JWST Science Highlights

for the Committee on Astronomy and Astrophysics (CAA) appointed by

The National Academies of Sciences, Engineering, and Medicine (NASEM)

Jane Rigby
JWST Senior Project Scientist
NASA Goddard Space Flight Center
Jane.Rigby@nasa.gov

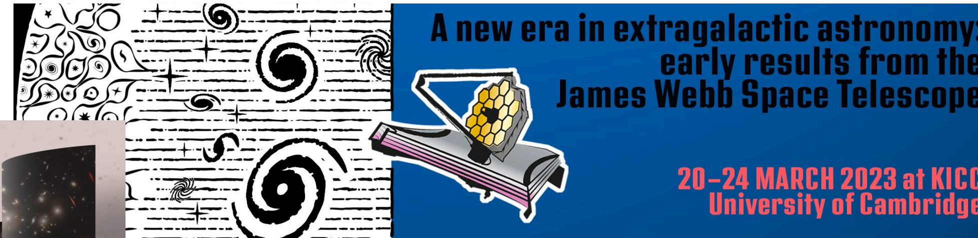
with MacarenaGarcia-Marin (STScI), & Knicole Colon & Chris Stark (GSFC)

The Big Picture

- JWST is the most powerful infrared space telescope, ever.
- Performance is marvelous, better than (high) expectations almost across the board. Gas in the tank for 20+ years.
- We are in our second year of science operations. JWST launched 12/2021; started science operations 7/2022.
- The scientific community submitted a record number of observing proposals (N=1930) for the third year, requesting 9 years of observing time.
- JWST is a partnership between NASA, ESA, & CSA.

Sesto, Italy, 7/2023

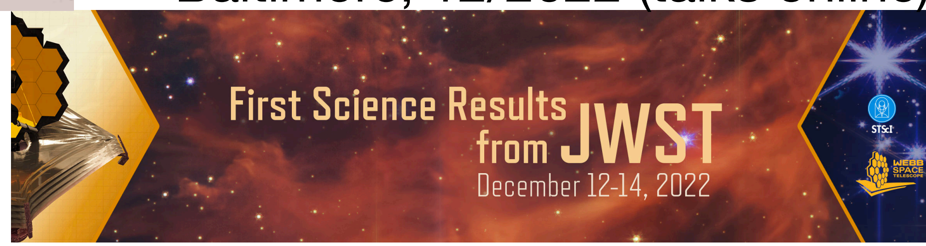
Bern, Switzerland, 3/2024



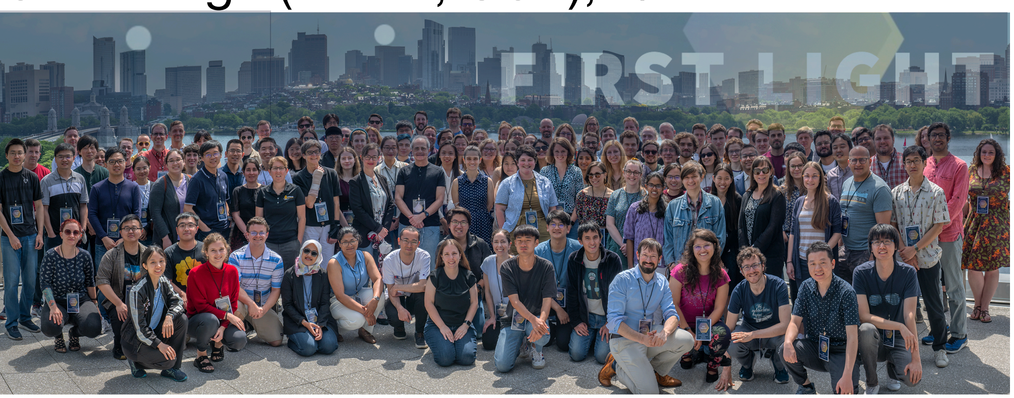
Cambridge, UK, 3/2023

Baltimore, 11/2023 (talks online)

Baltimore, 12/2022 (talks online)



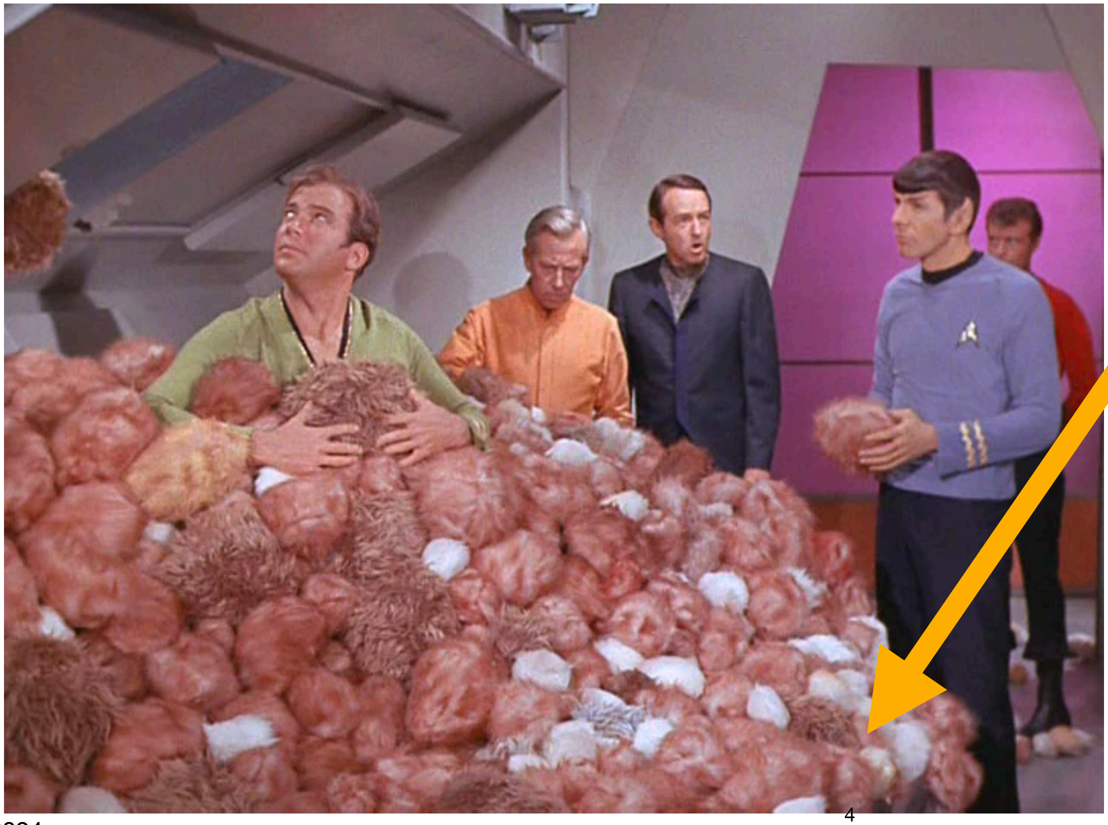
Cambridge (Mass., USA), 6/2023



Baltimore, 9/2023 (talks online)

The science community is turning JWST data into papers.

- >600 research papers based on JWST data have been published to date.

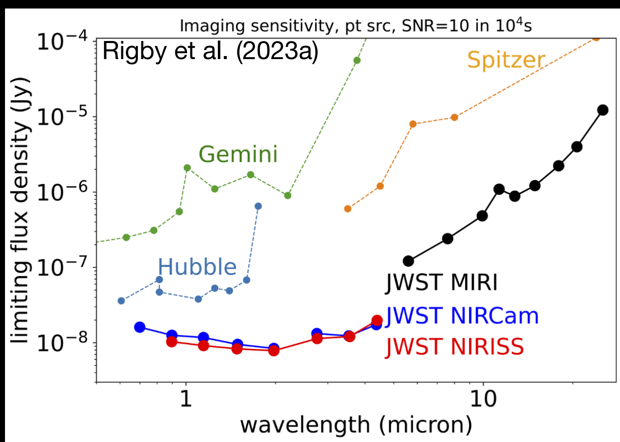


JWST
science papers

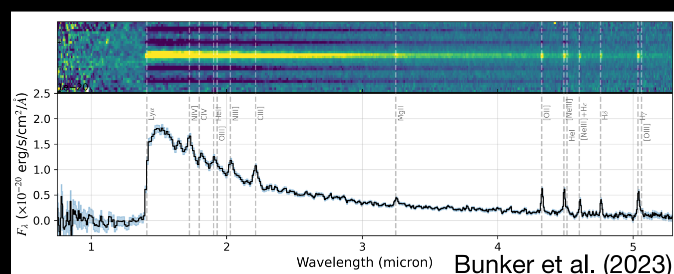
Disclosure: In this summary, I've mostly avoided science papers where I'm a co-author. I've indicated exceptions with *

Evolution of JWST science papers

How well JWST works



Previously-impossible measurements



Discoveries that change our understanding

JWST Overview:
a Special Issue of PASP

Please cite these instrumentation papers.

See also JDox user documentation

Publications of the Astronomical Society of the Pacific

JWST Overview

Guest Editor George Rieke *Steward Observatory, University of Arizona, USA*

Scope The articles in this focus issue describe the design, verification, and in-orbit performance of the James Webb Space Telescope (JWST) and its instrumentation… and an overall assessment of the JWST science performance as characterized during commissioning. **OPEN ACCESS**

Performance of NIRCam on JWST in Flight
Marcia J. Rieke *et al.* 2023, *PASP* **135** 028001

In-orbit Performance of the Near-infrared Spectrograph NIRSpec on the James Webb Space Telescope
T. Böker *et al.* 2023, *PASP* **135** 038001

The Mid-infrared Instrument for JWST and Its In-flight Performance
Gillian Wright *et al* 2023, *PASP* **135** 048003

In-orbit performance of NIRISS
René Doyon *et al. 2023, PASP* **135** 098001

The Science Performance of JWST as Characterized in Commissioning
Jane Rigby *et al.* 2023, *PASP* **135** 048001 *

How Dark the Sky: The JWST Backgrounds
Jane Rigby *et al.* 2023, *PASP* **135** 048002 *

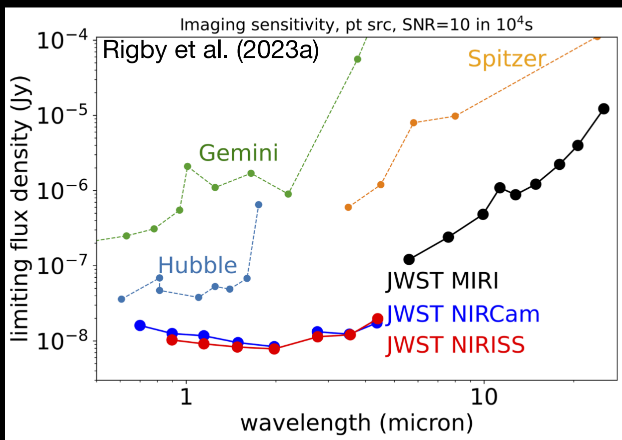
The James Webb Space Telescope Mission: Optical Telescope Element Design, Development, and Performance
Michael McElwain *et al.* 2023, *PASP* **135** 058001 *

The Design, Verification, and Performance of The James Webb Space Telescope
M. Menzel *et al.* 2023, *PASP* **135** 058002

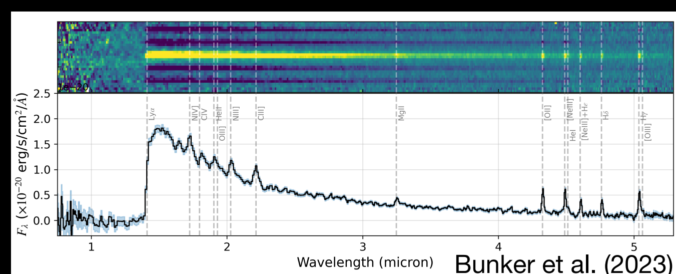
The James Webb Space Telescope Mission
Jonathan Gardner et al. 2023, *PASP* **135** 068001 *

