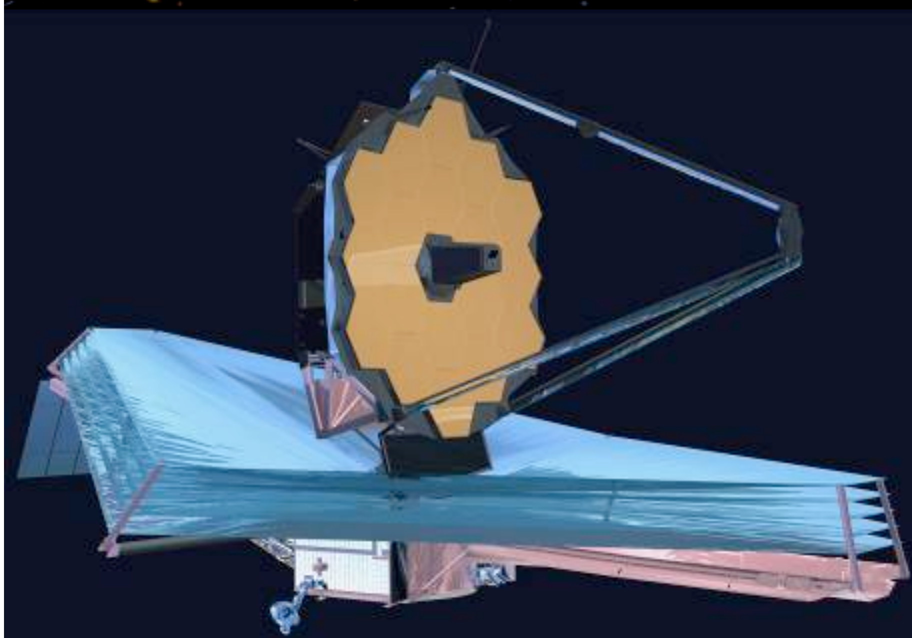
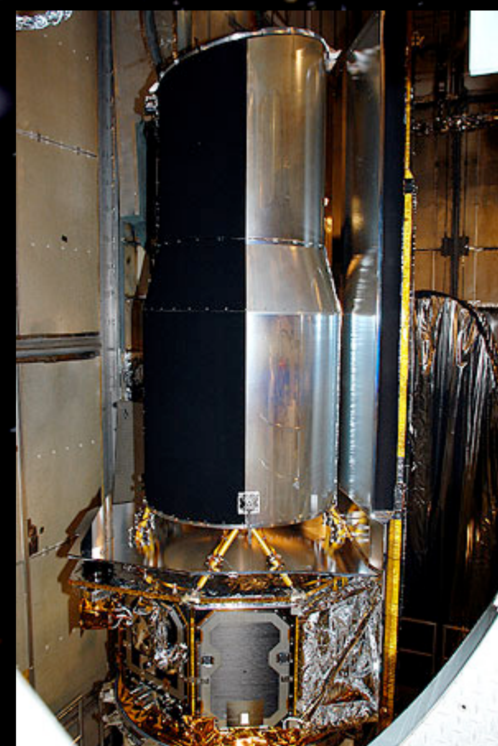
Science Frontiers with the James Webb Space Telescope: Building on Spitzer

Marcia Rieke

Steward Observatory

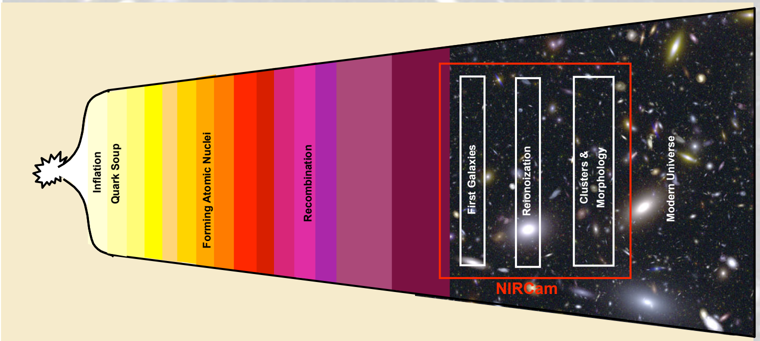


Mechanical Engineer's View of JWST



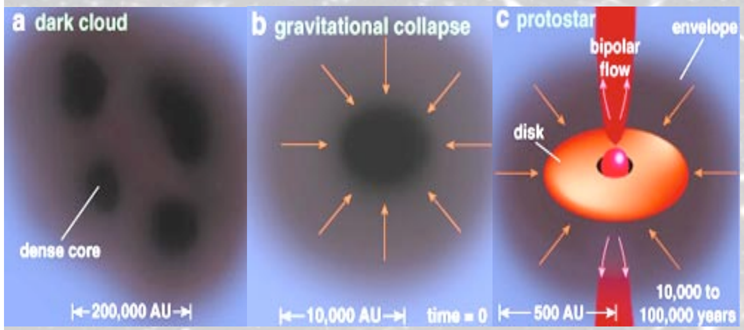
Real Spitzer on the Launch Pad

JWST's Science Themes



The First Light in the Universe:
Discovering the first galaxies, reionization
Need deep surveys to find and categorize objects, spectroscopy to probe z for reionization.

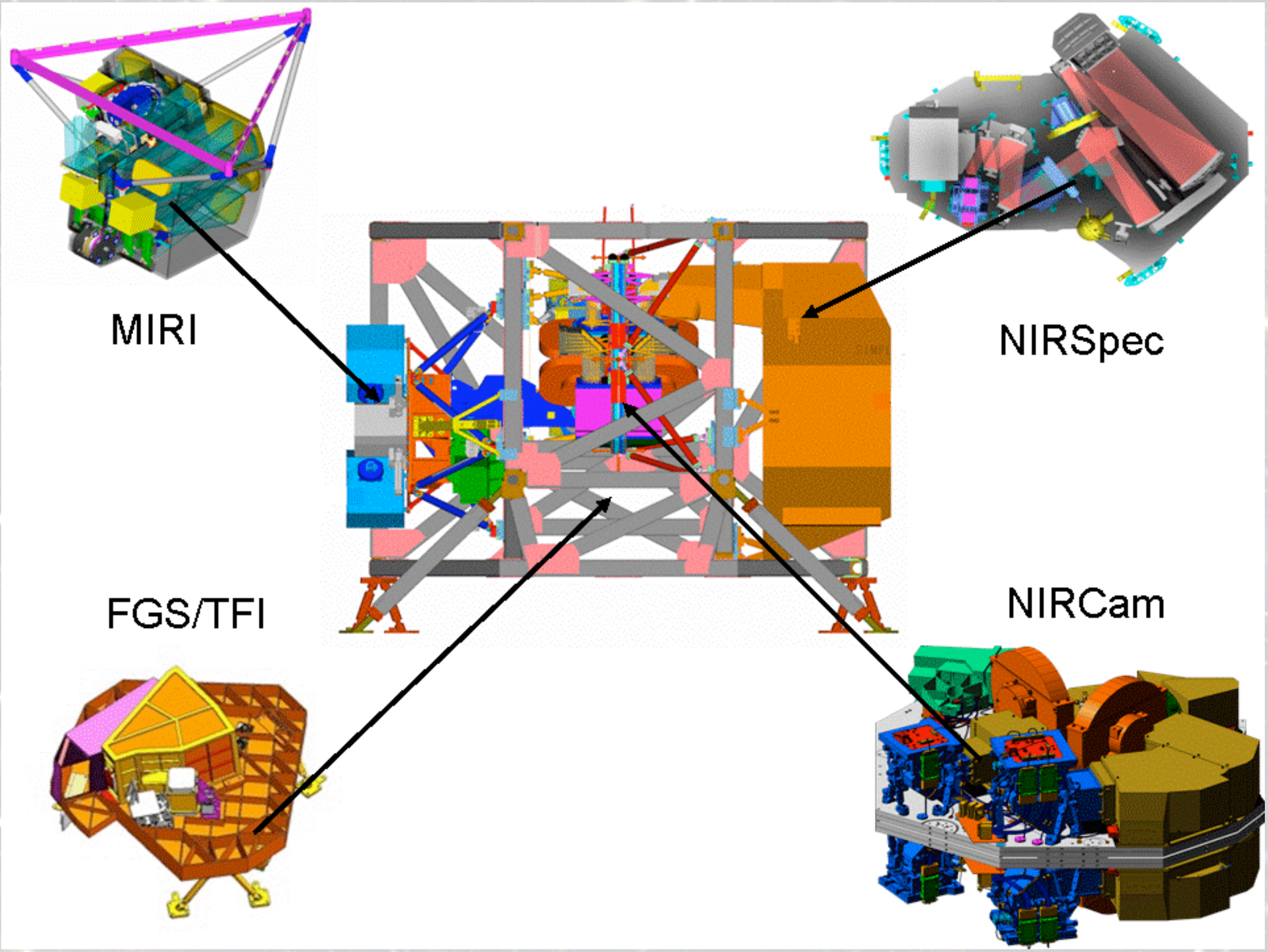
Period of Galaxy Assembly:
Establishing the Hubble sequence, growth of galaxy clusters
Need imaging for shapes and colors of galaxies, spectroscopy for star formation rates, metallicities



