Halo profiles from lensing observations of clusters

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This talk is based on:

"Combined strong and weak lensing analysis of 28 clusters from Sloan Giant Arcs Survey"

arXiv:1109.2594

Collaborators:

Matt Bayliss (Chicago → Harvard)
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Keren Sharon (Chicago)
Mike Gladders (Chicago)
Priya Natarajan (Yale)
Joe Hennawi (MPIA)
Ben Koester (Chicago)

Expected halo profile in ΛCDM

Cuspy

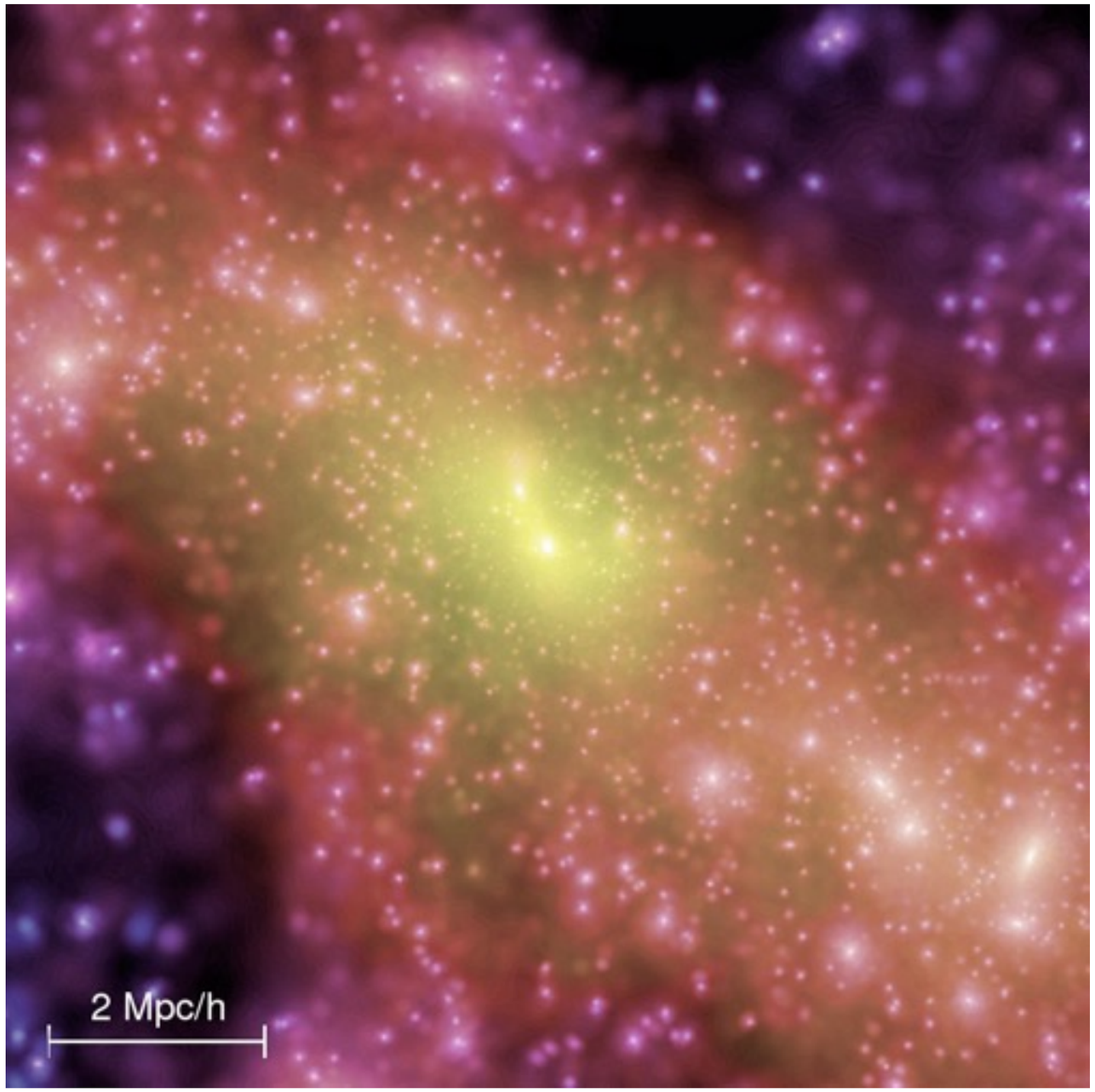
so-called NFW profile, slope gets shallower toward the center

Concentration

correlated with mass, more massive halos are less concentrated

Triaxial

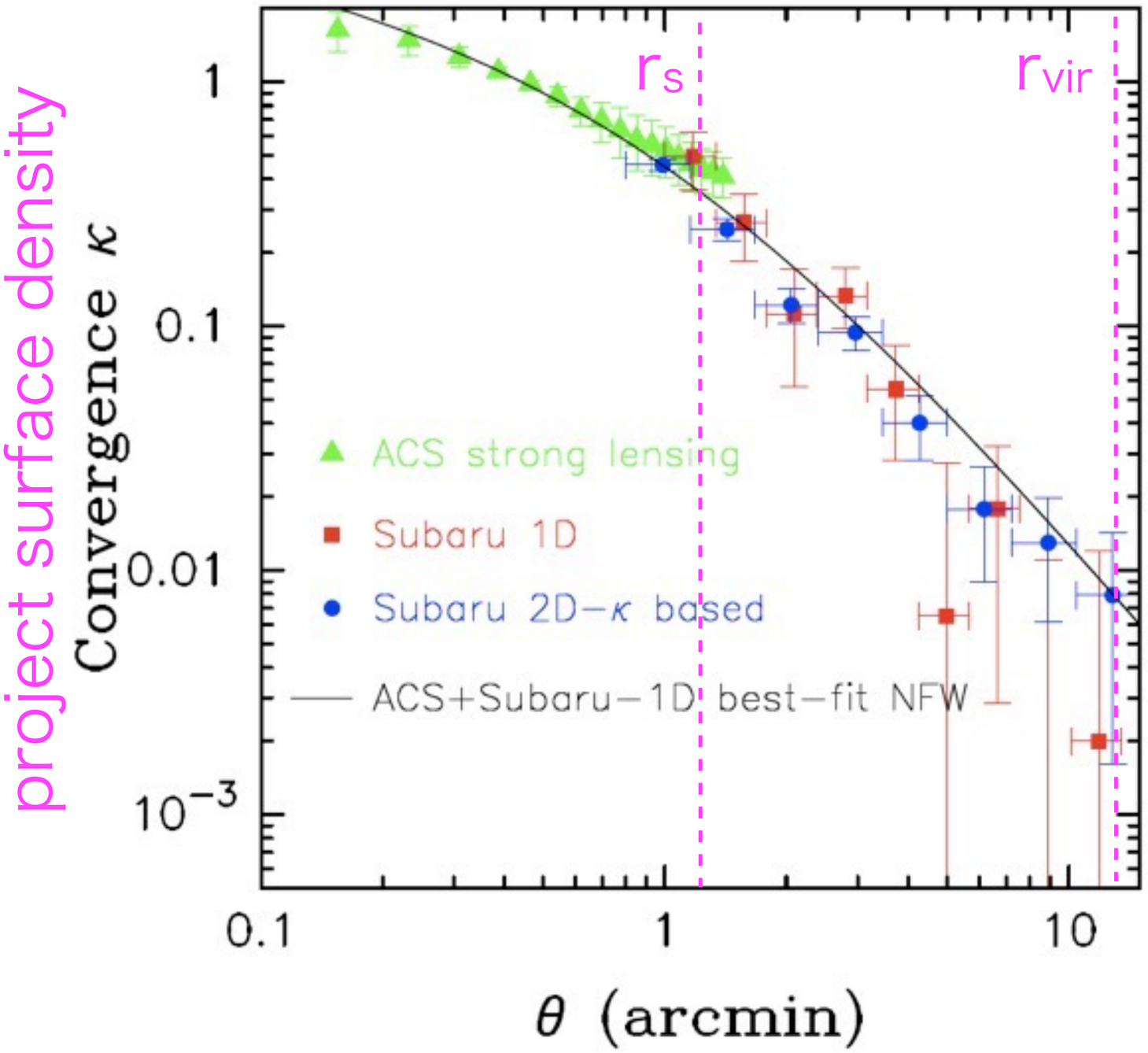
not spherical, highly elongated



http://www.mpa-garching.mpg.de/galform/millennium/

Anomalously high concentration?

Umetsu, Takada & Broadhurst (2007)



lensing analysis of Abell 1689

$c_{vir} \sim r_{vir}/r_s \sim 12$

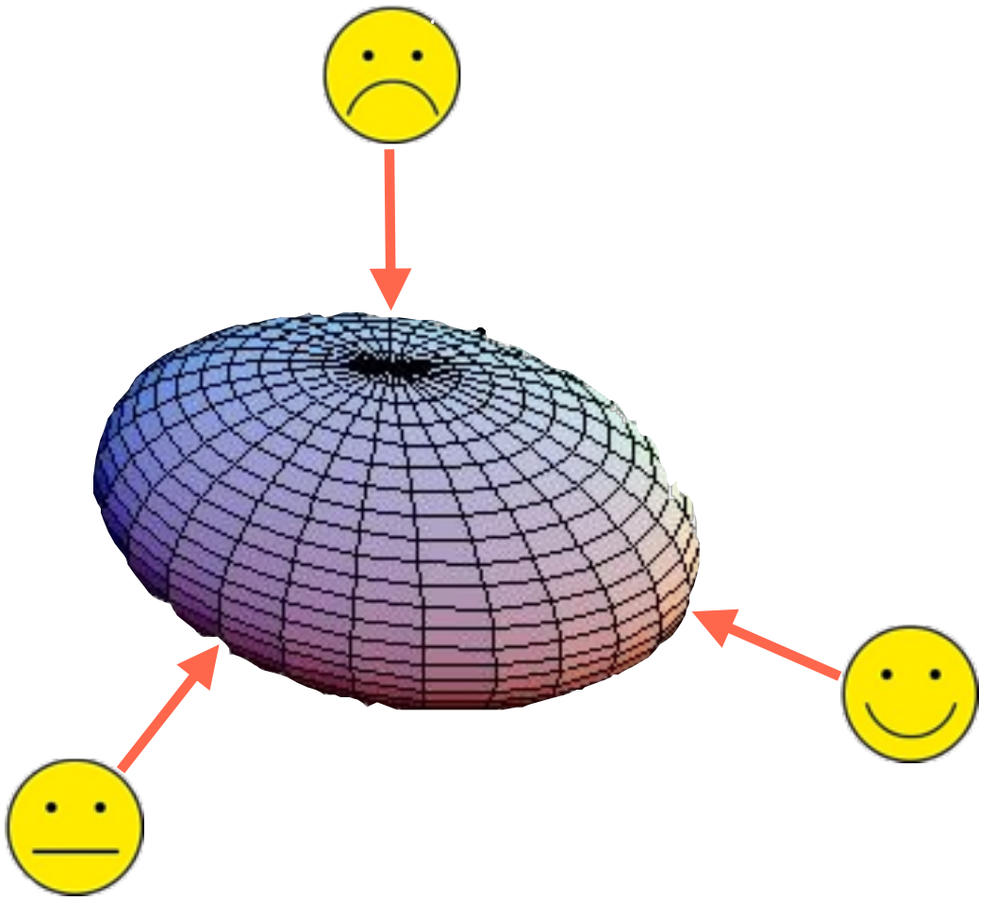
much larger than typical c_{vir} (~4), may be hard to reconcile with ΛCDM

