SZX HUNTSVILLE 2011

Mass and Hot Baryons from Cluster Lensing and SZE Observations

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Collaborators

Lensing collaborators:

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CLASH lensing collaboration:

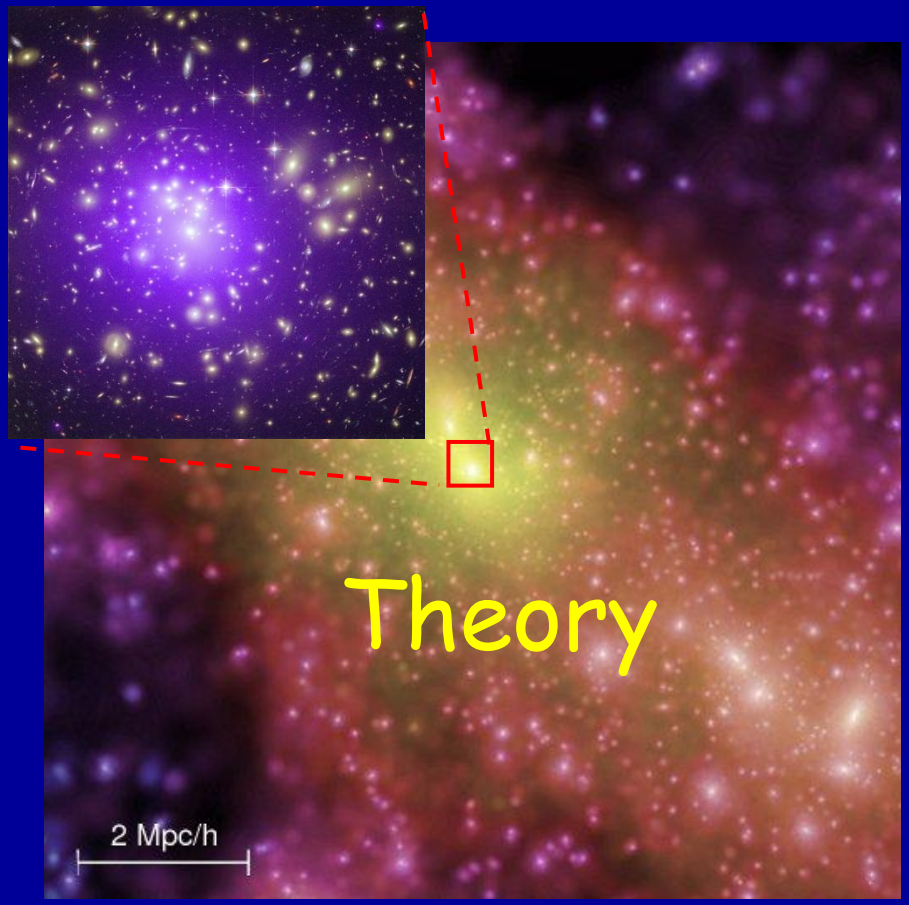
M. Postman (PI), H. Ford (Co-PI), E. Medezinski, M. Nonino, A. Zitrin,
T. Broadhurst, D. Coe, P. Melchior, M. Meneghetti, J. Mereten, A. Molino,
M. Bartelmann, N. Benitez, M. Donahue. D. Lemze, S. Seitz et al.

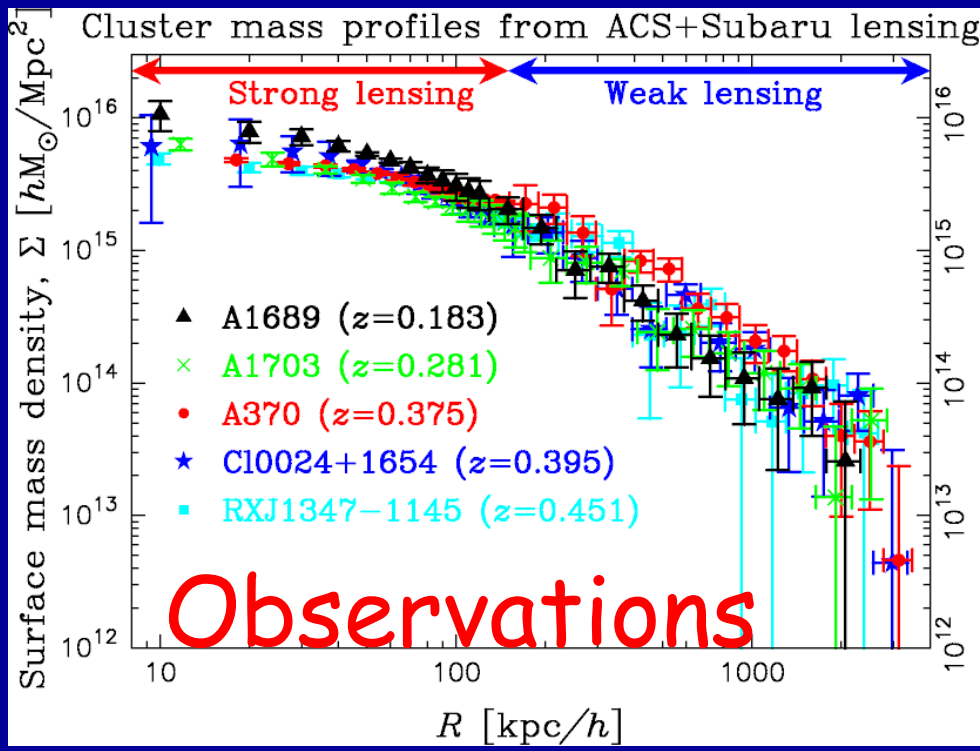
Bolocam/AMiBA CLASH-SZE collaboration:

S. Golwala (PI), J. Sayers, N. Czakon et al. (CLASH-Bolocam)
P.M. Koch, K.Y. Lin, S.M. Molnar (CLASH-Bolocam and AMiBA),
P.T.P. Ho (PI), M.T. Chen, G.C. Liu, H. Nishioka, C.W. Huang, C.T. Li,
Y.W. Liao, J.H.P. Wu, M. Birkinshaw et al. (AMiBA)

New Era of
Multi-λ Cluster Astrophysics and Cosmology

Comparing / combining high-quality multi-λ cluster observations [lensing/SZE/X-ray/optical/dynamics] for Cluster Cosmology and Astrophysics



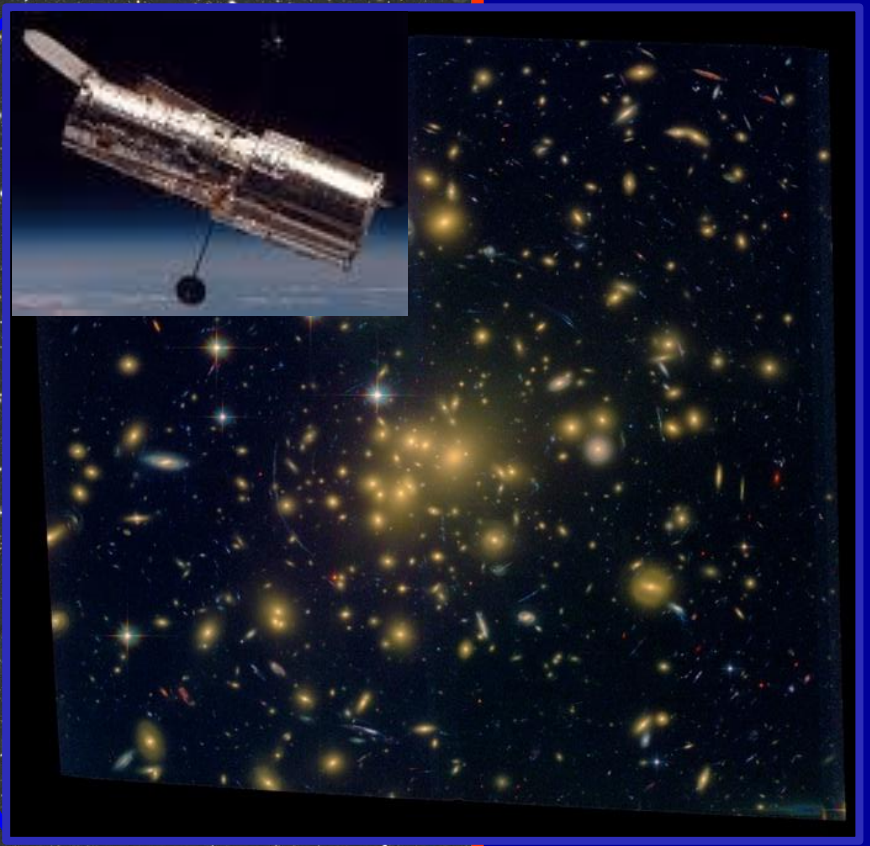


Umetsu et al. 2011a, ApJ, 729, 127

Cluster Lensing as a Primary Mass Probe

SUBARU **wide-field imaging (*Suprime-Cam*) for weak lensing**

High-resolution space imaging with *Hubble* for strong lensing



A1689 (z=0.183)

Umetsu & Broadhust (2008)

