

Distant Universe

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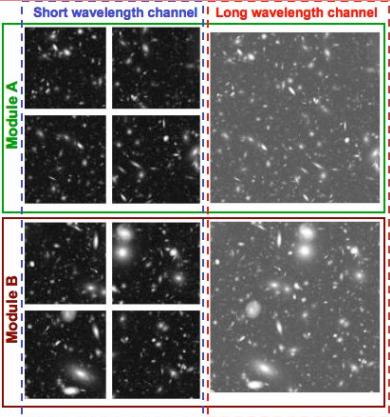
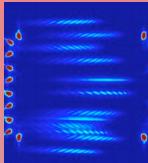
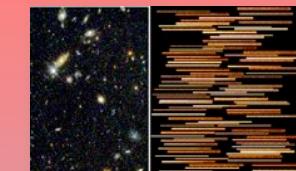
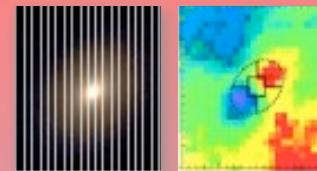
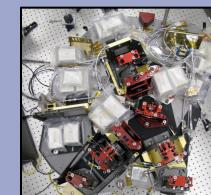
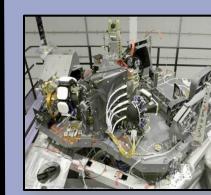
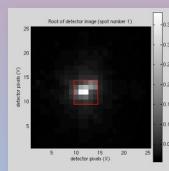
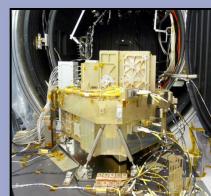
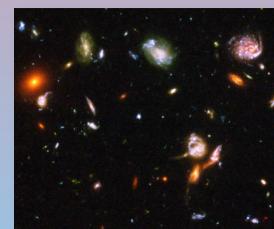
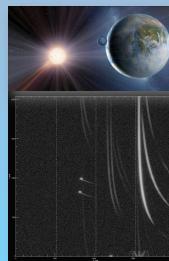
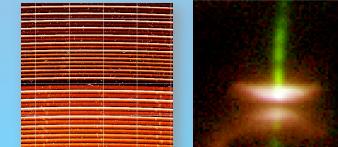
# Outline

- Overview of capabilities
- Two open questions:
  - How were the initial conditions for galaxy formation set?
  - How did galaxies evolve to their present form?
- Conclusions

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# JWST Science Instruments

 <p>Deep, wide field broadband-imaging</p> <p>Module A</p> <p>Short wavelength channel Long wavelength channel</p>	<p>Wavefront Sensing &amp; Control (WFSC)</p>  <p>Coronagraphic Imaging</p> 	<p>Multi-Object, IR spectroscopy</p>  <p>IFU spectroscopy</p> 
<p>NIRCam</p> 	<p>NIRSpec</p> 	<p>Long Slit spectroscopy</p> 
<p>Fine Guidance Sensor</p>  <p>Moving Target Support</p> 	<p>FGS/NIRISS</p>  <p>MIRI</p> 	<p>Mid-IR, wide-field Imaging</p> 
<p>Slitless Spectroscopy</p>  <p>Near-IR imaging</p> 	<p>High Contrast Closure Phase Imaging</p>  <p>Mid-IR Coronagraphic Imaging</p> 	<p>IFU spectroscopy</p> 

# JWST Science Instruments

The figure displays a grid of 12 panels, each representing a different science instrument or capability of the James Webb Space Telescope (JWST). The panels are arranged in three rows and four columns.

- Row 1:**
  - WFSC & Coronagraphic Imaging:** Shows two panels: "Wavefront Sensing & Control (WFSC)" and "Coronagraphic Imaging".
  - Multi-Object, IR spectroscopy:** Shows a panel of "Multi-Object, IR spectroscopy".
  - IFU spectroscopy:** Shows a panel of "IFU spectroscopy".
- Row 2:**
  - NIRCam:** Shows a panel of "NIRCam" with an inset image of the instrument.
  - NIRSpec:** Shows a panel of "NIRSpec" with an inset image of the instrument.
  - Long Slit spectroscopy:** Shows a panel of "Long Slit spectroscopy".
- Row 3:**
  - Faint object imaging to  $z \sim 40$ , rest frame optical imaging to  $z \sim 9$ , rest frame H-band imaging to  $z \sim 2$ :** A large red box highlights the "Slitless Spectroscopy" and "NIRCam" panels, indicating these capabilities.
  - MIRI:** Shows a panel of "MIRI".
  - Mid-IR, wide-field Imaging:** Shows a panel of "Mid-IR, wide-field Imaging".
- Row 4:**
  - FGS/NIRISS:** Shows a panel of "FGS/NIRISS".
  - High Contrast Closure Phase Imaging:** Shows a panel of "High Contrast Closure Phase Imaging".
  - Mid-IR Coronagraphic Imaging:** Shows a panel of "Mid-IR Coronagraphic Imaging".
  - IFU spectroscopy:** Shows a panel of "IFU spectroscopy".

**Annotations:**

- A large red box highlights the "Slitless Spectroscopy" and "NIRCam" panels in the third row.
- Text in the red box: "faint object imaging to  $z \sim 40$ , rest frame optical imaging to  $z \sim 9$ , rest frame H-band imaging to  $z \sim 2$ ".

# JWST Science Instruments

The figure displays a grid of 12 panels illustrating the science instruments of the James Webb Space Telescope (JWST). The panels are arranged in three rows and four columns.

- Row 1:**
  - WFSC & Coronagraphic Imaging:** Shows two panels: one for Wavefront Sensing & Control (WFSC) and one for Coronagraphic Imaging.
  - Multi-Object, IR spectroscopy:** Shows two panels: one for Multi-Object, IR spectroscopy and one for IFU spectroscopy.
- Row 2:**
  - NIRCam:** Shows an image of the NIRCam instrument.
  - NIRSpec:** Shows an image of the NIRSpec instrument.
  - Long Slit spectroscopy:** Shows an image of a star with a black circle indicating the slit position.
- Row 3:**
  - FGS/NIRISS:** Shows two panels: one for Fine Guidance Sensor (FGS) and Near-IR Imaging, and one for Slitless Spectroscopy and Near-IR Imaging.
  - MIRI:** Shows an image of the MIRI instrument.
  - Mid-IR, wide-field Imaging:** Shows an image of a galaxy cluster.

A red box highlights the **NIRSpec** panel, which contains the text:

**spectrograph with multi-object and IFU  
redshifts, kinematics and line strengths**

# JWST Science Instruments

The figure displays a grid of 12 panels illustrating the science instruments of the James Webb Space Telescope (JWST). The panels are arranged in three rows and four columns.

- Top Row:**
  - NIRCam:** Shows two panels: "Deep, wide field broadband-imaging" (Module A and Module B) and "restframe H-band imaging to  $z \sim 7$ , mid-IR spectroscopy". The latter is highlighted with a red box.
  - WFSC:** Shows "Wavefront Sensing & Control (WFSC)" and "Coronagraphic Imaging".
  - MIRI:** Shows "Multi-Object, IR spectroscopy" and "IFU spectroscopy".
  - NIRSPEC:** Shows "IFU spectroscopy" and "Long Slit spectroscopy".
- Middle Row:**
  - FGS/NIRISS:** Shows "Fine Guidance Sensor" and "Moving Target Support".
  - MIRI:** Shows "FGS/NIRISS" and "MIRI".
  - Mid-IR, wide-field Imaging:** Shows "Near-IR imaging" and "Mid-IR Coronographic Imaging".
- Bottom Row:**
  - Slitless Spectroscopy:** Shows "Slitless Spectroscopy" and "High Contrast Closure Phase Imaging".
  - IFU spectroscopy:** Shows "IFU spectroscopy" and "IFU spectroscopy".