Evolution of JWST science papers

How well JWST works



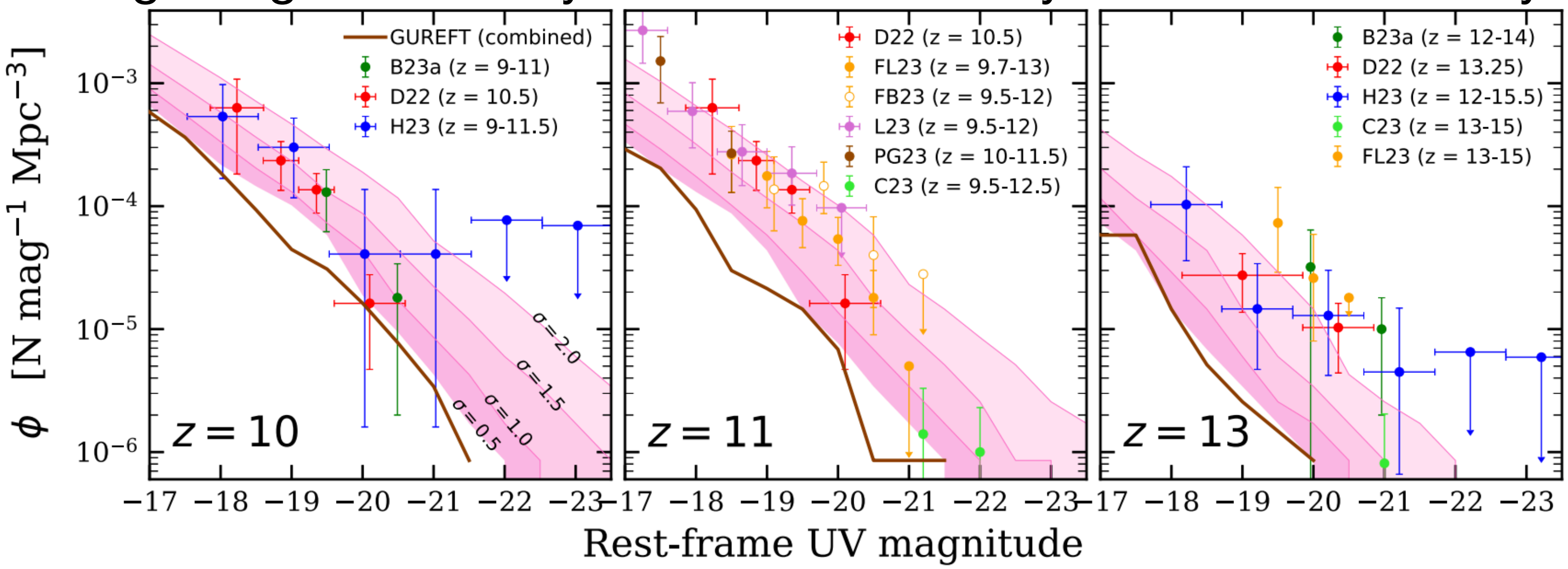
Previously-impossible measurements



Discoveries that change our understanding

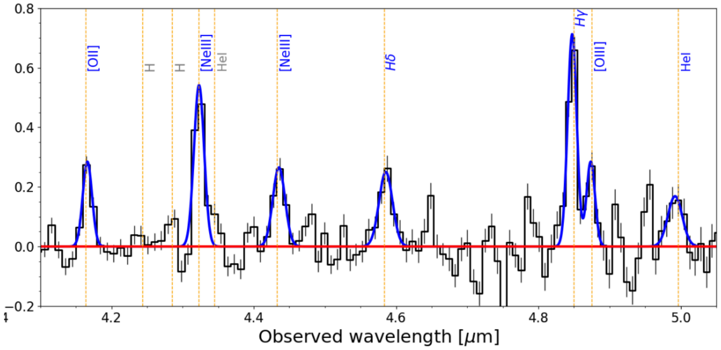
JWST has found thousands of galaxies at z>9, transforming our understanding of the first Gigayear of cosmic history.

Time after Big Bang: 480 Myr 420 Myr 330 Myr

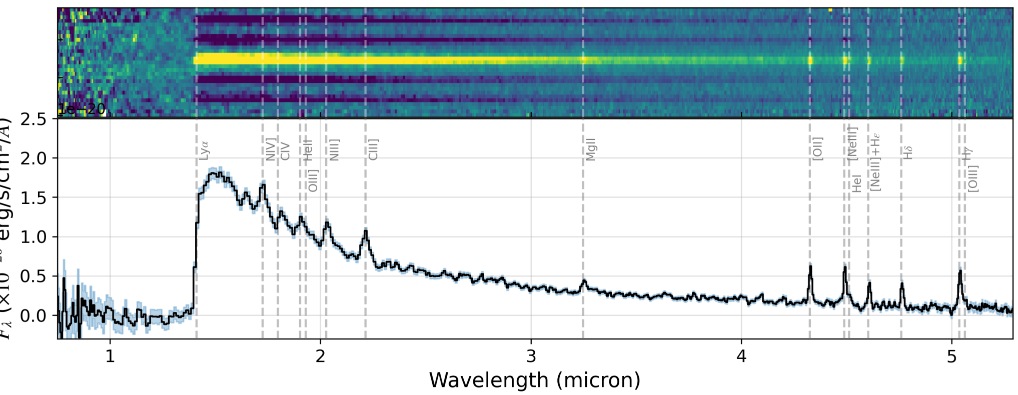


Yung et al. (2024), compiling results from Donnan et al. (2022), Harikane et al. (2023), Finkelstein et al. (2022a, 2022b, 2023a, 2023b), Bouwens et al. (2023a), Perez-Gonzáléz et al. (2023), Leung et al. (2023), and Casey et al. (2023)

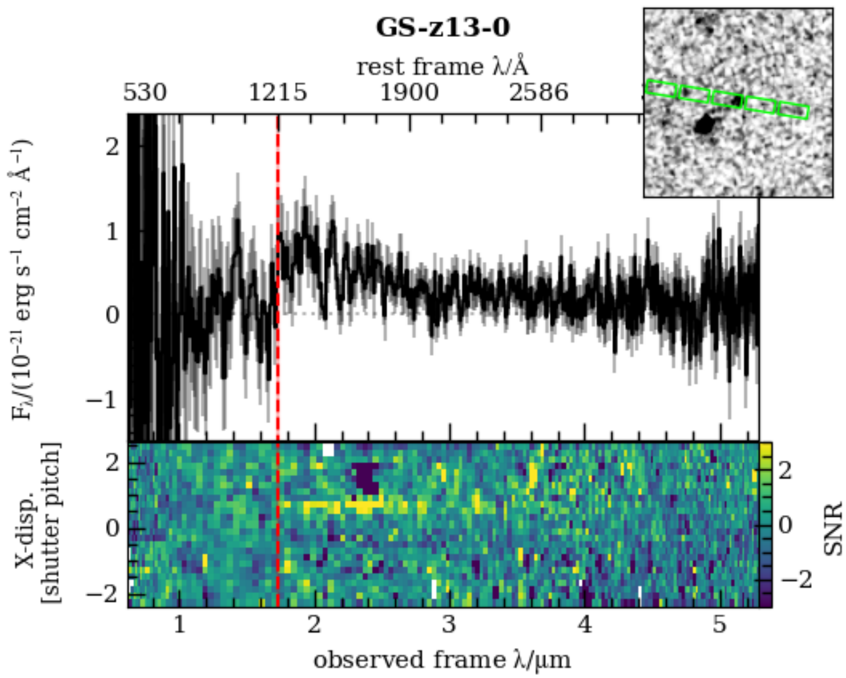
For the first time, we have diagnostic spectra for hundreds of galaxies as they looked ~500 Myr after the Big Bang.



Hsiao et al. (2023)*, NIRSpec prism spectra of a lensed z=10.2 galaxy (470 Myr after the BB)



Bunker et al. (2023), NIRSpec prism spectrum of galaxy GN-z11 at z=10.6 (440 Myr after the BB)



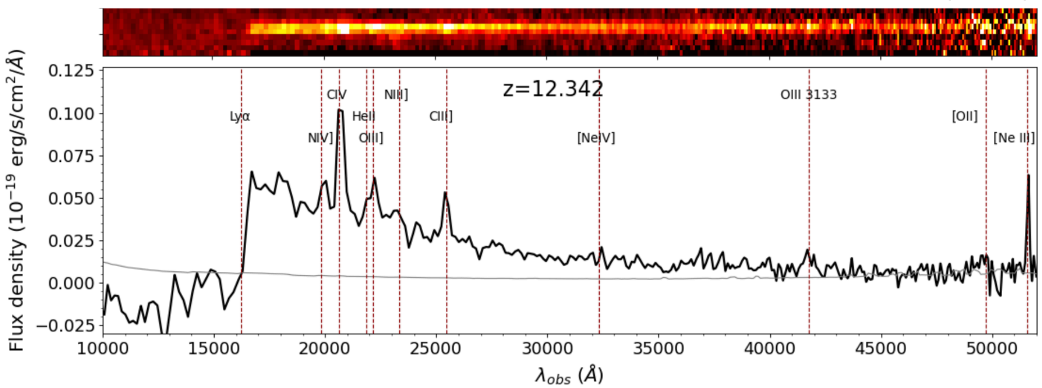
Curtis-Lake et al. (2022) and Robertson et al. (2022), a spectroscopic redshift of z=13.17 (320 Myr after the BB)

For the first time, we have diagnostic spectra for hundreds of galaxies as they looked ~500 Myr after the Big Bang.

ArXiv 18 Mar 2024: a galaxy at redshift z=12.3; lookback time of 13.4 Gyr; seen as it looked 350 Myr after the Big Bang (Planck 2018 cosmology)

Rest-frame optical diagnostics at z=12.3! Sub-solar oxygen abundance, apparent non-solar N/C/O abundance ratios, extremely high ionization, possible AGN

Castellano et al. (2024)



Zavala et al. (2024)

