Cosmological simulations of the Reionization with EMMA: successes and difficulties

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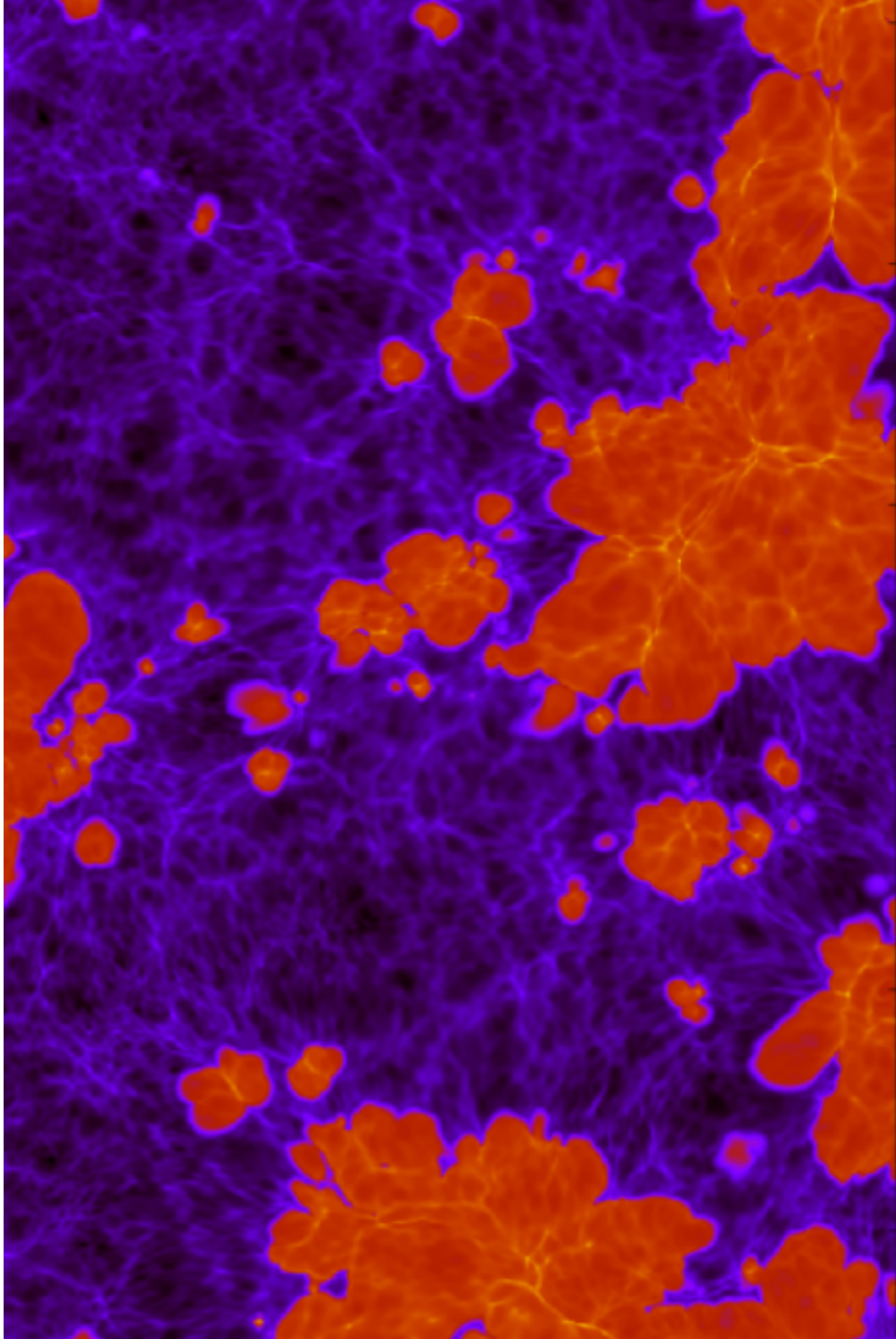
Collaborators: N. Deparis (Strasbourg), P. Ocvirk (Strasbourg), N. Gillet (Strasbourg),



Small galaxies in small reionization simulations

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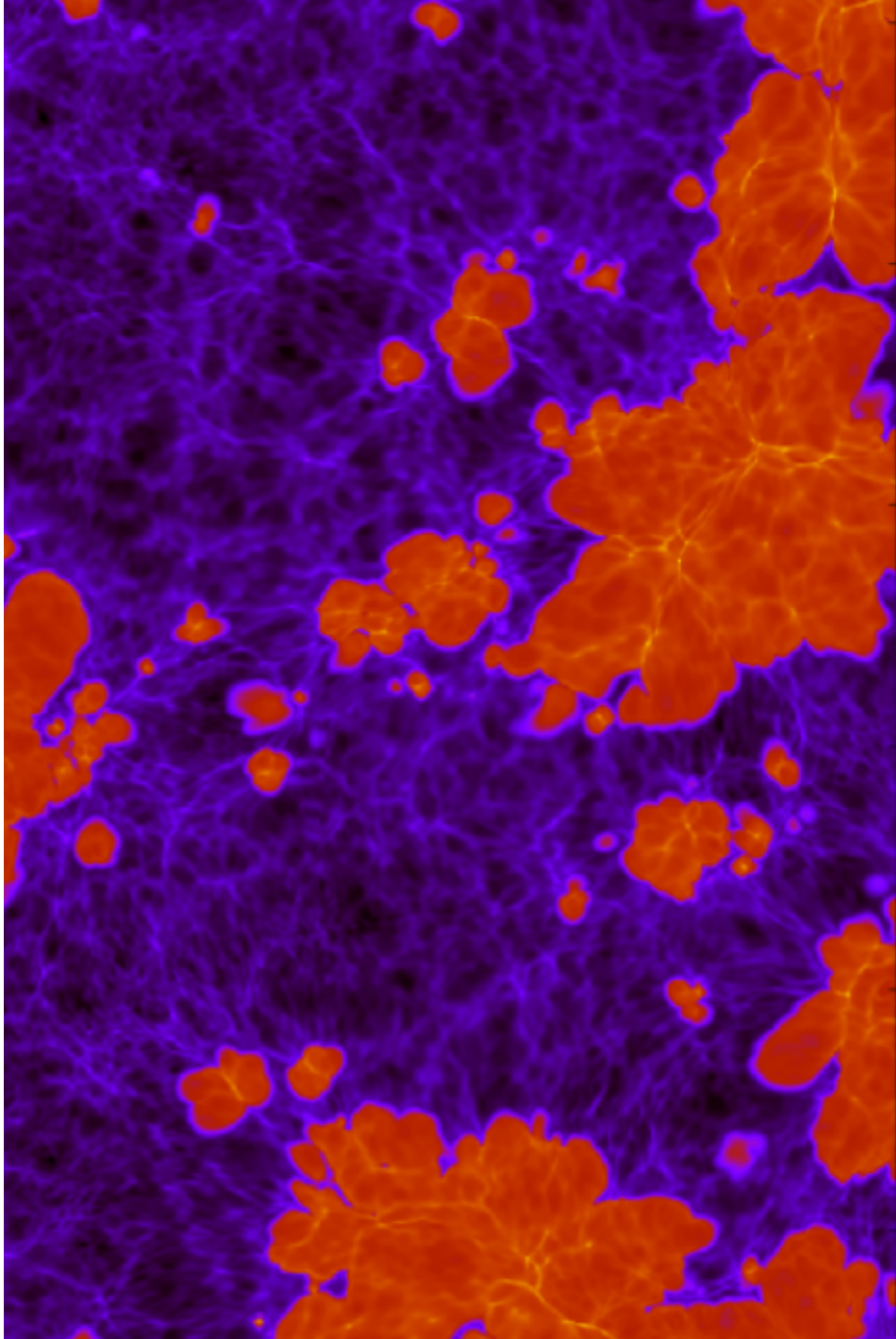
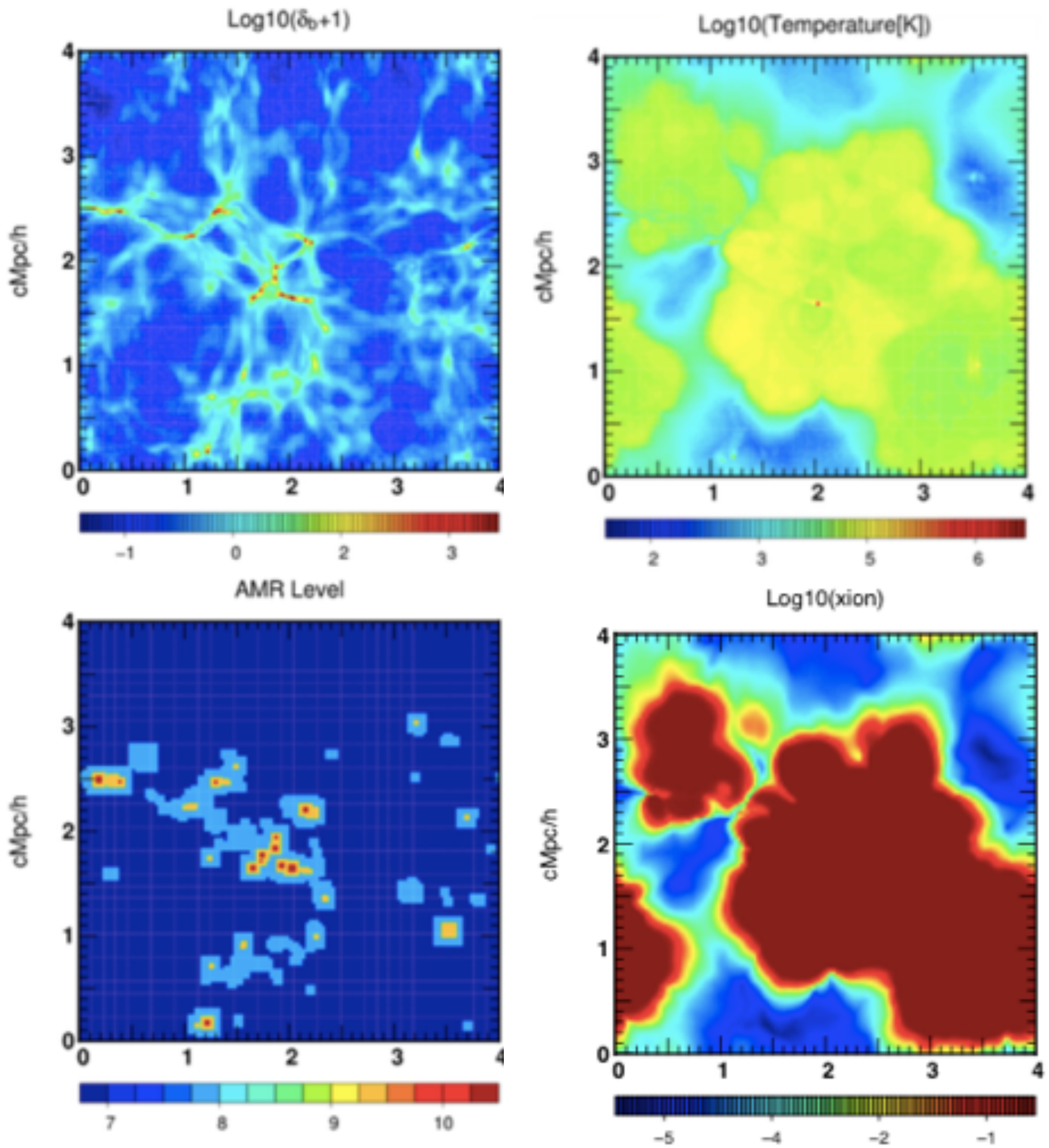


