STScI | SPACE TELESCOPE SCIENCE INSTITUTE

# JWST Science Highlights and Emerging Themes

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With contributions from Bryan Holler and Néstor Espinoza

# JWST is FANTASTIC

It out-performs its pre-launch requirements

⟶ Images twice as sharp (diffraction limited at 1 micron instead of 2 microns)

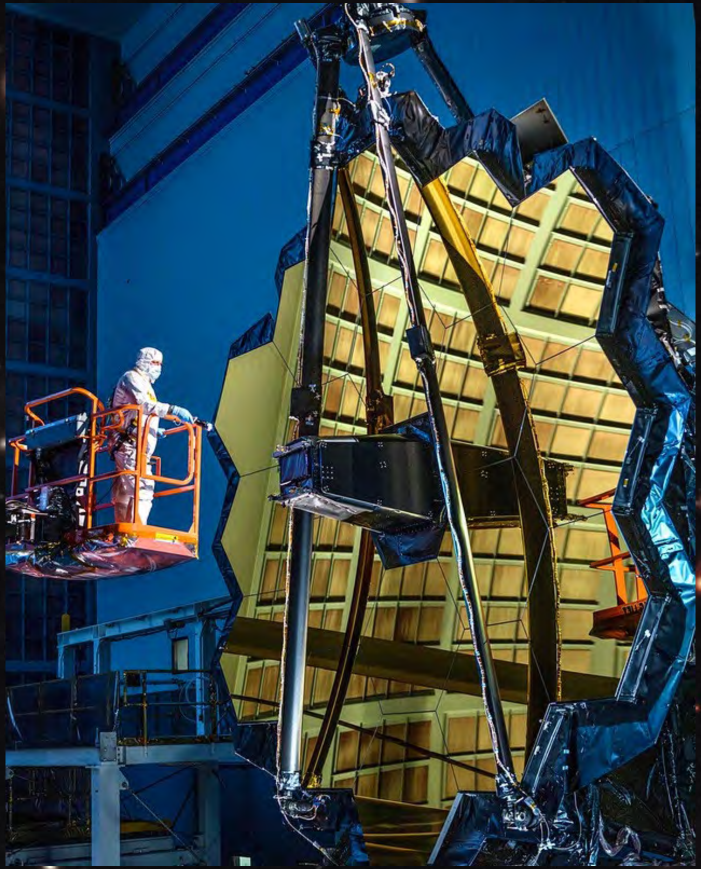
⟶ Optics more stable (over 6 months with no mirror corrections in 2024)

⟶ Most instruments modes are more sensitive

Fuel for >20 years

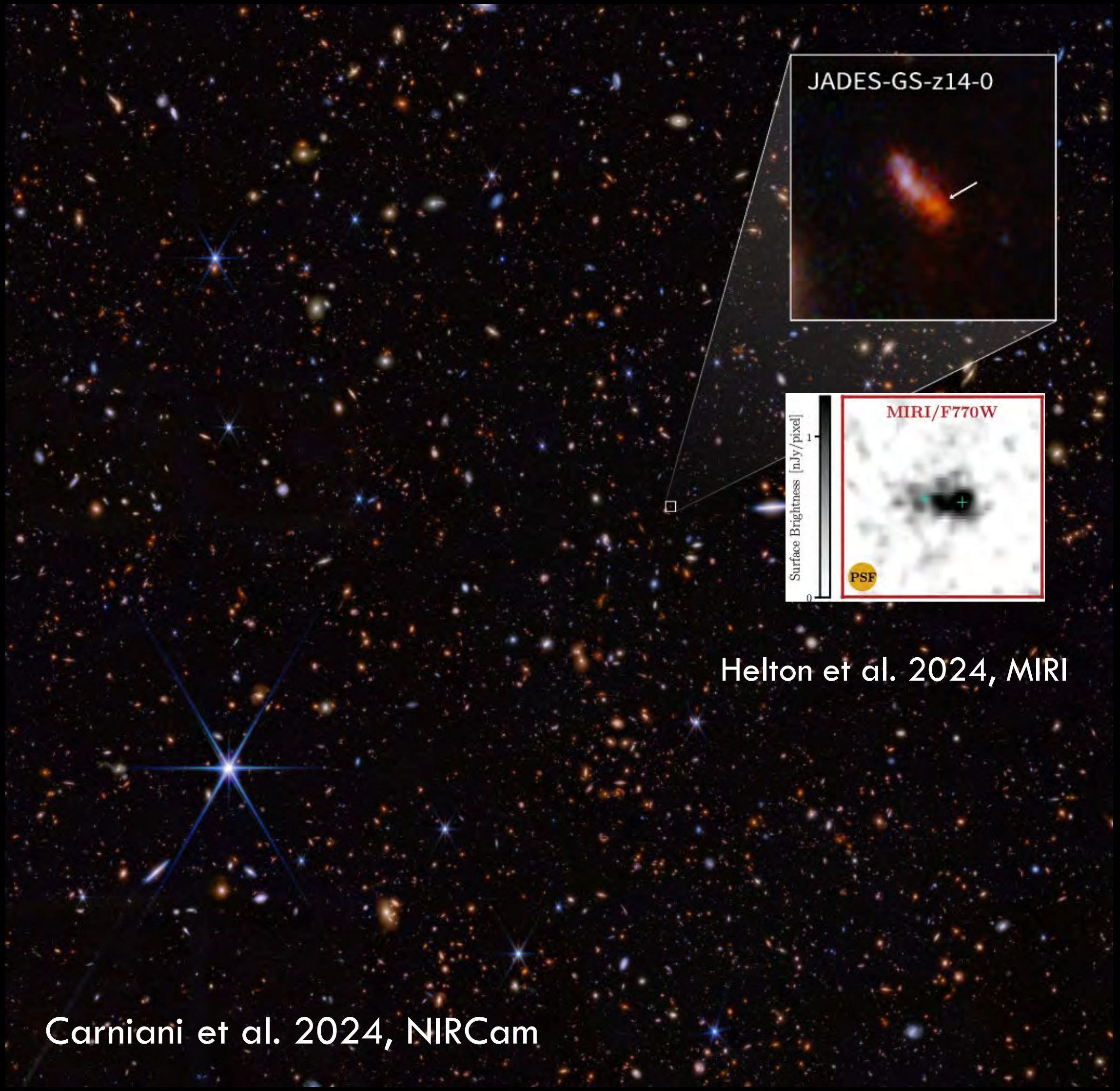
It is now on its third year of mission

It is fulfilling its promise of revolutionizing astronomy



# How is JWST Revolutionizing Astronomy?

By allowing previously impossible measurements



Helton et al. 2024, MIRI

Carniani et al. 2024, NIRCam

See also Kokorev et al. 2024, NIRCam for higher-z photometrically-selected candidates

