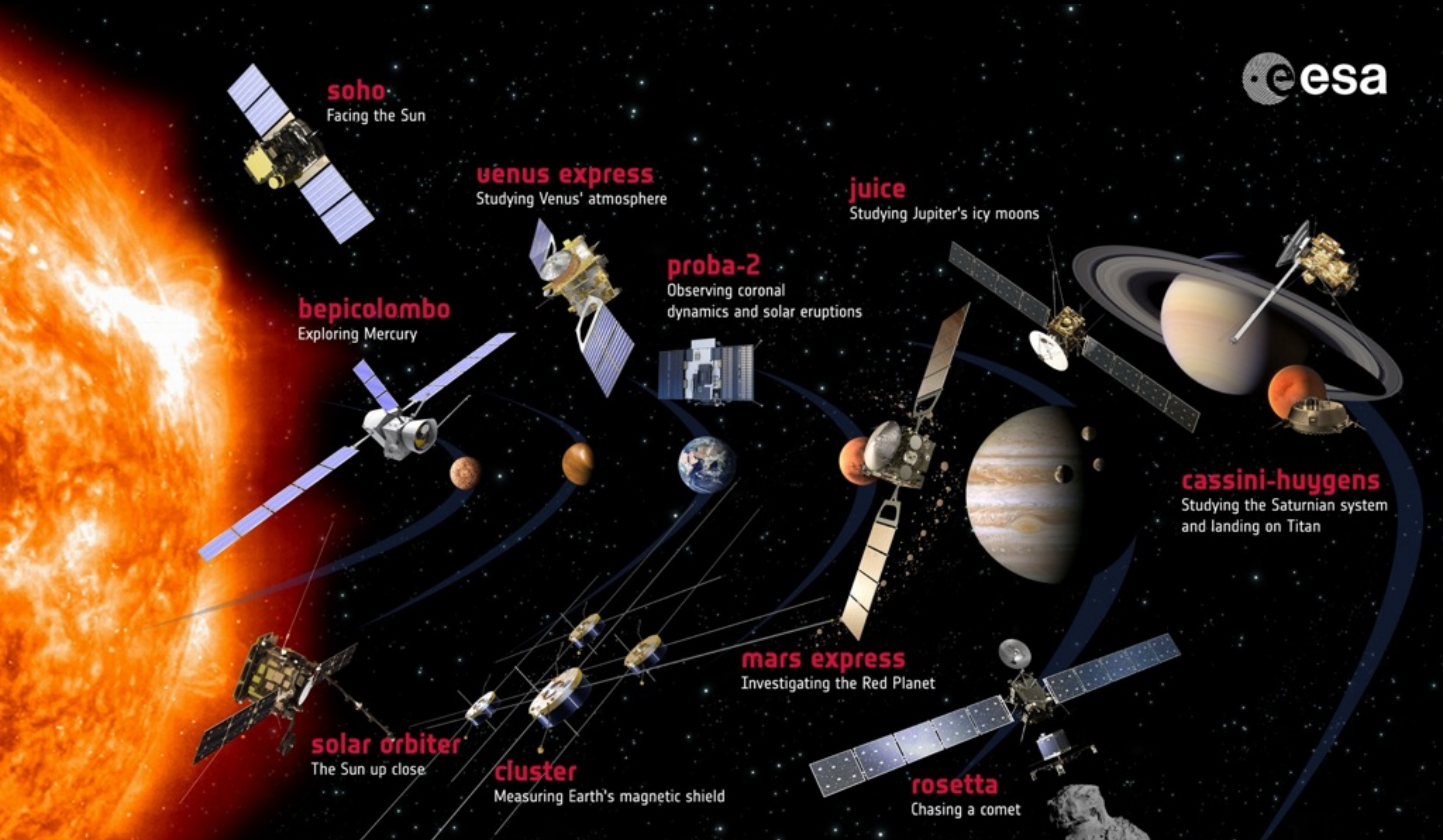
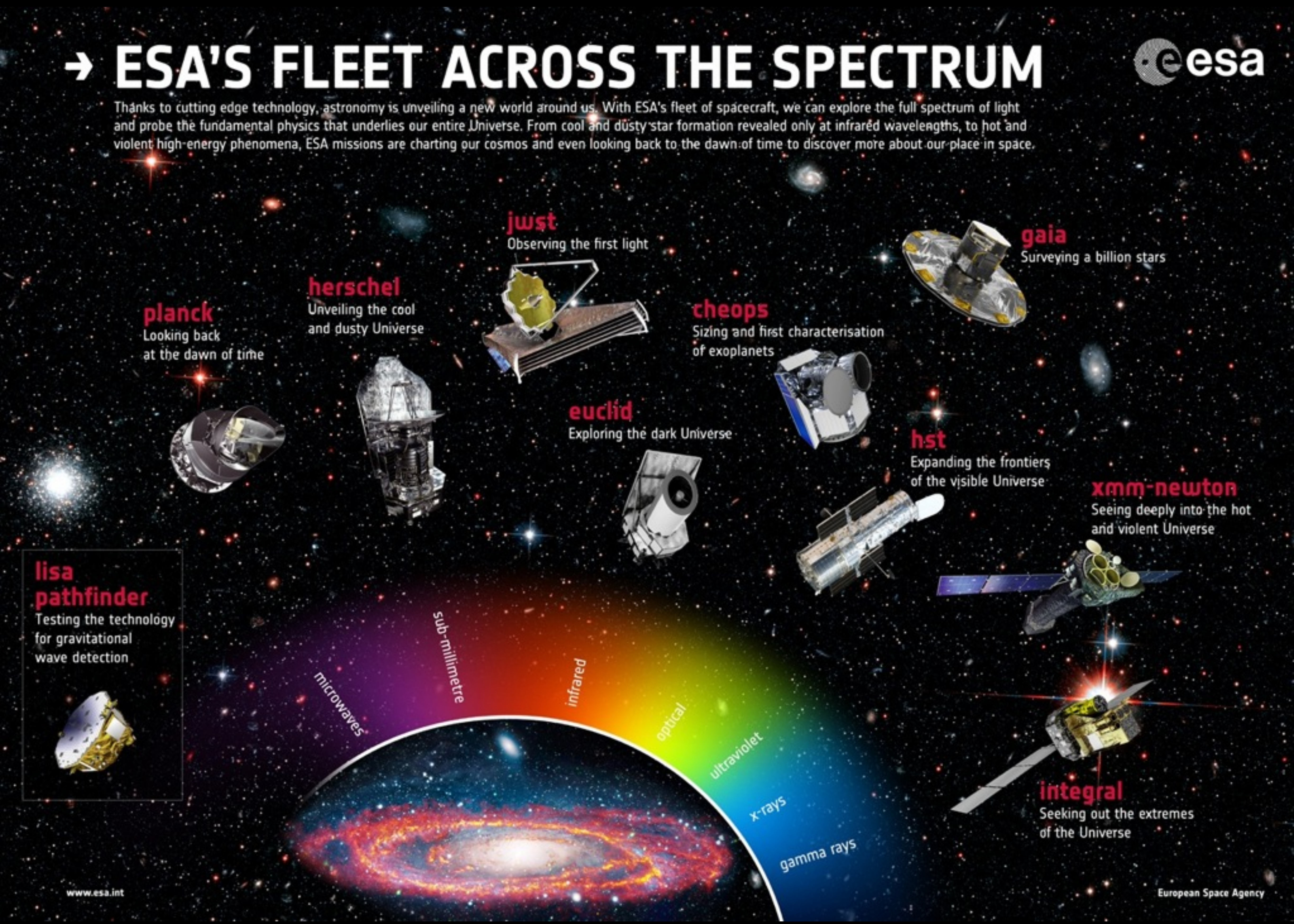
ESA space science & robotic exploration missions

Mark McCaughrean
European Space Agency
mjm@esa.int



→ ESA'S FLEET IN THE SOLAR SYSTEM

The Solar System is a natural laboratory that allows scientists to explore the nature of the Sun, the planets and their moons, as well as comets and asteroids. ESA's missions have transformed our view of the celestial neighbourhood, visiting Mars, Venus, and Saturn's moon Titan, and providing new insight into how the Sun interacts with Earth and its neighbours. The Solar System is the result of 4.6 billion years of formation and evolution. Studying how it appears now allows us to unlock the mysteries of its past and to predict how the various bodies will change in the future.



→ ESA'S FLEET ACROSS THE SPECTRUM
esa
Thanks to cutting edge technology, astronomy is unveiling a new world around us. With ESA's fleet of spacecraft, we can explore the full spectrum of light and probe the fundamental physics that underlies our entire Universe. From cool and dusty star formation revealed only at infrared wavelengths, to hot and violent high-energy phenomena, ESA missions are charting our cosmos and even looking back to the dawn of time to discover more about our place in space.
jwst
Observing the first light
gaia
Surveying a billion stars
herschel
Unveiling the cool and dusty Universe
planck
Looking back at the dawn of time
cheops
Sizing and first characterisation of exoplanets
euclid
Exploring the dark Universe
hst
Expanding the frontiers of the visible Universe
xmm-newton
Seeing deeply into the hot and violent Universe
lisa pathfinder
Testing the technology for gravitational wave detection
microwaves
sub-millimetre
infrared
optical
ultraviolet
x-rays
gamma rays
integral
Seeking out the extremes of the Universe
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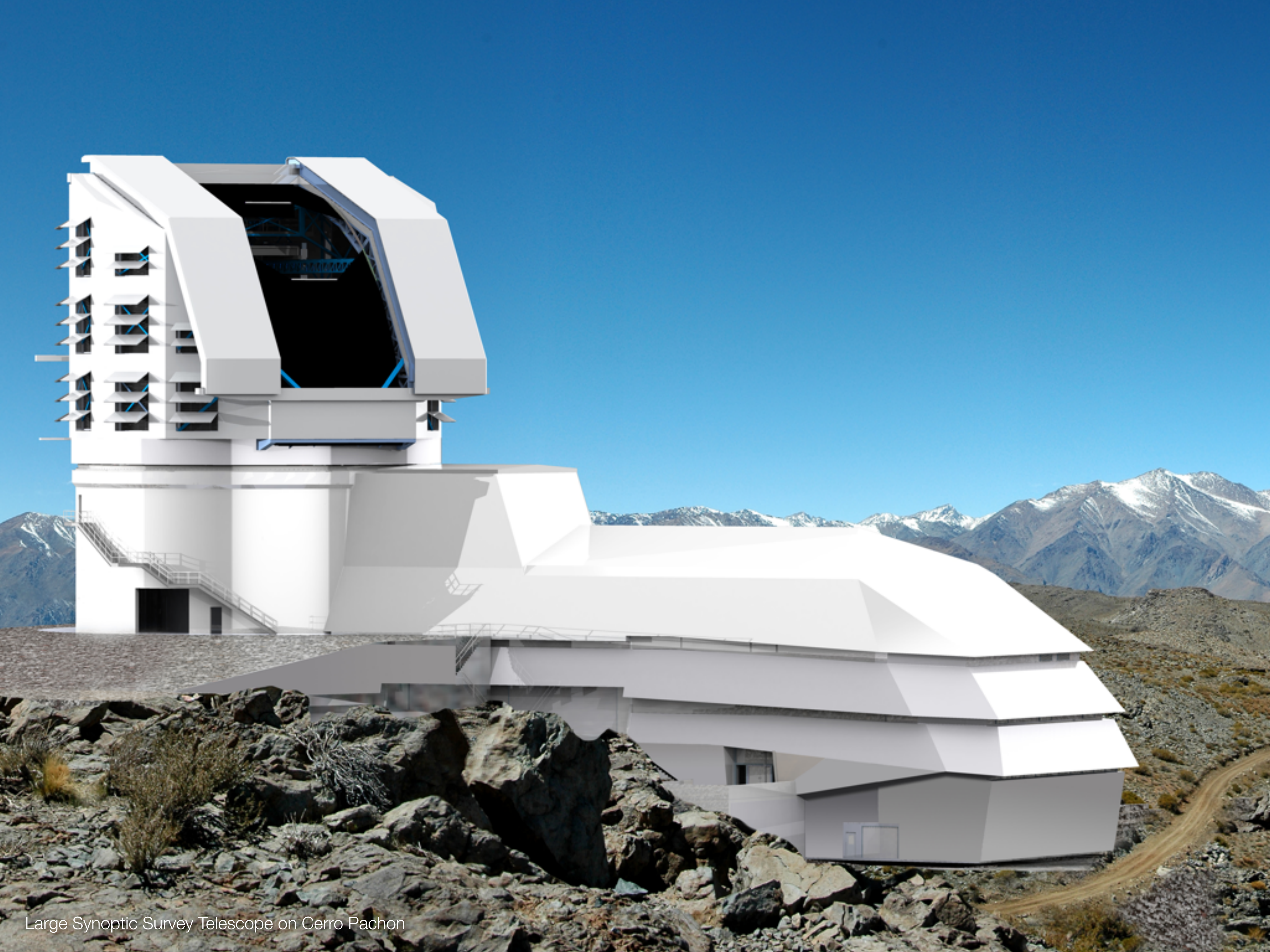
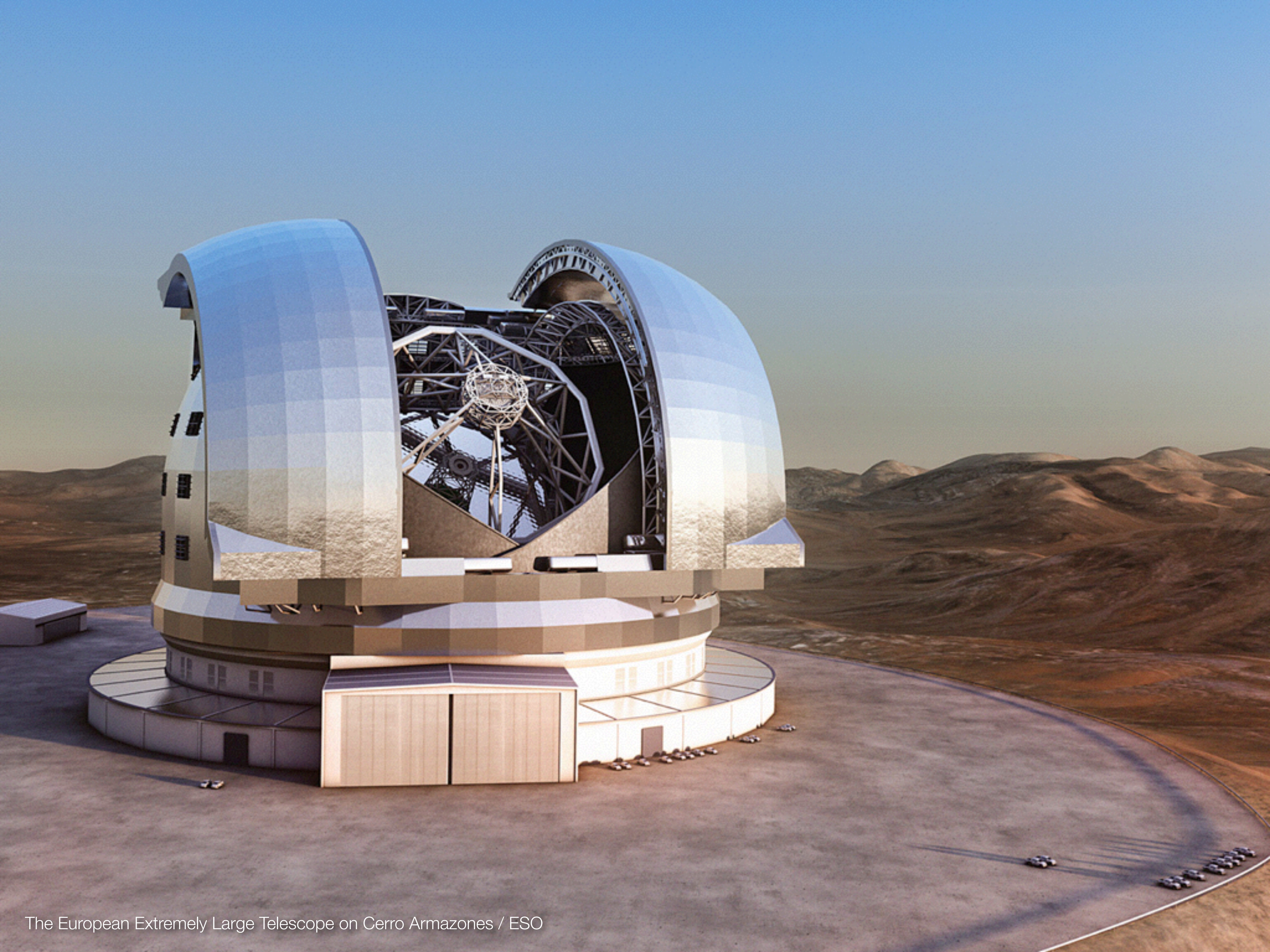
The Very Large Telescope on Cerro Paranal / ESO

Atacama Large Millimetre Array on the Chajnantor plateau / ESO, NRAO, NOAJ, NRC

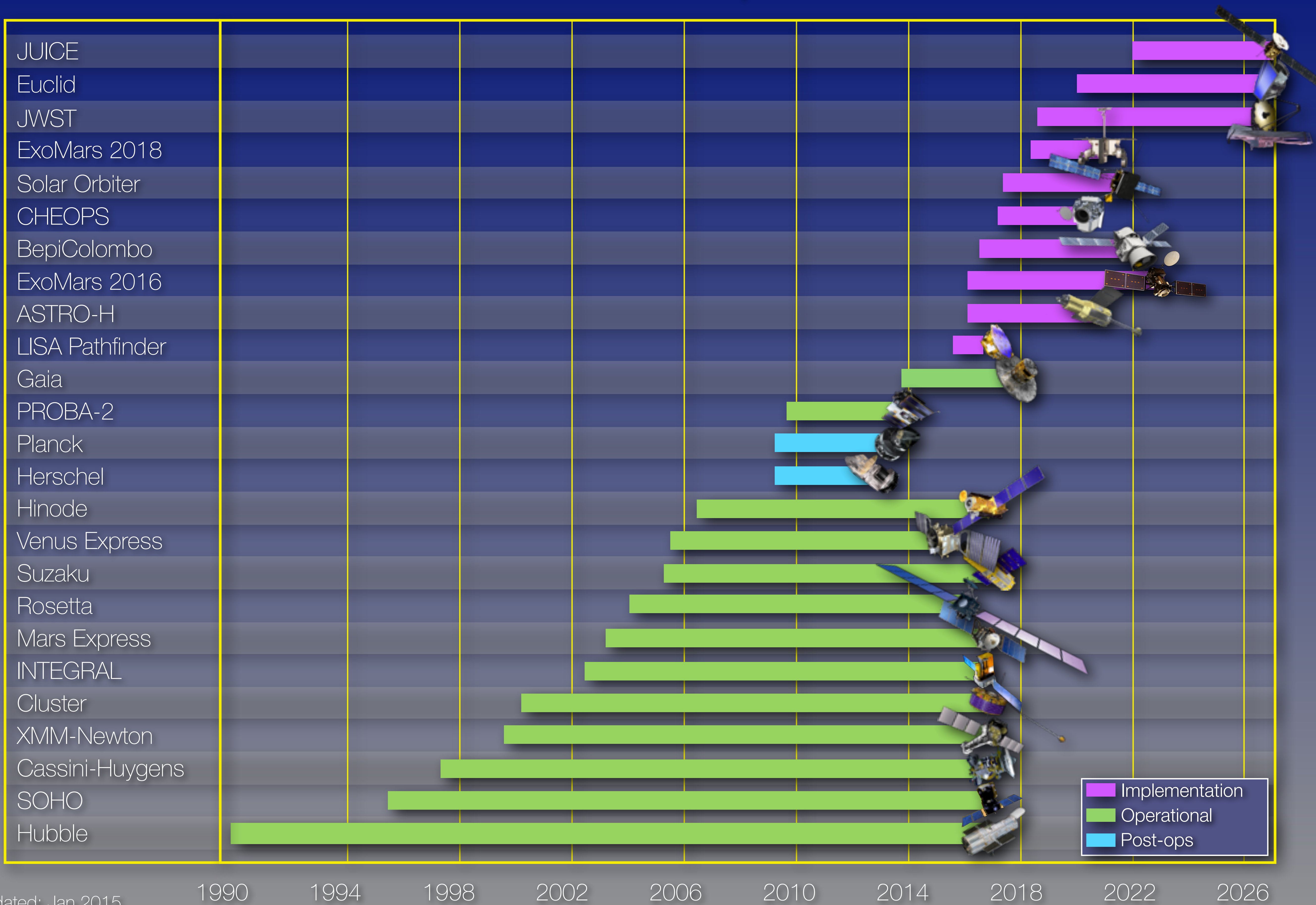

Large Synoptic Survey Telescope on Cerro Pachon



The European Extremely Large Telescope on Cerro Armazones / ESO


Square Kilometre Array

ESA science & robotic exploration missions



Updated: Jan 2015

Future ESA space science missions

Science missions in implementation

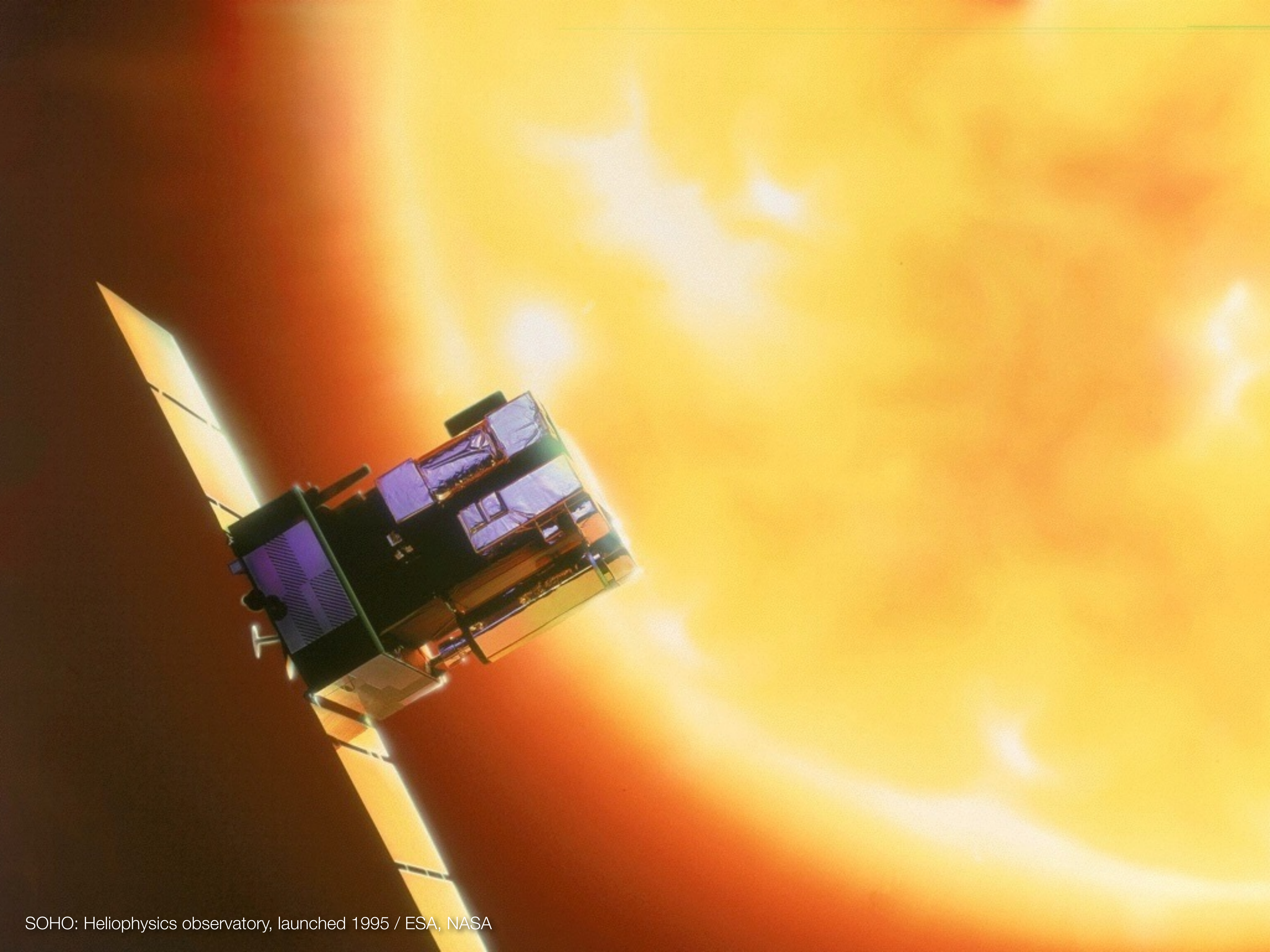
- LISA Pathfinder (2015)
- BepiColombo (with JAXA; 2016)
- Microscope (with CNES; 2016)
- ASTRO-H (with JAXA; 2016)
- Solar Orbiter (with NASA; 2017)
- CHEOPS (2017)
- JWST (with NASA, CSA; 2018)
- Euclid (2020)
- JUICE (2022)
- PLATO (2024)

ExoMars robotic exploration (with Roscosmos)

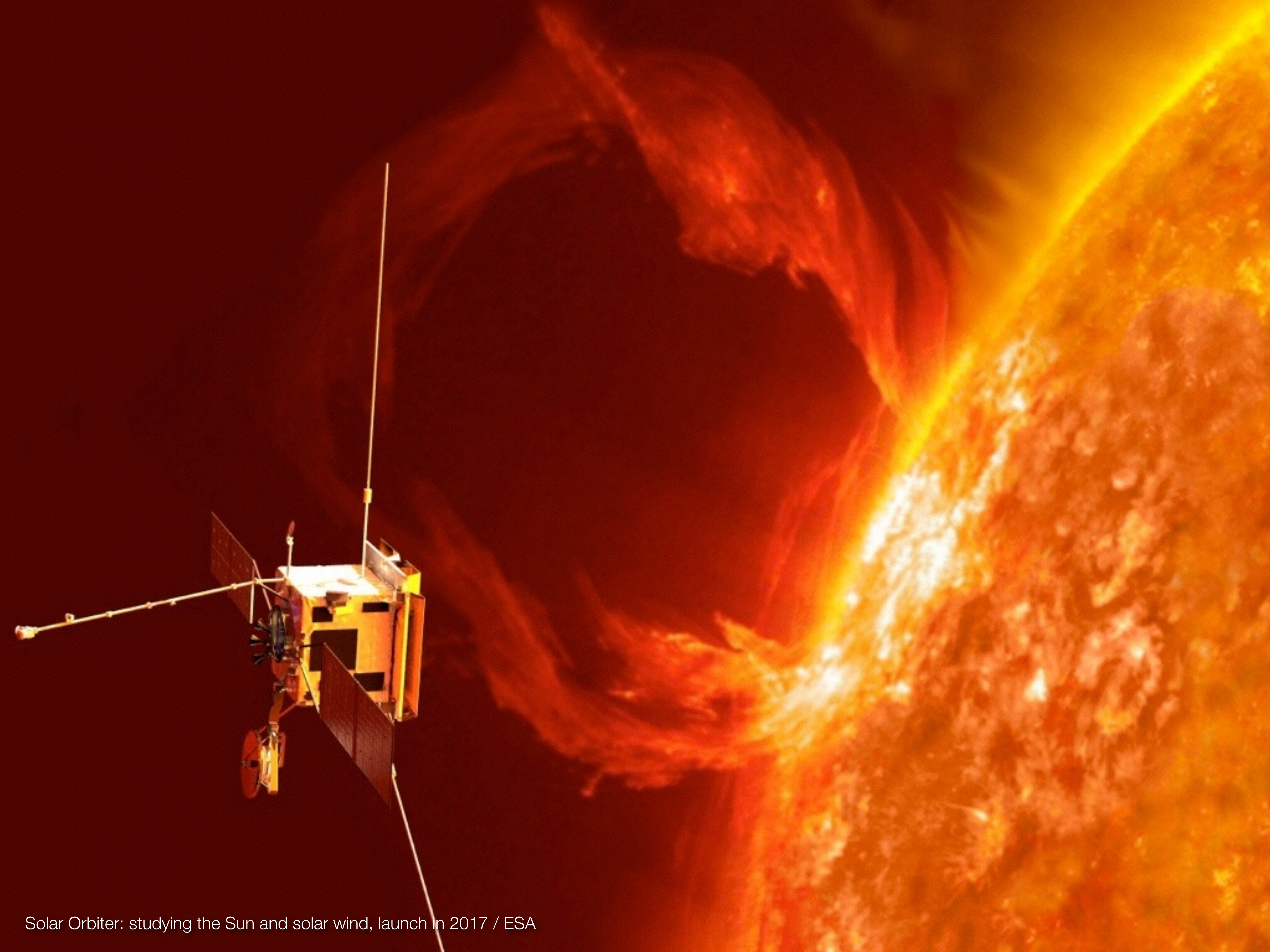
- Trace Gas Orbiter + EDL demonstrator (2016)
- Joint rover mission (2018)
- Goal: Sample Return

