CLASH Heidelberg 2011

CALSH Subaru Weak-Lensing and Sunyaev-Zel'dovich Effect Analyses

Keiichi Umetsu with the CLASH team

Academia Sinica IAA (ASIAA), Taiwan

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1. Keys for High-Accuracy Cluster Lensing

- **Weak Gravitational Lensing (WL)**
  - — ***Distortion*** *(shearing)*
  - — ***Dilution*** *(purity of BG sample)*
  - — ***Depletion*** *(magnification)*
  - — ***Deprojection*** *(2+1D analysis)*
  - — ***Stacked*** *lensing analysis*
  - — *Flexion*

$$\gamma = \partial\partial\psi / 2, F = \partial\partial\partial^{*}\psi / 2, G = \partial\partial\partial\psi / 2$$

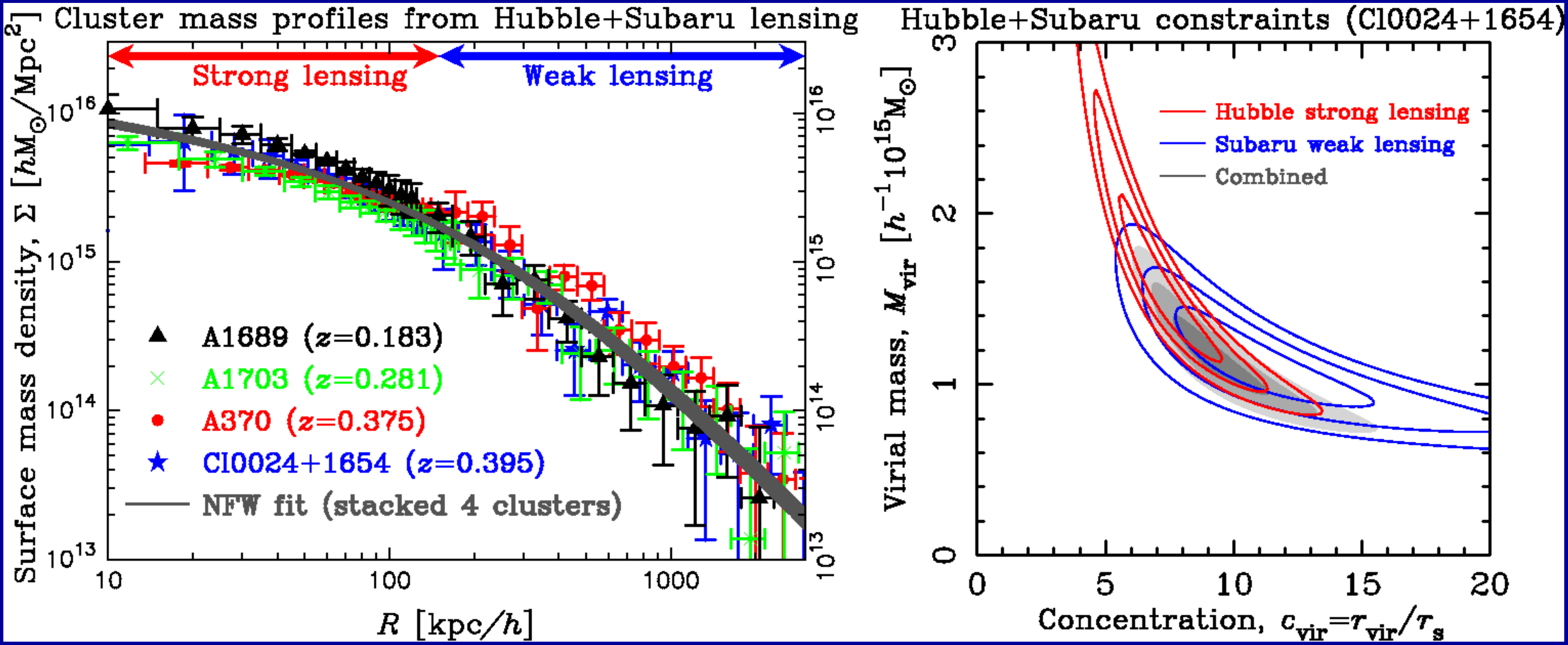
$$\frac{S(F)}{S(\gamma)} \sim \frac{L\phi / r^3}{\phi / r^2} \sim \frac{L}{r}$$

- **Strong Gravitational Lensing (SL)**

Combining Full Lensing Constraints [shear, magnification, strong lensing]

Strong and Weak lensing contribute equal logarithmic coverage of radial mass profile for massive clusters:

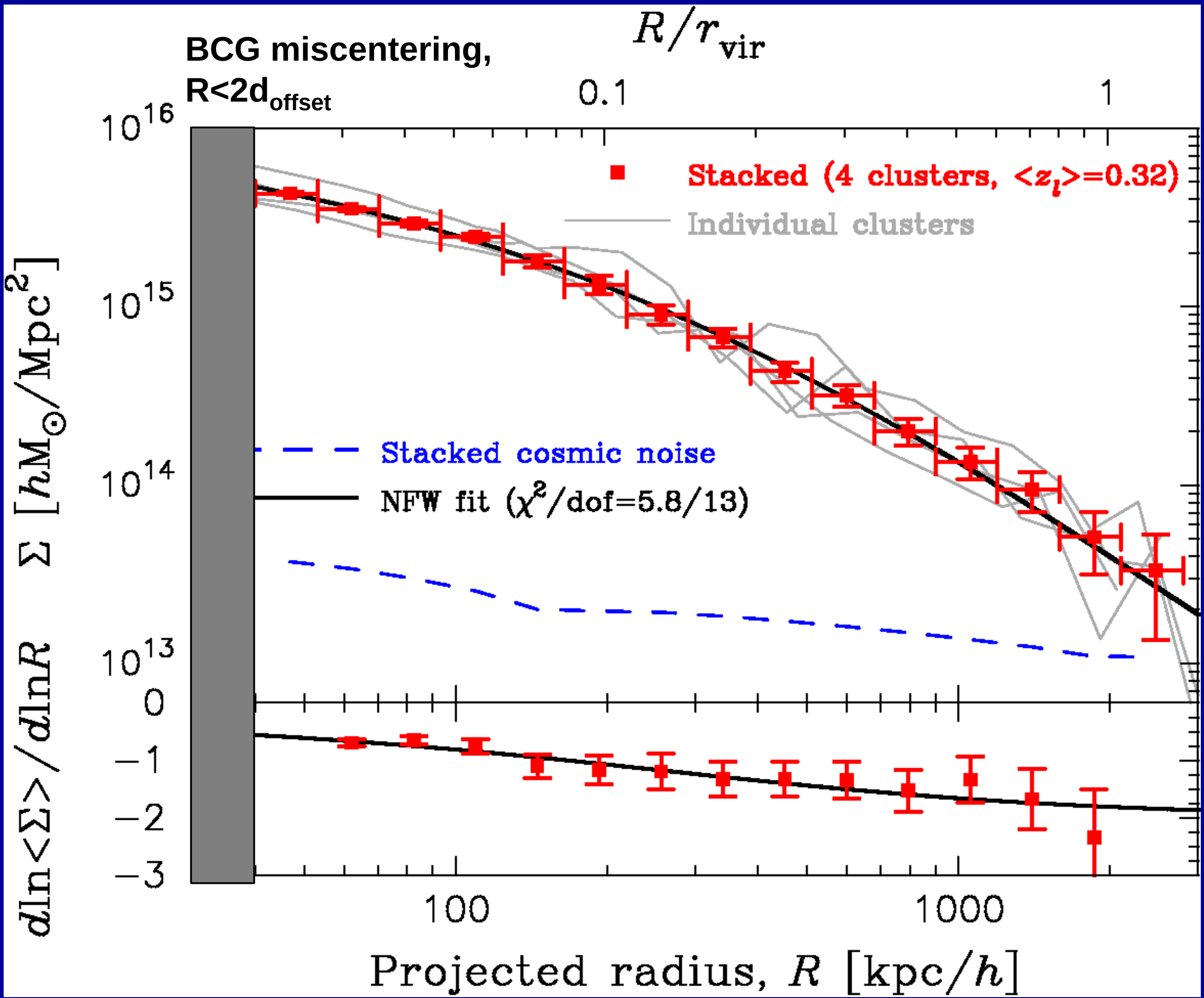
→ Combined SL + WL probes the full radial range [0.5%, 150%] R_{vir}