# JWST Science Instruments

blind searches for emission line galaxies to  $z \sim 40$

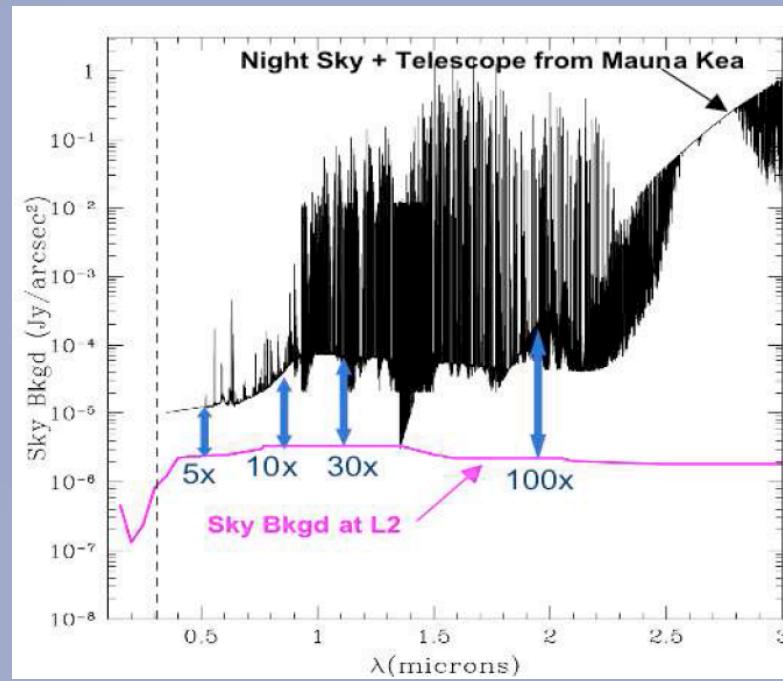
The figure displays a grid of 14 panels illustrating the science instruments of the James Webb Space Telescope (JWST). The panels are arranged in three rows:

- Top Row:**
  - WFSC & Coronagraphic Imaging:** Shows two panels: "Short wavelength channel" and "Long wavelength channel".
  - Multi-Object, IR spectroscopy:** Shows a grid of images and spectra.
  - IFU spectroscopy:** Shows a grid of images and spectra.
- Middle Row:**
  - Deep, wide field broadband-imaging:** Shows two panels: "Module A" and "Module B".
  - NIRCam:** Shows an image of the instrument.
  - NIRSpec:** Shows an image of the instrument.
  - Long Slit spectroscopy:** Shows an image of a spectrum.
- Bottom Row:**
  - Fine Guidance Sensor:** Shows a panel with a detector image and a coordinate grid.
  - Moving Target Support:** Shows an image of a target.
  - FGS/NIRISS:** Shows an image of the instrument.
  - MIRI:** Shows an image of the instrument.
  - Slitless Spectroscopy:** Shows an image of Earth with a light source and a spectrum.
  - Near-IR imaging:** Shows an image of galaxies.
  - High Contrast Closure Phase Imaging:** Shows a diagram of a hexagonal lattice and a corresponding image.
  - Mid-IR Coronagraphic Imaging:** Shows an image of a diffraction pattern.
  - IFU spectroscopy:** Shows two panels of spectra.

# JWST vs ELT: overview

- For either velocity dispersion measurements or velocity fields ELTs are extremely competitive especially with AO-fed IFU spectrographs.
- For measurements where line strength indices and kinematics are desired the uninterrupted wavelength range of JWST becomes an important consideration.