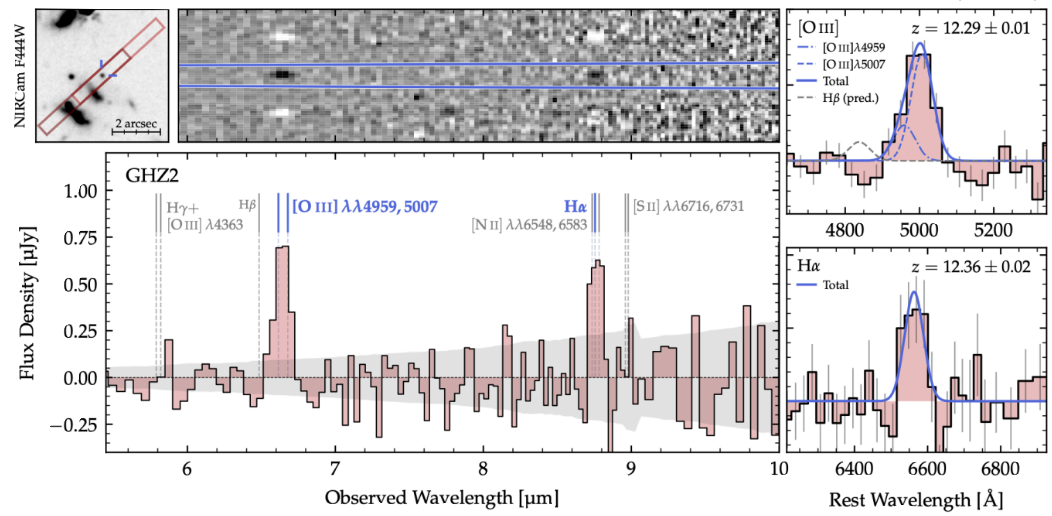
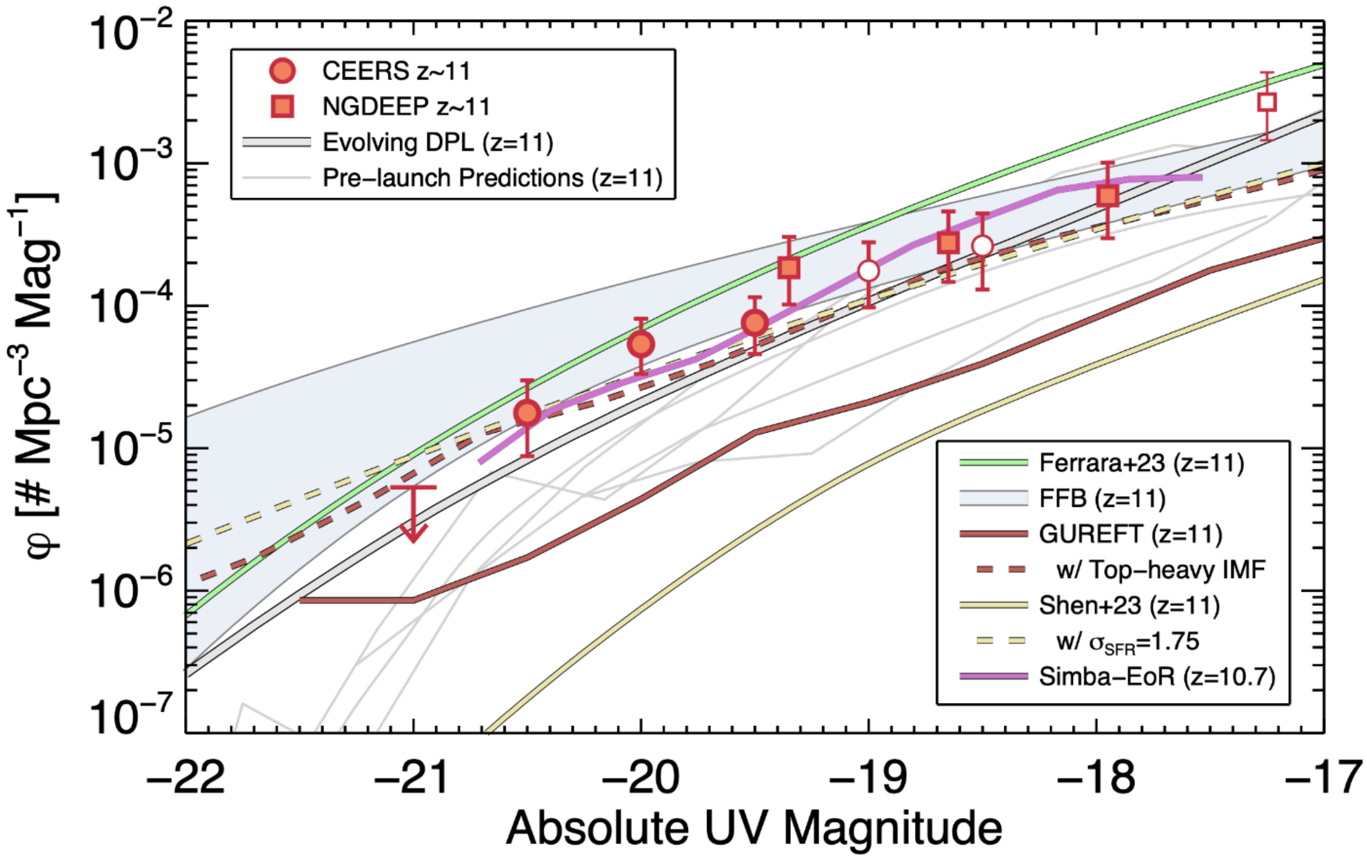


Figure 1: **JWST/MIRI spectrum of GHZ2 at $z = 12.3$. Top left:** NIRCam F444W cutout image ($5'' \times 5''$) centered at the position of GHZ2, with the MIRI/LRS slit illustrated with the red rectangle (at the two different dither positions). The combined 2D spectrum and the used aperture for the 1D extraction are also plotted (see details in the Section Methods). **Bottom left:** 1D extracted spectrum at the position of GHZ2 across the most sensitive wavelength range, $\lambda_{\rm obs} \approx 5.7 - 10\,\mu m$ and the associated 1σ uncertainty (gray region). The redshifted

JWST has revealed that z>10 galaxies are brighter and more numerous than expected.



Finkelstein et al. (2023)

Was star formation more efficient?

Does feedback not work at high redshift?

Are there preferentially more massive stars? (“top-heavy IMF”)

Is there some contribution from zero-metallicity stars? (“Pop III stars”)

JWST has found high redshift galaxies whose star formation has completely turned off.

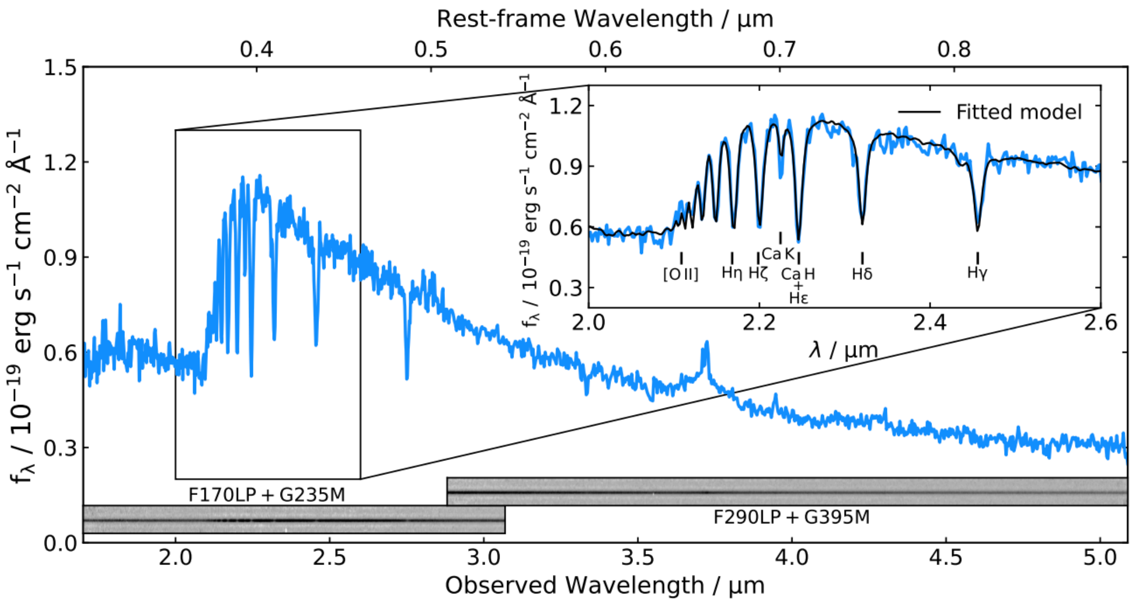


Figure 1: JWST NIRSpec observations of GS-9209. Data were taken on 16th November 2022, using the G235M and G395M gratings ($R = 1000$) with integration times of 3 hours and 2 hours respectively, providing wavelength coverage from $\lambda = 1.7 - 5.1\mu$m. The galaxy is at a redshift of $z = 4.6582 \pm 0.0002$, and exhibits extremely deep Balmer absorption lines.

z=4.7 (1.3 Gyr after the BB), Carnall et al. (2023), NIRSpec

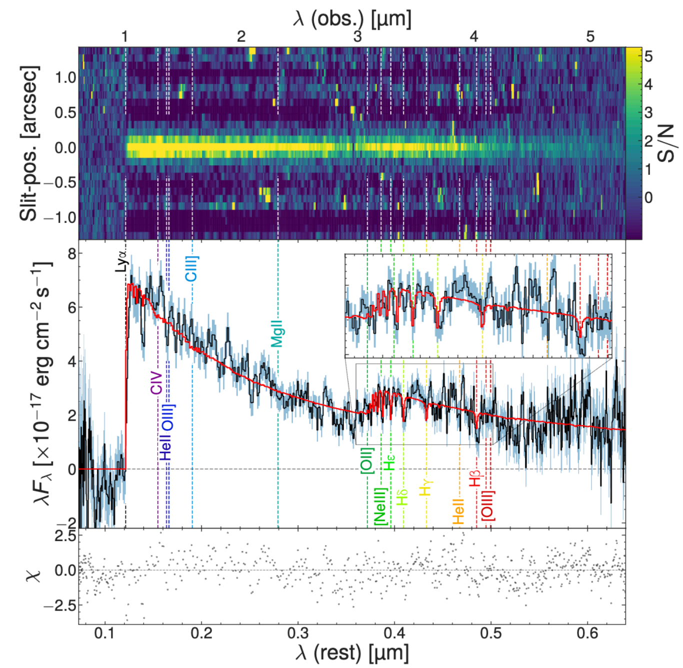
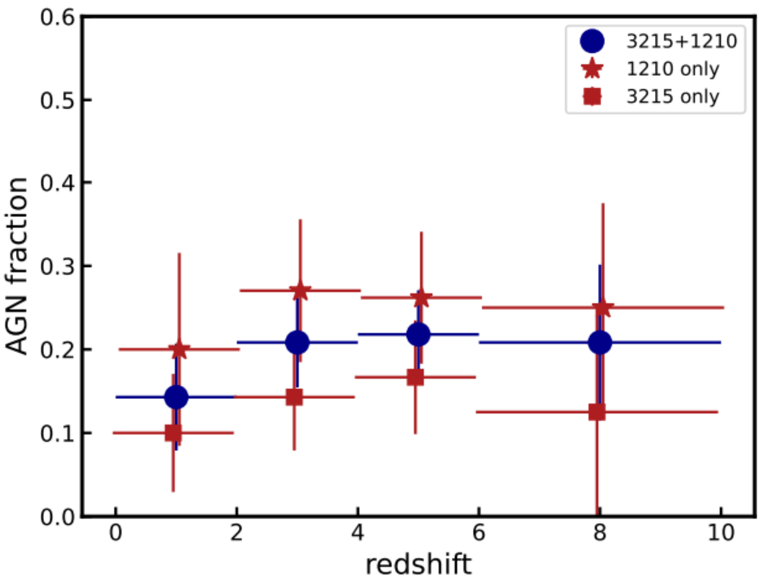
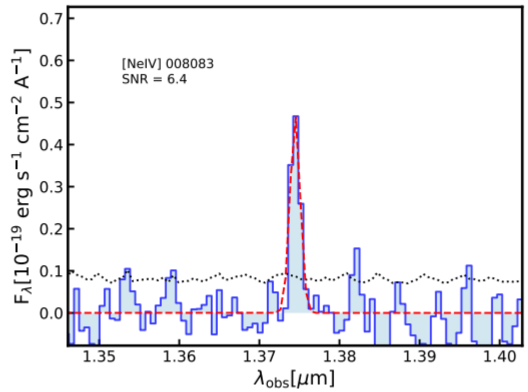


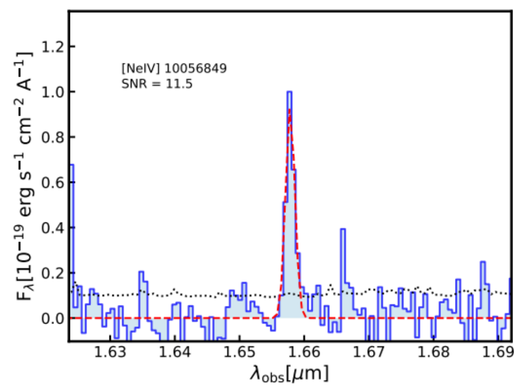
Fig. 1: NIRSpec R100/prism spectrum of JADES-GS-z7-01-QU. The clearly detected Lyα drop and the Balmer break unambiguously give a redshift of z=7.3. The absence of emission lines (together with the Balmer break) reveals

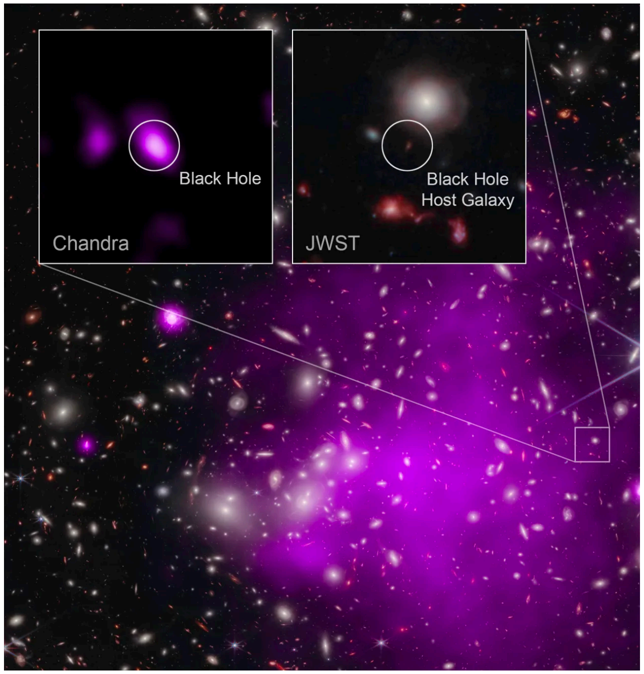
z=7.3 (730 Myr after the BB), Looser et al. (2023). NIRSpec

JWST is finding *a lot* of accreting supermassive black holes in the early universe.