4 high-mass clusters characterized by a large Einstein radius, θ_{Ein} ~ 40"(zs=2)

See Umetsu+2011a, 2011b (figures taken from Postman+11)

First Application of Stacked Strong + Weak Cluster Lensing



Stacking clusters by

$$\langle \Sigma \rangle = \left(\sum_n C_n^{-1} \right)^{-1} \left(\sum_n C_n^{-1} \Sigma_n \right)$$

$$C_{ij}^{\rm lss} = \int \frac{l\,dl}{2\pi} C^{\kappa\kappa}(l)\,\hat{J}_0(l\theta_i)\hat{J}_0(l\theta_j).$$

Total S/N=58σ

Exclude $R<2d_{off}$ =40kpc/h to avoid smoothing from *miscentering* !!

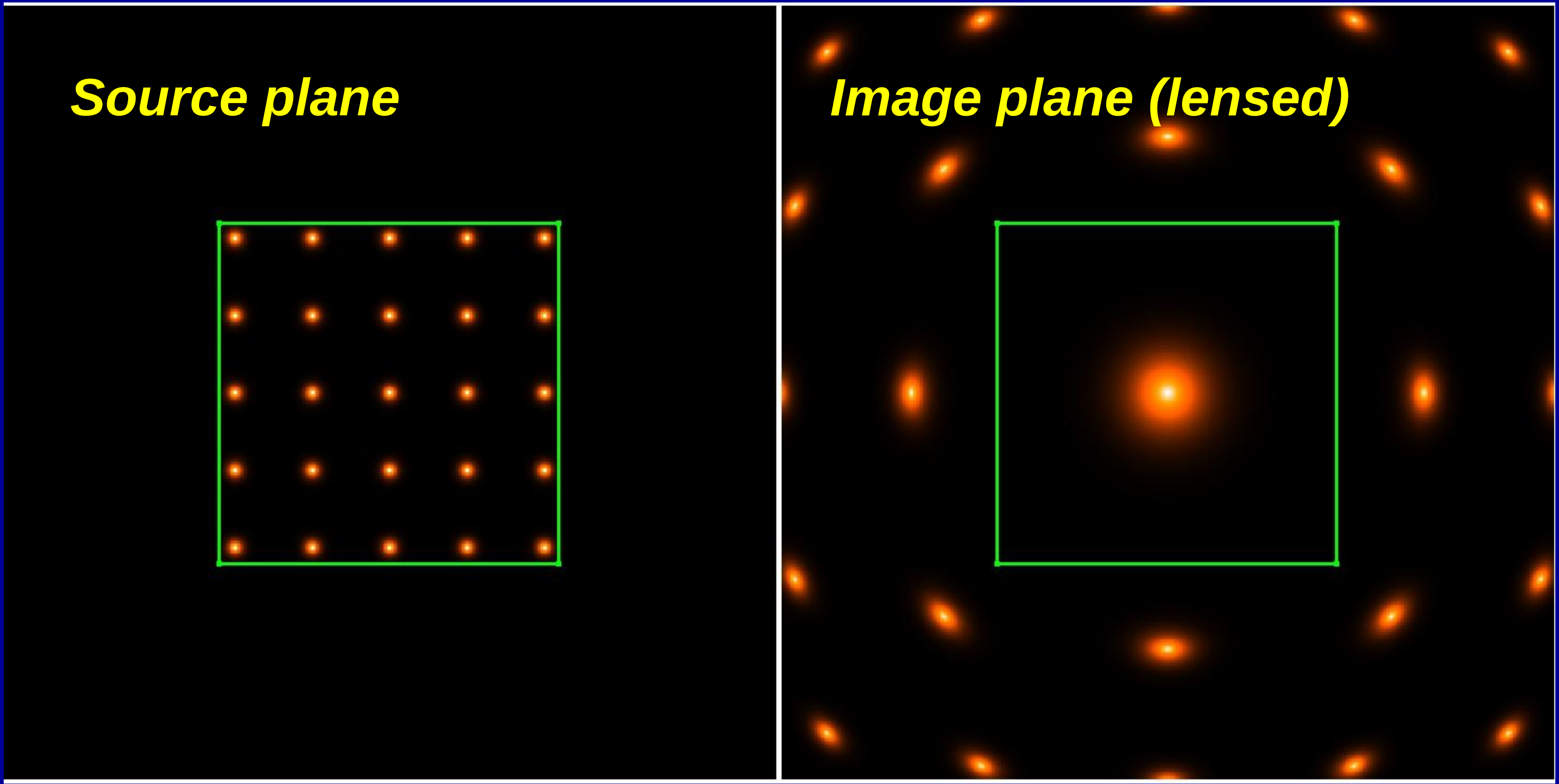
A single NFW gives an excellent fit over ~2-decades of radius

SIS model is rejected at >60σ significance

Umetsu et al. 2011b, ApJ, 738, 41 (arXiv:1105.0444)

Utility of Magnification Information

Sky expands due to gravitational magnification



Leading to a depletion of counts-in-cells

Simulations with *glafic* (M. Oguri)

Weak Lensing Magnification Bias

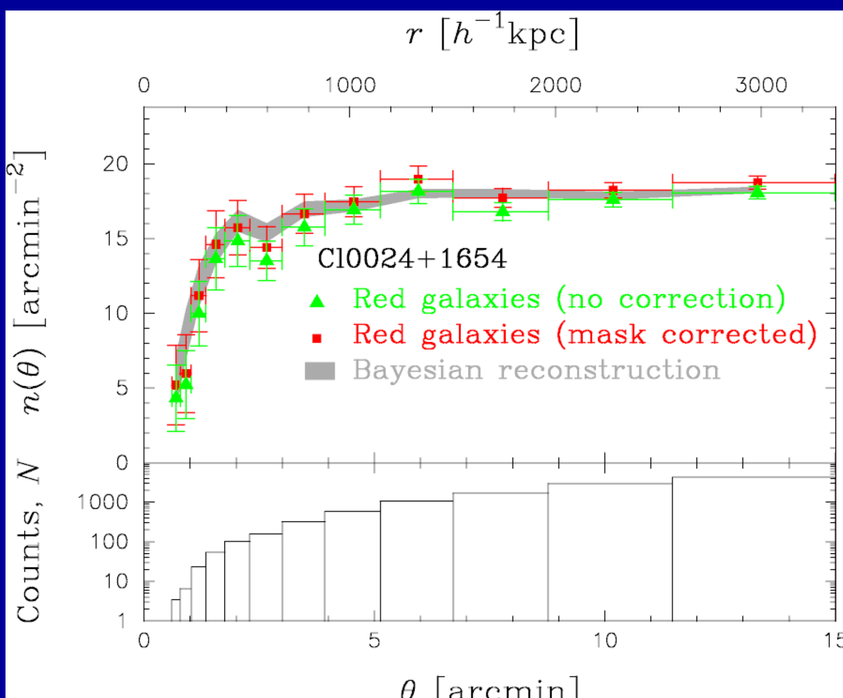
Lensing-induced fluctuations in background counts:

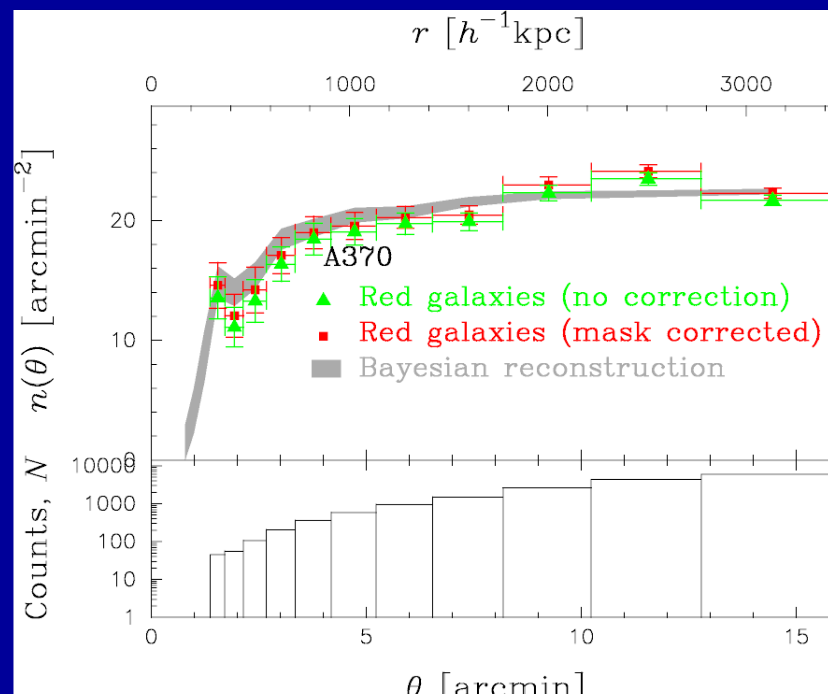
$$\frac{\delta n(\boldsymbol{\theta})}{n_0} = \mu^{s-1}(\boldsymbol{\theta}) - 1 \approx 2(s-1)\kappa(\boldsymbol{\theta})$$

with unlensed LF of BG galaxies

$$n_0(>F) \propto F^{-s}$$

When the count-slope is shallow (s<1), a net deficit of counts results: the case for **faint red galaxies** (Broadhurst, Taylor, Peacock 1995)





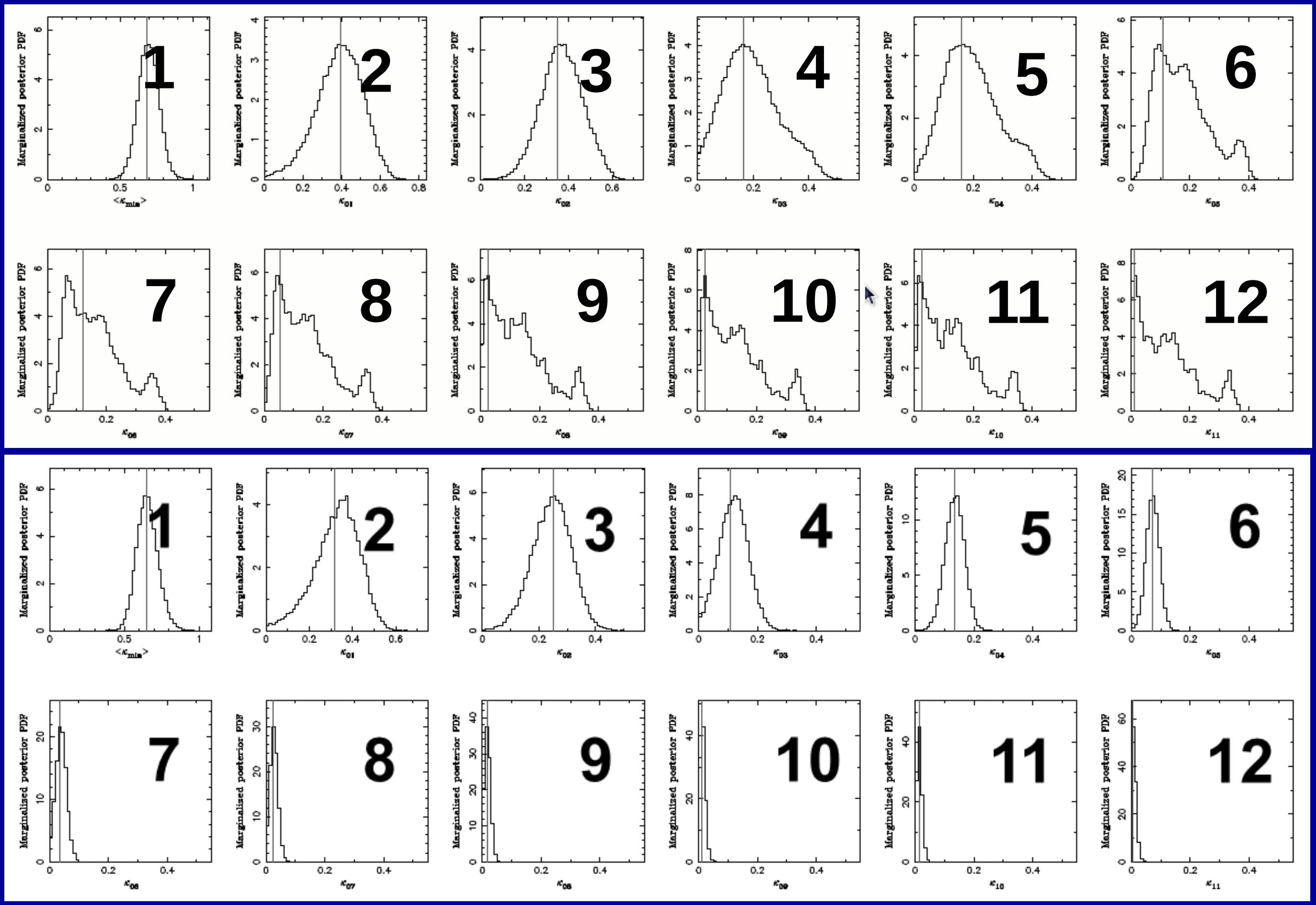
Umetsu et al. 2011a, ApJ, 729, 127

Gain by Adding Magnification in WL

Marginalized PDFs of Σ(R) in N=12 radial bins: A1689

Shear data alone

Shear + mag-bias

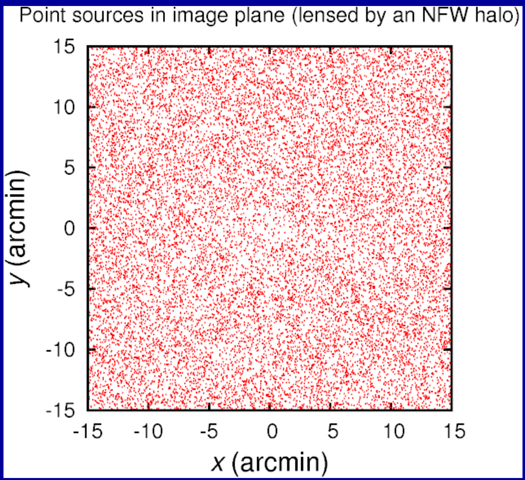


Umetsu et al. 2011a

- **Mass-sheet degeneracy is fully broken**
- **~30% improvement in mass determination**

