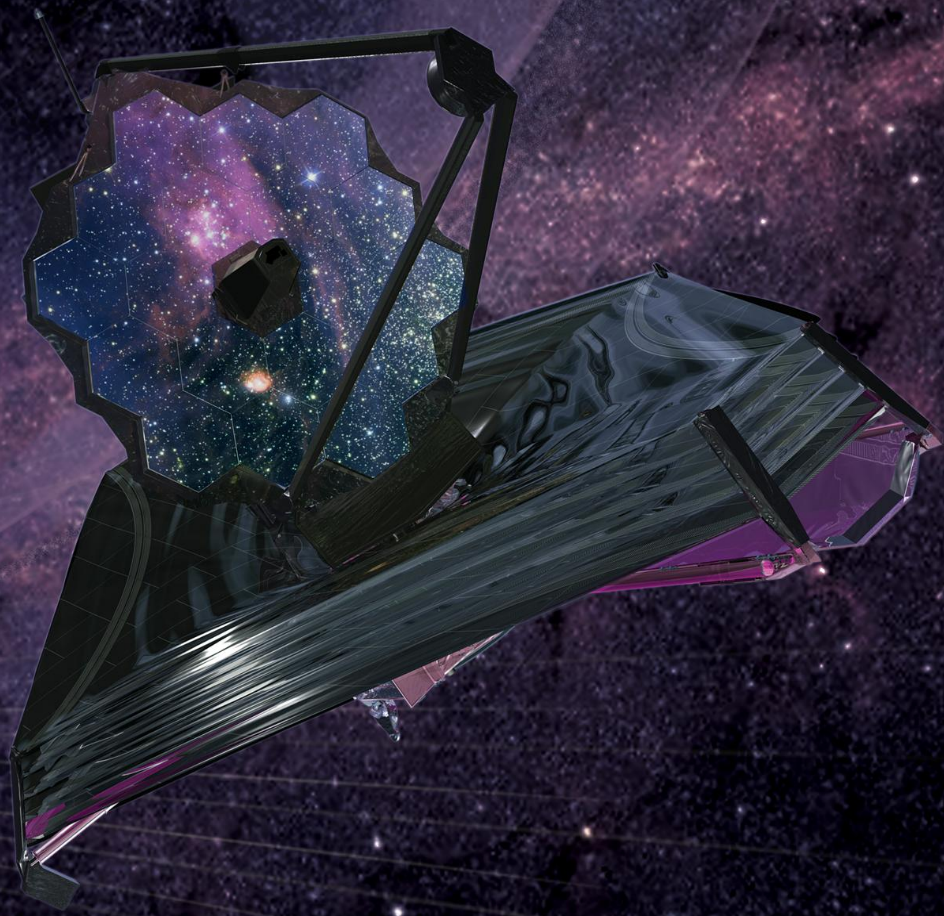
Jason Kalirai (STScI)

Frontier Science with the James Webb Space Telescope



Oct 20th, 2011

Astrophysics Subcommittee Meeting, NASA HQ

Frontier Science with JWST

Outline

1.) Two Slide Primer

2.) Instrumentation

3.) Frontier Science

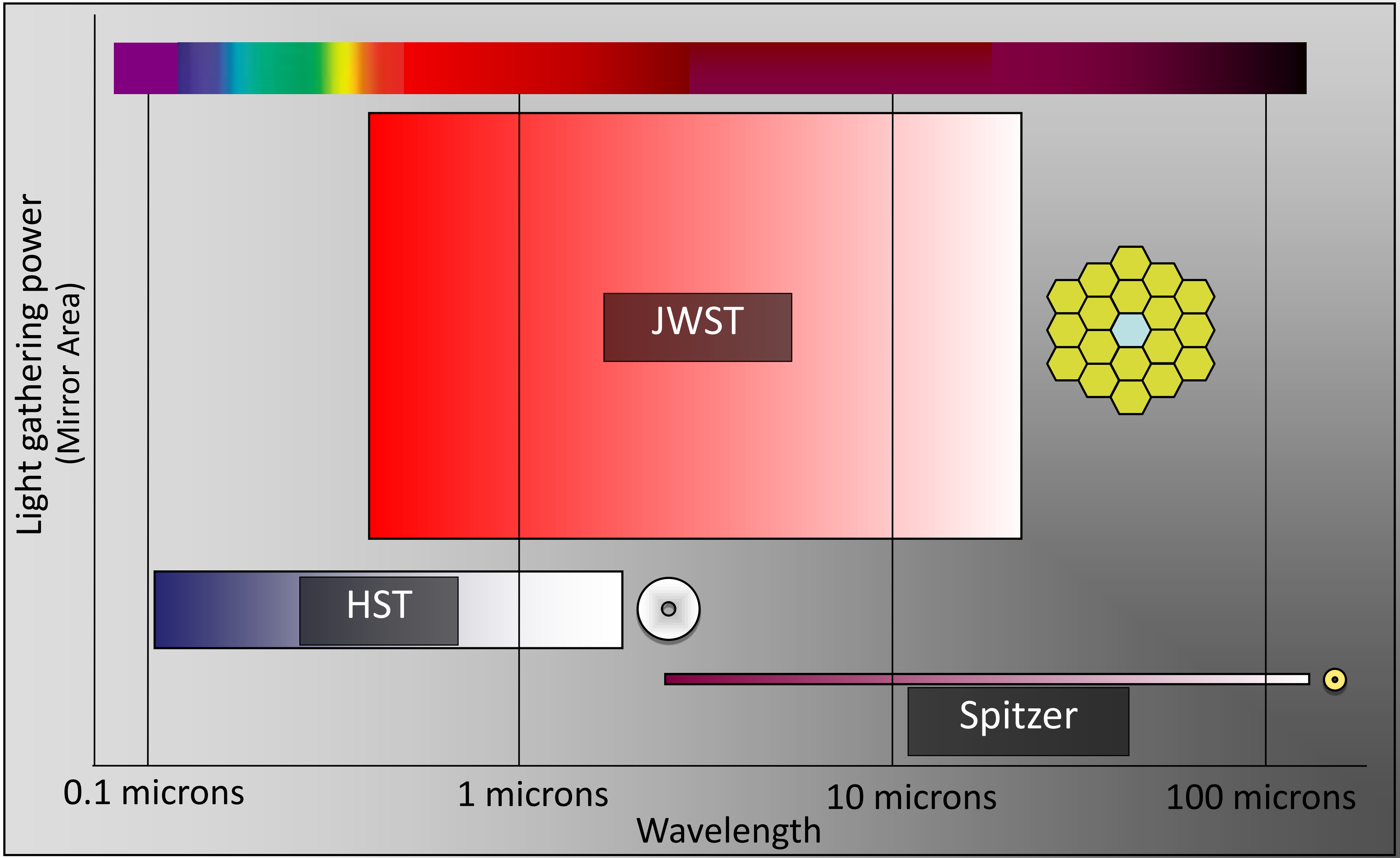
- Solar System
- Exoplanets
- Resolved Stellar Pops in the Milky Way
- Resolved Stellar Pops in the Local Volume
- First Galaxies and Stars
- Dark Energy

4.) Community Tools

JWST is Astronomy's Next Great Observatory

1.) Photon Limited Science

2.) Diffraction Limited Science



JWST is Astronomy's Next Great Observatory

1.) Photon Limited Science

2.) Diffraction Limited Science

Diffraction Limits

Hubble (D = 2.4 m)

ACS @ 0.5 μm = 0.043''

WFC3 @ 1.6 μm = 0.138''

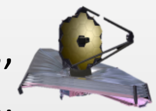
Spitzer (D = 0.8 m)

IRAC @ 3.6 μm = 0.93"

IRAC @ 8.0 μm = 2.06"

MIPS @ 24 μm = 6.18"

JWST (D = 6.5 m)



NIRCam @ 2 μm = 0.063''

NIRCam @ 4 μm = 0.126''

MIRI @ 10 μm = 0.317''

MIRI @ 20 μm = 0.635''

But, Hubble pixels are 0.04 – 0.05" at <1 μm and 0.13" at >1 μm

Spitzer pixels are 1.2" at <8 μm and 2.55" at 24 μm

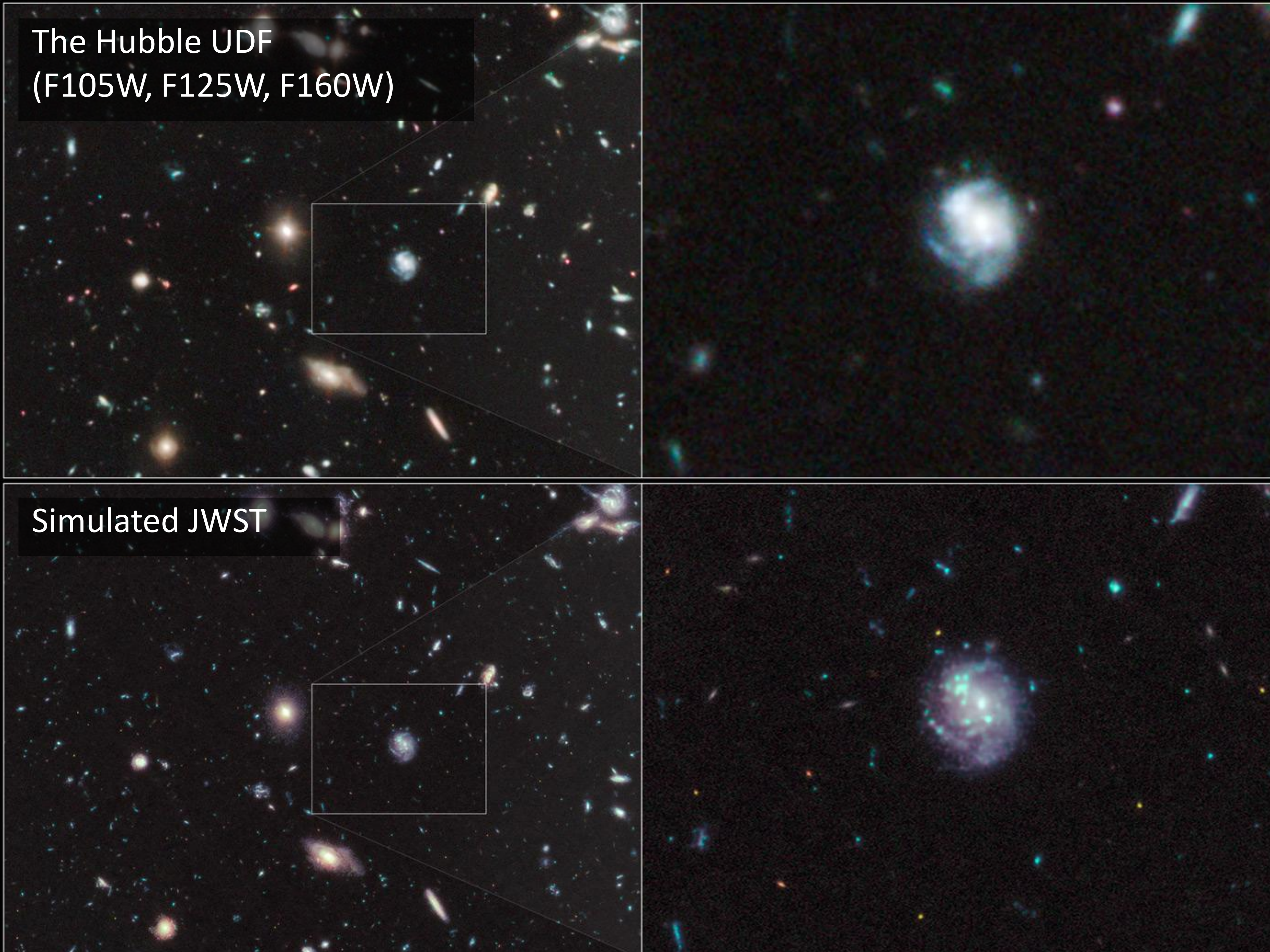
→ Hubble can not achieve Nyquist sampling of the diffraction limit

