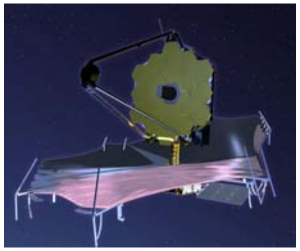
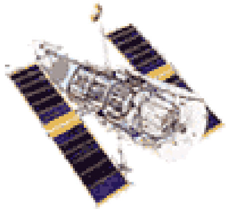


Detecting First Light: Ultradeep Surveys with Gravitational Telescopes and the JWST

M. Stiavelli

STScI, Baltimore

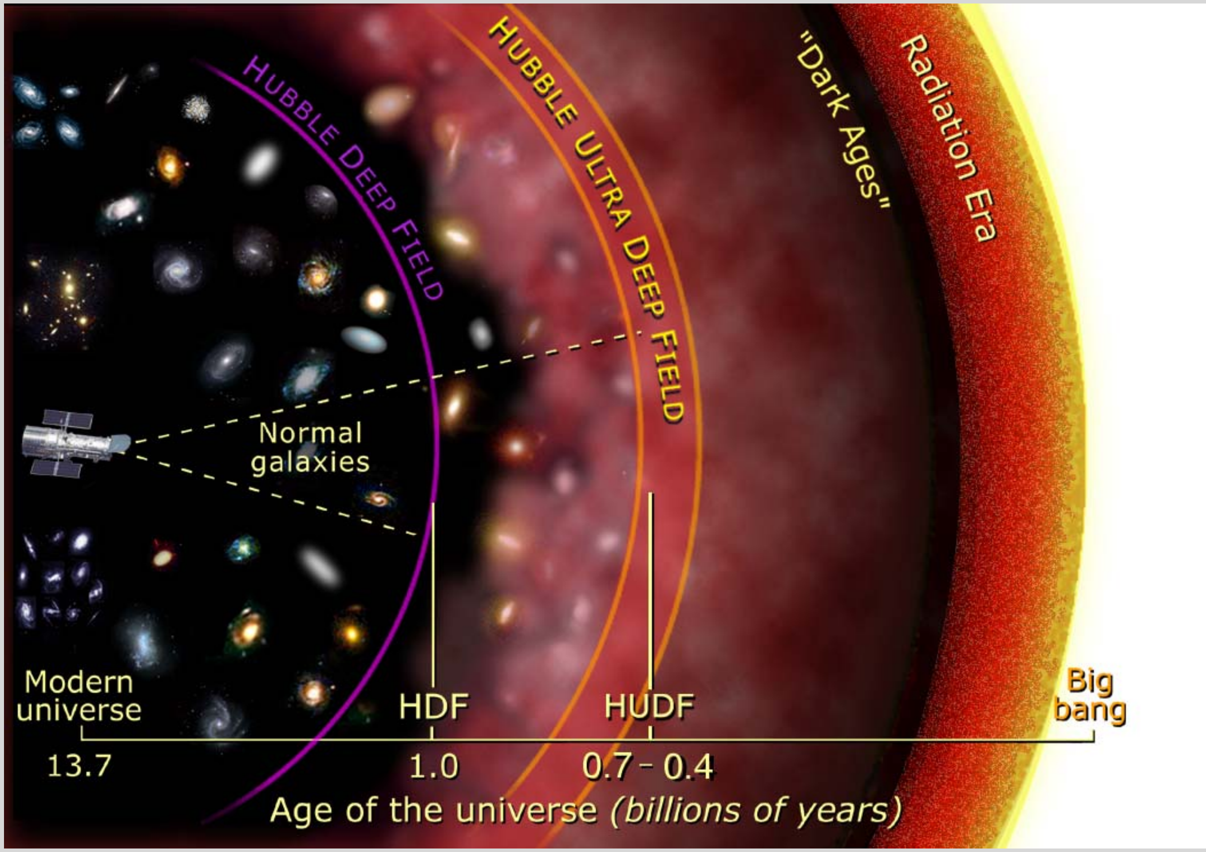


Plan:

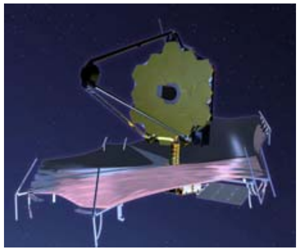
- Brief theoretical overview
- Observing first light with JWST
- Applications of gravitational lensing

End of the dark ages

- **first light sources**
- **Population III**
- reionization of H
- reheating of IGM



The "First Light Machine"



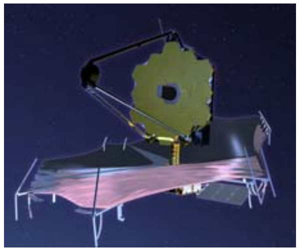
Probing the luminosity function of galaxies at z>12 (and probably already for z>8-9) or studying the properties of galaxies at z=6 requires an instrument more sensitive than HST :

the **James Webb Space Telescope**

End of the dark ages:

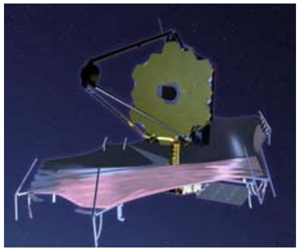
- **First light**
- Nature of reionization sources

Individual first light sources

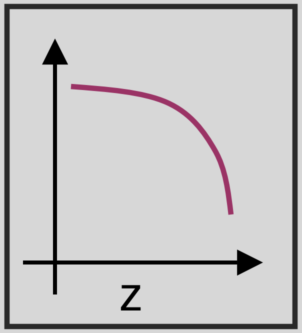


- Individual first light sources are most likely Population III stars and will be extremely faint, AB~35 for a 500 $M_{\odot}$ star.
- Individual stars will be detectable by JWST only thanks to large gravitational magnification or as (pair-instability) supernovae. Both detections should be attempted but they have low probability.
- In practice, JWST will focus on the detection of the beginning of the era of galaxy formation: few (dwarf?) galaxies with low metallicity and no pre-existing stellar populations.

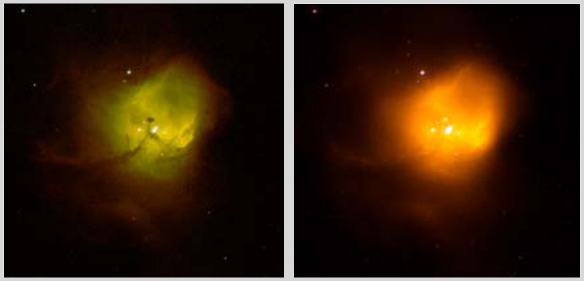
I. Detection of first luminous objects

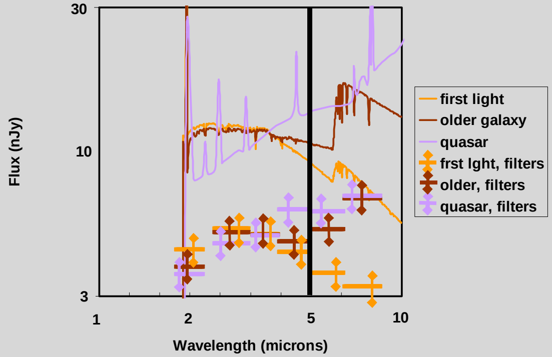


- Evolution of N(z). *Identify candidates with Lyman break technique* → **NIRCam**