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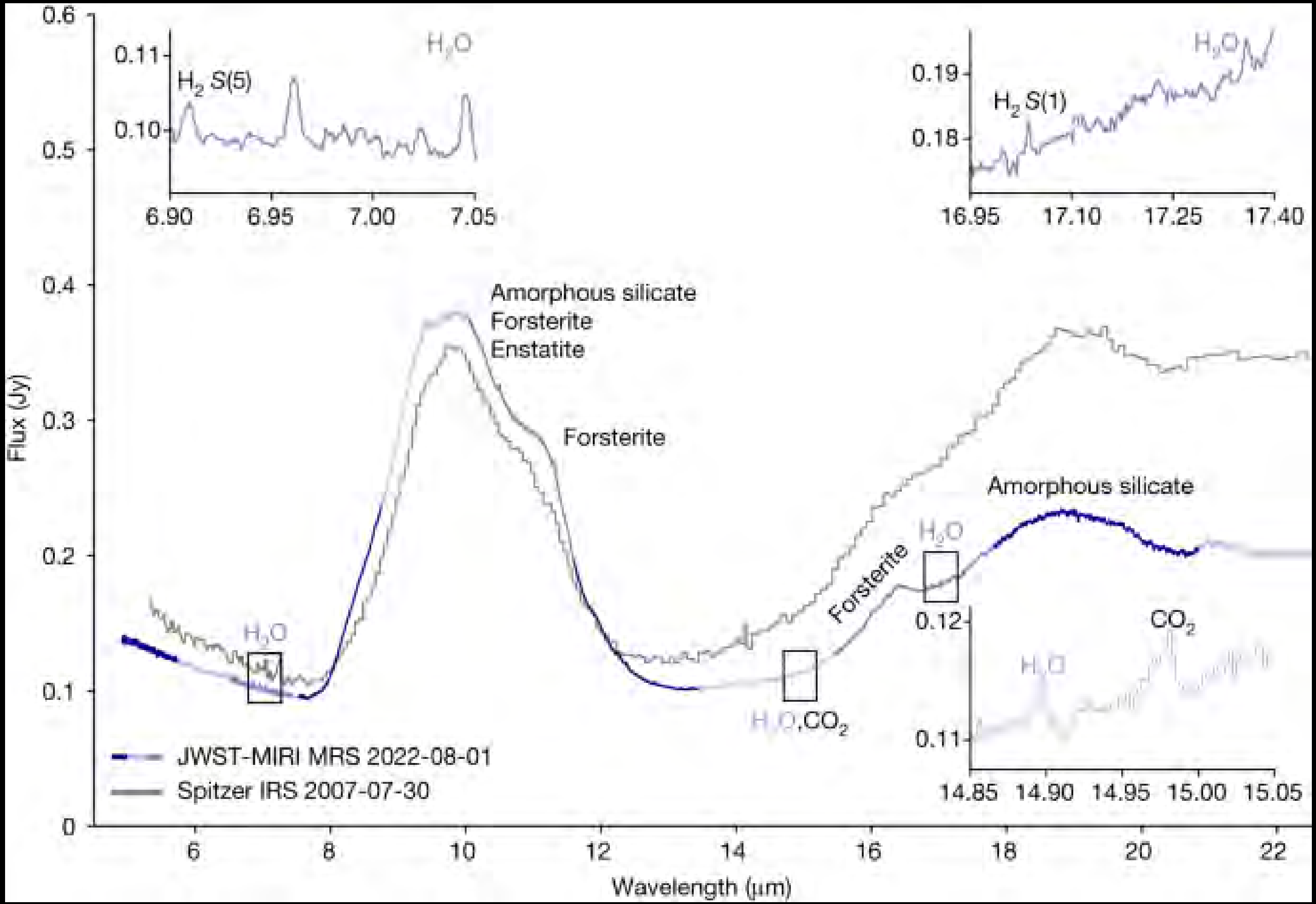
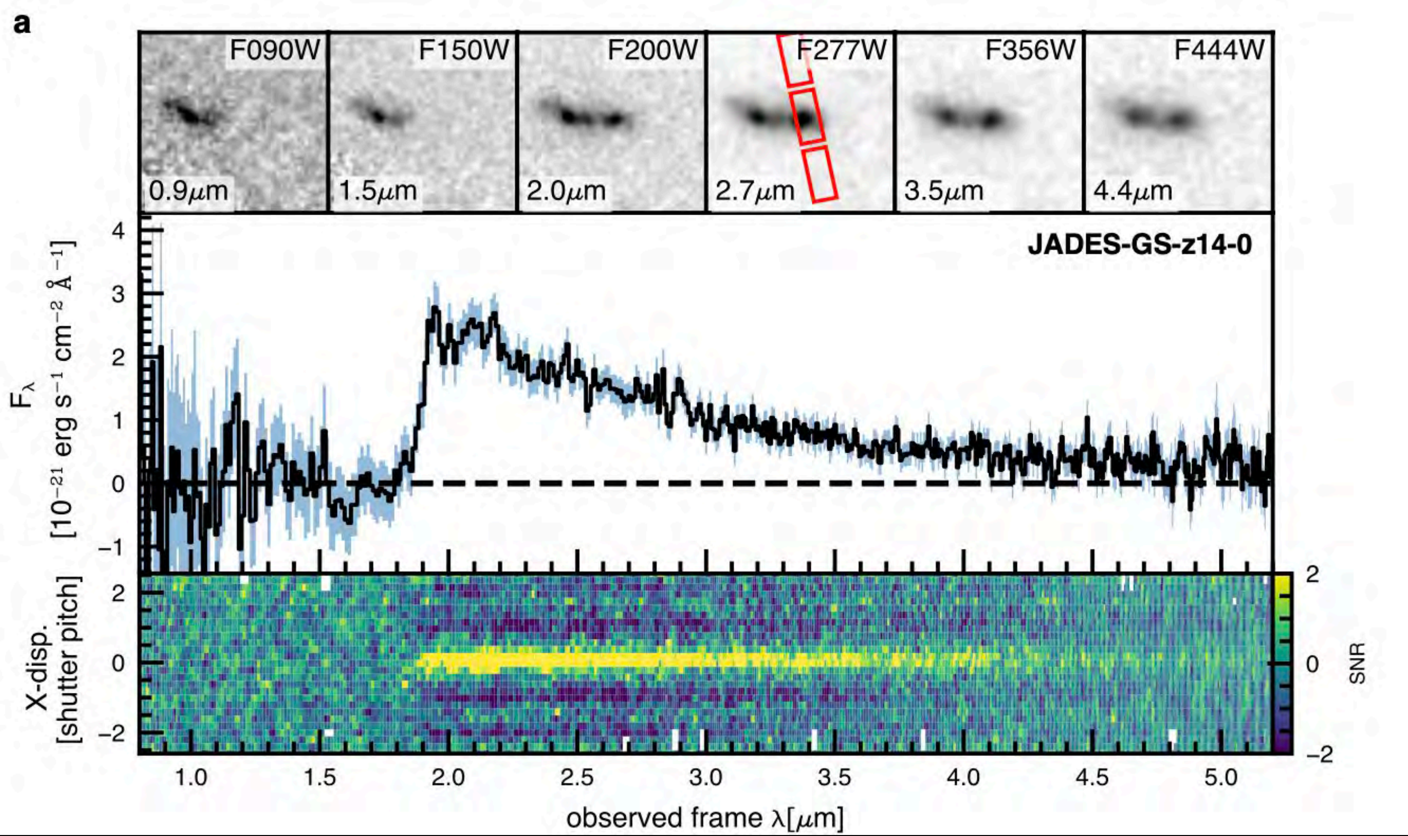



