

Title: Cooling flows as a useful reference solution for the hot CGM of massive galaxies

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Collection/Series: Cosmic Ecosystems

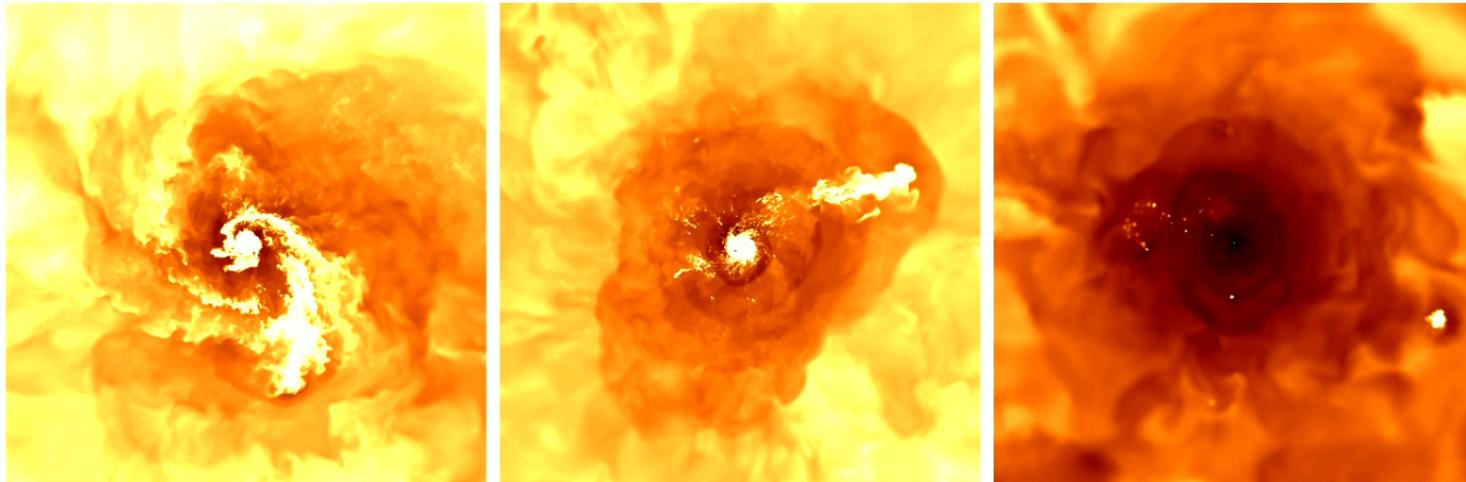
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Abstract:

TBD

Cooling flows as a useful reference solution for the hot CGM in galaxy-scale halos



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with [I. Sultan](#) (see poster!), [J. Stern](#), [Z. Hafen](#), [L. Byrne](#), [N. Wijers](#), [E. Mone](#),
[S. Rotshtein](#), [A. Kakoly](#), [D. Fielding](#), [E. Quataert](#), [C. Esmerian](#), [C. Trapp](#) + FIRE collab.

What is the structure of the hot CGM?

n , T , entropy profiles? What physical principles determine them?

Theoretically, an open problem:

- Hydrostatic balance $-\frac{1}{\rho} \frac{dP}{dr} = \frac{GM_{\text{tot}}(< r)}{r^2}$ constrains P profile
- But insufficient because infinite family of n , T give same $P \propto n T$

Many different assumptions in existing models:

- Isothermal ($T=\text{const}$), e.g. Faerman+17
- Isentropic ($K \propto T/n^{2/3}=\text{const}$), e.g. Faerman+20
- Prescribed entropy slope (e.g. $K \propto r^{1.1}$ from non-rad. cosmo sims; Voit+05)
- Precipitation-limited models ($t_{\text{cool}}/t_{\text{ff}} > 10$), e.g. Sharma+12, Voit+19
- Baryon pasting models (multiple params), see Nagai talk

