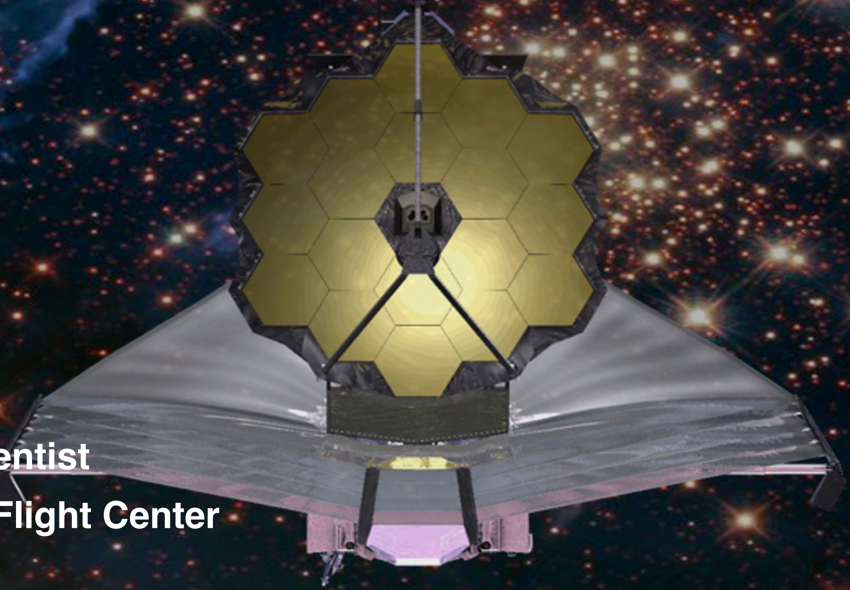
Opening the Infrared Treasure Chest with JWST



John Mather

JWST Senior Project Scientist

NASA's Goddard Space Flight Center

on behalf of 7.7 billion current humans, ~10,000 future observers, > 3000 engineers and technicians, ~ 100 scientists worldwide, 3 space agencies

How did we get here?

- Expanding universe starts smooth and hot
- Instability everywhere: energy release from reorganization into complex systems
- Infinite (?) and ancient universe explores every possibility, time enough for possibility → reality
- Stored information (DNA & decoders, language, etc.) enables unlimited complexity, life, evolution (survival of the lucky in changing environment), individuality, civilization
- Nested feedback loops & control laws stabilize systems (homeostasis, create recognizable identity), destabilize too (balance of nature is temporary)

The 4 forces + Thermodynamics

- QM (quantum mechanics of strong, weak, and electromagnetic forces) → the shapes and binding energies of all possible combinations of the wavy particles : all the Lego blocks
- Gravity (relativity) → binding energy for gas clouds into galaxies, stars, planets (negative specific heat!!)
- Equilibrium thermodynamics → local order from increasing disorder elsewhere
- Non-equilibrium thermo → nature finds a way to increase entropy with spontaneous heat engines (e.g. life)

When will a cloud of gas collapse?

- James Jeans, 1902
- Self-gravitational force > gas pressure
- Time for sound to cross the cloud > free-fall time
- Critical size = Jeans length ~ speed of sound / sqrt(G**ρ**)
- Self-heating: convert gravitational energy to kinetic energy to heat

Hubble showed galaxy velocity proportional to distance, 1929

Velocity away from us

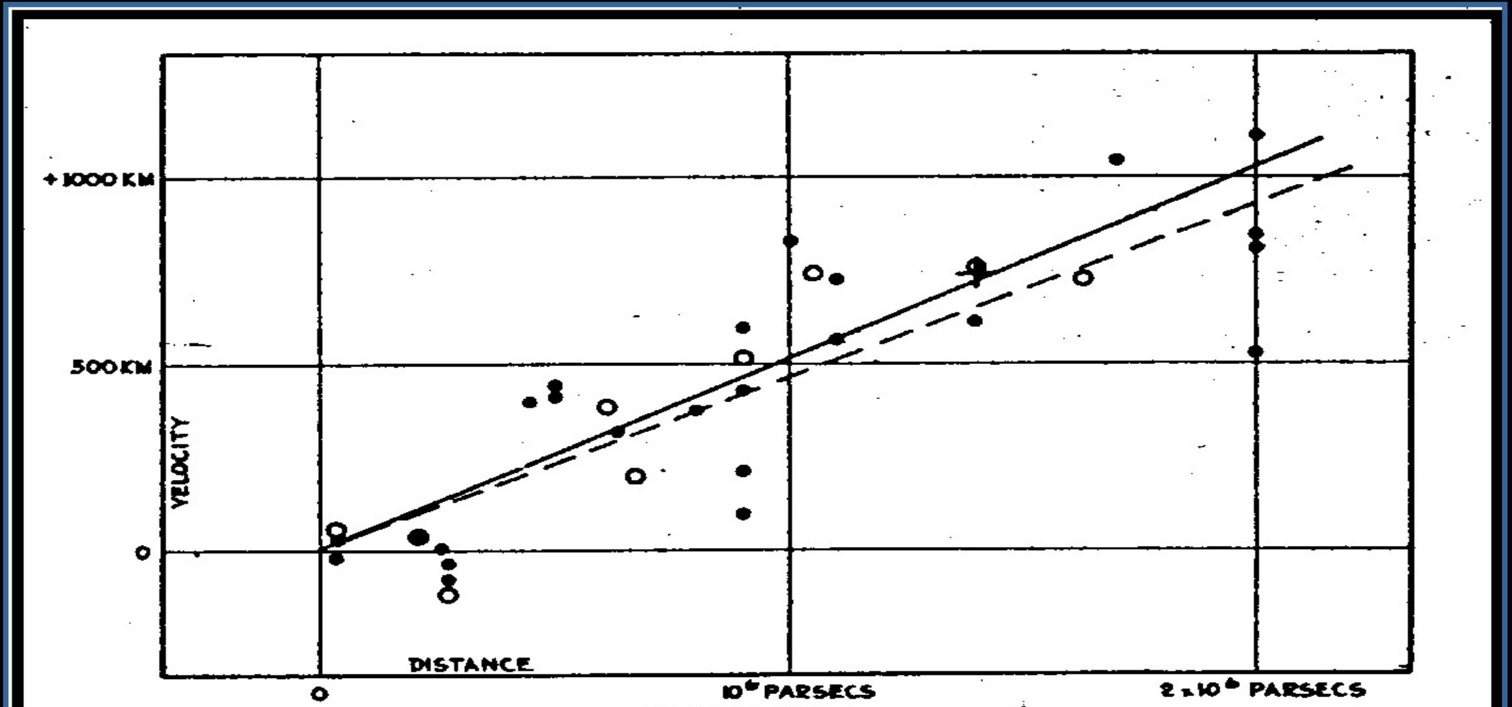


FIGURE 1

Distance, parsecs

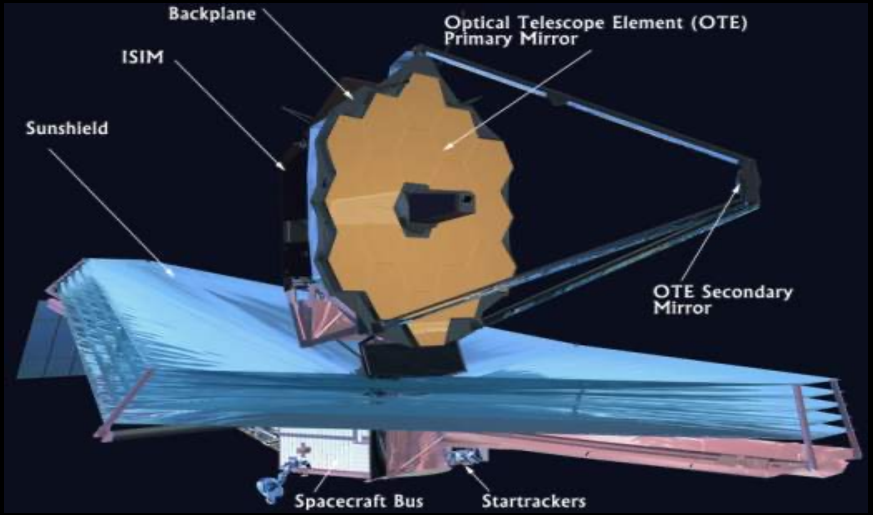
The early universe (standard picture)

very hot, very compressed
no center, no edge (infinite)
infinite universe expanding into itself
no first moment
t=0 not included, infinity is not a place
no instant of creation
not a “big firecracker”
probably no end…

Hubble is 30! And working well!

Launched April 24, 1990

James Webb Space Telescope (JWST)



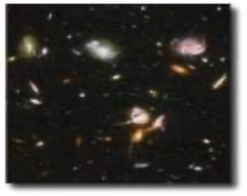
Organization

- Mission Lead: Goddard Space Flight Center
- International collaboration with ESA & CSA
- Contractor: Northrop Grumman Space Systems
- Instruments:
  - Near Infrared Camera (NIRCam) – Univ. of Arizona
  - Near Infrared Spectrograph (NIRSpec) – ESA
  - Mid-Infrared Instrument (MIRI) – JPL/ESA
  - Fine Guidance Sensor (FGS) and Near IR Imaging Slitless Spectrograph (NIRISS) – CSA
- Operations: Space Telescope Science Institute

Description

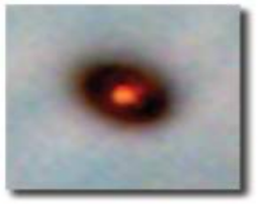
- Deployable infrared telescope with 6.5 meter diameter segmented adjustable primary mirror
- Cryogenic temperature telescope and instruments for infrared performance
- Launch on an ESA-supplied Ariane 5 rocket to Sun-Earth L2
- 5-year science mission (10-year goal)

JWST Science Themes

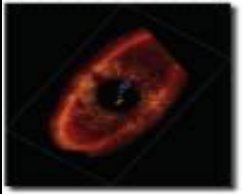


End of the dark ages: First light and reionization

The assembly of galaxies



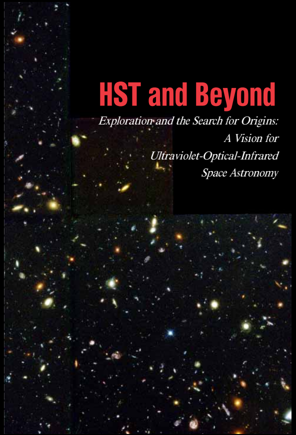
Birth of stars and proto-planetary systems



Planetary systems and the origin of life

www.JWST.nasa.gov

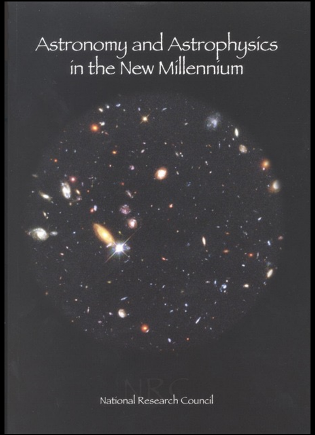
Conception and Endorsements



1995 AURA Committee

"I see Alan Dressler here. All he wants is a four meter optic that goes from a half micron to 20 microns. And I said to him, "Why do you ask for such a modest thing? Why not go after six or seven meters?" *(standing ovation after speech)*

