EXPLORING FORMATION AND EXPANSION OF THE ANCIENT COLD FRONT IN PERSEUS GALAXY CLUSTER

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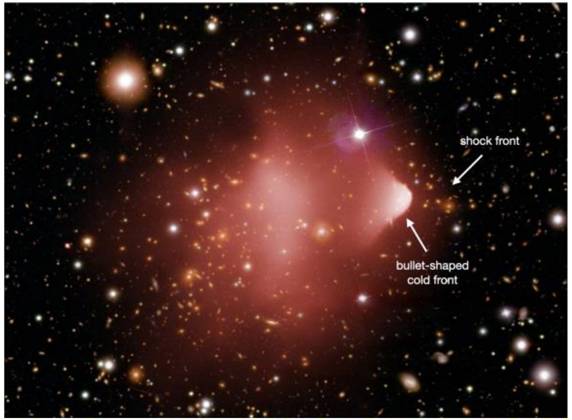
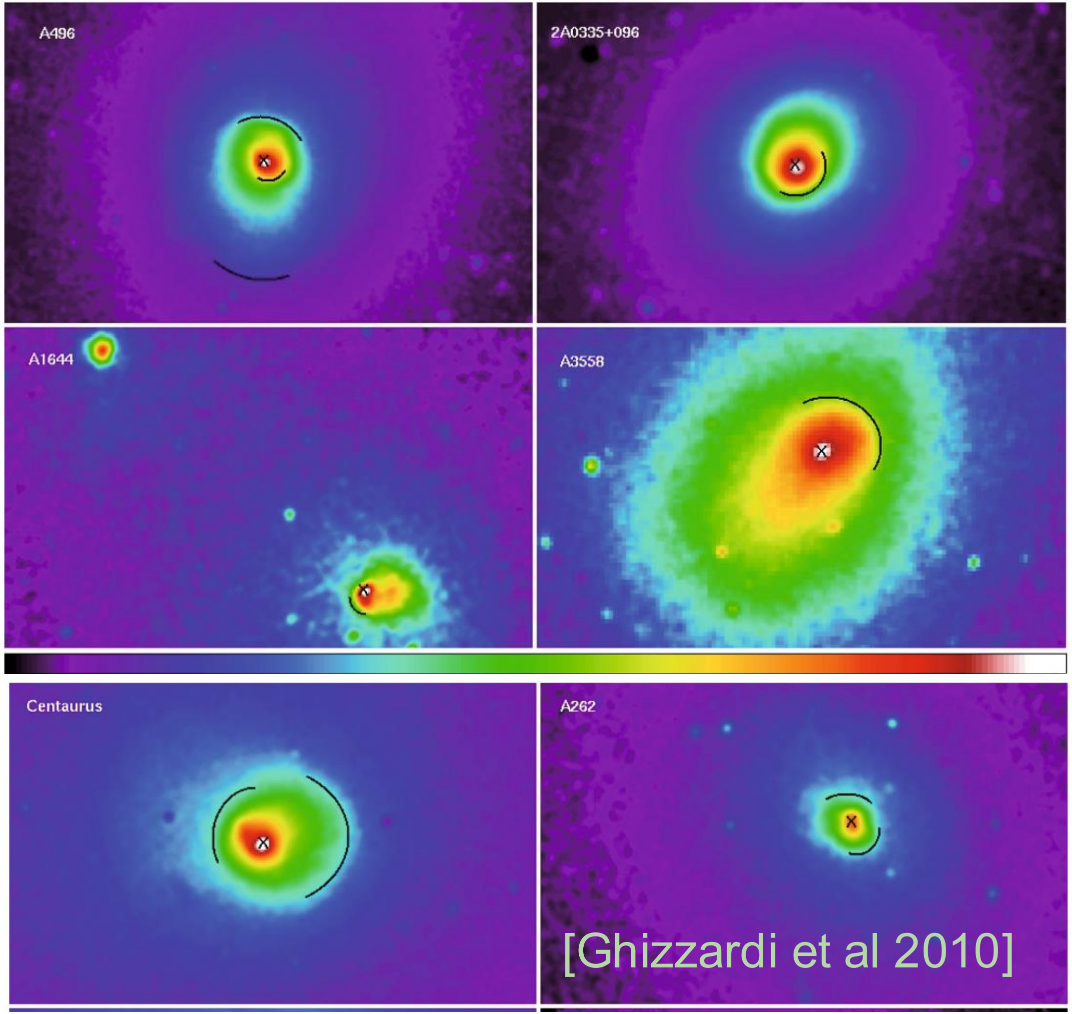
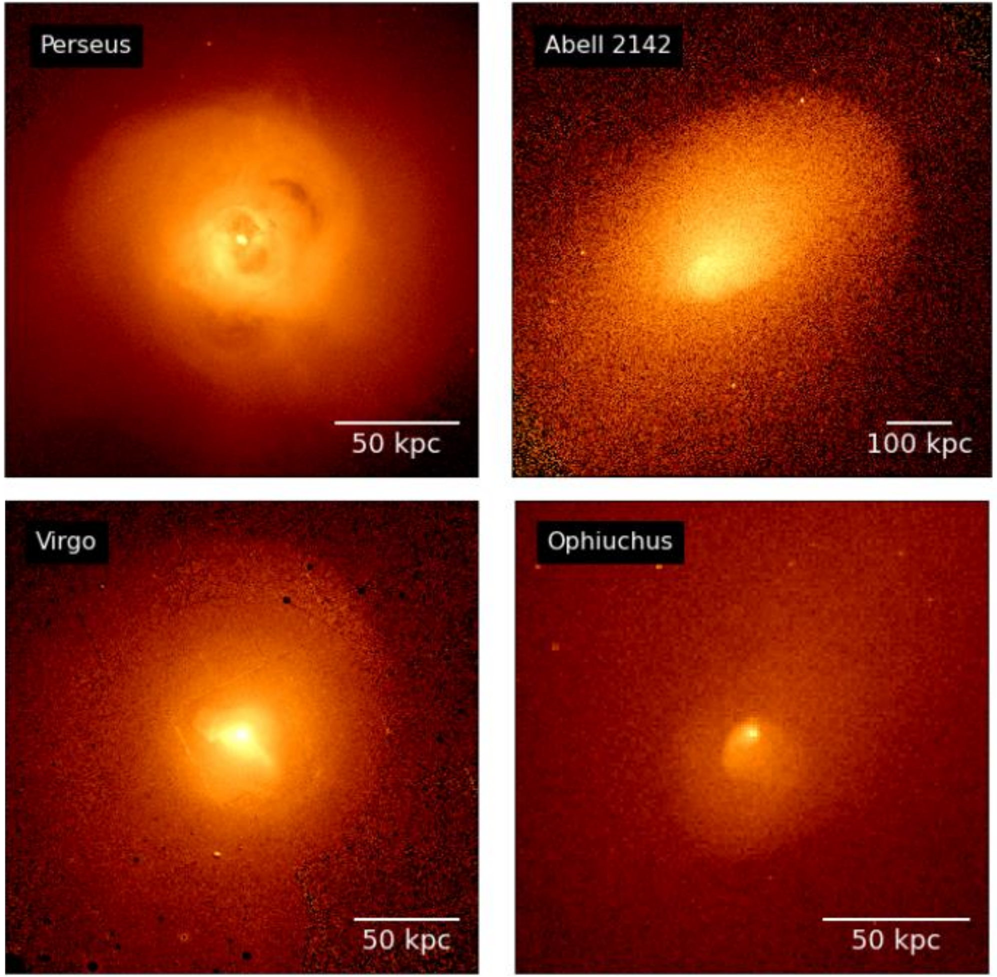
Cold Fronts are ubiquitous

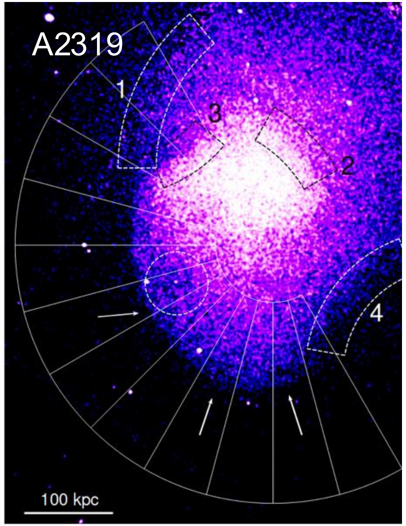


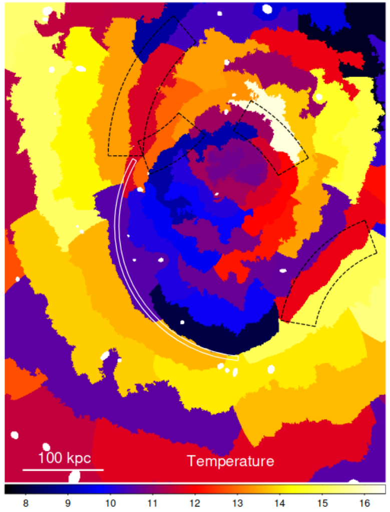


Sloshing cold fronts

- Spiral shaped cold front
- Observed in many galaxy clusters
- Promptly created in simulations of mergers (perturbation due to a subcluster)
- Due to gas sloshing in gravitational potential







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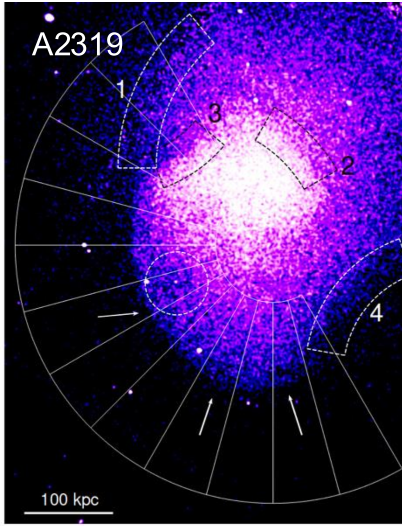
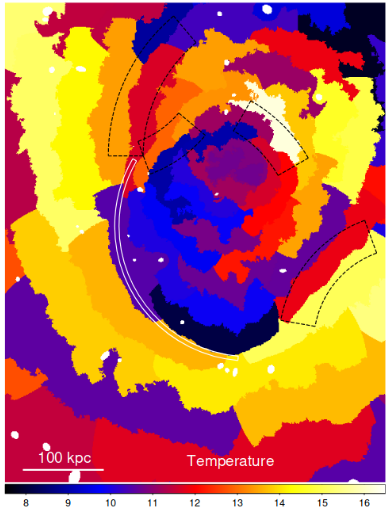
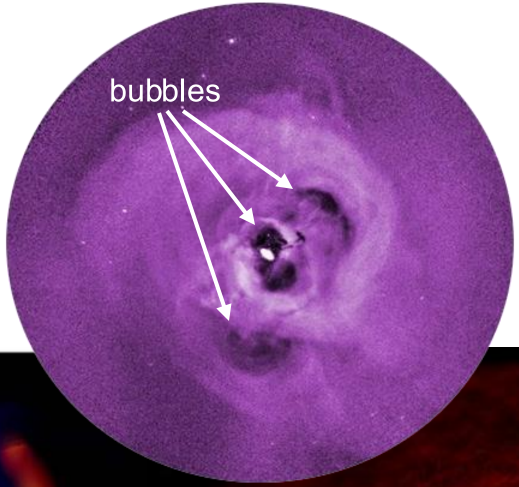


