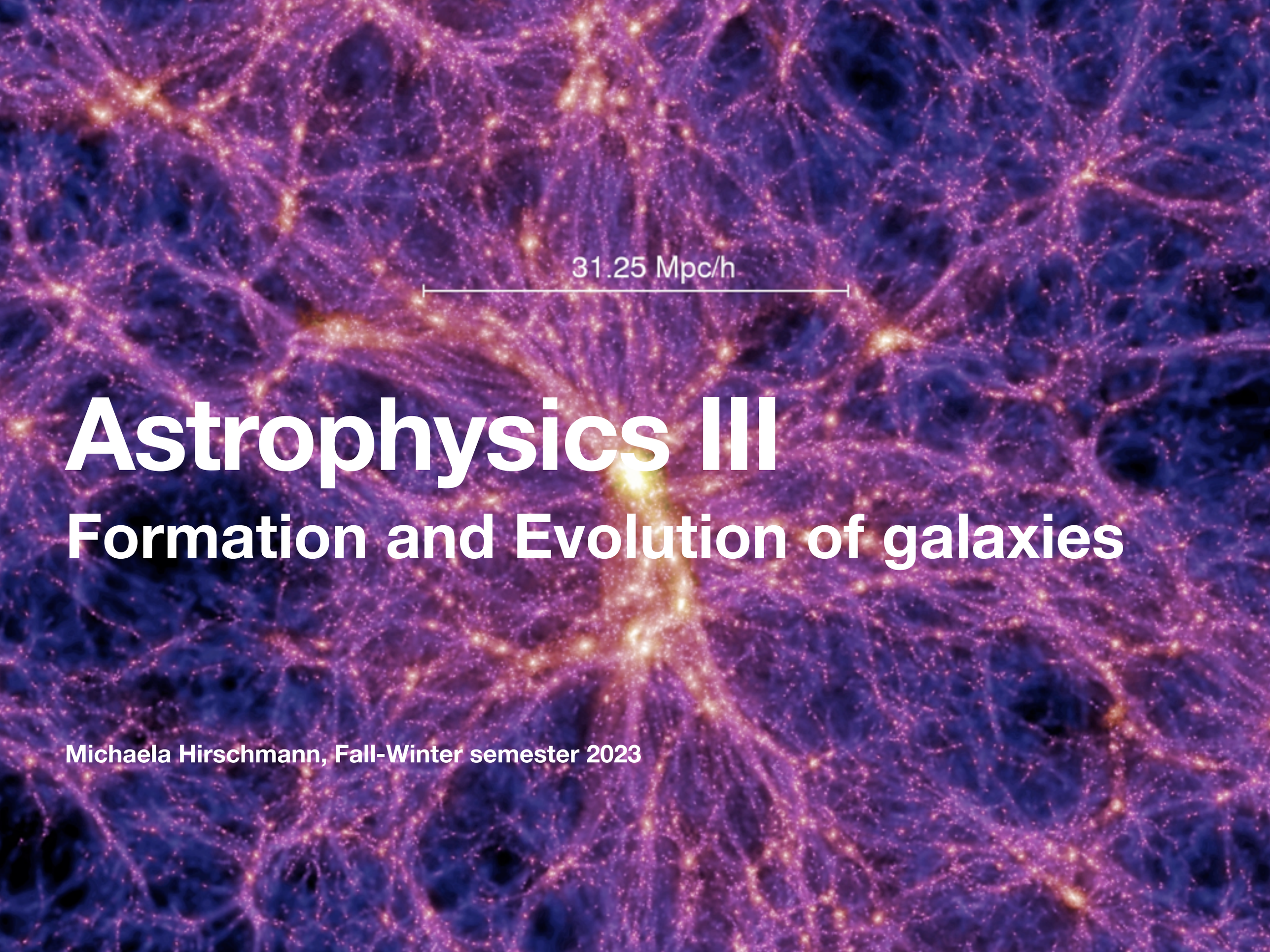

Astrophysics III

Formation and Evolution of galaxies

Michaela Hirschmann, Fall-Winter semester 2023

Lecture content and schedule

- *Chapter 1*: Introduction (galaxy definition, astronomical scales, observable quantities — repetition of Astro-I)
- *Chapter 2:* Brief review on stars
- *Chapter 3*: Radiation processes in galaxies and telescopes;
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Part I:
Observational basics & facts of galaxies
first 7 lectures

Part II:
Theory & models of galaxy evolution processes
second 7 lectures

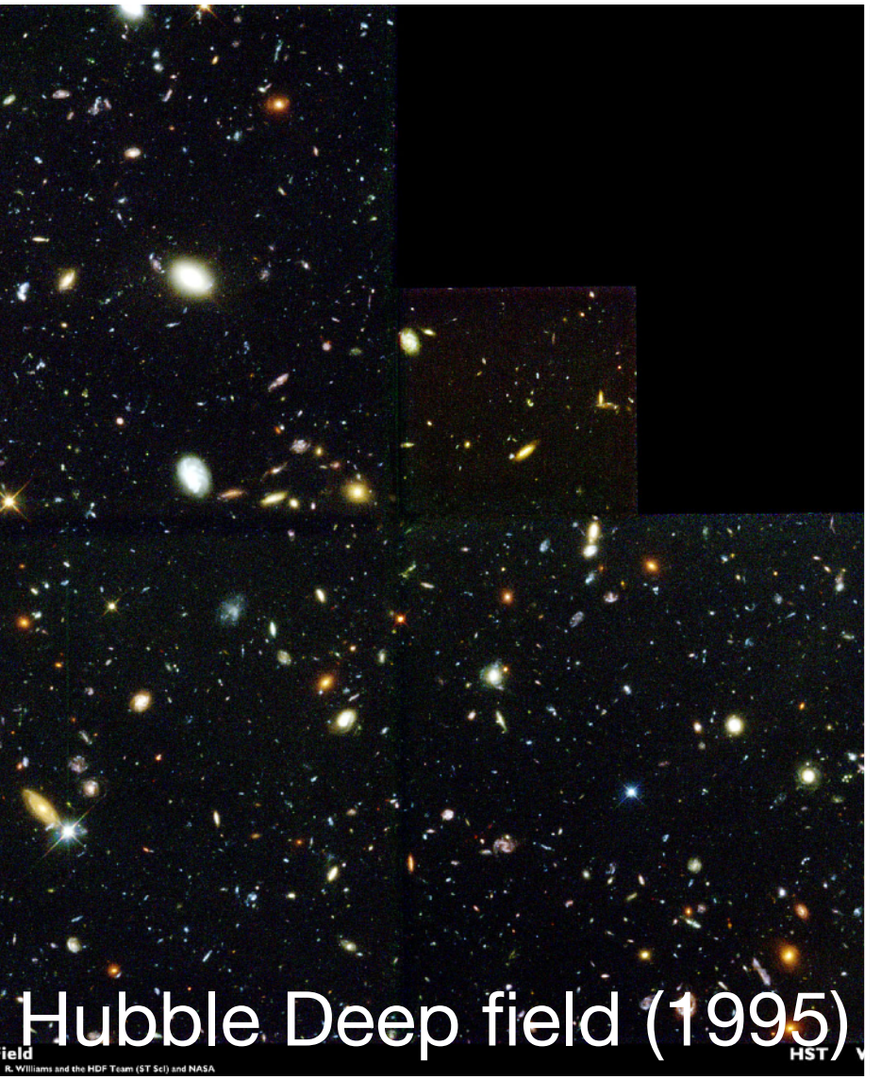
Outline of Chapter 9

- The high-redshift Universe
- Identification of high-redshift galaxies
- Observational facts pre-JWST
- New insights thanks to JWST

High-redshift galaxies — Identification

How can we observe galaxies at high redshifts?

- Until 1995, only few galaxies were observed above redshift = 1 (roughly half the age of the Universe)
- Big breakthrough came thanks to the Hubble Space Telescope and the “deep fields”



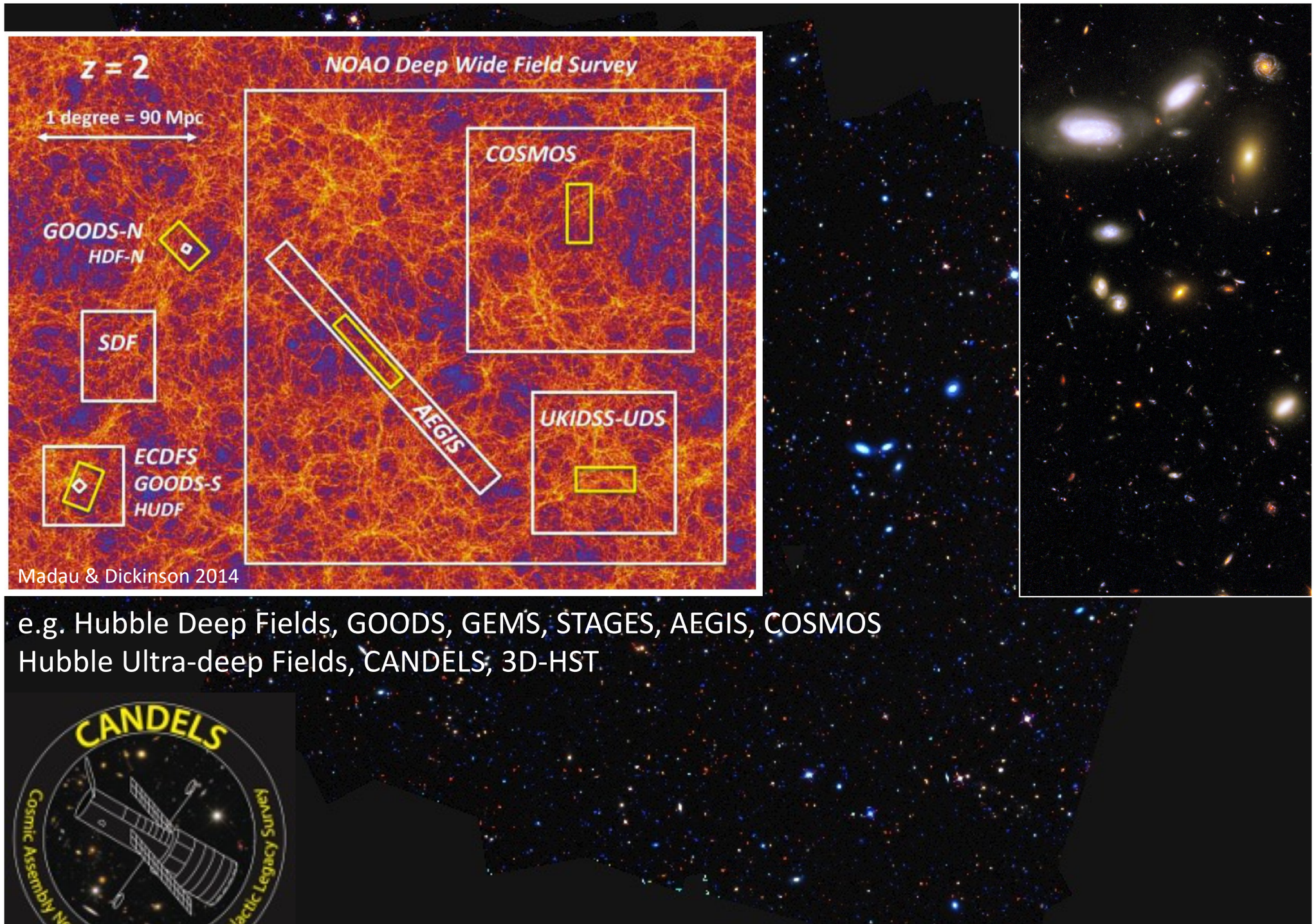
Hubble Deep field (1995)

Ultra deep field (2004)

Extreme deep f. (2012)

