Solar System / Exoplanet Synergy: Mission Timelines and Collaborative Opportunities

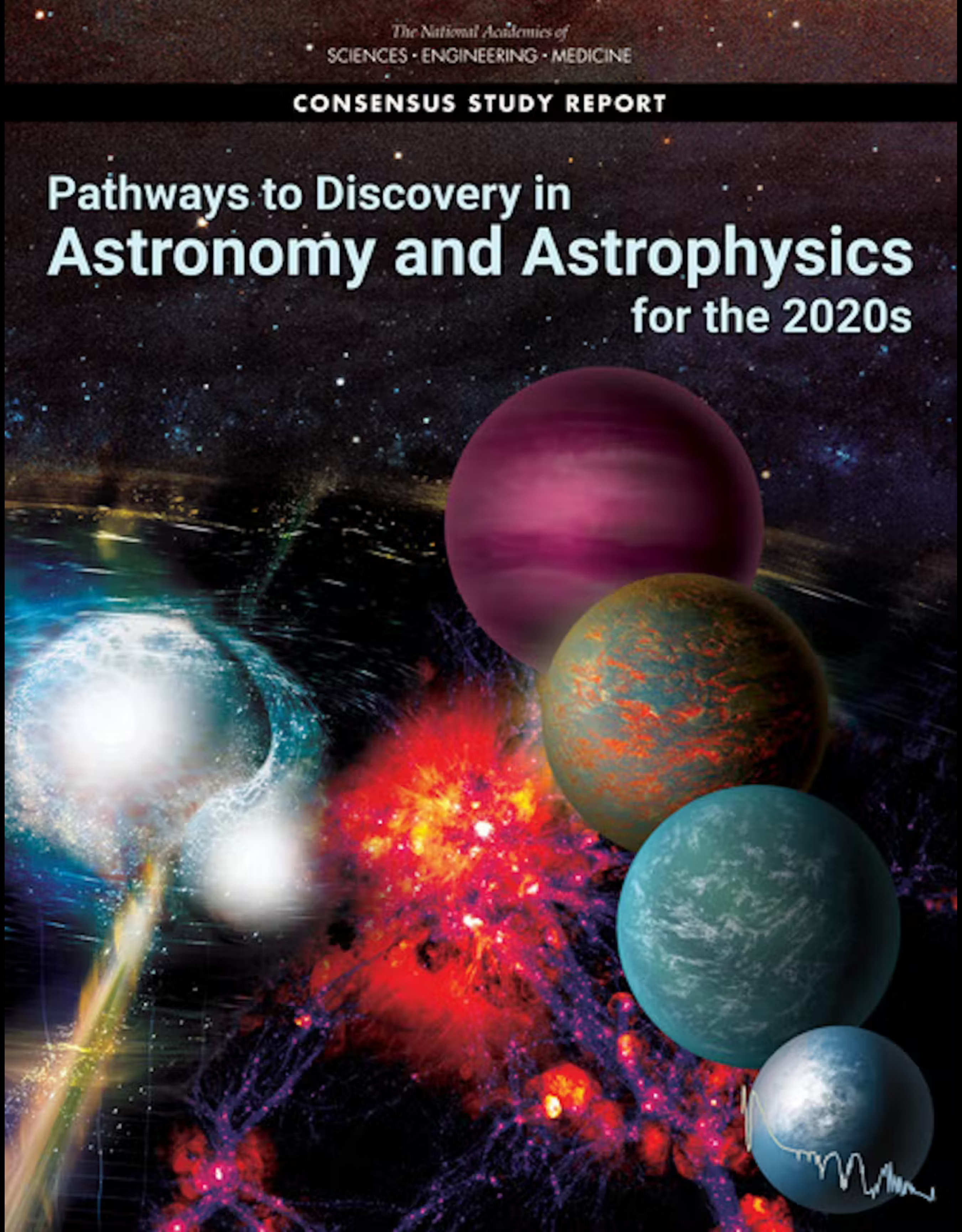
Stephen Kane

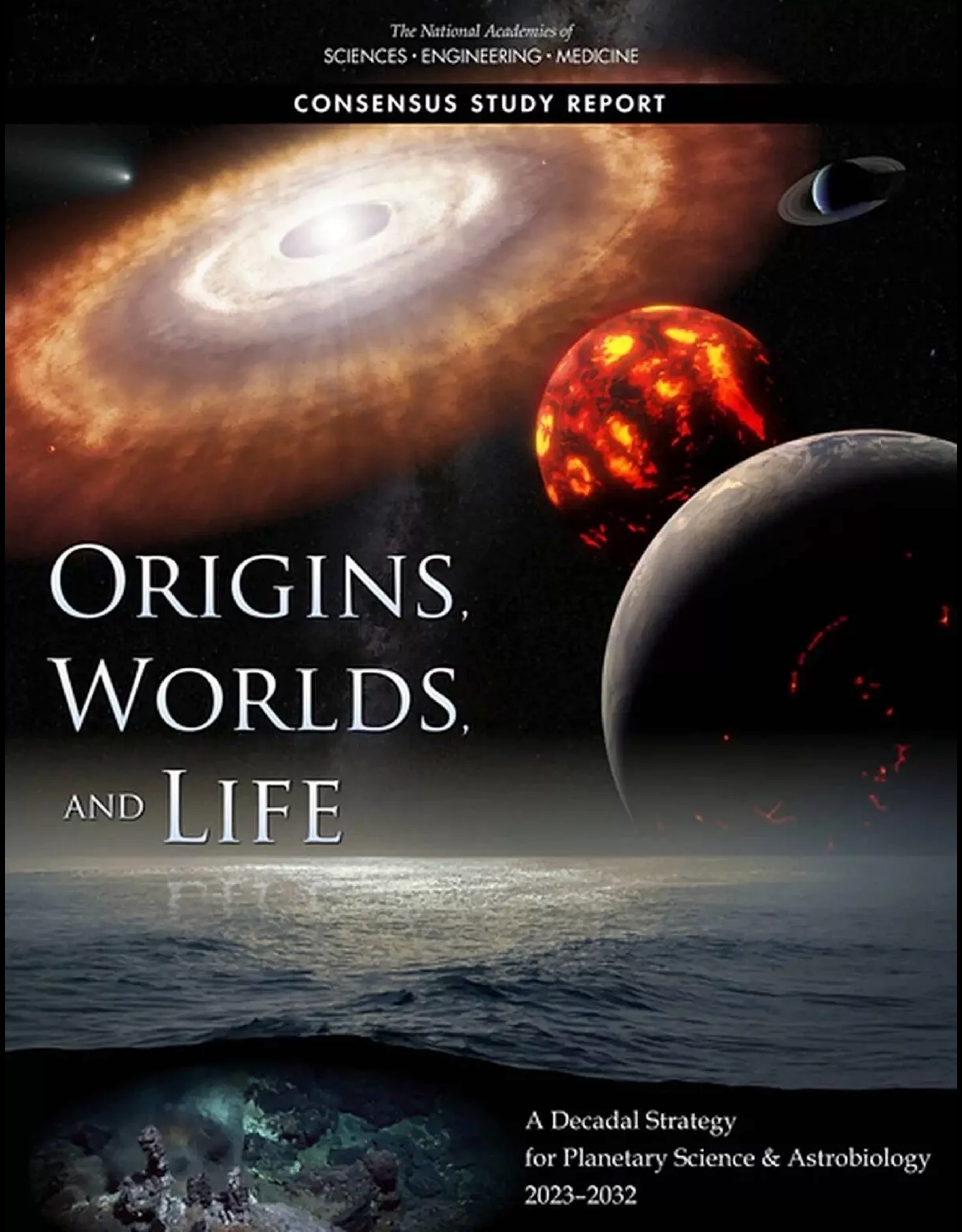
