Structure and large scale distribution of dark matter halos:

Overview and new horizons

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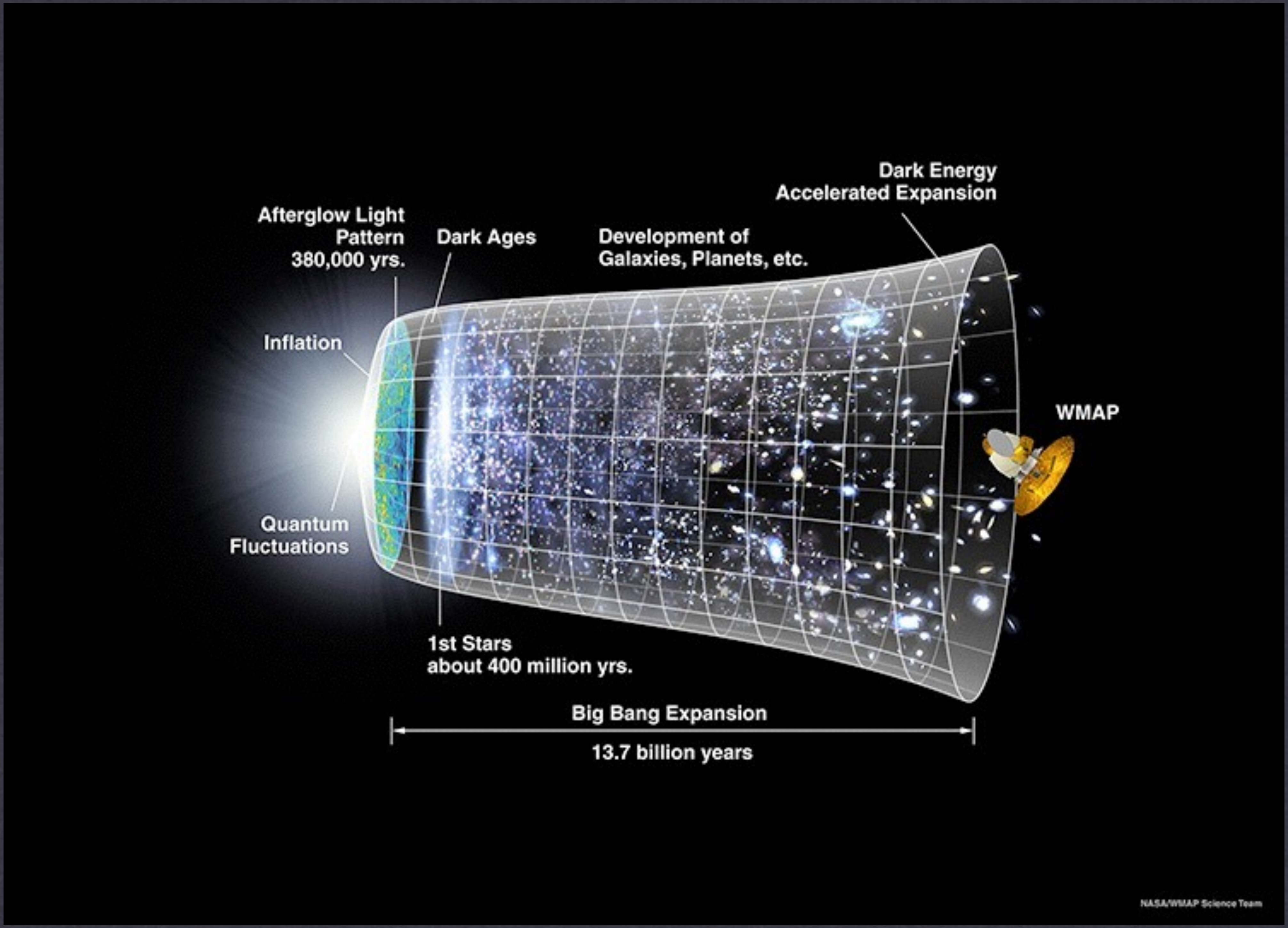
Cosmological paradigm



