The Dynamical Removal of Gas from Group and Cluster Galaxies

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with:
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John ZuHone (NASA GSFC)
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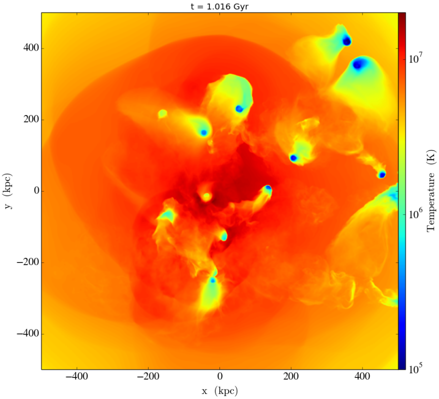
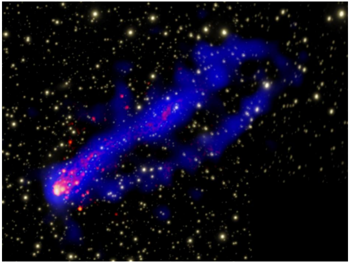


Gas Stripping in Groups and Clusters – Questions

- How do cluster and group and galaxies lose their gas?
  - Tidal vs. Ram-pressure stripping
- How important are group environments? (Pre-processing?)
- What is the time scale over which galaxies lose their hot halos?
- Can X-ray coronae of galaxies survive ram-pressure stripping?
- How can simulations constrain observed galaxy wakes and coronae?

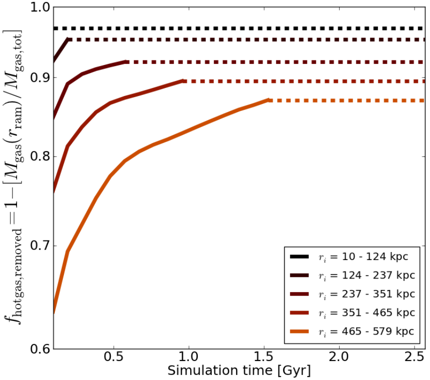


(ESO 137-001; M. Sun et al., Chandra, SOAR)

Galaxy Groups and Pre-processing of Galaxies

Group-cluster merger simulation, particles tagged with galaxy models

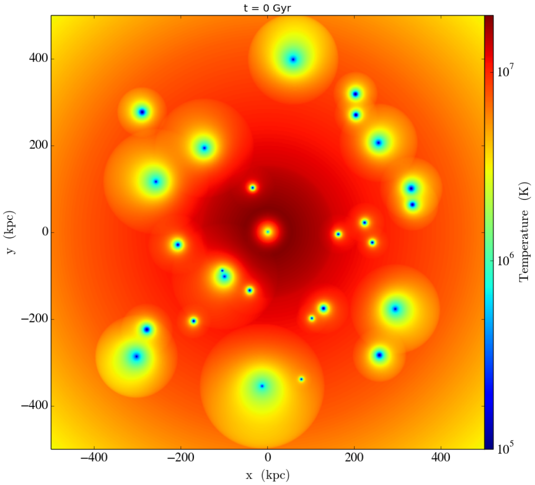
- ‘Pre-processing’: Transforming galaxies in groups, before eventual cluster infall.
- Group environments can efficiently strip galaxies of their hot coronal and cold disk gas.
- In a $3 \times 10^{13} \mathrm{M}_\odot$ group, $> 85\%$ of galactic hot gas is ram-pressure stripped before it cools.