Perotti et al. 2023, water in the terrestrial planet-forming zone of the PDS 70 disk

# JWST's Science Highlights and Emerging Themes

# Early Universe

JWST has discovered bright luminous galaxies <300 million years after Big Bang, found galaxies with overmassive black holes, massive red and dead (quiescent) galaxies that have stopped forming stars within the first two billion years, evolved grand design spirals a few billion years after Big Bang, and observed a galaxy with similar mass to the Milky Way in its early stages of evolution, in a 600-million-year-old Universe.




Carniani et al. 2024, NIRSpec

See Helton et al. 2024, Juodžbalis et al. 2024, Carnall et al. 2023, Kuhn et al. 2024, Mowla et al. 2025 and references therein

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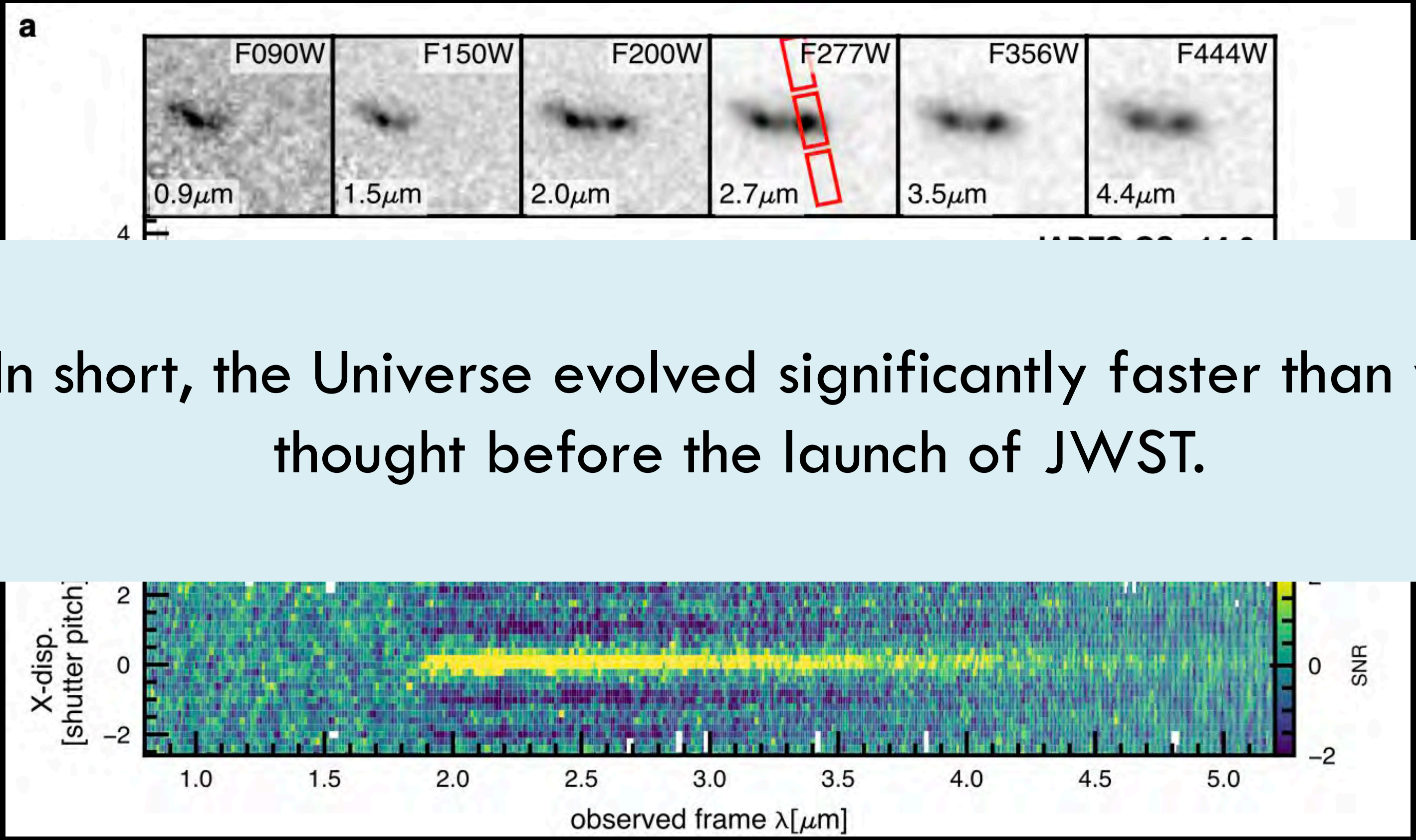



In short, the Universe evolved significantly faster than we thought before the launch of JWST.

See Helton et al. 2024, Juodžbalis et al. 2024, Carnall et al. 2023, Kuhn et al. 2024, Mowla et al. 2025 and references therein

# Early Universe Emerging Themes

What is the nature of Little Red Dots?

Where are Population III stars?

