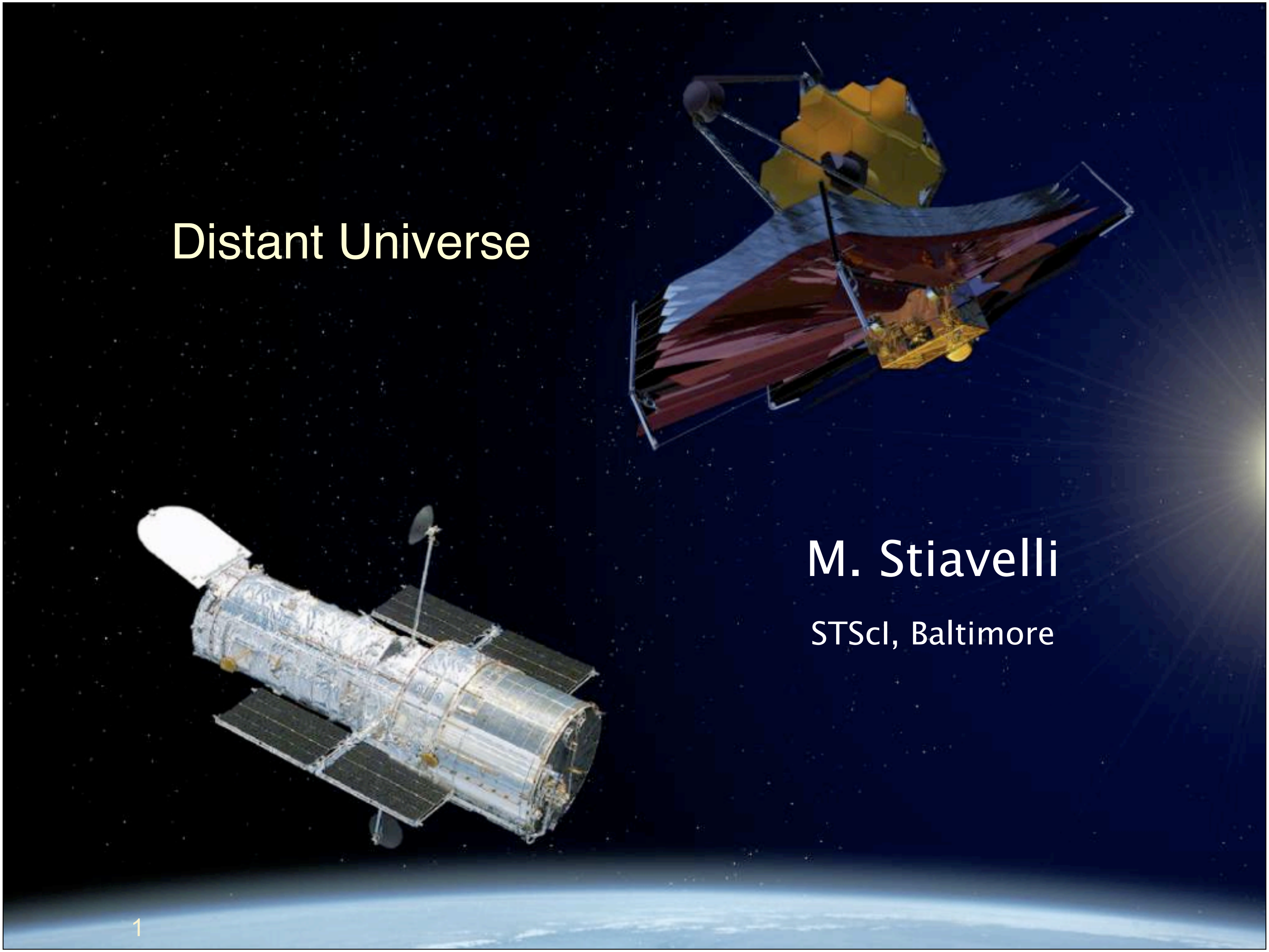
Distant Universe



M. Stiavelli

STScI, Baltimore

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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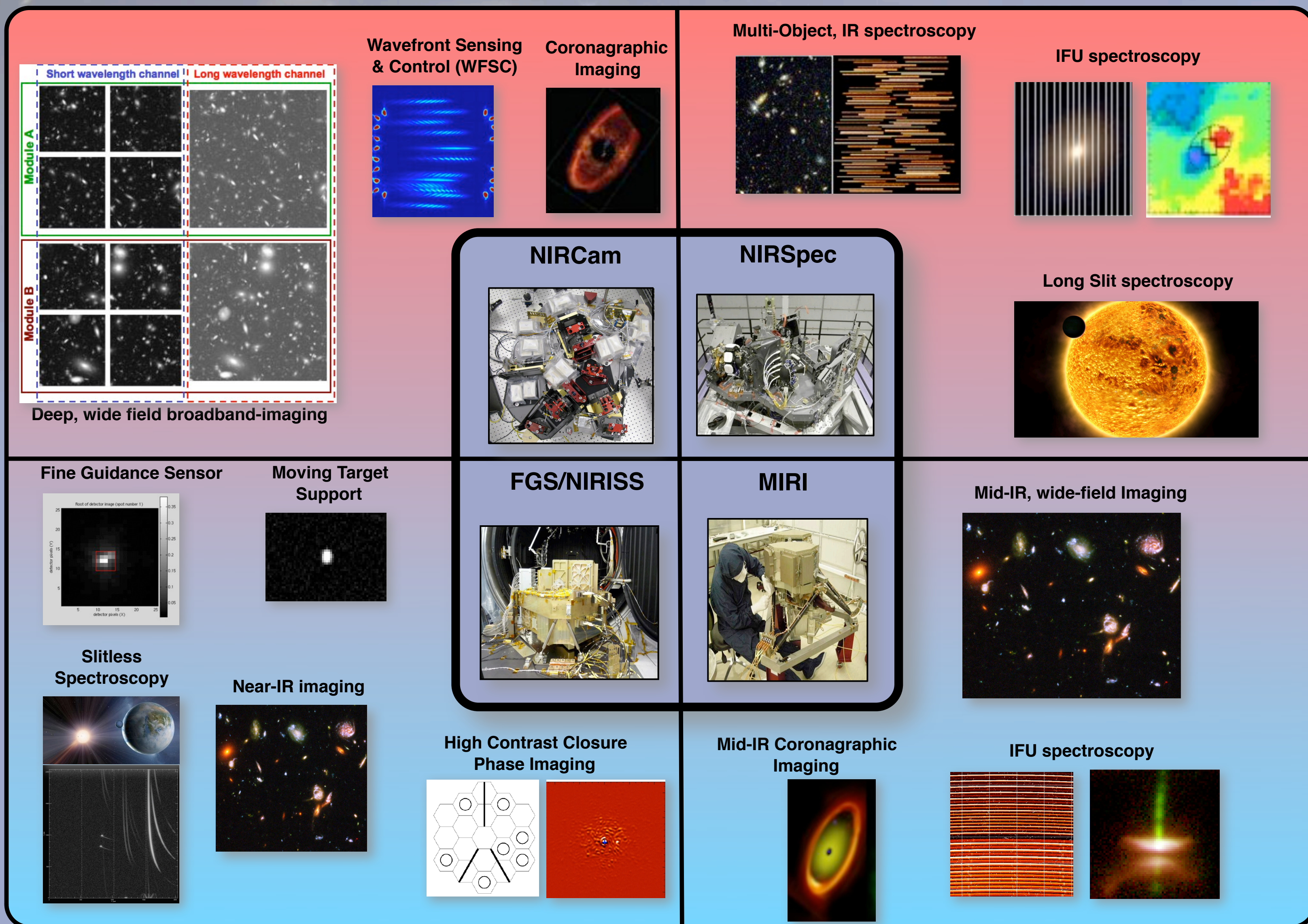
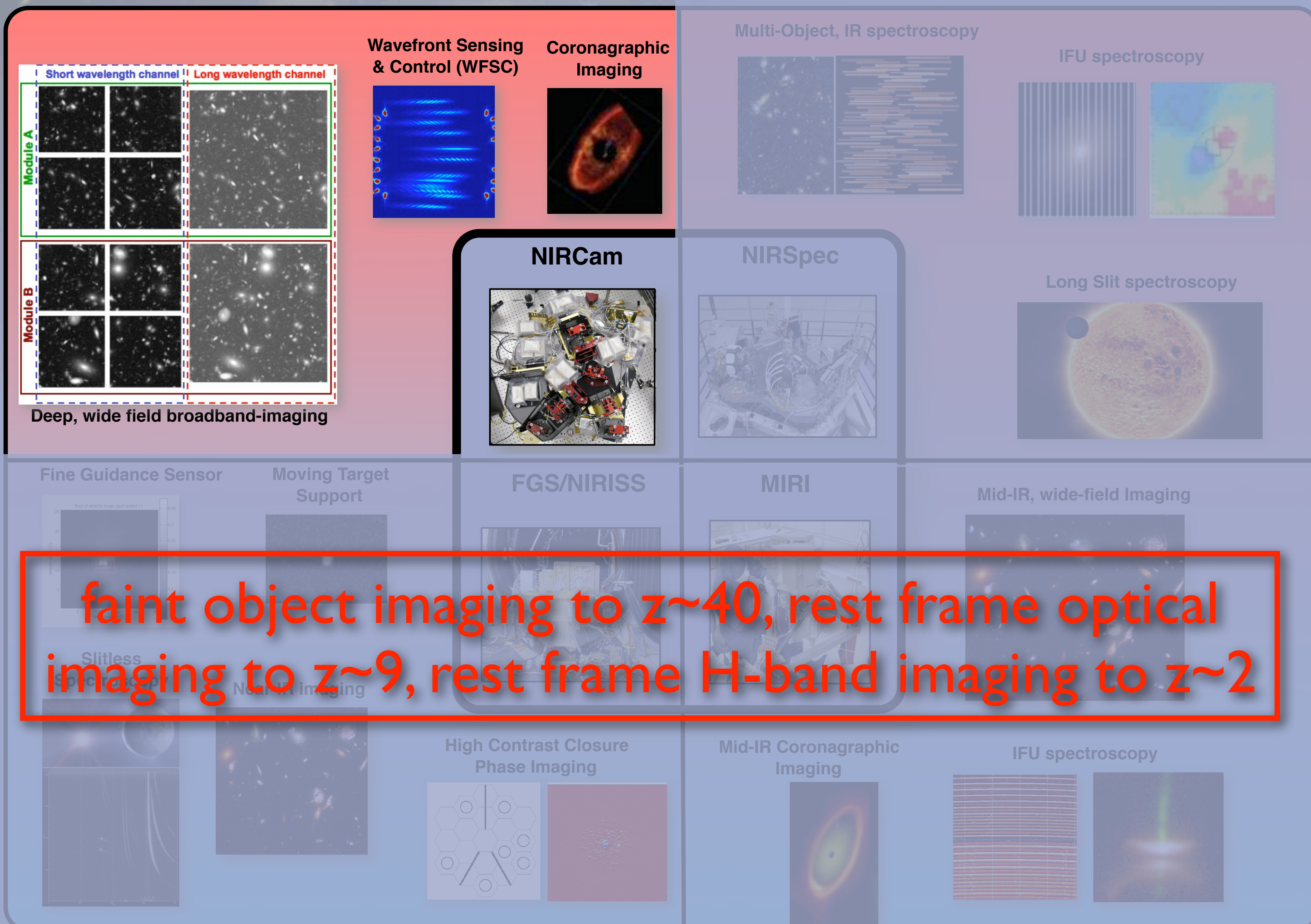
JWST Science Instruments

