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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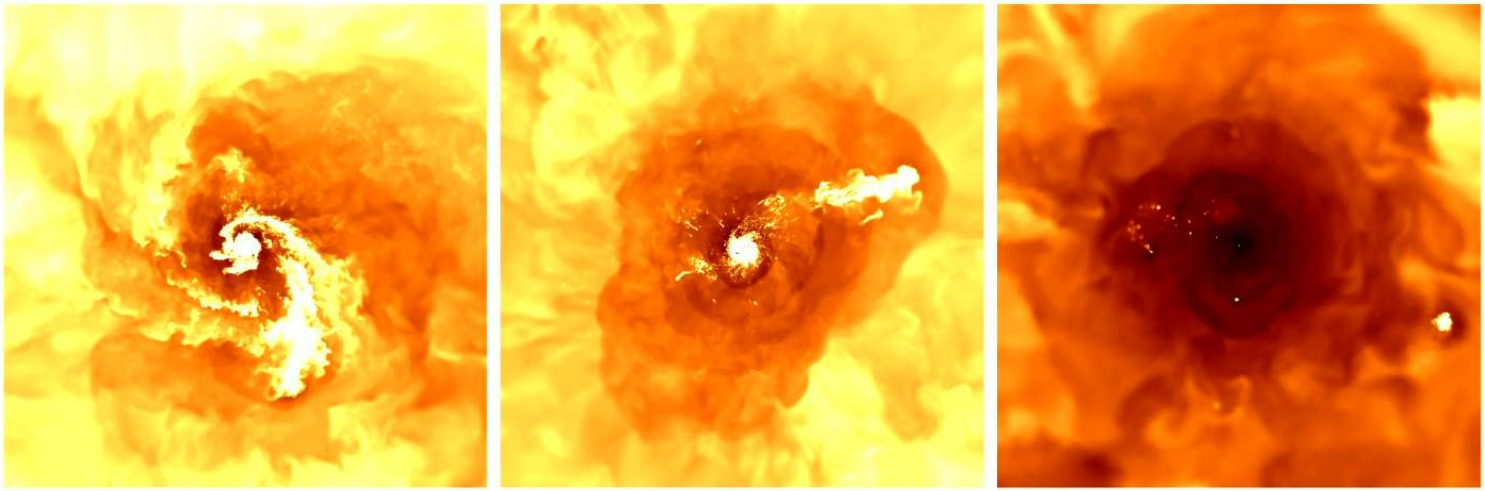
Abstract:

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 $-\frac{1}{\rho}\frac{dP}{dr} = \frac{GM_{\rm tot}(<r)}{r^2}$ 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*=const), e.g. Faerman+17
- Isentropic ($K \propto T/n^{2/3}$=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 ($t_{\rm cool}/t_{\rm ff}$>10), e.g. Sharma+12, Voit+19
- Baryon pasting models (multiple params), see Nagai talk

