ESA's Roadmap and the European Community

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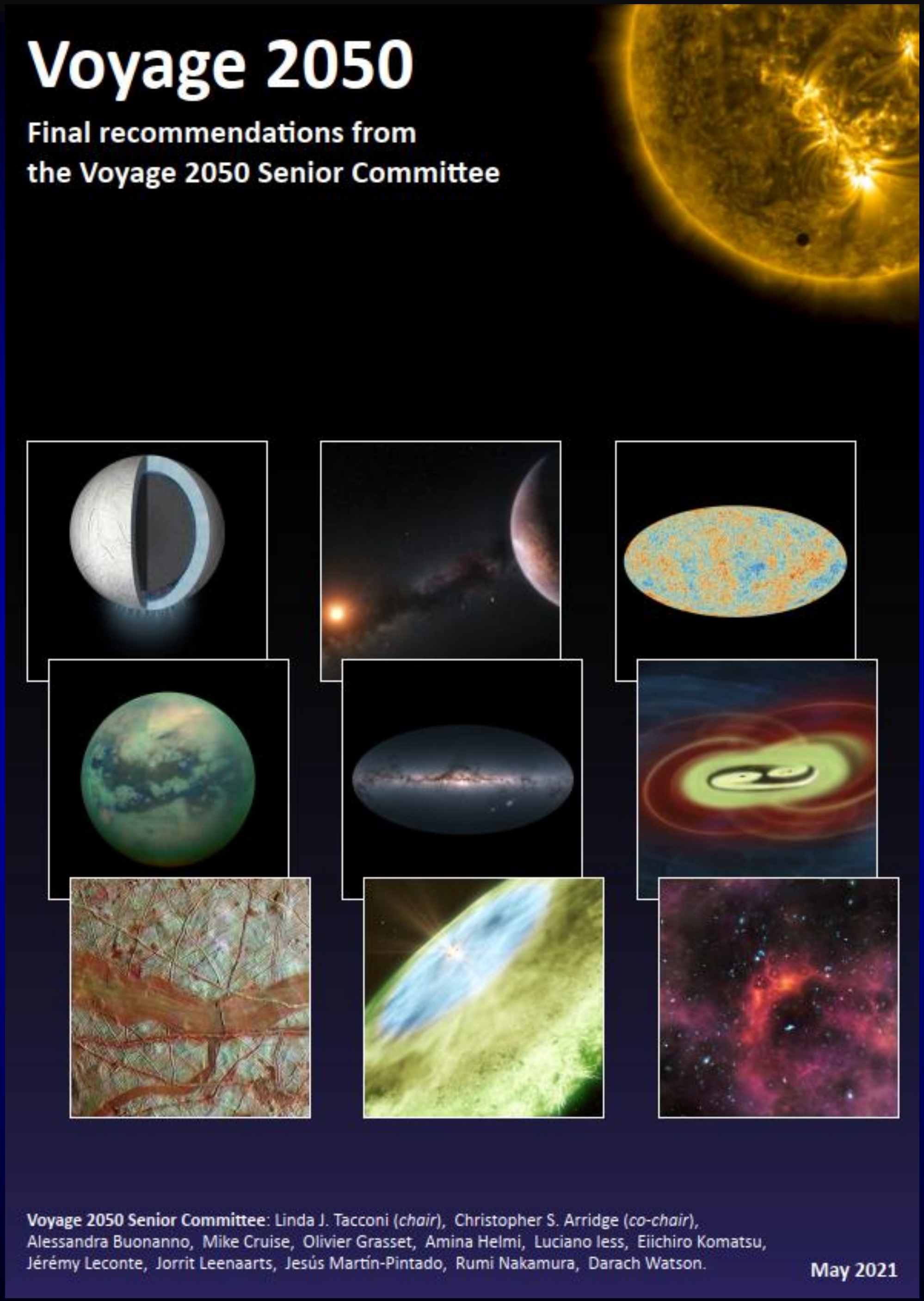
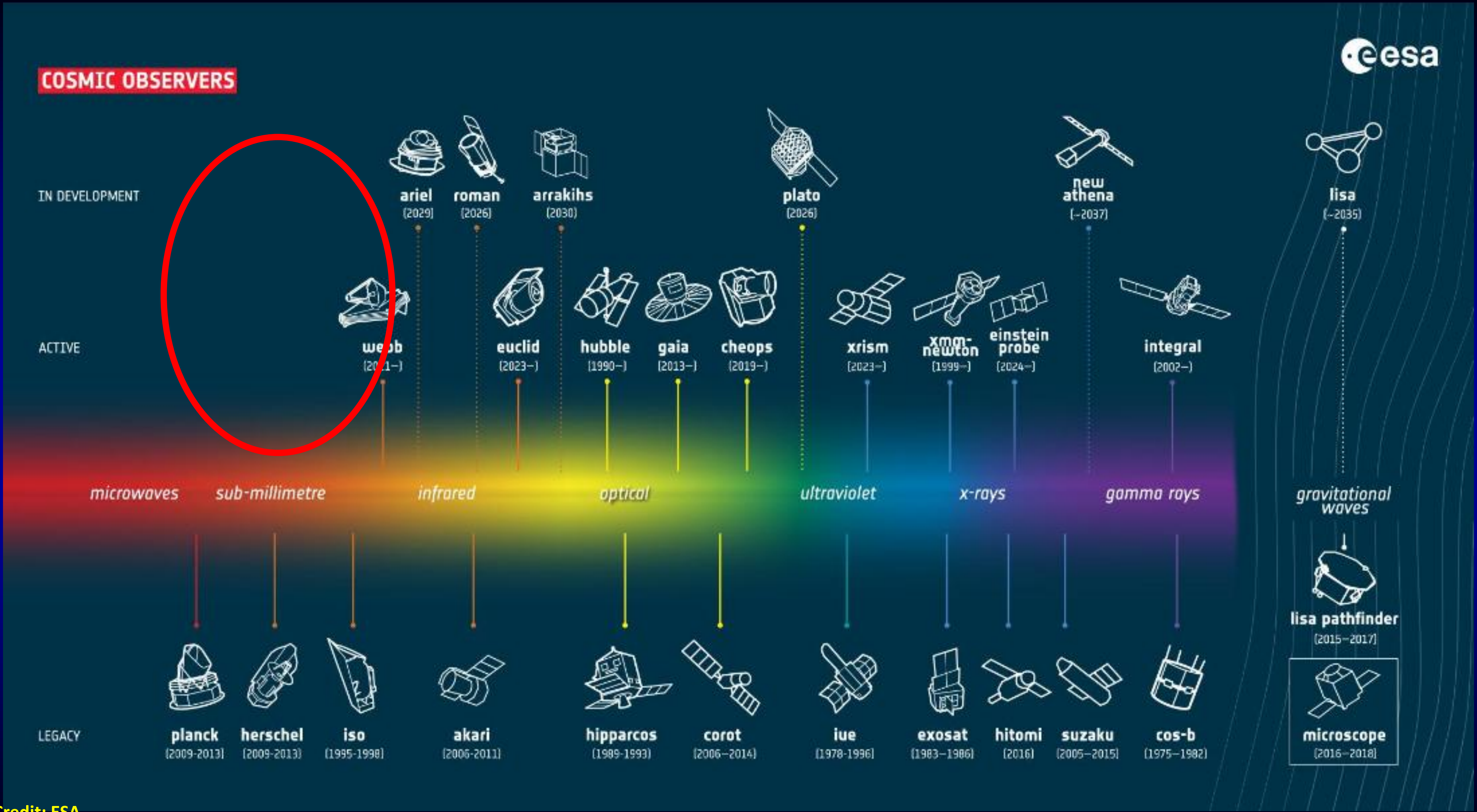
Future Role of FIR-Submm Space Observations
In honor of Thijs de Graauw and his collaborators
April 4, 2025





