The Distribution of gas in the Local Group

Results from Constrained Simulations

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Outline

- Introduction.
- Cosmological simulation.
- Gas distribution and properties at present epoch.
  - Within MW and M31 haloes.
  - Around and inbetween MW and M31.
- Gas distribution: Evolution and interaction history.
- Conclusions and future work.

Introduction

- Gas distribution is a key aspect to study galaxy formation and evolution.
- Gives important clues on the current evolutionary state and recent past history of galaxies:
  - Cold inflowing gas → immediate future of active star formation
  - Outflows → star formation and feedback in recent past
- The MW and neighboring galaxies represent the best known region in the universe, making the study of Gas distribution in the LG very useful.

Cosmological Simulation: Constrained Local UniversE Simulations (CLUES)

- Aim at simulating a realistic LG including the effects of the local environment and more prominent structures.
- IC using Hoffman-Ribak algorithm[1]: generate a set of Gaussian constraints at high z form a given observational sample at $z \approx 0$.
- Different realizations until emulation of the LG (two main gala- xies with masses and relative velocities within known observa- tional limits).
- GADGET3[2] with the extensions of Scannapieco et al.[3,4] (metal- dependent cooling chemical enrichment, multiphase model for the gas component and supernova -thermal- feedback).

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[1] Hoffman Y., Ribak E., 1991, ApJL, 380, L5

[2] Springel V., Wang J., Vogelsberger M., et al, 2008, MNRAS, 391,1685.

[3] Scannapieco C., Tissera P. B., White S. D. M., Springel V., 2005, MNRAS, 364, 552.

[4] Scannapieco C., Tissera P. B., White S. D. M., Springel V., 2006, MNRAS, 371, 1125.

Cosmological Simulation: Simulation properties

- Multiphase + feedback → study in a realistic manner the gas dist. in and around galaxy haloes

- Cosmological Parameters →

$\Omega_m = 0.279$
$\Omega_b = 0.046$
$\Omega_\Lambda = 0.721$

$H = 100h$ km s^{-1} Mpc^{-1}
$h = 0.7$
$\sigma_8 = 0.8$

- Re-simulated a gas sphere of 2 h^{-1} Mpc radius located in the center of the LG, embedded in a DM only cosmological box of 64 h^{-1} Mpc.

- Resolution (inside the high resolution region) →

$M_{gas} = 3.89 \times 10^5\ h^{-1} M_\odot$

$M_{DM} = 1.97 \times 10^6\ h^{-1} M_\odot$

The simulated LG

- Includes two main massive galaxies within the 2 h^{-1} Mpc high-resolution region, referred to as MW and M31.

Mass (in $10^{10} M_{\odot}$)	M31	MW
Total (gas + stars + DM)	168	125
Baryonic (gas + stars)	14.6	11.9
Total Gas	6.69	5.70
Neutral Gas	1.67	1.60
HI	1.27	1.21
Ionized Gas	5.02	4.10