Lowest background for  
JWST is at  $3\mu\text{m}$



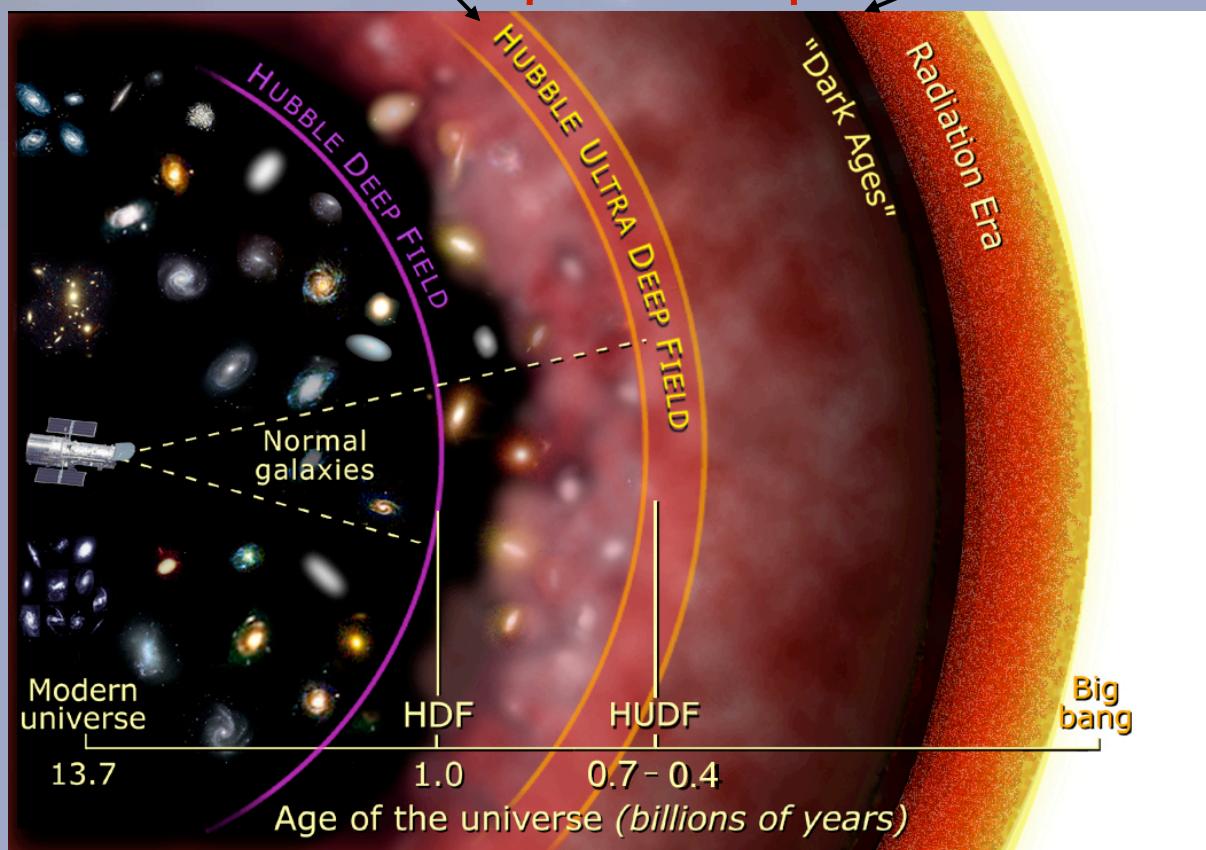
# Outline

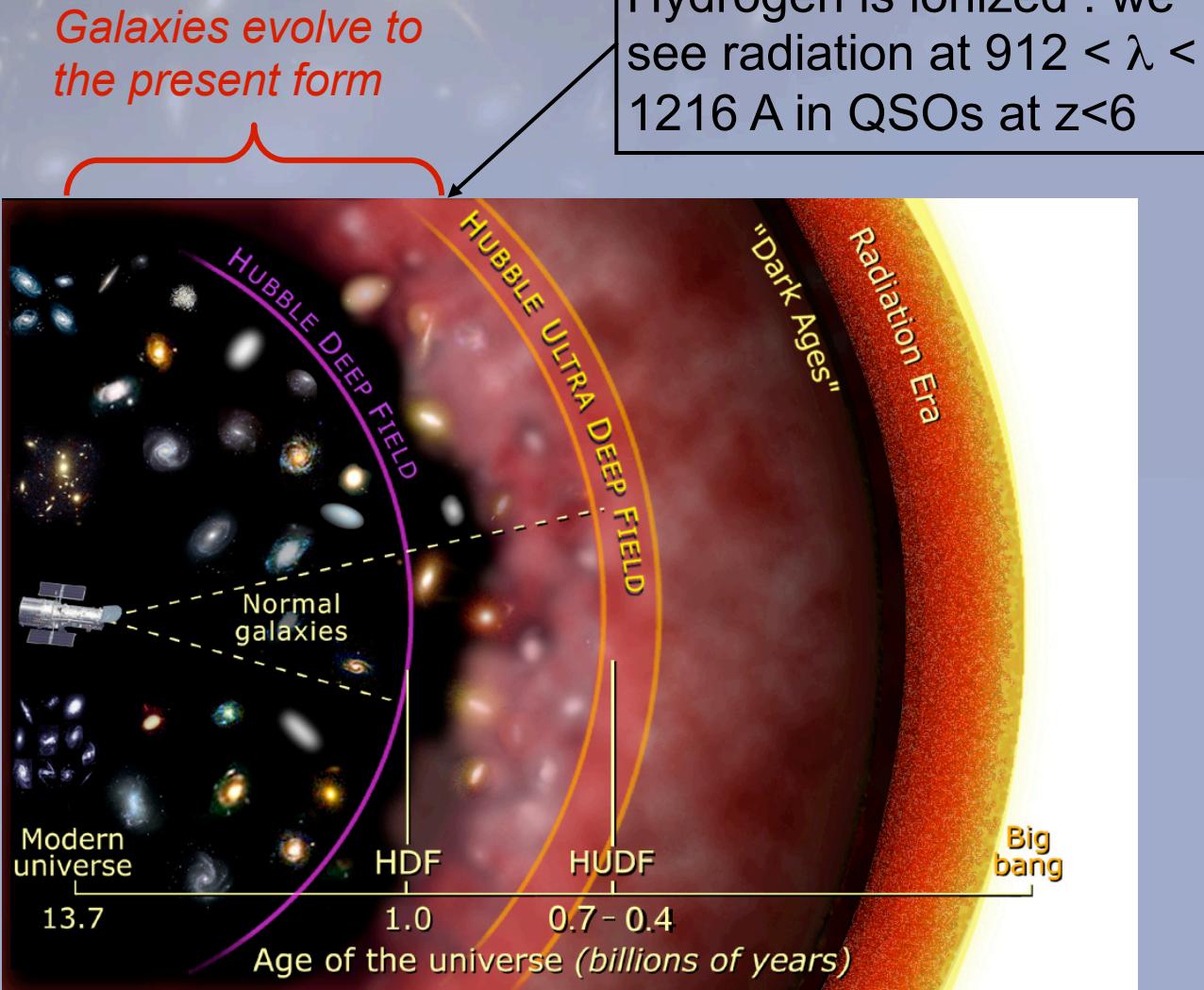
- Overview of capabilities
- Two open questions:
  - How were the initial conditions for galaxy formation set?
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- Conclusions

Hydrogen is ionized : we see radiation at  $912 < \lambda < 1216$  Å in QSOs at  $z < 6$

*Setting the initial conditions  
for galaxy formation*

$z \sim 1300$ , hydrogen recombines,  
CMBR “released”





# Two open questions

Two major open questions at the high-redshift frontier (from Stiavelli et al. 2009 and Windhorst et al. 2009 JWST SWG Decadal input white papers):

**How were the initial conditions for galaxy formation set?**

1. When and how did reionization occur?
2. What sources caused reionization?
3. What are the first galaxies?
4. When and how did the first stars form?
5. When and how did the active galactic nuclei form?

**How did galaxies evolve to their present form?**

6. When and how did the Hubble Sequence form?
7. How did the heavy elements form during galaxy assembly?
8. What physical processes determine galaxy properties?
9. What are the roles of starbursts and black holes during galaxy assembly?

In the light of recent progress I will review the expected contribution to JWST to answering these questions.

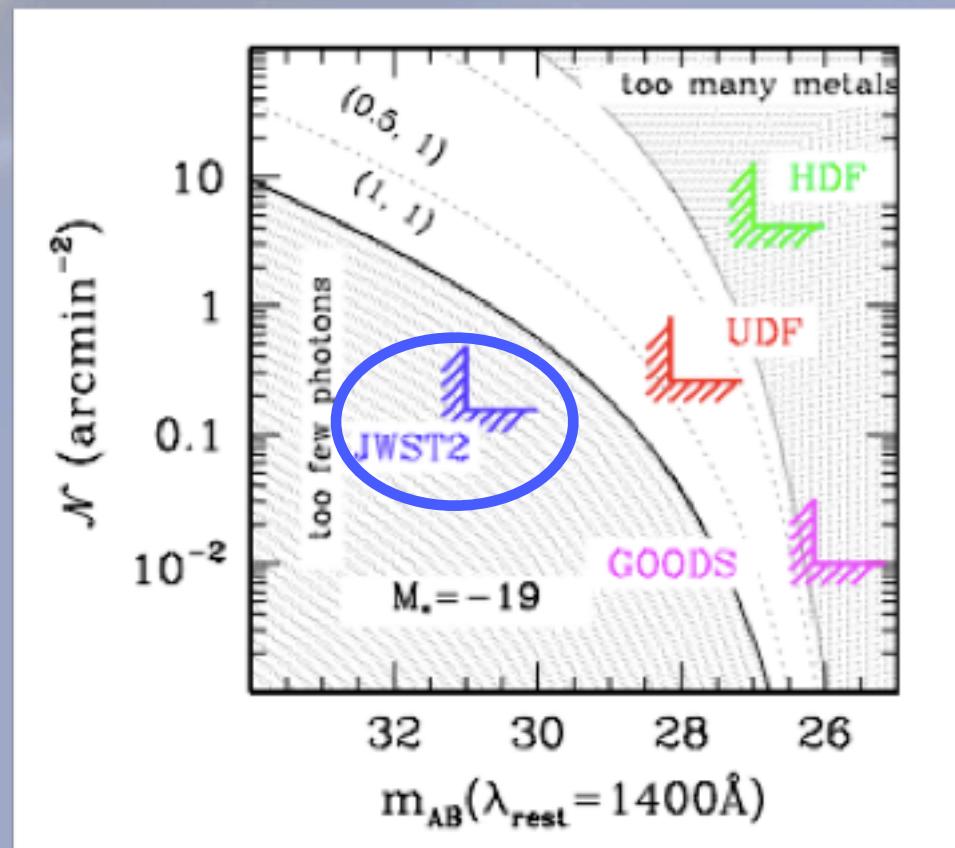
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# Reionization: JWST Ultra Deep Field

A deep field with JWST has the sensitivity to detect the objects responsible for reionization unless their luminosity function is very different from a Press-Schechter and made entirely of low-luminosity objects.