COSMIC OBSERVERS
esa
IN DEVELOPMENT
ariel (2029)
roman (2026)
arrakihs (2030)
plato (2026)
new athena (~2037)
lisa (~2035)
ACTIVE
webb (2021–)
euclid (2023–)
hubble (1990–)
gaia (2013–)
cheops (2019–)
xrism (2023–)
xmm-newton (1999–)
einstein probe (2024–)
integral (2002–)
microwaves
sub-millimetre
infrared
optical
ultraviolet
x-rays
gamma rays
gravitational waves
lisa pathfinder (2015–2017)
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)
microscope (2016–2018)

Credit: ESA

Voyage 2050: A Community Driven Process

Voyage 2050 in numbers

- From 2019-2021
- SPC approved in June 2021
- 97 Voyage 2050 White Papers
- Involvement of over 2000 scientists
- Full breadth of ESA's Science Program

Credit: Voyage 2050 White Paper Authors

Voyage 2050

Icy Moons of the giant planets

From temperate exoplanets to the Milky Way

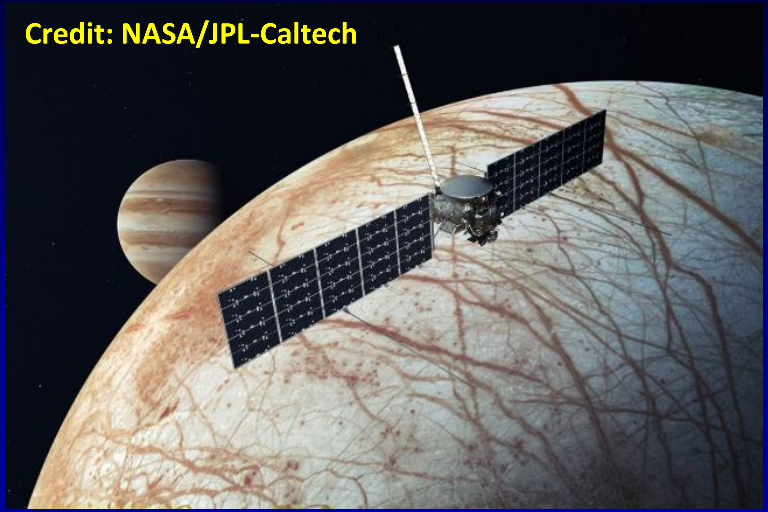
New physical probes of the early Universe