Gas distribution at z = 0: M31

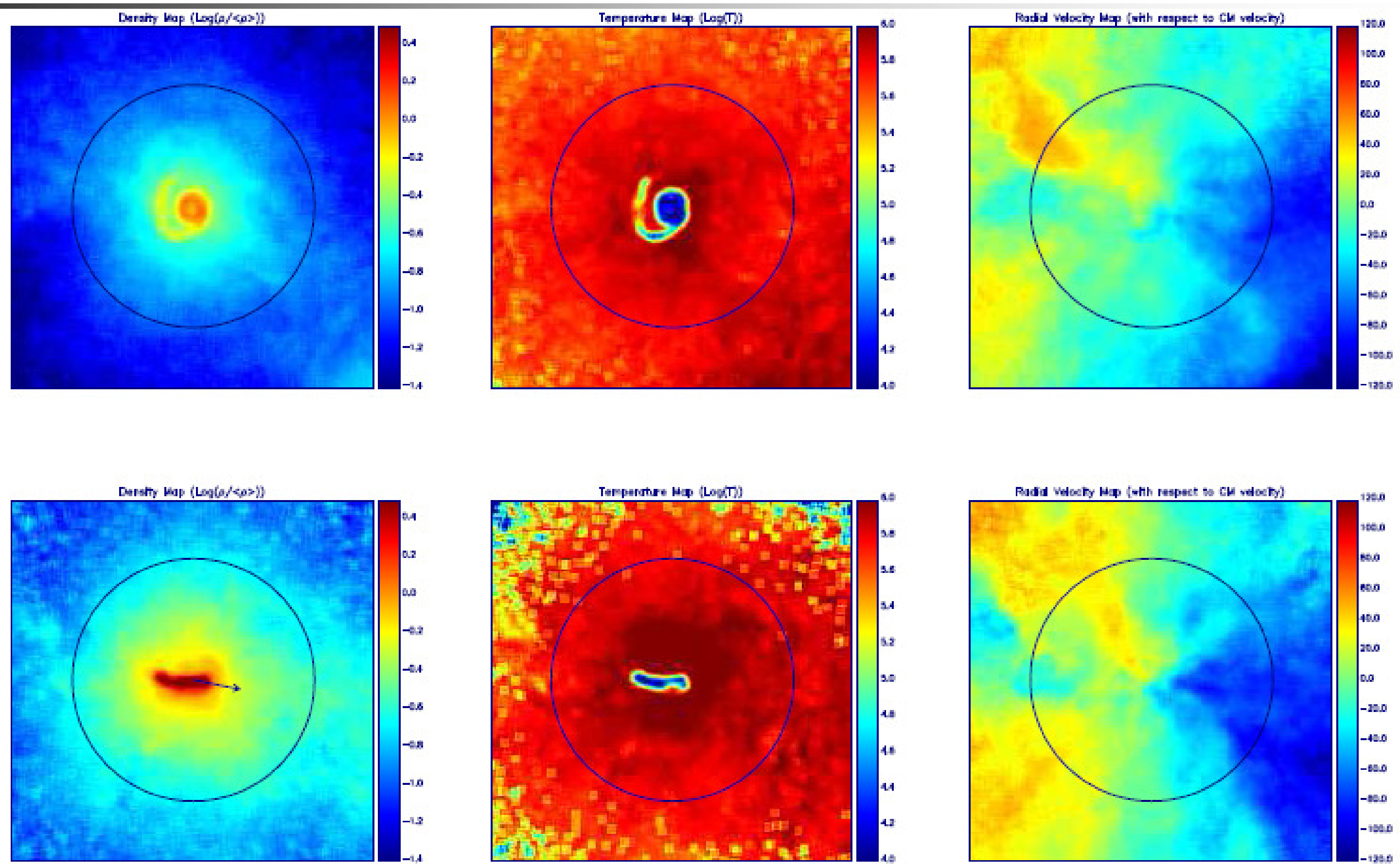

Fig 1: Face-on and edge-on maps of gas overdensity, temperature and radial velocity with respect to the simulated M31 CM, in a 1.5 R_{virial} cubic box.