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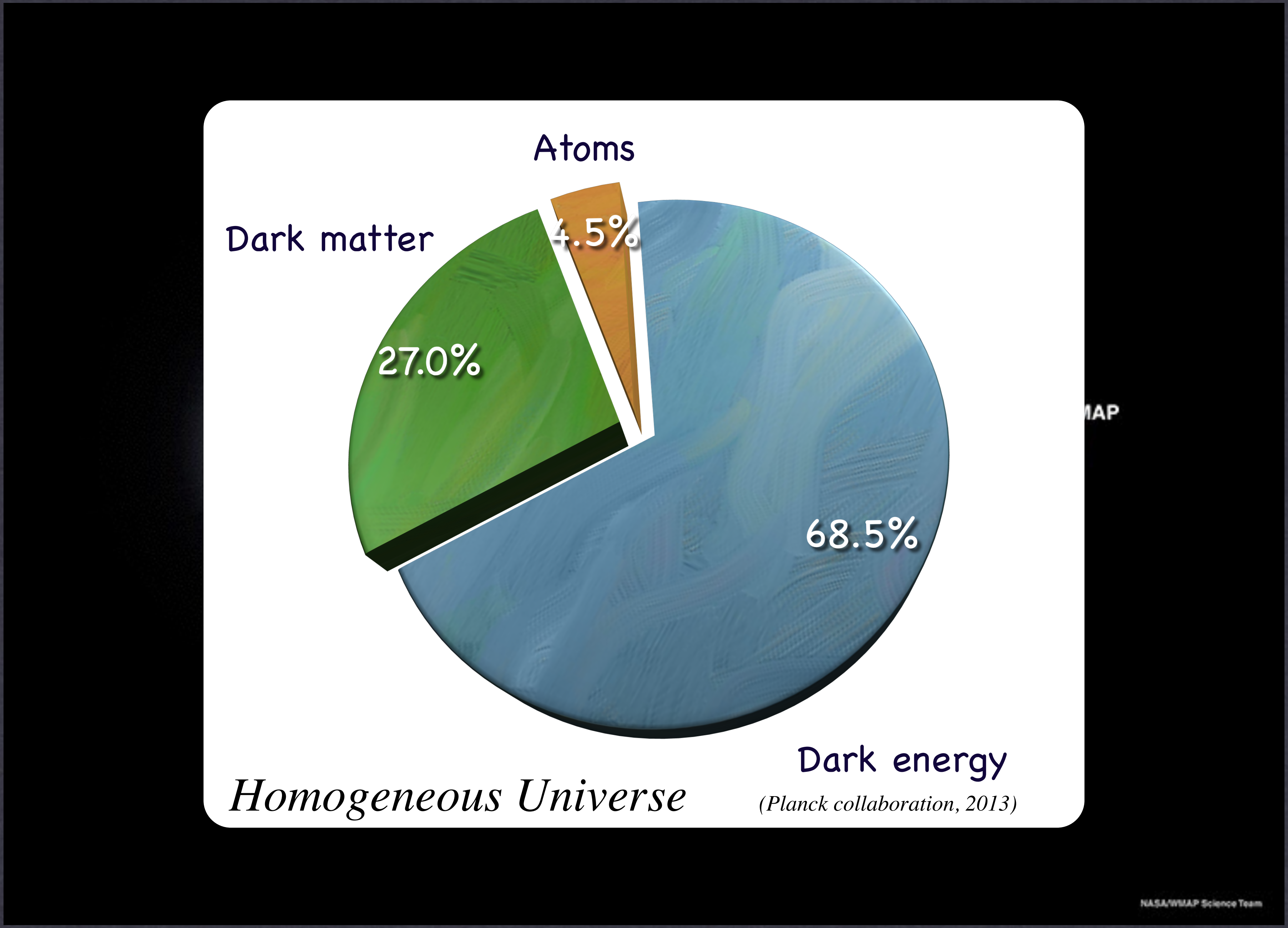
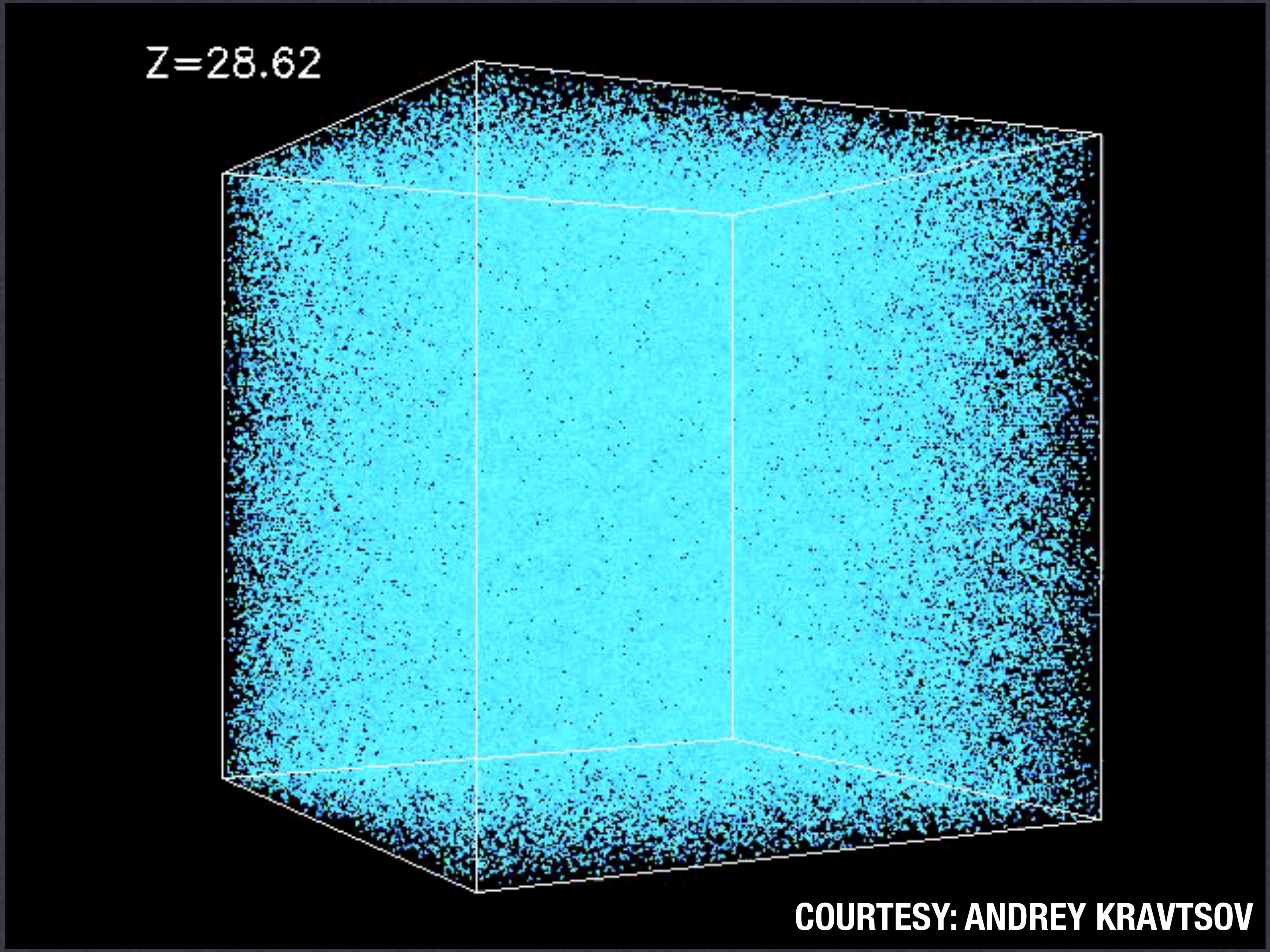
