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Subaru Suprime-Cam Weak Lensing Survey over 33 deg^2

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Abstract. Under the currently popular CDM model, mass plays the major role in evolution of large scale structure of the universe. In order to examine the paradigm based on observations, it would be ideal to use purely mass selected object catalog. Weak lensing surveys enable a blind search of cluster scale objects, and thus could provide such catalogs. We are working on a weak lensing survey using Subaru Prime Focus Camera (Suprime-Cam). In this note, we introduce our survey strategy, and the status as well as the performance of Suprime-Cam as a weak lensing surveyor.

1. Introduction

Clusters of galaxies provide a powerful cosmological tool because they are the most massive bound objects in the universe. The comparison of the observed mass function of clusters to theoretical predictions place strong constraints on the theory of structure formation and on the geometry of the universe. Until now however, cluster catalogs have been derived from *light* (either optical or X-ray) and are compromised by selection biases and by untested assumptions about the physical states of clusters. Therefore, a homogeneous cluster catalog whose members are selected by *mass* has long been awaited for.

Weak gravitational lensing directly measures the mass distribution of clusters, regardless of their physical state, and thus provides such a mass selected cluster catalog. In our pilot weak lensing cluster search in a GTO 2 deg^2 field, we had indeed detected 5 clusters with a significant signal (S/N$>$ 5) (Miyazaki et al. 2002), which demonstrated that the weak lensing survey is practical with Suprime-Cam. We are currently expanding the survey area so that our sample contains about 80 to 100 clusters. Based on the experiences of GTO, fields of view of approximately 30$\sim$40 deg^2 is needed to accomplish the goal.

2. Suprime33 Survey

2.1. *Survey Strategy*

X-ray telescopes probe the hot baryonic regions of the universe, and trace dark matter halos whose gravitational potential has trapped and heated the baryons. Thus, X-ray selected clusters have played the dominant role in cluster-based cosmology to date. Since comparisons with this well-established method is important, most of our survey is undertaken in fields with archival X-ray data. Since PSPC camera on-board ROSAT had a large field of view with a reasonable resolution, it had been useful for X-ray cluster surveys. We primarily chose the survey area where pointing PSPC archival data were available. Our selection criteria were the followings:

(a) The ROSAT exposure time T_R should be longer than 25 ks to achieve a detection limit of $L_x(0.5-2.0keV) \sim 2 \times 10^{43}$erg/s for clusters at z = 0.5 (for $H_0 = 75$,$\Omega_M = 0.3$,$\Omega_\Lambda = 0.7$). This corresponds roughly to $M \sim 10^{14} M_\odot$, which is comparable to the detection limit of our weak lensing analysis.

(b) Low elevations degrade the optical image quality and weak lensing analyses. Accordingly the declination,δ, is restricted to $-20^\circ < \delta < 60^\circ$.

(c) The primary PSPC target must not be a previously known cluster or a high redshift QSO.

More sensitive modern telescopes, XMM-Newton and Chandra, are now available, and they have started their wide blank field surveys, which we included in our survey area. We also covers DEIMOS DEEP2 survey field (Davis et al. 2002) where spectra of ~ 65000 faint galaxies will be available. We will make close correlations of galaxy mass and light in DEEP2 fields armed with the rich spectroscopic information. Although X-ray data is not available on these field, X-ray observation is being planned (and is partly scheduled).

Based on the GTO experience, an exposure time of 30 minutes exposure in R_c-band provides us with galaxy number density of about ~ 40 per square-arc-minutes, which, in turn, is sufficient to detect the weak lensing signal corresponding to a $\sim 3 \times 10^{14} h^{-1} M_\odot$ structure at $z = 0.5$. This corresponds roughly to a modest cluster of galaxies. All fields are observed in R_c-band except COSMOS field, which is observed in i'-band to make direct comparison with the ACS/HST's F814W images (See section 3).

2.2. *Current Survey status*

The imaging survey started on May 2003, and we have finished surveying over 22.78 deg^2, as is summarized in Table 1. The width is "net", which means that inappropriate area, such as bright stars and galaxies are located, are all excluded. The median seeing and the rms distribution is 0.65 arcsec and 0.14, respectively. We excluded the images whose seeing is worse than 0.9 arcsec because we noticed that weak lensing survey under the seeing over 0.9 arcsec is quite challenging, e.g. it is hard to obtain enough density of faint galaxies whose shapes are well-determined, if we adopt 30 minutes exposure. However, this reduced the survey area only by 5 %.

We have finished systematically uniform weak lensing analysis over the entire field. As is shown in Figure 1, numbers of mass concentration were detected whose weak lensing signal is significant (S/N> 5) (angular size of the objects are typically 1 to 2 arcmin.