→ Spitzer only achieves Nyquist sampling of limit at λ > 24 microns

JWST NIRCam has two modules, with pixel size 0.0317" at <2.5 μm and 0.0648 at >2.5 μm

JWST MIRI has pixel size of 0.11 arcsec

→ **JWST achieves Nyquist sampling of the diffraction limit at 2 μm, 4 μm, and 7+ μm**


The Hubble UDF
(F105W, F125W, F160W)
Simulated JWST

JWST Instruments: Imaging, Spectroscopy, & Coronography

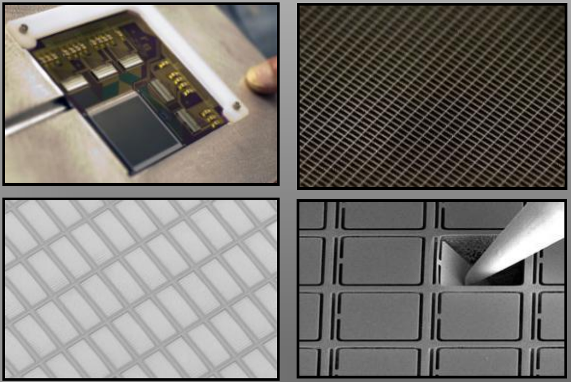
The Near Infrared Camera (NIRCam)

- Visible and near infrared camera (0.6 – 5 micron)
- 2.2’ x 4.4’ field of view, diffraction limited
- Coronographs

NIRCam

The Near Infrared Spectrograph (NIRSpec)

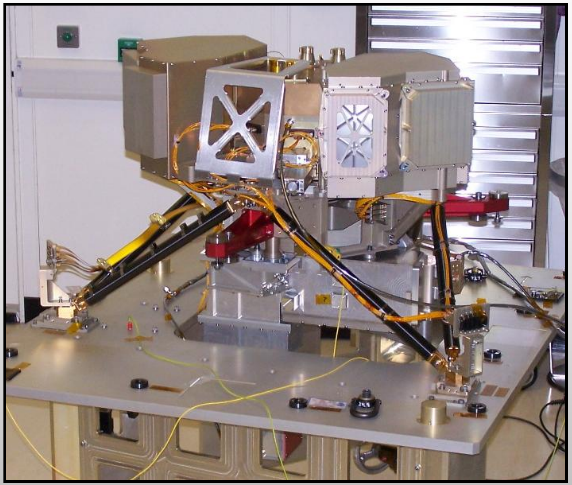
- Multi-object spectrograph (1 – 5 micron)
- 3.4’ x 3.4’ FOV, 0.1” pixels
- R = 1000 and 2700 gratings; R = 100 prism
- 3” x 3” IFU



NIRSpec

JWST Instruments: Imaging, Spectroscopy, & Coronography

The Mid Infrared Instrument (MIRI)
- Mid-infrared camera and spectrograph (5 – 28 microns)
- 1.9’ x 1.4’ imaging FOV, 0.11” pixels
- R = 100 slit spectrograph (5 – 10 micron) and IFU (R = 3000)
- Coronographs



MIRI

The Near Infrared Imager and Slitless Spectrograph (NIRISS)
- Infrared imager and slitless spectrograph
- 2.2’ x 2.2’ FOV

The Fine Guidance Sensor (FGS)
- 2.4’ x 2.4’ imager for target acquisition
- Rapid readout of subarray for ACS control
- 95% probability of finding a guide star anywhere in sky

NIRISS and FGS

Frontier Science Opportunities with JWST

Program

- Nearly 200 participants
- Mix of invited and contributed talks focusing on science potential
- 40 poster presentations
- 1/3 of total time was reserved for discussion
- PIs described instrument capabilities to deliver forefront science
- Public Talk, Education Display, Hubble 3D viewing, Science Writers Workshop, …

SOC Chair – Wendy Freedman

STScI – June 6 – 8th, 2011

Frontier Science Opportunities with JWST

Science Highlights

- Strong Lensing to Study the Evolution of Galaxies – *Tommaso Treu (UCSB)*
- High Precision Measurements of H_0 – *Adam Riess (STScI / JHU)*
- Finding the First Cosmic Explosions with JWST – *Daniel Whalen (Carnegie Mellon Univ.)*
- A Compendium of Kepler Discoveries for JWST Follow Up – *William Borucki (NASA ARC)*
- Observing the First Galaxies – *Richard Ellis (Caltech)*
- Solar System Opportunities with JWST – *Heidi Hammel (AURA)*
- Gas in Protoplanetary Disks – *Thomas Henning (MPIA)*
- Active Galactic Nuclei with JWST – *Jane Rigby (GSFC)*
- Star Formation in Galaxies in the Era of JWST – *Daniela Calzetti (UMass)*
- Mid Infrared Observations of High Redshift Galaxy Evolution – *Alexandra Pope (UMass)*

https://webcast.stsci.edu/webcast/
(Click "Webcast Archives")

Frontier Science Opportunities with JWST

Science Highlights

- Exotic Endings for Massive Stars – *Shri Kulkarni (Caltech)*
- Robust Predictions for High-z Galaxies: What will we Learn with JWST – *Andrew Benson (Caltech)*
- The "Final Frontier" of Star & Planet Formation:Piled Deeper & Wider – *Mike Meyer (ETH,Zurich)*
- Exoplanet Discovery and Characterization with JWST – *Jeff Valenti (STScI)*
- Weaving Circumgalactic Webs: The View from the Webb Telescope – *Crystal Martin (UCSB)*
- The Evolution of Chemical Enrichment and Outflows at z ~ 1-6 – *Alice Shapley (UCLA)*
- Probing Galaxy Stellar Mass Assembly in the Universe with JWST – *Karina Caputi (Edinburgh)*
- Resolved Stellar Populations in the Near IR – *Jason Kalirai (STScI)*
- Probing the Dissipation of K.E. In Phases of Galaxy Evol. with JWST – *Pierre Guillard (Caltech)*
- Star Formation in the Milky Way and its Neighbors in the Mid-IR – *Christine Wilson (McMaster)*

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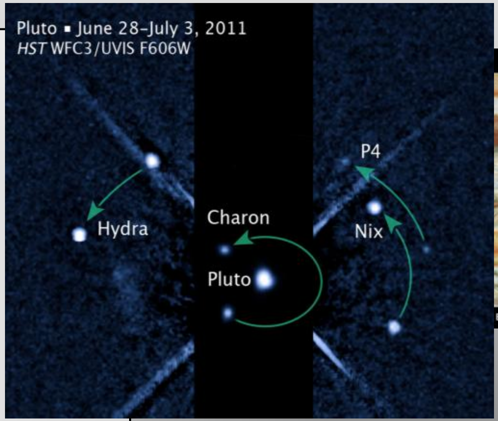
Solar System Science with JWST

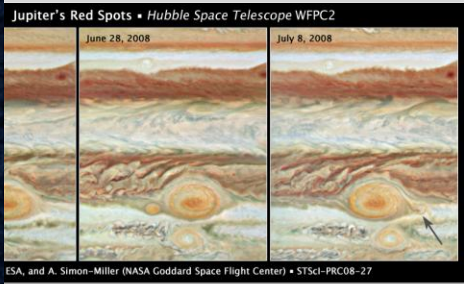
"There are three main areas in which collaboration with other parts of NASA could benefit the solar system exploration program....the Hubble Space Telescope has a long history of successful planetary observations, and this collaboration can be a model for future telescopes such as the James Webb Space Telescope."

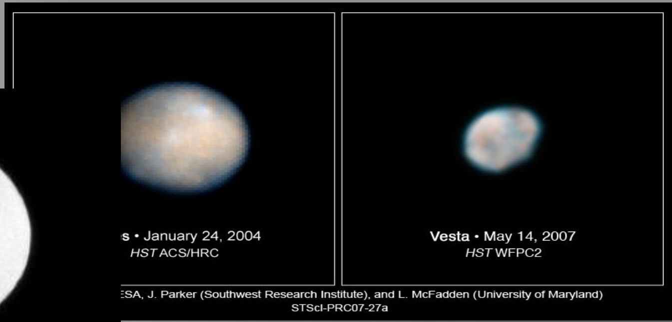
Vision and Voyages for Planetary Science in the Decade 2013-2022

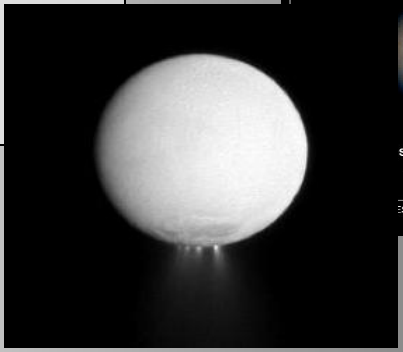
Hubble, Spitzer, and Herschel

- Discovery of new moons around Pluto
- Discovery of the largest ring around Saturn
- Characterization of Ceres and Vesta, others
- Discovery of new Kuiper Belt Objects (KBOs)
- Detailed studies of cloud structure in Gas Giants
- Torus of water vapor on Saturn
- Ocean-like water on Jupiter-family comet
- Long-term monitoring of the Martian atmosphere
- And much more…

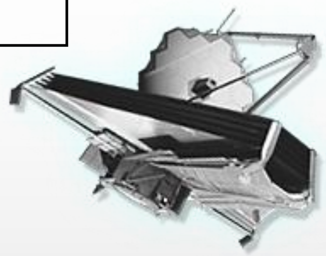








Solar System Science with JWST



Pointing Control System

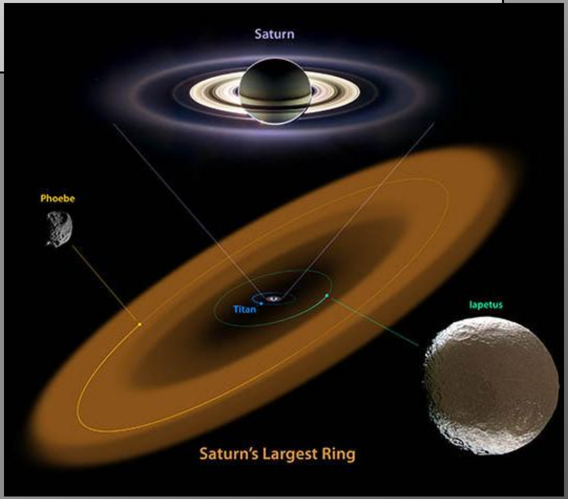
Enables observations of solar system objects with rates of motion up to 0.03 arcsec per second. Includes all planets and asteroids beyond Earth's orbit.