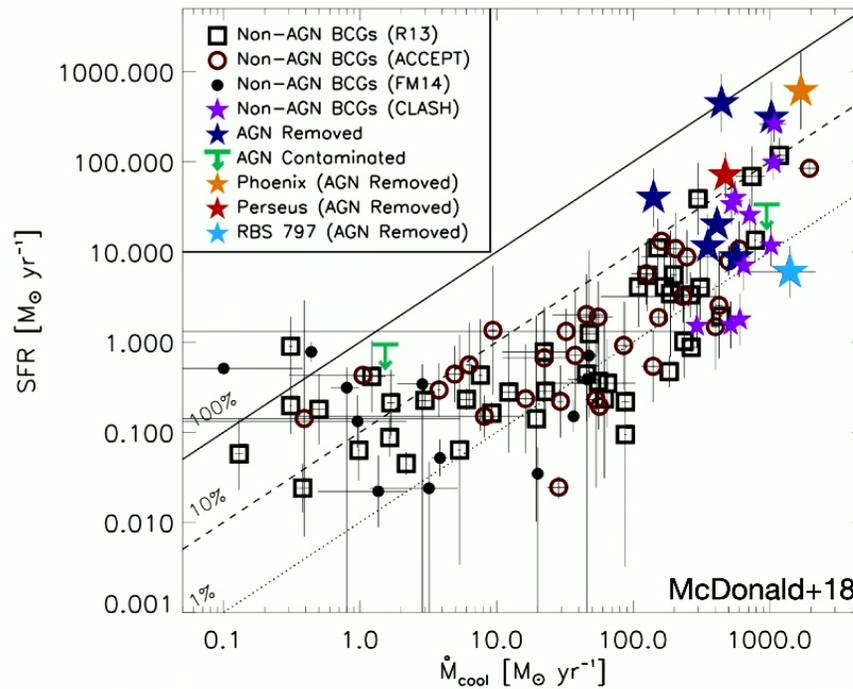
Cooling flows

Hot gas in grav. potential, inflow driven by rad. cooling (neglect feedback, etc.)

In steady-state, one-param. family. Given \dot{M} : n , T , K profiles fully determined

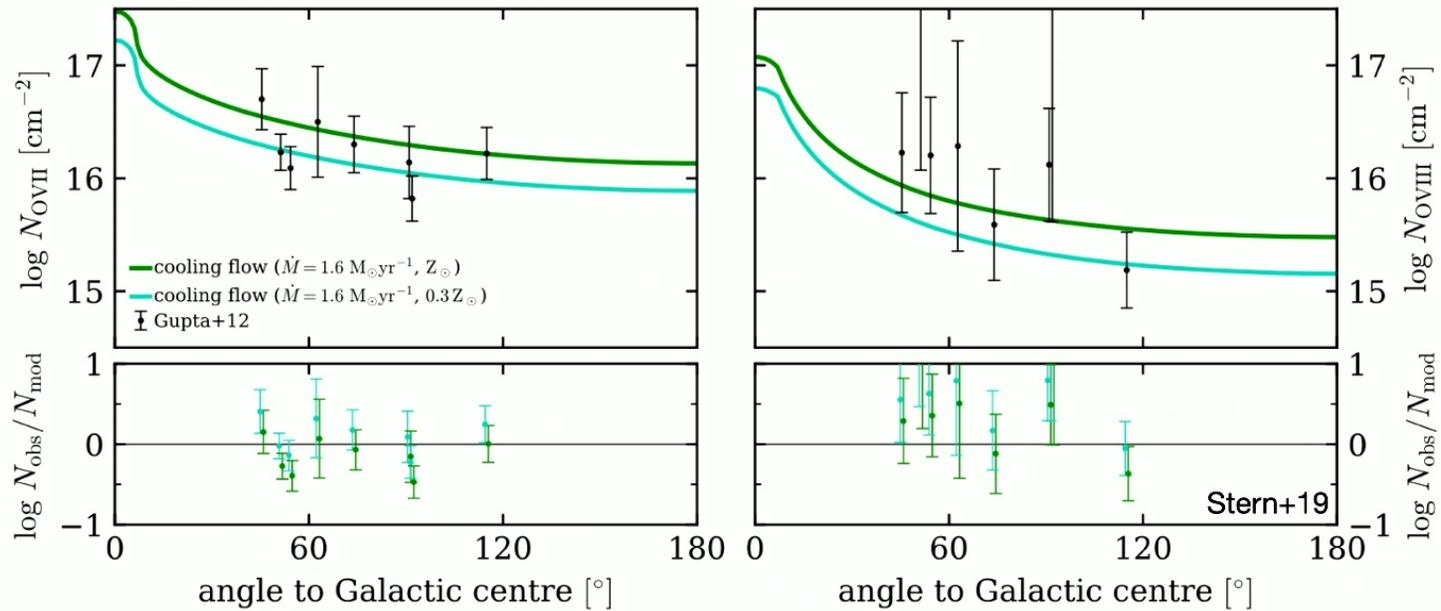
Classic model for the ICM
(e.g. Fabian+84)

