Galaxy Stellar Mass Assembly at High z

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Outline

- *Stellar mass assembly at $z>2$: a brief intro*

  Key questions and context

- *A (non-exhaustive) review of results with the latest near-/mid-IR galaxy surveys*

  Emerging trends and limitations

- *Prospects for JWST & Euclid*

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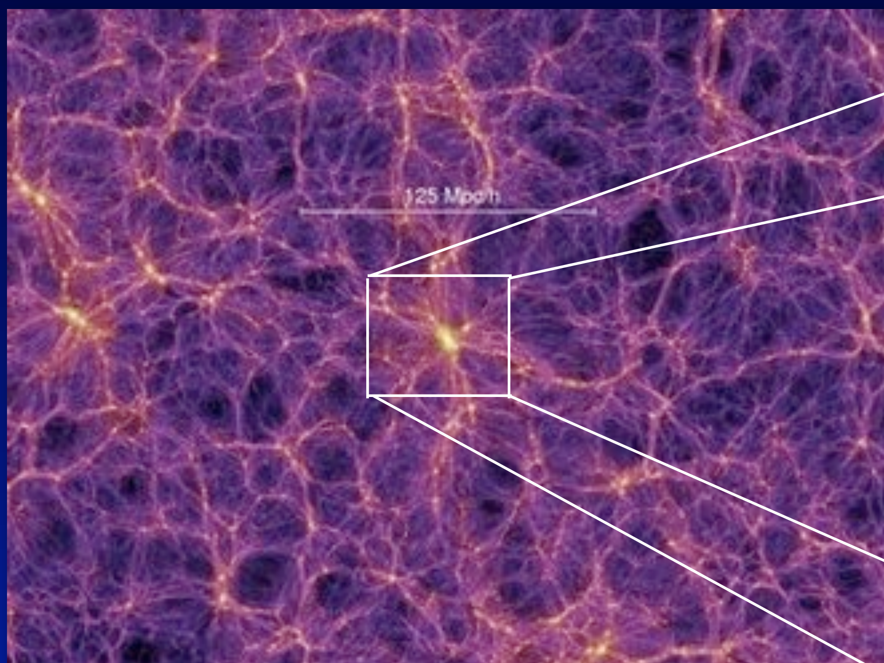
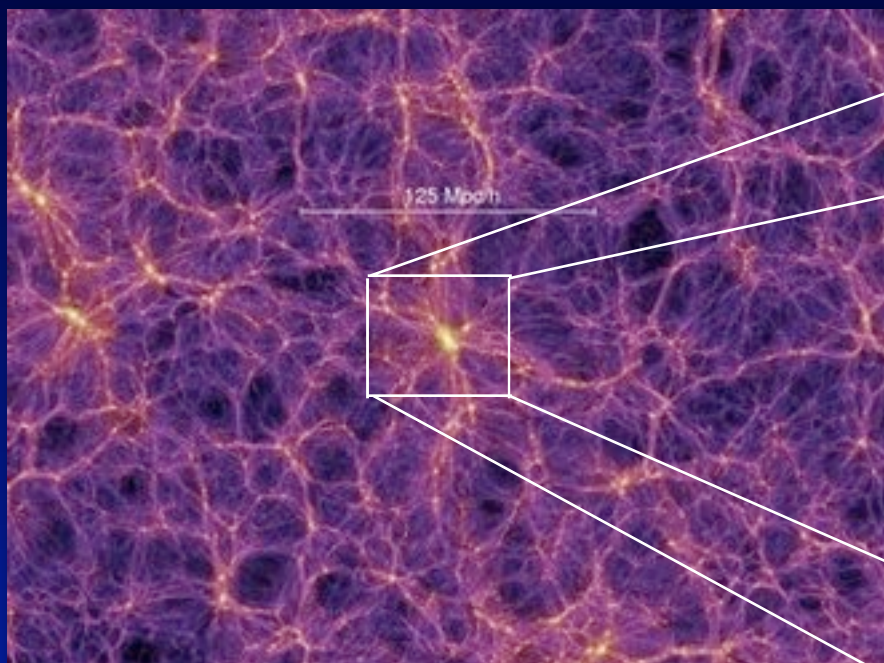
The overall picture



Millenium Run - z=0

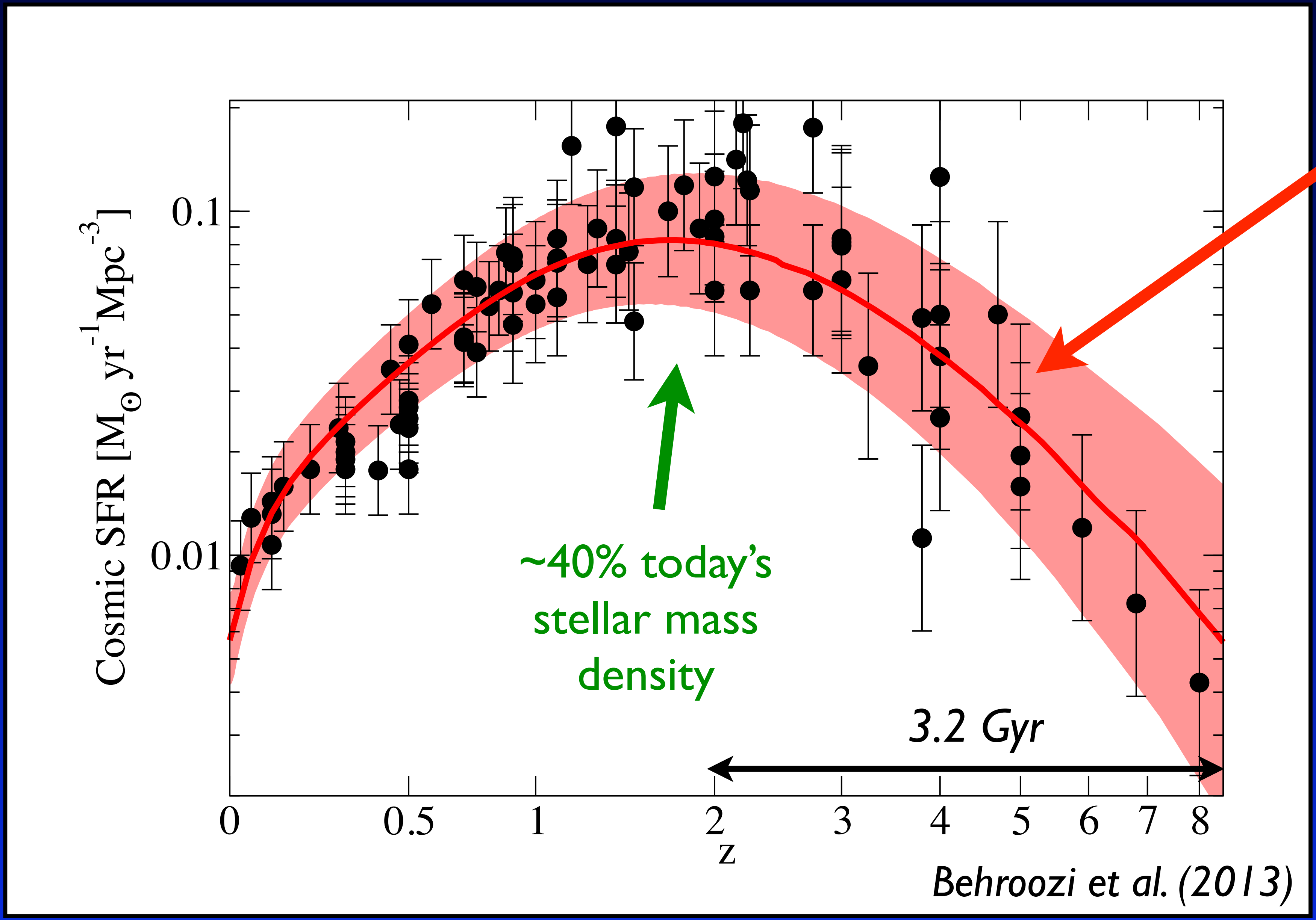
The overall picture



Millenium Run - z=0

- *When and how have the galaxies that we see today formed?*
- *How efficient was galaxy assembly at different z?*

Stellar mass assembly in context



suggests increasing efficiency in galaxy stellar mass assembly

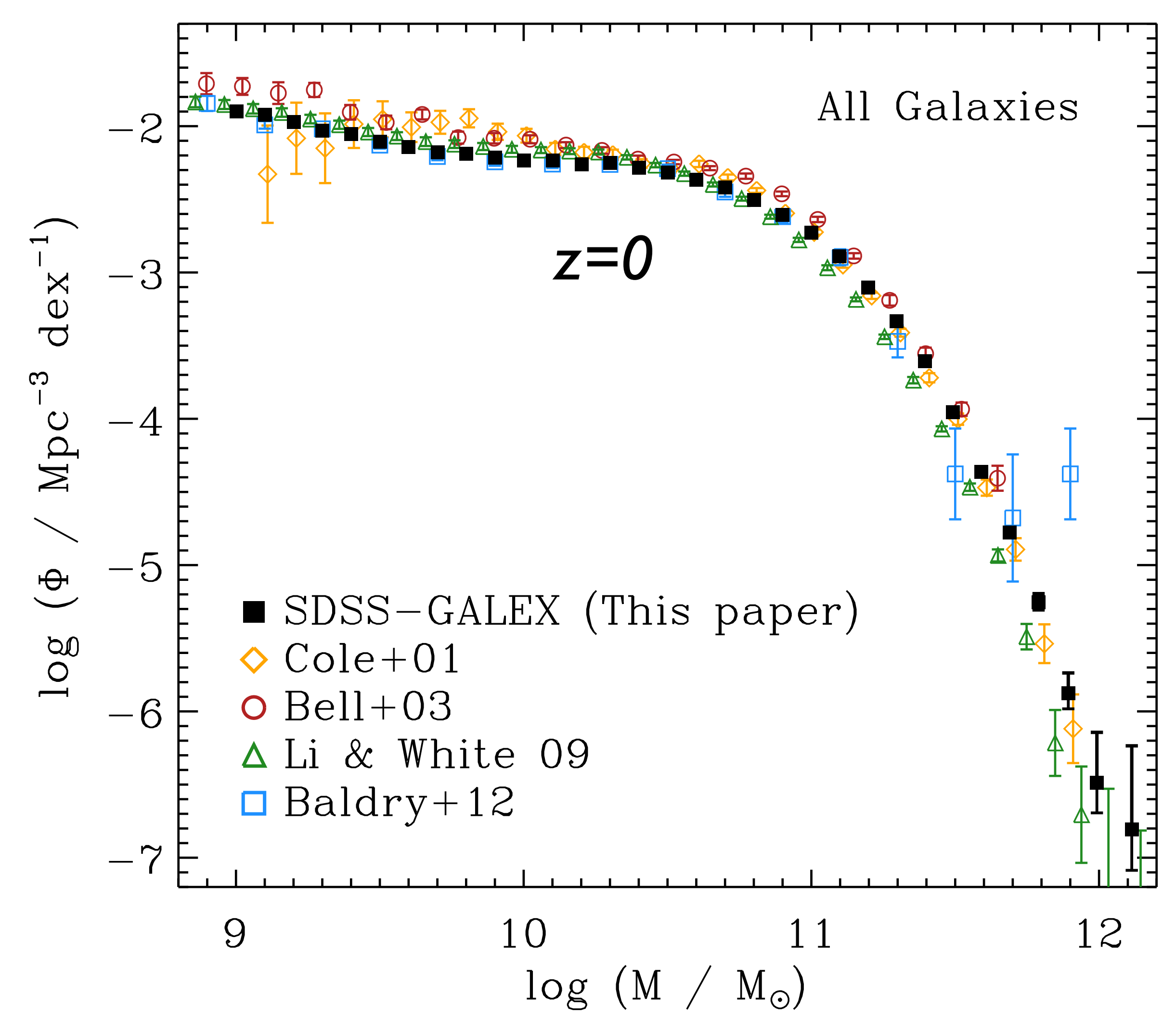
✓ was this a steady process?

