5. Simulations at the dwarf scale: from violent dwarfs at cosmic dawn and cosmic noon to quiet discs today

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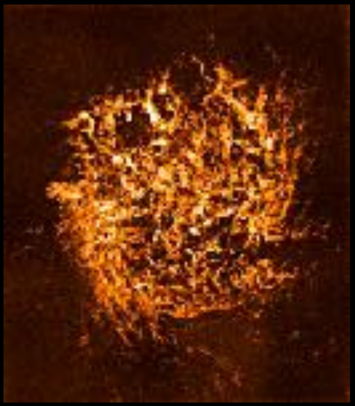
The Universe as a time machine: focusing on dwarfs

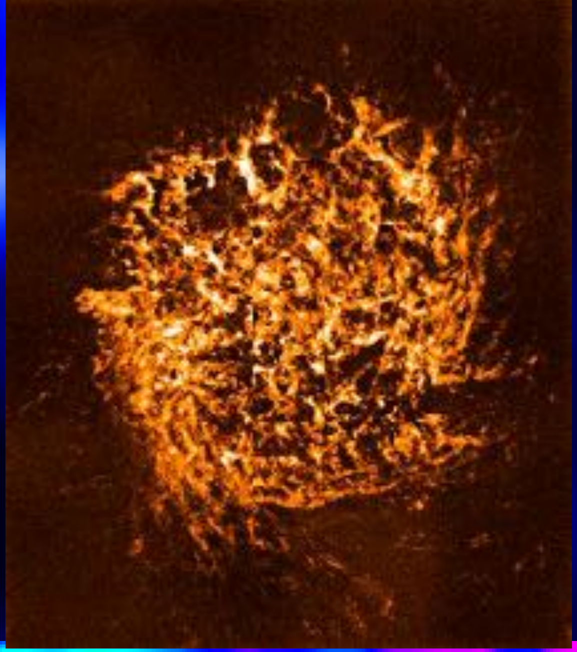
- The LMC scale (M_S=a few 10^9 $M_\odot$) at three different z
- z=0: AGORA (Ceverino et al. 2017b)
- z=2: VELA (Ceverino, Primack & Dekel 2015)
- z=6: FirstLight: Simulations of galaxy formation during cosmic dawn (Ceverino, Glover & Klessen 2016; Ceverino, Klessen & Glover 2018, 2019)
- Cosmological zoom-in simulations with the AMR code: ART (Kravtsov et al 1997, Kravtsov 2003, Ceverino & Klypin 2009, Ceverino et al. 2014)



Disc-dominated dwarfs at z=0

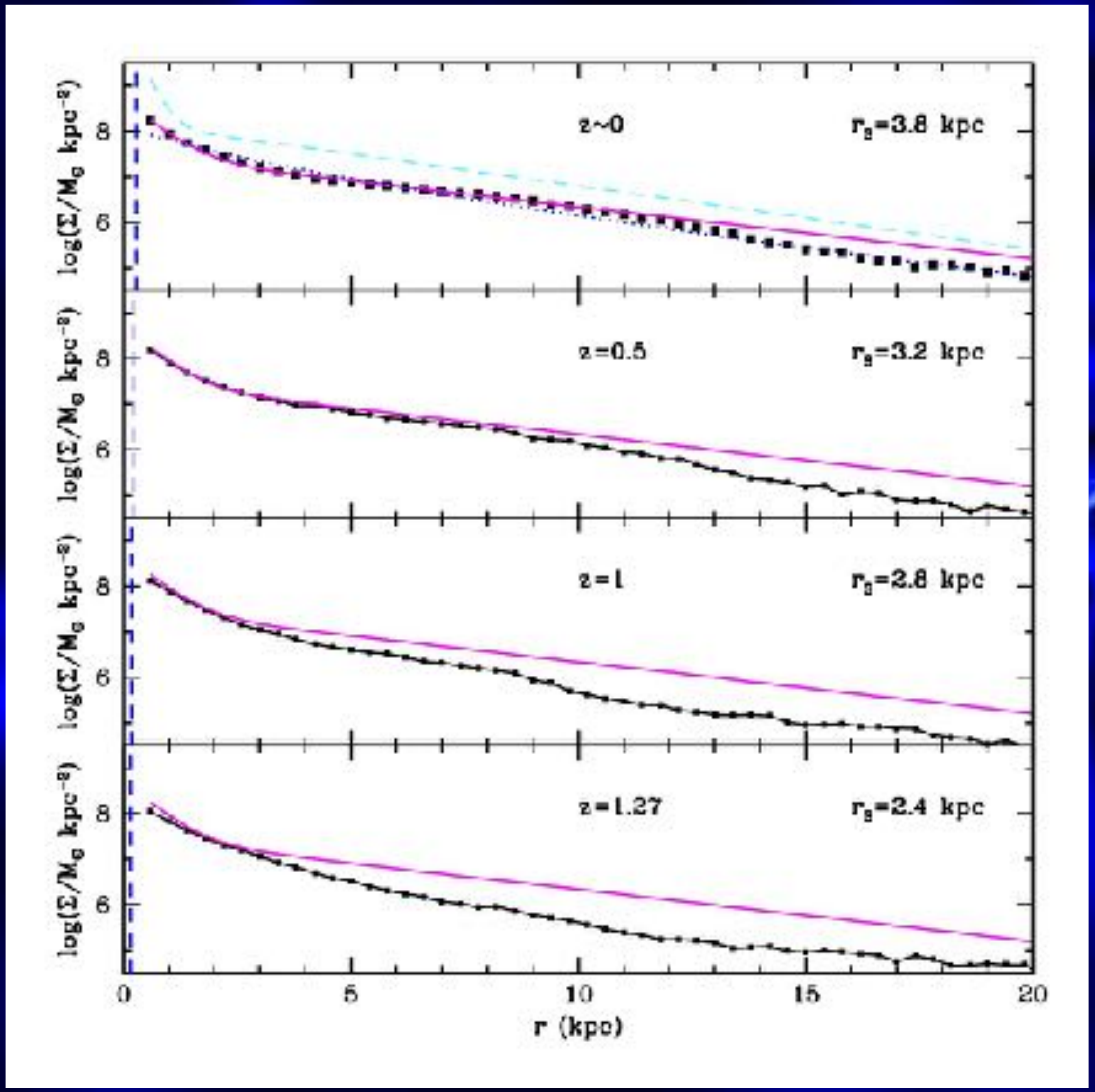
z=0	z=2	z=6
Mv=2 10^11 $M_\odot$	Mv=2 10^11 $M_\odot$	Mv= 10^11 $M_\odot$
Ms=3 10^9 $M_\odot$	Ms=10^9 $M_\odot$	Ms= 3 10^9 $M_\odot$
SFR= 0.2 $M_\odot$ /yr	SFR= 6 $M_\odot$ /yr	SFR= 20 $M_\odot$ /yr
Re = 4 kpc	Re = 2 kpc	Re = 0.5 kpc

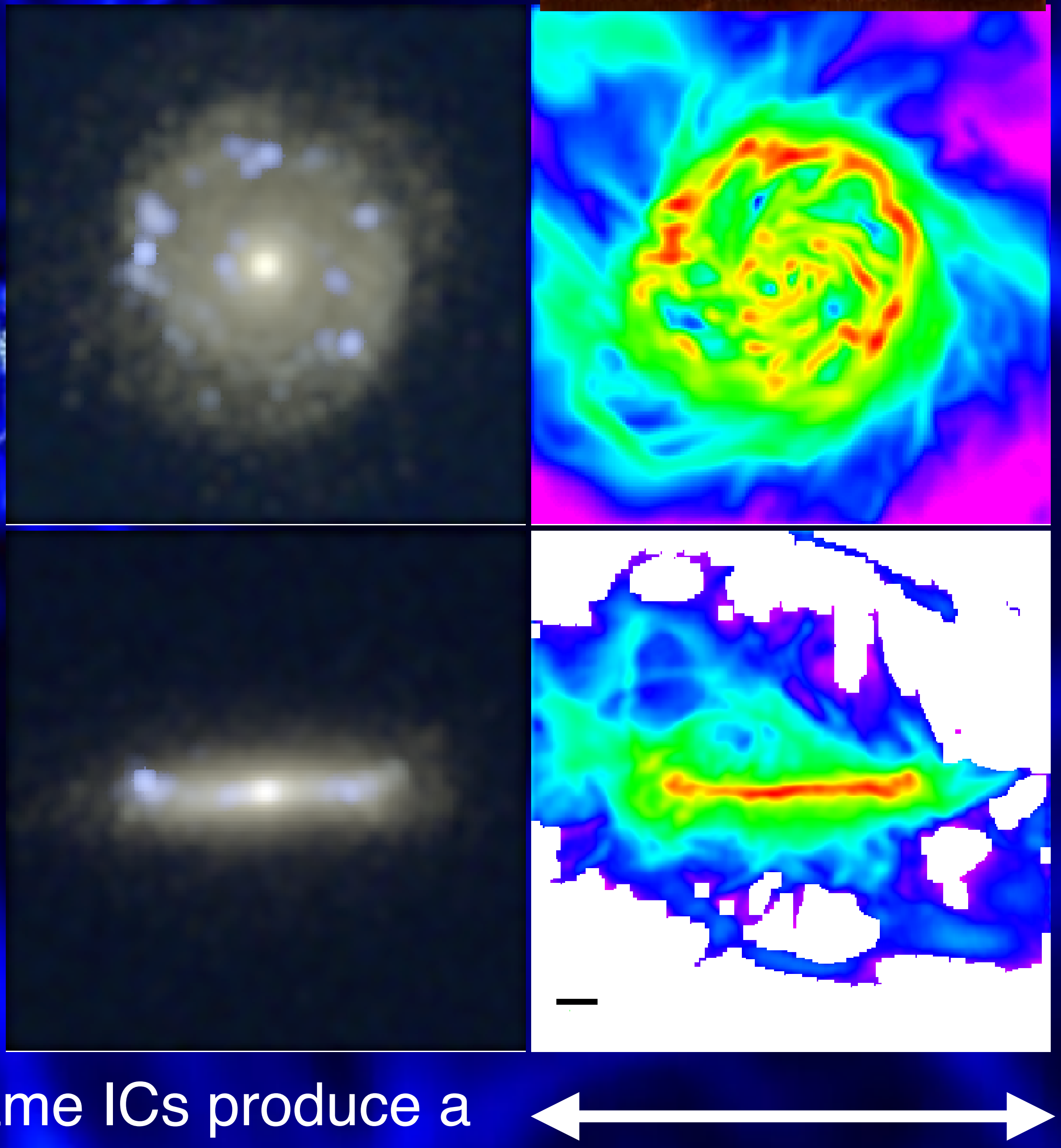
Disc-dominated galaxy



sersic n=1.4

stellar light



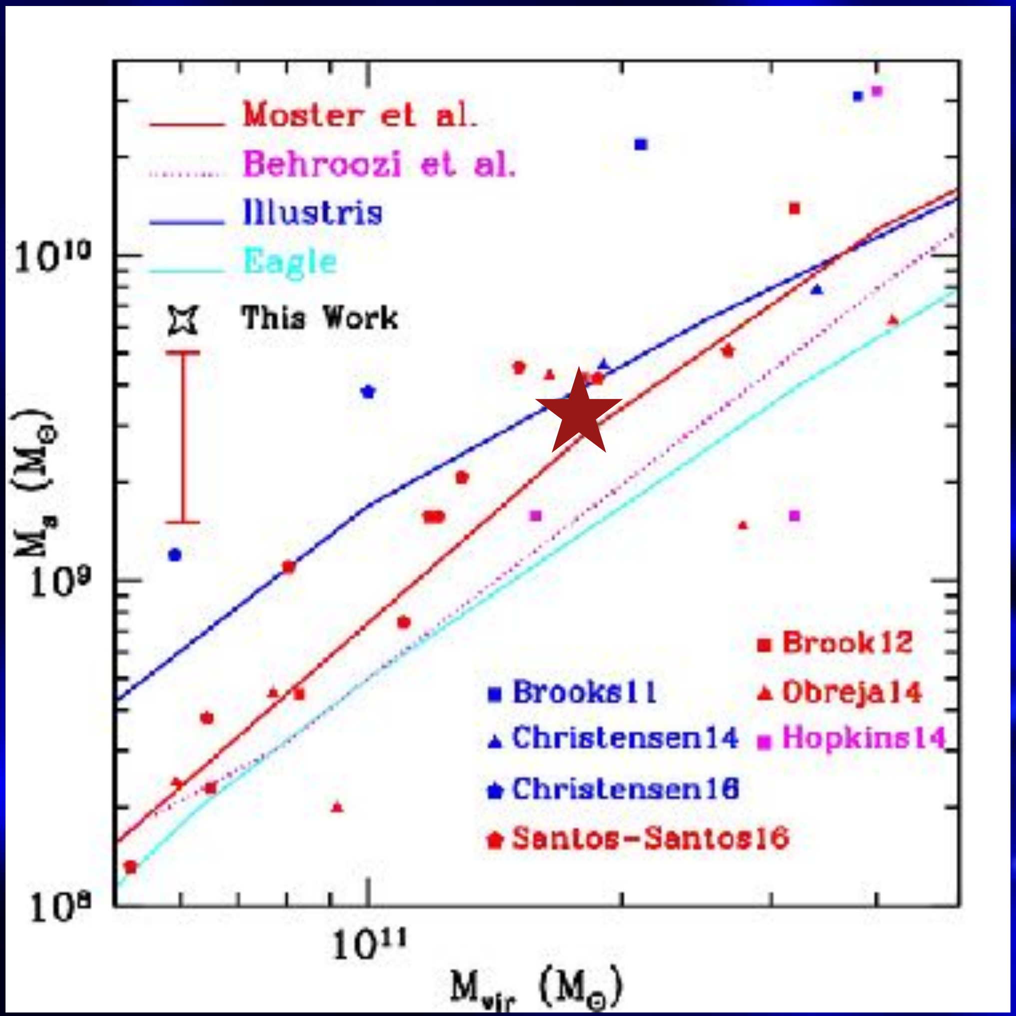


The FIRE simulations using the same ICs produce a “fluffy dwarf spheroidal” (Hopkins et al. 2014)

