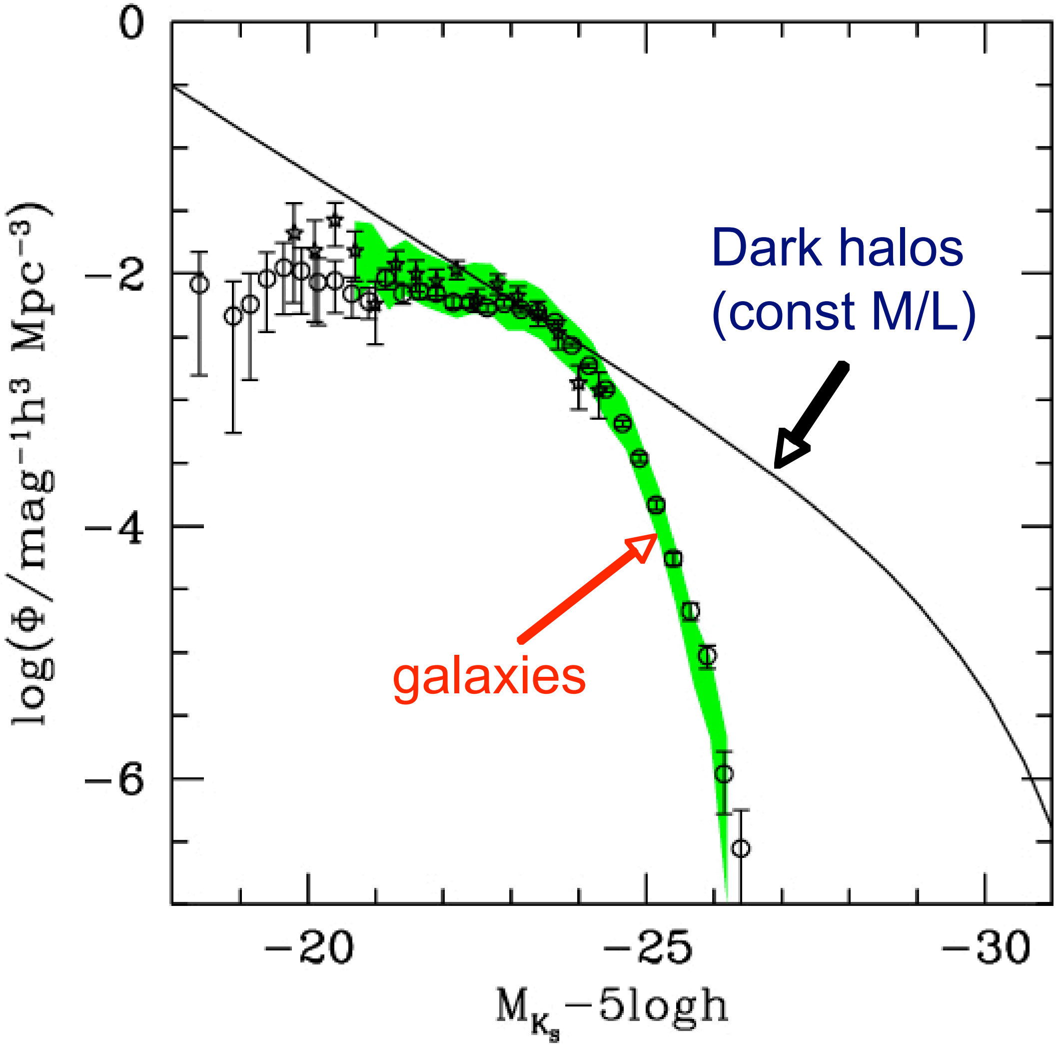
# The impact of AGN on galaxy formation

Durham University

唐沐

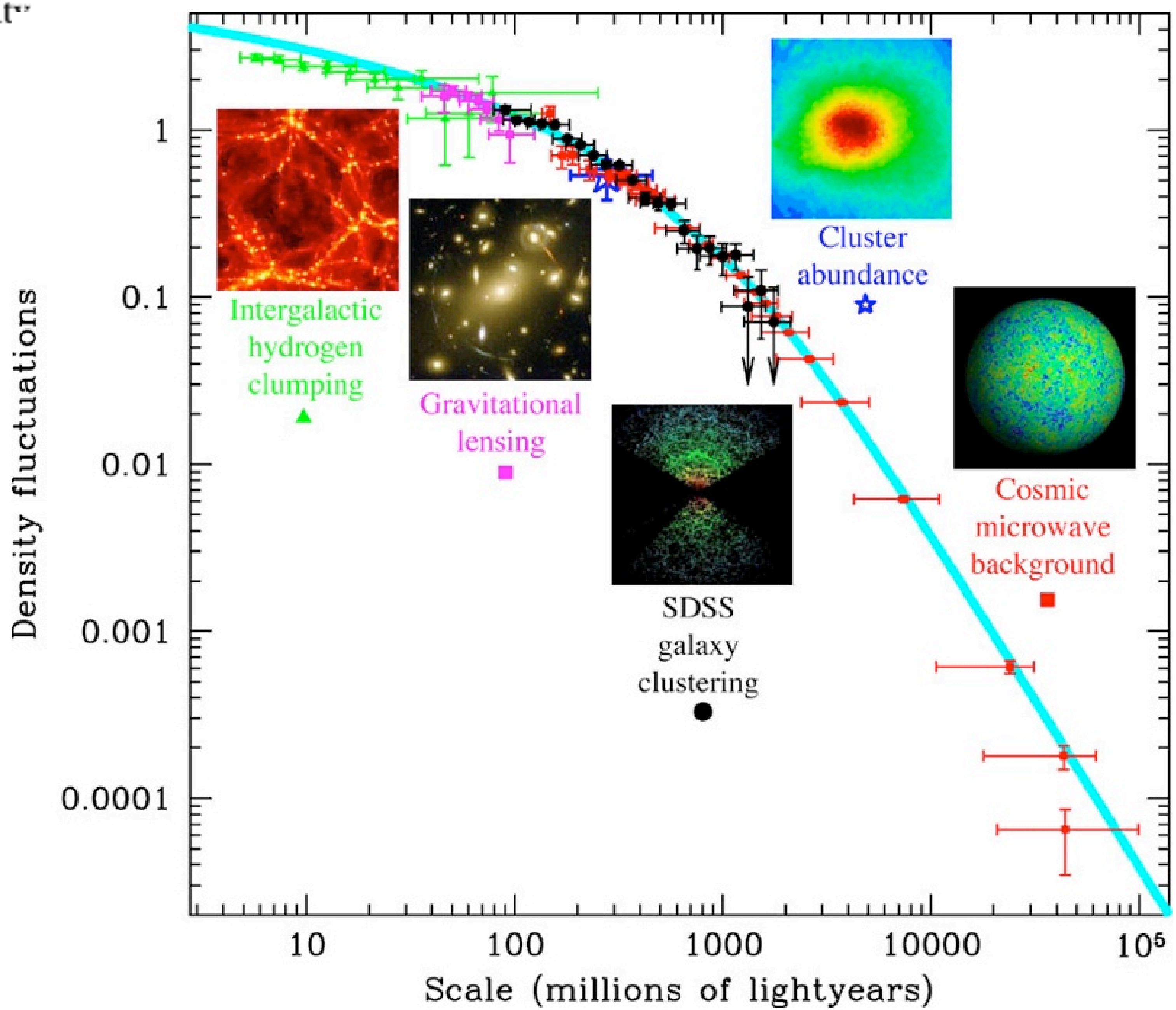
## Outline:

- Introduction
- Hydro-simulations
- Semi-analytical models
- Including AGN




## Thanks:

- •J Schaye (Leiden)
- •C Dalla Vecchia (Leiden)
- •V Springel (MPA)
- •R Bower (Durham)
- •Gao Liang (Durham)

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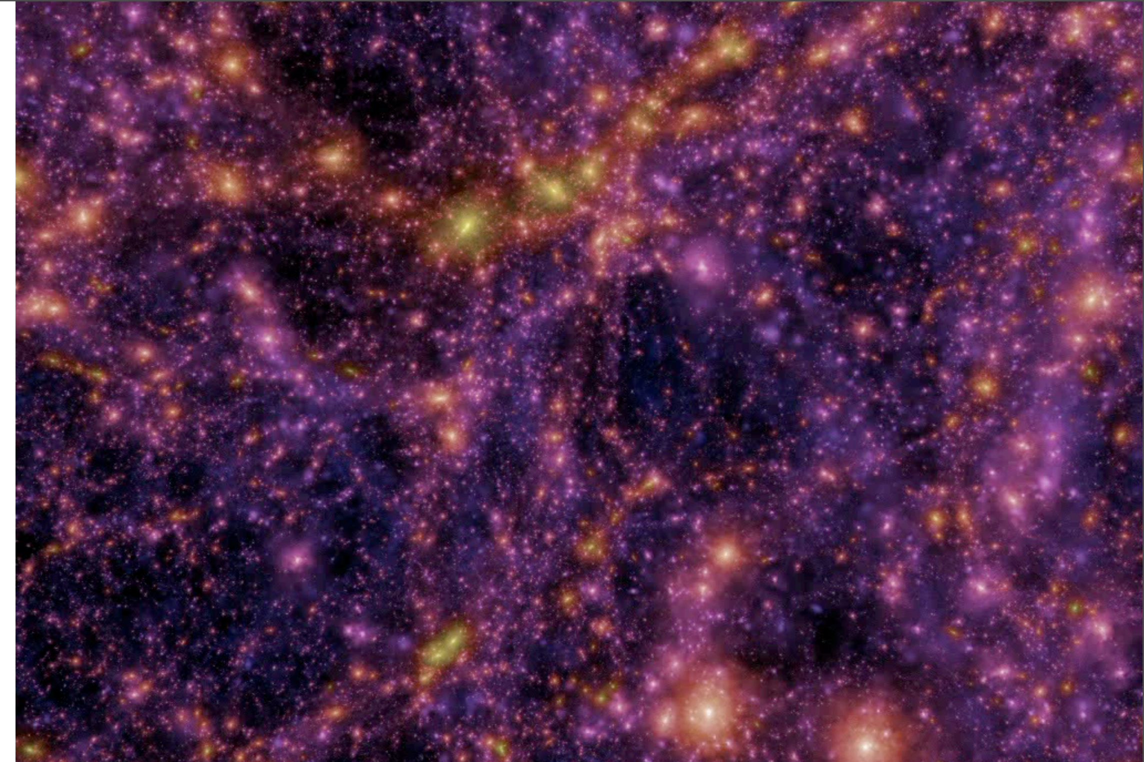

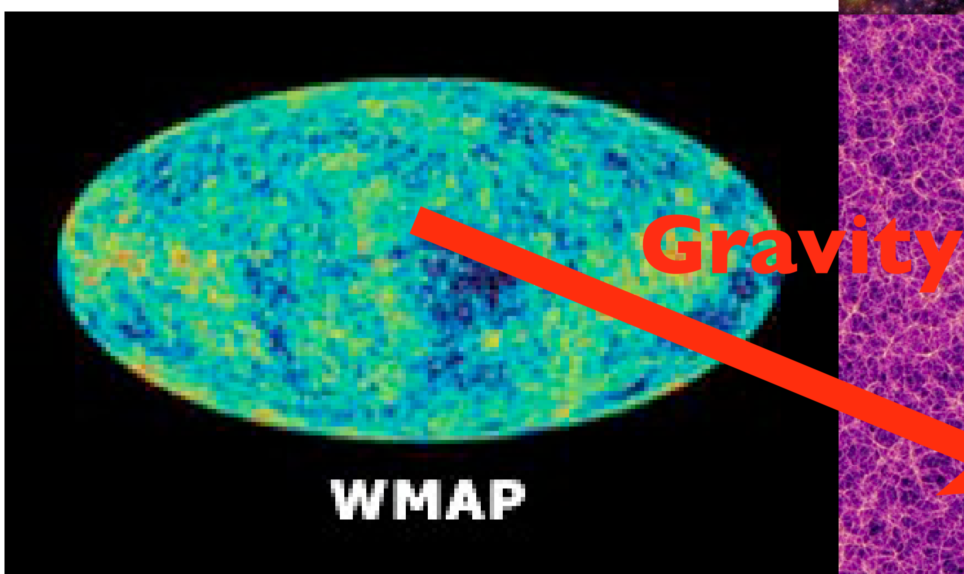


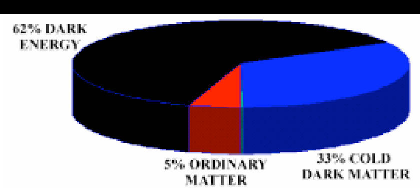


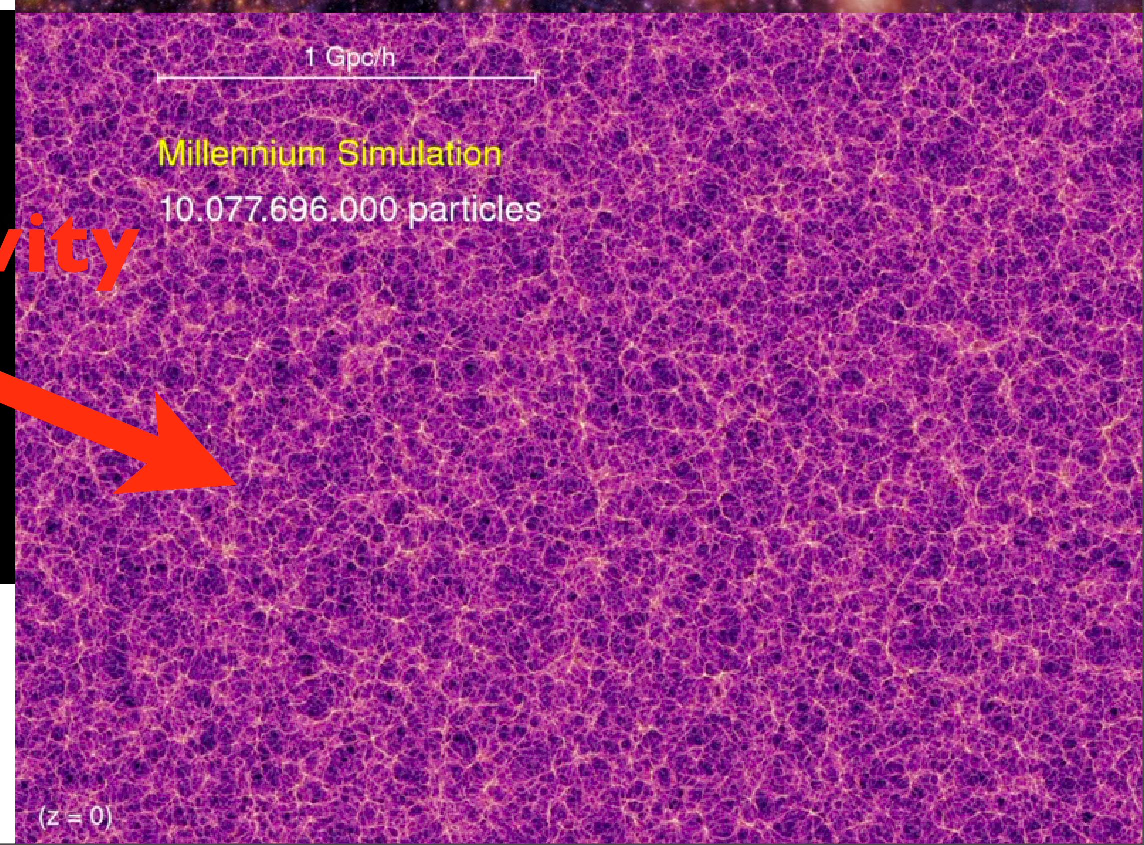


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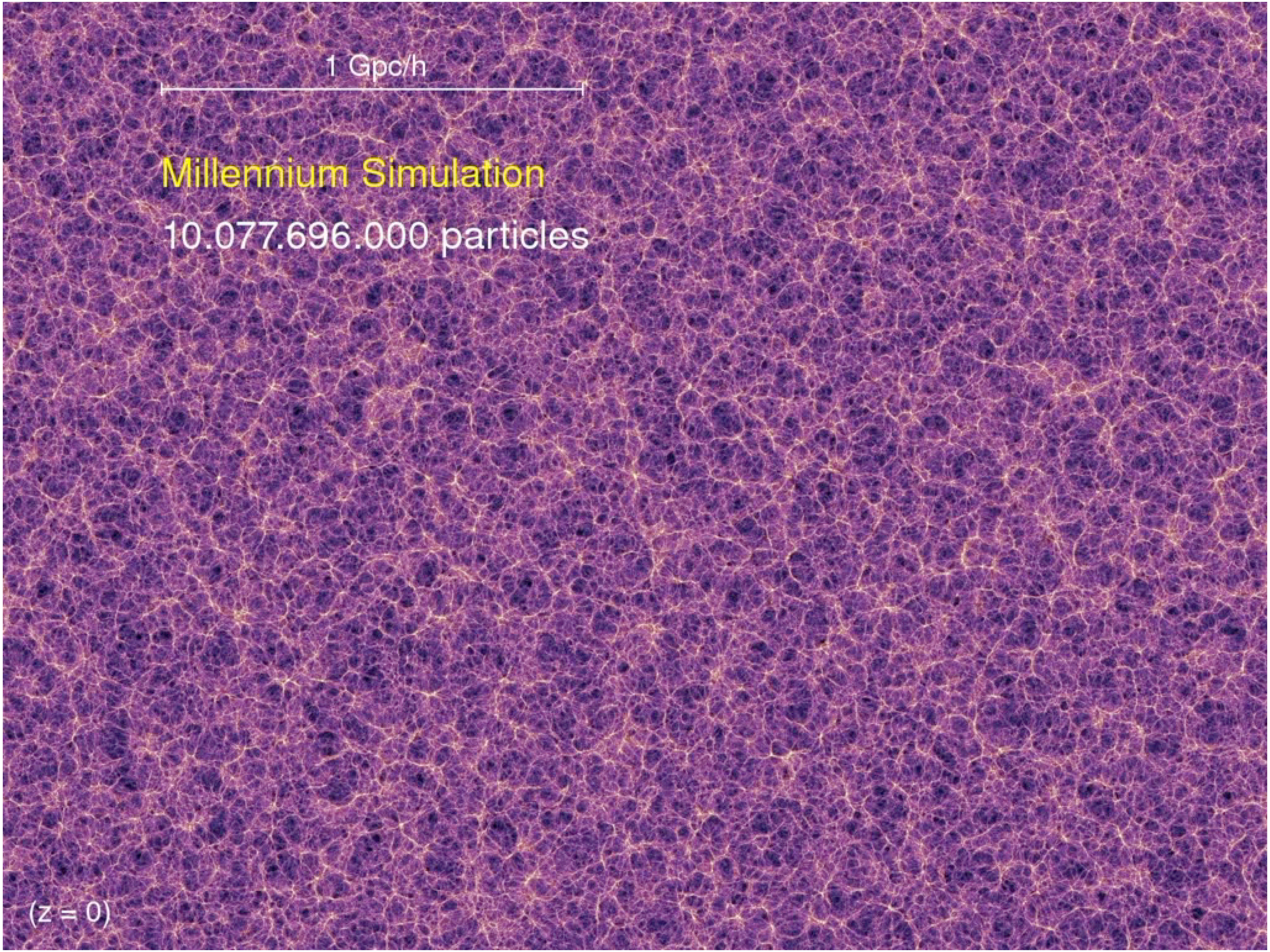
1 Gpc/h
Millennium Simulation
10.077.696.000 particles
(z = 0)

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## What is relation between dark matter halo and its visible galaxy?

Two approaches:

- Semi-analyic modelling
- Hydrodynamical Simulations

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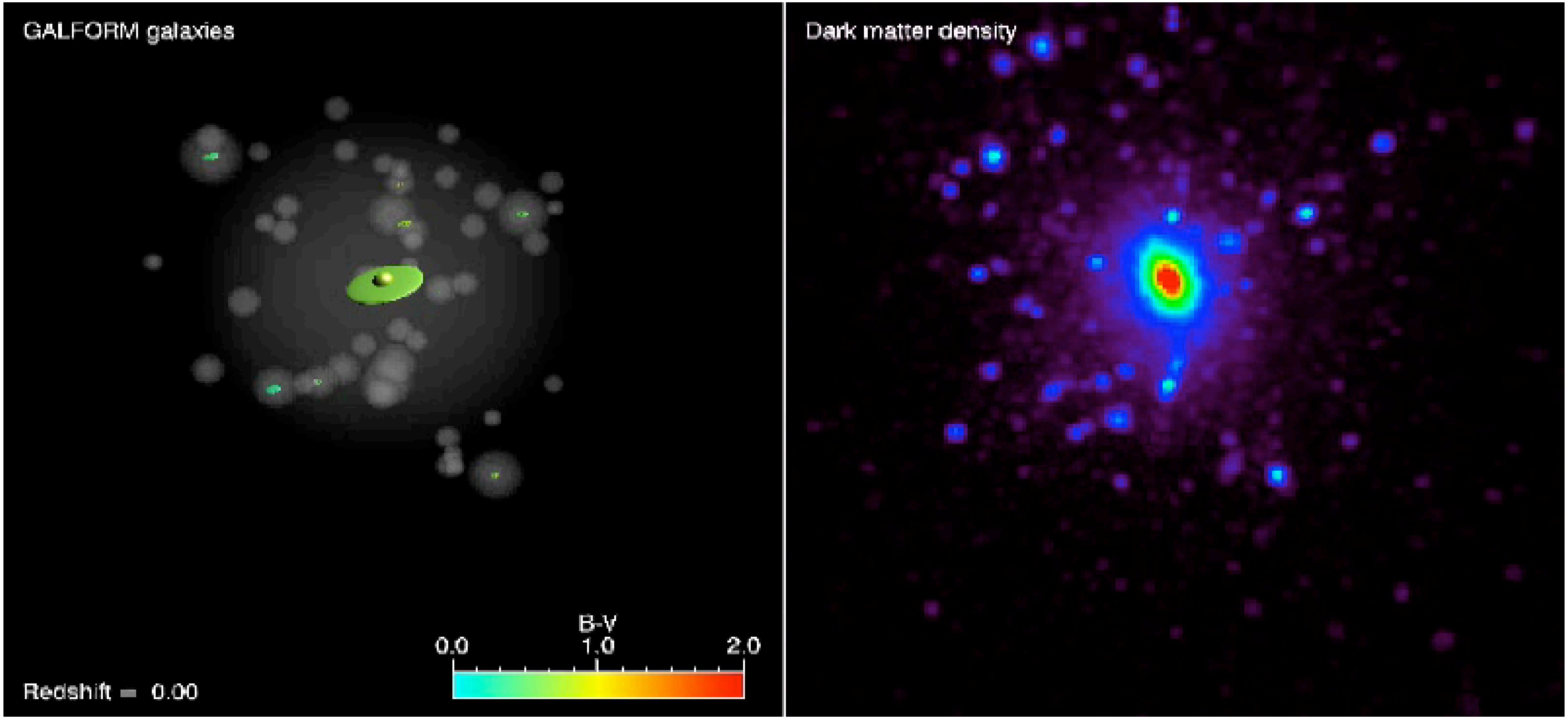
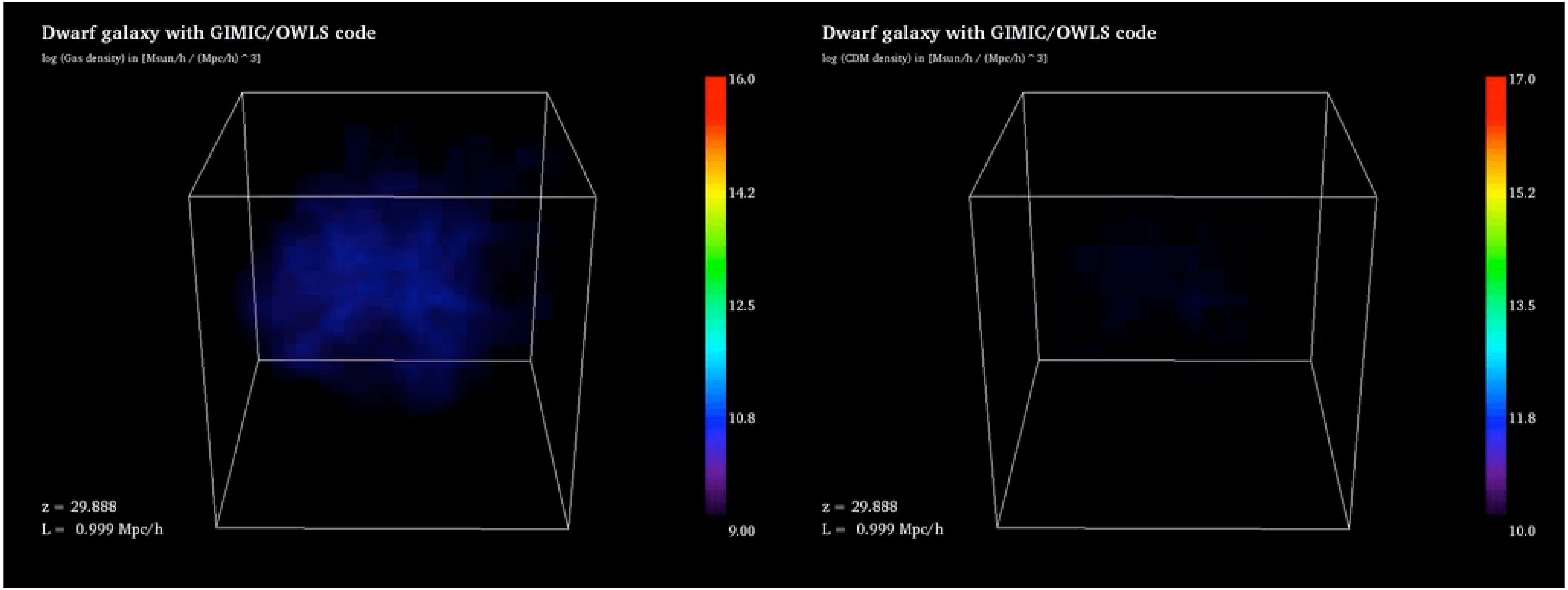
# Semi-analytic modelling: describe astrophysical processes by simple phenomenology