High-redshift galaxies — Identification

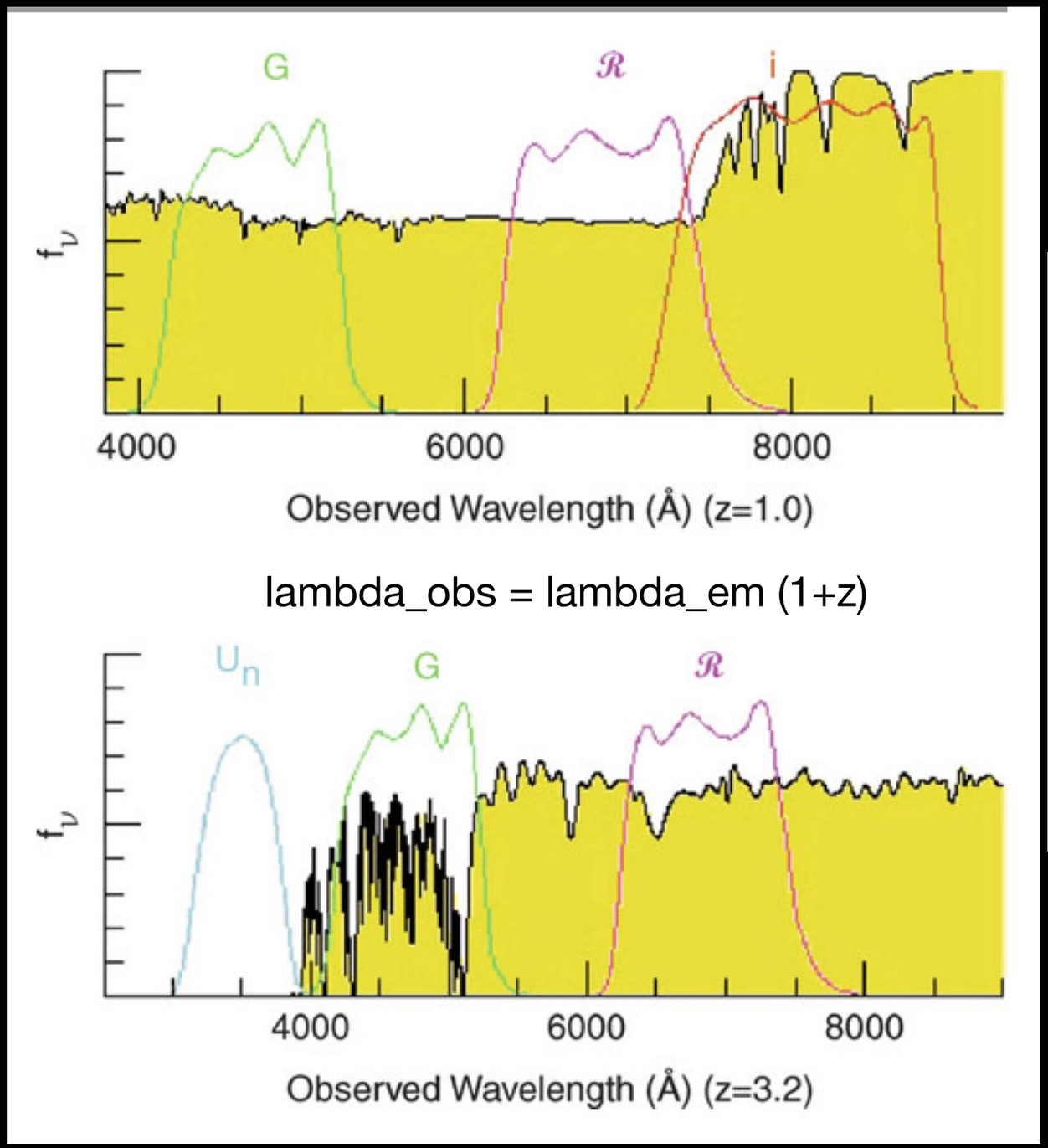
How can we observe galaxies at high redshifts?

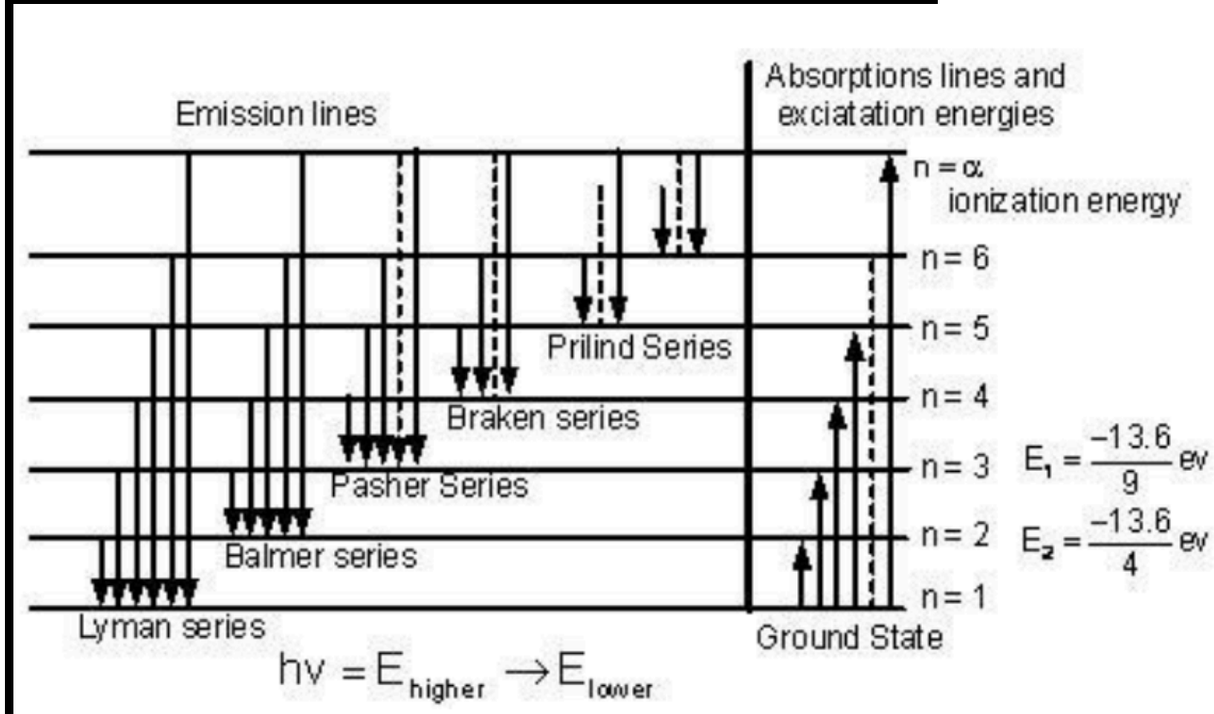


High-redshift galaxies — Identification

how can we identify high redshift galaxies?

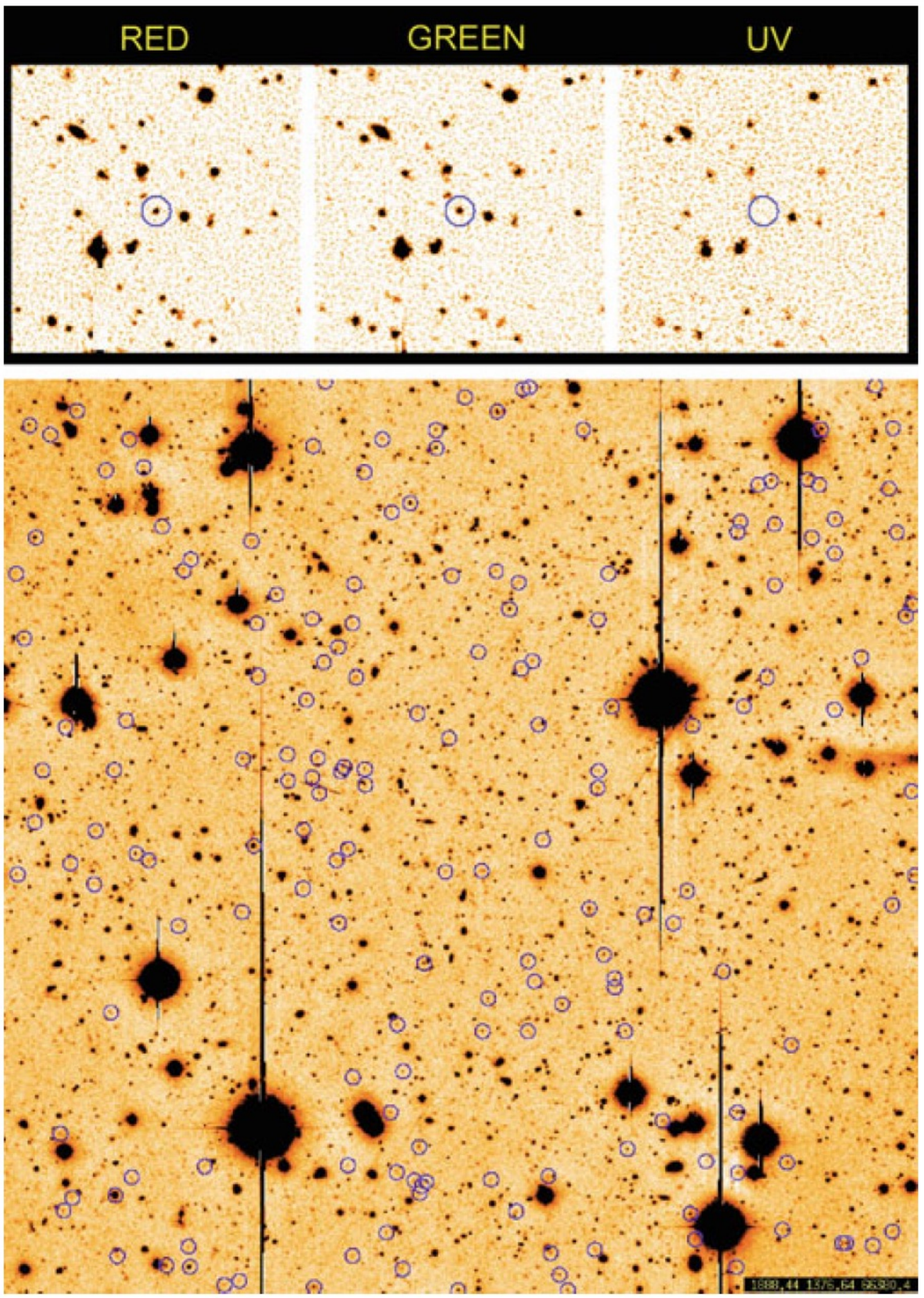
the Lyman break technique





wavelength of Lyman break: 912 A
No emission at lower wavelength as photons are absorbed by & ionise HI
Redshift related to where the Lyman-break appears

High-redshift galaxies — Identification



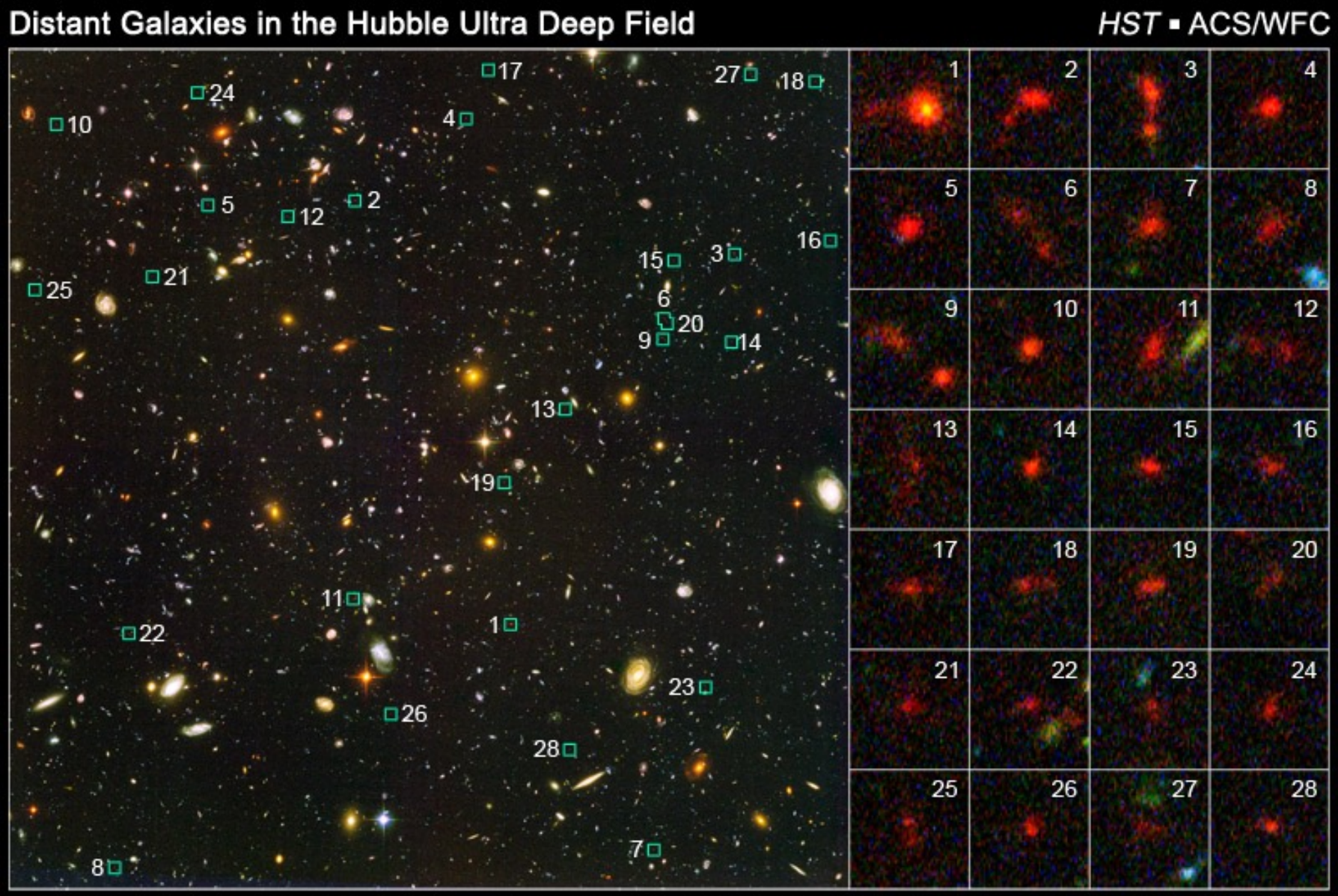
- Drop-out technique first systematically applied in 1996 for z > 3
- Other techniques: Lyman alpha (ground to n1 state of H) emitters via narrow band surveys allowed to identify galaxies up to z~7
- Background high-z galaxy lensed by a massive foreground source
- FIR emission from dust: Spitzer, Herschel
- submm emission for molecular gas: Alma

High-redshift galaxies — Identification

the most distant known galaxies

~13 billion ly away (Universe <5% of present age)

Pre-JWST!!!



