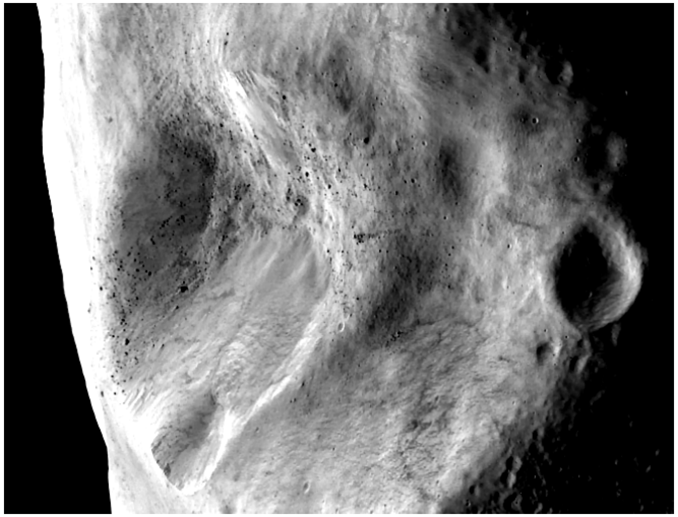
Asteroids

Properties of Asteroids

Asteroid spectra and meteorites

Water on Asteroids

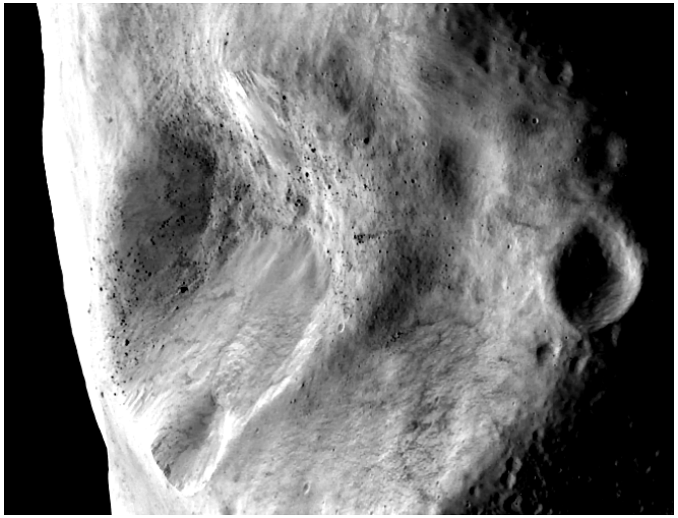
Missions to Asteroids



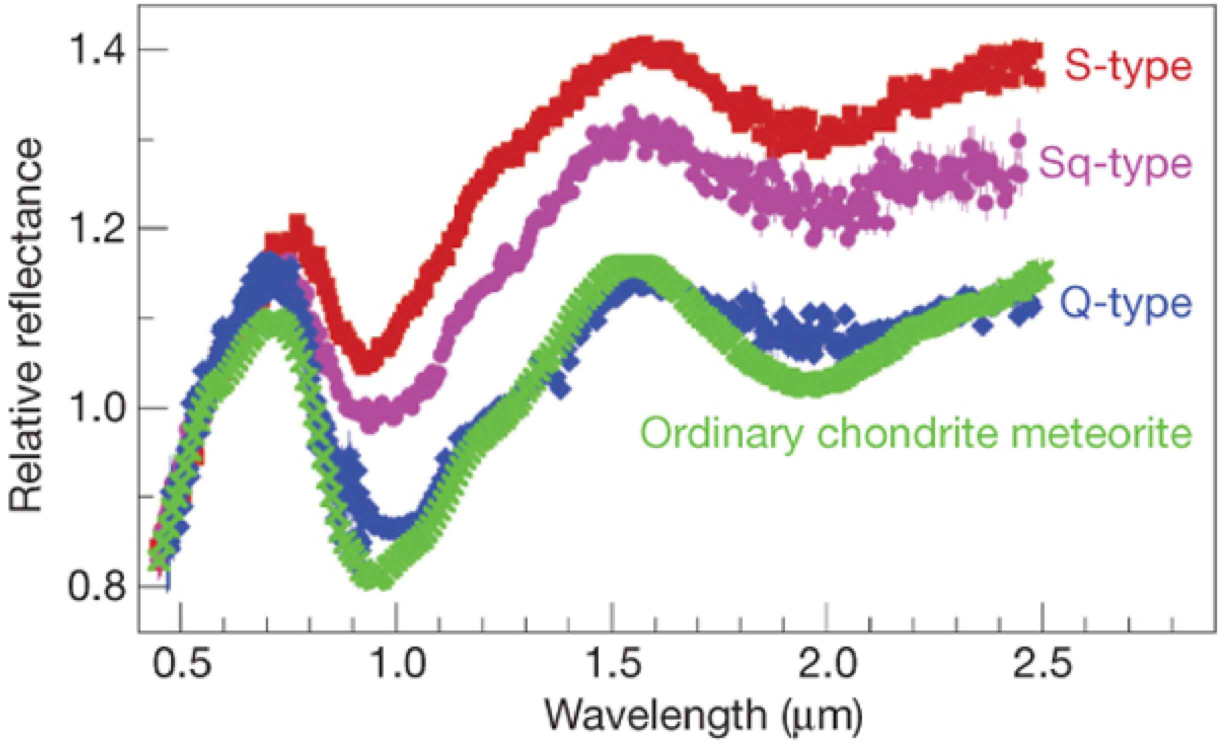
How do asteroids look like?

- Irregularly shaped bodies, covered with impact craters
  - Most of them are fragments from catastrophic impacts or “rubble piles” (re-accumulated material from disruptive impact)
- Composition: Silicate or metallic
  - Many “taxonomic types” with different spectra known
  - Corresponds to different composition

How do we know?



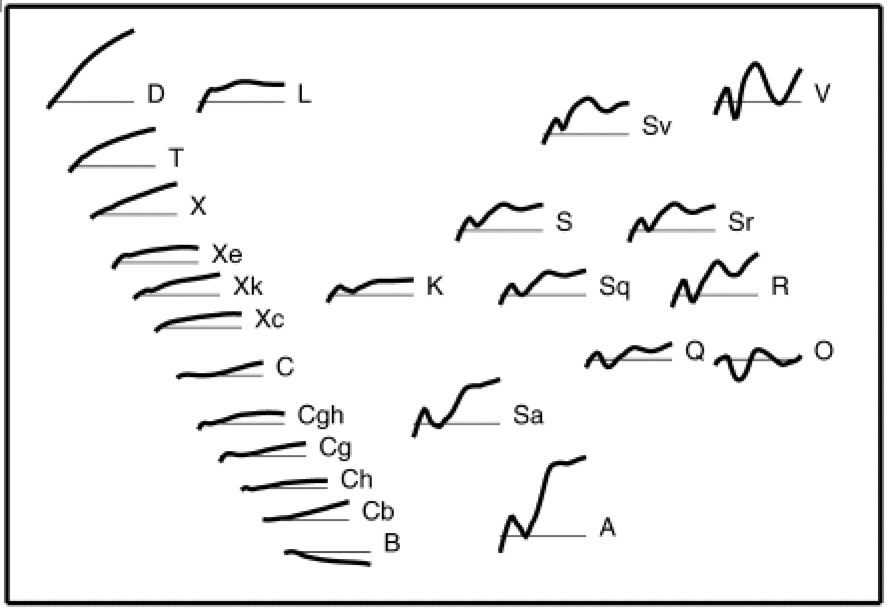
Asteroid vs. Meteorite spectra



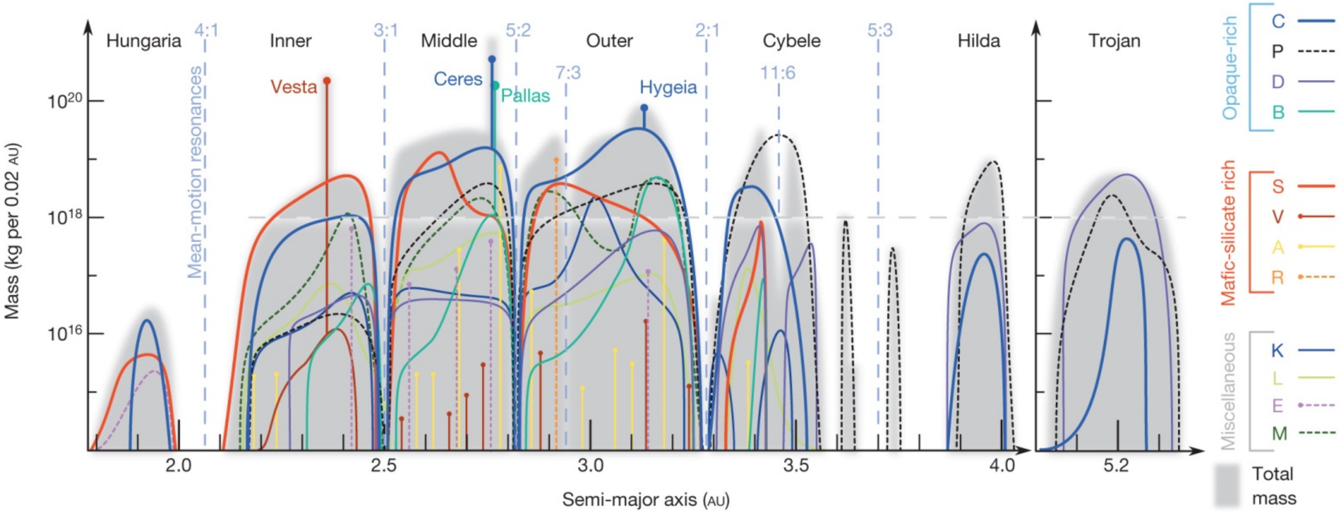
RP Binzel *et al. Nature* **463**, 331-334 (2010) doi:10.1038/nature08709

- Meteoritic analogues provide compositional information
- Complication due to space weathering

Solar system science with asteroid spectral types



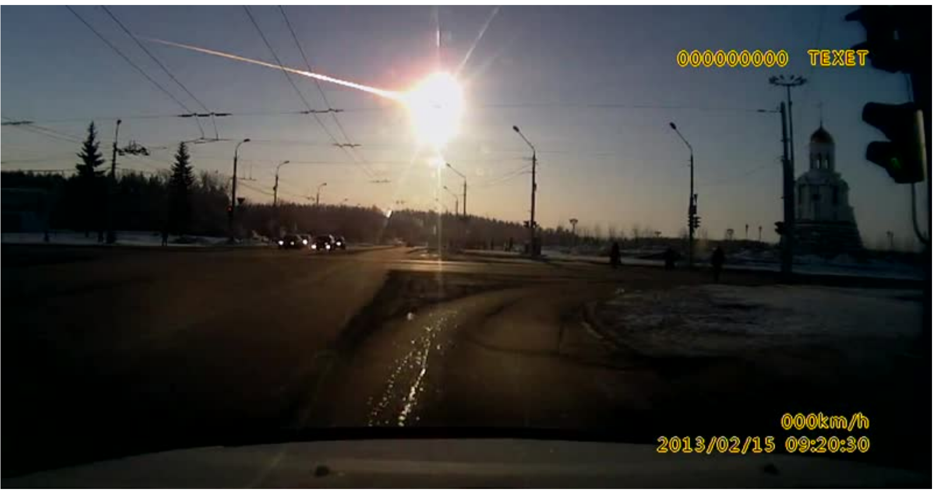
Asteroid classification (de Meo et al. 2009)



FE DeMeo & B Carry *Nature* **505**, 629-634 (2014) doi:10.1038/nature12908

- Taxonomic types vs. Position in the solar system

Asteroids: Connection with Meteorites



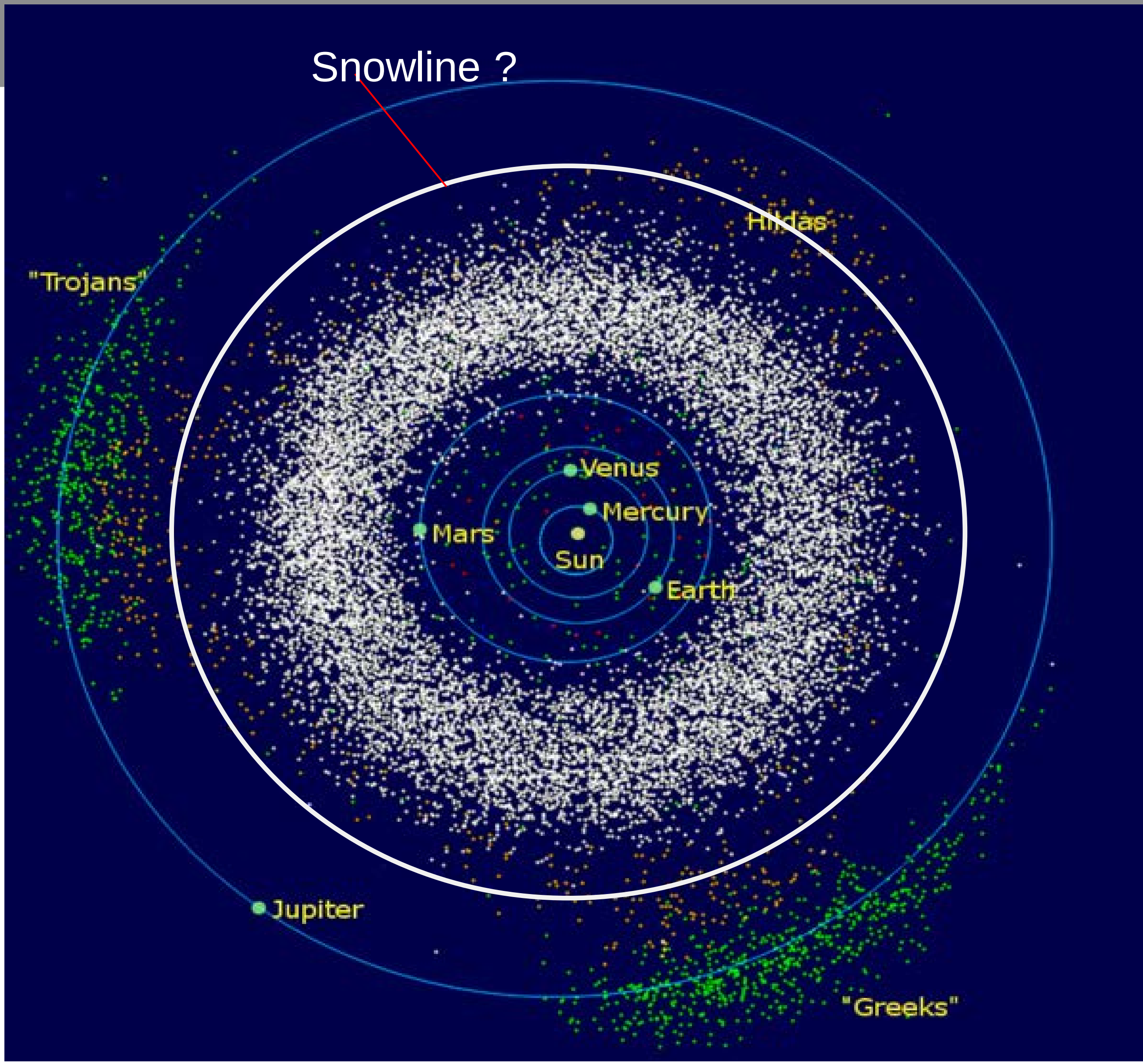
Explosion of asteroid close to Chelyabinsk, Russia, Feb. 2013