1996 NASA Administrator Dan Goldin's Speech "NASA in the Next Millennium" at the 187th AAS Meeting



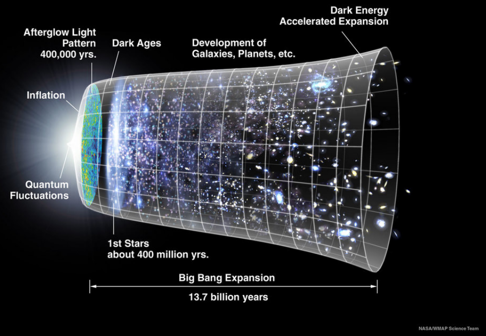
2000 Decadal Survey top priority

2010 Decadal Survey built around it

2021 Launch Date Planned Oct. 31, 2021

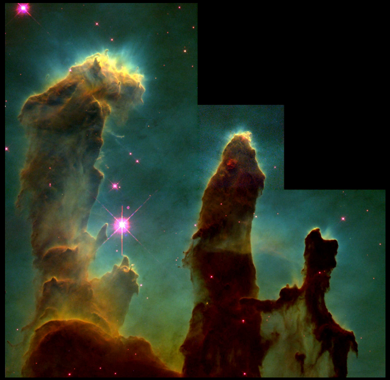
Webb Science Themes

First Light & Reionization

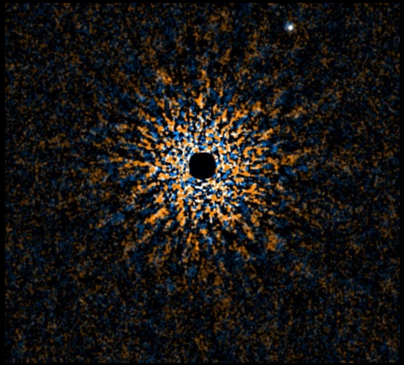


Assembly of Galaxies

Birth of Stars and Protoplanetary Systems



Planets and the Origins of Life



Webb Science Working Group


Rene Doyon
CSA PS


Pierre Ferruit
ESA PS


Jonathan Gardner
Dep Sr PS


Matt Greenhouse
ISIM PS


Heidi Hammel
IDS


Randy Kimble
I&T/Commissioning PS


Simon Lilly
IDS


Jonathan Lunine
IDS


Mark McCaughrean
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NIRSpec Science

Chair


John Mather
Senior Project Scientist


Mike McElwain
Observatory PS


Matt Mountain
Telescope Scientist


George Rieke
MIRI Science Lead


Marcia Rieke
NIRCam PI


Jane Rigby
Ops PS


Massimo Stiavelli
IDS

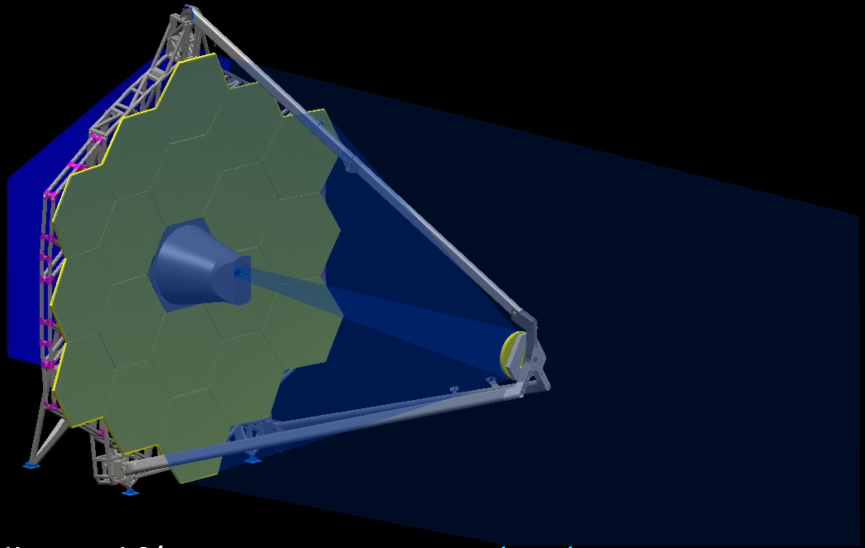

Jeff Valenti
SOC


Chris Willott
NIRISS Science


Rogier Windhorst
IDS


Gillian Wright
MIRI European Lead

JWST's Telescope Design



18 primary mirror segments

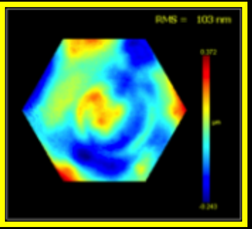
6 degrees of freedom + ROC (radius of curvature) adjustments

Beryllium mirrors, 2 mm thick, with ribs

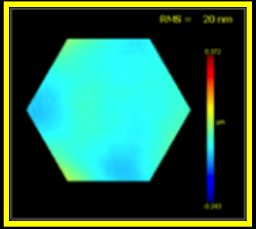
40 K operation

Polish to be correct shape when cold

Long lead time fabrication



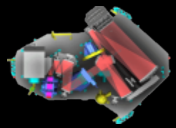
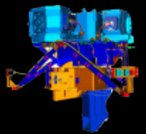
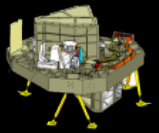
Ambient Surface



Cryo Surface

- *Elliptical* f/1.2 Primary Mirror (PM)
- *Hyperbolic* Secondary Mirror (SM)
- *Elliptical* Tertiary Mirror (TM) images pupil at *Flat* Fine Steering Mirror (FSM)
- Diffraction-limited imaging at ≥ 2 µm [150 nm rms wavefront error @ NIRCam focal plane]

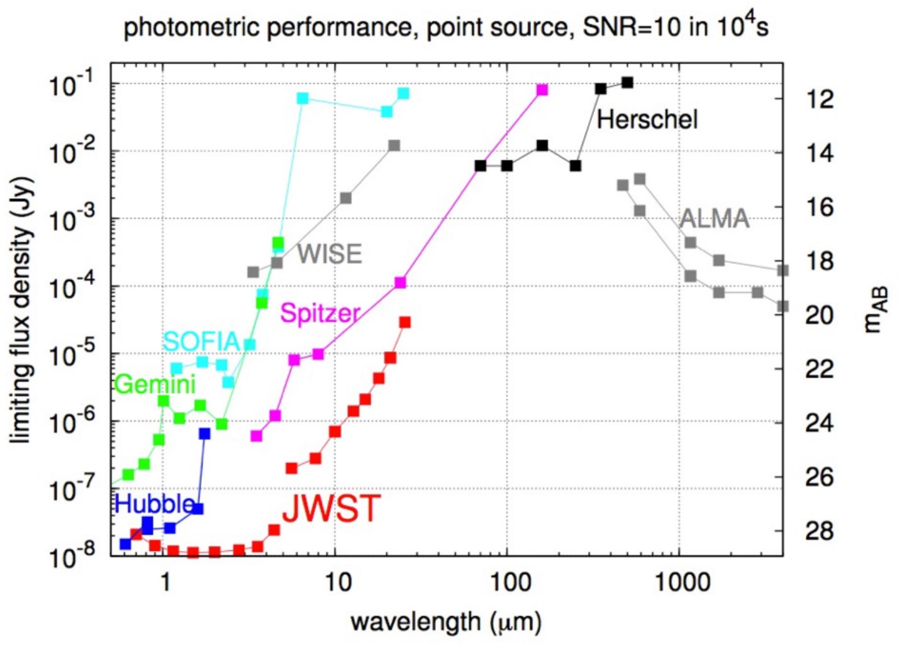
3 Near- and 1 Mid-Infrared Instruments

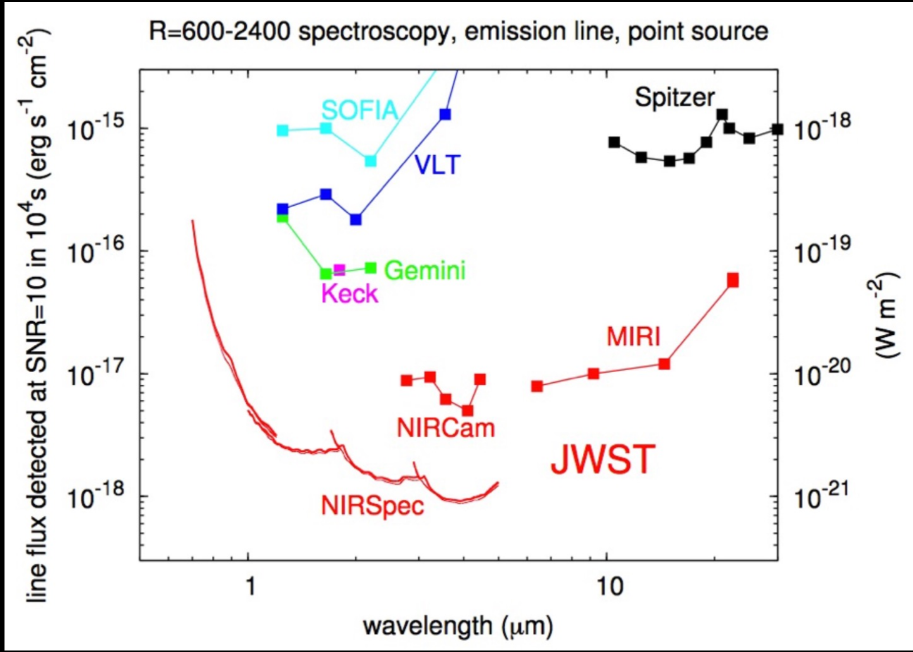
Instrument	Science Requirement	Capability
NIRCam Univ. Az/LMATC 	Wide field, deep imaging ▪ 0.6 µm - 2.3 µm (SW) ▪ 2.4 µm - 5.0 µm (LW)	2.2′ x 4.4′ SW at same time as 2.2′ x 4.4′ LW with dichroic Coronagraph
NIRSpec ESA/Astrium 	Multi-object spectroscopy ▪ 0.6 µm - 5.0 µm	9.7 Sq arcmin FOV + IFU + slits 100 selectable targets: MSA R=100, 1000, 3000
MIRI ESA/Consortium /UKATC/JPL 	Mid-infrared imaging ▪ 5 µm - 27 µm Mid-infrared spectroscopy ▪ 4.9 µm - 28.8 µm	1.9′ x1.4′ with coronagraph 3.7″x 3.7″ – 7.1″x 7.7″ IFU R=3000 - 2250
FGS/NIRISS CSA 	Fine Guidance Sensor ▪ 0.8 µm - 5.0 µm Near IR Imaging Slitless Spectrometer	Two 2.3′ x 2.3′ 2.2′ x 2.2′ R= 700 with coronagraph

Sensitivity

- Faint objects, long exposures: can see a bumblebee at distance of the Moon (nano-Jansky levels)
- Bright objects: short exposures, high resolution spectroscopy, special sub-array modes to read detectors faster – can observe all Solar system objects from Mars outwards, can do transit spectroscopy of all but brightest stars

Observatory Sensitivity





See https://jwst.stsci.edu/about-jwst/history/historical-sensitivity-estimates/

Cycle 1 Science Observations

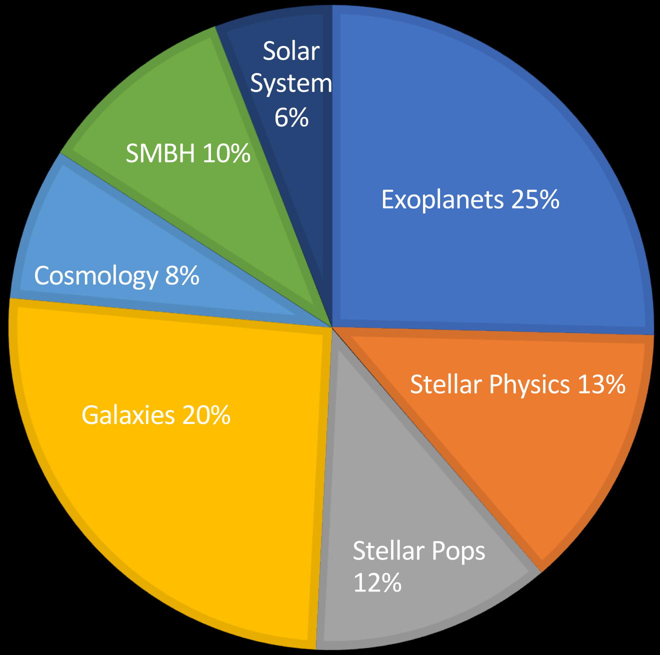
Cycle 1 Science observations are being assembled, which is comprised of:

1. Guaranteed Time Observations (GTO): ~4,000 hours
   - Time awarded to scientists who helped develop hardware/software for the Observatory or developed interdisciplinary science cases.
2. Early Release Science (ERS): 460 hours
   - 13 community-driven programs executed in the first 5 months of science operations and data made public *immediately*, covering broad science in the Solar System, Planets and Planet Formation, Stellar Populations, Stellar Physics, Massive Black Holes and Their Host Galaxies, and Galaxies and the Intergalactic Medium.
3. Guest Observers (GO): ~6,000 hours
   - Any scientist can apply for time; proposal review process will be dual anonymous.
   - A compilation of small (< 25 hrs), medium (25 < t < 75 hrs), and large (> 75 hrs) programs.
   - Cycle 1 Call for GO Proposals that closed on November 24, 2020, with 30 additional approved extension requests.