Under study / open calls

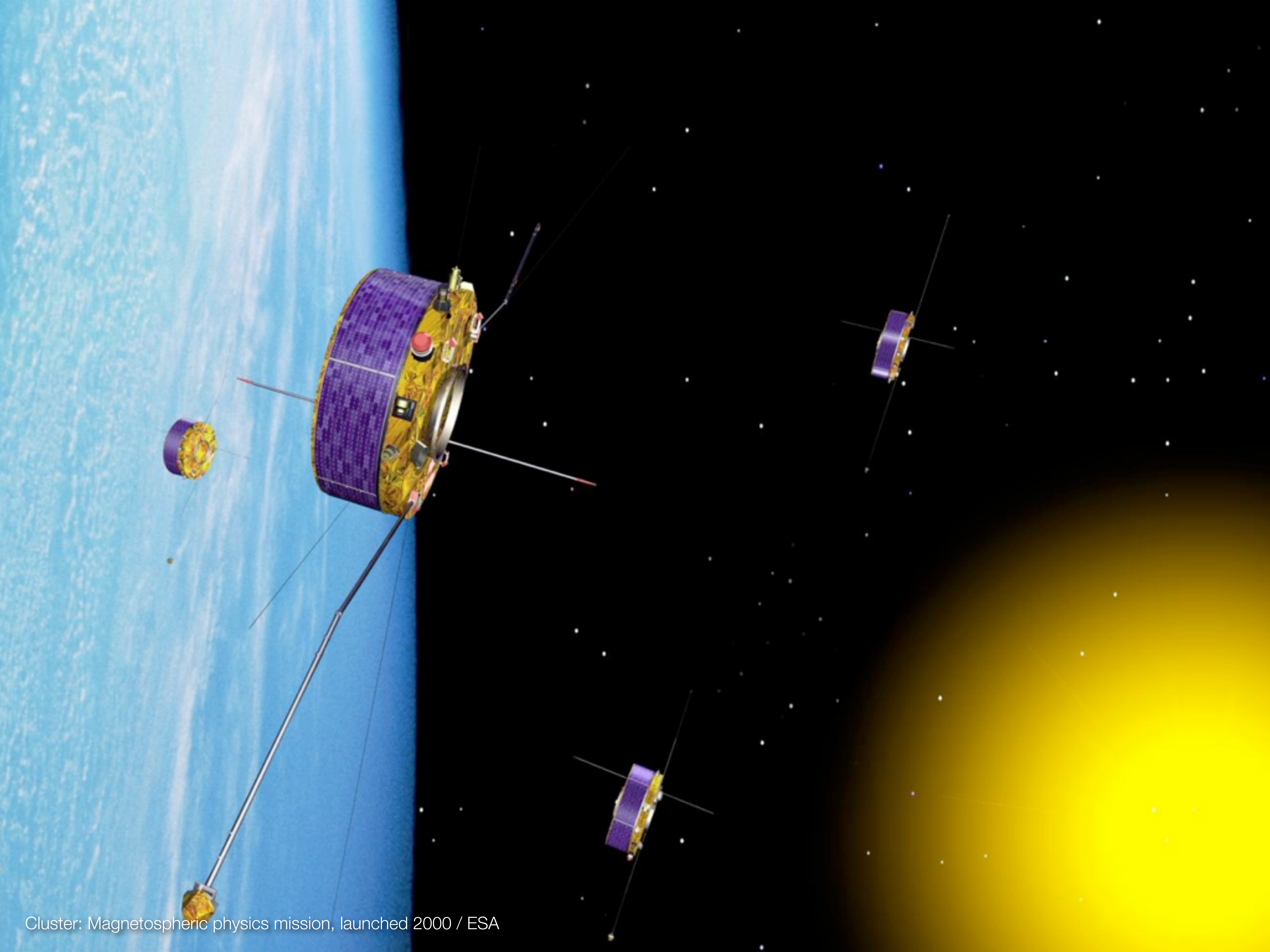
- Athena (2028)
- Future gravitational wave observatory (2034)
- Medium mission M4 (call just closed)
- Joint ESA-China small mission



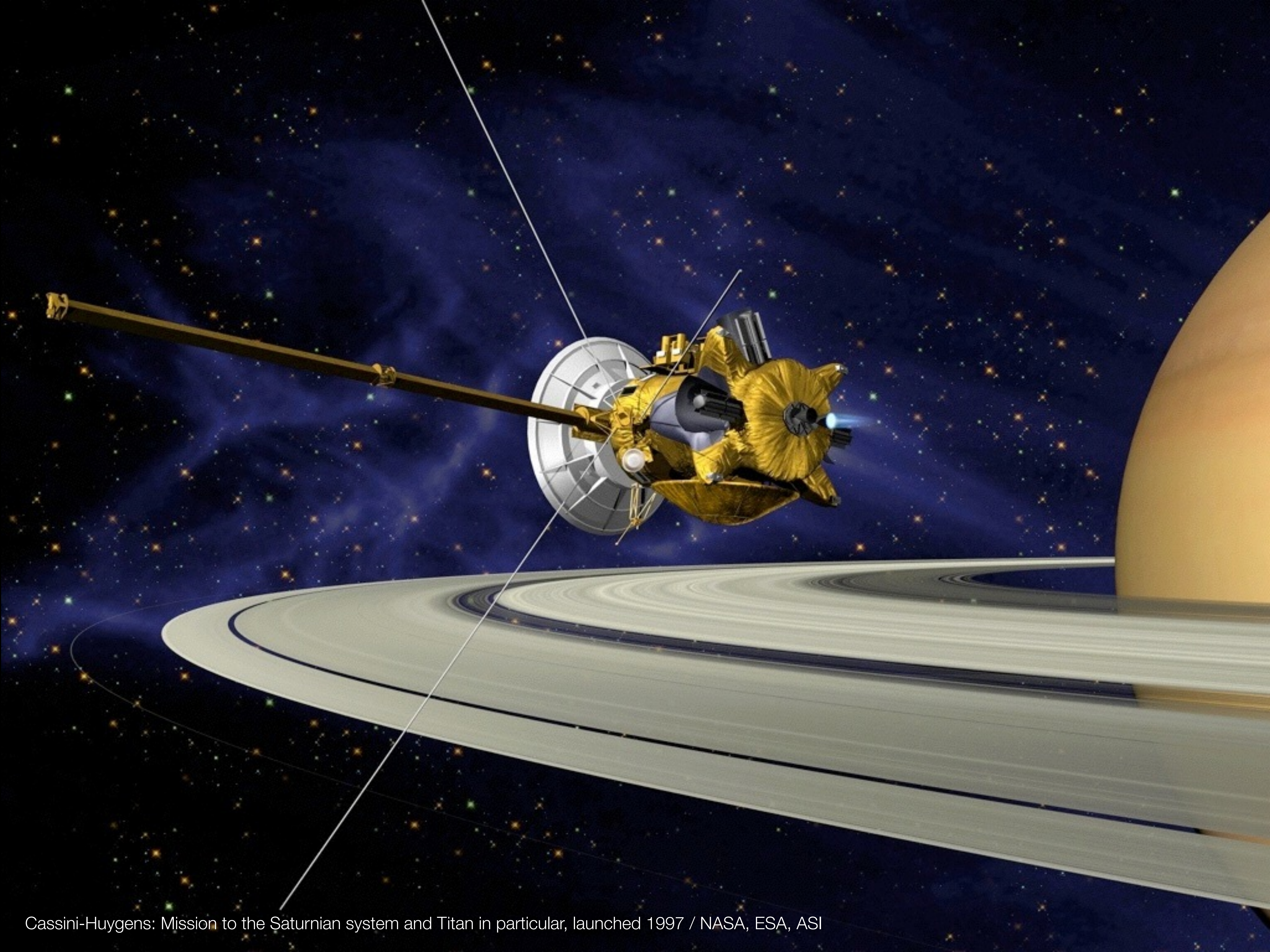
SOHO: Heliophysics observatory, launched 1995 / ESA, NASA



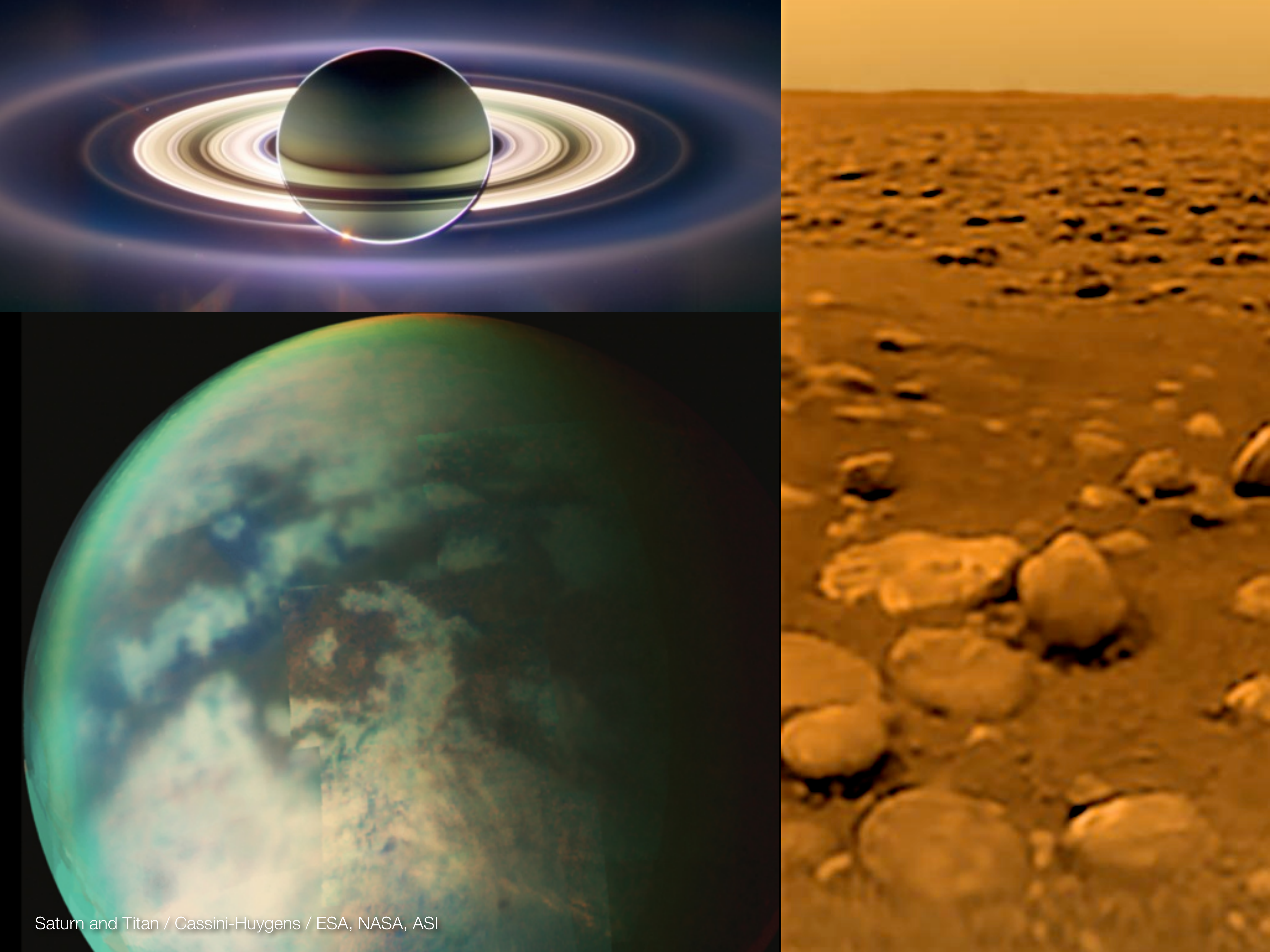
Solar Orbiter: studying the Sun and solar wind, launch in 2017 / ESA



Cluster: Magnetospheric physics mission, launched 2000 / ESA

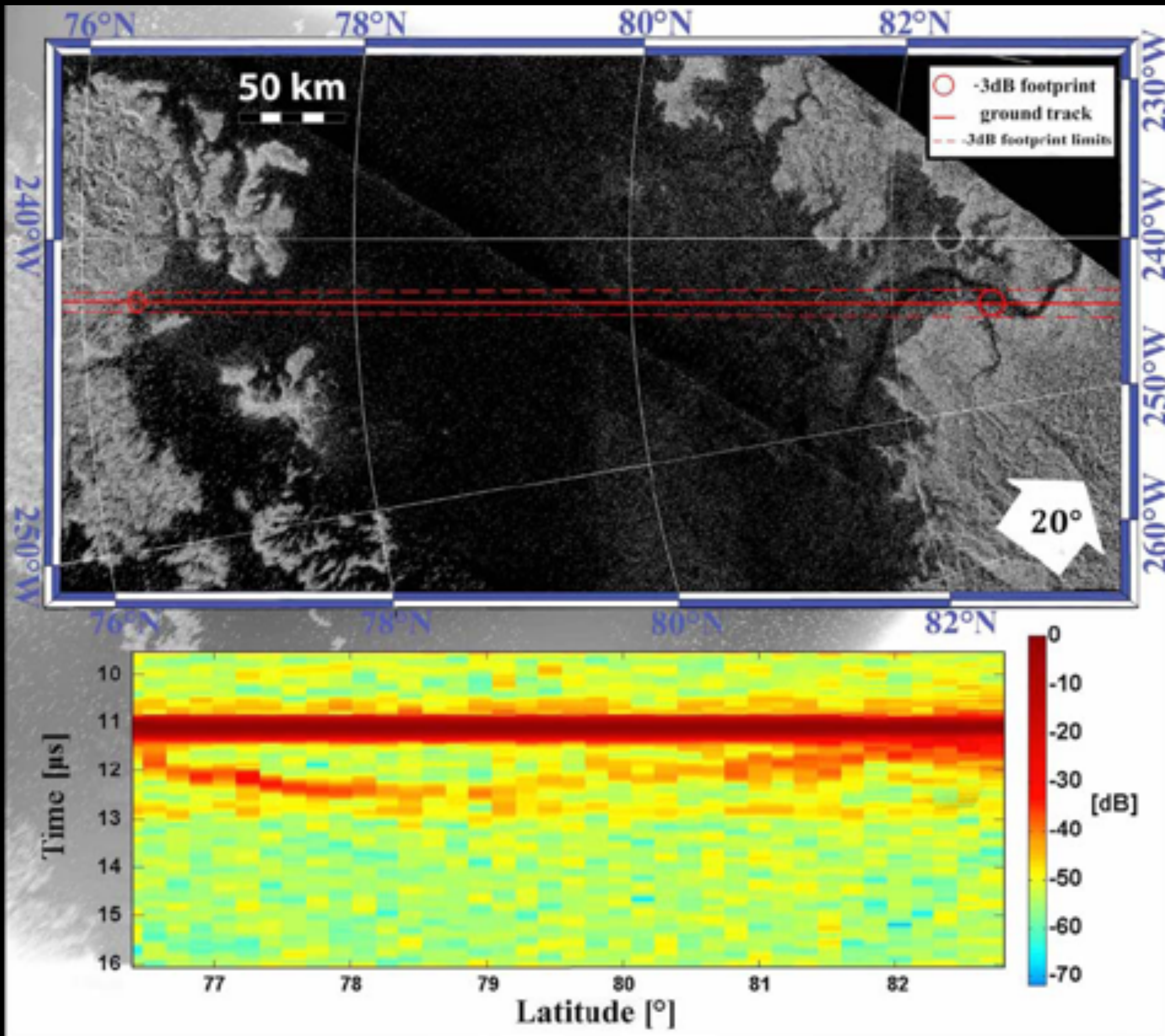


Cassini-Huygens: Mission to the Saturnian system and Titan in particular, launched 1997 / NASA, ESA, ASI



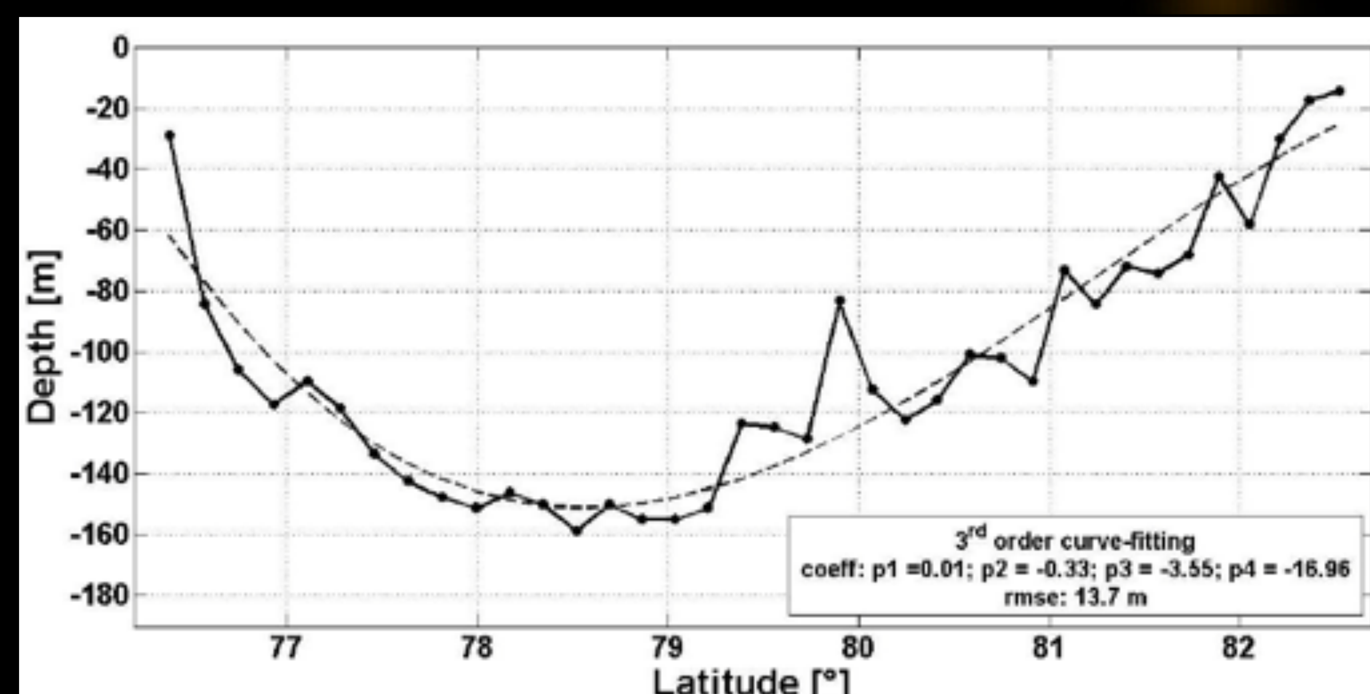
Saturn and Titan / Cassini-Huygens / ESA, NASA, ASI

Bathymetry of Ligeia Mare



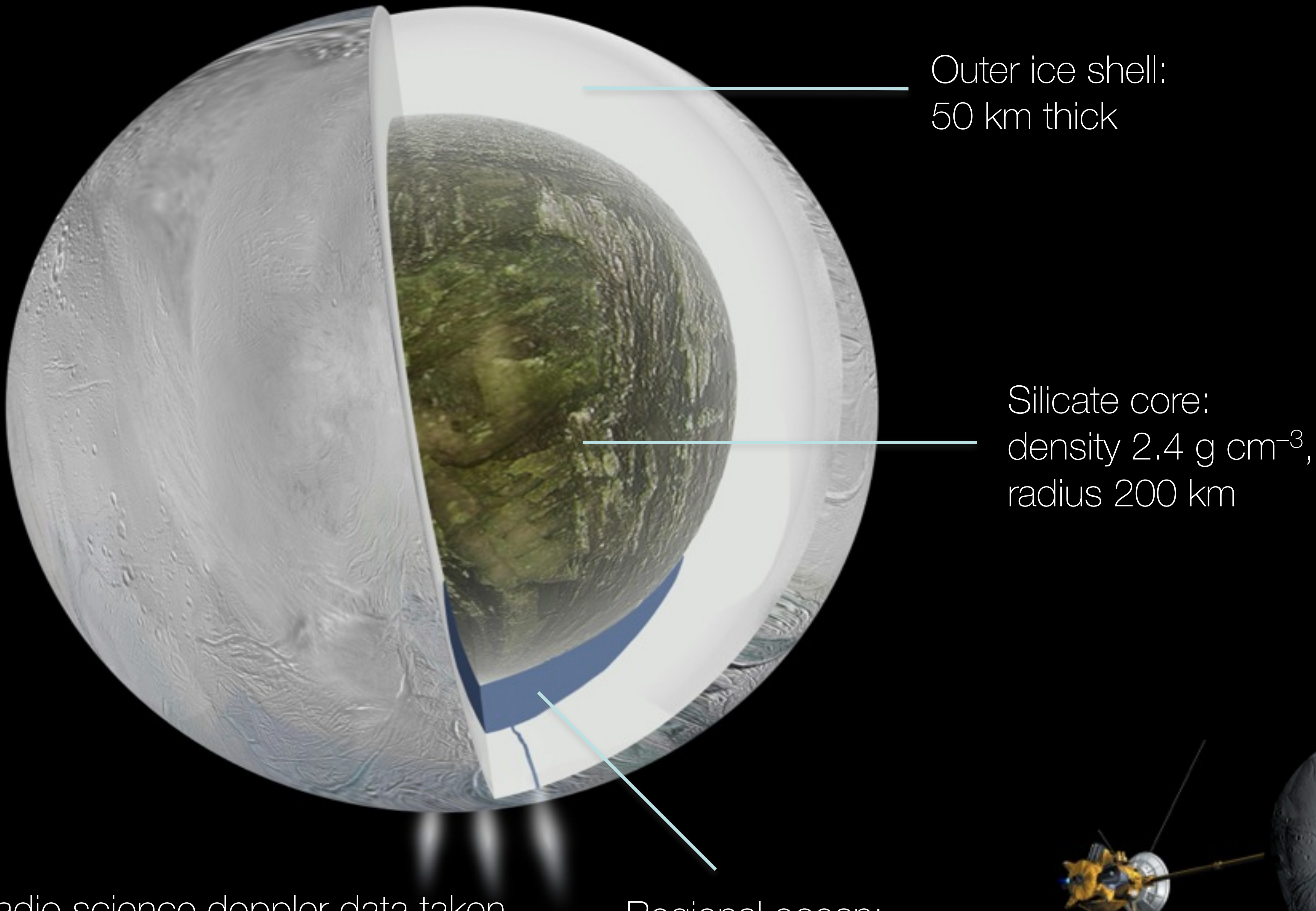
- Radar sounding at 2.17cm
  - 300km transect across second largest sea on Titan
  - Up to 160m deep
- Low radar attenuation
  - Indicates very pure methane-ethane mix
  - Other hydrocarbons, nitriles, suspended particles < 0.1% b.v.

