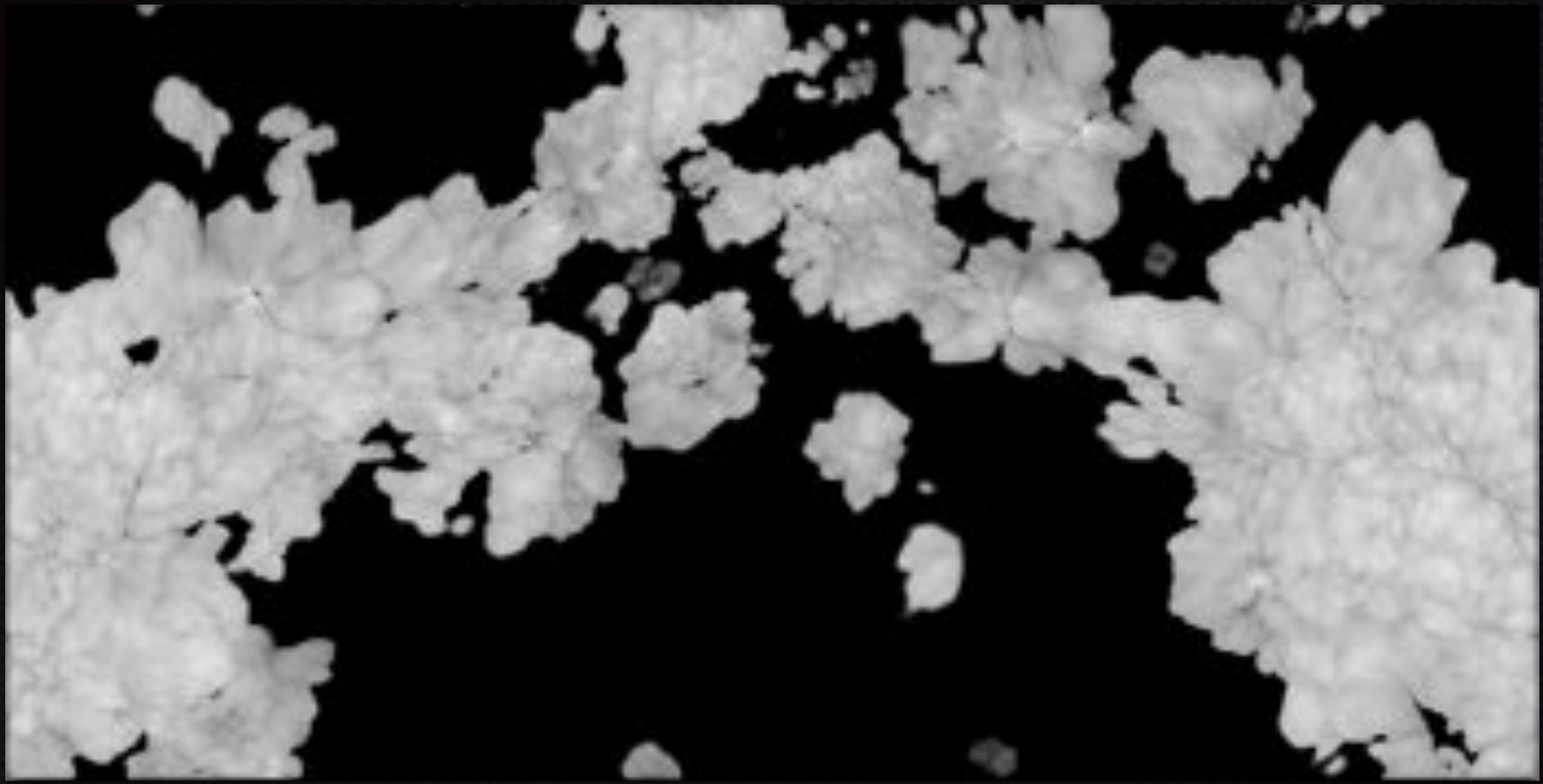
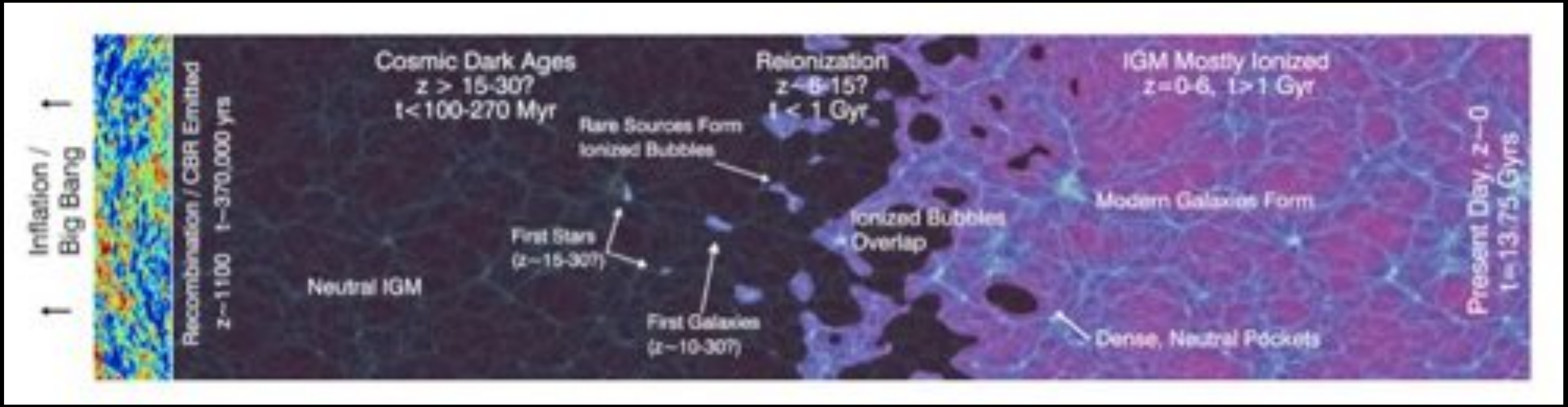


Numerical Models of the high-z Universe

Dominique AUBERT
Observatoire Astronomique, Université de Strasbourg

EOR

Robertson et al. 2010



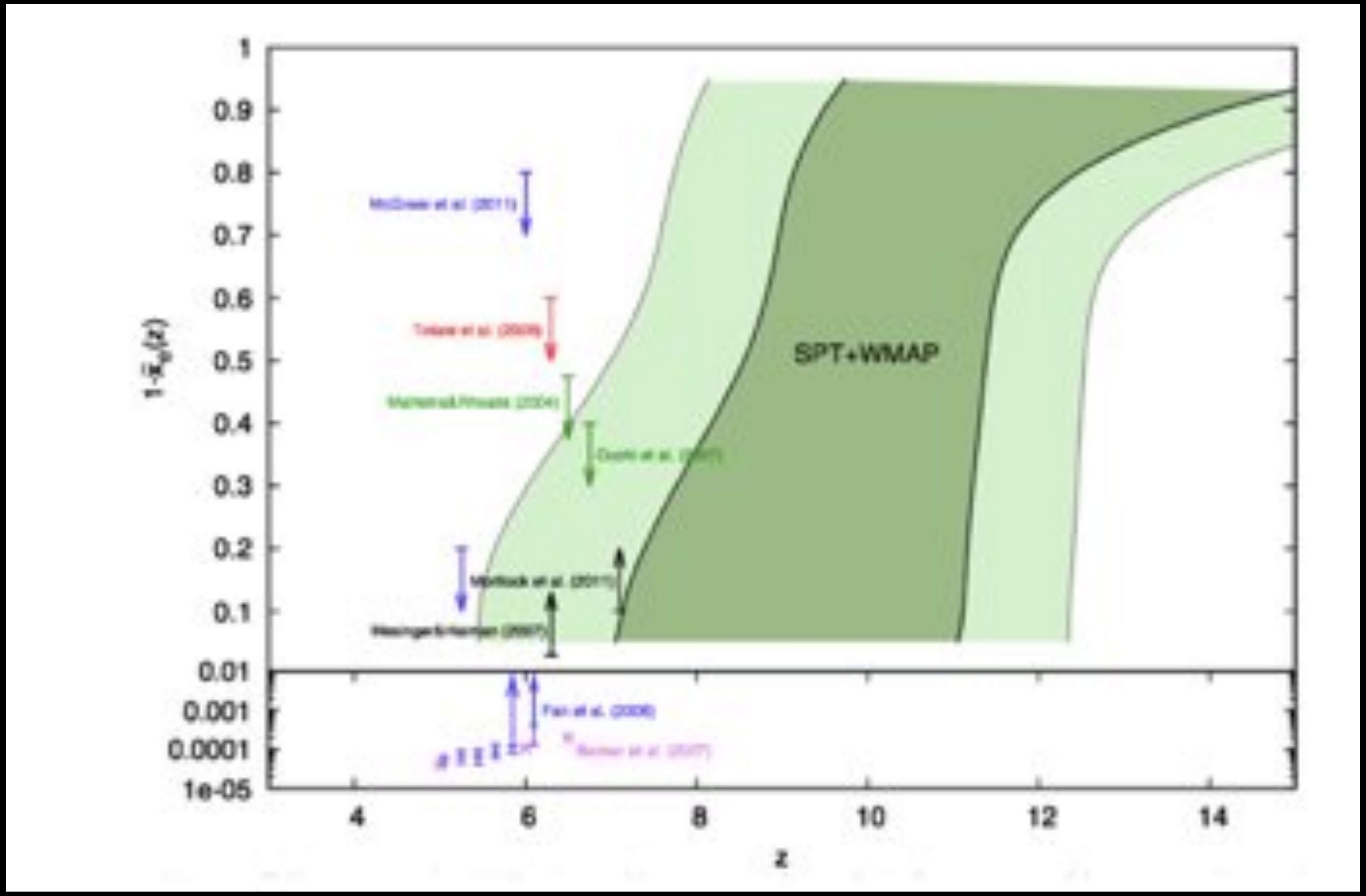
Epoch of Reionization ~200 Myrs - 1Gyr

z~30 - 6

<u>Challenge</u> :

Multiple & Simultaneous «coarse grained» quantities to fit, driven by source creation and light propagation