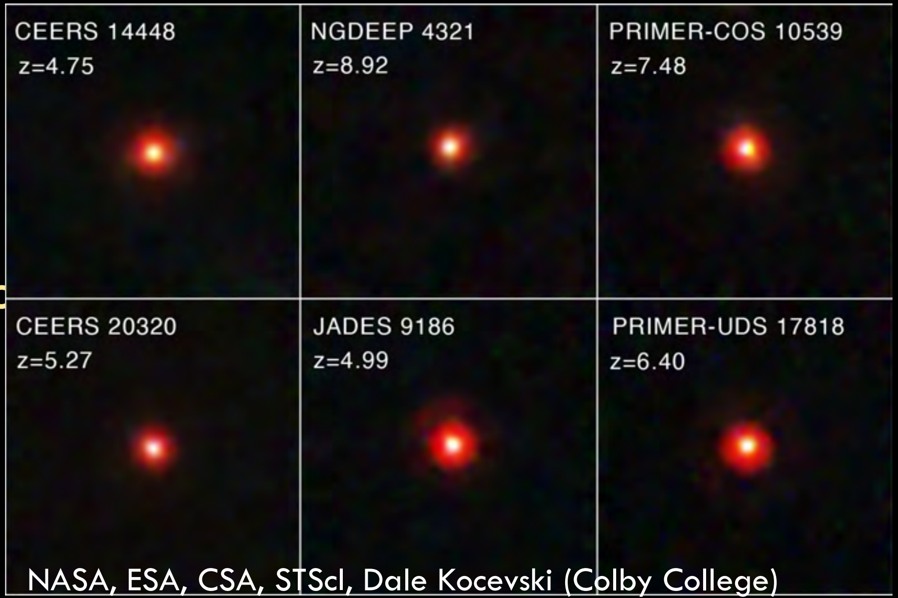
What is the origin of early massive galaxies and blac holes?

How did galaxy mass build up?

What are the drivers of reionization?

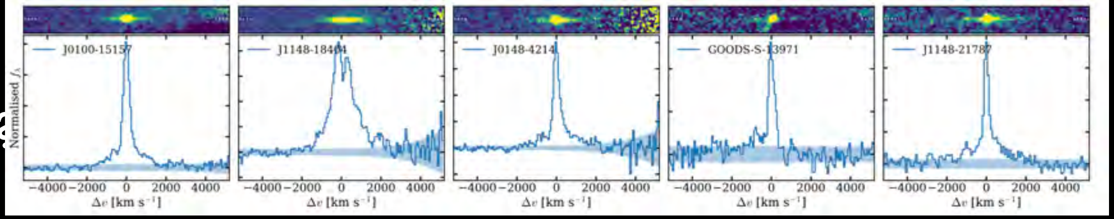
What can we learn about early quiescent galaxies?

Was star formation more efficient at early times?




NASA, ESA, CSA, STScI, Dale Kocevski (Colby College)

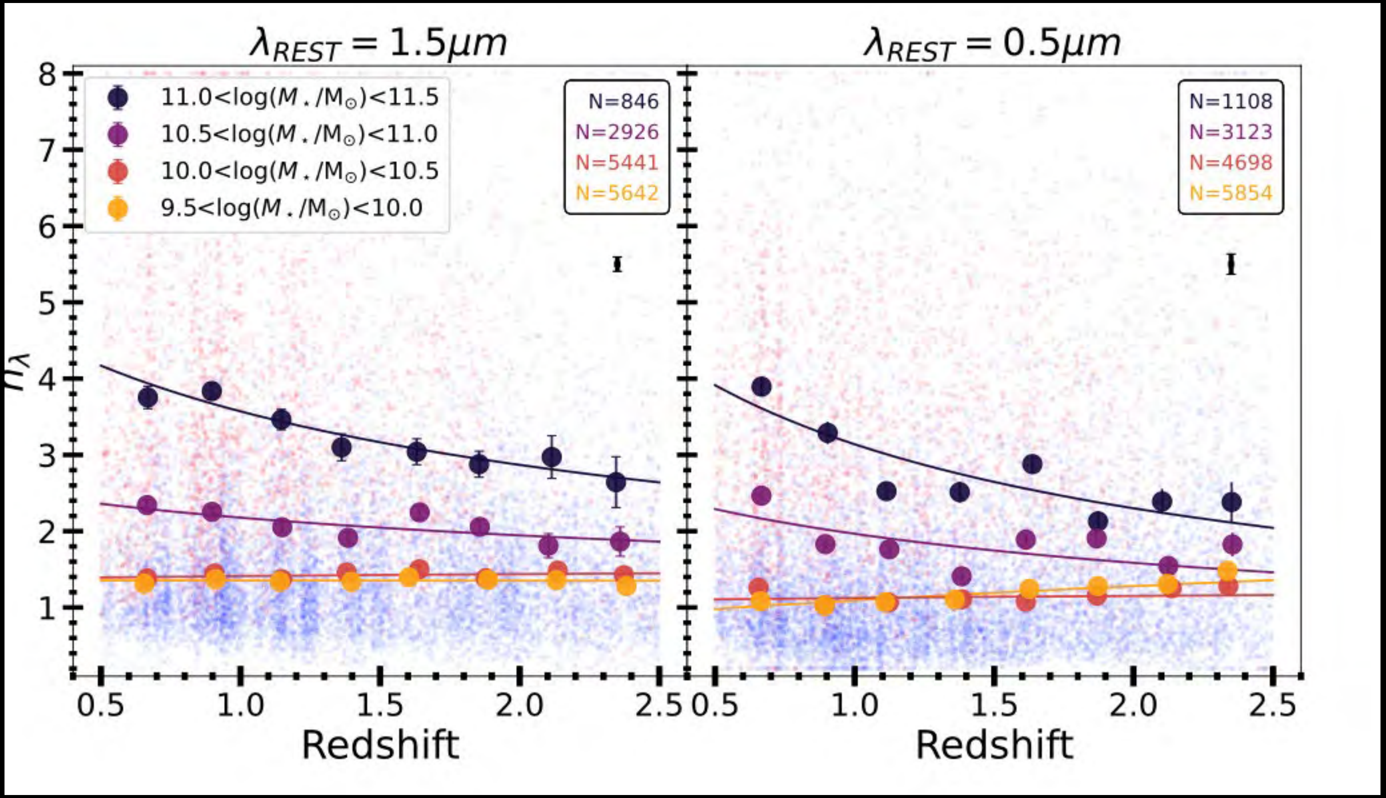
See also Perez-Gonzalez et al.2024b for selection effects discussion and the importance of MIRI data




Matthee et al. (2023) NIRCam Slitless Grism

# “Nearby” Galaxies

JWST has confirmed the tight correlation between PAH and CO emission from z ~ 0 to 4, mapped star formation via PAH 3.3 microns emission, revealed the physics of star formation, feedback, explosive activity and gas-dust clearing SF cycle in nearby galaxies, and studied nearby galaxies activity, outflows, and PAHs survival regions surrounding the AGN torus at sub-kpc scales.




