DENET 2011 Subaru HSC Workshop

Subaru Cluster Weak Lensing

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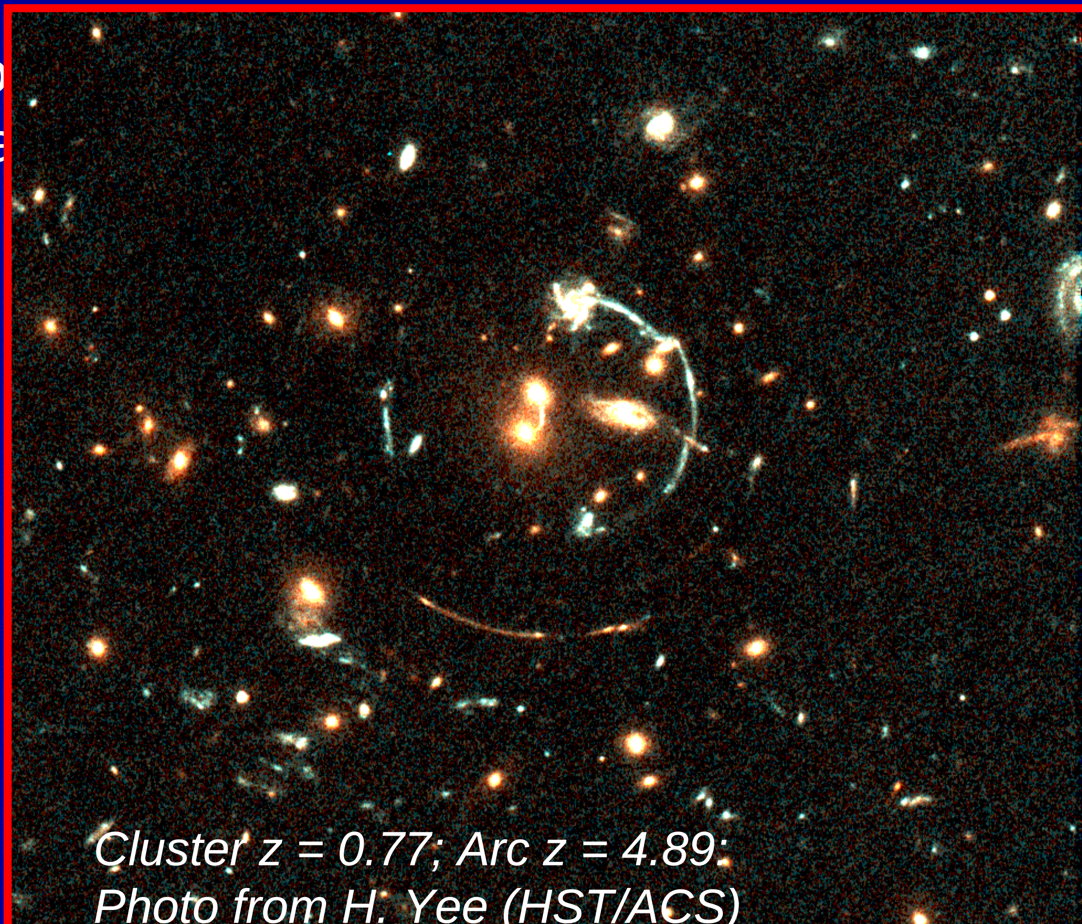
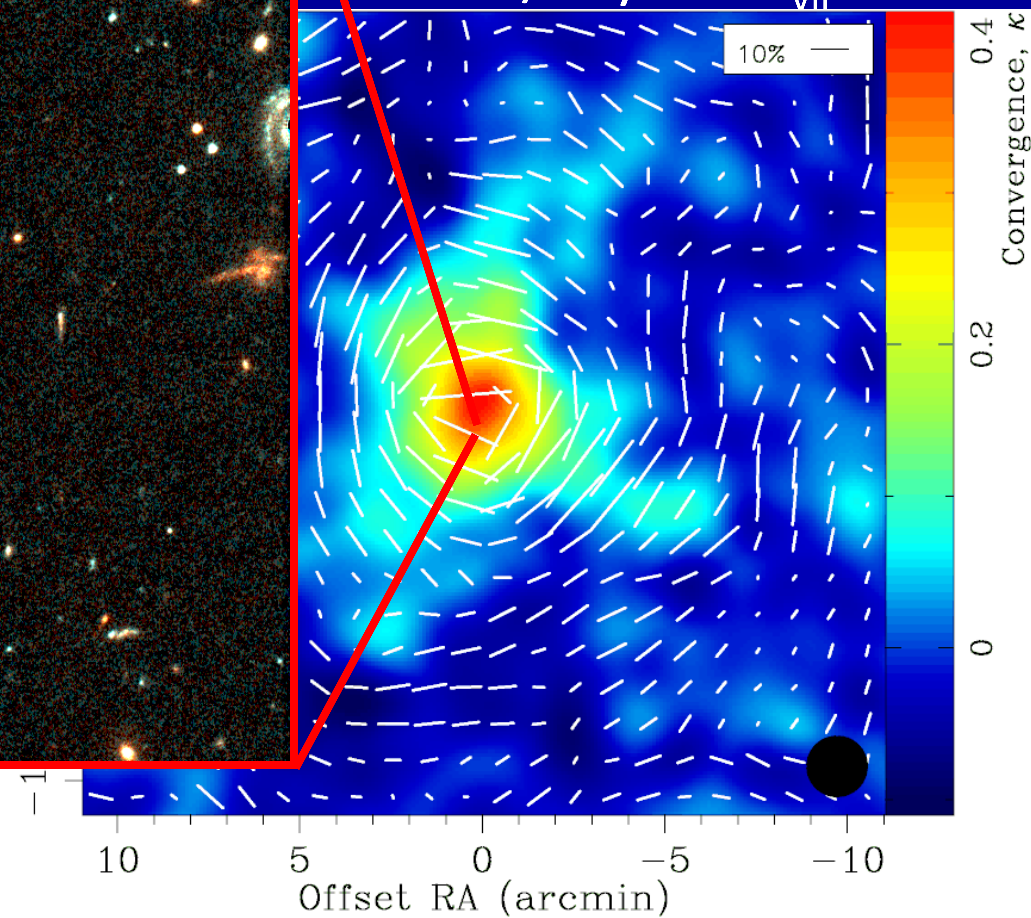
Weak Gravitational Lensing

The deep potential wells of massive clusters generate coherent tangential distortions of background galaxy images.

Ob… recover their deep gra… es out to/beyond R_{vir}.



Cluster z = 0.77; Arc z = 4.89: Photo from H. Yee (HST/ACS)



A1689 at z=0.183 (Umetsu & Broadhurst 08)

Cluster WL with HSC-Wide

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

- Deep i' imaging for accurate shape measurements
  - Sampling: n_g ~ 30 arcmin^{-2}
  - Mean depth: <z> ~ 1
  - 25% mass error per cluster with M_{vir}= 5e14M_{sun}/h @z=0.4

$$\frac{M_{\rm vir}}{\sigma(M_{\rm vir})} = 4.\left(\frac{M_{\rm vir}}{5\times 10^{14} M_{\rm sun}/h}\right)\left(\frac{n_g}{30\mathrm{arcmin}^{-2}}\right)^{1/2}\left(\frac{\sigma_g}{0.4}\right)^{-1} @\, z = 0.4$$

- grizY multicolor imaging, essential for separating unlensed cluster galaxies from background → radius dependent cluster "dilution" effect, leading to substantial underestimation of C_{vir}, M_{2500} etc.
  - Photoz estimates for individual galaxies
  - Cluster/foreground/background separation in color-color space (Medezinski, Broadhurst, Umetsu+2010, 2011)

Science Cases (HSC Cluster WL)

Scientific rationale: **clusters as cosmological probes (Oguri-san's talk)**

- **Strategies:**
  - **individual WL**: *cluster mass & structure parameters (concentration, ellipticity, etc.)*
  - **Stacking a sample of clusters**: *ensemble averaged cluster properties as a function of mass, redshift, etc. (Takada-san's talk)*
- **Science cases:**
  - **Representative cluster mass profile shapes**: M(r)
  - **Halo mass vs. concentration relation**: *C(M,z)*
  - **Magnification bias**: *improving cluster mass constraints*
  - **Nearby clusters**: *detailed WL mapping*
    - *1.5deg Fov → 3.7Mpc/h at z=0.05 (Coma at z=0.024)*
    - *1 arcmin resolution → 41kpc/h at z=0.05*
  - **Merging clusters**: *merger physics, high-velocity systems (bullets), with X-ray and SZE data*
  - **Cluster-cluster lensing** events (CCL: Cooray et al. 1999)
    - CCL abundance, sensitive to cosmological parameters (e.g., $\sigma 8$)

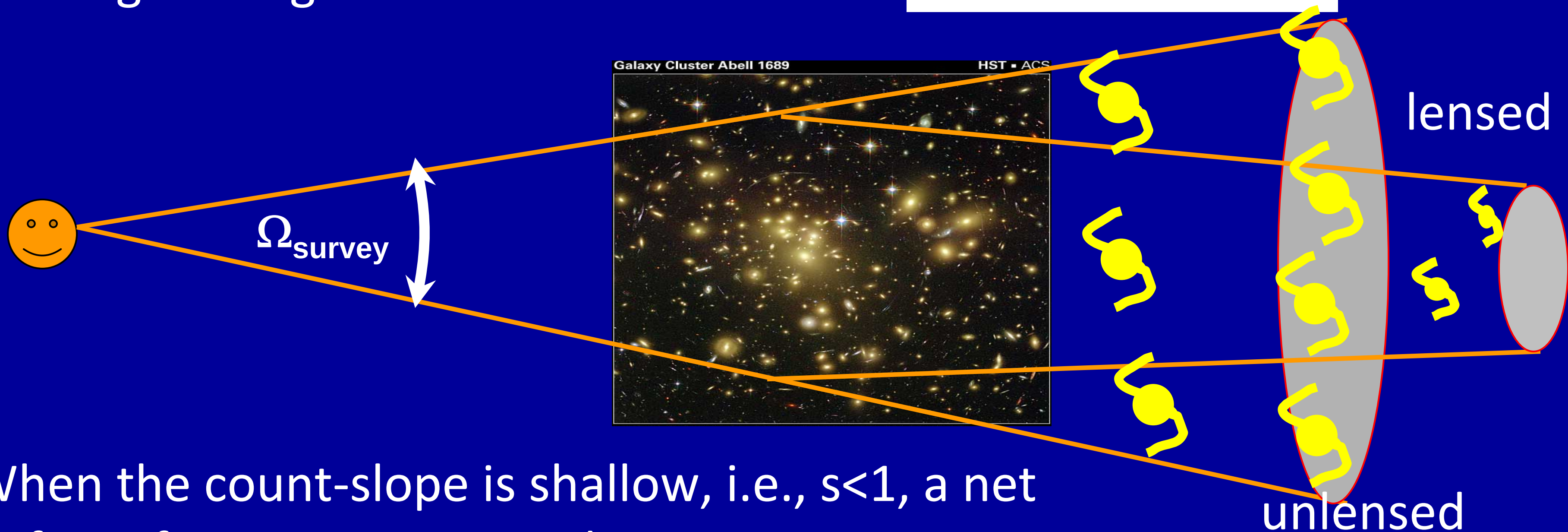
Weak Lensing: Magnification Bias

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

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

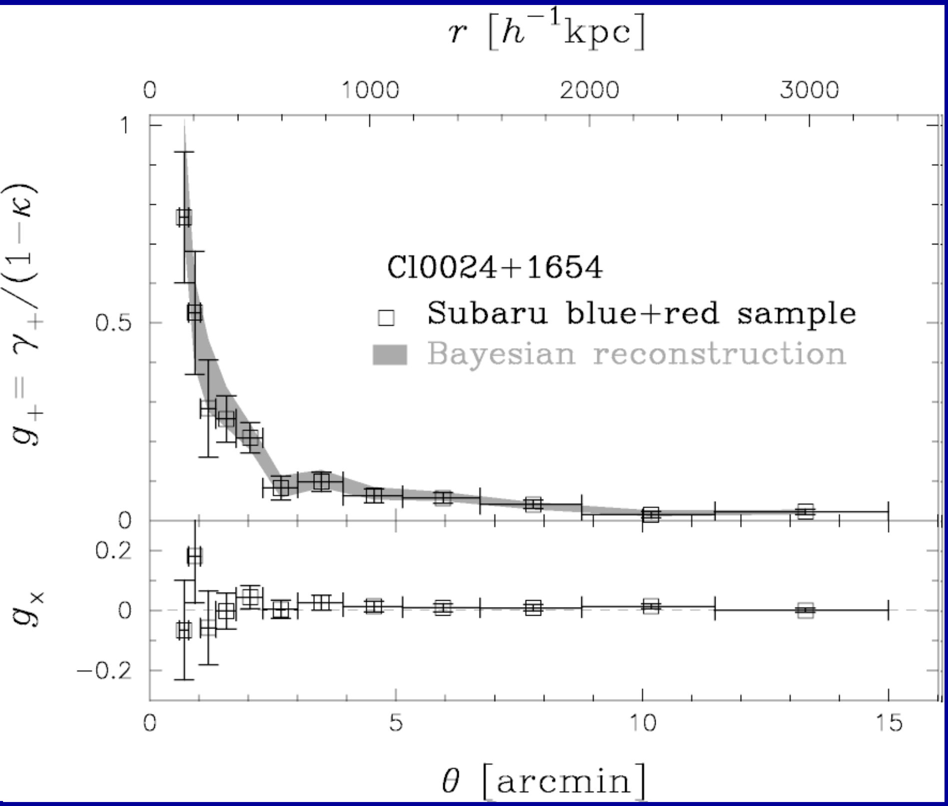


When the count-slope is shallow, i.e., s<1, a net deficit of counts is expected.