# Hydrodynamical simulations: follow processes numerically



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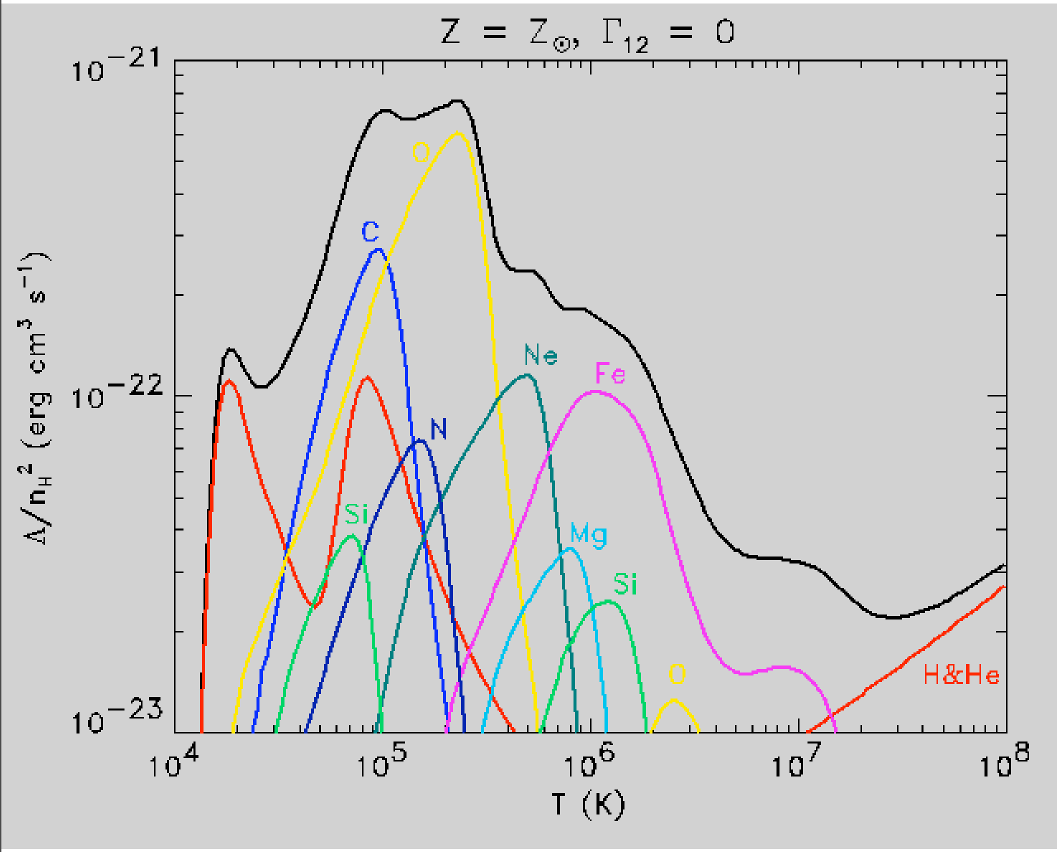
# (Minimum) Key physics included:

1. Gas cooling
2. Star formation
3. UV-background (reionization)
4. Feedback (SNe)
5. Enrichment (stellar evolution)

Caveats:

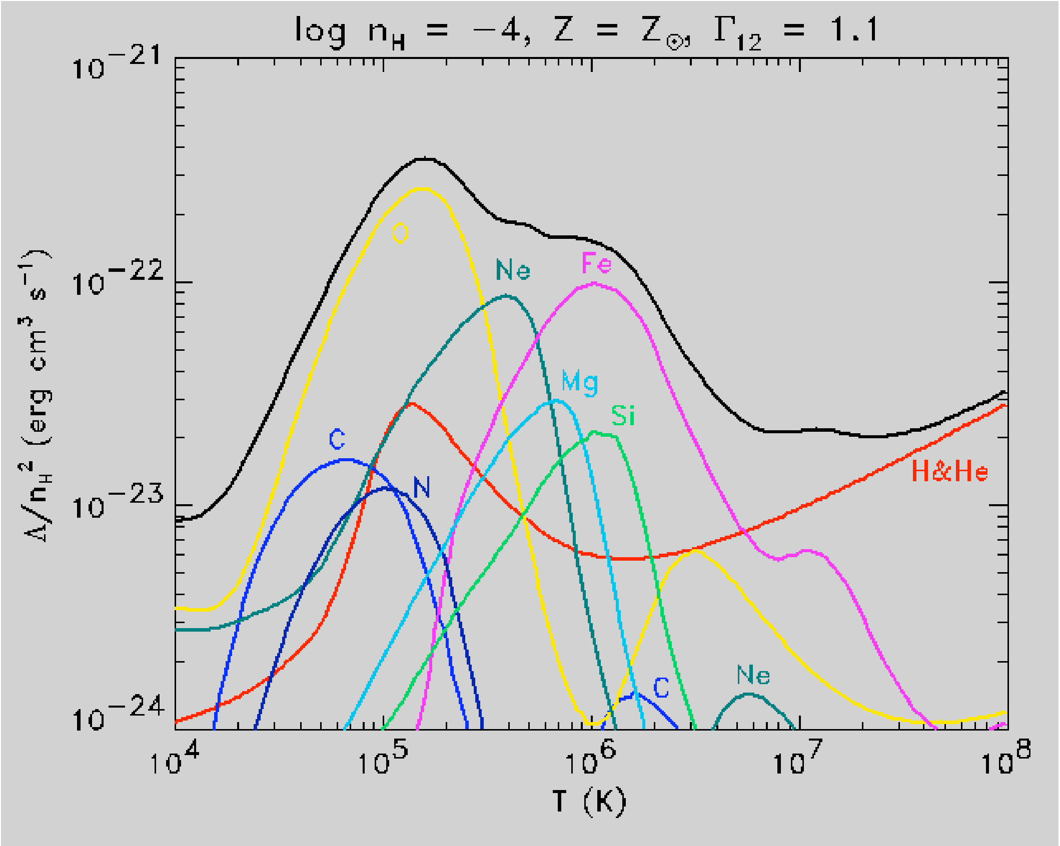
1. Numerical resolution versus dynamic range
2. Physics poorly understood (e.g. initial mass function)

# Cooling rate




Without ionizing background

With ionizing background from gals & AGN

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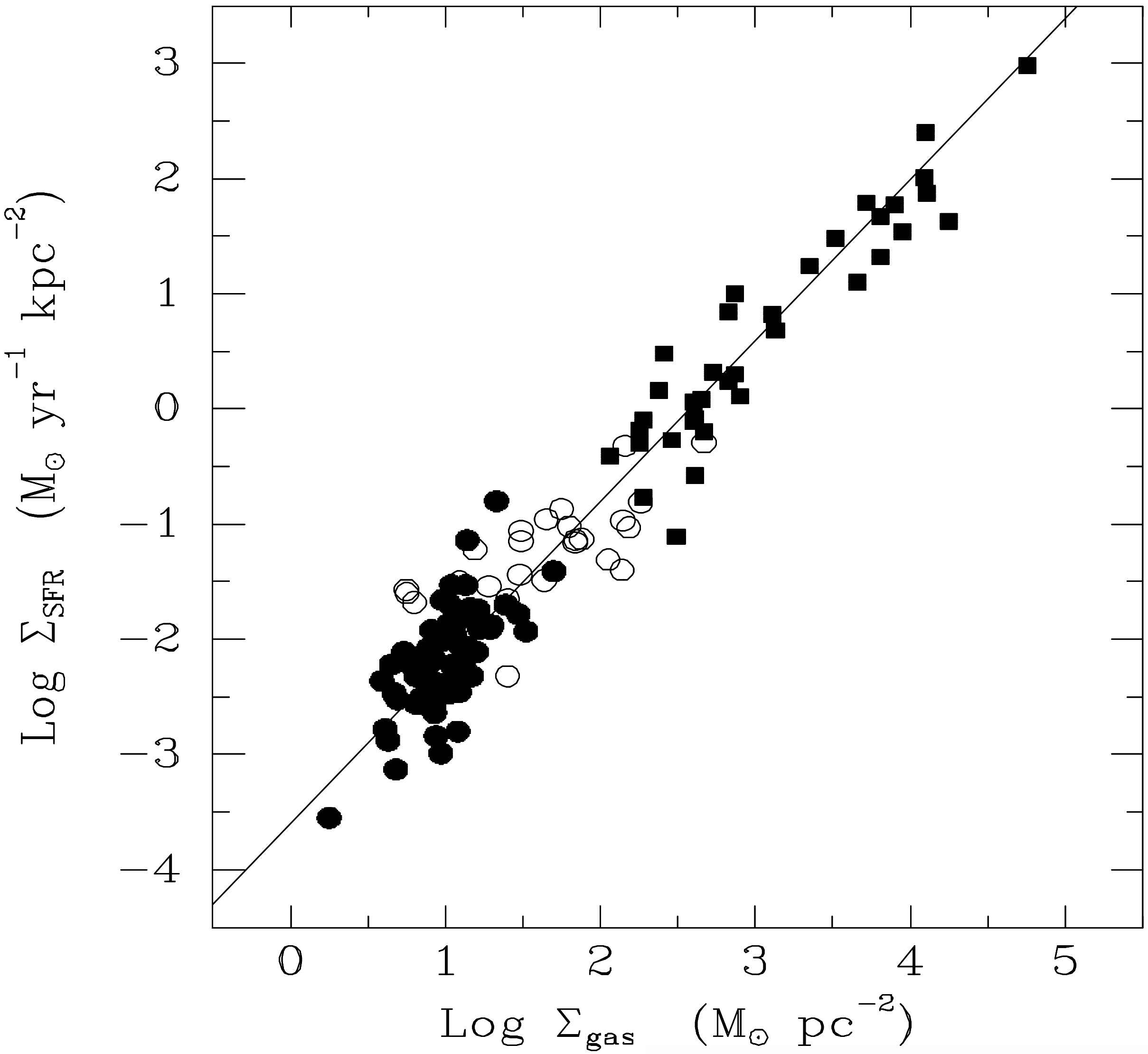
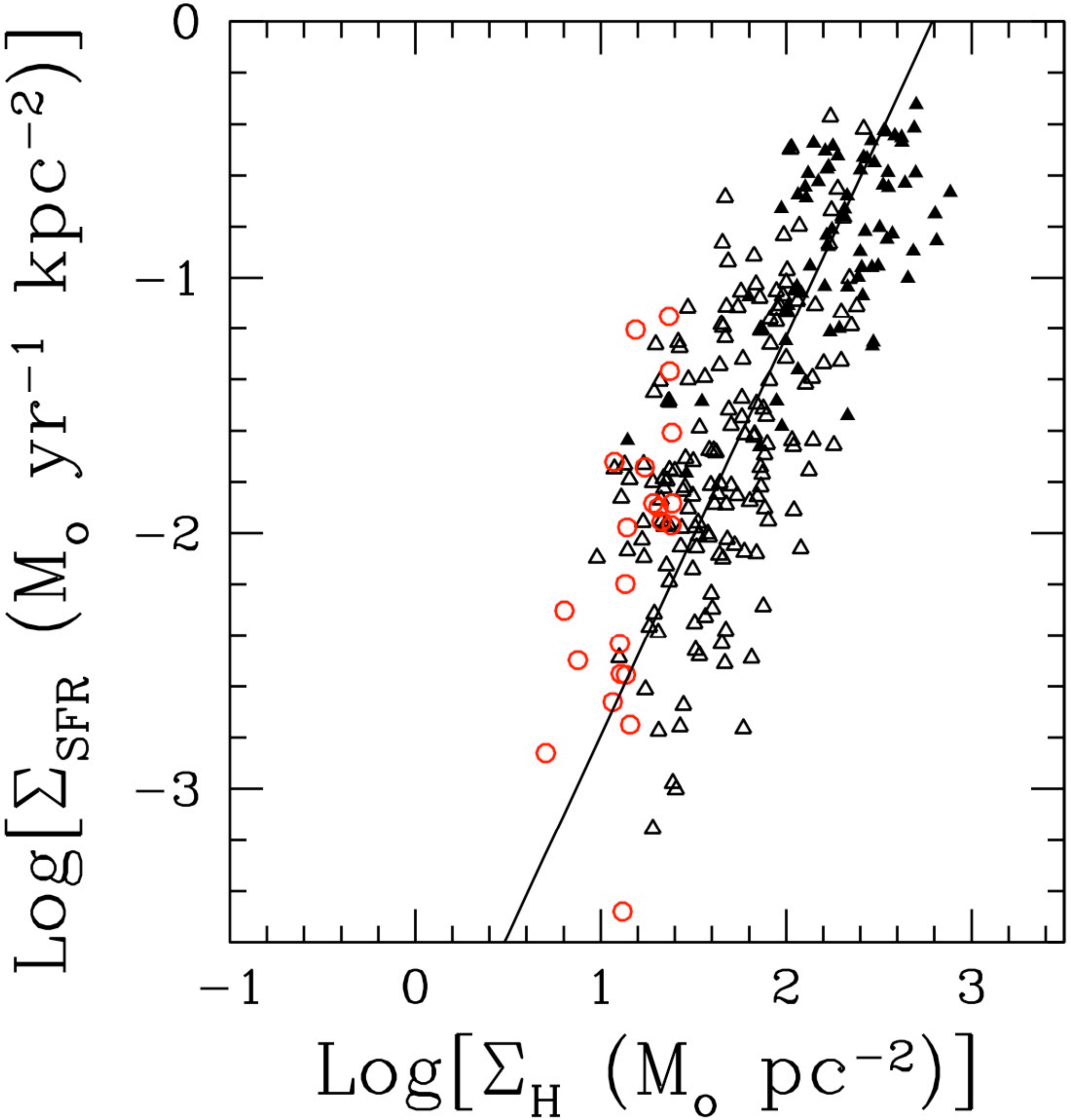
Schaye & Wiersma

## Star formation: what we want:
## Schmidt law

$$\Sigma_{\rm SFR} \propto \Sigma_{\rm gas}^n \quad (n = 1.4 \pm 0.15)$$



# Local Schmidt law




(Calzetti et al, in preparation)

# How to obtain Schmidt law? Sub-grid model for SF and ISM

- Insufficient resolution to model multiphase ISM
- Need effective pressure of unresolved, multiphase ISM
- Need star formation law that reproduces observed threshold and Schmidt law with the minimum number of free parameters
- We do not want to simulate more than we can

J Schaye

# Sub-grid model for SF and ISM

- What goes in

  Effective equation of state (gives the pressure of the gas)

$$P \propto \rho_{\rm gas}^{\gamma_{\rm eff}} \quad (\rho_{\rm gas} > \rho_{\rm thr})$$

  Schmidt law (surface densities)

$$\Sigma_{\rm SFR} \propto \Sigma_{\rm gas}^{n}$$

  Surface density threshold

- What comes out

  Volume density star formation law

  Volume density threshold

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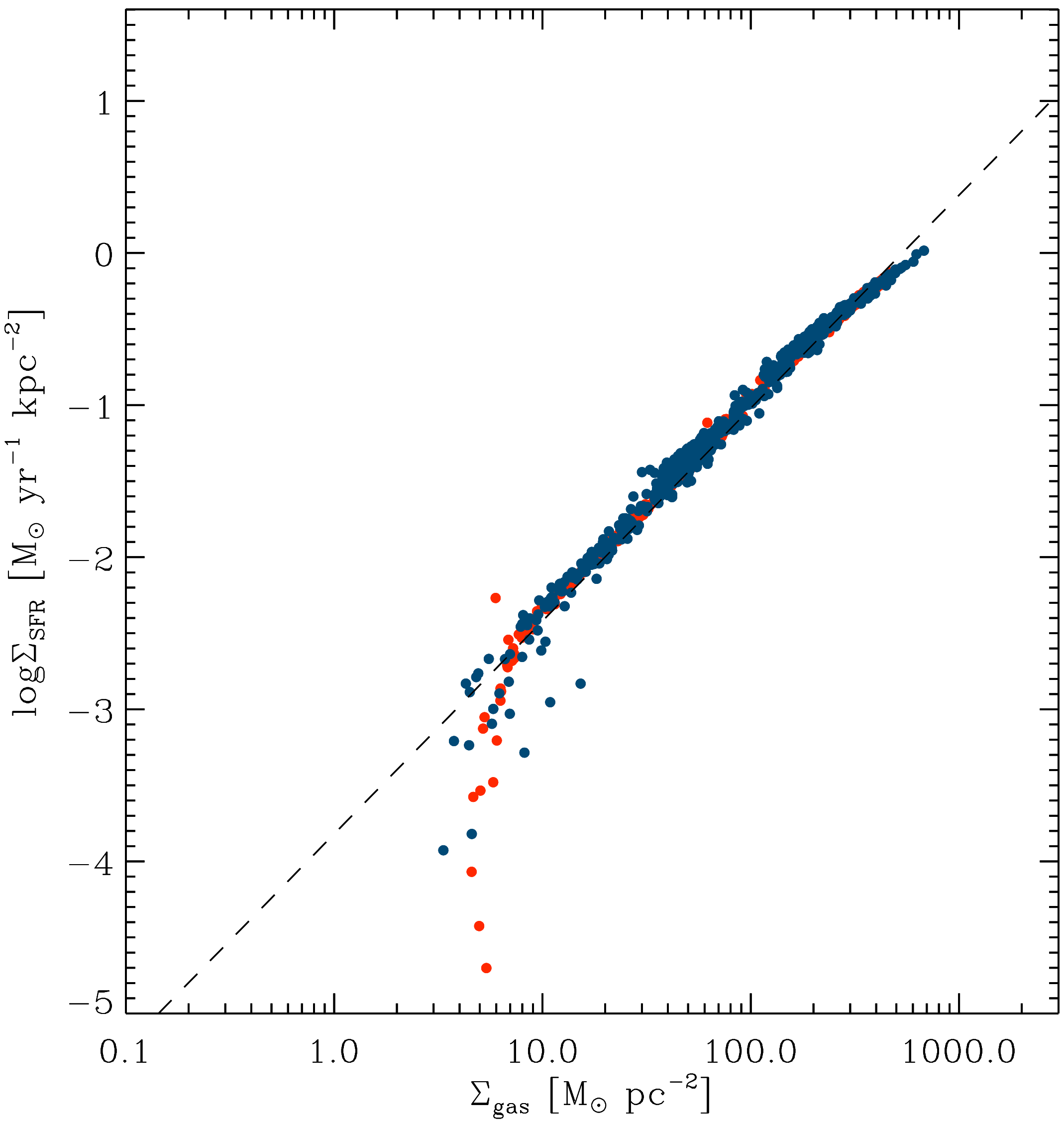
# Implementation guarantees a Schmidt law




- $N_{part} = 100$
- $N_{part} = 12$

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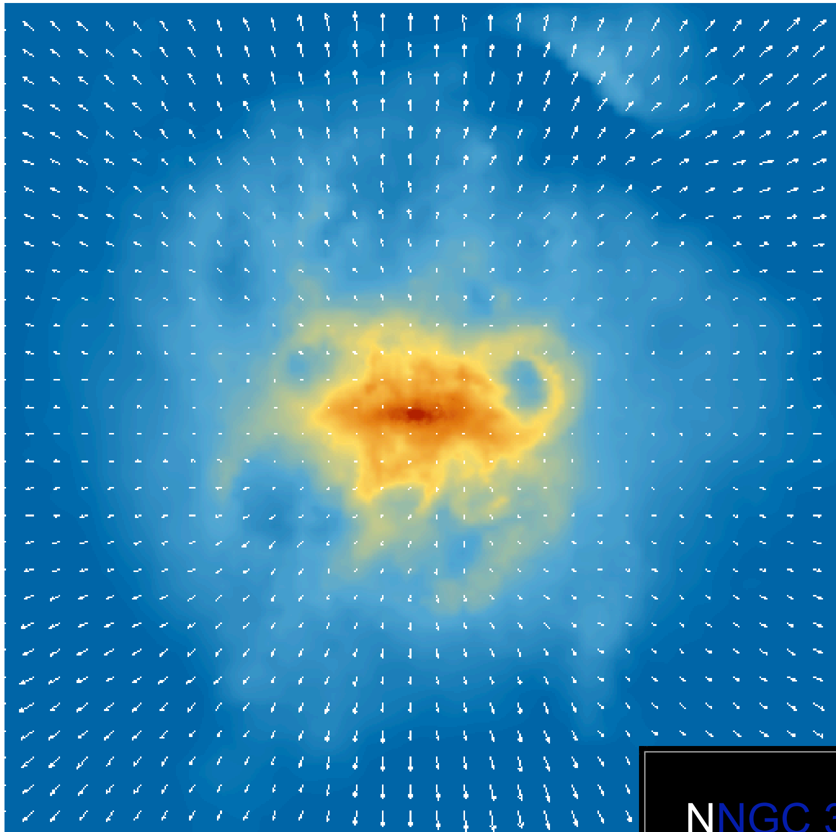
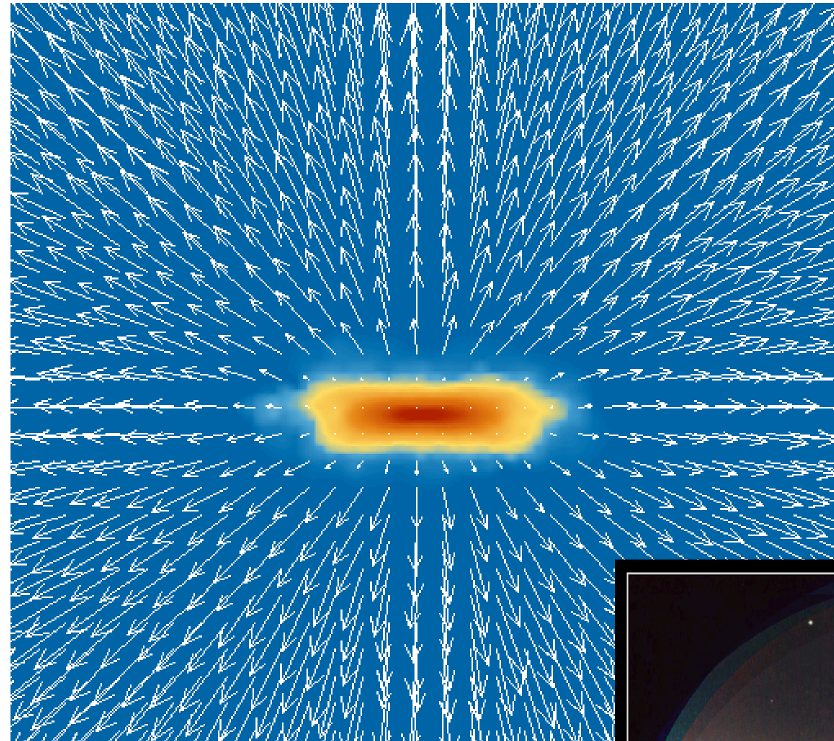
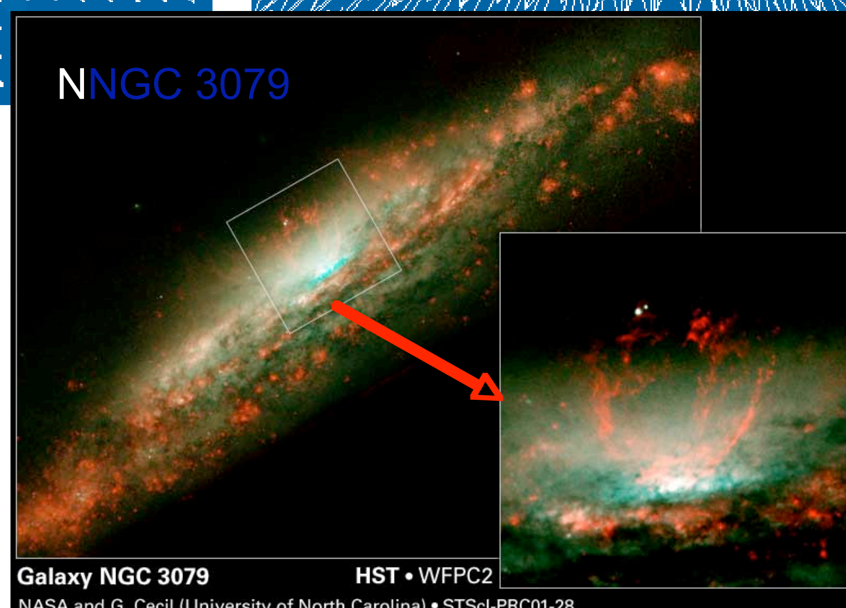
# Galactic winds:

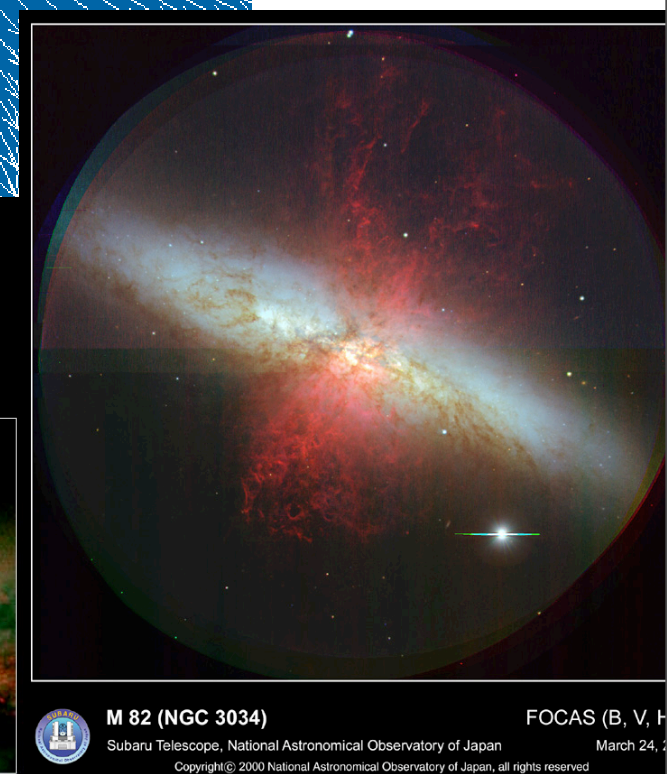
## Simulated:





## Observed:

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Schaye & Dalla Vecchia

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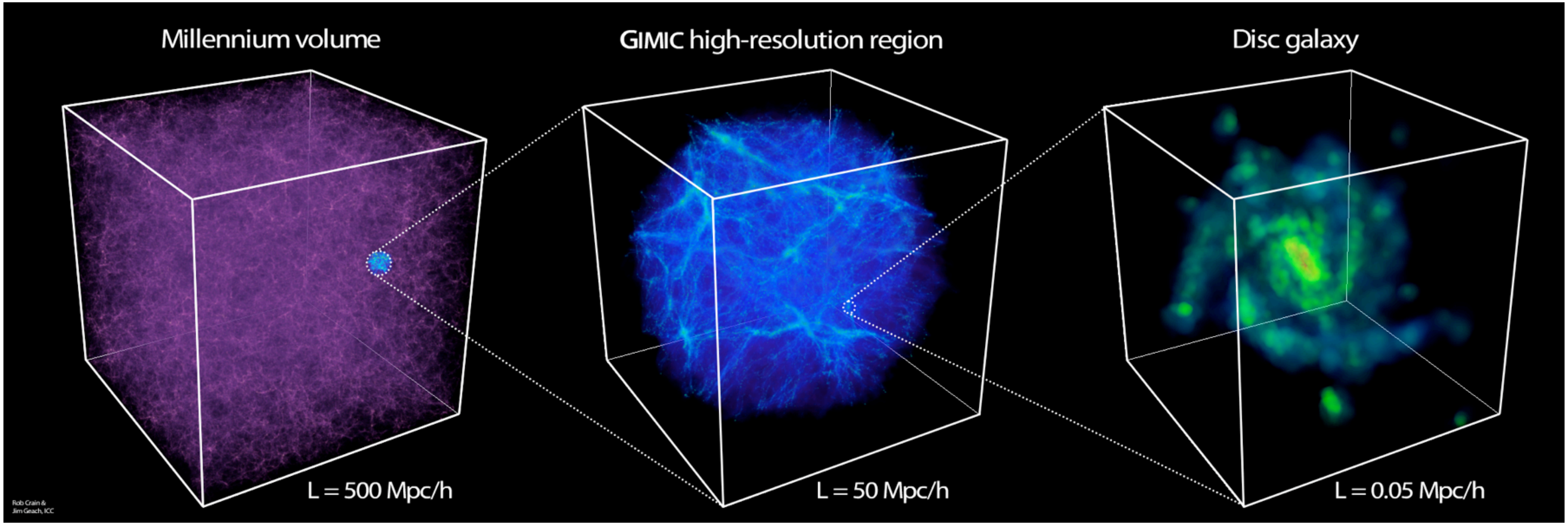
# Suite of simulations: GIMIC/OWLS

## Galaxy-Intergalactic Medium Interaction Calculation




Zoomed simulations of 5 spheres picked from the Millennium Simulation

Combine LSS with high numerical resolution

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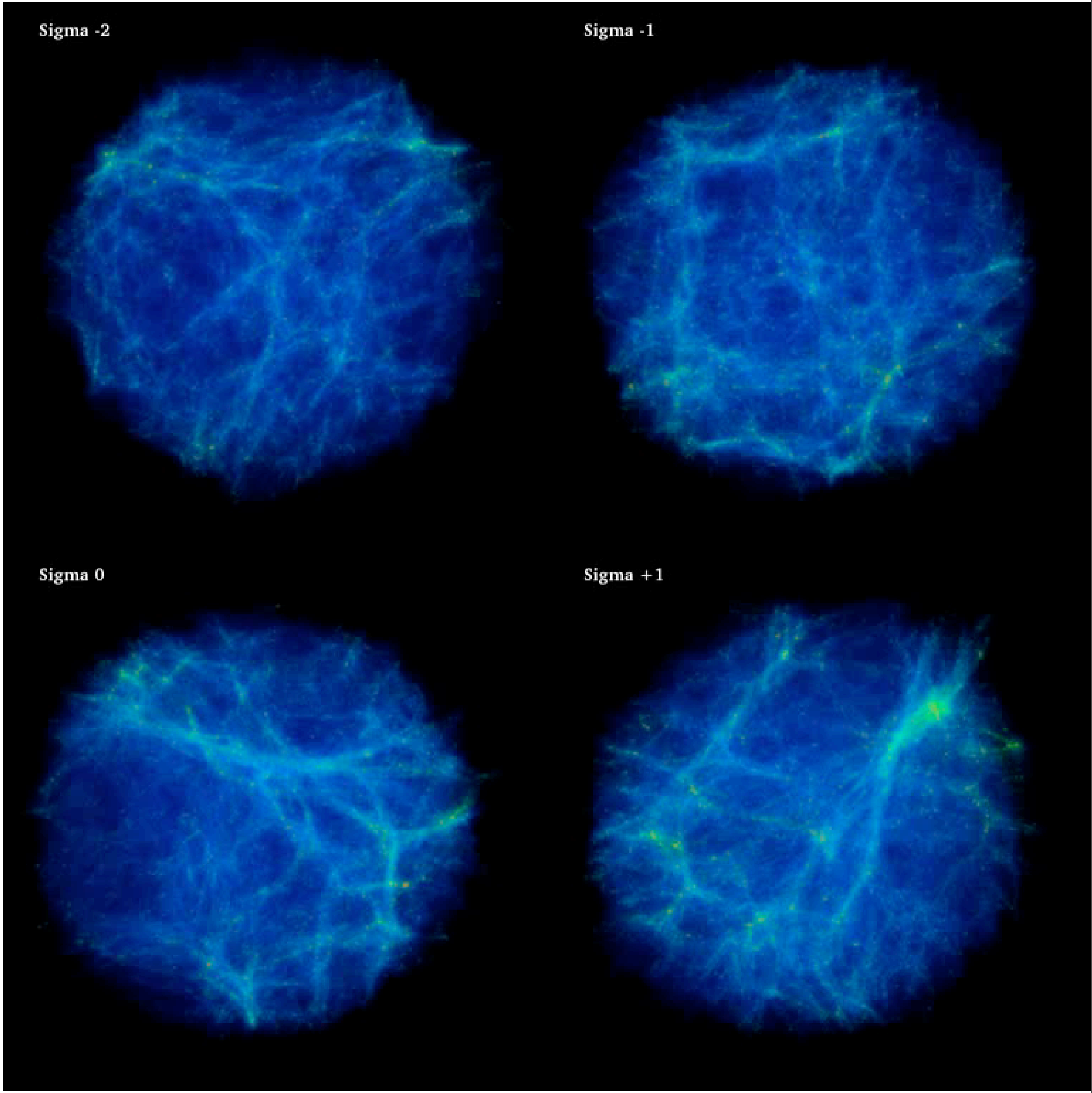


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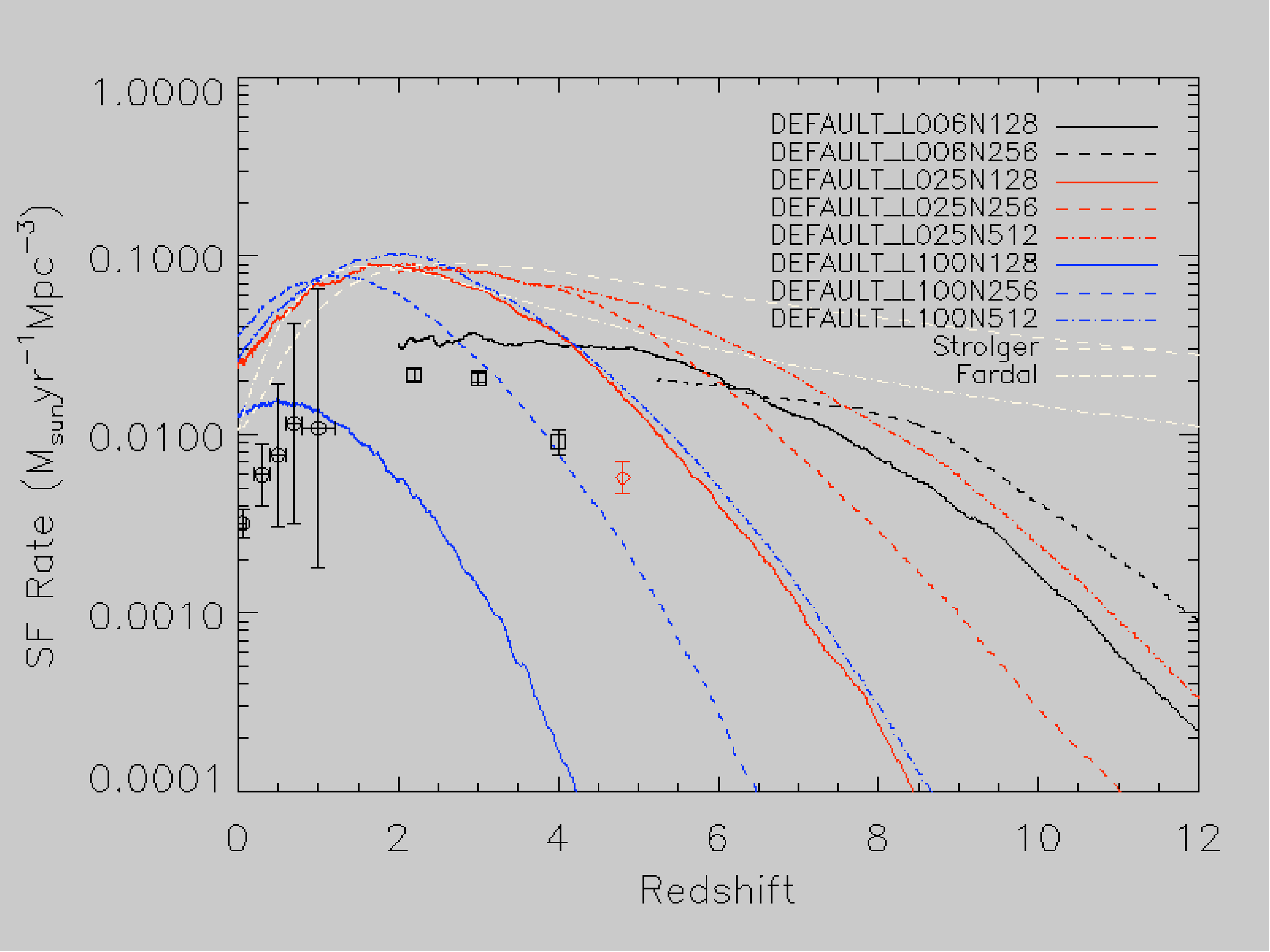
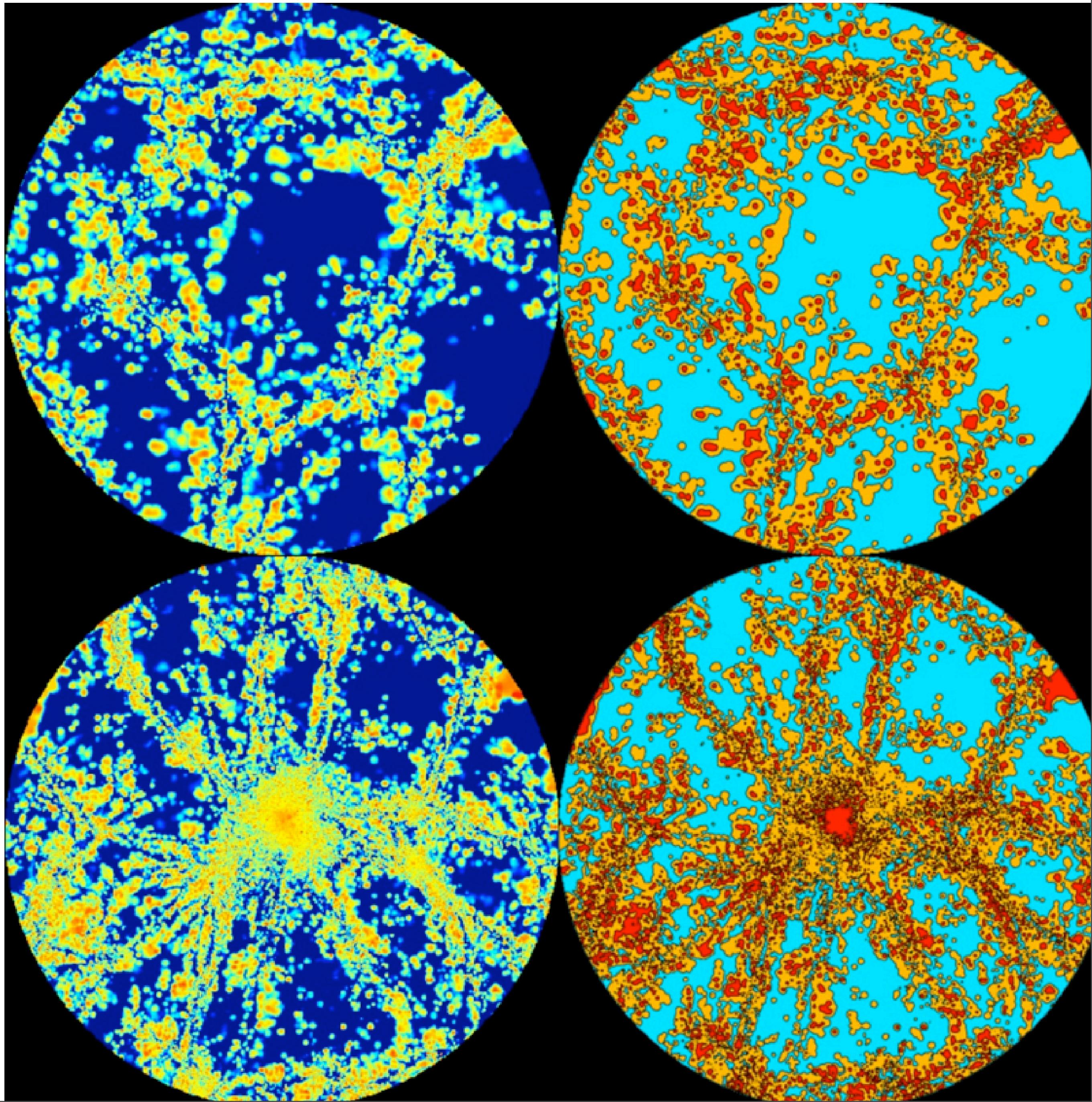
# Results:

## Star formation history (Madau-Lilly plot)



# Metal enrichement



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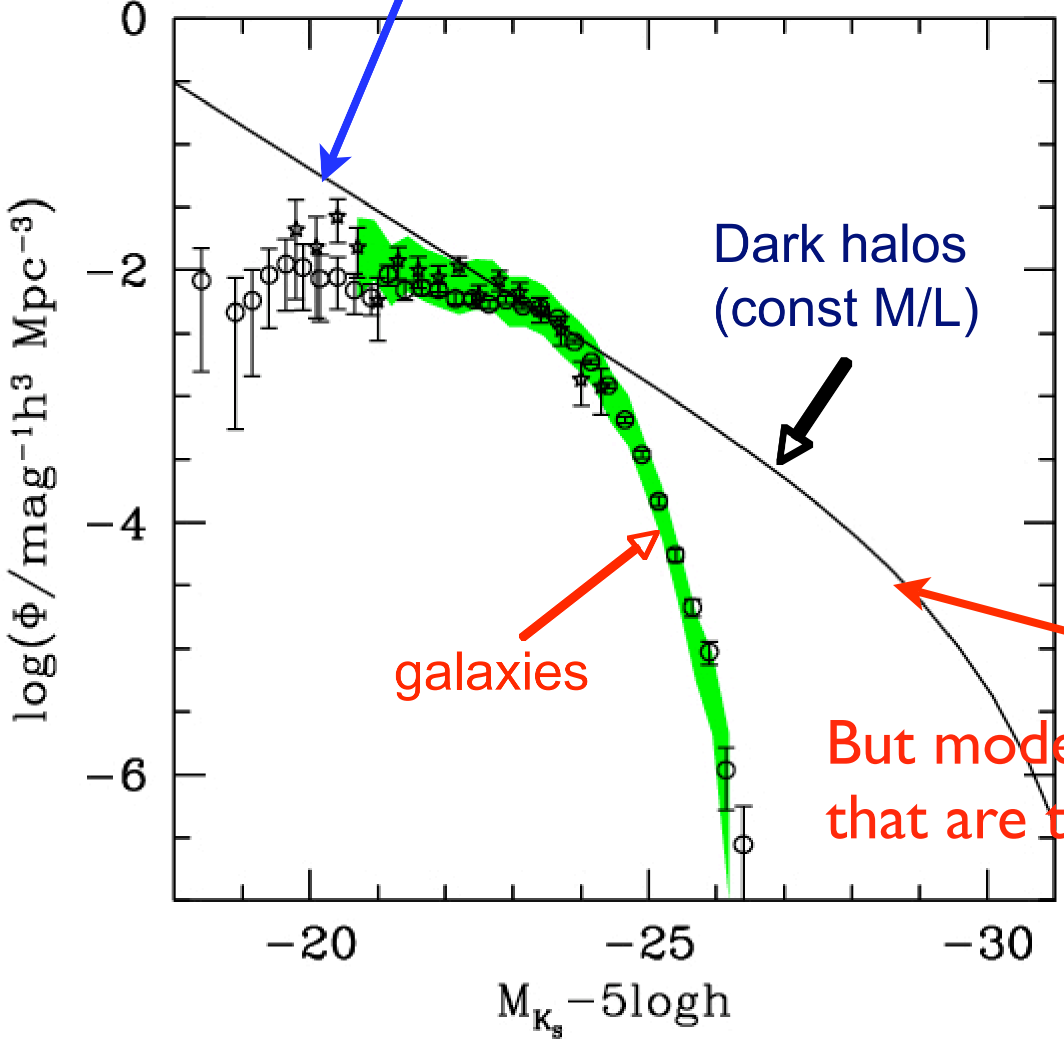
SNe feedback: can reproduce faint end slope




But models make galaxies that are too massive

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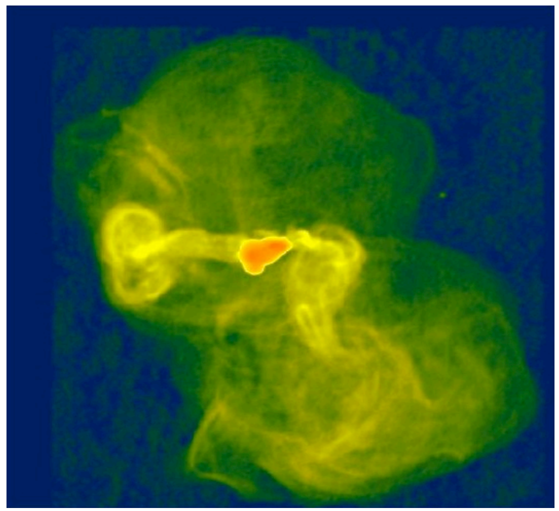
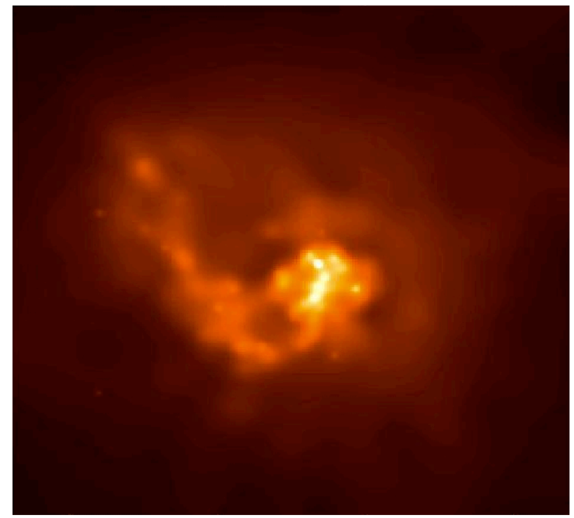
# Motivations

- Observationally, many clusters of galaxies show evidence for X-ray cavities filled with radio plasma, which are thought to be inflated by relativistic jets generated by the central BH (e.g. Owen, 2000; McNamara 2000, 2005; Blanton, 2001; Fabian 2002, 2006; Mazzotta, 2002; Birzan, 2004).

