European Space Agency Science Programme

Carole Mundell
Director of Science
and
Head of the European Space Astronomy Centre

Prof. Carole Mundell
Director of Science
European Space Agency

Head of the
European Space Astronomy Centre, Madrid

- BSc (Hons) Natural Philosophy & Astronomy, University of Glasgow
- PhD Astrophysics, University of Manchester
- Post-doctoral fellowships, Jodrell Bank & University of Maryland, USA
- Appointed Professor in 2007, Liverpool John Moores University
- Head of Astrophysics & Head of Physics, University of Bath (2015-2023)
  - Chief Scientific Adviser, UK Foreign & Commonwealth Office, 2018
  - Chief International Science Envoy, UK Foreign, Commonwealth, & Development Office, 2018–2021
  - President, UK Science Council, 2021–2023

- Research interests in accreting supermassive black holes,galaxy dynamics, gamma-ray bursts, robotic autonomous telescopes, ground- & space-based research across the EM spectrum, new technologies & policies for space sustainability

ESA Ministerial Council 2022

Accelerating the Use of Space in Europe

22–23 November 2022
Paris

Europe decides to invest almost €17 billion in space

→ THE EUROPEAN SPACE AGENCY

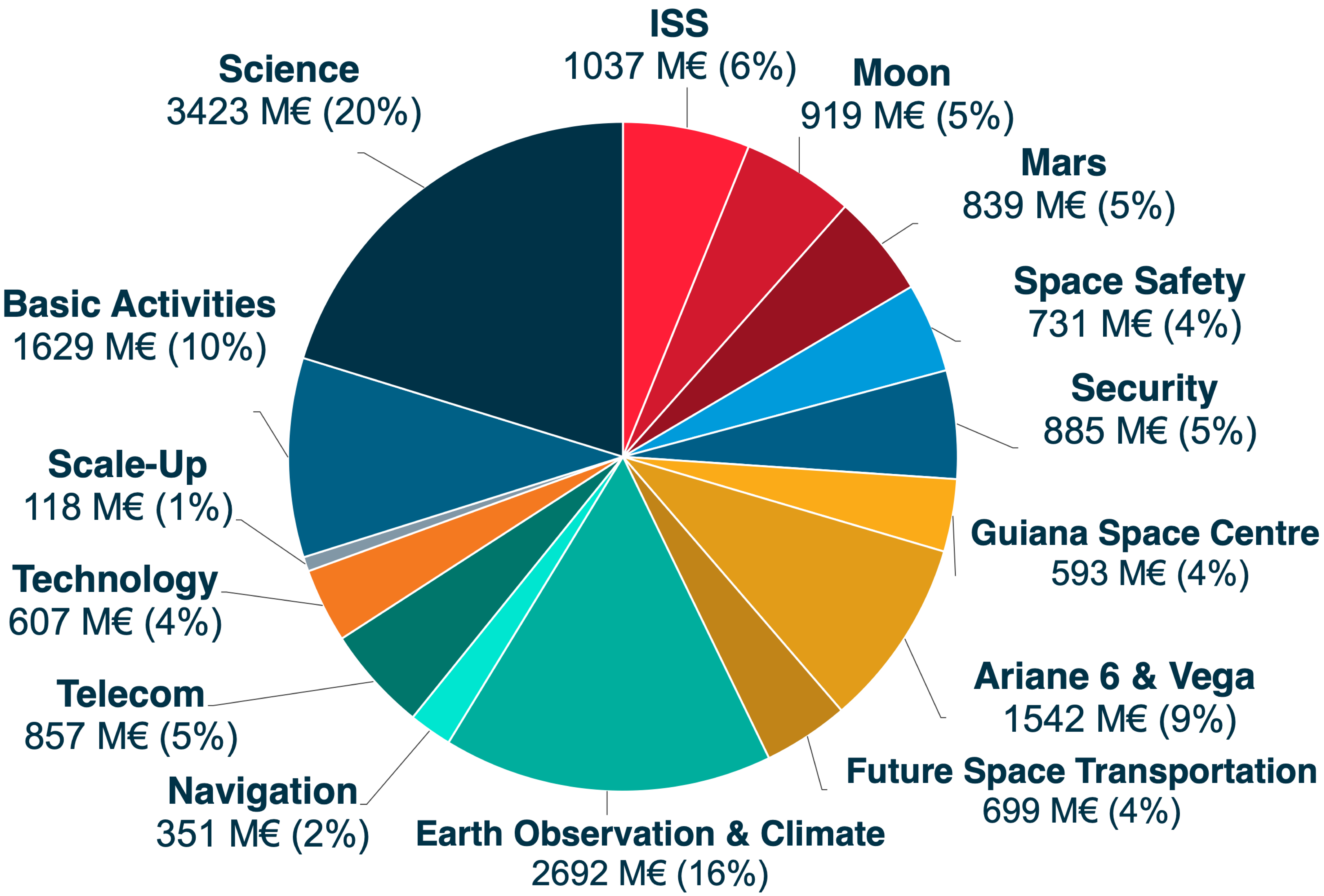
ESA Ministerial Council 2022

Record budget subscribed of

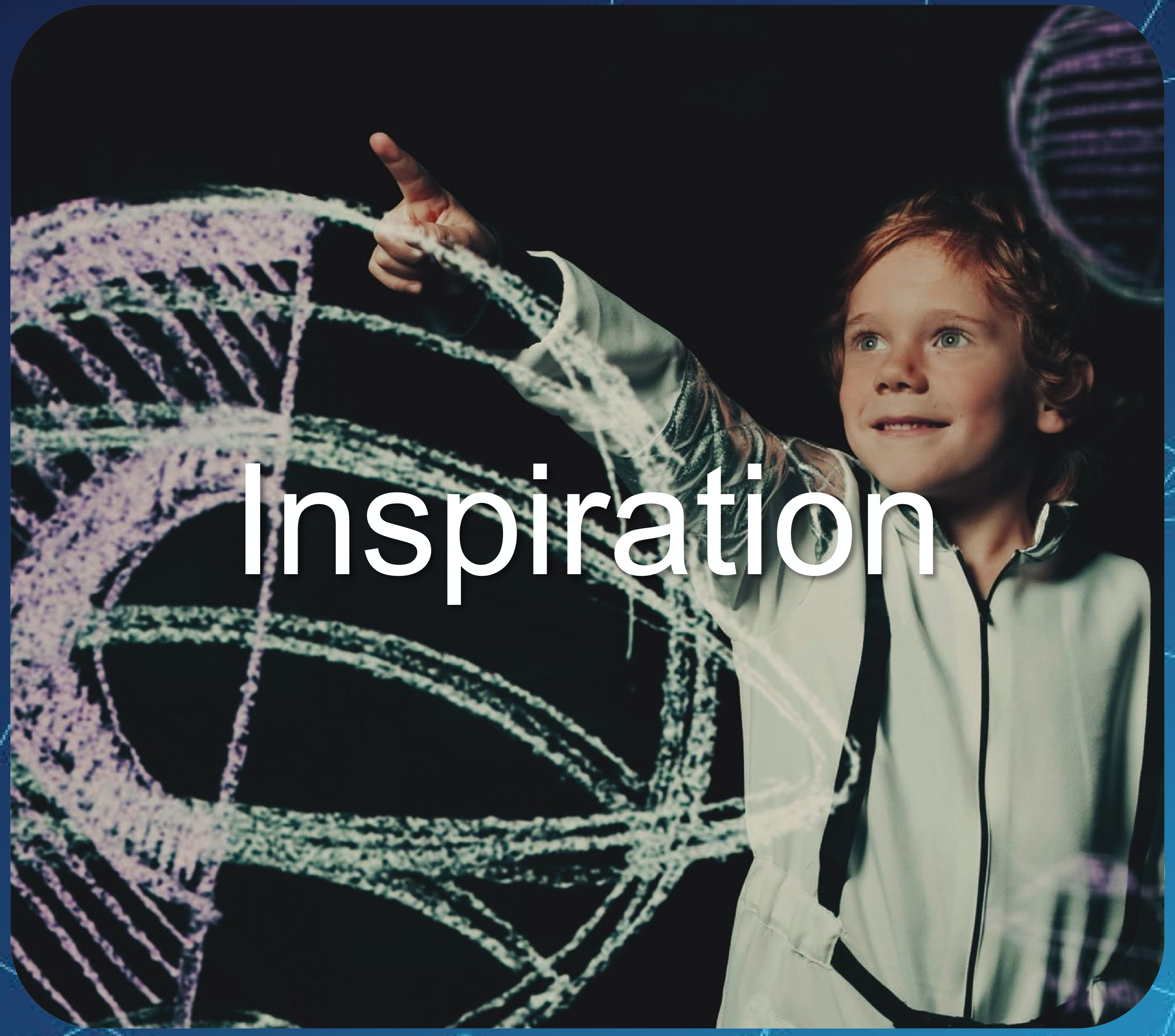
16.9

billion euro

including
1.3 billion euro **for** commercialisation

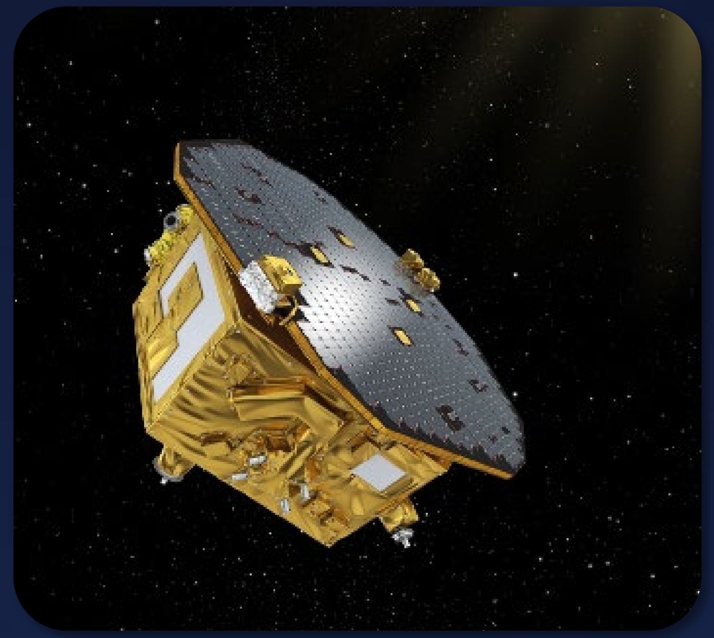


CM22 will boost Europe through:



Diverse Science Programme – Excellent, Unique

- Near-Earth Solar heliophysics
- Solar System, planetary, interplanetary
- Other worlds, exoplanets
- Universe science, galaxies, cosmology
- Fundamental physics, spacetime+
- Invention of new technologies
- Novel design, engineering and systems
- Orbital trajectories, long term operations
- Technology transfer, deep legacy data for discovery



L class

M class

F class

International collaboration

Missions of Opportunity

Uplifting Science

PRODEX

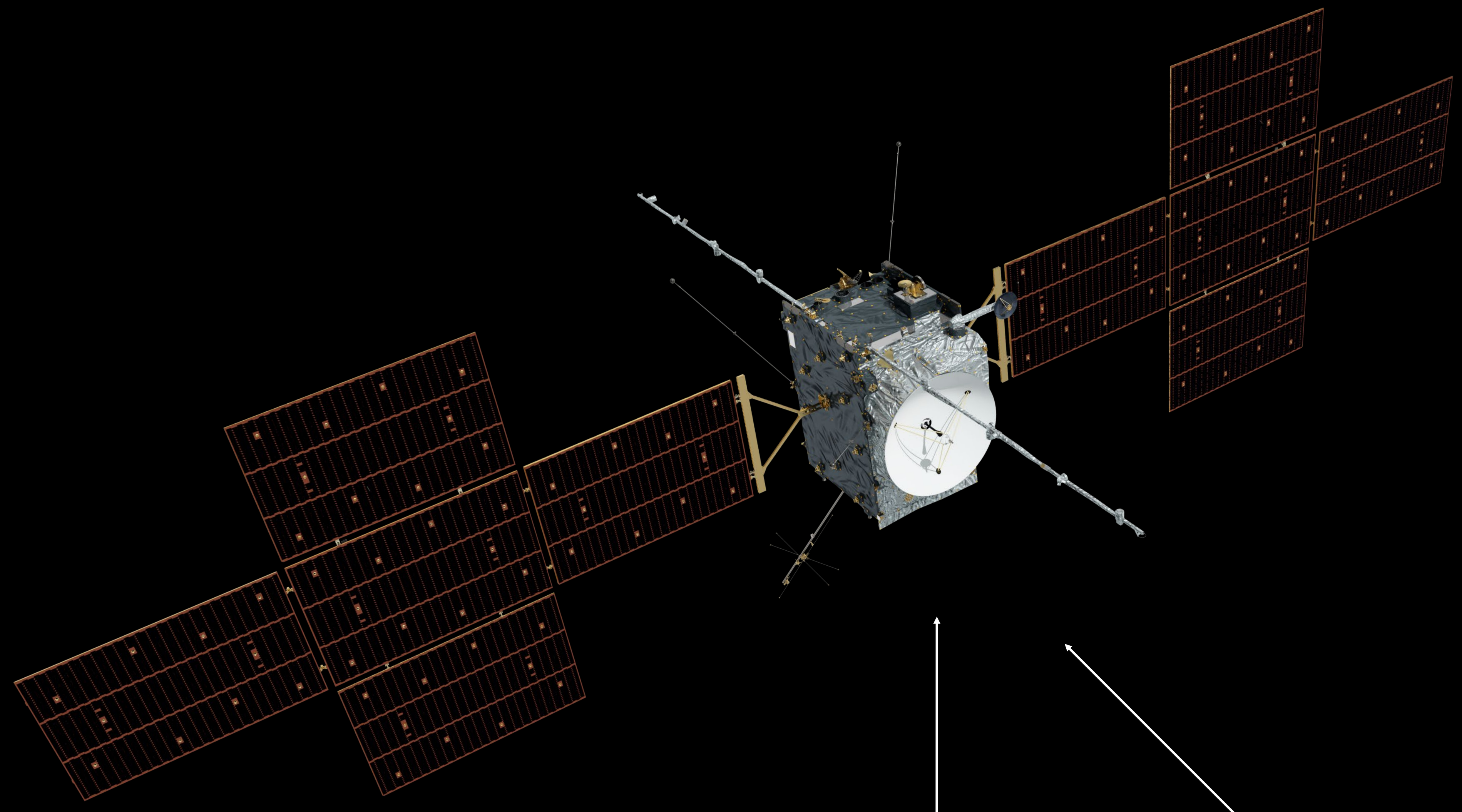
SOLAR SYSTEM EXPLORERS

COSMIC OBSERVERS
IN DEVELOPMENT
ariel
(2029)
roman
(2026)
plato
(2026)
einstein probe
(2023)
new athena
(~2036)
lisa
(~2035)
ACTIVE
webb
(2021–)
euclid
(2023–)
hubble
(1990–)
gaia
(2013–)
cheops
(2019–)
xrism
(2023–)
xmm-newton
(1999–)
integral
(2002–)
microwaves
sub-millimetre
infrared
optical
ultraviolet
x-rays
gamma rays
gravitational waves
LEGACY
planck
(2009-2013)
herschel
(2009-2013)
iso
(1995-1998)
akari
(2006-2011)
hipparcos
(1989-1993)
corot
(2006–2014)
iue
(1978-1996)
exosat
(1983–1986)
hitomi
(2016)
suzaku
(2005–2015)
cos-b
(1975–1982)
lisa pathfinder
(2015–2017)
microscope
(2016–2018)

ESA space science missions

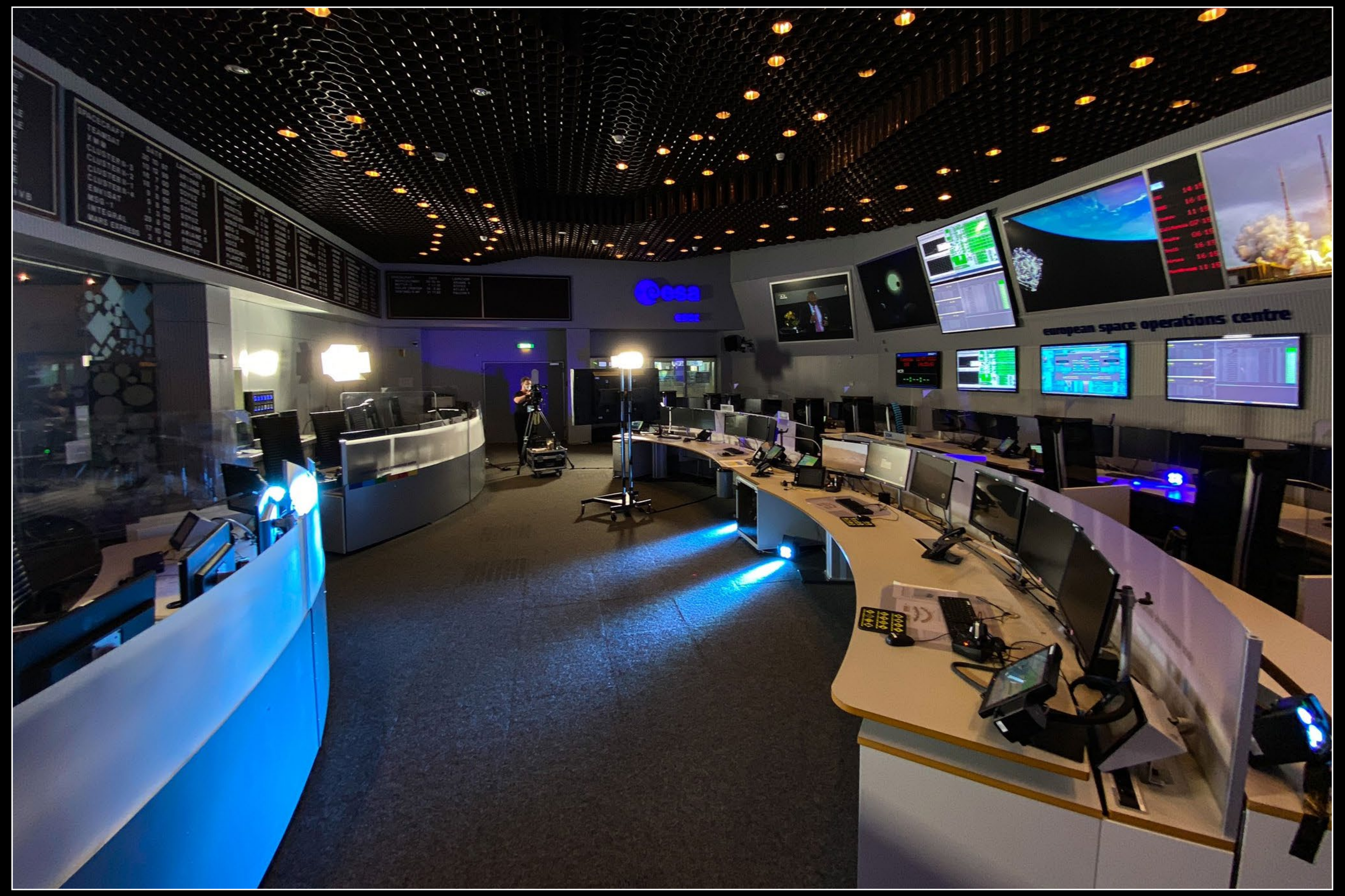
Latest update: October 2023

Elements of a Science Mission



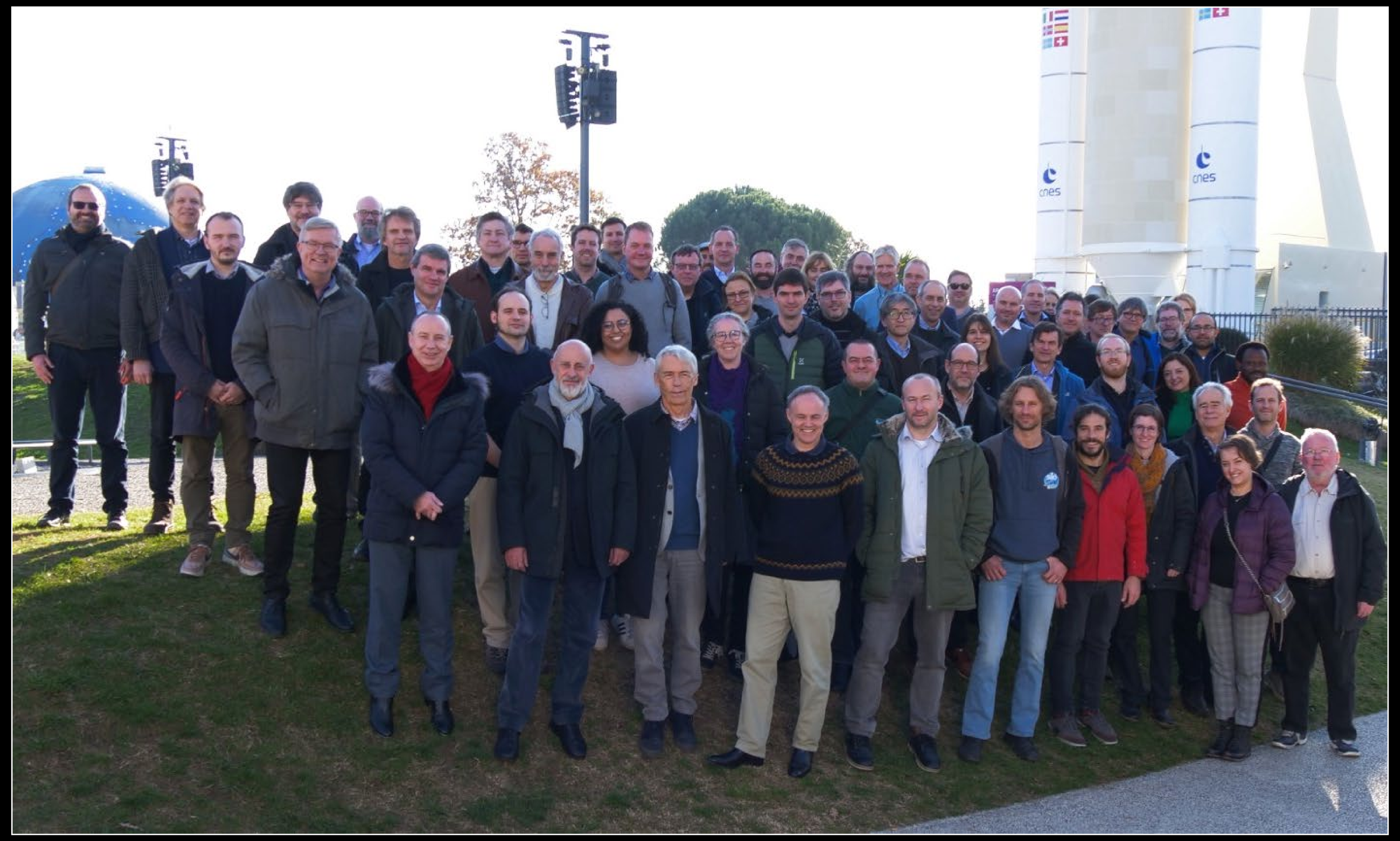
Spacecraft
Airbus D&S SAS

ESTRACK ground stations
Cebreros, New Norcia, Malargüe



Mission operations
ESOC, Darmstadt

Ariane 5 ECA launcher
Arianespace, CNES, ESA



JUICE science team, instrument PI's,
& wider academic community
Worldwide

Science operations
ESAC, Villafranca

Jupiter Icy Moons Explorer

- Studying Jupiter & its icy, ocean-bearing moons
- 4 planetary flybys, 35 Galilean moon flybys, 10 in situ + remote instruments
- ESA-led with NASA, JAXA, ISA participation
- Launched 14 April 2023 on Ariane 5, Jupiter arrival 2031, Ganymede orbit in 2034

