From Planets to the Early Universe:

The James Webb Space Telescope

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NASA ESA CSA

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The James Webb Space Telescope

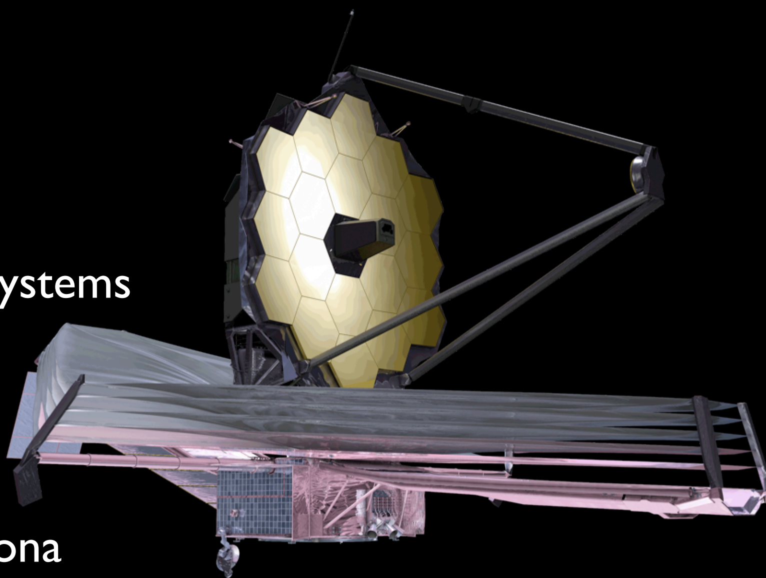
<u>Organization</u>

Mission Lead: NASA's Goddard Space Flight Center

Senior Project Scientist: Dr John Mather

International collaboration: ESA & CSA

Prime Contractor: Northrop Grumman Aerospace Systems



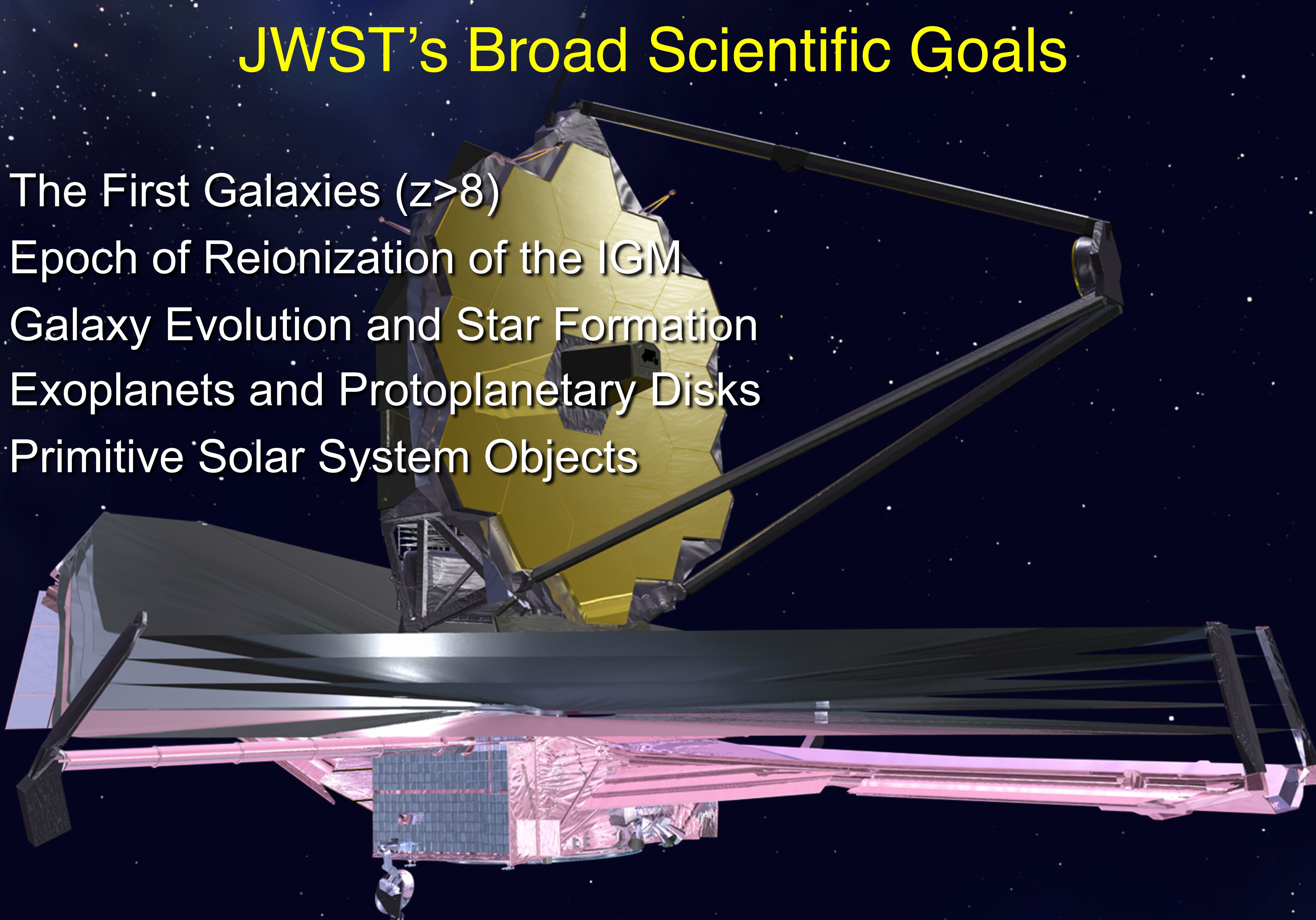
Instruments:

- Near Infrared Camera (NIRCam) – Univ. of Arizona
- Near Infrared Spectrograph (NIRSpec) – ESA
- Mid-Infrared Instrument (MIRI) – ESA/JPL
- Near IR Imaging Slitless Spectrometer (NIRISS) – CSA
- Fine Guidance Sensor (FGS) – CSA

Operations: Space Telescope Science Institute

JWST's Broad Scientific Goals

- The First Galaxies (z>8)
- Epoch of Reionization of the IGM
- Galaxy Evolution and Star Formation
- Exoplanets and Protoplanetary Disks
- Primitive Solar System Objects



Key Technical Design Drivers

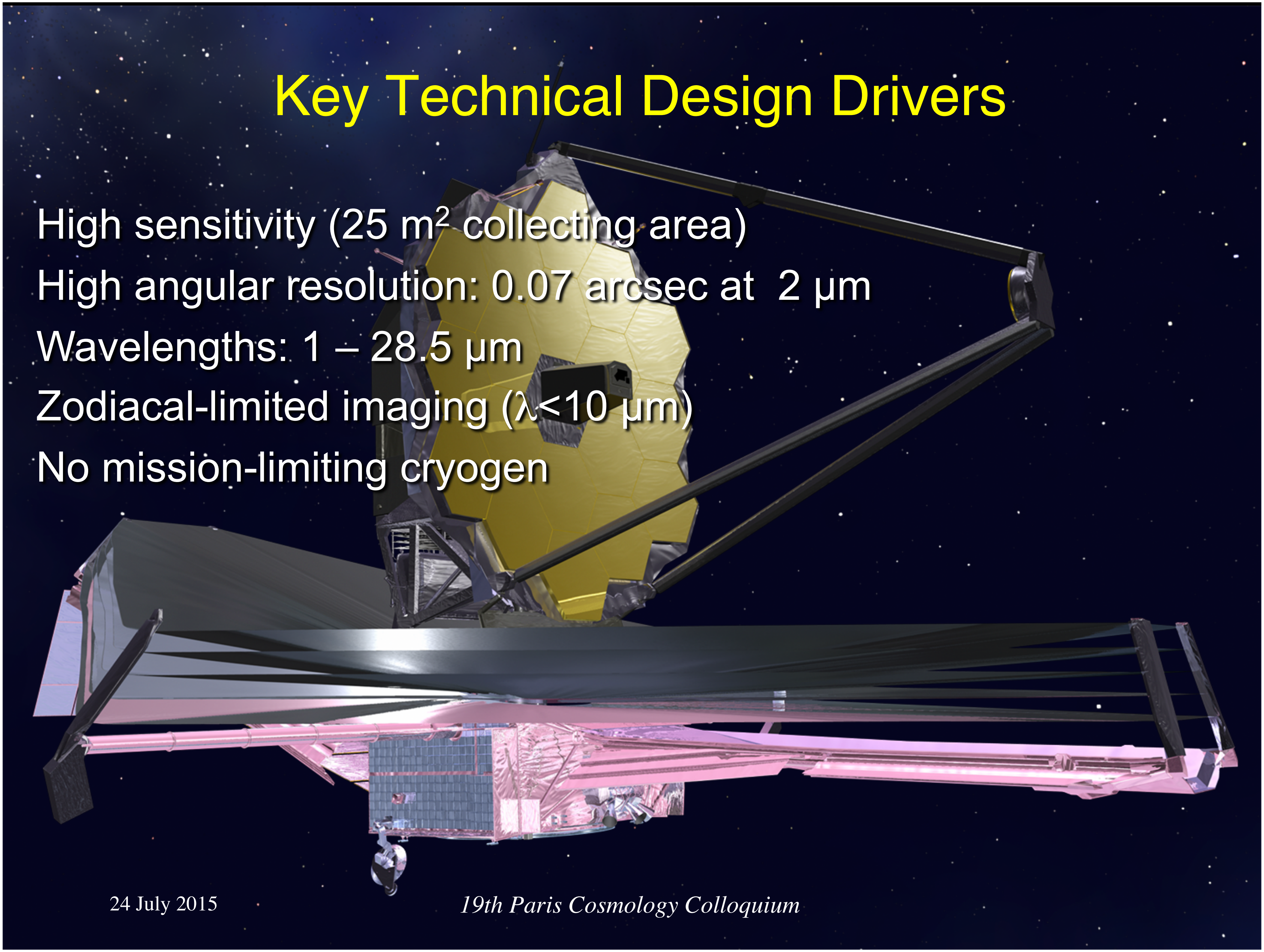
High sensitivity (25 m^2 collecting area)

High angular resolution: 0.07 arcsec at 2 μm

Wavelengths: 1 – 28.5 μm

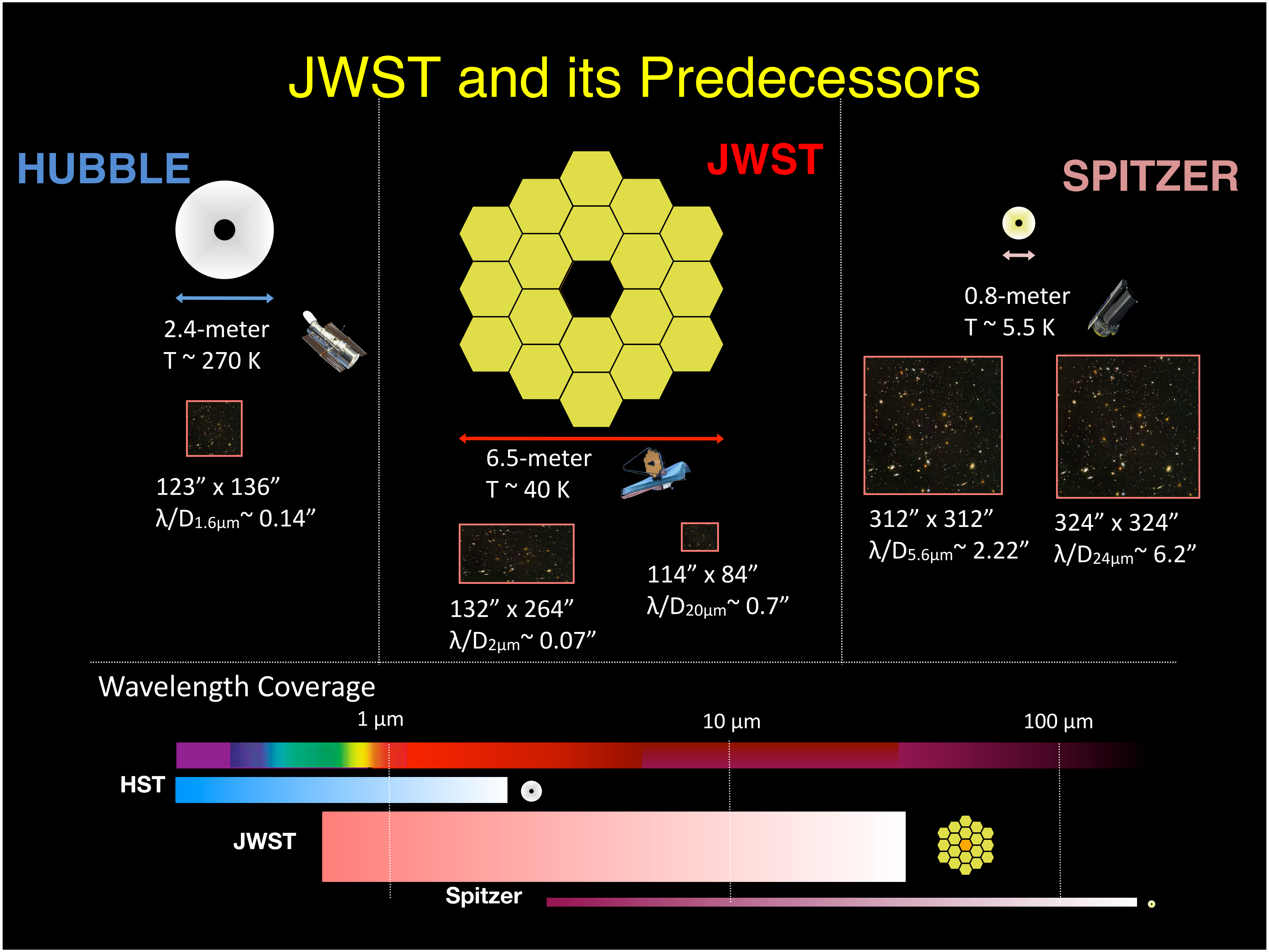
Zodiacal-limited imaging (λ<10 μm)

