XXL Collaboration Meeting 2011

Cluster Weak Gravitational Lensing with Subaru Observations

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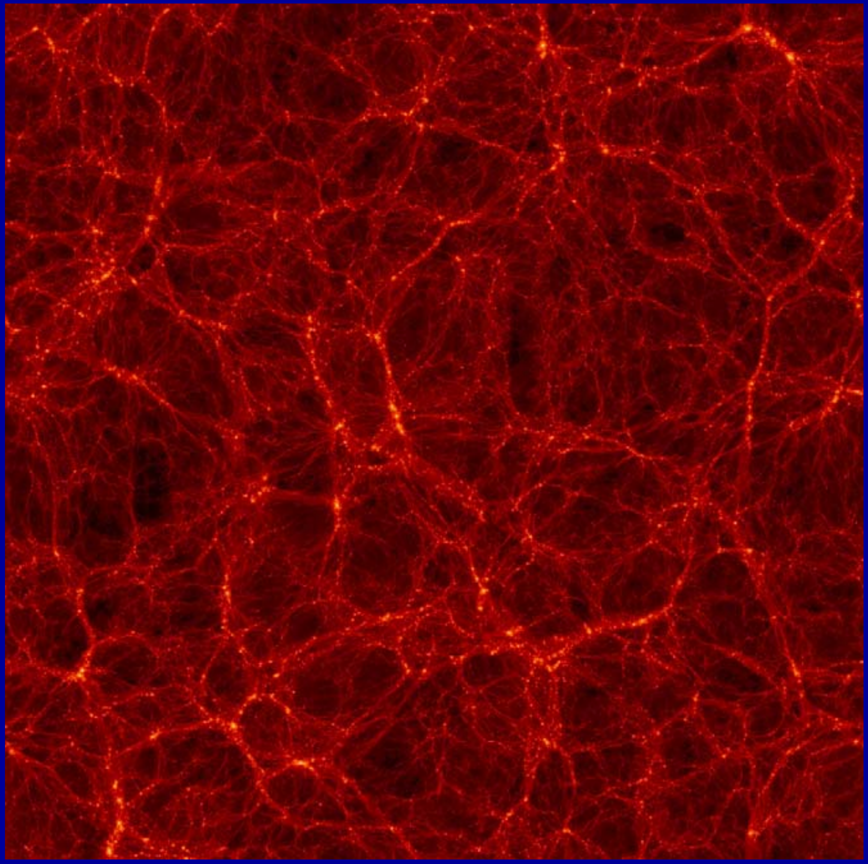
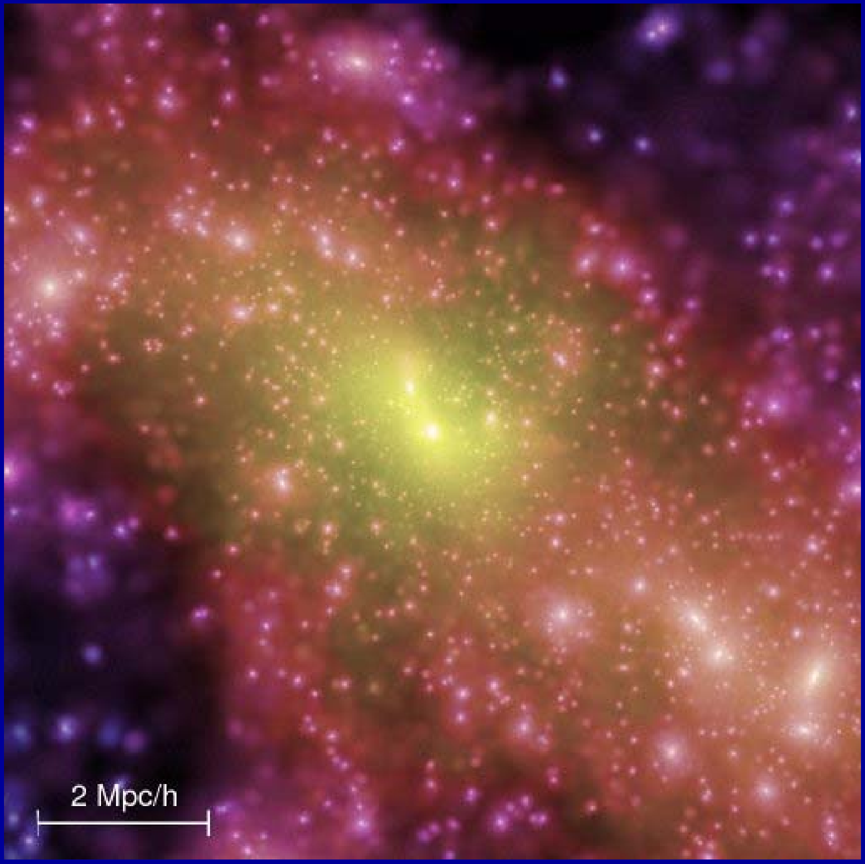
Clusters as Cosmological Probes

- **Representative mass profile shapes $M_{tot}(r)=M_{DM}(r) + M_{bar}(r)$**
- **Relations btwn $M_{tot}(r)$ and observables (baryons: ~17% in mass)**

are essential for cluster cosmology and DM astrophysics.



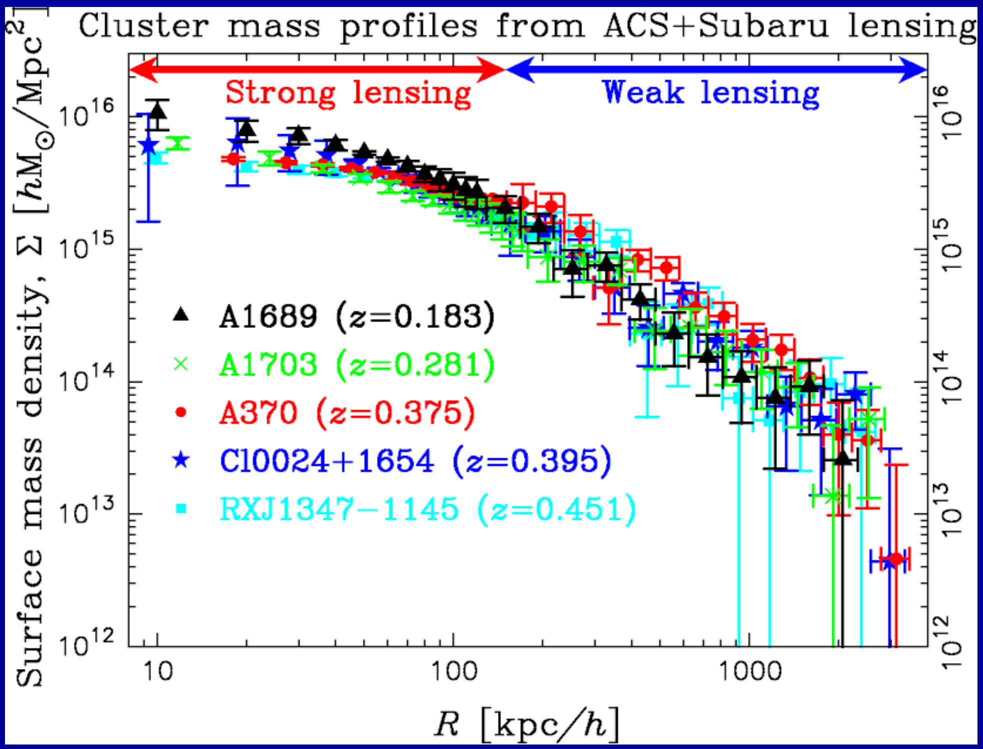


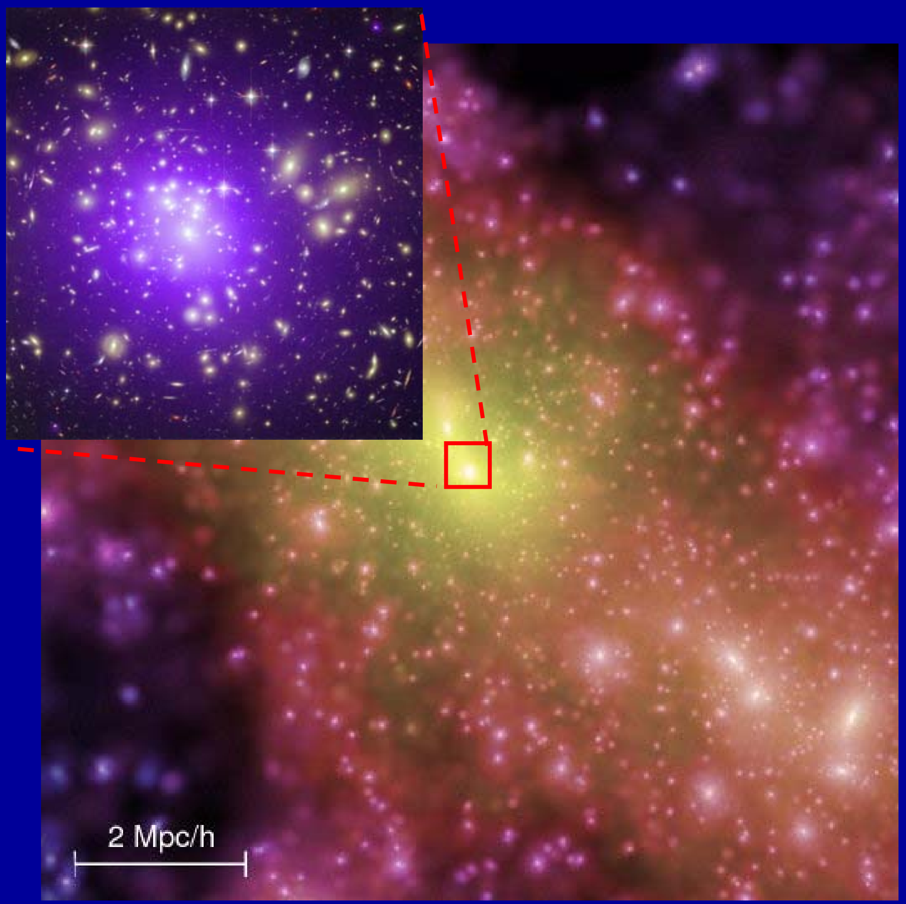
Millennium DM simulation (Springel et al. 2005)

Approach: Multi-wavelength Cluster Surveys

Combining high-quality , independent multi-λ cluster observations (lensing/SZE/X-ray/dynamics) for cluster cosmology/ DM astrophysics

XXL + Subaru HSC? + ACT? + AMiBA-SZE? + HST?

