

# Study of Two Temperature and Non-Equilibrium Ionization States of Plasma in Merging Galaxy Clusters

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Takuya Akahori

with Kohji Yoshikawa, FIRST project team

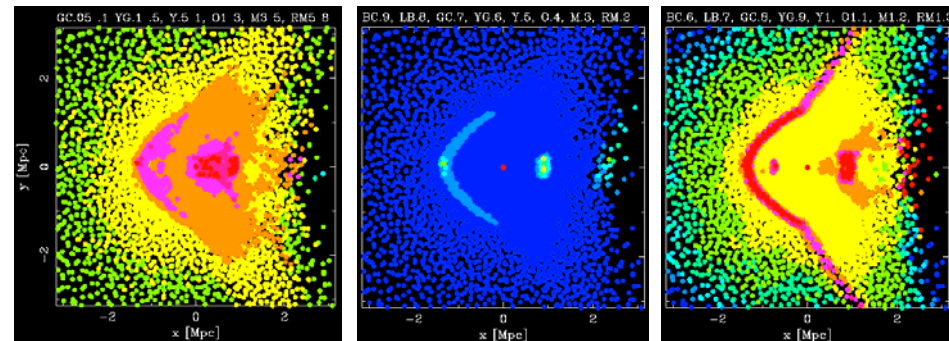
10/30-11/1@Center for Computational Sciences,  
University of Tsukuba



# Outline

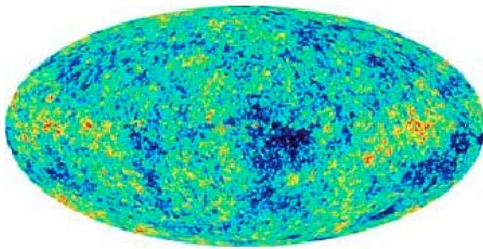
- Topic
  - **Non-EQ states** of ICM in merging G.C.
- Contents
  - Introduction
  - Model and Method
  - Results
  - Summary

Fig: the Mean temperature, electron temperature, and OVI ionization fraction of the intracluster gas in the merging galaxy cluster

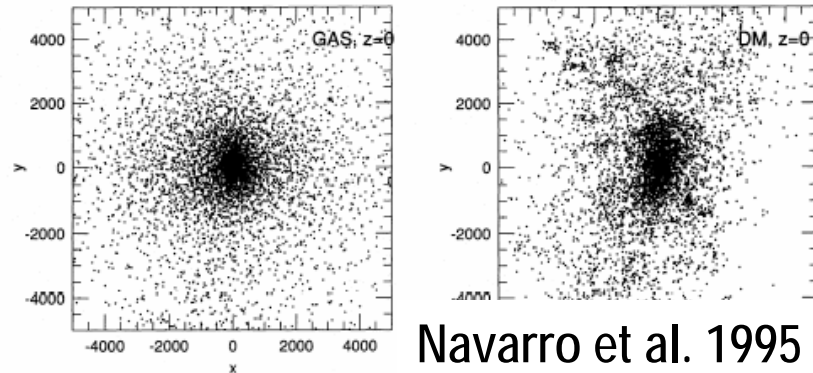
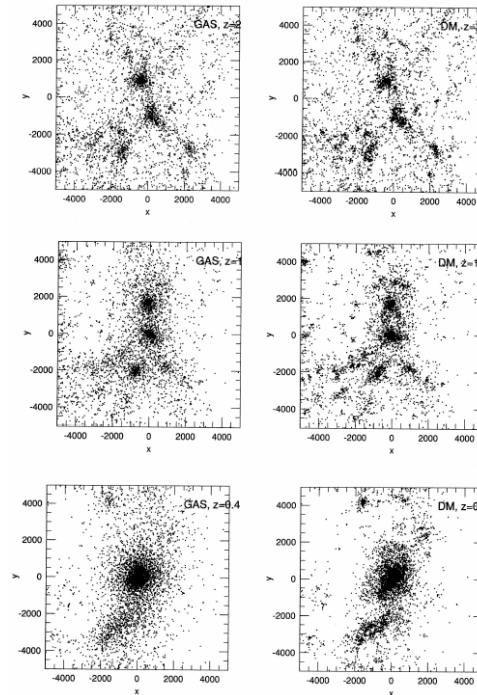