Meteorit found close to Chelyabinsk

Impact Craters

Meteor Crater, Arizona diameter 1200 m, age 50000 years

Volatile rich and inert (rocky) bodies



After: Wikipedia

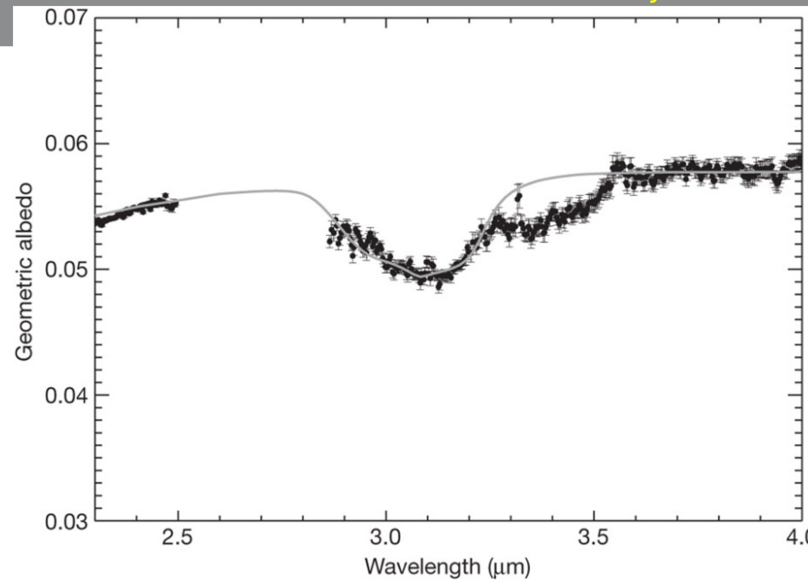
Classical picture:
Snowline in the solar system somewhere between asteroid main belt and Jupiter's orbit:

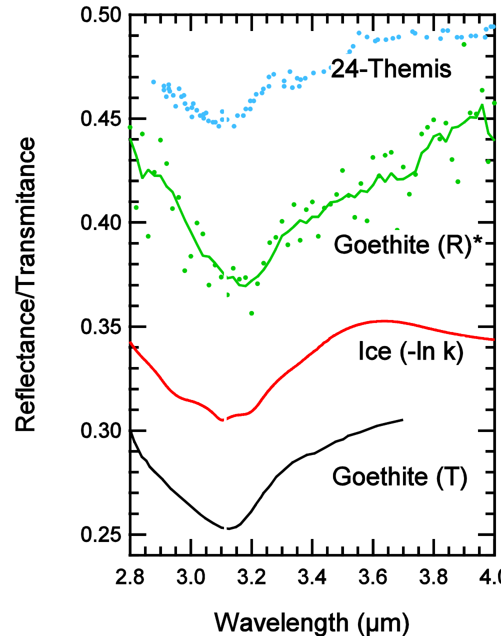
- Giant planets and comets are icy
- Terrestrial planets and asteroids are dry
  - Earth oceans come from outer solar system !?

Transition objects or: Water in the asteroid belt
I Hydrated features in asteroid spectra

- 3 micron absorption in spectra of some asteroids is indicative of hydrated minerals
- It is claimed that the spectrum of 24 Themis cannot be explained by hydrated minerals alone, but requires water ice on the surface (Campins et al. 2010, Rivkin & Emery 2010)
- The mineral goethite (FeO-OH) has been suggested as an alternative to water ice (Beck et al. 2011)

Rivkin & Emery 2010



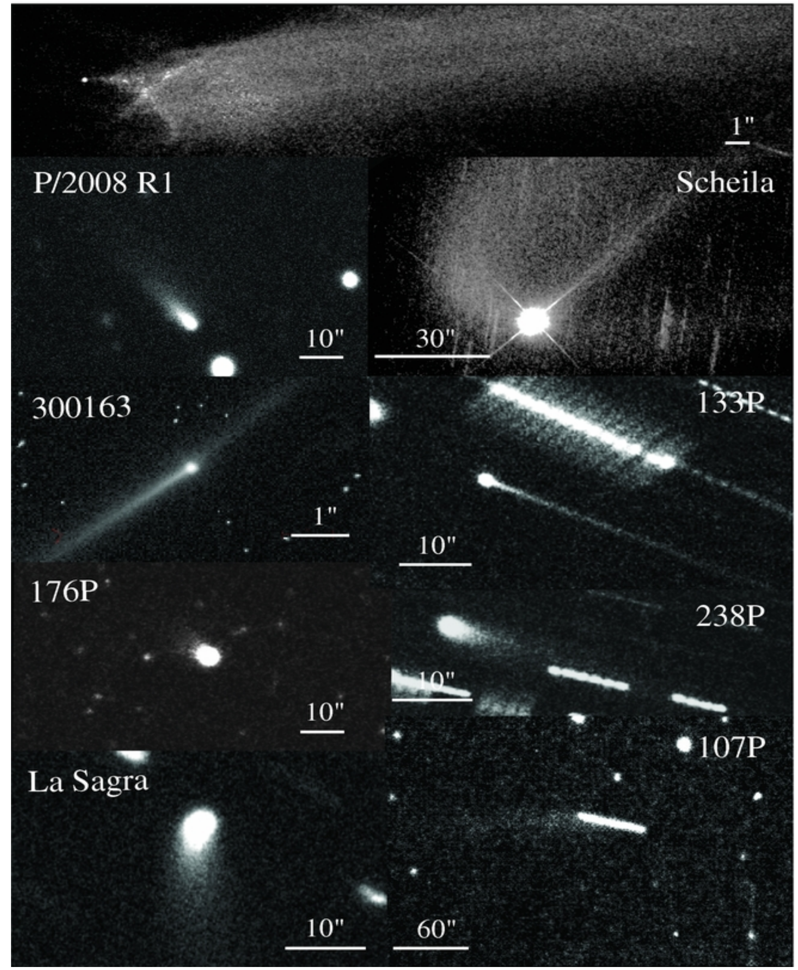


Beck et al. 2011

Water in the asteroid belt?

II Active asteroids or main belt comets

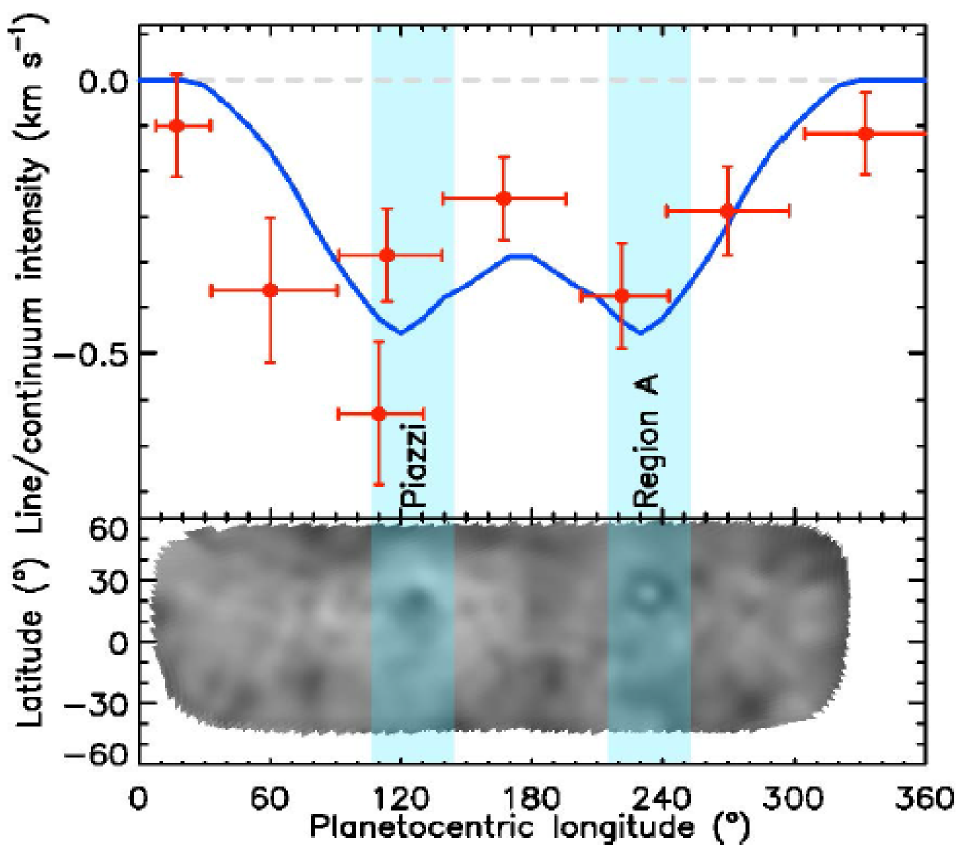
- While some of them are most likely driven by impact or fast rotation, some show recurrent activity around perihelion (133P and 238P)
  - ❑ Comet-like activity driven by water sublimation is the most natural explanation
- Several main-belt objects exhibit a dust coma and/or tail
  - ❑ No water or other volatiles detected so far

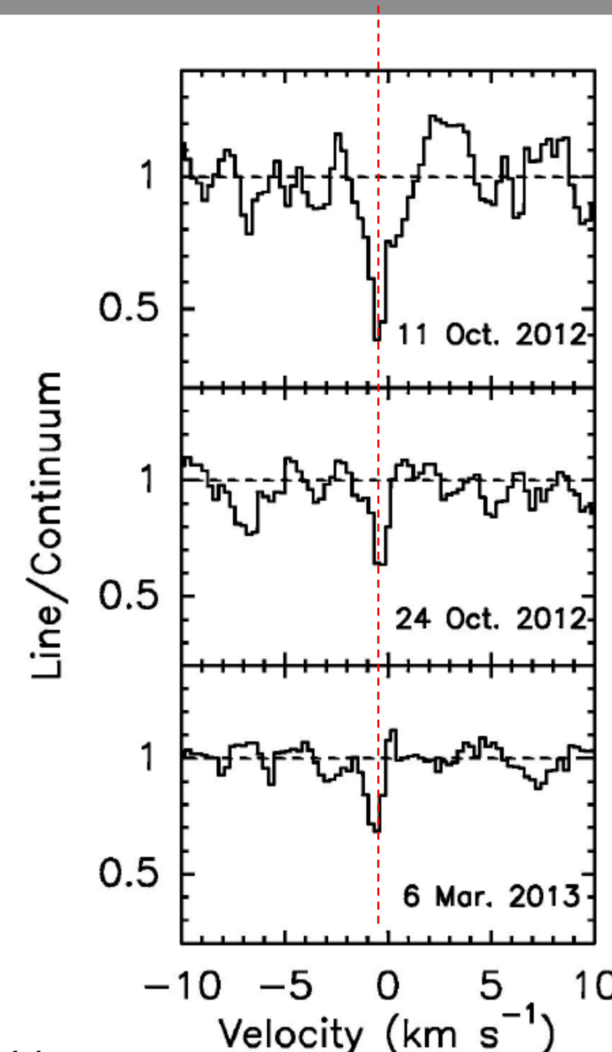


Jewitt 2012

Water detected on Ceres

- Water vapour detected with high resolution spectroscopy from Herschel Space Observatory

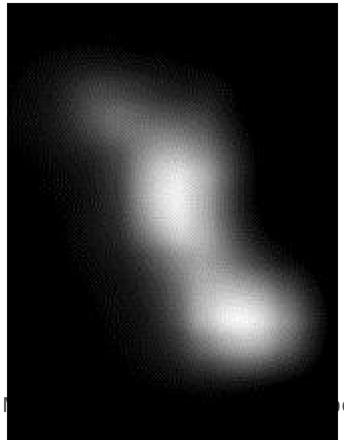




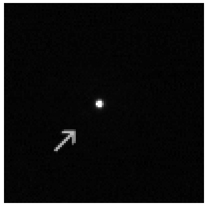
Küppers et al. 2014

- Flybys allow a quick look on individual asteroids
  - Many of them are a secondary target that can be passed by on the way to the main mission target (e.g. Galileo, New Horizons, Rosetta)
  - Allows high resolution imaging and spectroscopy
  - Ten successful asteroid flybys so far, large variety in quality of output data

Braille (DS 1)



Masursky (Cassini)



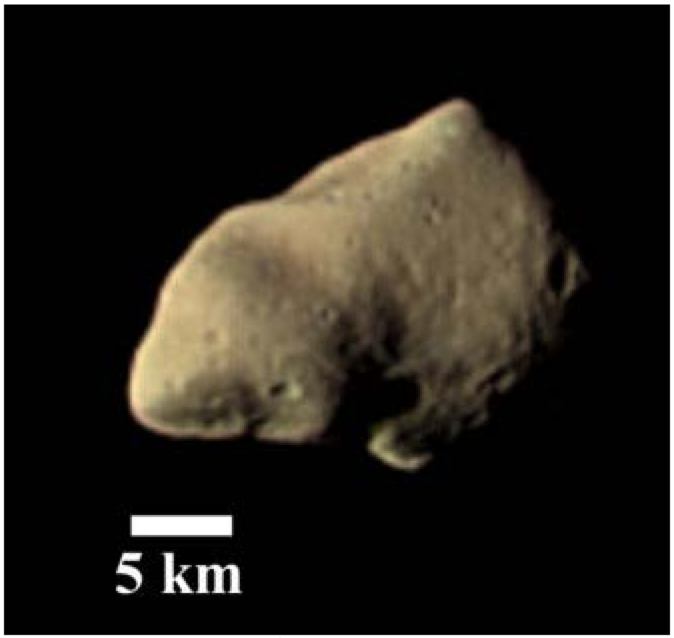
AnneFrank (Stardust)

APL (New Horizons)

Source: Wikipedia

Missions to Asteroids: Flybys (II)

- First Asteroid flybys: Galileo on its way to Jupiter



Source: Granahan 2011, Icarus

Gaspra: First asteroid observed from space (1991)

Source: NASA/JPL

Ida and Dactyl: First asteroid satellite detected! (1993)

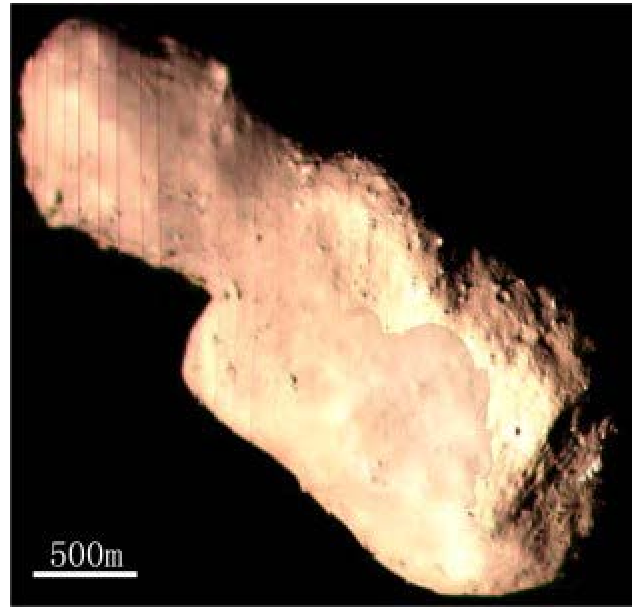
Missions to Asteroids: Flybys (III)

NEAR-Shoemaker flyby of Mathilde

Source:Wikipedia

Huge craters and low density:
Impact in porous bodies causes compression, not destruction?

