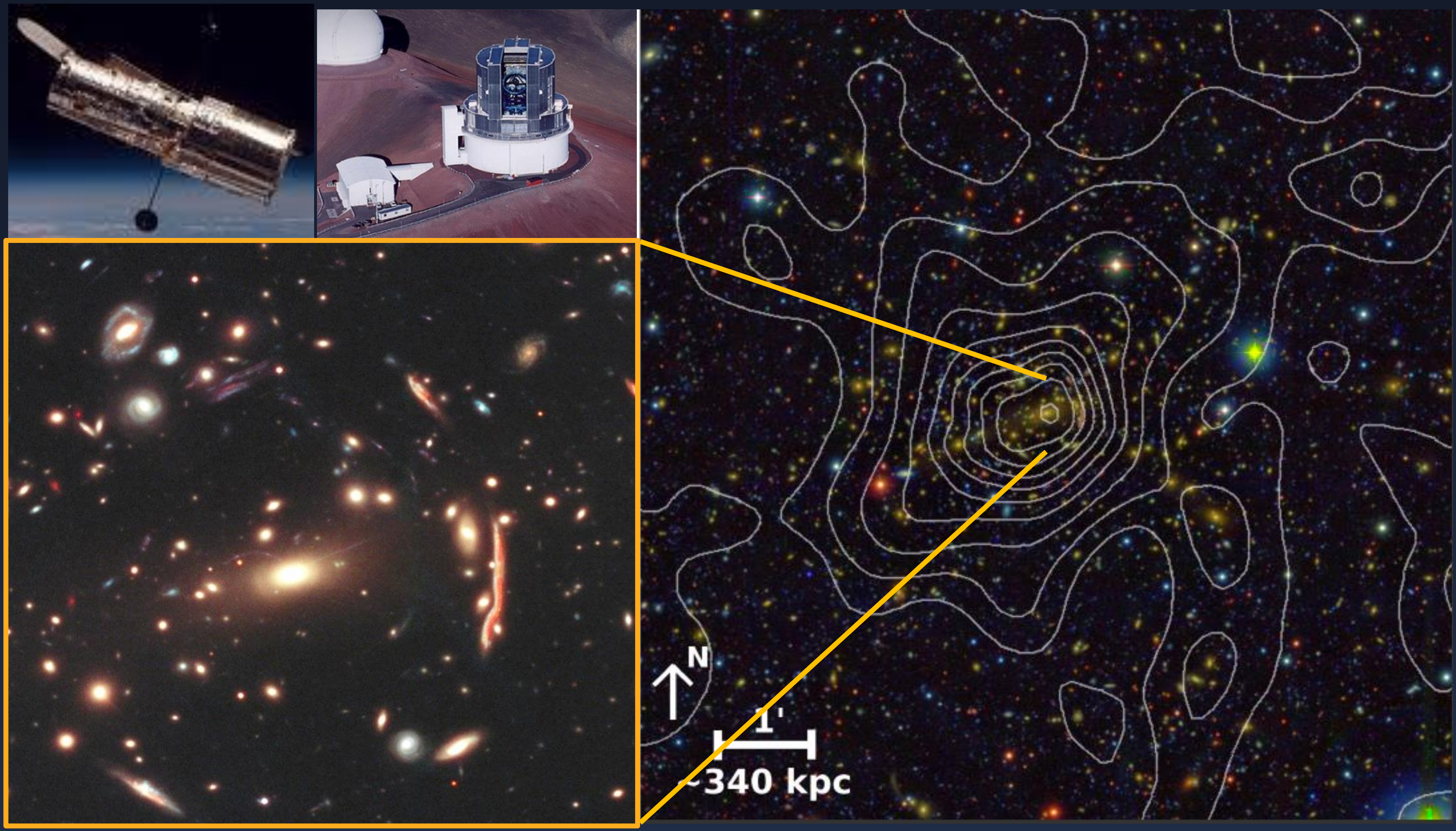
Cluster Gravitational Lensing with Subaru

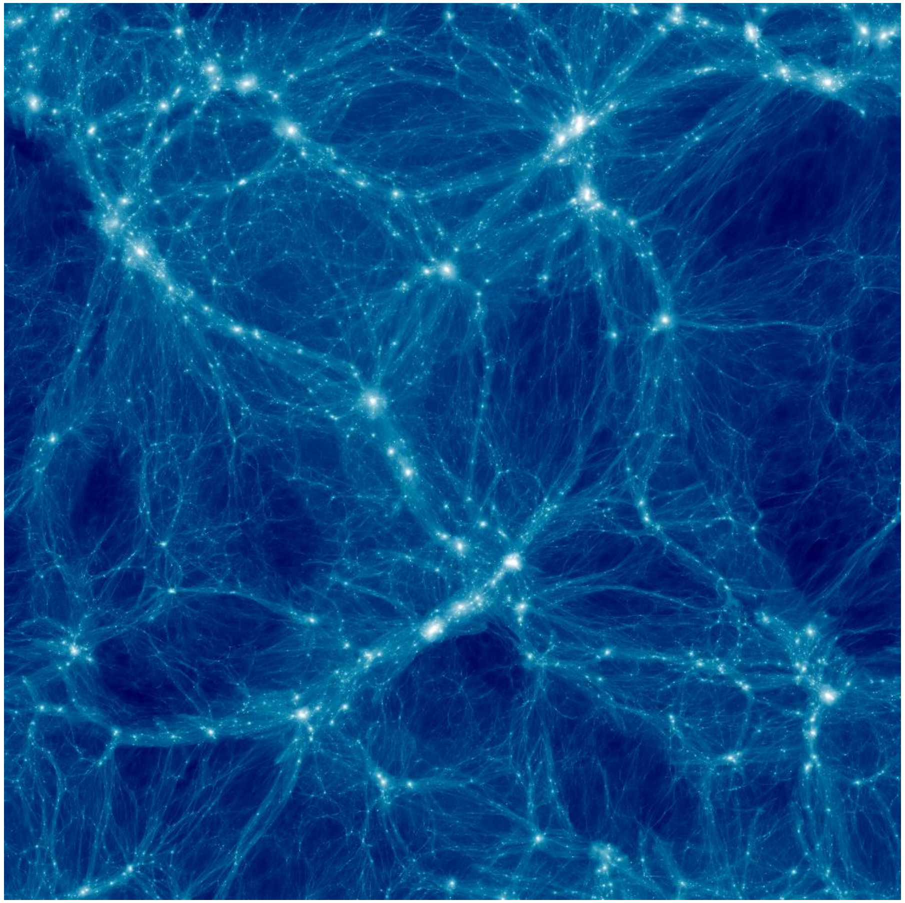


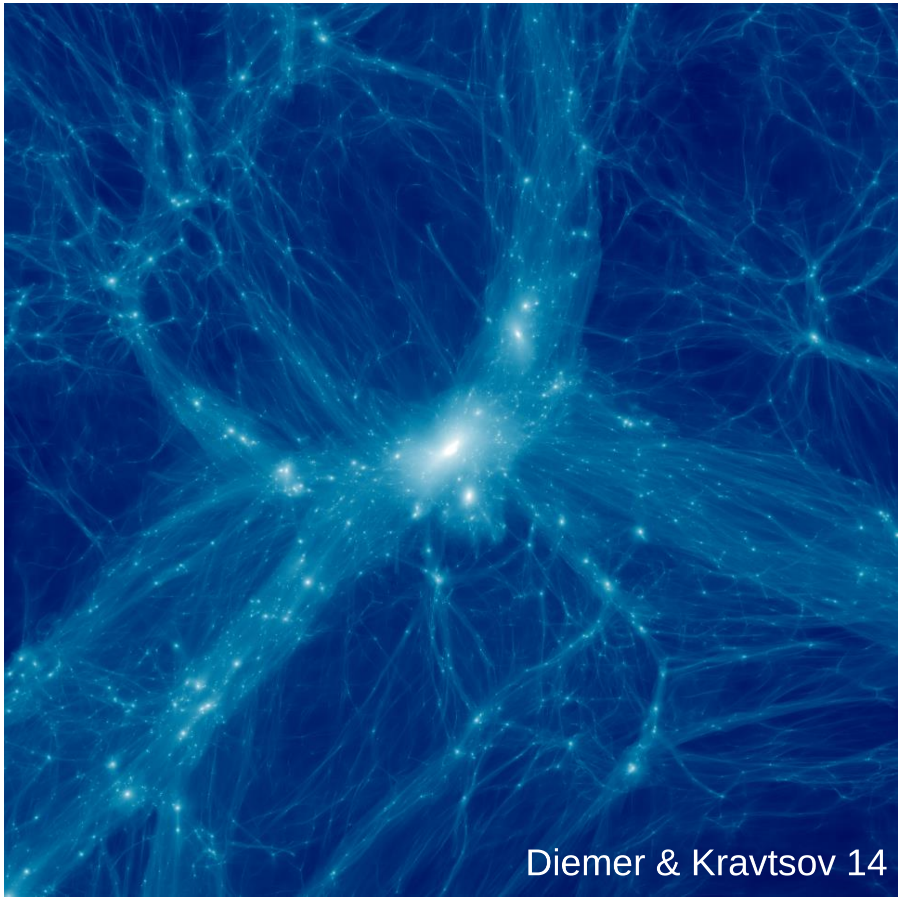
Keiichi Umetsu (ASIAA, since 2001)