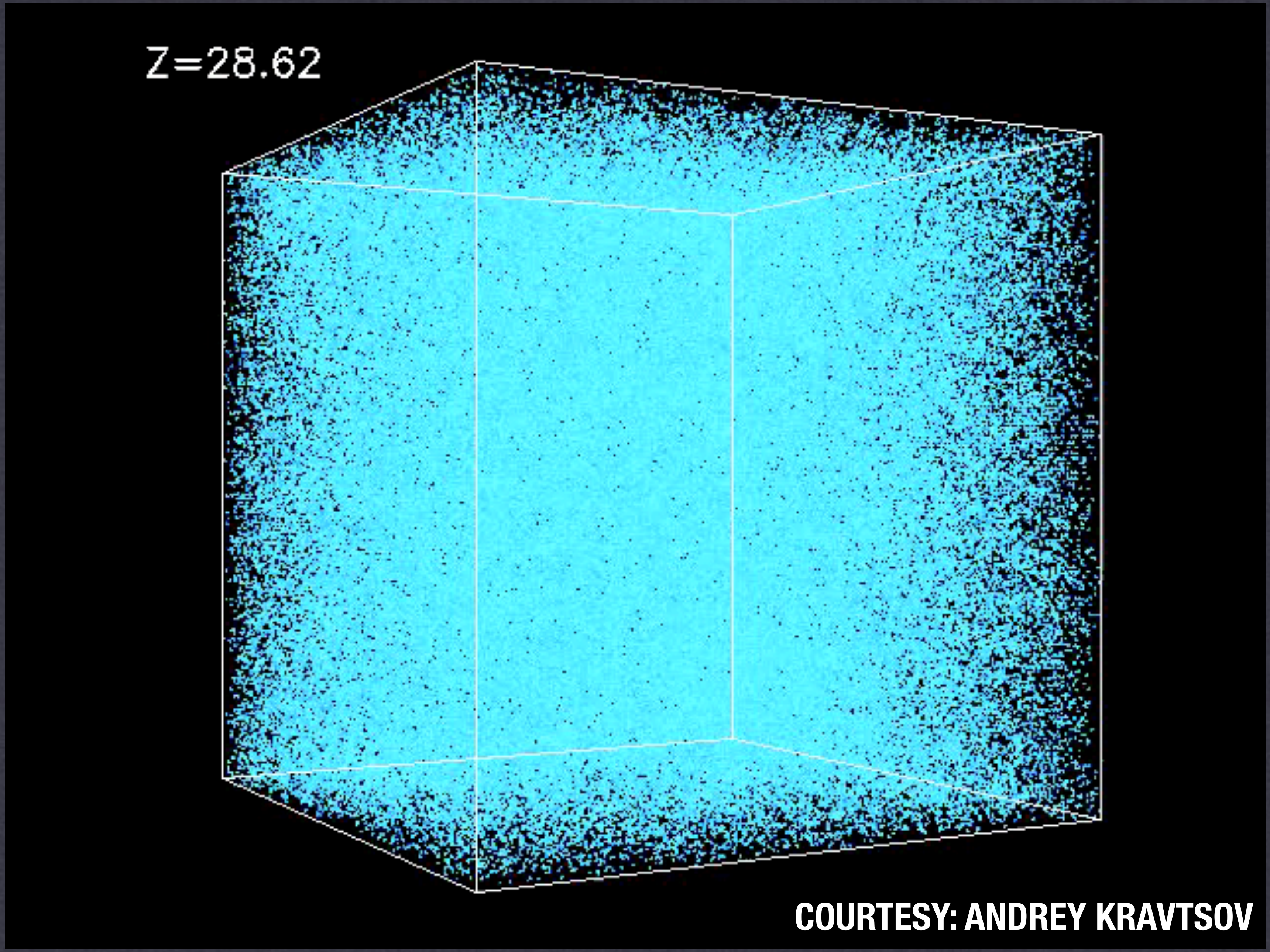