UNIVERSITY OF CALIFORNIA
UC RIVERSIDE

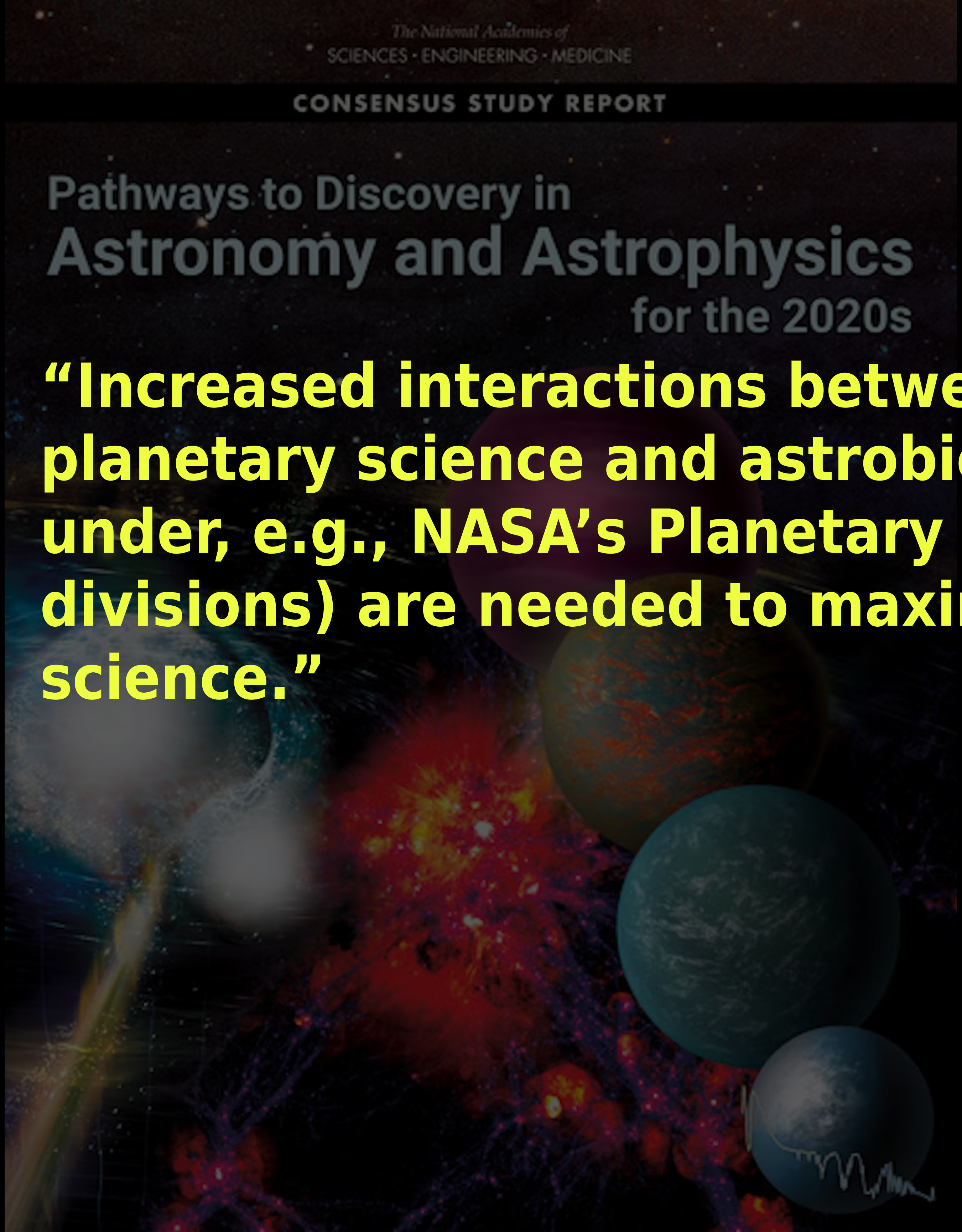
Solar System / Exoplanet Synergy: Mission Timelines and Collaborative Opportuniti