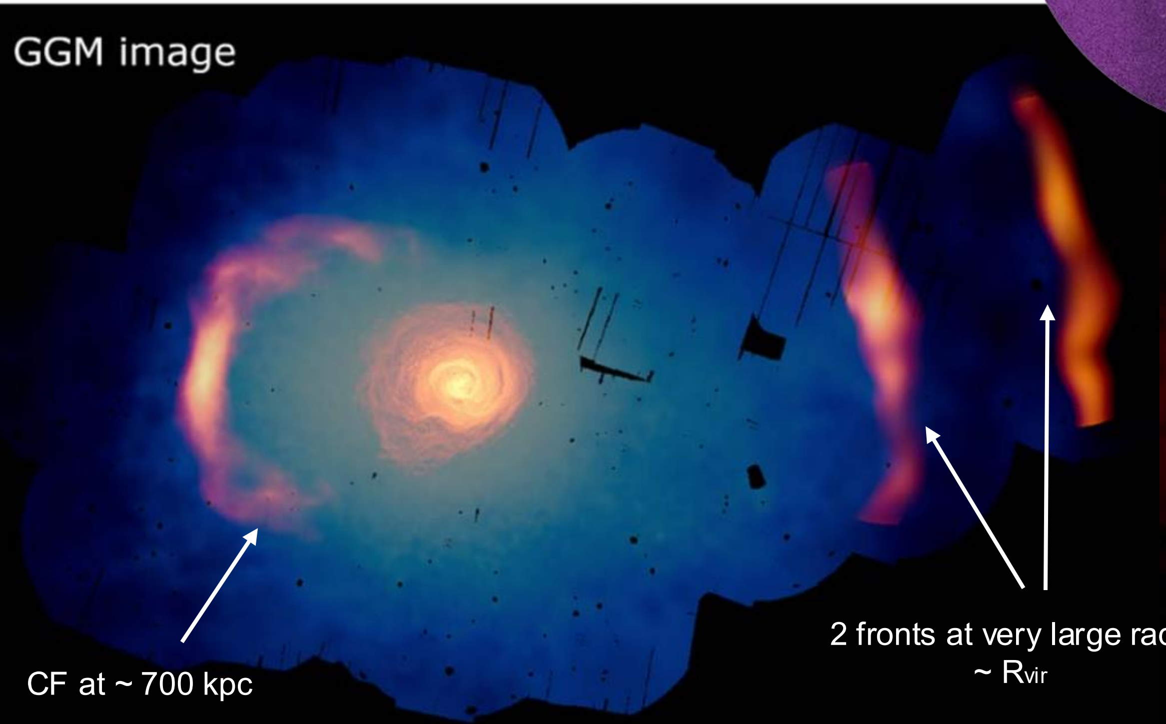


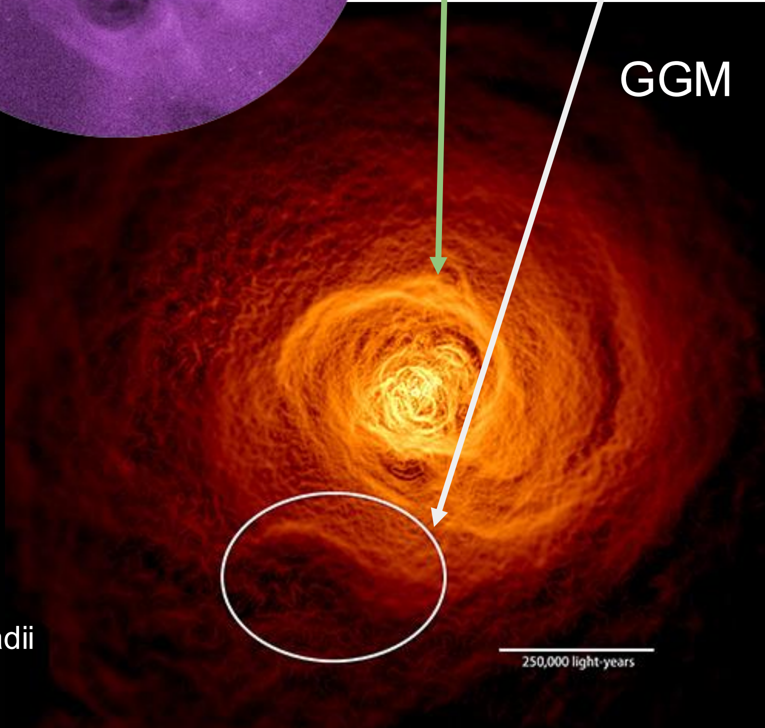
Perseus

The brighter galaxy cluster in X-ray

A **richness of features** appear

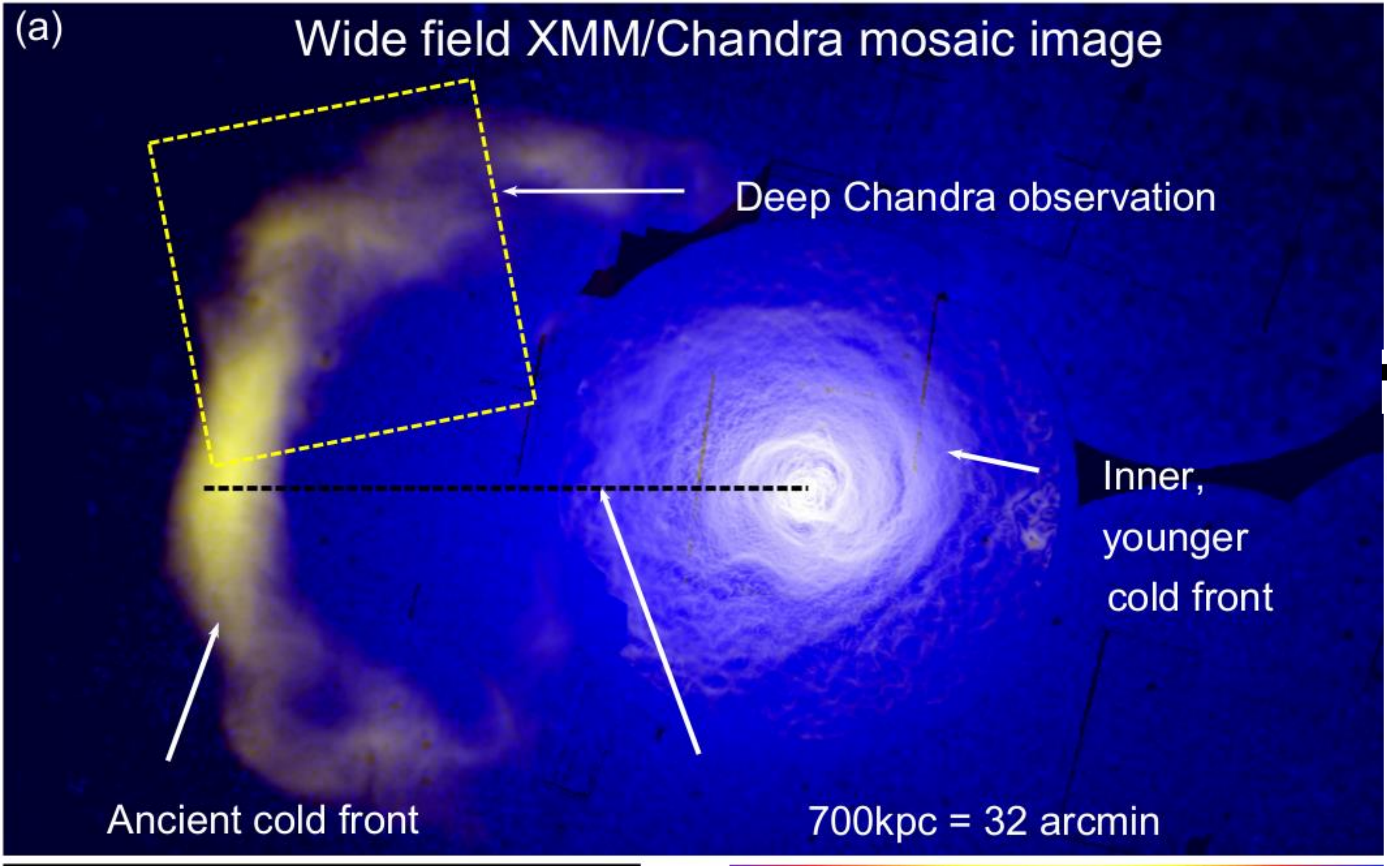


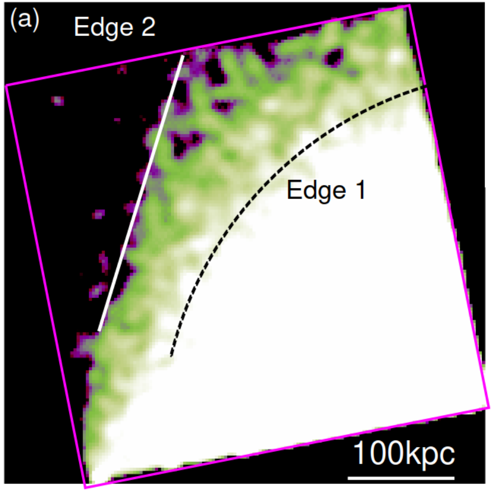




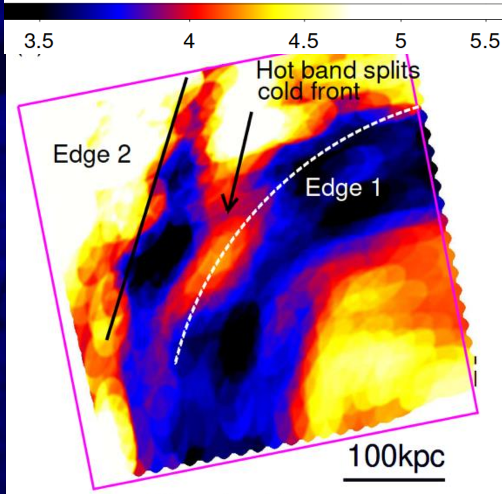
Large-scale CF in Perseus

[Walker et al 2016]



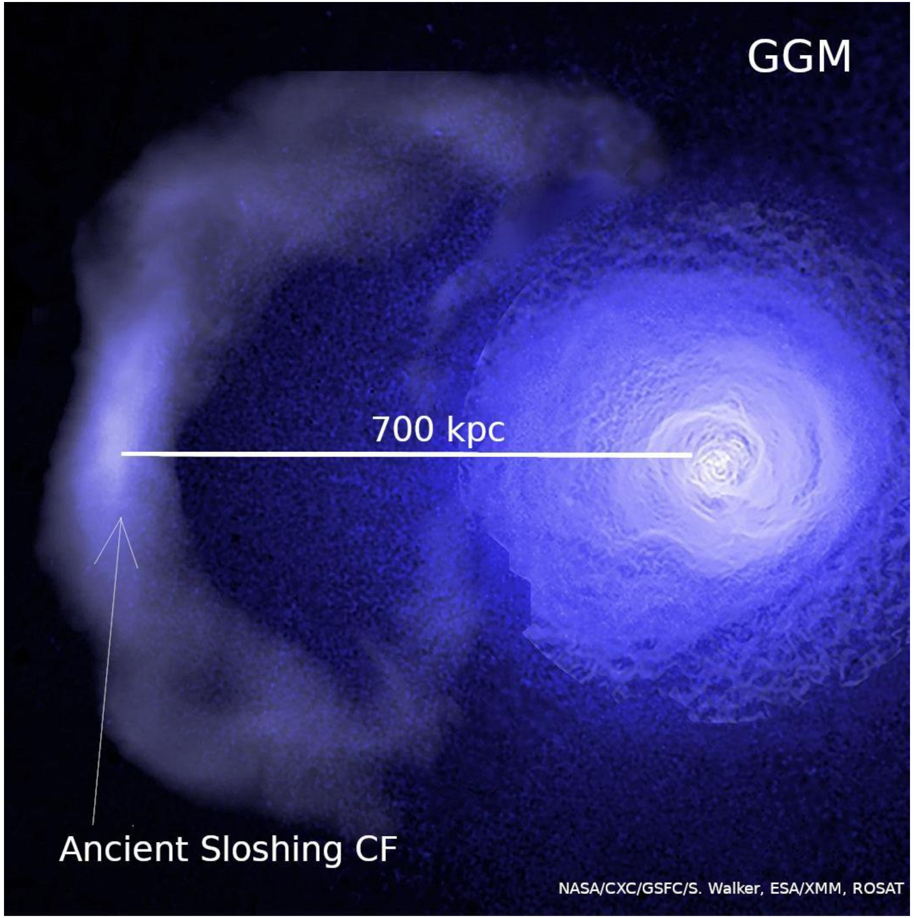


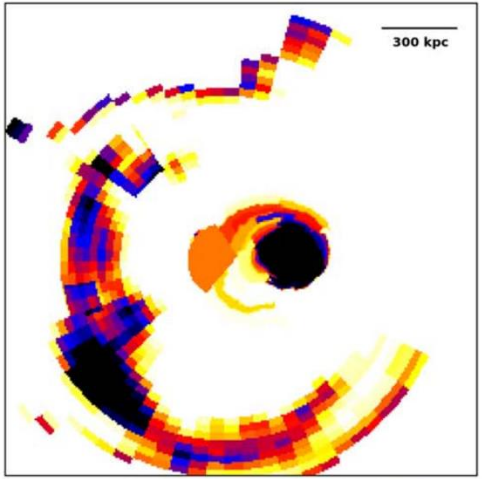
Deep Chandra observation

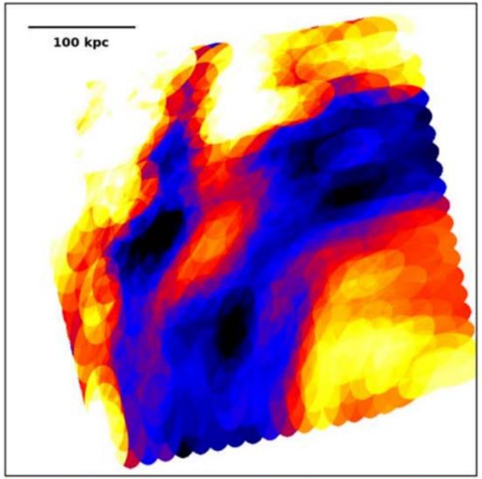


Chandra kT map

Perseus Large-Scale CF







What is required to create and sustain CF large radii?

