Cluster Lensing Science with HSC

Distortion, Depletion, and Dilution:

Key "Three D" Components in Weak Lensing

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Major Collaborators (alphabetical order)

HSC WL-WG

- Furusawa, H.
- Hamana, T.
- Miyazaki, S.
- Morokuma, T.
- Nishioka, H.
- Nishizawa, A.
- Okabe, N.
- Okura, Y.
- Takada, M.
- Utsumi, Y.
- Yamamoto, K. et al.

Cluster Lensing/Dynamics

- Broadhurst, T.
- Lemze, D.
- Medezinski, E.
- Zitrin, A.

LoCuSS

- Okabe, N.
- Smith, G.P.
- Takada, M. et al.

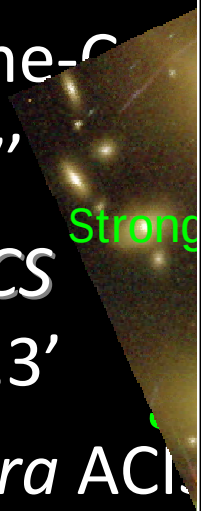
AMiBA SZE

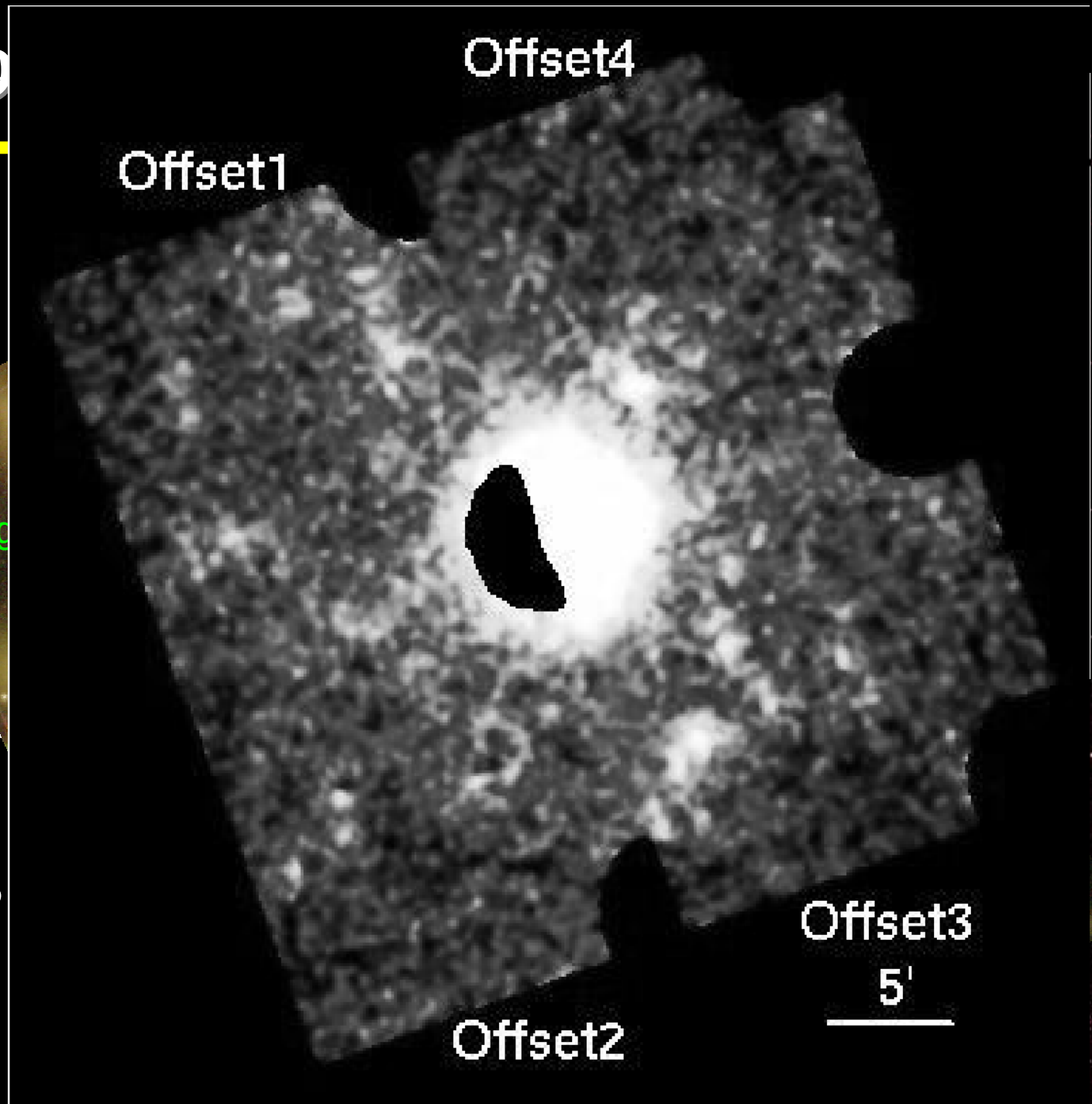
- Birkinshaw, M.
- Ho, P.T.P.
- Nishioka, H.
- Wu, J.H.P. et al.

A1689

z = 0.183

- *Subaru*
  Suprime-C
  34’x27’
- *HST ACS*
  3.3’x3.3’
- *Chandra* ACI
- AMiBA
- VLT/VIRMOS
- Suzaku/XIS





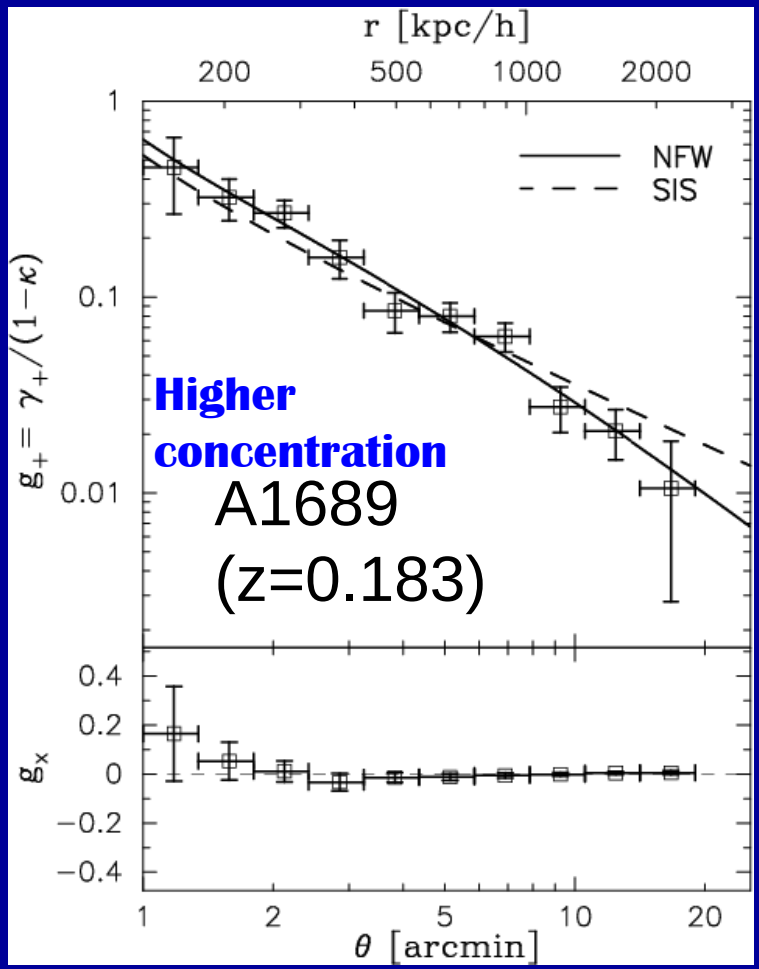
2. Distortion + Dilution Analysis

Improving weak lensing measurements

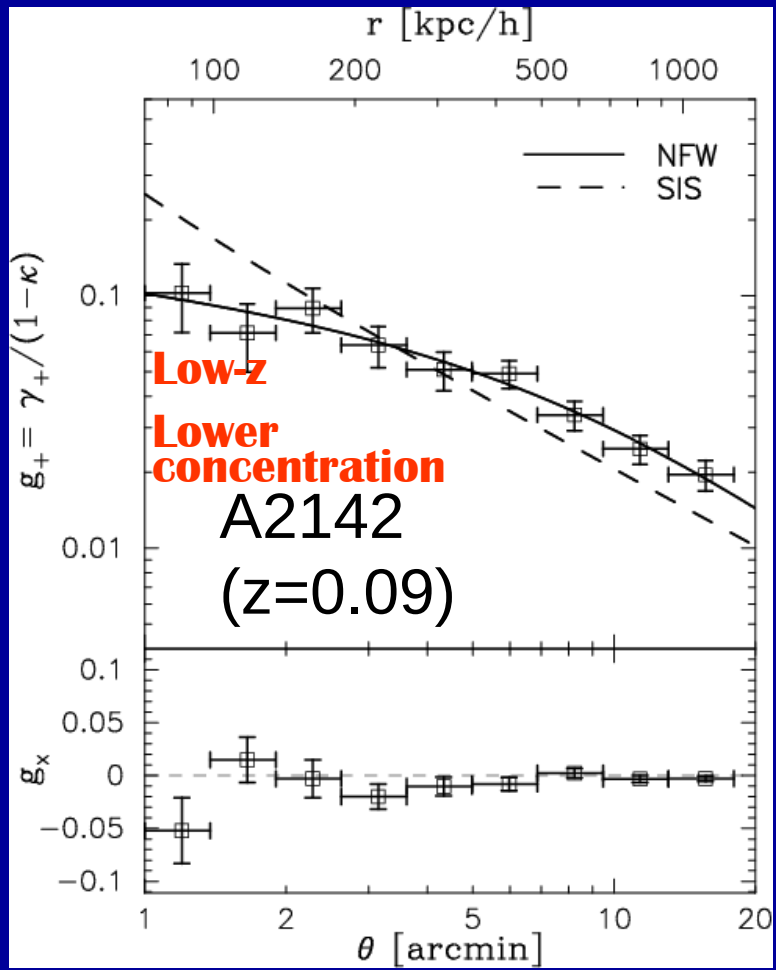
Tangential Distortion

$$\gamma_+(r) \propto \overline{\Sigma}_m(<r) - \Sigma_m(r)$$

A measure of tangential coherence of distortions around the cluster (Tyson & Fisher 90)