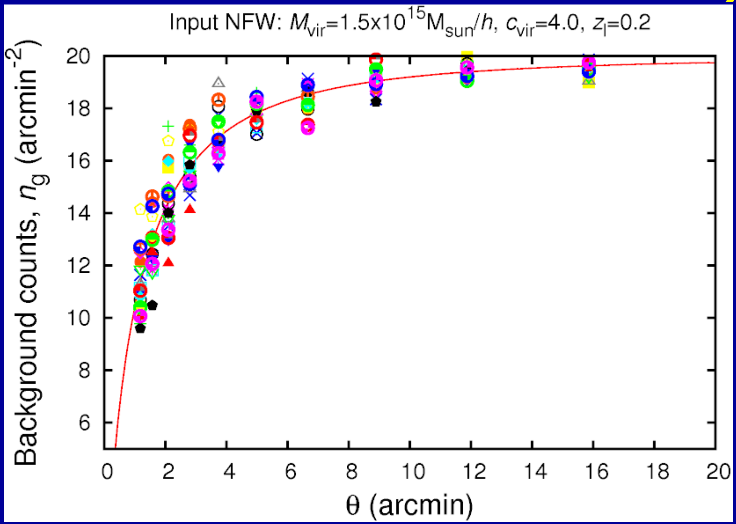
Mock Observations

Simulation with *glafic* software

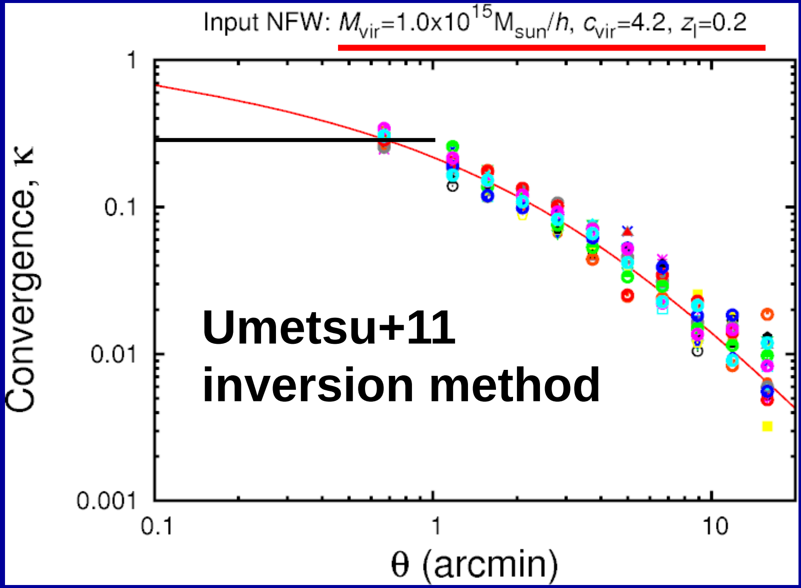


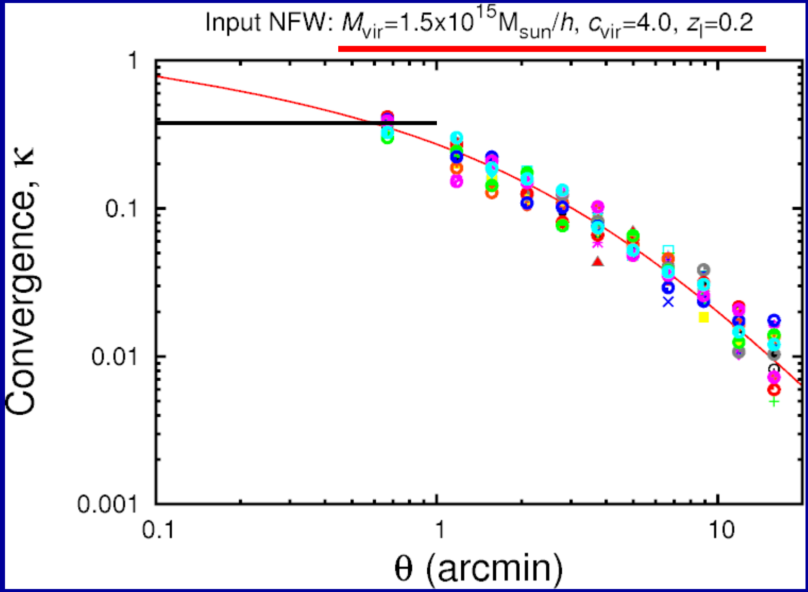
Sources:
n=20 arcmin^-2
z_s=1
s=0 (maximally depleted)
σ_g=0.4

Number count profiles (20 realizations)