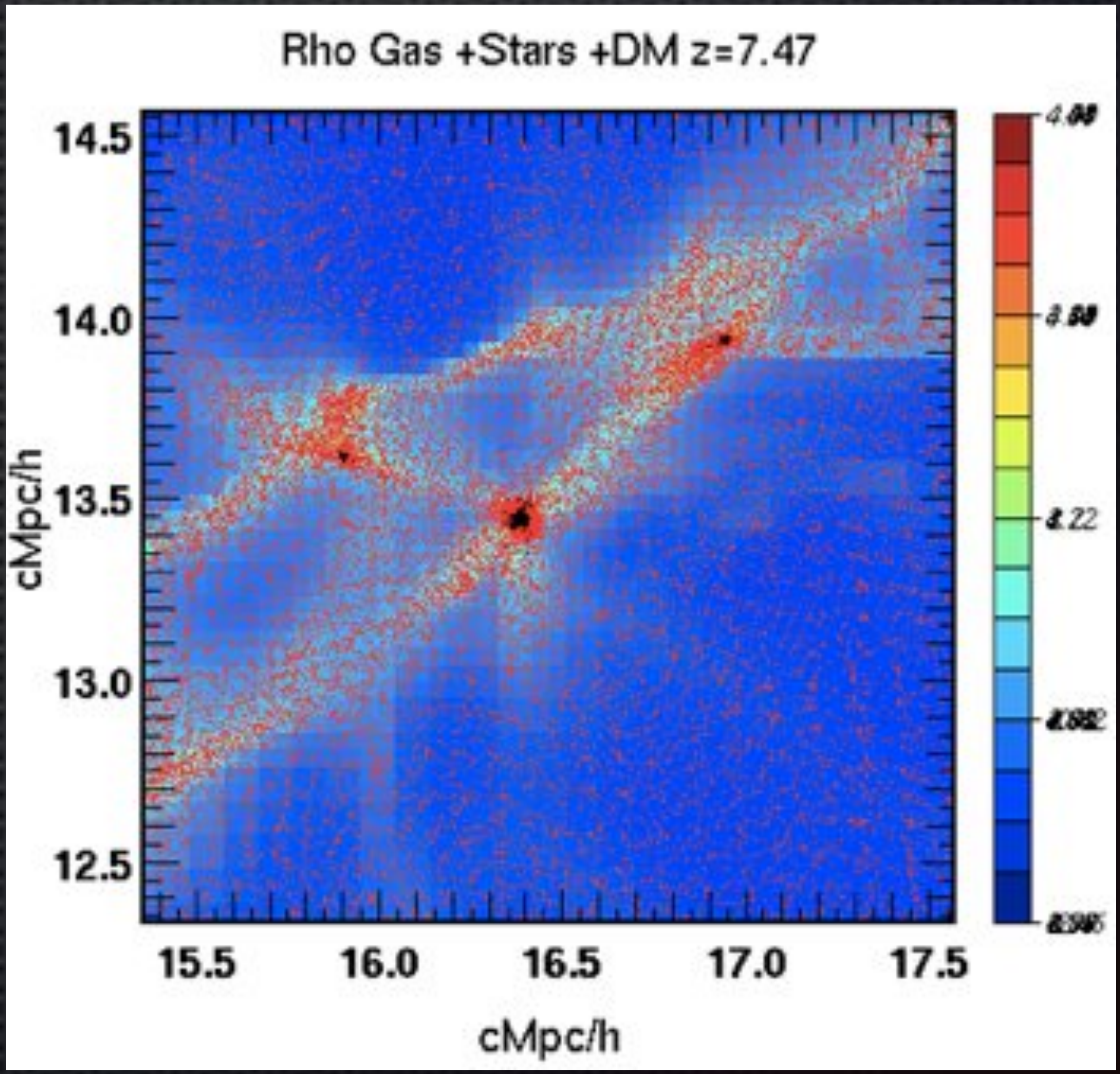
« Source / IGM connection »



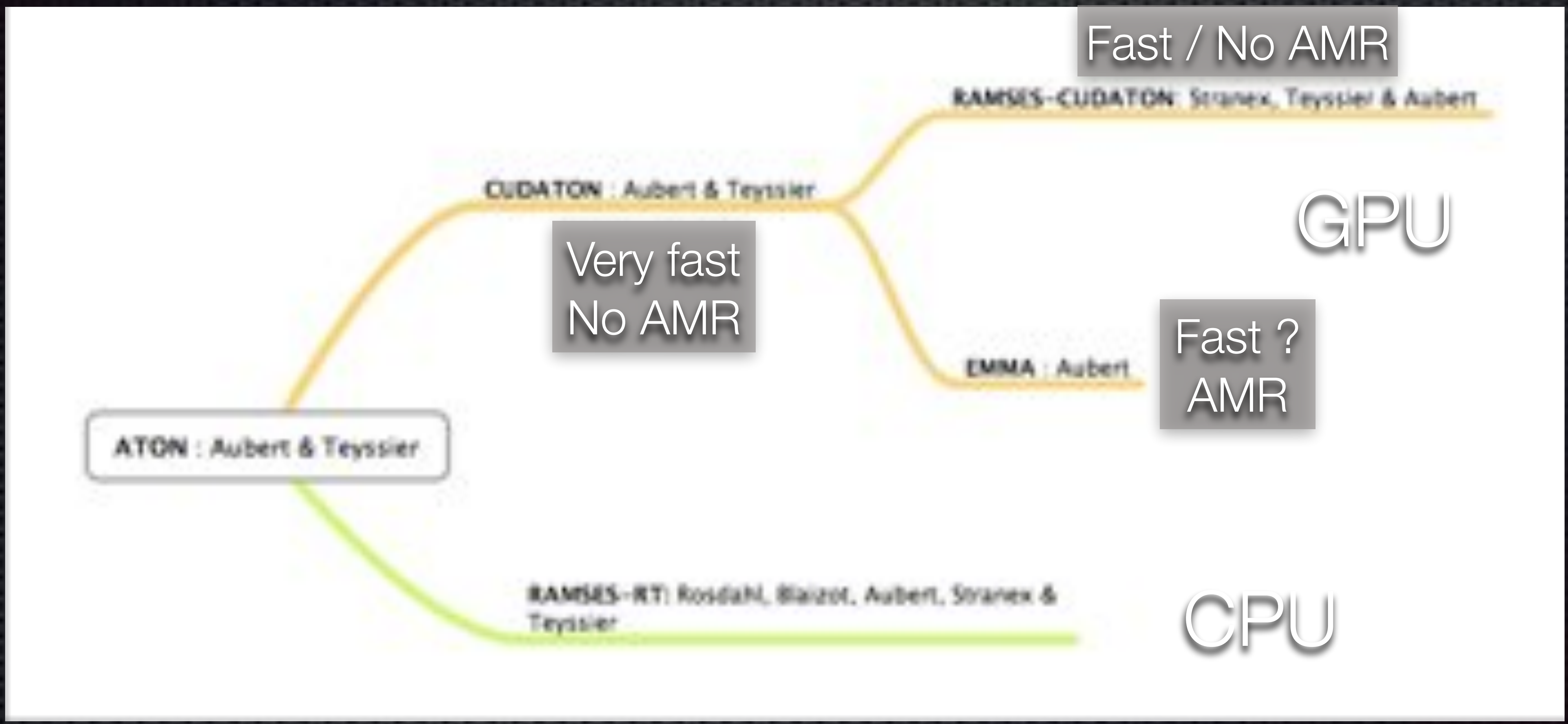
Zahn et al. 2012

What is different at z>6 (for numerical models) ?

- Light appears and has its own dynamics : RT, Light-matter interaction, No UV background, X-Rays ?,
- Cosmic Scales contraints are available and are tightly related to galactic (and sub galactic scales) process : scale dynamics
- Close to ICs / Small density contrasts : impact on halo detection, on star formation recipes, particle noise

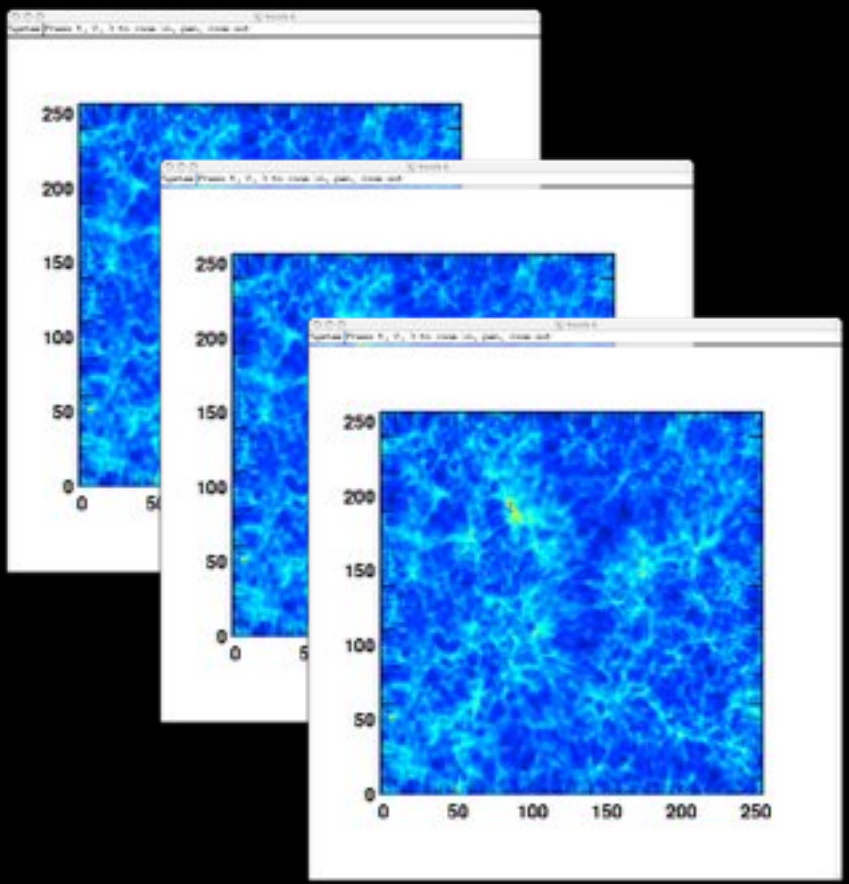


Family Tree



Not the most sophisticated tools, but surely among the fastest

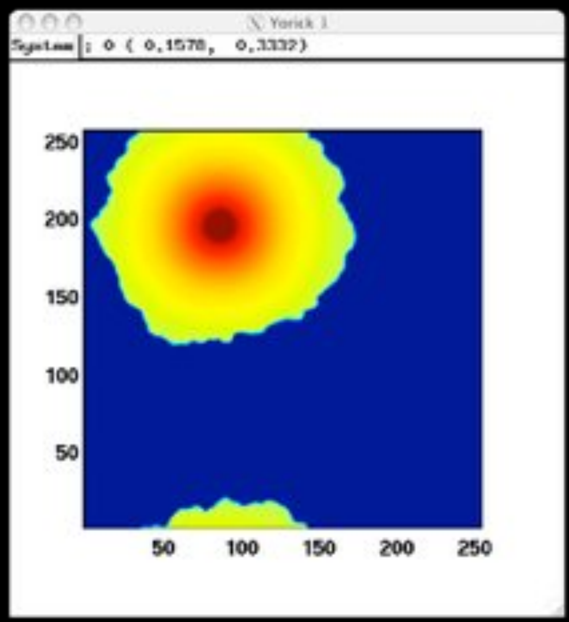
ATON



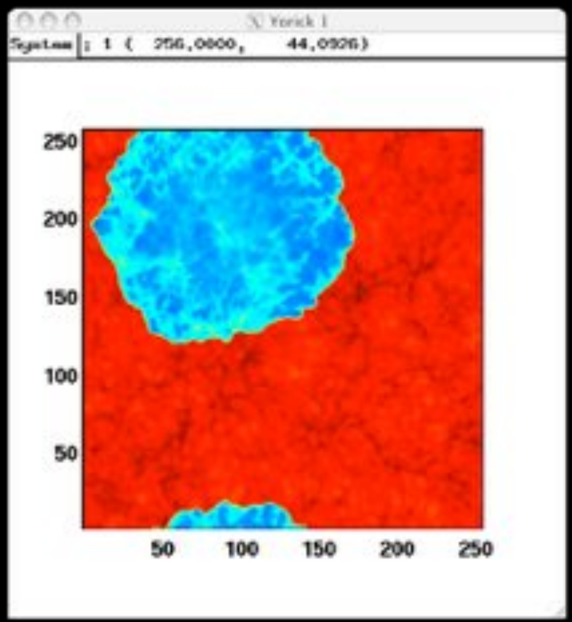
Gas & Source density
= outputs of
hydrodynamical code
(RAMSES/GADGET)