Inhomogeneous Universe



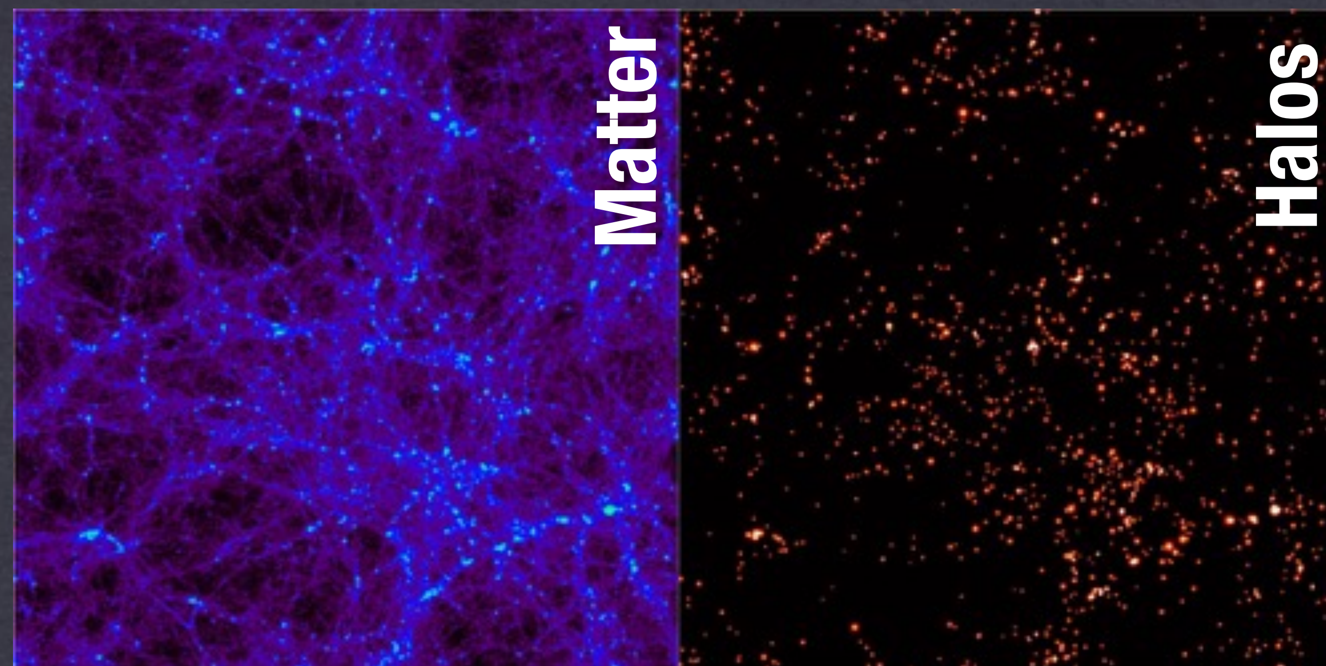
- **Evolution of structure: dark matter**

