J-P-T HSC WS (Jan. 19, 2009)

Cluster Multi-Wavelength Studies:

HSC/SC-WL + SL+ SZE + X-ray + Dynamics

Keiichi Umetsu

(ASIAA, LeCosPA/NTU)

Contents

1. Importance of Cluster Multi-Wavelength Studies for the HSC WL Survey
   - Weak and Strong Lensing
   - Weak/Strong Lensing and Dynamics
   - Weak/Strong Lensing, SZE, and X-ray
2. HSC Synergy with AMiBA
   - Wide (ACT) and targeted (AMiBA) follow-up

HSC WL and AMiBA Science Teams (alphabetical order)

HSC WL WG

- Furusawa, H.
- Hamana, T.
- Miyazaki, S.
- Morokuma, T.
- Nishioka, H.
- Nishizawa, A.
- Okabe, N.
- Umetsu, K.
- Utsumi, Y.
- Yamamoto, K.

AMiBA Science

- Ho, P.T.P. (ASIAA)
- Huang, C.-W.L. (NTU)
- Koch, P.M. (ASIAA)
- Liao, Y.-W. (NTU)
- Lin, K.-Y. (ASIAA)
- Liu, G.C. (TKU)
- Sandor, S.M. (ASIAA)
- Umetsu, K (ASIAA)
- Wang, F.-C. (NTU)
- Wu, J.-H.P. (NTU)

HSC Cluster Weak Lensing: Objectives

(Masahiro's talk on Jan 17)

- **WL cluster search, cosmology w/ cluster counts**
  - Searching for clusters by WL (→ $\nabla\nabla\Phi[x]$)
  - Measuring cluster abundances $dN/dz/d\Omega(z)$ with a weak shear selected cluster sample for cosmological tests

  (e.g., Miyazaki, Hamana+02; Hamana, Takada, & Yoshida 04; Miyazaki, Hamana+07; Hamana, Miyazaki+08)

- **Measurements of cluster mass density profiles and Mass-Concentration relations**
  - Examining the CDM prediction – NFW profile
  - Examining the LCDM prediction – M-c(z) relation

  (e.g., Broadhurst, Takada, KU+2005; KU+Broadhurst 08; Broadhurst,KU+08; KU+09; Okabe, Takada, KU+ in prep.)

- **Cross-correlating WL-mass and galaxy distributions for probing the cluster bias and stochasticity** (Hiroaki Nishioka & HSC WLWG)

Importance of Multi-Wavelength Studies
(Yen-Ting & Masamune's talks on Jan 17)

Two types of complementary follow up for the HSC WL survey

Wide-field surveys: NIR (UKIDS?, VIKING?), X-ray (eROSITA?: 2011~), SZE (ACT)

- Confirmation of WL/optical cluster detections; photo-z
- Establish statistical mass vs. observable (e.g., Tx, Y, N_{gal}) relations

Targeted follow up: X-ray (e.g., Suzaku, Astro-H: 2013~), SZE (AMiBA), spectroscopy (e.g., FMOS, WFMOS, Keck/DEIMOS)

*Conduct multi-wavelength targeted observations on "**subsamples**" of the HSC weak-lensing cluster sample for:*

- **+SZE**: Distributions of IC-gas pressure on large scales from deep SZE observations: NFW-consistent (Komatsu/Seljak) or isothermal beta (=2/3)?
- **+SZE**: Calibrating the mass vs. Y (integrated pressure) relation for SZE cluster cosmology
- **+X-ray + SZE**: Detailed cluster (merger) physics; Understanding the origin of scatters in cluster scaling relations
- **+X-ray + SZE**: Cluster hot-gas mass fractions; Tests of the degrees of hydro-static balance and IC-gas clumpiness
- **+Spectroscopy**: Dynamical structure of equilibrium-state DM halos: velocity anisotropy, pseudo phase-space density, ρ_{DM}/σ^3 \propto r^-a

Weak and Strong Lensing (Subaru/S-Cam + HST/ACS)

Equilibrium-State DM Density Profile

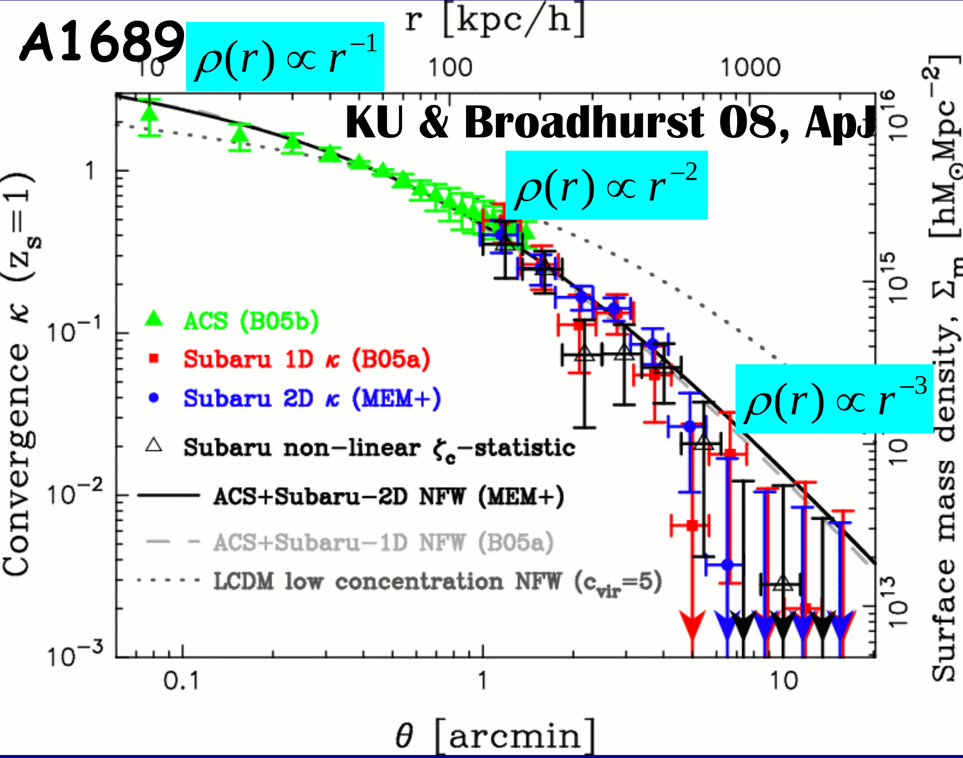
ACS high-resolution imaging → inner SL profile (<1')

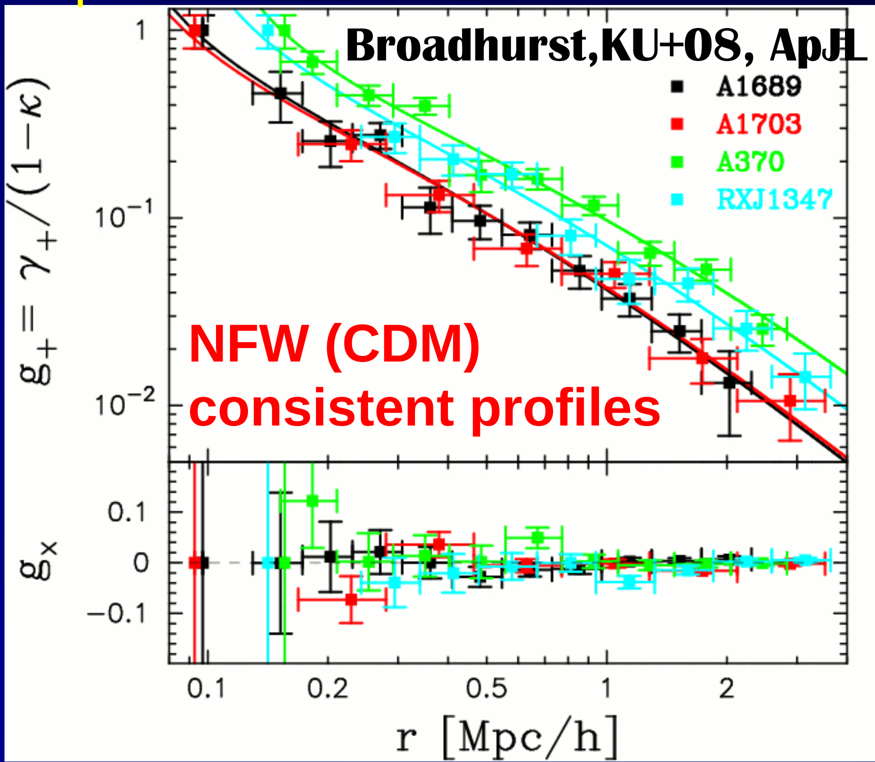
S-Cam wide-field imaging → outer WL profile (1'<r<20')