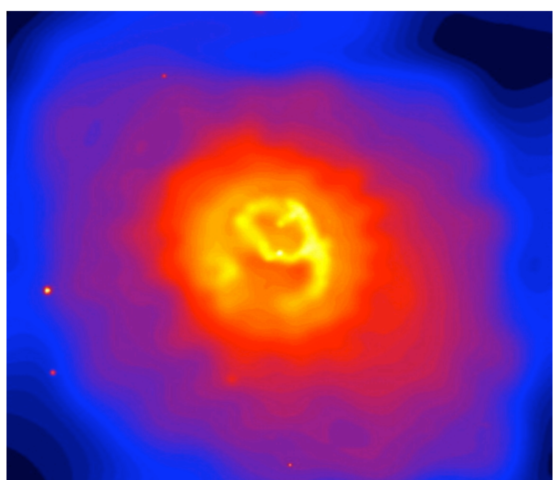
Owen, 2000: VLA radio image at 90cm of M87 (67kpc)

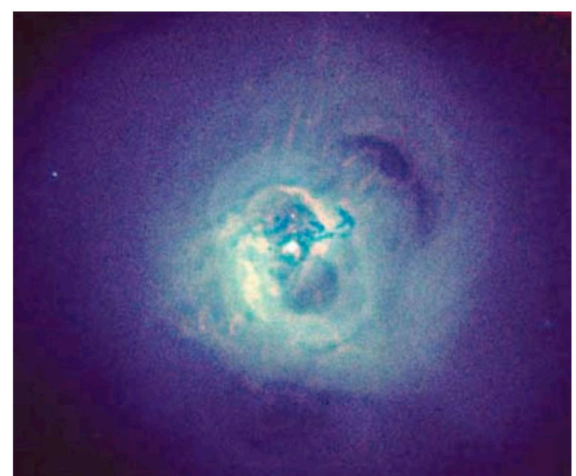




Sanders&Fabian 2002: Chandra 31ks image of Centaurus (50kpc)

Blanton,2001: Chandra 37ks image of Abell 2052 (140kpc)





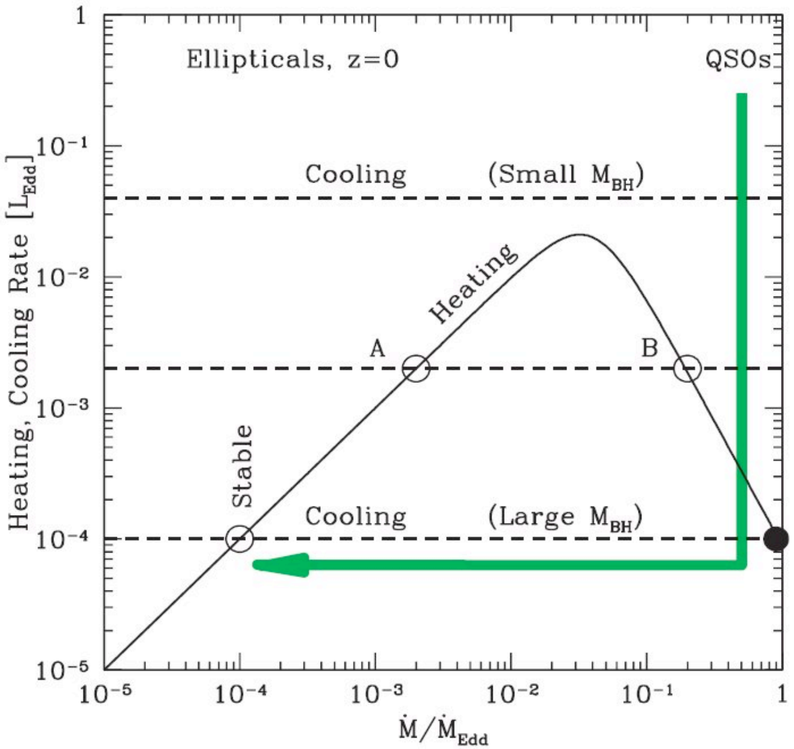
Fabian, 2006: Chandra 1Ms image of Perseus (220kpc)

# Theoretical notions

- In the newly emerging scenario AGN feedback might be composed of two modes:

1. At high z, due to the major mergers, large amount of gas can be accreted by the central BH => powerful QSO

2. SMBH at low redshifts, have very low $L_{bol}$ – but they show evidence of outflows (jets, bubbles), with $L_{mech} > L_{bol}$.




Churazov et al., 2005
-see also, Croton et al, Bower et al, Merloni et al.

- In analogy with X-ray binaries, the switch between these two modes of feedback might be determined by a threshold in BHAR => Aim: explore this simple, but attractive scenario in cosmological simulations of structure formation!

- two modes of BH feedback: “quasar” and “radio”
- a simple switch in BHAR regulates in which state a given BH

“Quasar” feedback:
- a small fraction of $L_{bol}$ coupled thermally, isotropically and continuously to the surrounding gas particles

$$\dot{E}_{\rm feed} = \epsilon_{\rm f} \, L_{\rm r} = \epsilon_{\rm f} \, \epsilon_{\rm r} \, \dot{M}_{\rm BH} \, c^2$$

with $\epsilon_{\rm r}$ = 0.1 and $\epsilon_{\rm f}$ = 0.05

“Radio” feedback:
- below $BHAR_{radio}$ = 0.01, AGN feedback is mechanical => recurrent, hot bubble episodes



Sijacki 08

# Two modes:

Cold accretion during mergers gives rise to QSOs

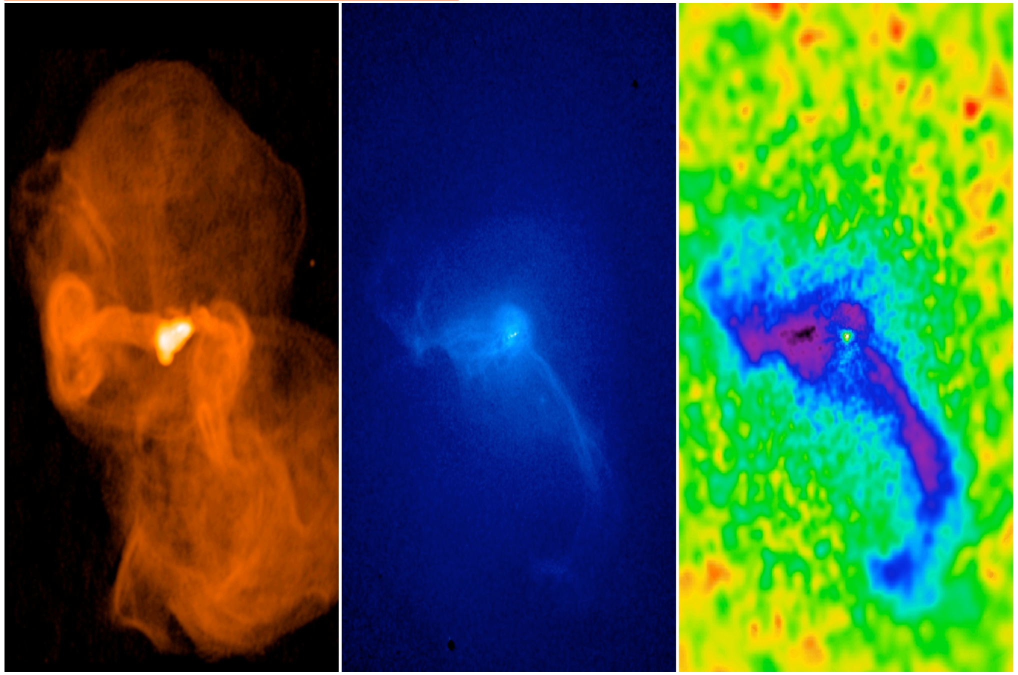
"Quasar" mode

(eg. Granato et al., 2004, Springel et al 2005)

Springel et al 2005

"Radio" mode feedback

(eg. Croton et al 2006, Bower et al 2006 Okamoto et al 2007)



Hot accretion from nearly hydrostatic halo gives jets and feedback, shutting-off star formation (cooling flow)

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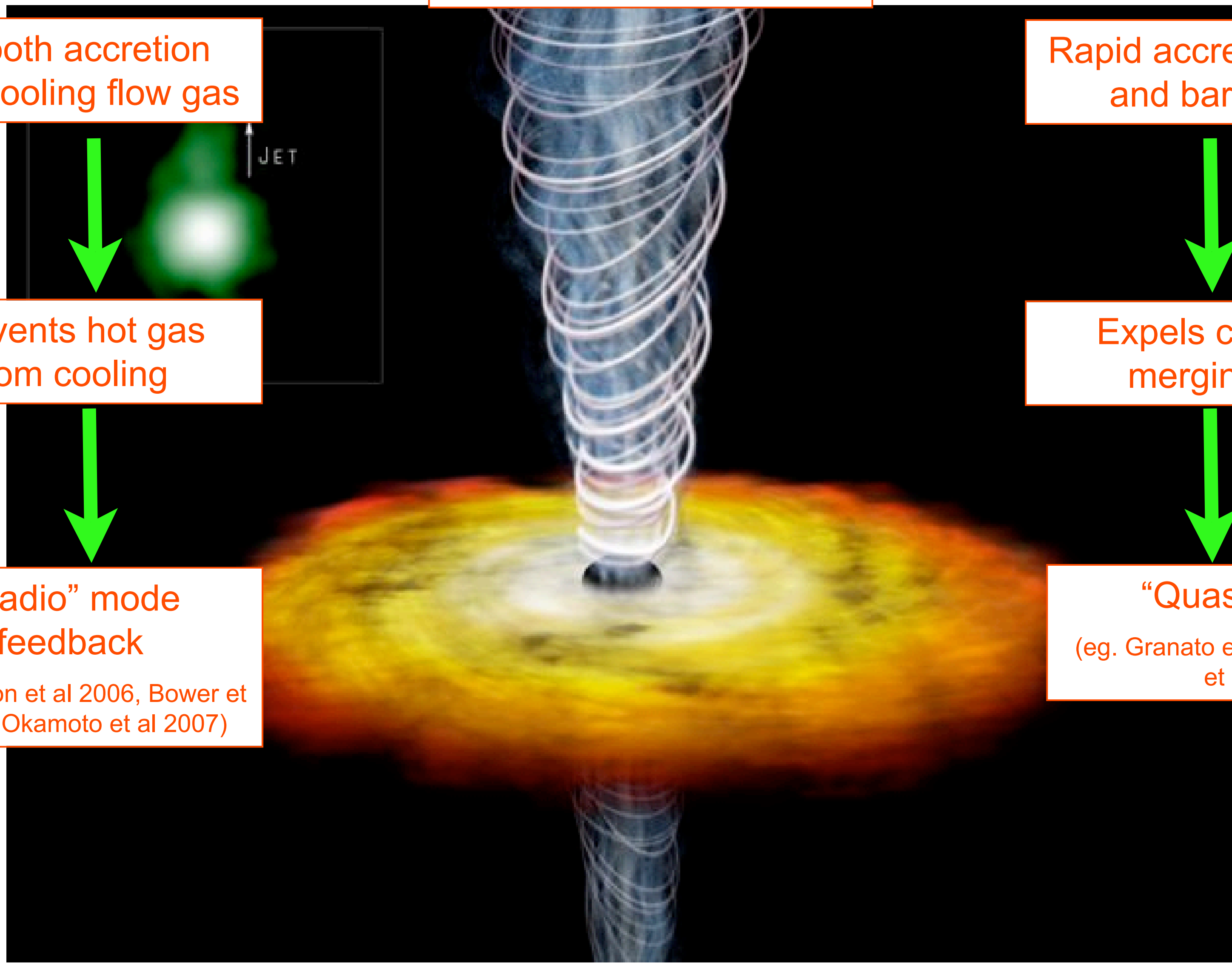
Two types of accretion?

SS – accretion energy is radiated

RIAF – accretion energy powers jet




| Smooth accretion from cooling flow gas | Rapid accretion in mergers and bar instabilities |
|---|---|
| ↓ | ↓ |
| Prevents hot gas from cooling | Expels cold gas from merging galaxies |
| ↓ | ↓ |
| “Radio” mode feedback (eg. Croton et al 2006, Bower et al 2006 Okamoto et al 2007) | “Quasar” mode (eg. Granato et al., 2004, Springel et al 2005) |

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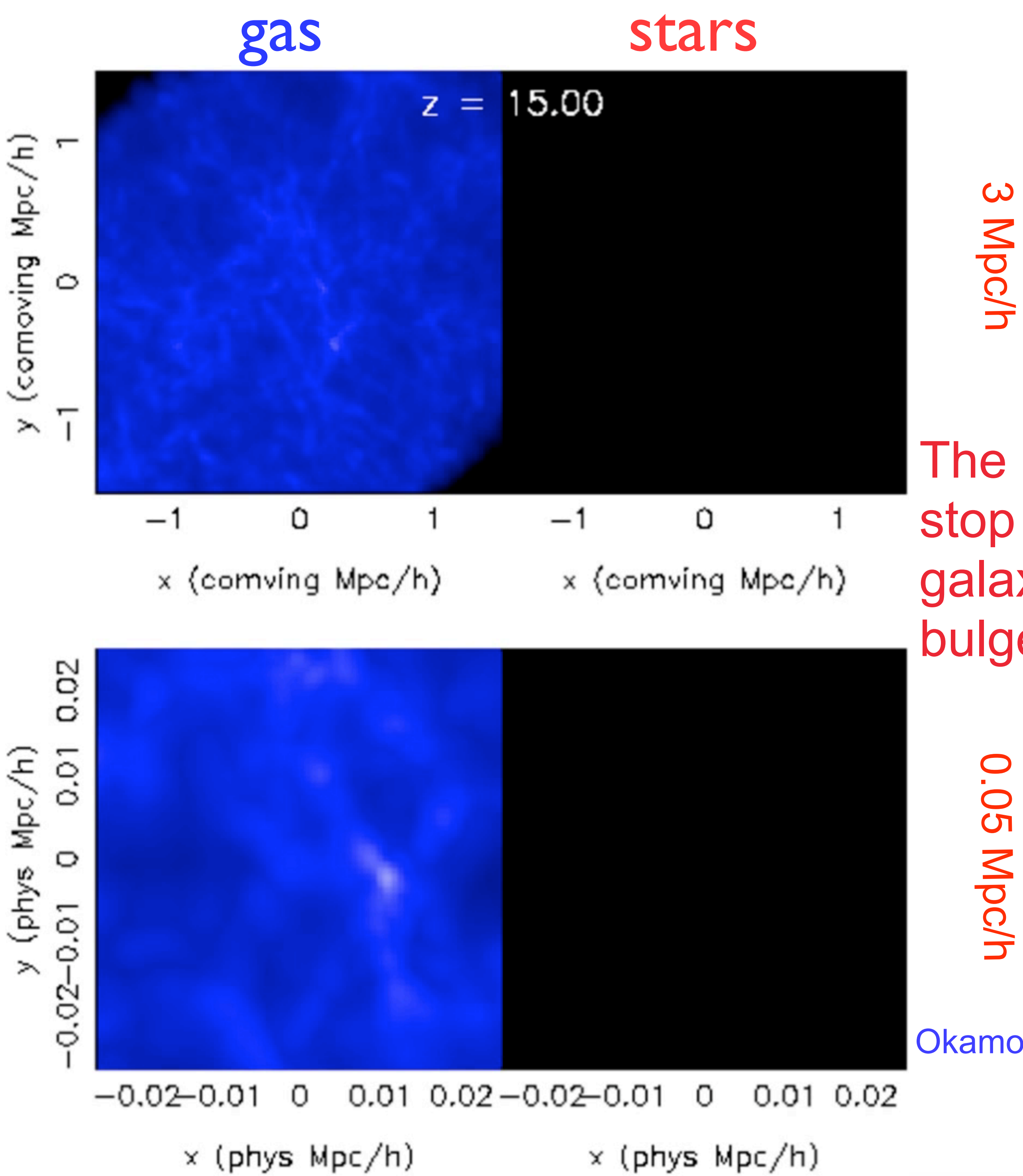
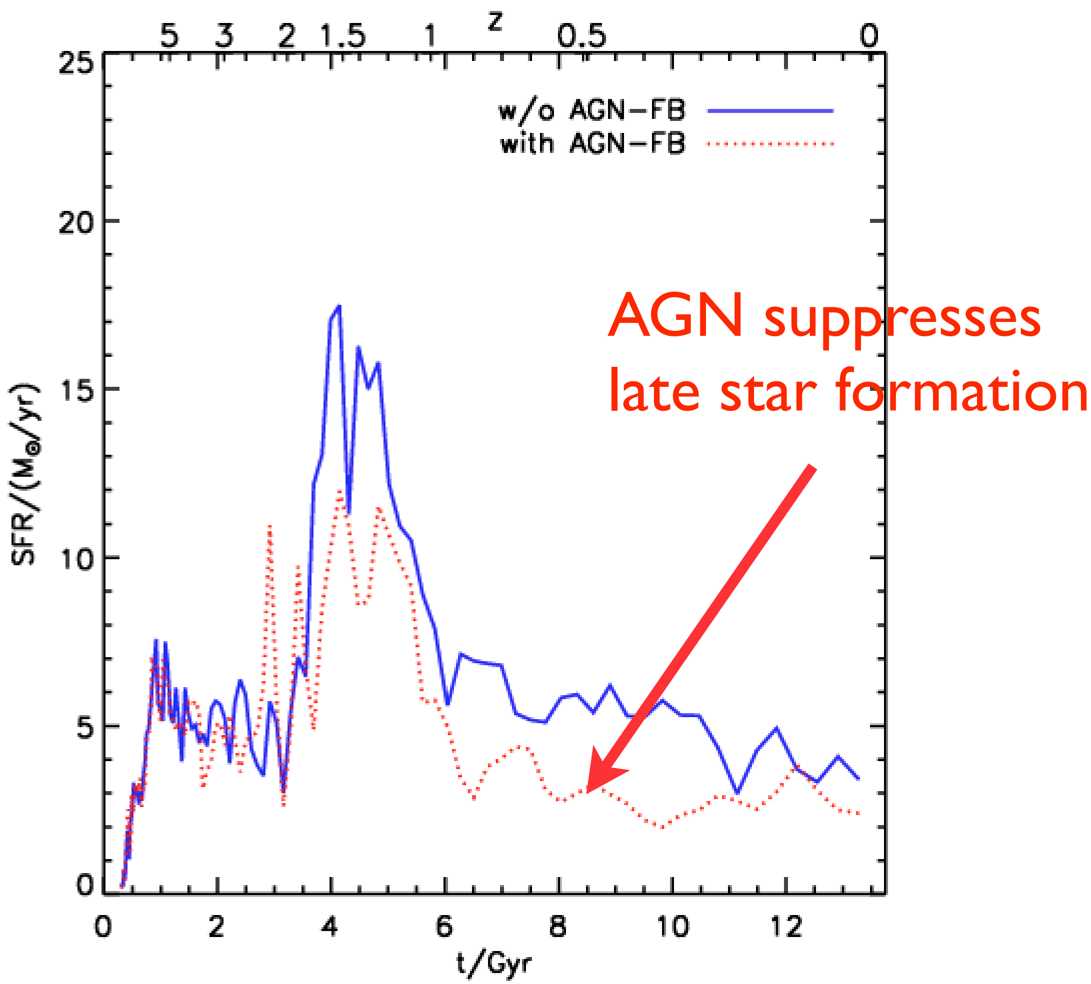



Red circles represent black holes and their radii are proportional to $\log(M_{BH})$

The problem is to stop this disk galaxy forming a bulge!!!

Okamoto et al 2007

# Star formation history for this galaxy:



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# Inclusion of AGN in models produces observed cut-off in number density of bright galaxies

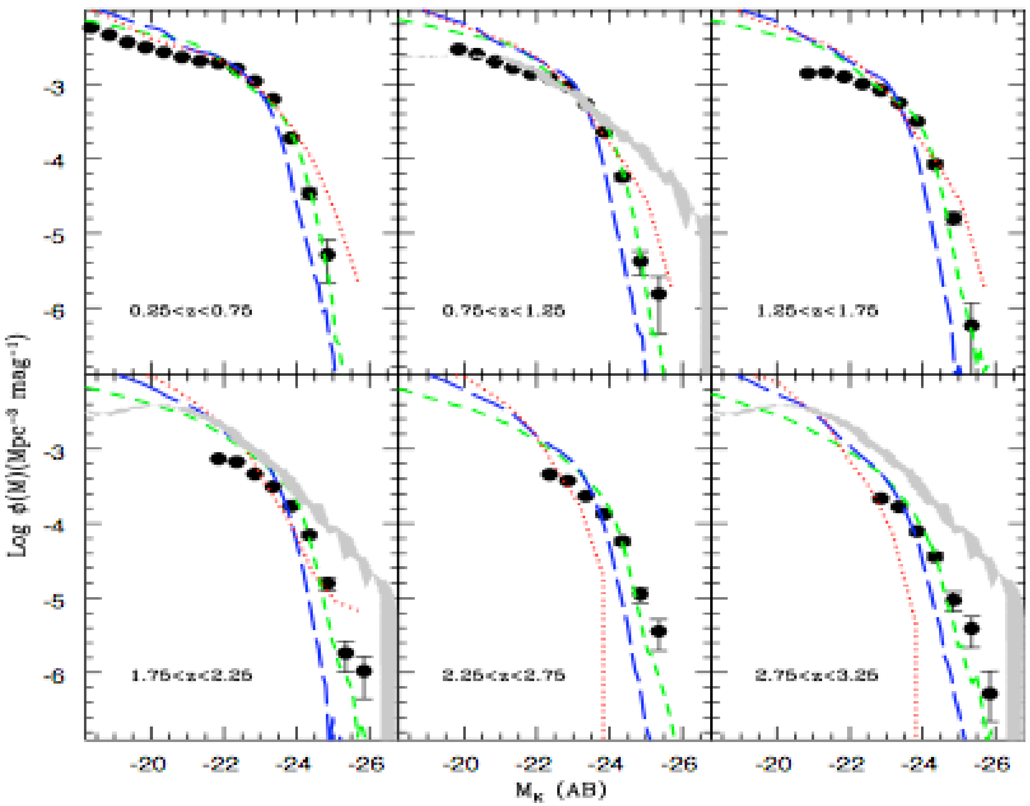


**Figure 6.** Comparison of our determination of the K-band LF (solid dots) with predictions of theoretical models. Short and long dashed lines are the predictions obtained by Bower et al. (2006) and De Lucia & Blaizot (2006), respectively. The predictions by Monaco et al. (2007) are shown with a dotted red curve. The gray area shows the prediction obtained by hydrodynamical simulations (Nagamine et al. 2006; Cen & Ostriker 2006).

