SuprimeCam Weak lensing cluster counts and their implication for the dark matter mass-concentration relation

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in collaboration with
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TH+2015 in prep.

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Mass-concentration relation

Dark matter haloes
• are building-block of cosmic structure
  • where galaxies and clusters of galaxies from
• have a universal density profile, “NFW profile”
  • resulting from the nature of “cold” dark matter

\[ \rho_{NFW} = \frac{\rho_s}{(r/r_s)(1 + r/r_s)^2} \]

\[ C = \frac{r_{vir}}{r_s} \]

concentration parameter

Navarro+1996
Mass-concentration relation

M-c relation

• resulting from different mass assembly history for different halo mass
• mass assembly history depends on cosmology (via expansion history)
• M-c relation depends on the cosmological model

\[
c(M_{\text{vir}}, z) = c_0(z) \left( \frac{M_{\text{vir}}}{10^{12} \ M_\odot} \right)^{-0.075} \times \left[ 1 + \left( \frac{M_{\text{vir}}}{M_0(z)} \right)^{0.26} \right],
\]

N-body simulation by Klypin+2011
Mass-concentration relation

What can we learn from M-c relation?

• Testing the “standard” structure formation scenario based on the Lambda-CDM cosmological paradigm (flat “lambda” cosmology +”cold” dark matter) through the mass assembly history
Mass-concentration relation

Studies on M-c relation so far
• using lensing (individual or stacked) shear profiles, and looks successful
• a slight excess over theoretical predictions
• sample bias --- X-ray bright clusters tend to be over concentrated
• something is wrong in theoretical models, e.g., assumed cosmological model?

see also Okabe-san’ talk, Mandelbaum+2008, Oguri+2012, Merten+2014
Mass-concentration relation

Here we propose a new approach
• using weak lensing cluster counts
  • free from selection bias
• allowing us to constrain the cosmological model & M-c relation simultaneously
weak lensing cluster counts

Searching for clusters on weak lensing mass map

3x3 mosaic SCam data combined

1st weak lensing cluster z=0.42

Miyazaki, TH+2002 SuprimeCam GTO data
We have been developing techniques to measure a tiny lensing signal accurately.
We have been examining its capability & reliability

Miyazaki, TH+ (2007)  
TH+ (2009)

12/15 WL peaks (SN>3.7) have optical and/or X-ray cluster-part

- **red**: WL-mass
- **blue**: galaxy density
- **circle**: WL-peak
- **square**: X-ray cluster
- **open-circle**: optical cluster
**Weak Lensing Cluster Counts**

Cluster finding on weak lensing mass map
- Techniques have been developed and now established
- Purity was tested with obs & sim; >90% for SN>5

Now weak lensing cluster sample is a practical cosmological tool:
- Number counts of weak lensing clusters
  - Methodologically simple, thus robust cosmological application
weak lensing cluster counts

Theoretical model of WL cluster counts

✓ ingredients for lensing signal
  • analytic descriptions of DM halo
    • NFW profile
  • c-M relation (from N-body sim.)
  • halo mass function (Press-Schechter)
  • diversity of halo properties (from N-body sim.)
  • n(z) of source galaxies (from photometric-redshift)

✓ ingredients for noise
  • noise from intrinsic galaxy shape (from obs data)
  • effect from large-scale structure (cosmic shear formalism)

\[
\mathcal{K}(\theta) = \int d^2\phi \, \gamma_t(\phi : \theta) \, Q(|\phi|),
\]

mass map \hspace{1cm} lensing shear + noise \hspace{1cm} window

Schneider (1996)
TH, Oguri, Shirasaki, Sato (2012)
weak lensing cluster counts

Theoretical model of WL cluster counts
• we have developed the model which nicely agrees with mock sim.
• $N_{\text{peak}}(\text{SN}>5)\sim 0.5\text{cluster/deg}^2$

Now the model is ready
weak lensing cluster counts

Dependence on the cosmology & M-c relation

\(\{\Omega_m, \sigma_8\} \rightarrow N_{\text{halo}} \rightarrow N_{\text{peak}}\)

c(M) \rightarrow \text{peak height} \rightarrow N_{\text{peak}}

Figure 9. Left-hand panels: different histograms show results for different filters. Blue, green, and red histograms are for the optimal filter, the PEX1 filter, and the PEX2 filter, respectively. The green histogram is the number count of peaks from the pure noise map. The other histograms show results for filters with some modification. Specifically, we make the following three changes: (1) We include the effect of the halo triaxiality via the halo shape noise as illustrated in Bartelmann et al. (2001) and Maturi et al. (2005). (2) The peak counts (in noise-added maps) above thresholds.