My Science Interests

Nature of dark matter and its role in cosmic structure formation

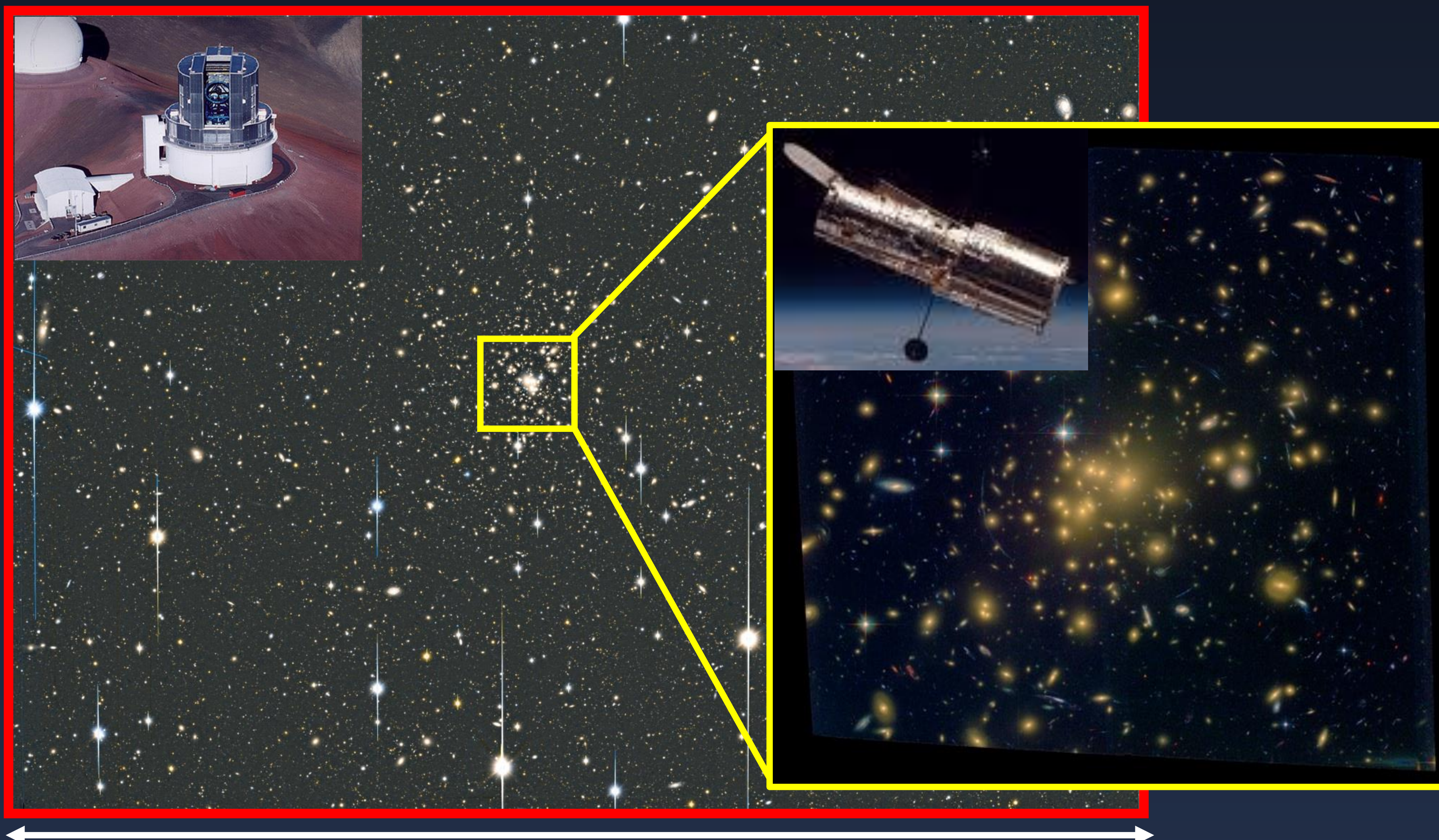
Study galaxy clusters and their surrounding environments using (weak + strong) gravitational lensing as a direct probe





Subaru/Suprime-Cam multi-color imaging for wide-field weak lensing

High-resolution space imaging with *HST* (ACS/WFC3) for strong lensing



34 arcmin

Cluster Lensing And Supernova survey with Hubble

CLASH

524-orbit *HST* Treasury Program (2010-2013) to deeply observe 25 high-mass clusters in 16 filters (ACS/WFC3)

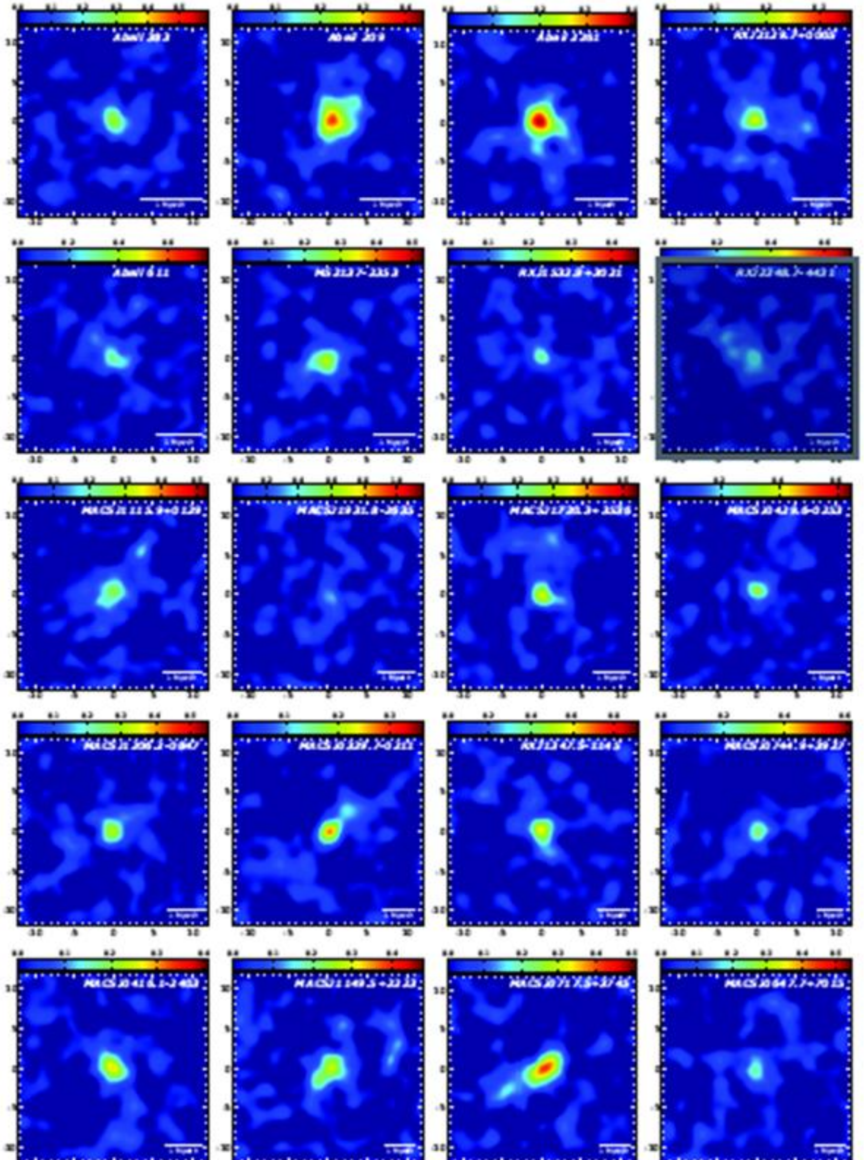
PI. Marc Postman (STScI)