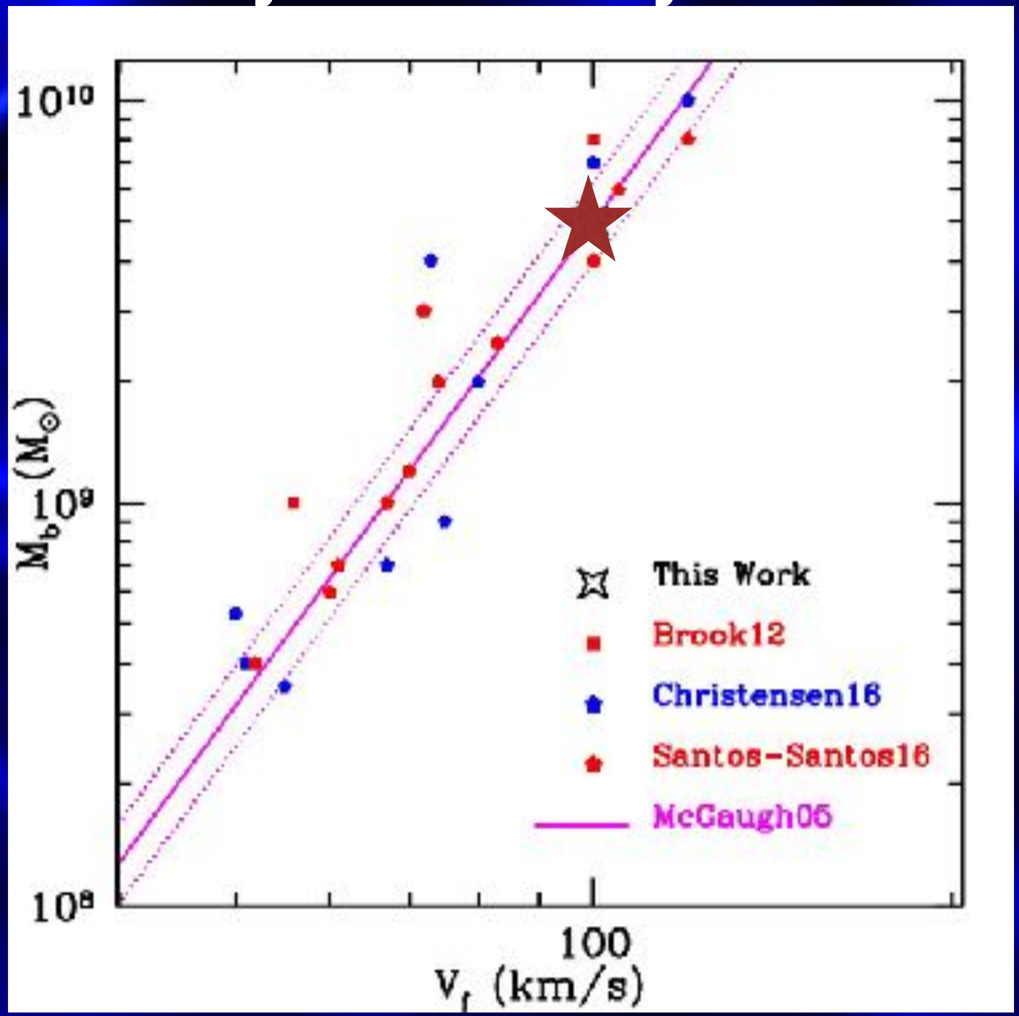
40 kpc

matching local relations

Stellar mass vs Halo mass



Baryonic Tully-Fisher



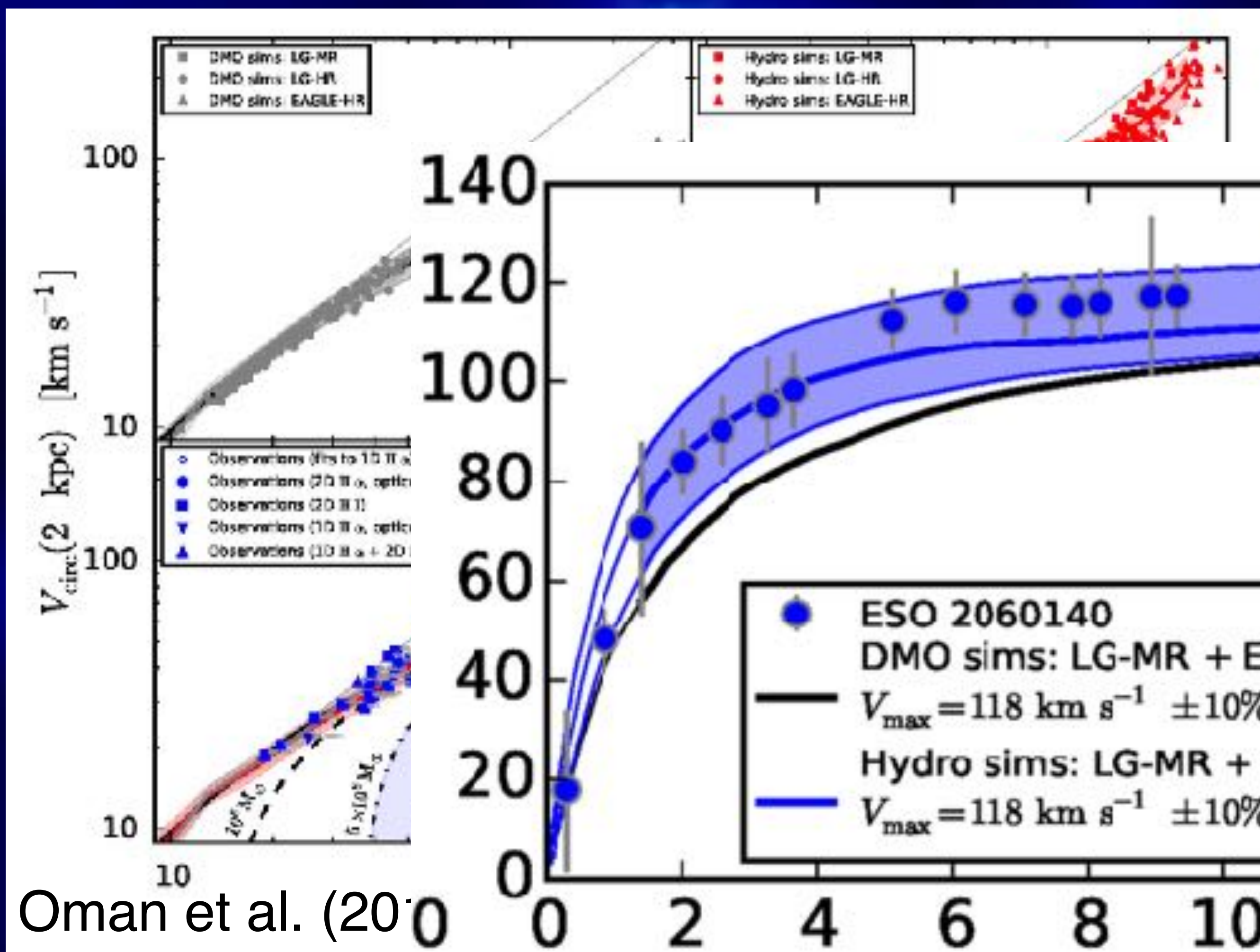
$M_H = 1.7 \times 10^{11}\ M_\odot$

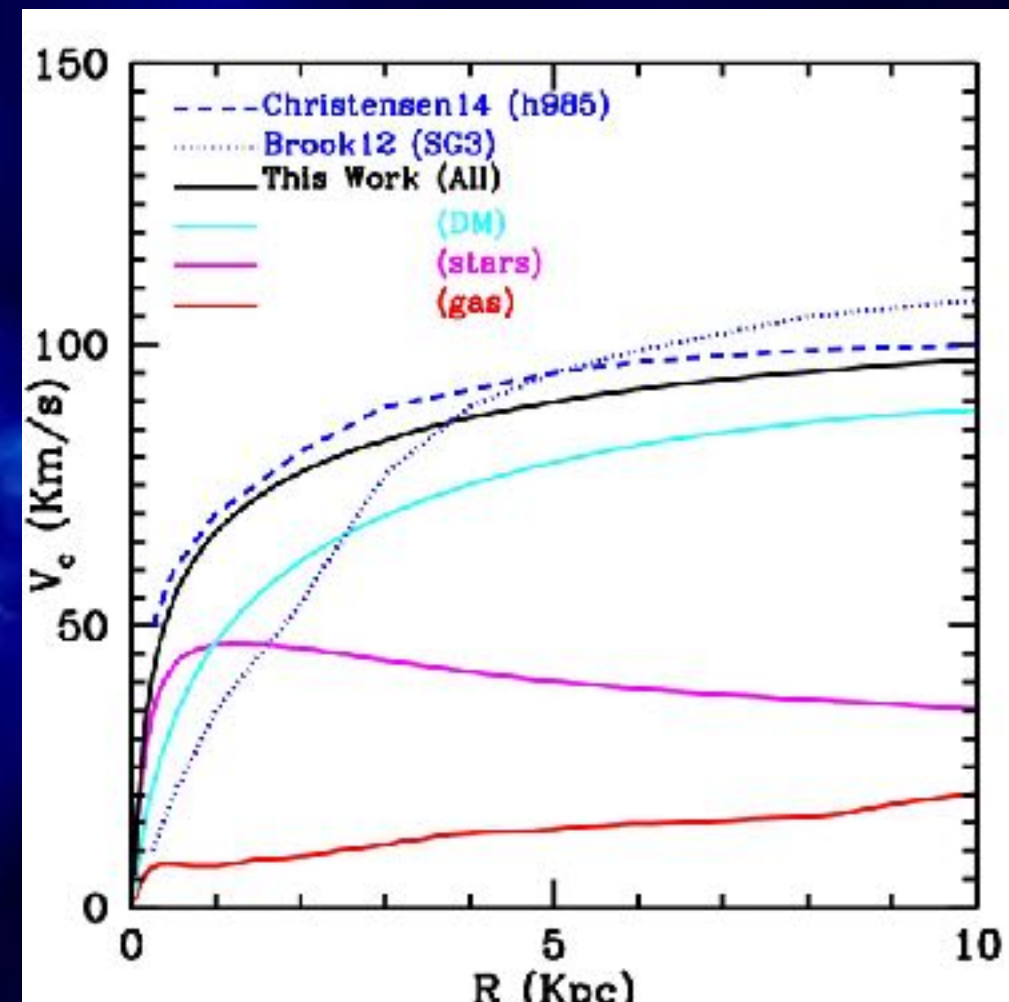
$M_S = 3 \times 10^{9}\ M_\odot$

$M_G = 2 \times 10^{9}\ M_\odot$

Ceverino et al. 2017

Circular velocity profile: $V_c=(GM/R)^{0.5}$

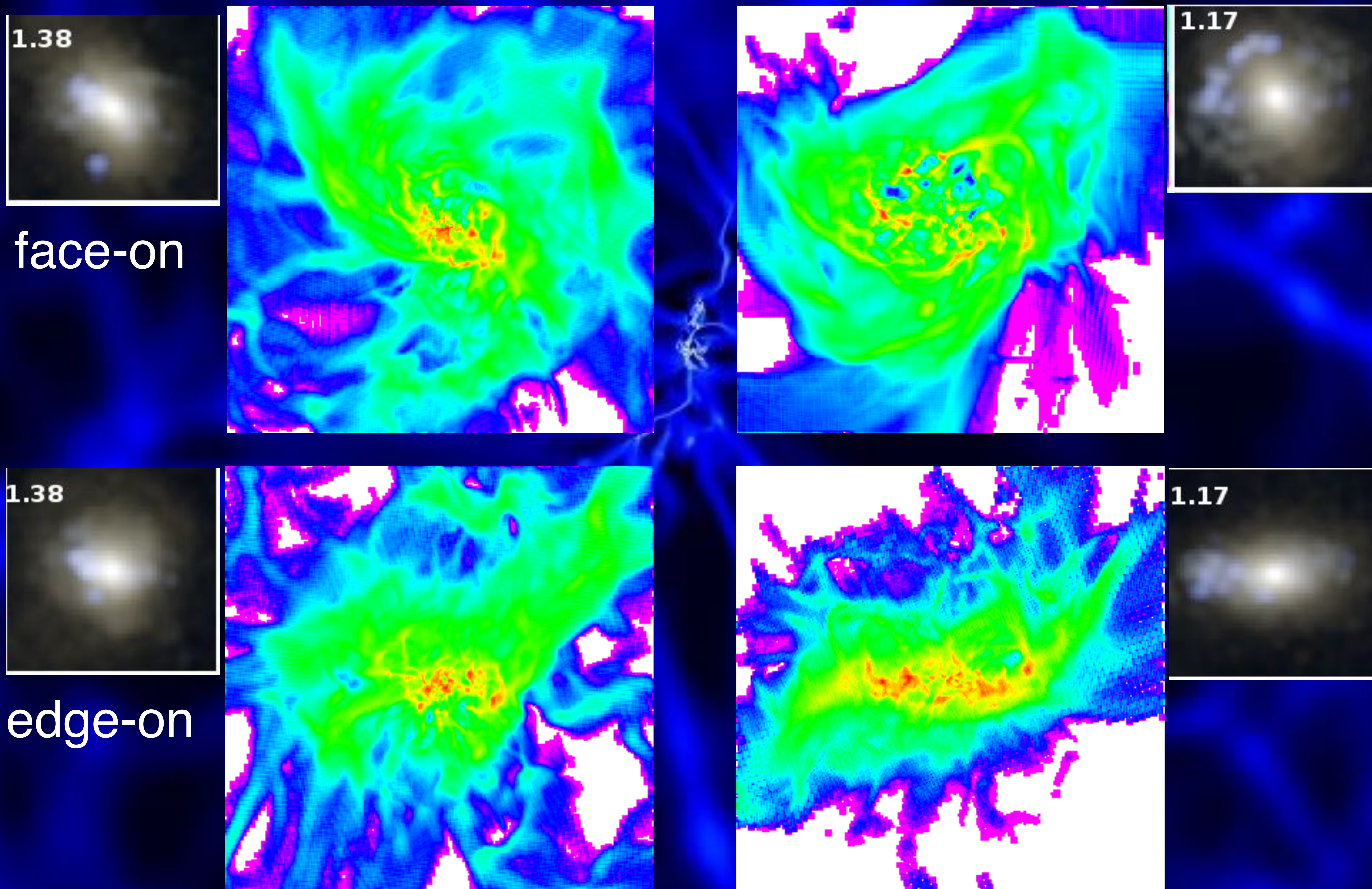




- Diversity of rotation curves in dwarf galaxies

Disc Formation and Settling

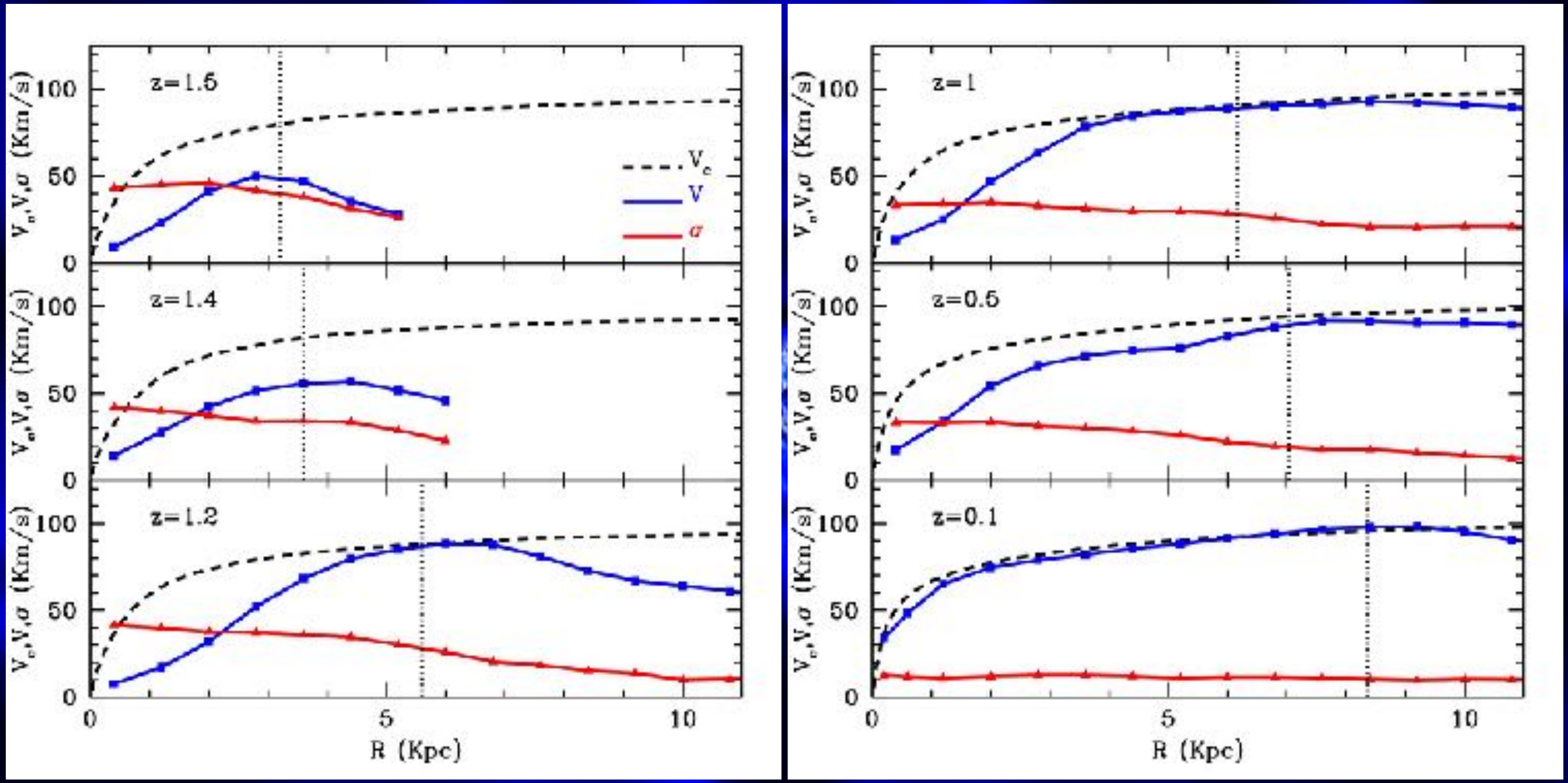
Compaction & Disc Formation