STEP 1

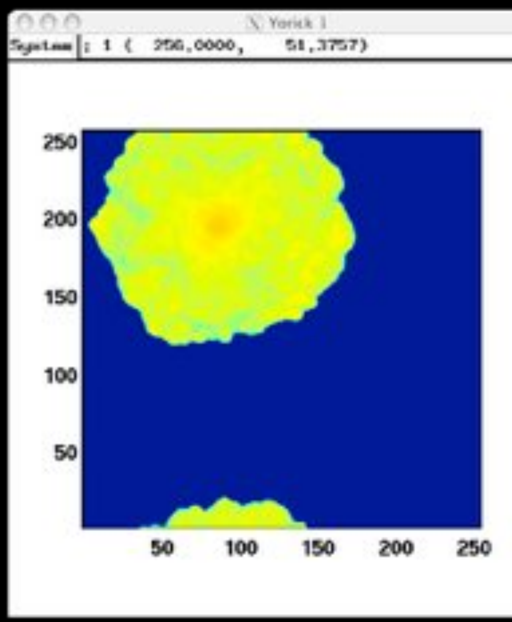
Radiative transport



Ionisation State



Temperature



ATON

Cartesian Grid

M1 Moment method

Explicit solver : dt < dx /c

STEP 2

GPUS: GRAPHICS PROCESSING UNITS

GPU=Graphics Devices

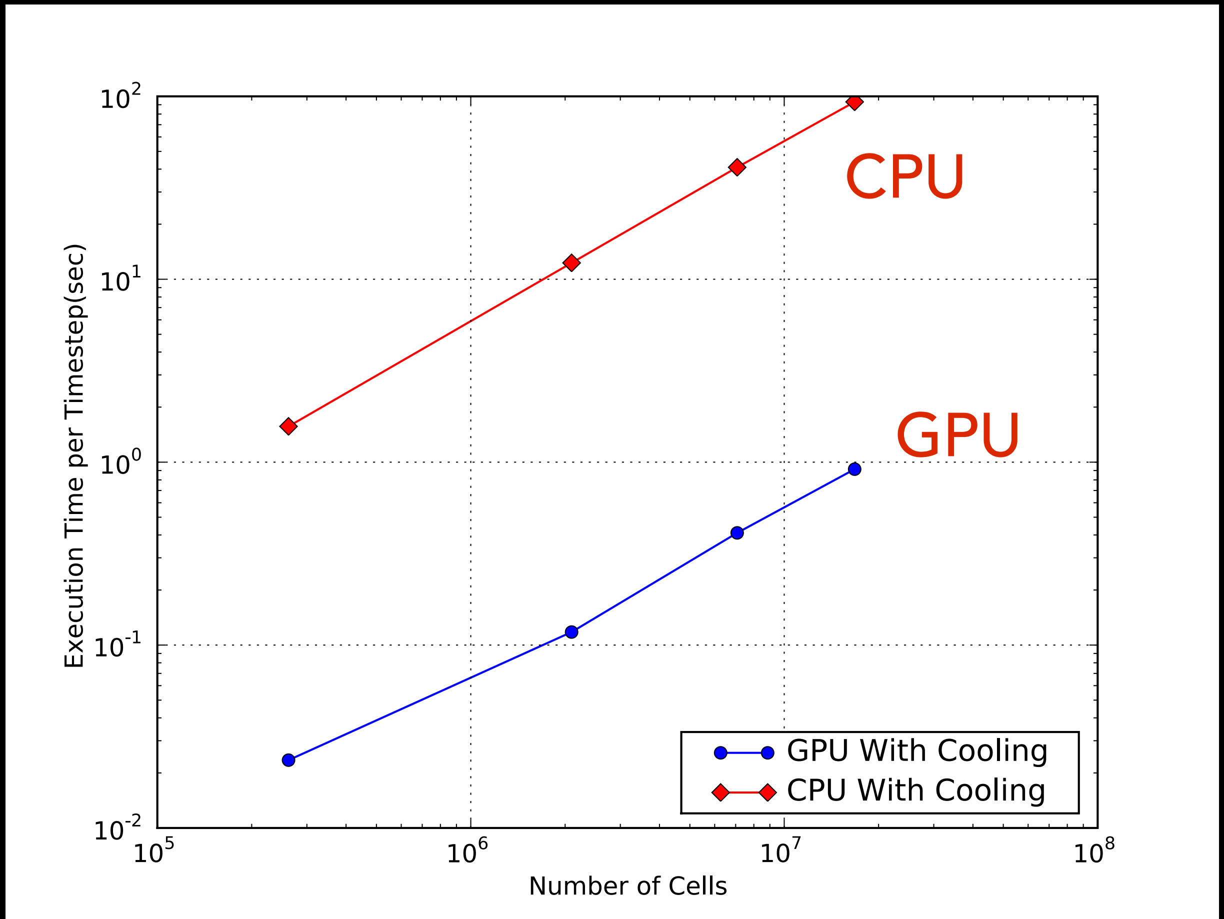
1 Device

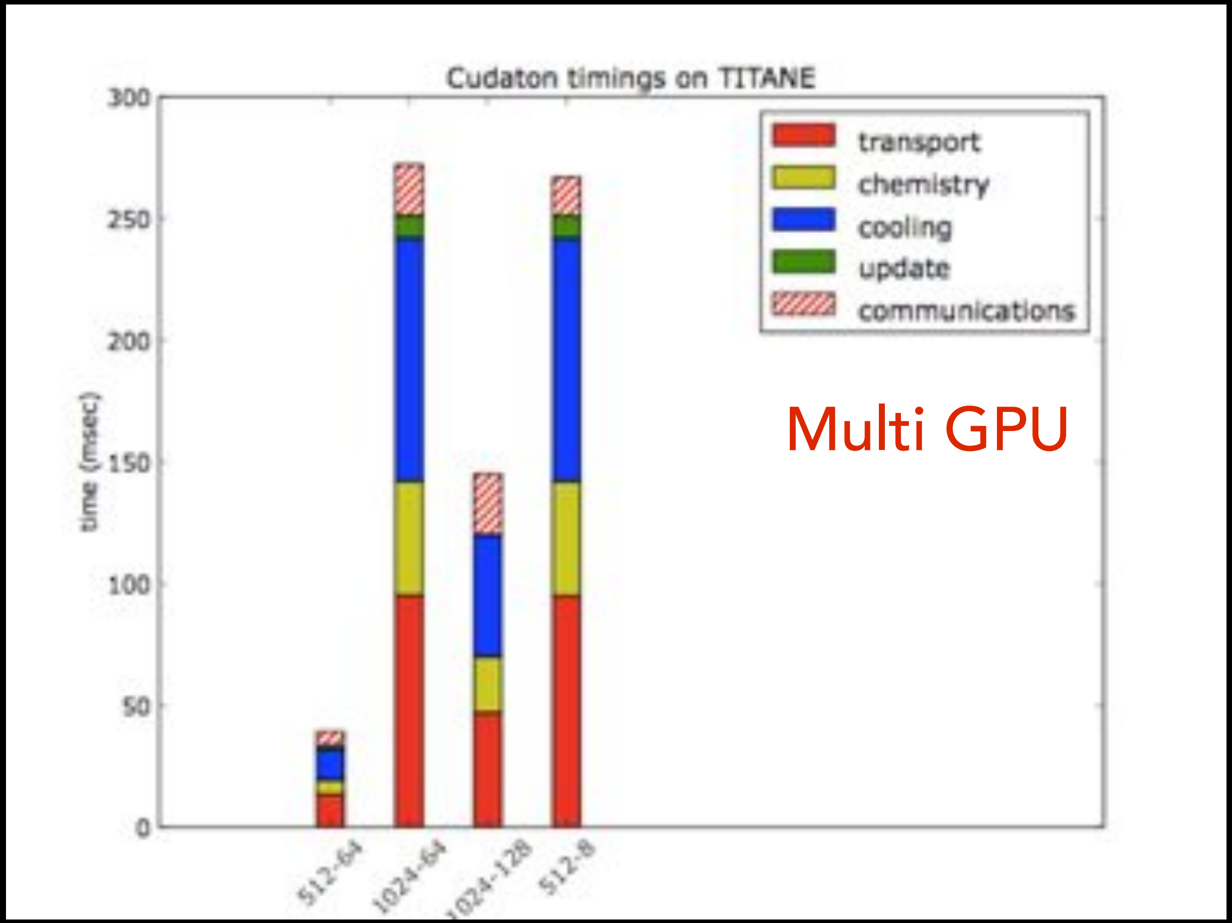
= 1 parallel computer highly efficient at crunching numbers