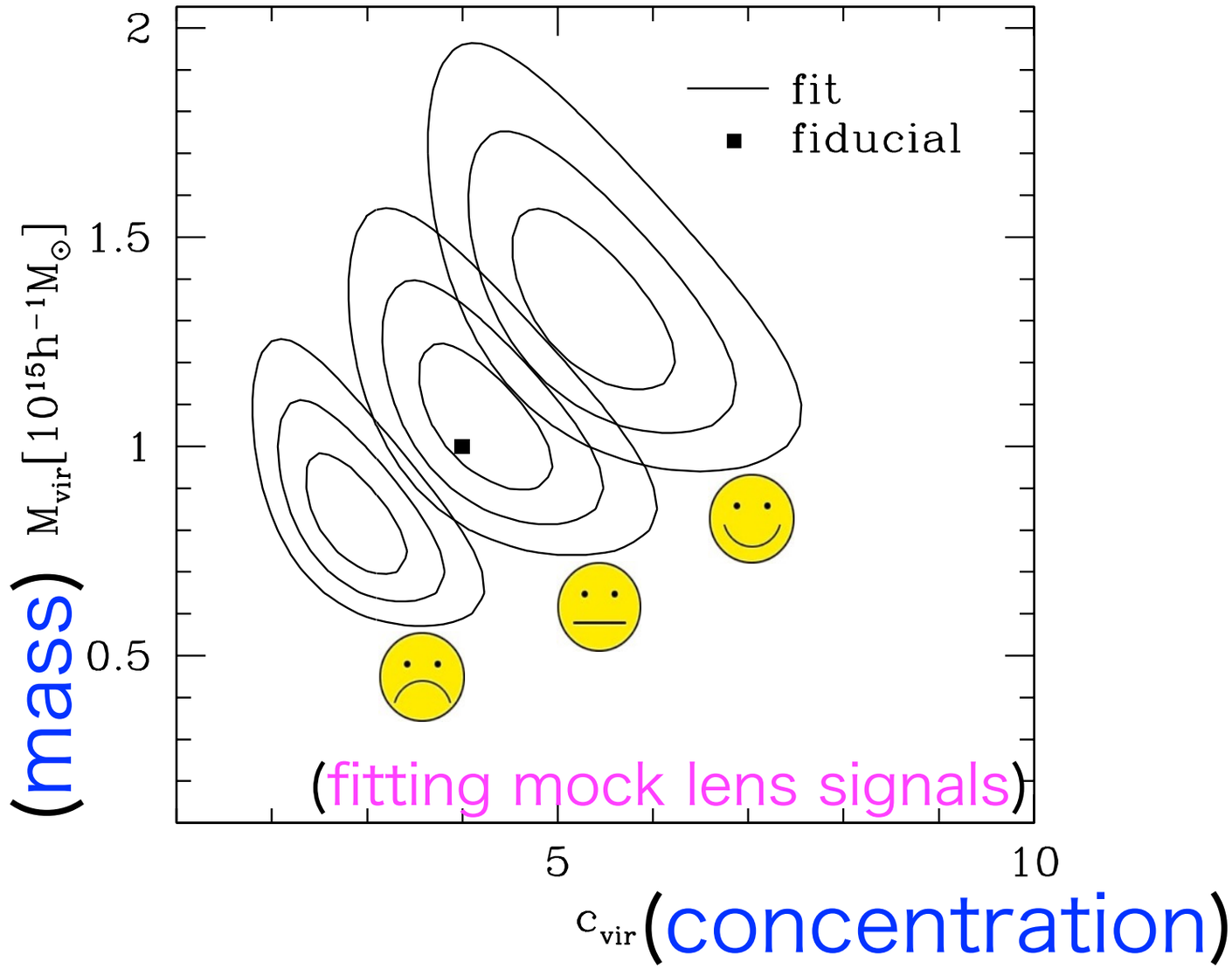
triaxiality?

other clusters?

Impact of triaxiality on lensing

Oguri, Takada, Umetsu & Broadhurst (2005)





lensing-derived masses and concentrations (assuming spherical halo) are significantly affected by the orientation of the cluster!

High concentration controversy

High concentrations inconsistent with ΛCDM?

Yes

Broadhurst et al. (2005)
Comerford & Natarajan (2007)
Broadhurst & Barkana (2008)
Broadhurst et al. (2008)
Oguri et al. (2009)
Sereno et al. (2010)
Zitrin et al. (2011)
Umetsu et al. (2011)
Meneghetti et al. (2011)
Gralla et al. (2011) [talk by M. Gralla]

No

Oguri et al. (2005)
Oguri & Blandford (2009)
Corless et al. (2009)
Okabe et al. (2010)
Richard et al. (2010)
Morandi et al. (2011)
Sereno et al. (2011)

(blue: I'm involved)

Sloan Giant Arcs Survey (SGAS)

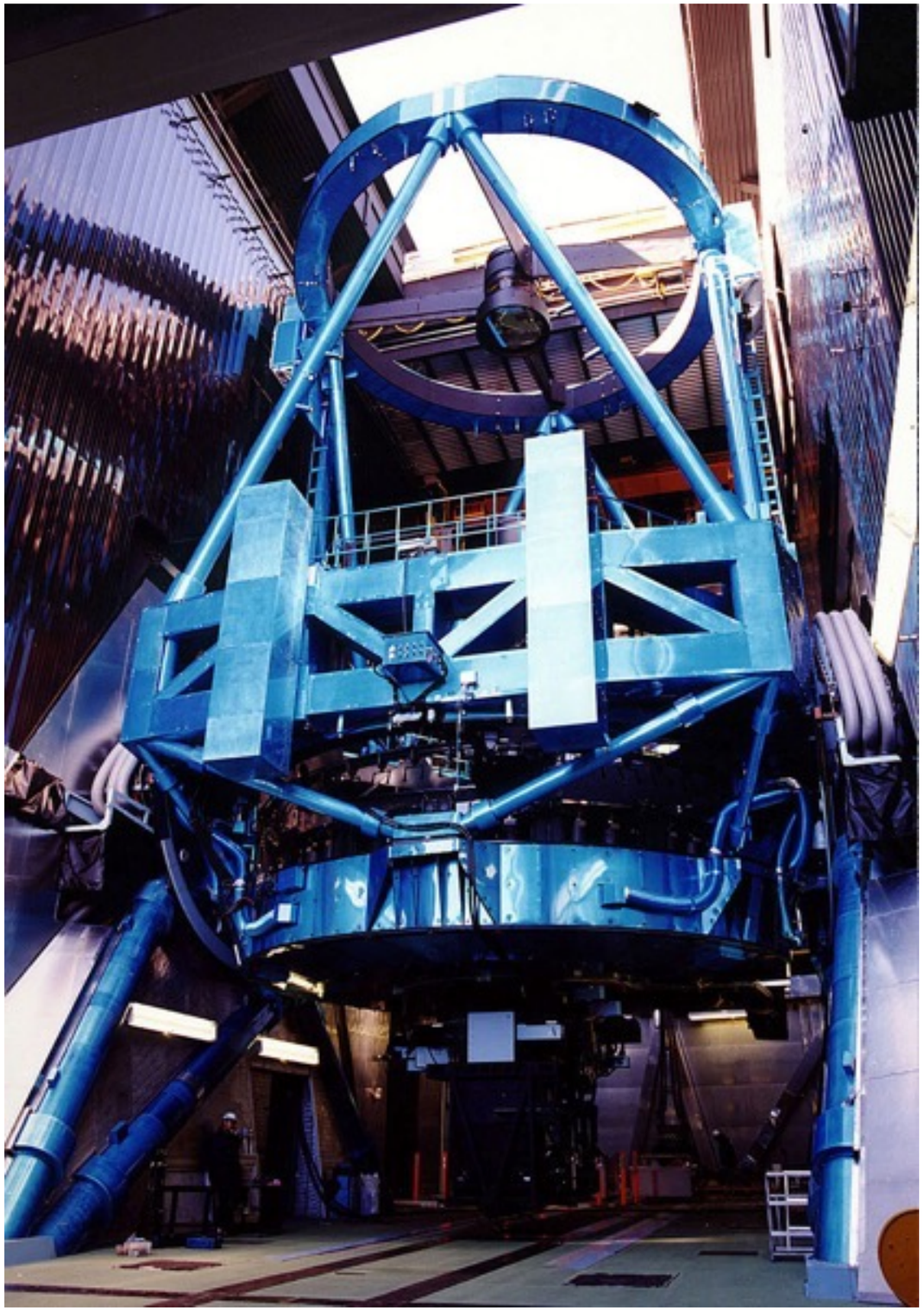
Hennawi et al. (2008), Bayliss et al. (2011)
Gladders et al., in prep.

based on optical (red-sequence) clusters from the Sloan Digital Sky Survey

look for strong lenses by visual inspection of SDSS or follow-up images

>40 clusters with prominent giant arcs discovered, extensive arc spectroscopy w/ Gemini/GMOS

