Gas infall into halos at z > 10

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Two numerical experiments on the formation of stars, disks and SMBH at z > 10.

The first experiment concerns ATOMIC COOLING DM halos

The second experiment concerns MOLECULAR COOLING DM halos

Both experiments show the role of mergers at setting the conditions for galaxy formation

Based on arXiv: 1301.5567 and 1307.1295 both MNRAS (2013) in press

Early work on the production of chemical elements by PopIII

YIELDS FROM STARS OF DIFFERENT CHEMICAL COMPOSITION (POP I AND POP III)

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Introduction

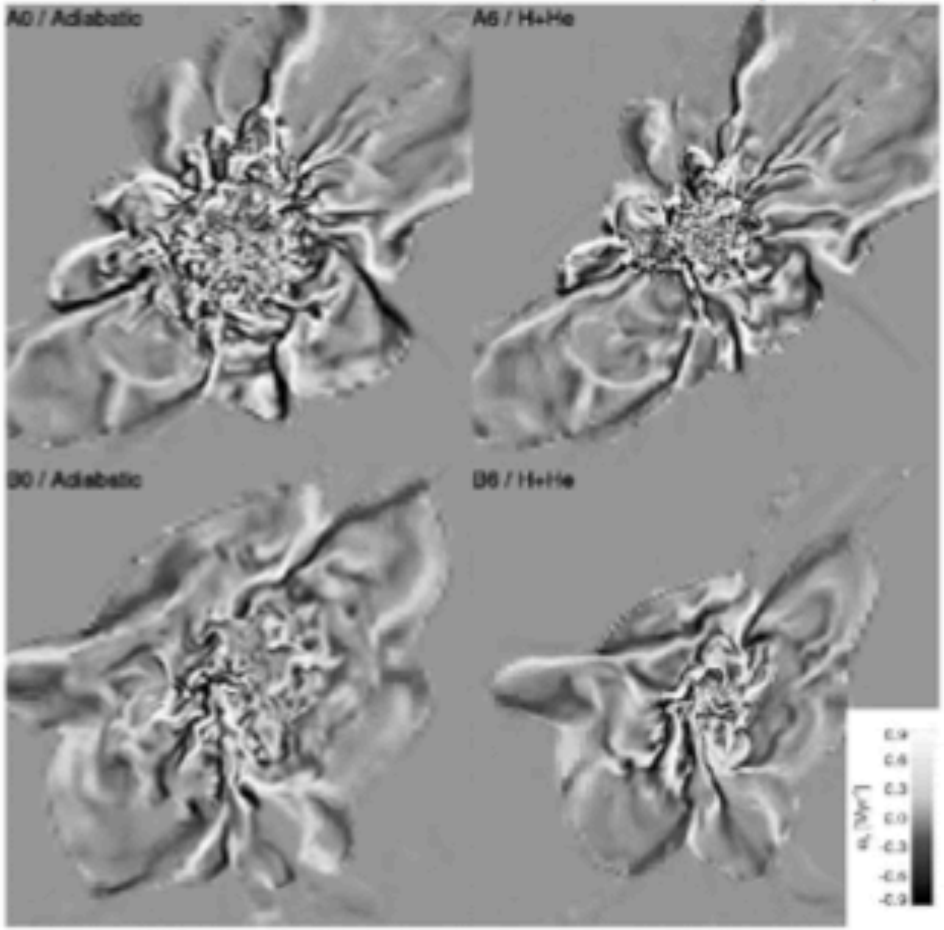
Over the past few years chemical yields have been the subject of a great deal of theoretical work, owing to their importance in studies of chemical evolution of galaxies. Yields of heavy elements from massive stars without mass loss have been derived by Arnett (1978), who followed the evolution of massive stars ($M > 10 M_{\odot}$) until the presupernova stage. Chiosi and Caimmi (1979) pointed out that mass loss by stellar wind, during the core H-andHe-burning phases, by changing the relationship between the initial mass and the mass of the He-core, may significantly affect the yields of primary elements. These latter, in fact, are expected to decrease with increasing rate of mass loss. This conclusion was however rejected by Maeder (1981) who computed models of massive stars in the range 9-170$M_{\odot}$ up to the C-exhaustion phase

First experiment: Atomic cooling haloes

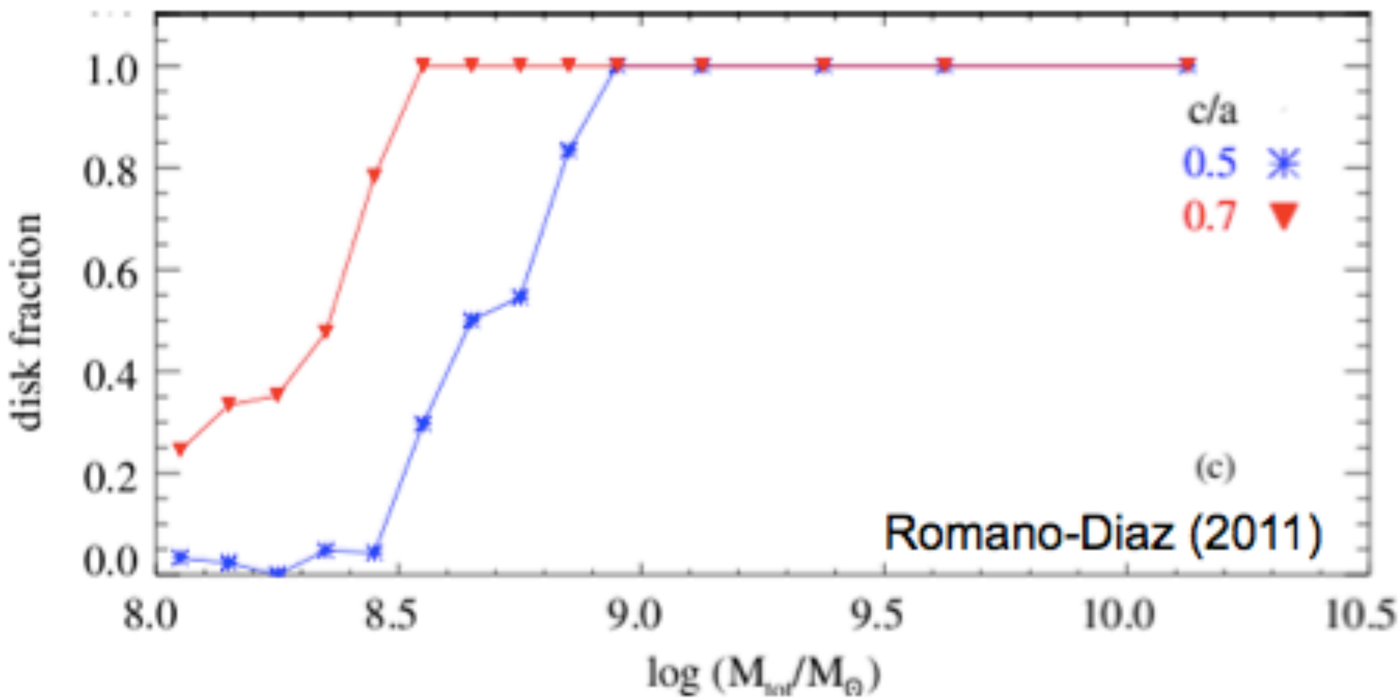
Motivation

- Atomic cooling (AC) haloes:
  - DM haloes with $T_{vir} \gtrsim 10^4 K$ $M_{vir} \gtrsim 10^7 M_\odot$
  - Primordial gas looses energy through atomic lines emission.