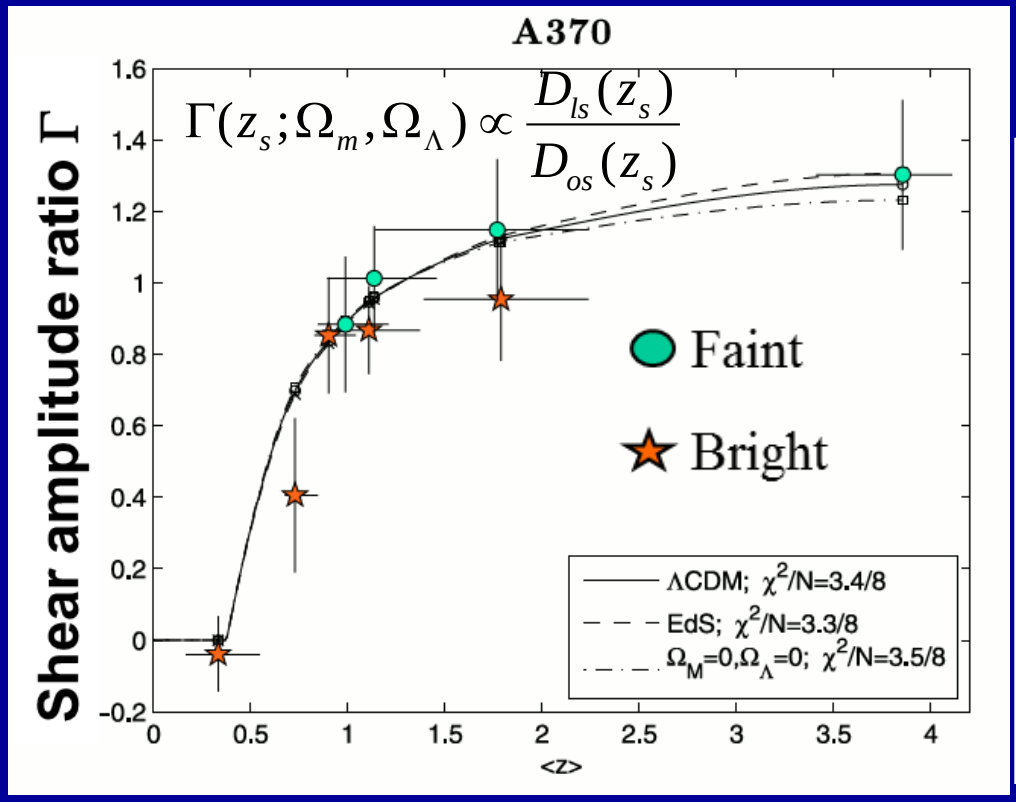
Full Lensing Analysis in the Cluster Regime

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

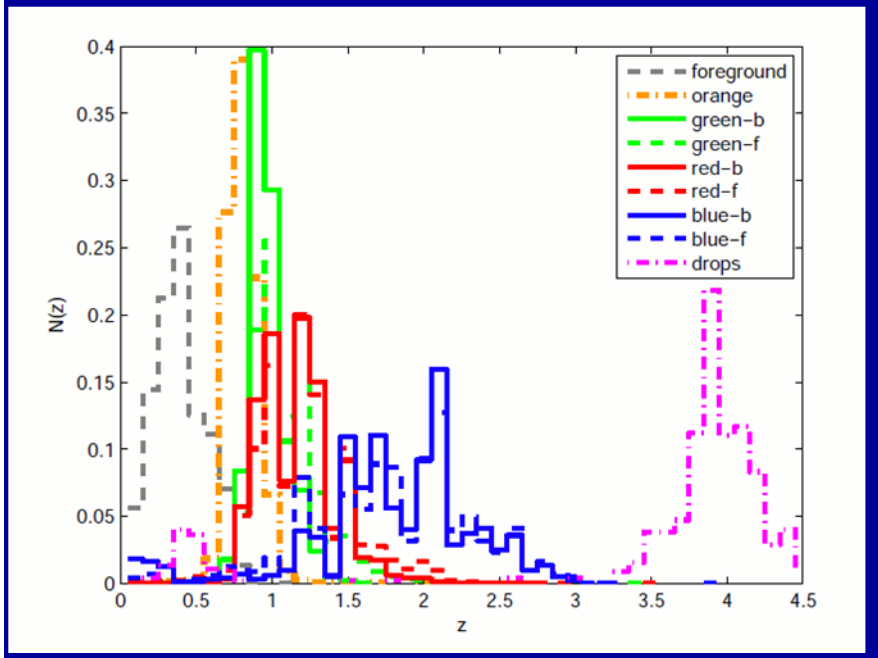
The Proof-of-Concept Consistency Test of Cluster Weak-Lensing

Mean tangential ellipticity of galaxies behind massive clusters (A370, Cl0024, RXJ1347) does increase with source redshift.

Model-Independent Single Cluster WL Tomography



COSMOS photo-z distributions of BR_cz'-selected background samples



Medezinski, Broadhurst, Umetsu, Benitez, & Taylor 2011 (MBU+11)

Keys: WL Distortion and Dilution

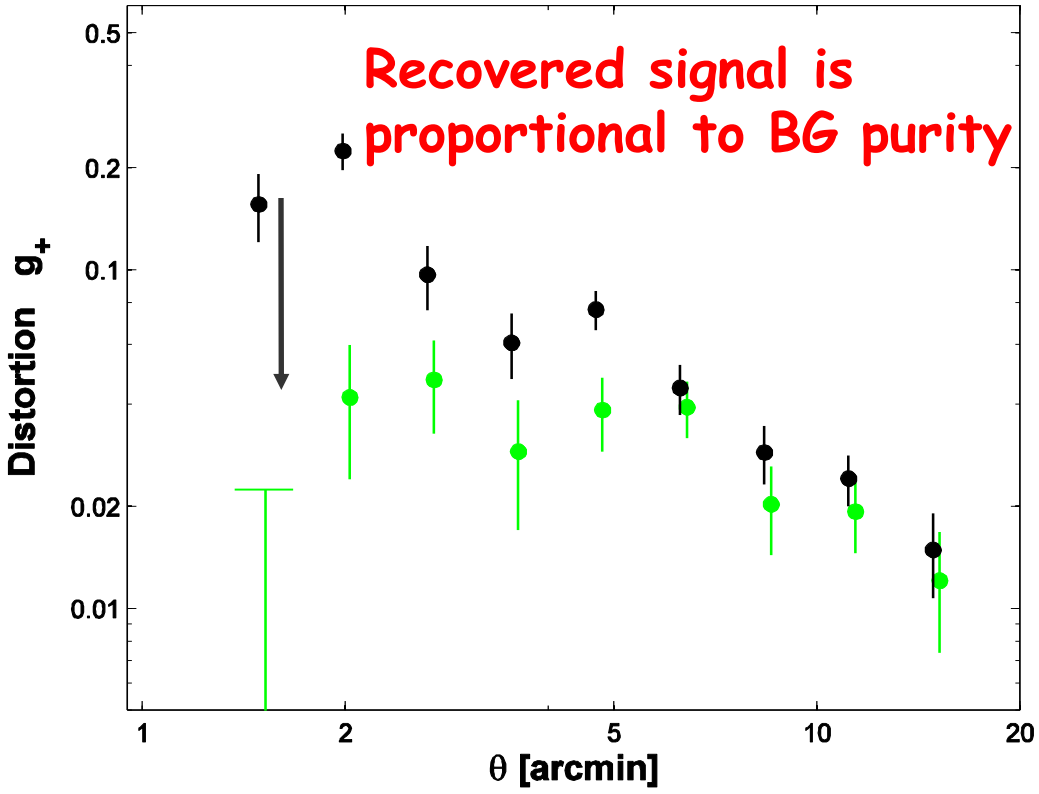
Tangential Distortion:

$$\gamma_+(R) \propto \Delta\Sigma_+(R) \equiv \overline{\Sigma}(<R) - \Sigma(R)$$

The Dilution Effect

Background (BG):
WL signal rises all the way to the center.

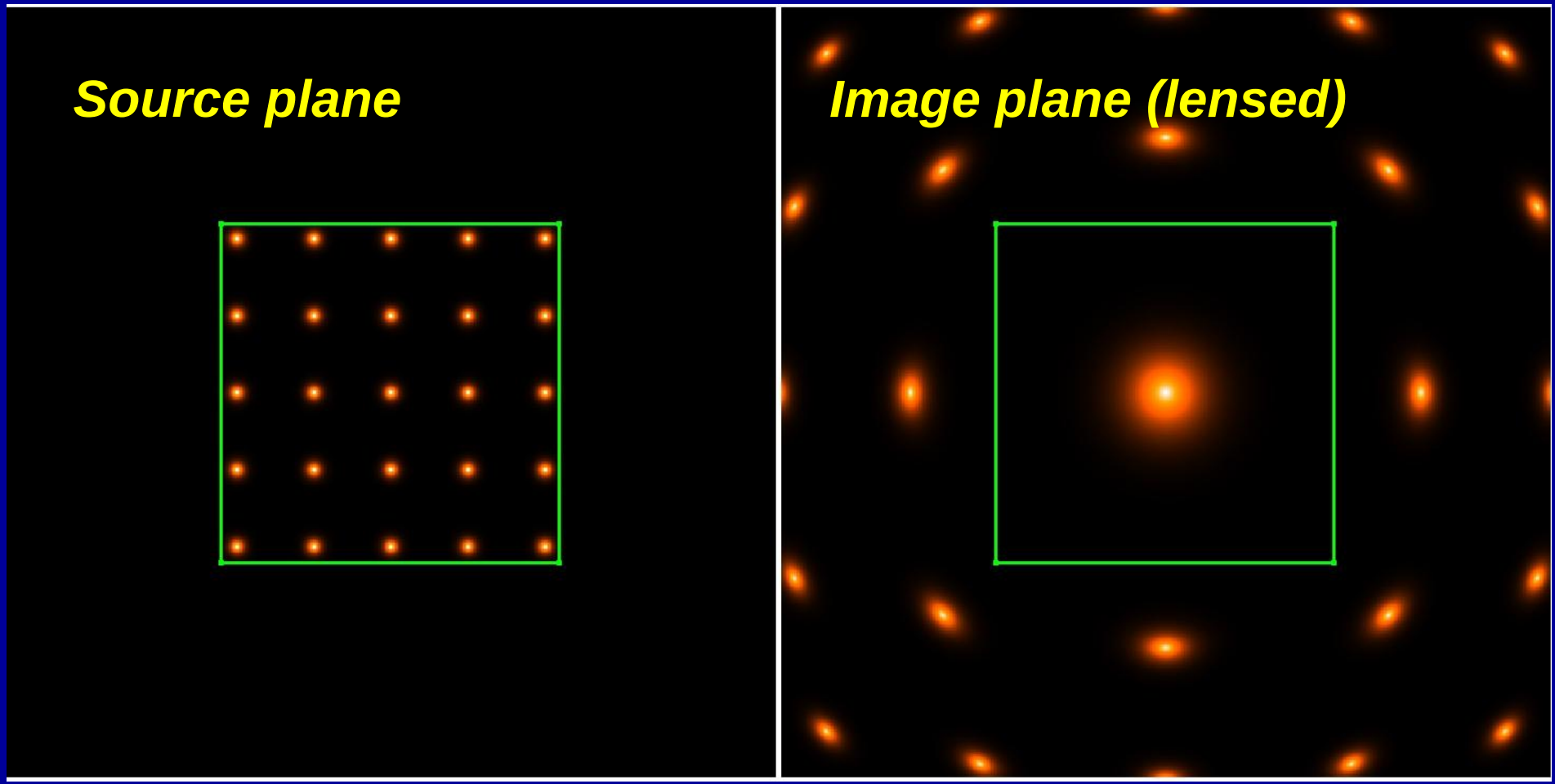
Green = Cluster+BG galaxies:
WL signal is diluted progressively toward the center by unlensed cluster members!