Martorano et al. 2025
JWST and HST are used to show the median Sèrsic index evolves slowly, or not at all with redshift, except for very high-mass galaxies

See Shivaei and Boogard 2024, Gregg et al. 2024, Thilker+23, Lee et al. 2024, Alonso-Herrero et al. 2024, García-Bernete, et al. 2024 and references therein

# “Nearby” Galaxies Emerging Themes

How do PAHs evolve with redshift, from cosmic noon to local galaxies?

What else can we learn about dark matter, using galaxy mergers, clusters, as well and stellar systems on our galaxy bulge?

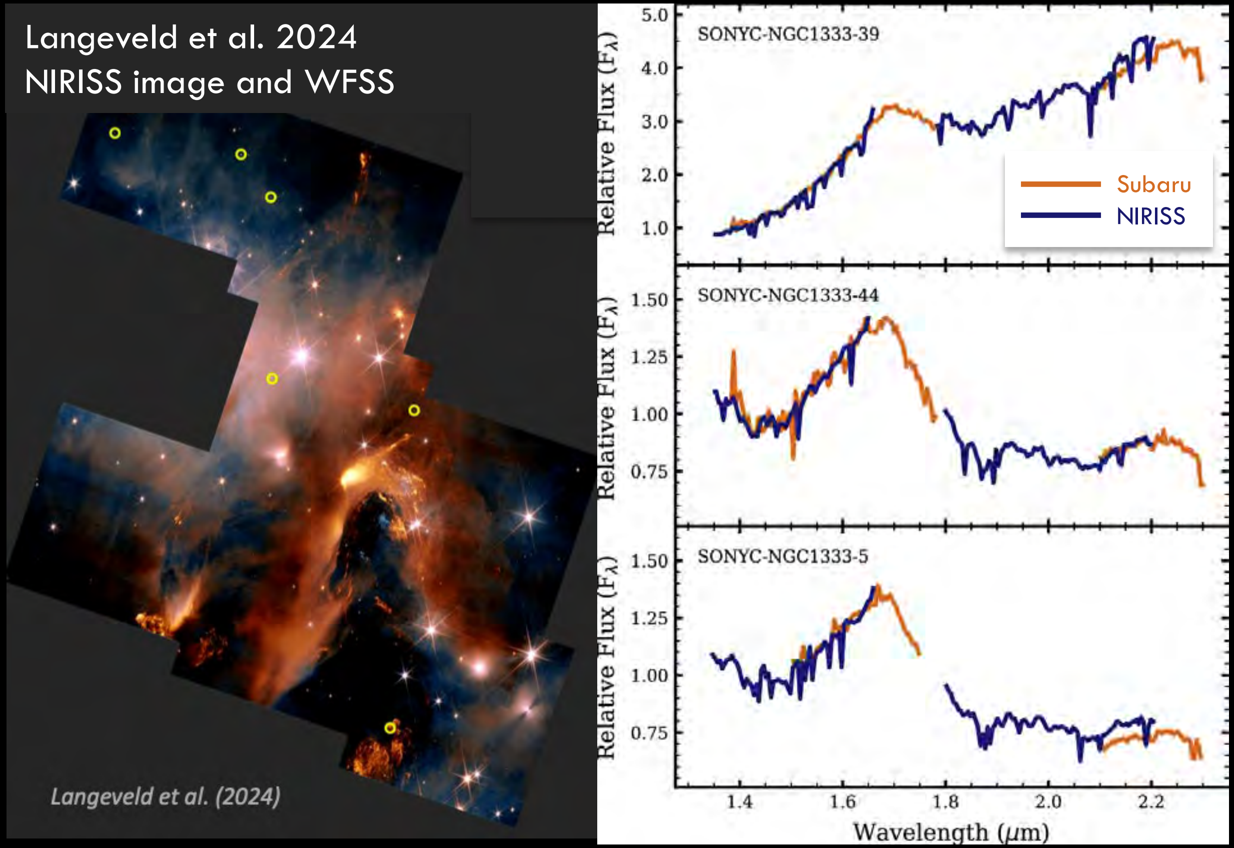
What is the impact of AGN on the environment and feedback (at sub-kpc scales)?

What can we learn about the stellar populations of local galaxies, as well as the formation and evolution of galaxy disks?

What are the additional and precise anchors to the distance ladder that can be stablished to further study the Hubble Tension?

# Stellar Evolution

JWST is tracing star cluster formation across cosmic time, and has observed a variety of objects, such as first white dwarf debris disc observed by JWST, very small free-floating brown dwarfs in the Orion nebula cluster, brown dwarf candidates in the SMC, planetary-mass objects in the reflection nebula NGC1333, and a likely Type II SN at z=3.6.




See Claeyssens et al. 2023, Swan et al. 2024, Luhman et al. 2023, Zeidler et al. 2024, Langeveld et al. 2024, Coulter et al. 2025 and references therein

# Stellar Evolution Emerging Themes

How does star formation changes across cosmic time?

What is the lowest mass limit to form a star? Is the IMF Universal?

How are very small brown dwarfs formed, and are they rogue planets?

How common are Free-Floating Planetary-Mass Objects, and do they exhibit any dependence with the environment?