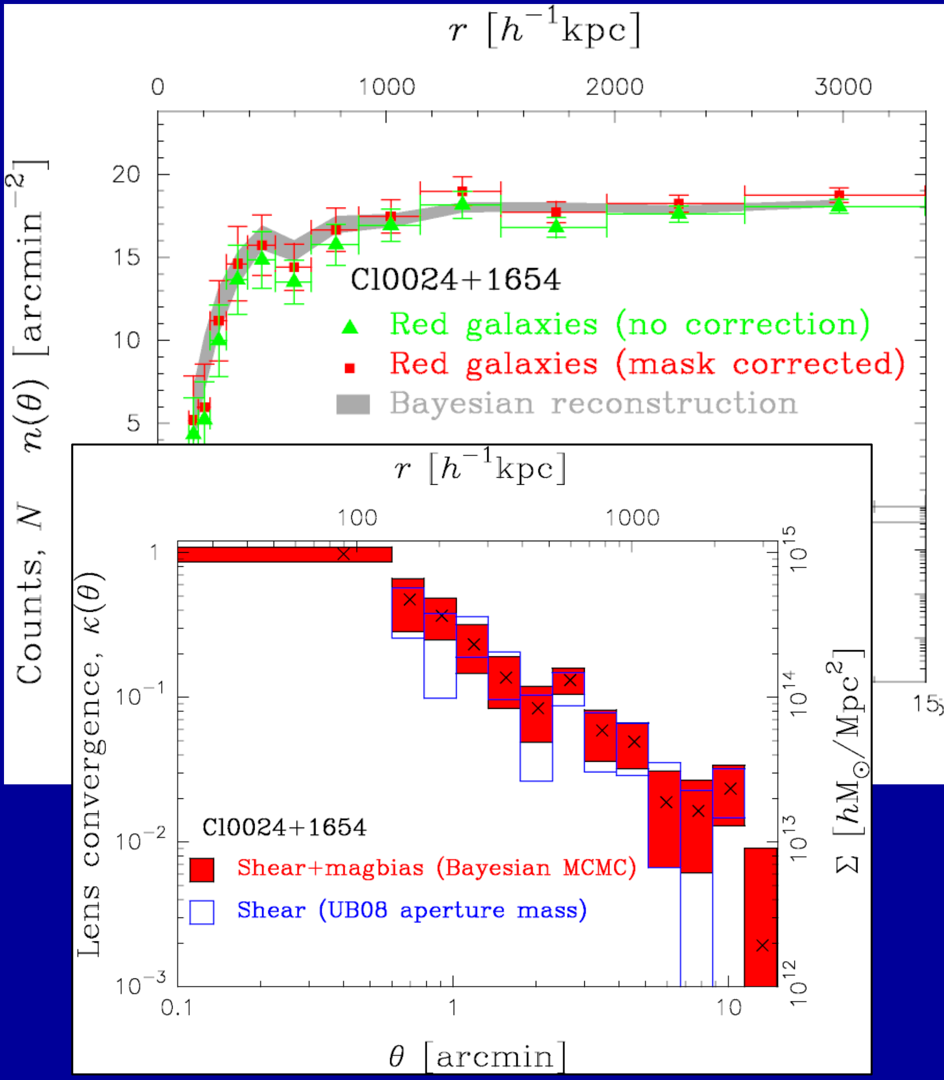
Figure courtesy of Masahiro Takada

Gravitational shear vs. magnification bias: Case (1) CL0024+1654

Tangential distortion (shear)



Number counts (magnification bias)

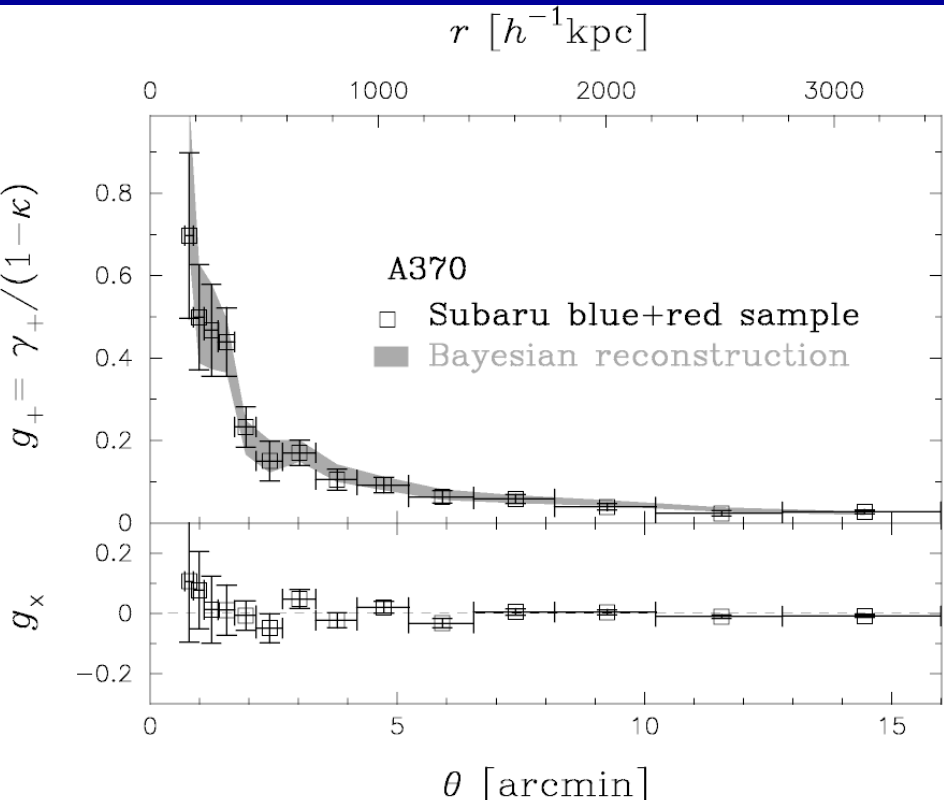


A unique mass profile solution (κ) can be obtained from joint WL distortion + count profiles:

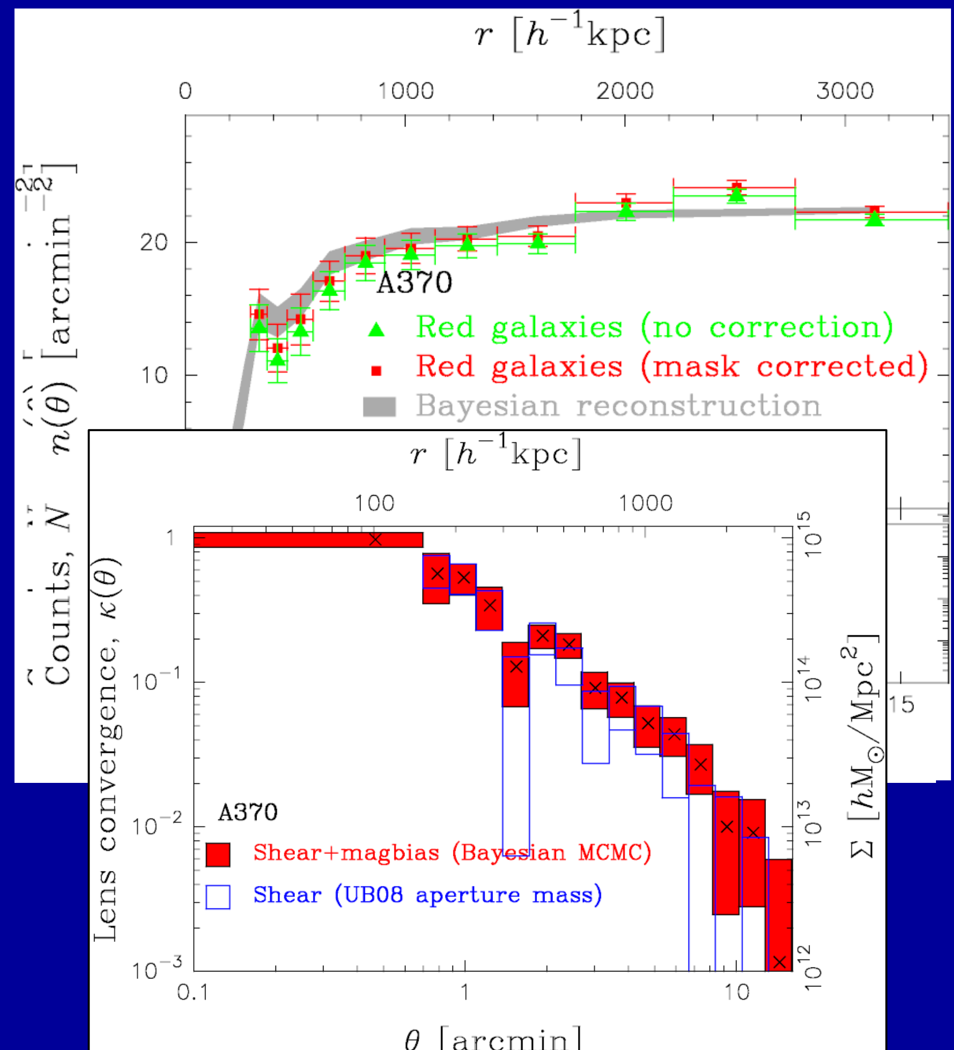
Umetsu+2011

Gravitational shear vs. magnification bias: Case (2) A370

Tangential distortion (shear)



Number counts (magnification bias)



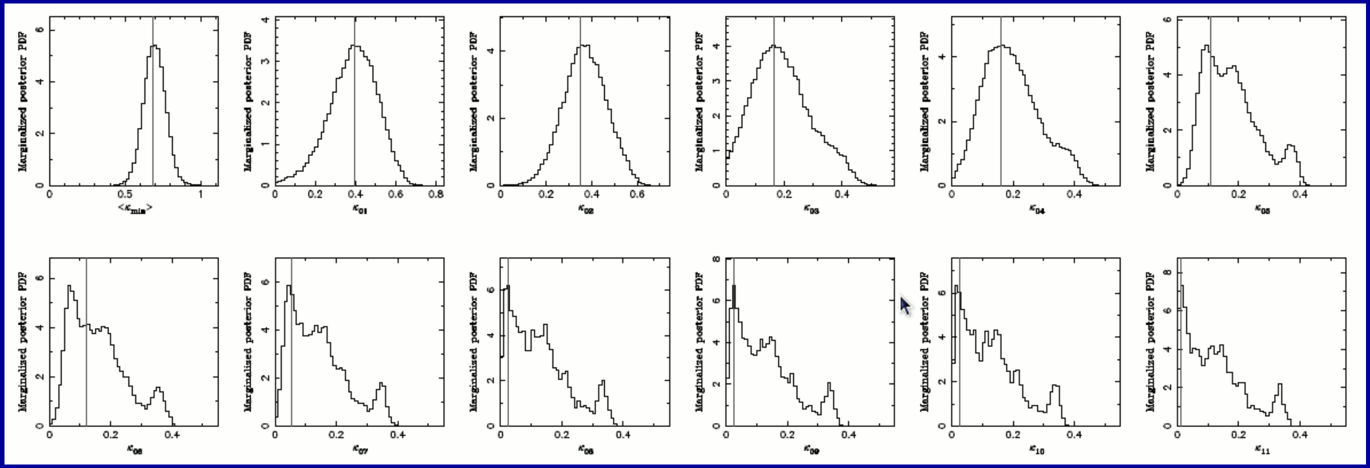
A unique mass profile solution (κ) can be obtained from joint WL distortion + count profiles:

Umetsu+2011

What we gain by adding magnification?