Broadhurst, Takada, Umetsu+05; Umetsu & Broadhurst 08; Medezinski+07,10

Count Depletion due to Magnification

Sky expands due to gravitational magnification



Leading to a depletion of counts-in-cells

Simulations with *glafic* (M. Oguri)

Weak Lensing Magnification Bias

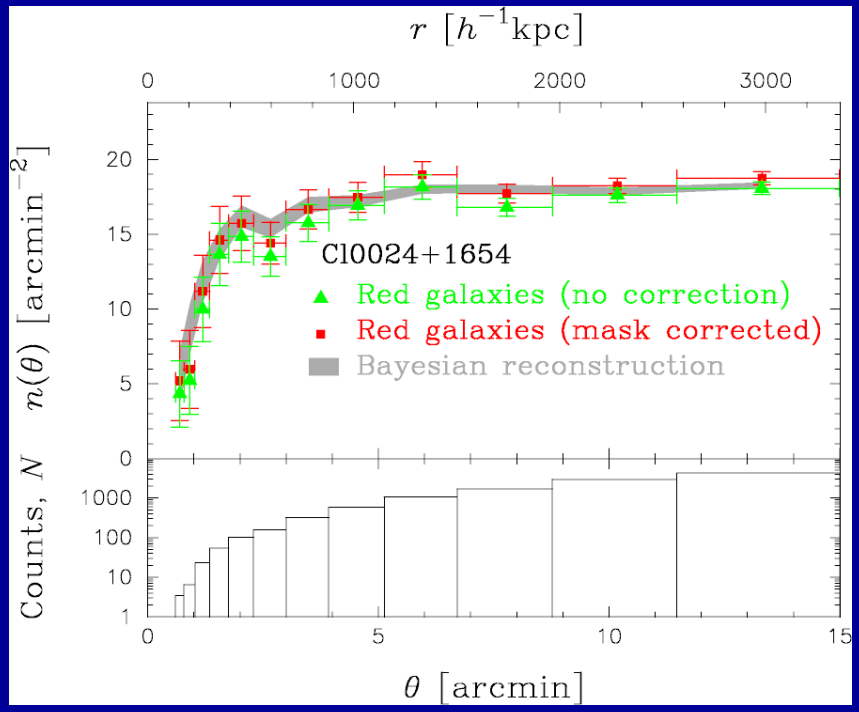
Lensing-induced fluctuations in background counts:

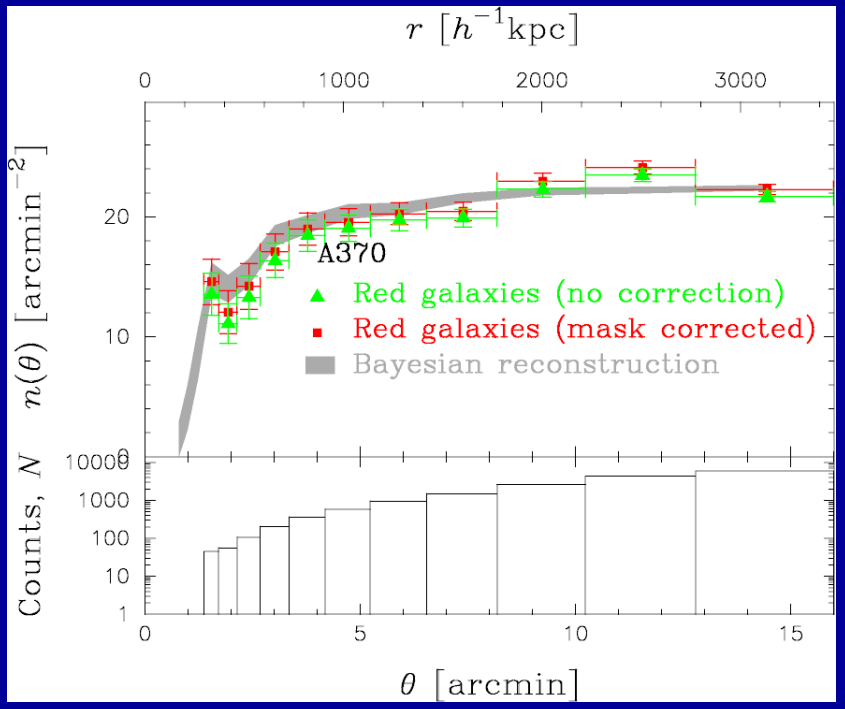
$$\frac{\delta n(\boldsymbol{\theta})}{n_0} = \mu^{s-1}(\boldsymbol{\theta}) - 1 \approx 2(s-1)\kappa(\boldsymbol{\theta})$$

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)