No mission-limiting cryogen



JWST Vital Statistics

- General purpose observatory: 5 years required; 10.5 year propellant lifetime
- Segmented, adjustable primary mirror, 6.5 m diameter
    - Diffraction limited at 2 μm (0.07 arcsec) [~0.7 arcsec @ 20 μm]
- Telescope and instruments passively cooled to ~40K by sunshield:
    - No consumable cryogen
- Sun-Earth L2 Orbit: 1.5 million km from Earth; Ariane 5 launch (ESA)
- Four Science Instruments covering 0.6–28.5 μm
    - Broad, medium, and narrow band imaging
    - Spectroscopy – Multi Object, Slit, Integral Field, Grism/Prism
    - Coronagraphy – Traditional Lyot, Four Quadrant Phase Masks
    - Aperture Mask Interferometry – Non-Redundant Mask (NRM)


JWST and its Predecessors
HUBBLE
2.4-meter
T ~ 270 K
123" x 136"
λ/D1.6μm~ 0.14"
JWST
6.5-meter
T ~ 40 K
132" x 264"
λ/D2μm~ 0.07"
114" x 84"
λ/D20μm~ 0.7"
SPITZER
0.8-meter
T ~ 5.5 K
312" x 312"
λ/D5.6μm~ 2.22"
324" x 324"
λ/D24μm~ 6.2"
Wavelength Coverage
1 μm
10 μm
100 μm
HST
JWST
Spitzer

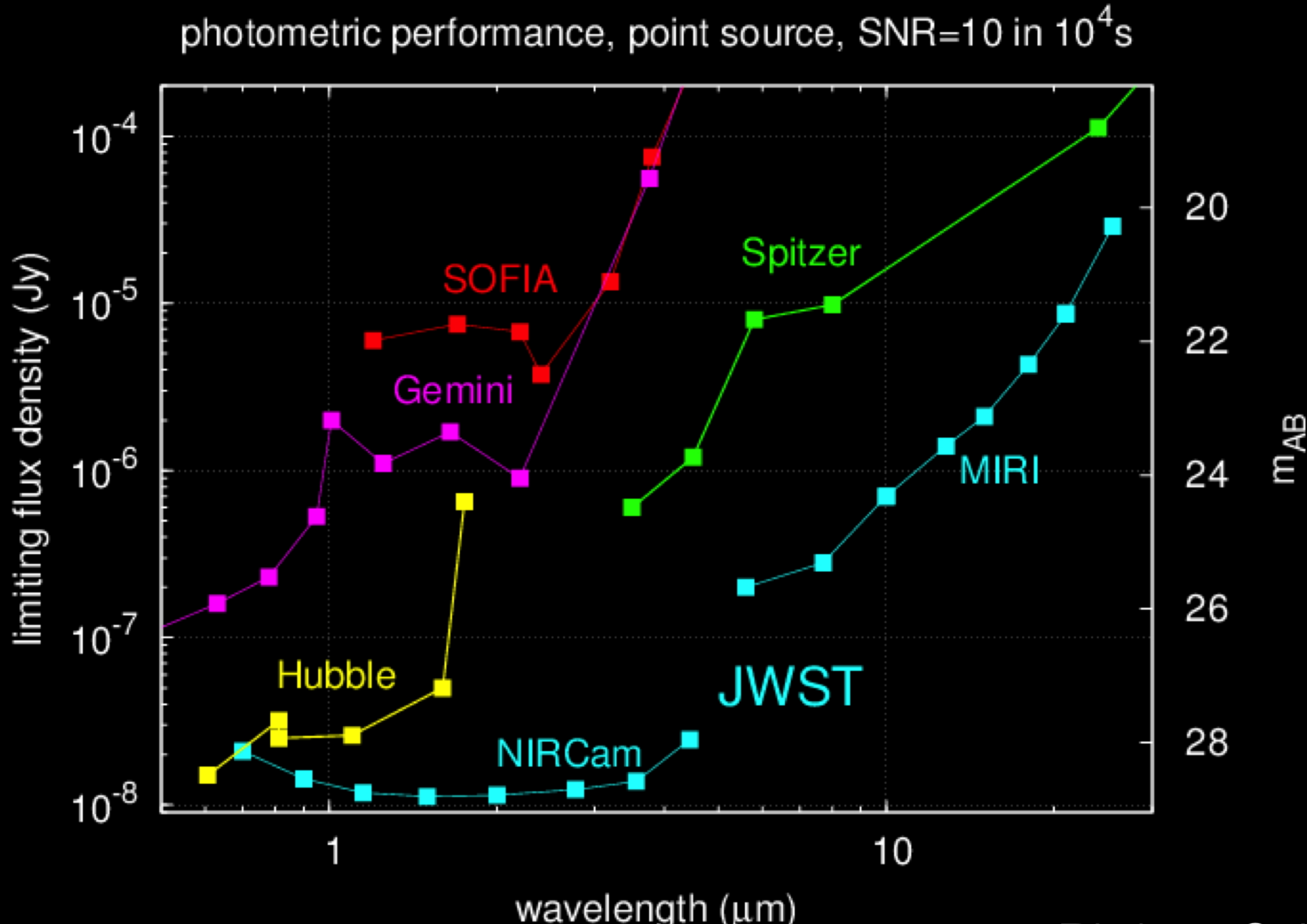
JWST Imaging Modes

Mode	Instrument	Wavelength (microns)	Pixel Scale (arcsec)	Full-Array* Field of View
Imaging	NIRCam*	0.6 – 2.3	0.032	2.2 x 2.2′
	NIRCam*	2.4 – 5.0	0.065	2.2 x 2.2′
	NIRISS	0.9 – 5.0	0.065	2.2 x 2.2′
	MIRI*	5.0 – 28.8	0.11	1.23 x 1.88′
Aperture Mask Interferometry	NIRISS	3.8 – 4.8	0.065	------
Coronography	NIRCam	0.6 – 2.3	0.032	20 x 20″
	NIRCam	2.4 – 5.0	0.065	20 x 20″
	MIRI	10.65	0.11	24 x 24″
	MIRI	11.4	0.11	24 x 24″
	MIRI	15.5	0.11	24 x 24″
	MIRI	23	0.11	30 x 30″

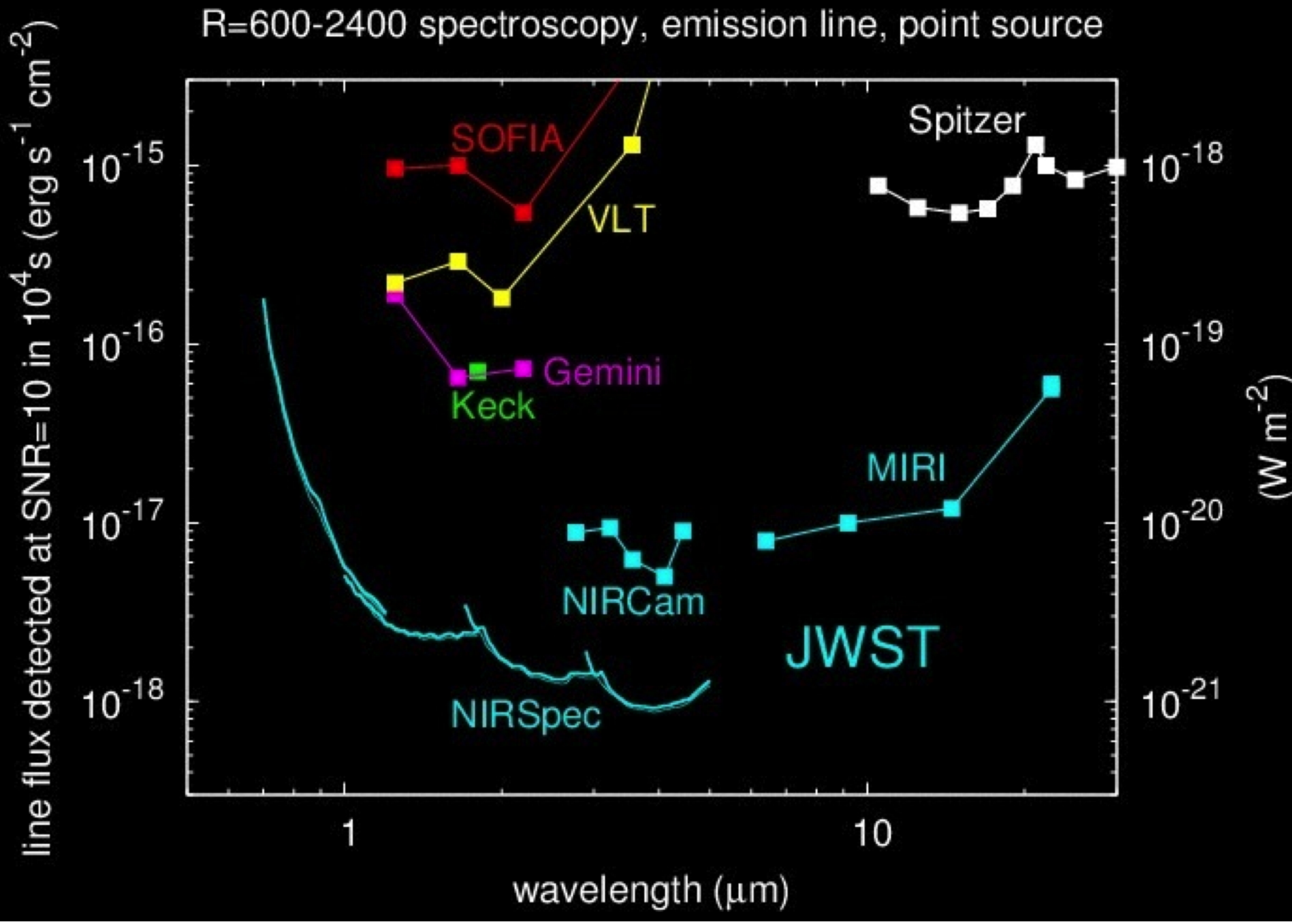
JWST Spectroscopic Modes

Mode	Instrument	Wavelength (microns)	Resolving Power ($\lambda/\Delta\lambda$)	Field of View
Slitless Spectroscopy	NIRISS	1.0 – 2.5	150	2.2' x 2.2'
	NIRISS	0.6 – 2.5	700	single object
	NIRCam	2.4 – 5.0	2000	2.2' x 2.2'
Multi-Object Spectroscopy	NIRSpec	0.6 – 5.0	100, 1000, 2700	3.4' x 3.4' with 250,000 0.20 x 0.46" apertures
Single Slit Spectroscopy	NIRSpec	0.6 – 5.0	100, 1000, 2700	slit widths 0.4" x 3.8" 0.2" x 3.3" 1.6" x 1.6"
	MIRI	5.0 – ~14.0	~100 at 7.5 microns	0.6" x 5.5" slit
Integral Field Spectroscopy	NIRSpec	0.6 – 5.0	100, 1000, 2700	3.0" x 3.0"
	MIRI	5.0 – 7.7	3500	3.0" x 3.9"
	MIRI	7.7 – 11.9	2800	3.5" x 4.4"
	MIRI	11.9 – 18.3	2700	5.2" x 6.2"
	MIRI	18.3 – 28.8	2200	6.7" x 7.7"

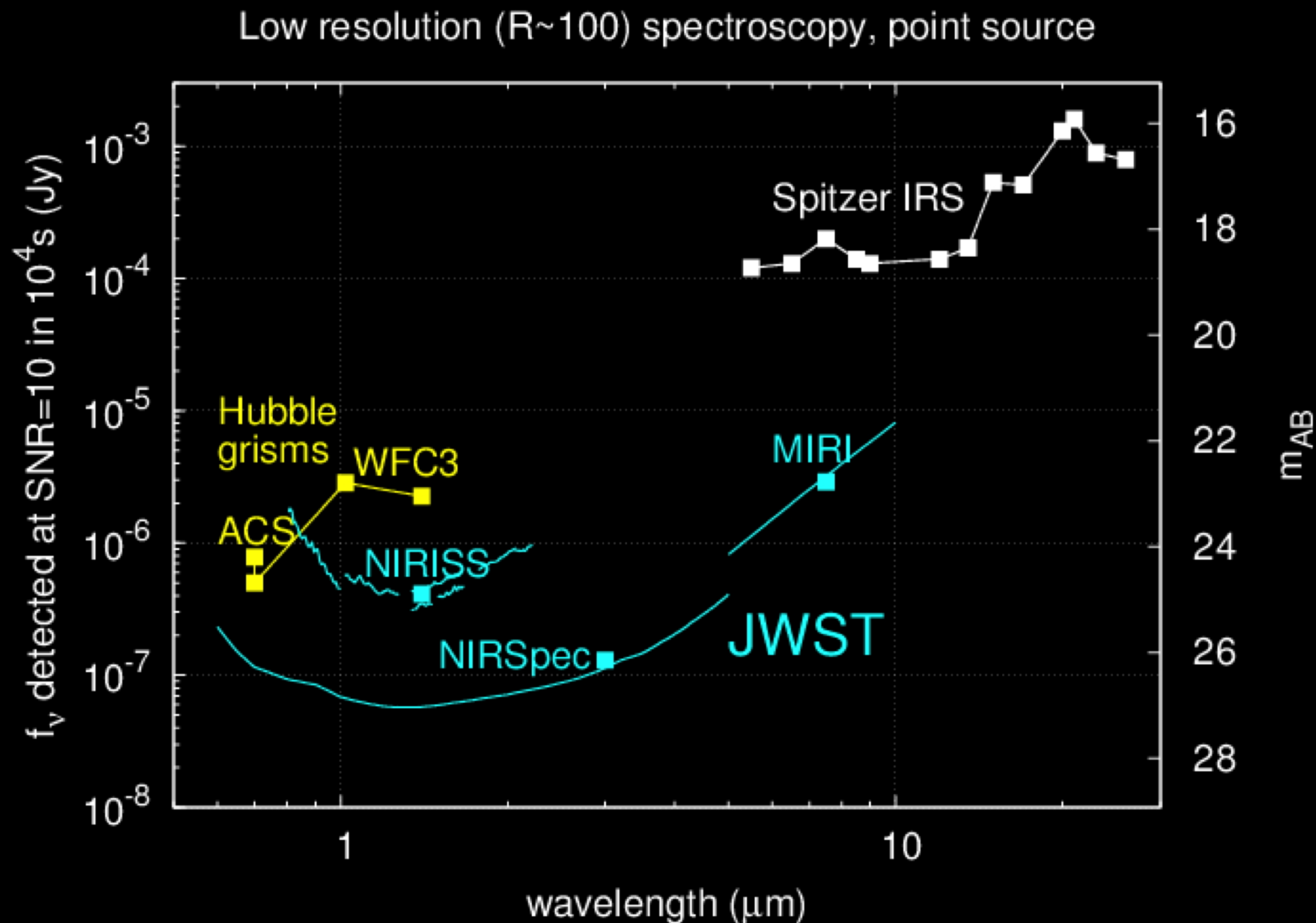
Imaging Sensitivity (10 ksec)