1D Bayesian (shear + mag-bias) inversion

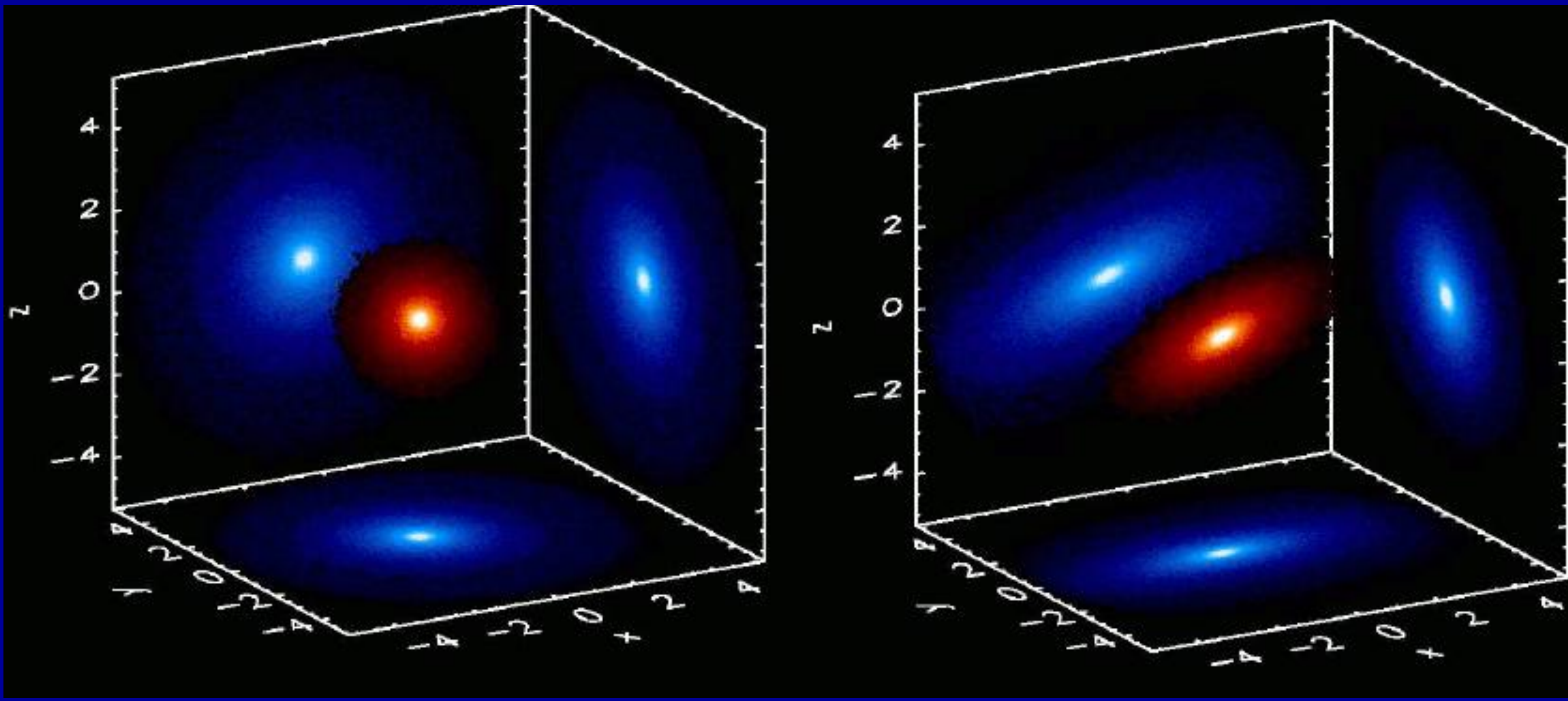




2. Various Projection Effects

1. Unresolved, uncorrelated LSS: cosmic noise
   - Produces covariance, increases uncertainty in (M,C): ~+20% increase in error for CC-selected BG samples.
2. Resolved clusters in LOS (Remember Dan's talk)
   - Can bias "individual cluster" parameter estimation if they're not taken into account
   - Seen as a dip (↓) in $g_T(R)$, as a bump (↑) in $\kappa(R)$
   - Can be improved with 2D-WL (Massimo's talk)
3. Halo triaxiality
   - Can bias low or high "individual cluster" (M,C)
   - 2D structure info can be used to constrain parameter space of triaxial model (Morandi+11, Sereno+Umetsu 11 on A1689)

Projection Effect by Halo Triaxiality



Spherical

Triaxial (prolate)

Hennawi, Dalal, Bode, Ostriker 2007

Remarks on the Triaxiality Modeling (I)

Triaxial Potential Approach

- Triaxial perturbation theory (Lee & Suto 03,04)
- Spherical averaging triaxial potential (Buote & Humphrey 11)
- Lensing+ applications: Morandi+ on A1689, A383
- **Pros**
  - Easy to describe IC-gas in HE with DM
  - Analytic modeling and fast computation
- **Cons**
  - Unphysical negative densities and non-elliptical isodensity contours can occur when ellipticity is large
  - How to compare with N-body simulations?

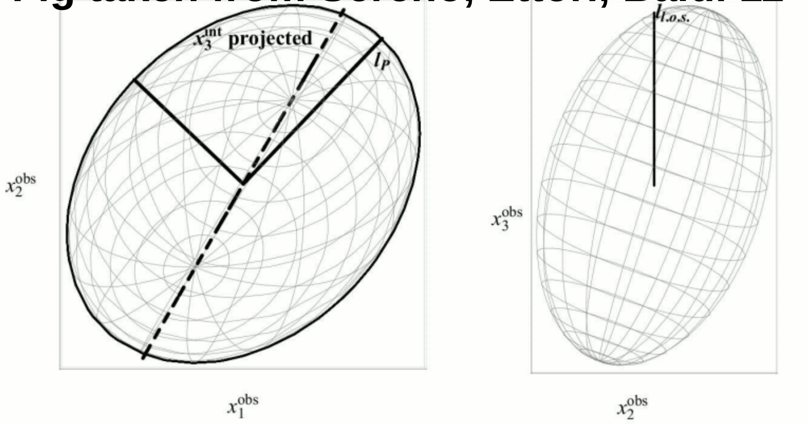
On the Triaxiality Modeling (2)

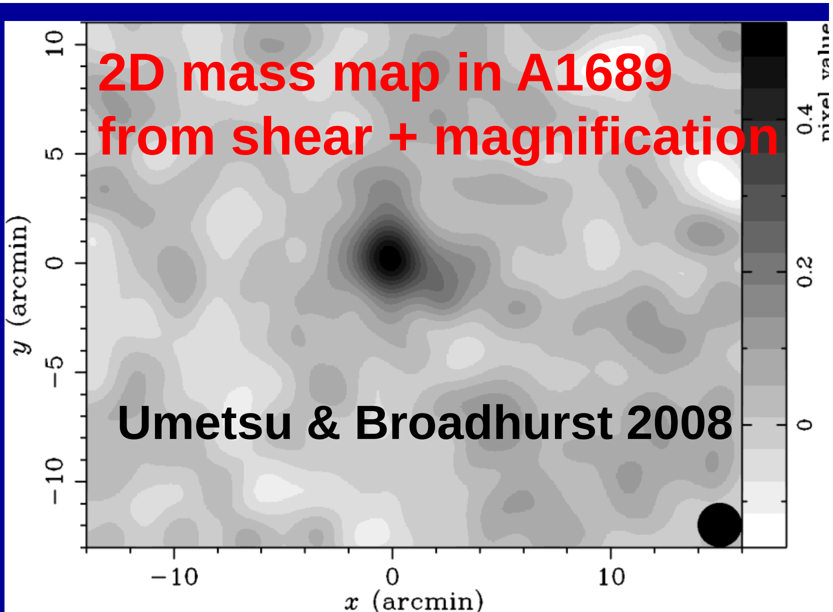
Ellipsoidal Halo Approach

- Ellipsoidal generalization of spherical “density” profiles (e.g., NFW)
- Lensing applications: Oguri, Takada, Umetsu+ 05; Sereno & Umetsu 11; Sereno & Zitrin 11
- **Pros**
  - Direct comparison with N-body results (e.g., Jing & Suto 02 N-body priors on axis-ratios)
  - Entire parameter space can be explored (no approx)
- **Cons**
  - Slow computation