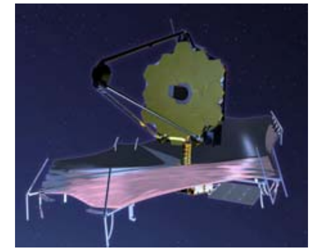


- Evolution of SFR(z). *Use Hα, Hβ and supernovae* → **NIRSpec and NIRCam**
- Evolution of <Z>(z). *Use [OIII]/Hβ.*
- Confirm nature of first light objects. *Place upper limit to metallicity, search for older stellar component.* → **NIRSpec and MIRI** (this will typically require lensed or intrinsically very bright sources)

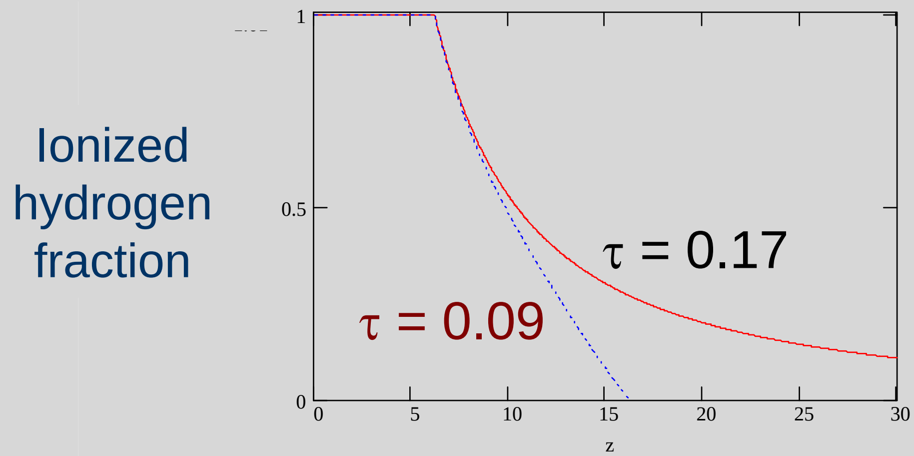




First light sources : detection



- WMAP indicates that reionization is an extended process

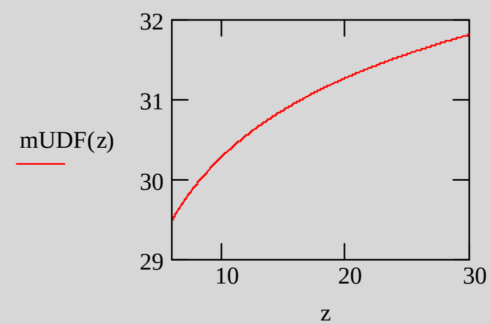


Extended reionization with τ = 0.09 gives first light at z=16 or higher.

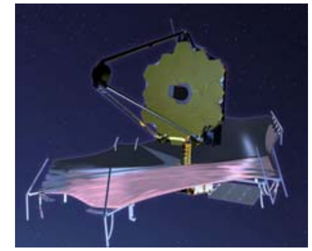
- Probing the LF to the same relative depth as that of z=6 from the UDF gives us a required depth:

from Trenti & Stiavelli 2006

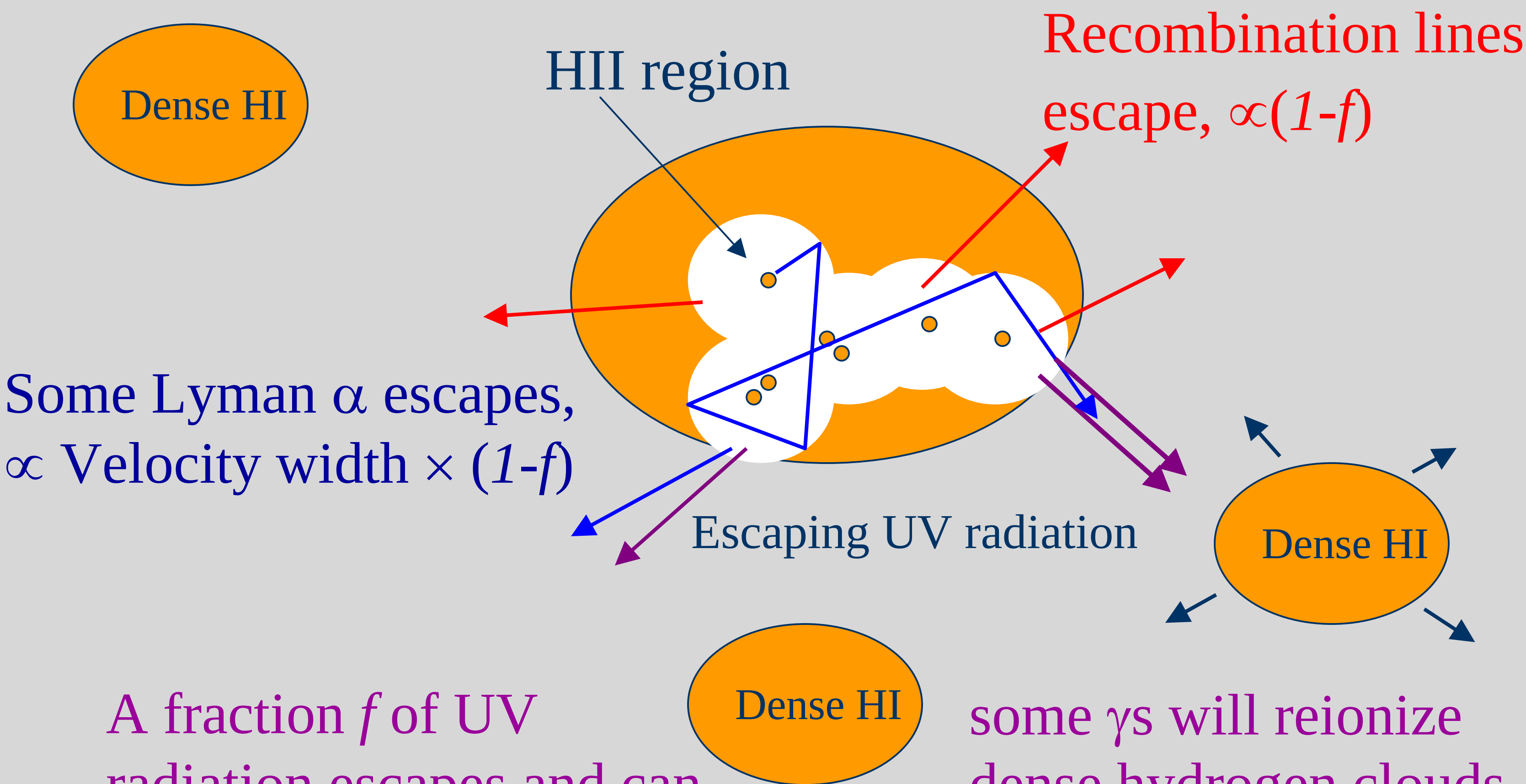
z	AB_1350	Fν (nJy)	λ (μm)	$\langle A_{1400} \rangle$	A_{1400}(90%)
10	30.284	2.80	1.34	0.08	0.18
12	30.551	2.19	1.58	0.07	0.15
15	30.869	1.63	1.95	0.05	0.12
20	31.267	1.13	2.55	0.04	0.08



These limits allow us to measure m_* even with 2+ magnitudes of evolution.