Vijayaraghavan & Ricker 2013

Idealized Simulations of a 3.2×10^{13} $M_\odot$ Group

Collisionless DM + hot gas, FLASH 4 + AMR, particle mass 10^6 $M_\odot$, max. resolution 1.6 kpc



Full length movie: `https://uofi.box.com/movTGroupGas500`, `https://uofi.box.com/movTGroupGas800`

Idealized Simulations of a $3.2 \times 10^{13}\ M_\odot$ Group

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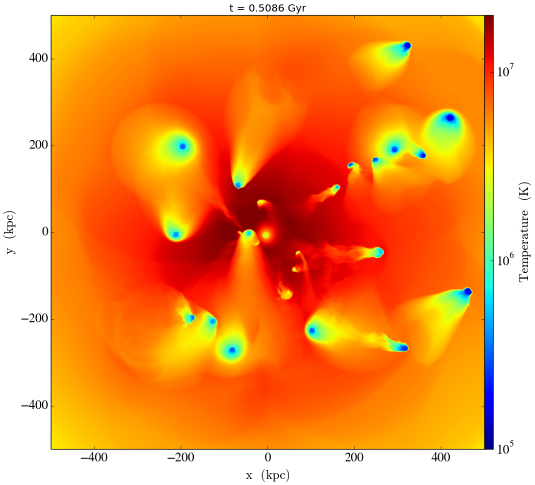

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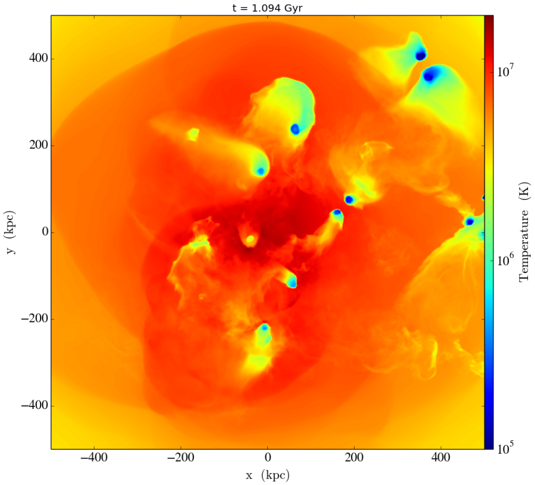

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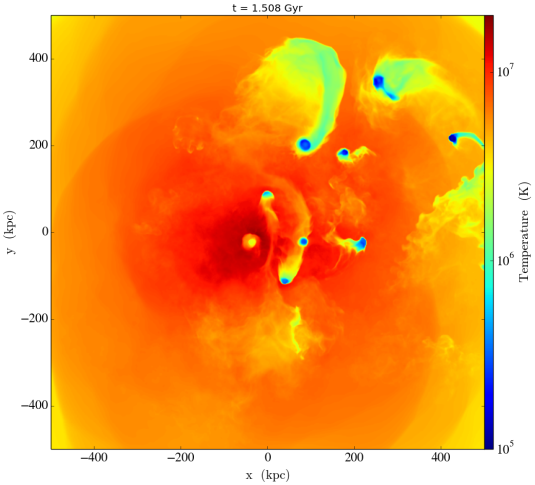

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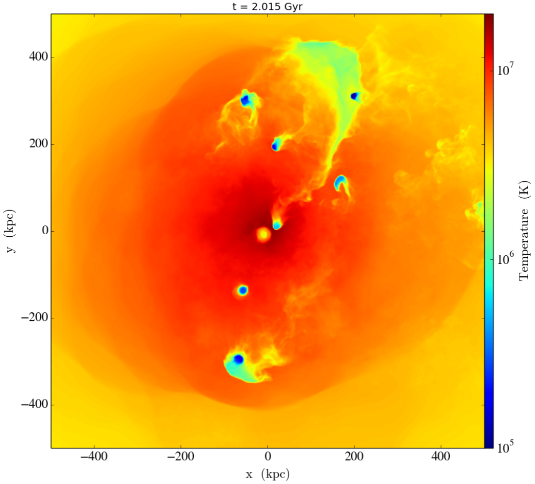