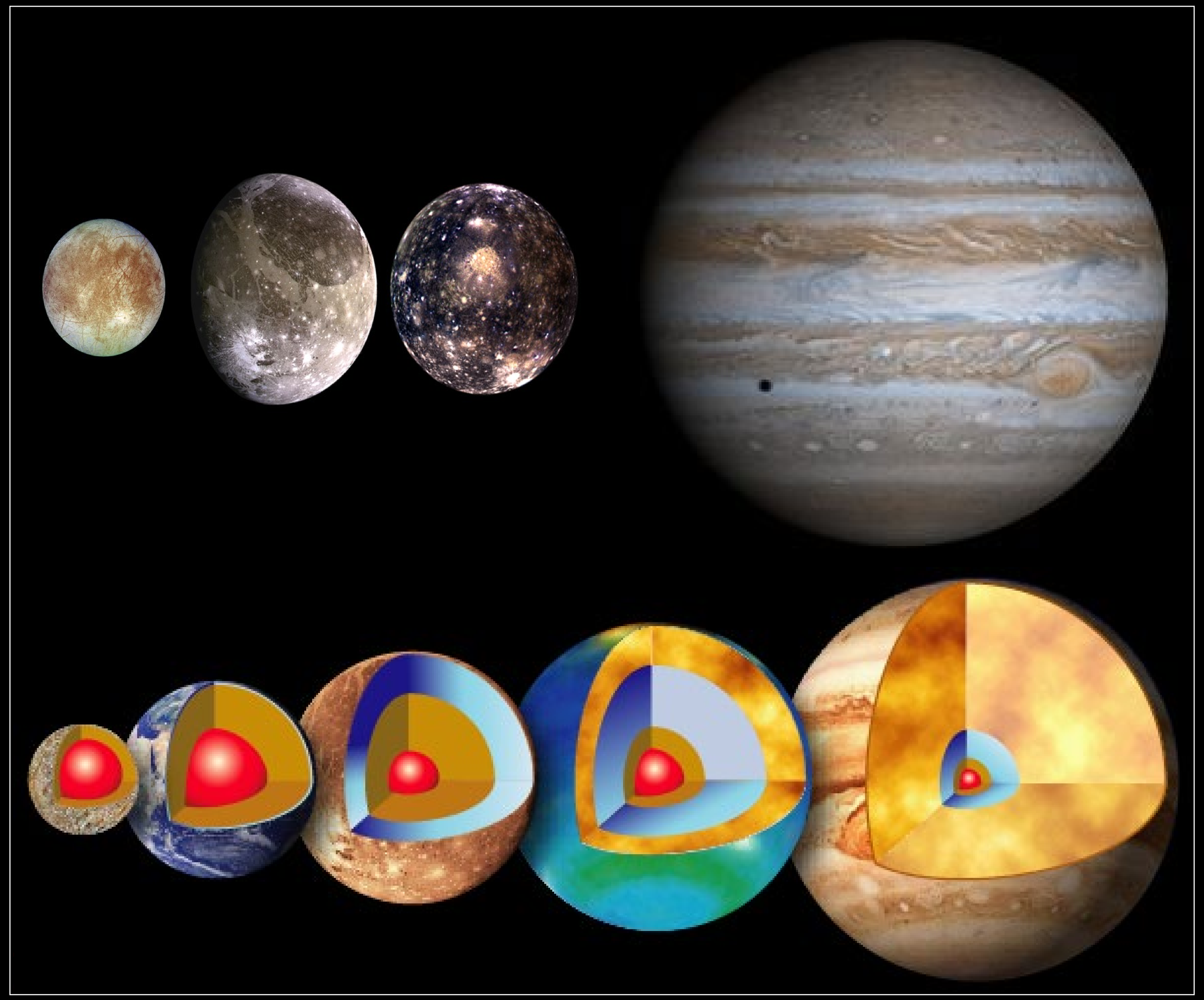
LusoSpace, Active Space Technologies, DEIMOS Engenharia, FHP – Frezite High Performance, Efacec and Celestia

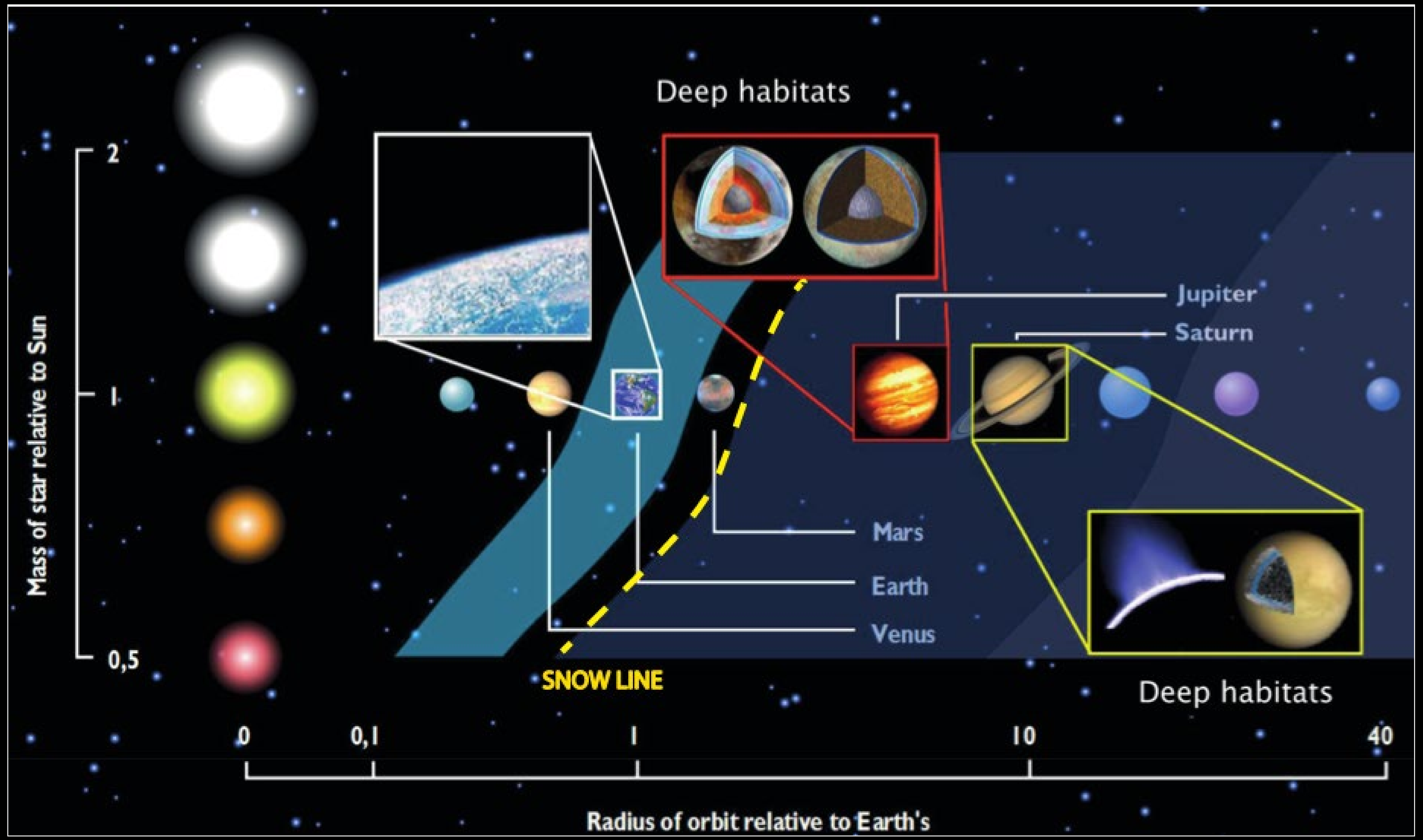
Spacecraft overview

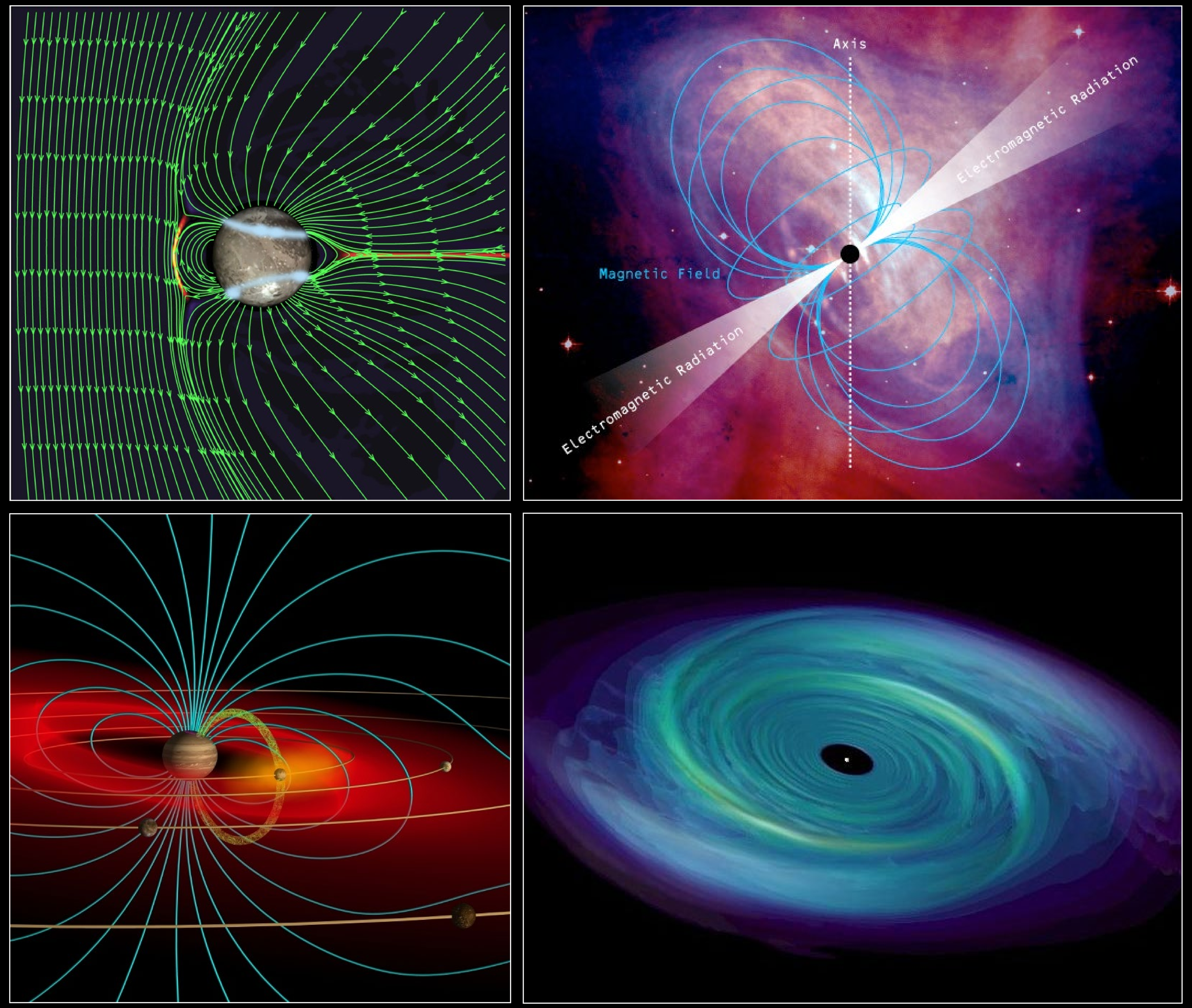
- Spacecraft dry mass: 2450 kg
- Propellant tank capacity: 3650 kg
- Launch mass: ~6.1 tonnes
- Solar array power: ~790 W at end-of-life
- On-board memory: 1.25 Tbits at end-of-life
- Data rate: > 1.4 Gbits/day
- Communications round-trip: ~90 minutes


esa
Io (1821 km)
Europa (1561 km)
Ganymede (2634 km)
Callisto (2410 km)
Frozen, volcanic crust (30–50 km)
Global magma layer (>50km)
Low-density mantle
Iron-rich core
Dynamic icy crust (15–25km)
Liquid water ocean (40–150 km)
Rocky mantle
Iron-rich core
Icy crust (~150km)
Liquid water ocean (100–800 km)
Icy mantle
Rocky mantle
Iron-rich core
Cratered ice + rock crust (80–150 km)
Liquid water ocean (150–300 km)
Rock + ice core
Possible interior configurations / ESA
The four Galilean moons to scale (radii in km) / NASA Voyager 1 & 2, Galileo, & Juno / Jónsson, Gill
→ THE EUROPEAN SPACE AGENCY

From the Jovian system to extrasolar planets & beyond







Planetary archetypes

- Waterworlds & gas giants are common among exoplanets
- Jovian system has key examples of both

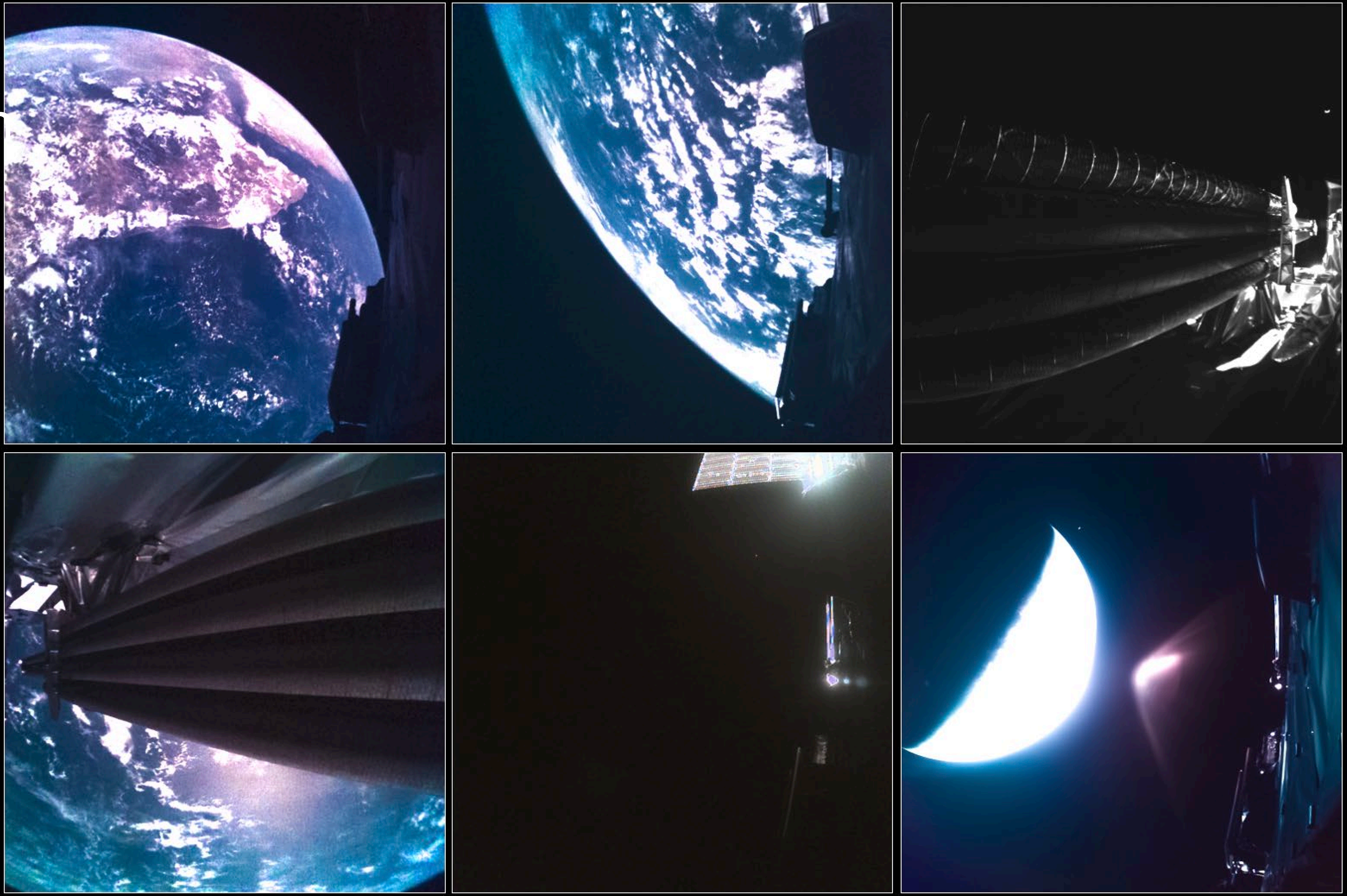
Search for habitable worlds

- Classical habitable zone applies to planetary surfaces
- Wider range of distances from star possible for “deep habitats”

Astrophysical analogues

- Plasma is fundamental component of many astrophysical environments
- Jovian system provides examples of reconnection & magnetodisc

JUICE–Earth Selfies !