2.3. *Progress of spectroscopic follow-up campaign*

In order to derive the actual physical size and mass of the detected clusters, spectroscopic follow-up is crucial (Figure 2). Measurements of the velocity dispersion of the member galaxies give the estimates of the dynamical mass. Comparison of the dynamical mass with the weak lensing mass enables arguments of the dynamical state of the clusters. Because we believe that systematic comparison based on the uniform catalog like this has been barely done before and that it is quite significant, we requested observing nights for Subaru FOCAS with a multi object spectrograph (MOS) mode to follow up our detected clusters.

Our program awarded three FOCAS nights in May of 2004. Unfortunately, most of the nights were lost due to poor weather condition. Three candidates, however, could be observed and those were actually confirmed as clusters of galaxies (13 hr Field:z=0.32, DEEP16 field:z=0.41, PG1159-035 field:z=0.52). We also have made preliminary long slit spectroscopies by Keck/LRIS of five of the candidates to examine the reliability of our

Table 1. Suprime33 Survey Field. T_R, T_C, and T_N is exposure time of the observation by ROSAT, Chandra, and XMM-Newton, respectively.

Field	RA	DEC	Width deg^2	T_R ksec	T_C ksec	T_N ksec
DEEP02	2:30	00	1.39			
XMM-wide	2:30	–04	3.92			10∼100
Lynx	08:49	+45	1.76		300	140
COSMOS	10:02	+01	1.92			30
Lockman Hole	10:52	+57	1.85	200	300	100
GD140	11:36	+30	1.83	33		
PG1159-035	12:04	–04	1.43	51		
13 hr Field	13:34	+38	2.06	110	120	130
Groth Strip	14:18	+52	0.96		200	80
GTO2deg^2	16:04	+43	2.01	26		
CMA DRA	16:34	+57	1.38	47		
DEEP16	16:52	+36	1.20			
DEEP23	23:30	00	1.07			
Total			22.78			

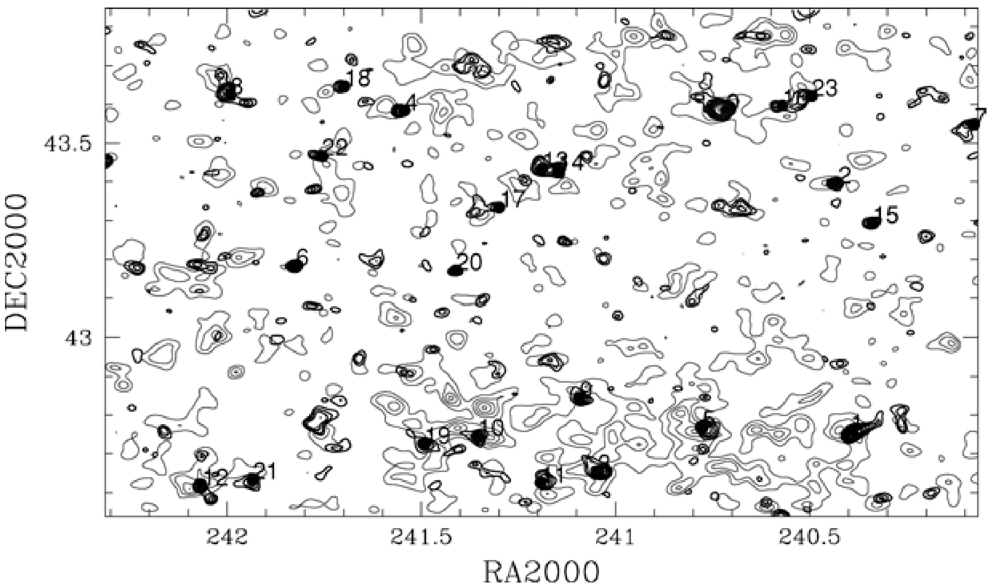

Figure 1. Demonstrating Suprime-Cam's ability for locating mass concentrations from weak lensing data in the 2 deg^2 GTO field (Miyazaki et al 2002). Thick contours indicate mass over-densities where the lensing (convergence) signal/noise exceeds 2. Thin (blue) contours show the surface number density of visible (21< R <23) galaxies.

catalog. All are confirmed as clusters of $z = 0.2 \sim 0.6$. Because our catalog turned out to be reliable, we become even more anxious to observe the rest of the candidates. Three nights have been allocated in December 2005, and we plan to continue the follow-up until enough number of samples are secured.

Figure 2. Optical counterpart of highest S/N halo at (240.715, 43.584) designated '0' in Figure 1 was identified as a new cluster at $z = 0.41$ with subsequent FOCAS spectroscopy. This cluster is not listed in the NASA/IPAC NED catalog.