Wise & Abel (2007)

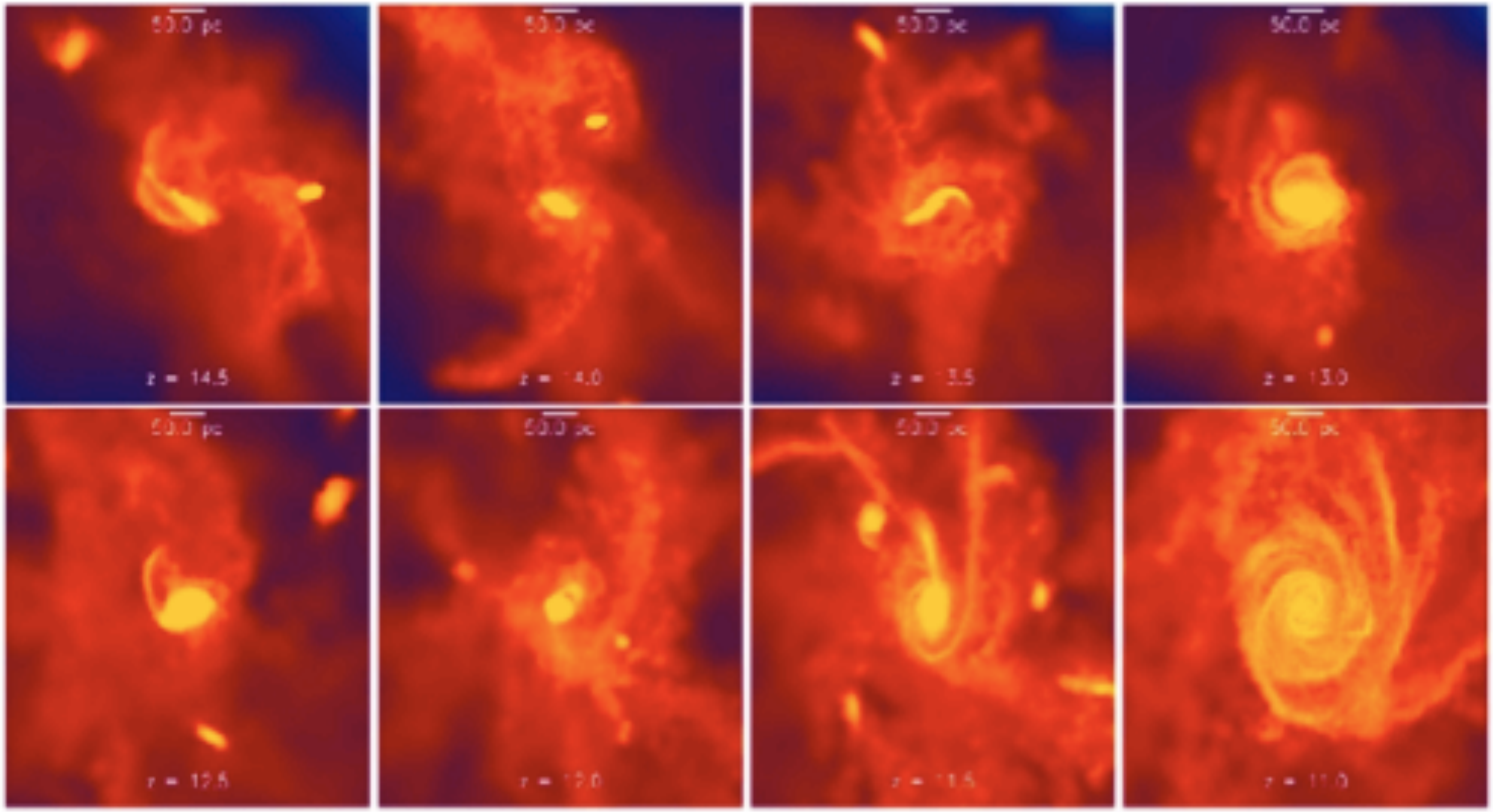


- First disk formation:
- With SPH simulations Romano-Diaz (2011) show that every halo with mass $M_{vir} \gtrsim 10^9 M_\odot$ is able to form a disk at z=10 (Gadget, box=20 Mpc/h, $m_{gas} \sim 10^5 M_\odot$, L_{soft}=300pc).



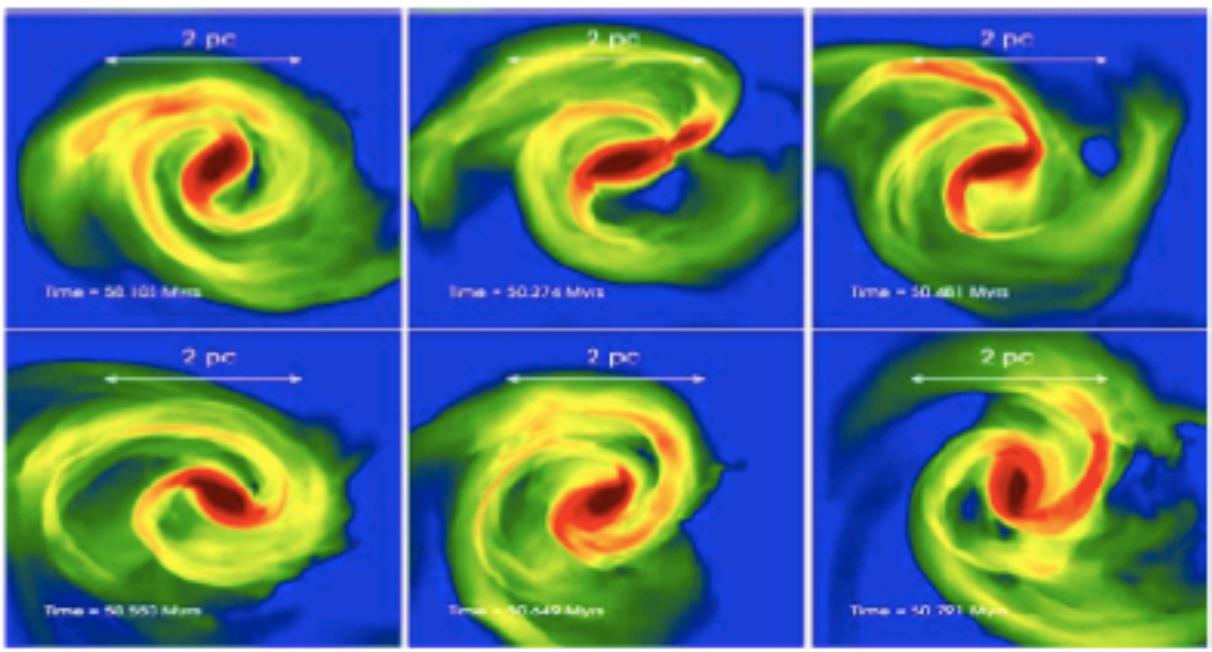
- Based on the c/a < 0.5 criteria, every halo above $\sim 10^9 M_\odot$ form a disk.

Pawlik et al. (2011)



- Pawlik et al. (2011) show the formation of an spiral galaxy at $z>10$ (SPH) in a $10^9 M_\odot$ halo.
- Gadget, box=3.125Mpc/h, L_{soft}=1pc/h.

- SMBH formation:
- Regan & Haehnelt (2099a,b) shows that AC haloes are able to create SMBH seeds.
- Without molecular/metal cooling the gas avoids fragmentation.
- Turbulece triggered by the collapse is able to dissipate angular momentum.



Enzo, $\Delta x \approx 10^{-2}$ pc at $z \sim 15$.