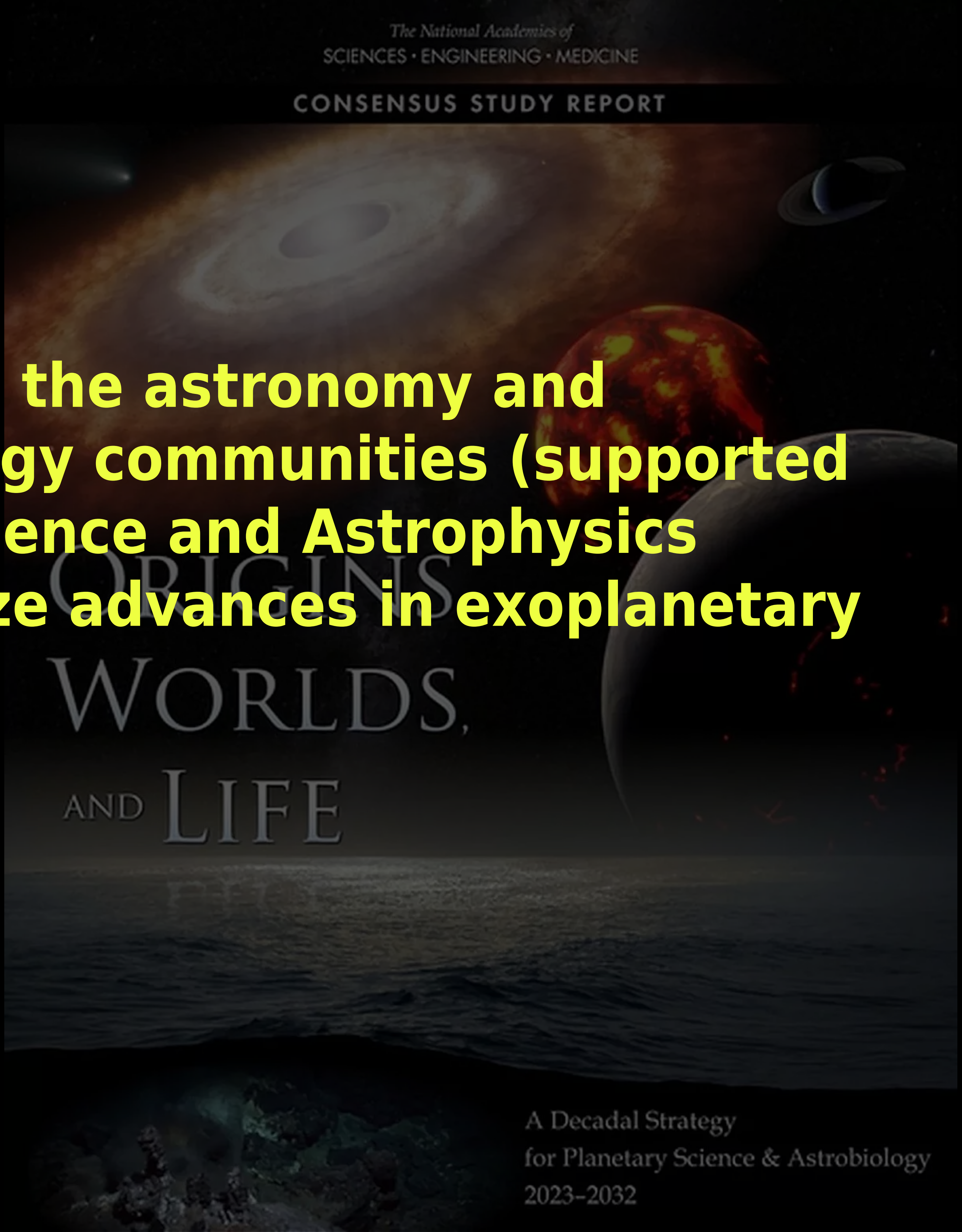
Stephen Kane

UNIVERSITY OF CALIFORNIA
UC RIVERSIDE

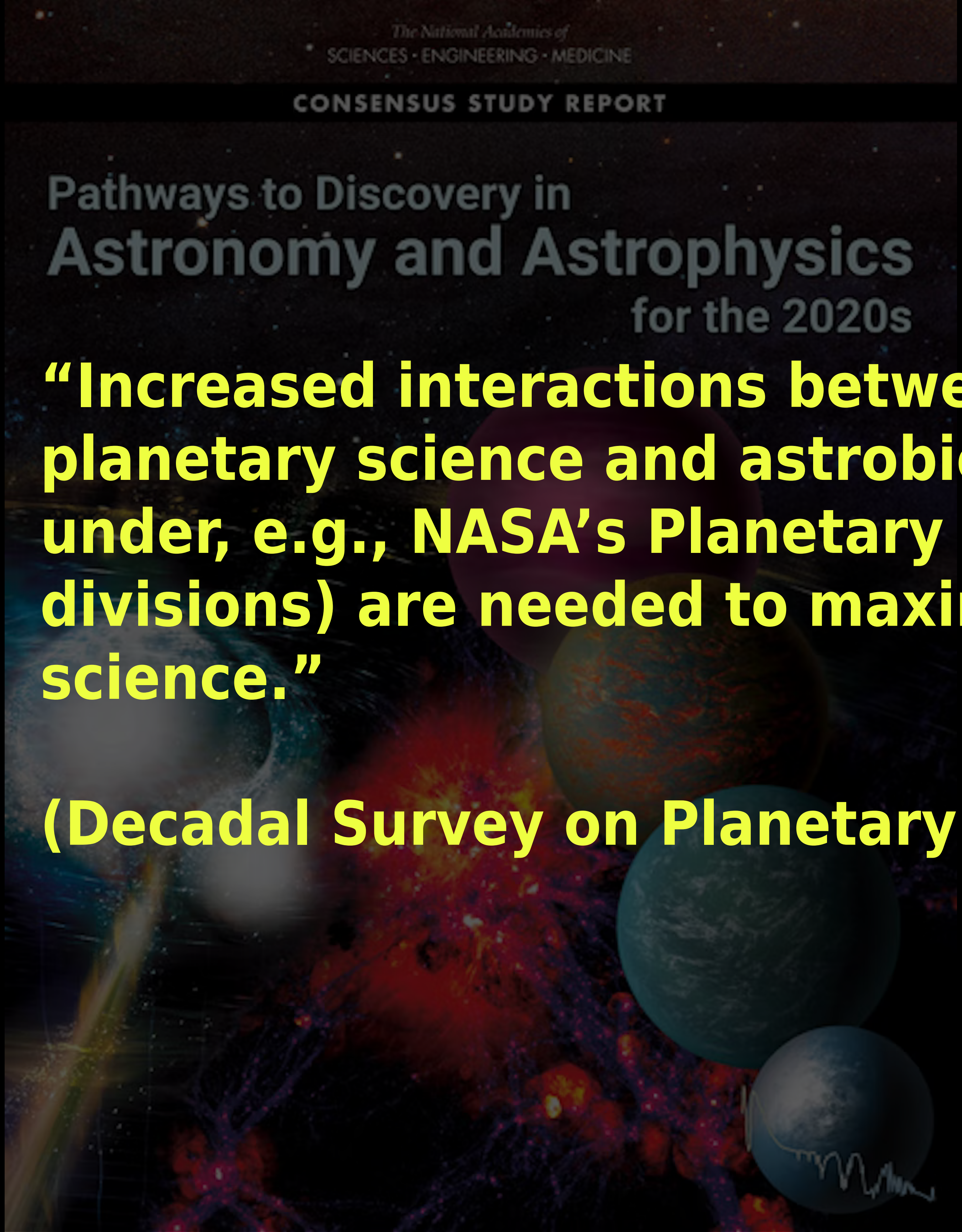

The National Academies of
SCIENCES · ENGINEERING · MEDICINE
CONSENSUS STUDY REPORT
Pathways to Discovery in
Astronomy and Astrophysics
for the 2020s


The National Academies of
SCIENCES · ENGINEERING · MEDICINE
CONSENSUS STUDY REPORT
ORIGINS,
WORLDS,
AND LIFE
A Decadal Strategy
for Planetary Science & Astrobiology
2023–2032





“Increased interactions between the astronomy and planetary science and astrobiology communities (supported under, e.g., NASA’s Planetary Science and Astrophysics divisions) are needed to maximize advances in exoplanetary science.”