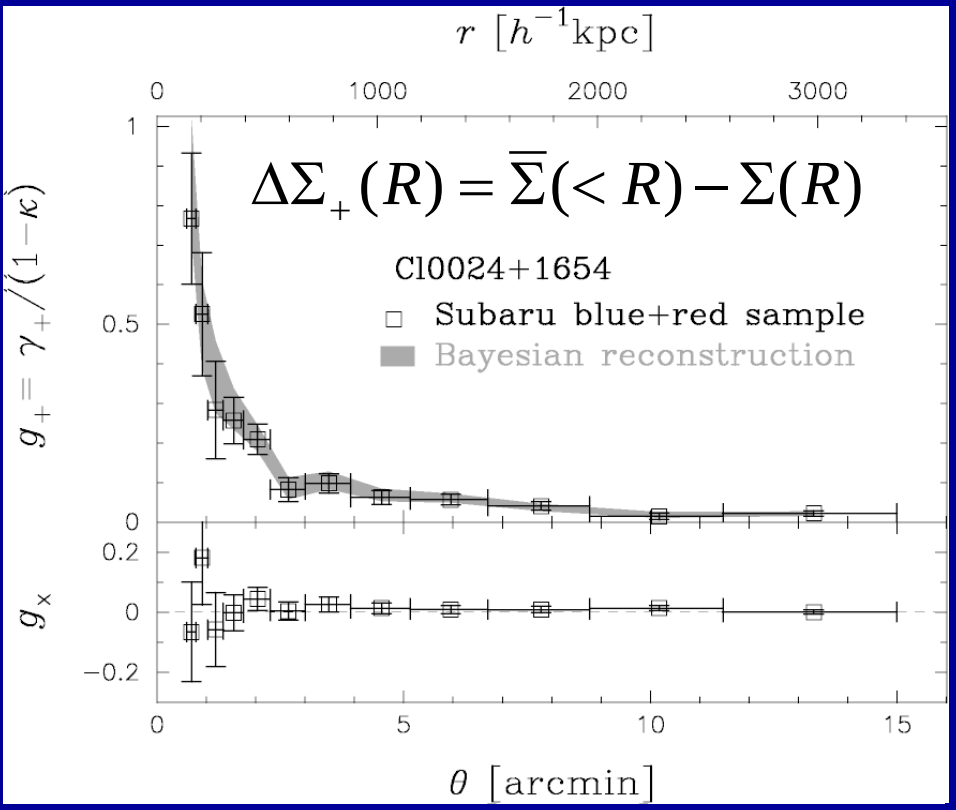




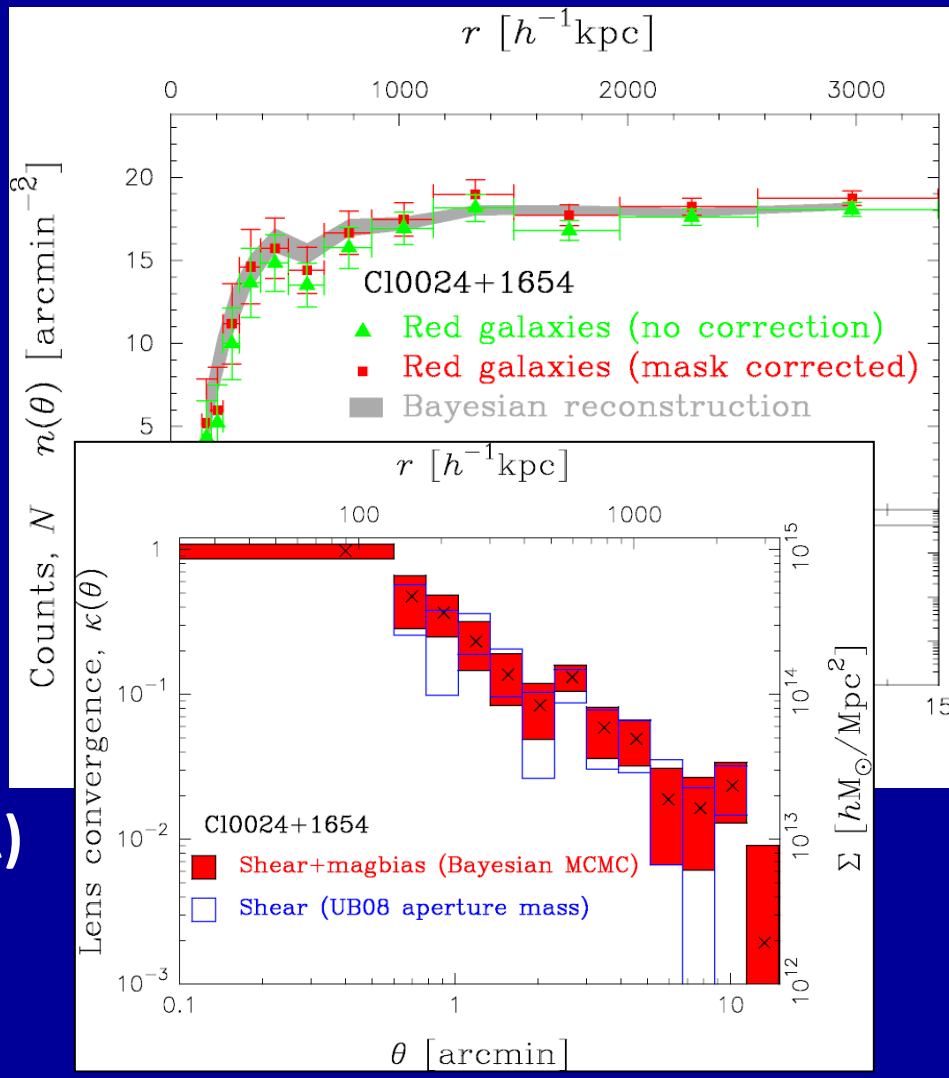
Umetsu et al. 2011a, ApJ, 729, 127

Combining WL Shear and Magnification

Tangential distortion (shear)



Number counts (magnification bias)

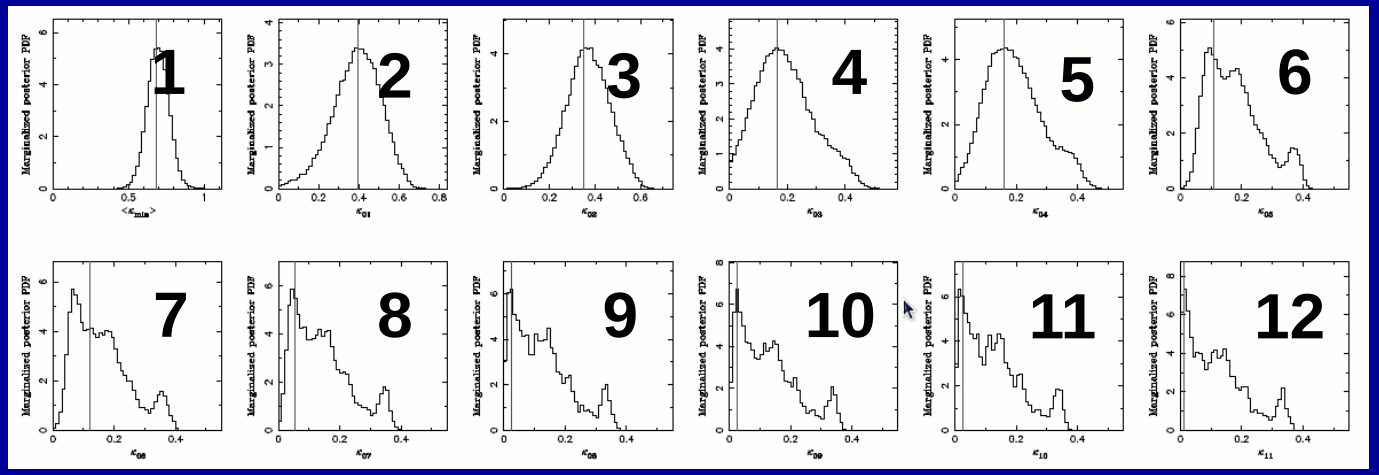


A unique mass profile solution Σ(R) can be obtained from Bayesian analysis of WL shear + mag-bias (Umetsu et al. 2011a)

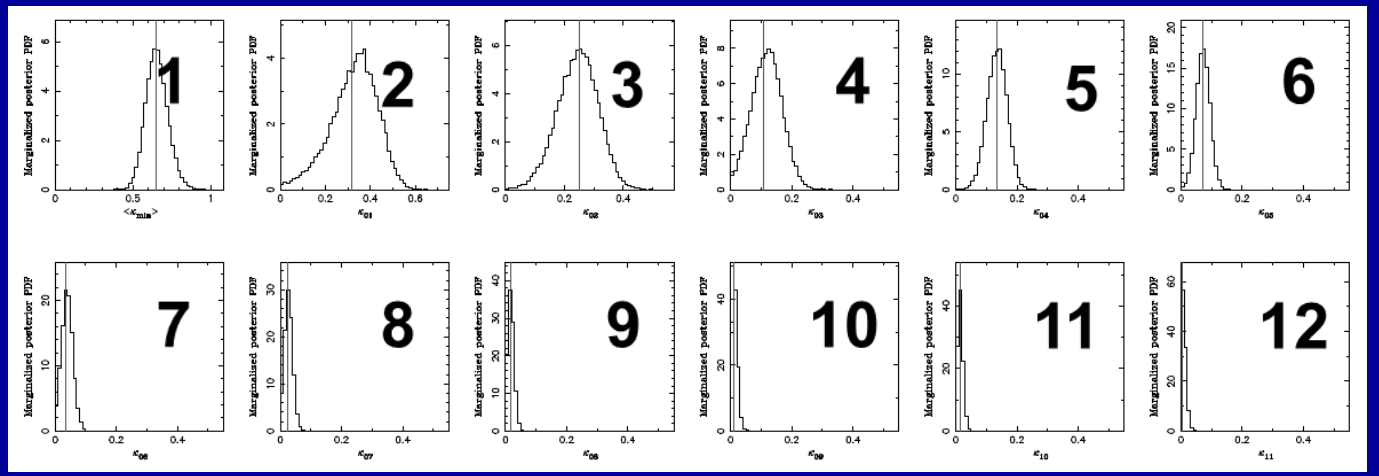
What we gain by adding magnification?

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

Shear data alone



Shear + mag-bias



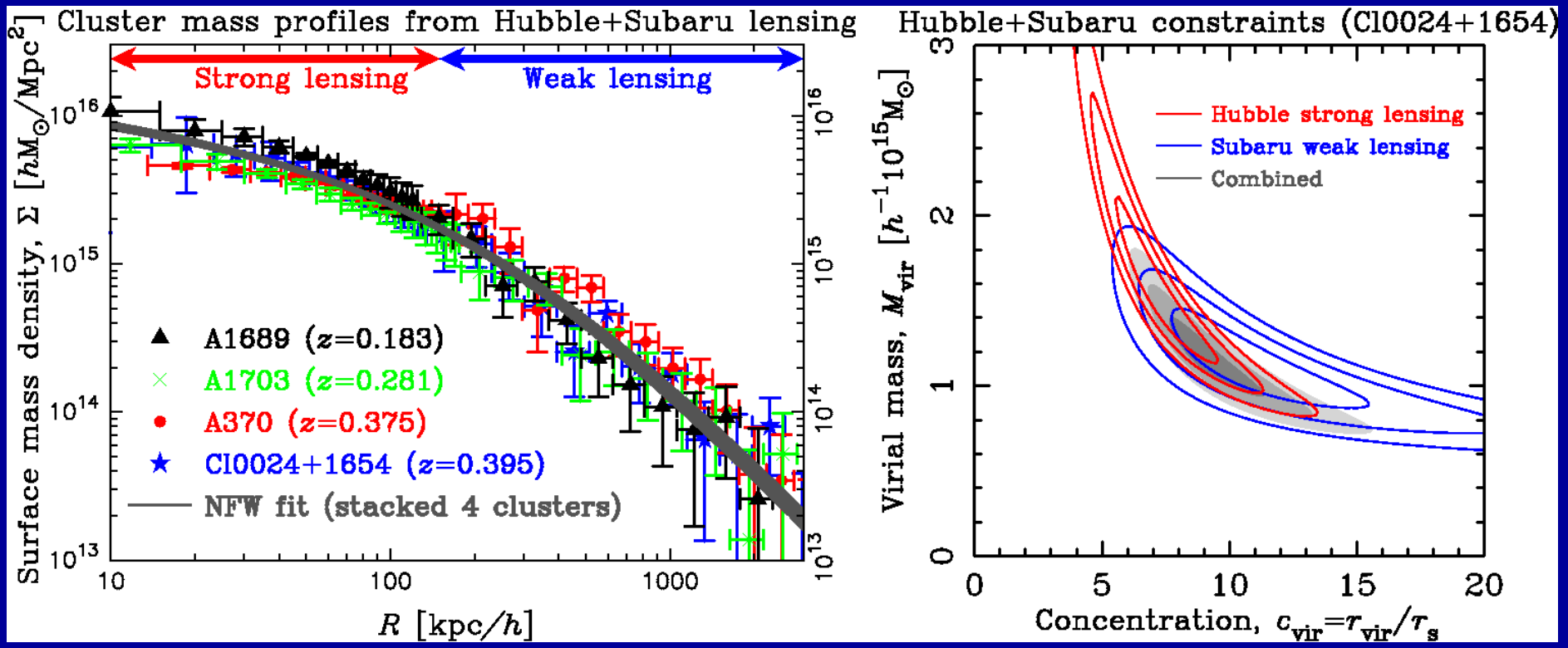
Umetsu et al. 2011a

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

Combining Full Lensing Constraints (shear, magnification, strong lensing)