Using CUDA extension to C language

aton -> CUDATON

PERFORMANCES
GPUS VS CPUS

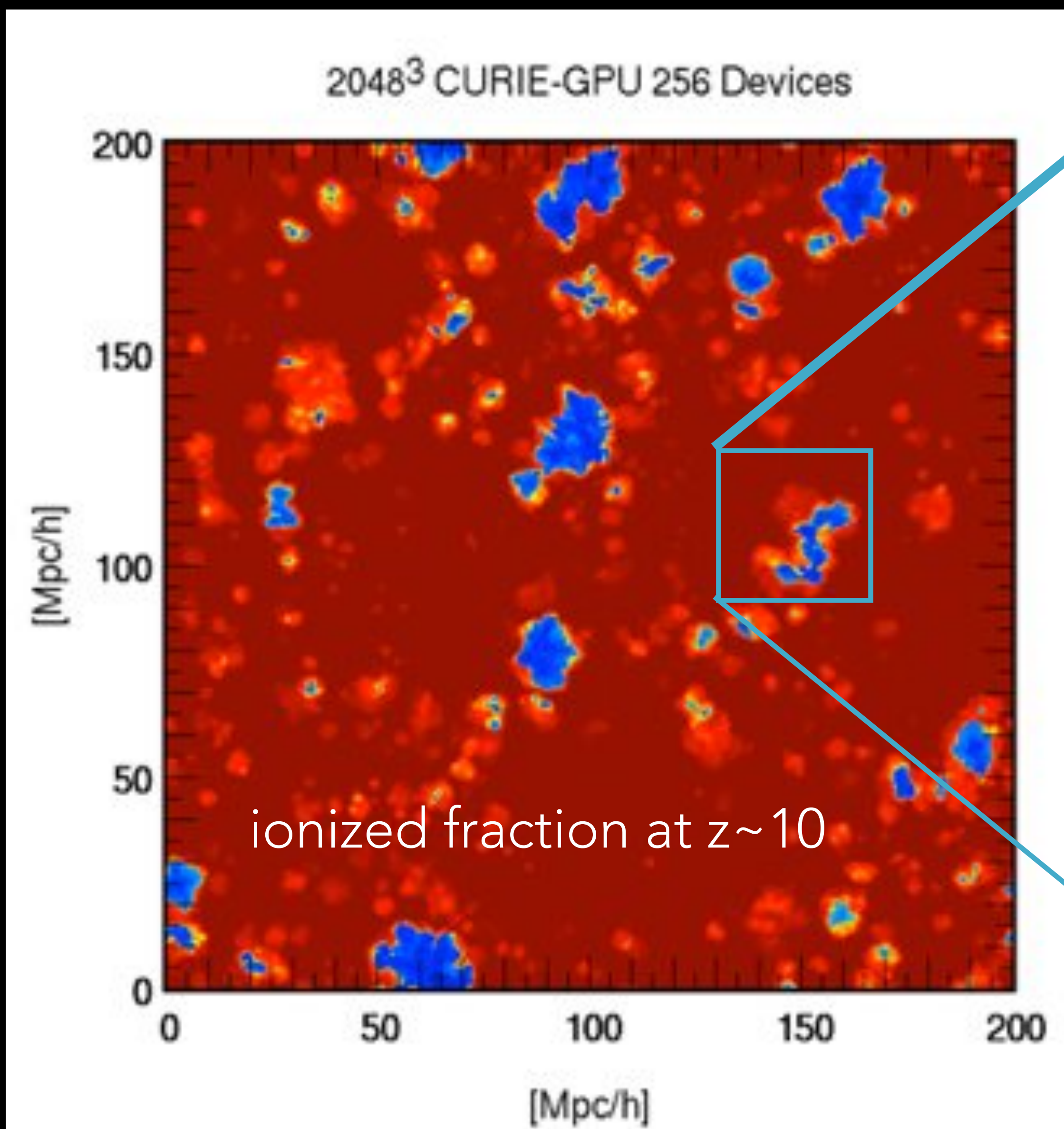


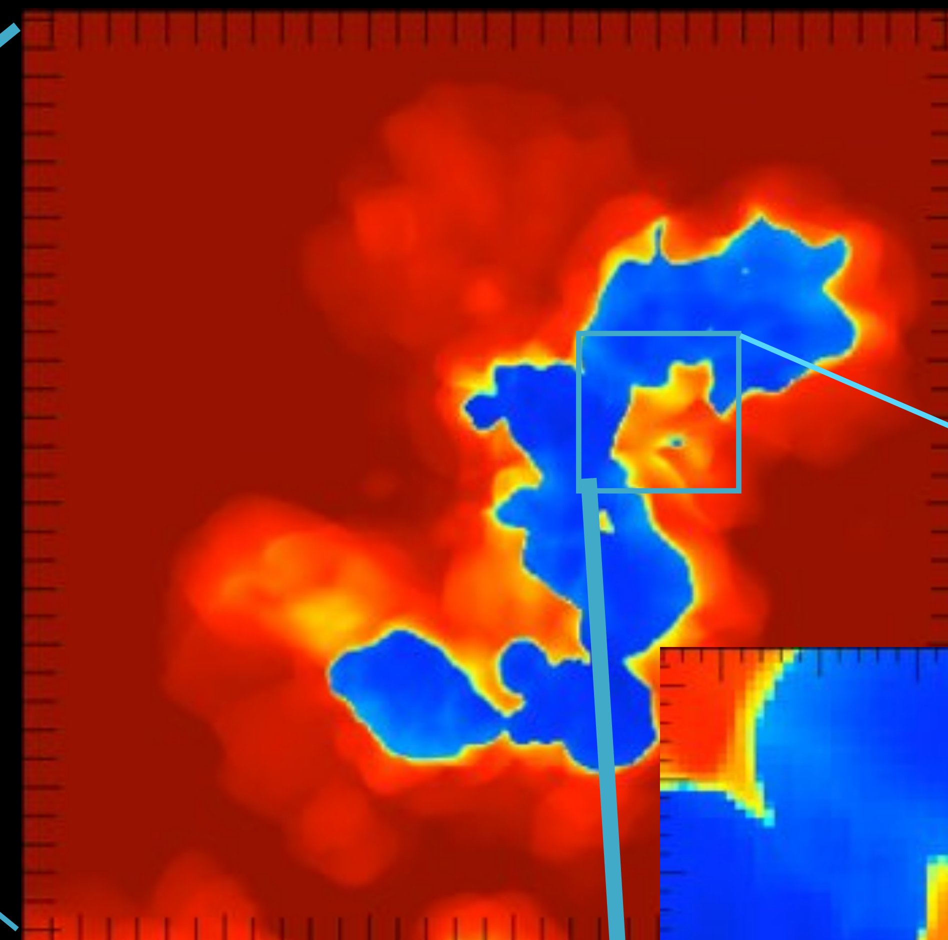


x 80 acceleration factor
Massively parallel

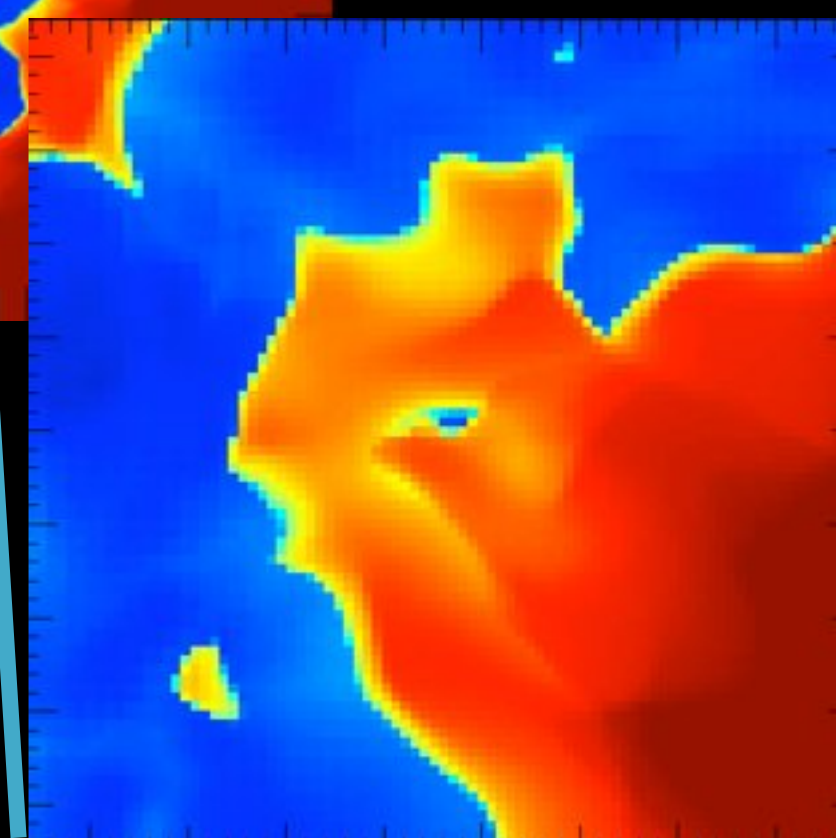
Aubert & Teyssier, 08,10

POST PROCESSING WITH CUDATON





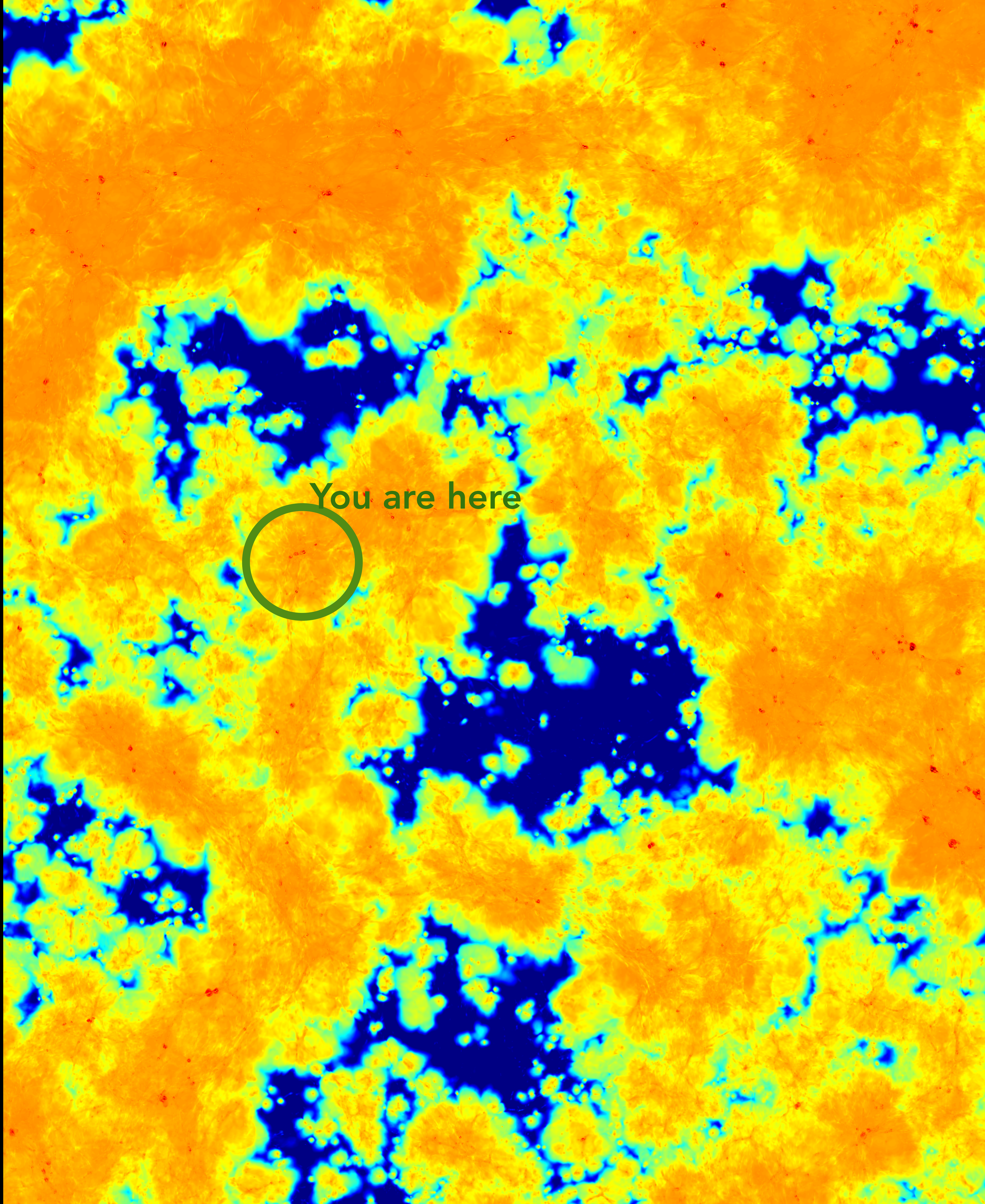
Grand Challenge
Curie-CCRT
256 GPUs
2048x2048x2048
60 000 pdt -15h



Curie, CCRT-CEA

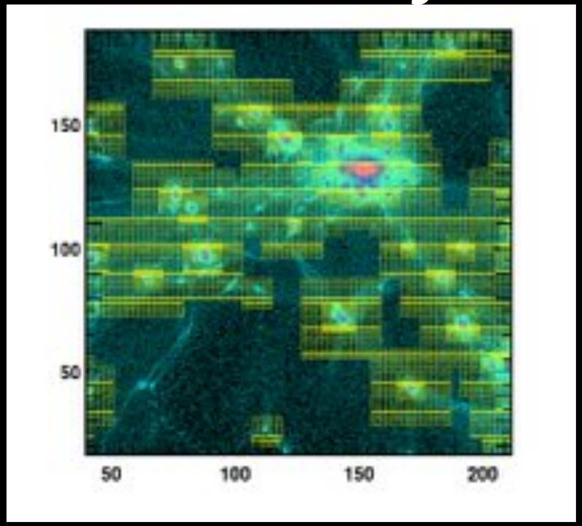
TITAN

- Hybrid code RAMSES/ CUDATON
- 4096^3, 64 Mpc/h
- End 2013 ~ 80 Millions CPU hours
- 8192 GPUs (TITAN/ORNL)
- Local Group in a cosmological environment
- PI : P. Shapiro (U.Texas) / Co-I P. Ocvirk (Strasbourg)



