

Workshop Synthesis 1:
Key Science Questions
for the 2030s and Beyond

Ryan C. Hickox

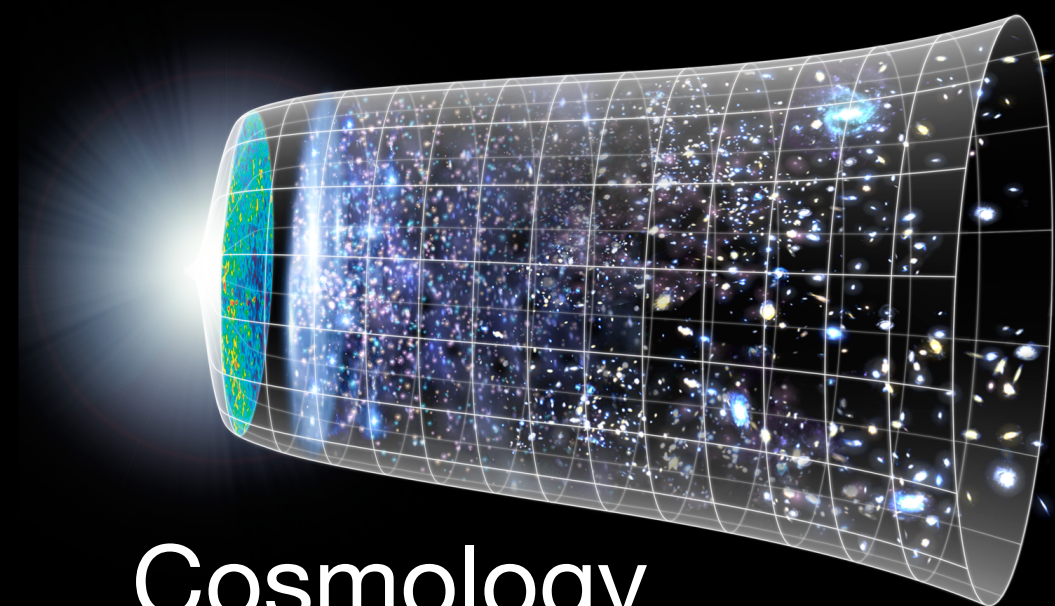
Ad ASTRA
Community Workshop
Pasadena, CA
3 September 2026

DARTMOUTH





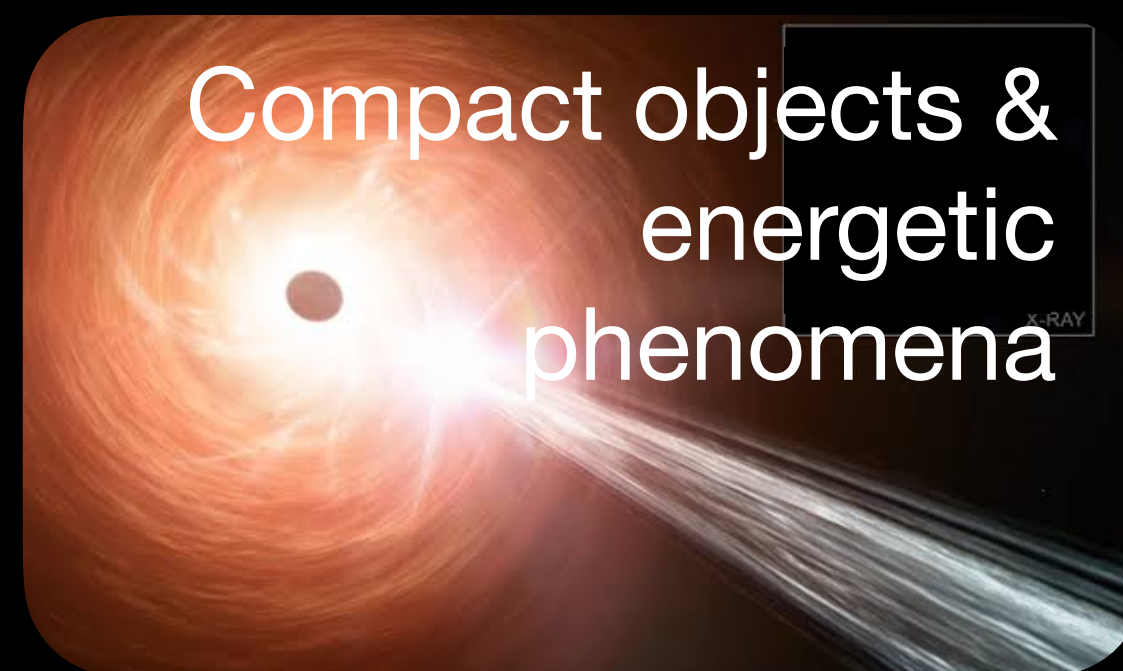
Galaxies



Cosmology



Stars & stellar populations



Compact objects & energetic phenomena

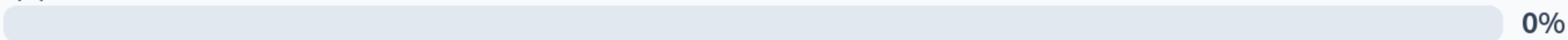


Exoplanets & astrobiology

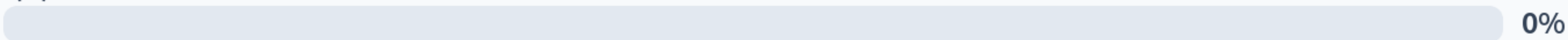


What best represents your current career position?