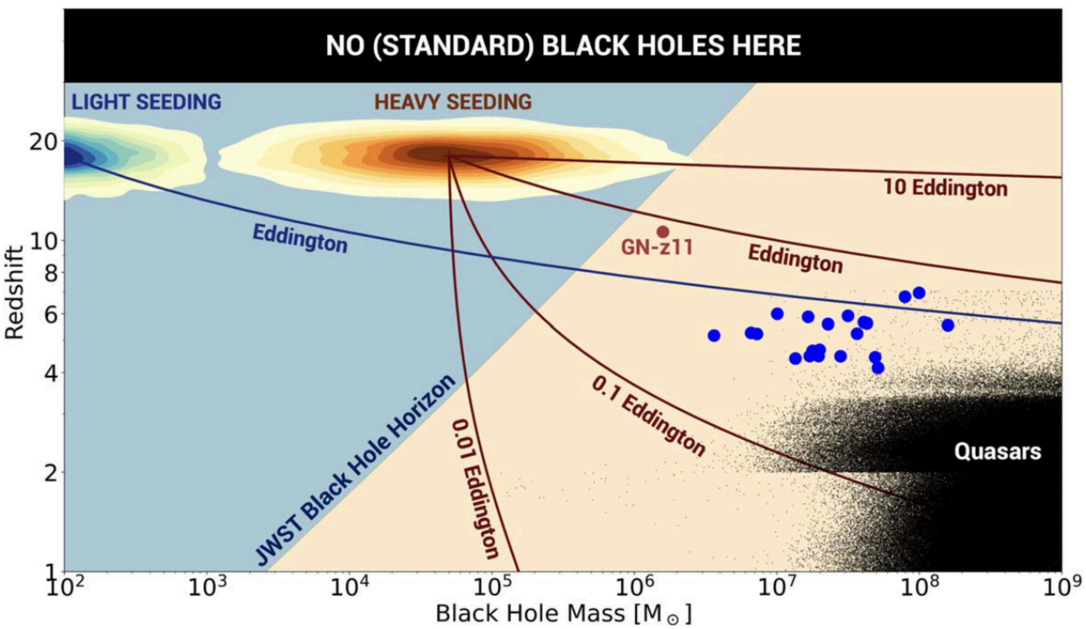


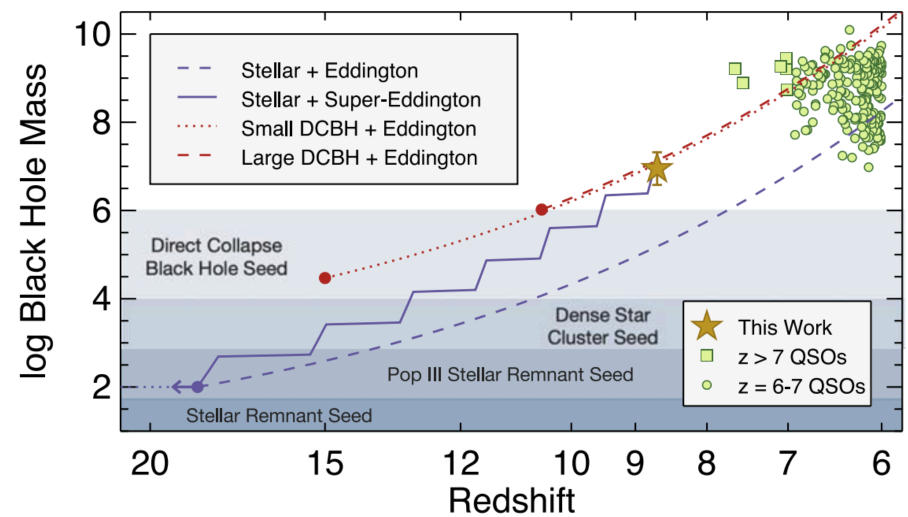


20% of galaxies in deep NIRSpec spectra show narrow-line AGN signatures. Sholtz et al. (2024)

Bogdan et al. (2023): an X-ray quasar with a photometric redshift of z=10.3 from JWST

Growing these AGN from solar-mass black holes would require (implausibly?) very high accretion rates. May need bigger seeds.

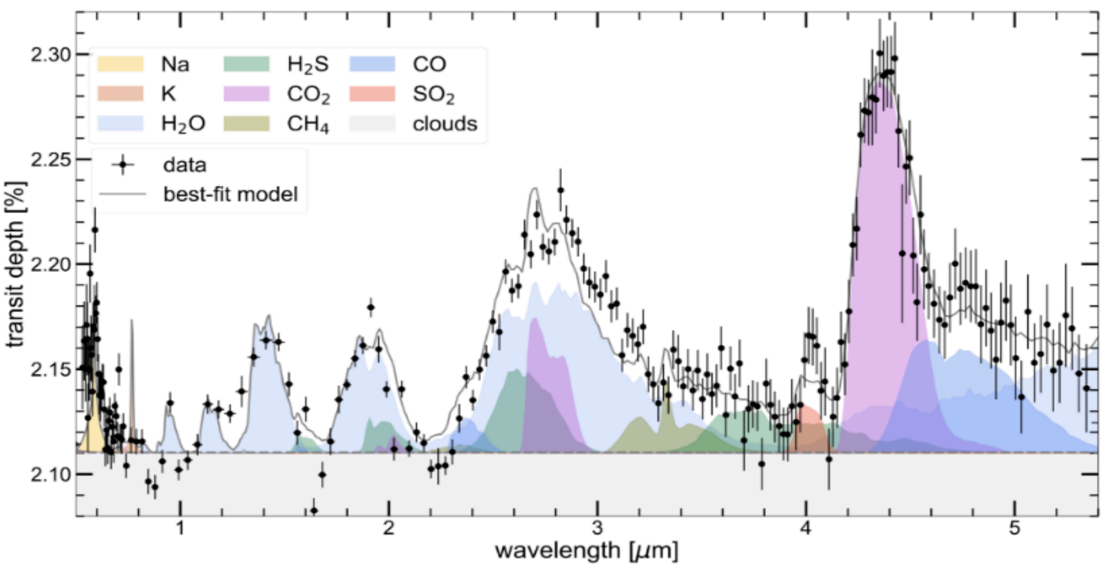




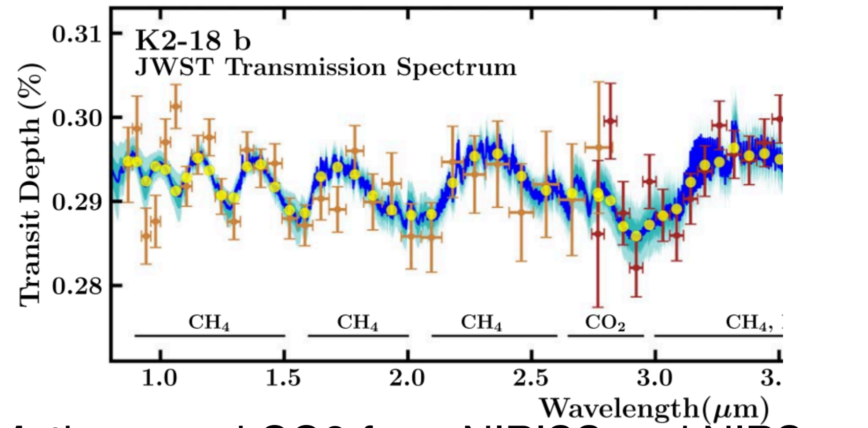
Larson et al. (2023)* from JWST, comparing to quasars from Inayoshi et al. (2020) and Fan et al. (2022)

Pacucci et al. (2023), showing AGN found by Harikane et al. (2023), Kocevski et al. (2023), Maiolino et al. (2023), and Ubler et al. (2023), from the ERO, GLASS, CEERS, JADES, and GA-NIFS datasets

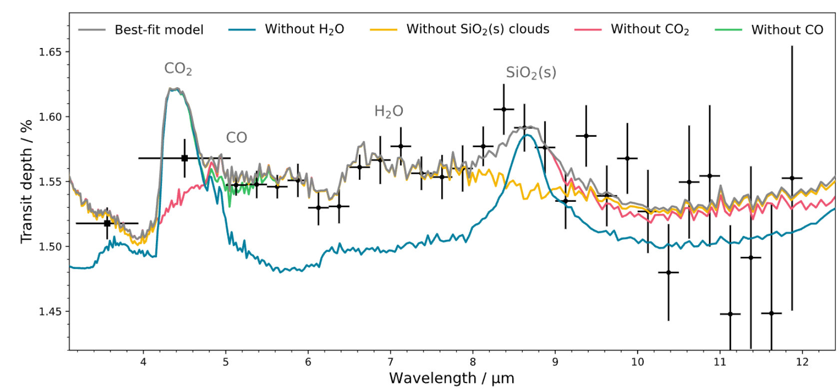
JWST made the first detections of key molecules CO_2, SO_2, CH_4, and SiO_2 in the atmospheres of transiting giant planets.



SO_2 and CO_2 from NIRSpec, Rustamkulov et al. (2023) and Alderson et al. (2023)



Methane and CO2 from NIRISS and NIRSpec, Madhusudhan et al. (2023)

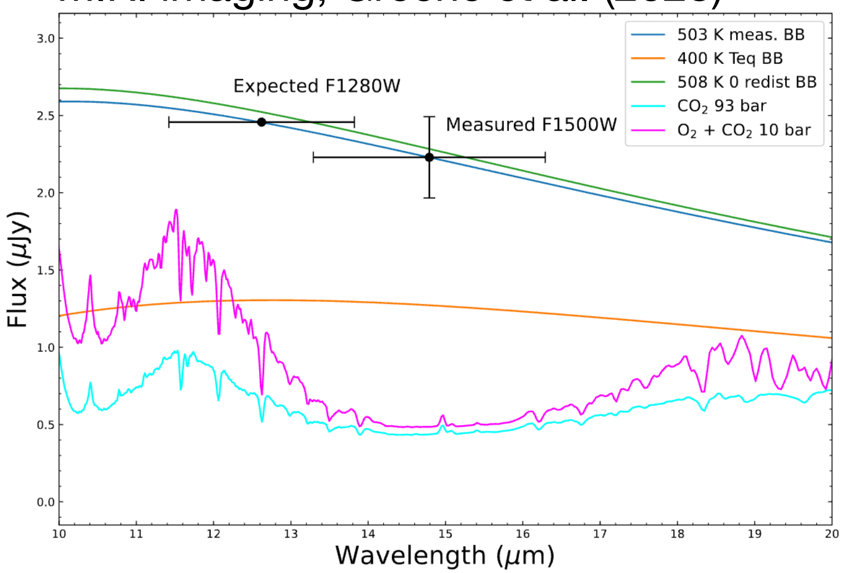


Quartz clouds from MIRI, Grant et al. (2023)

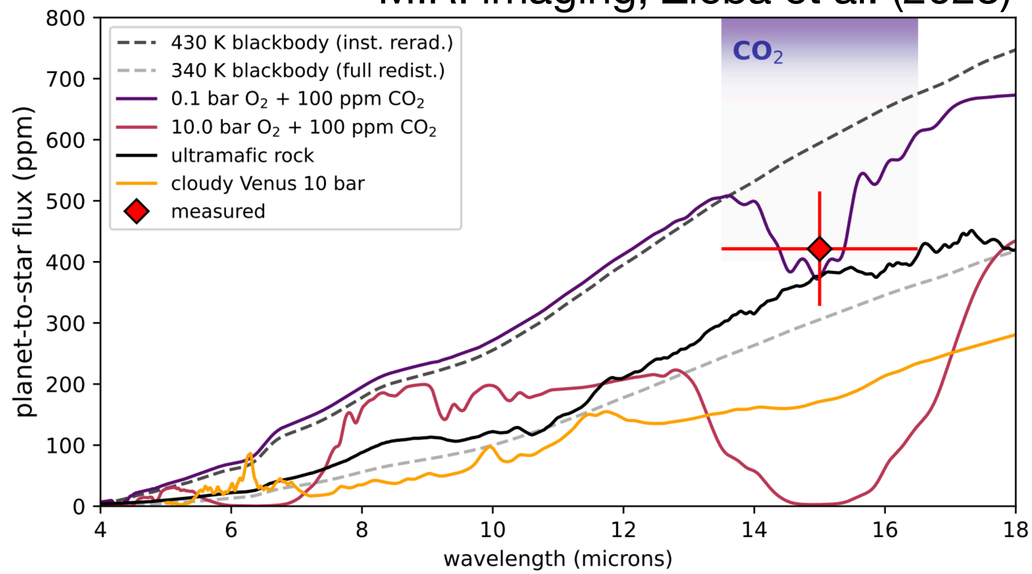
JWST is searching Earth-mass exoplanets for atmospheres. It's hard, because of clouds, host star activity, and the need for the highest precision.