evolution of gas kinematics

σ/V_{max}~1

σ/V_{max}~0.3



σ/V_{max}~0.1

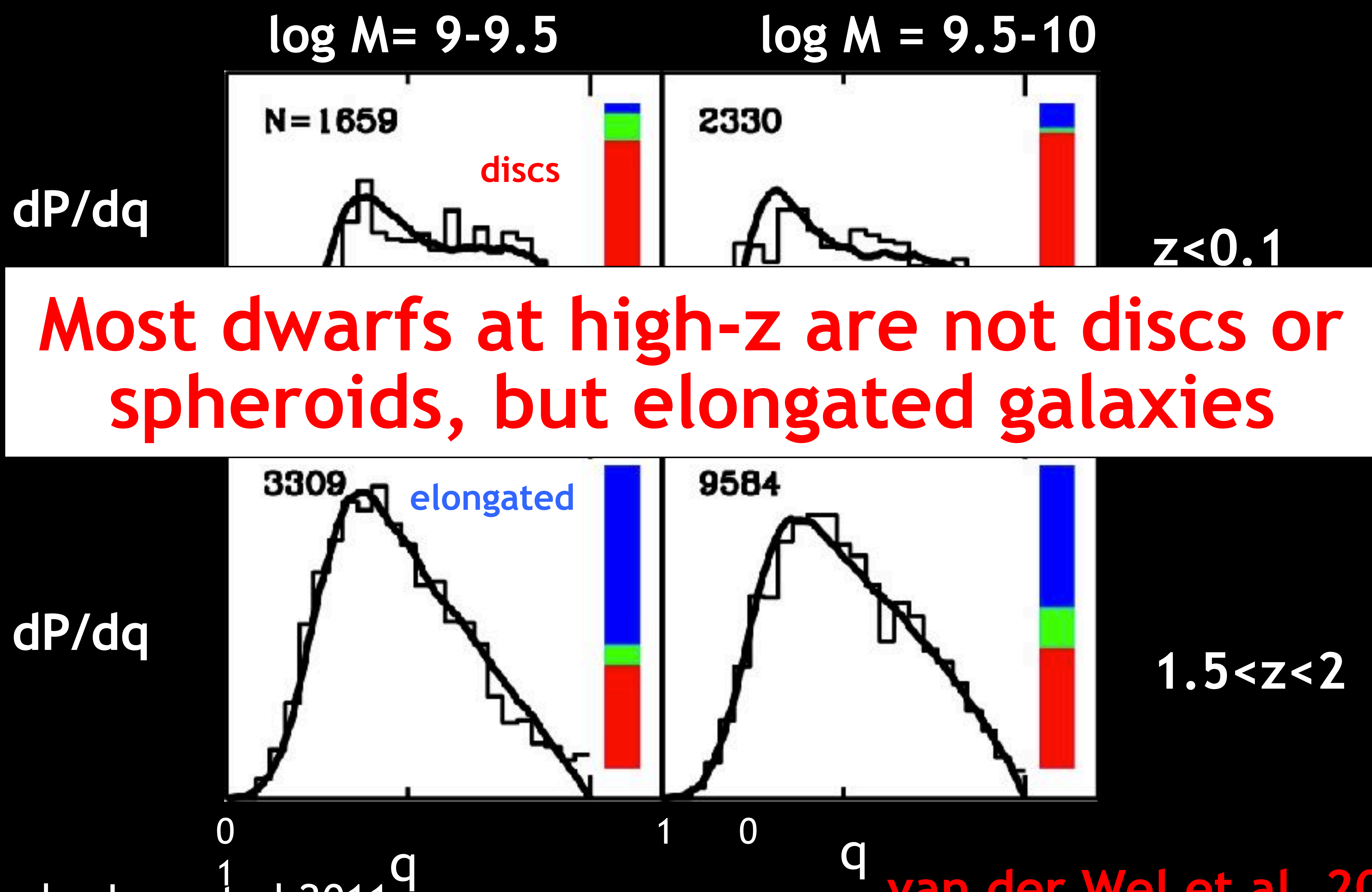
Formation of a rotating disc

Disc settling

Elongated dwarfs at z=2

z=0	z=2	z=6
Mv=2 10^11 $M_\odot$	Mv=2 10^11 $M_\odot$	Mv= 10^11 $M_\odot$
Ms=3 10^9 $M_\odot$	Ms=10^9 $M_\odot$	Ms= 3 10^9 $M_\odot$
SFR= 0.2 $M_\odot$ /yr	SFR= 6 $M_\odot$ /yr	SFR= 20 $M_\odot$ /yr
Re = 4 kpc	Re = 2 kpc	Re = 0.5 kpc

Distribution of projected axis ratio



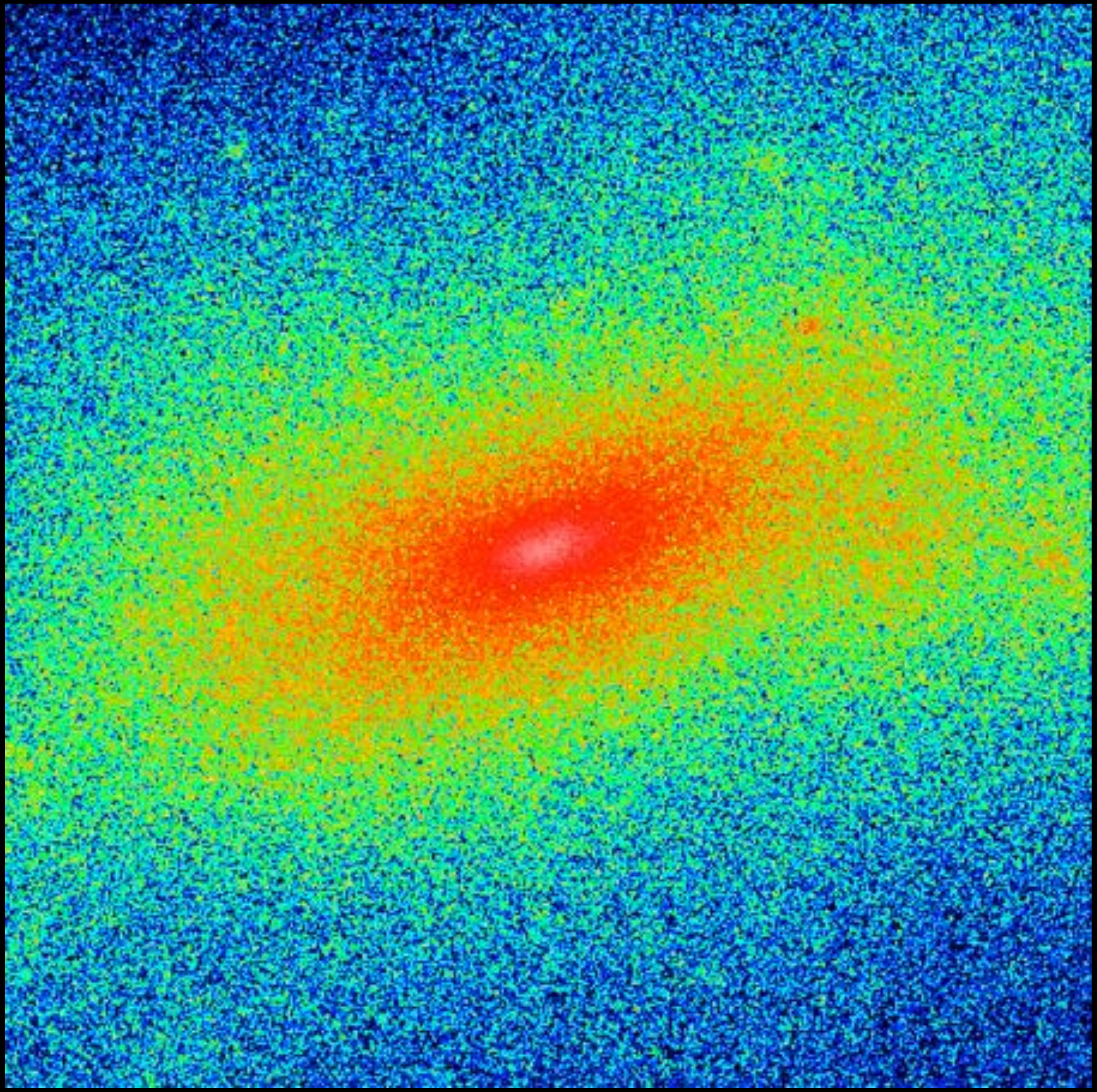
Most dwarfs at high-z are not discs or spheroids, but elongated galaxies