Stars and Stellar Systems: Physics of the IMF, Structure of pre-stellar cores, Emerging from the dust cocoon
Imaging for colors and numbers of stars in clusters, measuring extinction profiles in dense clouds, spectroscopy for stellar classification

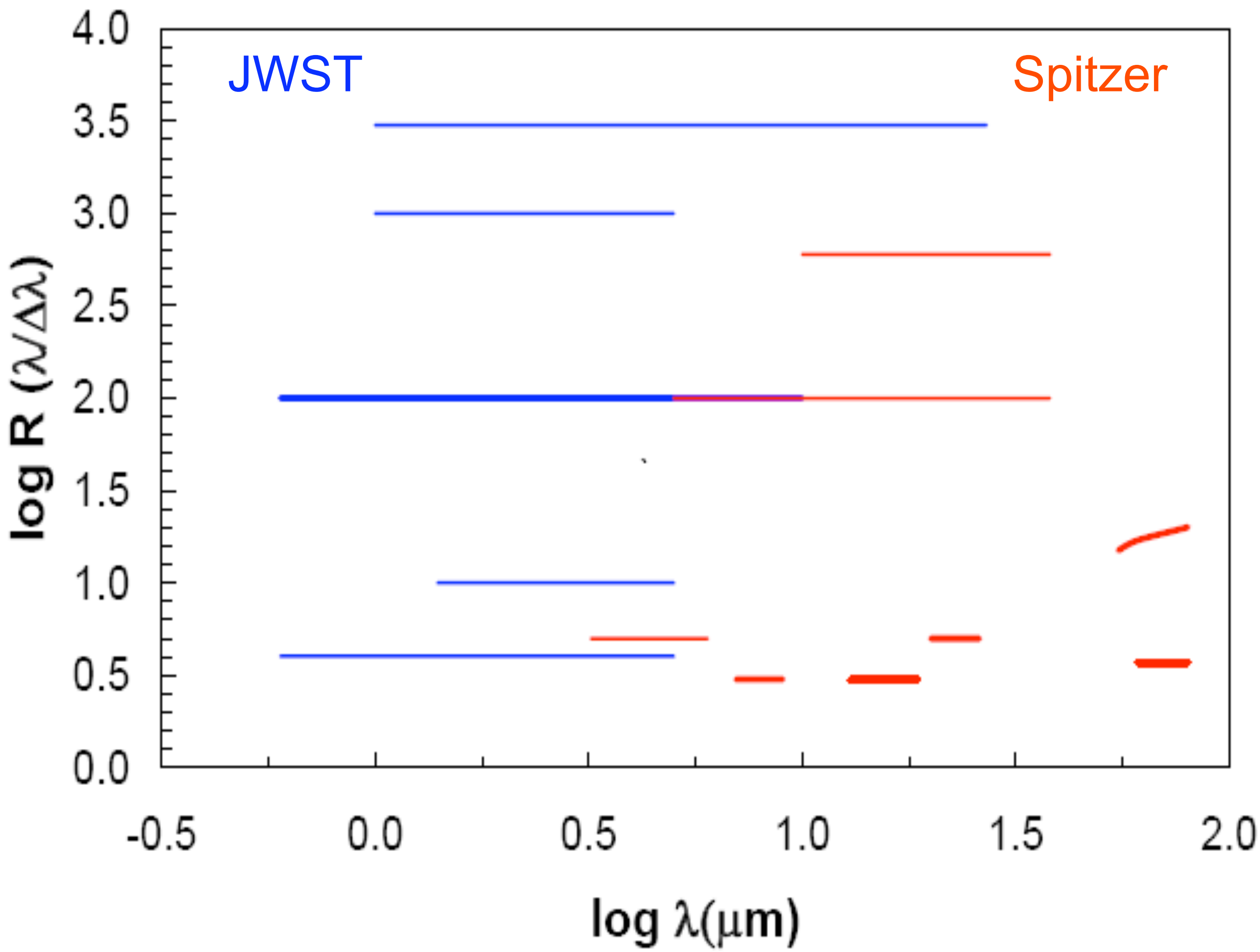
Planetary Systems and the Conditions for Life: Disks from birth to maturity, Survey of KBOs, Planets around nearby stars
Coronagraphy to image disks and planets, transits to characterize planets, spectroscopy for surface properties of KBOs

JWST's Instruments



Spitzer-JWST Instrument Comparison

JWST instruments are much more complicated than Spitzer's – NIRCam alone has 8 mechanisms!



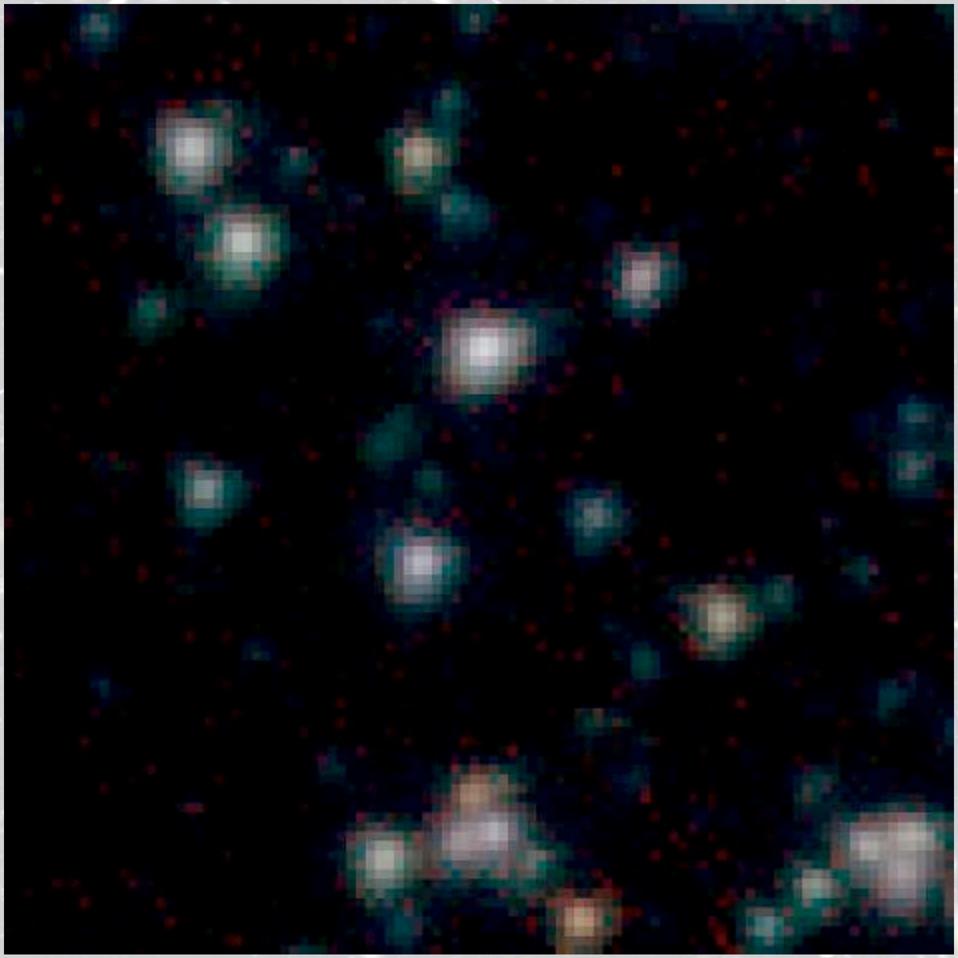
Other key facts:

-- telescope will be diffraction-limited at 2 microns

-- L2 orbit w/ large sunshade implies similar viewing constraints as for Spitzer

JWST-Spitzer Image Comparison

1’x1’ region in the UDF – 3.5 to 5.8 μm



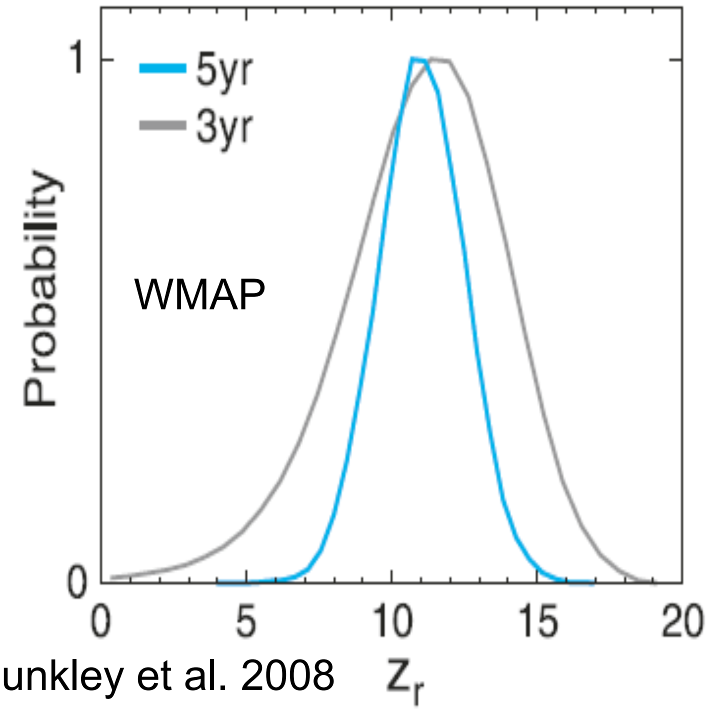
Spitzer, 25 hour per band
(GOODS collaboration)