Subaru/Suprime-cam follow-up



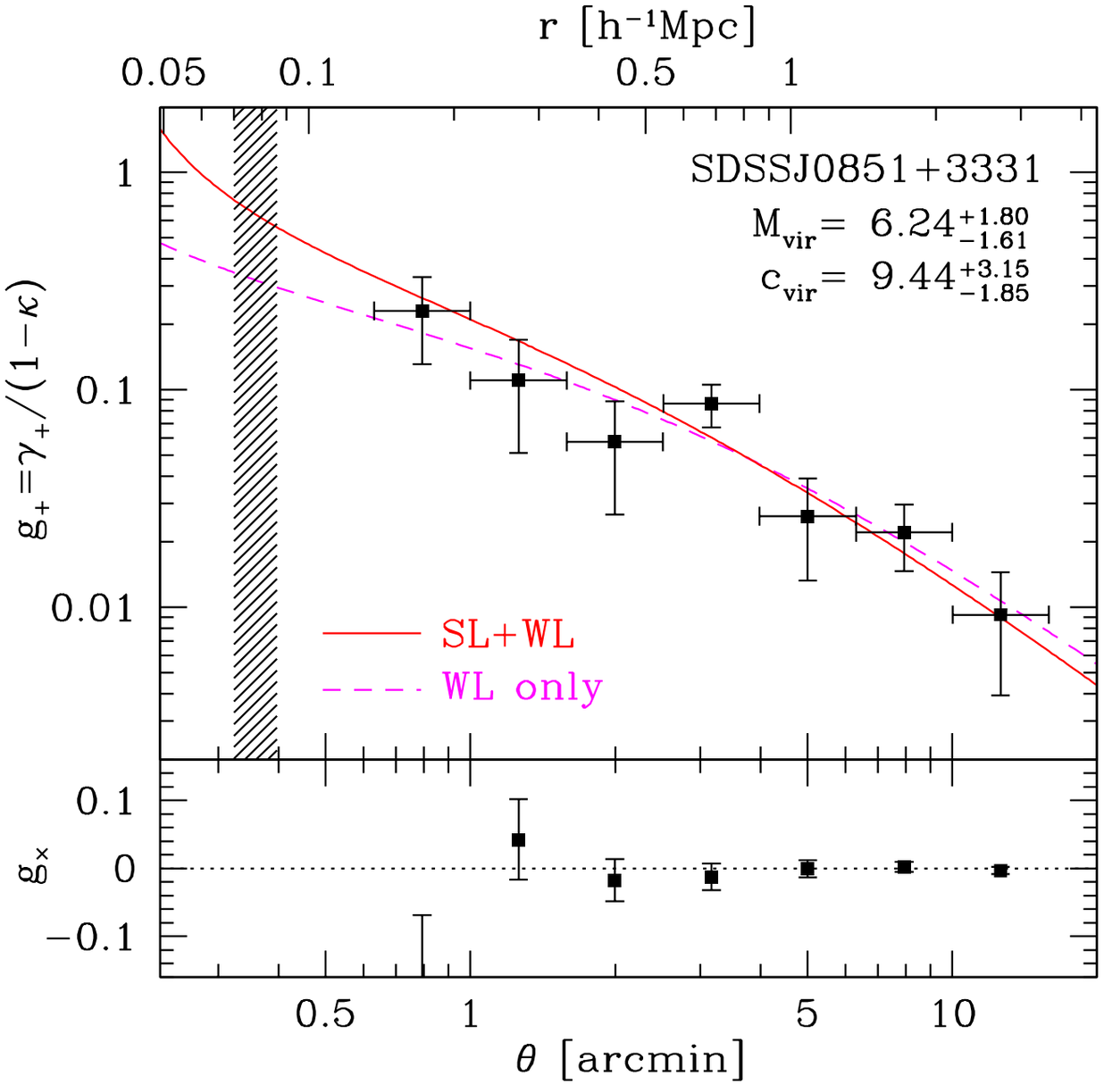
world best telescope
for cluster weak lensing!

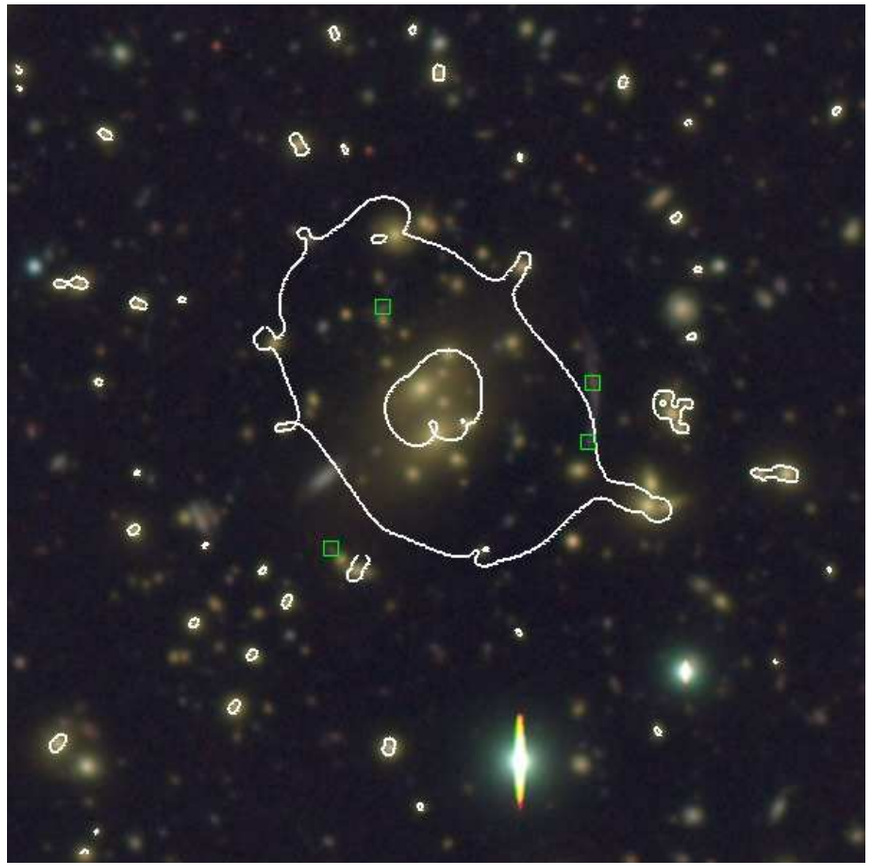
gri-band imaging
(g ~ 20min, r ~ 40min, i ~ 30min)

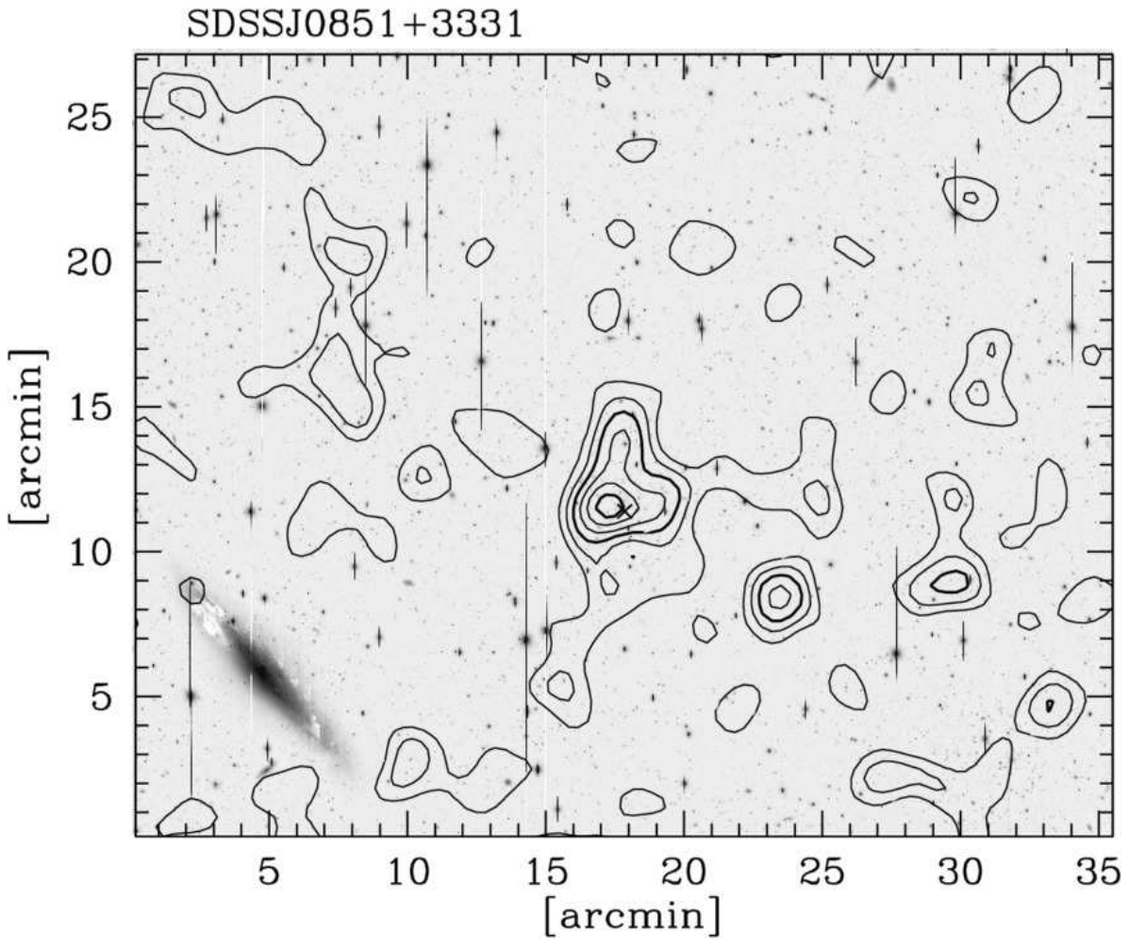
~7 nights allocated from
2007 to 2011
(PI: M. Oguri)