✓ when did galaxies become massive for the first time?

✓ can we trace the building blocks of massive galaxies in the early Universe?

The GSMF as cosmological probe of galaxy assembly

The GSMF is a powerful statistical tool to study
the evolution of stellar mass assembly



Moustakas et al. (2013)

Many physical processes folded in:

- ✓ star formation
- ✓ gas consumption
- ✓ feedback processes
- ✓ environment

See e.g. Peng et al. (2010)

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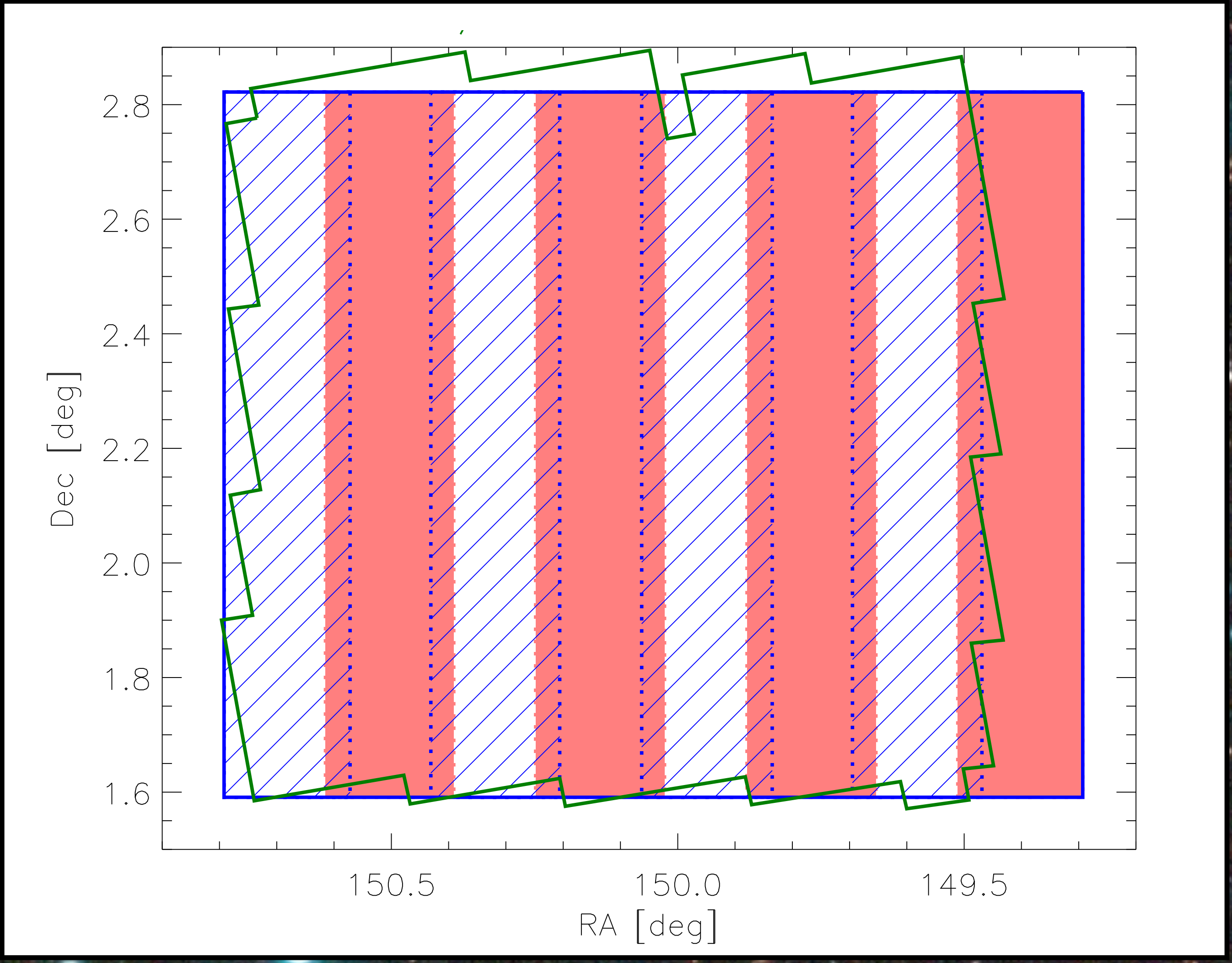
A wealth of deep near- and mid-IR surveys

IR galaxy surveys are necessary to study stellar masses of high-z galaxies

Several surveys carried out over last decade w/ different area/depth combinations

Multi-wavelength data essential for SED analysis

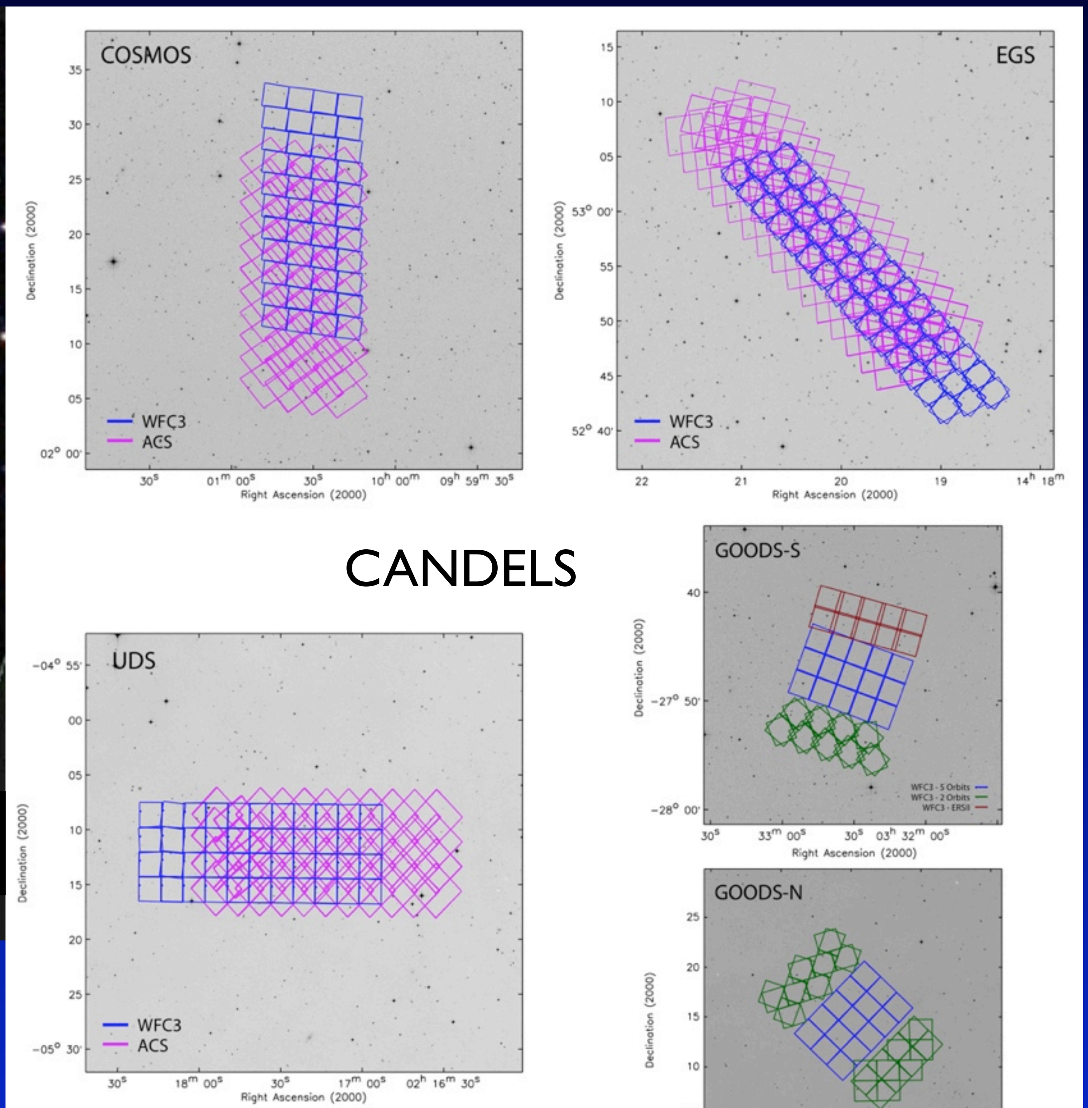


UltraVISTA
(McCracken et al. 2012)

Y, J, H & Ks + NB118
(see B. Milvang-Jensen's poster)

Deep: Ks~23.7 (5σ; AB)
Ultra-deep: Ks~25.4 (5σ; AB)

The CANDELS survey



Grogin et al. (2011)
Koekemoer et al. (2011)

