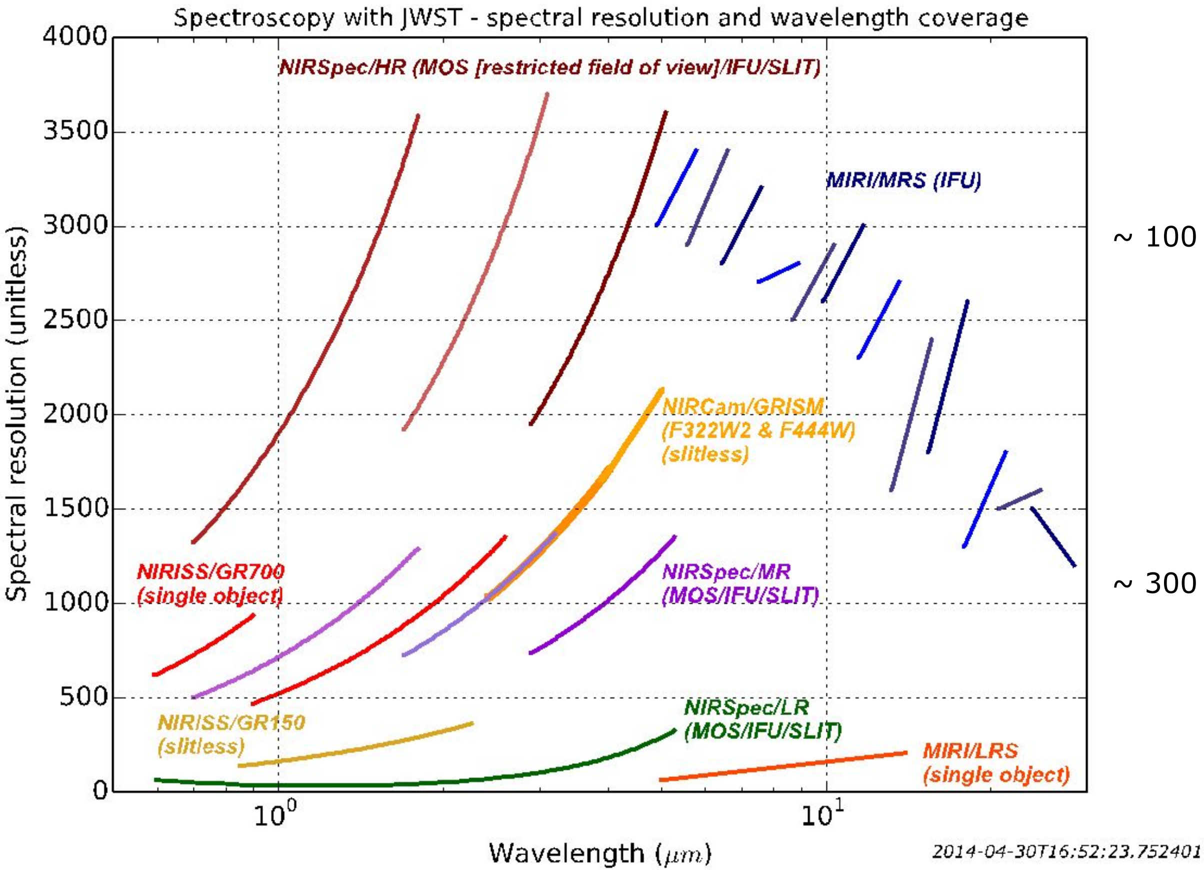
JWST spectroscopic capabilities

- **In JWST, spectroscopy comes in many different flavors…**
  - Can address many different scientific needs.
  - Unique combination of sensitivity & spatial resolution
  - First Multi Object Spectrograph in Space

Instrument	Type	Wavelength (microns)	Spectral resolution	Field of view
NIRISS	slitless	1.0-2.5	~150	2.2′ x 2.2′
NIRCam	slitless	2.4-5.0	~2000	2.2′ x 2.2′
NIRSpec	MOS	0.6-5.3	100/1000/[2700]	9 square arcmin.
NIRSpec	IFU	0.6-5.3	100/1000/2700	3″ x 3″
MIRI	IFU	5.0-28.8	2000-3500	>3″ x >3.9″
NIRSpec	SLIT	0.6-5.0	100/1000/2700	Single object
MIRI	SLIT	5.0-10.0	60-140	Single object
NIRSpec	Aperture	0.6-5.3	100/1000/2700	Single object
NIRISS	Aperture	0.6-2.5	700	Single object

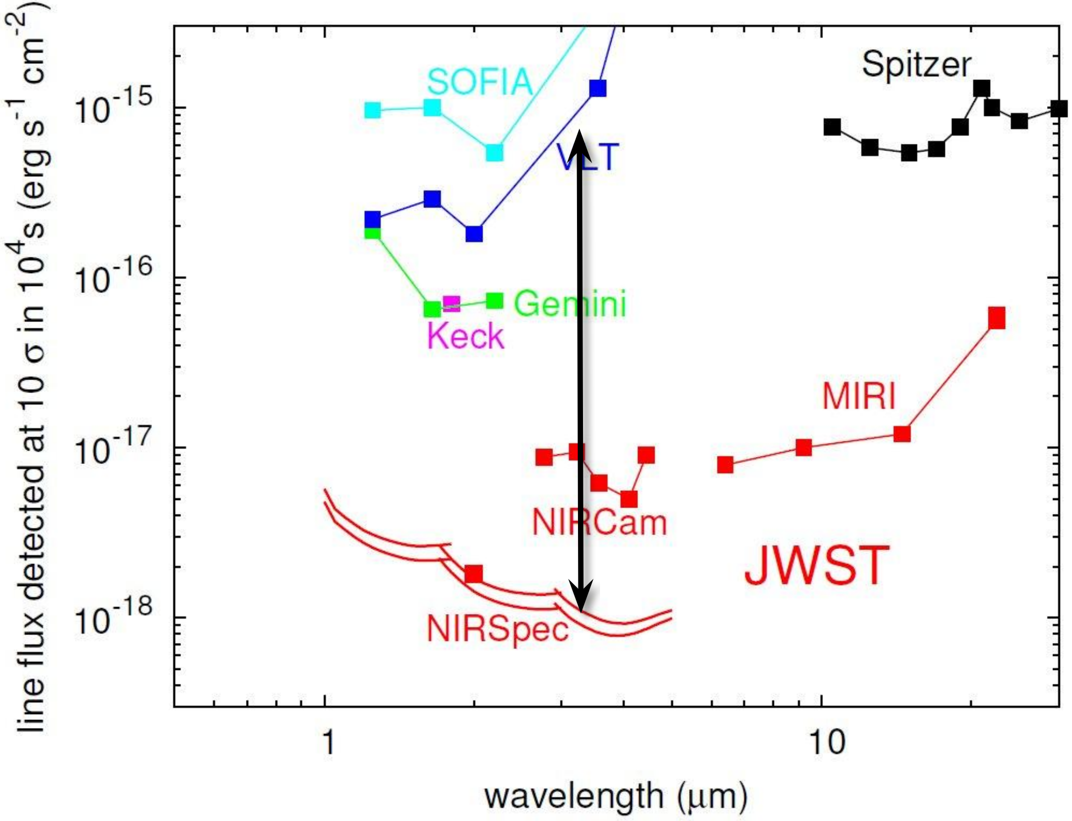
JWST spectroscopic capabilities
Spectral resolution



~ 100 km/s

~ 300 km/s

JWST spectroscopic capabilities
Spectral sensitivity



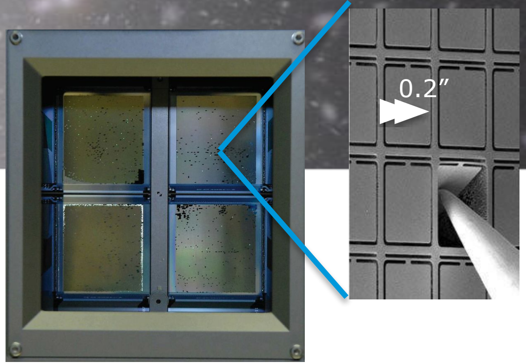
2,000 x more sensitive than current telescopes

Huge leap in sensitivity

...has happened very rarely in history of science

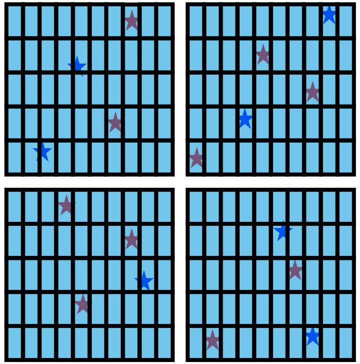
Equivalent to suddenly passing from Galileo's telescope to modern large telescopes

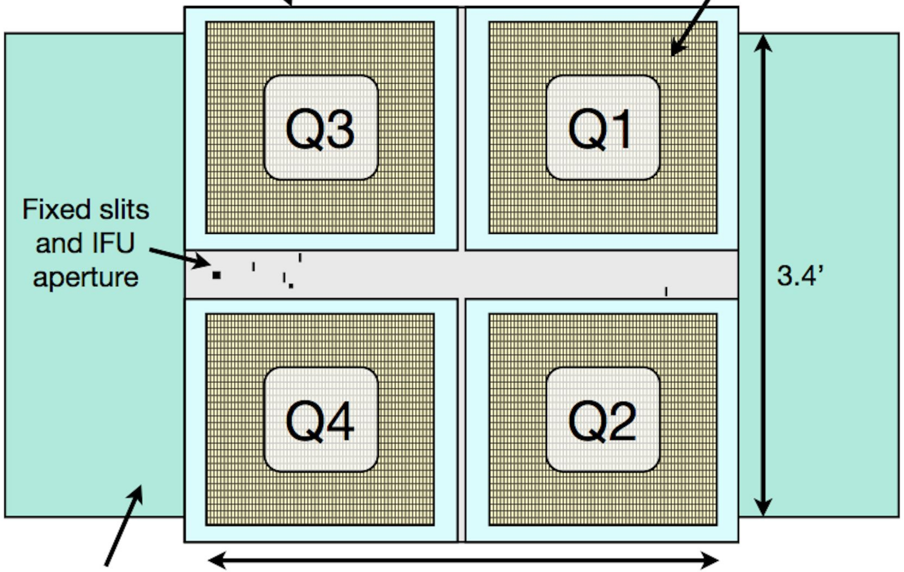
NIRSpec: the first multi-object spectrograph in space (the largest and most complex instrument of JWST)



Micro Shutter Array

4 quadrants, each with 171 rows of 365 shutters, totaling ~250,000 shutters
Each shutter is 0.46″ x 0.2″





RIGID ARRAY
⇒ implications for observing plan

Micro Shutter Array

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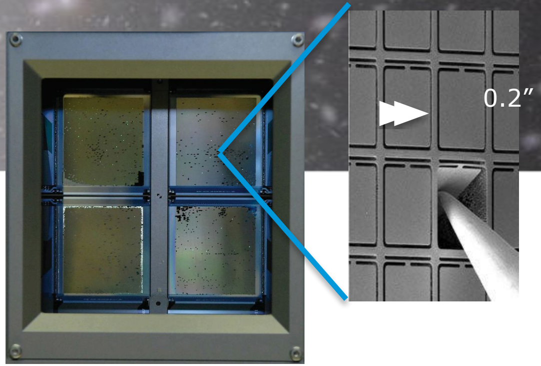
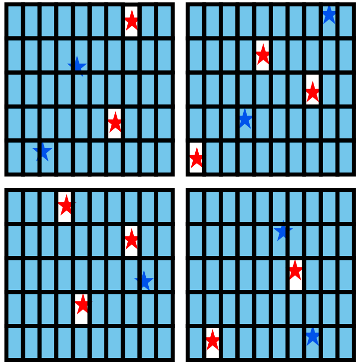
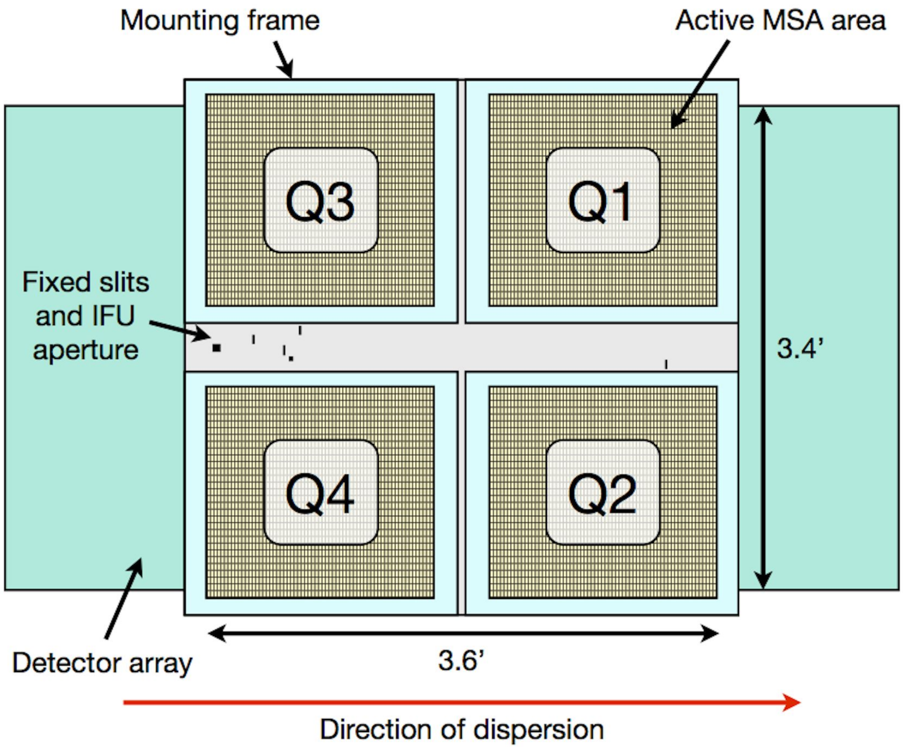