Estimate luminosity of firsts light and reionizing sources from first principles

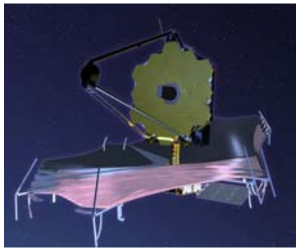


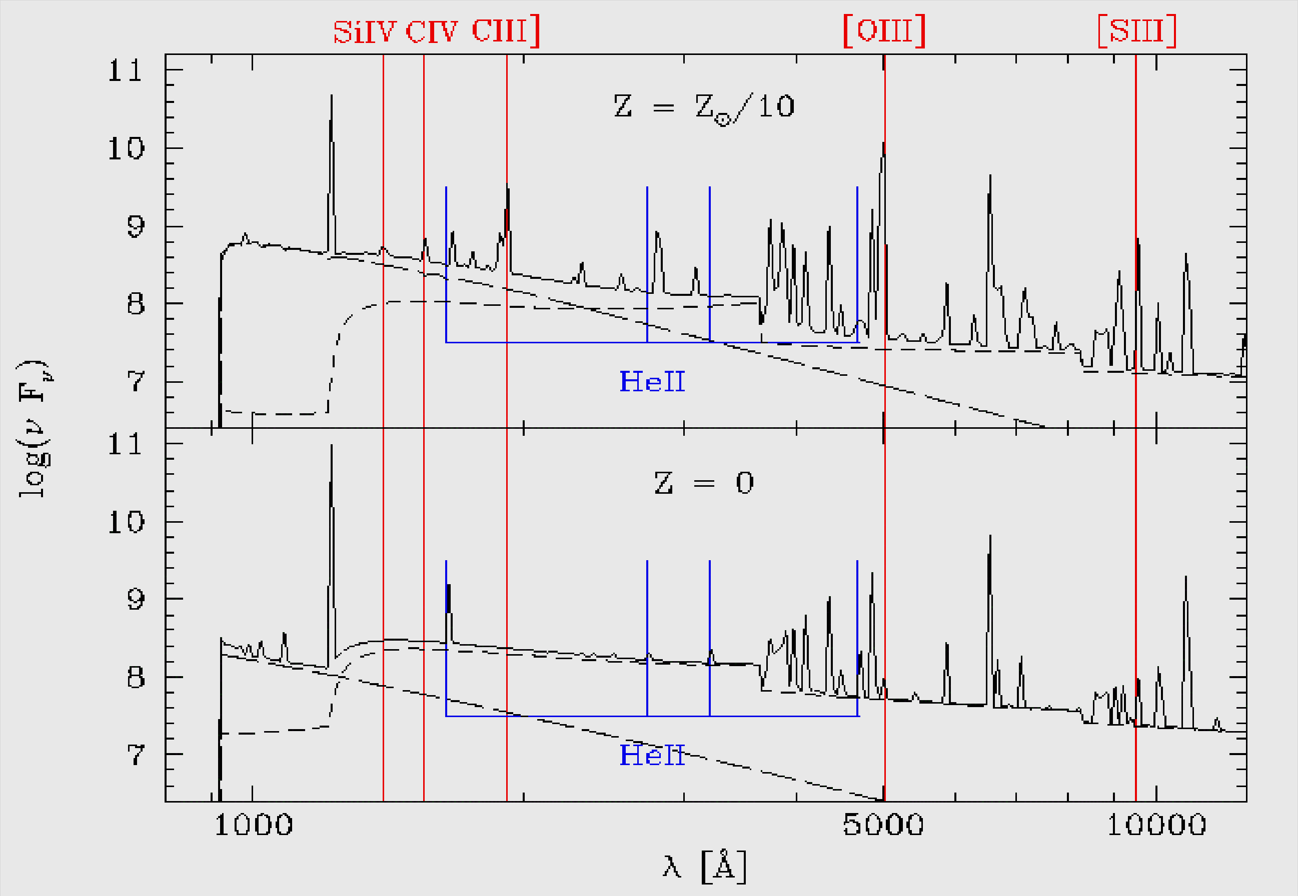
A fraction *f* of UV radiation escapes and can reionize the Universe

some γs will reionize dense hydrogen clouds that later recombine → *C*

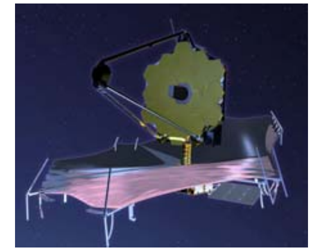
This prevents SF.

A primordial HII region (*f*=0)