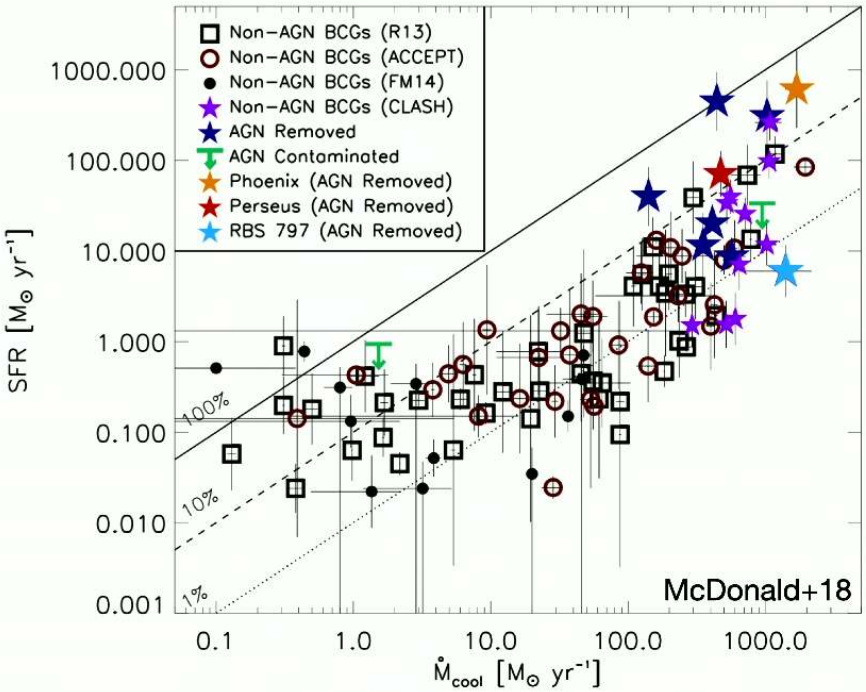
Cooling flows

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

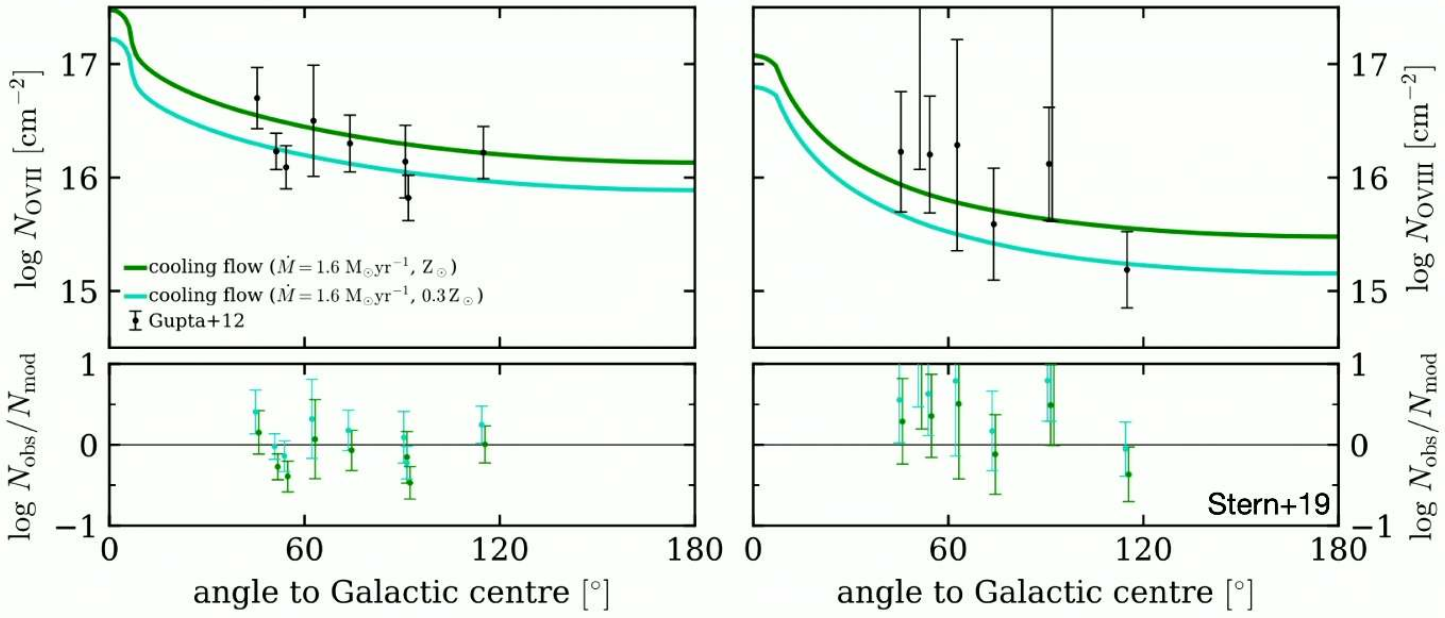
Classic model for the ICM
(e.g. Fabian+84)

Fell out of favor due to
"cooling flow problem":
SFRs ≪ obs. cooling rates



Cooling flows in galaxy-scale halos?