Context/Outline

- ‘First Light’ of EMMA, a new AMR cosmological simulation code with Radiative Transfer & GPU support (Aubert, Deparis & Ocvirk 2015).
- Small suite of small reionization simulations with varying parameters : mostly a test for EMMA.
- Tricky business: ‘stars’. In reionization simulations stars are active during their lifetime through UV radiation (+the usual SN feedback)
- Constraints on e.g. luminosity functions, ionization histories, magnitudes

AMR Cosmological RT with **EMMA**



4 Mpc - 128^3 + 5 AMR levels

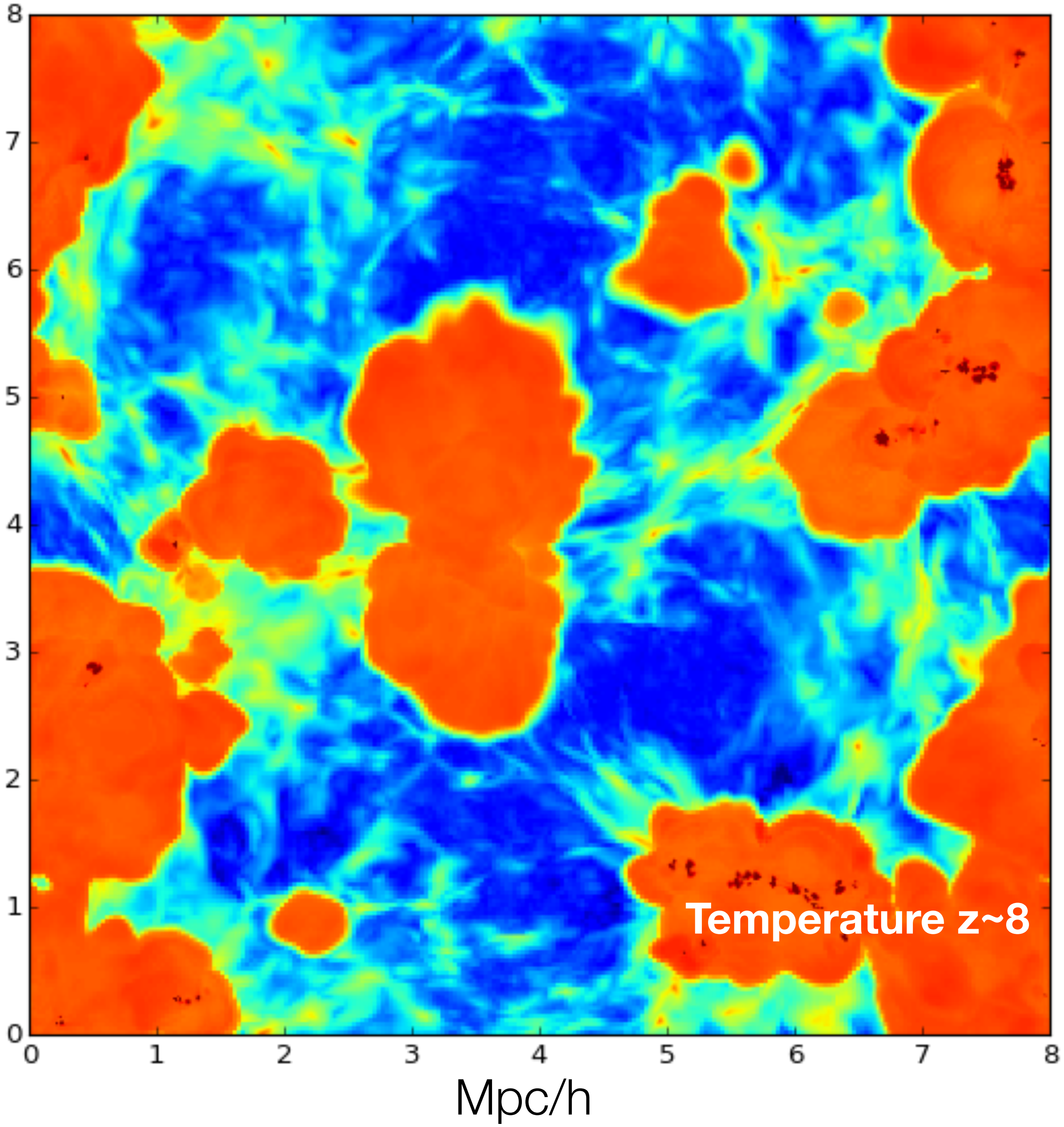
- **E**lectromagnétisme et **M**écanique sur **M**aille **A**daptative
- Full **standalone** cosmological code
- Collisionless Dynamics (PM)+ Hydro (MUSCL) +RT(**Moment Based M1**)
- Full **AMR** radiative transport (like e.g. Ramses-RT (Rosdahl et al. 2013)) or restricted to the Coarse grid with thermo-chemistry on refined levels
- Star Formation + SN Feedback
- C+MPI Parallelisation (scales up to 2048 cores and 1024^3 coarse cells)
- **Optional GPU** (CUDA) acceleration for the Poisson , Hydro and RT solver

Aubert, Deparis & Ocvirk, MNRAS 2015

The Factory

	ATON (or CUDATON) (Aubert & Teyssier 2008, 2010, Chardin+ 2015/16)	RAMSES-CUDATON Ocvirk et al. 2016, CODA sim 64Mpc/4096^3	EMMA Aubert et al. 2015
pitch	Rad. Post-Processing of a pre-existing hydro simulation	On the fly interaction of RAMSES (Teyssier 2002) & (CUDA)ATON	Multi-purpose cosmological simulation code with RT
Radiative hydrodynamics			
Adaptive Mesh refinement (AMR)			
Star formation + SN			
GPU	x 80 (RT only)	(x80) (RT cost ~ 0 thanks to GPU)	x4 vs single core (but x2 Vs 8-cores) (Poisson+Hydro +RT)

Test Models



In this talk:

EMMA (CPU) Simulations : NBody+Hydro + SF+ SN feedback + UV Radiative Transfer

- 16 Mpc/h - 512^3 RT+SN Feedback
- 8 Mpc/h - 256^3 RT+SN Feedback

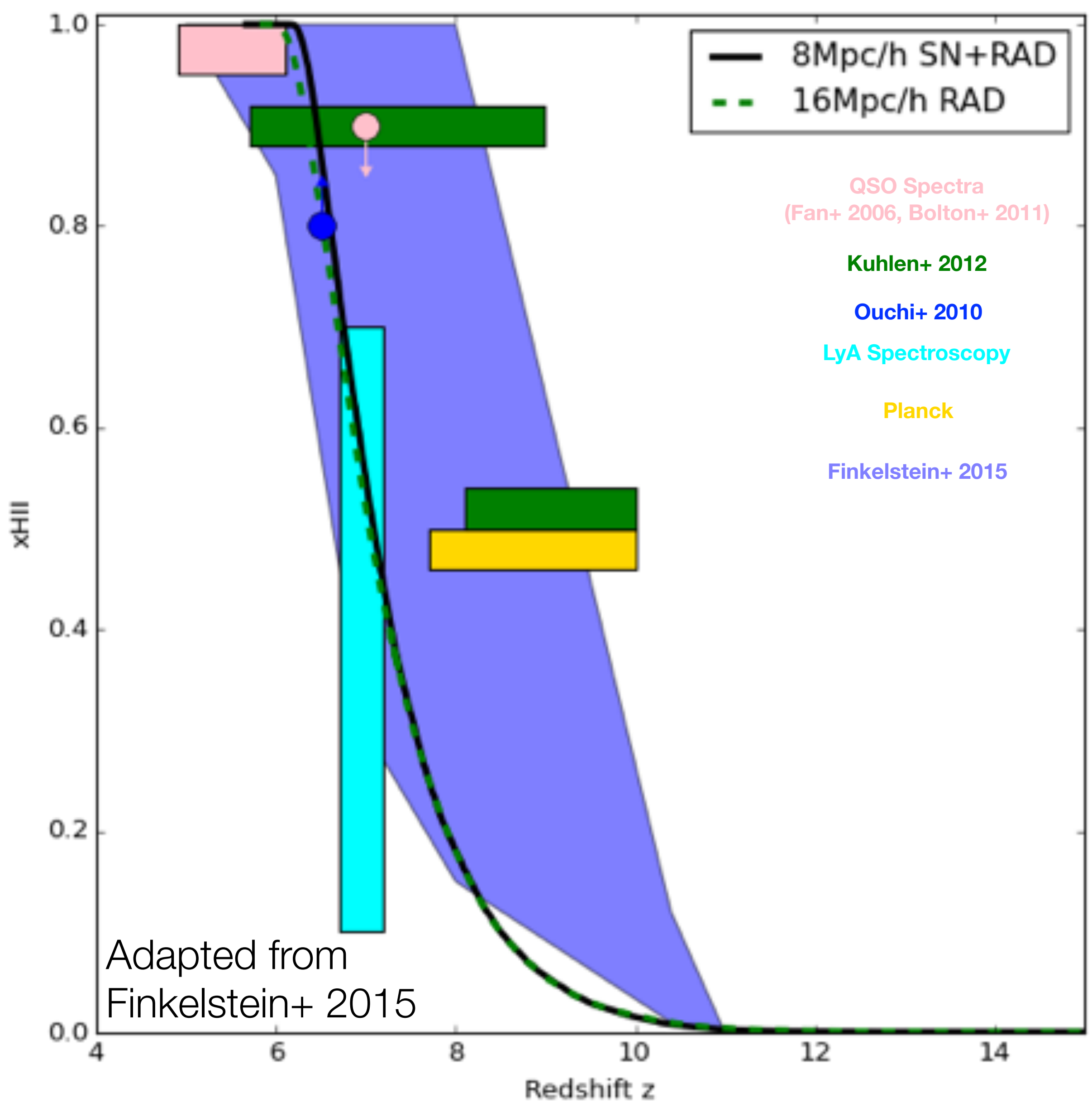
- 8 Mpc/h - 256^3 RT+SN Feedback eUV x 3