Webb Cycle 1 Response Overview

- 1173 proposals submitted.
- 1084 GO proposals for ~24,500 hours, ~4:1 oversubscription
- 14 Survey and 75 AR proposals (including theory, etc.)
- 374 proposals by ESA PIs (31.9%); 44 proposals by Canadian PIs (3.8%)
- 12766 Co-investigators in total – ~50% more than HST Cycle 28
- 4332 Unique investigators (PI, co-PI & co-I)
- 44 Countries, 45 US states + DC and the Virgin Islands
- TAC meeting is scheduled for February 16 - March 4, 2021

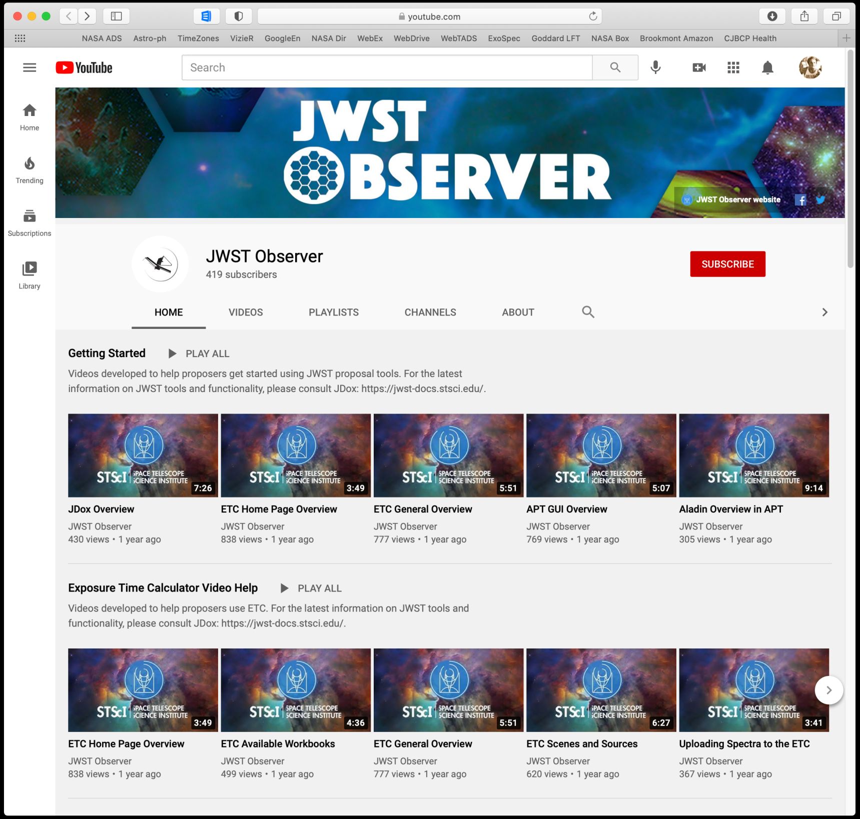
Proposals by Science Area



Courtesy Christine Chen, STScI

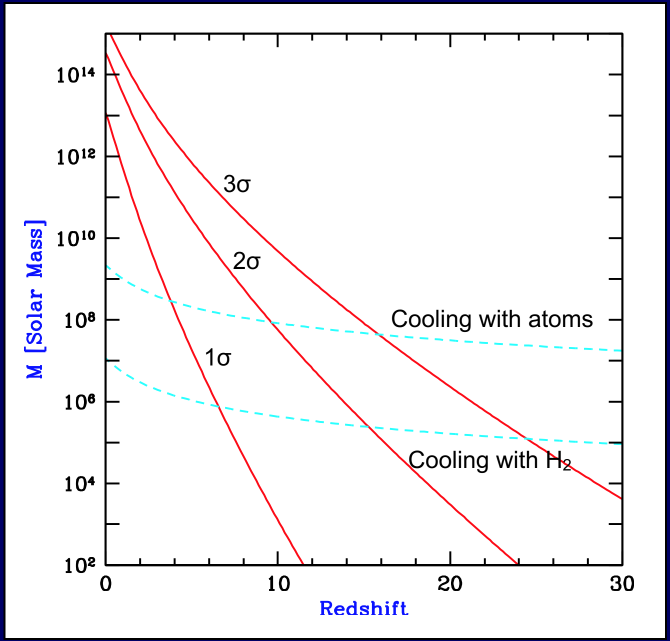
JWST Observer YouTube Channel

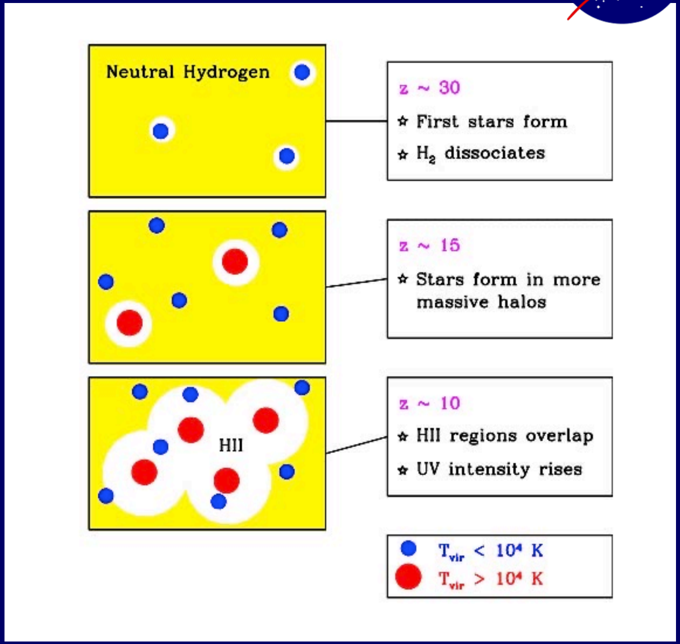
- Repository of information videos are being compiled on the JWST Observer YouTube channel.
- Early Release Science (ERS) Webinars.
- Assortment of talks.
- Instrument overviews.
- Proposal preparation.



Webb will see the very first galaxies

What are the first galaxies?





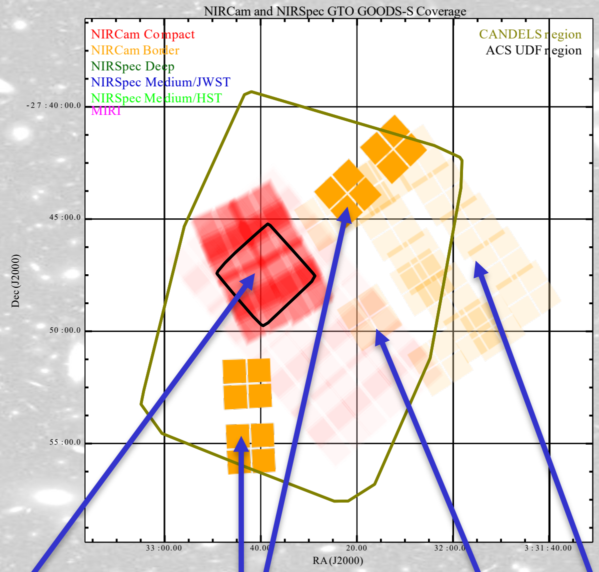
Barkana & Loeb 2001, Physics Reports, 349, 125

- Observations:
  - Ultra-deep NIR field, find z>15 H-band dropouts, 1.4 nJy
  - Follow-up Spect, MIR
  - Timing for transients to find SNe

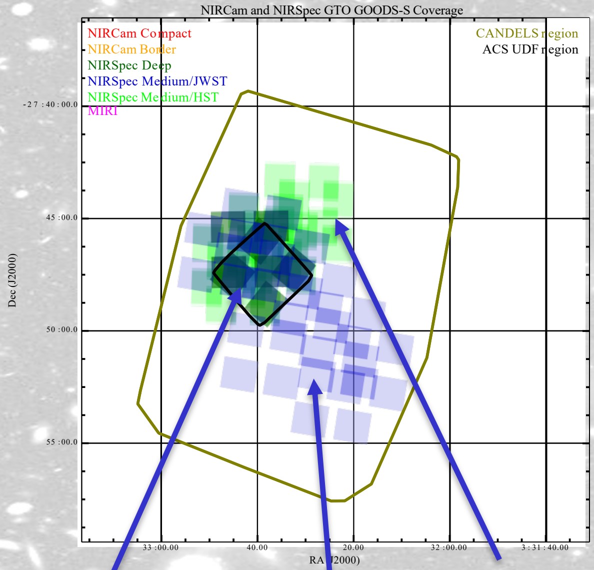
NIRCam and NIRSpec GTO Deep Survey

NIRCam Deep: 20 hrs/band, Med: 2 hrs/band -- NIRSpec Deep: 28 hrs, Med: 2.4 hrs

All proposed NIRCam imaging.