Bower 06, Croton 06

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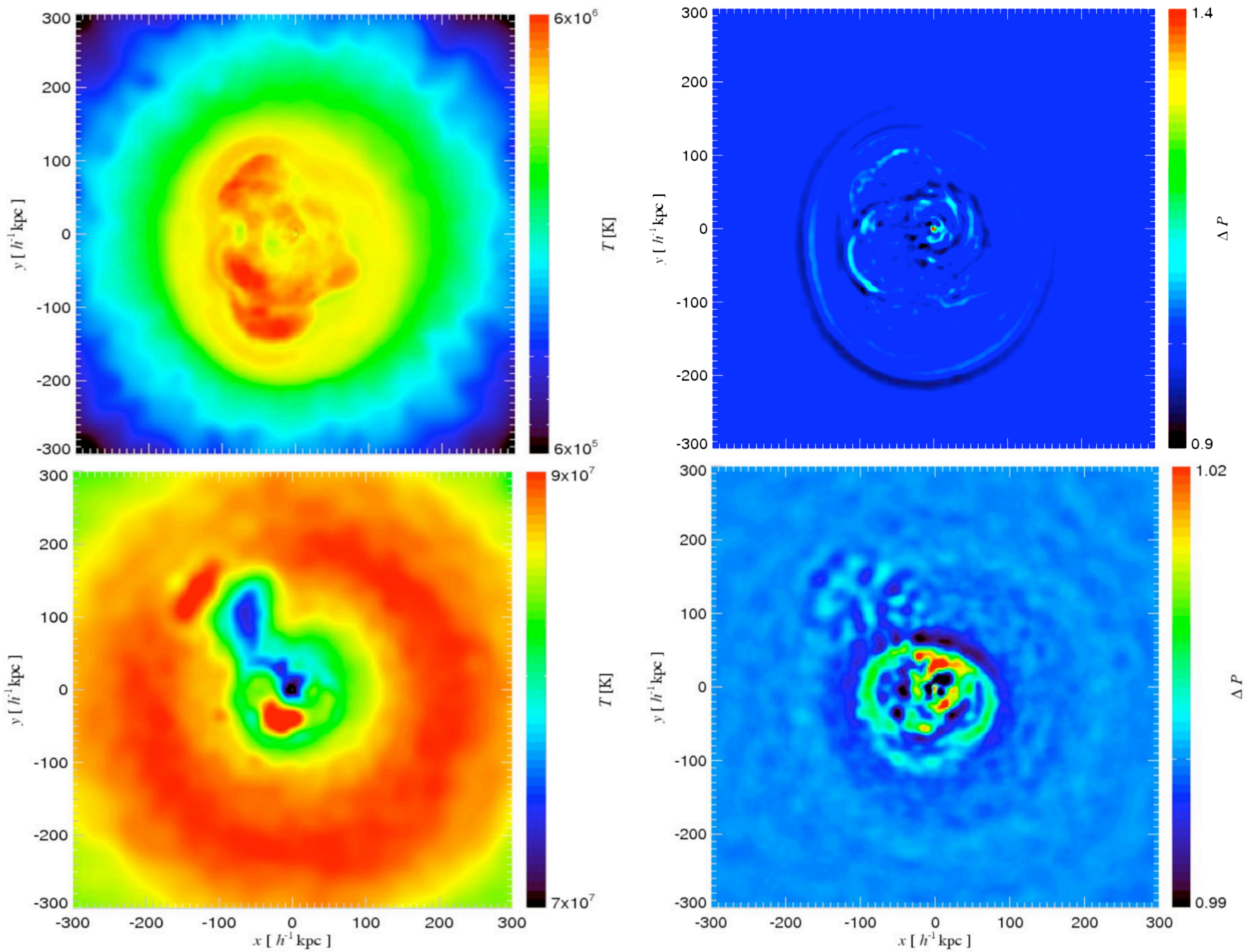
# Direct evidence:

## AGN feedback in isolated halos: bubbles, weak shocks and sound waves




$10^{13}$ HALO

$10^{15}$ HALO

TEMPERATURE MAPS

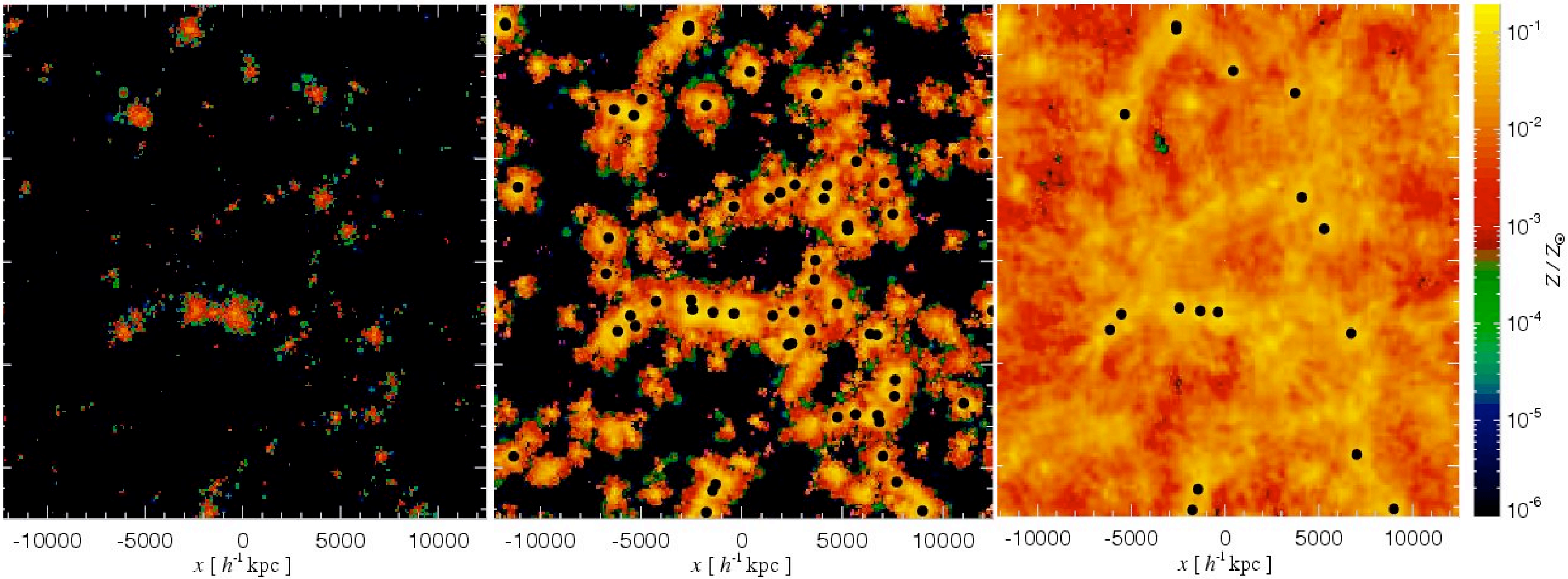
PRESSURE MAPS

Dalla Vecchia et al

Omma et al

Sijacki 08

# Metal distribution




no AGN
no galactic winds

with AGN
no galactic winds

with AGN
with galactic winds, v~480km/s

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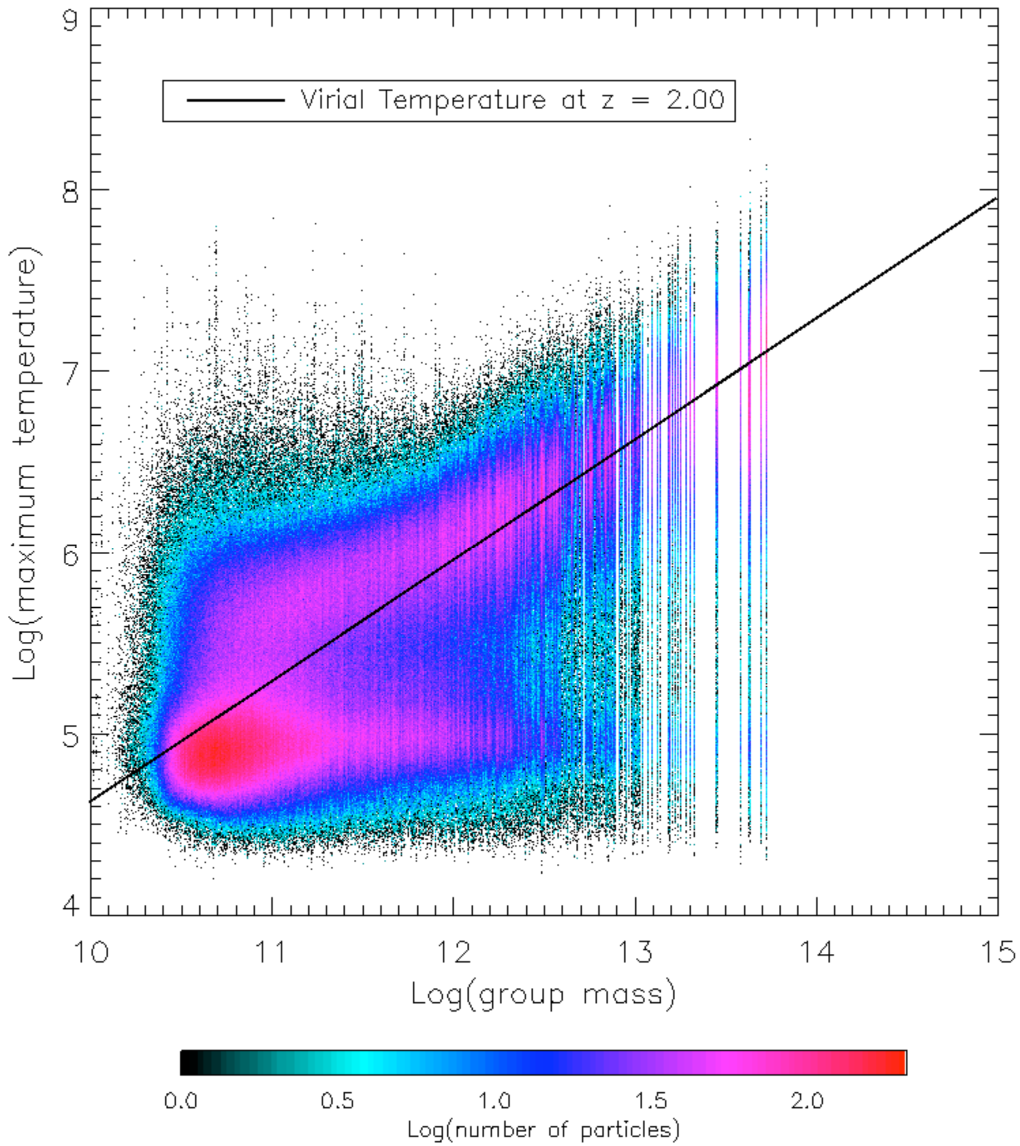
# Caveat: hot versus cold accretion

Division between cold +clumpy accretion and smooth+hot accretion sets-in at similar mass-scale




Van de Voort et al. (2008)

# And now for something completely different!

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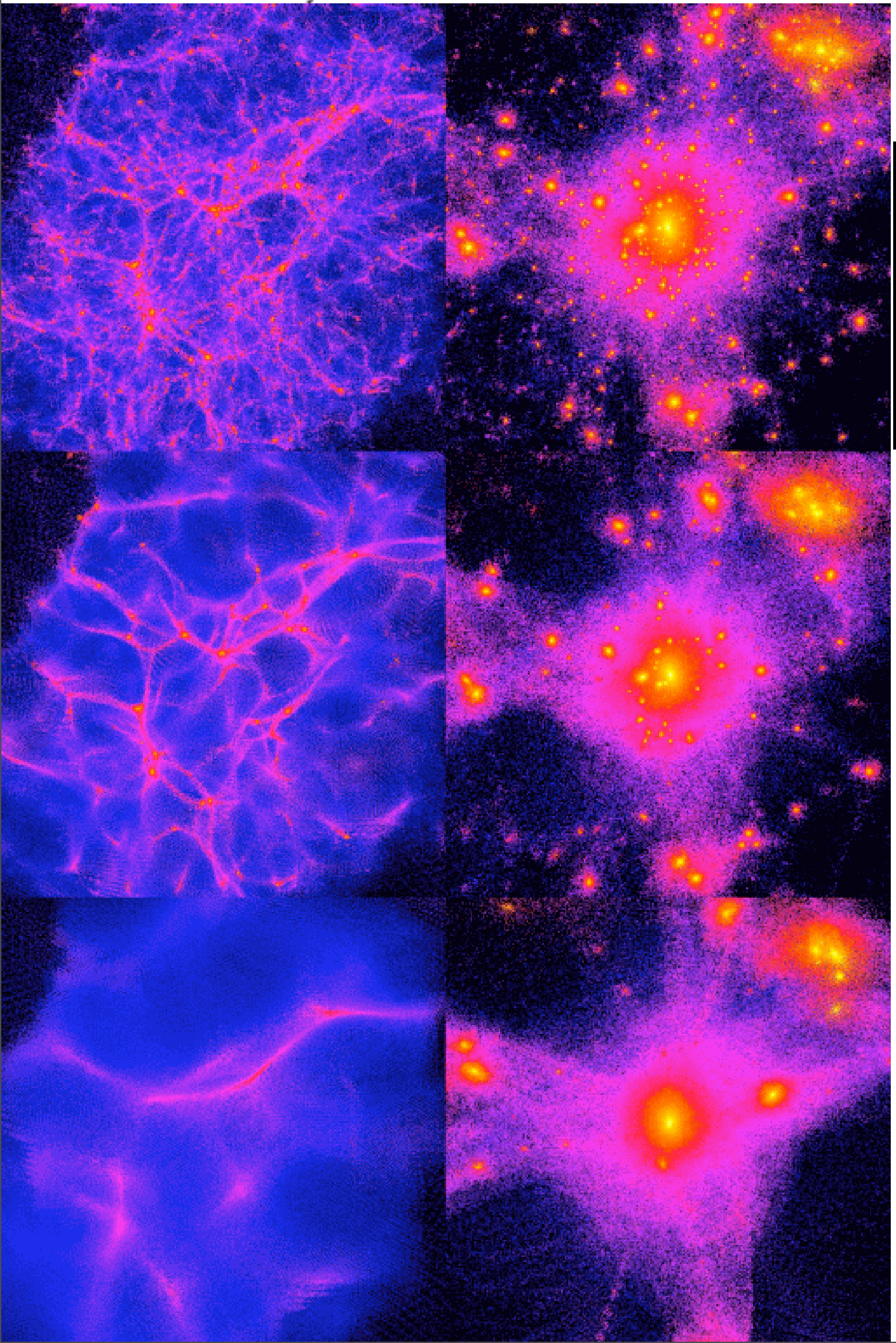
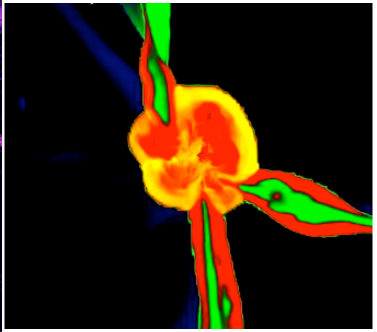
# First stars and the nature of the dark matter

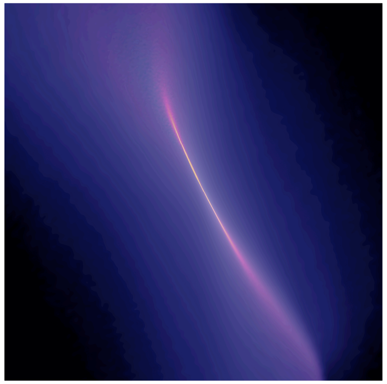


## Cold Dark Matter

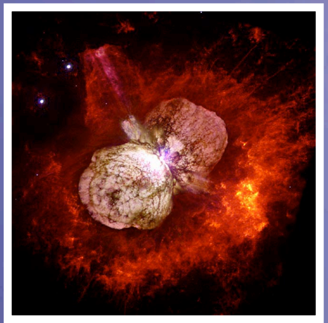


- Single star per halo
- Massive: 30-300 M_sun
- Short-lived: 2-4 Myr
- Very luminous
- No strong mass loss
- die as SN or BH

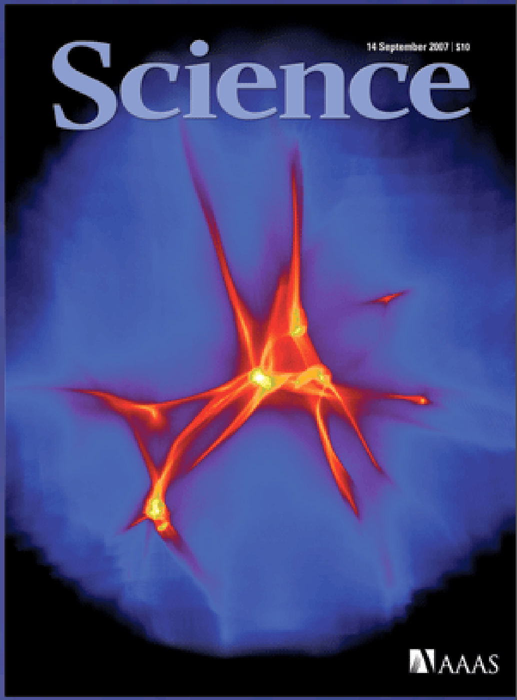
## Warm Dark Matter



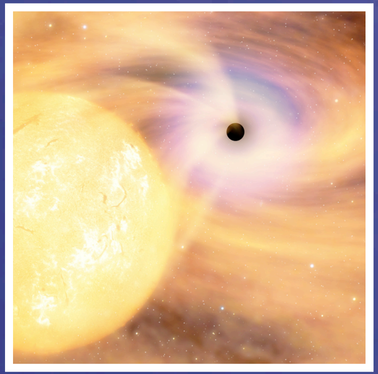
- Many stars per filament
- Low and high mass
- Milky Way remnants?



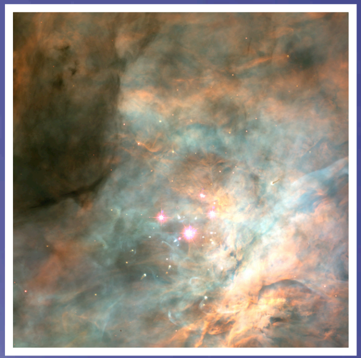
Massive stars




Gao & Theuns 07



Seed for super-massive BH



Low-mass stars

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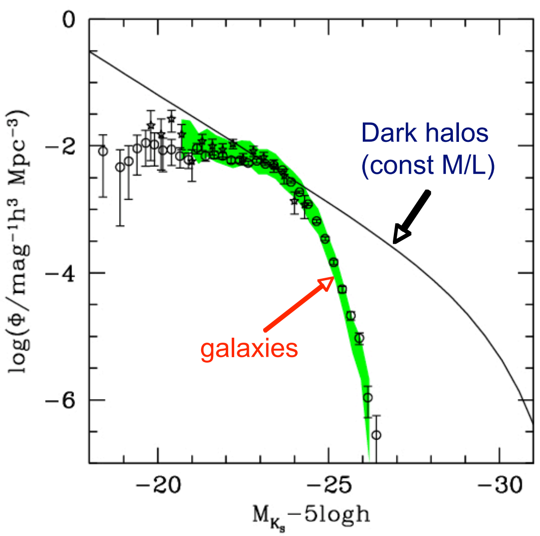
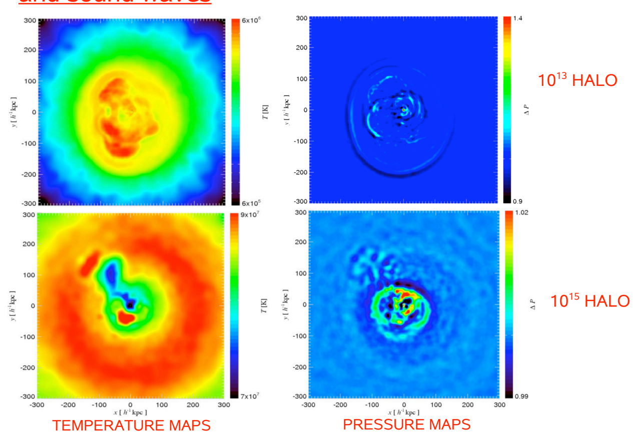
Summary:

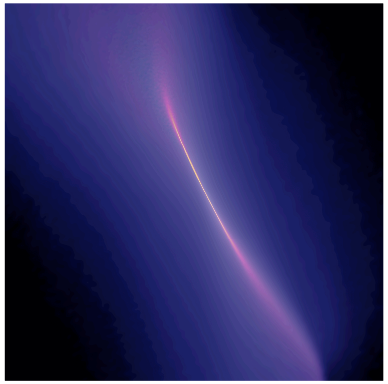
- Galaxy formation models may need AGN to shape the bright-end of the luminosity function
- Feedback needs to operate when stars form in nearly hydrostatic halo (cooling flow)
- Warm dark matter may provide seeds for super-massive black holes

谢谢




AGN feedback in isolated halos: bubbles, weak shocks and sound waves



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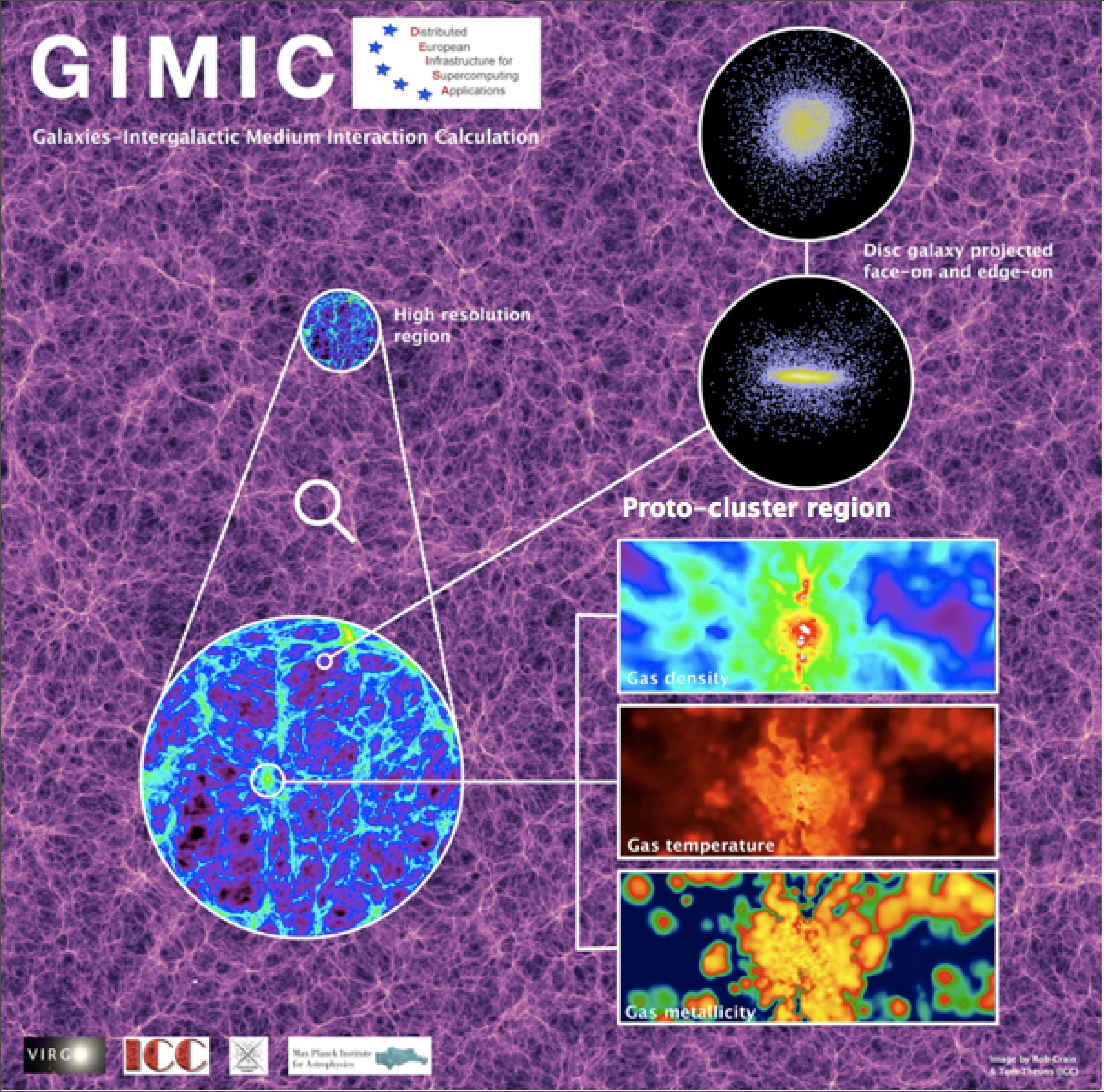