\(\theta(z) > 0.5\), i.e., haloes with major axes aligned with the line-of-sight direction, whereas the blue histogram is for anti-aligned haloes.

The green histogram is the number count of peaks from the pure noise map.

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data & analysis

✓ SuprimeCam i-band data from SMOKA
  • $T_{\text{exp}} > 40 \text{min}$
  • seeing $< 0.7''$
  • contiguous region $> 2 \text{ deg}^2$

✓ data reduction $\rightarrow$ hscPipe developed by Princeton-NAOJ-IPMU

✓ object detection $\rightarrow$ sextractor ($22<i<25 \text{ AB-mag}$)

✓ shear measurement $\rightarrow$ lensfit tuned for SuprimeCam data
  (great effort by J. Sakurai)

<table>
<thead>
<tr>
<th></th>
<th>area/area$^{\text{eff}}$ [deg$^2$]</th>
<th>n$_g$ / n$_g^{\text{eff}}$ [arcmin$^{-2}$]</th>
</tr>
</thead>
<tbody>
<tr>
<td>XMM-LSS</td>
<td>3.61/2.83</td>
<td>23.7/20.9</td>
</tr>
<tr>
<td>COSMOS</td>
<td>2.06/1.59</td>
<td>28.9/26.3</td>
</tr>
<tr>
<td>Lockman-hole</td>
<td>2.10/1.63</td>
<td>25.5/23.7</td>
</tr>
<tr>
<td>ELAIS-N1</td>
<td>3.62/2.84</td>
<td>24.7/22.0</td>
</tr>
<tr>
<td>合計</td>
<td>11.39/8.96</td>
<td></td>
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</tbody>
</table>
results XMM-LSS

XMM_g3c2_tg1.5; SN>4.5
results

COSMOS

COSMOS scamp_texp_g3c2_tg1.5; SN > 4.5
results  Lockman-hole

LH_g3c2_tg1.5; SN>4.5
ELAIS-N1 results

ELAIS_g3c2_tg1.5; SN>4.5
## results

WL peak counts

\[
N_{\text{peak}}(SN>5)=6 \text{ in } 8.96 \text{deg}^2
\]

<table>
<thead>
<tr>
<th>SN</th>
<th>known</th>
<th>unknown</th>
</tr>
</thead>
<tbody>
<tr>
<td>4-4.5</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>4.5-5</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>5-5.5</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>5.5-6</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>6-6.5</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>6.5-7</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>7-7.5</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>7.5-8</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>8-</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>
results

Sample (cosmic & Poisson) variance
• evaluated using mock survey data from full sky ray-tracing sim (by TH)

\[ N_{\text{peak}}(SN > 5) = 6 \pm 3.1 \text{ in } 8.96 \text{deg}^2 \]

\[ \text{Var}(N_{\text{peak}}) \simeq \text{Poisson} + CV^2 \]
\[ \rightarrow CV \simeq 1.8 \]

Full-sky weak lensing sim. by TH, Shirasaki, Takahashi (in prep.)
results

\[ N_{peak}(SN > 5) = 6 \pm 3.1 \text{ in } 8.96 \text{deg}^2 \]

\[ \chi^2(\Omega_m, \sigma_8, c_0) = \frac{(N_{model} - 6)^2}{3.1^2} \]

Theoretical model of WL cluster counts for Subaru WL survey

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Mock simulation with noise

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Noise-free simulation

---

model w/o noise

---

model w/ noise

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\[ \]
results

wait for publication
Summary & Future Prospects

1. Weak lensing cluster finding in 11 deg$^2$ SuprimeCam i-band data
   - 8 peaks with SN>4.5, all having optical/X-ray counter-part

2. Weak lensing peak counts
   - $N(SN>5)=6+/-3.1$ (in effective 8.96 deg$^2$)
     - *First constraints* on M-c & cosmological parameters from WL cluster counts, though the constraints are very broad
     - $c_0$ consistent with LCDM simulations
       - $c_0>8$ for Plank-LCDM
       - $c_0>9$ for WMAP9-LCDM

3. Prospect for HSC survey
   - $>200$ deg$^2$ by end of 2015
     - more than 100 WL clusters with 10% sample variance
   - photo-z from full 5-band color
     - better background galaxy selection