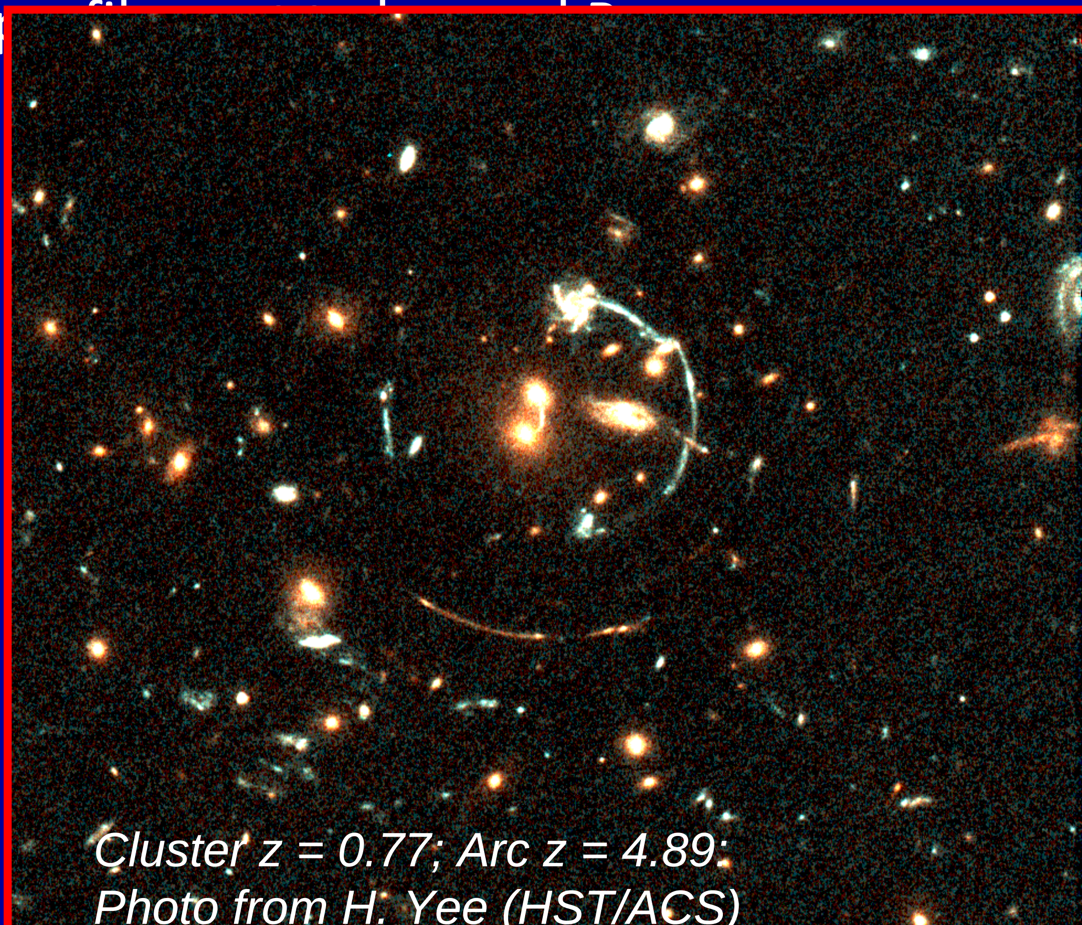




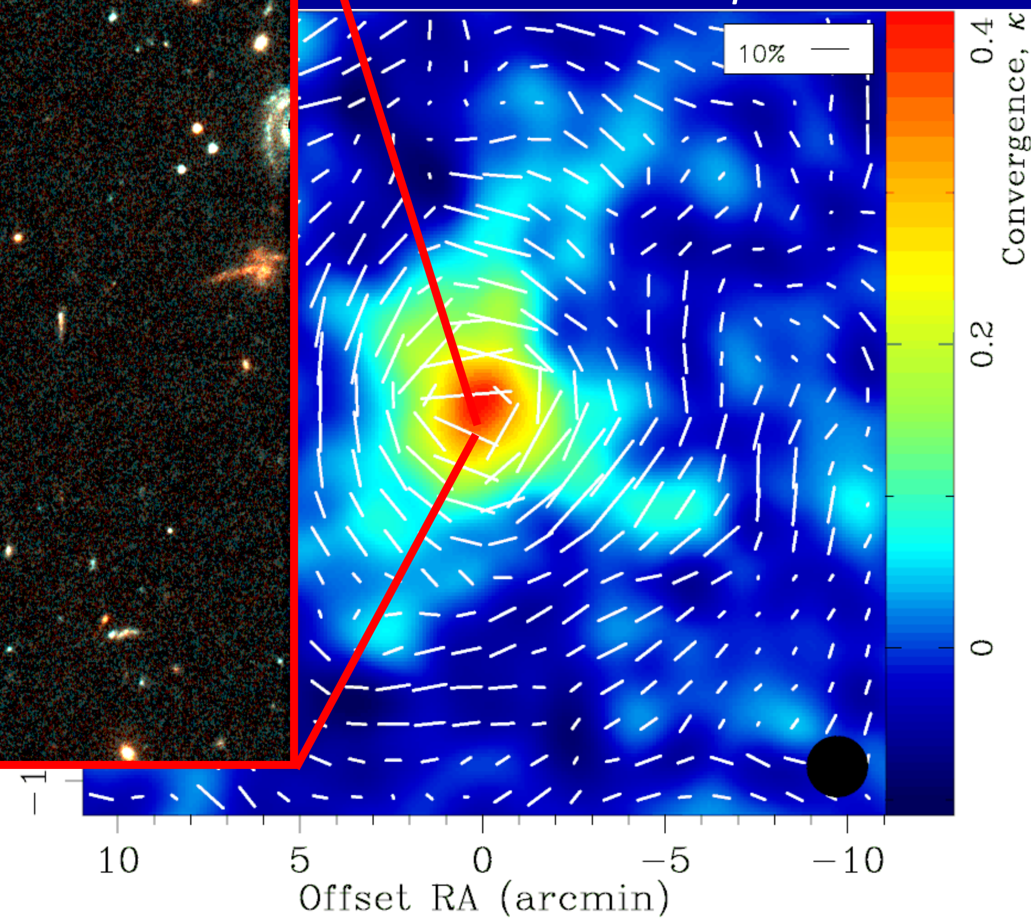
Umetsu et al. 2011, ApJ, 729, 127

Primary mass probe: **Weak Lensing**

Detectable image distortions can be used to recover their total mass



Subaru WL mass map



A1689@z=0.18
(Umetsu & Broadhurst 08)

Subaru HSC Survey (2012-2016) [Wide/Deep/Ultradeep]

Survey parameters

	g	r	i	z	y
Exp. Time (min)	10	10	20?	20?	20?
Magnitude*	26.2	25.9	26.2	25	24

*5σ detection for a point source with 2 arcsec aperture, AB magnitude

Preliminary

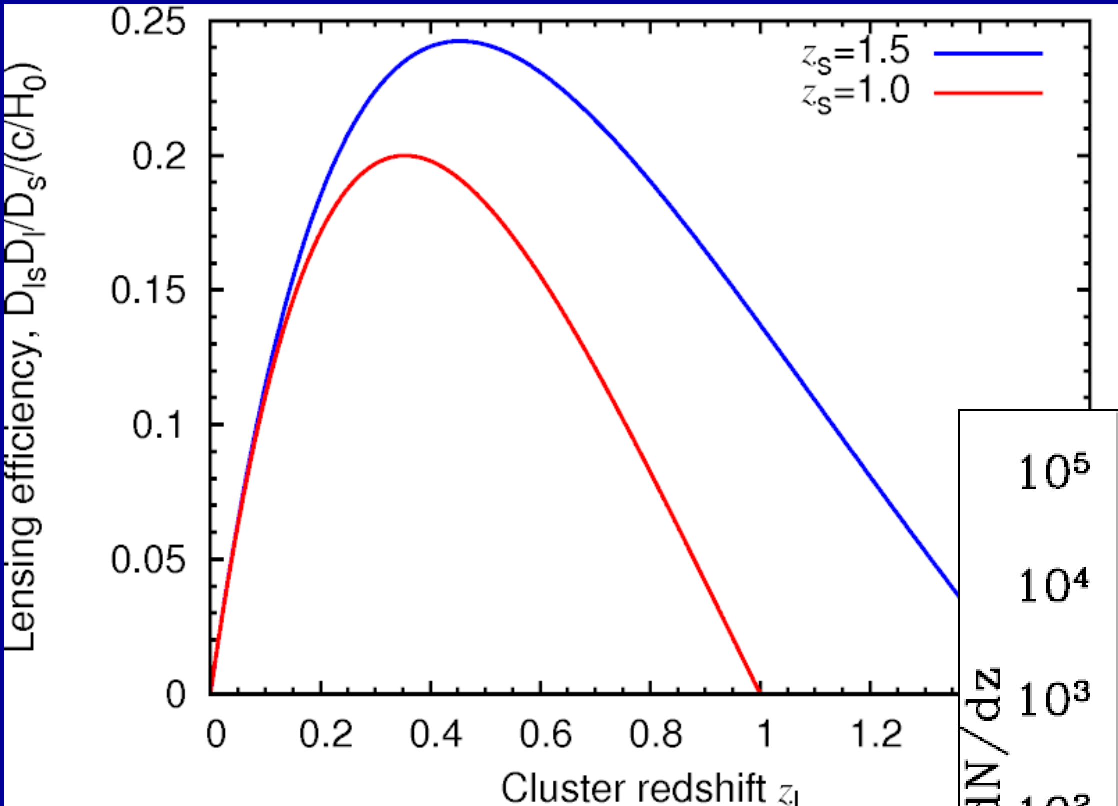
Ω=1500sqdeg for HSC Wide (covering XXL-N)

- Deep Subaru-HSC i' imaging for accurate shape measurements
  - Sampling: n_g ~ 30 (20) arcmin^{-2}
  - Mean depth: <zs> ~ 1
  - 30% mass error per cluster with M_{vir}= 4e14M_{sun}/h @zl=0.4

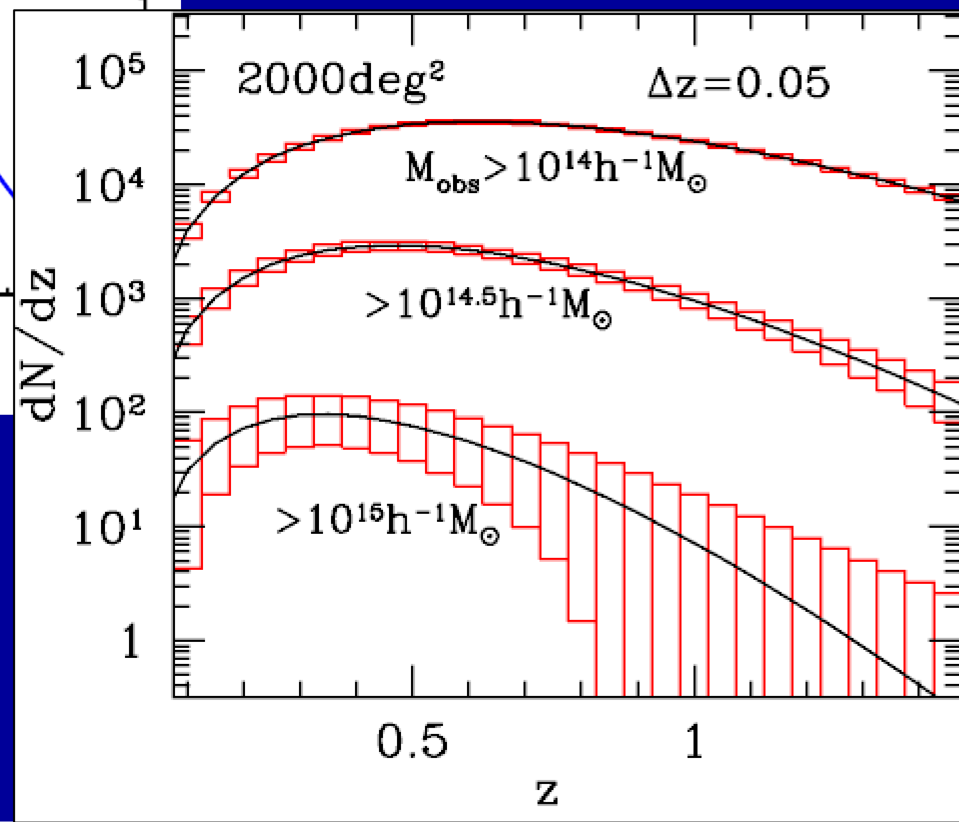
$$\frac{\sigma(M_{\mathrm{vir}})}{M_{\mathrm{vir}}} = 30\% \left(\frac{M_{\mathrm{vir}}}{4\times10^{14} M_{\mathrm{sun}}/h}\right)^{-2/3} \left(\frac{n_g}{20\mathrm{arcmin}^{-2}}\right)^{-1/2} \left(\frac{\sigma_g}{0.4}\right) \quad @\, z_l = 0.4$$

- Multicolor imaging, essential for separating unlensed cluster galaxies from background → otherwise, contamination by unlensed member galaxies will lead to substantial underestimation of central mass estimates, C_{vir}, M_{2500} etc.
  - Covered by Tom's talk!

Weak Lensing Efficiency: Subaru HSC

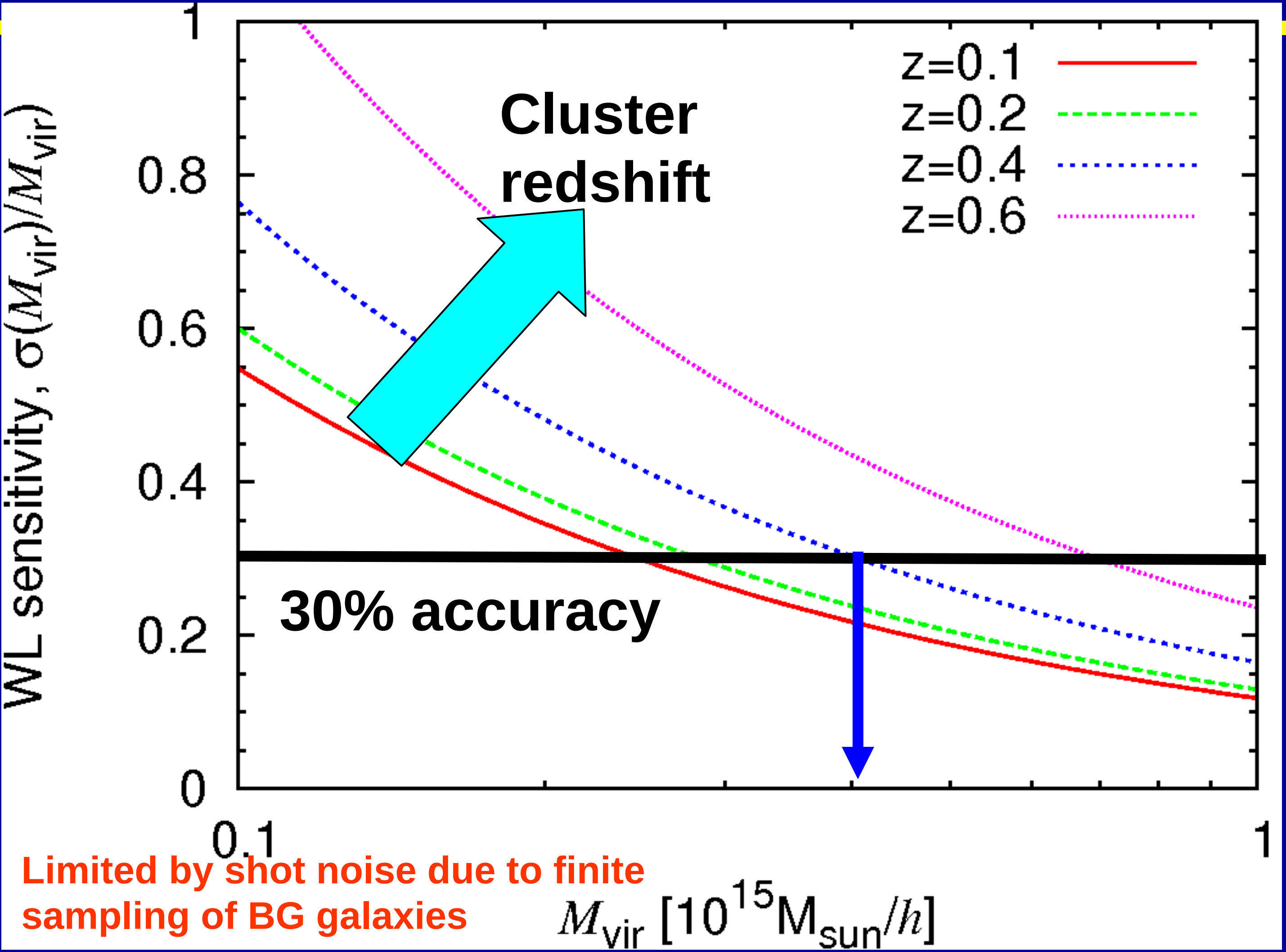


WL peak abundance
(Oguri & Takada 2011)



Per-galaxy per-cluster geometric lensing sensitivity function, $(\Sigma_{crit})^{-1}$

"Integrated"-WL signal (M_{vir}) sensitivity



$$\frac{\sigma(M_{\rm vir})}{M_{\rm vir}} \approx 30\% \left(\frac{M_{\rm vir}}{4\times10^{14} M_{\rm sun}/h}\right)^{-2/3} \left(\frac{D_{ls}/D_s(z_l)}{D_{ls}/D_s(0.4)}\right)^{-1} \left(\frac{n_g}{20\mathrm{arcmin}^{-2}}\right)^{-1/2} \left(\frac{\sigma_g}{0.4}\right)$$

How to improve WL precision?
How to assess sysmetiacs?