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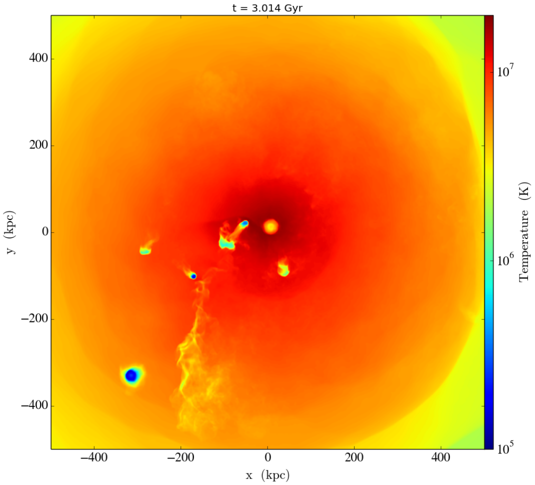

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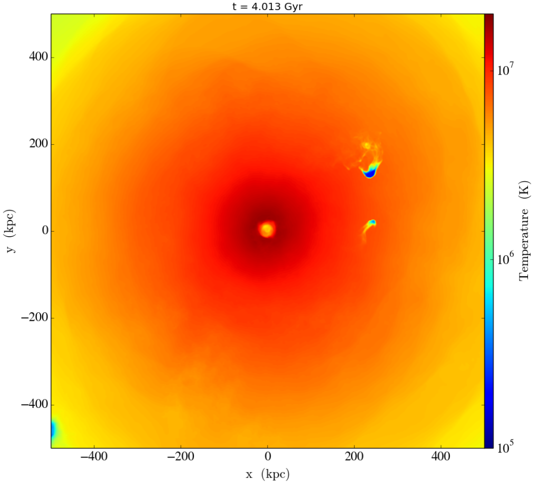

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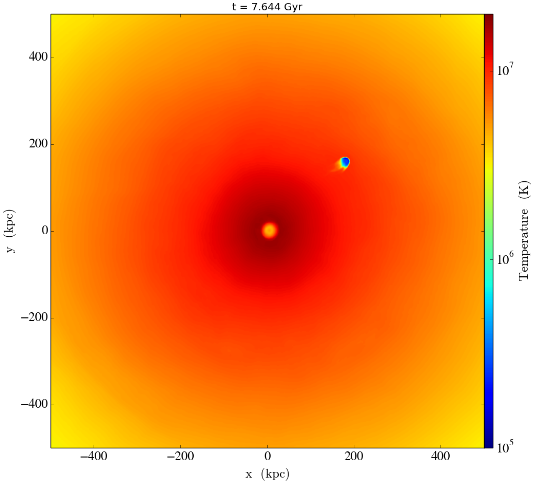

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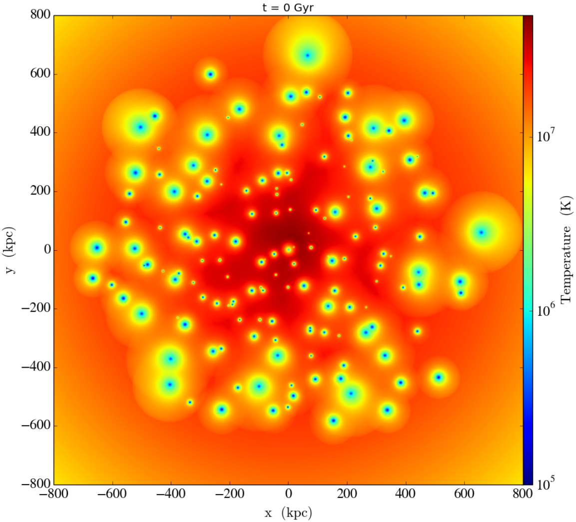
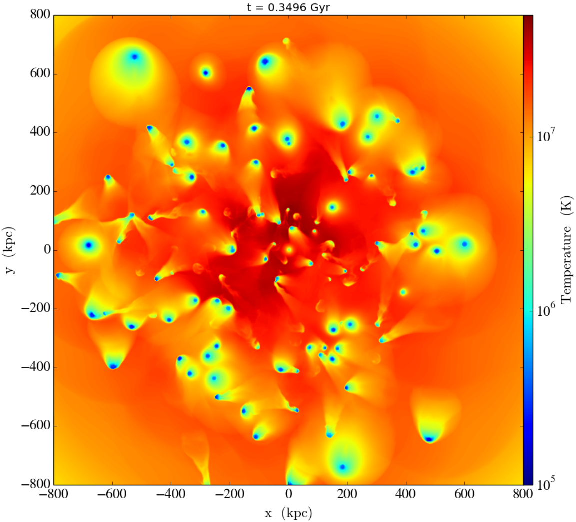
Idealized Simulations of a 1.2×10^{14} $M_\odot$ Cluster