Bayesian Deprojection of 3D Dark-Matter Structure

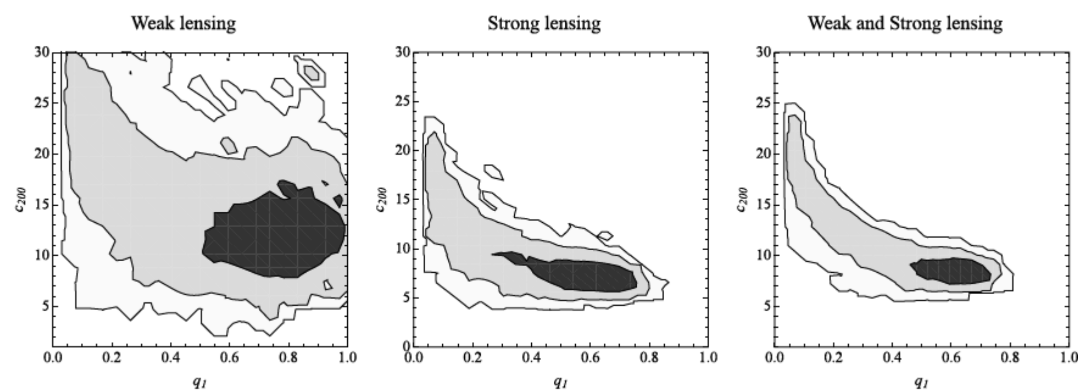
Fig taken from Sereno, Ettori, Baldi 11



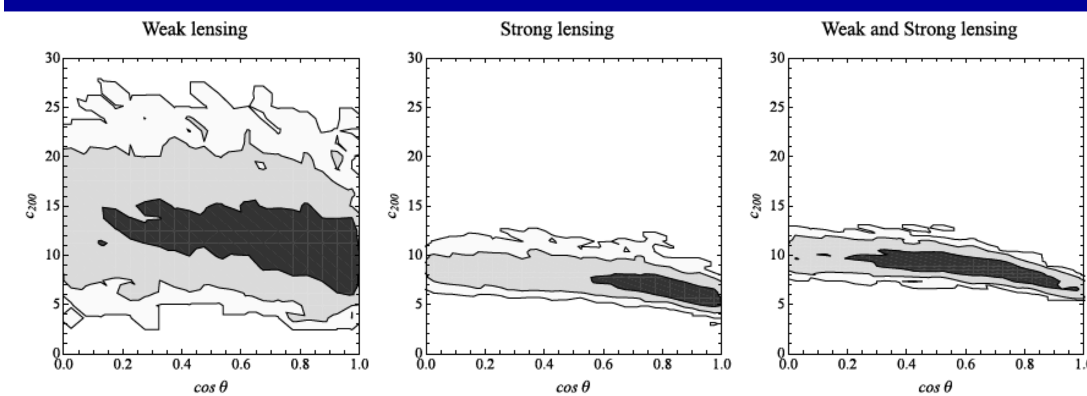


Full-2+1D SL+WL Bayesian analysis (A1689) by Sereno & Umetsu 2011

C200 vs. major-minor axis ratio, q_1



C200 vs. l.o.s. alignment, cos[θ]



SZE Multi-scale Multi-frequency Cluster Program

CLASH-SZE collaboration

- Collaboration between CLASH and several SZE groups: Bolocam, MUSTANG/GBT, AMiBA?, SZA? … (discussion needs to be resumed with AMI group)
- Forming an SZE consortium to study the CLASH sample (20 X-ray and 5 lensing selected clusters at $0.18<z<0.9$)

Aim: *Probing hot cluster baryons from small to large angular scales*

- **Large angular scale**: 1 to 10+ arcmin
  - Bolocam@150GHz (1 to 14 arcmin), typically out to R500+
  - AMiBA-13@94GHz (2 to 11 arcmin)
- **Small angular scale**: 0.1’ to 1’
  - GBT/Mustang@90GHz (9” to 40”)

Objective (1): Stacked SZE Profiles

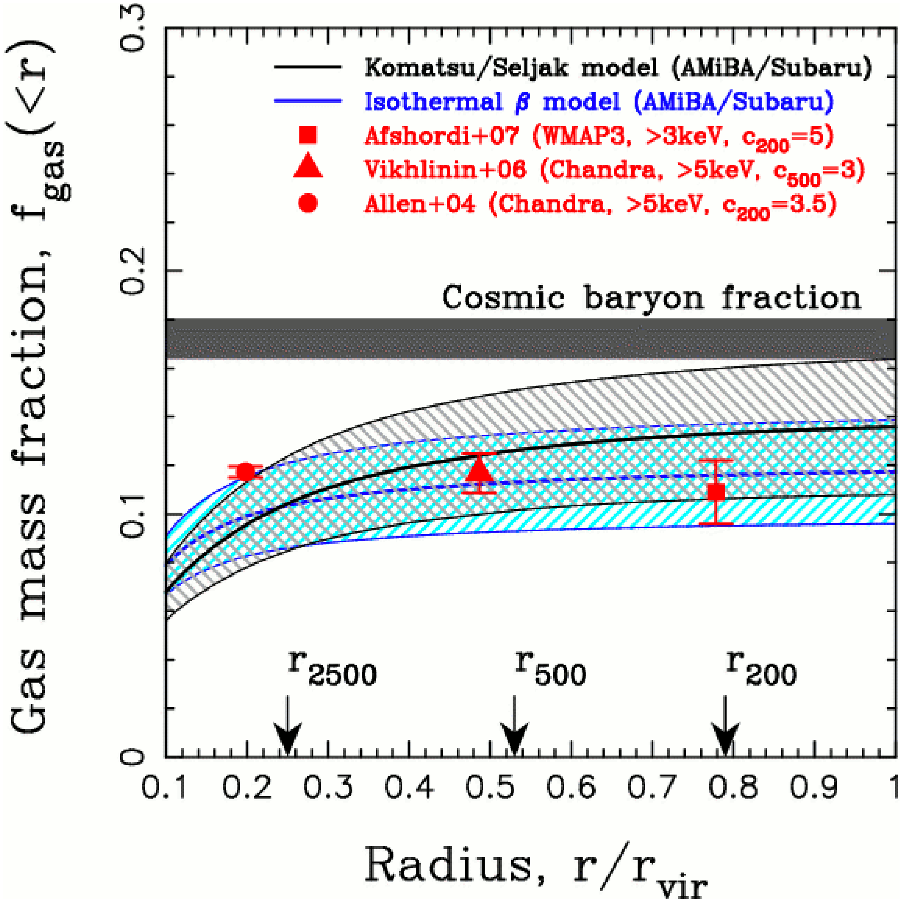
Stacked Bolocam-SZE pressure profile from 40 clusters

Figures by Jack Sayers
and the Bolocam team

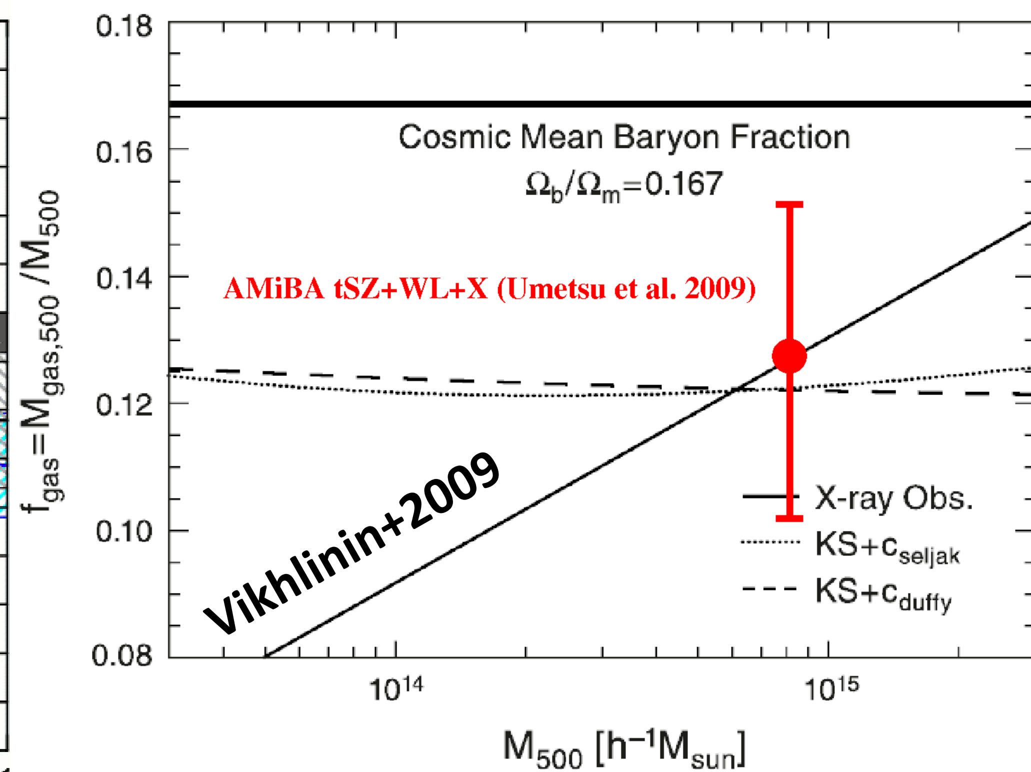
Objectives (2): Gas Fractions

Large-scale f_{gas} constraints from tSZE+WL+X, independent of dynamical state and level of hydrostatic equilibrium