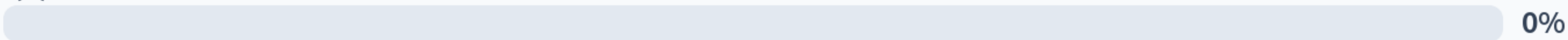
(A) Student



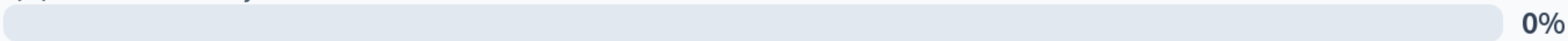
(B) Postdoc



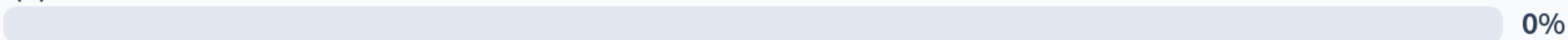
(C) Research scientist



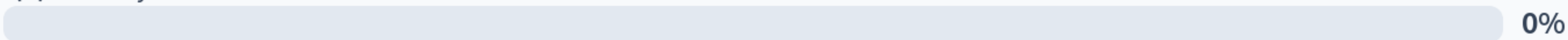
(D) Academic faculty



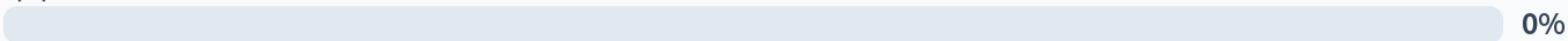
(E) Administration



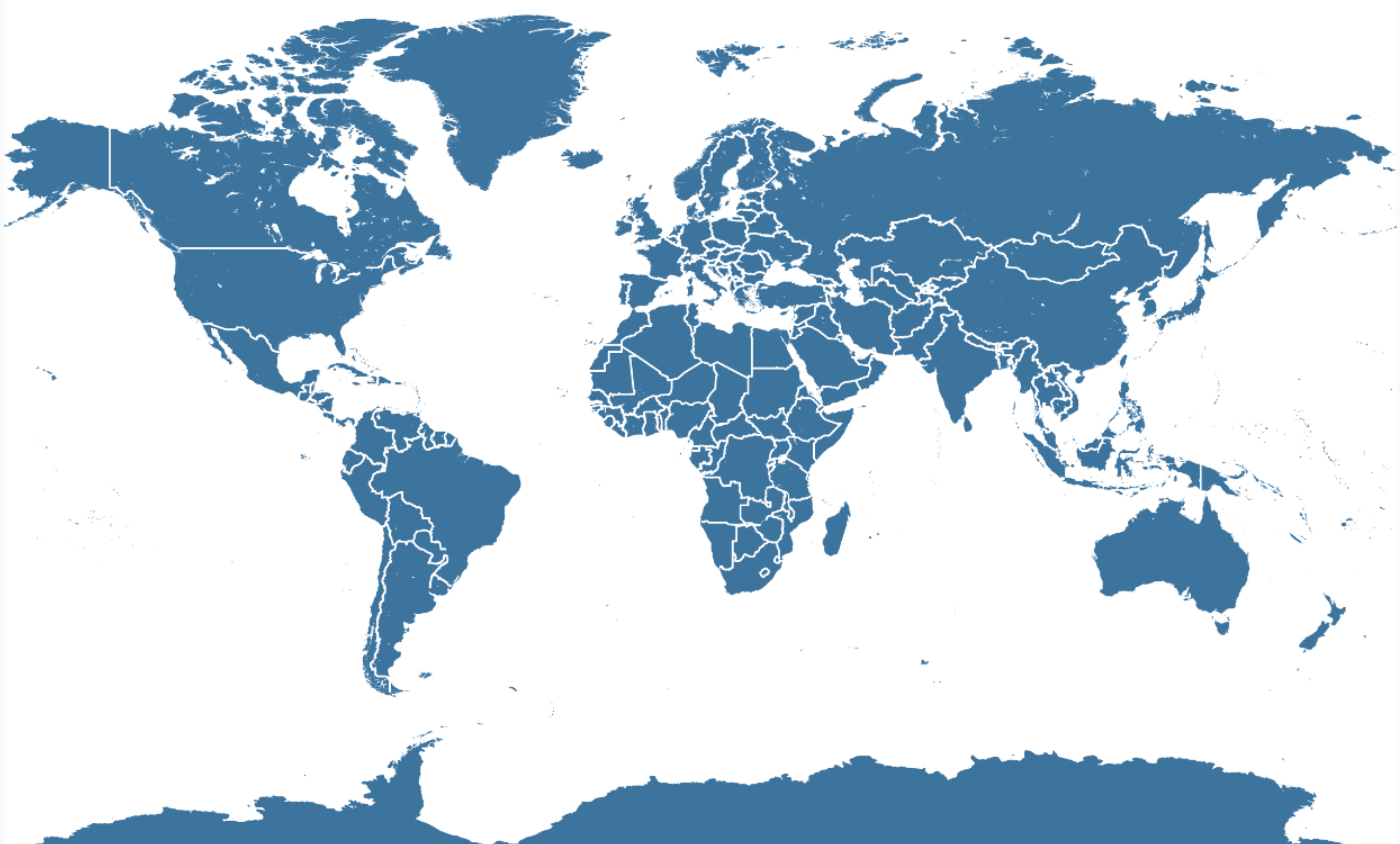
(F) Industry



(G) Other



Where is your institution based?

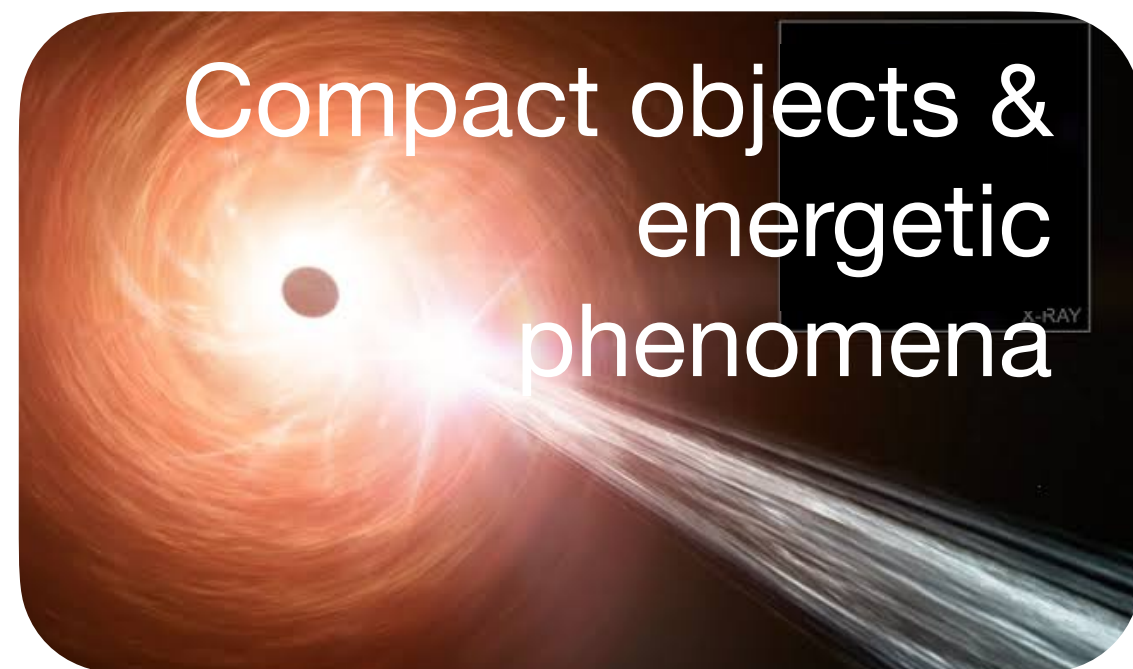


CONSENSUS STUDY REPORT

Pathways to Discovery in Astronomy and Astrophysics for the 2020s

TABLE 2.1 Science Panel Questions

Question	Theme(s)
<i>Panel on Compact Objects and Energetic Phenomena</i>	
What are the mass and spin distributions of neutron stars and stellar mass black holes?	New Messengers and New Physics
What powers the diversity of explosive phenomena across the electromagnetic spectrum?	New Messengers and New Physics
What do some compact objects eject material at nearly-light-speed jets, and what is that material made of?	New Messengers and New Physics
What seeds supermassive black holes and how do they grow?	New Messengers and New Physics, Cosmic Ecosystem
<i>Panel on Cosmology</i>	
What set the hot Big Bang in motion?	New Messengers and New Physics
What are the properties of dark matter and the dark sector?	New Messengers and New Physics
What physics drives the cosmic expansion and the large-scale evolution of the universe?	New Messengers and New Physics
How will measurements of gravitational waves reshape our cosmological view?	New Messengers and New Physics
<i>Panel on Galaxies</i>	
How did the intergalactic medium and the first sources of radiation evolve from cosmic dawn through the epoch of reionization?	Cosmic Ecosystem
How do gas, metals, and dust flow into, through, and out of galaxies?	Cosmic Ecosystem
How do supermassive black holes form and how is their growth coupled to the evolution of their host galaxies?	Cosmic Ecosystem, New Messengers and New Physics
How do the histories of galaxies and their dark matter halos shape their observable properties?	Cosmic Ecosystem
<i>Panel on Exoplanets, Astrobiology, and the Solar System</i>	
What is the range of planetary system architectures, and is the configuration of the solar system common?	Worlds and Suns in Context
What are the properties of individual planets, and which processes lead to planetary diversity?	Worlds and Suns in Context
How do habitable environments arise and evolve within the context of their planetary systems?	Worlds and Suns in Context
How can signs of habitable life be identified and interpreted in the context of their planetary environments?	Worlds and Suns in Context
<i>Panel on the Interstellar Medium and Star and Planet Formation</i>	
How do star-forming structures arise from, and interact with, the diffuse ISM?	Cosmic Ecosystem
What regulates the structures and motions within molecular clouds?	Cosmic Ecosystem
How does gas flow from parsec scales down to protostars and disks?	Cosmic Ecosystem
Is planet formation fast or slow?	Worlds and Suns in Context, Cosmic Ecosystem
<i>Panel on Stars, the Sun, and Stellar Populations</i>	
What are the most extreme stars and stellar populations?	Worlds and Suns in Context, Cosmic Ecosystem
How does multiplicity affect the way a star lives and dies?	Worlds and Suns in Context
What would stars look like if we view them like we do the Sun?	Worlds and Suns in Context
How do the Sun and other stars create space weather?	Worlds and Suns in Context



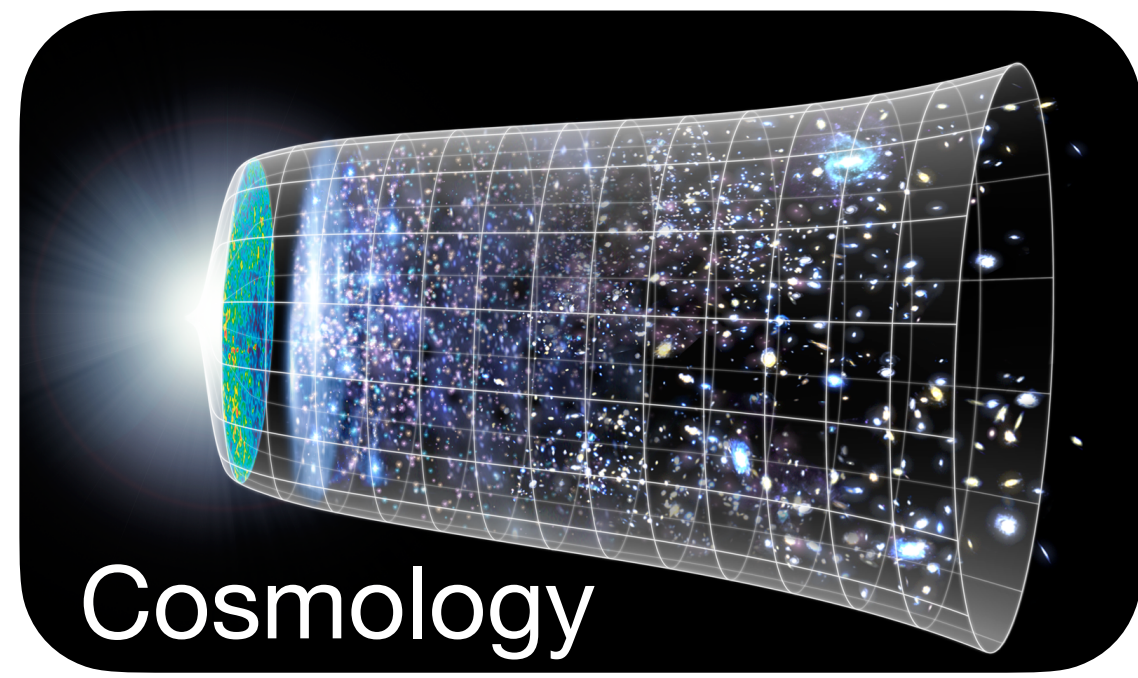
Panel on Compact Objects and Energetic Phenomena

What are the mass and spin distributions of neutron stars and stellar mass black holes?

