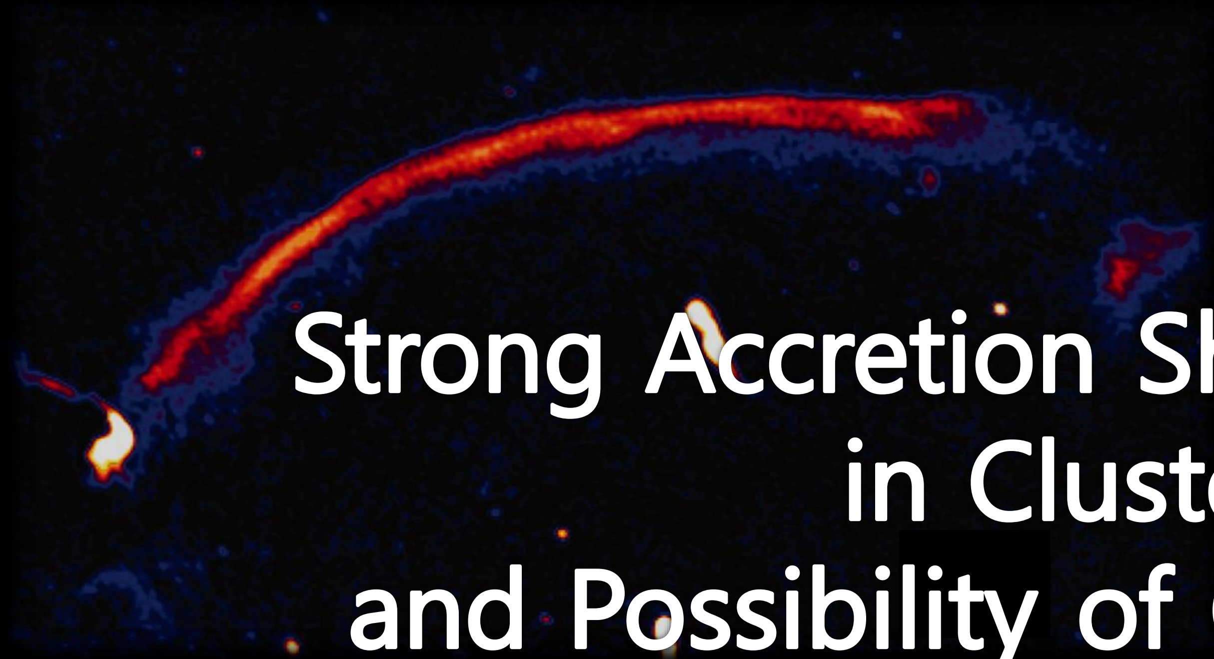


# Strong Accretion Shock Waves in Cluster Outskirts and Possibility of Cosmic Ray Population Inversion

Sungwook E. Hong (Chungnam Nat'l Univ.)
with Dongsu Ryu & Hyesung Kang

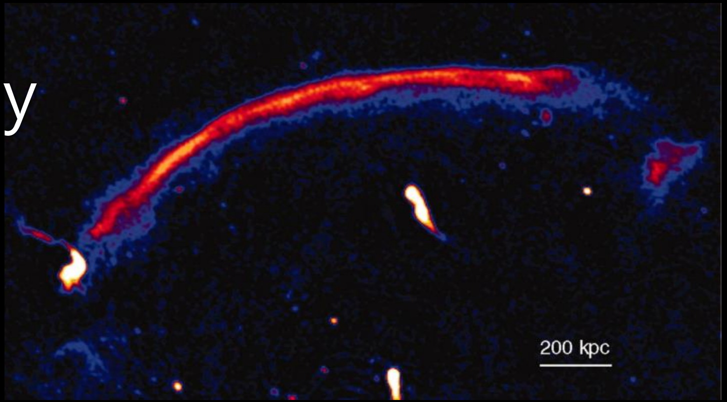
at KNAG meeting 2012, October 5th.

Theoretical Astrophysics Group

# Cosmological shocks

- Generated by the gas infall
  and the CDM hierarchical clustering

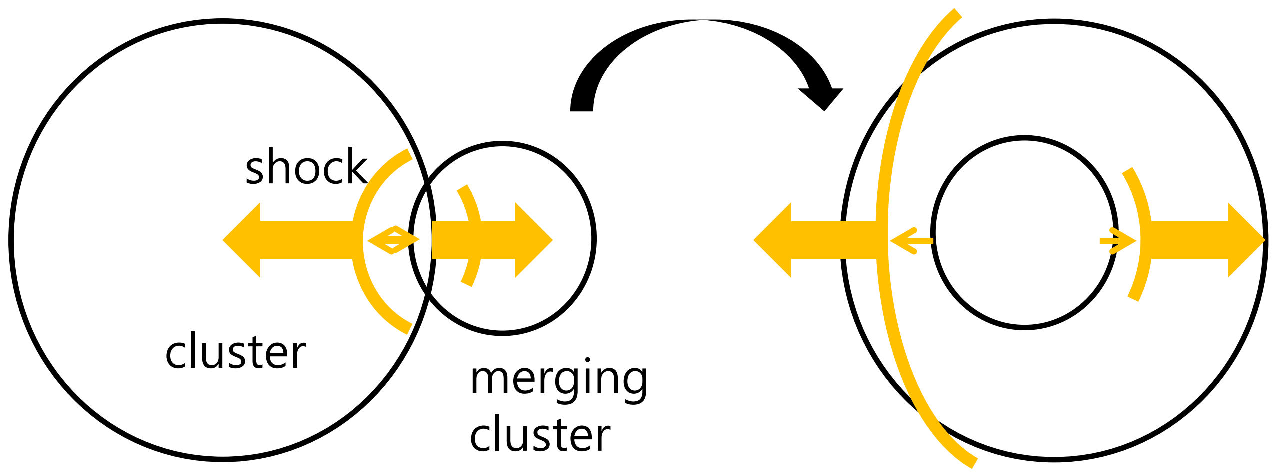
- Transform the gravitational energy
  to the gas thermal energy
  and the cosmic ray energy



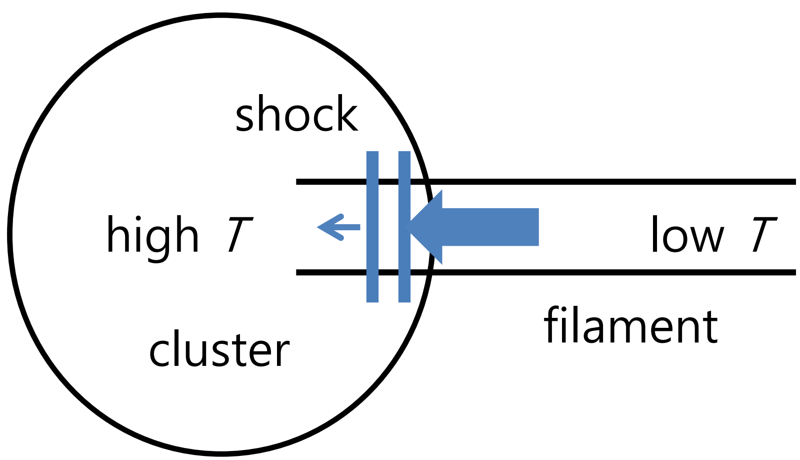

- Source of many radio structures
  such as radio relics

# Q1. Merger or Accretion?

merger:




accretion:



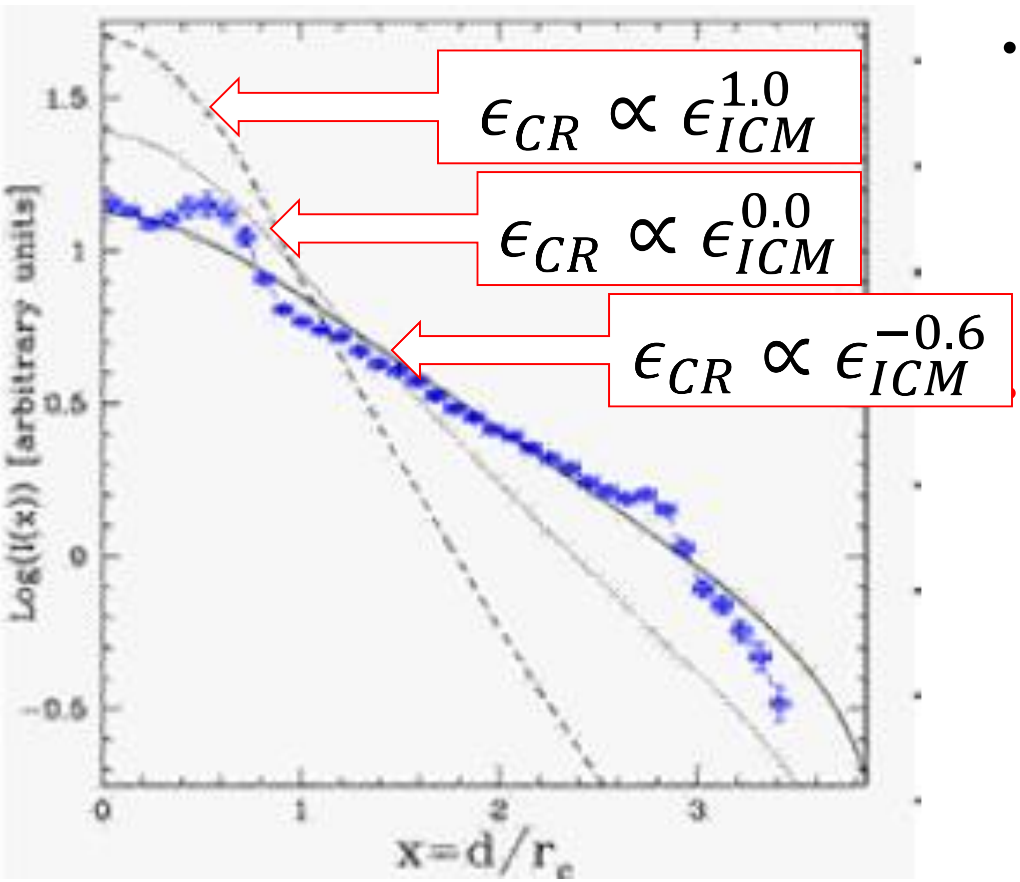
# Q1. Merger or Accretion?

- Accretion shocks has a larger Mach number $M \sim 10^{1-2}$.

- Accretion shocks are expected to be in the cluster outskirts, hence usually regarded as less important at the cluster center than the merger shocks.

# Q2. Inverted CR population?

**Radio brightness profile of Coma cluster**




Brunetti et al (2012)

- This may indicate the existence of inverted CR population at the cluster center – greater population at larger radius.

**Strong accretion shock in the cluster outskirts?**

# Simulations

**Ryu et al (1993)**

***HD simulation***
- density
- velocity
- pressure
- temperature
- X-ray emissivity
- magnetic field

16 sets of $1024^3$ 100Mpc/h
adiabatic

+ $2048^3$ 100Mpc/h
with heating/cooling (Cen & Chisari 2011)

***Clusters***
- mass
- X-ray luminosity

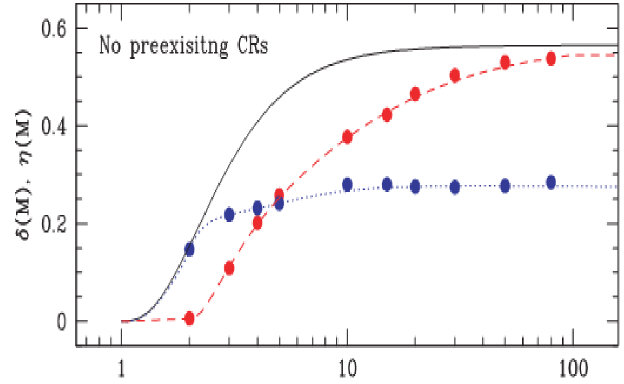
- Using local maximum X-ray luminosity
- Using large clusters with T > 2keV