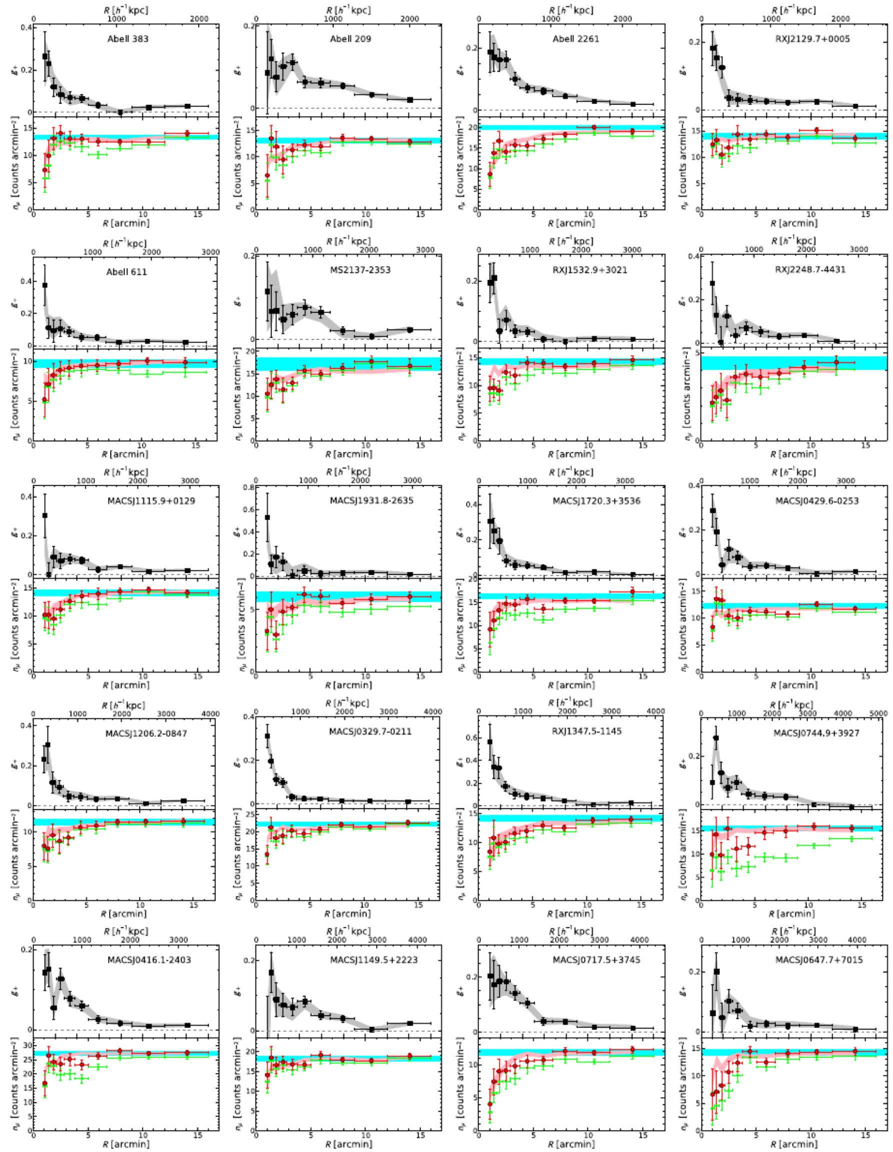
Major science goals, targeting

1. **20 X-ray-selected relaxed high-mass clusters**
   - Establish the equilibrium cluster density profile
   - Test LCDM predictions of the concentration-mass relation
2. **5 high-magnification clusters**
   - Search for and study magnified high-z (z>8) galaxies