Fell out of favor due to
“cooling flow problem”:
SFRs \ll obs. cooling rates



Cooling flows in galaxy-scale halos?

Cooling flows with $\dot{M}_{\text{cool}} \approx \text{SFR}$ consistent with many hot gas observations in $\sim 10^{12} M_{\text{sun}}$ halos, e.g. OVII, OVIII X-ray absorption from the MW's CGM:



(feedback can push out some baryons at high z)

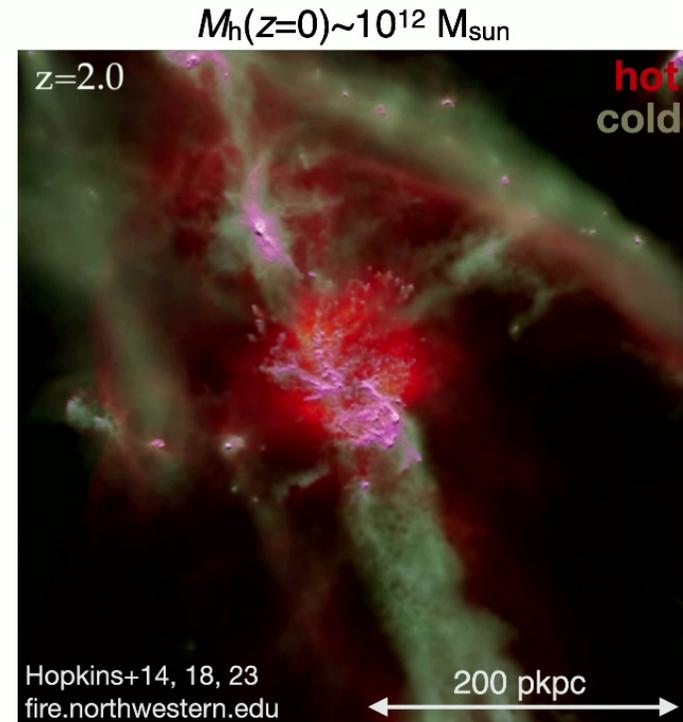
Testing cooling flows in FIRE galaxy formation simulations

► Zoom-ins including:

- cosmological environment and evolution
- stellar feedback (SNe II&Ia, winds, radiation)
- in some runs, B fields