Toward highest possible lensing precision:

① Weak Lensing **Shear** (Distortion)

② Weak Lensing **Magnification** (Depletion)

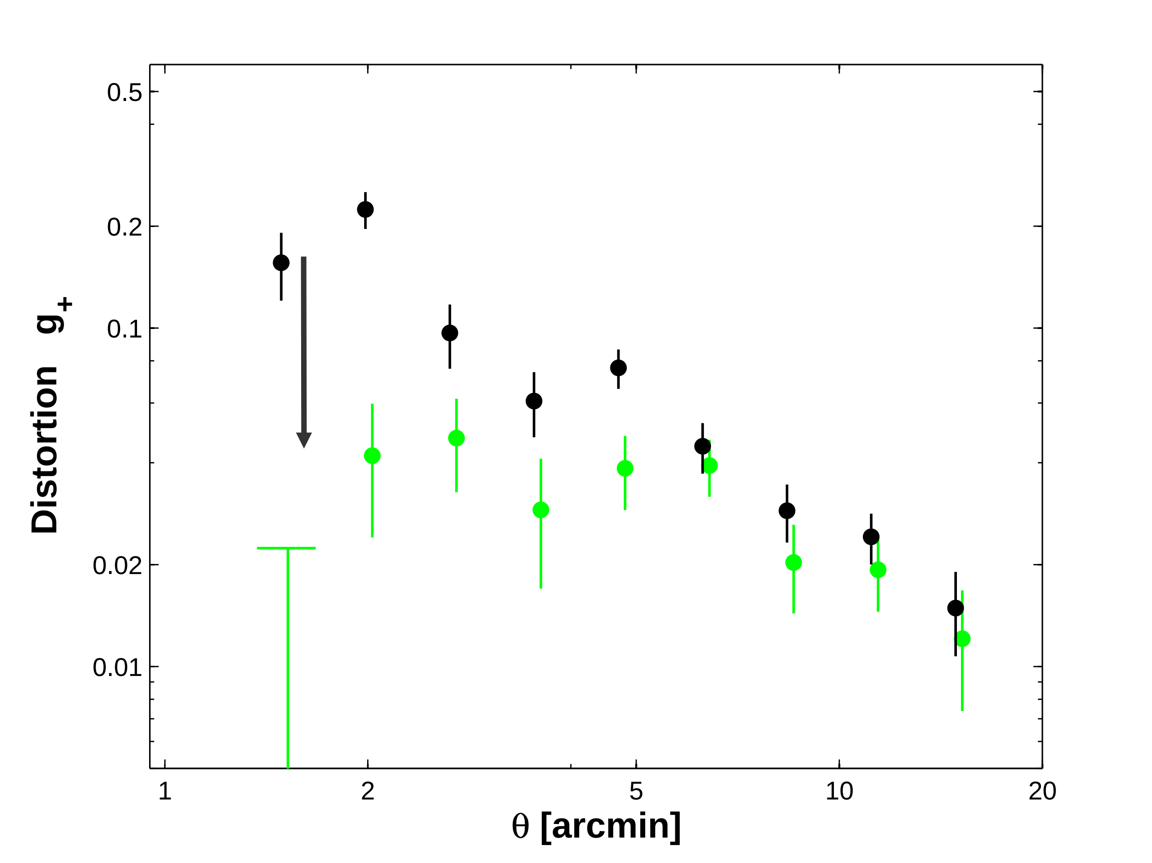
③ **Stacked** Weak Lensing Analysis

Weak Lensing [I]: Tangential Shear (Distortion)

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

The "Dilution" Effect

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



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

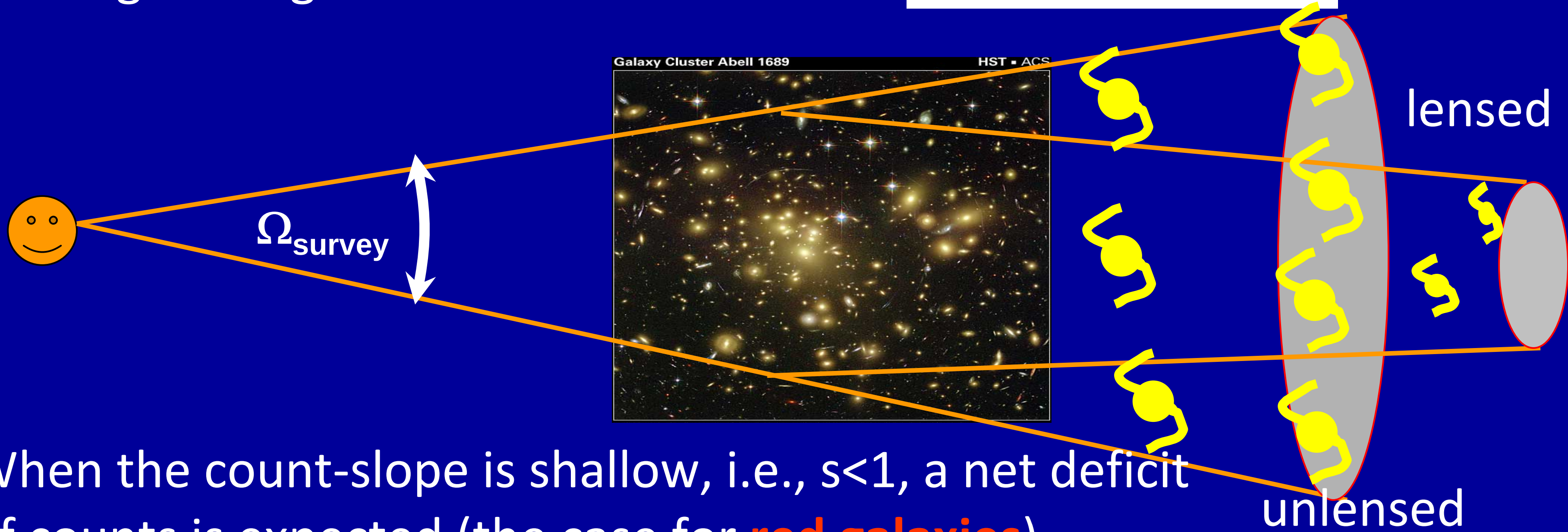
Weak Lensing [2]: Magnification Bias

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

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

with unlensed Luminosity Function of background galaxies

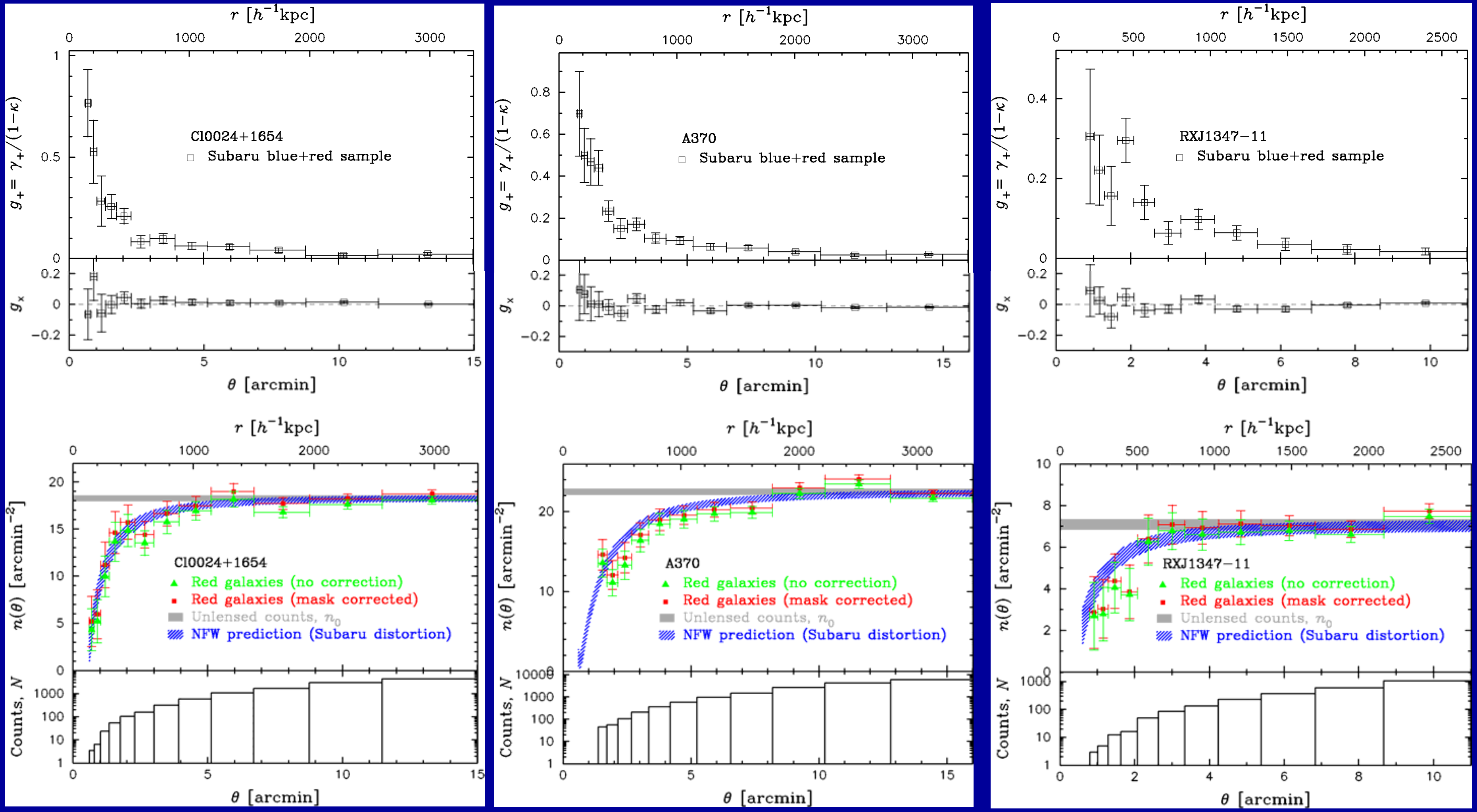
$$n_0(>F) \propto F^{-s}$$



When the count-slope is shallow, i.e., s<1, a net deficit of counts is expected (the case for red galaxies)

Step 1: WL Internal-consistency Test

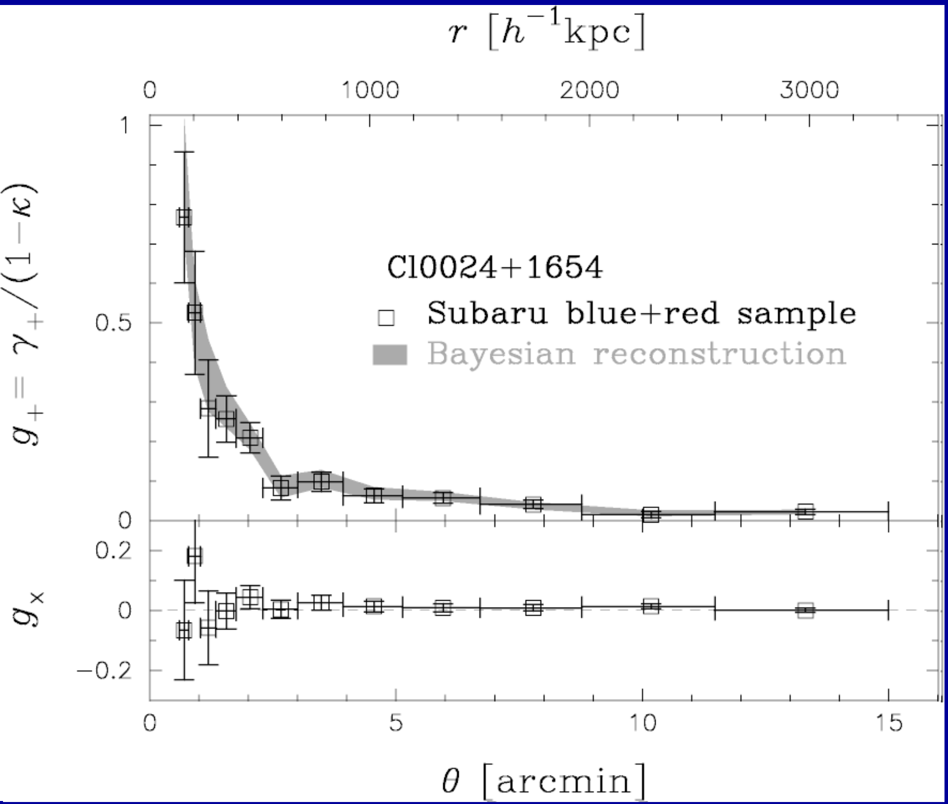
Cl0024+17 (z=0.395) **A370 (z=0.375)** **RXJ1347-11 (z=0.451)**



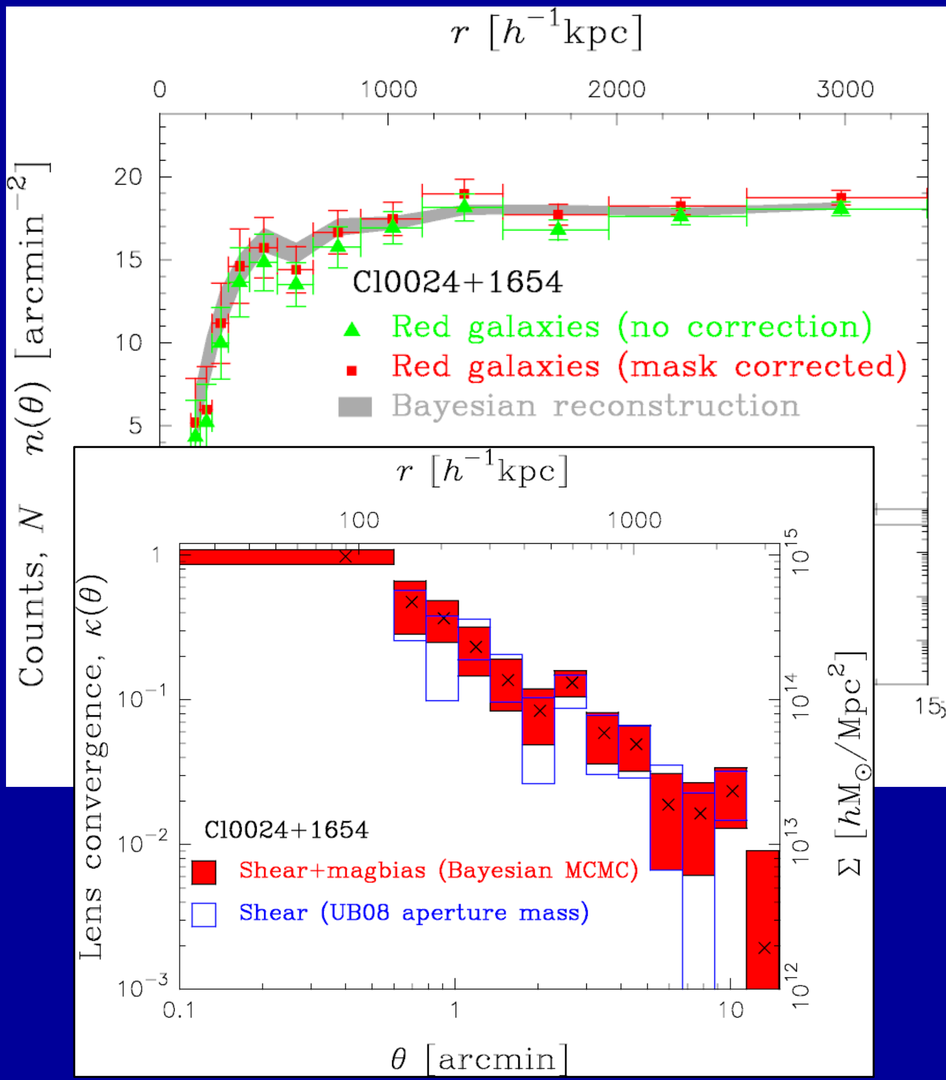
Umetsu et al. 2011, ApJ, 729, 127

Step 2: Combining WL Shear and Magnification: Example) CL0024+1654

Tangential distortion (shear)