Inhomogeneous Universe



- **Evolution of structure: dark matter**

Bias of dark matter halos



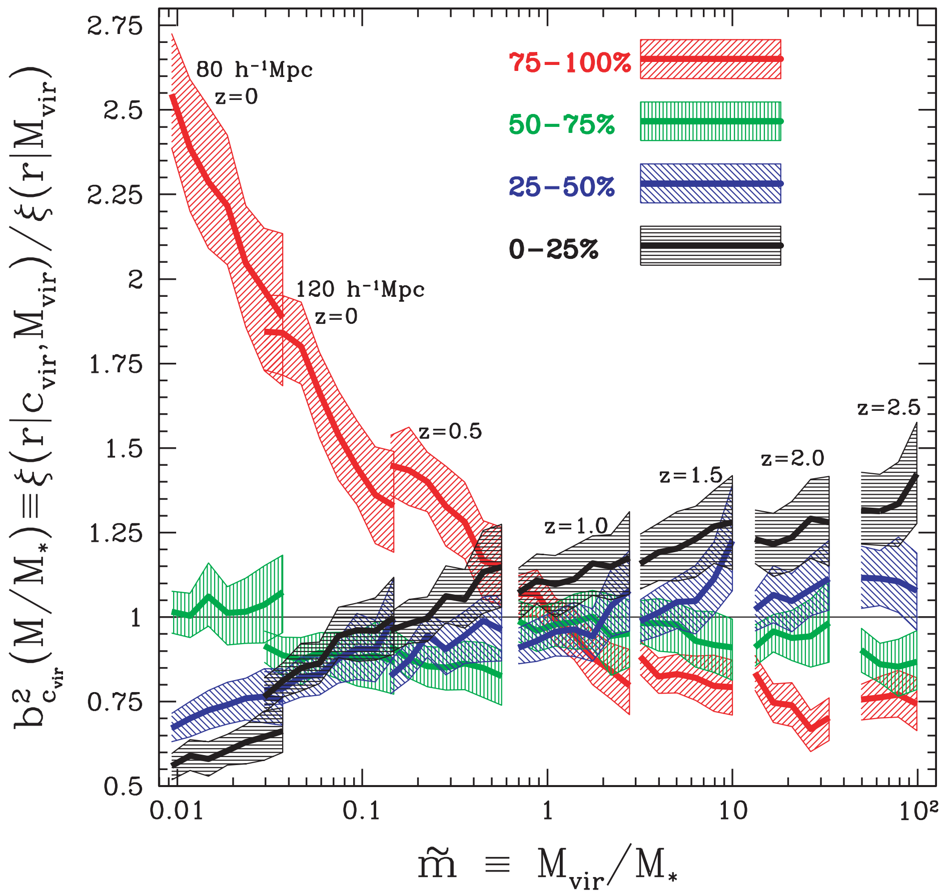
Massive

More clustered

- The spatial distribution of halos is biased with respect to the matter distribution
- The bias of halos changes with their mass, more massive halos are more strongly clustered : b(M)
