A Dynamically Driven, Universal Thermal Profile of Galaxy Groups and Clusters

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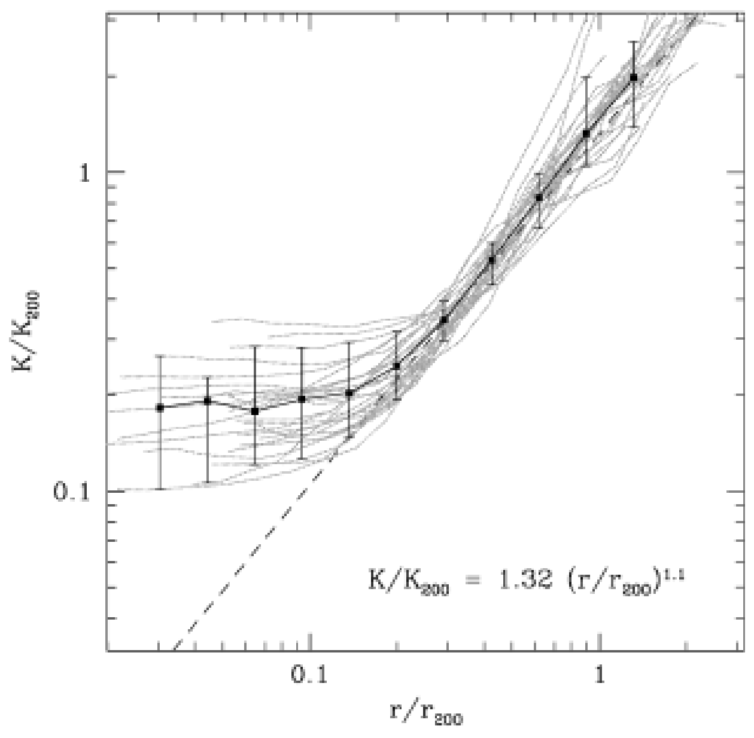
SELF-SIMILAR MODEL (Voit+05)

Cosmological simulation (both SPH and AMR)

No baryonic feedback → Self similar, power-law entropy profile



$K(r) = 1.45 \pm 0.01\, K_{200}\, (r/r_{200})^{1.21\pm0.01}$

for the SPH clusters and

$K(r) = 1.51 \pm 0.03\, K_{200}\, (r/r_{200})^{1.24\pm0.03}$

for the AMR clusters.

$$K_{200} \propto M_{200}^{2/3}$$

ENTROPY PROFILES

The sample: 16 cool-core clusters and 12 groups from the literature, all deprojected

