Make sure that the Earth is habitable for as long as possible
- Research formation of life
- Explore life, conditions and habitability outside the Earth
- Prepare for the expanse outside the Earth

What asteroids have to do with it?

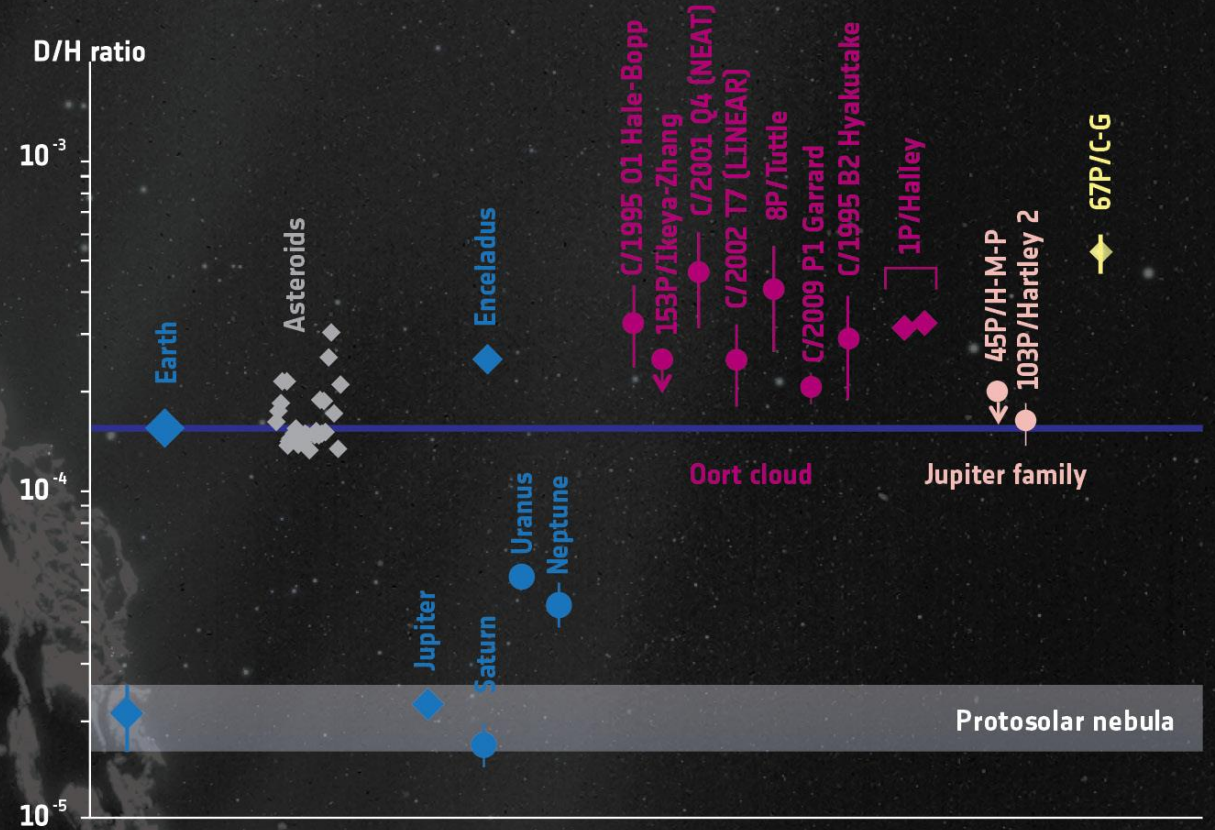




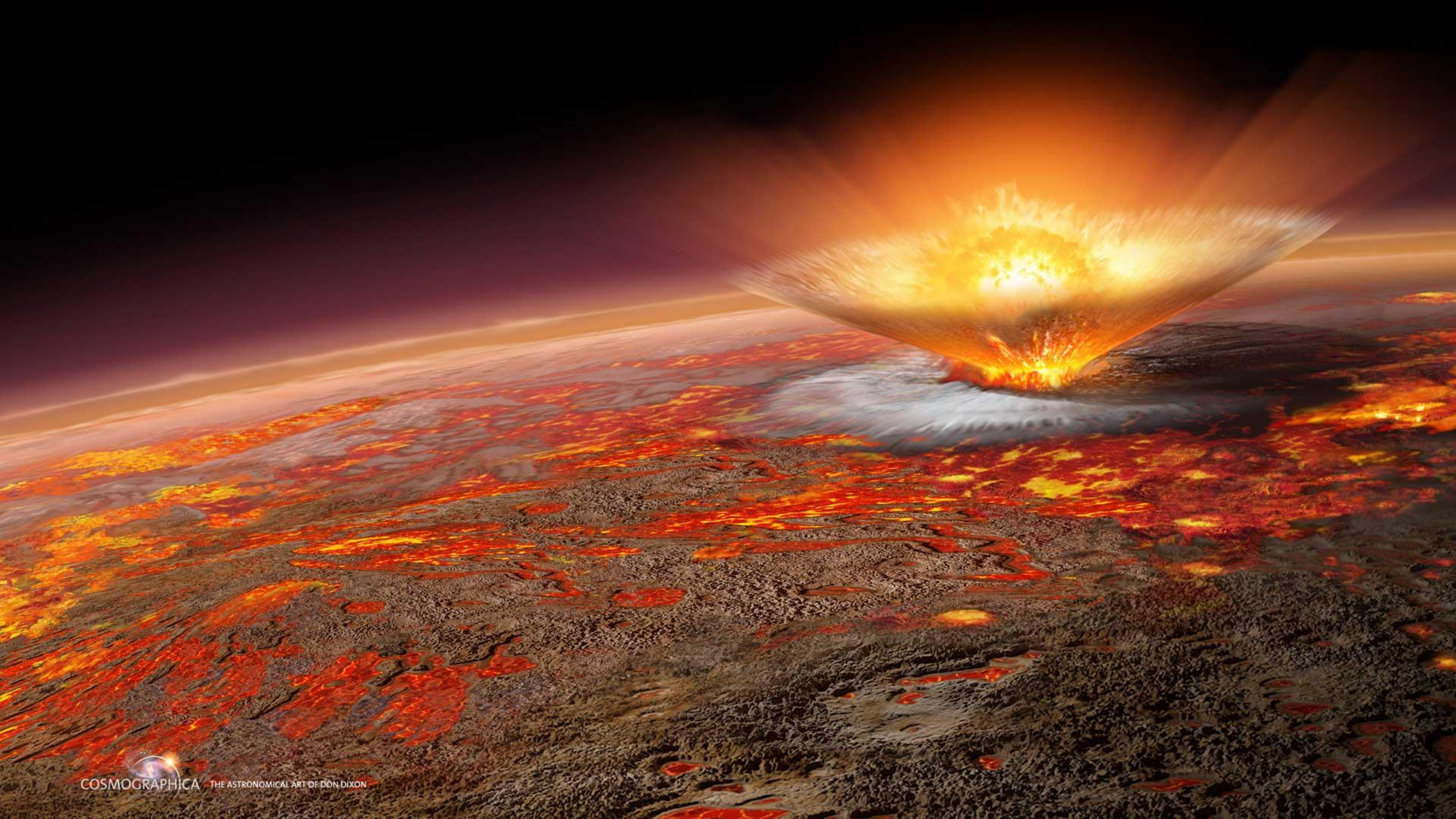
Rosetta's ROSINA instrument finds Comet 67P/Churyumov-Gerasimenko's water vapour to have a significantly different composition to Earth's oceans.



The ratio of deuterium to hydrogen in water is a key diagnostic to determining where in the Solar System an object originated and in what proportion asteroids and comets may have contributed to Earth's oceans



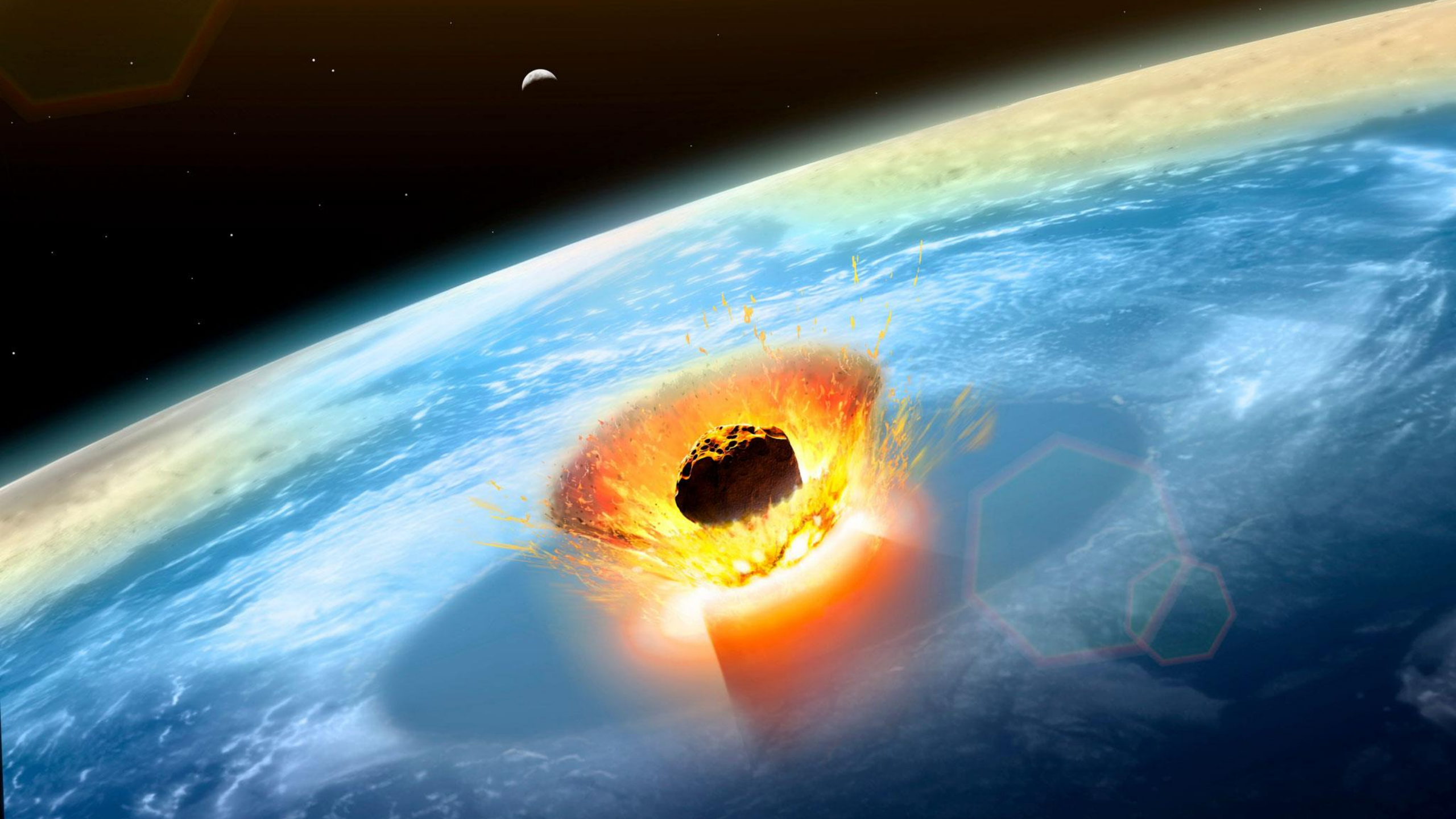
D/H ratio for different Solar System objects, grouped by colour as planets and moons (blue), chondritic meteorites from the Asteroid Belt (grey), comets originating from the Oort cloud (purple) and Jupiter family comets (pink). Comet 67P/C-G, a Jupiter family comet, is highlighted in yellow. ♦ = data obtained in situ ● = data obtained by astronomical methods

