

Zoom-in cosmological simulations of cold flows-hot halo gas interaction:

Refinement focused on cold gas filaments

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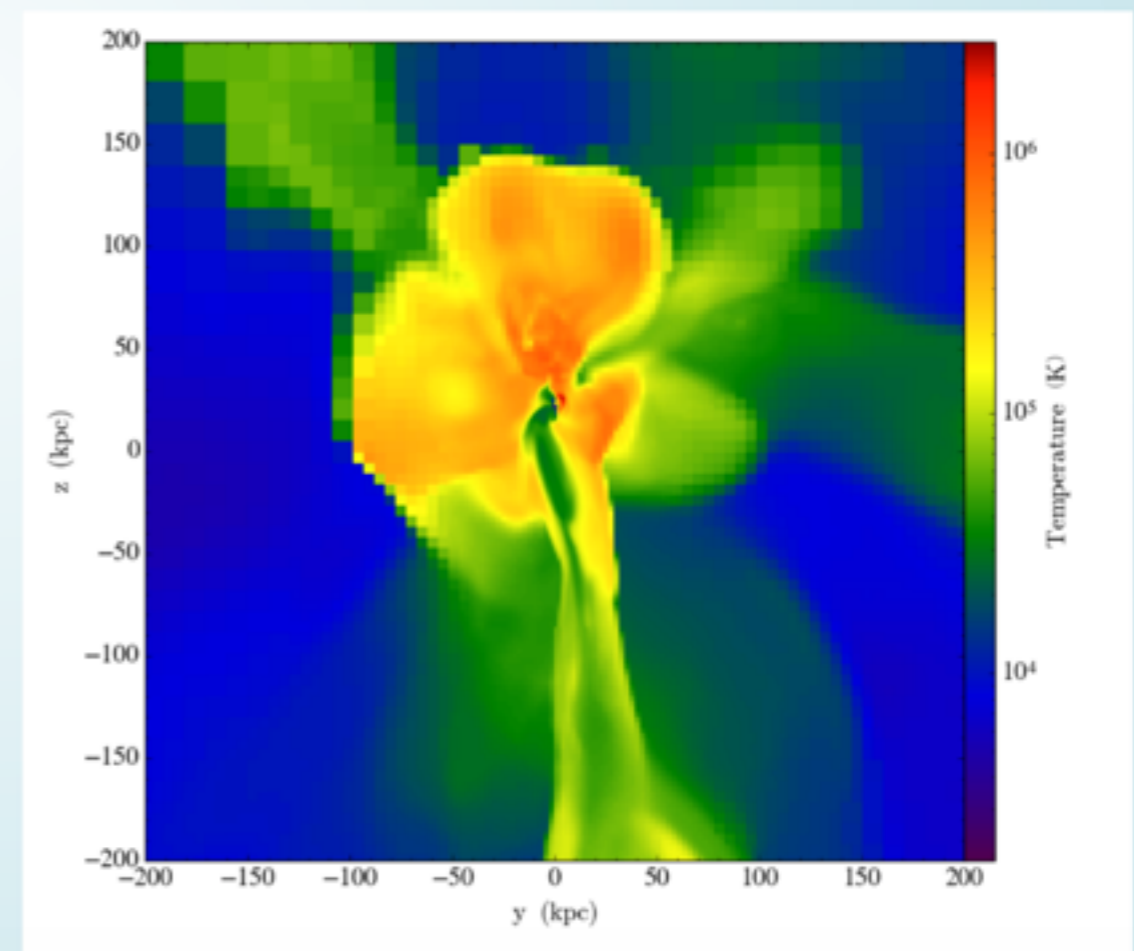
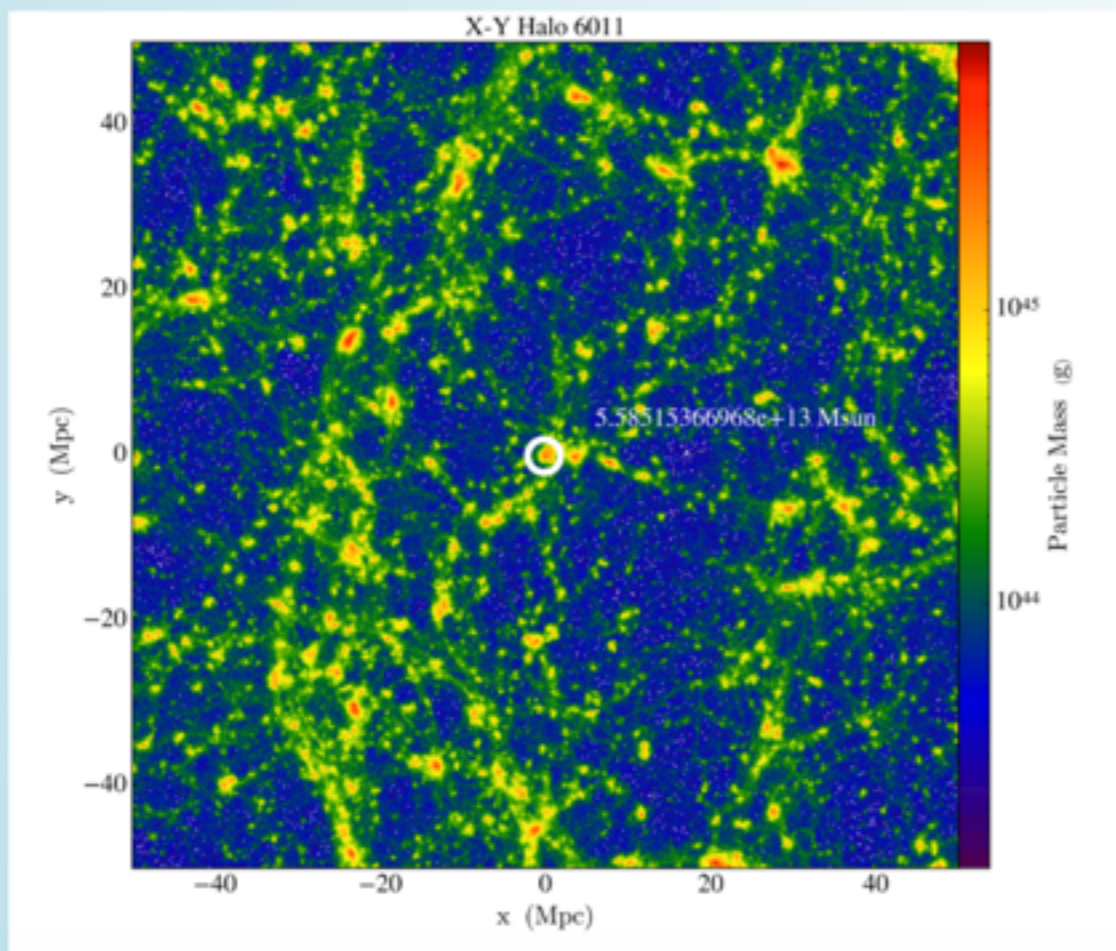
High Resolution simulations of cold gas flows in a cosmological box

Goal: To study the evolution of cold flow instabilities in a cosmological context (following Nir Mandelker et al 2016a)