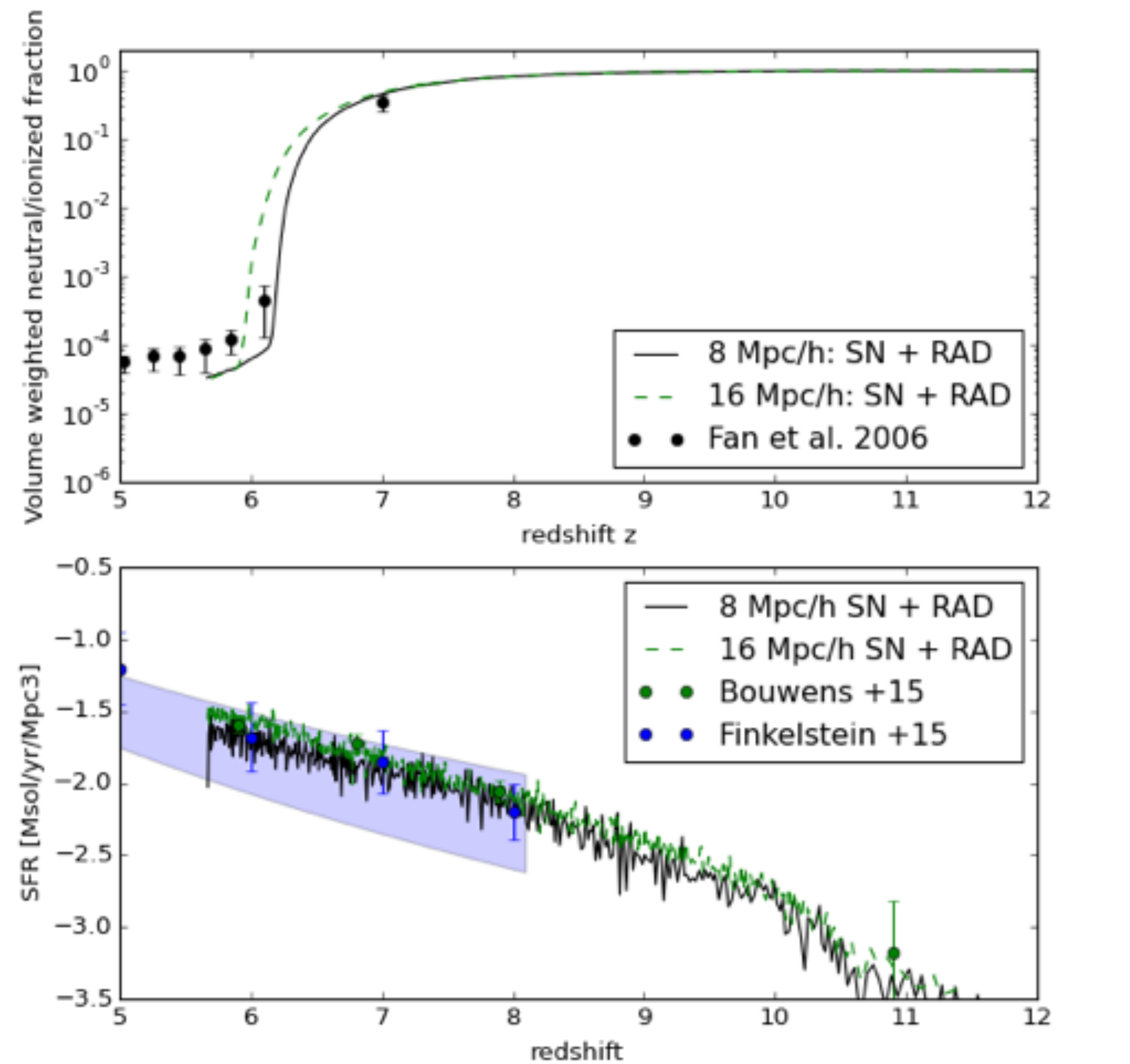
- 8 Mpc/h - 256^3 RT+~~SN Feedback~~
- 8 Mpc/h - 256^3 ~~RT~~+SN Feedback
- 8 Mpc/h - 256^3 ~~RT+SN Feedback~~

- 8 Mpc/h - 256^3 RT+SN Feedback Mstar/64

Mass DM ~3.5e6 Msol
Mass star (Fiducial) ~7e4 Msol
Spatial Resolution 500 pc (physical) : ~3 AMR levels
Stellar Properties : Starburst 99, Z=0.001, Top-Heavy IMF
Massive Star phase ~3 Myrs + SN Feedback, ‘fesc’ =0.3
Reduced Speed of Light c=0.1
Planck+ 2015 Cosmology, Eisenstein & Hu TF

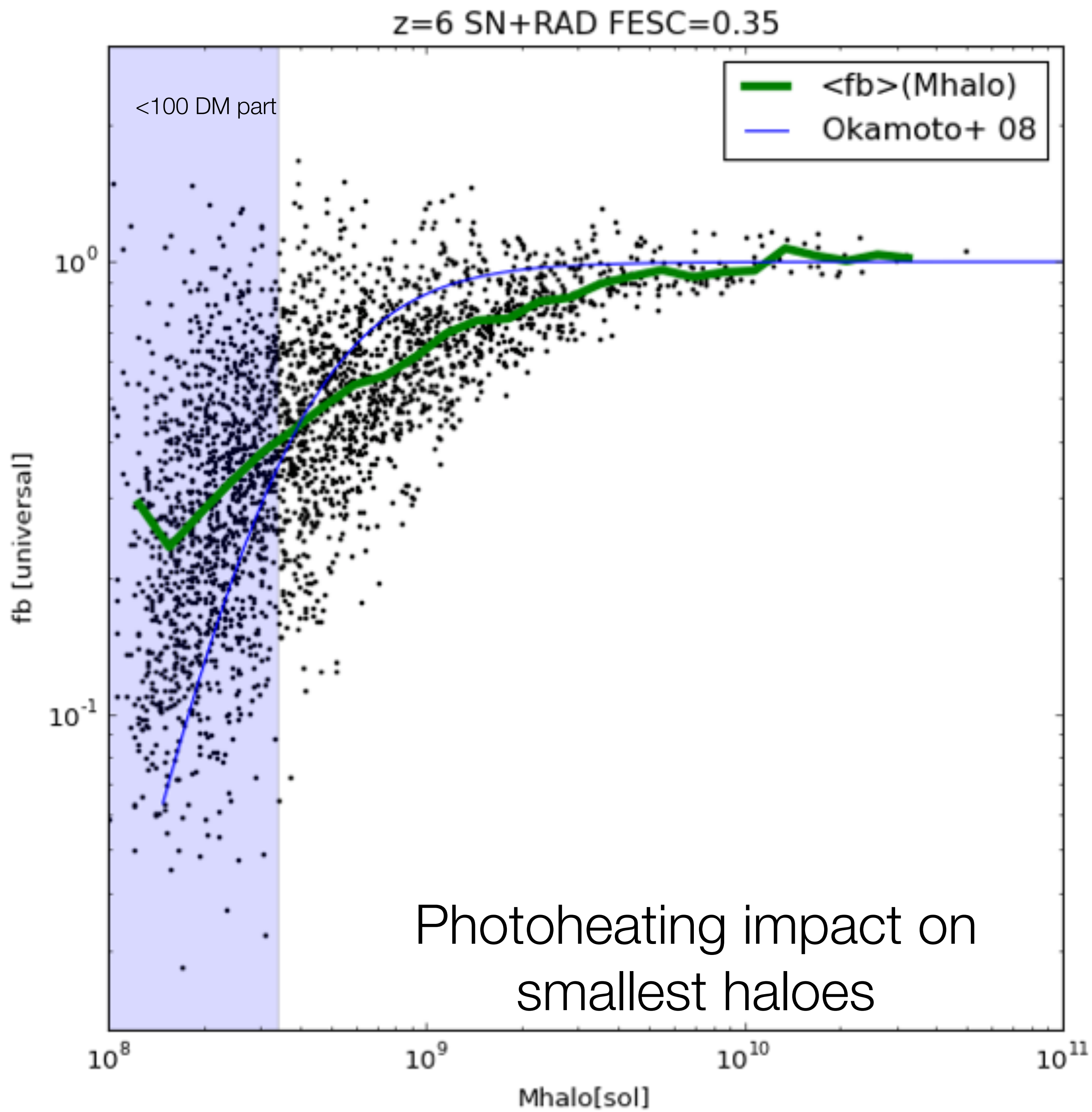
Global Reionization and Star formation history



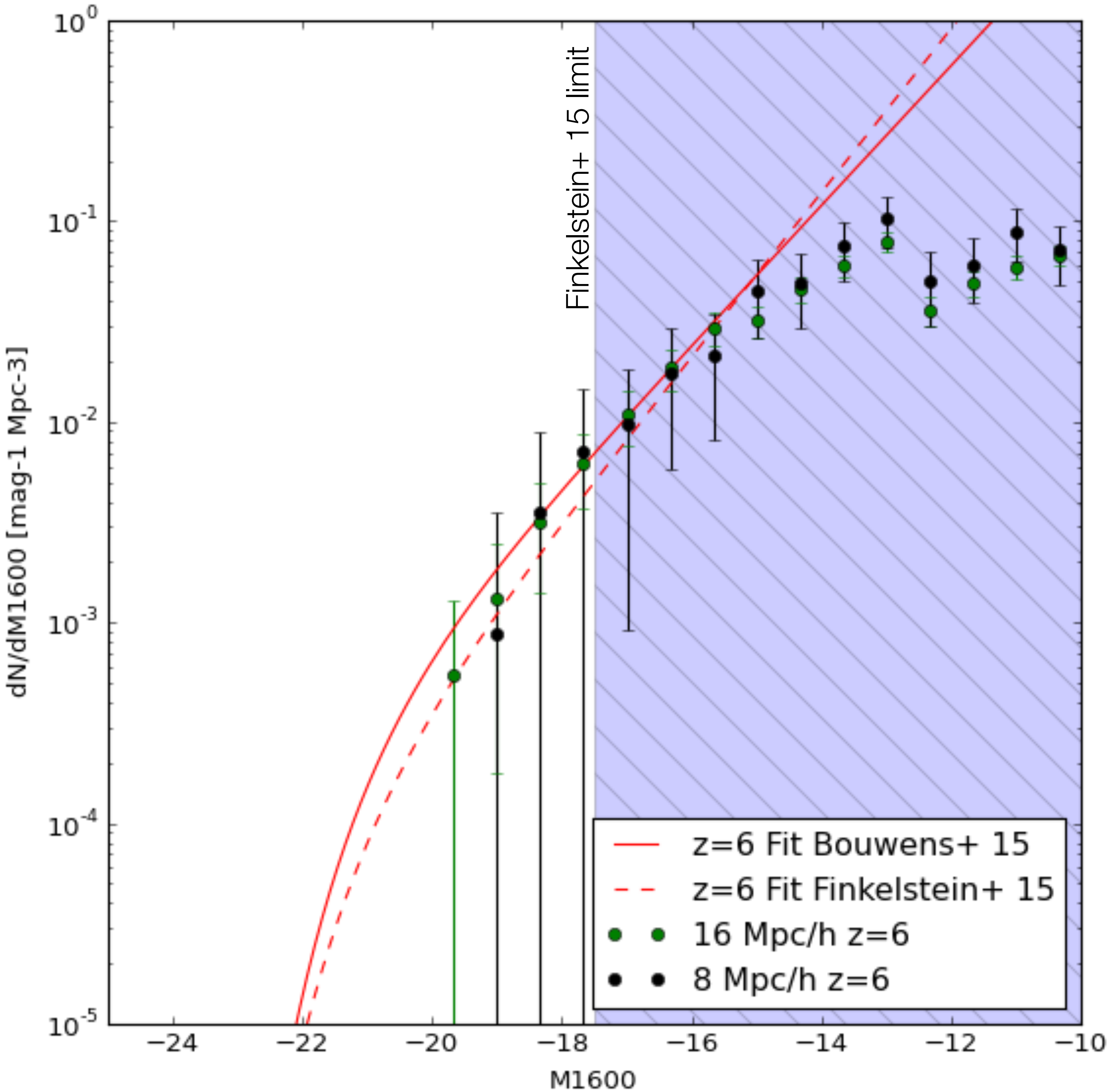


Reasonable agreement can be found with xion/SFR cosmic constraints
(Note : boxes are small)