Chang'e 2 flyby of Toutatis

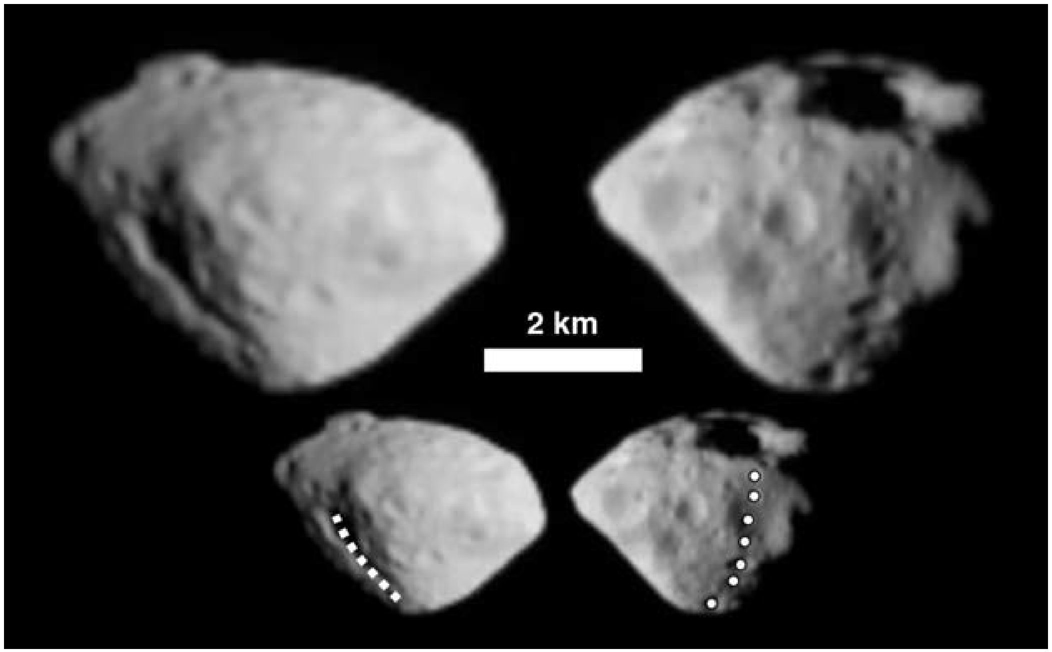


Source: Zou et al., Icarus 2014

Missions to Asteroids: Flybys (IV)

Rosetta flyby of Steins en route to comet Churyumov- Gerasimenko

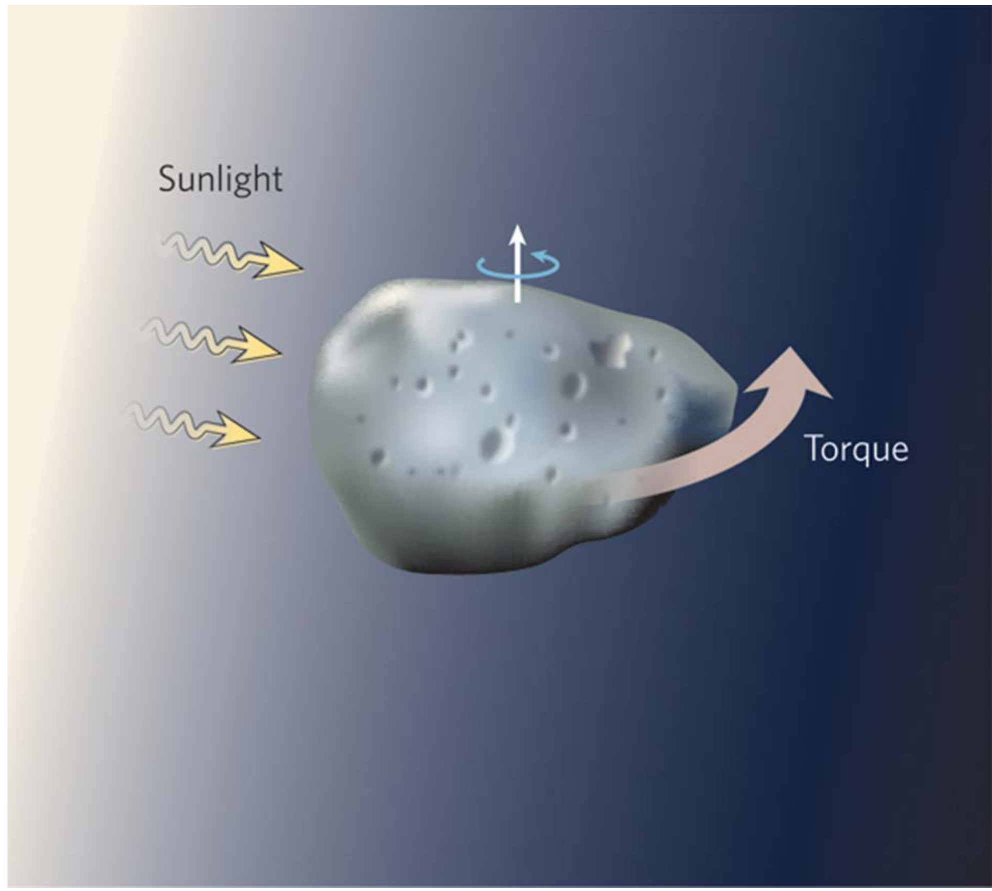
Asteroid Steins



Source: Keller et al. 2010, Science

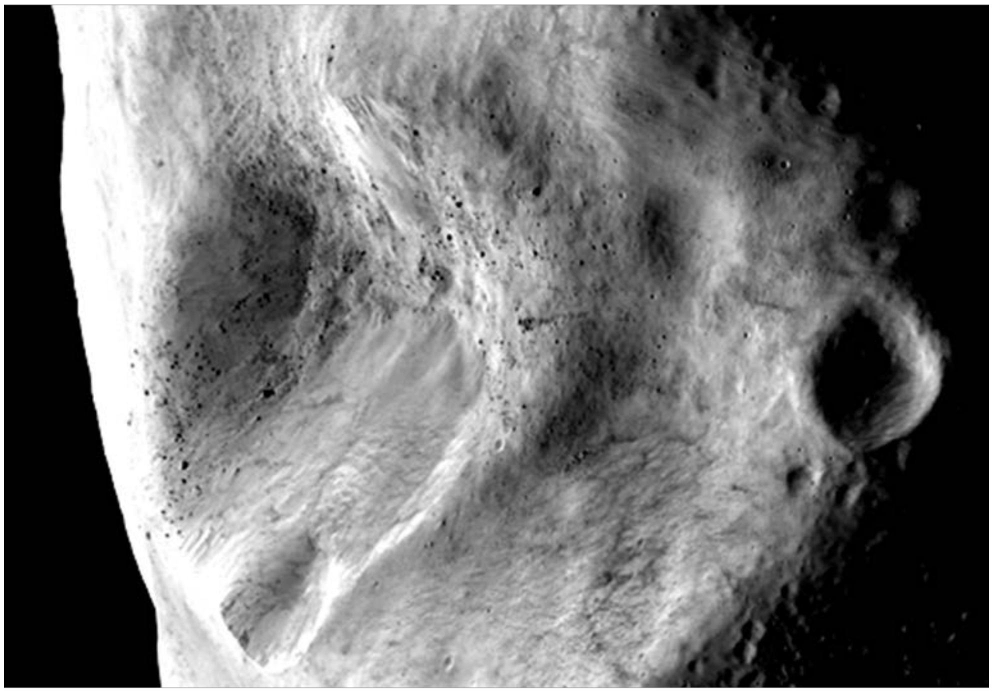
First spacecraft observation of object shaped by fast rotation («YORP-Effect»)

YORP effect



Rosetta flyby of Lutetia

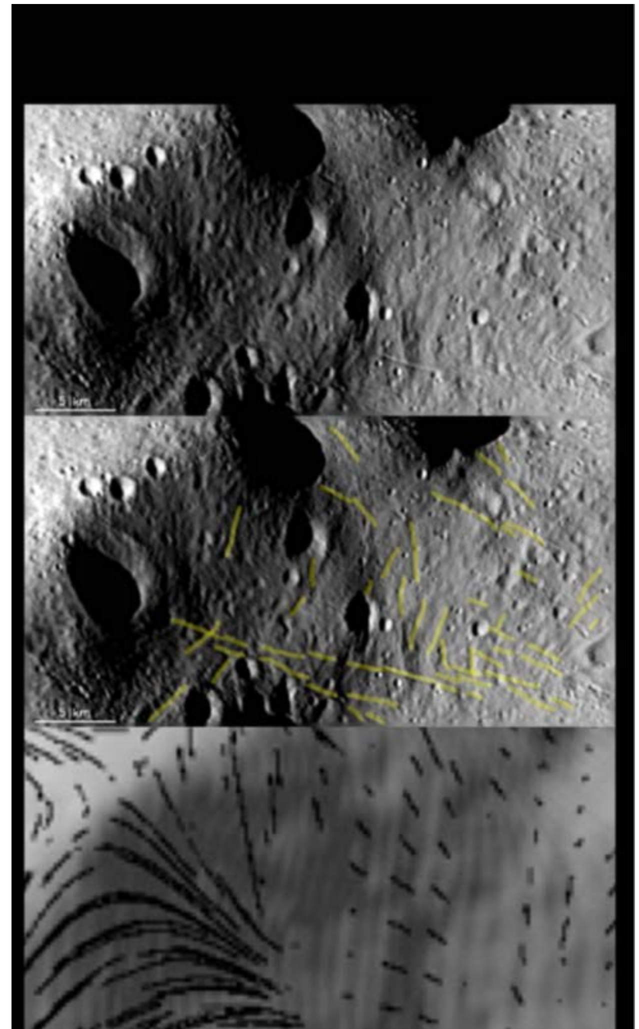
Asteroid Lutetia



Credit: ESA 2010 MPS for OSIRIS Team
MPS/UPD/LAM/IAA/RSSD/INTA/UPM/DASP/IDA

Linear structures explained by waves from big impacts

Example of lineaments and modelled velocity field



Source: Jutzi et al.

Missions to Asteroids: Rendezvous I

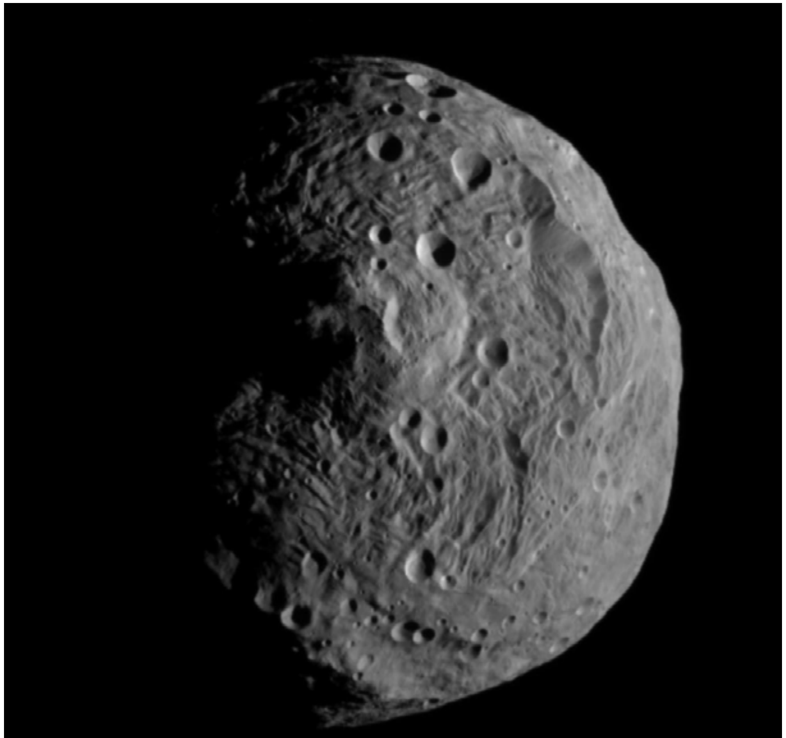
- NEAR-Shoemaker mission Rendezvous with asteroid Eros: First Asteroid Rendezvous
- Orbit insertion failed in 1999, than successful in 2000
  - NEAR stayed at its target for a year
- Mission ended with improvised landing
- First detailed explanation of regolith processes (e.g. boulder formation and destruction)