- Total volume of liquid hydrocarbons on Titan
  - 5000 gigatonnes
  - ~100 x known terrestrial oil and gas reserves
  - And 70 x more methane vapour in Titan's atmosphere

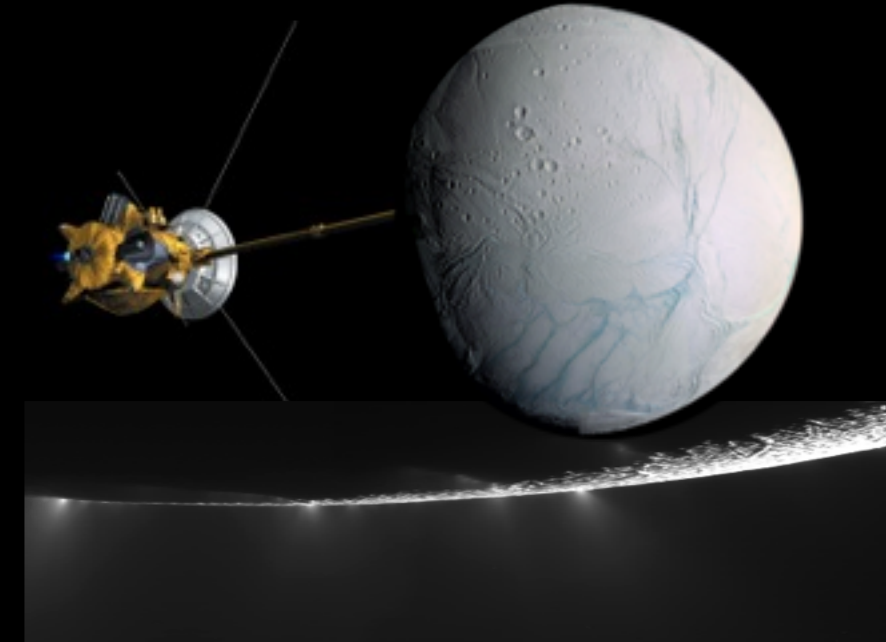


Mastrogiuseppe et al. 2014, GRL / Kraken Mare image, NASA, JPL, DLR

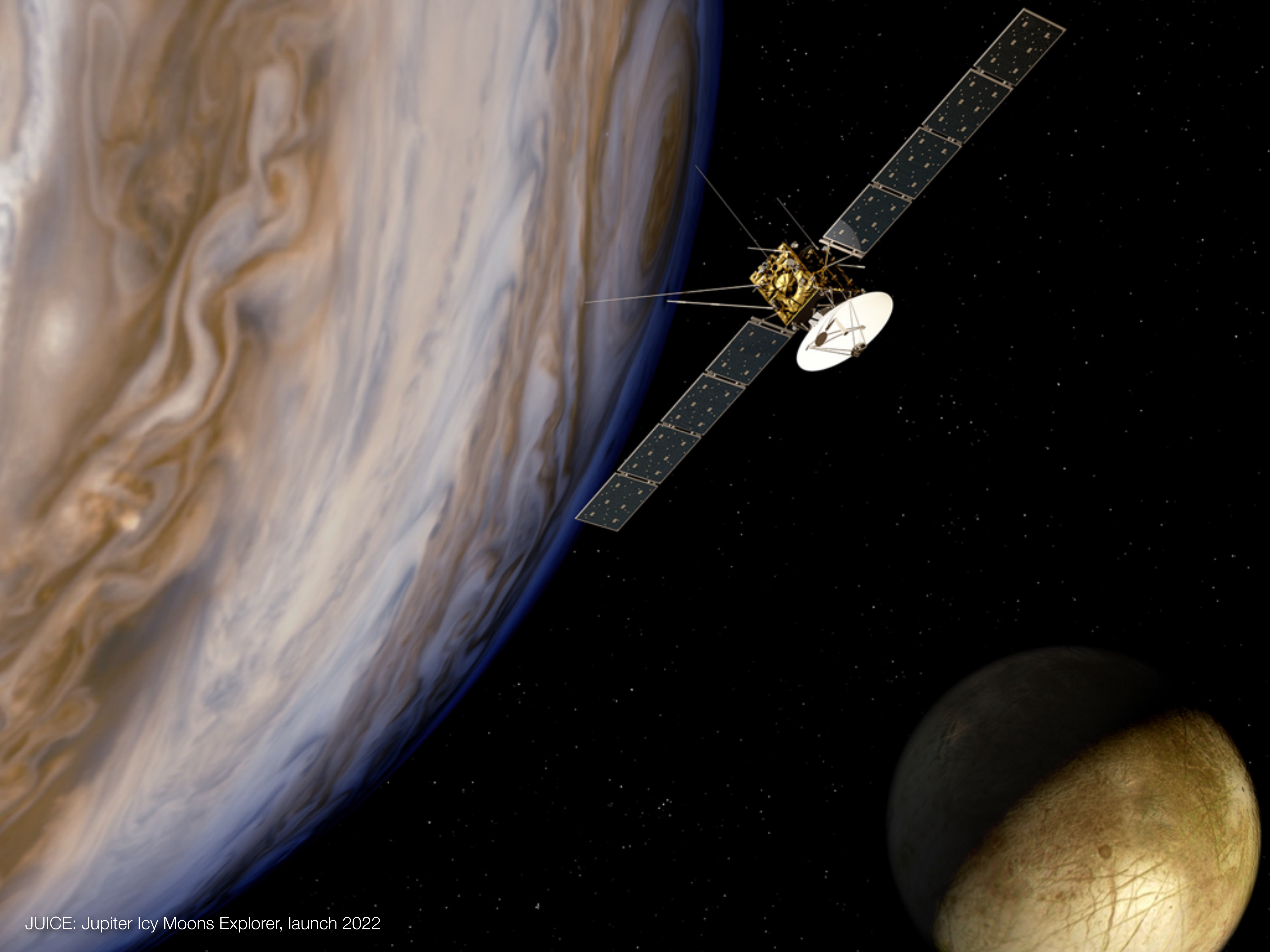
A regional ocean under Enceladus



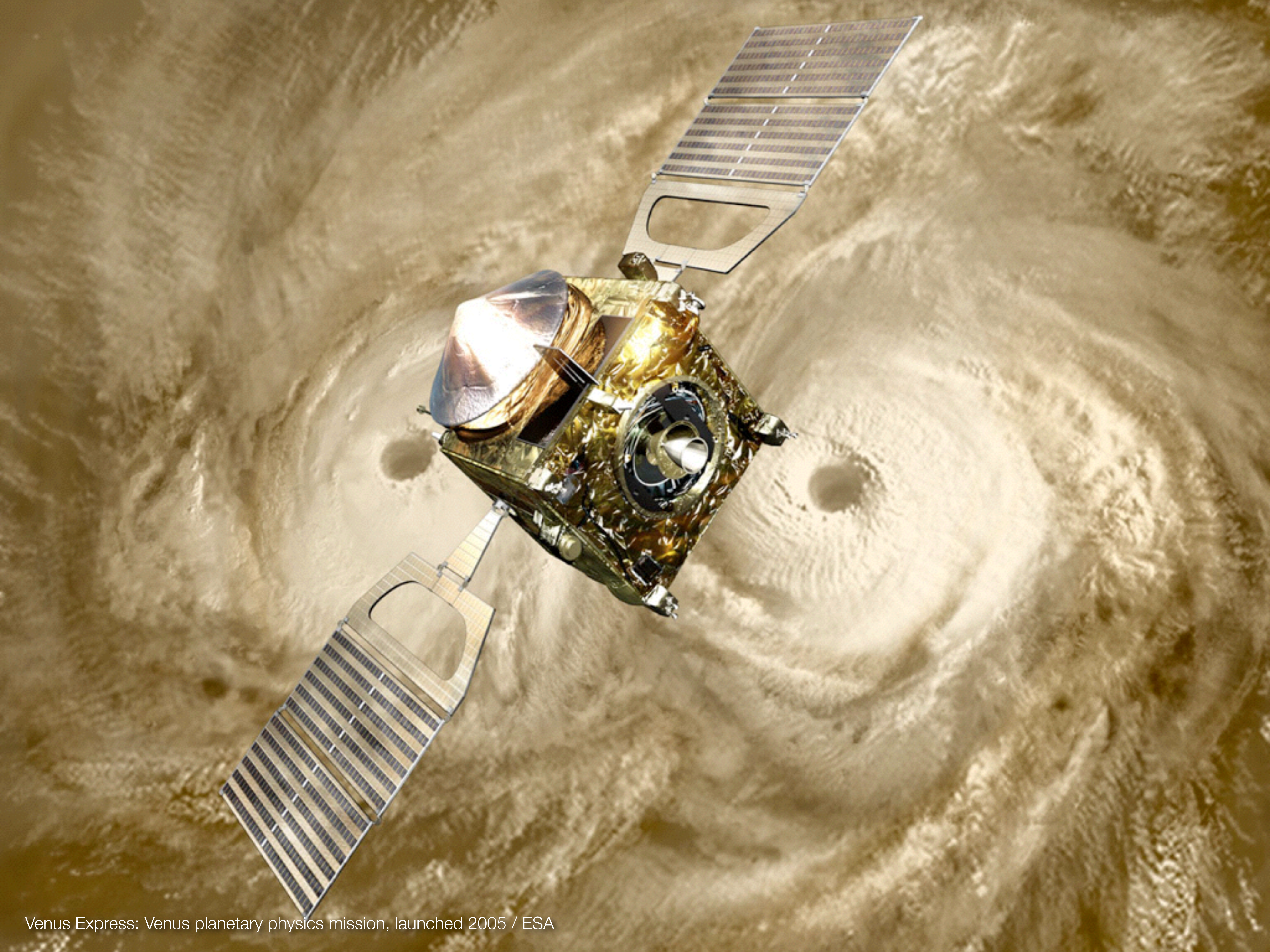
Radio science doppler data taken
during three fly-bys of Enceladus
Perturbations of ~0.2–0.3 mm s^{-1}



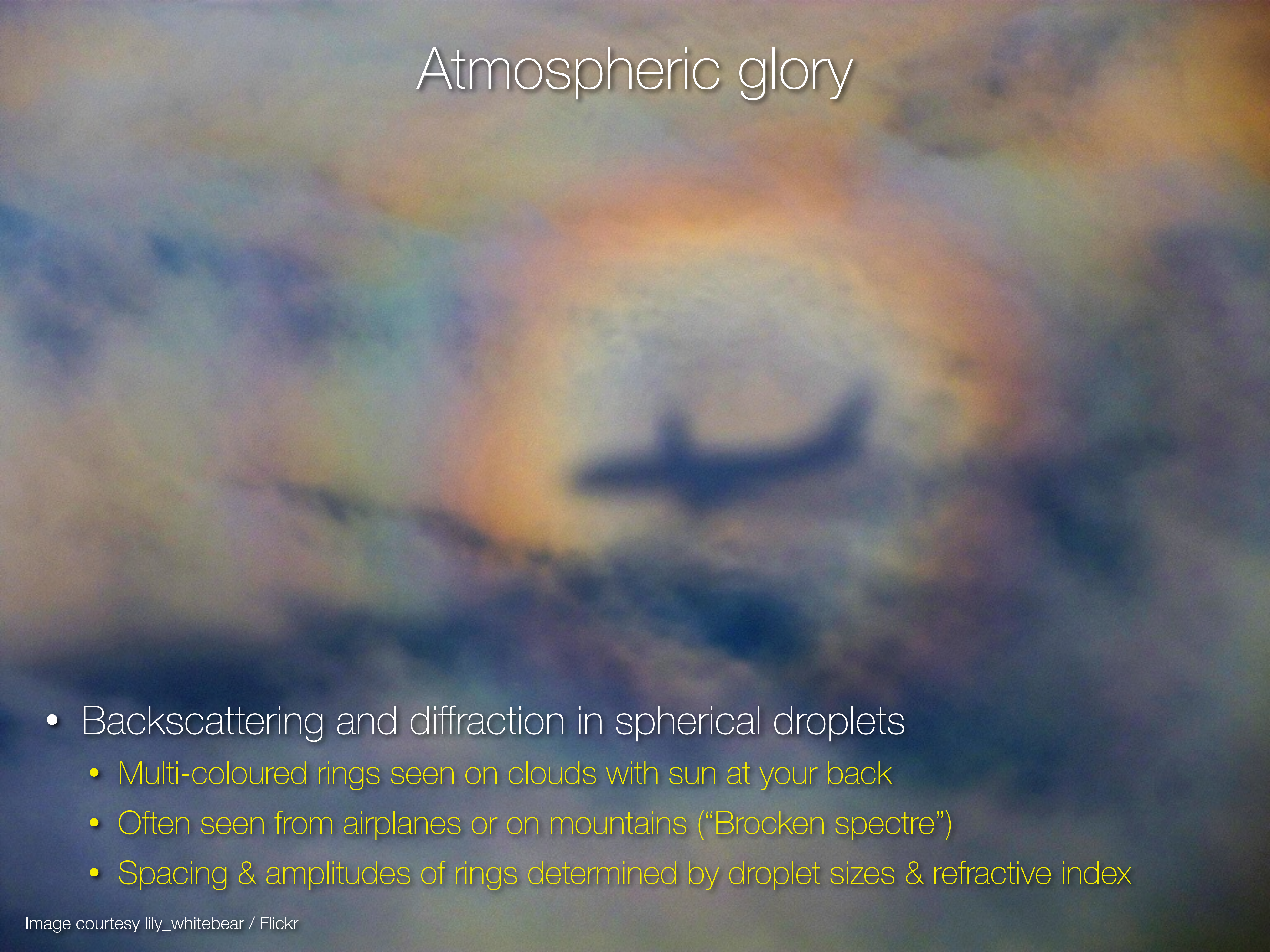
Iess et al. 2014, Science



JUICE: Jupiter Icy Moons Explorer, launch 2022



Venus Express: Venus planetary physics mission, launched 2005 / ESA

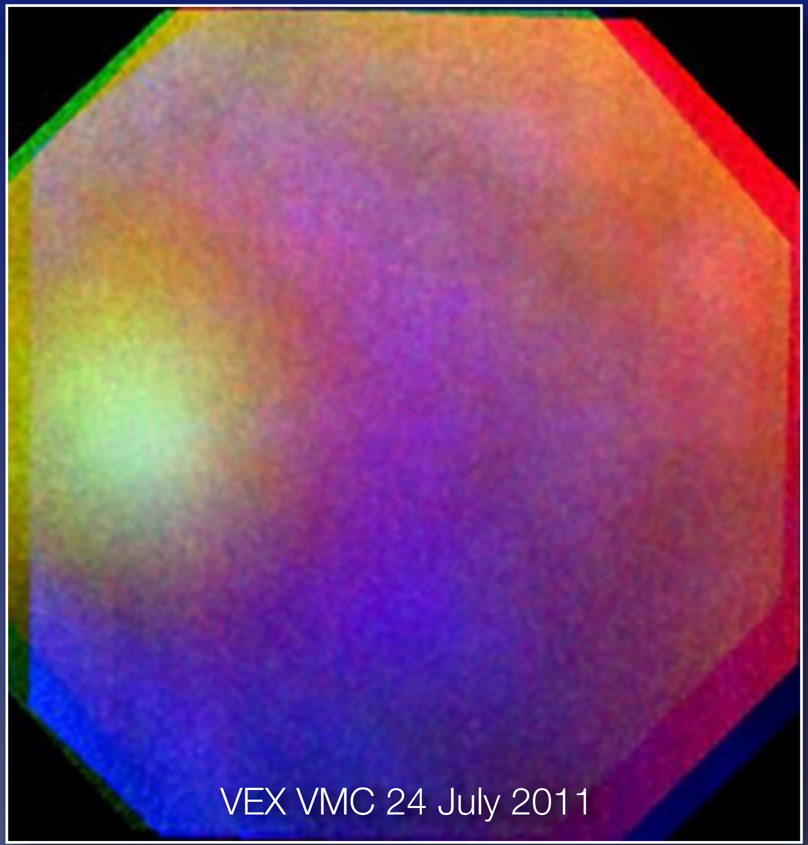


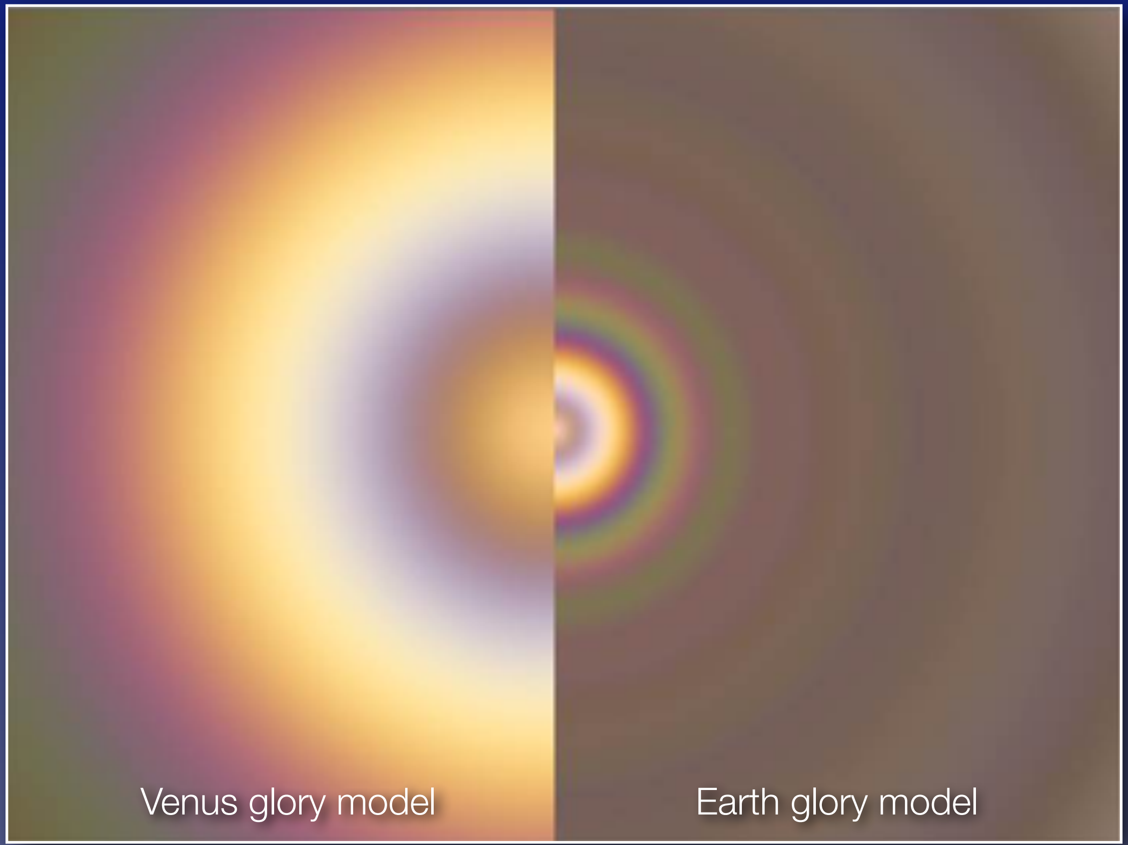
Atmospheric glory

- Backscattering and diffraction in spherical droplets
  - Multi-coloured rings seen on clouds with sun at your back
  - Often seen from airplanes or on mountains (“Brocken spectre”)
  - Spacing & amplitudes of rings determined by droplet sizes & refractive index

Image courtesy lily_whitebear / Flickr

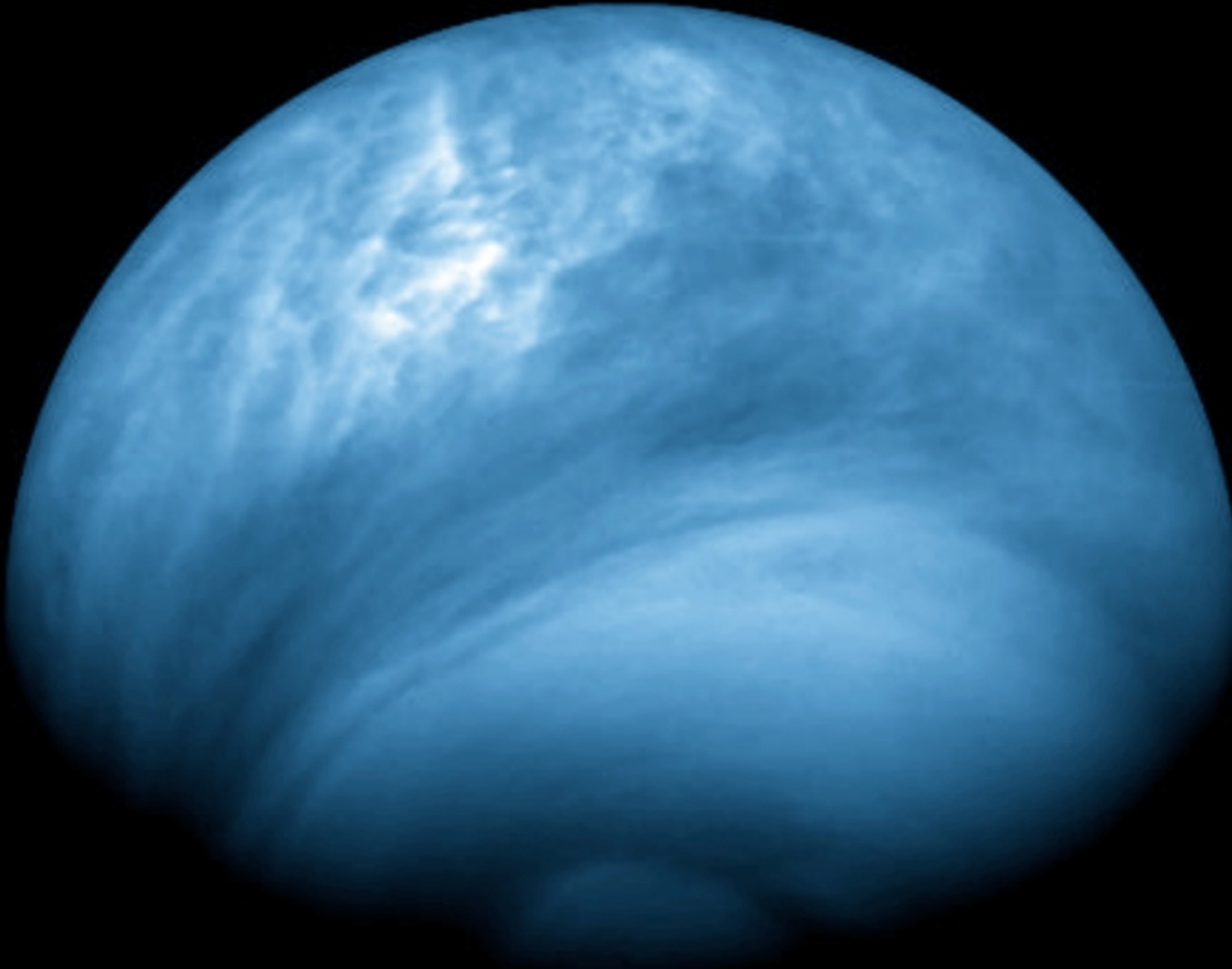
First image of a extra-terrestrial glory



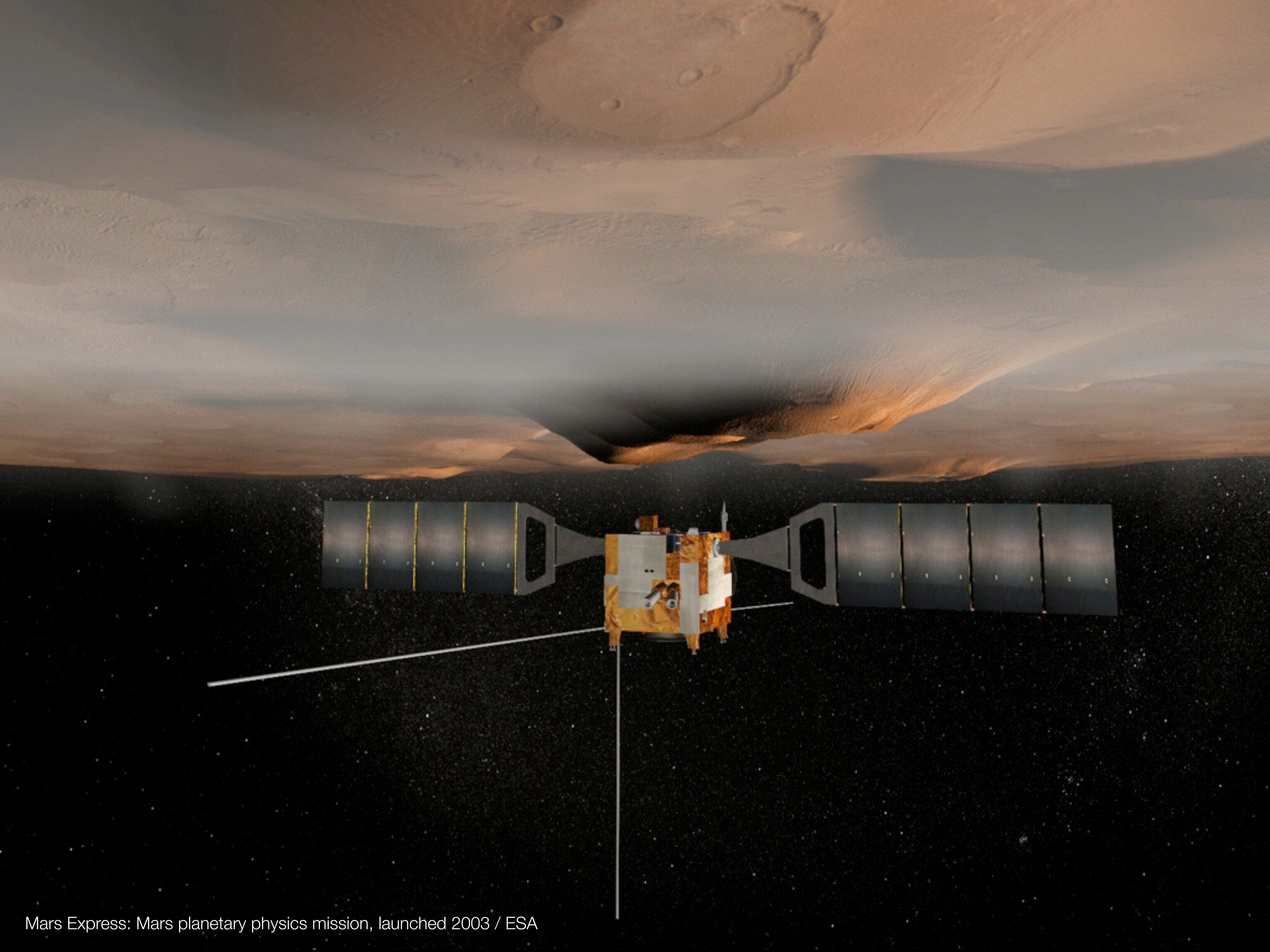


- VEX Venus Monitoring Camera images
  - Glory seen from ~70 km cloud layer in backscattering geometry from ~6000 km
  - Sequence of narrow-band filter (0.365, 0.513, 0.965μm) images
- Mie-scattering models used to provide best fit to observations
  - Requires wide distribution of uniform 1.2μm droplets with n=1.48
  - Higher than n=1.44 for pure H_2SO_4 droplets at 250K: contaminant?
  - Could be sulphur or ferric chloride: related to mysterious “UV absorber”?

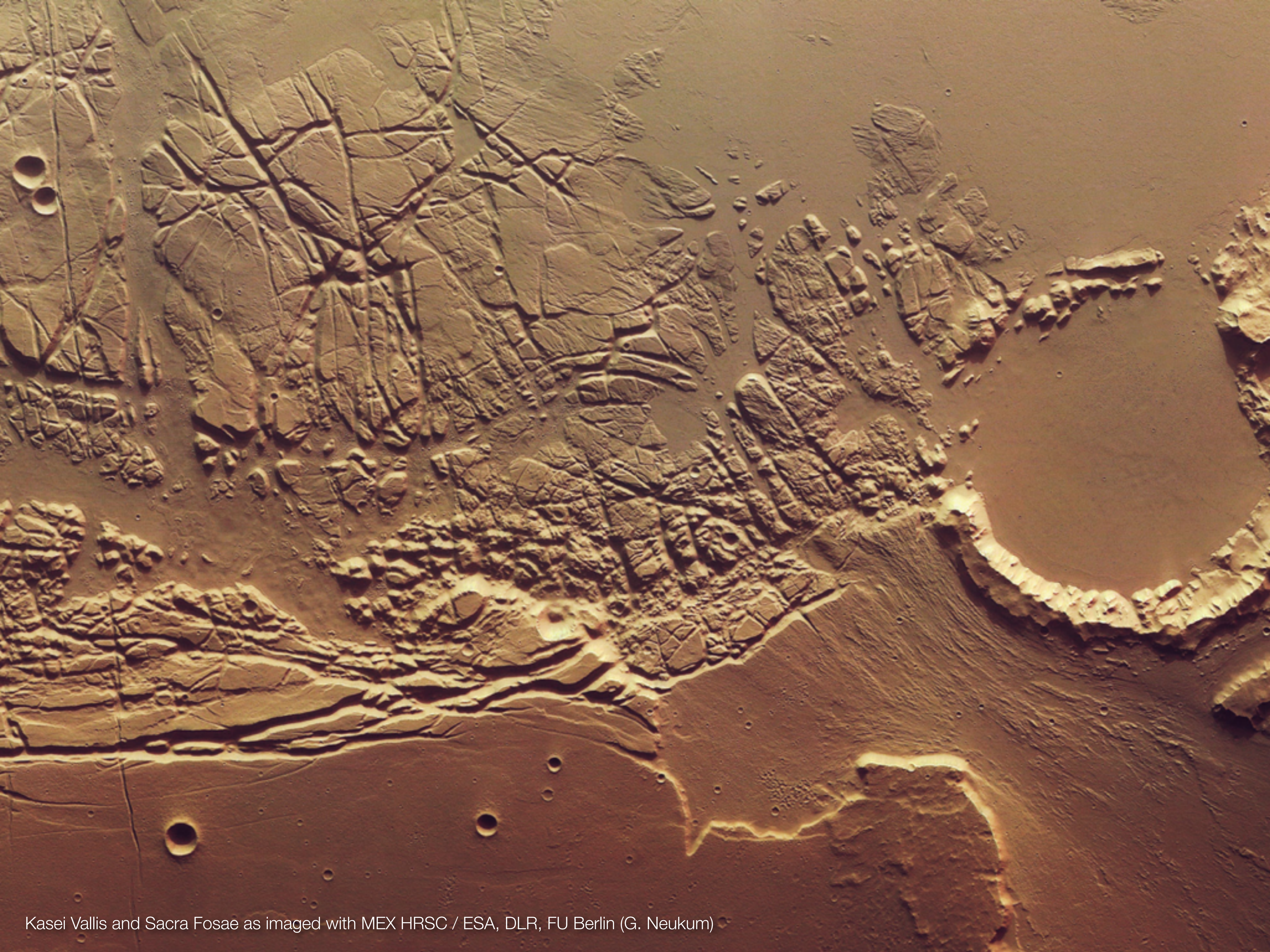
Markiewicz et al. 2014, Icarus



VEX VMC image of Venus in the UV / ESA



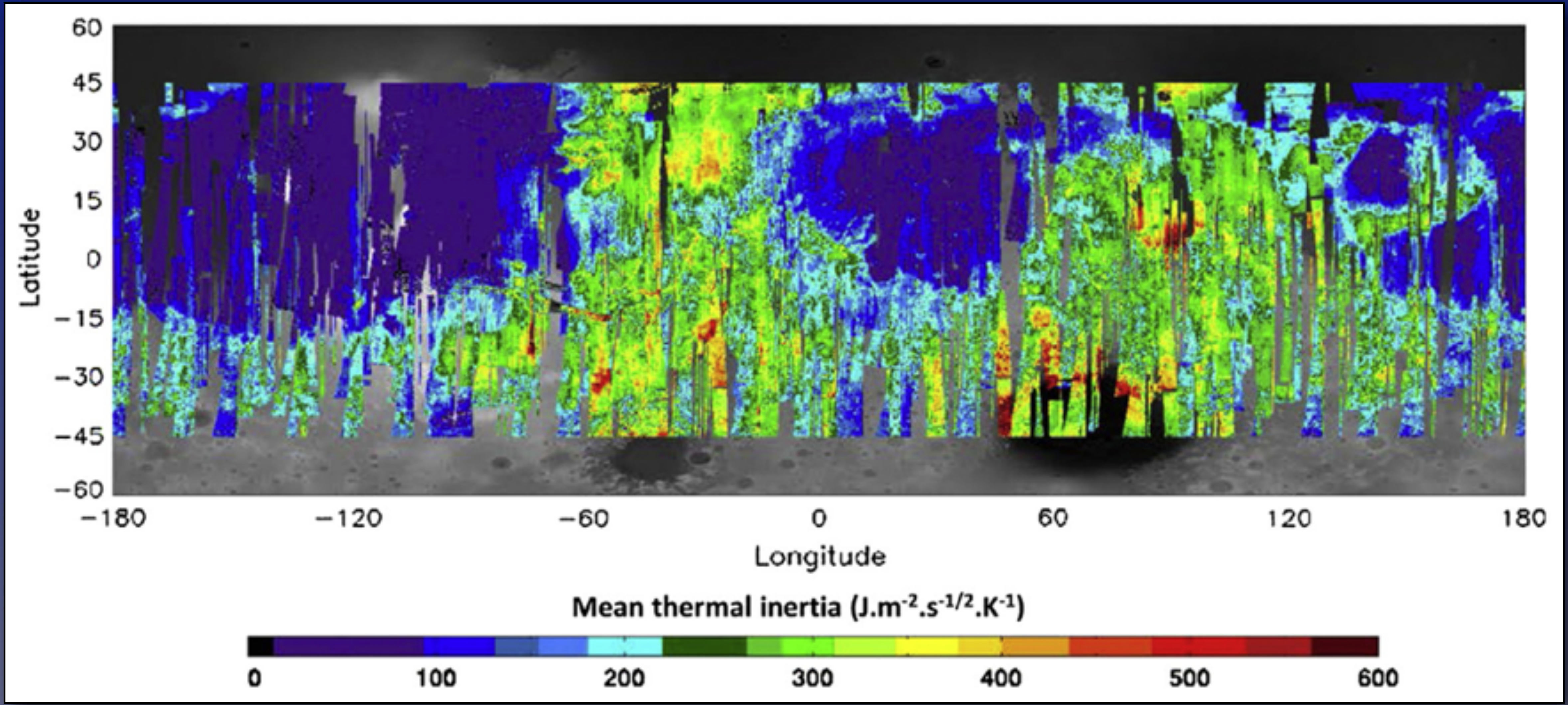
Mars Express: Mars planetary physics mission, launched 2003 / ESA