Baryon Fraction



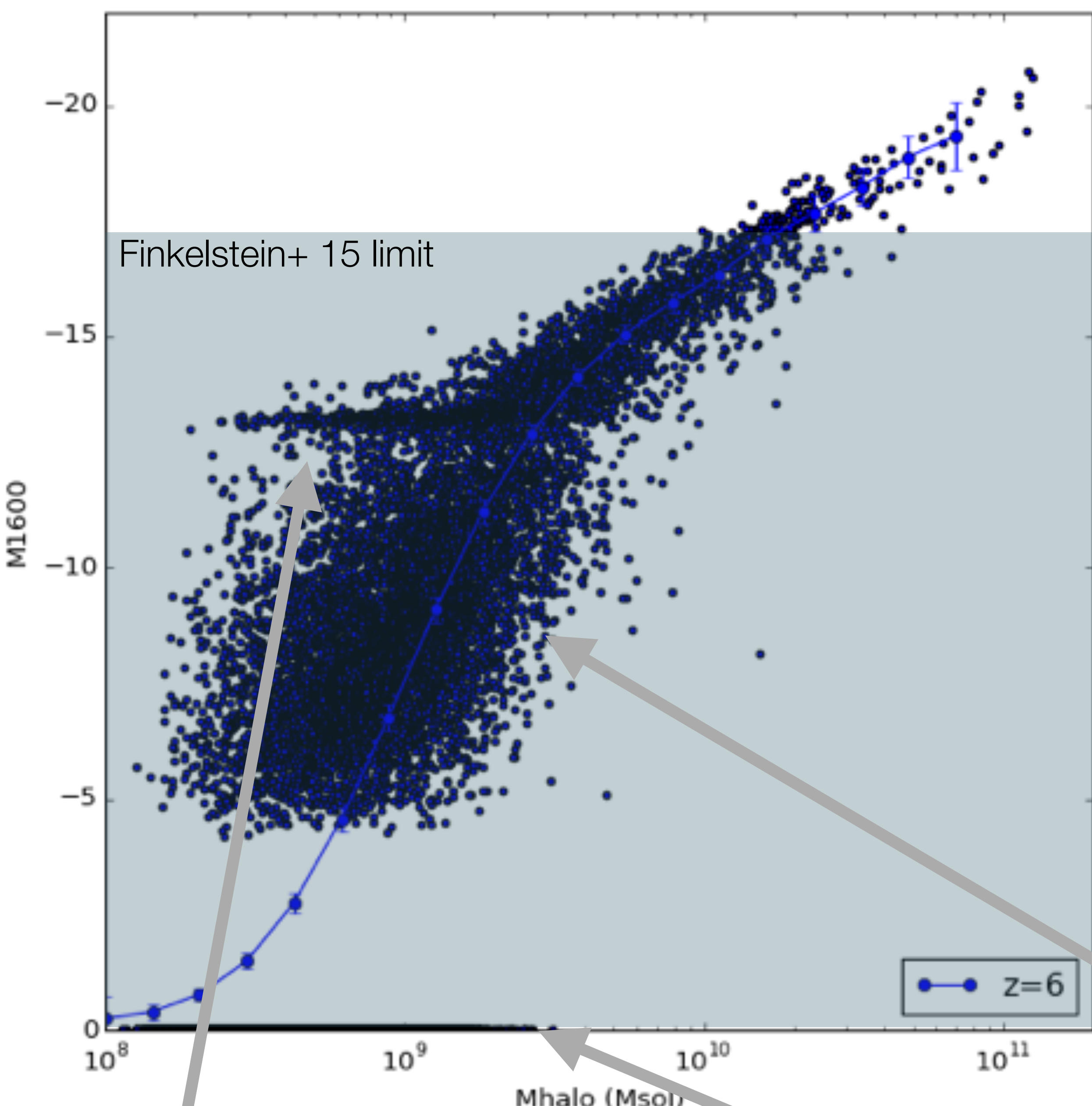
UV Luminosity Function (z=6)

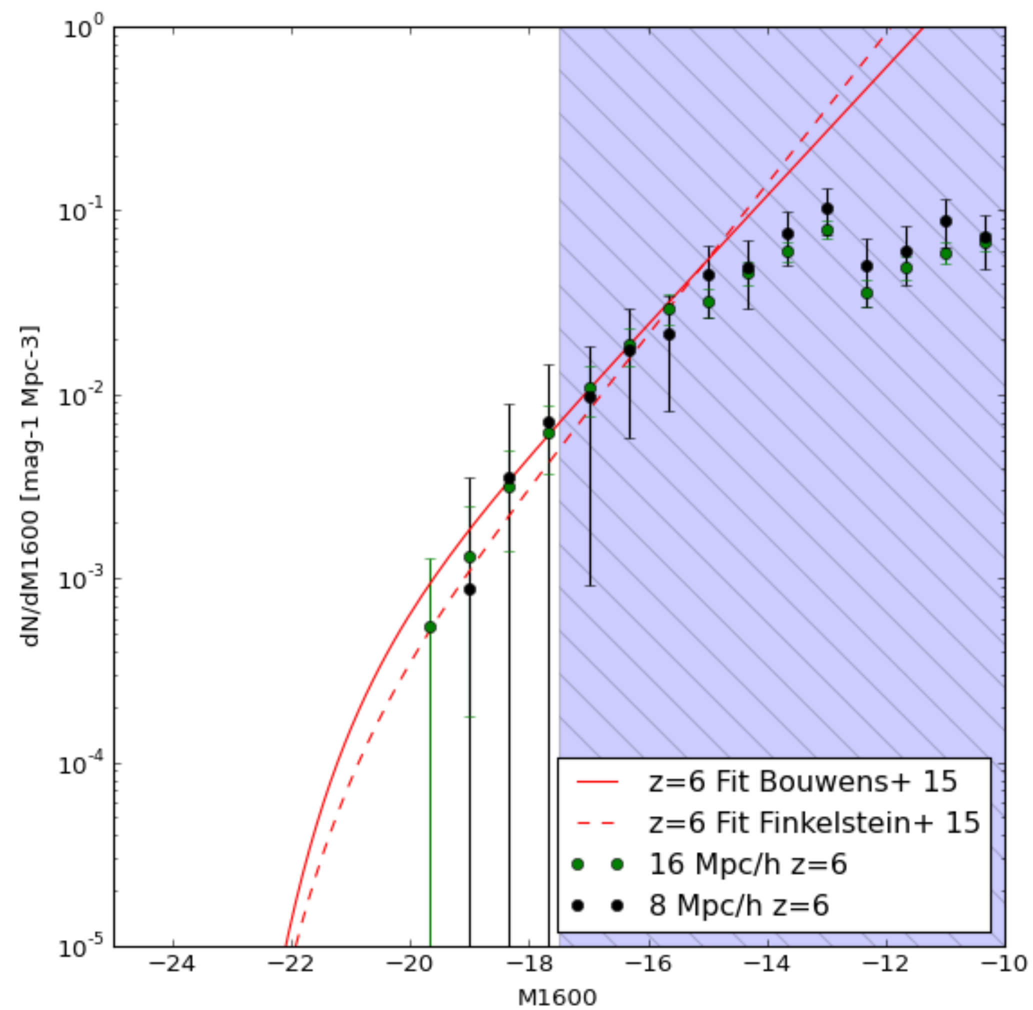


No Obvious flattening for M1600>-15
Different slope for -13 <M1600 <-15 **?**
Flattening M1600>-13 **???**

Glitch @ M1600~ -13 ?

Mass-UV Magnitude Relation (z=6)