Number counts (magnification bias)



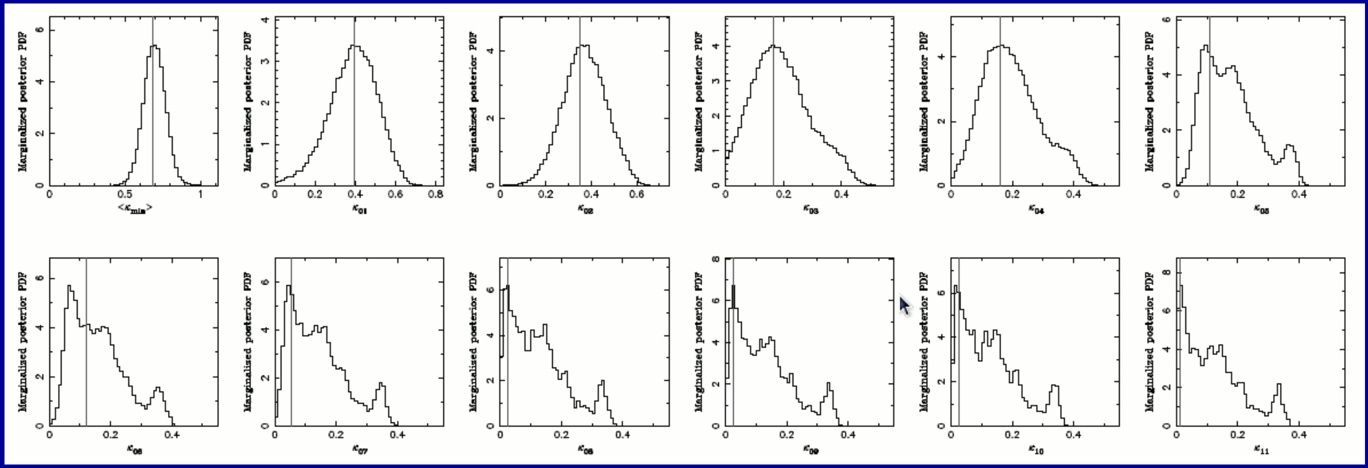
A unique mass profile solution (Σ) can be obtained from joint WL distortion + count profiles:

Umetsu+2011a

What we gain by adding magnification?

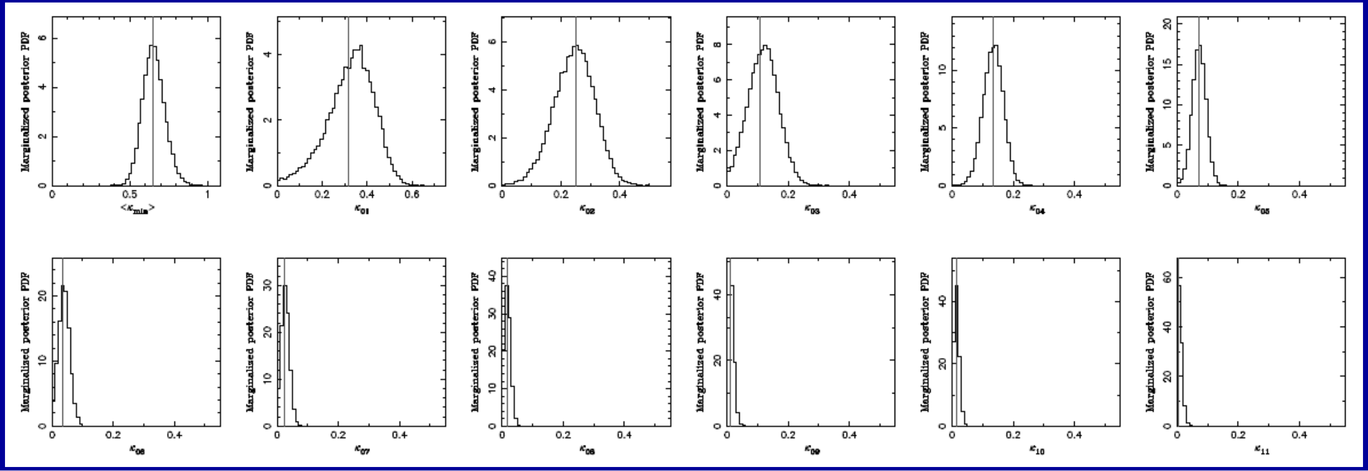
Marginalized posterior distributions of Σ(R) in 12 radial bins

Shear data alone
(A1689)



- **Mass-sheet degeneracy is fully broken (↓)**
- **~30% improvement in the mass determination**

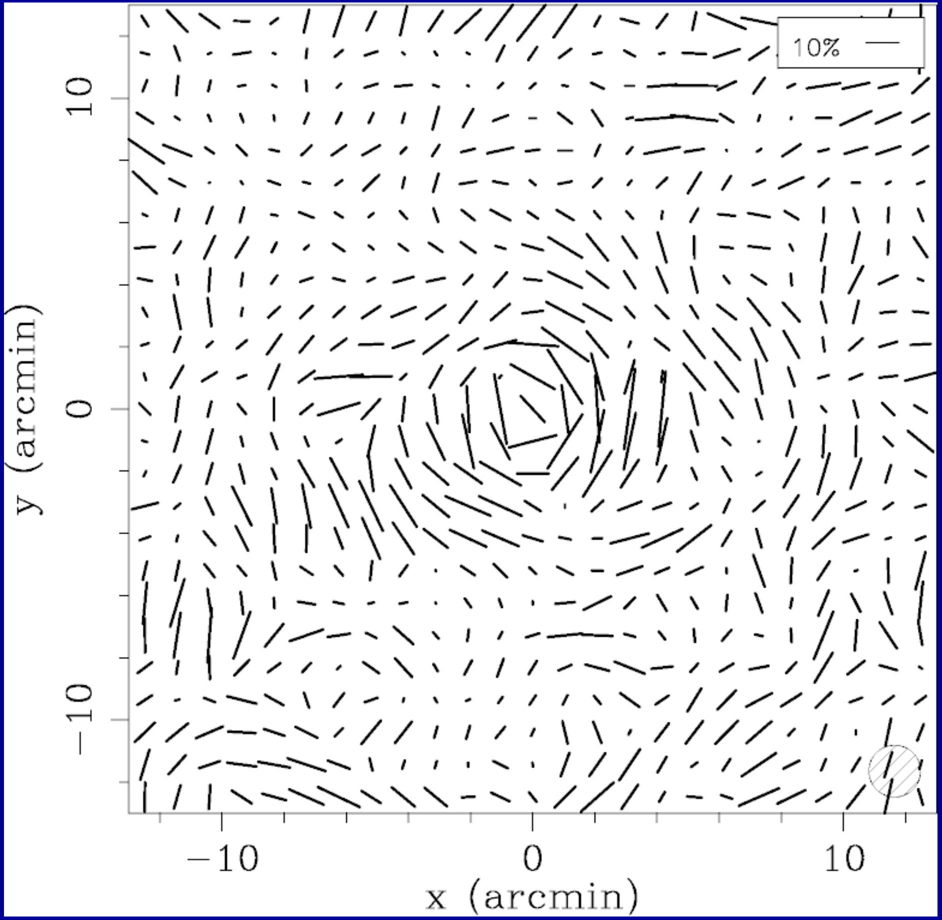
Shear + mag data
(A1689)