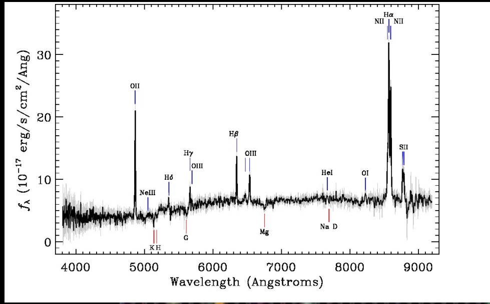


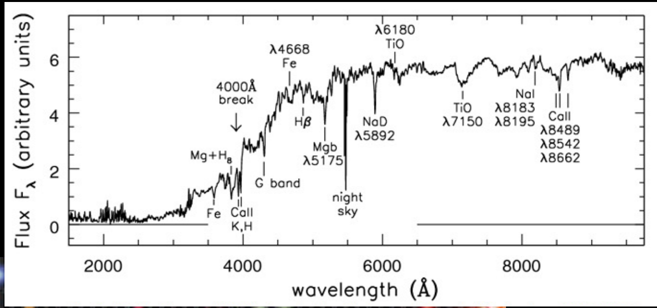
All proposed NIRSpec MOS spectroscopy

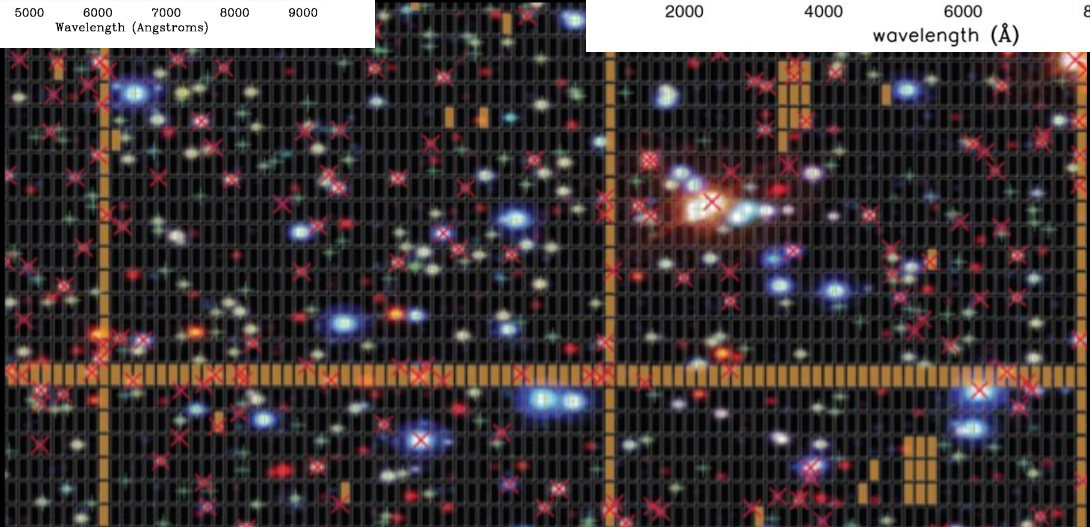


Model-Dependent Rule of Thumb: MOS

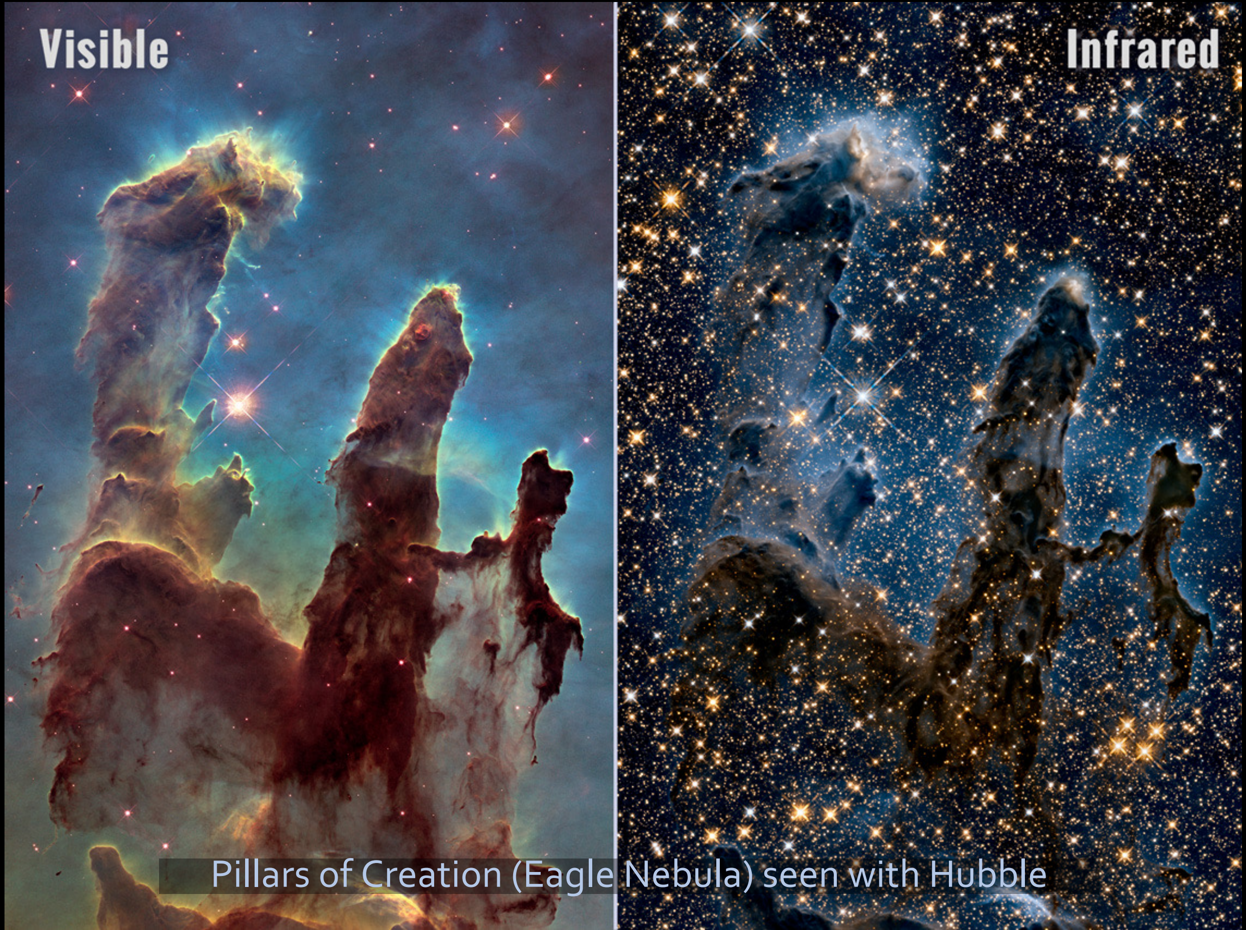
- JWST's multi-object spectrograph will have a huge impact on galaxy evolution science
  - Full rest-frame optical spectrum from z~1 to z~6.
  - Up to ~100 sources at a time (or more).





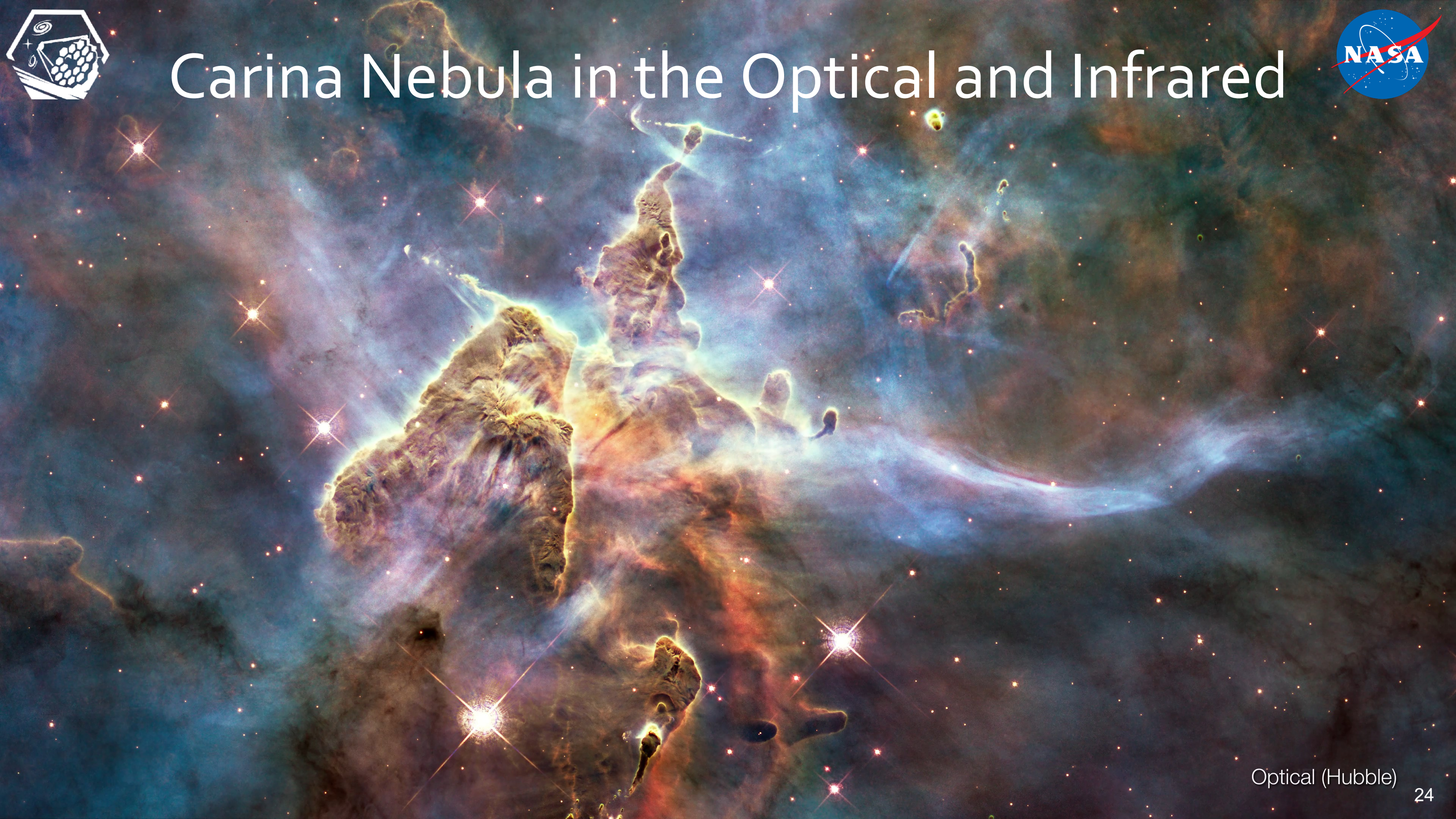


Webb will peer into dusty gas clouds



Pillars of Creation (Eagle Nebula) seen with Hubble

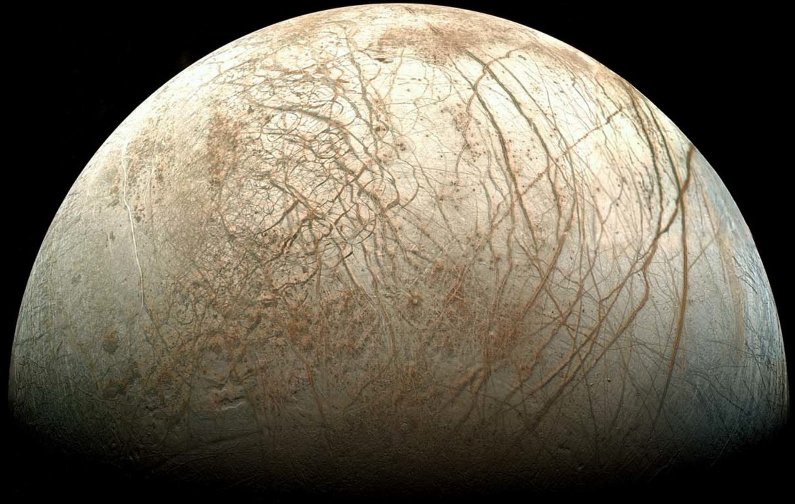
Carina Nebula in the Optical and Infrared



Optical (Hubble)

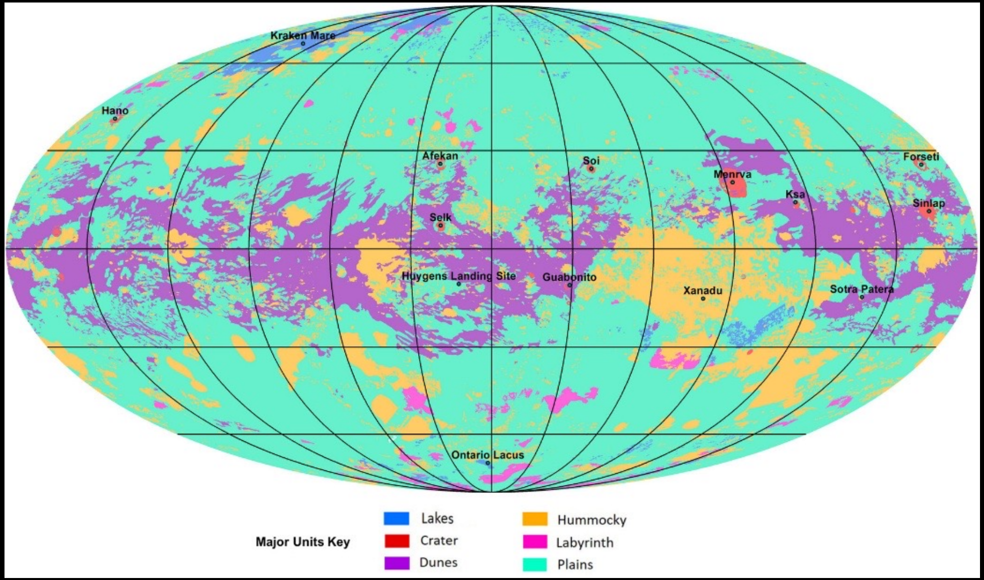
Webb will observe solar system Mars and beyond