What powers the diversity of explosive phenomena across the electromagnetic spectrum?

What do some compact objects eject material at nearly-light-speed jets, and what is that material made of?

What seeds supermassive black holes and how do they grow?



Panel on Cosmology

What set the hot Big Bang in motion?

What are the properties of dark matter and the dark sector?

What physics drives the cosmic expansion and the large-scale evolution of the universe?

How will measurements of gravitational waves reshape our cosmological view?



Panel on Galaxies

- How did the intergalactic medium and the first sources of radiation evolve from cosmic dawn through the epoch of reionization?
- How do gas, metals, and dust flow into, through, and out of galaxies?
- How do supermassive black holes form and how is their growth coupled to the evolution of their host galaxies?
- How do the histories of galaxies and their dark matter halos shape their observable properties?

Panel on Exoplanets, Astrobiology, and the Solar System

What is the range of planetary system architectures, and is the configuration of the solar system common?

What are the properties of individual planets, and which processes lead to planetary diversity?

How do habitable environments arise and evolve within the context of their planetary systems?

How can signs of habitable life be identified and interpreted in the context of their planetary environments?



Stars & stellar populations

Panel on the Interstellar Medium and Star and Planet Formation

How do star-forming structures arise from, and interact with, the diffuse ISM?

What regulates the structures and motions within molecular clouds?

How does gas flow from parsec scales down to protostars and disks?

Is planet formation fast or slow?

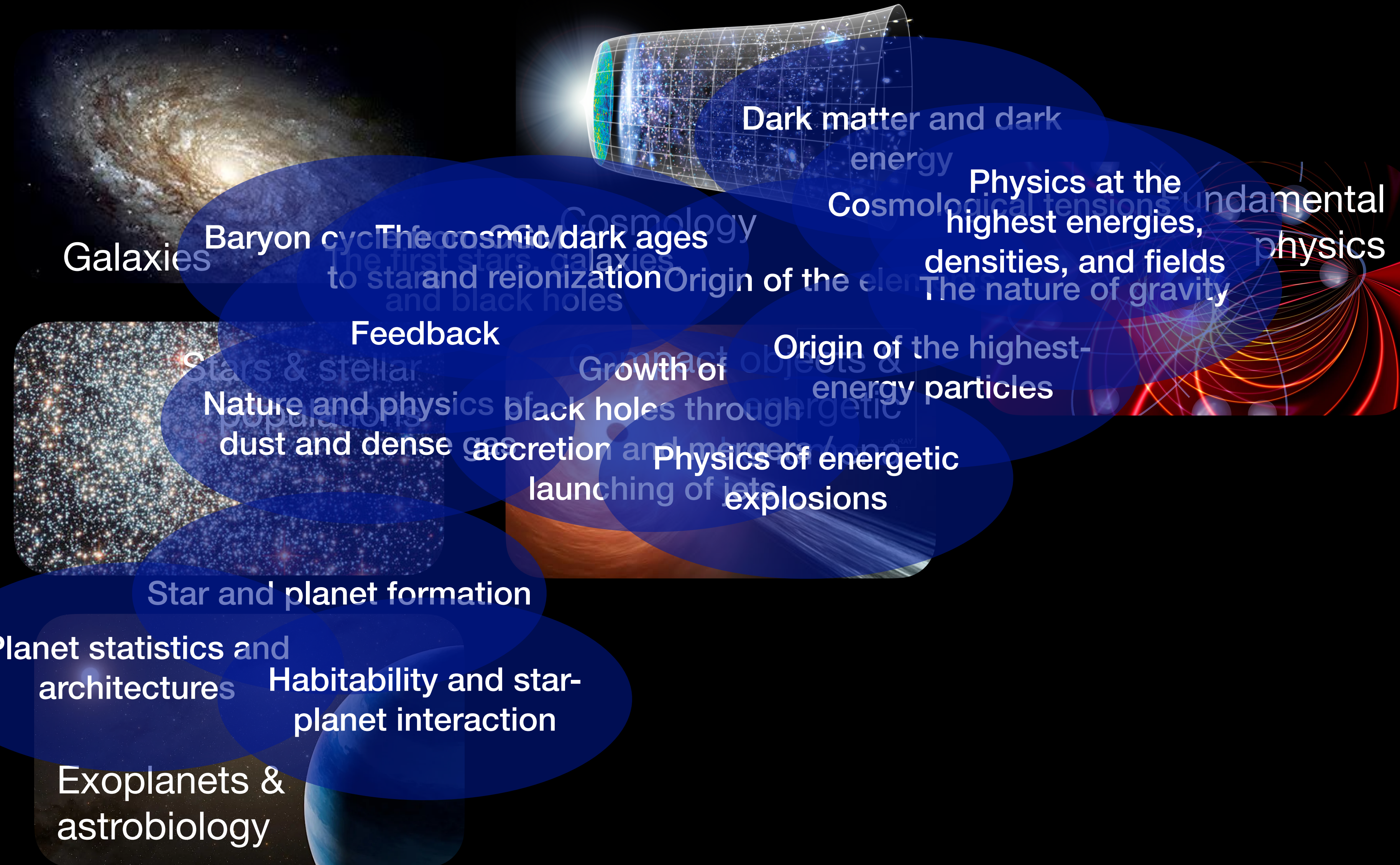
Panel on Stars, the Sun, and Stellar Populations

What are the most extreme stars and stellar populations?

How does multiplicity affect the way a star lives and dies?

What would stars look like if we view them like we do the Sun?

How do the Sun and other stars create space weather?



How does the universe work?

How did we get here?

Are we alone?

New Messengers & New Physics

Cosmic Ecosystems

Worlds & Suns in Context

The nature of gravity

Baryon cycle from CGM to stars

Planet statistics and architectures

Physics at the highest energies, densities, and fields

The cosmic dark ages and reionization

Star and planet formation

The first stars, galaxies, and black holes

Habitability and star-planet interaction

Cosmological tensions

Growth of black holes through accretion and mergers / launching of jets

Nature and physics of dust and dense gas

Origin of the highest-energy particles

Origin of the elements

Feedback

Dark matter and dark energy

Physics of energetic explosions

New science since Astro2020 (not at all exhaustive)

Little red dots / origin of black holes and nature of BH accretion

Measurement of the low-frequency gravitational wave background

Vacuum birefringence in a magnetar (motivates photon splitting)

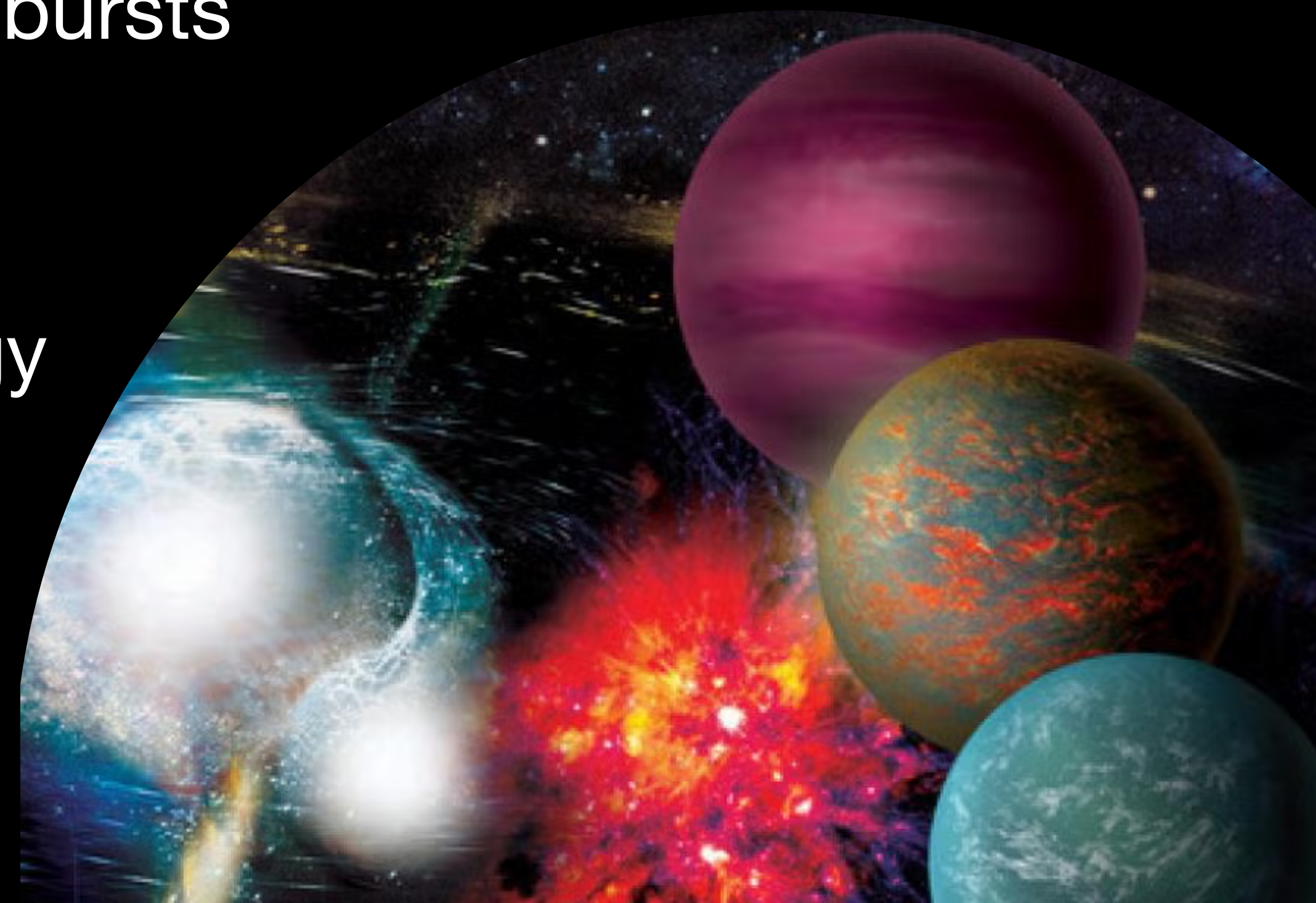
Localization and characterization of fast radio bursts

Neutrinos from AGN and Galactic plane

Cosmological tensions / dynamical dark energy

Characteristics of early galaxies with JWST

Complexity of planetary systems



Some key takeaways: Science questions

How did the Universe begin?