Mars

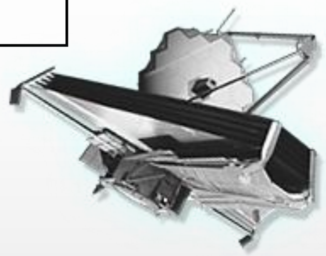
- Time-resolved NIR spectroscopy will reveal the variability of atmospheric species including CO_2, CO, and H_2O and constrain radiative and absorptive properties of airborn dust, enabling photochemical and dynamical modeling of the Martian climate.

Jupiter and Saturn

- MIR med-res. spectroscopy and IFU data will explore phosphine and methane fluorescence, which link to the vertical dynamics and thermal structure of the upper atmosphere.
- Provide a global context on large-scale weather patterns for high-resolution studies from complementary planetary missions (e.g., Juno and Cassini).



Solar System Science with JWST



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Uranus and Neptune

- Image spectral features from high latitudes in each planet with high sensitivity and map clouds.
- Spectral characterization of H_3^+, CO in fluorescence, detailed mapping of 5 micron window, search for minor species, and measure isotopic ratios of major elements.
- MIR observations will measure temporal variations in temperature, resolve sources of underlying driving dynamics, and disentangle causes of rotation modulation.

Solar System Science with JWST

Kuiper Belt Objects (KBOs)

•Image all known KBOs in the MIR

•R = 100 NIR spectroscopy with S/N = 20 in 3 hours (V < 25); R>100 for bright KBOs

1.) Constrain surface compos. (H_2O,CH_4,CH_3OH) & volatile inventories; first spectra at 2.5–5 microns.

2.) Address the dynamical and chemical history of the solar system; test formation theories.

Artist's impression of a binary KBO

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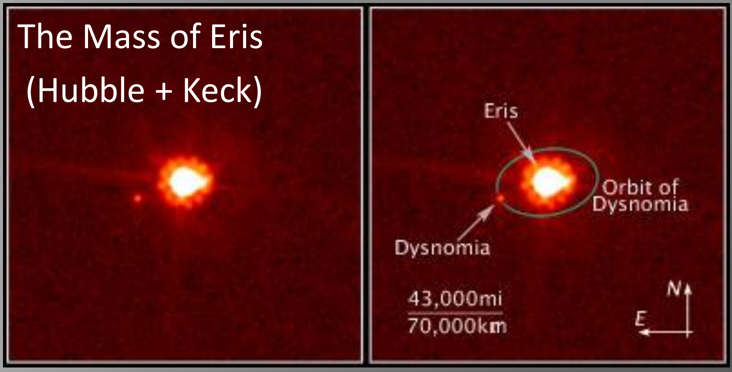
Dwarf Planets

- Time-resolved imaging of Pluto, Eris, Sedna and other dwarf planets
- IR spectroscopy of large bodies in the outer solar system

1.) Reveal seasonal behaviors and surface compositions.

2.) Track variations in N_2 and CH_4; discover new organic molecules/ices.

3.) Explore correlations between atmospheric chemistry changes and albedo.



Solar System Science with JWST

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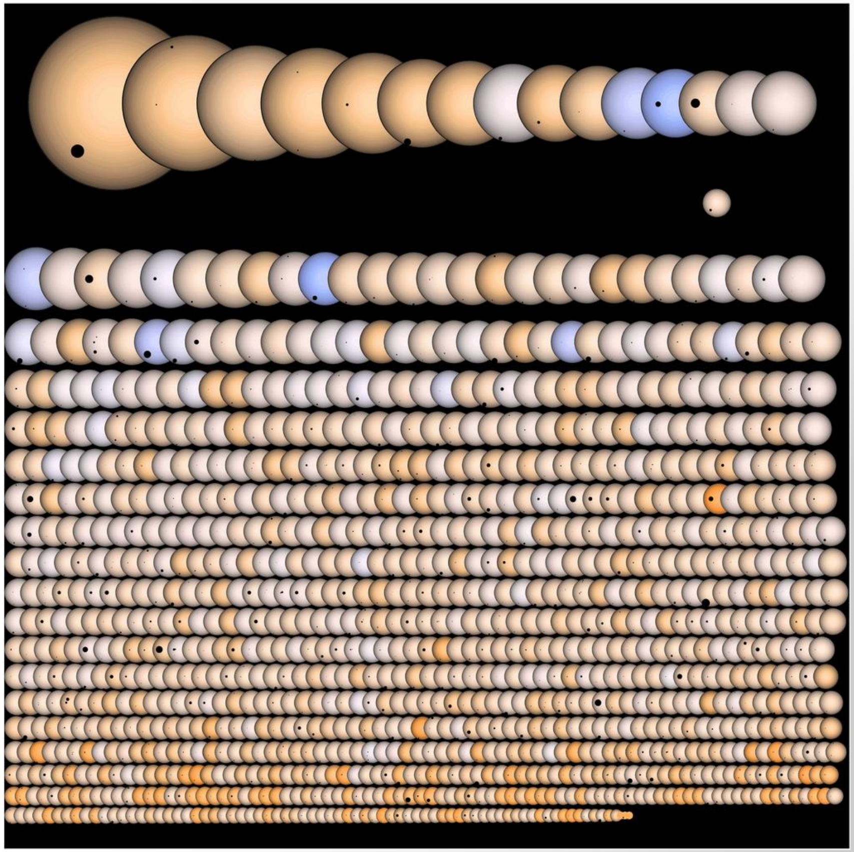
…and much more, including Icy Moons and Comets

1.) Lunine, J. et al. (2010), *"JWST Planetary Observations within the Solar System"*

2.) Sonneborn, G. et al. (2009), *"JWST Study of Planetary Systems and Solar System Observations"*

3.) Planetary Science with JWST Flyer, http://www.stsci.edu/jwst/news/2011/DPS2011_JWSTFlyer.pdf

Exoplanet Discovery and Characterization with JWST



Kepler

Planetary candidates in 1st data release

- 1235 candidates
- 68 Earth-sized planets
- 54 candidates in habitable zone
- 5.4% of stars host Earth sized planetary candidate

Transiting Exoplanet Survey Satellite (TESS)

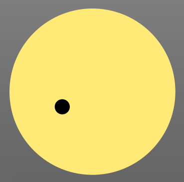
- Selected NASA Explorer Proposal for Potential Future Mission

Exoplanet Discovery and Characterization with JWST

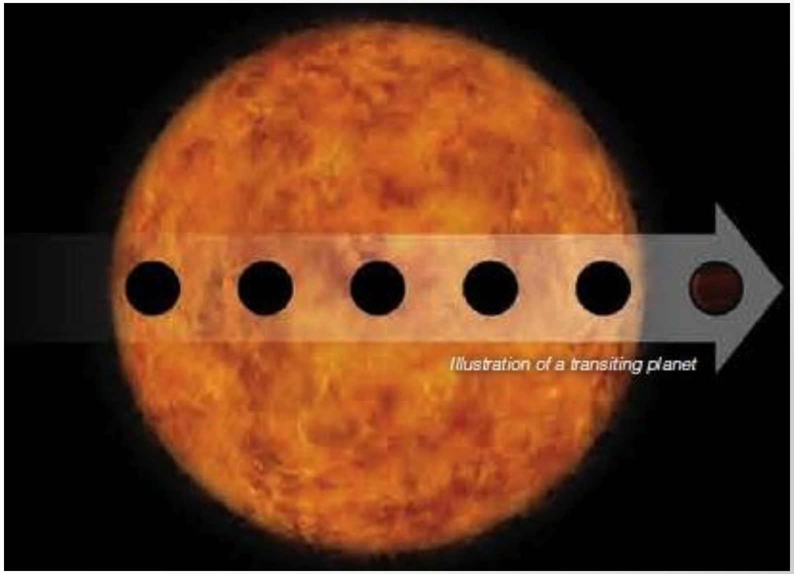
Application	Planet Type	Res.	JWST Scientific Investigations
Transit Light Curves	Gas Giants Intermediate Mass Super Earths Terrestrial Planets	5 5 5 5	- Planet prop. w/ RVs (mass, radius) → physical structure - Detection of terrestrial transits - Transit timing: detection of unseen planets
Phase Light Curves	Gas Giants Hot Neptunes	5 5	- Day to night emission mapping - Dynamical models of atmospheres
Transmission Spectroscopy	Gas Giants Intermediate Mass Super Earths	3000 100-500 <100	- Spectral line diagnostics - Atmospheric composition measurements (C, CO_2, CH_4) - Follow up of survey detections
Emission Spectroscopy	Gas Giants Intermediate Mass Super Earths	3000 100-500 <100	- Spectral line diagnostics - Temperature measurements - Follow up survey detections

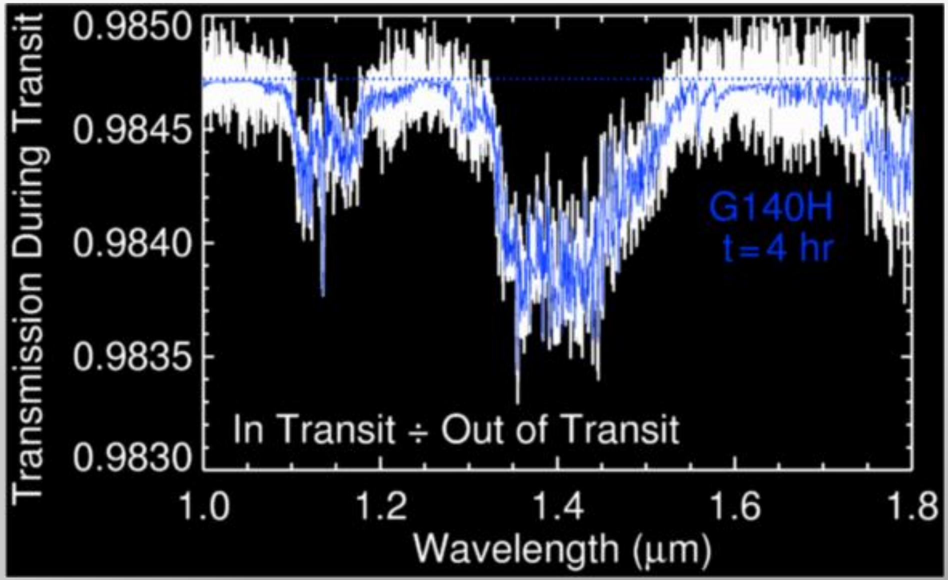
M. Clampin et al. (2009), JWST White Paper,
"Comparative Planetology: Transiting Exoplanet Science with JWST"

⟶ JWST/NIRSpec will measure phase curves of exoplanets around nearby M dwarfs in 1 hour.