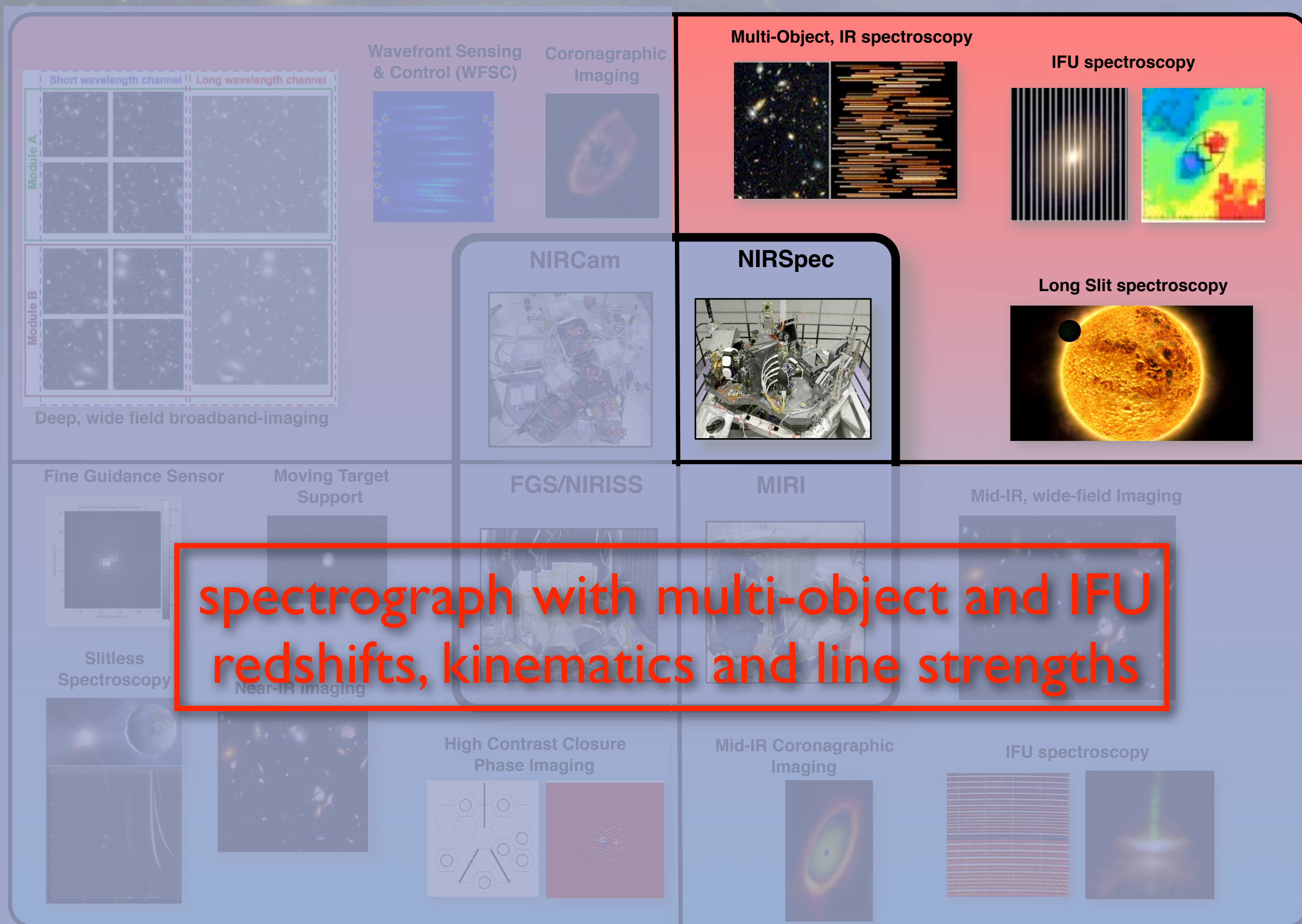


JWST Science Instruments



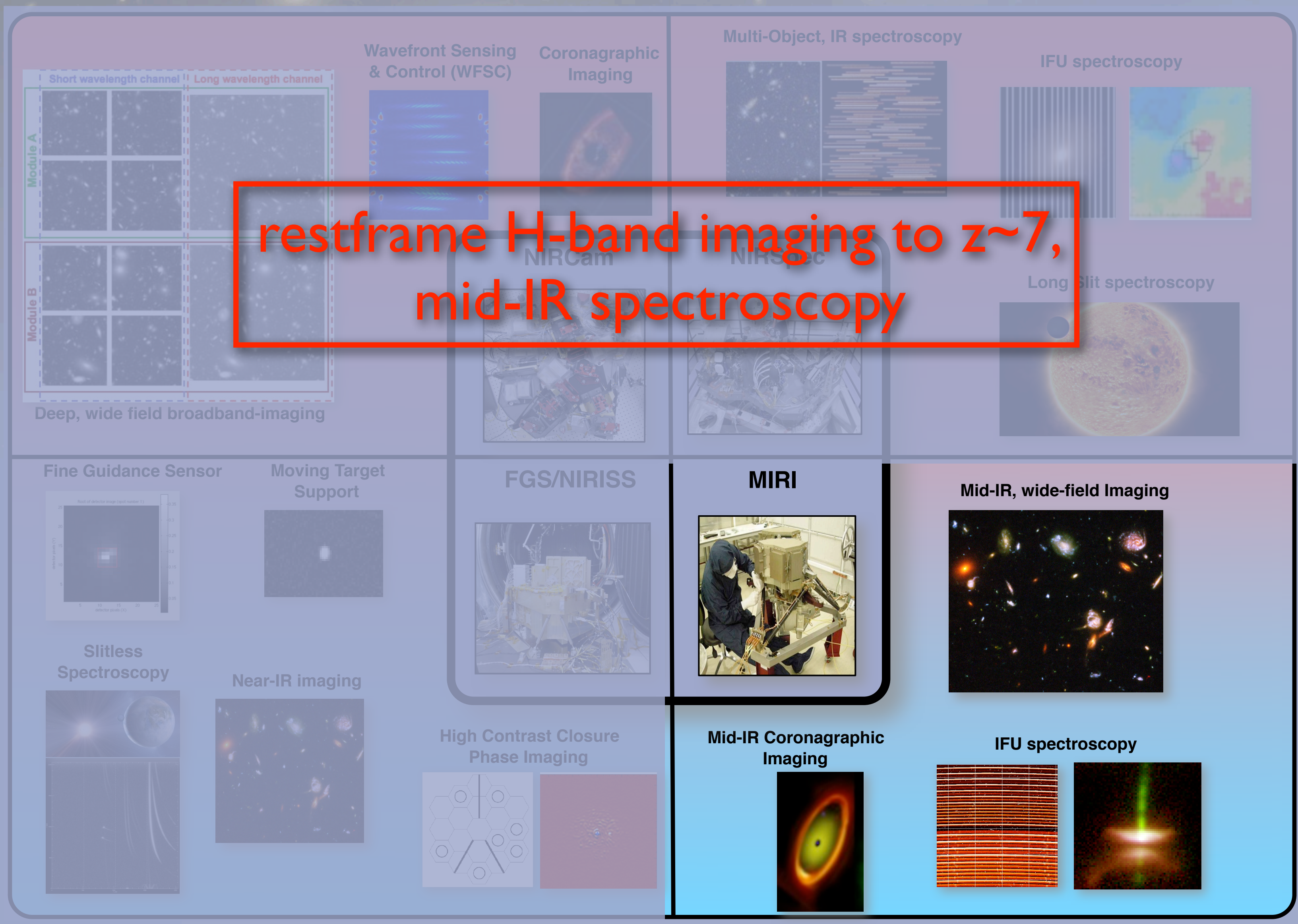
faint object imaging to z~40, rest frame optical imaging to z~9, rest frame H-band imaging to z~2