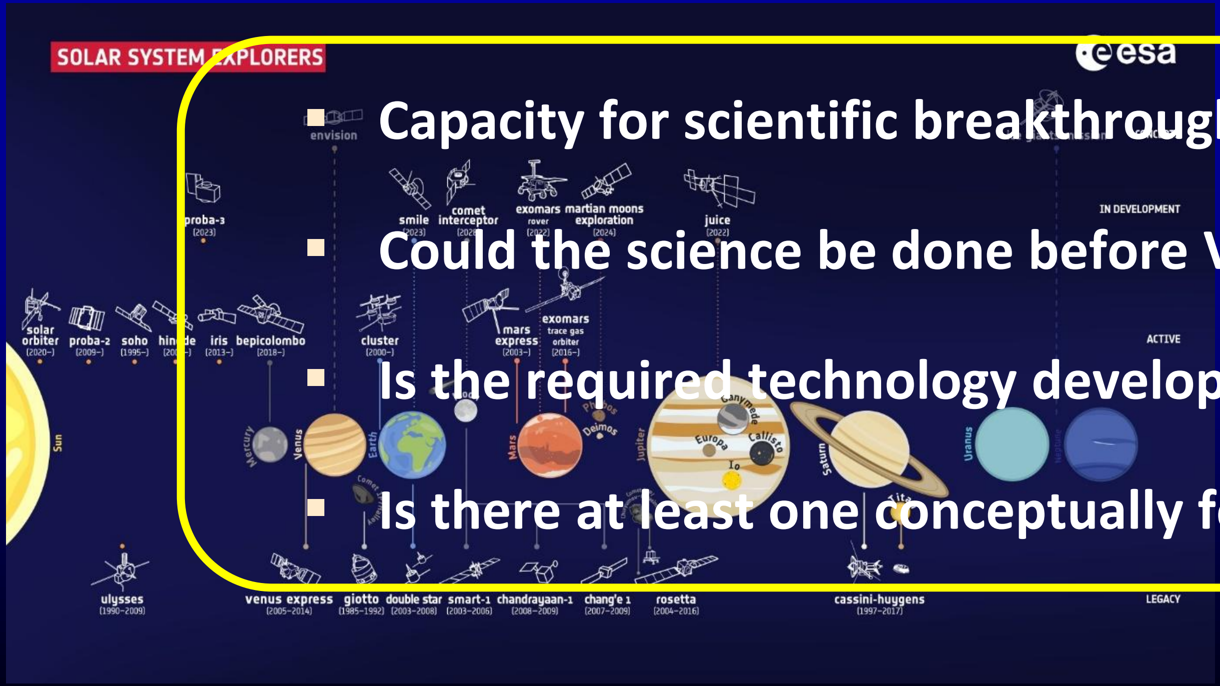
A. Recommend **three science themes for three Large missions** during Voyage 2050 timeframe, which starts after launching LISA and NewAthena (Cosmic Vision).

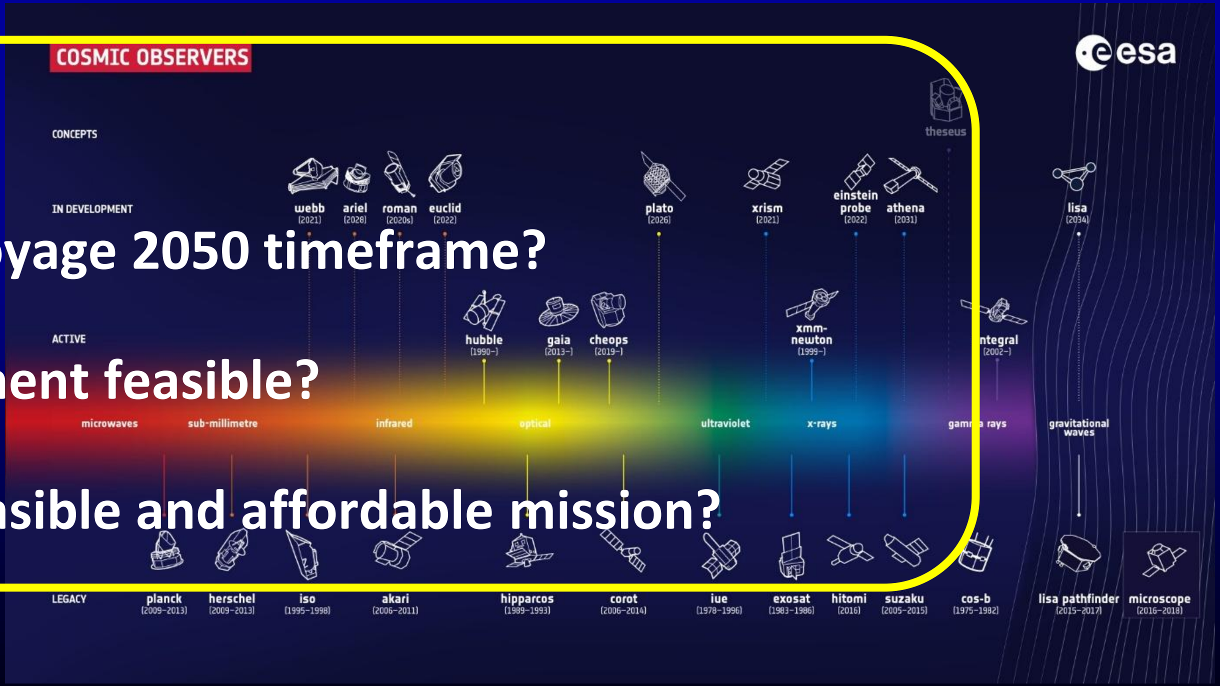
B. Identify potential **high-impact science themes that could be implemented through Medium missions** during the plan's timespan.