***Shocks***
- Mach number
- shock speed
- kinetic energy

• • •

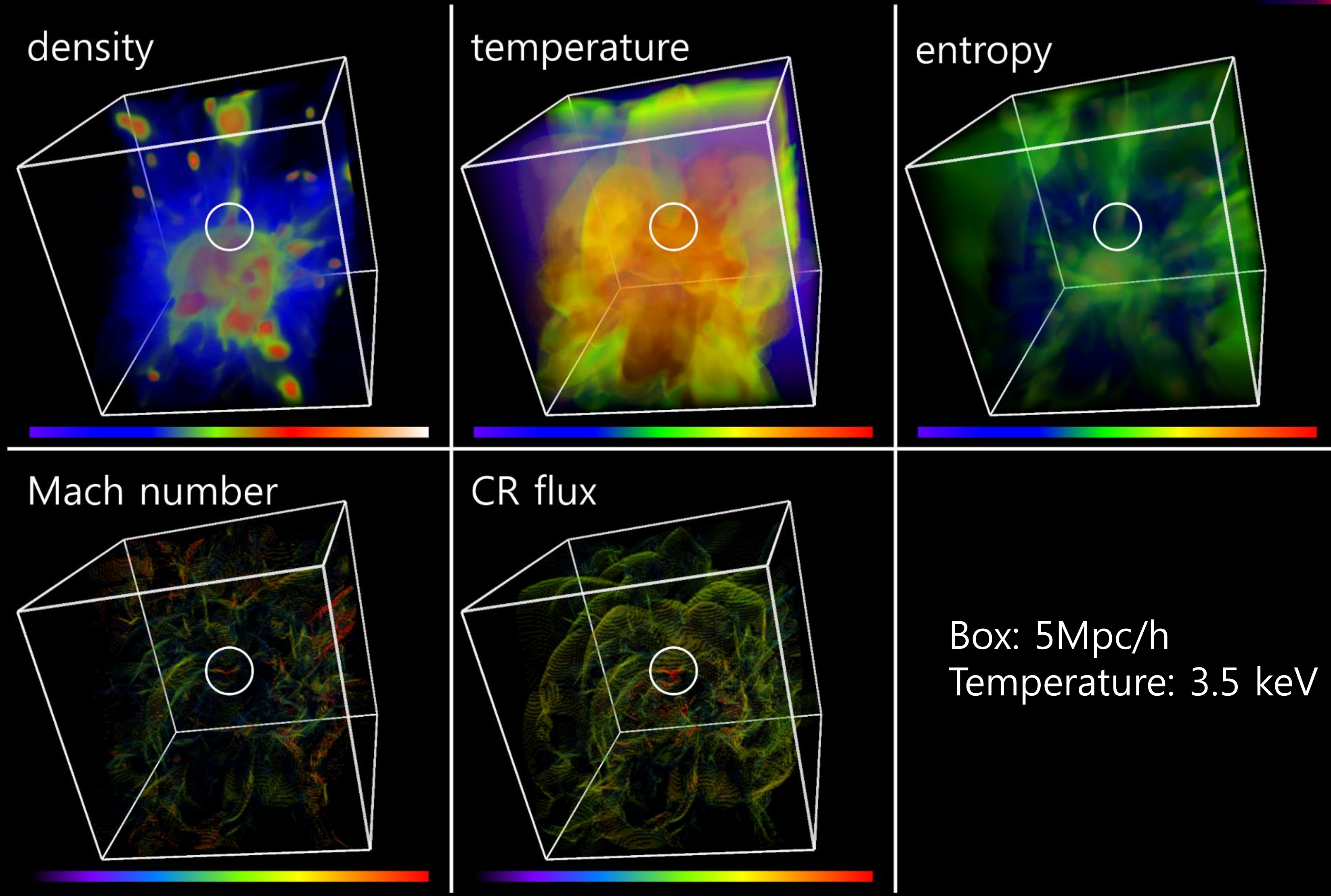
- Detect only M > 1.5

CR flux = $\frac{1}{2}\rho(c_s M)^3\eta(M)$

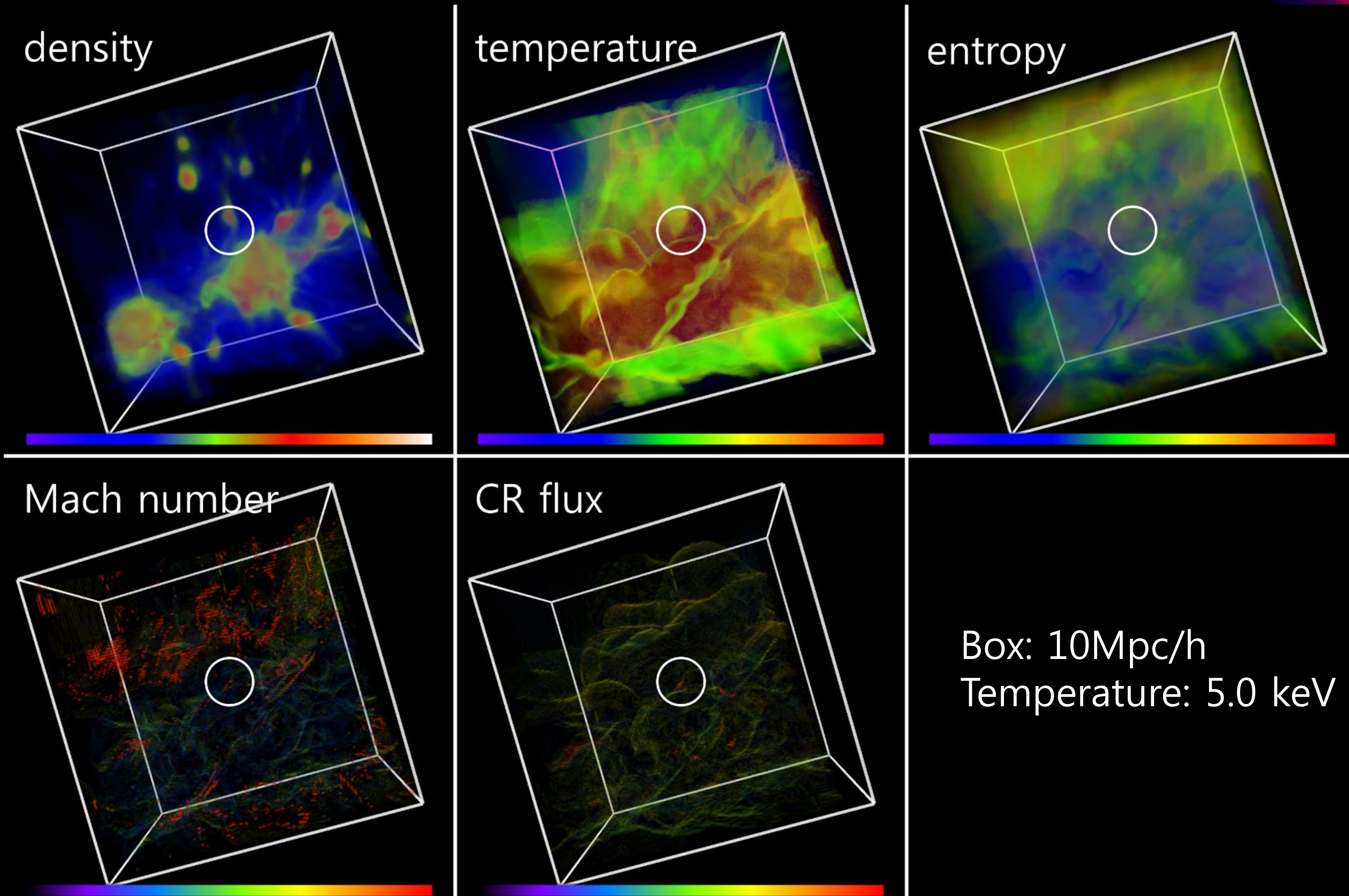



Kang et al (2007)