JWST Science Instruments

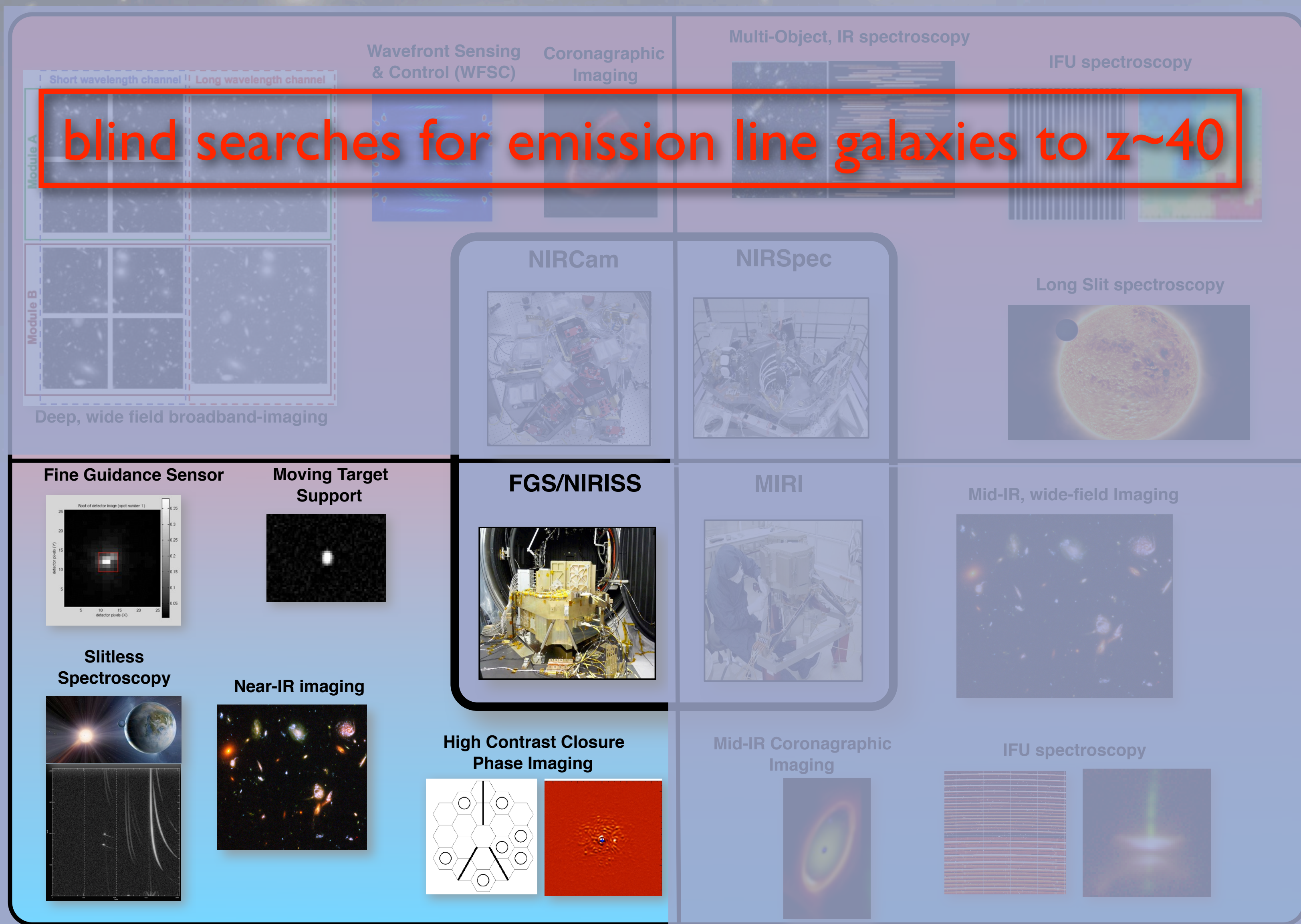


spectrograph with multi-object and IFU
redshifts, kinematics and line strengths

JWST Science Instruments



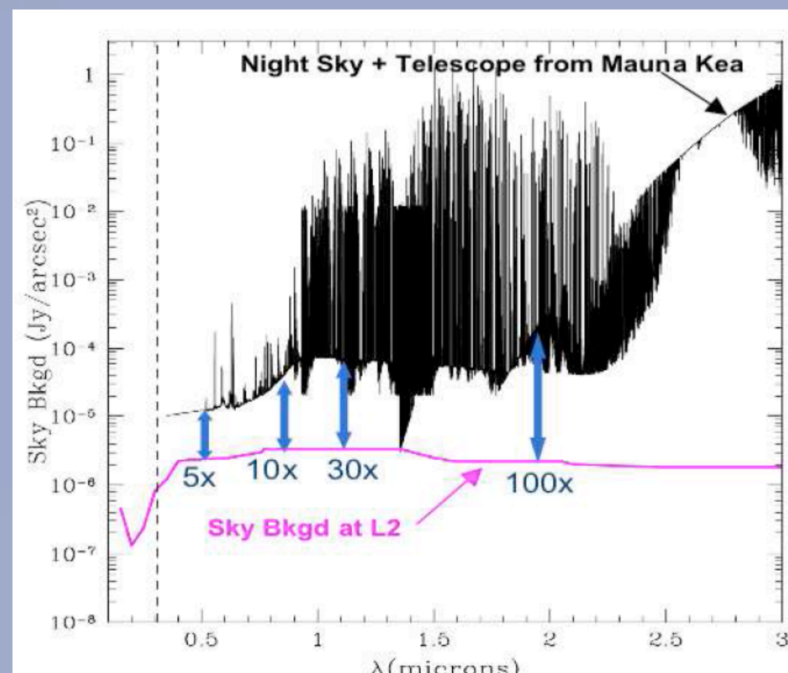
JWST Science Instruments



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 3μm