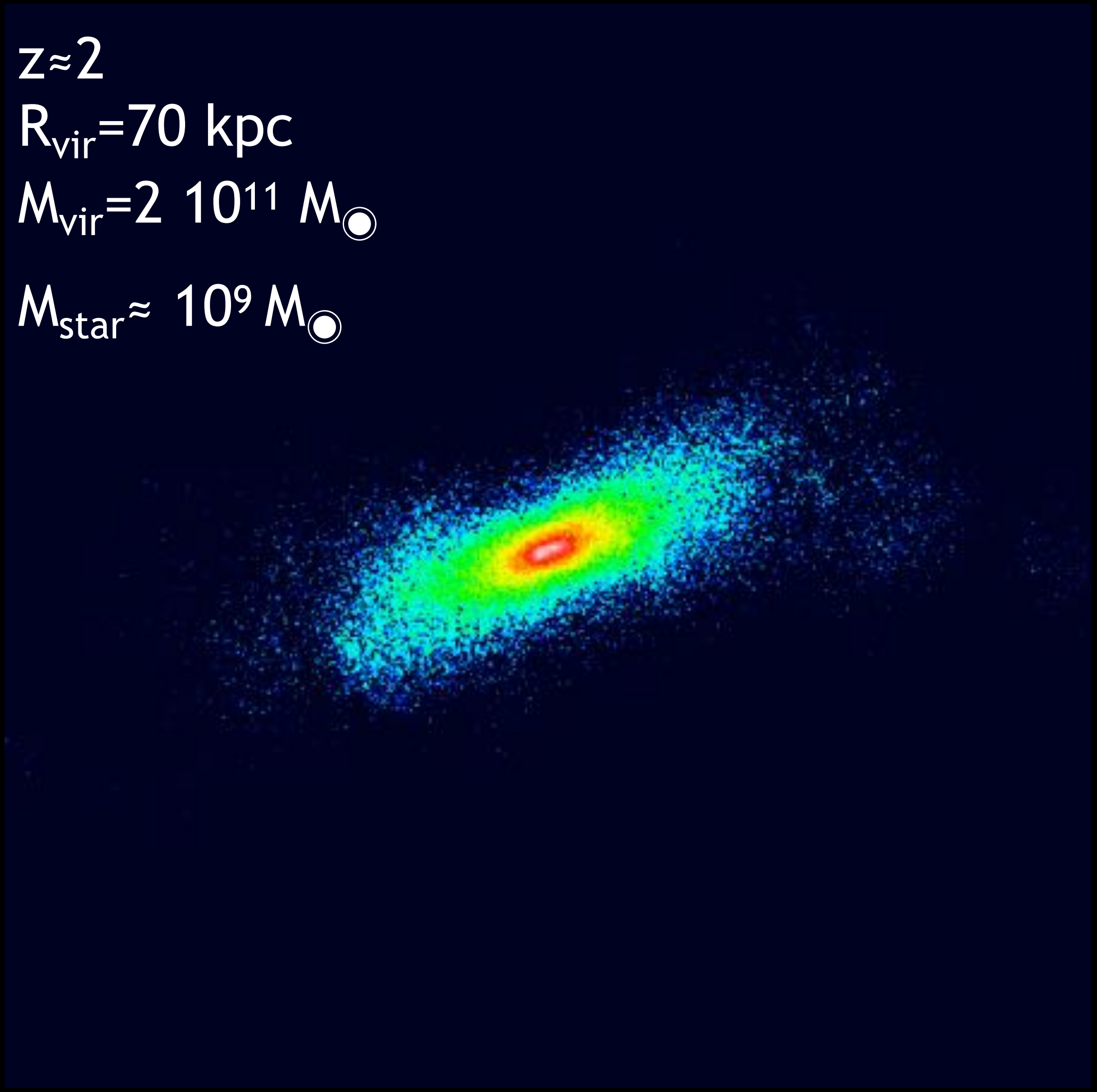
See also Law et al 2011

van der Wel et al. 2014

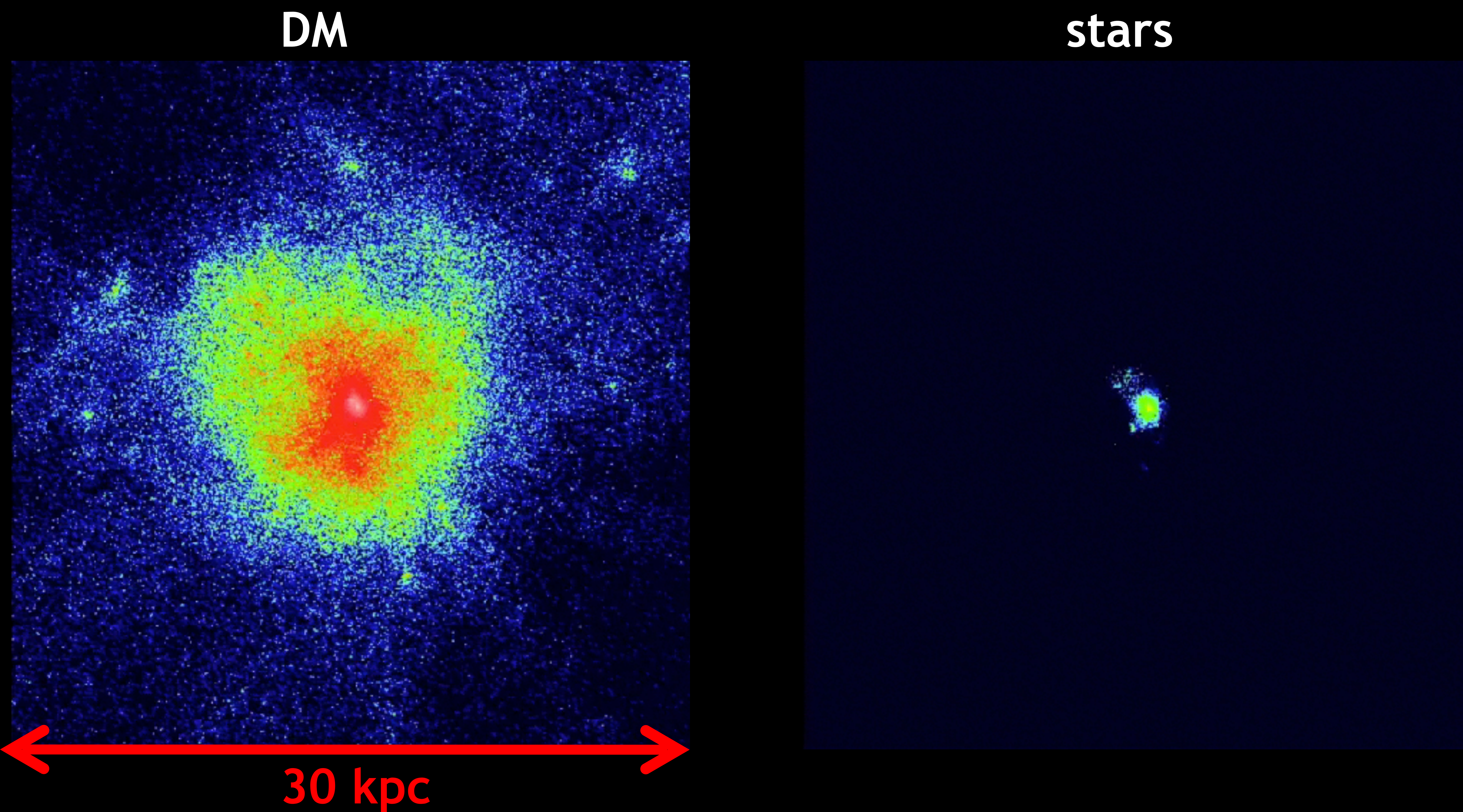
Prolate DM halo → elongated galaxy

DM VELA28 stars



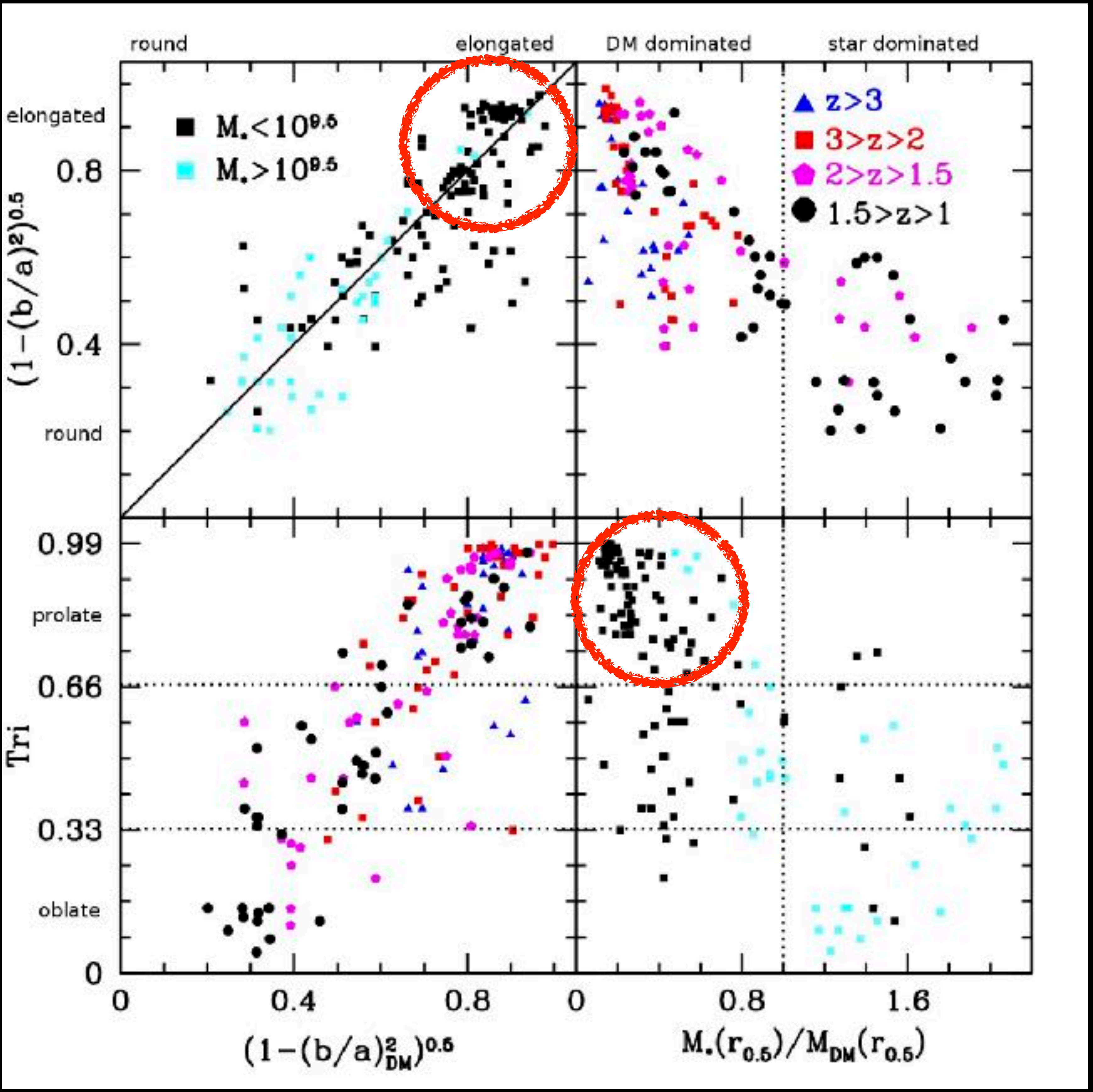


30 kpc


DM
stars
30 kpc

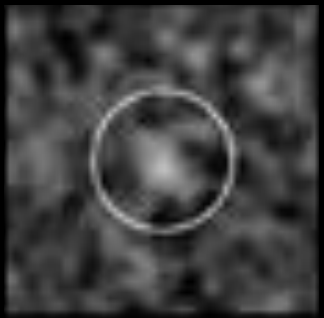
$M_* < 10^{9.5} M_\odot$

$M_*(r_{50}) < M_{DM}(r_{50})$



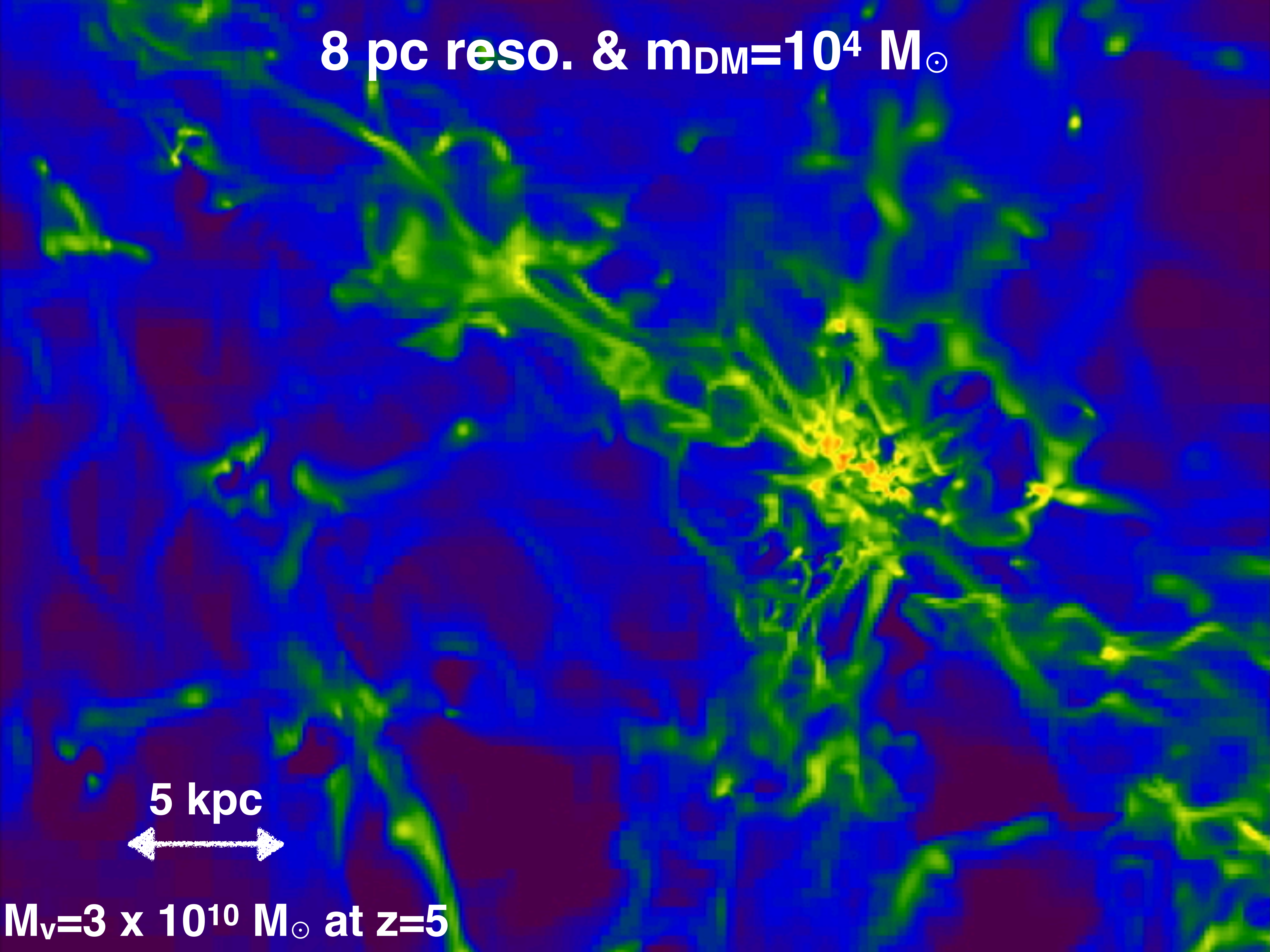
See also Tomassetti+16, Zhang+18

Ceverino, Primack & Dekel 2015



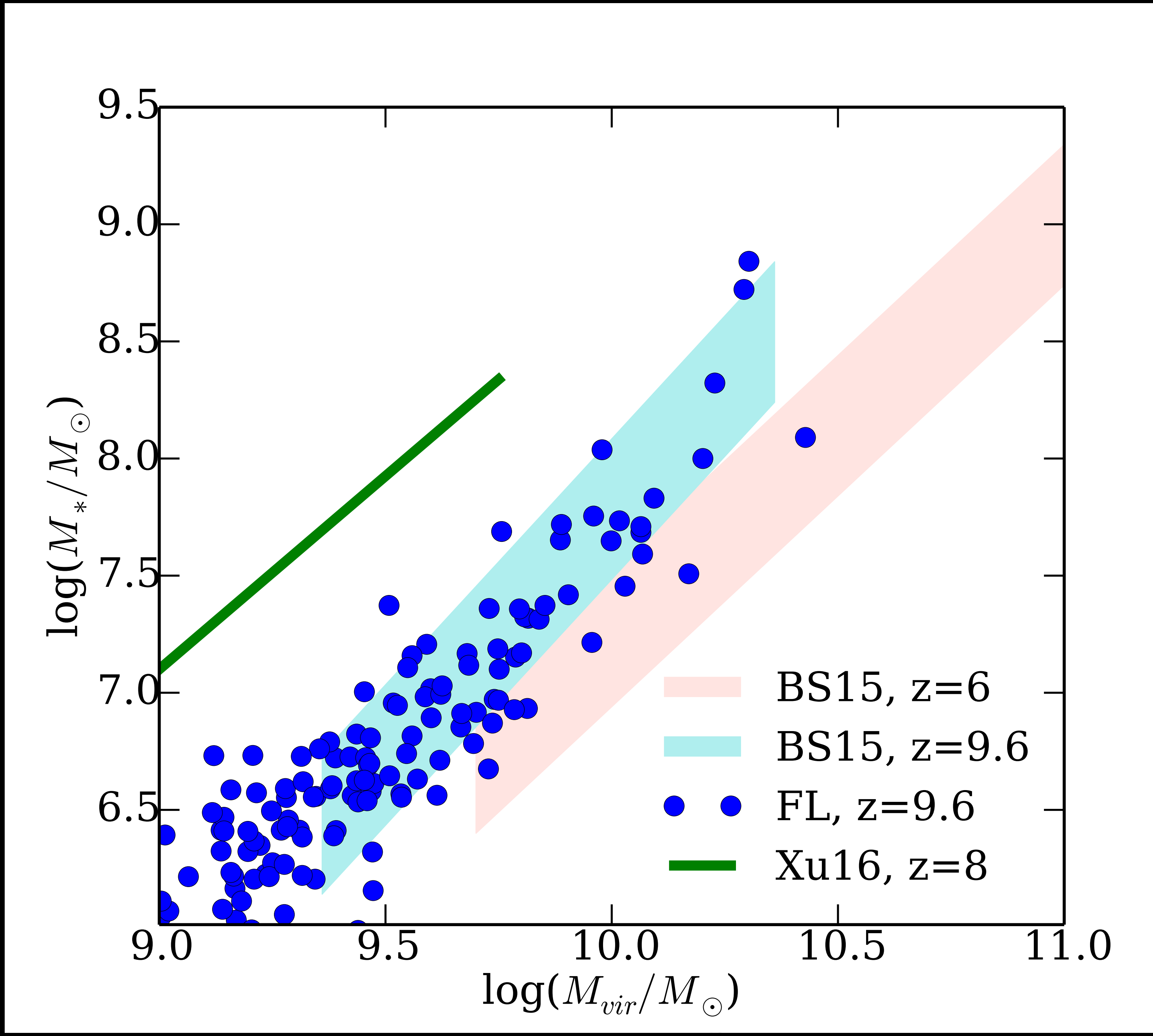
Dwarf starbursts at z=6

z=0	z=2	z=6
Mv=2 10^11 $M_\odot$	Mv=2 10^11 $M_\odot$	Mv= 10^11 $M_\odot$
Ms=3 10^9 $M_\odot$	Ms=10^9 $M_\odot$	Ms= 3 10^9 $M_\odot$
SFR= 0.2 $M_\odot$ /yr	SFR= 6 $M_\odot$ /yr	SFR= 20 $M_\odot$ /yr
Re = 4 kpc	Re = 2 kpc	Re = 0.5 kpc


8 pc reso. & $m_{DM}=10^4\ M_\odot$
5 kpc
$M_V=3 \times 10^{10}\ M_\odot$ at z=5

Evolution of the Stellar-Halo mass relation

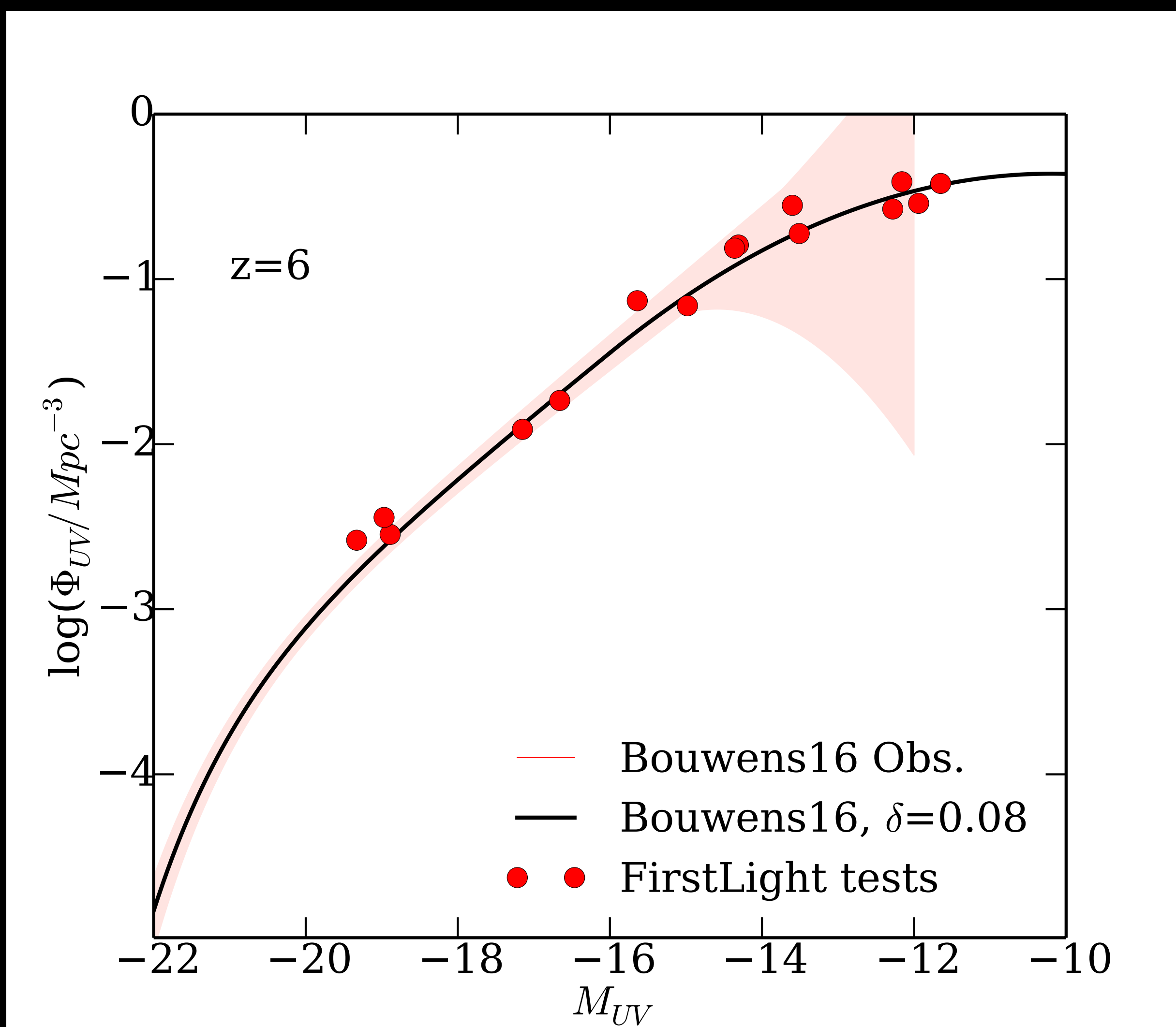
- Good comparison with the predictions from abundance matching (Behroozi & Silk 2016)
- higher normalization and a steeper slope at higher z
- That combination drives little evolution at low masses.