Marginalized posterior distributions of κ (12 radial bands)

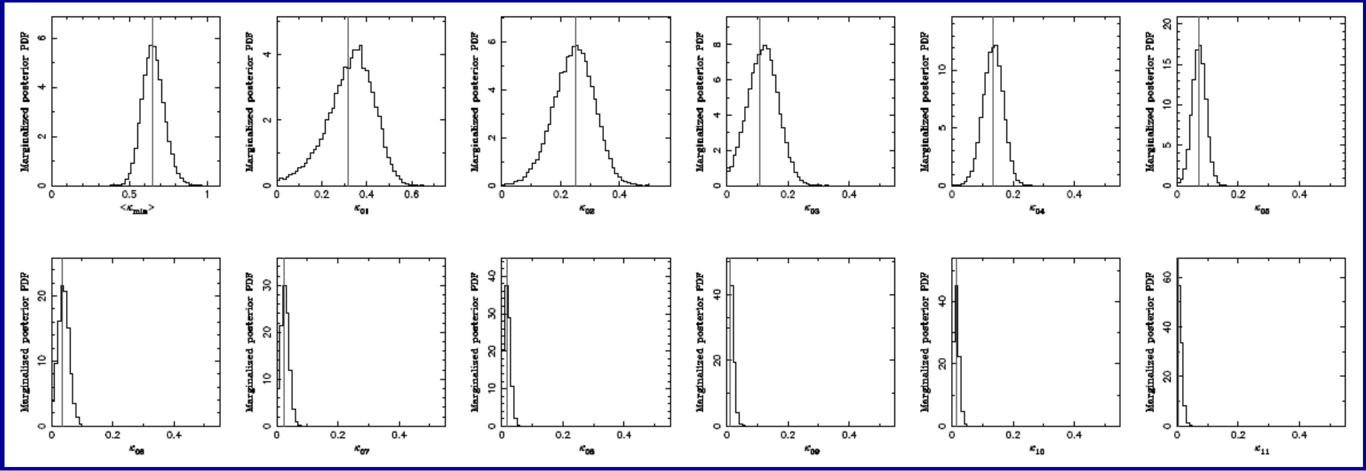
Shear data alone (A1689)



Mass-sheet degeneracy is fully broken (↓)

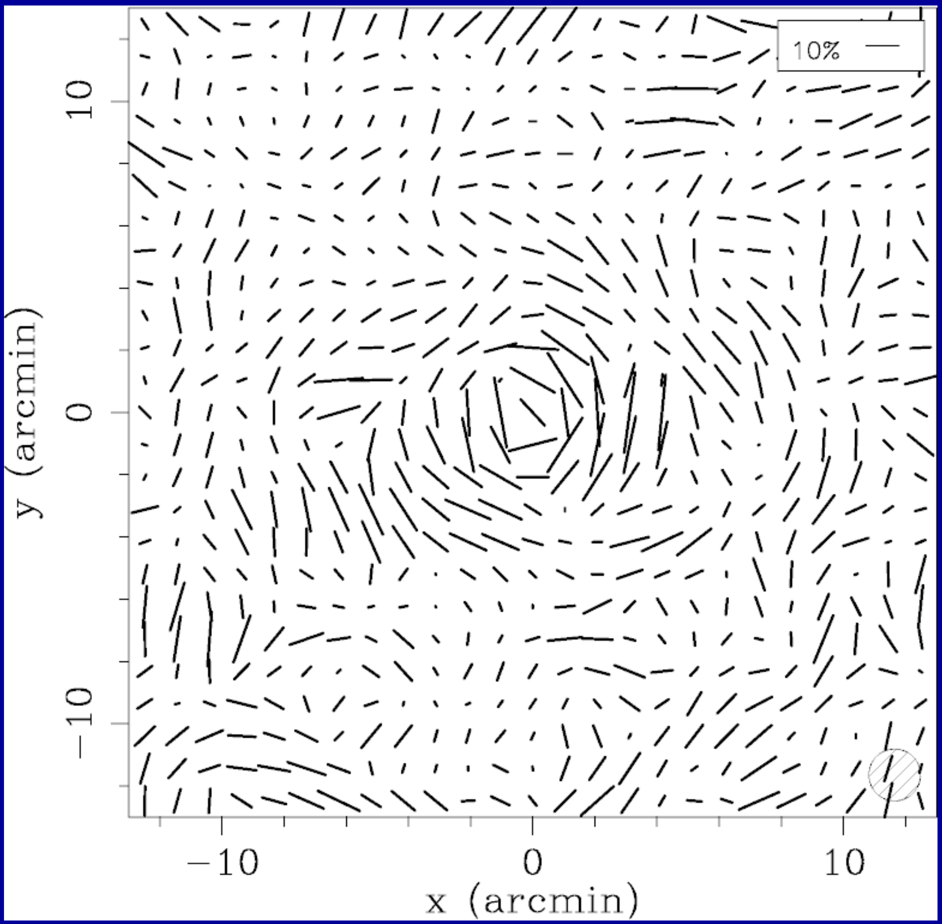
Shear + mag data (A1689)