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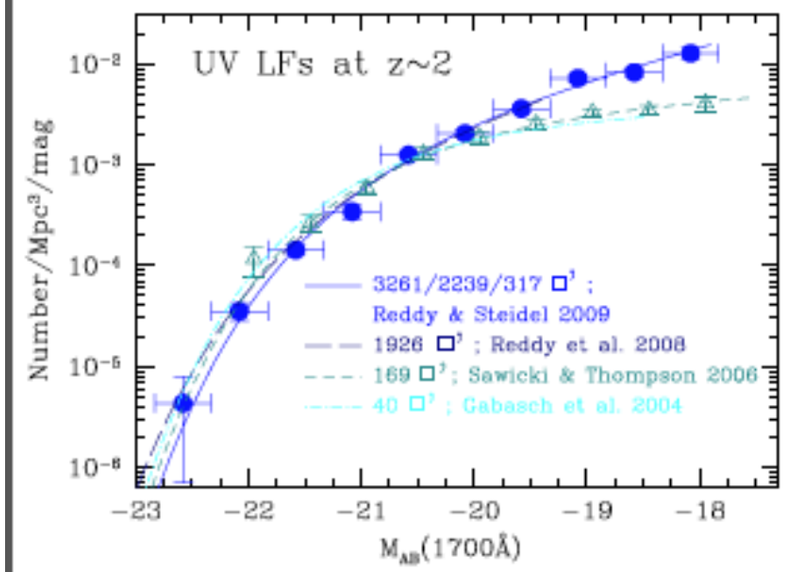
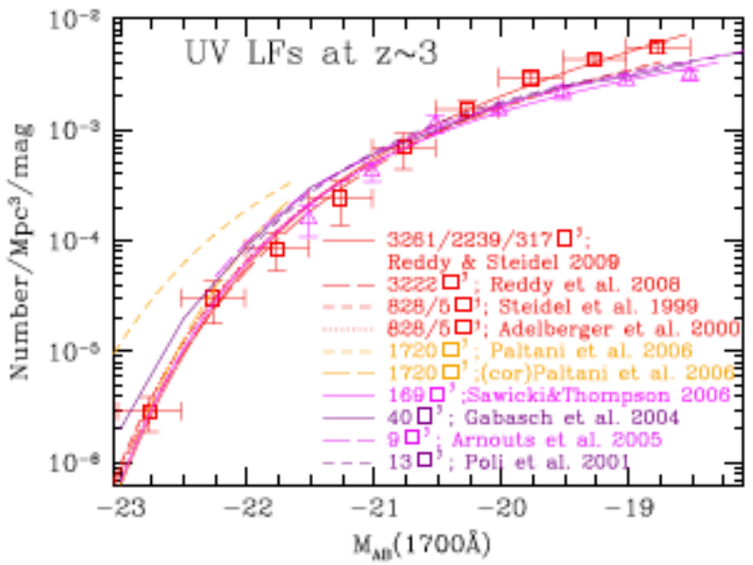
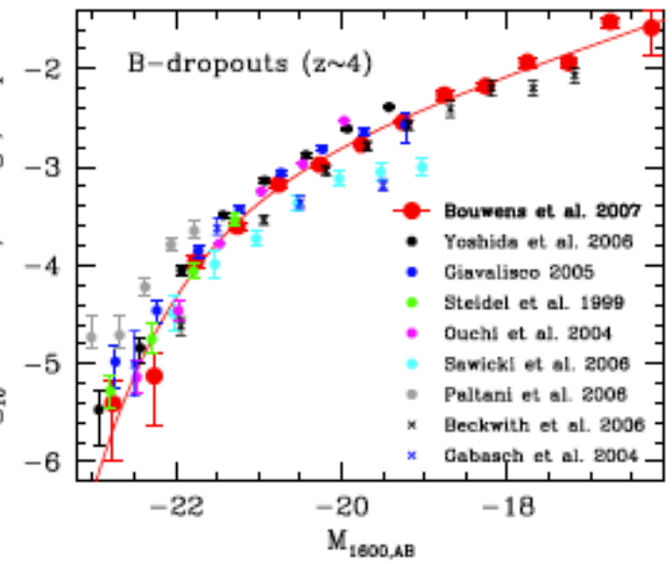
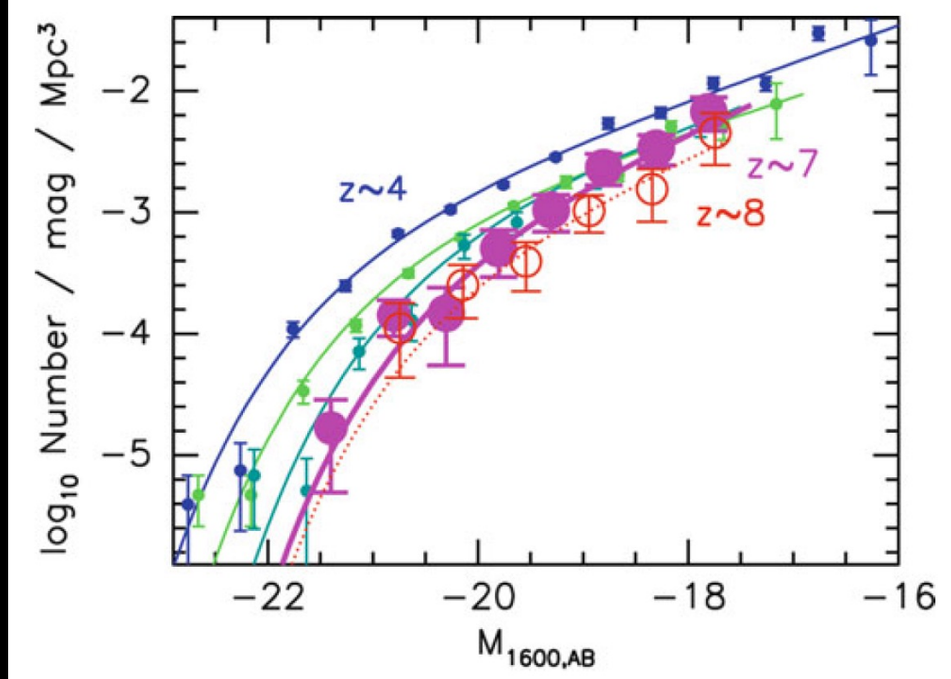
High-redshift galaxies — observational facts