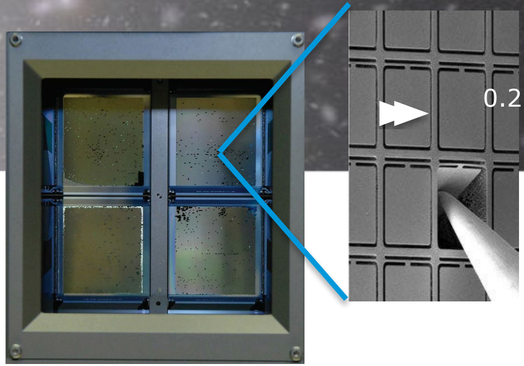




RIGID ARRAY

⇒ implications for observing plan

Micro Shutter Array



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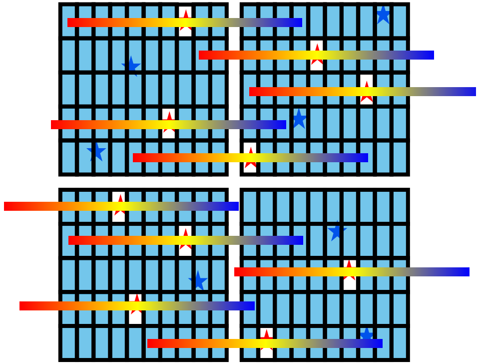
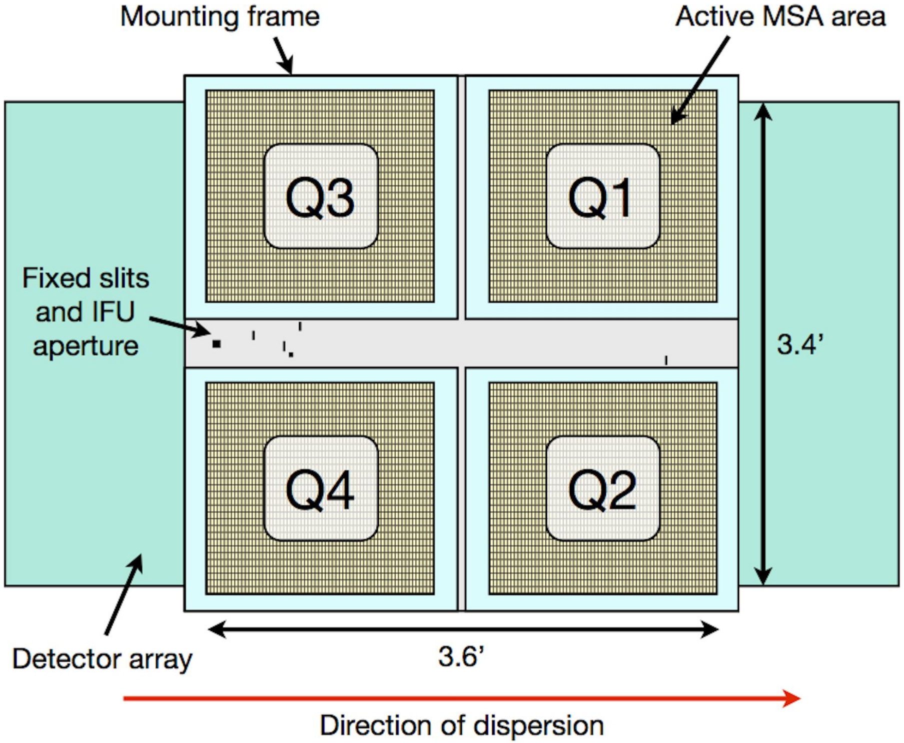
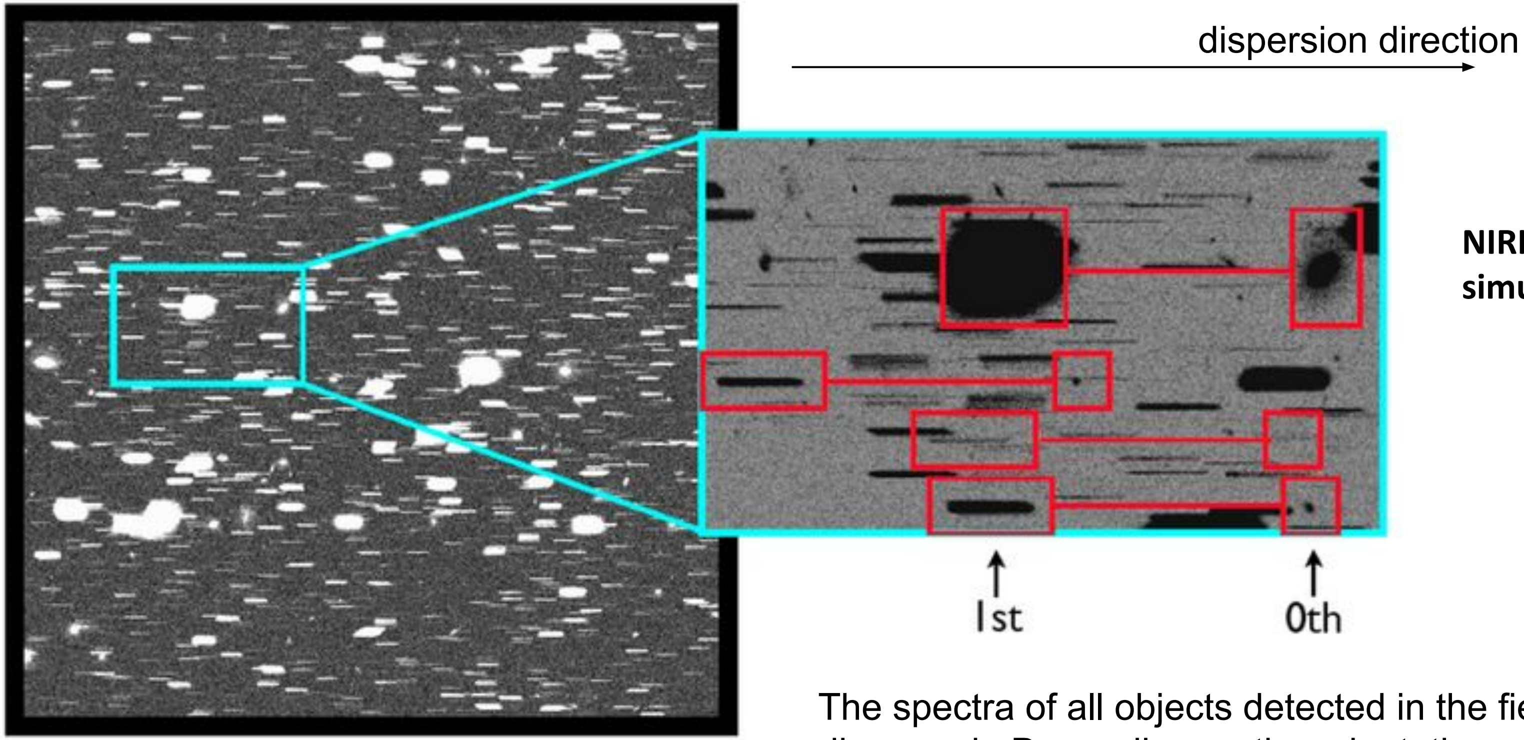




RIGID ARRAY
⇒ implications for observing plan

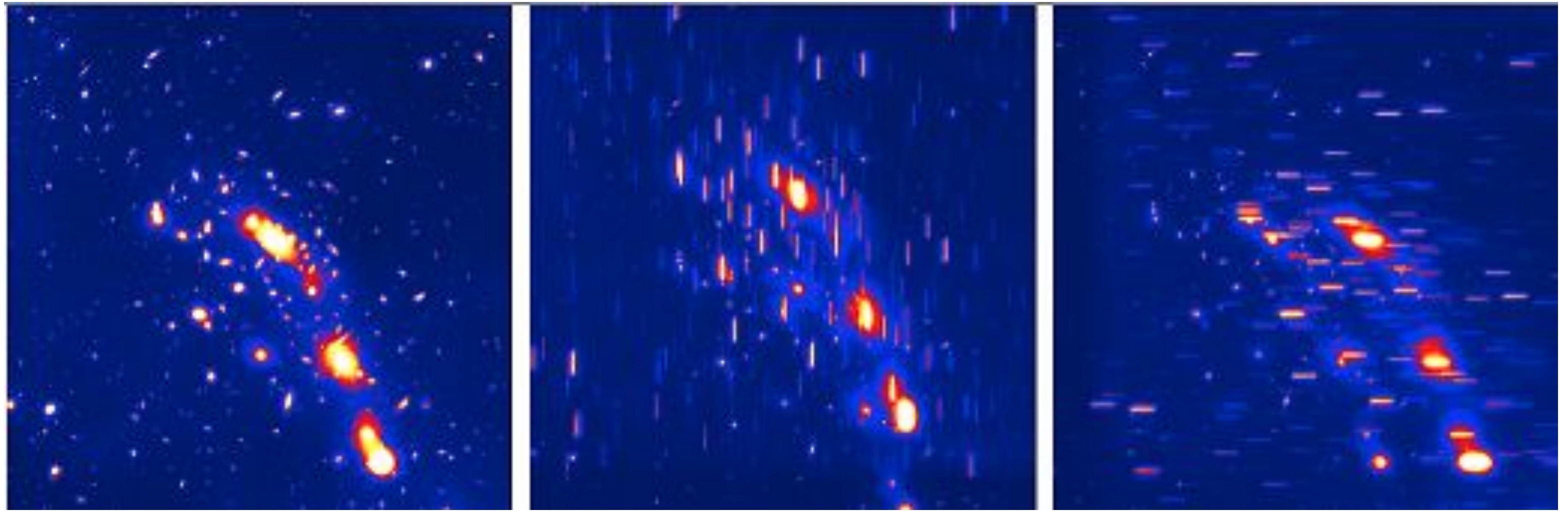
Slitless spectroscopy =spectroscopy of everything in the field
→ no preselection!!



NIRISS simulated spectra

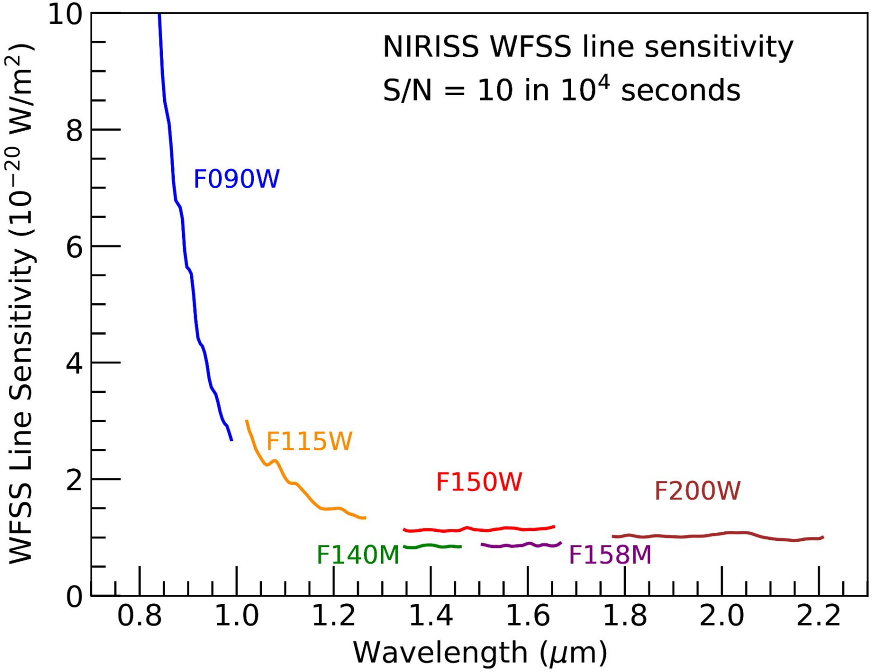
The spectra of all objects detected in the field are dispersed. Depending on the orientation, spectra of different objects can overlap. 0th order is the direct image

The two low-resolution grisms (GR150R & GR150C) are located in the FW and blazed at 1.3 μm. They are identical except that they disperse light 90◦from one another with respect to the detector. Both grisms are operated in a slitless manner



NIRISS Wide-Field Slitless Spectroscopy simulations of the gravitationally lensed cluster MACS J0416.1-2403. Left: Image through the F200W filter. Middle and right: Slitless spectra through the F200W filter with the GR150R grism and the GR150C grism. **Observations with orthogonal dispersion directions can be used to disentangle blended spectra in crowded fields.**

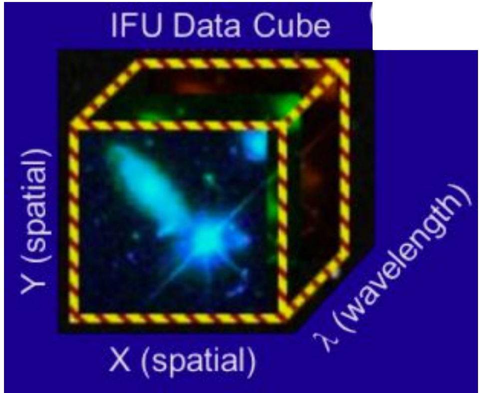
NIRISS   Slitless spectroscopy =it has a lower sensitivity but gets spectroscopy of everything in the field → no preselection!!

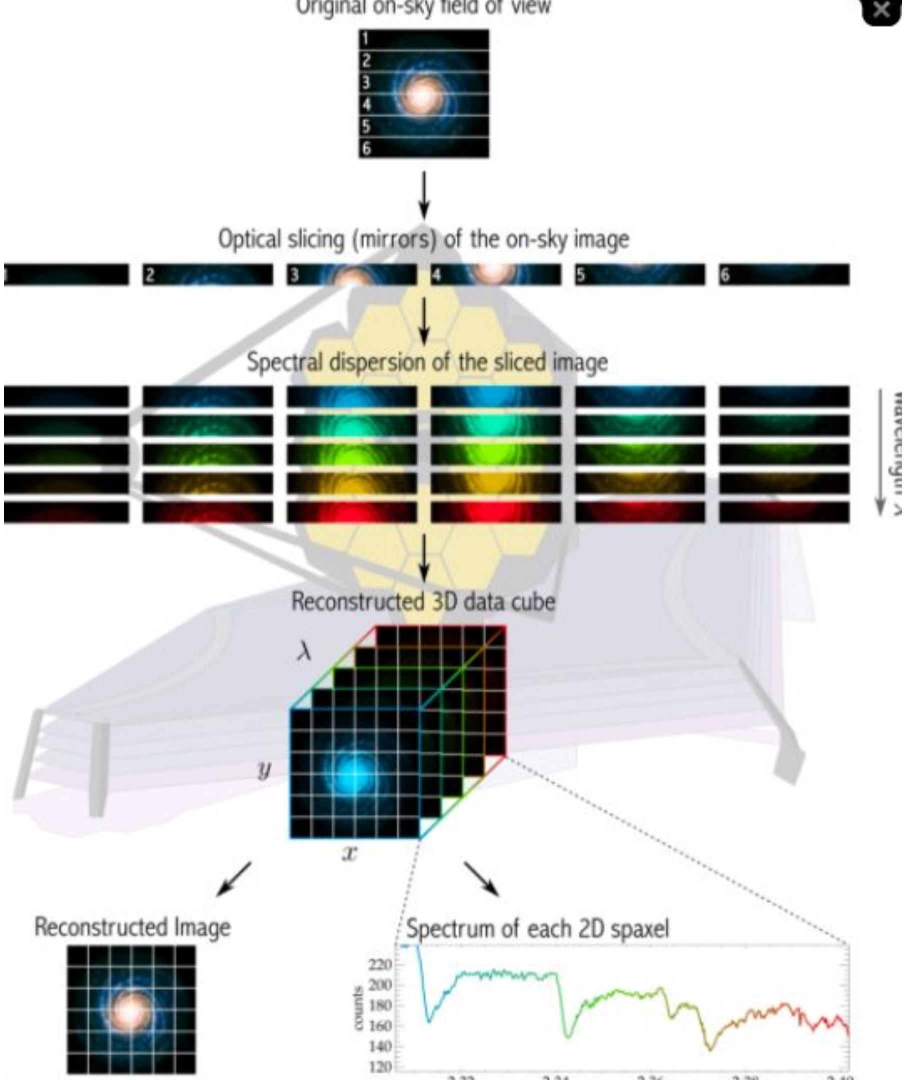


Integral field spectroscopy: the concept

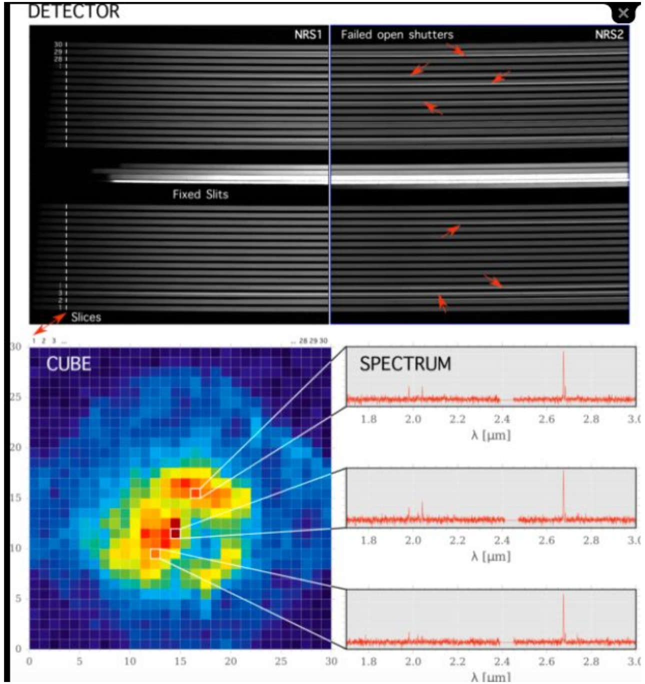
Integral field Unit (IFU) provides a 3-D imaging spectroscopy of a small region in the sky
Every image location has a spectrum associated with it