→ strong+weak lensing
analysis for ~30 clusters

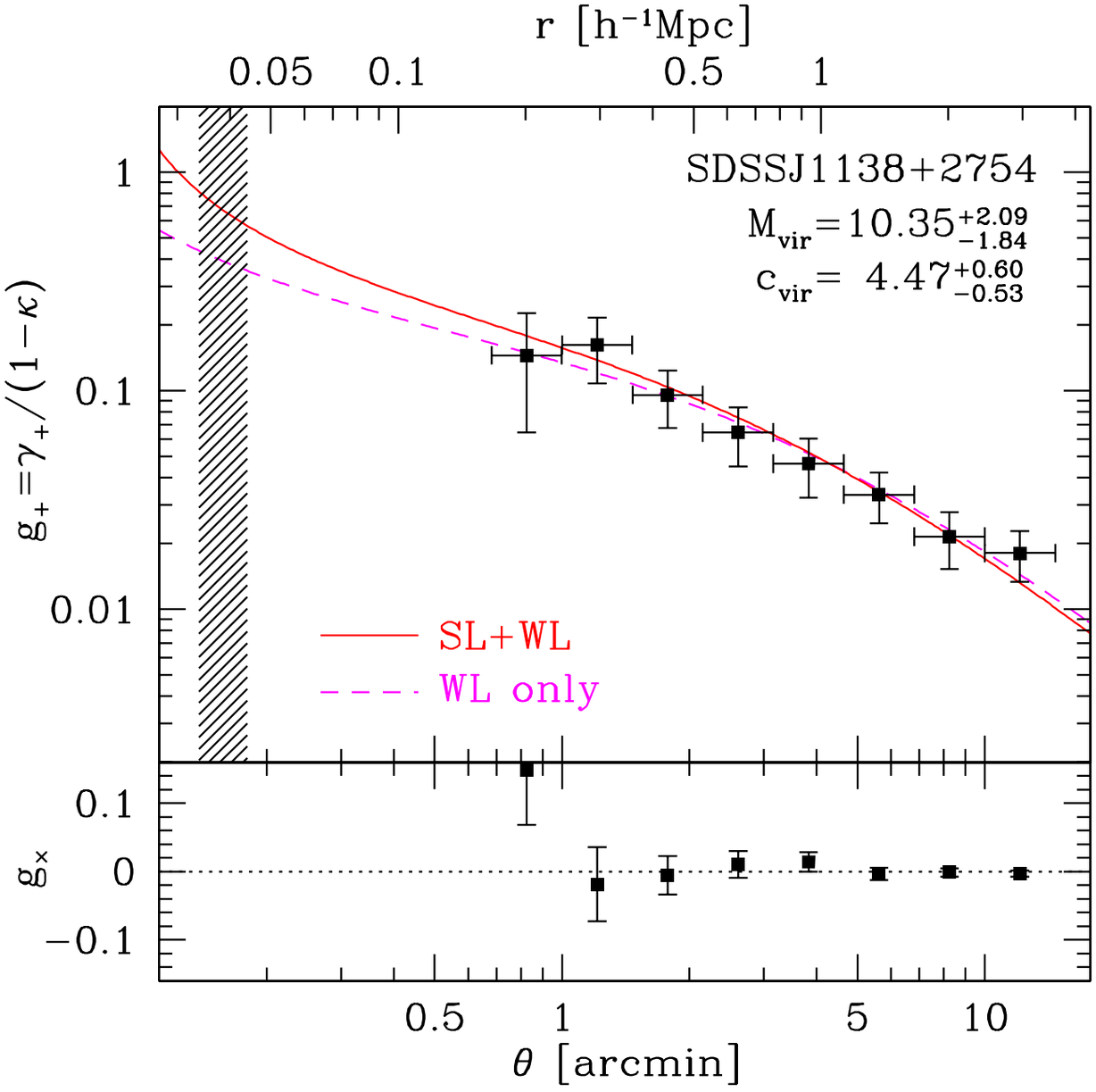
Example: SDSS0851

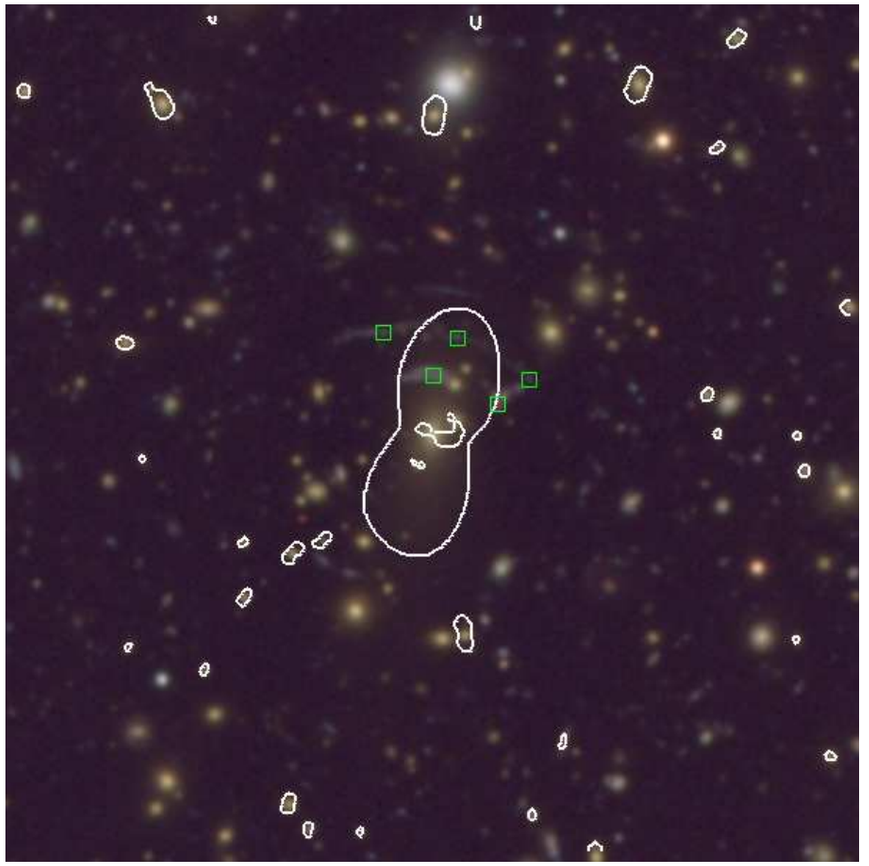


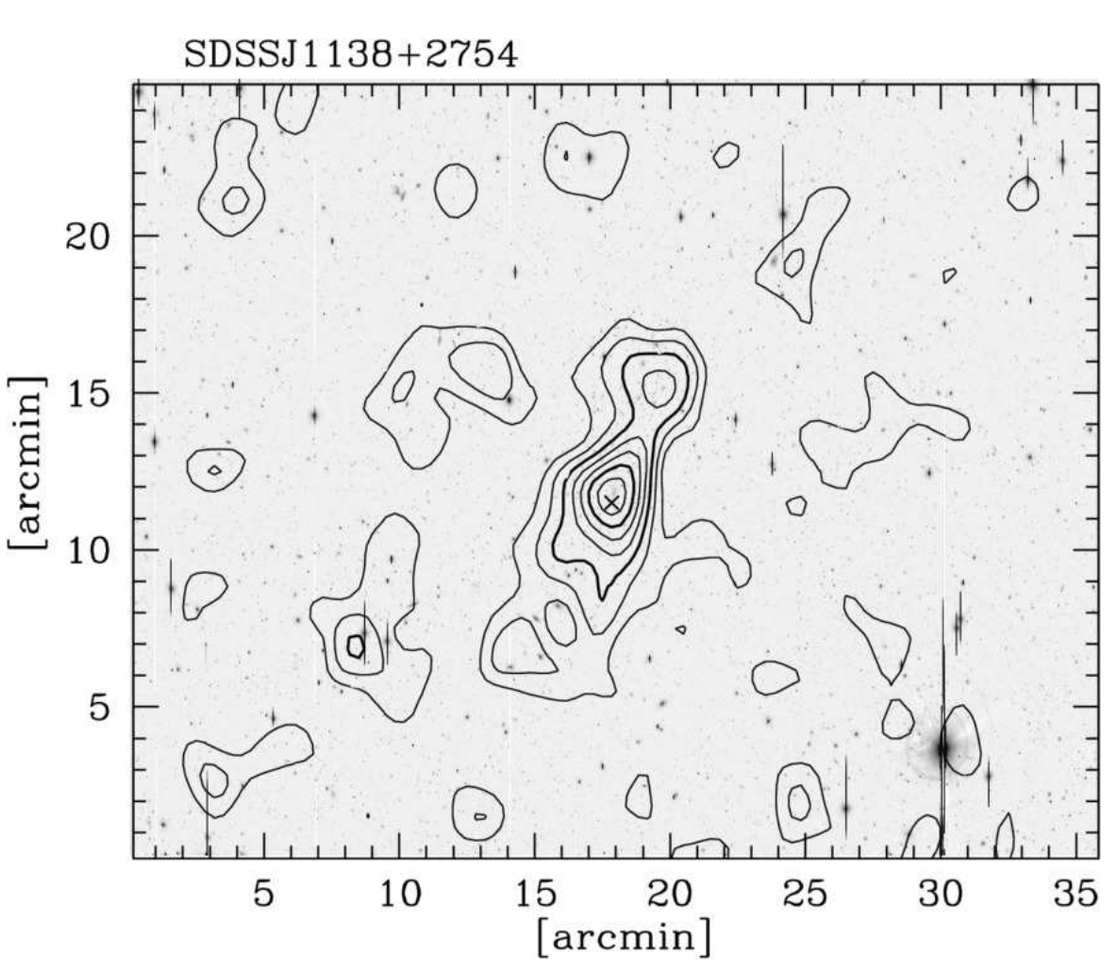




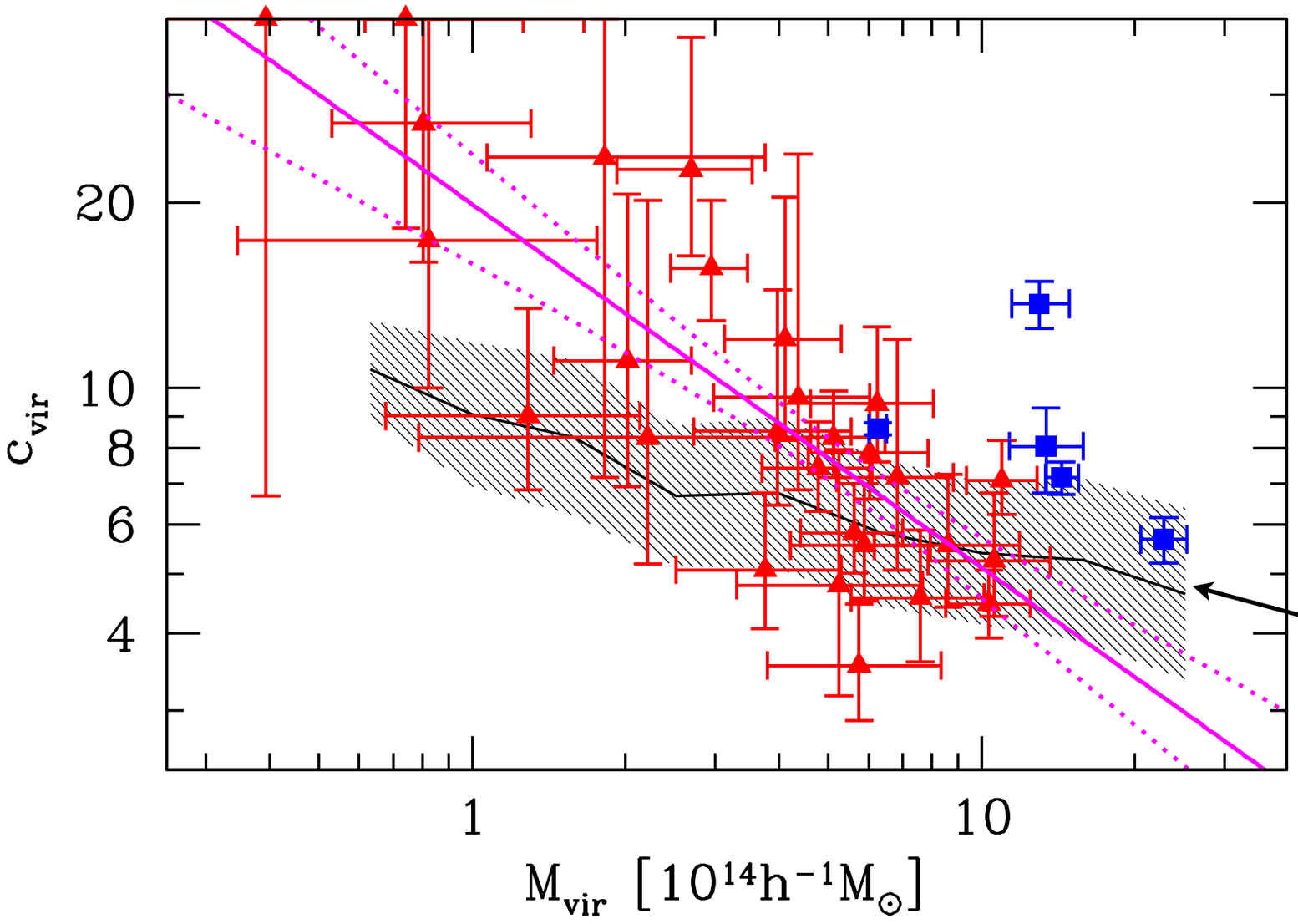
Example: SDSS1138







Mass-concentration relation



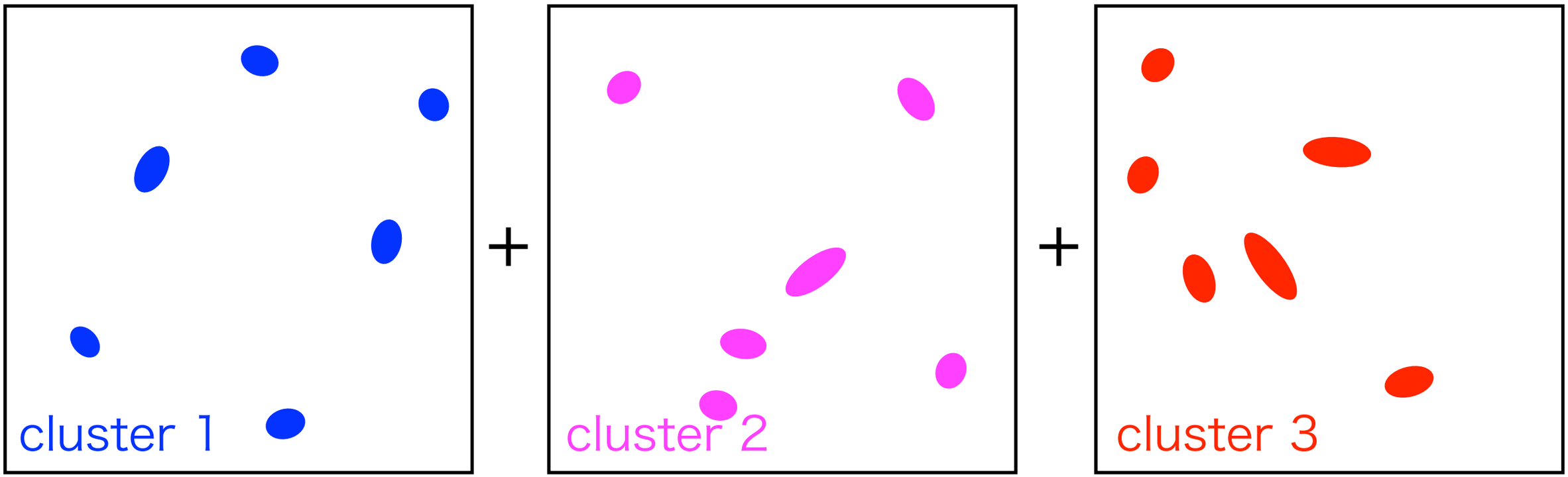
our sample

from literature