Europa has an ocean, ice sheets, warm water geysers, and we're going back



NASA / Jet Propulsion Lab-Caltech / SETI Institute

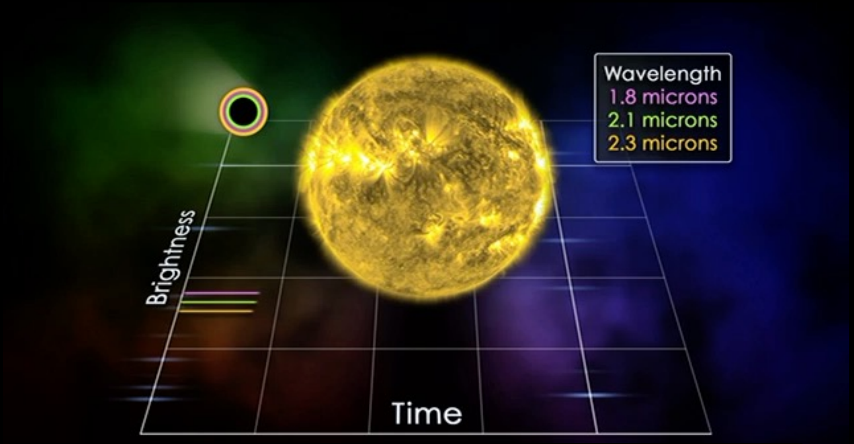
Titan has clouds, hydrocarbon rain, lakes, rivers, craters, dunes, weather, ice rocks, and we're going back

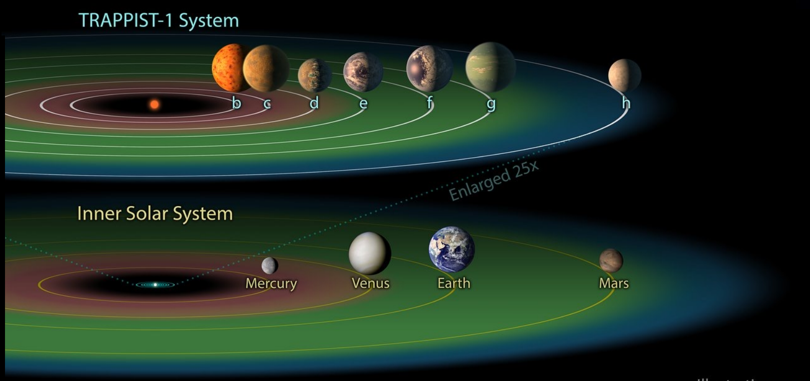


NASA/JPL-Caltech/ASU

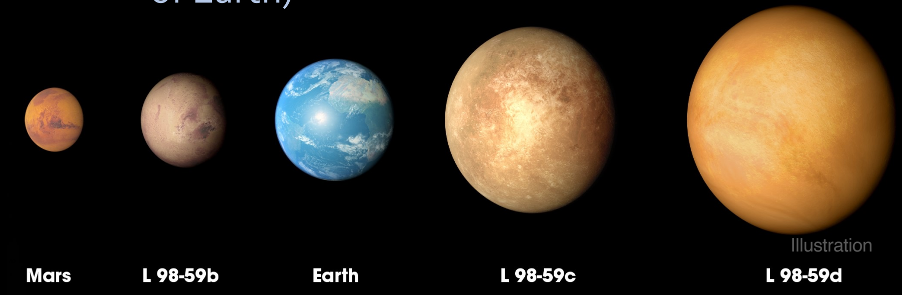
Webb will observe the chemistry of exoplanets

- Webb will observe transits of exoplanets at different wavelengths of light
- Water, carbon dioxide, methane, and other molecules
- Plans include:
  - 9 Earth-size exoplanets (around 1-2x the size of Earth)
  - 5 Neptune-size exoplanets (around 3-8x the size of Earth)
  - 16 Jupiter-size exoplanets (more than 8x the size of Earth)





Illustration



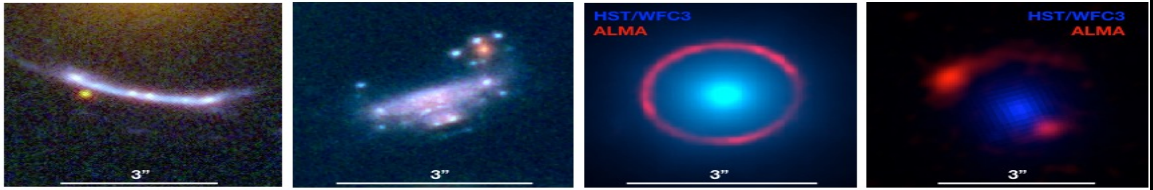
Early Release Science Program

- ERS purpose:
  - Public JWST data early in Cycle 1
  - Demonstrate science and capabilities
  - Teams return higher-level data products to the archive
- 106 proposals submitted: 13 selected for 460 Hours
- The selected programs represent participation by 253 investigators from 18 countries, 22 U.S. states, and 106 unique institutions.
- 4 webinars were recorded with overviews of the 13 ERS programs.

ERS programs: Distant Galaxies and Cosmic Dawn

Source	S1723+34	S1226+21	SPT0418-47	SPT2147-50
redshift	1.32	2.92	4.22	3.76
magnification	20	40	32	6.6

Image Plane



TEMPLATES: Highly lensed galaxies. PI: Jane Rigby

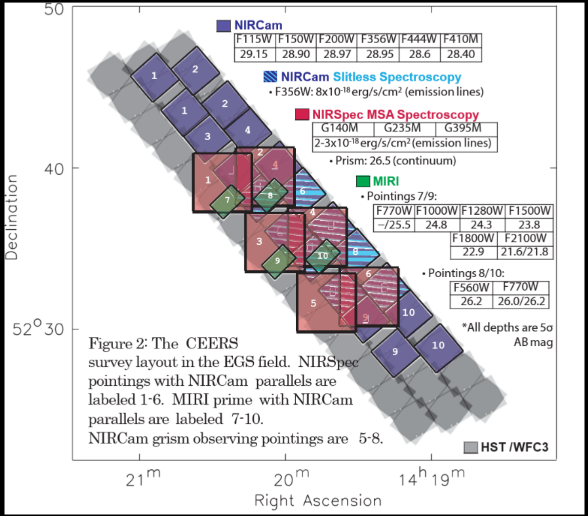
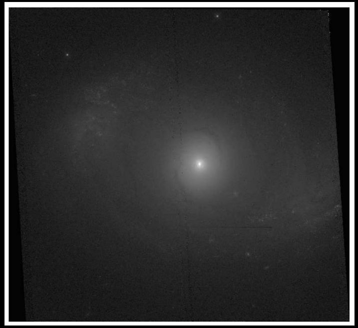


Figure 2: The CEERS survey layout in the EGS field. NIRSpec pointings with NIRCam parallels are labeled 1-6. MIRI prime with NIRCam parallels are labeled 7-10. NIRCam grism observing pointings are 5-8.

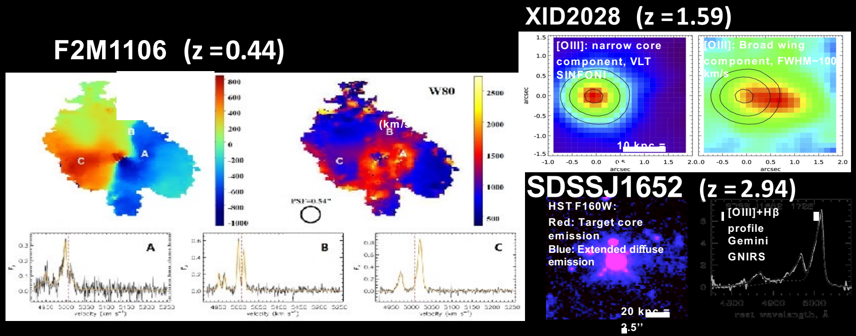
CEERS: Imaging and Spectroscopy of a CANDELS field. PI: Steve

GLASS: Slitless and MOS Spectra of a Frontier Field Cluster. PI: Tomasso Treu

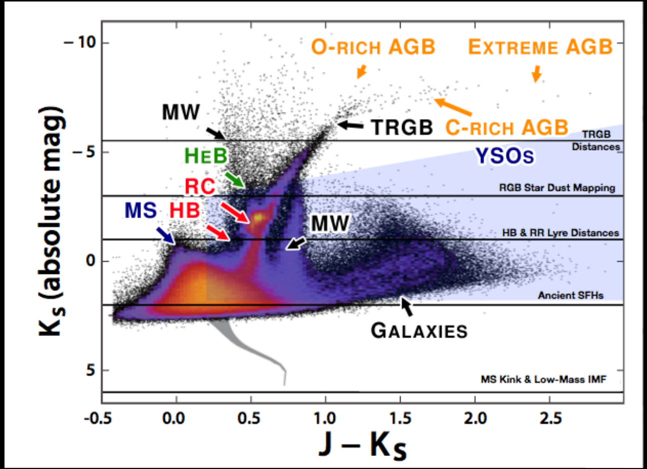
ERS programs: Nearby and Resolved Galaxies



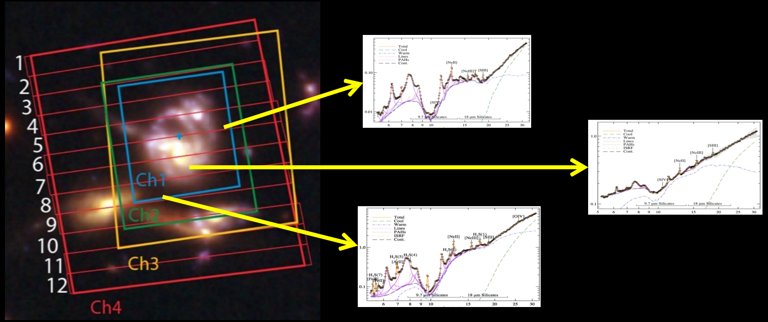
Nuclear Dynamics of a Seyfert. PI: Misty Bentz



Q-3D: IFU of Quasar Hosts.
PI: Dominika Wylezalek

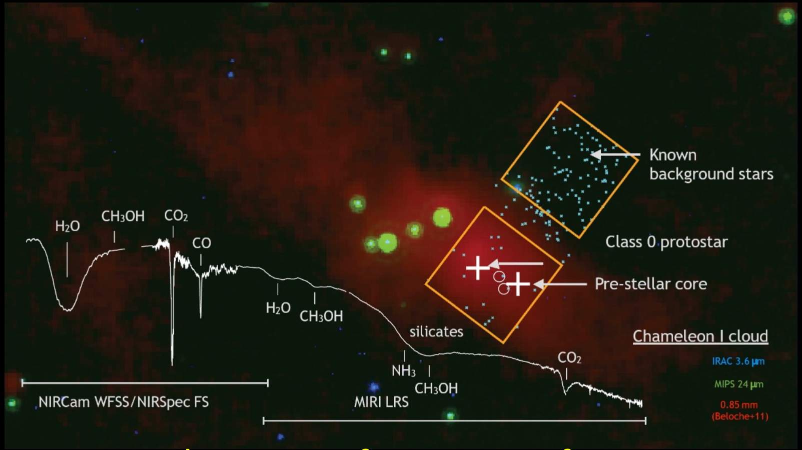


Resolved stellar populations in globular and 2 dwarf galaxies.
PI: Dan Weisz

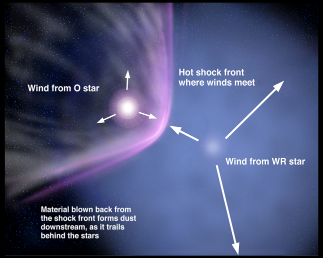


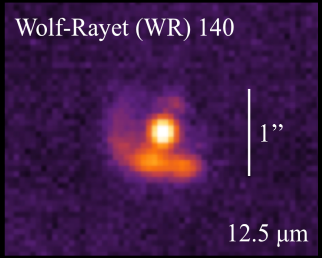
The Starburst-AGN connection in LIRGs.
PI: Lee Armus