Fit: Pure power law for r>10kpc

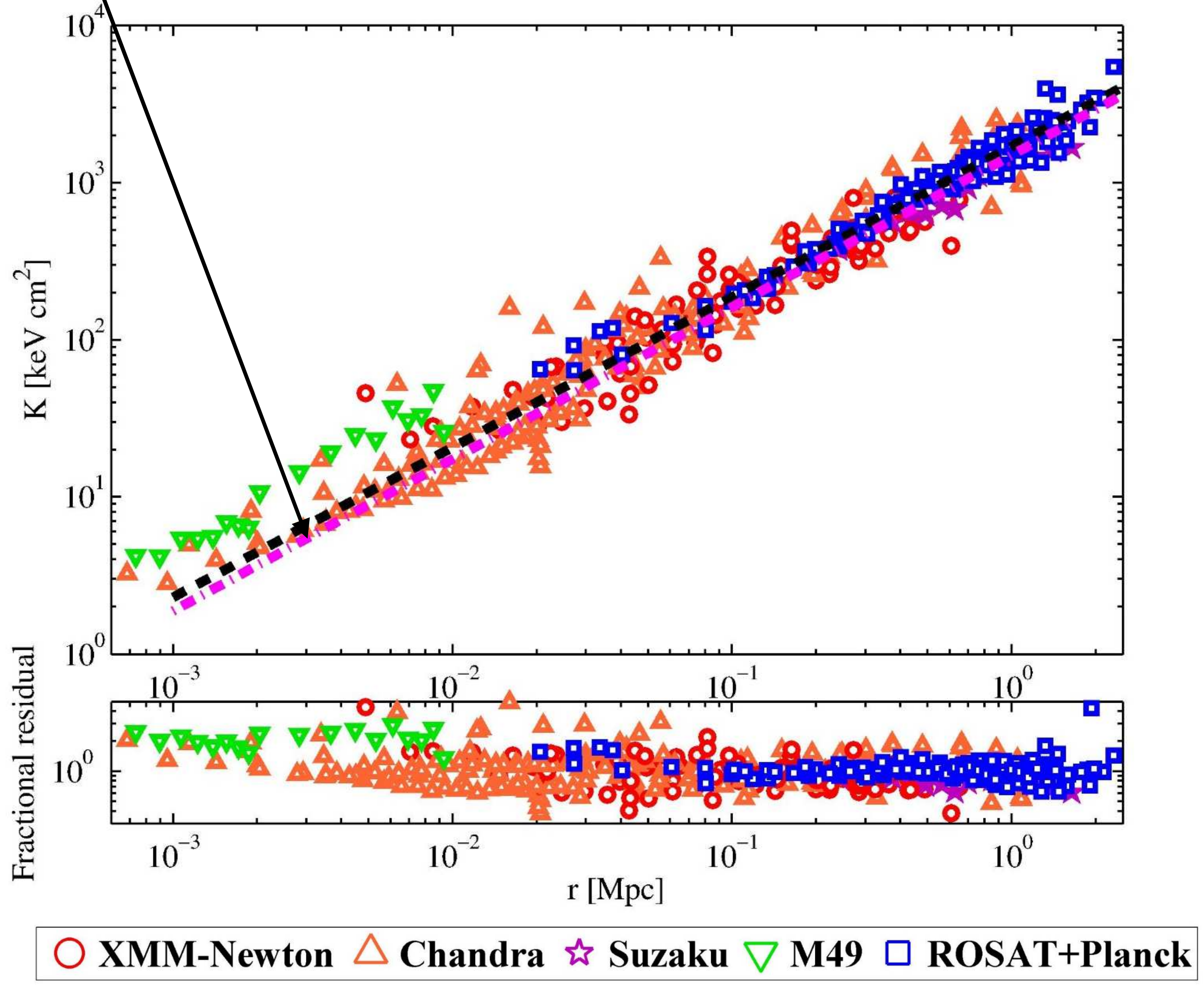
$K = K_{100}\,(r/100\text{ kpc})^{\lambda_K}$