Source:Wikipedia

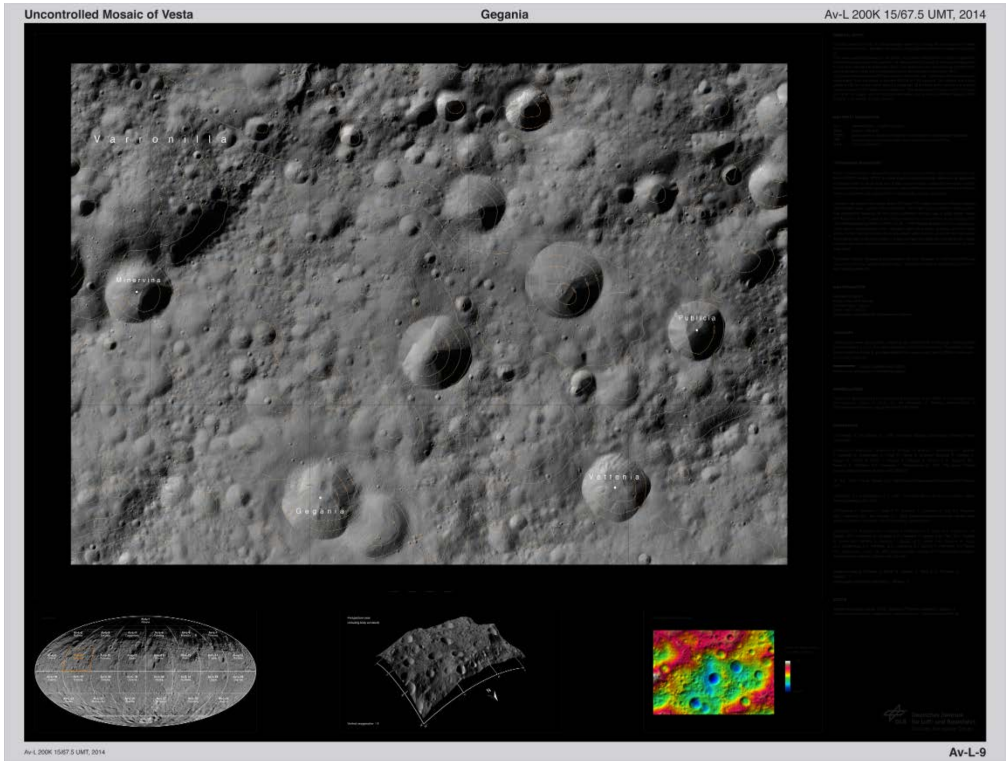
Source:NASA/APL

Missions to Asteroids: Rendezvous II

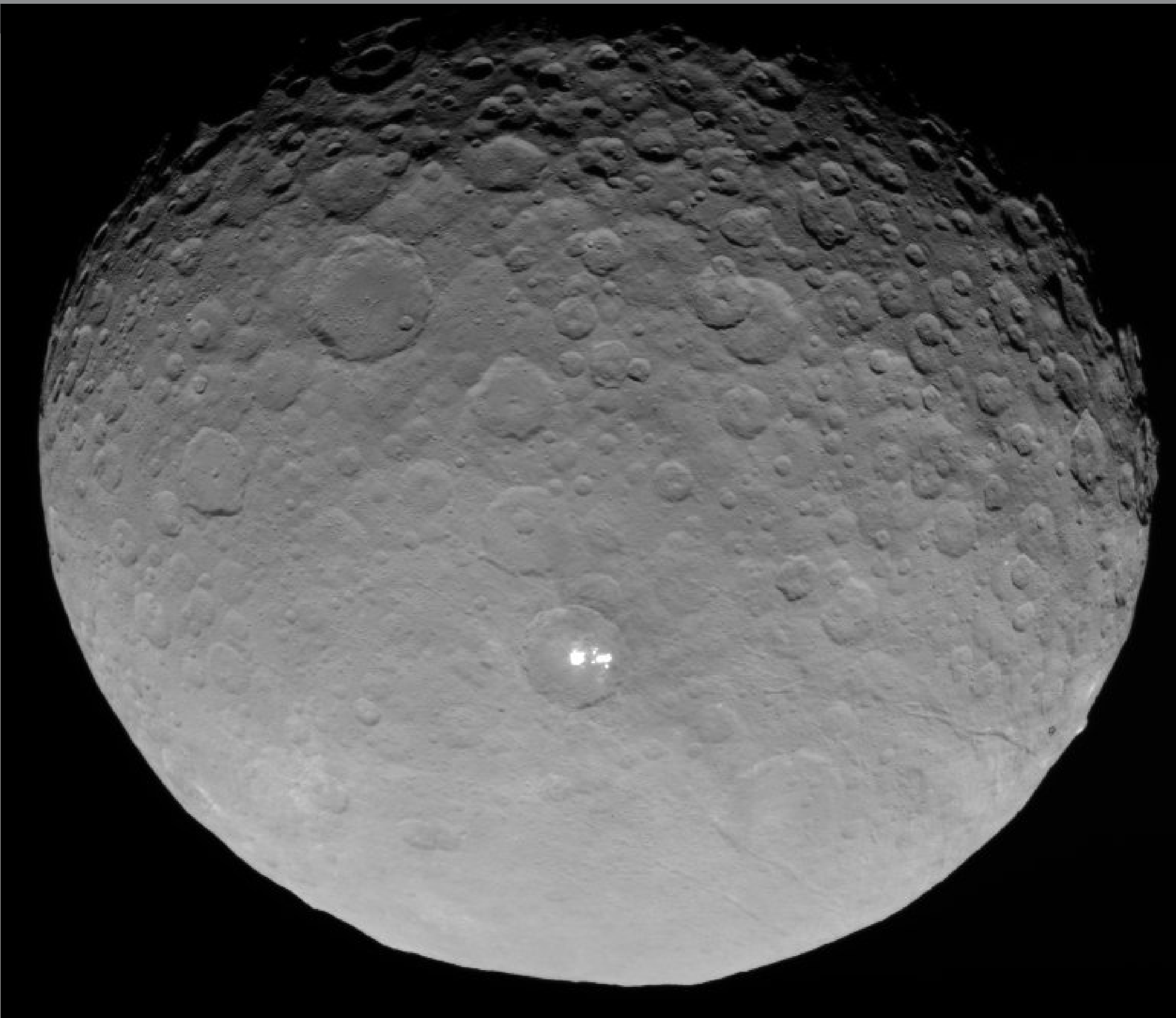
- DAWN mission to Vesta and Ceres
  - Visit of largest asteroids (Ceres is actually classified as dwarf planet)
  - Orbit around Vesta in 2011
  - Rendezvous with dwarf planet Ceres in 2015
  - Surface features on Vesta interpreted as transiently flowing water (perhaps)

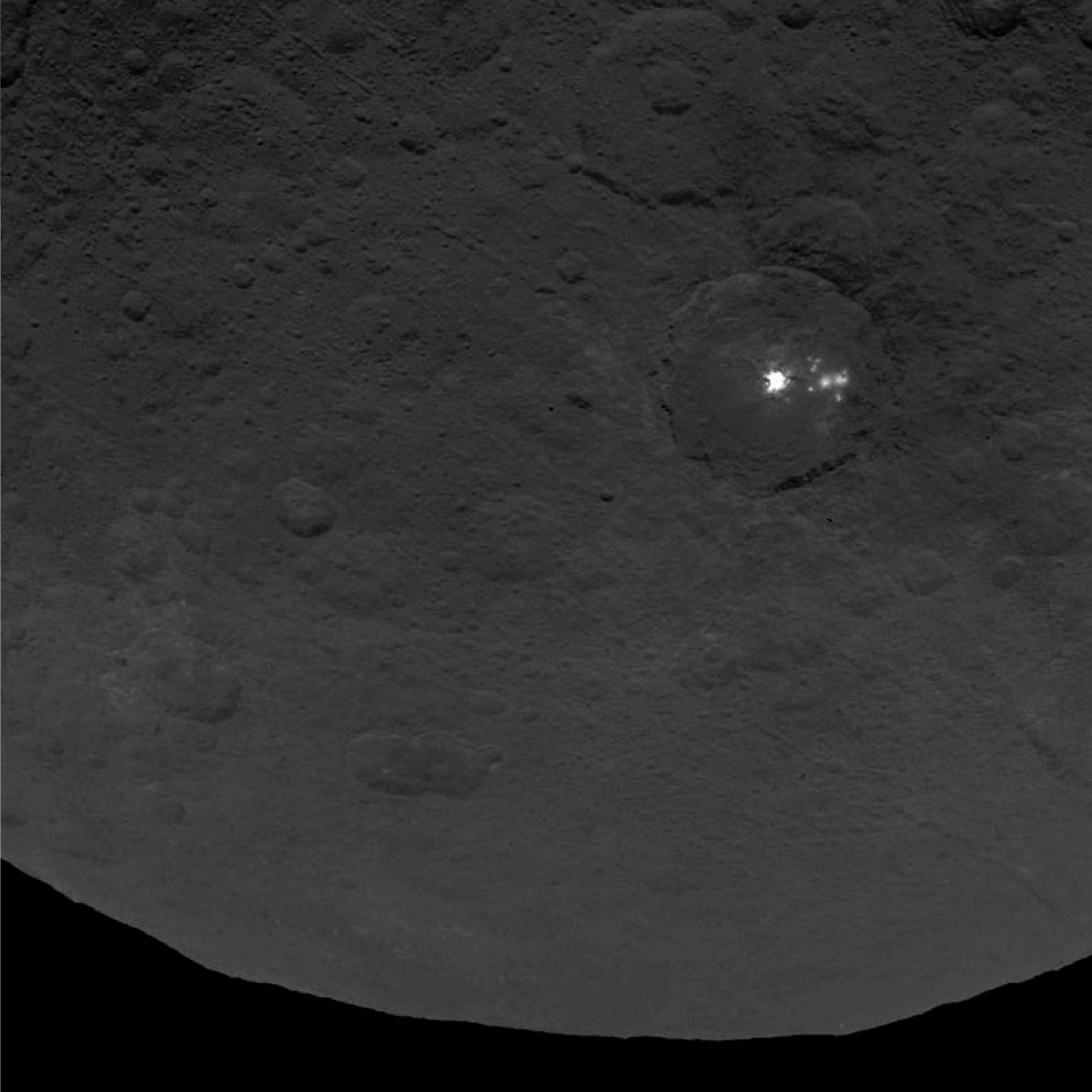


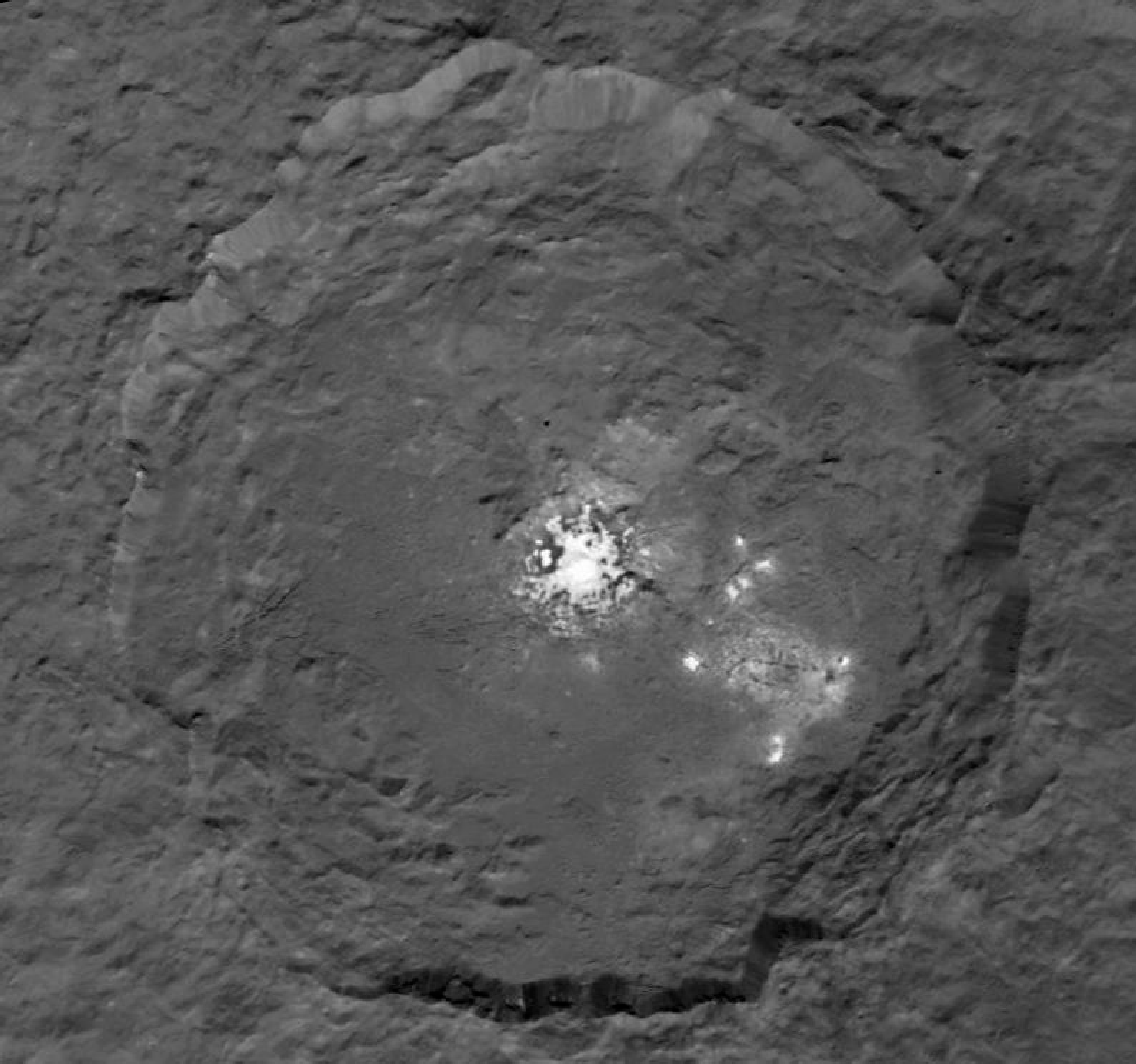
Credit: NASA/JPL-Caltech/UCLA/MPS/DLR/IDA