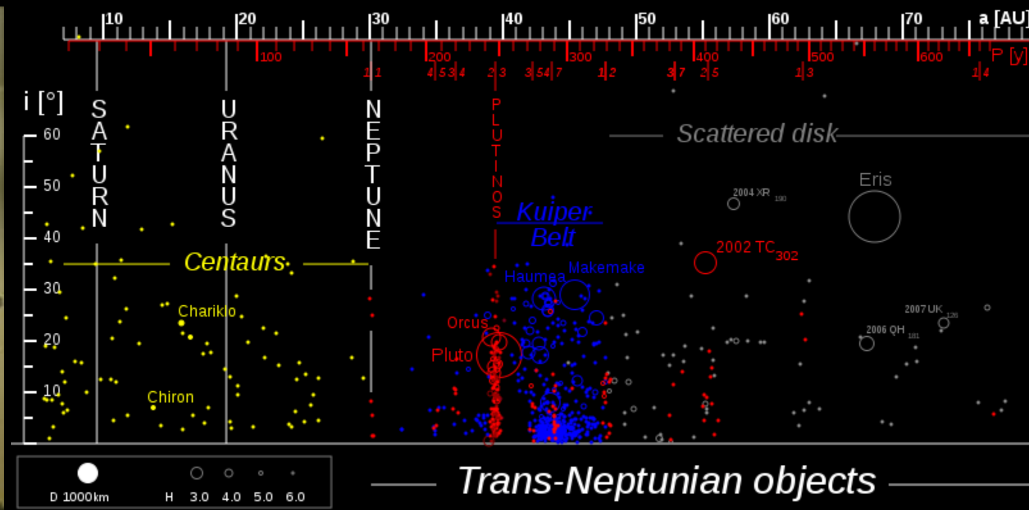
Emission-Line Spectroscopy (R ~2000)



Continuum Spectroscopy (R~100, 10 ksec)



JWST will observe how planetary systems form and evolve

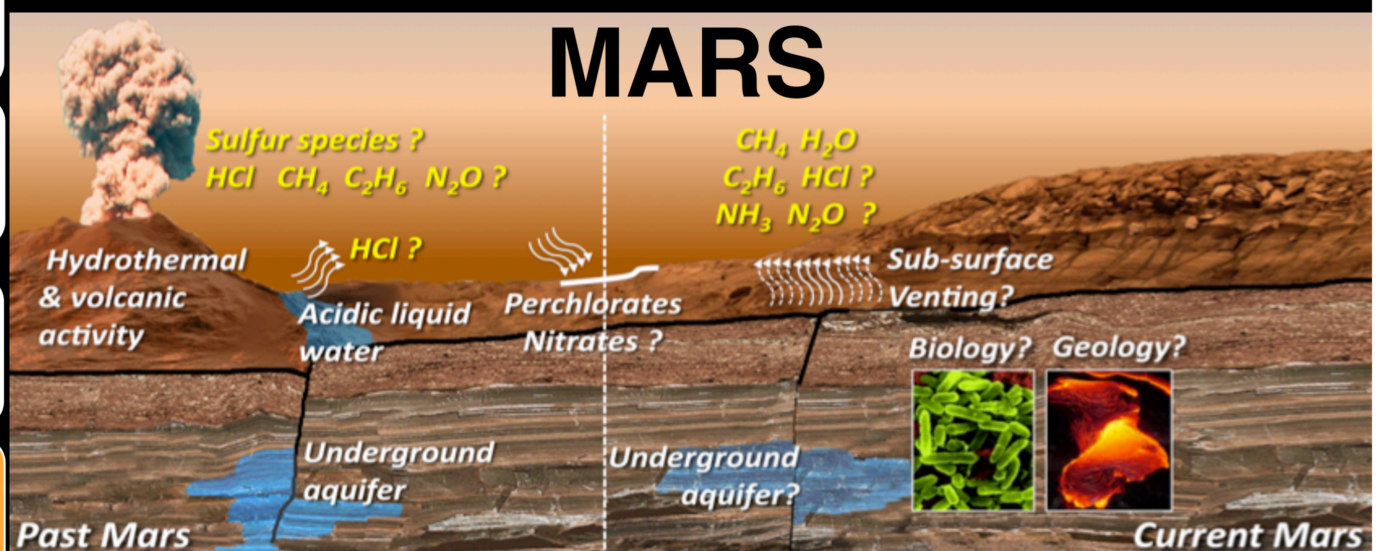


First Light (After the Big Bang)
First luminous objects, proto-galaxies, supernovae, black holes

Assembly of Galaxies
Merging of proto-galaxies, effects of black holes, history of star formation

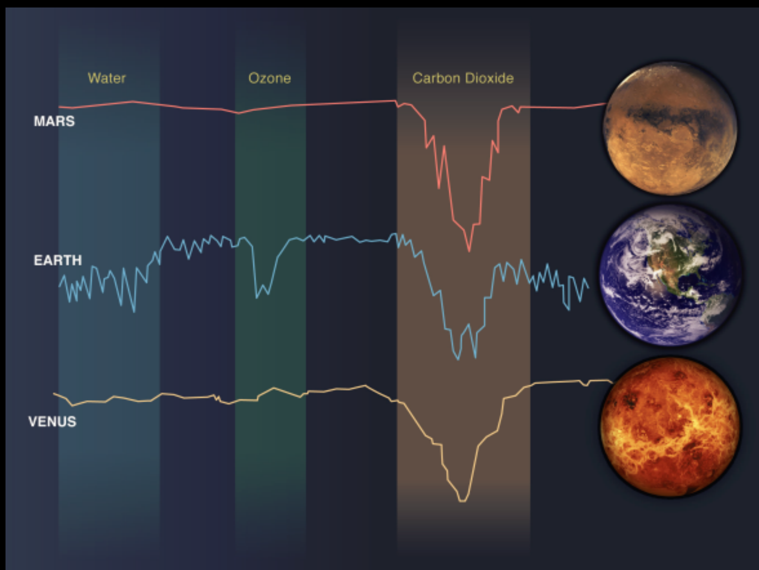
Birth of Stars and Planetary Systems
How stars form and chemical elements are produced

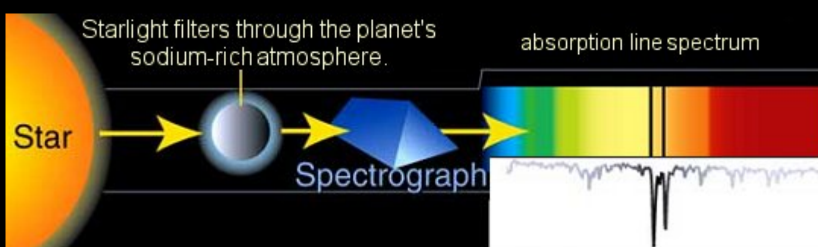
Planetary Systems & Origins of Life
Formation of planets and solar systems



JWST will revolutionize understanding of exoplanet atmospheres

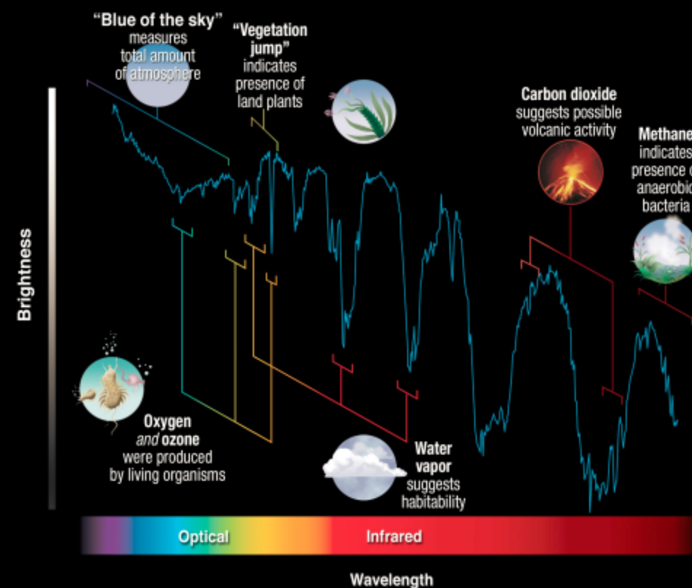
Composition is revealed by spectroscopy

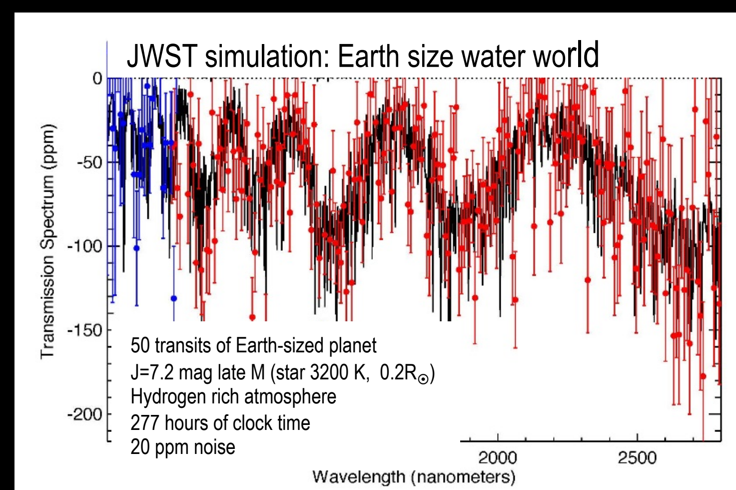




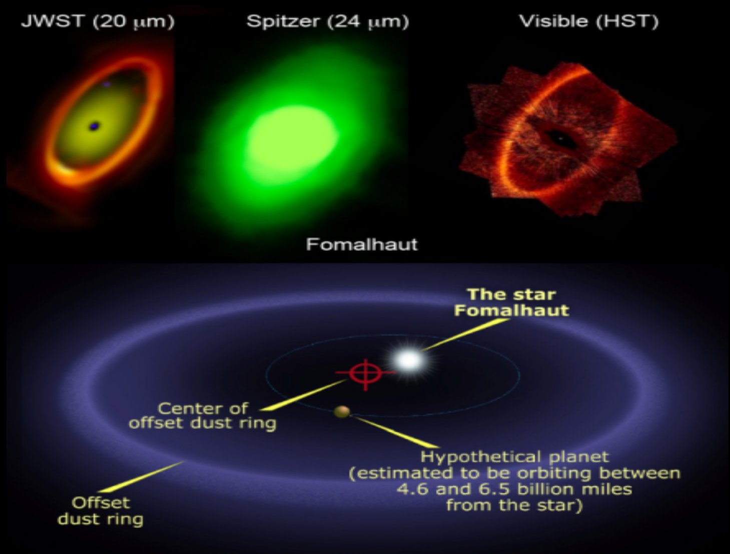
JWST can detect liquid water on an exoplanet that is a few times the size of the Earth.

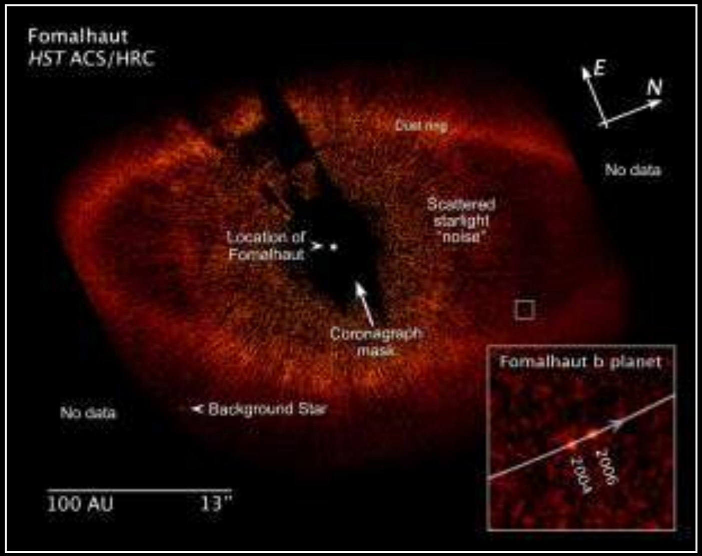
So is the presence of life!