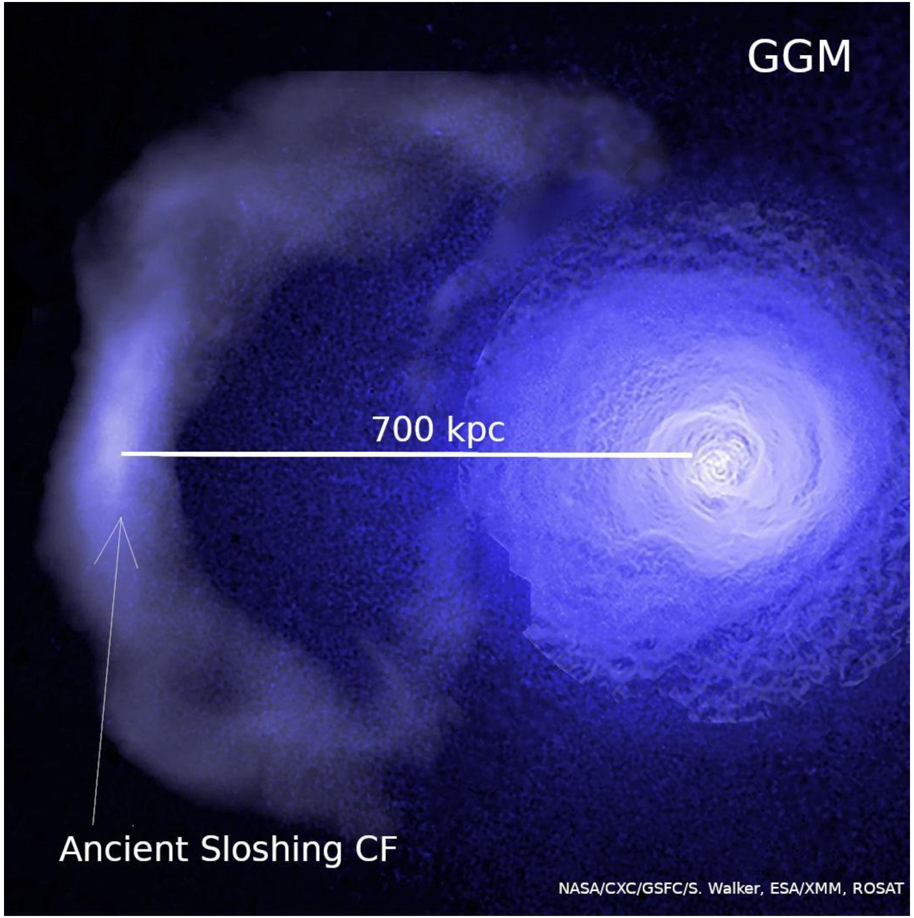
How old is that large scale cold front (CF)?

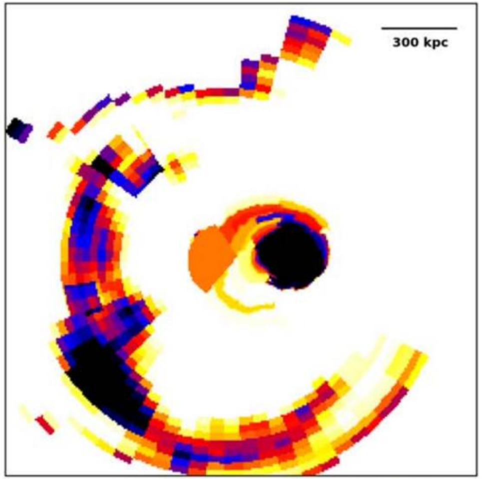
What prevents the disruption of the CF?

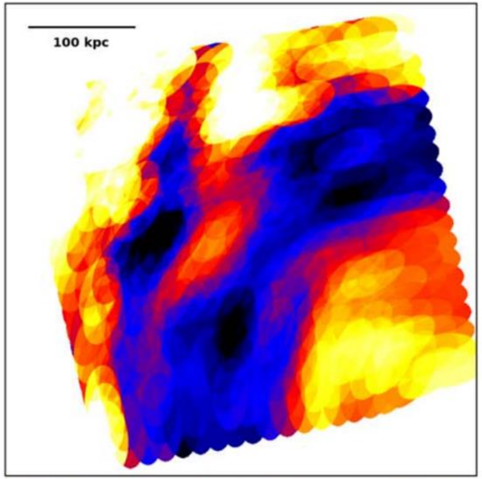
The subcluster is not readily apparent, but can the presence of this CF constraints on number of passages, subcluster position etc?

Where does the split in the temperature come from?

Perseus Large-Scale CF







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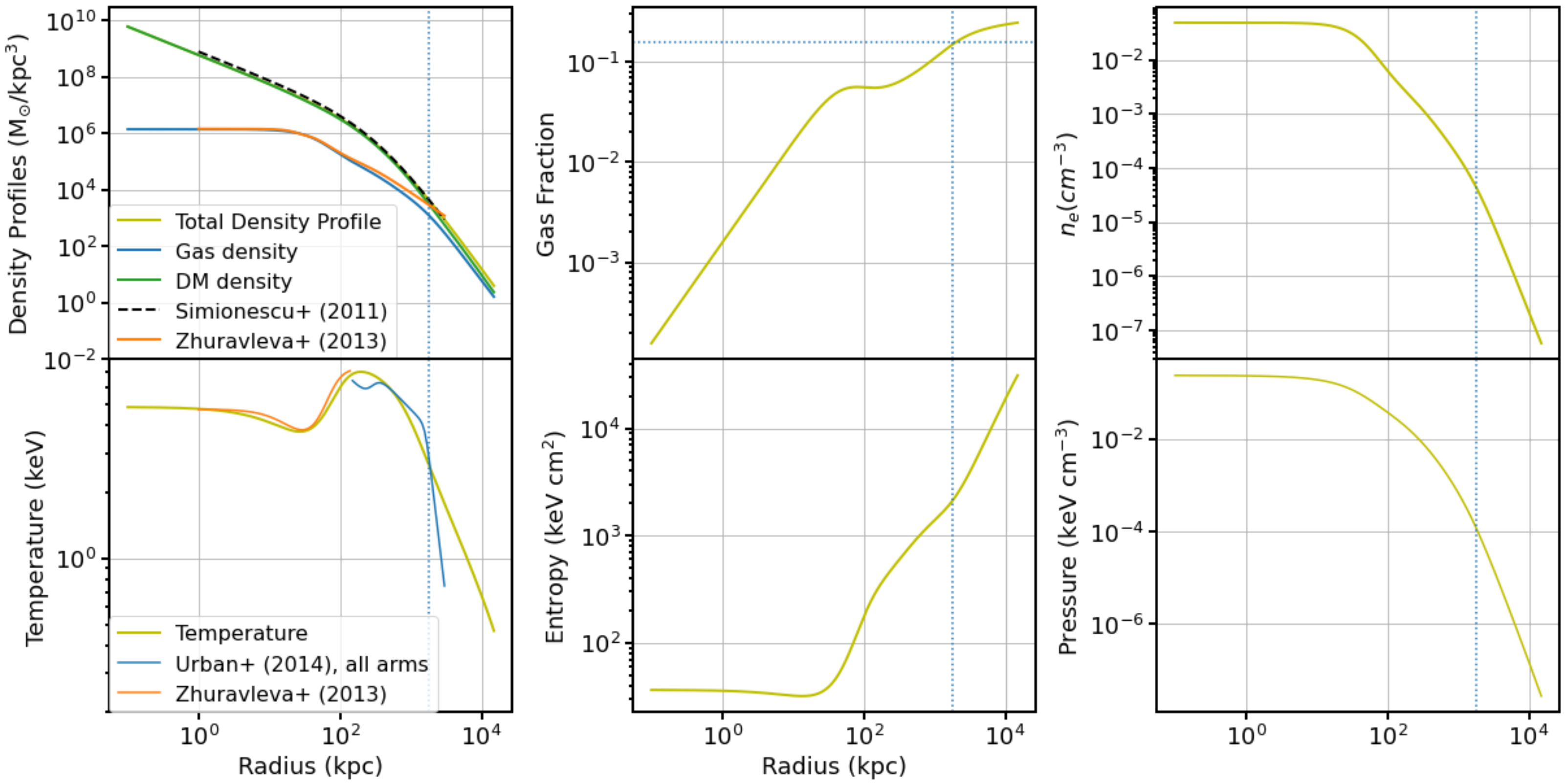
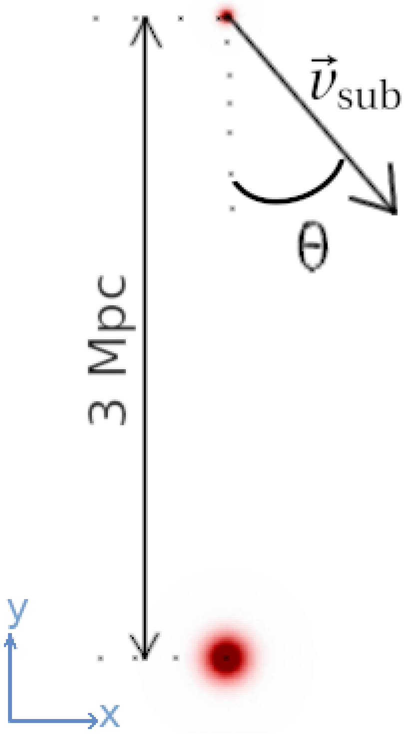
Perseus initial profiles:



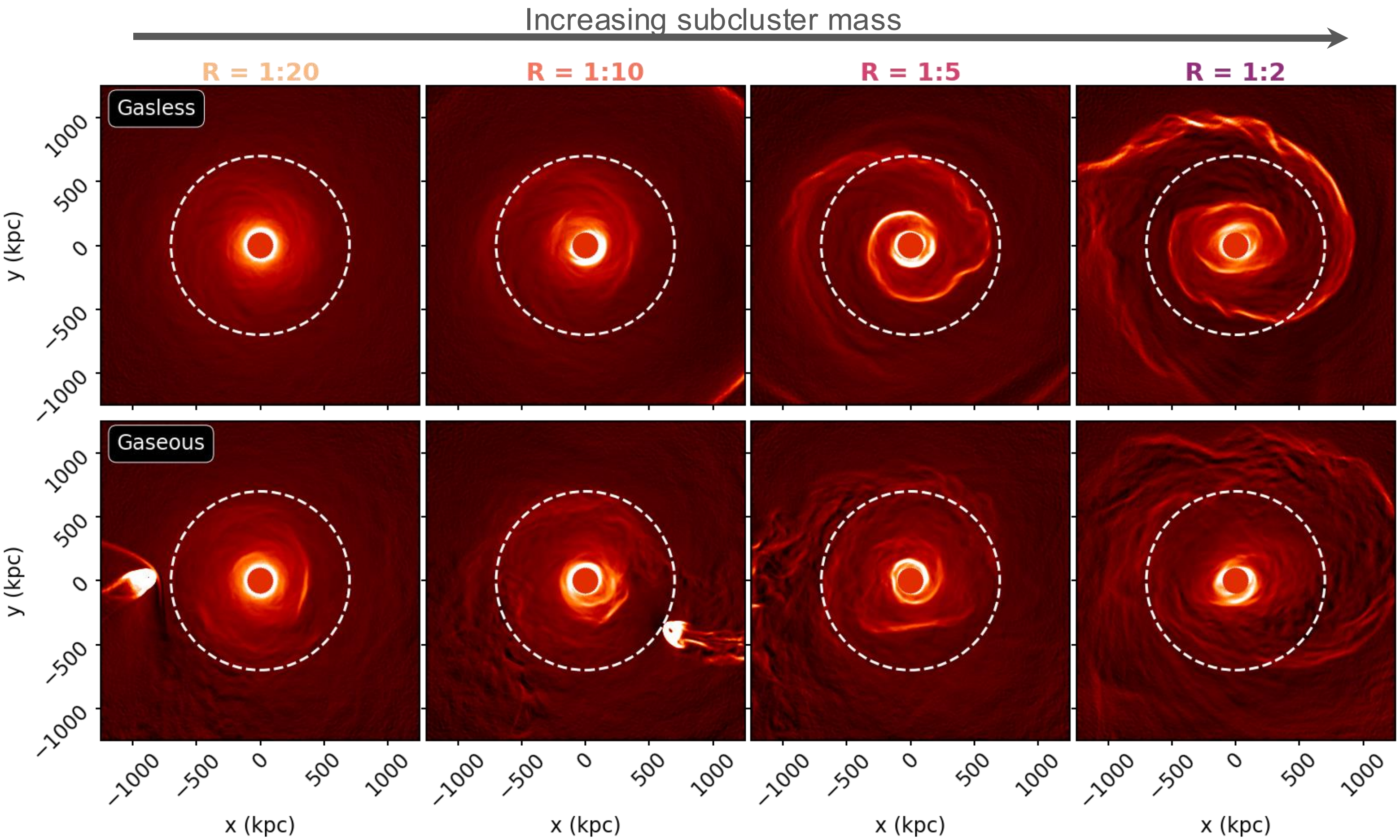
Set-up:



AREPO simulations
- isolated box
- fully ionized ideal fluid
- MHD $\beta = P_{th}/P_B$
- virialized DM halos

Physical Parameter	**Possible Values**
gas content of the gas	gaseous / gasless
mass ratio	R = 1:20, 1:10, 1:5, 1:2
incident angle	$\theta = 10^\circ,\ 20^\circ,\ 30^\circ,\ 40^\circ$
impact parameter	$3000\ \sin(\theta) \sim 529, 1092, 1732, 2517, 3575$ kpc
initial velocity	$v = v_{sub} = 1380,\ 1500,\ 2000$ km s^{-1}
magnetic field	$\beta = 100, 200, 1000$