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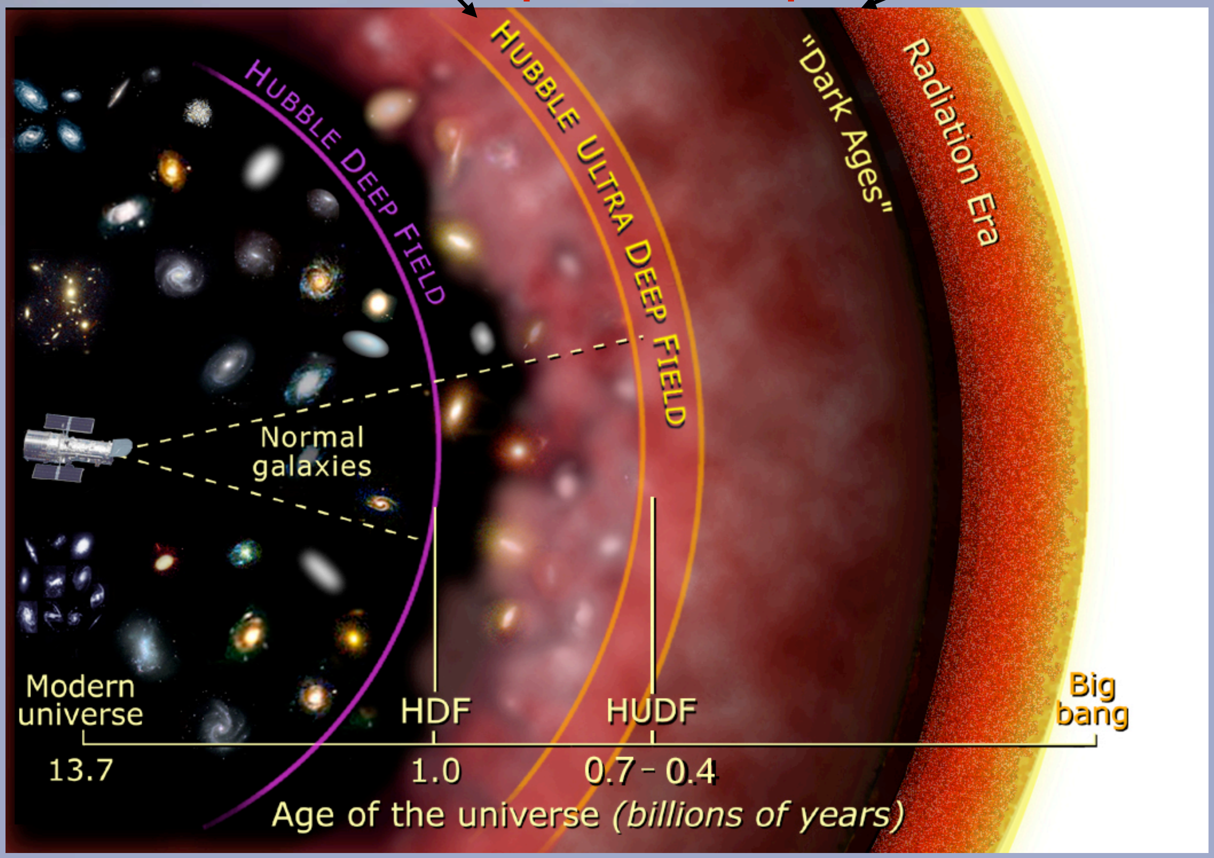
Hydrogen is ionized : we see radiation at 912 < λ < 1216 A in QSOs at z<6

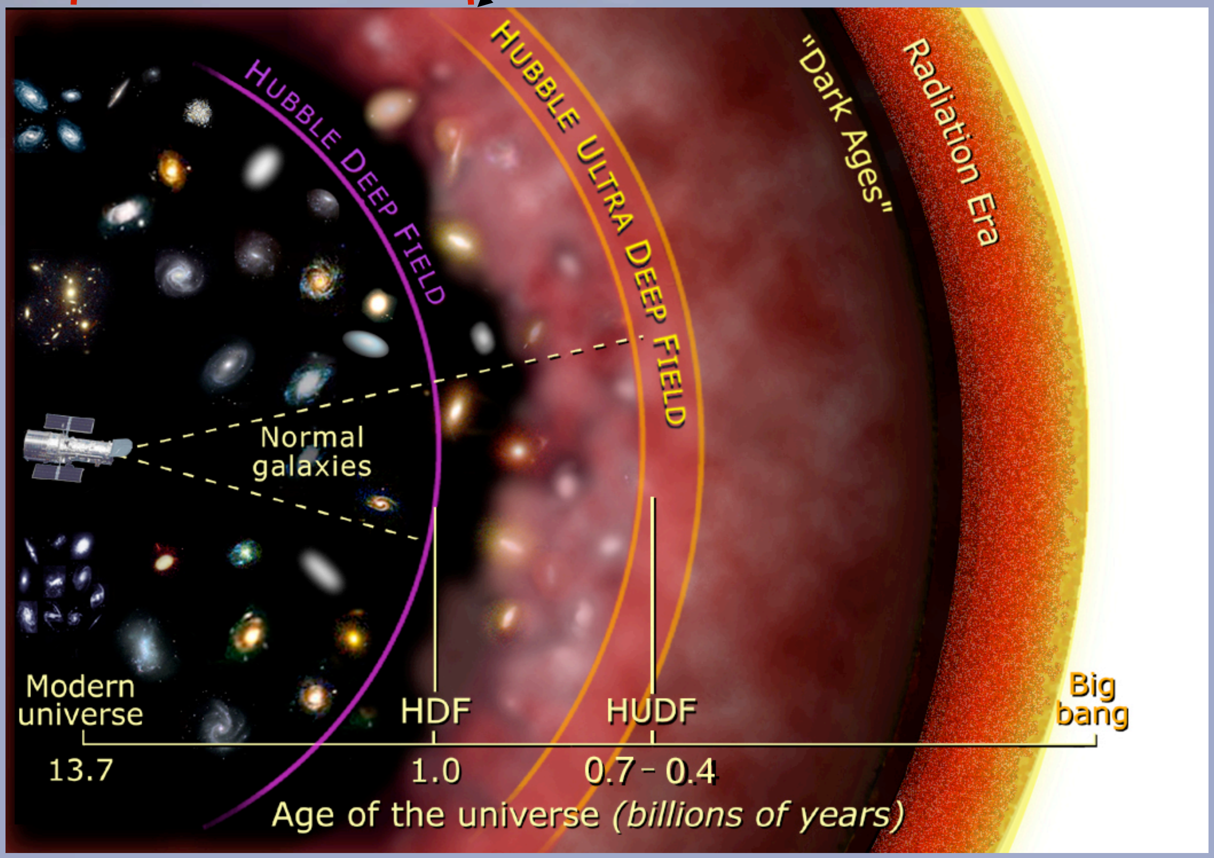
Setting the initial conditions for galaxy formation

z~1300, hydrogen recombines, CMBR “released”