Regan & Haehnelt (2009a)

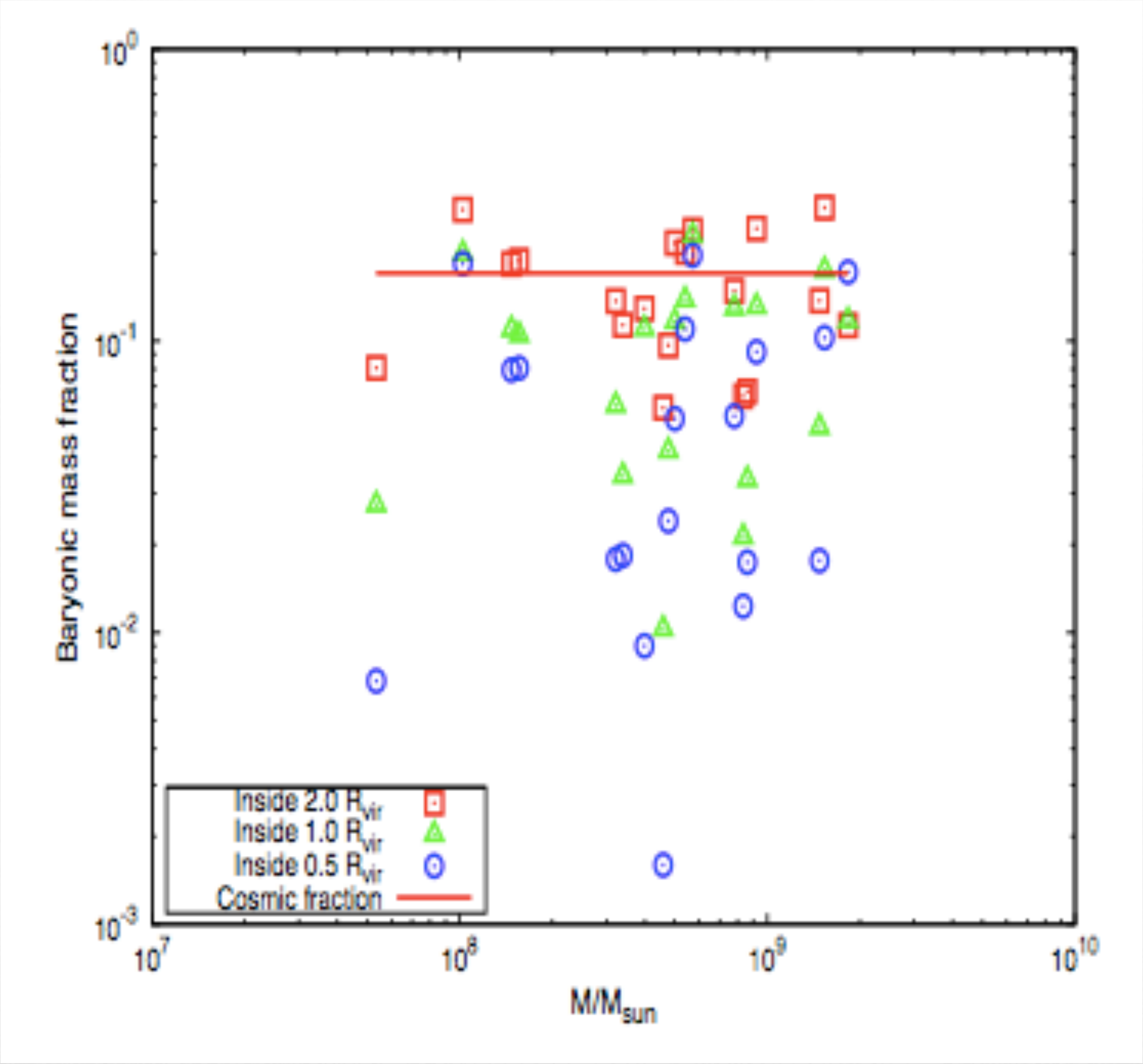
Results

- RAMSES simulations of 19 AC haloes.
- Truelove criteria resolves $\Delta x \approx 10$pc at $z=10$ (very low resolution).
- Temperature floor.
- Primordial gas without molecular cooling
- Only atomic lines cooling.
- No stellar formation/feedback, no sub-grid physic and no magnetic fields.
- To study the basic hydrodynamic of the system.