DAWN at Ceres



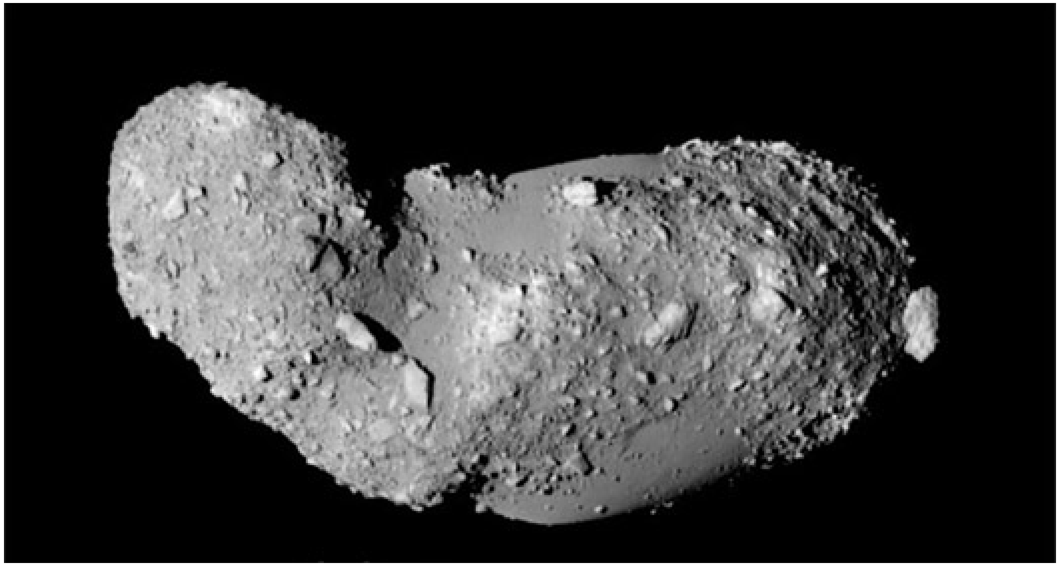


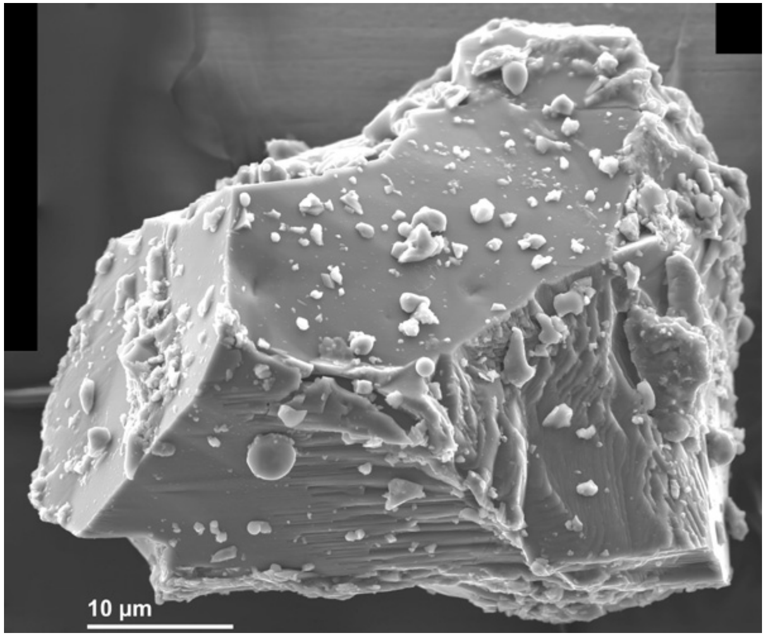


European Space Agency

Missions to asteroids: Sample return

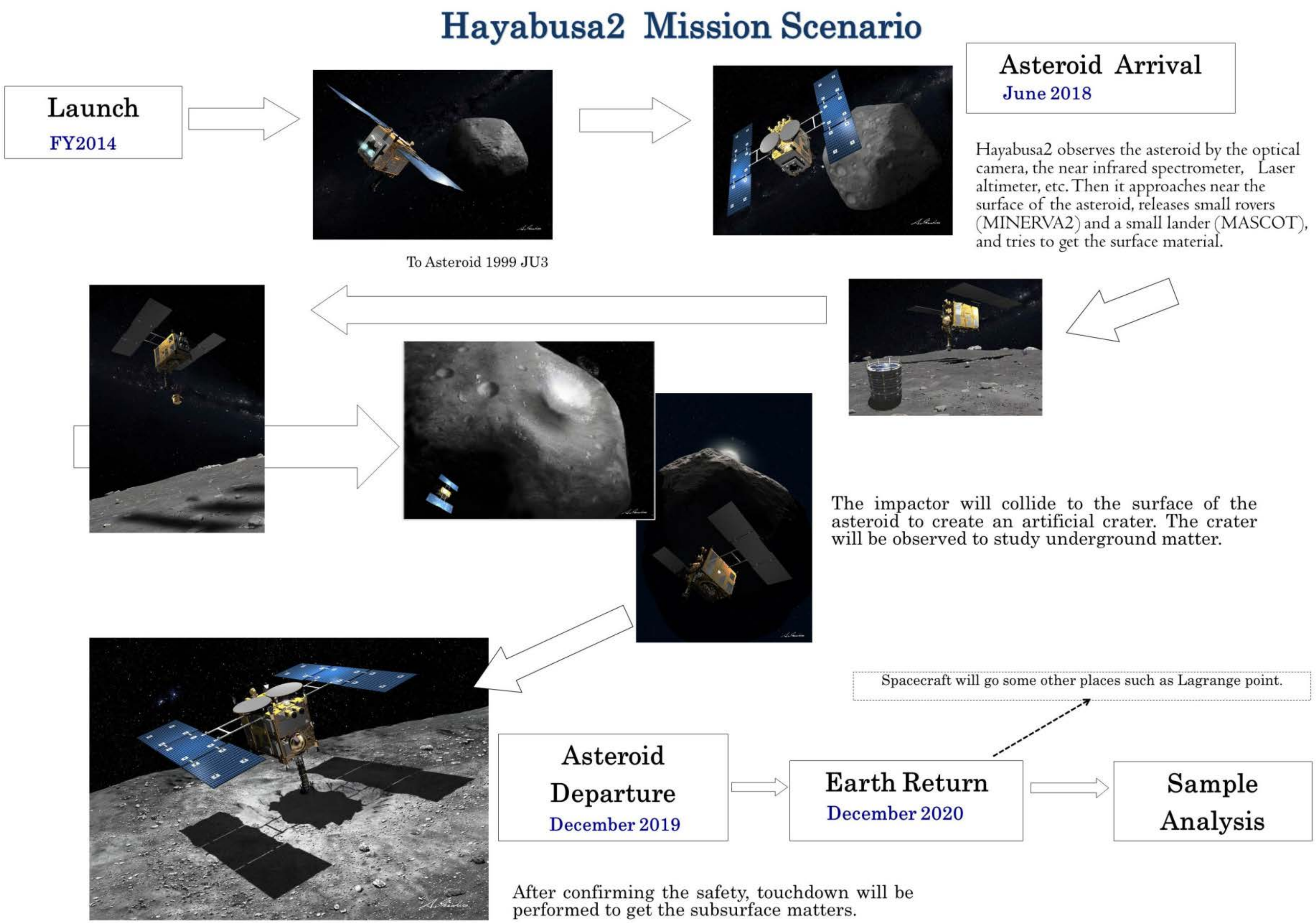
- First sample return mission: Hayabusa to Asteroid Itokawa
- Launch in 2003, at Itokawa 2005-2006, return to Earth 2010
- Hayabusa fired a pellet into the asteroid surface and collected ~1500 dust grains (<300 μm, most <10 μm)
  - Firing most likely actually failed!
- Meteorite analog of asteroid confirmed, direct measurement of space weathering





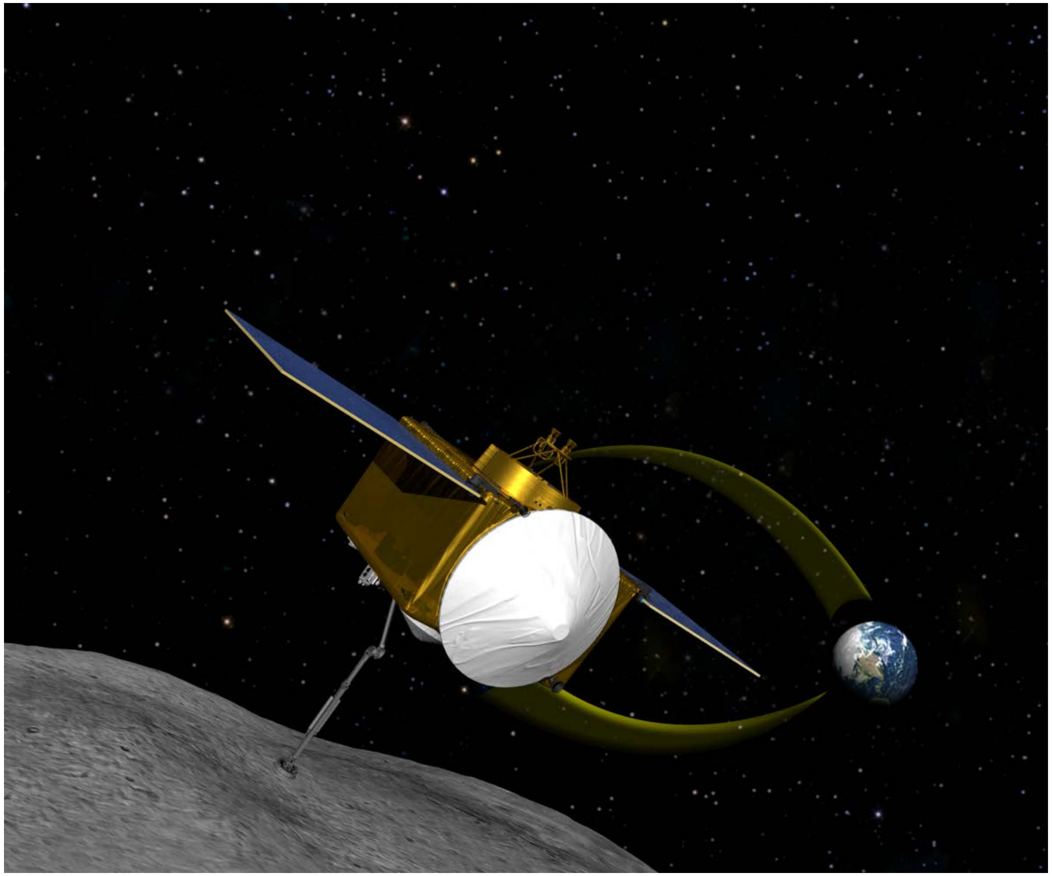
Credit: Okayama University/JAXA

Missions to asteroids: Future sample return missions: Hayabusa 2



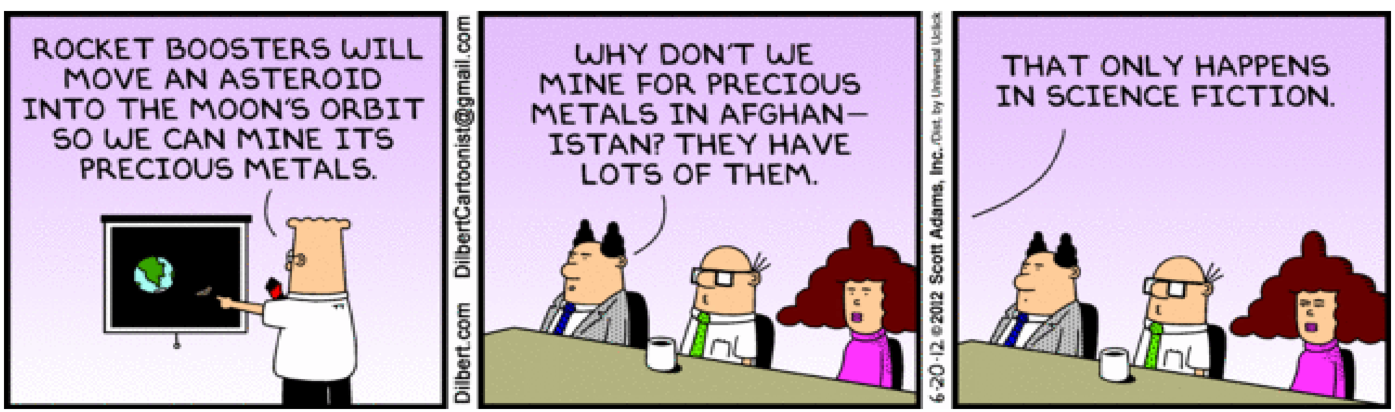
Missions to asteroids: Future sample return missions: OSIRIS-Rex

- Launched October 2016, return 2023
- Sampling with an robotic arm, up to 2 kg of material



Missions to Asteroids: Asteroid mining?

- Idea of asteroid mining became popular with «Planetary Resources» project
  - Idea is to return precious elements that are rare on Earth
- Economic feasibility?
  - See price per kg of sample return missions
- Maybe a future option for in space utilisation