Observational evidence of the continuously steepening density profile, dlnρ/dlnr(r), expected for collisionless, non-relativistic (Cold) DM

Surface mass density profile $\kappa(r) \propto \Sigma_m(r)$

Tangential shear profile $\gamma_+(r) \propto \bar{\Sigma}_m(<r) - \Sigma_m(r)$





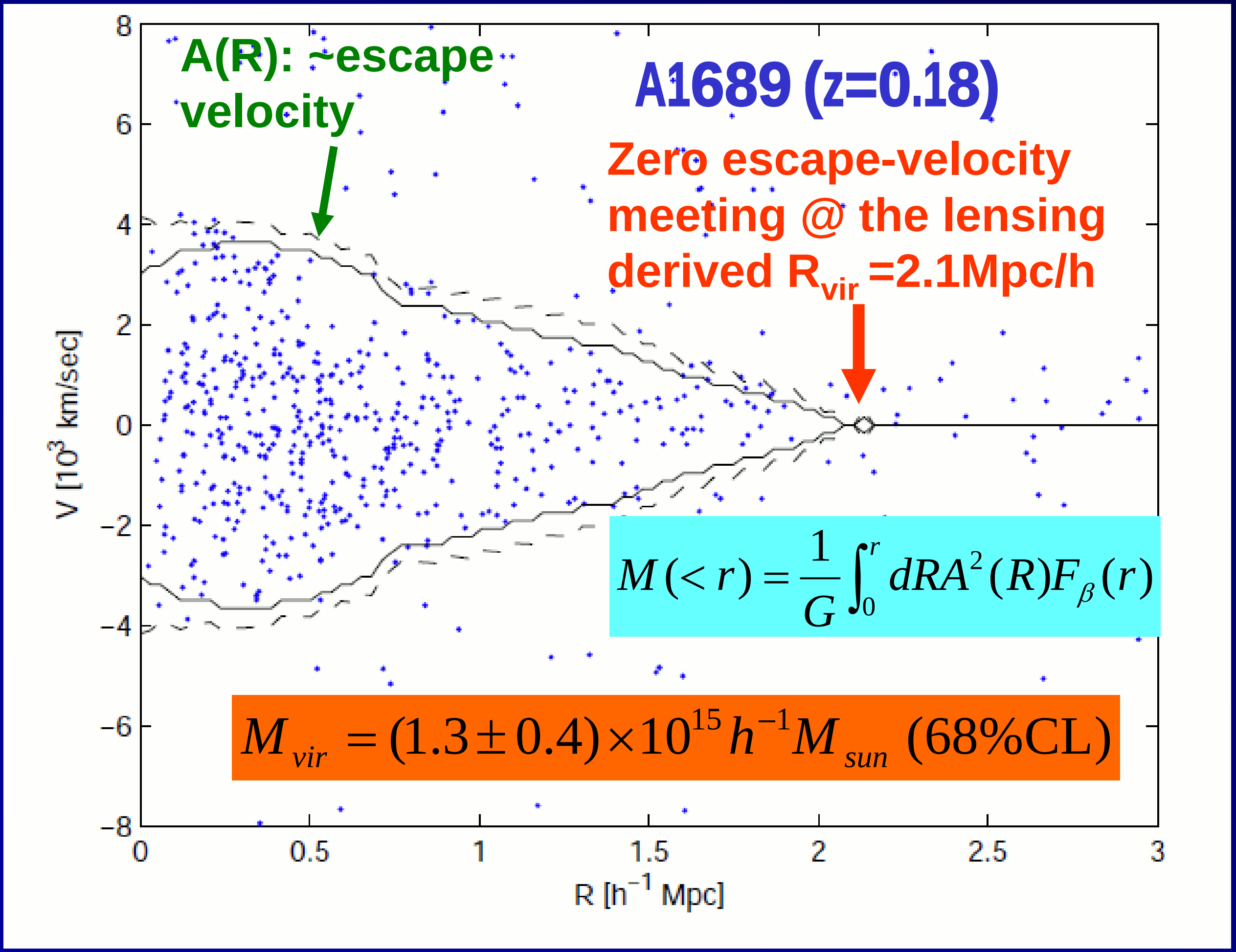
Weak/Strong Lensing and Cluster Dynamics

(Subaru/S-Cam, HST/ACS, VLT/VIMOS)

Velocity Caustic Structure

Velocity Caustic Diagram (Diaferio 1999) -- *Application to A1689*

Projected velocity distribution of ~500 members from VLT/VIMOS spec data



- Symmetric, smooth caustic curves steadily declining @ r>300kpc → *relaxed, no-prominent velocity substructure*
- Reaching the zero velocity @~2Mpc/h, matching the lensing-derived virial radius → *clear boundary at R_{vir}, well-isolated cluster*
- Caustics clearly separate cluster and field galaxies, allowing for an accurate measurement, σ_{1D}= (1400 +/- 60) km/s

Lemze, Broadhurst, Rephaeli, Barkana, & KU 2008 (arXiv:0810.3129)

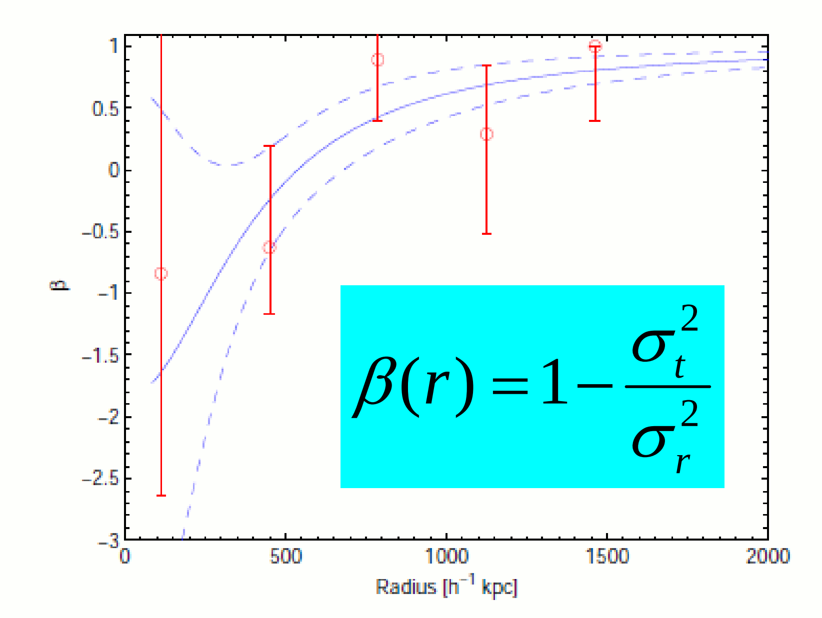
Multi-Wavelength Dynamical Analysis for the 3D Velocity Anisotropy

Jeans equation with "steady-state", "spherically symmetric" spatial distributions, but including 3D velocity anisotropy

$$\frac{1}{n_{gal}(r)}\frac{d}{dr}\left[n_{gal}(r)\sigma_r^2(r)\right]+\frac{2\beta(r)}{r}\sigma_r^2(r)=-\frac{GM(<r)}{r^2}$$

from strong/weak lensing

Solve J.Eq. for (1) the 3D galaxy density profile ($n_{gal}(r)$) and (2) the 3D velocity anisotropy profile ($\beta(r)$) constrained by observed projected profiles:



- Projected galaxy distribution as measured from S-Cam (Vi') imaging

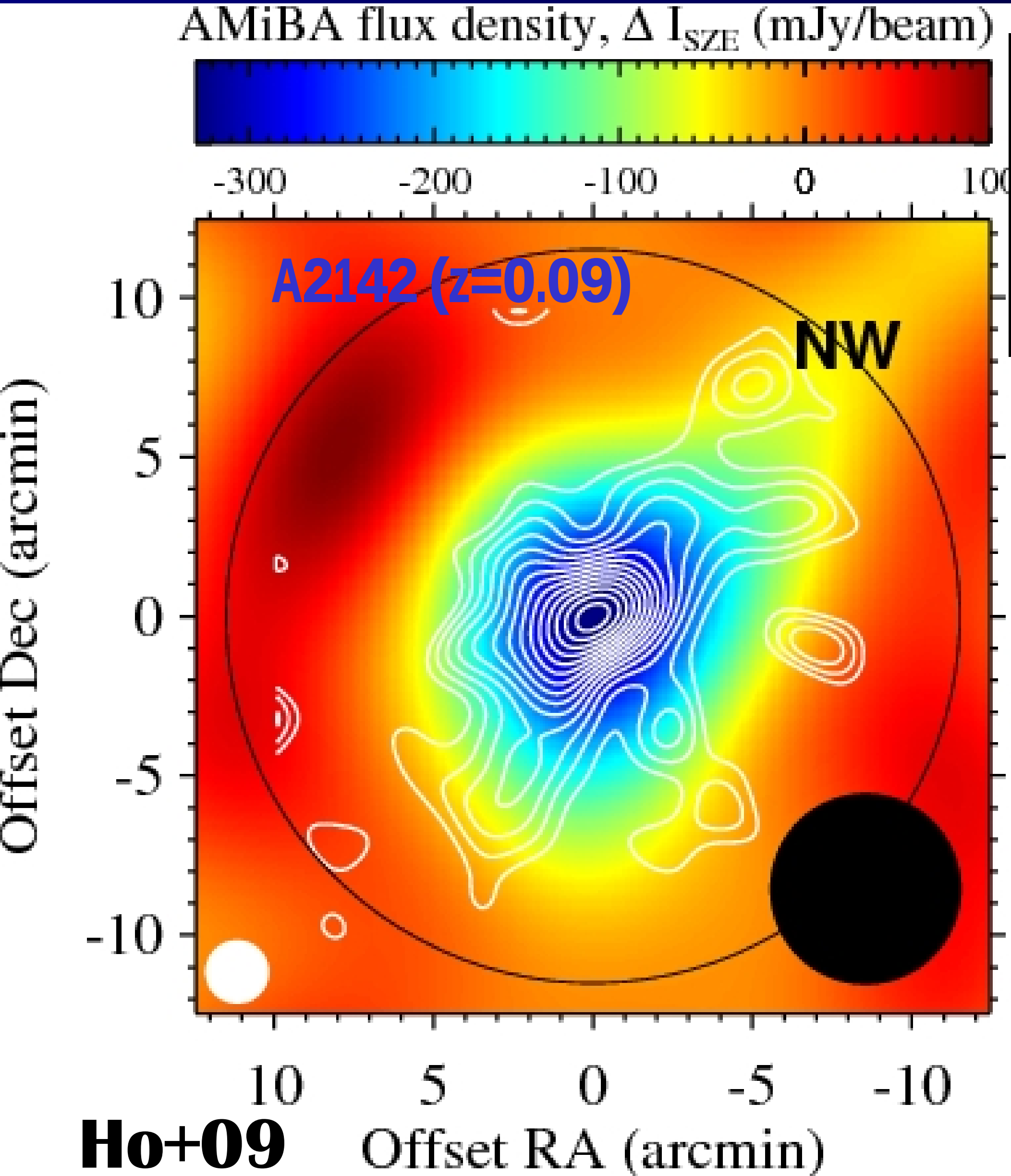
$$n_{gal}^{(proj)}(\theta)=2\int_{D_A\theta}^{\infty}\frac{n_{gal}(r)rdr}{\sqrt{r^2-(D_A\theta)^2}}$$

- Projected velocity dispersion profile from 500 caustic-identified member galaxies

$$\sigma_{(proj)}^2(\theta)=\frac{2}{n_{gal}^{(proj)}(\theta)}\int_{D_A\theta}^{\infty}\sigma_r^2(r)\left[1-\beta(r)\frac{(D_A\theta)^2}{r^2}\right]\frac{n_{gal}(r)rdr}{\sqrt{r^2-(D_A\theta)^2}}$$

Weak Lensing and SZE
(Subaru/S-Cam + AMiBA)

Mass and Hot Baryons in a Merging Cluster



Color: AMiBA SZE decrement (Wu+09) → electron pressure

Contours: Subaru WL (Okabe & Umetsu 08; Umetsu+09) → mass (~DM)

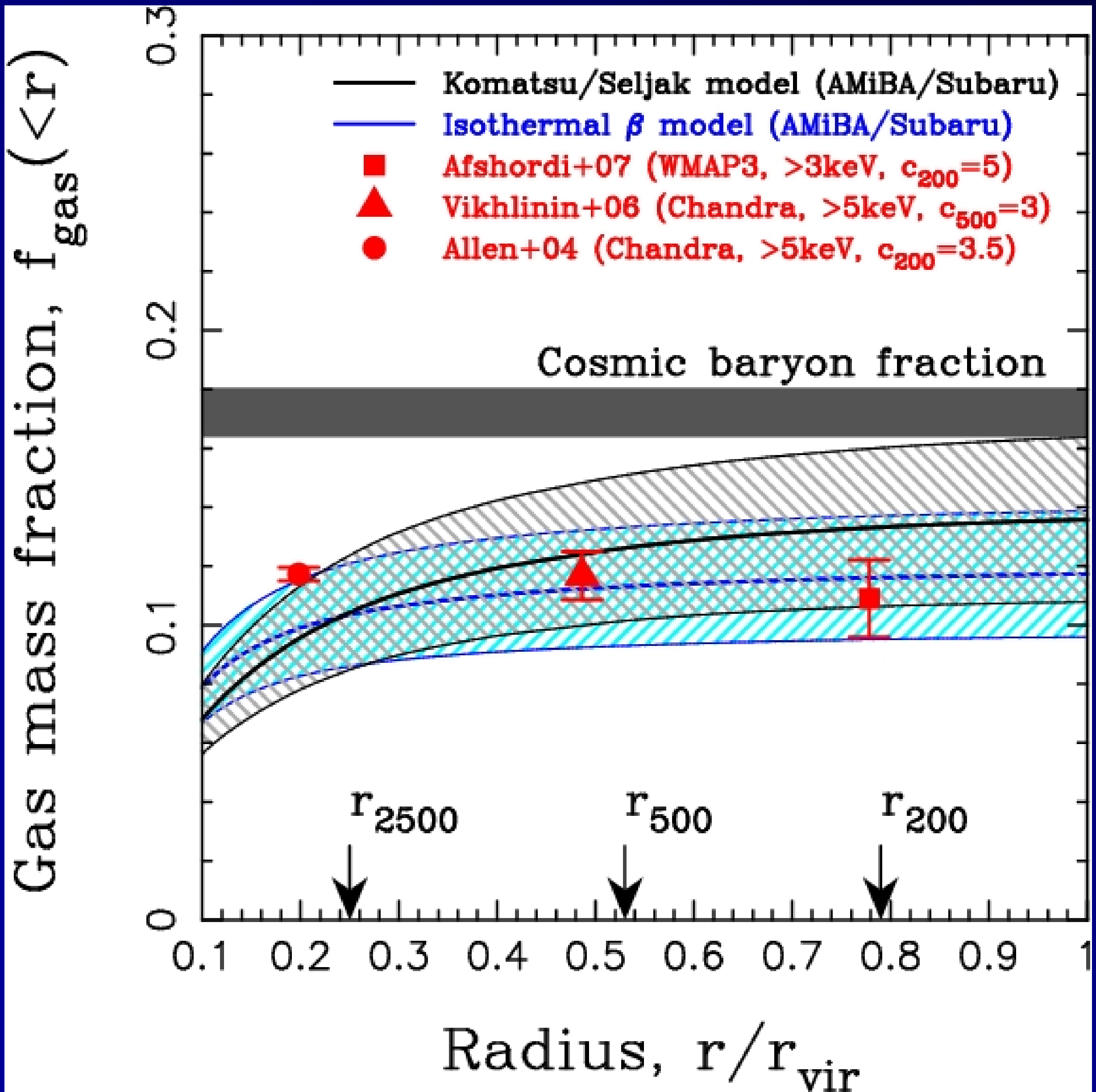
First AMiBA7 papers:

- Ho et al. 2009, ApJ in press (arXiv:0810.1871)
- Nishioka et al. 2009, ApJ in press (arXiv:0811.1675)
- Umetsu et al. 2009, ApJ in press (arXiv:0810.0969)
- Wu et al. 2009, ApJ in press (arXiv:0810.1015)
- Koch et al., ApJS, submitted
- Lin et al., ApJ, submitted

A few more science/instrumentation papers to be submitted to ApJ soon

Weak/Strong Lensing, SZE, and X-ray (Subaru/S-Cam + HST/ACS + AMiBA + T_X)

Cluster Hot-Baryon Fractions



Averaged f_{gas} profile of 4 AMiBA-lensing clusters with $\langle M_{vir} \rangle$=1.2e15 M_{sun}/h
(**A1689,A2142,A2261,A2390**)

- (22 +/- 16)% of the baryons are missing from the "hot" cluster environment (~5% accounted for by cold baryons)
- First WL+SZE based f_{gas} measurements on large scales (up to r200) without the hydrostatic-equilibrium assumption
- Consistent with X-ray based measurements with the hydro-equilibrium assumption

Umetsu+09, ApJ in press (arXiv:0810.0969)

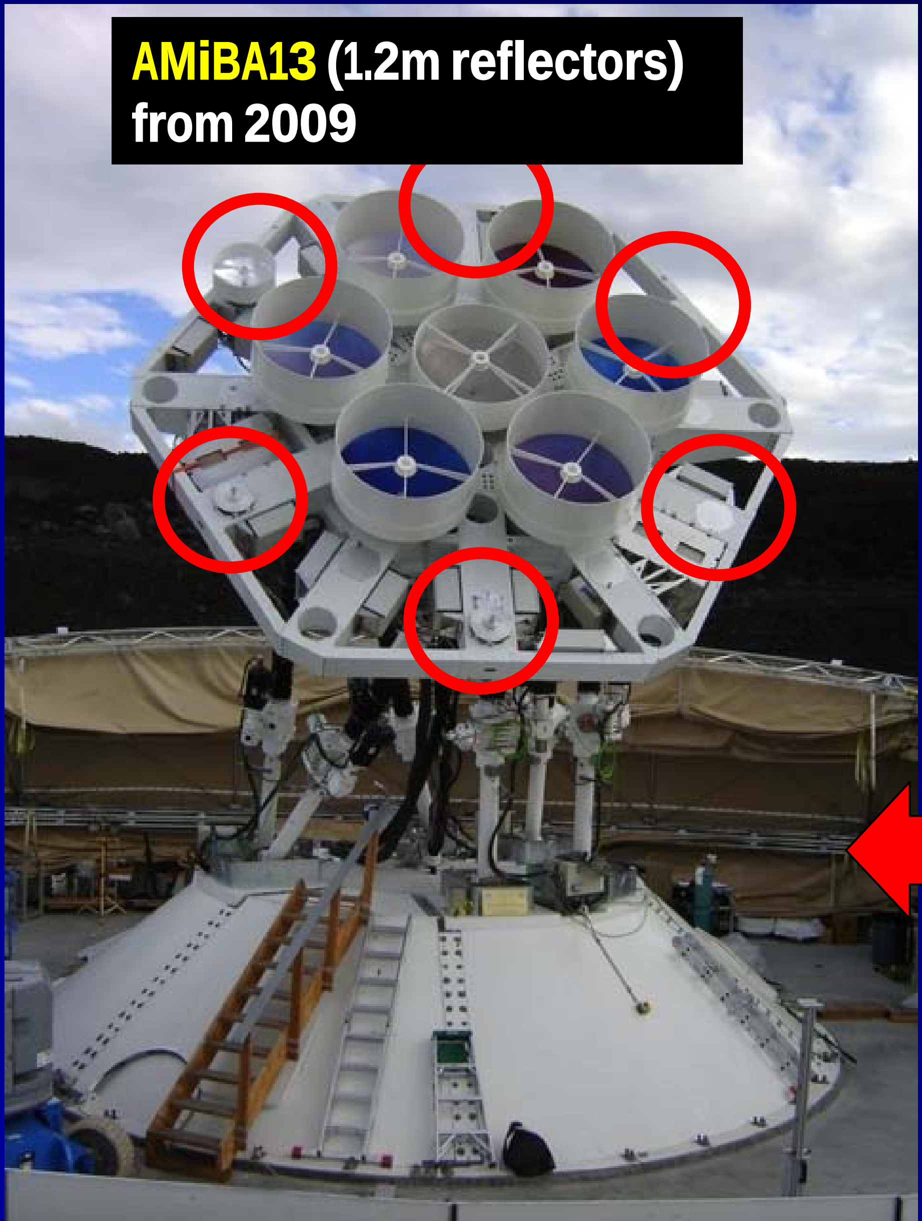
Subaru-HSC/S-Cam and AMiBA-13 Observations of Massive Clusters

HSC Synergy with SZE Observations

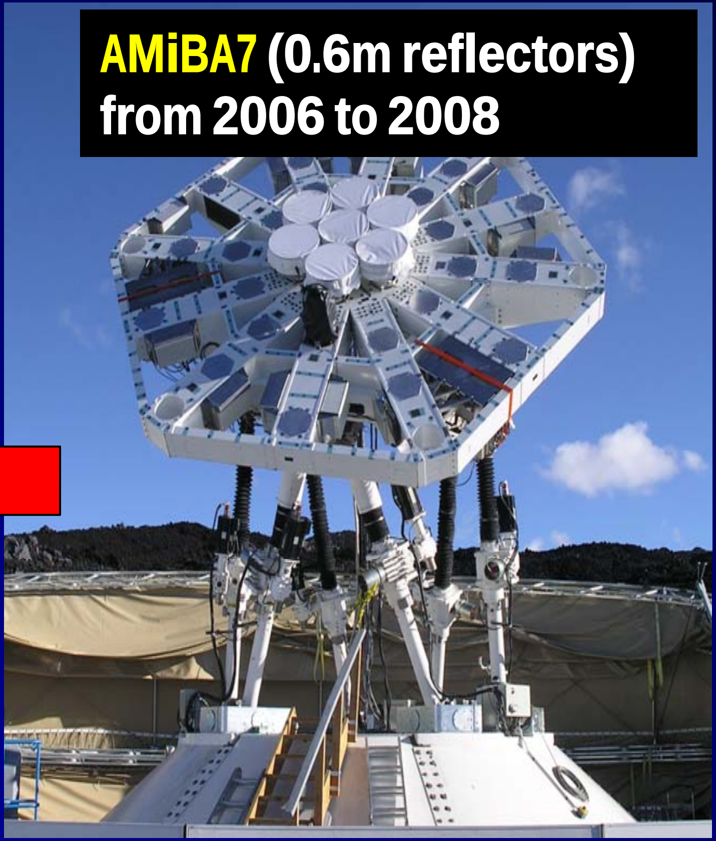
SZE Follow-up by "Two" Complementary SZE Telescopes

- **Wide-field follow-up by ACT** (Yen-Ting's talk)
  - ACT large-sky SZE surveys will provide a **nearly mass-limited cluster sample**
  - Cross correlating SZE and WL surveys will improve cluster detections
  - For cosmological tests with SZE clusters, we need to establish **accurate mass-observable (SZE flux, or integrated Compton Y) relations**
- **Detailed targeted follow-up by AMiBA** (Proty's talk)
  - Interferometers utilize cross correlations → **suppressed systematic effects**; **well-understood flux/phase calibrations**
  - Long integrations, providing a **detailed cluster pressure map**.
  - Joint Subaru+AMiBA observations, allowing for a calibration/understanding of the **M vs. Y**, required for SZE-based cosmological tests
  - Follow up imaging of high-z cluster candidates from the HSC survey (z=1-2)