UV luminosity functions





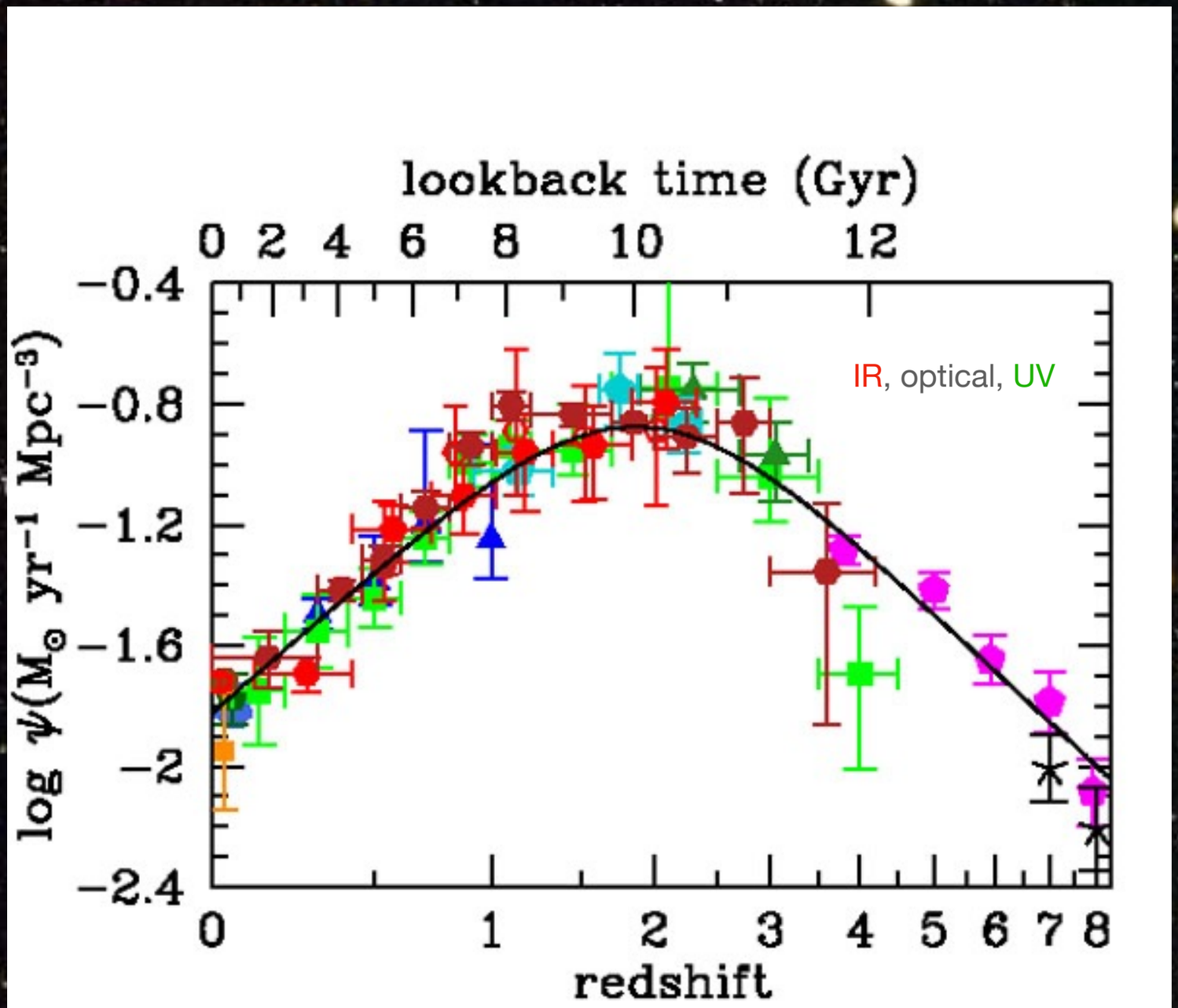




High-redshift galaxies — observational facts

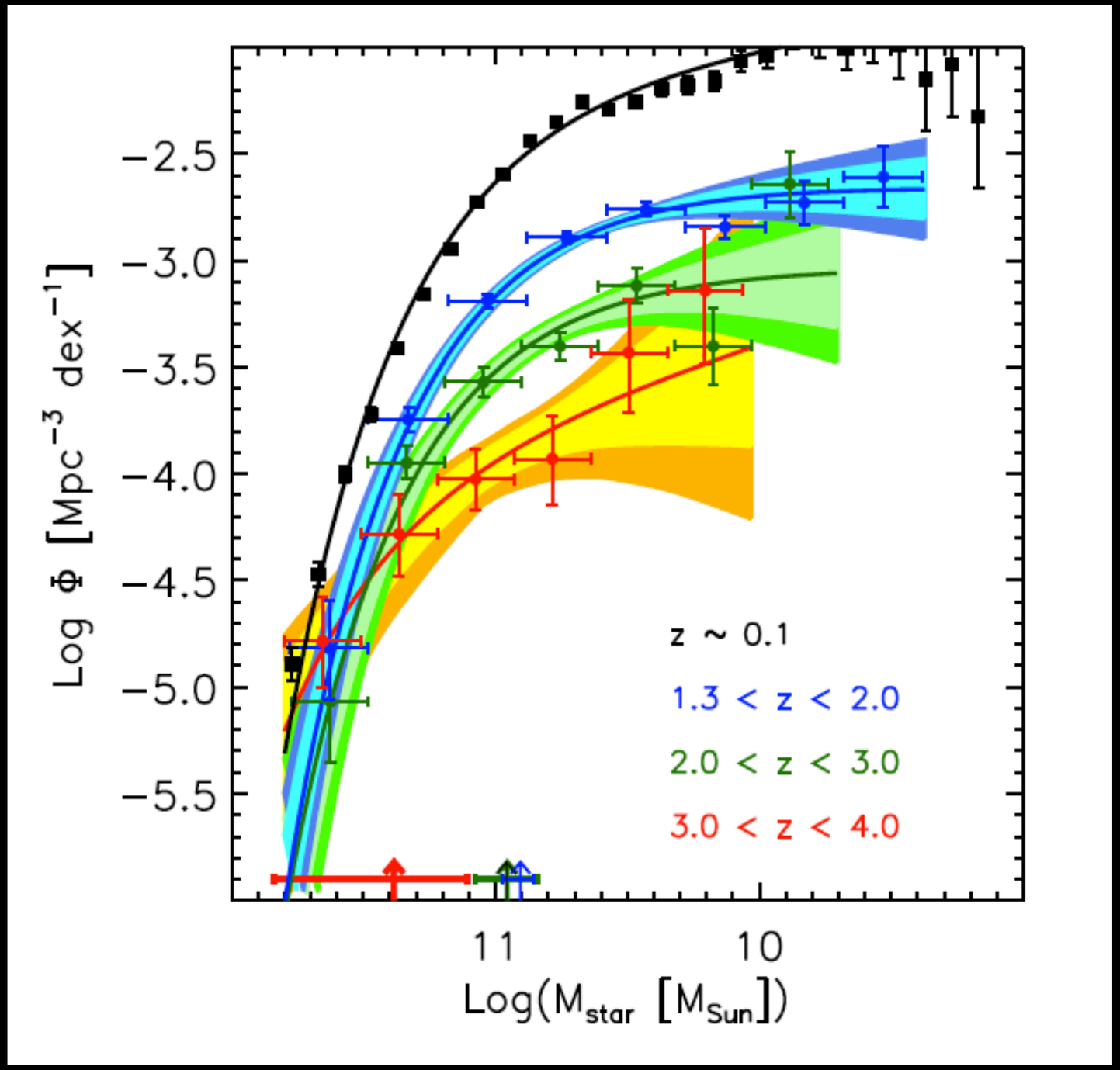
the cosmic star formation history of the universe

"Madau"-Plot



High-redshift galaxies — observational facts

STELLAR MASS DOWNSIZING

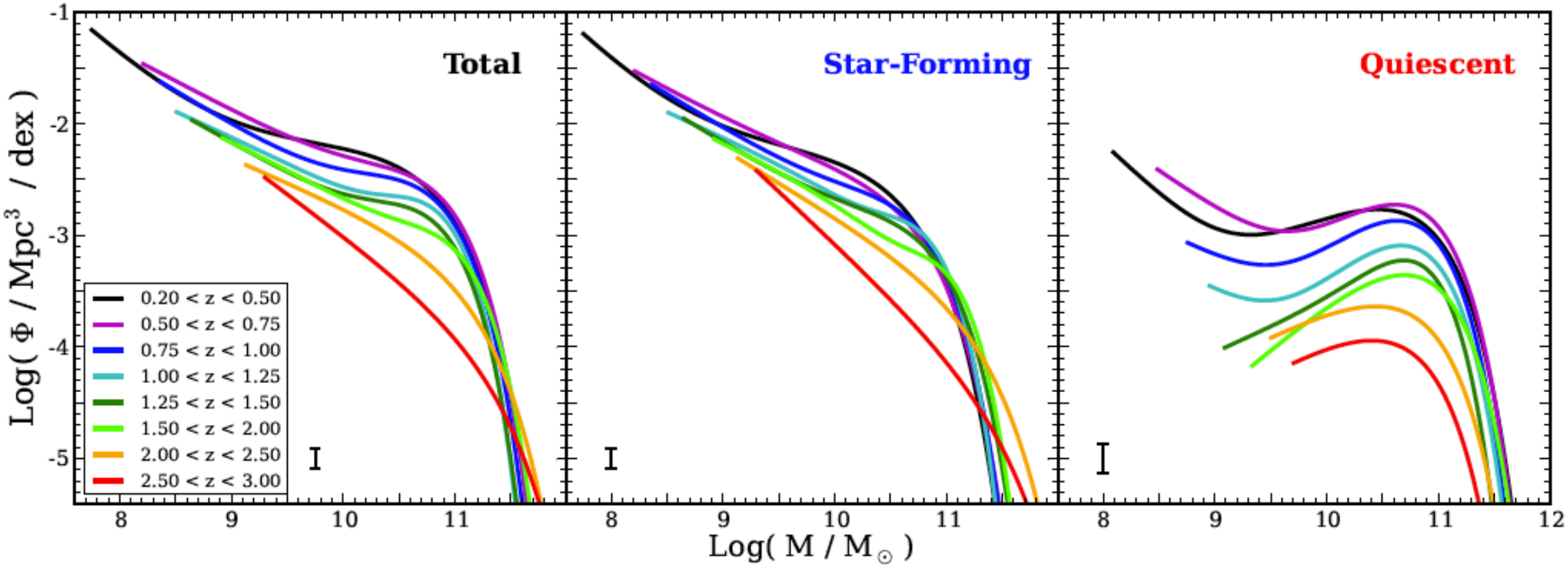


less evolution on high-mass end of stellar MF (at least since z~2)

Marchesini et al. 2009

High-redshift galaxies — observational facts

galaxy demographics & quenching



the number density of massive galaxies is building up over time

number/mass in SF galaxies increases little or not at all

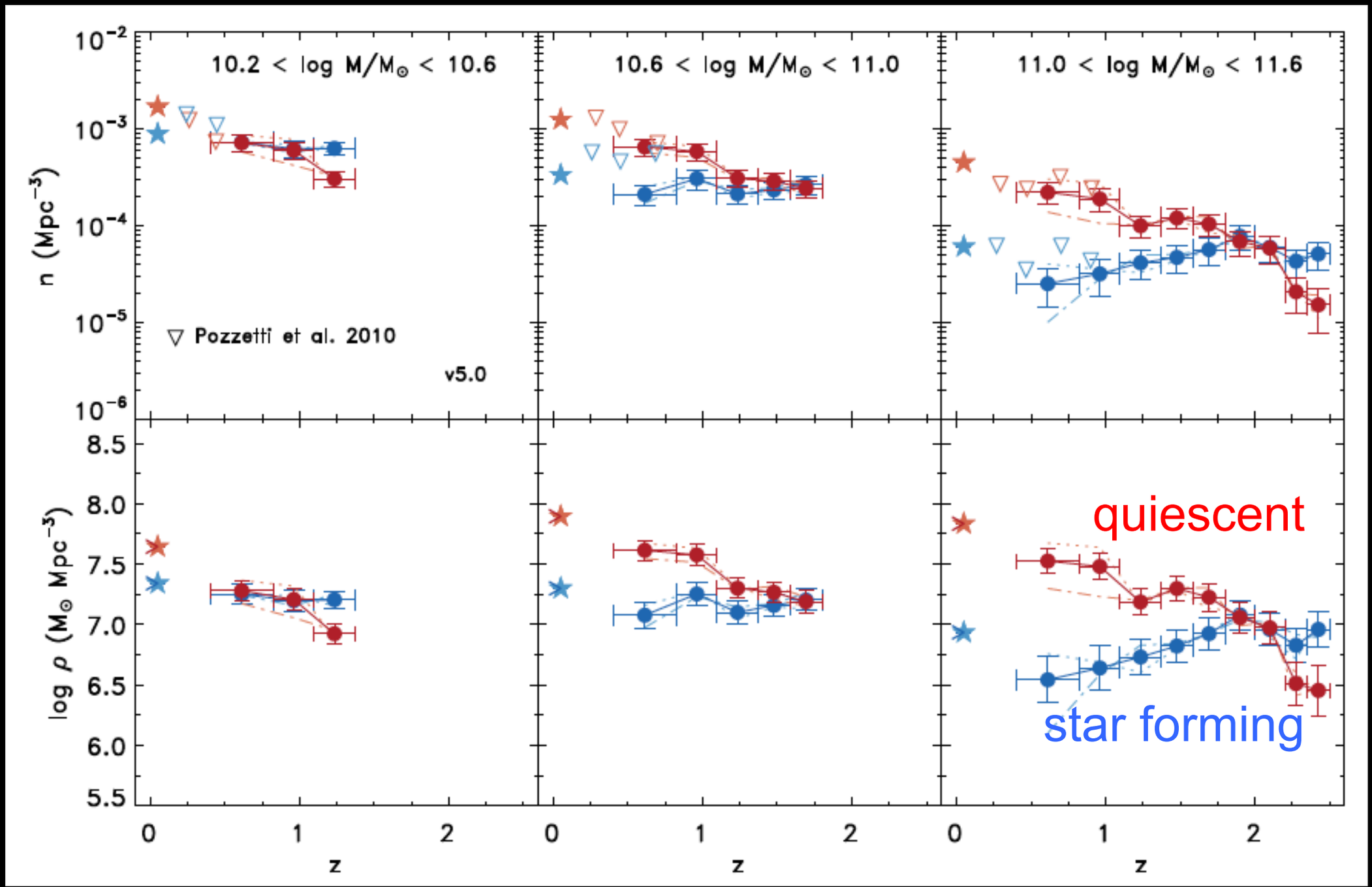
number/mass of quiescent galaxies increases rapidly

Tomczak et al. 2014 zFOURGE

→*implies SF galaxies are being transformed into quiescent galaxies (quenching)*

High-redshift galaxies — observational facts

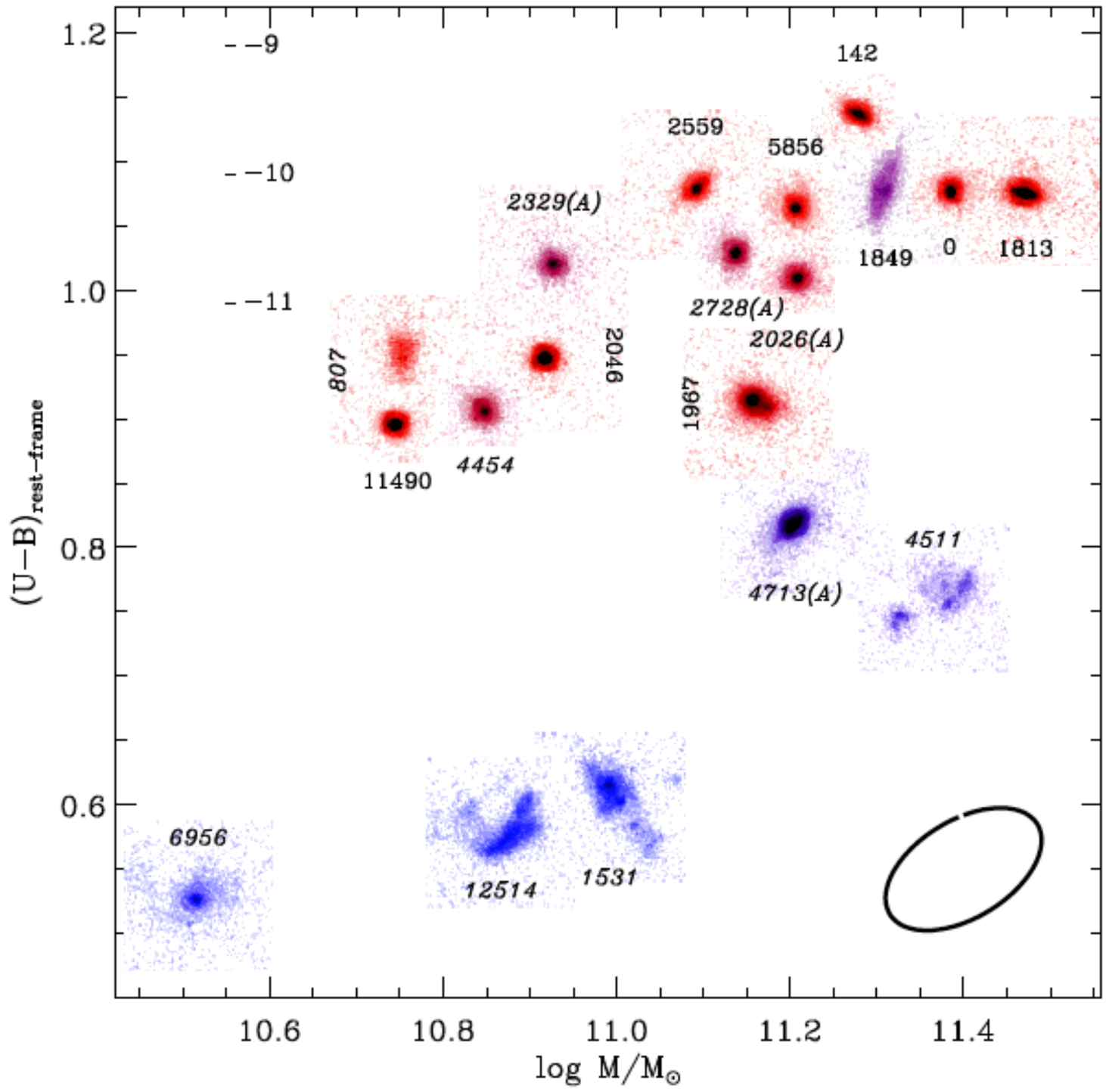
build-up of quiescent (red) galaxies over time…