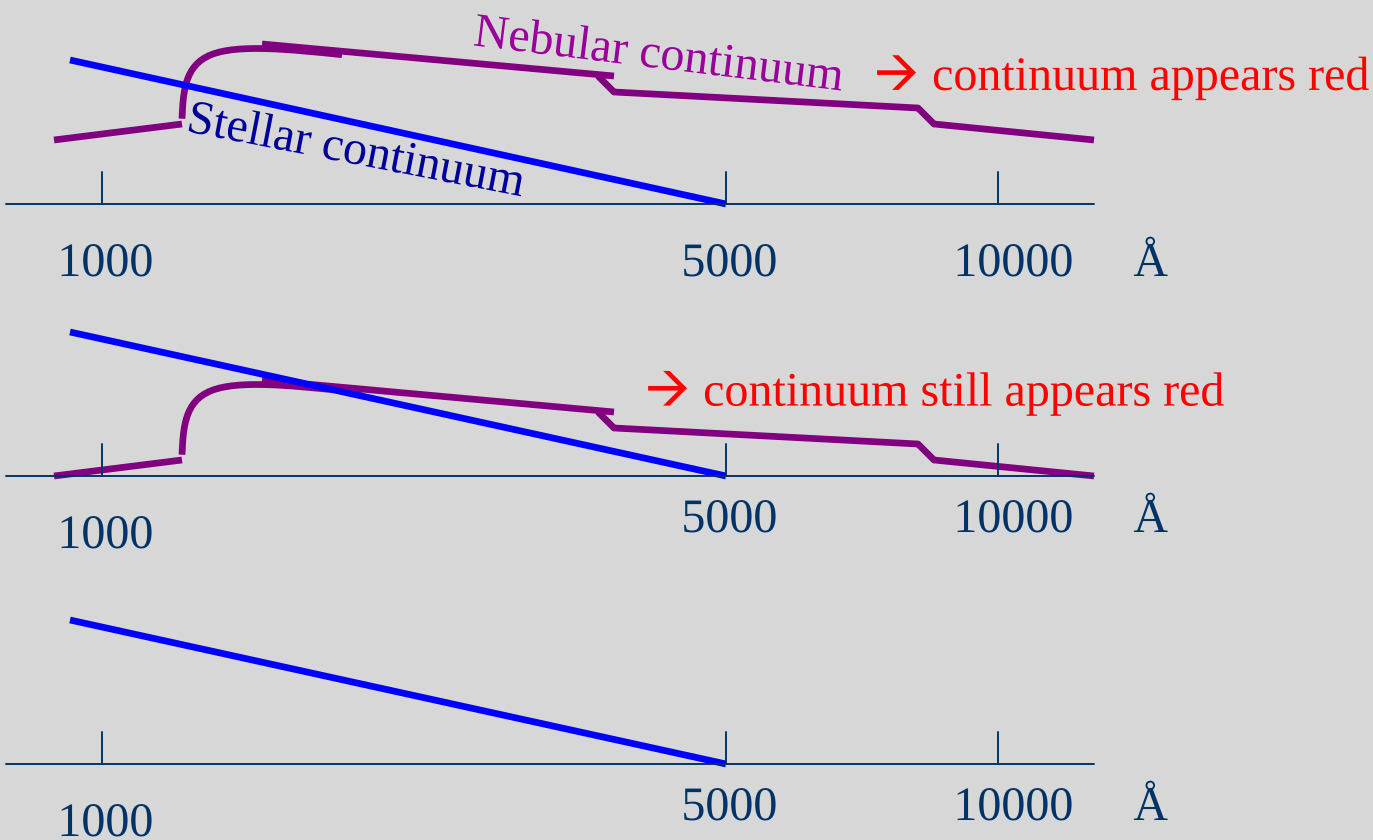
Spectra for zero-metallicity sources



f=0
No ionizing
γ escape

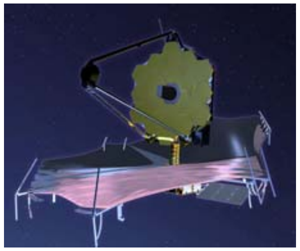
f=0.9
Most ionizing
γ escape

f=1
All ionizing
γ escape

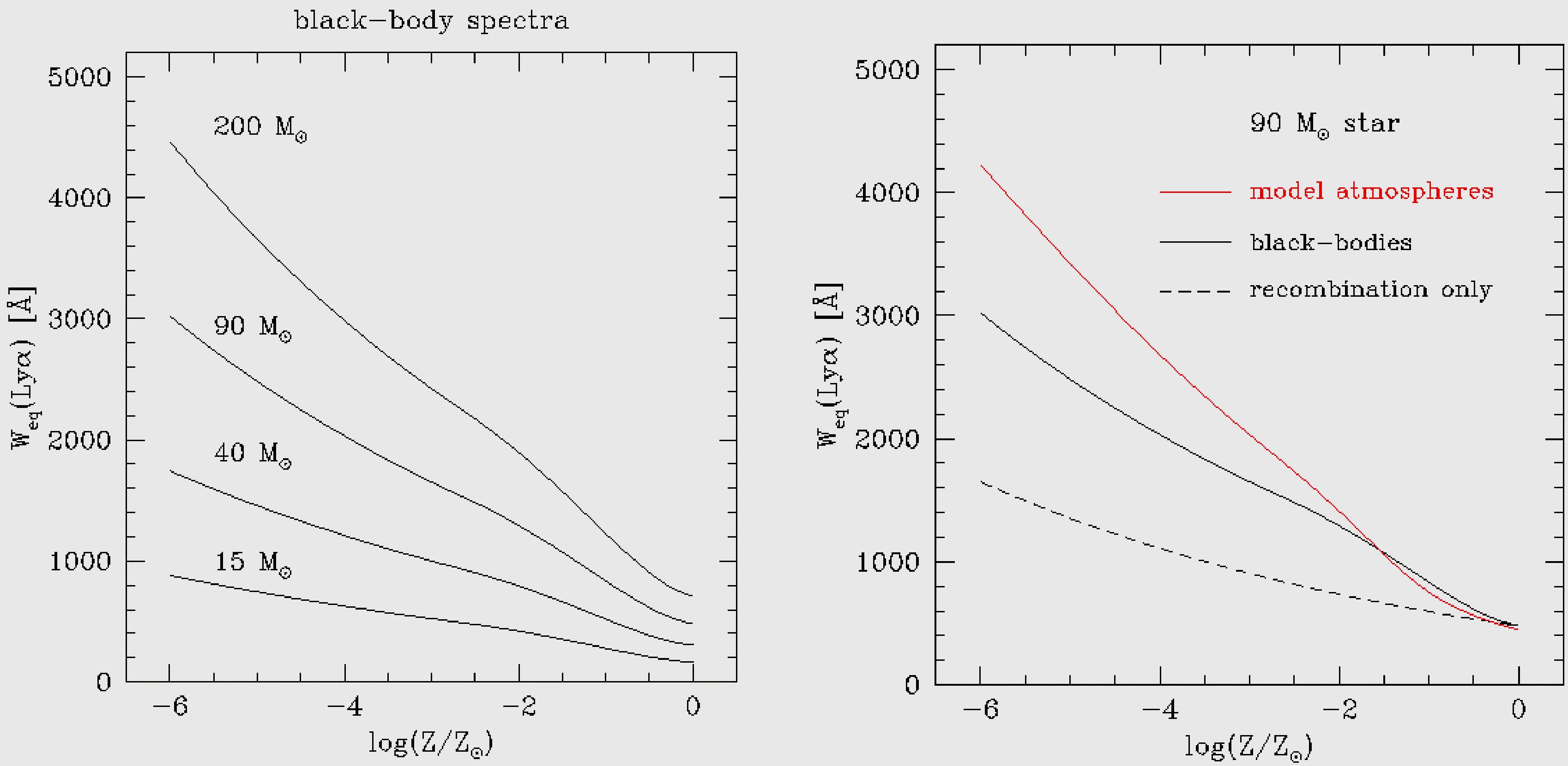


At higher metallicity the SED at 1400 Å is always dominated by stars.

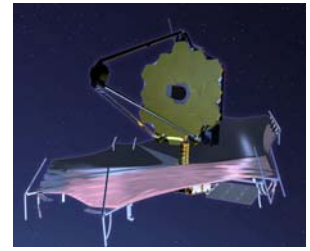
Ly-α Equivalent Width dependence on metallicity