“Increased interactions between the astronomy and planetary science and astrobiology communities (supported under, e.g., NASA’s Planetary Science and Astrophysics divisions) are needed to maximize advances in exoplanetary science.”

(Decadal Survey on Planetary Science and Astrobiology 2020)

Themes	Priority Science Question Topic and Scope
Origins	**Q1. Evolution of the protoplanetary disk** What were the initial conditions in the Solar System? What processes led to the production of planetary building blocks, and what was the nature and evolution of these materials?
	Q2. Accretion in the outer solar system How and when did the giant planets and their satellite systems originate, and did their orbits migrate early in their history? How and when did dwarf planets and cometary bodies orbiting beyond the giant planets form, and how were they affected by the early evolution of the solar system?
	Q3. Origin of Earth and inner solar system bodies How and when did the terrestrial planets, their moons, and the asteroids accrete, and what processes determined their initial properties? To what extent were outer Solar System materials incorporated?
Worlds & Processes	**Q4. Impacts and dynamics** How has the population of Solar System bodies changed through time, and how has bombardment varied across the Solar System? How have collisions affected the evolution of planetary bodies?
	Q5. Solid body interiors and surfaces How do the interiors of solid bodies evolve, and how is this evolution recorded in a body's physical and chemical properties? How are solid surfaces shaped by subsurface, surface, and external processes?
	Q6. Solid body atmospheres, exospheres, magnetospheres, and climate evolution What establishes the properties and dynamics of solid body atmospheres and exospheres, and what governs material loss to space and exchange between the atmosphere and the surface and interior? Why did planetary climates evolve to their current varied states?
	Q7. Giant planet structure and evolution What processes influence the structure, evolution, and dynamics of giant planet interiors, atmospheres, and magnetospheres?
	Q8. Circumplanetary systems What processes and interactions establish the diverse properties of satellite and ring systems, and how do these systems interact with the host planet and the external environment?
Life & Habitability	**Q9. Insights from Terrestrial Life** What conditions and processes led to the emergence and evolution of life on Earth, what is the range of possible metabolisms in the surface, subsurface and/or atmosphere, and how can this inform our understanding of the likelihood of life elsewhere?
	Q10. Dynamic Habitability Where in the solar system do potentially habitable environments exist, what processes led to their formation, and how do planetary environments and habitable conditions co-evolve over time?
	Q11. Search for life elsewhere Is there evidence of past or present life in the solar system beyond Earth and how do we detect it?
All Themes	**Q12. Exoplanets** What does our planetary system and its circumplanetary systems of satellites and rings reveal about exoplanetary systems, and what can circumstellar disks and exoplanetary systems teach us about the solar system?

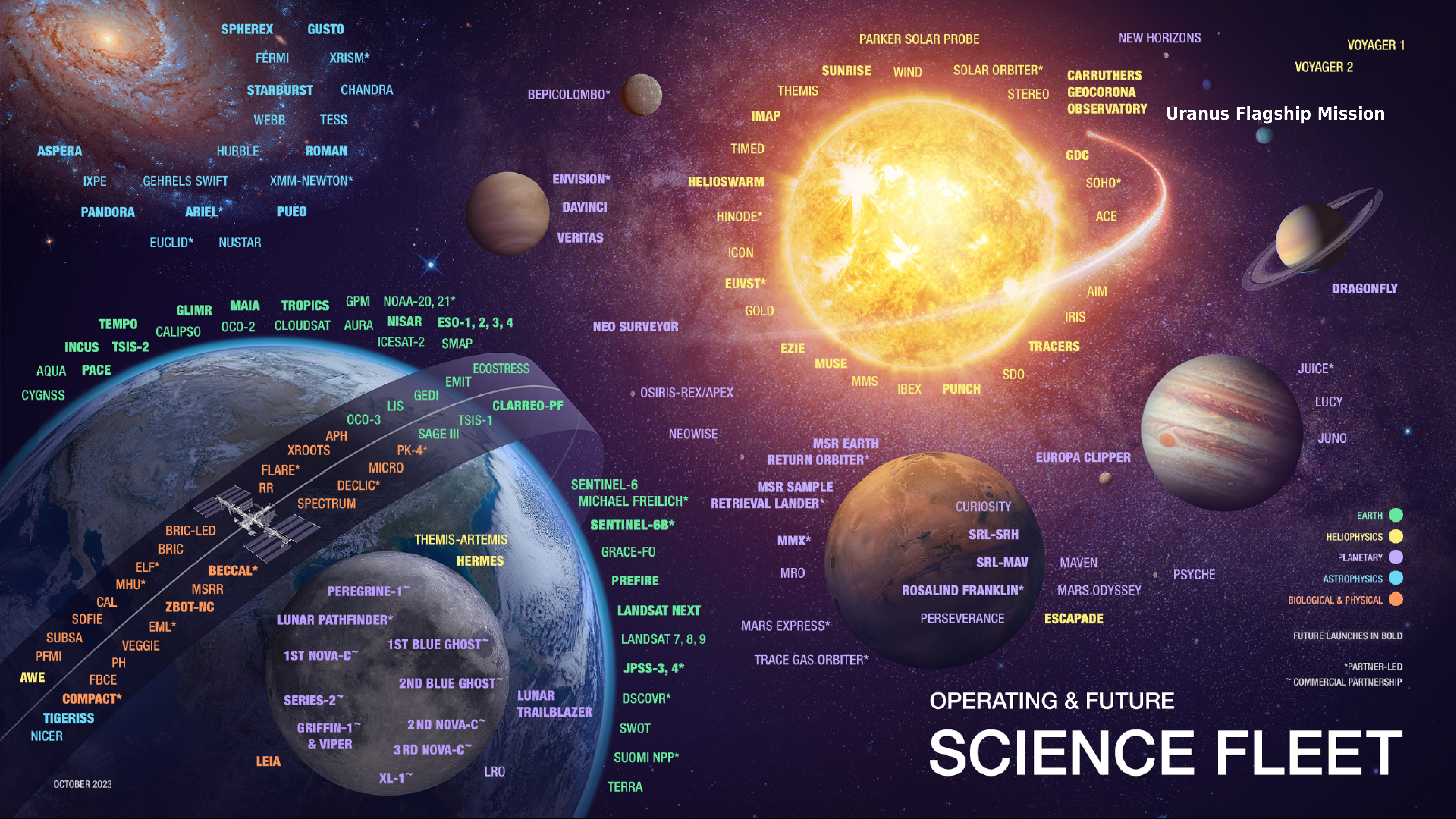
Why Exoplanet / Solar System Collaboration Should Increase

1. We will never have in-situ data for an exoplanet. Uncertainties in solar system models can translate directly into catastrophic uncertainties for exoplanets. Many questions remain for the solar system terrestrial planets, the answers of which will directly benefit exoplanets.