Method: Zoom-in cosmological simulations using RAMSES code (with no BHs/AGN) + new refinement criteria

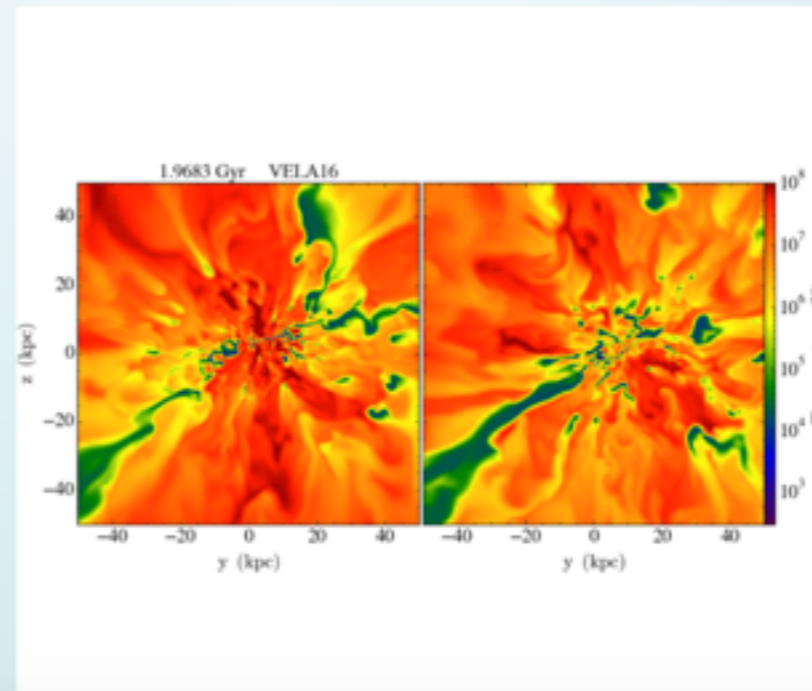
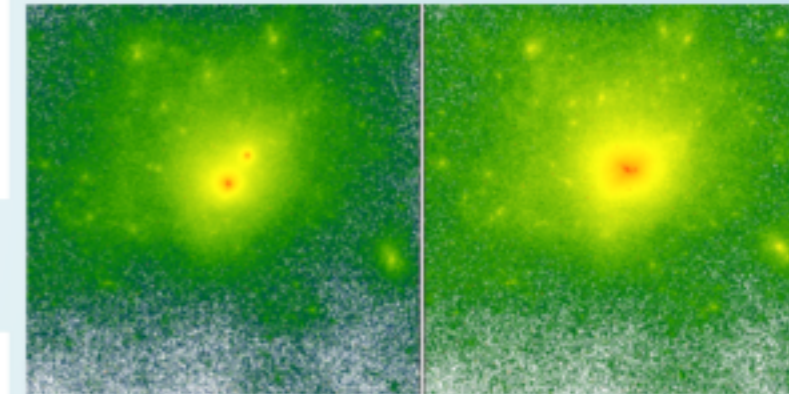
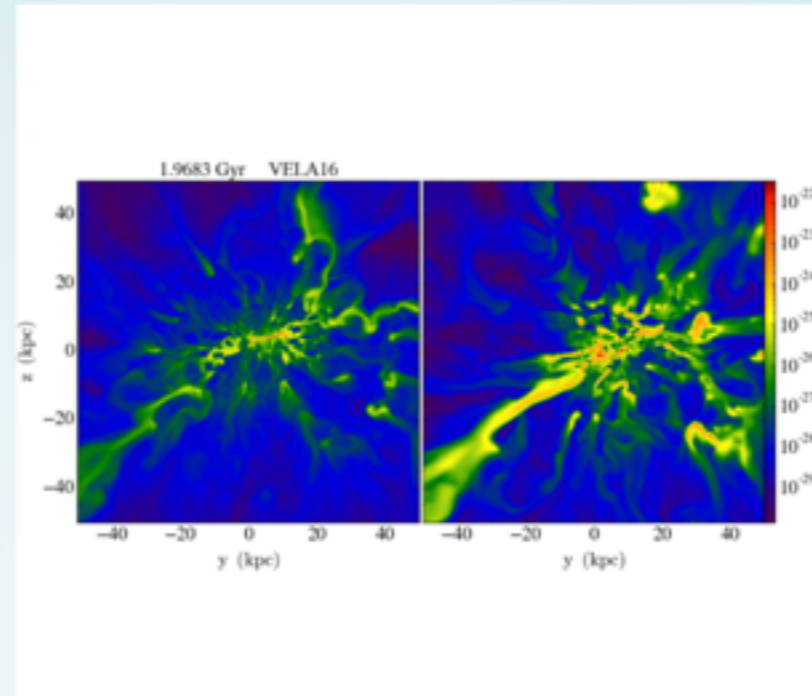
Cold flows - Hot CGM interaction

- Massive galaxies at $z=1-4$ in nodes of the cosmic web
- $M_{\text{vir}} \sim 10^{12} M_{\text{sun}}$. Virial shock, hot halo at $T \sim 10^6 \text{K}$
- Feed by cold gas streams penetrating the hot halo