H~27 AB mag - 0.25 sq. deg.
H~28 AB mag - GOODS fields

Spitzer surveys

At z>3, mid-IR surveys are necessary to study stellar masses

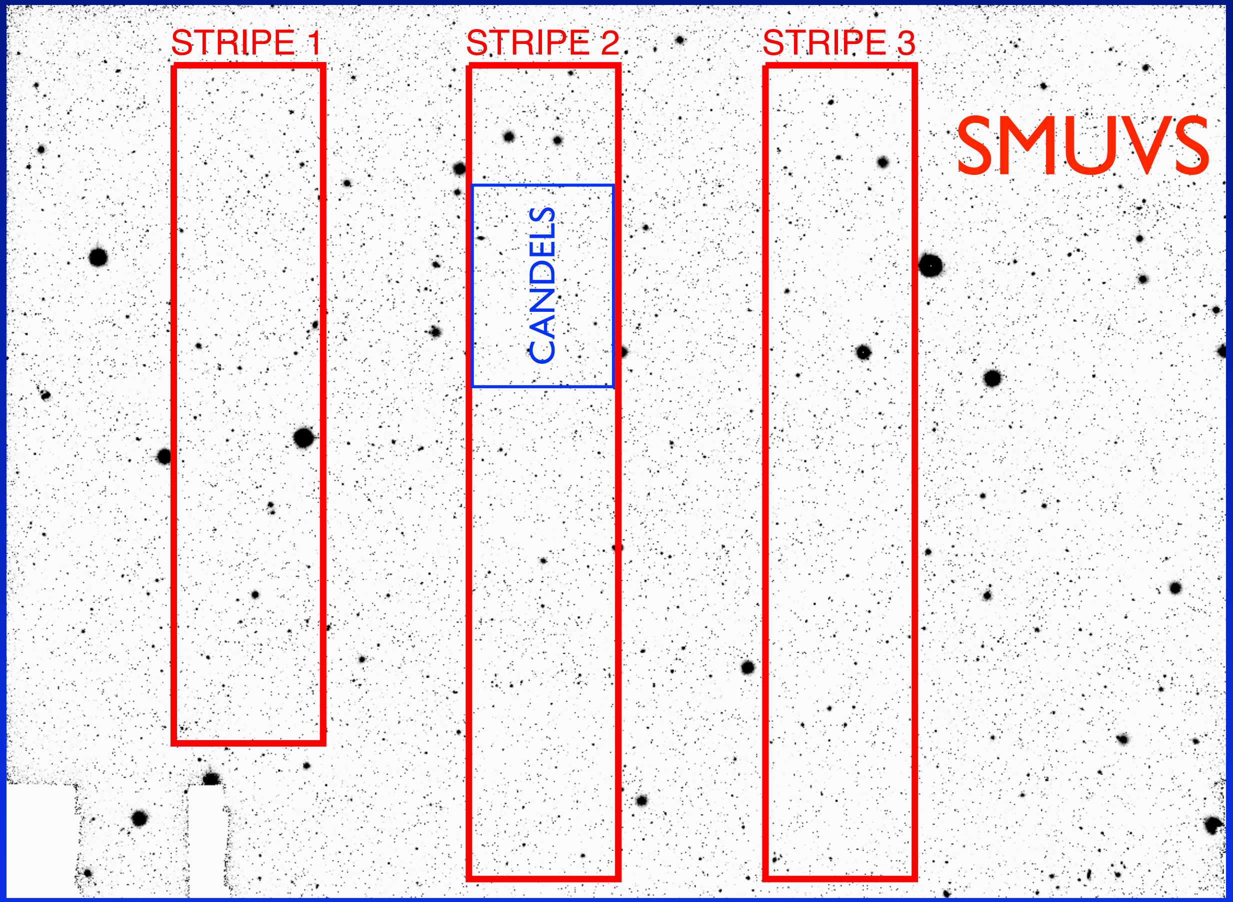
Spitzer matching data necessary and unique

✓ SCANDELS (PI Fazio) - *50h/pointing*

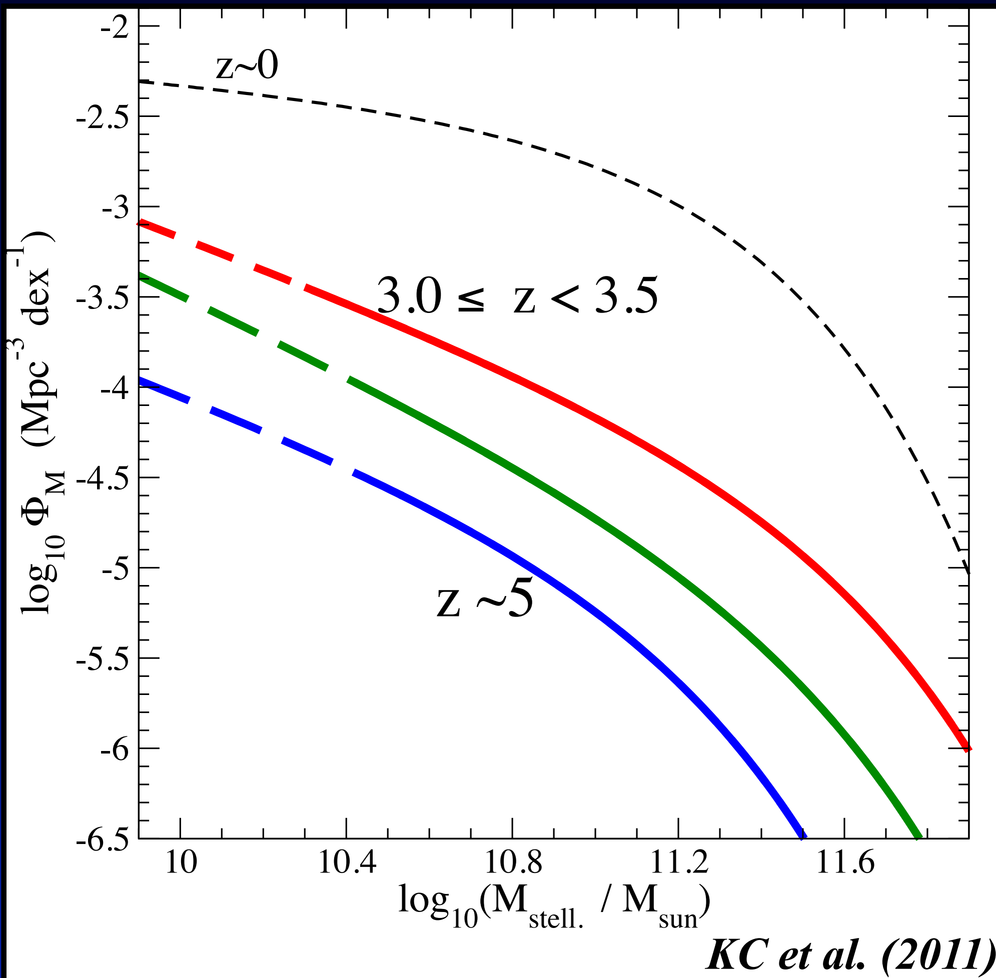
✓ SCOSMOS+SPLASH (PI Sanders/Capak)
entire COSMOS field at *~10h/pointing*

✓ SMUVS (PI Caputi) - *just started!*
1800 h on Spitzer
three ultra-deep stripes at *~40h/pointing*

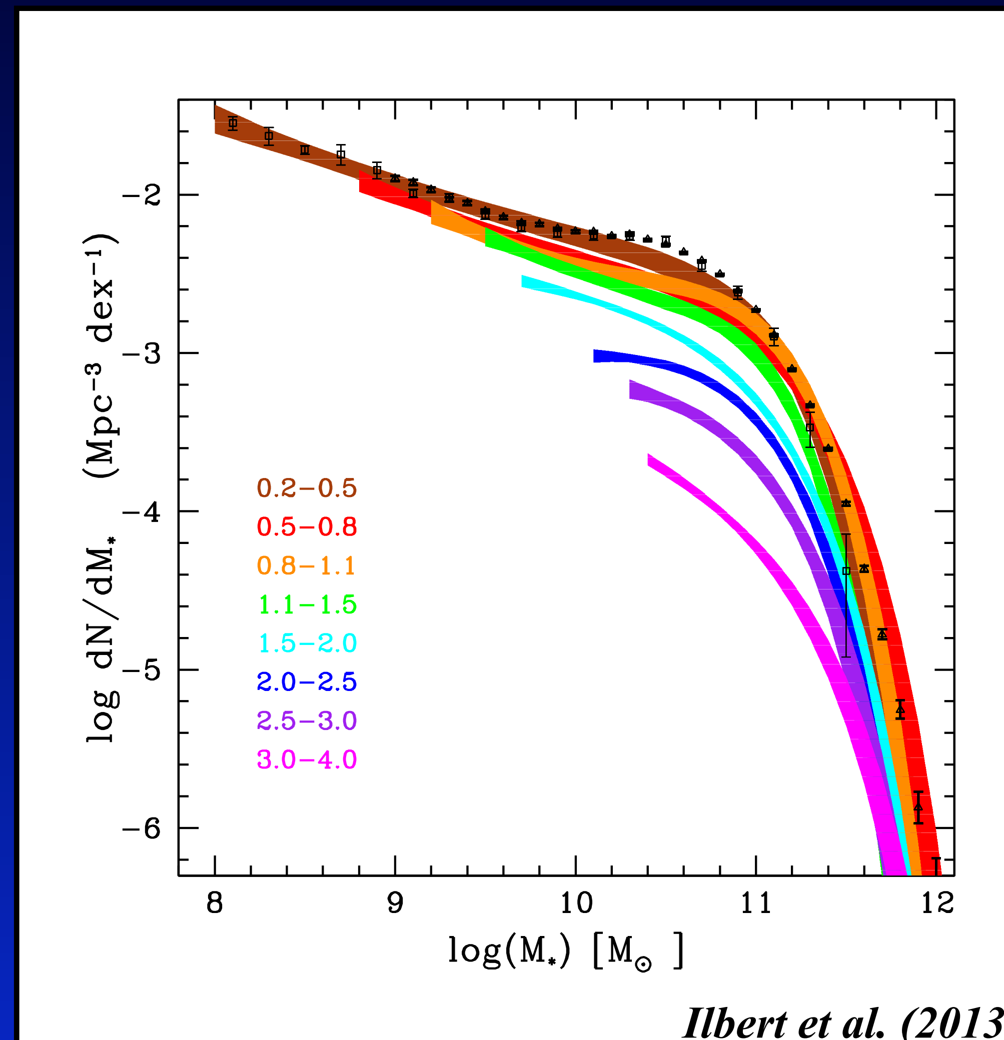
benefits from homogeneous data in COSMOS