How do stars and their planets form?

How do we place habitable worlds in the population of stars and planets?

What are dark matter and dark energy?

How does physics work at the extremes of gravity, density, fields, and energy?

How does feedback shape the growth of galaxies, black holes, and stars?

How do black holes form and grow over cosmic time and how do they power energetic phenomena?

Some key takeaways: Science questions

Many links in **science topics** between different broad science fields

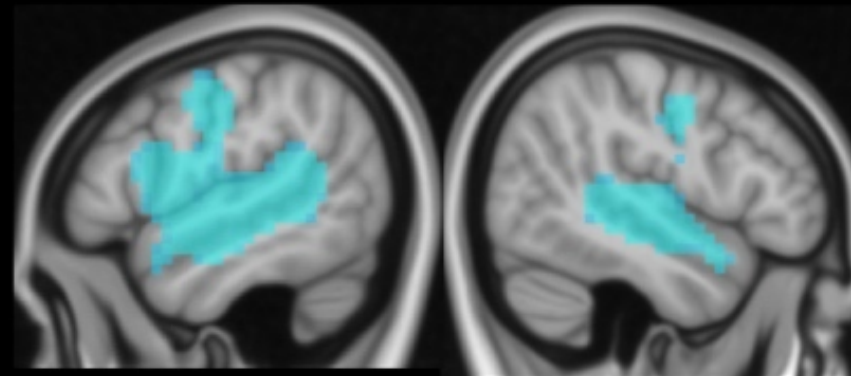
Recent progress has been a combination of addressing previous questions and entirely new discoveries

Some big picture questions remain similar to previous decades; but science **progress** doesn't mean that the big questions are no longer interesting!

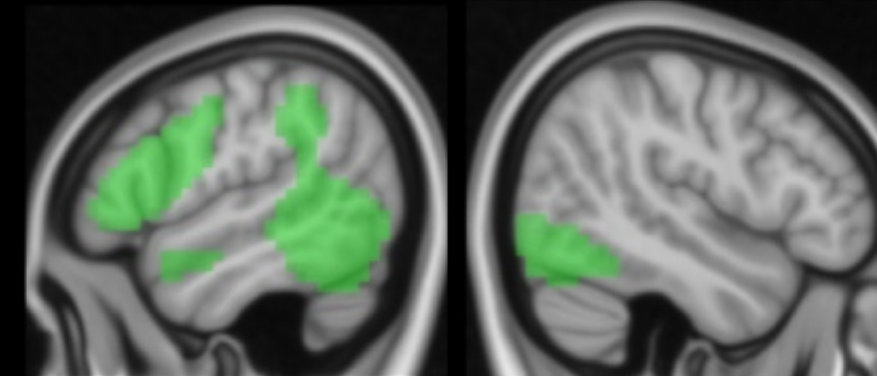
How does the **brain** work?