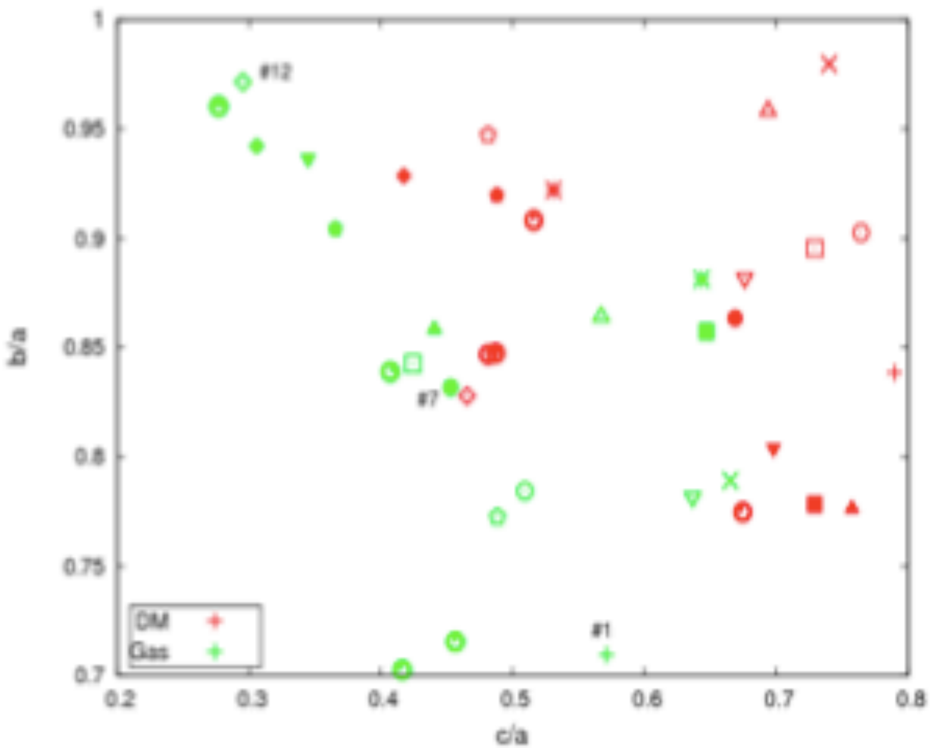
BUT, we simulated 2000 (comoving) Mpc^3

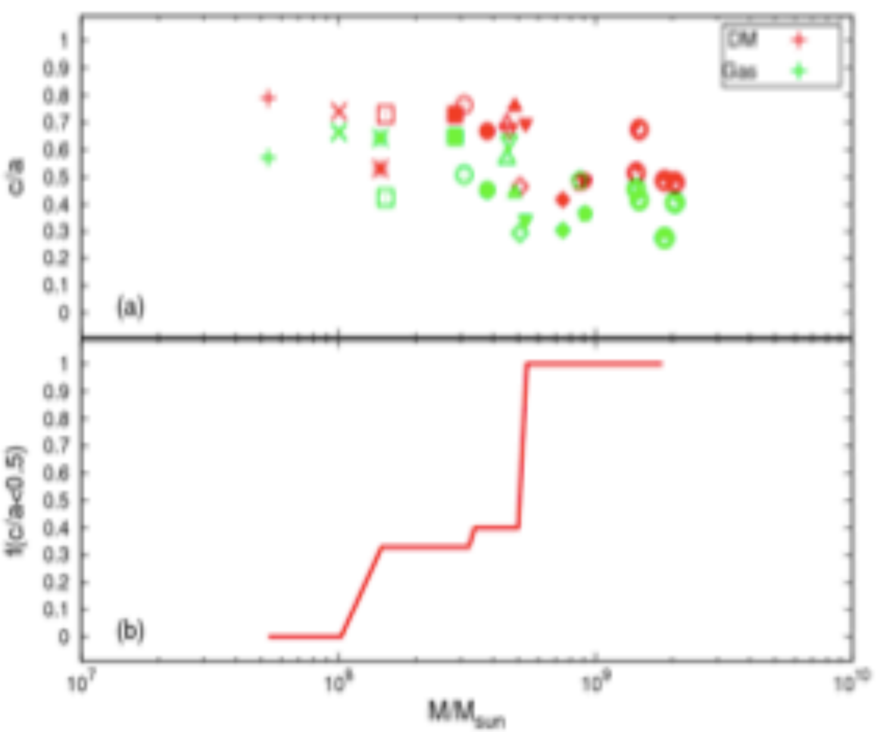
Halo (number)	Halo mass ($M_\odot$)	T_{vir} (K)	R_{vir} (kpc)	Object	Box (Mpc)	m_{DM} ($M_\odot$)	Resolution (pc)
1	5.35×10^7	2.34×10^4	0.72	RSC	3.0	7.38×10^3	8.3
2	1.02×10^8	3.60×10^4	0.89	–	3.0	7.38×10^3	8.3
3	1.47×10^8	4.59×10^4	1.00	–	3.0	7.38×10^3	8.3
4	1.56×10^8	4.78×10^4	1.02	–	3.0	7.38×10^3	8.3
5	3.21×10^8	7.73×10^4	1.31	–	3.0	7.38×10^3	8.3
6	3.39×10^8	8.02×10^4	1.33	–	3.0	7.38×10^3	8.3
7	3.99×10^8	8.94×10^4	1.40	RSC	5.5	4.55×10^4	15.3
8	4.59×10^8	9.81×10^4	1.47	–	5.0	3.42×10^4	13.9
9	4.78×10^8	1.00×10^5	1.49	–	3.0	7.38×10^3	8.3
10	5.00×10^8	1.03×10^5	1.51	–	3.0	7.38×10^3	8.3
11	5.40×10^8	1.09×10^5	1.55	–	5.0	3.42×10^4	13.9
12	5.72×10^8	1.13×10^5	1.58	RSC	5.5	4.55×10^4	15.3
13	7.81×10^8	1.39×10^5	1.76	–	3.0	7.38×10^3	8.3
14	8.35×10^8	1.46×10^5	1.80	–	5.5	4.55×10^4	15.3
15	8.60×10^8	1.49×10^5	1.81	–	3.0	7.38×10^3	8.3
16	9.22×10^8	1.56×10^5	1.86	COB	3.0	7.38×10^3	8.3
17	1.48×10^9	2.14×10^5	2.18	–	5.5	4.55×10^4	15.3
18	1.53×10^9	2.19×10^5	2.20	COB	5.0	3.42×10^4	13.9
19	1.87×10^9	2.50×10^5	2.35	–	8.0	1.39×10^5	22.1

Baryon fraction

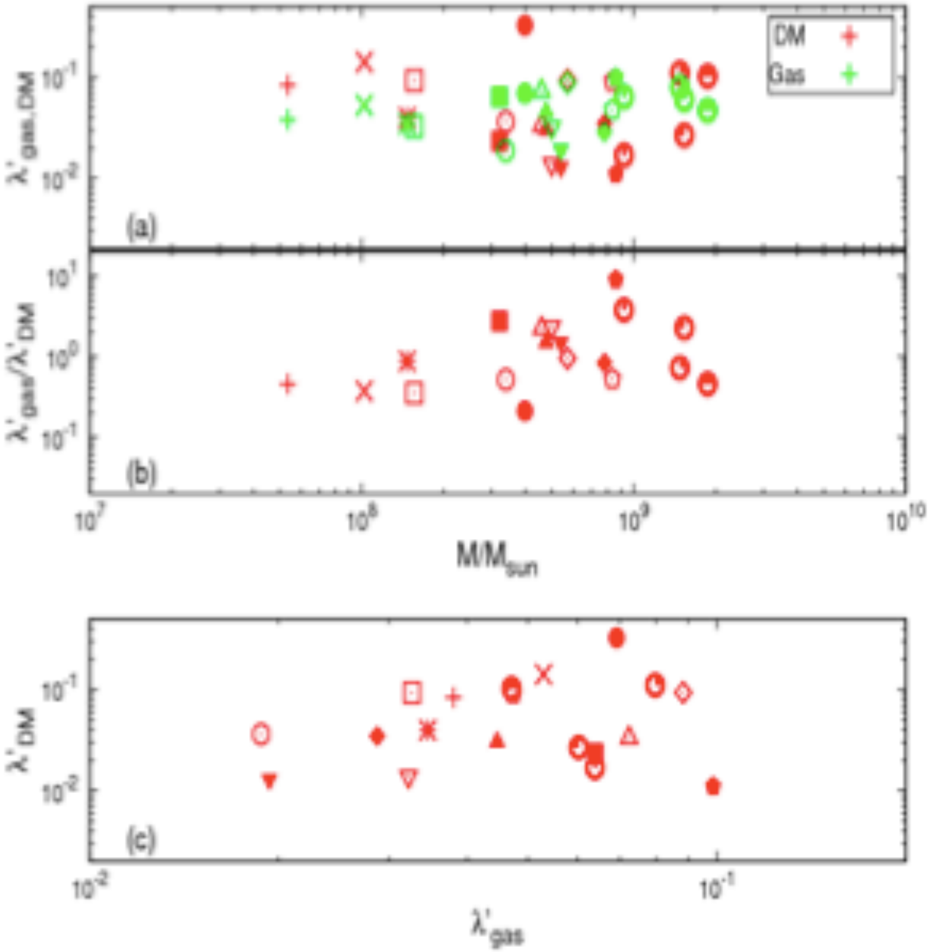


- Gas component tend to shrink more than the DM component.
- Applying the c/a<0.5 criteria.