C. Identify compelling science themes where the **technology not sufficiently mature** for implementation before 2050.

Voyage 2050 in the Worldwide Landscape







- Capacity for scientific breakthrough.
- Could the science be done before Voyage 2050 timeframe?
- Is the required technology development feasible?
- Is there at least one conceptually feasible and affordable mission?

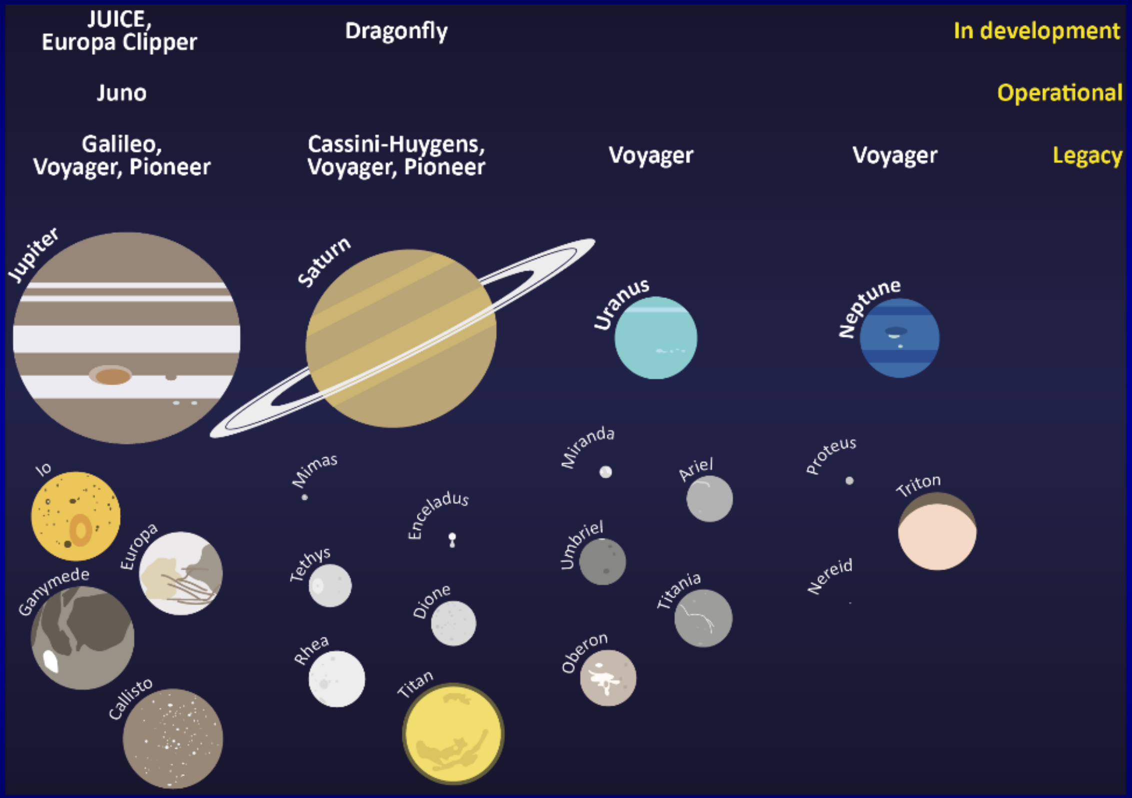
Moons of the Giant Planets

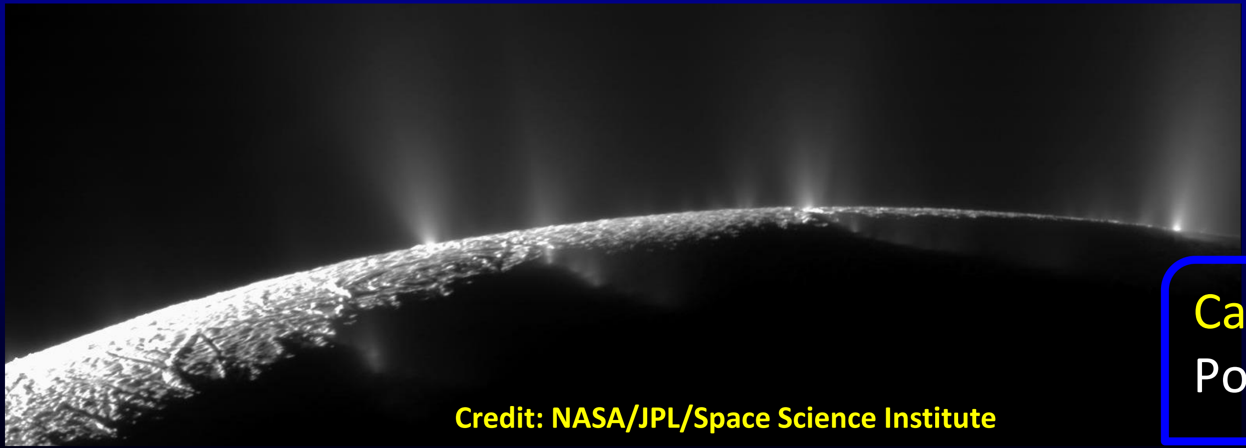
Move beyond discovery into **characterisation**.