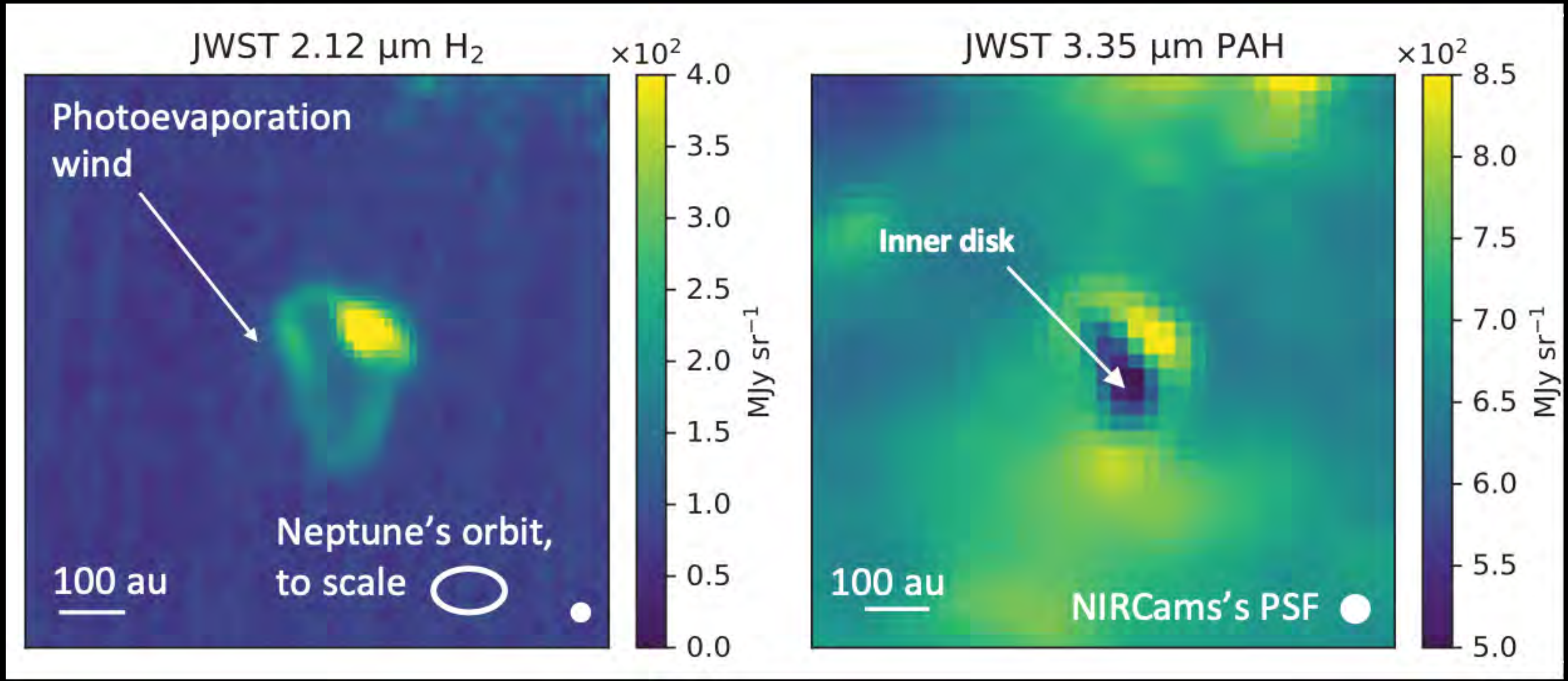
What else can we learn about SN progenitor stars and dust formation history in supernova?

How will time domain astronomy impact our understanding  of the variable universe?

# Planet-Forming Disks

JWST allows to perform detailed studies of externally UV-irradiated proto-planetary disks, has been able to probe inner disk structures and their rich chemistry, demonstrated that icy pebbles enter into the warmer region within the "snowline" and release large amounts of cold-water vapor, shown that debris disks may be more dynamic than previously thought, can recover planets as small as ~0.1 Jupiter masses beyond ~2" (~20 au), and has found that planet-forming disks lived longer in the early universe.

d203-506
Berne et al. 2024,
PDRs4ALL, NIRCam




See Goicoechea et al. 2024, van Dishoeck et al. 2024, Rebollido et al 2024, Lawson et al. 2023, De Marchi et al. 2024 and references therein.

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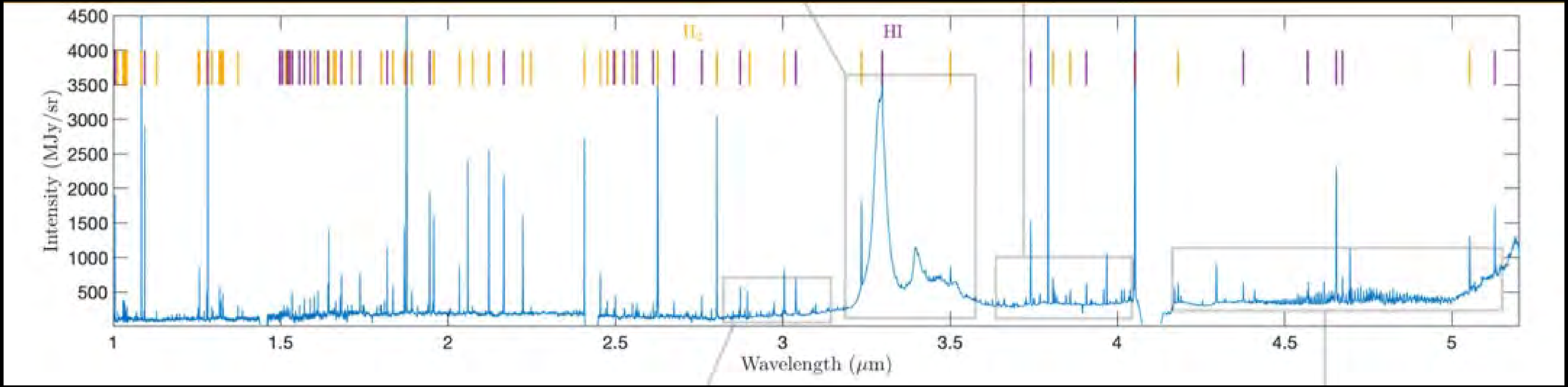


Berne et al. 2024, PDRs4ALL, NIRSpec

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# Planet-Forming Disks Emerging Themes

What are the dust properties of planet opened-gaps and debris disks?

What else can we learn from in-depth analysis of icy volatiles in disks?