Postman e al. 2012, *ApJS*, 199, 25

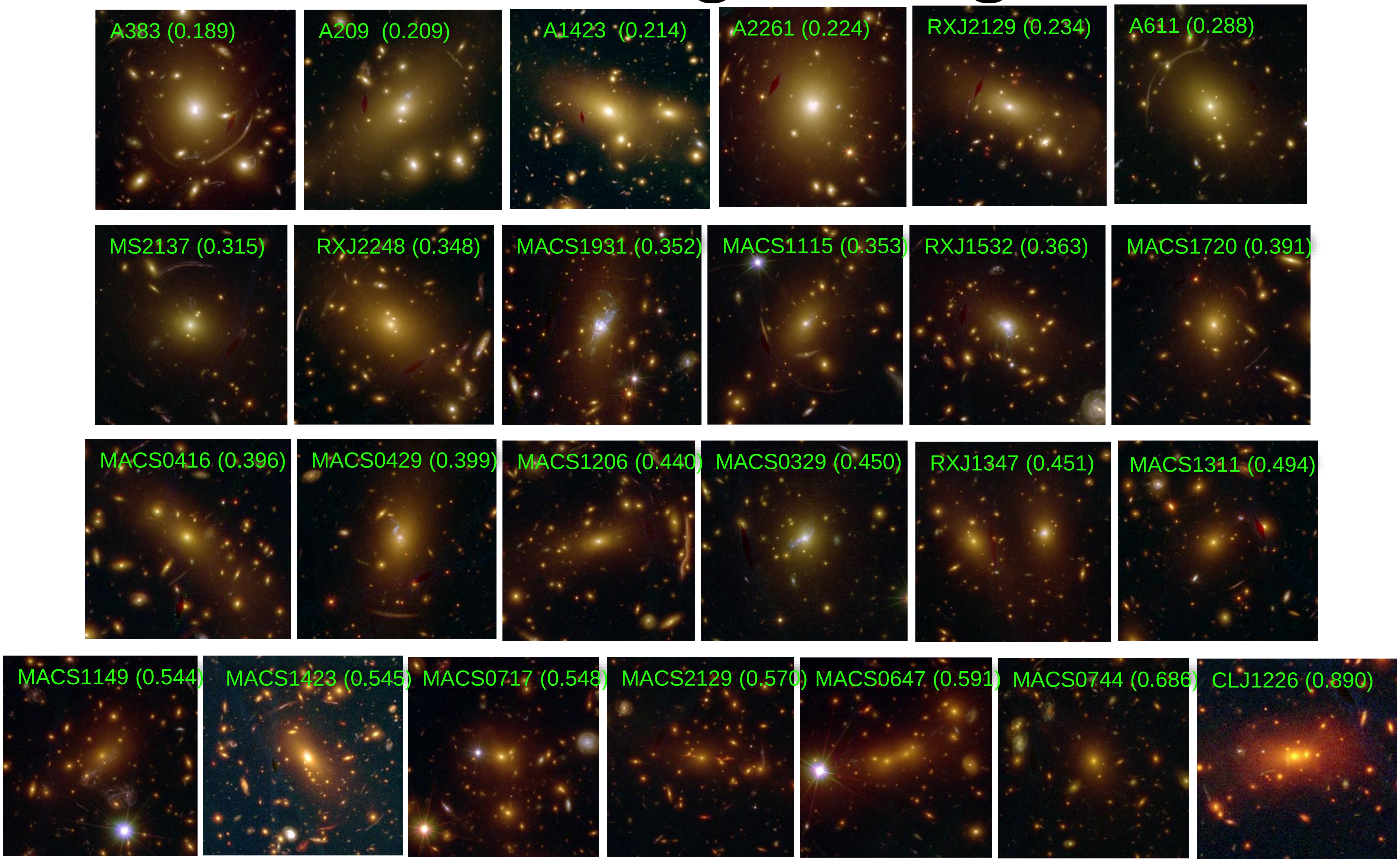
CLASH Subaru Weak-lensing Dataset





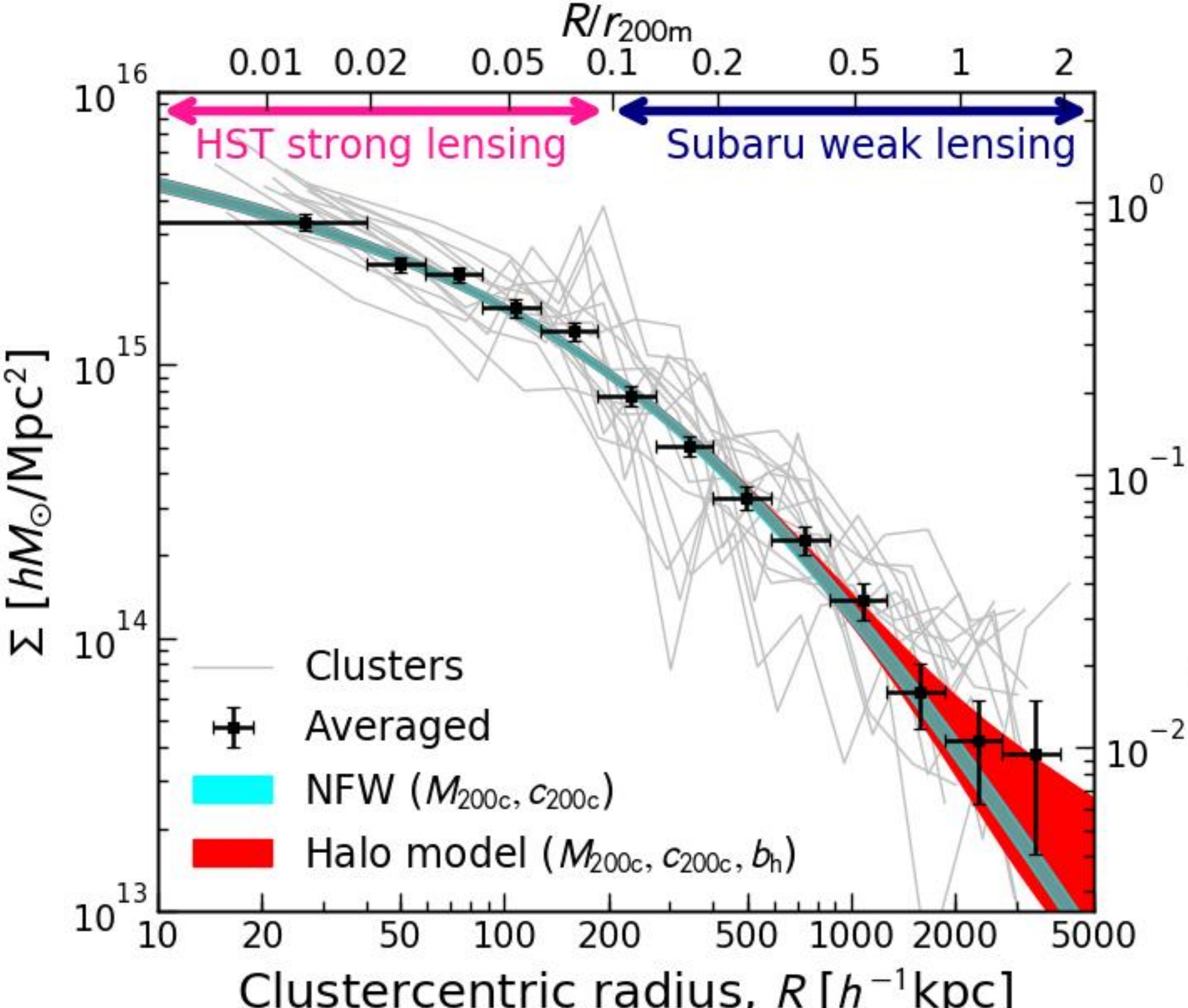
Umetsu, Medezinski, Nonino et al. 2014, *ApJ*, 795, 163

CLASH *HST* Strong-lensing Dataset



Zitrin et al. 2015, *ApJ*, 801, 44

Results: Ensemble Mass Density Profile



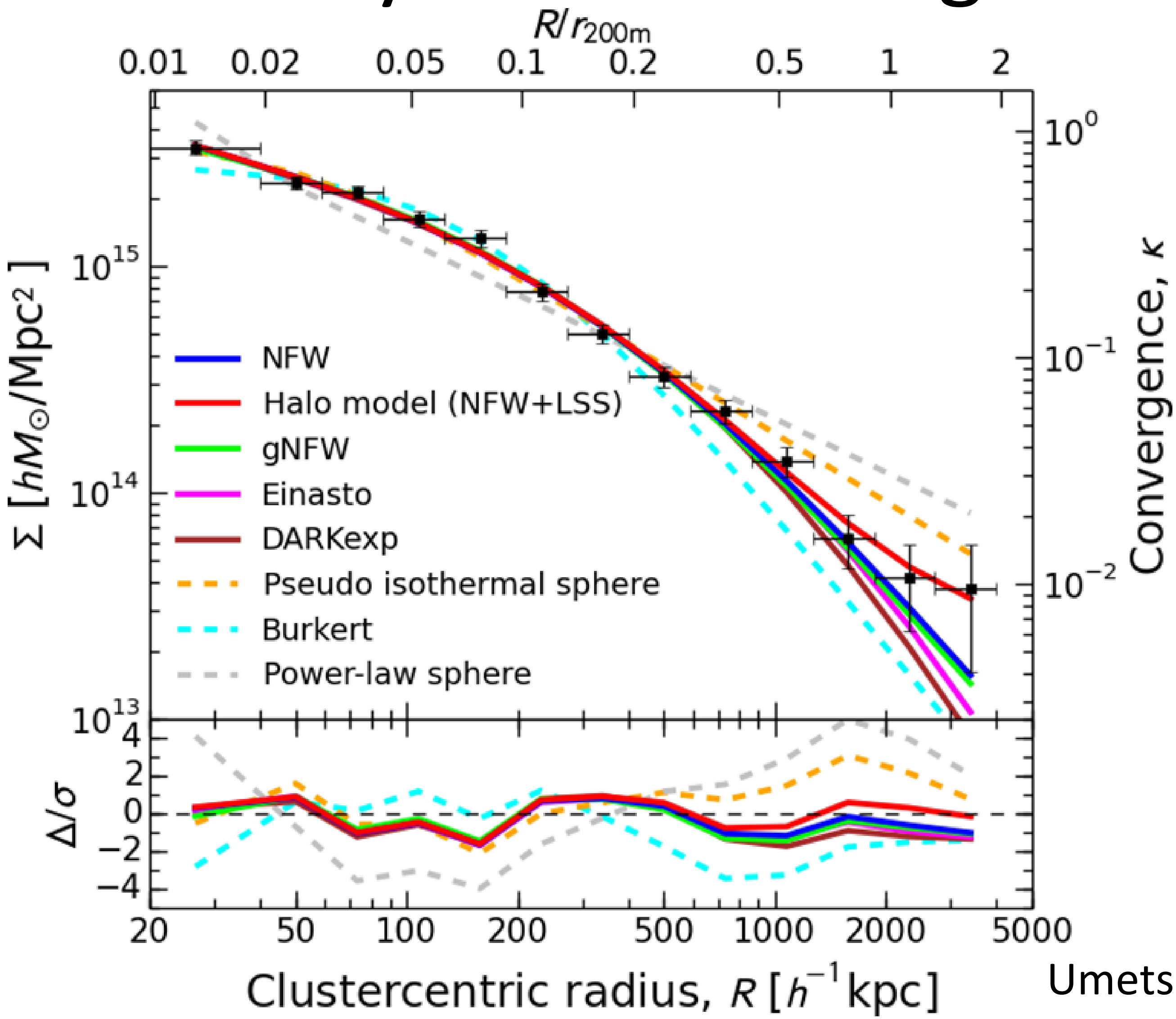
$$c_{200c} := \frac{R_{200c}}{r_s} = 3.79^{+0.30}_{-0.28}$$