(Umetsu et al. 2011;
Zitrin et al. 2011)
[talk by K. Umetsu]

ΛCDM prediction
w/ lensing bias

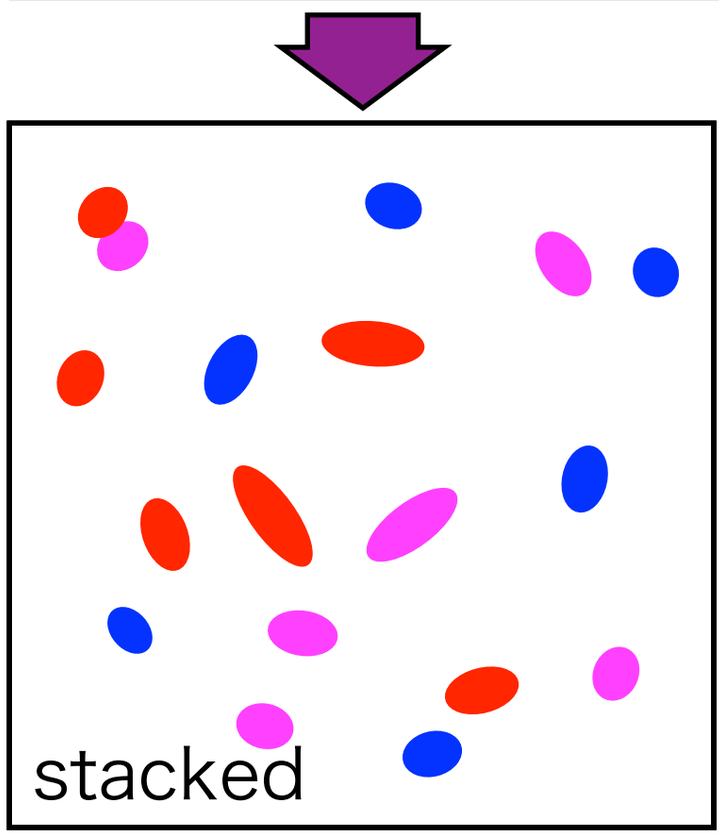
mass dependence of c_{vir} detected
slope too steep? ($c_{vir} \propto M_{vir}^{-0.59\pm0.12}$) (cf. Okabe et al. 2010)
c_{vir} consistent w/ theoretical prediction at high mass
low mass excess probably due to baryon cooling