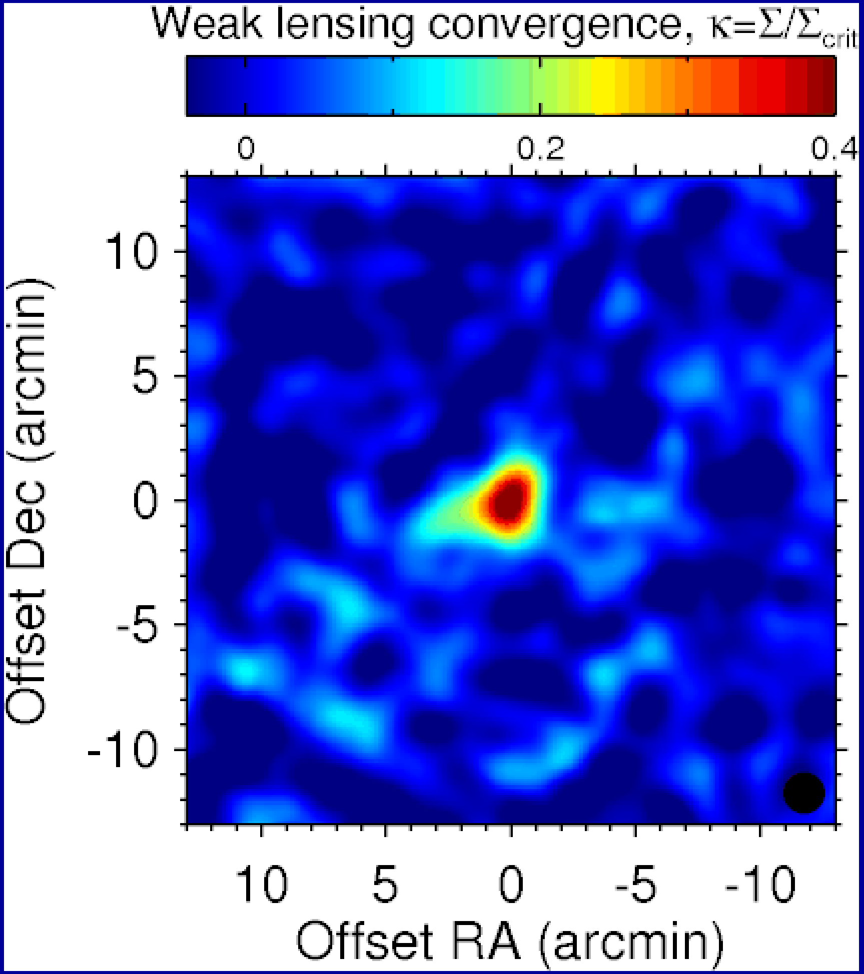


Umetsu+ 2011a

Weak Lensing [3]: Power of Stacking Analysis

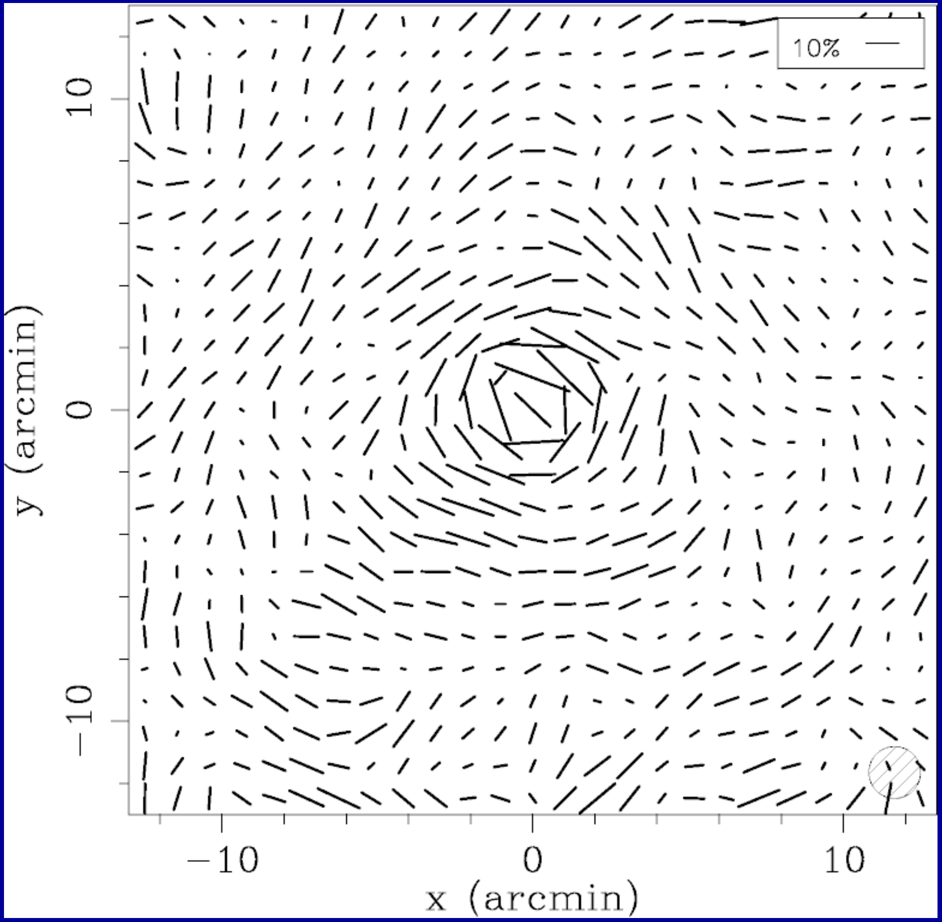
Subaru shear data: N=1

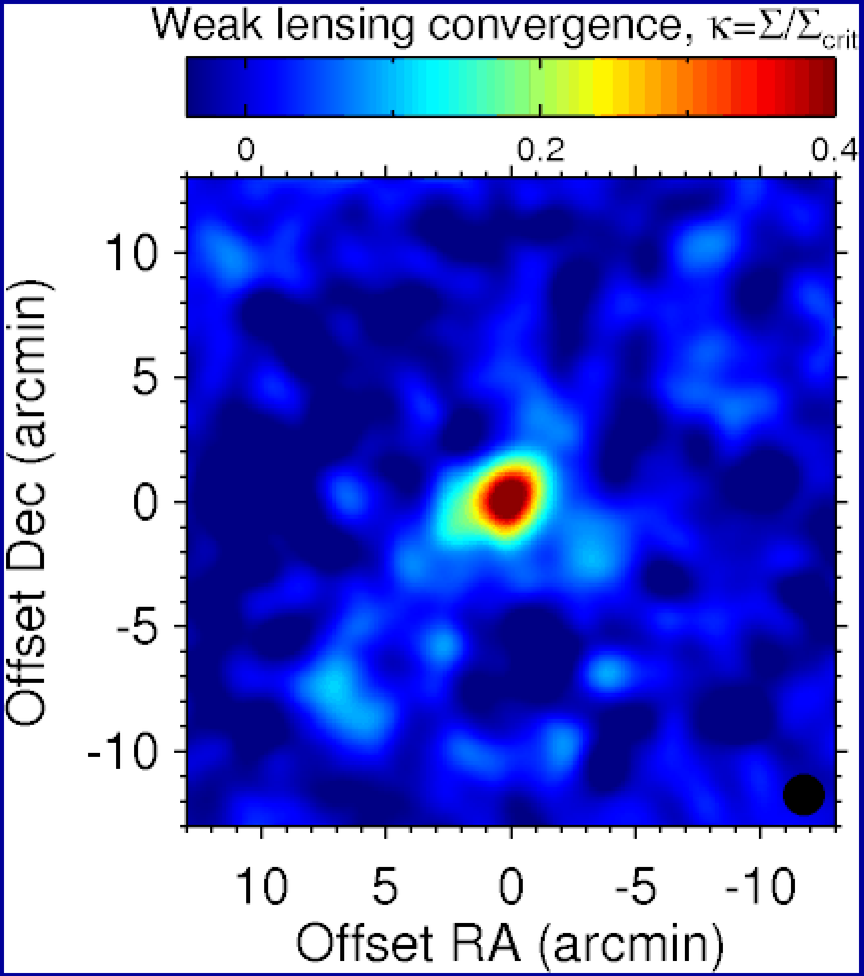




Weak Lensing [3]: Power of Stacking Analysis

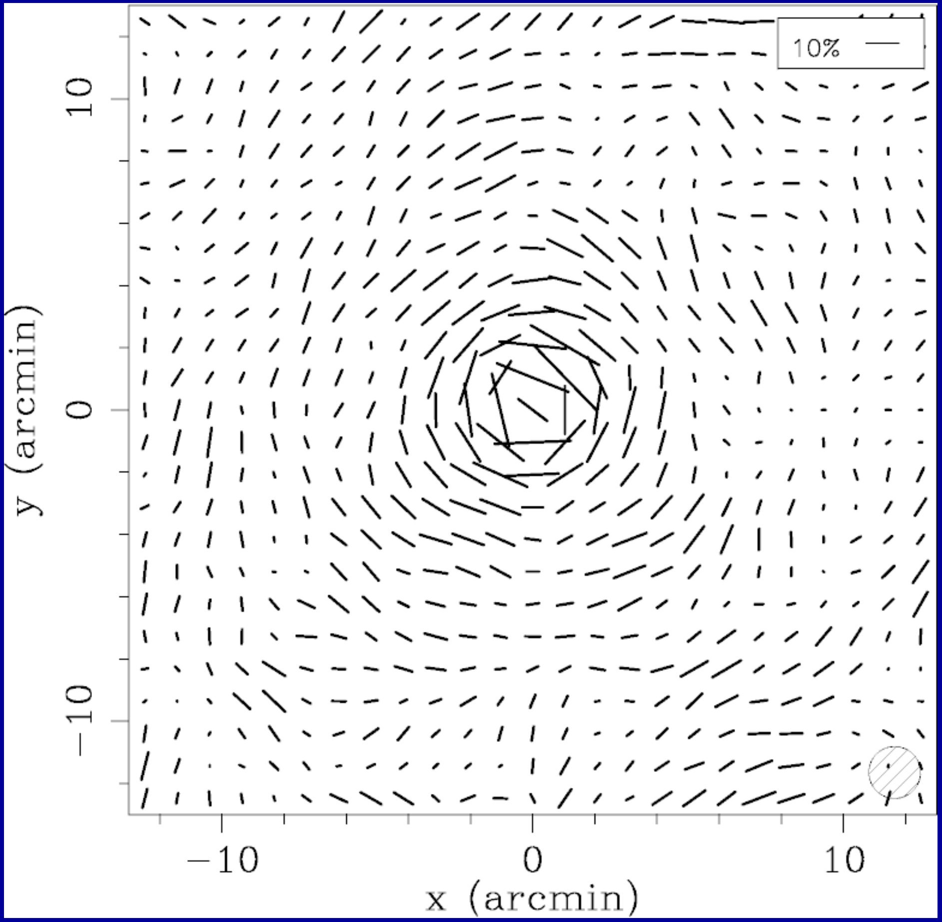
Subaru shear data: N=2

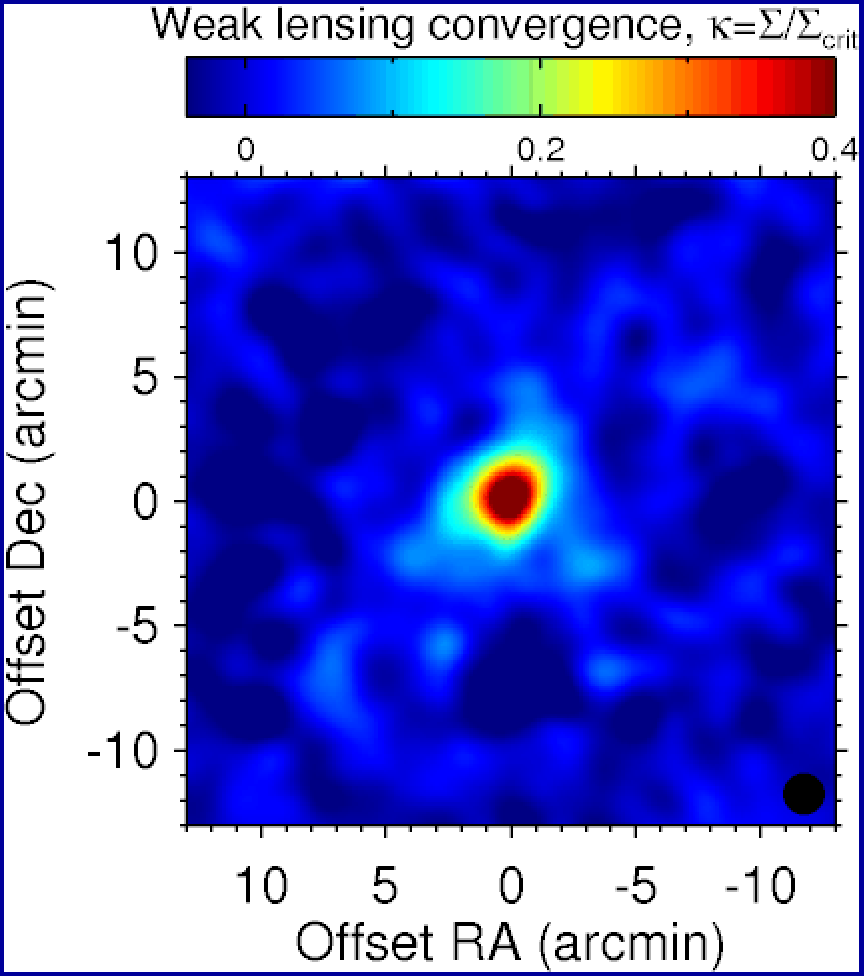




Weak Lensing [3]: Power of Stacking Analysis

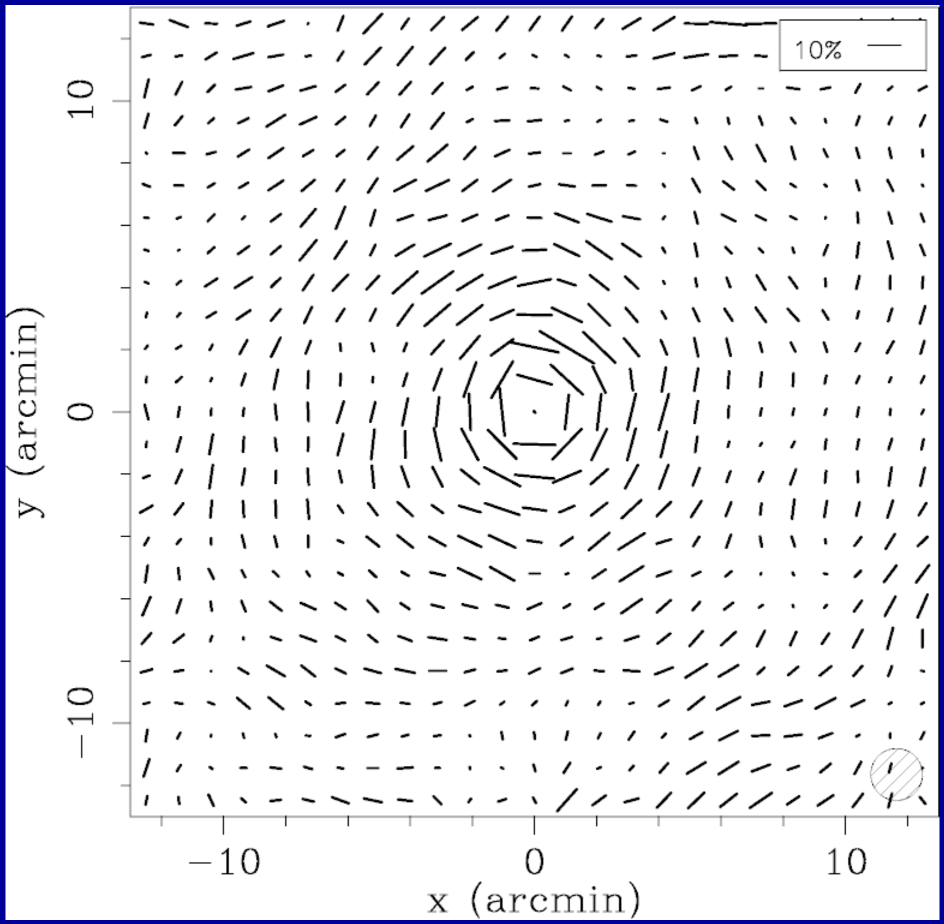
Subaru shear data: N=3

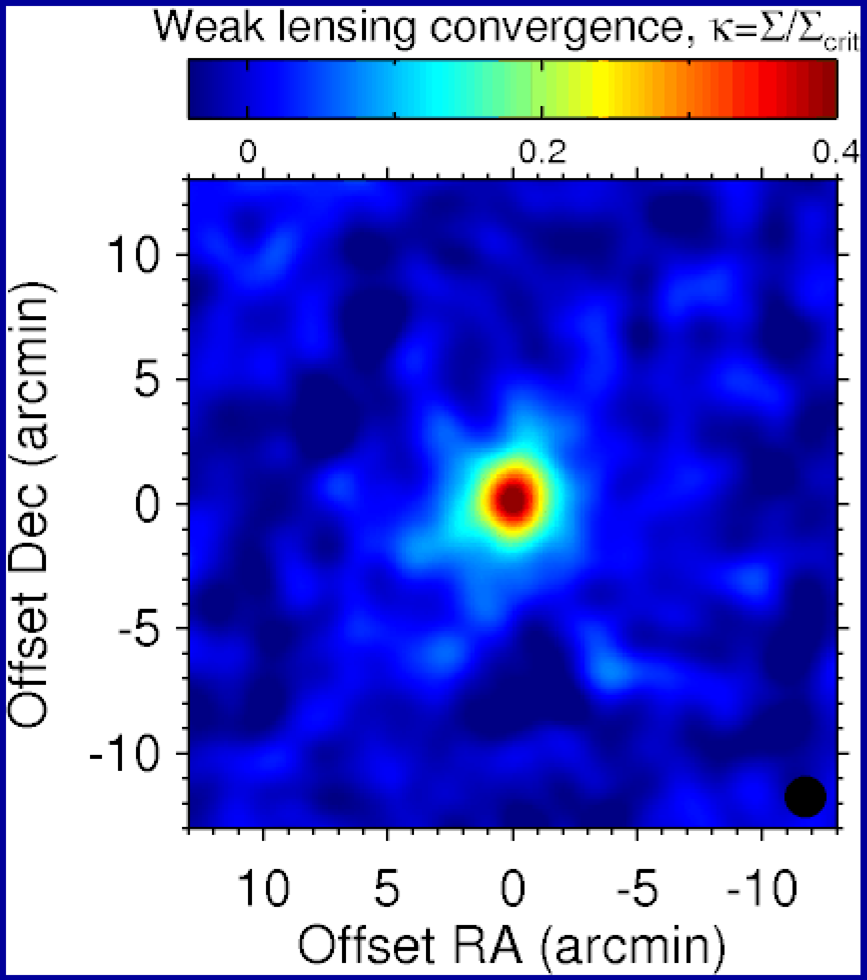




Weak Lensing [3]: Power of Stacking Analysis

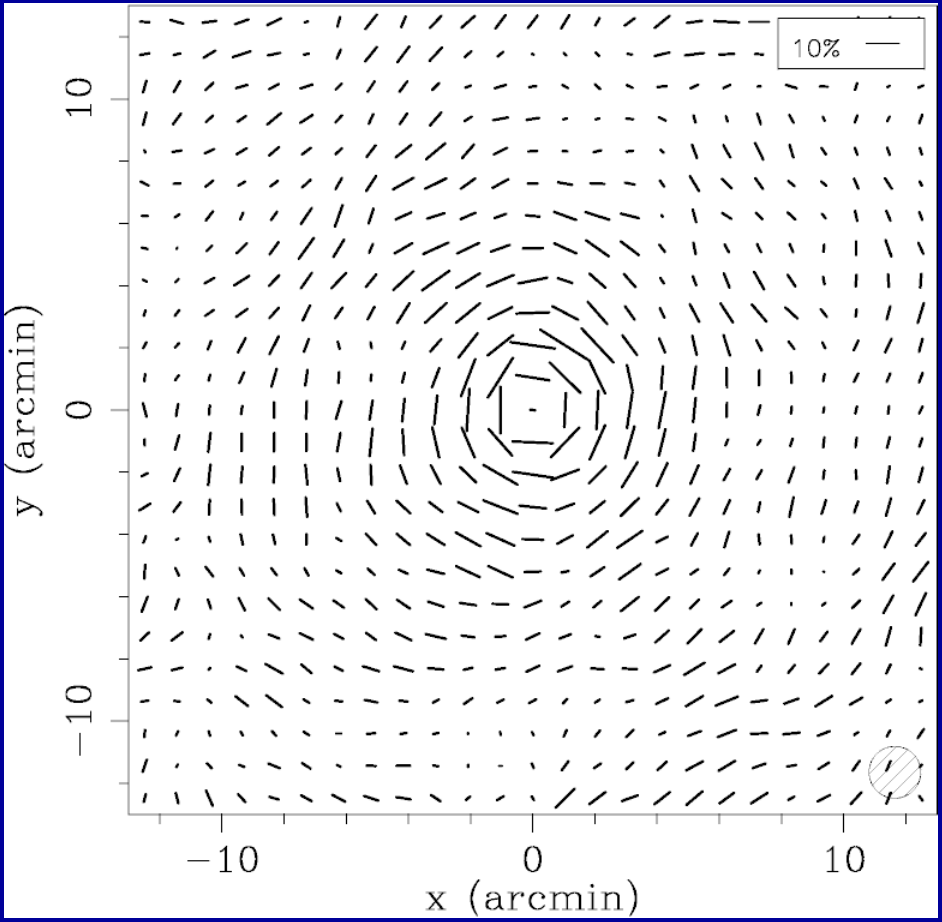
Subaru shear data: N=4