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

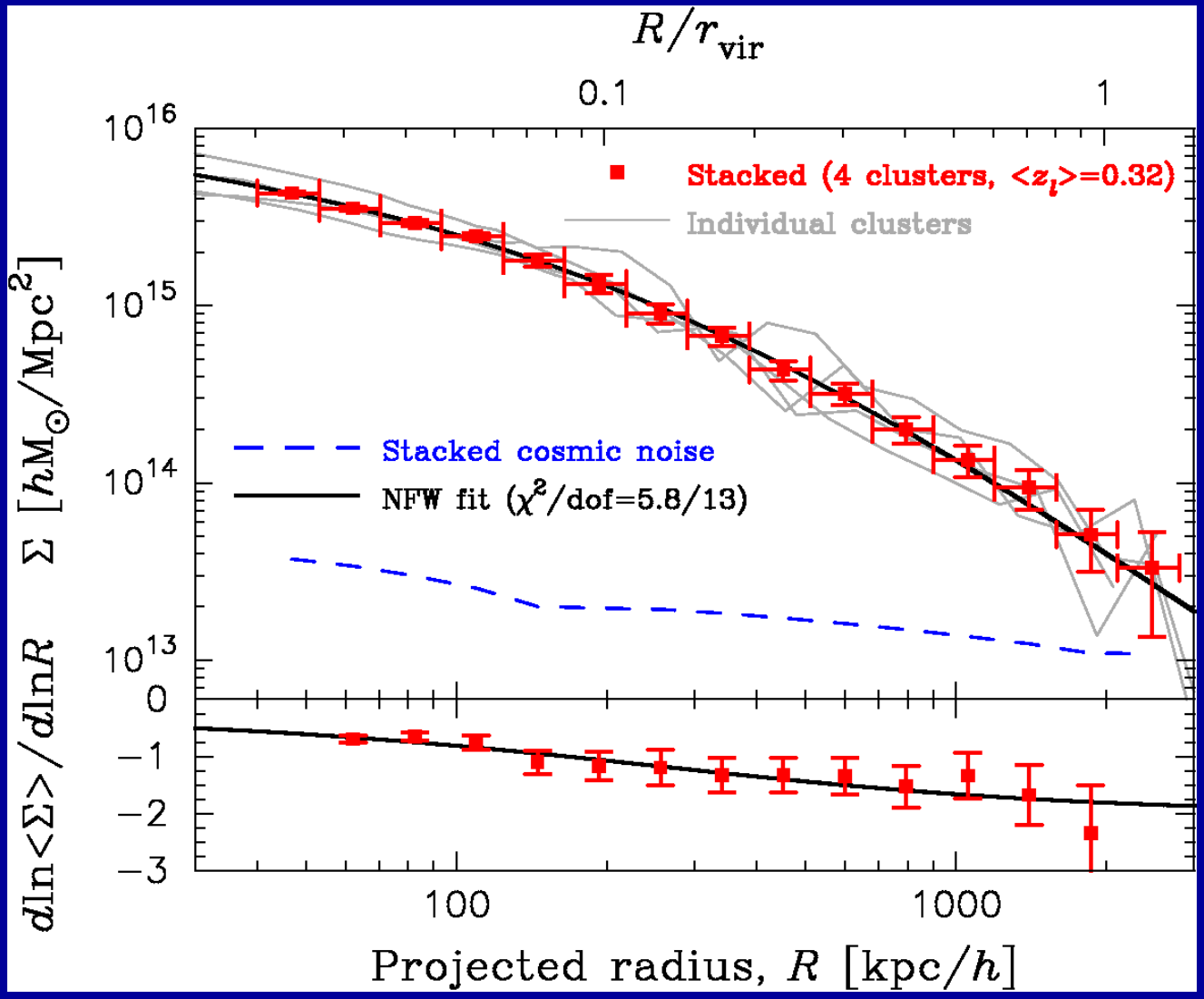
→ Combined SL + WL probes the full radial range [0.5%, 150%] R_{vir}



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

Umetsu+2008, 2009, 2010, 2011a, 2011b (figures taken from Postman+11)

A Precise Cluster Mass Profile Averaged from the Highest-Quality SL+WL Data



Stacking clusters by

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

Total S/N=58σ

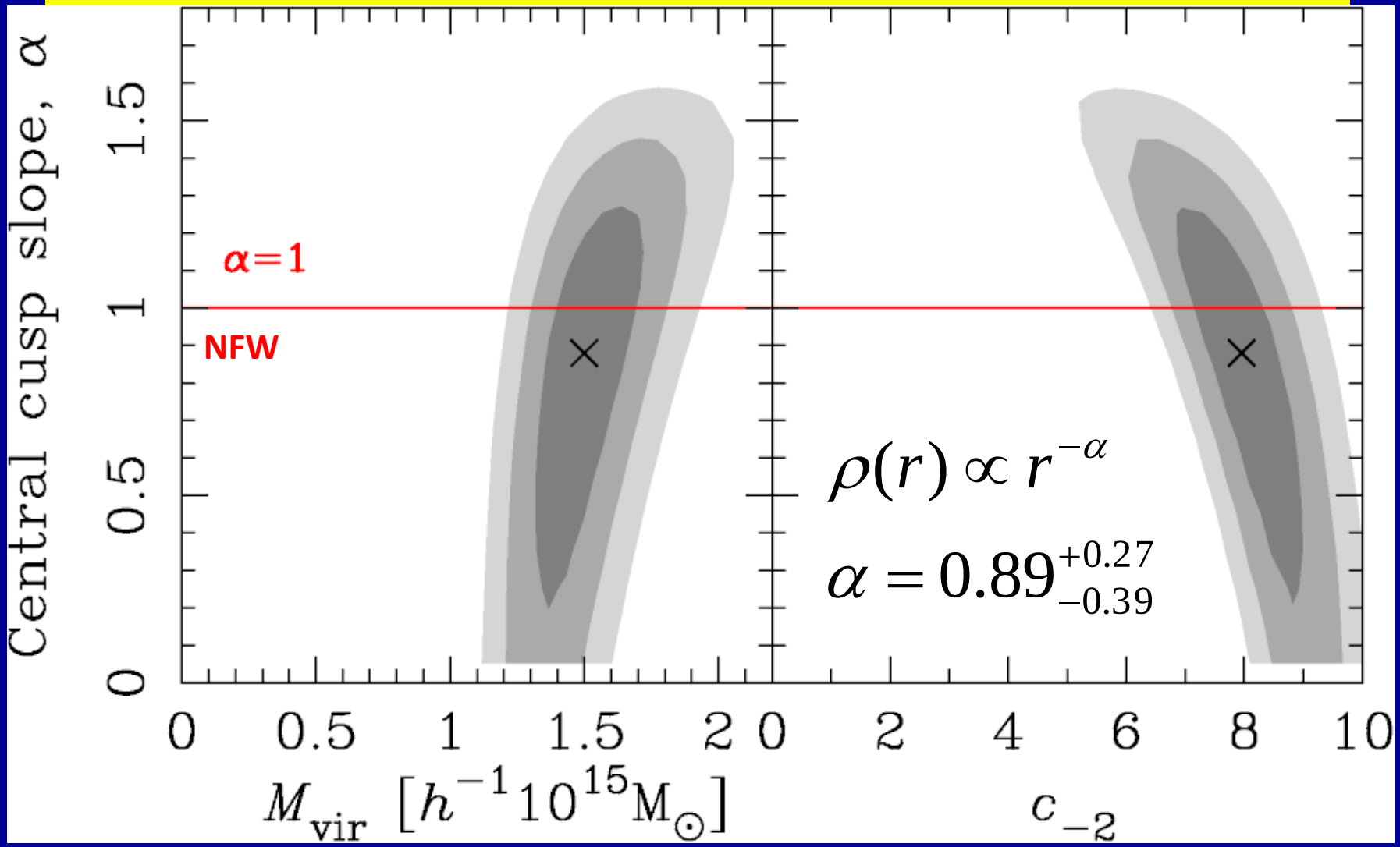
A single NFW gives an excellent fit over ~2-decades of radius

SIS model is rejected at >60σ significance

Lensing observations are consistent with that, DM is non-relativistic (cold) and effectively collisionless on the relevant scales.