# Formation History

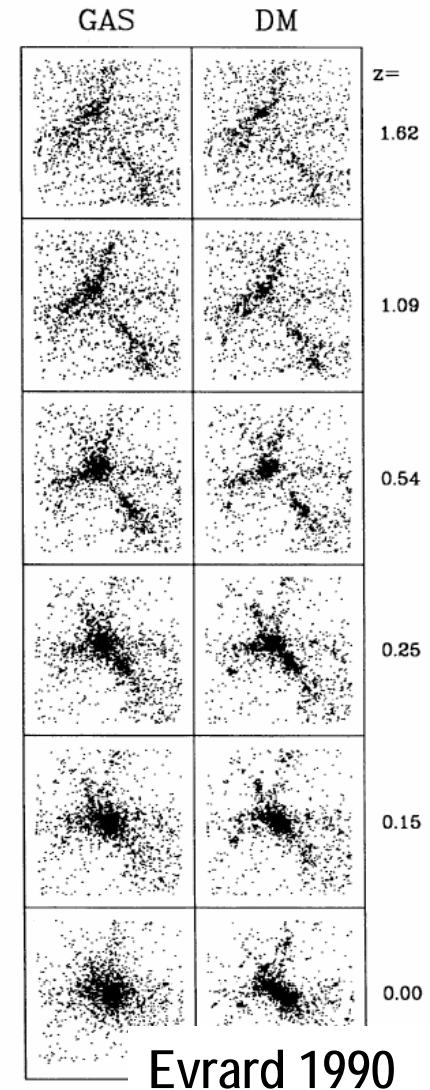
- Standard  $\Lambda$ CDM model
  - Primordial perturbation
  - Jean's instability
  - Galaxy clusters are formed in the dense region
  - Through mergers of smaller objects such as galaxies, galaxy groups and clusters



3K CMB (WMAP obs.)



Navarro et al. 1995



Evrard 1990

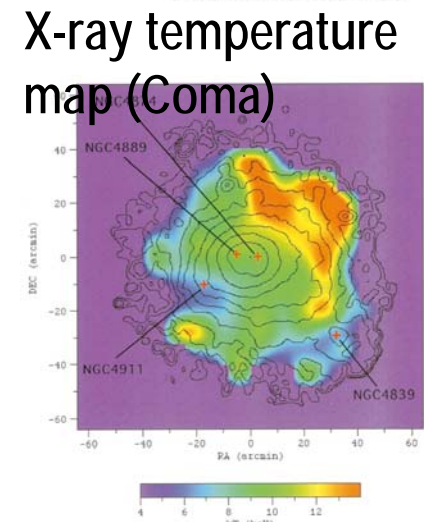
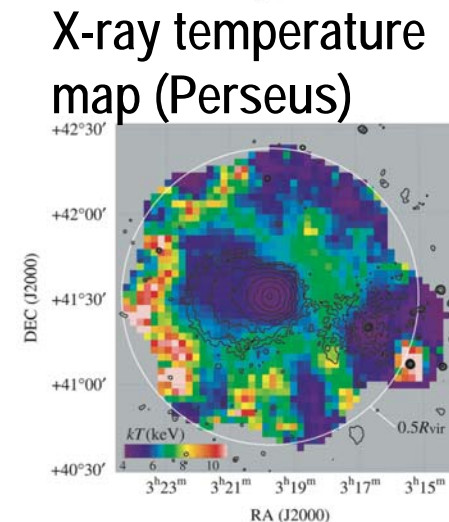
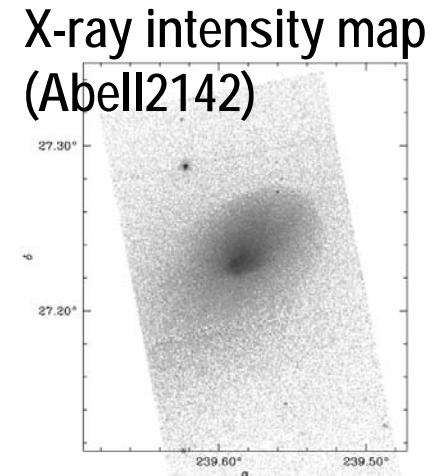
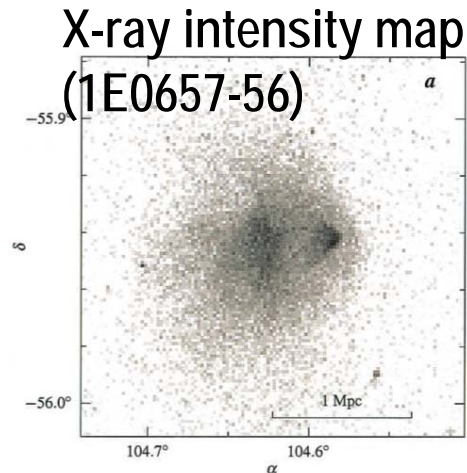
# Observations