AMiBA with 1.2m Reflectors

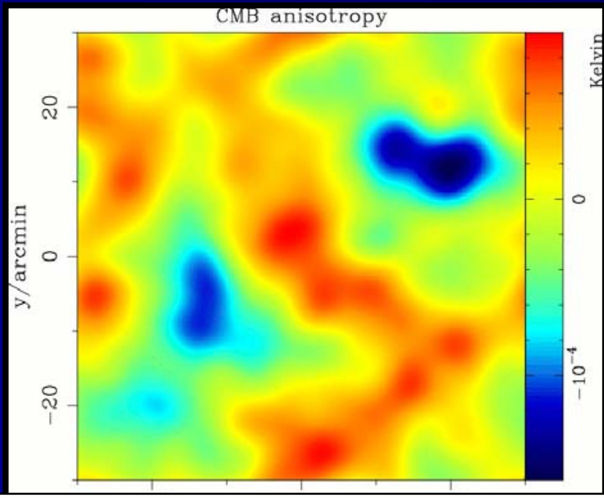


- ✓ Increasing the photon-collecting area by a factor of ~7.4
- ✓ For unresolved targets, AMiBA13 is **~50 times faster** than AMiBA7
- ✓ Angular resolution is 2 arcmin (10' FoV)



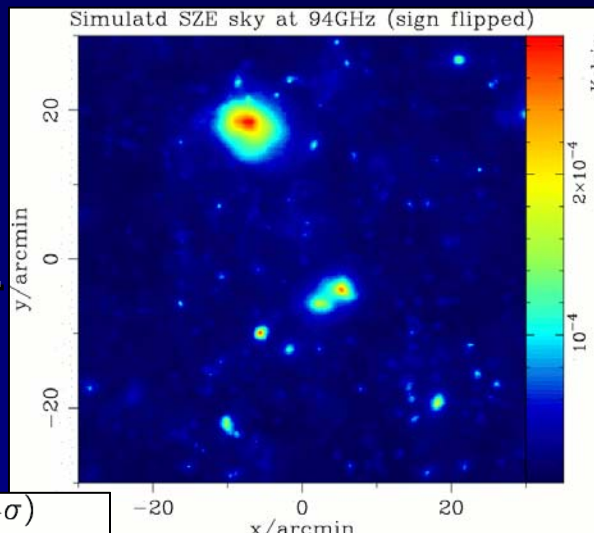
Simulated AMiBA13 Deep Survey

Primary CMB



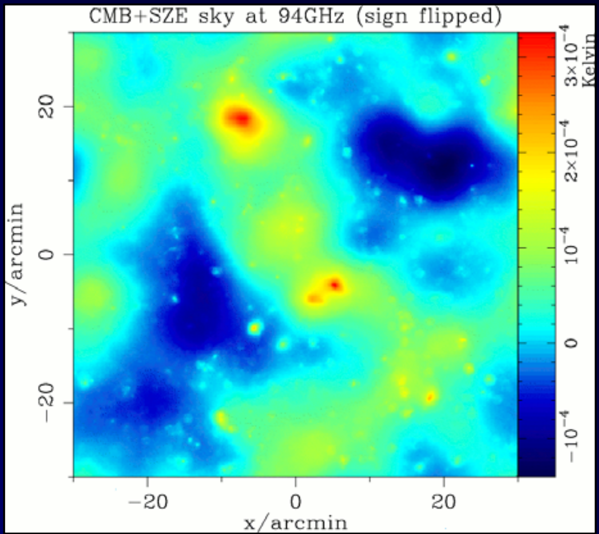
+

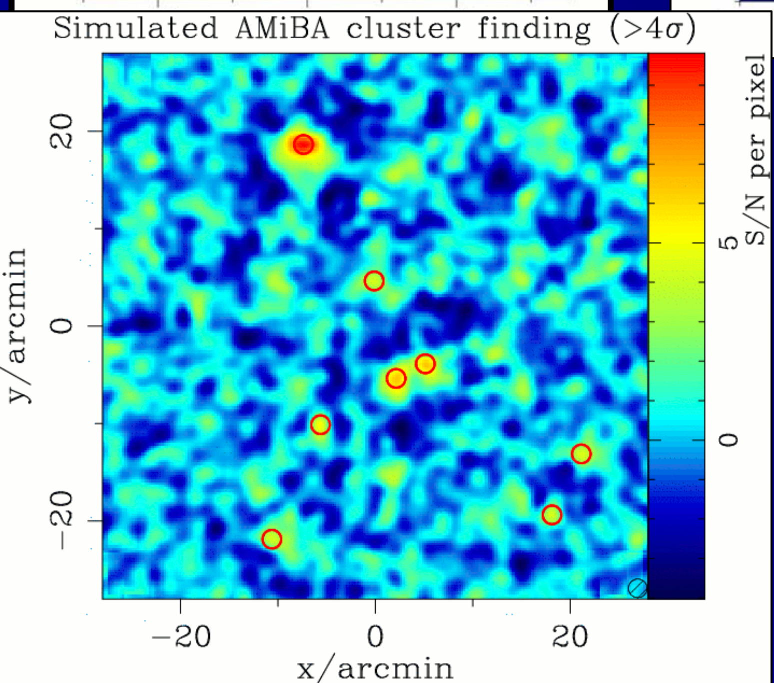
T-SZE (ΛCDM, preheating)



=

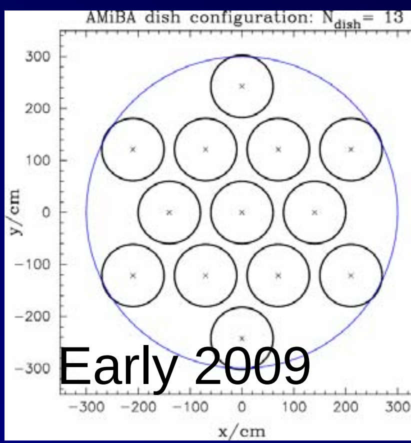
CMB+TSZE sky @94GHz





Simulated AMiBA13 survey

- 400ks integration over 1deg^2 (**14 nights**)
- 20cm gap between adjacent dishes filters out **primary CMB contamination**
- **Sensitivity**: 1.1mJy per 2' beam: 0.5mJy primary contribution included