$K_{100} = 187 \pm 6\text{ keV cm}^2$

$\lambda_K = 0.96 \pm 0.01$

λ_K Inconsistent with Voit+05 by >8σ

$$K = n_e^{-2/3} k_B T$$

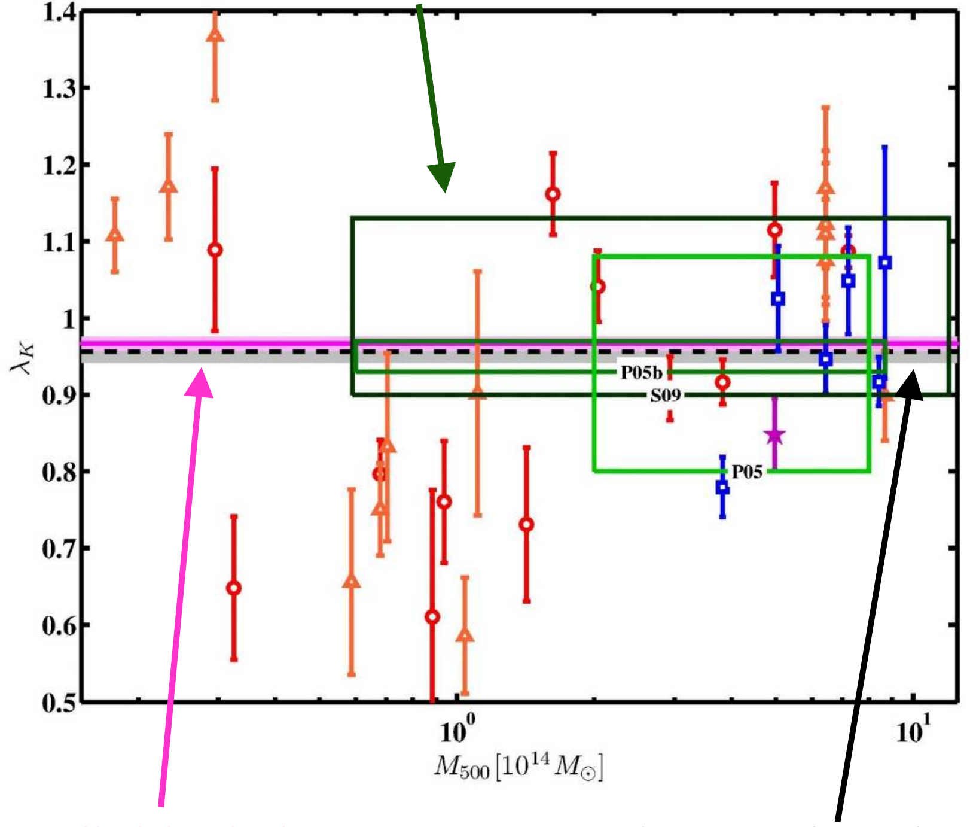


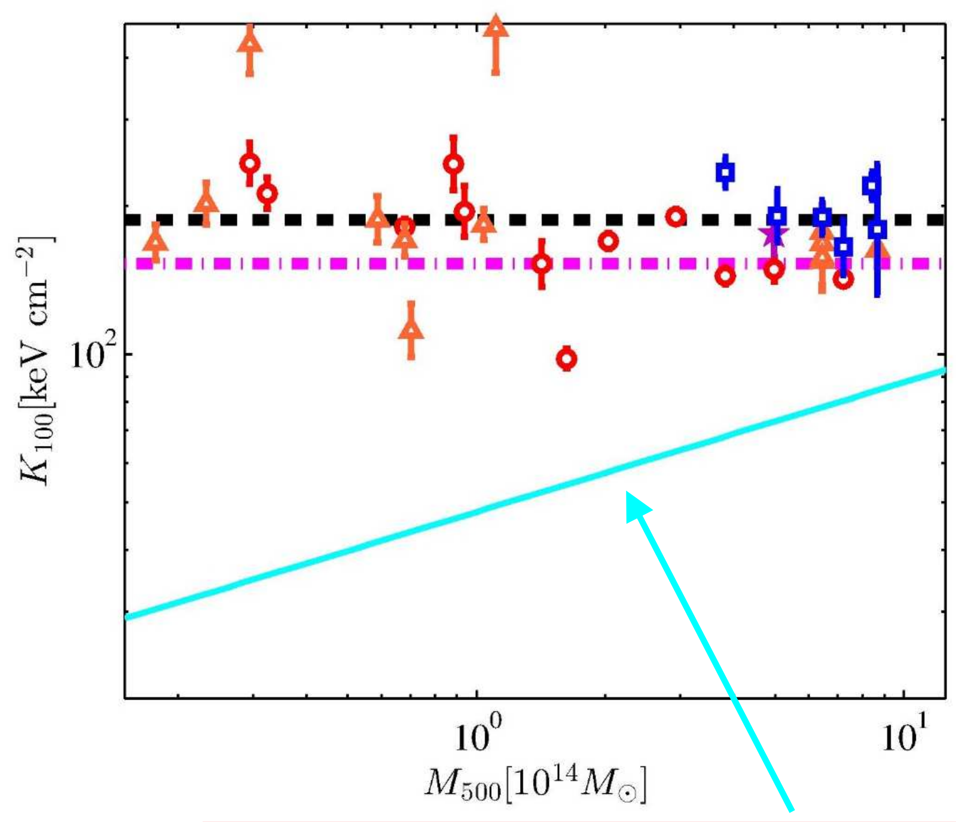
INDIVIDUAL PROFILES

Showing results for individual cluster with >4 points for r>10kpc

Previous Samples:
P05 – Pratt+05
P05b – Piffaretti+05