Galaxies evolve to the present form

Hydrogen is ionized : we see radiation at 912 < λ < 1216 A in QSOs at z<6



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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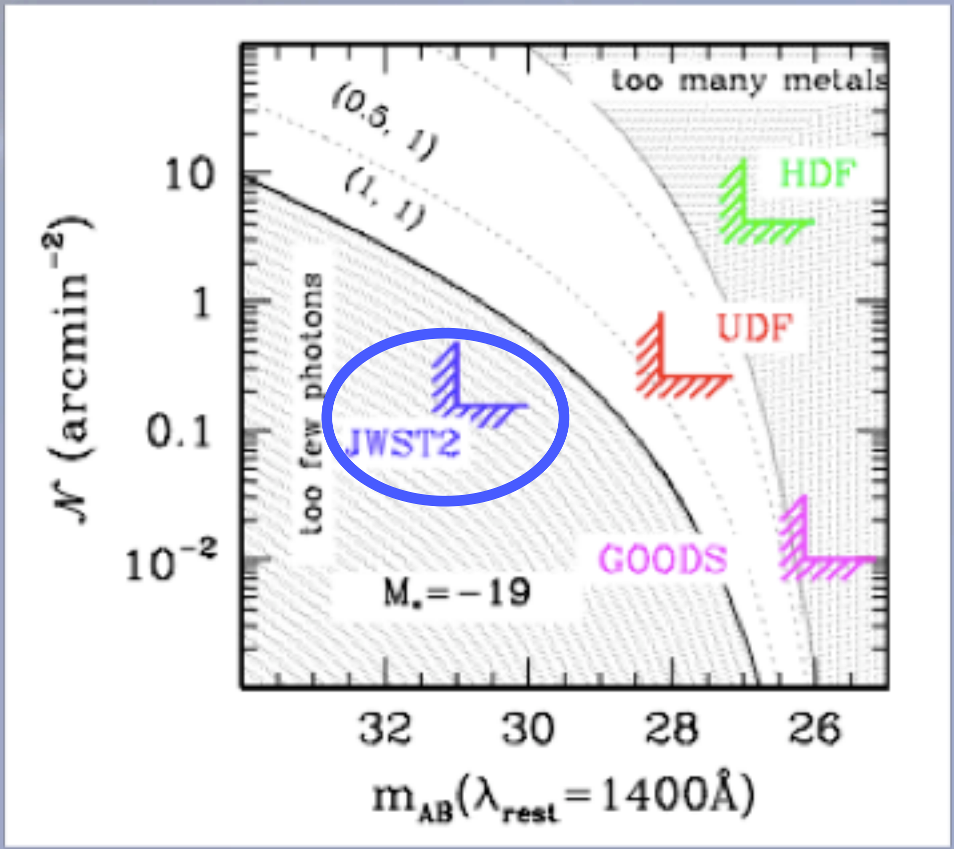
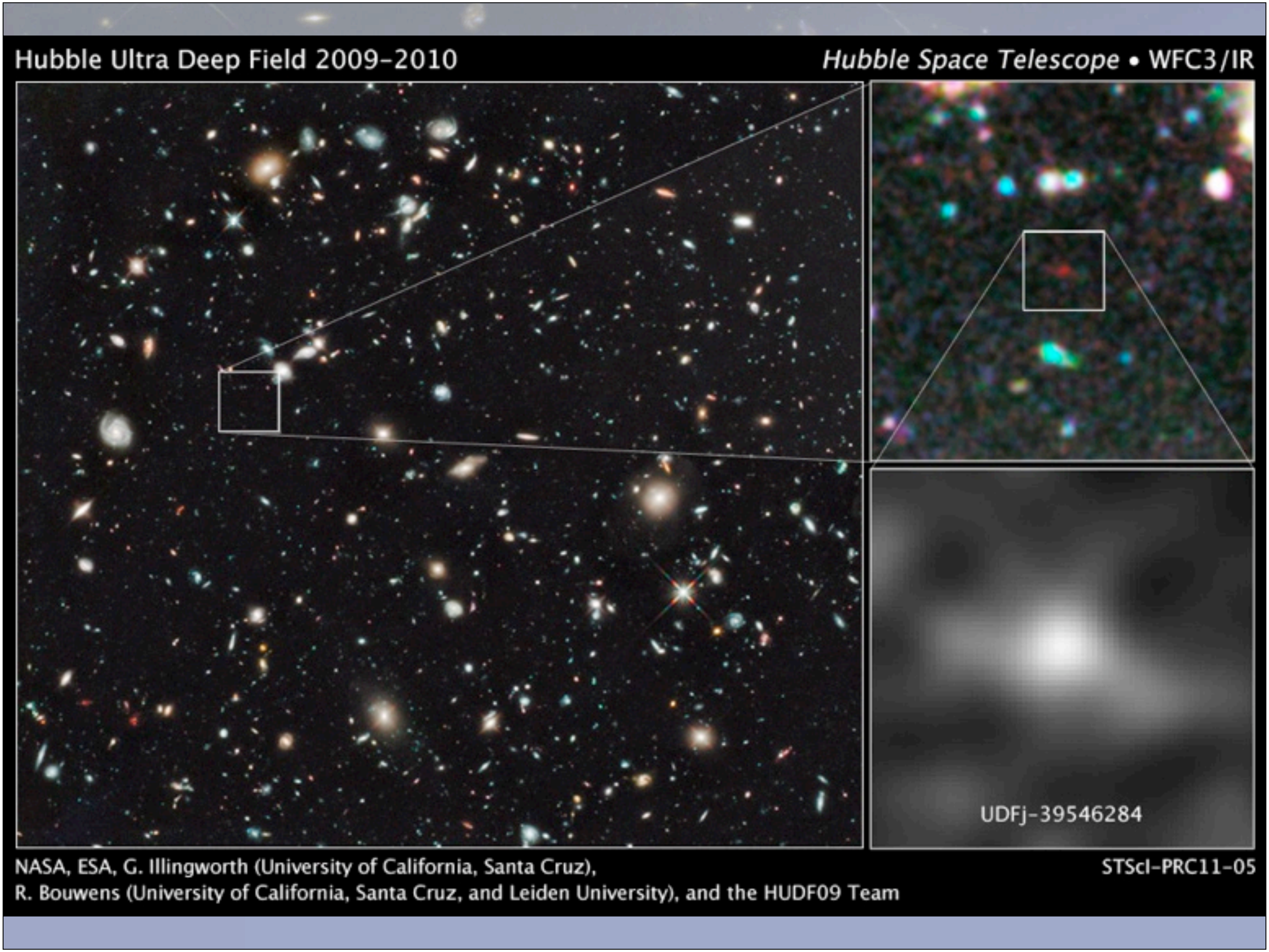
Reionization: JWST Ultra Deep Field

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
UDFj-39546284
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^{ν} (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

Integrated dust along line of sight is not important

A Strategy

Need a multi-pronged strategy including:

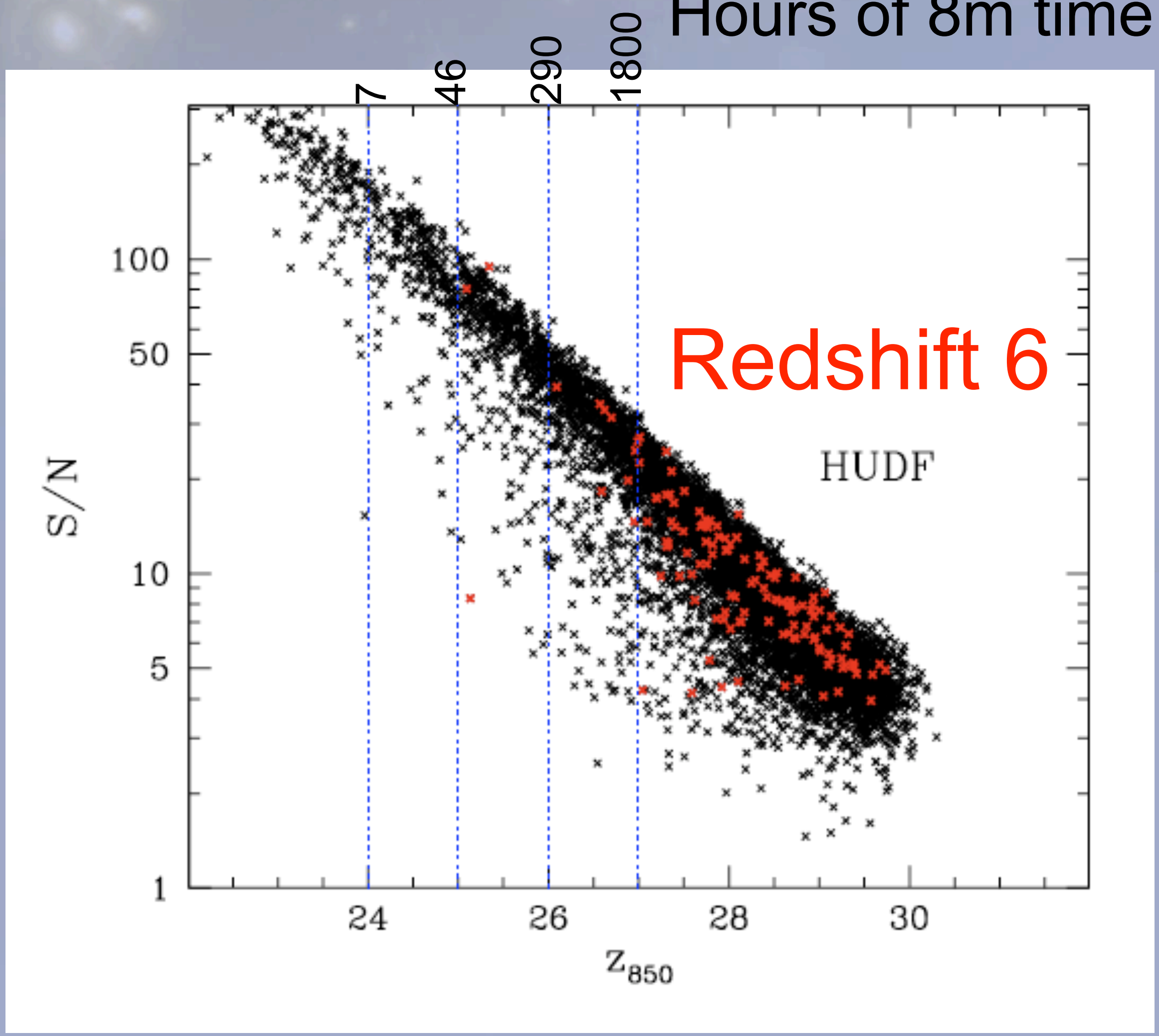
- Deep fields
- Medium wide fields
- Exploiting lensing amplification for spectroscopic followup