The Effect of the Mass and the Gas Content:



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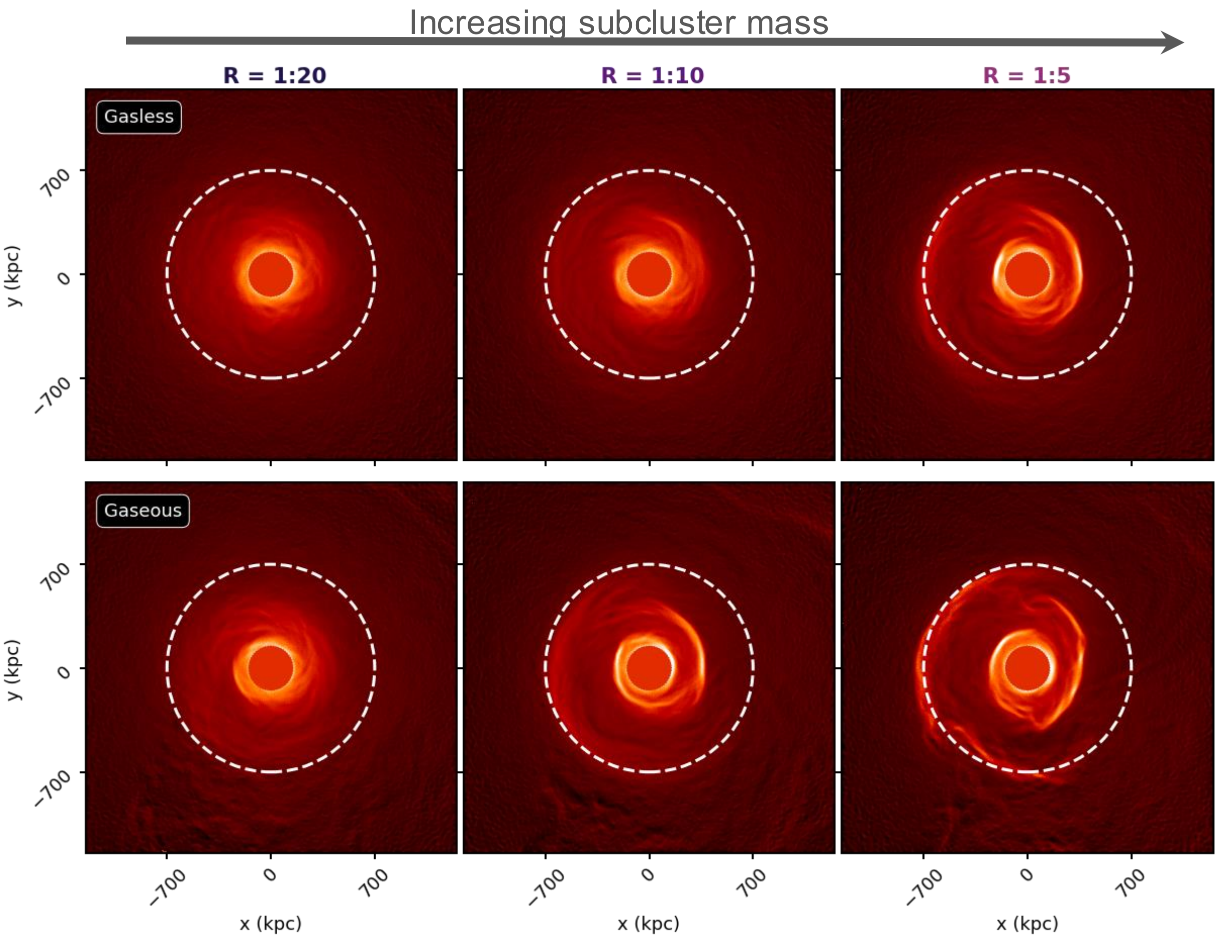
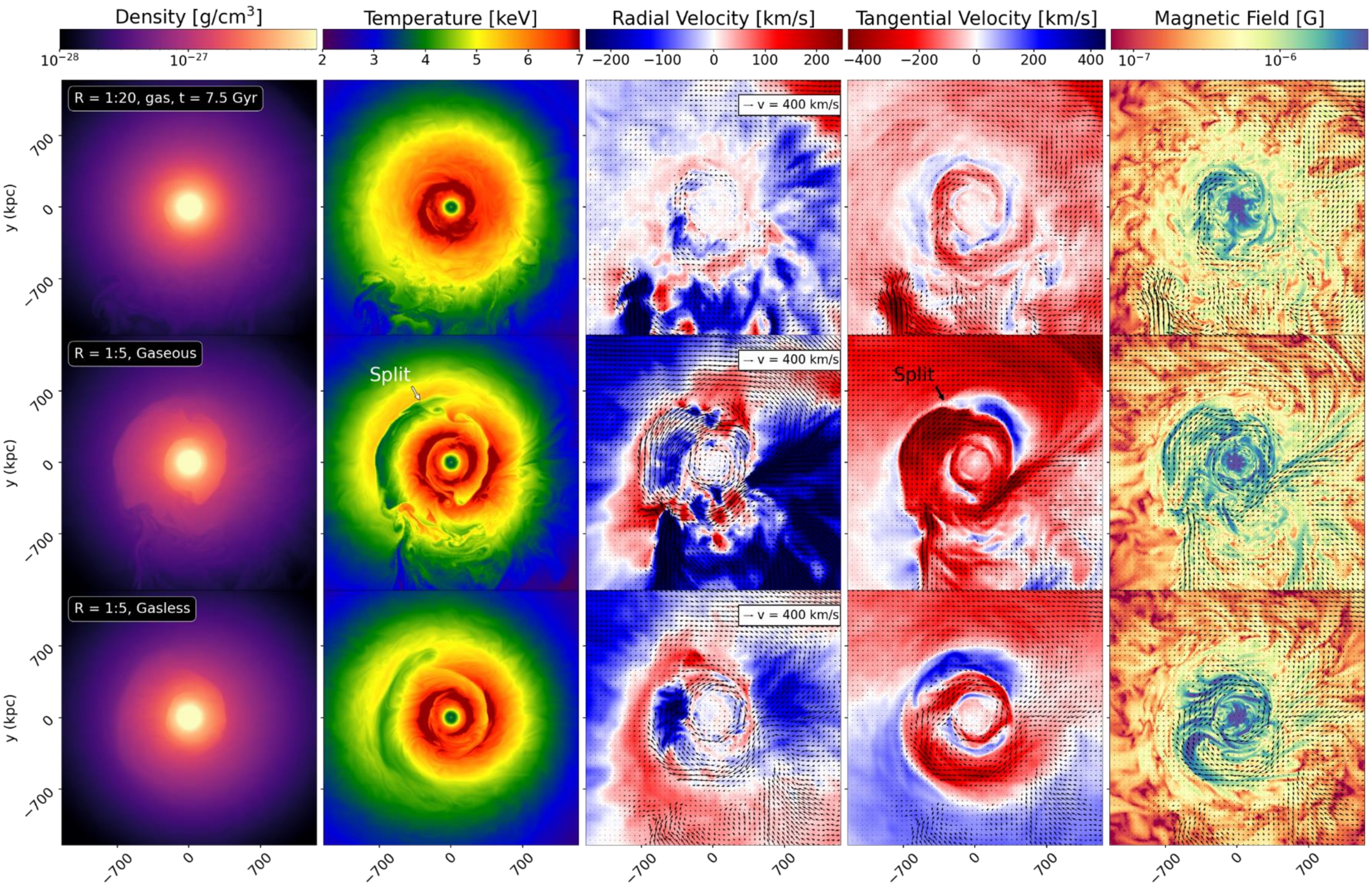
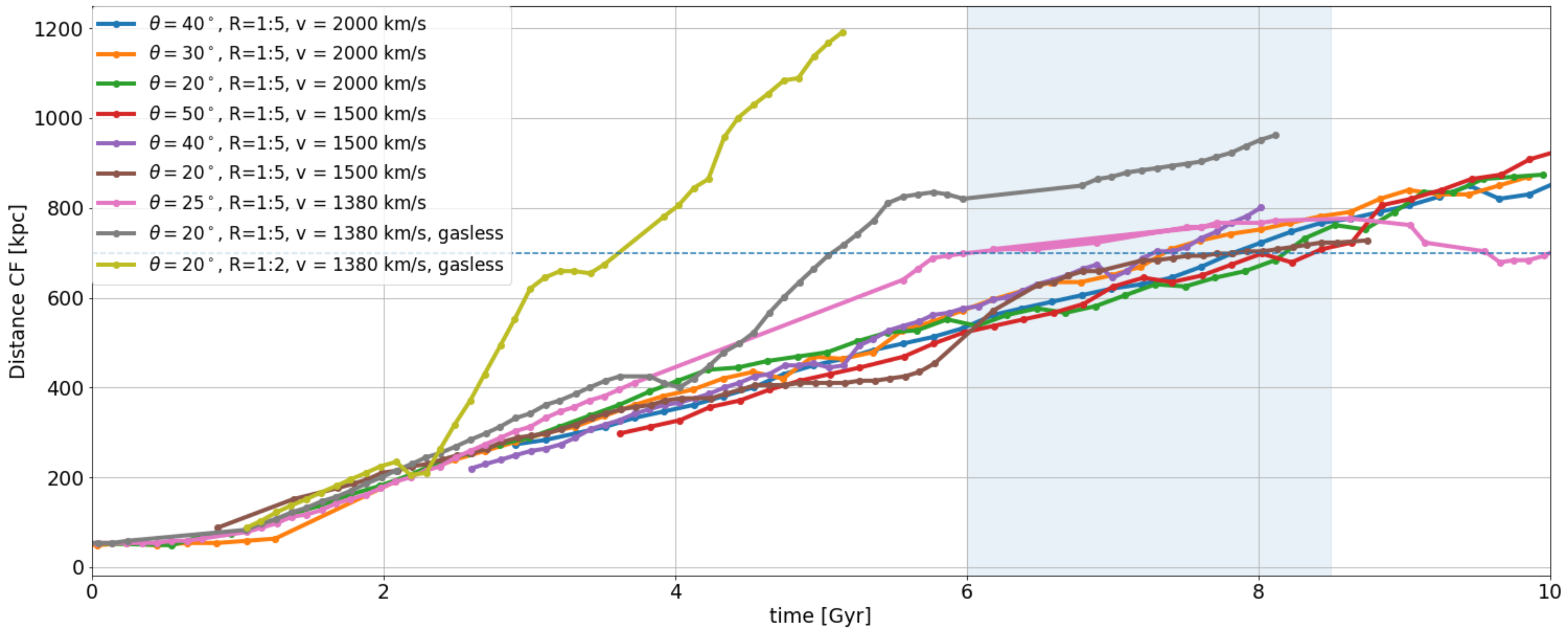


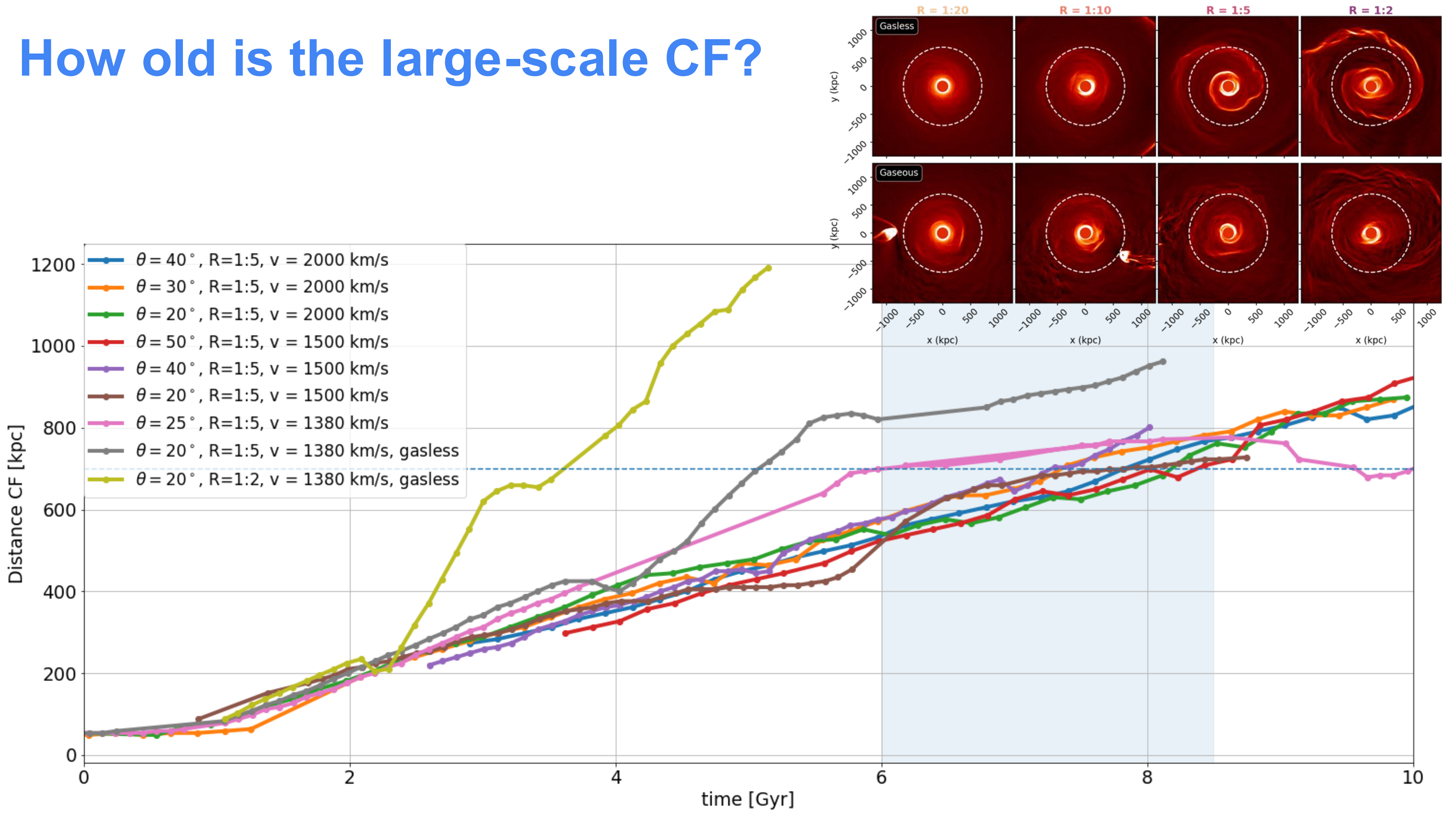


Density [g/cm^3]
10^{-28}
10^{-27}
Temperature [keV]
2
3
4
5
6
7
Radial Velocity [km/s]
−200
−100
0
100
200
Tangential Velocity [km/s]
−400
−200
0
200
400
Magnetic Field [G]
10^{-7}
10^{-6}
R = 1:20, gas, t = 7.5 Gyr
R = 1:5, Gaseous
R = 1:5, Gasless
Split
Split
→ v = 400 km/s
y (kpc)
700
0
−700