A 3-D data cube is the end-product





Integral field spectroscopy with JWST

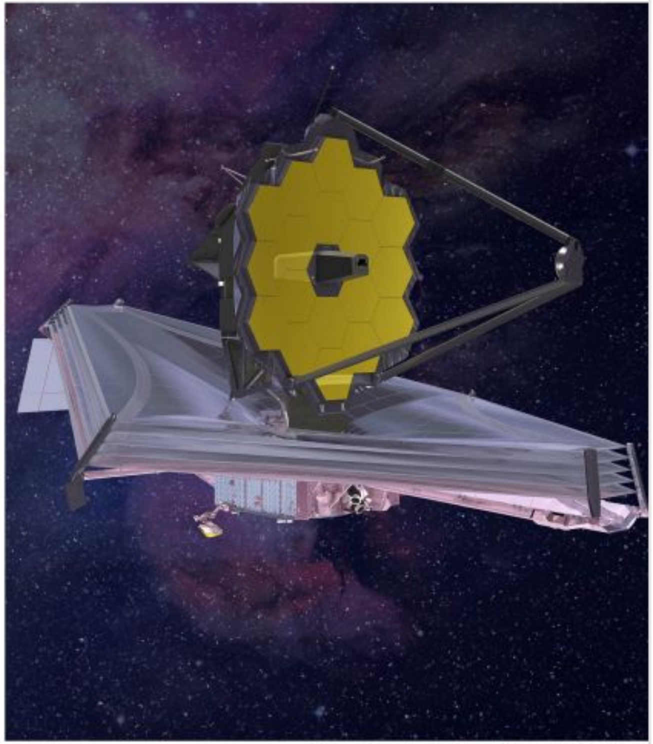


NIRSpec: 1-5μm
3"x3" field
0.1" spatial sampling (1 sqaare spaxel)
R=100/1000/2700 (like MOS)

MIRI 5-25μm
spectra are acquired with 4 IFUs
>3"x3.9" field of view
(IFU spatial fields scale with wavelength)
R=3000

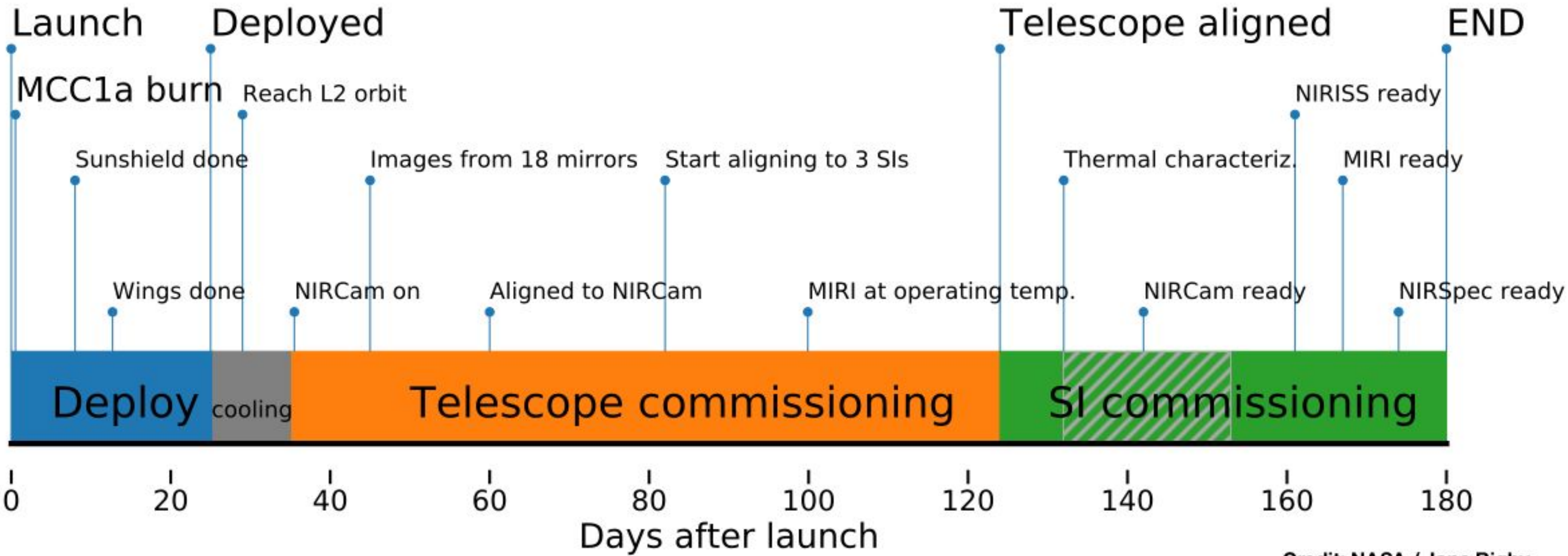
Commissioning JWST: the first month

- An Ariane 5 will launch JWST to the L2 Earth-Sun Lagrange point.
- 30 min after launch, JWST will separate from the launch vehicle. The solar array will deploy to get power.
- Less than a day after launch, JWST must burn a mid-course correction to send it toward L2.
- In the first two weeks after launch, JWST will deploy the tower, the sunshield, the secondary mirror, and the wings of the primary mirror.
- Two weeks after launch, the primary mirrors segments will slowly rise from their stowed positions.



Deployed JWST. Credit: NASA

Commissioning JWST



Credit: NASA / Jane Rigby

J. Rigby — JWST Town Hall, AAS235, 1/2020

Starting JWST Cycle 1

- **Six months after launch, commissioning is planned to end, and science operations to begin.**
- **The Cycle 1 schedule will intersperse observations from GO, GTO, ERS, and calibration programs.**
- **Many of the calibrations will be done in parallel.**
- **Scheduling JWST is not trivial. 39% of the sky is observable at any time; 100% over the course of a year. Zodiacal background for a given target varies seasonally.**

GO: General Observer
GTO: Guaranteed Time Observer
ERS: Director's Discretionary Time Early Release Science

Assembled JWST. Credit: Northrop Grumman

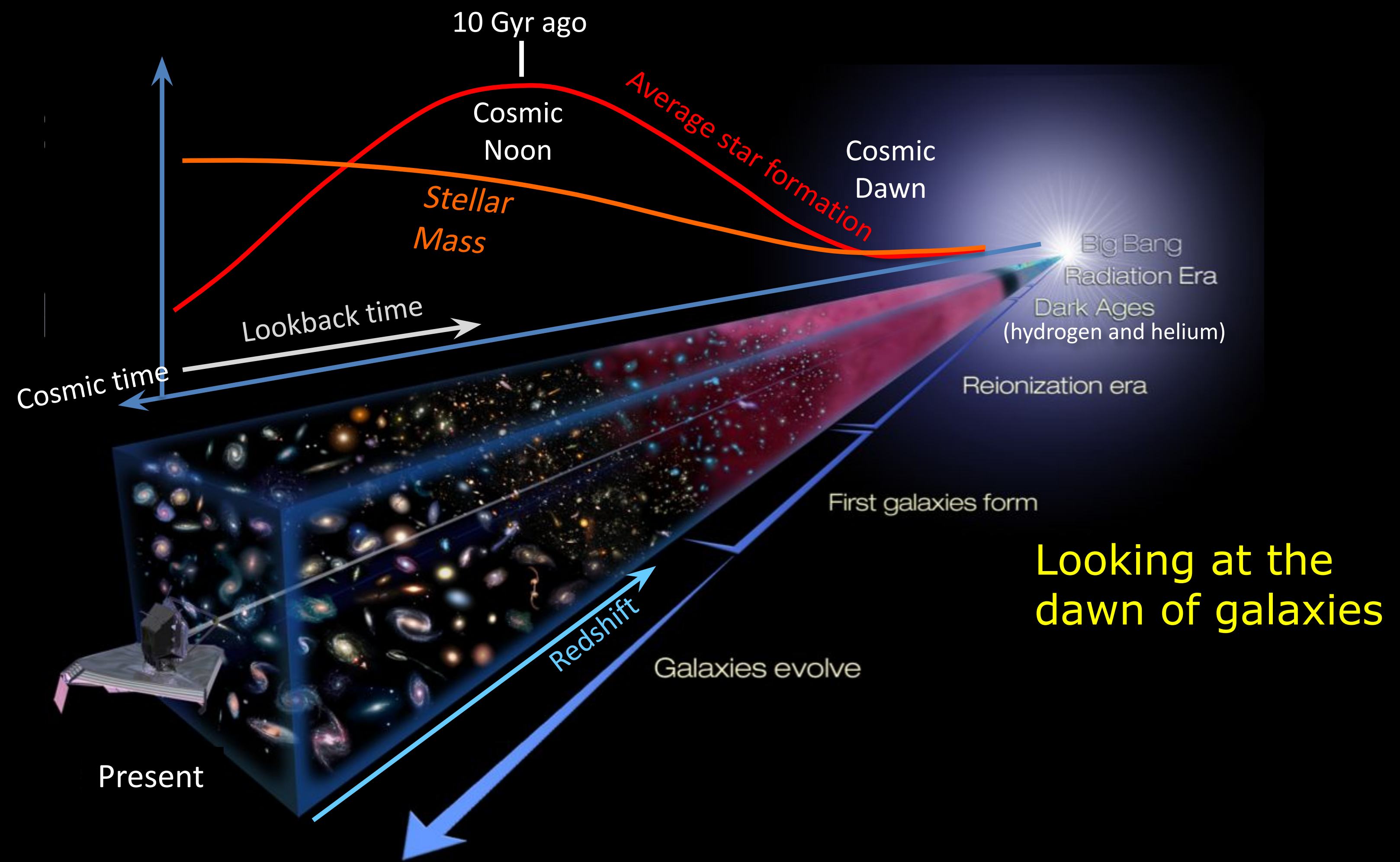
Availability of early JWST data

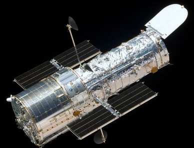
- **Commissioning data goes public at the end of commissioning. Mostly stars for wavefront sensing, but some observations may have some scientific value.**
- **Early Release Science (ERS) programs are front-loaded toward the first half of Cycle 1. Data will be public immediately, and ERS teams will deliver high-level data products ASAP.**
- **Large GO programs and <u>some GTO programs</u> will go public immediately.**
- **Initially, science data will be calibrated based on ground test data, plus some initial calibrations from commissioning. Calibration will improve as we go deeper into Cycle 1.**

JWST telescope at Goddard in 2017.
Credit: NASA / Desiree Stover

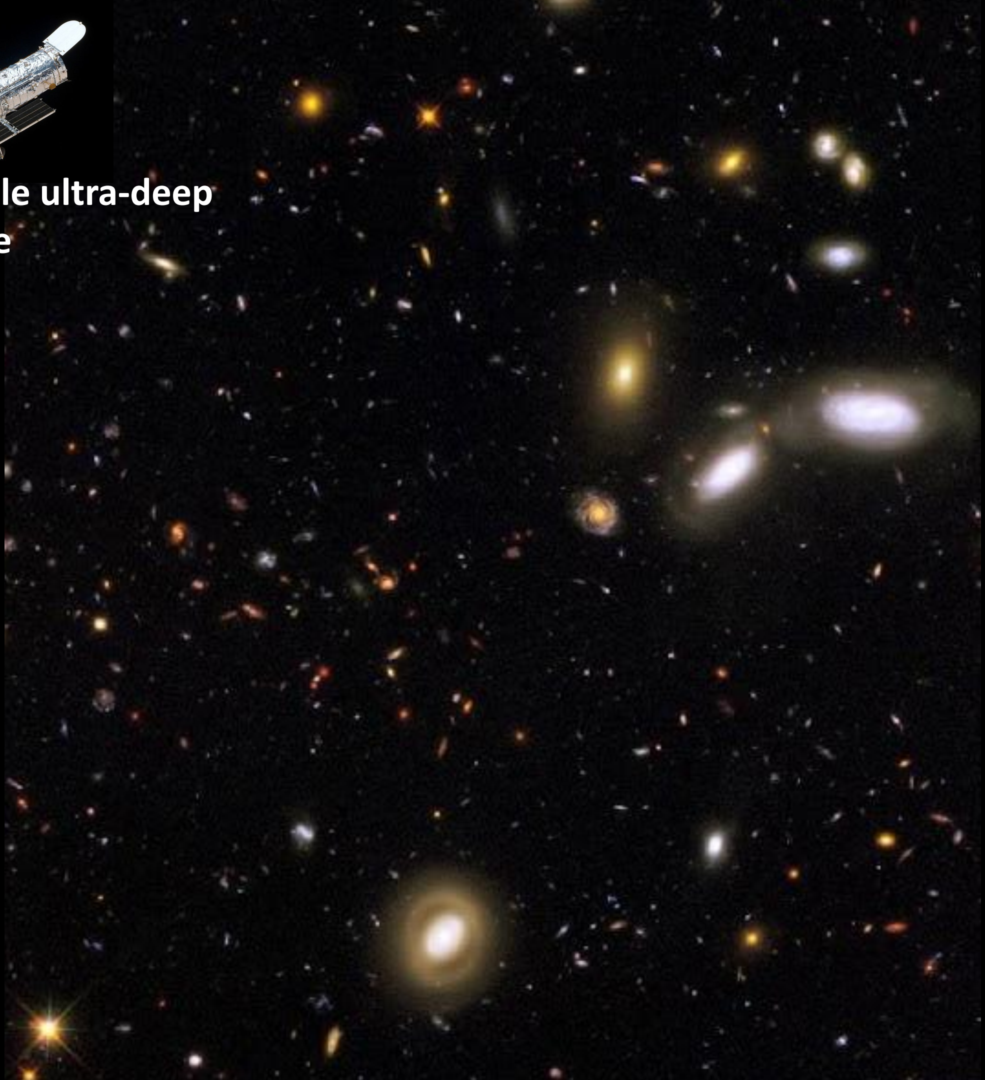
A few examples of fantastic science goals with JWST