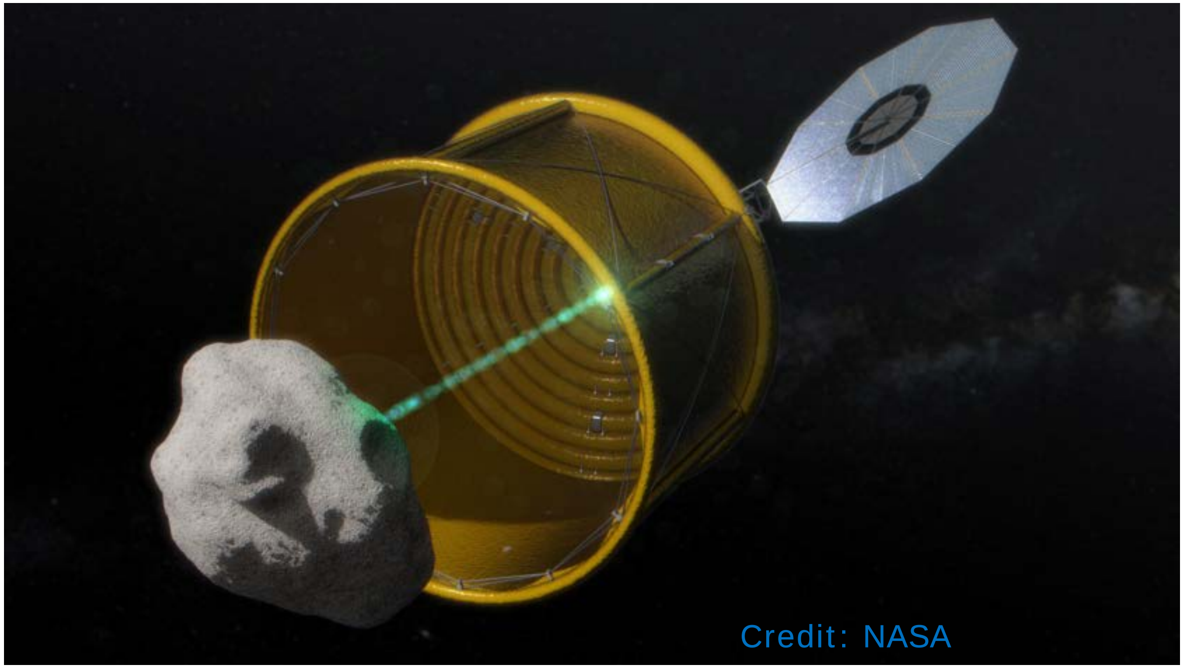


Missions to asteroids: Manned missions

- Asteroid Redirect Mission

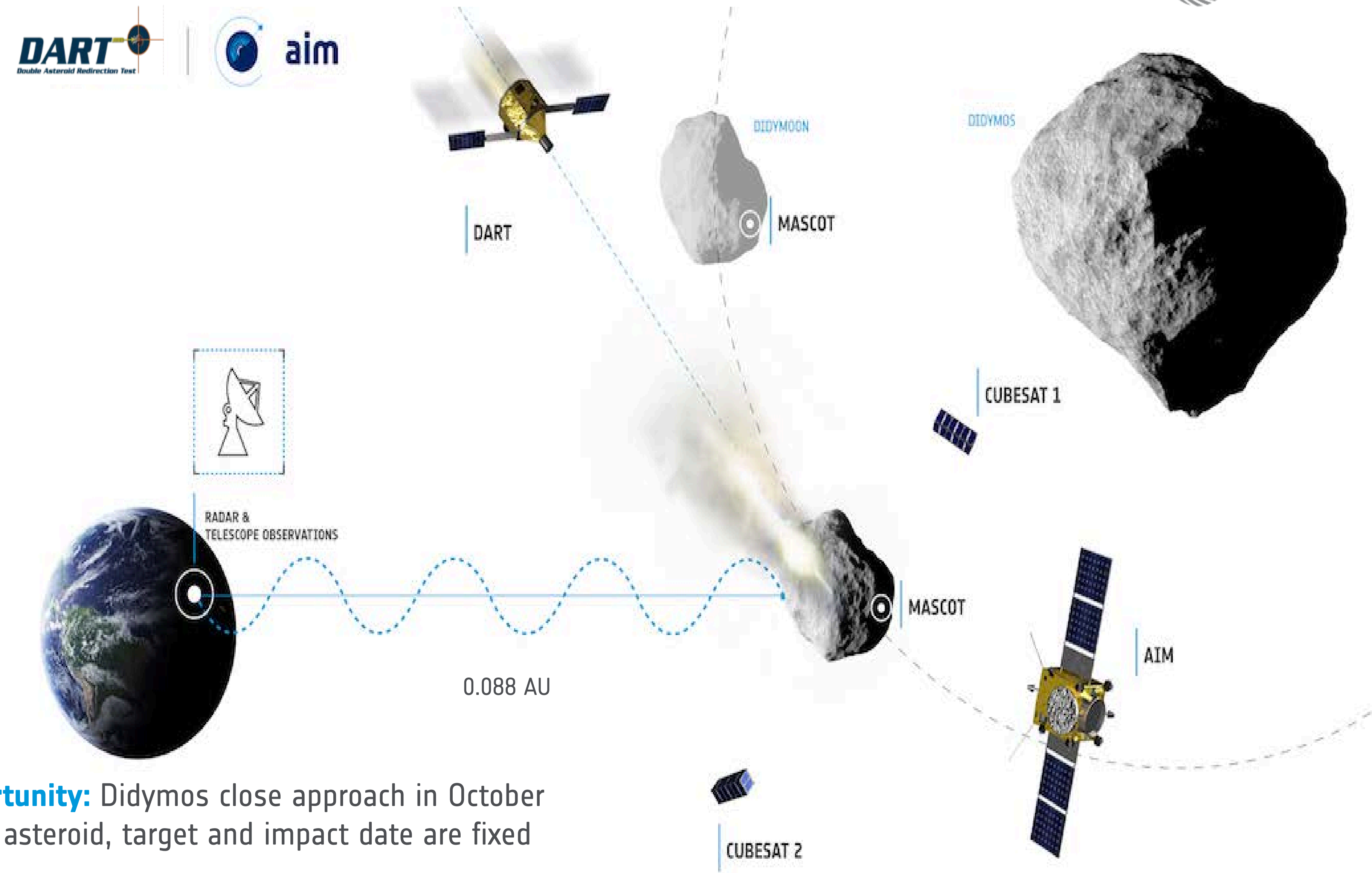
  -> See presentation by Humberto Campins

Original concept



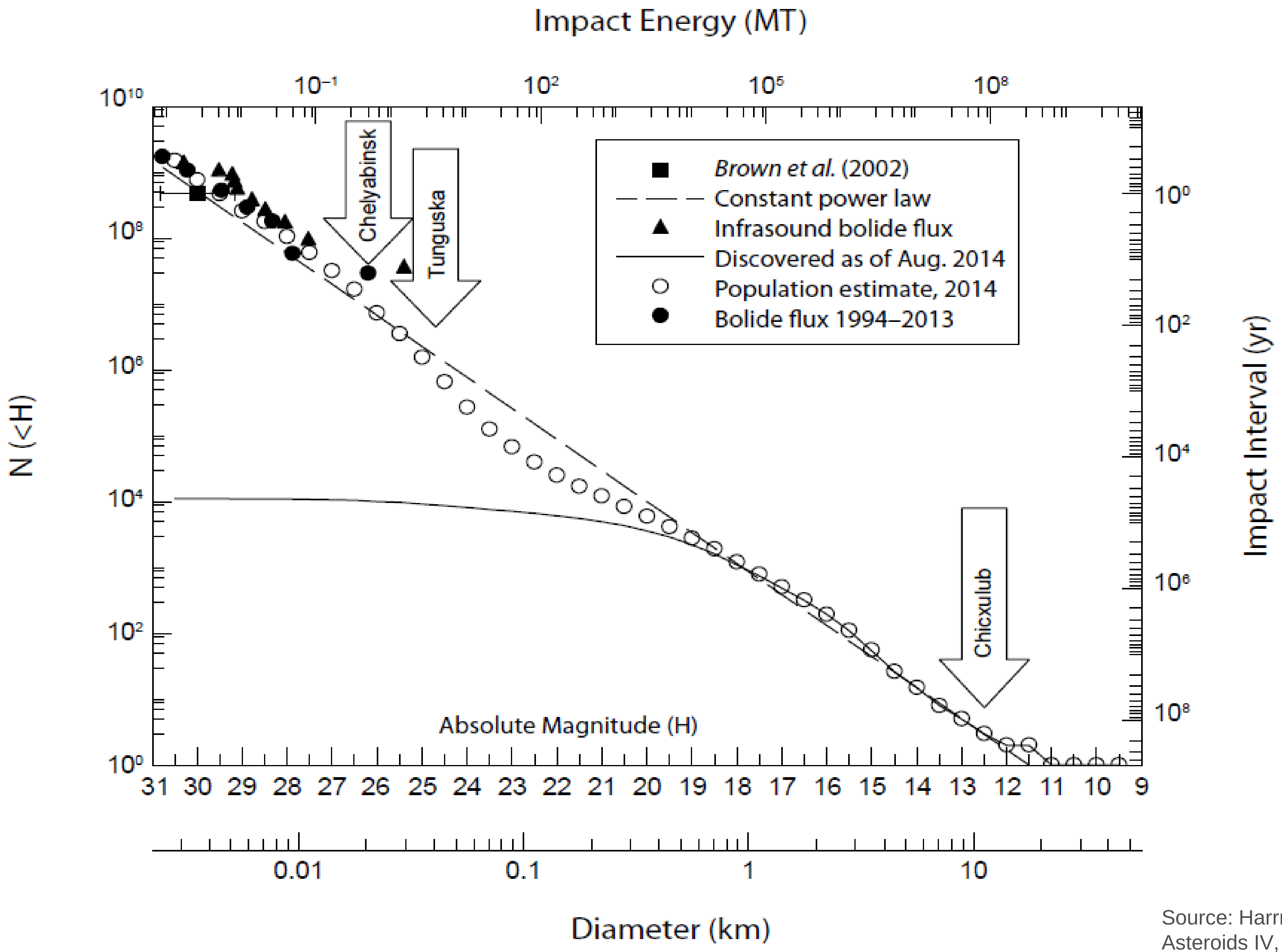
Credit: NASA

AIDA COOPERATION: Asteroid deflection



→ **opportunity:** Didymos close approach in October 2022 asteroid, target and impact date are fixed

Asteroid impacts: What is the danger?