$$M_{200c} = 1.4^{+0.1}_{-0.1} \times 10^{15} M_{sun}$$

$$\langle z \rangle \approx 0.34$$

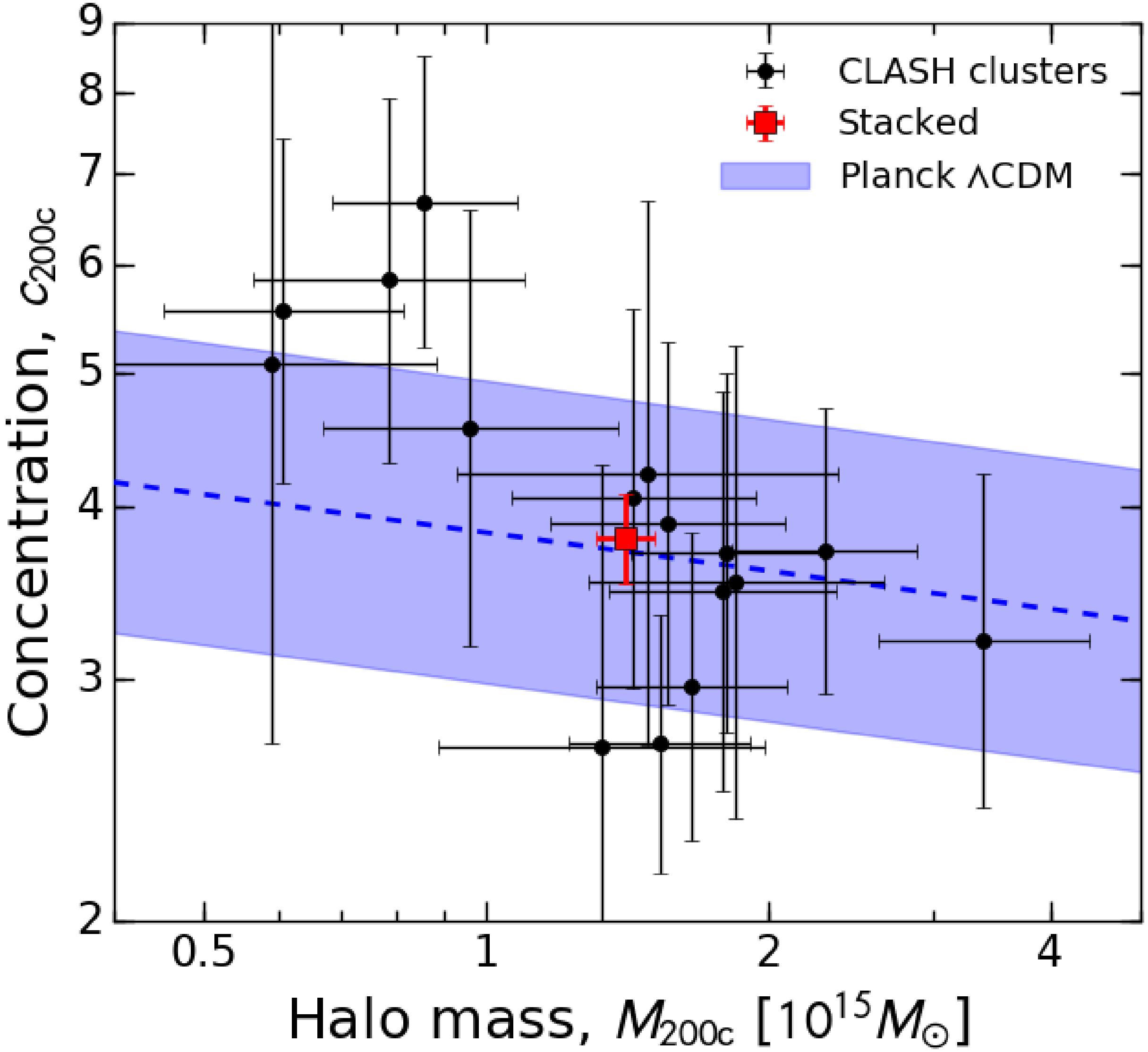
Umetsu et al. 2016

Cuspy outward steepening profiles favored by CLASH lensing data



Umetsu et al. 2016

Results: Concentration–Mass Relation



Stacked CLASH lensing

$$c_{200c} = 3.79^{+0.30}_{-0.28}$$

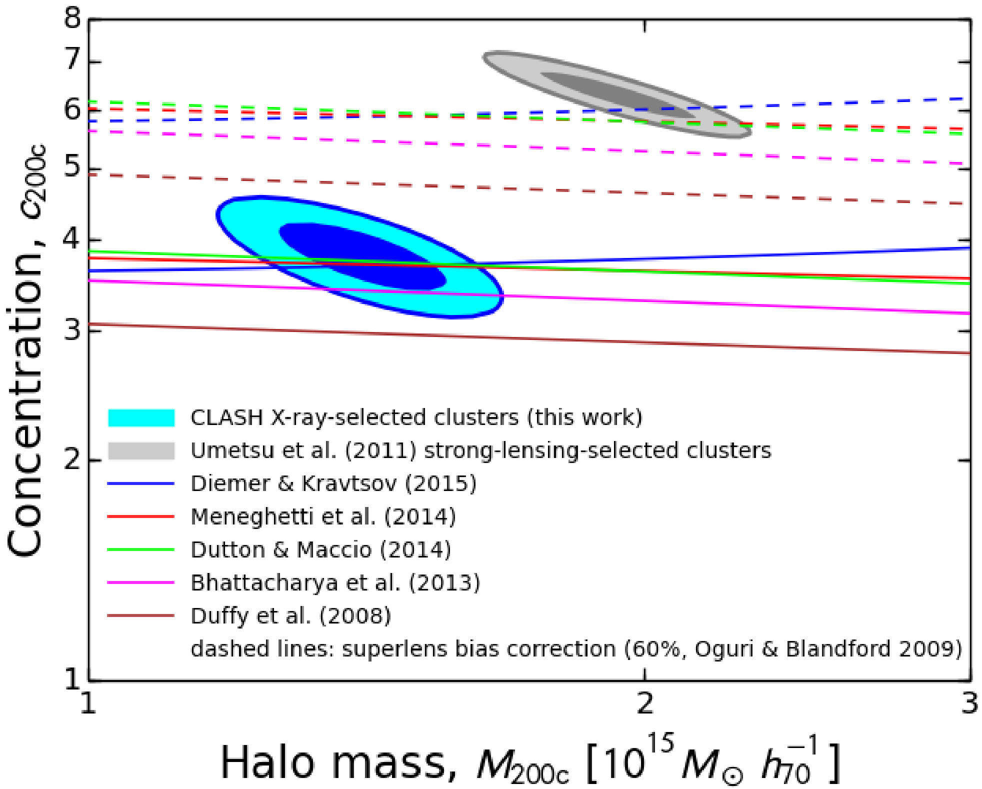
$$\text{at } M_{200c} = 1.4^{+0.1}_{-0.1} \times 10^{15} M_{sun}$$

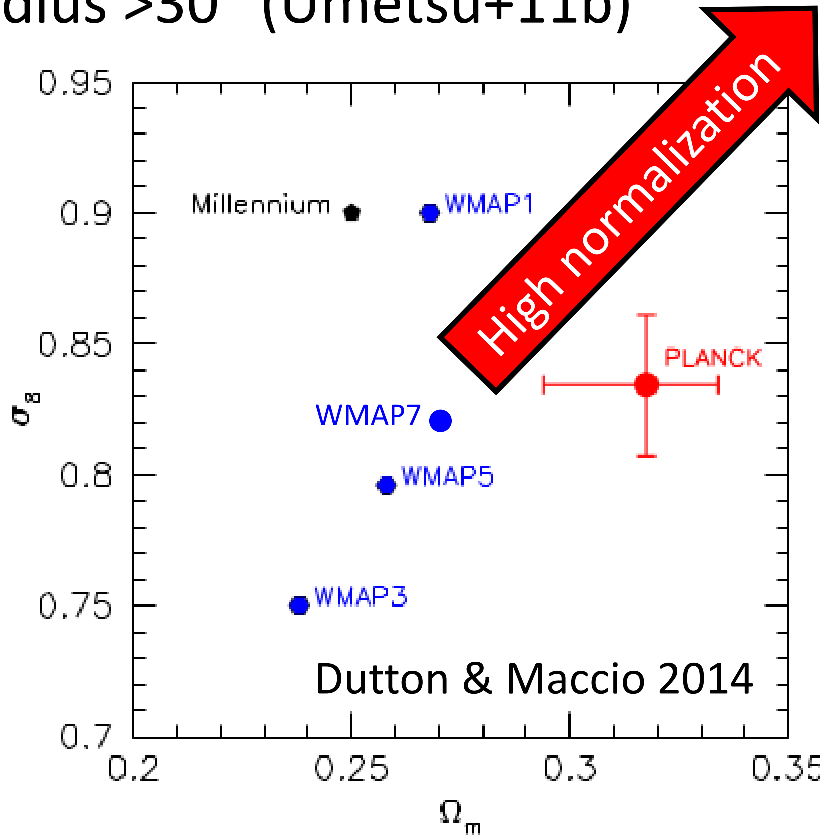
Consistent with *c*-*M* relations calibrated for recent cosmologies (WMAP7 and later)

Umetsu et al. 2016

CLASH vs. Superlens Clusters

- **16 lensing-unbiased** CLASH clusters (Umetsu+16)
- 4 **superlens** clusters with Einstein radius >30” (Umetsu+11b)





Higher normalization LCDM cosmology (WMAP7 and later) + predicted 60% superlens correction can explain superlens mass profiles!