Trappist 1b (Greene et al. 2023) and Trappist 1c (Zieba et al.) likely do NOT have thick atmospheres.

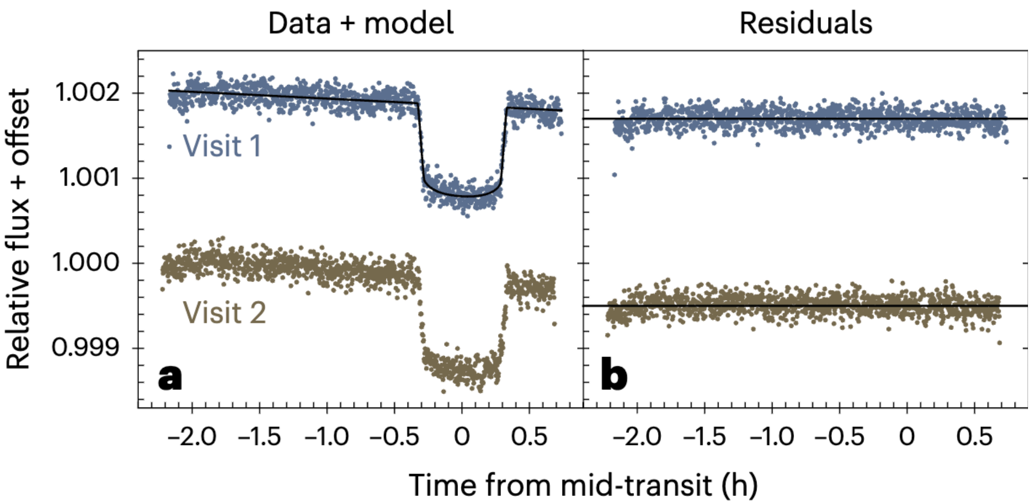
MIRI imaging, Greene et al. (2023)

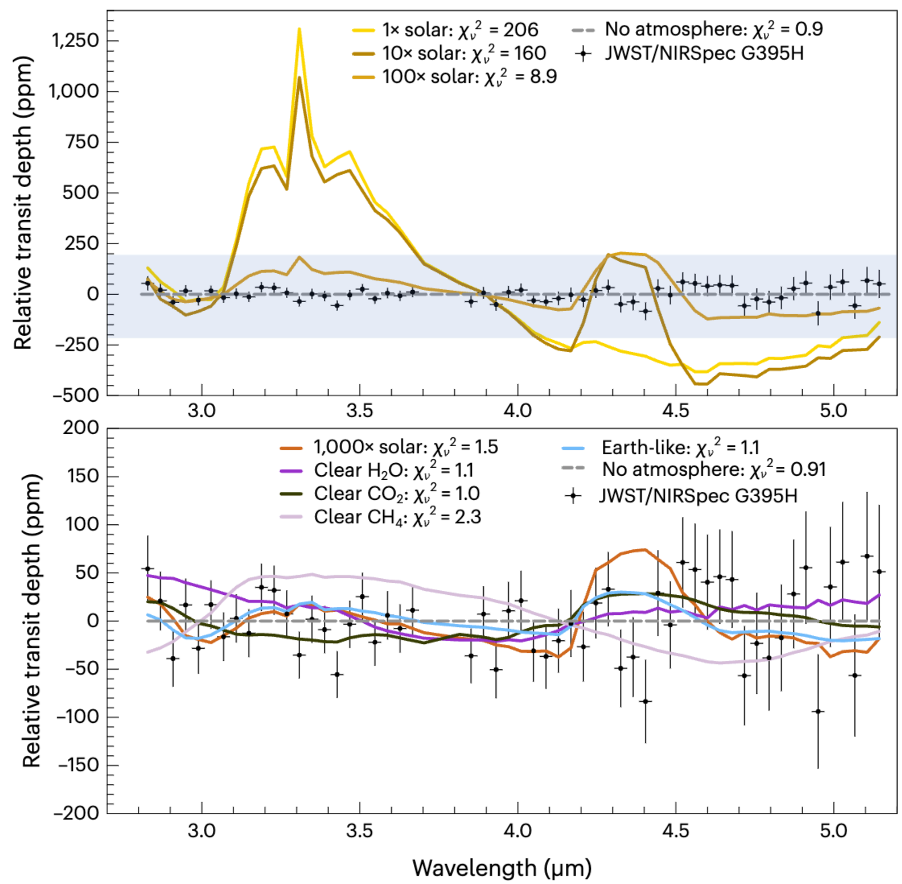


MIRI imaging, Zieba et al. (2023)



JWST is searching Earth-mass exoplanets for atmospheres. It's hard, because of clouds, host star activity, and the need for the highest precision.

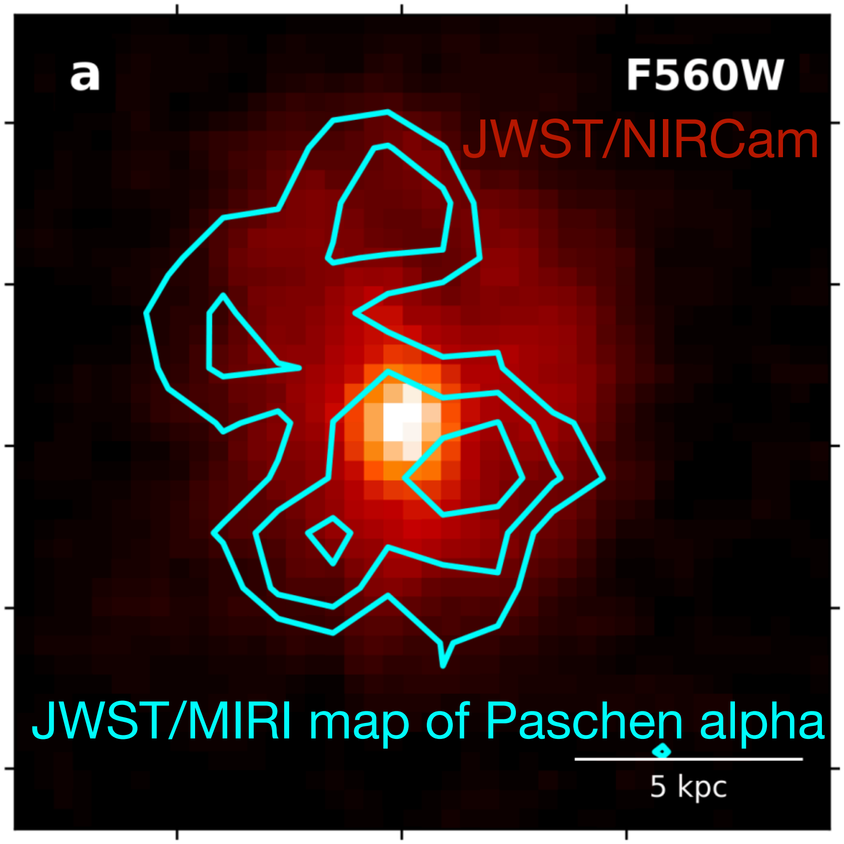




LHS475b seen with NIRSpec, Lustig-Yaeger et al. (2023)

See May et al. (2023) for the importance of multi-visit repeatability with JWST, before claiming atmospheric detections on super-Earth like planets.

JWST has studied the dustiest of galaxies, obtaining diagnostics that were previously impossible.



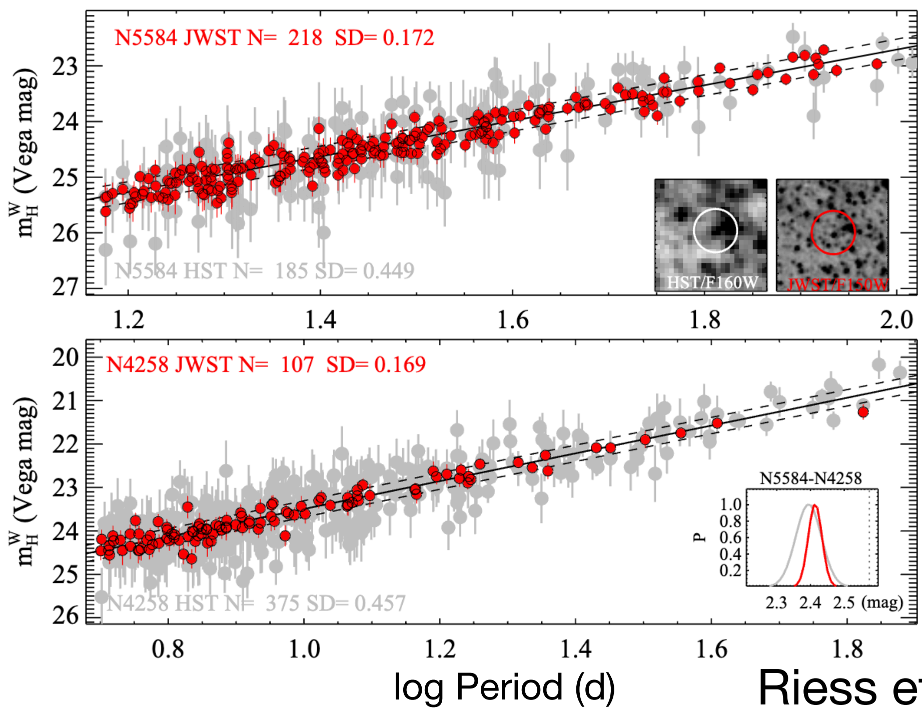
The dusty galaxy GN20 at z=4.0.

The dust attenuation is measured as A_V=44 $\pm$ 3 magnitudes.

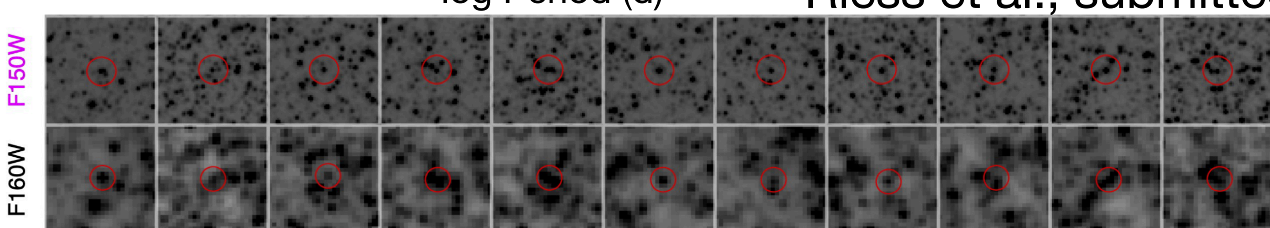
The gas kinematics are dominated by rotation.

