Subaru Weak Lensing Study of Merging Clusters of Galaxies

Reference:

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Introduction: Clusters of Galaxies

**Baryons**

- $M_{\text{baryon}} \sim 20\% \, M_{\text{tot}}$

- Stars (in galaxies)
  - $M_\star \sim \text{a few } \% \, M_{\text{tot}}$

- ICM (hot baryons)
  - $M_{\text{ICM}} \sim 20\% \, M_{\text{tot}}$

**Dark Matter**

- $M_{\text{DM}} \sim 80\% \, M_{\text{tot}}$

DM governs the Dynamics

Total mass distributions could be derived from X-ray data alone:

$$\frac{1}{\mu m_p n_g(r)} \frac{dP_g}{dr} = -\frac{d\Phi}{dr}$$

... but with the hydrostatic equilibrium assumption
2. Motivation

Chandra and XMM-Newton X-ray satellites have revealed complex ICM structures associated with cluster mergers: Cold Fronts = "contact discontinuities", associated with a dense cold core. Far from hydrostatic equilibrium!!
3. Method: Gravitational Lensing

The images of BG sources carry the imprint of $\Phi(x)$ of intervening cosmic structures:

WL distortions of BG images can be used to derive the underlying mass map in a model independent way!!
Power of Subaru Weak Lensing

A1689 (z=0.183)

A relaxed, massive cluster with large Einstein radius $\theta_E=45''$ ($z_s=1$)

Mass (~DM)

Cluster Galaxies

$r = 20 - 2000 \ (r_{vir}) \ kpc/h$

Umetsu & Broadhurst 2007,
ApJ submitted
4. Distributions of Mass and Baryons in “Merging Clusters”

Various Merging Stages

- **Binary**
- **On-going**
- **2nd impact**

Mergers are driven by $\Phi (\text{Mass} \sim \text{DM})$...
What is the relation between Mass ($\sim \text{DM}$) and Baryons during the merging process??
Cluster Targets

Merging clusters with detailed Chandra arXMM data in the local universe (z=0.05-0.3)

Table 2. Cluster X-ray Features

<table>
<thead>
<tr>
<th>Cluster</th>
<th>$z$</th>
<th>Type</th>
<th>1 arcmin $(\text{kpc}/h_{70})$</th>
<th>Components</th>
<th>$T_{\text{ave}}$ $(\text{keV})$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
<td>(4)</td>
<td>(5)</td>
</tr>
<tr>
<td>A754</td>
<td>0.0542</td>
<td>On-going</td>
<td>63.1</td>
<td>A1750C</td>
<td>10.0 ± 0.3$^a$</td>
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<td>A1750</td>
<td>0.0860</td>
<td>Binary</td>
<td>96.7</td>
<td>A1750N</td>
<td>3.87 ± 0.10$^b$</td>
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<td>A1758</td>
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<td>A1758N</td>
<td>2.84 ± 0.12$^b$</td>
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<tr>
<td>A1758</td>
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<td></td>
<td></td>
<td>A1758S</td>
<td>8.2 ± 0.4$^c$</td>
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<tr>
<td>A1914</td>
<td>0.1712</td>
<td>On-going</td>
<td>174.9</td>
<td></td>
<td>6.4$^{+0.3}_{-0.4}$</td>
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<tr>
<td>A2034</td>
<td>0.1130</td>
<td>Cold Front</td>
<td>123.2</td>
<td></td>
<td>10.9 ± 0.7$^a$</td>
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<tr>
<td>A2142</td>
<td>0.0909</td>
<td>Cold Front</td>
<td>101.7</td>
<td></td>
<td>7.9 ± 0.4$^d$</td>
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<tr>
<td>A520</td>
<td>0.1990</td>
<td>On-going</td>
<td>197.2</td>
<td></td>
<td>8.1 ± 0.4$^e$</td>
</tr>
</tbody>
</table>

Archival data

This talk will only focus on the results for the 3 merging clusters of different merging stages...
Pre-Merger (Binary)
A1750 (z=0.086) Optical vs. X-ray

Subaru image + X-ray contours (XMM)

A1750N

900kpc

A1750C

Δv_los~1300km/s

BCGs

Merger shocks: M~1.6

Temperature map

Belsole+ (2004)