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

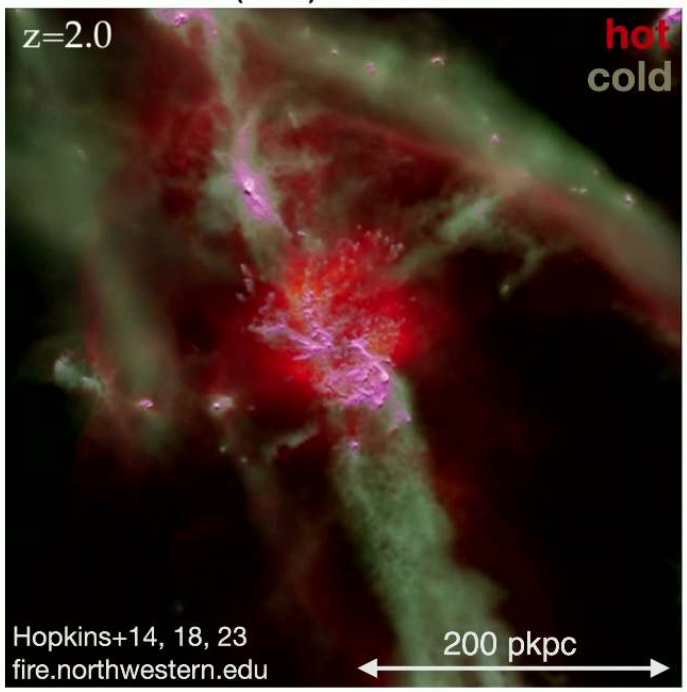


(feedback can push out some baryons at high z)

Testing cooling flows in FIRE galaxy formation simulations

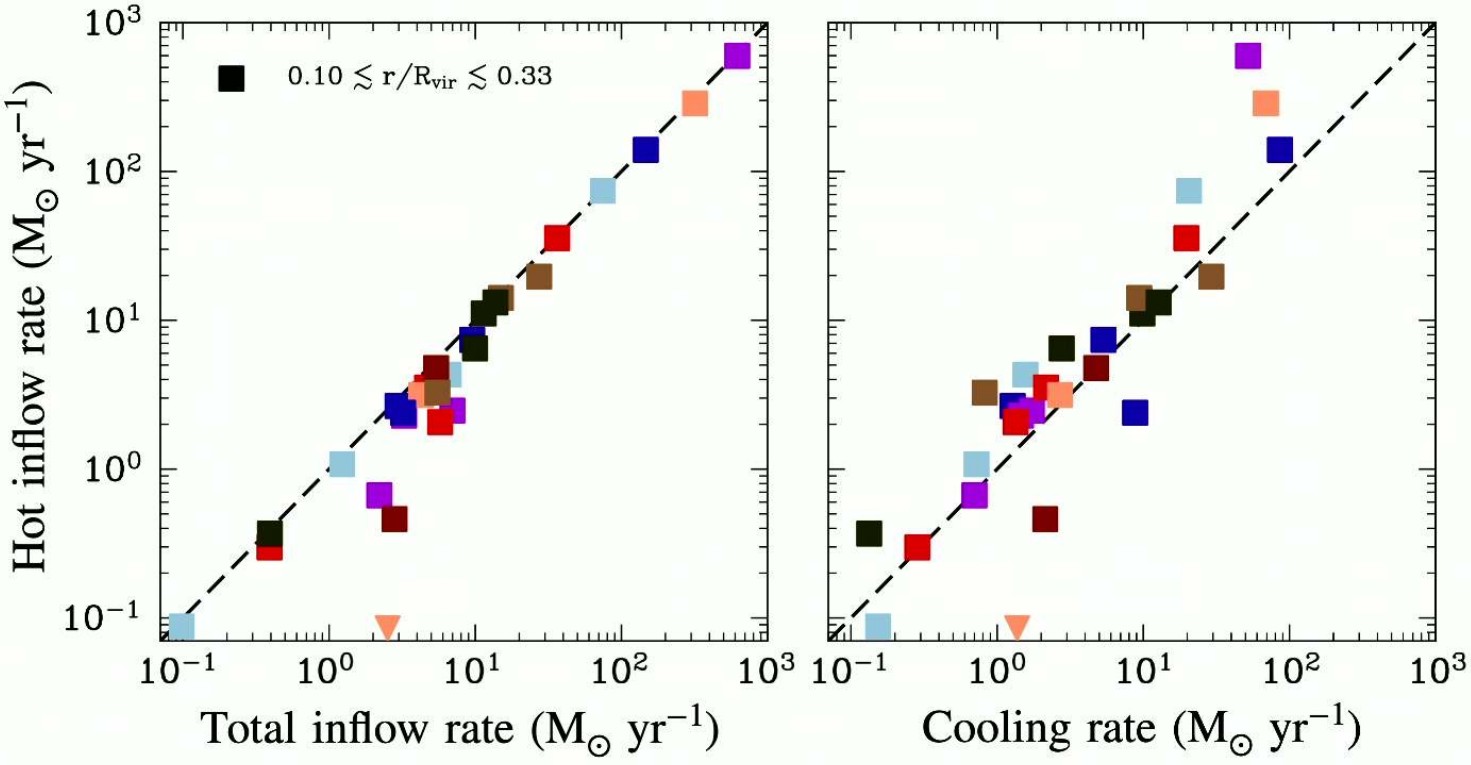
- Zoom-ins including:
  - cosmological environment and evolution
  - stellar feedback (SNe II&Ia, winds, radiation)
  - in some runs, *B* fields
- Focus on M_h~10^{12}-10^{13} M_{sun} and z~0
- Neglect AGN feedback in this study