S09 – Sanderson+09

No mass Correlation for K100 – inconsistent with Voit+05 by >8σ





Individual cluster mean

Entire r>10kpc data mean

Voit+05 prediction – too low by >6.5σ

COOLING TIME TO FREE-FALL TIME RATIO

Free fall time

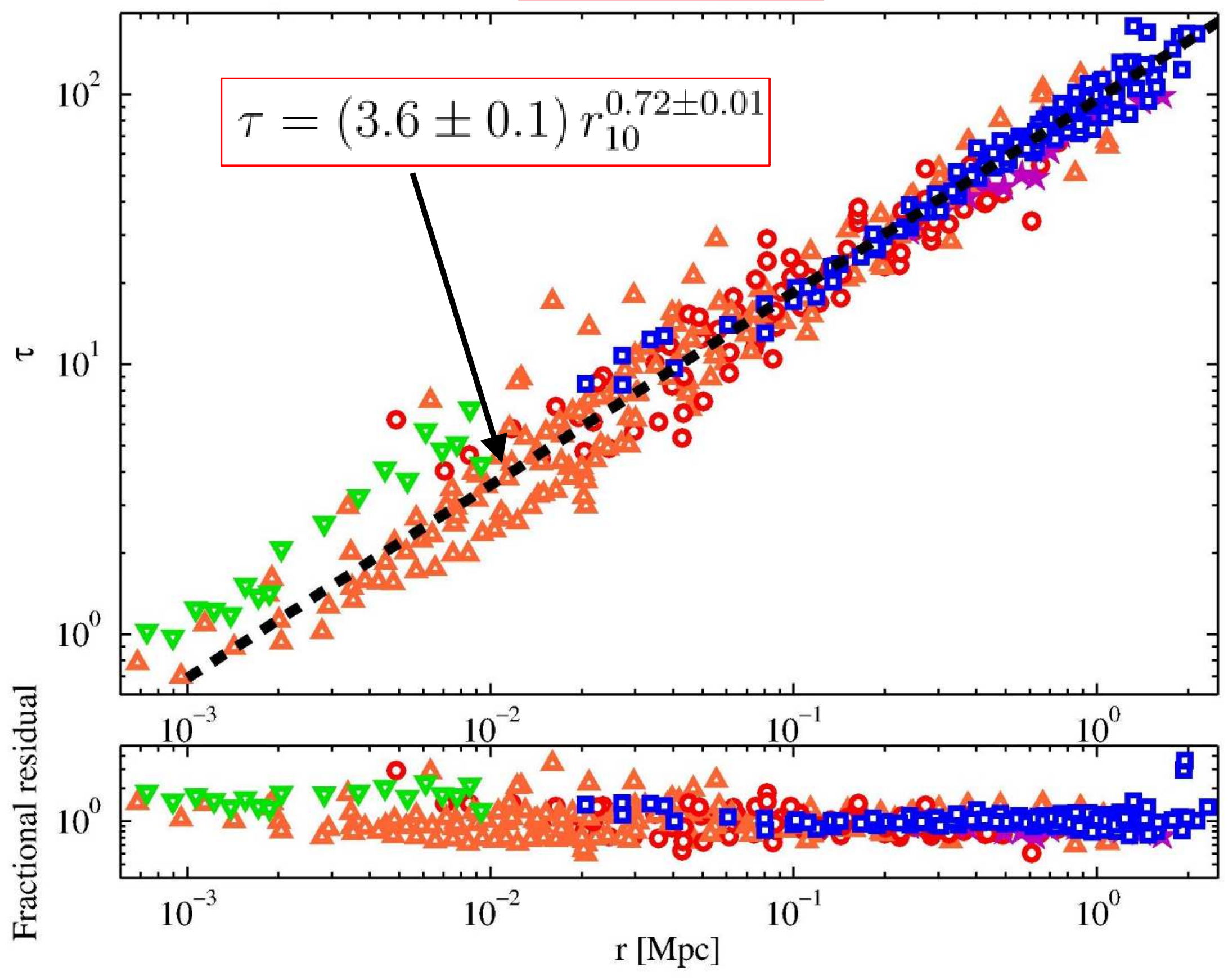
$$t_{\rm ff} \equiv (G\rho_{\rm tot})^{-1/2} = (f_{\rm g}/G\rho)^{1/2}$$