- Mpc scale density substructures

- **1E0657-56 (Bullet)**
  - Markevitch et al. 2002
- **Abell2142**
  - Markevitch et al. 2000

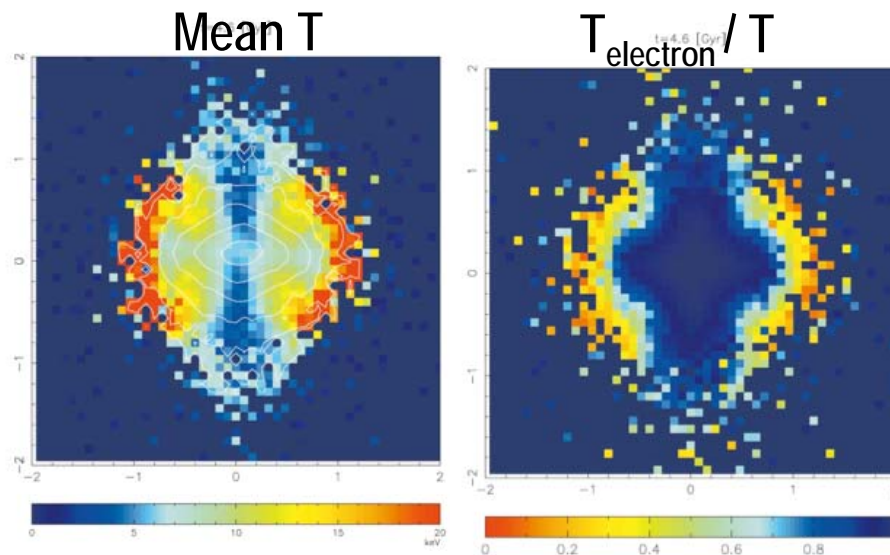
- Mpc scale temperature substructures

- **Perseus**
  - Furusho et al. 2001
- **Coma**
  - Watanabe et al. 1999

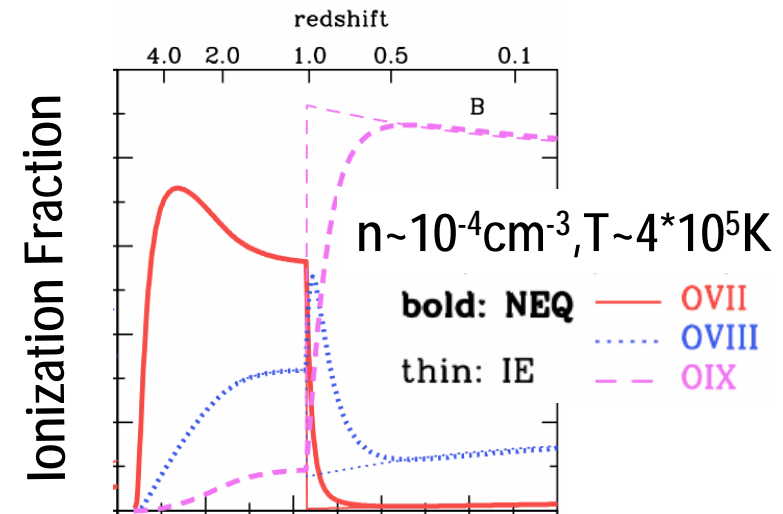


# Effects of Mergers

- What kind of effects are seen in mergers?
  - Compression/Heating  $\leftrightarrow$  Expansion/Cooling
- Deviation from the equilibrium state
  - non-eq. e-i temperature state, non-eq. ionization state