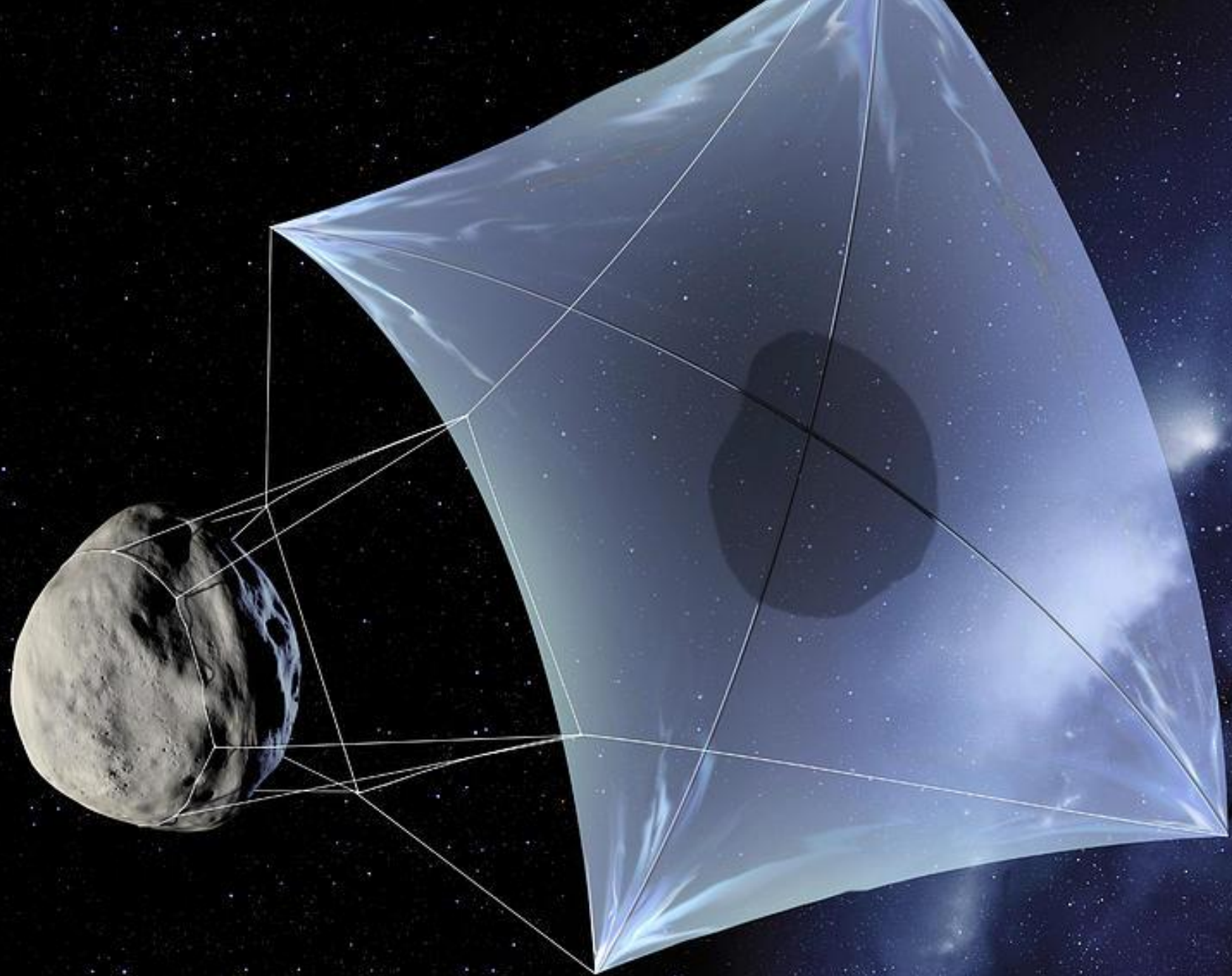


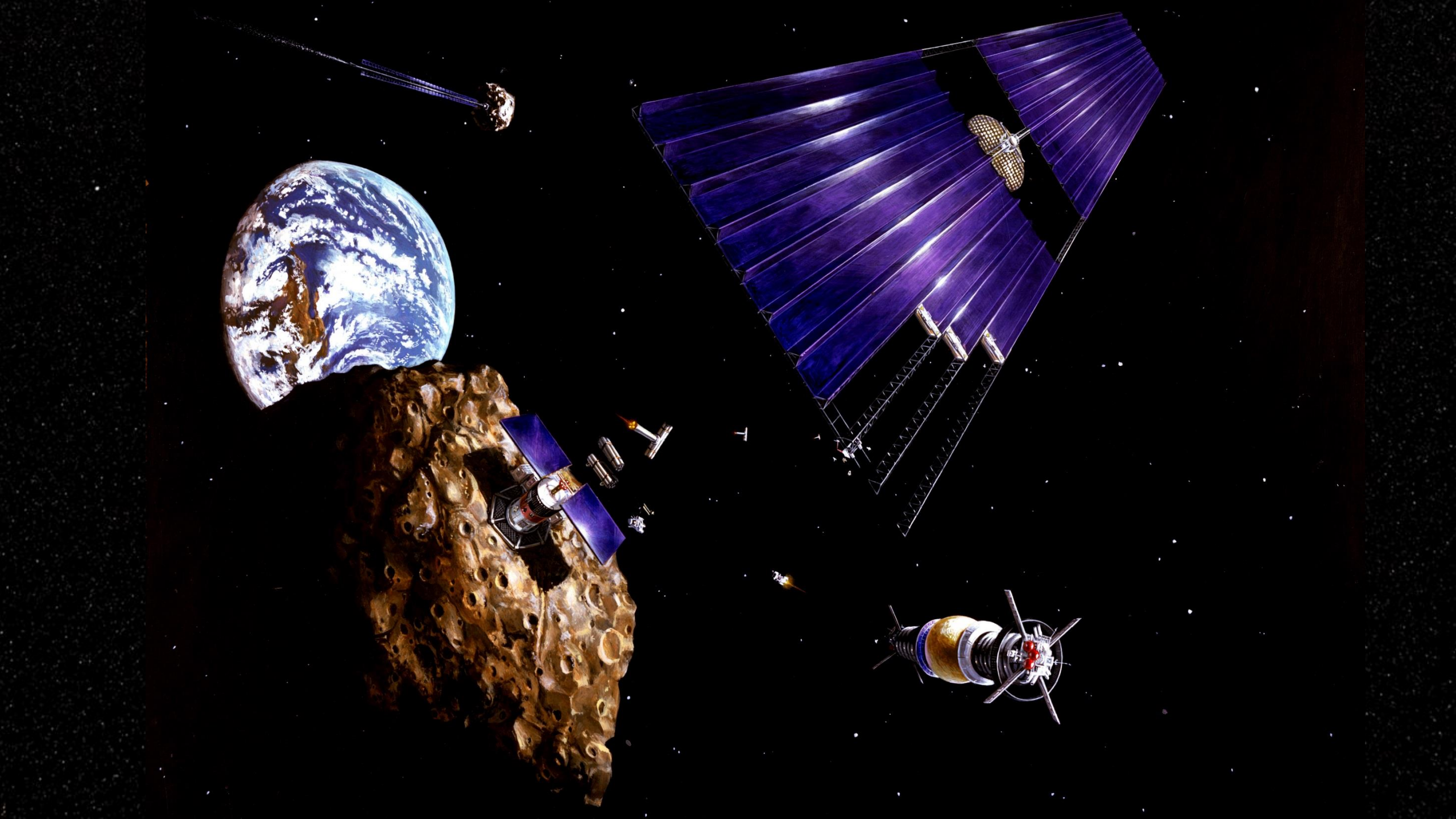


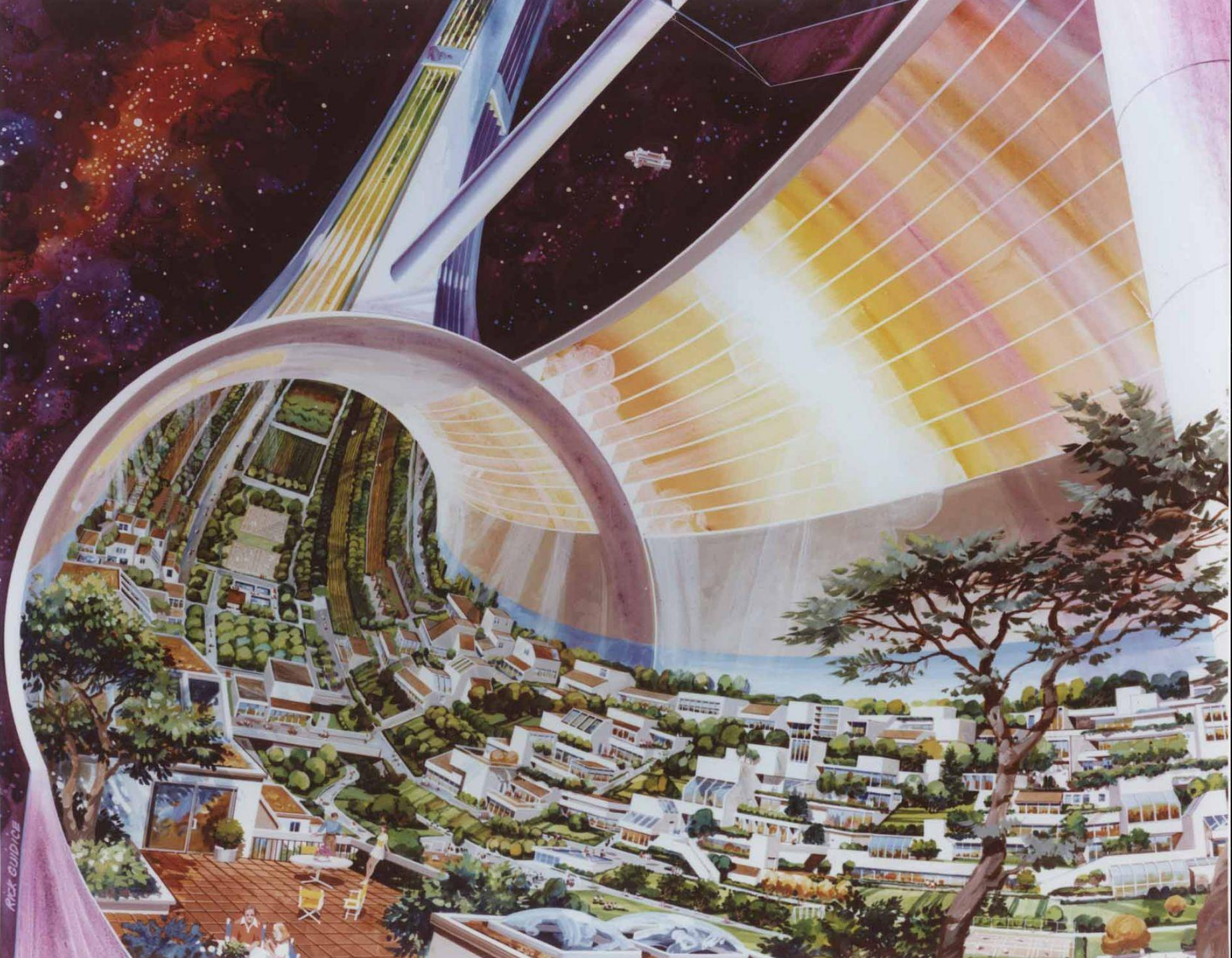


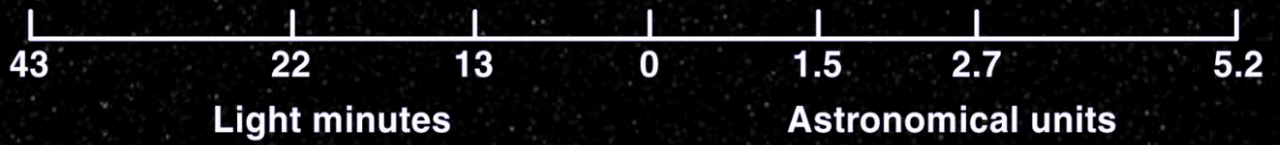
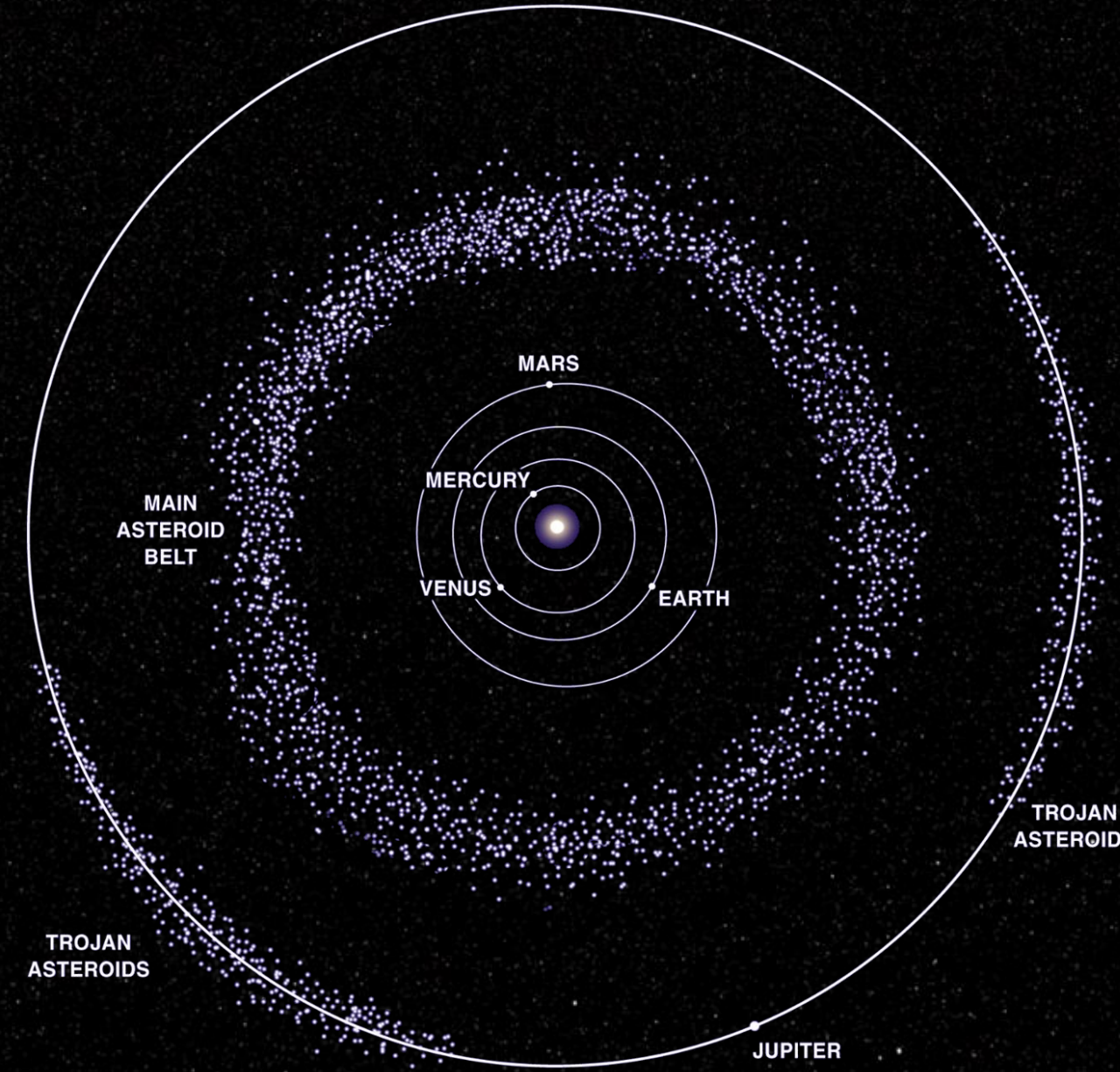












Boring slide

- 752,000+ known asteroids + constantly increasing
- 508,000+ numbered asteroids + constantly increasing
- 138,000+ with known size and albedo + 350,000 by Gaia
- \approx 4,000 with known spectral type + 100,000s by Gaia and Euclid
- 12 studied by space missions
- +10 more with launched and developed missions

1 Ceres

Image Credit: NASA /
JPL-Caltech / UCLA /
MPS / DLR / IDA /
Justin Cowart



25143 Itokawa Hayabusa/JAXA



4 Vesta



5535 Annefrank Stardust/JPL/NASA



9969 Braille Deep Space 1 NASA/JPL/USGS

Images: NASA / JPL / MPS / DLR / IDA
Dawn 2011-07-24 08:35 to 2011-07-24 09:36
Image processing: Björn Jönsson