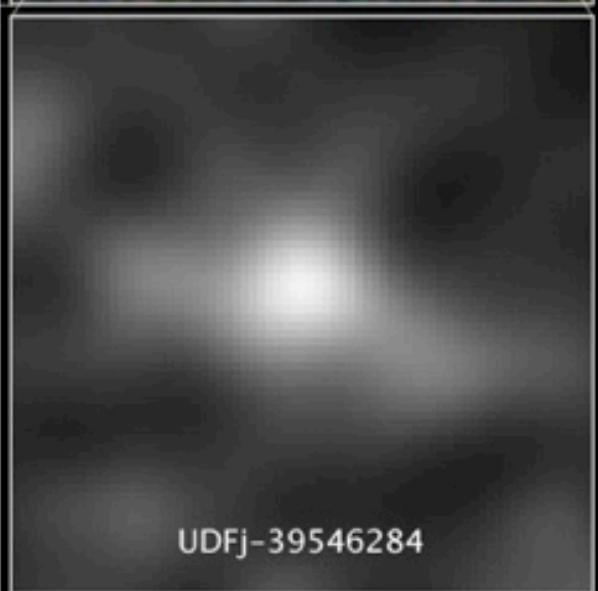
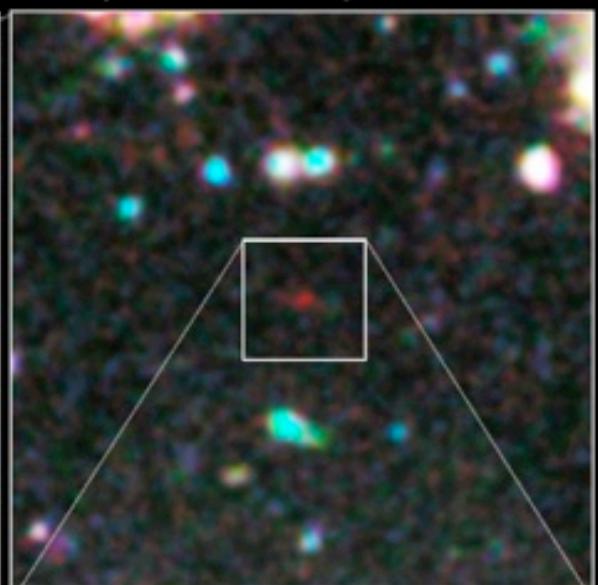
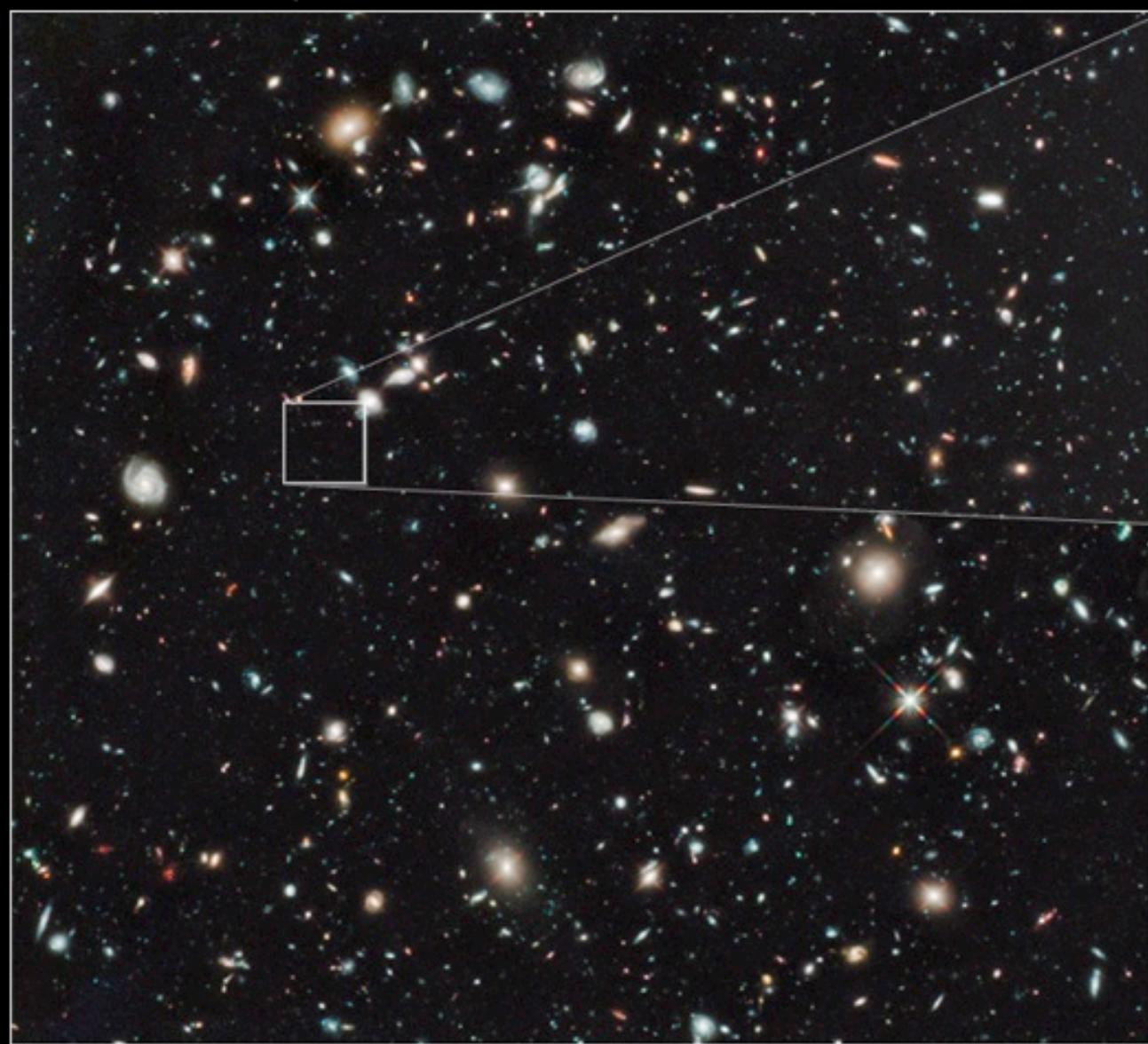
In addition to JDF we may need JWST “GOODS” .