Bik et al., submitted

JWST has improved cosmological constraints - showing that the Hubble tension is not due to the systematic effect of crowding.

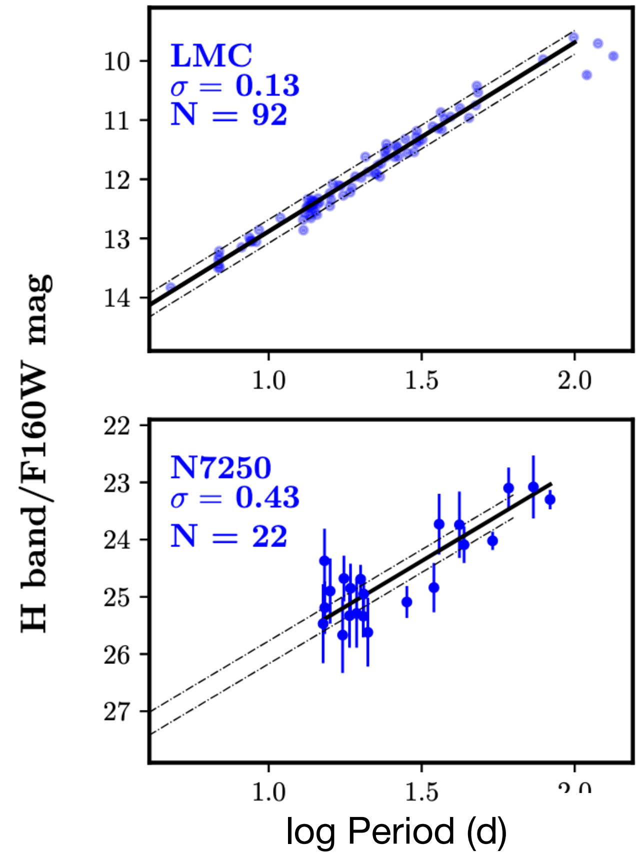


Riess et al., submitted



JWST

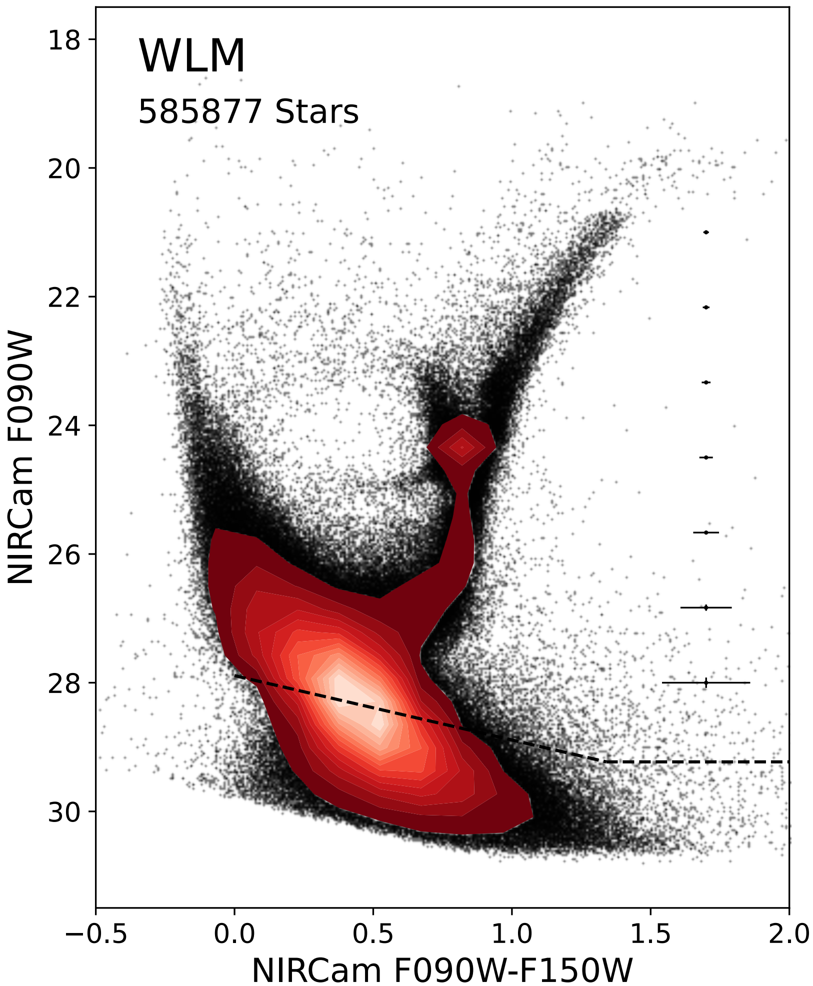
Hubble

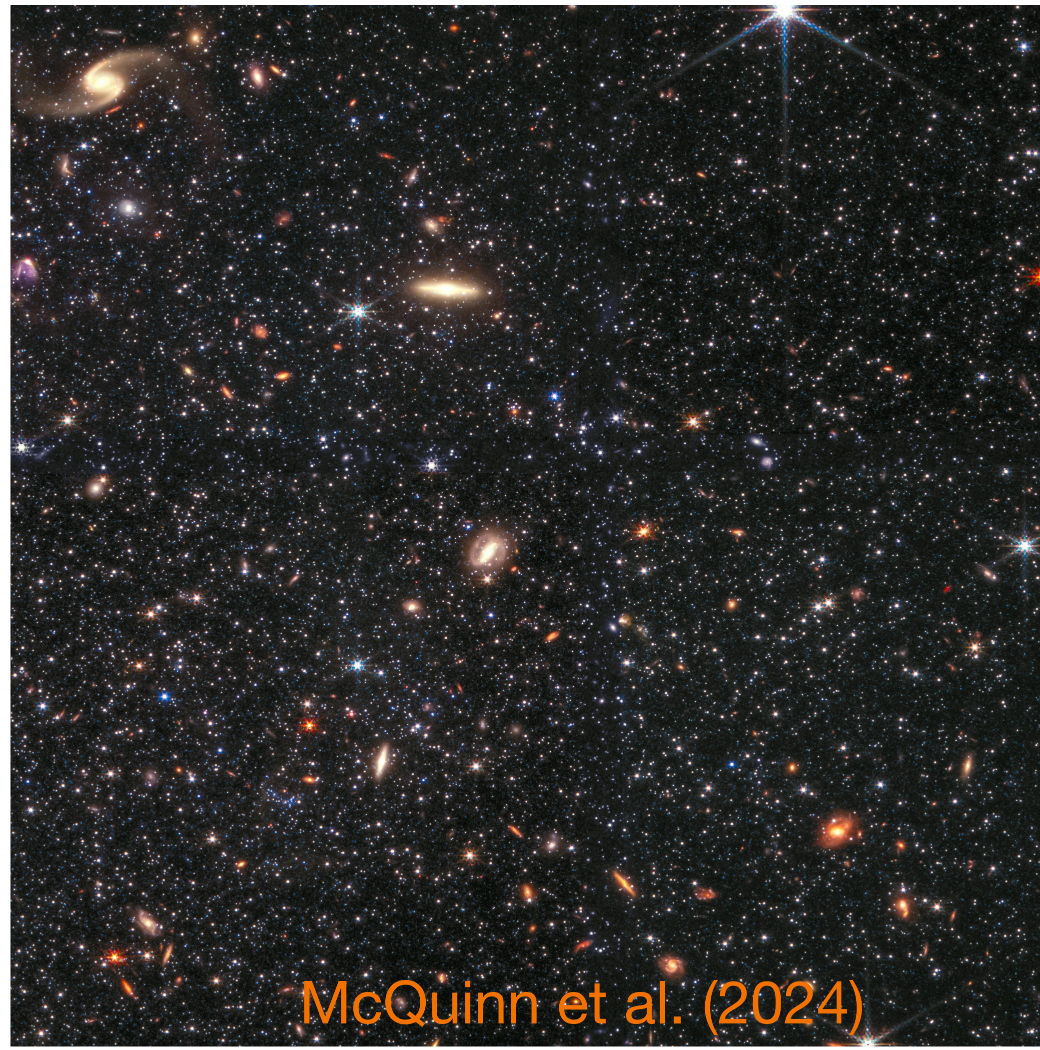


Friedman et al. (2023)

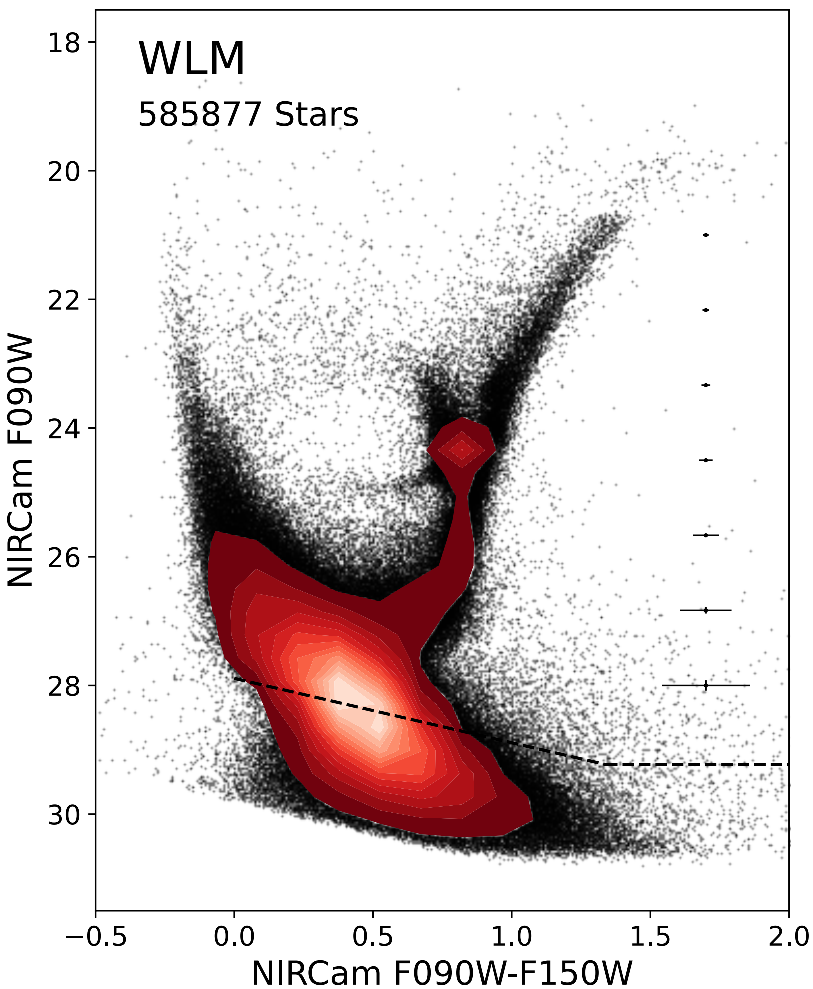
JWST has charted star-by-star the star formation history of a dwarf galaxy, complete down below the oldest main sequence turnoff.