4179 Toutatis Chang'e/CNSA



951 Gaspra Galileo/NASA / JPL/USGS



2867 Šteins Rosetta ESA MPS for OSIRIS Team MPS/UPD/LAM/IA A



21 Lutetia ESA 2010 MPS for OSIRIS Team MPS/UPD/LAM/IAA/RS SD/INTA/UPM/DASP/I DA



243 Ida and Dactyl Galileo/NASA



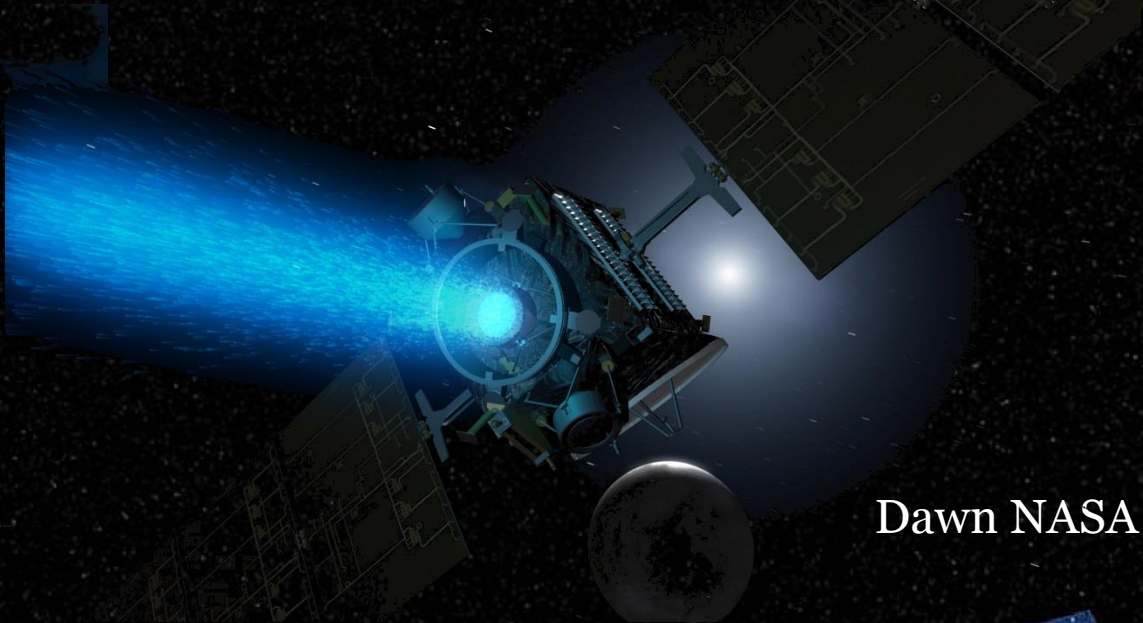
433 Eros NEAR Shoemaker NASA/JPL/JHUAPL

253 Mathilde NEAR/NASA

Near Shoemaker
NASA



Galileo NASA



Dawn NASA

Hayabusa JAXA



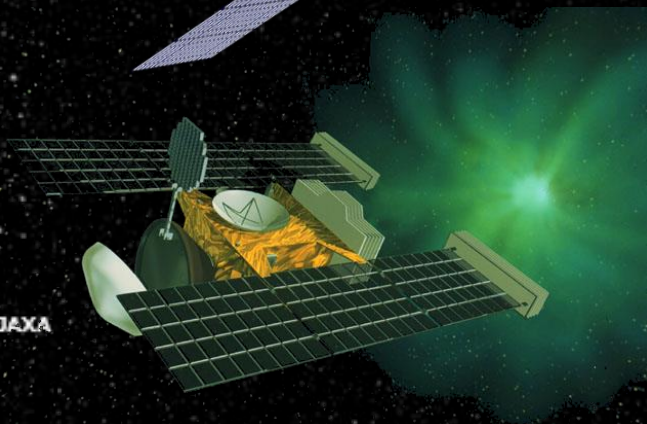
Deep Space 1
NASA



Chang'e 2 CAST



Stardust
NASA



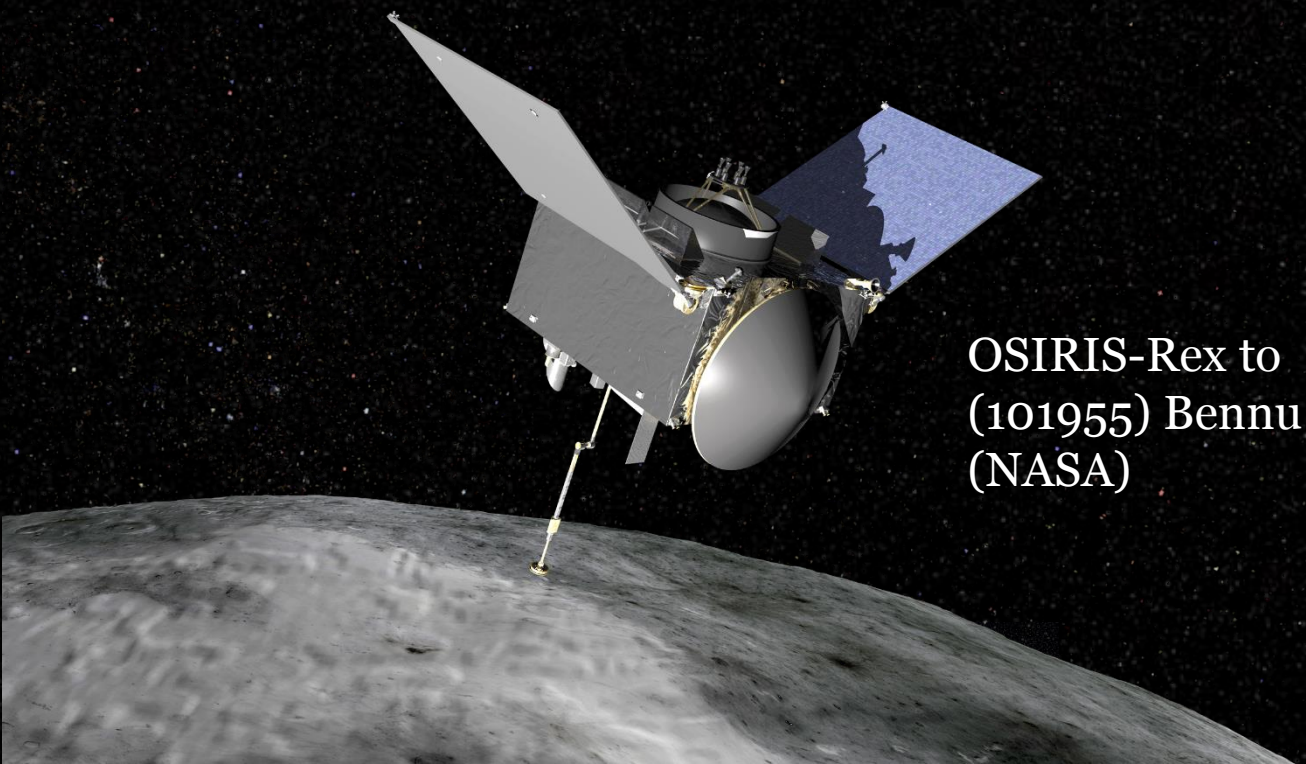
A.IKESHITA / JAXA

Rosetta ESA