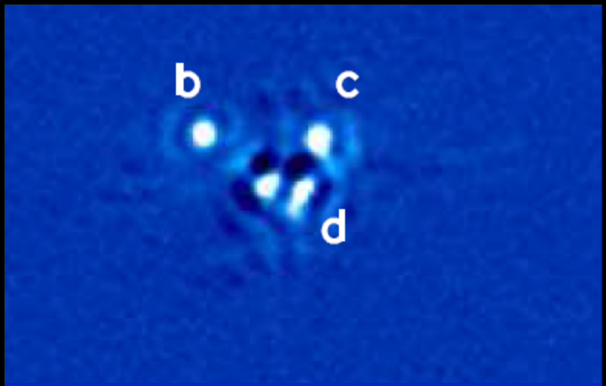




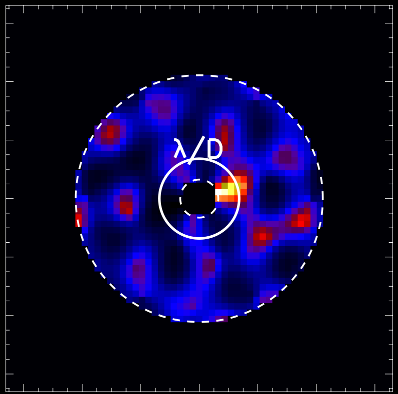
JWST will image exoplanets (planets orbiting other stars)







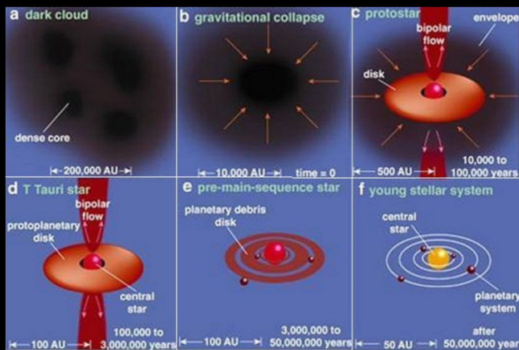
JWST simulated mid-infrared image of planets orbiting star HR 8799.

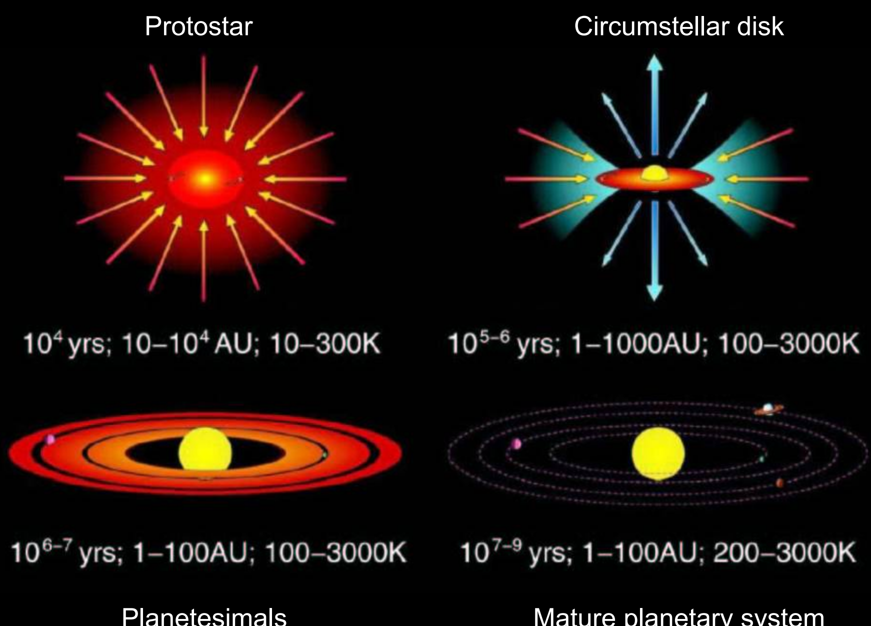


JWST simulated near-infrared image of a 1-2 M_{Jup} planet at ~1 AU of a M0V star 10 pc from the Sun.

JWST will see into the birthplaces of stars to reveal how they form and evolve

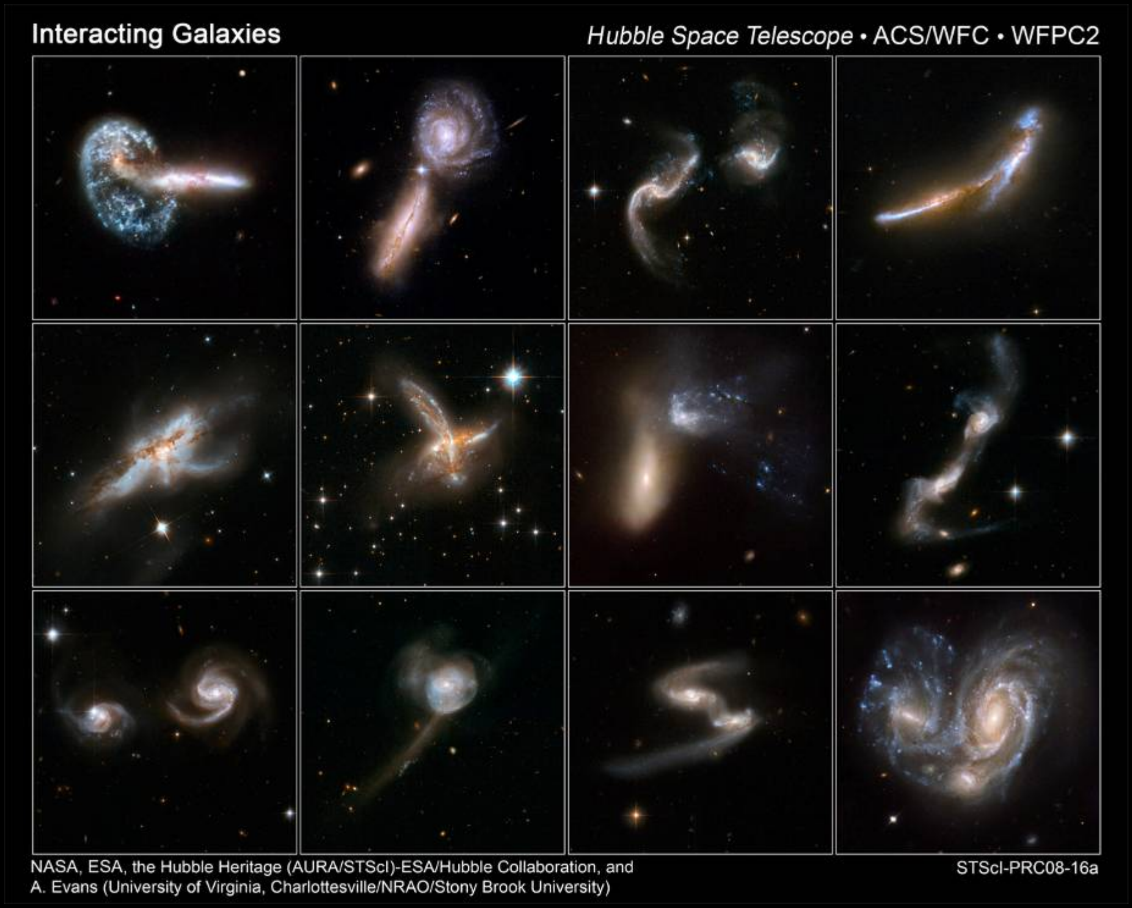
Birth of Stars and Planetary Systems
How stars form and chemical elements are produced





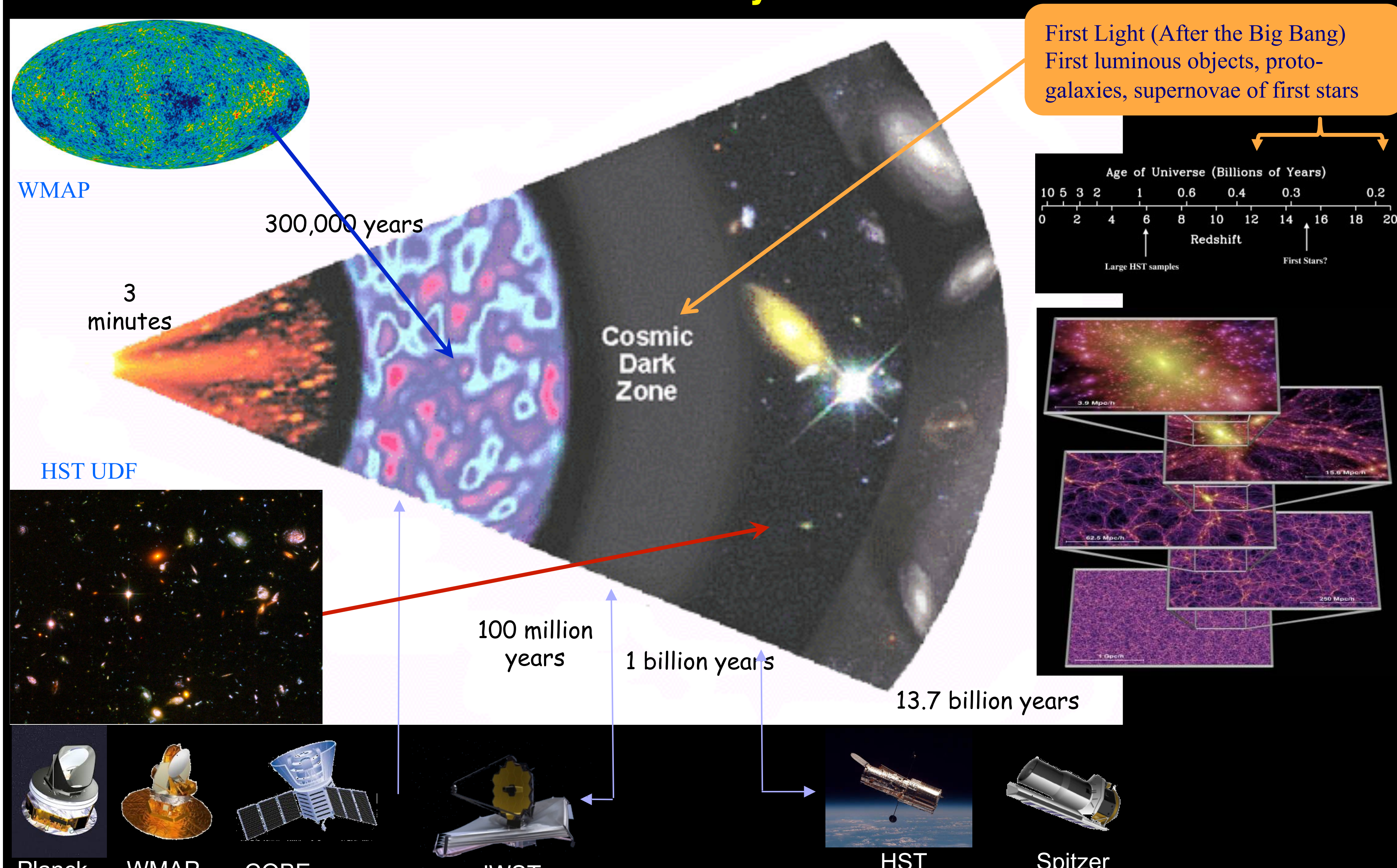
The Eagle Nebula as seen in the near-infrared

JWST will see how the structure and composition of galaxies evolve across cosmic time



JWST is designed to look back in time to see the first galaxies

A Brief History of Time

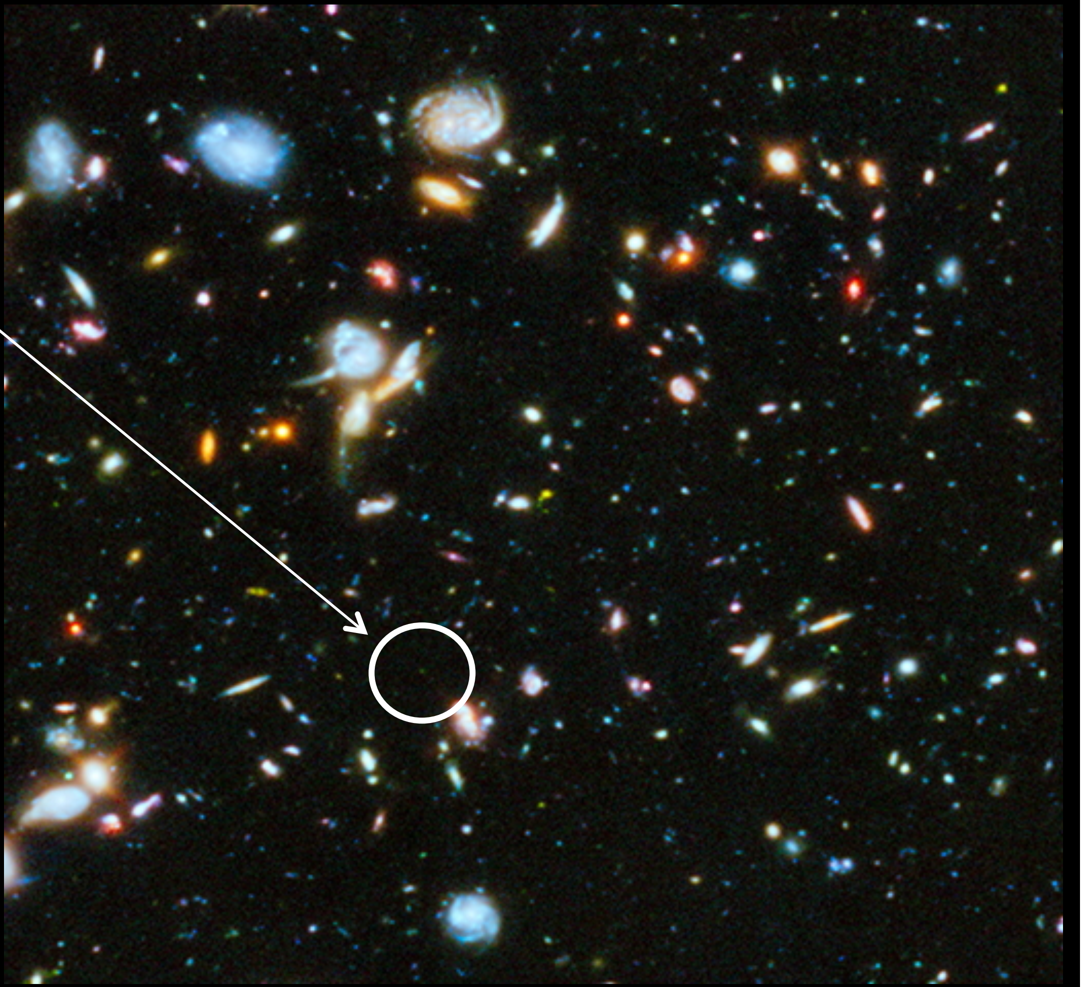


How Can JWST Observations Contribute to Cosmology? (1)

- Find galaxy candidates to z>20 (HST limit is z~9)
  - NIRCam imaging (1-5 μm) – wide and medium filters
  - Supporting 5-28 μm imaging (MIRI)
- Obtain 1-5 μm spectra with NIRSpec of galaxies discovered by NIRCam
  - Galaxy candidates need spectroscopic confirmation of z
  - Rest-frame far ultraviolet $\lambda > 911$Å
- Search for Lyman-alpha emission-line galaxies at $7 < z < 17$
  - Blind search with wide-field grism spectra (NIRISS)
- High-z transients (PISN, GRBs, etc)? Time dilation is significant and a challenge to identifying variable objects.