Cooling time

$$t_{\rm cool} \equiv \frac{U_{th}}{dE/dt} = \frac{(3/2)\zeta n_e k_{\rm B} T}{n_e^2 \Lambda(T)}$$

$$\tau \equiv t_{\rm cool}/t_{\rm ff}$$

$$\tau = (3.6 \pm 0.1)\, r_{10}^{0.72\pm0.01}$$



$$\tau \propto \left[\frac{T^{1/4}}{f_{\rm g}^{1/2}\Lambda(T)}\right] K^{3/4}$$

A broader temperature span is needed in order to determine which is a better fit

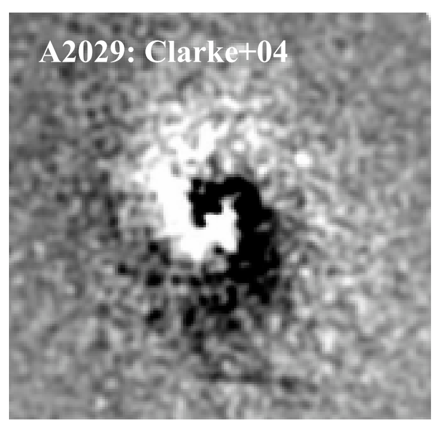
- **No minimum in τ.**
- **For small radii, τ≈1.**
- **No distinction between cluster with and without Hα (Unlike McCourt+12).**

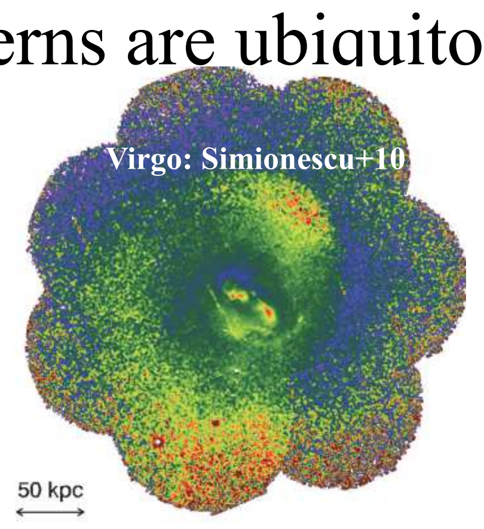
DYNAMIC ORIGIN OF THE UNIVERSAL PROFILE

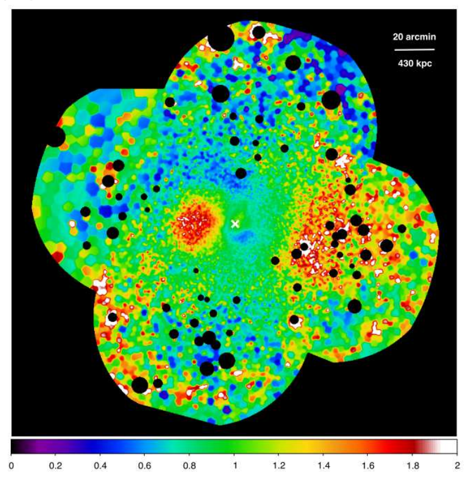
- **Self similar model (Voit+05) is ruled out: (i) no break in core; (ii) no K_{100} - M_{500} correlation; (iii) wrong normalization; (iv) wrong power-law**
- **Radial Heat Conduction (Zakamska+03, Dolag+04) unlikely in both side of temperature peak**
- **A robust, dynamical, nonlocal mechanism is needed to sustain the universal profile**