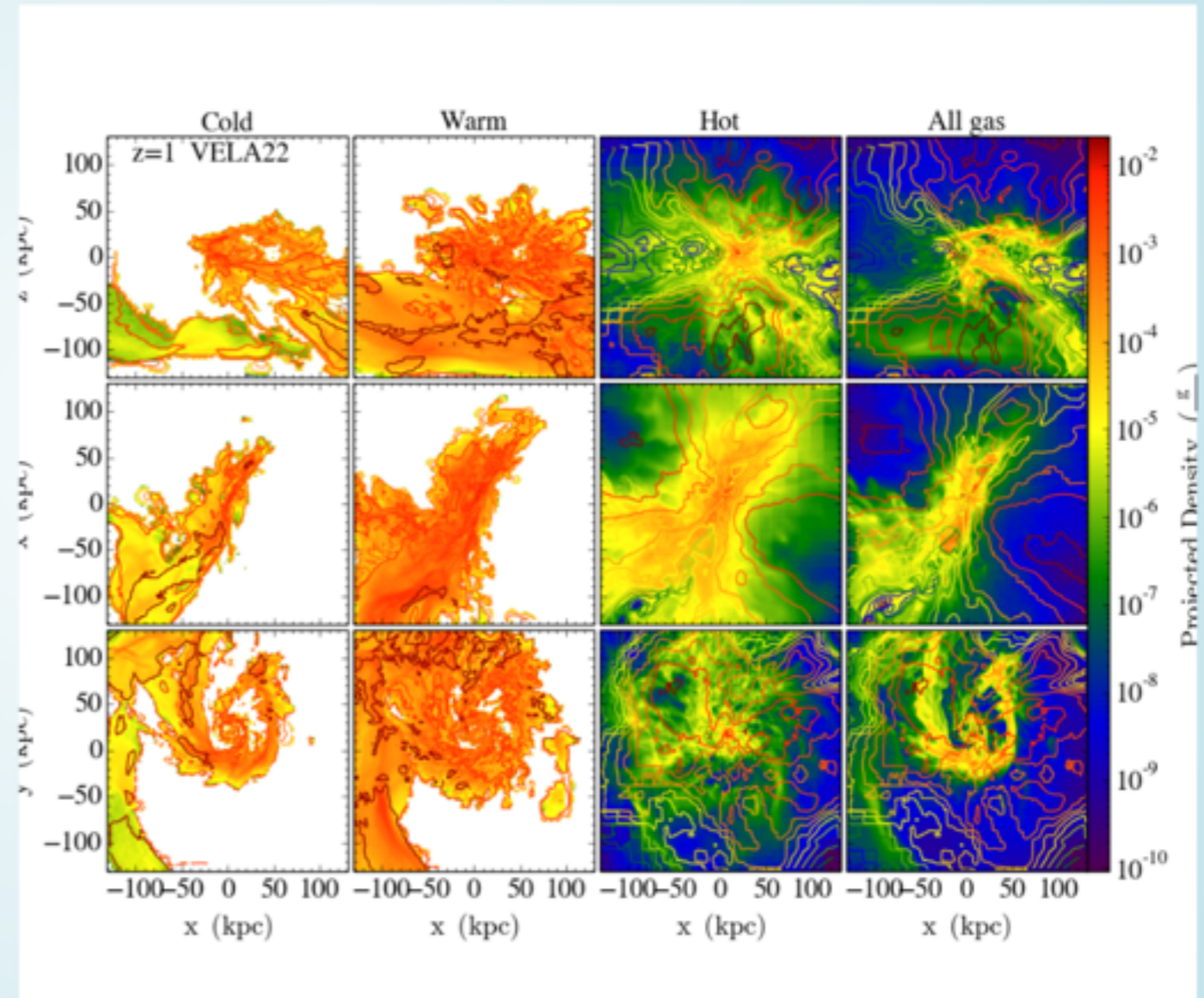
Cold flows - Hot CGM interaction

- Cold filaments narrower than R_{vir}
- About half of the gas that cross R_{vir} ends in the central region (SFR, angular momentum)
- Infall at constant velocity (from simulations)
- Stability? Break into clumps? Comparison with observations.



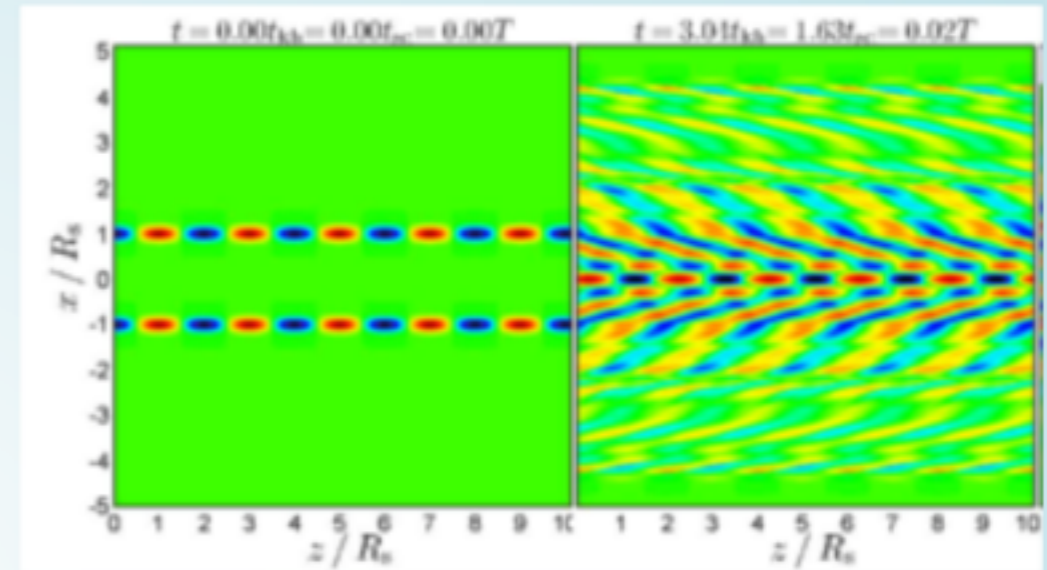
Cold flows - Hot CGM interaction: Models

- To study the cold flow - hot halo CGM interaction we need:
 - Realistic physical processes for gas hydrodynamics
 - High spatial and temporal resolution (cold flows are of tens of parsecs)
 - Cosmological context
 - Understanding of the individual processes that drive instabilities.



Cold flows - Hot CGM interaction: Models

- Mandelker et al. 2016a:
 - First paper of a series
 - Study of the Kelvin-Helmholtz instability
 - Ramses CODE
 - No magnetic fields
 - No thermal conduction
 - No cooling
 - No gravity (no halo potential, no self-gravity)
 - Adiabatic processes
 - Supersonic flow of cold-dense gas through hot underdense gas medium
 - Slab or cylinder 3D
 - Study of Kelvin-Helmholtz instability



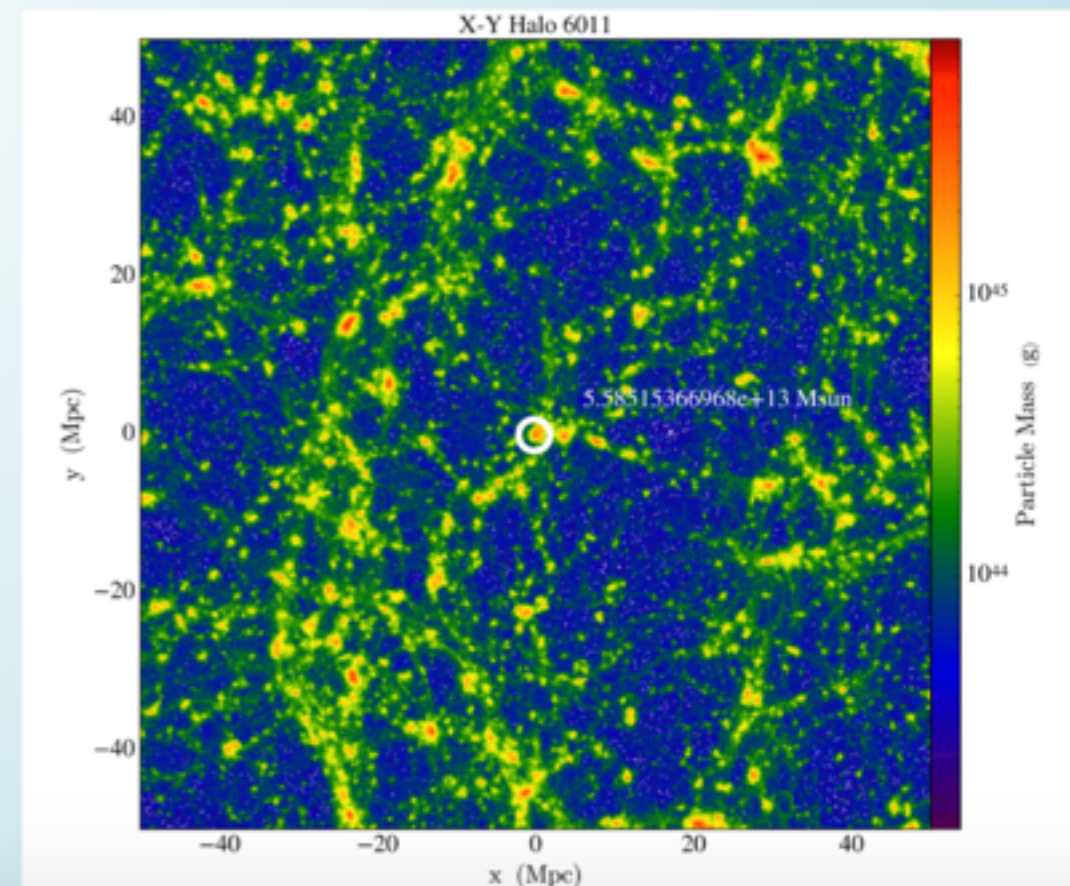
High Resolution simulations of cold gas flows in a cosmological box