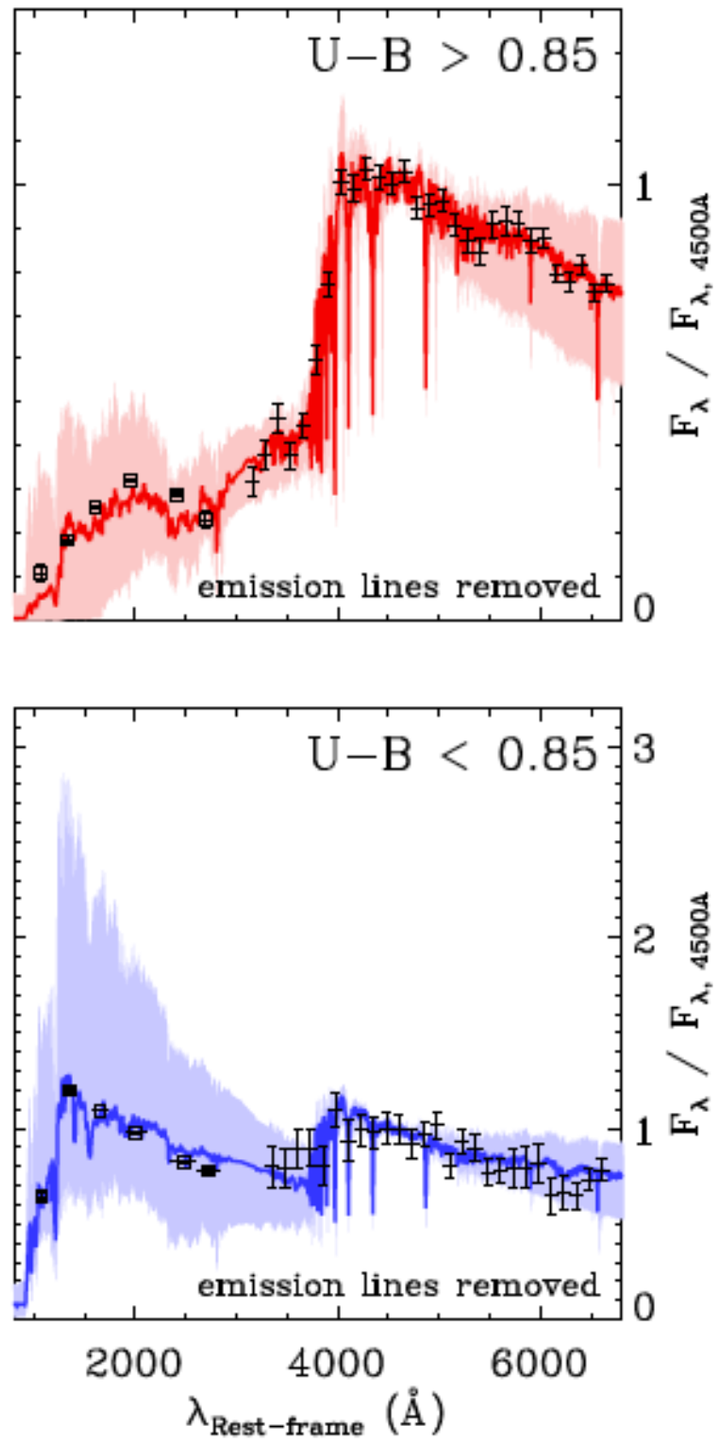


Brammer et al. 2011

High-redshift galaxies — observational facts

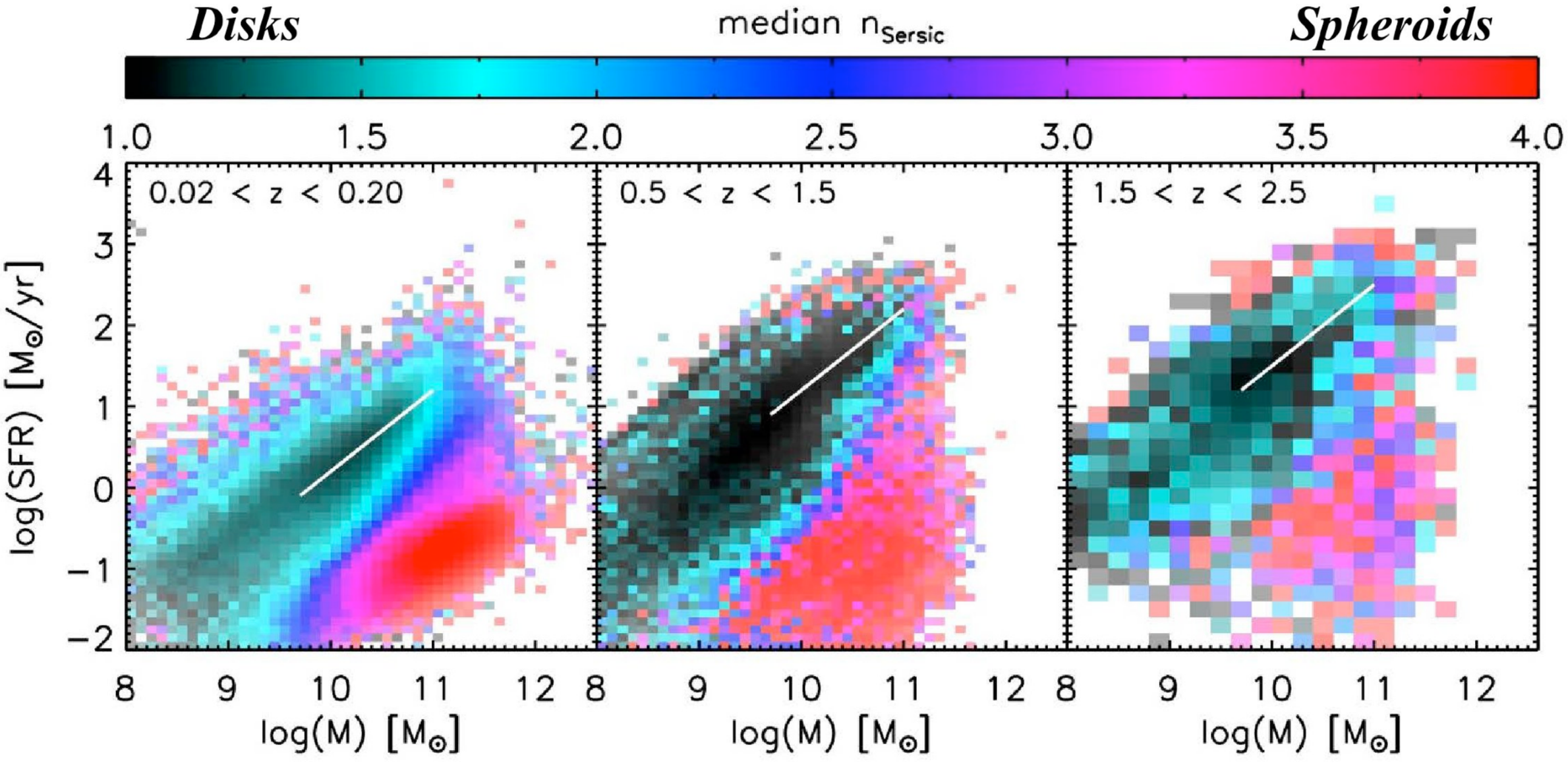
the same qualitative correlation between morphology, color and stellar populations still holds at z~2





Galaxies — Scaling relations

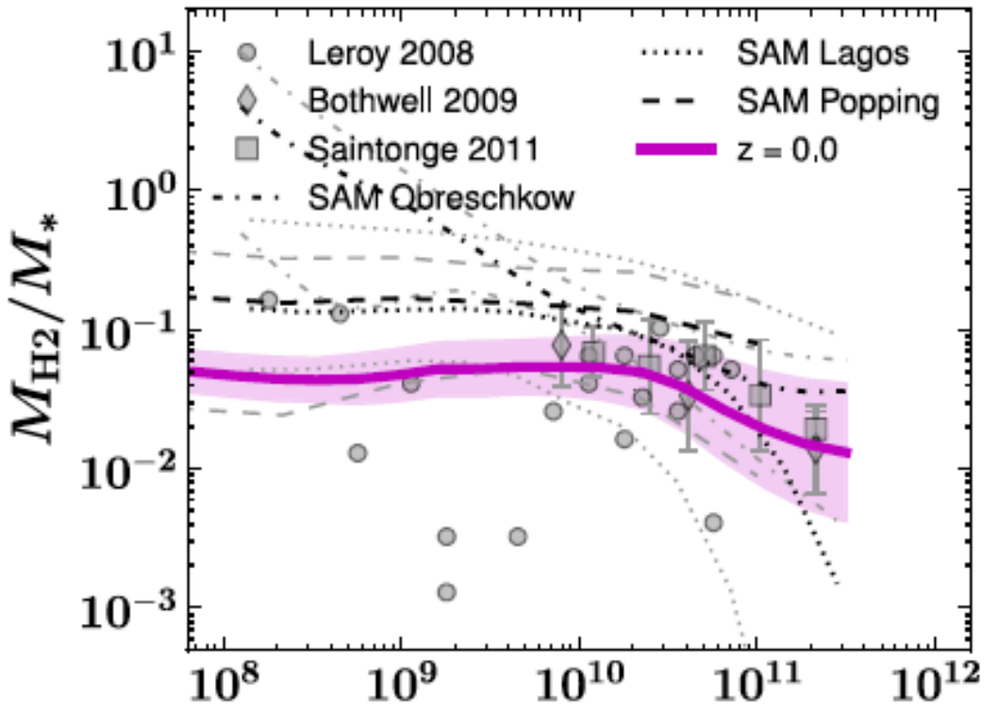
Star-forming main sequence

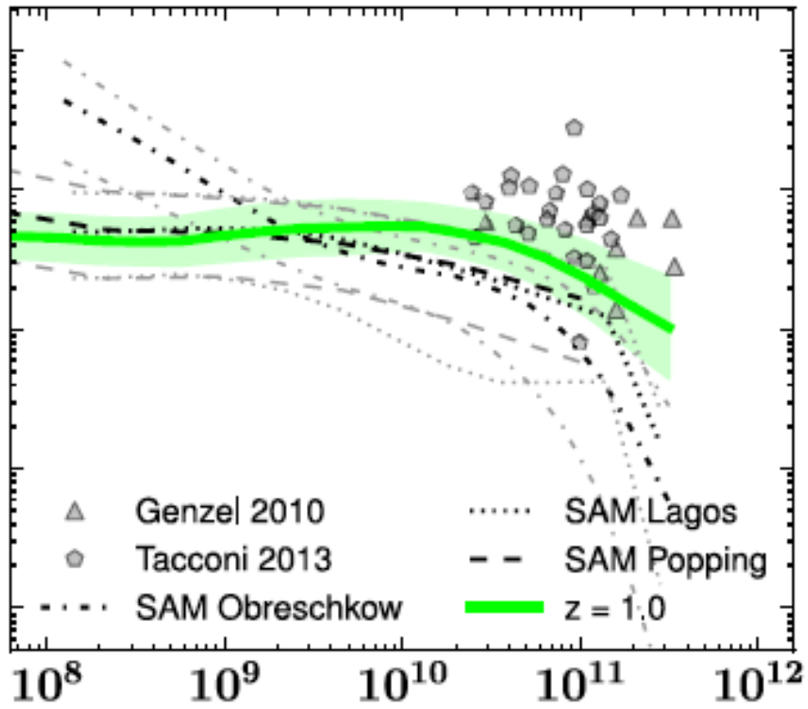


- For star-forming (disk-like) galaxies: the more massive the higher the SFRs
- Spheroids/Early-types primarily quiescent
- Persists out to higher redshift but with different normalisation