# Strong accretion shocks at cluster outskirts

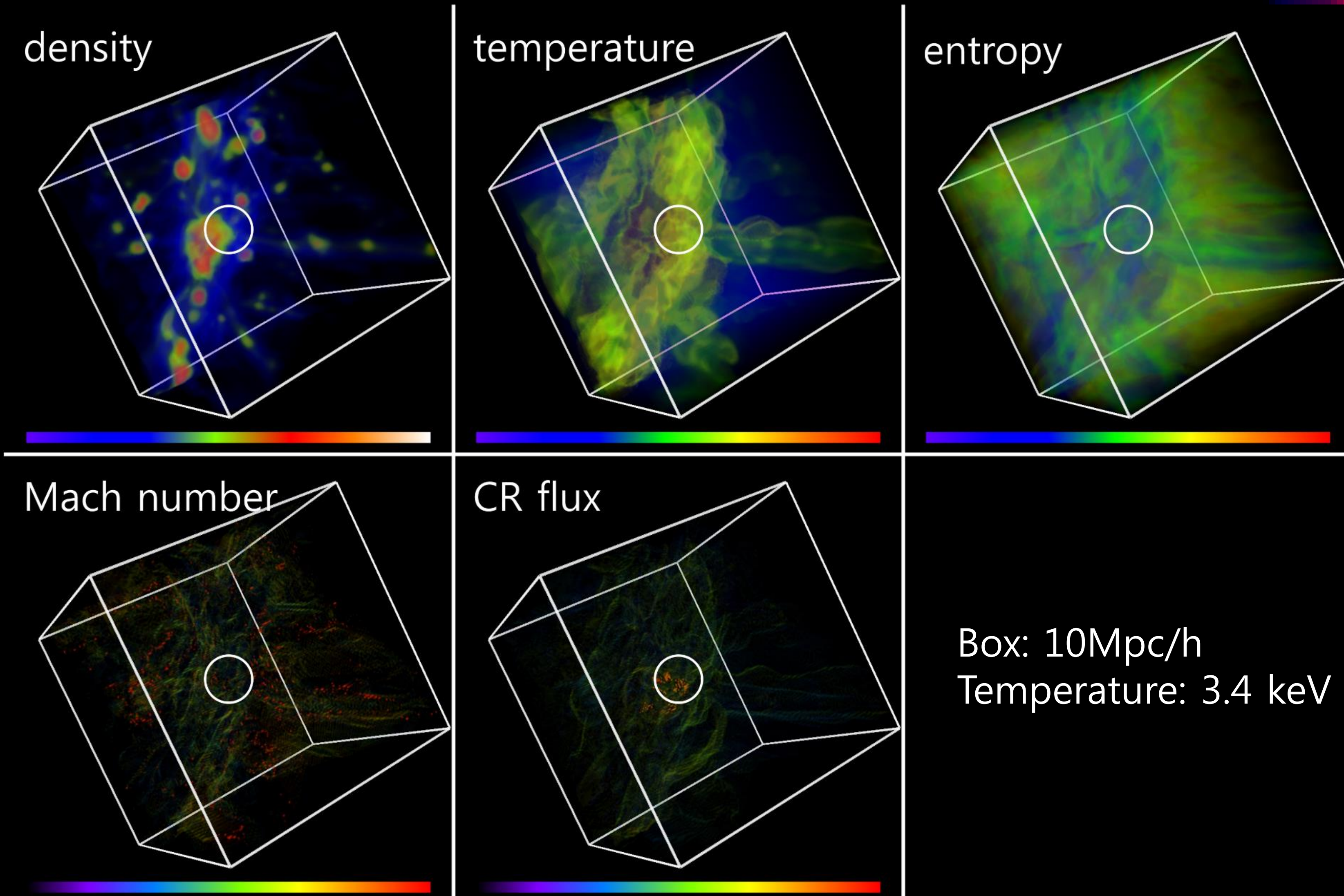


# Strong accretion shocks at cluster outskirts

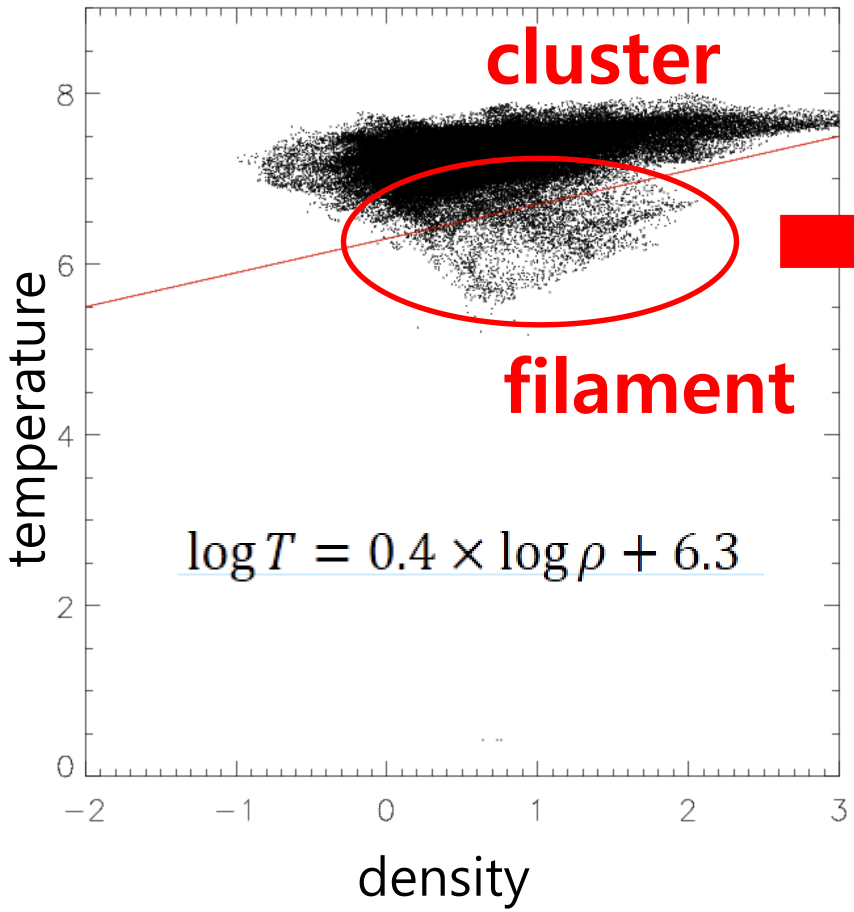



Box: 10Mpc/h
Temperature: 5.0 keV

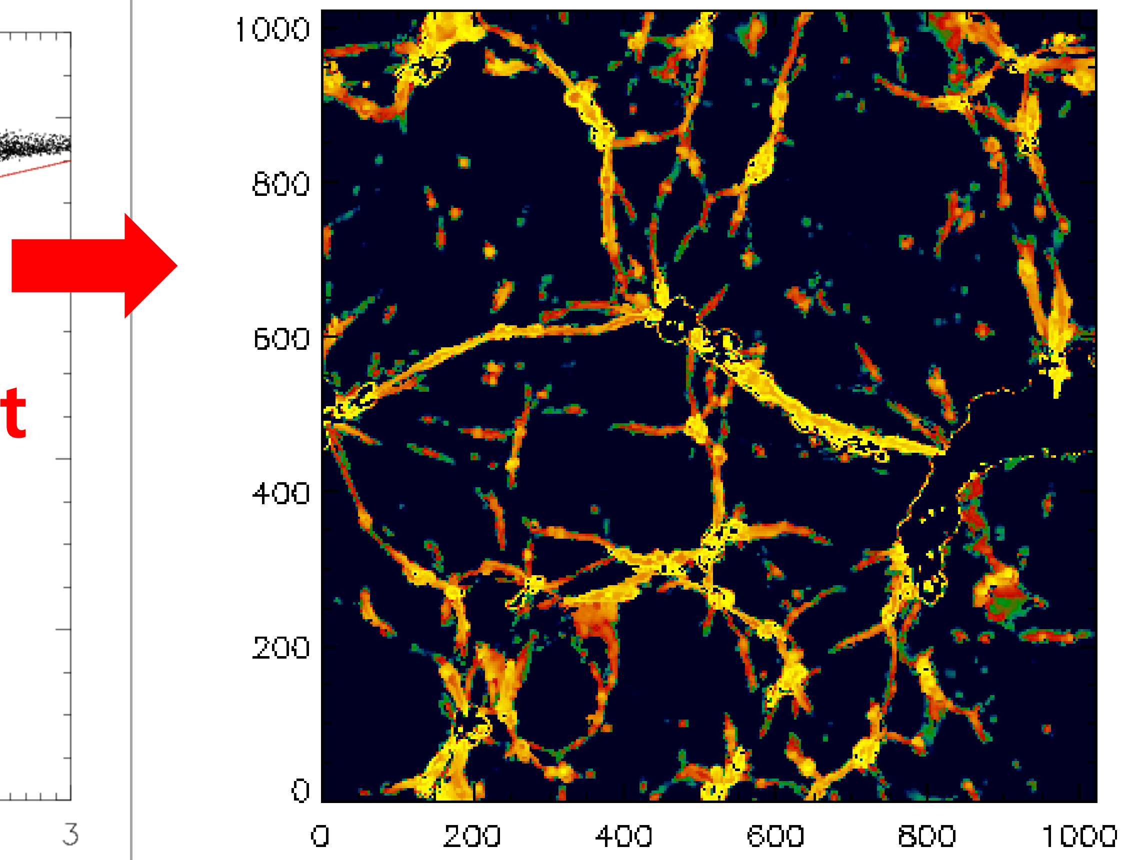
# Strong accretion shocks at cluster outskirts