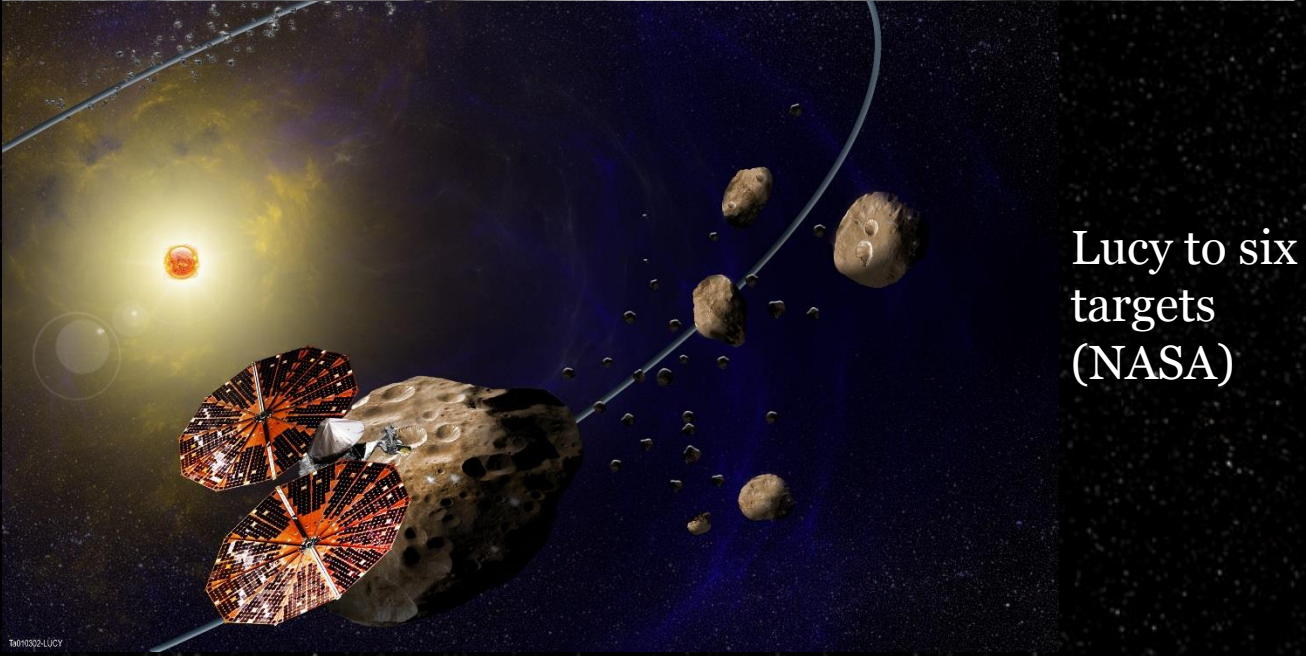
Hayabusa 2 to (162173) Ryugu (JAXA)



OSIRIS-Rex to (101955) Bennu (NASA)

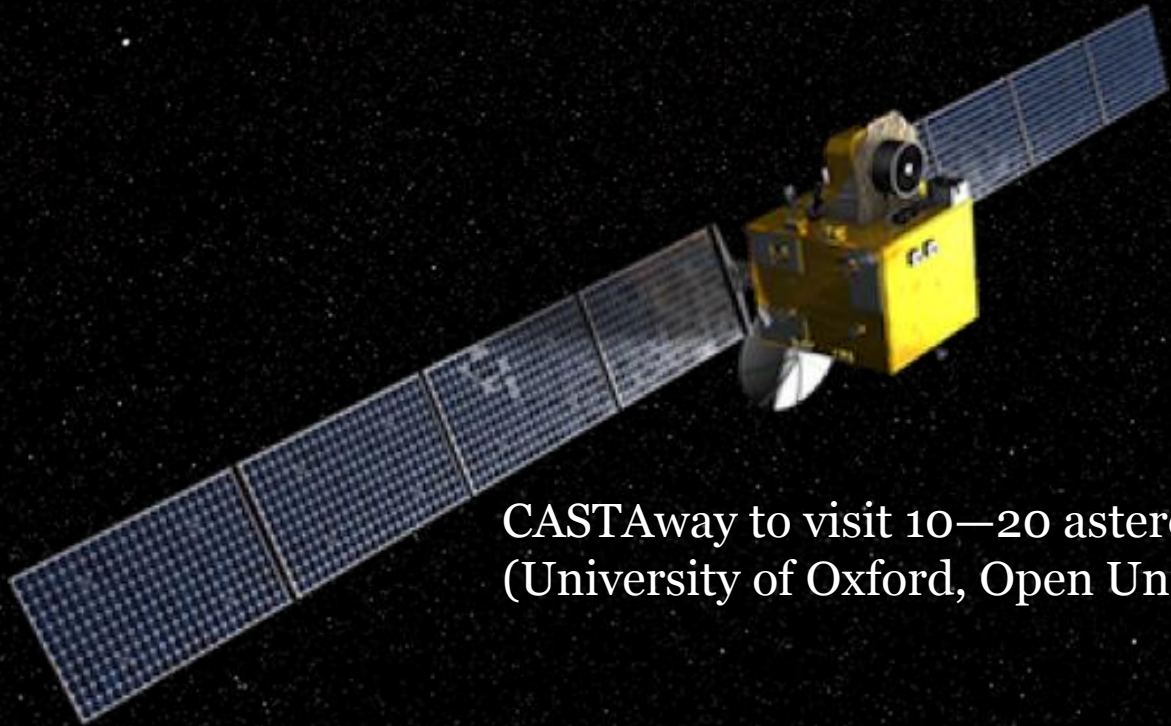


Psyche to (16) Psyche (NASA)



Lucy to six targets (NASA)

Asteroid touring concepts



CASTAway to visit 10–20 asteroids
(University of Oxford, Open University)



MANTIS to visit ~10 asteroids
(Johns Hopkins University Applied Physics Laboratory)

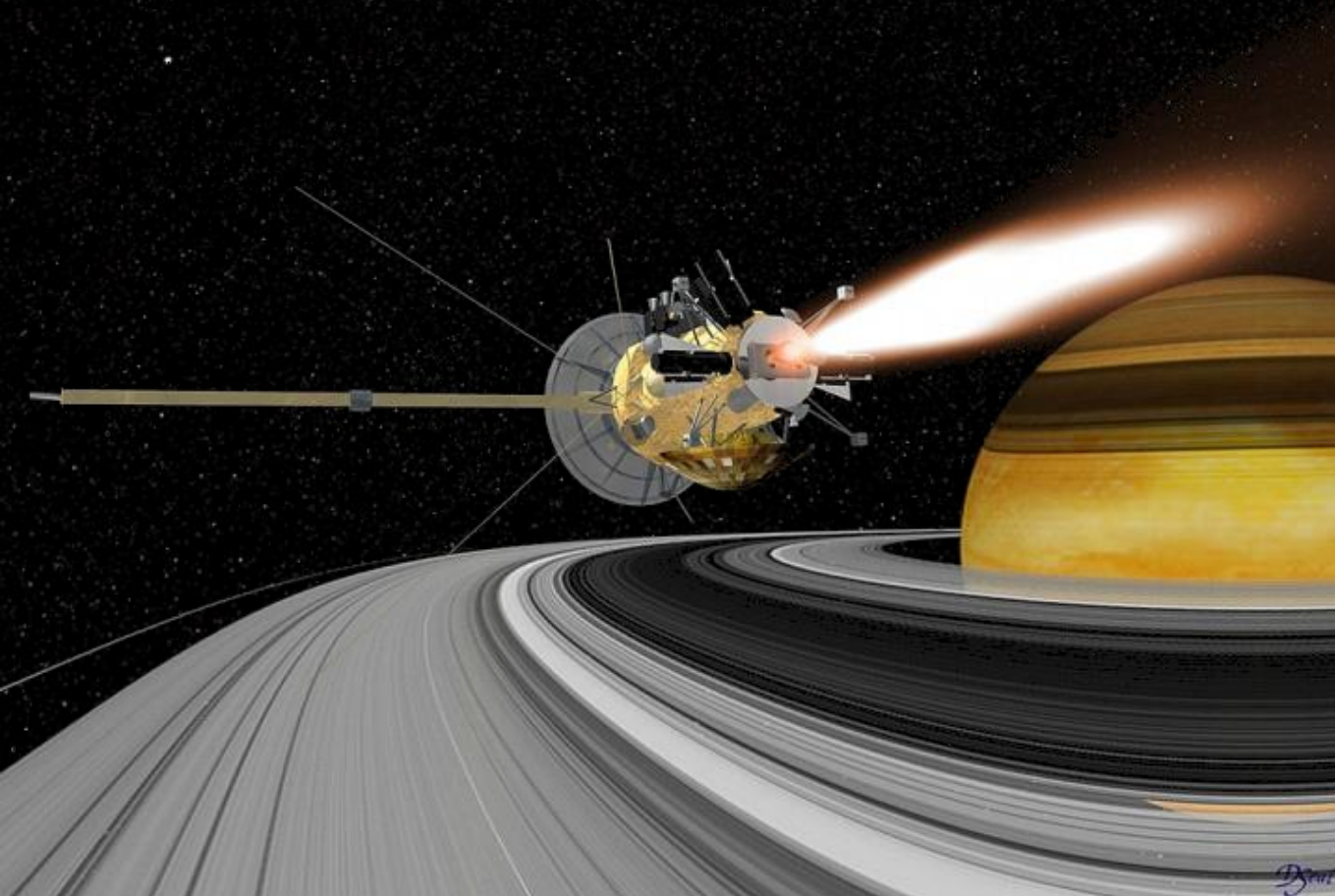
Distributed Earth monitoring systems



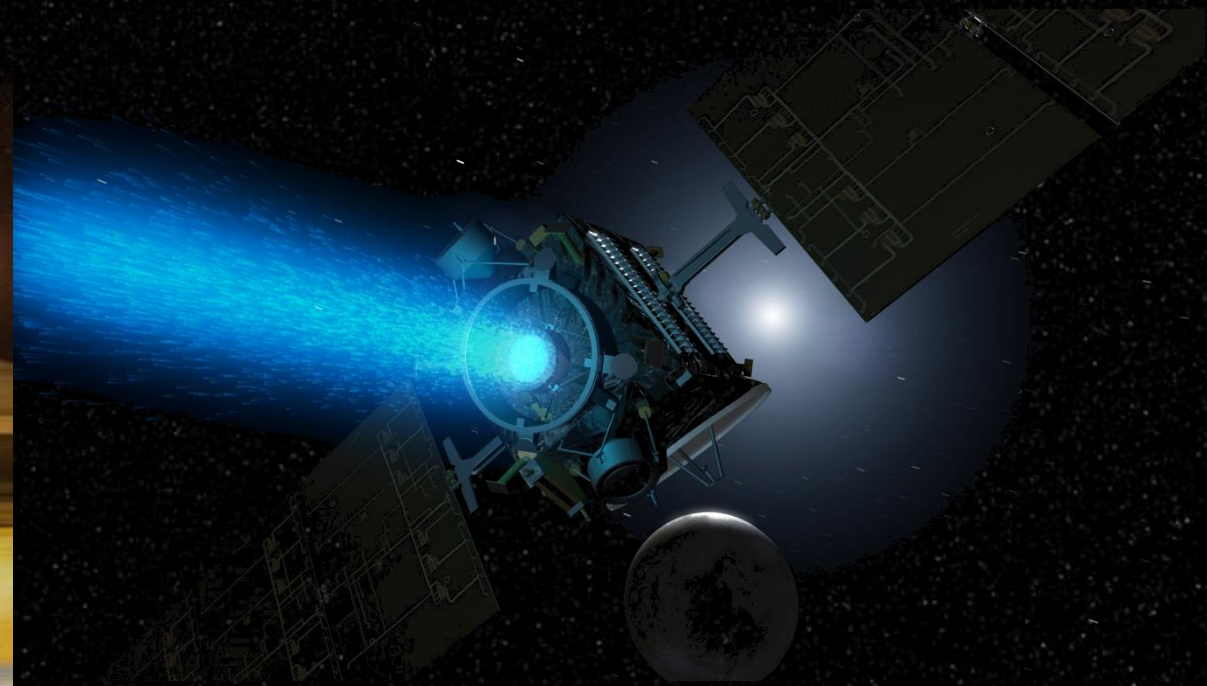
Planet Labs provide global imagery once a day with 200+ CubeSats