CLASH Lensing Constraints on the Splashback Radius of Galaxy Clusters

Umetsu & Diemer 2017, *ApJ*, 836, 231

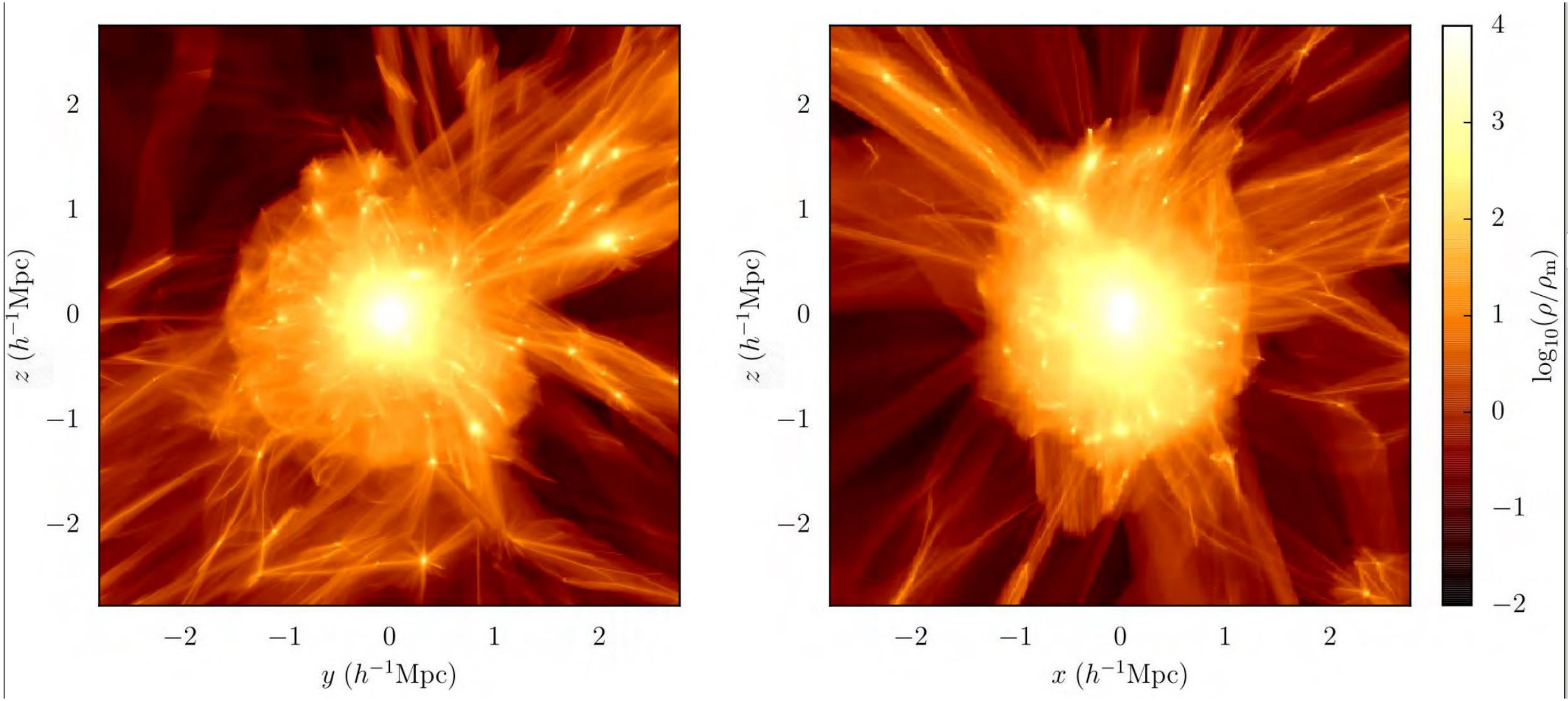
Splashback radius, R_{sp}: Physical halo boundary

Slow accreting halos

$R_{sp} >> R_{200m}$

Fast accreting halos

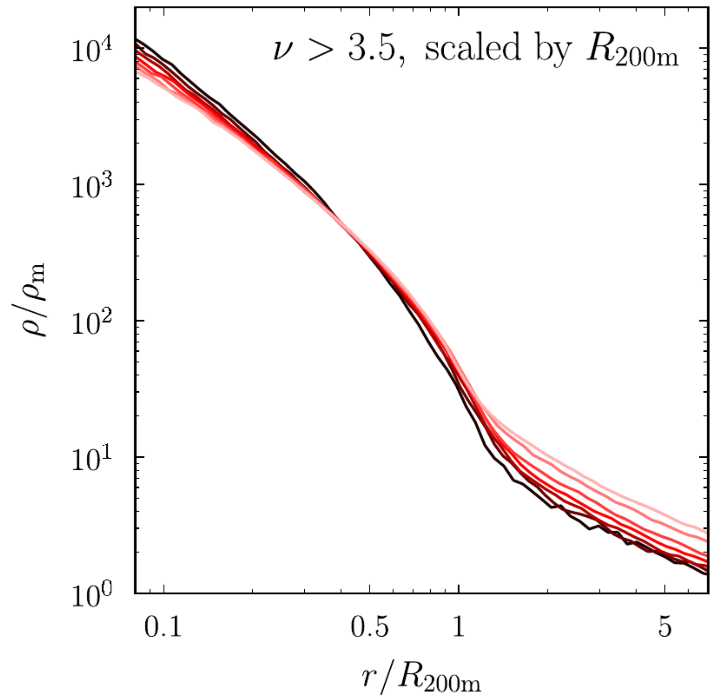
$R_{sp} \sim R_{200m}$

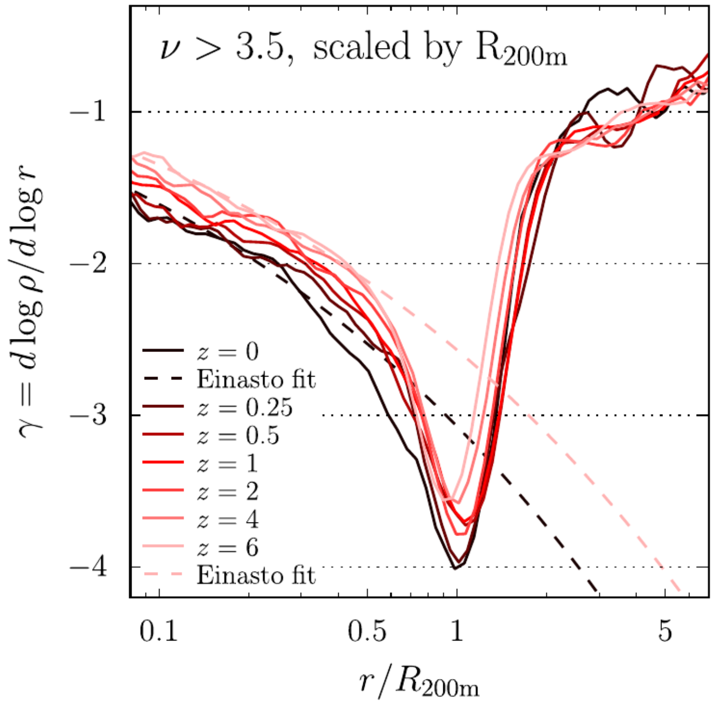


More, Diemer, & Kravtsov 2015

Splashback feature in real space

Steepest "3D" gradient point as splashback radius R_{sp}





N-body simulations (Diemer & Kravtsov 14, DK14)

Practical issues

- CLASH spans a factor of ~5 (1.7) in mass (radius), so that sharp gradient feature is washed out when stacked in physical length units.
- In 2D, the splashback feature is weakened by projection of shallow 2-halo term

Solution: Parametric forward modeling of “scaled” cluster lensing profiles

Mass distribution around halos in ΛCDM (DK14)

$$\Delta\rho(r) = \rho(r) - \rho_{\rm m} = \rho_{\rm inner} \times f_{\rm trans} + \rho_{\rm outer}$$