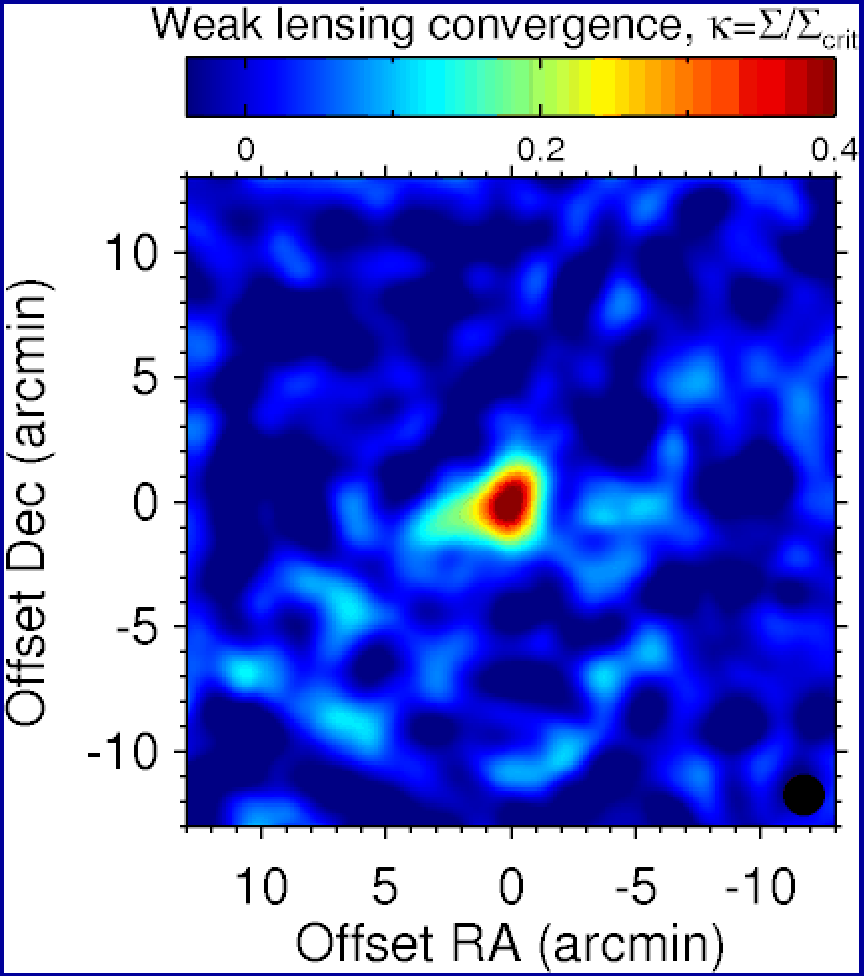
Umetsu+ 2011



Weak Lensing [3]: Power of Stacking Analysis

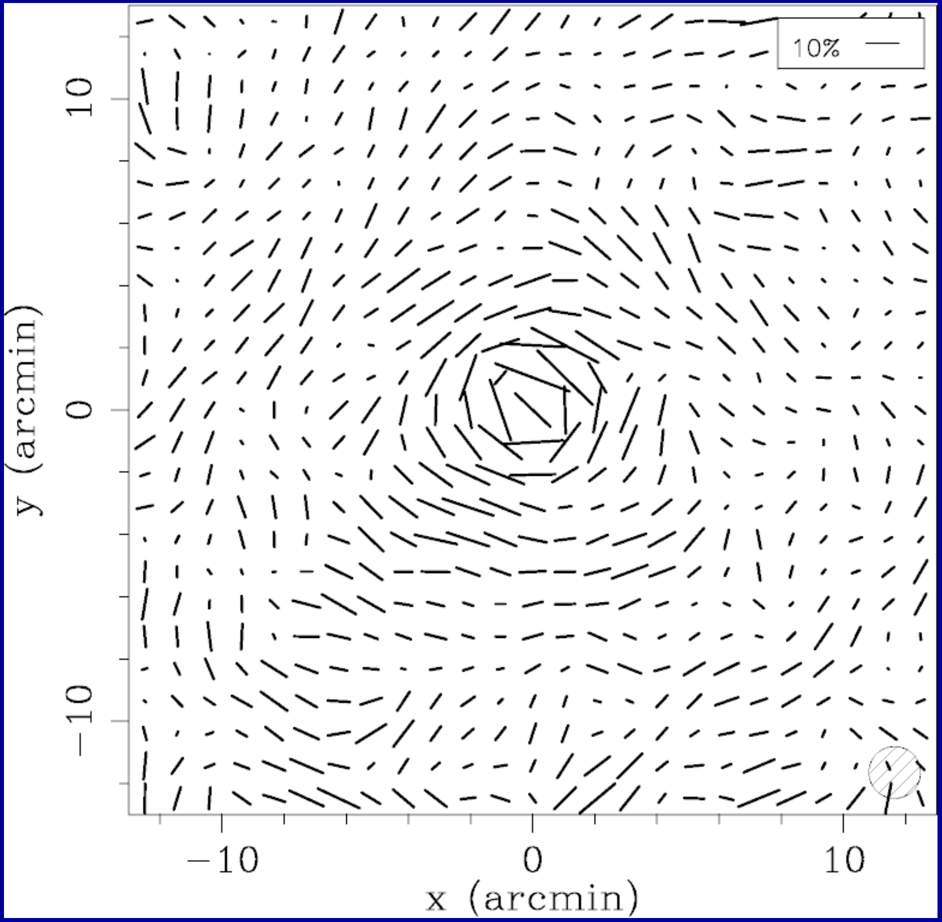
Subaru shear data: N=1

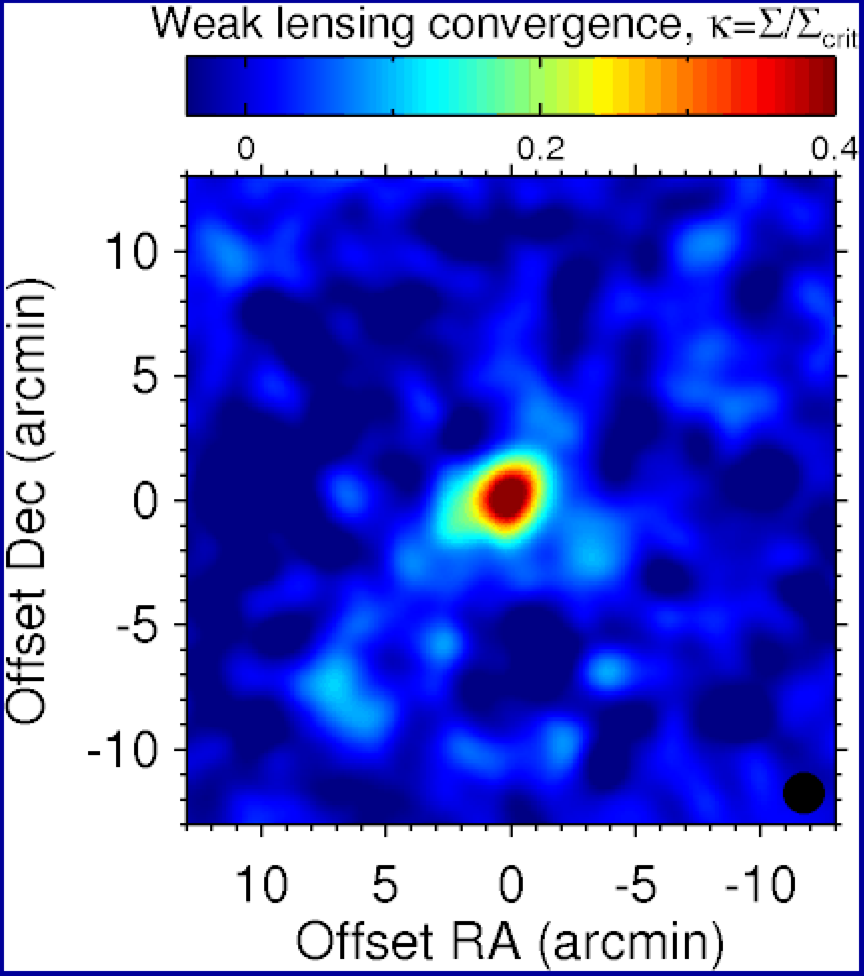




Weak Lensing [3]: Power of Stacking Analysis

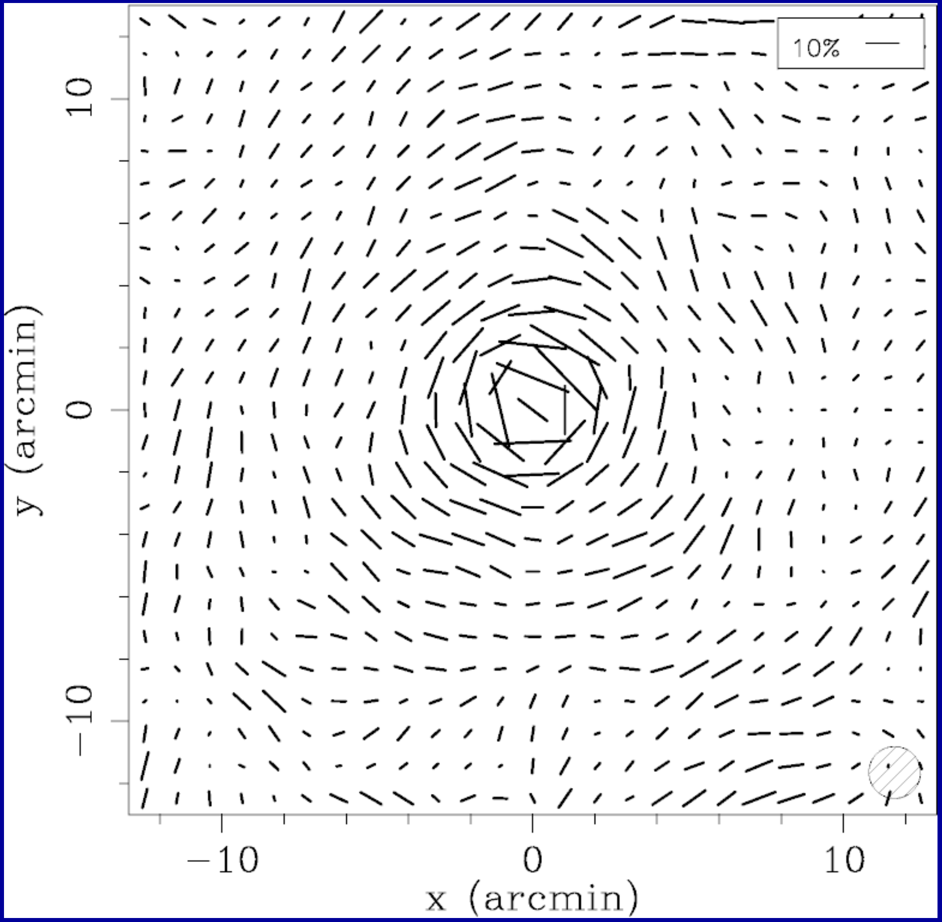
Subaru shear data: **N=2**

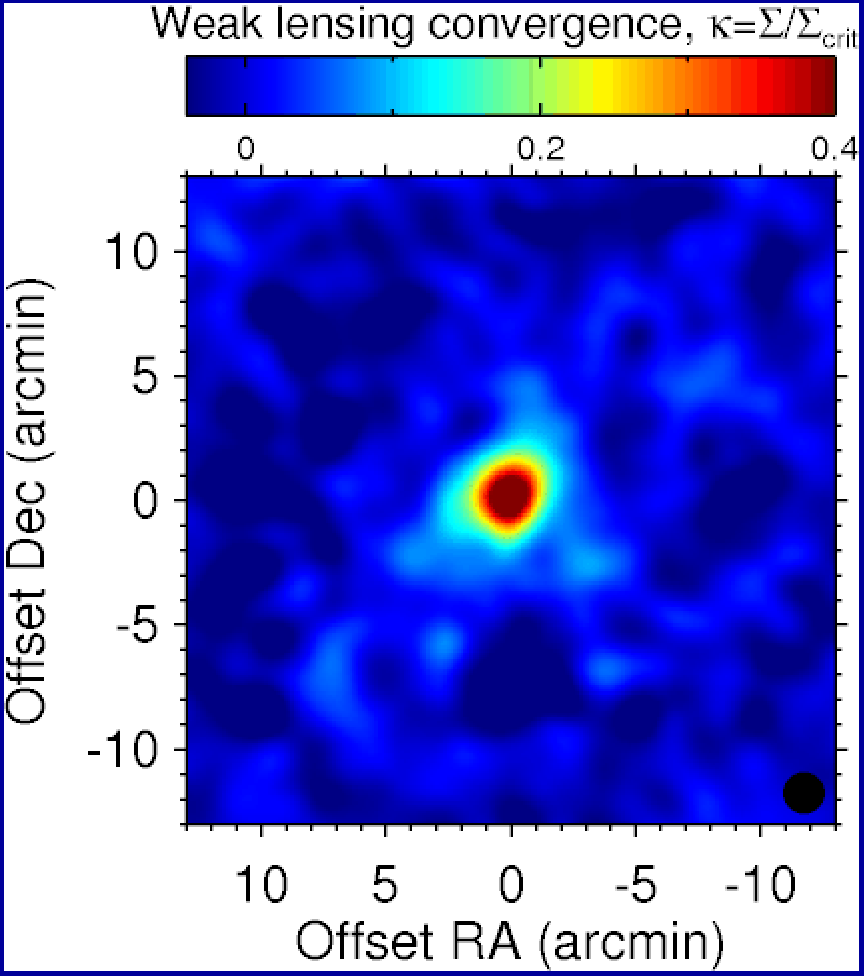




Weak Lensing [3]: Power of Stacking Analysis

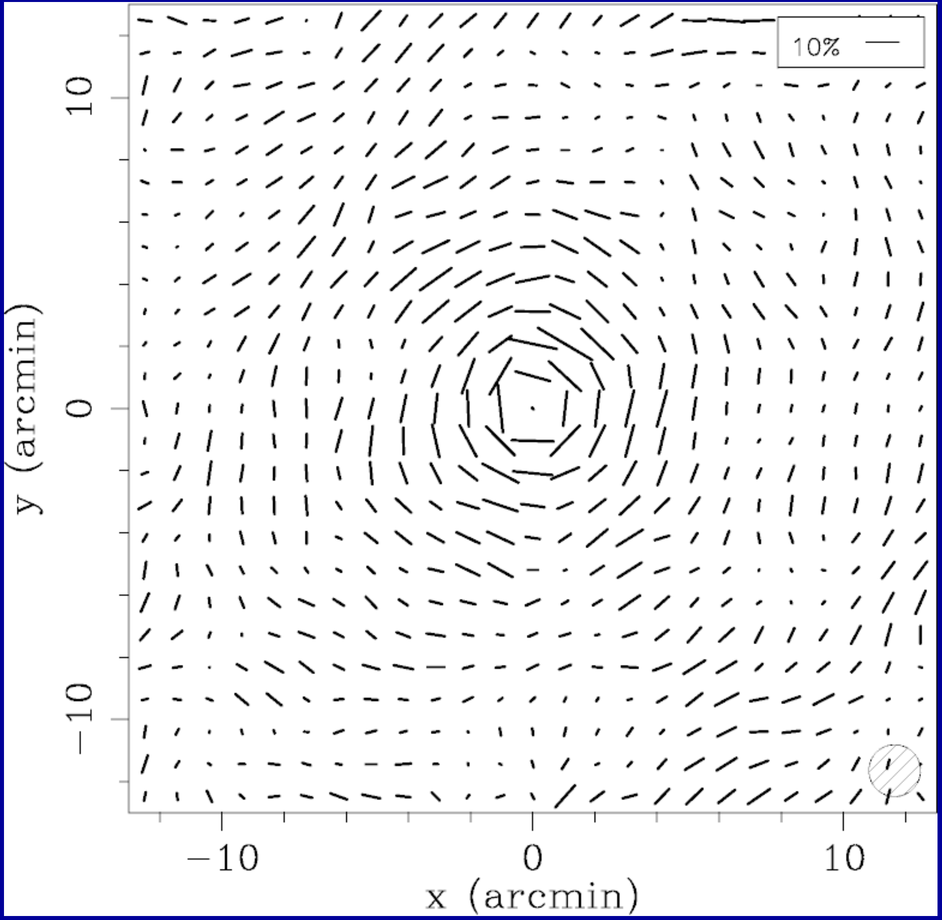
Subaru shear data: **N=3**

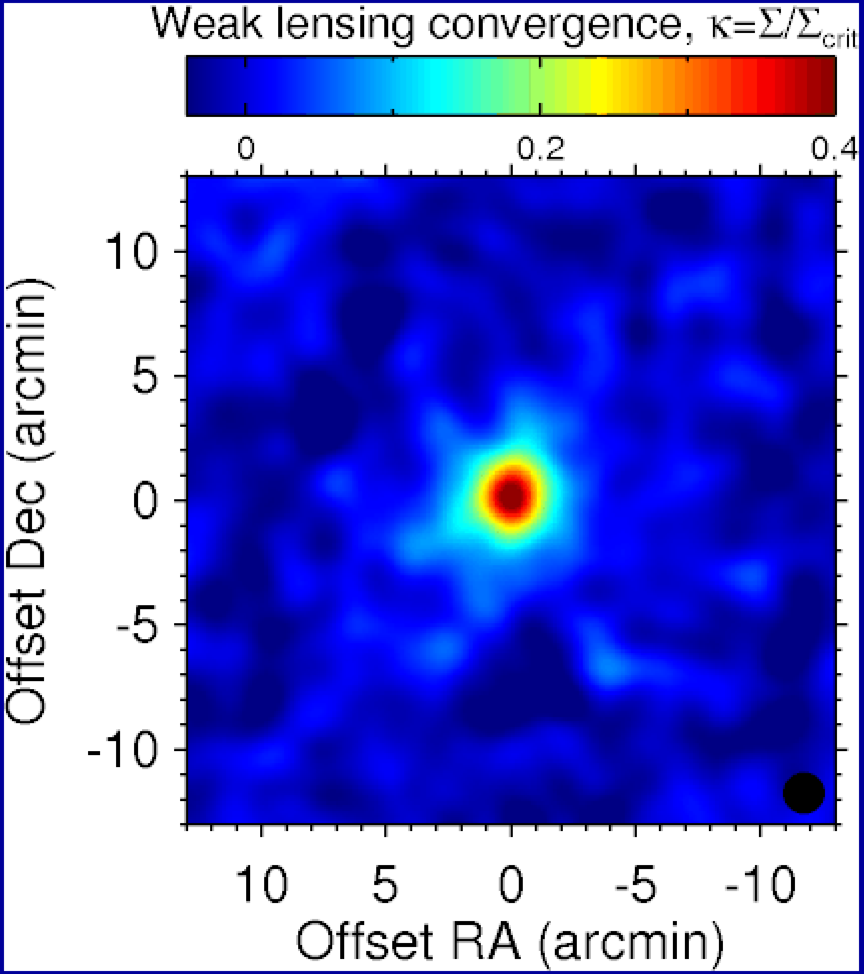