Finding the First Galaxies (1)

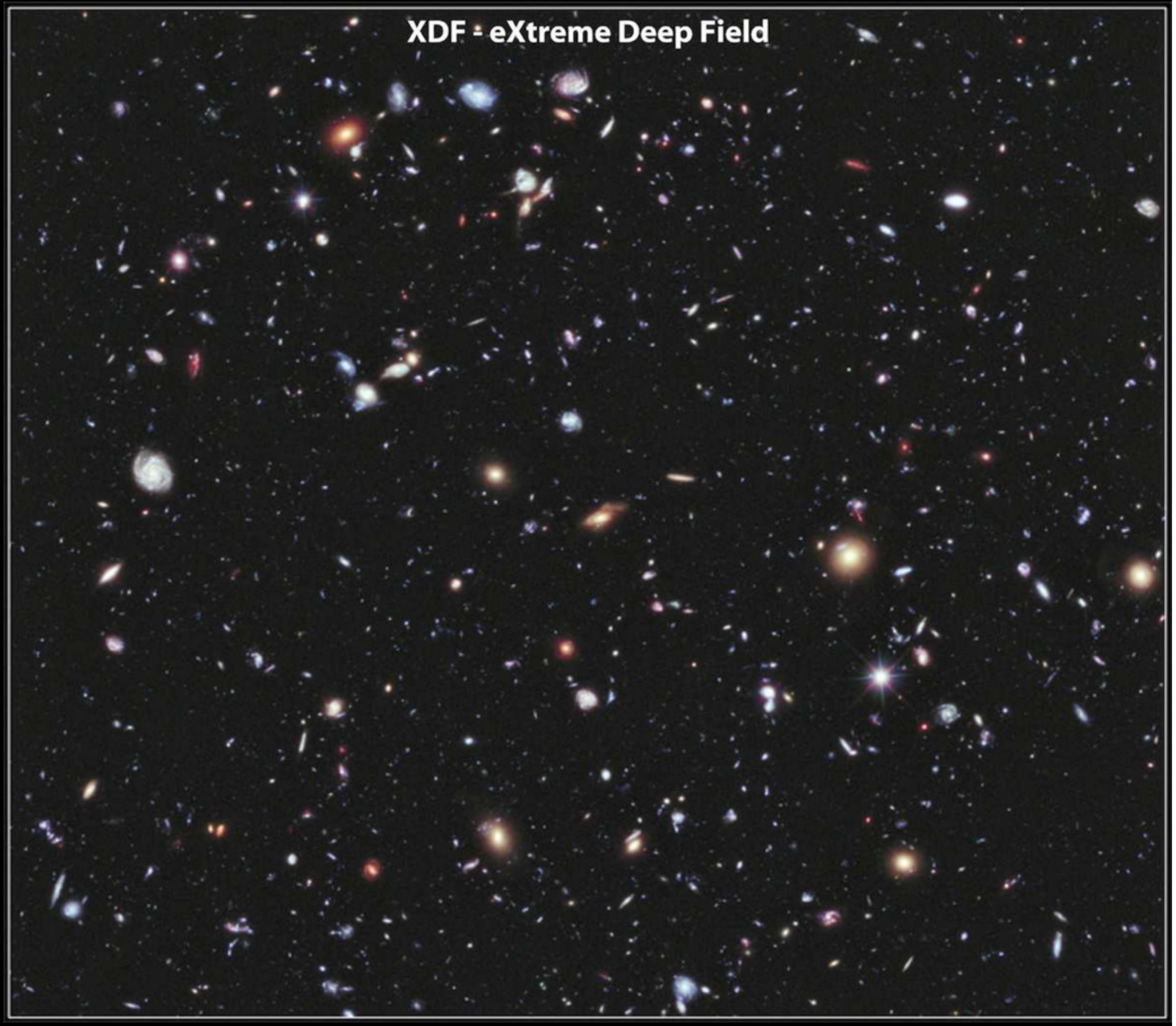
- Highest redshift candidates found with HST (z~9) are faint and red.
- Higher redshift objects are invisible to HST, but will be found by JWST and studied spectroscopically.



Hubble Ultra Deep Field IR

Finding the First Galaxies (2)

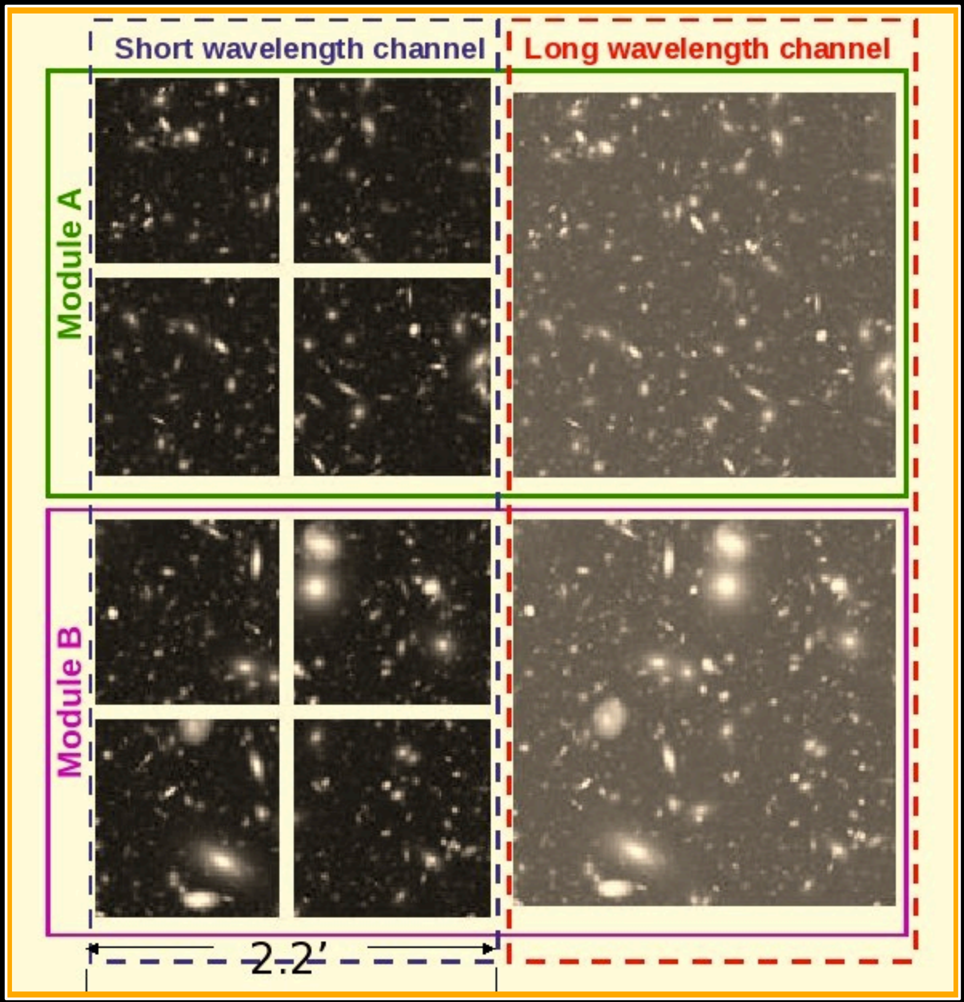
- Latest HST deep field: the WFC3-IR UDF (at right), imaged in 4 filters (1.05-1.60 μm). Took 16 days!
- NIRCam on JWST can repeat that UDF (same depth, better angular resolution) in only 6 hr clock time.
- JWST has sensitivity over 1-5 microns to find galaxies to z>20.



Illingworth+ 2013

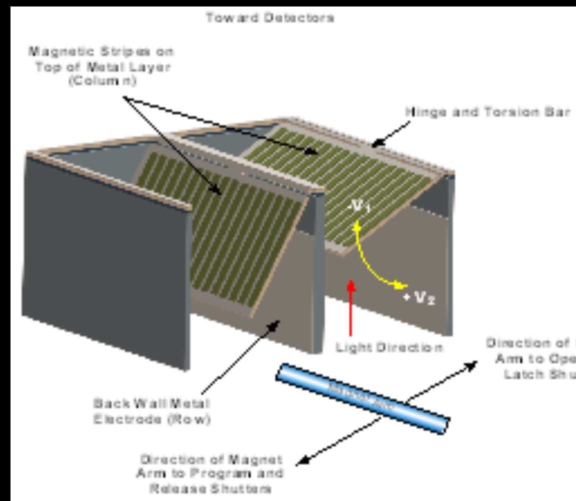
NIRCam – Near Infrared Imaging

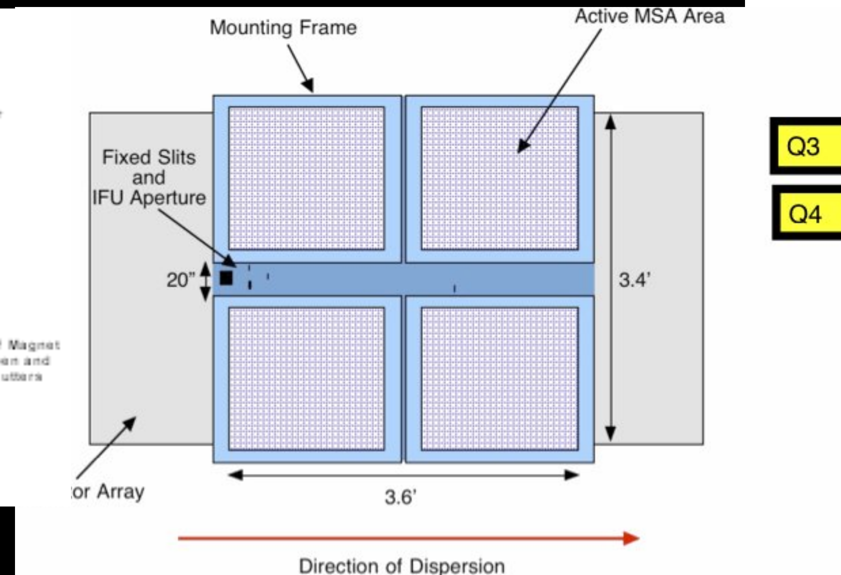
- Two identical instrument modules
- A dichroic splits the beam at 2.35 μm
- Each module observes simultaneously in short (0.6-2.3 μm) and long (2.4-5 μm) wavelengths.
- Each channel has several wide (R~4), medium (R~10), and narrow (R~100) band filters
- Each module has five 2048x2048 HgCdTe detectors.
- Short wave detectors: 0.032"/pixel
- Long wave detectors: 0.065"/pixel
- NIRCam also has chronographic masks and a R~2000 grism (2.5-5 μm)

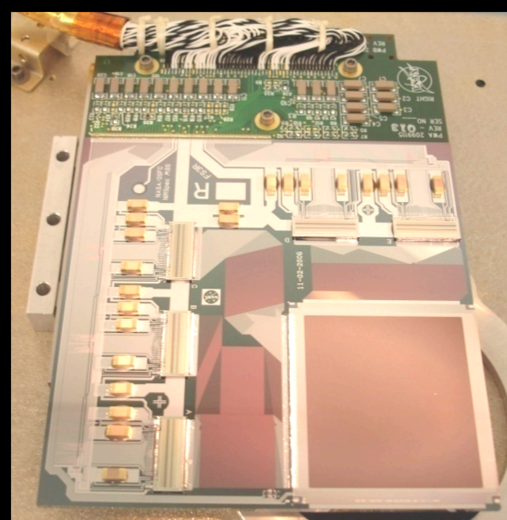


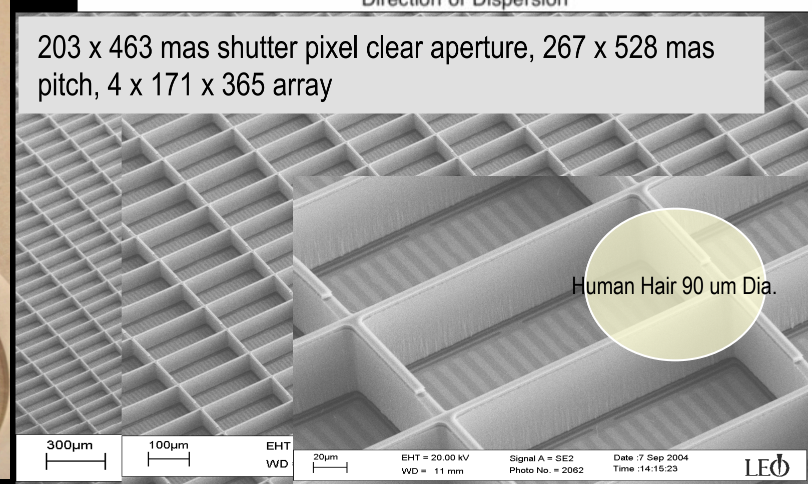
NIRSpec Microshutter Array

- First multi-object spectrograph in space
- 250K programmable apertures
- Simultaneous spectra of >100 objects over ~10 sq arc min
- Four MSA Quadrants, each with 365 shutters (dispersion) X 171 shutters (spatial)
- Each shutter has ~0.2” x 0.45” clear aperture