(Stiavelli, Fall, Panagia, 2004a)

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

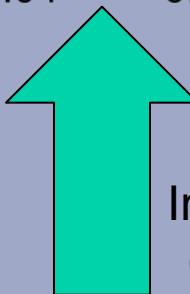
STScI-PRC11-05

# First Galaxies : Detection

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 ApJ

$z$	$AB_{1350}$	$F^V$ (nJy)	$\lambda$ ( $\mu$ m)	$\langle A_{1400} \rangle$	$A_{1400}(90\%)$
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



Integrated dust along line  
of sight is not important

# A Strategy

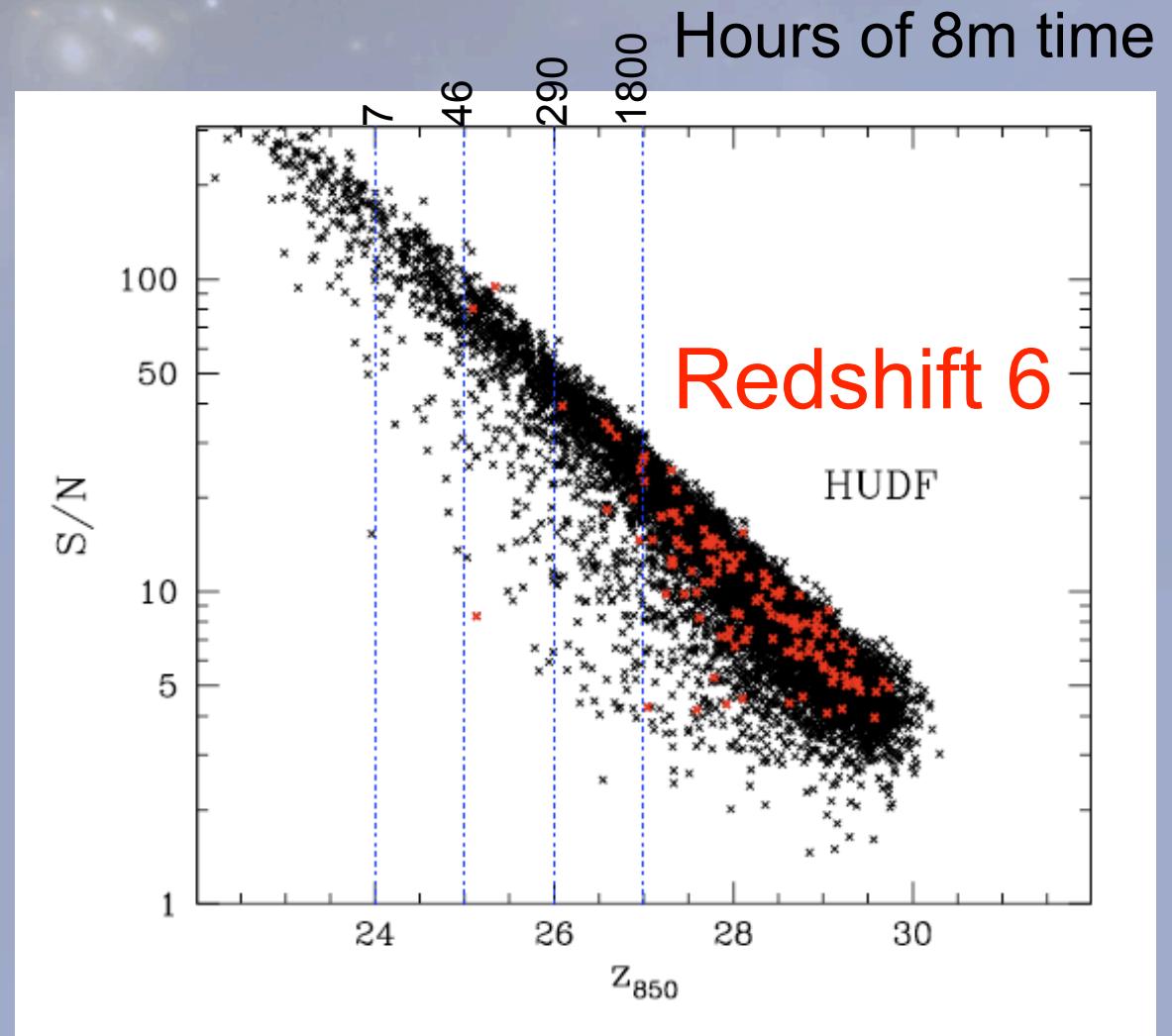
Need a multi-pronged strategy including:

- Deep fields
- Medium wide fields
- Exploiting lensing amplification for spectroscopic followup

# Spectroscopy is very hard

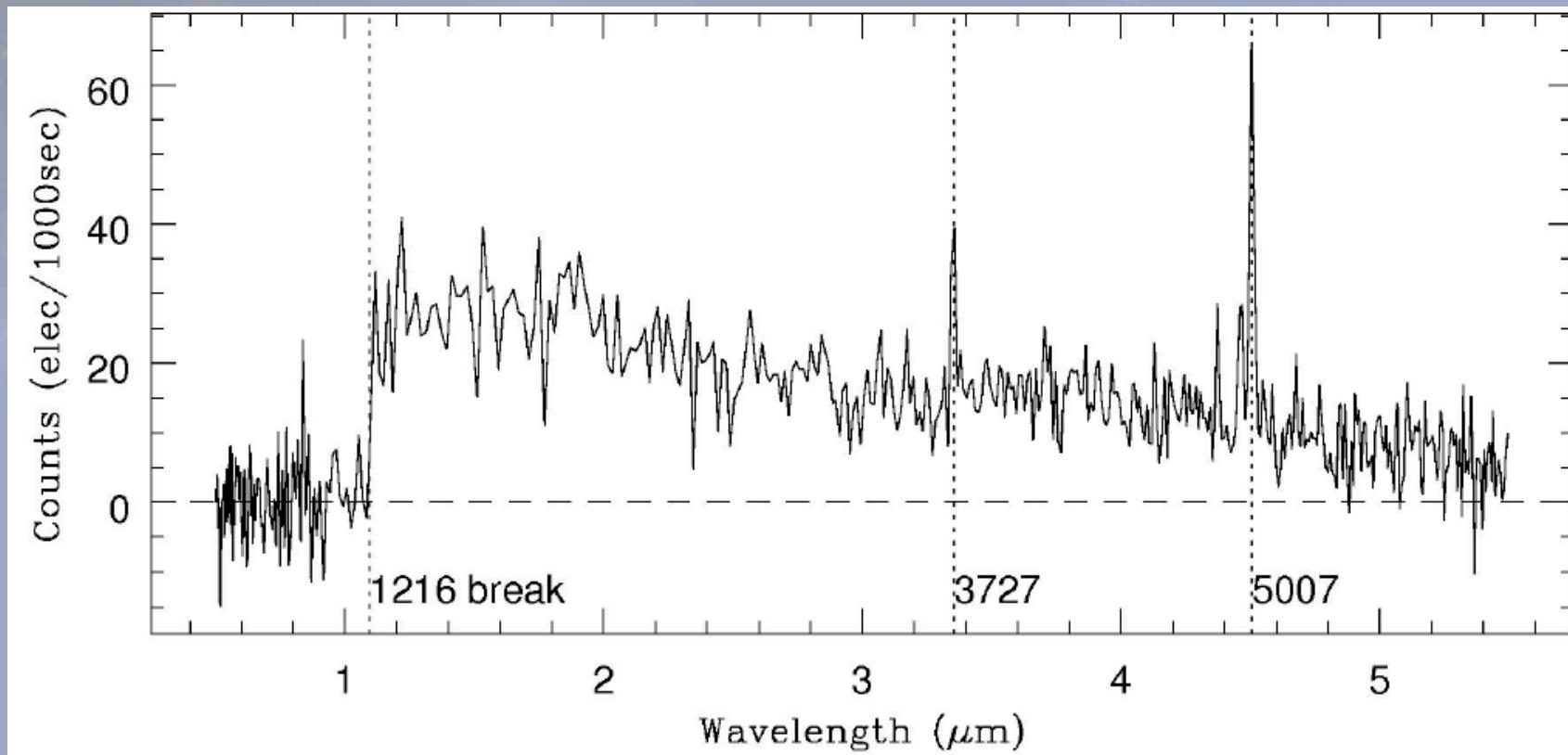
It is very hard to obtain spectra for the faintest objects in the UDF.

Red squares are i-dropout galaxies. The 4 vertical lines are the magnitude limits at S/N=3 for VLT+FORST2 in 7, 46, 290, 1800 hrs.