Weak Lensing [3]: Power of Stacking Analysis

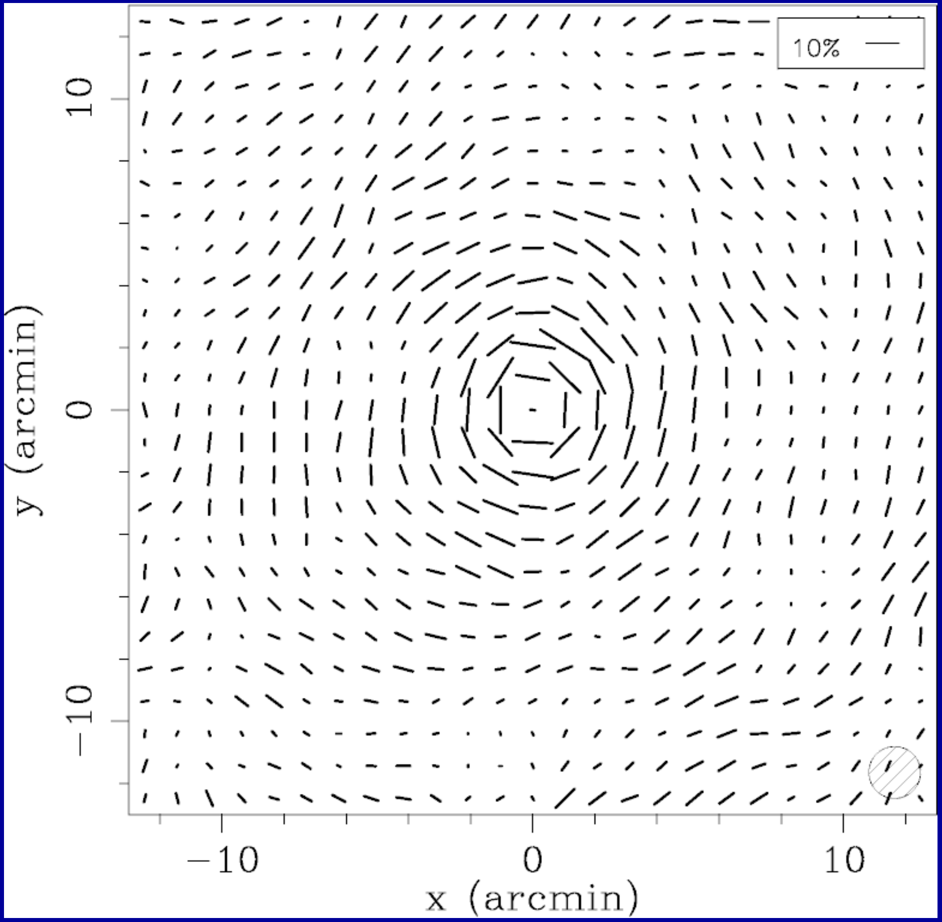
Subaru shear data: N=4

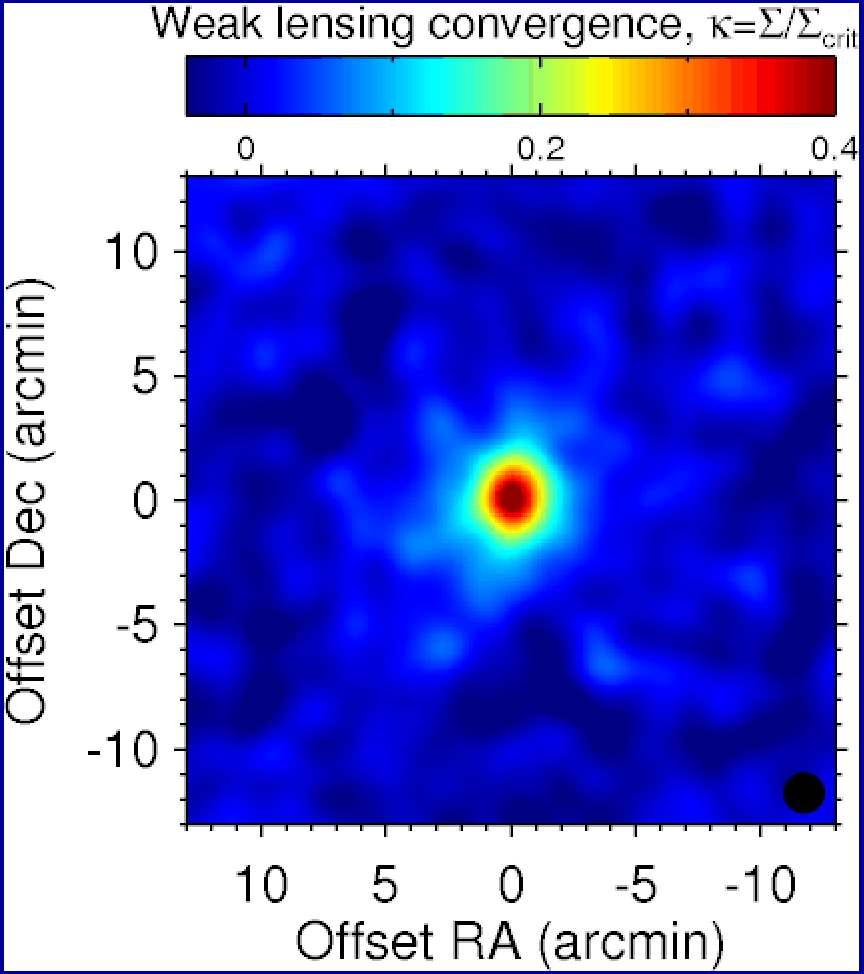




Weak Lensing [3]: Power of Stacking Analysis

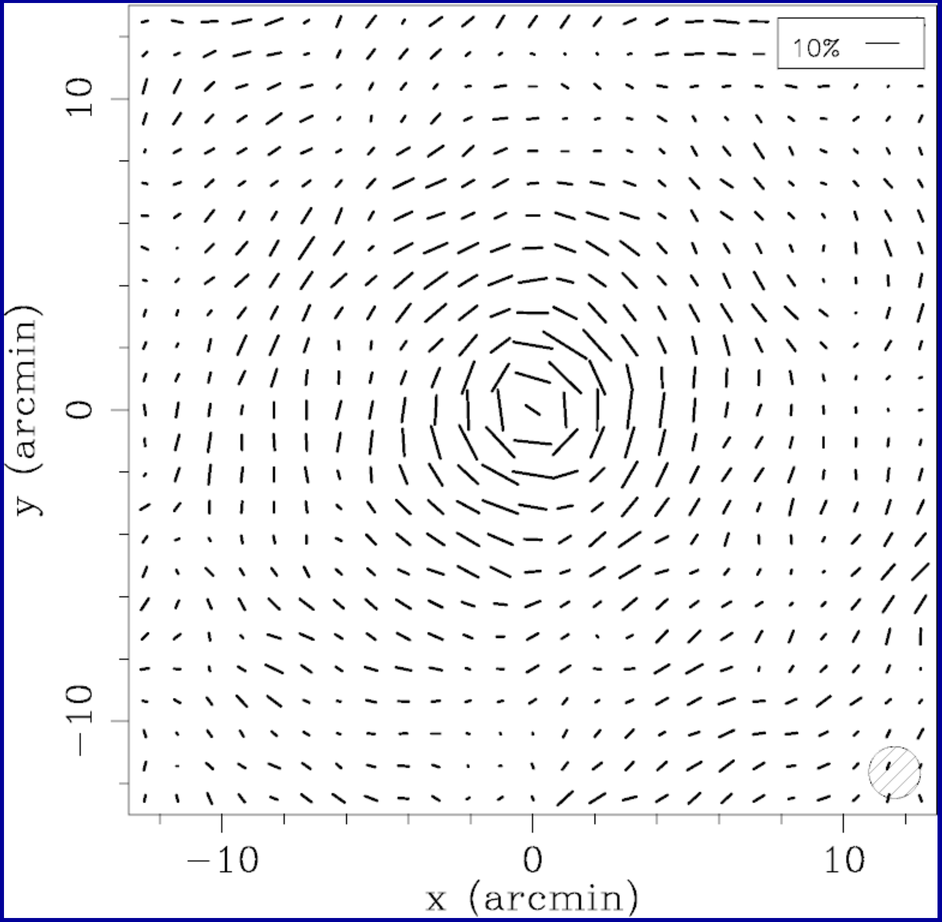
Subaru shear data: N=5

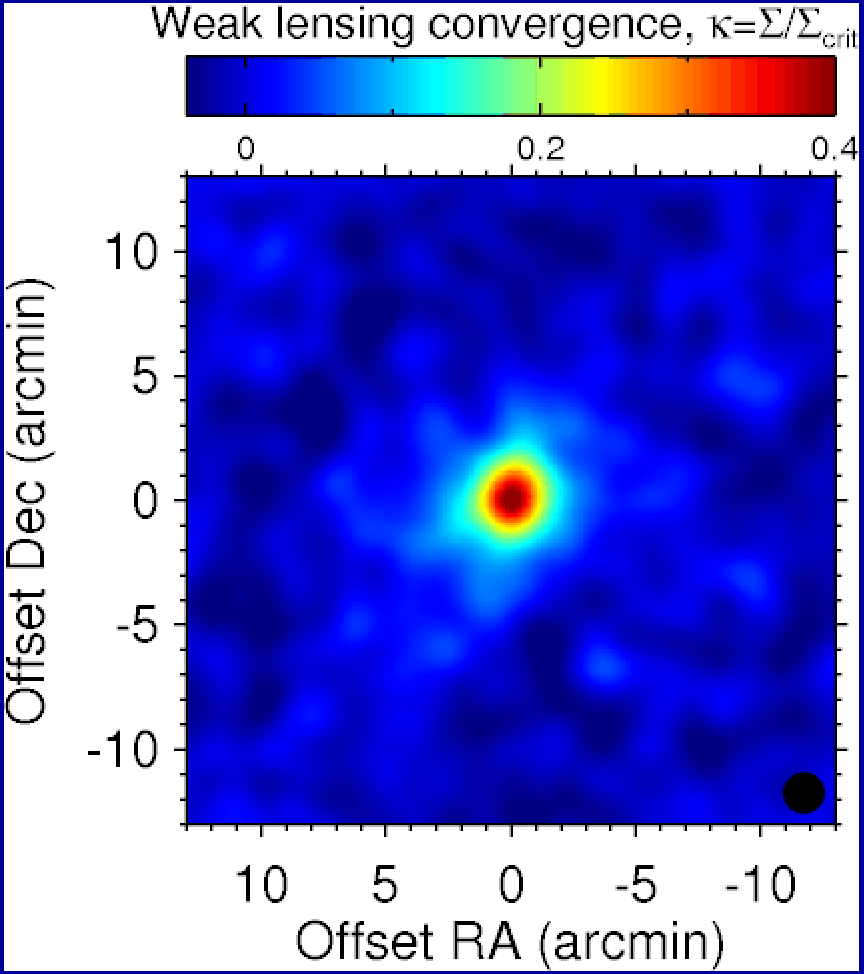




Weak Lensing [3]: Power of Stacking Analysis

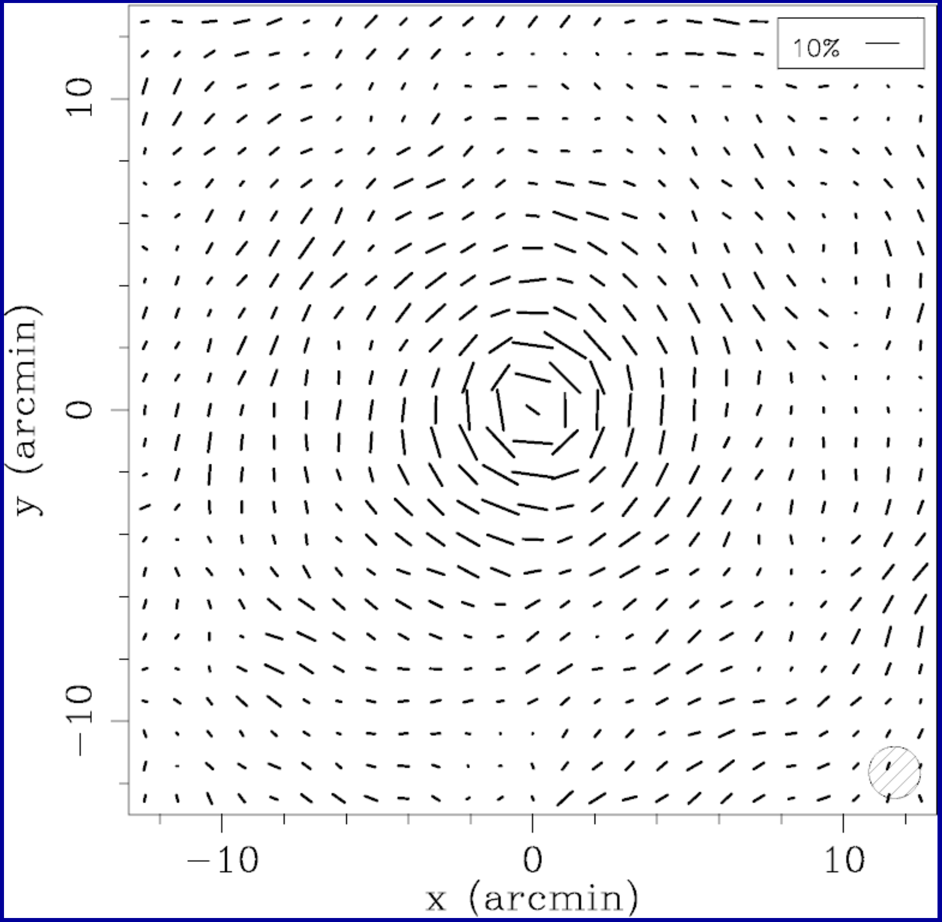
Subaru shear data: N=6

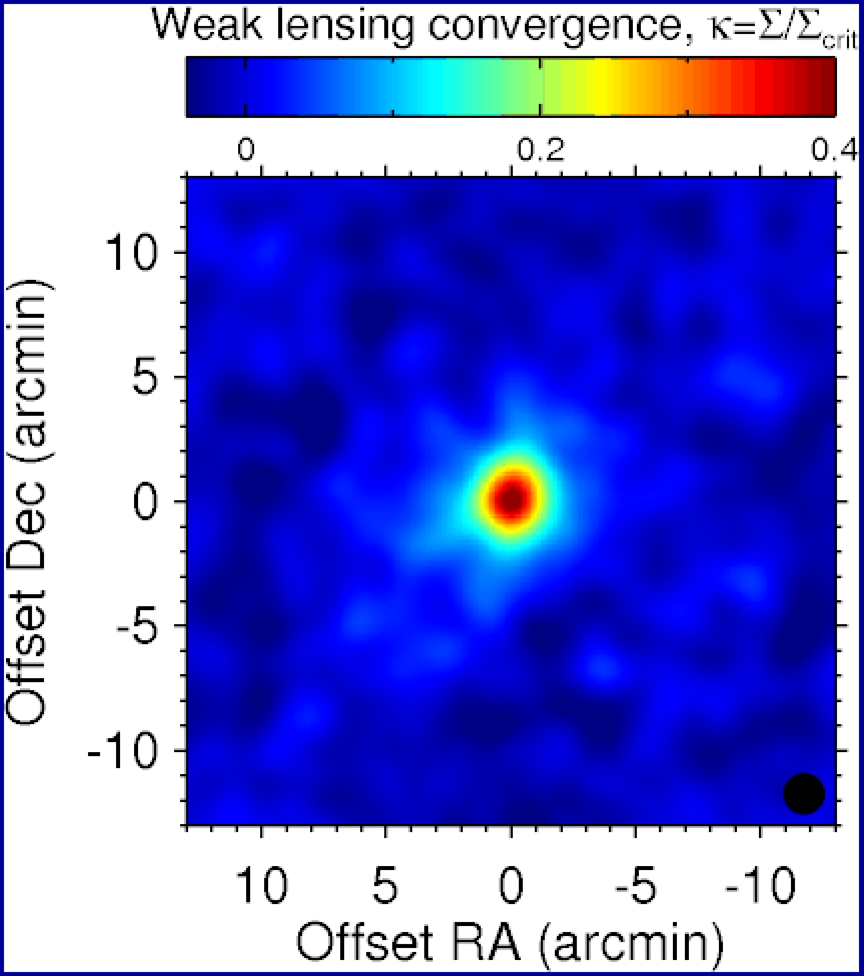




Weak Lensing [3]: Power of Stacking Analysis