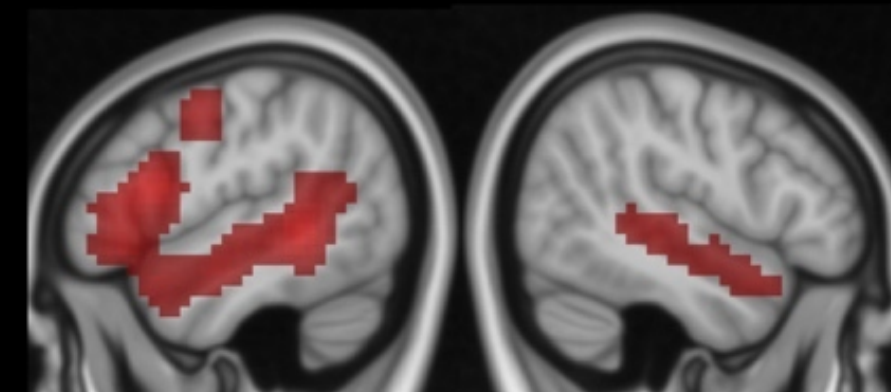
Phonemic



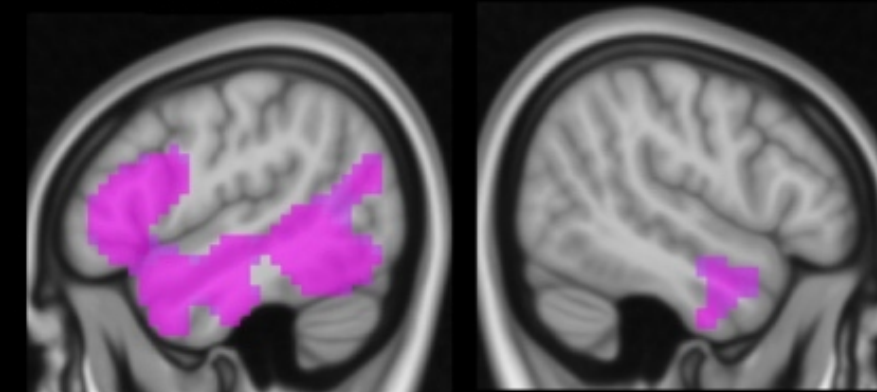
Reading



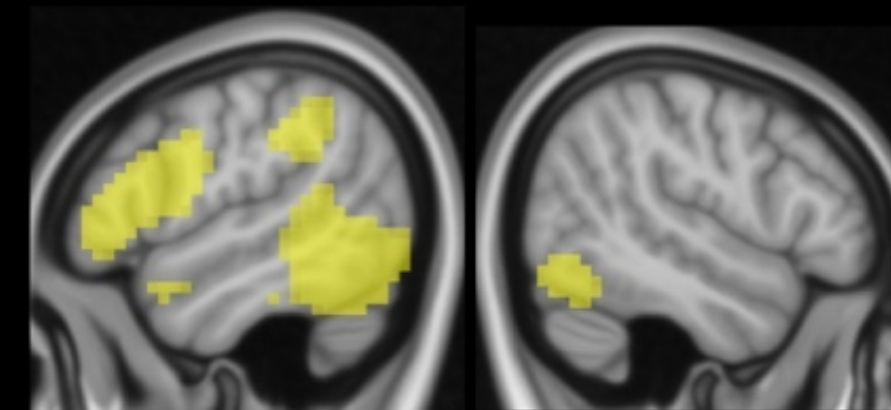
Comprehension



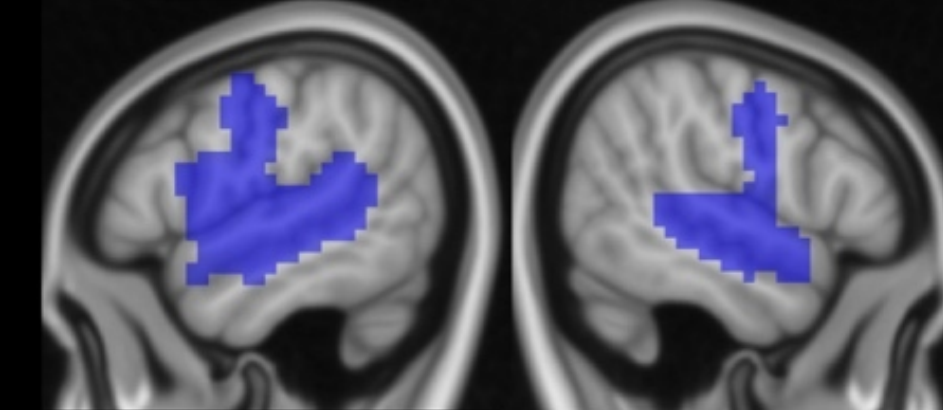
Semantic



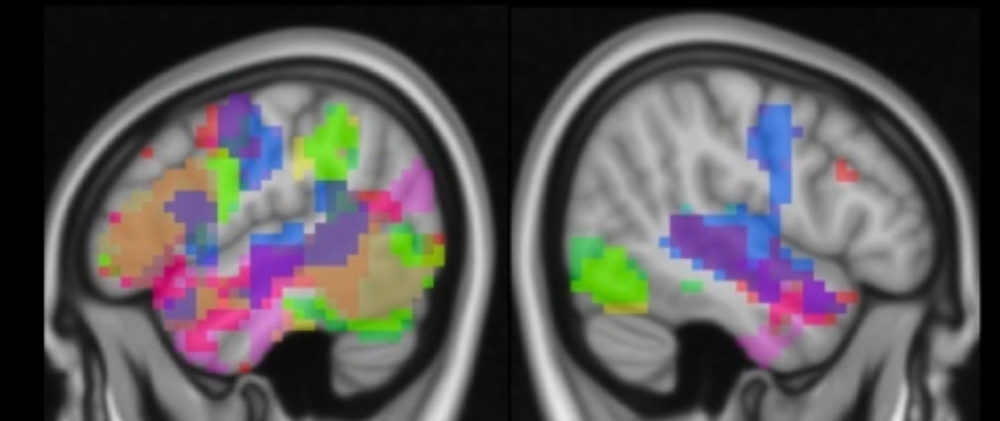
Naming



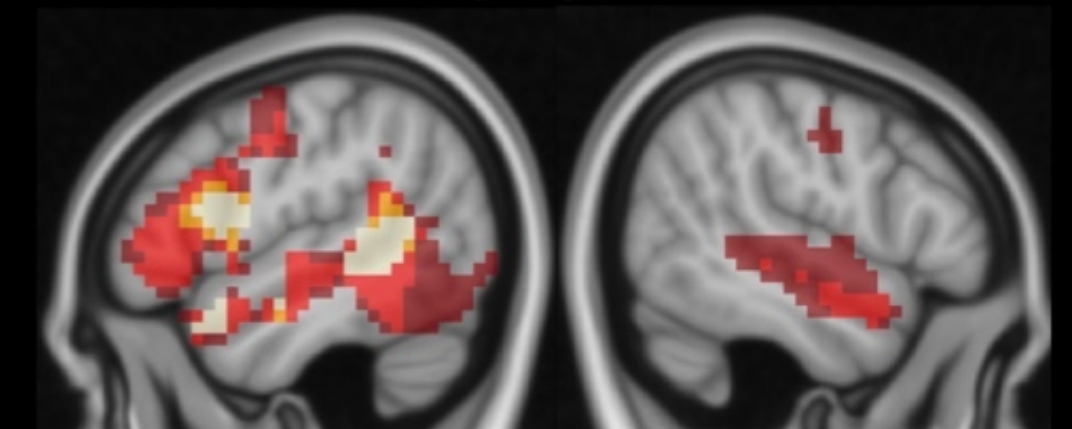
Articulation



All processes: overlap map



Regions involved in at least 2 of the language processes



Voets et al. (2025)

Observational capabilities

Radio FIR
MIR NIR
optical UV
X-ray
gamma-ray
GW CR
neutrinos

Monitoring

Field of
view

Rapid
response

Spectral
resolution

Polarization

Timing

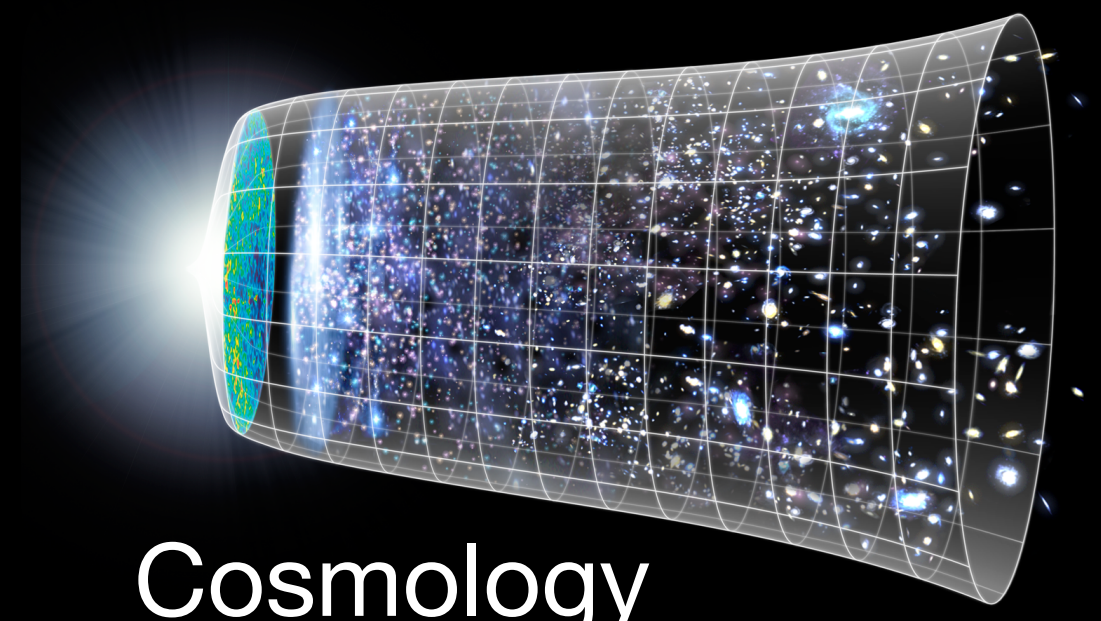
Contrast

Sensitivity

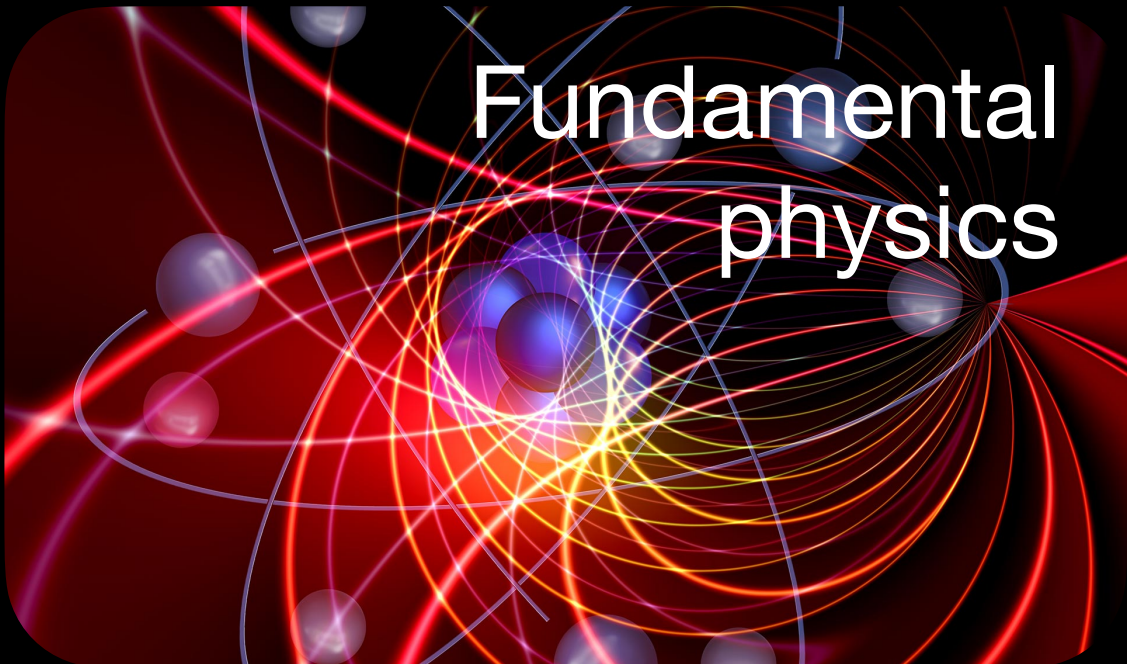
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Cosmology