Kasei Vallis and Sacra Fosae as imaged with MEX HRSC / ESA, DLR, FU Berlin (G. Neukum)

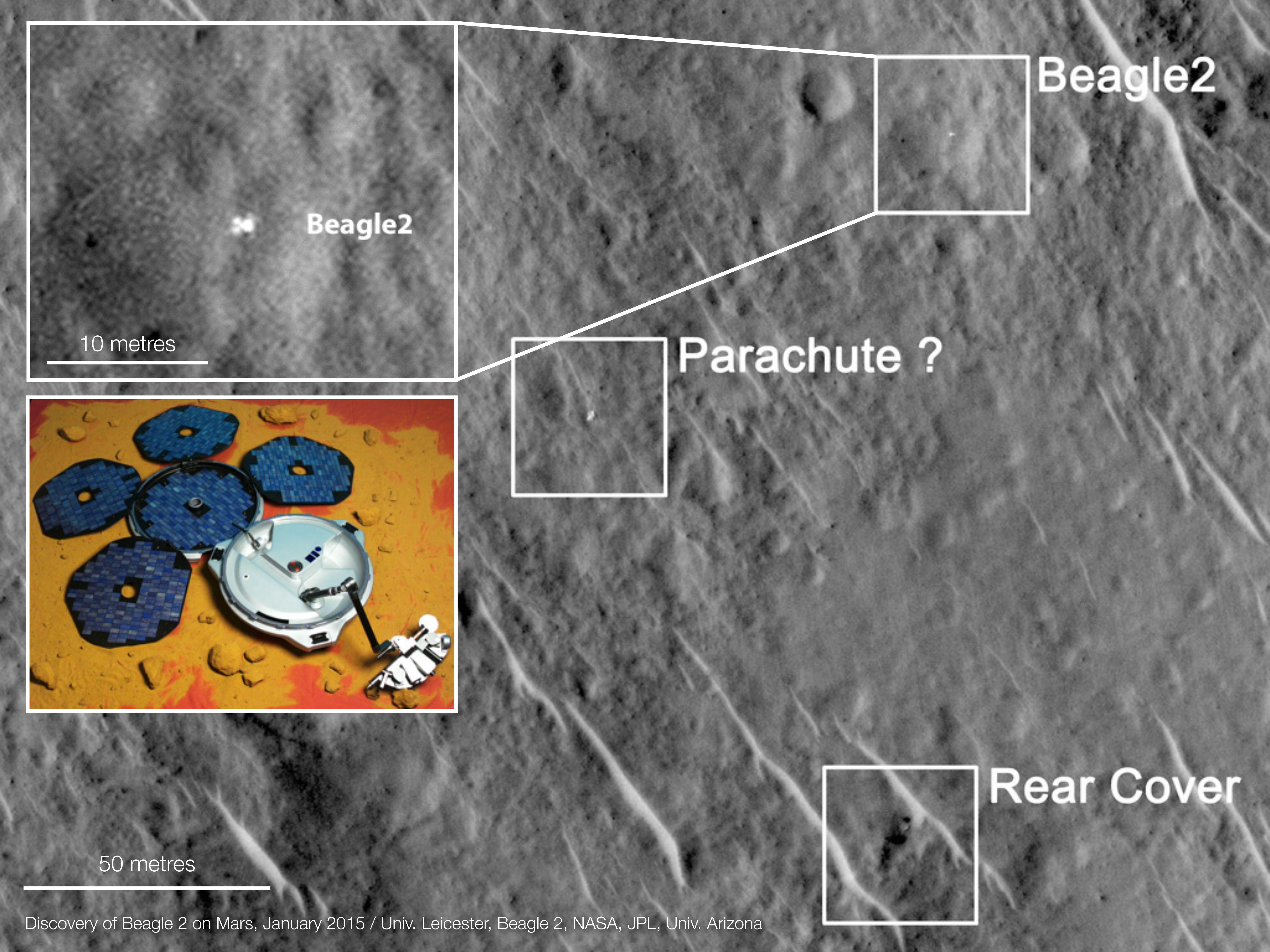
Extent of MEX HRSC global mapping as of mid-2013 / ESA, DLR, FU Berlin (G. Neukum), Fred Jansen

Thermal inertia mapping of the martian surface



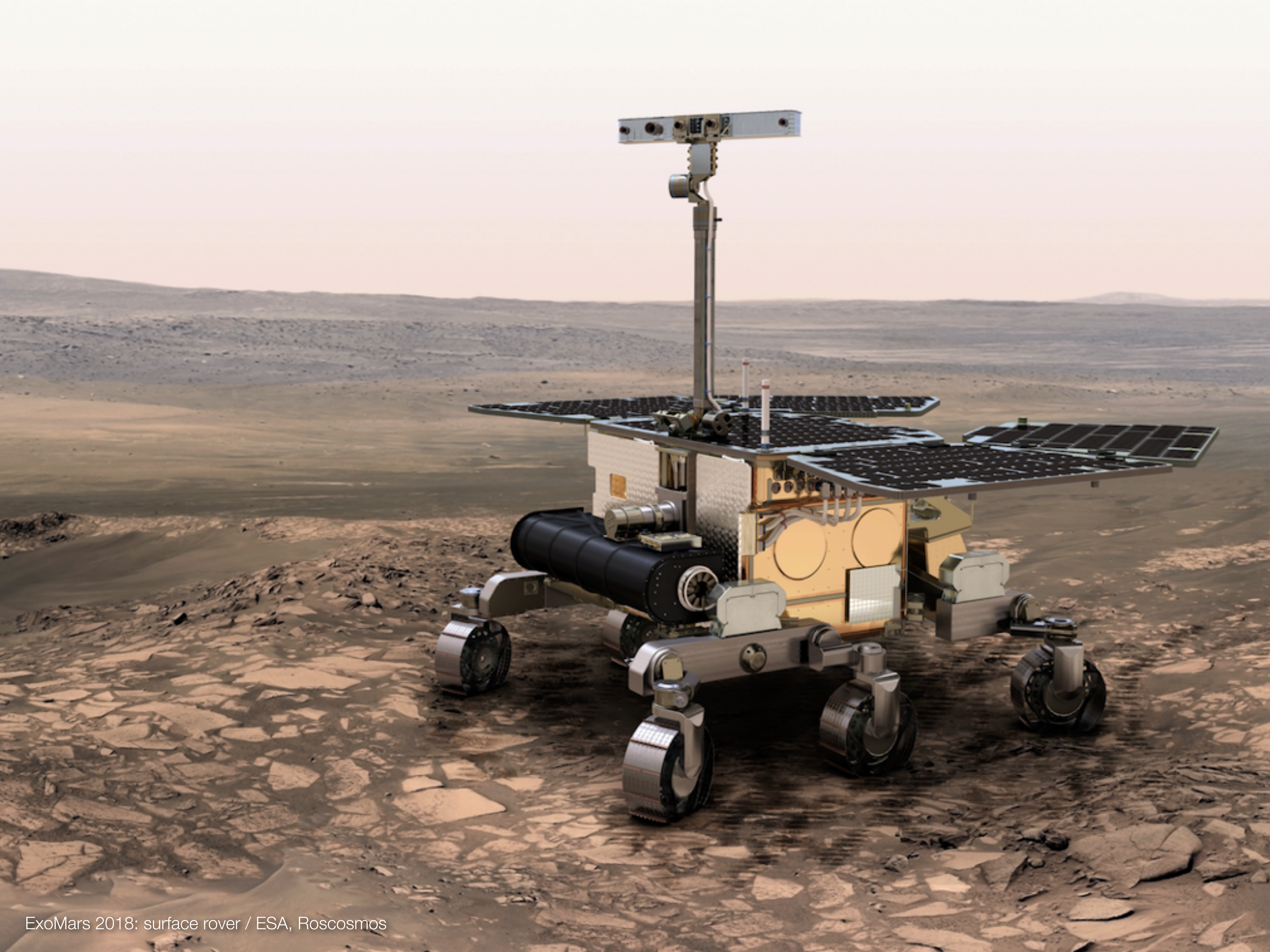
- Mars Express OMEGA thermal-IR mapping at 5–5.1μm over 8 yrs
  - TI derived from radiance converted to temperature, + atmospheric model
- Thermal inertia depends on surface material and structure
  - Diurnal variations (~2–3 larger PM than AM): due to horizontal (e.g. rock abundance, slopes) and vertical (layering, dust covering) heterogeneities

Audouard et al. 2014, Icarus

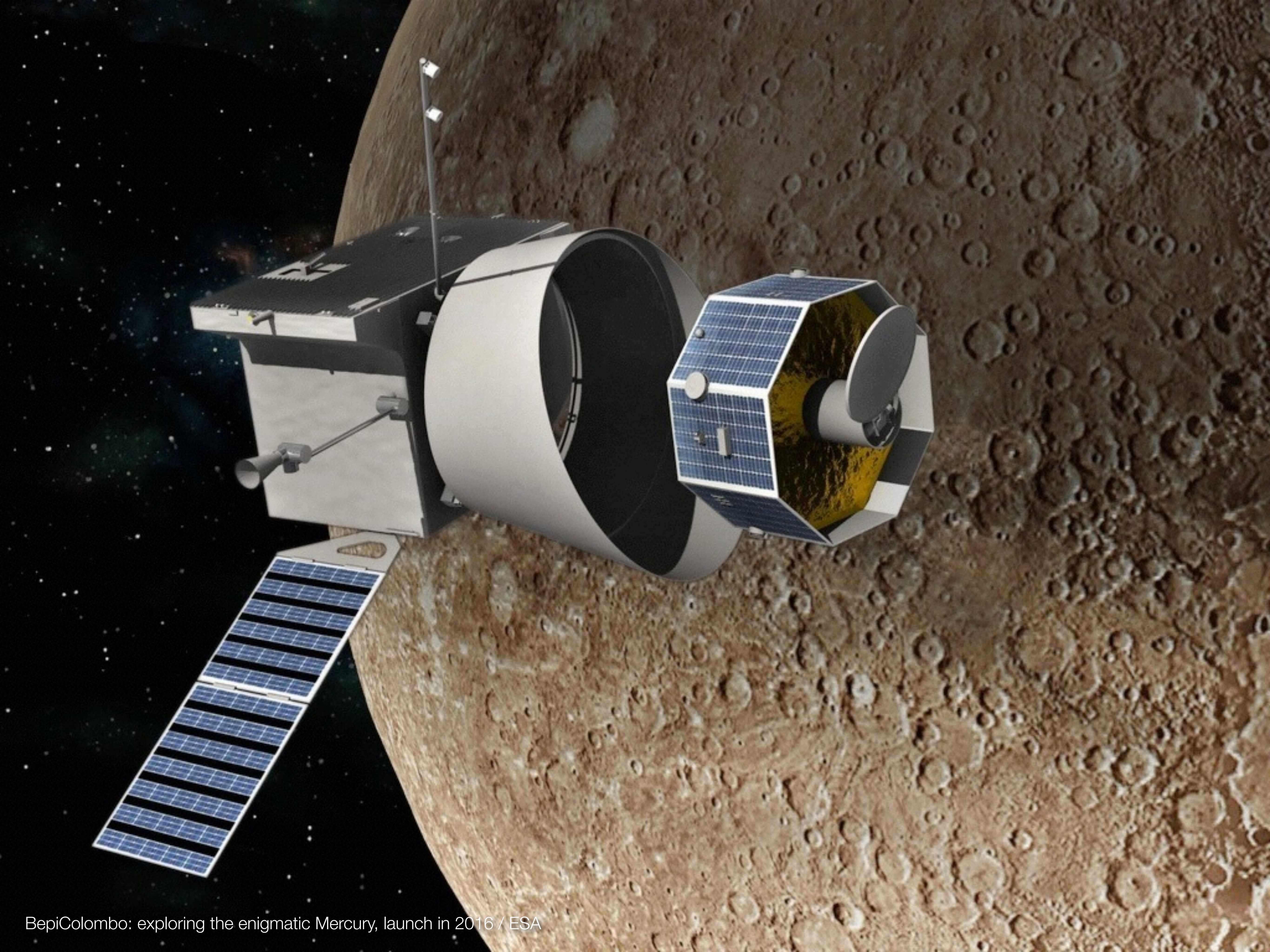


Discovery of Beagle 2 on Mars, January 2015 / Univ. Leicester, Beagle 2, NASA, JPL, Univ. Arizona

ExoMars 2016: Trace Gas Orbiter + Entry, Descent, Landing Demonstrator / ESA, Roscosmos



ExoMars 2018: surface rover / ESA, Roscosmos

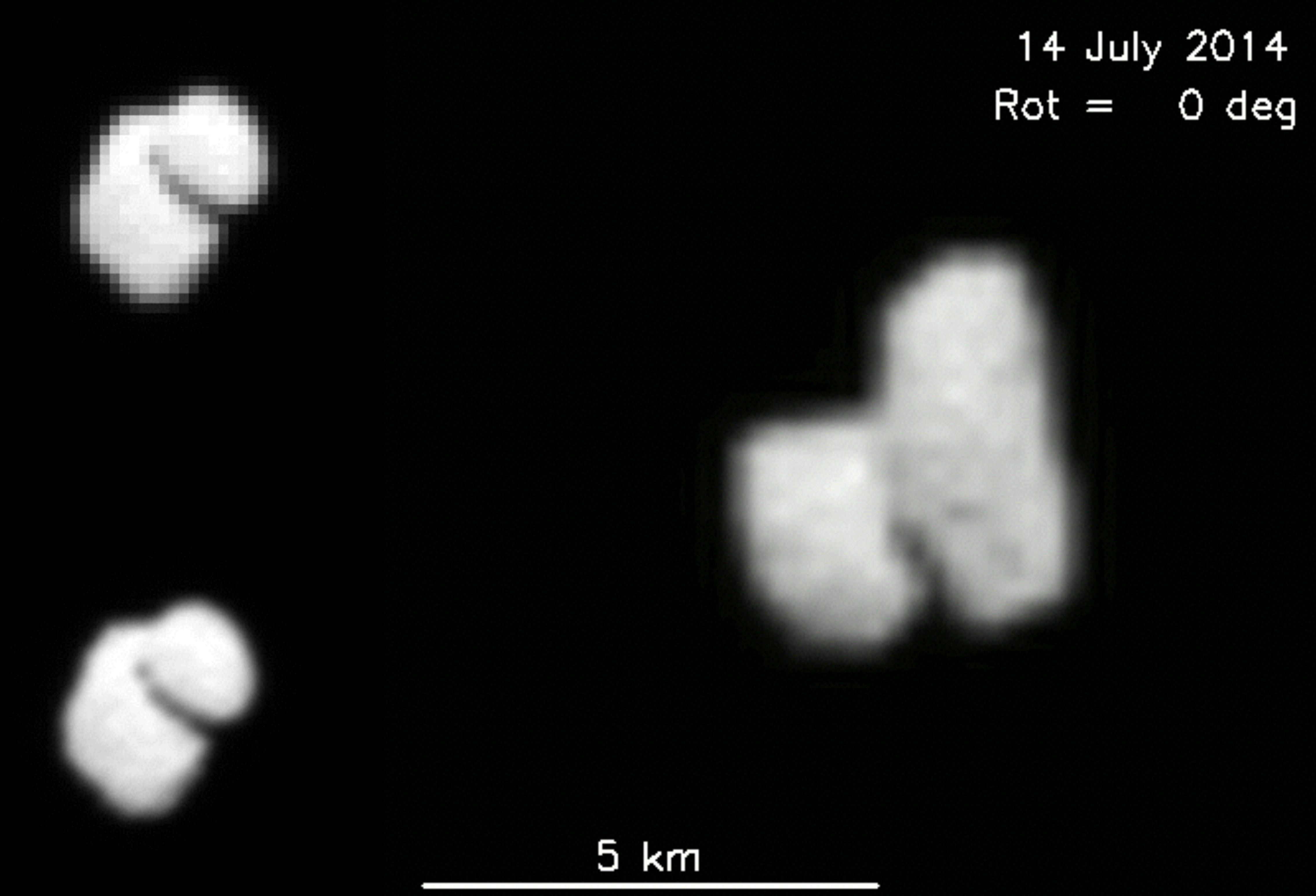


BepiColombo: exploring the enigmatic Mercury, launch in 2016 / ESA

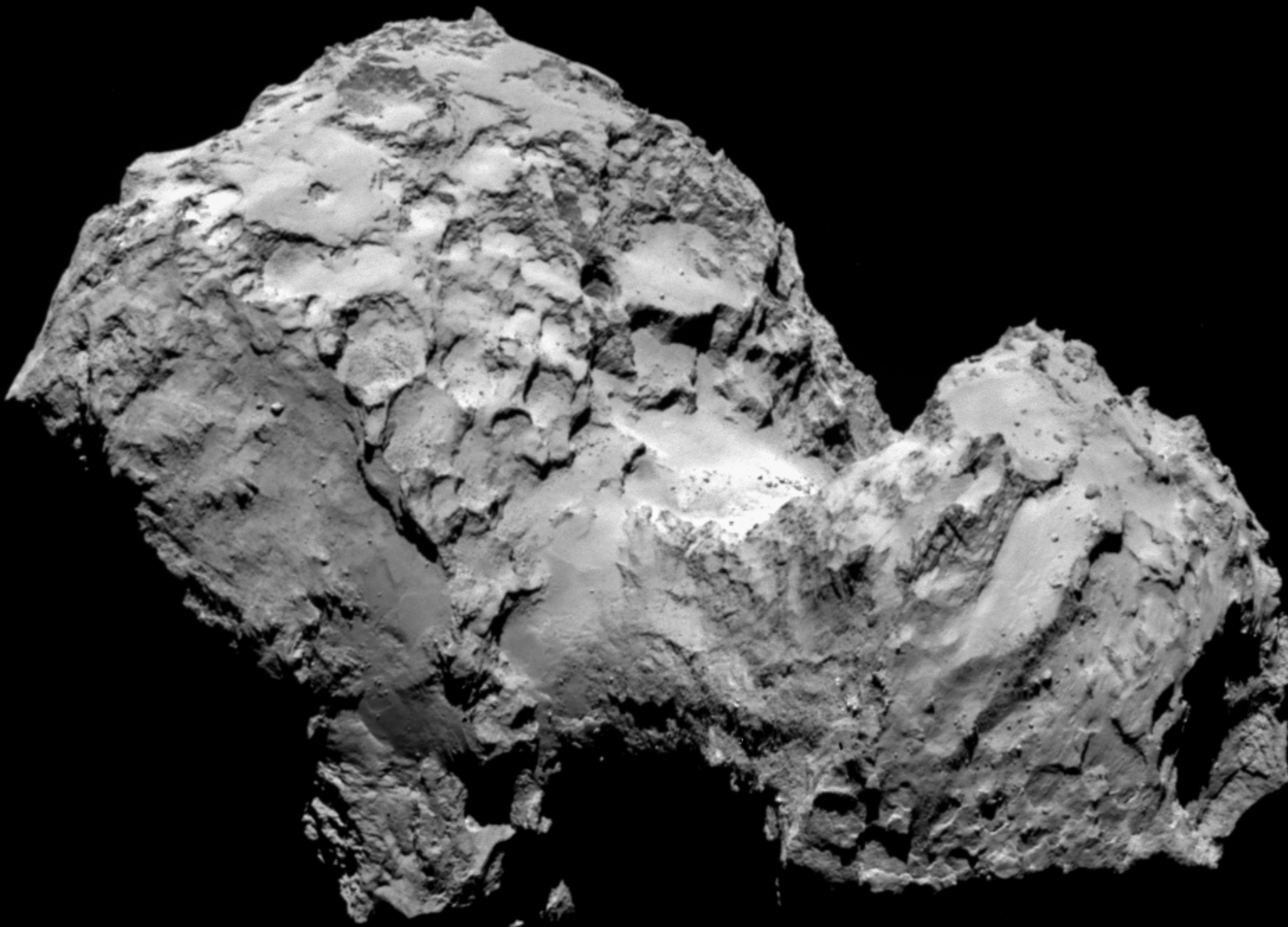
Rosetta: Comet rendezvous, escort, and landing mission, launched 2004 / ESA

67P/C-G from Rosetta 27 March to 4 May 2014 / ESA, MPS for OSIRIS team


Comet 9P/Tempel 1 seen by Deep Impact, 4 July 2005 / NASA



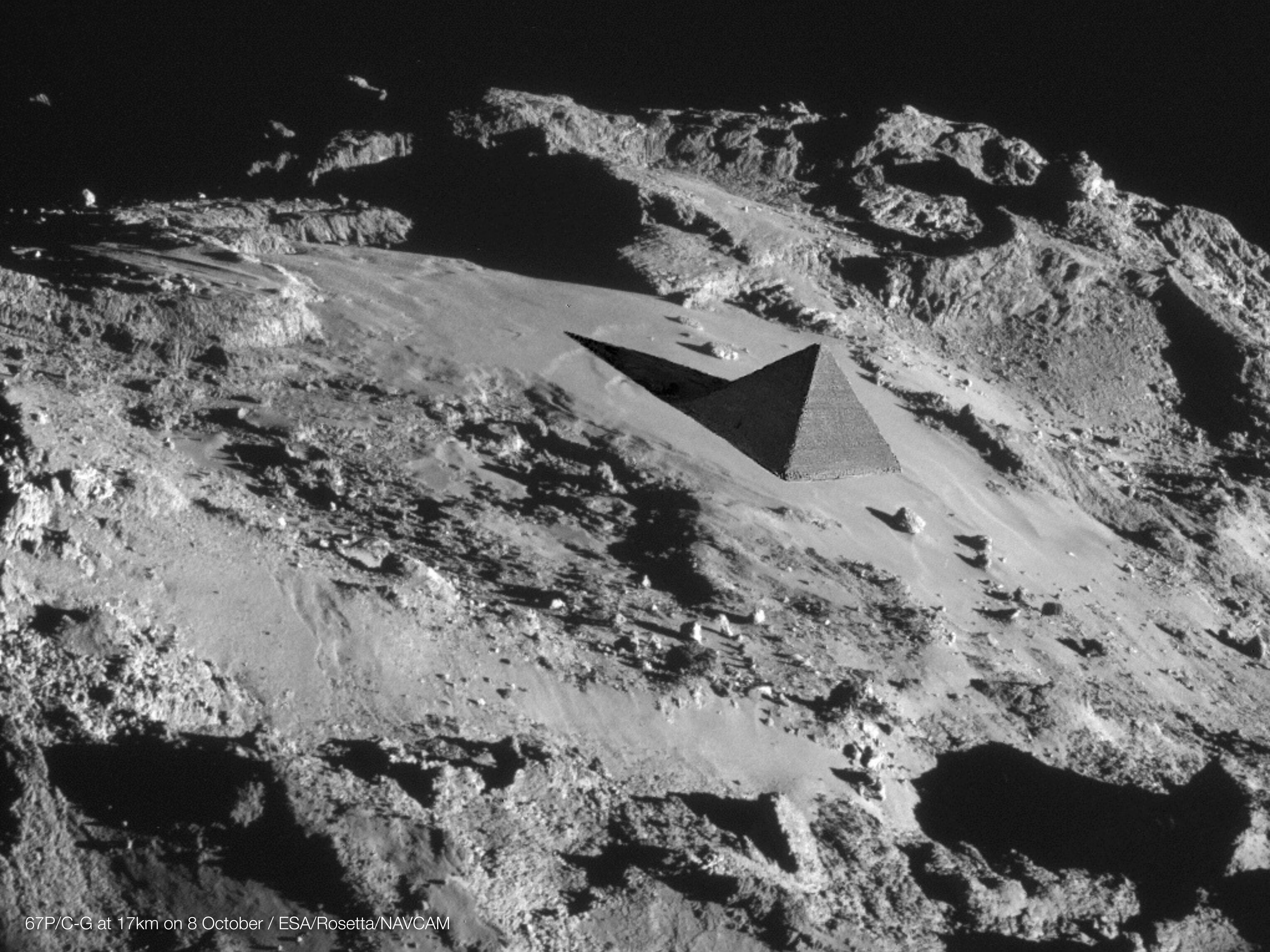
67P/C-G approach images from OSIRIS NAC / ESA/Rosetta/MPS for OSIRIS team