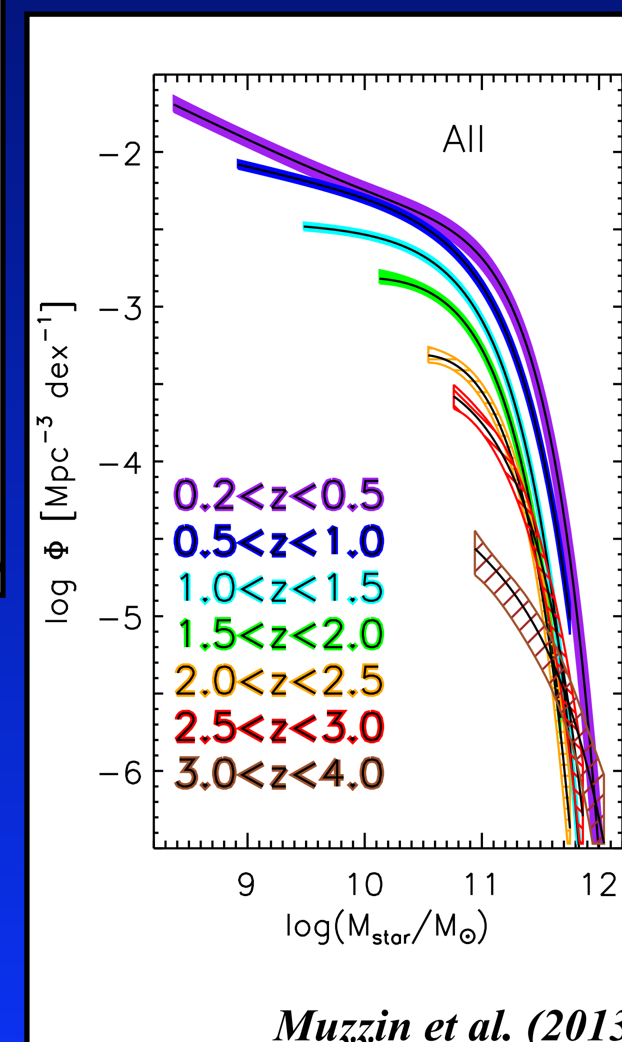
The GSMF up to z~5 - high-mass end



UKIDSS / UDS



COSMOS
UltraVISTA

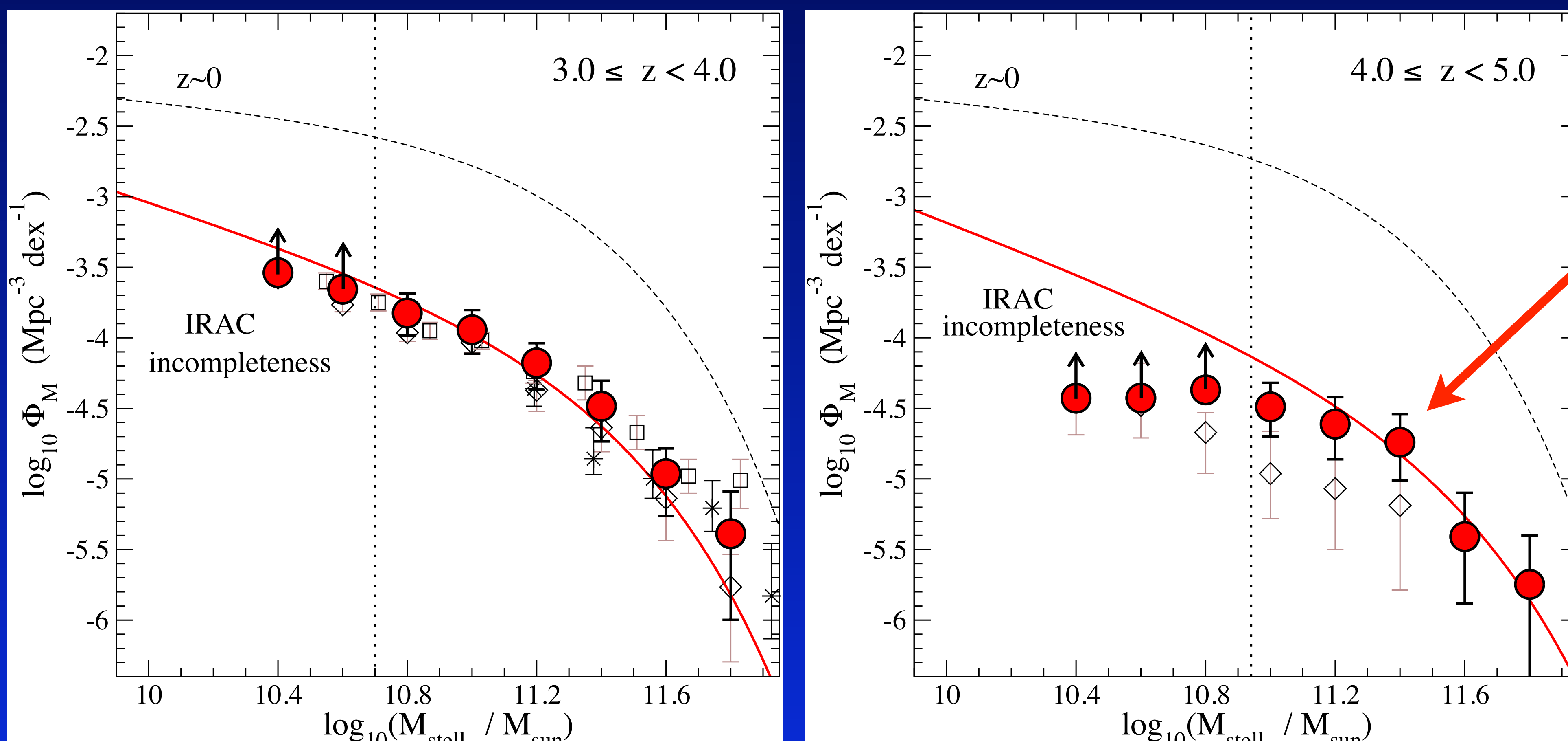


The assembly rate of massive galaxies proceeded much faster at 2<z<5 than at 0<z<2.

Massive galaxy buildup was very efficient over the first few billion years!

Are we missing massive galaxies to z~5?

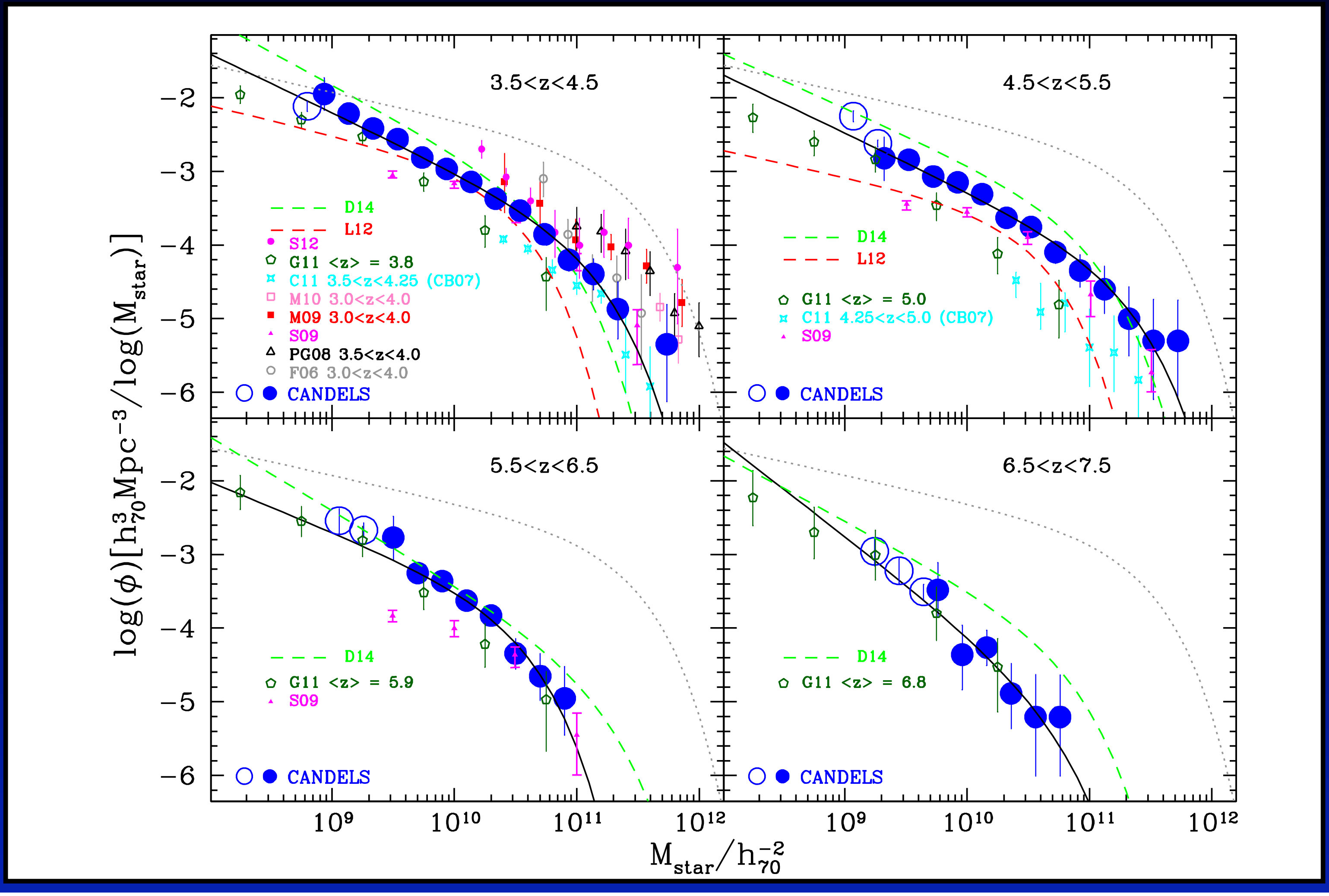
UltraVISTA (ultra-deep)



[4.5]<23 (AB)
Ks>24

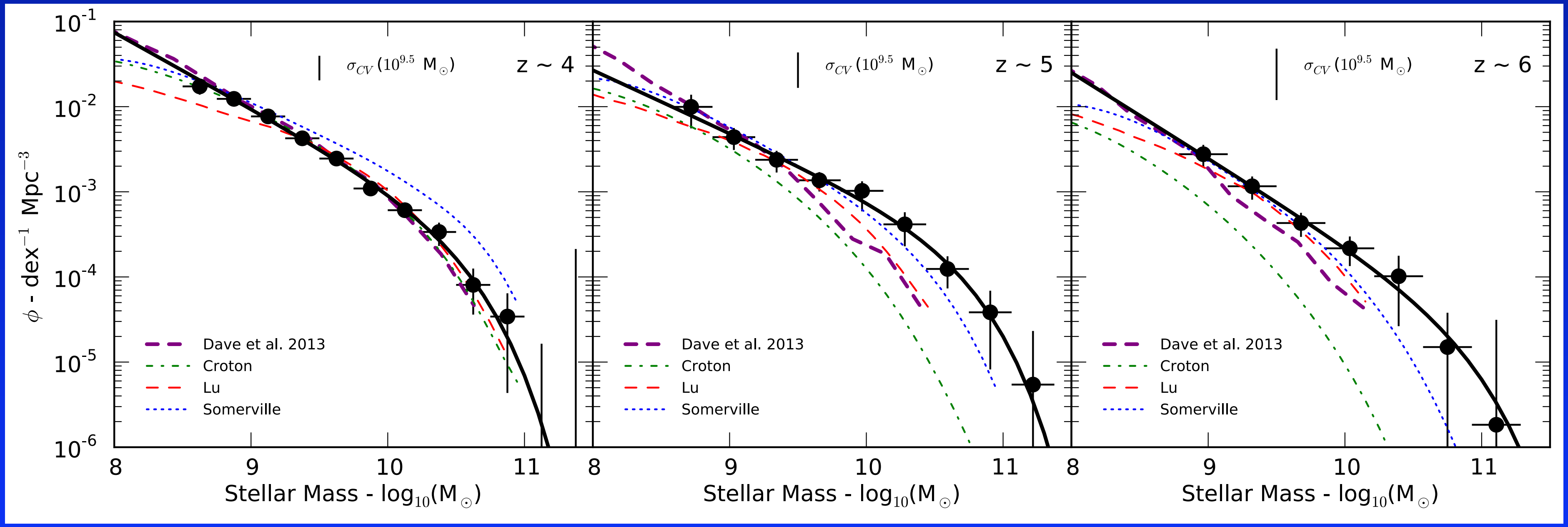
KC et al. (2015, in prep.)