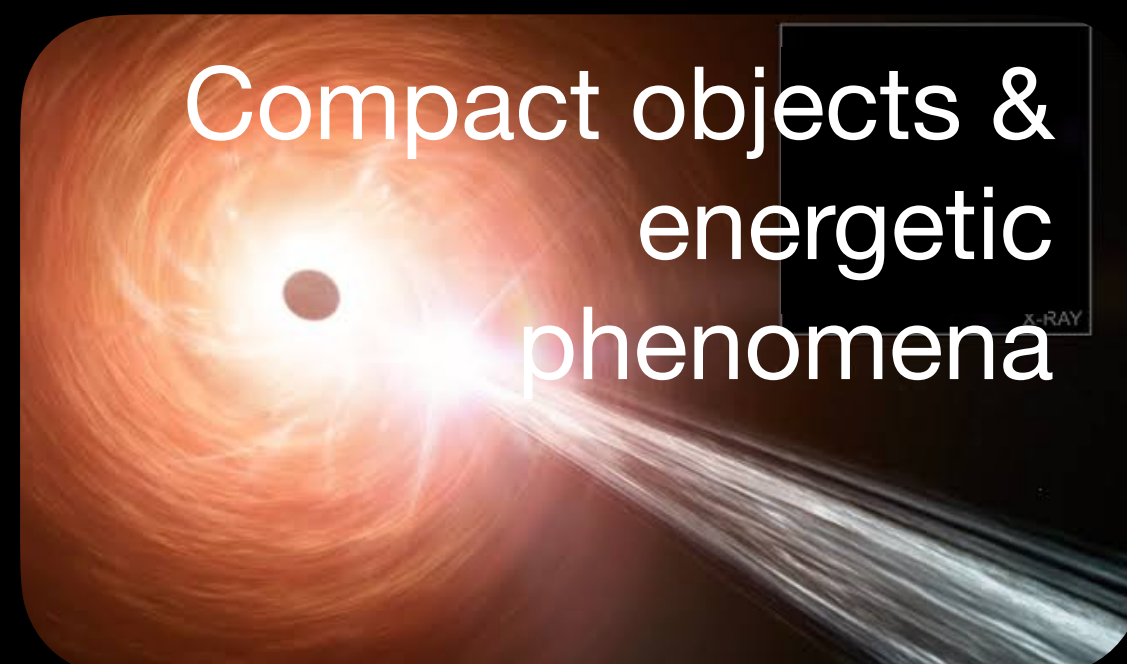


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Stars & stellar
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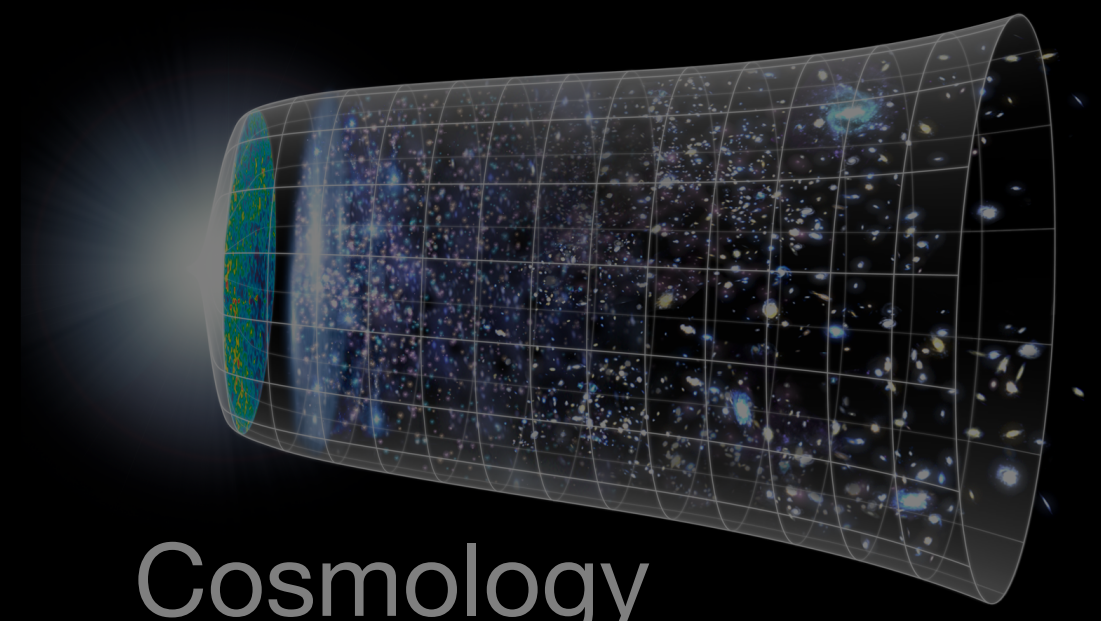
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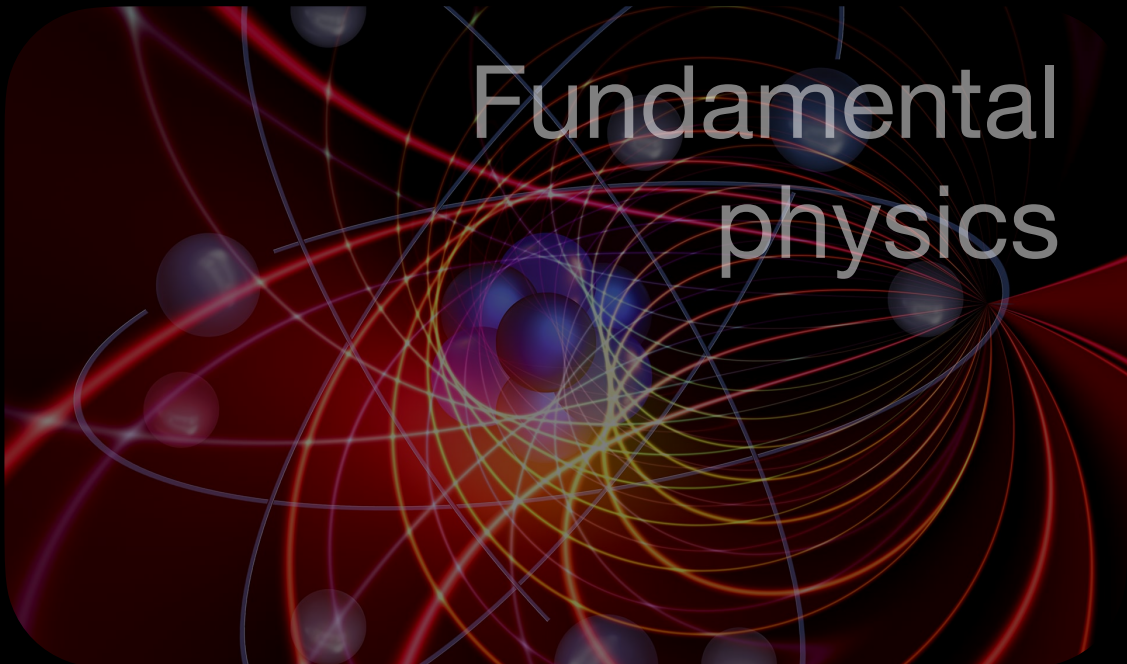
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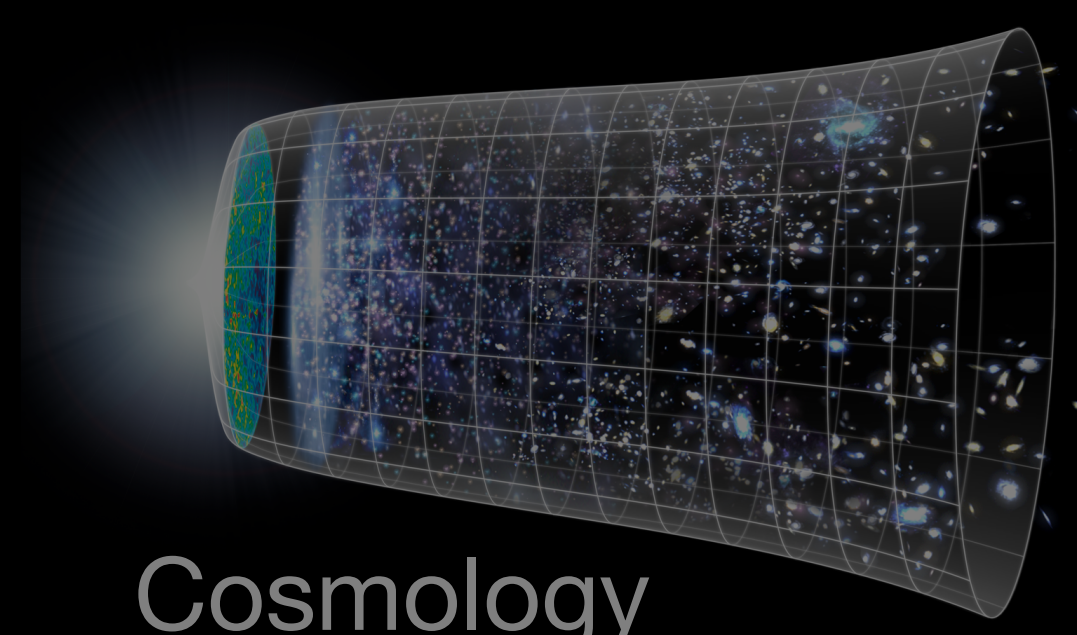
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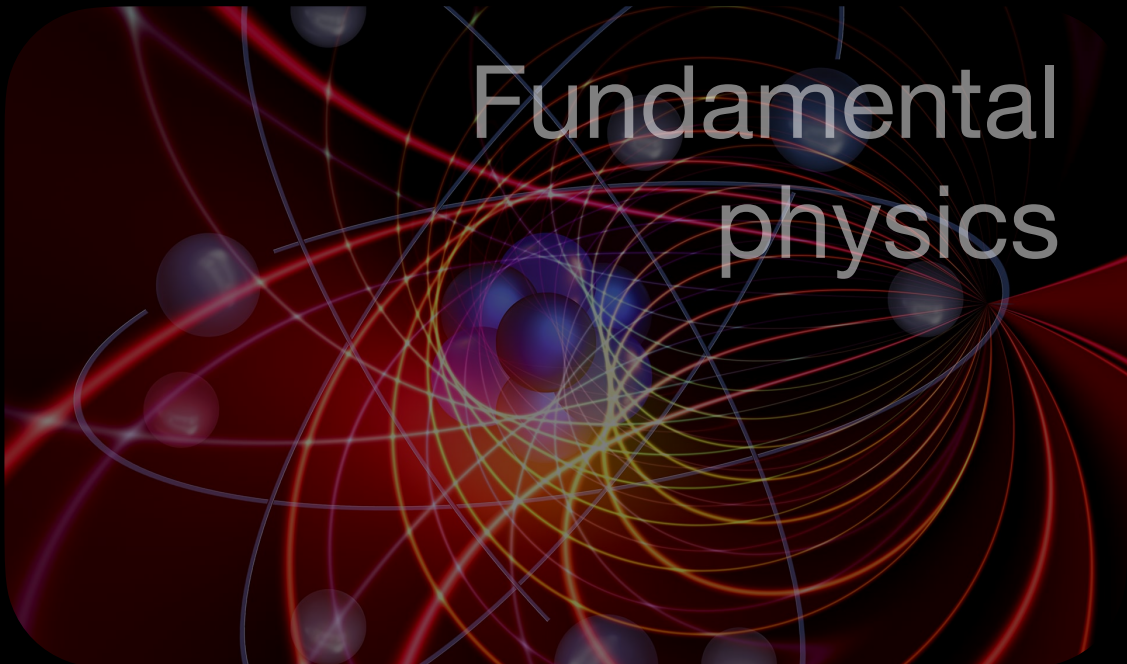
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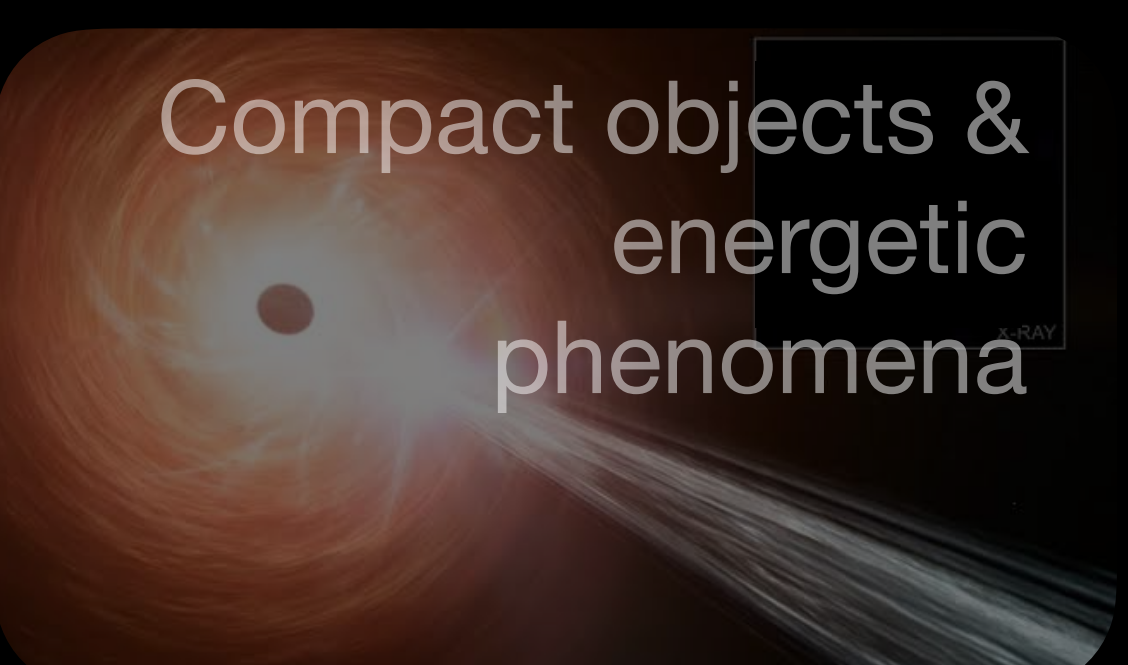