Exoplanet Discovery and Characterization with JWST





Atmospheric transmission spectrum (4 hours) for HD209458-like Kepler source using NIRSpec (R=3000). Simulation from J. Valenti

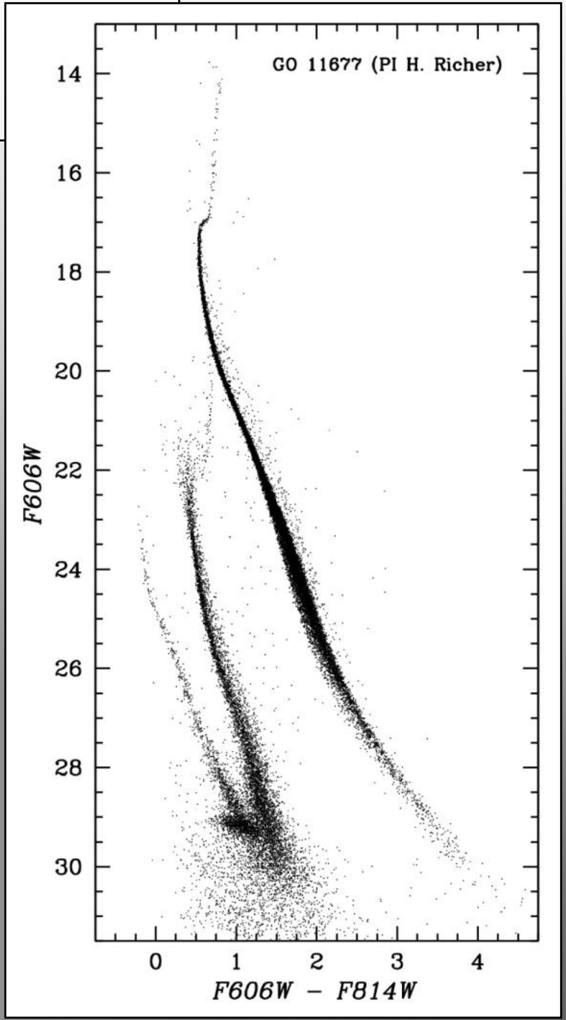
⟶ JWST can detect water in habitable zone Super Earths.

JWST and Resolved Stellar Pops in the Milky Way

Local Calibrators

- Star clusters represent excellent tools for testing stellar evolution models
- Constituent stars are coeval, iso-metallic, and co-spatial
- HST has been a game changer, especially at visible wavelengths

A wide-field view of 47 Tuc and the SMC

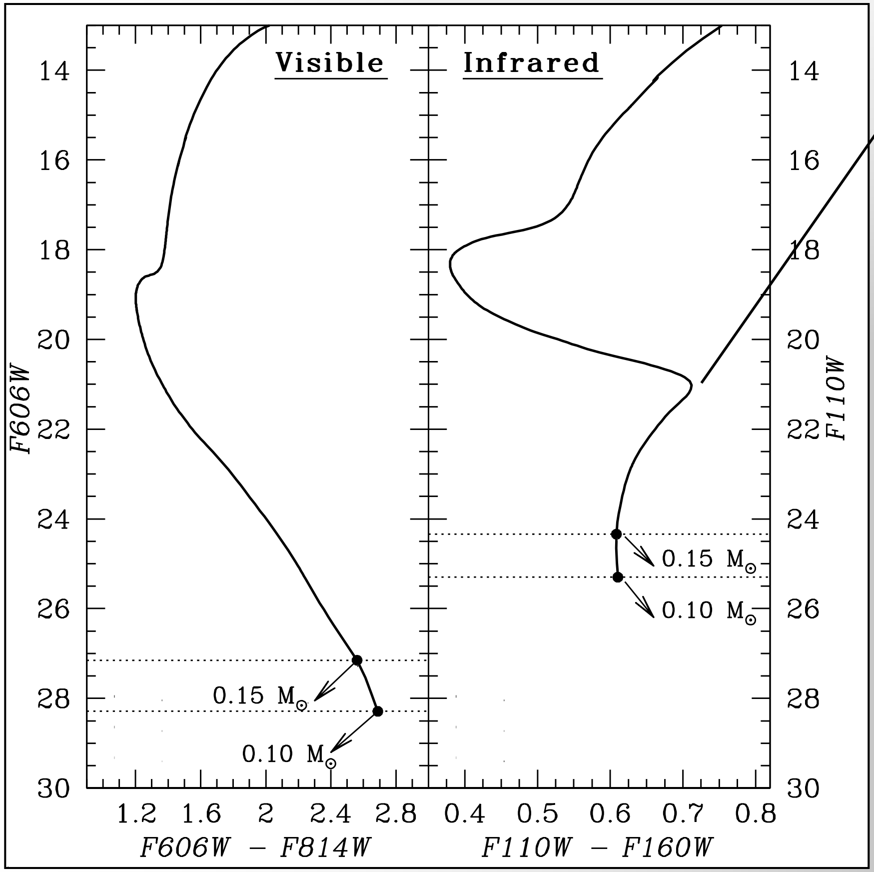


Complete Stellar Pops of a Cluster
J. Kalirai et al. (2011, submitted)

JWST and Resolved Stellar Pops in the Milky Way

Local Calibrators

- **JWST will be a game changer with IR high resolution, wide field capability**

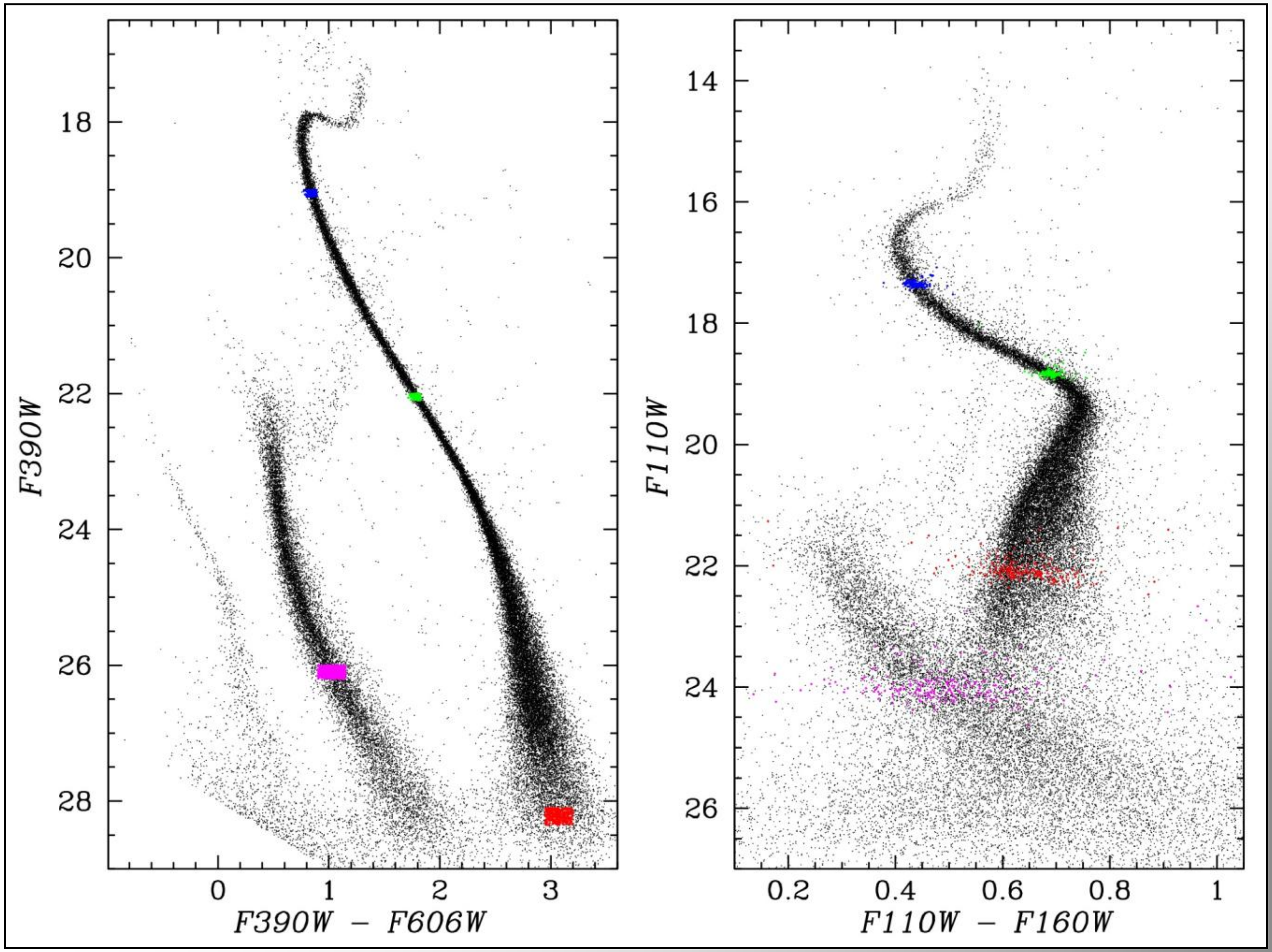


The predicted color-magnitude diagram shape for a coeval population at 10 kpc

- "Kink" is age insensitive, removes degeneracies
- Accurate fundamental parameters
- New tests of stellar evolution models in the IR
- New generations of pop. synthesis models
- Measure total stellar pop more efficiently

JWST and Resolved Stellar Pops in the Milky Way

First hints from WFC3/IR



J. Kalirai et al. (2011, submitted)

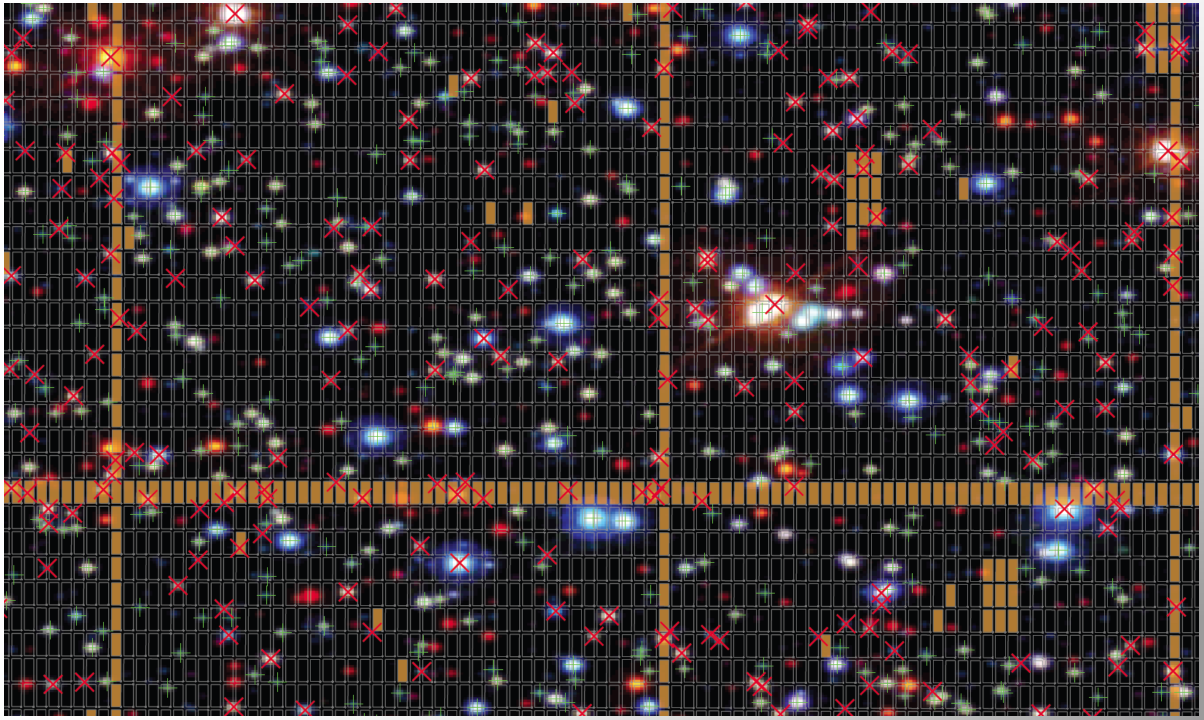
⟶ JWST will measure V = 30 M dwarfs in 10 minutes.