The GSMF up to z~6-7 - intermediate stellar masses



CANDELS

Grazian et al. (2015)



Duncan et al. (2014)

See also Mortlock et al. (2011), Santini et al. (2012), etc.

Emerging trends

* There is a significant evolution in the GSMF from z~6-7 down to z~2-3

Mainly number density evolution

* Characteristic slope (α) is significantly higher at z>2-3 than z=0-1

General consensus, although values not as high as initially thought

* The cosmic stellar mass density rises from ~ a few % (z=6) to ~40% (z=2)

Stellar mass assembly was very efficient overall over period elapsed at 2<z<6

Outstanding Problems

* Still significant differences in GSMF results at z>5: cosmic variance + other issues

✓ *zphot uncertainties*

✓ *different methods to derive stellar masses*

homogeneous analysis of further surveys necessary to constraint galaxy models

* Strong assumptions (metallicities, IMF) - *don't lead to disagreements, but still there*

* The importance of TP-AGB stars in the rest near-IR

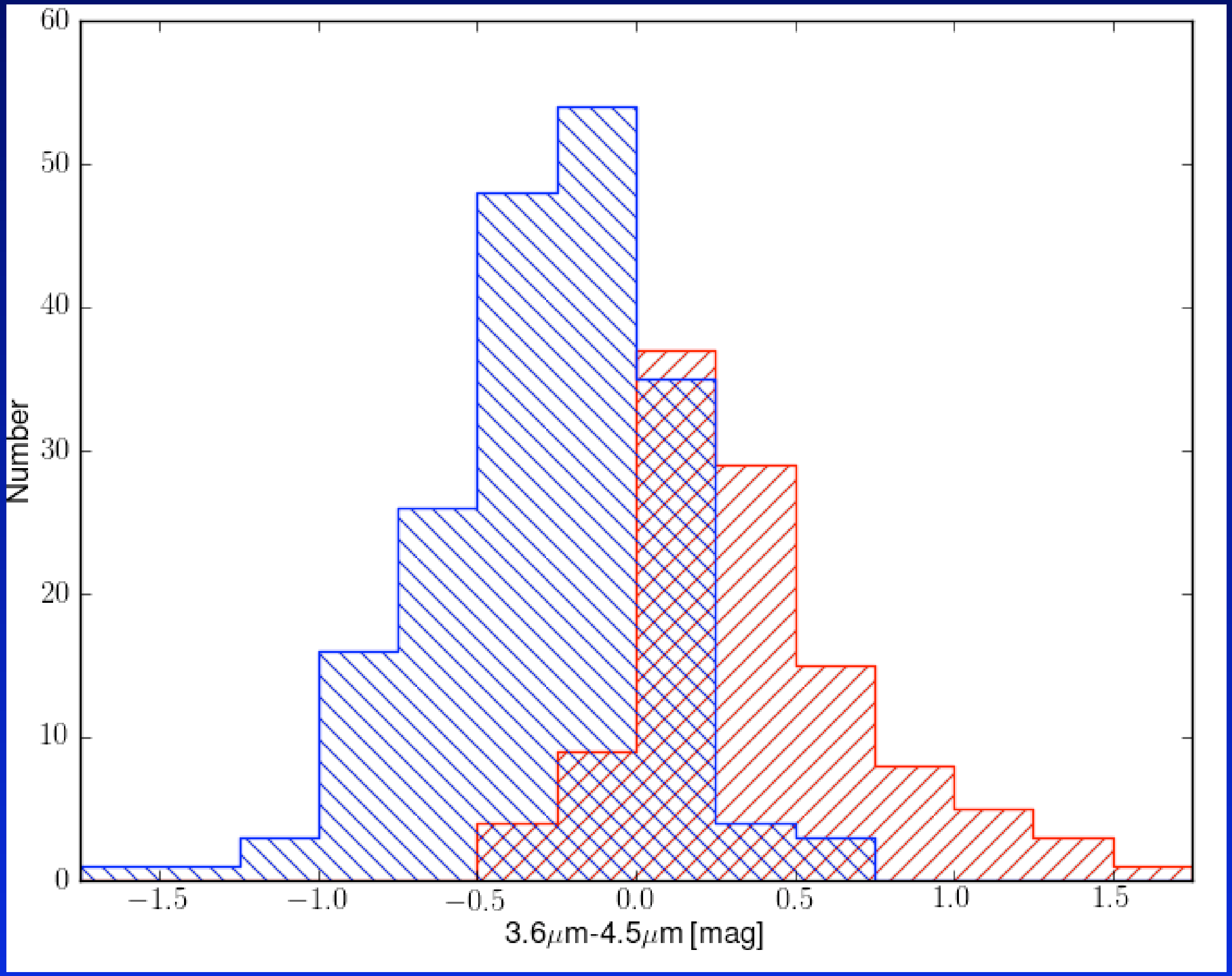
not so important as once thought?

See Maraston et al. (2006), but also Kriek et al. (2008), Zibetti et al. (2013)

The effect of emission lines

Emission lines can affect stellar mass determinations of high-z galaxies

However, importance depends strongly on galaxy colour

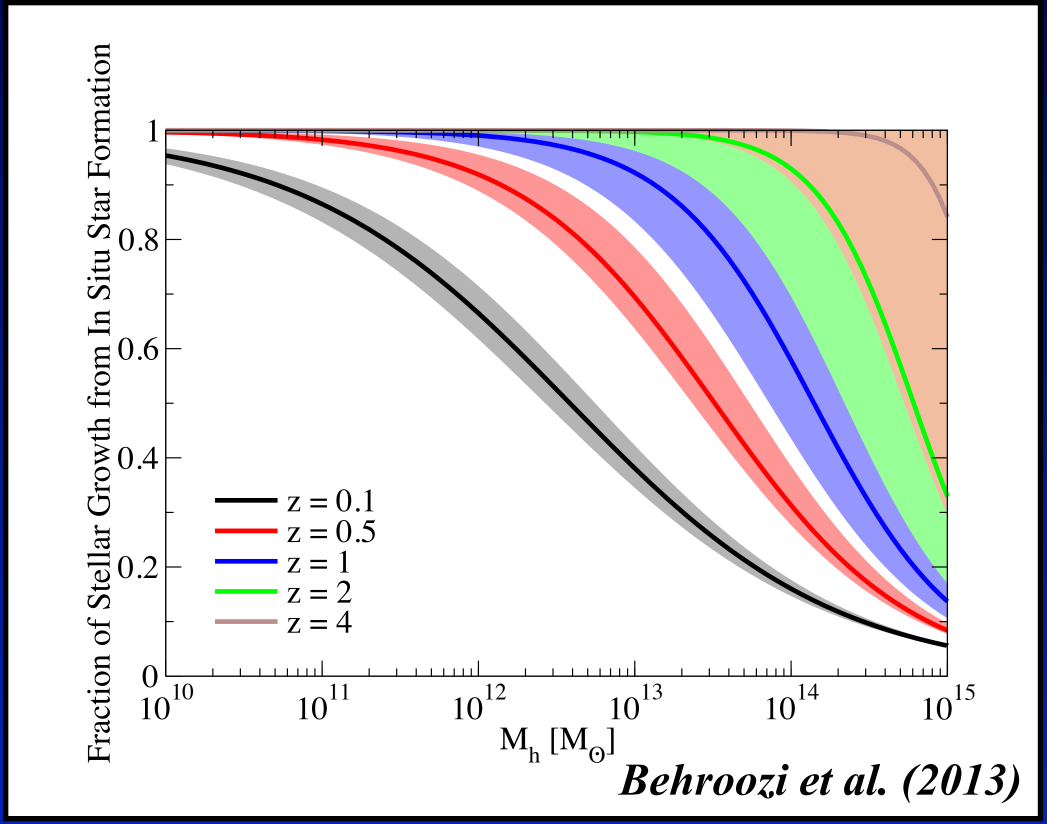


de Barros et al. (2014)

de Barros' talk on Thursday

The Physics of Galaxy Mass Assembly

We know very little about the physics of stellar mass assembly



- ✓ *galaxy mergers? cold accretion?*
- ✓ *importance of gas outflows? (stellar feedback)*