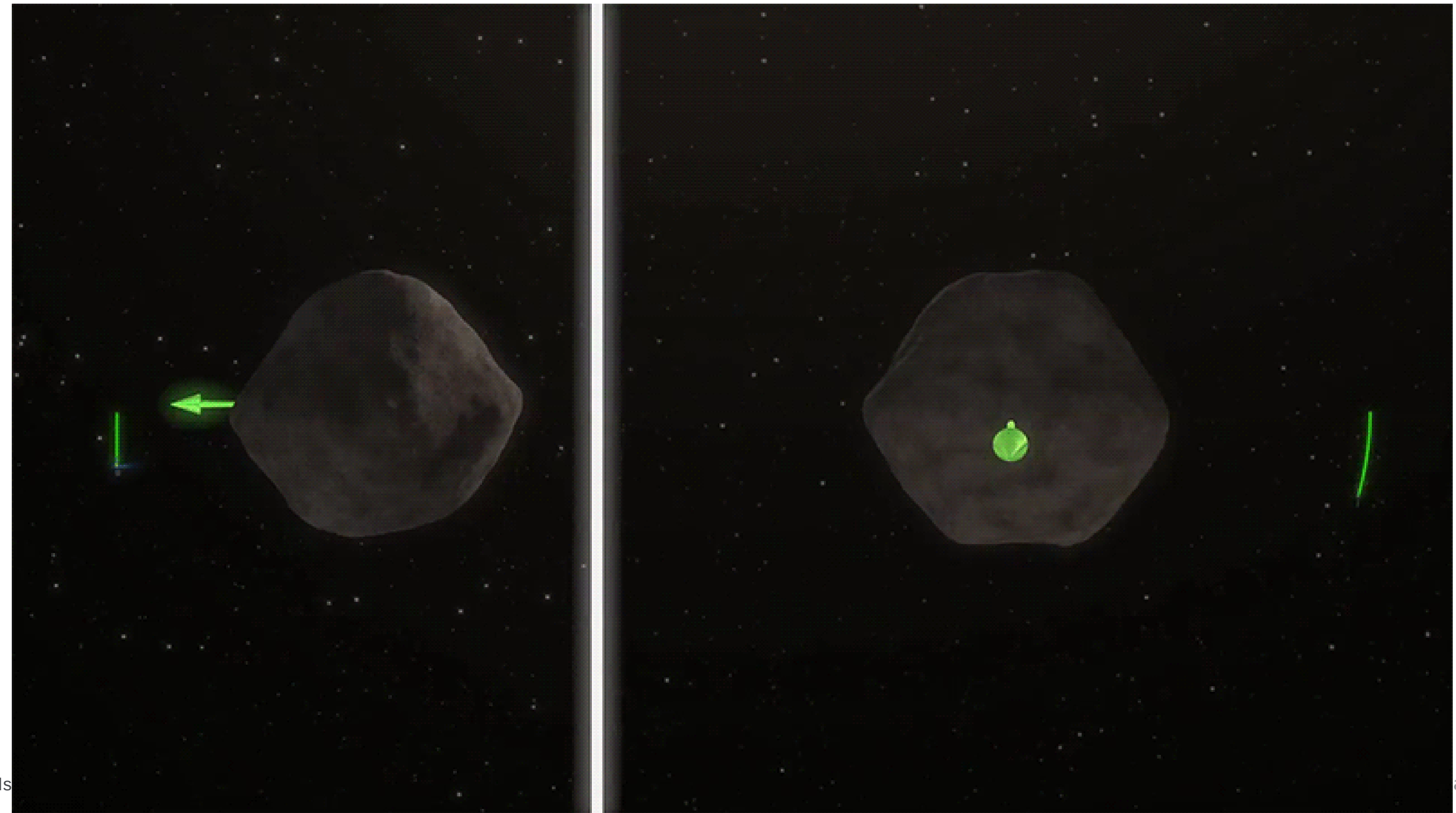


Source: Harrris et al.,
Asteroids IV, in press

cy

Methods of asteroid deflection

I Gravity tractor: Gentle, safe, but not very efficient

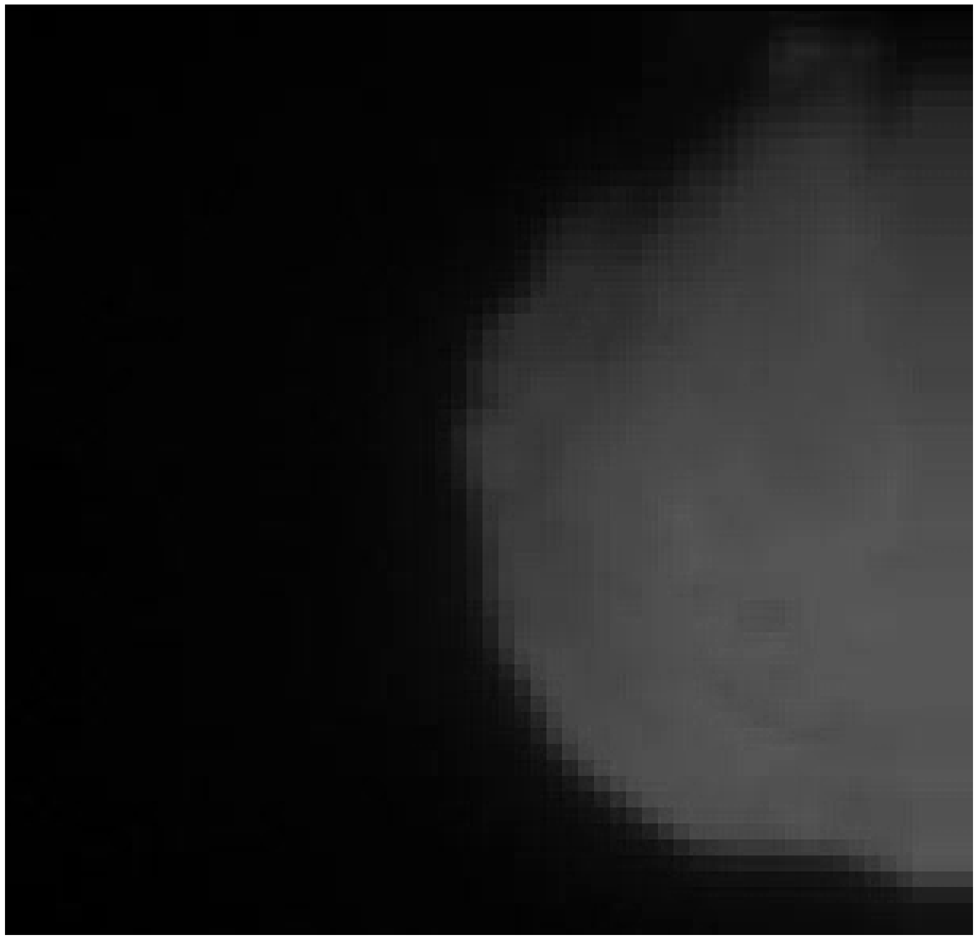


Methods of asteroid deflection

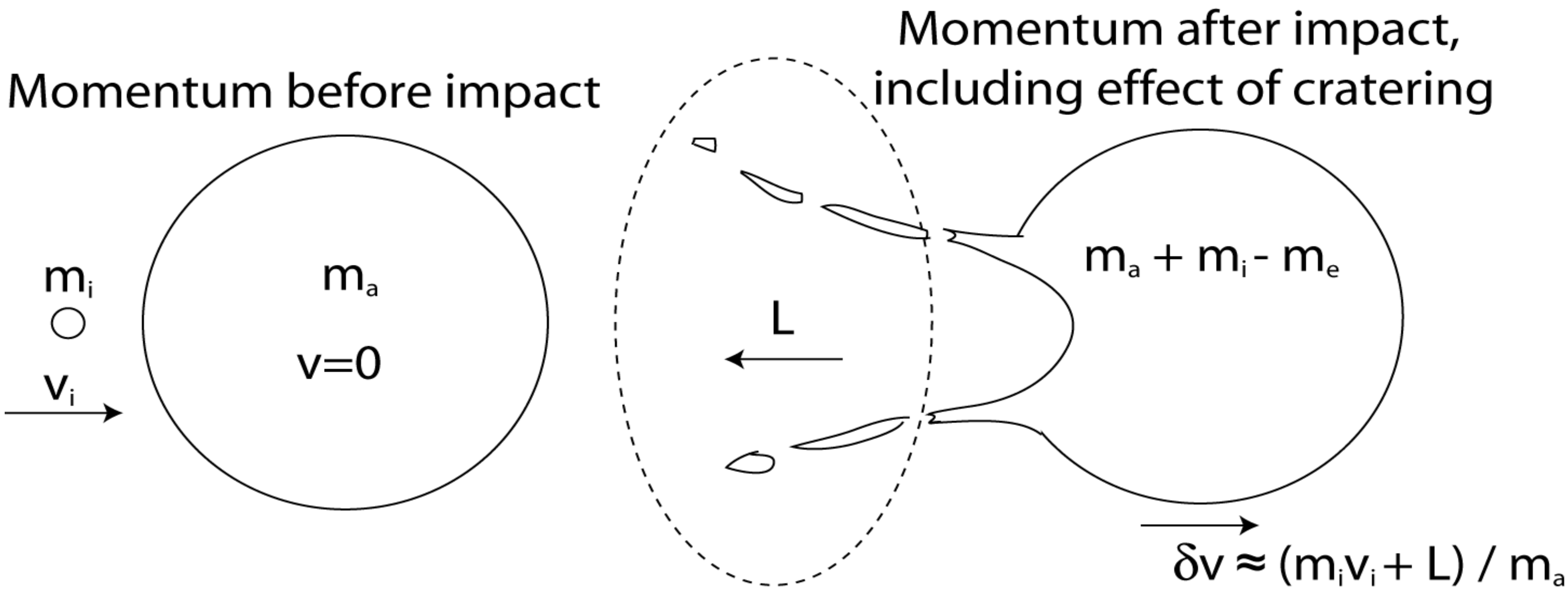
II Nuke: Efficient, but highly dangerous

Methods of asteroid deflection

III Kinetic impactor: intermediate efficiency, tecnically most advanced



Efficiency of an impact



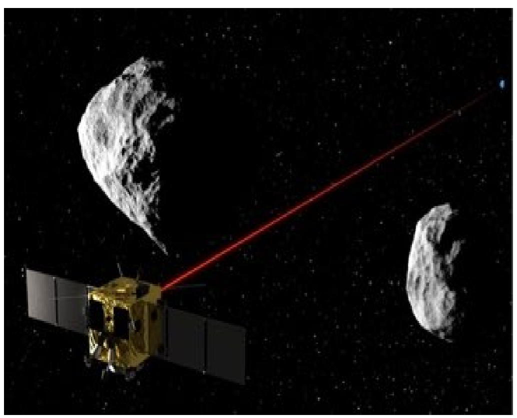
ASTEROID IMPACT MISSION (AIM)

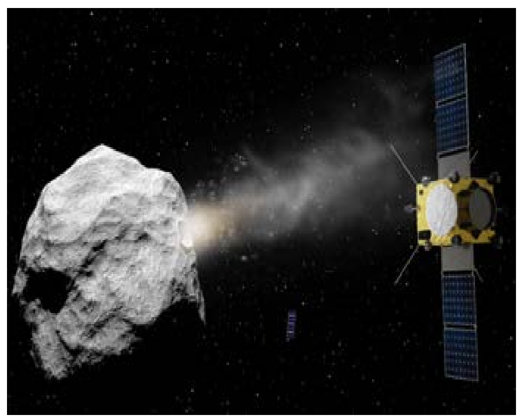
- Technology demonstration mission
  - ➢ Fast turnaround allows test of technologies being developed for later missions
- Science is “ride-along”

TECHNOLOGY DEMONSTRATION

ASTEROID IMPACT MITIGATION

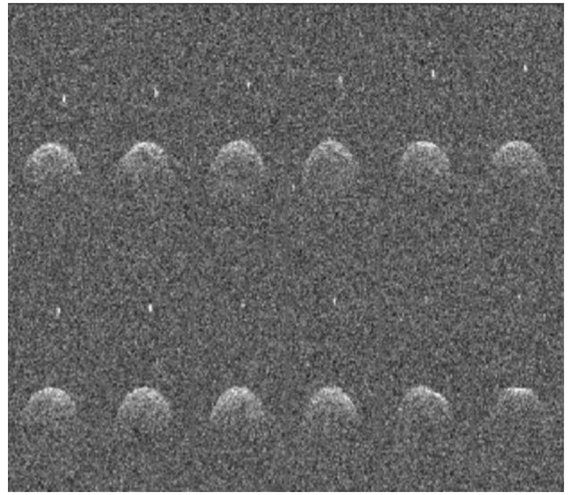
SCIENCE

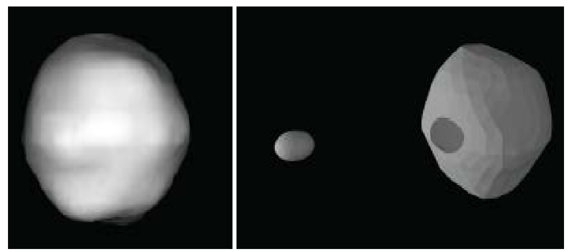




DIDYMOS: A PERFECT TARGET

- Asteroid observed by ground telescopes and radars
- Heliocentric orbit well known
- Shape and size of primary well known (not Didymoon)
- Orbit plane orientation to be confirmed in 1Q 2017 Didymoon
- Size representative of a potentially hazardous object (generating casualties independently from impact location on Earth)
- Mission takes advantage of close flyby of earth in 2022 (0.07 AU)





Chelyabinsk meteor (Feb 2013): 1500 injuries, 7200 damaged buildings

AIM TECHNOLOGY RESEARCH OBJECTIVES

T#1	**Demonstrate deep-space inter-satellite communication network**	☐ Deploy up to two 3U cubesats (or any combination of units) ☐ Demonstrate inter-satellite link network between AIM, COPINS and MASCOT-2
T#2	**Demonstrate asteroid landing and extended operations on Didymoon**	☐ Demonstrate landing on small (170 m) asteroid and inter-satellite link in deep-space ☐ Test long-lived payload operation i.e. transmission radar, surface imaging, radiometry.
T#3	**Infra-Red Instrument Navigation Aid** *(IRINA)*	☐ To demonstrate the use of an IR instrument potential to support rendezvous phases
T#4	**Qualify an end-to-end 2-way deep-space optical communications system**	☐ Primary goal: transmit full asteroid 1m resolution map before DART arrival (goal, transmit images of the impact)

AIM (alone) PRIMARY SCIENCE OBJECTIVES

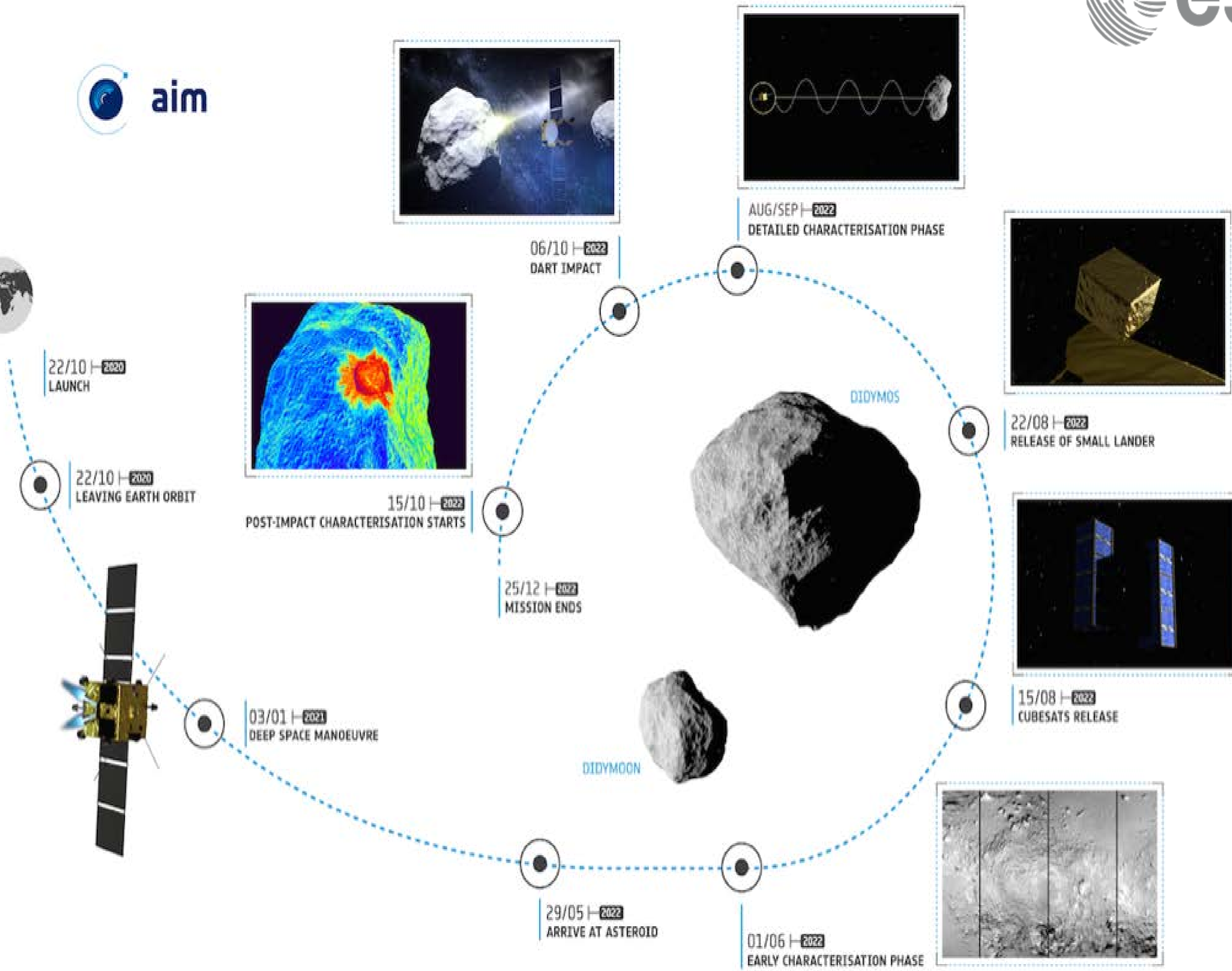
S#1 **Didymoon size, mass, shape, density**	Mass => momentum size => shape, volume, gravity density => internal structure	Camera (VIS), LIDAR (OPTEL-D), radio tracking
S#2 **Didymoon dynamical state**	Momentum transfer Indirect constraints on interior structure	VIS
S#3 **Geophysical surface properties, topology, shallow subsurface**	Composition, mechanical properties, thermal inertia =>Interpretation of impact	VIS, Thermal Infrared Imager (TIRI), High Frequency Radar (HFR), Accelerometer on MASCOT
S#4 **Deep-internal structure of the moonlet**	Interpretation of the impact Origin of binarity	Low Frequency Radar (LFR)
S#5 **Optical, IR, Radar calibration**	Simultaneous ground and space-based measurements to calibrate ground-based observations and extrapolate to other objects observed from the ground.	VIS, TIRI, HFR

AIM (with DART) SECONDARY SCIENCE OBJECTIVES

S#6 **Didymoon post-impact characterisation**	Changes due to impact	All
S#7 **Didymain characterisation**	Origin of the system	VIS, TIRI, HFR, LFR
S#8 **Impact ejecta**	Porperties of ejected dust	VIS, TIRI, HFR
S#9 **Ambient dust**	Dust in Didymos environment	VIS, TIRI, HFR
S#10 **Chemical and mineralogical composition**	Asteroid classification, origin of the system	VIS (TBC), TIRI, MASCOT-2 lander