⟶ JWST will measure the stellar mass function to the H burning limit in stellar populations out to 25 kpc in <3 hours.

JWST and Resolved Stellar Pops in the Milky Way

A Simulated Field of Omega Cen and the NIRSpec Microshutter Array (MSA)

Combine JWST photometry with JWST spectroscopy



+ Targets in operable shutter
x Targets outside shutters

- NIRSpec will obtain large (~10^4) statistical samples of spectra in dense fields, 10-40% recovery.
- MSA reconfiguration once, no dithering. Sky background exposures are "free".
- Use cases in globular clusters, star forming regions, Galactic disk, Galactic bulge, *provided user requires statistical sampling of stars.*

JWST and Resolved Stellar Pops in the Milky Way

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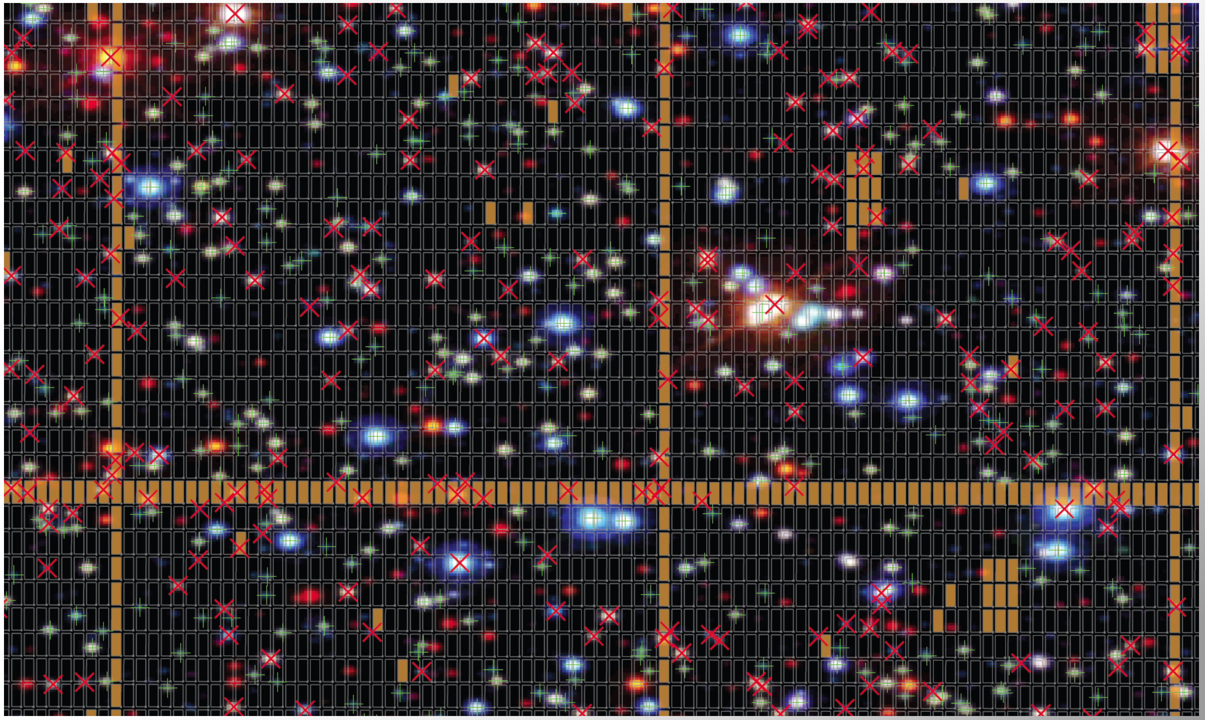
Combine JWST photometry with JWST spectroscopy



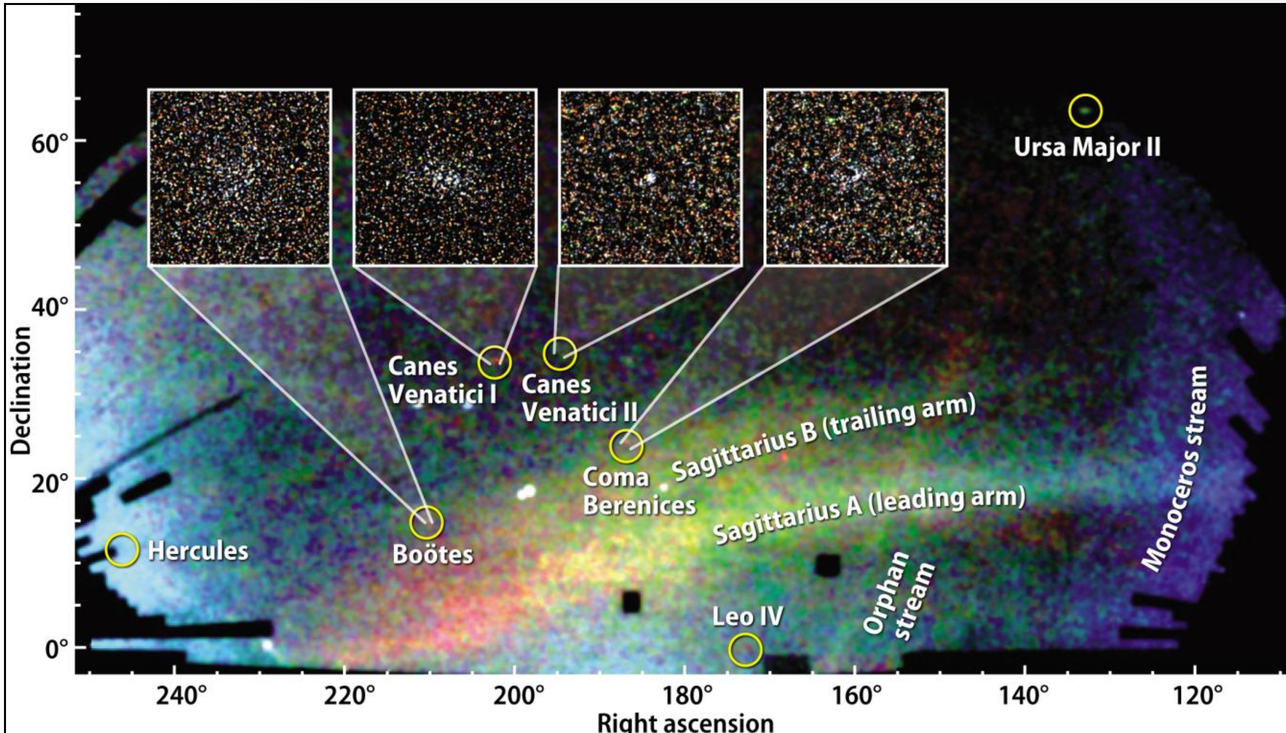
+ Targets in operable shutter
x Targets outside shutters

Putting it Together

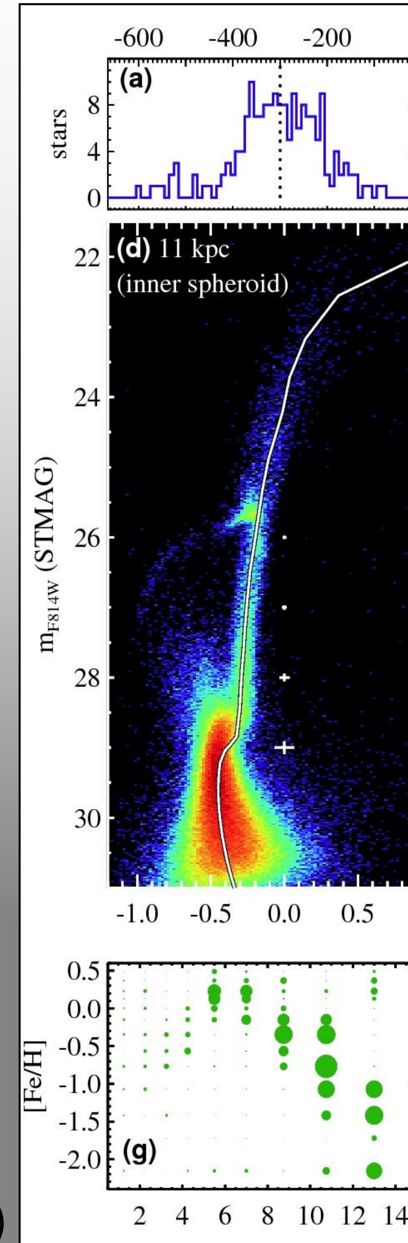
- NIRCam, NIRISS imaging & NIRSpec MOS spectroscopy of clusters, MW components, and star forming regions will provide age & abundances and test formation & assembly models.
- NIR imaging completes stellar inventory of MW pops and informs the Galactic mass budget.
- MIRI imaging & spectroscopy provides T_{eff}, log(g), and mass for stellar and substellar objects.

JWST and Resolved Stellar Pops in the Local Volume

Synergy between wide-field ground based imaging, HST ultra-deep imaging and and 10-m spectroscopy



SDSS Field of Streams

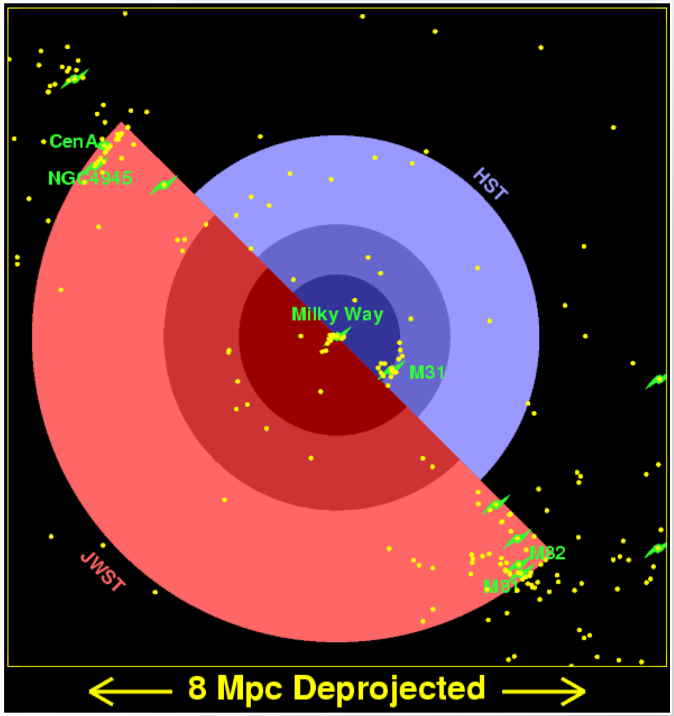


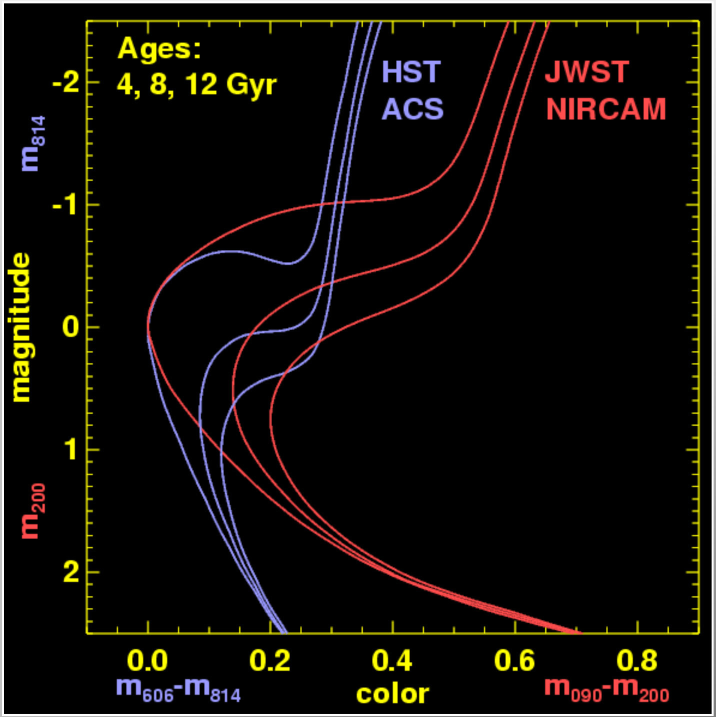
⟶ SDSS, HST, & Keck work together to yield substructure maps, metallicity, ages, and kinematics of nearby Local Group galaxies.