# How often does it occur?




$$\log T = 0.4 \times \log \rho + 6.3$$



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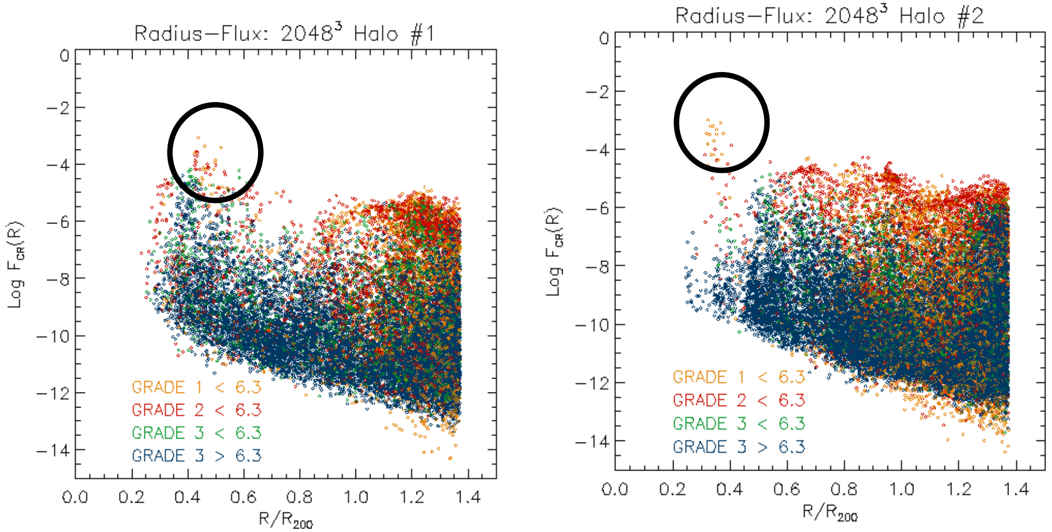
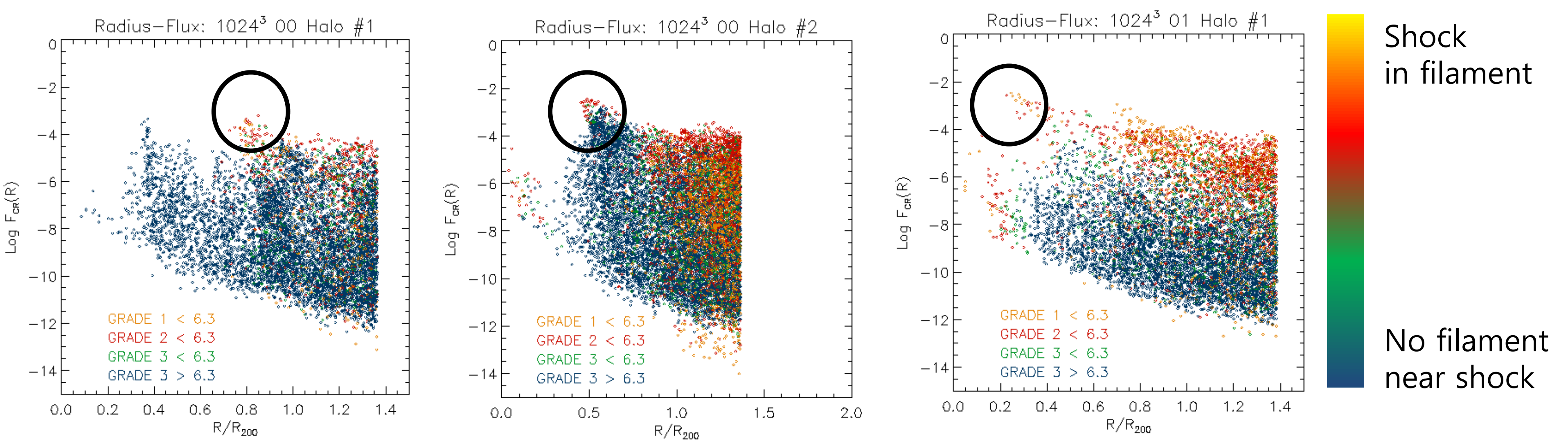