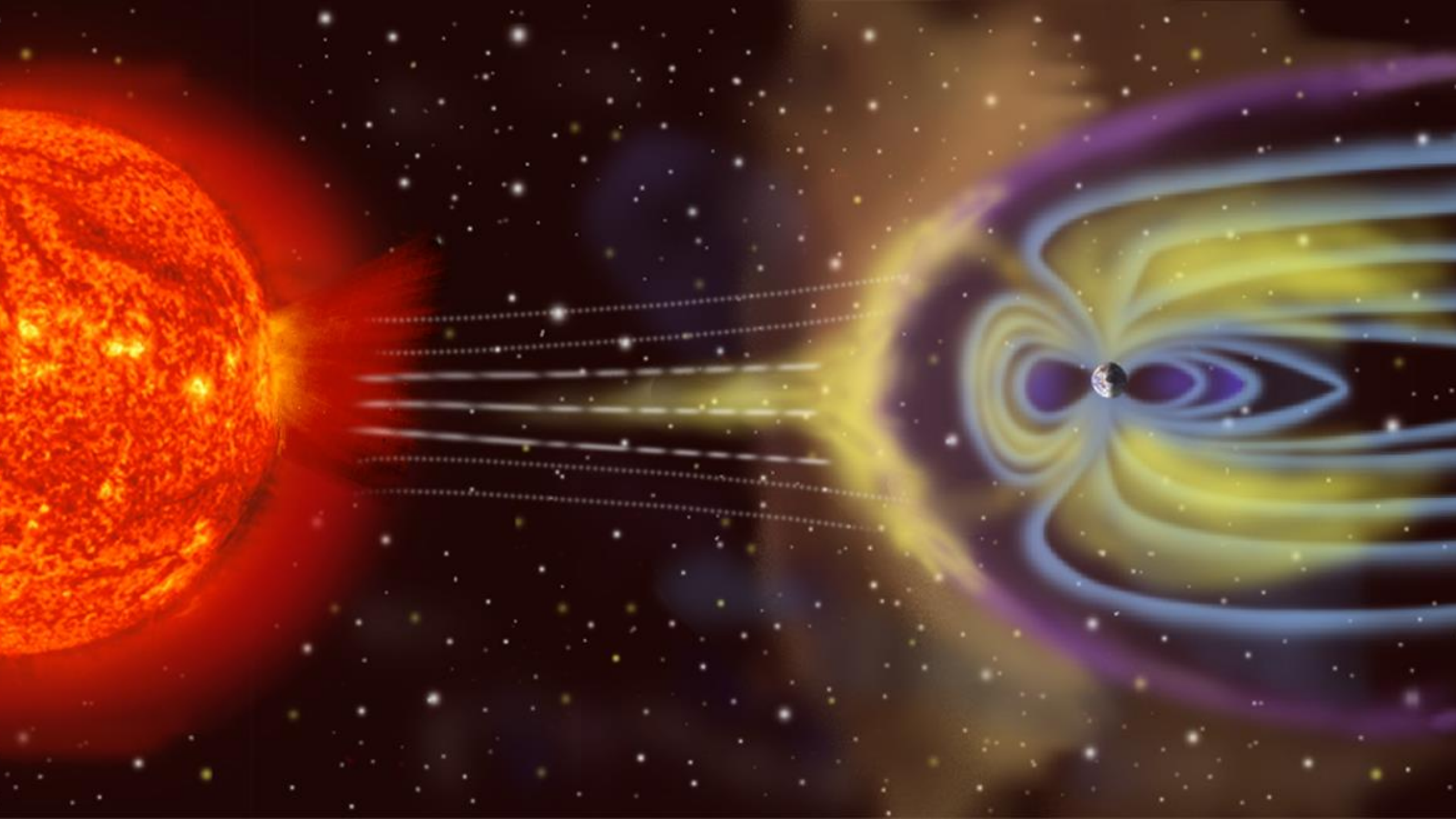
Spire provides global sensing for maritime, weather and aviation once a day with 50+ CubeSats

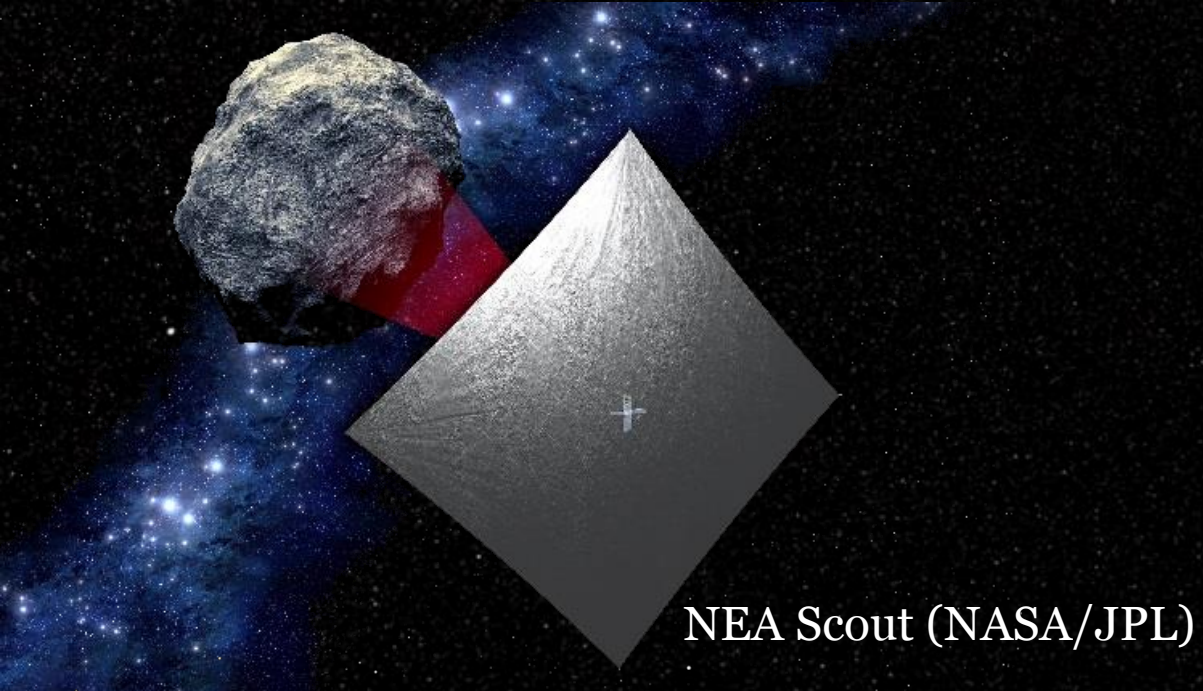


Bipropellant rocket engine
Example: Cassini (NASA)
~3100 kg of propellant out of 5712 kg launch mass
 $\Delta v = 2 \text{ km/s}$

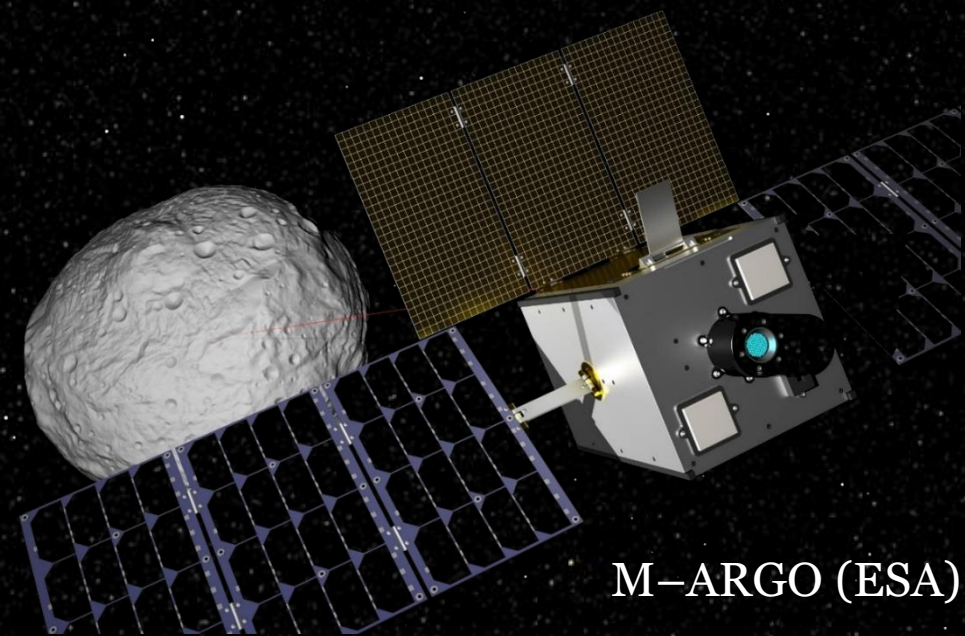


Ion engine
Example: Dawn (NASA)
425 kg of xenon out of 1200 kg launch mass
 $\Delta v = 10 \text{ km/s}$



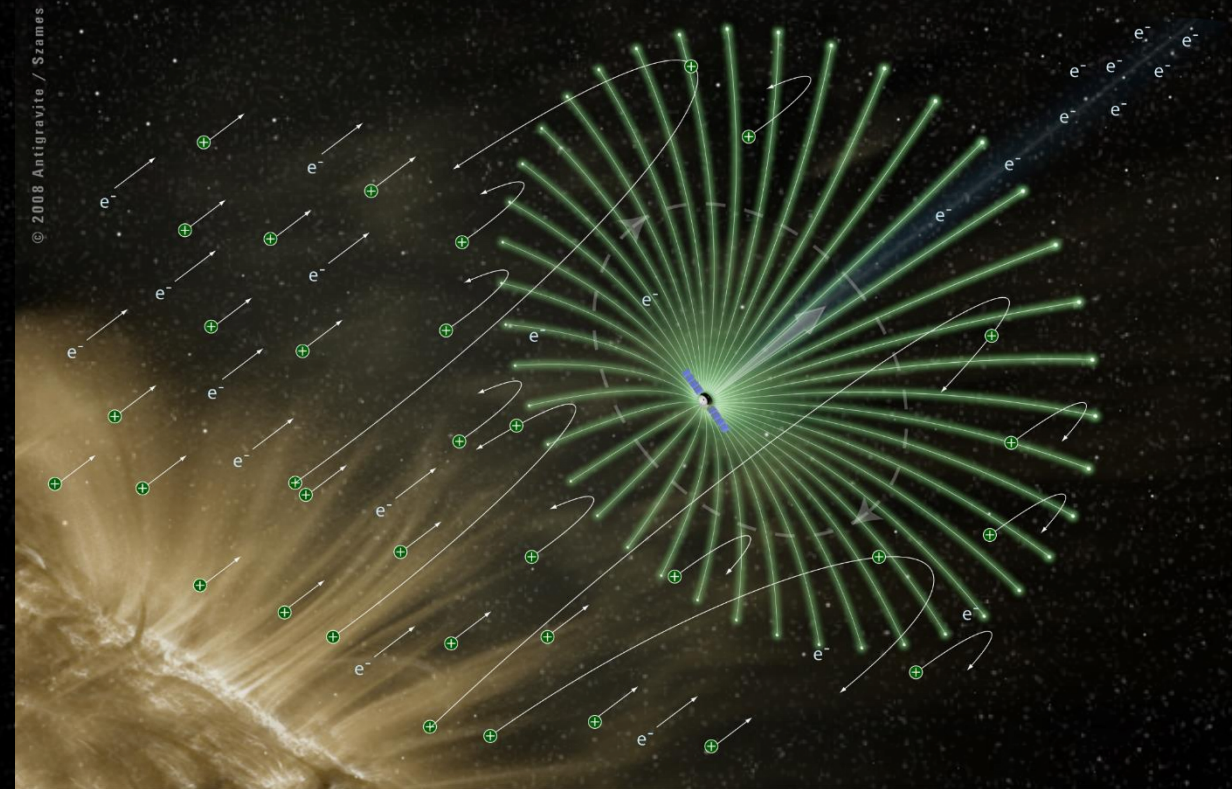


NEA Scout (NASA/JPL)