# Bright galaxy at $z \sim 8$

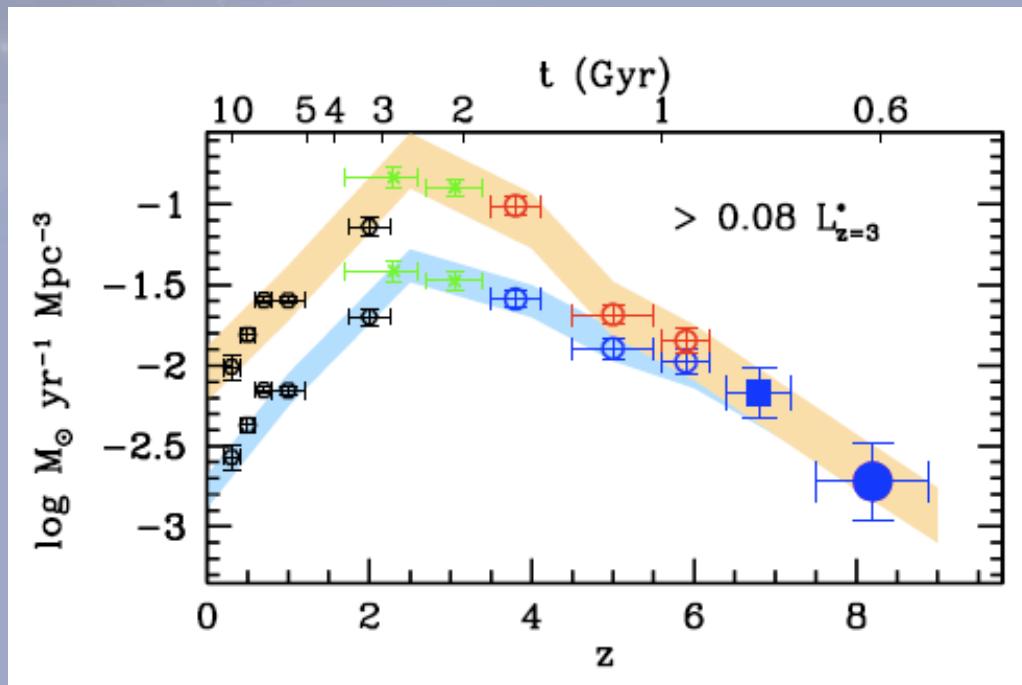
For galaxies at  $m_{\text{JAB}}=26$ , JWST can obtain high S/N spectra.



Simulation courtesy of M. Franx

## Implications of the luminosity function evolution

In the last 7 years we have moved the boundary of known galaxies from redshift 6 to redshift 8 and beyond, i.e. into a time of fast evolution of the luminosity density of galaxies. There is evidence for a steep - and steepening - LF.



The number density of galaxies above the WFC3 UDF limit is decreasing with  $z$  and goes below  $1 \text{ arcmin}^2$  at  $z \sim 8-9$ .

Bouwens et al.

# JWST and the First light objects

First light stars are extremely rare.

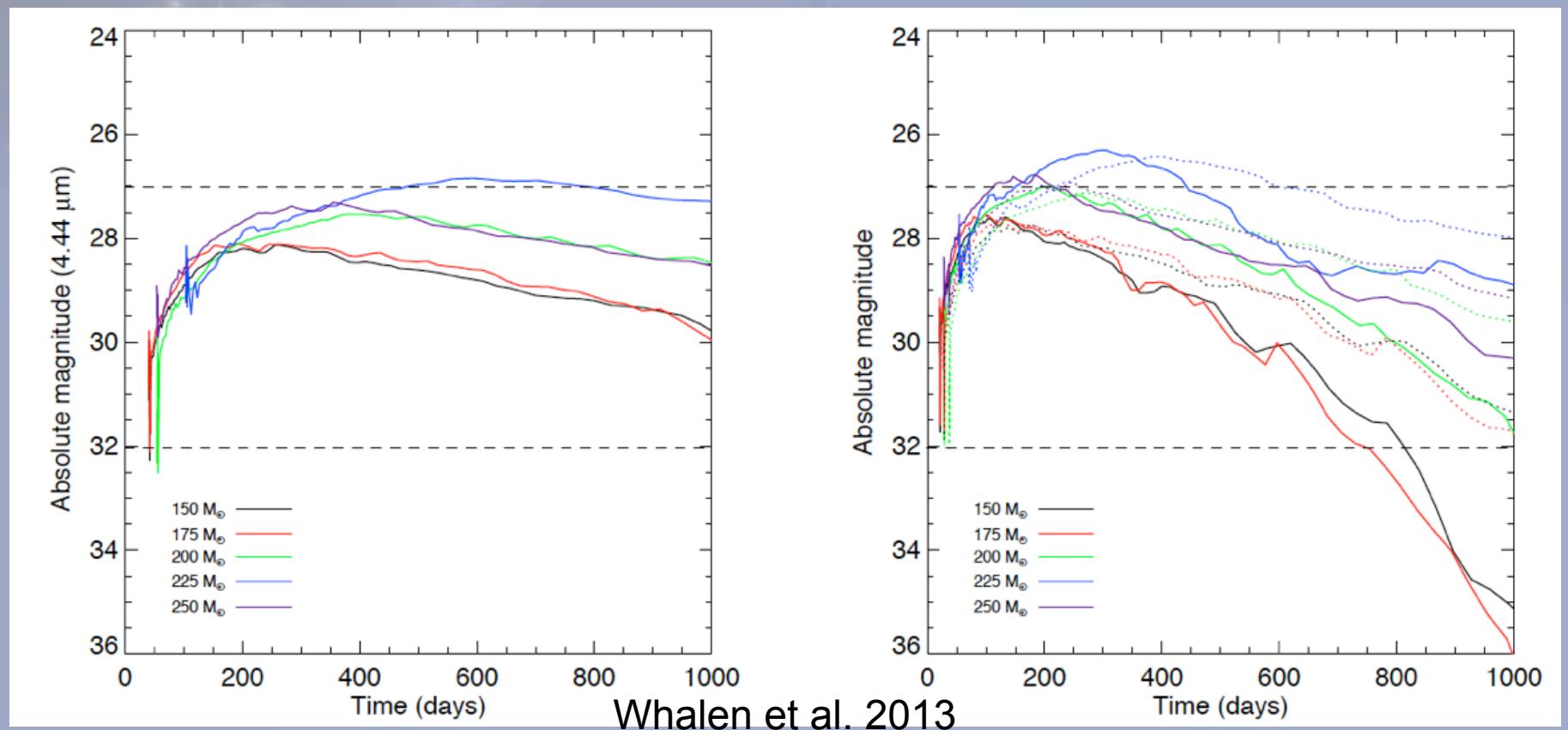
JWST can observe first light stars only as supernovae (and large area searches with, e.g., WFIRST/AFTA are needed to find them) or as lensed individual stars (or small cluster).

JWST will study the “first galaxies”, i.e. second generation objects pre-enriched by Pop III stars.

Theoretical investigation of the first light stars and their observational signatures must continue.

# Seeing the First Stars

They are too faint to be seen directly but their supernovae are promising.