The code:

- RAMSES code (bitbucket last version)
- Cooling (H, He, metals) / Heating below $z=10$ (reionization)
- SF: 0.1 H/cm^3 , $\text{eps}=0.02$ ($t_0=8 \text{ Gyr}$)
- SNe: Blastwave, 50% kinetic
- No AGN

Initial conditions (zoom-in technique):

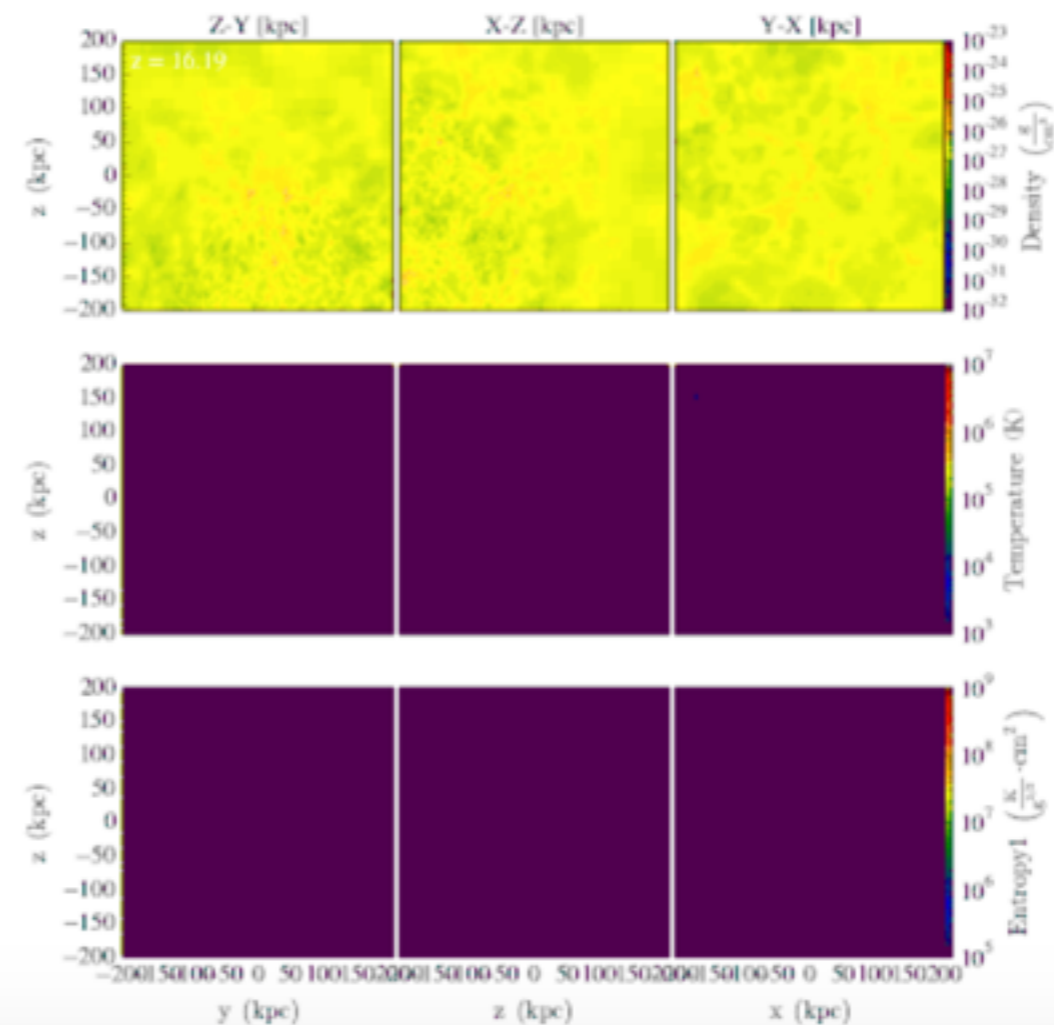
- Low resolution DM-only run, up to $z=0$
- Halo selection: by mass + by environment



High Resolution simulations of cold gas flows in a cosmological box

Main simulation:

- Using usual refinement prescription (DM/gas mass/density threshold)
- Up to $z \sim 2$ (defined cold filaments penetrating hot gas halo)
- Resolution ~ 600 pc.