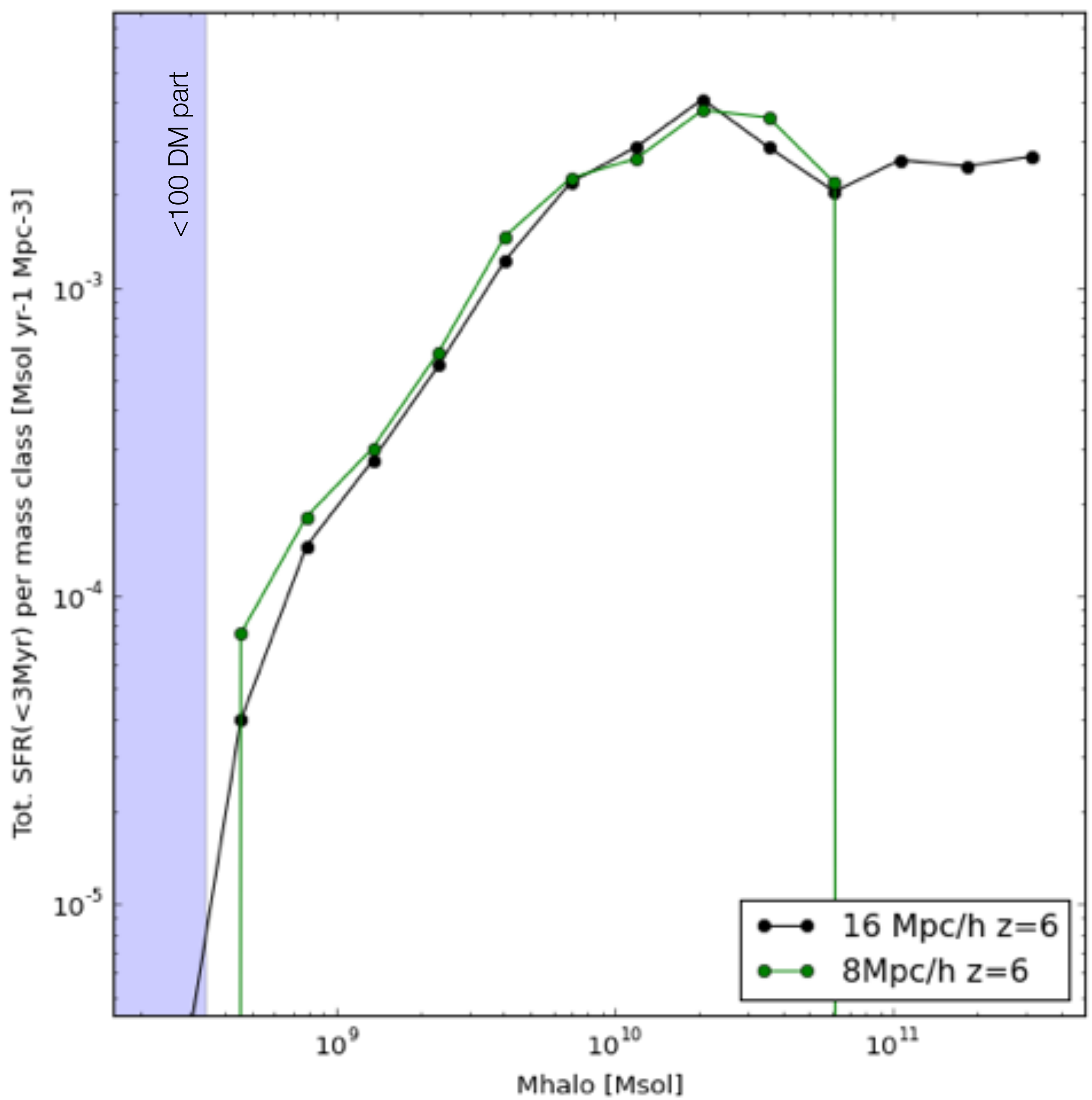
Large Scatter :
up to 7 orders at a given Mass
up to 1 order at a given Magnitude
Two slopes in the Muv - Mass space ?

Dark Halos

Ageing populations, controlled by stellar population model

Discreteness Spike
Single star magnitude

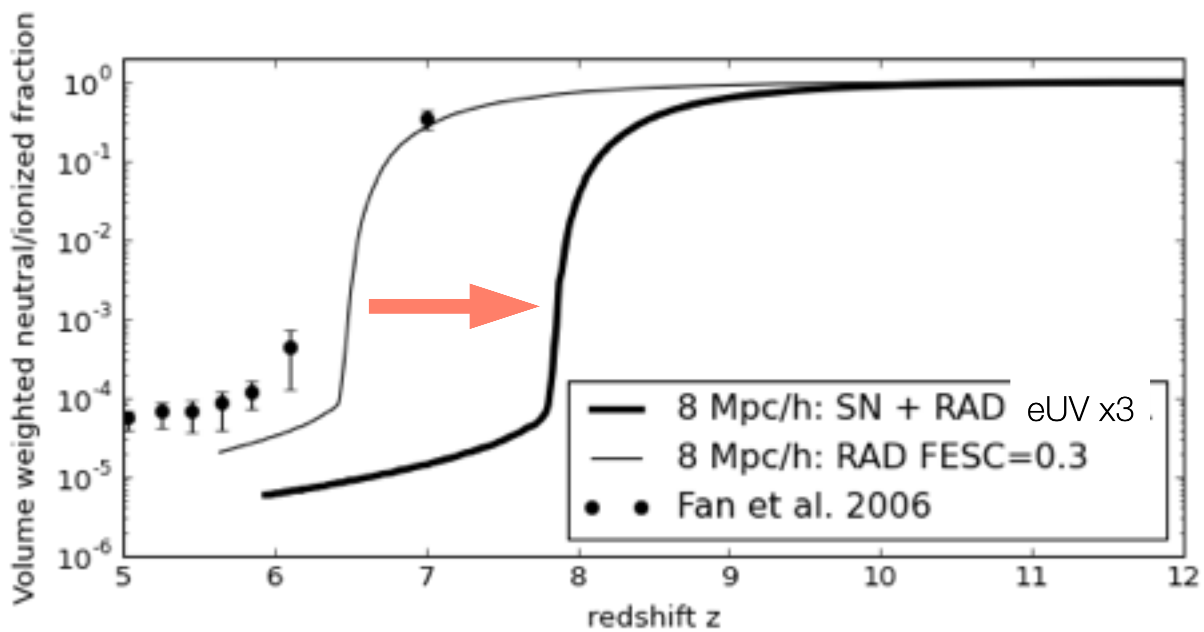
Star Formation Contribution per Mass Class

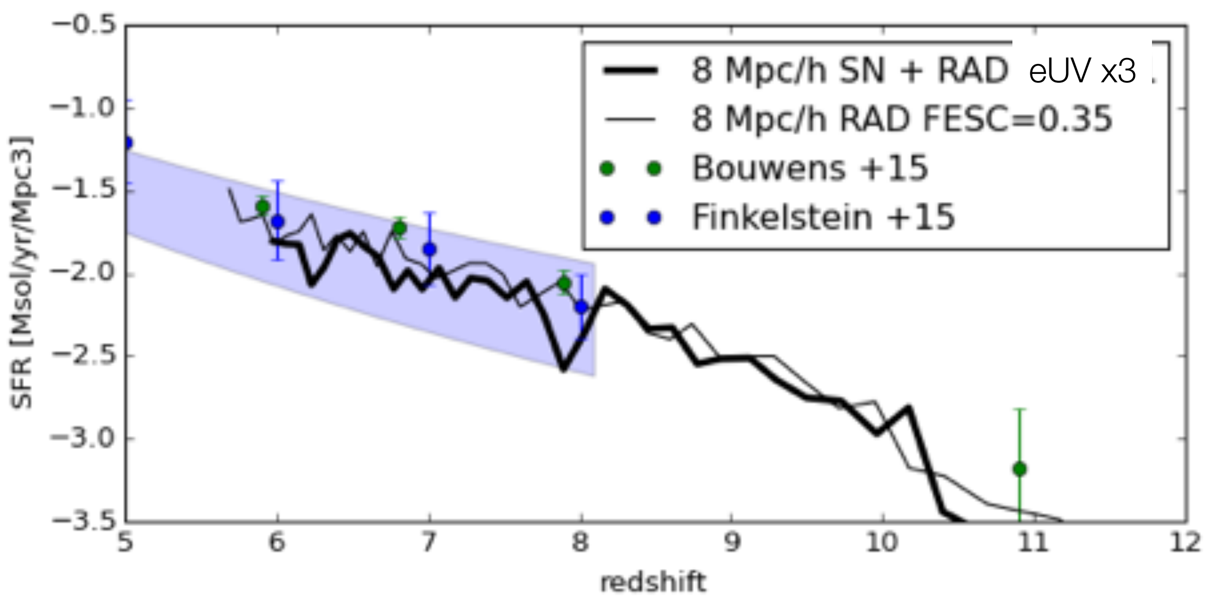


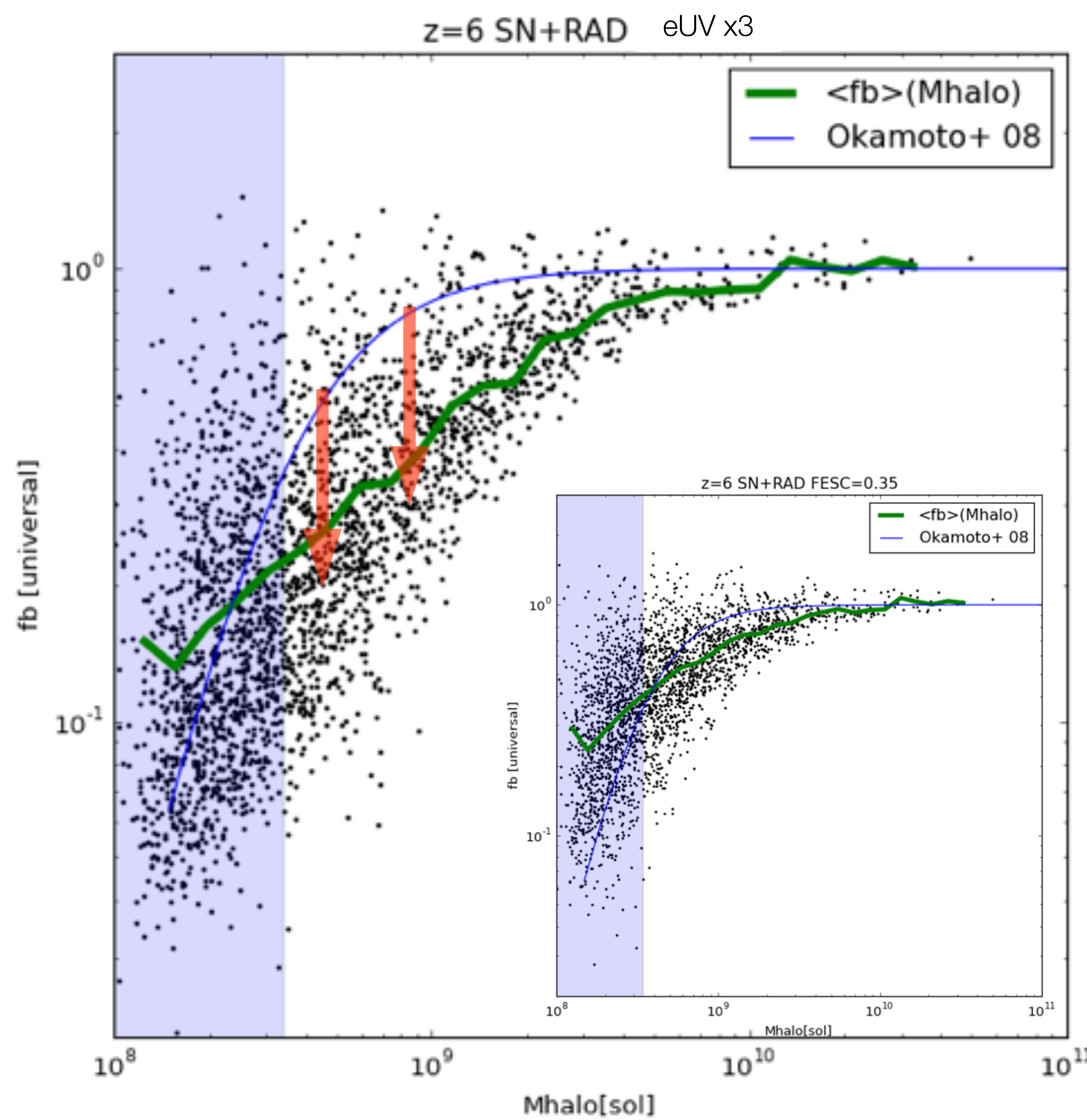
$$N(M_{\rm halo}) \times {\rm SFR}(M_{\rm halo})$$

Severe drop in SF contribution for M < 1e10 Msol
Role of large halos -> convergence ?