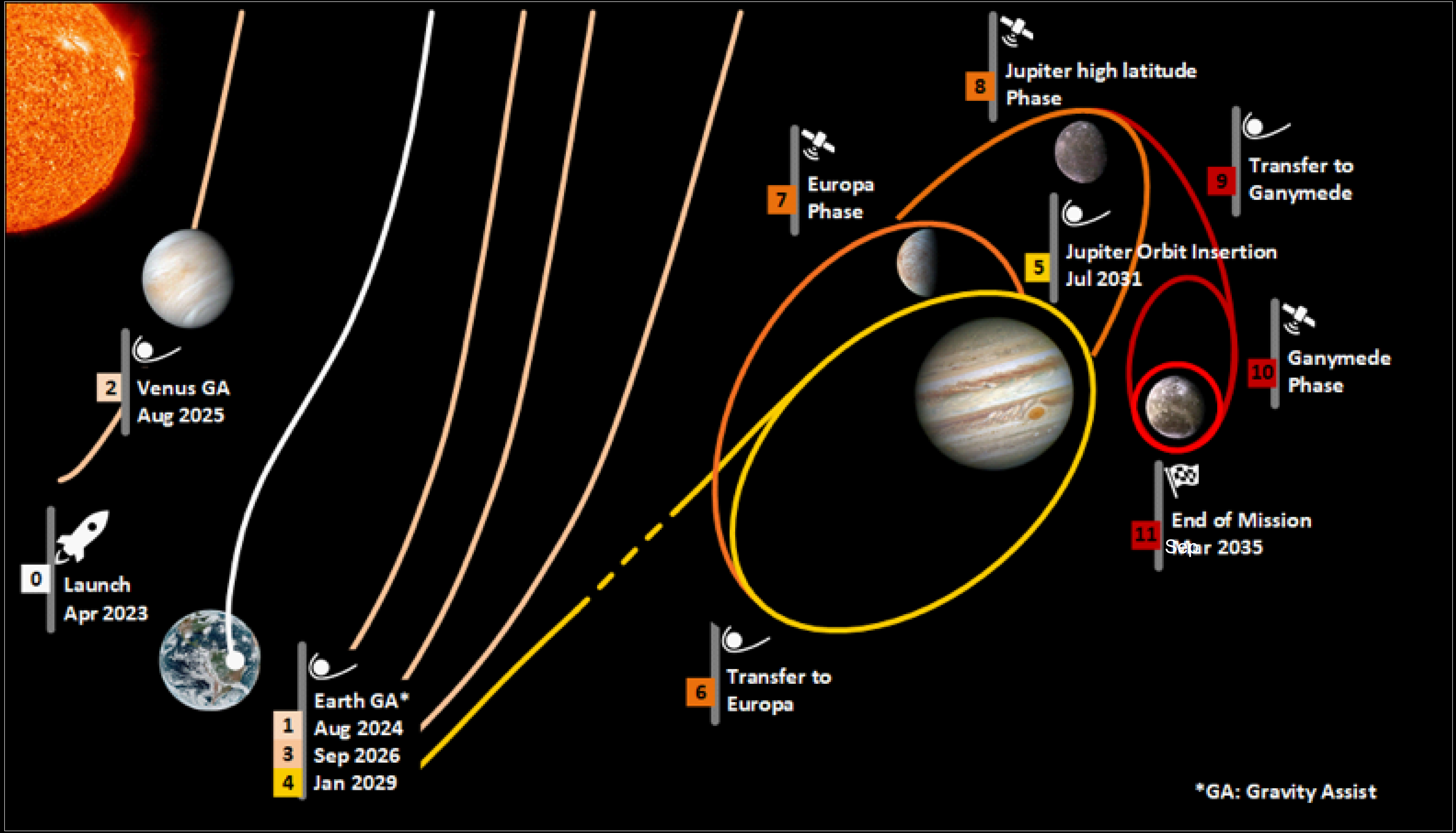


Monitoring Camera ‘Selfies’ after launch on 14 April / ESA Juice, JMC CC BY-SA 3.0 IG

Antennas Deployed

12 May 2023

Mission overview



BepiColombo

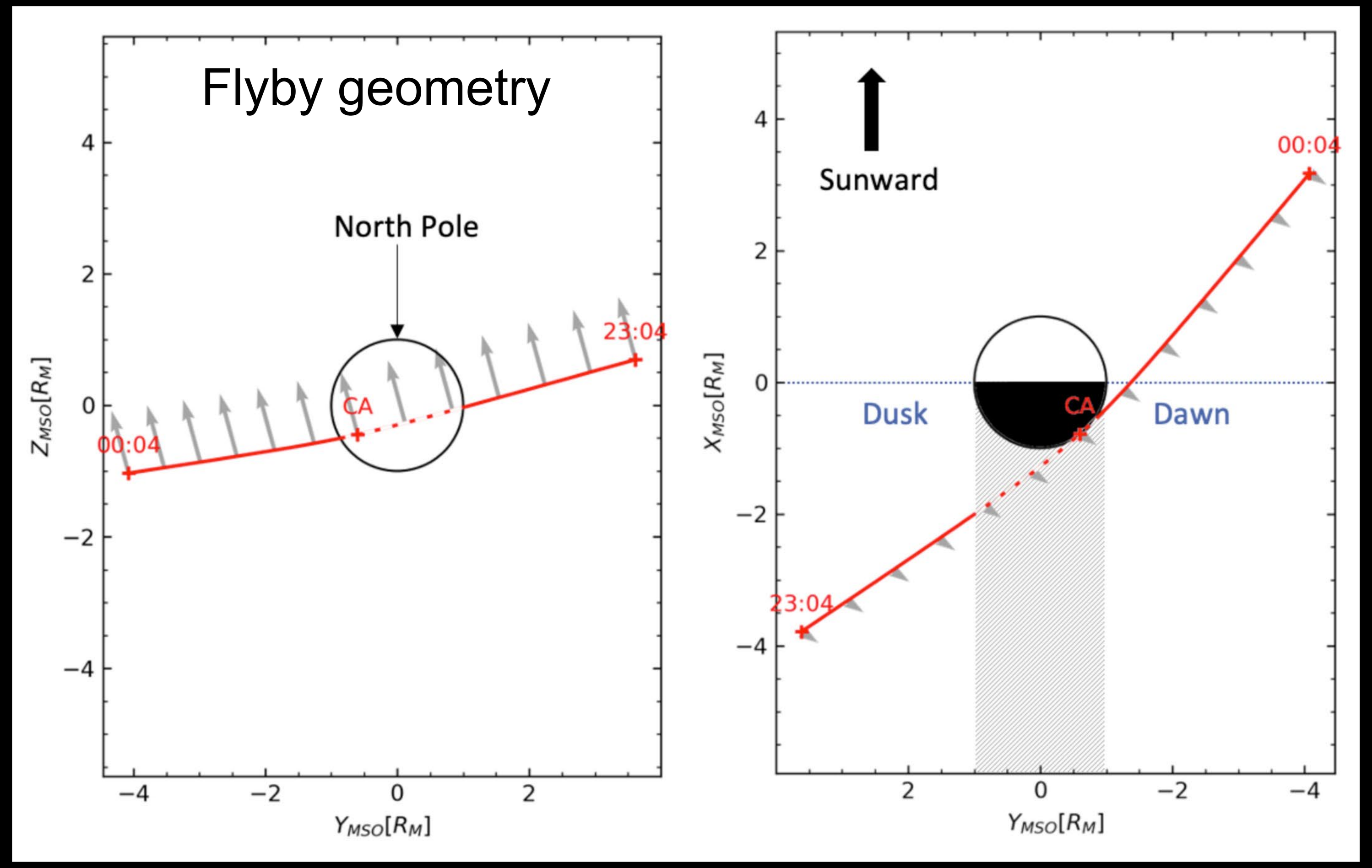
- Studying Mercury & its magnetic environment
- 3 spacecraft, 9 planetary flybys & solar-electric propulsion, 16 in situ + remote instruments
- ESA/JAXA mission
- Launched 2018 on Ariane 5, enters Mercury orbit December 2025

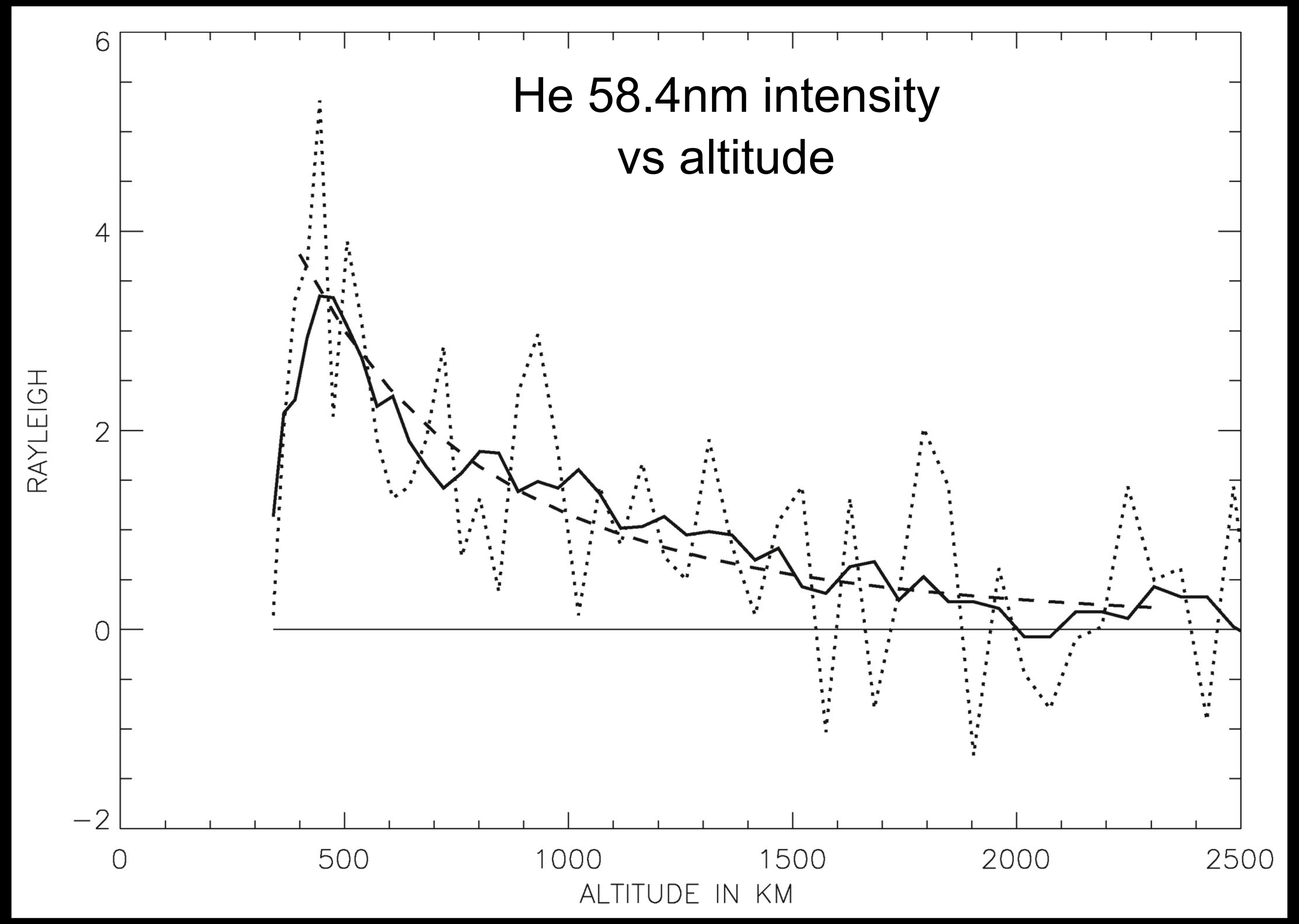
BepiColombo during a Mercury flyby / Ignacio de la Calle

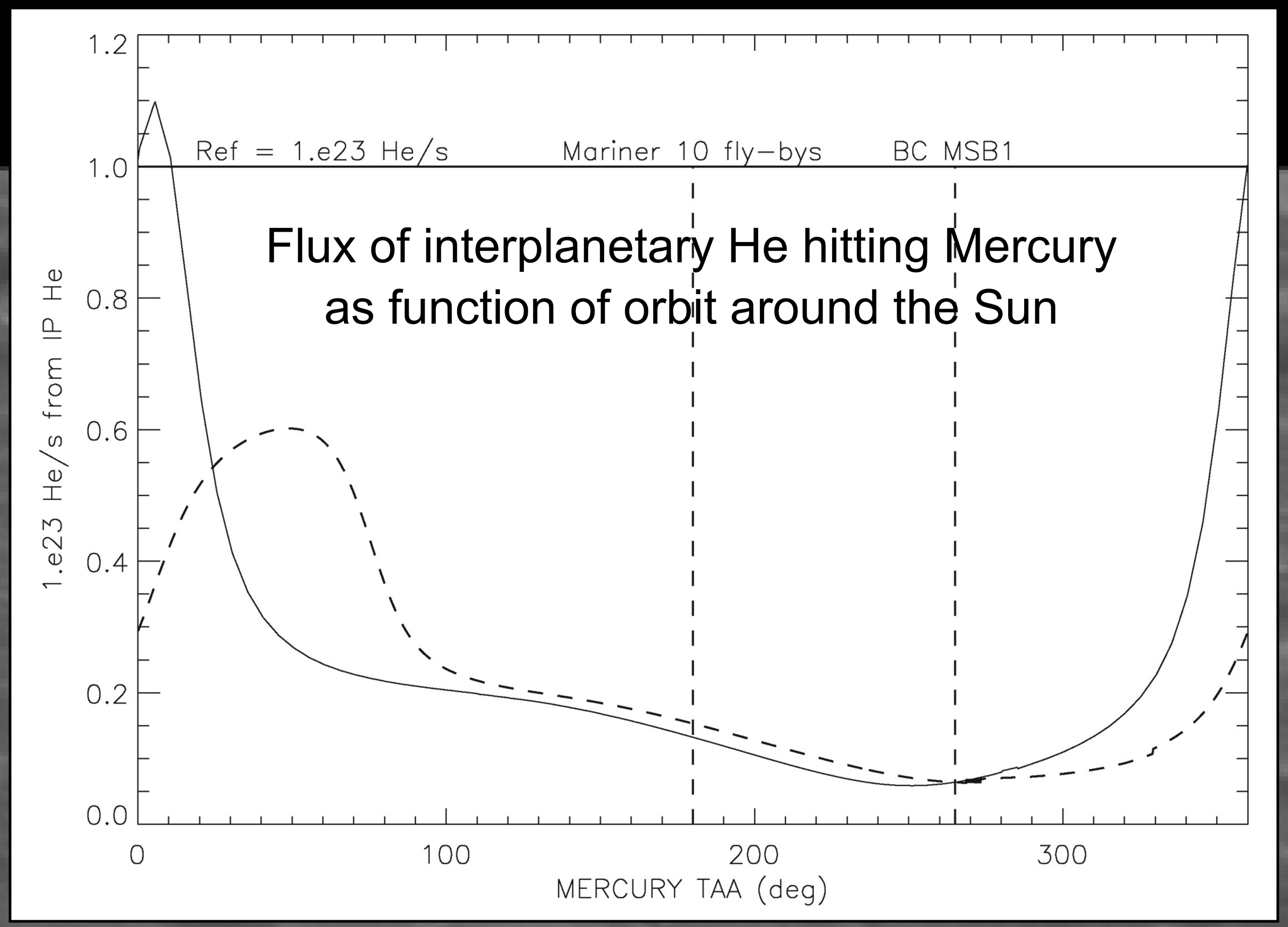
BepiColombo Mercury Swingby #2, 23 June 2022 / ESA, JAXA

The limb of Mercury in the Van Eyck region, near the Caloris basin, in 2011 / MESSENGER MDIS / NASA, JHU APL, CIW

- Mercury and its exosphere
  - Highly variable, with density ~10^{-14} bar
  - Particles ballistic, moving under gravity & solar wind, rarely colliding
  - Composition: H, He, O, Na, Ca, K, Mg, Al, Mn, Fe, H_2O^+, H_2S^+, H_3O^+, OH, O_2^+, Si^+
  - From solar wind, meteorite impacts, evaporation, sputtering, etc.
- Measurements of helium at Mercury at 58.4nm in UV
  - Detected by Mariner 10 in 1974, but not by MESSENGER
  - Seen by PHEBUS on BepiColombo during 1 Oct 2021 first flyby
  - 450–550K, 600–1000 cm^{-3}, 4.5–7.5 x lower density than Mariner 10
- Why is helium at Mercury so variable?
  - Sources of He at Mercury: solar wind (He^{2+}) & interstellar clouds (He)
  - Sun is moving through the interstellar medium at 26 km s^{-1}: interstellar He is gravitationally focussed behind it
  - Density & velocity of interstellar He contribution varies as Mercury orbits Sun





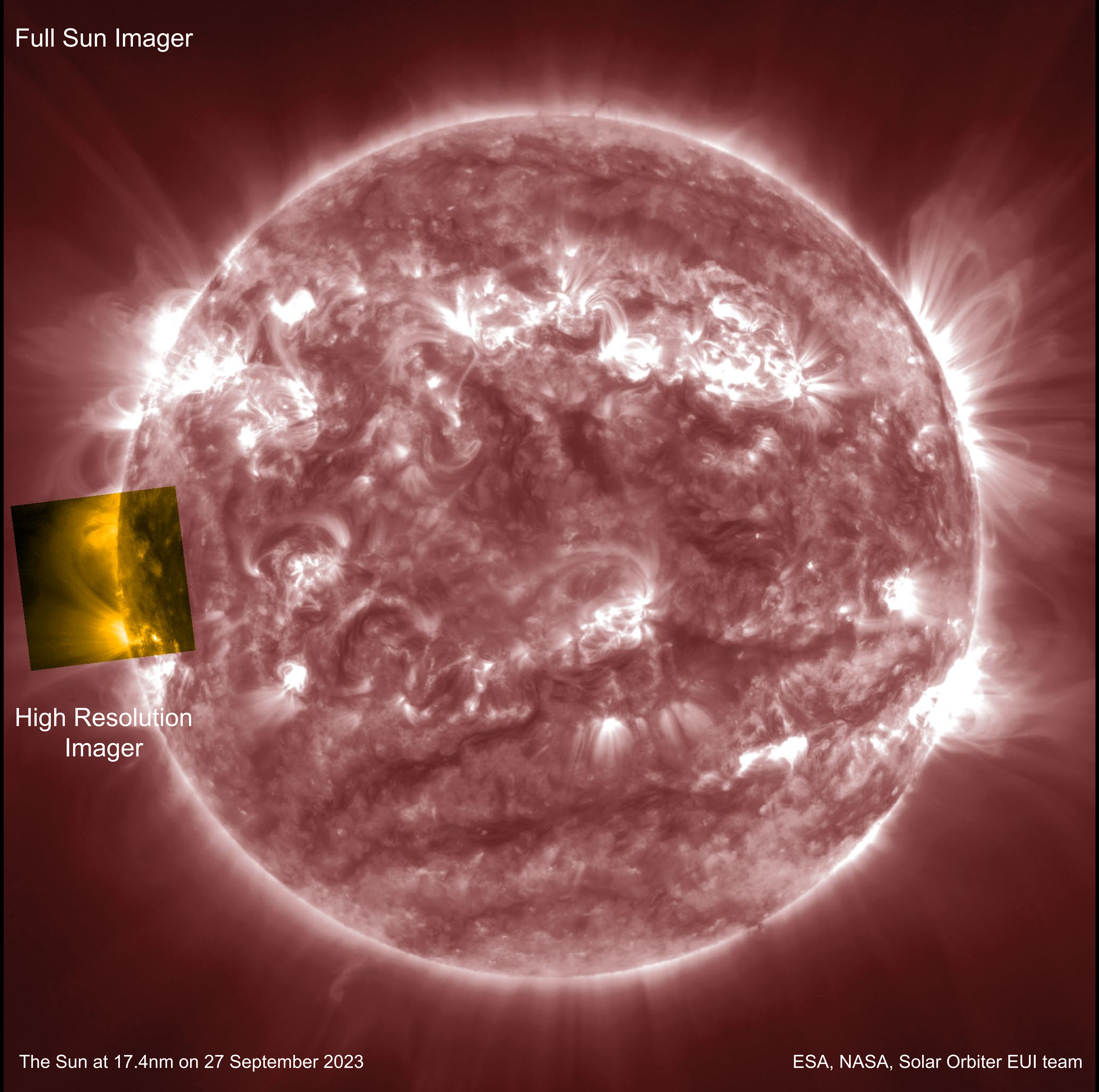


The limb of Mercury in the Van Eyck region, near the Caloris basin, in 2011 / MESSENGER MDIS / NASA, JHU APL, CIW

Quémerais et al. 2023, JGR Planets

Solar Orbiter mission, launched 10 February 2020 / ESA, NASA

Joint Solar Orbiter & Parker Solar Probe observations on 27 September 2023



Full Sun Imager
High Resolution Imager
The Sun at 17.4nm on 27 September 2023
ESA, NASA, Solar Orbiter EUI team

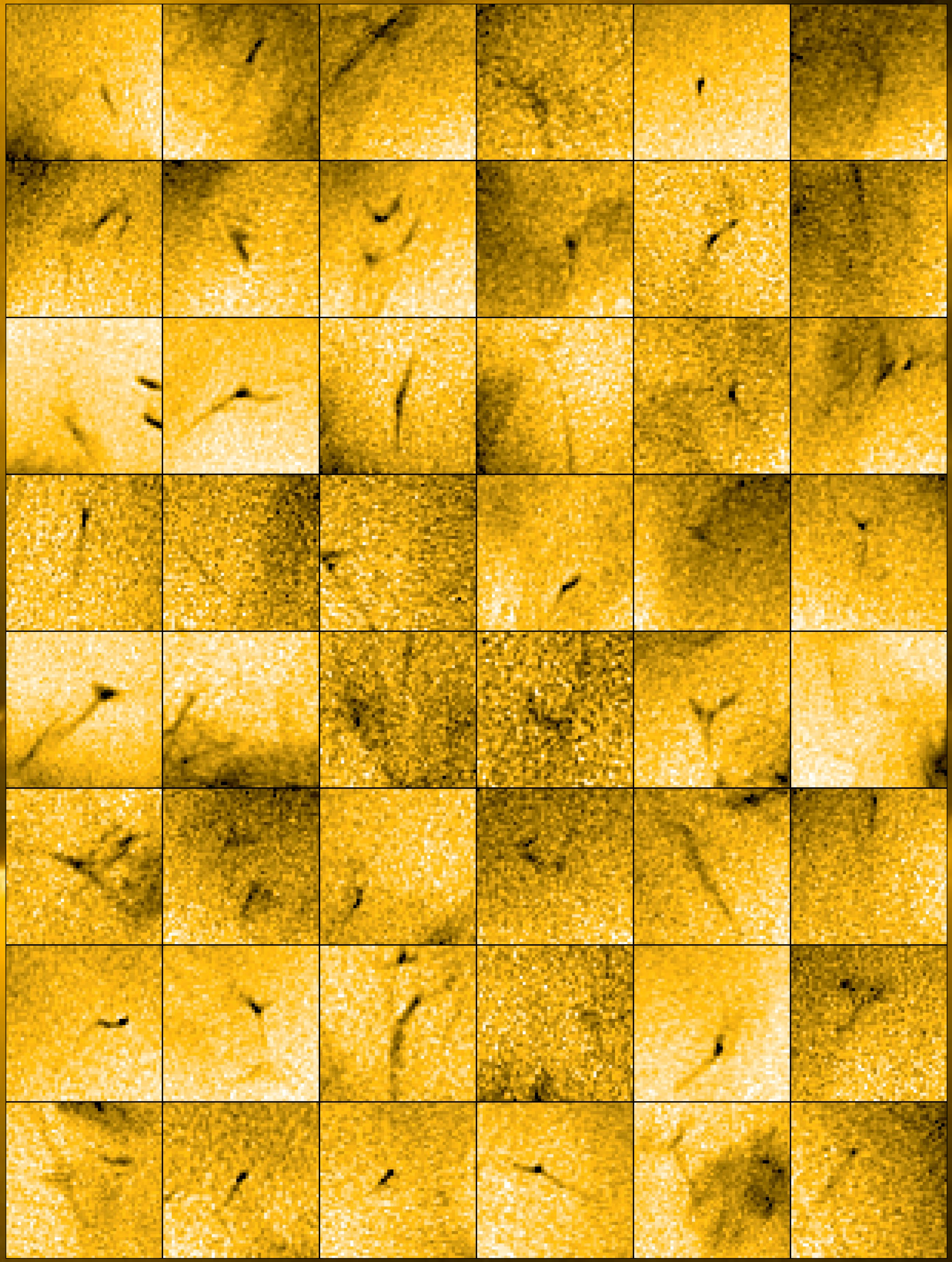

EUI HRI 17.4nm cadence: 1 image per 10 seconds
Movie runs at 30 fps, so 1 sec = 5 mins of real-time
2023-09-27T02:35:04.720
ESA, NASA, Solar Orbiter EUI team