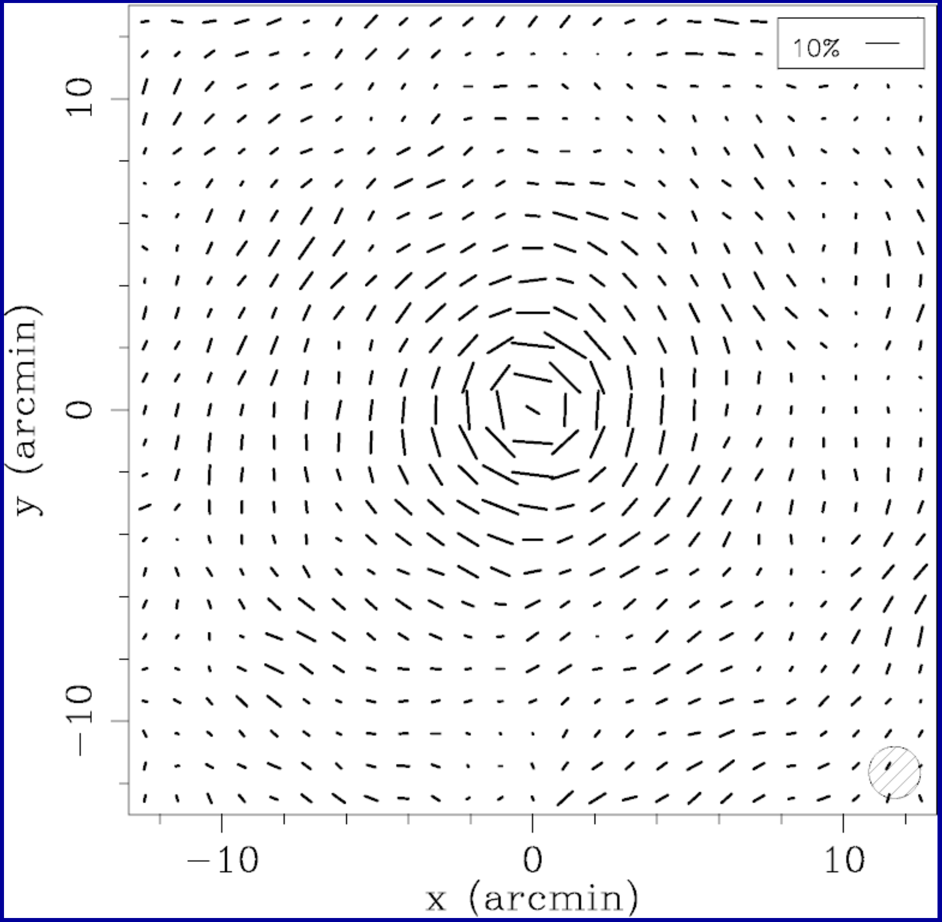
Subaru shear data: N=7

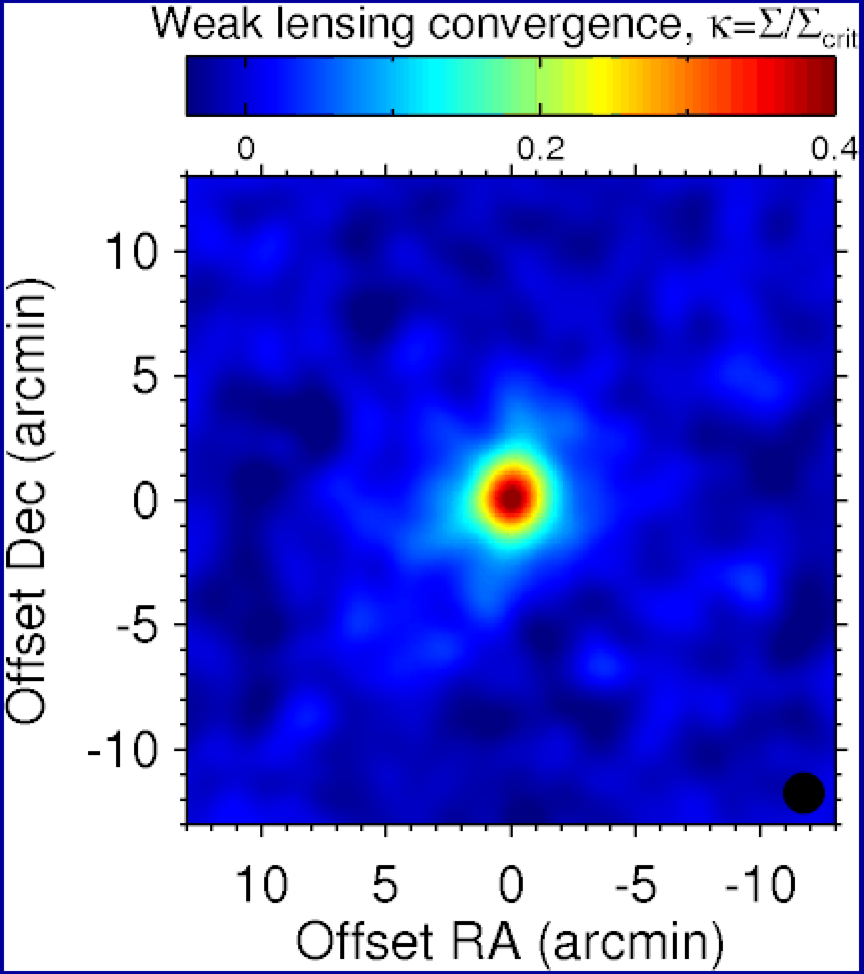




Weak Lensing [3]: Power of Stacking Analysis

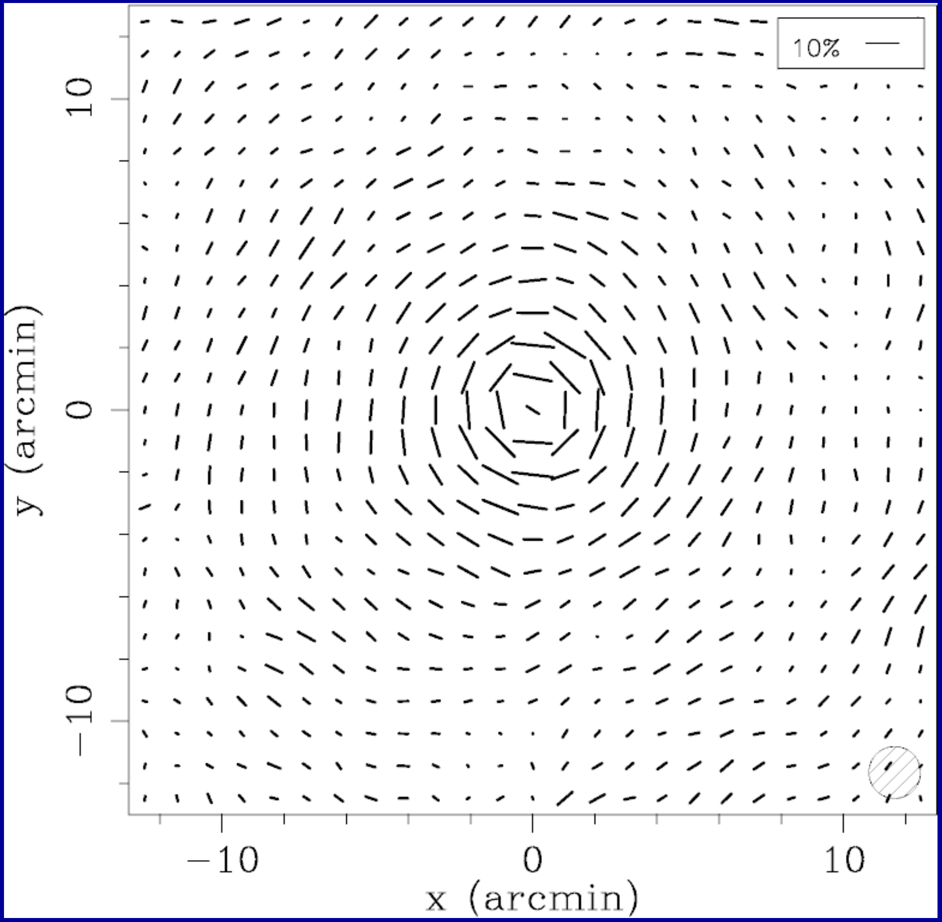
Subaru shear data: **N=8**

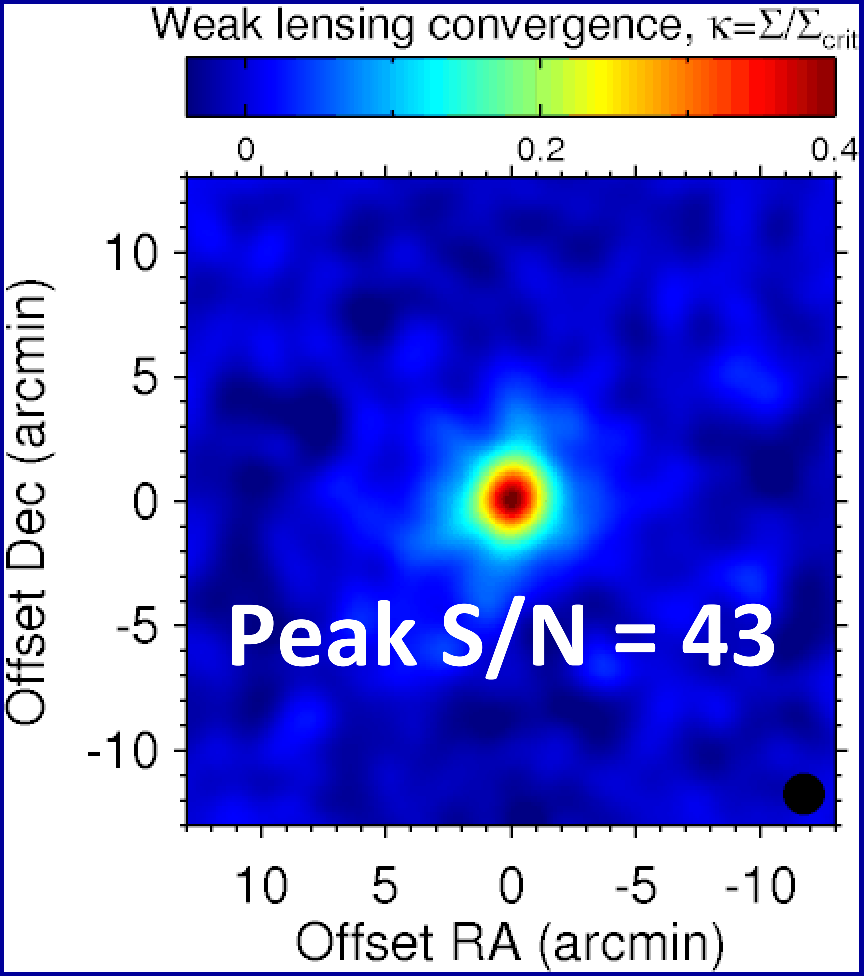




Weak Lensing [3]: Power of Stacking Analysis

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

Subaru Weak Lensing Highlights (Taiwan)

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

   Umetsu et al. 2011, ApJ, 729, 127