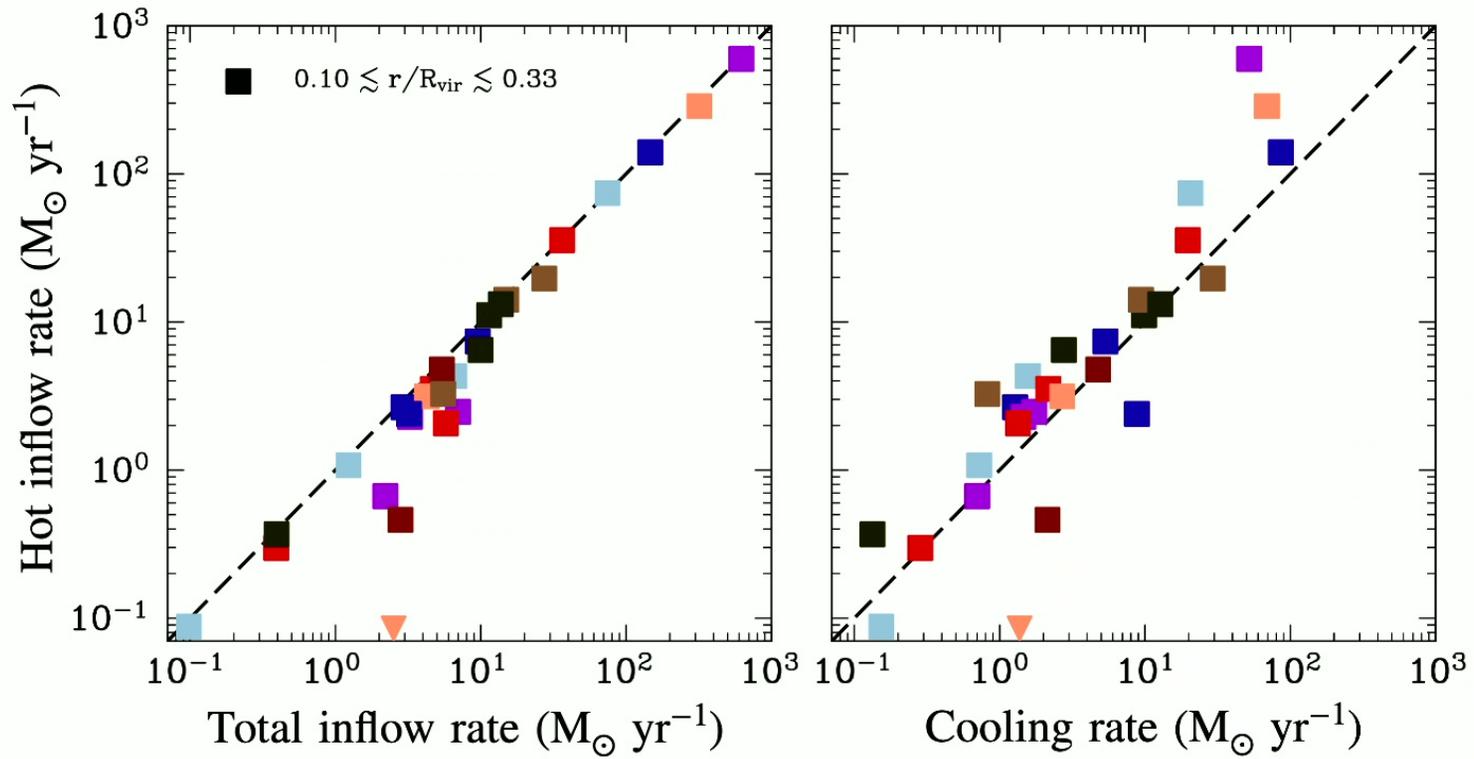
► Focus on $M_h \sim 10^{12} - 10^{13} M_{\text{sun}}$ and $z \sim 0$