JWST, 1000s per band (simulated)

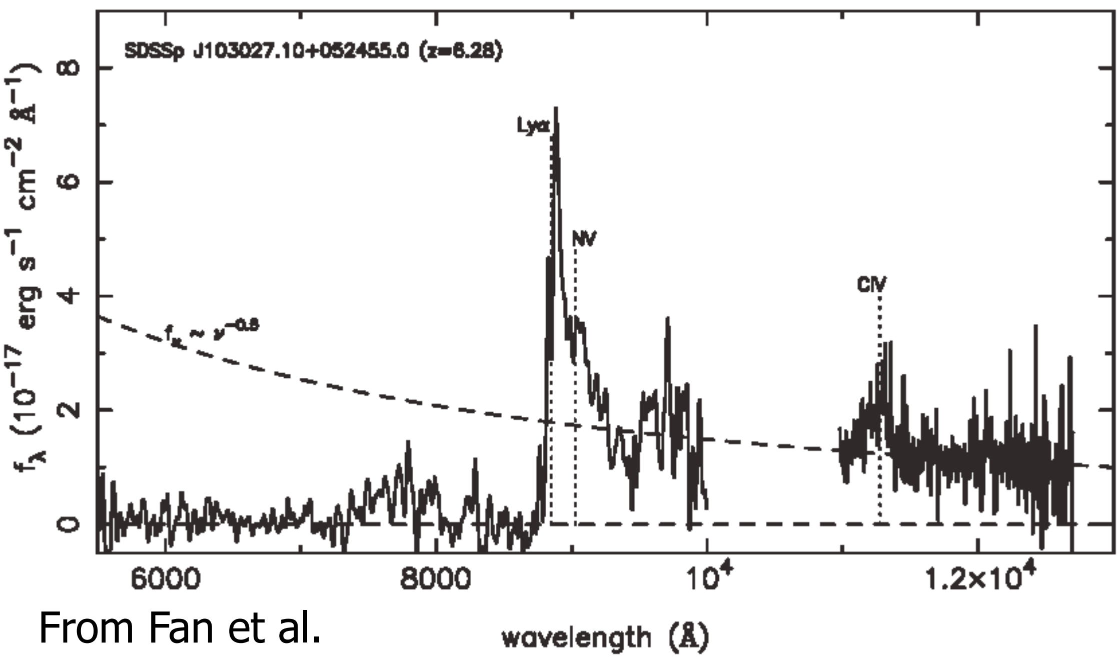
Courtesy of S. Casertano & M. Stiavelli

When Did Reionization Occur?

- Year 5 WMAP release has reduced the uncertainties in the electron optical depth so the epoch of reionization is constrained to z~11.0 ± 1.4, equivalent to ~350Myr after Big Bang.
- Spectra of SDSS z~6 QSOs show hints that Universe was reionized at only somewhat higher z than 6.5.
- Need to search from z~7 to z~15



Dunkley et al. 2008

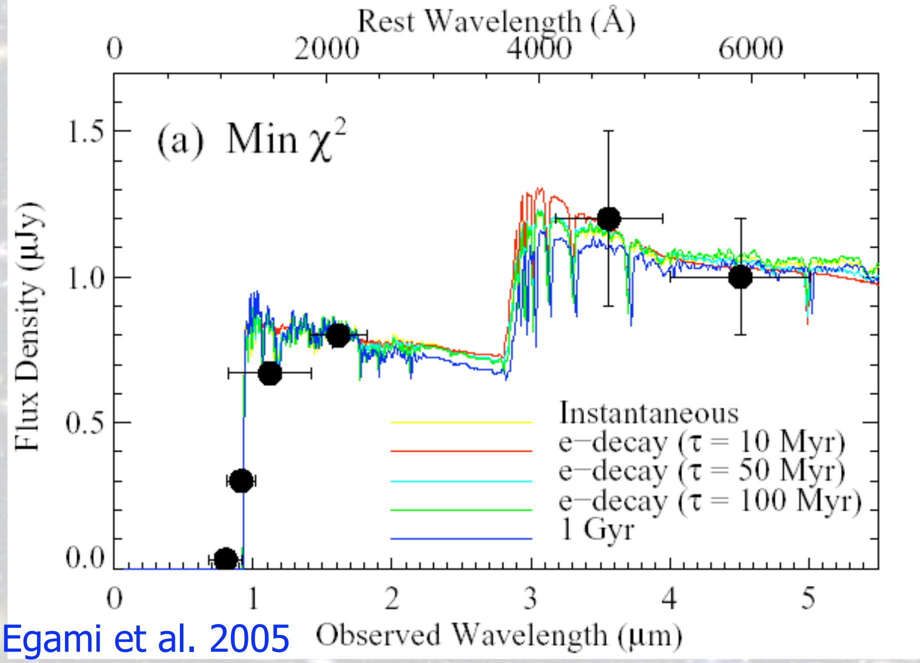


From Fan et al.

Spitzer Contributions

- The star formation rate as a function of z is much better known.
- Stellar mass assembly rate can be characterized for the first time.
- Spitzer is showing us that galaxies at z~7 formed stars as much as 200-400 million years earlier (around z~10)

➔ Epoch of first star formation now seem likely to have been around z~10-15 from combining Spitzer and WMAP results.



Egami et al. 2005

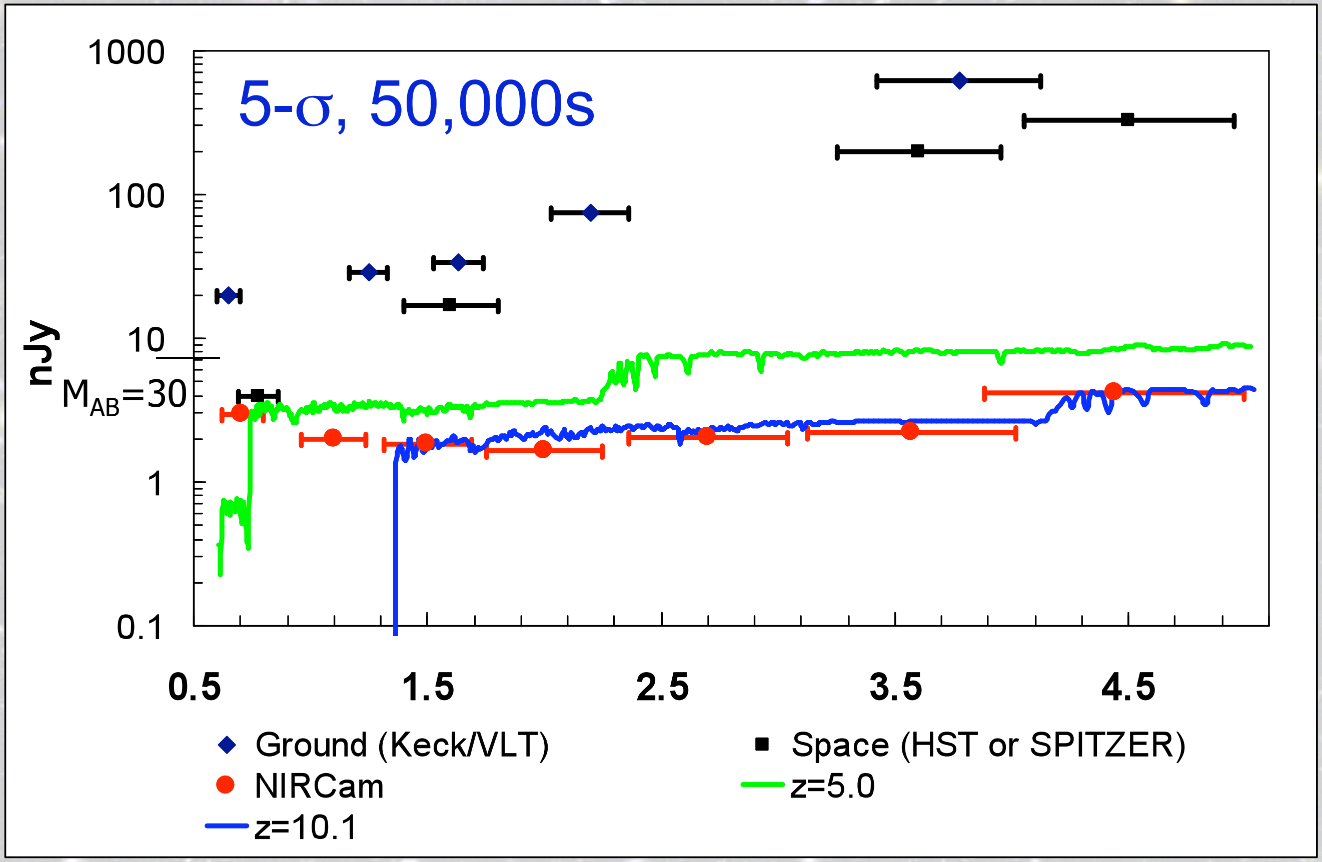
Imagine such a galaxy at 2x the redshift => z~14

- roles of NICMOS and IRAC correspond to NIRCam and MIRI on JWST.