# Aims:

- Unusual regions
- Go to z=0

## Status of runs:

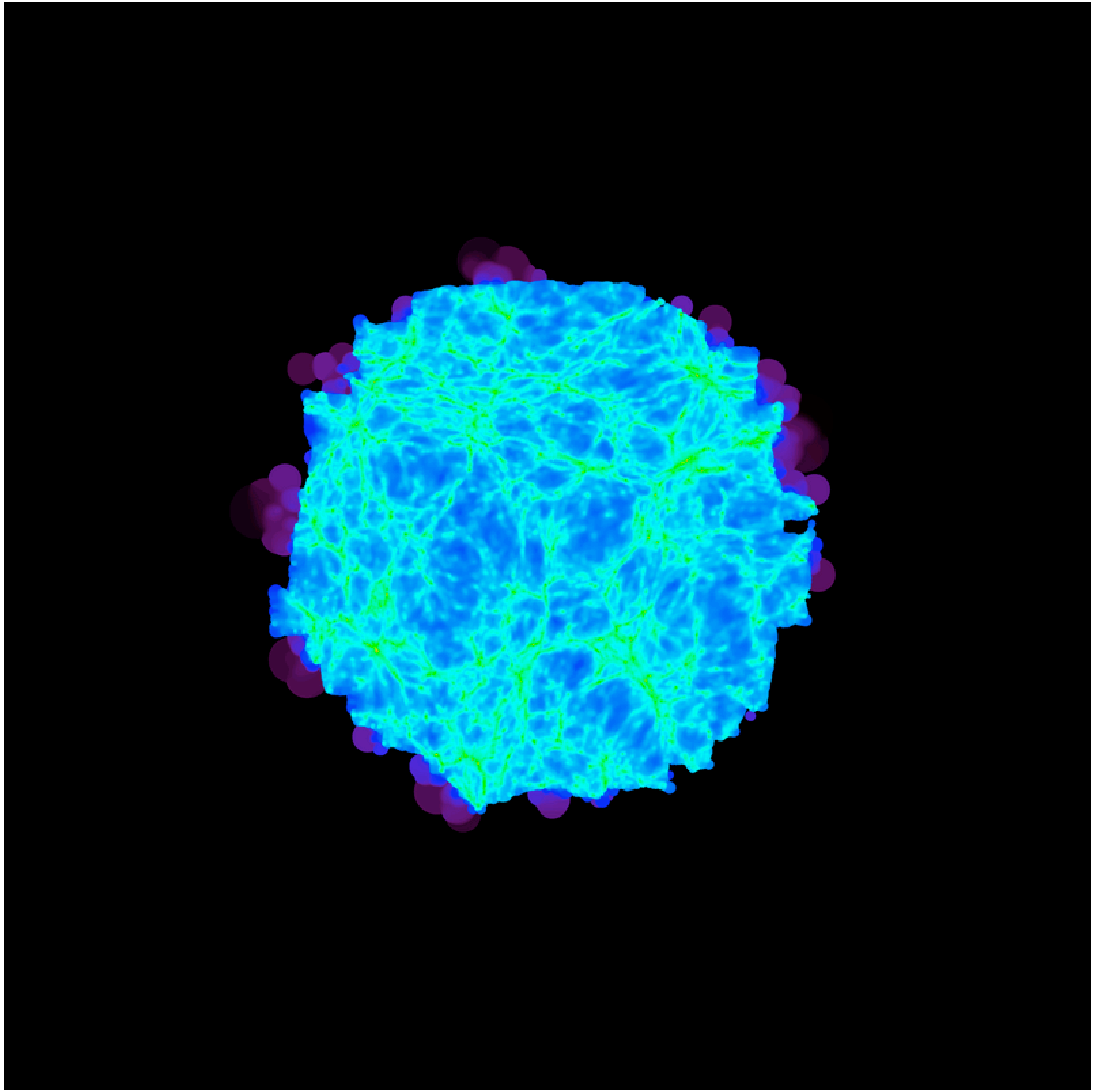
### Low-resolution

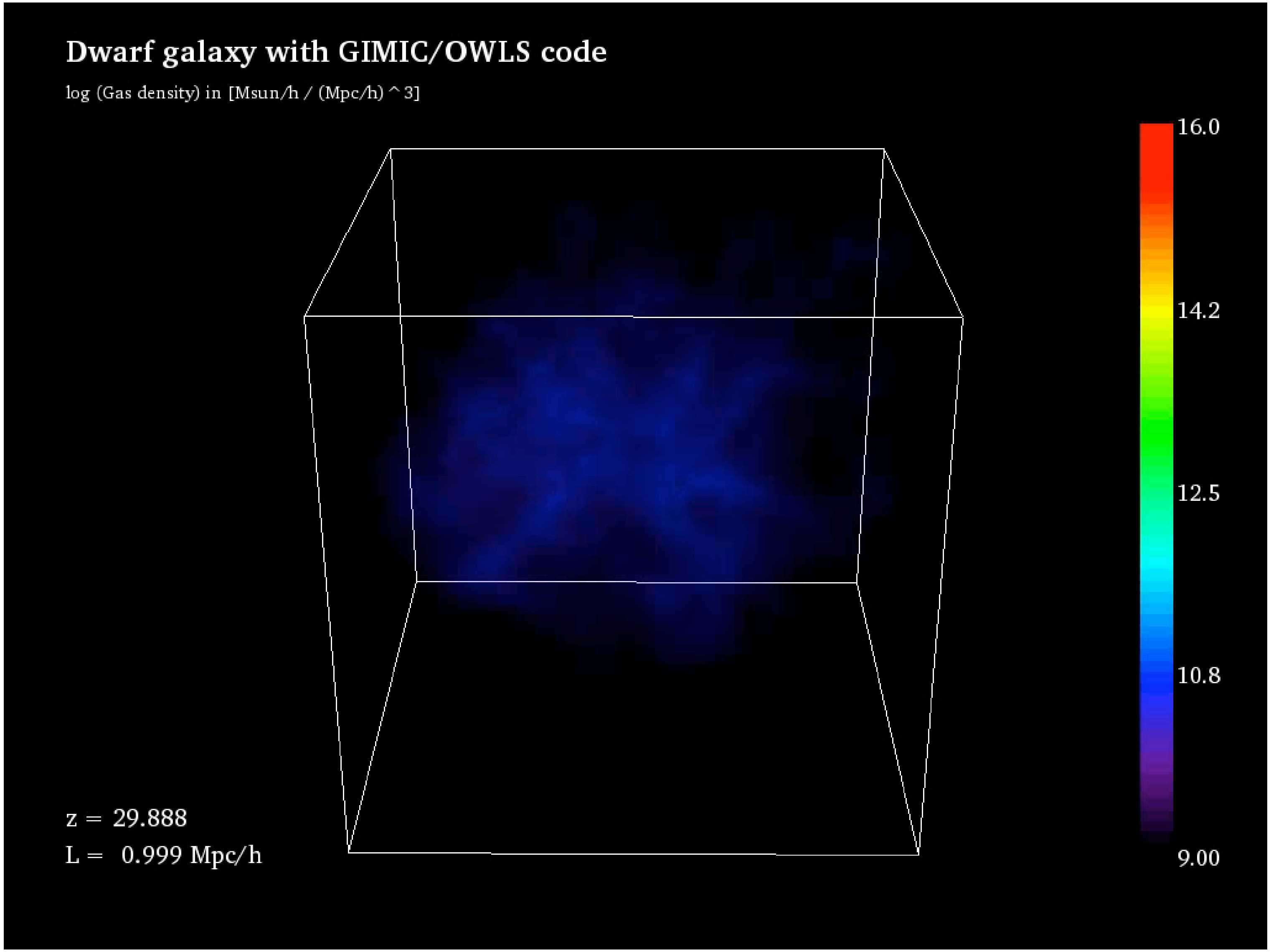
| Run: | -2 | -1 | 0 | 1 | 2 |
|---|---|---|---|---|---|
| z | 0 | 0 | 0 | 0 | 0.15 |

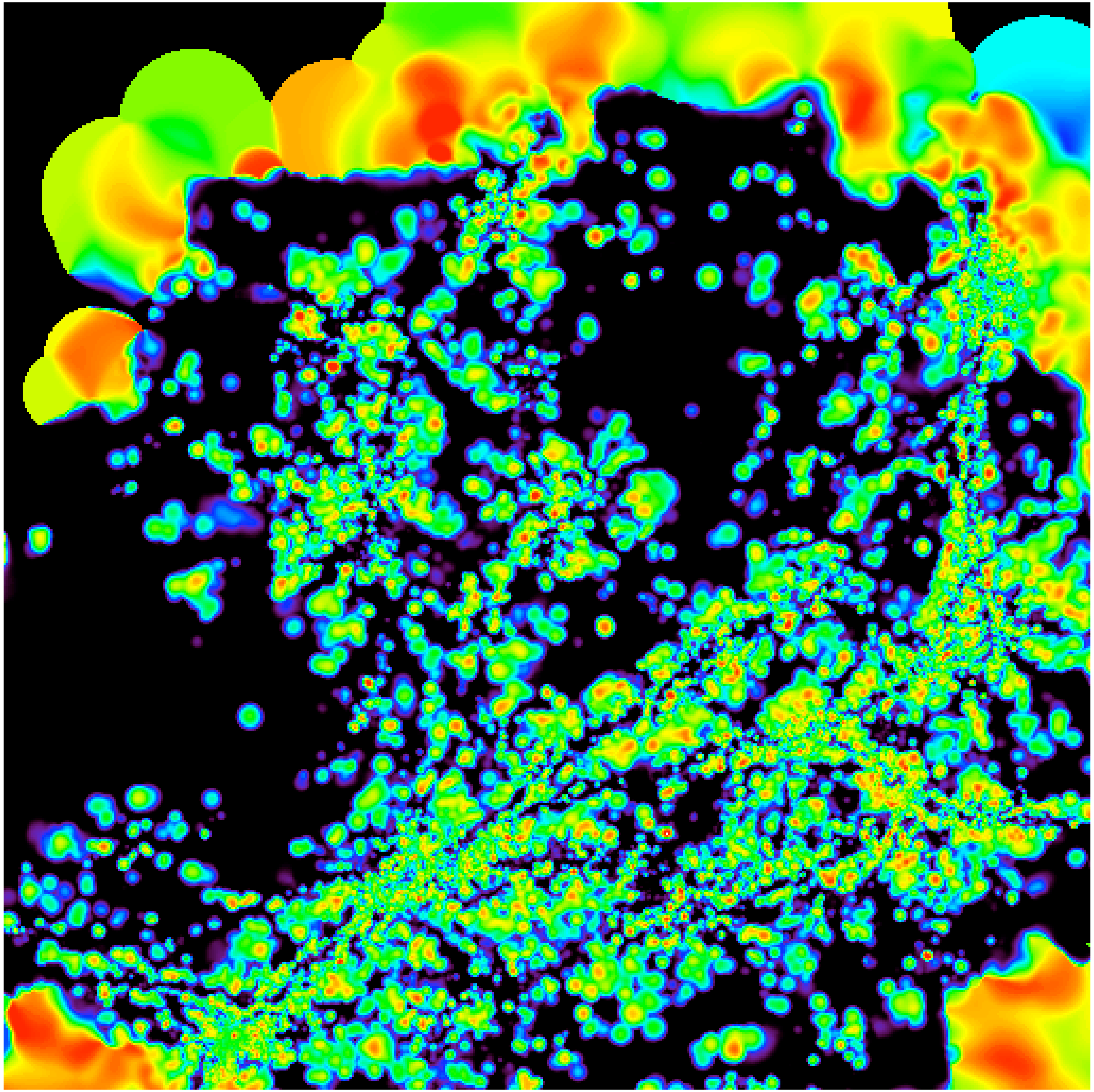
### High-resolution

| Run: | -2 | -1 | 0 | 1 | 2 |
|---|---|---|---|---|---|
| z | 0.9 | 2 | 2 | 2 | -- |

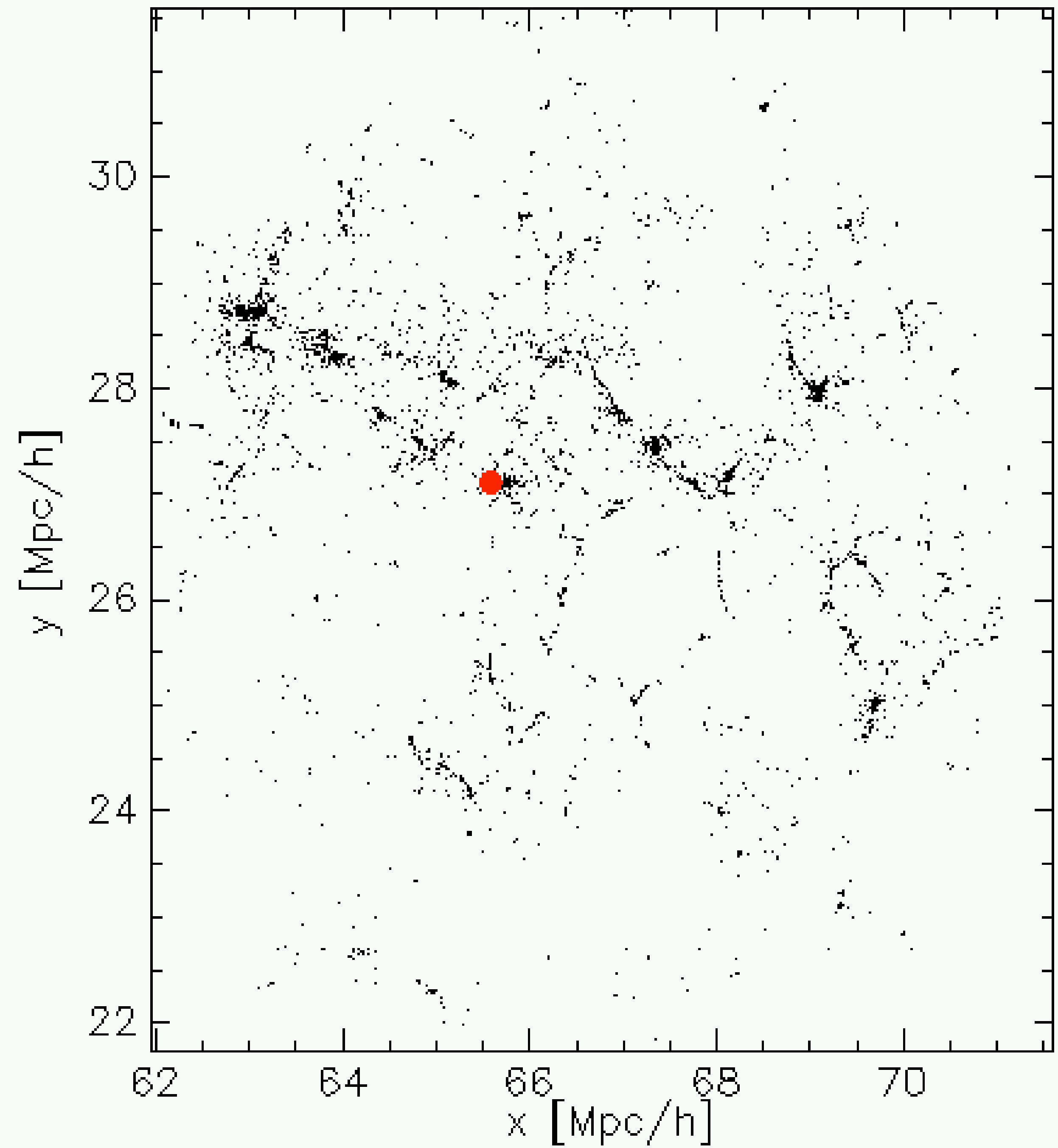
Gas mass = 1.5 $10^6$ $M_0/h$



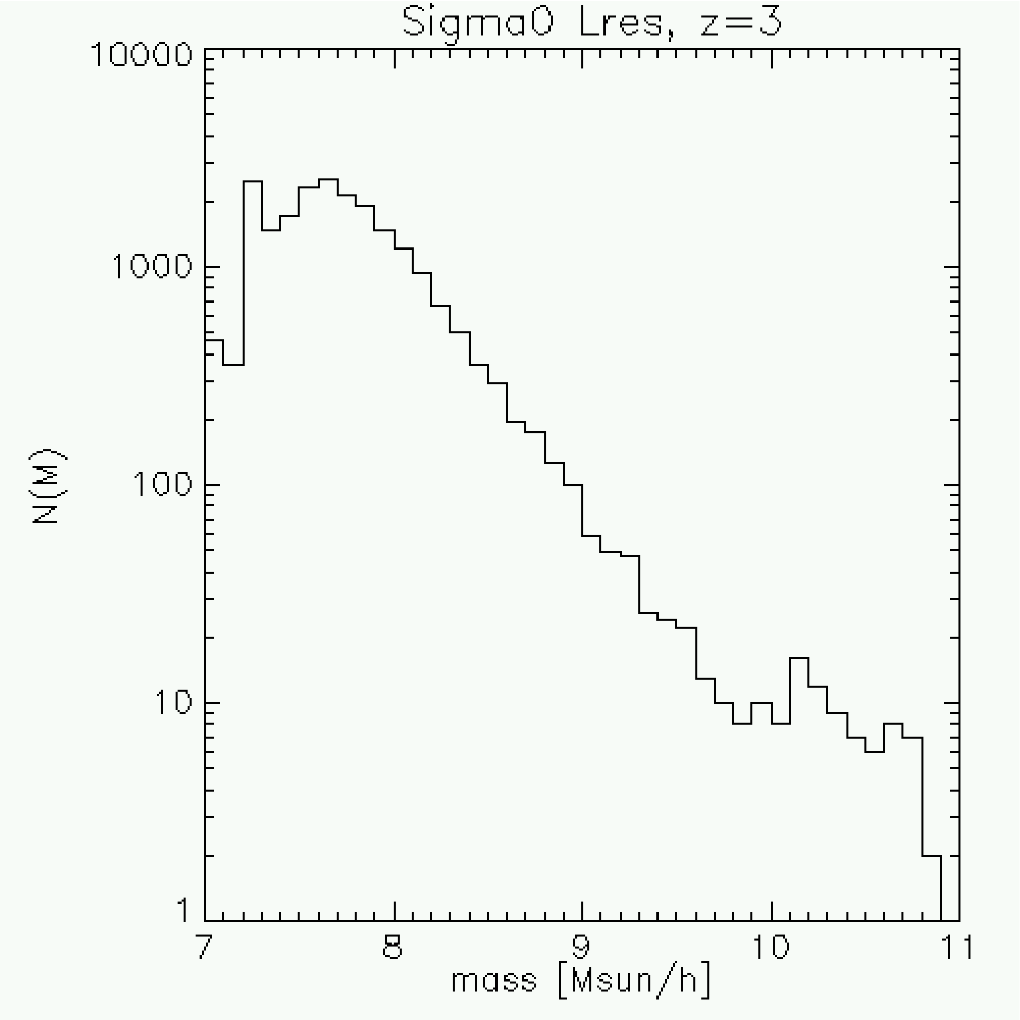

Dwarf galaxy with GIMIC/OWLS code
log (Gas density) in [Msun/h / (Mpc/h) ^ 3]
16.0
14.2
12.5
10.8
9.00
z = 29.888
L = 0.999 Mpc/h

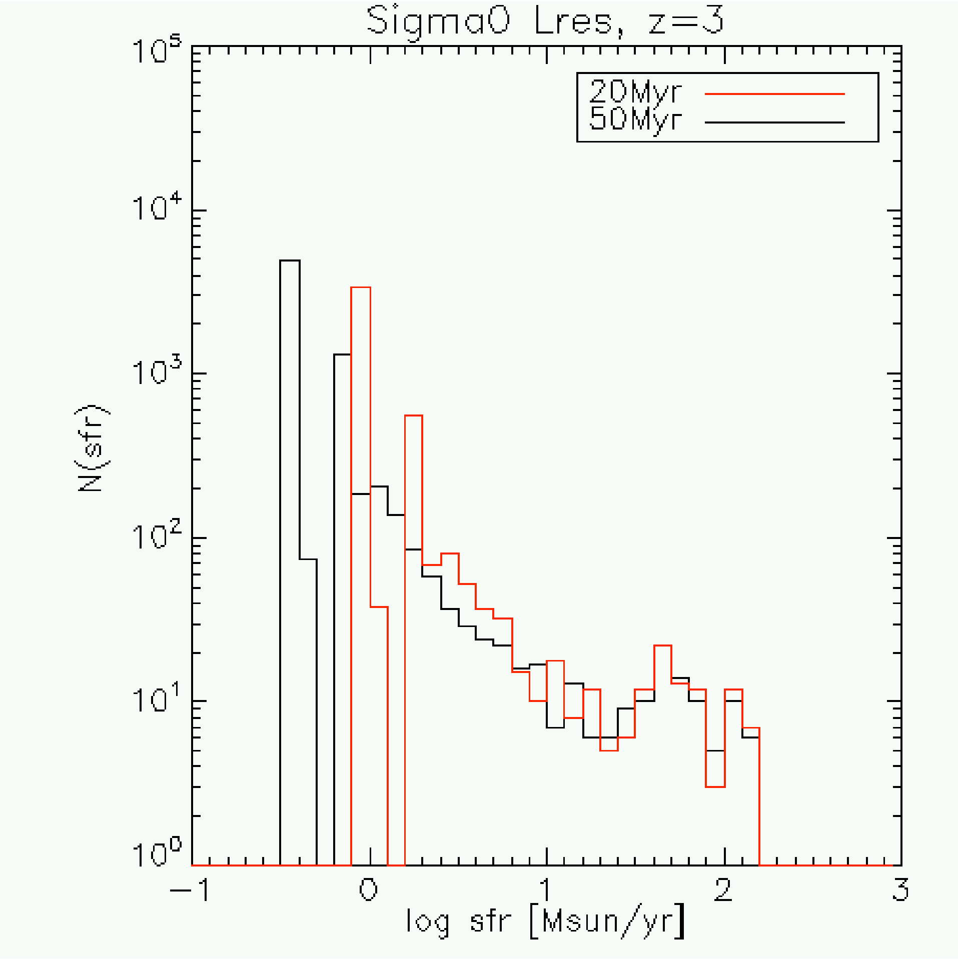


# GIMIC Sigma$_0$ galaxies at z=2.75

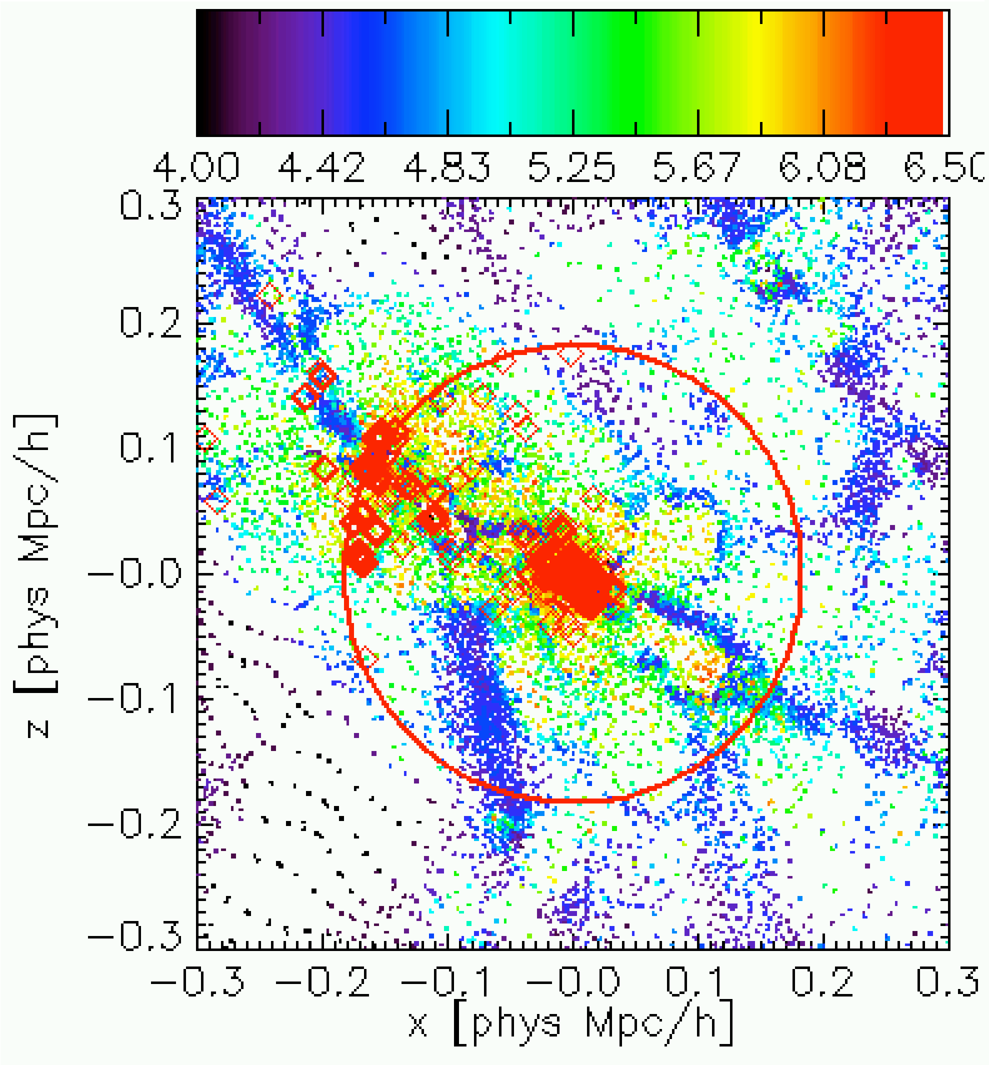


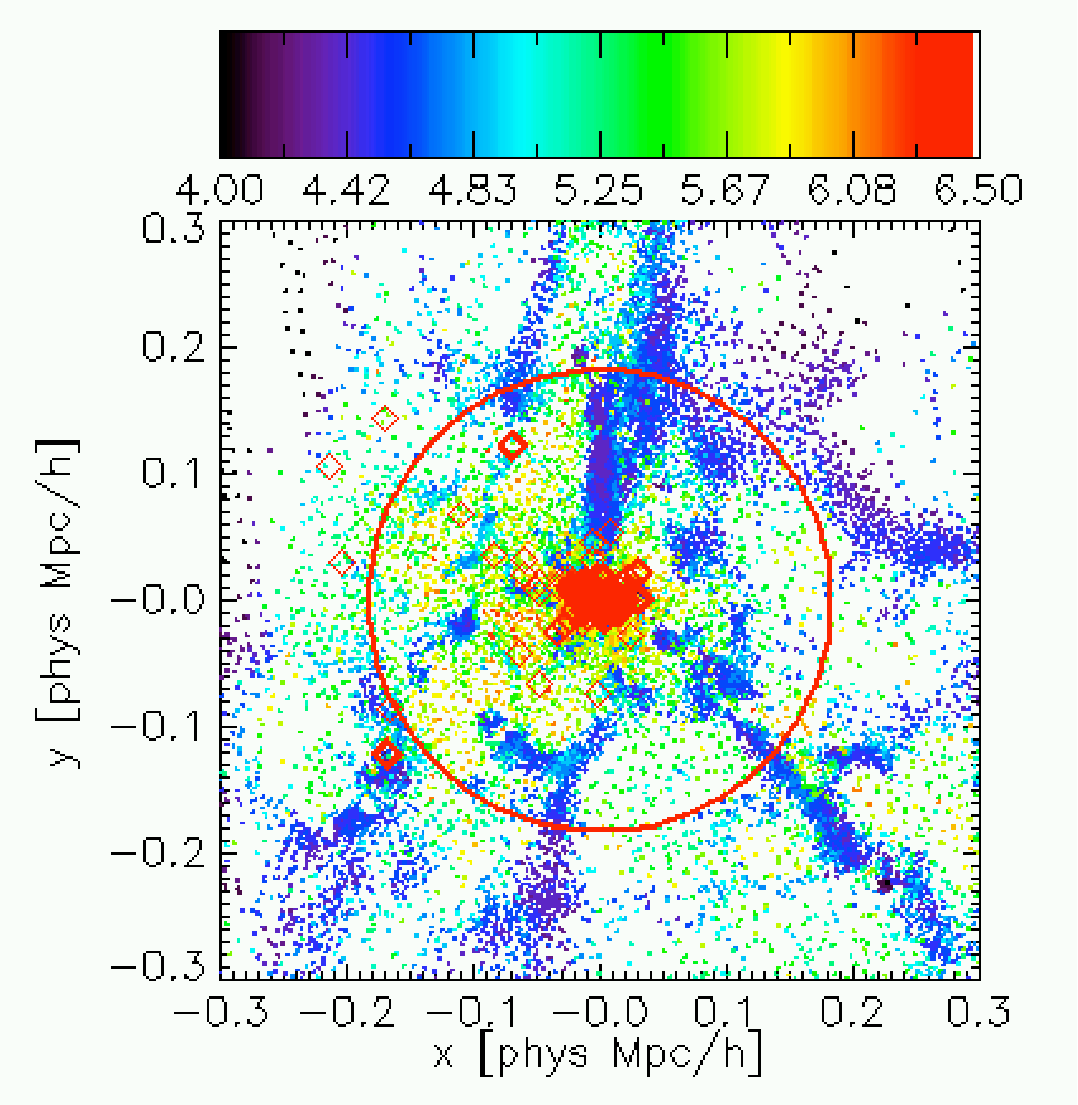
# $M_*=10^8\ M_0$, SFR=5 $M_0$/yr, z=2.75