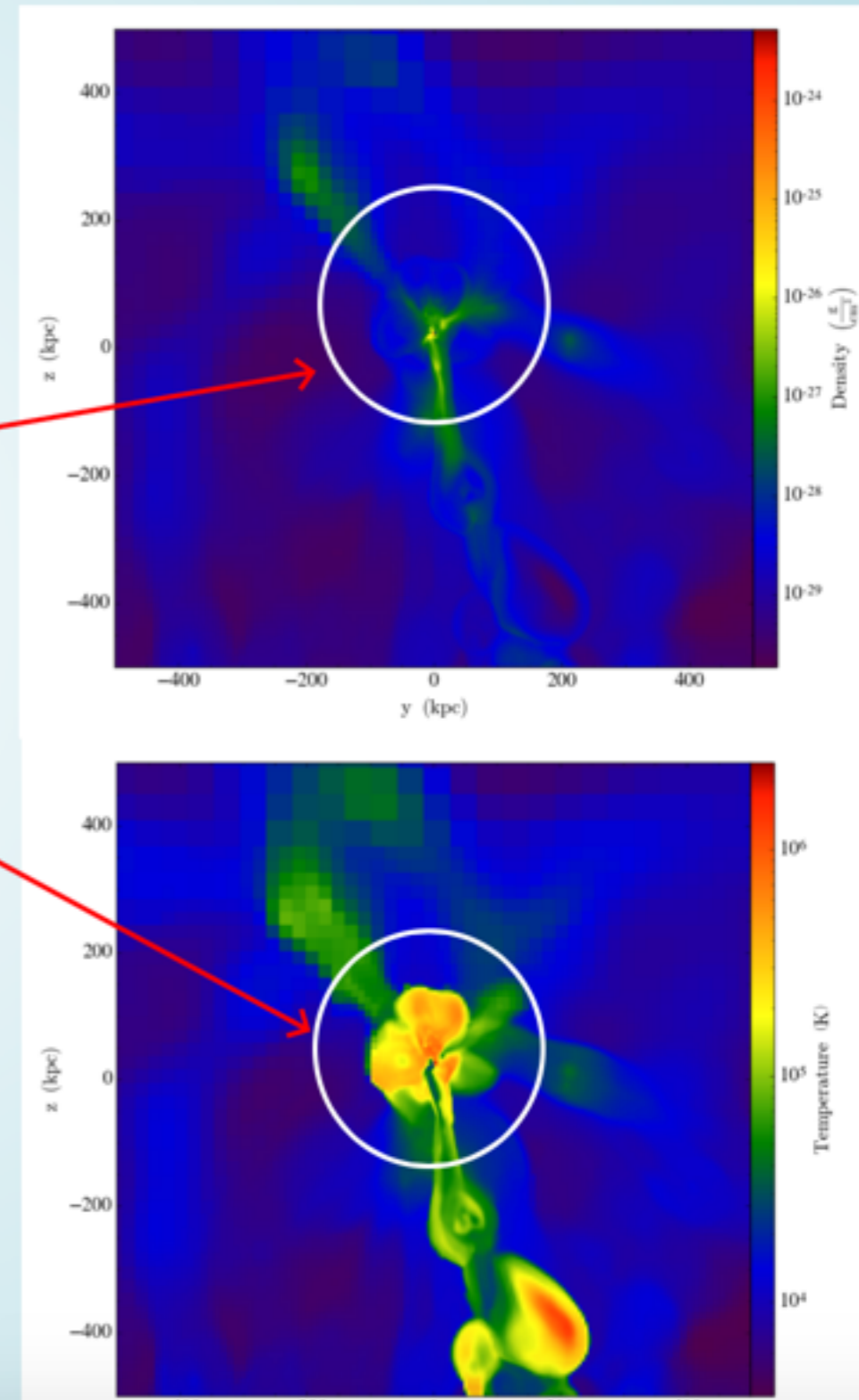
High Resolution simulations of cold gas flows in a cosmological box

Simulation with new refinement criteria

New refinement criteria:

- Geometrical limits ($2 R_{\text{vir}}$)

Required spatial resolution $< \sim 10$ pc

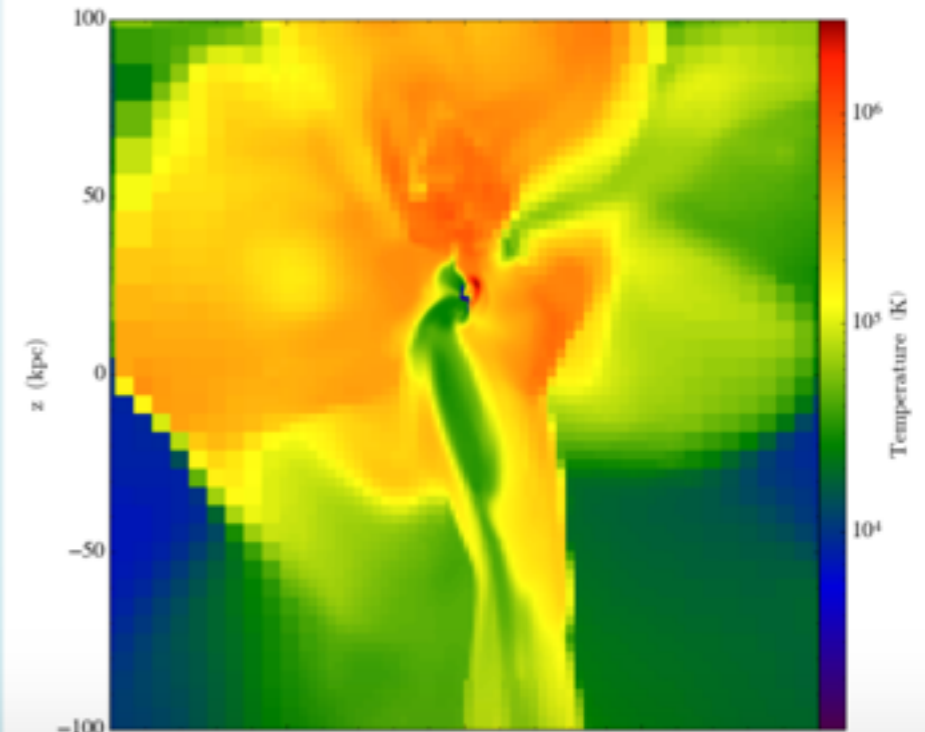
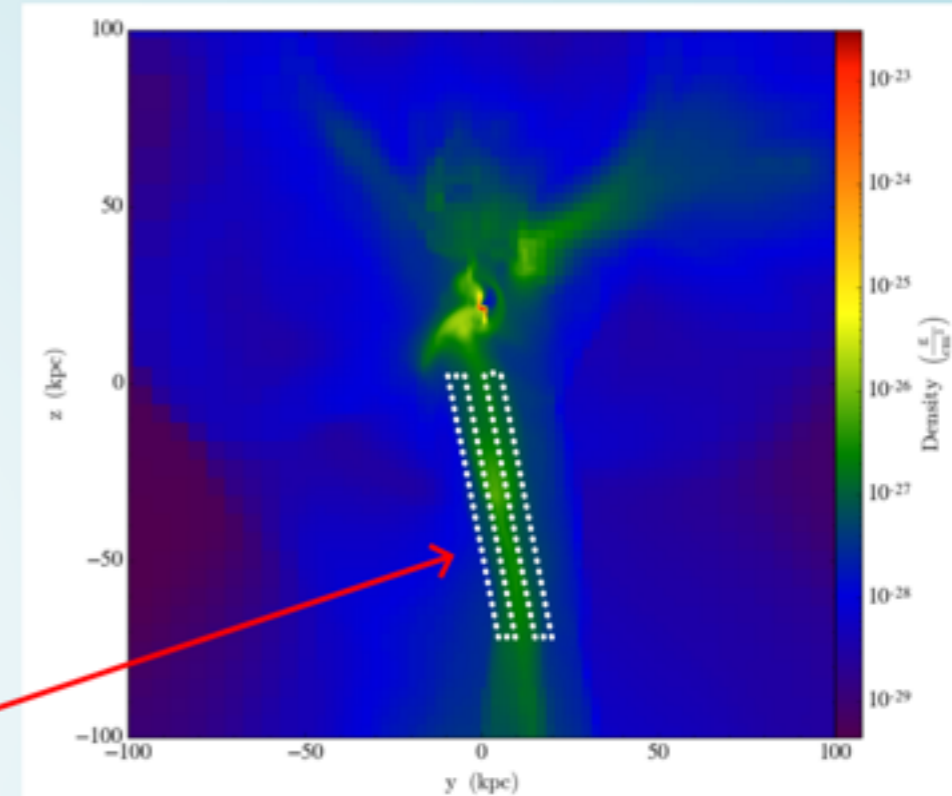


High Resolution simulations of cold gas flows in a cosmological box

Simulation with new refinement criteria

New refinement criteria:

- Geometrical limits ($2 R_{\text{vir}}$)
- Top/low limit in density gradients (refinement in cold flow walls)



Required spatial resolution $< \sim 10$ pc

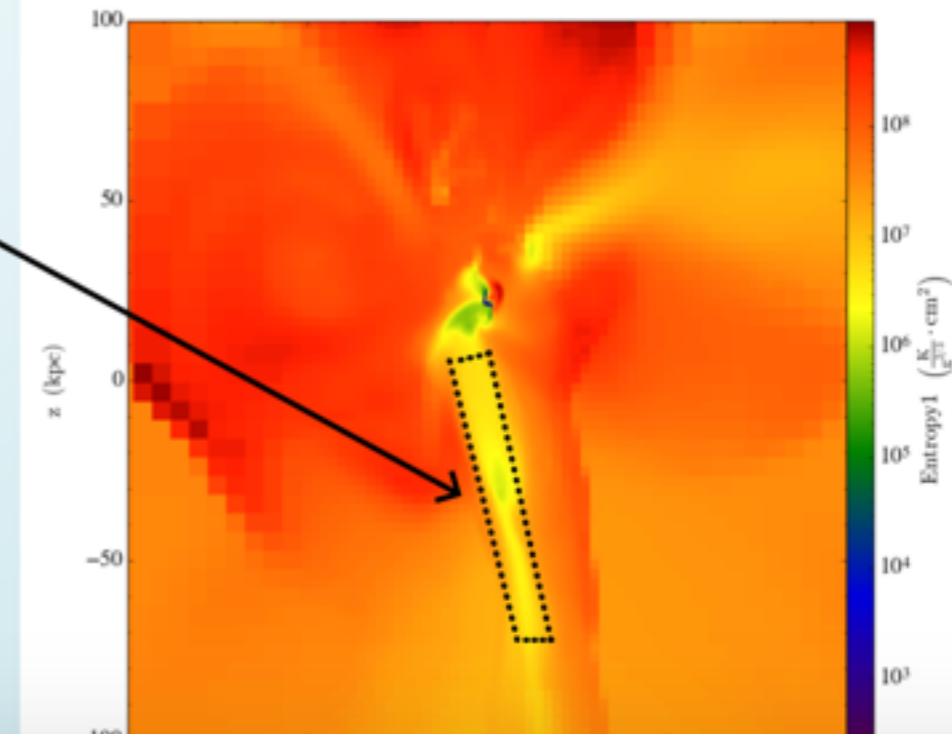
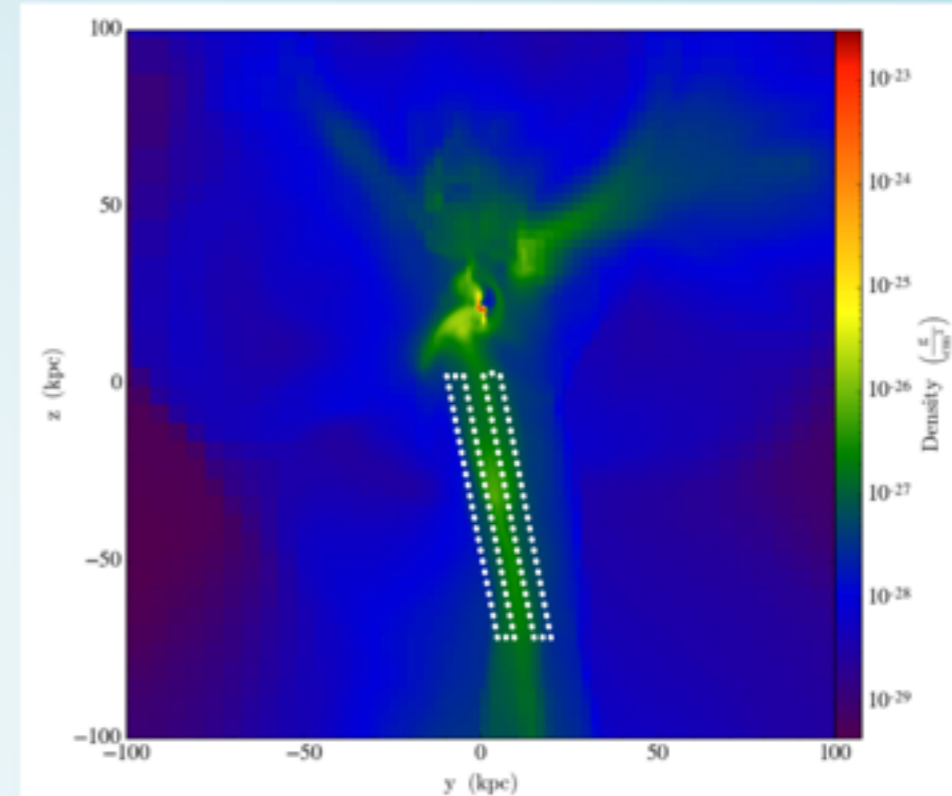
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Simulation with new refinement criteria

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- Top limit in entropy (refine central region of the filament)

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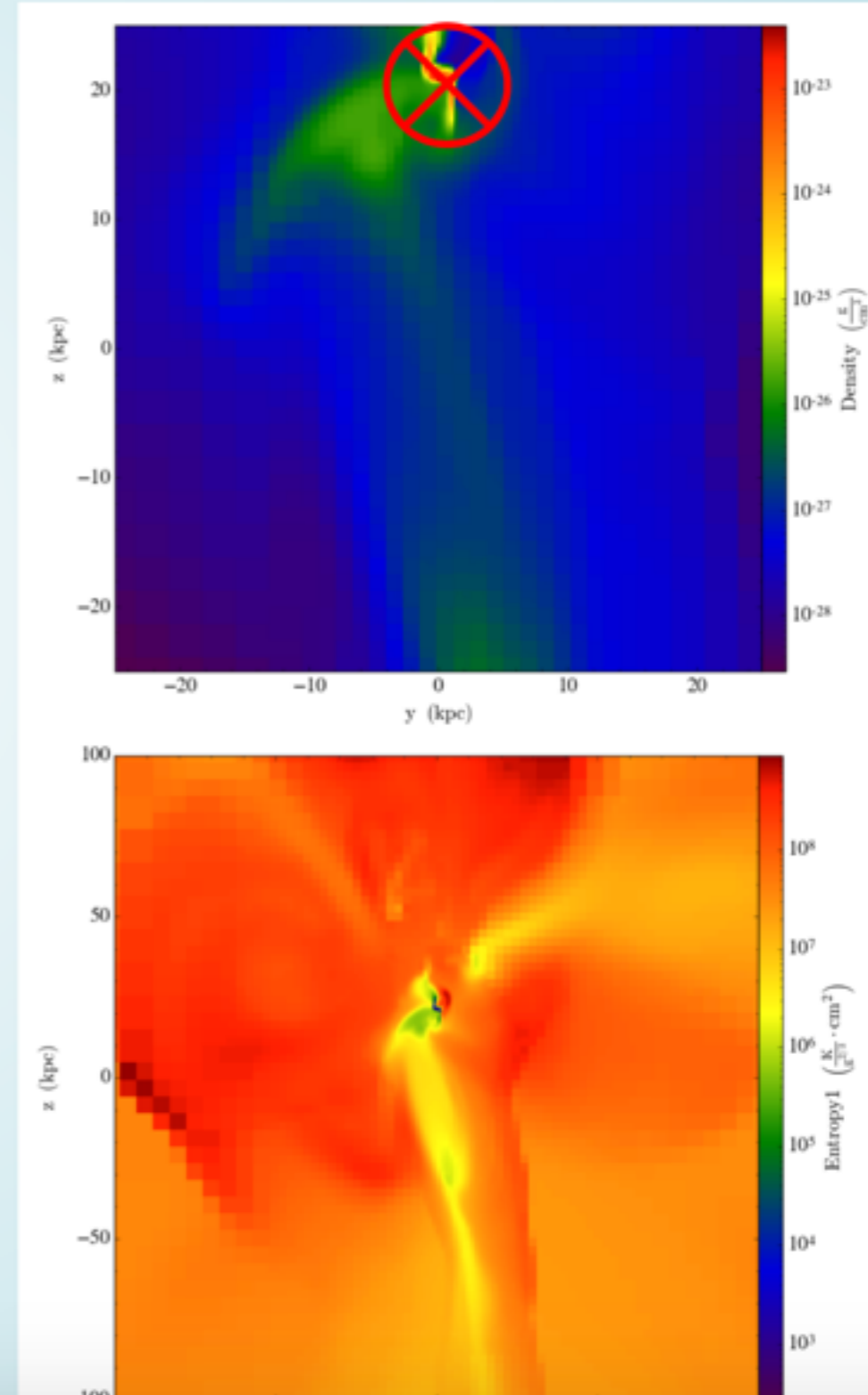
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- Top limit in density (no refinement in central galaxy region)