MISSION SCENARIO

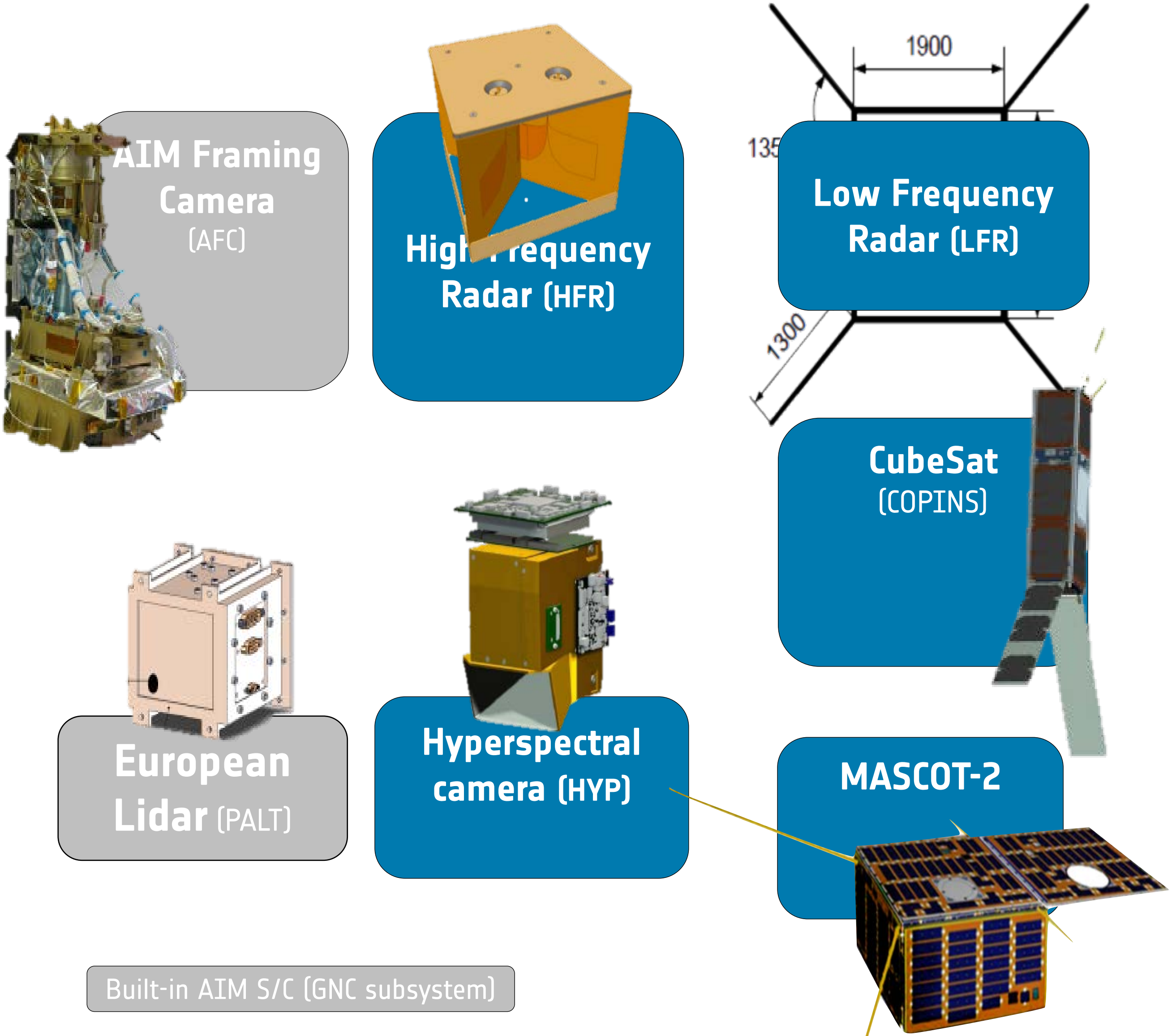
aim



PAYLOAD

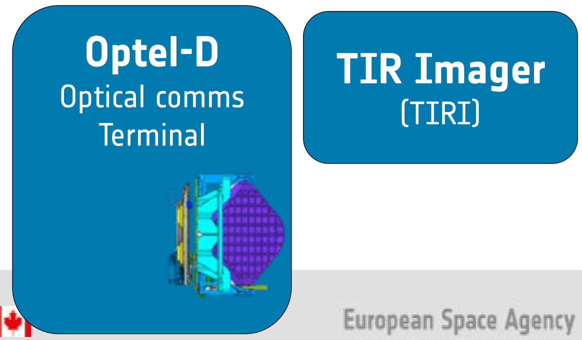
- VIS
- Mascot-2 + LFR
- HFR
- Hyperspec./TIRI
- Optel-µ
- CubeSats

AIM REFERENCE PAYLOAD



- Several options studied in detail to prepare for proper **interfaces** and **proximity operations**.
- Some payload expected to be commited when mission is approved in Dec.
- Announcement for payload opportunities to be released in **Jan 2017** for any remaining available payload

Options

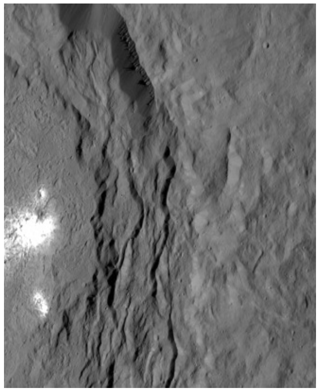


AIM Framing Cameras (AFC), Hyperspectral Imager

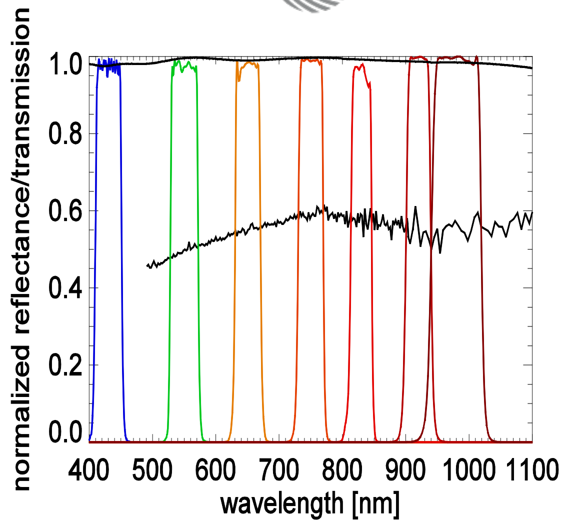
➢Flight Spares of the DAWN cameras

(5.5° FOV, 93.7 µrad/pixel, 400-1000 nm, 7 filters)

- spacecraft GNC system, provided by MPI for solar system research
- Used for spacecraft navigation but also science
- Navigation currently being tested at GMV with QM

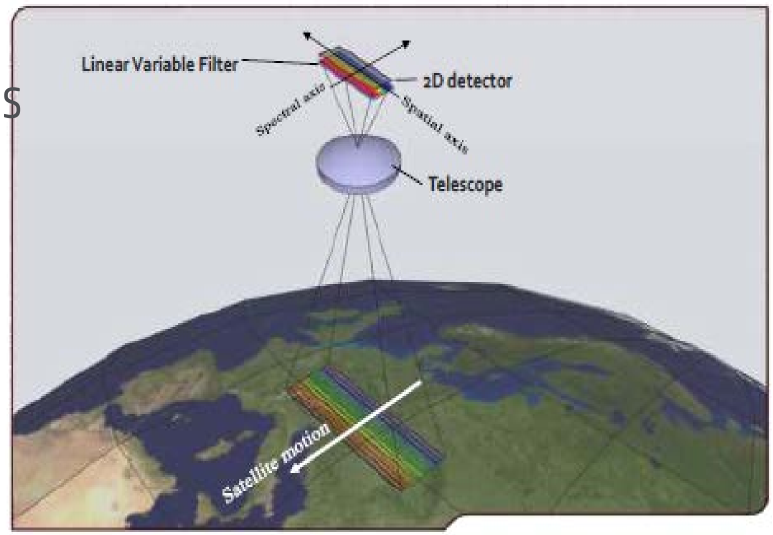


DAWN FC image of Ceres

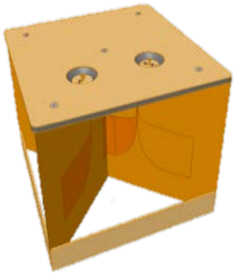


Compact Hyperspectral imager

- Grating spectrometer or linear filter fixed on CMOS detector
- Large detector, 7 x 9 deg. FOV at 8 arcsec/pix
- Spectral resolution 5-10 nm
- Wavelength range 470-950 nm
- Developed for Earth observation



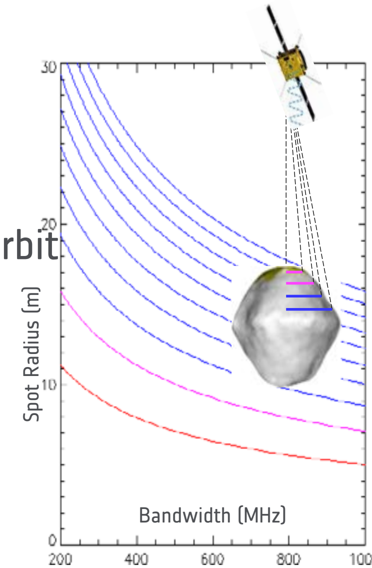
HIGH-FREQUENCY RADAR (HFR), LOW-FREQUENCY RADAR (HFR)

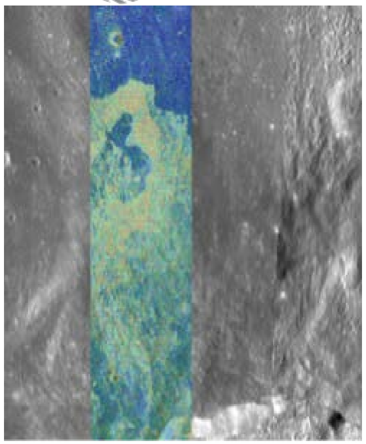


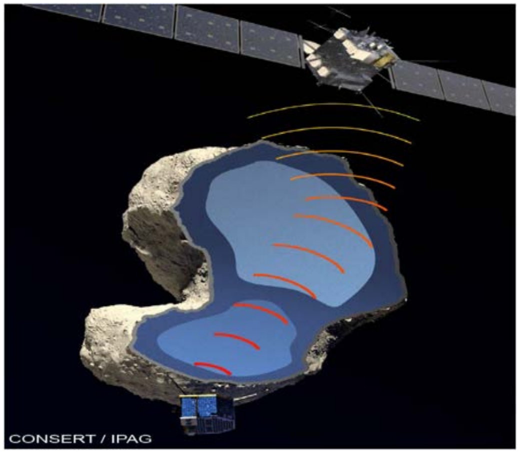
Stepped high-frequency frequency radar

(300MHz to 2.4GHz, 108W power, 2.86kg, 37 x 37 x 27 cm3)

- determine structure and layering of shallow sub-surface
- support asteroid mass determination, shape modelling and orbit characterisation
- observe ejecta cloud
- support ground-based bi-static radar measurements Arecibo, Goldstone, SRT

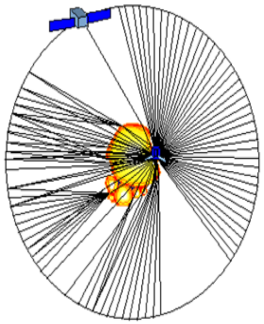






Instrument design based on CONSERT (Rosetta)

- Spare components available and TRL6
- Radar type: Bistatic radar (between AIM and MASCOT-2)
- Carrier frequency: 60 MHz
- Bistatic operation through the secondary asteroid



IMAGER (TIRI), MASCOT-2 µLANDER

➤ TIRI strawman design

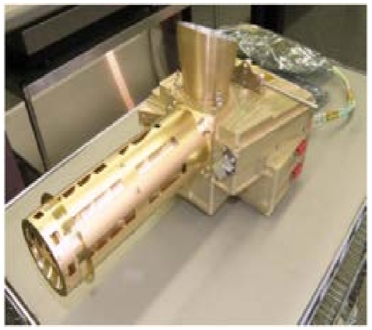
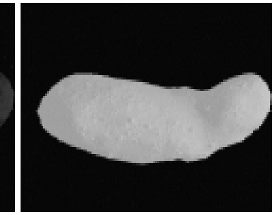
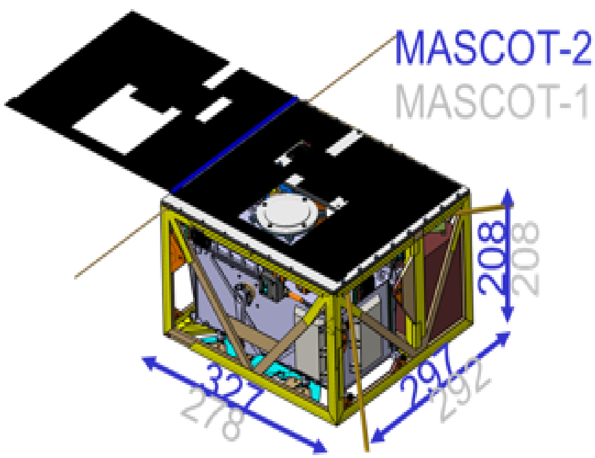


Figure: MERTIS

- Heritage: MERTIS (Bepi-Colombo), MAIR, HIBRIS, AMS
- Temperature range: 200 K – 450 K
- Spectral range: 8 µm – 13 µm (spectral resolution 0.3 µm)
- Spatial resolution (goal): 2 m @ 10 km
- Field of view: ~5 deg., similar to cameras
- Thermal and physical surface properties



VISUAL @ 5 km   IR @ 5 km



MASCOT-2 µlander

- Development based on MASCOT-1 currently on JAXA's Hayabusa-2 mission
- Size: 33 x 30 x 21 cm
- Mass: 15 kg
- Deployable solar generator cover (supports orientation)
- 3 months operational lifetime
- Carries: µ-camera (CAM), low-frequency radar (LFR), radiometer (MARA), accelerometer (DACC)

COPINS: CUBESATS IN DEEP SPACE

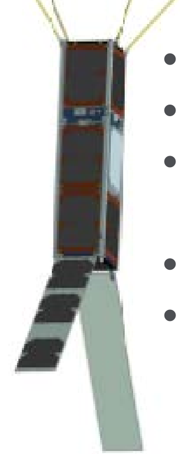
ASPECT

- Vis-NIR imaging spectrometer
- Space Weathering
- Shock experiment
- Plume Observations

AGEX

- Mechanical properties of surface material
- Seismic properties of sub-surface
- Determine kinematics prior and after DART

PALS

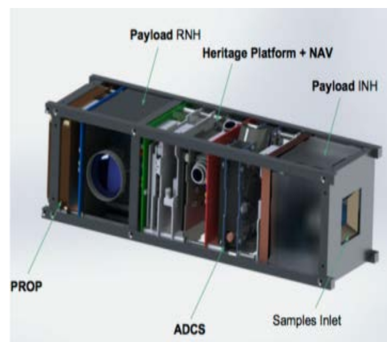


- Characterize magnetization
- Composition of volatiles
- Volatiles released from DART impact
- Super-resolution imaging
- DART collision and plume observation

CUBATA

- Gravity field
- Observe DART impact
- Perform seismology
- Velocity field of the ejecta

DUSTCUBE



- Dust properties with Nephelometer
- Mineralogical composition
- Compliment com demo
- Reflectance of the asteroid surface

Summary

- Distribution of asteroids today may show traces of migration in the solar system
- Water is present in the asteroid belt
- Asteroid deflection mission may be the next European Small body mission after Rosetta
  - Decision will be made 2nd Dec.