$M_h(z=0)$~10^{12} M_{sun}



Sultan, FG, Stern+25

Inflows dominated by hot phase, ~consistent with cooling rates



Sultan, FG, Stern+25

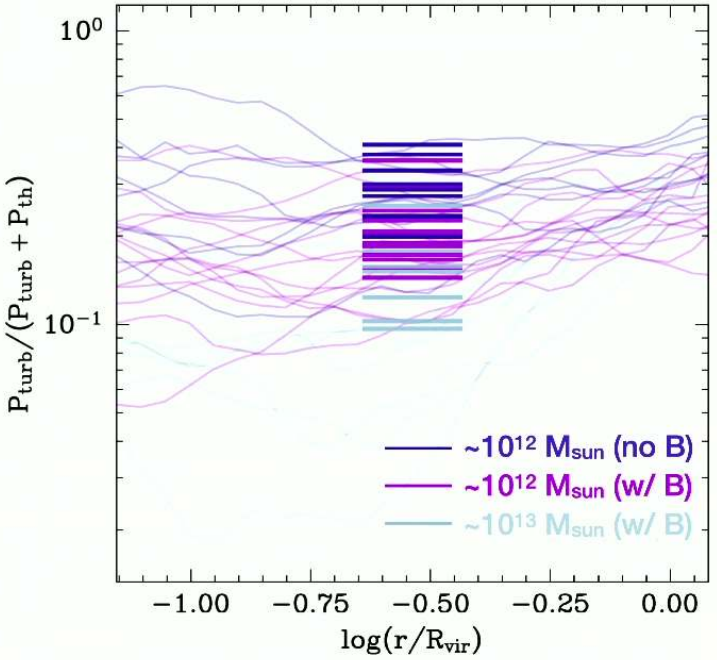
Fitting cooling flows: full thermodynamic profiles