Stacked lensing analysis

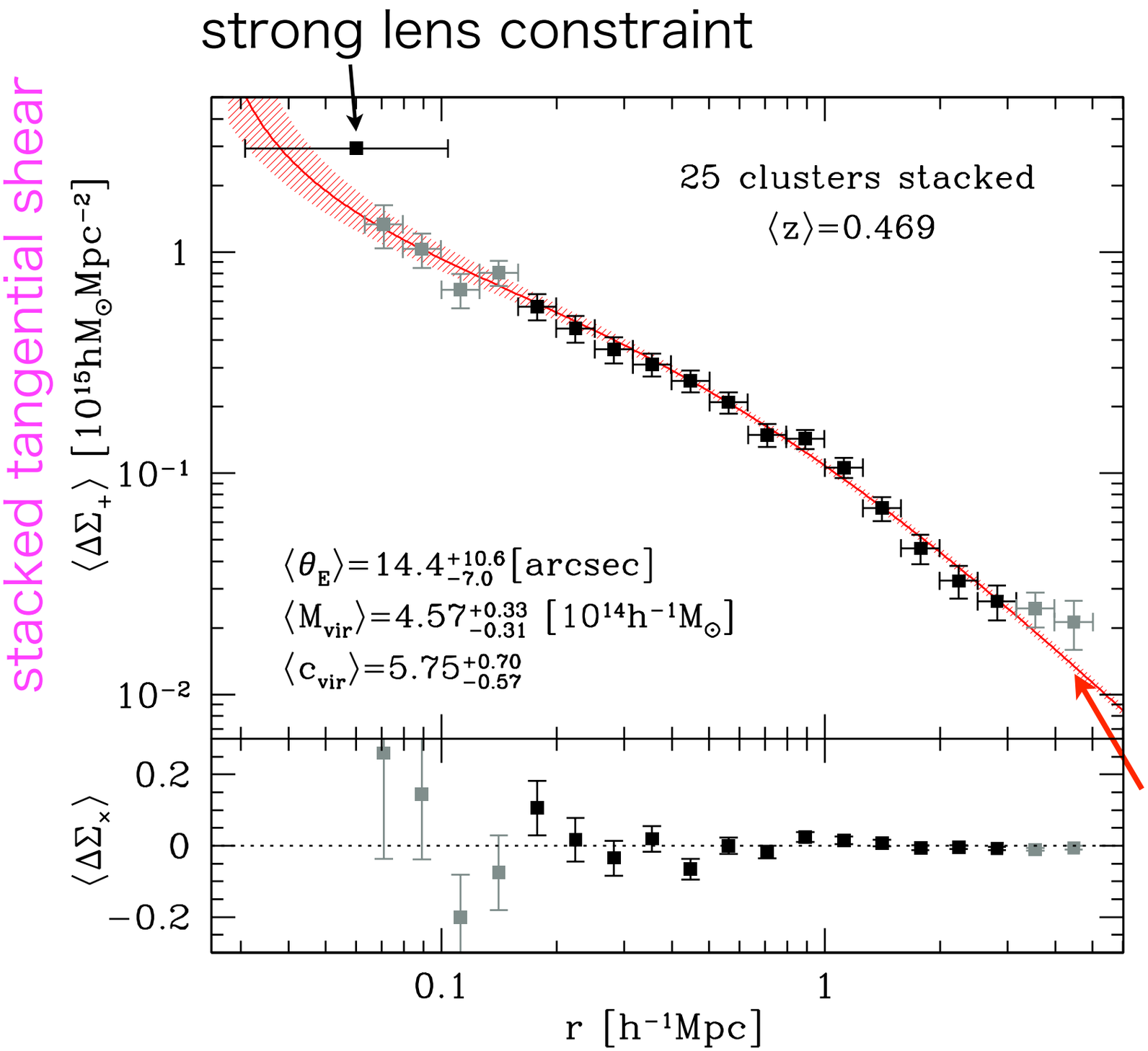


combine weak lensing shear measurements for many clusters

higher S/N, leading to accurate mean profile measurement



Stacked lensing analysis

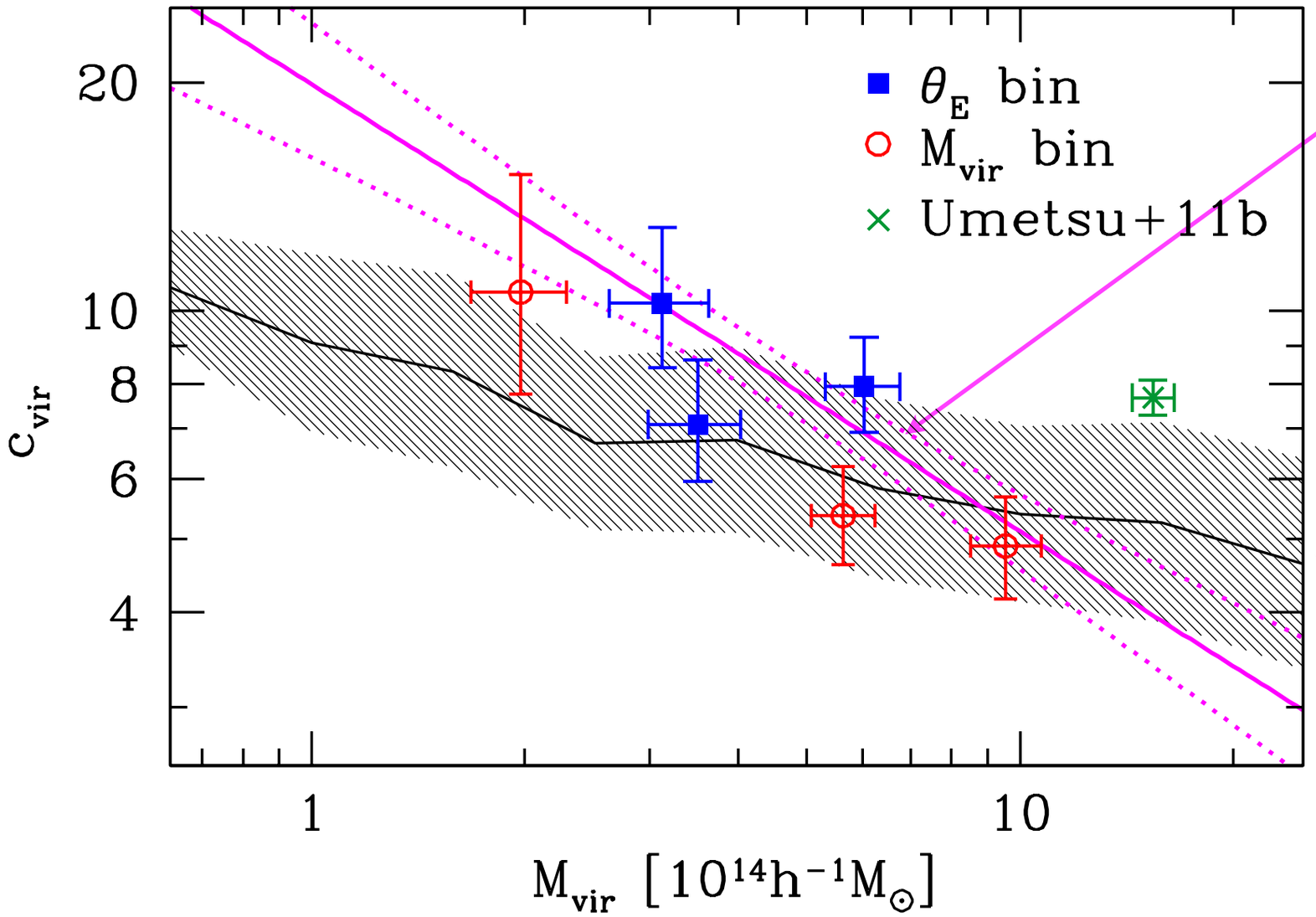


high S/N lensing shear profile by stacking 25 clusters

follow NFW well

NFW fit

Stacked lensing analysis



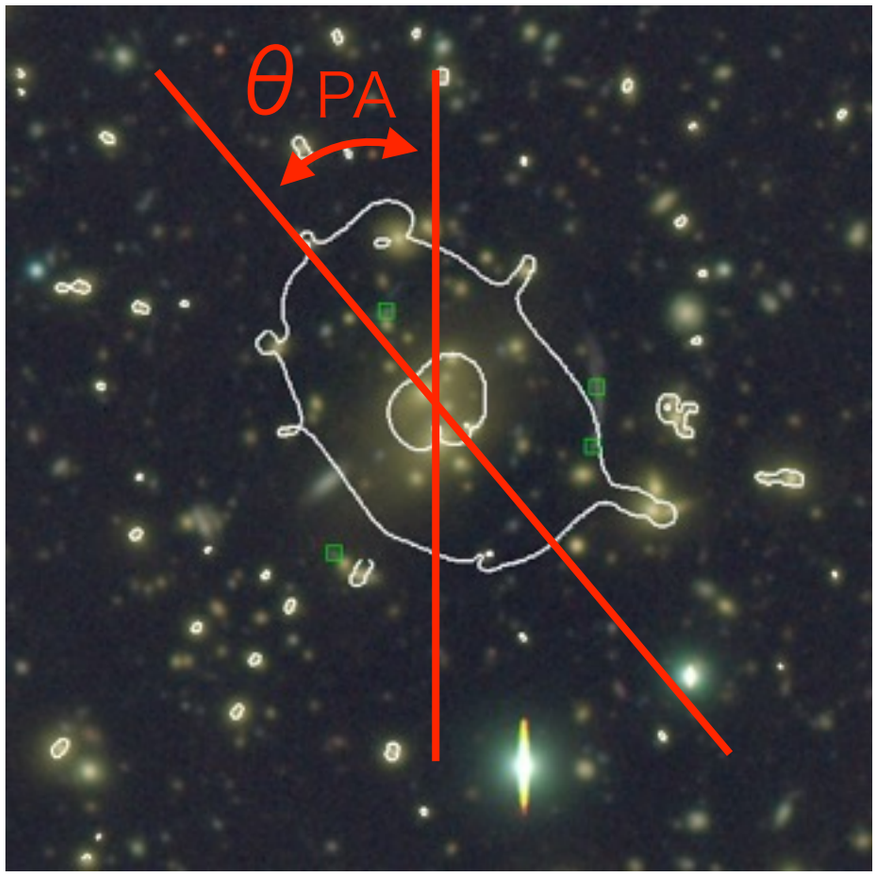
best-fit M-c relation from individual analysis of clusters