2T hydro-simulation (Takizawa 1999)



Non-eq. ionization simulation  
(Yoshikawa, Sasaki 2006)



# Objective

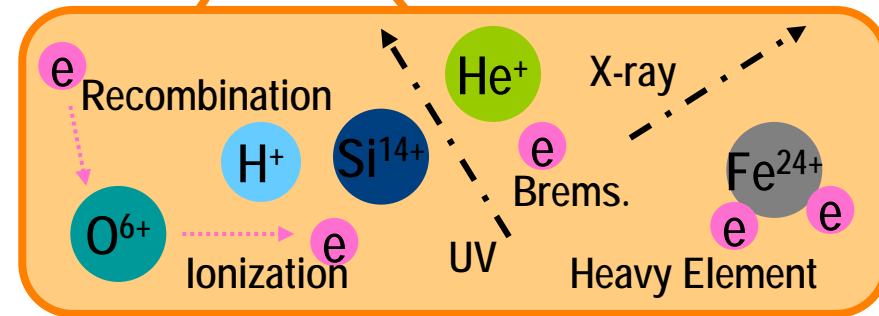
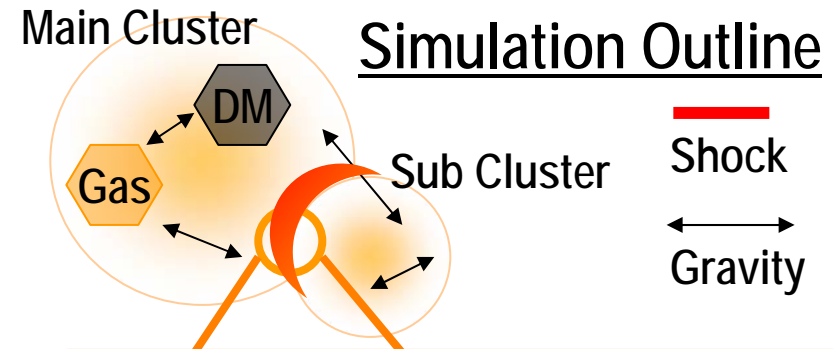
- In merging clusters, electron-ion temperature non-equilibrium, and ion ionization non-equilibrium have been suggested.
- Up to now, there are no 3D hydrodynamical simulation which considers both the non-eq. states.

## Objective

- To see both the non-equilibrium states
  - When/Where do the non-EQ states appear?
- To predict the plasma state in observed merging clusters
  - Do 2T state and non-EQ ionization state really exist in the clusters?

# Method

- N-body + SPH simulations
- High performance PC Cluster is the key to success.
  - Non-EQ states
  - Virialization shock
- We have an excellent solution,
  - ***FIRST Simulator!***
    - 36.1 TFlops
    - 1.6 TB memory
    - 22 TB storage



FIRST project logo, 256 nodes PC cluster

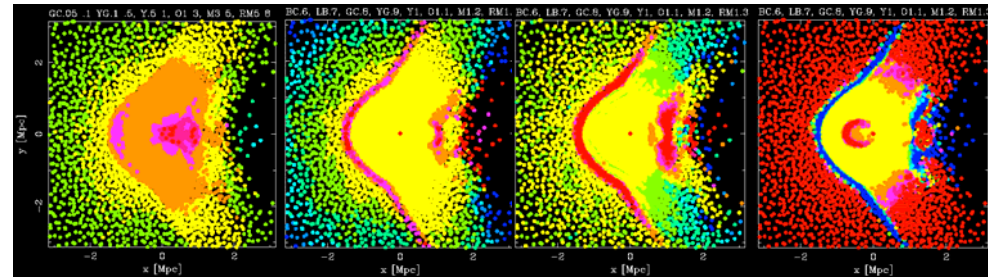


|                   |      |     |     |     |     |      |      |      |      |
|-------------------|------|-----|-----|-----|-----|------|------|------|------|
| kT(keV)           | .005 | .01 | .05 | .1  | .5  | 1    | 3    | 5    | 8    |
| Xe                | .95  | .85 | .75 | .65 | .55 | .45  | .35  | .25  | .15  |
| f/f <sub>eq</sub> | .55  | .65 | .75 | .85 | .95 | 1.05 | 1.15 | 1.25 | 1.35 |

# Results

- A shock wave ( $M \sim 2$ ) passed
  - Non-EQ temperature and ionization states are appreciable, and remains for several Gyr.