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

Constraint on Central Cusp Slope

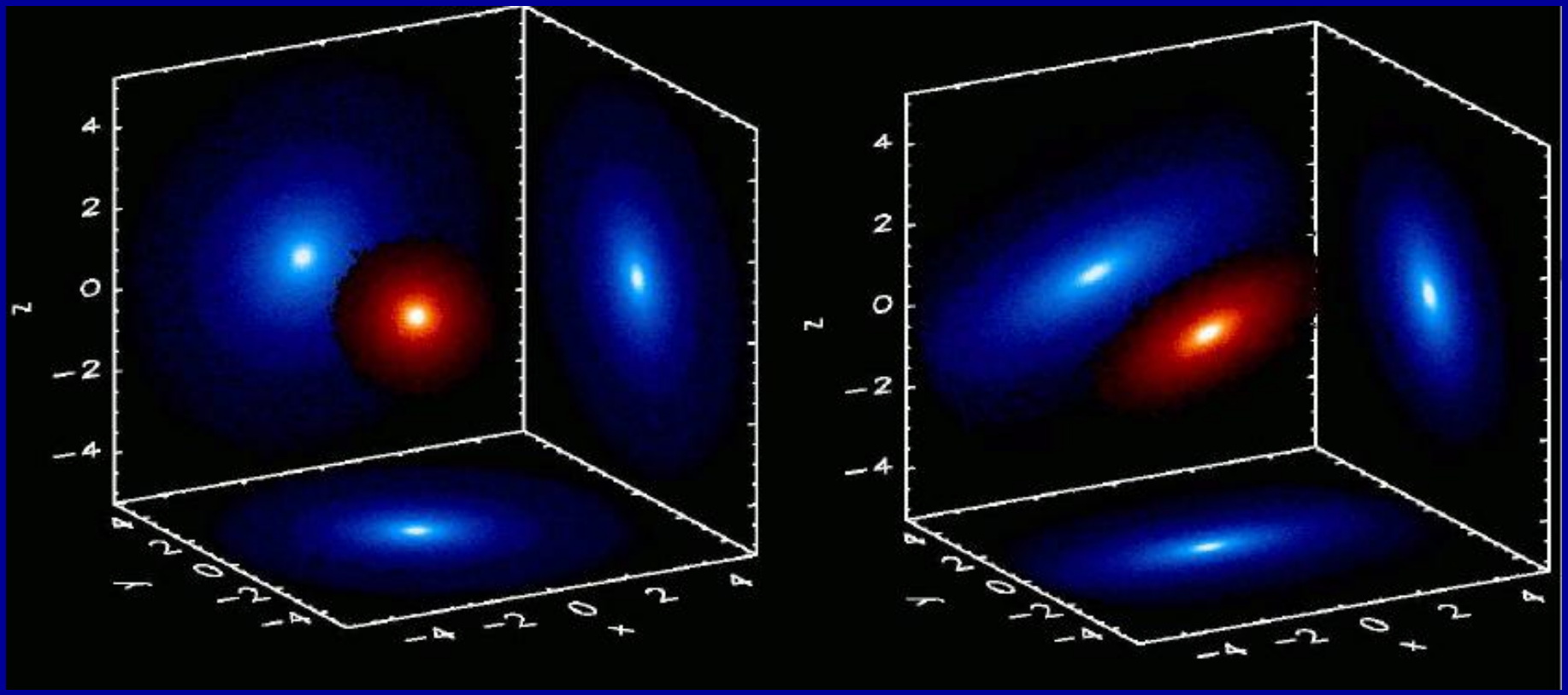


Slightly shallower than, but consistent with, NFW

(cf. Merrit+06, Graham+06, Navarro+10)

Umetsu et al. 2011b

Projection Effect by Halo Triaxiality



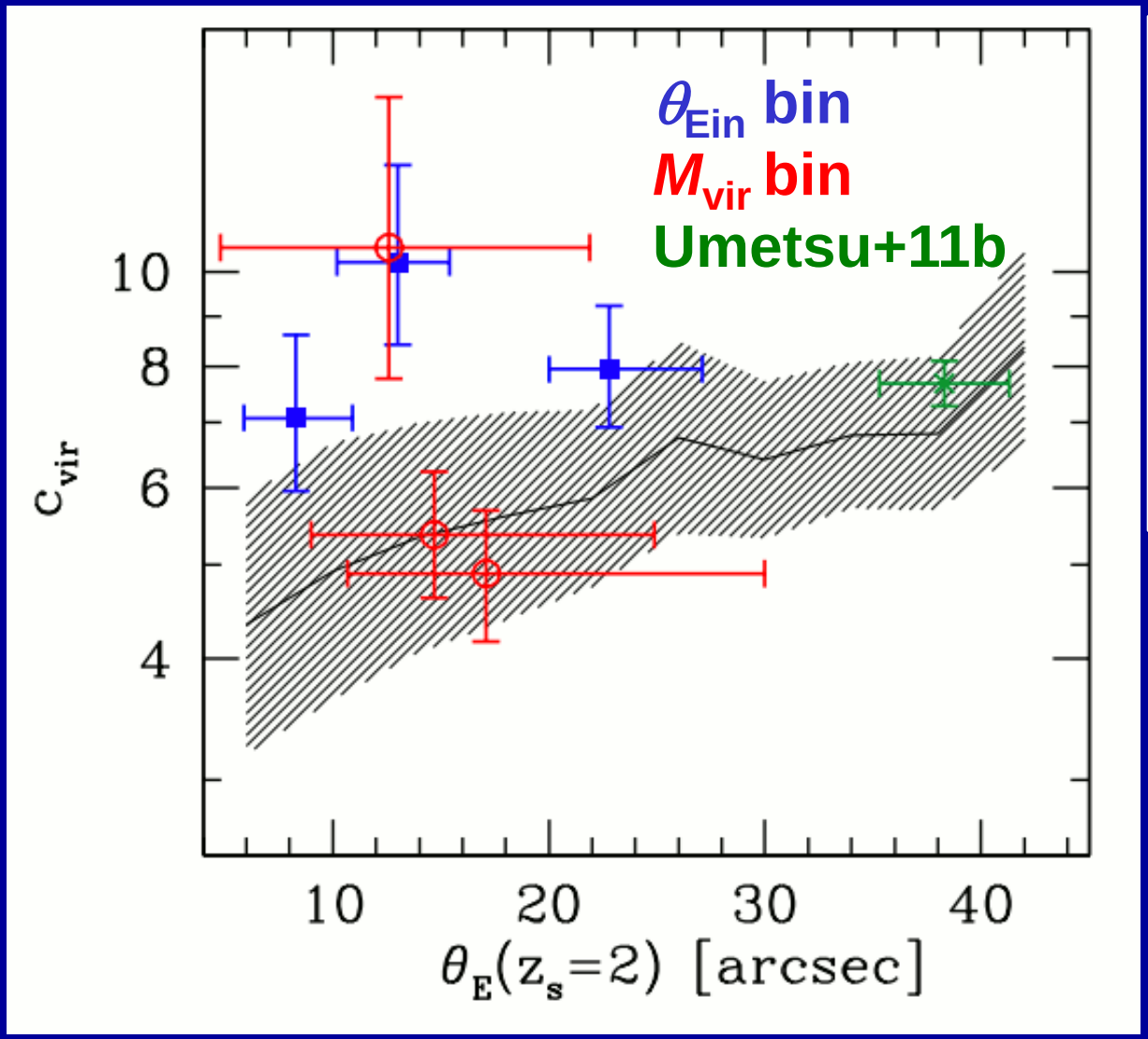
Spherical

Triaxial (prolate)

Hennawi, Dalal, Bode, Ostriker 2007

Mean Concentrations for SL Clusters (θ_{Ein}=40")

Figure 10, Oguri et al. 2011 (arXiv:1109.2594)



Umetsu+ method

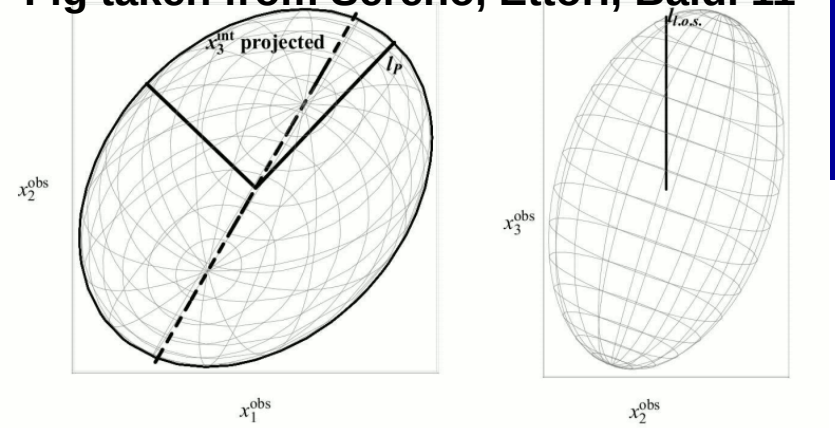
SL mass profile +
WL shear profile +
WL mag-bias profile

Oguri+ method

Einstein radius +
WL shear profile

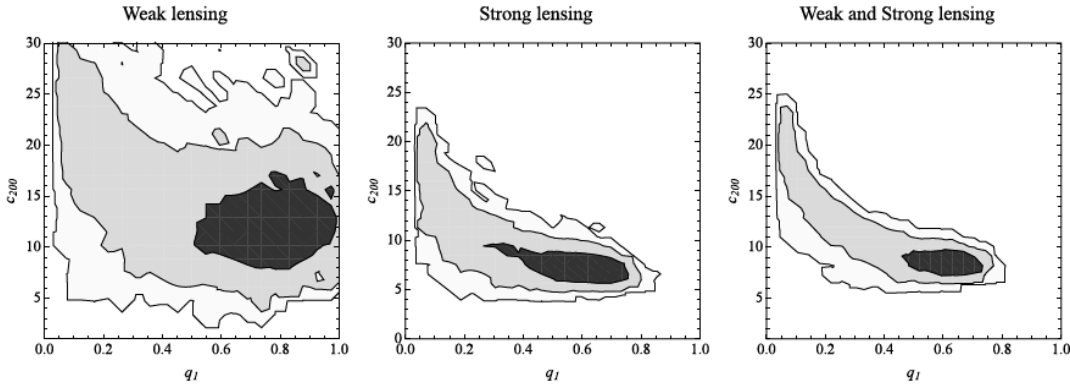
Bayesian Deprojection of 3D Dark-Matter Structure