► Neglect AGN feedback in this study



Sultan, FG, Stern+25

Inflows dominated by hot phase, ~consistent with cooling rates

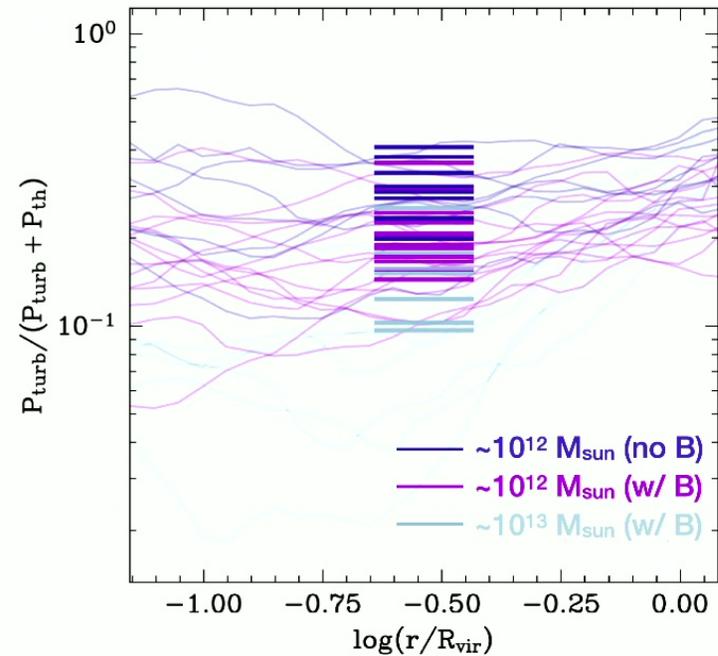


Sultan, FG, Stern+25

Fitting cooling flows: full thermodynamic profiles

- ▶ For each halo, measure: grav. potential, CGM metallicity
- ▶ Given these, cooling flow model uniquely predicts n , T , K , ... profiles (normalization set by \dot{M})

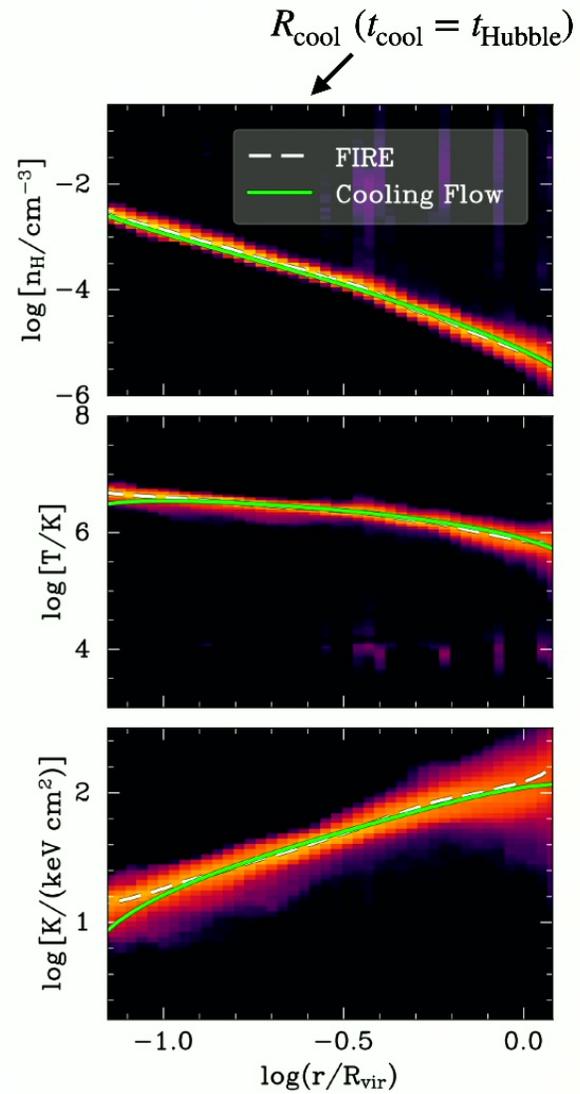
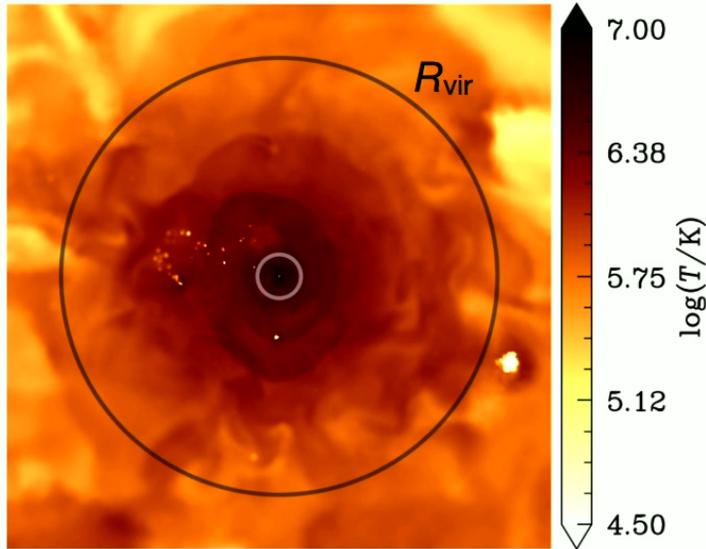
- ➡ turbulence is included as non-thermal pressure
- ➡ lowers by cooling flow T by ~10-20% on avg