Collisionless DM + hot gas, FLASH 4 + AMR, particle mass 10^6 $M_\odot$, max. resolution 1.6 kpc



Idealized Simulations of a $1.2 \times 10^{14}\ M_\odot$ Cluster

Collisionless DM + hot gas, FLASH 4 + AMR, particle mass $10^6\ M_\odot$, max. resolution 1.6 kpc



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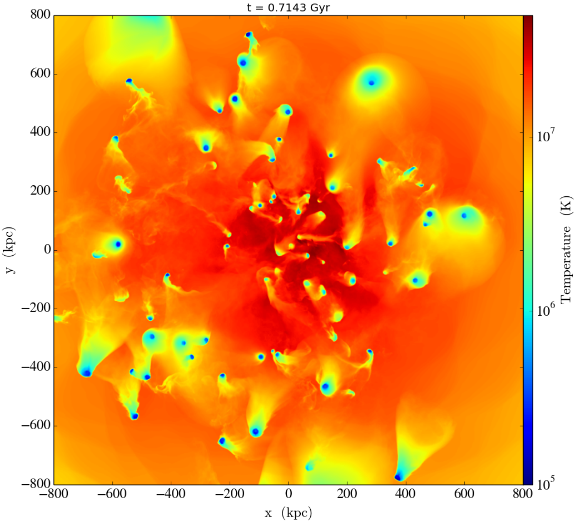
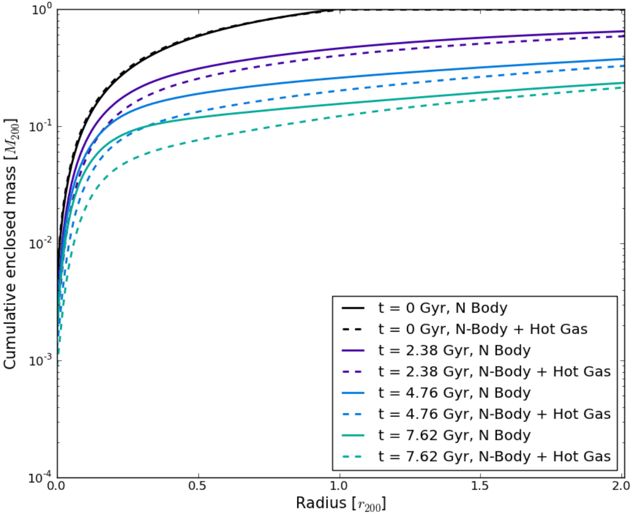