  needs deep spectroscopy
  currently difficult at z>2

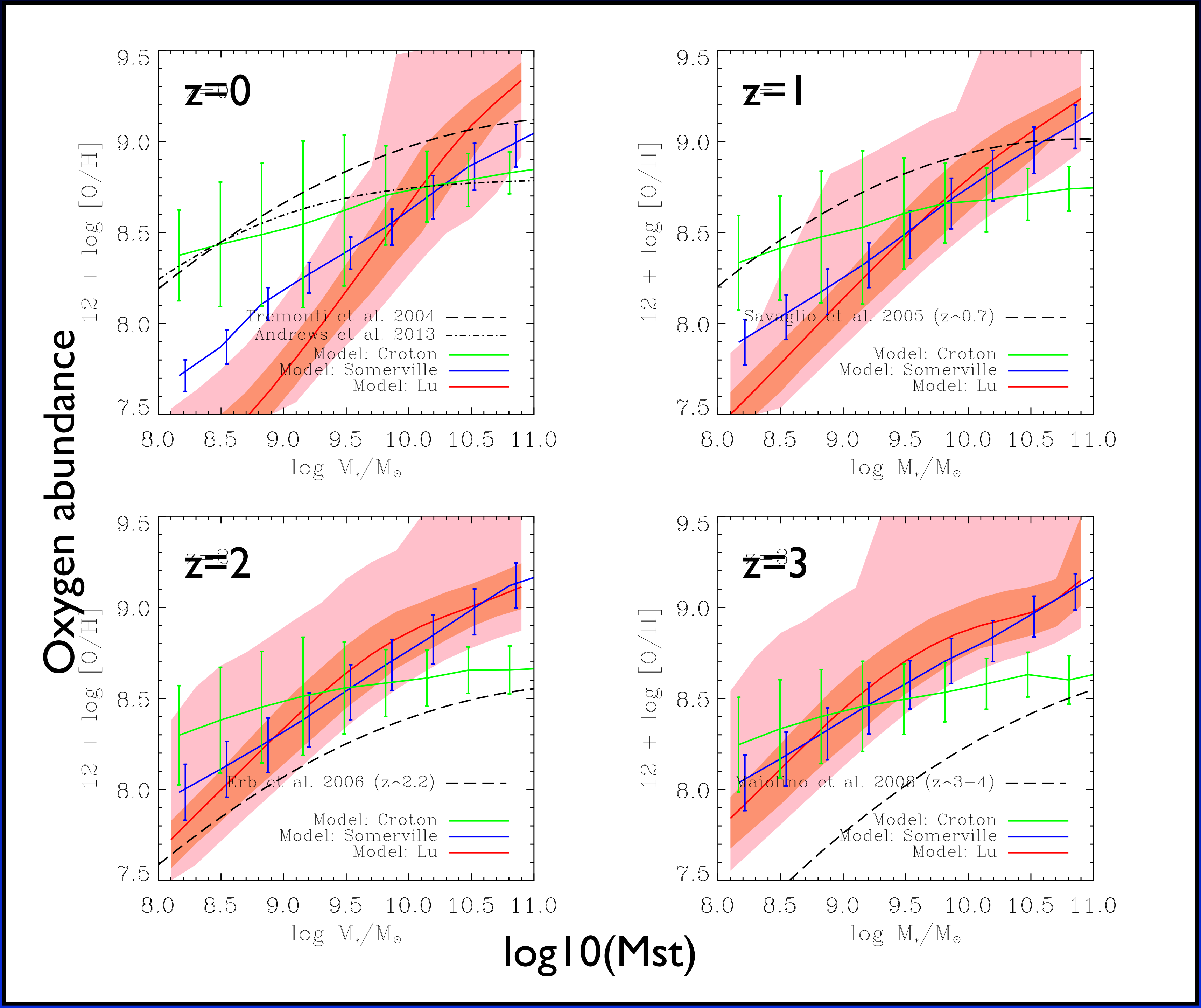
- ✓ *dust-obscured star formation?*

  needs far-IR data

- ✓ *AGN feedback in massive galaxies*

  models predict AGN in all massive galaxies to quench star formation

Stellar mass - metallicity relation

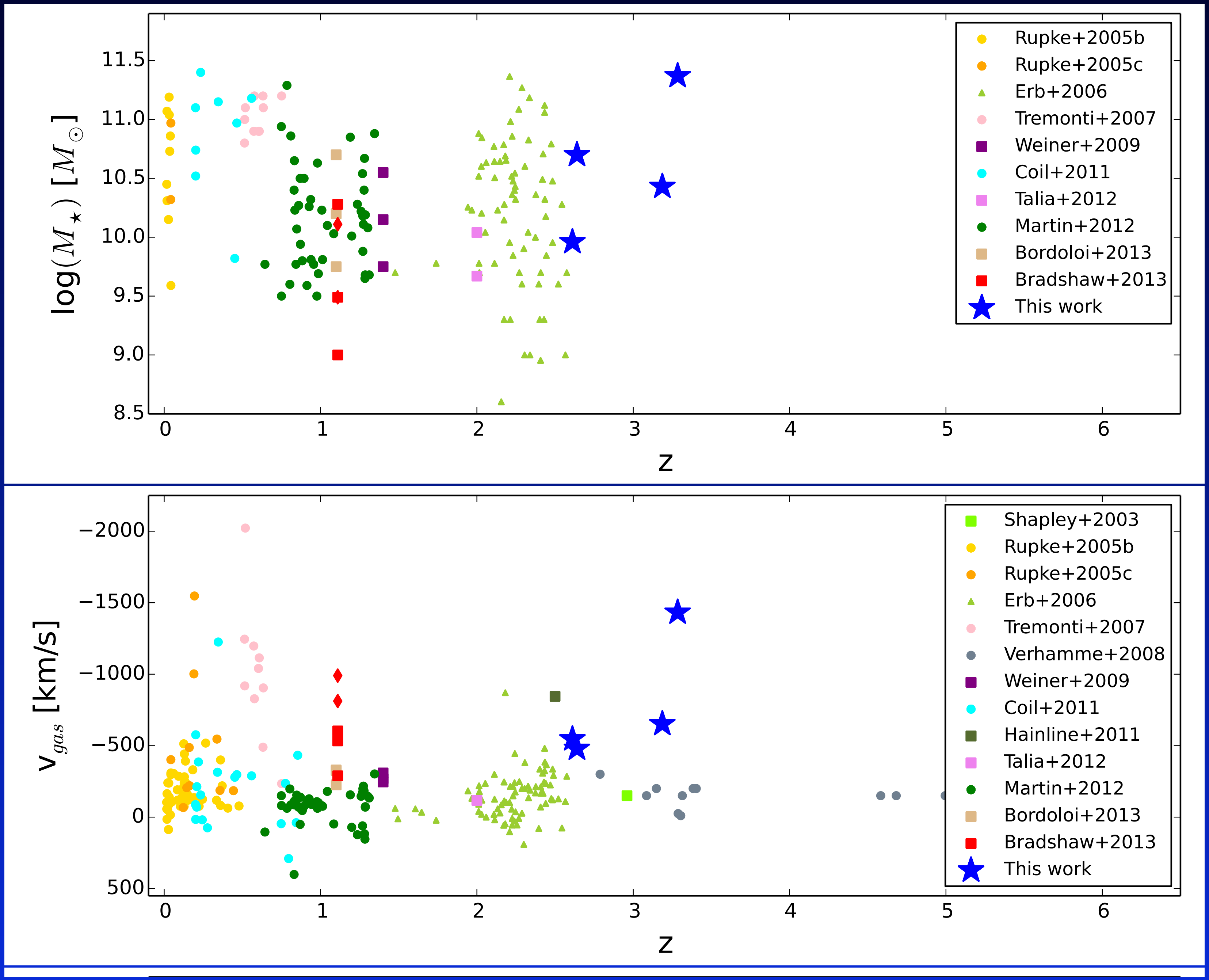


Lu et al. (2014)

models cannot reproduce GSMF and other galaxy properties consistently at high z

See also e.g. Cousin et al. (2015)

Gas outflows in galaxies up to z~3



Karman et al. (2014)

evidence of galaxy outflows still scarce to constrain galaxy models

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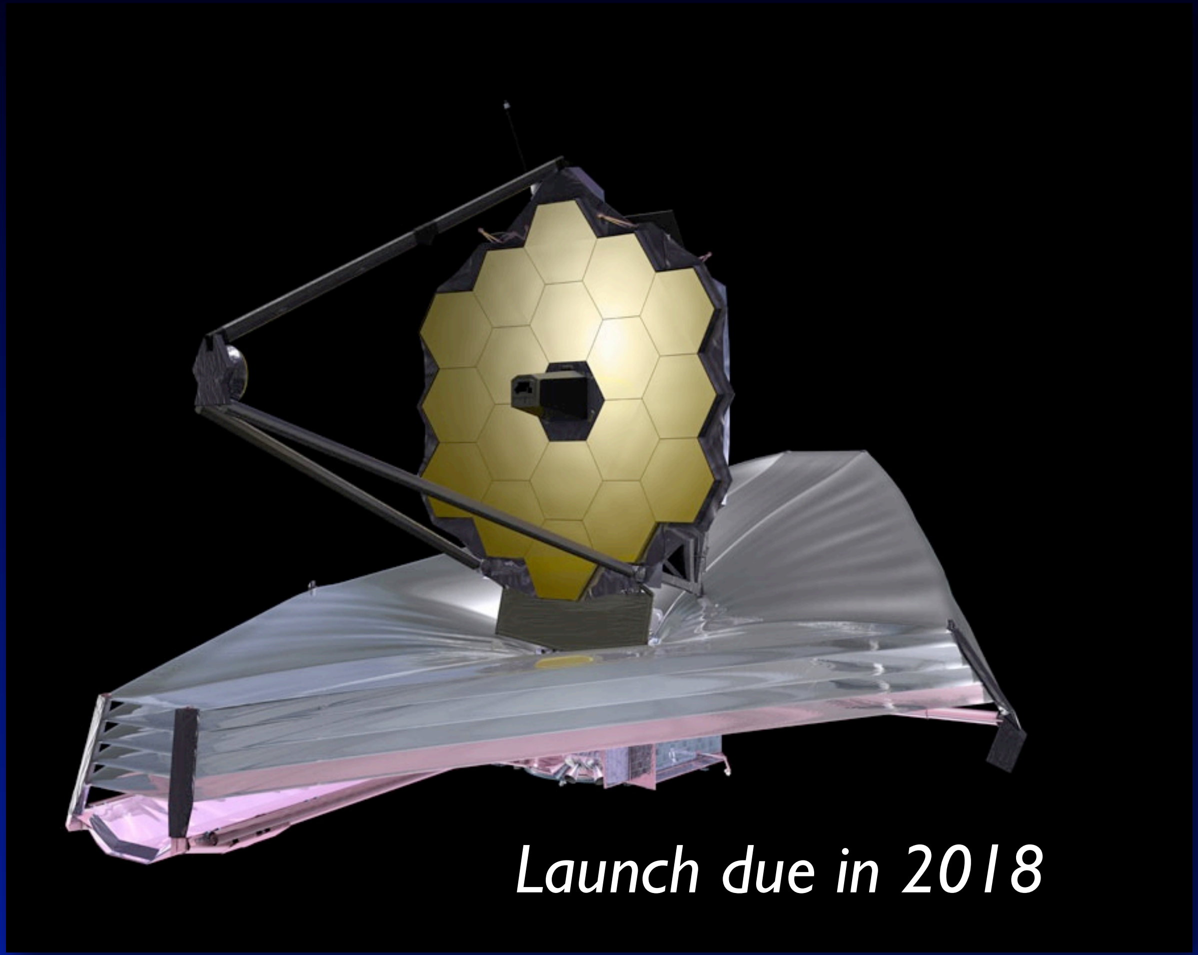
The *James Webb Space Telescope*

The *JWST* will be *the* telescope to discover the first galaxies, and the building blocks of massive galaxies at high z