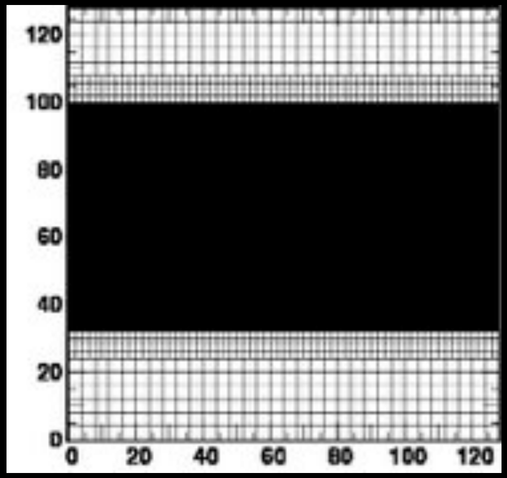
EMMA: INGREDIENTS

Gravity



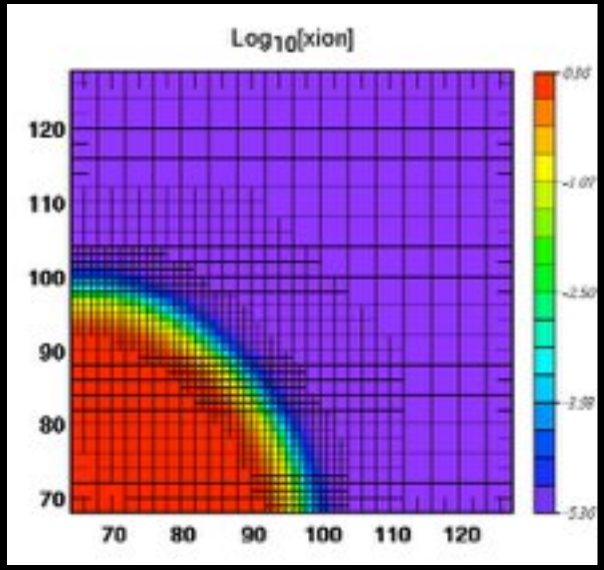
PIC
CIC
Multigrid + RB
GSeidel

Hydrodynamics



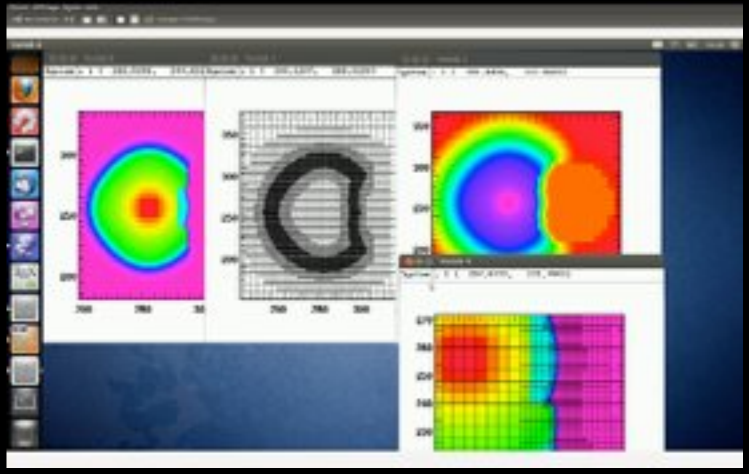
MUSCL
HLLC
Dual Energy

Radiation

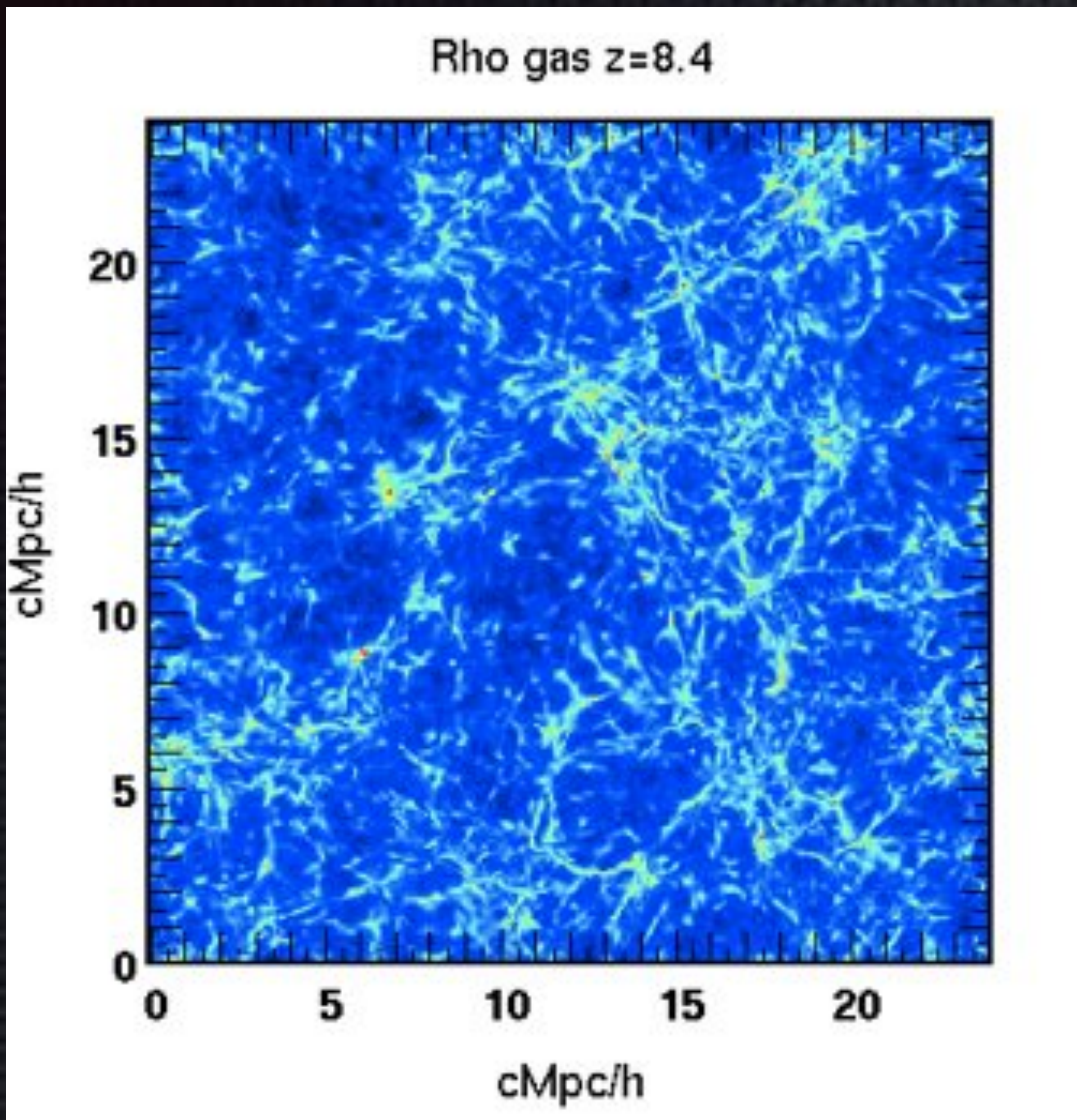


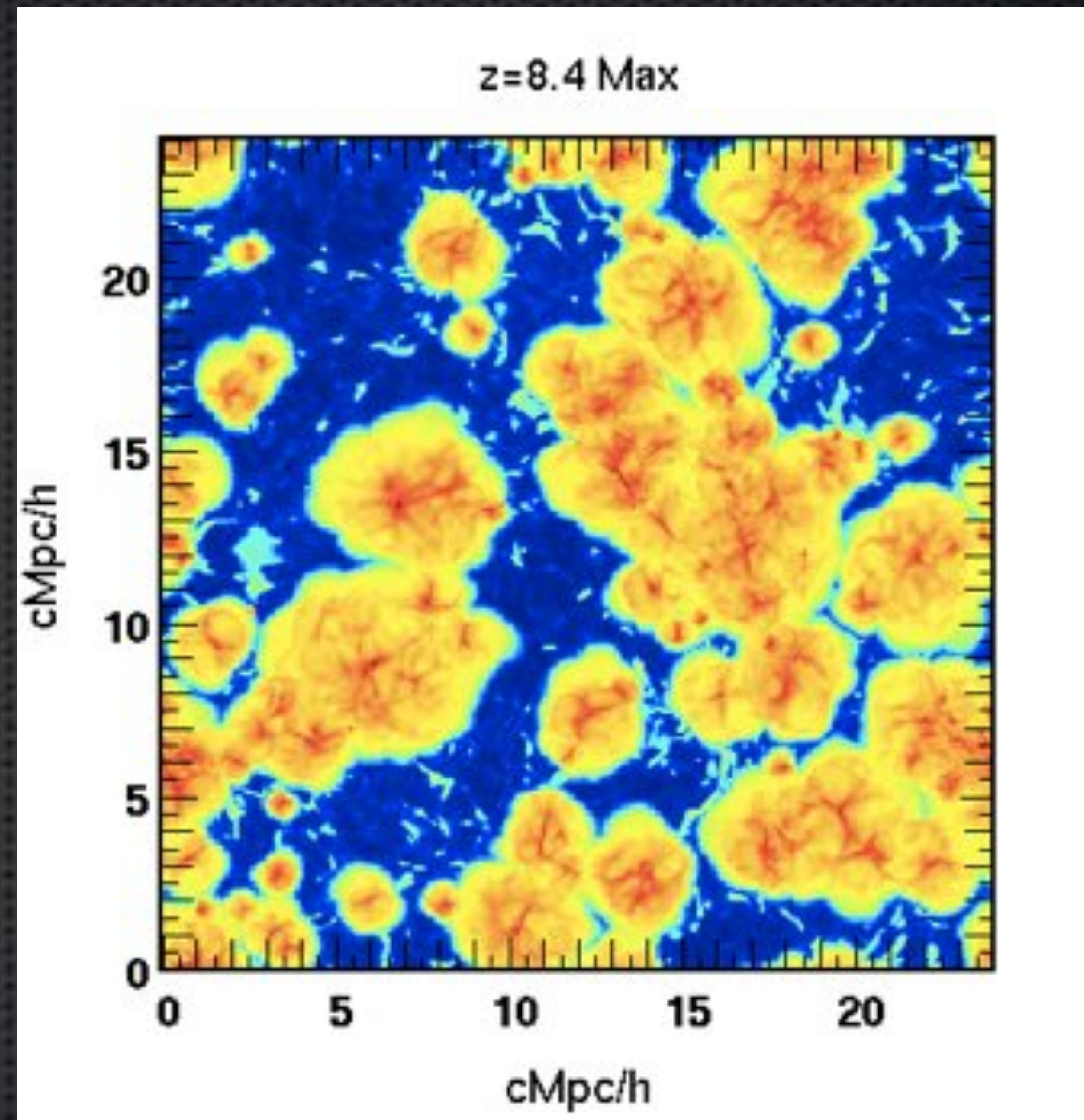
M1
Out of equilibrium
H Chemistry
Multi-frequency
transfert (incl. X
rays)