EUI HRI 17.4nm / ESA, NASA, Solar Orbiter team
2022-03-30T04:32:04.046
Chitta et al. 2023, Science

- Coronal holes
  - Regions of cooler, lower density plasma with open magnetic field lines
  - Appear as dark patches in EUV images of Sun
  - Allows solar wind to escape at ~2 x normal velocity, i.e. 600–800 km s^{-1}
- EUI HRI imaging of a coronal hole near south pole
  - Short-lived (~20–100 s), short (~2000–4000 km), narrow (~200–400 km) jet-like structures at ~1 million K, expelling plasma at ~100 km s^{-1}
  - Intermittent but widespread within the coronal hole: ~70 jets seen in 30 min
  - Narrower jet-like features associated with plume from hole
- These "picoflare jets" could power the solar wind
  - Likely driven transiently by reconnection in granular-scale magnetic features
  - Velocity shear between adjacent jet flows could drive instabilities leading to solar wind features including magnetic switchbacks

EUI HRI 17.4nm / ESA, NASA, Solar Orbiter team

2022-03-30T04:32:04.046

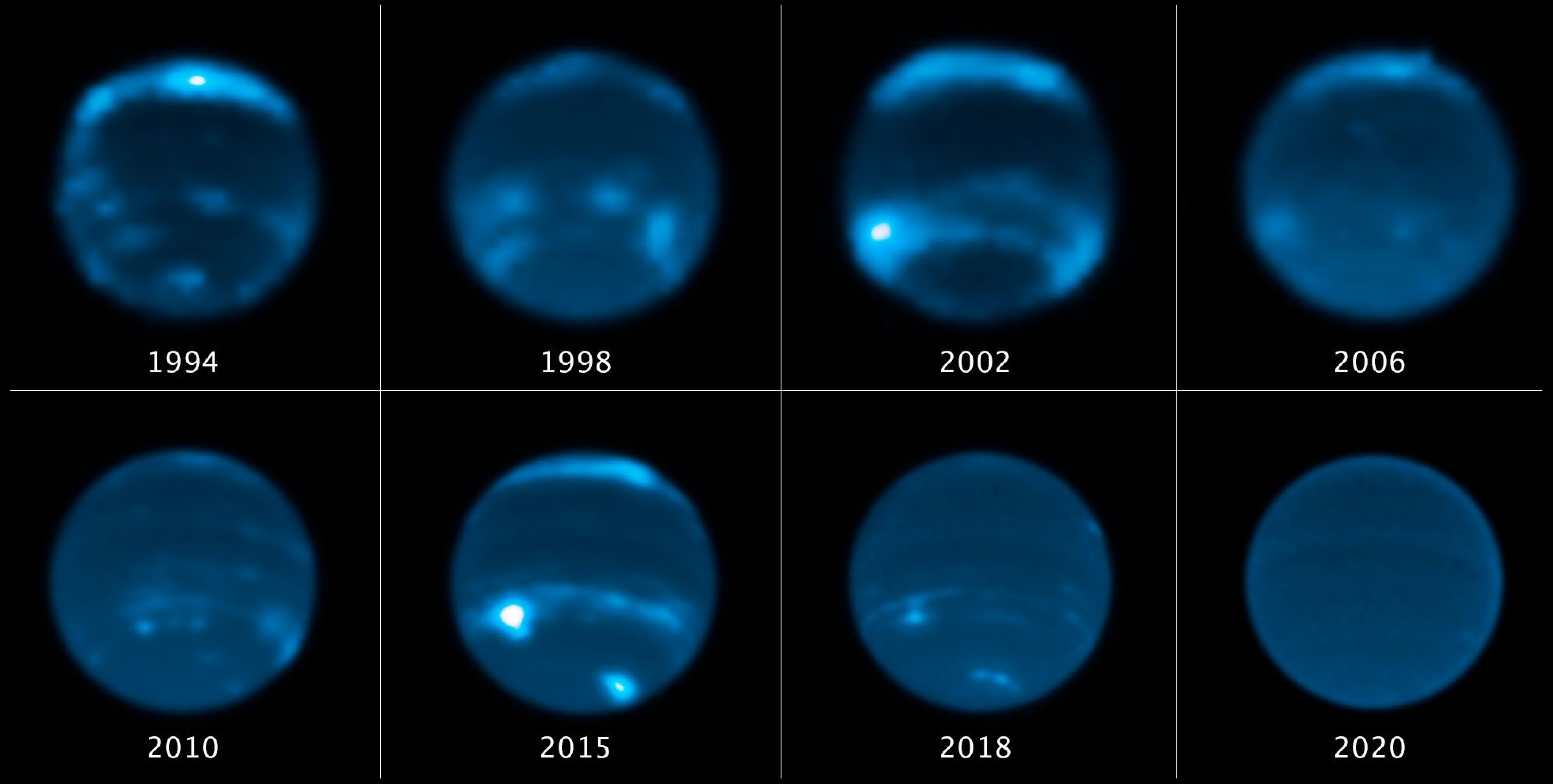


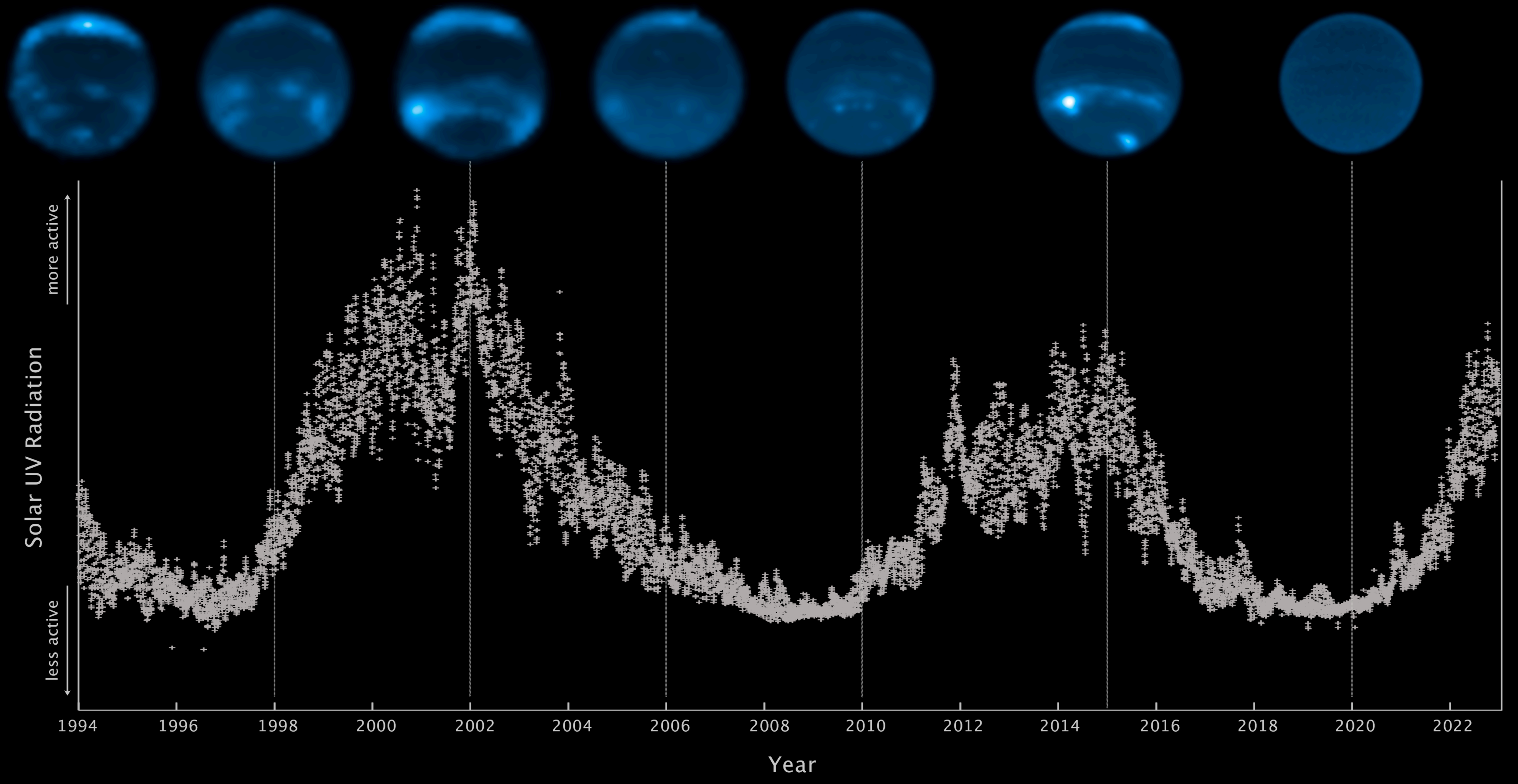
Picoflare jets seen on 30 March 2022
(rendered in negative; each box is 6000 km square)

Chitta et al. 2023, Science

Hubble Space Telescope on 19 May 2009 / NASA, ESA, STS-125

Synoptic observations of clouds in the atmosphere of Neptune





- Long-term monitoring of clouds with HST & ground-based near-IR imaging
  - Clear correlation between cloud cover and solar activity, with peak at the end of solar maximum
  - Increased UV radiation causes changes deep in Neptune's atmosphere: complex interactions between photochemical & radiative processes involving CH_4, hydrocarbons, & hazes
  - These changes percolate into upper atmosphere after a couple of years, increasing cloud cover
- Major transition in Neptune's atmosphere in late 2019/early 2020, persisting until now
  - Disappearance of mid-latitude clouds, blank haze-dominated disk, south polar region still cloudy though

HST imaging of Neptune / NASA, ESA, Chavez & de Pater

Chavez et al. 2023, Icarus

CHEOPS exoplanet transit mission, launched 18 December 2019 / ESA, CH et al.

- Four warm "mini-Neptunes" seen in tight orbits around parent stars
  - Hints of existence from TESS, but CHEOPS use to catch predicted transits & confirm periods
  - "Missing link" planets intermediate in mass between Earth & Neptune: expected to be very common

CHEOPS / ESA, CH et al.

Garai et al. 2023, A&A; Osborn et al. 2023, MNRAS; Tuson et al. 2023, MNRAS; Ulmer-Moll 2023, A&A

- LTT 9779b: an ultrahot, extremely high albedo Neptune-mass planet
  - Found by TESS, characterised by HARPS, 10 secondary eclipse measurements by CHEOPS
  - Surprisingly deep secondary transits: 115 ± 24 parts per million
  - Yields very high albedo $0.80^{+0.10}_{-0.17}$ (cf. Venus = 0.77), temperature ~2000K
  - Best-fit model: hot, metal-rich atmosphere (400 x solar) with titanium-bearing condensates + silicates

CHEOPS / ESA, CH et al.

Hoyer et al. 2023, A&A


All images: NASA, ESA, CSA, STScI
Carina Nebula
Eagle Nebula
VLA1623 in ρ Ophiuchi

Orion image: Rogelio Bernal Andreo

Orion Nebula in the visible / HST Treasury project, NASA, ESA, Robberto et al.

Orion Nebula in the visible / HST Treasury project, NASA, ESA, Robberto et al.

Orion Nebula & Trapezium Cluster with JWST NIRCam: long wavelengths

NASA, ESA, CSA / McCaughrean & Pearson

Orion Nebula & Trapezium Cluster with JWST NIRCam: short wavelengths

NASA, ESA, CSA / McCaughrean & Pearson

Jupiter-Mass Binary Objects in the Orion Nebula / JWST NIRCam short-wavelength composite

Pearson & McCaughrean 2023, Nature, submitted


esa
Exoplanet gallery
Martin Vargic
THE EUROPEAN SPACE AGENCY
Kepler 264 c
Venus
Kepler 124 d
Kepler 126 c
Kepler 55 f
Kepler 158 b
Kepler 127 d
Kepler 274 c
Gliese 176 b
Gliese 667 b
Kepler 48 d
Kepler 69 c
Kepler 184 c
Kepler 54 d
HD 219134 d
Kepler 286 e
Kepler 313 c
HD 136352 c
Kepler 220 c
HD80606 b
Kepler 158 c
Kepler-377 c
Kepler 215 e
HIP 116454 b
Kepler 49 c
Kepler 93 b
Kepler 49 e
Kepler 174 b
Kepler-123 c
GU Piscium B
Kepler 247 b
Kepler 124 d
Kepler 161 c
Kepler 144 b
Kepler 49 d
Kepler 314 b
Kepler 10 b
Kepler 62 b
Kepler 55d
Kepler 322 b
Kepler 323 b
WASP-89 b
Kepler-172 b
5 g/cm3 / 312 lb/ft3
OGLE 05 390 L b
GJ 667C g
NY Vir c
HD 219134 e
HD 192310 c
Gj 163 d
Kepler 178 d
Kepler 444 d
Kepler 260 c
Kepler 288 d
Kepler-439 b
Kepler 174 d
HD 192310 c
Kepler 442 b
HD 7199 b
Kepler 22 b
Gliese 581 c
LKCA 15 b
OGLE 2005 BLG 169 Lb
HD 134060 c
HD 10180 g
Mars
KIC 5522786 b
HD 126614 b
HD 28185 b
HD 47186 c
Kepler 93 b
1 UMi b
HD 204941 b
Kepler 172 d
Kepler-445 c
Kepler 149 c
Kepler-61 b
Kepler 220 d
Kepler-220 e
Gj 163 c
Kepler-85 e
Kepler 331 b
Kepler 49 b
Kepler 169 d
Kepler 55 e
Kepler 173 c
Kepler 325 d
Kepler 325 c
Kepler 186 d
Kepler 176b
Kepler 181 b
Kepler 186 c
Kepler 181 c
Kepler-297 c
Kepler-293 c
Kepler-357 d
Kepler 158 c
Kepler 251 d
Kepler 187 c
Kepler-11 g
Kepler 28 b
Kepler 219 c
Kepler-147 b
Kepler-68 b
Kepler 335 c
Kepler 31 d
Kepler 248 c
Kepler-315 c
Kepler 251 e
Kepler 199 c
Kepler 172 e
Kepler 169 e
Kepler 84 e
Kepler 20 c
Kepler 11 b
XO-3 b
Kepler 185 b
4 g/cm3
3 g/cm3 / 187 lb/ft3
HD 183263 c
HD 166724 b
BD-114672 b
KIC 12454613 b
Beta Umi b
Kepler 138 d
HU Aqr(AB) c
HD 30669 b
Wasp-41 C
HD 33564 b
HD 215456 c
Kepler 111 c
HD 67087 b
Kepler-413 b
Kepler-146 c
Kepler 9 b
TYC+1422-614-1 c
Kepler 31 c
Kepler 89 c
KOI-1089.02
HD 73526 c
KIC 6436029 b
Kepler 47 c
HD 134060 c
Kepler-164 d
Kepler-169 f
Kepler-175 c
Kepler-96 b
Kepler-170 c
Kepler-11 c
Kepler 176 c
Kepler 88 c
Kepler 4 b
Kepler-101 b
Kepler-175 b
Kepler-150 d
HATS-4 b
Kepler 58 d
Kepler 359 d
Kepler 281 b
2 g/cm3 / 125 lb/ft3
PSR B1620-26 b
Fomalhaut b
55 Cnc d
MOA 2007 BLG 192Lb
HD 13931 b
Pluto
GJ 317 c
HD 85390 c
Kepler 86 b
Kepler 424 c
Kepler-396 c
Kepler-198 c
Kepler 229 c
Kepler 154 b
GJ 229 b
HD 20782 b
HD 69830 d
Gliese 436 b
Kepler 278 c
WASP 7 b
HD 38858 b
Kepler 47 b
Kepler-164 c
HD 134987
Kepler-229 d
Kepler 103 c
XO-25 c
Kepler-170 b
Kepler 56 b
Kepler-40 b
OGLE-2015-BLG-0966 b
HIP 57274 d
Neptune
OGLE-06-109L c

PLATO

- Transit survey with focus on terrestrial-mass exoplanets orbiting nearby Sun-like planets
- 26 x 12cm aperture cameras, each 81.4 megapixels, 25 sec cadence, >2 years per star
- ESA mission
- Launch 2026 on Ariane 6 to L2, nominal mission 4 years, up to 8.5 years

Background image: ESO, M Kornmesser

PLATO exoplanet transit survey mission, planned launch 2026 / ESA

Ariel

- Atmospheric chemistry & thermal properties of ~1000 exoplanets via transit spectroscopy
- 1.1 x 0.7 metre cryogenic telescope, photometry + spectroscopy from 0.5–7.8 microns
- ESA-led mission with NASA participation
- Launch 2029 on Ariane 6 to L2, nominal mission 4 years

Image: STFC RAL Space, UCL, Europlanet – Science Office

Comet Interceptor

- Close flyby & study of dynamically-new long period comet or interstellar object
- 3 spacecraft for in situ & remote observations at 400–1000 km at closest approach
- First ESA F-class mission, with JAXA participation
- Launch 2029 on Ariane 6 with Ariel to L2, loiter 2–3 years awaiting interesting target

Background: Comet 67P/C-G from 213km on 4 June 2015 / ESA, Rosetta, OSIRIS WAC

Gaia Milky Way surveyor, launched Dec 2013 / ESA

The Gaia Sky as of Early Data Release 3, 3 December 2020 / ESA, DPAC

40,000 selected stars within 100pc with known proper motions & radial velocities
Projected over 1.6 million years; trailing arc at each point is 80,000 years long

Brown, Jordan, Roegiers, Luri, Masana, Prusti, & Moitinho

Gaia lensed system positions superimposed on images from Pan-STARRS or Dark Energy Survey

Gaia Collaboration, Krone-Martins et al. 2023, A&A

- Strongly-lensed quasars important in cosmology
  - Direct measurement of H_0 via time delay between lensed components
  - Detailed studies of dark matter haloes & substructures
  - Constraining the Dark Energy equation of state

- New gravitationally-lensed quasars discovered by Gaia
  - 3,760,032 quasars searched for companions: 4,760,920 sources within 6” including original quasar
  - Various classification techniques, including similar Gaia spectra used to seek lensed counterparts
  - Final list of candidate systems: 381, of which 49 are strong

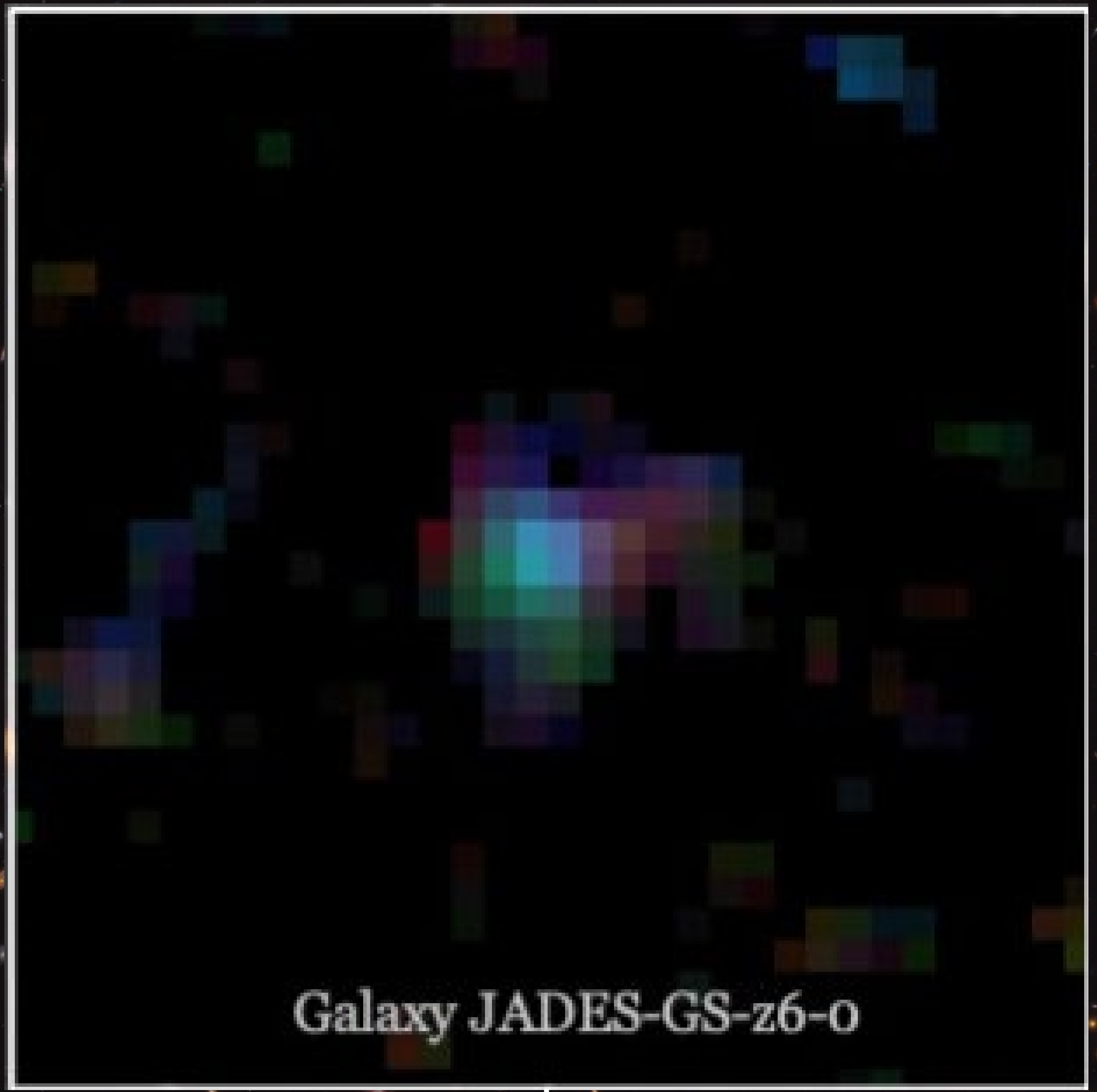
Gaia lensed system positions superimposed on images from Pan-STARRS or Dark Energy Survey