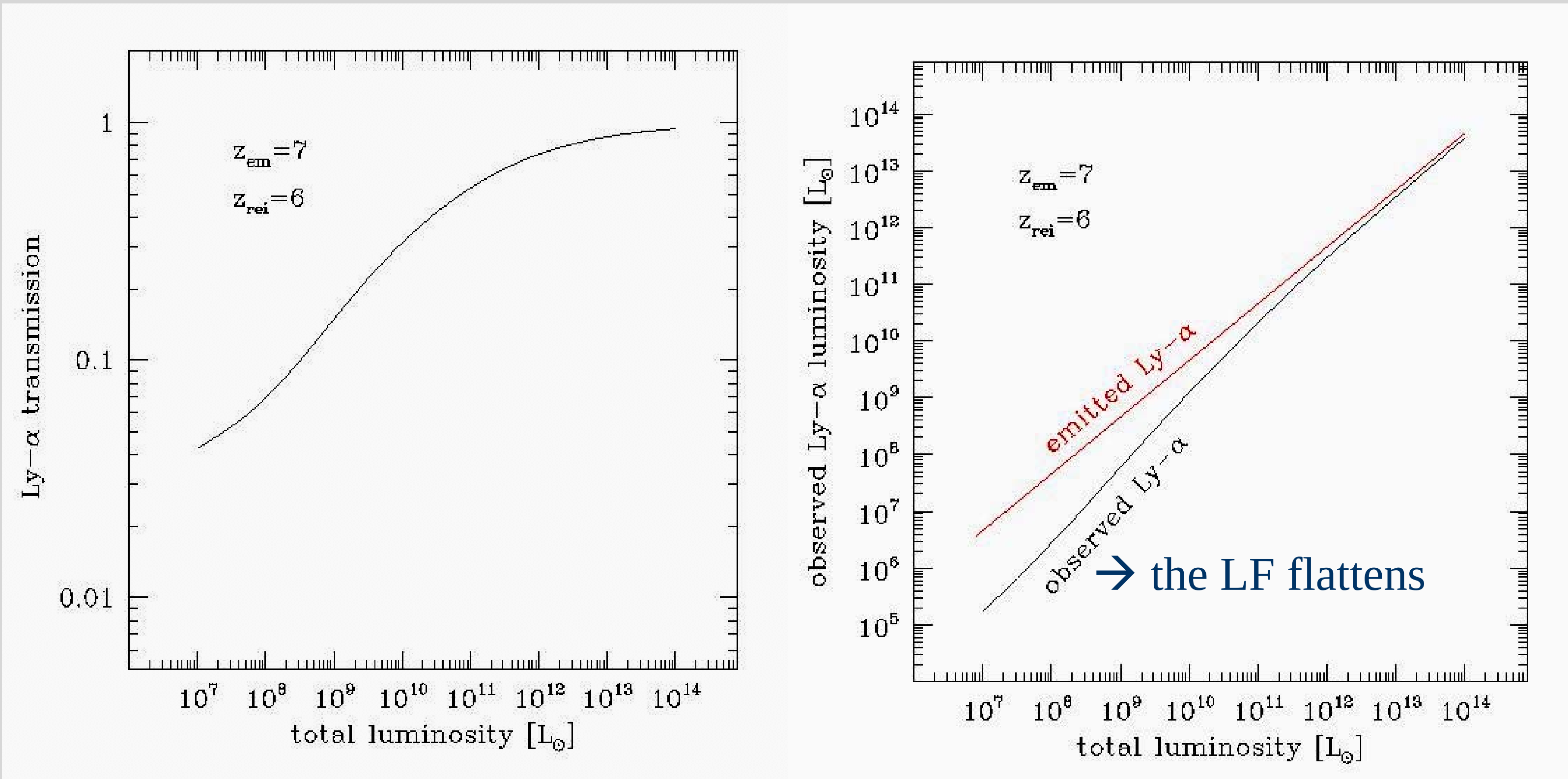


The Ly-α EW increases strongly at low Z because :
(a) the line intensity increases and
(b) the continuum flux decreases



Observed Ly-α Luminosity: a considerable fraction of the emitted one!

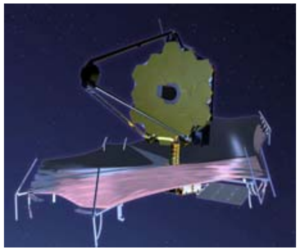




Model calculations assuming a Ly-α line width of 250 km s^{-1}

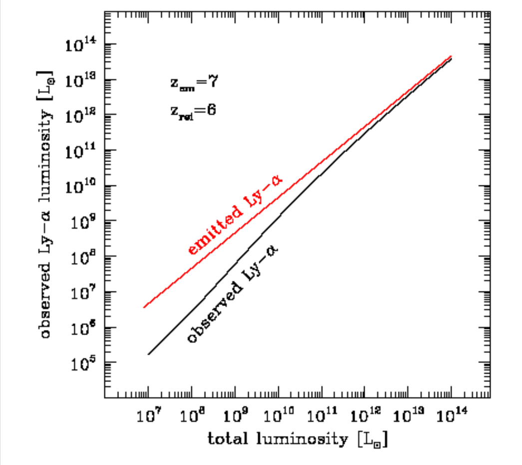
For smaller line widths a smaller fraction of the photons escape. If fainter sources have smaller widths this effect will further flatten the observable Ly-α LF.

First Light Sources : Ly α & properties



Assumptions: Pop III, ionizing photons escape fraction = 0.5.

Adopt: Lyα escape fraction of 0.2.

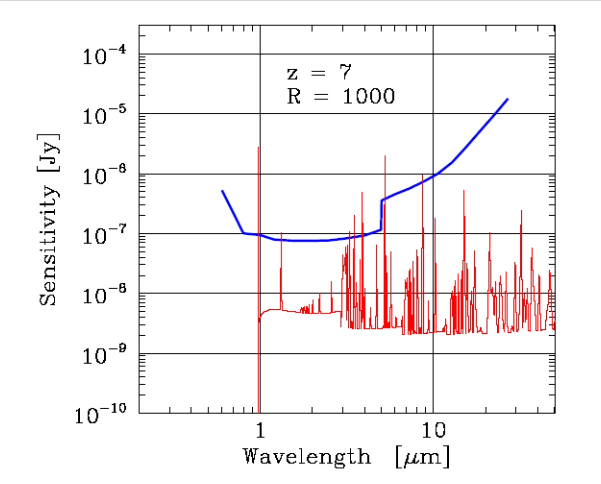


z	AB_1350	Ly α (cgs)	λ (μm)
10	30.284	1.7e-18	1.34
12	30.551	8.89e-19	1.58
15	30.869	4.02e-19	1.95
20	31.267	1.47e-19	2.55

Measuring the metallicity of first light sources

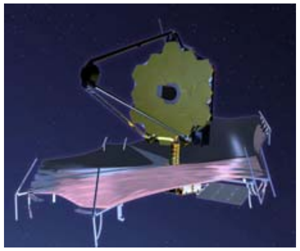
Let's consider a 5 nJy source with metallicity 1/1000 solar. The O line at 1665A will have a strength of:

4.5 10^{-19} erg cm^{-2} s^{-1}



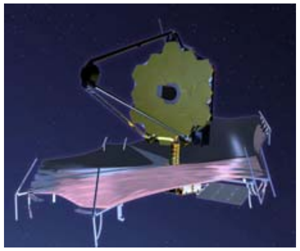
The metallicity measurement or the detection by MIRI will be possible for bright sources or sources amplified by lensing.