2. Addressing these questions requires a variety of mission concepts, including orbiters, gliders, balloons, and landers. In-situ analyses of the geology and composition-temperature-pressure profile of atmospheres are critical.

3. The solar system science questions have strong overlap with the data/model needs of future exoplanet missions, and such overlap areas should be prioritized.

4. Both Decadal reports advocate for representation from both sides on mission teams.


SPHEREX
GUSTO
FERMI
XRISM*
STARBURST
CHANDRA
WEBB
TESS
ASPERA
HUBBLE
ROMAN
IXPE
GEHRELS SWIFT
XMM-NEWTON*
PANDORA
ARIEL*
PUEO
EUCLID*
NUSTAR
BEPICOLOMBO*
ENVISION*
DAVINCI
VERITAS
PARKER SOLAR PROBE
SUNRISE
WIND
SOLAR ORBITER*
THEMIS
STEREO
IMAP
TIMED
HELIOSWARM
HINODE*
ICON
EUVST*
GOLD
EZIE
MUSE
MMS
IBEX
PUNCH
SDO
TRACERS
IRIS
AIM
ACE
SOHO*
GDC
CARRUTHERS
GEOCORONA
OBSERVATORY
NEW HORIZONS
VOYAGER 1
VOYAGER 2
Uranus Flagship Mission
DRAGONFLY
JUICE*
LUCY
JUNO
EUROPA CLIPPER
PSYCHE
GLIMR
MAIA
TROPICS
GPM
NOAA-20, 21*
TEMPO
CALIPSO
OCO-2
CLOUDSAT
AURA
NISAR
ESO-1, 2, 3, 4
INCUS
TSIS-2
ICESAT-2
SMAP
AQUA
PACE
CYGNSS
NEO SURVEYOR
OSIRIS-REX/APEX
NEOWISE
ECOSTRESS
EMIT
GEDI
LIS
CLARREO-PF
OCO-3
TSIS-1
APH
SAGE III
XROOTS
PK-4*
FLARE*
MICRO
RR
DECLIC*
SPECTRUM
BRIC-LED
BRIC
ELF*
BECCAL*
MHU*
MSRR
CAL
ZBOT-NC
SOFIE
EML*
SUBSA
VEGGIE
PFMI
PH
AWE
FBCE
COMPACT*
TIGERISS
NICER
SENTINEL-6
MICHAEL FREILICH*
SENTINEL-6B*
GRACE-FO
PREFIRE
LANDSAT NEXT
LANDSAT 7, 8, 9
JPSS-3, 4*
DSCOVR*
SWOT
SUOMI NPP*
TERRA
THEMIS-ARTEMIS
HERMES
PEREGRINE-1~
LUNAR PATHFINDER*
1ST BLUE GHOST~
1ST NOVA-C~
2ND BLUE GHOST~
SERIES-2~
LUNAR
TRAILBLAZER
GRIFFIN-1~
& VIPER
2ND NOVA-C~
3RD NOVA-C~
XL-1~
LRO
LEIA
MSR EARTH
RETURN ORBITER*
MSR SAMPLE
RETRIEVAL LANDER*
CURIOSITY
SRL-SRH
MMX*
SRL-MAV
MAVEN
MRO
ROSALIND FRANKLIN*
MARS ODYSSEY
PERSEVERANCE
ESCAPADE
MARS EXPRESS*
TRACE GAS ORBITER*
EARTH
HELIOPHYSICS
PLANETARY
ASTROPHYSICS
BIOLOGICAL & PHYSICAL
FUTURE LAUNCHES IN BOLD
*PARTNER-LED
~ COMMERCIAL PARTNERSHIP
OPERATING & FUTURE
SCIENCE FLEET
OCTOBER 2023

Planetary Mission Timeline

- Juno (Launch 2011)
- JUICE (Launch 2023, Orbit insertion 2031)
- Asteroids (DART, OSIREX-Rex, Psyche, Lucy)

Present day

- Gaia (Launch 2013)
- TESS (Launch 2018)
- JWST (Launch 2021, could last 20+ years)

Astrophysics Mission Timeline

Planetary Mission Timeline

- Juno (Launch 2011)
- JUICE (Launch 2023, Orbit insertion 2031)
- Asteroids (DART, OSIREX-Rex, Psyche, Lucy)

- Europa Clipper (Launch October 2024, Orbit insertion 2030)

Present day

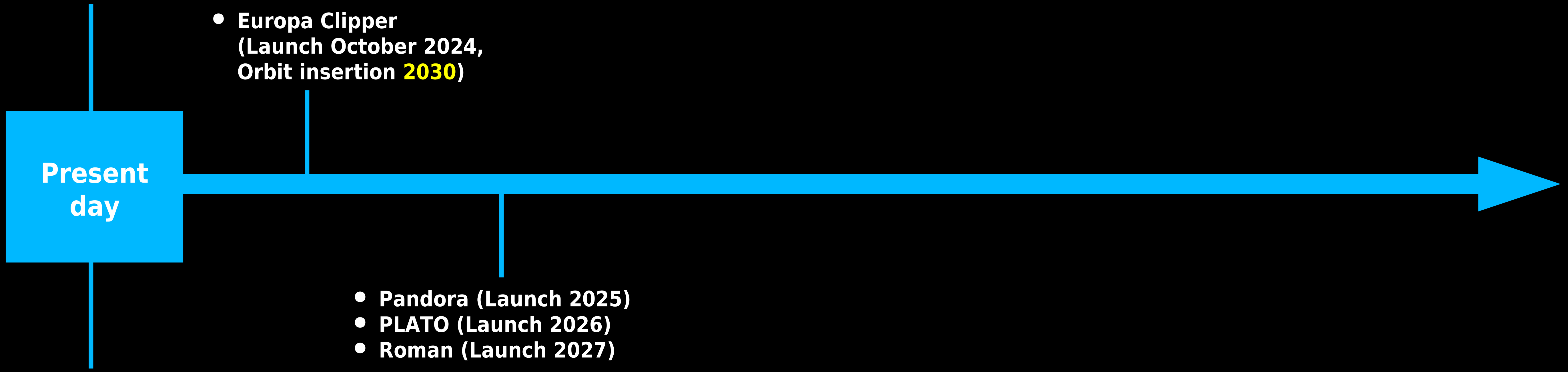
- Gaia (Launch 2013)
- TESS (Launch 2018)
- JWST (Launch 2021, could last 20+ years)

Astrophysics Mission Timeline

Planetary Mission Timeline

- Juno (Launch 2011)
- JUICE (Launch 2023, Orbit insertion 2031)
- Asteroids (DART, OSIREX-Rex, Psyche, Lucy)