Astrobiological interest – largest moons and Enceladus **liquid water**, **energy**, **complex chemistry…**

- Habitability: characterise interior and subsurface oceans.
- Search for biosignatures and evidence of prebiotic chemistry.

No expected major technological challenges: can build on JUICE heritage





Cassini/Huygens deep oceans/water layers inside moons. Possible hydrothermal vents from Enceladus' ocean.

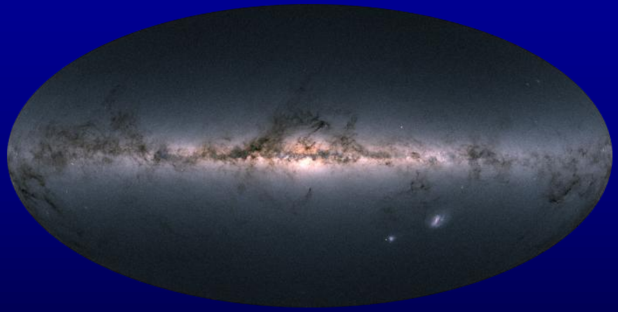
From Temperate Exo-planets to the Milky Way

Fundamental questions of our local Galactic Environment: How many exo-planets might be habitable? How did our Milky Way Galaxy form?

Two scientific areas timely for Voyage 2050, where Europe has or could take the lead, and where space needed for breakthrough:

- Characterisation of temperate exo-planets
- Gaia-like mission in the near infrared

Credit: ESO/M. Kornmesser



Credit: ESA/Gaia/DPAC

From Temperate Exo-planets to the Milky Way

CHEOPS, JWST, Ariel will make progress on characterising and understanding diversity of warm/hot planets.

How common are colder, terrestrial planets with "habitable" surface conditions?

Mid-infrared is optimum to measure radius and temperature of the planet to test whether planet is habitable:

- Radius => density => is it rocky?
- Temperature structure => Can it host liquid water?
- Signatures of important molecules


Credit: ESO/M. Kornmesser

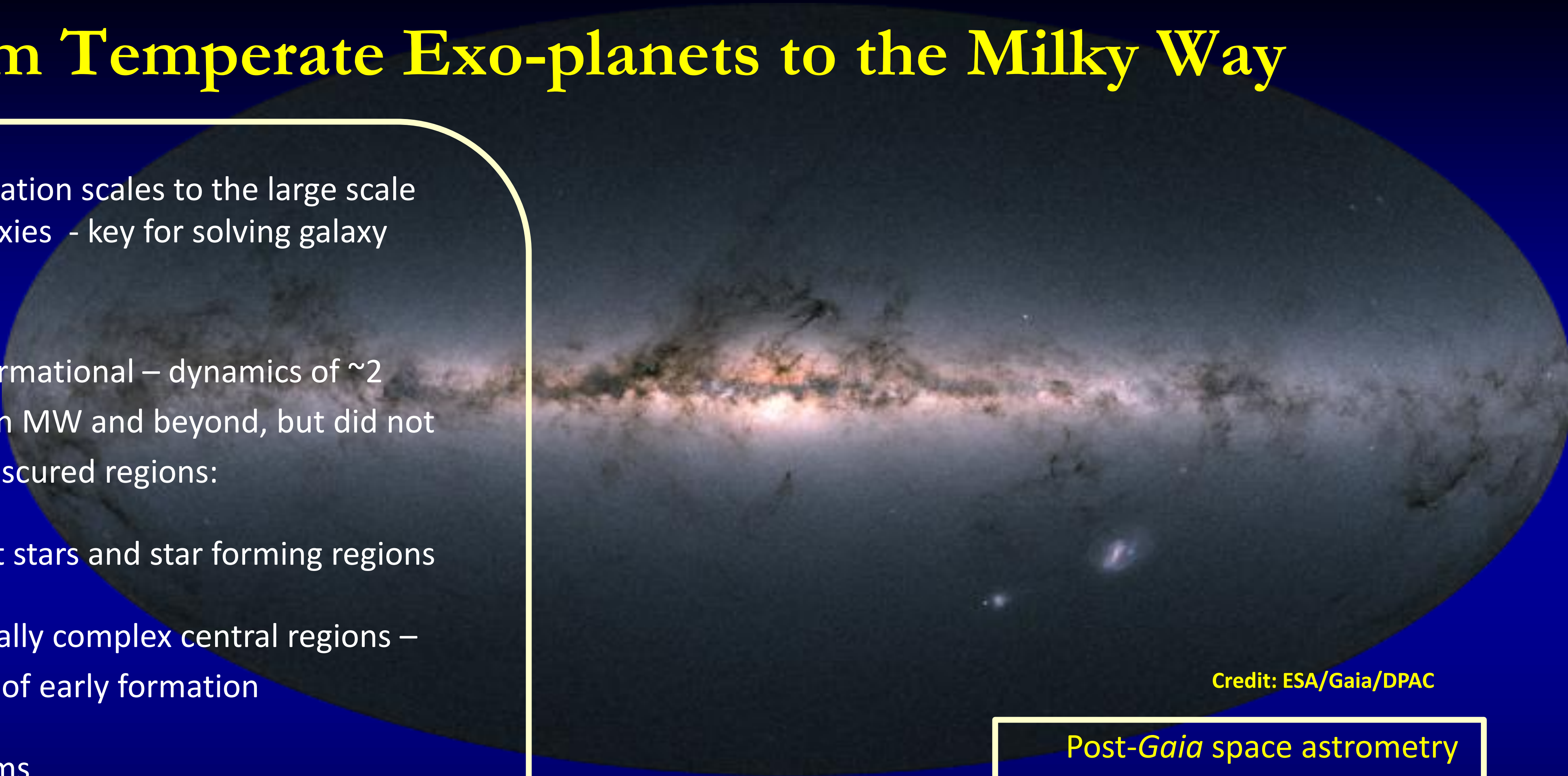
ESA Large Mission: could be first to measure spectrum of thermal emission of a *temperate* exoplanet.