## Two competing primordial BH formation scenarios

- A  $\sim 100 \text{ M}_\odot$  BH seed from a Pop III star grows at the Eddington rate since  $z > 30$  to form the  $10^9 \text{ M}_\odot$  BH we see in  $z \sim 6$  QSOs.
  - CONs: low probability, risk of ejection
  - PROs: many seeds, could afford low efficiency, prefers BH in rich halos.
- A  $10^8 \text{ M}_\odot$  halo directly collapses to a  $\sim 10^4 \text{ M}_\odot$  BH
  - CONs: most  $10^8 \text{ M}_\odot$  pre-enriched in metals would fragment, anti-bias of primordial BHs
  - PROs: easier to grow to required mass by  $z \sim 6$

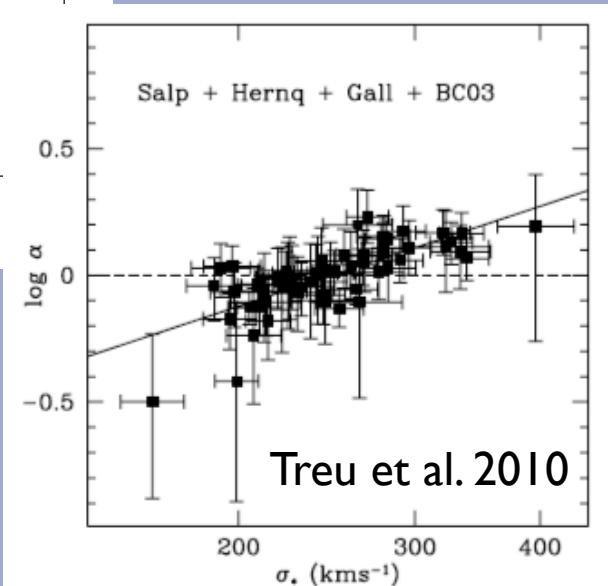
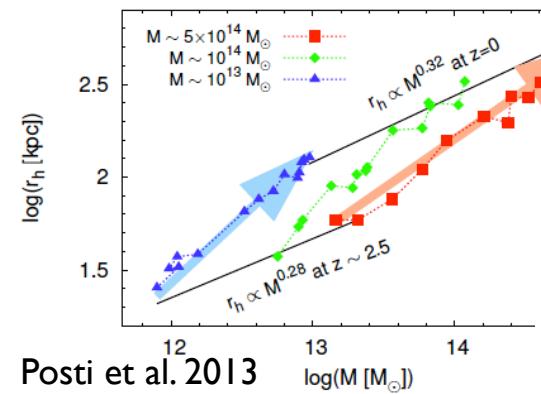
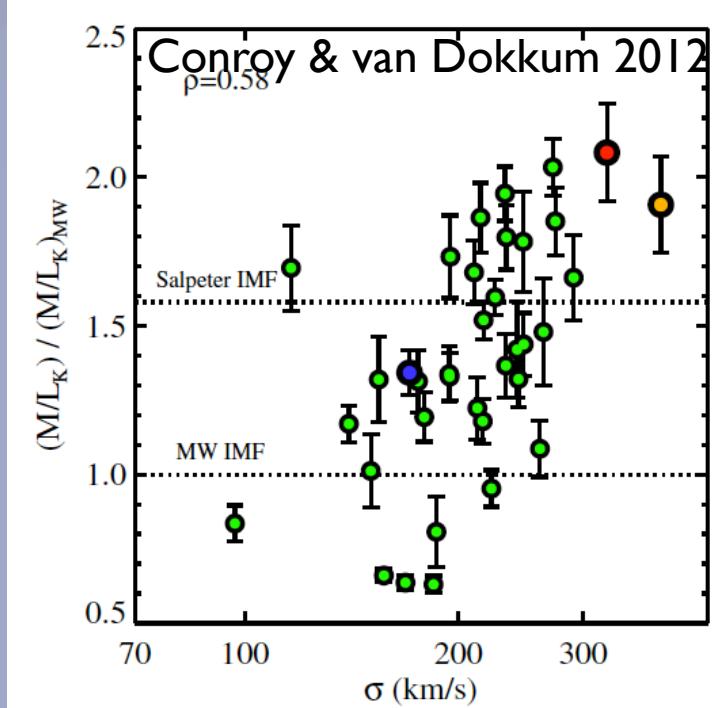
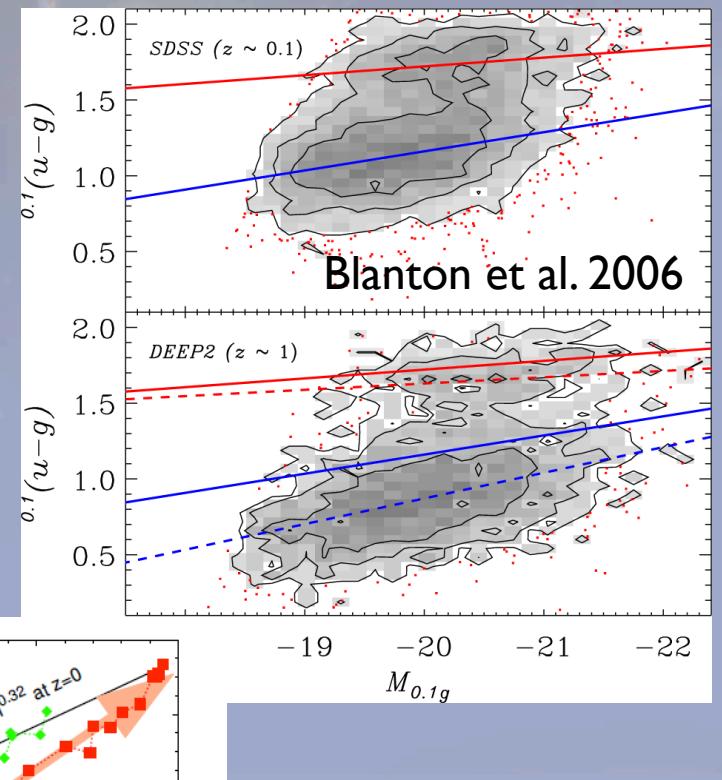
This may be hard for JWST alone.

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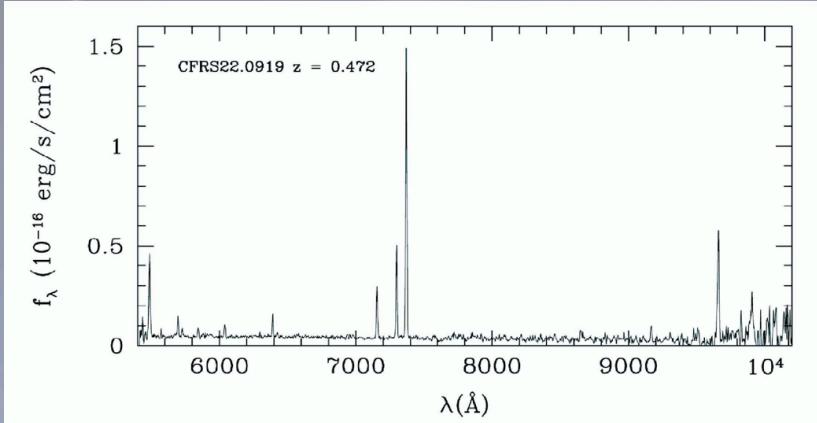
# Quenching and the red sequence

- Red sequence quenching. Green valley visitors and permanent residents (see Faber)
- High-z ellipticals are more compact than their local analogs (van Dokkum et al 2010)



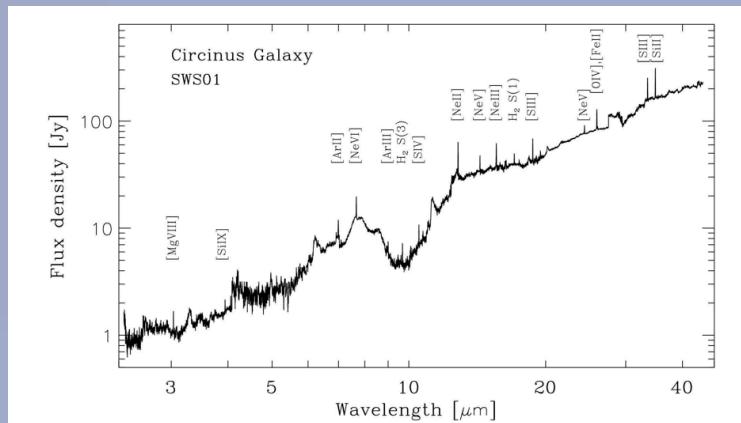
JWST spectroscopy

# JWST Spectroscopy



Both absorption and emission line diagnostics require broad coverage of the rest frame visible. The figure shows a CFRS spectrum from Lilly et al. 2003.