Varying the UV Emmisivity (X 3)

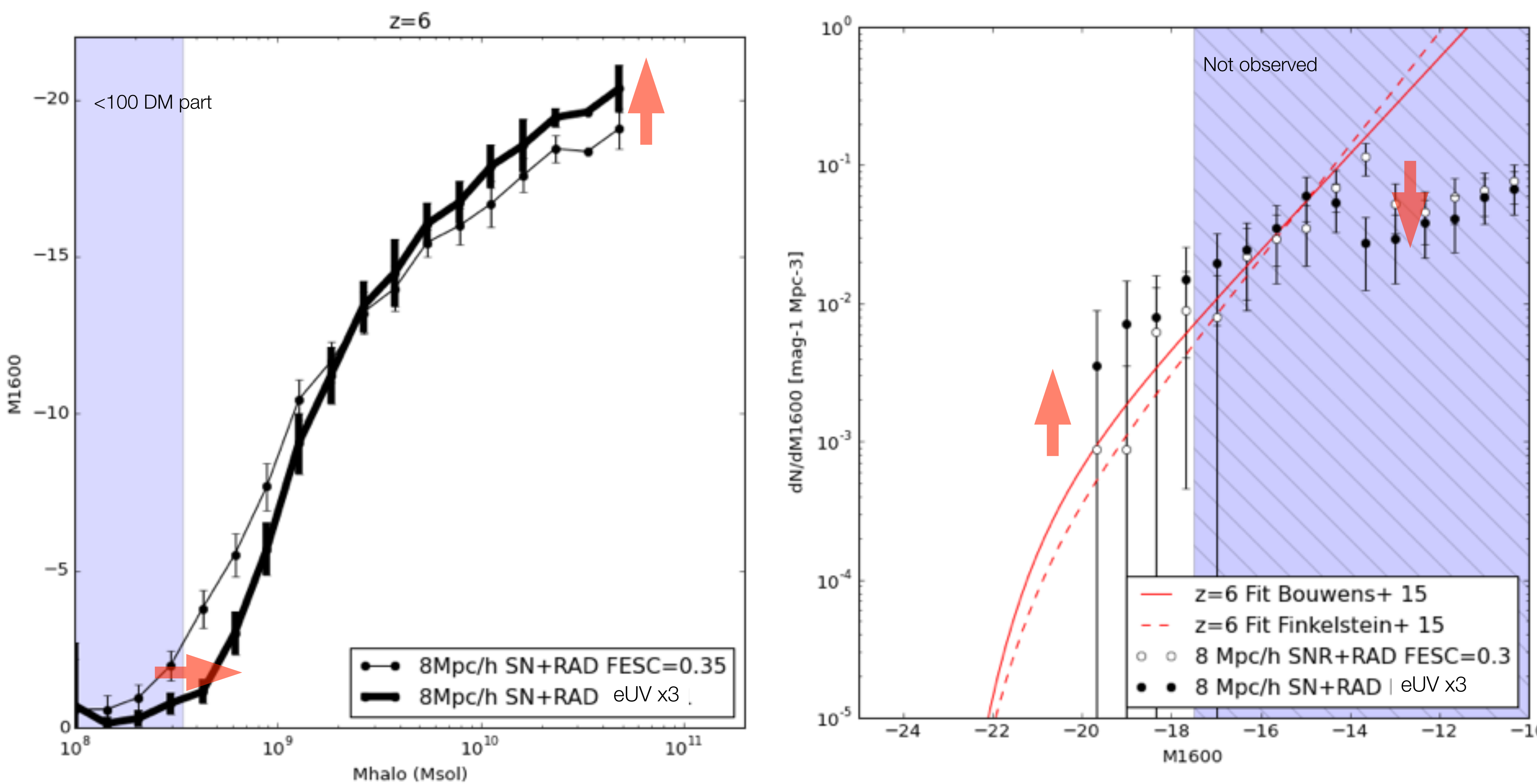






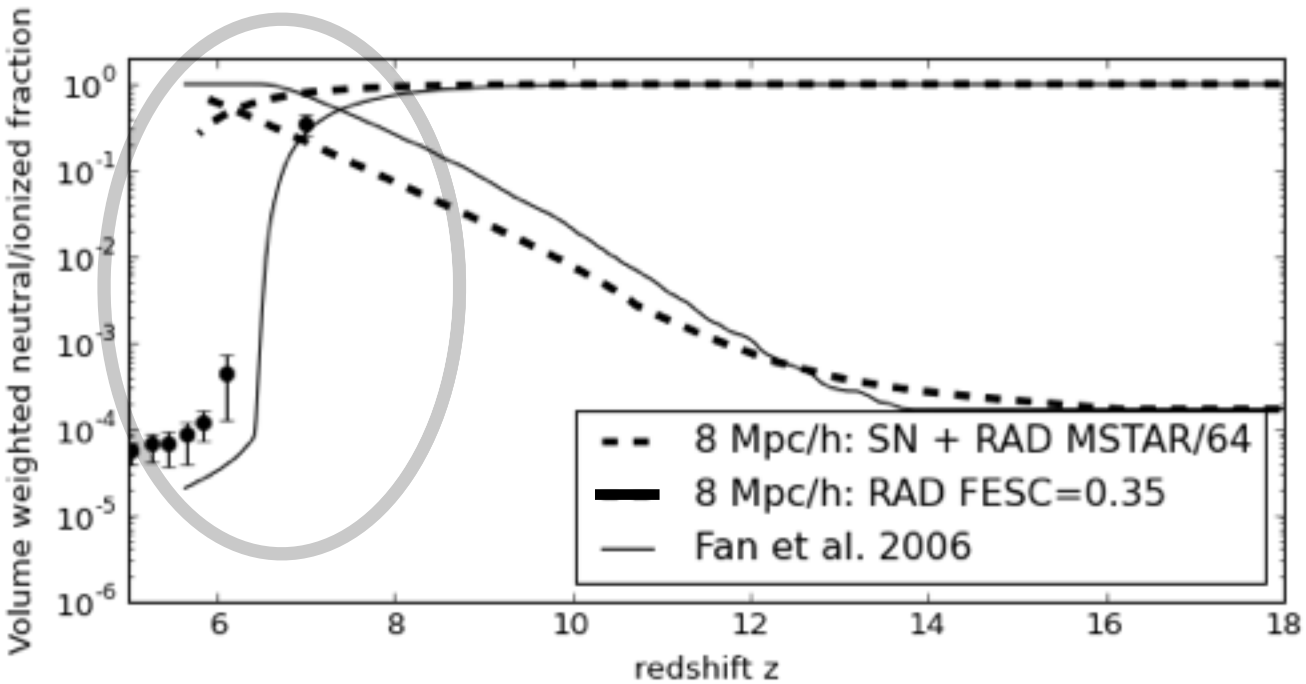
A greater emissivity leads to a faster reionization without significant impact on the global star formation history

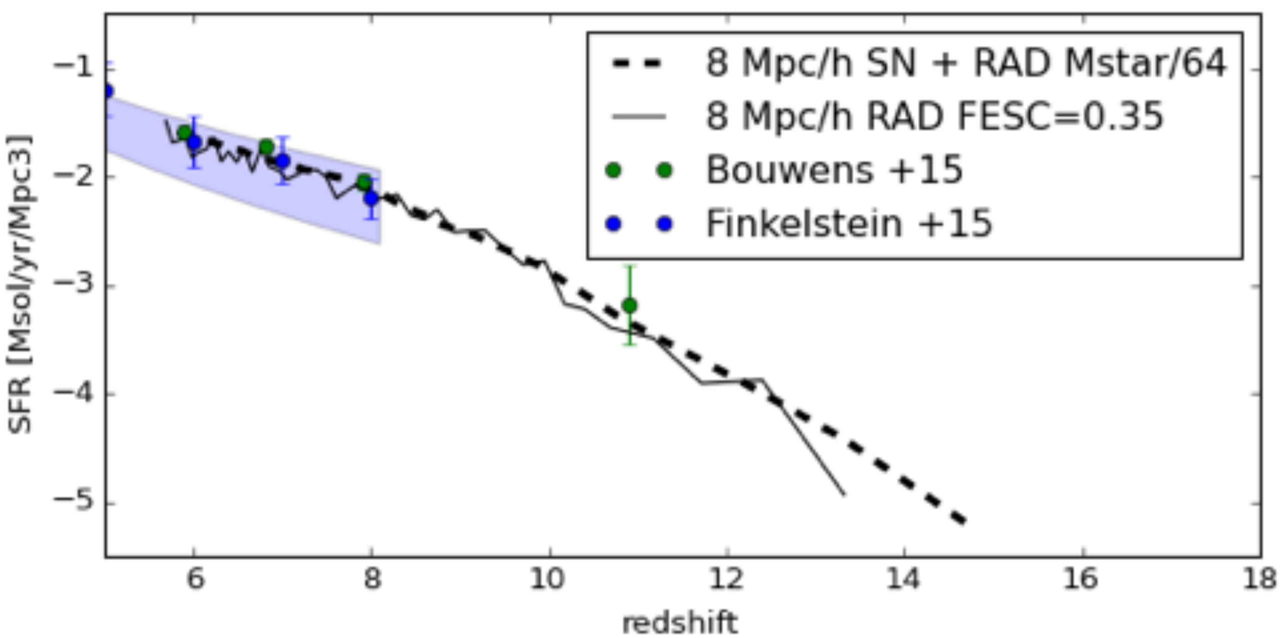
Varying the UV Emmisivity (II) : impact on brightness