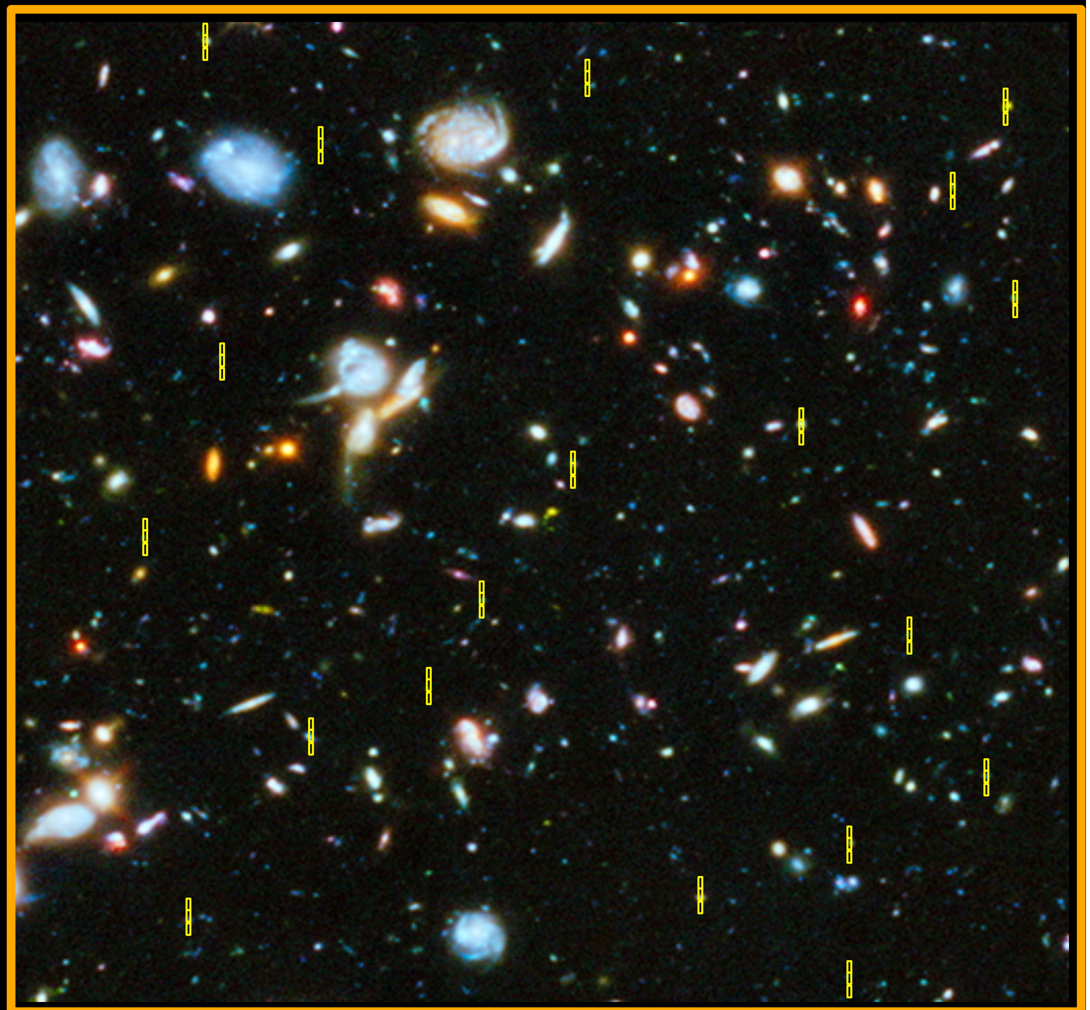






NIRSpec Multi-Object Spectroscopy Example

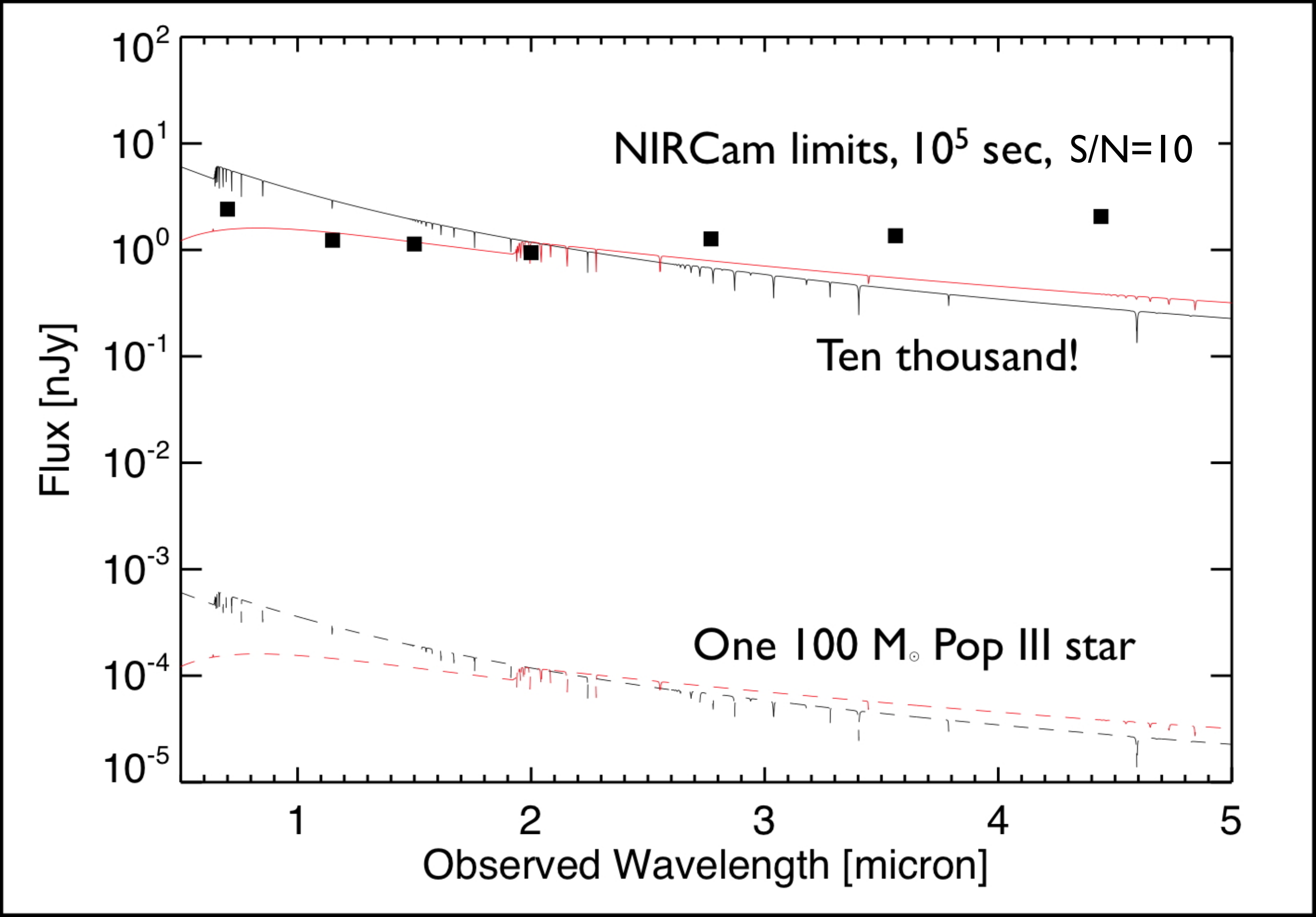
- Observer defines open/closed shutter pattern for each observation
- Trios of microshutters (background –source-background) opened
- Other shutters remain closed
- Requires ~0.005” astrometry of targets relative to stars in the same field for target acquisition.



One MSA quadrant

→ λ

Will JWST See the First Stars?



If current theory of Pop III star formation is roughly correct it will be impossible for JWST to detect them directly in the high-z Universe!

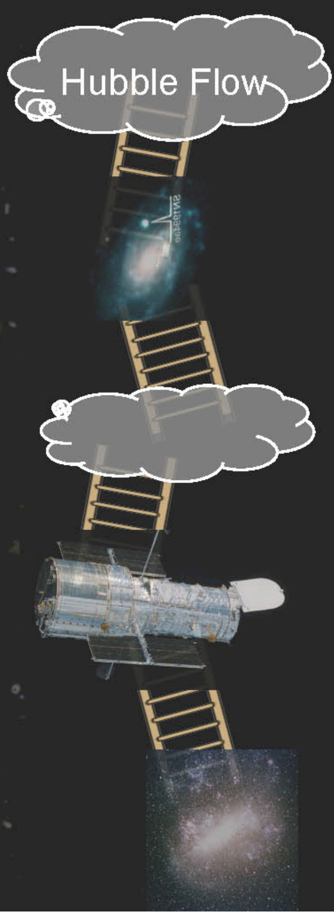
How Can JWST Observations Contribute to Cosmology? (2)

- IR light curves of supernovae are insensitive to dust extinction
- Spectroscopy of low-z Type Ia supernovae, especially at late times
  - SN Ia nucleosynthesis and explosion geometry
  - Sensitivity to obtain late-time spectra of any SN Ia within ~100 Mpc
- Reduce uncertainty in H_0 to <1% by continuation of Cepheid and SN Ia studies in more galaxies
- Your new ideas!!

HUBBLE CONSTANT: REBUILD DISTANCE LADDER (Riess 2011)

Eliminating sources of *systematic error* between anchor and calibrator:
1) use same instrument 2) same Cepheid parameters (Period,Z) 3) better anchor

PRESENT DISTANCE LADDER (100 Mpc)



11% error

1% # Modern, distant SNe Ia

3% # Modern, local hosts

3.5% SN Ia hosts,
Metal poor to Metal rich

4% long to short Period Cepheids

4.5% Ground to HST

5% Anchor: LMC

NEW LADDER (100 Mpc)