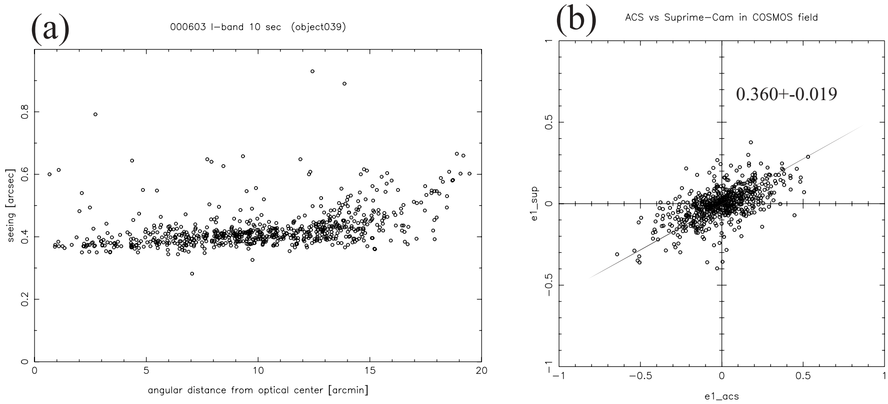

Figure 3. (a)Field angle versus seeing size (FWHM). The exposure time was 10 sec and the filter was I-band.(b)Comparison of the first component of ellipticities of galaxies detected on ACS and Suprime-Cam image.

3. Performance of Subaru/Suprime-Cam as a weak lensing surveyor

In this section, we will quickly review the performance of Suprime-Cam as a tool for weak lensing survey. Most of of description here is rather qualitative, and the detail discussion will be done in the subsequent paper (Miyazaki et al. in prep).

First of all, the image quality of Suprime-Cam is fairly uniform over the entire field of view. Figure 3(a) shows the field angle, θ, dependence of the point spread function characterized by gaussian FWHM of stellar objects. The image is taken under ~ 0.4 arcsec seeing. Slight increase of the PSF size is visible as one goes further from the center. This can be accounted for by the aberration of the prime focus corrector. Although the corrector design is optimized at $\theta \leqslant 15'$, the outside area is practically usable up to $\theta \sim 17'$.

Characterization of the PSF anisotropy and its calibration is the most critical path in weak lensing analysis. The anisotropy is represented as ellipticities of stellar objects (e.g.

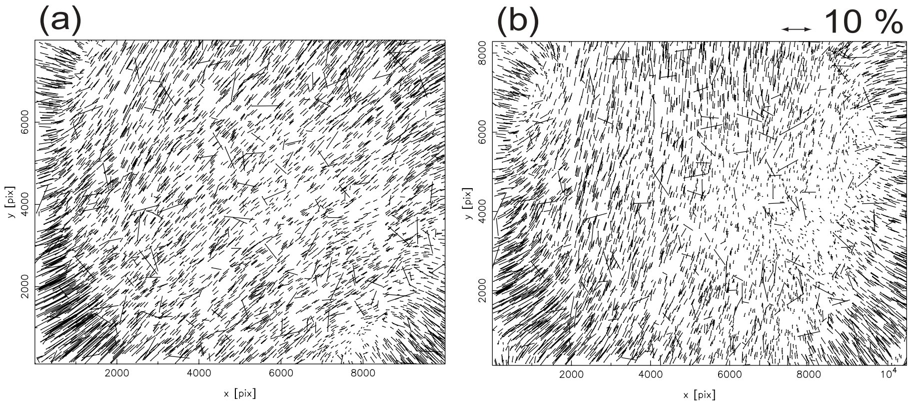

Figure 4. Ellipticities of stellar objects. Orientation of each bar shows the direction of the major axis, and the length scales as the ellipticity. No subtraction of the offset is made. Arrow on left top of the panel shows the size of 10 % ellipticity.

Kaiser, Squires & Broadhurst 1995). In order to characterize the anisotropy of Suprime-Cam, we took sequences of images of dense stellar fields over one night long. Two examples of the ellipticities fields are shown in Figure 4. General tendency is that the fields can be represented as a super-position of (1) almost unidirectional field (variable) and (2) radial field at four corners (almost invariant). Although detail study of the origin of the anisotropy is still underway we suppose that the variable components is due mainly from the telescope shaking whereas the invariant component can be explained by the optical aberration of the corrector. Note here that the ellipticities field varies slowly on the field of view, and no discontinuity is seen across the bondary of the CCDs. Therefore, the ellipticity field can be represented as simple polynomial of the field position. This is very important because general science field has few stars that can be used for this calibration. We abandon the field of $\theta > 17$ because the PSF cannot be represented as simple polynomial there.