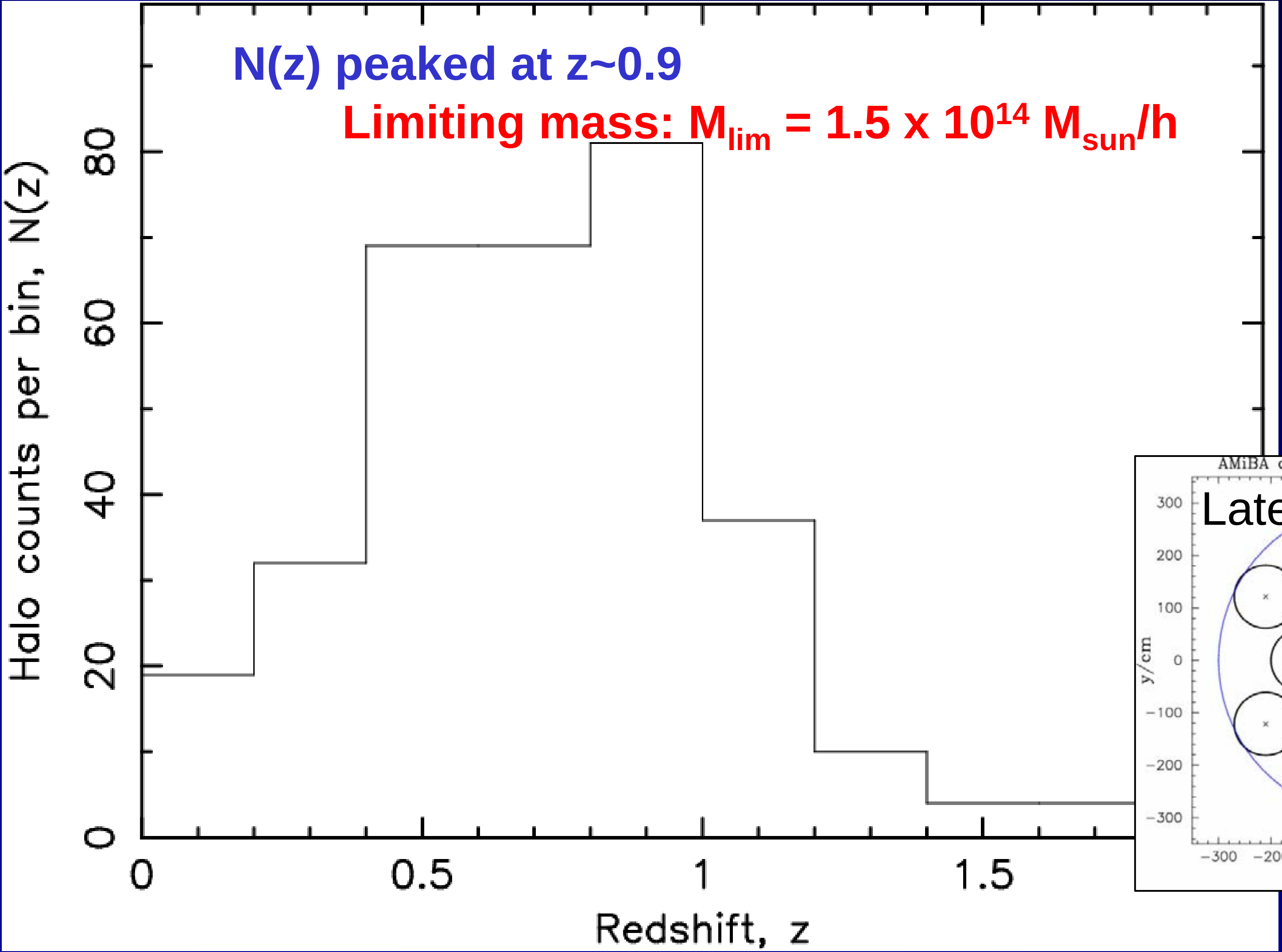


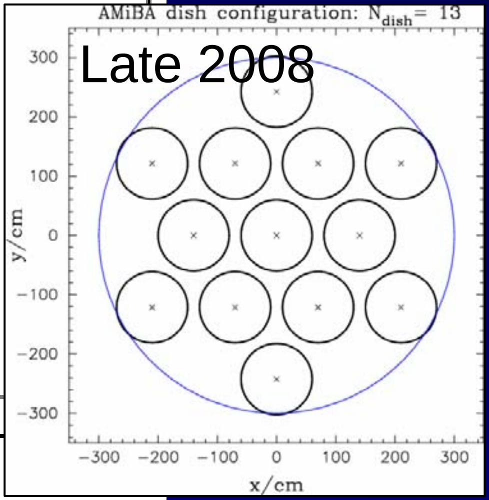
Early 2009

Umetsu+04

SZE – Probing High-z Clusters

Forecasts: Redshift distribution of AMiBA clusters:





Umetsu et al. 2004

Summary

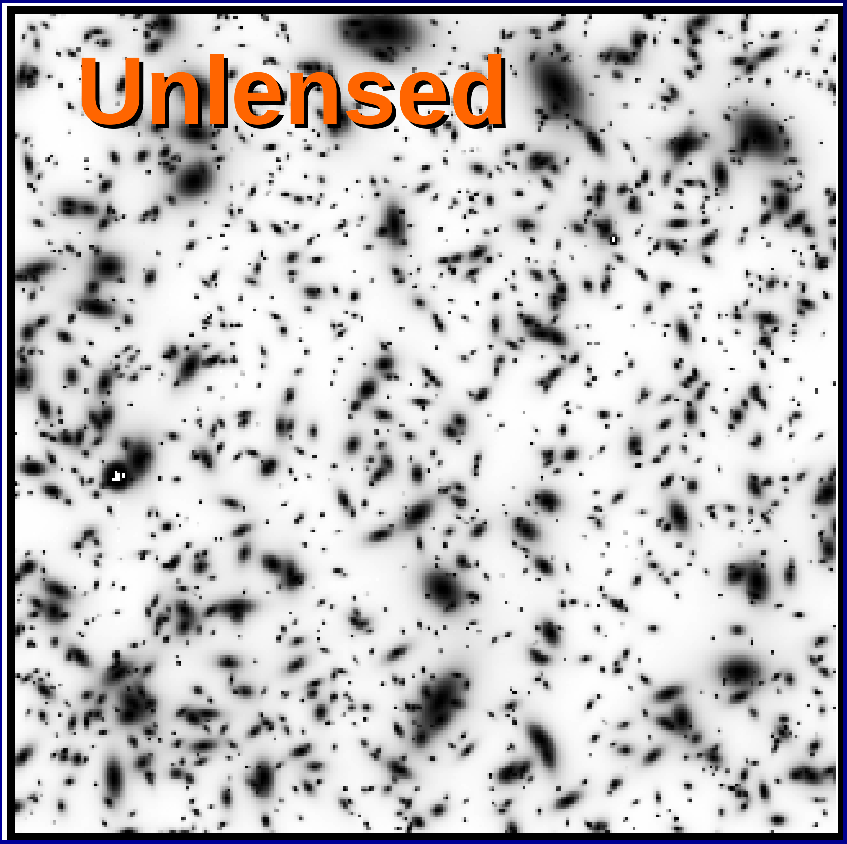
- HSC wide-field imaging (1.5deg) will be extremely important to probe the DM structure of clusters out to large radii: *mass profile, hot-baryon fraction profile, mass-observable relations, velocity profile → detailed multi-wavelength studies of nearby (z<0.1) clusters will be of great interest.*
- *AMiBA targeted follow up observations of high-z (z<2) cluster candidates (which HSC would discover) will be interesting to explore the nature of high-z clusters and possibly to put a constraint on the structure formation model.*

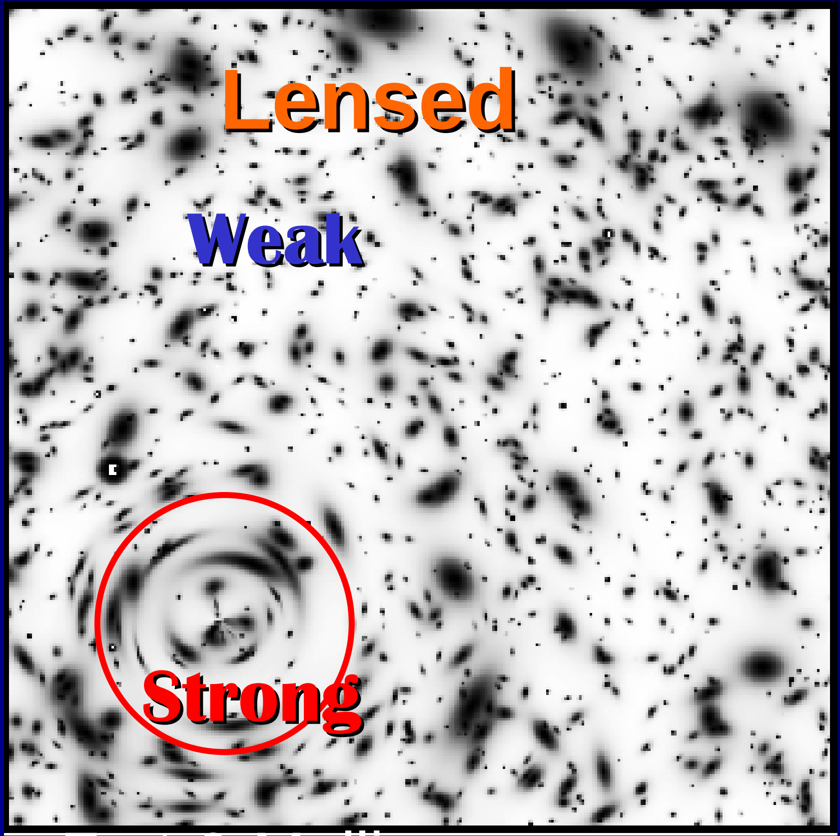
FIN

Cluster Gravitational Lensing

Lensed images of background galaxies carry the imprint of $\nabla\nabla\Phi(x)$ of intervening cosmic structures:

Observable shape distortions can be used to map the distribution of matter in clusters.