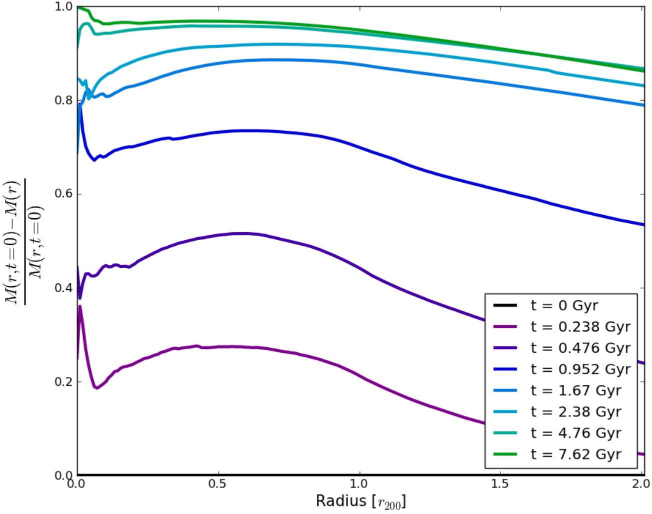
Tidal vs. Ram-Pressure Stripping

Stacked galaxy mass profiles, in simulations with and without gas

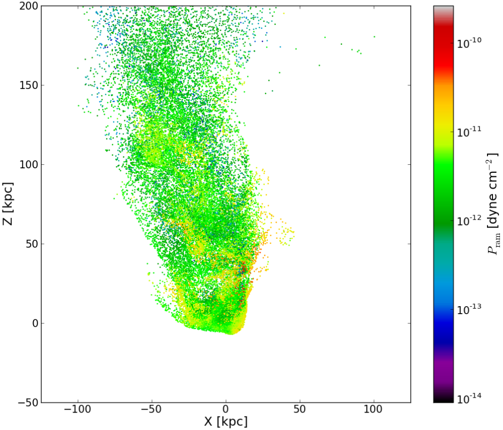


Gas Mass Loss: $\sim$ 80% gas stripped within 2.4 Gyr

Stacked differential gas mass profiles



Ram-Pressure Stripping: Confinement Surface



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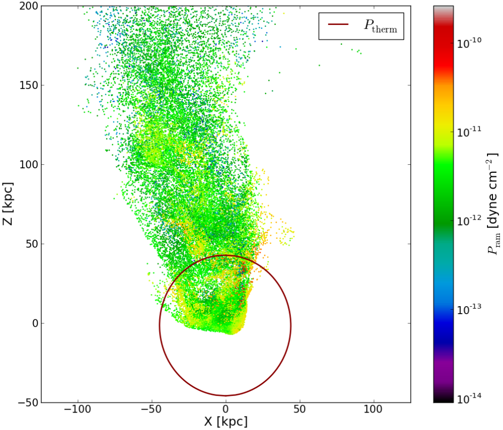
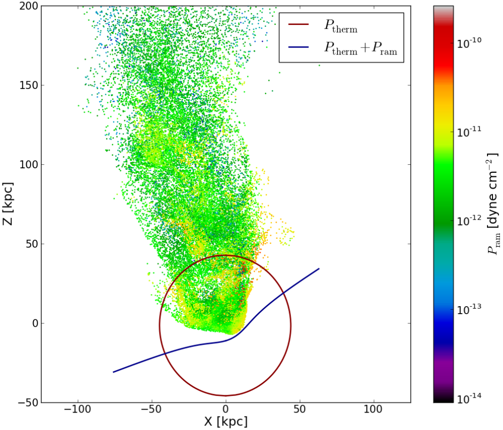


$$P_{\rm therm,galaxy}(\mathbf{r}_{\rm conf}) = P_{\rm therm,ICM}(\mathbf{r}_{\rm group} + \mathbf{r}_{\rm conf})$$

Ram-Pressure Stripping: Confinement Surface

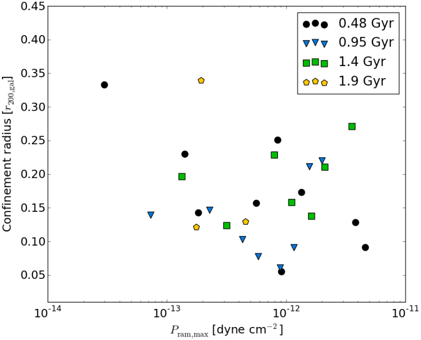


$$P_{\rm therm,galaxy}(\mathbf{r}_{\rm conf}) = P_{\rm therm,ICM}(\mathbf{r}_{\rm group} + \mathbf{r}_{\rm conf}) + P_{\rm ram,ICM}(\mathbf{r}_{\rm group} + \mathbf{r}_{\rm conf})\hat{\mathbf{v}} \cdot \hat{\mathbf{r}}$$
$$(P_{\rm ram,ICM} = \rho_{\rm ICM} v_{\rm gal}^2)$$