ERS programs: Astrochemistry and the ISM

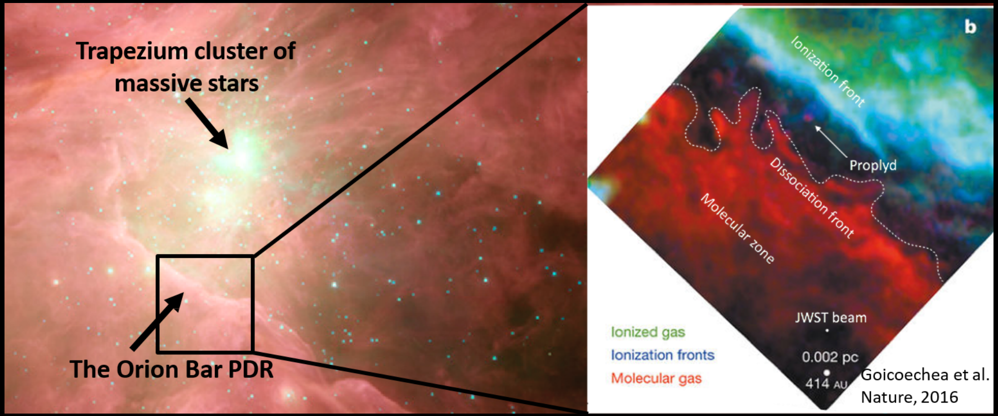


ICEAGE: Chemistry of ices in star formation.
PI: Melissa McClure



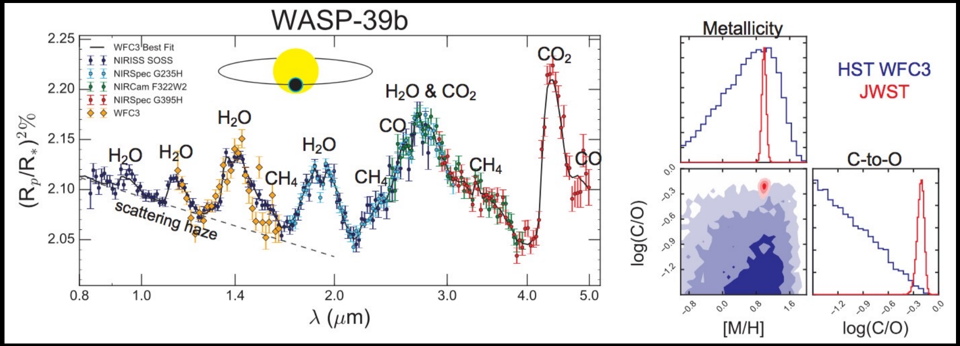


WR DustERS: Dust formation in colliding-wind Wolf-Rayet stars.
PI: Ryan Lau

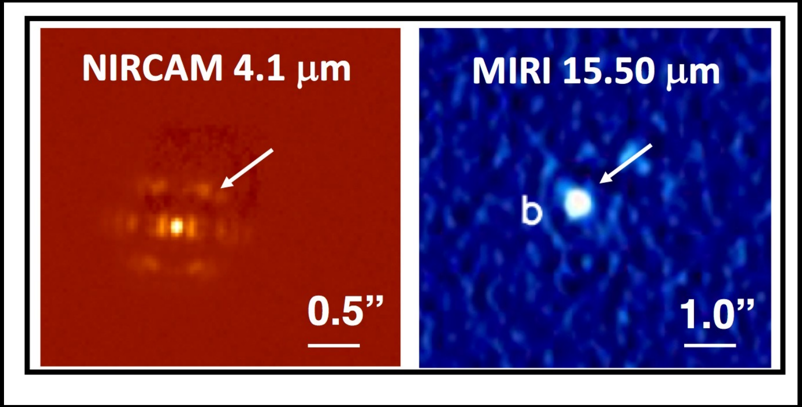


Radiative Feedback from Massive Stars: PDRs in Orion.
PI: Olivier Berné

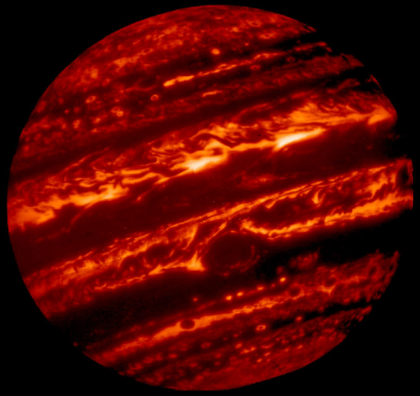
ERS programs: Planets



Transiting Exoplanets. PI: Natalie Batalha



Exoplanet Coronagraphy. PI: Sasha Hinkley

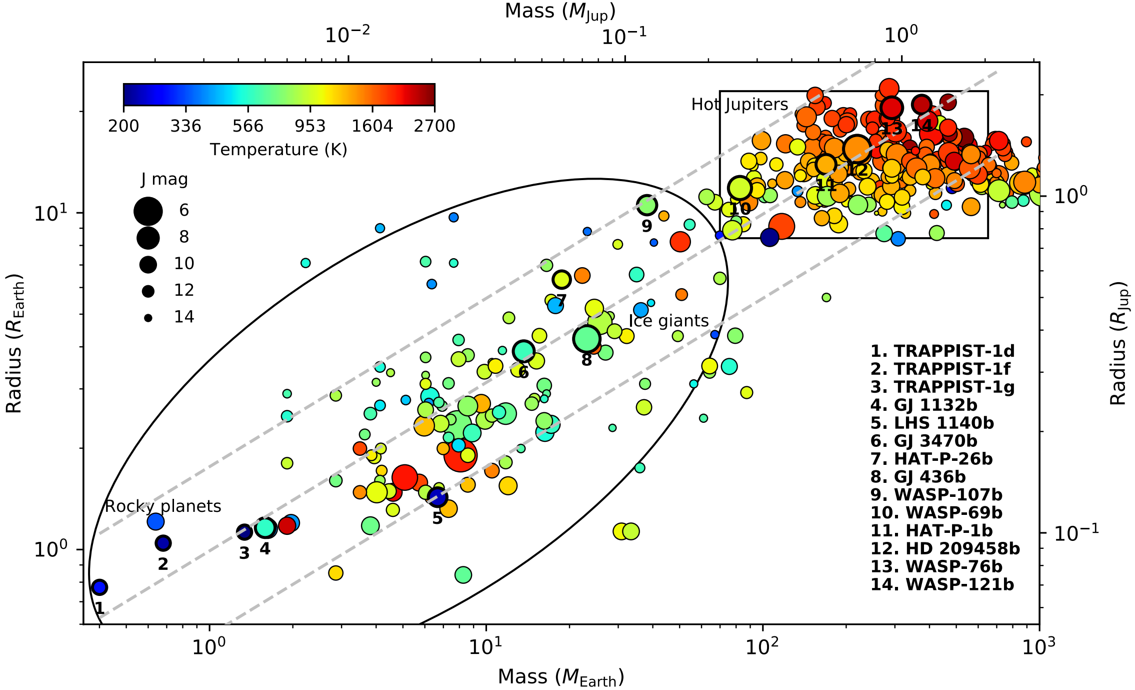


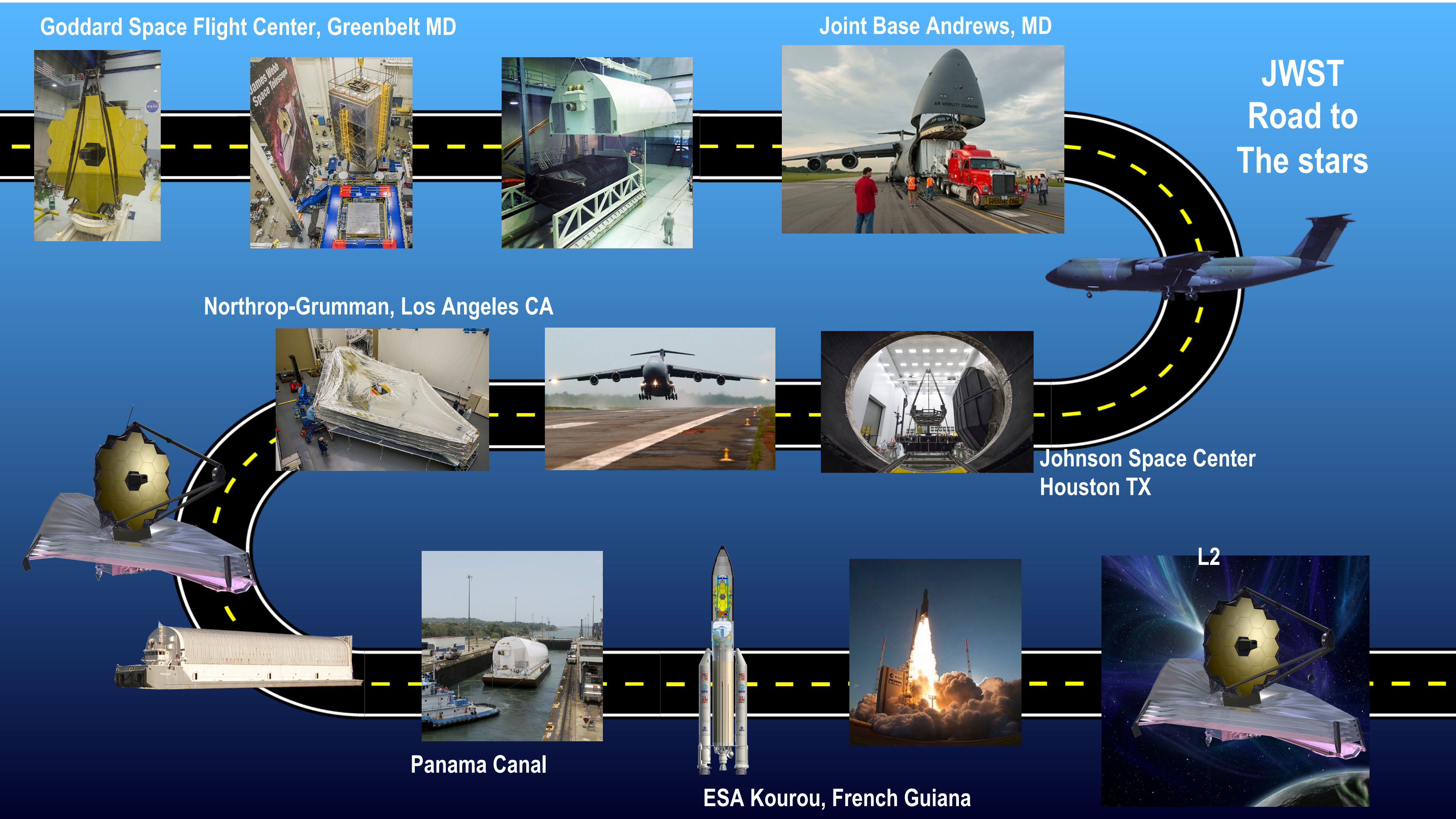
The Jovian System.
PI: Imke de Pater

NEAT: NIRISS Exploration of the Atmospheric diversity of exoplaneTs

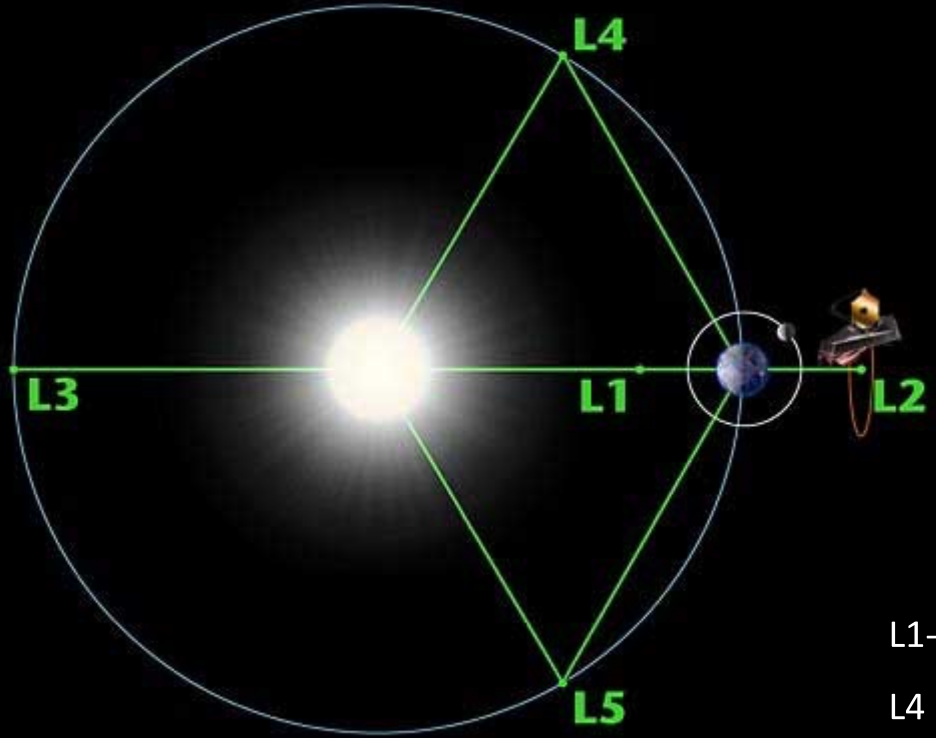
David Lafrenière and the NIRISS Exoplanet spectroscopy working group