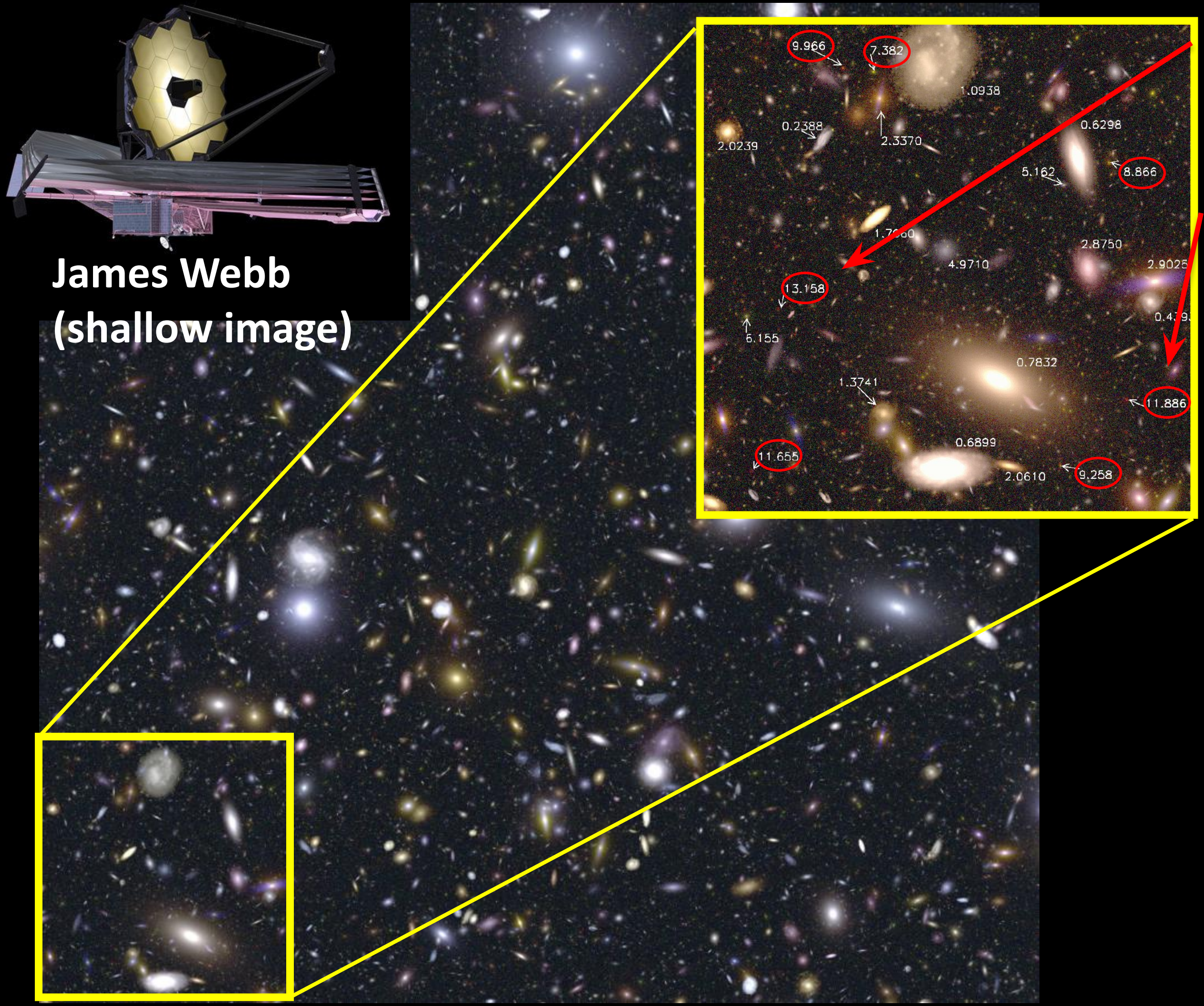
Primeval galaxies


10 Gyr ago
Cosmic
Noon
Average star formation
Cosmic
Dawn
Stellar
Mass
Big Bang
Radiation Era
Dark Ages
(hydrogen and helium)
Lookback time
Cosmic time
Reionization era
First galaxies form
Looking at the
dawn of galaxies
Redshift
Galaxies evolve
Present



Hubble ultra-deep image



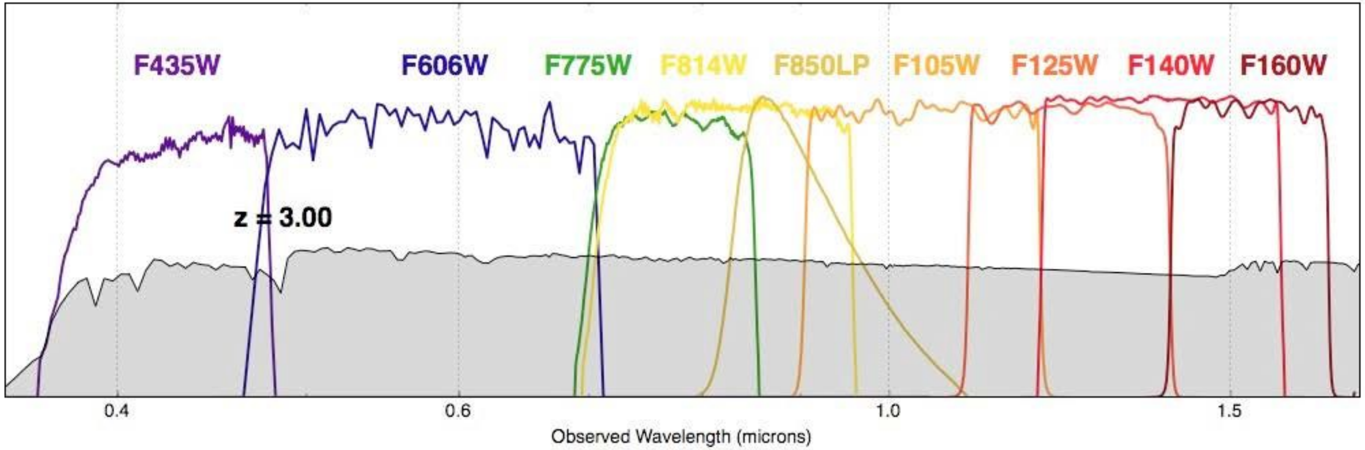


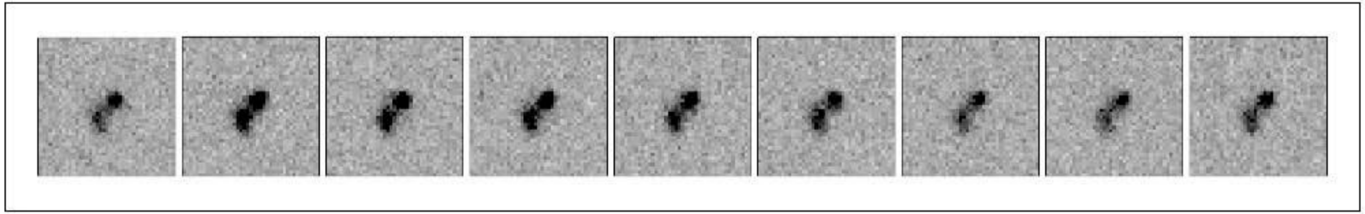
James Webb (shallow image)

Primordial galaxies (age of the Universe ~3% of current age)

Multi-color imaging is used to select high redshift galaxies: star forming galaxies at each redshift have a spectra that produces characteristic colors (the so called Lyman break technique (Steidel et al 2003) which is recasted at each redshift

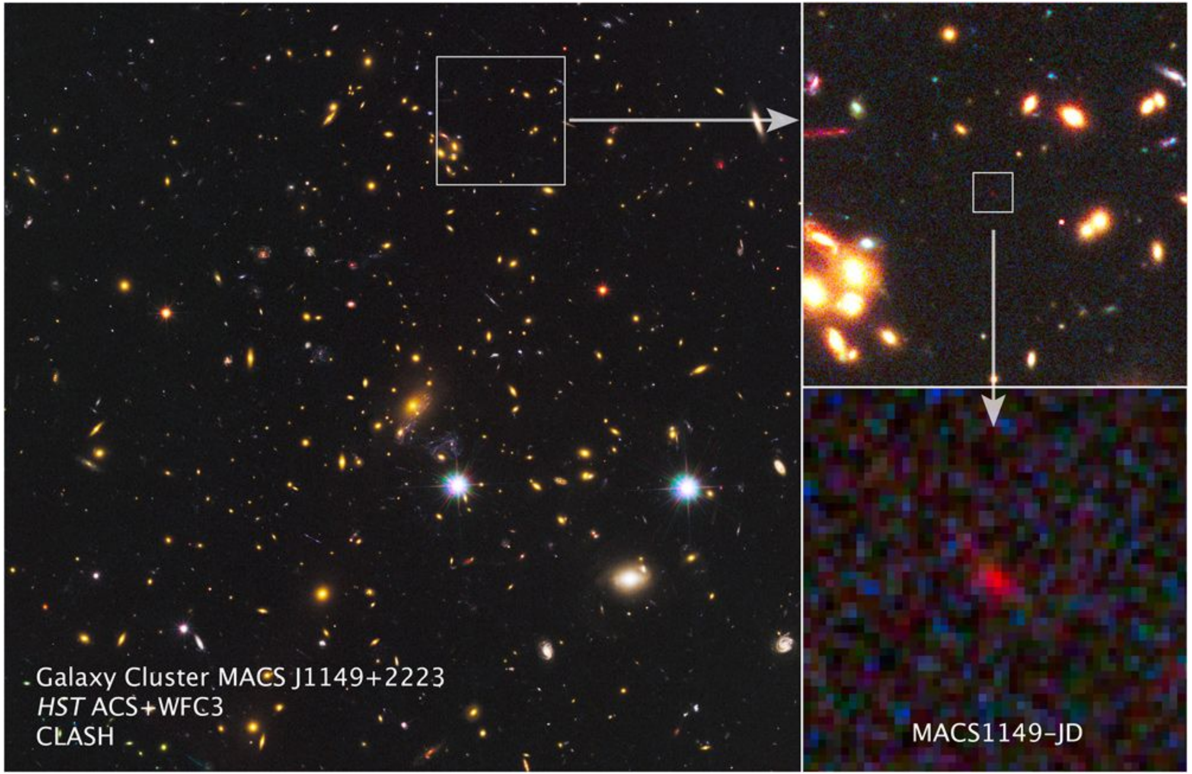
here the spectrum of a galaxy imaged with HST filters





https://xdf.ucolick.org/img/xdf_filters_sed_v1.mov

Using cluster as magnification lenses



Looking at the tiny red galaxies.

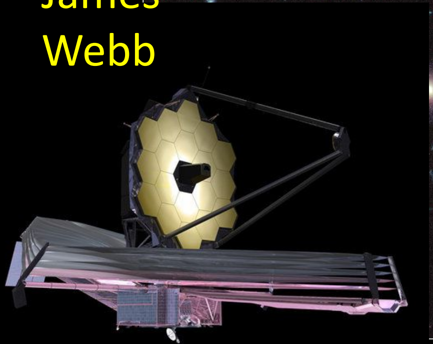
Example from the Hubble Space Telescope. Very distant galaxy magnified by a foreground cluster of galaxies (strong gravitational lensing).

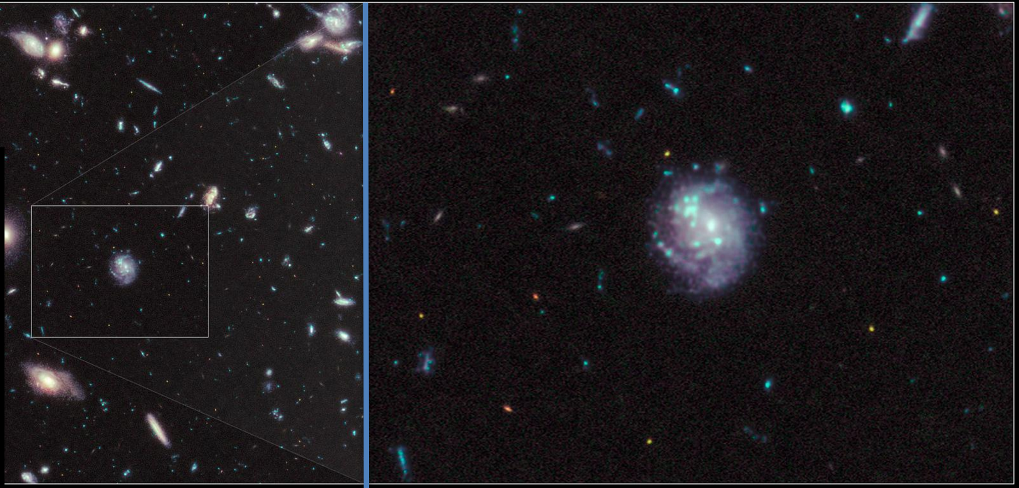
Credit: STScI

Much sharper images than with Hubble

Hubble

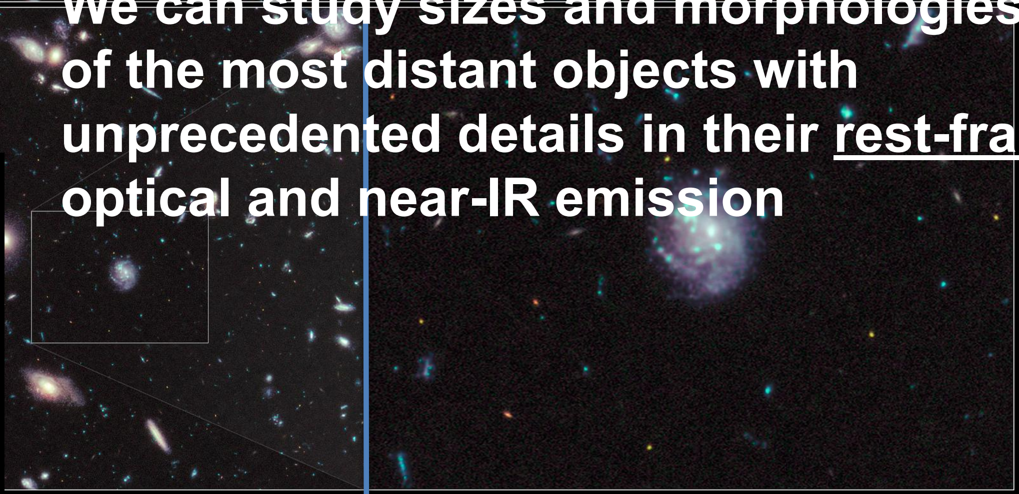
James Webb



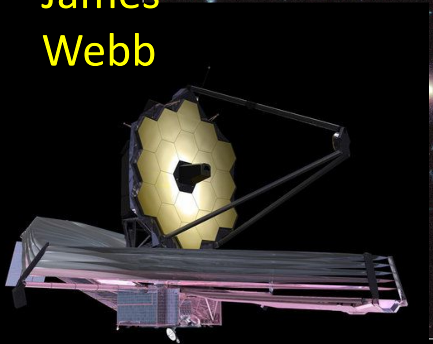


Much sharper images than with Hubble

Hubble



James Webb



We can study sizes and morphologies of the most distant objects with unprecedented details in their <u>rest-frame</u> optical and near-IR emission