Strong accretion shocks exist for many clusters with T>3keV



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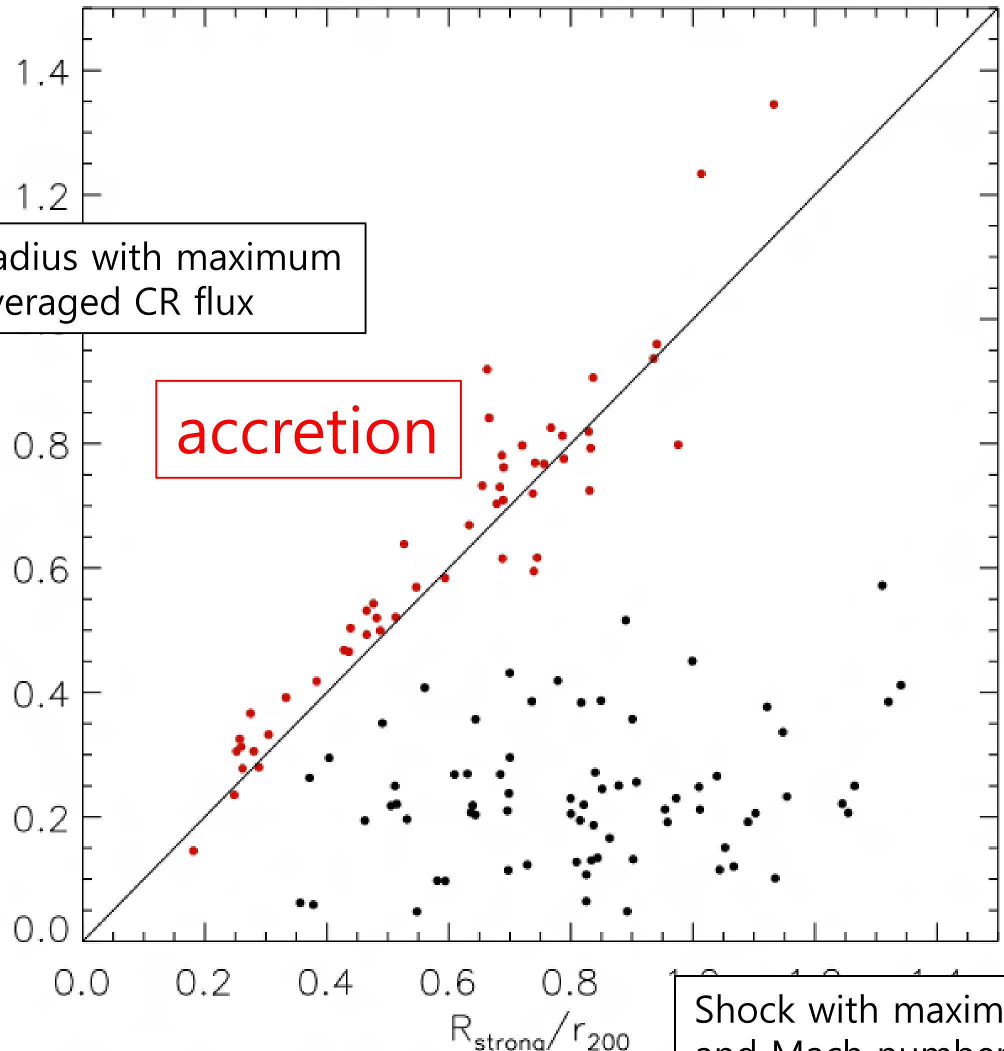
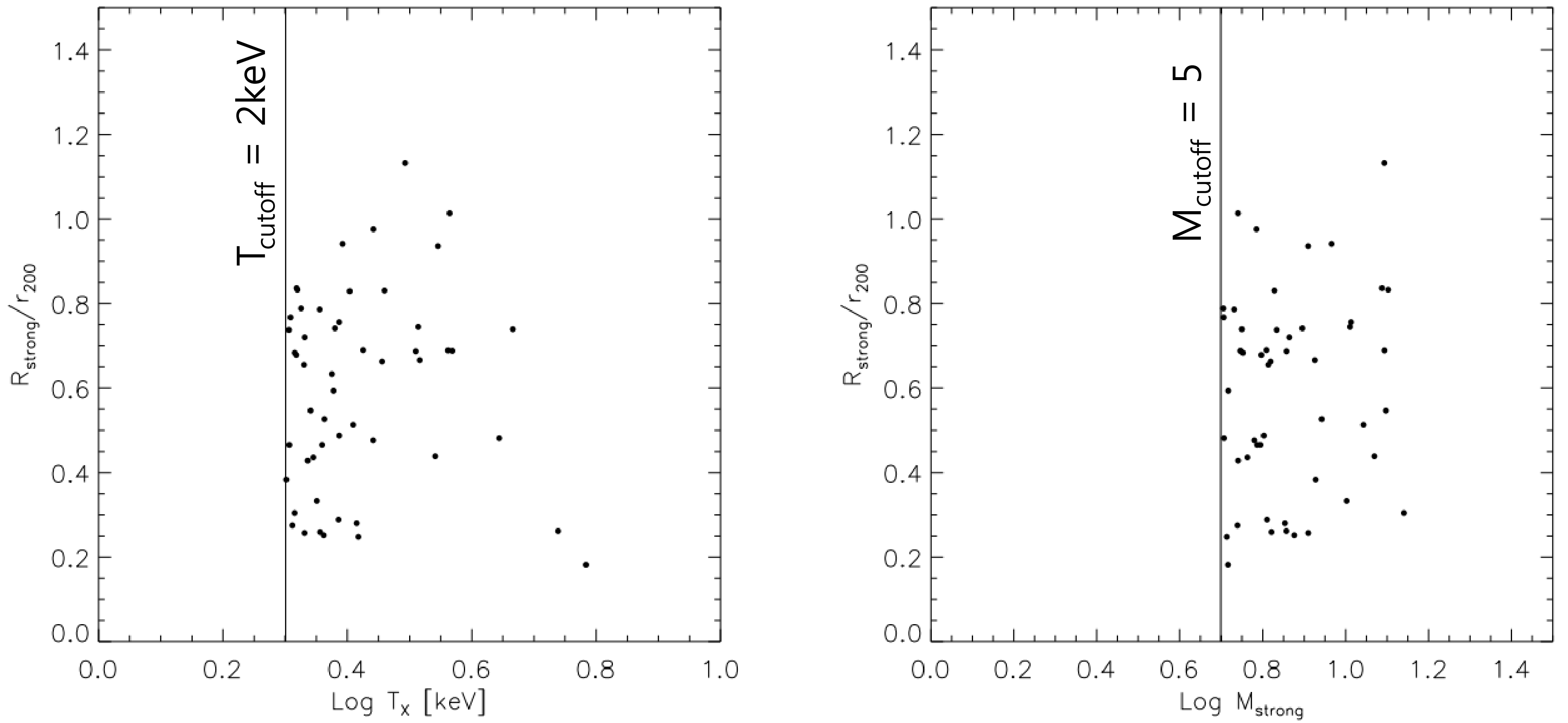



adius with maximum
veraged CR flux

Shock with maximum CR flux
and Mach number > 5 (CR efficiency > 10%)