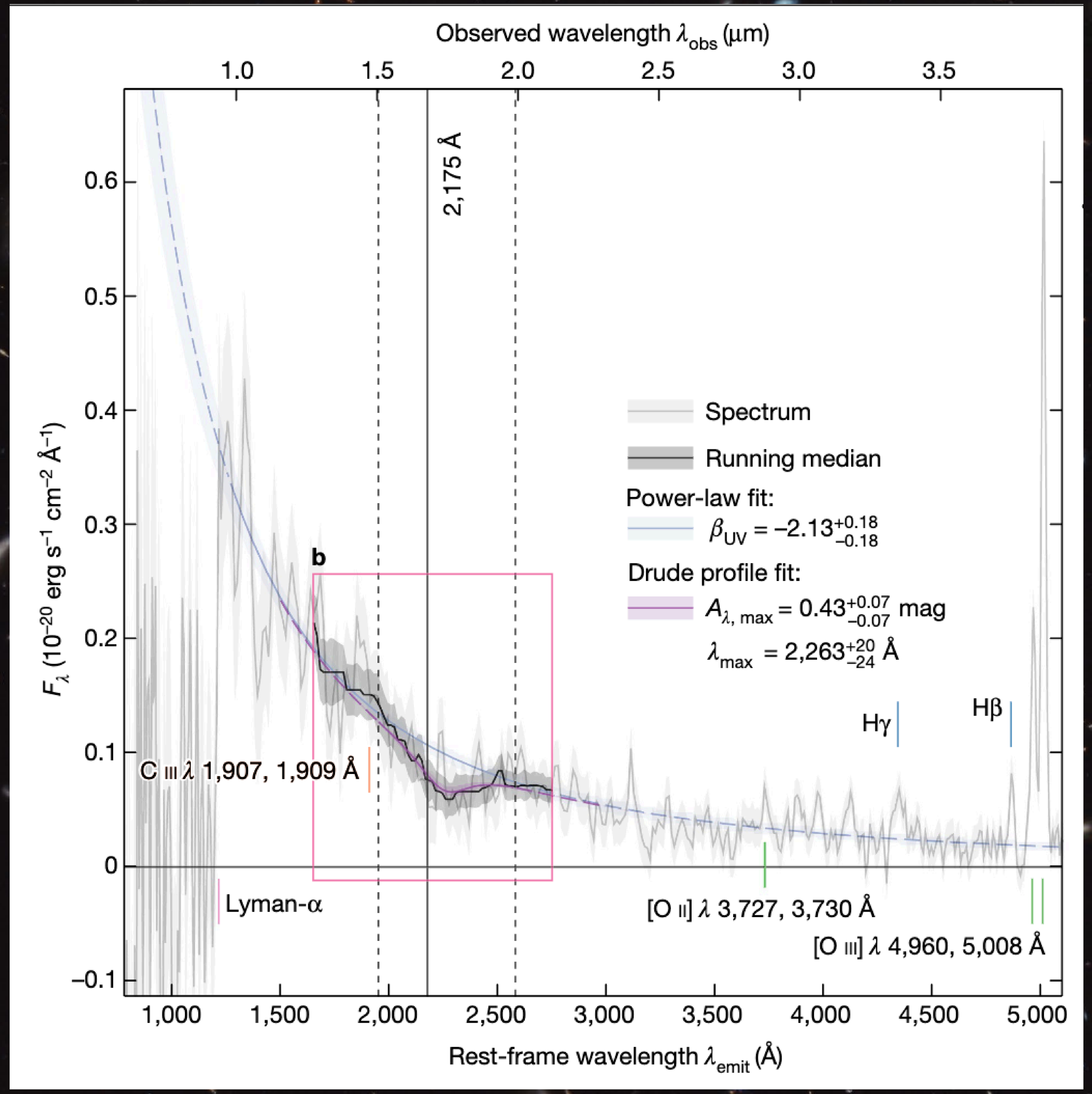
Gaia Collaboration, Krone-Martins et al. 2023, A&A

Great Observatories Origins Deep Survey field south (GOODS-S), 2016 / NASA, ESA

JWST JADES survey in the GOODS-S field / NIRCam & NIRSpec GTO teams / NASA, ESA, CSA

- Dust-rich galaxies in the first billion years
  - Massive dust reservoirs (~10^8 M$_\odot$) by z=8, 600Myr after Big Bang
  - Poses problems for dust formation via supernovae, AGB stars, etc.
  - Need additional diagnostics beyond total mass alone
- NIRSpec spectroscopy of galaxies in the JADES GOOD-S field
  - Target redshifted 2175Å UV attenuation bump due to PAHs
  - R=100 prism + multi-shutter array, total integration 9.3–27.9 hrs
  - Strong signal in JADES-GS-z6 at z=6.71 (~800Myr after Big Bang)
- What can produce so much carbon-rich dust so quickly?
  - Traditional route via low-mass (0.5–8 M$_\odot$) stars in AGB phase at end of life
  - But at 800Myr after the Big Bang, stars typically only 400 Myr old & will not yet have evolved into AGB phase
  - Needs faster dust production channels: supernovae & Wolf-Rayet stars
  - For standard IMF, carbon-rich WR stars relatively rare
  - Conversely, supernovae can produce substantial dust in ejecta
  - Observations place new constraints on dust production models



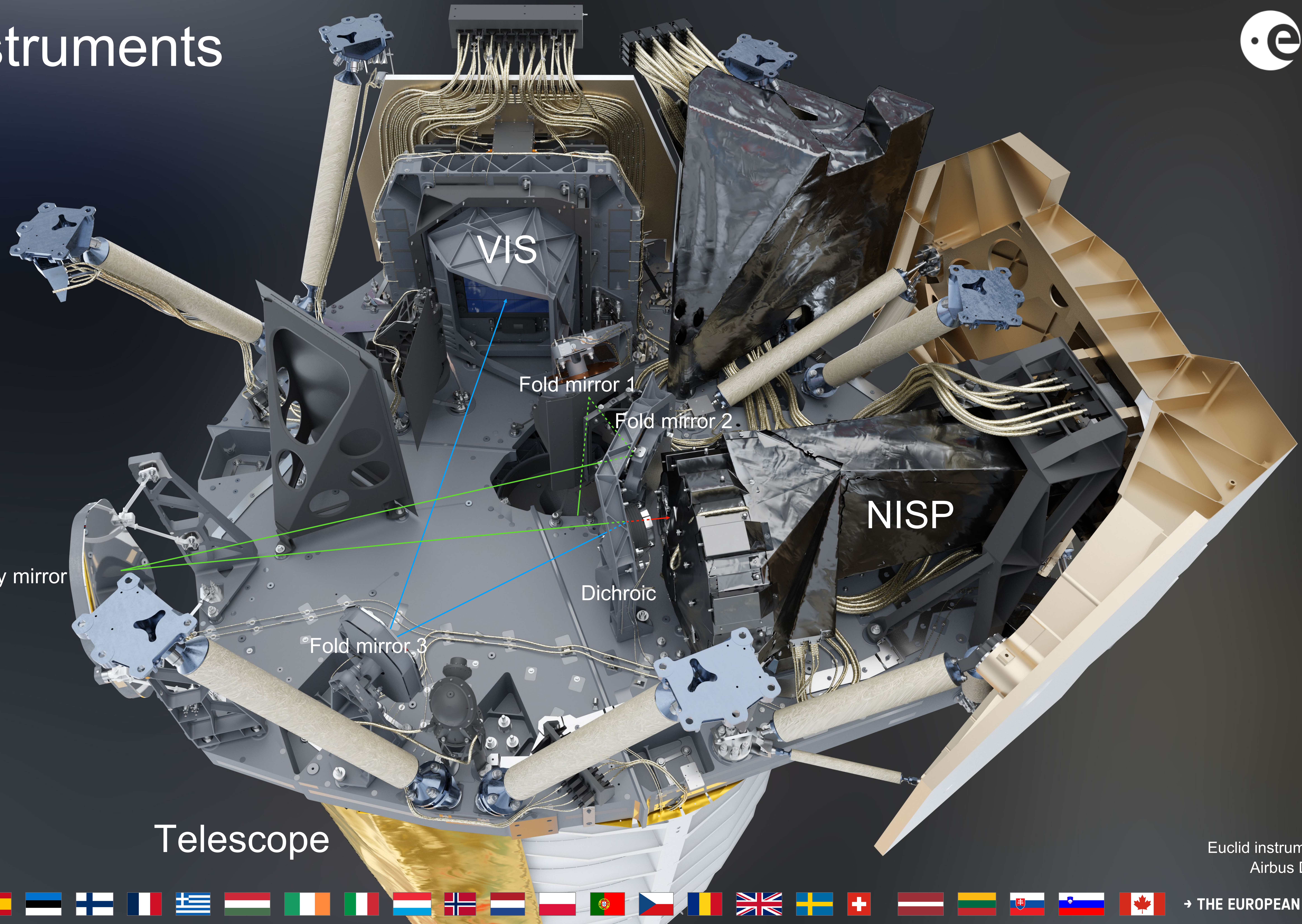


Witsok et al. 2023, Nature

JWST JADES survey in the GOODS-S field / NIRCam & NIRSpec GTO teams / NASA, ESA, CSA


esa
Euclid Mission
mos, FHP, GMV, Active Soace, Ai, FCUL
ESA, ATG medialab, CC BY-SA 3.0 IGO

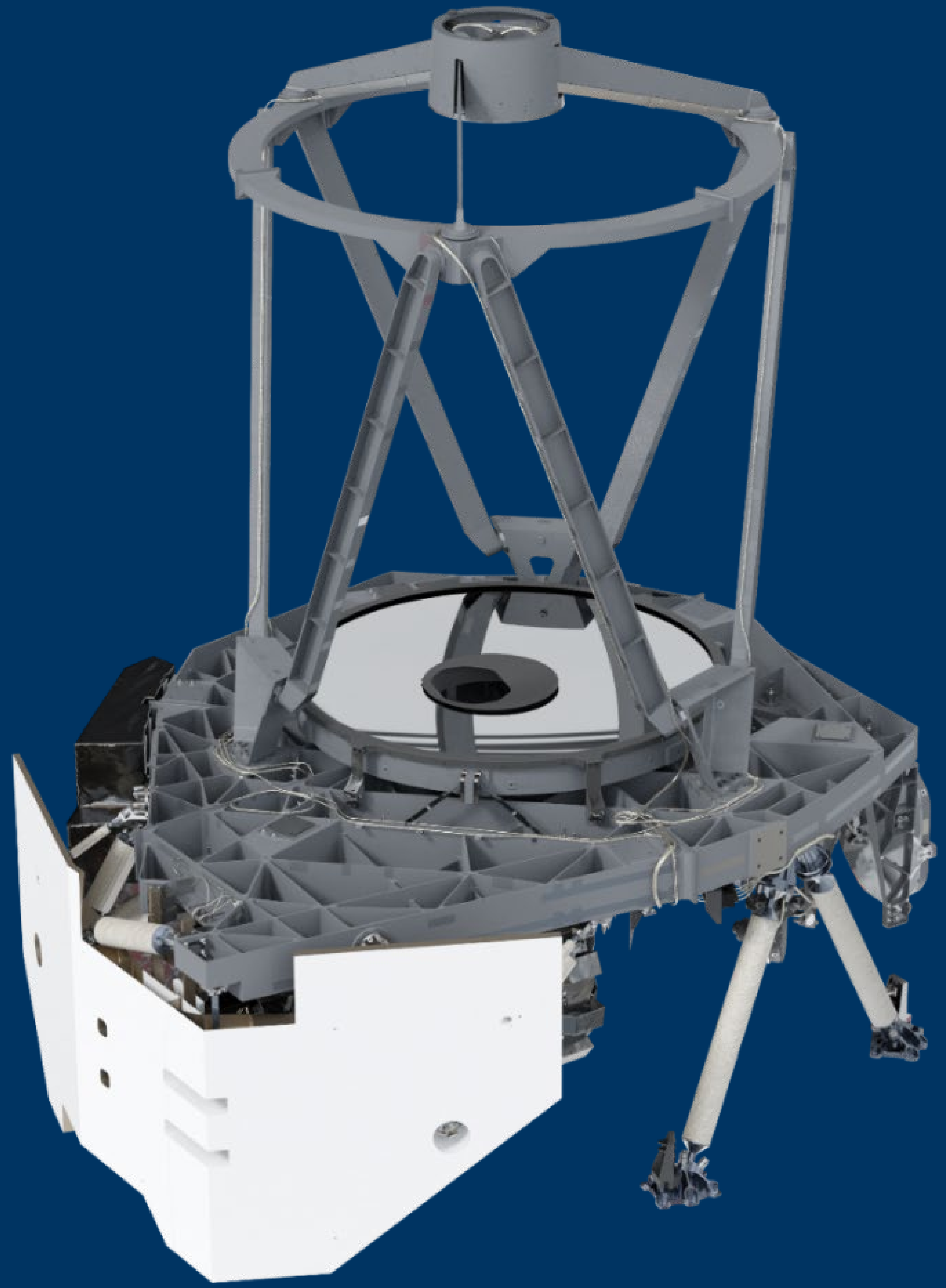
Instruments



Euclid instruments VIS & NISP
Airbus Defence & Space

→ THE EUROPEAN SPACE AGENCY

Telescope



- All silicon carbide 3-mirror Korsch anastigmat, with a 1.2 metre primary diameter
- Wide field-of-view & stable, diffraction-limited imaging

Euclid telescope in testing at CSL Liège
ESA, Airbus Defence & Space


EUCLID
esa

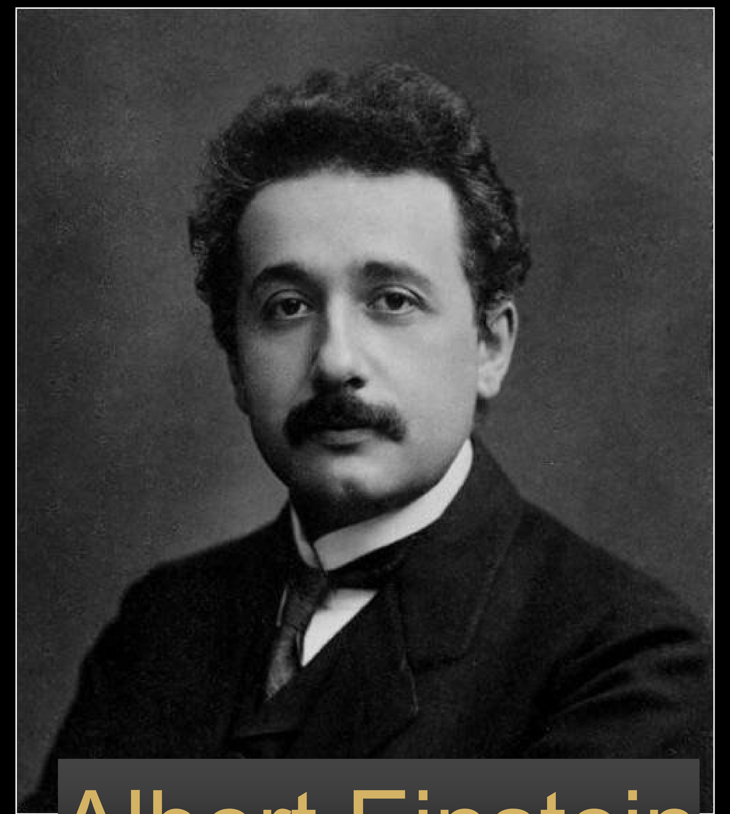
Euclid spacecraft immediately prior to fairing encapsulation at Astrotech, June 27 2023

ESA, SpaceX

Euclid launch from SLC-40 at Cape Canaveral, 1 July 2023 / SpaceX

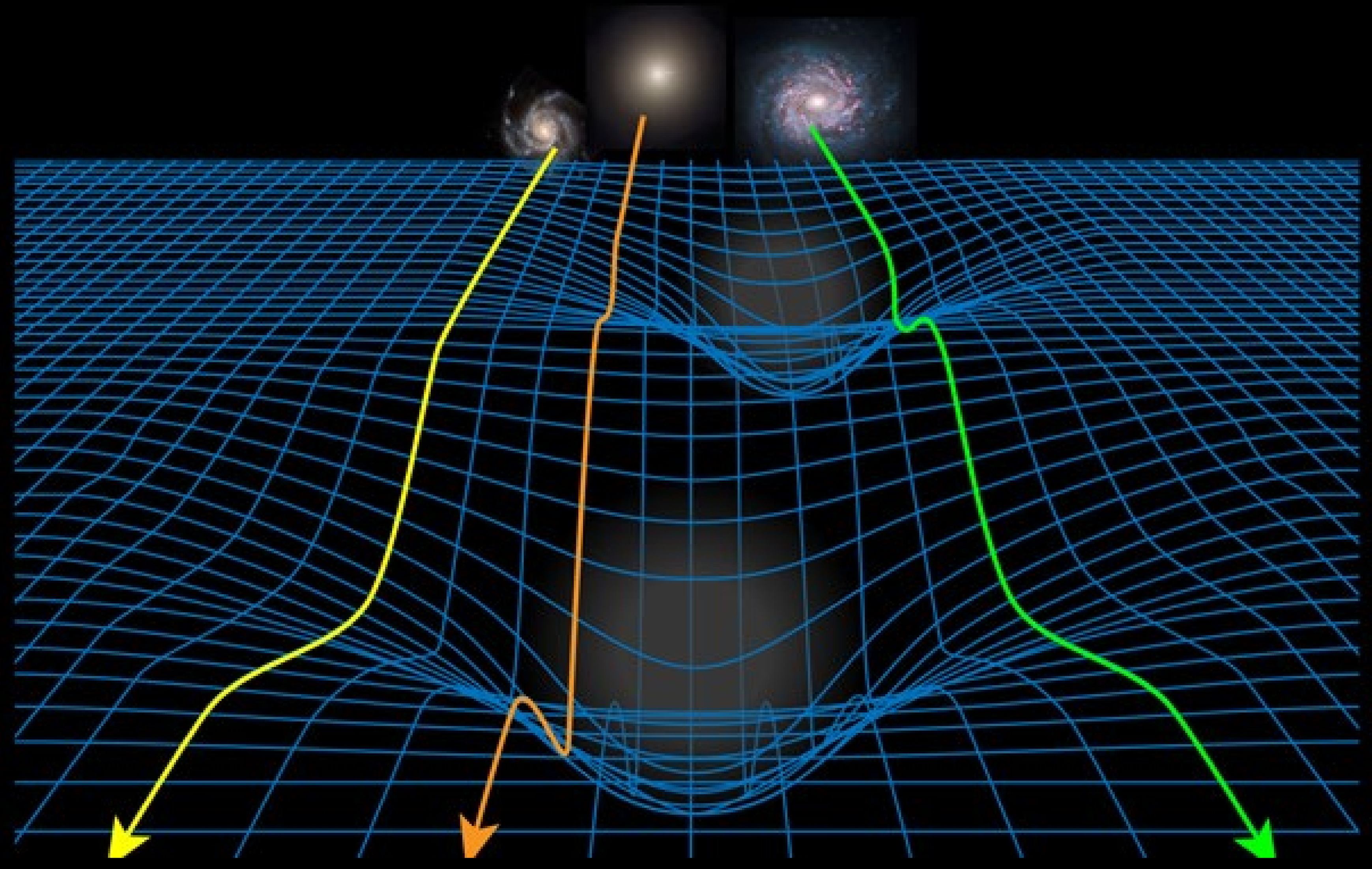
The Nature of Space-Time ?