M-ARGO (ESA)

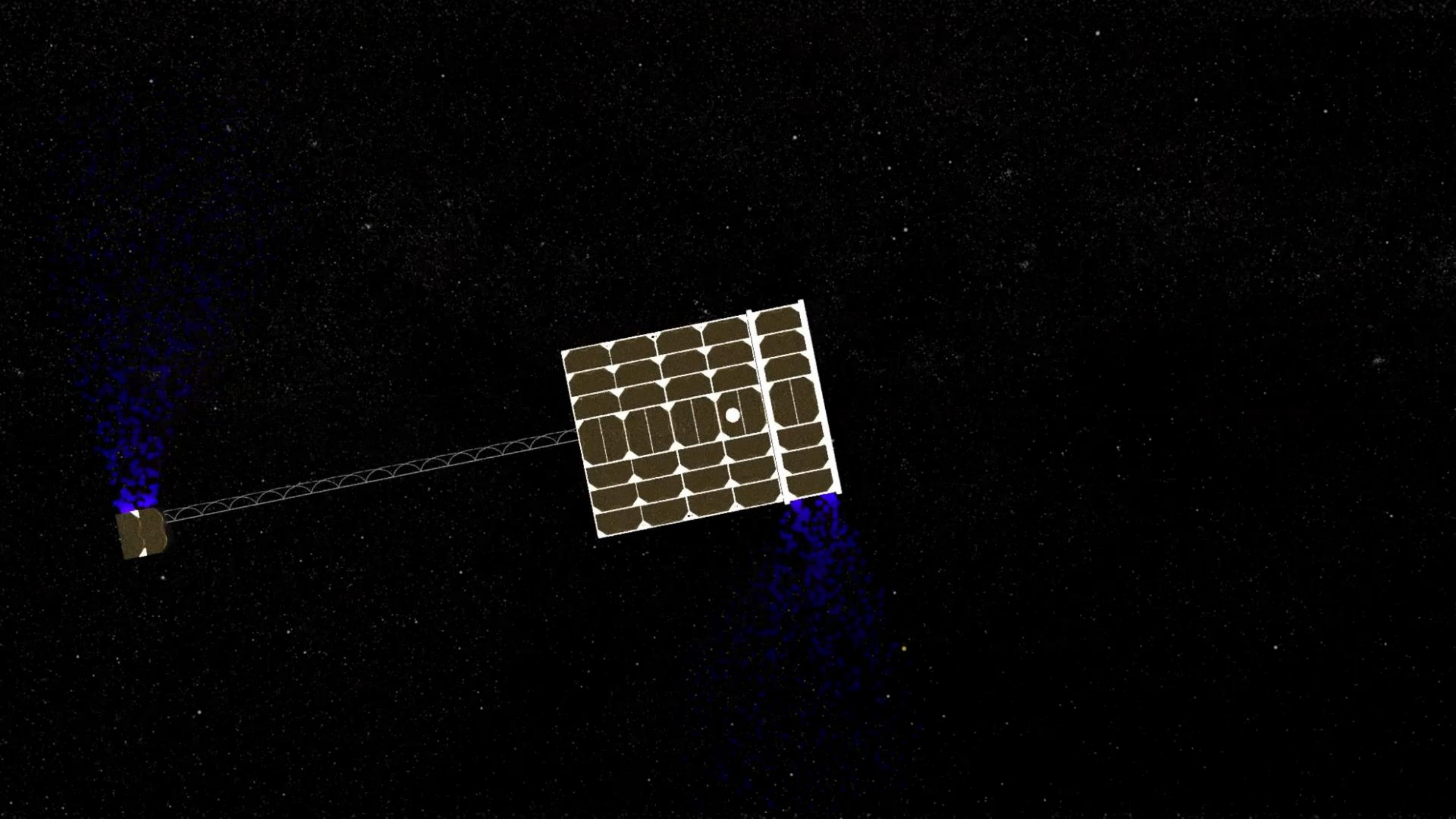
Photonic sail and ion engine
(power) thrust decays as $1/r^2$



Electric solar wind
sail thrust decays
as $1/r^{7/6} \approx 1/r$

Multi-asteroid touring

- Tens of nanospacecraft
- Hundreds of targets
- More than ten times increase in the number of visited asteroids

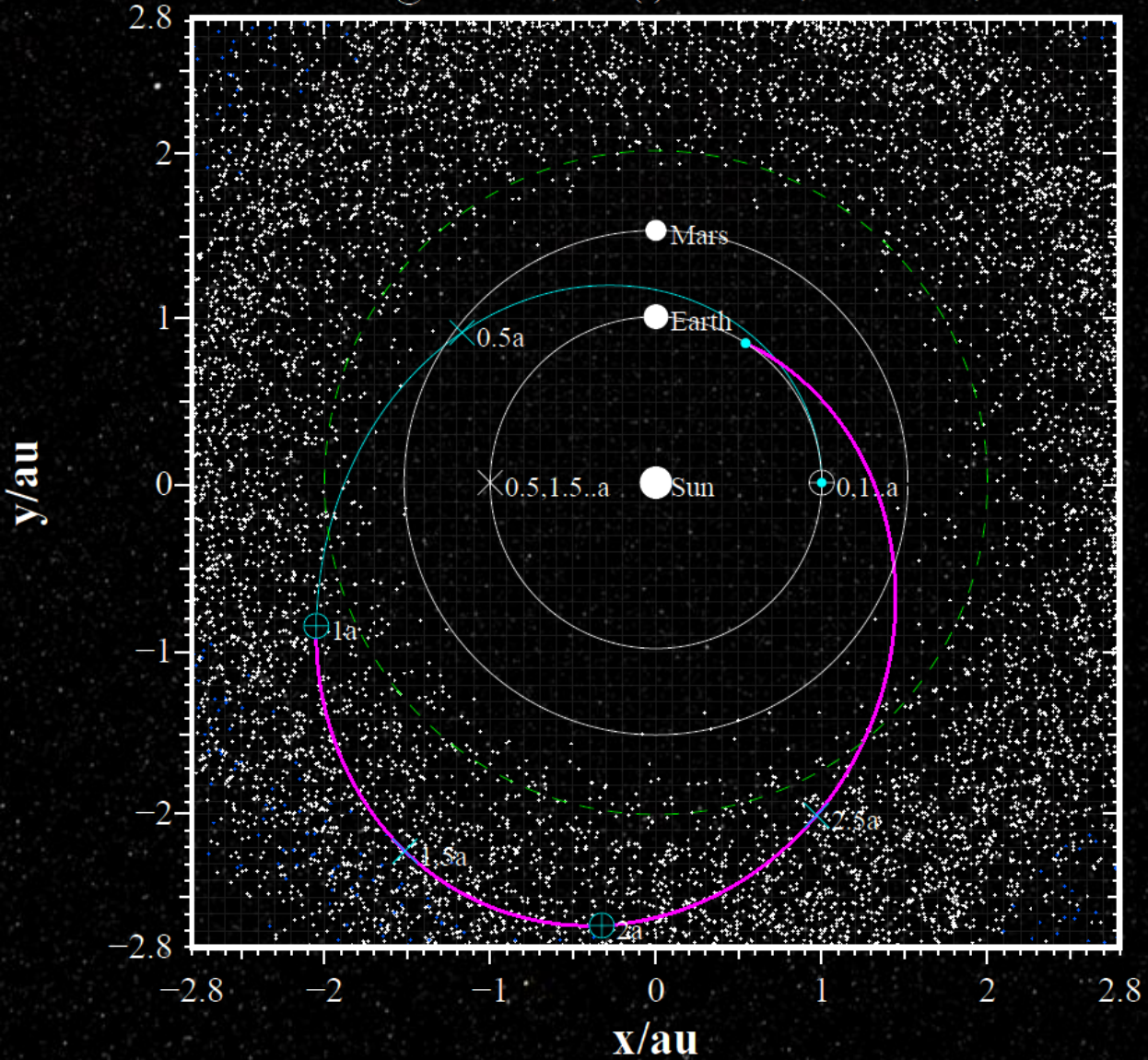




2017-08-15T11:58:44.753
Distance: 199.86 km

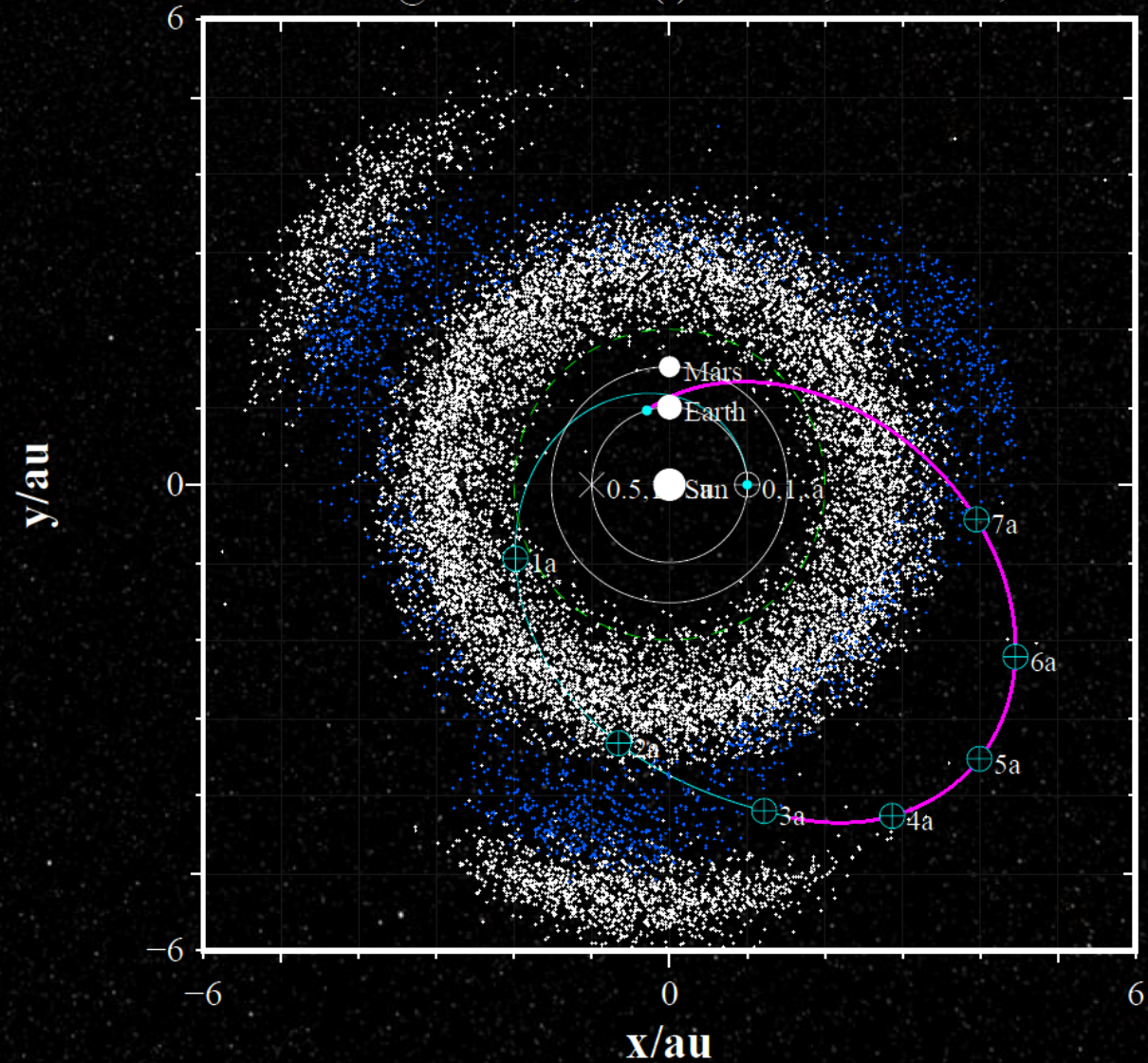
3.2-year asteroid tour, $ac0=1 \text{ mm/s}^2$