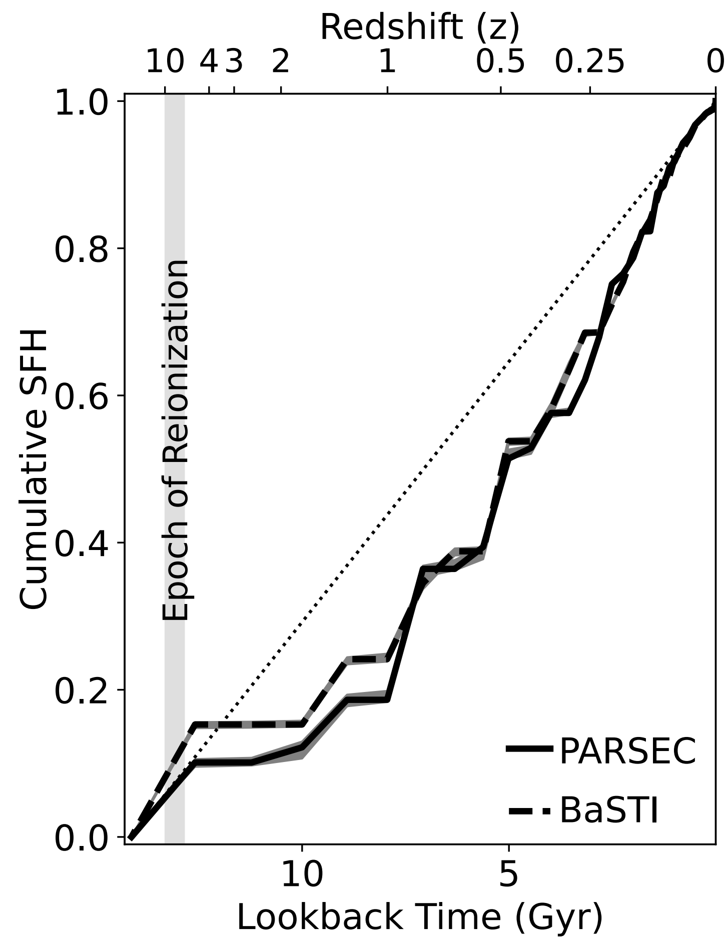
JWST has charted star-by-star the star formation history of a dwarf galaxy, complete down below the oldest main sequence turnoff.





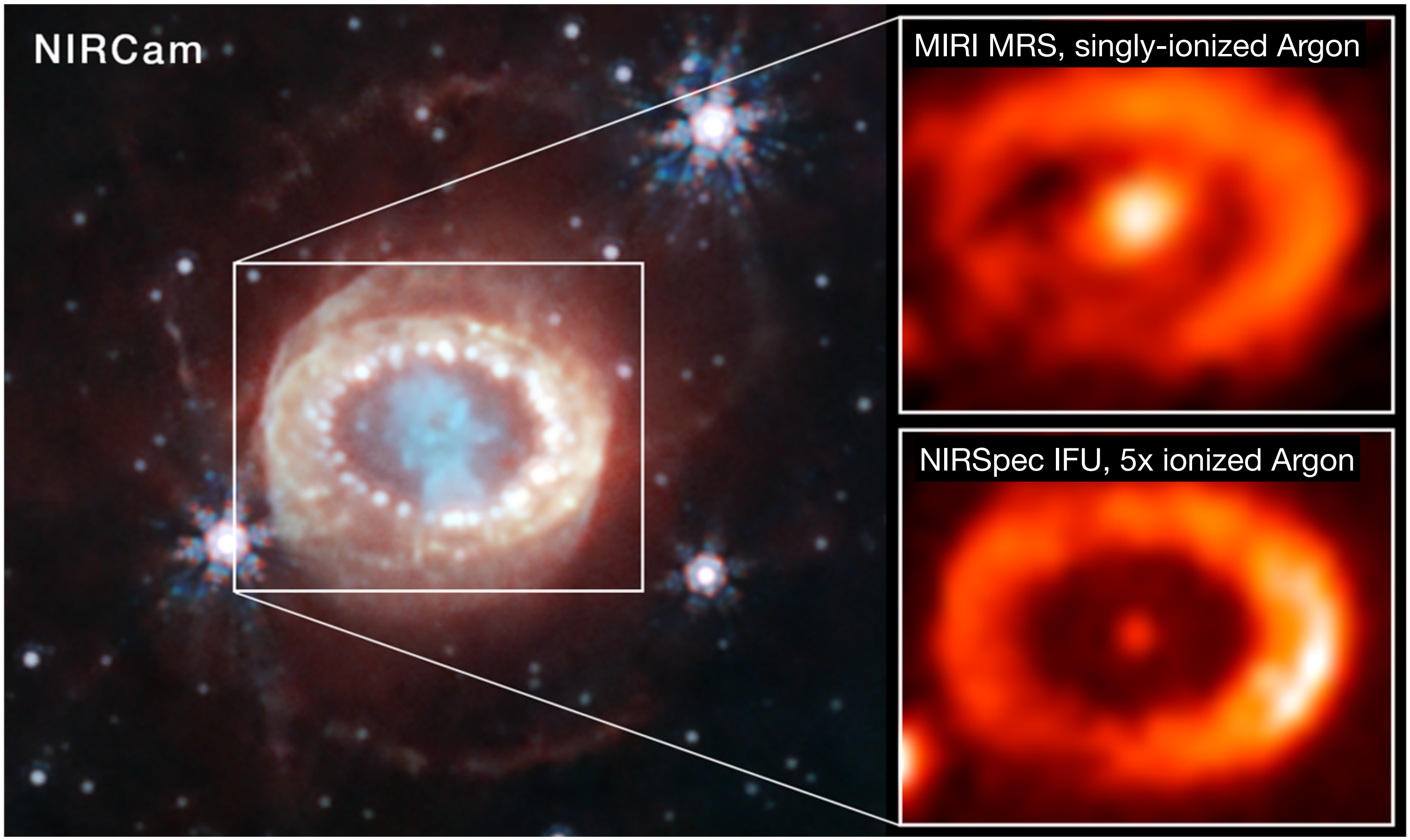
JWST has charted star-by-star the star formation history of a dwarf galaxy, complete down below the oldest main sequence turnoff.





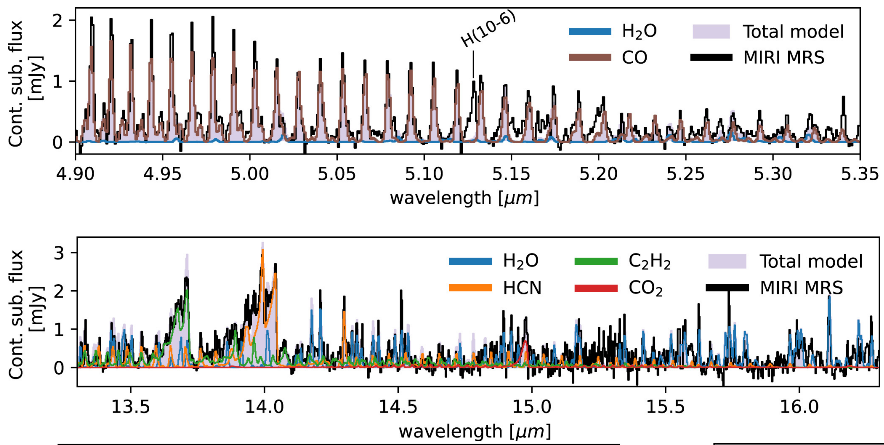
McQuinn et al. (2024)

JWST has identified a compact object in the remnants of supernova SN1987A.

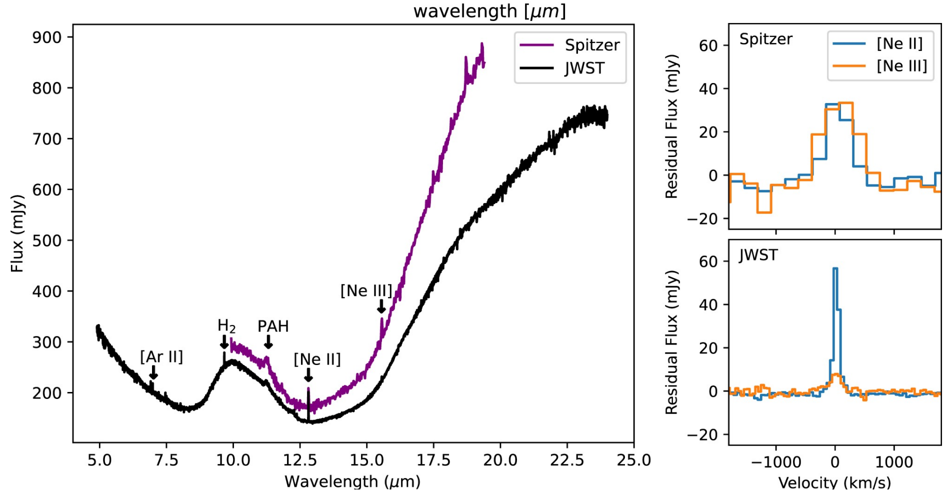


Fransson et al. (2024)

JWST is improving our understanding of the mechanisms governing planet-forming disks



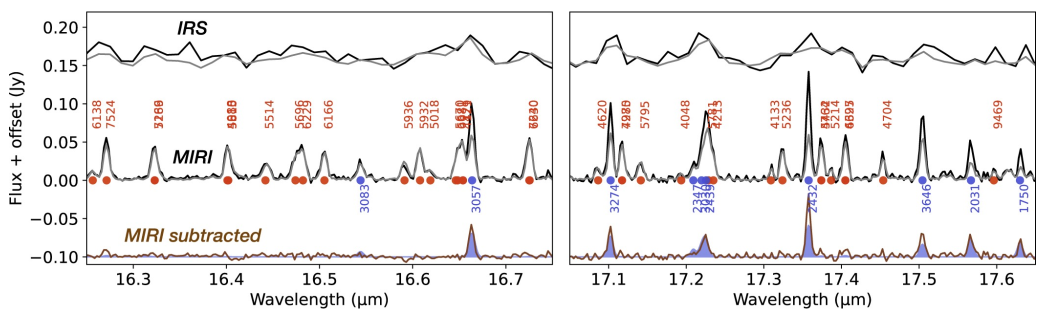
Ramírez-Tannus et al. (2023) report abundant water, CO, $^{12}CO_2$, HCN, and C_2H_2 in the inner few au of XUE 1, a highly irradiated disk in NGC 6357.



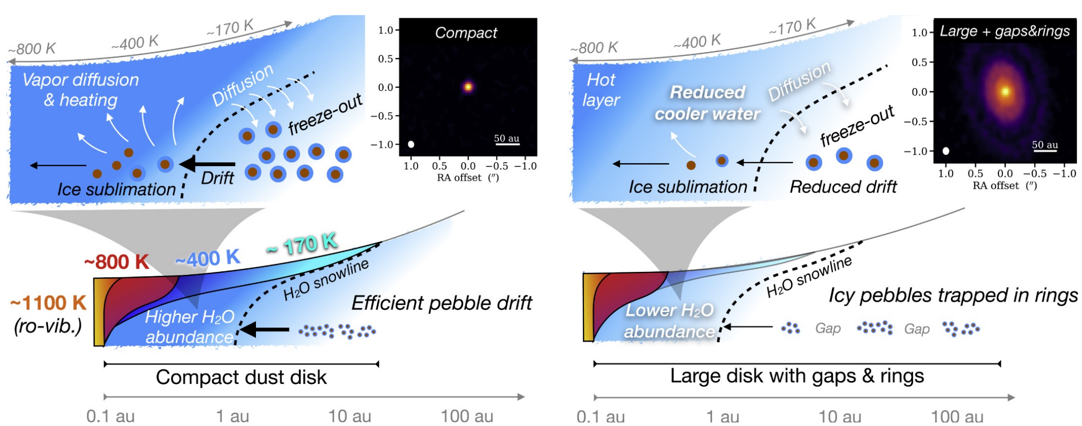
Espaillat et al. (2023): Left: JWST MIRI MRS spectrum from 2023 and Spitzer IRS SH spectrum from 2008 Right: comparisons between the [Ne II] and [Ne III] lines within the same observation.
[NeIII] to [NeII] ratio is 1.4 +-0.4 for Spitzer and 0,2 +-0.06 for JWST

Slide from Macarena Garcia-Marin

JWST is improving our understanding of the mechanisms governing planet-forming disks