How old is the Large-Scale Cold Front?

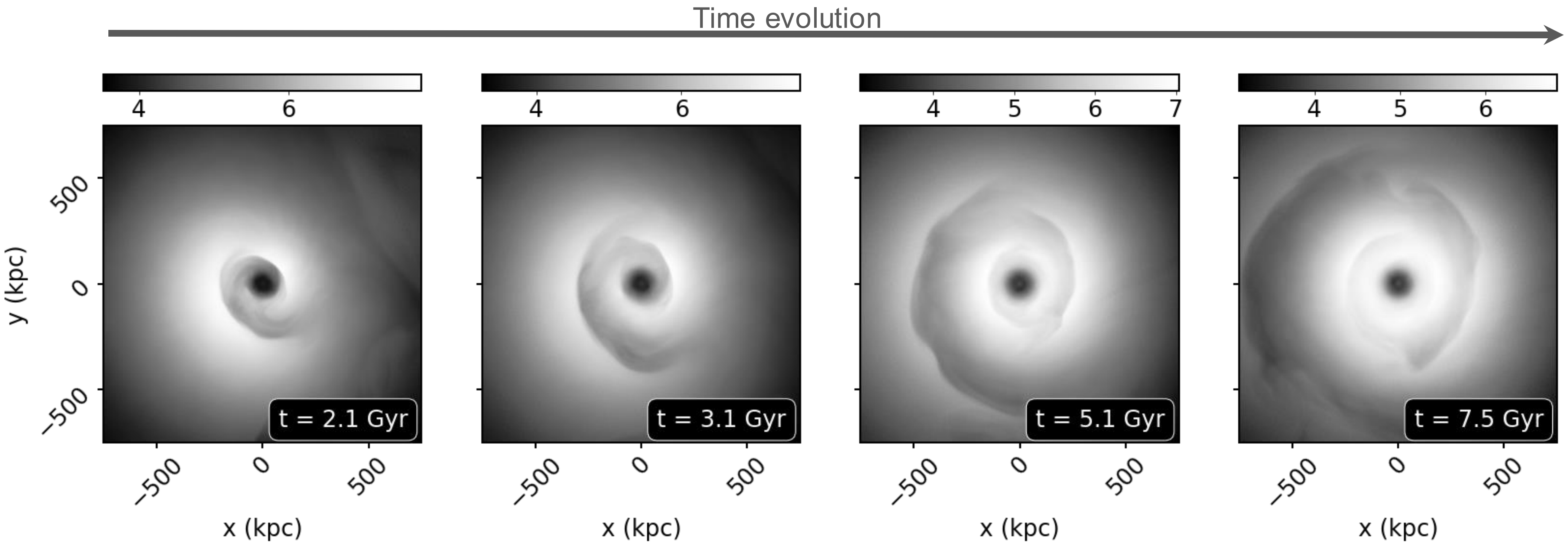


How old is the large-scale CF?



The Evolution of the Temperature Split

(R = 1:5, v = 2000 km/s)



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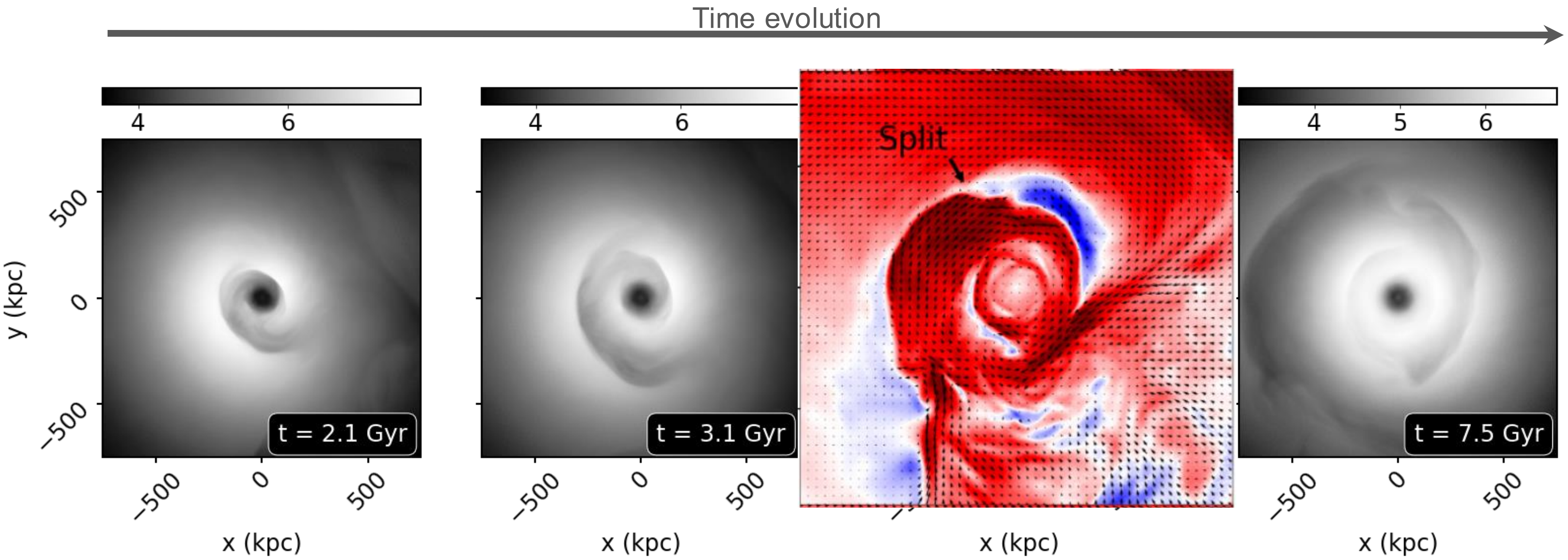
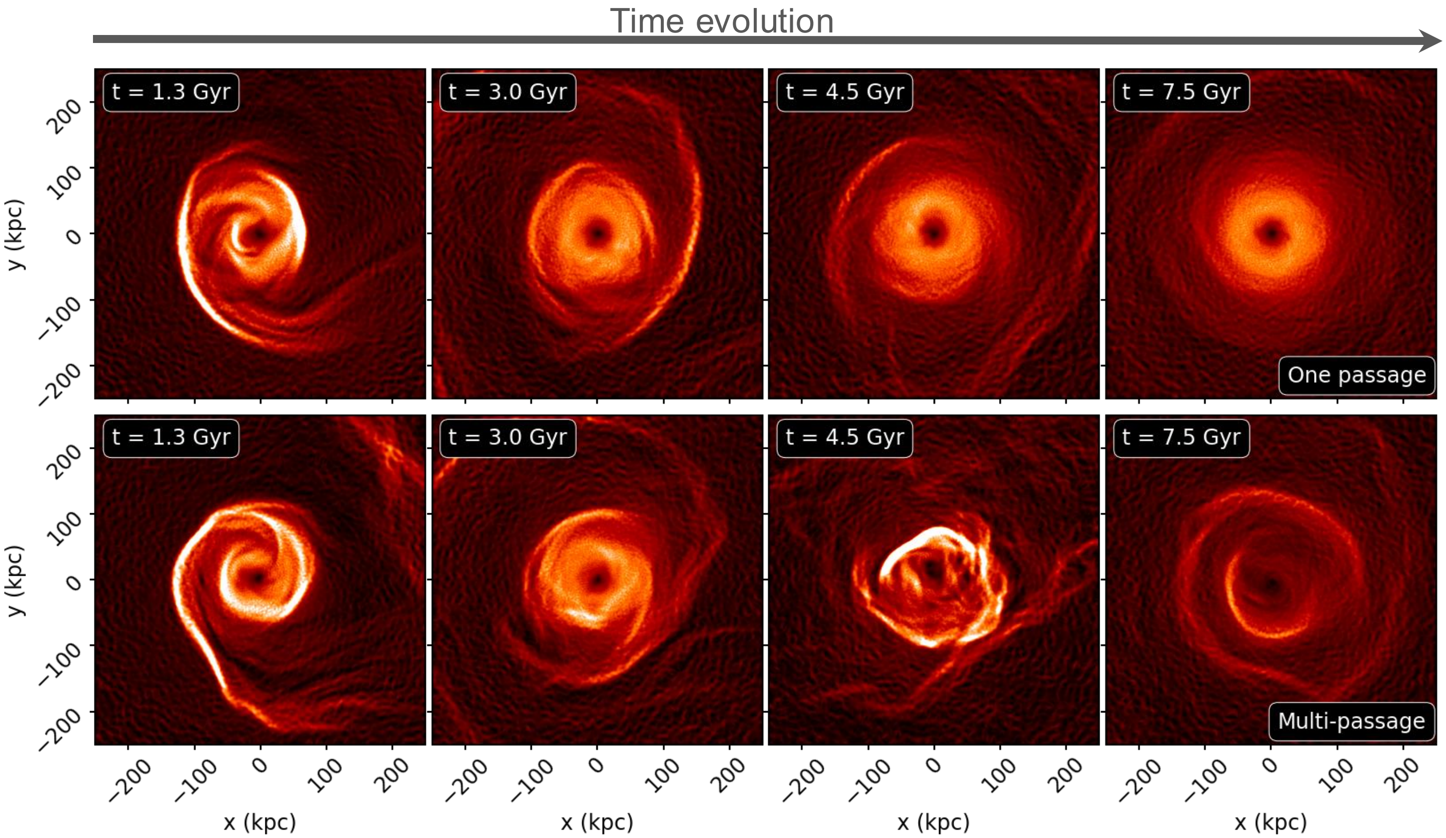