~50% of strong CR flux is associated with the strong accretion shocks

# Distribution of strong shocks



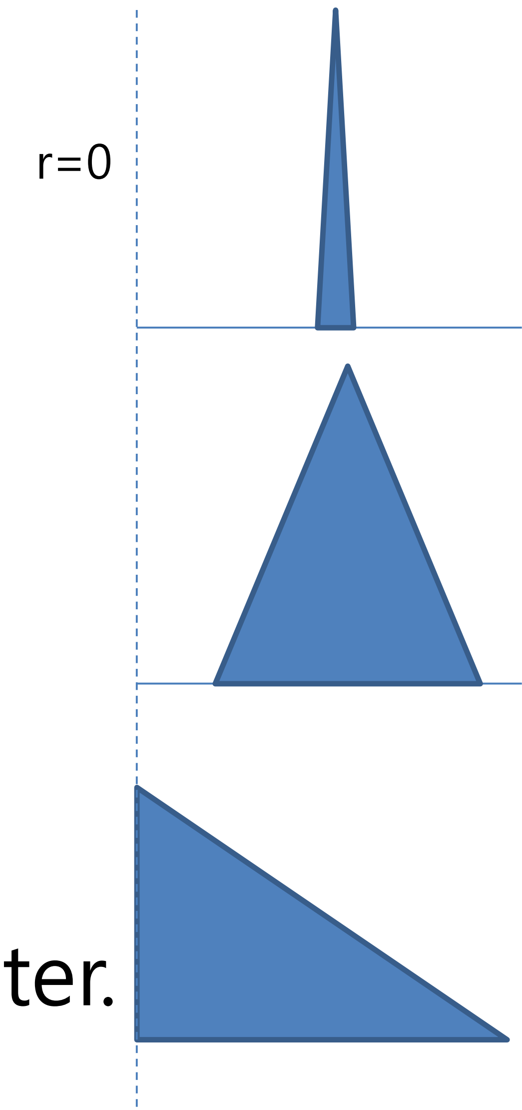

Strong shocks exist around the virial radius

# Modeling the CR inverted population

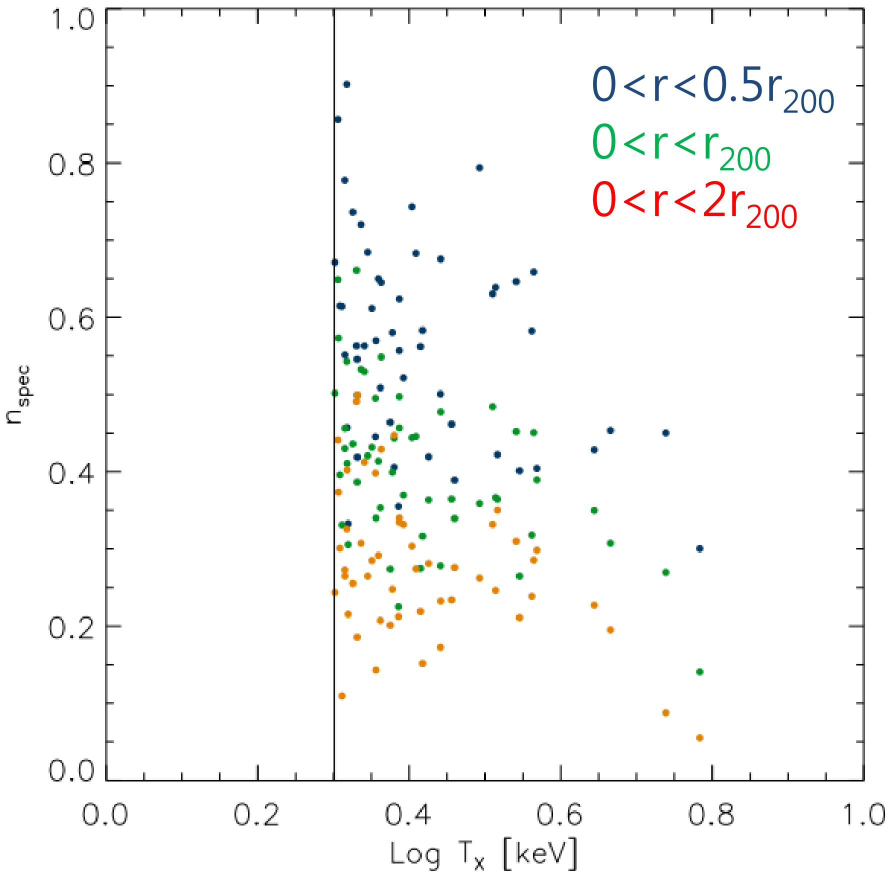
- CR generated at $r=R_{strong}$
- It diffuses the cluster with diffusion coefficient

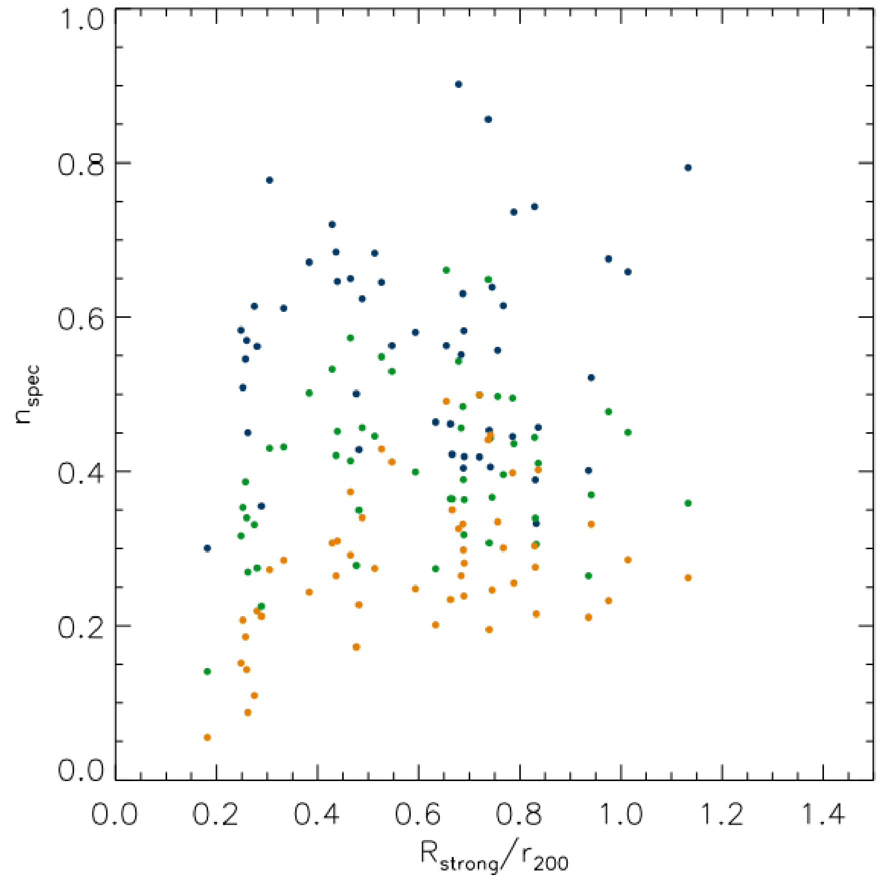
$$D(r) = rV(r) \sim r^{n+1}$$

- CR population may be temporally inverted before reaching the cluster center.