Once we have selected the distant galaxies, JWST will allow for the first time to confirm their redshifts and study their detailed spectroscopic properties

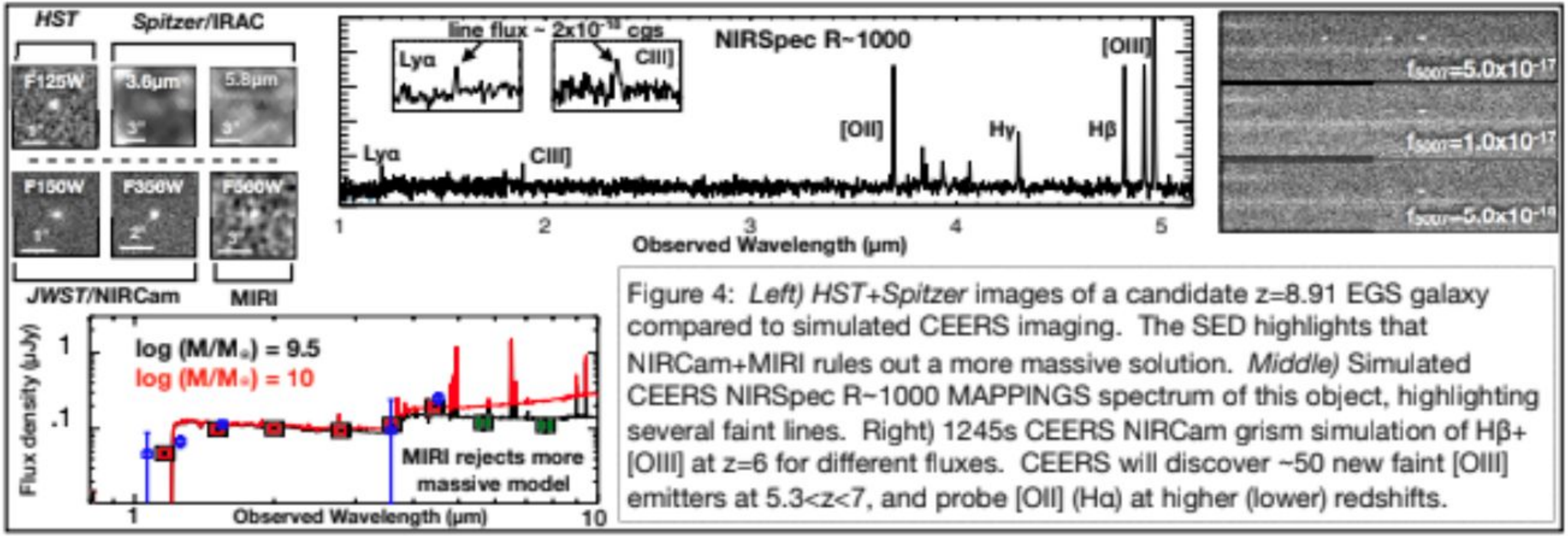
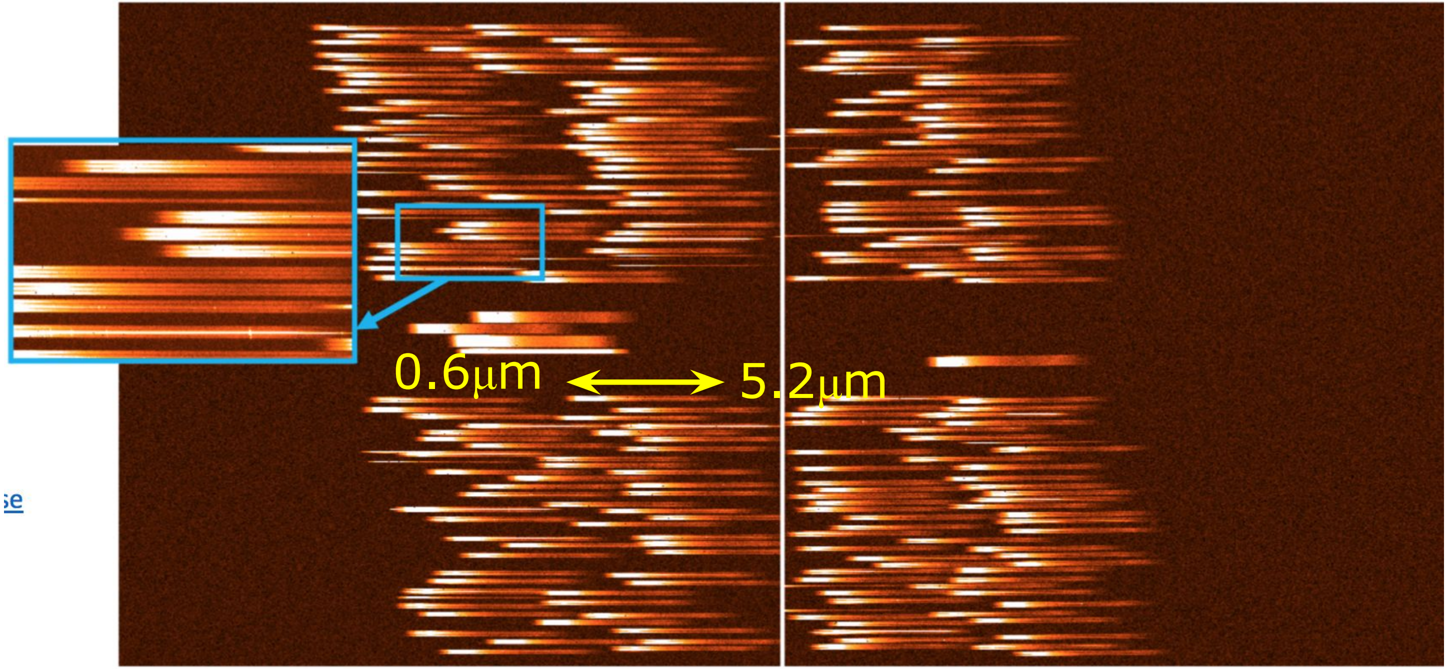


Figure 4: *Left) HST+Spitzer* images of a candidate z=8.91 EGS galaxy compared to simulated CEERS imaging. The SED highlights that NIRCam+MIRI rules out a more massive solution. *Middle)* Simulated CEERS NIRSpec R~1000 MAPPINGS spectrum of this object, highlighting several faint lines. Right) 1245s CEERS NIRCam grism simulation of Hβ+[OIII] at z=6 for different fluxes. CEERS will discover ~50 new faint [OIII] emitters at 5.3<z<7, and probe [OII] (Hα) at higher (lower) redshifts.

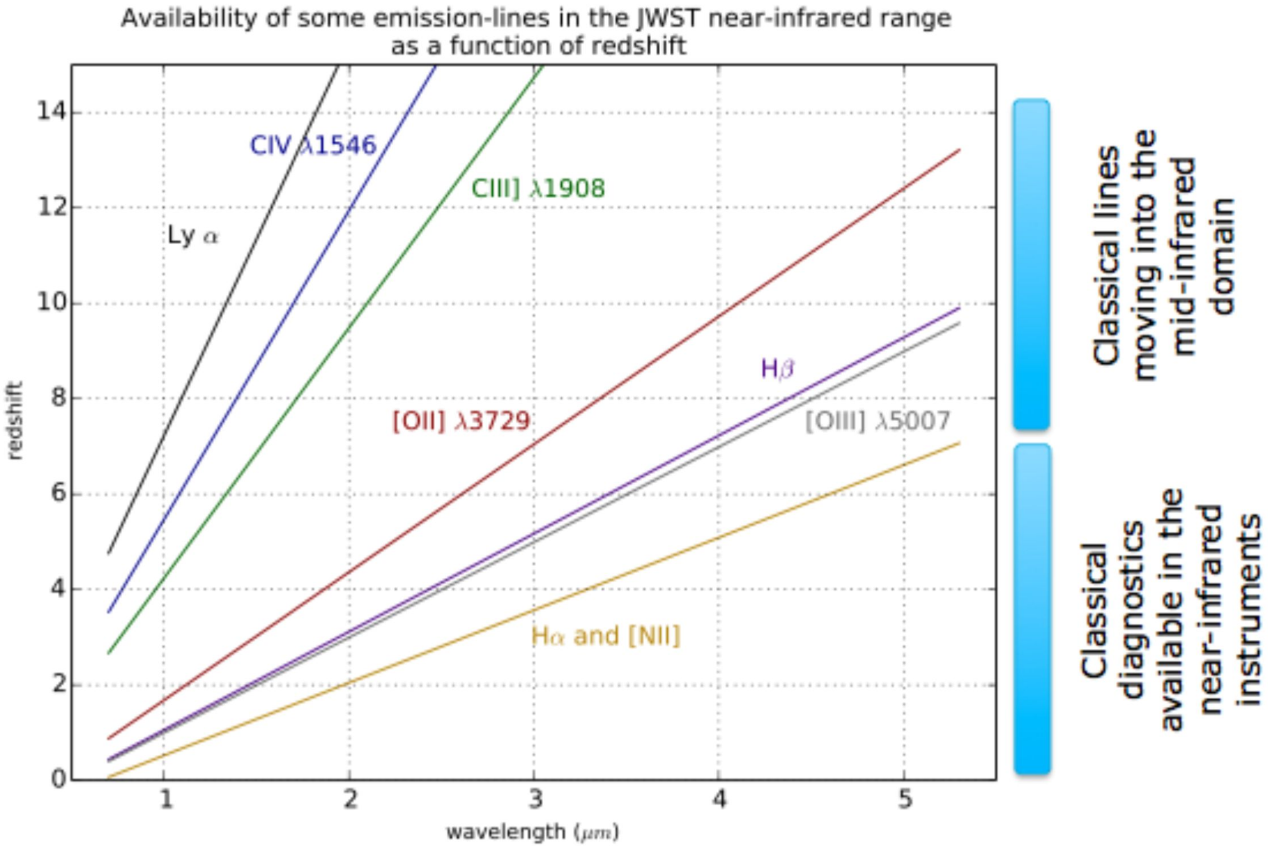
NIRSpec simulation in HUDF in 45min
(~10% of total of a deep pointing) R=100

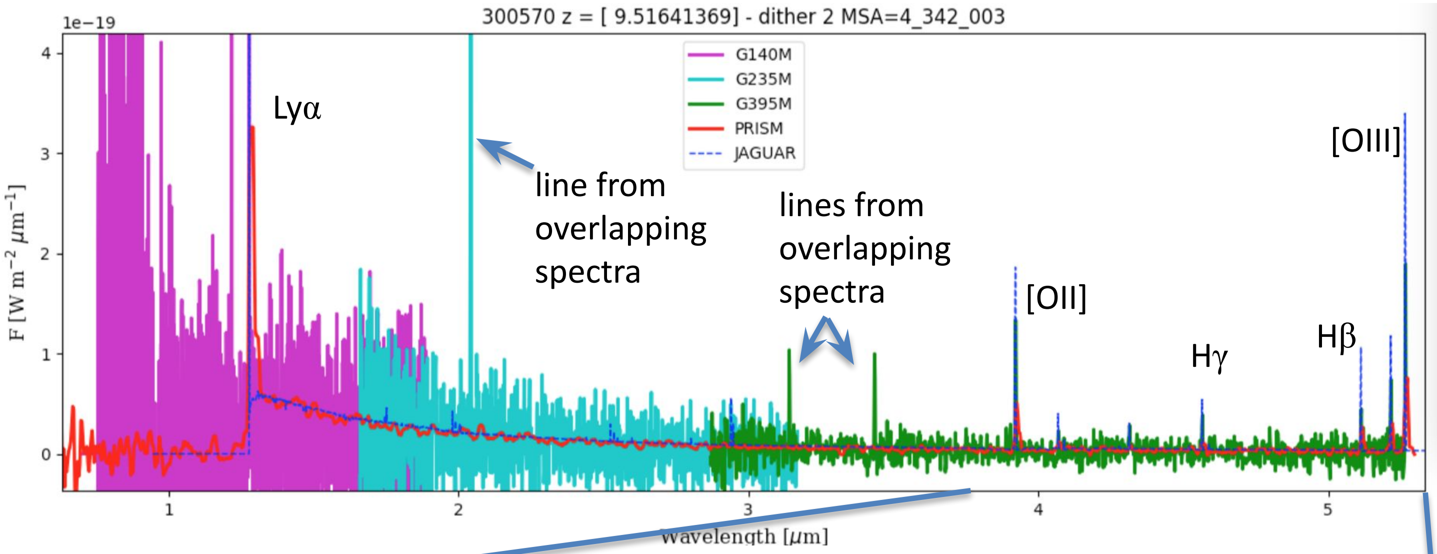
214 galaxies allocated (with non-overlapping spectra)