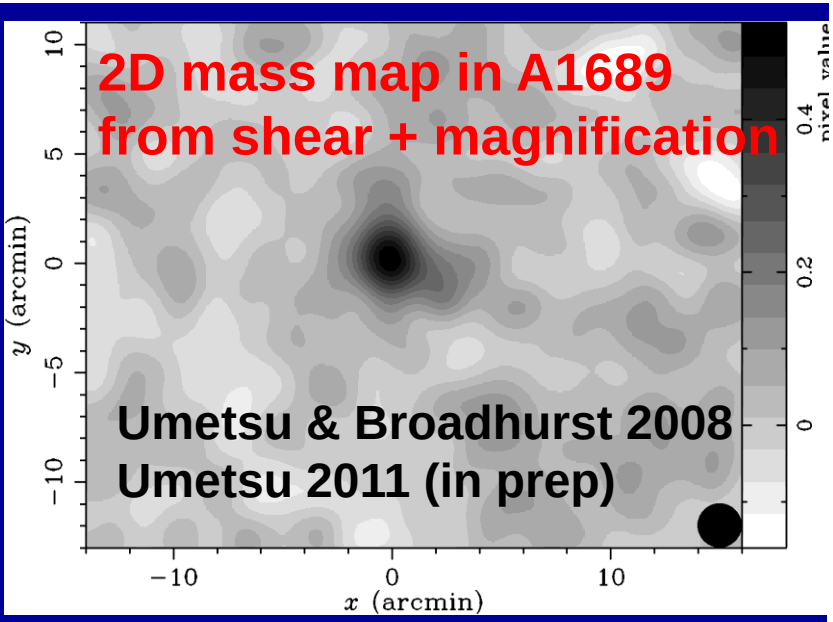
Fig taken from Sereno, Ettori, Baldi 11



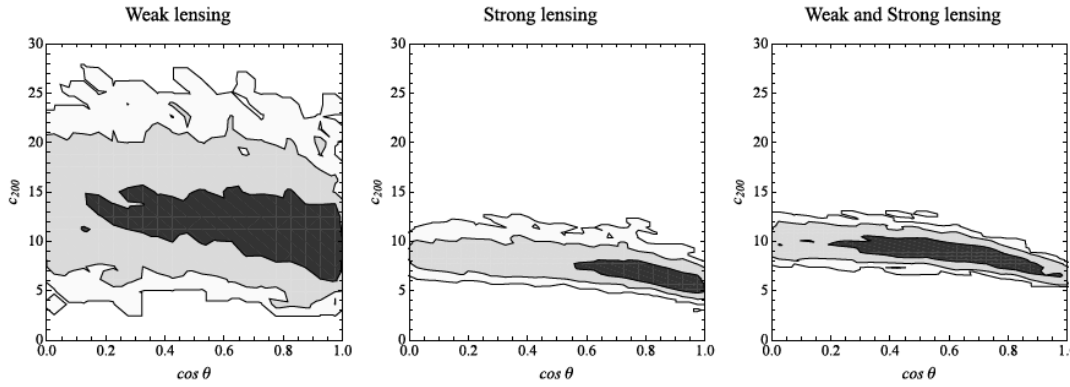
Full-2+1D SL+WL Bayesian analysis (A1689) by Sereno & Umetsu 2011

C200 vs. major-minor axis ratio, q_1





C200 vs. l.o.s. alignment, cos[θ]



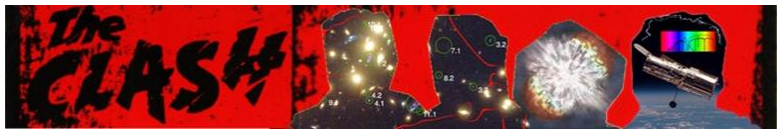
SZE Multi-scale Multi-frequency Cluster Program

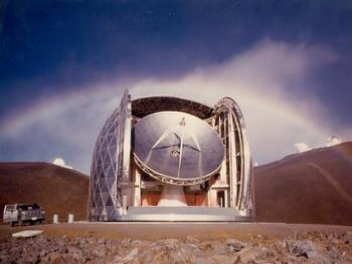
CLASH-SZE collaboration

- Collaboration between CLASH and several SZE groups: Bolocam, MUSTANG/GBT, AMiBA, … (discussion going on 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)
  - AMiBA-13@94GHz (2 to 11 arcmin)
- **Small angular scale**: 0.1’ to 1’
  - GBT/Mustang@90GHz (9” to 40”)





Bolocam/CSO 150GHz

Ongoing Bolocam-CLASH SZE collaboration

- Angular coverage of $\Delta\theta$ = 1 to 14 arcmin
- Probing IC-gas structure out to R500+
- 23/25 CLASH clusters observed with Bolocam, with a typical peak S/N=10

See N. Czakon's talk and J. Sayers's poster

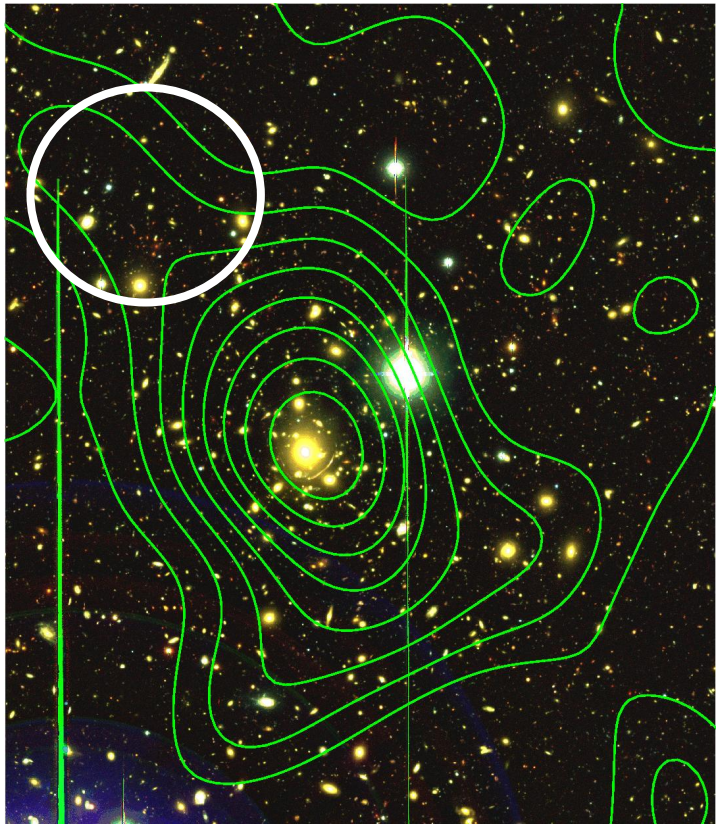
CLASH sample will be completed in this October to a peak sensitivity of S/N>10

CLASH WL and SZE Collaboration:

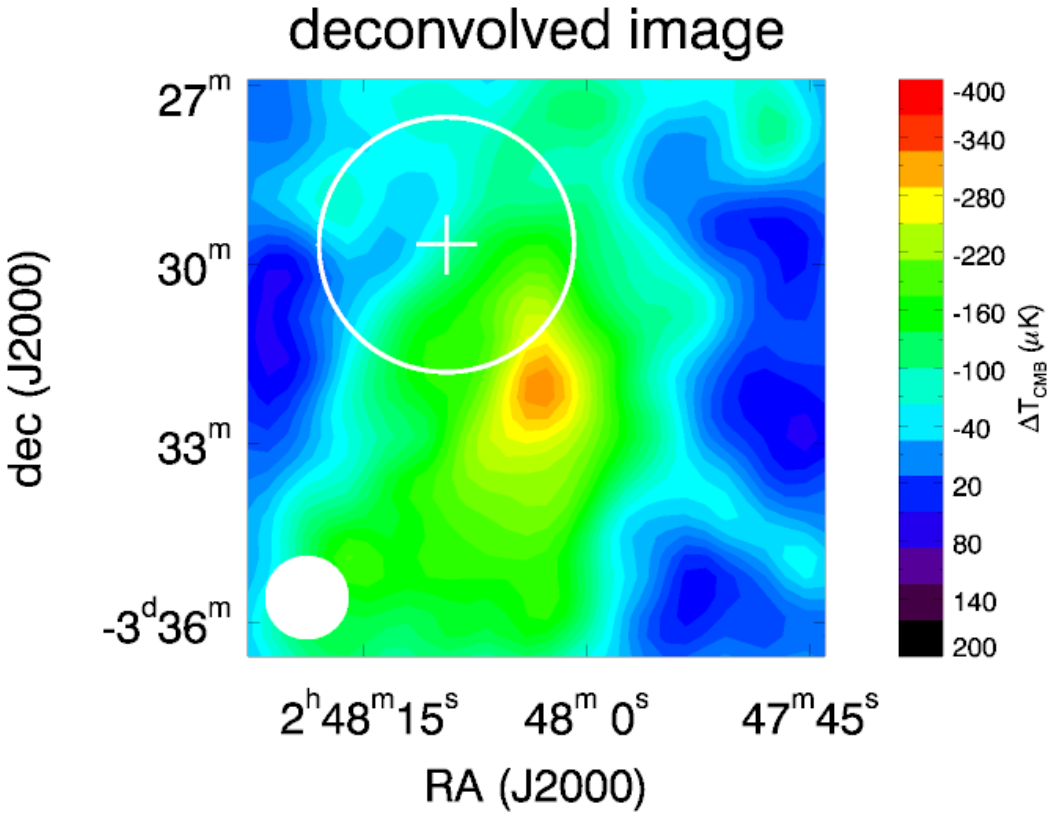
Cluster-Cluster Lensing in A383 (z=0.19)