Important to note that a number of similar galaxies have now been found by many observers

High Sensitivity is Paramount

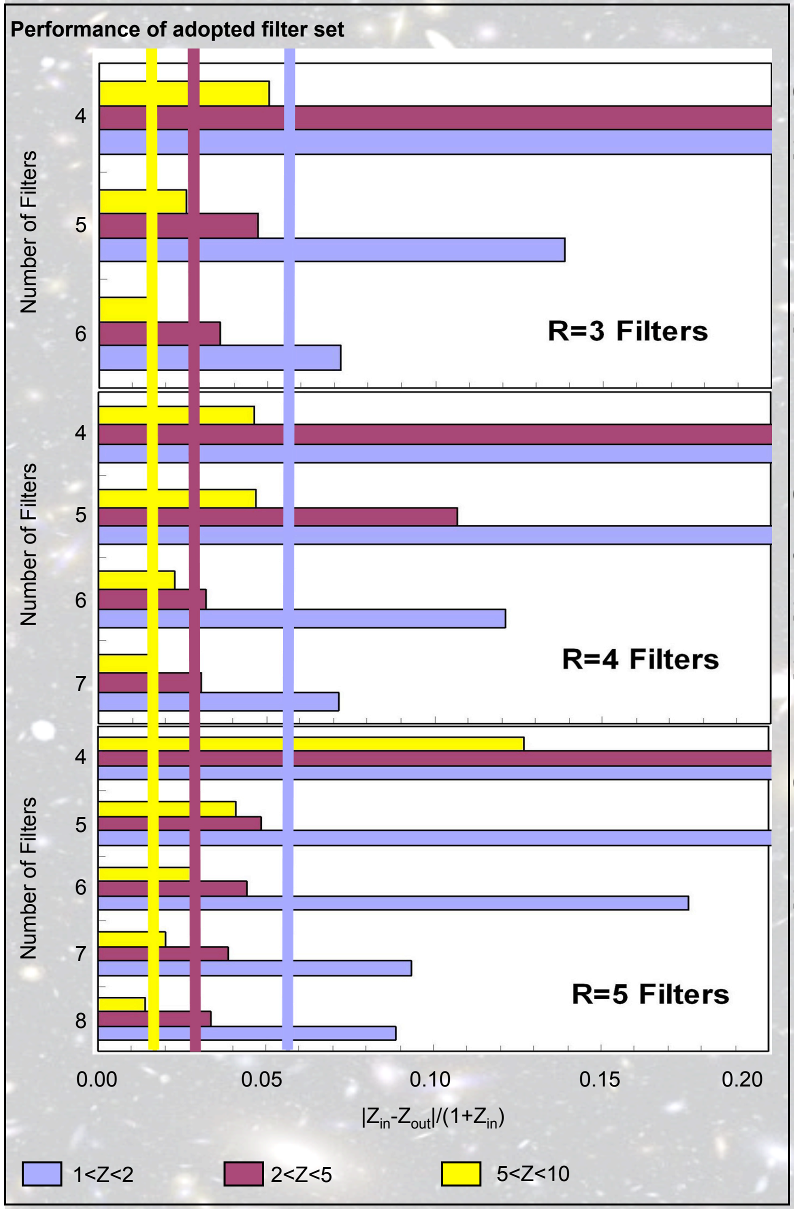
- NIRCam sensitivity is crucial for detecting “first light” objects
- At 3-5μm, NIRCam can detect objects 100x fainter than Spitzer opening up new survey possibilities



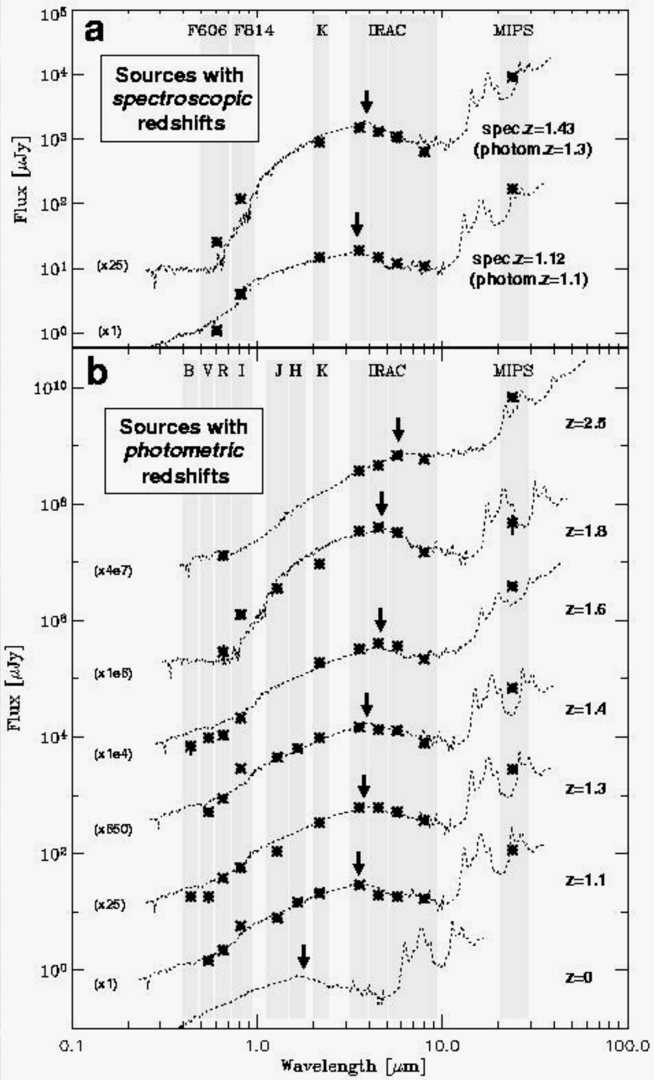
The z=10 galaxy has a mass of $4x10^8 M_{Sun}$ while the mass of the z=5 galaxy is $4x10^9 M_{Sun}$.

Above assumes 50,000 sec/filter with 2x time on longest wavelength

Photometric Redshifts Important

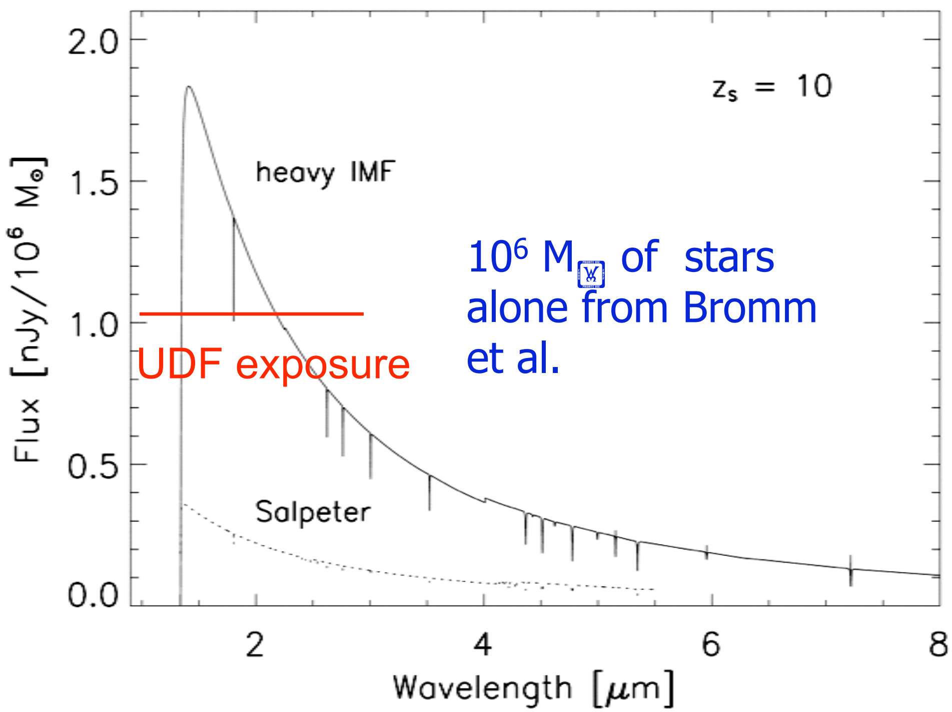


NIRCam will detect objects too faint for spectroscopy and will rely on photometric redshifts for statistical studies. The large number of broad filters in NIRCam have been optimized for this task as illustrated by the simulation results shown at the left. Right: Spitzer data demonstate that galaxy SEDs have sufficient structure for phot-zs.