Characterizing Galaxy Wakes

Higher $P_{\rm ram} \Rightarrow$ smaller confinement surface, particularly for massive galaxies.

$M_{\rm galaxy} > 10^{11}\ {\rm M}_\odot$



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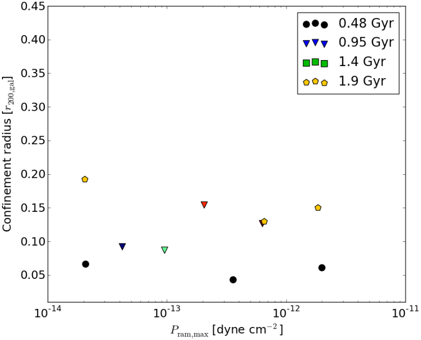
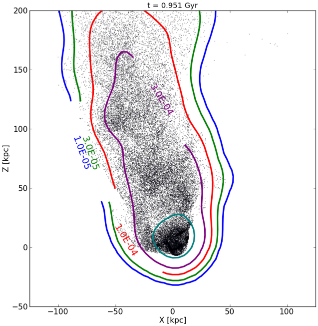
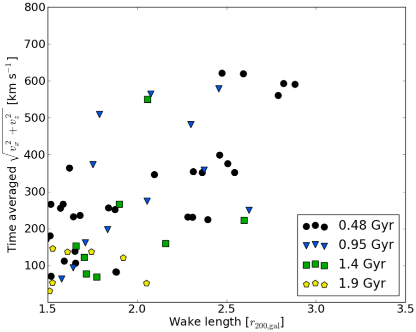


Characterizing Galaxy Wakes

Higher transverse velocities ⇒ longer galaxy wakes.