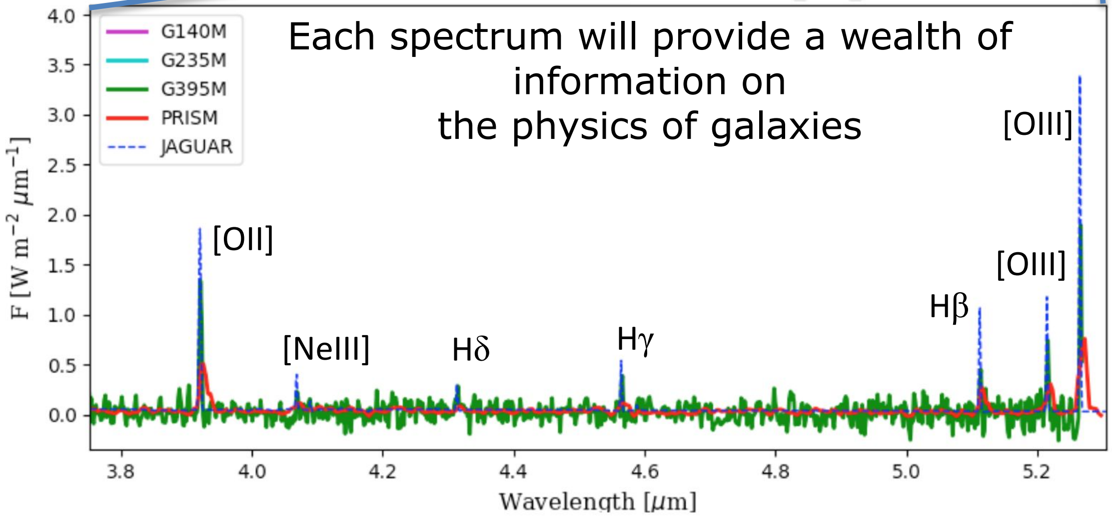


se

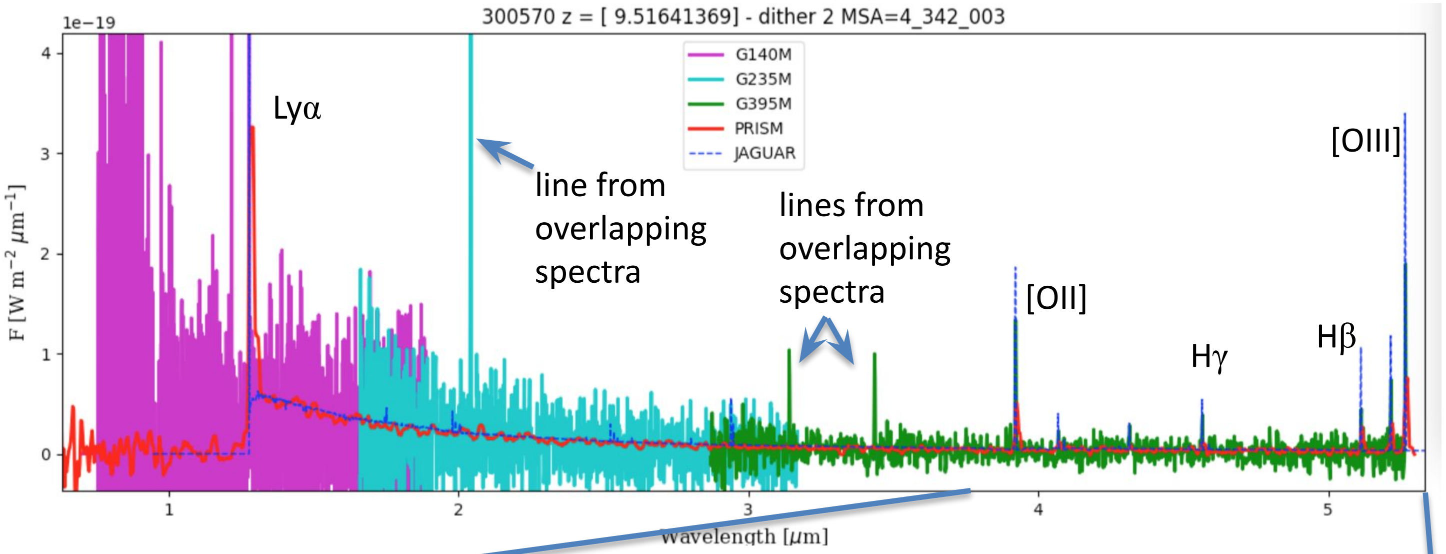
We will be able to detect UV and optical emission lines up the the highest redshift: for example the Hα emission (which is e.g. an indicator of star formation rate) will be observable up to z=7, Lyα (a common bright emission, often used as a redshift indicator) can be observed up to z>15 and so on







simulated spectrum at z=9.5, m_{AB}=27.6 only 0.7hr/grating (10% of total deep exposure)



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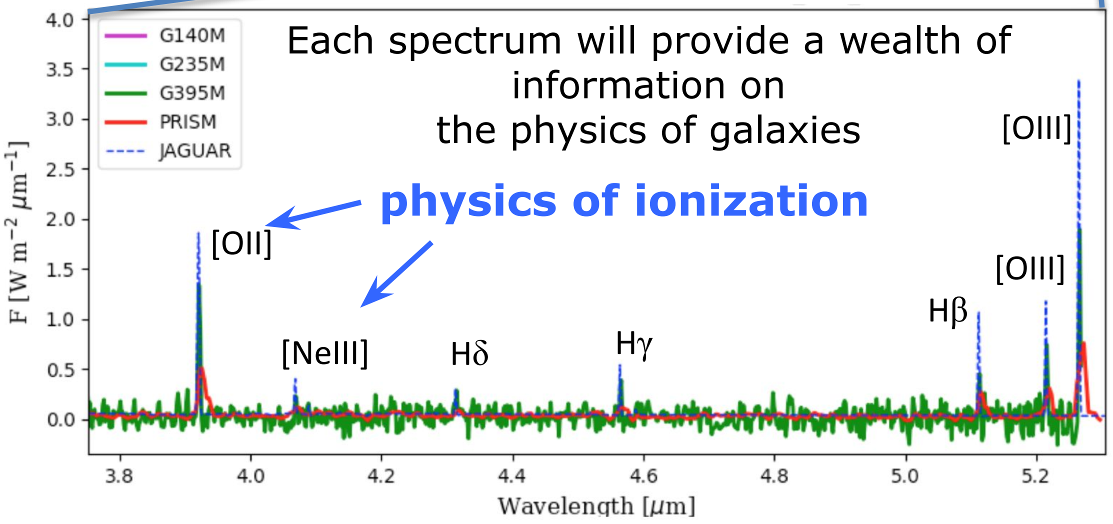

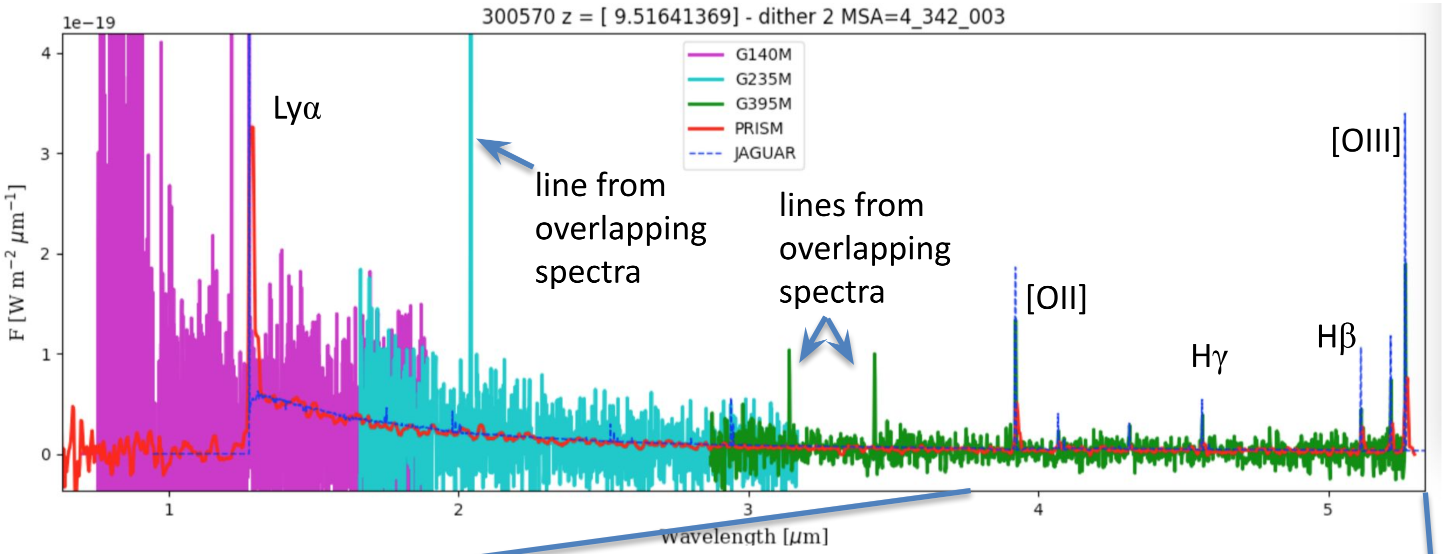

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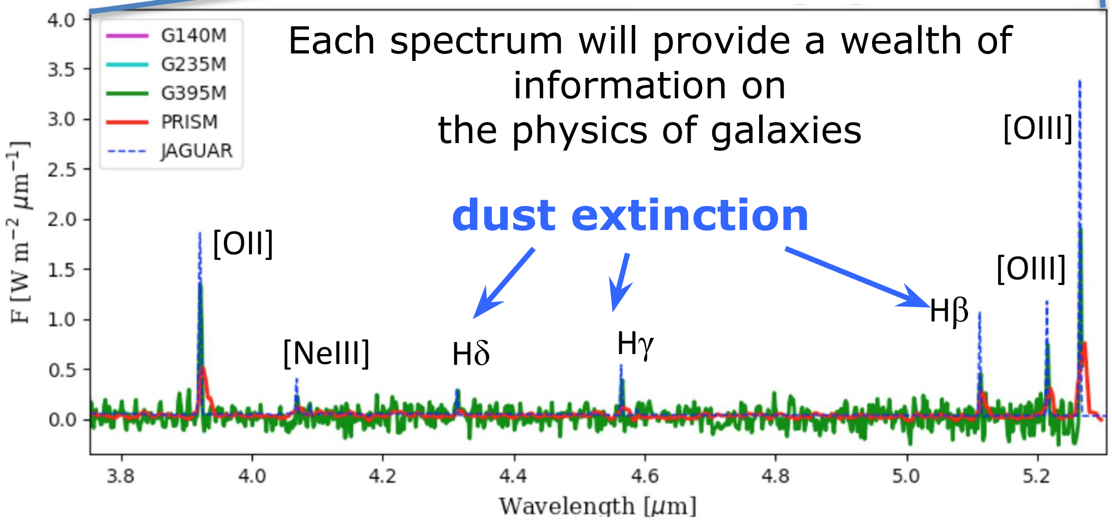

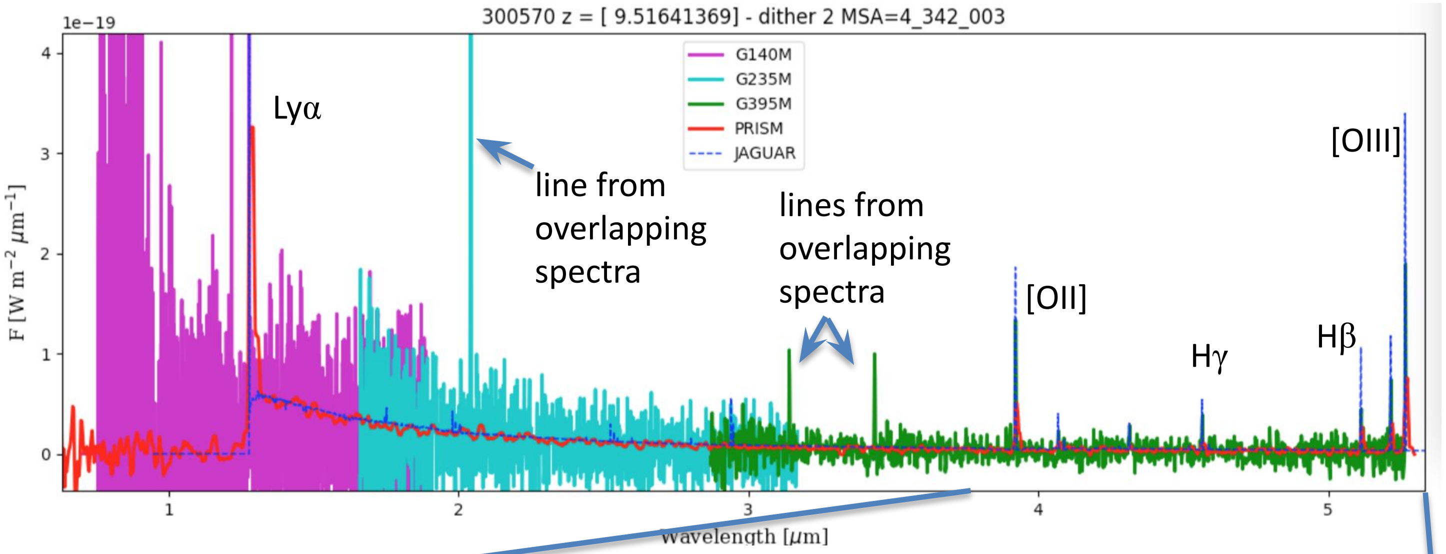

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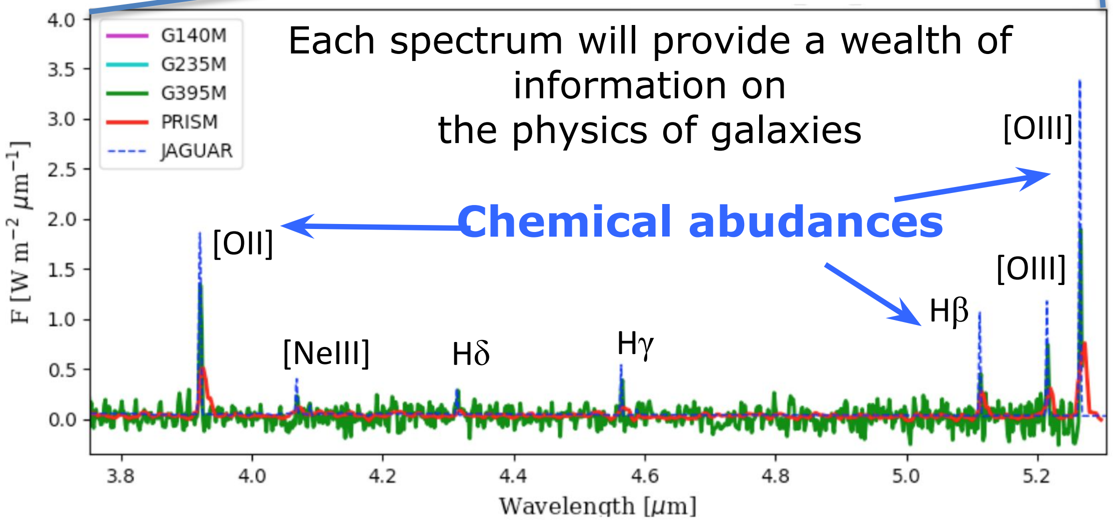