Umetsu & Broadhurst 08, ApJ

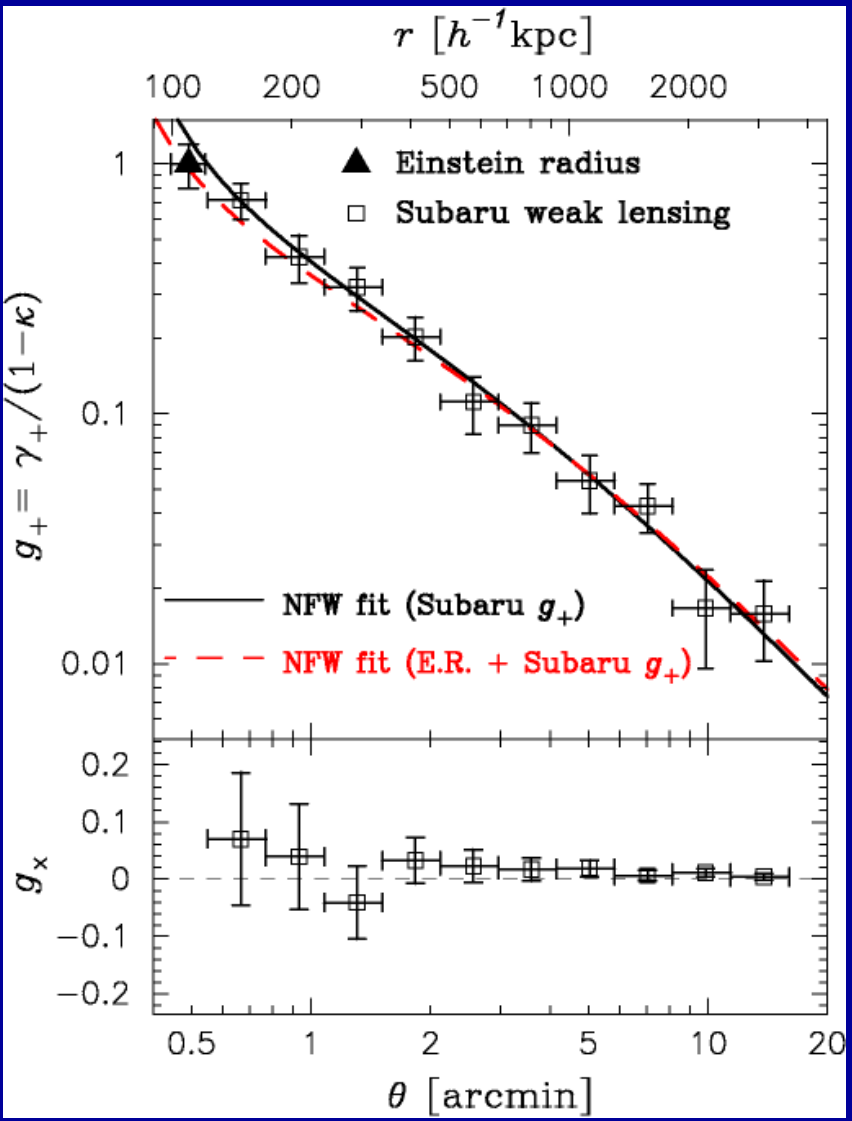


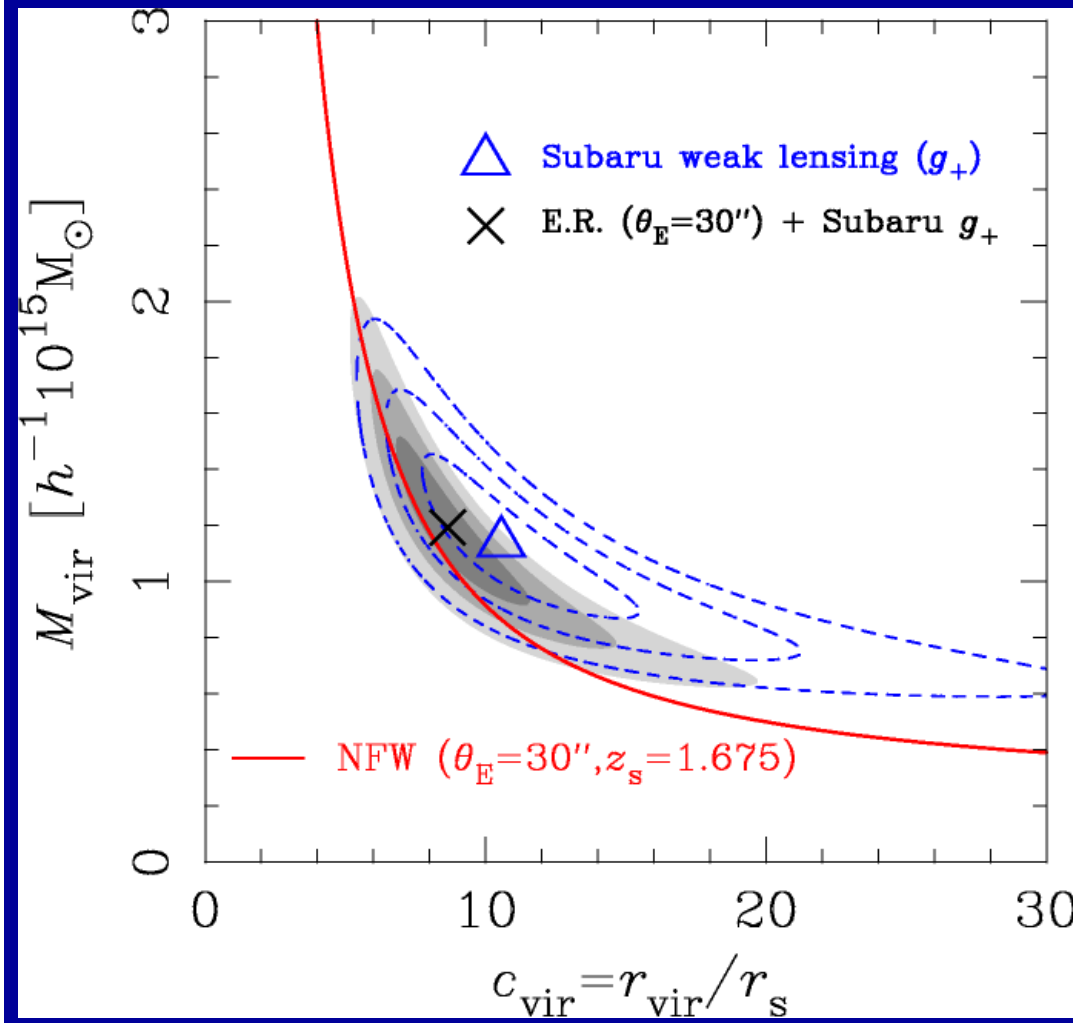
Umetsu, Birkinshaw, Liu+ 09, ApJ

Distortion + Einstein Radius

CL0024+1654 (z=0.395)

Joint constraints on the NFW parameters

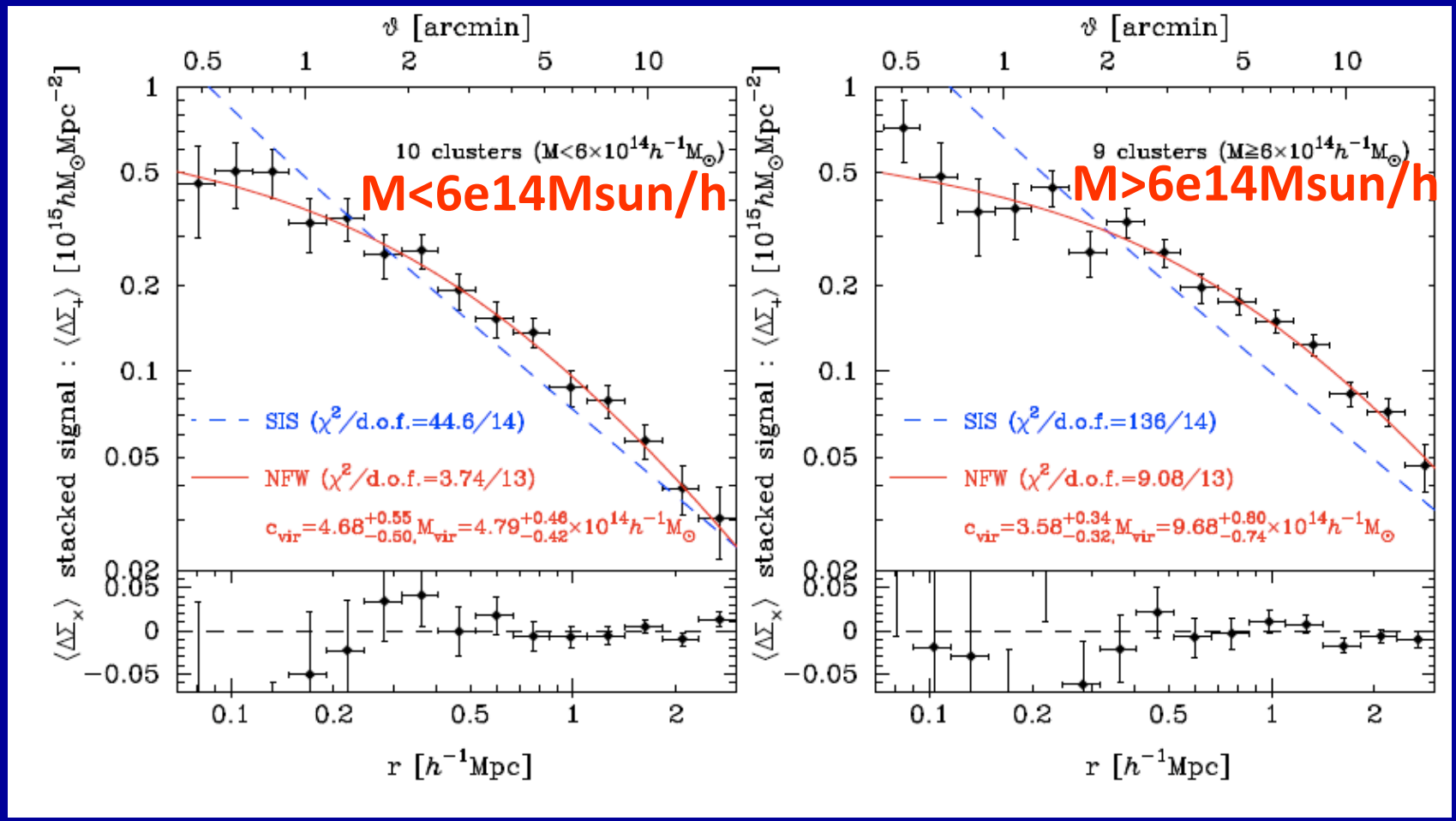




Umetsu, Medezinski, Broadhurst+ (2009)

Stacked Lensing Analysis

Stacked lensing analysis (already mentioned by Hamana-san)
less sensitive to substructures/asphericity of individual clusters



SIS rejected @6 and 11 σ levels (Okabe,Takada,Umetsu+ 09)

YES, Cluster Weak Lensing is so **POWERFUL.**

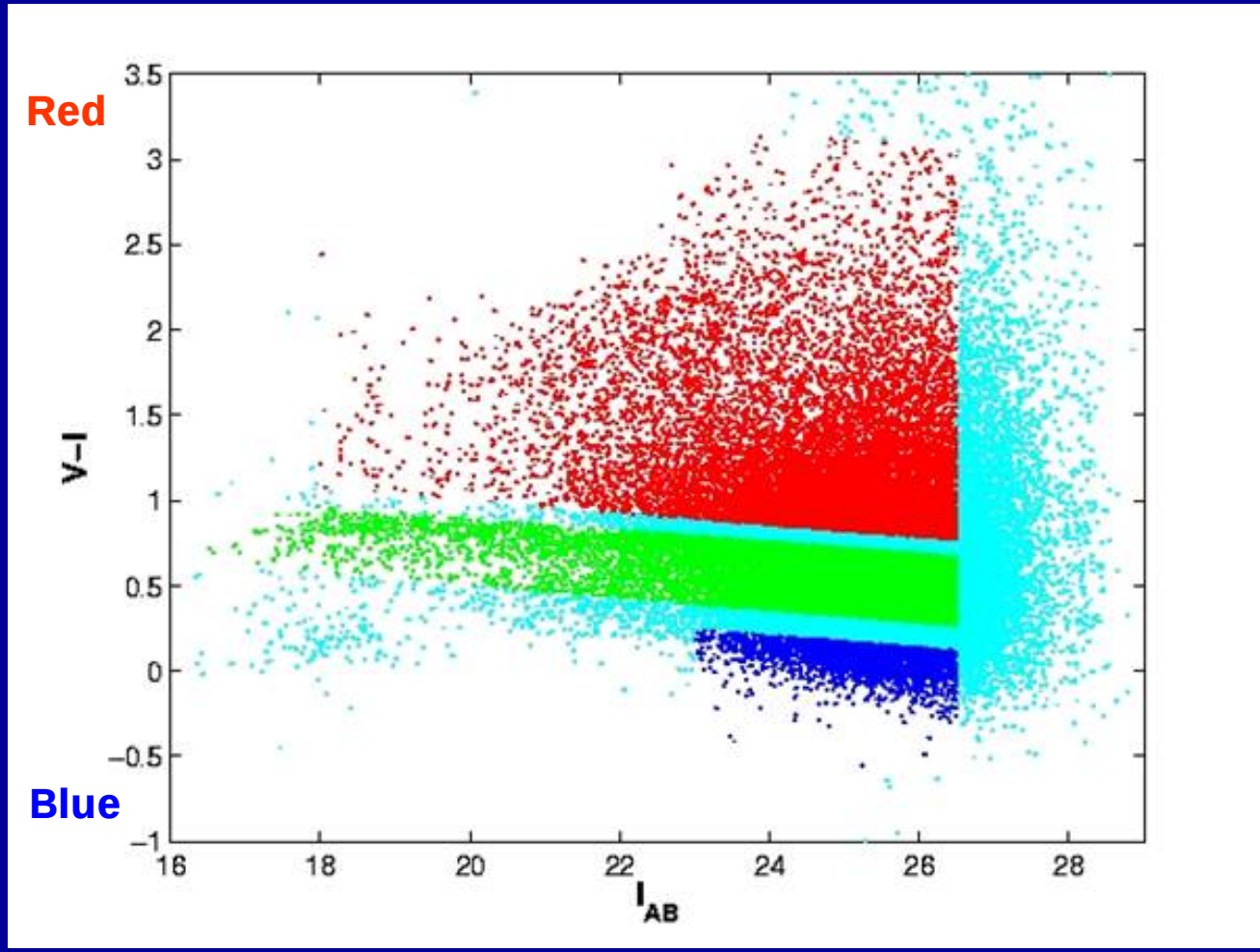
However,

You first need a **CLEAN** background sample!!

To do so, **Deep Multiband photometry** is necessary!!

Galaxies in Color-Magnitude Space

- E/S0 sequence galaxies
- Three galaxy samples
  - **Green** – cluster +background
  - **Red** – background. (redder than sequence)
  - **Blue** – faint background. (determine by comparing WL signal to red)

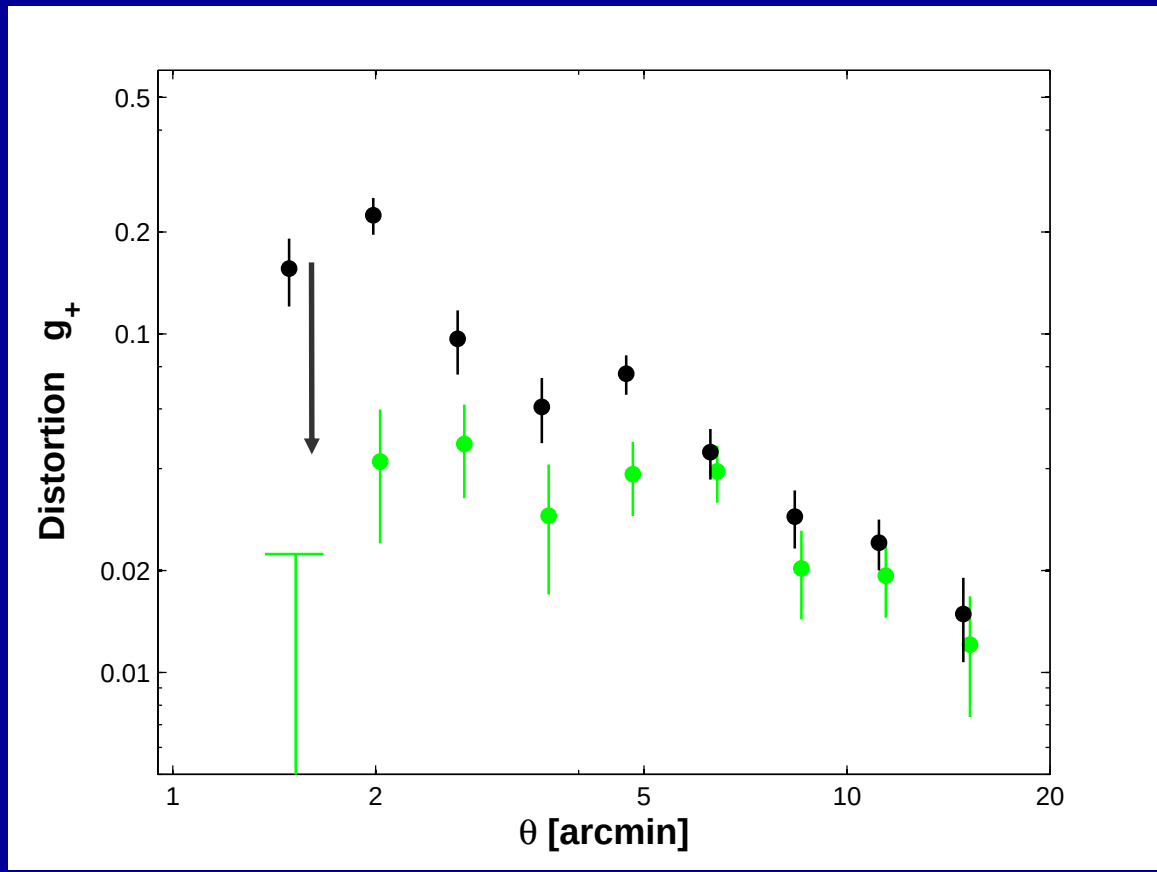


- Medezinski, Broadhurt, Umetsu+ 2007, ApJ, 663, 717
- Umetsu & Broadhurst 2008, ApJ, 684, 177

Weak Lensing Distortion

- **Background** – WL distortion rises all the way to the center
- **Green** (cluster members + BG) – distortion diluted towards the center by **unlensed** cluster members