Logistics

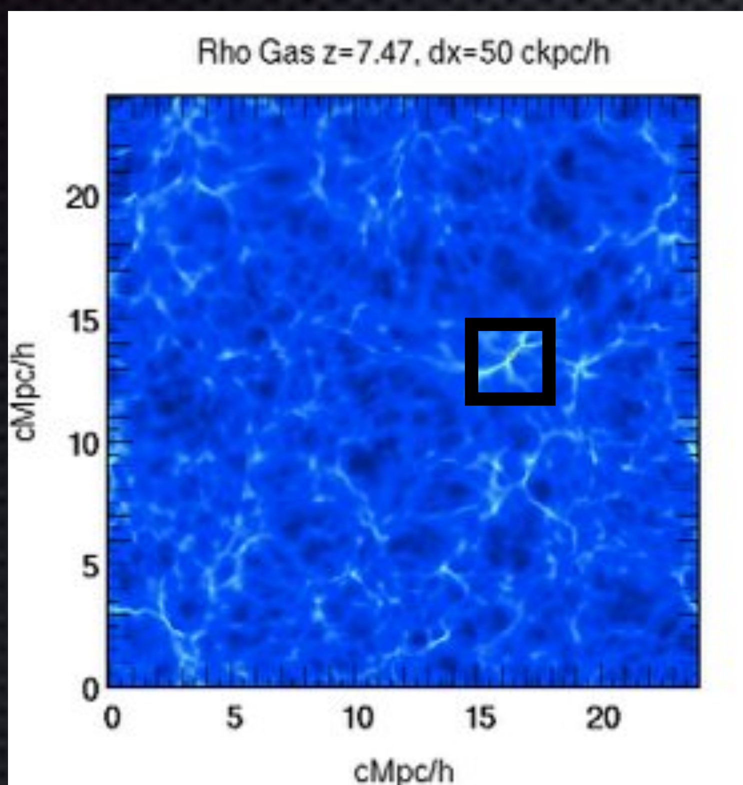


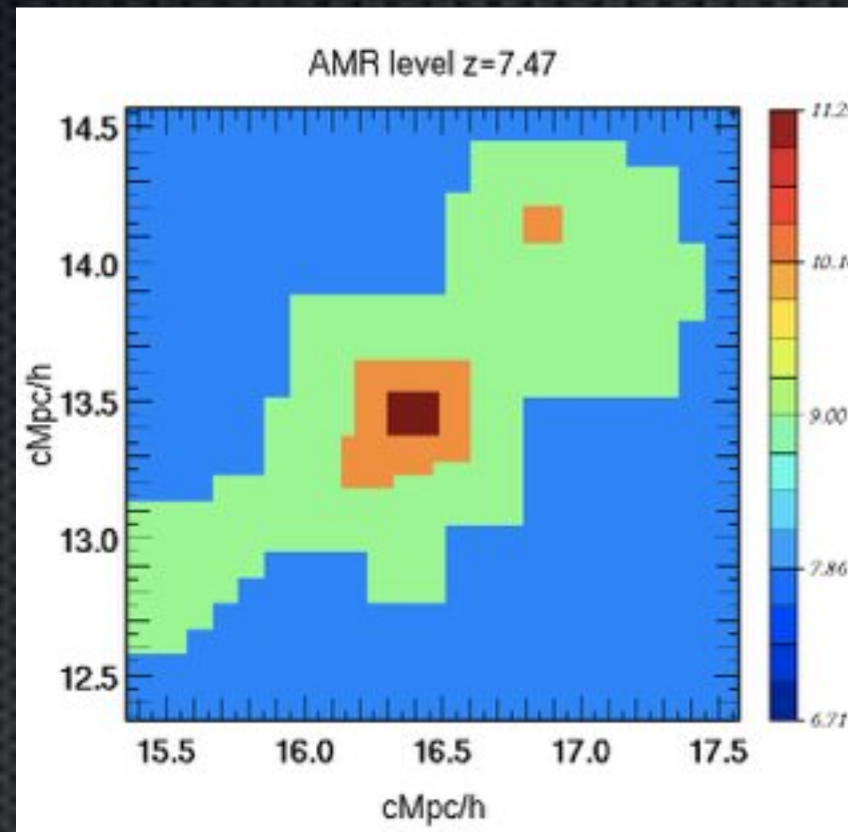
Fully-Threaded Tree
AMR
MPI
Space-Filling Curve
Essential Tree
C + CUDA

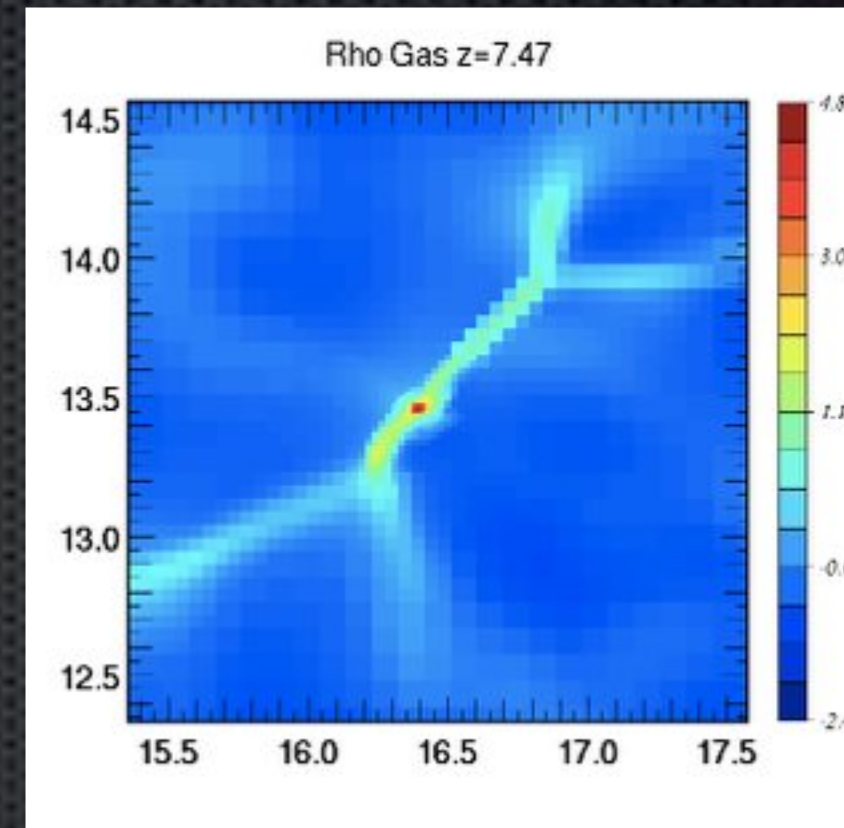


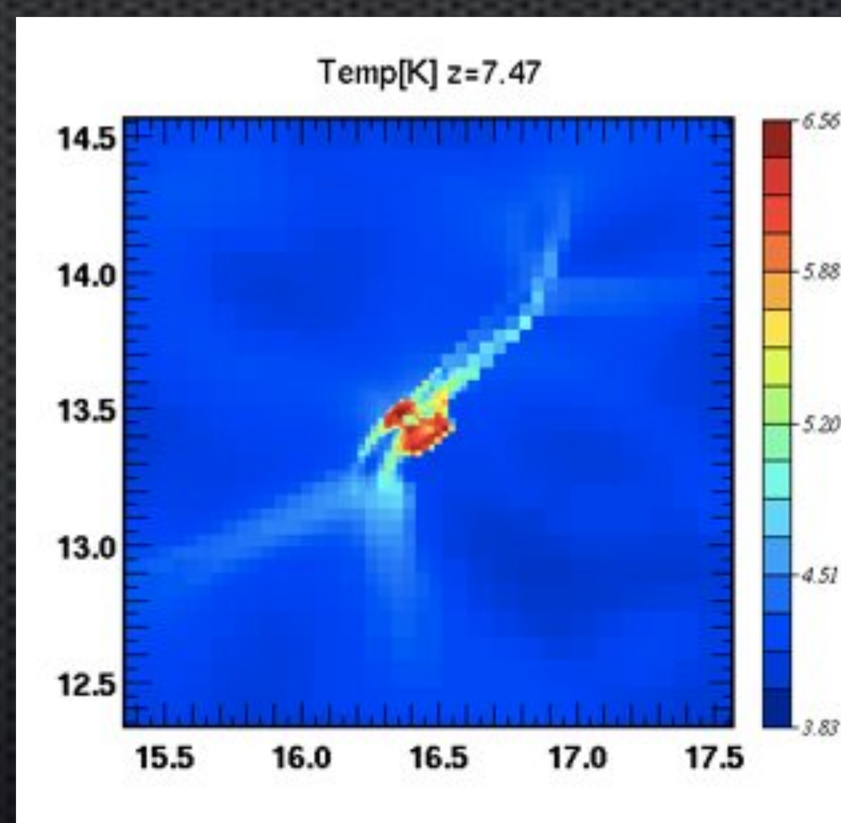


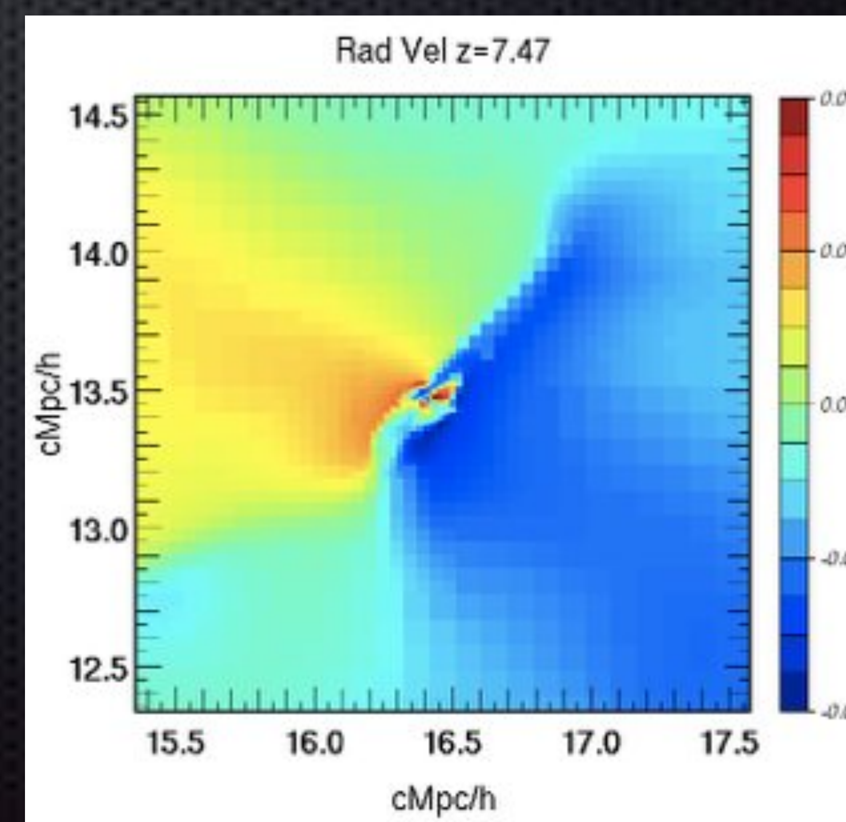
16 millions coarse cells + DM particles - 24 Mpc/h
Mass resolution: 1e8 Ms
Spatial resolution : 93 kpc/h (coarse) 6 kpc/h (AMR level 12)
~15 hours on 256 processors


Rho Gas z=7.47, dx=50 ckpc/h
20
15
10
5
0
cMpc/h
0
5
10
15
20
cMpc/h


AMR level z=7.47
14.5
14.0
13.5
13.0
12.5
cMpc/h
15.5
16.0
16.5
17.0
17.5
cMpc/h
11.29
10.14
9.00
7.86
6.71