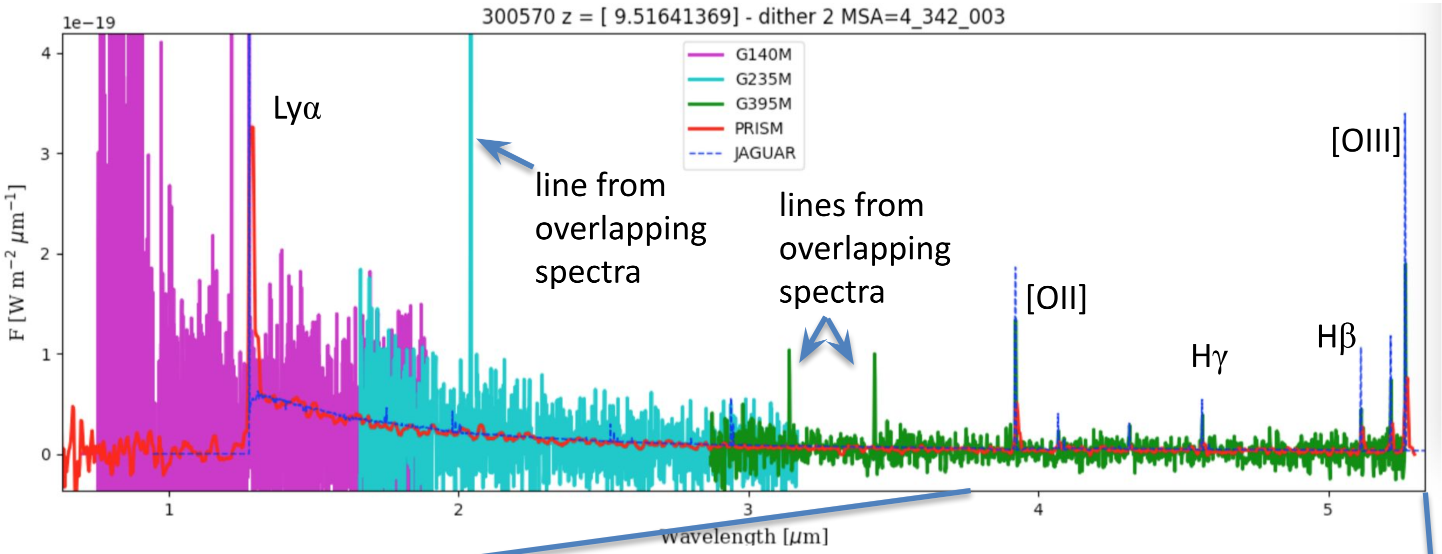

simulated spectrum
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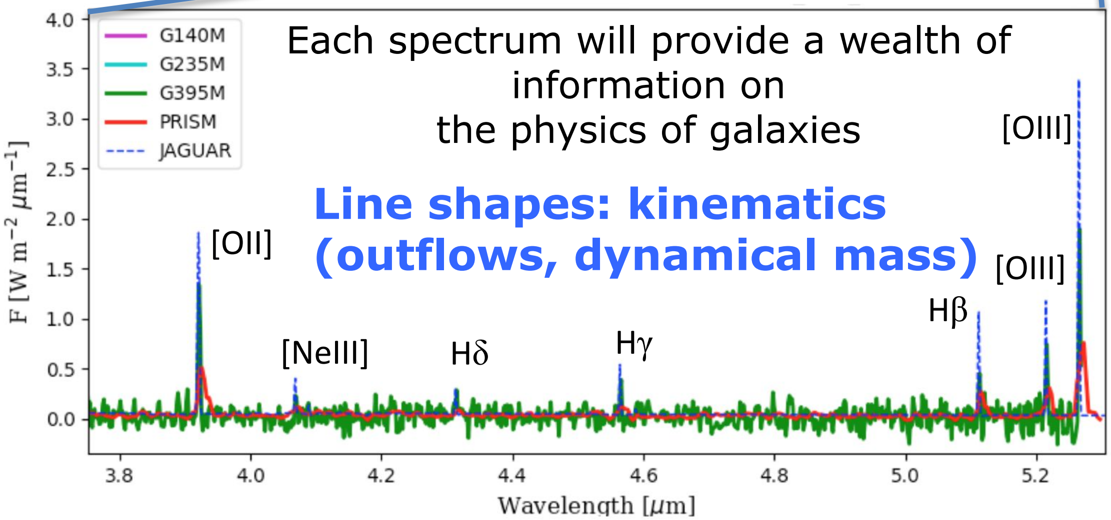
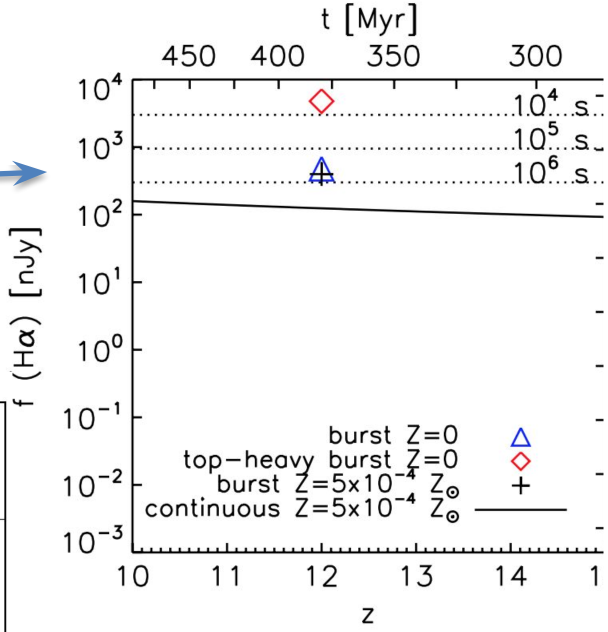
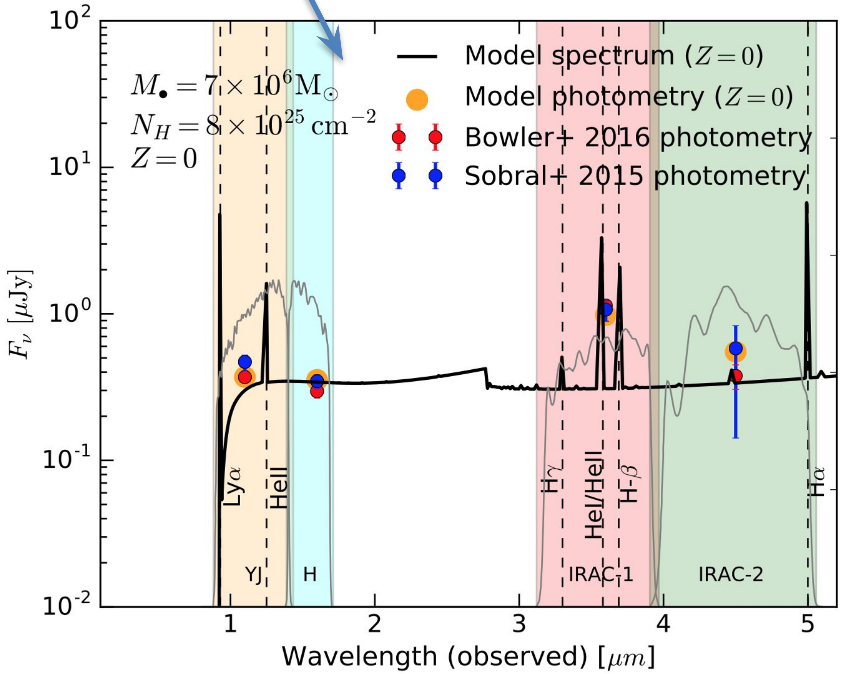


Ultimate goal: detection and characterization of

- PopIII galaxies
- Primeval Direct Collapse Black Hole seeds



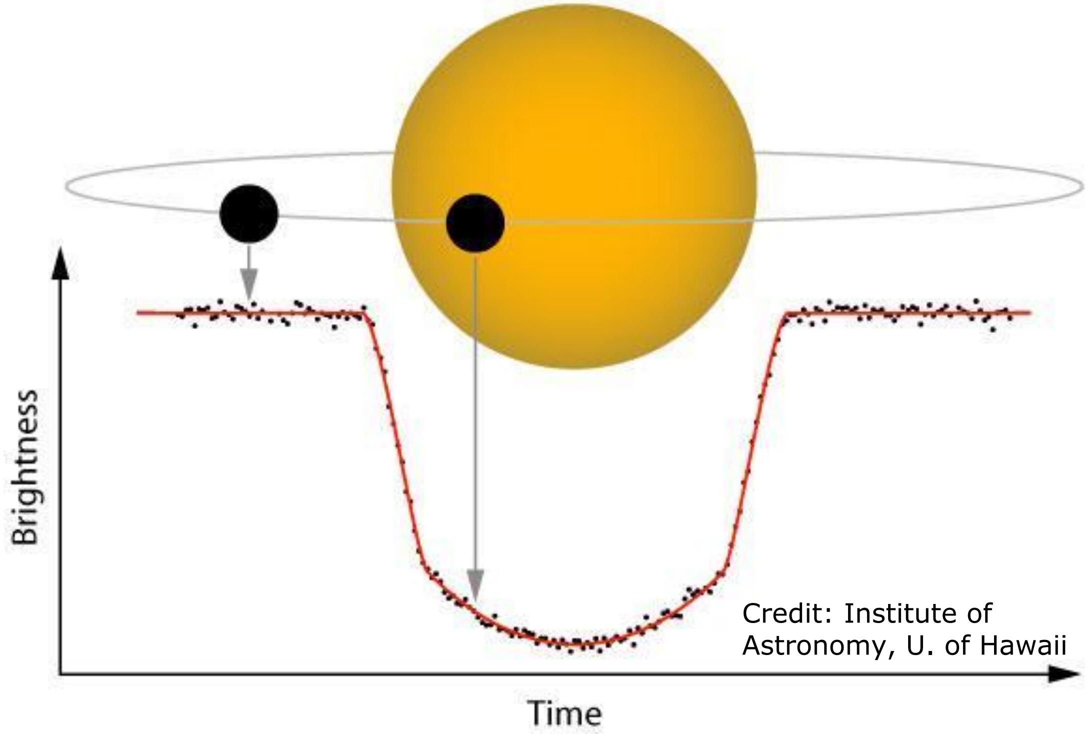
Pawlik+11



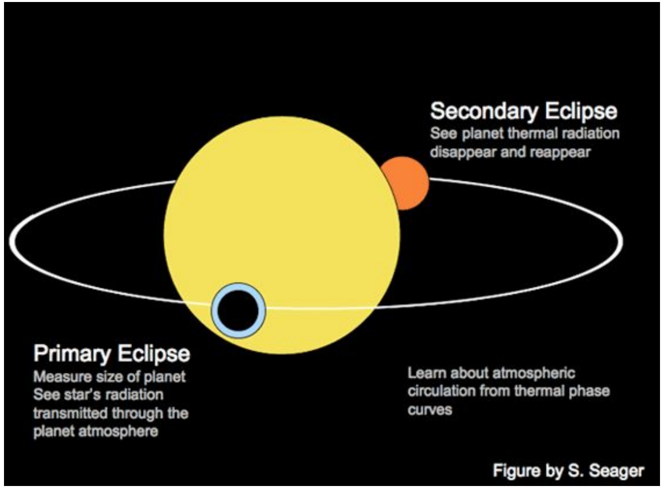
Pacucci+17

Exoplanet atmospheres

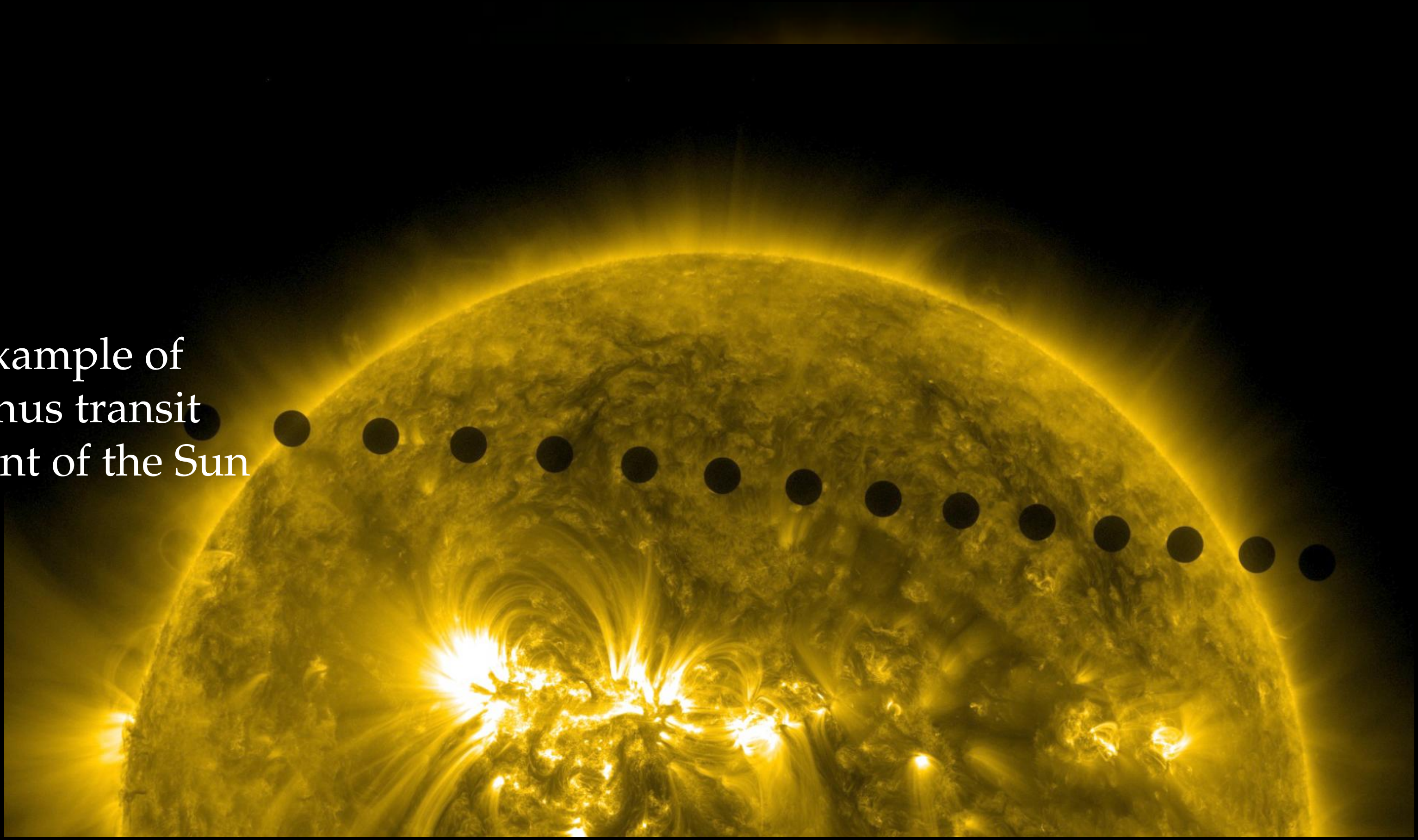
Characterizing the atmosphere of transiting exoplanets.
Learning about the physical conditions in foreign worlds!