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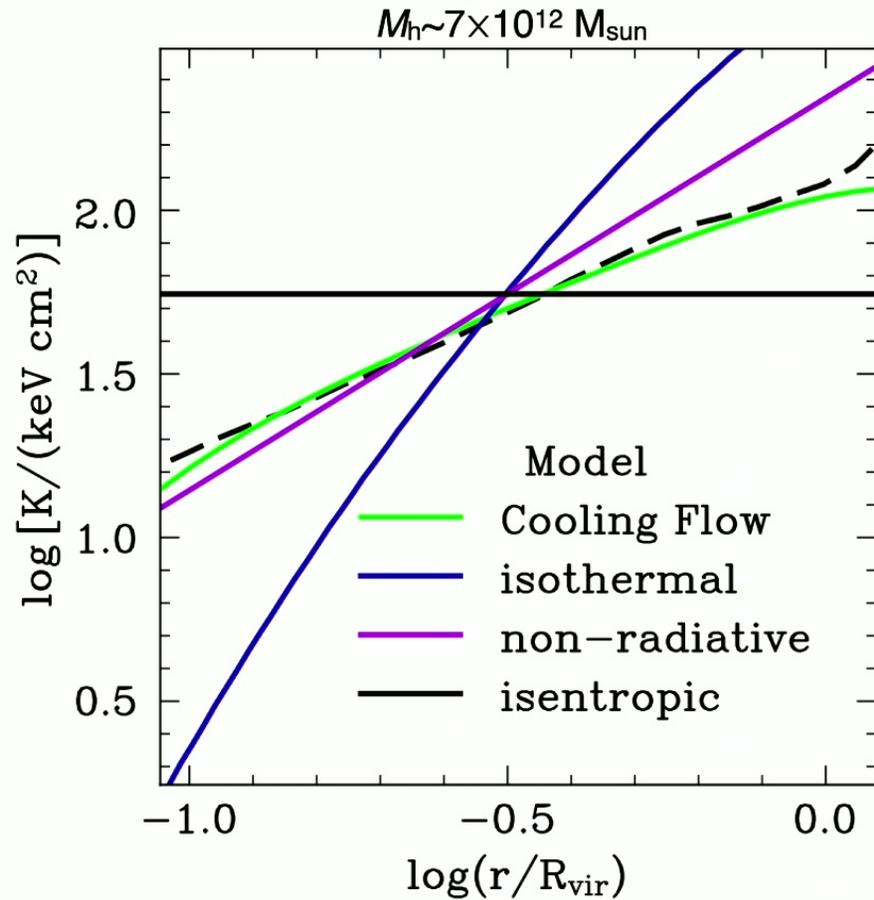
Example cooling flow fit

$M_h \sim 7 \times 10^{12} M_{\text{sun}}, R_{\text{vir}} \sim 500 \text{ kpc}$



Sultan, FG, Stern+25

Cooling flows vs. other analytic models



FIRE simulations

include: -cosmology
-stellar feedback
-*B* fields

neglect: -AGN
-cosmic rays
-...