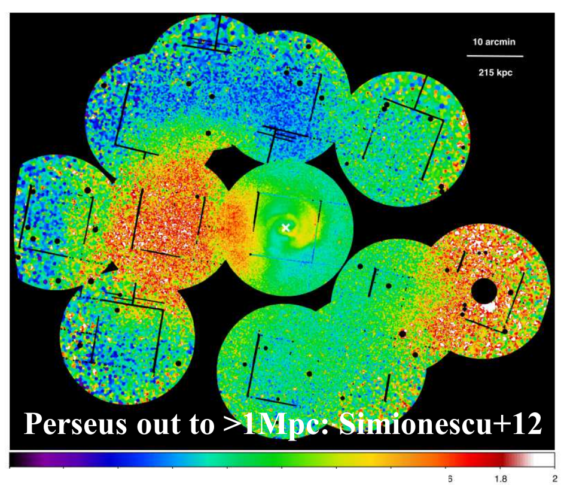
POSSIBLE SPIRAL ORIGIN

- Spiral patterns are ubiquitous


A2029: Clarke+04


Virgo: Simionescu+10




Perseus out to >1Mpc: Simionescu+12

- The azimuthal gradients govern the flow. If $\partial_\phi \log \sim L/(2\pi r)$

Balancing cooling and azimuthal heat conduction

$$\frac{K}{r} = \frac{k_{\rm B}T}{n_e^{2/3} r} \simeq k_{\rm B}\left(\frac{2\pi\Lambda_0}{\kappa_0 L}\right)^{1/3} = \text{const.},$$

$$L \simeq 10\text{ kpc}$$

Balancing cooling and radial heat advection

$$\frac{\tau^{4/3}}{r} \simeq C\frac{(k_{\rm B}T)^{2/3}}{n_e^{2/3} r} \simeq \left(\frac{9\pi\zeta^4}{2\gamma f_{\rm g}^2}\right)^{1/3} \frac{1}{L_0^{2/3} L^{1/3}} = \text{const.},$$

$$L \simeq 1\text{ kpc}.$$

Similar values of order of the base of the spiral

- Solved a simple, analytic, two flow model along spiral CFs (Based on Keshet 12): (i) Fast, cold adiabatic flow below the CF; (ii) Slow, Hot inflow above the CF.
- **Entropy is nearly linear and independent of pressure slope**

Property A	Logarithmic derivative $\lambda_A = d\log\lvert A\rvert/d\log(r)$	
Pressure P	$\lambda \equiv \lambda_P$	
Spiral slope γ	$\frac{-2\lambda+4\Gamma(1+\lambda)}{7\Gamma} = \frac{4}{7}+\frac{2}{5}\lambda$	
Curvature	$\frac{r}{R_\theta} = -\frac{\lambda}{\Gamma}$	
	Fast phase	Slow phase
Density ρ	$\frac{\lambda}{\Gamma} = \frac{3\lambda}{5}$	$\frac{-4\Gamma+(3\Gamma+2)\lambda}{7\Gamma} = -\frac{4}{7}+\frac{3}{5}\lambda$
Temperature T	$\frac{\Gamma-1}{\Gamma}\lambda = \frac{2\lambda}{5}$	$\frac{-2\lambda+4\Gamma(1+\lambda)}{7\Gamma} = \frac{4}{7}+\frac{2}{5}\lambda$
Radial velocity v	$\frac{-3\Gamma+(4\Gamma-2)\lambda}{7\Gamma} = -\frac{3}{7}+\frac{2}{5}\lambda$	$\frac{\Gamma+(3+\Gamma)\lambda}{7\Gamma} = \frac{1}{7}+\frac{2}{5}\lambda$
Tangential velocity w	-1	$-\frac{3\Gamma-(5-3\Gamma)\lambda}{7\Gamma} = -\frac{3}{7}$
Entropy K	0	$\boxed{\frac{4\Gamma+(5-3\Gamma)\lambda}{7} = \frac{20}{21}}$

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