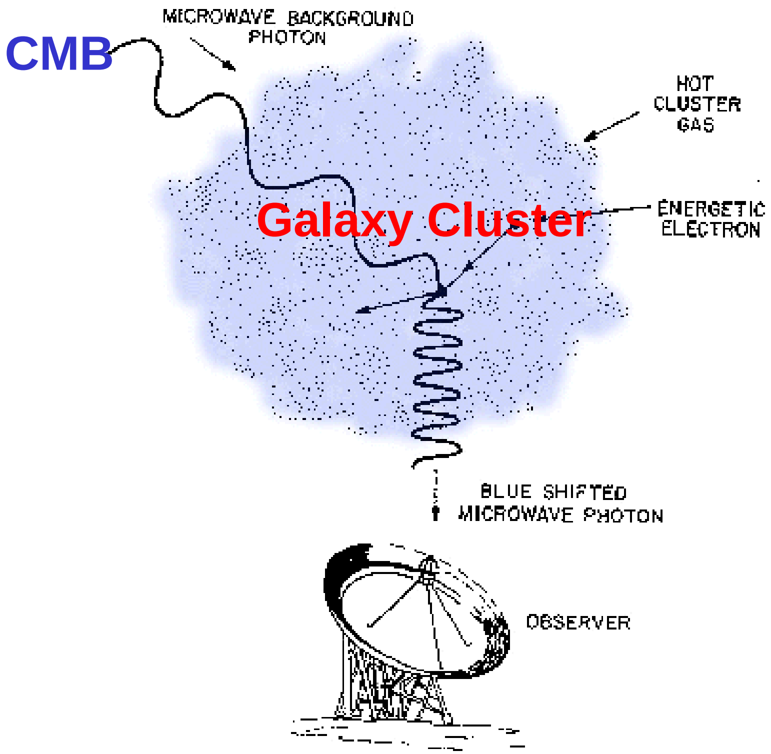
Fort & Mellier

Cluster Thermal Sunyaev-Zel'dovich Effect (T-SZE)

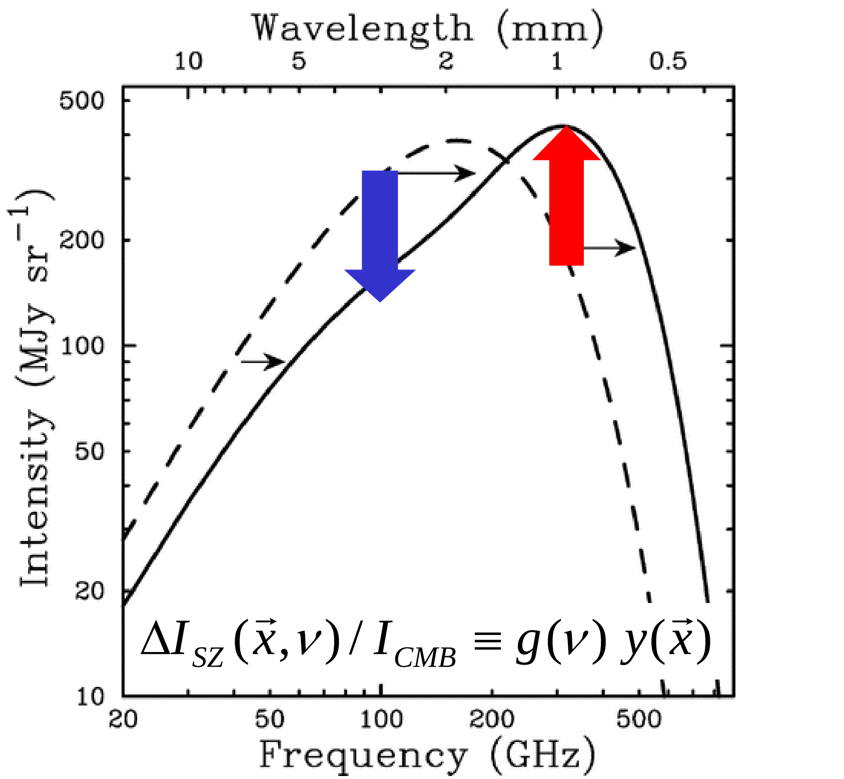
10^-2 10^-2

$$y \equiv \int_0^{\lambda_{\rm LSS}} d\tau \, \frac{k_{\rm B}(T_e - T_{\rm CMB})}{m_e c^2} \approx \int \frac{k_{\rm B} T_e}{m_e c^2} \sigma_{\rm T} n_e dl \propto \int dl \, P_e$$

Energy transfer from **hot cluster gas** to **cold CMB** via inverse Compton scattering



Spectral distortion of CMB spectrum



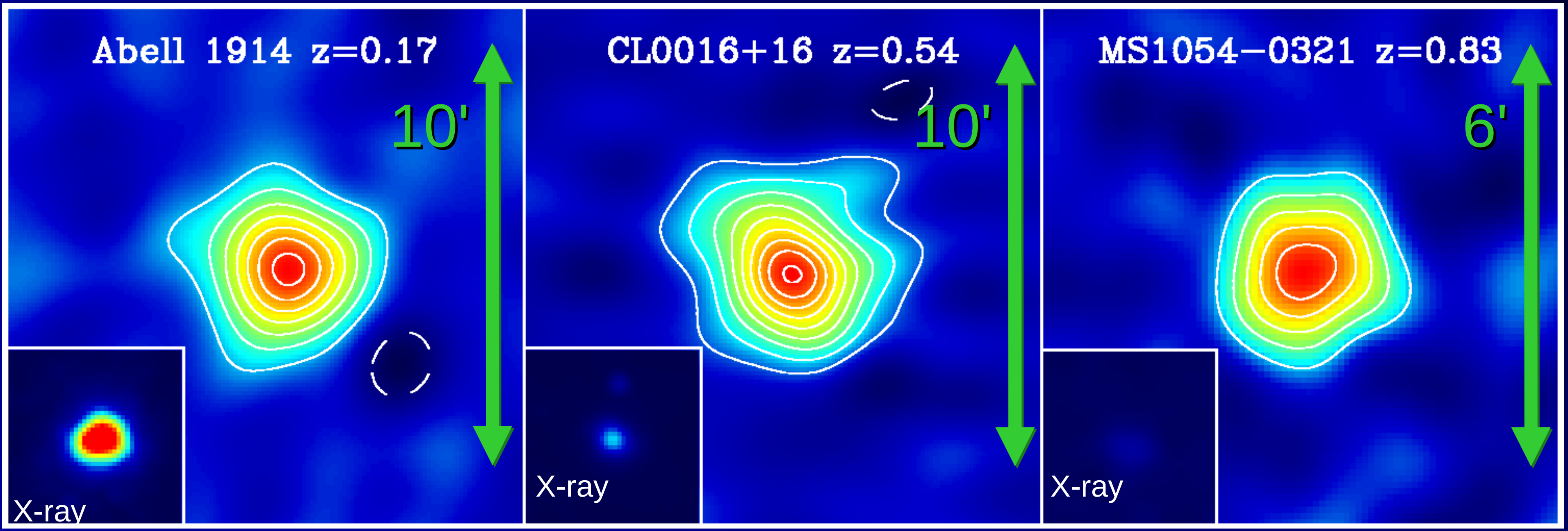
Thermal Sunyaev-Zel'dovich Effect

SZE signal

$$\Delta I_{SZ}(\vec{x},\nu)/I_{CMB}(\nu) \equiv g(\nu)\, y(\vec{x})$$

10^-2 10^-2

$$y \equiv \int_0^{\lambda_{\rm LSS}} d\tau \, \frac{k_B(T_e - T_{\rm CMB})}{m_e c^2} \approx \int \frac{k_B T_e}{m_e c^2} \sigma_T n_e dl \propto \int dl \, P_e$$