- 15 targets: rocky/Earth-size planets, sub-Neptunes, hot Jupiters
- One full phase curve (Wasp-18b)
- 29 visits



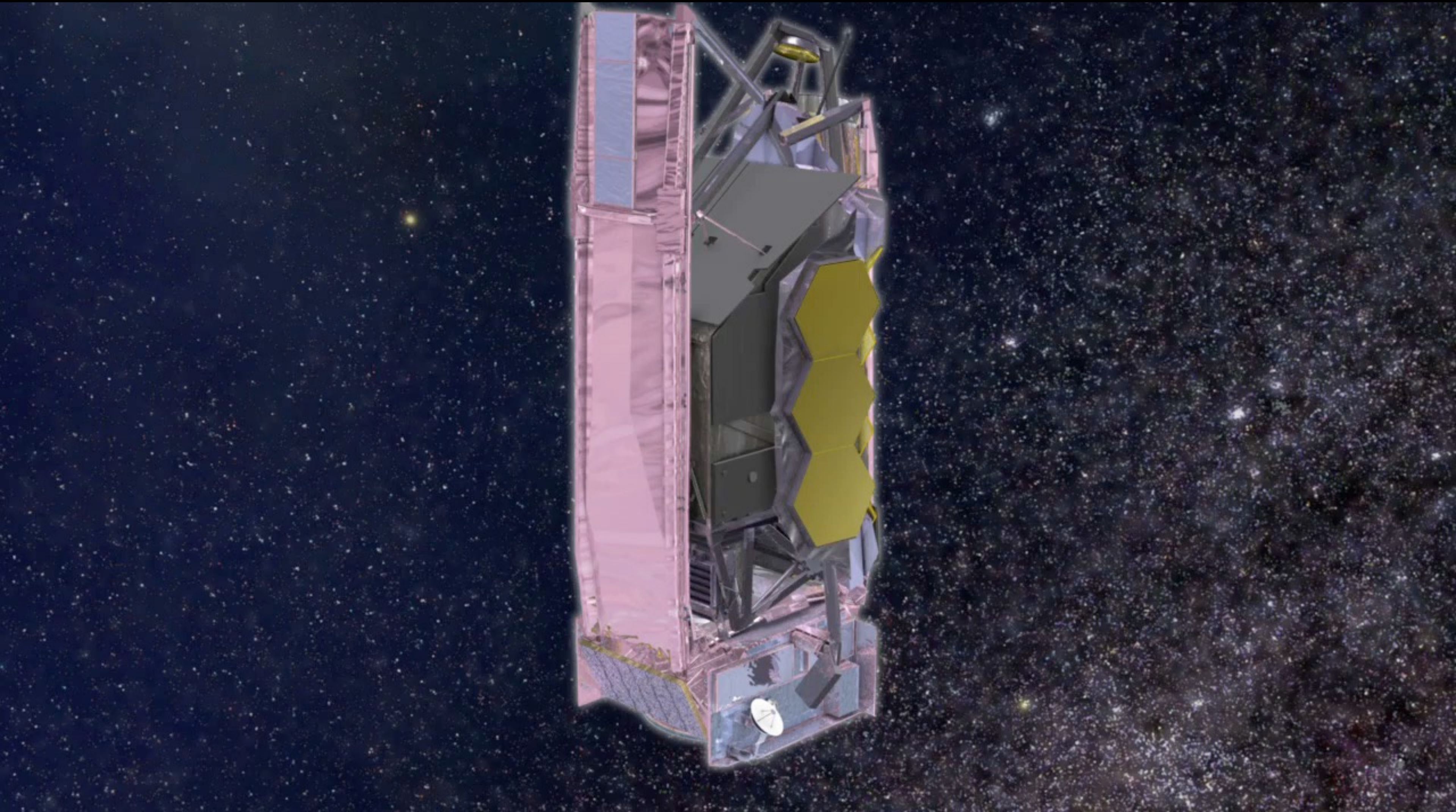

JWST
Road to
The stars
Goddard Space Flight Center, Greenbelt MD
Joint Base Andrews, MD
Northrop-Grumman, Los Angeles CA
Johnson Space Center
Houston TX
L2
Panama Canal
ESA Kourou, French Guiana

JWST Orbits the Sun-Earth Lagrange Point L2



L1-3, Leonhard Euler, 1750.

L4 & 5, Joseph-Louis Lagrange, 1772



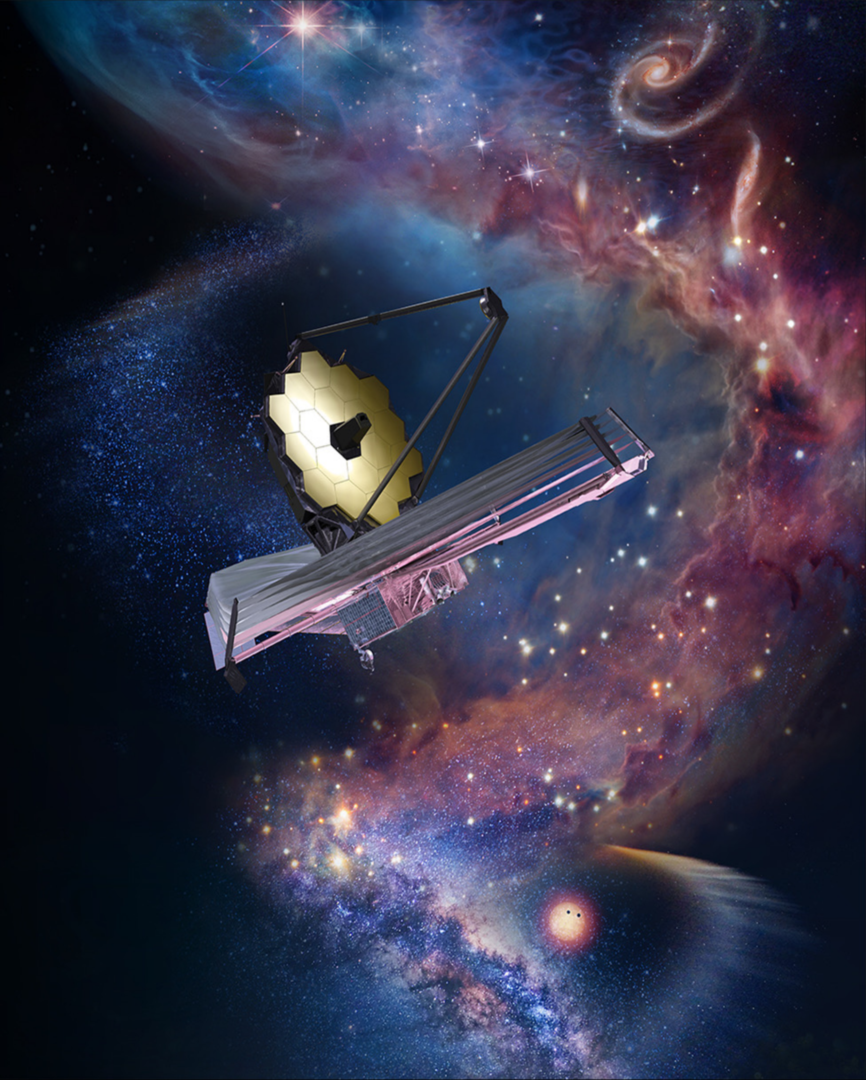
Following Webb

@NASAWebb

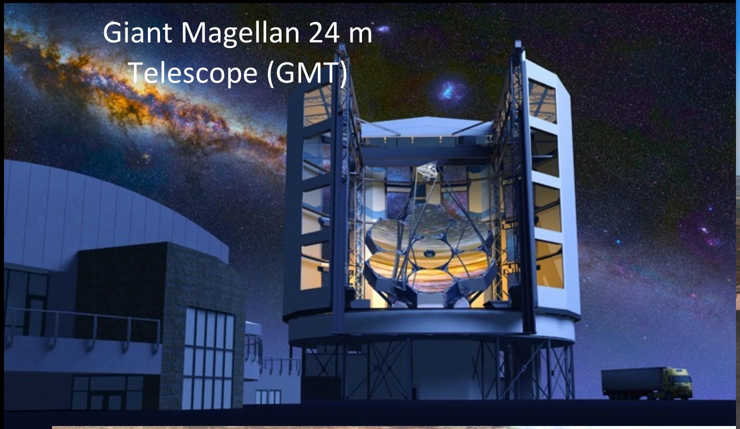
nasa.gov/webb

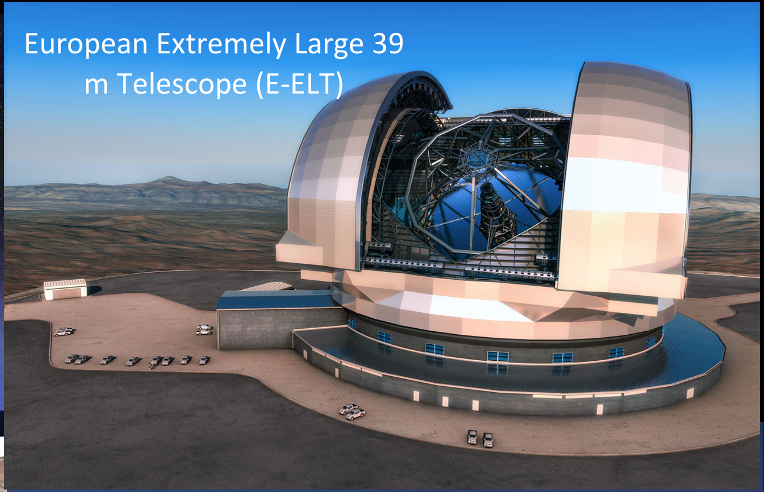
jwst.nasa.gov

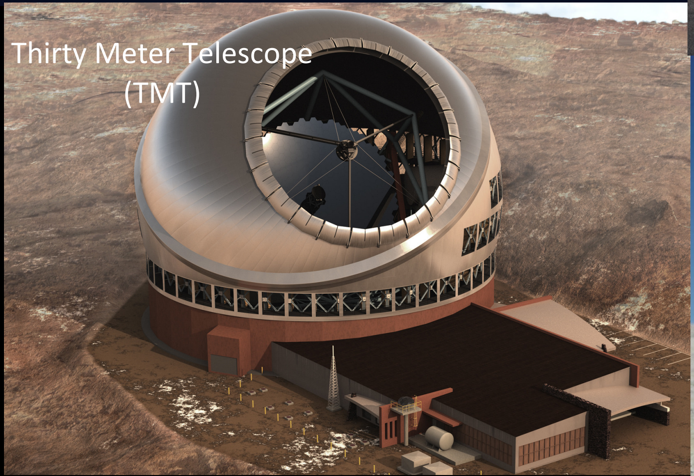
webbtelescope.org



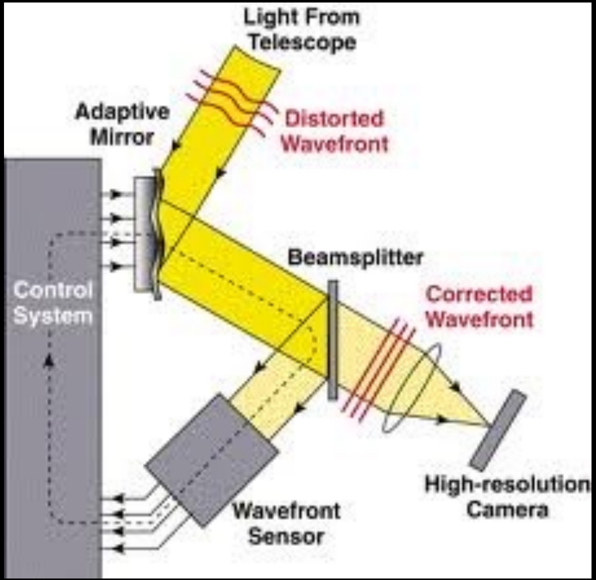
24 meters (1000 inches) and up!