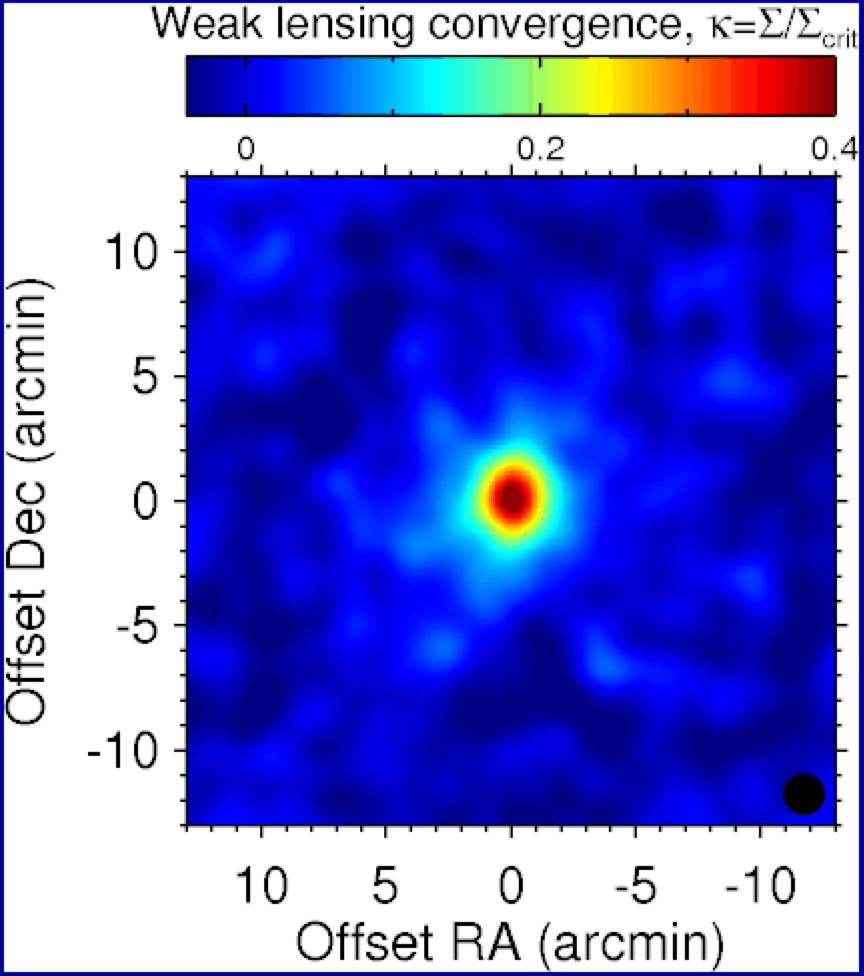




Weak Lensing [3]: Power of Stacking Analysis

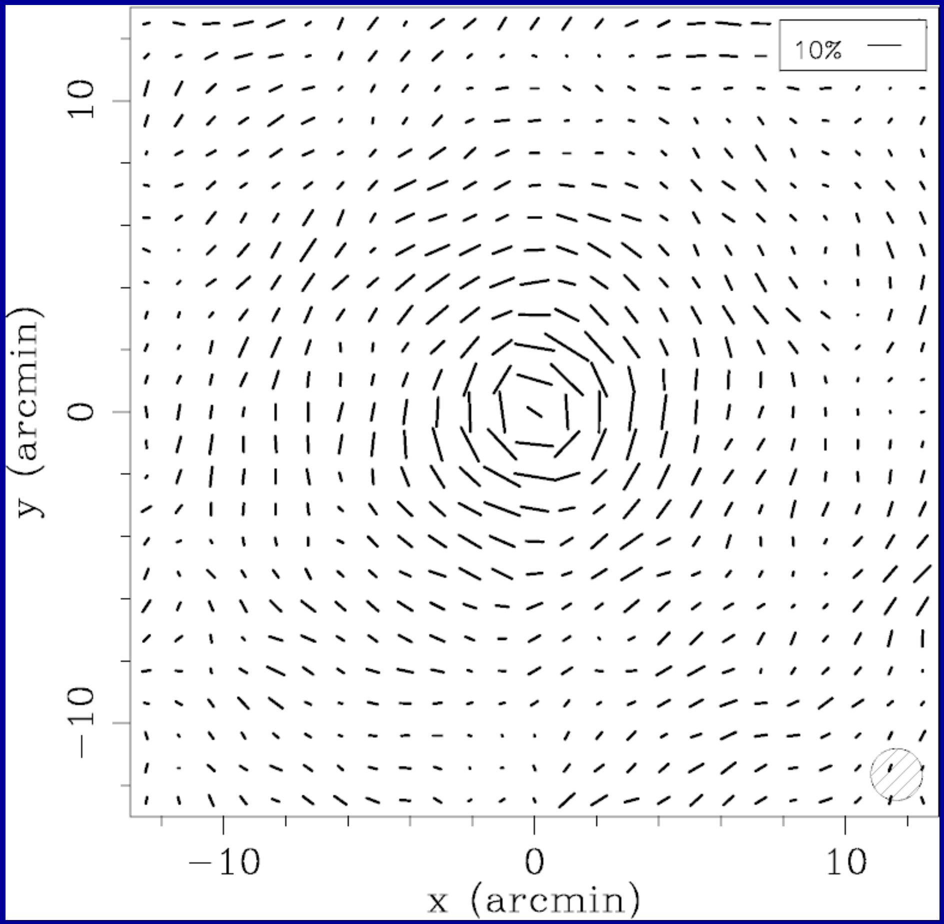
Subaru shear data: N=5

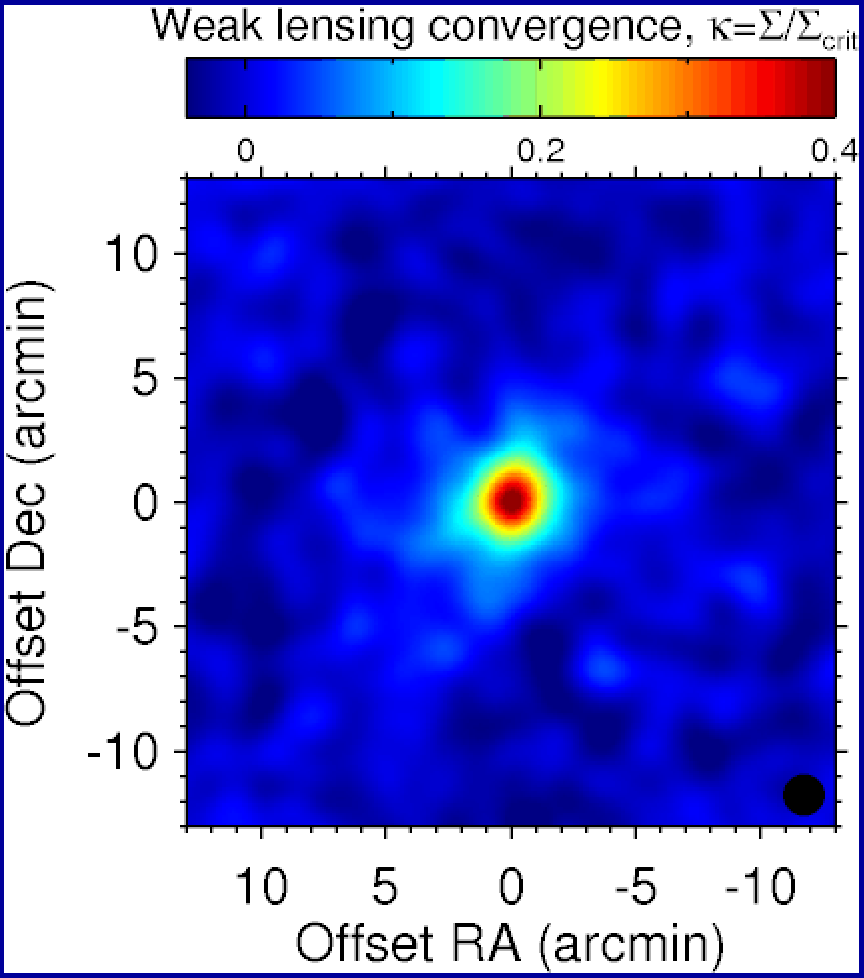




Weak Lensing [3]: Power of Stacking Analysis

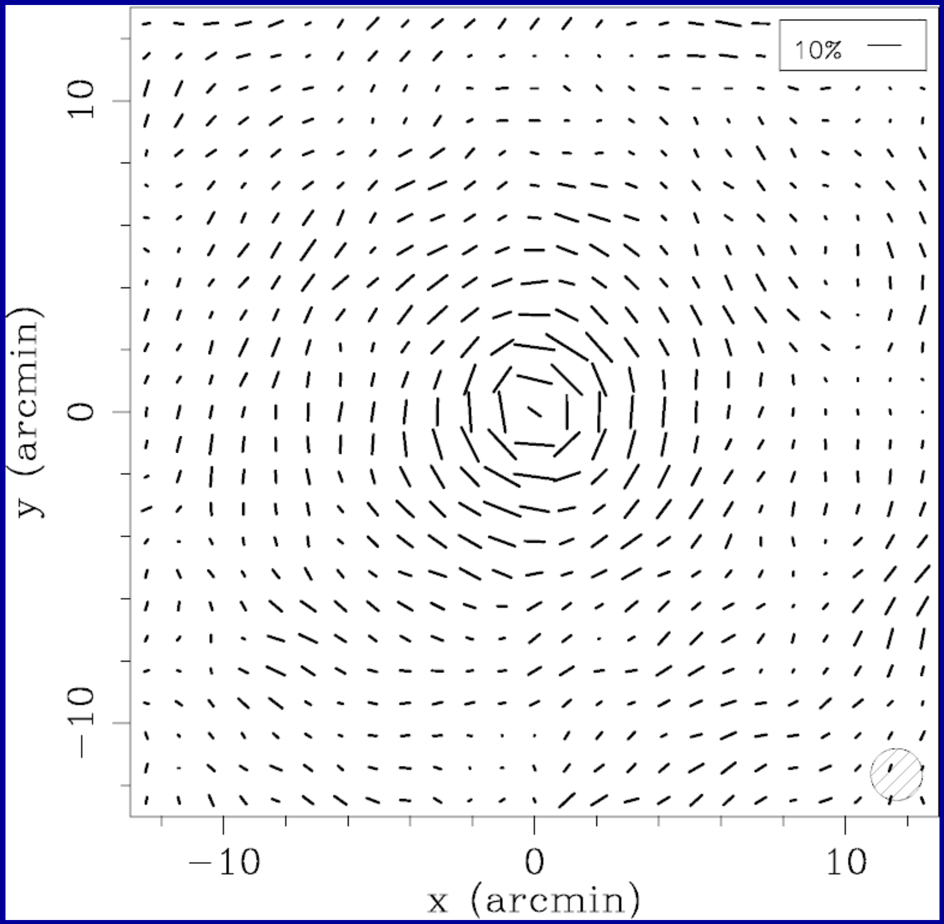
Subaru shear data: N=6

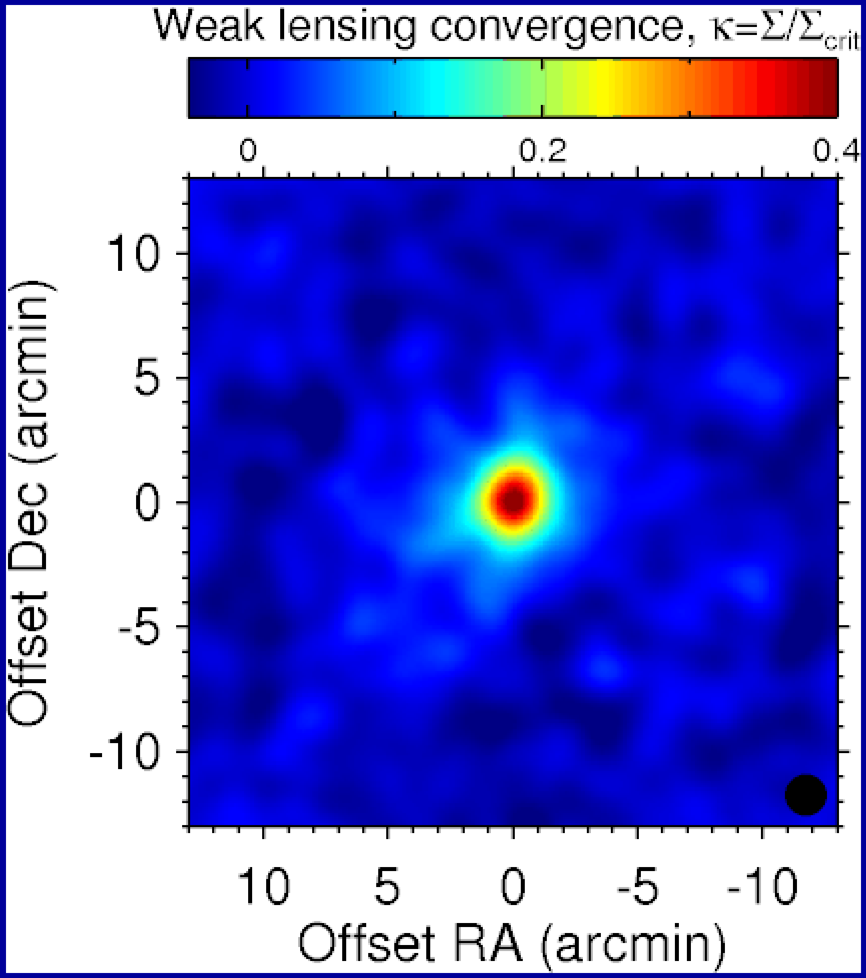




Weak Lensing [3]: Power of Stacking Analysis

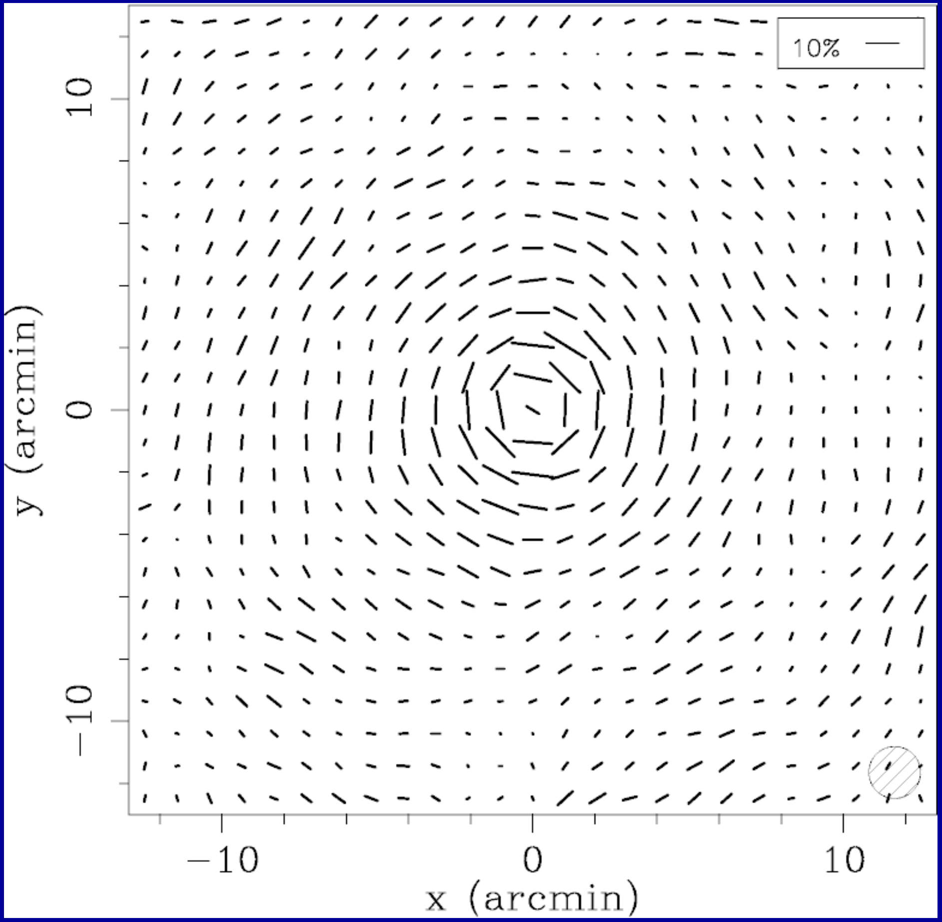
Subaru shear data: N=7

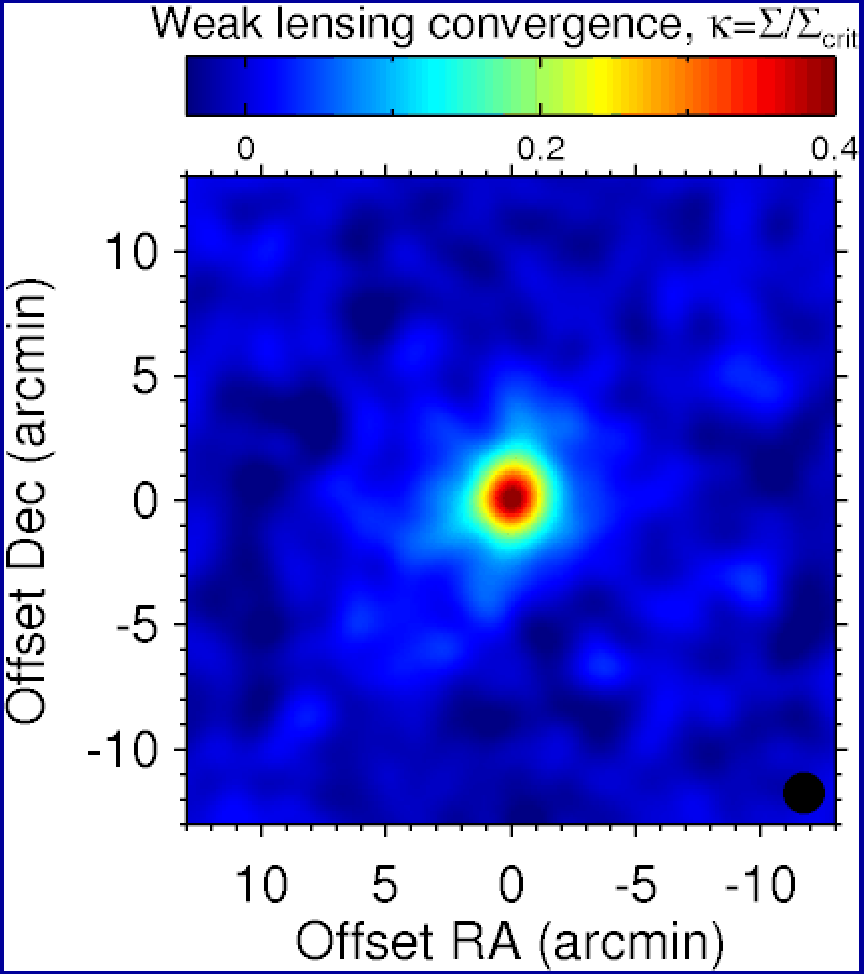




Weak Lensing [3]: Power of Stacking Analysis

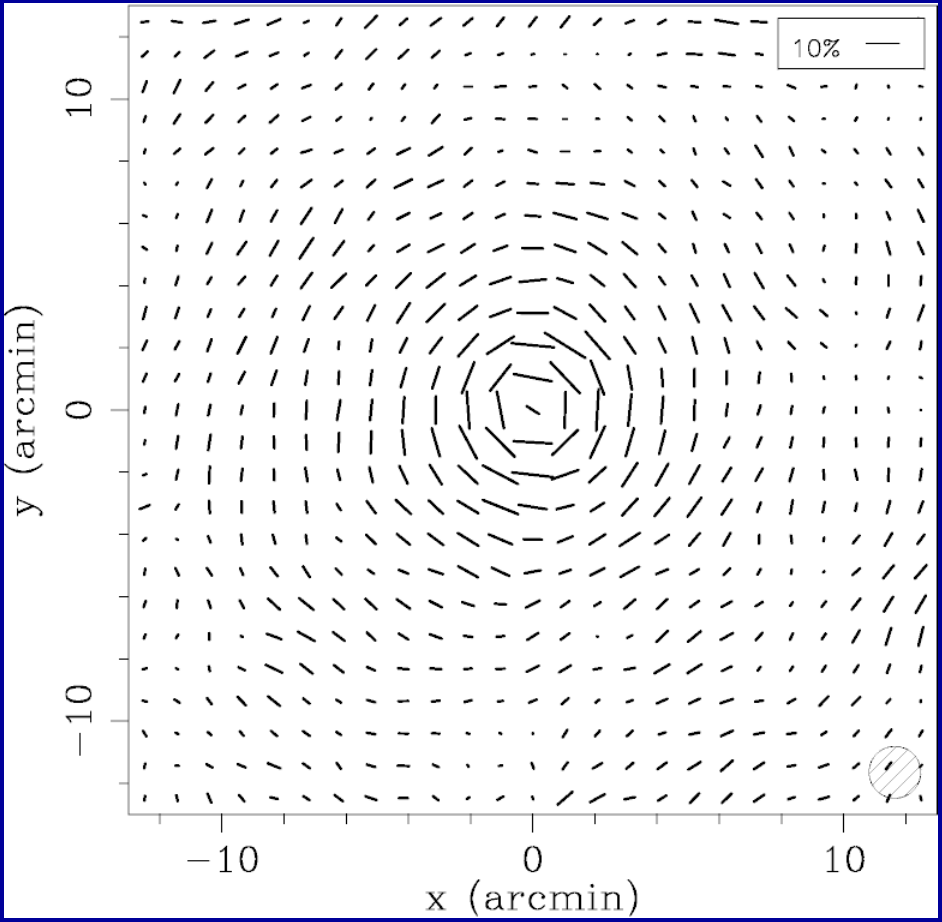
Subaru shear data: N=8

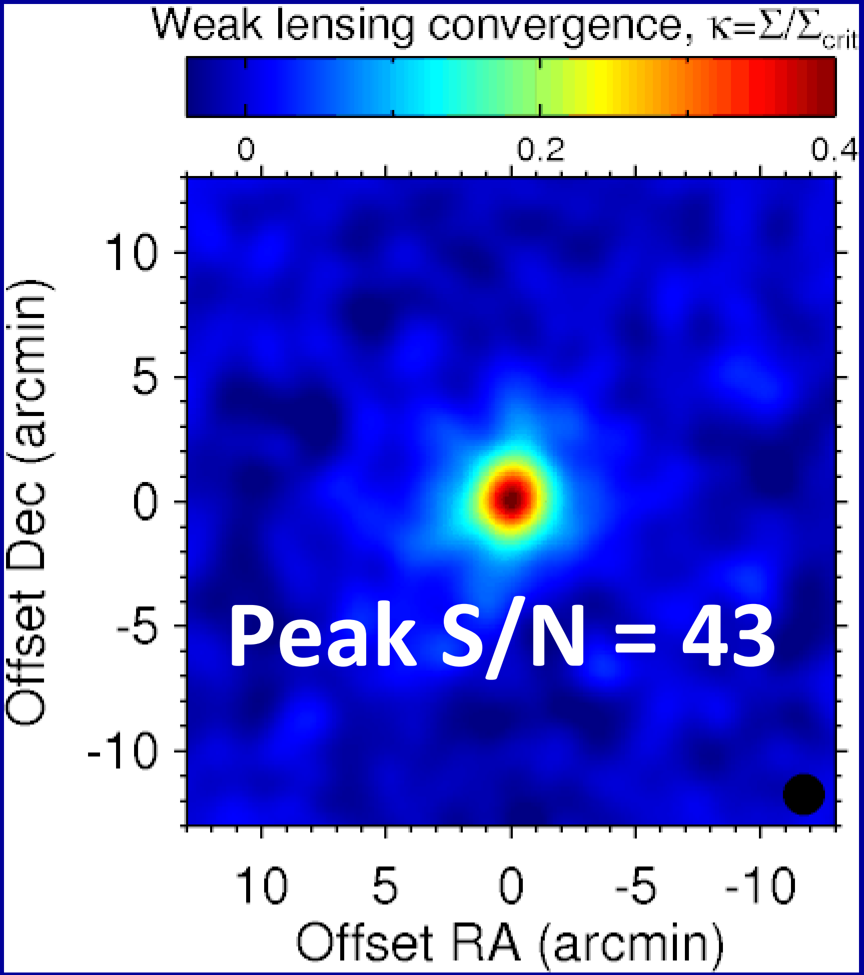