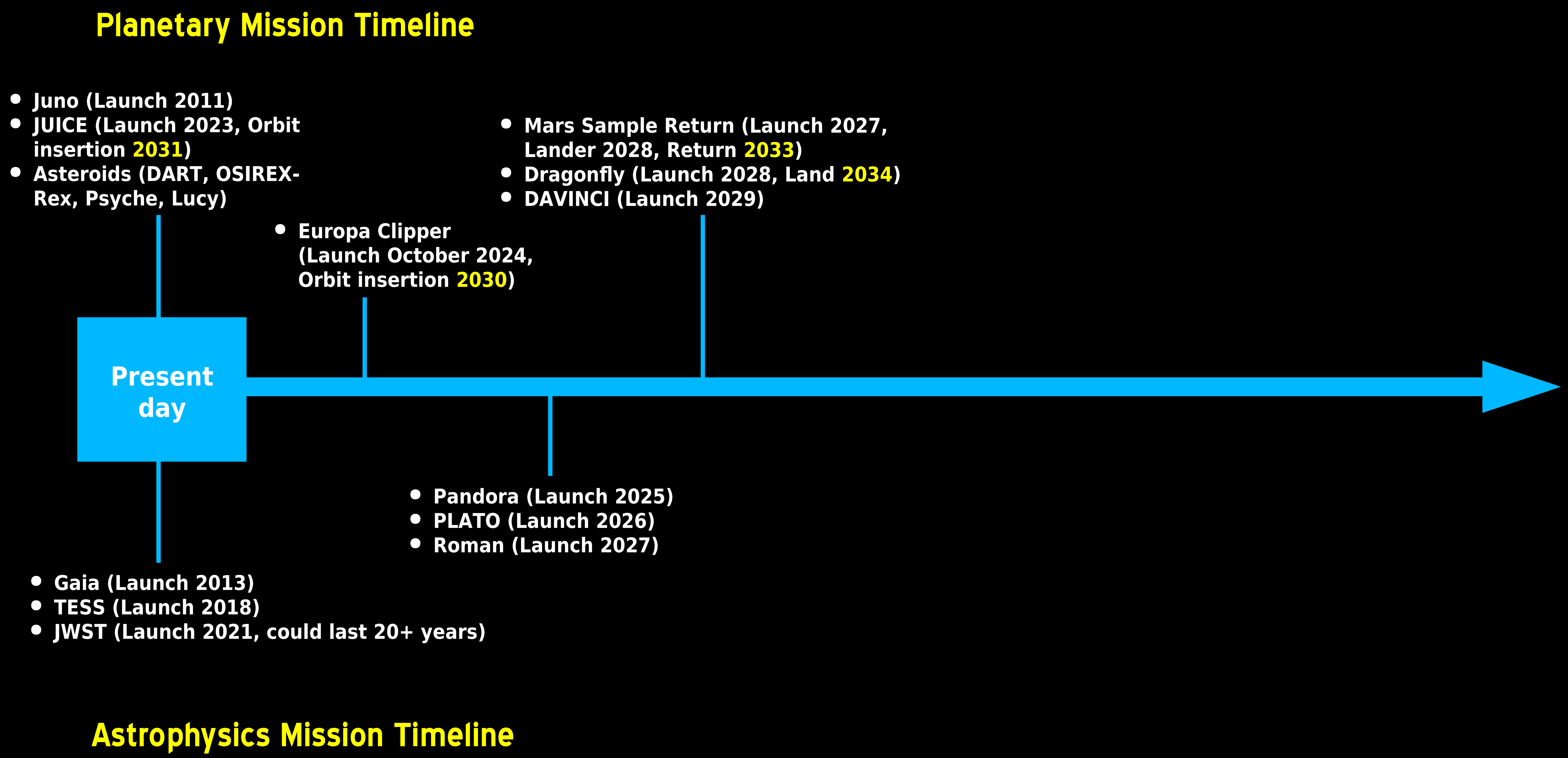
- Europa Clipper (Launch October 2024, Orbit insertion 2030)



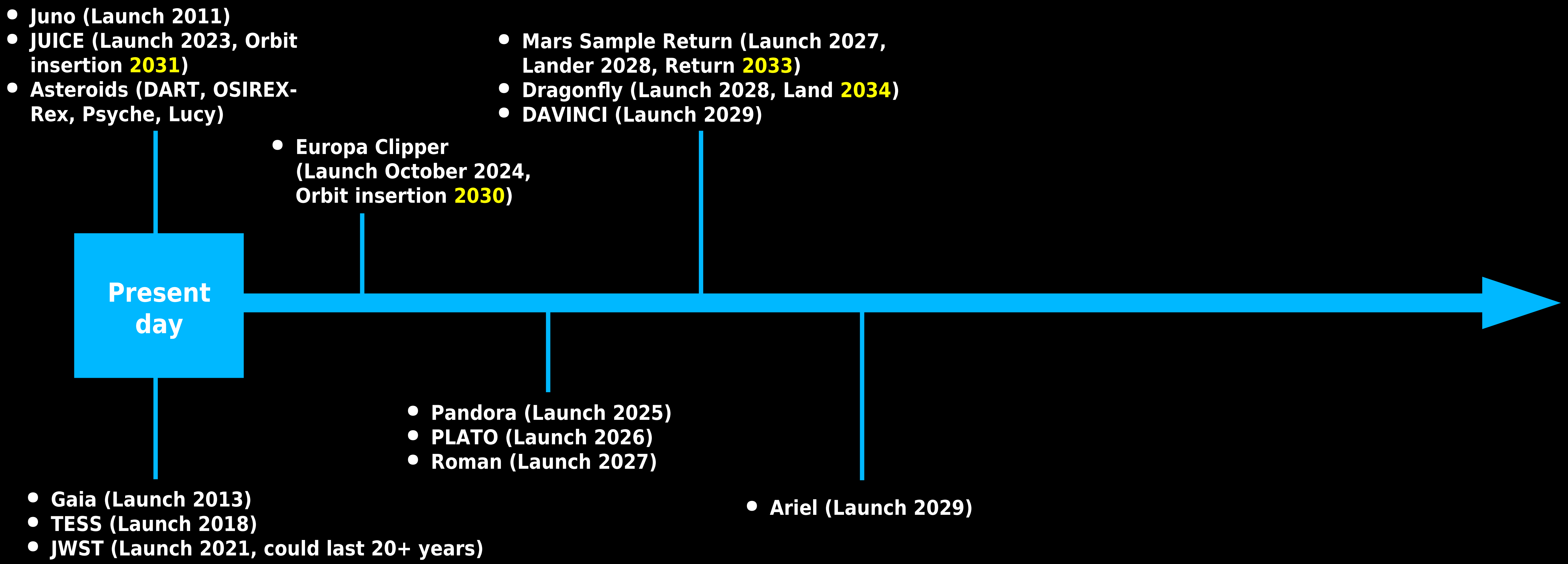
- Pandora (Launch 2025)
- PLATO (Launch 2026)
- Roman (Launch 2027)