AMiBA-7 tSZE + WL + X-ray



WMAP7 tSZE and X-ray constraints



Komatsu et al. 2010, WMAP-7yr

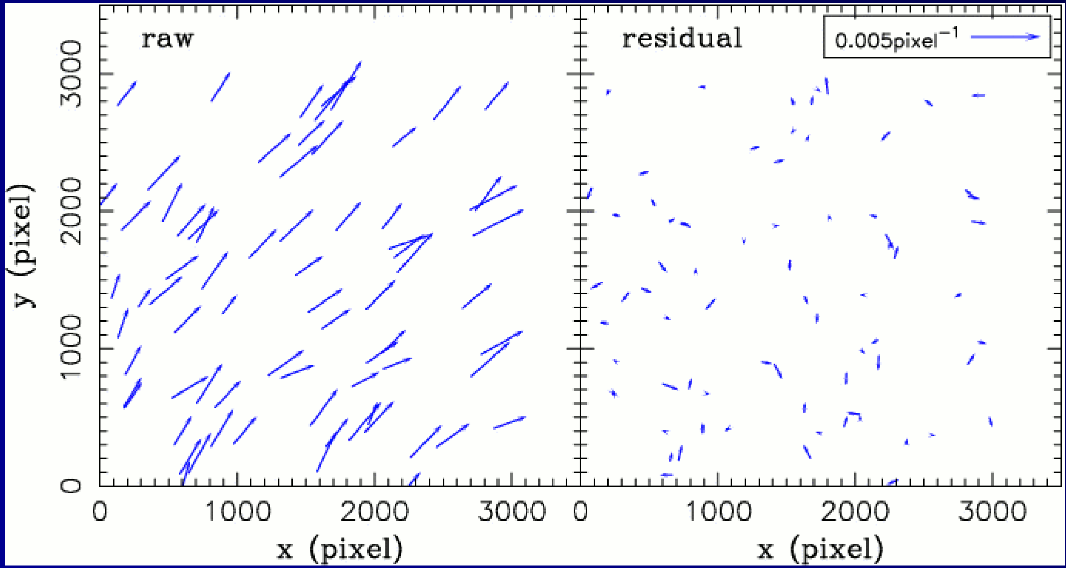
Umetsu, Birkinshaw, Liu et al. 2009, ApJ, 694, 1643 (arXiv:0810.969)

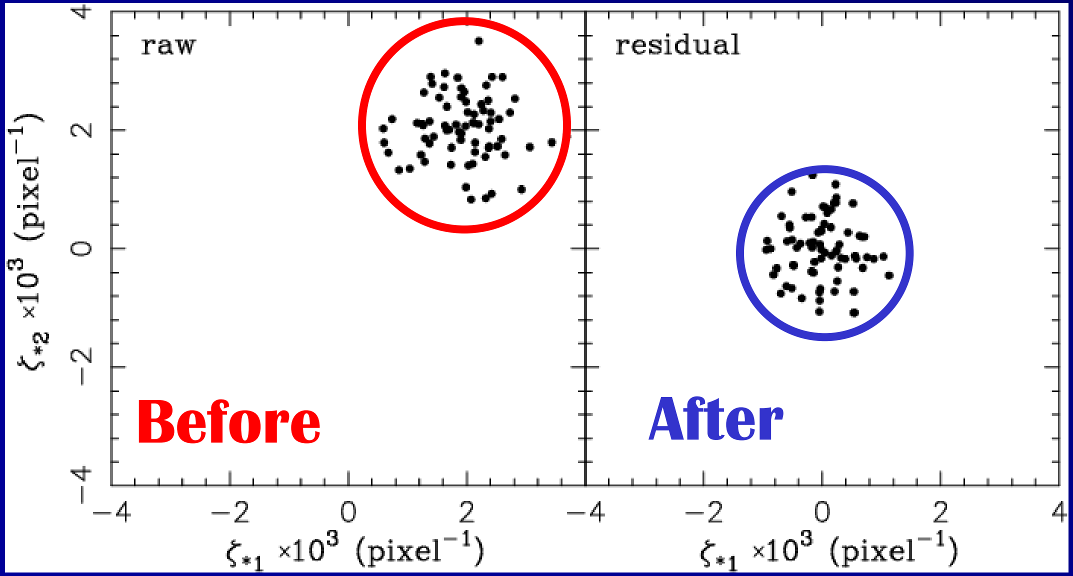
Summary

- **We explored the utility of high-quality Hubble + Subaru data by combining all possible lensing information available in the cluster regime:**
  - **WL Distortion (shear)**
  - **WL Dilution (purity of BG sample)**
  - **WL Depletion (magnification)**
  - **Flexion?**
  - **Strong lensing (SL)**
  - **Stacking SL+WL**
  - **Deprojection of 2D SL + 2D WL**
- **Implementations and tests of independent lensing dprojection methods are needed**
- **Joint SL+WL+X+SZE analyses**

$$\frac{S(F)}{S(\gamma)} \sim \frac{L\phi / r^3}{\phi / r^2} \sim \frac{L}{r}$$

Spin-1 PSF Anisotropy Correction: Application to Subaru A1689 data





Spin-1 PSF anisotropy from stellar shape moments

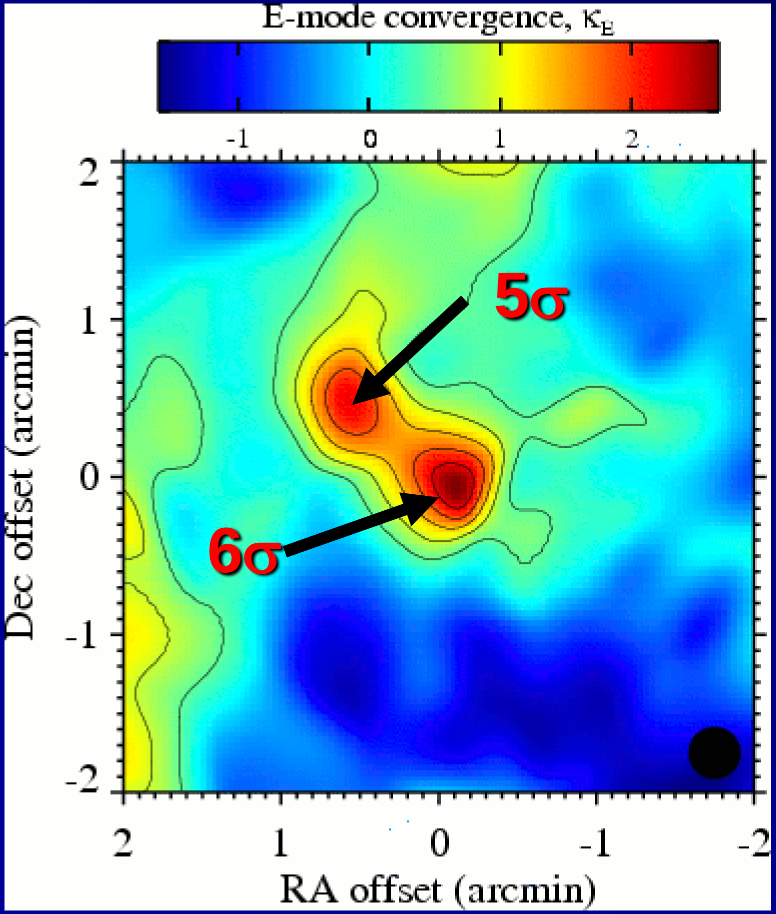
$$\varsigma_\alpha^* = (C^q)^*_{\alpha\beta}(\varsigma_q^*)_\beta$$