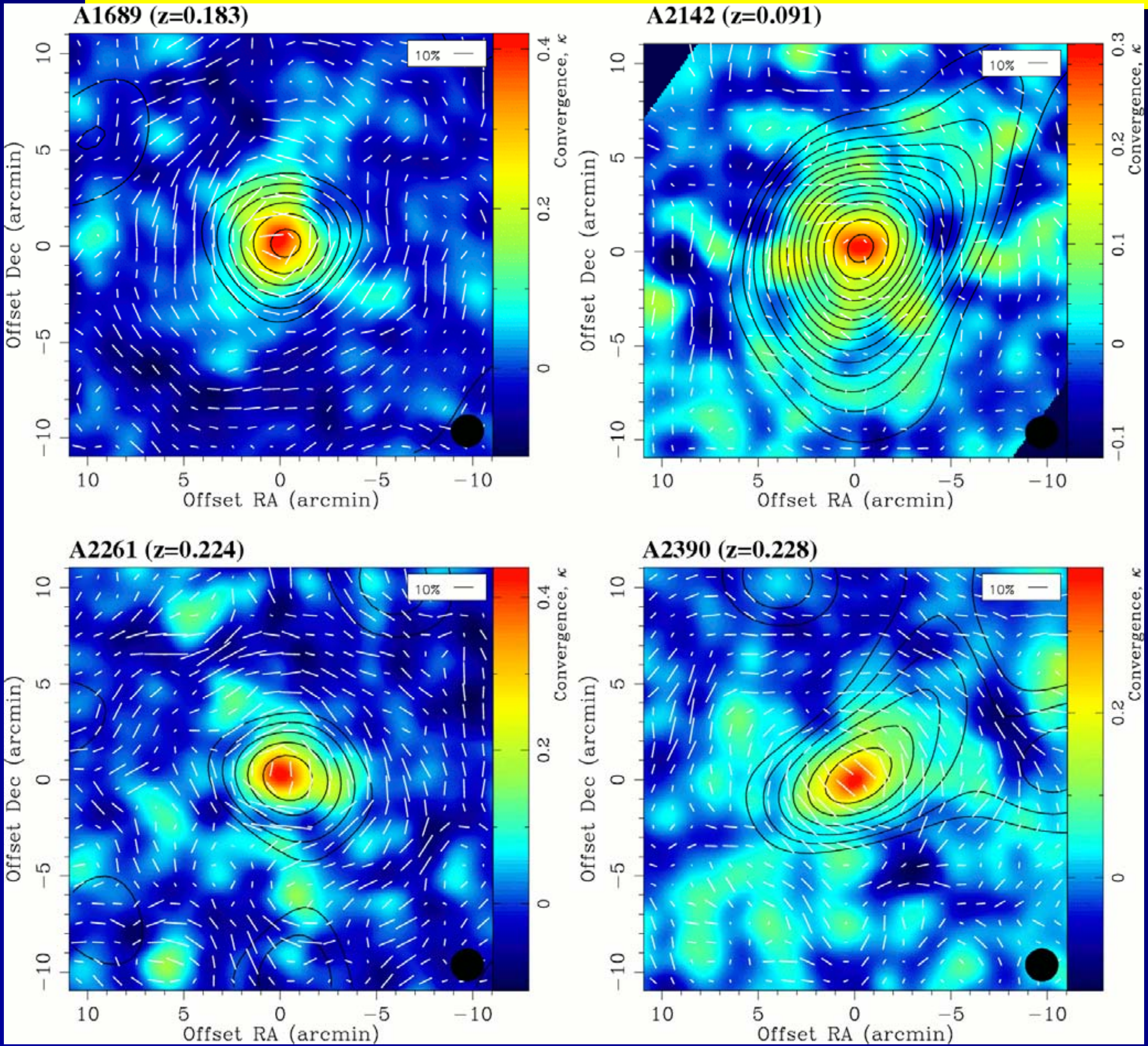


(Carlstrom+99)

SZE brightness independent of distance (z),

while X-ray/Optical/Lensing signal of clusters gets fainter

Distribution of Mass and Hot Baryons in Massive Cluster Environment



AMiBA (contours)

T-SZE decrement (pressure map)

23 arcmin FoV

6 arcmin FWHM

Subaru WL (color)

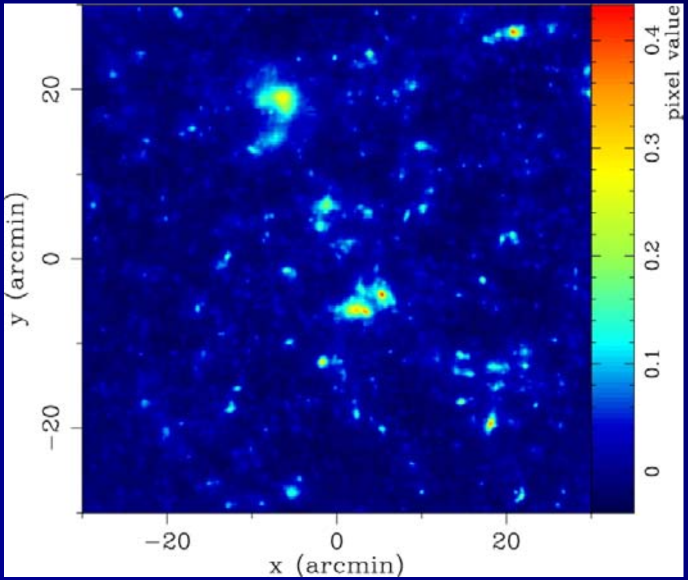
Lens convergence (projected mass map)

~30 arcmin FoV

2 arcmin FWHM

Umetsu+2009, ApJ in press

Simulated AMiBA and Subaru Surveys

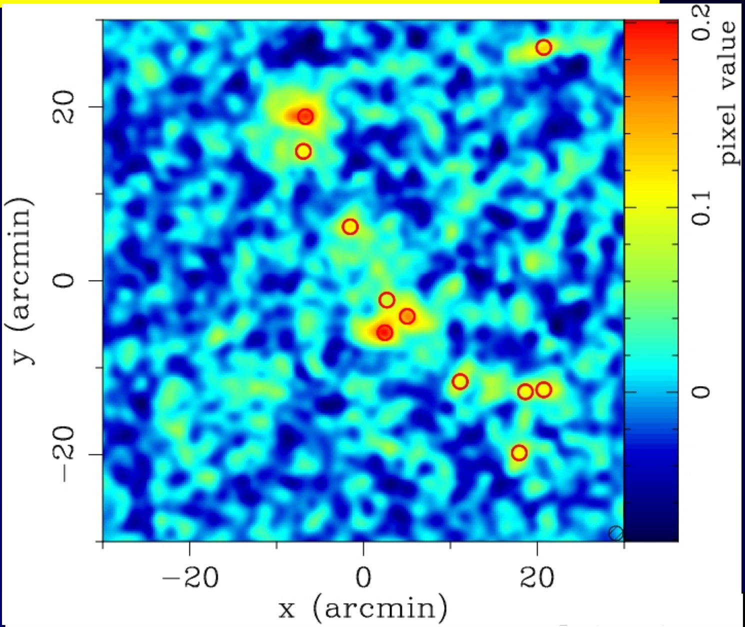


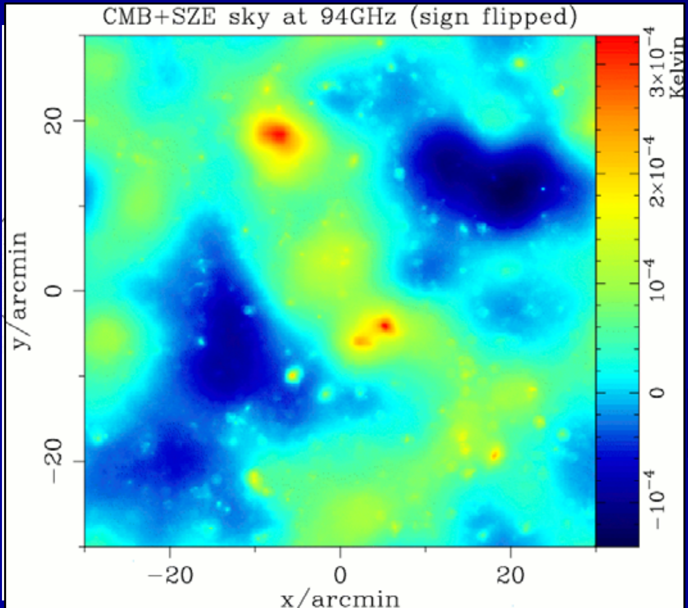
Subaru WL

ng=30 arcmin^-2

zs=1

σ(g)=0.4





AMiBA13 SZE