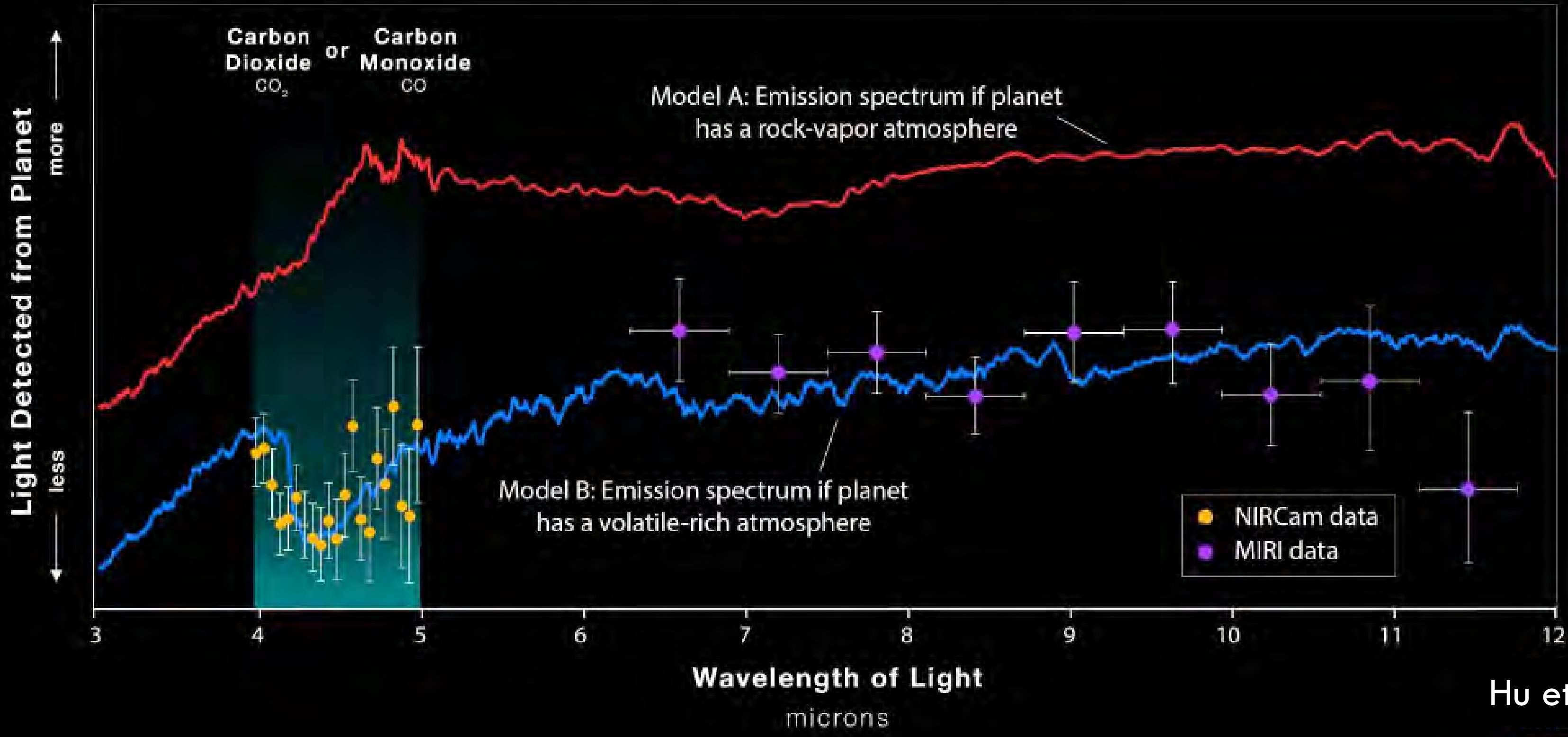
How will studies of large disks samples will affect our understanding of the rich chemistry in their inner regions of disks?

How will larger statistical studies shed additional light on the processes governing disks, such as radial drift of icy pebbles in dust traps from the outer to the inner parts?

What else can we learn about the impact of radiation on disks?

# Exoplanets

From gas giants to small rocky exoplanets, JWST has obtained the most precise spectra ever obtained of exoplanet atmospheres. It has provided the first detections of many molecules in giant planet atmospheres (CO2, SiO2), has measured morning/evening variations in transmission spectra in a gas giant, and detected an atmosphere on the rocky exoplanet 55Cancri e.




Hu et al. 2024

See Grant et al. 2023, Rustamkulov et al. 2023, Espinoza et al. 2024, Hu et al. 2024, Ducrot et al 2024 and references therein

# Exoplanets Emerging Themes

What can we learn by studying precision atmospheric chemistry & structure of giant exoplanets?

How does exoplanet atmospheric chemistry & structure vary throughout an exoplanet?

How do disequilibrium processes (e.g., photochemistry) operate on exoplanet atmospheres, and how does it impact our inferences about them?

What defines the chemical composition and structure of sub-Neptune exoplanets?

What are the atmospheres and surfaces of Super Earths made of?

Can rocky exoplanets around M-dwarfs hold an atmosphere?

# Exoplanets Emerging Themes

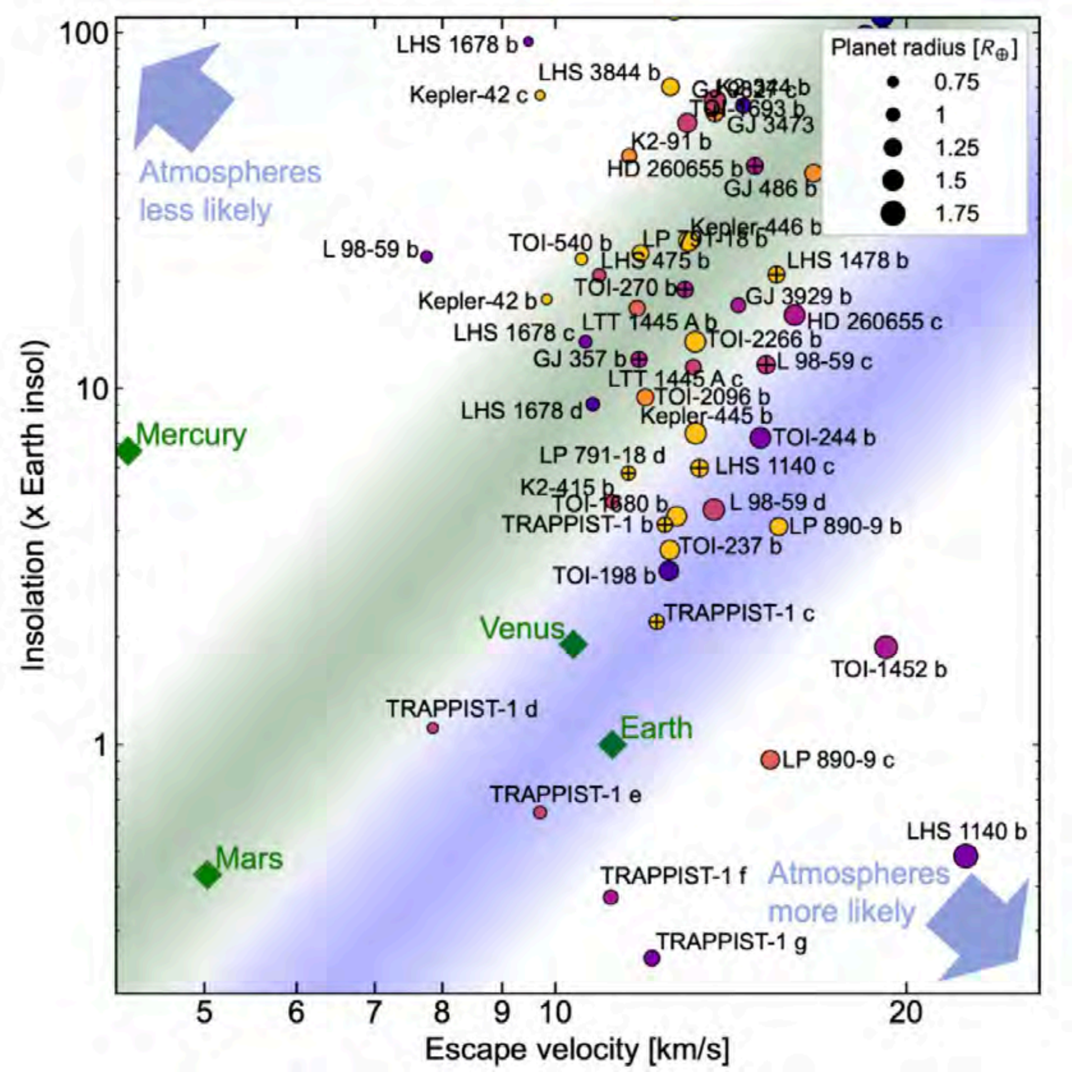
Can rocky exoplanets around M-dwarfs hold an atmosphere?