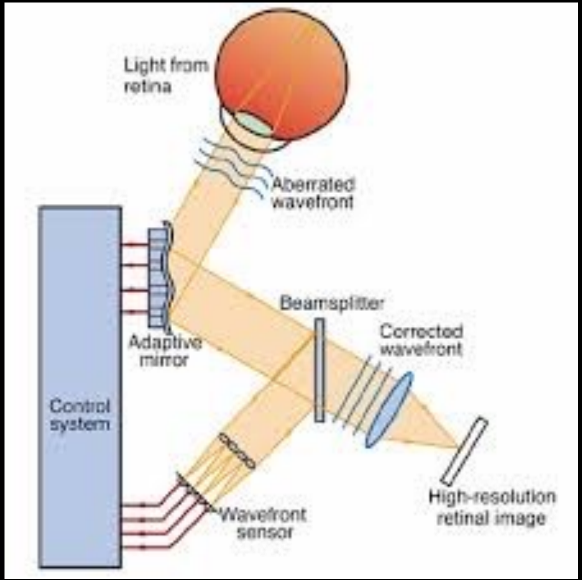




Adaptive Optics (AO) was for weapons, now astronomy & football

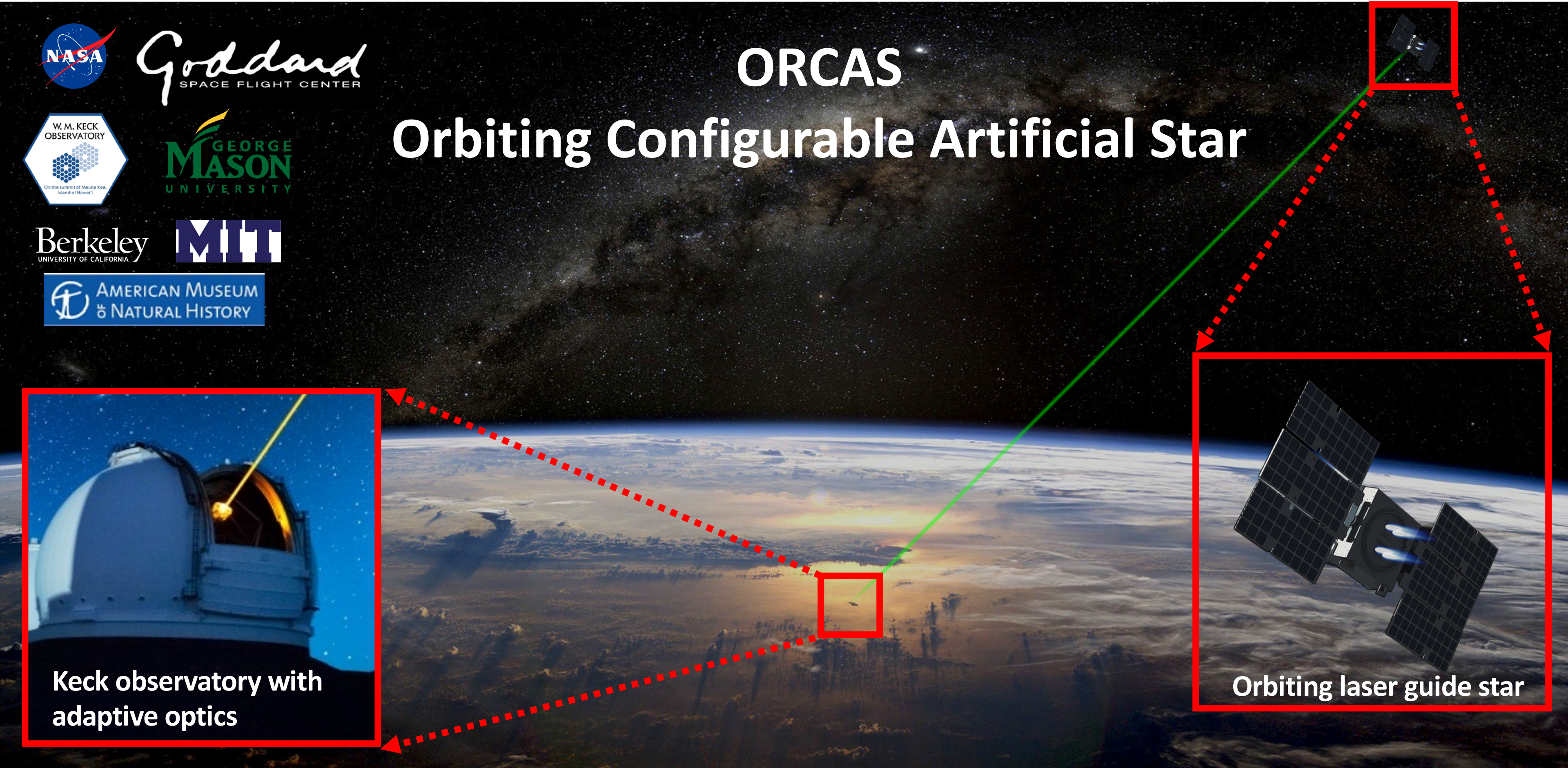


Needs bright guide star(s); how about a satellite beacon?



See through natural eye lens; get 20/10 vision

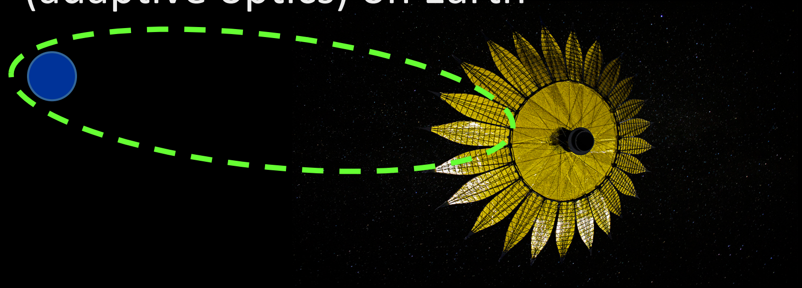
ORCAS
Orbiting Configurable Artificial Star



John C. Mather, Eliad Peretz, and many more
John.C.Mather@nasa.gov, 240-393-3879; Eliad.Peretz@nasa.gov, 607-882-0458

With a 100 m starshade, could see and get spectra for hundreds of solar systems

24-39 m Extremely Large Telescope (ELT) with visible AO (adaptive optics) on Earth



* 170,000 km altitude matches observatory v ~ 400 m/sec
* Laser beacon enables AO

Solar System at 5 pc in 1 minute

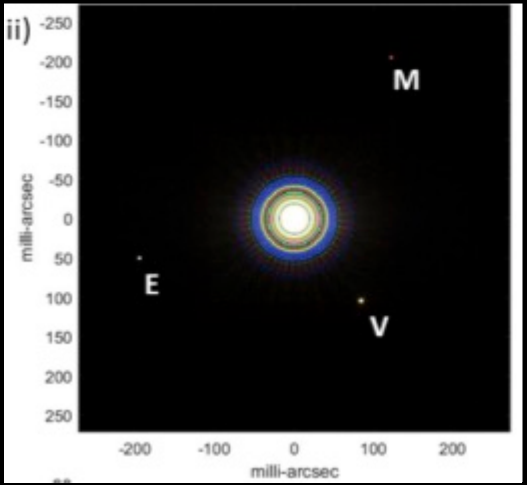
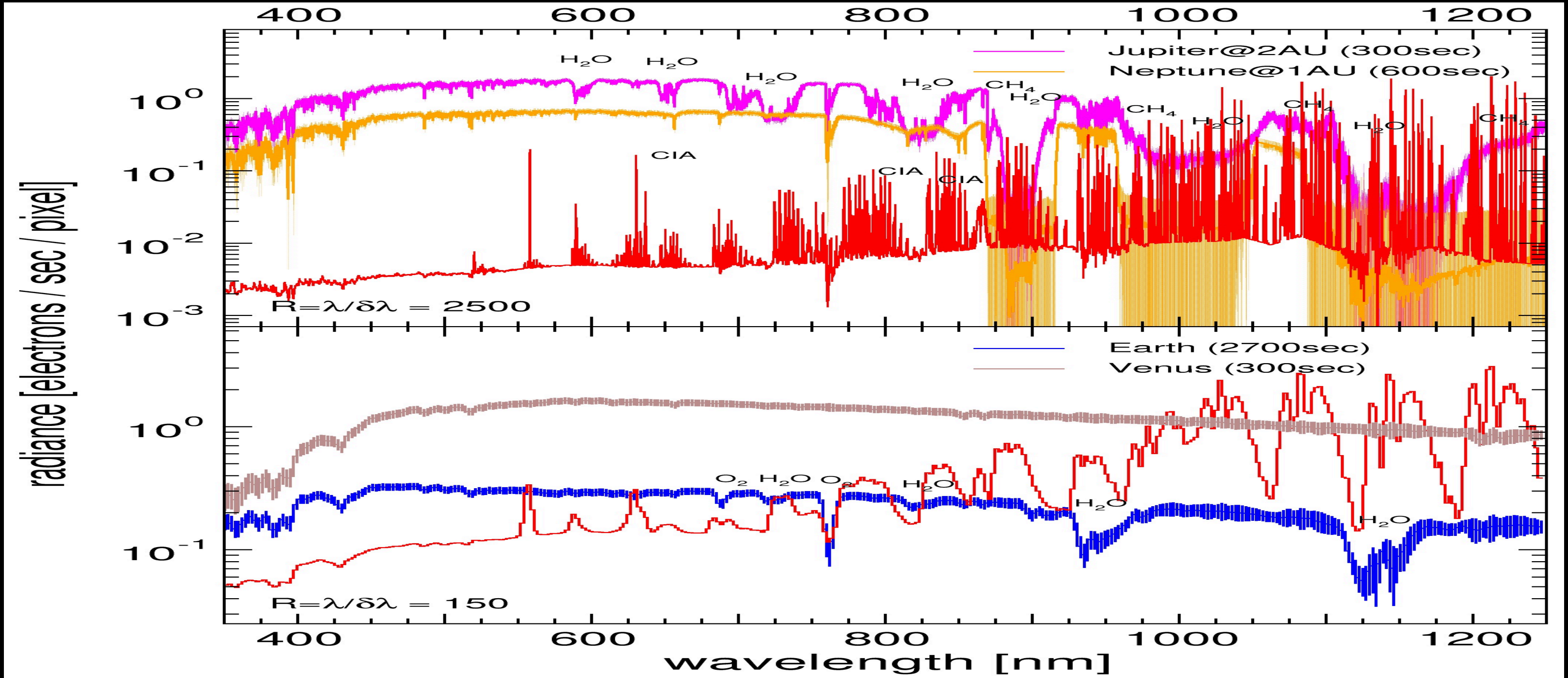


Image by Shaklan

Spectra at 5 pc: Exo-Earth H_2O and O_2 measurable through air



Simulated spectra for planets at 5 pc with Strehl = 0.5. Top panel R = λ/δλ = 2500, bottom R=150. 1 pixel = $\lambda_0/2R$ = 0.14 nm for R = 2000 and 2.34 nm for R = 150 at λ_0 = 700 nm. Red curves are sky brightness at the ELT in Chile. Widths of curves are ± 1σ. Water and oxygen are seen on exo-Earth and not on exo-Venus, and methane registers on a 2 AU Jupiter. [S. Kimeswenger, W. Kausch, S. Noll, N. Przybilla]

Questions