The "Dilution" Effect



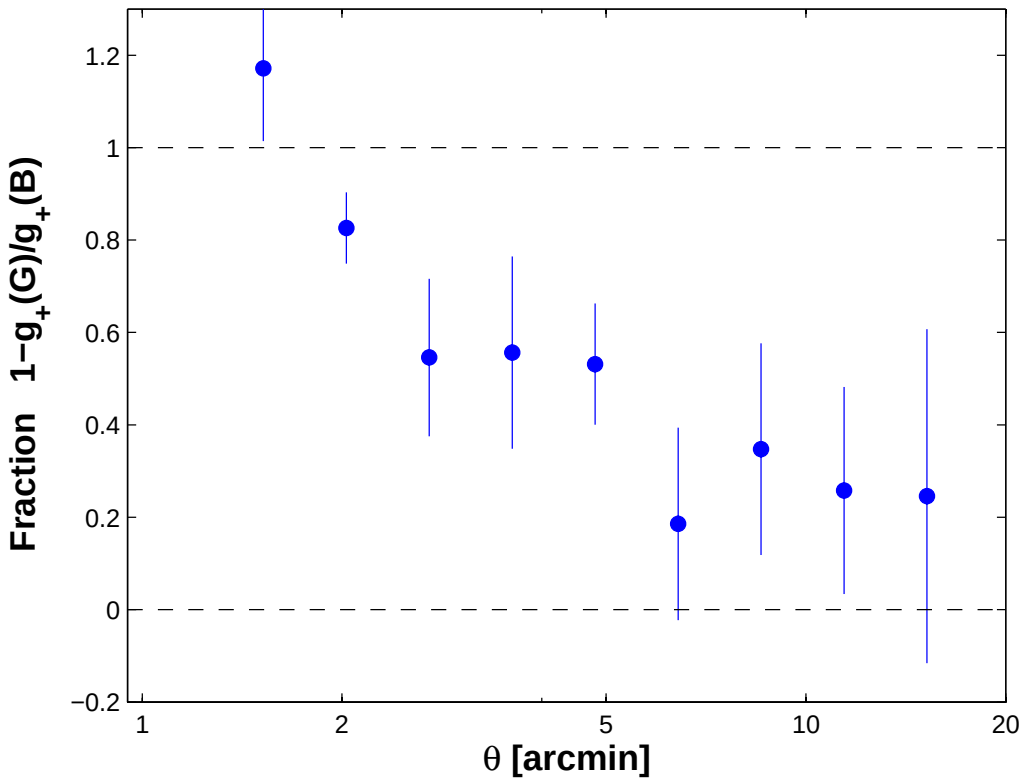
Cluster Membership Fraction

Cluster fraction from lensing strengths

$$f_{cl} = \frac{N_{\rm Cluster}}{N_{\rm Green}} \approx 1 - \frac{g_+(\rm Green)}{g_+(B.G.)} \frac{\langle \beta(B.G.) \rangle}{\langle \beta(\rm Green) \rangle}$$

$$\beta(z_s) = \frac{D_{ls}}{D_{os}}$$

- **Dilution** to measure cluster membership
- Cluster luminosity functions and profiles can be derived (Medezinski+07,09)



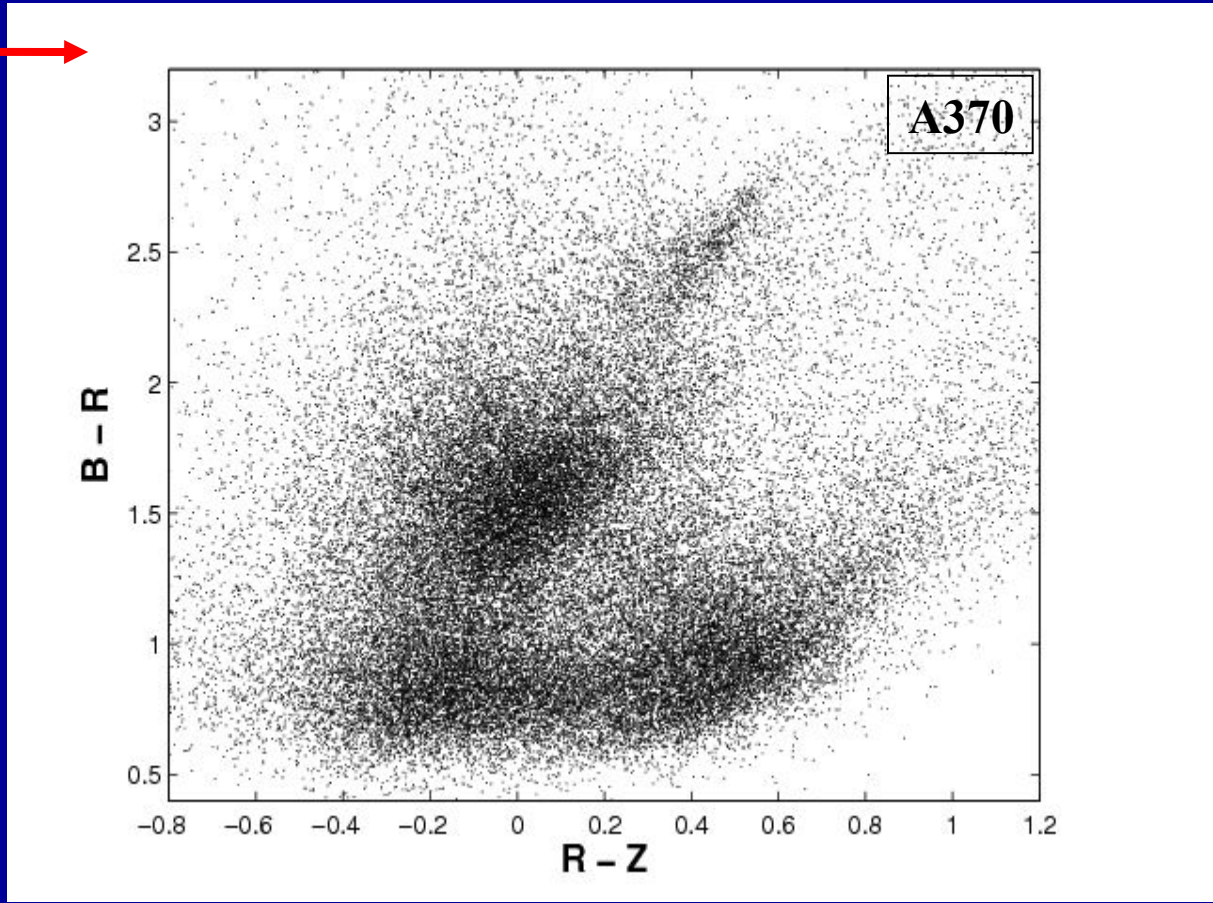
The central region (<200kpc/h) is highly dominated by unlensed cluster galaxies – blue cluster galaxies are difficult to separate out. Even problematic in high-z and Butcher-Oemler clusters!!

New Color-Color Diagram Approach

Wide/uniform Optical-λ coverage with Subaru BRz photometry

- B,R,z' for CL0024
- B,R,z' for A370
- V,R,z' for RXJ1347
- g',r',i' for A1703

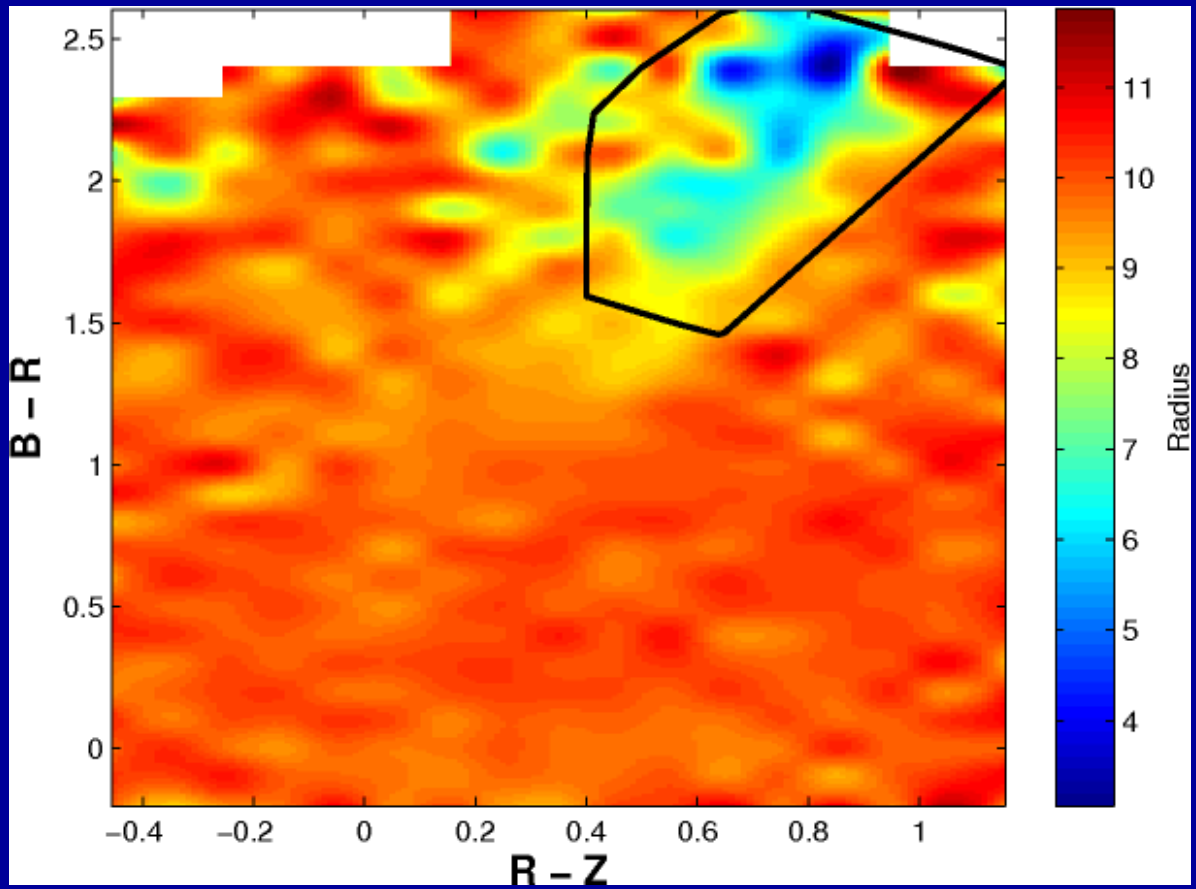
- Color, positional, and lensing correlations explored in CC-space
- Density peaks in CC-space – different galaxy populations



- Medezinski, Broadhurst, Umetsu+ 09, ApJ submitted (arXiv:0906.4791)
- Umetsu, Medezinski, Broadhurst+ 09, ApJ submitted (arXiv:0908.0069)

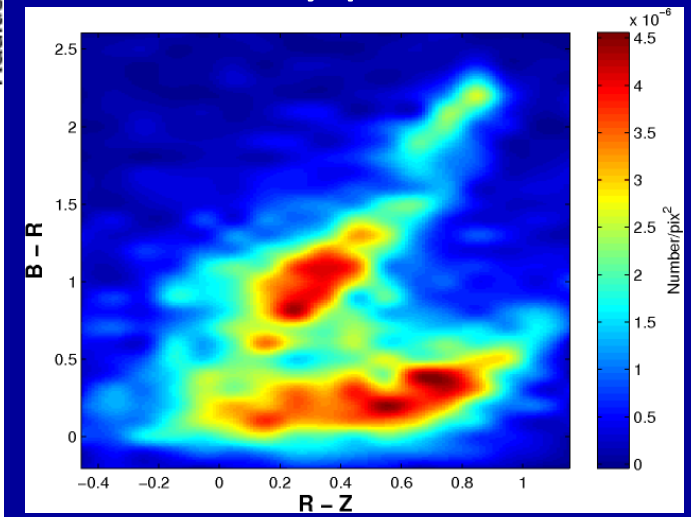
Mean Radius Statistic in CC-Space

Mean radius of galaxies from the cluster center



Example in CL0024+1654 at z=0.395 (Umetsu+09b)

Density plot

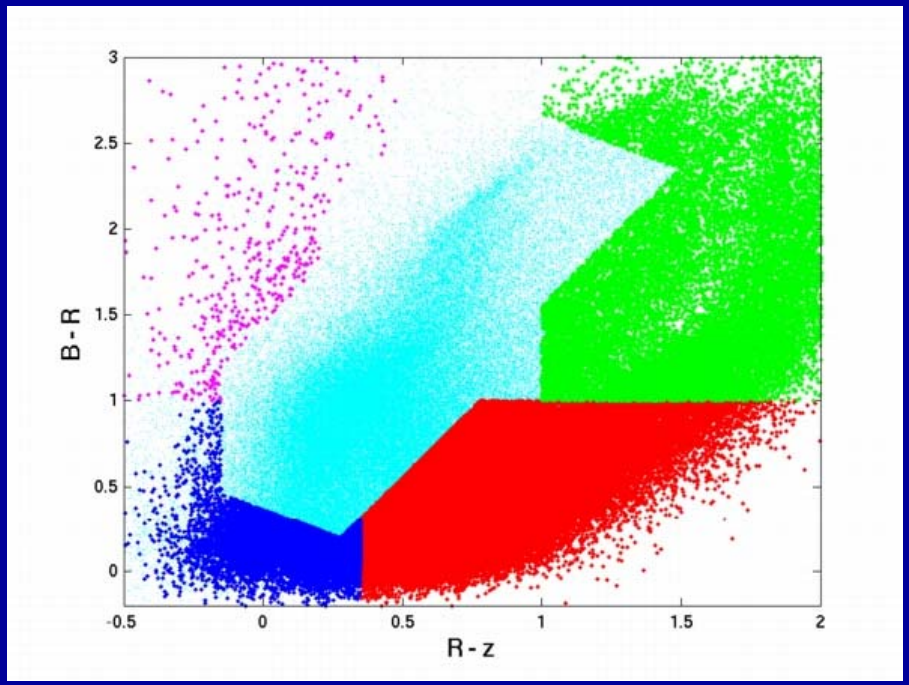


- First identify the cluster sequence in CC-space.
- Cluster members appear as a distinct cloud with small mean radii.