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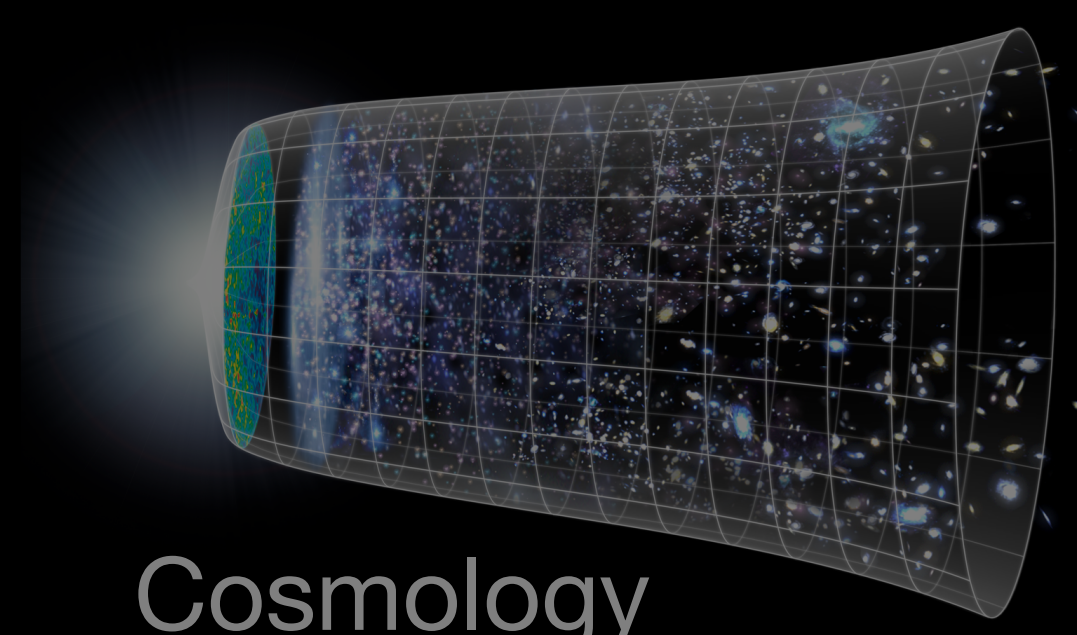
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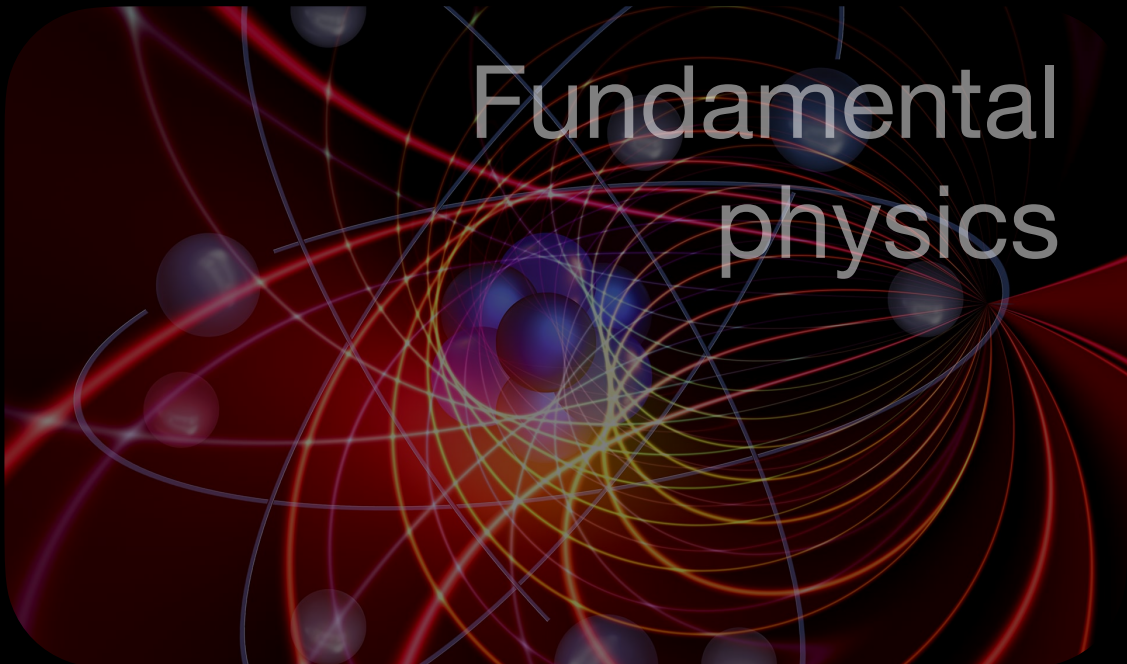
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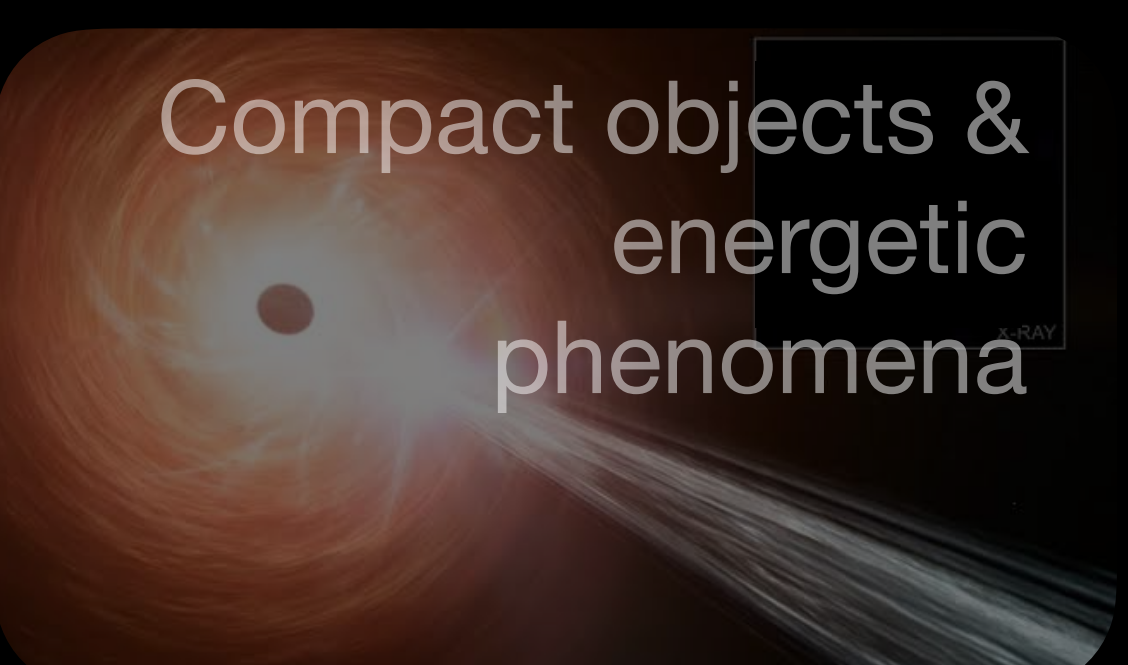