Brown et al. (2008)

JWST and Resolved Stellar Pops in the Local Volume

Future synergies between LSST, JWST, and 30-m telescopes will
1.) Push beyond the Local Group
2.) Increase leverage to probe sensitive age variations.



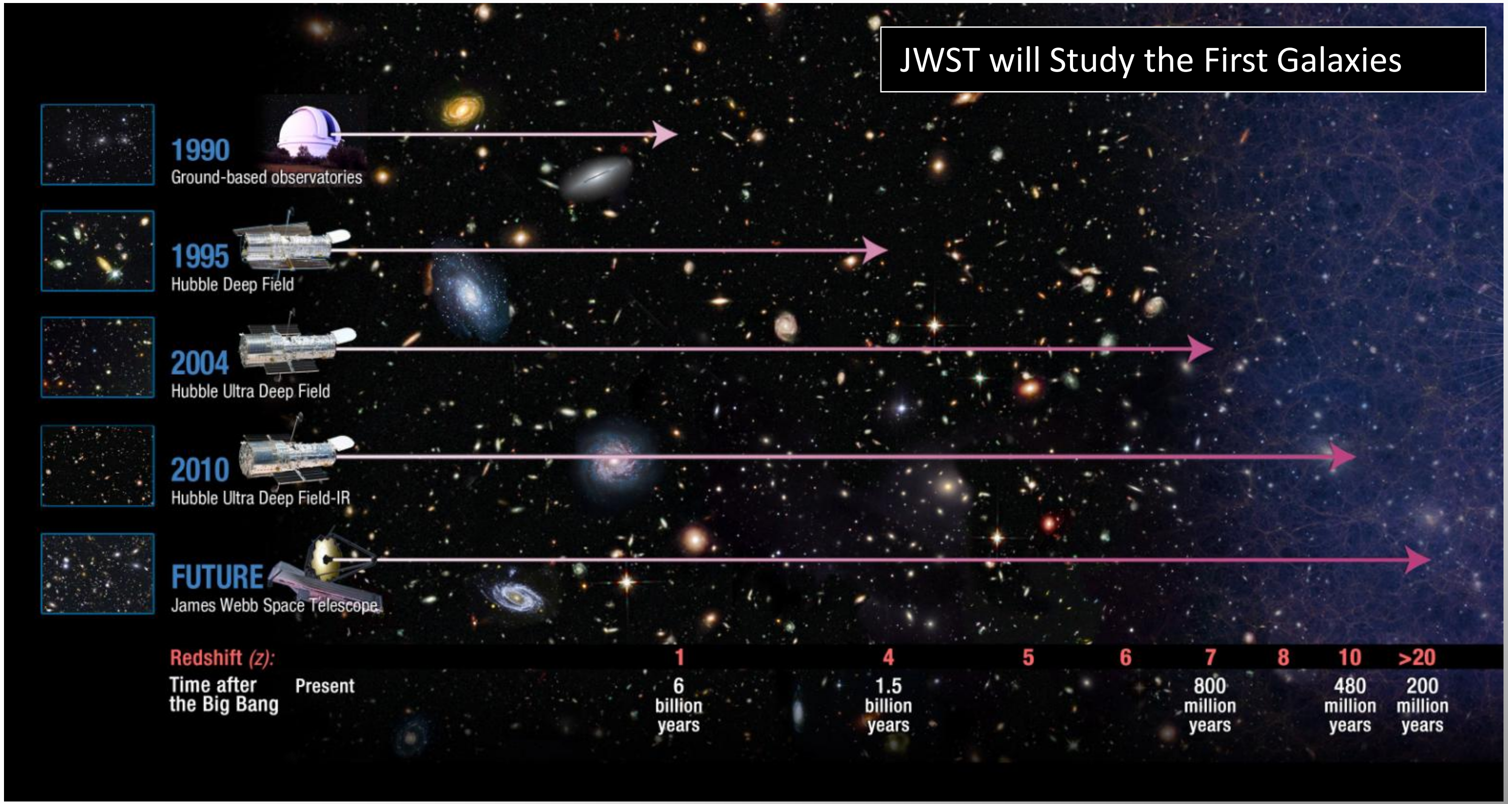


T. Brown et al. (2008), JWST White Paper, *"Studying Resolved Stellar Populations with JWST"*

⟶ JWST will yield the first direct ages in galaxies outside the Local Group in 10 hours.

⟶ Extended SFH will be efficiently measured with filters well-separated in wavelength and with larger FOVs than Hubble.

JWST and First Galaxies

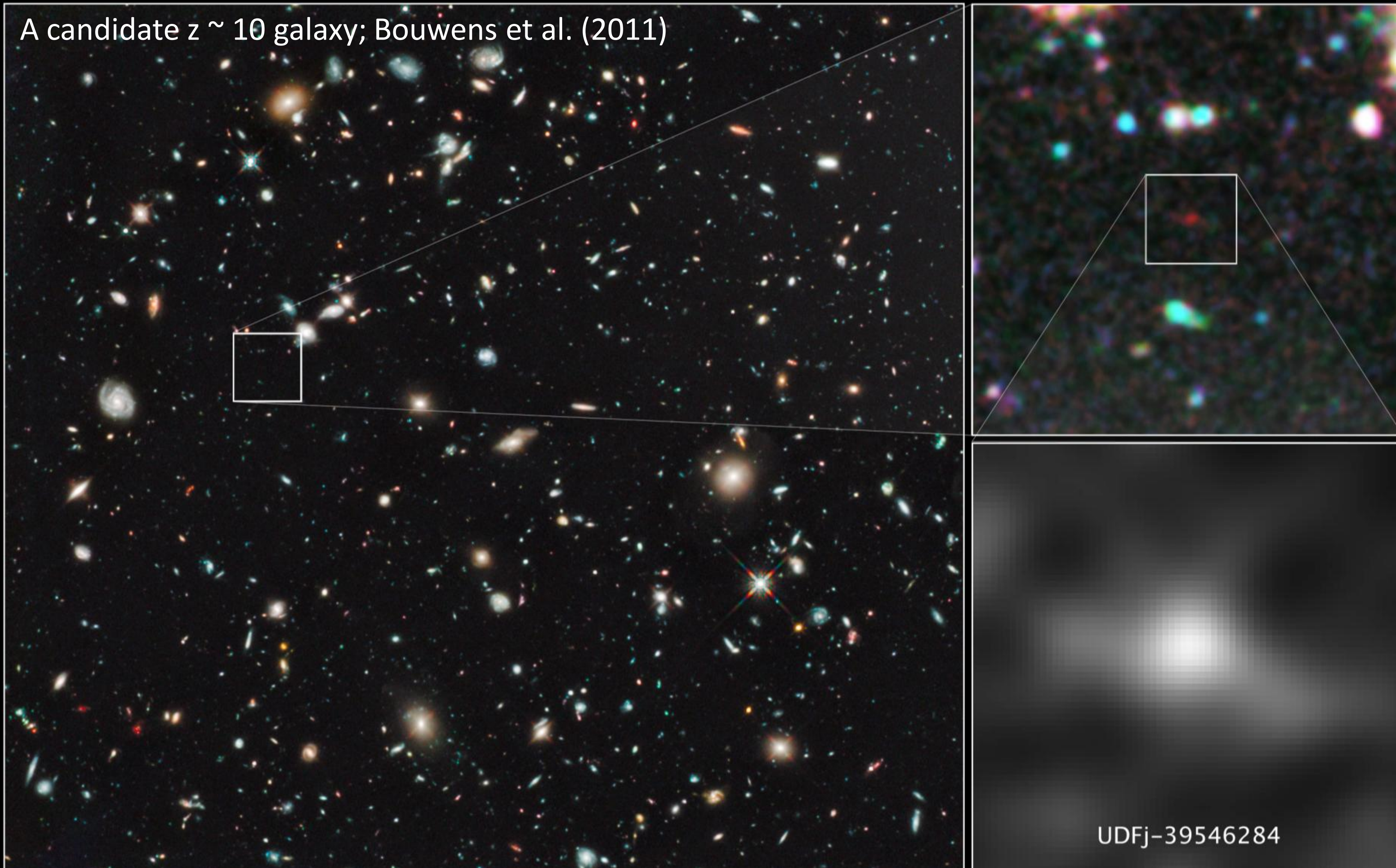


→ Why measure galaxies in the Universe's first billion years?

- Seeds of today's galaxies started growing.
- Dark matter halos of massive galaxies first formed.
- Significant metals first formed.
- When the Universe was reionized.

→ JWST will resolve ambiguities from Hubble and Spitzer in fitting SEDs by spectroscopically characterizing early systems at $z = 9$, and characterizing stellar contributions to $z > 10$.