2.8keV

3.9keV

Entropy excess in A1750C
A1750 (z=0.086) Mass vs. Baryons

XMM image + mass contours

Optical light map + mass contours

Distributions of the ICM

~ Member galaxies

~ Mass (~DM)

at an initial stage of the merging process

Mass substructure coincides with a slight X-excess

Mass

$M_{\text{vir}} \sim 2 \times 10^{15} \text{M}_{\odot}/h$ (N)

$M_{\text{vir}} \sim 3 \times 10^{15} \text{M}_{\odot}/h$ (C)
On-going Mergers
A1914 (z=0.172) Optical vs. X-ray

Subaru image + Chandra contours

Chandra image + contours

2 small cores embedded in a round shaped halo (Govoni et al. 2004)

16'x16' (2.8Mpc on a side)
ICM distribution is fairly round, while the DM distribution is highly disturbed by the merger, showing an irregular morphology. The collisionless galaxy distribution coincides well the DM (~mass) distribution. The light and mass peaks of the primary cluster coincide well.
Cold Front Clusters
A2034 (z=0.113) Optical vs. X-ray

- Subaru image + XMM contours
- XMM image + contours

Sharp discontinuity

South X-ray excess
(Kempner & Sarazin 03)

- Northern sharp-discontinuity in X-ray emission – but no significant jump in Tx
- Kempner & Sarazin 03 argued the excess emission likely to be a background structure
A2034 (z=0.1130) Mass vs. Baryons

Subaru Image + Mass Contours

1.2 FWHM Gaussian (140kpc)

XMM Image + Mass Contours

South X-ray excess

A2034 (z=0.1130) Filament?

Light map + mass contours
1.2 FWHM Gaussian (~140kpc)

Western structure

Line-of-sight Velocity distribution

“Western mass structures” found to be associated with filamentary structure of background galaxies
→ LOS com. separation of ~ 10Mpc/h (assuming v_poc=0)
4. **Tx vs. WL-derived Virial Temperature**

**Tx**: from the literatures  
**Twl**: this study (w/ red background gals.)

- **Ongoing**  
- **Cold front**  
- **Pre-merger**

**Tx** is (2-3) times higher than **Twl** in ongoing mergers: **Merger boosts?**  
(Sarazin & Ricker 02)

- **A1750C**: Entropy excess  
- **A520**: **Tx** including the pre-shock (low-T) region, under-estimated by ~1.7
Summary

- **Joint WL/X-ray/Optical analysis:**
  - 1st systematic WL study of merging clusters
    cf. Clowe+ 04 on Bullet cluster; Bradac+ 06 on 1ES0657@z~0.3
    → Provides an important clue to understand the cluster merger

- **Distributions of Baryons & DM:**
  - **Initial phase:** ICM and Galaxies tracing the Mass
  - **Ongoing:** “Mass ~ Galaxies” but highly irregular, offset from “ICM” in a various way
  - **Cold front:** DM clumps always found in front of dense cores
    (all of 3 cold fronts) as found in the Bullet Cluster (Clowe+04)

- **Cluster global properties:**
  - \( T_x \sim T_{wl} \) in a pre-merging phase
  - \( T_x \sim (2-3) T_{wl} \) during mergers
    → **merger boosts**? (Sarazin & Ricker 02; Rowley+ 04) as a function of dynamical-phase, initial merger conditions, & masses.
Future Work

Ongoing Project
LoCuSS: Local Cluster Substructure Survey

Flux limited, unbiased sample of >100 clusters in the local universe (Lx>5x10^44 erg/s, 0.15<z<0.3)

Utilizing HST(SL/WL) + Subaru(SL/WL) + XMM/Chandra + Spitzer + SZ (SPT…)

WL analysis of 29 clusters completed

A209 (Okabe, Takada, Umetsu & Futamase in prep)

CFHT/12K (Bardeau et al 2007)
Special Thanks to Lensing Collaborators

**LoCuSS**
- N. Okabe, M. Takada, T. Futamase (Tohoku), G.P. Smith (P.I.)

**AMiBA SZE + WL**
- AMiBA Science Team (ASIAA, NTU/Phys)
  - See the AMiBA poster by K.Y. Lin

**HSC WL Working Group**
- S. Miyazaki, T. Hamana, H. Furusawa, Y. Utsumi (NAOJ), M. Takada (Tohoku), K. Yamamoto (Hiroshima), H. Nishioka (ASIAA)

**Fexion and HOLICs**
- Y. Okura, T. Futamase (Tohoku)

**Dark Halo Density Profiles**
- T. Broadhurst, E. Medezinski (Tel Aviv)
FIN