Emmy Nöther
(1882 – 1935)

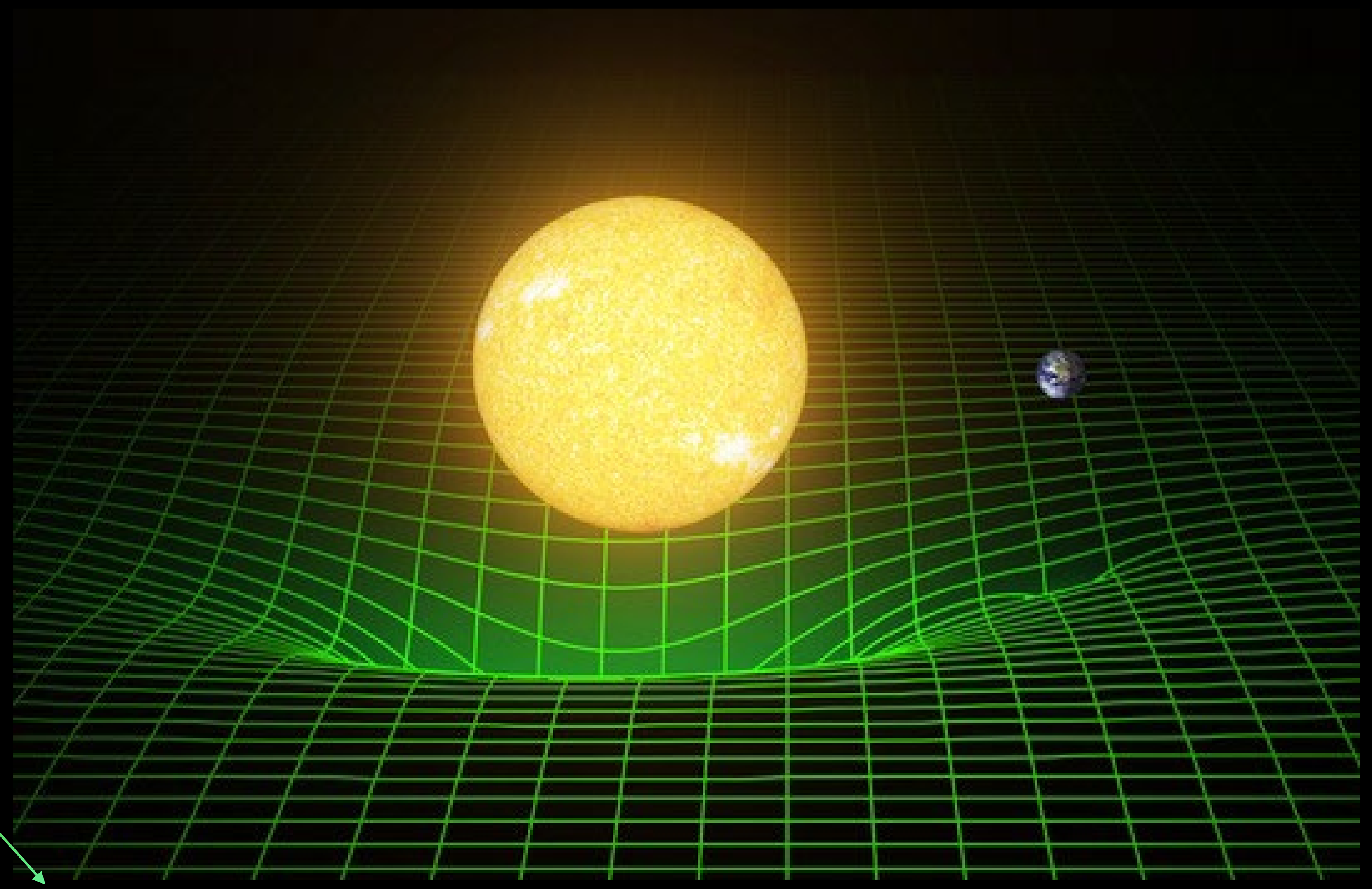


Albert Einstein
(1879 – 1955)

$$G_{\mu\nu} = \frac{8\pi G}{c^4} T_{\mu\nu}$$



"Space-time tells matter & light how to move"



"Matter & energy tell space-time how to bend"

APS/Alan Stonebraker

LIGO Lab/Caltech

→ THE EUROPEAN SPACE AGENCY

The Nature of Space-Time ?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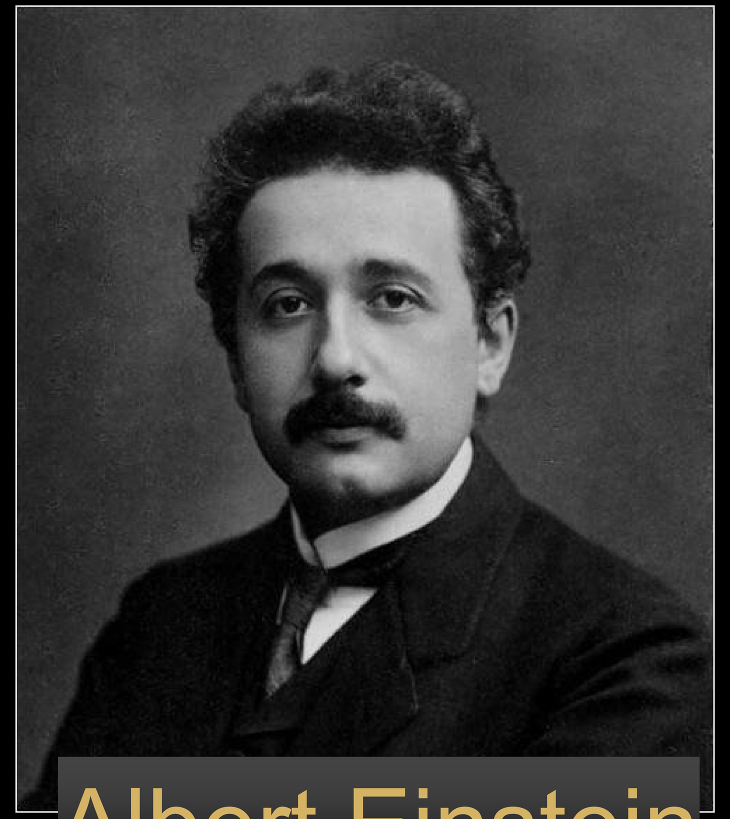
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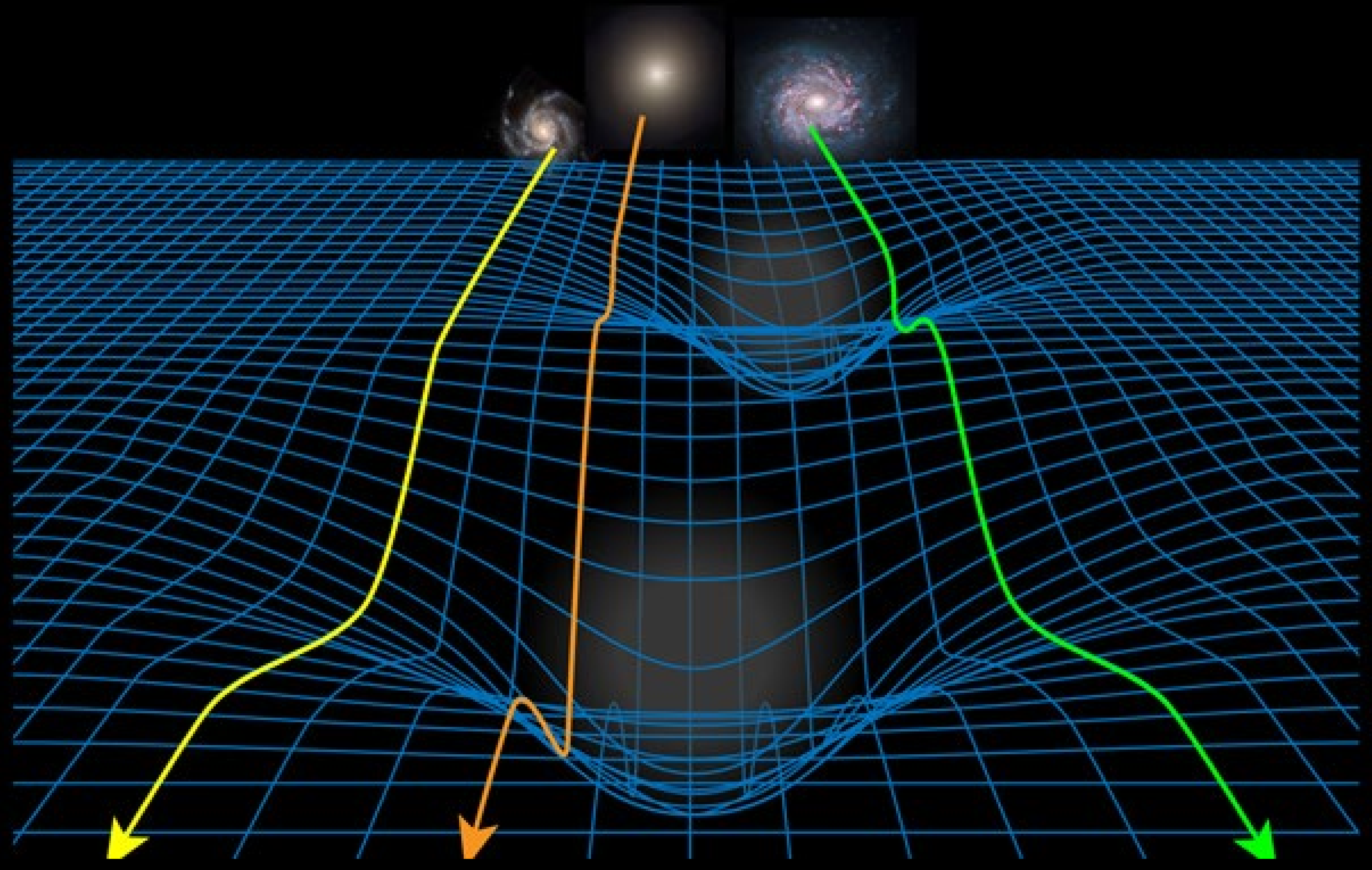
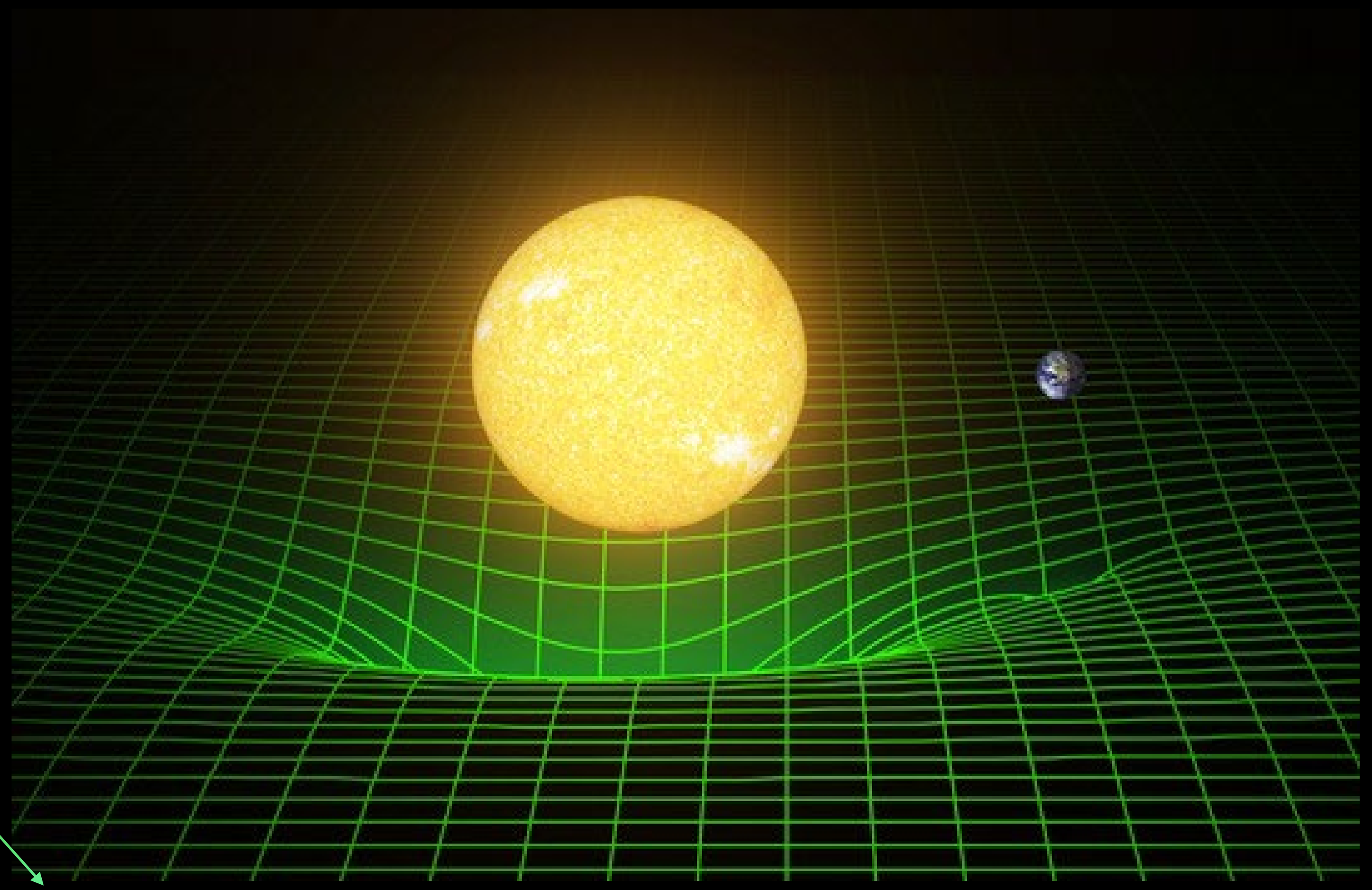


Space-time tells matter & light how to move”

+ ?

Evolution of Expansion



“Matter & energy tell space-time how to bend”

APS/Alan Stonebraker

LIGO Lab/Caltech

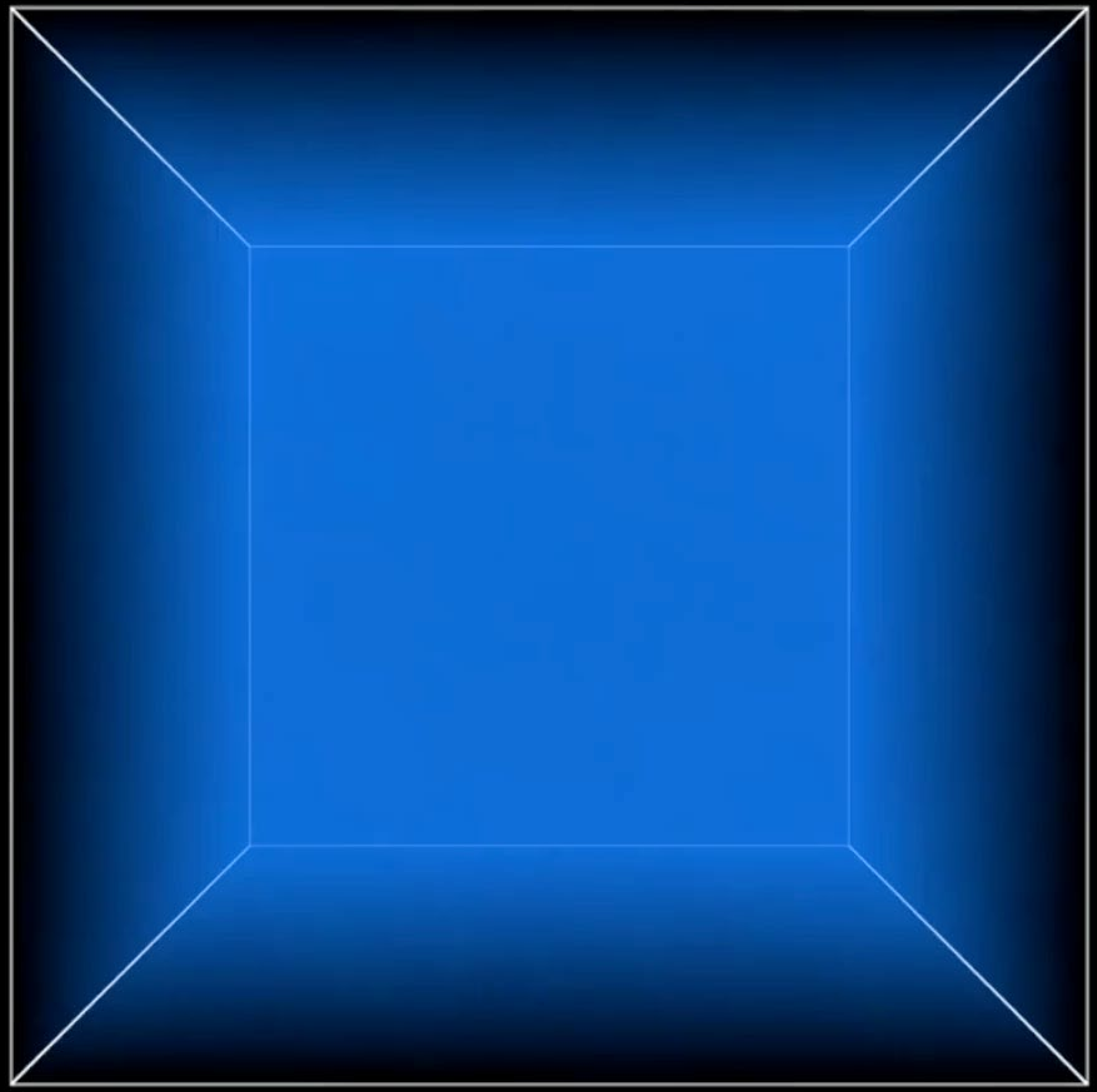
Schematic history of the universe

WMAP Science Team, NASA, Wikimedia

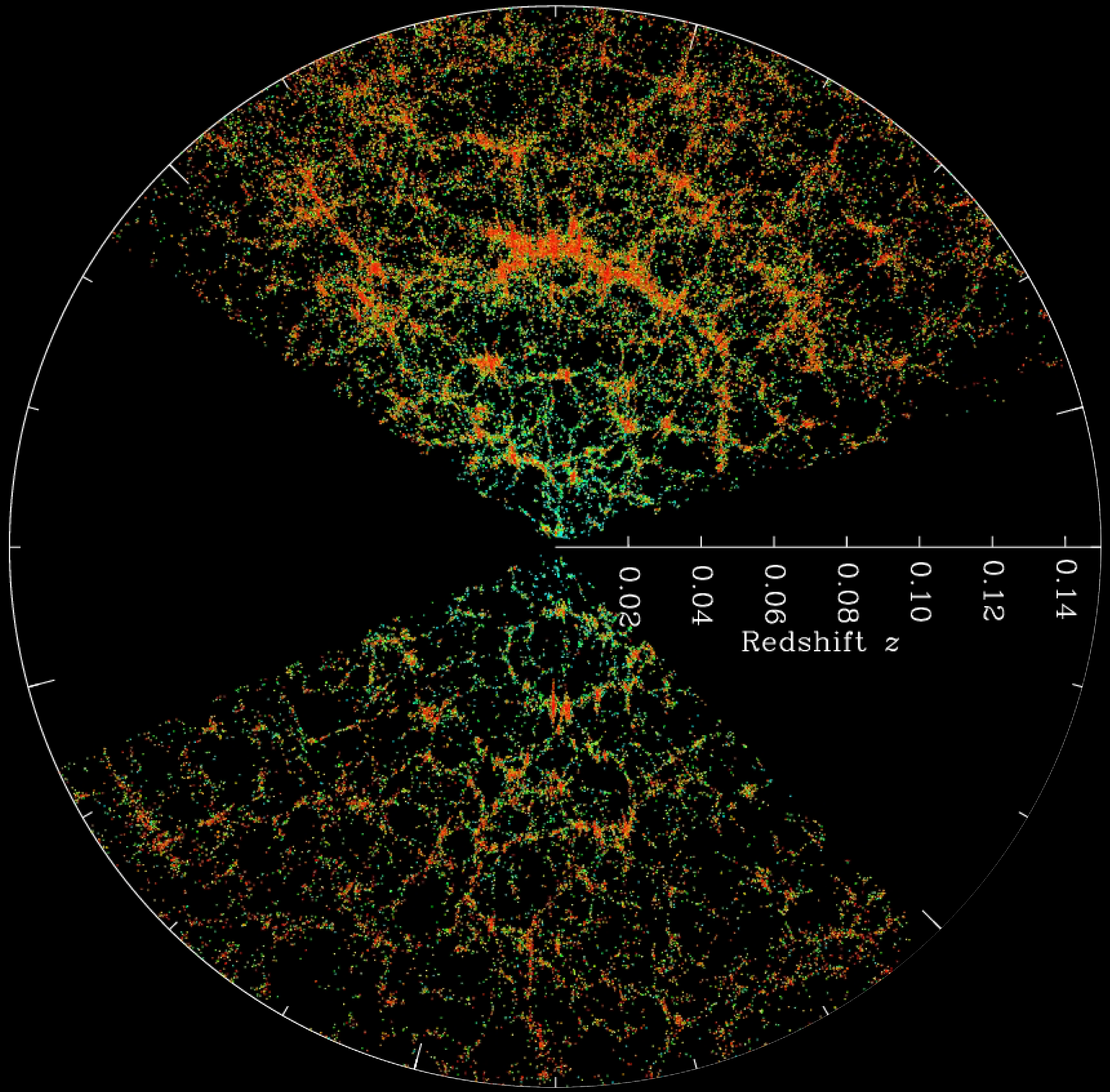
The CMB – the universe 380,000 years after the Big Bang

Planck, ESA

Evolution of gas density from Big Bang to present day

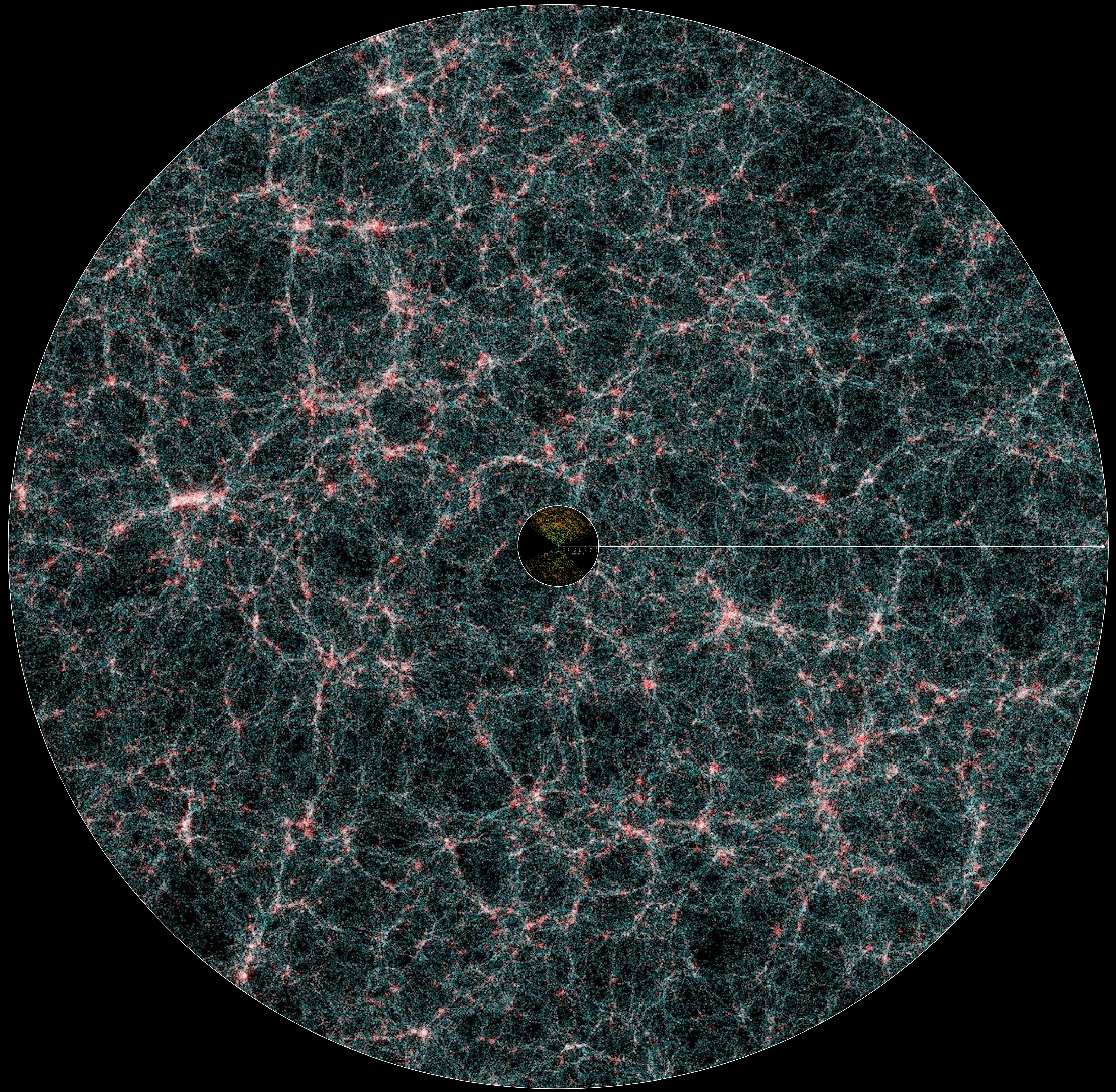


Mapping the cosmic web with redshift surveys



Simulation of the evolution of cosmic structure over lifetime of the universe / B Villasenor, UCSC