67P/C-G from 180km on 3 August / ESA/Rosetta/MPS for OSIRIS Team


67P/C-G from 100km on 7 August / ESA/Rosetta/MPS for OSIRIS Team

67P/C-G from 62km on 5 September / ESA/Rosetta/MPS for OSIRIS Team

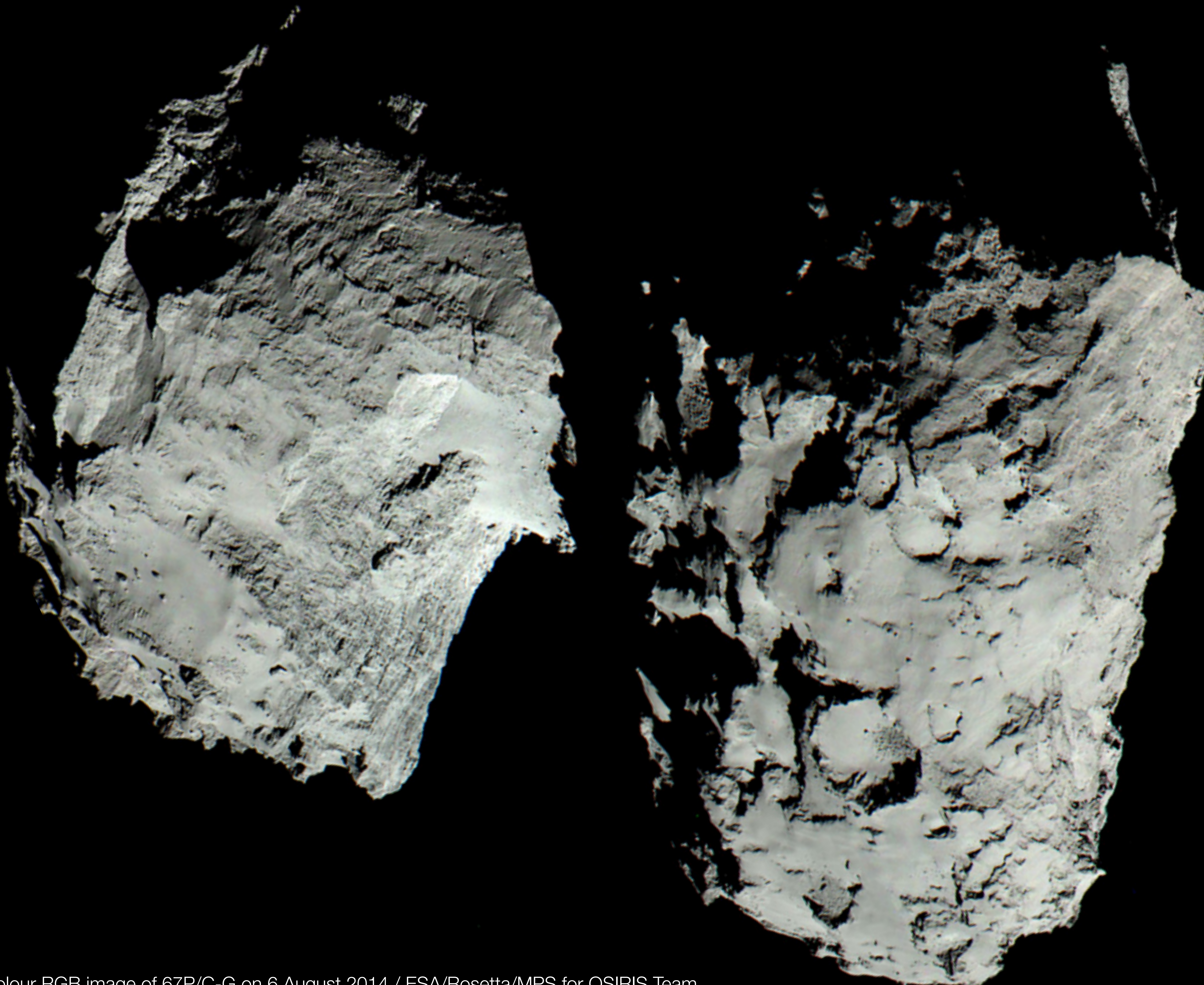


67P/C-G at 17km on 8 October / ESA/Rosetta/NAVCAM

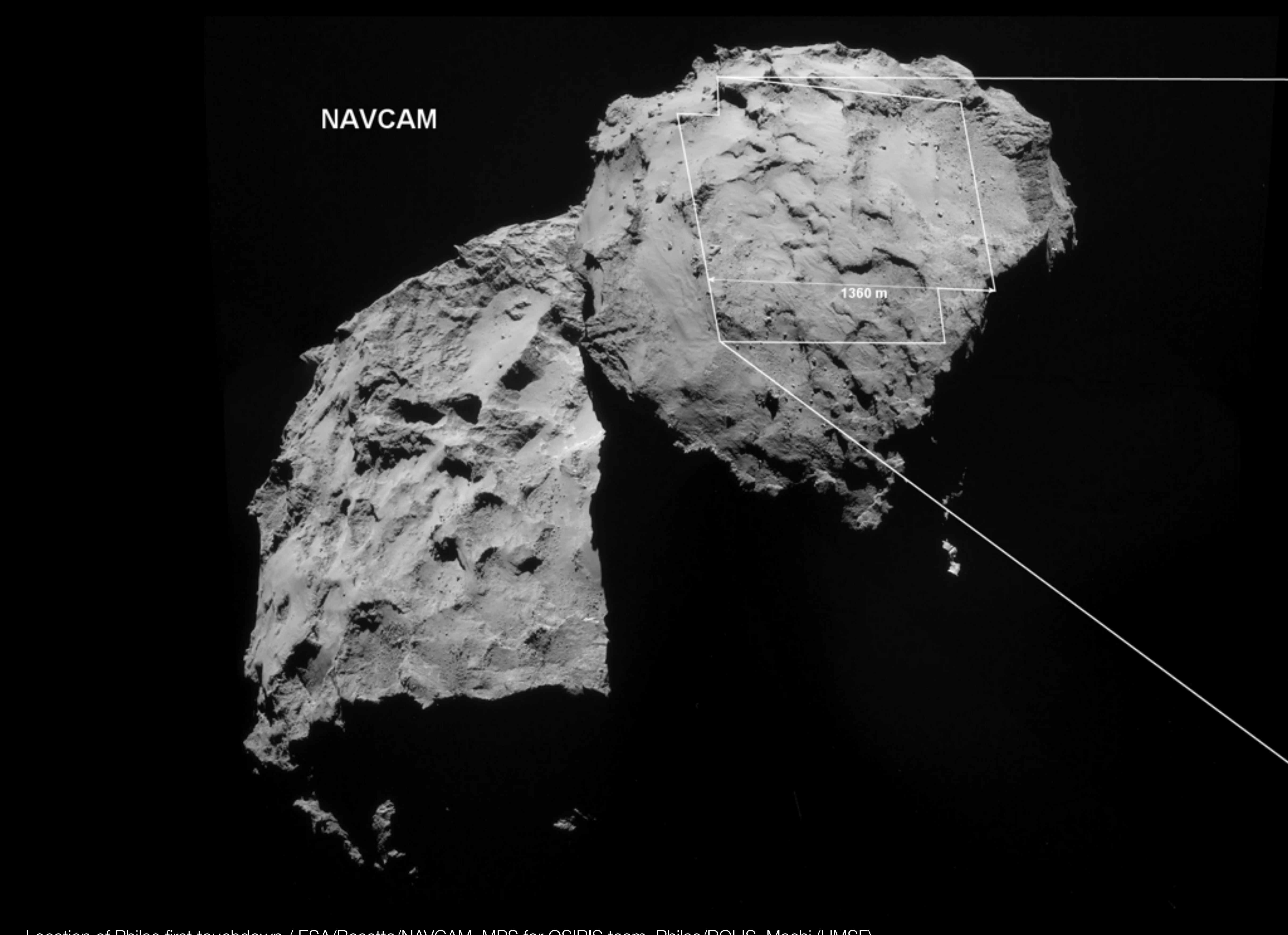
67P/C-G 3D shape model and surface model based on Rosetta images / Mattias Malmer, ESA/Rosetta/NAVCAM, ESA/Rosetta/MPS for OSIRIS team

Enceldaus albedo ~ 1.0
Cassini/NASA/JPL/SSI

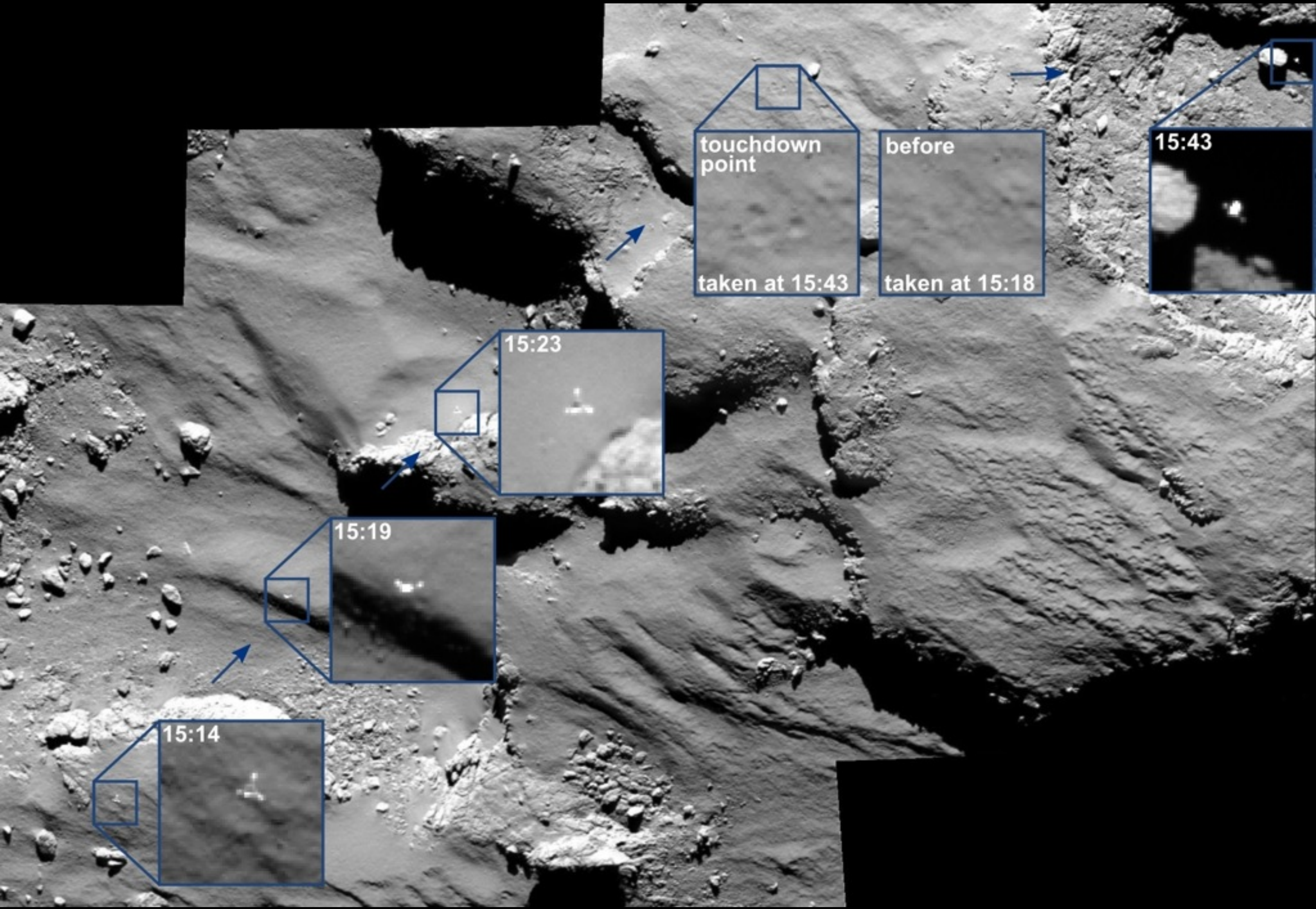
Intensity scaled according to albedo



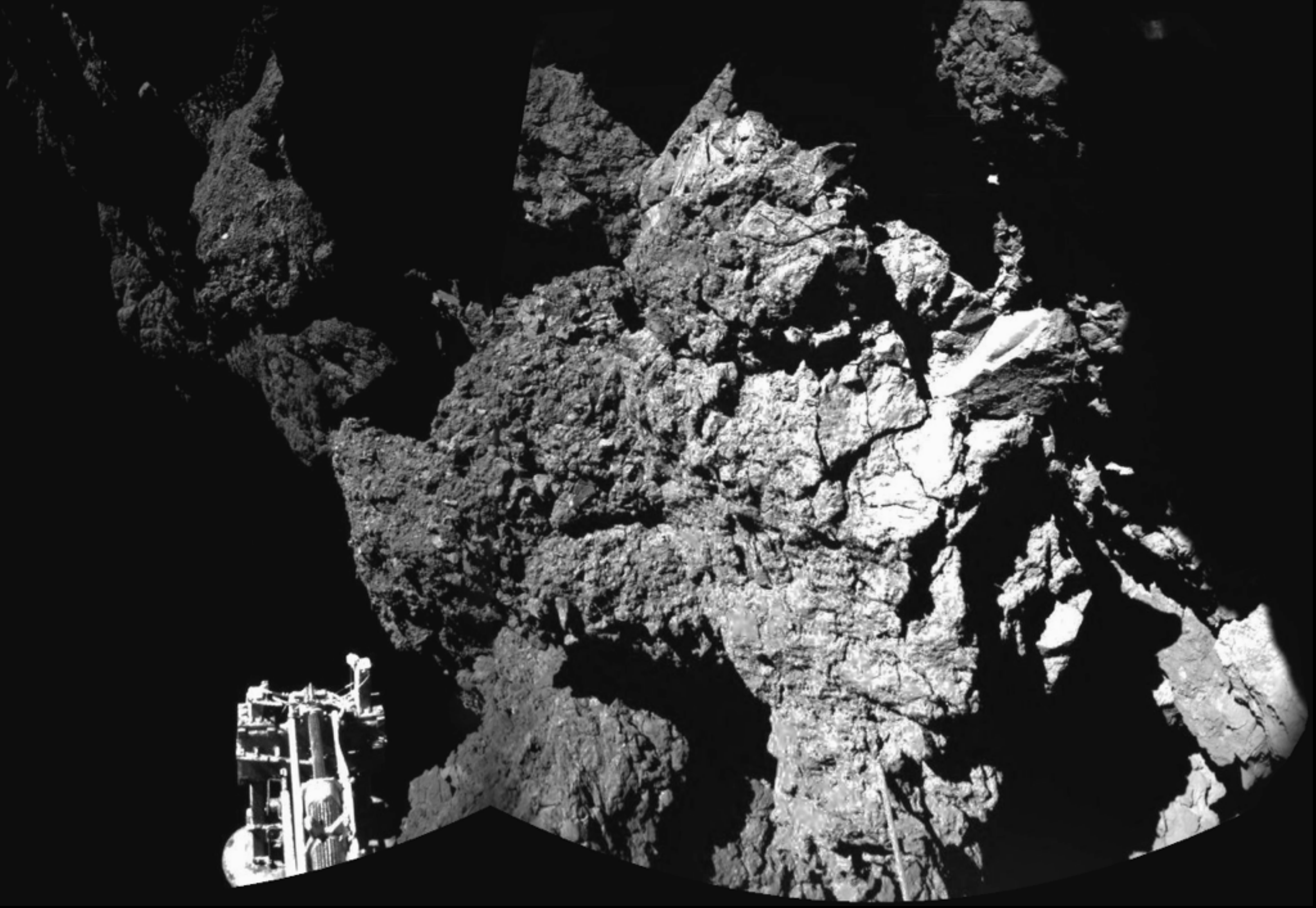
True-colour RGB image of 67P/C-G on 6 August 2014 / ESA/Rosetta/MPS for OSIRIS Team



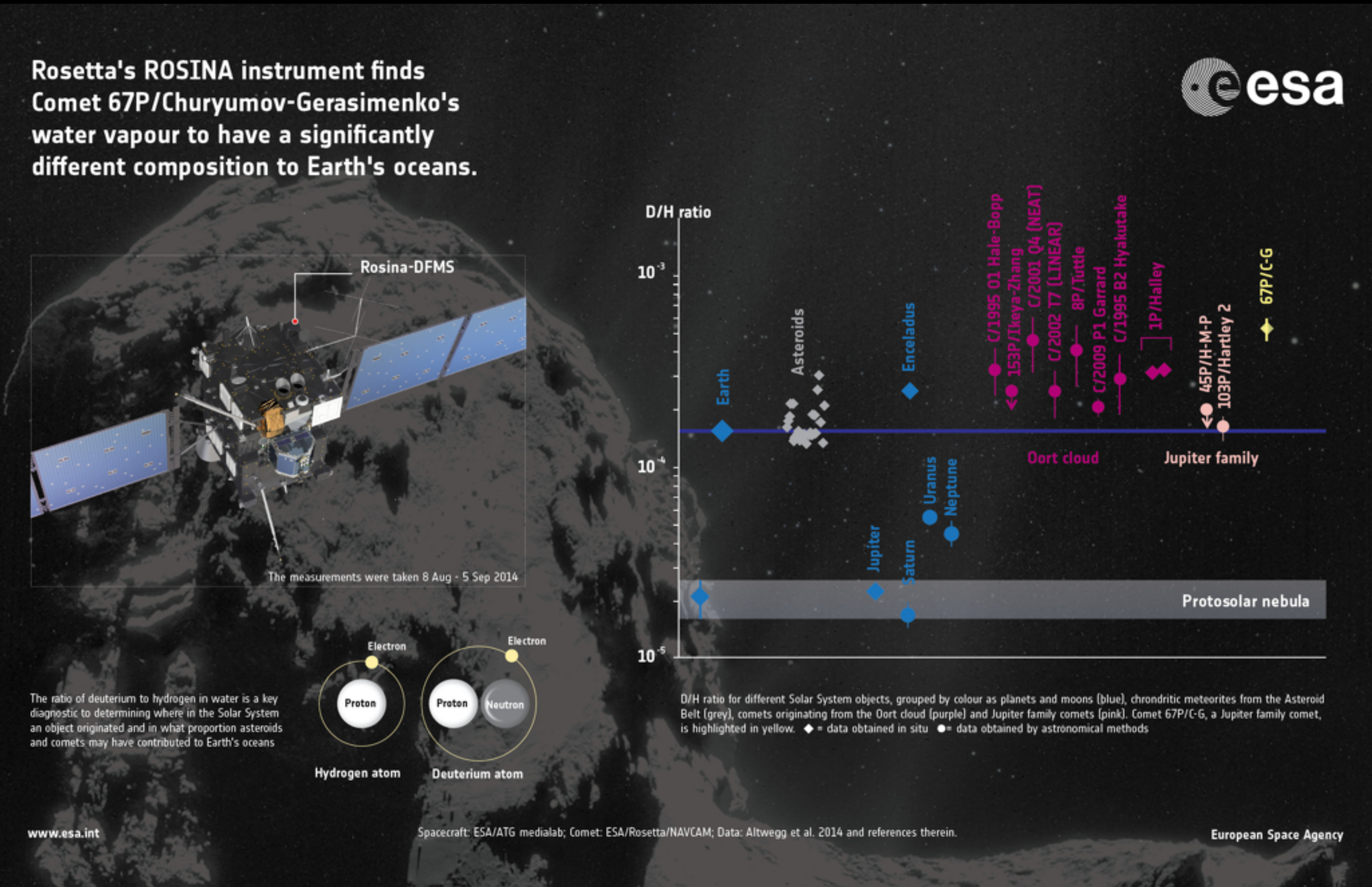
Location of Philae first touchdown / ESA/Rosetta/NAVCAM, MPS for OSIRIS team, Philae/ROLIS, Machi (UMSF)



Philae's descent to the surface of Comet 67P/C-G and first bounce, 12 November 2014 / ESA/Rosetta/MPS for OSIRIS team



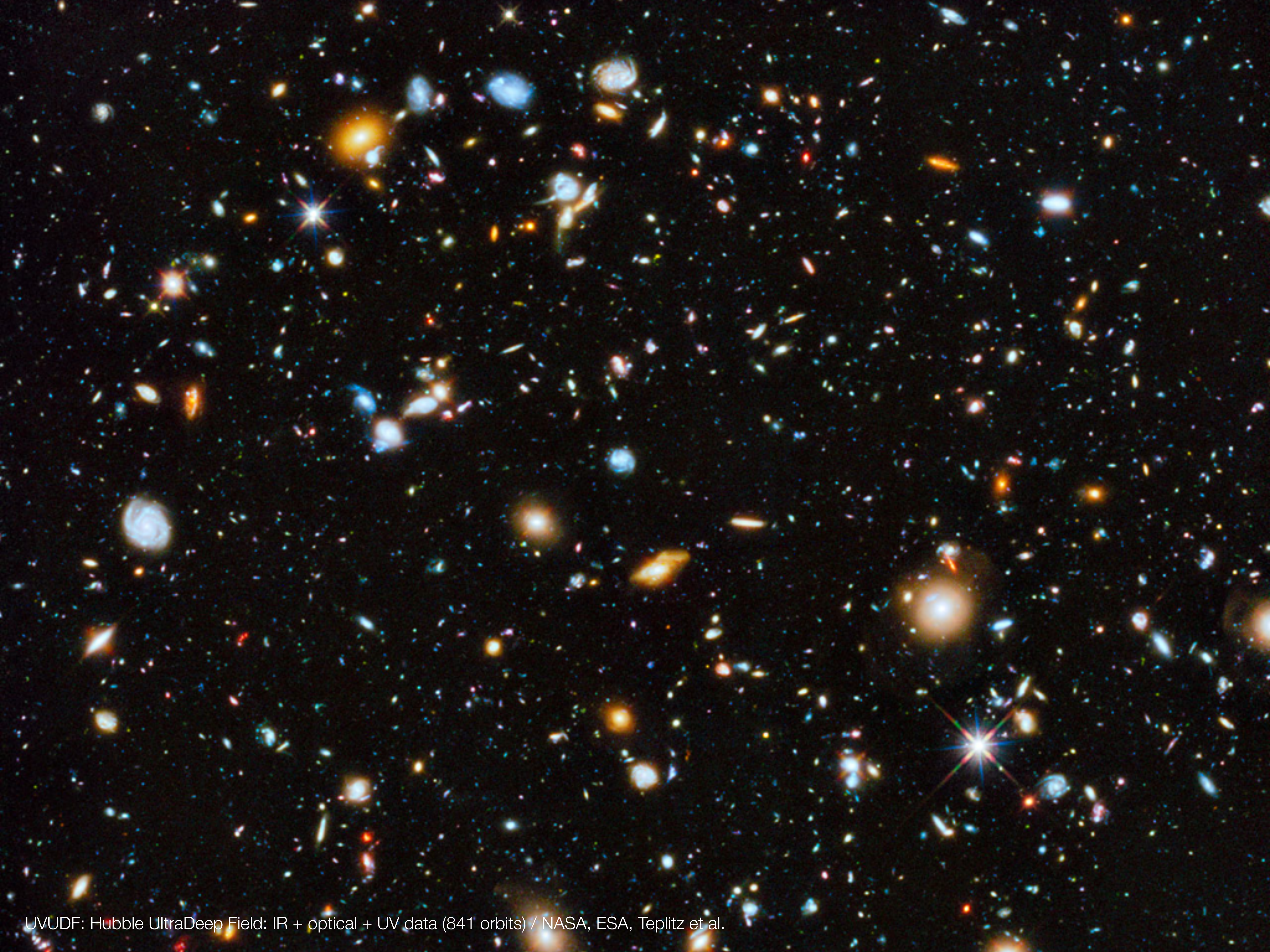
Philae’s location on Comet 67P/C-G, 13 November 2014 / ESA/Rosetta/Philae/CIVA



Altwegg et al. 2014, Science

Activity on 67P/C-G on 22 November 2014 / ESA/Rosetta/MPS for OSIRIS Team

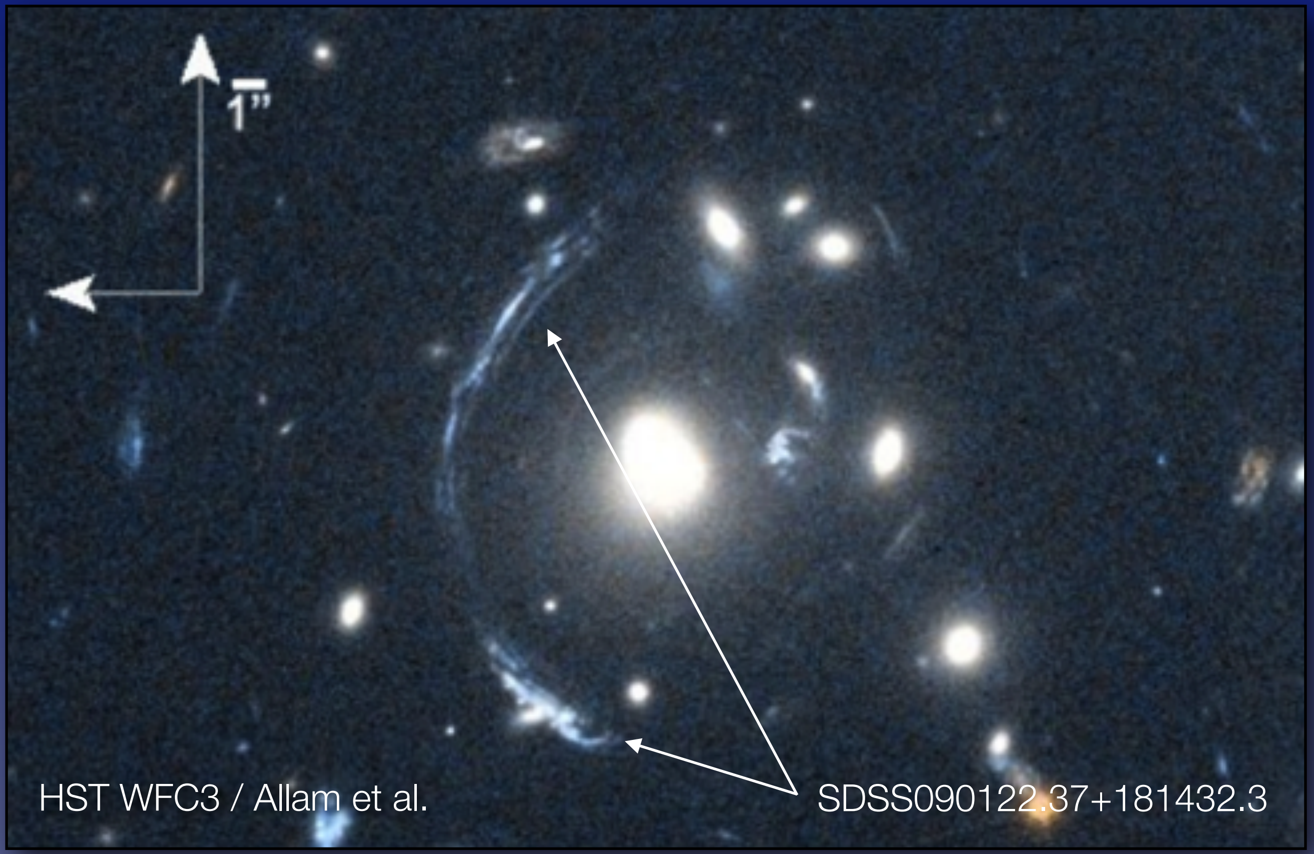
Hubble Space Telescope: UV-optical-IR astrophysical observatory, launched 1990 / NASA, ESA

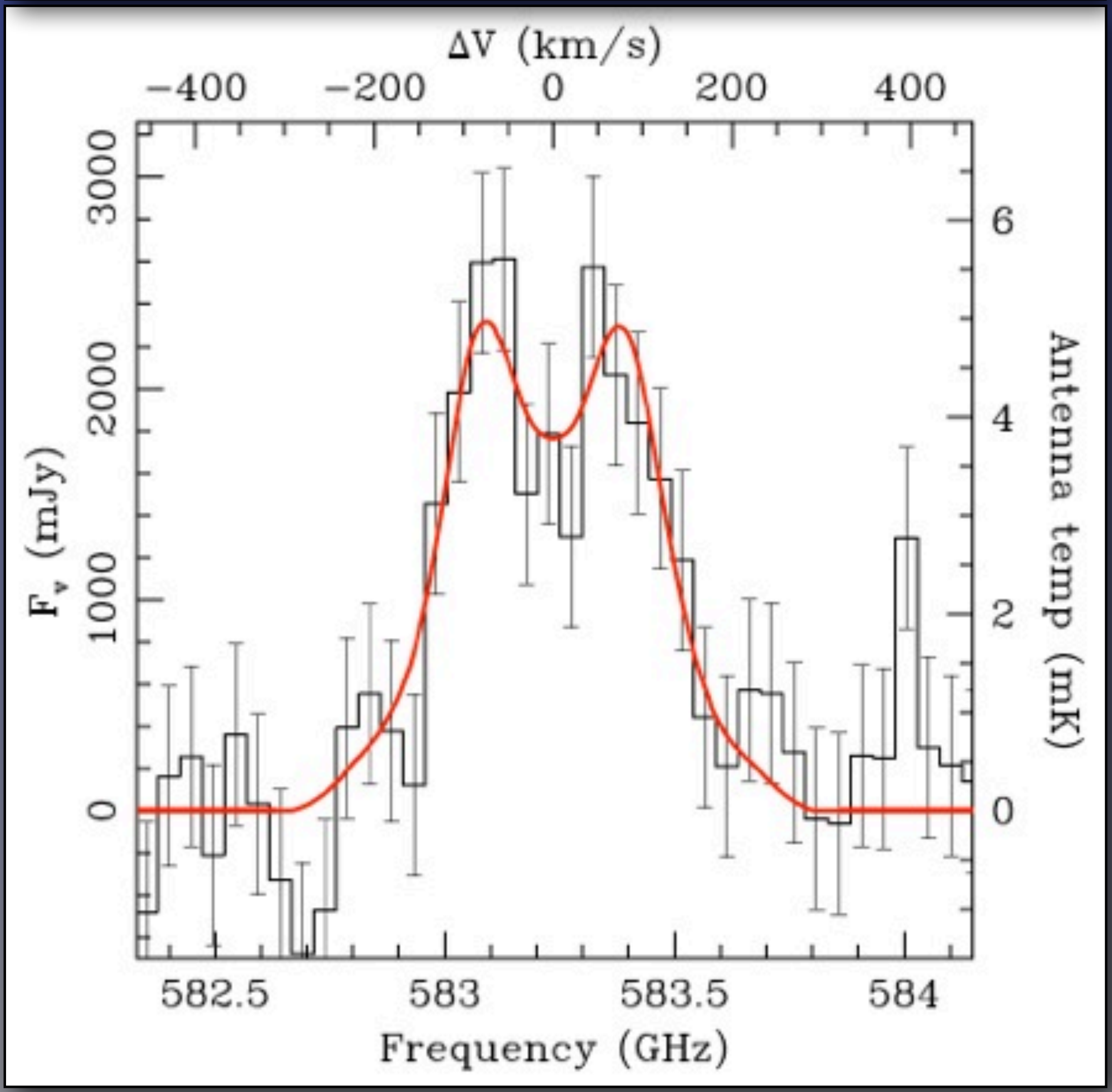


UVUDF: Hubble UltraDeep Field: IR + optical + UV data (841 orbits) / NASA, ESA, Teplitz et al.