Spectroscopy is very hard

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

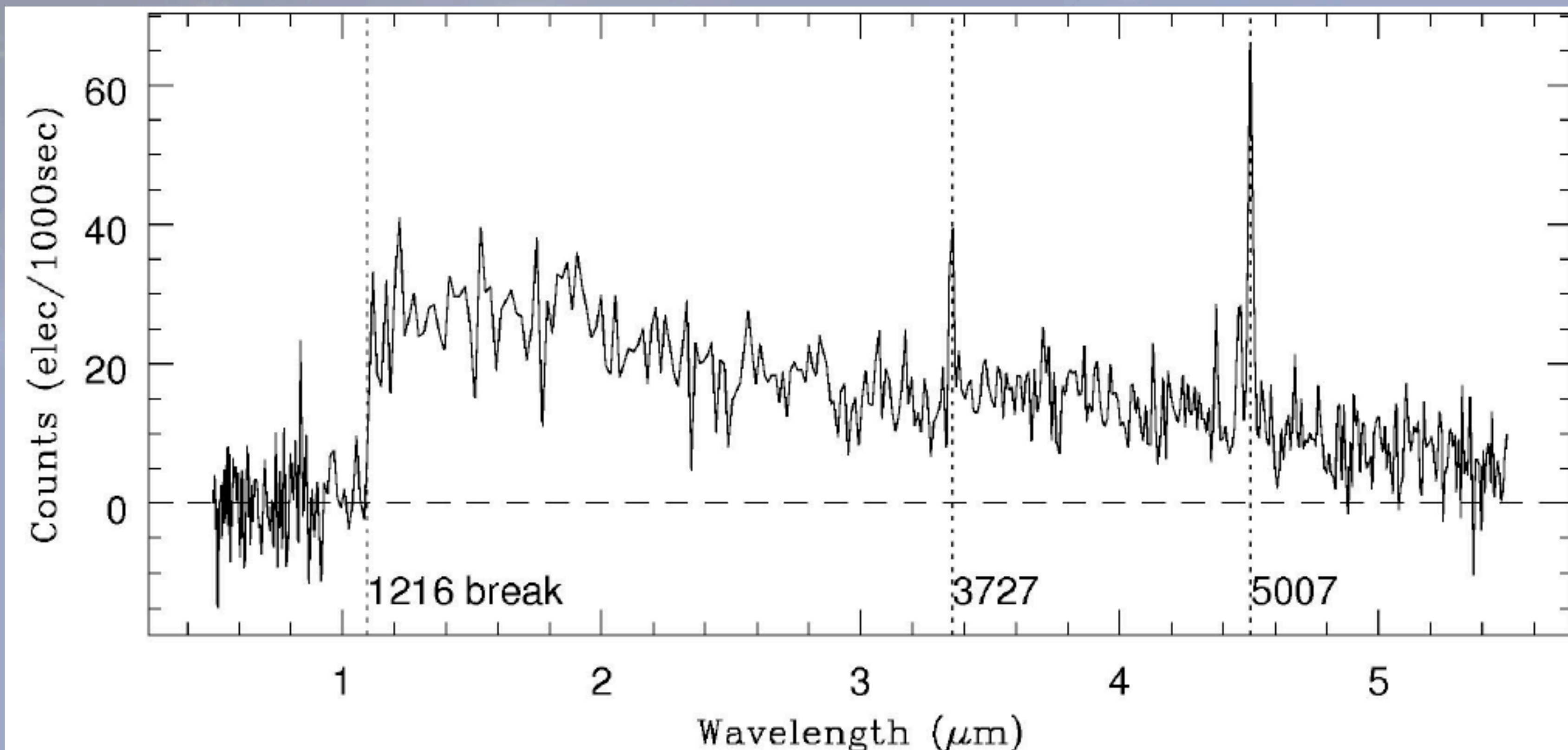
Red squares are i-dropout galaxies. The 4 vertical lines are the magnitude limits at S/N=3 for VLT+FORS2 in 7, 46, 290, 1800 hrs.

Hours of 8m time



Bright galaxy at z~8

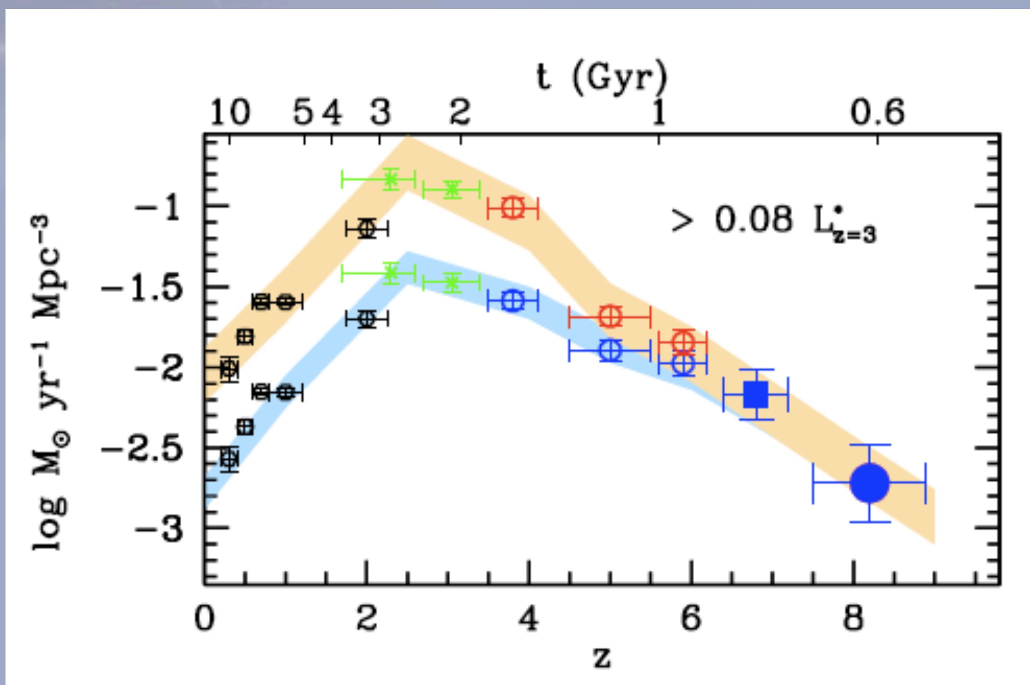
For galaxies at m_{JAB}=26, JWST can obtain high S/N spectra.



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.



Bouwens et al.

The number density of galaxies above the WFC3 UDF limit is decreasing with z and goes below 1 arcmin^2 at z~8-9.

JWST and the First light objects

First light stars are extremely rare.

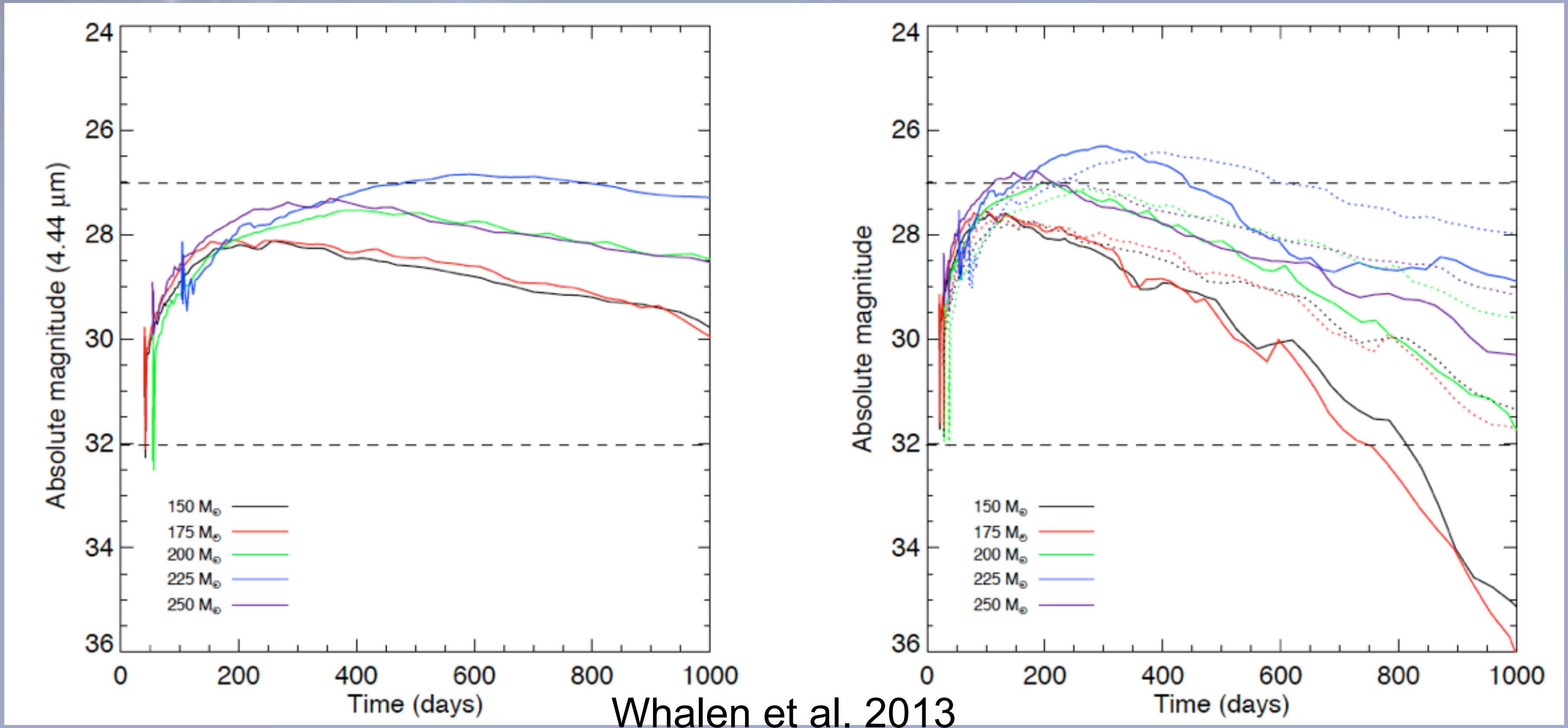
JWST can observe first light stars only as supernovae (and large area searches with, e.g., WFIRST/AFTA are needed to find them) or as lensed individual stars (or small cluster).