Gas distribution at z = 0: M31

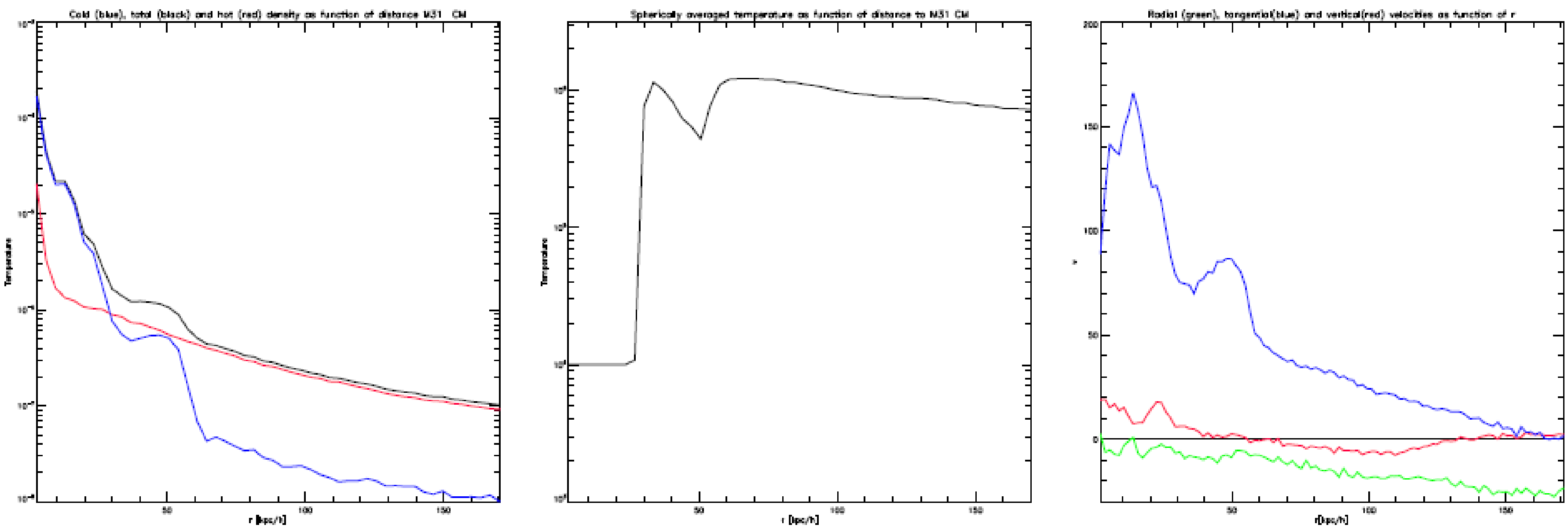

Fig 2: Spherically averaged radial profiles of gas density (cold, total and hot), temperature and velocity components in cilindrical coords.