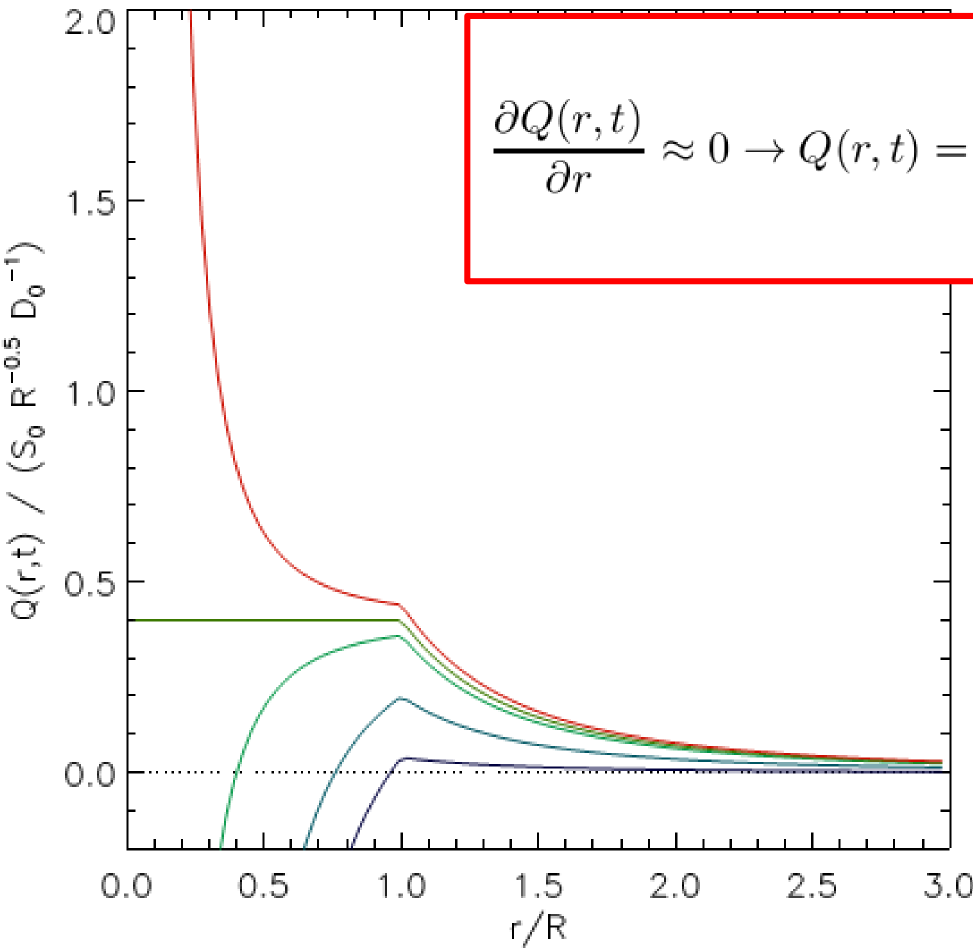
# Modeling the CR inverted population




$V(r)\sim r^{0.5}$ near the strong shocks

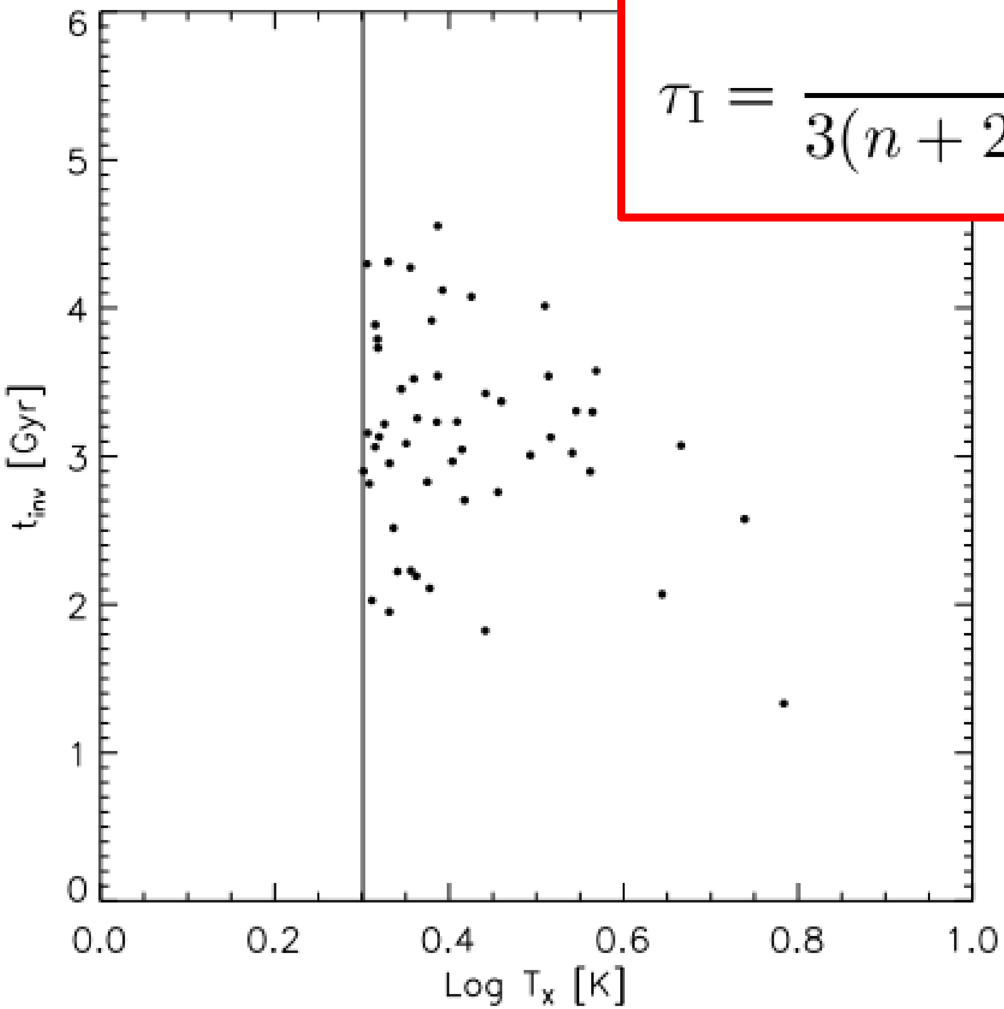
# Modeling the CR inverted population




$$\frac{\partial Q(r,t)}{\partial r} \approx 0 \rightarrow Q(r,t) = \begin{cases} \frac{1}{n+2}\frac{S_0 R^{-n} - C(t) r^{-(n+2)}}{D_0} & \text{for } r < R \\ \frac{1}{n+2}\frac{S_0 R^2 - C(t)}{D_0} r^{-(n+2)} & \text{for } r > R \end{cases}$$

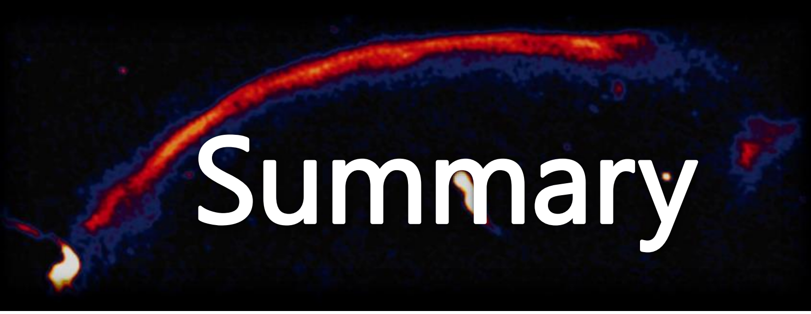
CR population is inversed while C(t)>0

# Modeling the CR inverted population




$$\tau_{\rm I} = \frac{1}{3(n+2)(1-n)} \frac{3r_{\rm max}^{1-n} - (n+2)R^{1-n}}{D_0}$$

Inverted CR population may exist for some clusters



# Summary

- We study the properties of the strong accretion shocks in the cluster outskirts.

- ~50% of the strong accretion shocks contribute the strong CR flux source, which may induce the CR population inversion.