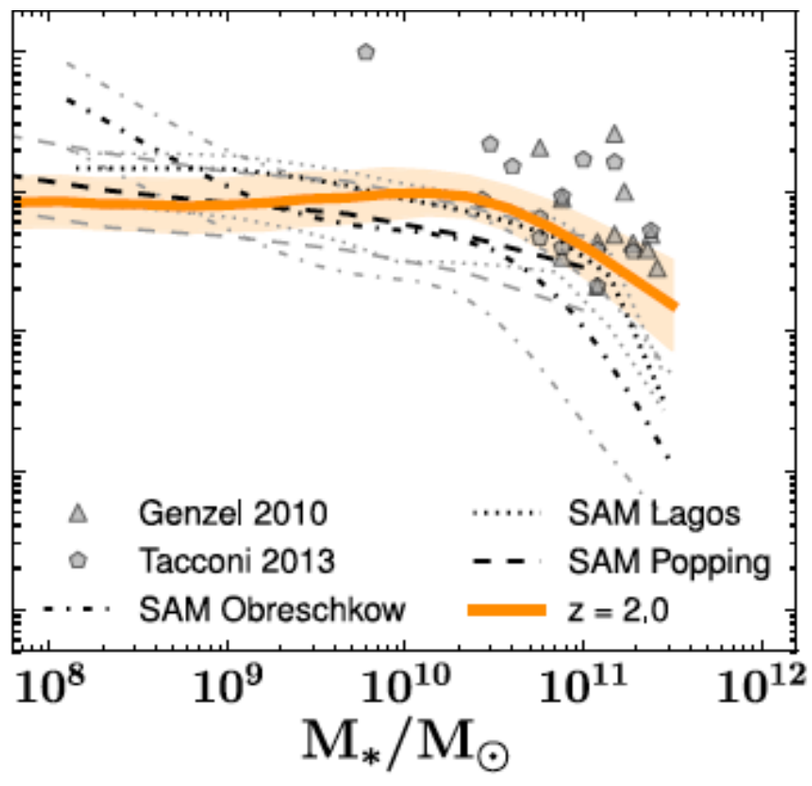
Galaxies — Scaling relations

Evolution of H2 gas fractions



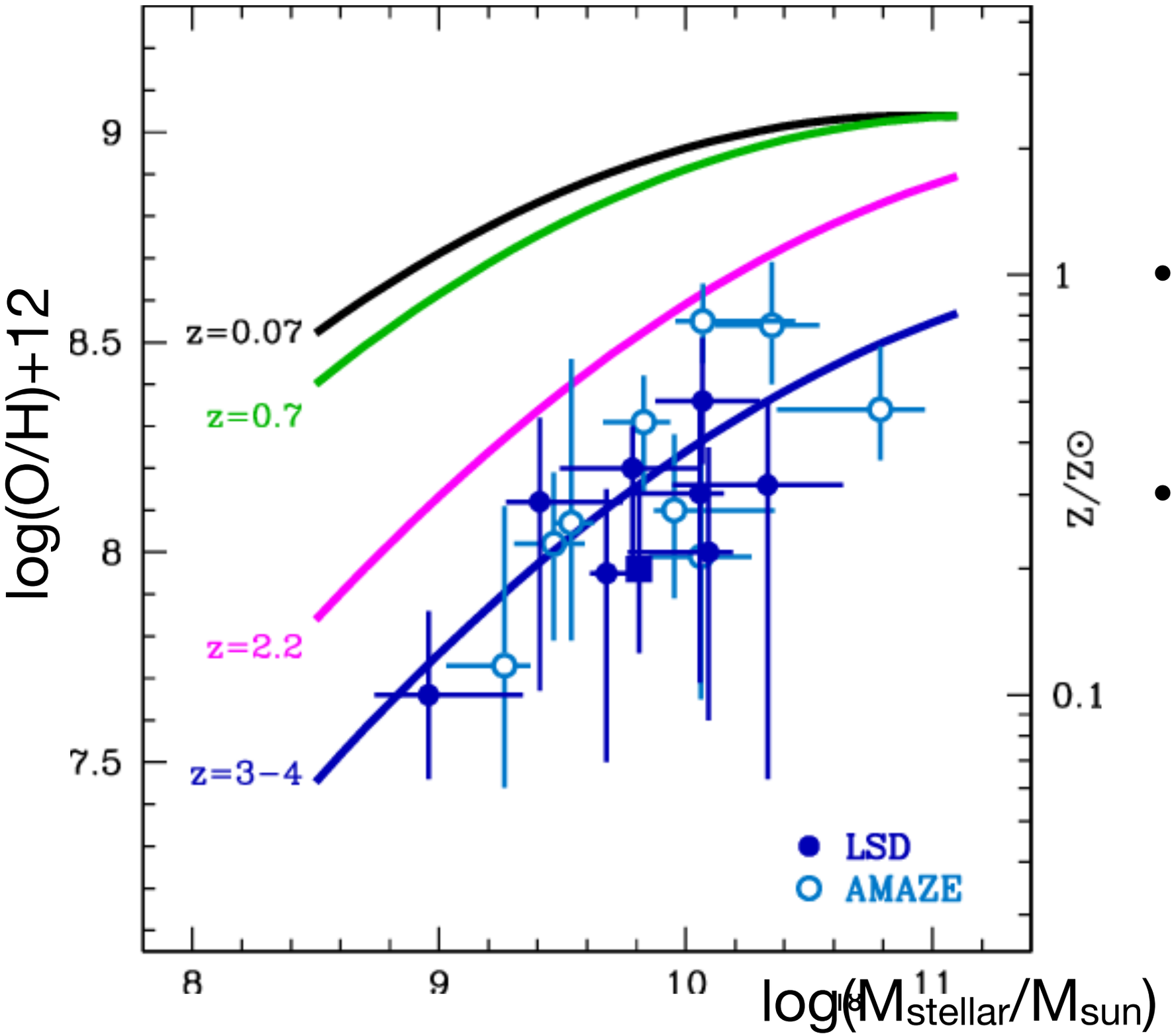


- Evolution of molecular gas fractions
- Higher-z galaxies are more gas-rich



Galaxies — Scaling relations

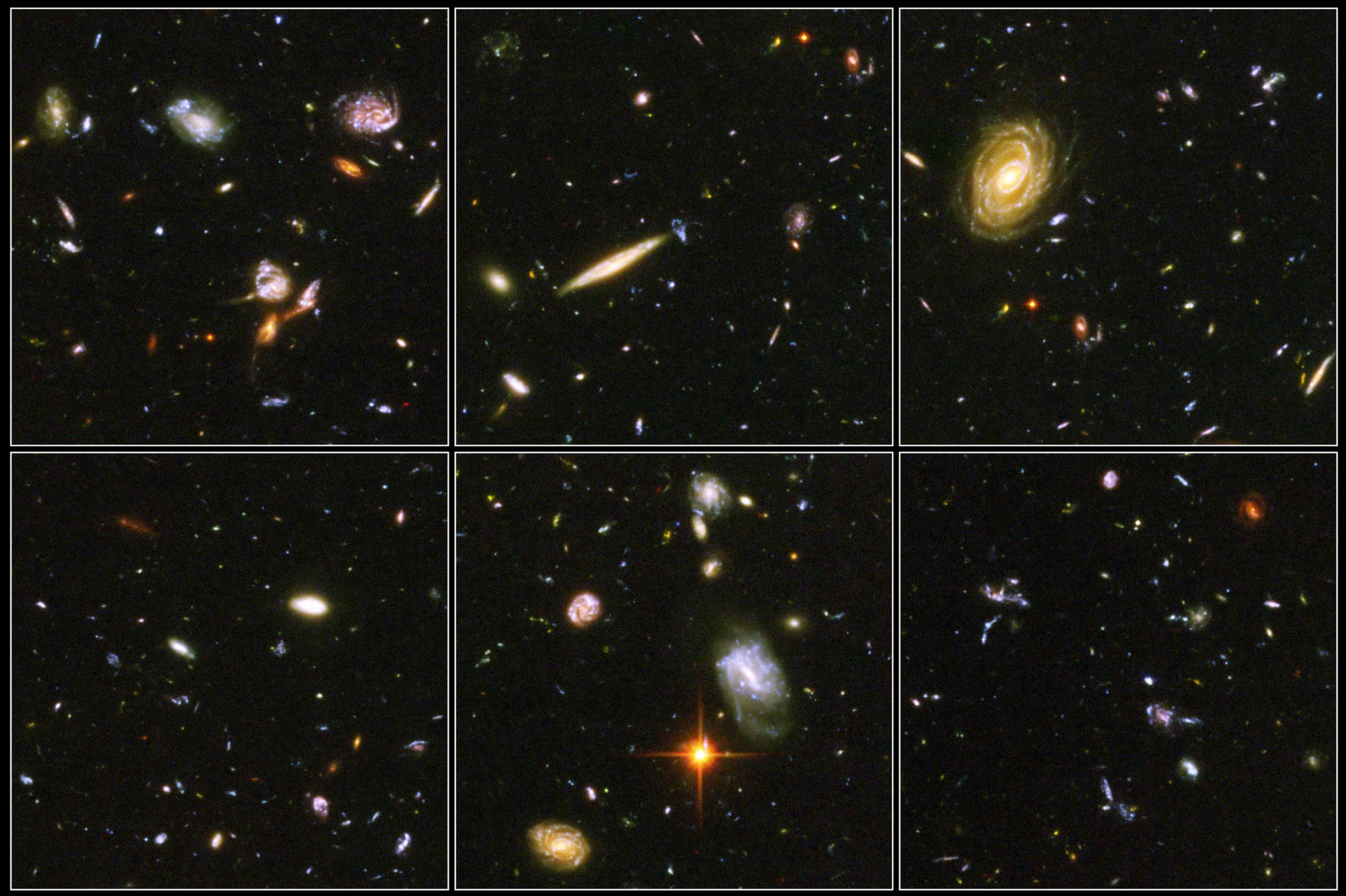
Mass-metallicity relation



- Mass-metallicity relation in place as early as z~4 (and likely before)
- Evolution over time, high-z galaxies are more metal-poor at given stellar mass compared to later epochs

High-redshift galaxies — observational facts

galaxy structure and morphology at high redshift



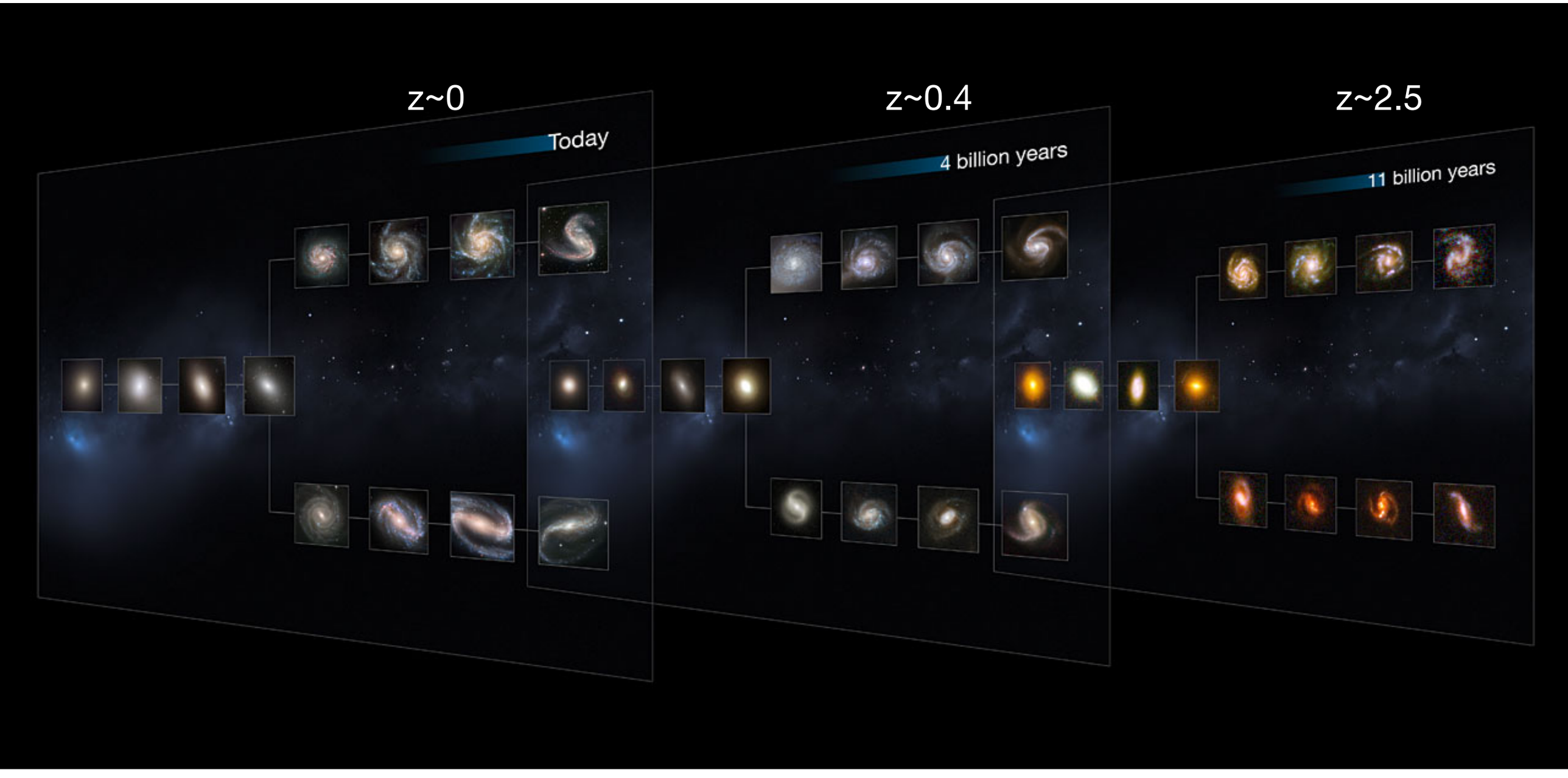
Hubble Ultra Deep Field Details
Hubble Space Telescope • Advanced Camera for Surveys