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.



Whalen et al. 2013

Two competing primordial BH formation scenarios

– A ~100 M⊙ BH seed from a Pop III star grows at the Eddington rate since z>30 to form the 10^9 M⊙ BH we see in z~6 QSOs.

- CONs: low probability, risk of ejection
- PROs: many seeds, could afford low efficiency, prefers BH in rich halos.

– A 10^8 M⊙ halo directly collapses to a ~10^4 M⊙ BH

- CONs: most 10^8 M⊙ pre-enriched in metals would fragment, anti-bias of primordial BHs
- PROs: easier to grow to required mass by z~6

This may be hard for JWST alone.

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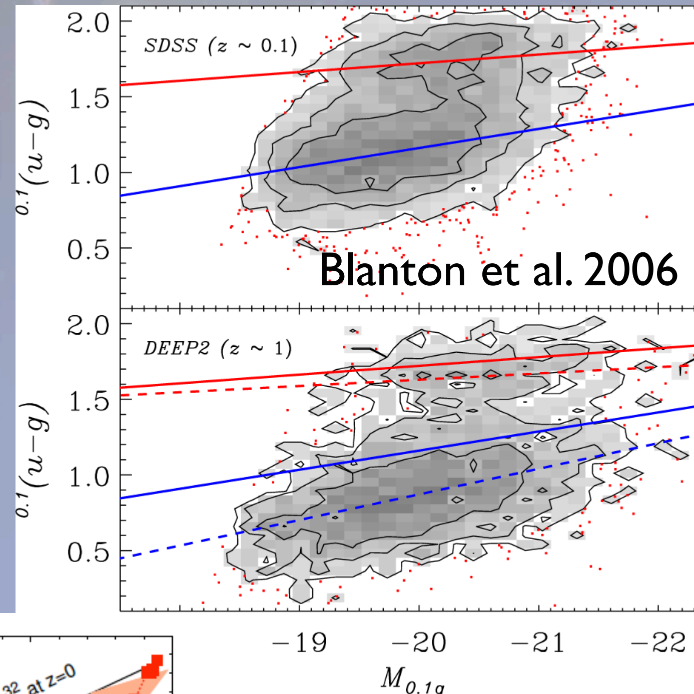
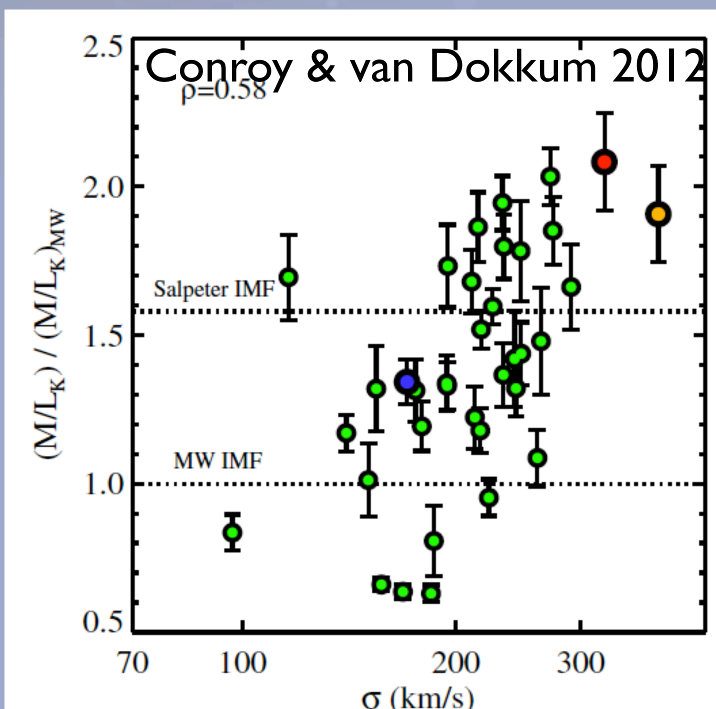
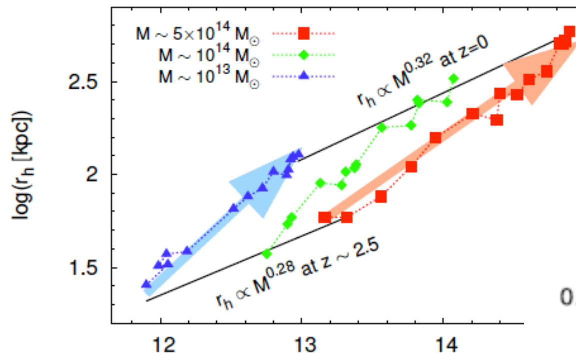
Quenching and the red sequence

- 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)

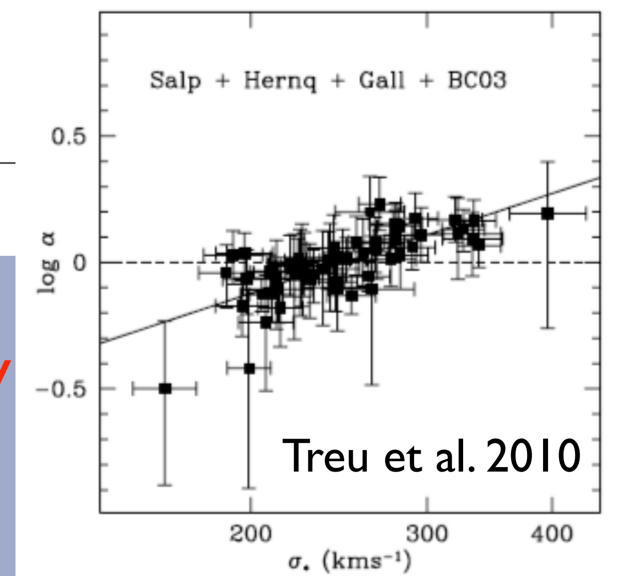




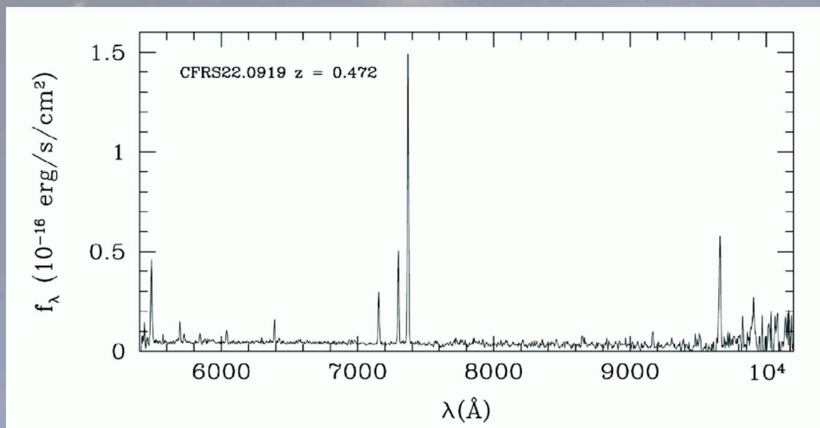


Posti et al. 2013

JWST spectroscopy

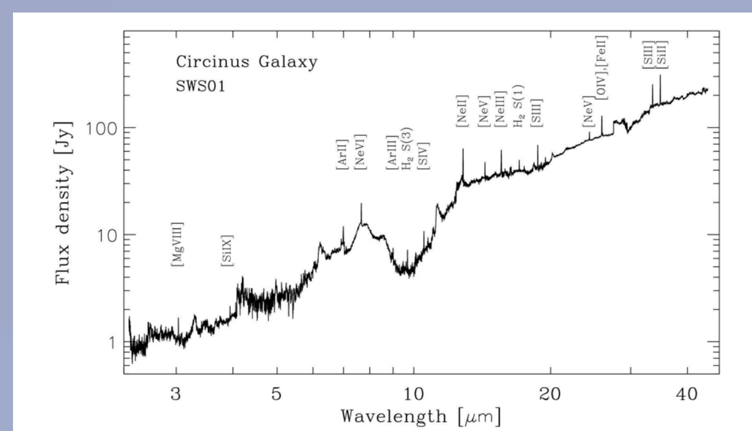


JWST Spectroscopy



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.