A scaled version of DK14 density profile (Umetsu & Diemer 17)

$$\begin{aligned}\Delta\rho(r = r_\Delta x) &= \mathcal{N}\left\{\exp\left[-\frac{2}{\alpha}c_\Delta^\alpha(x^\alpha - 1)\right]\left[1 + \left(\frac{x}{\tau_\Delta}\right)^\beta\right]^{-\gamma/\beta} + \frac{B_\Delta}{\epsilon_\Delta + x^{s_{\rm e}}}\right\} \\ &\propto f_{\rm inner}(x) f_{\rm trans}(x) + f_{\rm outer}(x),\end{aligned}$$

$$y(x) := \frac{\Sigma(R = r_\Delta x)}{\Sigma(r_\Delta)}$$

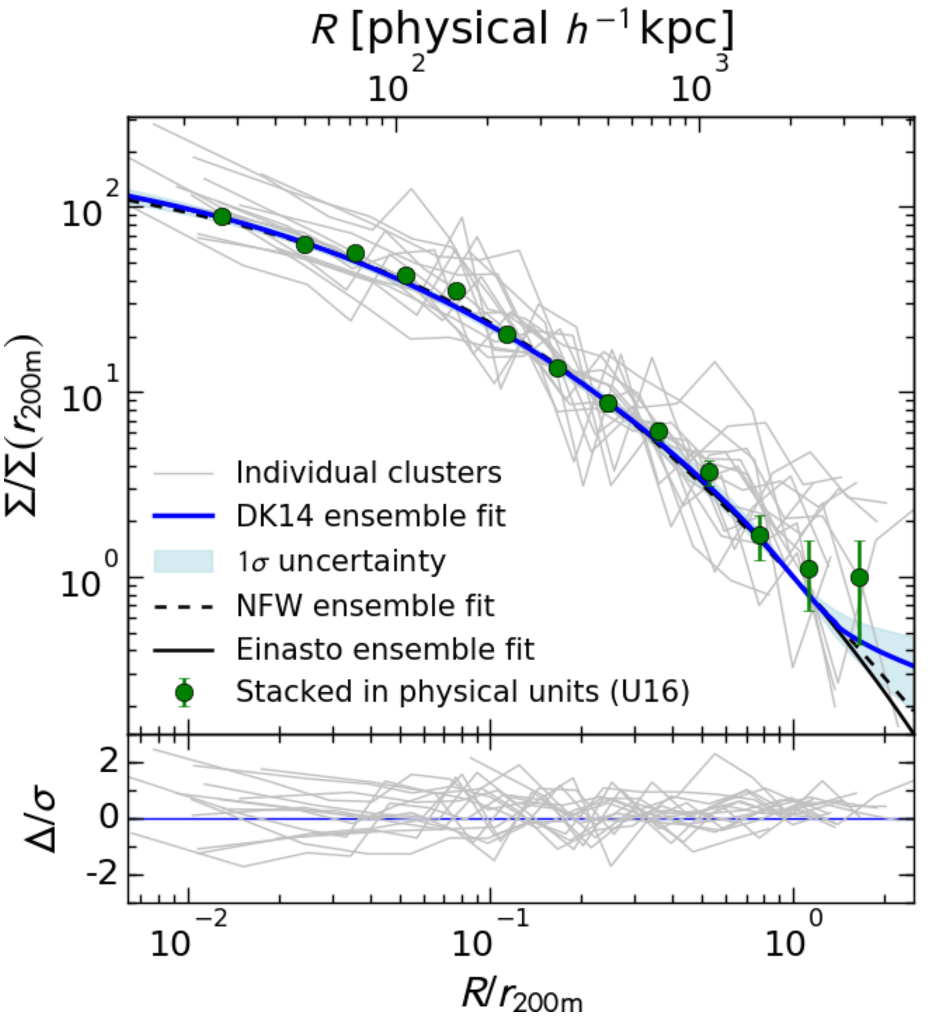
specified by $\boldsymbol{p} = \{c_\Delta, \alpha, \tau_\Delta, B_\Delta, s_{\rm e}, \beta, \gamma\}$.

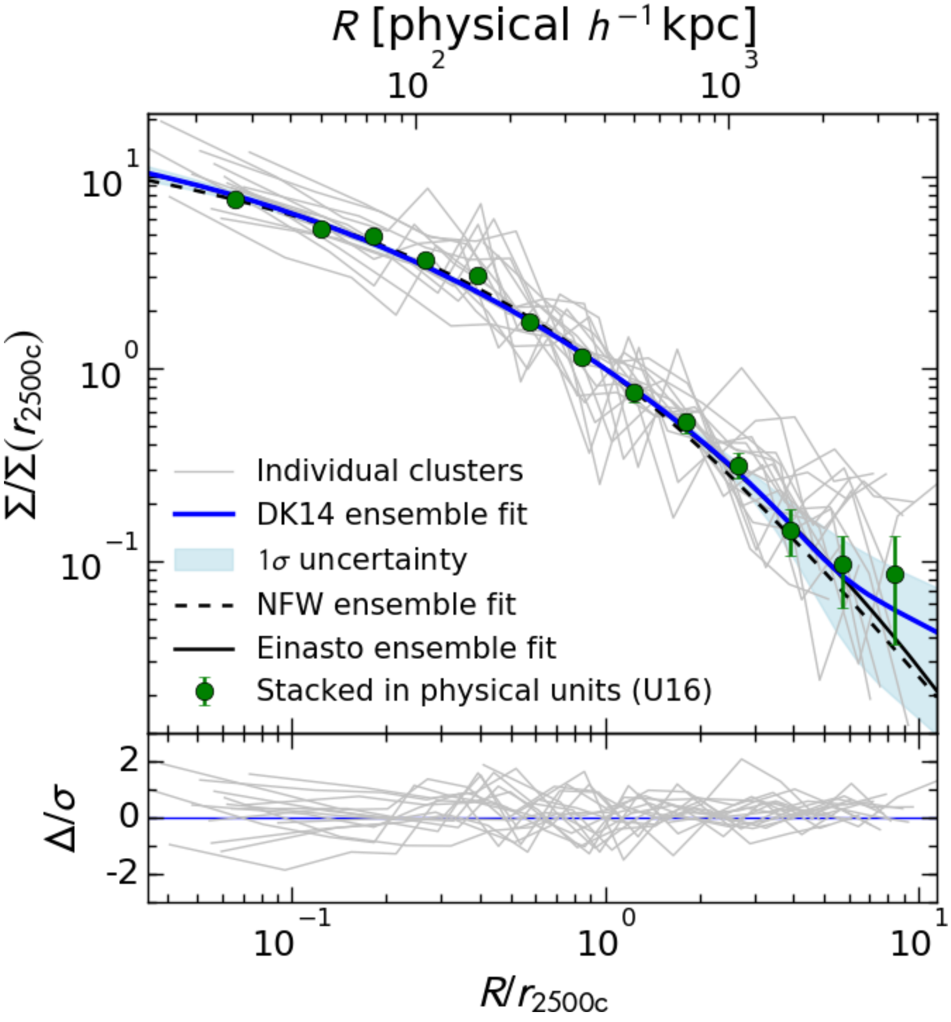
We marginalize over nuisance shape parameters ($s_{\rm e}$, β, γ) using “generic” priors found from *N*-body simulations of DK14

Results: CLASH scaled density profiles

$r_{\Delta} = r_{200\mathrm{m}}$

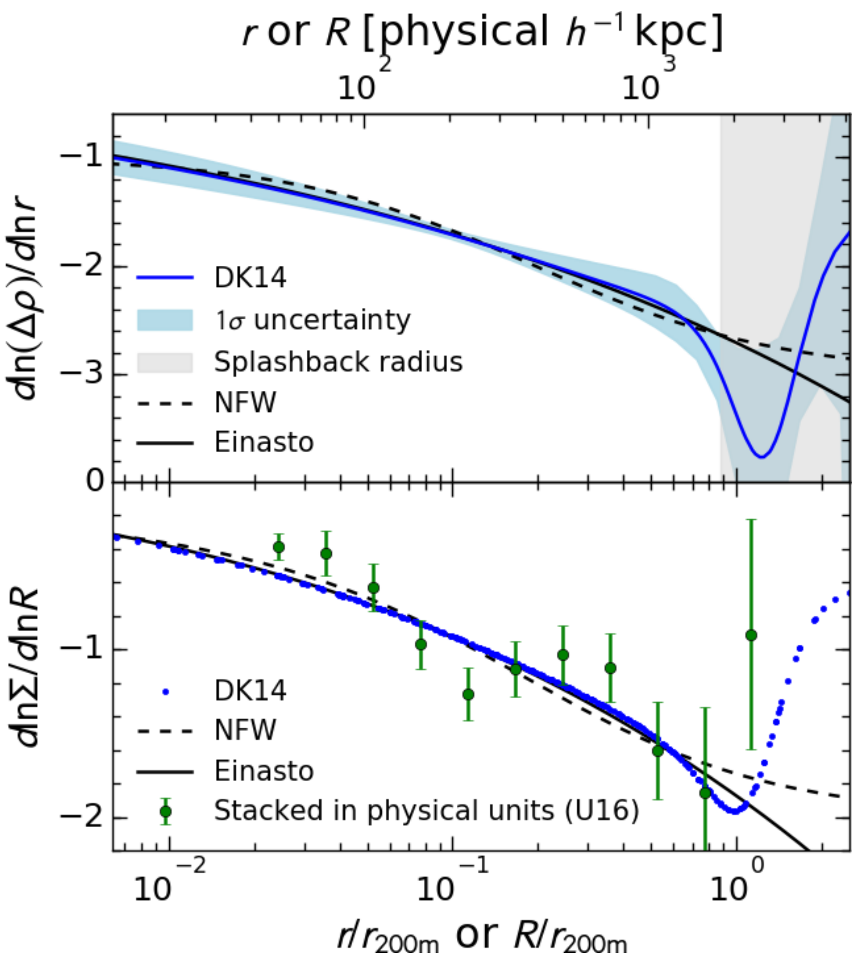
$r_{\Delta} = r_{2500\mathrm{c}} \sim 0.2 r_{200\mathrm{m}}$