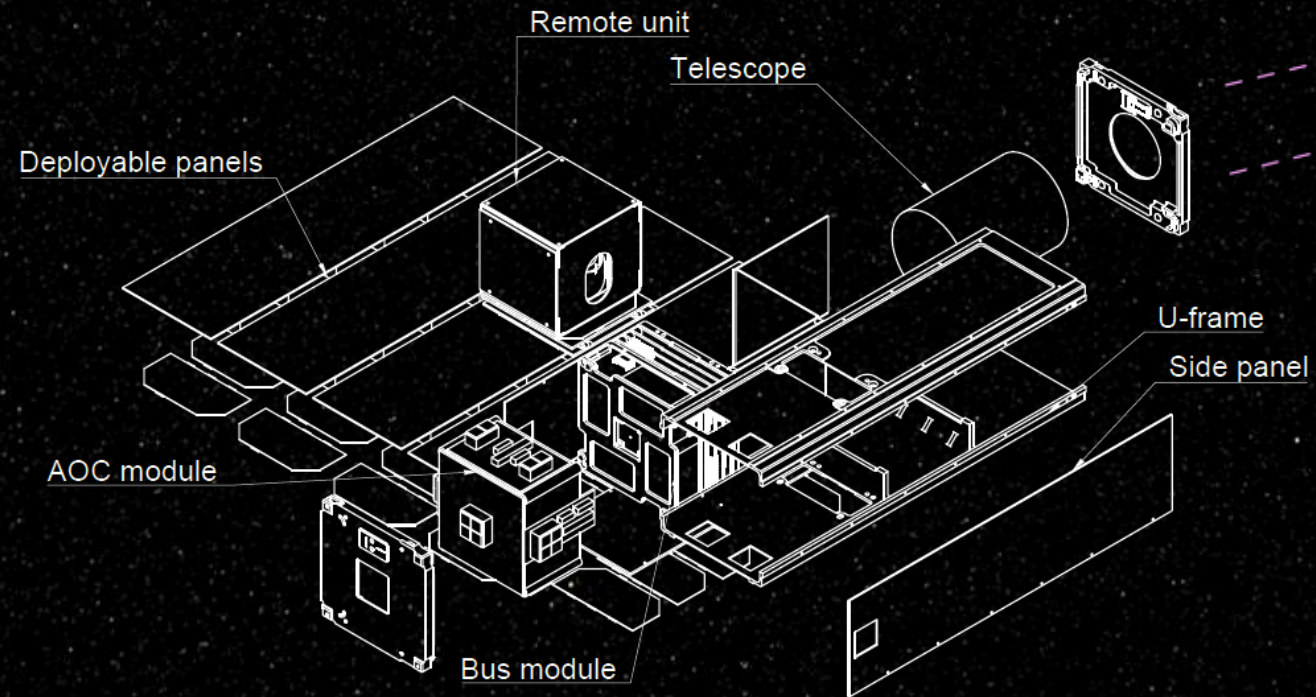
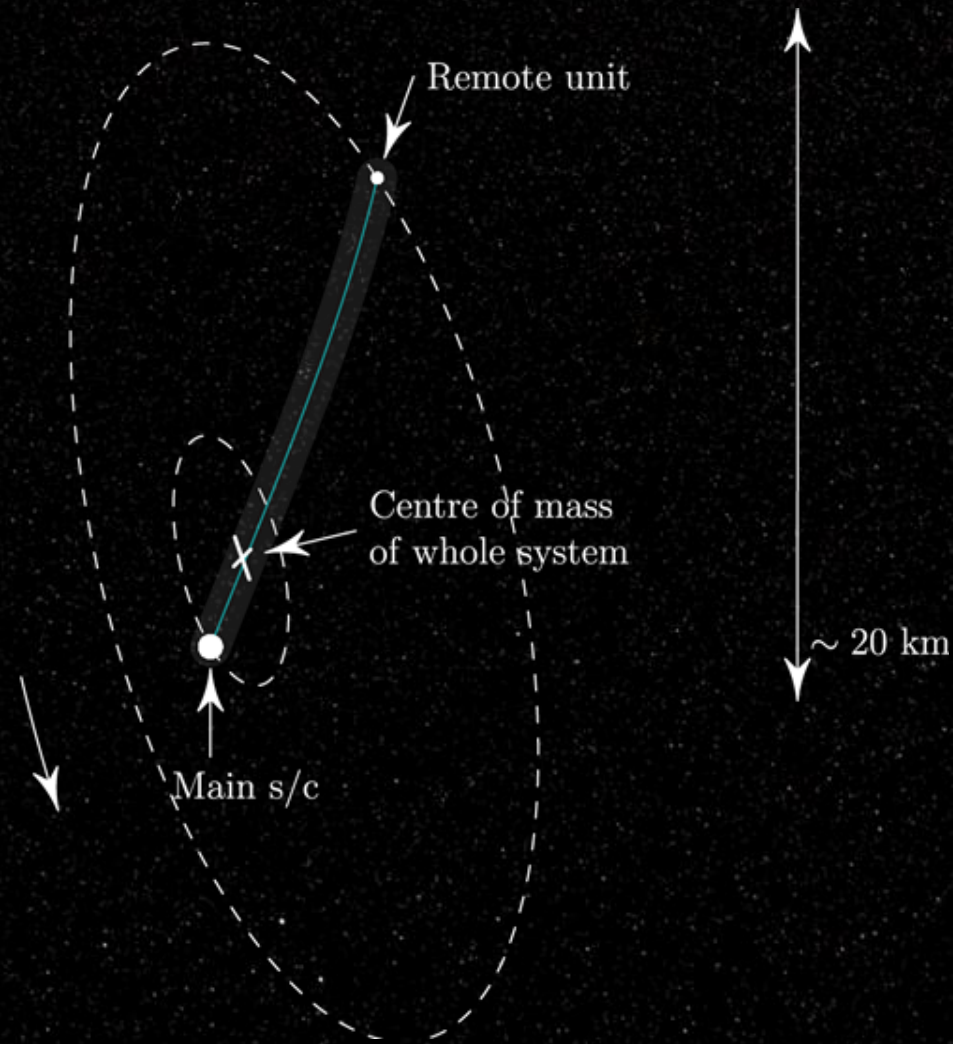
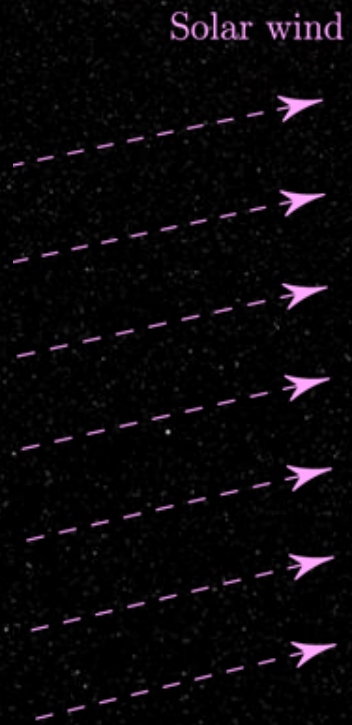
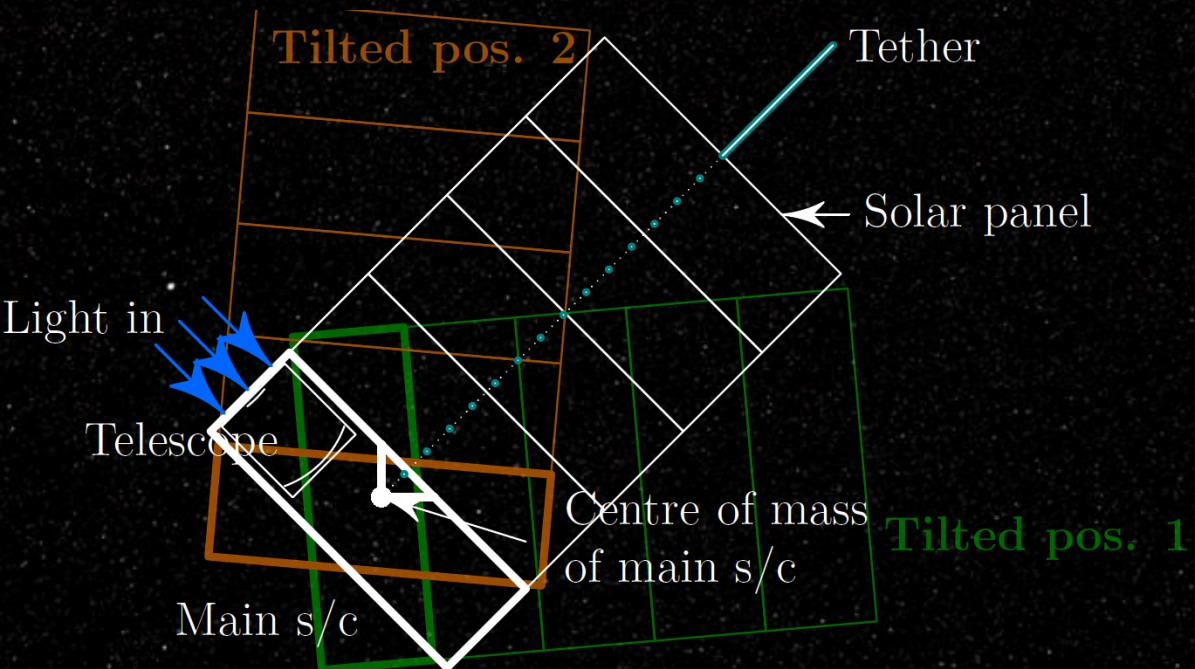
Earth DV=5.93km/s @ 1498km, max(r)=2.744au, dvtot=31.8, dvsci=13.6 km/s