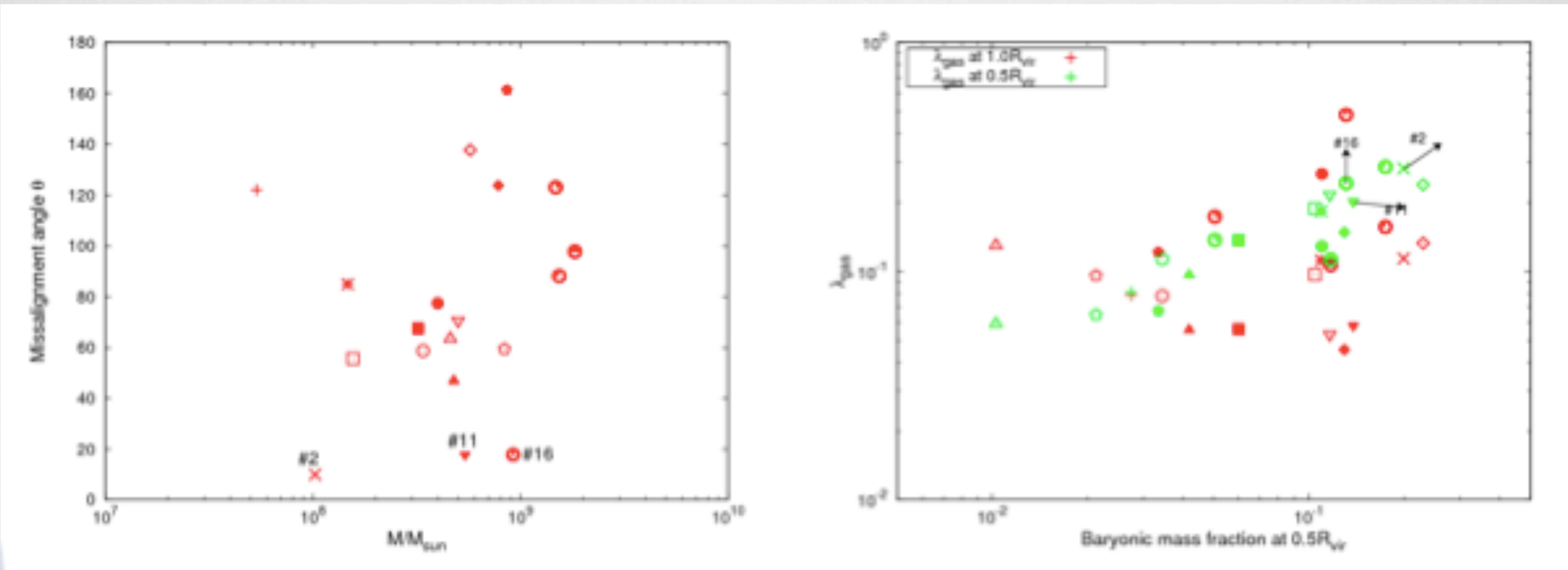


- Spin parameter:
  - $\lambda' = J/M(GMR)^{1/2}$, Bullock et al. (2001a)
  - $<\lambda'_{DM}> = 0.046$
  - $<\lambda'_{gas}/\lambda'_{DM}> = 1.65$
  - Gas tends to rotate faster than the DM component.

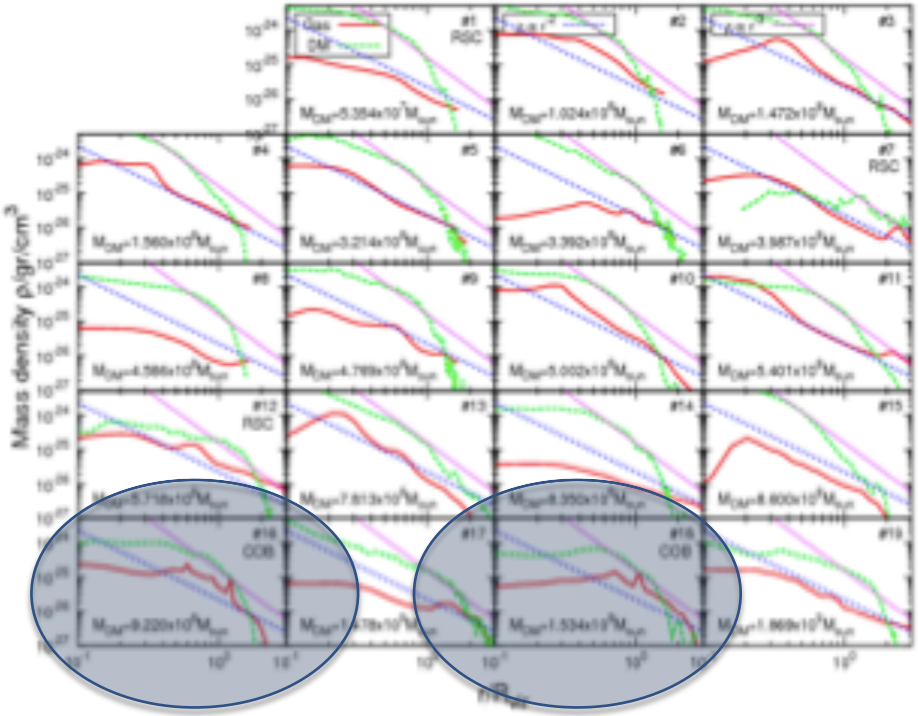


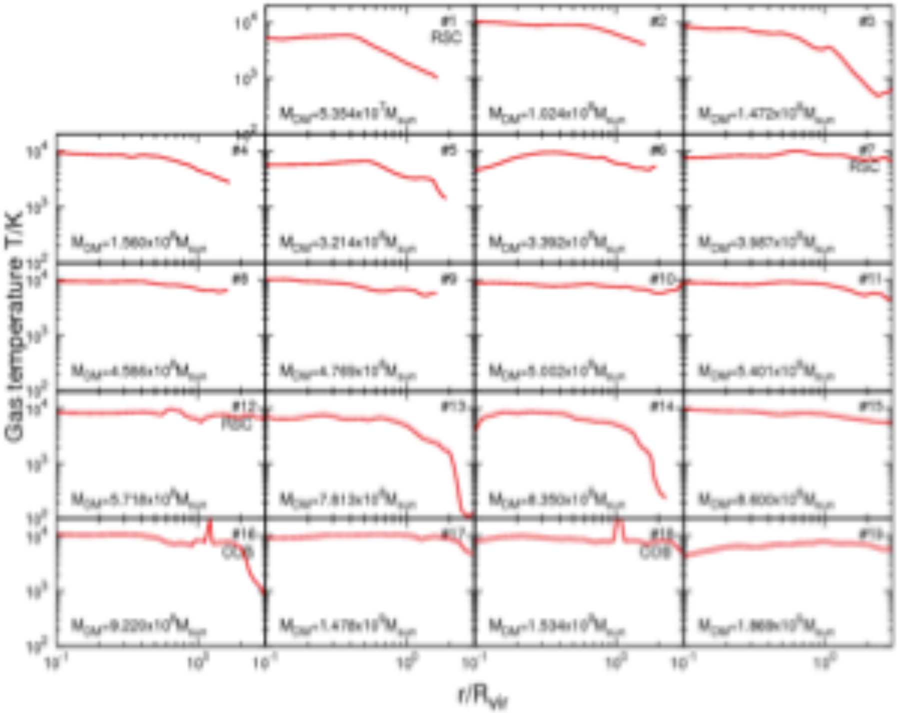
There is a clear misalignment between gas and DM

Some of the halos with the lowest value of Θ have the highest value of λ

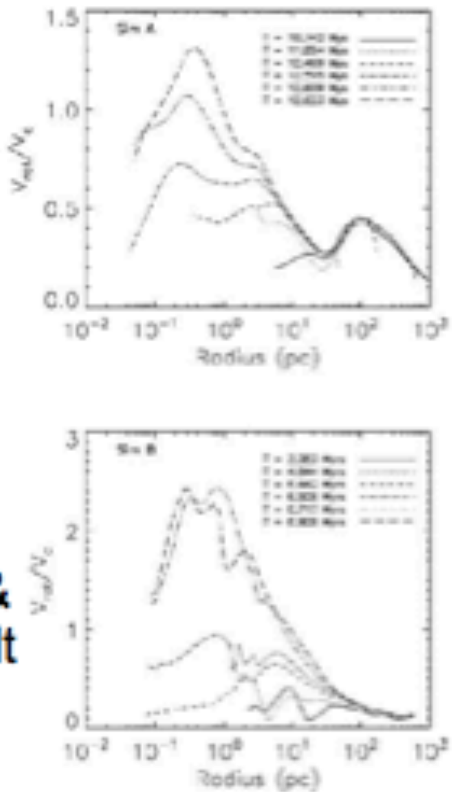


- Density and temperature profiles.
- Two of the mos massive haloes develope compact overdense blobs (COB).
- The gas is isothermal with T≈10^4K.