Gas distribution at z = 0: MW

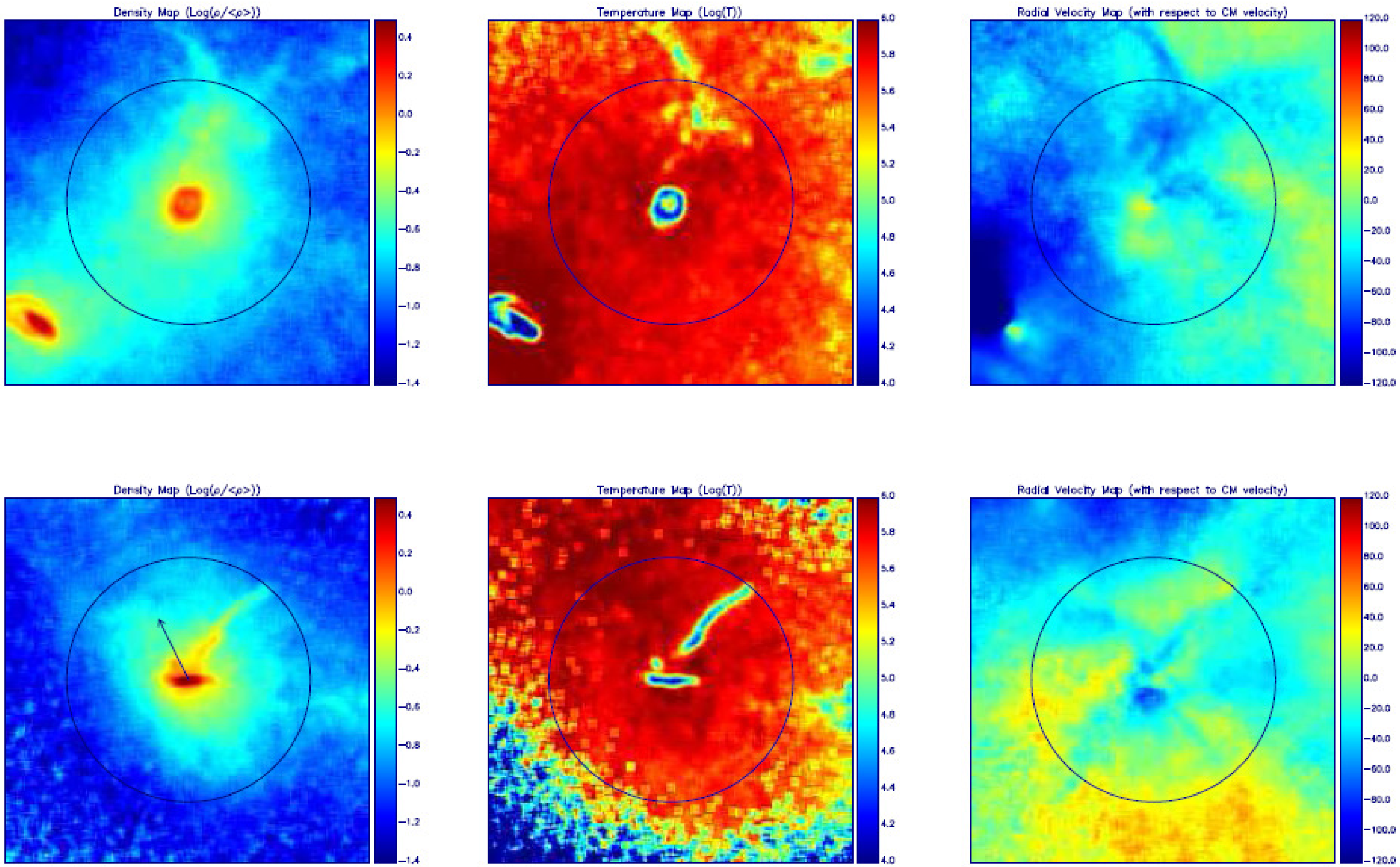

Fig 3: Face-on and edge-on maps of gas overdensity, temperature and radial velocity with respect to the simulated MW CM, in a 1.5 R_{virial} cubic box.

Gas distribution at z = 0: MW

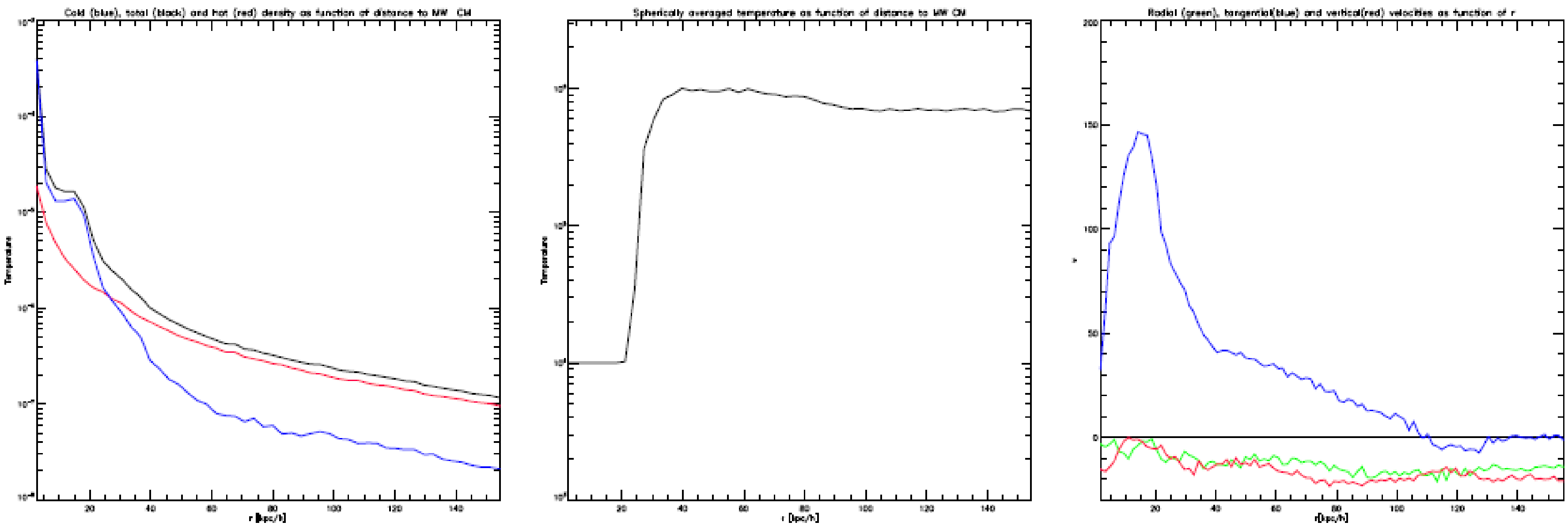

Fig 4: Spherically averaged radial profiles of gas density (cold, total and hot), temperature and velocity components in cilindrical coords.

Gas distribution at z = 0: Amount and nature of gas within the haloes

Amount of cold, hot and HI gas for the simulated galaxies, within the corresponding virial radii.

	Cold gas $[10^{10}\ M_\odot]$	Hot gas $[10^{10}\ M_\odot]$	HI gas $[10^{10}\ M_\odot]$
M31	1.67	5.02	1.27
MW	1.60	4.10	1.21

- X-ray absorption features of OVII and OVIII indicate a total mass of gas present in the MW of $M_{GAS} > 6.1\times10^{10} M_\odot$ [5]
- Total mass of gas in the simulated MW: $M_{GAS} = 5.70\times10^{10} M_\odot$

[5] Gupta A., Mathur S., Kronglod Y., Nicastro F., Galeazzi M., 2012, ApJL, 756, L8.