8.3-year asteroid tour, $ac0=0.989 \text{ mm/s}^2$

Earth DV=12.4km/s @ 59491km, max(r)=5.332au, dvtot=55.9, dvsci=17.6 km/s



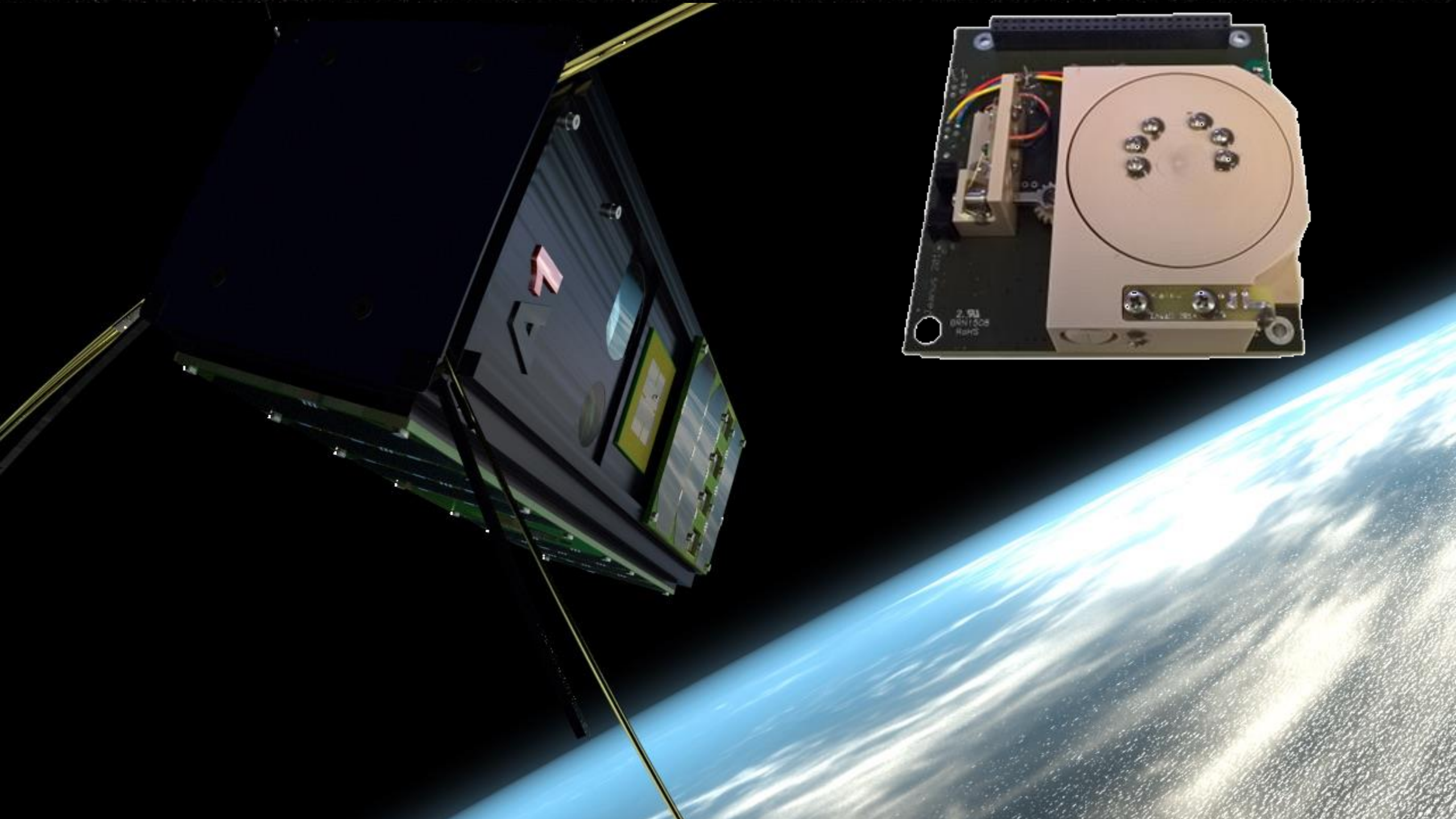


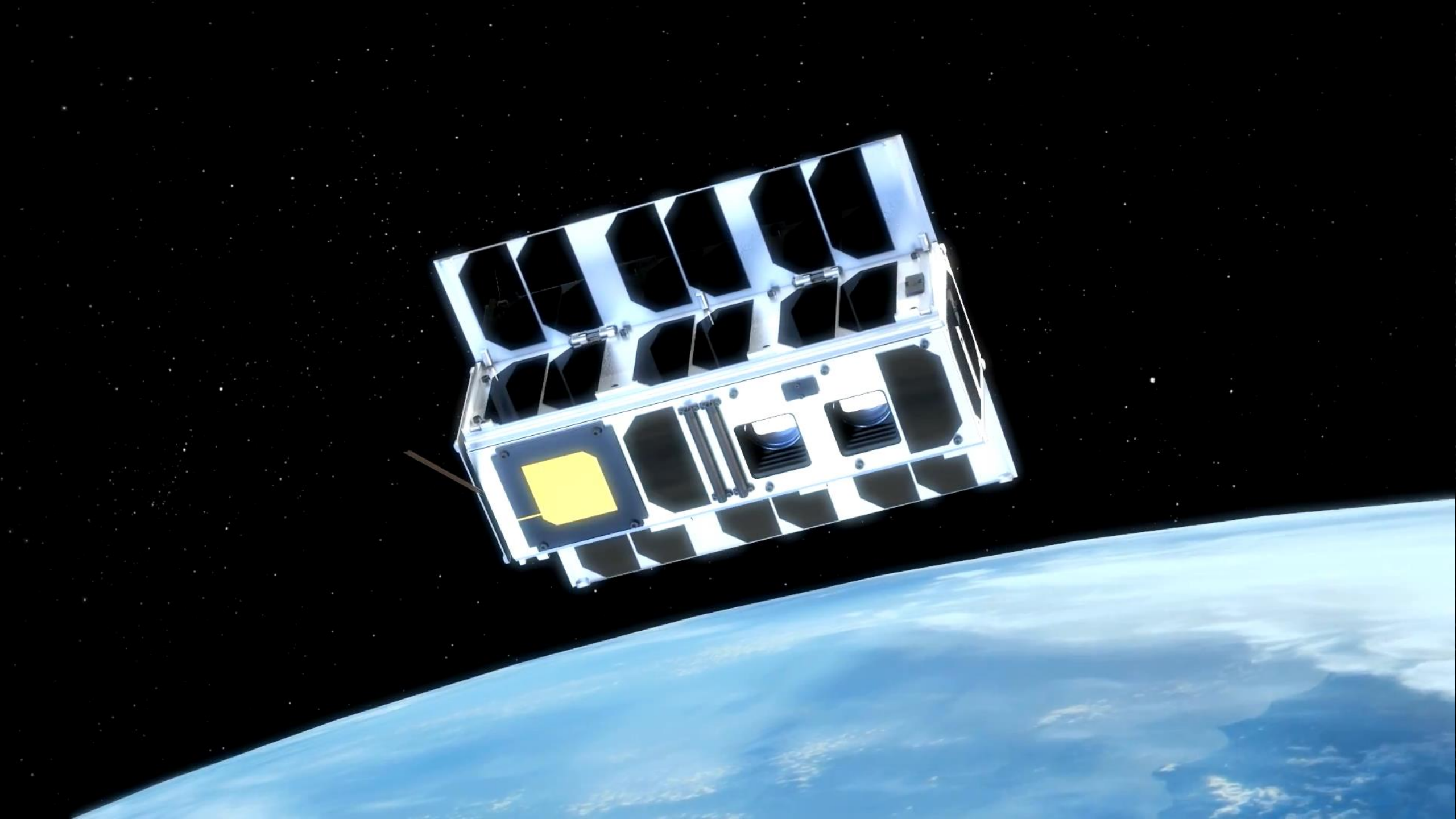
Technological Challenges

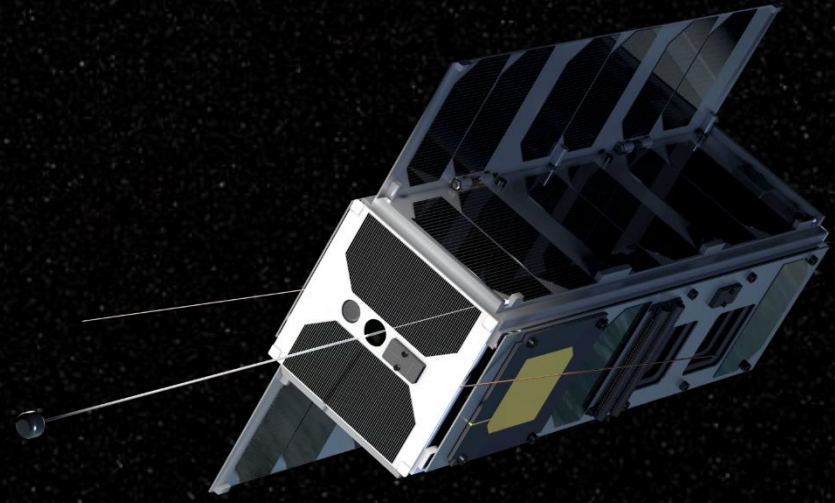
- Propulsion
- Communications
- Navigation and autonomy
- Interplanetary nanospacecraft platform and instrumentation

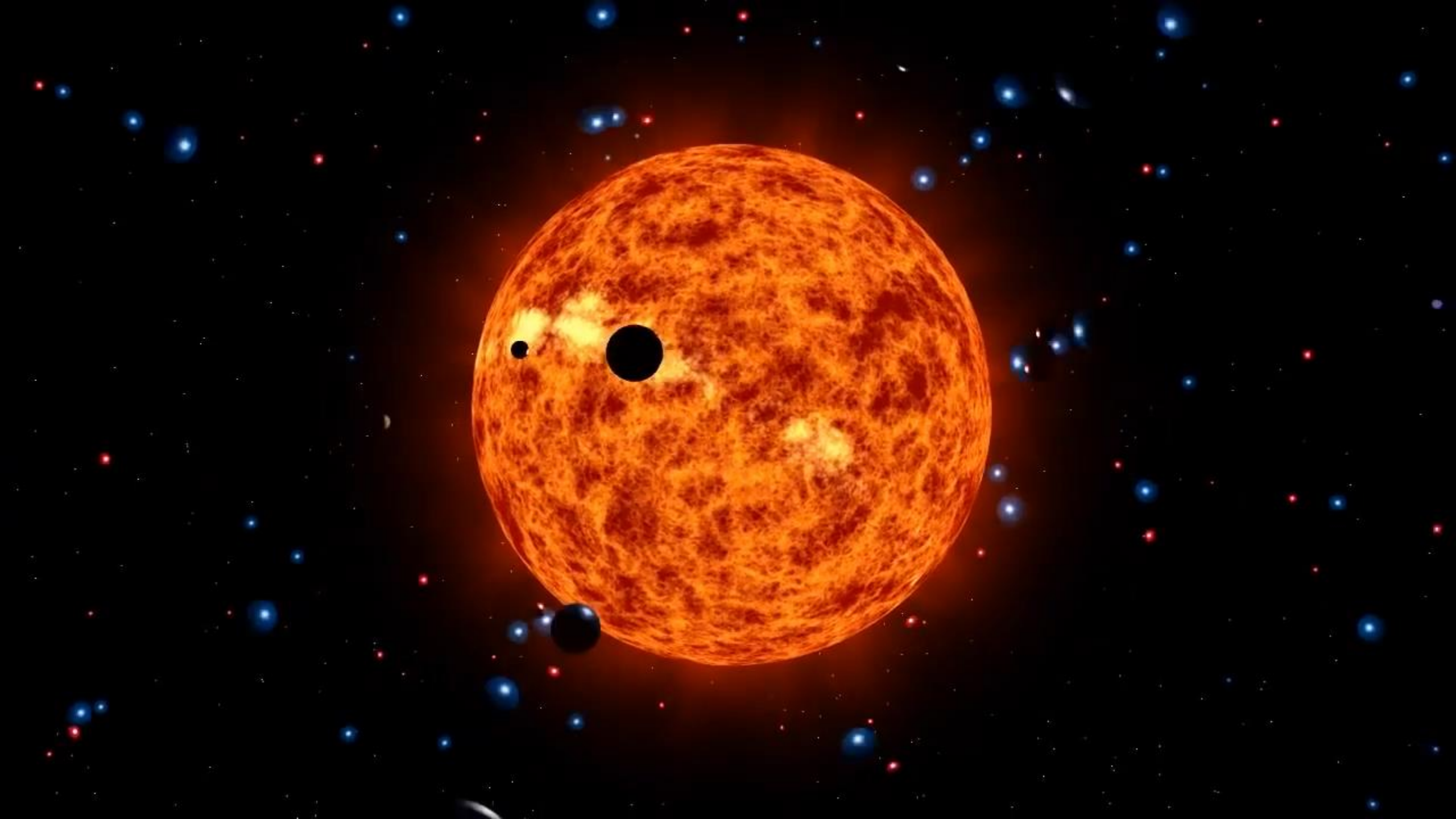
E-sail tether deployment starts











Contributing authors of initial “Multi-Asteroid Touring” mission proposed for ESA’s Call for “New Science Ideas”:
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References

- MAT computer renders and animations: Mihkel Pajusalu
- The Flare and the Galaxy: Martin Mark
- Asteroid impact drawings: Cosmographica
- Rosetta and M-ARGO: ESA
- 67P: ESA/Rosetta/NAVCAM
- Meteor shower: Business Insider
- Chelyabinsk meteor: Aleksandr Ivanov
- Tunguska: History Rundown
- Photon sail: Detlev Van Ravenswaay
- Asteroid mining: NASA
- Asteroid distribution: NASA
- MAT trajectories and spacecraft concept: Pekka Janhunen
- MAT spacecraft assembly: Iaroslav Iakubivskiy
- ESTCube-1/2 animations: Taavi Torim and Erik Kulu
- Aalto-1: Aalto University/Finnish Meteorological Institute
- HERTS video: Marshall Space Flight Center