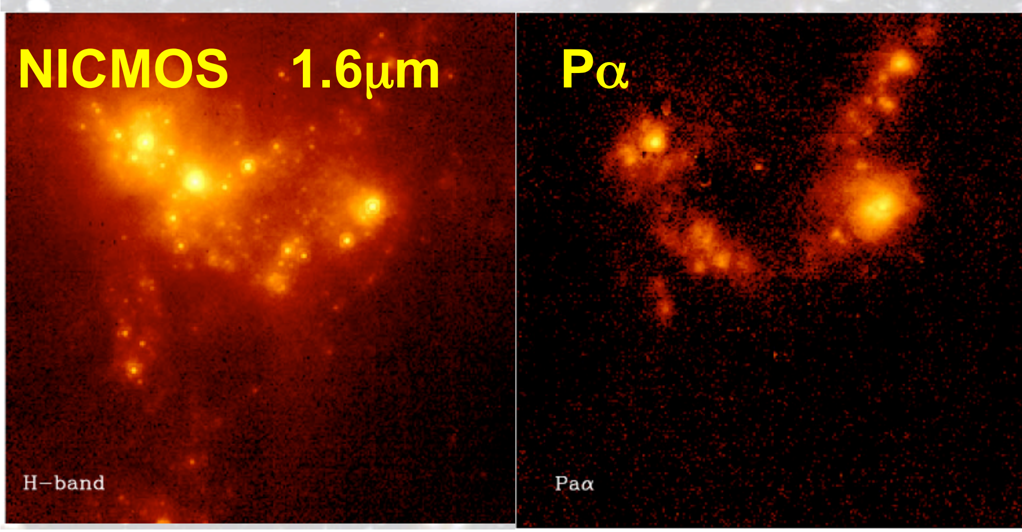


Le Floc'h et al. 2004, ApJS

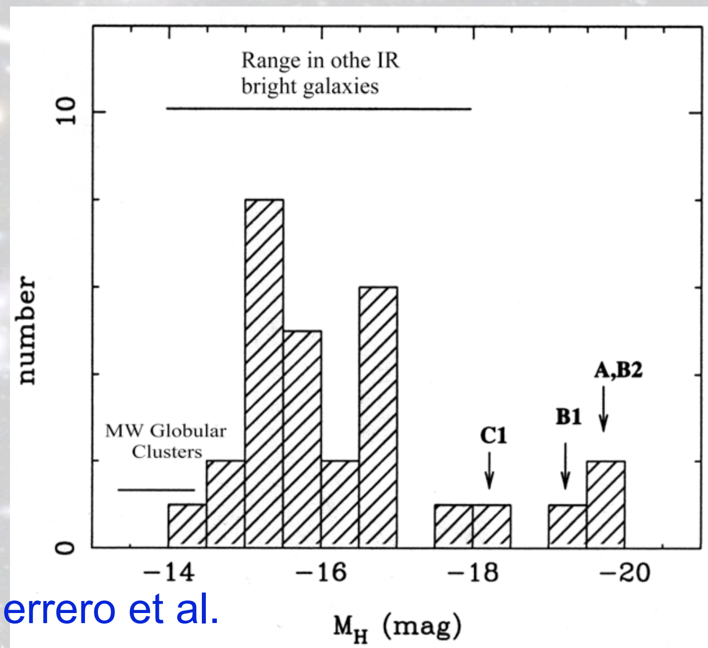
Super Star Clusters Good First Light Candidates



Super star clusters analogous to what's been found in galaxies like the Antennae or Arp 299 would be detectable at z=10 – larger clusters with $M=10^7\ M_\odot$ will be readily detectable in a deep survey which spends 14 hours/filter.

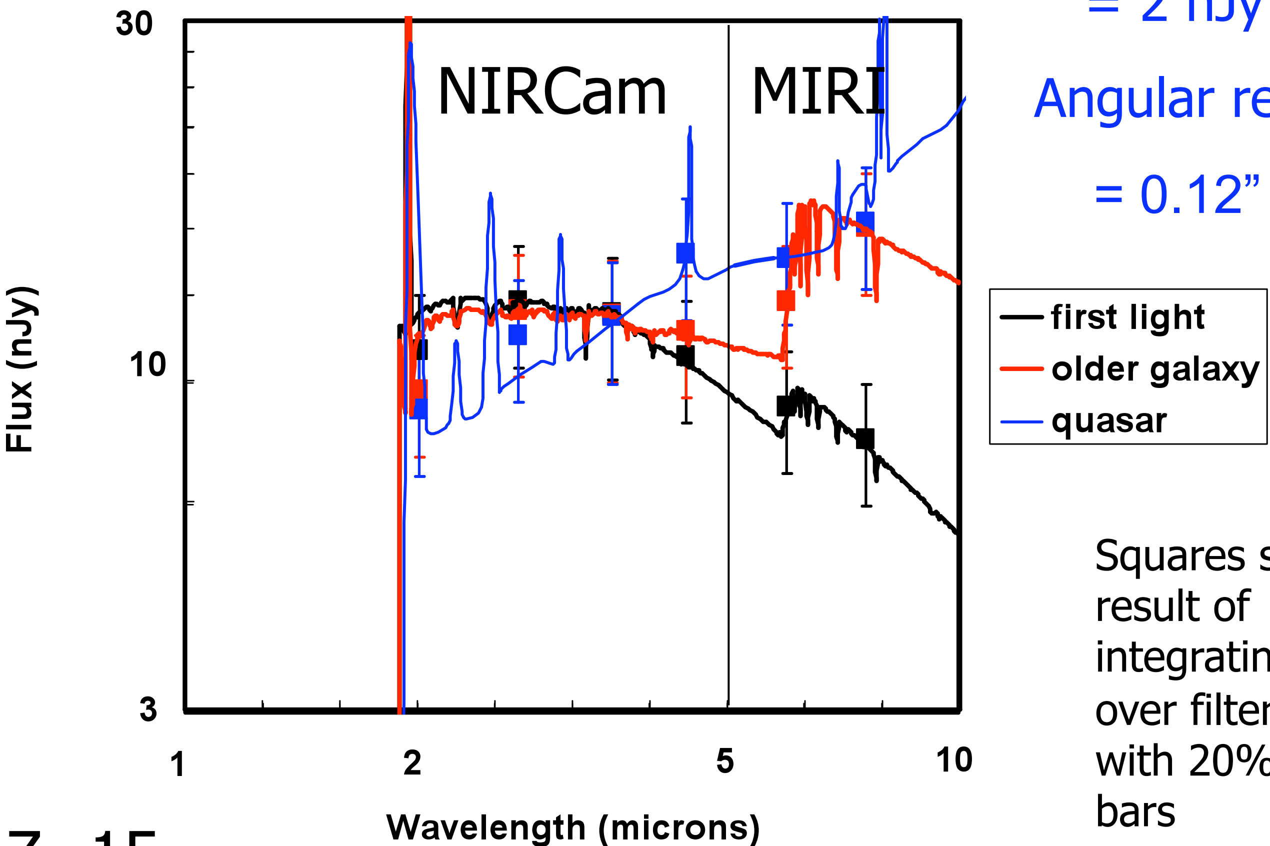


NGC 3690 =Arp 299



Alonso-Herrero et al. 2000

NIRCam & MIRI Provide Robust Discriminators



Z=15

Sensitivity:

5-σ in 50,000 sec

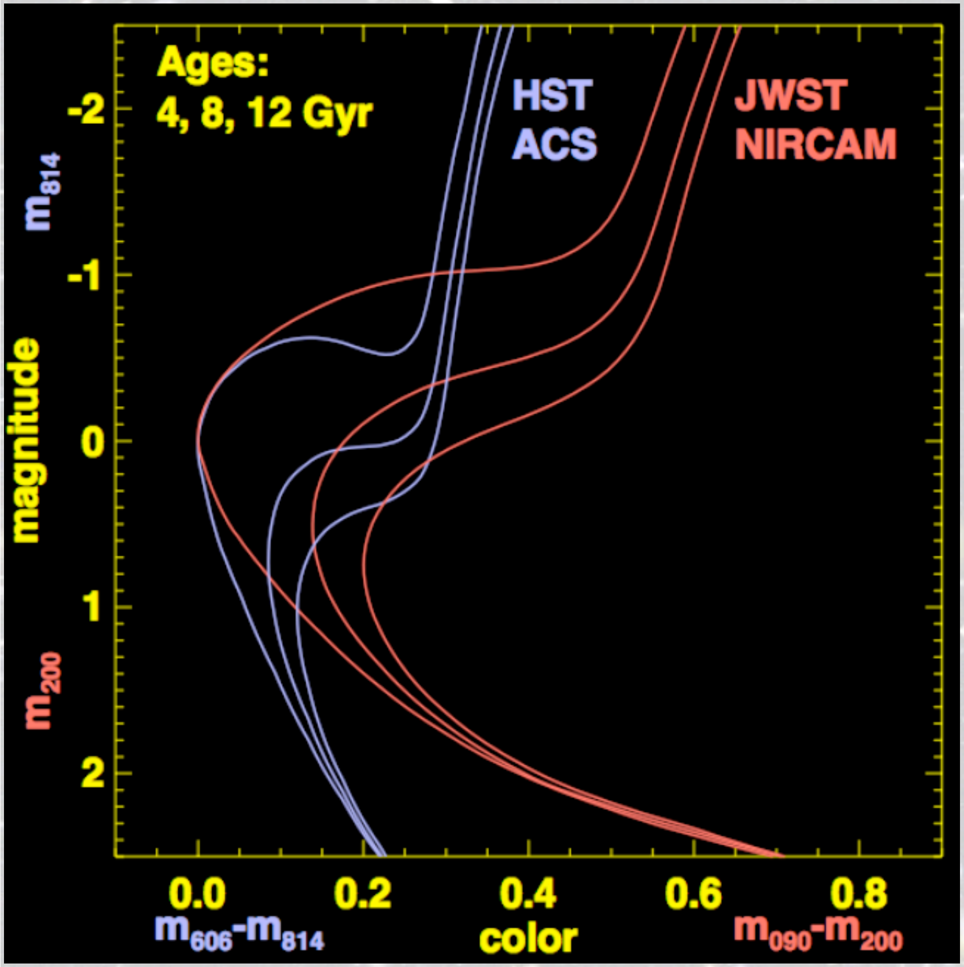
= 2 nJy at 3.6μm.