Tim Lichtenberg talk

From Temperate Exo-planets to the Milky Way

Linking star formation scales to the large scale dynamics of galaxies - key for solving galaxy formation.

- *GAIA* transformational – dynamics of ~2 Billion stars in MW and beyond, but did not penetrate obscured regions:
  - youngest stars and star forming regions
  - dynamically complex central regions – imprints of early formation
  - spiral arms



Credit: ESA/Gaia/DPAC

Post-*Gaia* space astrometry in near-infrared to explore the Milky Way in regions unreachable for Gaia. Retain ESA leadership in key field.

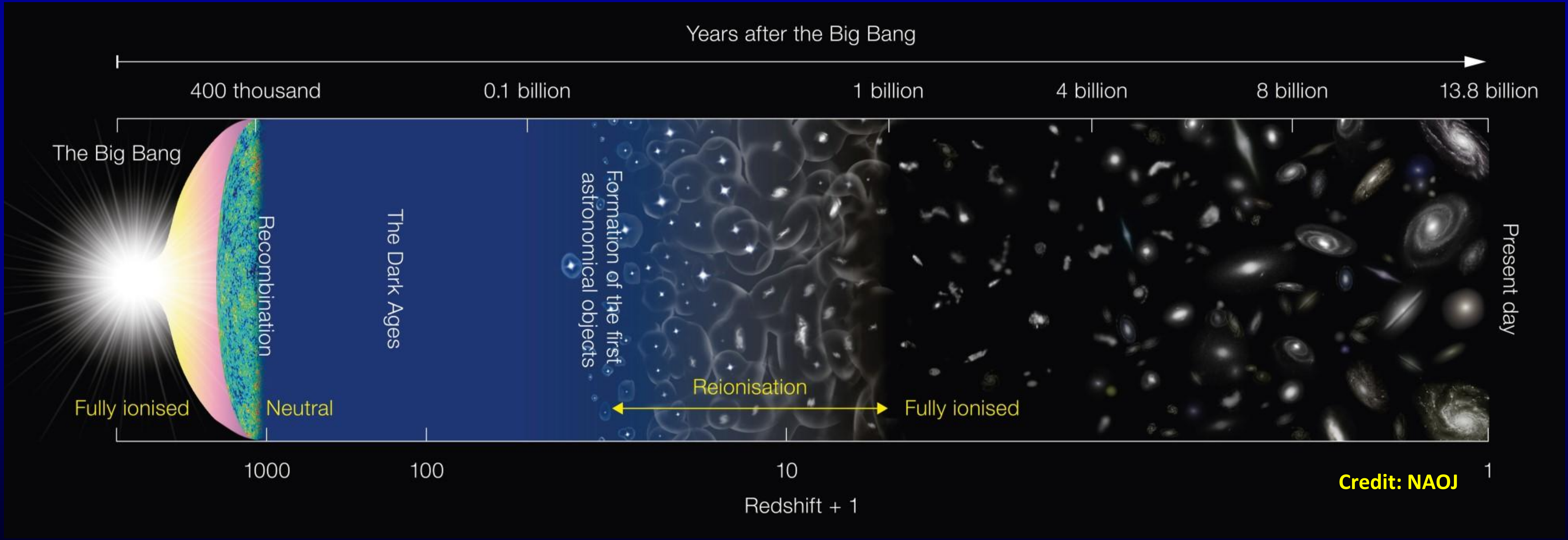
New Physical Probes of the Early Universe

How did the Universe begin? How did the first cosmic structures and black holes form and evolve?

Aim to understand earliest stages of Universe: structure formation, earliest galaxies, stars, and primordial black holes:

- **Gravitational waves**
- **High-precision spectroscopy**

Bruno Maffei and Jonathan Aumont talks



Credit: NAOJ

New Physical Probes of the Early Universe

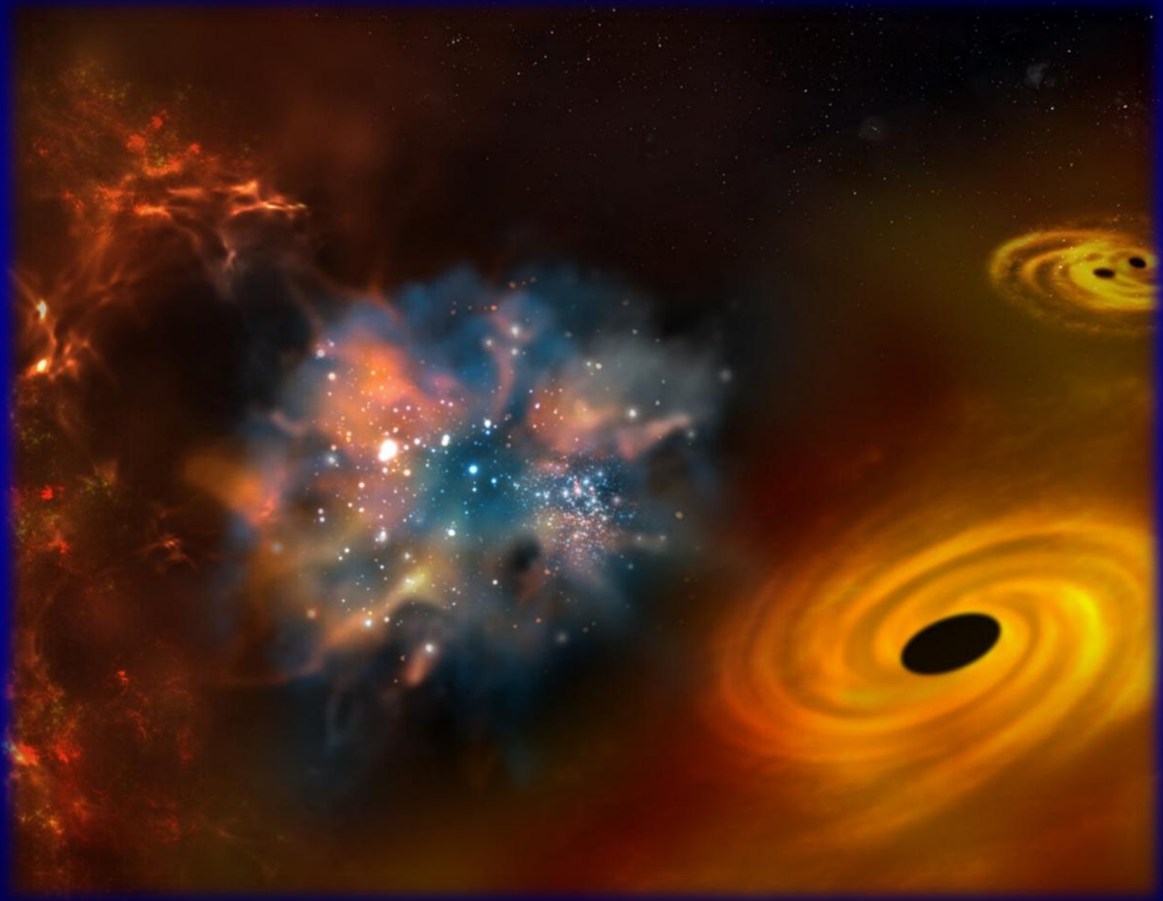
High-precision spectroscopy

Measure distortions in the black-body spectrum of CMB produced by:

- recombination lines from H and He formation (1 part in 1 billion) -> how the Universe became transparent
- Growth of first structures: damping of sound waves through plasma – distorts spectrum (1 part in 100 million) -> amplitude of small-scale structure

➡ Needs absolutely calibrated spectrograph, which Planck did not carry

➡ Builds on **ESA leadership with Planck**



New Physical Probes of the Early Universe

Gravitational waves

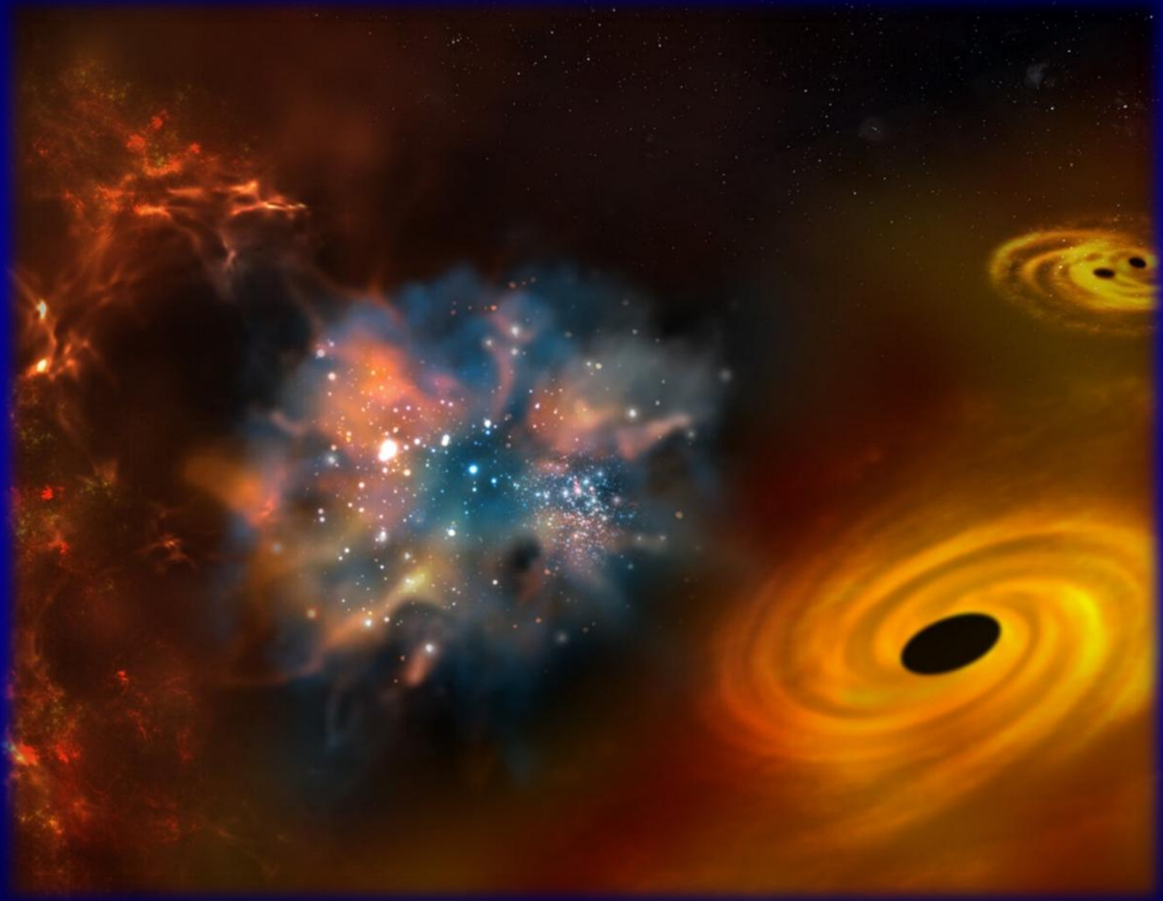
- Unobstructed view – weak interaction with matter: waves travel through space without scattering or absorption