→ “reference solution” to isolate effects of neglected processes

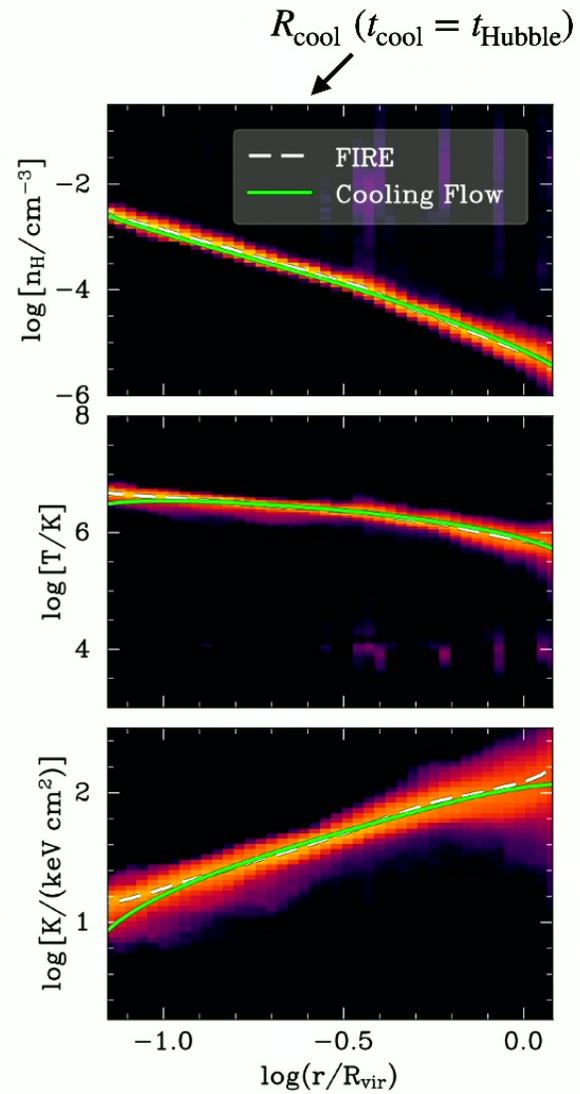
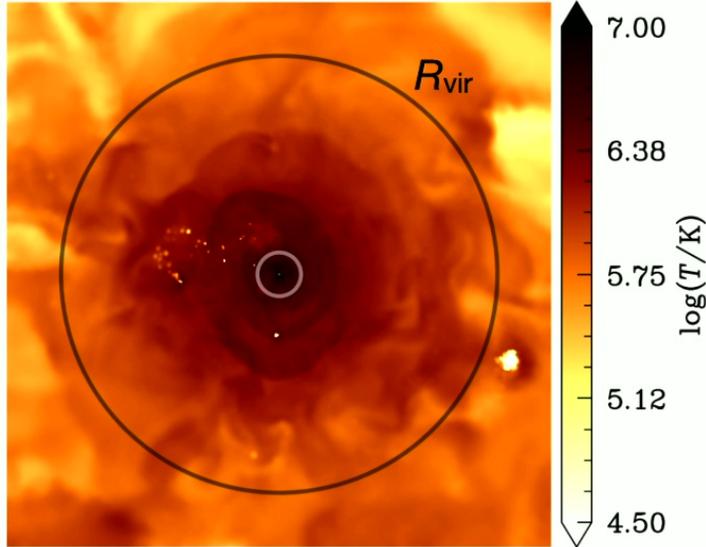
→ understand CGM virialization (outside-in; Stern+20, 21)

→ formation of thin disks (promoted by hot accretion; Hafen+22, Gurvich+23, Stern+24)

Sultan, FG, Stern+25 (statistics on ~30 halos in the paper)

Example cooling flow fit

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