Gas distribution around the MW and M31

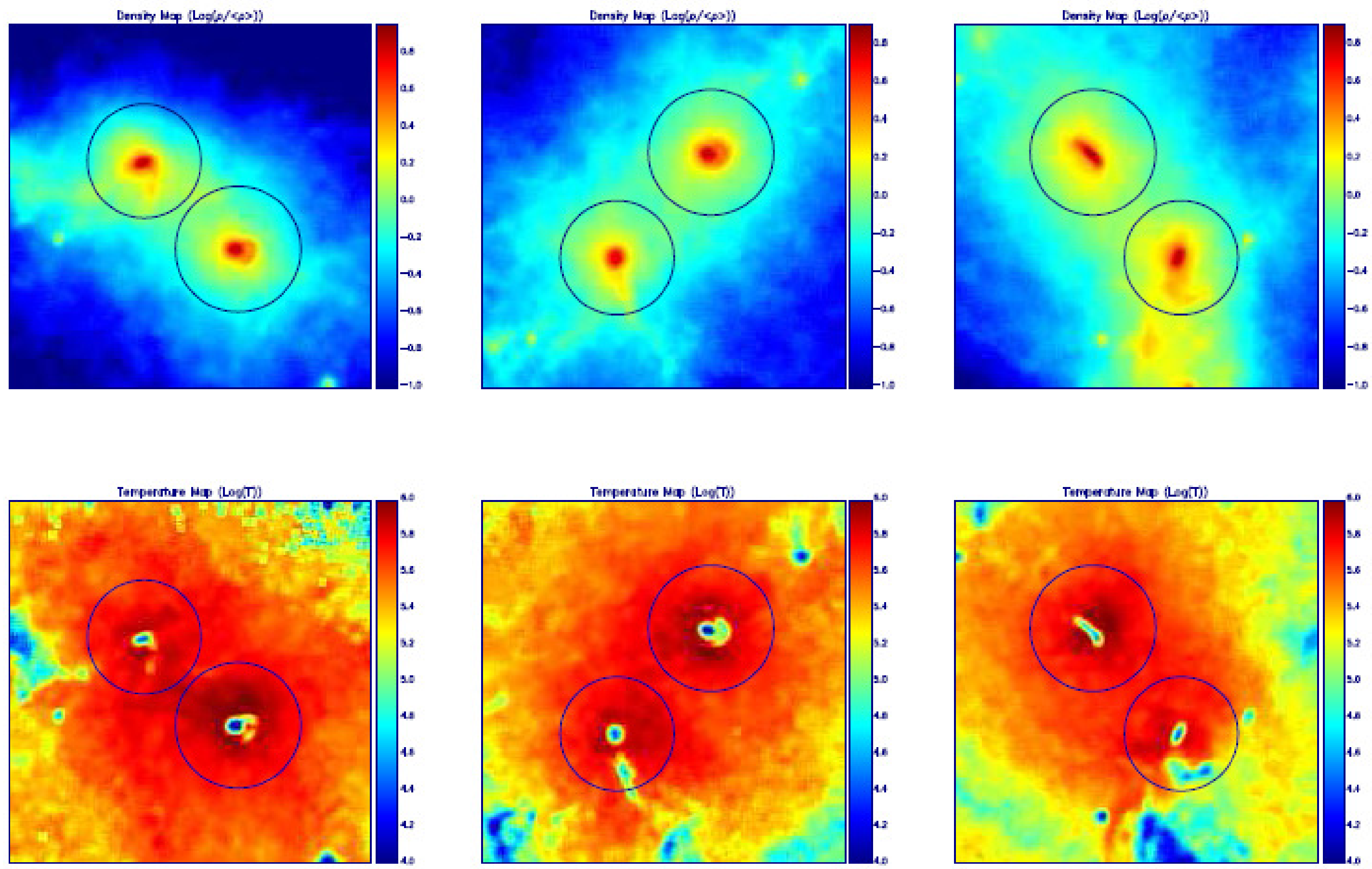

Fig 5: Gas overdensity and temperature maps for the M31-MW system in three perpendicular projections to highlight the 3D distribution.

Gas distribution at z = 0

Is there a gas excess between MW and M31?