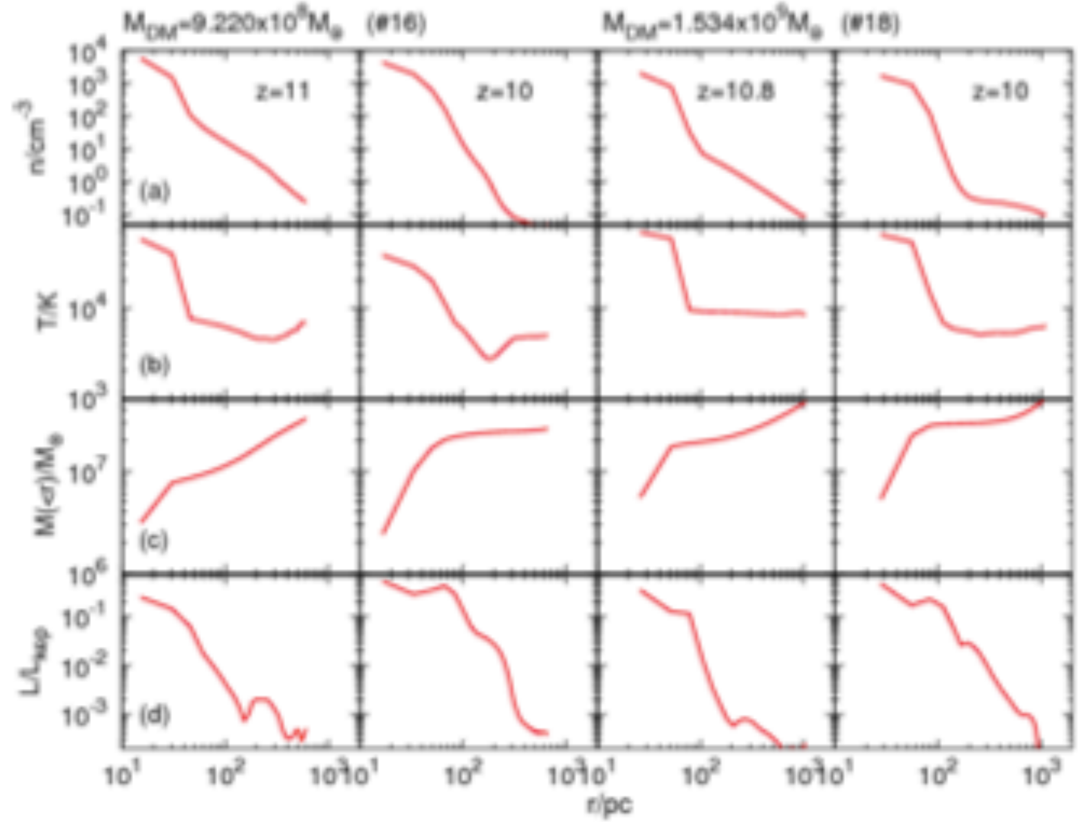




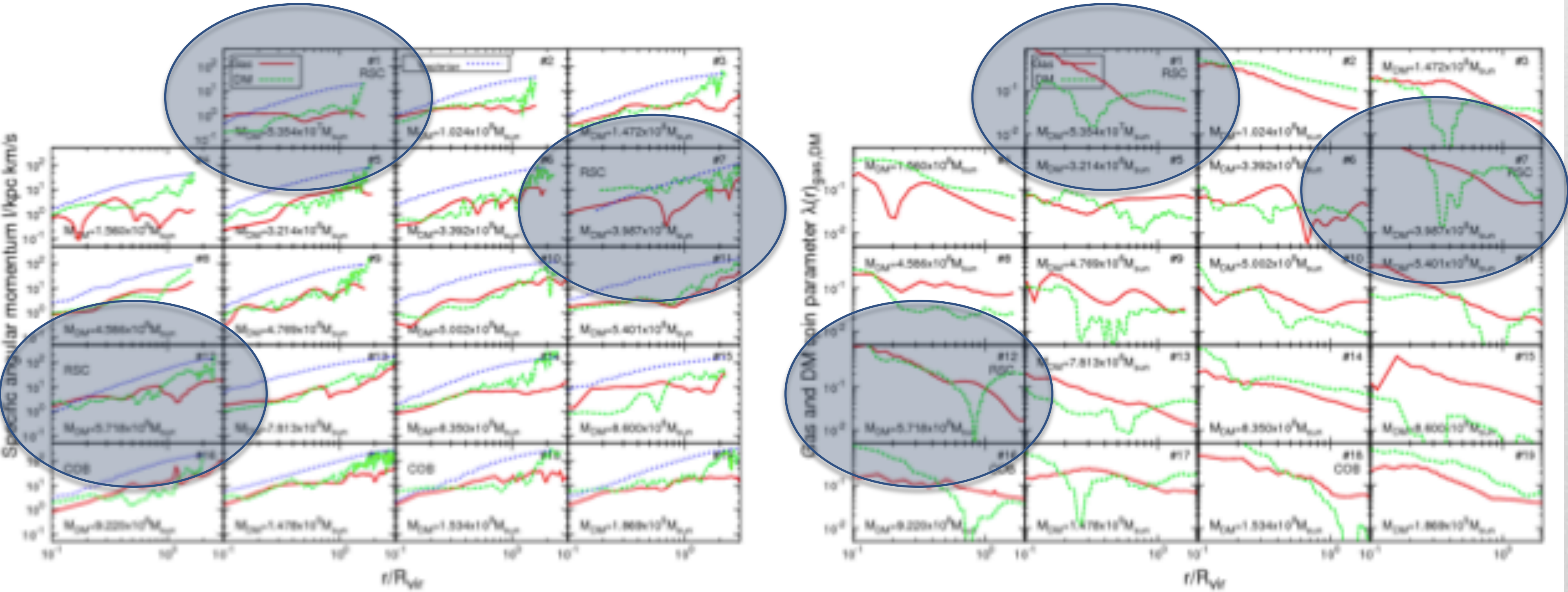
- COB profiles:
- COBs have M ~ few $10^7 M_\odot$ halo.
- Rotational velocity is comparable to the one mesured by Regan & Haehnelt (2009a) at ~10pc.



Regan & Haehnelt (2009a)



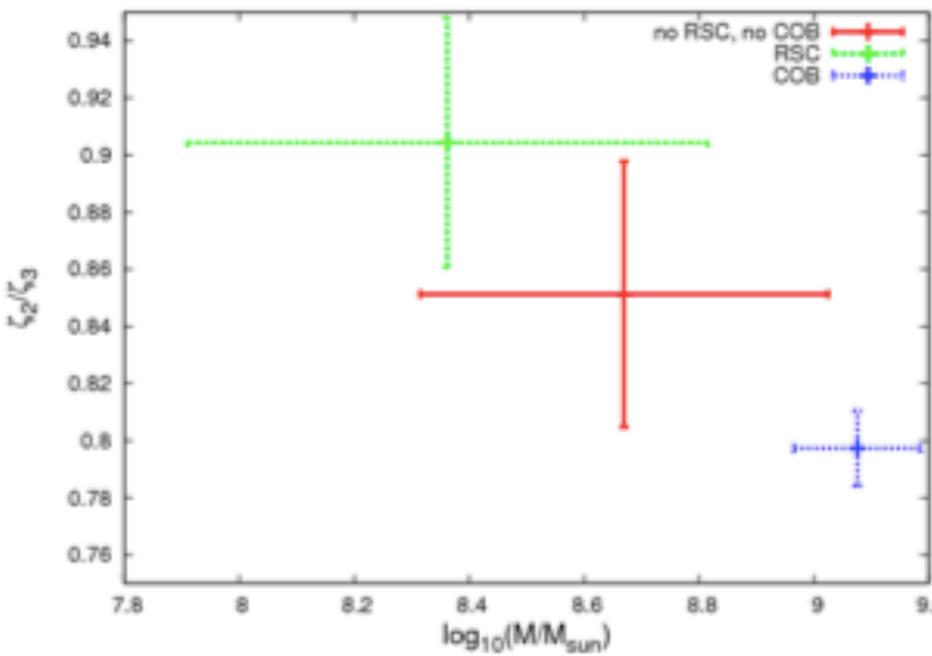
- Specific angular momentum and λ' as a function of radius.
- 3 objects show $v_{rot} \approx v_{Kep}$ and $\lambda' \approx 1$ at $r<0.1R_{vir}$ as rotationaly supported cores (RSC)