Primary mirror ø = 6.5 m

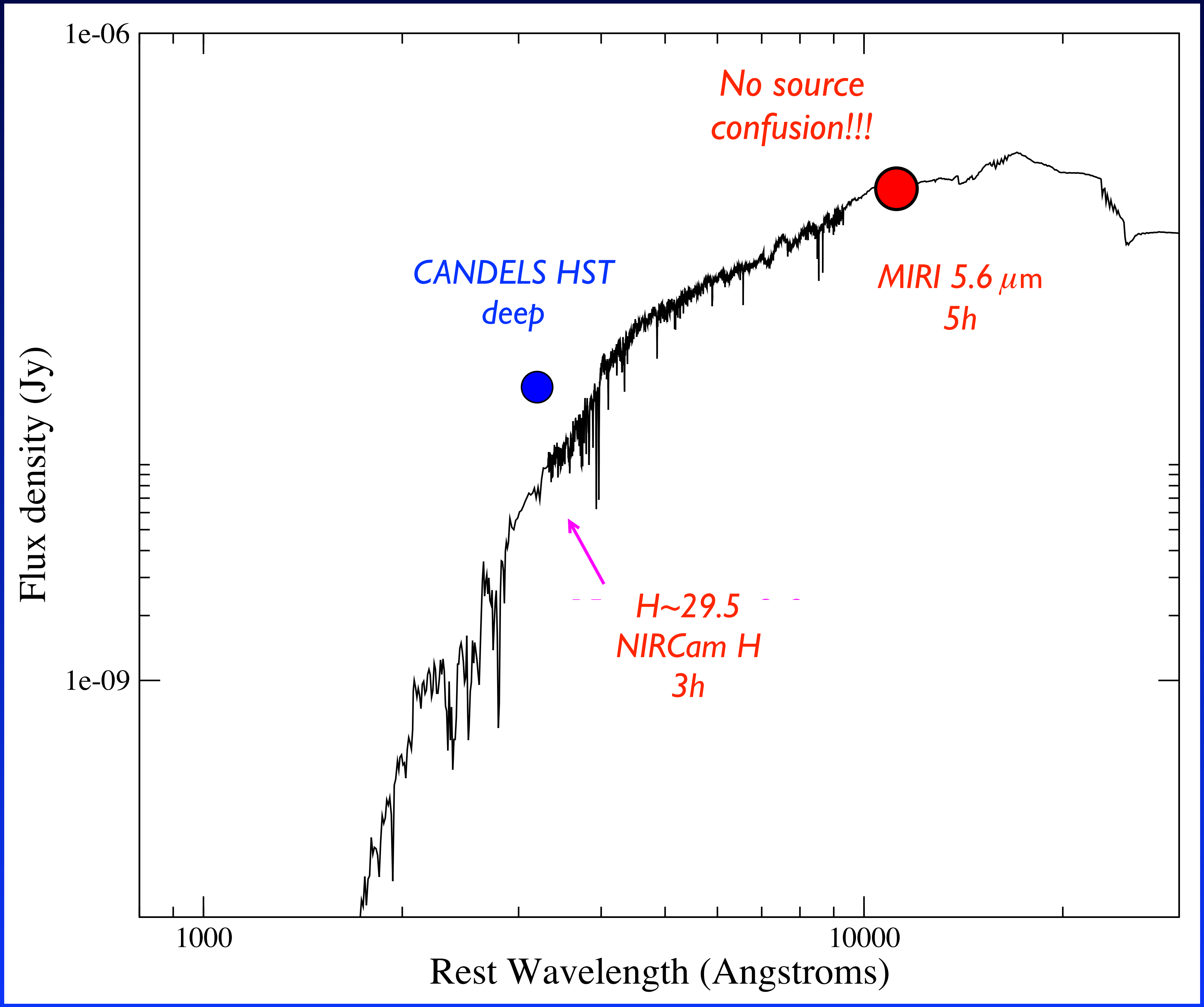
4 instruments on board: MIRI, NIRCam, NIRSpec, NIRISS

Integrated Science Instrument Module testing to be completed at the end of this year