Sloan Digital Sky Survey galaxy map / M Blanton, SDSS



Euclid will survey galaxies out to redshift = 2,
3.3 billion years after the Big Bang

Euclid Consortium Flagship Simulation

esa

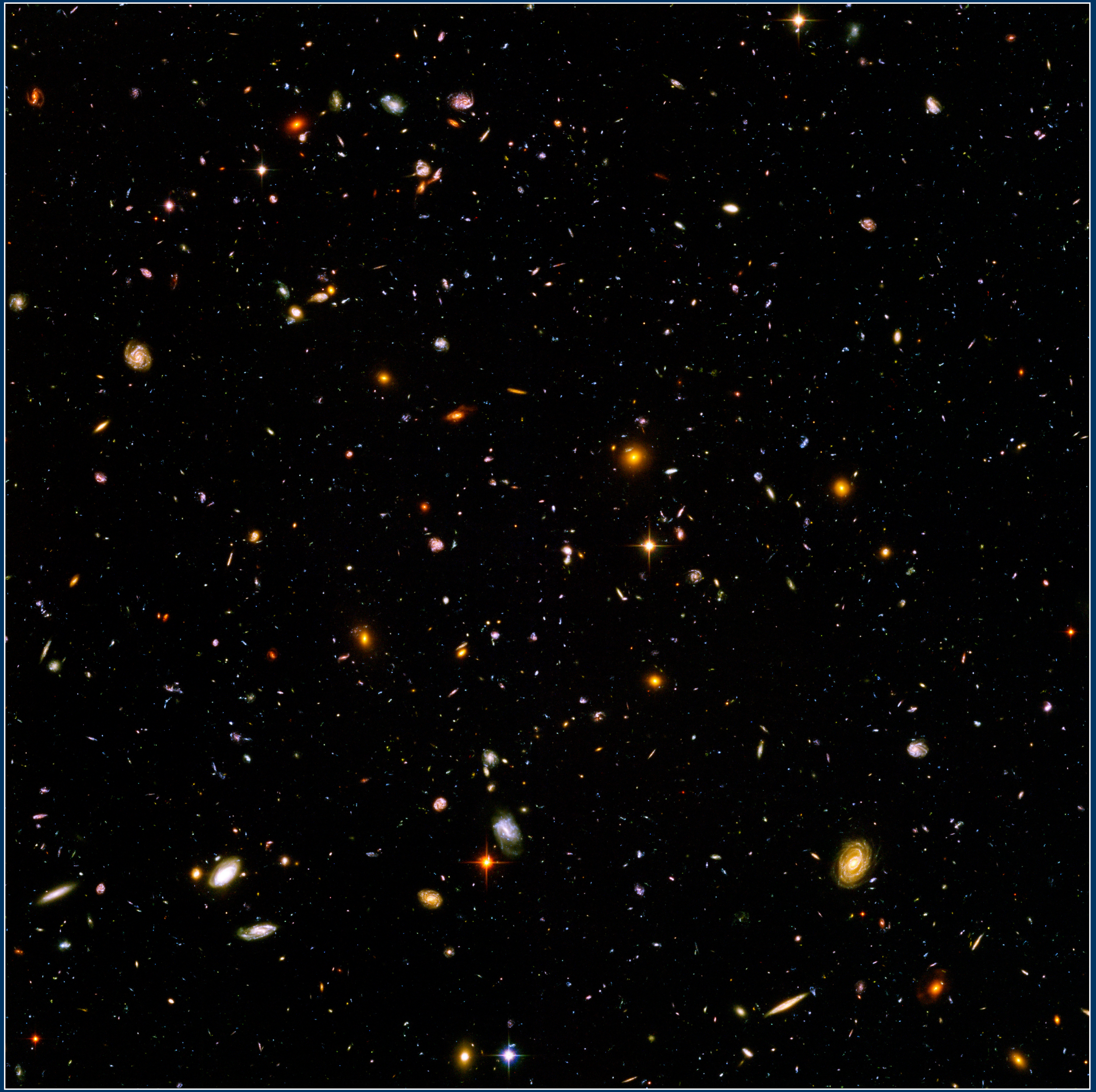
Euclid will survey ~1.5 billion galaxies in the universe looking back 10 billion yrs

Their positions, distances, & apparent shapes will map the distribution of Dark Matter

The evolution of structure will measure the accelerated expansion of the universe due to Dark Energy

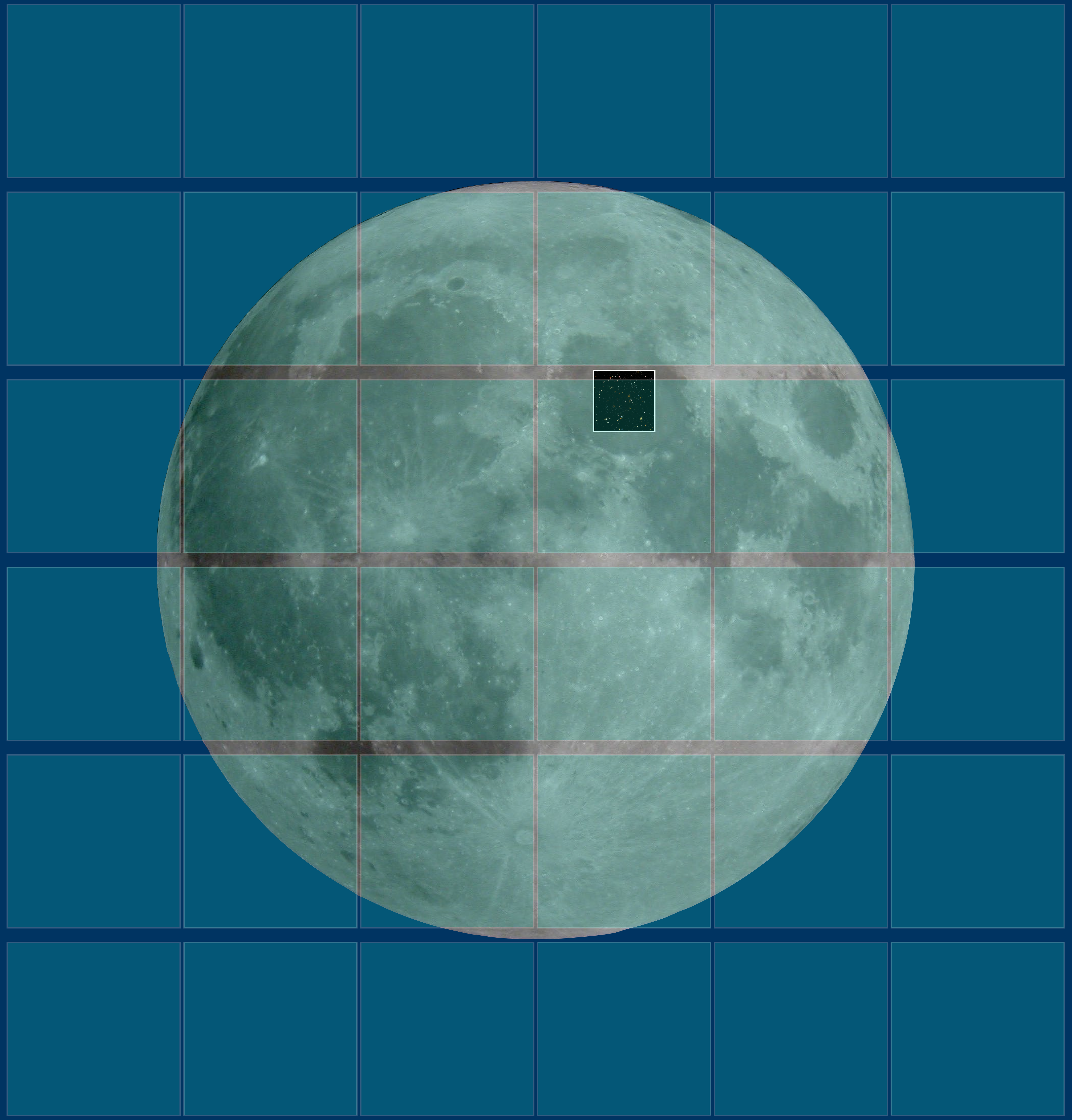
The growth of structure will also test our understanding of gravity acting on cosmic scales over cosmic time

Optimised for wide-field imaging & spectroscopy



Hubble Ultra Deep Field in Fornax: 2.6 x 2.6 arcmin

Optimised for wide-field imaging & spectroscopy



Euclid field-of-view: 42 x 44 arcmin

600 million pixels in 1 shot !

VIS:

36 4096 x 4132 pixel Si CCDs, supplied by Teledyne e2v

0.1 arcsec/pixel, 0.53–0.92 μm wide-band imaging

NISP:

16 2048 x 2048 pixel HgCdTe arrays, supplied by Teledyne & key NASA contribution to Euclid

0.3 arcsec/pixel, 0.95–2.02 μm Y/J/H-band imaging & R > 400 slitless spectroscopy

Total of ~30,000 independent fields to be studied with imaging & spectroscopy with diffraction-limited resolution

Moon / Matt Wedel

Euclid Release Image Nov 2023

The Perseus galaxy cluster

ESA, Euclid Consortium, NASA

The Perseus galaxy cluster

ESA, Euclid Consortium, NASA

The Perseus galaxy cluster

ESA, Euclid Consortium, NASA


The Perseus galaxy cluster

ESA, Euclid Consortium, NASA

The Perseus galaxy cluster

ESA, Euclid Consortium, NASA


IC342, "The Hidden Galaxy"
ESA, Euclid Consortium, NASA

Irregular galaxy NGC6822

ESA, Euclid Consortium, NASA

Irregular galaxy NGC6822

ESA, Euclid Consortium, NASA

The Horsehead Nebula & NGC2023 in Orion B

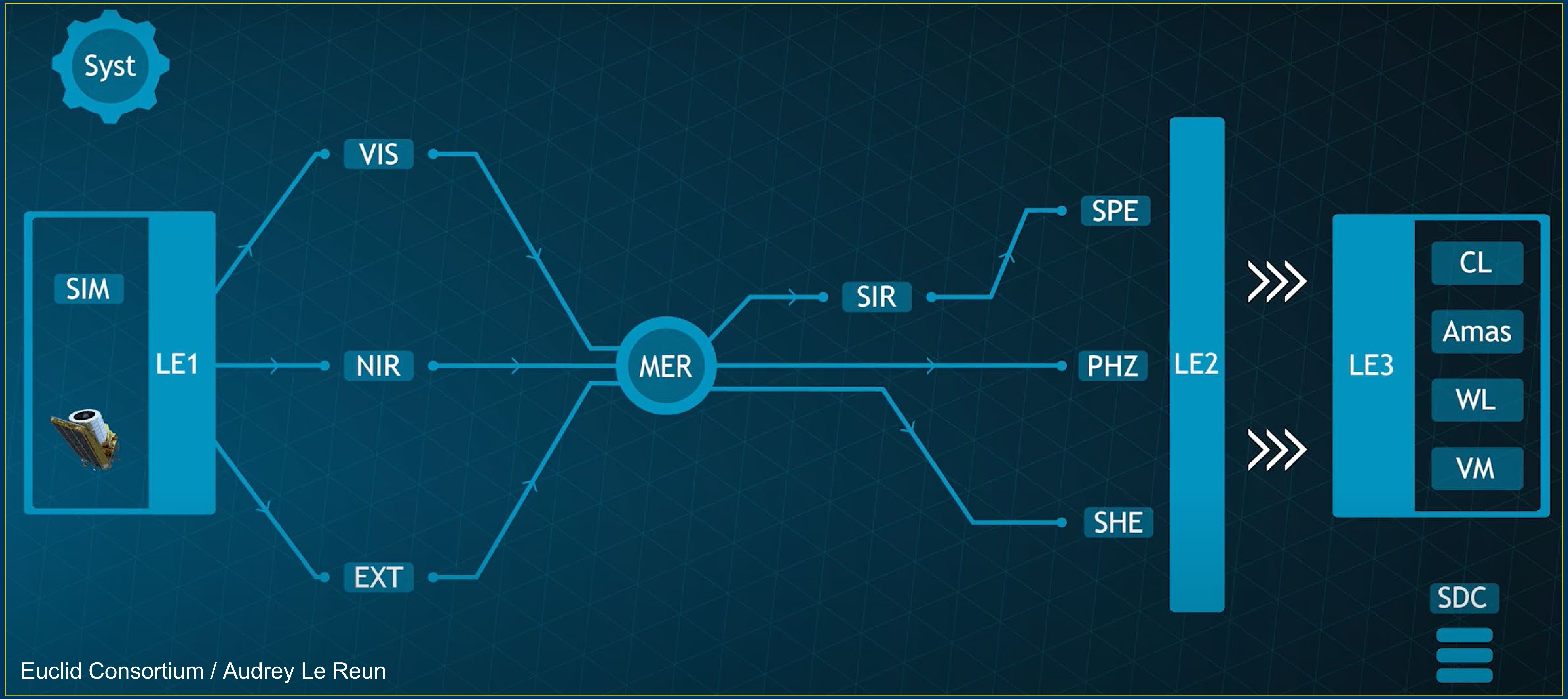
ESA, Euclid Consortium, NASA


Globular cluster NGC6397
ESA, Euclid Consortium, NASA

Euclid step-and-stare mapping

ESA

Science data processing



- Pipeline split across 9 Science Data Centres
- Each processing different patches of sky
- Products returned to central archive at ESAC

- Level 1 – raw data
- Level 2 – calibrated data products
- Level 3 – cosmology science-ready products

Total data volume: 170 petabytes (170,000,000 GB)

Euclid by numbers – Incredible European Teamwork!

Countries involved: 21

Science institutions: 300

Science personnel: ~2500

Companies involved: 80

Industry contracts: 140

Industry personnel: ~2000

Spacecraft mass: 2.2 tonnes

Telescope temperature: –140ºC

Number of pixels: 676 million

Survey duration: 6 yrs

Area of sky: 15,000 deg^2

Number of galaxies: 1.5 billion

Mission cost: ~ € 1.4 billion

Distance from Earth: 1.5 million km

Data download: 106GB/day

EnVision

- Studying the atmosphere, surface, & interior of Venus
- 3 optical spectrometers, S-band radar for altimetry & radiometry, HF radar to probe sub-surface
- ESA-led mission with key NASA contributions
- Launch 2031 on Ariane 6, 15 month cruise, 15 month aerobraking, 5 years science

Magellan SAR image: NASA, JPL-Caltech
Akatsuki UV image: JAXA, ISAS, DARTS, Damia Bouic

Render: ESA, NASA, Paris Observatory, V2RPlanets

LISA

- Gravitational wave observatory: colliding massive black holes, galactic binaries, Big Bang remnants
- 3 spacecraft separated by 2.5 million km, tracking free-falling test masses to picometres
- ESA-led mission with NASA participation
- Launch mid-2030’s on Ariane 6 to 1AU heliocentric orbit, nominal 4 year all-sky survey

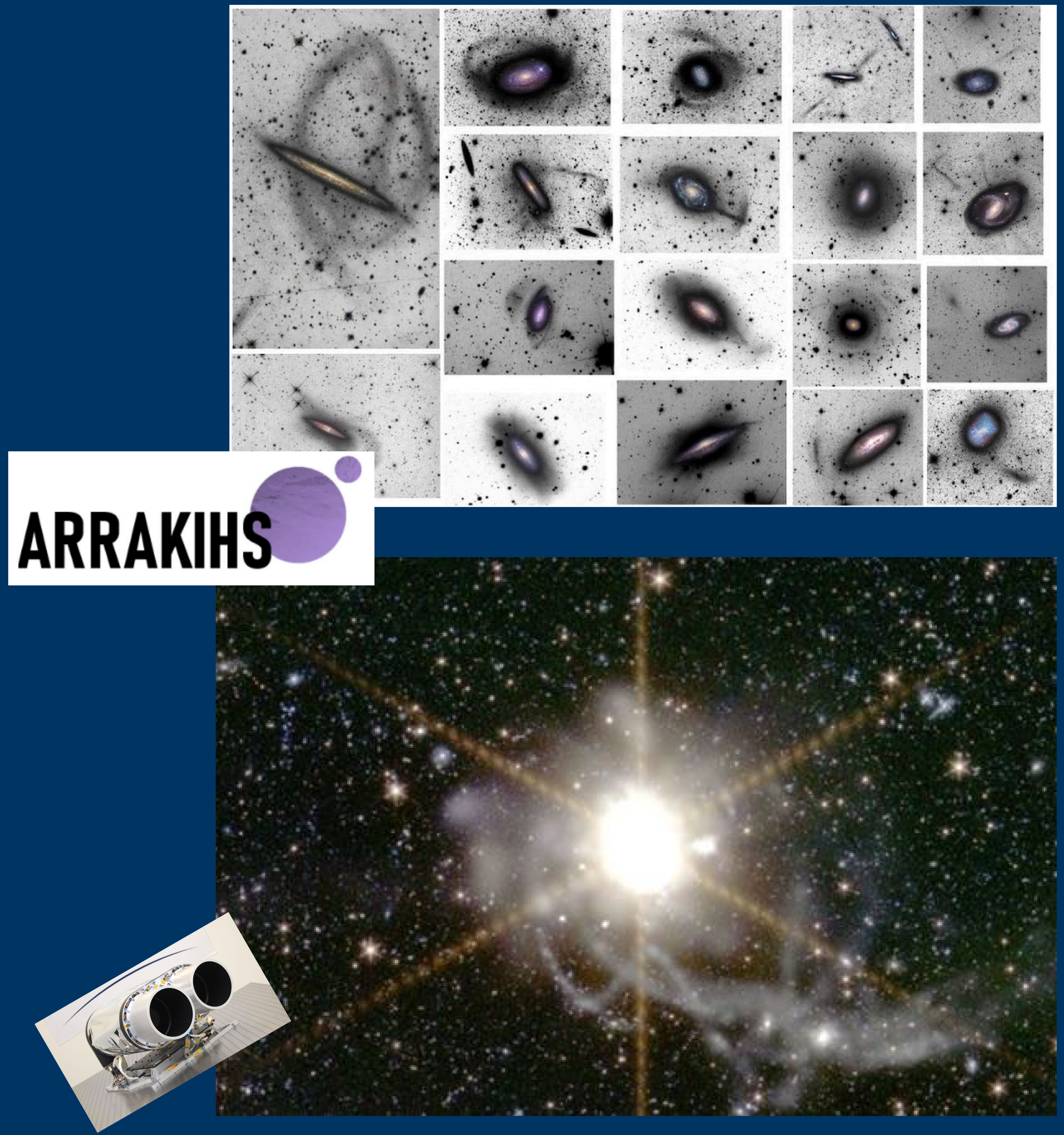
NewAthena

- Large x-ray observatory: formation of large-scale structures, growth & impact of massive black holes
- Silicon pore optic telescope + wide-field imager/spectrometer + cryogenic integral field spectrometer
- ESA-led mission with key contributions from NASA & JAXA
- In reformulation – adoption 2027 for launch 2037s on Ariane 6 to L1, nominal 4 year mission