- 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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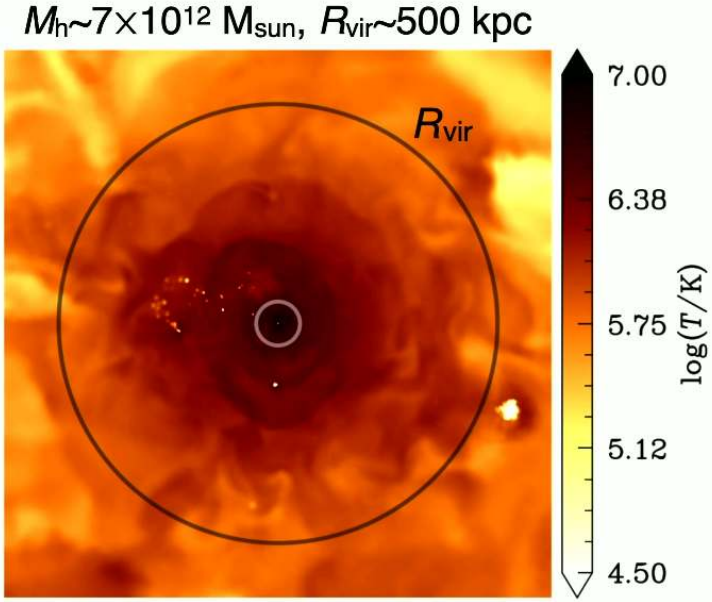
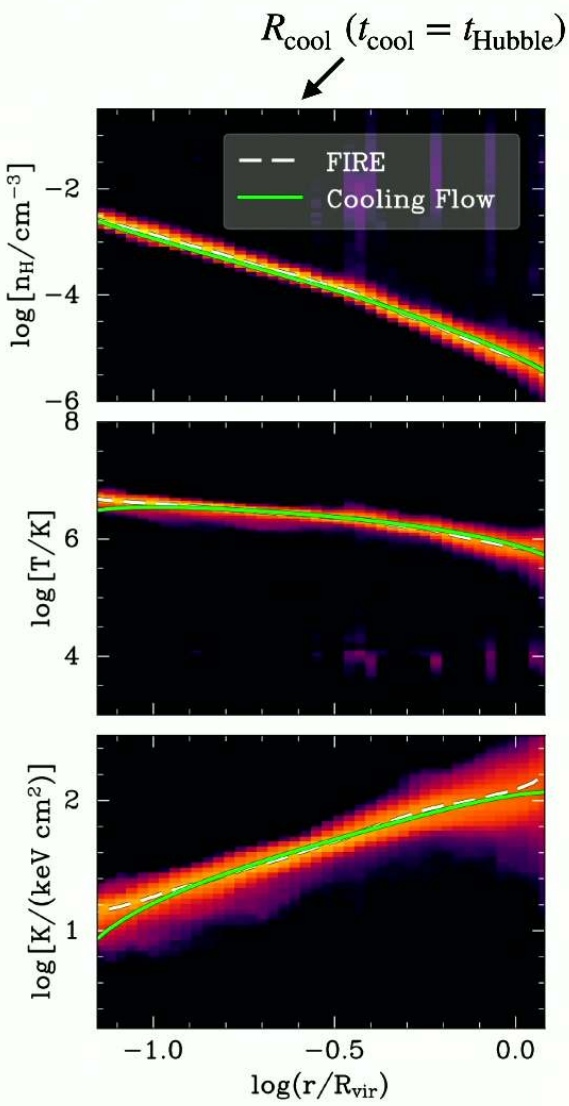
Example cooling flow fit





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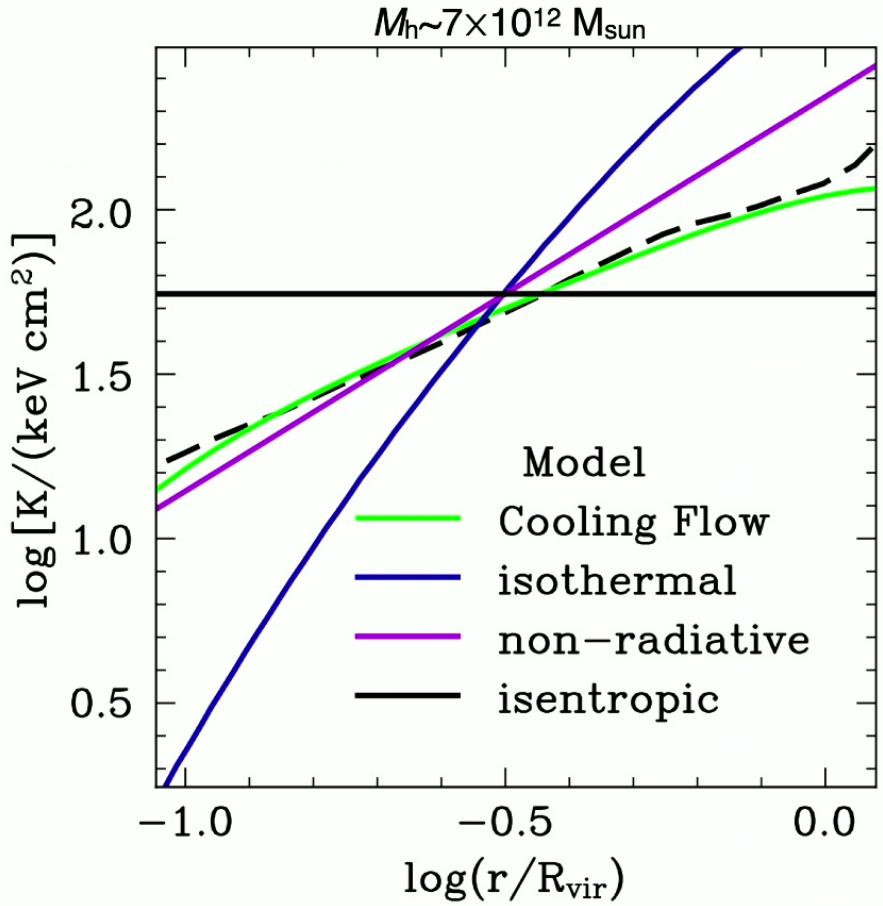
Cooling flows vs. other analytic models