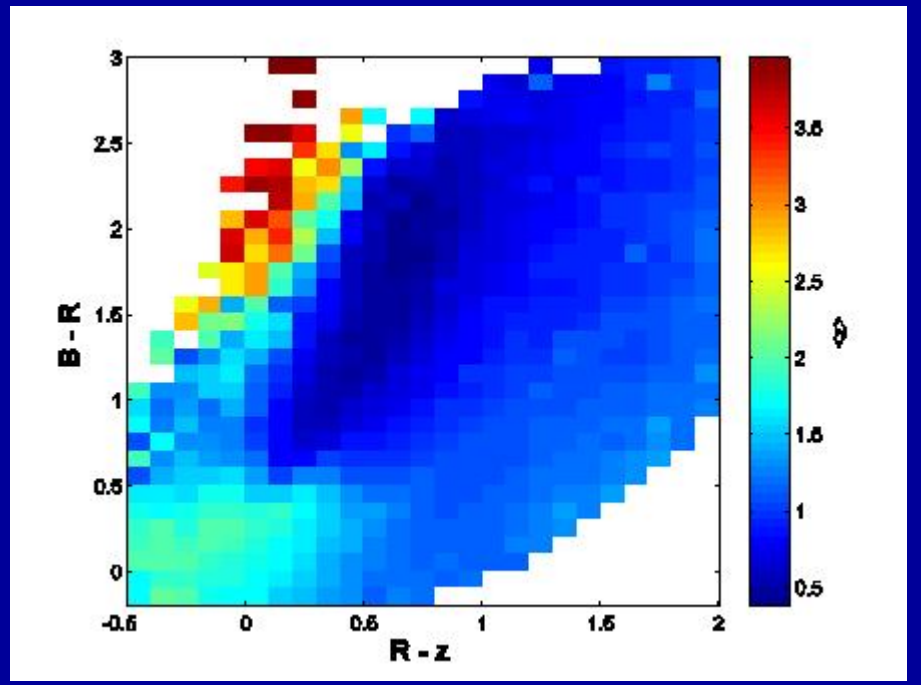
COSMOS Photometry and Redshifts

- 30-band wide-field (2 sqdeg) survey (Capak et al. 2007)
- Photometric-redshift catalog (Ilbert et al. 2009)
- Deep COSMOS survey as a reference for "CC-selection" and "depth calibration"

Galaxy samples in CC-space

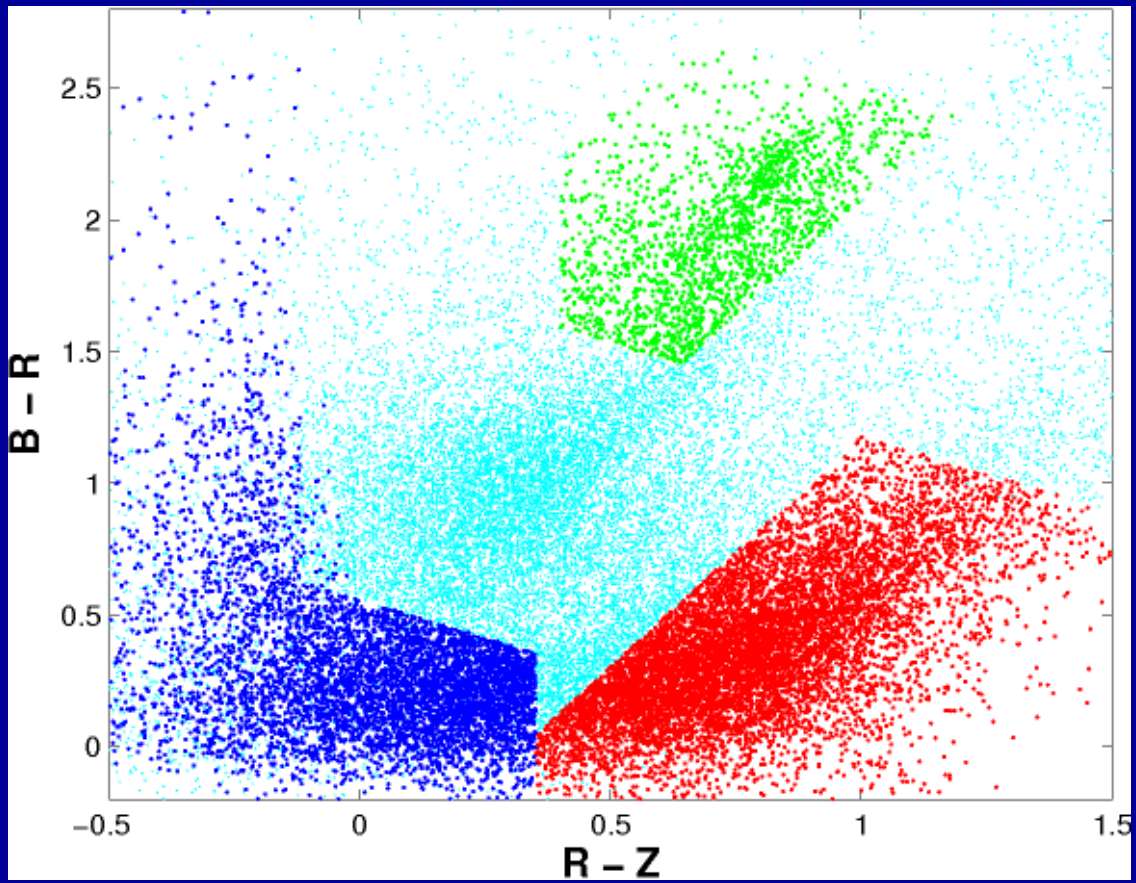


<z> in CC-space



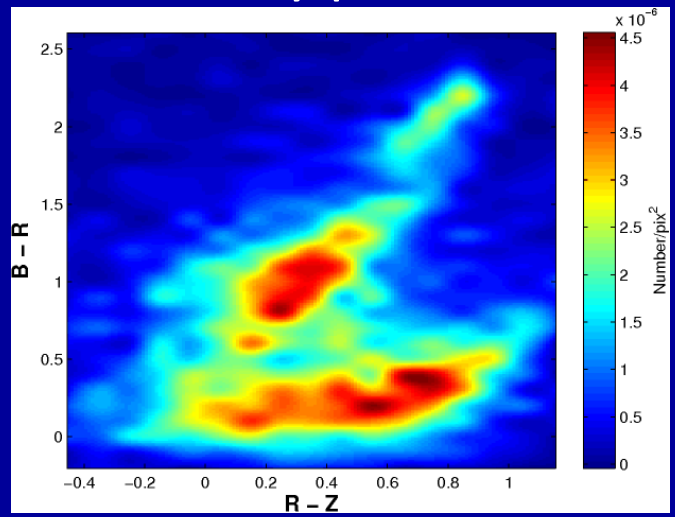
Color-Color Selected Samples

Color boundaries for Red, Green, Blue galaxy samples



Example in CL0024+1654 at z=0.395 (Umetsu+09b)

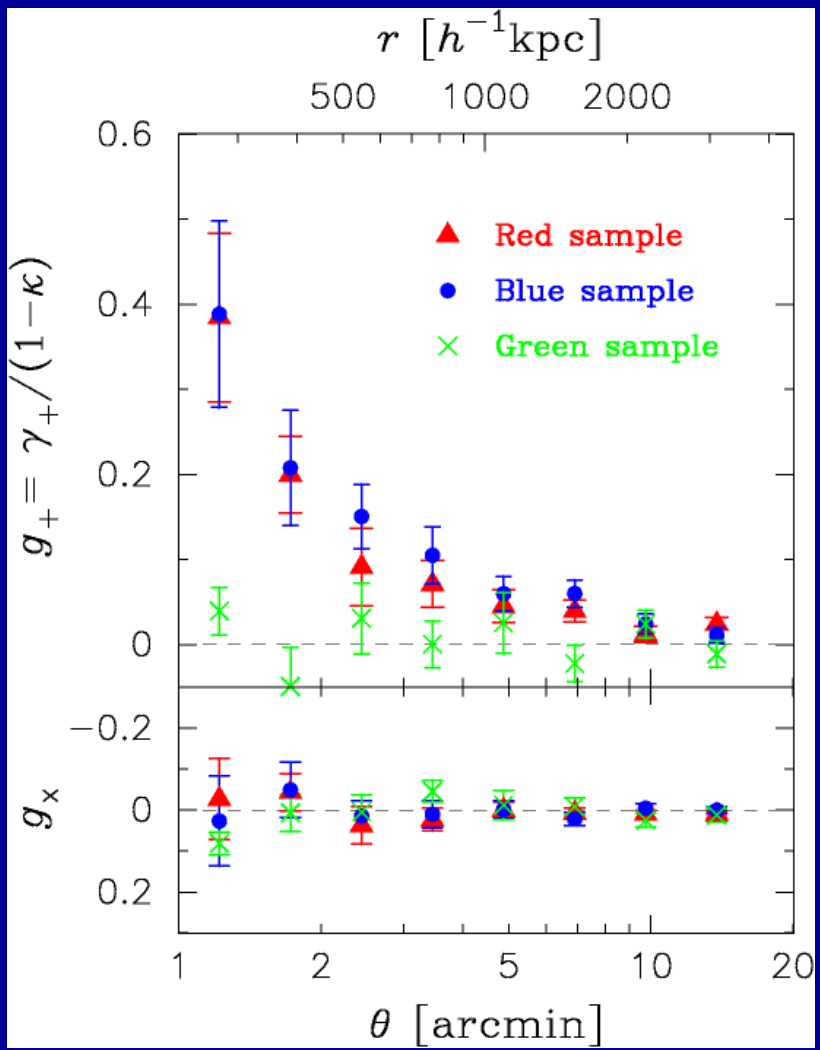
Density plot



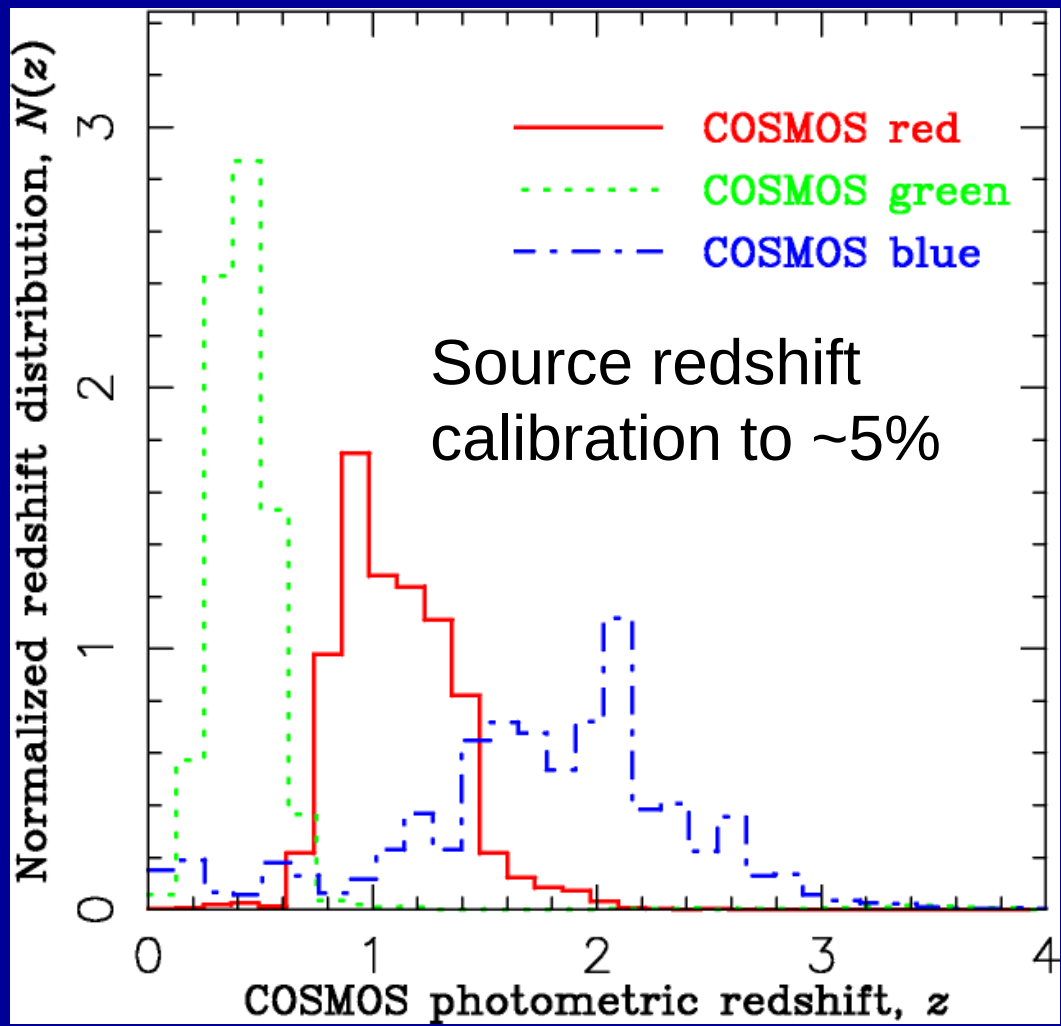
- The red and blue boundaries are chosen so as to maximize the lensing signal (minimizing dilution)

Lensing Strengths of Color Samples

Lens distortions in CL0024 Umetsu+09b, arXiv:0908.0069



N(z) of RGB samples in COSMOS



3. Distortion + Depletion Analysis

Combining full-lensing information

Count Depletion: Magnification Bias

Magnification bias: Lensing-induced fluctuations in the background density field (Broadhurst, Taylor, & Peacock 1995)

$$\delta n(\boldsymbol{\theta}) / n_0 \approx -2(1-2.5\alpha)\kappa(\boldsymbol{\theta})$$