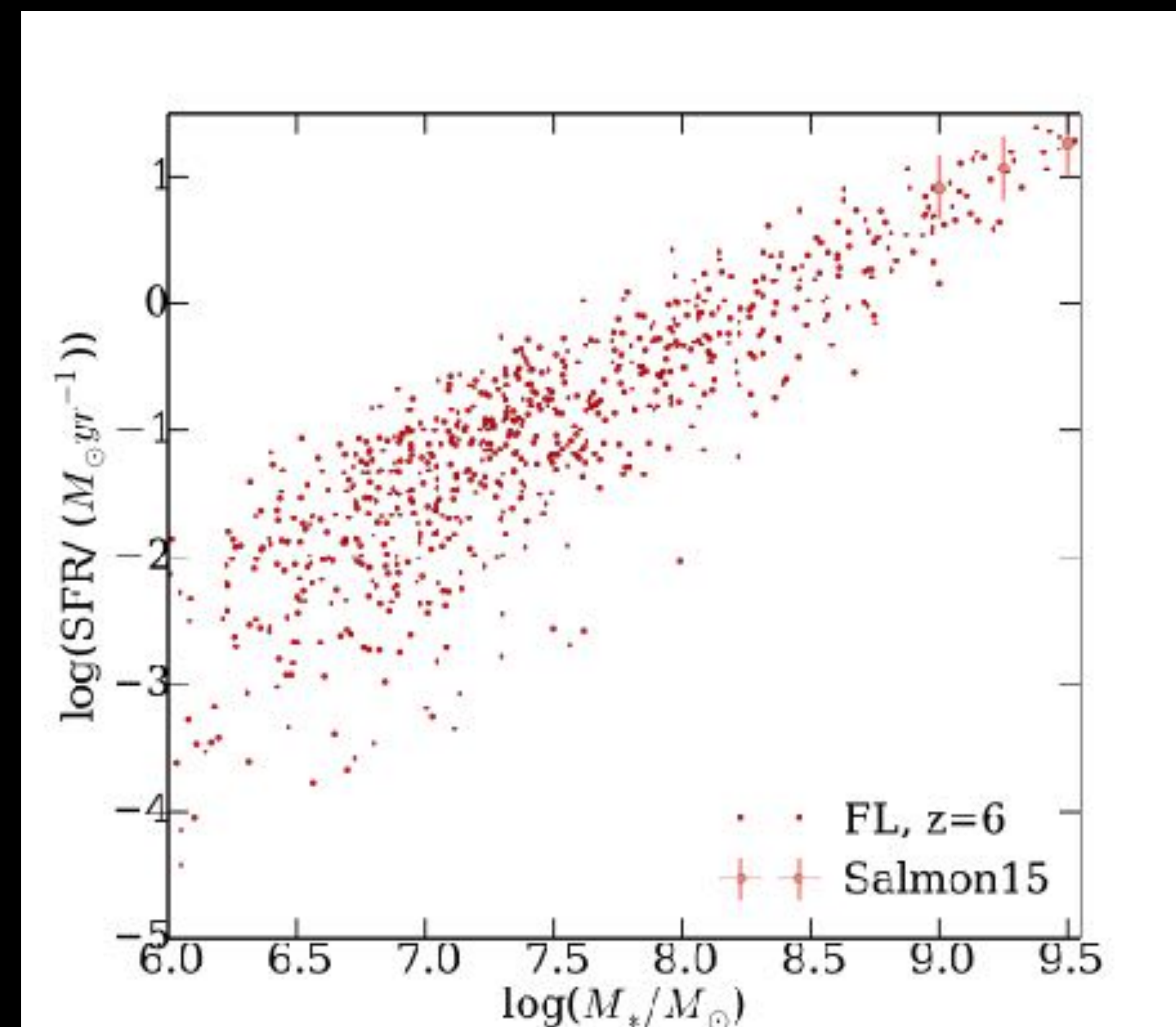
Ceverino, Klessen & Glover 2017

First Results

- Overall good agreements with observations

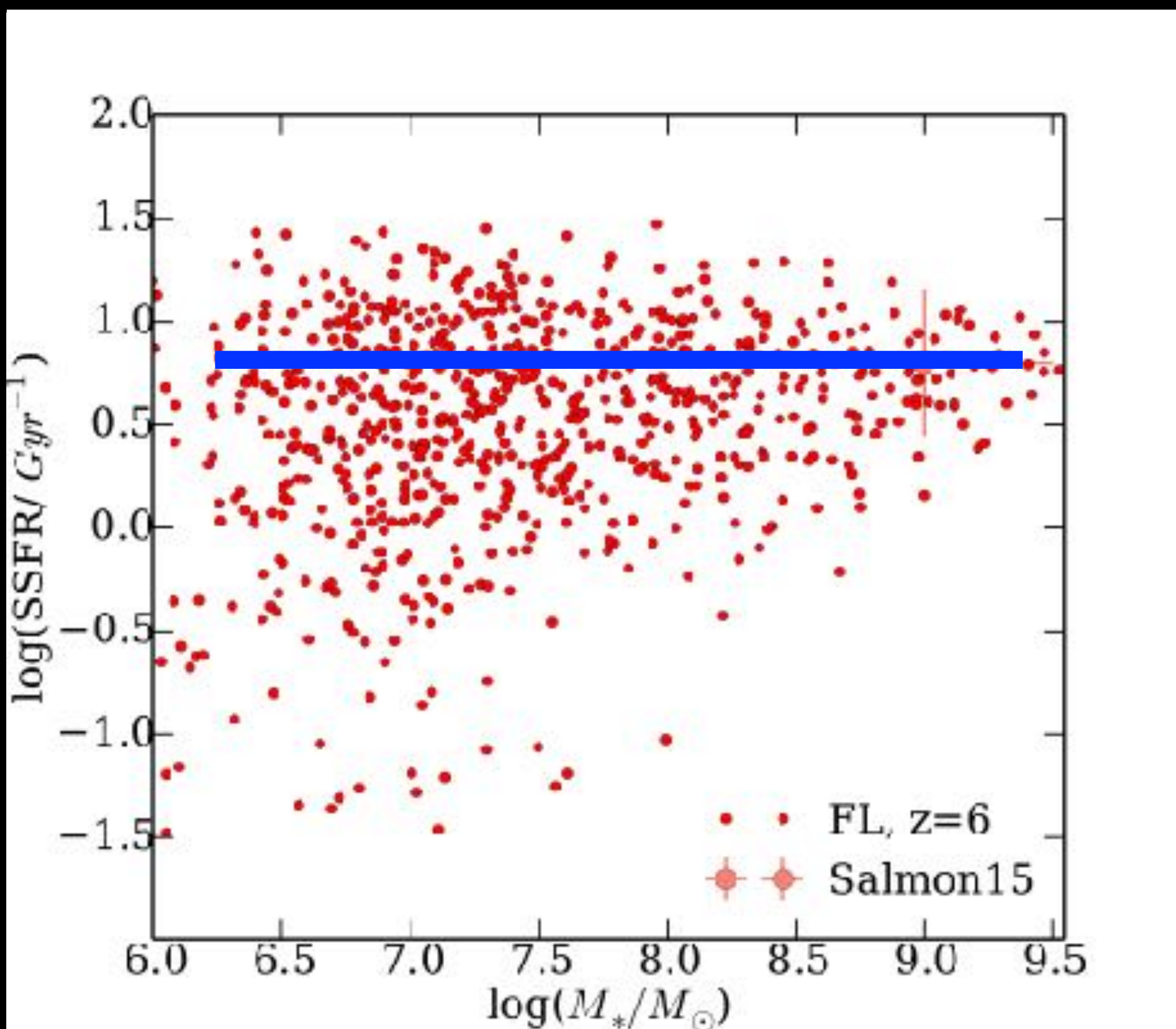


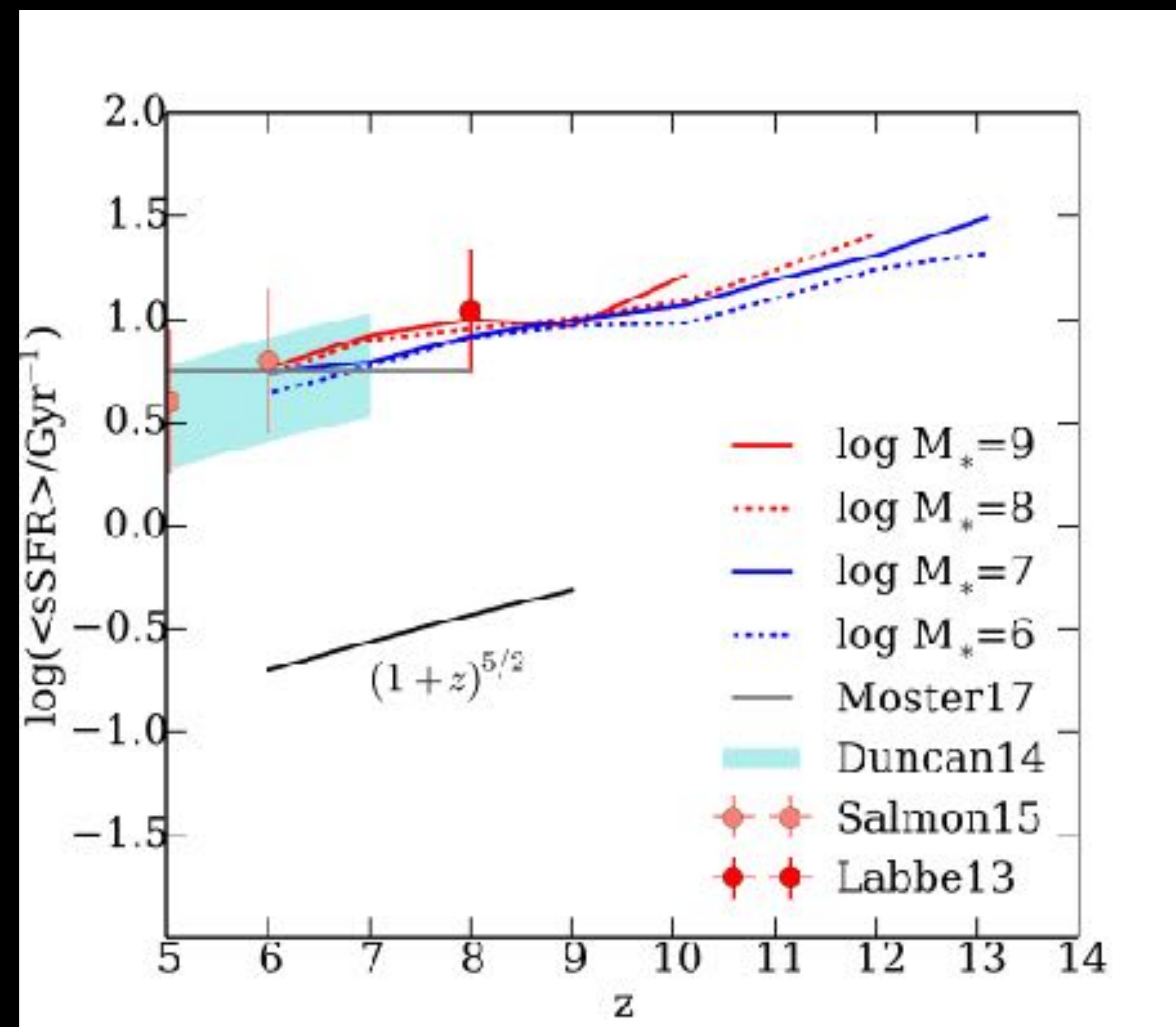
Ceverino, Glover & Klessen 2017



Ceverino, Klessen & Glover 2018

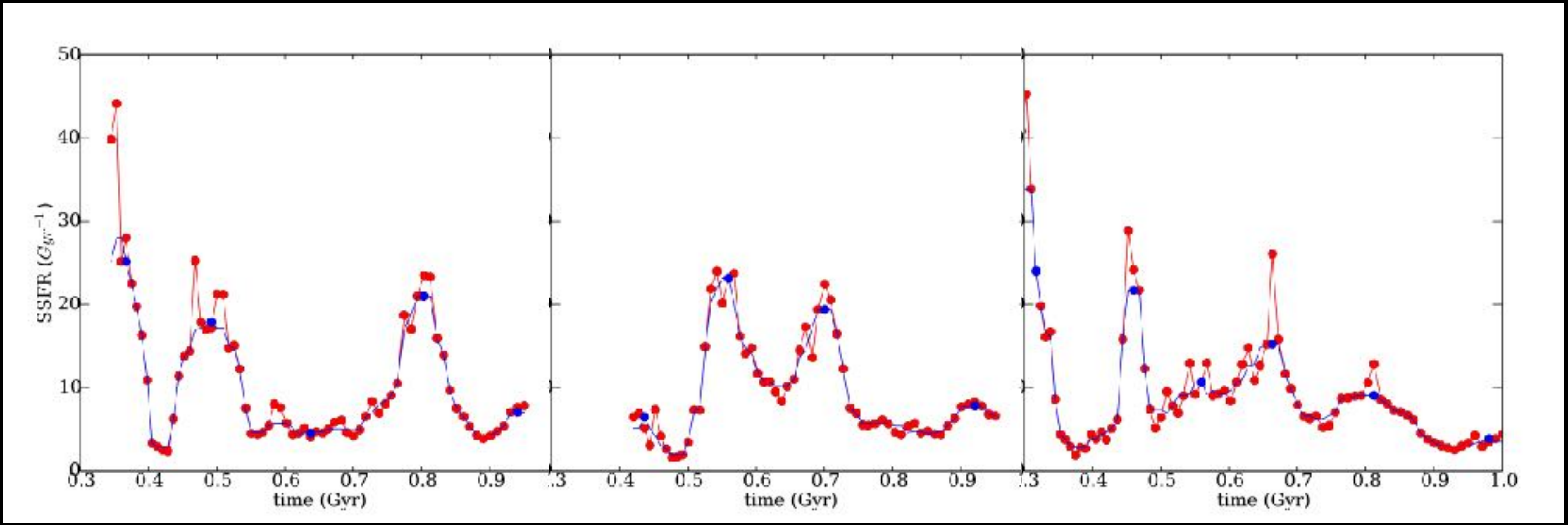
Star-forming Sequence at z=5-15





Ceverino, Klessen & Glover 2018

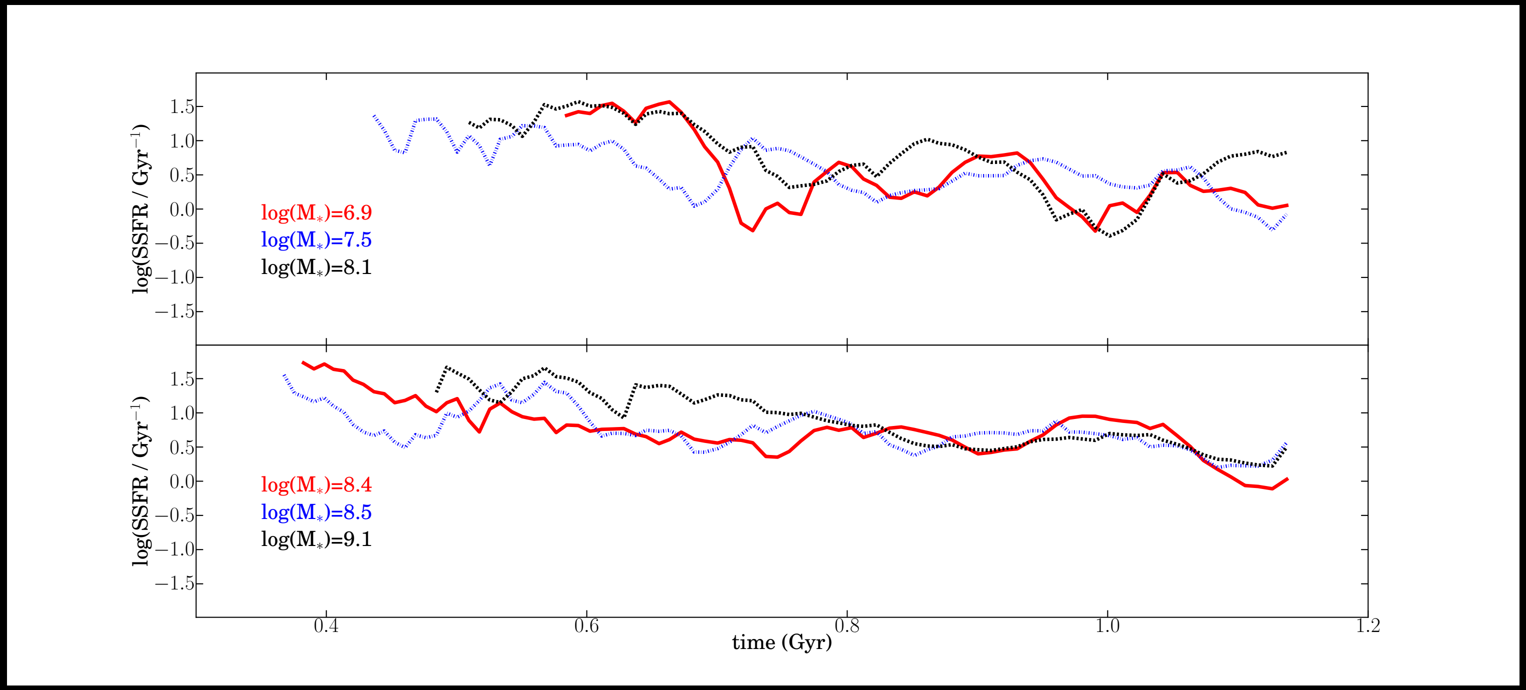
all galaxies are bursty



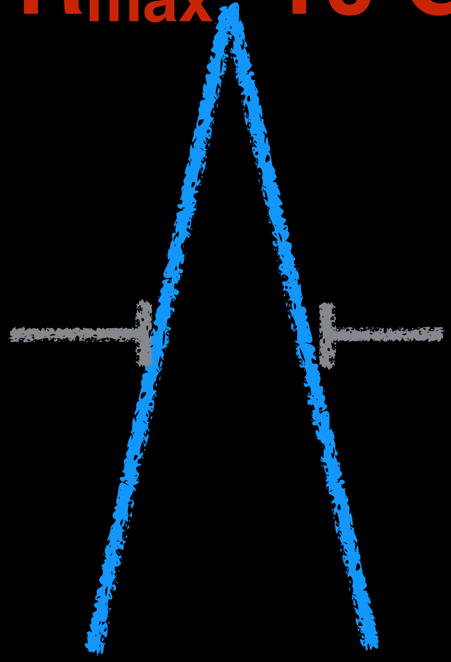
Galaxies expend 70% of their time in SF bursts