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

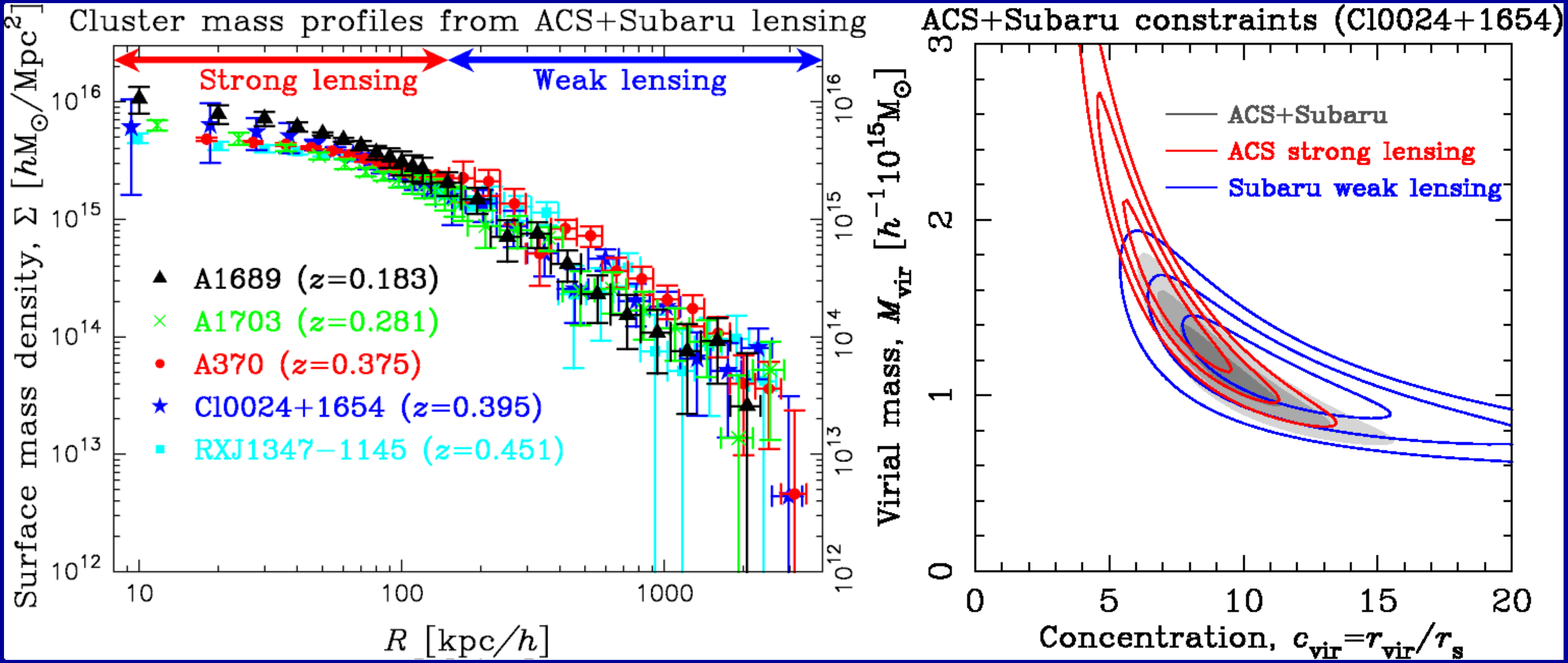
   Nobuhiro Okabe et al., in prep (with M. Takada, K. Umetsu, T. Futamase, G. Smith)

C. **Cluster-Cluster Lensing?**

(A) Cluster Mass Profiles from Full Weak and Strong Lensing

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

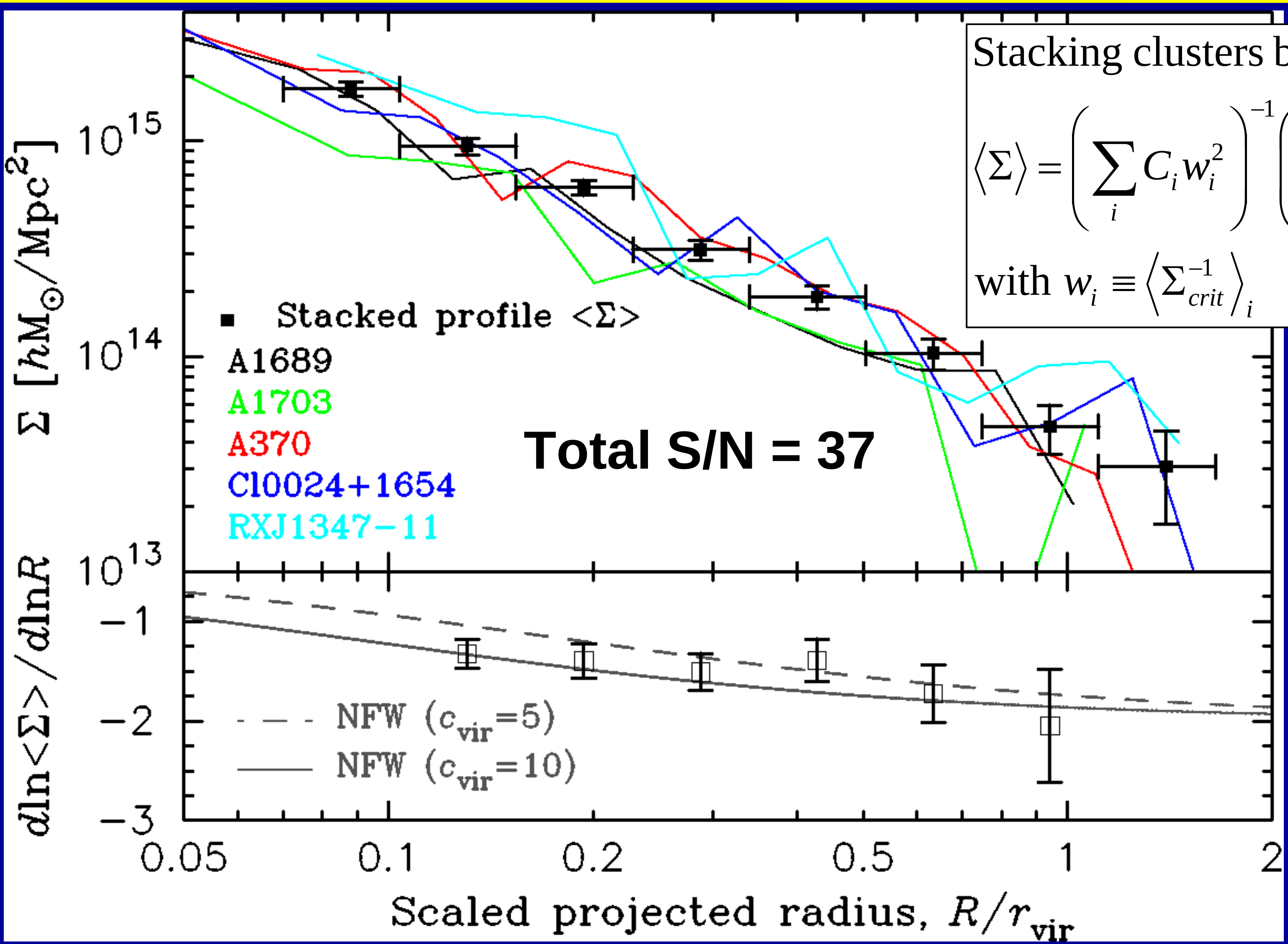
→ Probing the mass density profile in the range [1%, 150%] R_{vir}



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).