A candidate z ~ 10 galaxy; Bouwens et al. (2011)

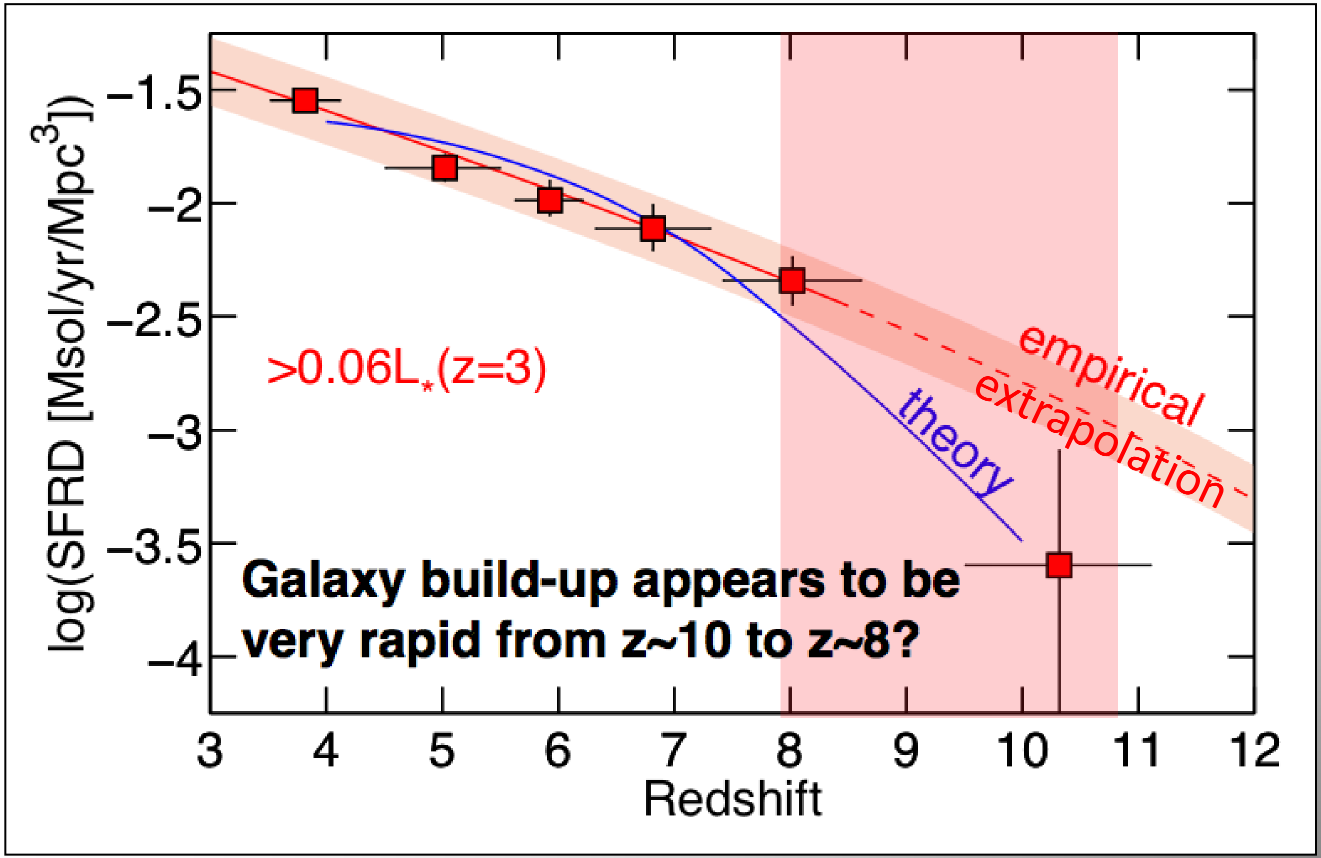


Hubble Ultra Deep Field 2009-2010
Hubble Space Telescope • WFC3/IR

NASA, ESA, G. Illingworth (University of California, Santa Cruz),
R. Bouwens (University of California, Santa Cruz and Leiden University), and the HUDF09 Team

STScI-PRC11-05

JWST and First Galaxies



The Star Formation Rate Density vs Redshift; Oesch et al. (2011)

⟶ Hints from Hubble that a big change is occurring 400 – 600 Myr after the Big Bang.

⟶ JWST will provide a robust picture of the number of galaxies and their properties.
May need help from gravitational lensing (do homework now).

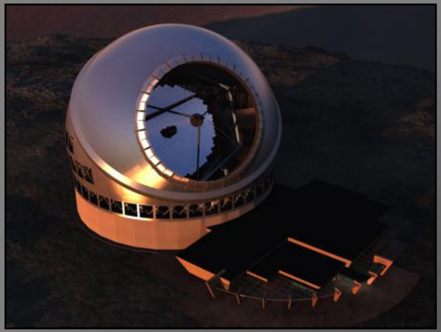
⟶ How do we know if we've found the *first* galaxies? See R. Ellis' talk on Frontiers webcast.

JWST and First Galaxies

JWST and 30-m Telescopes Synergy

“The nature of “first-light” objects and their effects on the young universe are among the outstanding open questions in astrophysics. Here TMT and the James Webb Space Telescope (JWST) will work hand-in-hand, with JWST providing the targets for detailed study with TMT’s spectrometers.”

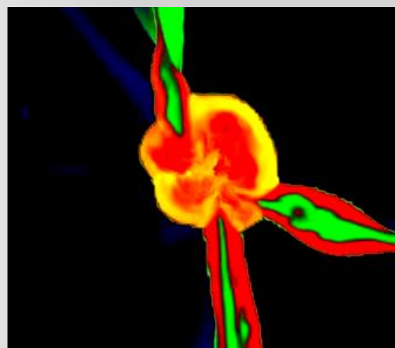
http://www.tmt.org/science-case

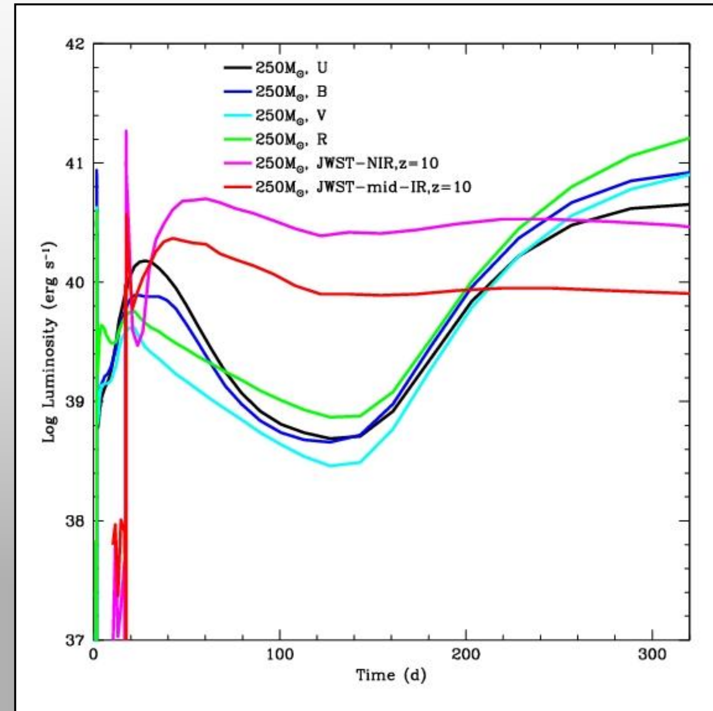


JWST and First Supernovae

<u>Properties</u>

- Thought to be very massive (25 – 500 Msun)
- Form in isolation
- $T_{surface}$ ~ 100,000 K
- Luminous sources of ionizing photons (> 10^{50} /s)
- 2-3 Myr lifetimes





D. Whalen – Frontiers Talk

⟶ New simulated light curves show late time rise over > 100 days.

⟶ Infrared energy diffuses out through dense ejecta of PI SNe…
can be measured with JWST to z > 10 and maybe 15 with strong lensing in this model.

⟶ Ground based follow up with 30-m telescopes will help distinguish progenitors.

JWST and Dark Energy

A. Riess' Talk at Frontiers Meeting

1.) JWST is the only telescope that can measure type Ia SNe out to z = 3.5

2.) JWST will characterize Cepheids in further galaxies

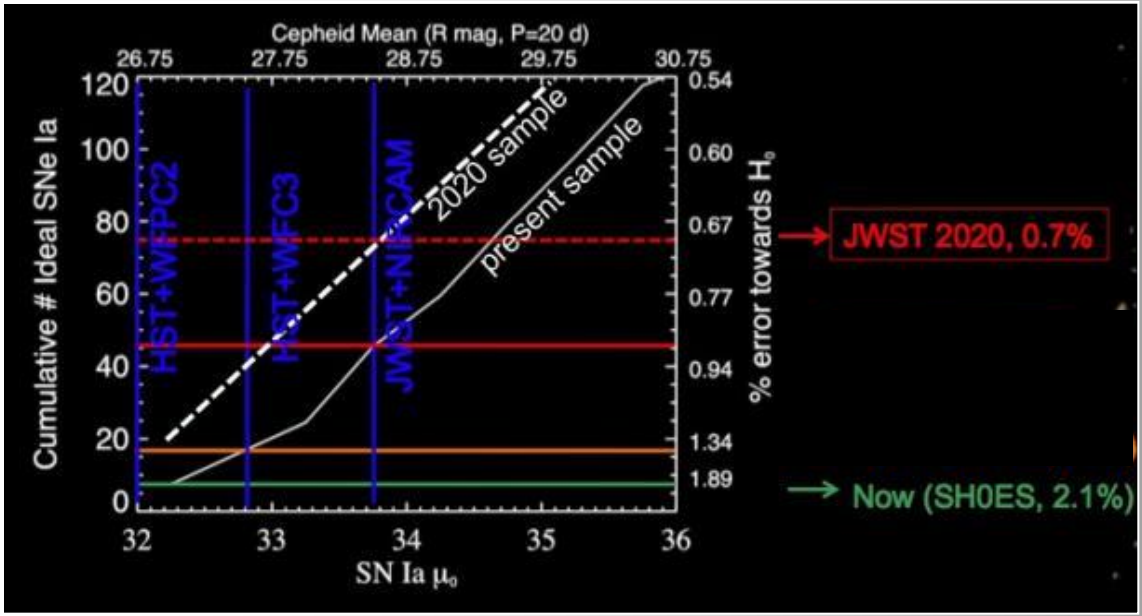
•Calibrate more type Ia SNe

•Simpler in the IR, less scatter

3.) H_0 to 1%, ties down ties local expansion rate.

4.) Planck CMB gives distance scale at z = 1000.

⟶ Two measurements provide an over constrained problem. Take one of the measurements, vary the cosmological model (i.e., *w*) to match the other.



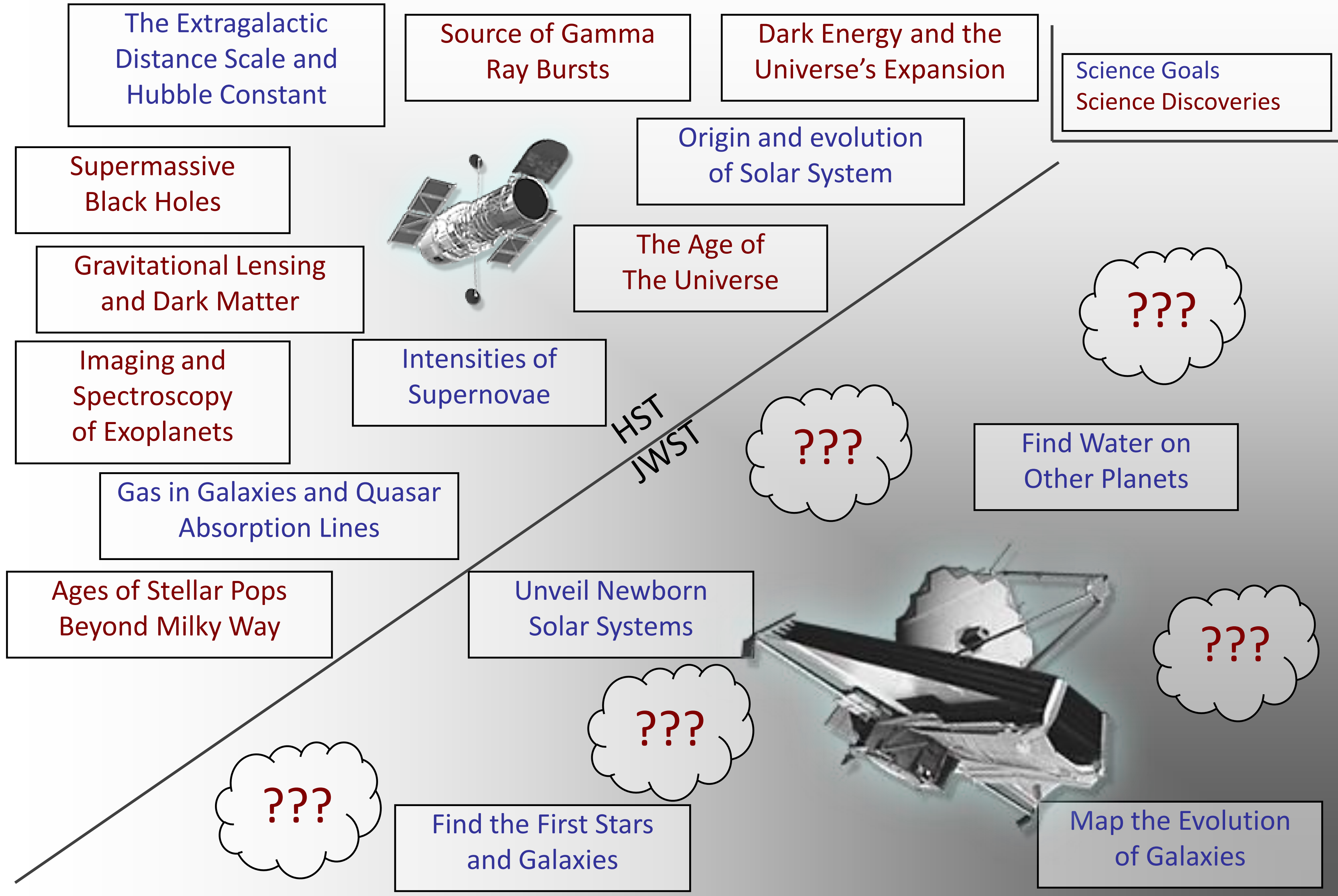
Frontier Science Opportunities with JWST