NASA, ESA, S. Beckwith (STScI) and the HUDF Team

STScI-PRC04-07c

High-redshift galaxies — observational facts

Evolution of the Hubble sequence

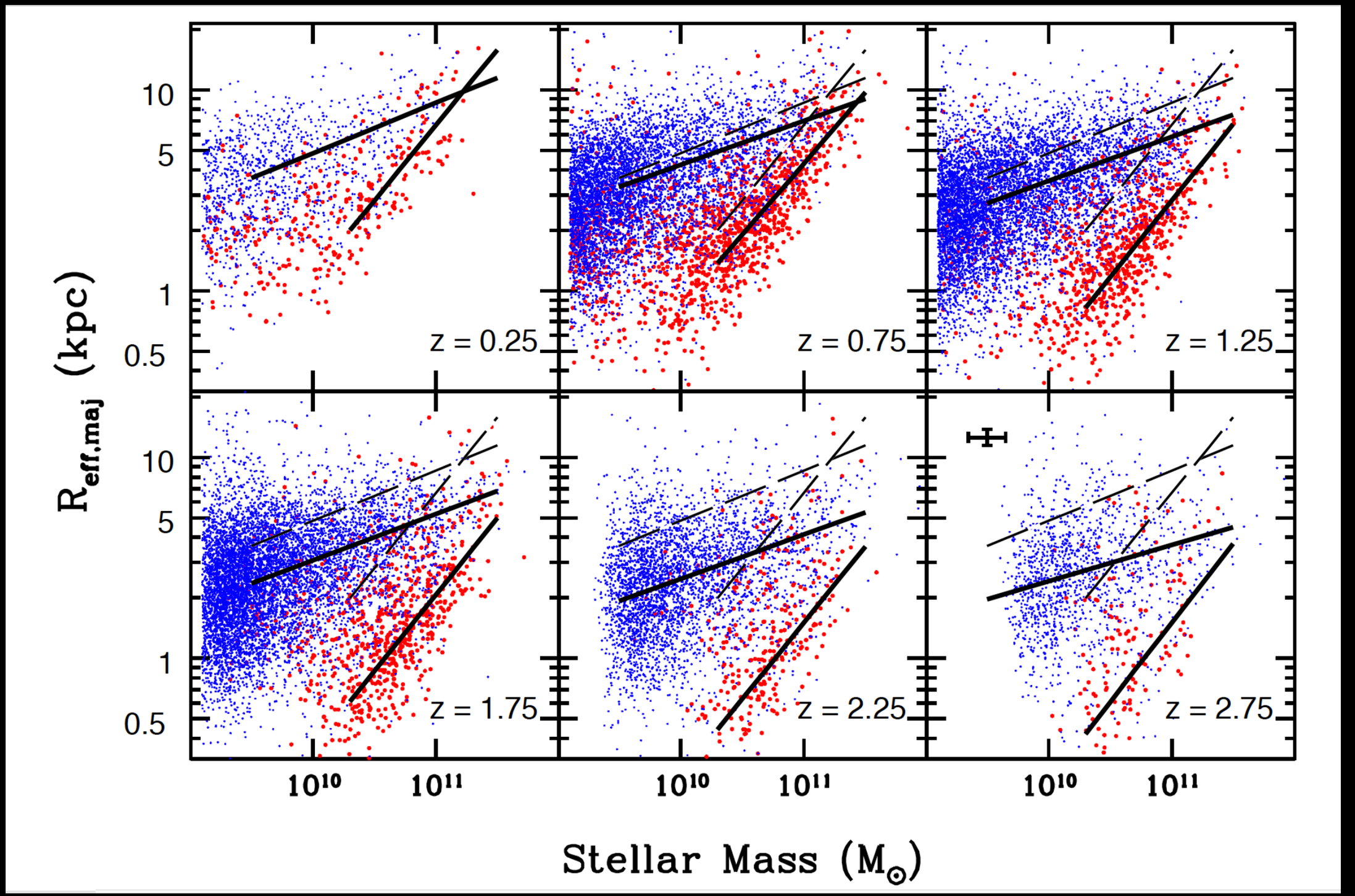


The Hubble sequence

- —gradually builds up over cosmic time, with high-z morphologies being very different
- —as we know it from the local Universe, has been in place roughly since z~1

High-redshift galaxies — observational facts

size mass relation evolution for star forming and quiescent galaxies



van der Wel et al. 2014

High-redshift galaxies — observational facts

Summary

- SFR densities increase to z~2 and decrease down to z~0
- Galaxies seem to build up in an anti-hierarchical fashion, massive galaxies are in place early-on
- Population of quiescent (red and dead) massive galaxies has grown over time, while the number of SF galaxies remained constant (or declined) —> transformation
- High-z galaxies bluer, more luminous, and more SF
- High-z galaxies also more gas rich and more metal-poor
- Many scaling relations in place at higher redshift
- Galaxies were smaller/more compact in the past (both disk and spheroids)
- Galaxies were more morphologically irregular and clumpy in the past

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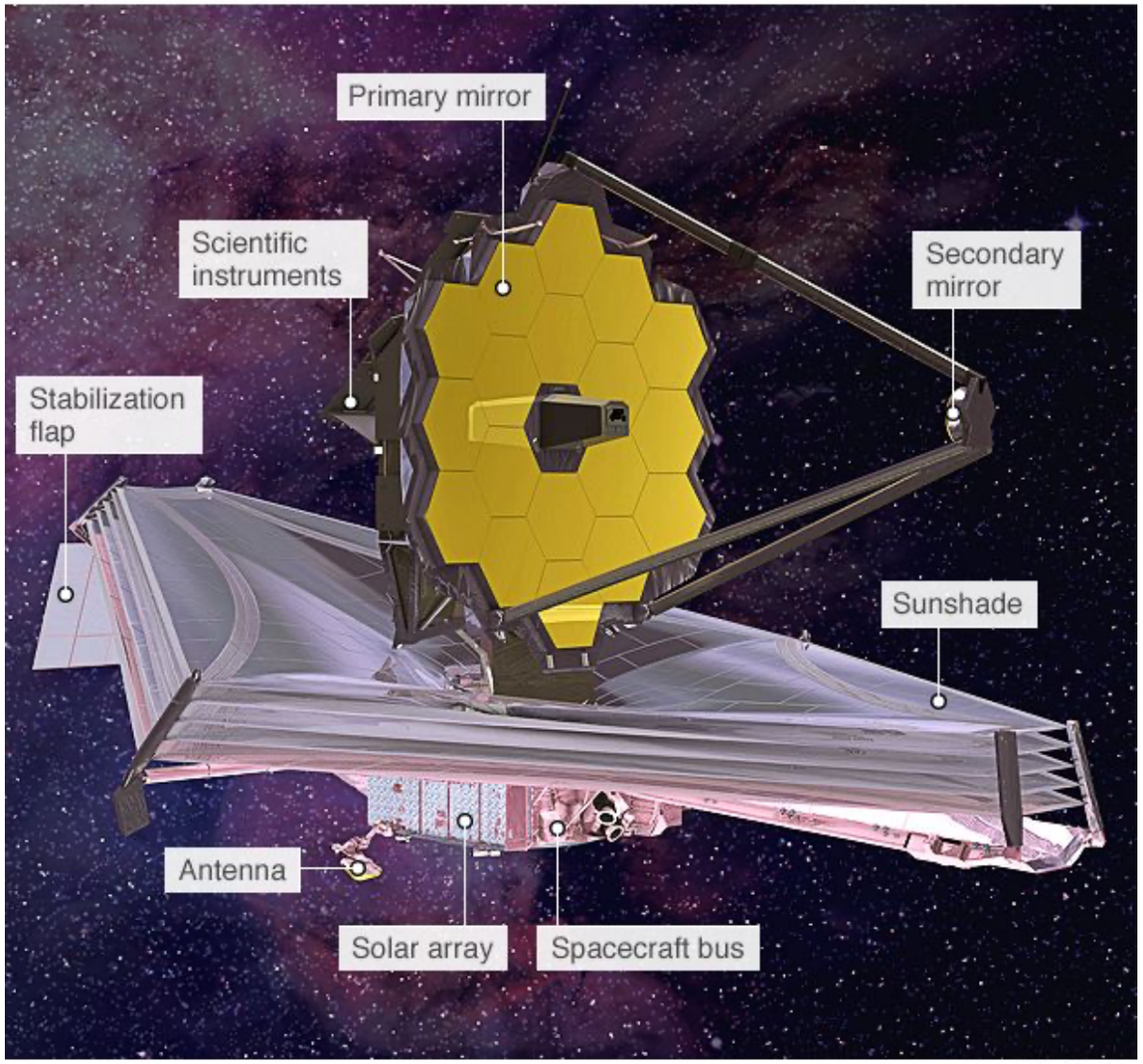
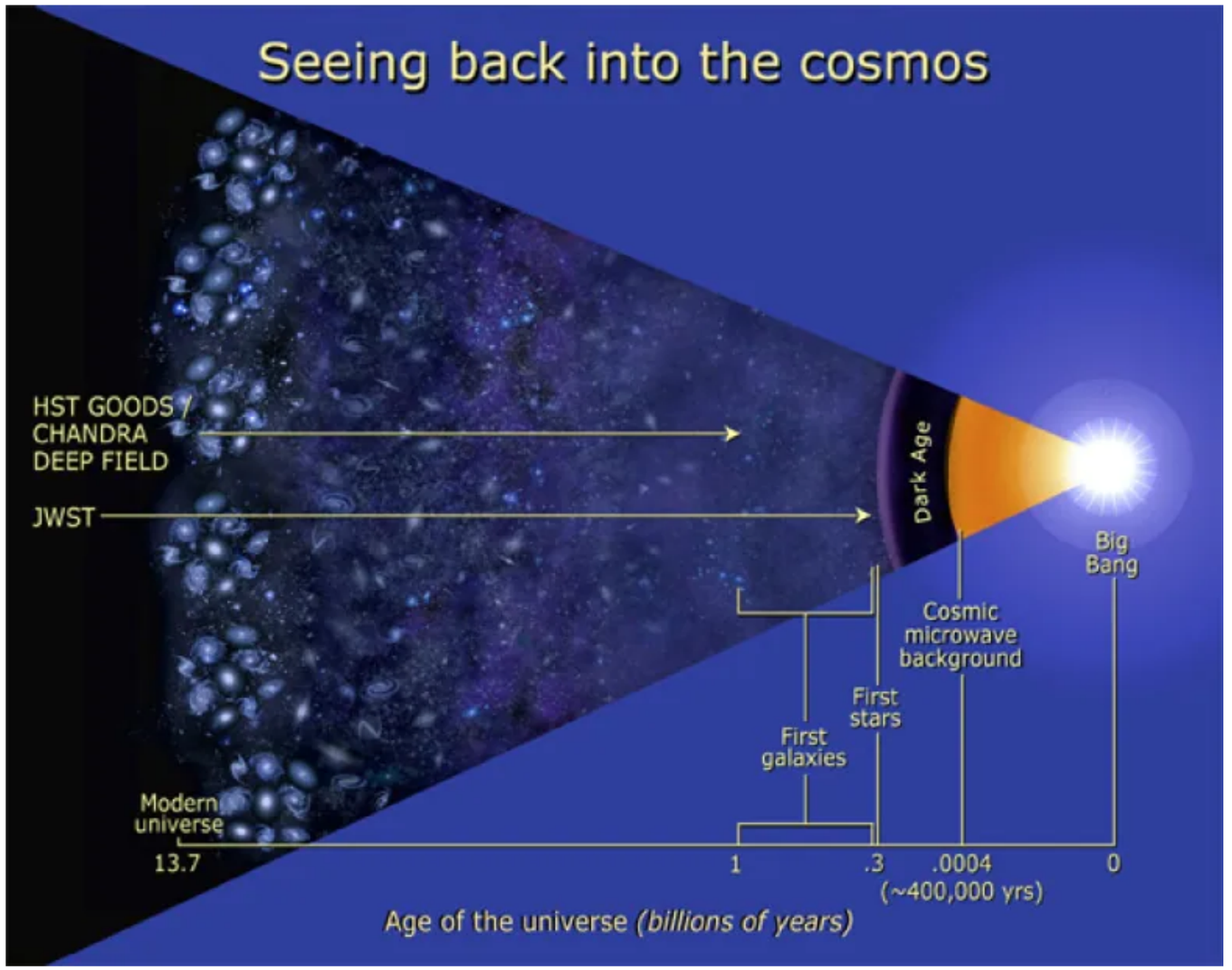
High-redshift galaxies — News from JWST

The James Webb Space Telescope — a revolutionary new era for observing most distant galaxies!