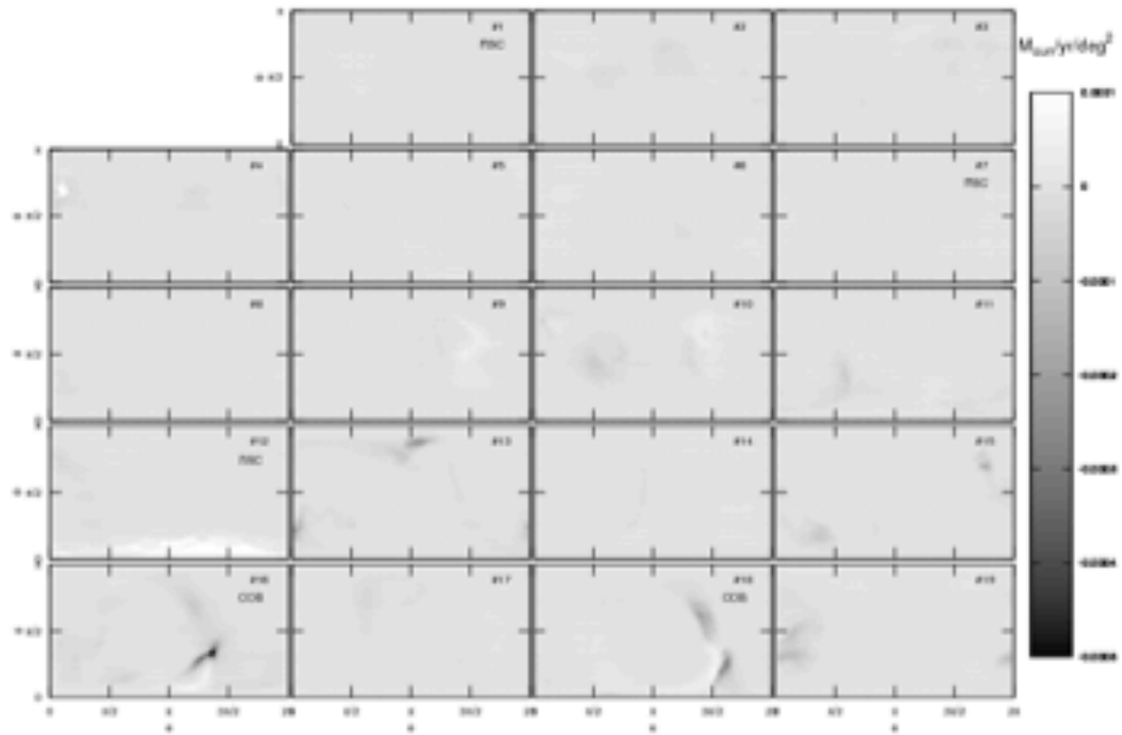
- 2º and 3º order structure function.
- Structure function of order p: $S_p(l) = \langle |u(x+l) - u(x)|^p \rangle \propto l^{\zeta(p)}$
- The ratio between different structure function is well described by (Padoan et al 2004):

$$\frac{\zeta(p)}{\zeta(3)} = \frac{p}{9} + 1 - (1/3)^{(p/3)},$$

- R_{RSC}=0.90, R_{COB}=0.79
- COB haloes are more turbulent.

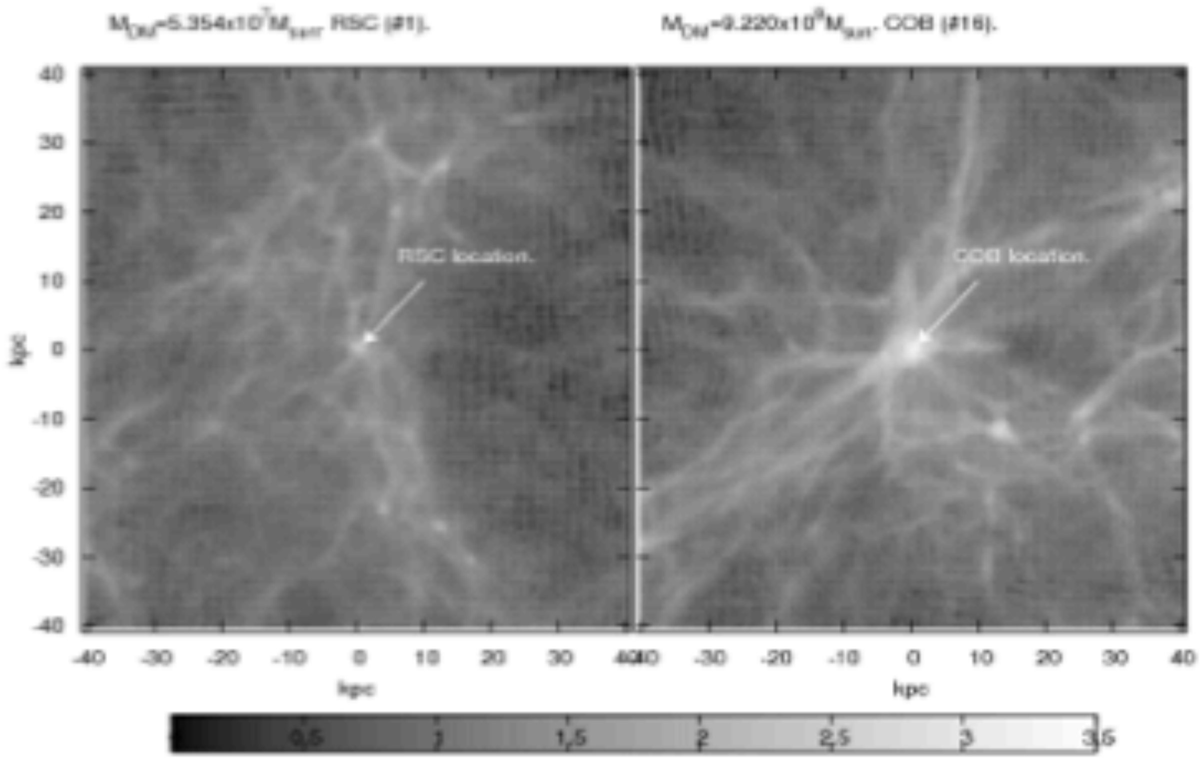


- Mass accretion:
- The COBs are among the haloes with the highest mass accretion rate.
- The COBs experienced a high number of minor mergers.



