Cosmological constraints from Subaru weak lensing cluster counts


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outline
1. Weak lensing cluster finding
2. Theoretical model of weak lensing cluster counts
3. Data and analysis
4. Results
5. Summary & Future prospects for HSC survey

2015/7/24 LSS conference @Garching
Expected weak lensing SN(M,z) for Subaru weak lensing survey

- Narrower z-range than SZ
- Higher $M_{\text{min}}$ than Xray
- Not rely on baryon physics but based on dark matter concentration

Weak lensing cluster finding

Searching for peaks in matched filtered weak lensing mass map

Schneider 1996

\[ \mathcal{K}(\theta) = \int d^2 \phi \kappa(\phi - \theta)U(|\phi|), \]

\[ \mathcal{K}(\theta) = \int d^2 \phi \gamma_1(\phi : \theta)Q(|\phi|), \]

\[ Q(\theta) = \int_0^\theta d\theta' \theta'U(\theta') - U(\theta). \]

✓ Serendipitous finding
  - Erben+2000
  - Umetsu & Futamase 2000
  - Dahel+2003

✓ Systematic survey
  - Wittman+2001 (CTIO)
  - Miyazaki, TH+2001 (Subaru)
  - Schirmer+2007 (MPG/ESO)
**Weak lensing cluster finding**

Searching for clusters in weak lensing mass map

3x3 mosaic SCam data combined

1st weak lensing cluster $z=0.42$

Miyazaki, TH+2002 SuprimeCam Rc-band data

SL J1602.8+4335
Weak lensing cluster finding

We examined capability of weak lensing cluster finding

Miyazaki, TH+(2007)

100 peaks (SN>3.7) in 18deg²
Weak lensing cluster finding

✓ cluster detection rate VS observational condition

seeing VS lensing-useable galaxy density

Cluster detection VS galaxy density

noise \propto 1/\sqrt{n_g}

Good seeing is key to have more lensing-useable galaxies and to find more clusters

Miyazaki, TH+(2007)
Weak lensing cluster finding

✓ Purity (contamination rate)

XMM-LSS

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

Xray data from XMM-LSS & spectroscopic follow-ups of WL peaks (TH+2007)

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

➡ ~20% false for SN>4 peaks

red cont. : WL-mass
blue cont. : galaxy density
circle : WL-peak
square : Xray cluster
open-circle: z_{spec} cluster
**Theoretical model of WL cluster counts**

\[ n_{\text{halo}}(M, z) \]

- Signal from each halo
  - NFW profile
  - M-c relation
  - \( n_s(z) \)

\[ \gamma_t(M, z) \]

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

\[ SN = K / \sigma_{\text{shape}} \]

\[ n_{\text{peak}}(SN) \]

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Bartelmann+(2001)
TH, Oguri, Shirasaki, Sato (2012)

Noise from intrinsic galaxy shape noise

\[ \sigma_{\text{shape}} = \frac{\sigma_e}{2n_g} \int d^2\theta \, Q^2(\theta) \]
Theoretical model of WL cluster counts

✓ modeling various effects
  • large-scale structures (TH+2004,2012,Marian+2010)
  • diversity of halo properties
    • tri-axiality & orientation (TH+2012, Tang&Fan2005)
    • scatter in M-c relation (Cardone+2014, Manini&Romano2014)
  • spatial variation of observational condition (TH+2015)
  • lensing magnification effect (Schmidt&Rozo2011)
  • baryon effect (Osato+2015)

✓ optimization of window function
  • get higher SN with a matched filter
  • reduce the dilution effect by member galaxies

see Chieh-An Lin’s poster for an alternative approach
Theoretical model of WL cluster counts
✓ tested against mock numerical simulation of weak lensing survey

Theoretical model of WL cluster counts

- Tested against mock numerical simulation of weak lensing survey

![Graph showing WL cluster counts for Subaru WL survey](image)

- Good agreement with the mock simulation result
- \( N_{\text{peak}}(\text{SN}>5) \approx 0.5 \text{ cluster/deg}^2 \) for a Subaru-like data (\( n_g \approx 25/\text{arcmin}^2 \))
- Sensitive to \( n_g \) — \( N_{\text{peak}}(\text{SN}>5) < 0.1/\text{deg}^2 \) for \( n_g \approx 15/\text{arcmin}^2 \)
- Need \( n_g > 20/\text{arcmin}^2 \) to have “moderate mass cluster sample”
Theoretical model of WL cluster counts

✓ purity (1-contamination)
  • $\sim$90% for SN=5
  • >98% for SN>6 (due to LOS projections)
  • <50% for SN<4
Theoretical model of WL cluster counts

- Dependence on the cosmology & M-c relation

\[ \{ \Omega_m, \sigma_8 \} \rightarrow N_{\text{halo}} \rightarrow N_{\text{peak}} \]