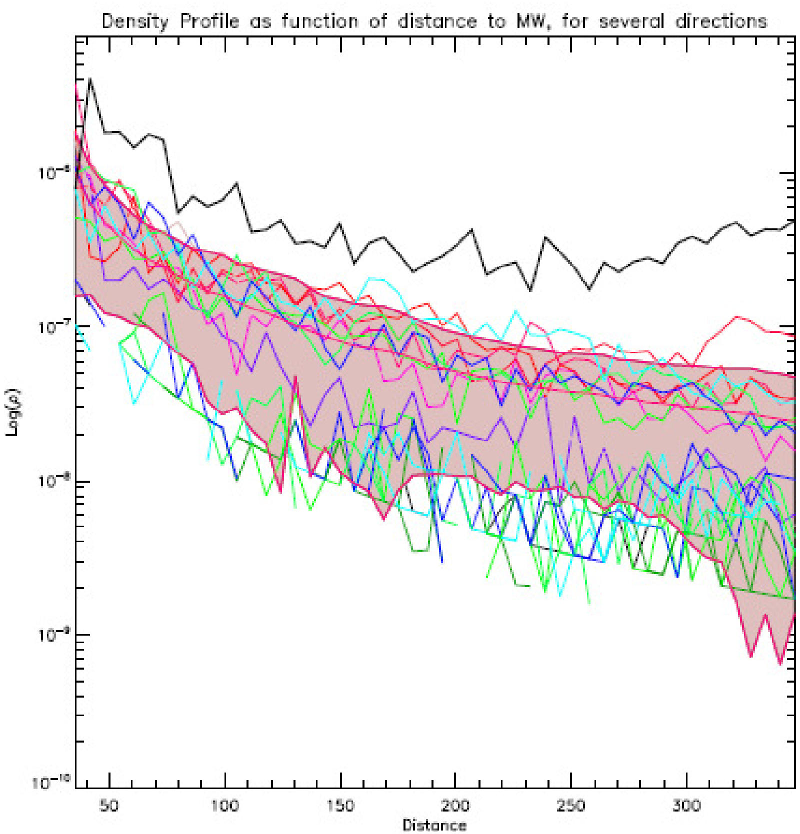

Fig 6: Gas density along several radial directions as function of distance to the MW center of mass. The thick black line corresponds to the density profile in the direction towards M31.

Cold, total and hot as distribution at z = 0

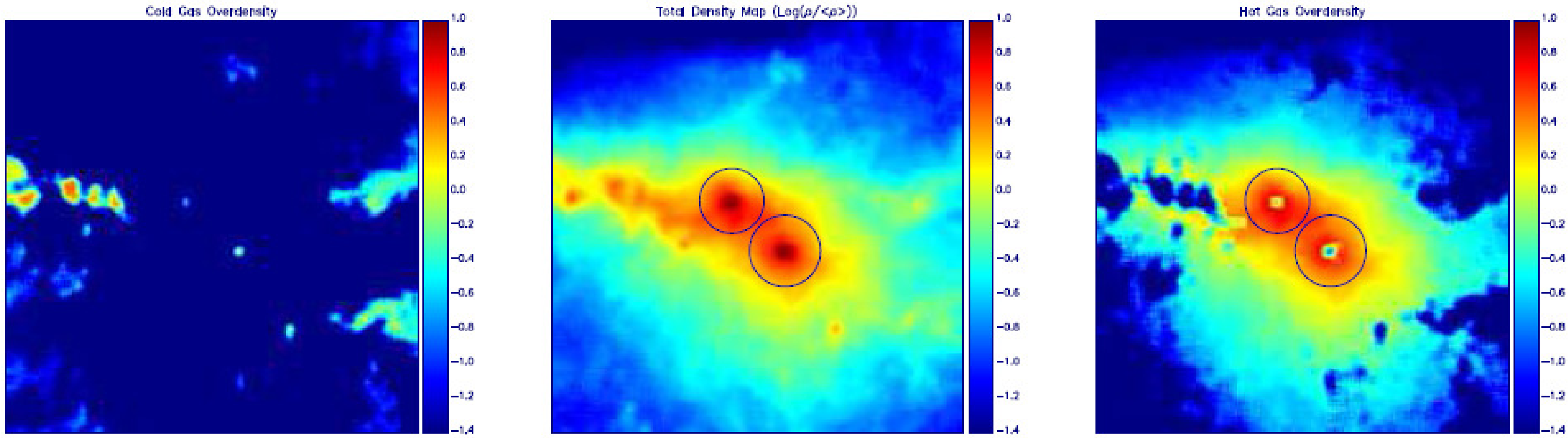

Fig 7: From left to right, cold, total and hot gas overdensity in a 1 h^{-1} Mpc cubic box. The cold gas is located in the very centers of the galaxies, while the hot gas is distributed within and around the haloes. Note the presence of several clumps of cold, dense gas near the M31-MW system.