ΛCDM prediction w/ lensing bias

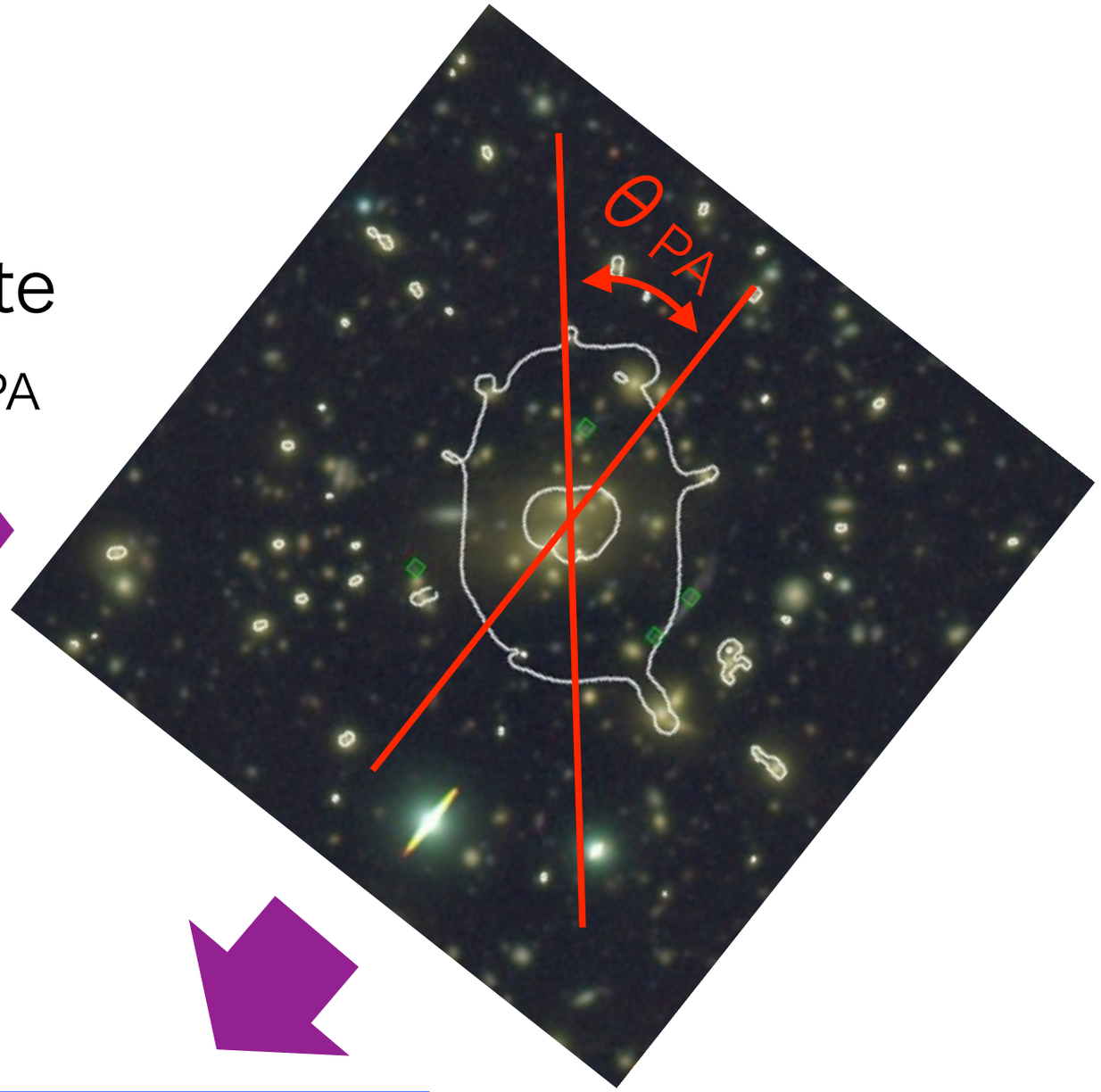
consistent with individual analysis

Shape: 2D stacking analysis

strong lens modeling



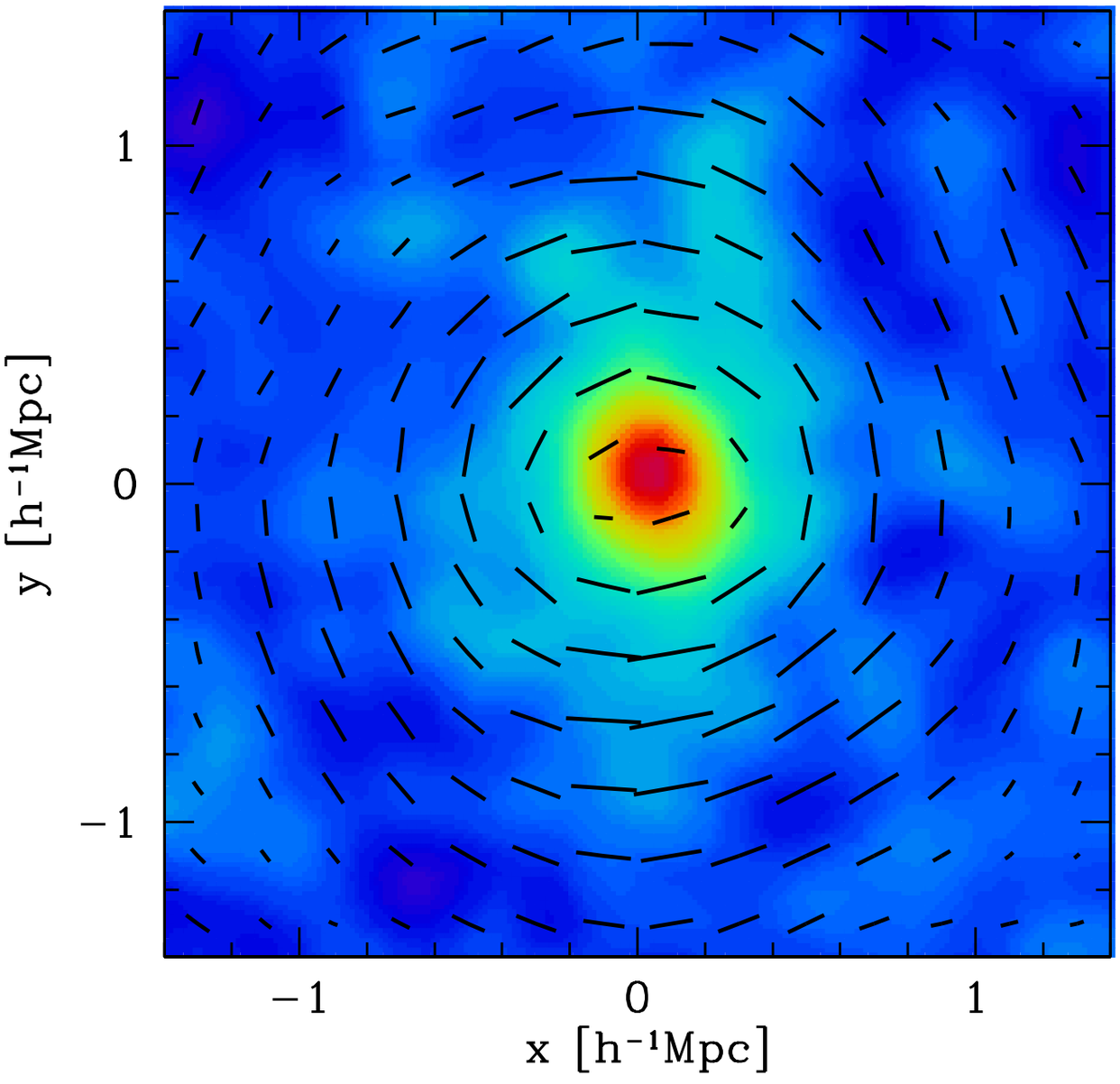
rotate
$-\theta_{\mathrm{PA}}$



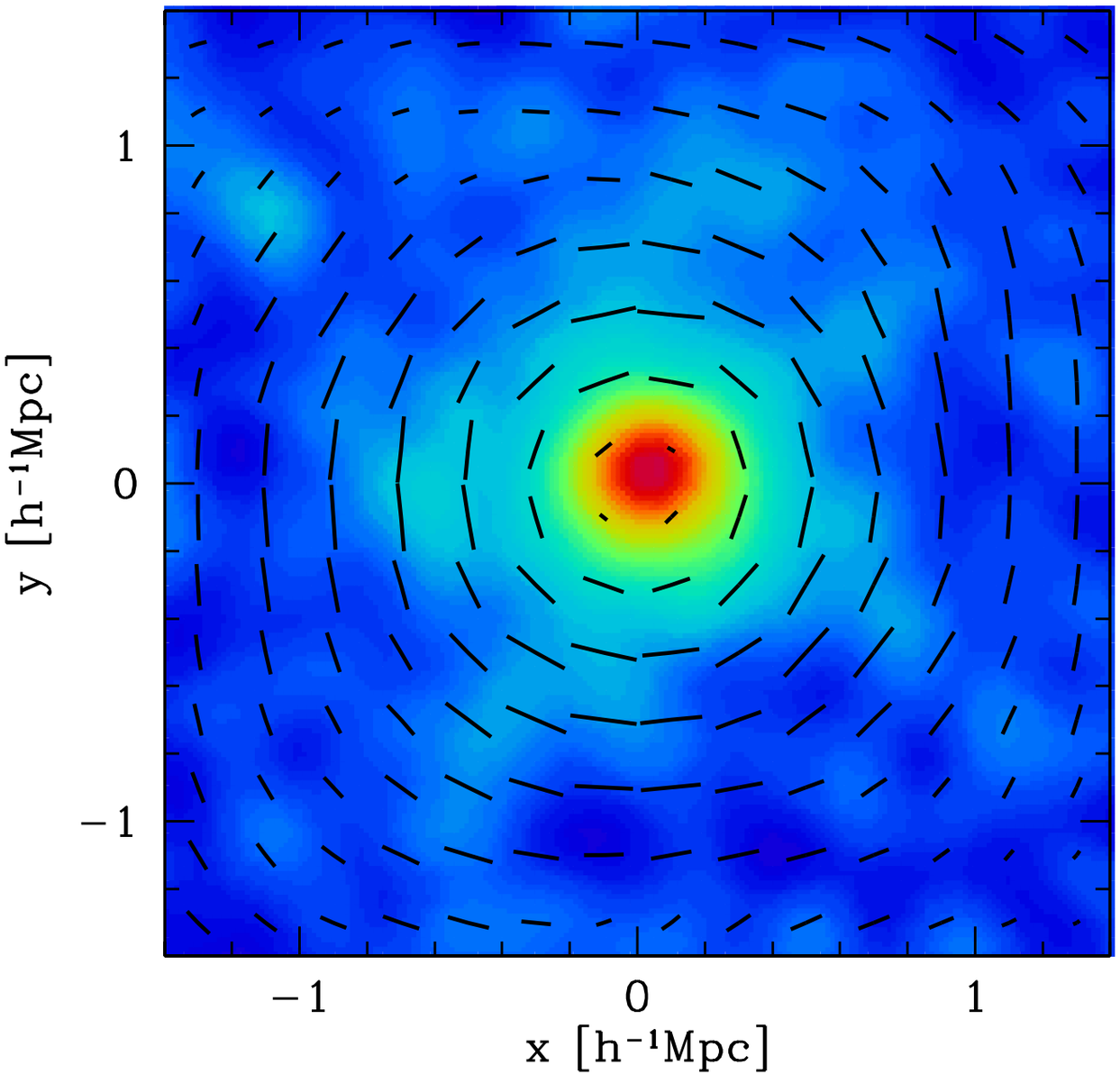
stacked weak
lensing analysis

(No assumption on mass-light alignment!)

stacked 2D weak lensing map

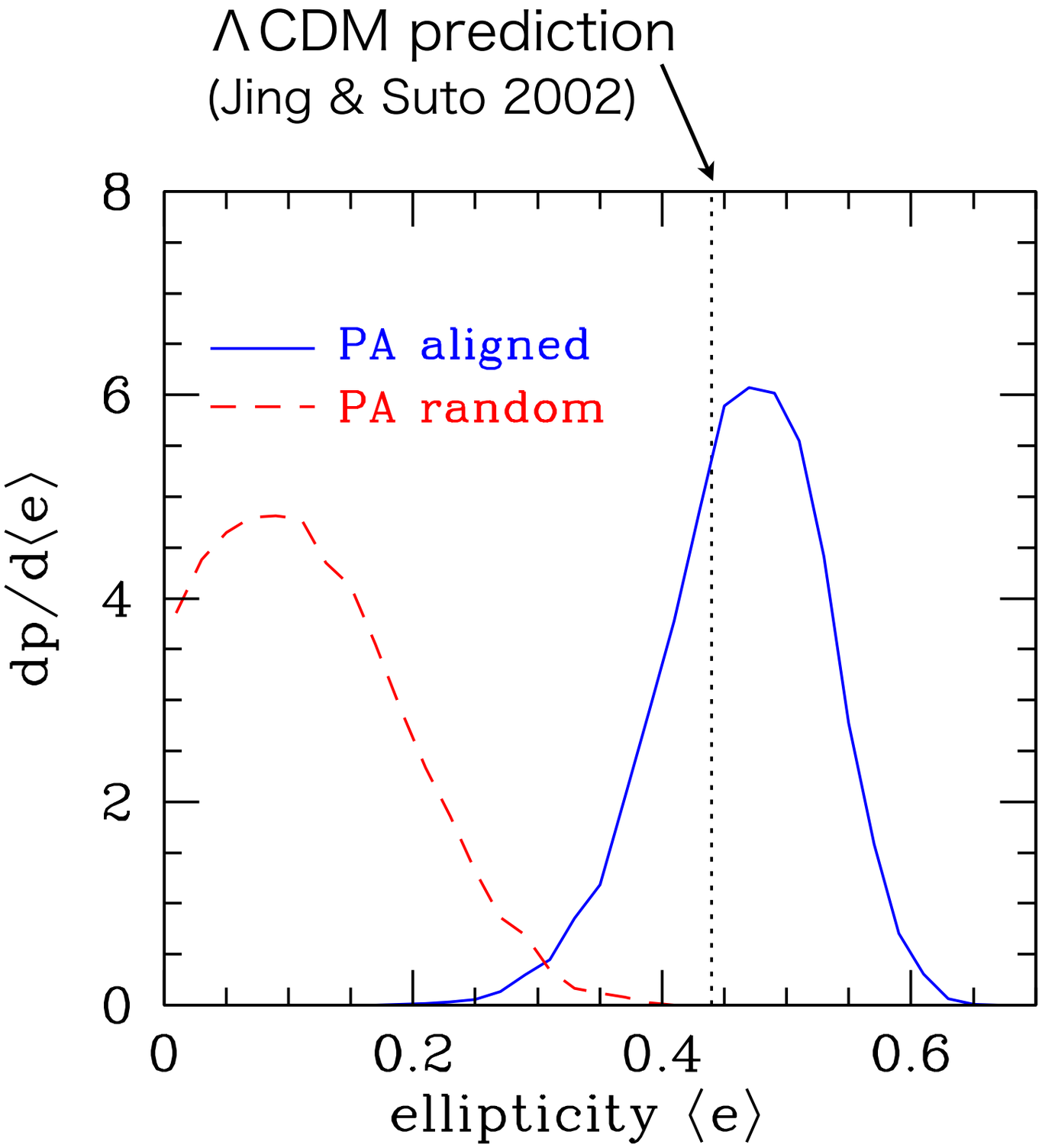


stacking w/ PA aligned



stacking w/ random PA

Constraint on mean ellipticity



Aligned PA:

$e = 0.47 \pm 0.06$

Random PA:

$e < 0.19$

ellipticity detected at 5σ level

mean ellipticity consistent w/ ΛCDM

(cf. Oguri et al. 2010)

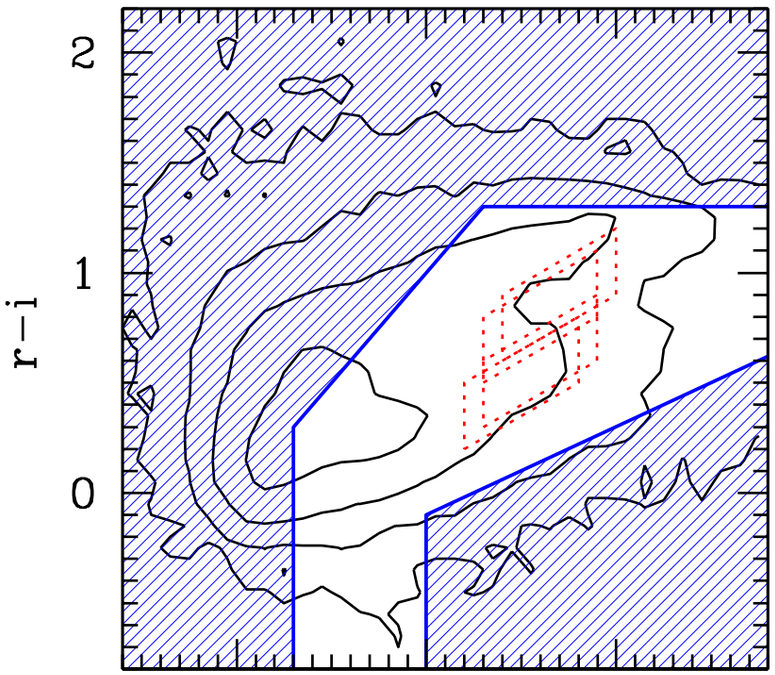
Summary: testing halo profiles

– NFW-like radial density profile (r^{-1} inner, r^{-3} outer)
observed profile consistent with NFW

– concentration (low, correlated with mass)
steep mass dependence
consistent with ΛCDM at high mass
larger c_{vir} at small mass, due to baryon cooling?