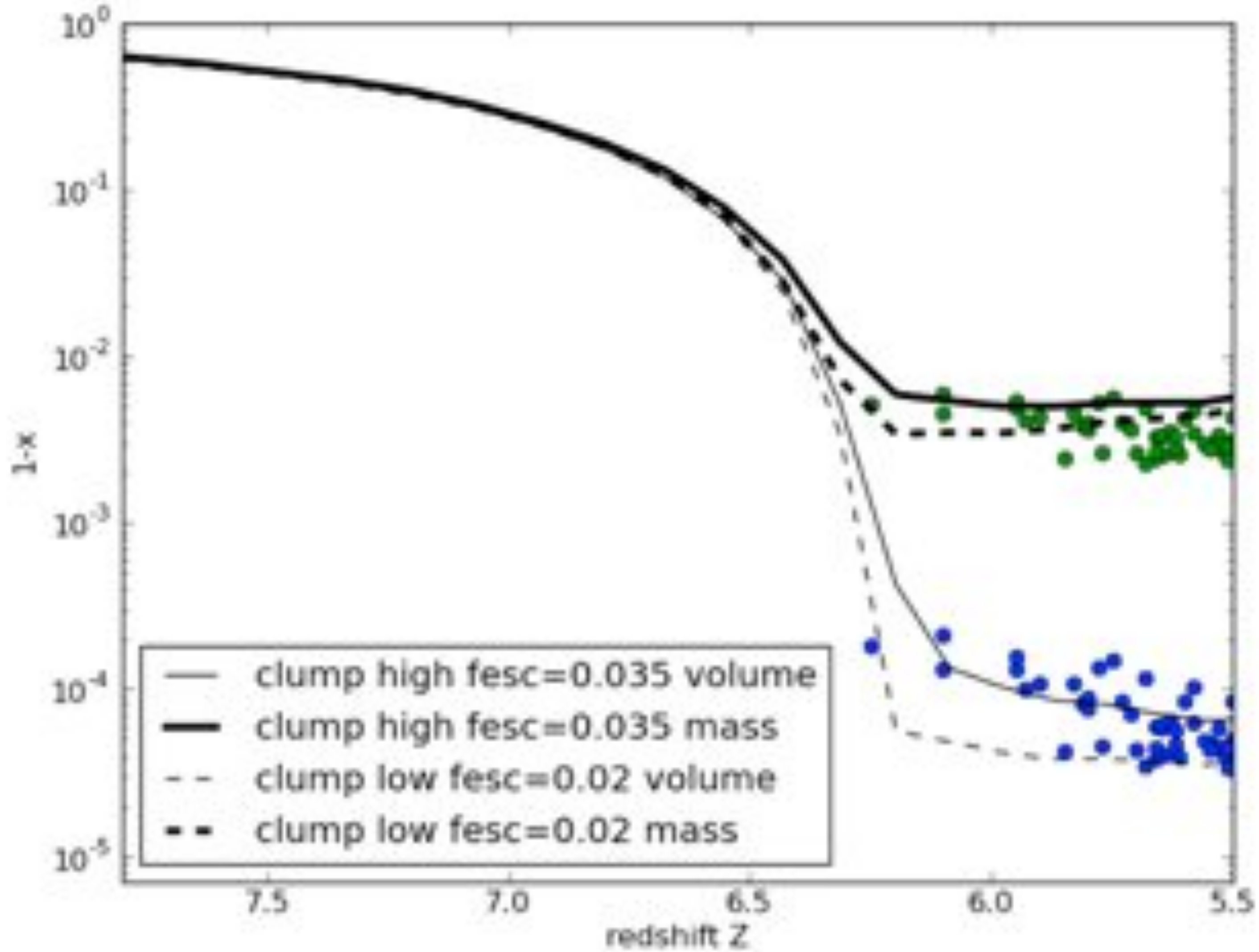

Rho Gas z=7.47
14.5
14.0
13.5
13.0
12.5
15.5
16.0
16.5
17.0
17.5
4.83
3.01
1.19
-0.63
-2.46

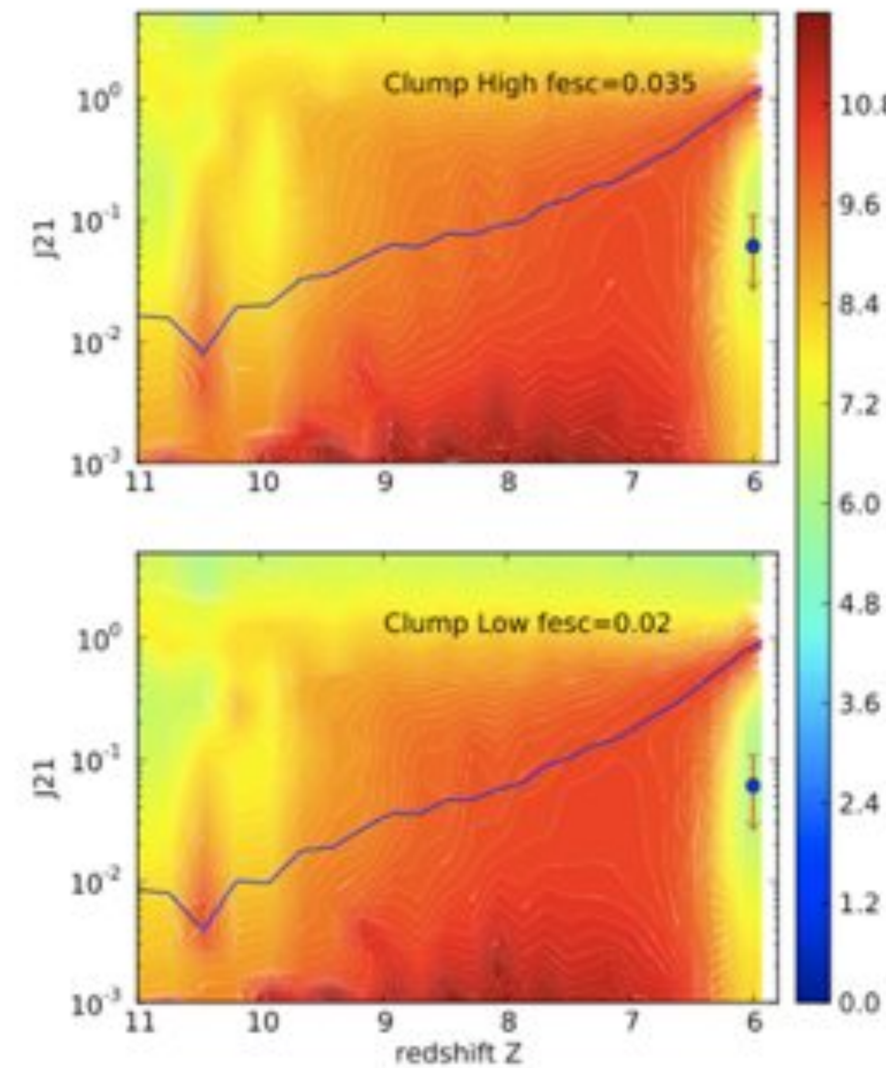

Temp[K] z=7.47
14.5
14.0
13.5
13.0
12.5
15.5
16.0
16.5
17.0
17.5
6.56
5.88
5.20
4.51
3.83


Rad Vel z=7.47
14.5
14.0
13.5
13.0
12.5
cMpc/h
15.5
16.0
16.5
17.0
17.5
cMpc/h
0.04
0.02
0.00
-0.01
-0.03

SOURCES & IGM REIONISATION CONNEXION

Neutral fraction vs redshift



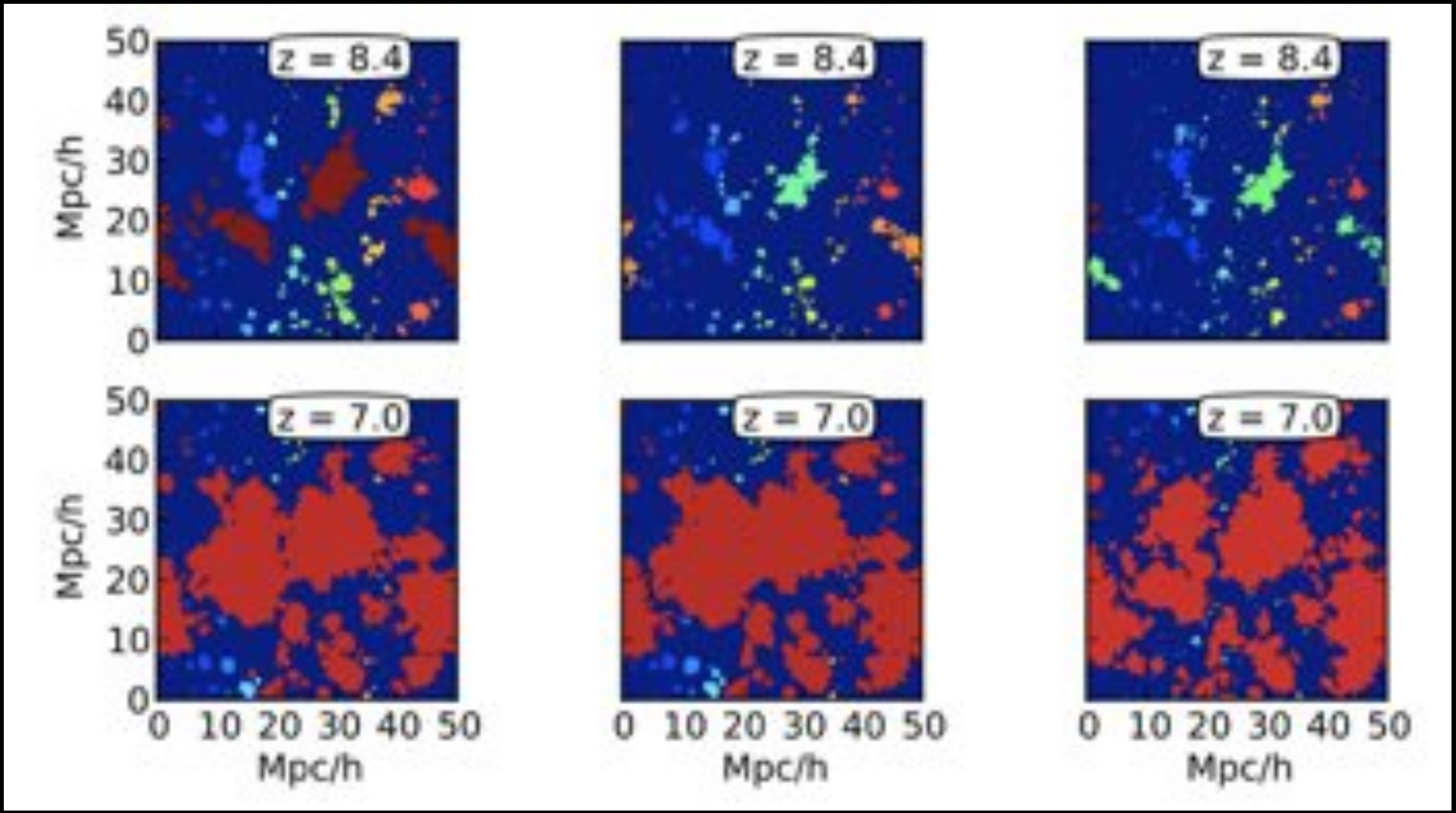


UV intensity vs redshift

Lack of simultaneous fit for xion and J21 to observations :
POC Photon Overproduction (Crisis)