4 % error

1%

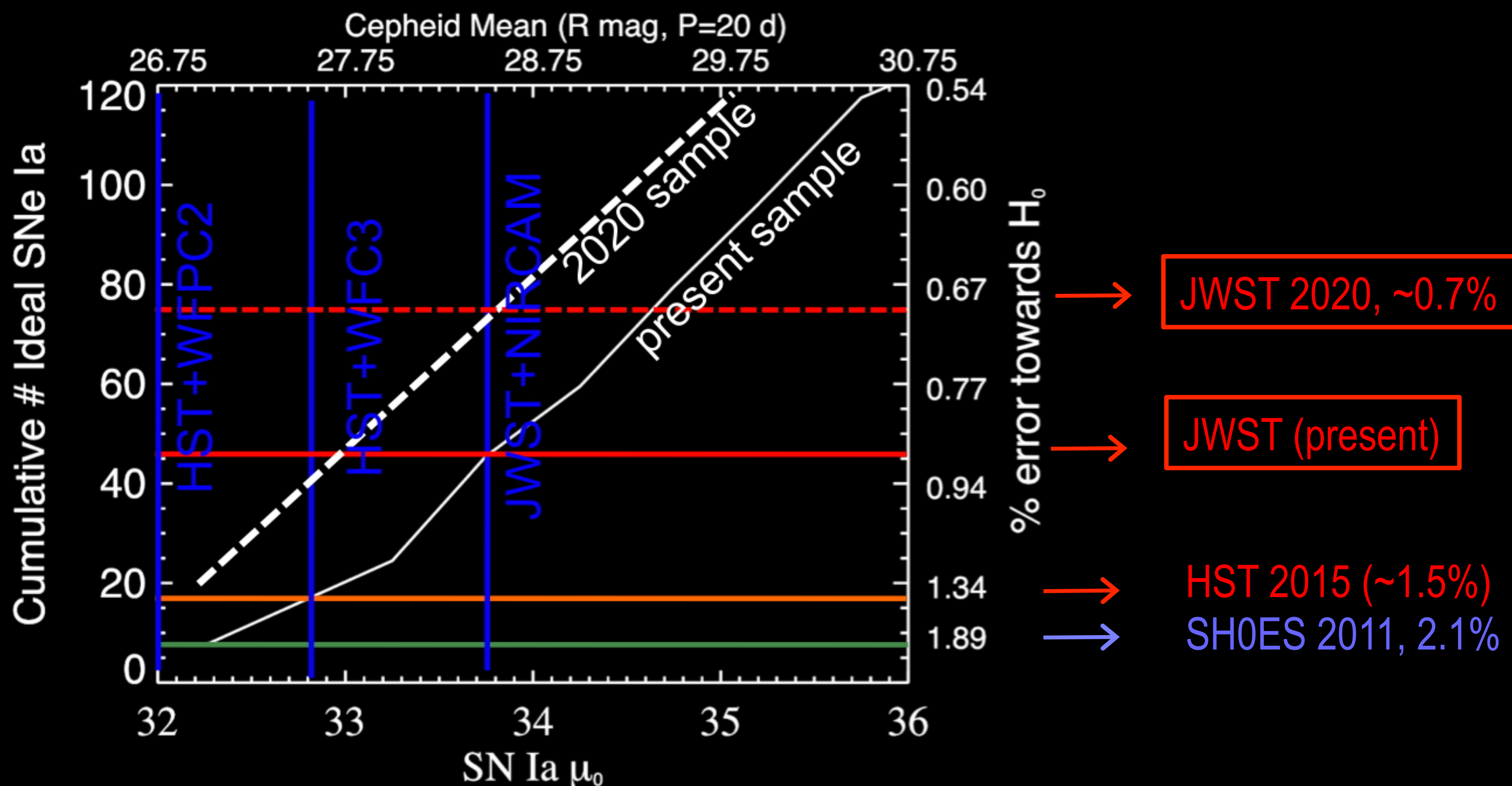
2%

Calibrator

NA

3% Anchor:
NGC4258

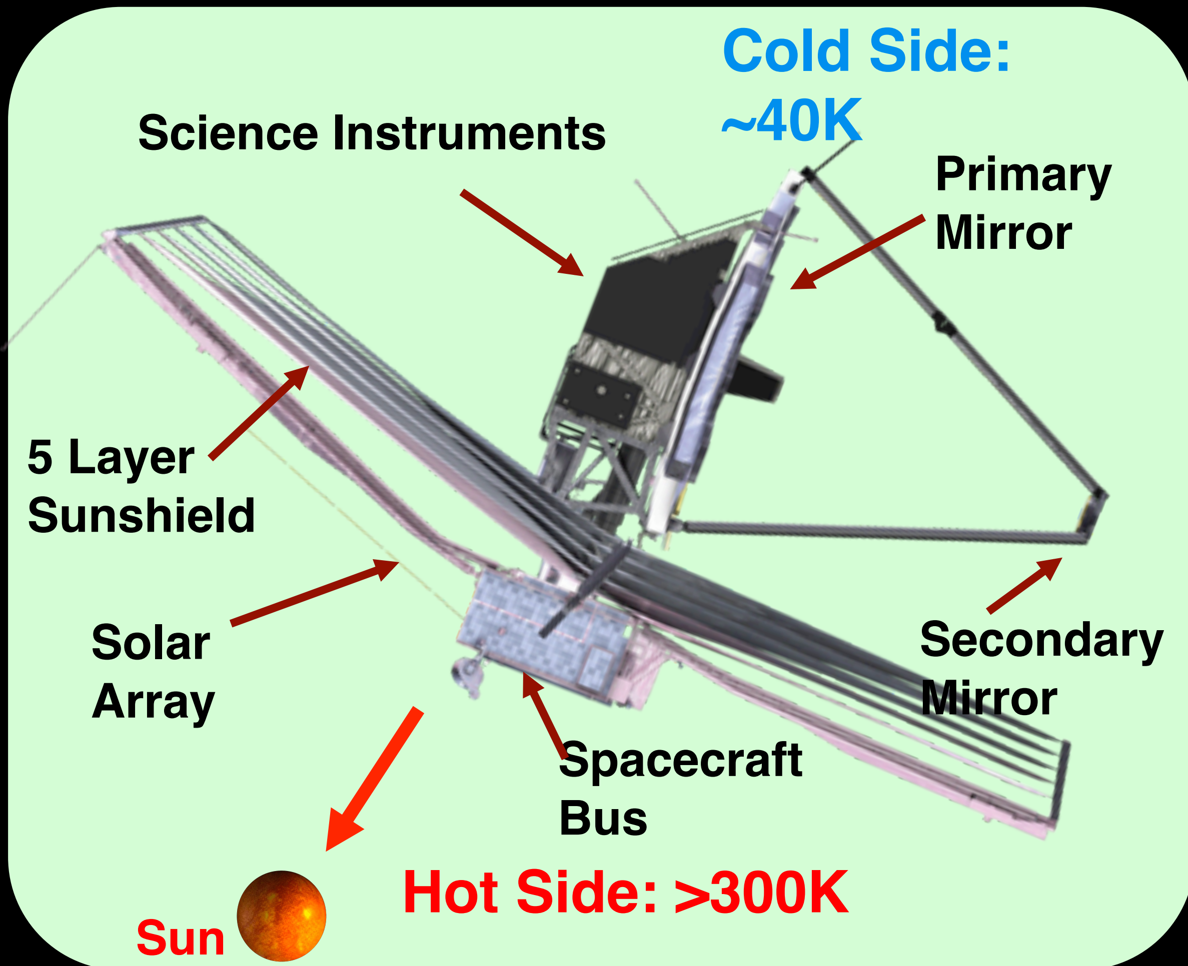
JWST extends volume and sample for SN Ia calibration



A Little High-Redshift History

- When JWST was first imagined (1995) the highest redshift QSO was z=4.75 (highest-z galaxy much less than that)
- The first galaxies were thought to be at z > 7.
- HST and ground-based observatories pushed the redshift frontier over the last 20 years and the first galaxies still have not been found.
- They lie at z>9, beyond the reach of HST and ground based telescopes.
- JWST's capabilities are needed now more than ever to address this problem.

How does JWST Work?



JWST is folded and stowed for launch on an Ariane 5.

Observatory is unfolded after launch.

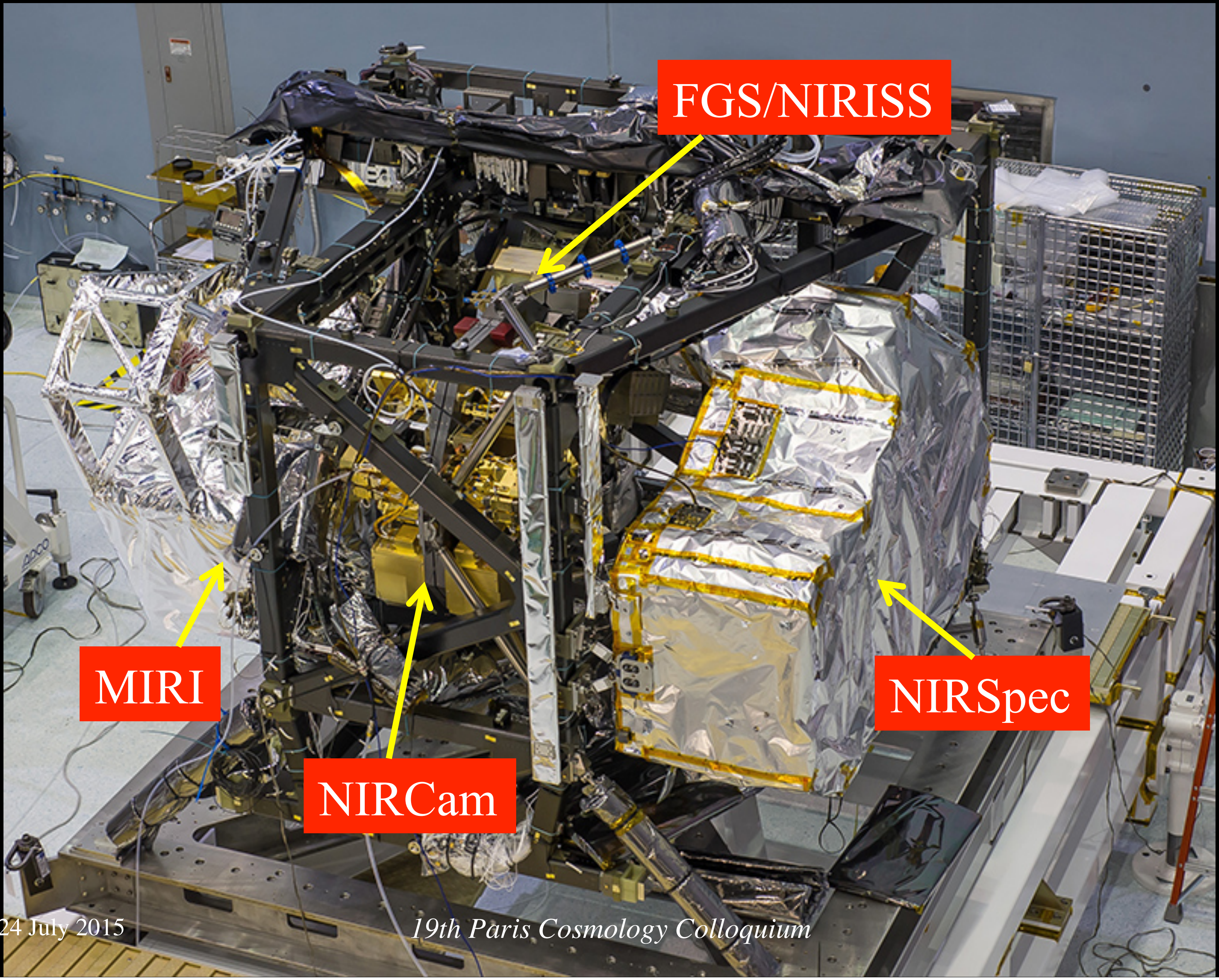
JWST Orbits the 2nd Sun-Earth Lagrange Point (L2)

1.5 million km

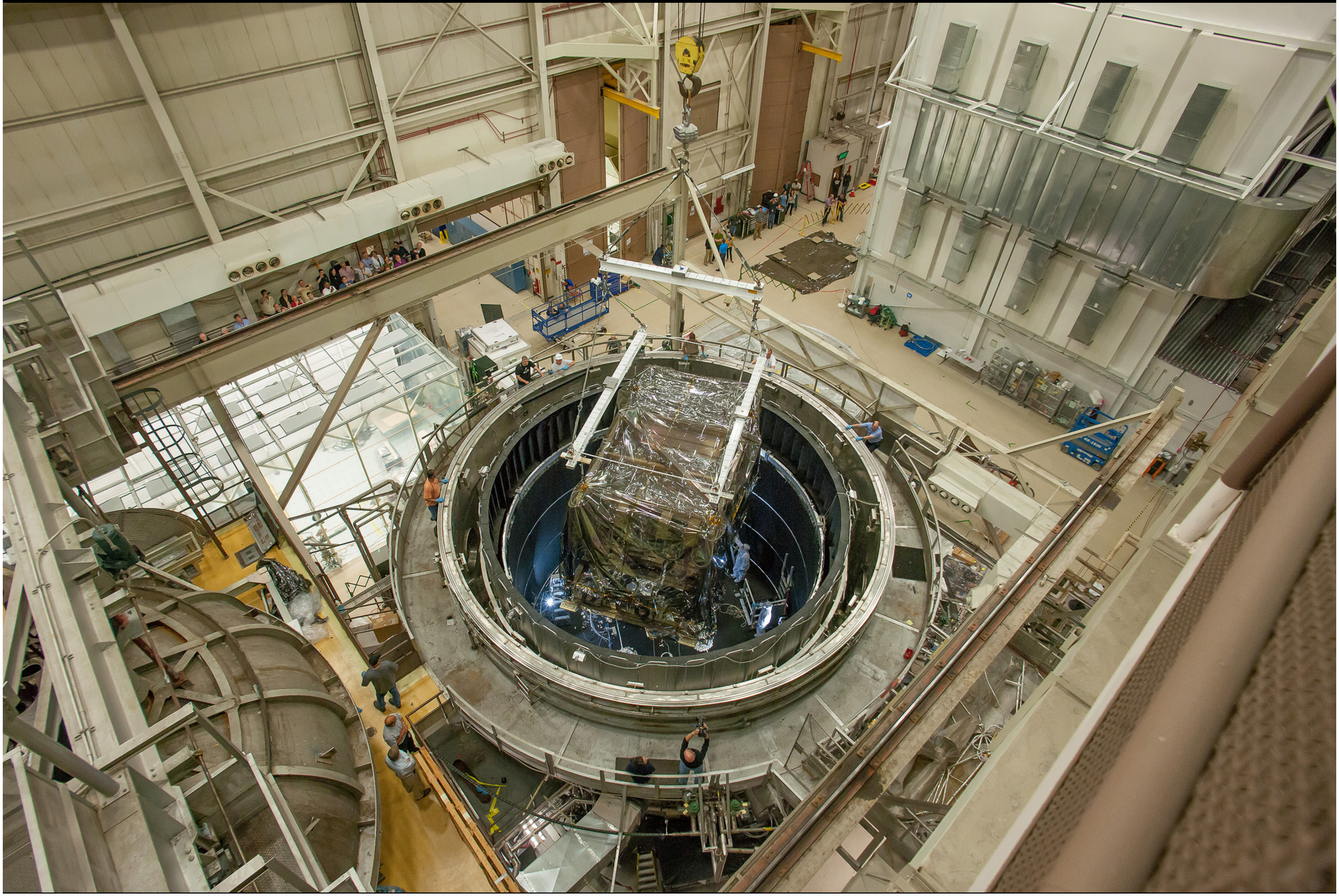
JWST Status

- On schedule for launch in October 2018
- Instruments completed and undergoing cryo-vacuum testing
- Telescope mirrors and backplane structure finished
  - Telescope assembly begins Fall 2015
- End-to-end thermal/optical test of telescope and instruments in 2017
- Spacecraft and sunshield are under construction
- Flight and ground software systems being written and tested