Background: artist impression of an AGN / ESA, NASA, AVO, Padovani

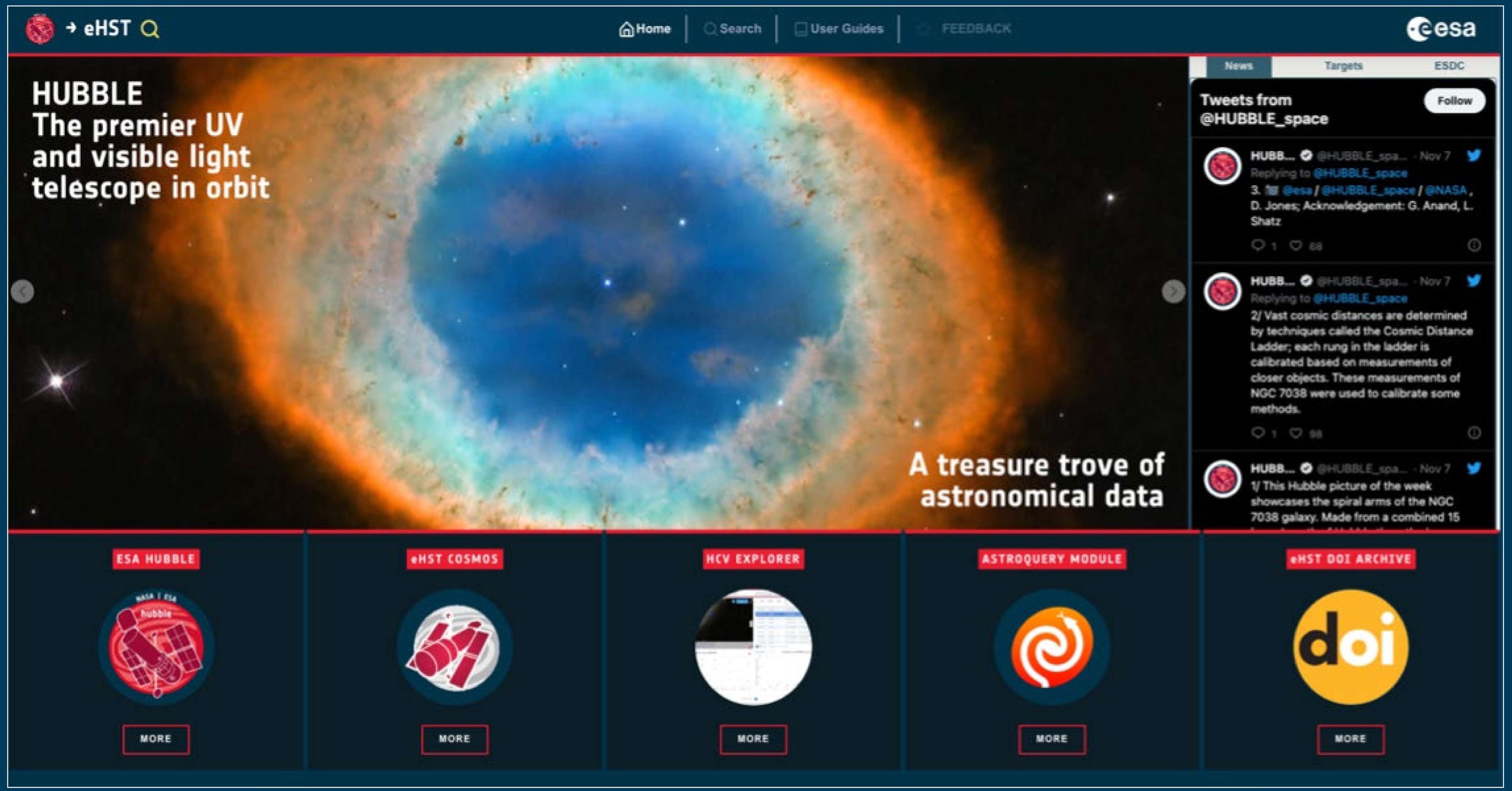
Voyage 2050 begins

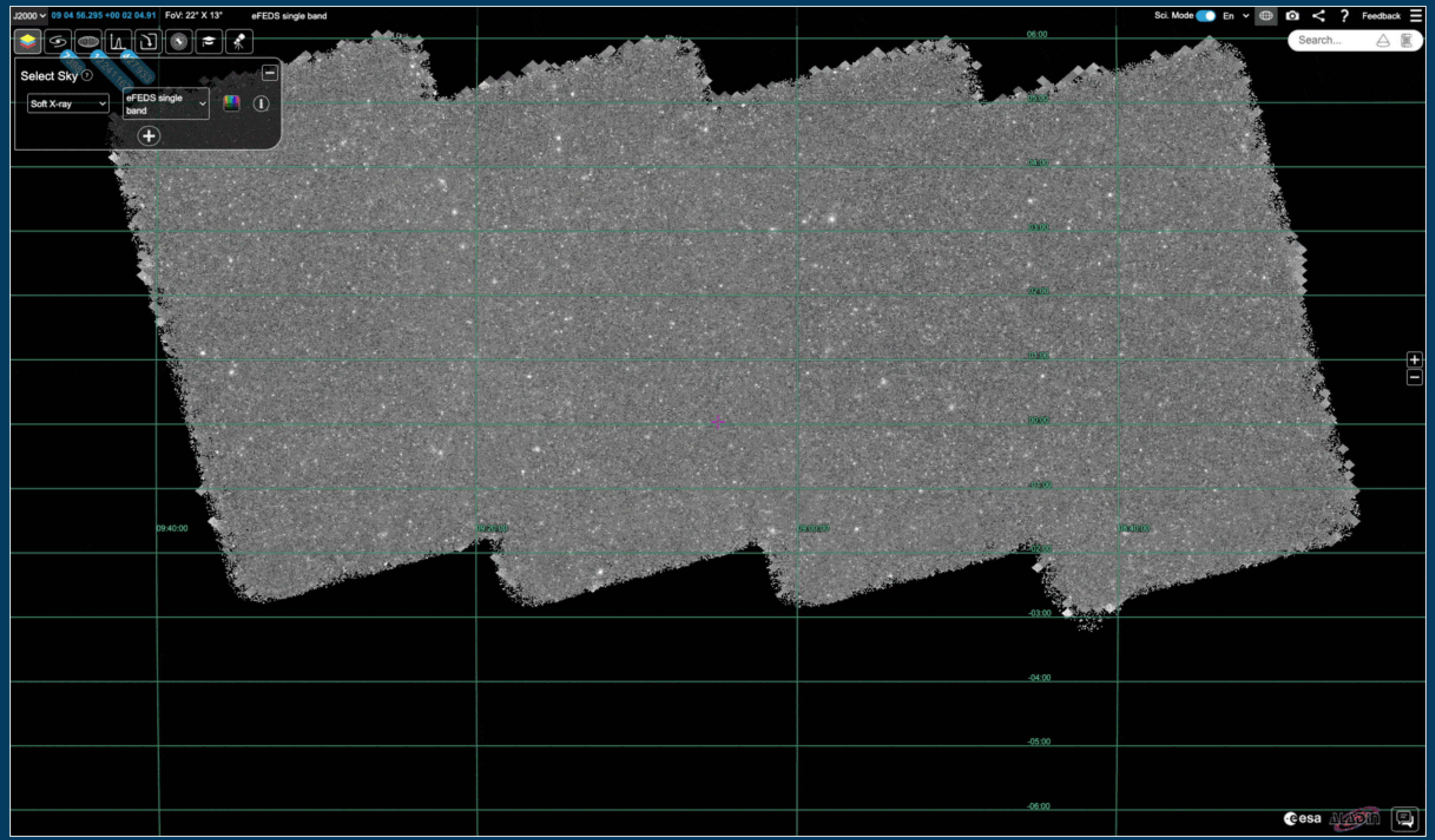
- M7 and F2 missions selection
- F2 ARRAKIHS mission selected in 2021; technical design work underway
- M7 finalists announced November 2023 : M-Matisse, Plasma Observatory, Theseus
- Phase A industry deisng studies underway. Final selection expected 2026

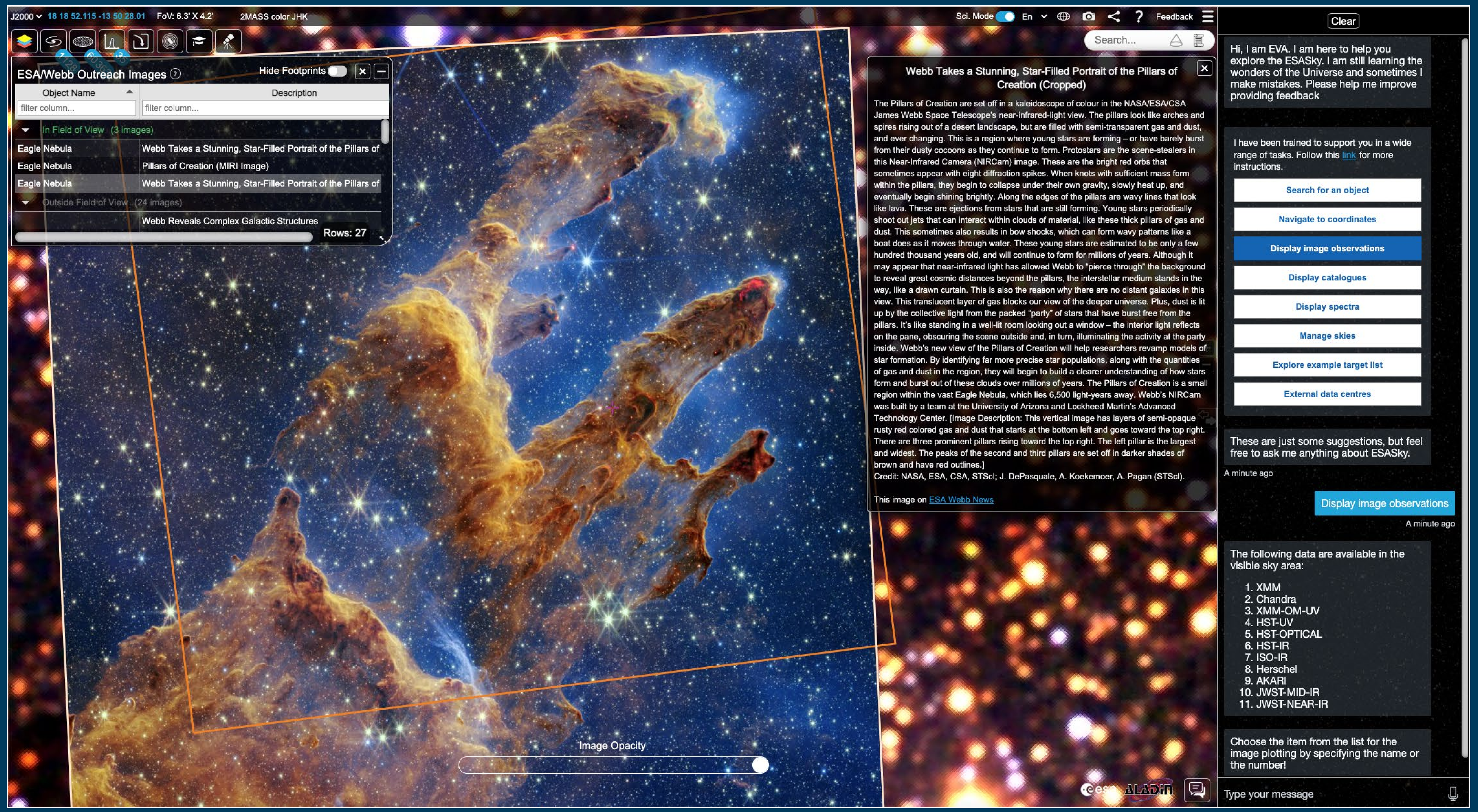


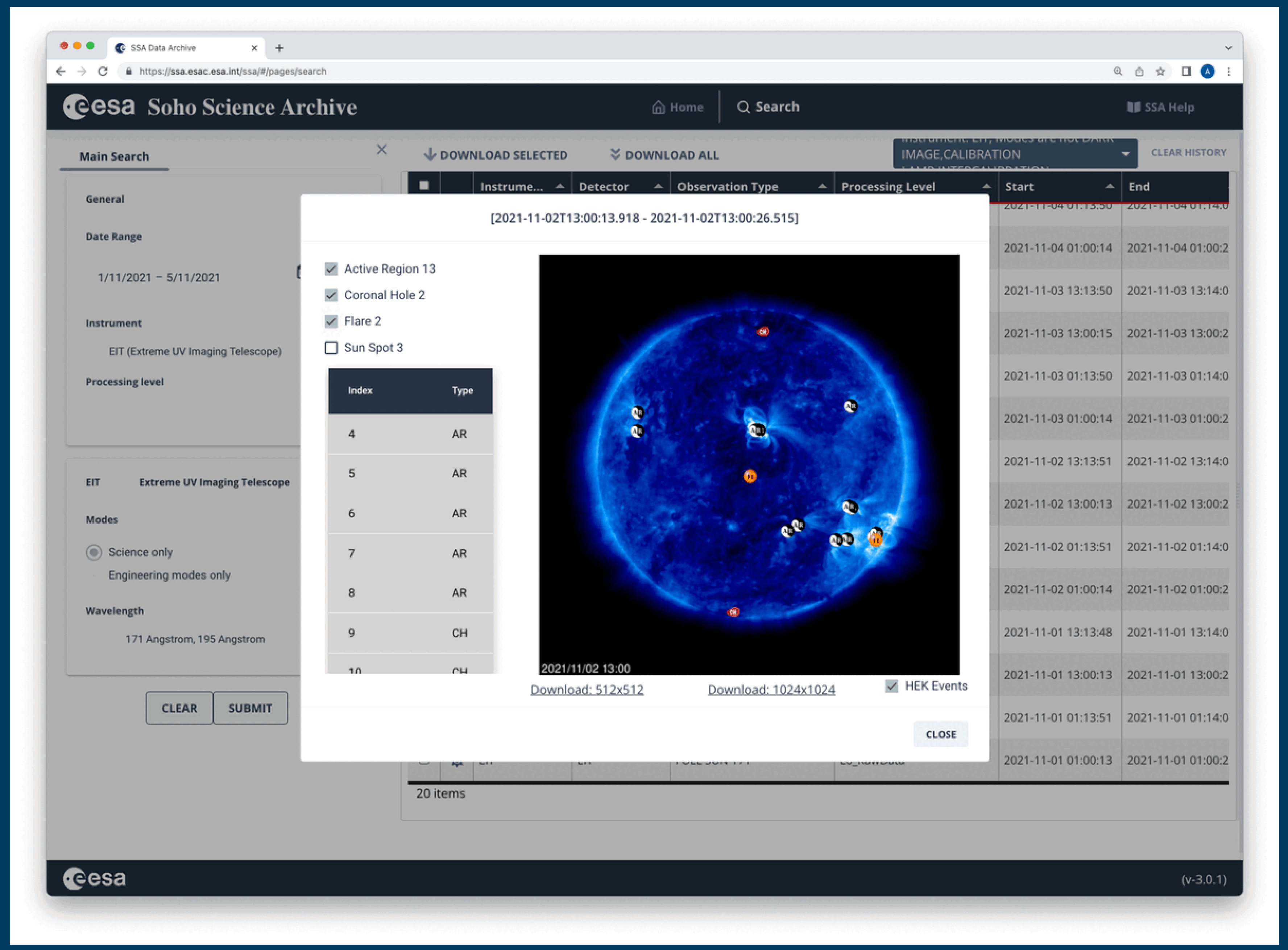
Science Archives

Serving 120 TB to 25,000 users each month

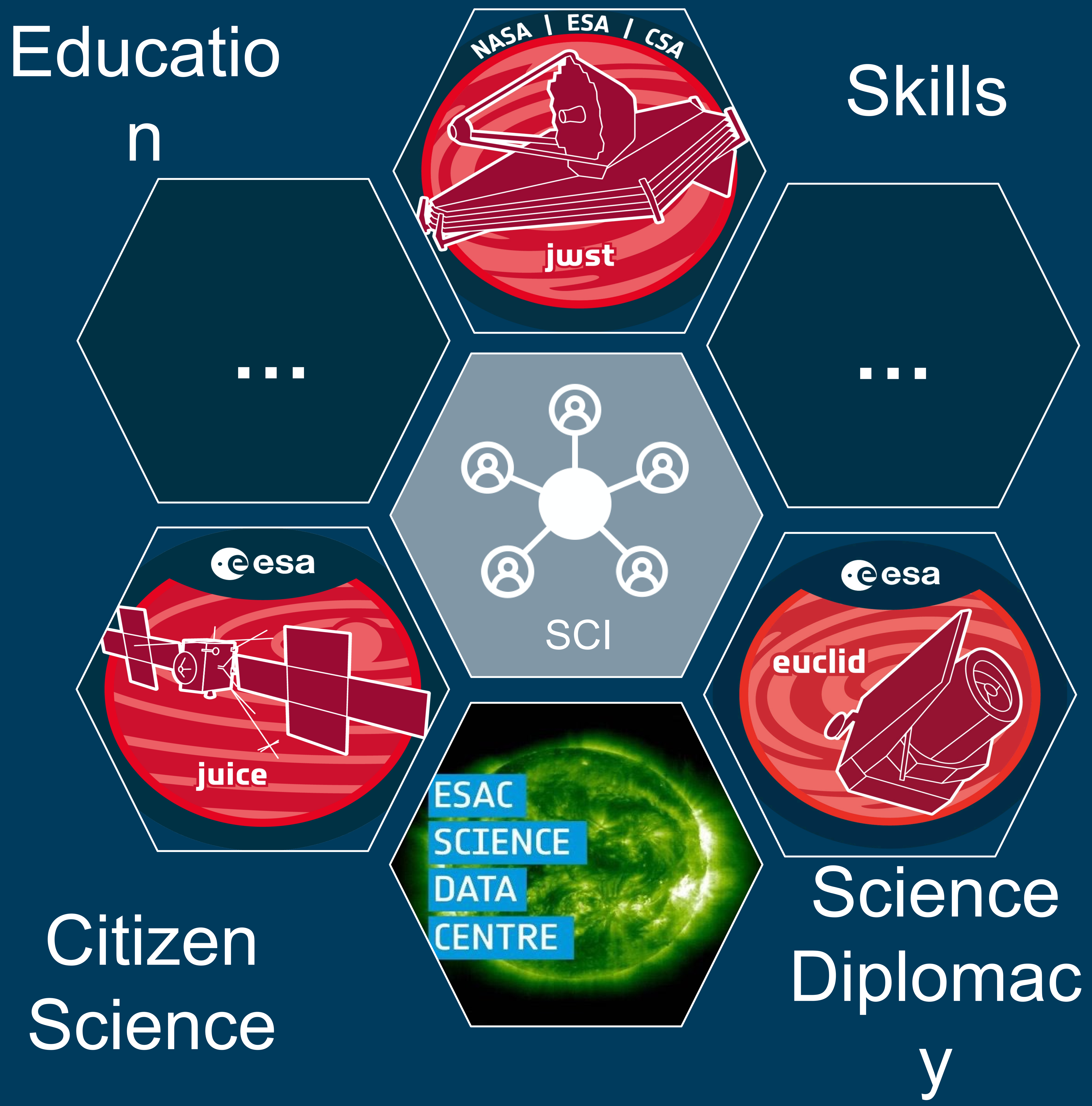


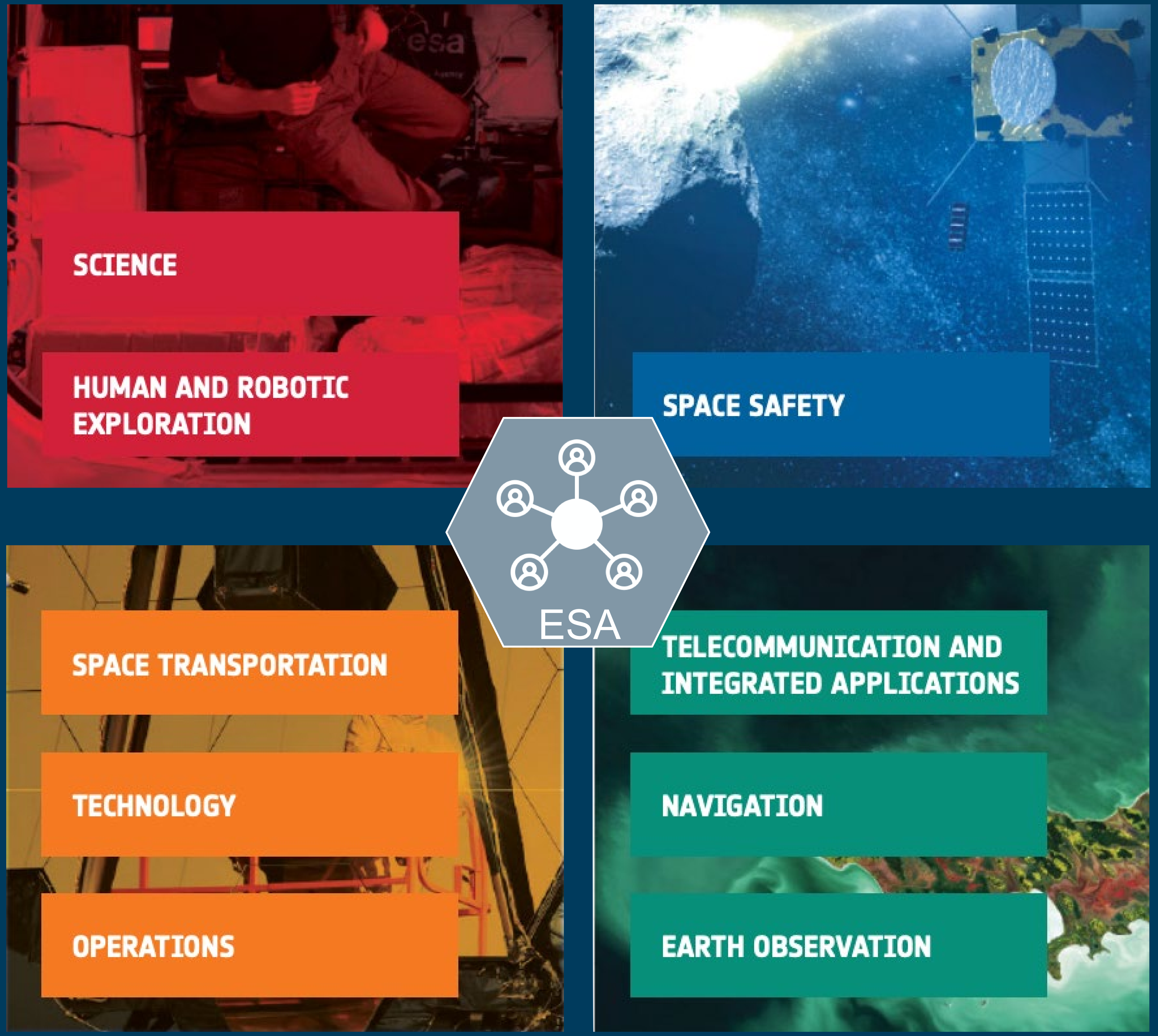






SCI-Driven multi-domain & multi-mission digital platform





Towards Ministerial 2025

Ambition

Uplifting Science

Soverign Access to Space

Sustainability

Exploration

Thank you!

osmic Visions 2015 – 2035; Voyage 2050