Ceverino, Klessen & Glover 2018

Typical & Extreme SF bursts at z=6

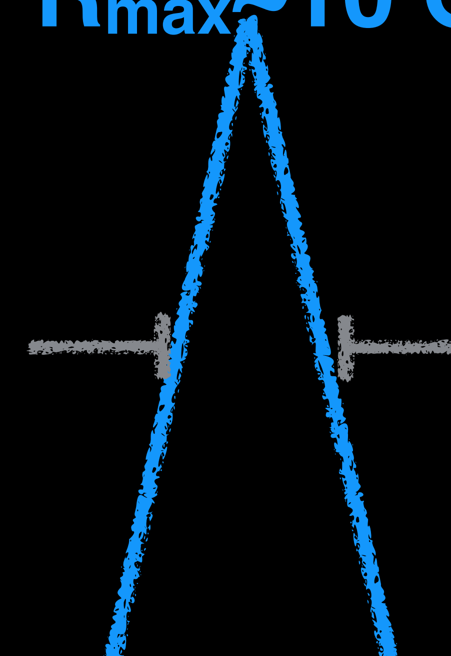


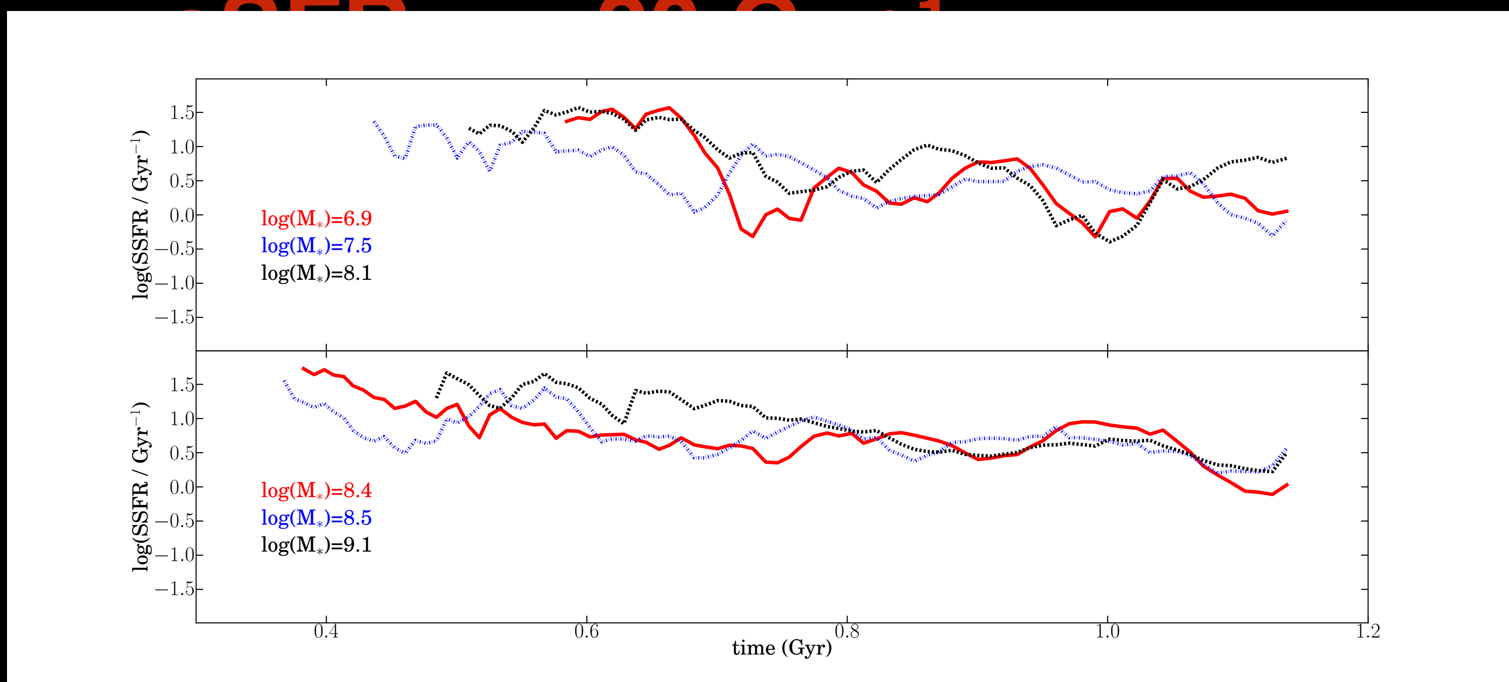
$sSFR_{max}$~10 Gyr^{-1}

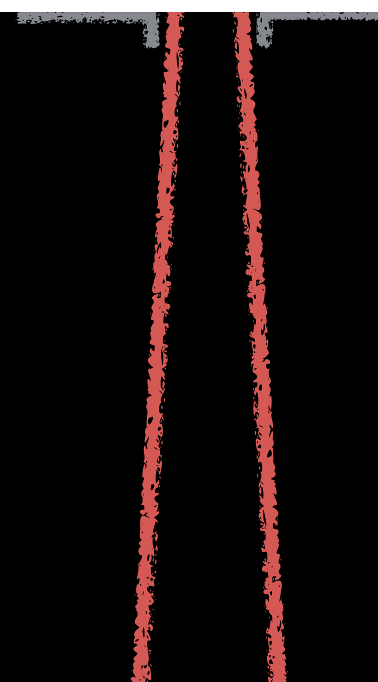


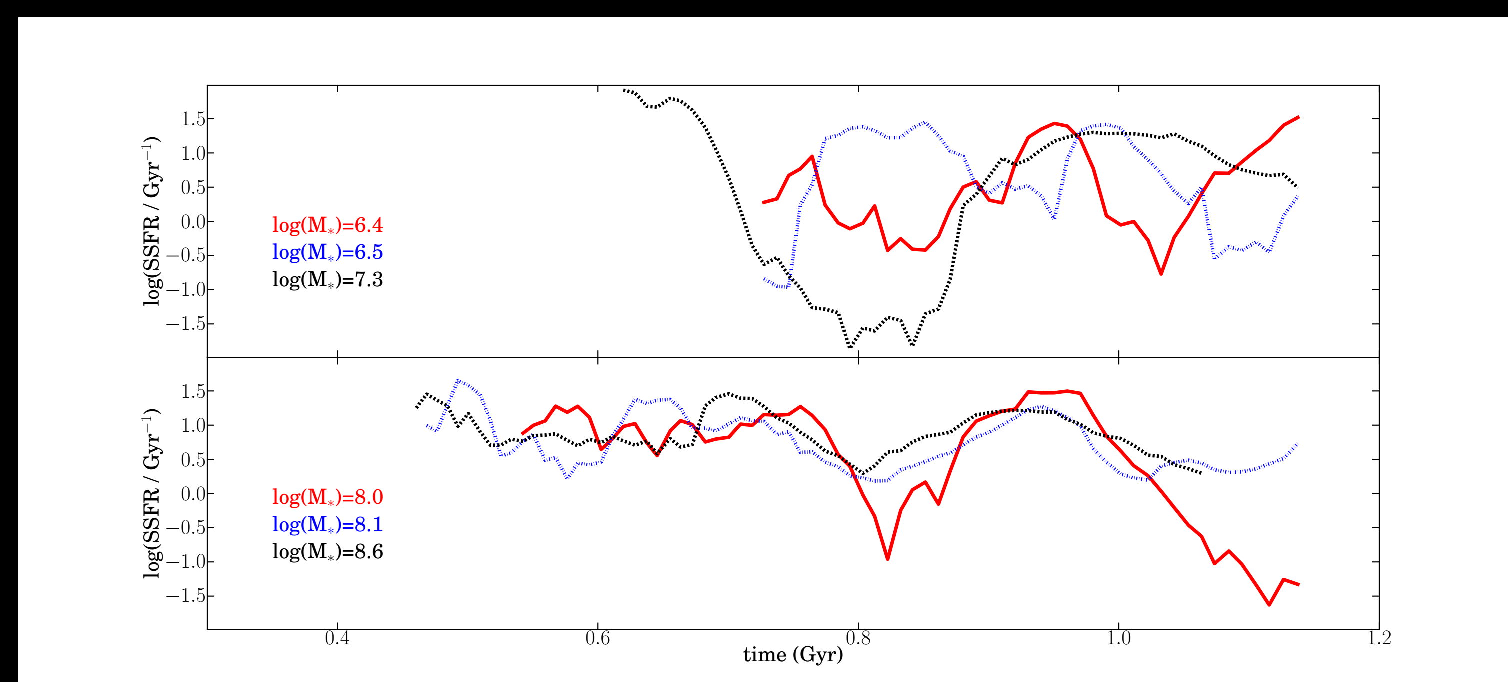
100 Myr

Typical & Extreme SF bursts at z=6

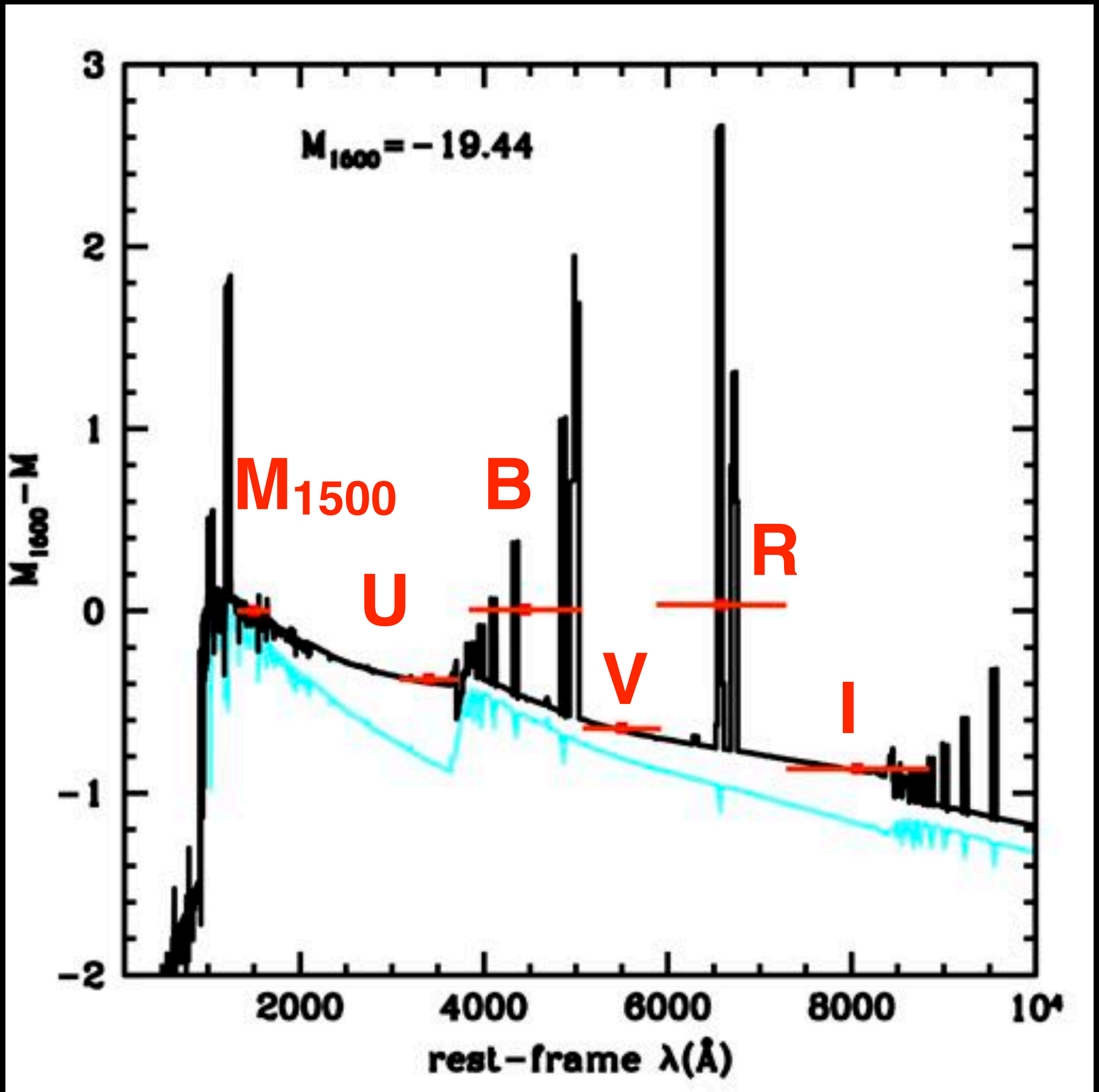


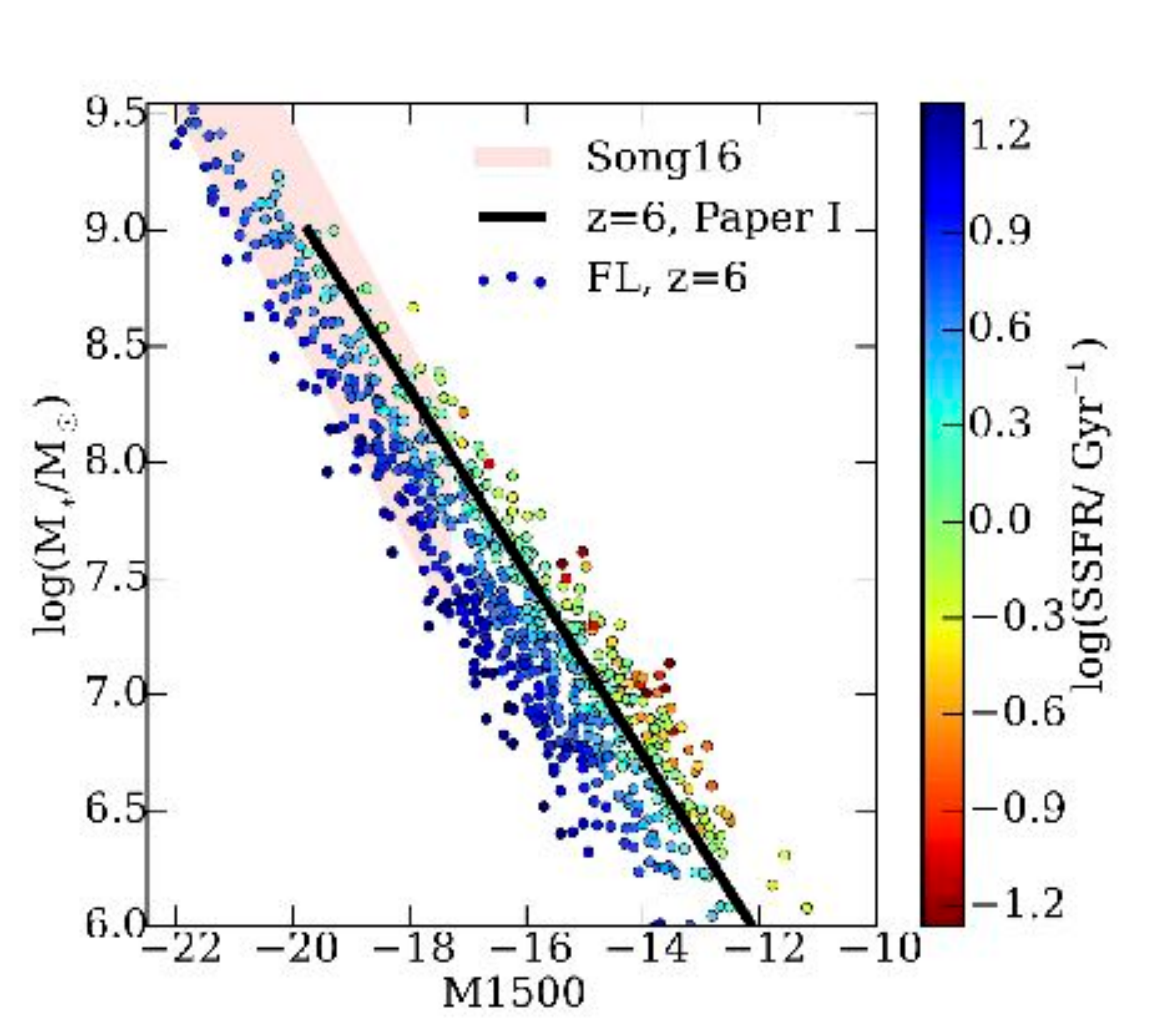






SEDs