- Gaia (Launch 2013)
- TESS (Launch 2018)
- JWST (Launch 2021, could last 20+ years)

Astrophysics Mission Timeline

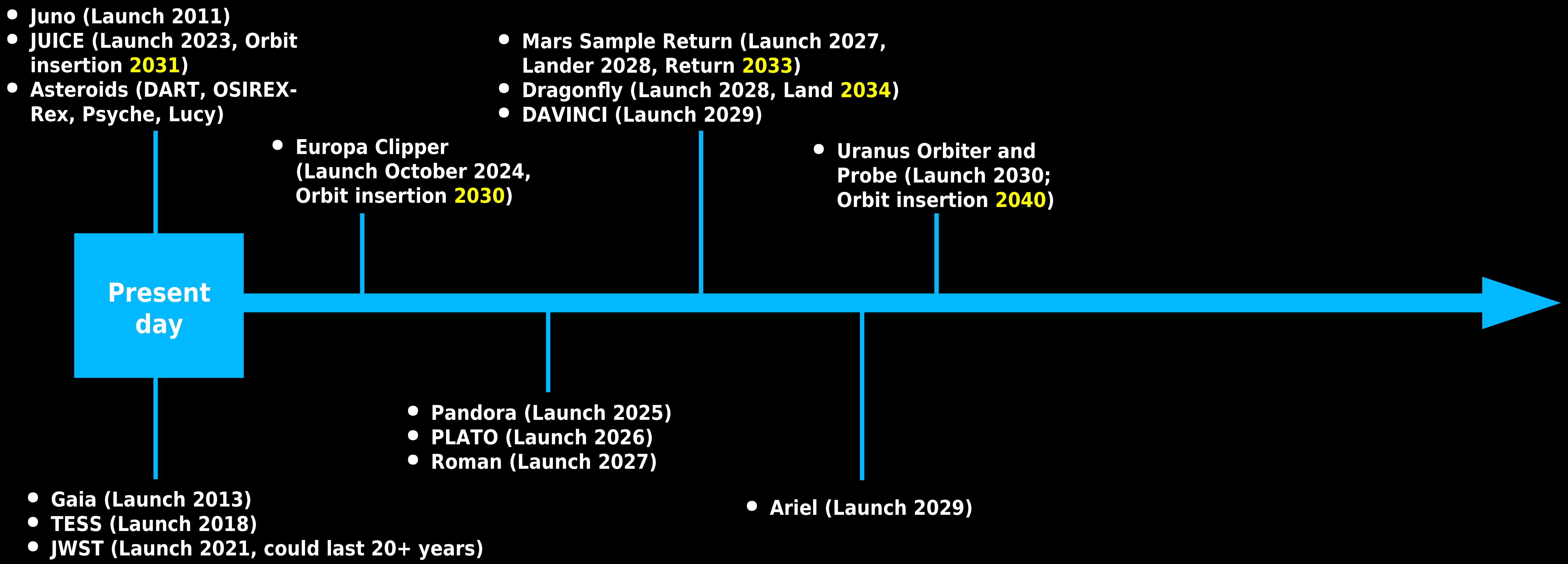

Planetary Mission Timeline
Juno (Launch 2011)
JUICE (Launch 2023, Orbit insertion 2031)
Asteroids (DART, OSIREX-Rex, Psyche, Lucy)
Europa Clipper (Launch October 2024, Orbit insertion 2030)
Mars Sample Return (Launch 2027, Lander 2028, Return 2033)
Dragonfly (Launch 2028, Land 2034)
DAVINCI (Launch 2029)
Present day
Pandora (Launch 2025)
PLATO (Launch 2026)
Roman (Launch 2027)
Gaia (Launch 2013)
TESS (Launch 2018)
JWST (Launch 2021, could last 20+ years)
Astrophysics Mission Timeline

Planetary Mission Timeline



Astrophysics Mission Timeline

Planetary Mission Timeline



Astrophysics Mission Timeline

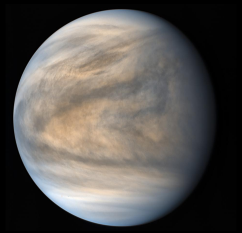
Planetary Mission Timeline

- Juno (Launch 2011)
- JUICE (Launch 2023, Orbit insertion 2031)
- Asteroids (DART, OSIREX-Rex, Psyche, Lucy)

- Europa Clipper (Launch October 2024, Orbit insertion 2030)

- Mars Sample Return (Launch 2027, Lander 2028, Return 2033)
- Dragonfly (Launch 2028, Land 2034)
- DAVINCI (Launch 2029)

- Uranus Orbiter and Probe (Launch 2030; Orbit insertion 2040)



- VERITAS (Launch 2031)
- EnVision (Launch 2031)