Finally, we compare the Suprime-Cam image with that of ACS/HST's in Figure 5. Although the image of ACS is apparently sharper than Suprime-Cam's, the detection limit of extended object (galaxies) is comparable or slightly deeper on the Suprime-Cam image. Ground-based observation is affected by atmospheric smearing. In order to quantify the effect of the smearing, we compare the first component of the ellipticities of galaxies in Figure 3. The result is that ground base observation suffers approximately 60 % loss of the lensing signals. However, if we work out the correct calibration procedure, then we will statistically recover the original lensing strength. However, because the detection limit cannot be improved by the calibration, space-based observations still have the advantage in surveying less massive objects.

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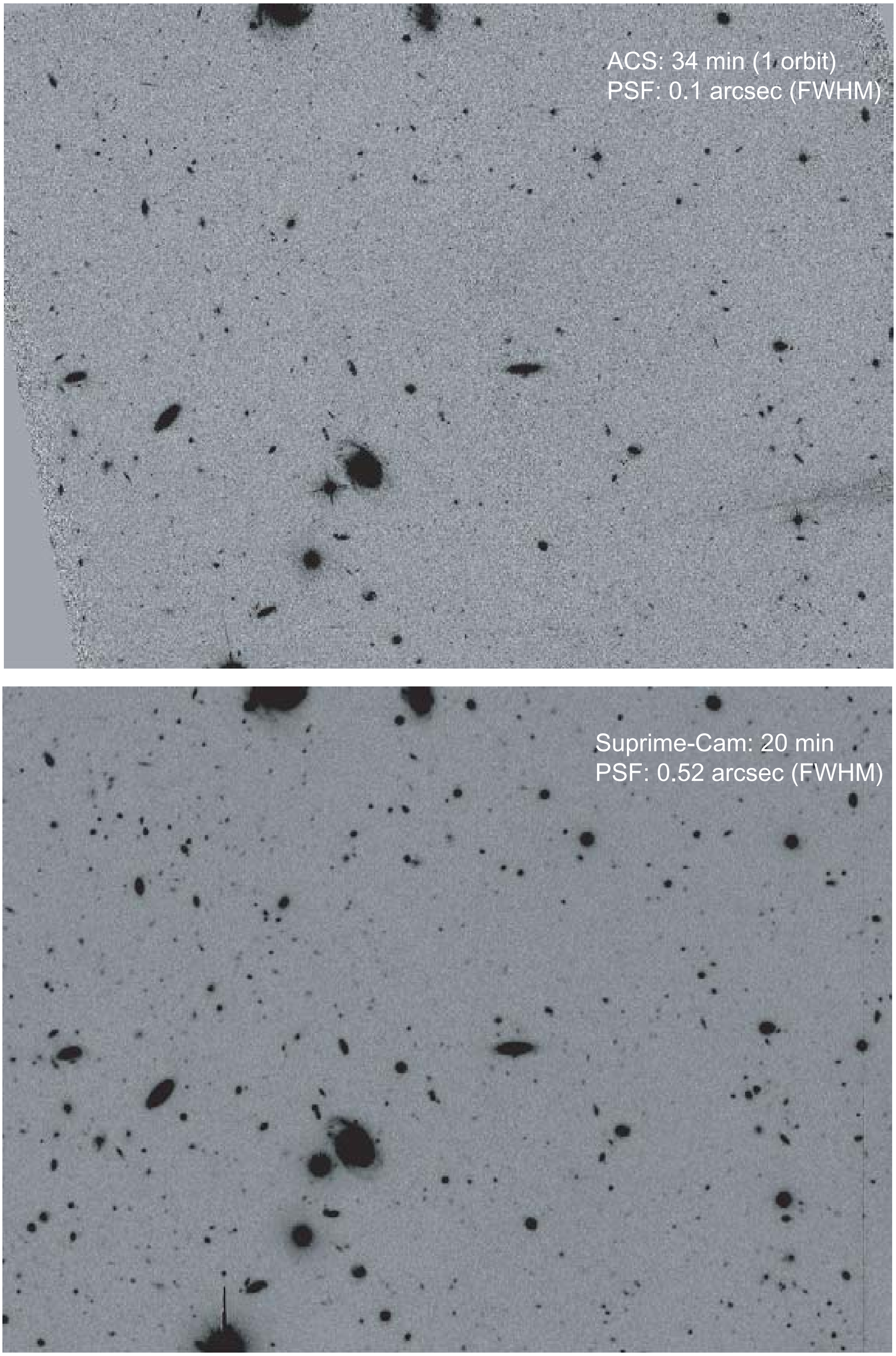

Figure 5. Top: a part of COSMOS field taken with HST/ACS with F814W filter. The exposure time is one orbit (34 minutes) which is a typical length for a degree scale wide field survey such as COSMOS. The field size of this image is 3'.4×2'.4. Bottom: Suprime-Cam i'-band 20 minutes exposure of the correspondent field. The seeing is 0.52 arcsec (FWHM)