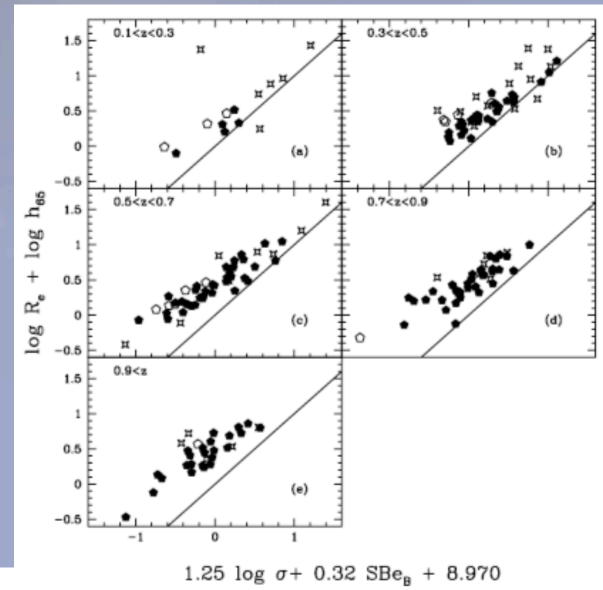
Studies of the power sources of ULIRGs and AGN will require Mid-IR spectroscopy. The spectrum on the right is an ISO spectrum of Circinus (Moorwood et al. 1996).



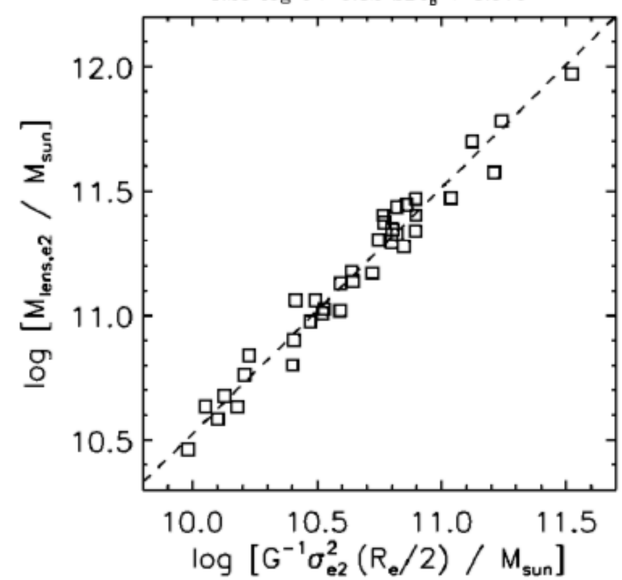
Global properties of galaxies

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

“new” fundamental plane: total mass derived from lensing



Treu et al. 2005

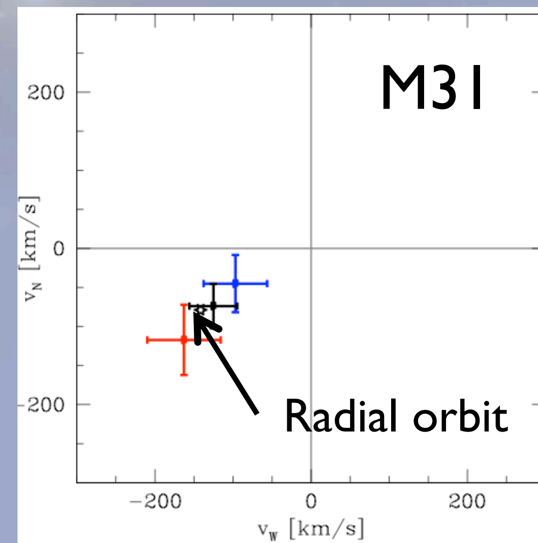


Bolton et al 2007

JWST will continue and improve on HST work.

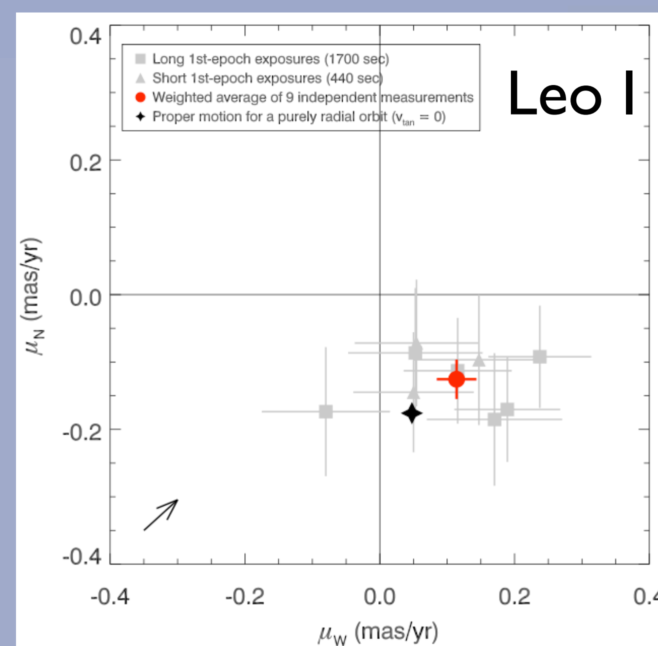
3D Kinematics and dynamics enabled by extragalactic proper motions

GAIA will revolutionize Milky Way proper motion studies but Hubble is needed for fainter, more distant objects (see van der Marel) → 30 μas/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

THE ASTROPHYSICAL JOURNAL, 718:86–104, 2010 July 20 doi:10.1088/0004-637X/718/1/86

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

K. Kovač[1], S. J. Lilly[1], C. Knobel[1], M. Bolzonella[2], A. Iovino[3], C. M. Carollo[1], C. Scarlata[4], M. Sargent[5], O. Cucciati[6], G. Zamorani[2], L. Pozzetti[2], L. A. M. Tasca[6,7], M. Scodeggio[7], P. Kampczyk[1], Y. Peng[1], P. Oesch[1], E. Zucca[2], A. Finoguenov[8], T. Contini[9], J.-P. Kneib[6], O. Le Fèvre[6], V. Mainieri[10], A. Renzini[11], S. Bardelli[2], A. Bongiorno[8], K. Caputi[1], G. Coppa[2], S. de la Torre[3,6,7], L. de Ravel[6], P. Franzetti[7], B. Garilli[7], F. Lamareille[9], J.-F. Le Borgne[9], V. Le Brun[6], C. Maier[1], M. Mignoli[2], R. Pello[9], E. Perez Montero[9], E. Ricciardelli[12], J. D. Silverman[1], M. Tanaka[10], L. Tresse[6], D. Vergani[2], U. Abbas[6,13], D. Bottini[7], A. Cappi[2], P. Cassata[6,14], A. Cimatti[15], M. Fumana[7], L. Guzzo[3], A. M. Koekemoer[16], A. Leauthaud[17], D. Maccagni[7], C. Marinoni[18], H. J. McCracken[19], P. Memeo[7], B. Meneux[8,20], C. Porciani[1,21], R. Scaramella[22], and N. Z. Scoville[23]

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Astronomy & Astrophysics

The great observatories origins deep survey

VLT/VIMOS spectroscopy in the GOODS-south field

P. Popesso[1], M. Dickinson[4], M. Nonino[3], E. Vanzella[2,3], E. Daddi[8], R. A. E. Fosbury[5], H. Kuntschner[5], V. Mainieri[7], S. Cristiani[3], C. Cesarsky[7], M. Giavalisco[6], A. Renzini[2], and the GOODS Team

A&A 434, 53–65 (2005)
DOI: 10.1051/0004-6361:20041532

Astronomy & Astrophysics

The Great Observatories Origins Deep Survey

VLT/FORS2 spectroscopy in the GOODS-South Field⋆,⋆⋆

E. Vanzella[1,2], S. Cristiani[2], M. Dickinson[3], H. Kuntschner[4], L. A. Moustakas[5], M. Nonino[2], P. Rosati[6], D. Stern[8], C. Cesarsky[6], S. Ettori[6], H. C. Ferguson[5], R. A. E. Fosbury[4], M. Giavalisco[5], J. Haase[4], A. Renzini[6], A. Rettura[6,7], P. Serra[4,9], and the GOODS Team

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.