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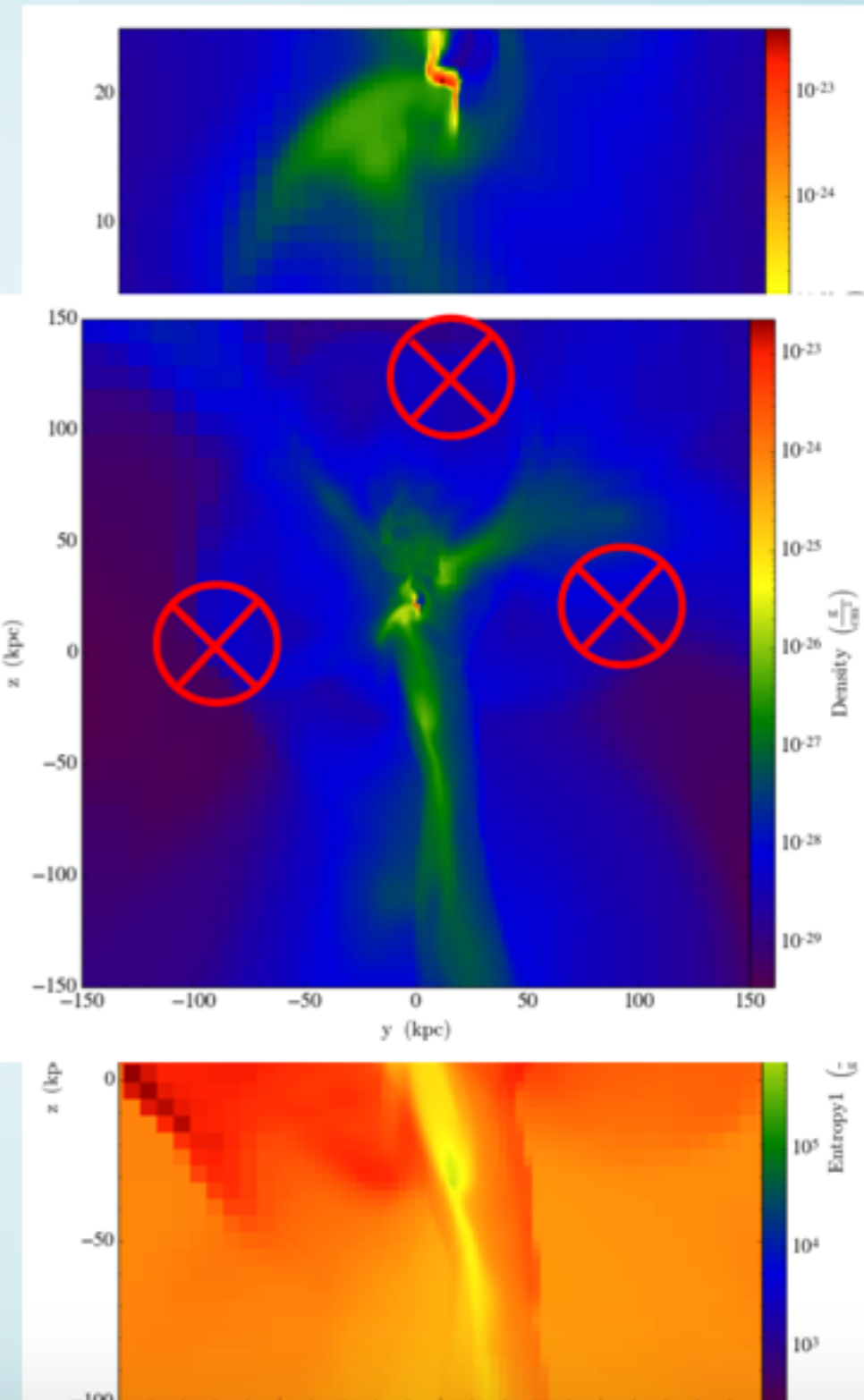
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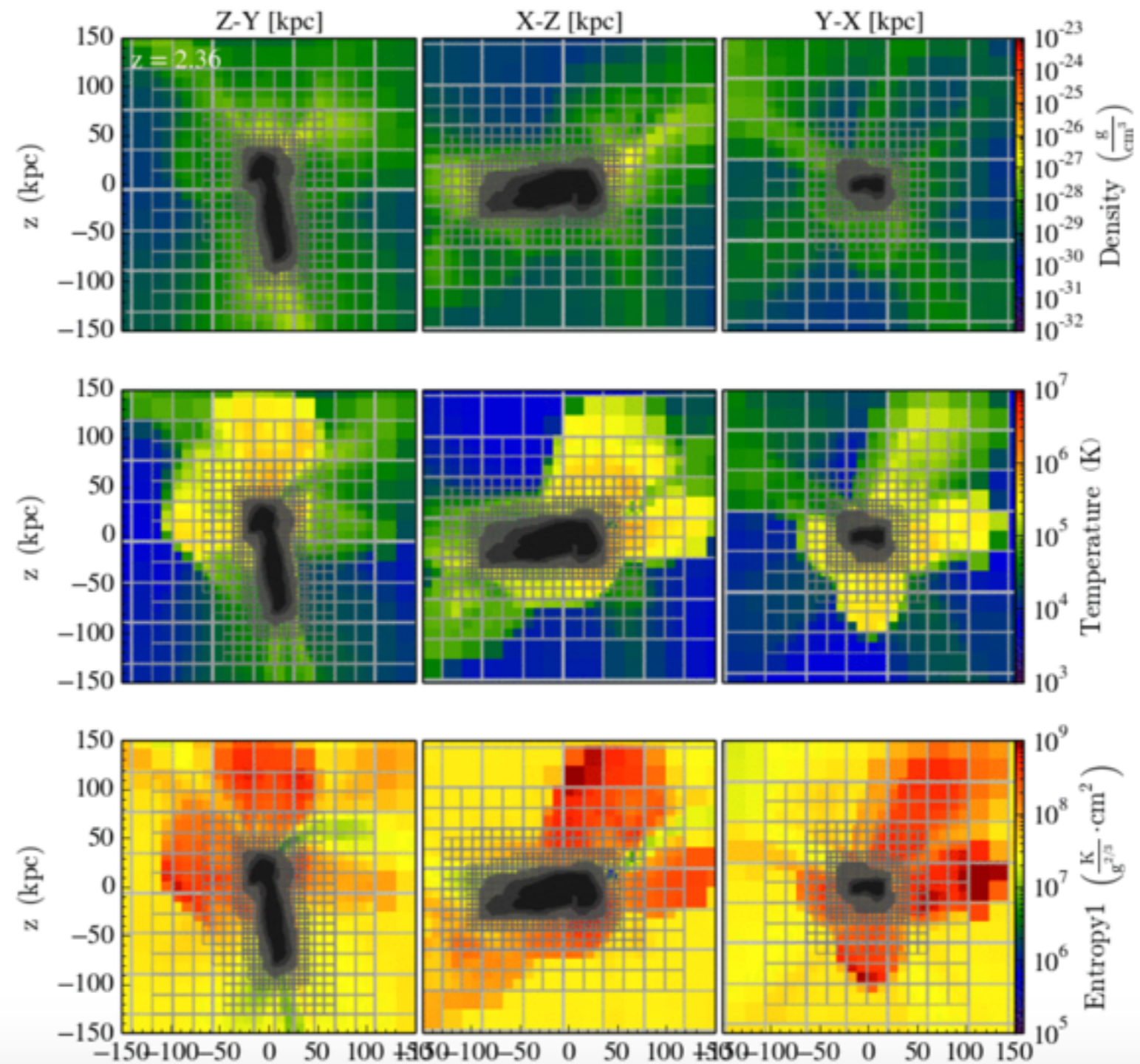
- Geometrical limits ($2 R_{\text{vir}}$)
- Top/low limit in density gradients (refinement in cold flow walls)
- Top limit in entropy (refine central region of the filament)
- Top limit in density (no refinement in central galaxy region)
- Low limit in density (no refinement in CGM)