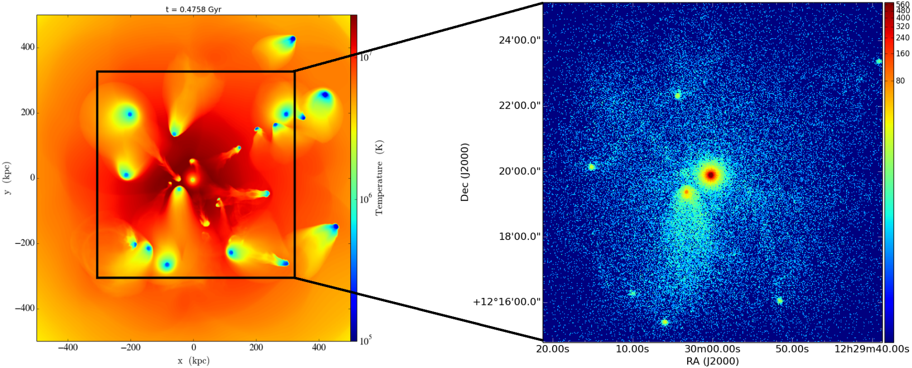
Surface Density Contours





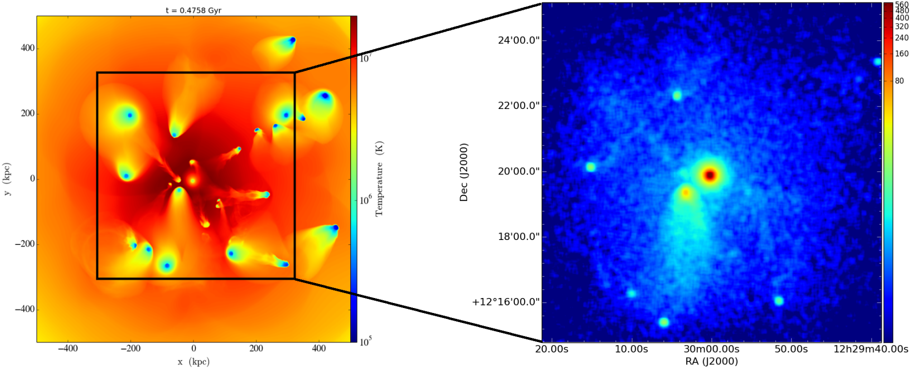
Mock X-ray Images with YT photon simulator

Simulated 400 ks *Chandra* image reblocked by a factor of 4 (t = 0.48 Gyr)



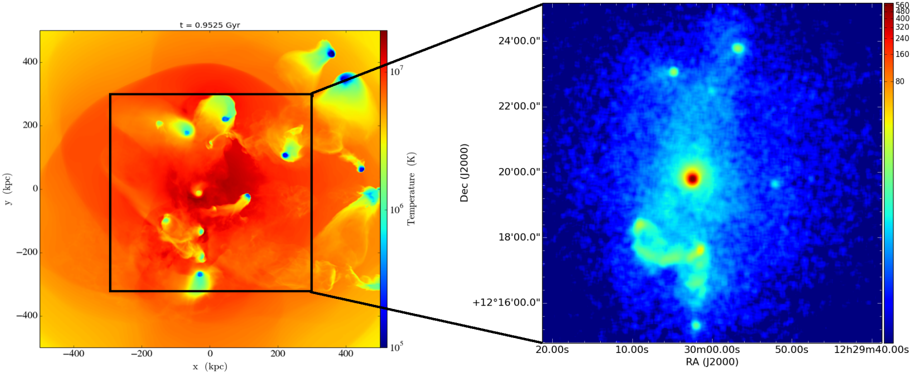
Mock X-ray Images with YT photon simulator

Simulated 400 ks *Chandra* image, smoothed so $\langle N_{\mathrm{photons}}/\mathrm{pixel}\rangle \simeq 5$ (t = 0.48 Gyr)



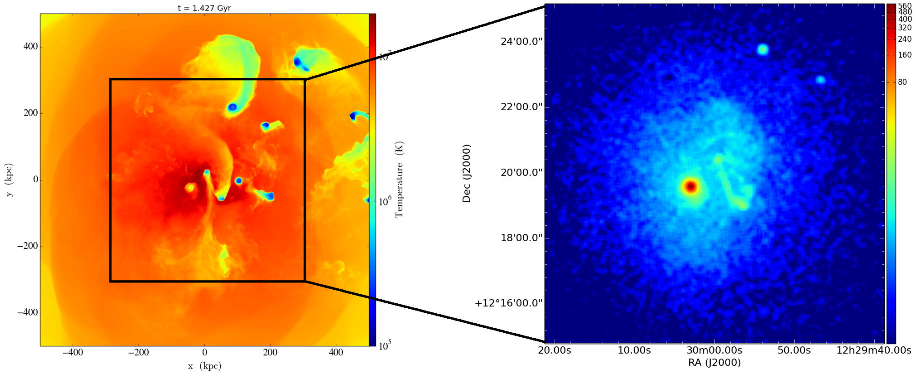
Mock X-ray Images with YT photon simulator

Simulated 400 ks *Chandra* image, smoothed so $\langle N_{\rm photons}/{\rm pixel}\rangle \simeq 5$ (t = 0.95 Gyr)