A z=0.9 BG cluster (M_{vir}~2e14M_{sun}) weakly magnified (~14%) by A383

See Zitrin et al. 2011 (arXIv:1108.4929)

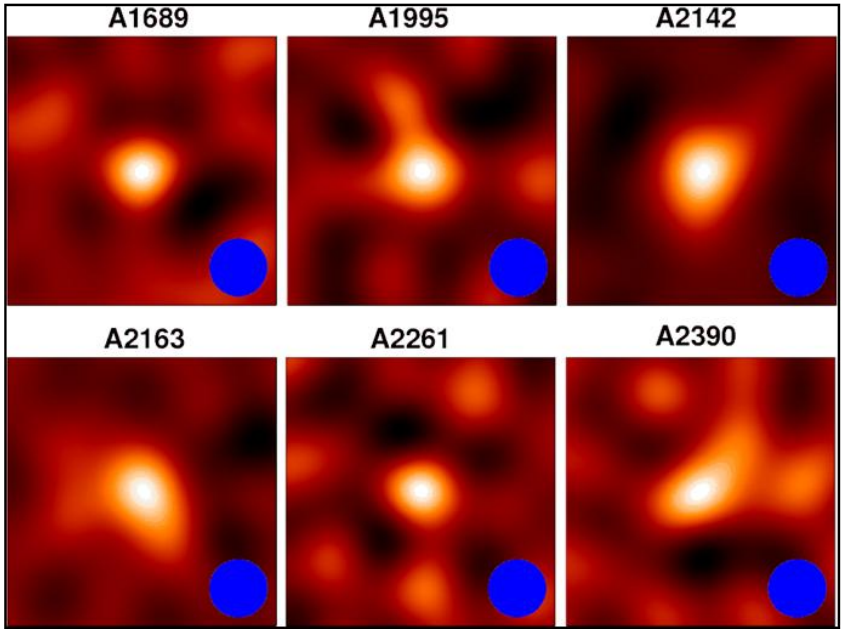


Umetsu, Medezinski, Nonino +CLASH

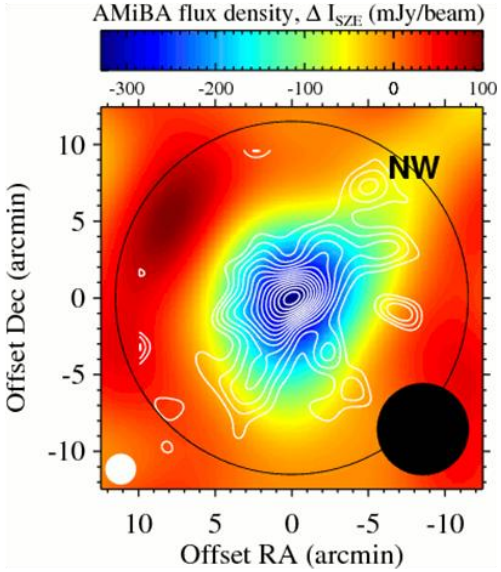


Sayers, Czakon, Sunil et al.

AMiBA/MLO at 94GHz (ASIAA+NTU,Taiwan)



P.T.P. Ho+09, ApJ, 690, 1610

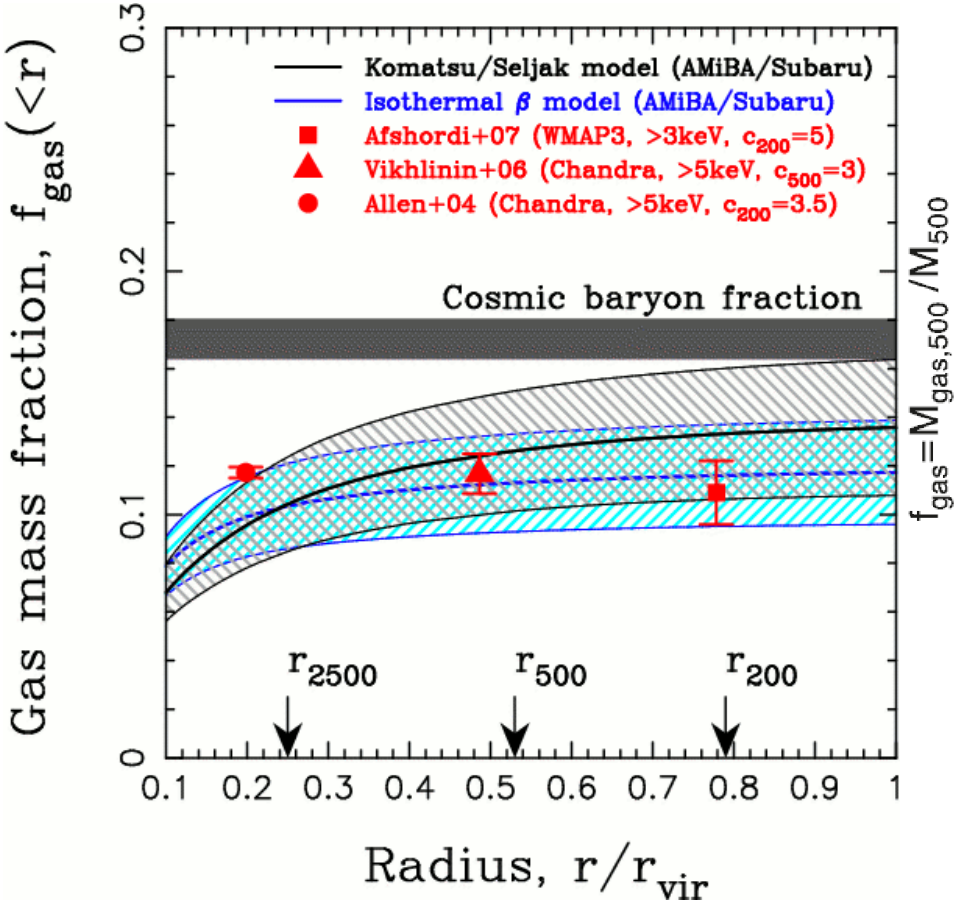


K.Y. Lin+ in prep.

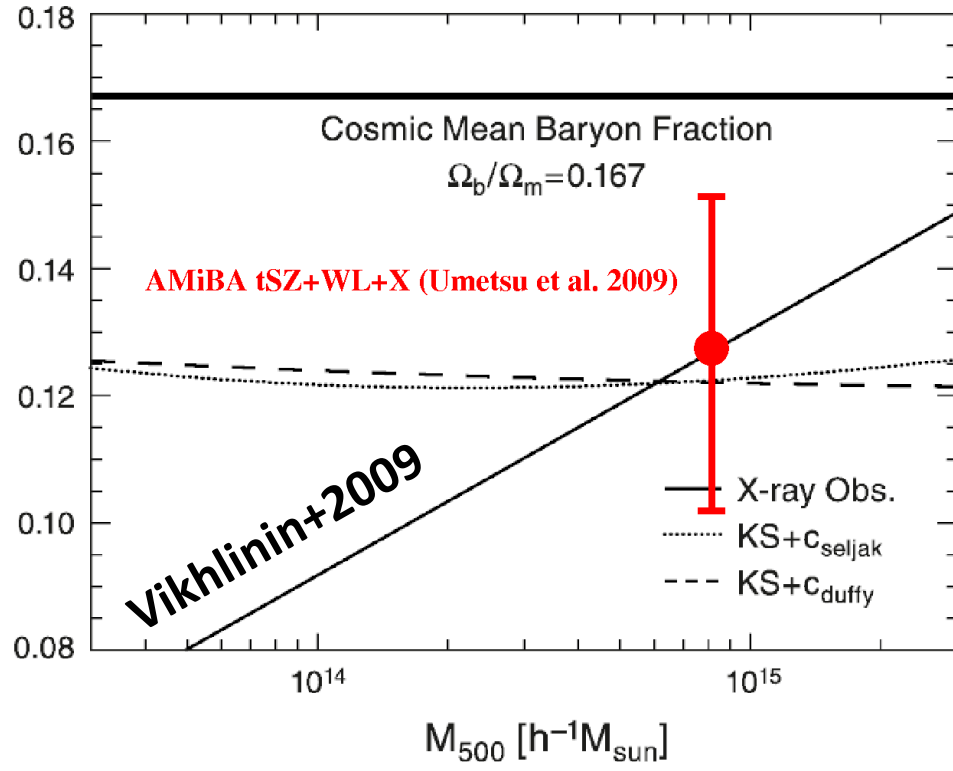
Combining Lensing w/ SZE+X-ray: Hot Baryon Fractions in Clusters

Large-scale f_{gas} constraints (~0.8r_{vir}, <z>=0.2) 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 lensing data by combining all possible lensing information available in the cluster regime:**
  - **WL Distortion (shear)**
  - **WL Dilution (purity of BG sample)**
  - **WL Depletion (magnification)**
  - **Strong lensing (SL)**
  - **Stacking SL+WL (shear + magnification)**
  - **Deprojection of 2D SL+WL**
- **Cluster lensing and LCDM come closer:**
  - **Stacked cluster mass profile shapes are in good agreement with latest N-body simulations.**
- **Multi-scale Multi-frequency SZE collaboration is going on along with the CLASH program.**