- This dependence is used to infer halo masses of objects such as galaxies by measuring their clustering

Halo assembly bias

Wechsler et al. 2006

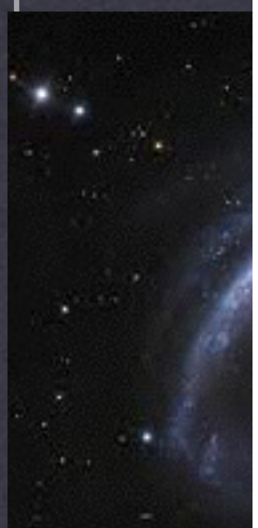


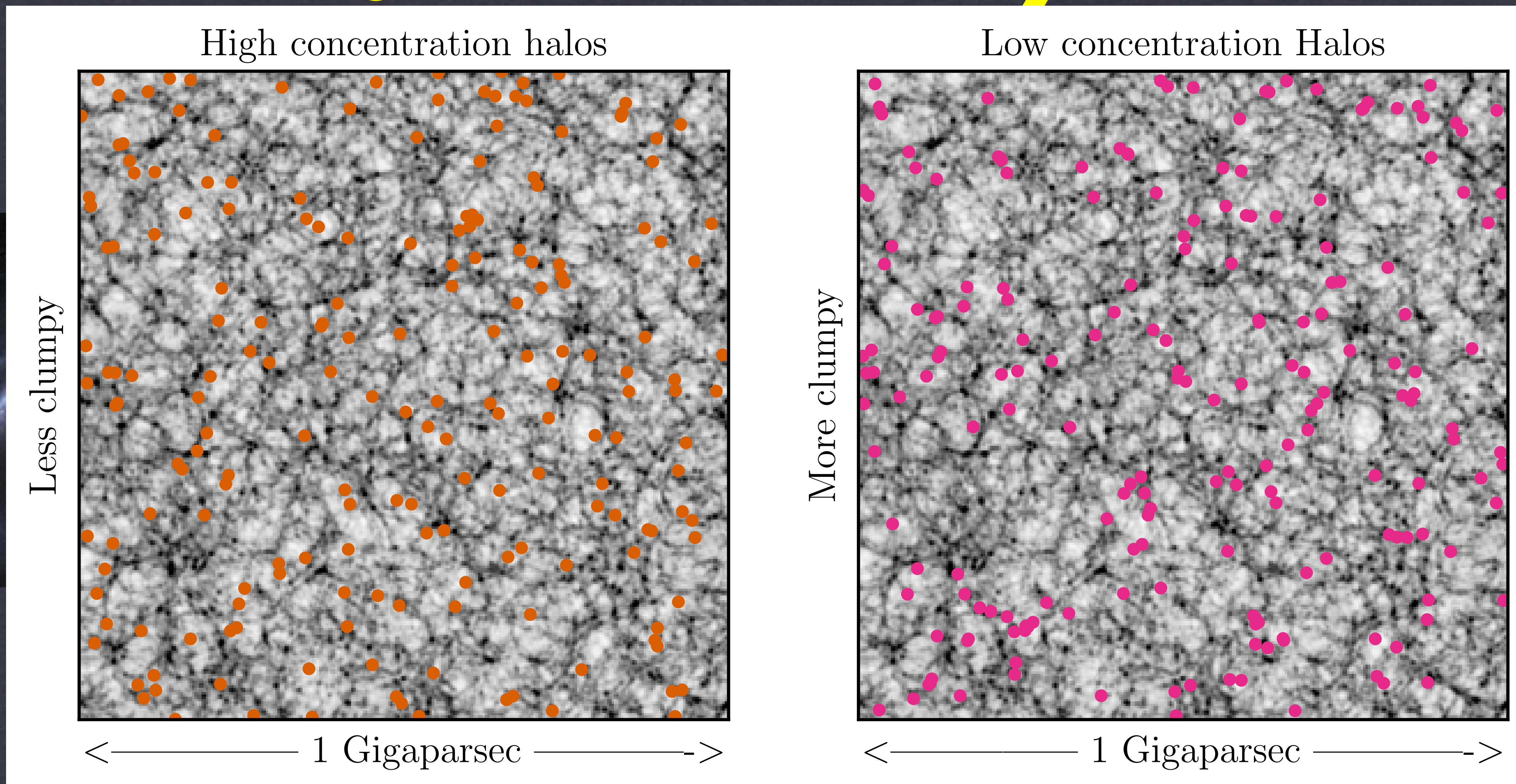
- Dependence of the large scale clustering amplitude on secondary parameters other than the halo mass.
- Notice the asymmetric behaviour on either side of Mnl.

