The cousin of the Bullet cluster
MACSJ0025-1222

Maruša Bradač

Steve Allen, Tommaso Treu, Harald Ebeling, Richard Massey, Glenn Morris, Anja von der Linden, Doug Applegate
Paul's prophecies

1. The Hubble constant as determined from lensing will never have a smaller uncertainty than the current best determination.

2. The central maxima of lensed images will never be seen.

3. Something is terribly wrong with lensing estimates of the cosmological constant.

4. Lensing determinations of the radial profiles of galaxy potentials cannot be trusted.

5. Lensing determinations of the radial profiles of cluster potentials cannot be trusted.

6. Weak lensing has nothing to add to LSS as determined from redshift surveys and the CMB.
Paul’s prophecies

7. Microlensing will never have the impact of Doppler, astrometric, and photometric searches for planets.

8. The large observed ratio of quadruple to double lenses is due to unaccounted observational selection effects.

9. Flux ratio “anomalies” are the result of bad macro-models.

10. Lensing masses of clusters are inferior to X-ray determinations.

11. Microlensing has added little to what we know of the Milky Way structure beyond what has been measured from proper motions.

12. Lensing has told us nothing about DM that wasn’t known or suspected.

13. Too few lenses are known to tell us anything new about the masses and velocities of galaxies.
Maruša’s prophecies

1. Paul is a pessimist.

2. Lensing is fantastic!!!
The Bullet Cluster

Clowe, MB et al. 2006
Baby Bullet* Cluster MACSJ0025-1222

* Neither baby nor bullet (S. Allen)

* F450W WFPC2 5 orbits

* F555W ACS 2 orbits

* F814W ACS 2 orbits

Ozlens, Sydney, September 29 - October 3 2008
Galaxy Distribution

$z = 0.5857$

$\sigma_v = 835^{+58}_{-59}$ km/s

108 galaxies within 3.0 $\sigma_v$ and 1.5 Mpc
Galaxy Distribution

* Two cluster at the same redshift \((0.586\pm0.001)\) separated by 600 kpc (projected)

* Velocity separation of the BCG's radial direction
  \(\Delta z = 0.0005\pm0.0004\) \((100\pm80\text{ km/s})\)

* Richness / stellar masses of an average massive cluster.

  \[
  \text{SE(<300kpc): } 2.7 \times 10^{12} \, M_\odot (3.6 \times 10^{12} \, L_\odot) \\
  \text{NW(<300kpc): } 1.9 \times 10^{12} \, M_\odot (2.5 \times 10^{12} \, L_\odot)
  \]
Gas Distribution

- 38ks Chandra (115ks more to come)
- Gas peak
- Too shallow to see a shock front
Why is Baby Bullet not a “Bullet”

- The Bullet cluster is a merger of a cool core (low entropy gas) and a non-cool core cluster
- Baby Bullet is a merger of two non-cool core clusters
- Dynamical information from the shock – still likely
Why is Baby Bullet not a “Bullet”
Strong AND Weak

- Strong and Weak lensing reconstruction: combine strong and weak lensing constraints with parametrisation as general as possible.

- Following the idea of Bartelmann et al (1996) we parametrise the lens by values of the potential $\psi_k$ on a regular grid.

- In collaboration with D. Applegate we are developing an adaptive grid method -> combine Subaru and ACS data self consistently.

- Will allow us to include flexion and higher order lensing information (while still being fast).

- Weak lensing is not happily reproducing strong lensing ($\times 2$ difference in kappa for the Bullet cluster).
Strong Lensing Information
Strong Lensing Information

\[ z = 1.0^{+0.5}_{-0.2} \]

\[ z = 2.8^{+0.4}_{-1.8} \]

\[ z = 2.38 \]
Weak Lensing Information

- ACS F814W (2 orbits) is the primary weak lensing band
- PSF correction follows COSMOS (Massey et al. 2007)
- RRG (Rhodes et al. 2000) shape measurement
- Color information (from F450W-F555W-F814W) to exclude likely cluster members
Weak Lensing with WFPC2 - Good Luck
Total Mass Distribution

S&W Lensing

Bradač et al. 2008b
Mass vs. Light

S&W Lensing
K-band Light

Bradač et al. 2008b
Mass vs. Gas

Bradač et al. 2008b
Dissecting MACSJ0025-1222 Into Dark Matter and Baryons

* Significant offset of both sub-cluster peaks from the gas peak

> 4σ
Dissecting MACSJ0025-1222 Into Dark Matter and Baryons
Dissecting MACSJ0025-1222 Into Dark Matter and Baryons

2-D projected enclosed mass within a radius of 300 kpc centered on BCG1 and BCG3 and within 500 kpc centered on the gas peak.

<table>
<thead>
<tr>
<th>Location</th>
<th>Component</th>
<th>Mass [10^{14} M_\odot]</th>
</tr>
</thead>
<tbody>
<tr>
<td>SE - BCG1</td>
<td>total</td>
<td>$2.5^{+1.0}_{-1.7}$</td>
</tr>
<tr>
<td></td>
<td>galaxies</td>
<td>$0.027 \pm 0.008$</td>
</tr>
<tr>
<td>NW - BCG3</td>
<td>total</td>
<td>$2.6^{+0.5}_{-1.4}$</td>
</tr>
<tr>
<td></td>
<td>galaxies</td>
<td>$0.019 \pm 0.006$</td>
</tr>
<tr>
<td>Gas peak</td>
<td>total</td>
<td>$6.2^{+1.2}_{-4.0}$</td>
</tr>
<tr>
<td></td>
<td>gas</td>
<td>$0.55 \pm 0.06$</td>
</tr>
<tr>
<td></td>
<td>galaxies</td>
<td>$0.05 \pm 0.01$</td>
</tr>
</tbody>
</table>
**The “global” gas-to-total mass ratio and the stellar-mass-to-total-mass ratio are typical for a massive cluster**

\[
\text{Gas} \quad 9^{+7}_{-3}\% \\
\text{Stars} \quad 1.0^{+0.7}_{-0.4}\%
\]

**The mass-to-light ratio for the SE and NW peak:**

\[
\frac{M}{L_K}(< 300\text{kpc}) = 70^{+40}_{-50} \text{ and } 100^{+40}_{-60}
\]

and the stellar-to-total mass ratios

\[
1.0^{+0.7}_{-0.4}\%
\]
**Dark Matter Properties**

- Combining the Chandra data with lensing mass maps \( \rightarrow \) place an upper bound on the dark matter self-interaction cross section 
  \( \sigma/m < 4 \text{ cm}^2\text{g}^{-1} = 8 \text{ barn/GeV} \).

  \( \rightarrow \) Significant offset between subcluster X-ray gas core and dark matter peak

  \[ \tau = \sum \frac{\sigma}{m} \]

  \( \rightarrow \) Survival of the subcluster \( \text{(need velocity info)} \)

  \( \rightarrow \) No loss of mass from subcluster

- The Bullet Cluster: \( \sigma/m < 0.7 \text{ cm}^2\text{g}^{-1} = 1.3\text{ barn/GeV} \) (Randall et al. 2008)

- SI dark matter \( \sigma/m < 0.5 - 5 \text{ cm}^2\text{g}^{-1} \) (Davé et al. 2001).
High-z Universe through 1E0657-56
Rachel’s scorecard

★ What is the astrophysical question you are trying to answer?

   -> The nature of dark matter.

★ Why is gravitational lensing better than other methods?

   -> Few HST and Chandra orbits/ks vs. $$$$$$ and potential for Earth destruction.

★ What are the tradeoffs?

   -> PS
Baby Bullet Cluster