  LIGO/VIRGO – deca–to-kilohertz GW bands – binary black hole mergers
  LISA – millihertz regime – supermassive black holes, intermediate redshifts

- Mission dedicated to decihertz or microhertz to study growth of cosmic structures – peer back to earliest moments of the Universe.

- First black hole seeds, first quasars, GW background

➡ Build on **ESA leadership with LISA,** at new frequencies to add "color" to gravitational wave sky.



Voyage 2050 M-class Themes Relevant to this Meeting

- Space (Radio) Interferometry with Ground-based Telescopes for Probing the Physics of Black Holes (Eric Villard talk)
- The Role of the Multiphase ISM in Star Formation and Galaxy Evolution (Dimitra Rigopoulou talk)
- High Precision Astrometry (downscaled version of L-mission theme 2)
- Contribution to next generation space telescope far beyond Large mission envelope (NASA HWO)

Could any of these be candidates for the ESA M8 Call?

ASTRONET Roadmap 2022-2035

- Overview of status of European astronomy as of 2022 & recommendations for next decade.
- Prioritized ground and space facilities with expected first light by 2035
- Expert panels with community consultation

Credit: ASTRONET

- What is the nature of dark matter and dark energy?
- Are there deviations from the standard theories and models (general relativity, cosmological model, standard model of particle physics)?
- What are the properties of the cosmic microwave background, first stars, galaxies and black holes in the Universe?
- How do galaxies form and evolve, and how does the Milky Way fit in this context?
- What are the progenitors of astronomical transients?
- What physical and chemical processes control stellar evolution at all stages, from formation to death, and how?
- What are the necessary conditions for life to emerge and thrive? Are we alone?
- How do planets and planetary systems form and evolve?
- What is the impact of the Sun on the heliosphere and on planetary environments?
- What are/were the characteristics and habitability of various sites in the solar system, such as Mars or Jupiter's icy moons?
- What is the origin of cosmic rays of all energies?
- How can extreme astrophysical objects and processes probe new fundamental physics?

ASTRONET Roadmap 2022-2035: FIR/Submm
Outlook Beyond 2035

- Points o… …ng no FIR mission
- … …pport for PRIM…
- … …ow redshift…
- … …ses fo…

- **The first stars, galaxies, and the epoch of reionisation:**
To fully capitalise on the discoveries that JWST will enable, we will need the capabilities of SKA2 and new far-infrared/submillimeter facilities to characterise the interstellar medium, stellar populations and black holes of the first galaxies, and their impact on the inter… medium.

- **The formation of planets, stars and galaxies:**
Understanding the assembly of planets, stars and galaxies requires information across the entire electro-magnetic spectrum, with a particular need in the next decades for new far-infrared and UV space telescopes, astrometric missions (e.g. G…?), and high-resolution, wide-field … capabilities.

- **Cryogenics and detector technology for far-infrared space telescope:**
Among the major needs of the community in the mid- and long-term is a next generation far-infrared, large-collecting-area space telescope. Such a facility will require the development of improved cooling systems for both the telescope and its instruments, and detectors allowing for significant improvement in sensitivity and resolution over predecessors Spitzer and Herschel.

Ted Bergin's PRIMA talk

Credit: ASTRONET

Concluding Thoughts

- Voyage 2050 Recommendations not limited by ideas, but resources
- Trade-off between dreaming big and staying within realistic global funding envelopes
- Lessons learned from SPICA – too big to fit into M-class envelope, yet was it too incremental relative to Herschel? Does PRIMA address this issue?
- In challenging funding environment, need "killer" science cases for expensive space (and ground-based) facilities. Will the science still be breakthrough in 25-30 years?

Thank you Thijs!

Extragalactic Molecules, Green Bank 1981