Studies of the power sources of ULIRGs and AGN will require Mid-IR spectroscopy. The spectrum on the right is an ISO spectrum of Circinus (Moorwood et al. 1996).

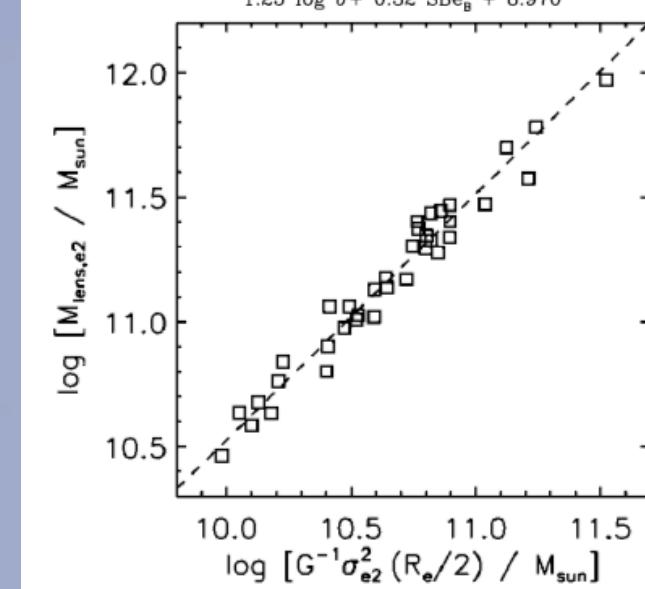
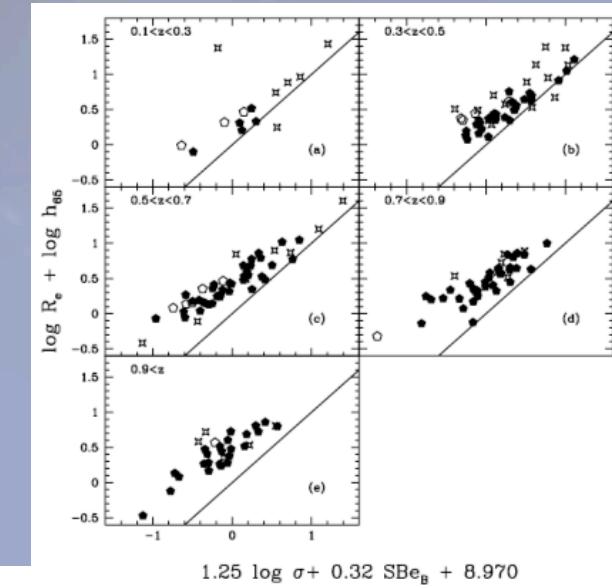


# Global properties of galaxies

“classical” fundamental plane:  
Kinematic mass measurement  
from radius and velocity  
dispersion

“new” fundamental plane: total  
mass derived from lensing

JWST will continue and improve  
on HST work.

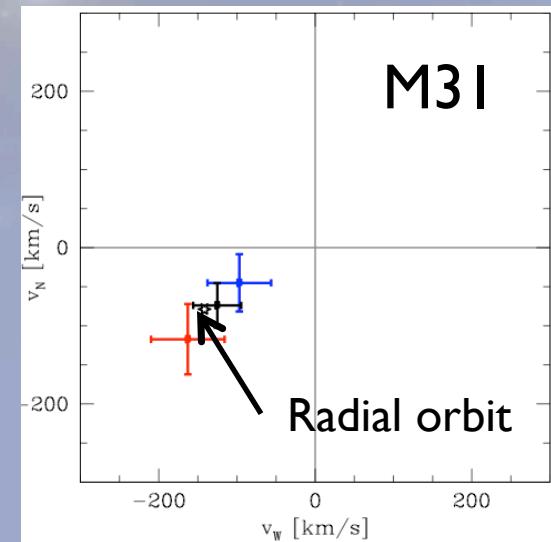


Treu et al. 2005

Bolton et al 2007

# 3D Kinematics and dynamics enabled by extragalactic proper motions

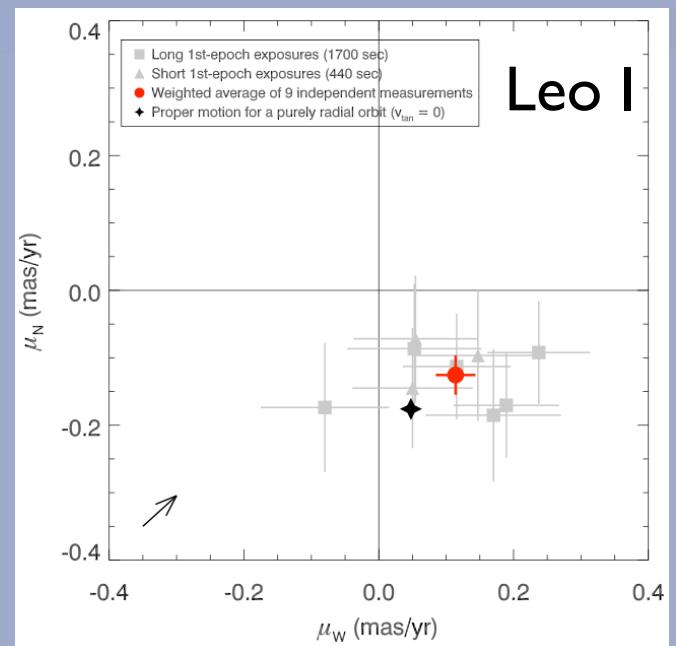
GAIA will revolutionize Milky Way proper motion studies but Hubble is needed for fainter, more distant objects (see van der Marel)  $\rightarrow 30 \mu\text{as/yr}$



[Sohn et al. 2012, vdMarel et al. 2012]

JWST astrometry can be calibrated to the same accuracy as HST and will be able to continue these studies to similar accuracy and for fainter stars.

[Sohn et al. 2013]



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# Paradigm

Hubble images faint objects

8–10m ground based telescope take their spectra

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## THE 10k zCOSMOS: MORPHOLOGICAL TRANSFORMATION OF GALAXIES IN THE GROUP ENVIRONMENT SINCE $z \sim 1^*$

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## The great observatories origins deep survey

### VLT/VIMOS spectroscopy in the GOODS-south field

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# Paradigm change

With the ELT and JWST things are going to be more complex:

Best for faint object imaging depends on wavelength and intrinsic size.

	visible	near-IR	mid-IR
star	ELT	ELT	JWST
0.1" galaxy	ELT	JWST	JWST

Best for spectroscopy depends on wavelength, resolving power and intrinsic size.