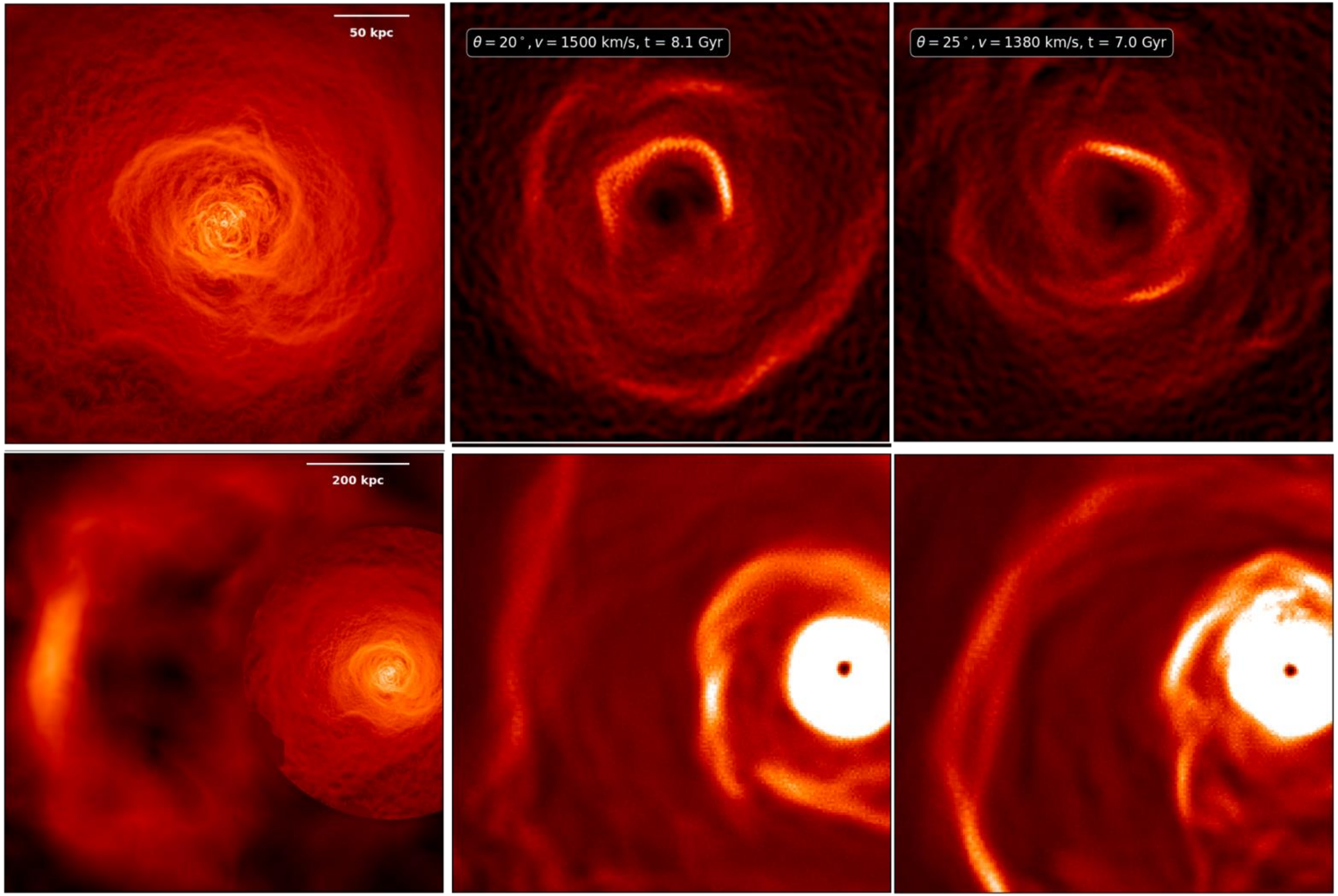
What happens in the center?



Comparison with Observations

Walker et al 2016

Walker et al 2018



Summary

➔ Perseus has multiple interesting features in X-ray (e.g. core CF, **large ancient CF, hot tongue**, fronts at large radii..)

➔ We performed a parameter study (AREPO) of a two-body merger

➔ **Mass and gas content** have big effect on CF existence, shape and position (larger mass = bigger jumps = more visible CF)

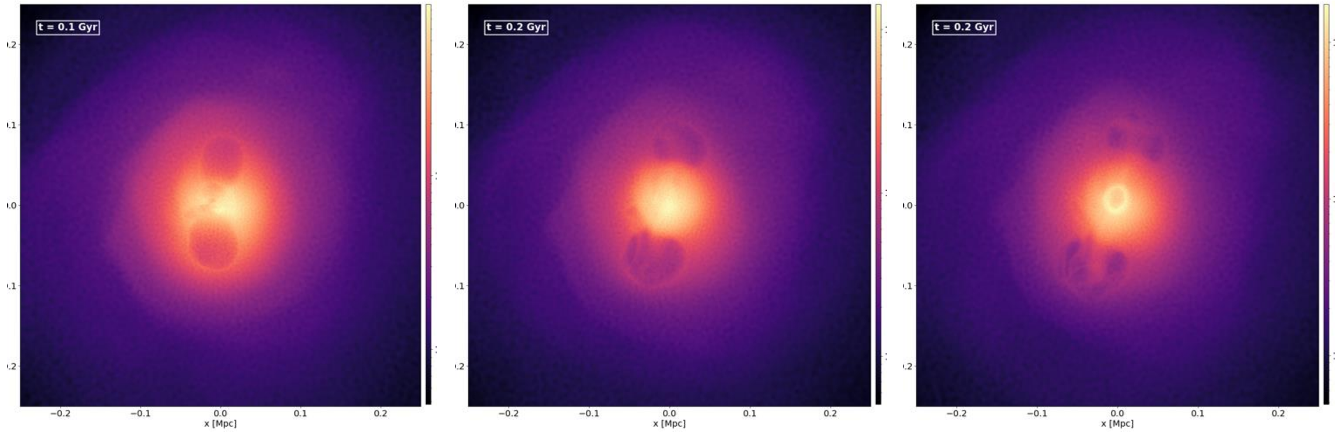
➔ Gaseous subcluster = stronger jumps in temperature and density, and more turbulence

➔ Multiple passages are more messy but one-passage sims cannot produce inner CFs and large-scale one

➔ Almost constant CF expansion speed (~100 km/s), independent of initial params unless multiple kicks

➔ Some sloshing CFs show a split (hot tongue) in the northern part (moving in opposite direction)

In future work we will consider the effects of radiative cooling, accretion onto a central SMBH, and AGN feedback and their interplay with sloshing CFs



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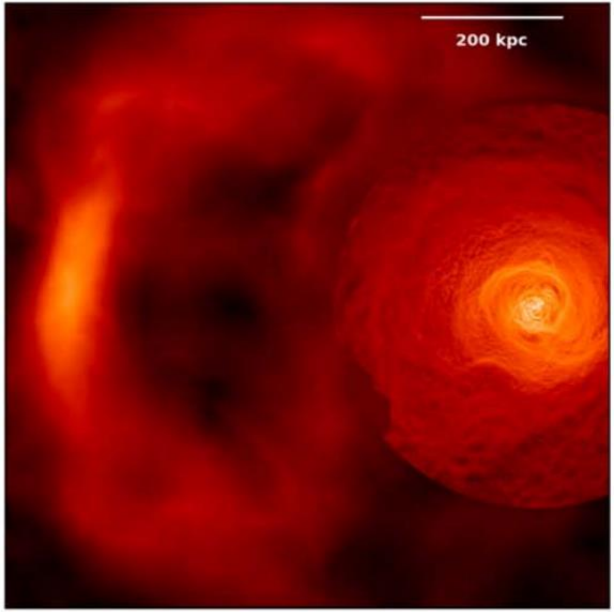
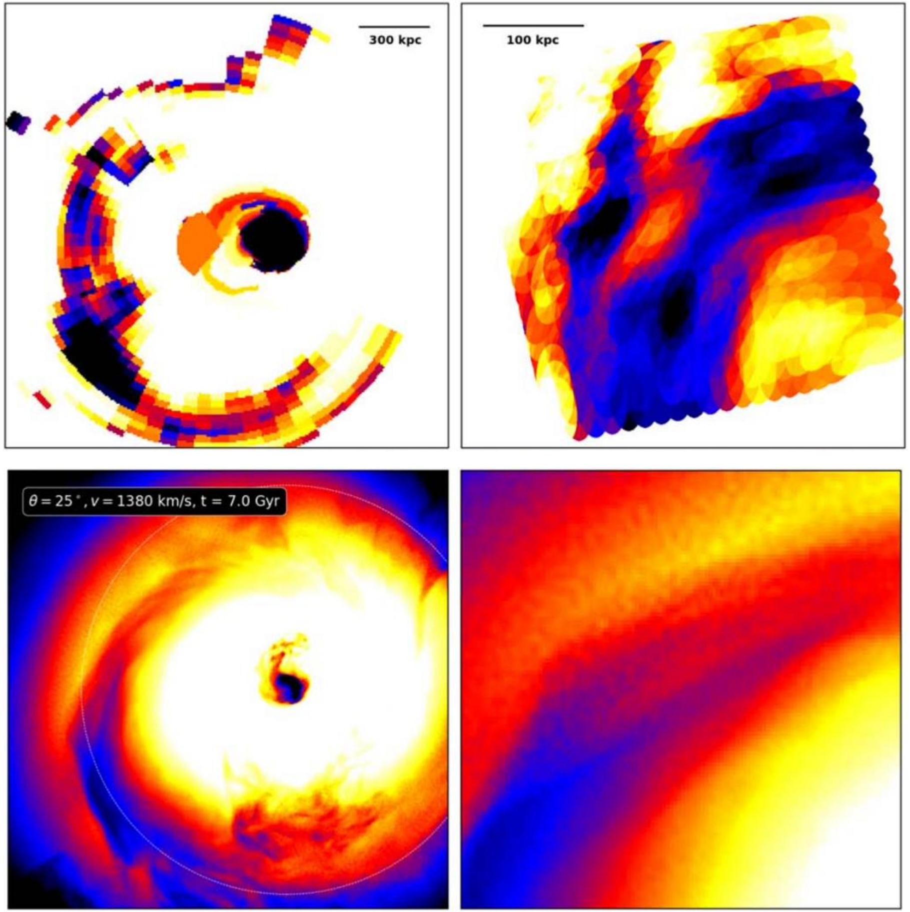
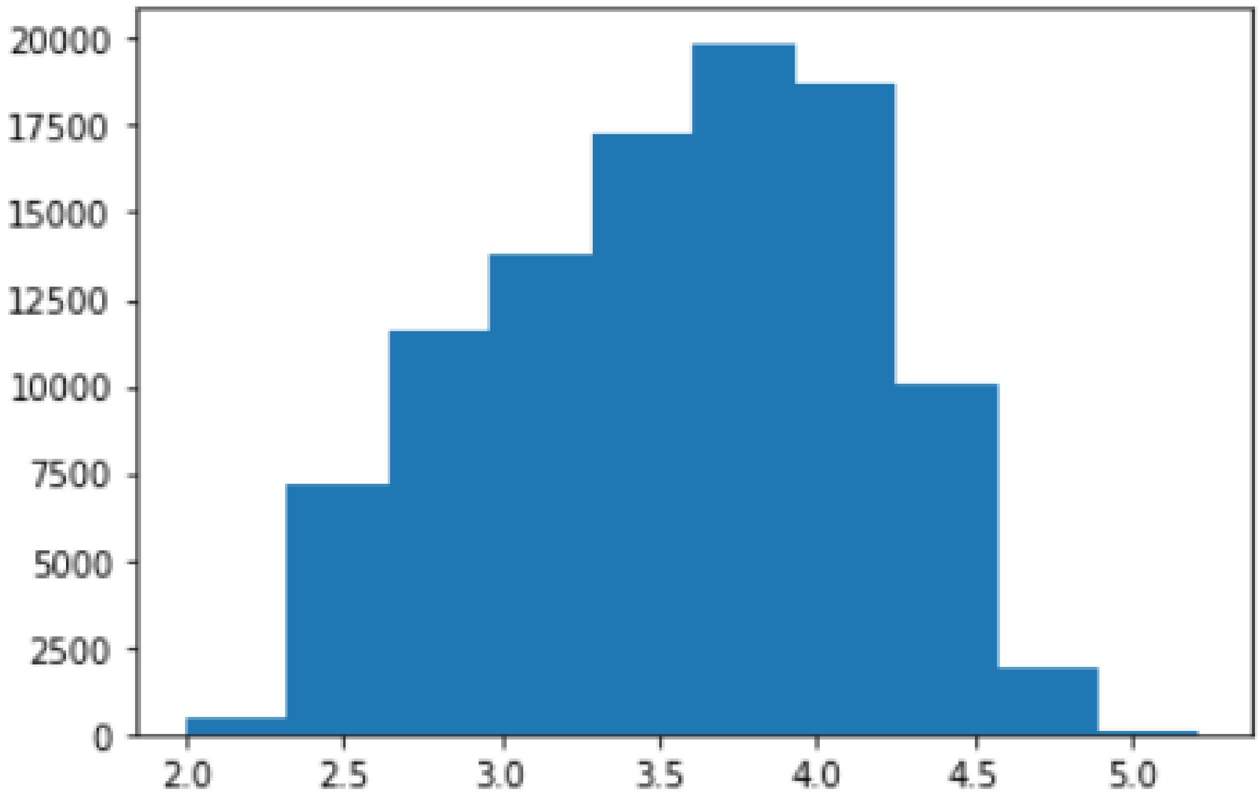