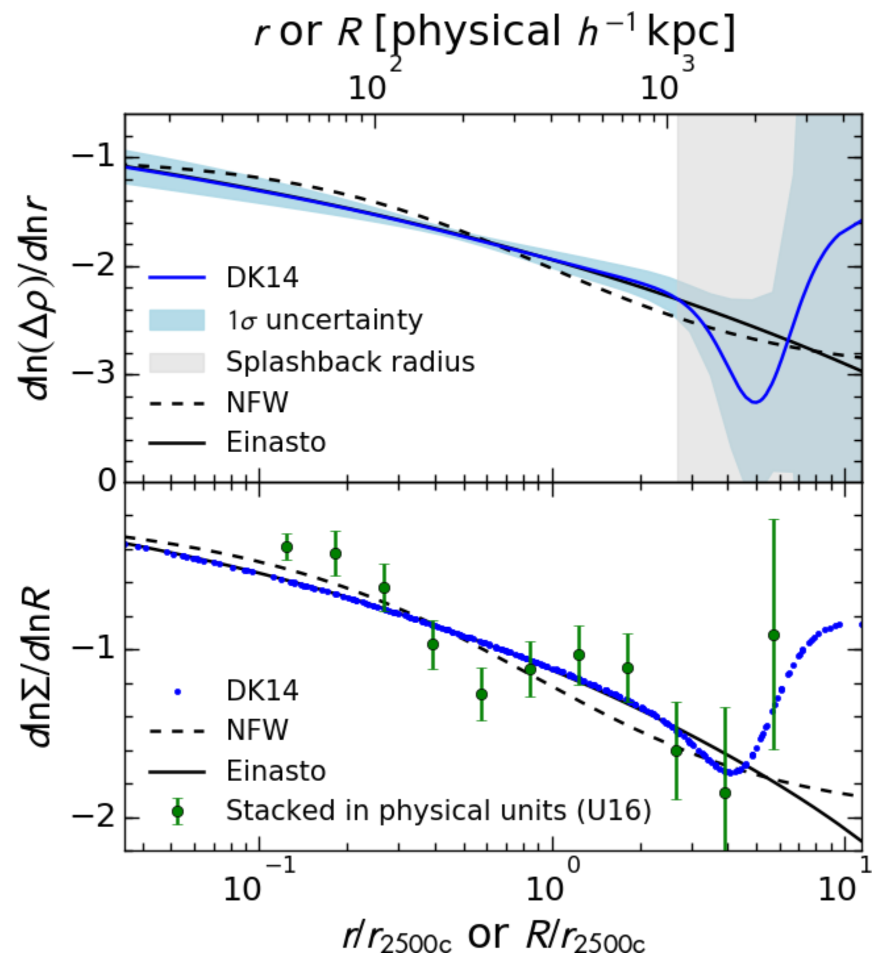


Results: CLASH logarithmic density gradient

$r_\Delta = r_{200\mathrm{m}}$

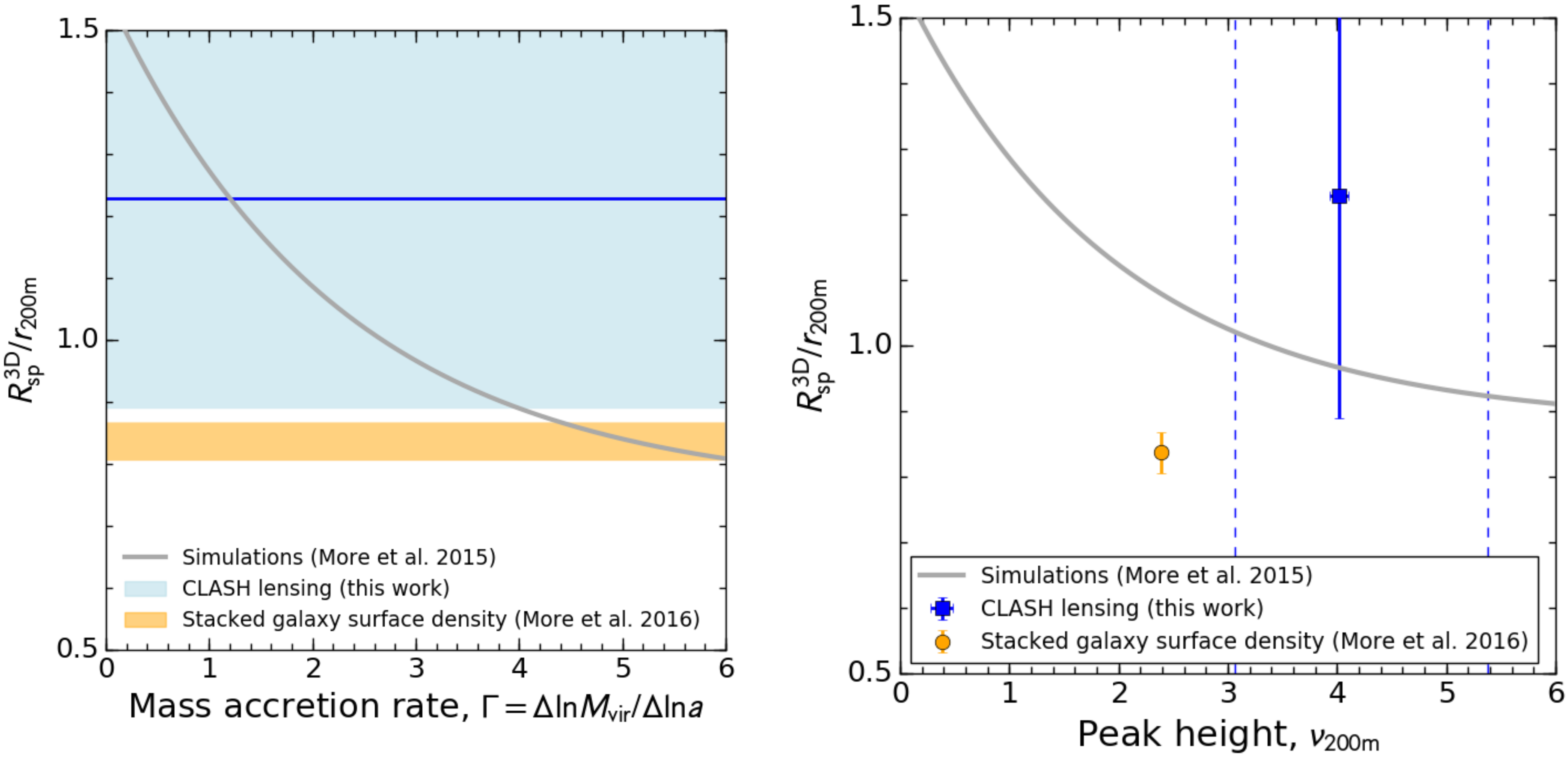


$r_\Delta = r_{2500\mathrm{c}} \sim 0.2 r_{200\mathrm{m}}$



First lensing constraints on $R_{\rm sp}$

$$R_{\rm sp}^{\rm 3D}/r_{\rm 200m} = 1.23^{+2.33}_{-0.34} \quad \Rightarrow \quad \Gamma := \frac{\Delta \ln M_{\rm vir}}{\Delta \ln a} < 4.0\ (1\sigma)$$



CLASH data consistent with a representative range of MAR

Next steps?

- Exploring low mass clusters/groups, higher-z systems (z>1) with HSC-SSP (1400 deg^2)
- Lensing “detection” of R_{sp} using improved statistics with HSC-SSP
- Large statistics of merging clusters with HSC-SSP.
- BCG-cluster-LSS connection: tidal effects, alignments, assembly histories of dark matter halos