Science Instruments Integrated - 2014



ISIM Moves to Cryo-Vac Chamber at GSFC



Full-Scale Sunshield Deployment Test - 2015

Telescope Optics Completed

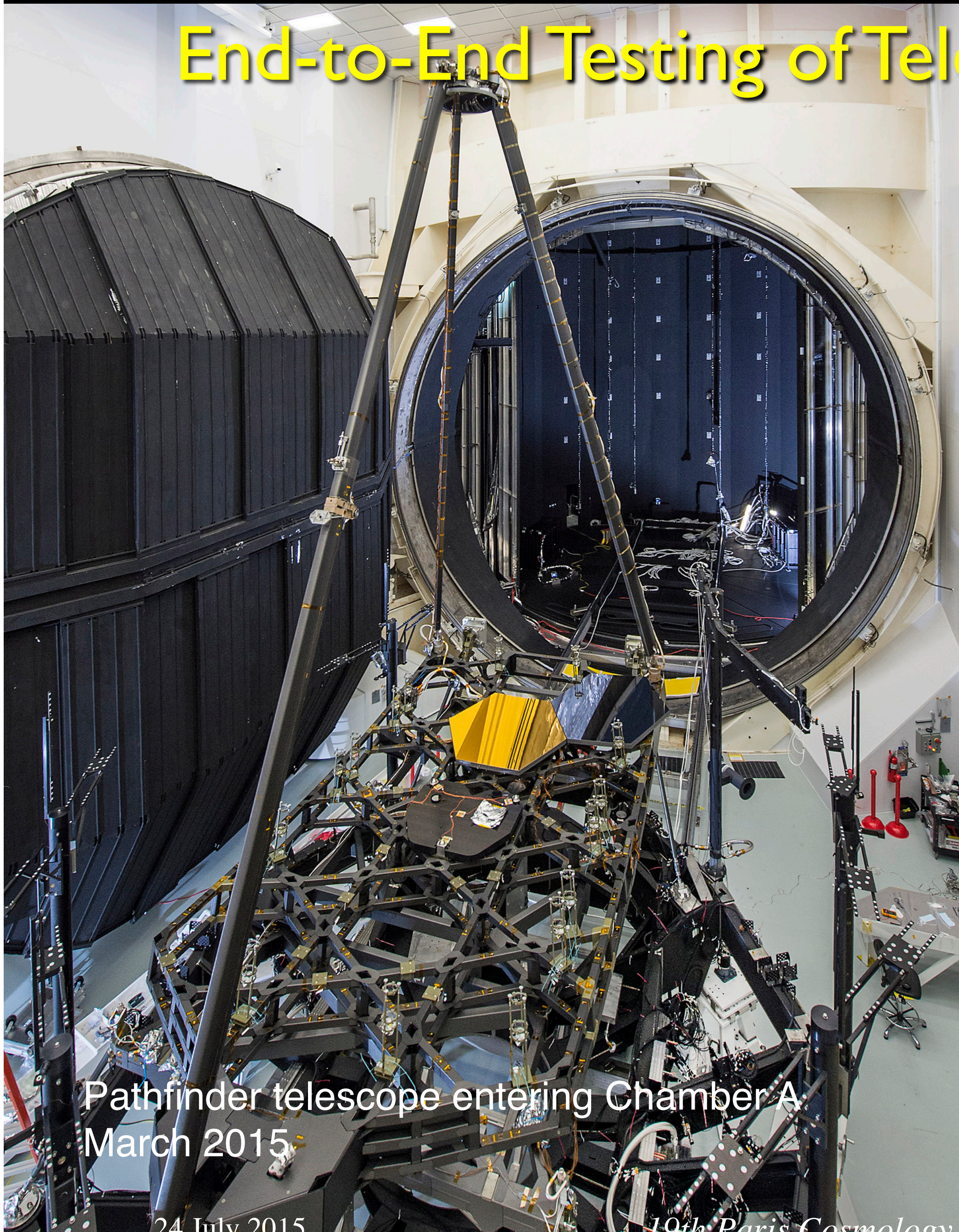
- All telescope optics completed, cryo-tested, and ready for I&T
- Telescope composite structures being tested prior to I&T
- Pathfinder telescope now at JSC

Telescope Structure Completed

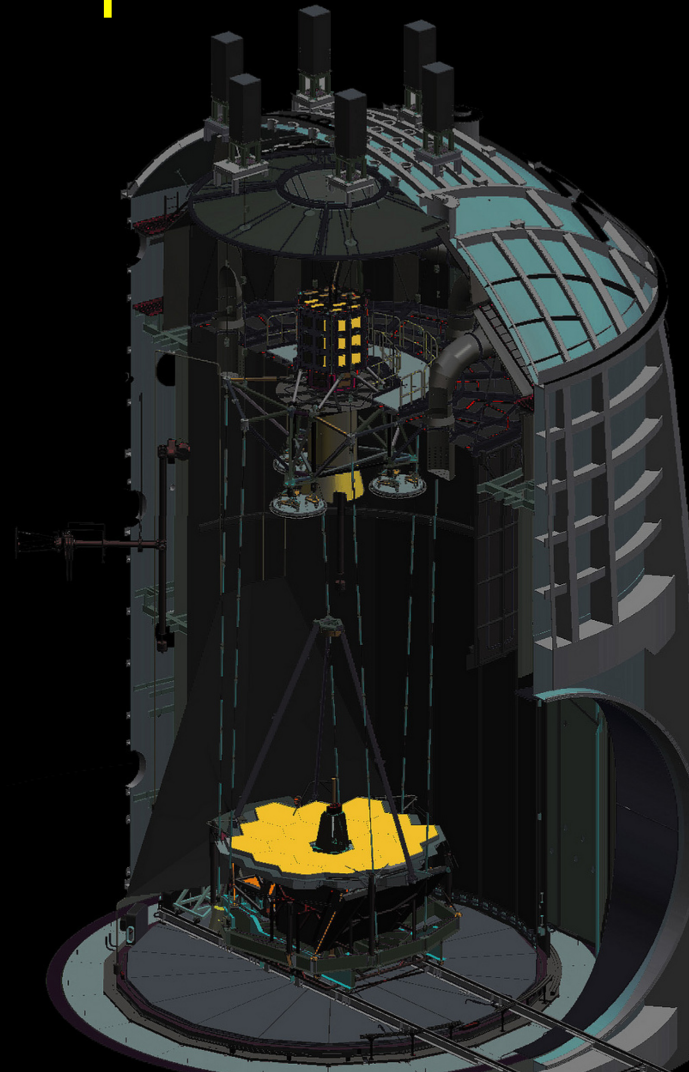
JWST transport by airplane

Cleanroom and door to Chamber A at Johnson Space Center

End-to-End Testing of Telescope + Instruments



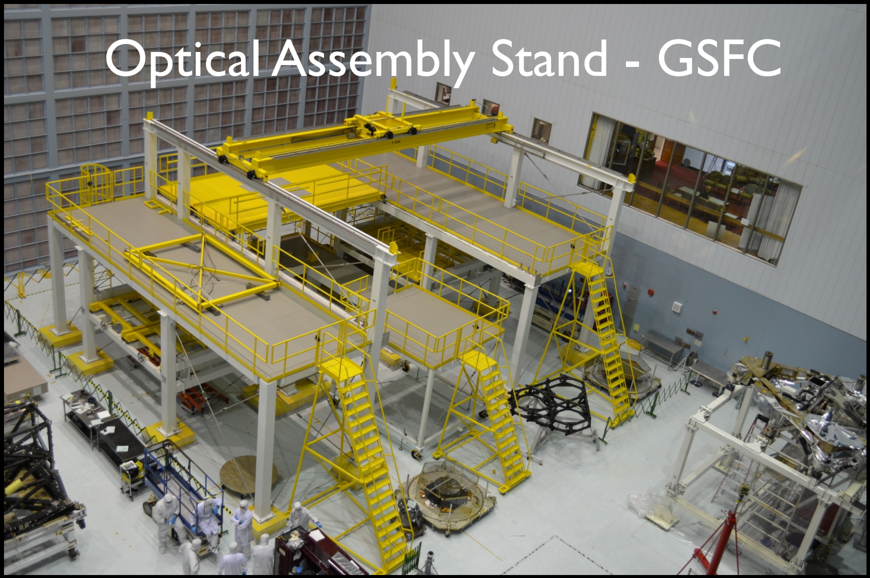
Pathfinder telescope entering Chamber A
March 2015



Johnson Space Center Chamber A

From Now to Launch

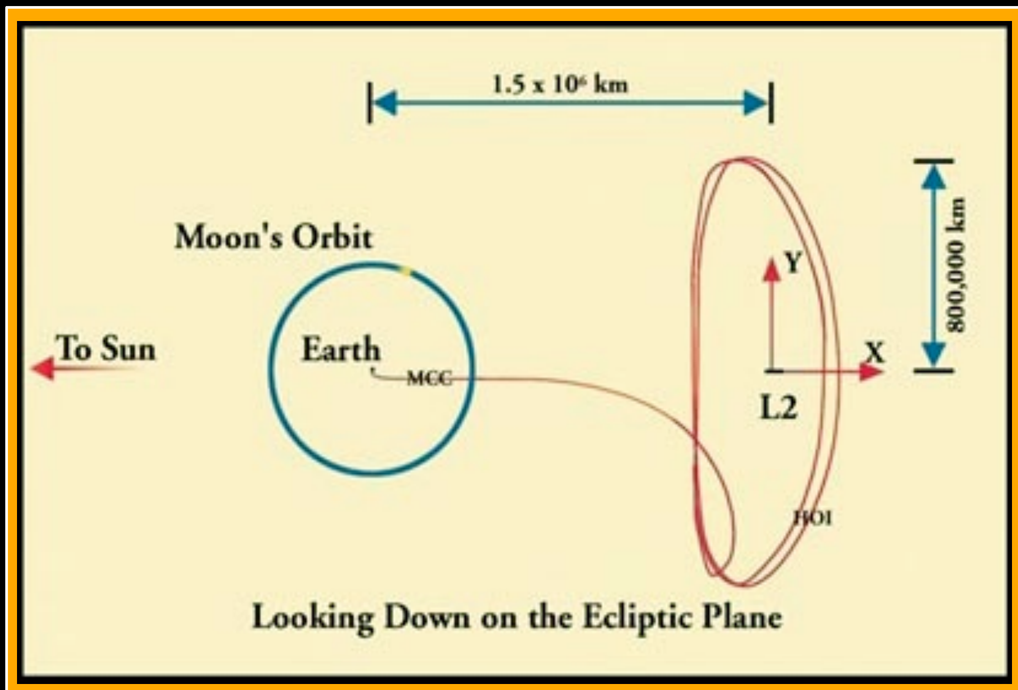
- Test instrument module (2015)
- Build and test sunshield (2015-16)
- Build and test spacecraft (2015-17)
- Assemble and test telescope (plus instruments) (2015-17)
- Integrate and test telescope-instrument system with spacecraft and sunshield (2017-18)
- Develop and test ground system and Science & Operations Center (2015 –17)
- Transport by ship from California to French Guiana for launch (2018)



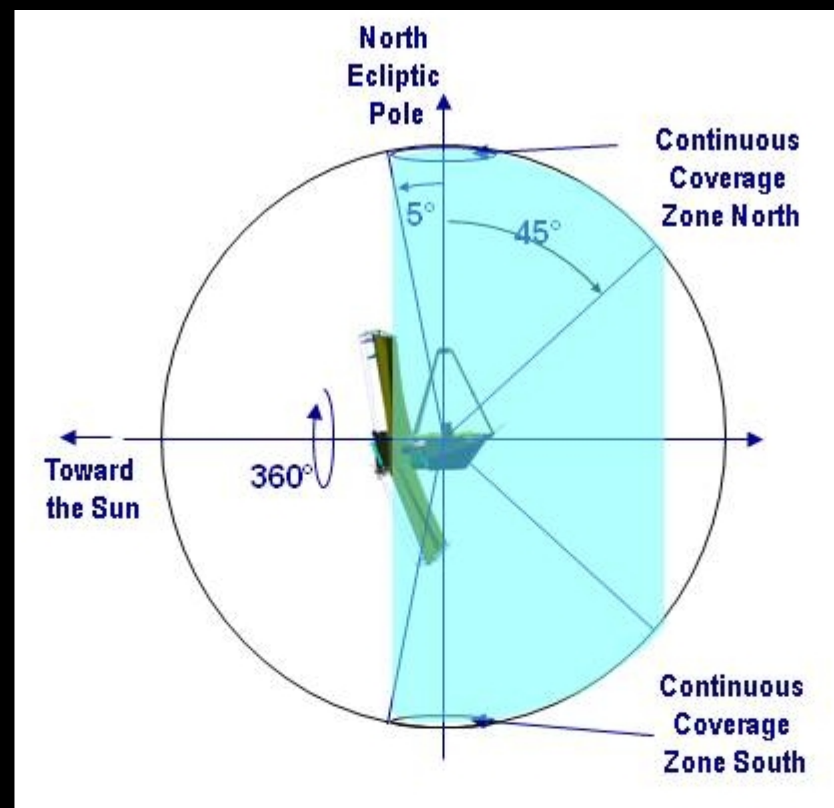
JWST Operations in One Chart

- Flight and science operations at STScI in Baltimore
- Annual call for proposals; vast majority of time to GOs
  - Small, Medium, Large proposals starting with Cycle 1
- Science planning supports wide range of observations
  - Imaging mosaics, parallels, time/phase critical, moving targets, etc
- Target of Opportunity response as short as 2 days
- Calibration pipelines will produce science-quality data
- Data archive continuously updated with latest processing
- Very rich spectral data sets (MOS and IFUs); supporting analysis tools being developed

The JWST Orbit



No occultations of Sun by Earth or Moon



- 100% sky coverage over year
- Targets generally observable 2X/yr
- ~35% sky coverage on any day
- No observations within 45° of anti-sun

Countdown to Science

Sept 2017	Guaranteed Time Observers finalize targets/observations
Nov 2017	Cycle 1 General Observer Call for Proposals Released
Feb 2018	Deadline for Cycle 1 GO proposals
Oct 2018	LAUNCH (observatory commissioning lasts 6 months)
April 2019	Cycle 1 observations begin
~Sept 2019	Cycle 2 GO Call for Proposals released
~Dec 2019	Deadline for Cycle 2 GO proposals

Summary

- JWST will provide tremendous advances in infrared sensitivity and spatial resolution.
- Imaging and spectroscopic capabilities designed to address high-redshift and cosmology science.
- Launch in October 2018
- Cycle 1 Call for Proposals in late 2017 (~2 years)

http://www.jwst.nasa.gov/

http://www.stsci.edu/jwst/

http://jwstinput.wikidot.com/