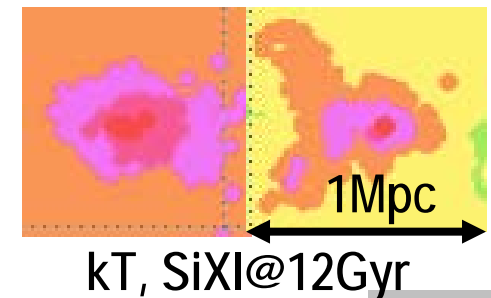
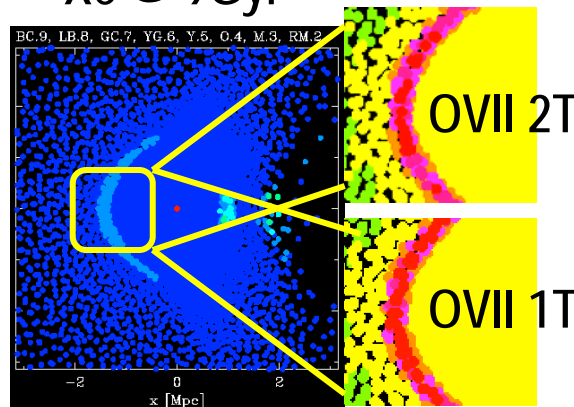
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kT, OVII, SiXIII, FeXXV@9Gyr

Xe @ 9Gyr

QuickTime<sup>®</sup> C<sup>2</sup>  
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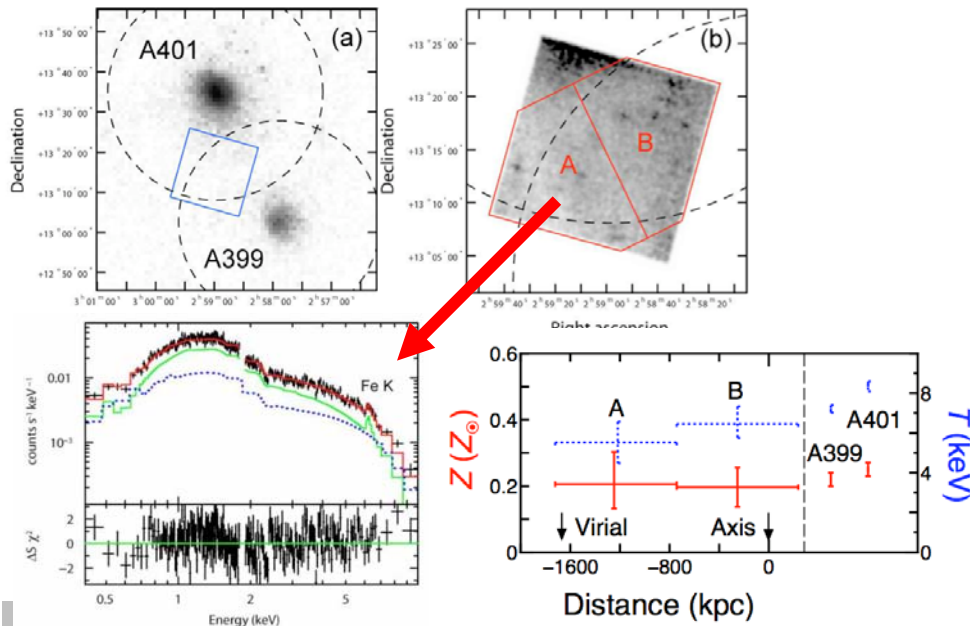
kT, SiXI@12Gyr



# Summary

- Numerical simulation of two temperature and non-equilibrium ionization states in merging galaxy clusters were carried out.
  - The non-EQ states caused by mergers remained for several Gyr.
  - We provided a good constraint for metal abundance.

## Application (preliminary!) Abell399/Abell401 -Fujita et al. (2007)



## kT, FeXXV(He-like K $\alpha$ 6.7keV)