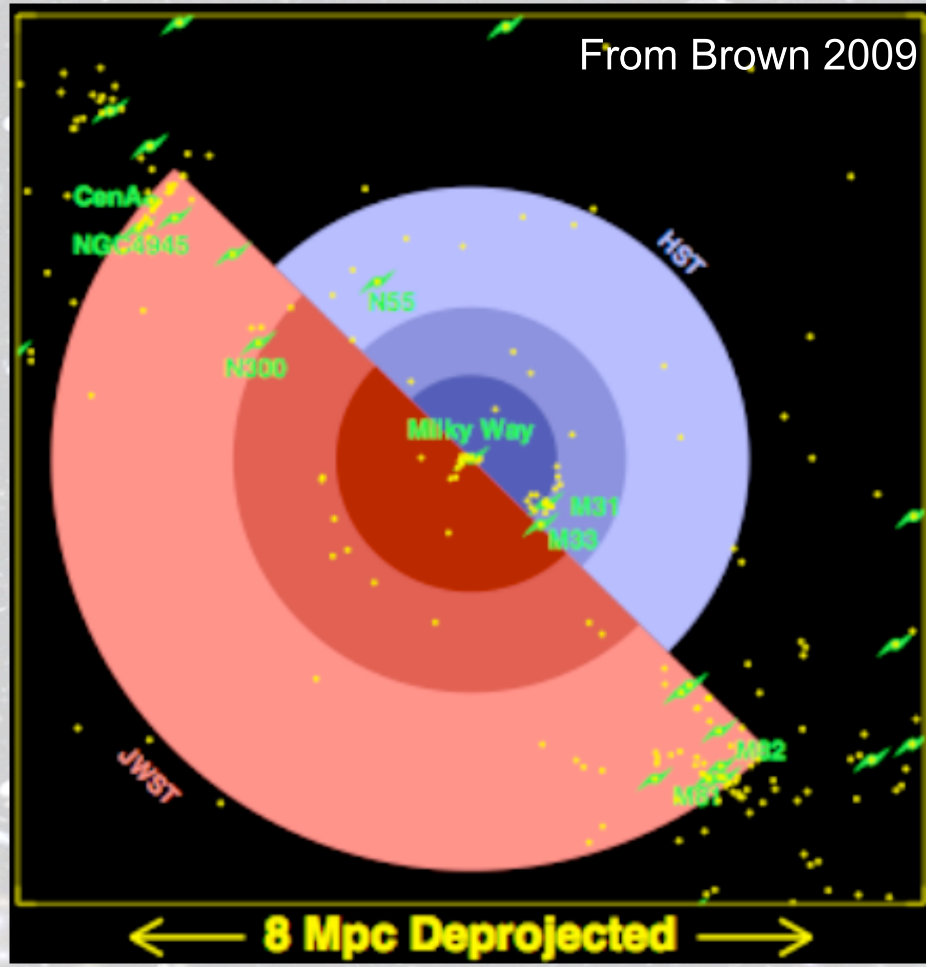
Angular resolution

= 0.12” at 4μm.

Squares show result of integrating over filters with 20% error bars

JWST Contributions to Stellar Population Studies

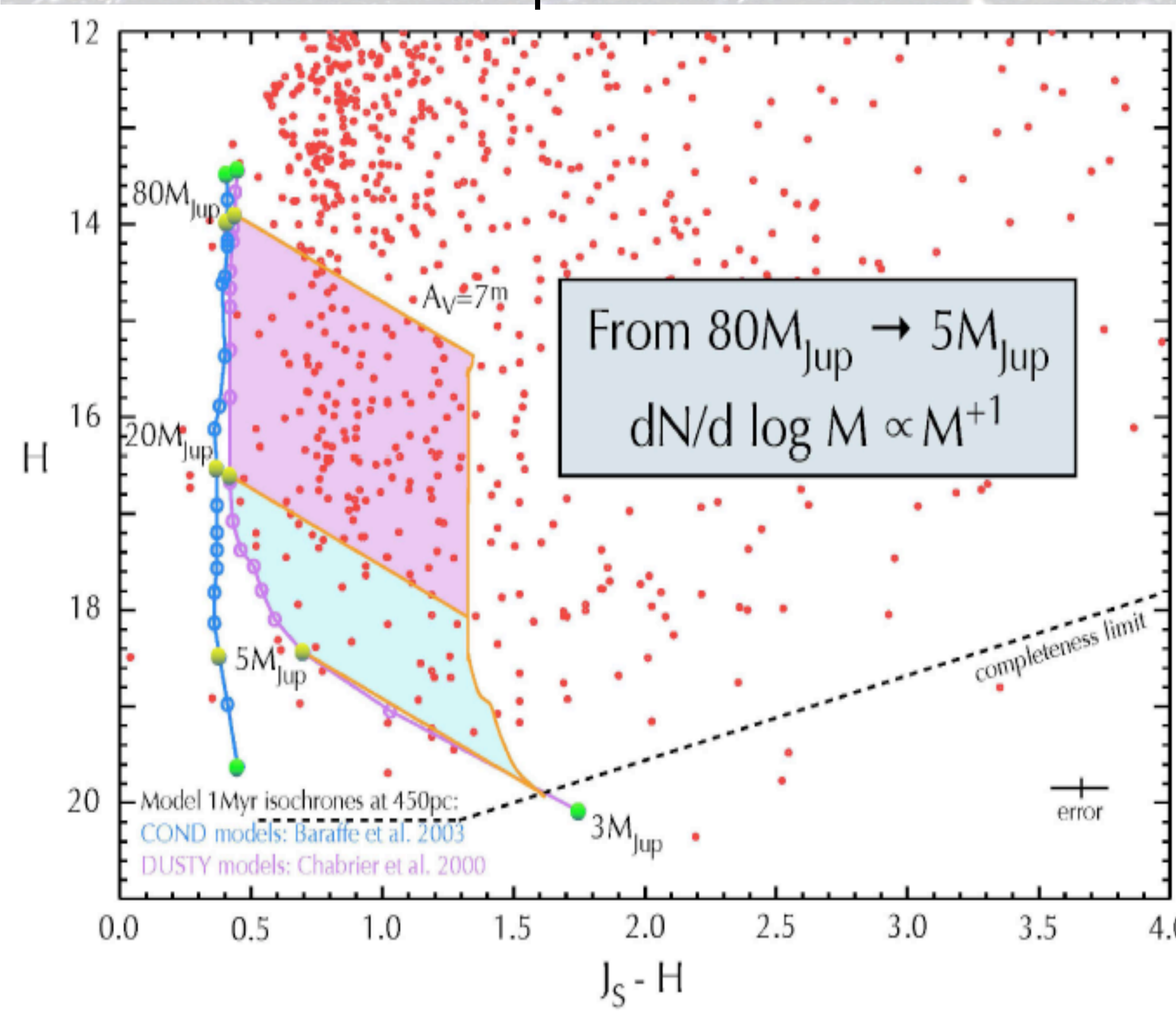




Near-infrared colors provide diagnostic information.

What Controls the IMF?

Orion Trapezium Cluster

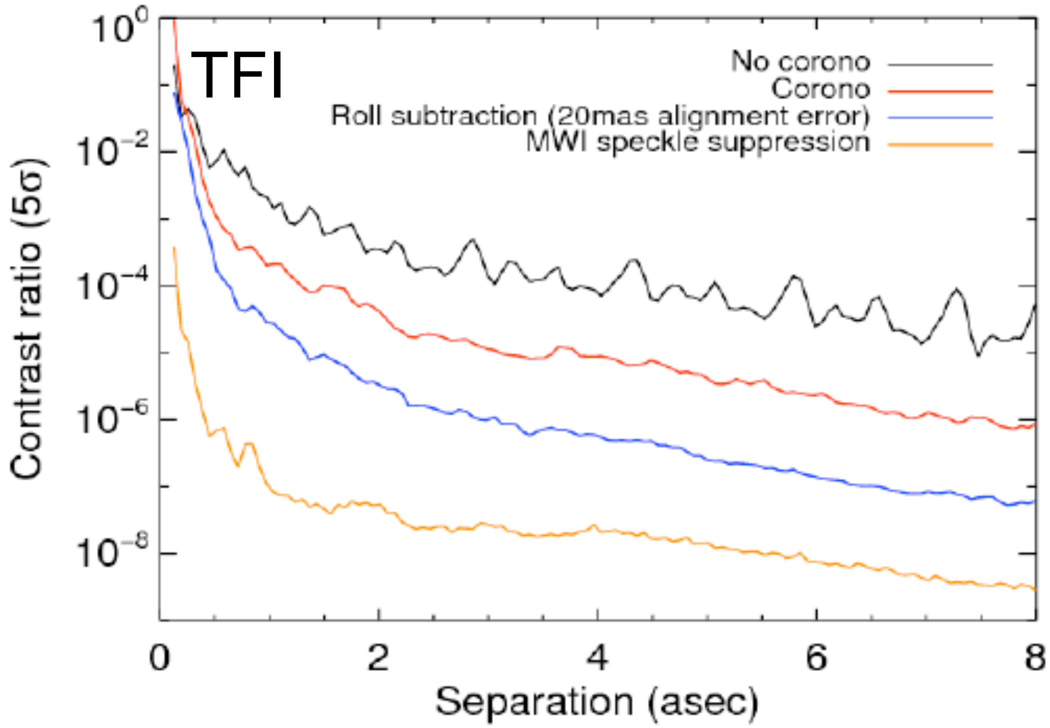


- JWST will be able to detect 1 M_{Jup} objects at a distance of 5 kpc and 10 M_{Jup} at 50 kpc
- IMF can be studied as a function of metallicity
- Whether there is a limit to fragmentation at low masses due to opacity can be tested