First light sources and lensing

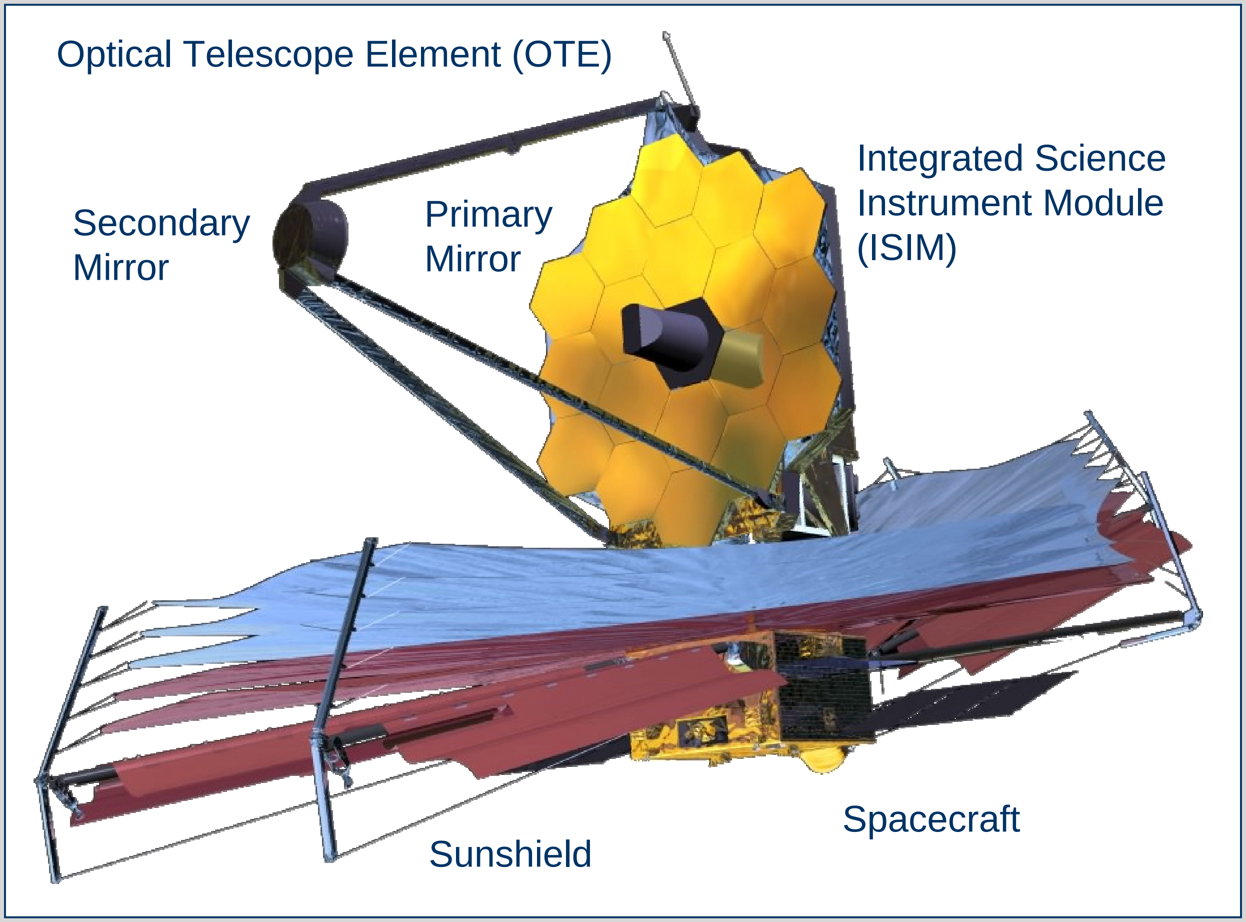


- First light sources will be very faint (AB=30 or fainter).
- Before reionization we expect the LF to be steep, ie. rich in dwarf galaxies that haven't yet been suppressed.
- It is unclear whether the small volume probed by high amplification with let us obtain significant statistics on the LF for AB >> 30. Probably Lyman-break searches more promising than Lyman α searches.
- Gravitational lensing amplification is probably the only way to obtain spectra of typical "first galaxies" down to AB=30.

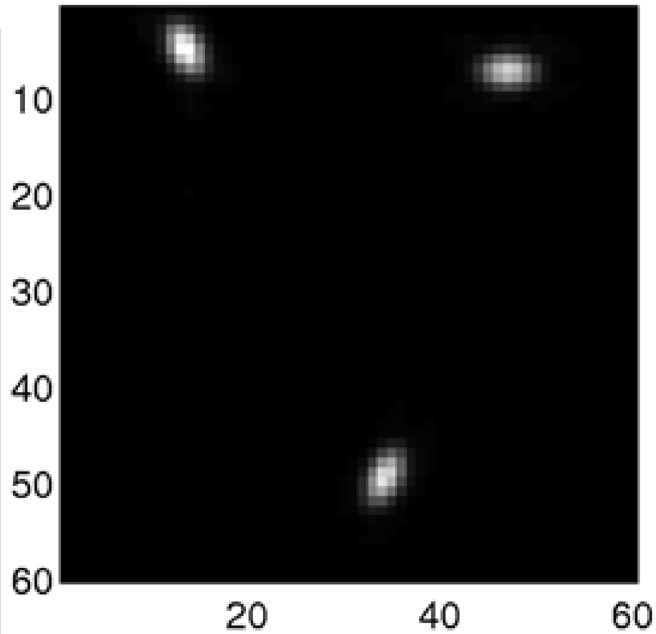
James Webb Space Telescope



- 6.6m Telescope
- Launch in 2013 to L2.
- Successor to Hubble & Spitzer.
- Demonstrator of deployed optics.
- Passively cooled to 50K.
- Named for 2nd NASA Administrator
- NASA + ESA + CSA
- Lead: Goddard Space Flight Center
- Prime: Northrop Grumman Space Technology