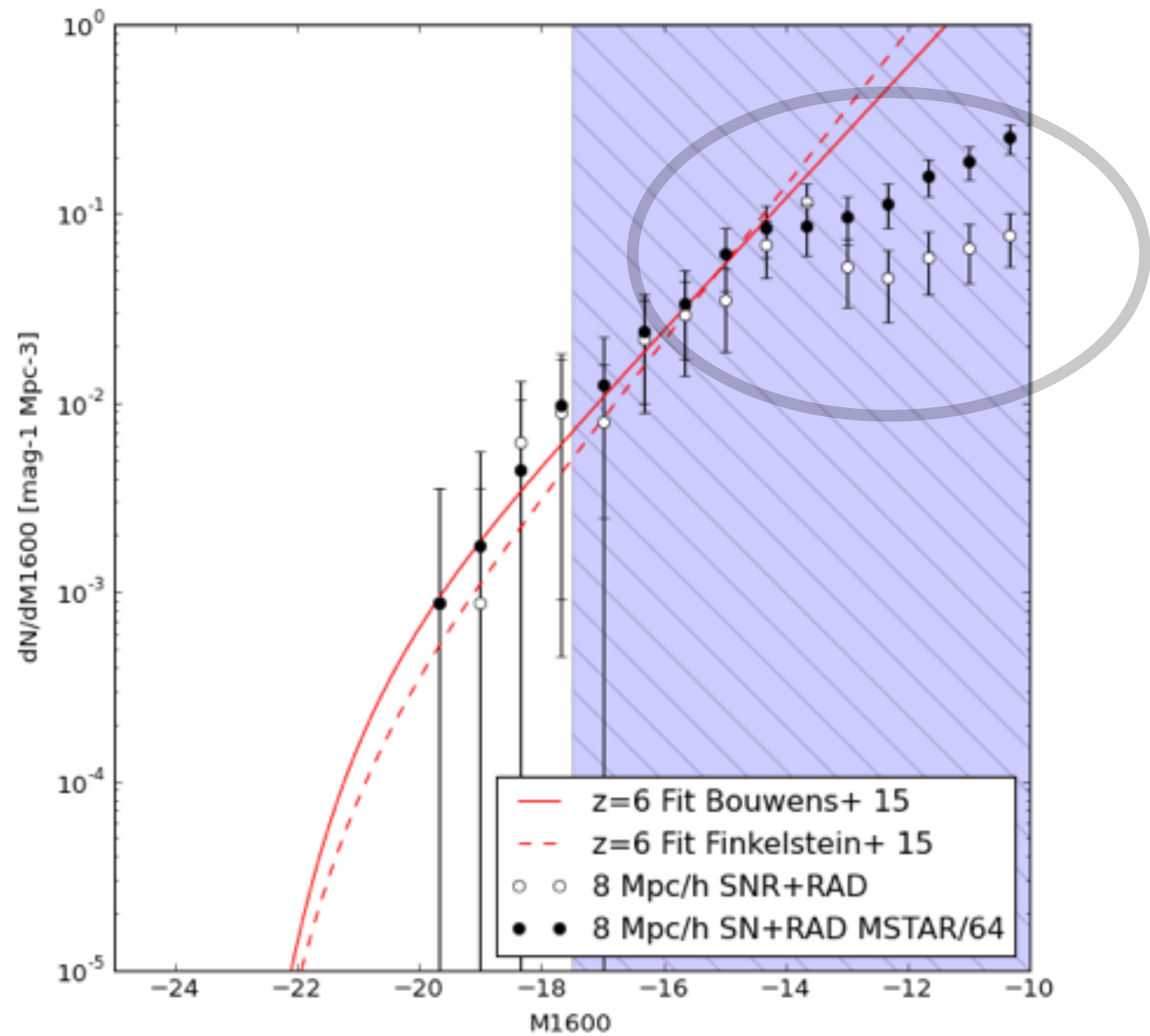


Small Objects are further suppressed by a greater emissivity
Larger ones are brighter
The LF slope present a global flattening + greater amplitude at bright end + decline at faint-end