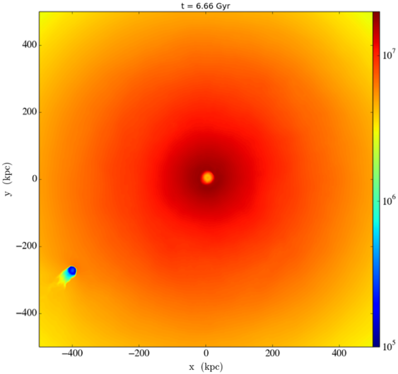
Mock X-ray Images with YT photon simulator

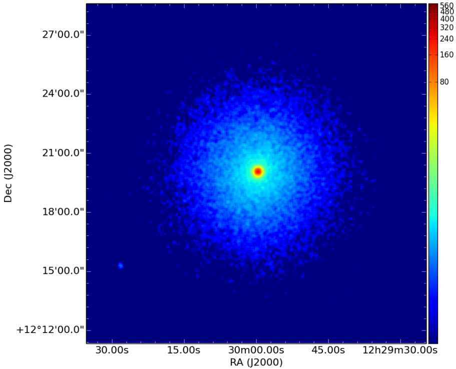
Simulated 400 ks *Chandra* image, smoothed so $\langle N_{\mathrm{photons}}/\mathrm{pixel} \rangle \simeq 5$ (t = 1.43 Gyr)



Are surviving X-ray coronae visible at $\sim$ 7 Gyr?

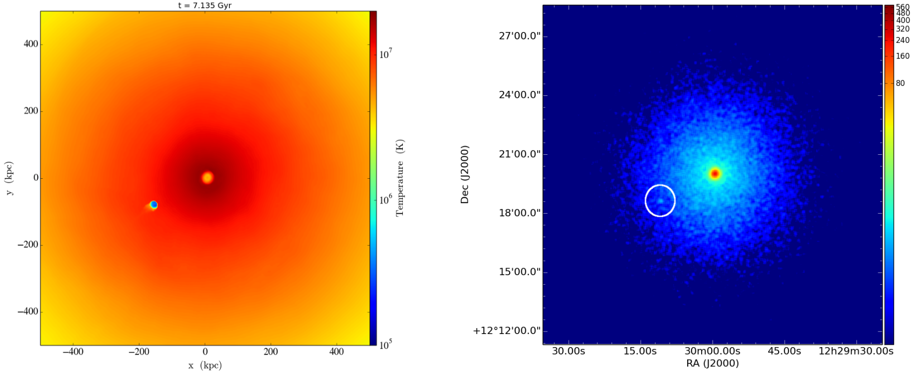
Simulated 400 ks *Chandra* image of 500 $\times$ 500 kpc region at 6.66 Gyr, smoothed such that $\langle N_{\mathrm{photons}}/\mathrm{pixel} \rangle \simeq 5$ – visible, but low SNR





Are surviving X-ray coronae visible at $\sim$ 7 Gyr?

Simulated 400 ks *Chandra* image of 500 $\times$ 500 kpc region at 7.13 Gyr, smoothed such that $\langle N_{\rm photons}/{\rm pixel}\rangle \simeq 5$ – visible, but low SNR



Summary

- Groups 'pre-process' galaxies, strip $\sim 85\%$ of their gas within ~ 2 Gyr.
- We have simulated a realistic population of galaxies that are stripped by tidal forces and the ram pressure of the ICM.
- The presence of gas and ram pressure increases the rate of gas loss, as opposed to purely tidal stripping.
- Most galaxies lose all their gas within $\sim 2.5 - 3.5$ Gyr, some coronae survive up to ~ 7 Gyr.
- Caveat: cooling, gas replenishment, viscosity, and magnetic fields not included.
- Galaxy wakes have well defined 'confinement surfaces', whose radii correlate with the strength of ram pressure.
- Faster moving galaxies have longer wakes.
- Mock X-ray images with YT photon simulator, wakes are visible with long (400 ks) observations. Multiple wakes can be confused as one.
- Surviving coronae are visible at late times, with low SNR ($\simeq 2$).