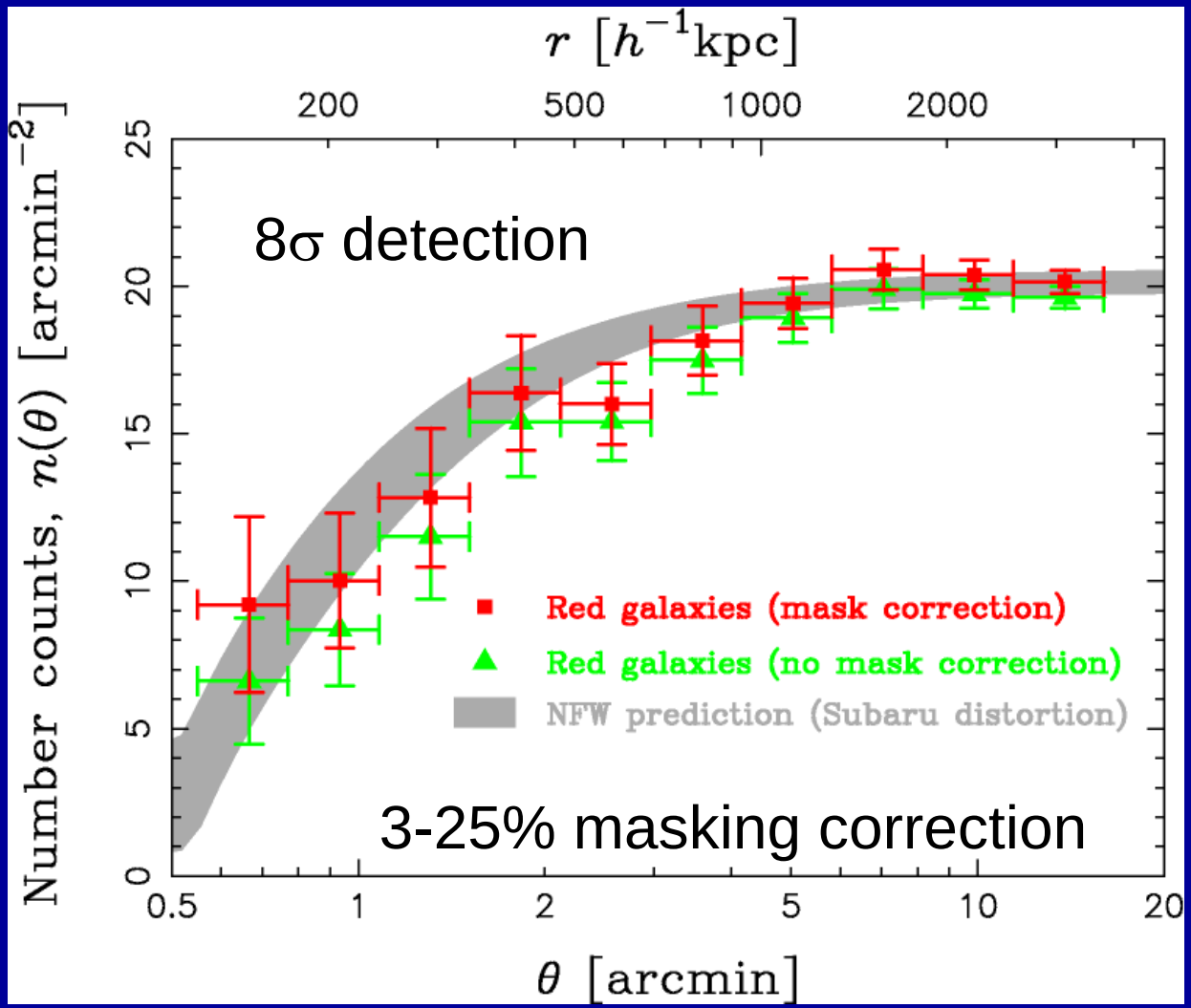
with unlensed counts of background galaxies $n_0(<m) \propto 10^{\alpha m}$

When the count-slope is <0.4 (=lens invariant slope), a net deficit is expected.

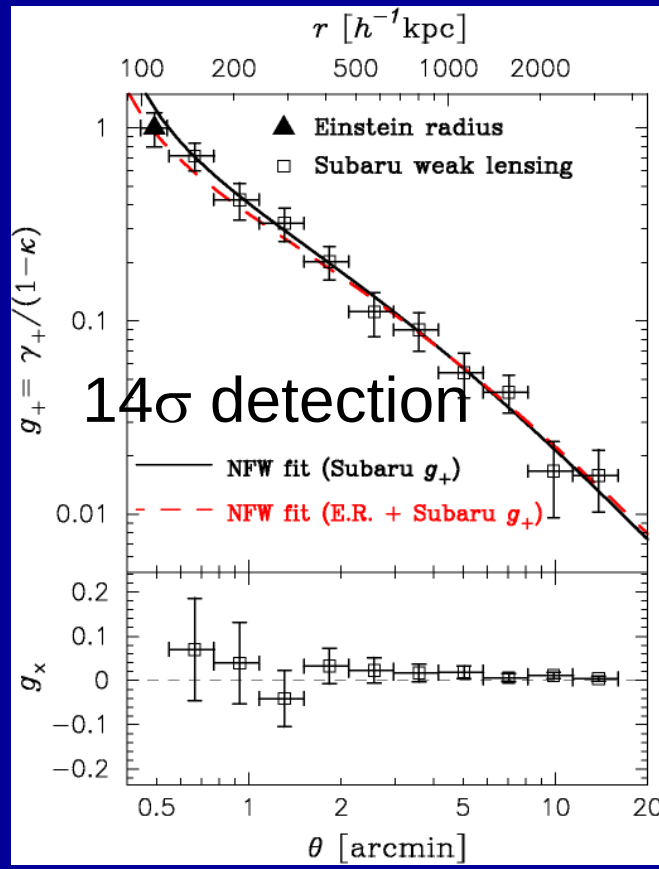
Slide by M. Takada

Depletion Profile in CL0024

Count depletion of "red" galaxies in CL0024



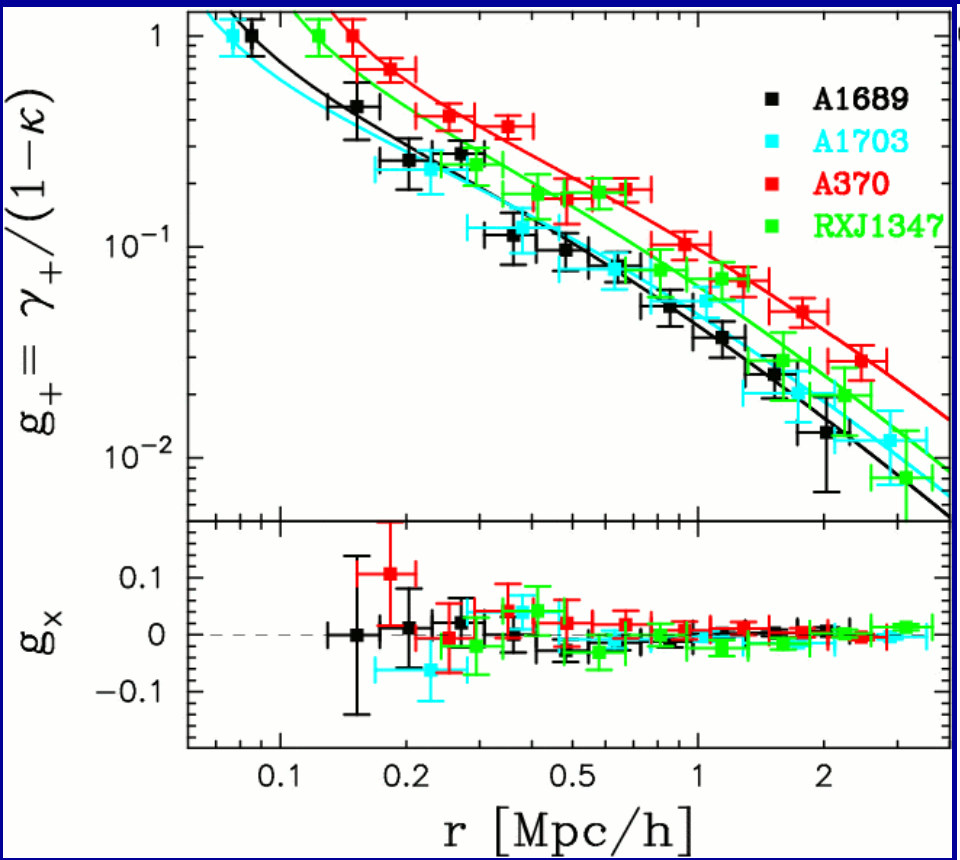
Distortion of "blue+red" sample

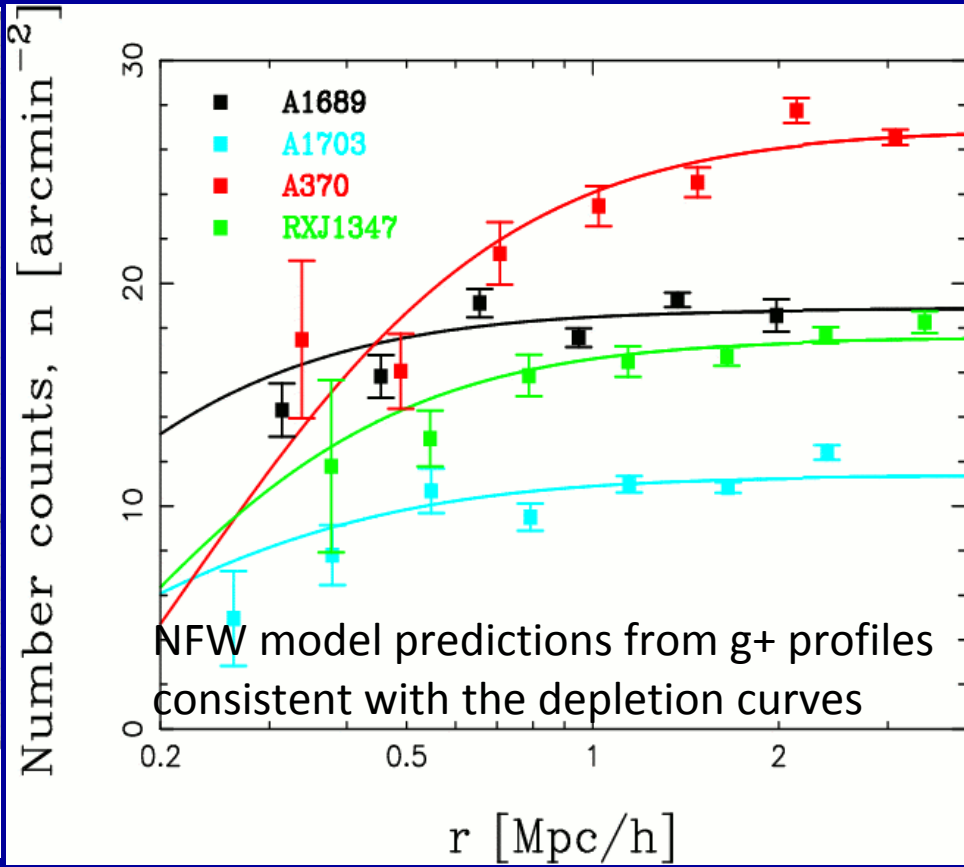


Umetsu et al. 2009b, arXiv:0908.0069

Count Depletion in Other Clusters

Lens distortion (left) vs. depletion (right) in high-mass clusters





Observed curves are similar in form, well described by NFW

Broadhurst, Umetsu, Medezinski+ 2008, ApJ, 685, L9

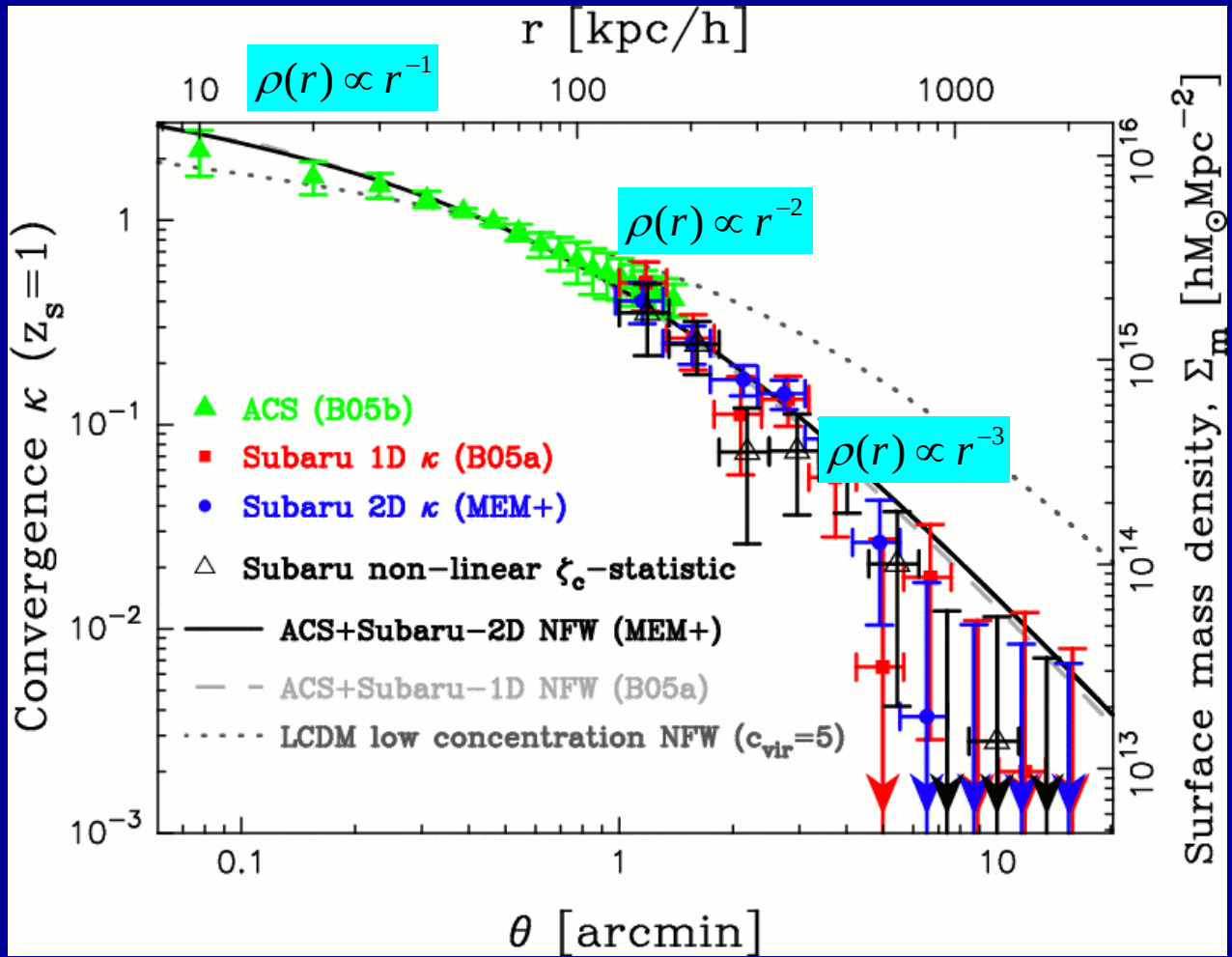
Mass Profile of A1689 from Full Lensing

Mass profile and full covariance matrix in (10, 2000)kpc/h derived from distortion, depletion (Scam), and strong lensing (ACS) datasets