Source Discreteness :
massive stellar particles Vs light ones







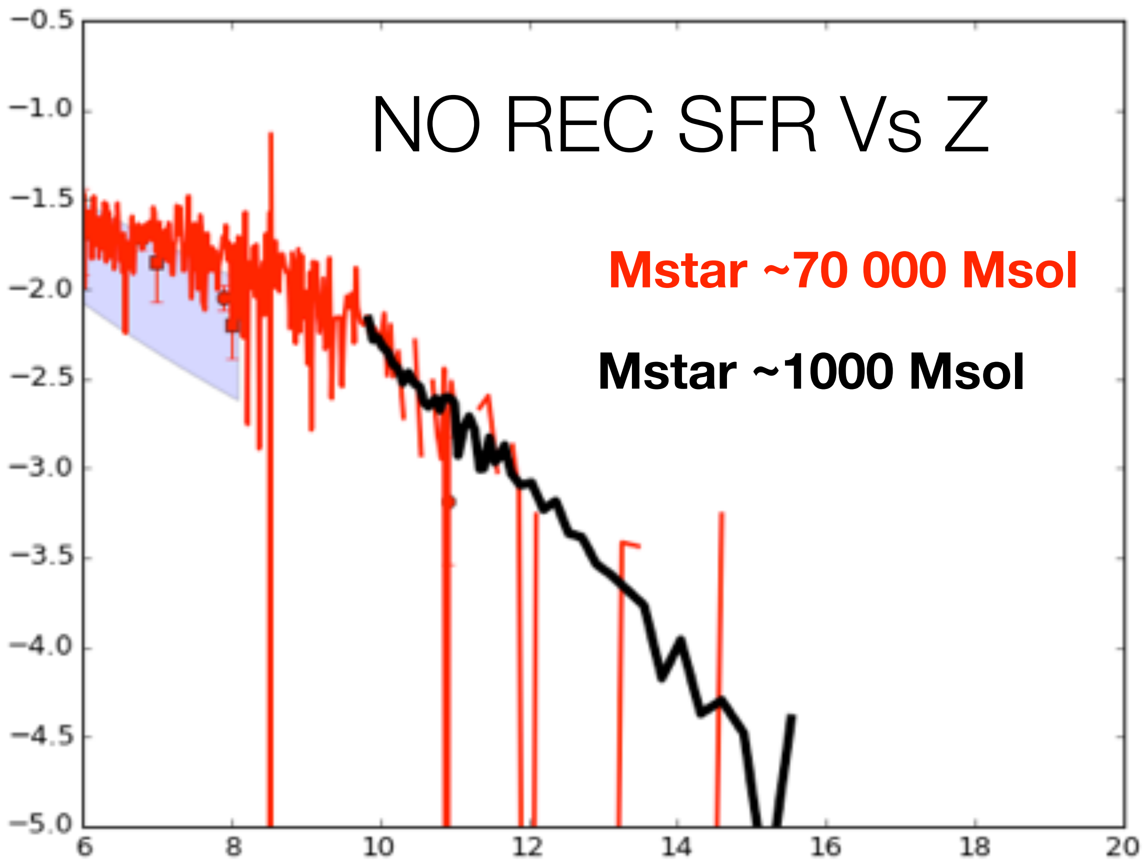
Mstar~ 70 000 Msol

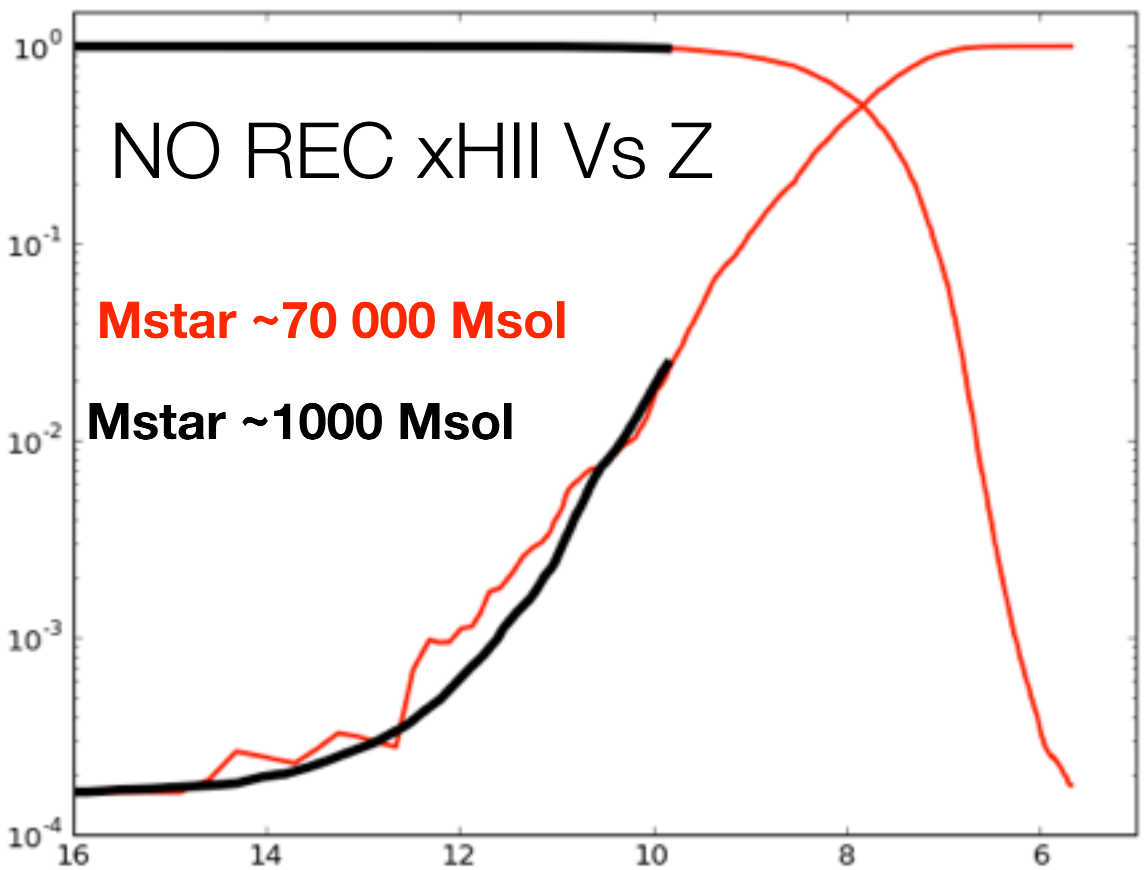
Mstar/64 ~1000 Msol

Different reionization with similar SFR/LF

Also seen in RAMSES-CUDATON…

Reducing recombinations in source cells



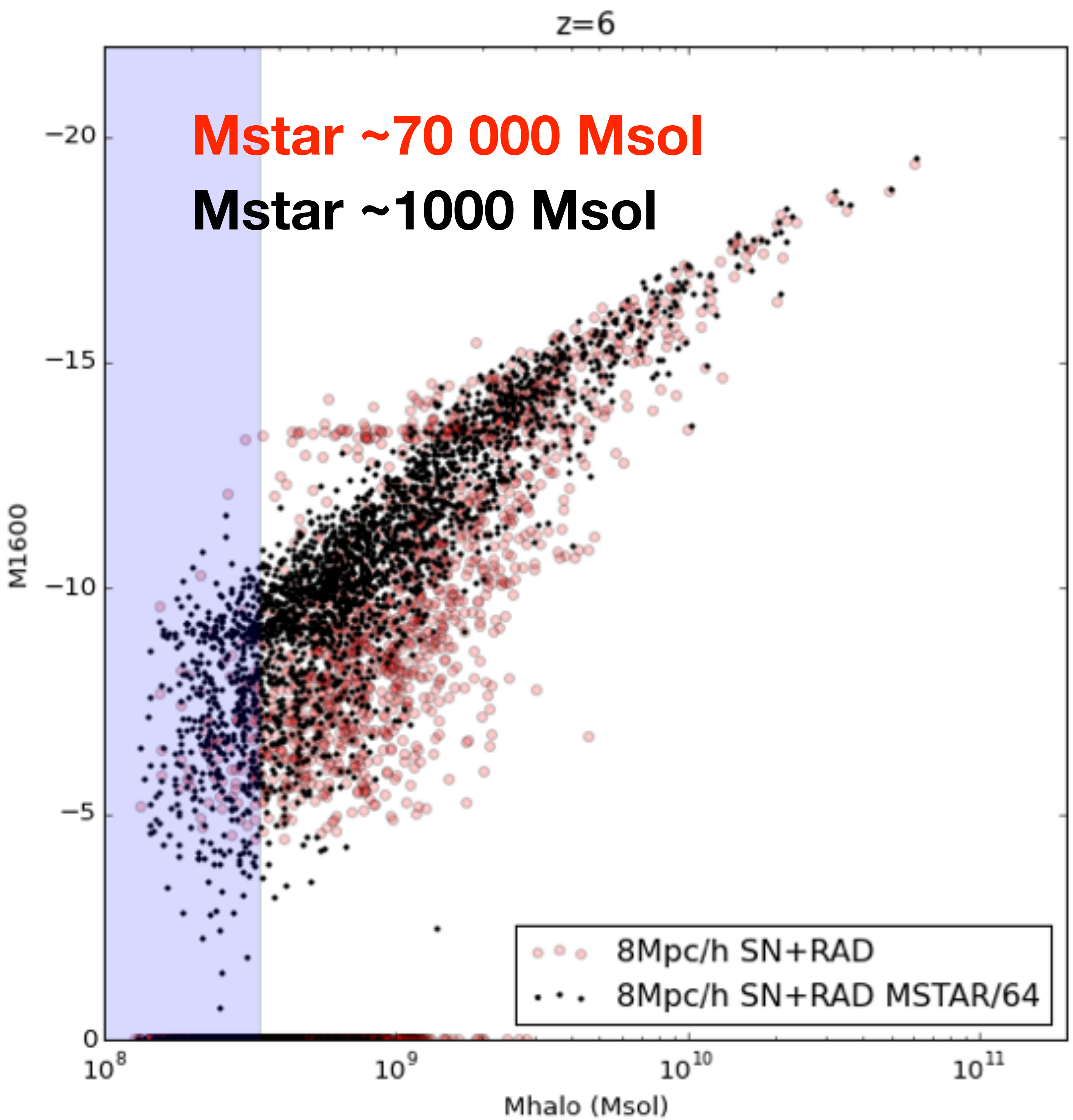


Radiation can be trapped locally (within a cell) is the source is too small
The effective escape fraction is sensitive to spatial resolution

$$r_{\rm cell} \sim r_{\rm HII}$$

By reducing recombination (hence increasing r HII) in source cells, convergence is recovered

Source Discreteness (II)



- Larger populations -> larger scatter
- The 10^9 Msol bend seems real
- Does it tell us something about bursty star formation ?
- escape fraction is resolution dependent
- Stell Pop Model & Stochasticity could be essential for further progress

Conclusions

- New AMR code EMMA
- Small set of tests simulations
- Simultaneous match of SFR, xion(z), LF

- Results seem to be quite sensitive to source modeling
  - population models (e.g. ageing)
  - discretization (e.g. effective escape fraction)

Cosmological radiative hydrodynamics simulations open new possibilities to understand the physics at play but also comes with new challenges and difficulties

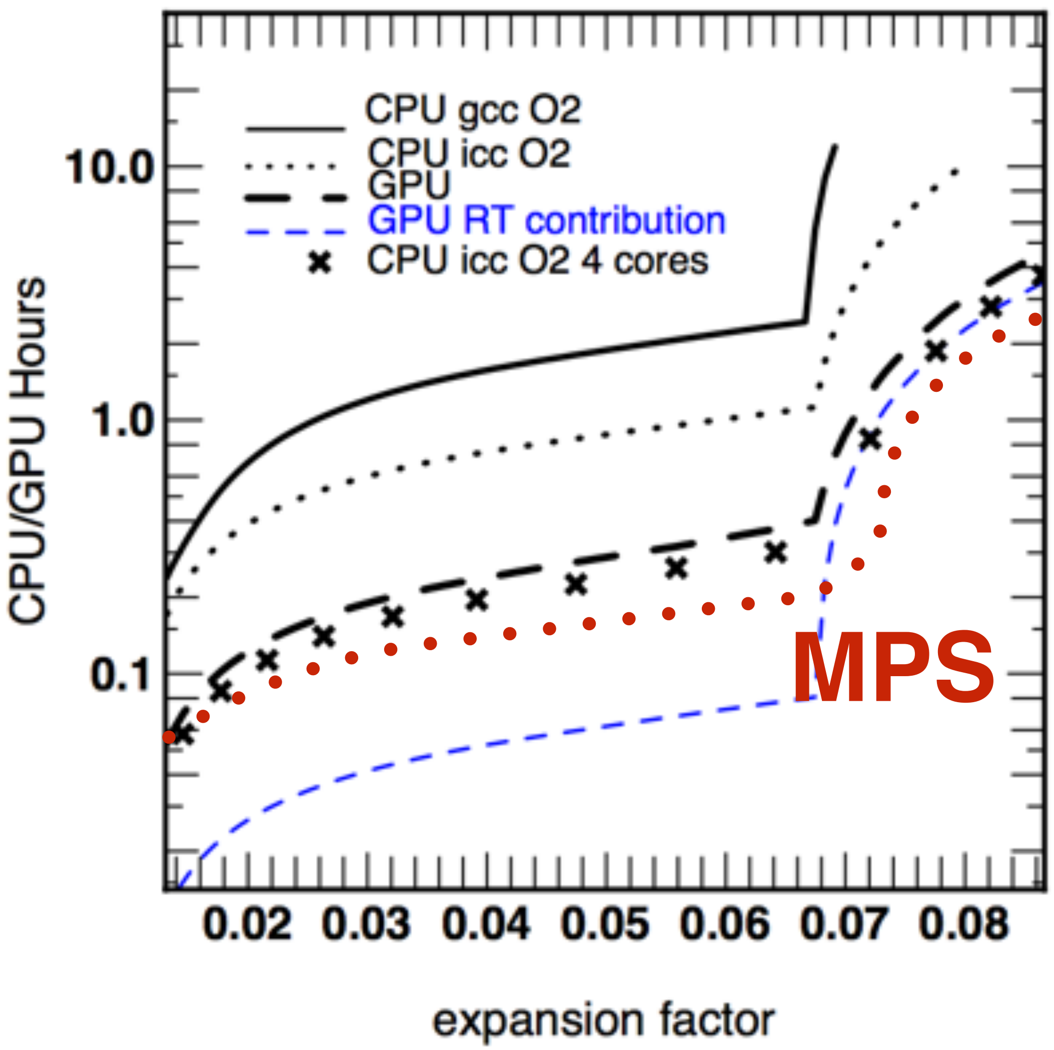
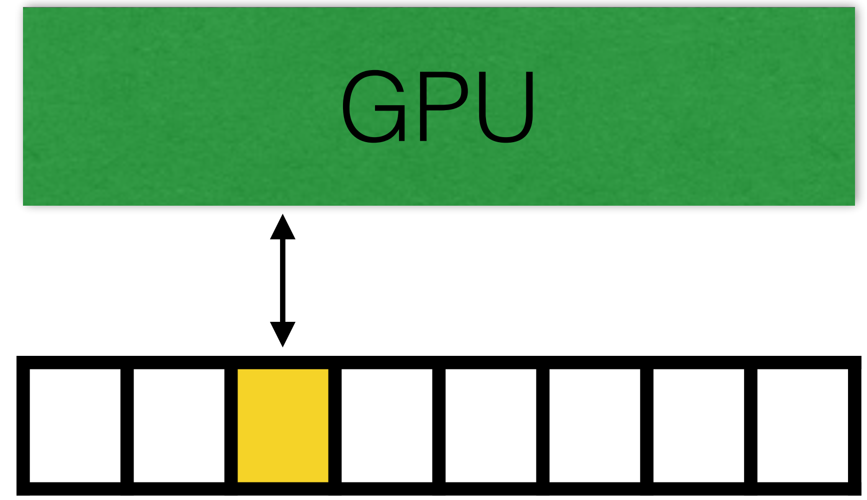
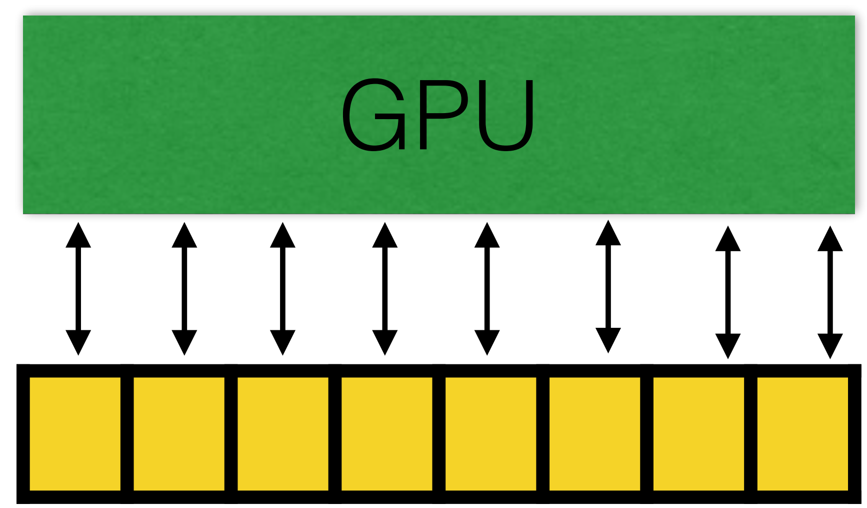


Figure 22. Comparison of the cumulative time spent to reach a given expansion factor for a 4 Mpc/h-128^3 cosmological simulation of the reionization. Times are given for a single computing device (i.e. 1 GPU or 1 CPU core). The thick black dashed line stands for the GPU run performed on a M2090 Nvidia GPU whereas the thin dashed blue line stands for the contribution of radiative transfer to this cost. The black solid (resp. dotted) line stands for a single CPU core (2.7 GHz Sandybridge Westemere) using the *gcc-O2* (resp. *icc-O2*) binary. The symbols stand for a 4-core CPU calculation using *icc-O2* on a Curie node.



1 core +1 GPU **(x4)**



MPS Enabled

8 cores +1 GPU (**X2**)

1 core Vs 1 core +1GPU x4
8 cores Vs 8 cores +1GPU x2

MPS on Titan