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

\[
\text{n(\nu)} \left[ \text{deg}^2/\text{bin} \right] = \{ \Omega_m, \sigma_8 \} \rightarrow \text{N_{halo}} \rightarrow \text{N_{peak}} \]

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

TH+ (2012)
Data & Analysis

✓ SuprimeCam i-band data from archive
  • $T_{\text{exp}} > 40\text{min} \ (i_{\text{lim}} > 25.5)$
  • seeing FWHM < 0.7"
  • contiguous region > 2 deg$^2$
✓ data reduction → hscPipe developed by Princeton-NAOJ-IPMU
✓ object detection → sextractor (22<i<25 AB-mag)
✓ shear measurement → lensfit tuned for SuprimeCam data

<table>
<thead>
<tr>
<th></th>
<th>area/area$^{\text{eff}}$ [deg$^2$]</th>
<th>ng / ng$^{\text{eff}}$ [arcmin$^{-2}$]</th>
</tr>
</thead>
<tbody>
<tr>
<td>XMM-LSS</td>
<td>3.6/2.8</td>
<td>24/21</td>
</tr>
<tr>
<td>COSMOS</td>
<td>2.1/1.6</td>
<td>29/26</td>
</tr>
<tr>
<td>Lockman-hole</td>
<td>2.1/1.6</td>
<td>26/24</td>
</tr>
<tr>
<td>ELAIS-N1</td>
<td>3.6/2.8</td>
<td>25/22</td>
</tr>
<tr>
<td>total</td>
<td>11.4/9.0</td>
<td></td>
</tr>
</tbody>
</table>
Results

COSMOS

SN = 4.8
z = 0.36

SN = 5.1
z = 0.37
Results

Lockman-hole

SN=7.6
z=0.23
**Results**

Sample (cosmic & Poisson) variance

• evaluated using mock survey data from full sky ray-tracing sim

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

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

\[ \rightarrow CV \approx 1.9 \]

Full-sky weak lensing sim.
by TH, Shirasaki, Takahashi
(see also Shirasaki+2015)
$$N_{peak}(SN > 5) = 6 \pm 3.1 \text{ in } 8.96 \text{deg}^2$$

$$c(M, z) = 9.6 \left( \frac{M_{vir}}{10^{12} h^{-1} M} \right)^{-0.075} (1 + z)^{-0.7}$$

M-c relation by Klypin+2011 was assumed.
$N_{\text{peak}}(SN > 5) = 6 \pm 3.1$ in 8.96 deg$^2$

$c(M, z) = c_0 \left( \frac{M_{\text{vir}}}{10^{12} h^{-1} M} \right)^{-0.075} (1 + z)^{-0.7}$

$\Omega_m = 0.278$
\[ N_{\text{peak}}(SN > 5) = 6 \pm 3.1 \text{ in } 8.96\text{deg}^2 \]

\[ \Omega_m = 0.278 \]

\[ \sigma_8 = \begin{cases} \text{Planck} \\ \text{WMAP9} \end{cases} \]
Hyper SuprimeCam survey

• Hyper SuprimeCam — 1.7deg$^2$ FoV ~ 7xSuprimeCam
• $r_{AB}=26$mag with 10min exposure

whole M31 in one shot
Hyper SuprimeCam survey

- Good image quality confirmed by engineering data (Miyazaki+TH+2015)

Abell 781 super cluster (z=0.3)
Hyper SuprimeCam survey

- Japan-Princeton-Taiwan project
- ~5 years from 2014
- 3 layers
  - UltraDeep — 3.5° deg$^2$
  - Deep — 27° deg$^2$
  - Wide — 1400° deg$^2$

Figure 11: The location of the HSC-Wide, Deep (D) and Ultradeep (UD) fields on the sky in equatorial coordinates. A variety of external data sets and the Galactic dust extinction are also shown. The shaded region is the region accessible from the CMB polarization experiment, ACTPol, in Chile.