## Rocky Worlds DDT Program

Survey of 15-20 rocky M-dwarf exoplanets to detect atmospheres down to habitable zone.

• 500 hours JWST/MIRI observations to probe atmospheres
• 250 orbits of HST COS/STIS UV to characterize the activity of the host stars

STScI leads: Nestor Espinoza
Hannah Diamond-Lowe



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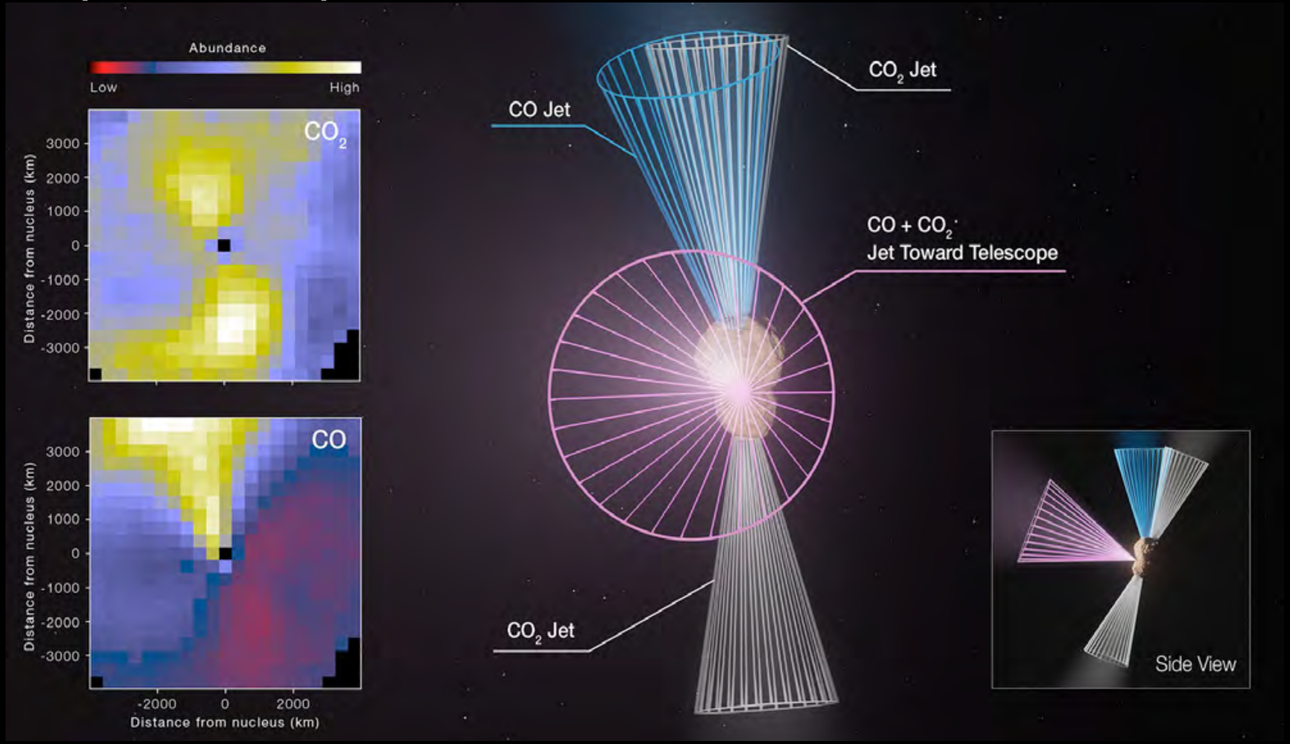
Information session on January 21st at 11 a.m. (ET)

# Solar System

JWST has observed every class of object that it can point to in the Solar System. It has detected plumes of water leaking out of Enceladus, measured endogenous carbon dioxide over "chaos terrain" in Europa, mapped Saturn's northern summertime hemisphere, detected jets of volatile gas from an icy centaur, obtained new measurements of aurorae in outer planets, and provided insights into the primordial Solar System by studying trans-Neptunian objects




NASA, ESA, CSA, Leah Hustak (STScI), Sara Faggi (NASA-GSFC, American University)

29/P Schwassman-Wachman 1, spewing out gas from jets
Faggi et al. 2024, NIRSpec

See Villanueva et al 2023a, Villanueva et al 2023b, Melin et al 2024, Faggi et al. 2024, Pinilla-Alonso 2025 and references therein

# Solar System Emerging Themes

What are the characteristics of water outgassing in main belt-comets?

How did heliocentric distance influence the compositions of trans-Neptunian objects?

Is Uranus' large satellite Ariel an ocean world?

What does auroral activity reveal about the magnetospheres of the ice giants?

Where did the various minor body and irregular satellite populations originate?

Why is CO2 so prevalent across the solar system?

# JWST Science Press Releases

- Require a peer-reviewed journal paper
  - Exception: Findings presented at AAS conferences

- Discuss scientific findings and why they are significant

- Post to Science.NASA.gov and WebbTelescope.org

- Don't wait! News release will not post until paper is accepted
- Contact at the time of submitting your paper
  - 1. Visit STScI.edu News Center: https://www.stsci.edu/news/scientist-resources
  - 2. Contact STScI JWST news chief Christine Pulliam: cpulliam@stsci.edu, 410-338-4366

## Across every field JWST delivers cutting-edge science…

Every new discovery raises new questions…and to answer them we usually need more data. We also need to keep providing strong support to the JWST community!

IC 2163 and NGC 2207, JWST + HST

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Across every field JWST delivers cutting-edge science…

We look forward to many years of exciting science with JWST!

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