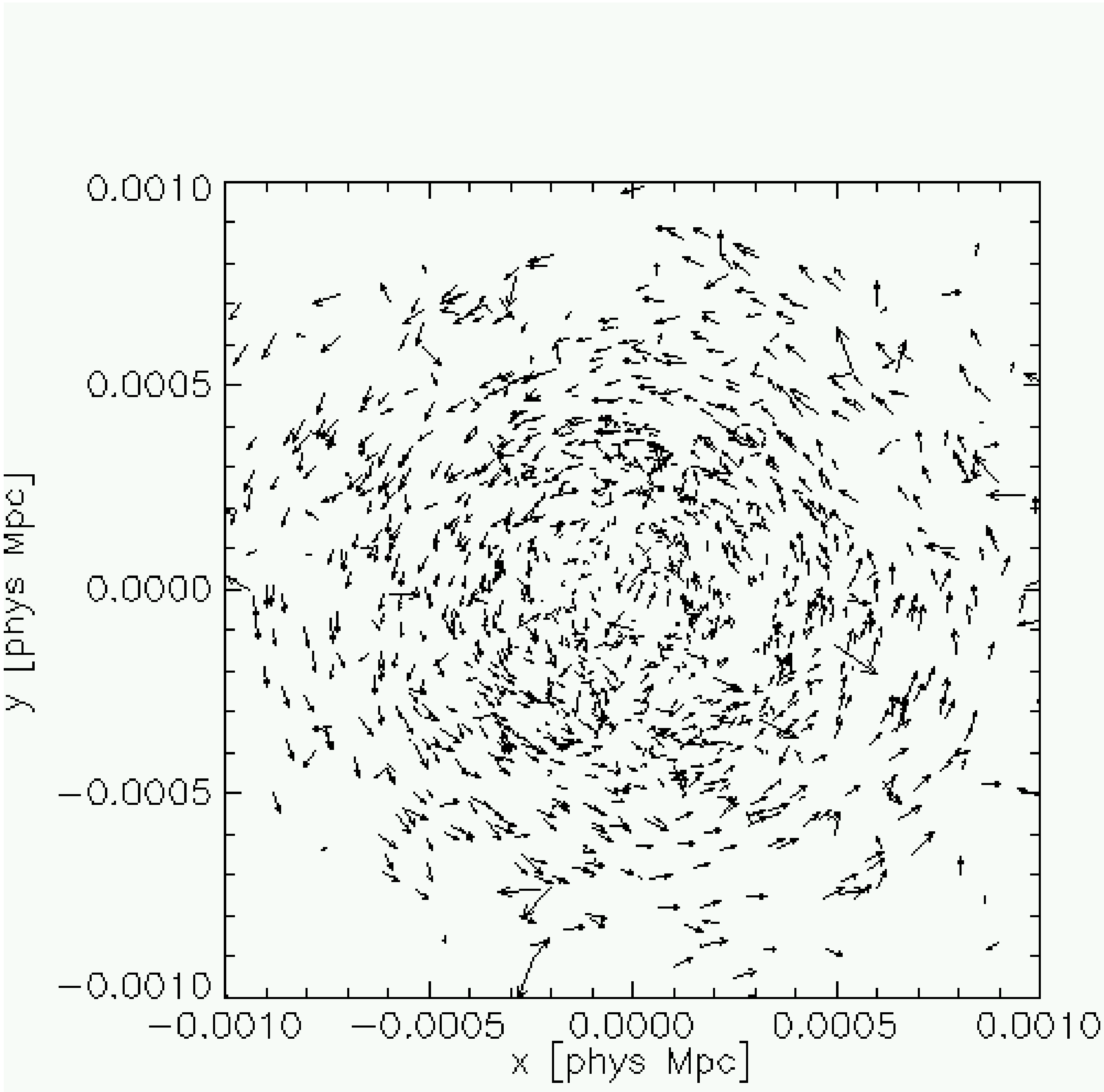



$M_* = 10^8\ M_0$, SFR=5 $M_0$/yr, z=2.75

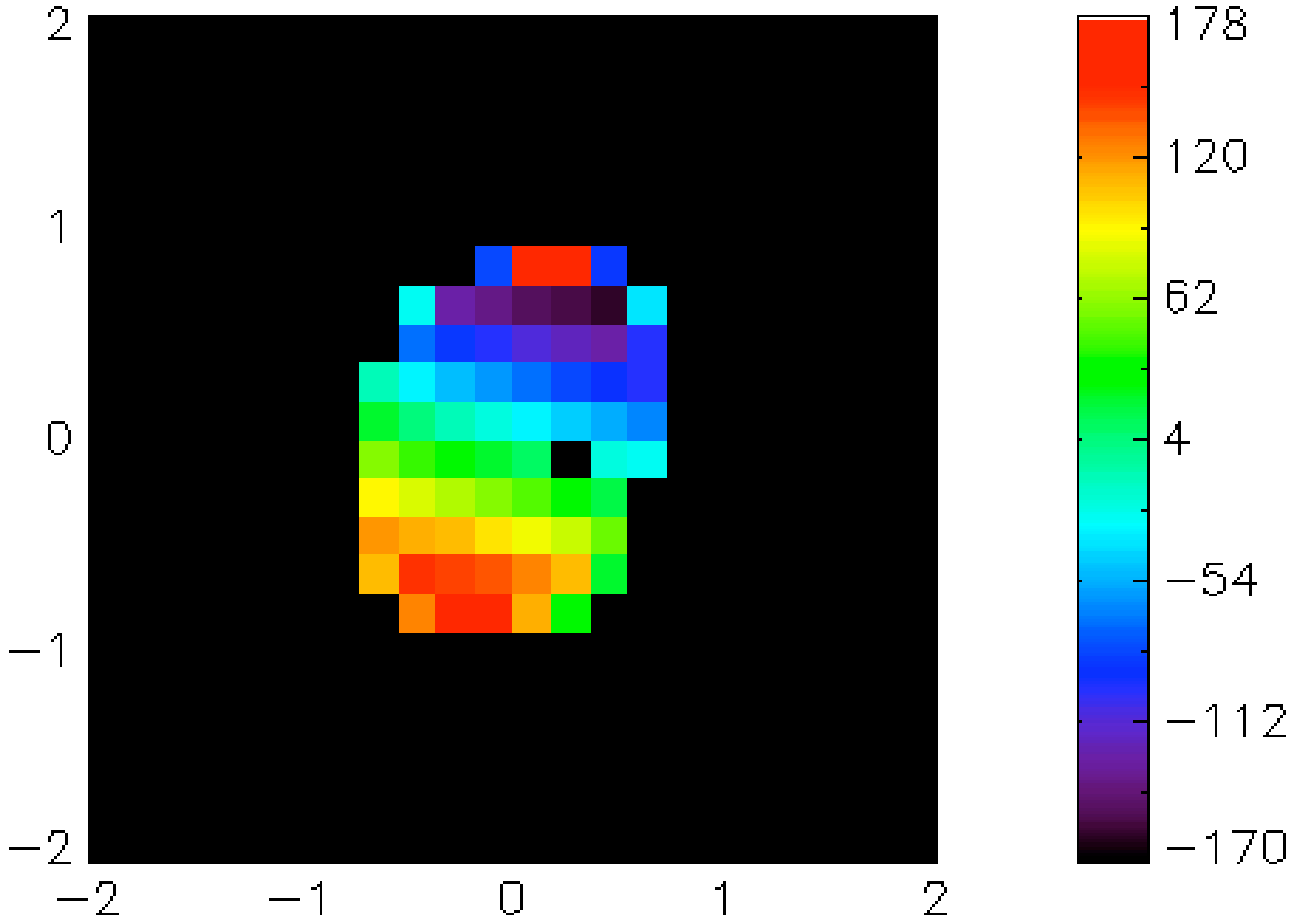


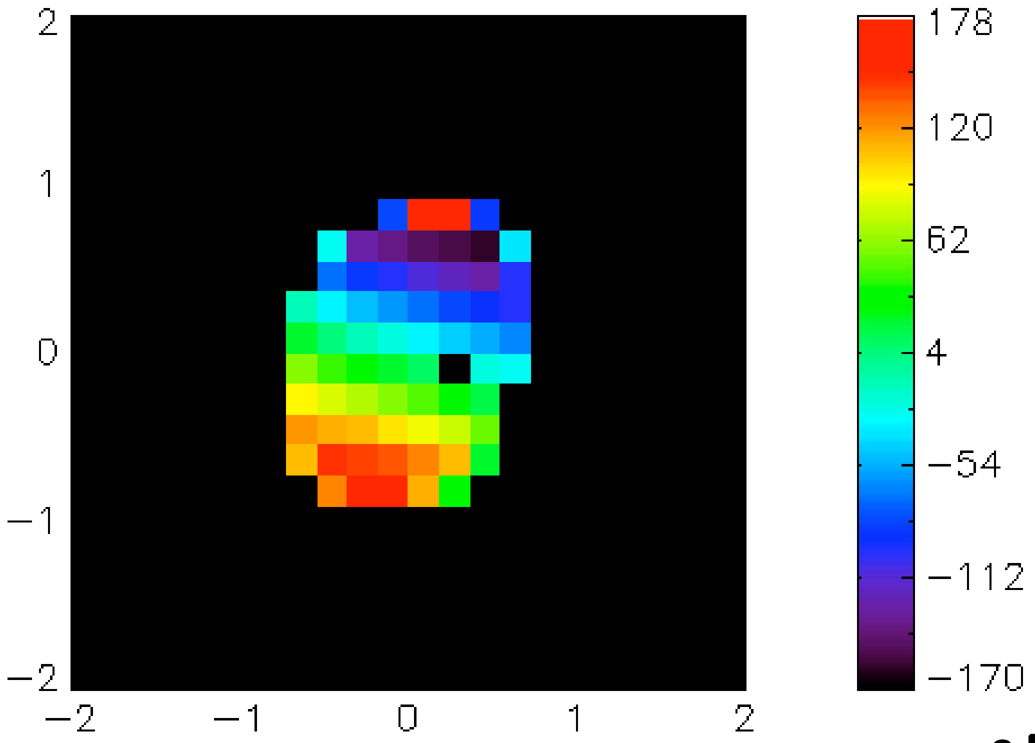



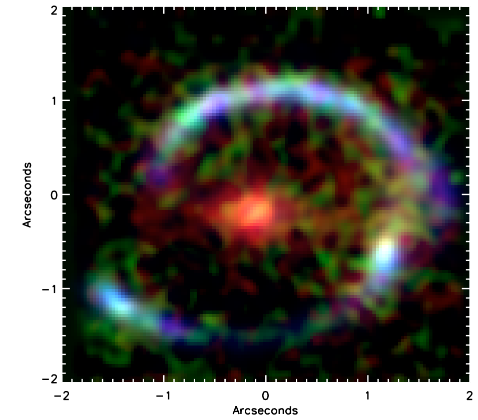
# $M_*=10^8\ M_0$, SFR=5 $M_0$/yr, z=2.75



# $M_* = 10^8\ M_0$, SFR=5 $M_0$/yr, z=2.75

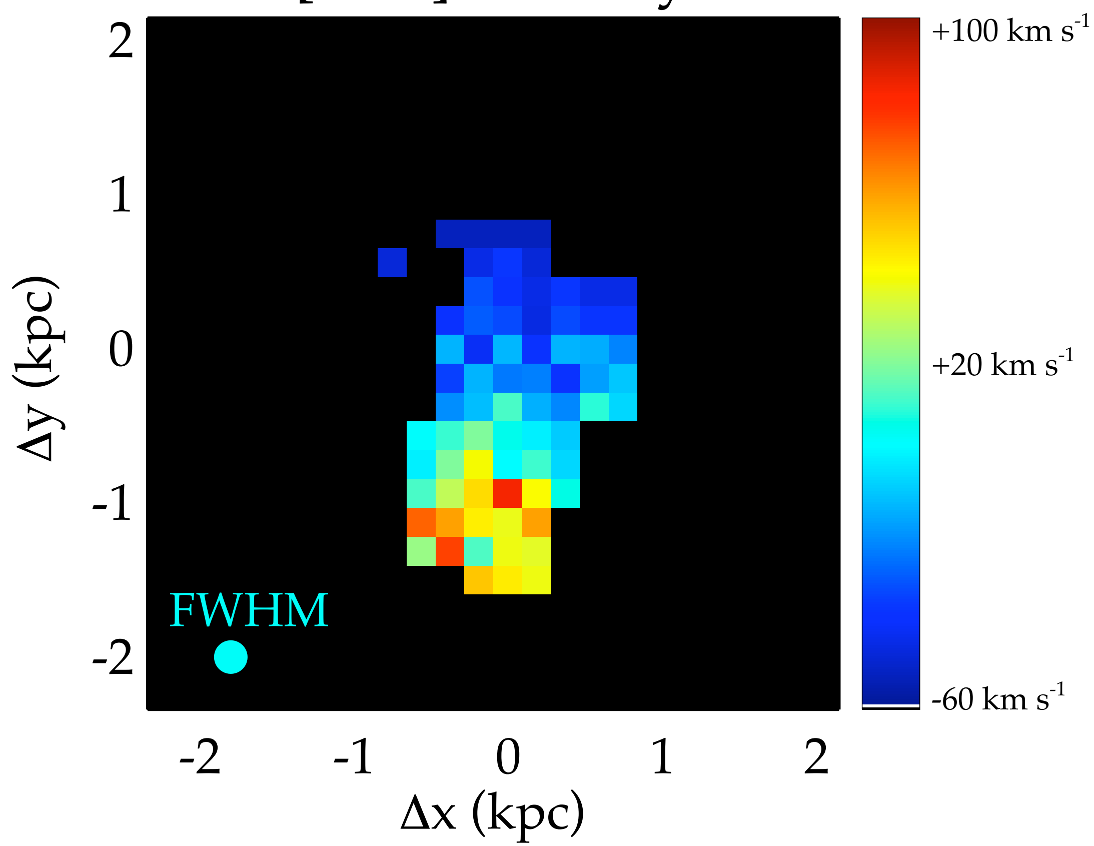


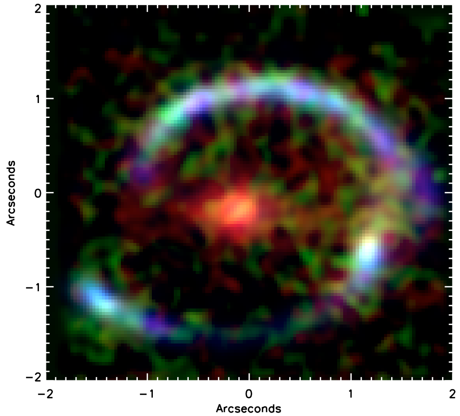


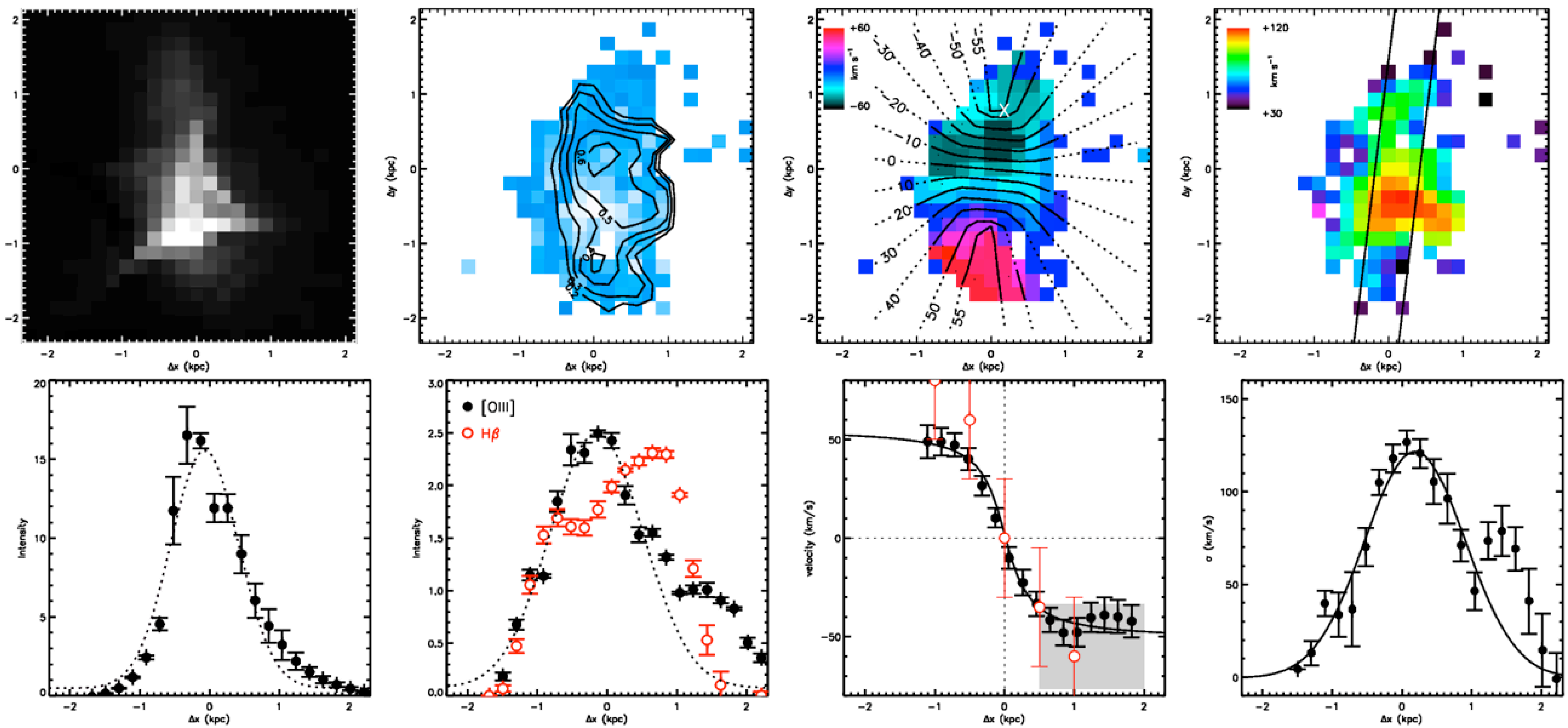

# AMS 1

## [OIII] velocity



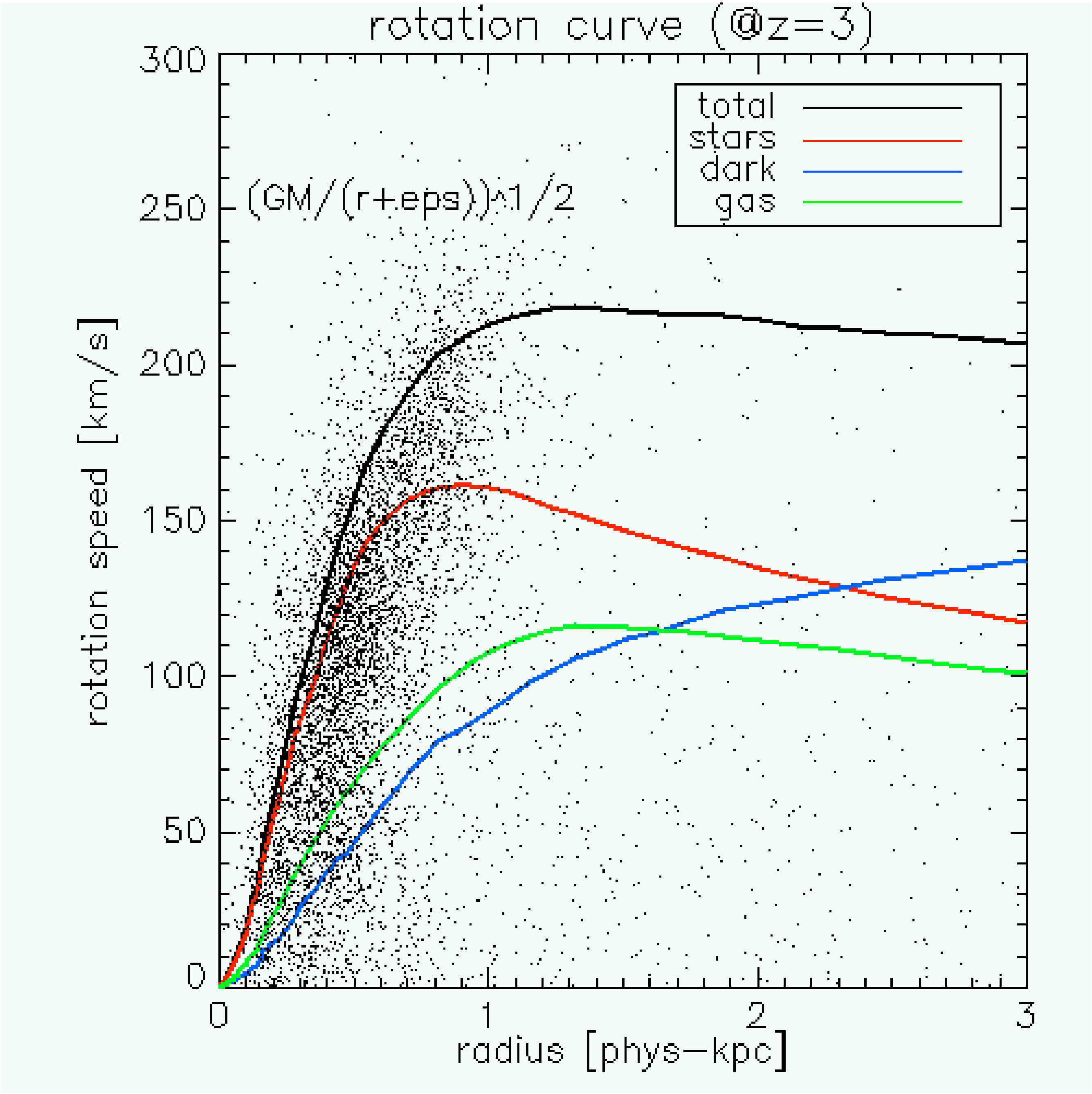


Arcseconds
Arcseconds

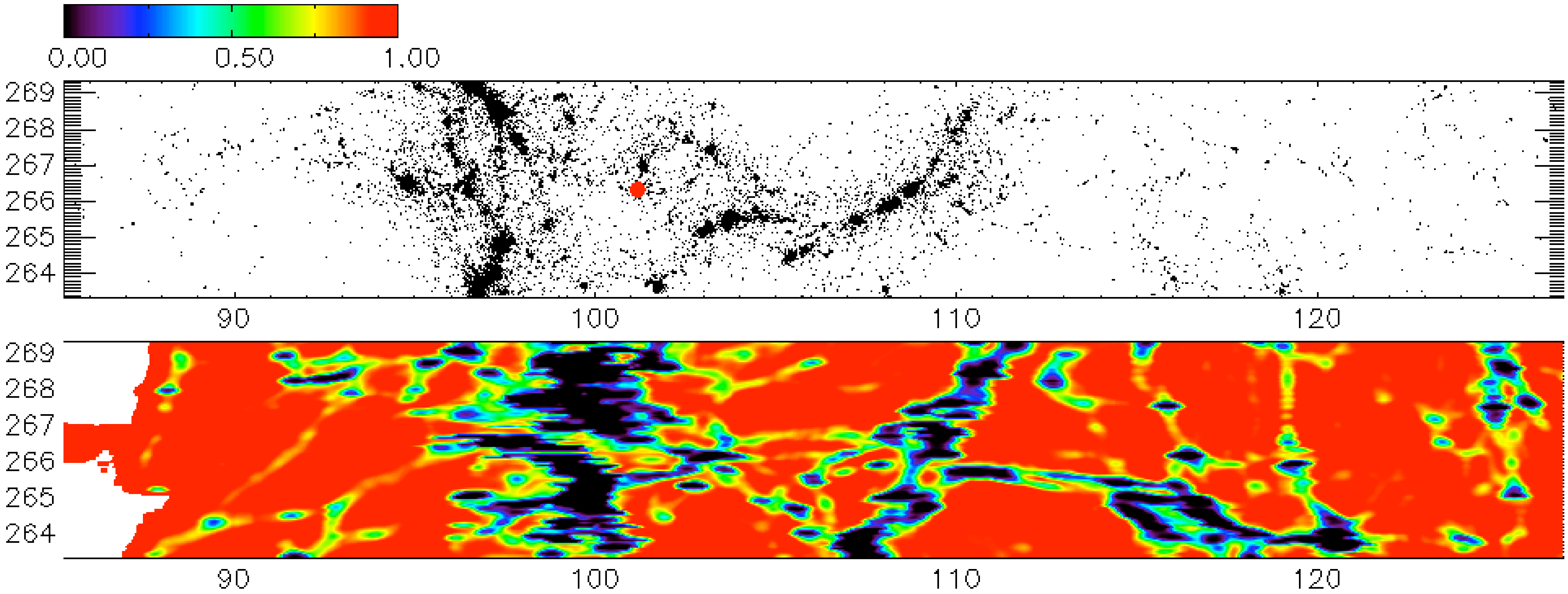



Δx (kpc)
Δy (kpc)
km s⁻¹
+60
−60
+120
+30
Intensity
[OIII]
Hβ
velocity (km/s)
σ (km/s)