Required spatial resolution $< \sim 10$ pc



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Results



High Resolution simulations of cold gas flows in a cosmological box

Next steps

- Increase the spatial resolution up to 10pc or more (**CRITICAL to properly simulate instabilities!**)
- More halos and more massive (**to have statistics and different scenarios**)
- Begin the analysis, following Mandelker et al. 2016

Simulating VELA models up to $z=0$ using RAMSES

Goal

- Get models of VELA galaxies using RAMSES code, up to $z=0$, and using SNe + BH + AGN.

Motivation

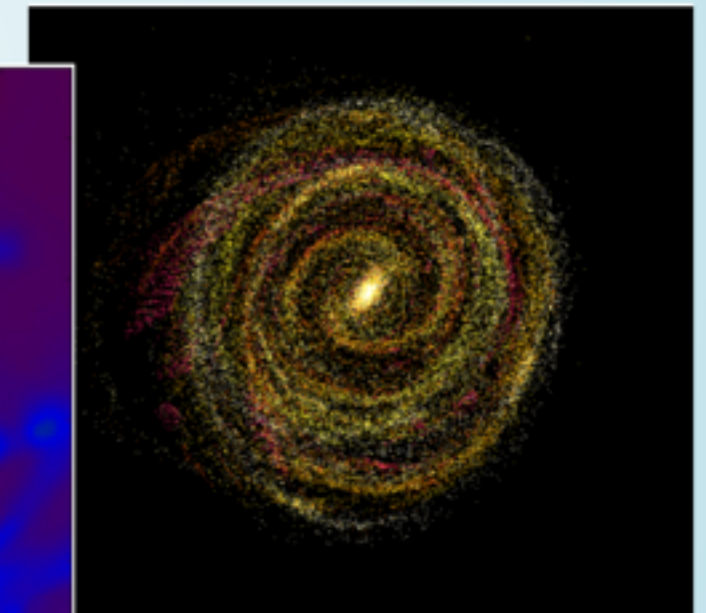
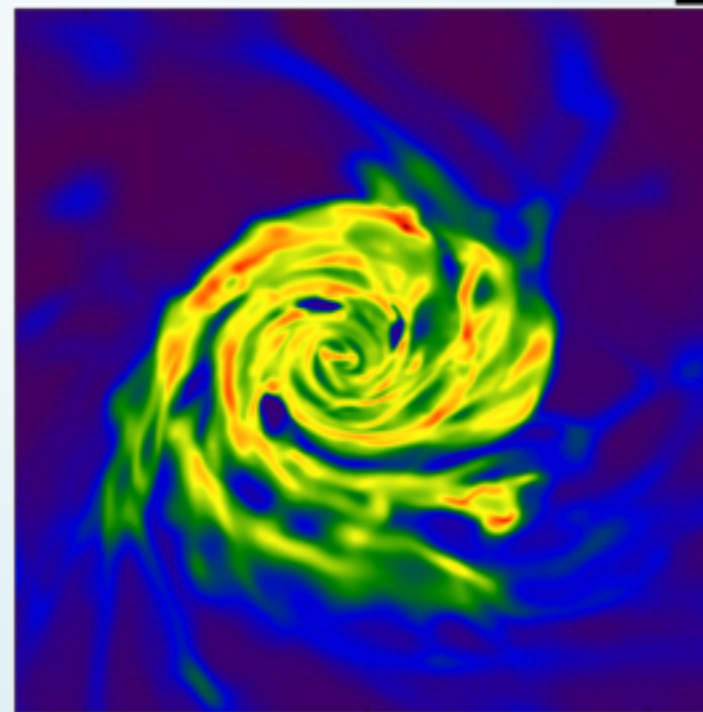
- The group in Jerusalem + collaborators have a deep knowledge of the 35 VELA galaxy models (run using ART by D. Ceverino, with different SNe feedback recipes).
- ART is not very well parallelized, very difficult to reach $z=0$ with high resolution when simulating massive galaxies.
- Several properties of external galaxies can only be observed at low redshifts (0-0.5), e.g. cool/hot CGM.

Simulating VELA models up to $z=0$ using RAMSES

How to proceed?

- Convert full ART-VELA initial conditions to RAMSES?
- Convert DM-only ART-VELA initial conditions to RAMSES and then add baryons independently?
- Convert the first time step?

Does it has been done before?



Thank you!

GARROTXA models (Roca-Fabrega et al 2016)