Umetsu+11; Umetsu & Broadhurst 08; Umetsu et al. 09, 10; Zitrin et al. 09, 10

Outer density slopes: Stacking 5 high-mass clusters (WL)



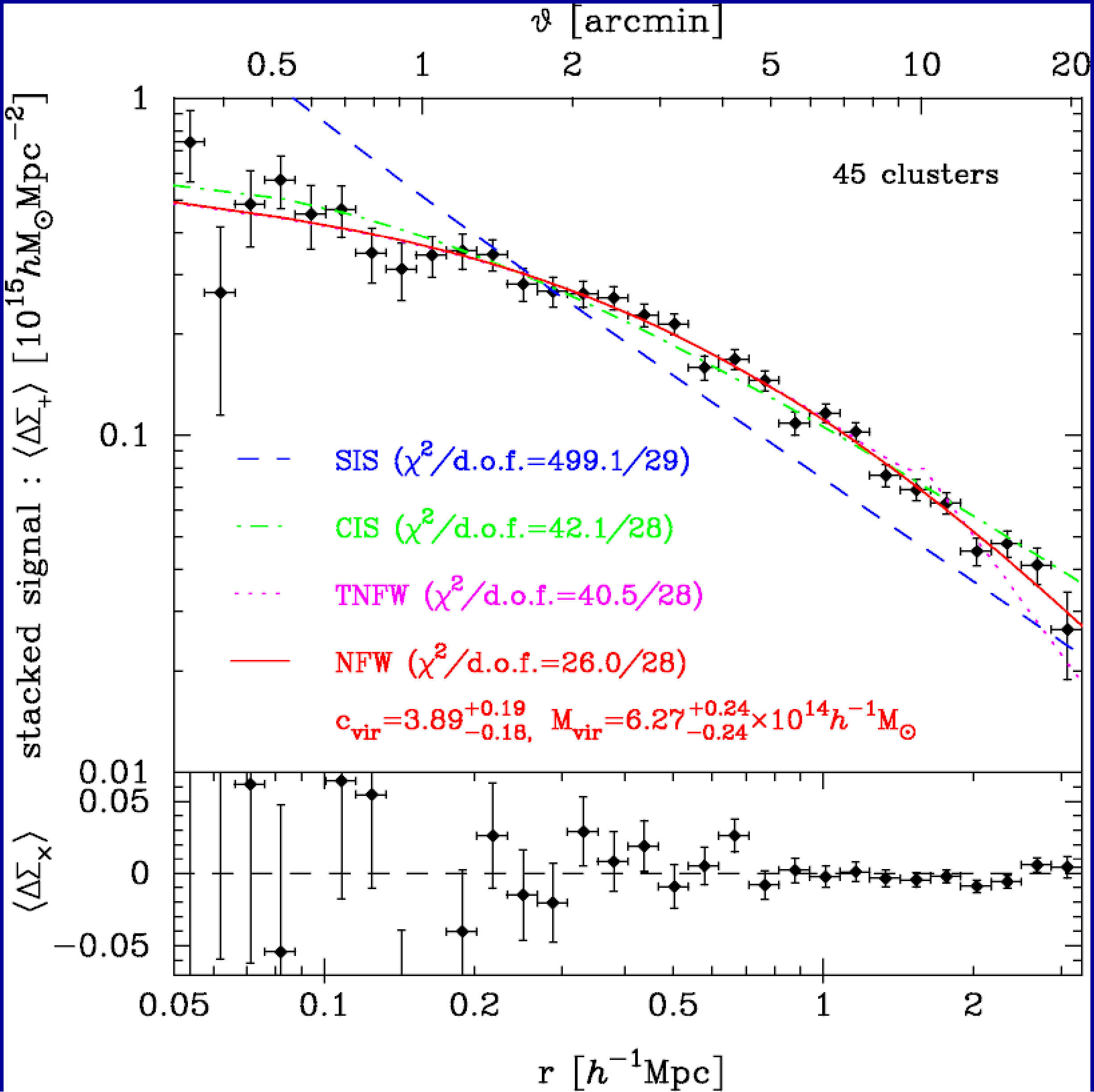
Stacking clusters by

$$\langle\Sigma\rangle = \left(\sum_i C_i w_i^2\right)^{-1}\left(\sum_i C_i w_i \kappa_i\right)$$

with $w_i \equiv \langle \Sigma_{crit}^{-1}\rangle_i$

Umetsu et al. 2011, ApJ, 729, 127

(B) Stacked Weak Lensing: 45 Clusters

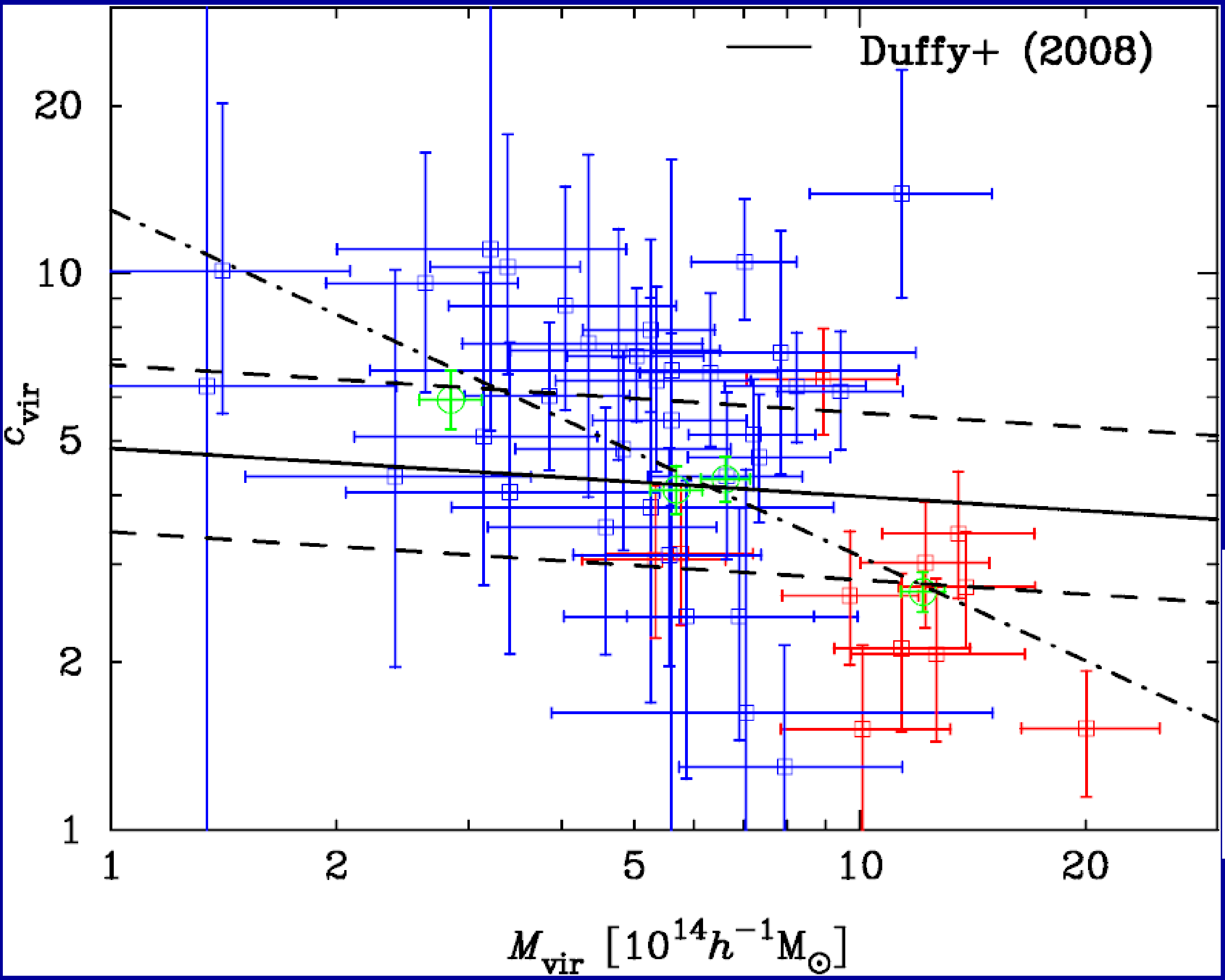


Stacking a sample of 45 clusters (that can be well fitted with an NFW) out of 52 high X-ray LoCuSS clusters (0.15<z<0.3, $L_x/E(z)^{2.7}$ > 4.2e44 erg/s).

SIS/CIS and truncated-NFW models rejected, while only NFW fits the stacked profile

Okabe et al. in prep (with Takada, Umetsu, Futamase, Smith)

Cluster M_{vir}-C_{vir} relation of 45 X-ray luminous clusters



$$c_{vir} = c_0 (M_{vir} / 10^{14} M_{sun} / h)^{-\alpha}$$

$$c_0 = 13.0^{+3.5}_{-2.3}$$

$$\alpha = 0.62^{-0.10}_{-0.09}$$

$$\Delta\alpha_{sys} = 0.01^{+0.09}_{-0.07}$$

Red: SIS rejected

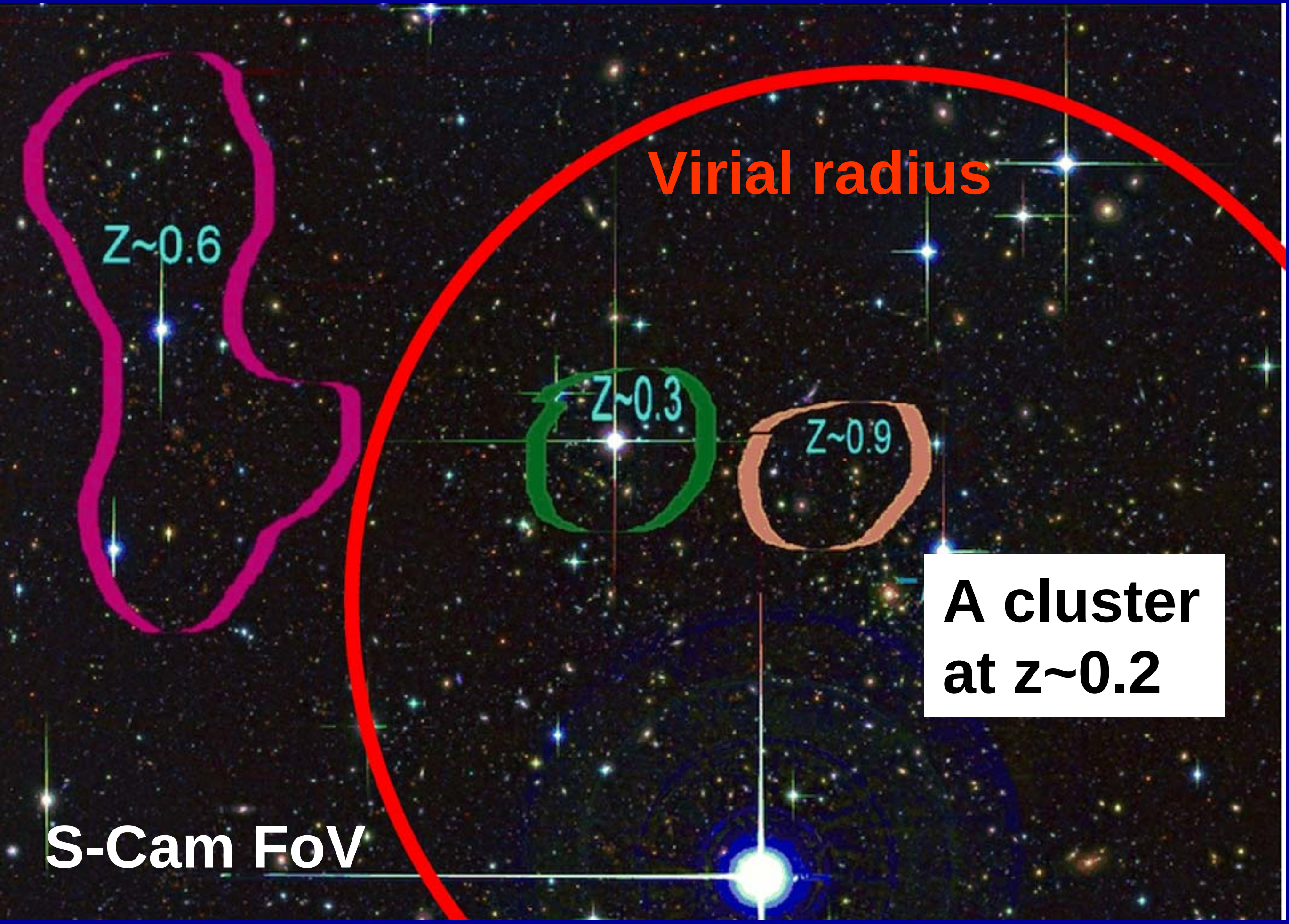
Blue: NFW consistent

Green: stacked WL

5σ detection of the C-M relation, i.e., *"the more massive the clusters, the less concentrated"*. Okabe et al. in prep

Cluster-Cluster Lensing (CCL)

Deep HSC color-imaging will reveal a number of groups and clusters in a single FoV, revealing potential CCL events.



In WMAP7 cosmology, we expect only ~10 CCL events in the all sky survey with a ST mass function (>5e12 Msun), which is a few factor less than what was predicted by Cooray et al. (1999) due to the discrepancy in $\sigma 8$.

Several CLL events have been already reported.

Zitrin et al. in prep.

Summary

- **Cluster WL techniques have been fully developed and deployed in the past several years, ready for HSC**
  - 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 HSC**
- **Multicolor imaging with HSC will reveal a number of interesting merging and CCL events**
- **Hyper wide FoV of HSC will be an excellent instrument to probe nearby clusters in full details.**