Aubert & Teyssier 2010

GEOMETRY OF OVERLAPING HII REGIONS



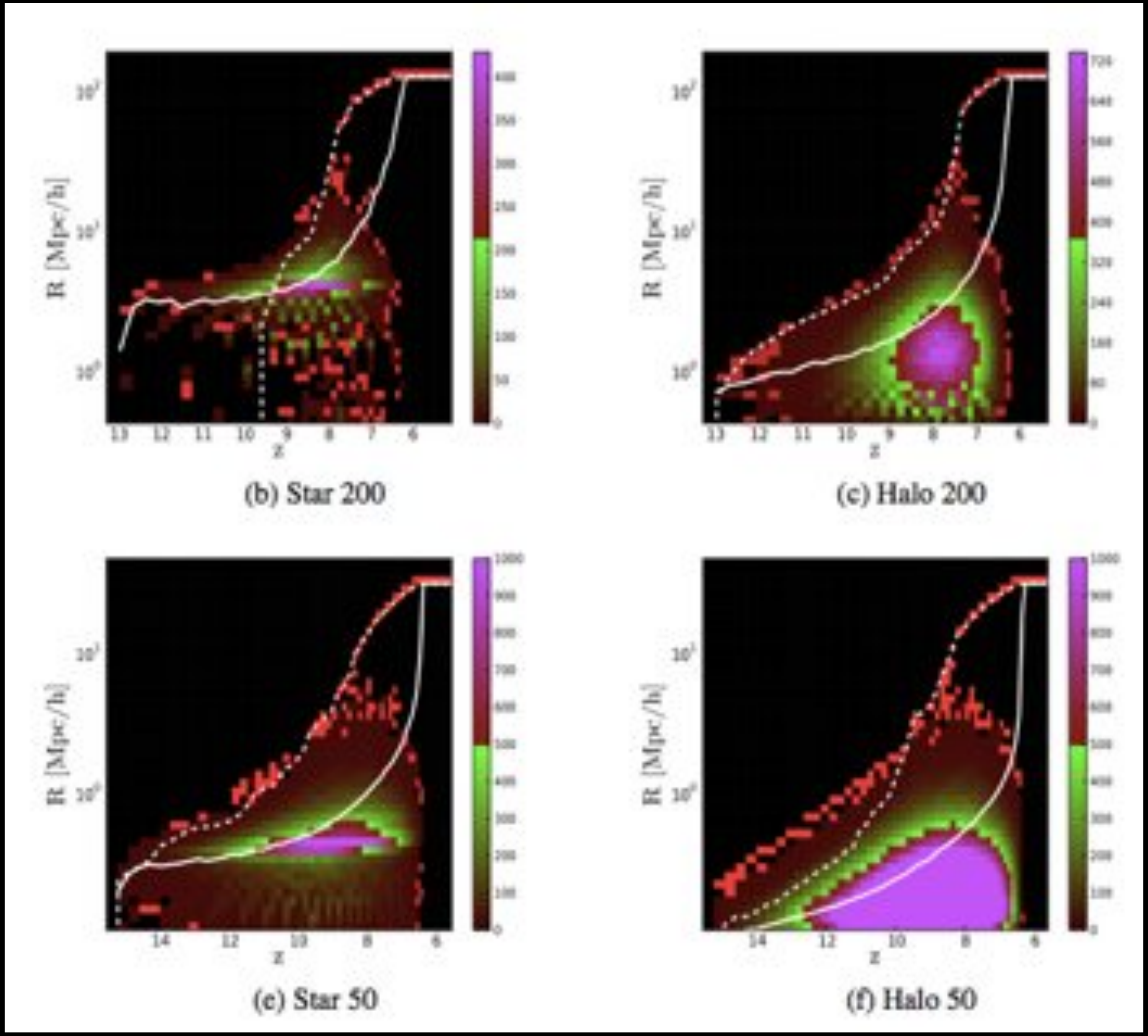
Emission=S(t) Em.=Cst Em.=Mhalo

Star particles Star particles Halo

The 3 models have similar reionization histories

Chardin, Aubert et al. 2012

SIZE DISTRIBUTION OF HII REGIONS



Rise of a master HII region

Large Scale equivalence Halo and Stellar models

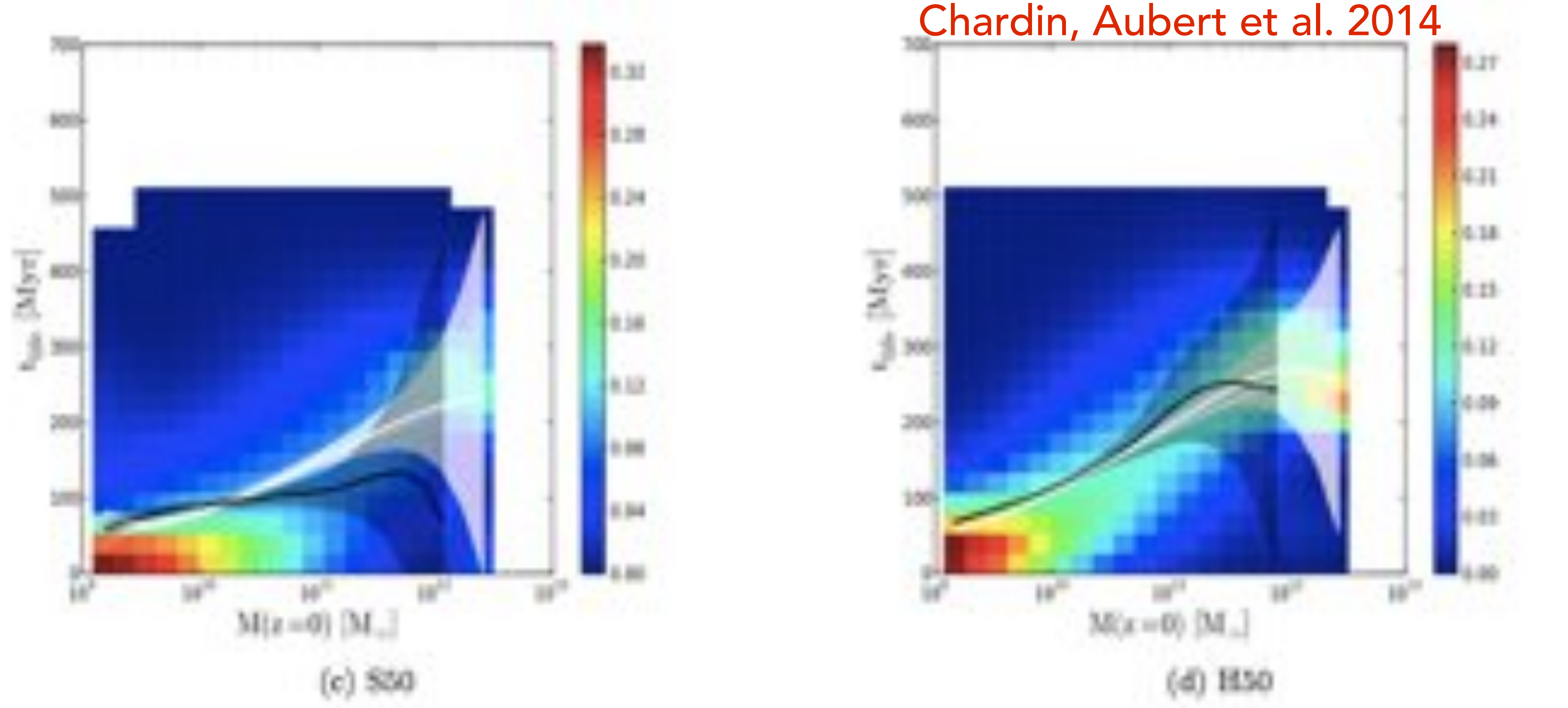
Halo models produce small HII regions, which are not found for Stellar models

Chardin, Aubert et al. 2012

Different source properties lead to
different reionization histories + geometry + evolution

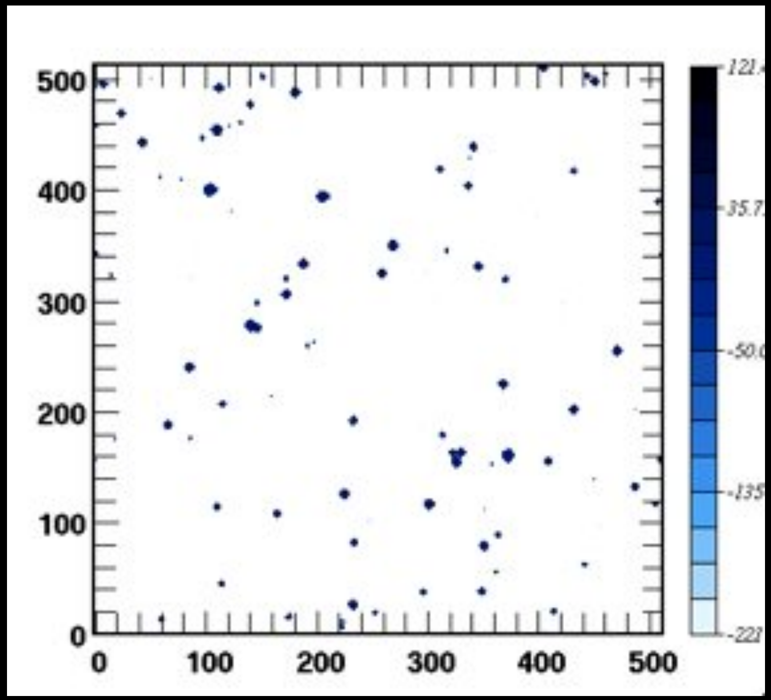
Statistical constraints on these properties will tighten the range of possible reionization scenarios

In fact we found that galaxies experience very different local reionization histories which could lead to different SFH
We also know that there is variance in the LF
Hence the need to undestand the **population** of high z sources

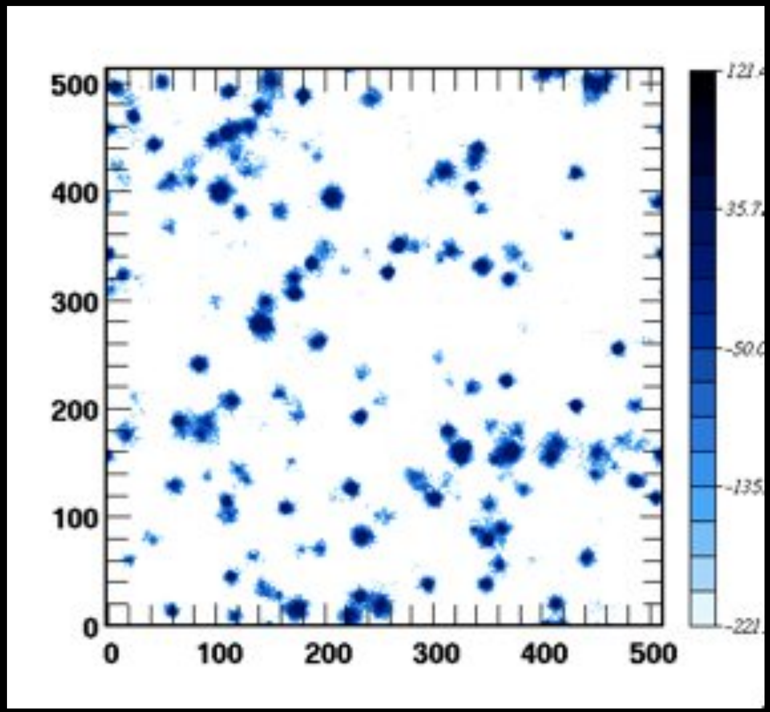


Chardin, Aubert et al. 2014

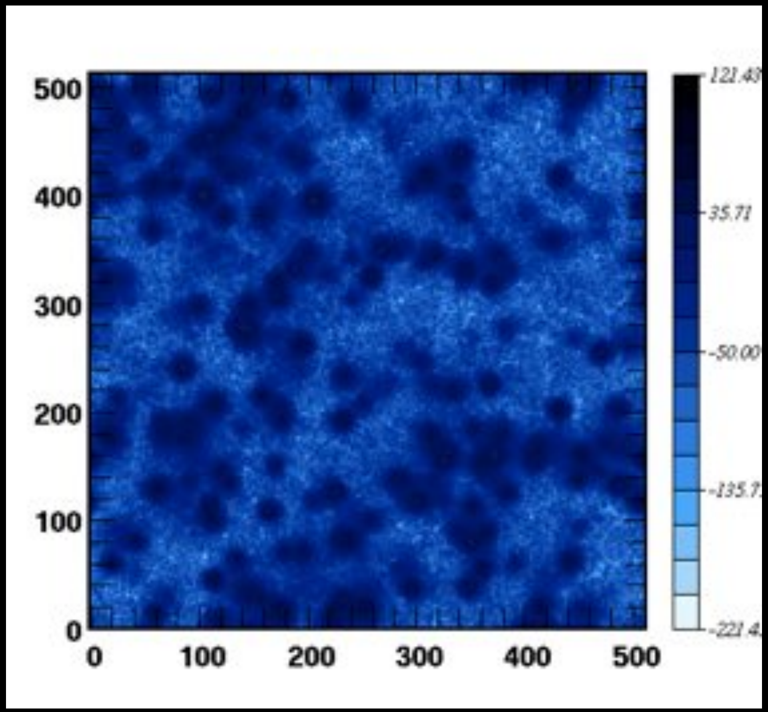
IGM 21 CM SIGNAL



0% X



1% X



10% X

L = 1 Gpc, z~10, xion= 0.5 %

To sum up…

The Reionization process is dependant on
the source description (geometry, timing, SFR, LF)

We have the tools to probe some of these dependances

In a few years, we obtained tighter constraints on SFR, LF

At the same time, the models will have to fit constraints on IGM

This IGM-Source Connection must be probed.