JWST science -- example 1

z=4 -- M~10 ^{9} Msun

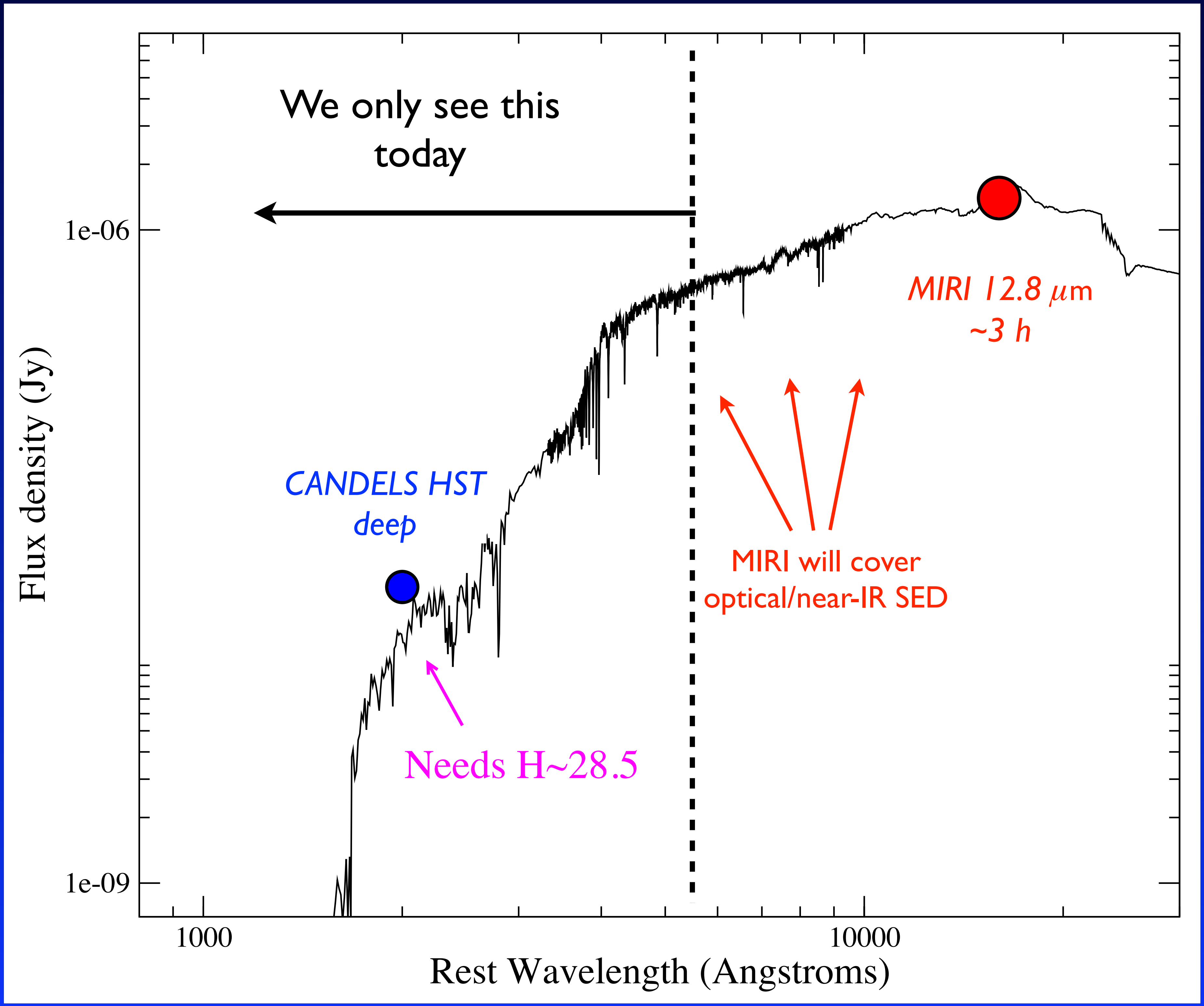


oldest galaxy with Av=0

JWST will probe the low-mass end of the GSMF up to z~7

JWST science -- example 2

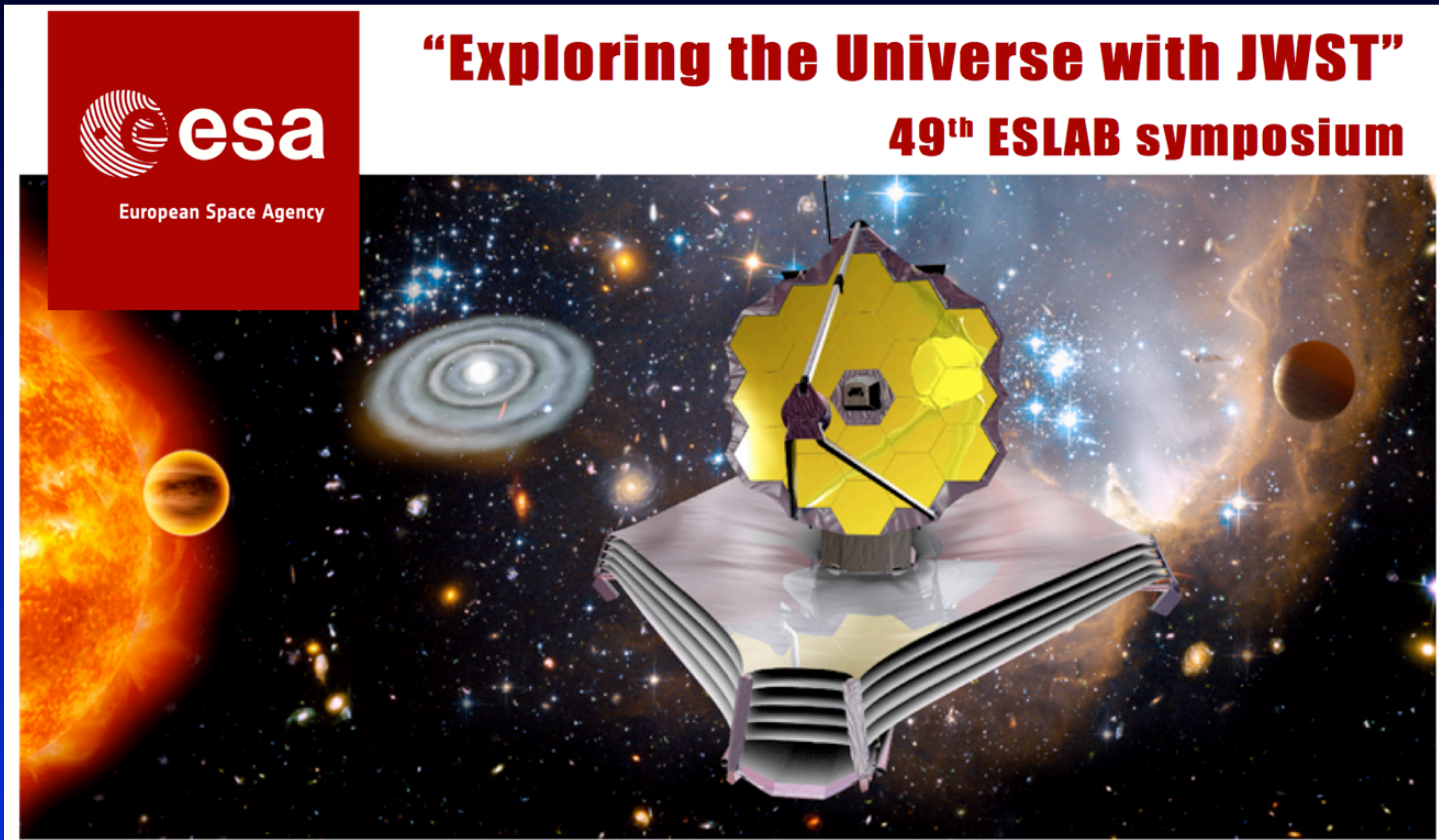
z=7 -- M~3x10^{10} Msun



JWST will discover the bulk of galaxy populations at z>7

MIRI crucial to constrain old stellar populations and stellar masses

ESA/NASA JWST conference

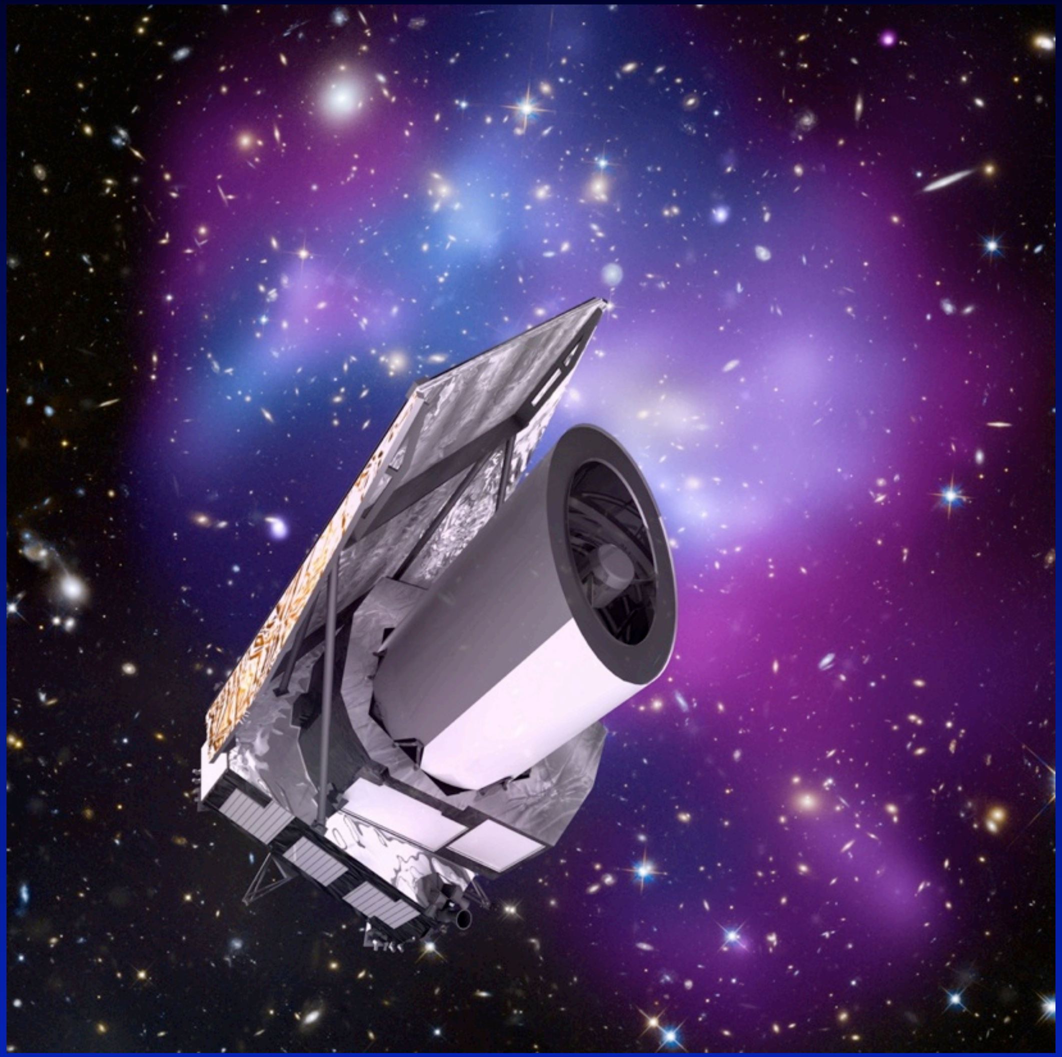


ESTEC, Noordwijk - 12-16 October 2015

Euclid science

- ✓ ultimate statistics (all sky!)
- ✓ deep survey: 40 x UltraVISTA
- ✓ spectroscopic redshifts

A high precision era for stellar mass assembly



Talk this morning by A. Cimatti

Summary

❖ Good constraints to GSMF up to z~5, and first constraints at higher z

Emerging trends:
- mainly density evolution
- increasing slope
- ~40% STMD at 2<z<6

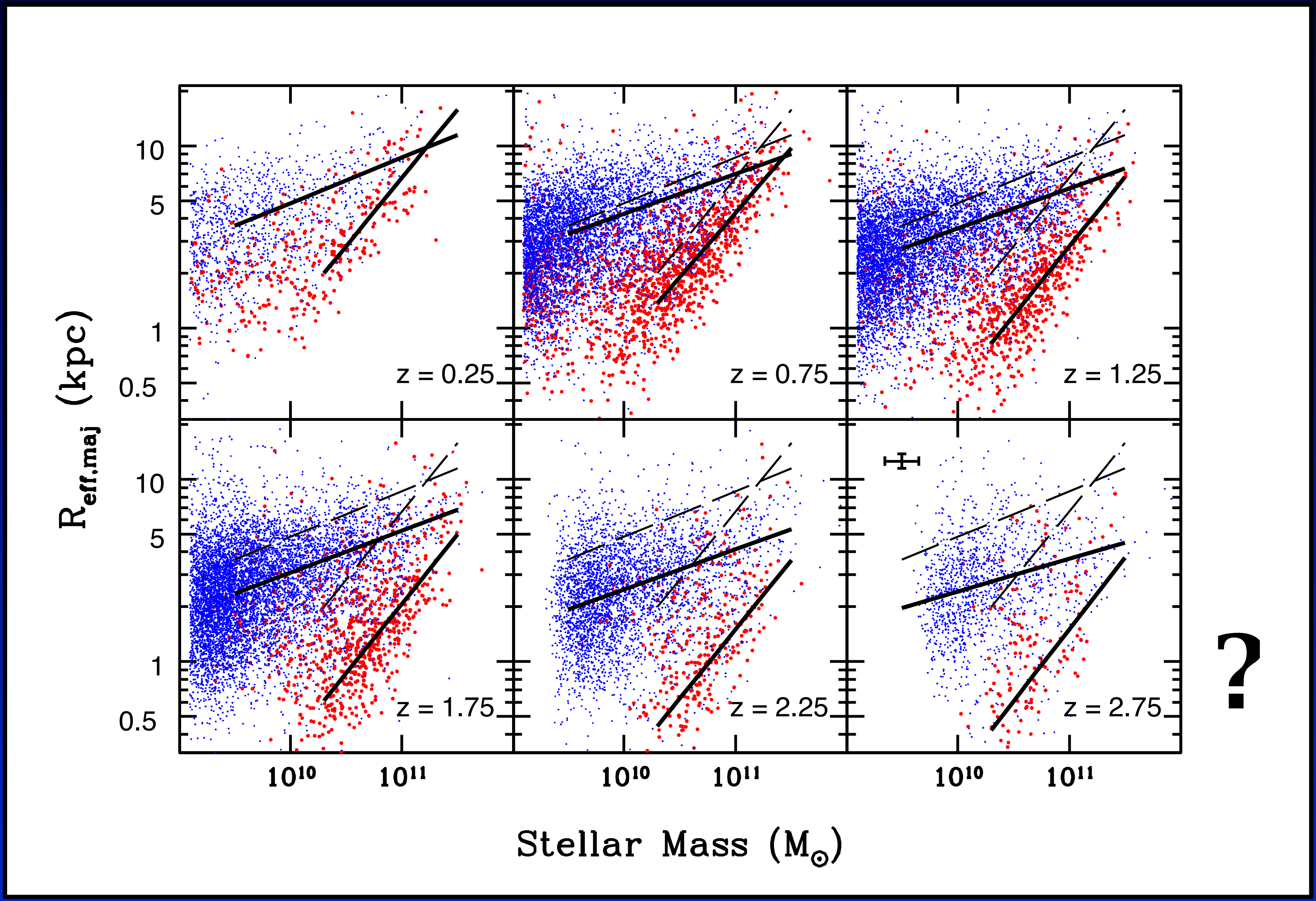
Limitations:
- zphot/Mst uncertainties
- systematic effects
- galaxy models at near-IR

❖ The physics of galaxy stellar mass assembly is still very poorly known
resolving galaxies with good S/N at z>3 currently challenging >> JWST & ALMA

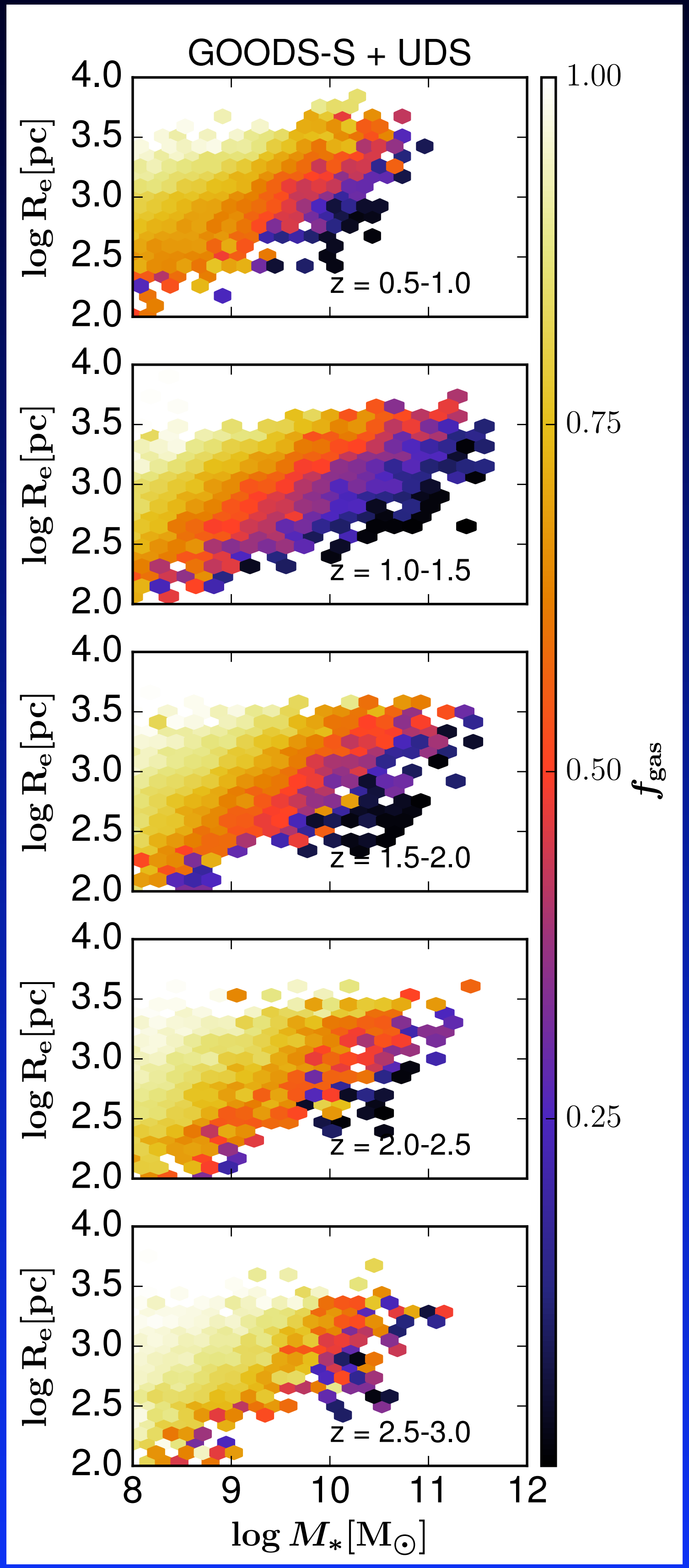
❖ JWST and Euclid -- *wait for them: it is worth it !*
JWST: finding the building blocks of massive galaxies & physics of stellar mass assembly
Euclid: the ultimate probe of galaxy stellar mass assembly to z~2-3

Thanks!

Stellar mass - size relation



van der Wel et al. (2014)



Popping et al. (2015)

constant slopes suggest SF quenching/end mass assembly lead to universal relation

...but what happens at higher z?