Herschel: Far-infrared astrophysics observatory, launched 2009 / ESA

A kinematically-mature galaxy at z~2

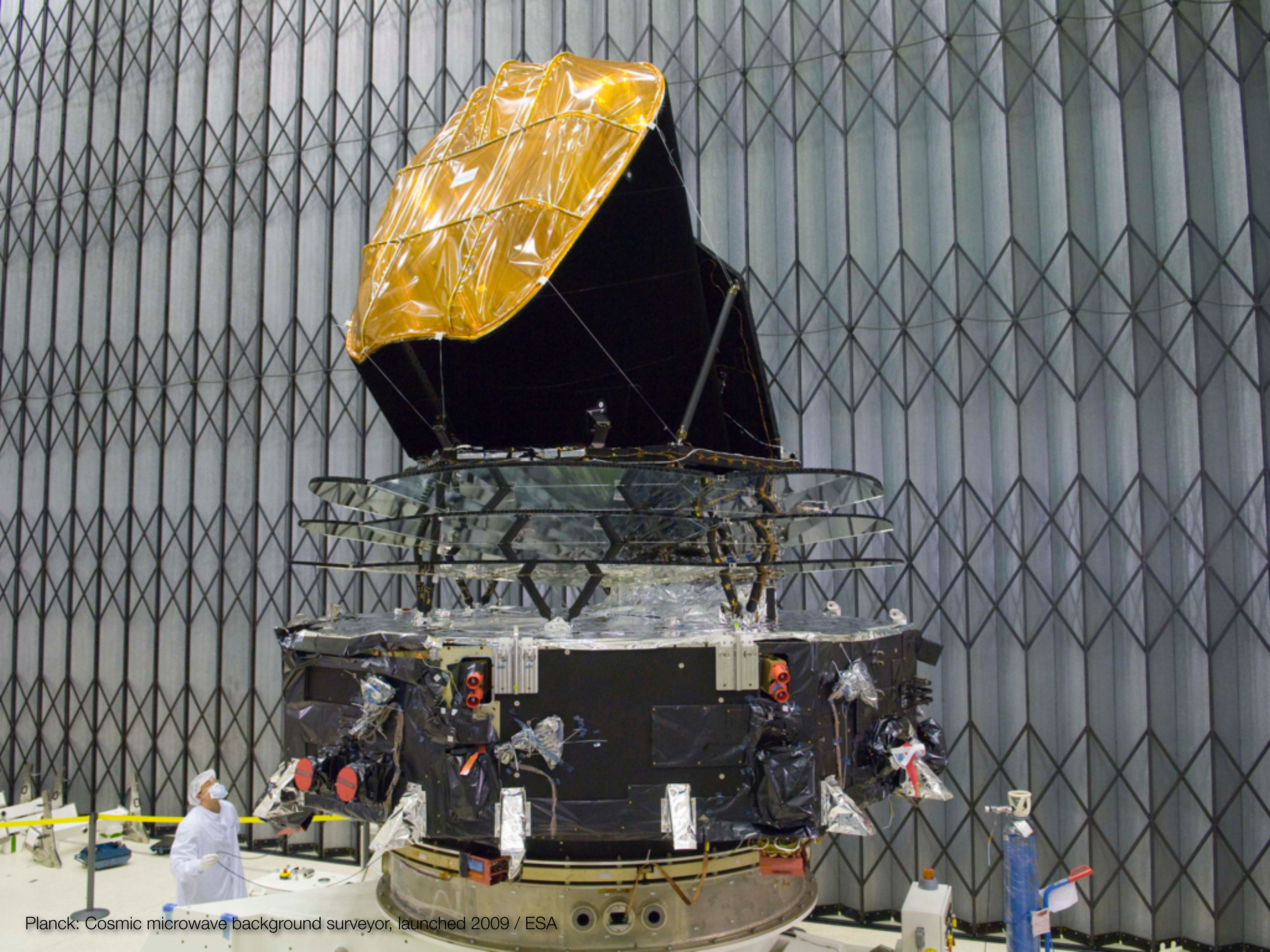




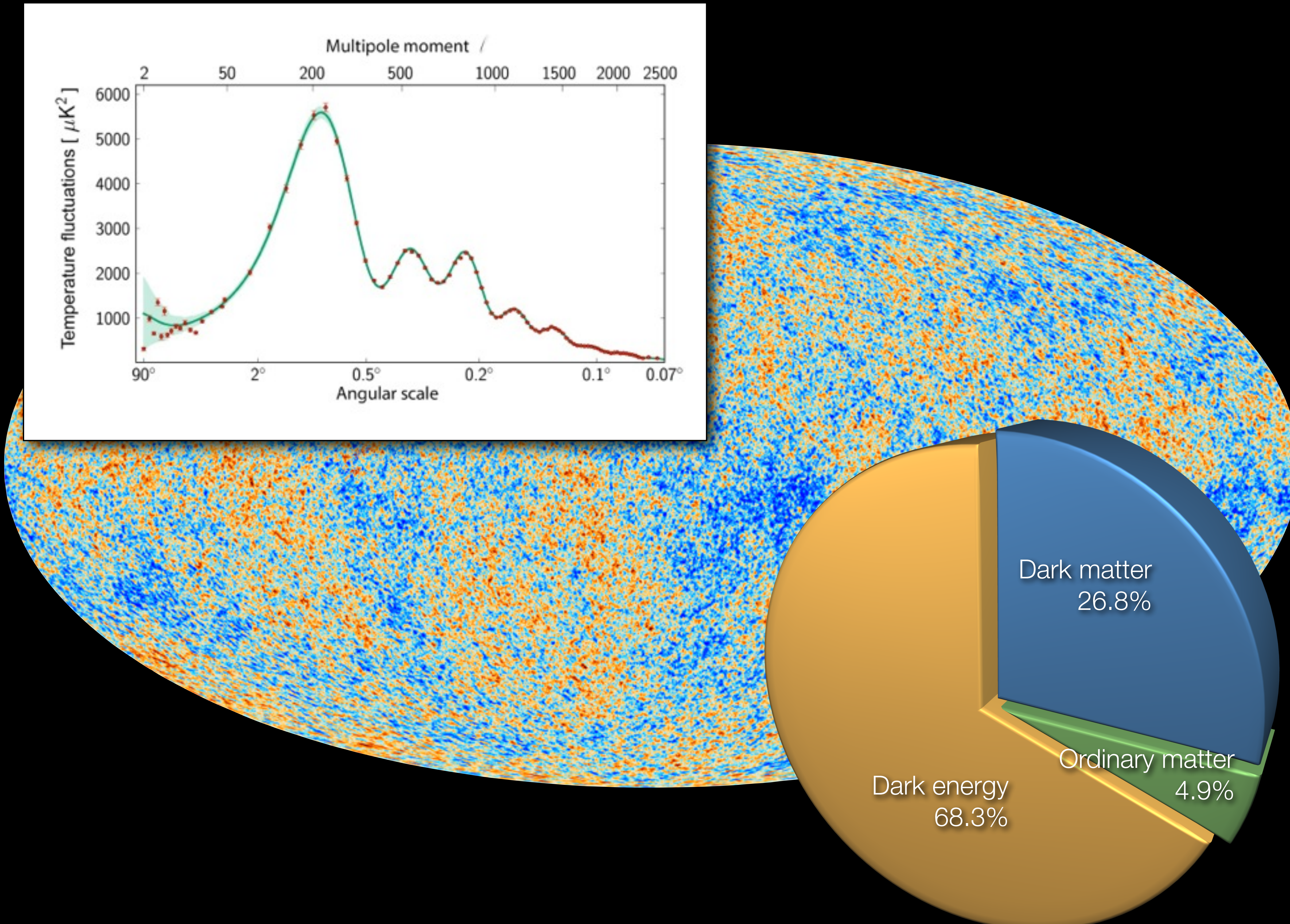
- Strongly-lensed z~2 galaxy
  - HIFI observations of [C II] 158μm line
- Shows well-established rotation
  - Twin-horned line profile typical of mature galaxy with rotating gas disk, limited contribution from accretion
  - Not expected for young galaxies, still heavily accreting gas from surroundings

Rhoads et al. 2014, ApJ

583GHz = 515μm = 158μm line at z=2.256

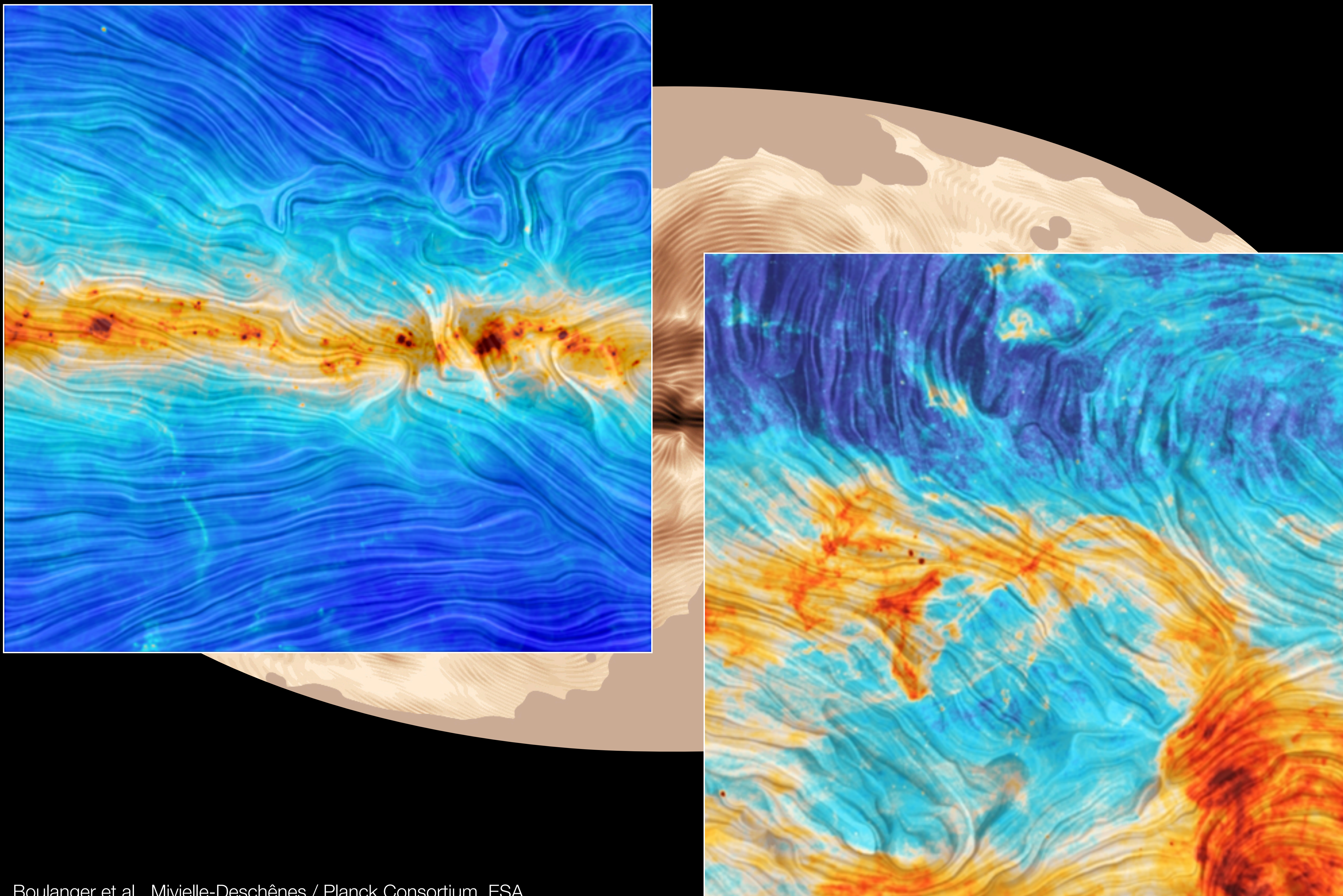


Planck: Cosmic microwave background surveyor, launched 2009 / ESA



Cosmic microwave background: the echo of the Big Bang / Planck, HFI, LFI, ESA

Galactic foreground polarisation



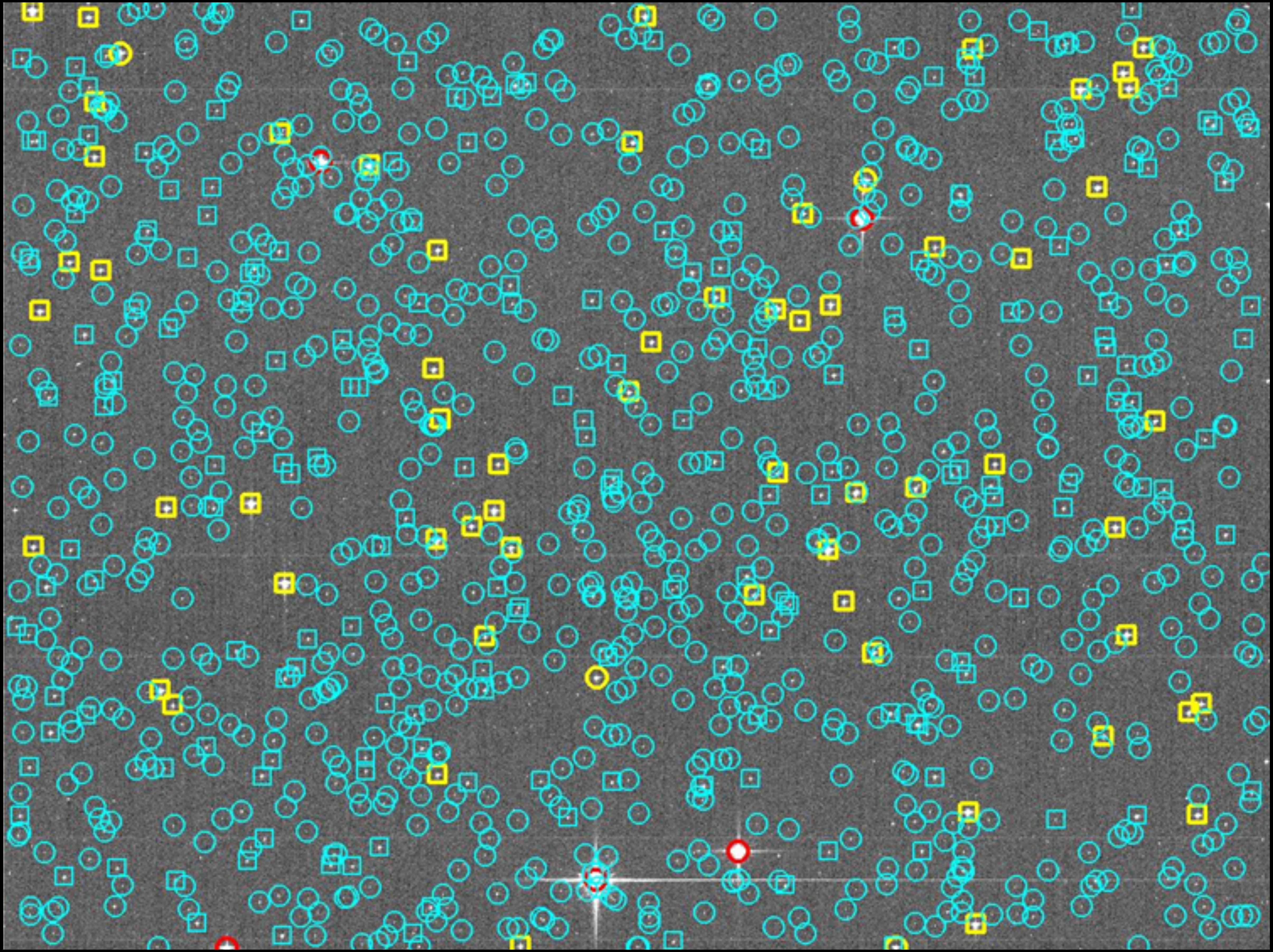
Boulanger et al., Mivielle-Deschênes / Planck Consortium, ESA

Gaia: Milky Way Surveyor, launched 2013 / ESA

Gaia "first image"

ESA, DPAC, Airbus DS

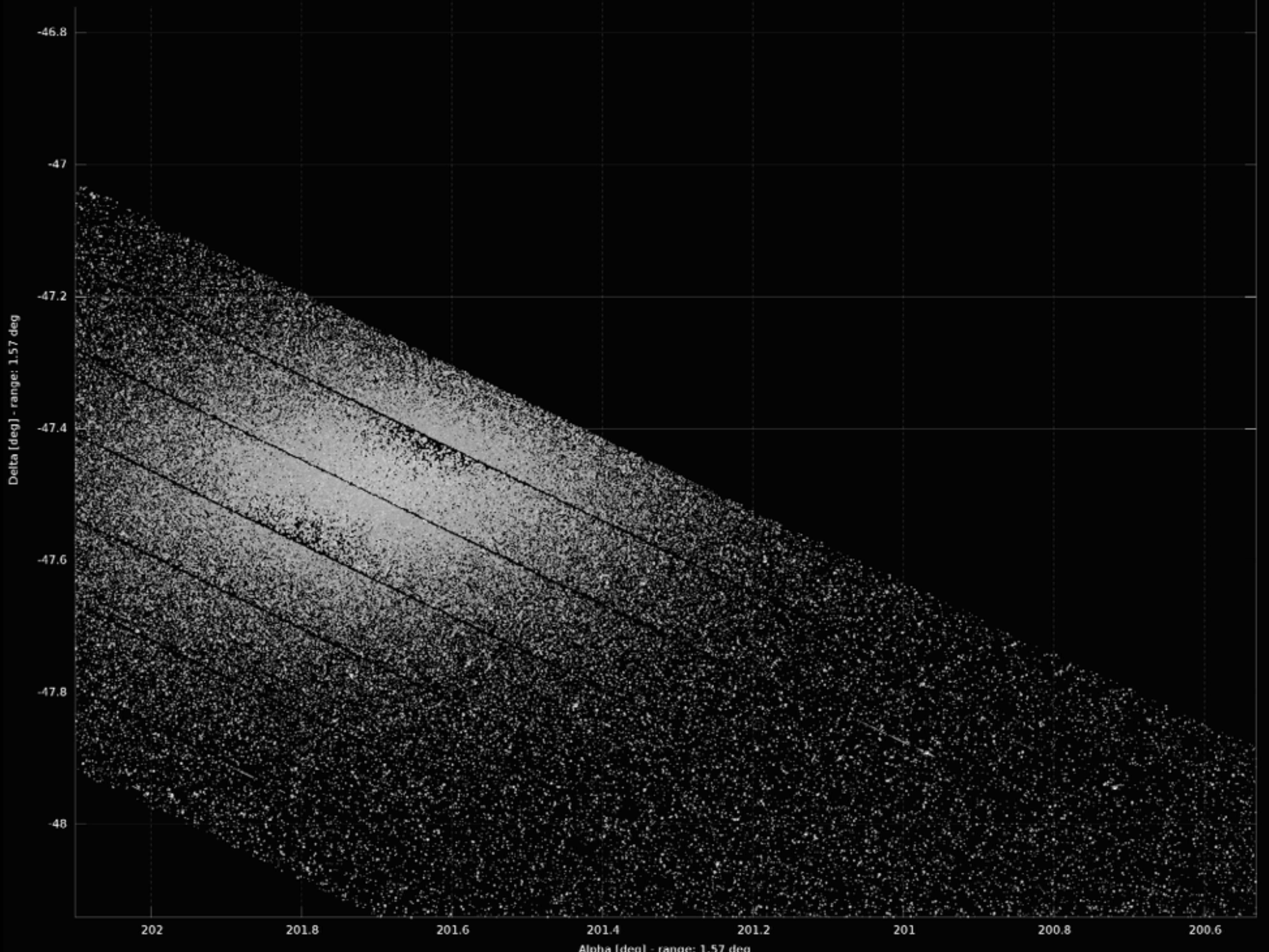
NGC1818 in LMC / 212 x 212 arcsec / 2.85 s int. time / white light SM data