# $M_*=10^8\ M_0$, SFR=5 $M_0$/yr, z=2.75

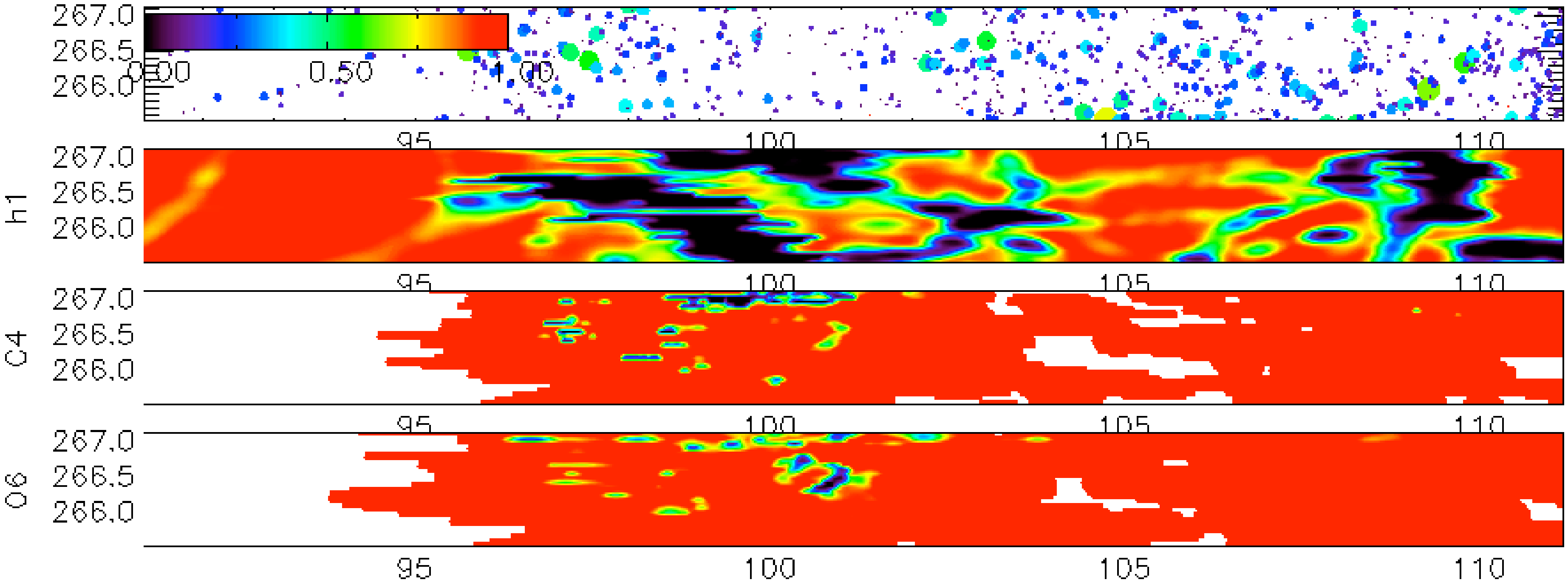


# Spectra

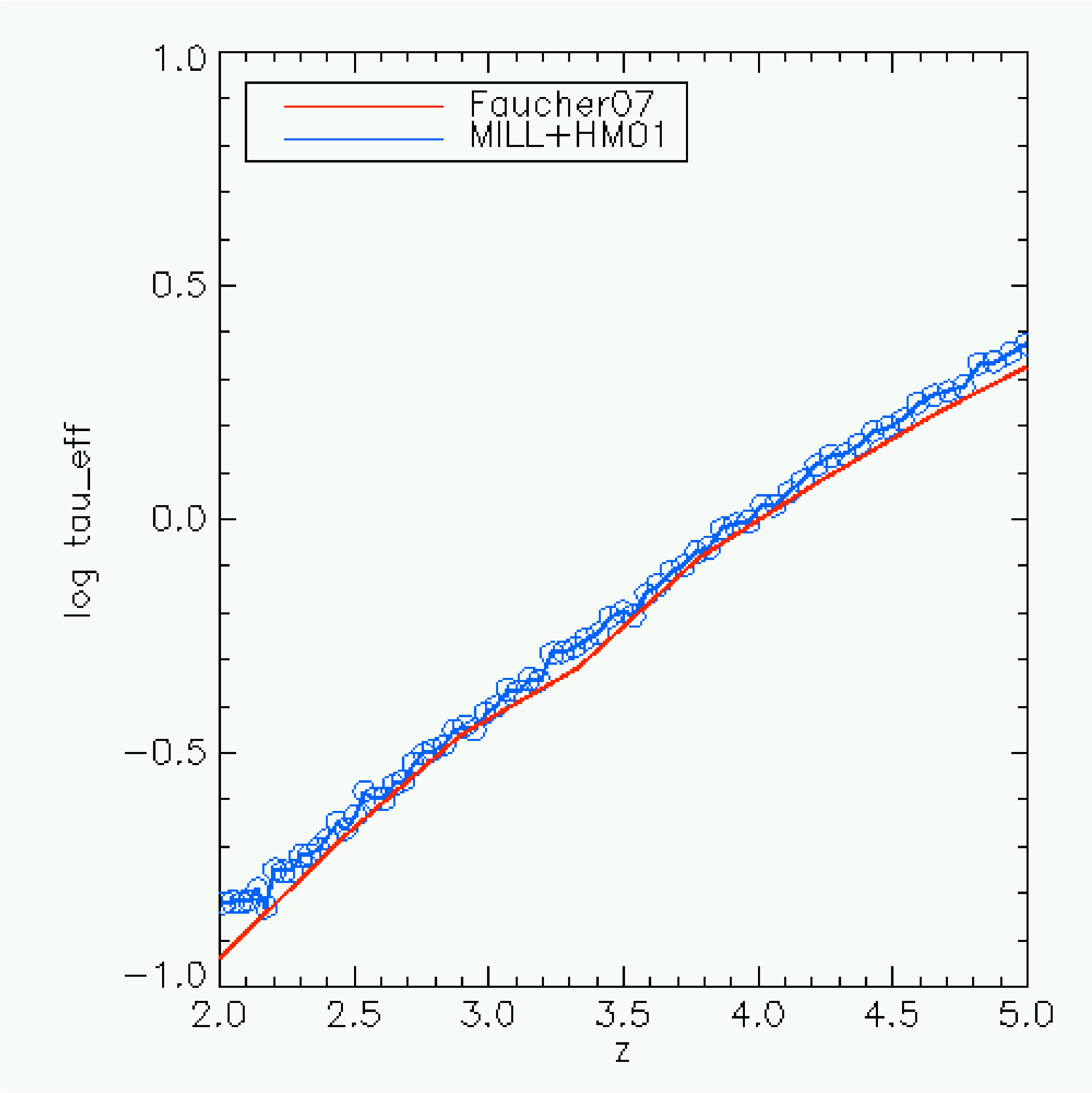


0.00
0.50
1.00
269
268
267
266
265
264
90
100
110
120
269
268
267
266
265
264
90
100
110
120

# Spectra

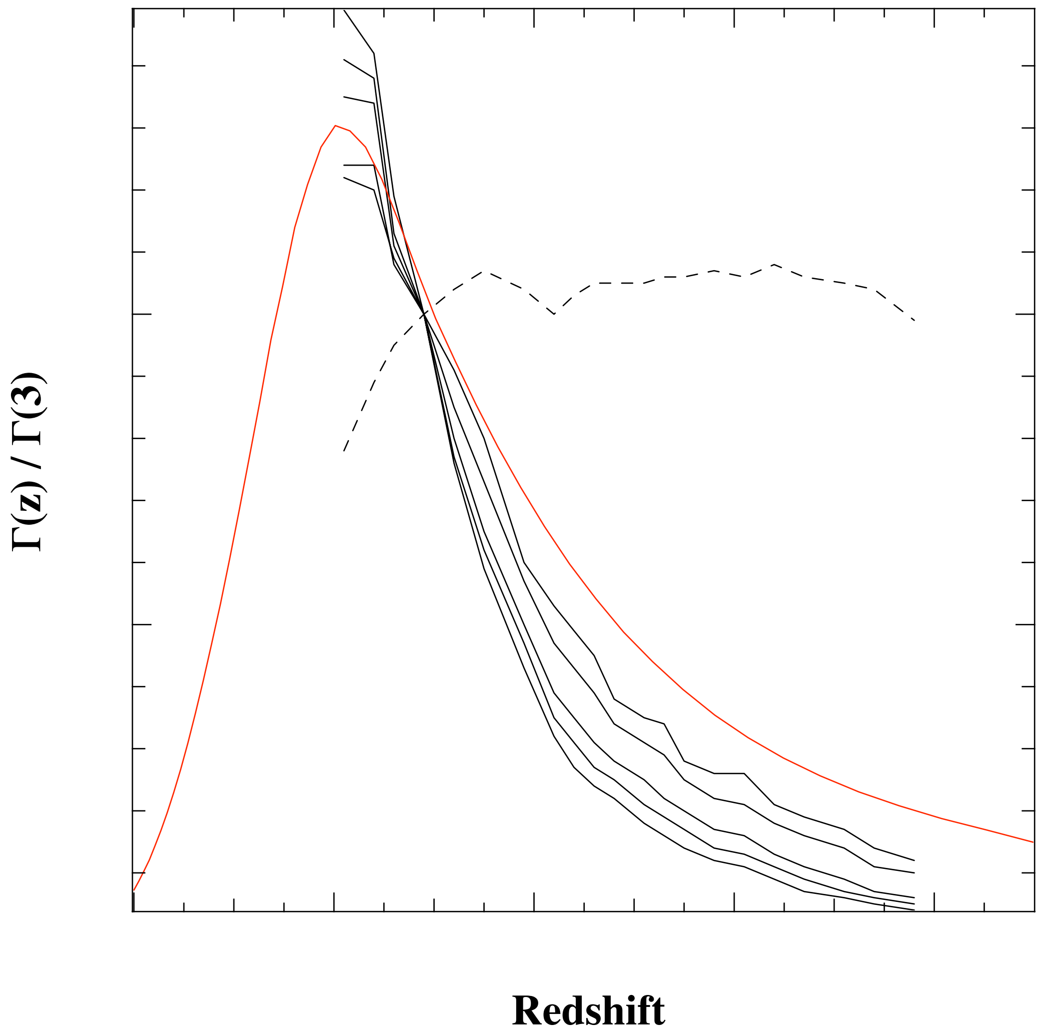


# Spectra

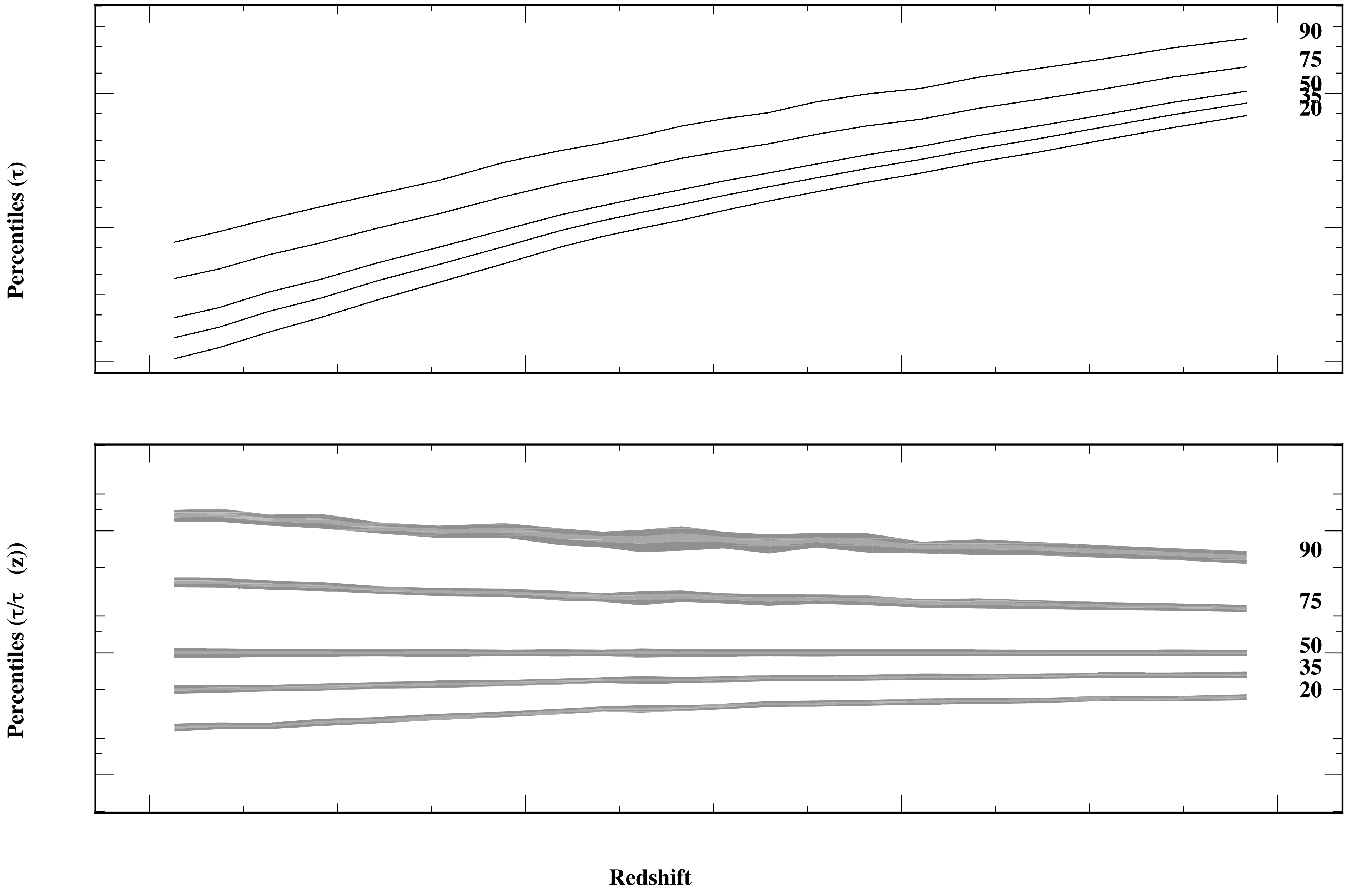


Faucher07
MILL+HM01
log tau_eff
z
1.0
0.5
0.0
−0.5
−1.0
2.0
2.5
3.0
3.5
4.0
4.5
5.0

# Spectra

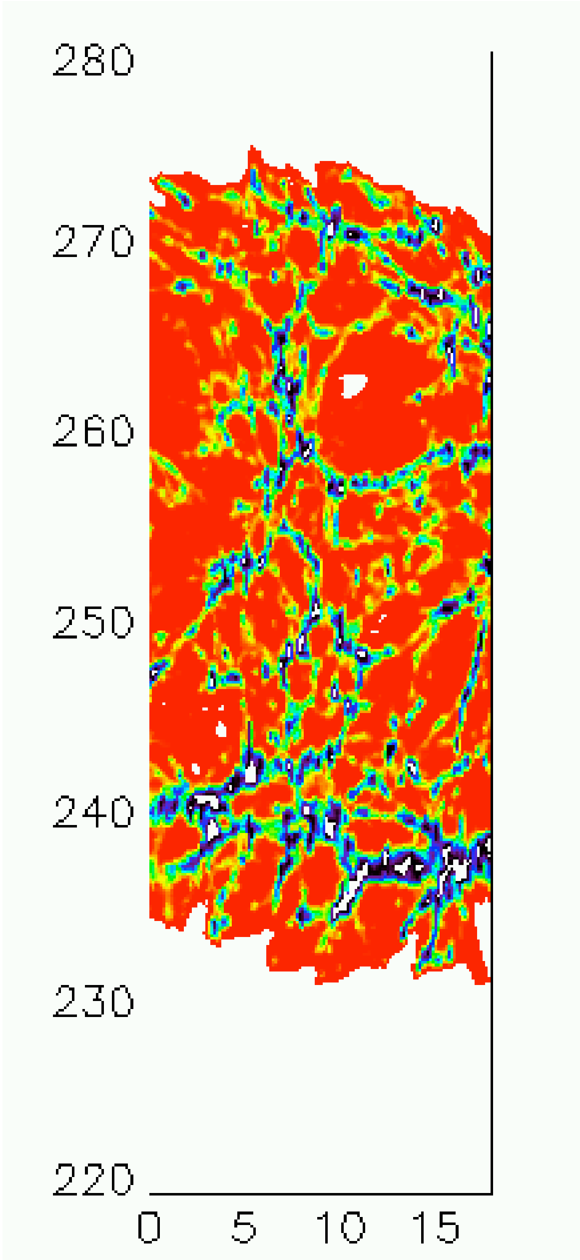


# Spectra

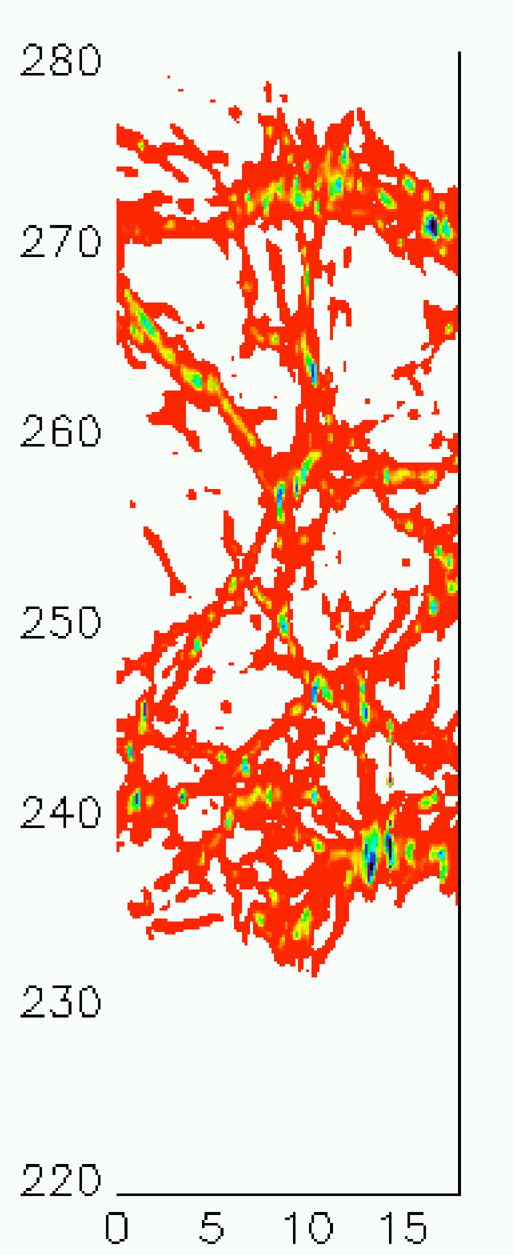


Percentiles (τ)
90
75
50
35
20
Percentiles (τ/τ (z))
90
75
50
35
20
Redshift

Sigma0

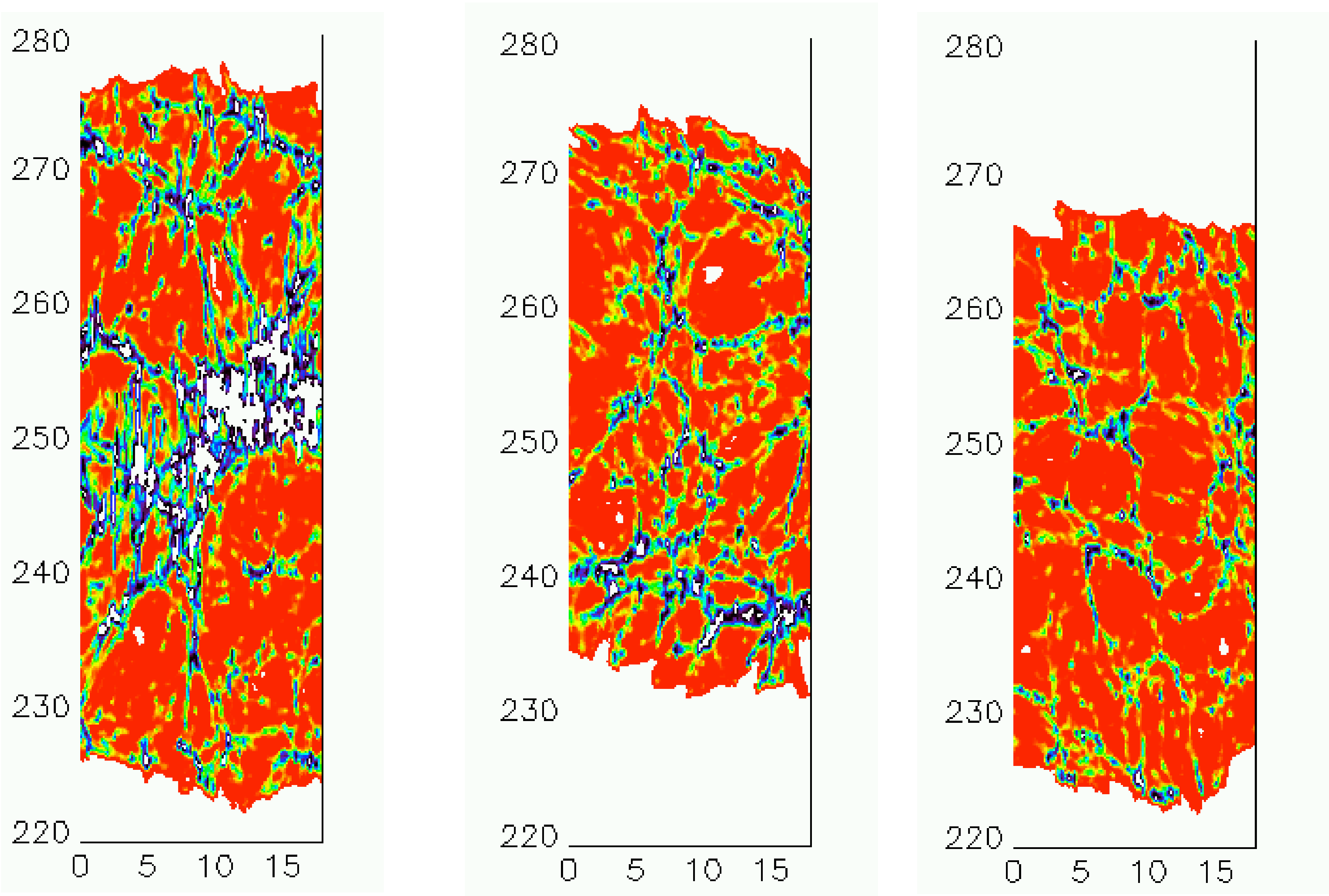



z=2.75




z=1

z=2.75




+2 0 -2