JWST and Other Science from the Frontiers Science Meeting

- Gas in Protoplanetary Disks – *Thomas Henning (MPIA)*
- Star Formation in Galaxies in the Era of JWST – *Daniela Calzetti (UMass)*
- Exotic Endings for Massive Stars – *Shri Kulkarni (Caltech)*
- The "Final Frontier" of Star and Planet Formation: Piled Deeper and Wider – *Mike Meyer (ETH Zurich)*
- Star Formation in the Milky Way and its Neighbors in the Mid-IR – *Christine Wilson (McMaster)*
- Strong Lensing to Study the Evolution of Galaxies – *Tommaso Treu (UCSB)*
- Active Galactic Nuclei with JWST – *Jane Rigby (GSFC)*
- Mid Infrared Observations of High Redshift Galaxy Evolution – *Alexandra Pope (UMass)*
- Weaving Circumgalactic Webs: The View from the Webb Telescope – *Crystal Martin (UCSB)*
- The Evolution of Chemical Enrichment and Outflows at z ~ 1-6 – *Alice Shapley (UCLA)*
- Probing Galaxy Stellar Mass Assembly in the Early Universe with JWST – *Karina Caputi (Edinburgh)*
- Probing the Dissipation of K.E. In Phases of Galaxy Evolution with JWST – *Pierre Guillard (Caltech)*

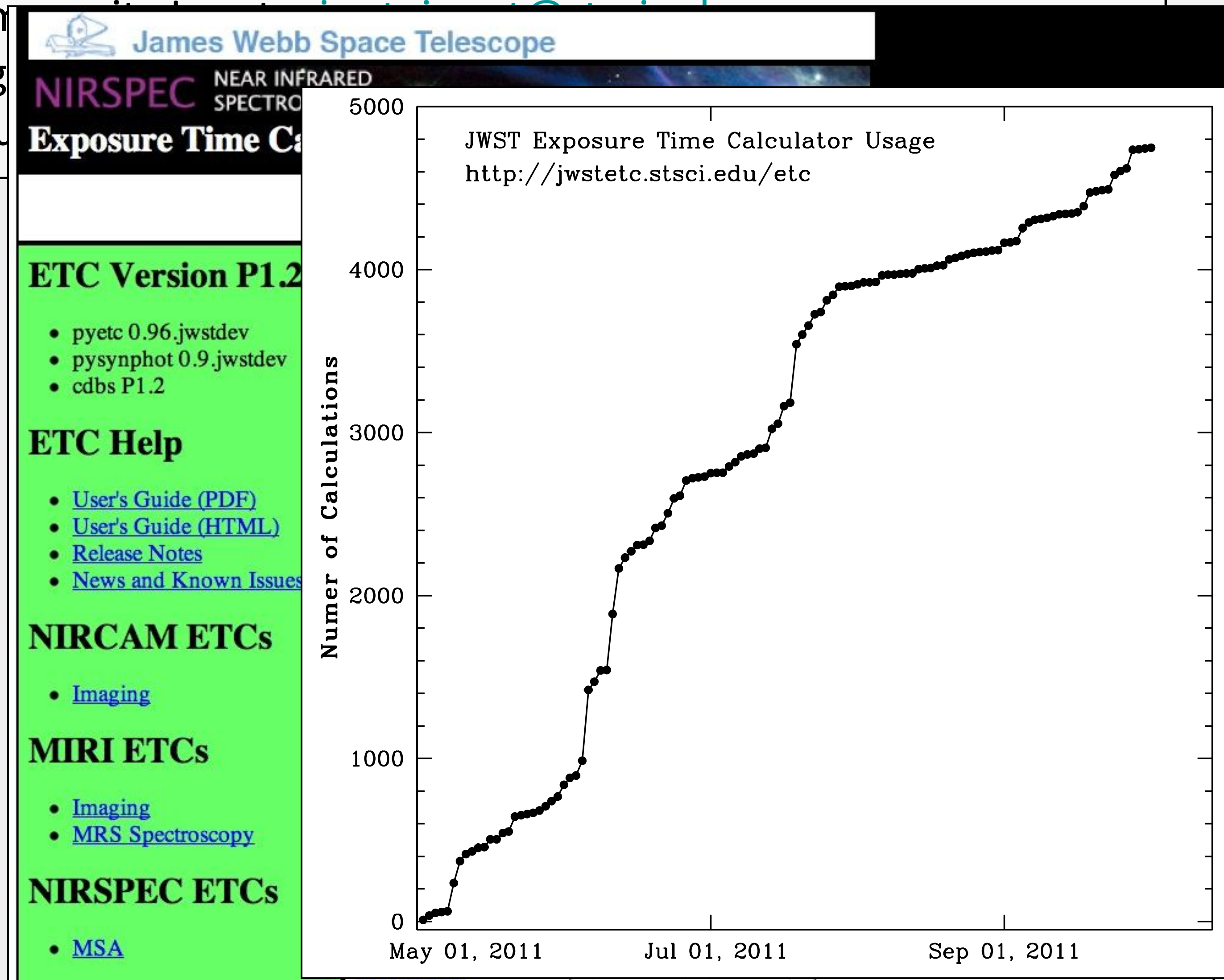
https://webcast.stsci.edu/webcast/
(Click "Webcast Archives")

Scientific Discovery Potential



Frontier Science Opportunities with JWST

JWST Exposure Time Calculator – http://jwstetc.stsci.edu/etc/
JWST PSF Tool – http://www.stsci.edu/jwst/software/webbpsf.html
JWST Email For Com
JWST Facebook Pag
JWST Twitter – @au



Frontier Science Opportunities with JWST

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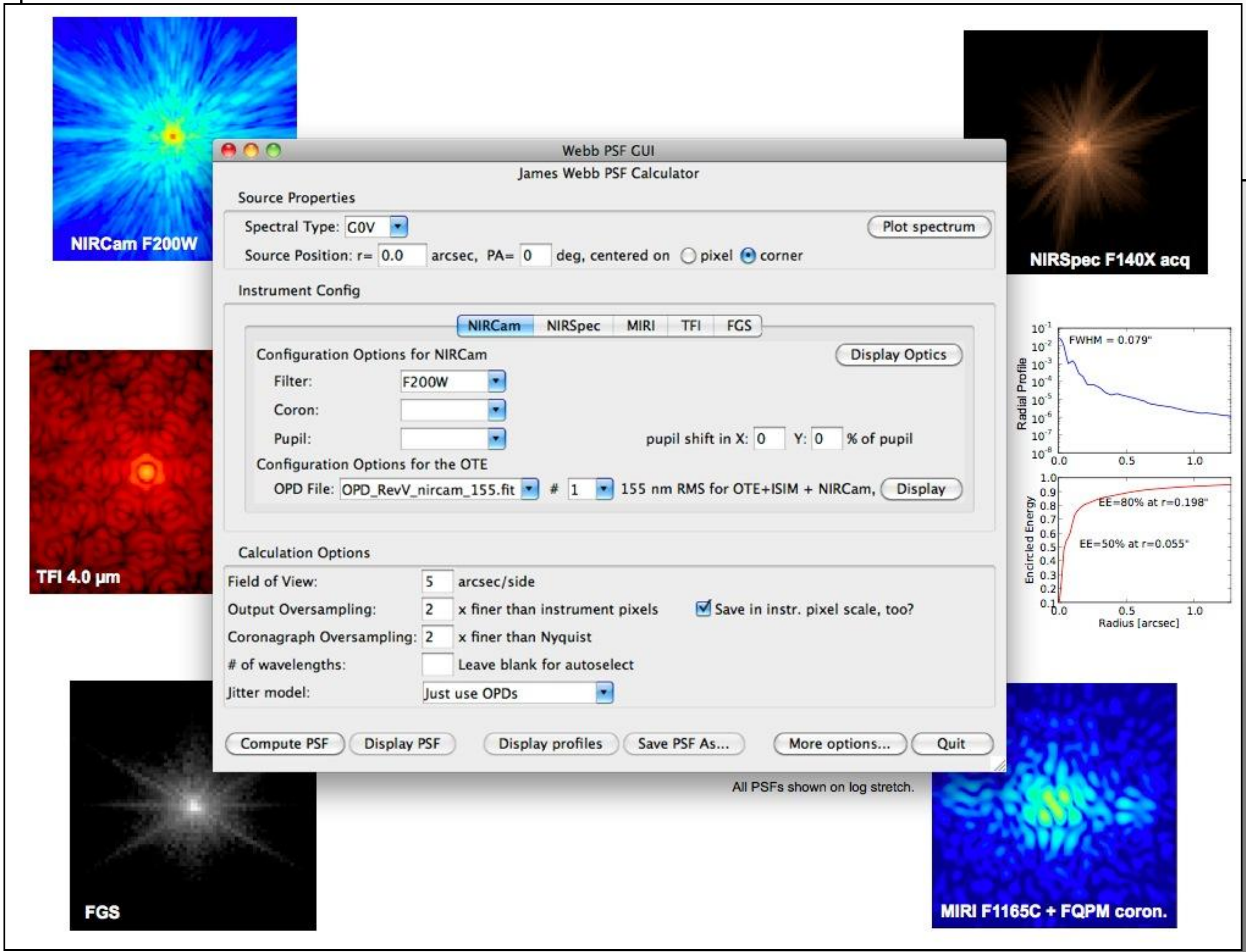
JWST PSF Tool – http://www.stsci.edu/jwst/software/webbpsf.html



Frontier Science Opportunities with JWST

JWST Exposure Time Calculator – http://jwstetc.stsci.edu/etc/

JWST PSF Tool – http://www.stsci.edu/jwst/software/webbpsf.html

JWST Email For Community Input – jwst_input@stsci.edu

JWST Facebook Page For Astronomers – “JWST Observer”

JWST Twitter – @auraJWST