Present day

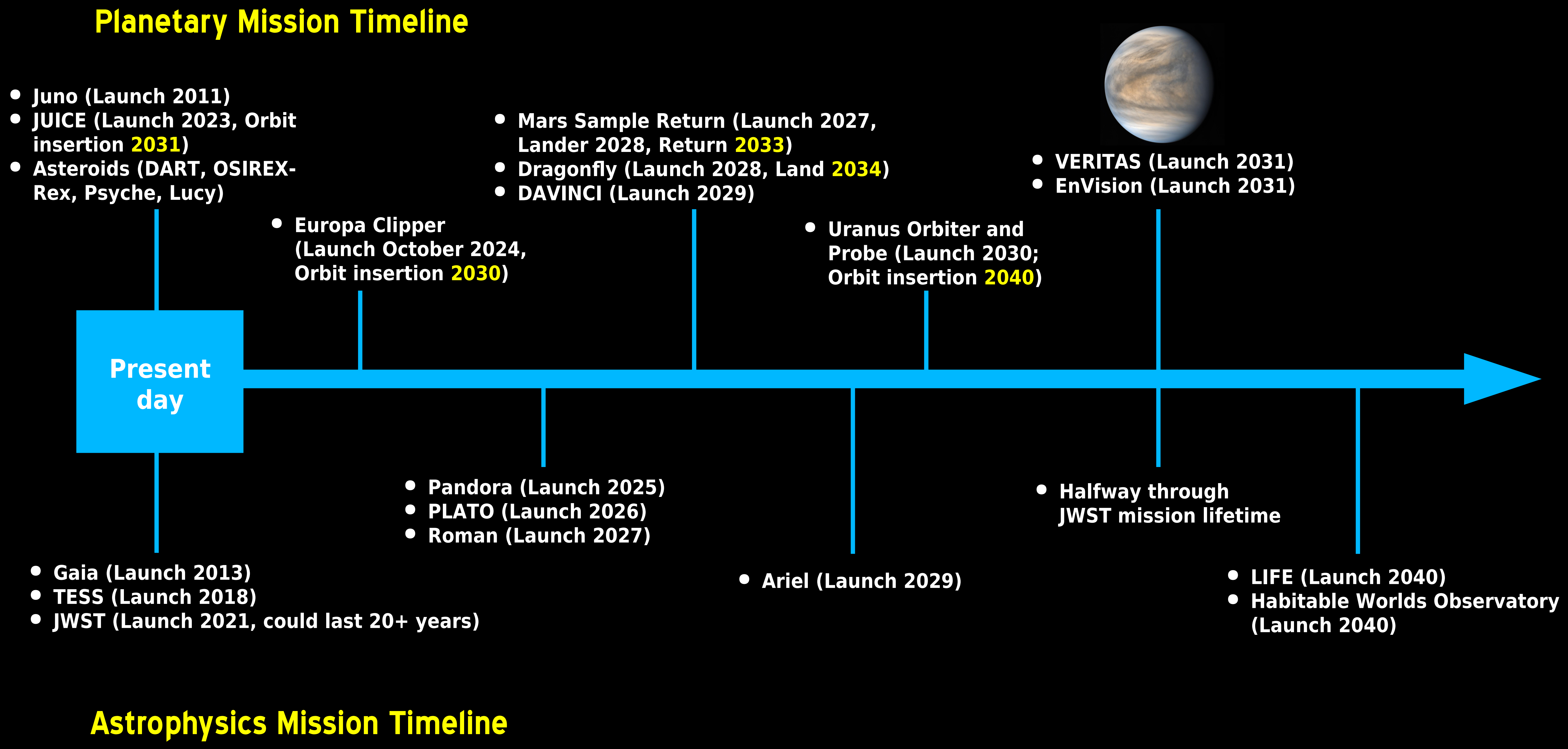
- Gaia (Launch 2013)
- TESS (Launch 2018)
- JWST (Launch 2021, could last 20+ years)

- Pandora (Launch 2025)
- PLATO (Launch 2026)
- Roman (Launch 2027)

- Ariel (Launch 2029)

- Halfway through JWST mission lifetime

Astrophysics Mission Timeline


Planetary Mission Timeline
Juno (Launch 2011)
JUICE (Launch 2023, Orbit insertion 2031)
Asteroids (DART, OSIREX-Rex, Psyche, Lucy)
Europa Clipper (Launch October 2024, Orbit insertion 2030)
Mars Sample Return (Launch 2027, Lander 2028, Return 2033)
Dragonfly (Launch 2028, Land 2034)
DAVINCI (Launch 2029)
Uranus Orbiter and Probe (Launch 2030; Orbit insertion 2040)
VERITAS (Launch 2031)
EnVision (Launch 2031)
Present day
Gaia (Launch 2013)
TESS (Launch 2018)
JWST (Launch 2021, could last 20+ years)
Pandora (Launch 2025)
PLATO (Launch 2026)
Roman (Launch 2027)
Ariel (Launch 2029)
Halfway through JWST mission lifetime
LIFE (Launch 2040)
Habitable Worlds Observatory (Launch 2040)
Astrophysics Mission Timeline

The Pathway Forward: Finding the Connections

1. Current operations of JWST will extend beyond the planned deployment of Venus missions (DAVINCI, VERITAS, EnVision), and both sides will be providing critical information regarding atmospheric structure of dense planetary atmospheres. The Venus missions will also address the time dependence of planetary habitability and the evolution of surface conditions.

2. The Uranus flagship mission (Uranus Orbiter and Probe) is slated for launch in early 2030s, and orbital insertion in early 2040s. This creates a time scale synergy with Habitable Worlds Observatory, and the need to detect true Uranus/Neptune analogs (low insolation flux) for comparative planetology science and planet formation processes at the edge of circumstellar discs.

3. Coming icy moon missions (Europa Clipper, Dragonfly, and the decadal recommended Enceladus Orbilander) have the potential to significantly advance the understanding of planetary habitability under extreme environments and the nature of sub-surface oceans. Given the current models of ocean worlds at the outer edge of the Habitable Zone, these planetary mission data will be directly applicable to the astrobiology component of exoplanet missions.

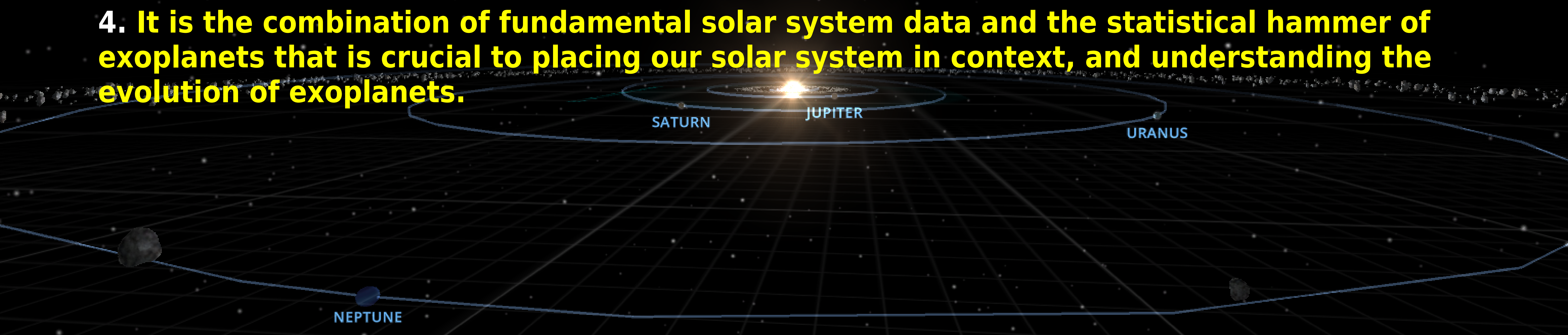
The Pathway Forward: Forging the Connections

1. Examine the planetary science literature. Solar system science is continually advancing, with frequent, and often significant, revisions to prevailing models of atmospheres, surfaces, and interiors. Attending SIG 3 talks is a great gateway!

2. Attend relevant meetings. These are often listed on the various analysis group web sites (OPAG, VEXAG, etc) and are sometimes held in conjunction with collaborative meetings (e.g., Exoplanets in our Backyard).

3. Contact planetary science mission scientists. They DO want to know how their mission can serve you and vice versa.

4. It is the combination of fundamental solar system data and the statistical hammer of exoplanets that is crucial to placing our solar system in context, and understanding the evolution of exoplanets.



Kane et al. 2021, “The Fundamental Connections between the Solar System and Exoplanetary Science”, JGR Planets, 126, e06643