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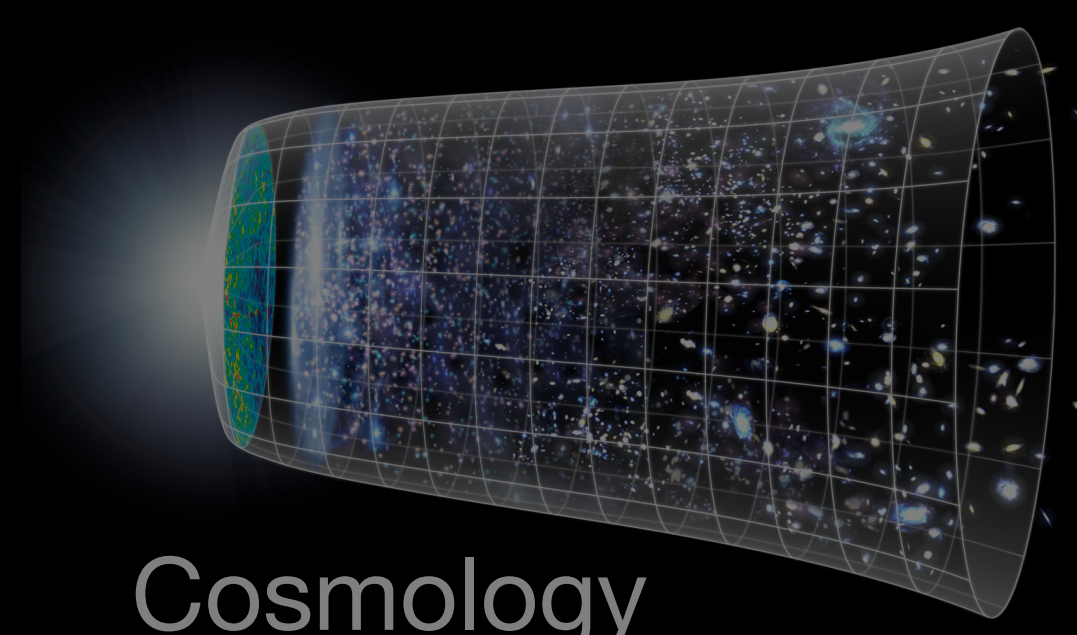
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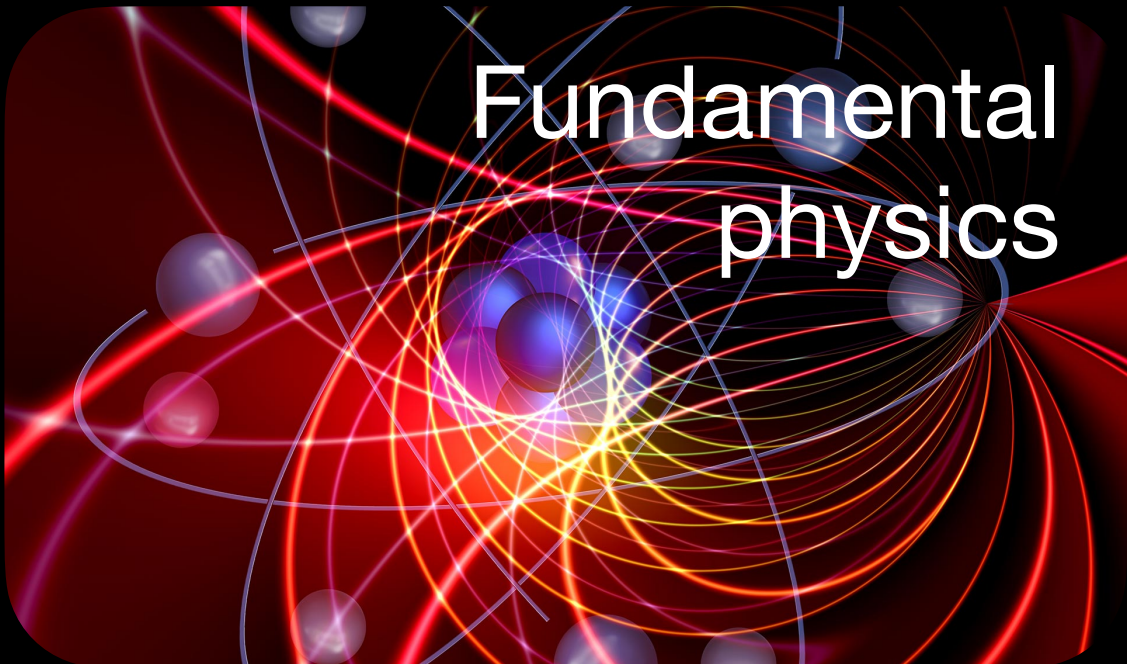
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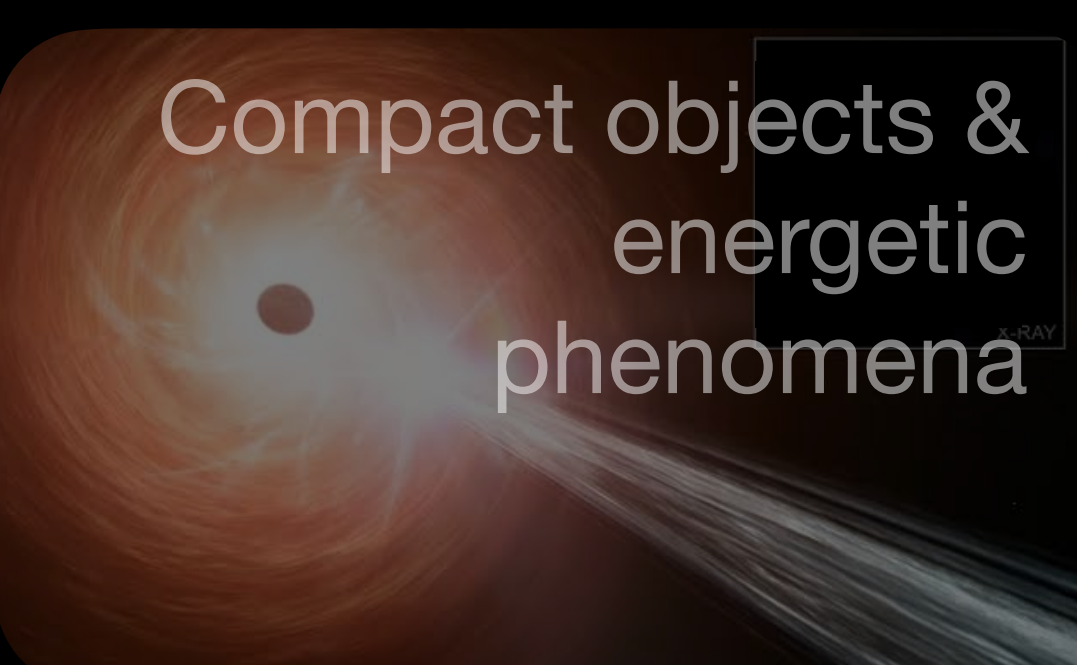


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Some key takeaways: Capabilities

Many of the science questions are intrinsically **multiwavelength** and **multimessenger** in nature

Many of the science questions require **simultaneous observations** or ones **closely matched in resolution / sensitivity**

Some current capabilities will soon be **lost**

Importance of synergy between **ground- and space-based observations**

Science topics discussed extensively at this meeting
(inevitably incomplete and in no particular order)
The “**billion dollar questions**”

The first stars, galaxies,
and black holes

Growth of
black holes through
accretion and mergers /
launching of jets

Dark matter and dark
energy

The nature of gravity

Nature and physics of
dust and dense gas

Baryon cycle from CGM
to stars

Cosmological tensions

Physics at the
highest energies,
densities, and fields

Star and planet formation

Origin of the elements

The cosmic dark ages
and reionization

Physics of energetic
explosions

Planet statistics and
architectures

Habitability and star-
planet interaction

Origin of the highest-
energy particles

Feedback

The “multi-billion dollar questions”

How did the Universe begin?

How do stars and their planets form?

How do we place habitable worlds in the population of stars and planets?

What are dark matter and dark energy?

How does physics work at the extremes of gravity, density, fields, and energy?

How does feedback shape the growth of galaxies, black holes, and stars?

How do black holes form and grow over cosmic time and how do they power energetic phenomena?

The “trillion dollar question”

What is all
this, and *why*?