Weak Lensing [3]: Power of Stacking Analysis

Subaru shear data: N=9





Incoherent contributions, such as asphericcity, substructures, cosmic shear (uncorrelated LSS contributions), as well as intrinsic shape noise, being averaged out by stacking clusters, due to the isotropic nature of the universe

Applications to Subaru S-Cam Data

A. **Combining strong lensing, weak lensing distortion and magnification effects**

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

Umetsu et al. 2011b, submitted to ApJ

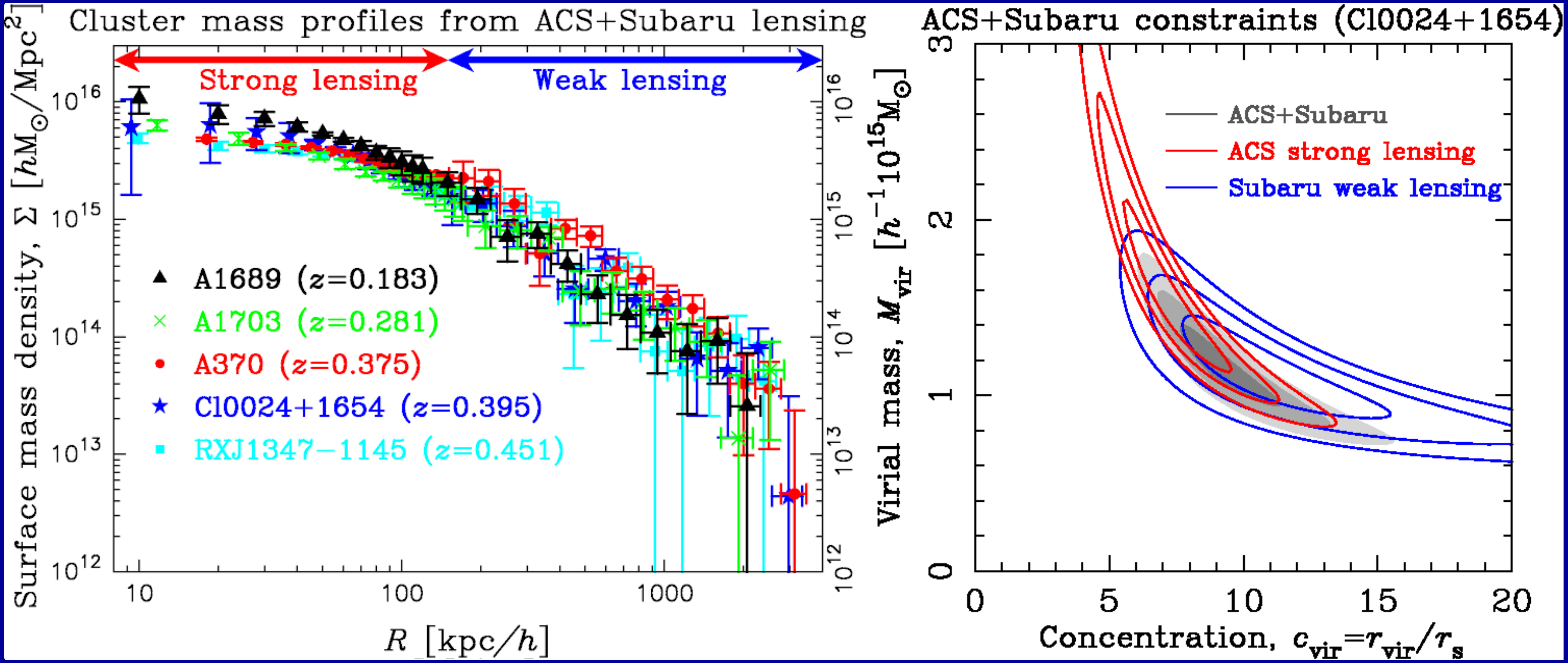
B. **Stacked weak lensing analysis of 45 X-ray selected clusters (LoCuSS)**