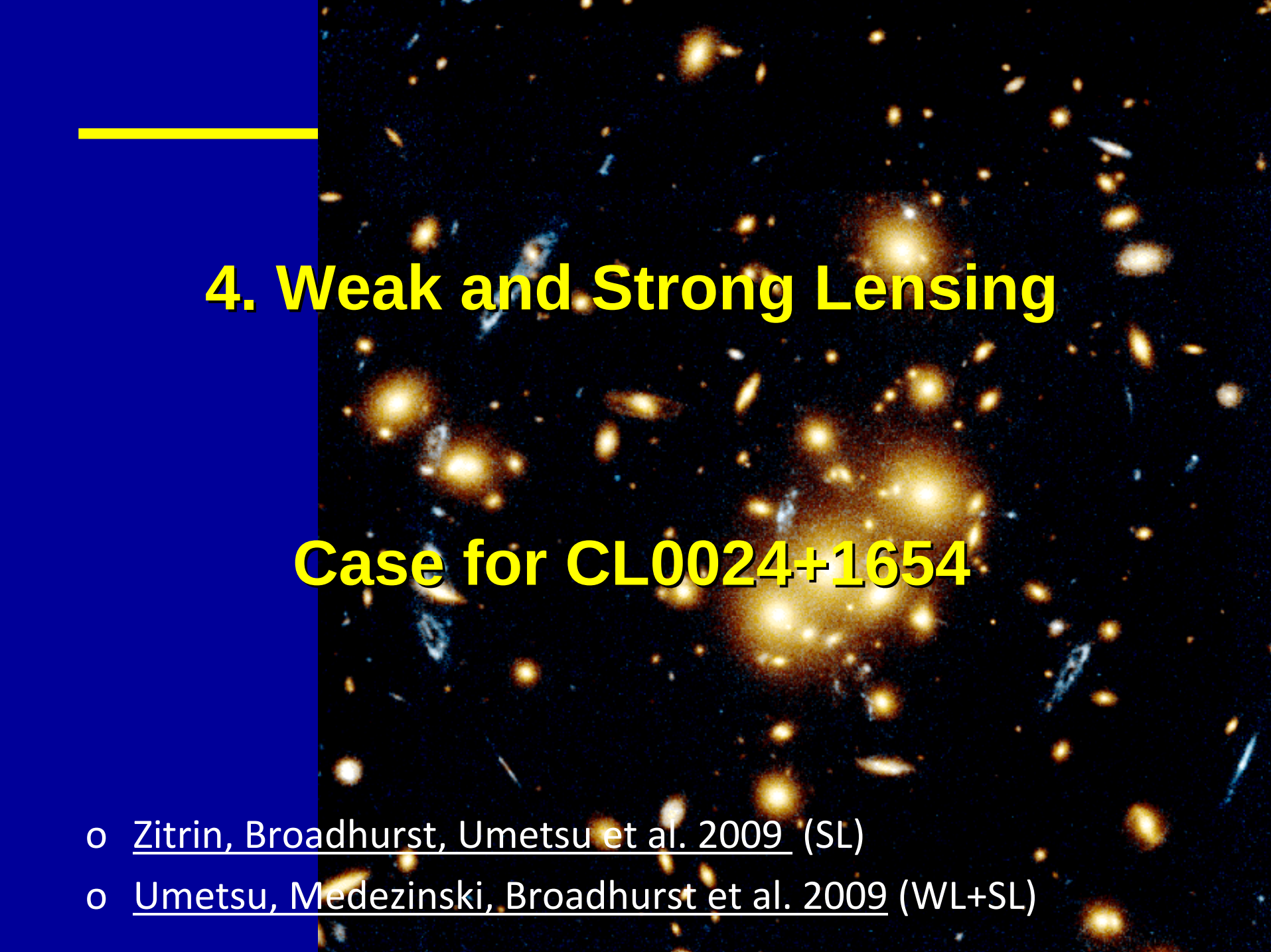
Mass profiles are useful for a multi-λ analysis:

Example of A1689

- Lemze+08: +Chandra
- Lemze+09: +VLT/VIRMOS
- Umetsu+09a: +AMiBA
- Kawaharada, Okabe, Umetsu, .. Hamana, Miyazaki .. 09 in prep.: +Suzaku X-ray



Umetsu & Broadhurst 2008, ApJ, 684, 177



4. Weak and Strong Lensing

Case for CL0024+1654

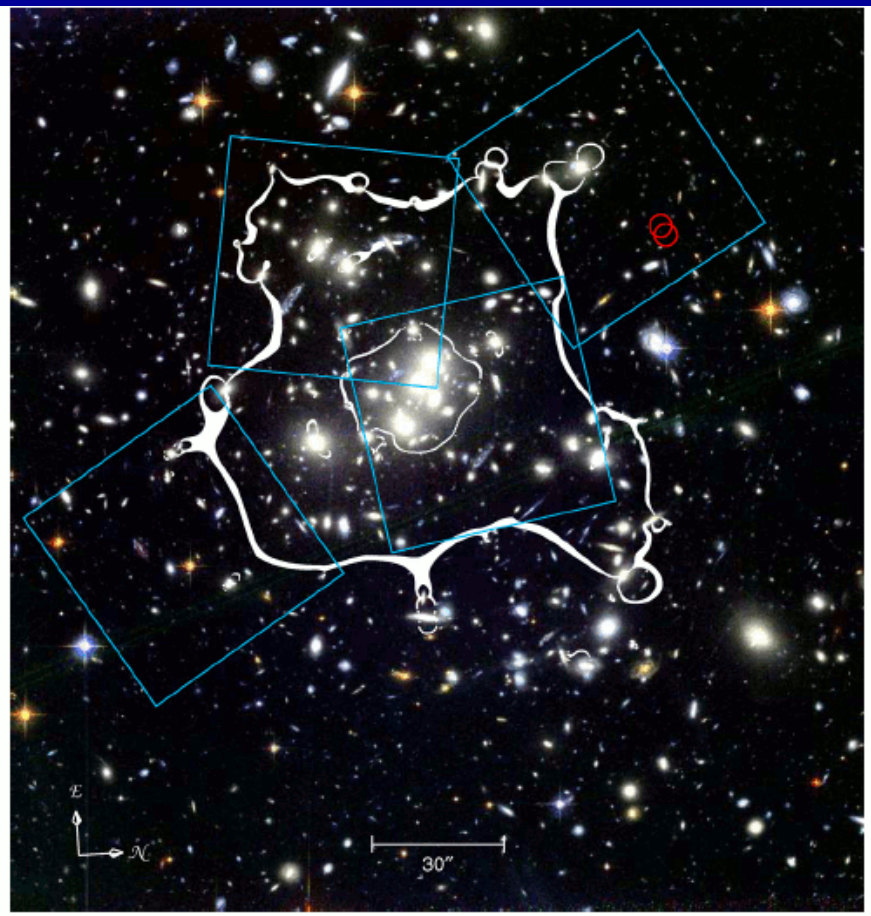
- Zitrin, Broadhurst, Umetsu et al. 2009 (SL)
- Umetsu, Medezinski, Broadhurst et al. 2009 (WL+SL)

HST/ACS Strong Lensing Analysis

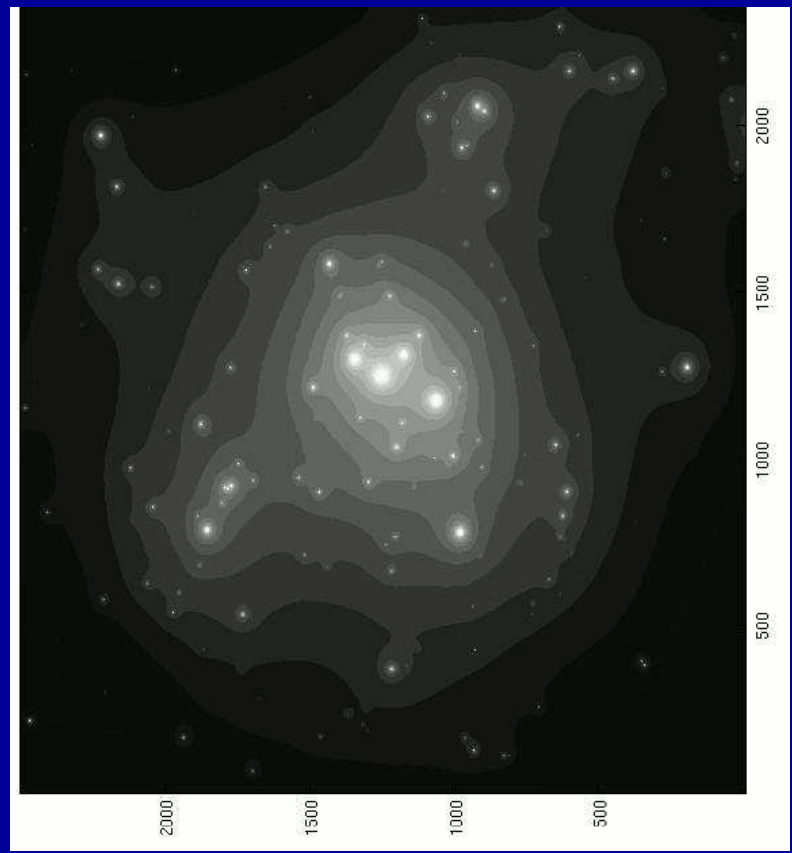
ACS+NIC3 "BVg'r'i'z'JH" photometry for accurate photo-z

Identified 33 multiply-lensed images of 11 BG galaxies in 8"<r<48" (R_{ein}=30", z=1.7)

Strong-lens critical curves



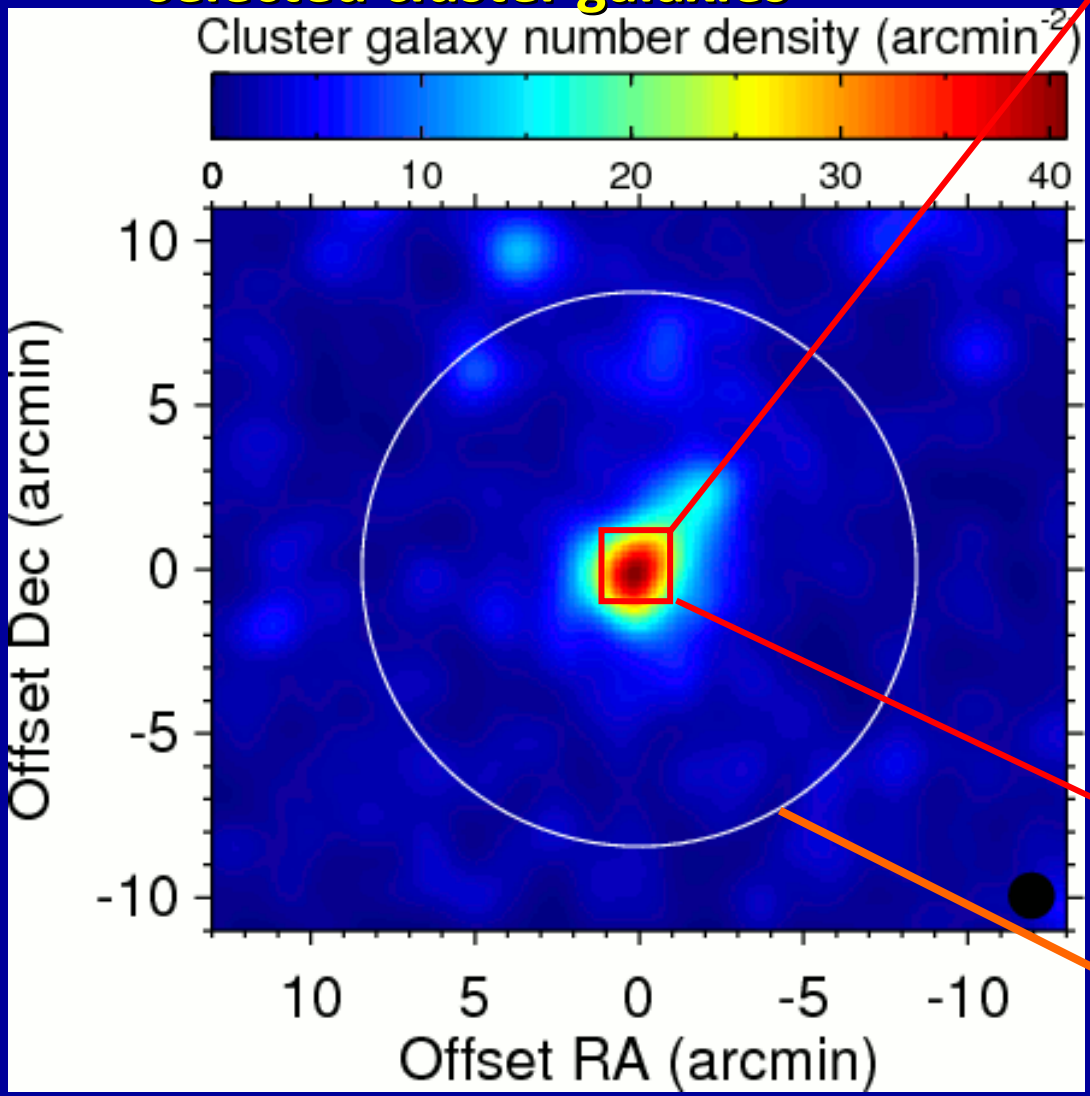
Smooth-DM + lumpy-galaxy mass map



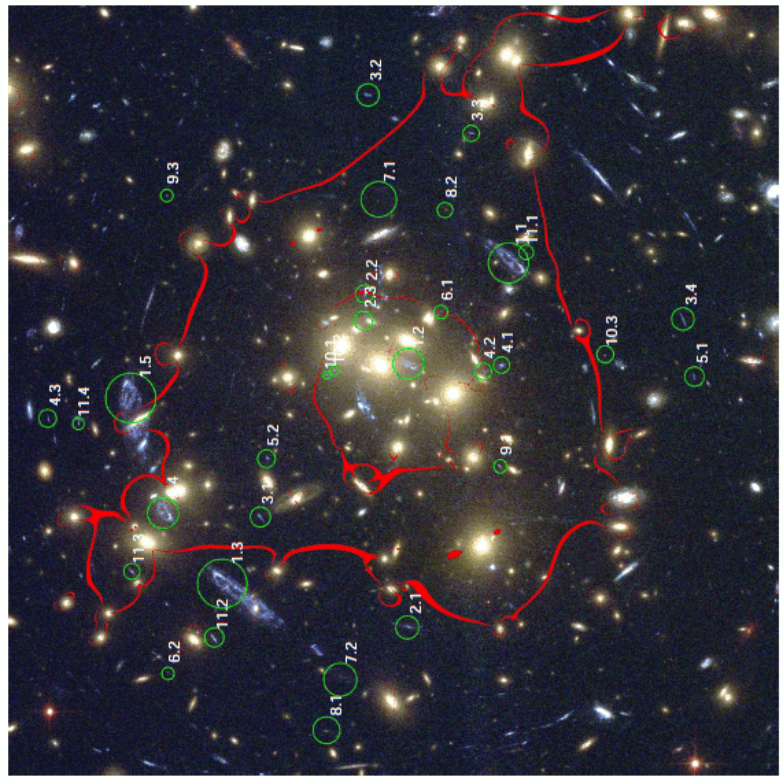
Zitrin, Broadhurst, Umetsu+ (2009)

HST/ACS vs. Subaru/S-Cam Data

Surface number density of CC-selected cluster galaxies



HST/ACS (2'x2' region)