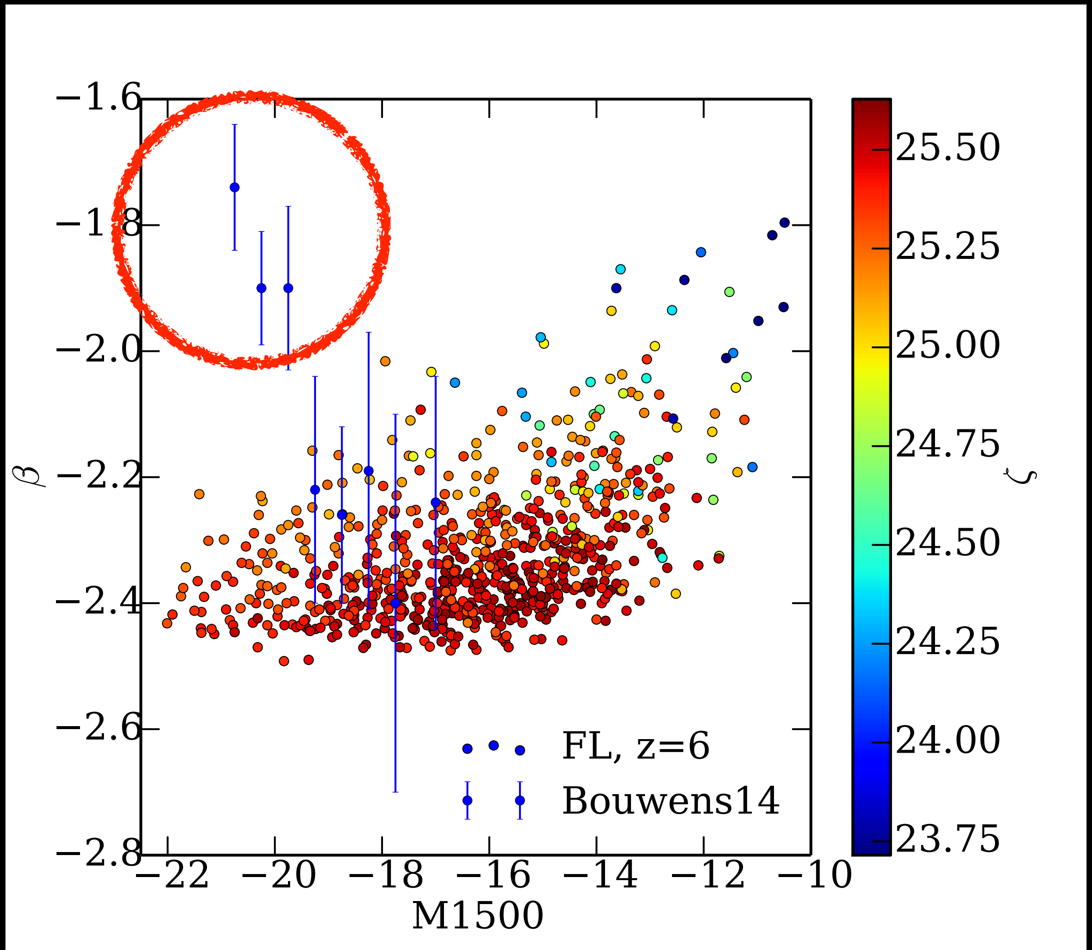


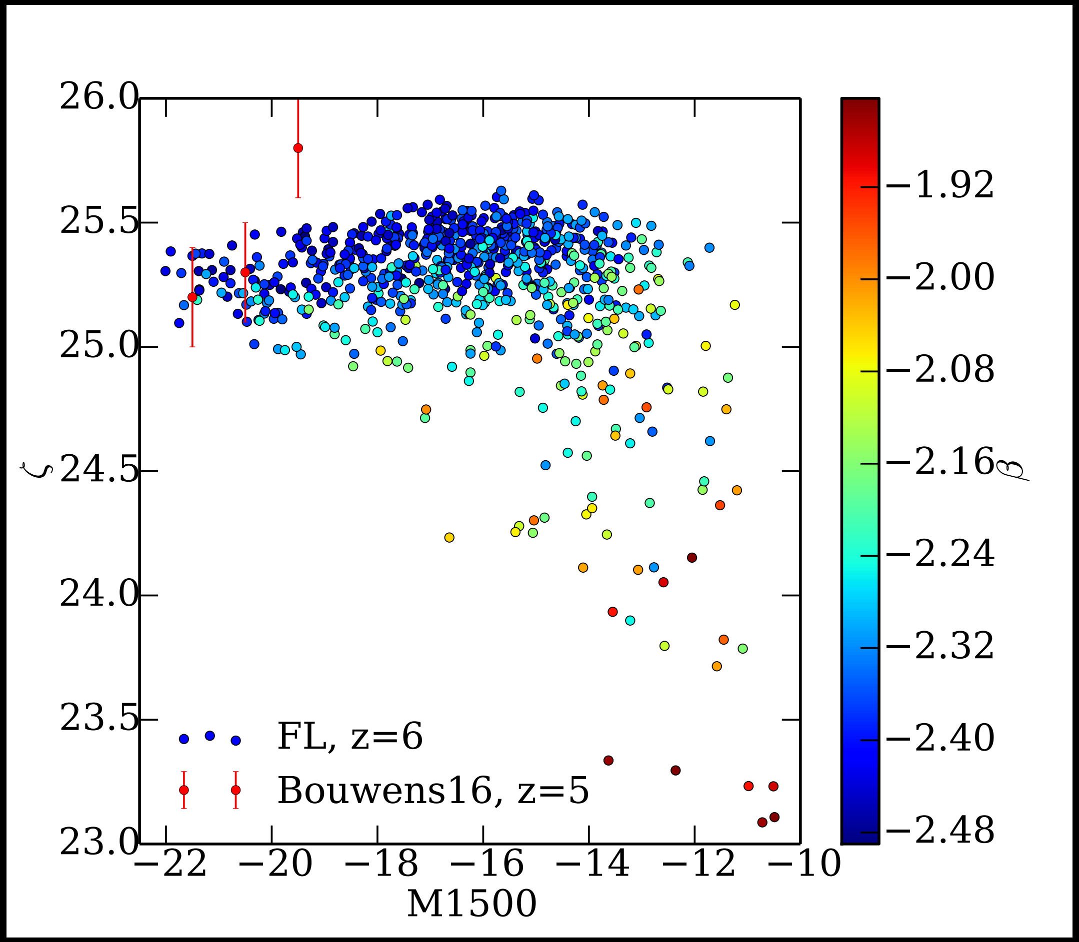


Ceverino, Klessen & Glover 2019

restframe UV properties

Dust attenuation?

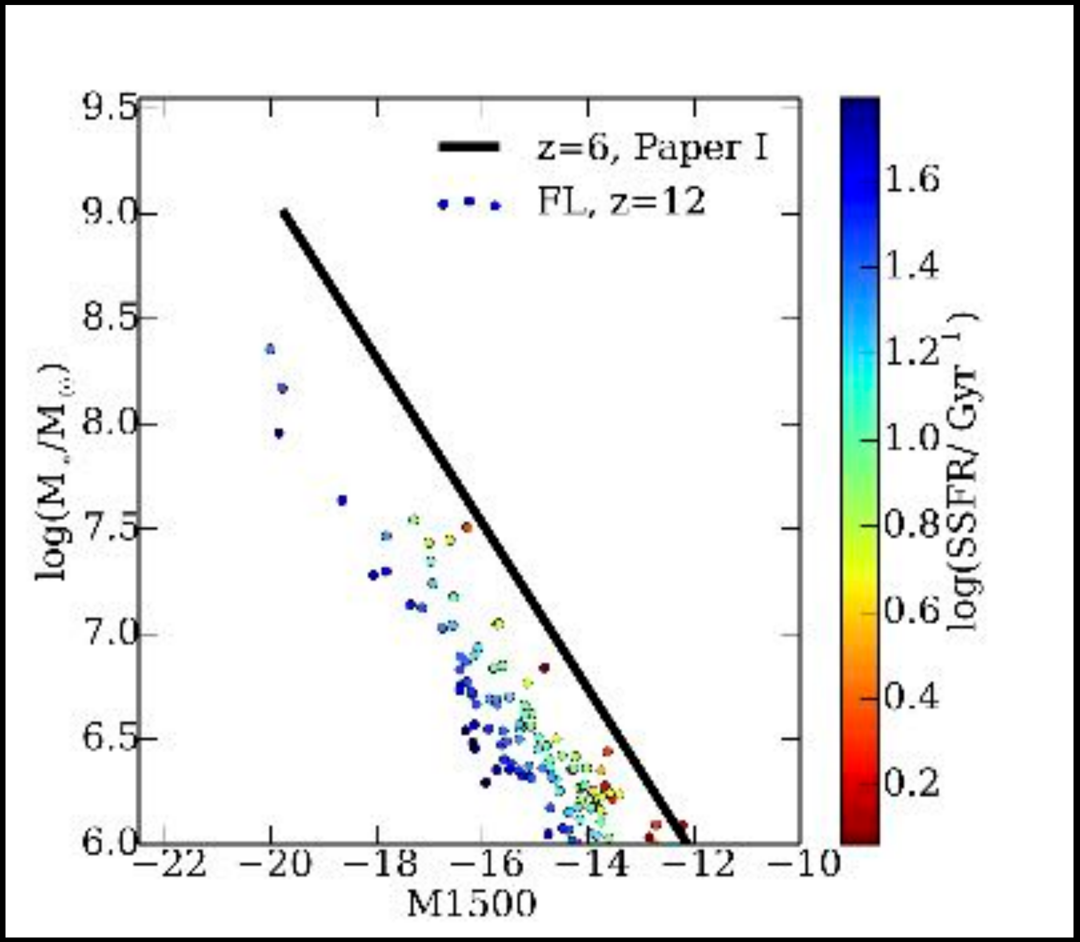




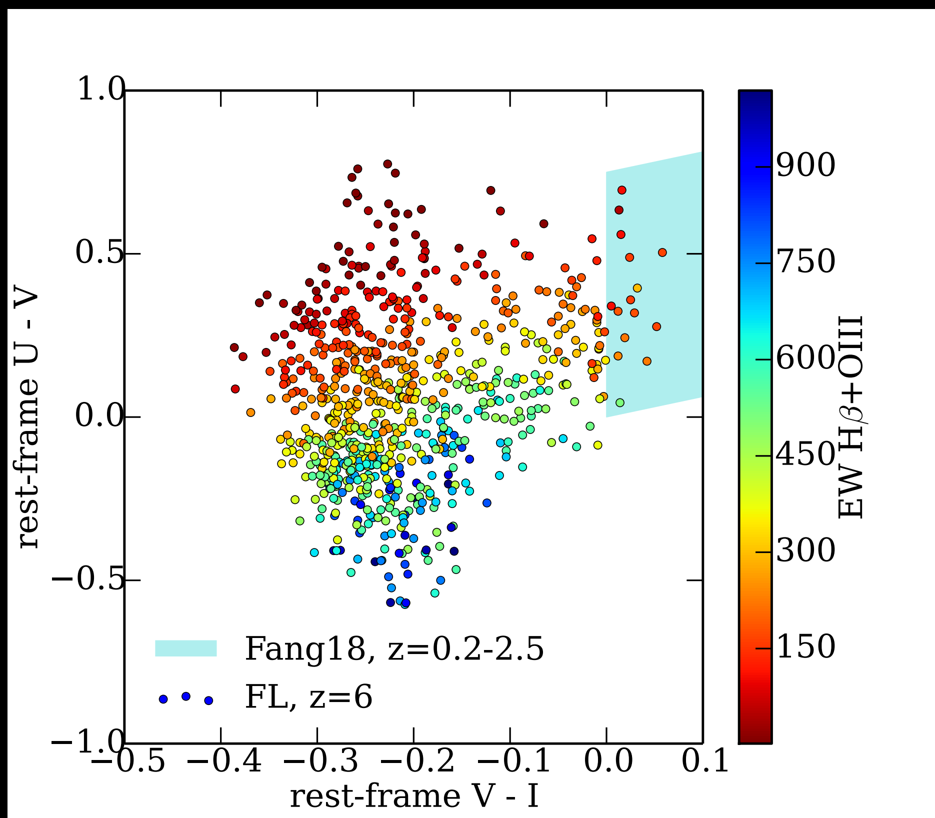
High production efficiency of LyC photons

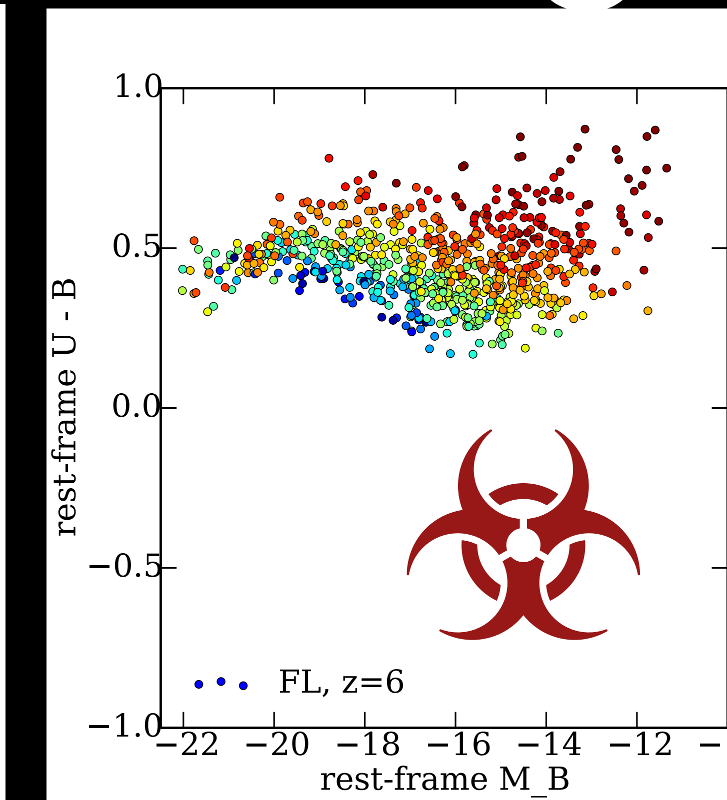
restframe UV properties

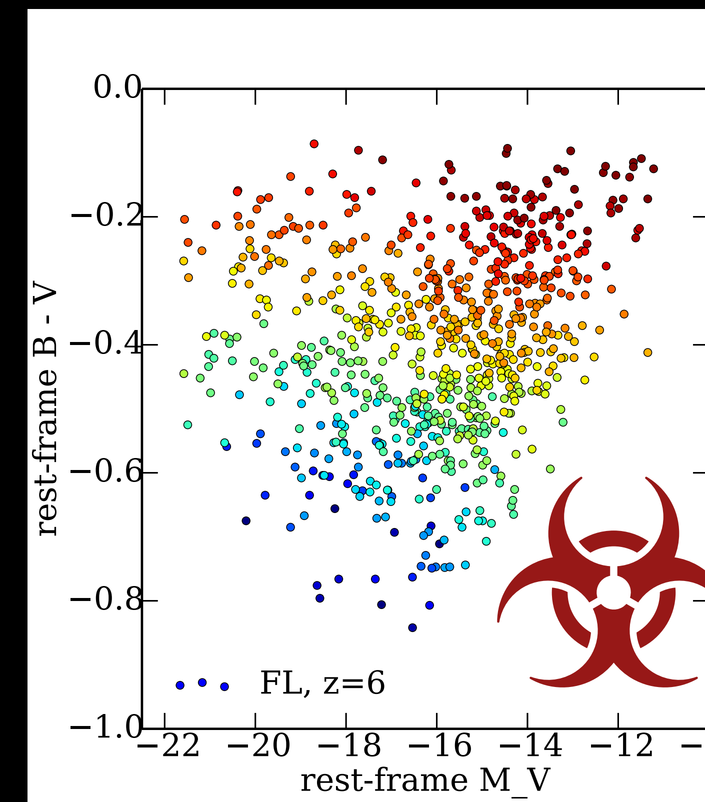
Evolution !