Nobuhiro Okabe et al., in prep (with M. Takada, K. Umetsu, T. Futamase, G. Smith)

(A) Cluster Full Mass Profiles from Independent Strong + Weak Lensing

Combining Weak shear+magnification (Subaru) and Strong (HST/ACS) lensing data:

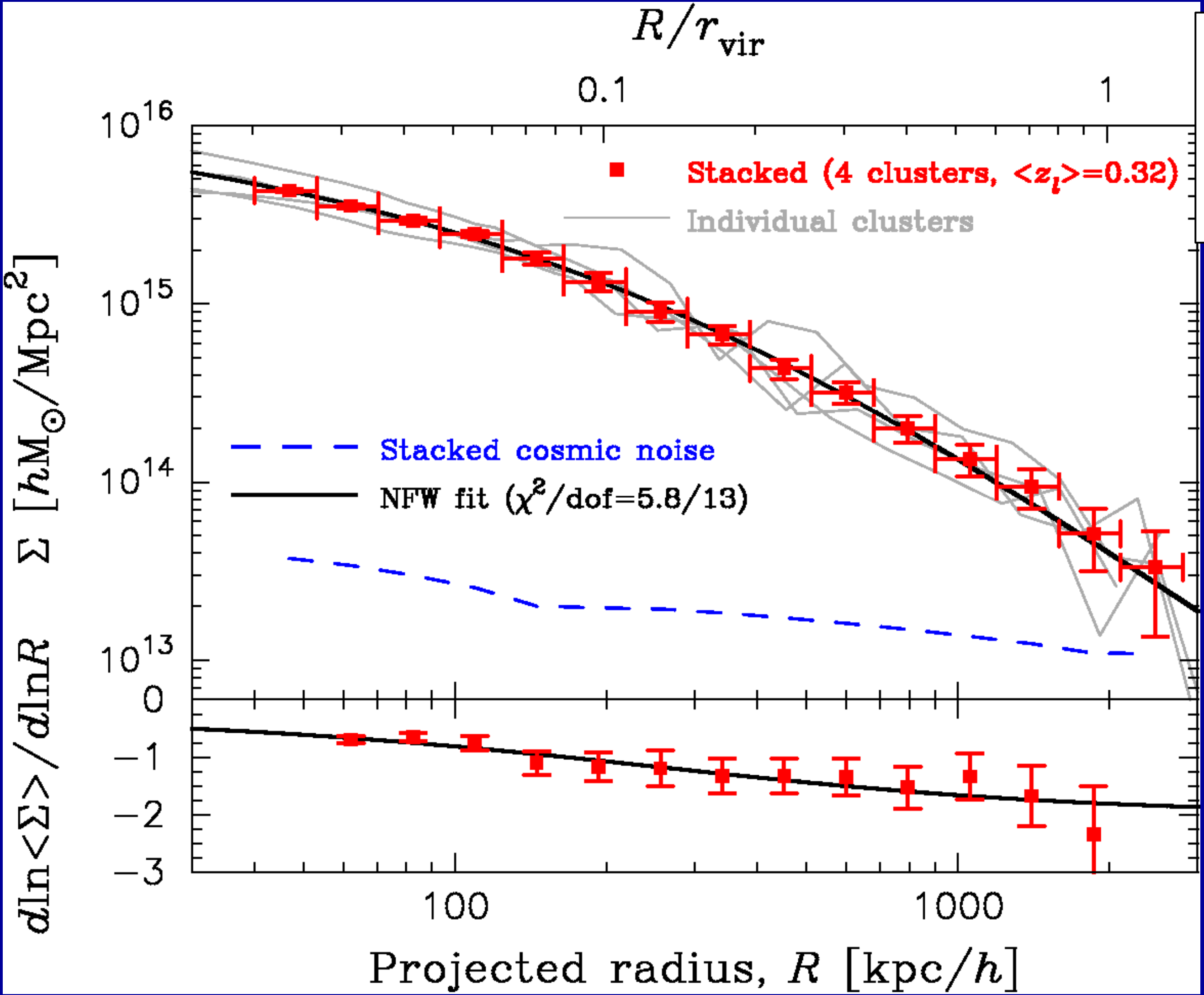
→ Probing the mass density profile in the range [1%, 150%] R_{vir}



The profile shapes are consistent with a generalized form of the NFW density profile, except for the ongoing merger RXJ1347-11, with modest variations in the central cusp slope (α= -dlnρ/dlnr <~ 0.9).

<u>Umetsu+11a</u>; Umetsu & Broadhurst 08; Umetsu et al. 09, 10; Zitrin et al. 09, 10

58σ cluster mass profile averaged from the highest-quality SL+WL data



Stacking clusters by

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

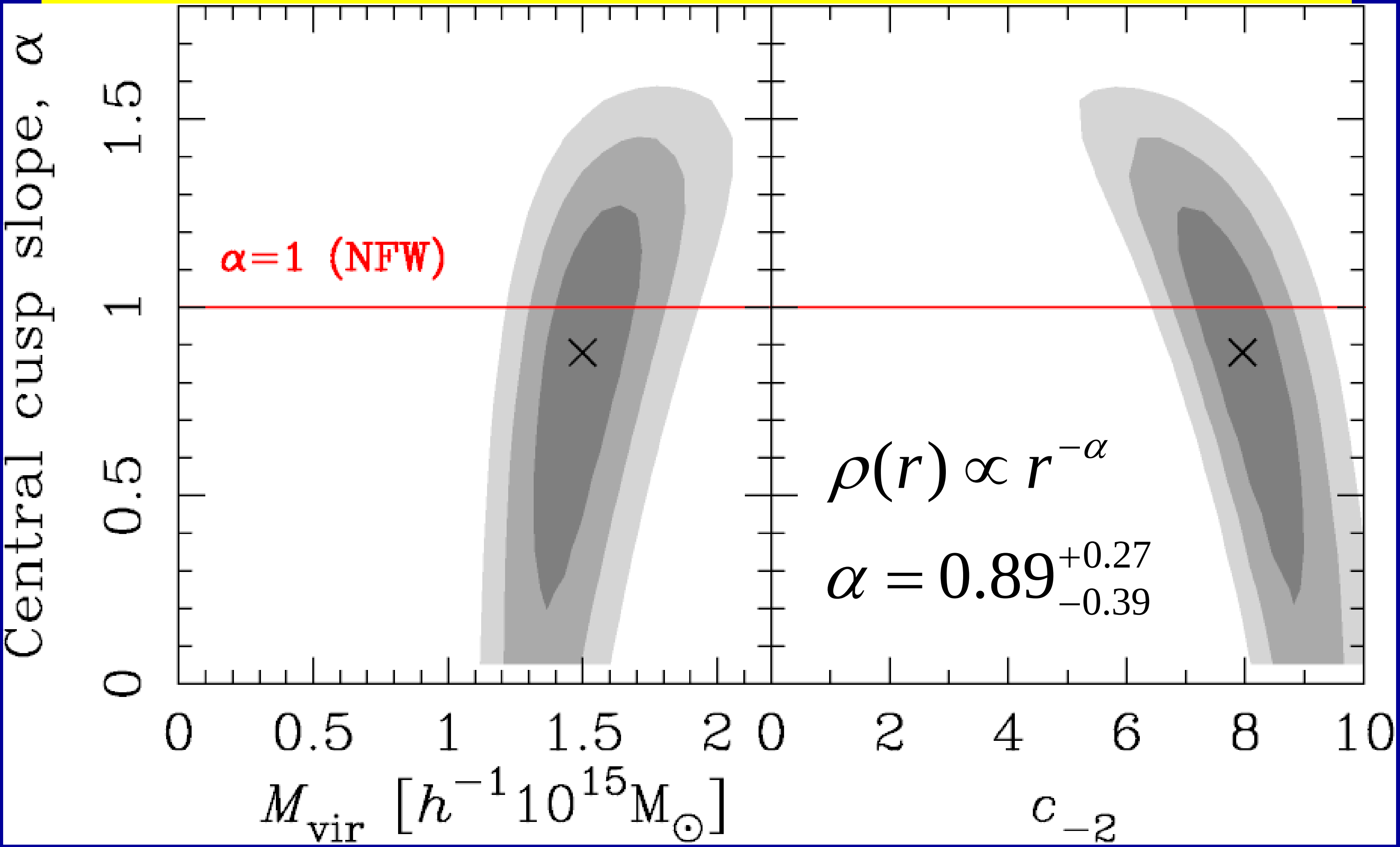
2-parameter NFW gives an excellent fit over ~2-decades of radius

BCG-DM offset is found to be <20kpc/h, where R< 40kpc/h region is excluded from the analysis to avoid miscentering

SIS model is rejected at >60σ significance

Umetsu et al. 2011b, submitted to ApJ (to appear in arXiv tomorrow)

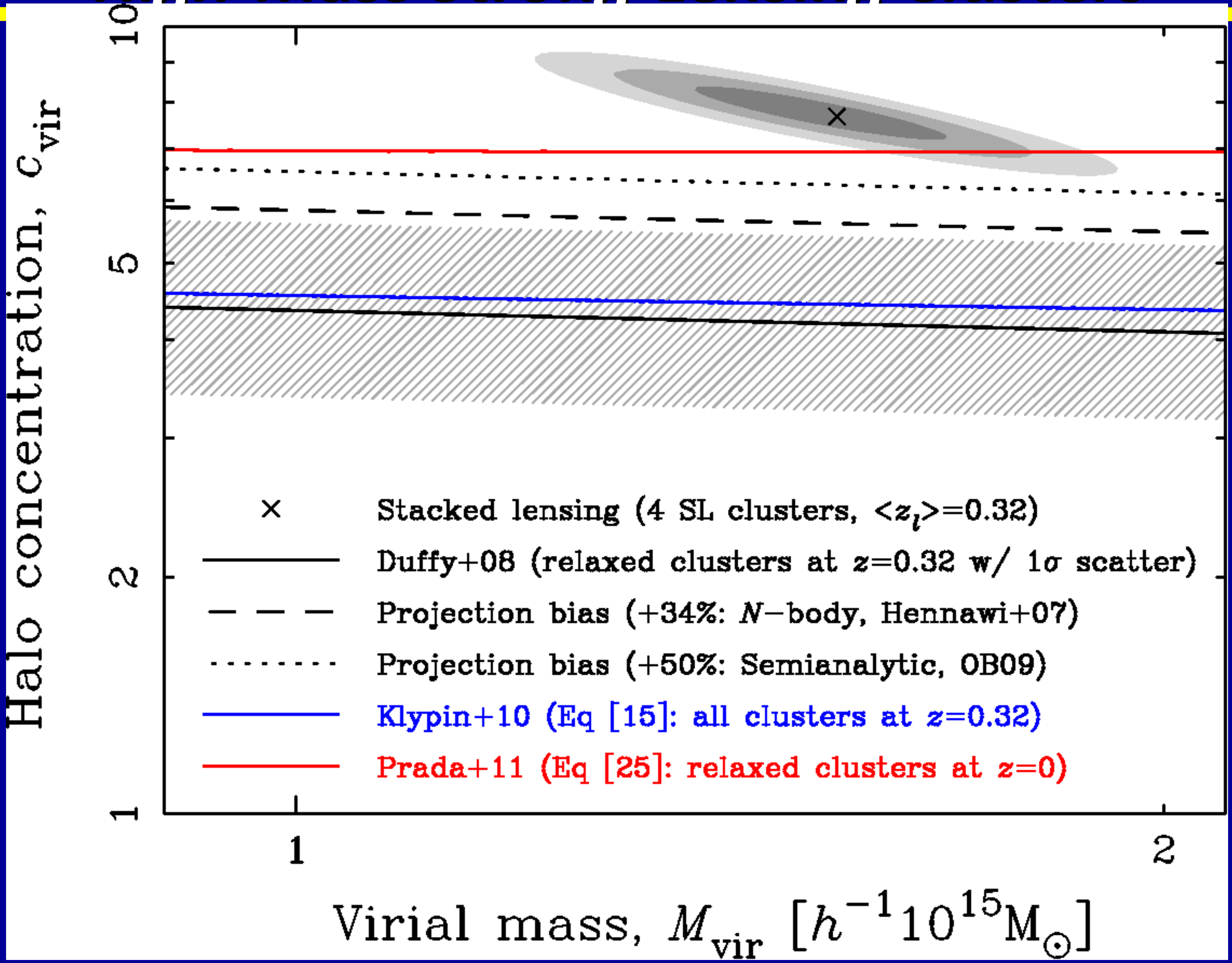
3D Central Cusp Slope (generalized NFW)



Slightly shallower than, but consistent with, NFW (cf. Navarro et al. 2010)

Umetsu et al. 2011b

Halo Concentrations for High-Mass Strong-Lensing Clusters



CLASH (PI: M. Postman) will establish this for a lensing-unbiased sample of representative clusters

Umetsu et al. 2011b

Summary

- **Cluster WL techniques have been fully developed and deployed in the past several years, ready for the Subaru HSC survey (2012-2016)**
  - Weak lensind distortion (shear)
  - Weak lensing depletion (magnification bias)
  - Weak lensing dilution (background selection in color-color space)
- **New statistical stacking techniques will be extremely useful to explore low-mass and high-z cluster regimes with Subaru HSC**
- **Multicolor imaging with HSC will reveal many Bullet-like cluster systems.**
- **Hyper wide FoV of HSC will be an excellent instrument to probe nearby clusters in full details.**