MW accretion rates

Velocity of gas particles that lay near the MW virial radius + The time it would take them to enter (leave) the galaxy halo

Rate ($M_\odot$ yr^{-1})	Accretion	Ejection
Total Gas	1.59	0.84
Cold Gas	0.63	0.03
Hot Gas	0.96	0.81
HI	0.48	0.02

Observed accretion rates: 0.7$M_\odot$ yr $^{-1}$ for neutral gas
0.5$M_\odot$ yr $^{-1}$ for HI [6]

[6] Richter P., 2012, ApJ, 750, 165.

Gas distribution: evolution and interaction history.

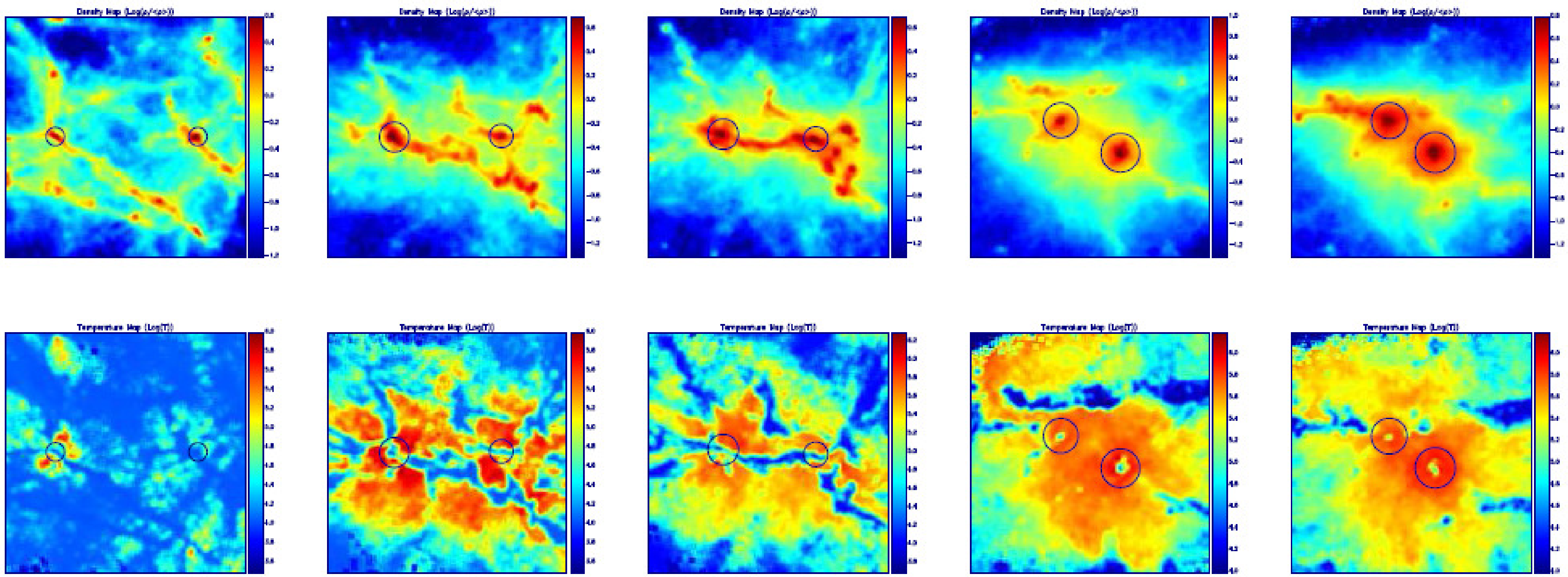

Fig 8: Gas overdensity and temperature maps in a 2 h^{-1} Mpc comoving cubic box, centered at the middle point between M31 and MW. From left to right: z = 2.30, z = 1.18, z = 0.96, z = 0.25 and z = 0.13.

Gas distribution: evolution and interaction history.