Resolution: cell size in the inner 100 kpc for snap 86, size ~3.5 kpc



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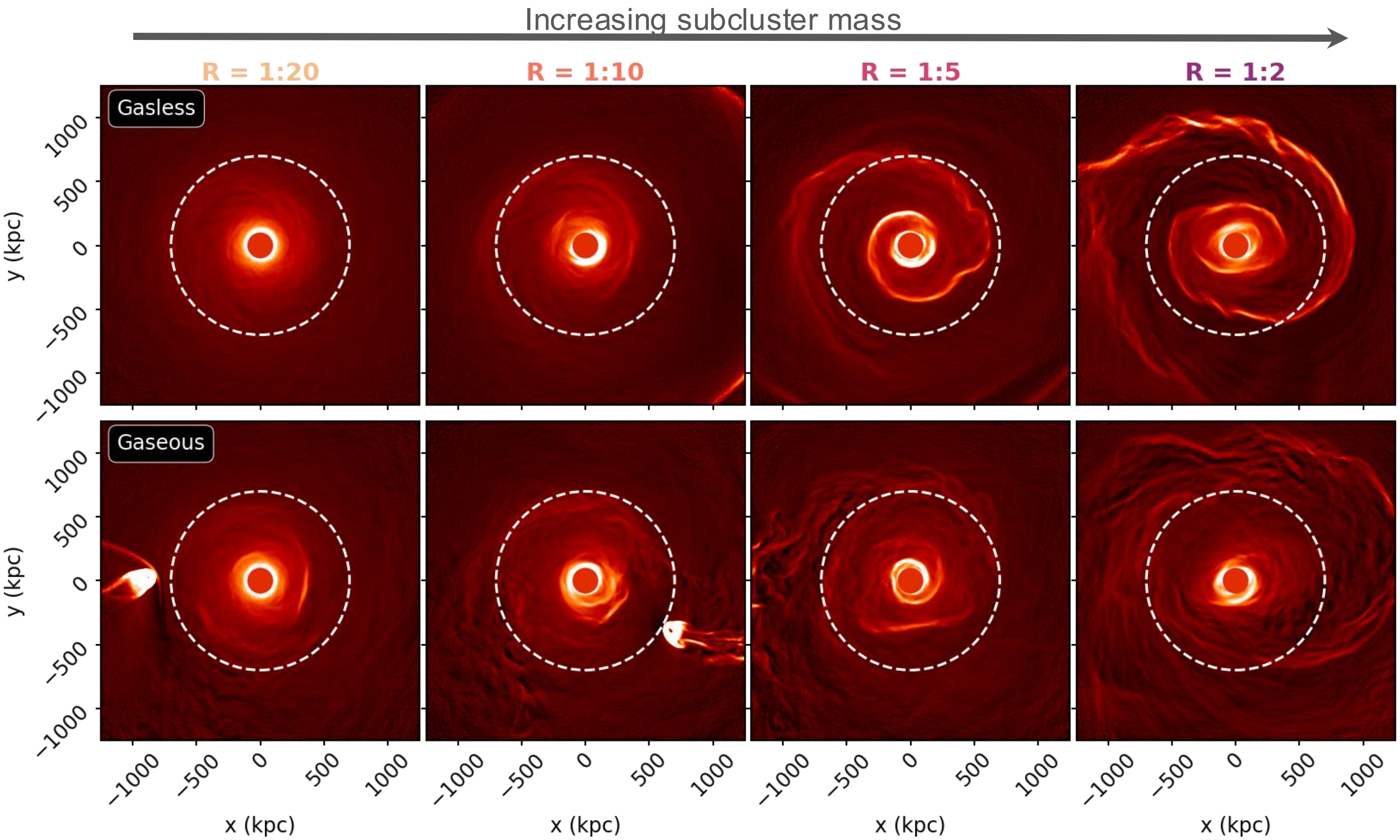
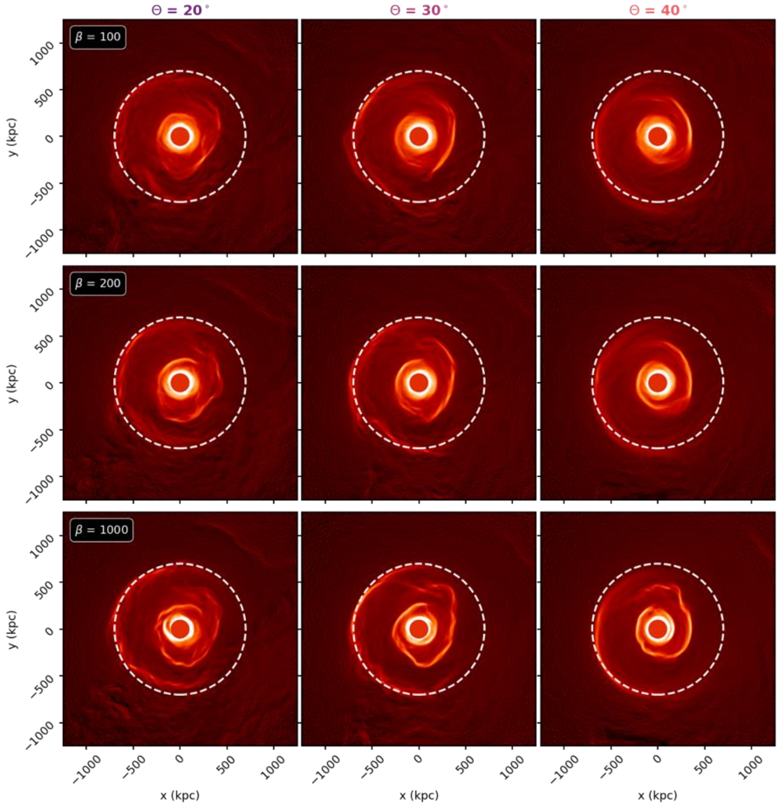
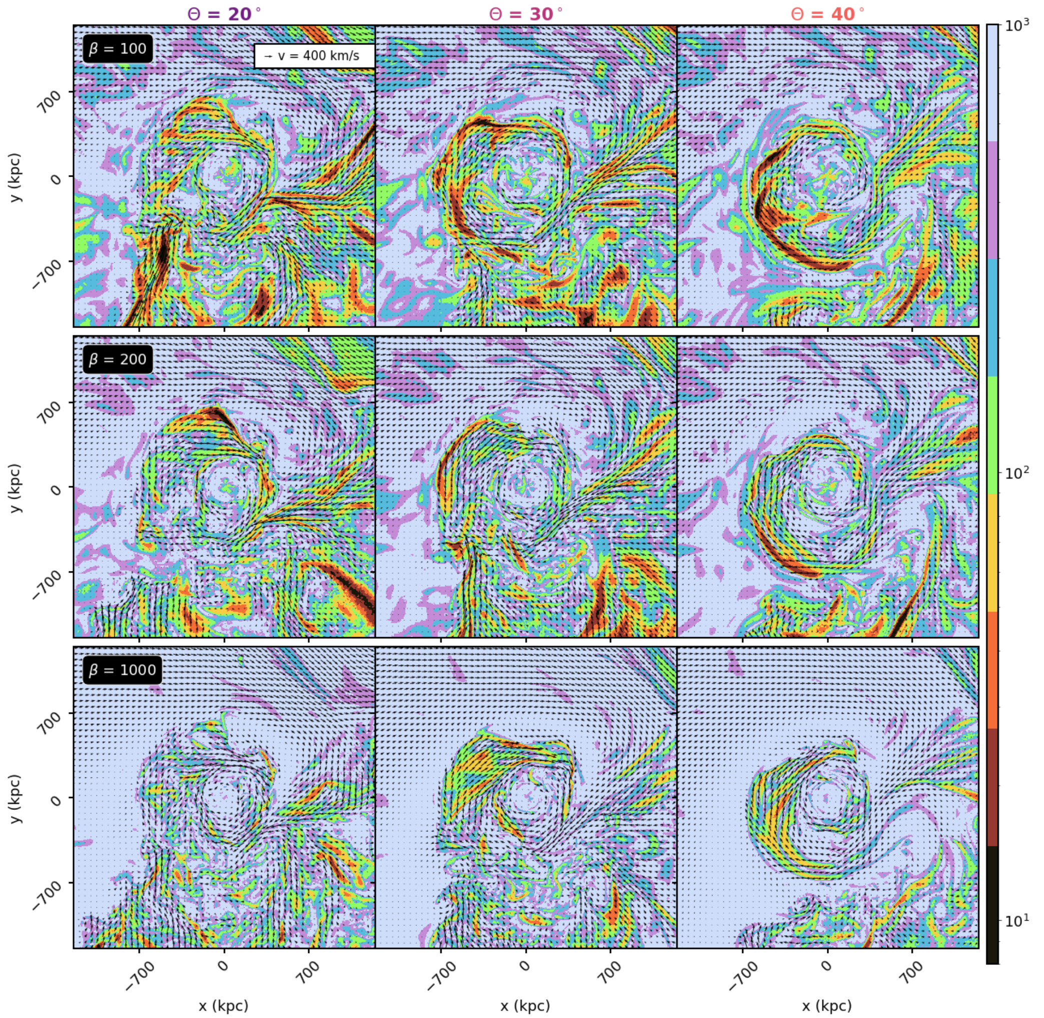
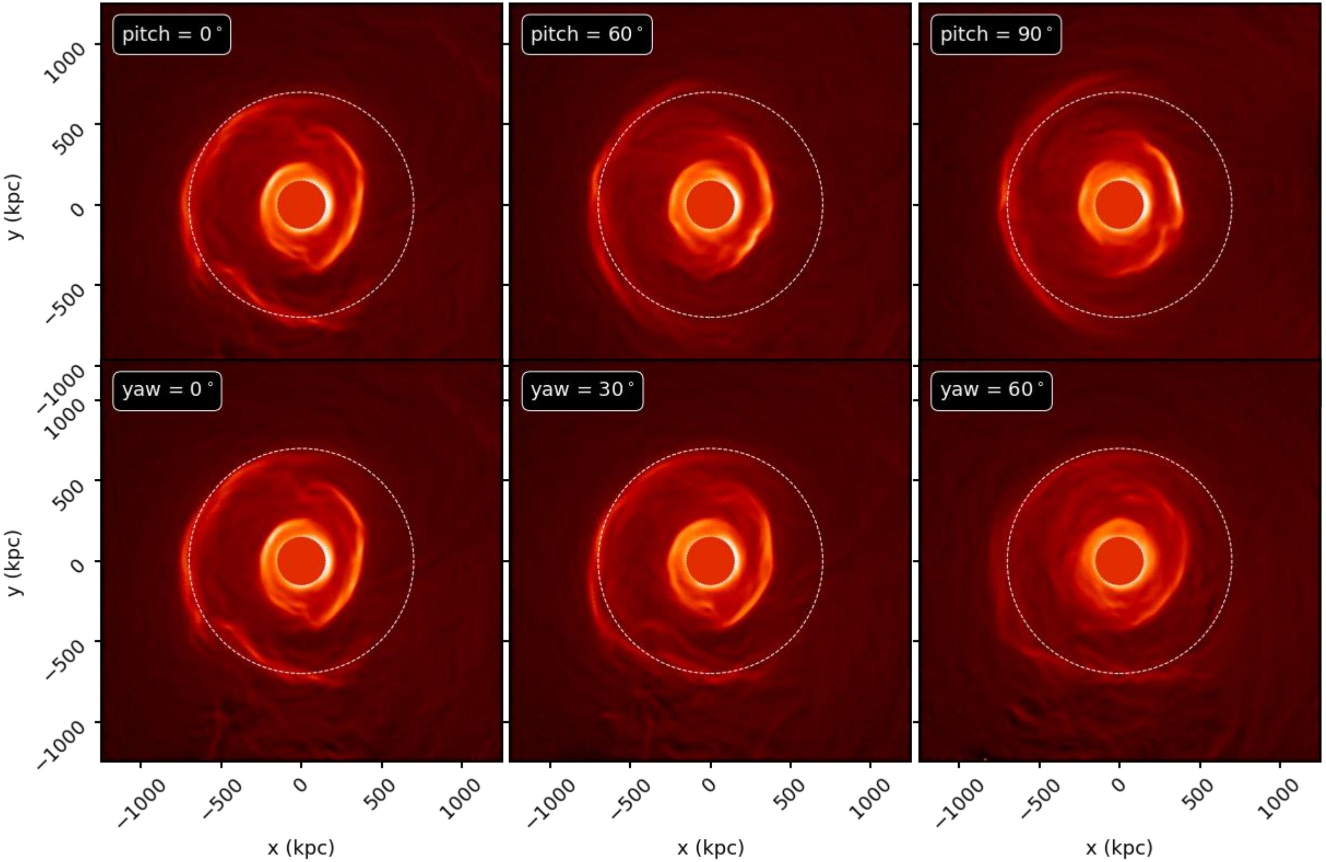