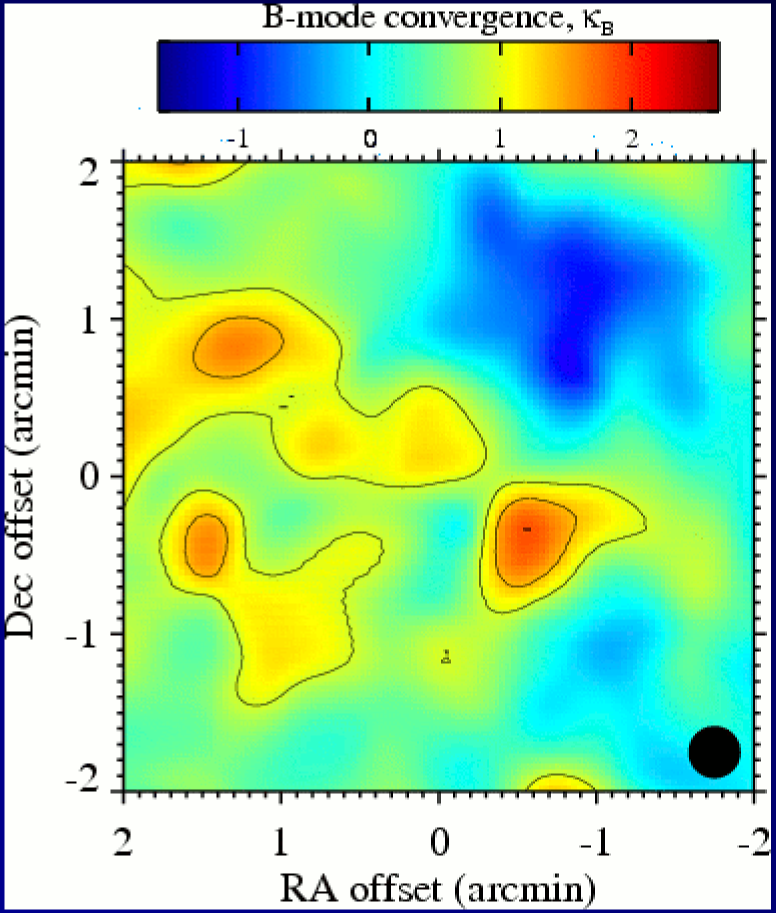
Okura, Umetsu, Futamase 2008

Mass Map of A1689 from Spin-1 Flexion

Mass reconstruction in the 4’x4’ core region of A1689 (z=0.18)

E-mode (lensing) **B-mode (noise)**





n_g=8 arcmin^-2

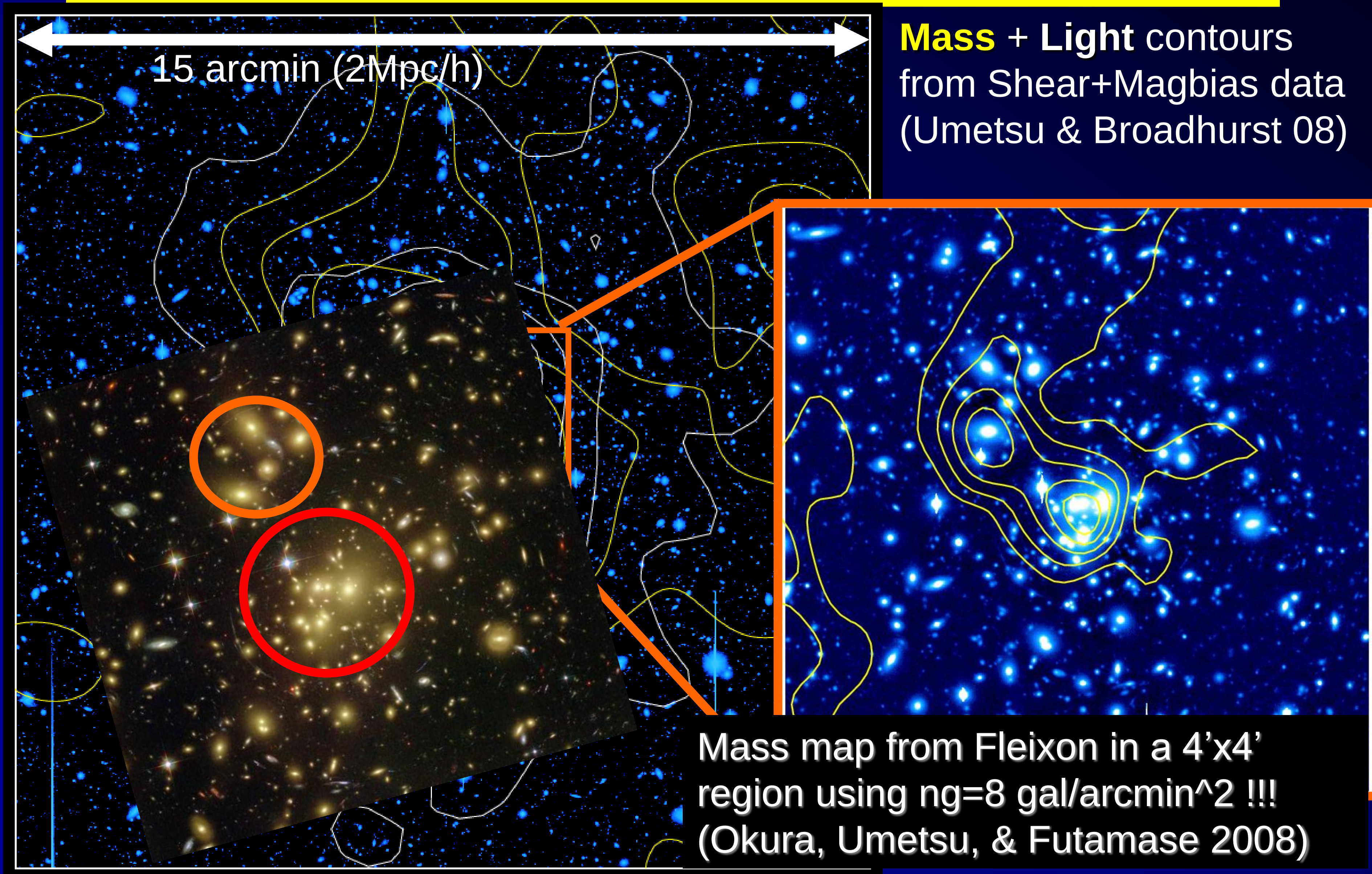
0.’3FWHM Gaussian

530kpc/h

Okura, Umetsu, Futamase 2008

Mass and Light in A1689 (Subaru)

Mass + **Light** contours from Shear+Magbias data (Umetsu & Broadhurst 08)



Mass map from Fleixon in a 4’x4’ region using ng=8 gal/arcmin^2 !!! (Okura, Umetsu, & Futamase 2008)