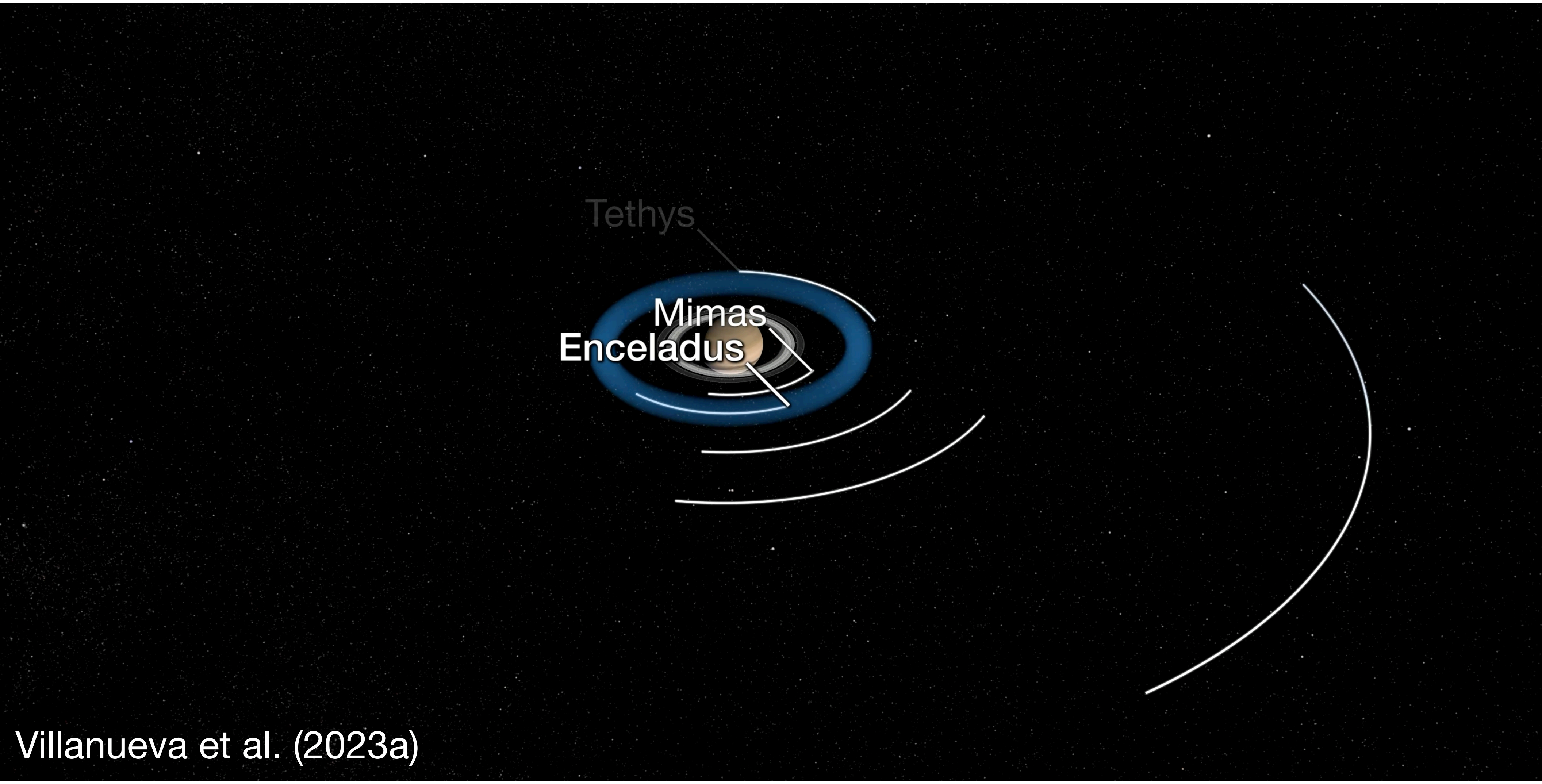
Banzatti et al. (2023). Continuum-subtracted infrared water spectra of the compact disk GK Tau (in black) and the large disk CI Tau (in gray). Excess emission in the low-energy lines in compact disks compared to large disks; enhanced cool component with $T \approx 170$–400 K and equivalent emitting radius $R_{eq} \approx 1$–10 au.



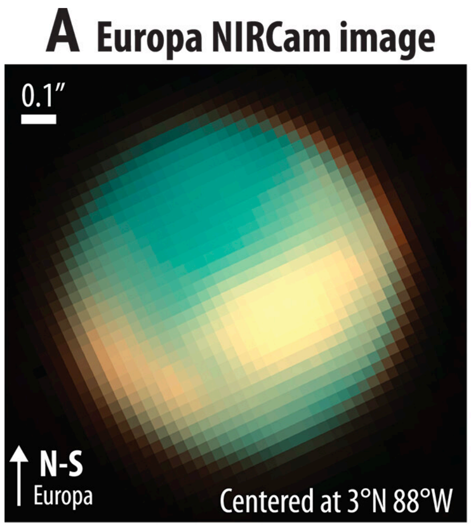
Banzatti et al. Illustration of the interpretation of the results in the context of the long-proposed scenario of inner water enrichment by pebble drift

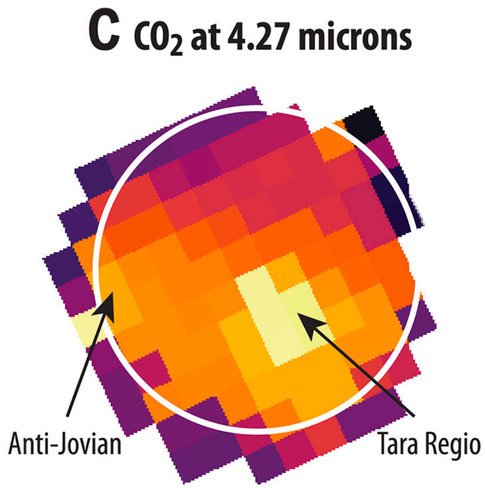
Slide from Macarena Garcia-Marin

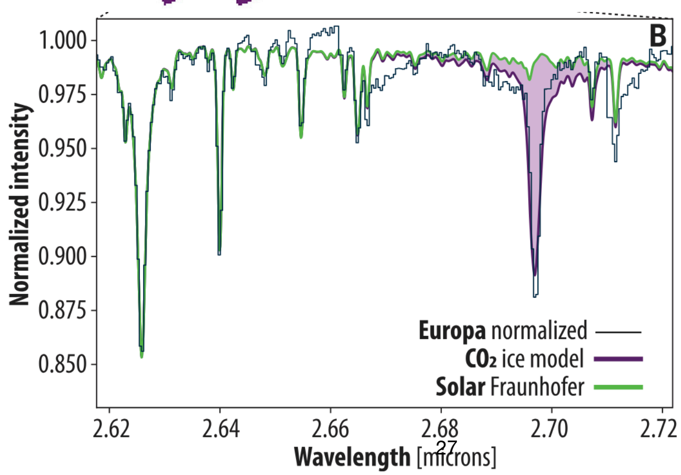
Plumes of water leaking out of Saturn’s moon Enceladus



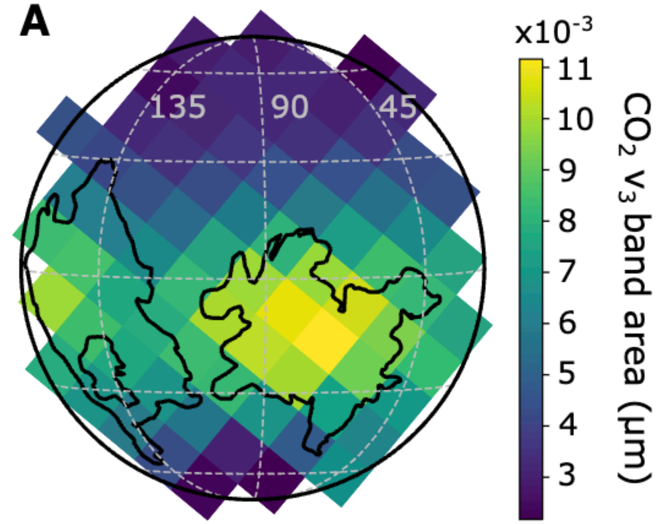
JWST has detected carbon dioxide over “chaos terrain” regions of Jupiter’s moon Europa — presumably leaking from the ocean.







Villanueva et al. (2023b)

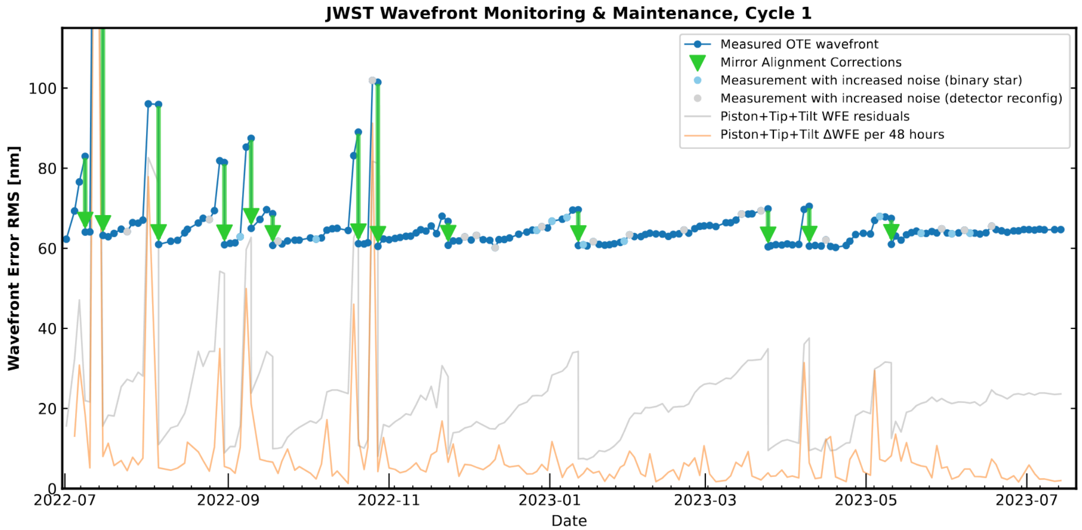


Trumbo et al. (2023)

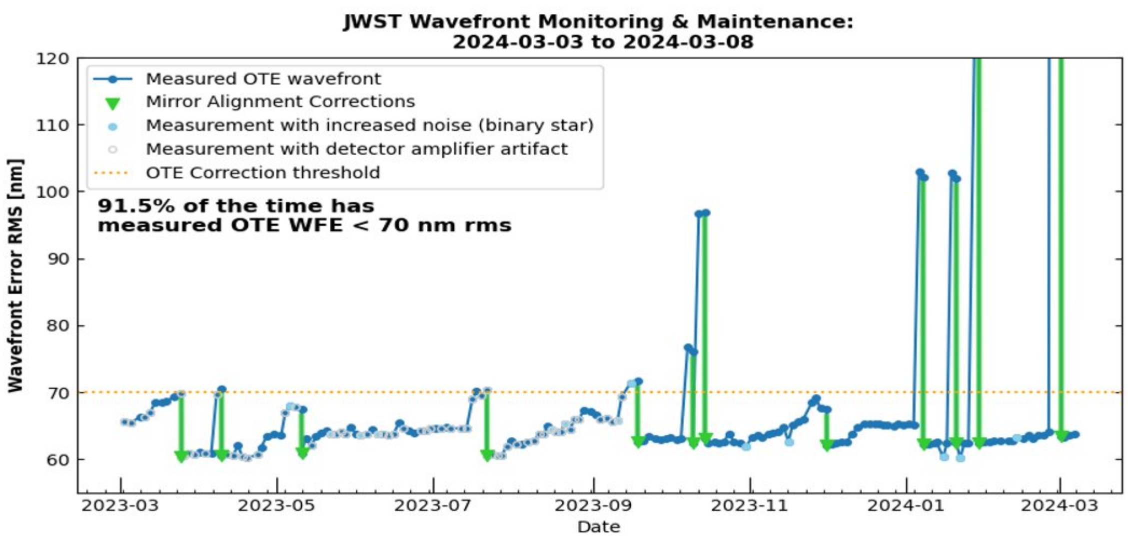
Summary

- JWST is performing better than requirements, better than we dared hope.
- JWST papers (N>600 to date) cover an extremely broad range of science.
- JWST's capabilities have transformed our view of the high-redshift universe, and are determining the chemical composition of giant planets.
- The user community is analyzing high-quality data, making discoveries, and proposing new observations.
- Improvements to the pipeline and calibrations will make it easier to make data science-ready, with the potential to broaden the user community.
- It's still early days — the most significant discoveries lie ahead.

Backup Slides



Lajoie et al. (2023)



Lajoie, to JWST Users Committee, 3/2024