Table 10: Survey Fields

<table>
<thead>
<tr>
<th>Layer</th>
<th>Name</th>
<th>RA, Dec</th>
<th>Area</th>
<th>Key Other data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wide</td>
<td>Fall equatorial</td>
<td>22:00 ≤ RA ≤ 02:40 &amp; -1.0 ≤ Dec ≤ +7.0</td>
<td>≃ 640</td>
<td>ACT(ACTPol), VIPERS, DEEP2, 01:50 ≤ RA ≤ 02:40 &amp; -7.0 ≤ Dec ≤ -1.0</td>
</tr>
<tr>
<td></td>
<td>Spring equatorial</td>
<td>08:30 ≤ RA ≤ 15:00 &amp; -2.0 ≤ Dec ≤ +5.0</td>
<td>≃ 680</td>
<td>ACT(ACTPol), VIKING/KIDS, UKIDSS, GAMA, Herschel</td>
</tr>
<tr>
<td></td>
<td>Northern sky</td>
<td>13:20 ≤ RA ≤ 16:40 &amp; +42.5 ≤ Dec ≤ +44.0</td>
<td>55spec</td>
<td>HectoMAP: r&lt;21.3</td>
</tr>
<tr>
<td>Deep</td>
<td>XMM-LSS</td>
<td>02:25:00 -04° 30′ 00′′</td>
<td>5.3</td>
<td>UKIDSS-DXS(NIR), VIDEO-XMM-LSS(NIR), VVDS(spec−z), PRIMUS(spec−z)</td>
</tr>
<tr>
<td></td>
<td>E-COSMOS</td>
<td>10:00:29 +02° 12′ 21′′</td>
<td>7.2</td>
<td>UKIRT/CFHT(NIR), VVDS(spec−z)</td>
</tr>
<tr>
<td></td>
<td>ELAIS-N1</td>
<td>16:10:00 +54° 00′ 00′′</td>
<td>7.2</td>
<td>UKIDSS-DXS(NIR), LOFAR-Deep(radio)</td>
</tr>
<tr>
<td></td>
<td>DEEP2-3</td>
<td>23:30:00 +00° 00′ 00′′</td>
<td>7.2</td>
<td>DEEP2(spec−z), PRIMUS(spec−z)</td>
</tr>
<tr>
<td>UD</td>
<td>SXDS/UKIDSS</td>
<td>02:18:00 -05° 00′ 00′′</td>
<td>1.8</td>
<td>UKIDSS-UDS(NIR), SpUDS(MIR), VVDS(spec−z), CANDELS(HST), PRIMUS(spec−z), UDSz(spec−z)</td>
</tr>
<tr>
<td></td>
<td>COSMOS</td>
<td>10:00:29 +02° 12′ 21′′</td>
<td>1.8</td>
<td>UltraVISTA(NIR), CANDELS(HST), VVDS(spec−z), zCOSMOS(spec−z), PRIMUS(spec−z), Spitzer</td>
</tr>
</tbody>
</table>

We were recently approved for 1250 hours of warm Spitzer time for deep observations of the COSMOS field.

The fields should be well distributed over a wide range of RA, such that fields are reachable at all times of the year.

The fields should overlap other multi-wavelength data sets to maximize scientific potential when combined with the HSC data. The major data sets which offer unique synergy with HSC data are the arcminute-resolution, high-sensitivity CMB survey by ACT in Chile, and its polarization extension ACTPol, for which Princeton is playing a major role; X-ray surveys from XMM and eROSITA; near-/mid-infrared imaging surveys (e.g., VIKING/VIDEO and UKIDSS); and deep spectroscopic surveys (e.g., VIPERS, GAMA, COSMOS, HectoMAP).

The Ultradeep regions should be included in the Deep fields, and (with one exception, see below) the Deep fields should be included in the Wide fields.

The fields should be low in Galactic dust extinction.

One of our wide fields matches a unique 55° deg$^2$ region, the HectoMAP field, where Kurtz et al. (2012) are carrying out a spectroscopic survey for galaxies with r<21.3 with Hectospec, a wide-field multi-object optical spectrograph, on the 6.5m MMT telescope. We will use the spatially-dense spectroscopic galaxy catalog to calibrate cluster finding methods for the Wide data.

Although it is not listed in Table 10, we will also obtain broad-band images in grizy for the All-wavelength Extended Groth Strip (AEGIS) field (RA = 14 h 17 m, Dec = +52° 30′) to the depths of the Deep layer. The AEGIS data is the largest field with publicly available densely sampled spectroscopic redshifts down to R<24.1, including the DEEP2 and DEEP3 spectroscopic samples; this sample is key for calibrating photometric redshifts. The field can be observed with HSC with a single pointing, thus the...
Hyper SuprimeCam survey

• Japan-Princeton-Taiwan
• ~5 years from 2014
• 3 layers
  • UltraDeep — 3.5deg$^2$
  • Deep — 27deg$^2$
  • Wide — 1400deg$^2$
• i-band data for lensing shape measurement, thus good seeing time for it
Summary & Future prospects

prospect for HSC survey in 2015 (>200deg²)

\[ N_{\text{peak}}(SN > 5) \sim 100 \pm 10 \]

\[ \Omega_m = 0.278 \]
Summary & Future prospects

1. Weak lensing cluster finding in 11 deg$^2$ SuprimeCam i-band data
   • 6 peaks with SN>5 (in clean area)
     • all the peaks having optical/Xray counter-part
     • First constraints on M-c & cosmological parameters from WL cluster counts, though the constraints are very broad
     • $c_0$ consistent with LCDM simulations

2. Prospect for HSC survey
   • >200 deg$^2$ by end of 2015
     ➡~100 WL clusters (sample variance ~10%)
     ➡may place useful constraints
   ✓ more accurate theoretical model may be needed

see Shirasaki’s poster for comprehensive study on future prospects