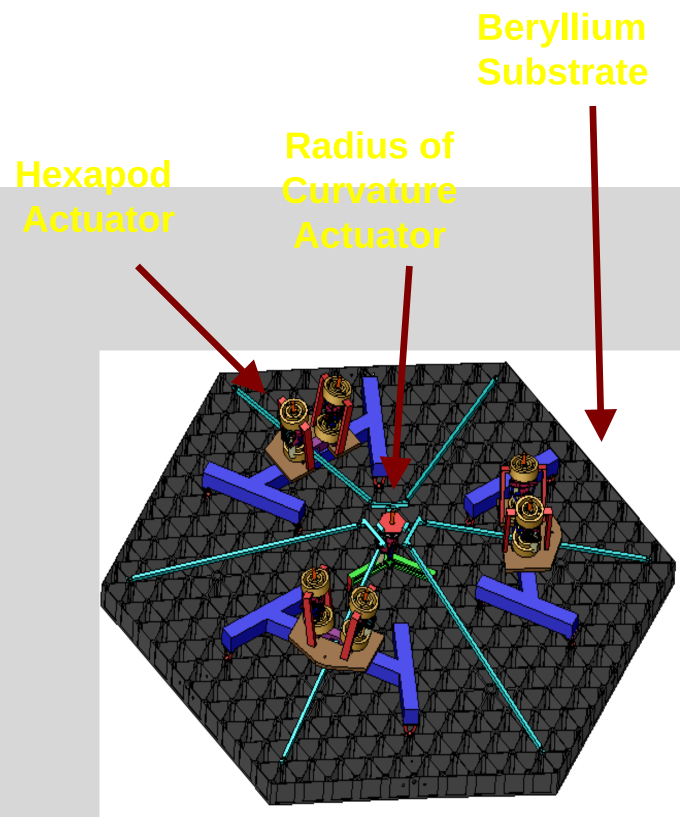


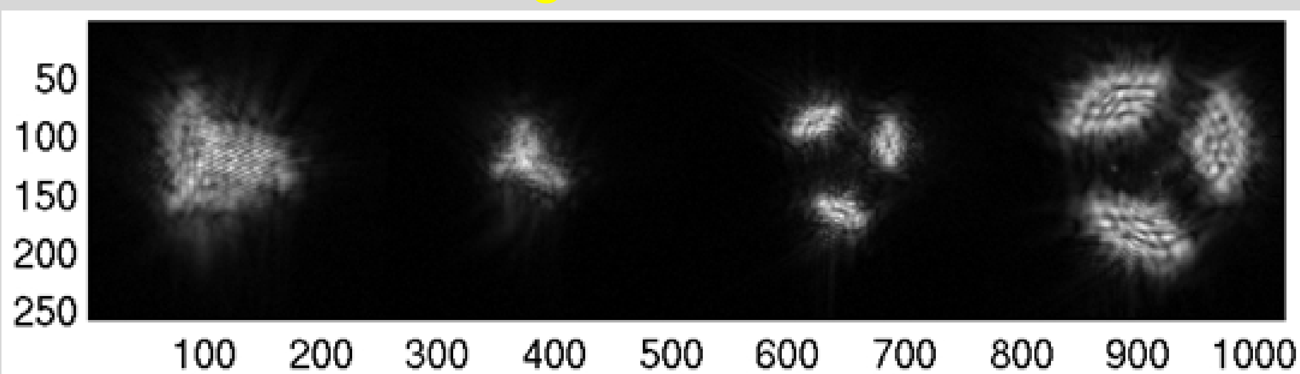
Mirror Segment Control



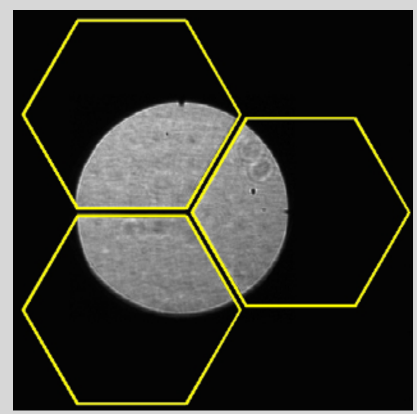
Focused Image

Testbed Mirror with 3 Segments

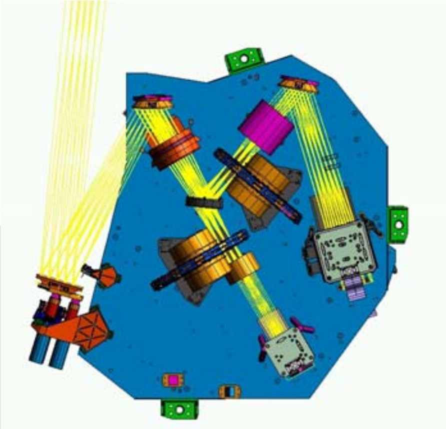




Unfocused Images



Instrumentation



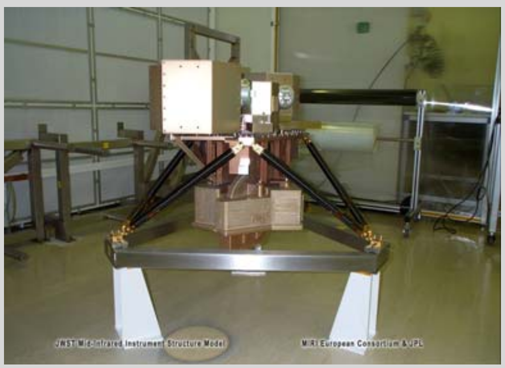
Arizona: Marcia Rieke PI

Lockheed-Martin & Rockwell

ESA: Peter Jakobsen

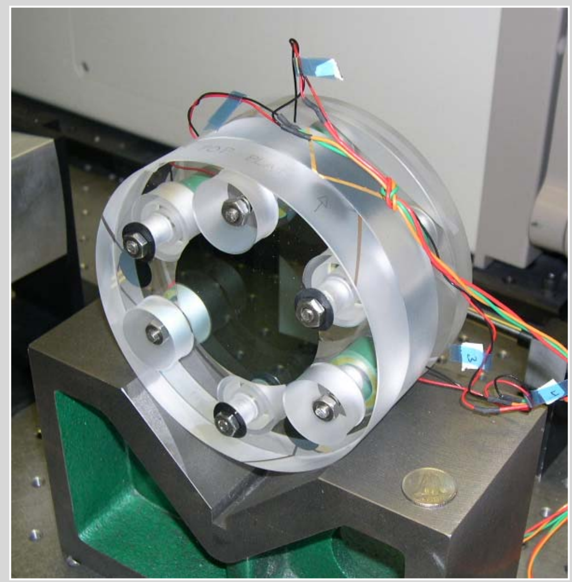
EADS Astrium & GSFC

- NIRCam, 0.6 to 5.0 micron:
  - 2.3 x 4.5 arcmin FOV
  - Broad & narrow-band imaging
- NIRSpec, 0.6 to 5.0 micron
  - 3.4 x 3.4 arcmin FOV
  - Micro-shutter, IFU, slits
  - R~100, 1000, 3000
- TFI, 1.6 to 4.8 micron
  - 2.2 x 2.2 arcmin FOV
  - R~100 narrow-band imaging
- MIRI, 5.0 to 27.0 micron
  - 1.4 x 1.9 arcmin FOV imaging
  - 3 arcsec IFU at R~3000
- Coronagraphy
  - NIRCam, TFI & MIRI



George Rieke & Gillian Wright

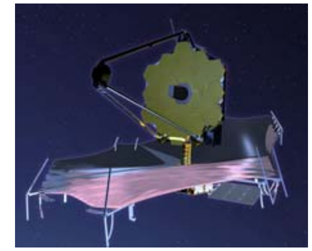
JPL and European Consortium



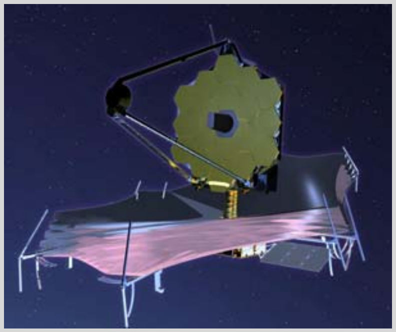
CSA: Rene Doyon

COM DEV

Operations



THE ASTROPHYSICAL JOURNAL



JWST at L2

Ka

S

Astronomer

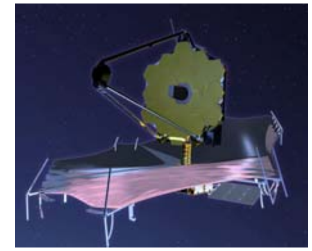
- STScI has been designated as Science Operations Center
- GO, Legacy/Treasury and GTO programs similar to HST