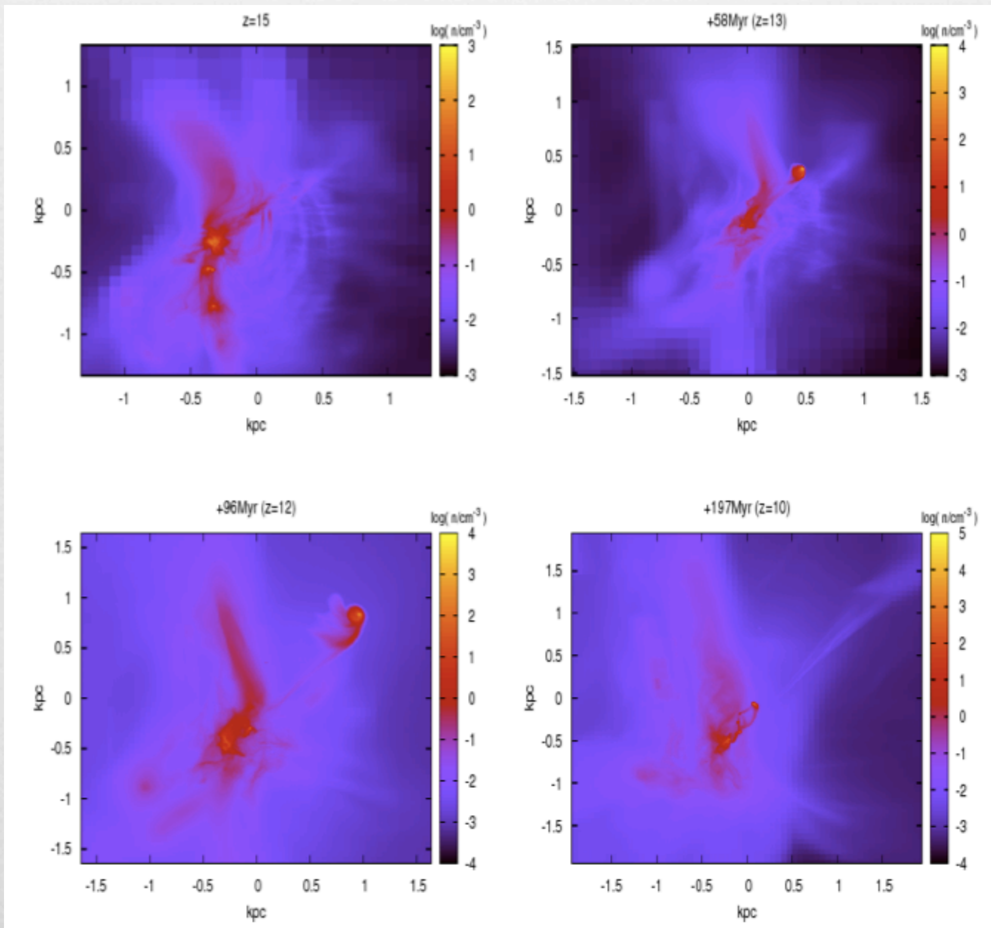
Objects location

- RSC located in filaments.
- COB located in knots of the cosmic web.

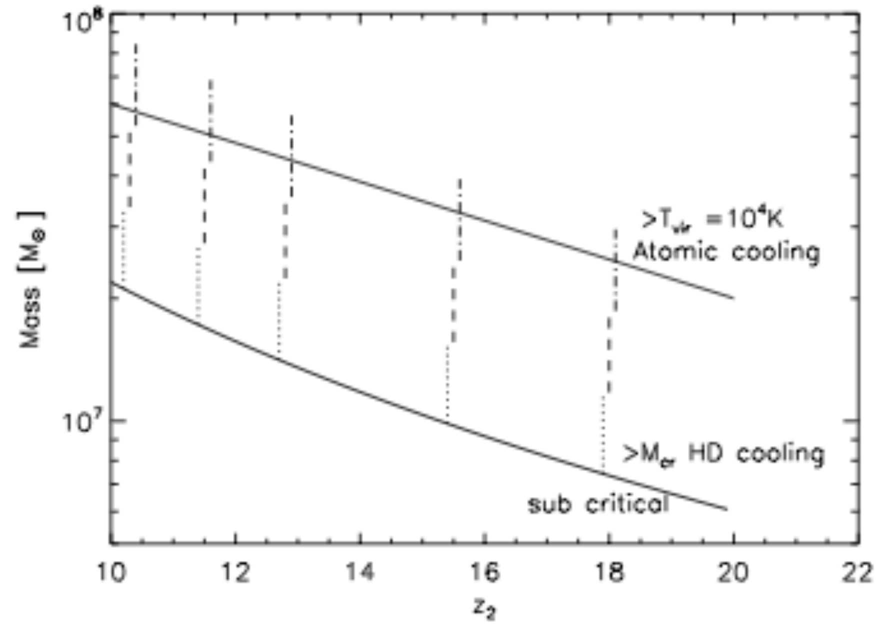


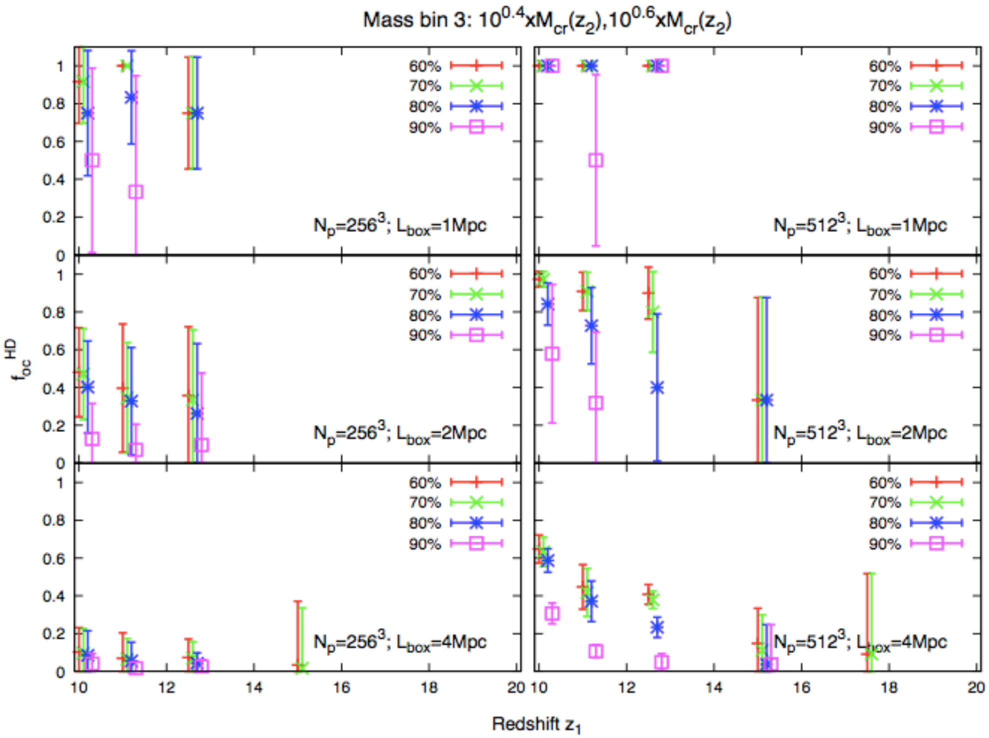
Overcooled Halos via formation of HD

The large scale baryonic accretion process and the merger of few ~ 10^6 $M_\odot$ DM halos, triggered by the gravitational potential of the biggest halo, is enough to create super sonic ($M_s > 10$) shocks and develop a turbulent environment. In this scenario the post shocked regions are able to produced both H2 and HD molecules very efficiently reaching maximum abundances of n_{H2} ~ 10^{-2}nH and n_{HD} ~ few × 10^{-6}nH, enough to cool the gas down to the CMB temperature in some regions.



The mass range of DM halos considered in this work





Fraction of over-cooled halos

Conclusions/Questions.

- Turbulent conditions inside AC at high z>10 are set by gas accretion and mergers (without stellar feedback).
- Both the merger history and the gas accretion depend on the environment/large scale structure around the haloes.
- It seems RSC and COB form under very different conditions: COB in very turbulent (low angular momentum) gas whereas RSC in less turbulent (keeping most of their angular momentum) gas.
- The gas spin parameter is higher than the DM spin and in most of the cases their are misaligned.

AND… mergers can overcool the primordial galaxy and favor low-mass popIII formation