From McCaughrean et al. 2002

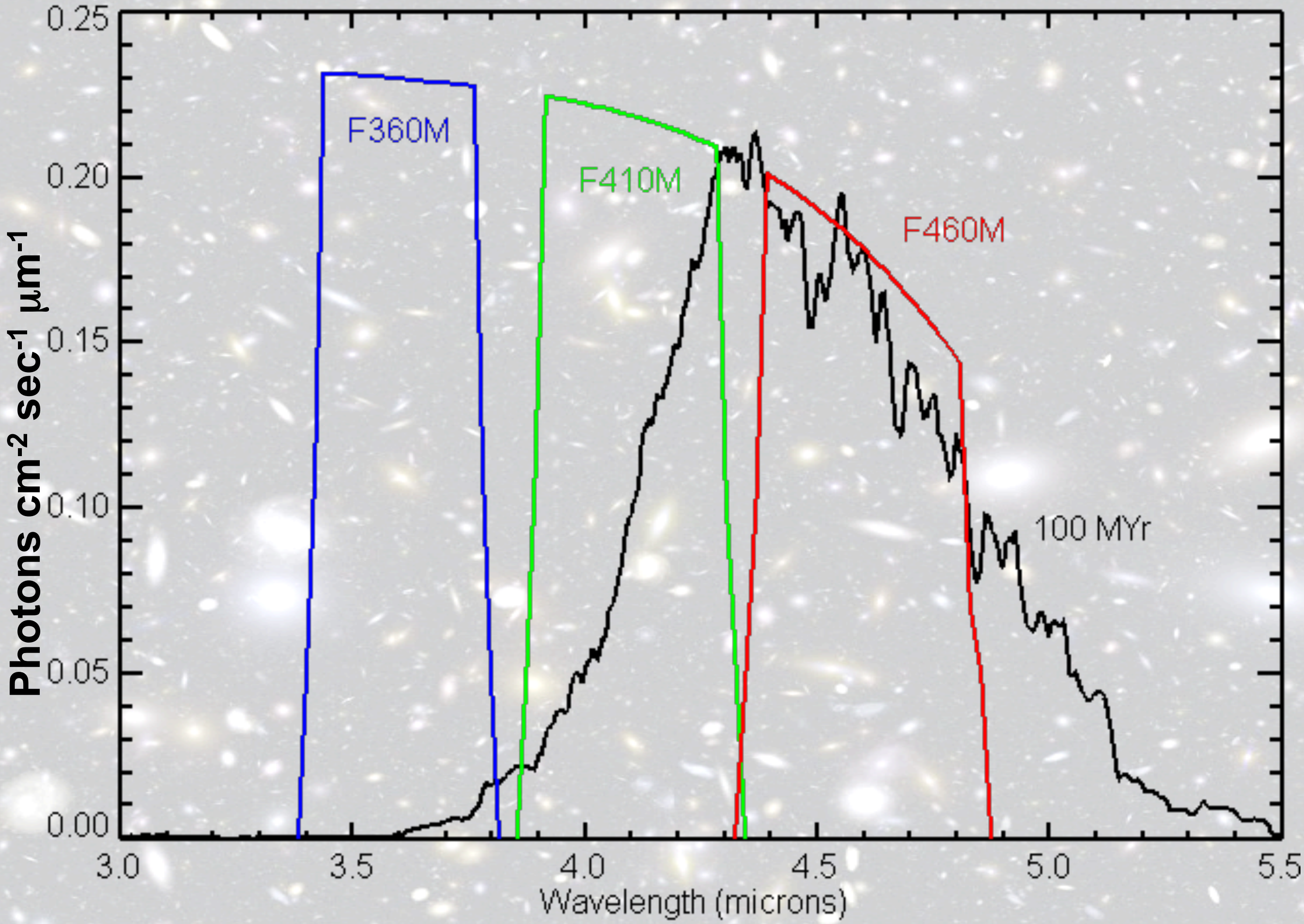
JWST Observes Planets:Coronagraphy

- All of JWST's imagers have coronagraphs
- Choice of circular and bar occulters with matching Lyot stops for 1-5 mircon cameras
- MIRI has both quadrant phase masks and Lyot occulter
  - Phase masks optimized for 10.65, 11.4, and 15.5 microns
  - Lyot occulter optimized for 23 microns



- Coronagraph performance is improved by trading throughput for diffraction suppression.
- NIRCam and TFI effective for hot planets, MIRI best for cooler ones

100 Myr-Old, 2 M_{Jup} Planet



A background star would be brightest at F360M.

Spectrum from Burrows, Sudarsky, & Lunine (2003)

JWST Observes Planets: Transits

All of JWST's instruments may be used for transit work.

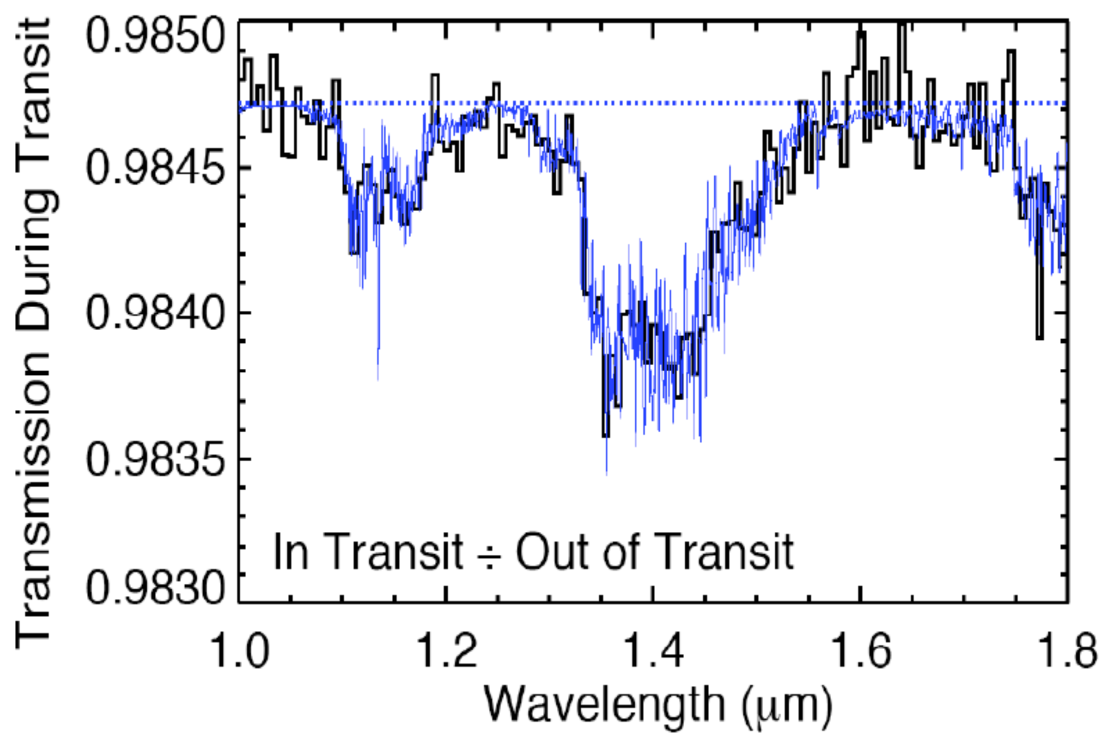
Instrument Mode	λ (μm)	R (λ/δλ)	FOV	Application
NIRCam Imaging	0.6 - 2.3 2.4 - 5.0	4, 10, 100 4, 10, 100	2 x (2.2' x 2.2') 2 x (2.2' x 2.2')	High precision light curves of primary and secondary eclipses.
NIRCam Phase Diversity Imaging	0.6 – 2.3	4, 10, 100	Image diam. - 57 pixels - 114 pixels	High precision light curves of transits for bright targets that need to be defocused to avoid saturation within the minimum t_{int}
MIRI Imaging	5 – 29	4-6	1.9' x 1.4'	High precision light curves of secondary eclipses.
TFI Imaging		100		High precision light curves
NIRCam Spectroscopy	2.4 – 5.0	1700	2 x (2.2' x 2.2')	High precision transmission and emission spectroscopy
NIRSpec Spectroscopy	1.0 – 5.0	100, 1000, 2700	1.6" x 1.6" slit	Transmission and emission spectroscopy of transiting planets.
MIRI Spectroscopy	5 - 11	100	Slitless	High precision emission spectroscopy
MIRI Spectroscopy	5.9 – 7.7 7.4 – 11.8 11.4 – 18.2 17.5 – 28.8	3000 3000 3000 3000	3.7" x 3.7" 4.7" x 4.5" 6.2" x 6.1" 7.1" x 7.7"	High precision emission spectroscopy