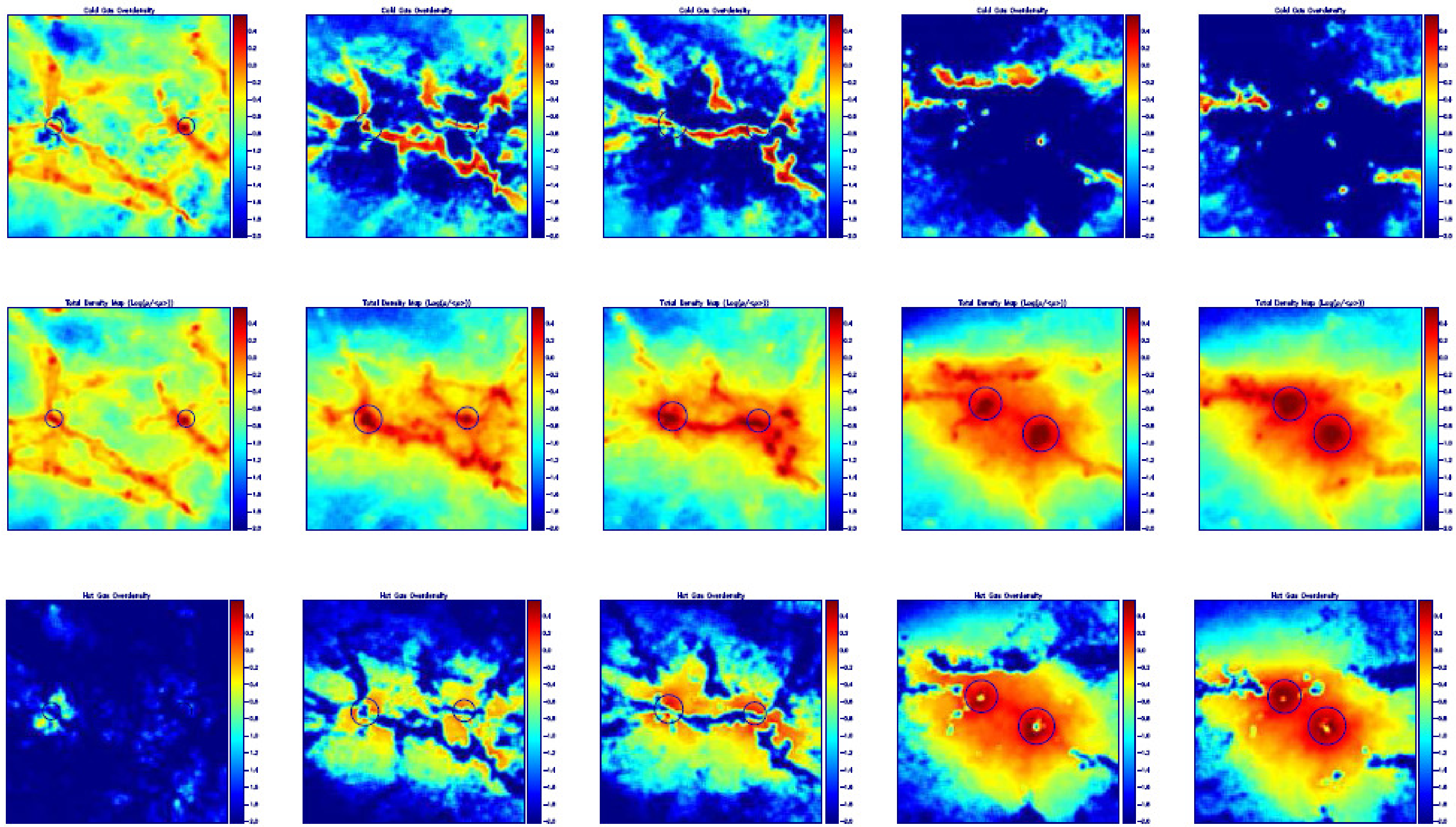

Fig 9: Cold, total and hot gas overdensity for the same redshifts as previous figure

Main conclusions

- The simulated LG at present times includes two main massive galaxies that qualitatively resemble the actual MW and M31.
- Both objects present a distinguishable thin disk of cold gas, as well as a more diffuse hot gas halo.
- The gas distribution of the two haloes significantly overlap, giving raise to a noticeable overdensity in the direction that connects M31 and MW.
- The simulated MW is accreting gas at ~ 1.59 $M_{\odot}\ yr^{-1}$, of which 60% corresponds to hot gas. The accretion rates are in very good agreement with observations.

Main conclusions

- There is also a significant amount of material flowing out of the halo, consequence of supernova feedback.

- The history can be separated into three epochs: filamentary distribution at early epochs with separate filaments, same filament and two separate but overlapping objects.

- The two galaxies seem to have evolved independently. While the MW has grown in a smooth progresive way, M31 exhibits a more chaotic evolution.

END