Source: NASA BBC

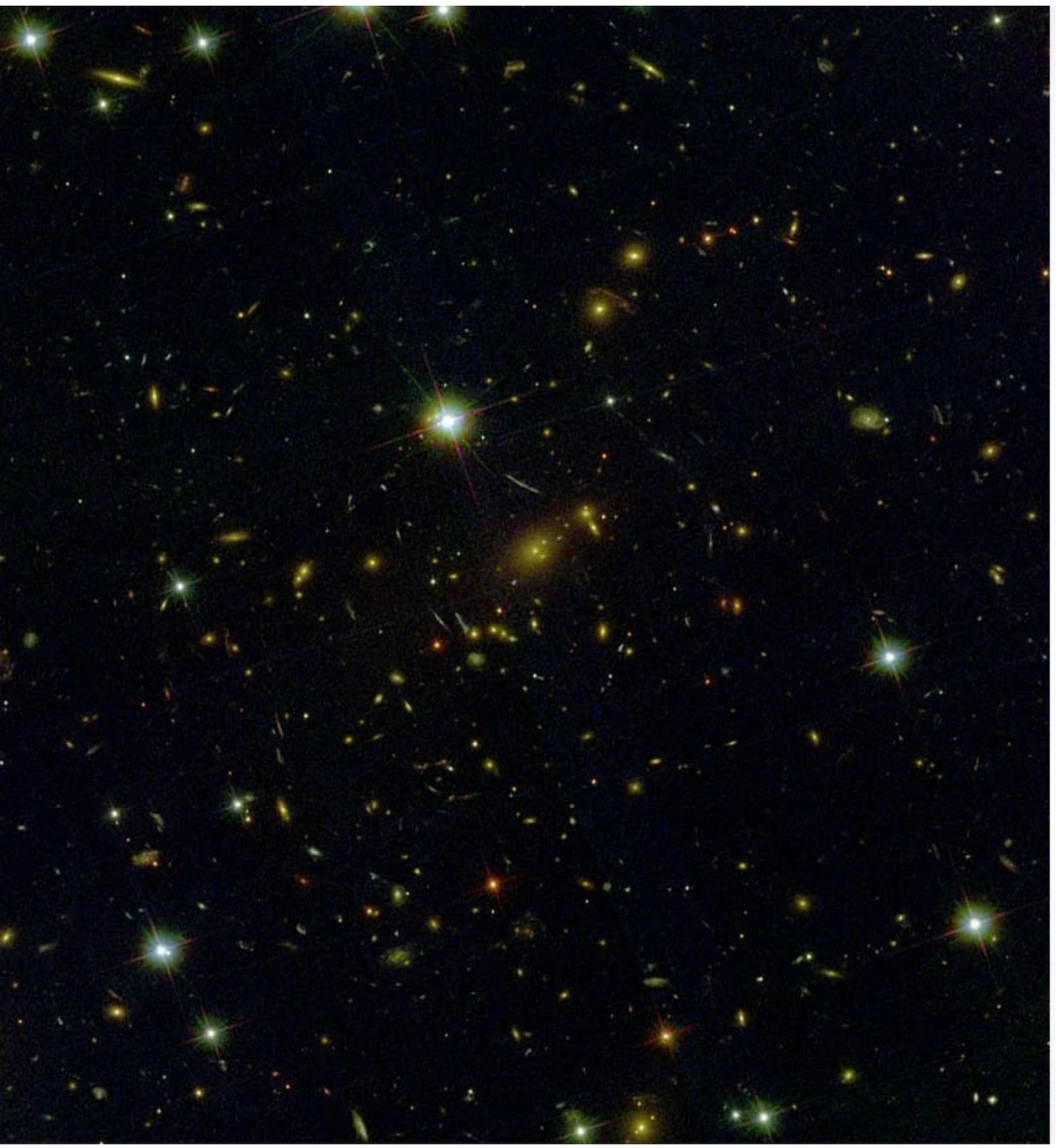


Higher sensitivity than before + NIR Camera & Spectrograph + 6.5m mirror

—> faintest, most distant galaxies, for the first time with spectra!

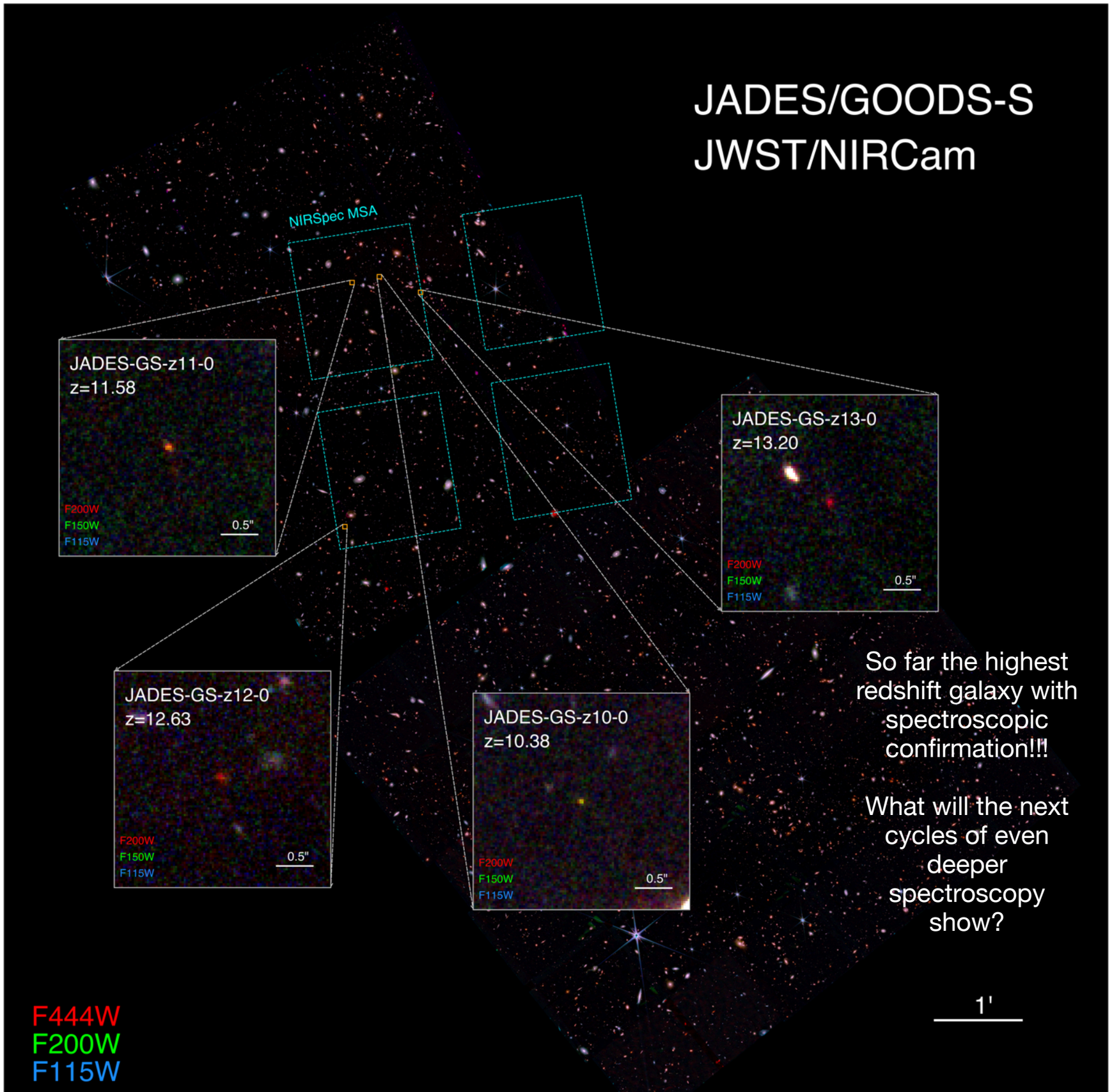
High-redshift galaxies — News from JWST

Which image was observed with HST and JWST?



A new era for extragalactic astronomy!!

High-redshift galaxies — News from JWST

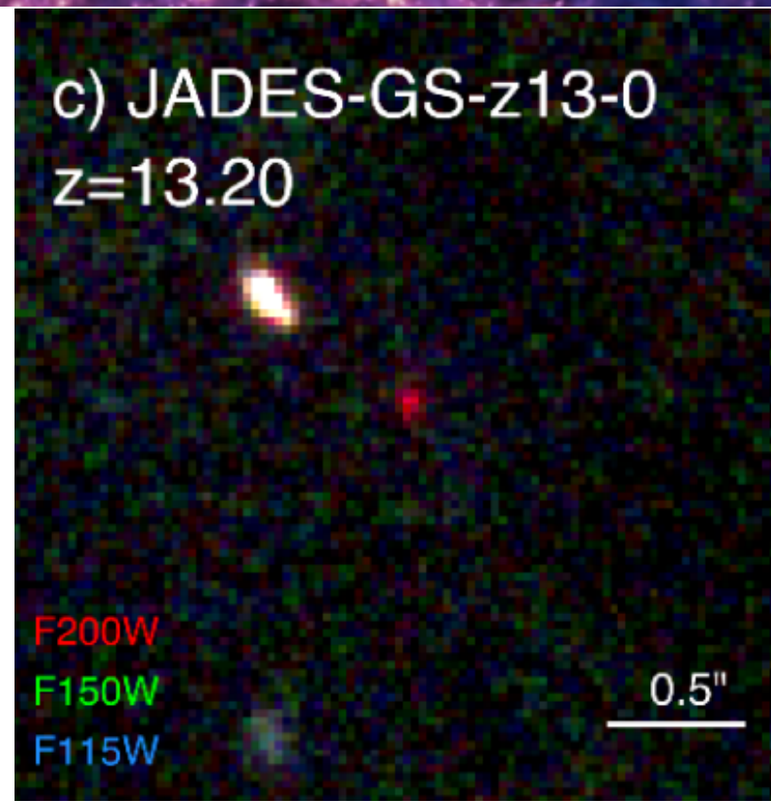


High-redshift galaxies — News from JWST

Main discoveries so far

- Highest-redshift galaxies discovered out to almost z~14 (pre-JWST: z~10)

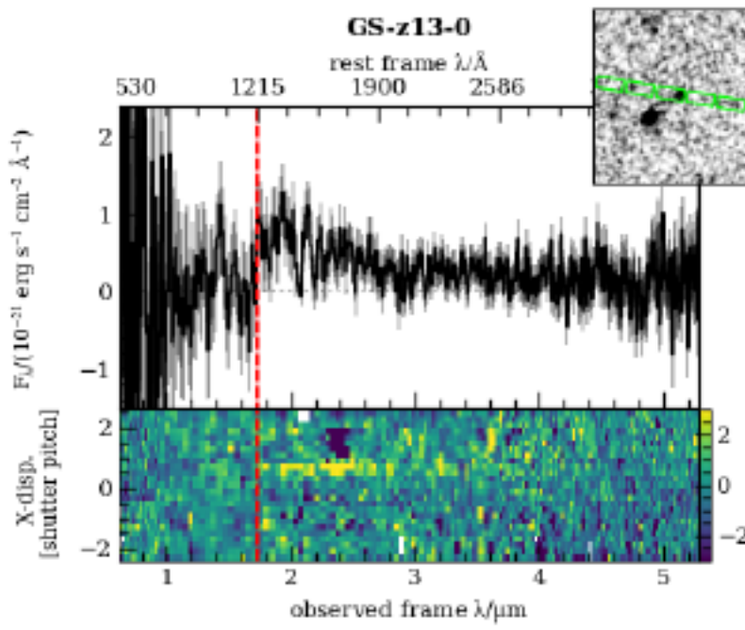
- Highest-redshift galaxy spectrum detected at z~13.2, allowing to study details as the metallicity of the gas (pre-JWST: z~7)



- These z>10 galaxies turn out to be brighter and more massive than expected, challenging current models of galaxy formation

- Faint, low-mass AGN turn out to ubiquitously exist at earliest epochs (highest z AGN at z~10.6)

—> Contain unique information on BH seeding and growth!



Just the start — many discoveries still to come!

Why modelling galaxy formation?

Why an interpretative theoretical framework ?

- How do the first galaxies form and evolve?
- What is the origin of the huge observed diversity of galaxies, different scaling relations and statistical properties?
- Which are the key physical mechanisms for their emergence?

HOW CAN WE ACHIEVE THAT?

- Theoretically, since structure formation is dominated by gravity, in the early U., start from Newtonian, linear perturbation theory within a given cosmology, but break-down for over-densities larger than one
- This complexity and physical, baryonic processes related to galaxy formation cannot be captured by pure analytic calculations, instead use COSMOLOGICAL NUMERICAL SIMULATIONS/GALAXY EVOLUTION MODELS

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