Impact of the sloshing on the magnetic field

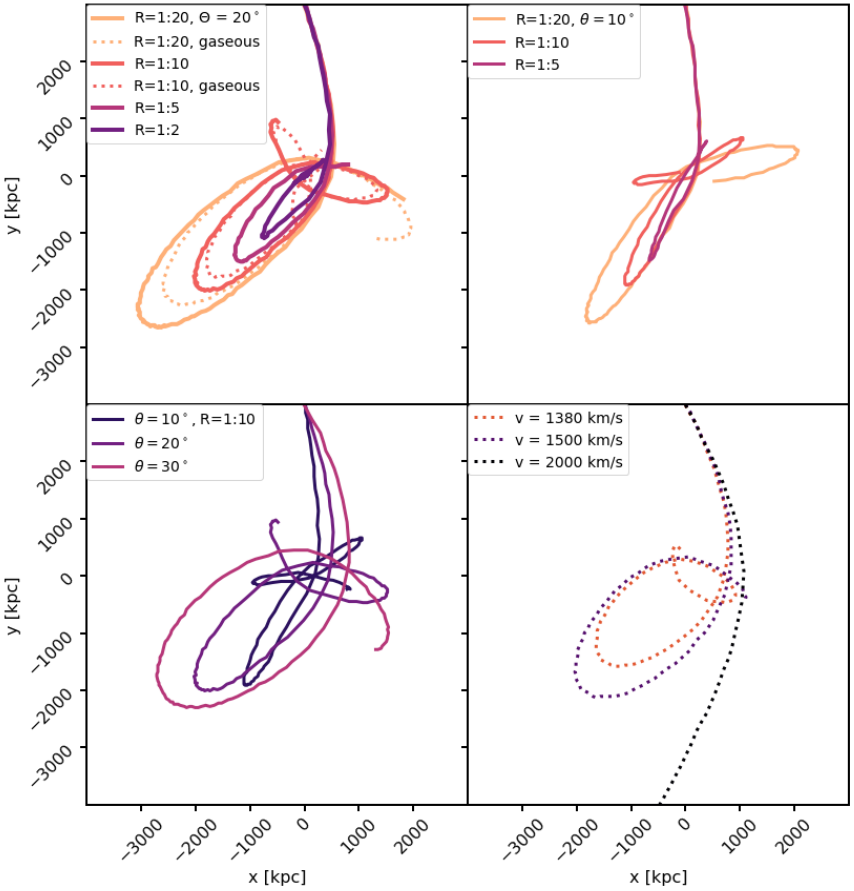


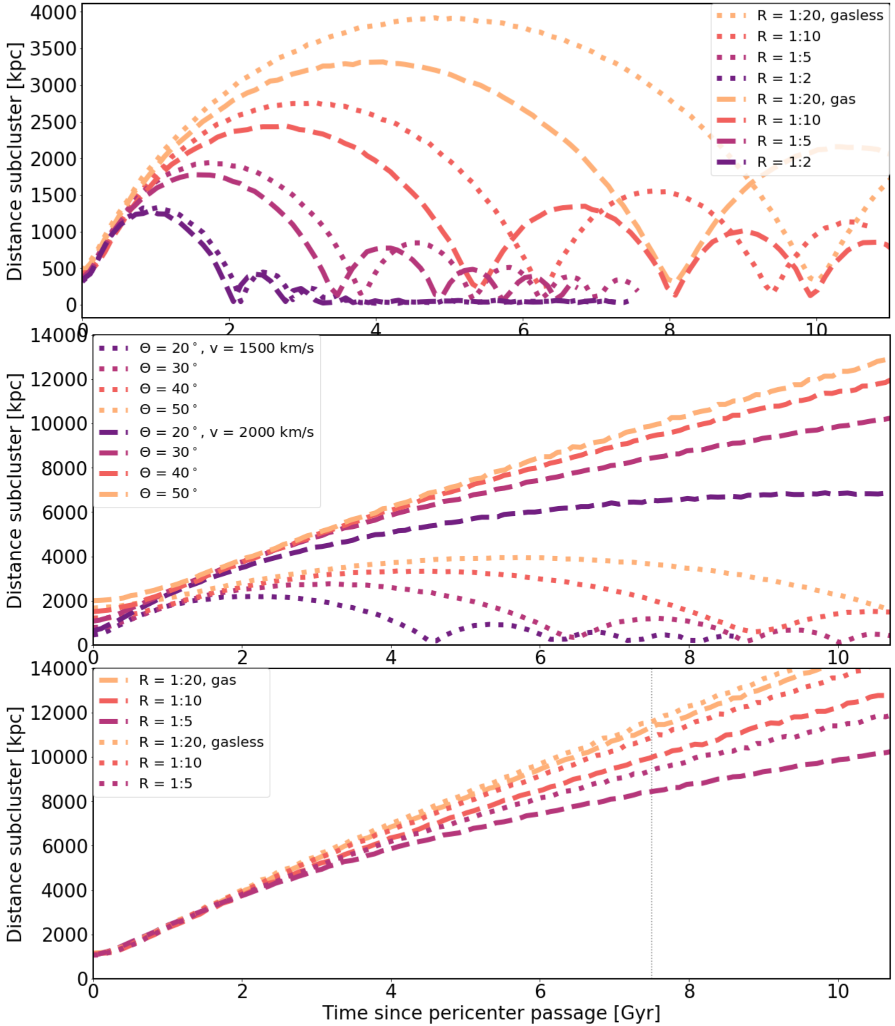


Projection Effects



Subcluster distance





Zhang et al 2020

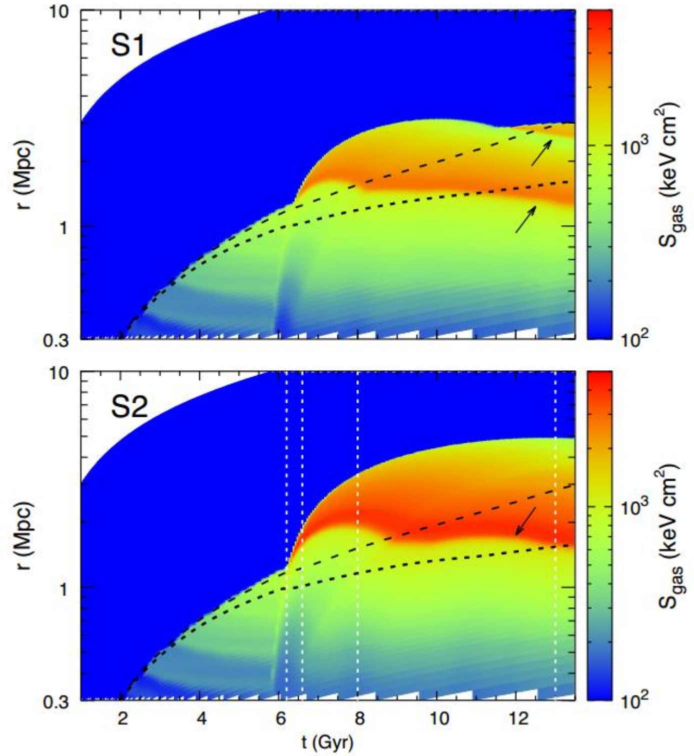


Figure 2. Evolution of gas entropy profile in the 1D simulations S1 (top panel) and S2 (bottom panel). The CDs formed from the shock collisions are marked by the black arrows. The black dashed and dotted lines show the virial radii r_{200m} and r_{200c} of the cluster, respectively. The gas profiles at the moments marked by the white vertical lines in the run S2 are shown in Fig. 3. This figure illustrates the formation of CDs near the cluster virial radius, when the runaway shock overtakes the accretion shock (see Section 3).

Li et al. 2020

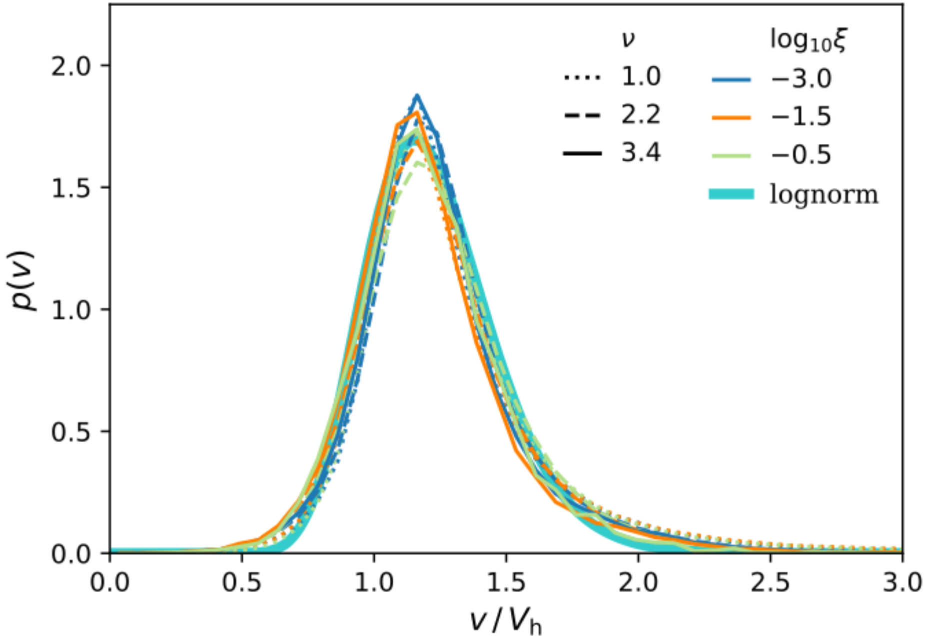


Figure 4. Infall velocity distribution for different host mass ν and sub-to-host ratio ξ bins. ν and ξ of each bin are indicated by the line style and color, respectively. The cyan thick solid line shows our model (Equation (1)), which is a log-normal distribution.

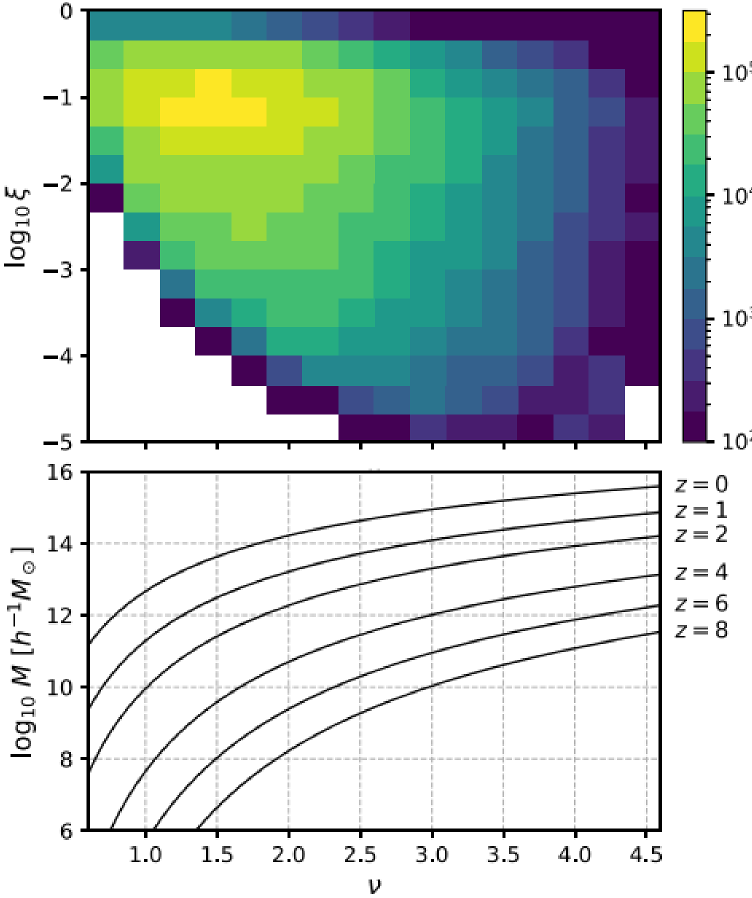


Figure 1. Number of halo pairs binned by the host halo's peak height, ν, and the sub-to-host mass ratio, $\xi = m/M_{\rm h}$. The relations between mass and ν at various z are shown in the lower panel for reference.

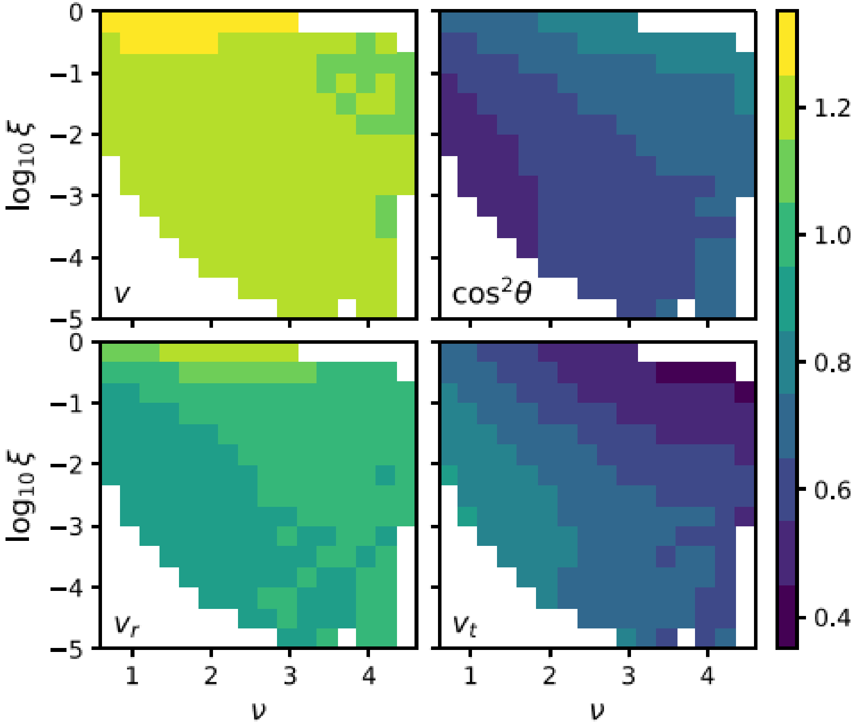


Figure 3. Orbital parameters as a function of the host mass ν and sub-to-host ratio ξ. The four panels show respectively the median values of v, $v_{\rm r}$, and $v_{\rm t}$ and the mean of $\cos^2\theta = v_{\rm r}^2/v^2$ for merging halos binned by ν and ξ. All velocities are shown in units of the host virial velocity. The subhalos with higher ν or ξ are more likely to fall along the radial direction due to smaller $v_{\rm t}$, though they have a similar $v_{\rm r}$ and almost the same total velocity as their low ν, ξ counterparts.