Credit: Institute of Astronomy, U. of Hawaii

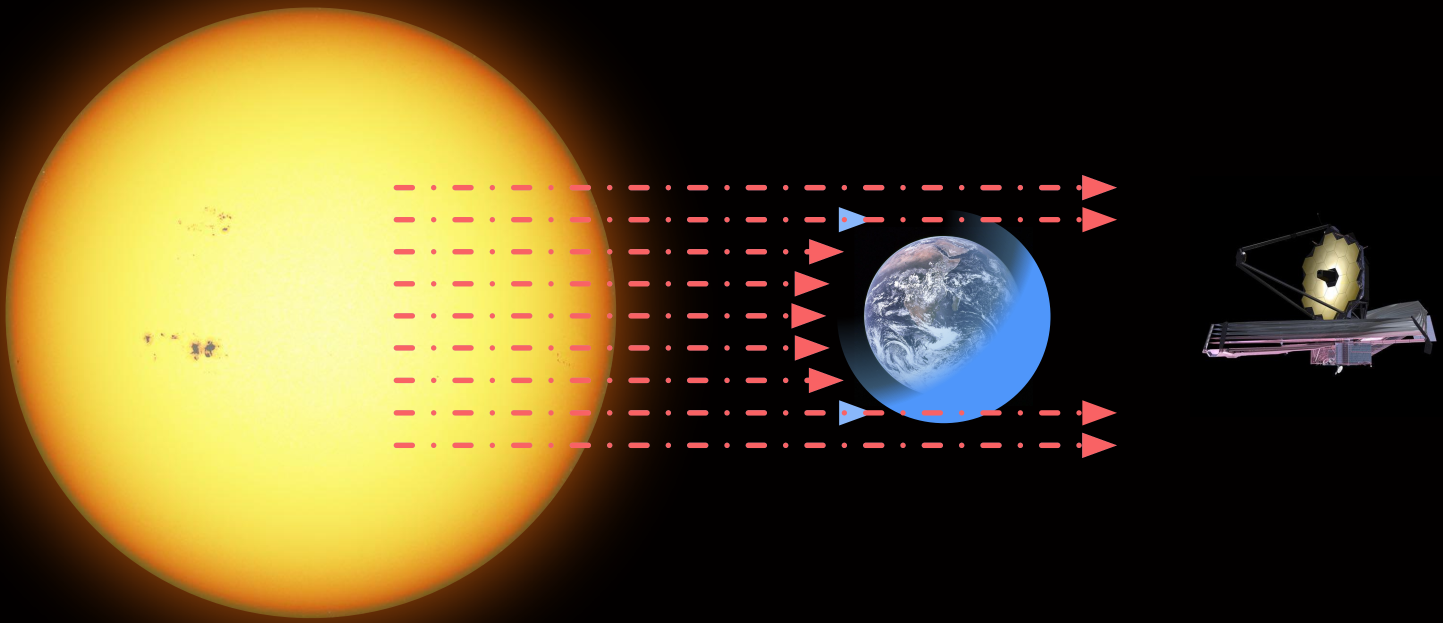


Occultation of stellar light when an exoplanet transits in front of its star



Example of Venus transit in front of the Sun

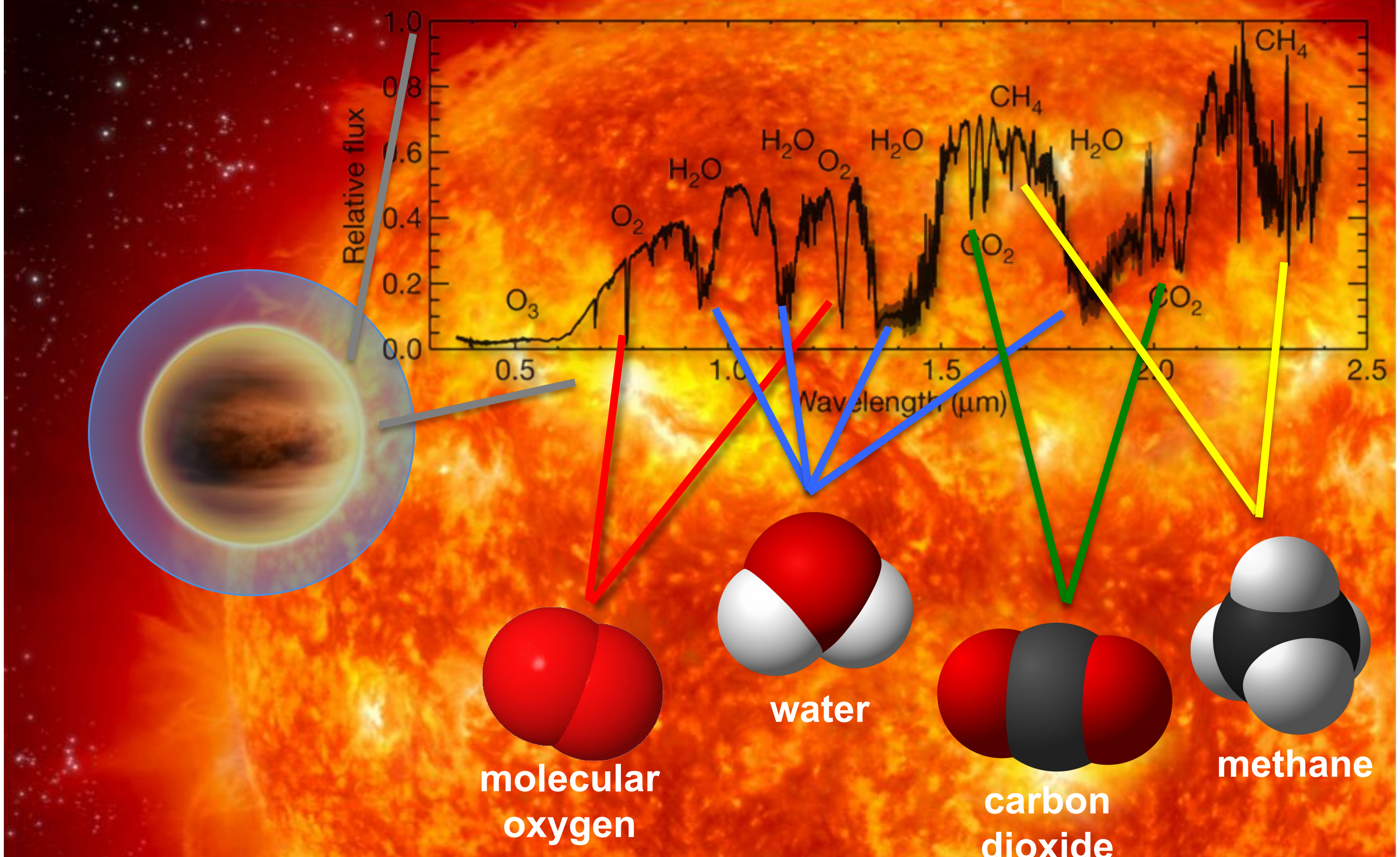
During transit is (in principle) possible to
detect the signature of the exoplanet's atmosphere



EARTH ECLIPSING THE SUN SEEN FROM APOLLO 12

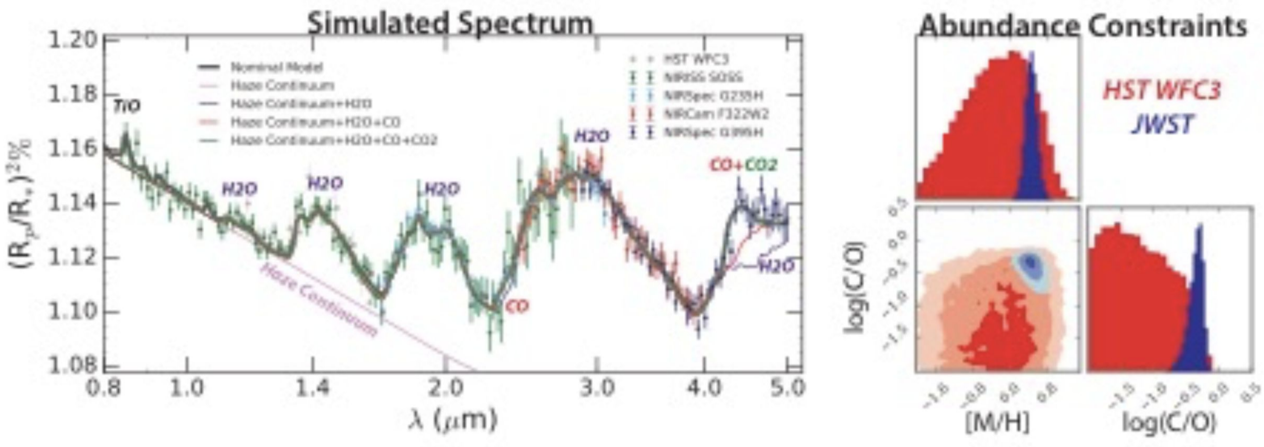
NOV 22 1969

NASA



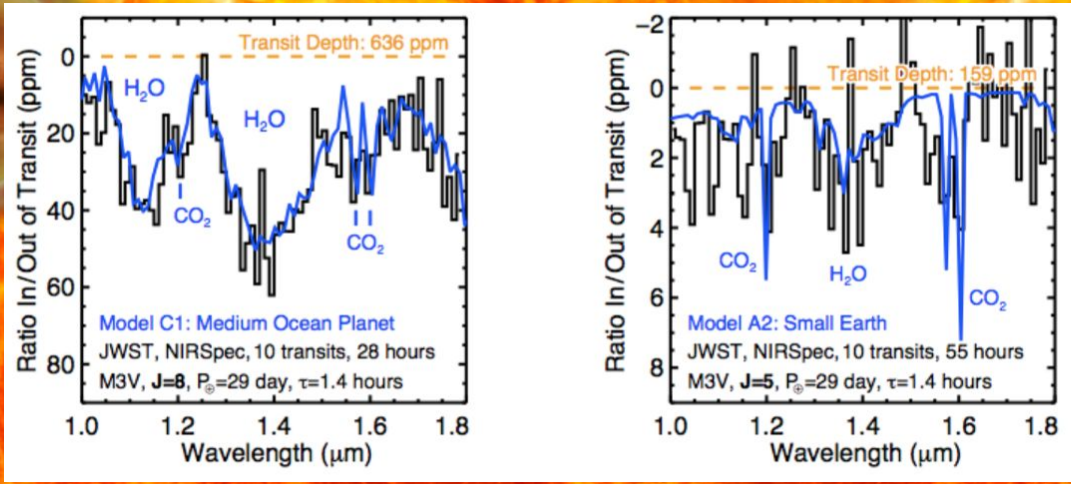
The different molecules in the exoplanet's atmosphere
leave a clear imprint in the light passing throught

During the transit, looking at the signature of key molecules like water and carbon dioxide.
Being in space, above our atmosphere is critical to be able to observe these molecules in astronomical objects.



From a presentation by H. Wakeford https://www.cosmos.esa.int/web/jwst/ewass-2018

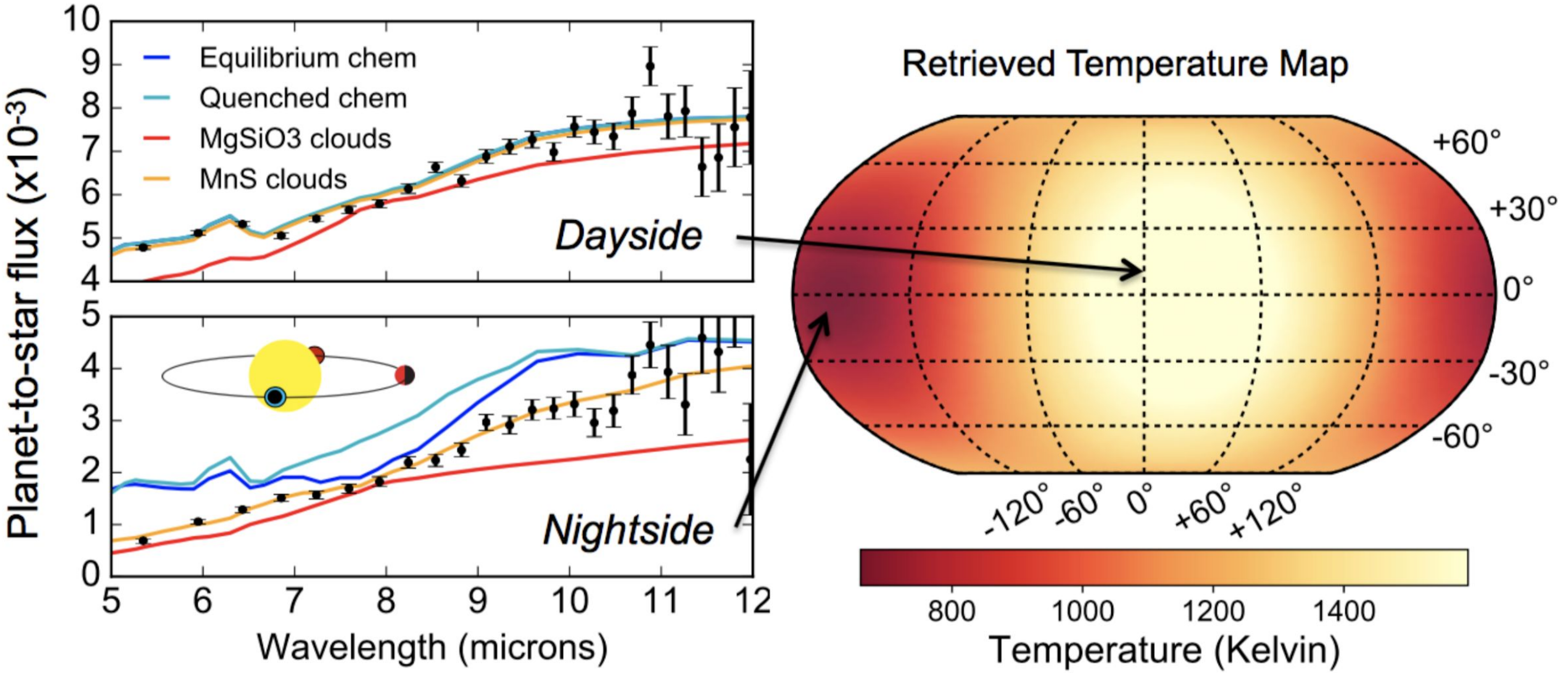
Exoplanet atmospheres characterization



Seager+09

SIMULATED MIRI LRS PHASE CURVE OF WASP-43b

From a presentation by H. Wakeford
https://www.cosmos.esa.int/web/jwst/ewass-2018



This was just a glimpse!
Many more science cases!
Stay tuned for ~mid-late 2022
(or join one of the science teams
for an early insight)