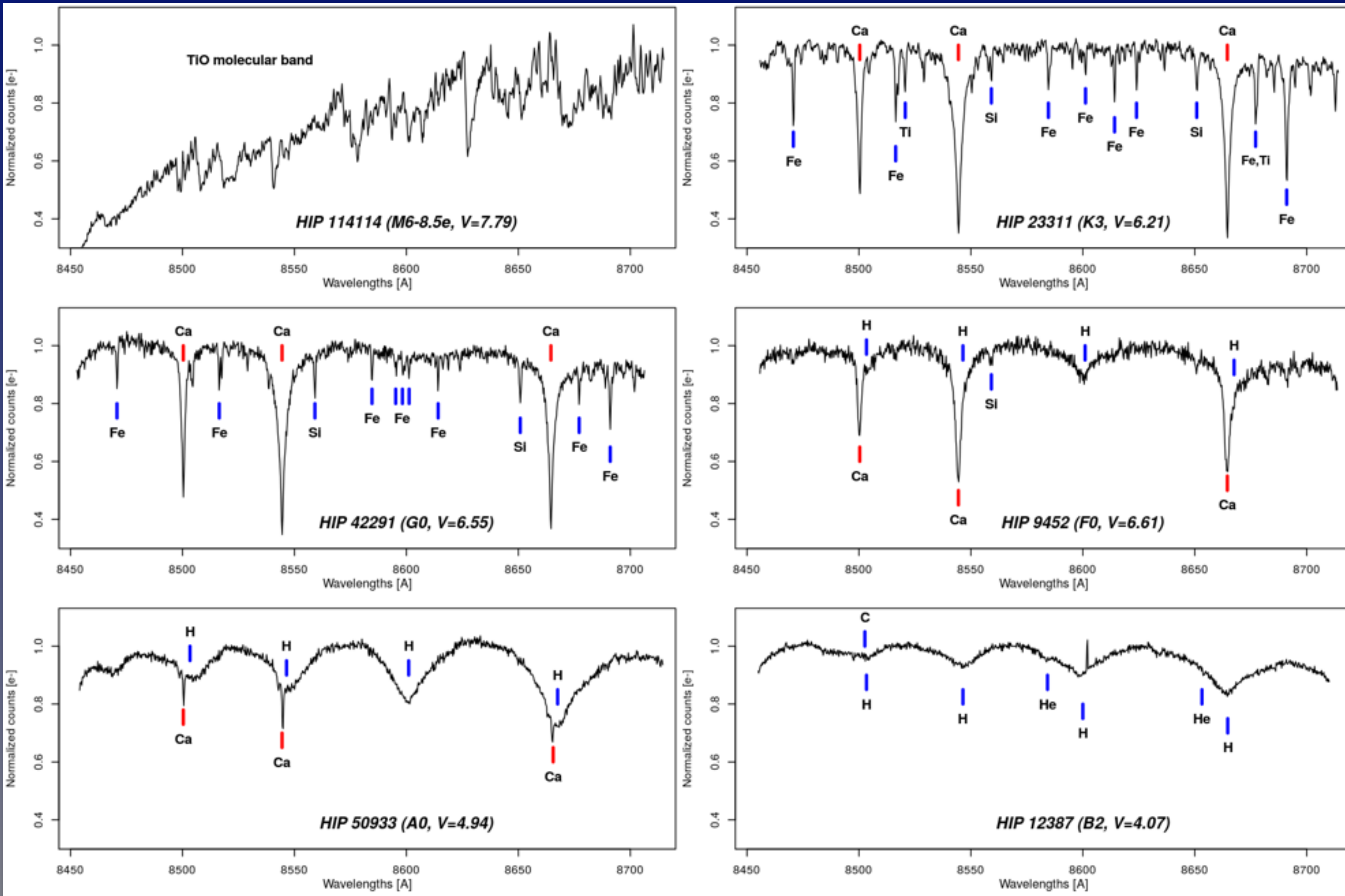
ESA, DPAC, Airbus DS

Identification of sources passing through Sky Mapper arrays

Omega Cen as seen by Gaia / ESA, DPAC, UB, IEEC

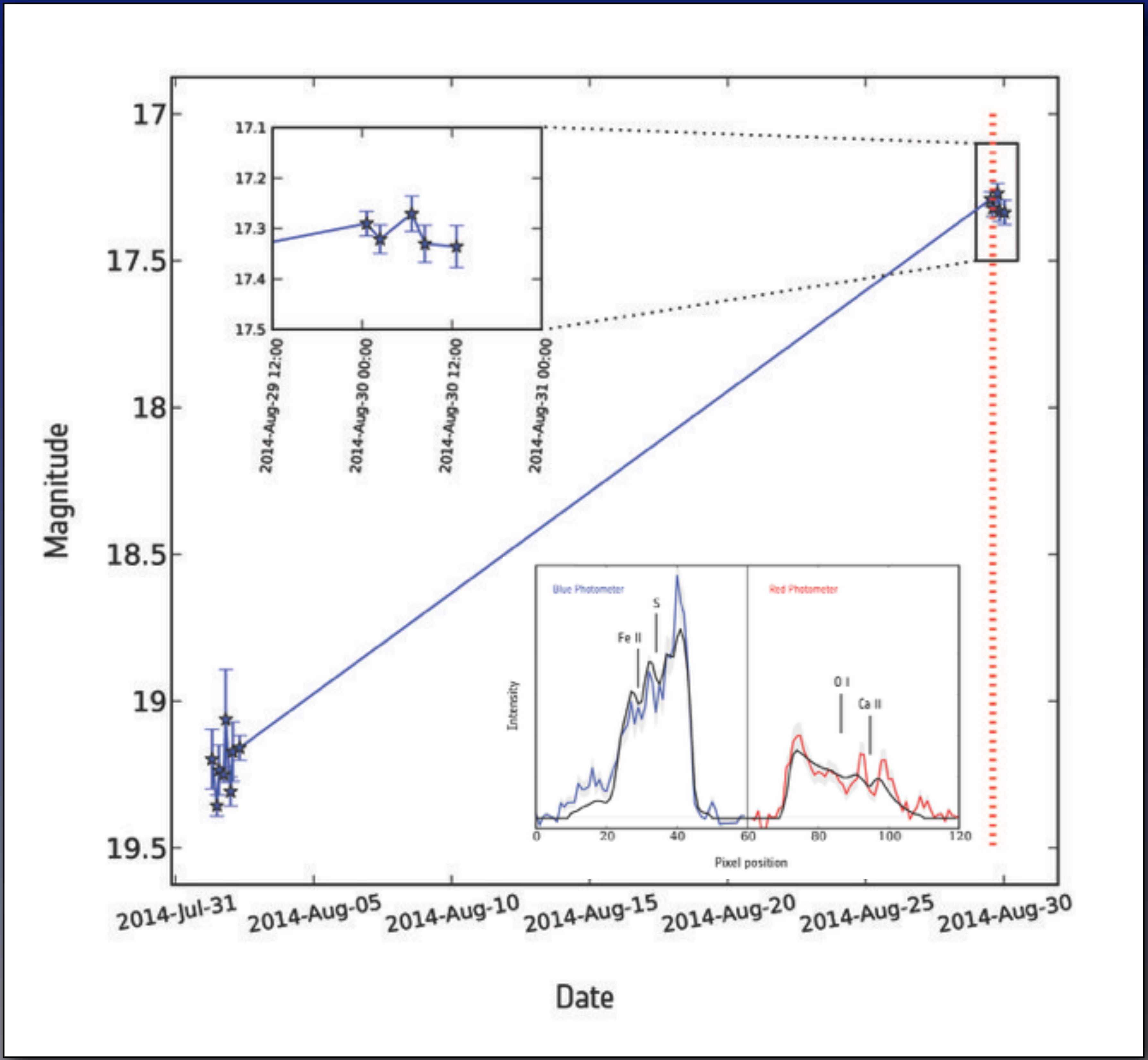


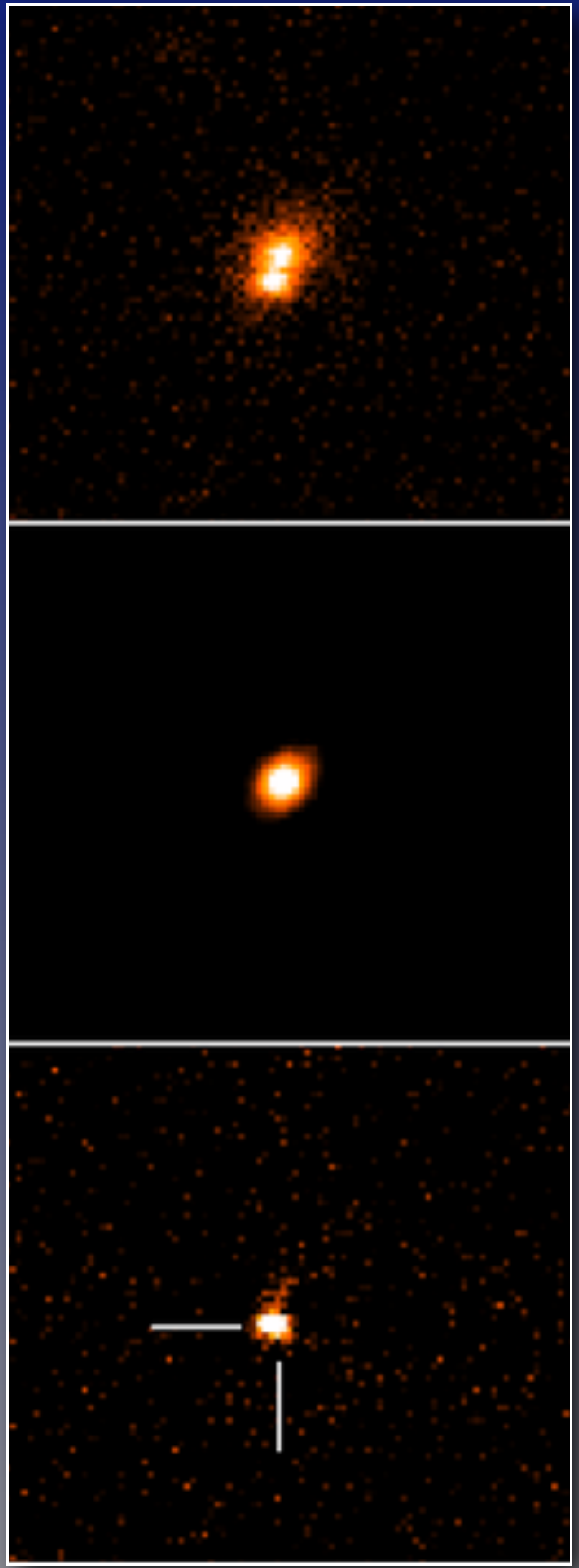
Omega Cen as seen by Gaia / ESA, DPAC, UB, IEEC



Gaia RVS spectroscopy / ESA, DPAC, O. Marchal, D. Katz

Gaia's first supernova: Gaia14aaa

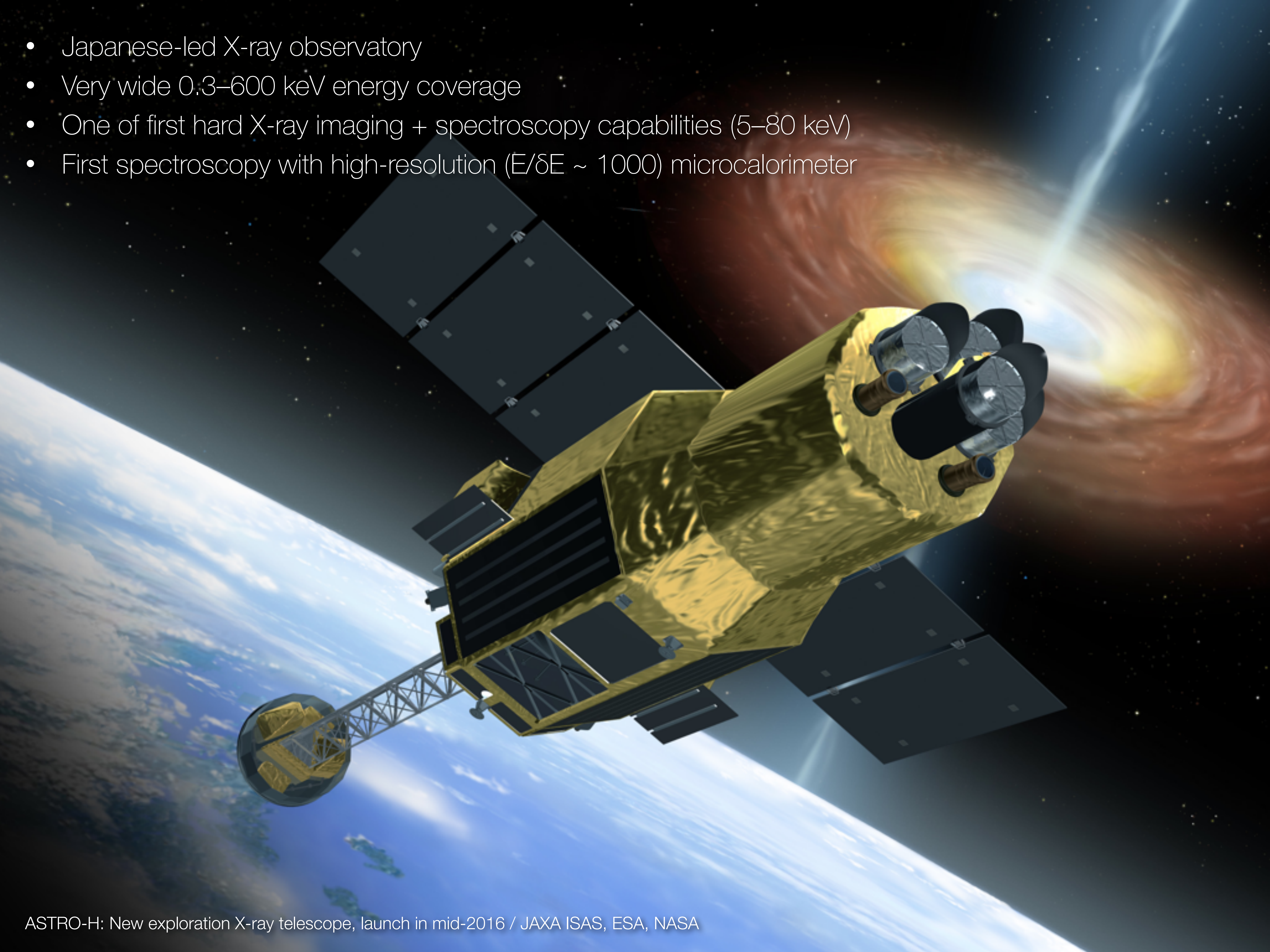




ESA, Gaia, DPAC / Kostrzewa-Rutkowska et al., Blagorodnova et al., Fraser et al.

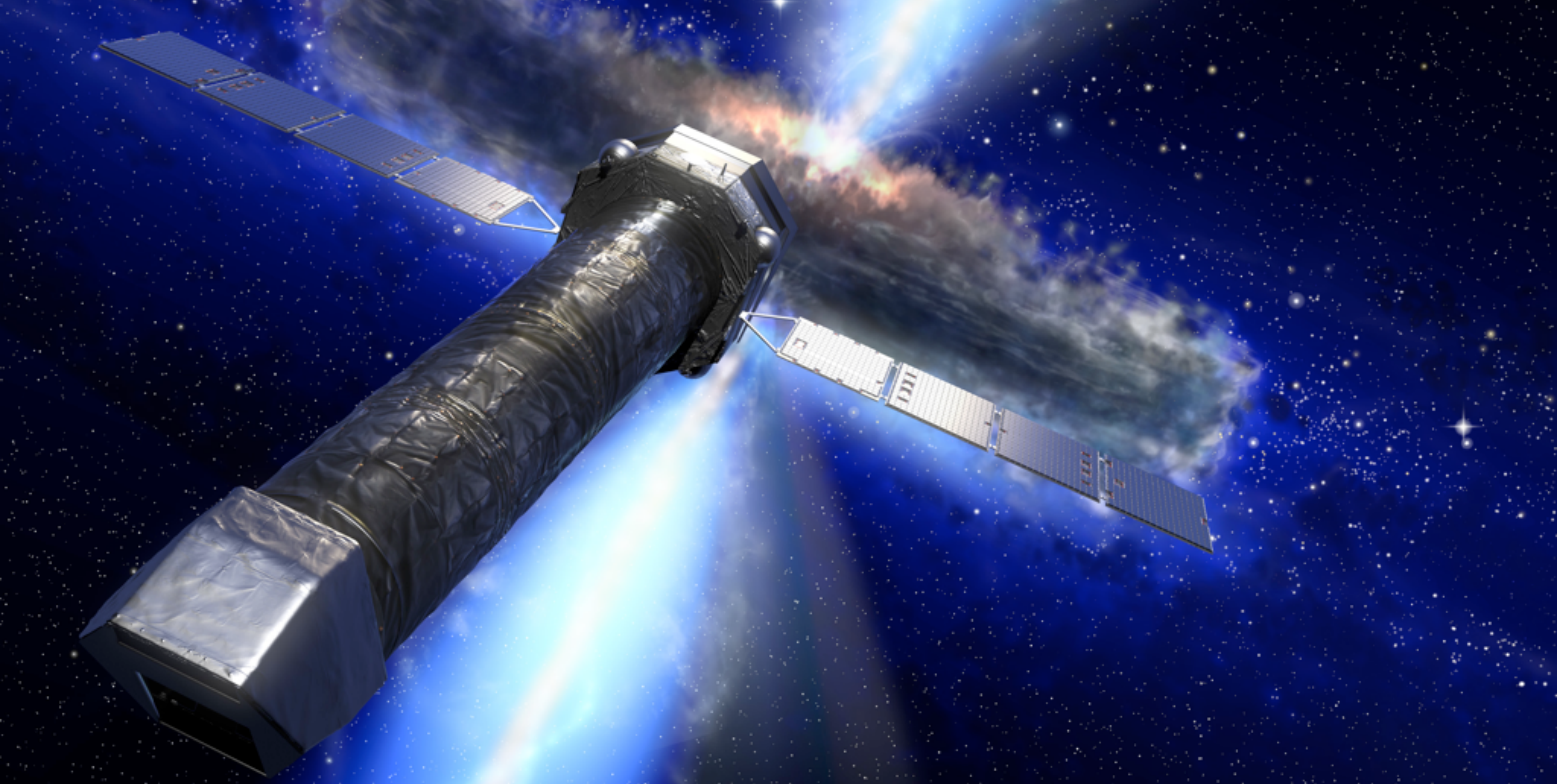
XMM-Newton: X-ray astrophysics observatory, launched 1999 / ESA

- Japanese-led X-ray observatory
- Very wide 0.3–600 keV energy coverage
- One of first hard X-ray imaging + spectroscopy capabilities (5–80 keV)
- First spectroscopy with high-resolution ($E/\delta E \sim 1000$) microcalorimeter

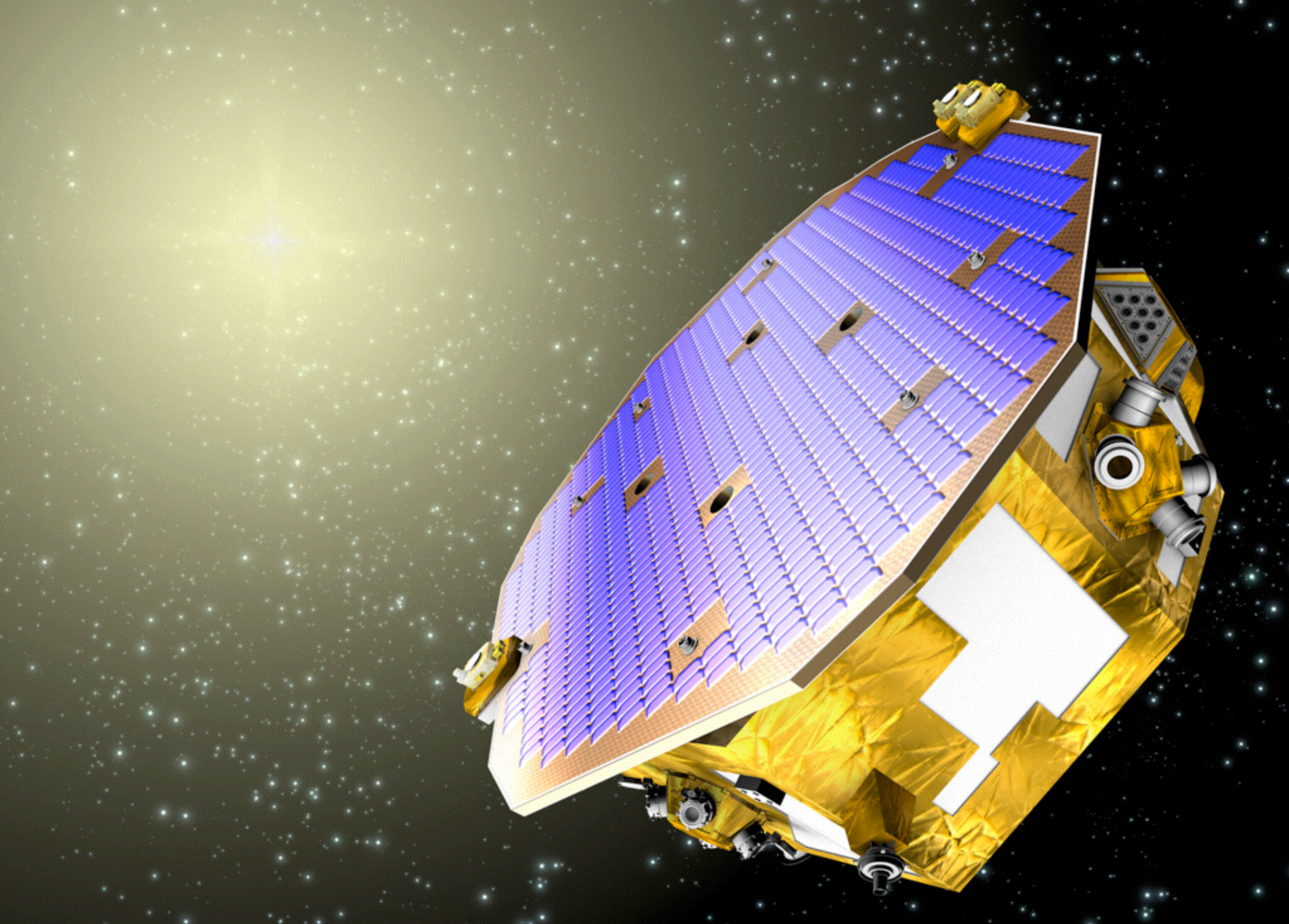


ASTRO-H: New exploration X-ray telescope, launch in mid-2016 / JAXA ISAS, ESA, NASA

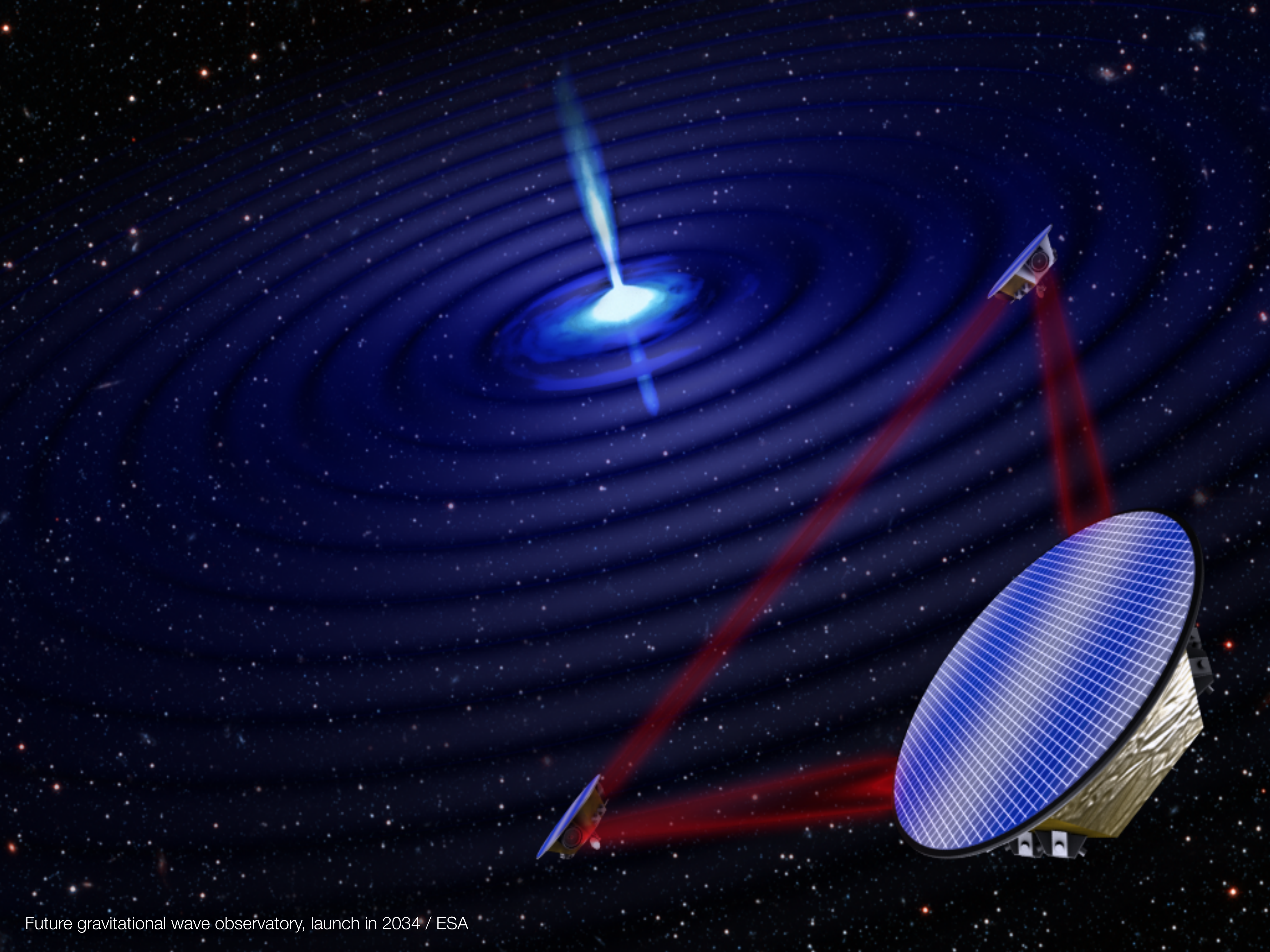
- Next-generation large X-ray observatory
- Evolution of hot baryons in Universe, formation and evolution of black holes, hot & energetic Universe
- 12m focal length, 2m2 collecting area, 3 arcsec resolution, ToO's within 1 hr
- Cryogenic IFU spectrometer E/δE ~ 3000, 4 arcmin diameter
- Wide-field imager E/δE ~ 10–50, 35 x 35 arcmin, <50μs timing
- Substantial follow-up: IR, ALMA for obscured objects, transients to and from SKA/LSST, GRB redshifts



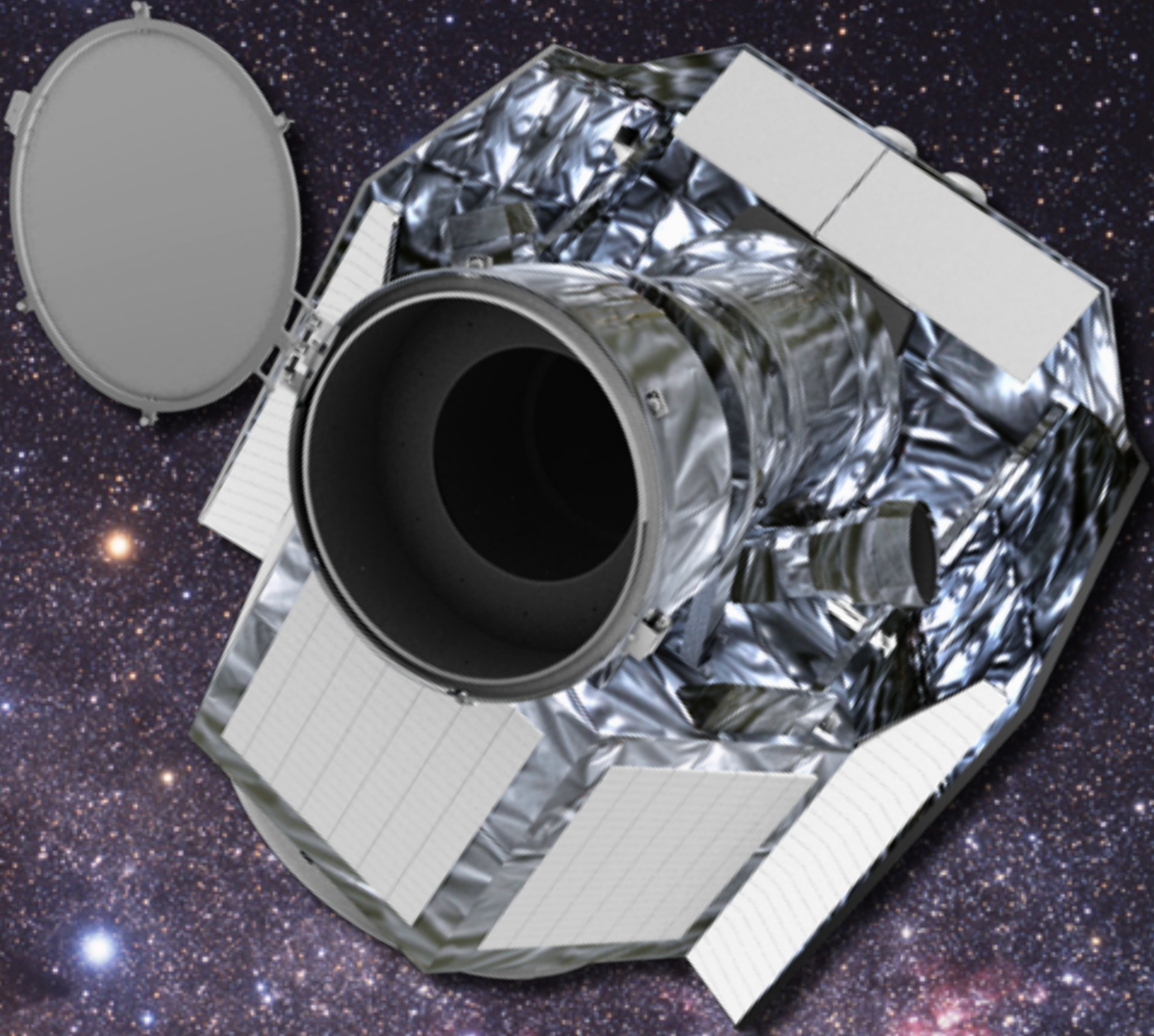
Athena: high-energy astrophysics mission, launch in 2028 / ESA



LISA Pathfinder: gravitational wave detection technology testbed, due for launch in 2015 / ESA



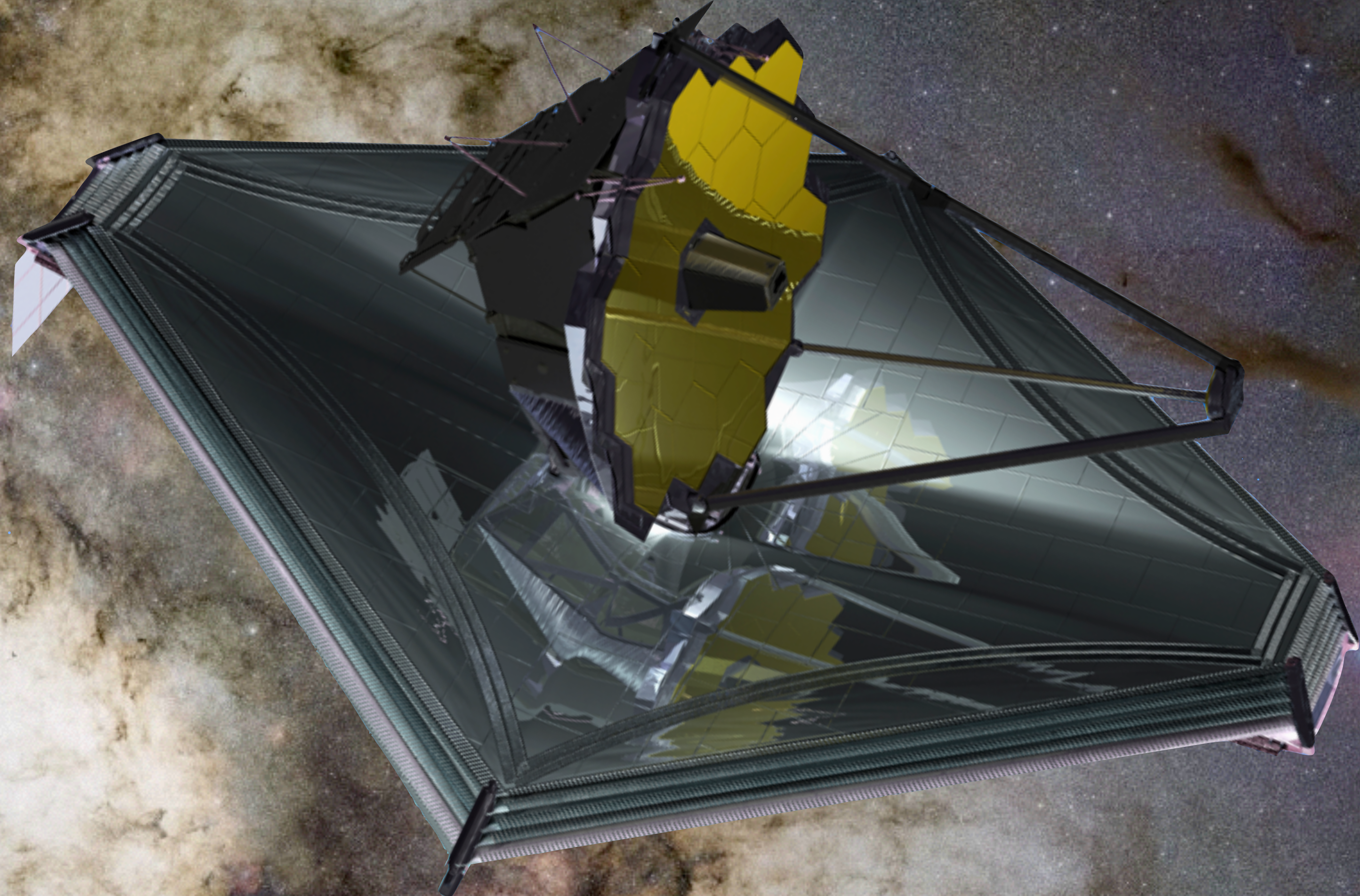
Future gravitational wave observatory, launch in 2034 / ESA