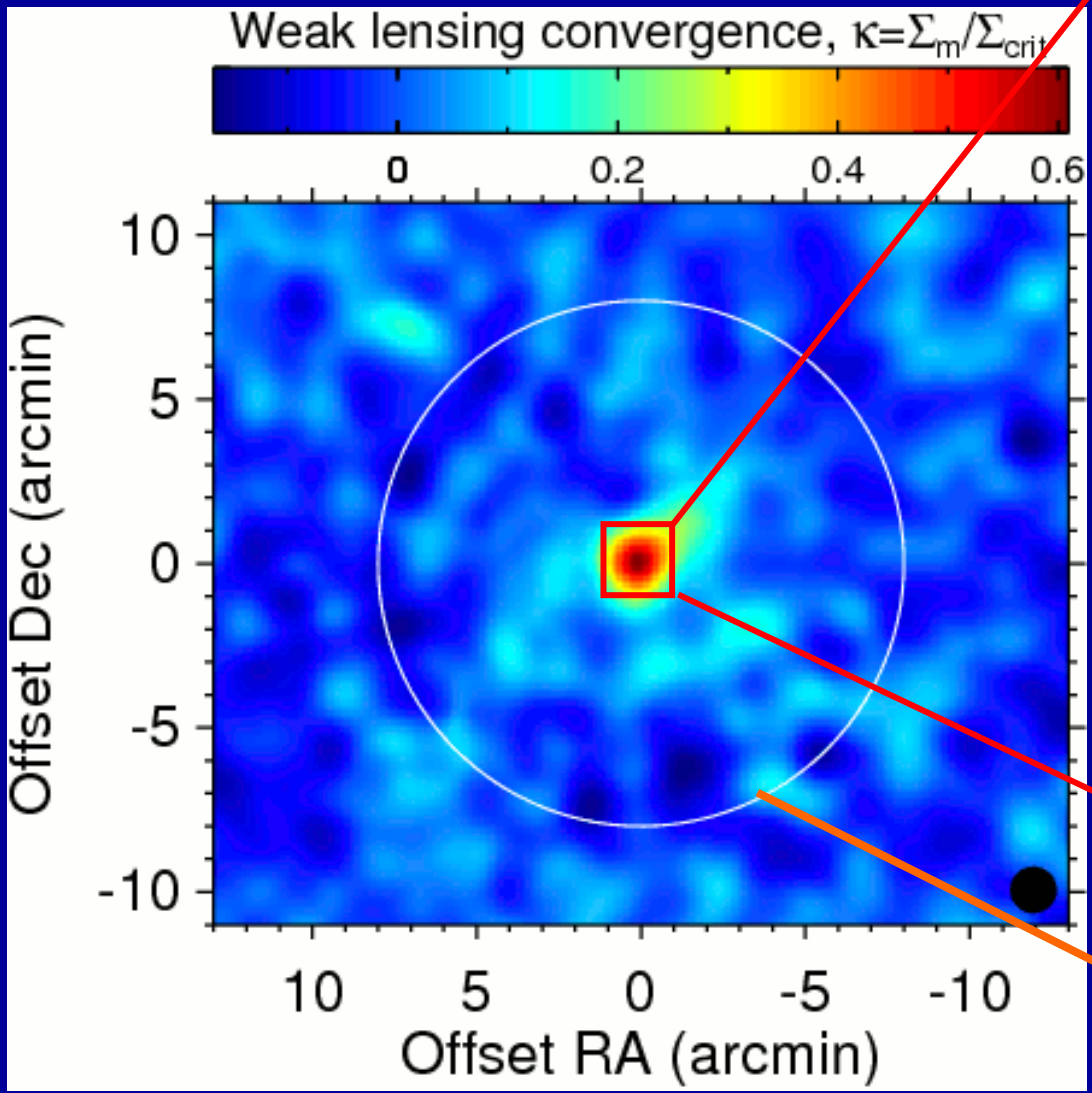
Virial radius (~8' @z=0.395)

R_{vir}=~ 1.8Mpc/h

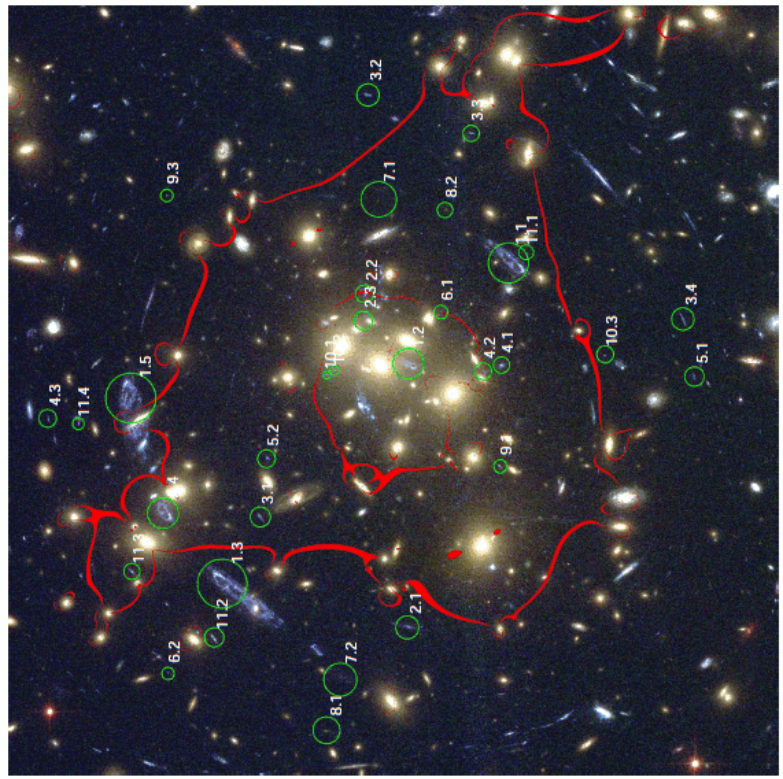
Umetsu et al. 2009b

HST/ACS vs. Subaru/S-Cam Data

Weak Lensing mass map



HST/ACS (2'x2' region)



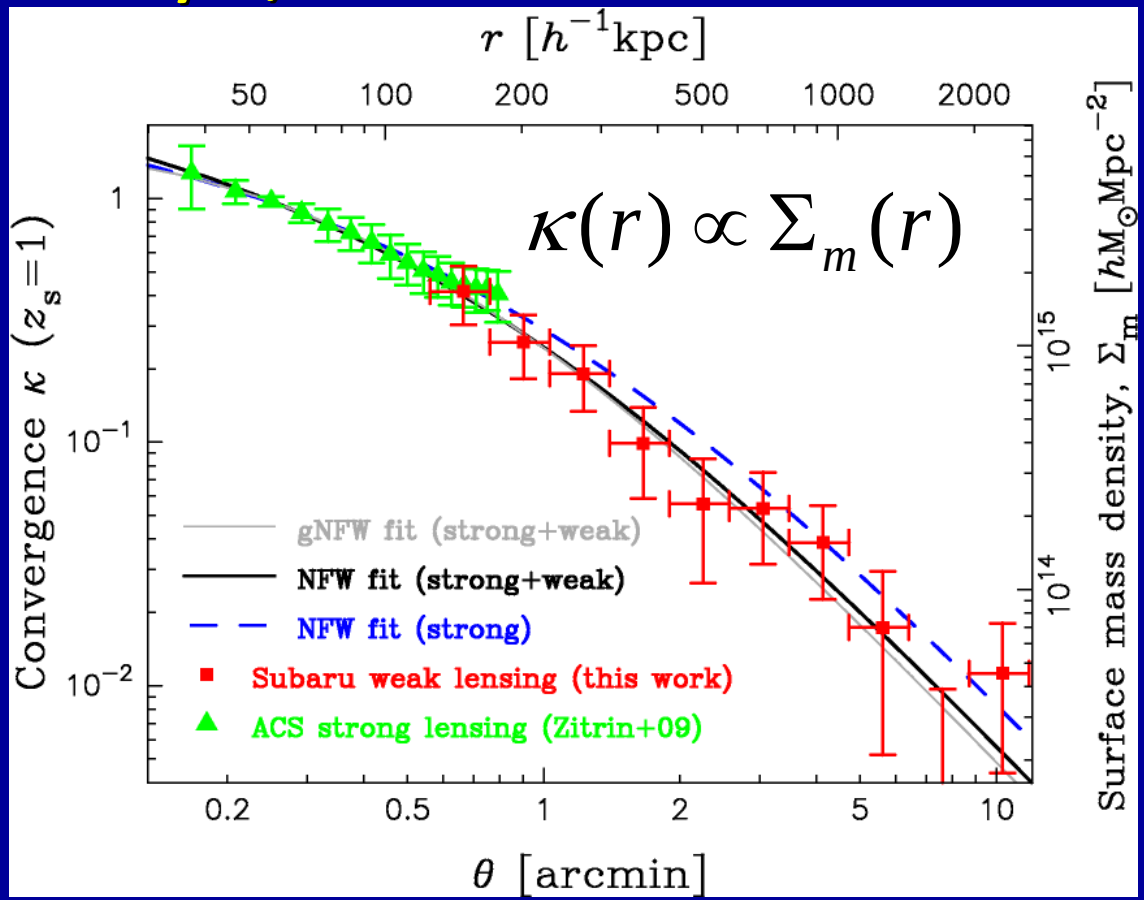
Virial radius (~8' @z=0.395)

R_{vir}=~ 1.8Mpc/h

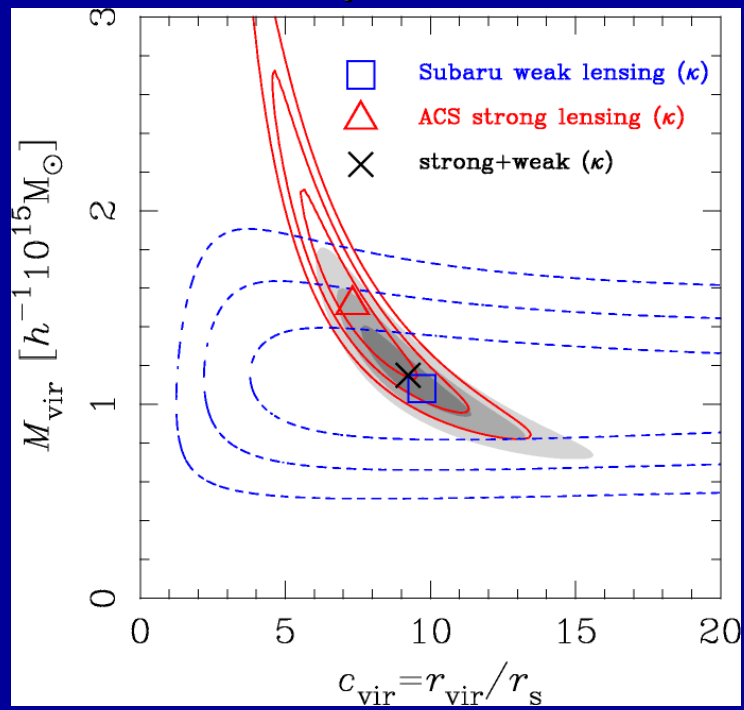
Umetsu et al. 2009b

Joint Mass Profile of CL0024

Model-independent mass profile from joint Subaru+ACS lensing analysis, derived for the entire cluster R=(40,2300)kpc/h



Joint ACS+Subaru constraints on the NFW parameters:



- NFW gives an excellent fit
- gNFW with α~0.2 preferred

Umetsu et al. 2009b

5. Subaru Weak Lensing and SZE

Interferometer arrays:

ALMA, AMI, AMiBA, SZA (CARMA), ..

Bolometer arrays:

ACT, APEX-SZ, GBT/MUSTANG, SPT, …

First SZE Results with AMiBA-7

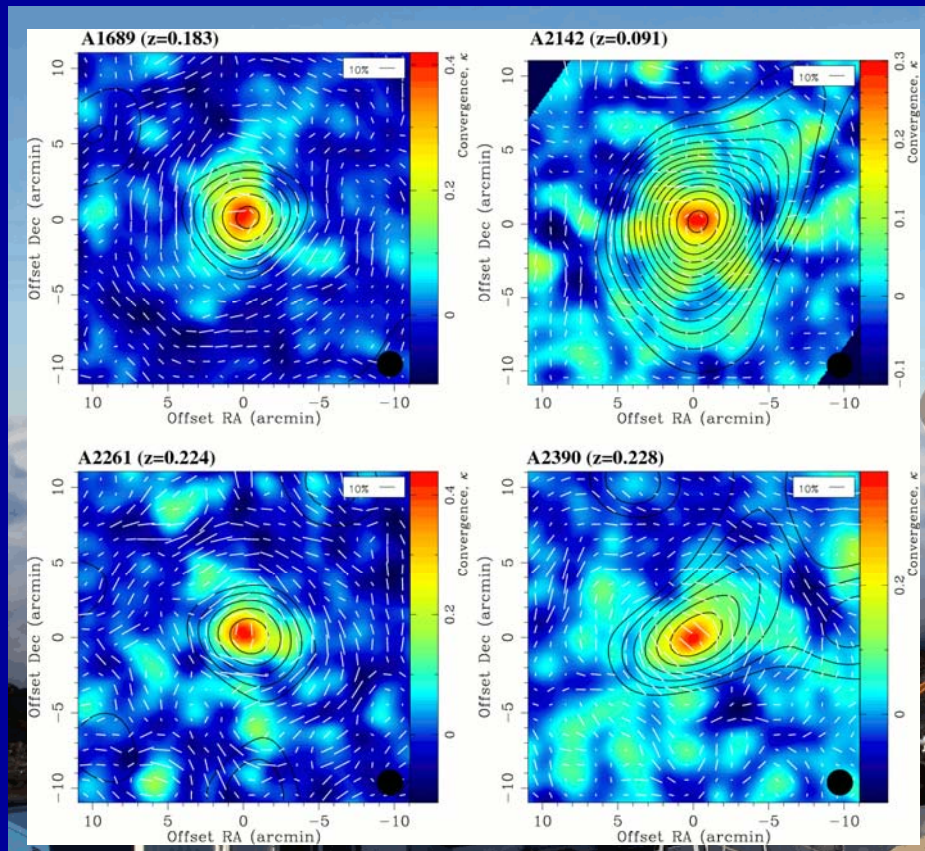
First AMiBA papers published in ApJ, 694, 2009, April 1:

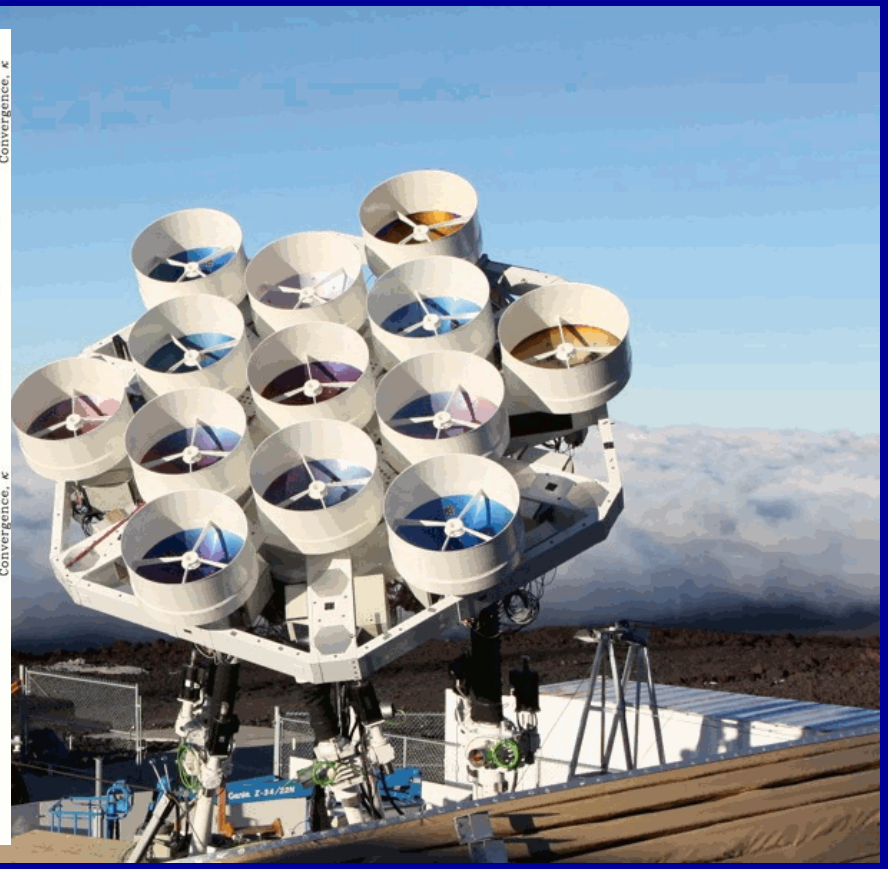
- **Design/Results:** **Ho, P.T.P.** et al.
- **Instrumentation:** **Chen, M.T.** et al.
- **Hexapod mount:** **Koch, P.M.** et al.
- **System performance**: **Lin, K.Y.** et al.
- **Data integrity tests**: **Nishioka, H.** et al.
- **SZE + Weak Lensing:** **Umetsu, K.** et al.
- **Analysis pipeline**: **Wu, J.H.P.** et al.

More papers (2009-2010):

- **Cluster scaling relations**: **Huang, C.W.L.** et al., ApJ accepted
- **Correlator system**: **Li**, C.T. et al., ApJ submitted
- **Fore/CMB Contamination**: **Liu, G.C.** et al., ApJ submitted
- **X-ray + SZE for H_0**: **Koch, P.M.** et al., ApJ submitted
- **Radial profiles of IC-gas**: **Molnar, S.M.** et al., ApJ submitted
- **Cluster SZE properties:** **Liao, Y.W.** et al., to be submitted

13-element AMiBA (94GHz), Hawaii

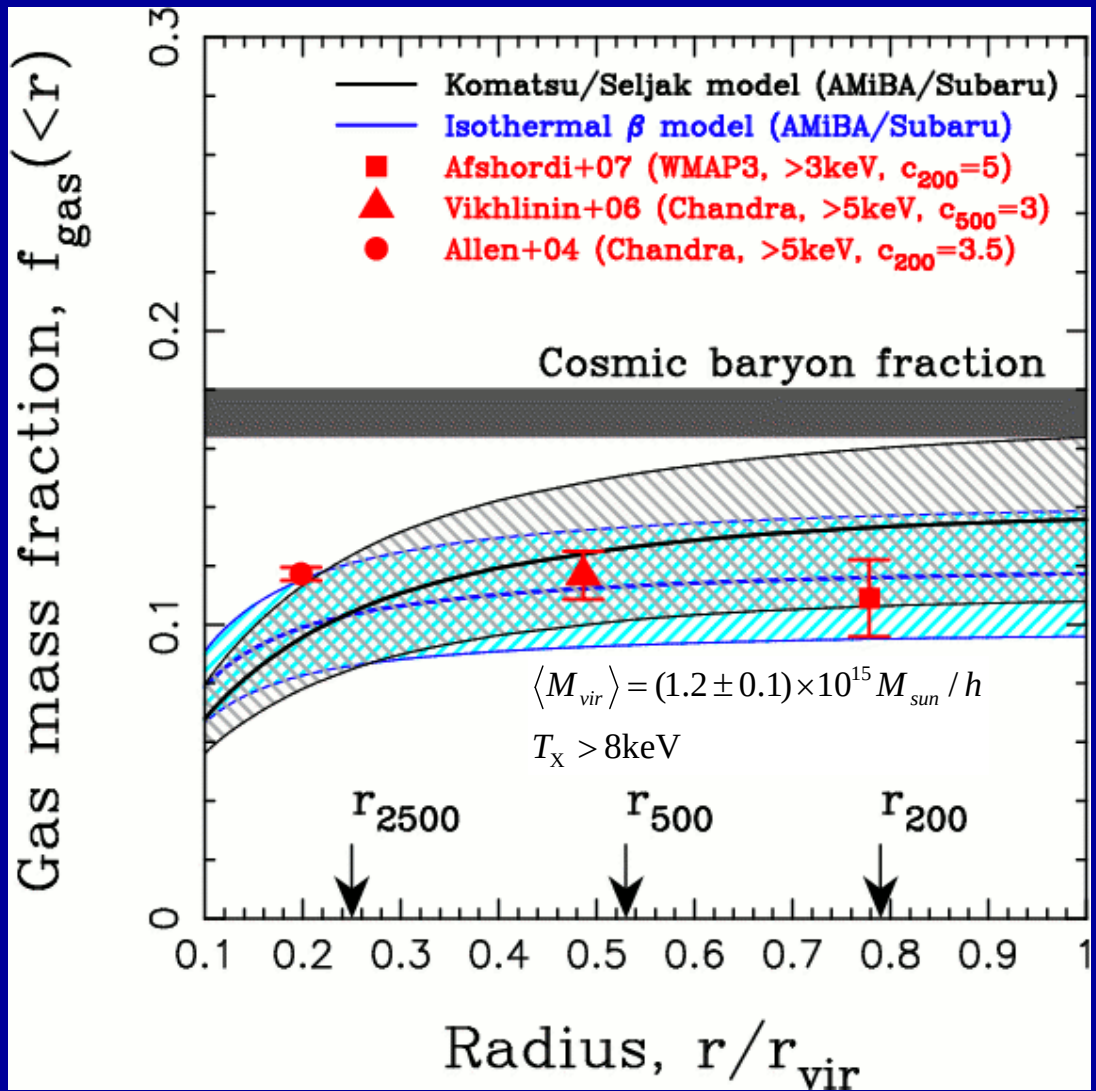




- 7-element AMiBA science operation (2007-2008) completed (8 papers published/accepted in ApJ)
- Science operation with AMiBA-13 will start this month (A370 as a first target)

Cluster Gas Fractions from Subaru/WL + AMiBA/SZE

"Lensing+SZE" based cluster gas fraction measurement out to large radii (r_{200}), without assuming the hydrostatic equilibrium



$$\left\langle f_{gas}(r_{200})\right\rangle \equiv \frac{M_{\rm gas}(r_{200})}{M_{\rm tot}(r_{200})} = 0.133 \pm 0.027$$
$$\leq \frac{\rm B}{\rm DM+B}$$

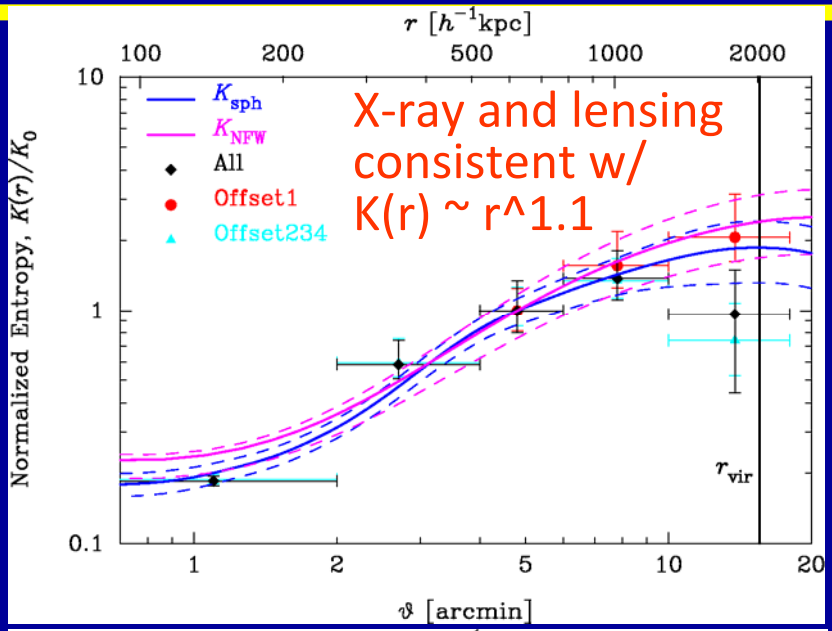
$$\left\langle f_{gas}(r_{200})\right\rangle / f_b = \frac{\rm Hot.B.}{\rm Hot.B.+Cold.B.} = 0.78 \pm 0.16$$
$$\text{with } f_b \equiv \Omega_b/\Omega_m = \frac{\rm B}{\rm DM+B}$$
$$= 0.171 \pm 0.009$$

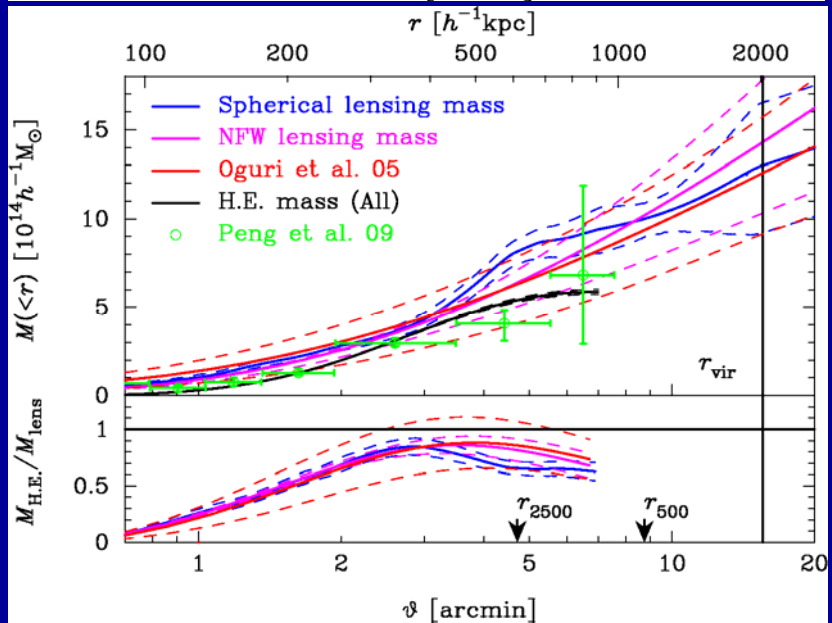
- (22 +/- 16)% of the baryons are missing from the *hot plasma phase* in the clusters
- ~5% can be accounted for by "cool" baryons (stars in galaxies, diffuse IC-light): cf. Gonzalez+05

Umetsu et al. 2009a

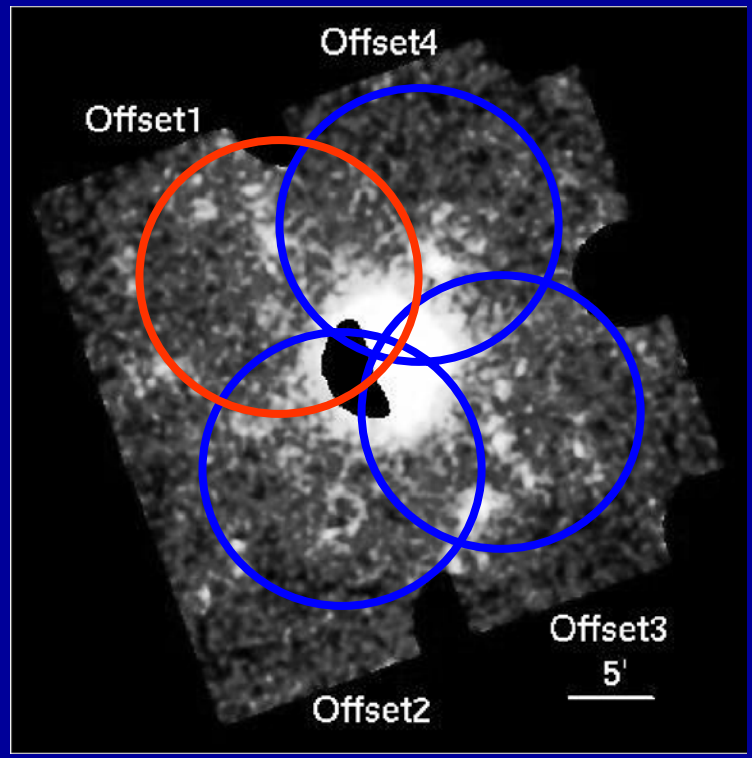
5. Subaru Weak Lensing and Suzaku X-ray Analysis

Suzaku-X vs. Subaru/ACS-GL: A1689





Suzaku/XIS, 4 x 39s



Suzaku - unique facility to detect X-ray emission in the cluster outskirts

Kawaharada, Okabe, Umetsu, .., Hamana
Miyazaki .. et al. 09, in prep.

Summary for Discussion

- Removal of blue cluster and foreground galaxies is the most critical issue in cluster weak lensing. Due to dilution, inner distortion profiles from WL measurements will be ALMAYS underestimated.
- "Deep multicolor" photometry is essential for individual cluster lensing analysis – We may be able to combine deep i'-band HSC imaging with multiband photometry from other surveys.
- Not only distortion/dilution but also depletion (magbias) can be examined to achieve the maximum lensing precision. Wide-field HSC imaging will be a big plus for the count normalization (n0). Proper declustering and masking corrections better than 5% accuracy (matching the dilution analysis) will be required for a full lensing analysis.
- Deeper HSC imaging will be extremely useful for multi-λ cluster studies (X-ray, SZE, dynamics) where the Subaru HSC imaging will play a most crucial role to probe the DM distribution in clusters.