FIRE simulations

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

neglect: -AGN
-cosmic rays
-…

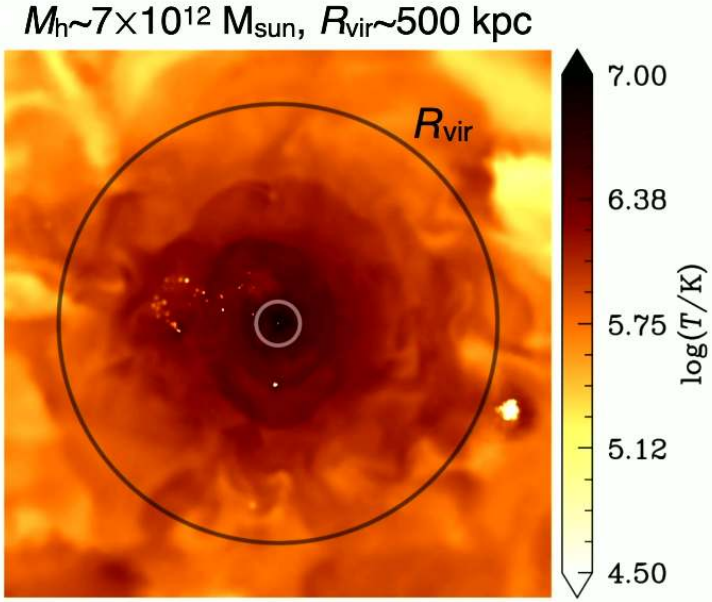
→ "reference solution" to isolate effects of neglected processes

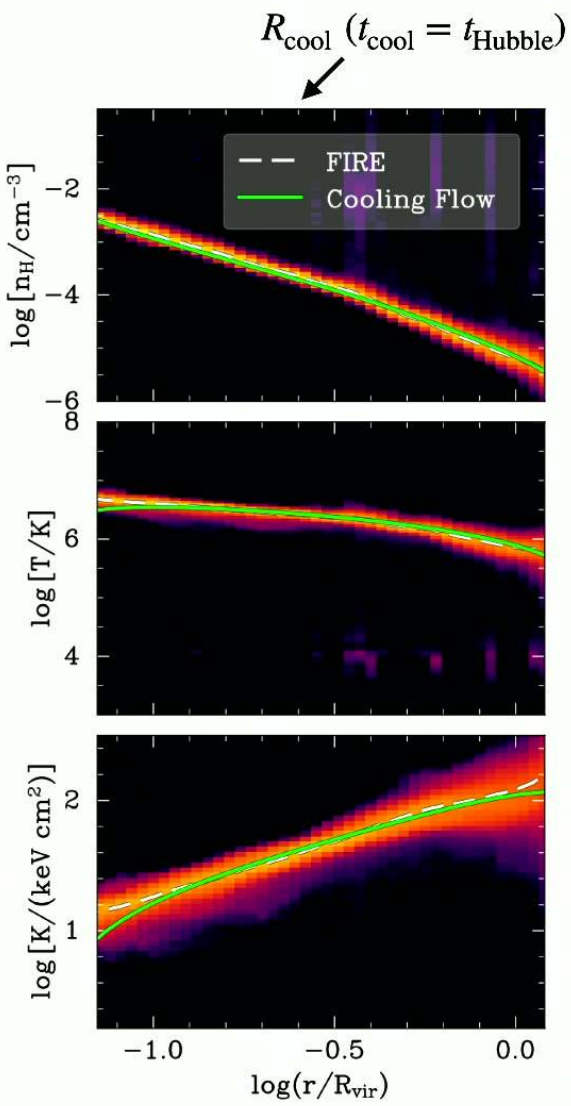
→ understand CGM virialization
(outside-in; Stern+20, 21)

→ 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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