- Precision radii, densities of known transiting exoplanets
- Detection of super-Earths around $6<V<9$ stars (20ppm in 6 hrs)
- Characterisation of Neptune-type light curves around $9<V<12$ stars (85ppm in 3hrs)
- 320mm telescope with single-band 0.4–1.1μm photometer (1k x 1k CCD)
- 250kg satellite, 650–800km sun-synchronous terminator orbit, 3.5 (5) yrs lifetime
- Targets: NGTS, HARPS, ESPRESSO, NIRPS, HIRES
- Follow-up: HARPS, NIRPS, ESPRESSO, CRIRES, E-ELT HIRES, METIS

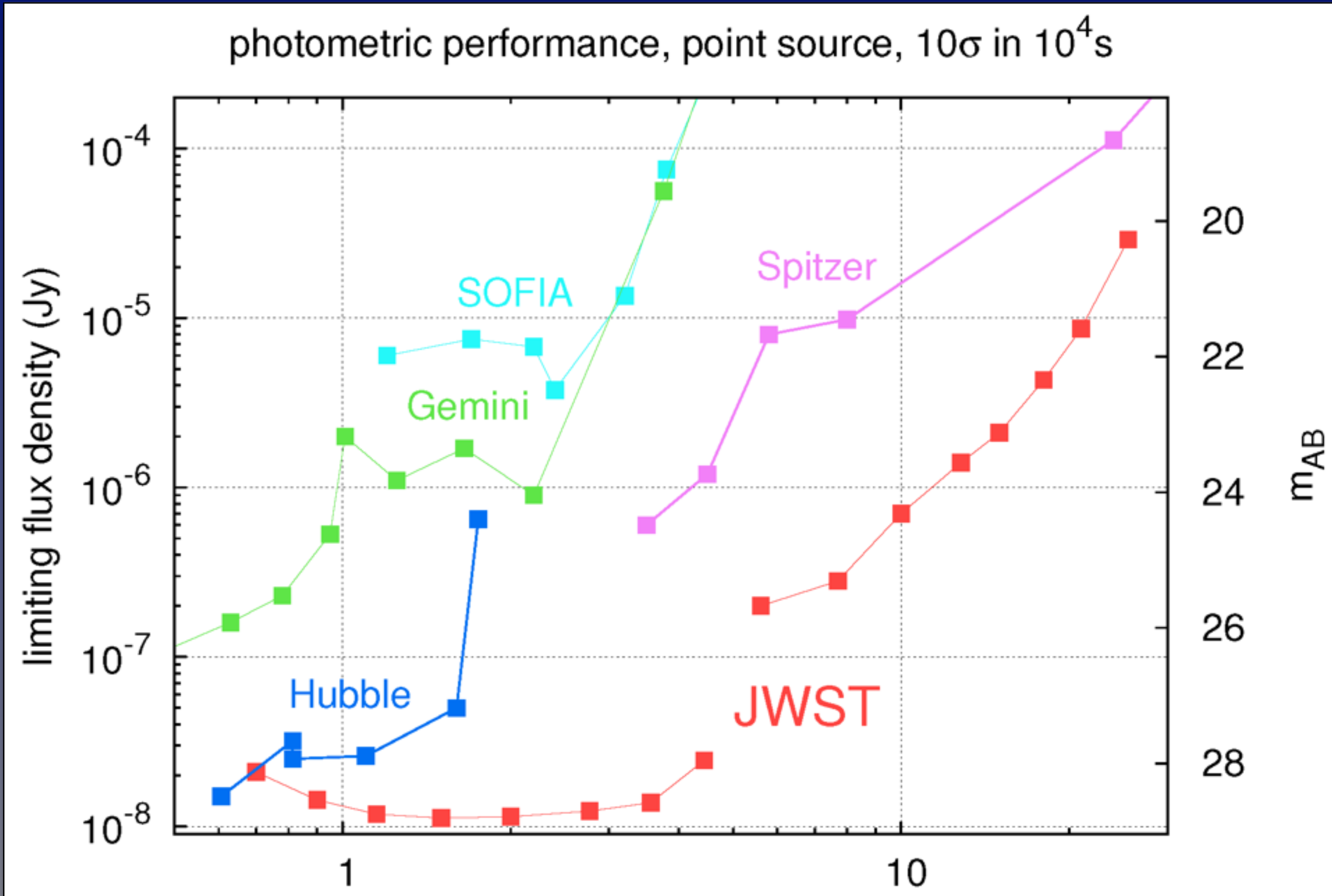
CHEOPS: exoplanet characterisation mission, launch 2017 / ESA, Swiss Space Office

Background image: Akira Fuji



- General purpose infrared (0.6–28μm) observatory with core goals in first light, galaxy formation and evolution, birth of stars and proto-planetary systems, planetary systems and the origins of life
- 6.5m deployable primary, Ariane 5 to L2 orbit
- Diffraction-limited imaging at > 2 μm, zodiacal light limited < 10 μm
- Near/mid-IR imaging, multi-object, slitless, IFU spectroscopy, coronography, aperture masking

James Webb Space Telescope: infrared observatory, launch in 2018 / NASA, ESA, CSA

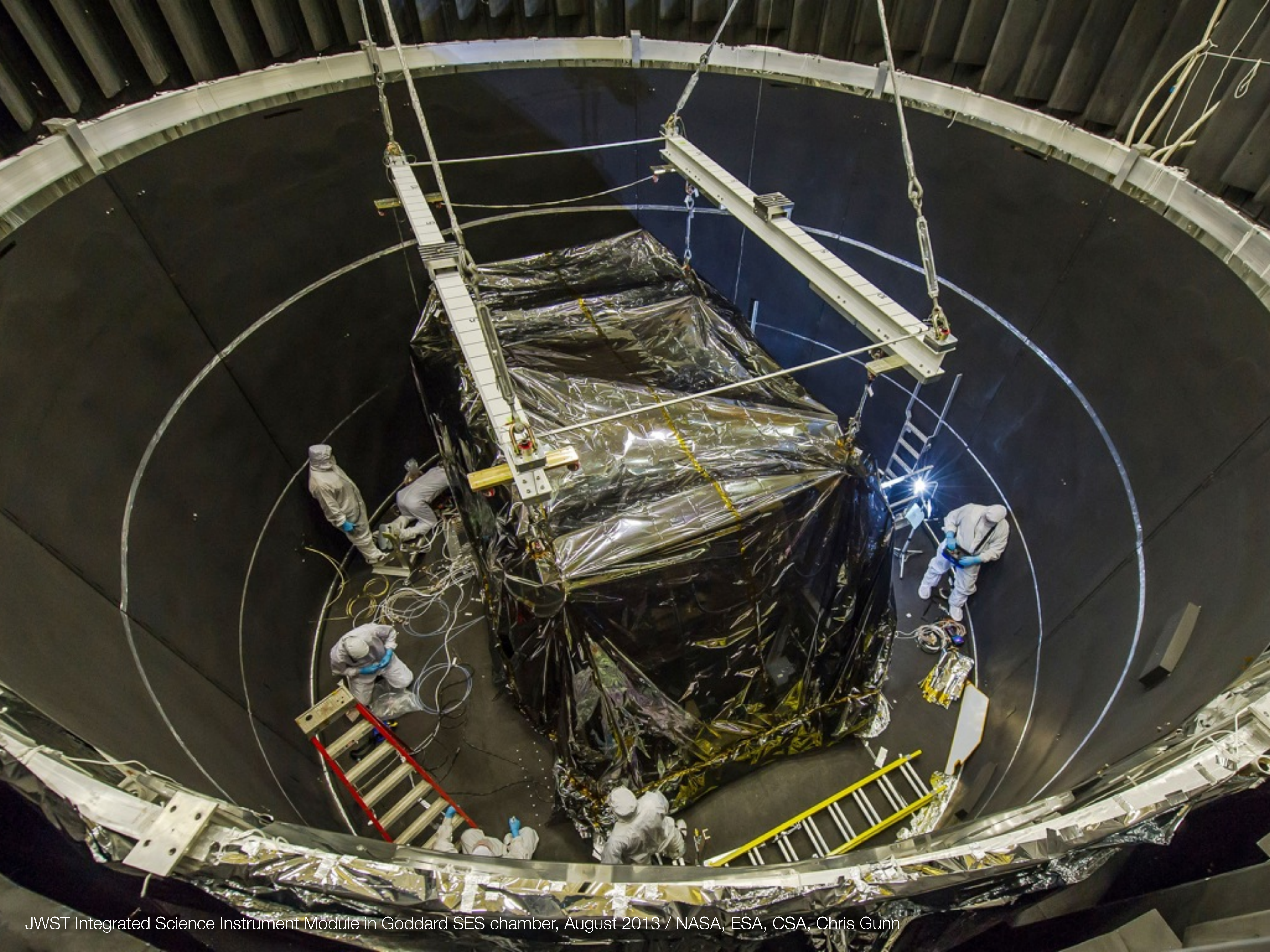


Calibration: 10 nJy at 2μm is equivalent to 75 zeptowatts or 1 photon per second

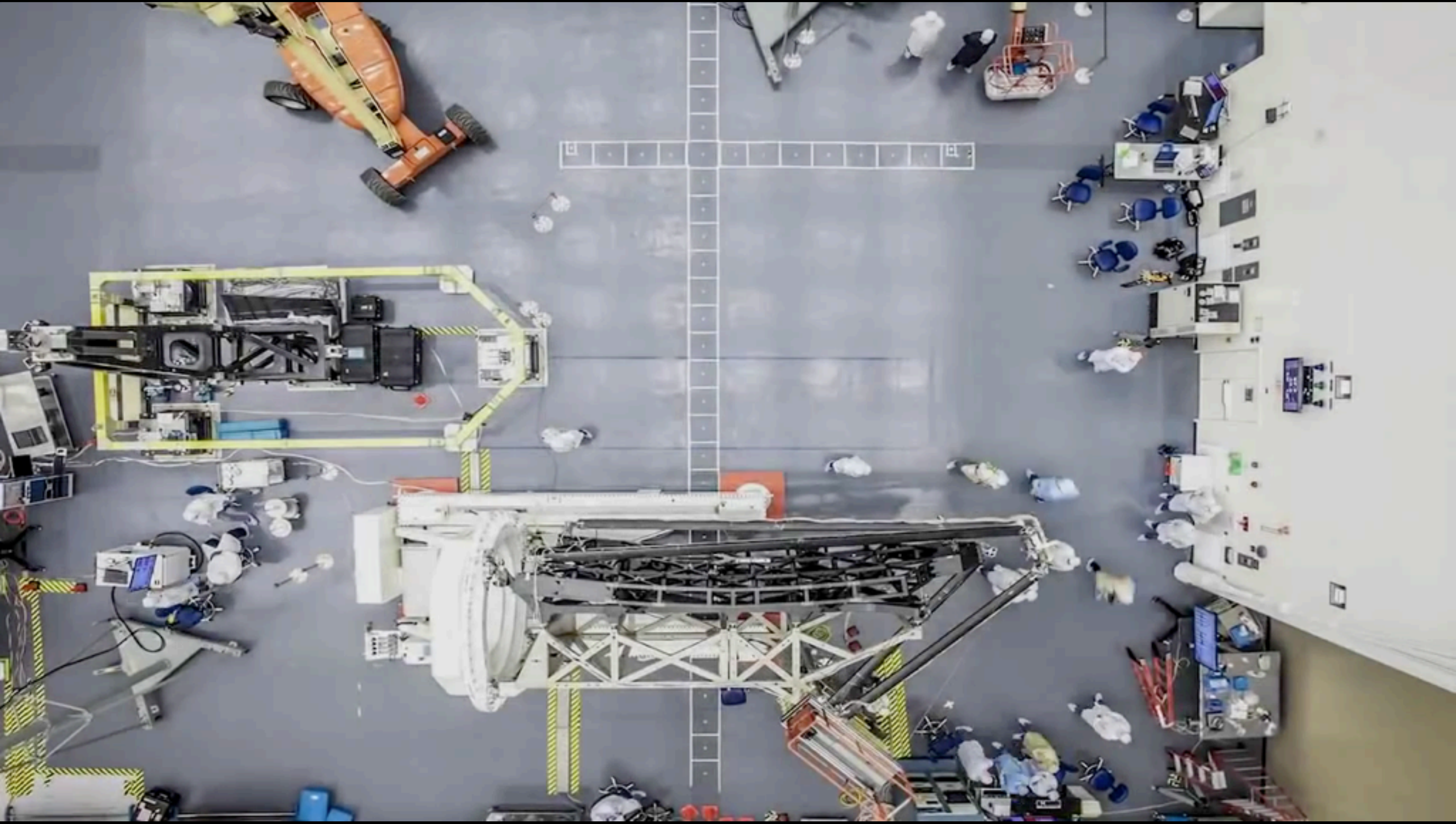
Representative JWST sensitivity figures

Instrument	λ (μm)	Resolution	Sensitivity
NIRCam	2.7	4	11.2 nJy, AB = 28.8
TFI	3.5	100	126 nJy, AB = 26.1
NIRSpec low	2	100	120 nJy, AB = 26.2
NIRSpec medium	2	1000	900 nJy, AB = 24.0
NIRSpec high	2	3000	3.3 μJy, AB = 22.6
MIRI imaging	10	4.2	700 nJy, AB = 24.3
MIRI imaging	21	5	8.7 μJy, AB = 21.6
MIRI spectroscopy	9.2	2400	1.0 x 10
MIRI spectroscopy	22.5	1200	5.6 x 10

10σ point source detections in 10^4 secs (~2.5 hrs) at North Ecliptic Pole

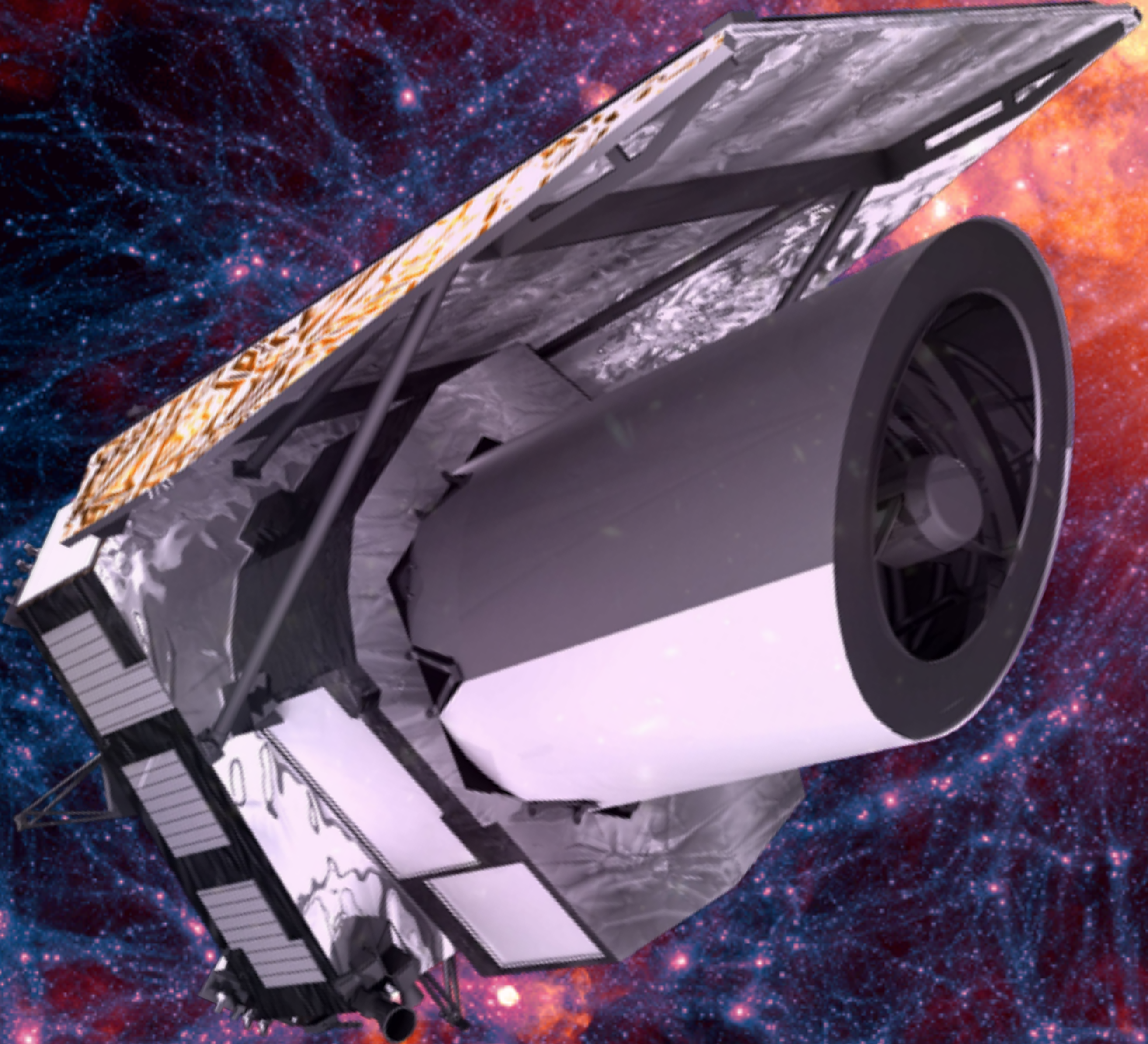


JWST Integrated Science Instrument Module in Goddard SES chamber, August 2013 / NASA, ESA, CSA, Chris Gunn



JWST secondary mirror support deployment test, October 2014 / NASA, ESA, CSA, Northrop Grumman

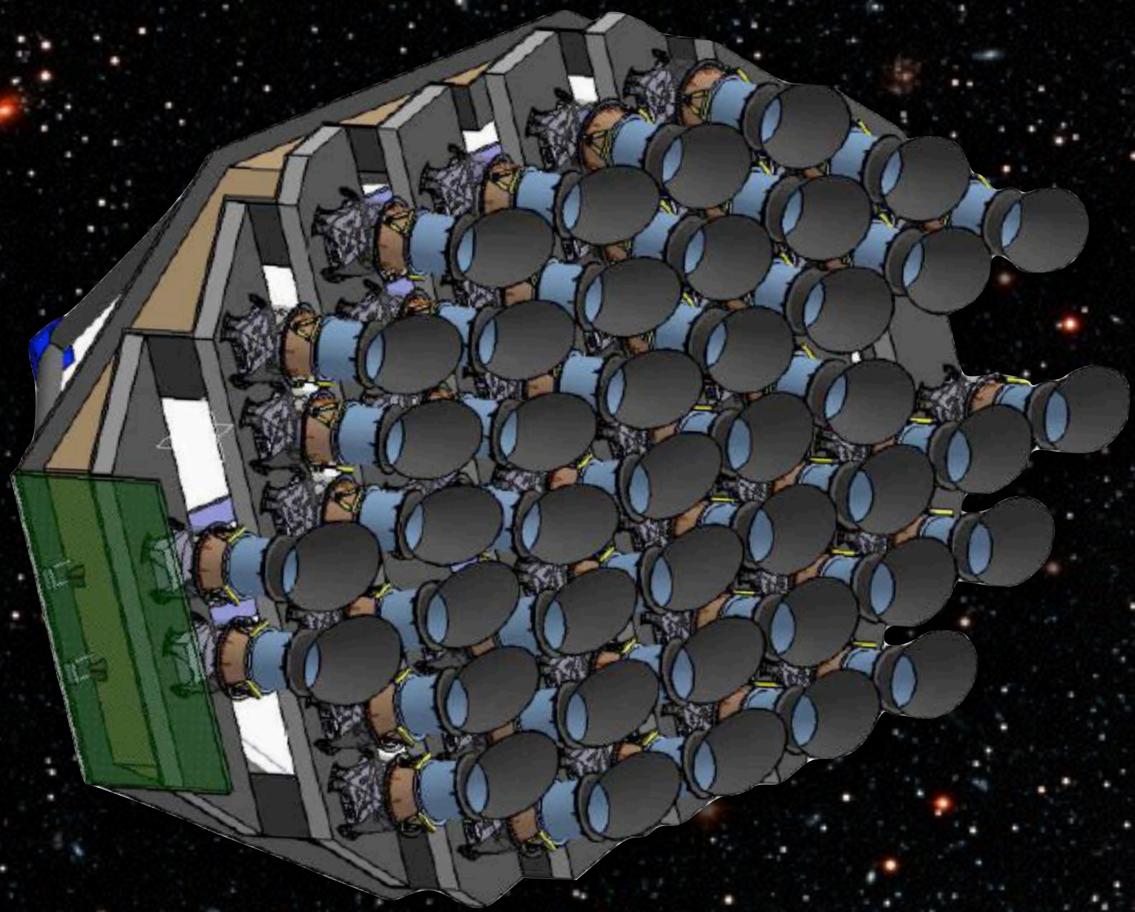
JWST sunshield deployment test, July 2014 / NASA, ESA, CSA, Northrop Grumman

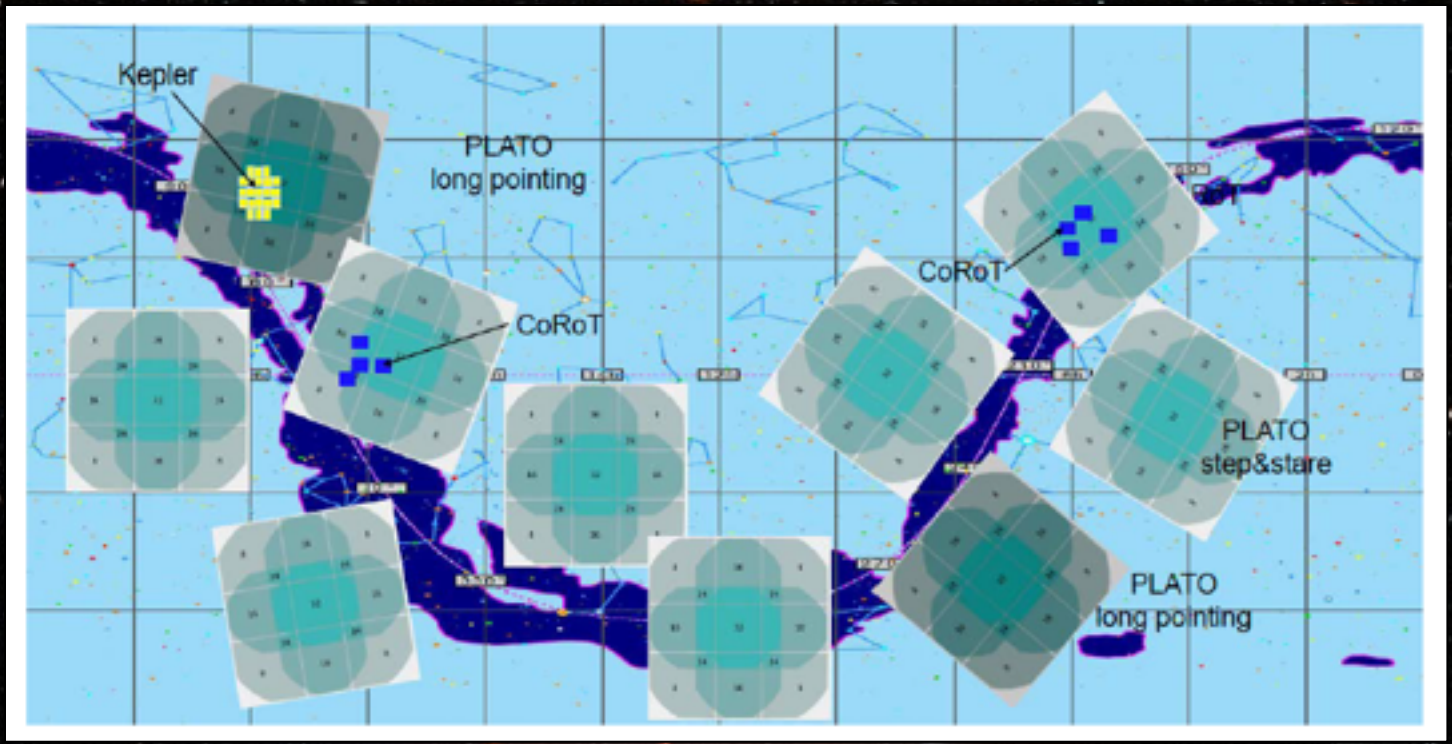


- Weak lensing (shear + photo-z's) and BAO's (redshifts) to probe dark matter and dark energy
- 2100kg satellite, Soyuz to L2, 6.25 yr mission, 1.2m Korsch telescope, common 0.53 deg^2 FOV
- Wide-field (15,000 deg^2) and deep (40 deg^2) surveys
- VIS: 576Mpix, 0.1"/pix, R+I+z imaging for shear (AB 24.5 10σ extended)
- NISP: 64Mpix, 0.3"/pix, Y,J,H imaging photo-z's (AB 24 5σ) + slitless R~250 spectroscopy (redshifts)
- Requires substantial ground-based data e.g. MOONS, 4MOST, DES, CFHT, LSST, MSE, Gaia
- Targets to: JWST, ALMA, E-ELT, SKA
- Euclid consortium leads payload provision, data analysis, ground-based inputs

Euclid: Exploring the dark Universe, launch 2020 / ESA

Background image: Illustris Collaboration





- Transit search for Earth-like (1–10M_E) planets in habitable zone of bright solar-type stars; characterisation of thousands of rocky, icy, and giant planets; asteroseismology of parent stars
- Wide-field multi-telescope payload at L2
- 2 long pointings: ~2–3 yrs (4,300 deg^2): step-and-stare: 2–5 months/pointing (total 20,000 deg^2)
- 34 ppm/√hr at V=11: 22,000 / 85,000 stars; 80 ppm/√hr at V=13: 267,000 / 1,000,000 stars
- 32 “normal” + 2 “fast” cameras, each 4 4.5k x 4.5k CCD’s: instantaneous FOV 2250 deg^2
- Most data immediately available after validation: small fraction 1 yr proprietary period
- Substantial follow-up effort by PLATO consortium: existing RV spectrometers, ESPRESSO, CARMENES, SPIROU, NIRPS, HIRES/E-ELT, ESPRESSO-N

PLATO: ESA transiting rocky planet discovery and characterisation mission, launch in 2024 / ESA

Summary

- Astonishing array of powerful new space- and ground-based astronomical facilities on, just over, or above the horizon
- Increased need for forward planning to ensure appropriate cooperation, synergies, and complementarities between them