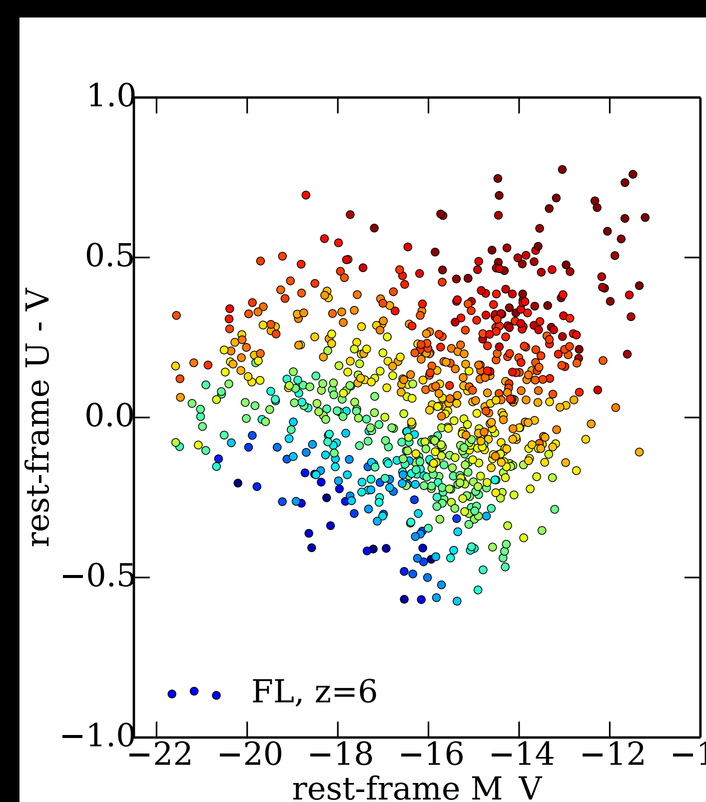


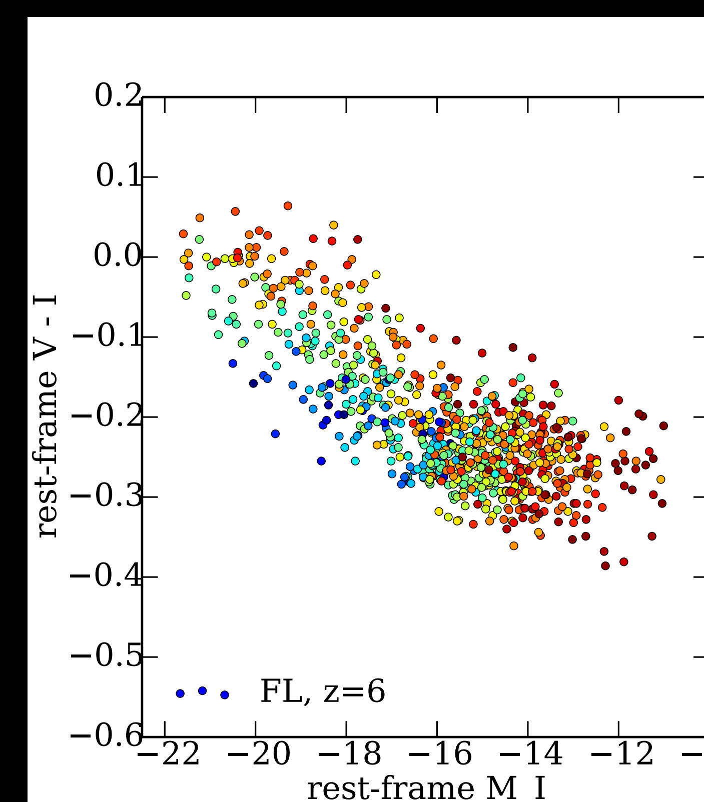
Colors and magnitudes



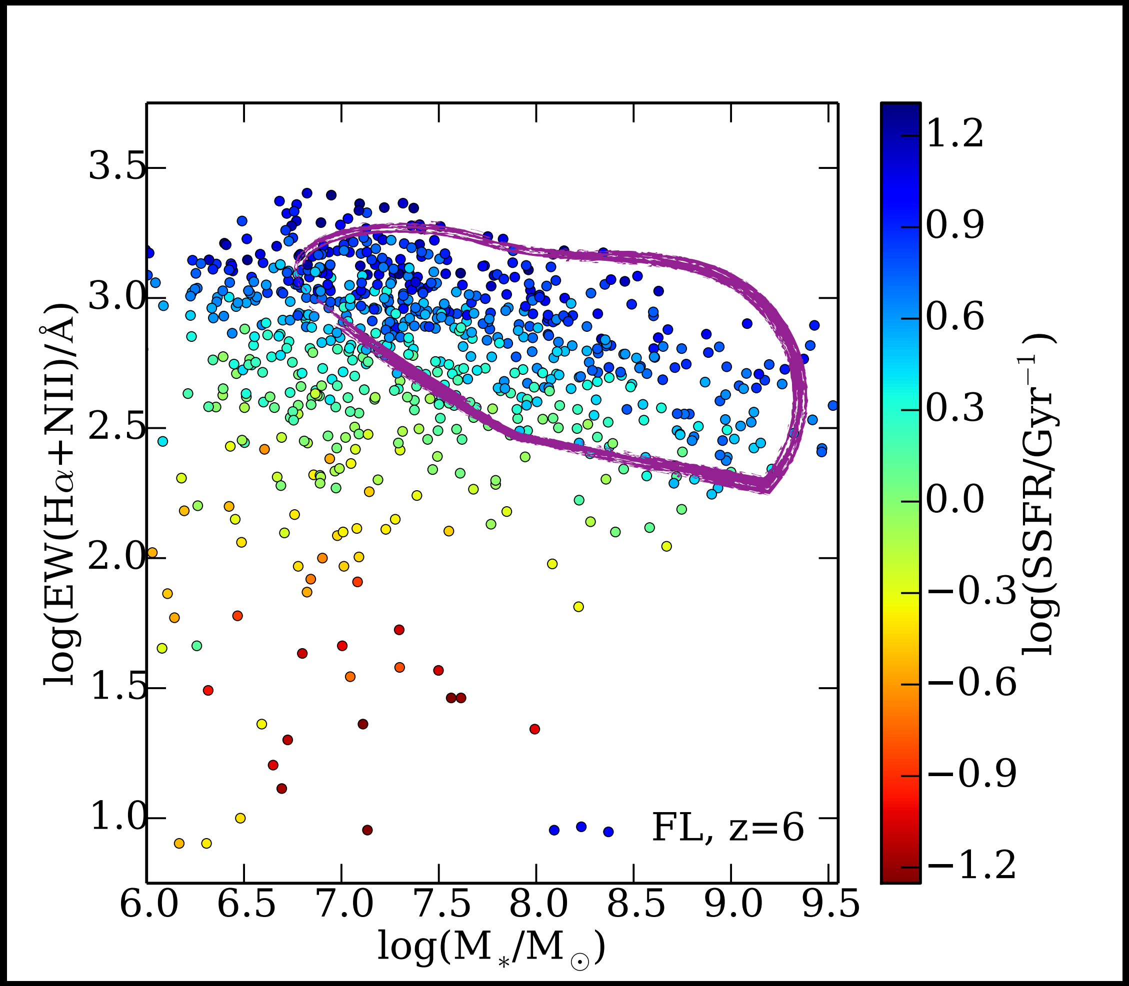


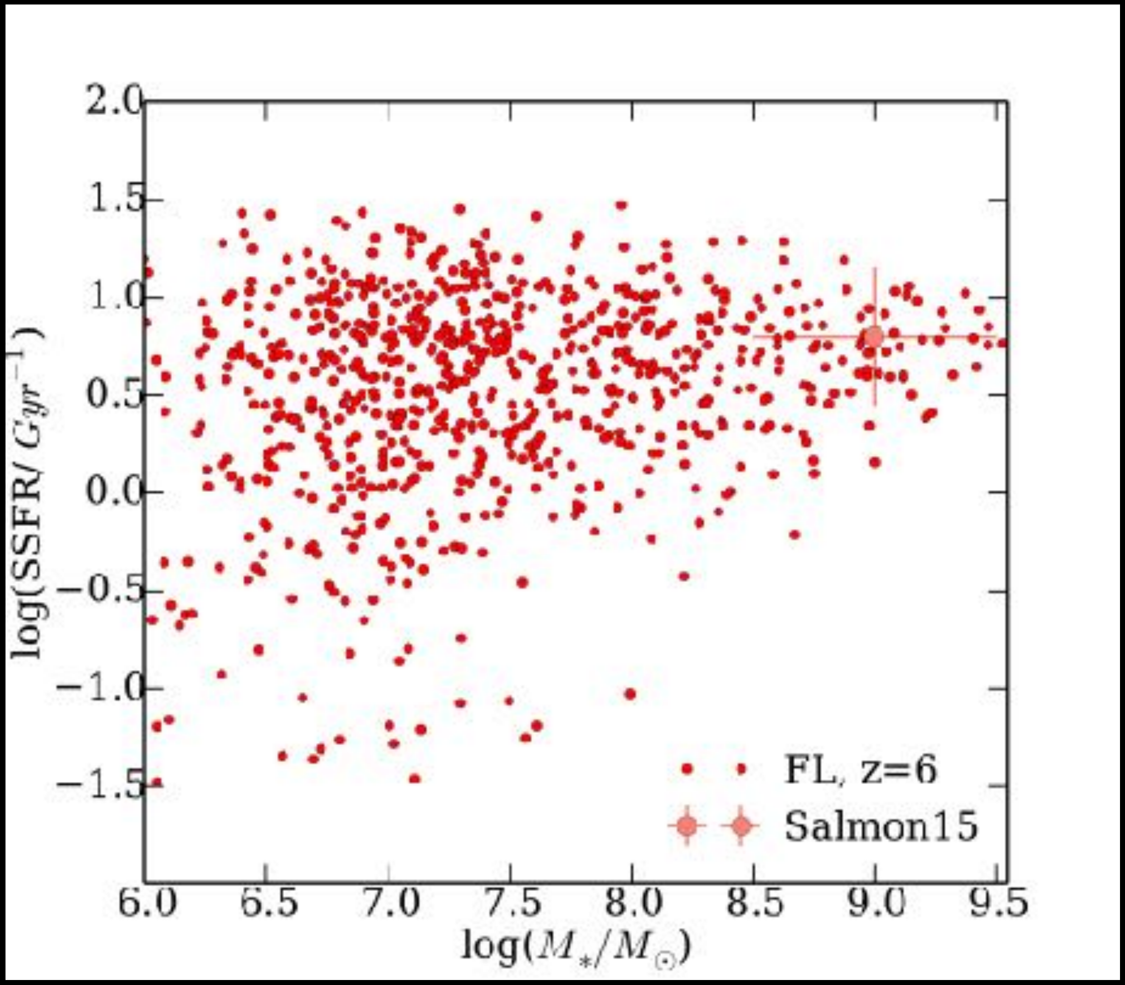




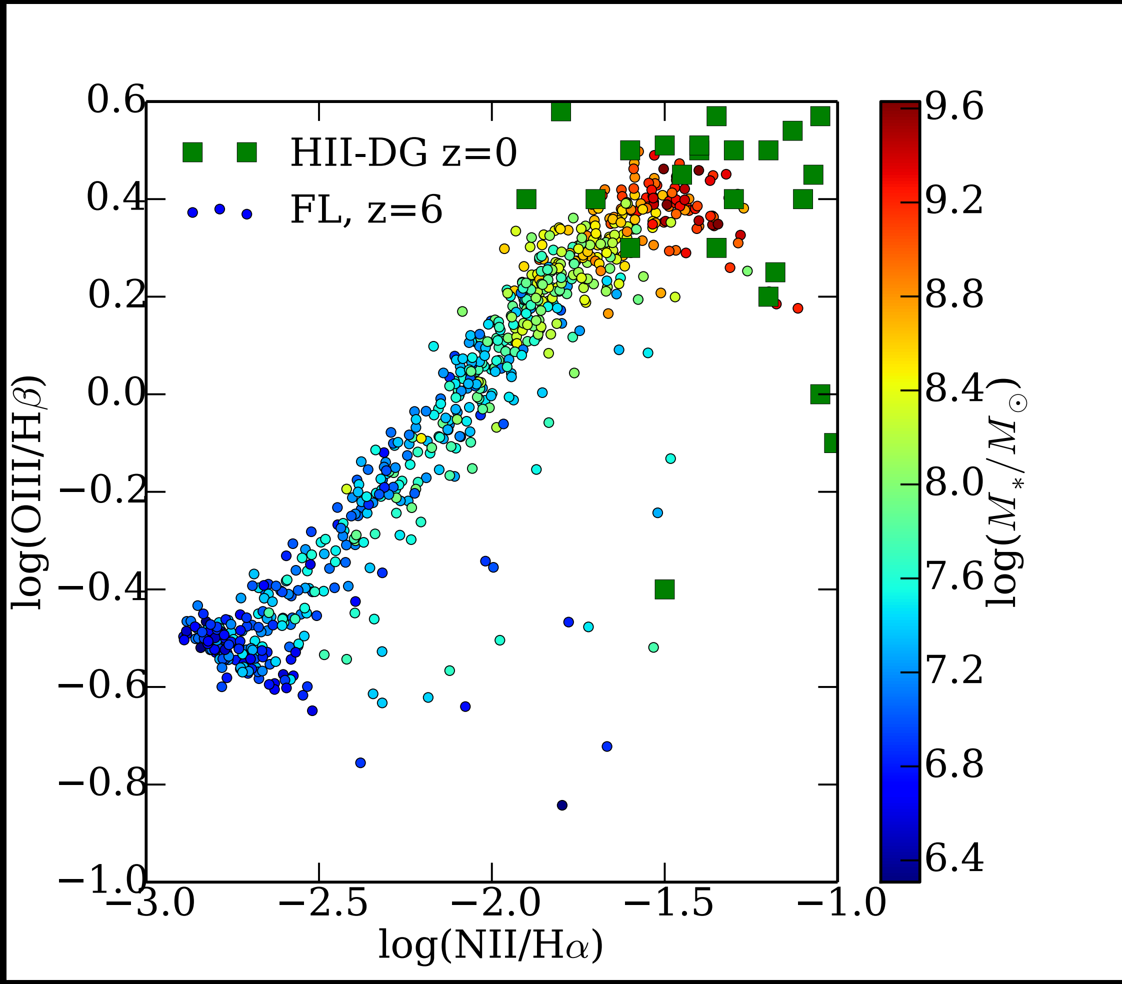


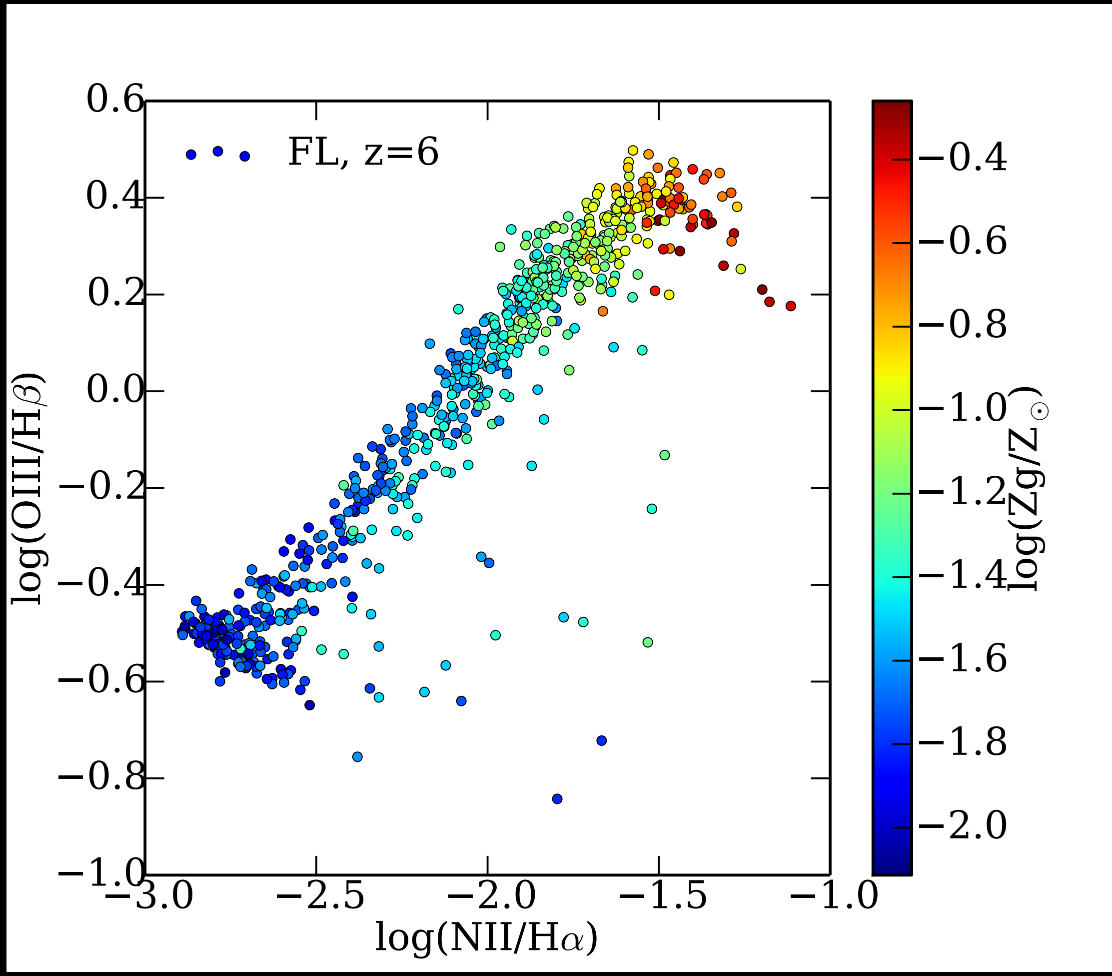
Star-forming main sequence





BPT diagrams





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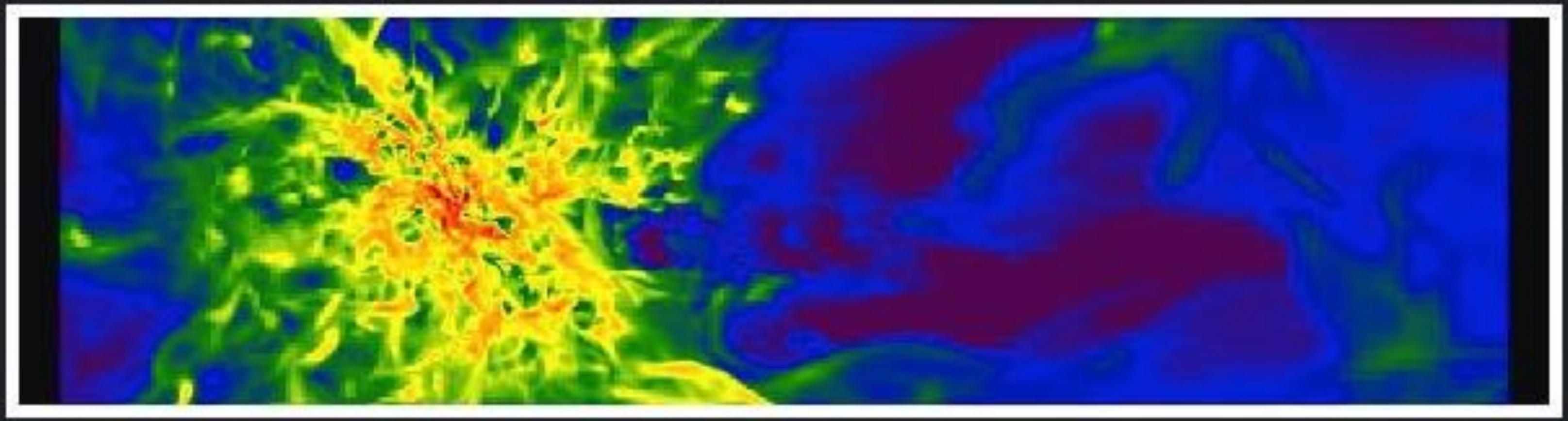
FIRST LIGHT

SIMULATIONS OF FIRST GALAXIES IN THE EARLY UNIVERSE (redshift z=15 to z=5) by Daniel Ceverino



The FirstLight project aims to follow the formation of the first galaxies during Cosmic Dawn (z=5-15), by using the N-body+gas-dynamics code, ART with novel models of feedback and a resolution below 10 parsecs.

DATA RELEASE OF THE FIRSTLIGHT DATABASE:

This release includes the basic properties of the main galaxy progenitor of 290 zoom-in simulations (Ceverino, Klessen & Glover, 2018): virial mass and radius, stellar and gas mass of the galaxy and its SFR aproximately every 10 Myr.

Using this database you can build the star-formation histories of about 300 galaxies with stellar masses between 10^6 and 3 x 10^9 Msun. The evolution of the SFR in each galaxy is complex and diverse, characterized by bursts of star formation. Overall, first galaxies espend 70% of their time in these bursts. This diversity sets the mean and the mass-dependent scatter of the star-forming main sequence at z=5-15. More results can be found in Ceverino, Klessen & Glover, (2018).

DATABASE

How to use this database?

Make a querry

Advanced Tools

Stellar spectra using BPASS2.1_imf135_100

Three take-home messages

- AGORA: Formation and Settling a low-mass disc: V_{max}~100 kms at z~0
- VELA: Formation of elongated Galaxies
- FirstLight: dwarf starbursts during cosmic dawn

THANKS

Fifth Tutorial Section