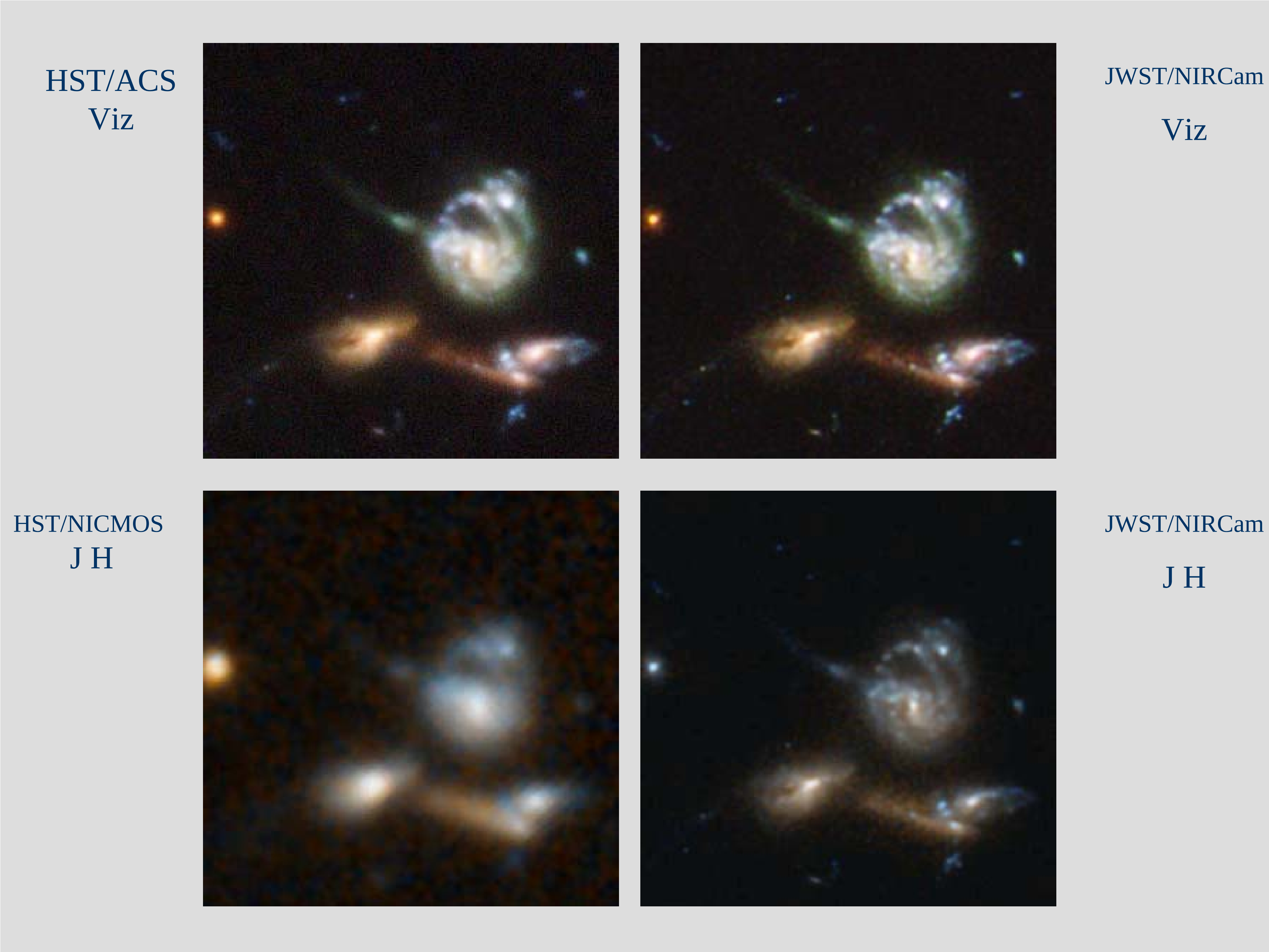
DSN

STScI

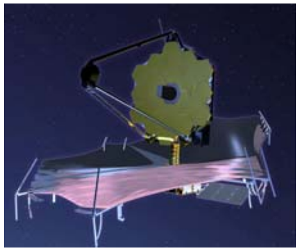
TAC

JWST is on track

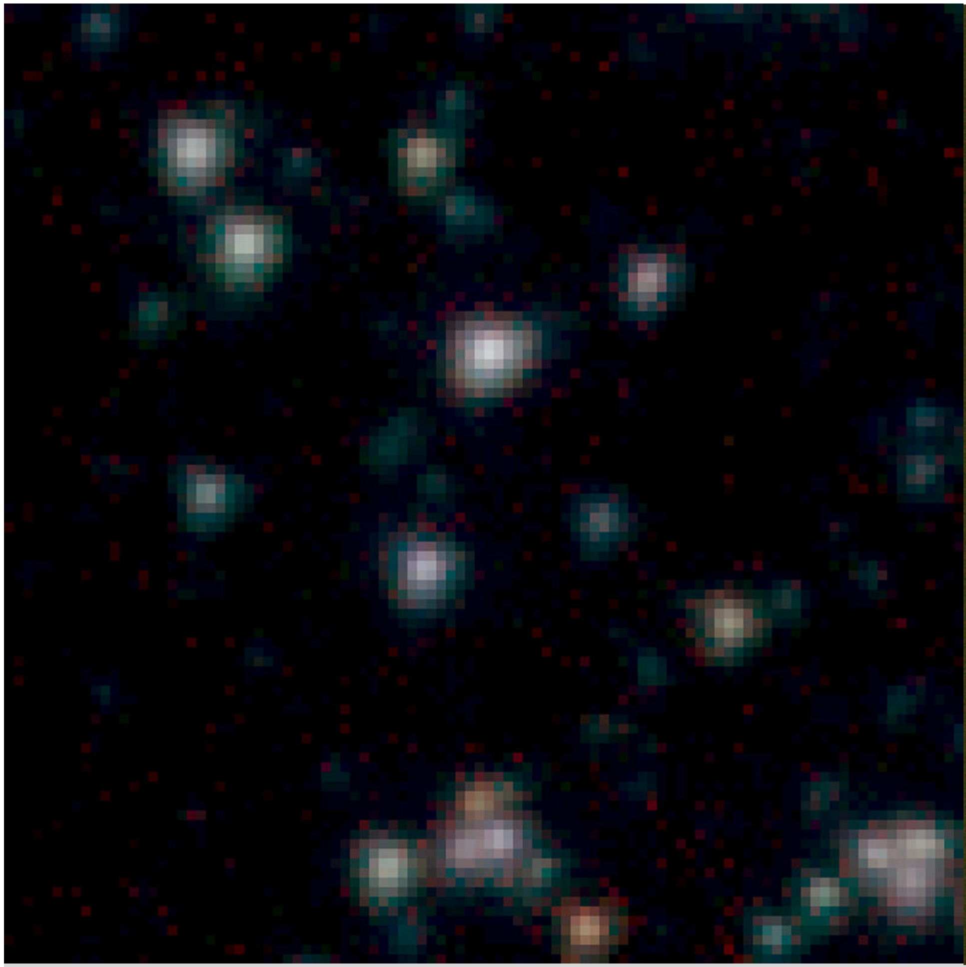



HST/ACS
Viz
JWST/NIRCam
Viz
HST/NICMOS
J H
JWST/NIRCam
J H

JWST-Spitzer image comparison



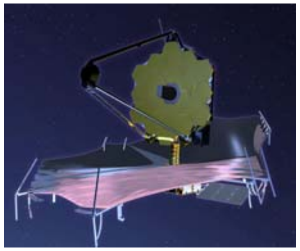
1'x1' region in the UDF – 3.5 to 5.8 μm



Spitzer, 25 hour per band (GOODS collaboration)

JWST, 1000s per band (simulated)

JWST Plan of attack

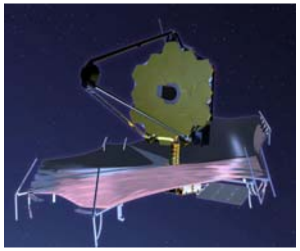


- Ultra deep survey to 1-2 nJy
  - Combine UDF with a north ecliptic pole survey (JWST CVZ) for z>6 SN searches
- Cluster survey:
  - 5 clusters to 5-8 nJy (amplified sources for followup)
- FGS-TF search
  - $10^{-18} – 10^{-19}$ erg cm^{-2} s^{-1}
- Spectroscopy
  - Lensed candidates
- MIRI Imaging
  - Lensed candidates

CDFS/GOODS-S/UDF is the best field:

- low cirrus
- well placed for ALMA followup
- reasonably well placed for JWST

Conclusions : First light objects



- JWST can observe first light stars only as supernovae (and it will be difficult!)
- JWST will study the "first galaxies", i.e. second generation objects pre-enriched by Pop III stars.
  - **We need an operational definition of these "first galaxies"**
  - **Two ways of being first:**
    - **Chronologically (highest z) → absolute first**
    - **Chemically (primordial metallicity) → locally first**
- Detailed physical study of this sources will be best done for lensed objects.