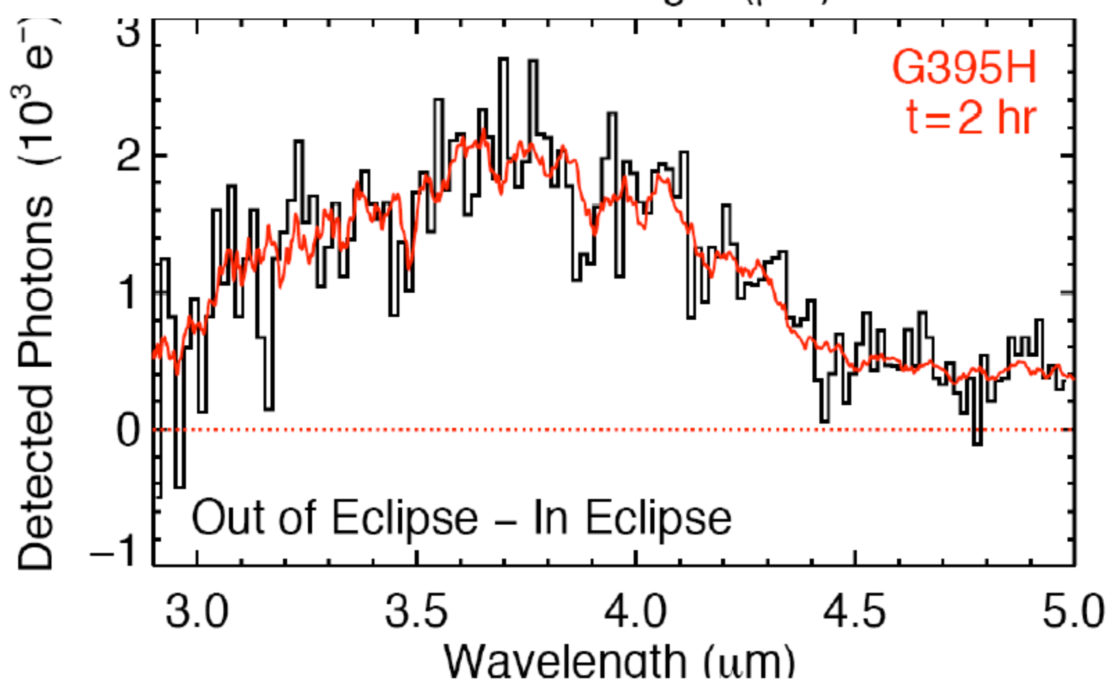
Simulated Transit Observations

Upper plot shows a Kepler hot Jupiter transmission observation using NIRSpec at R~3000 smoothed to R~100 in a 6hr observations centered on a 2hr transit.

Lower plot shows similar planet in an emission observation with NIRSpec at R~2700 smoothed to R~100.

NIRSpec's 1.6"x1.6" slit will be useful for transit studies.





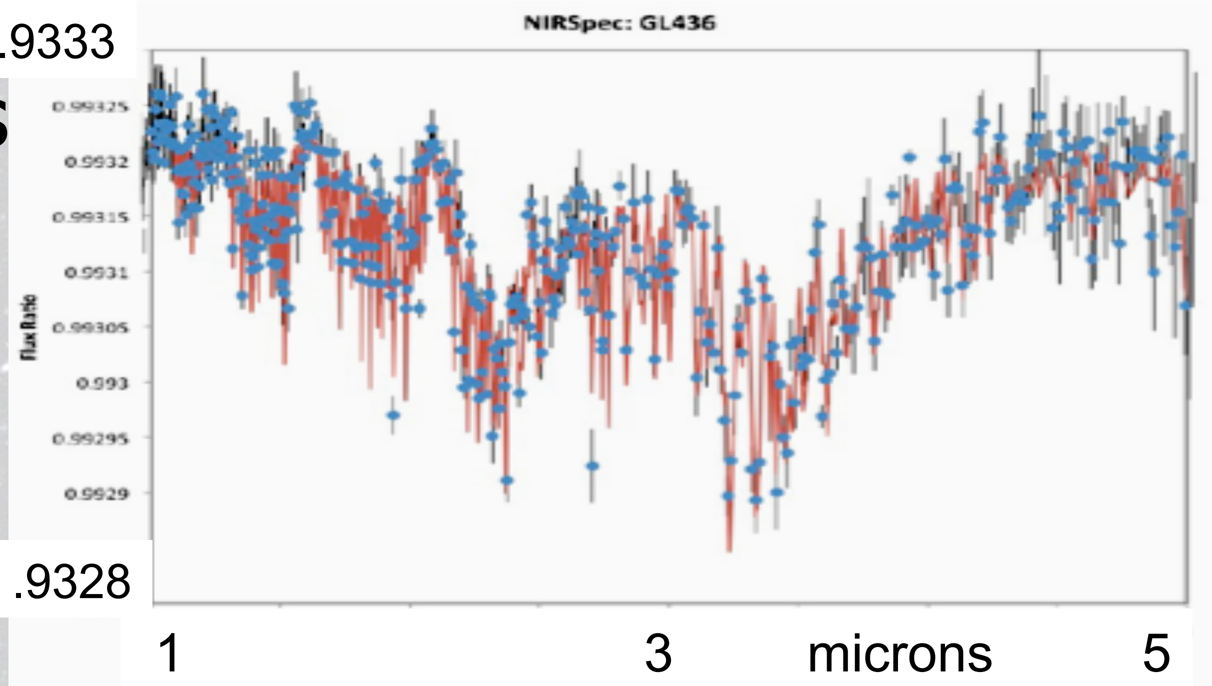
More Transits

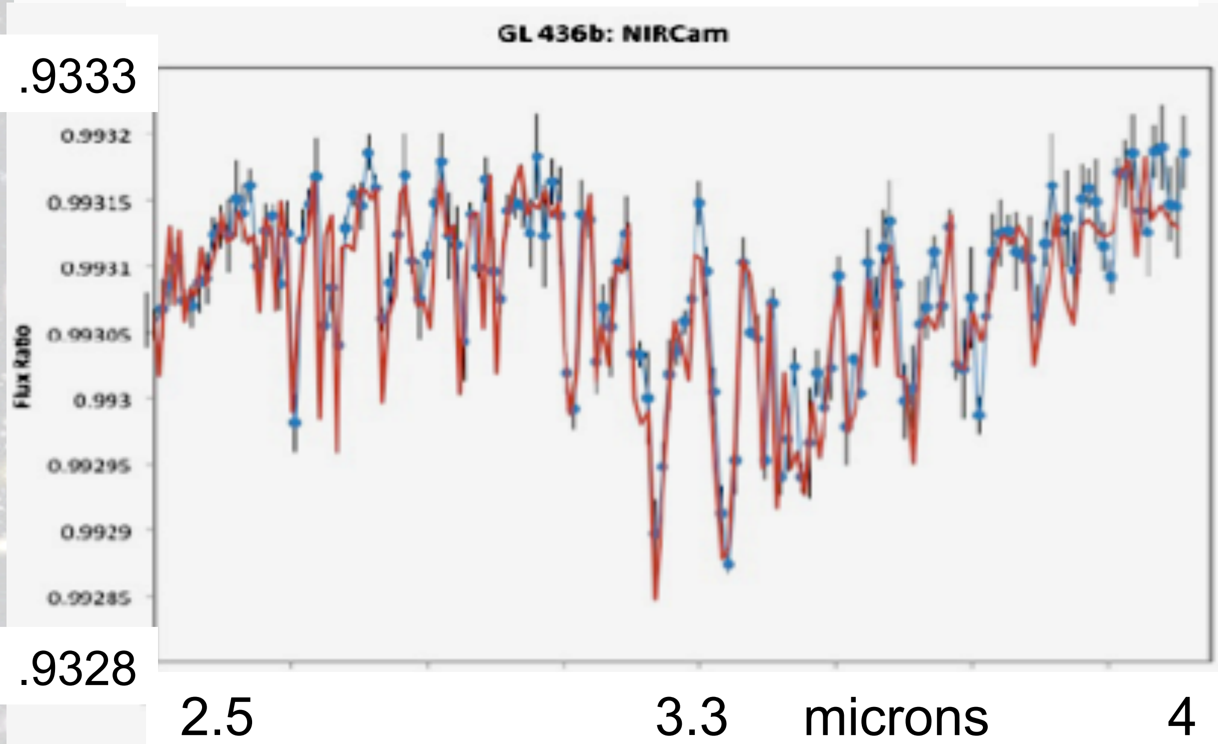
Simulated NIRSpec and NIRCam spectra of GJ 436b's hot Neptune, combining four transit observations (simulated spectrum of GJ 436b was provided by Sara Seager).

The simulation includes the effects of real contributions from pointing jitter, flat field errors and pixel response functions.

In the plots the exoplanet spectrum is shown in red and the blue points are the simulated observations with error bars.

NIRCam's long wavelength grisms will be useful for transits.






ADS astrium
NIRSpec
NIRCam
TFI
MIRI