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Numerical Simulations of Merging Galaxy Clusters: Ram Pressure-stripping in the Subclusters and Magnetic Fields Evolution

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(Abstract)

Merging clusters of galaxies are the sites of the structure formation in the universe that can be investigated in detail through different types of observations. Mergers cause various temporal structures, which give us clues to investigate physical process in the intracluster medium and dark matter. In this poster, we'd like to present our recent results of the numerical simulations of merging galaxy clusters.

Using an N-body + hydrodynamical code, we study X-ray and mass distribution, and ram pressure-stripping process in the subclusters. We also estimate the ram pressure-stripping conditions in mergers of two NFW dark halos using a simple analytical model. These results are compared with a famous merging cluster 1E0657-56.

Furthermore, we investigate magnetic field evolution in merging clusters using an N-body + magnetohydrodynamical code. We find that the dynamical motion of the substructure produces relatively ordered magnetic field configurations both along the boundary layer and just behind of the subclusters. These structures could be observed as the regions with high Faraday rotation measure.

1E0657-56 cluster

- The highest temperature (∼17keV) galaxy cluster
- The first observational examaple of shocks in the ICM
- Clear off-set of X-ray peaks from the mass peaks (galaxy distribution is quite similar to mass distribution)
- Likely Ram pressure-stripped gas

Numerical Method

- N-body: Particle Mesh (PM)
- Hydrodynamics: Roe TVD
- Self-gravity: FFT with isolated boundary conditions
- Simulation Box
  - 18Mpc × 9Mpc × 9Mpc (256 × 128 × 128)
  - Particle number N= 256 × 128 × 128 (≒ 4×10^6)
- VPP5000@NAOJ

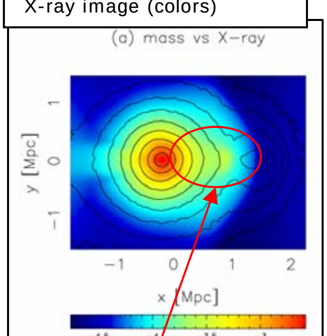
Model

- $M_1=10^{15}$ solar mass, $M_2=M_1/16$,head-on collision
- DM profile --- NFW profile ($\Omega_0=0.25$ $\lambda_0=0.75$)
- Gas profile --- β model、$r_c=r_s/2$
- Collision velocity --- about 2/3 of free fall velocity

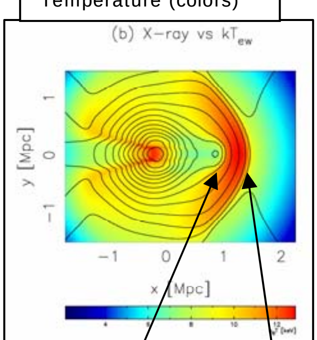
Simulation Results

Mass ratio 16:1, head-on collision, 0.67 Gyr after the core passage

Mass distribution (contours)
X-ray image (colors)



X-ray image (contours)
Temperature (colors)



X-ray peak lagged behind mass peak

Cold front (contact discontinuity)

Bow shock

Discussion on the Ram Pressure-Stripping Conditions

Consider the head-on merger of two NFW clusters with masses M_1 and M_2 ($M_1>M_2$). If the gravity on the subcluster's ICM is weaker than the ram pressure force, the ICM will be stripped from the subcluster's potential.

$$\frac{Gm_2\rho_2}{r_2^2} < A(\pi r_2^2 \rho_1 v^2)(\frac{4}{3}\pi r_2^3)^{-1},$$

$\rho_{1,2}$: central gas density r_2: scale radius m_2: mass inside r_2
A: fudge factor of an order of unity, likely A<1

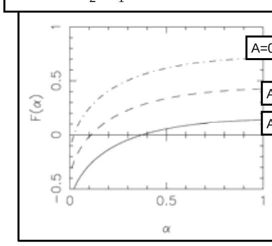
Collision velocity v $$v^2 \simeq \frac{2G(M_1+M_2)}{R_1+R_2},$$

$R_{1,2}$: virial radius
Introduce a new parameter $\alpha \equiv M_2/M_1$. Then, $R_2/R_1= \alpha^{1/3}$, $\rho_1/\rho_2= \alpha^{-x}$ (in the ΛCDM, x∼0.25). The above-mentioned condition becomes

$$F(\alpha : M_1) \equiv \alpha^{2/3-x}\frac{1+\alpha^{1/3}}{1+\alpha} - \frac{3A}{2g(\alpha M_1)c(\alpha M_1)} < 0.$$

Where, $c=r_2/R_2$ and $g=m_2/M_2$ are functions that depend on M weakly.

$F(\alpha) \propto$ (gravity) − (ram pressure)
$\alpha = M_2/M_1$



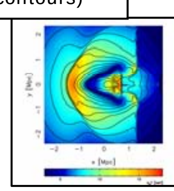
- gravity ≫ ram pressure
  - Gas behaves like DM.
  - DM peaks will correspond with X-ray peaks.
- gravity ≪ ram pressure
  - ICM in the subcluster cannot penetrates the larger cluster's center.
  - The larger cluster's ICM is so hot that it cannot be bound by the subcluster's potential.
  - Mass peaks are associated with no X-ray peaks.
- gravity ≒ ram pressure
  - Clear off-set of the mass peak from the X-ray peak.

Magnetic Field Evolution

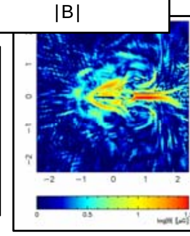
- Numerical method: PM + Roe-like TVD MHD
- Initial magnetic field
  - random Gaussian vector potential with $A(k) \propto k^{(-5/3)}$
  - $A(x,y,z) \propto \rho^{(2/3)}$
  - $P_B=0.01P_{gas}$

Mass ratio 4:1, head-on collision, 0.66 Gyr after the core passage

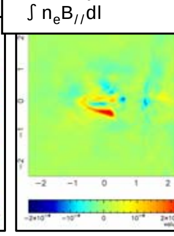
temperature (colors)
density (contours)



Magnetic field
|B|



Faraday rotation measure
$\int n_e B_{//} dl$



- Low temperature regions surrounded by magnetic field, which could be observed as ones with high Faraday rotation measure.
- High magnetic field region just behind the moving substructure.

Summary

- We investigate the X-ray and mass structure in the merging galaxy cluster 1E0657-56 using N-body + hydrodynamical simulations.
- We discuss the ram pressure-stripping conditions in the mergers of two clusters with an NFW density profile using a simple analytic model.
- We also investigate the magnetic field evolution with N-body + magnetohydrodynamical simulations.