– large non-sphericity (axis ratio a/c ~ 0.4)
excellent agreement with ΛCDM!

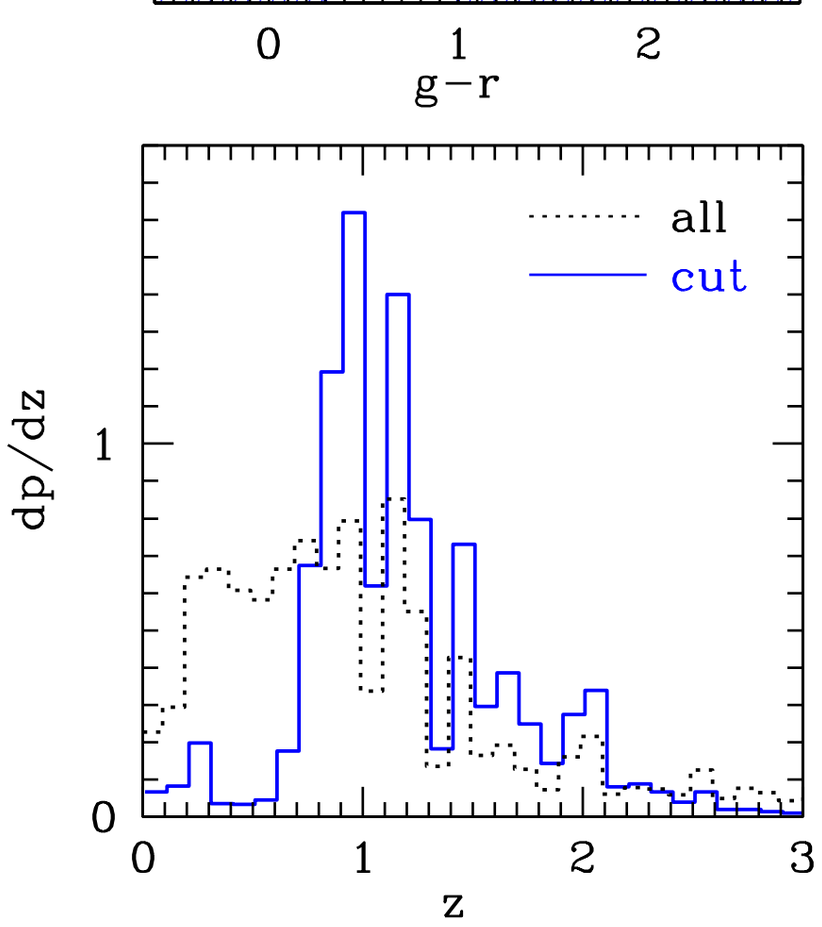
Importance of multiband imaging



cluster member galaxies dilute weak lensing signals

(e.g., Medezinski et al. 2007)

efficient background galaxy selection in color-color space



use COSMOS photo-z catalog for determining cut, selecting $z > 0.7$ galaxies only

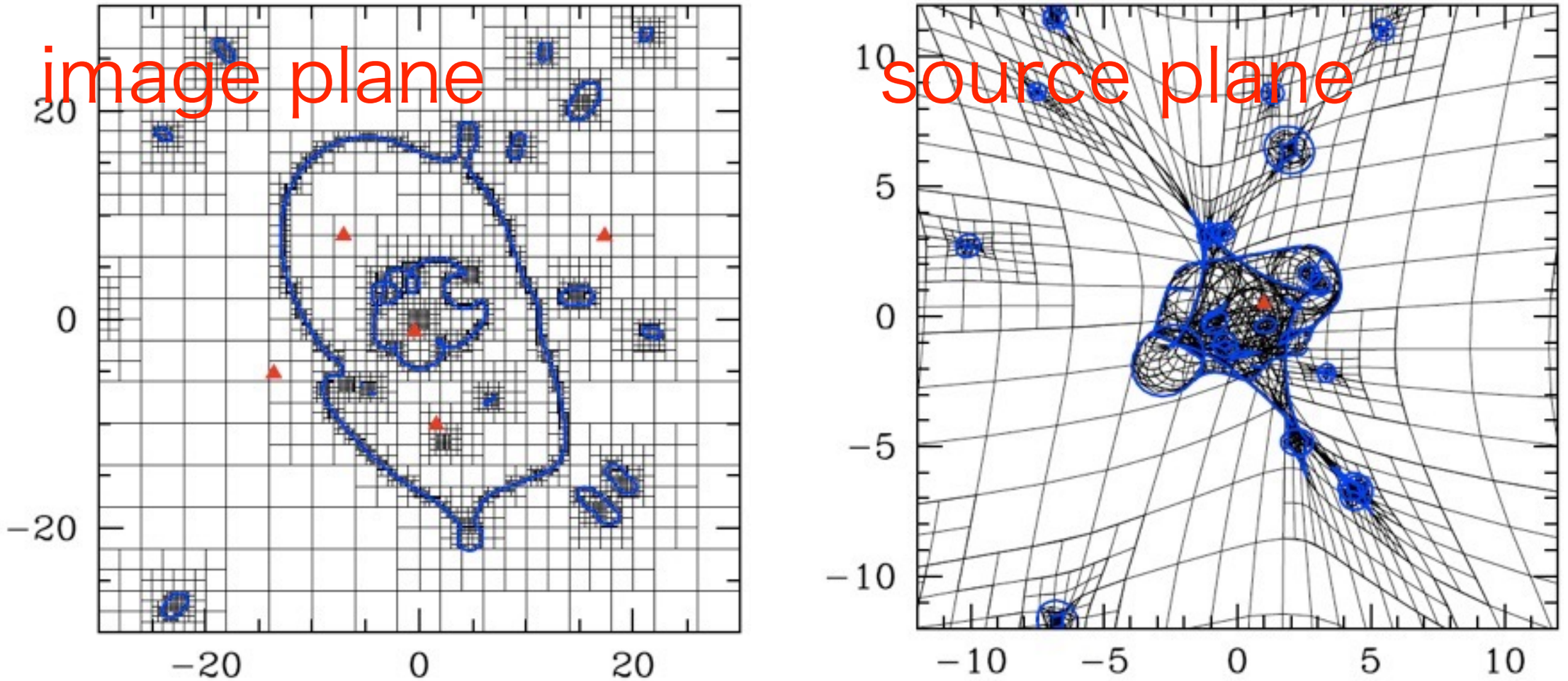
glafic URL: http://www.slac.stanford.edu/~oguri/glafic/

fast lens equation solver w/ adaptive grid

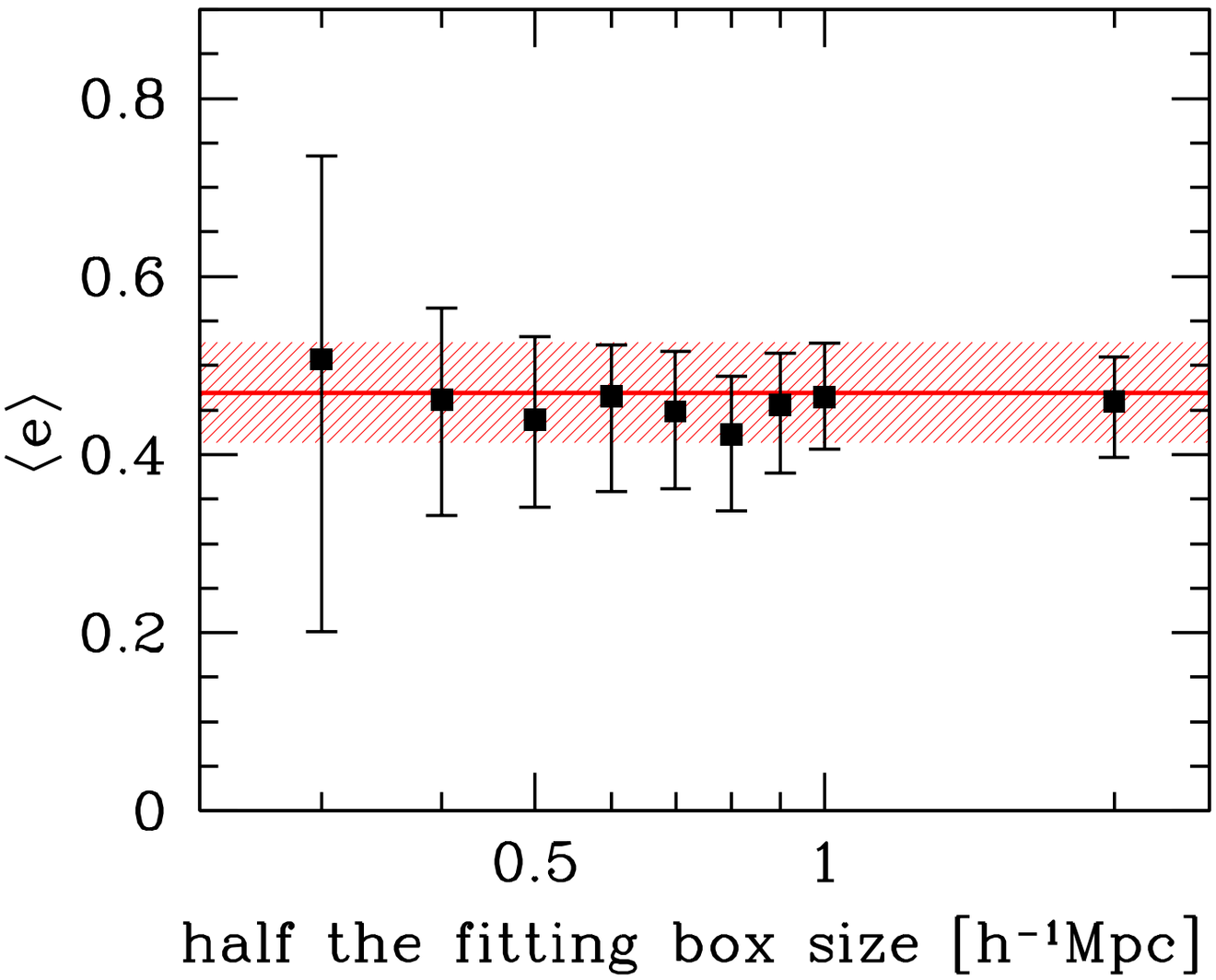
model optimization from observations

support various mass models

software is publicly available [Oguri (2010)]



Effect of fitting region



best-fit for fiducial fitting box size

constraints do not change for smaller box sizes
→ ellipticity does not change very much with radius