See also: Lemson & Kaufmann 99, Gao et al. 2005, 2008

Observationally: Yang et al. 2006, Weinmann et al. 2006, Kauffmann et al. 2013, Hearin et al. 2014, but cf. Lin et al. 2015

Halo assembly bias





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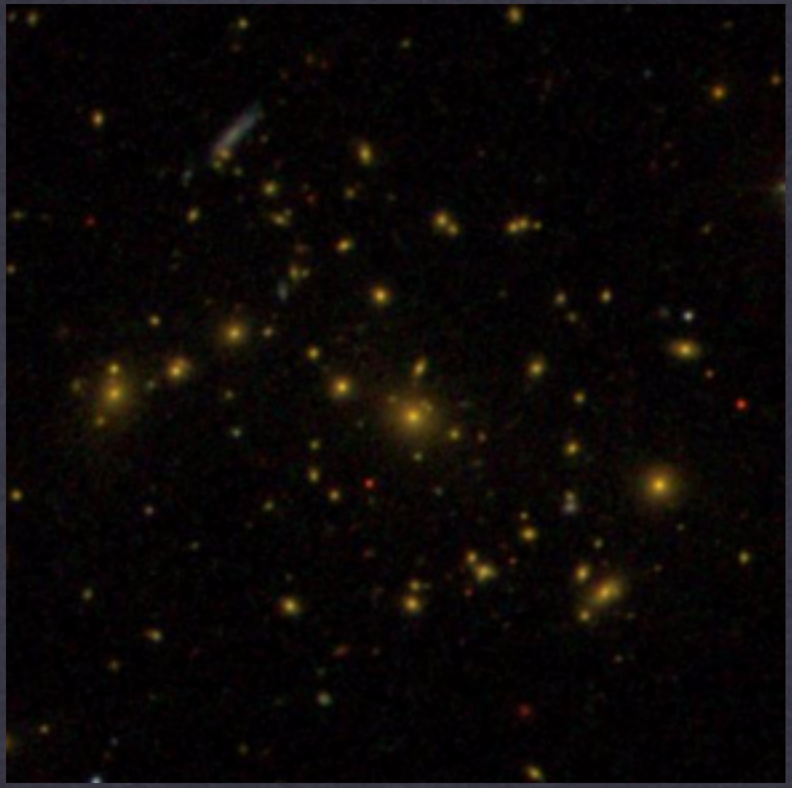
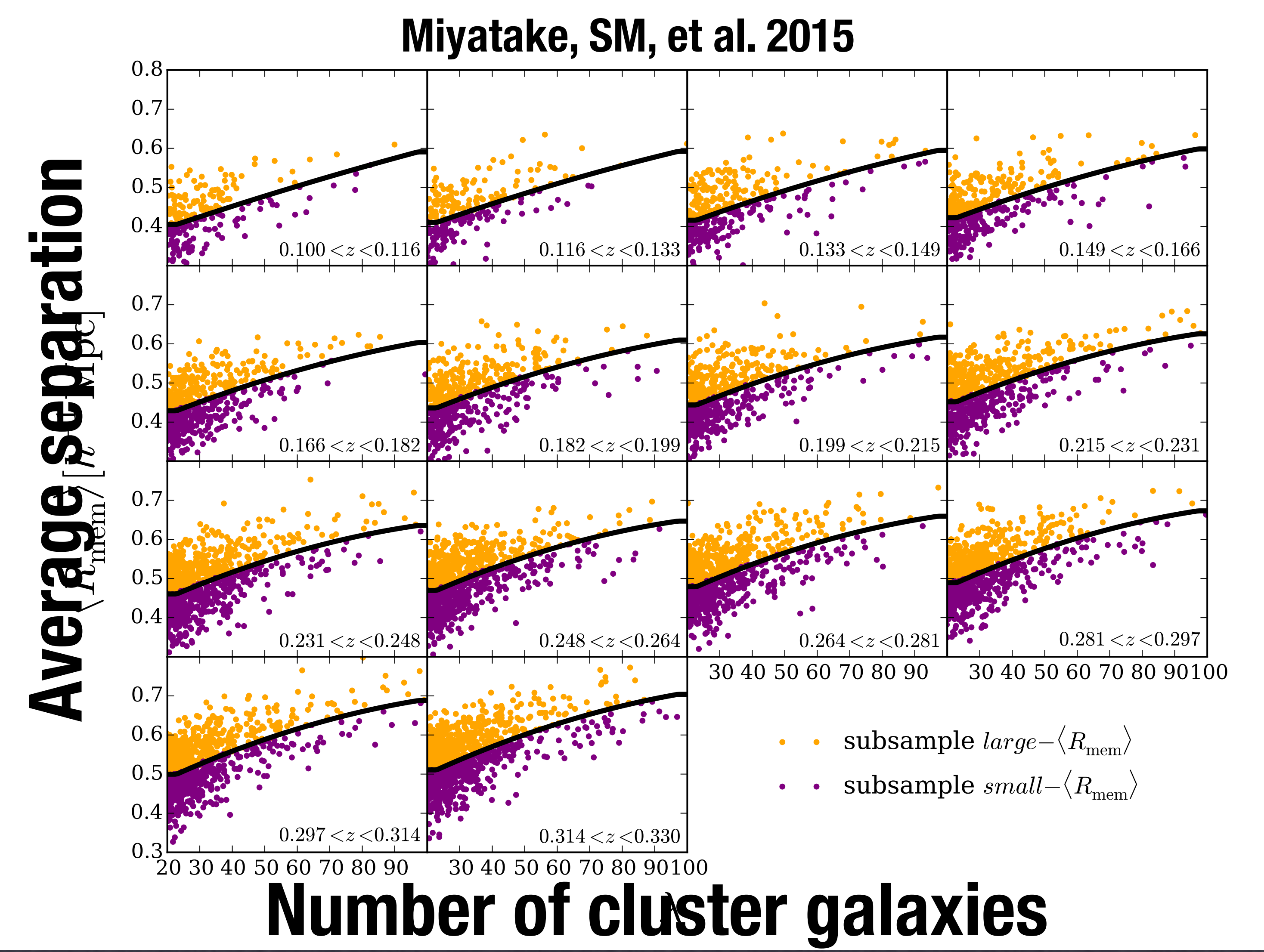
redMaPPer cluster catalog



Rykoff et al. 2014

- Clusters found as overdensities of red galaxies
- Bayesian formalism to select clusters

redMaPPer cluster subsamples

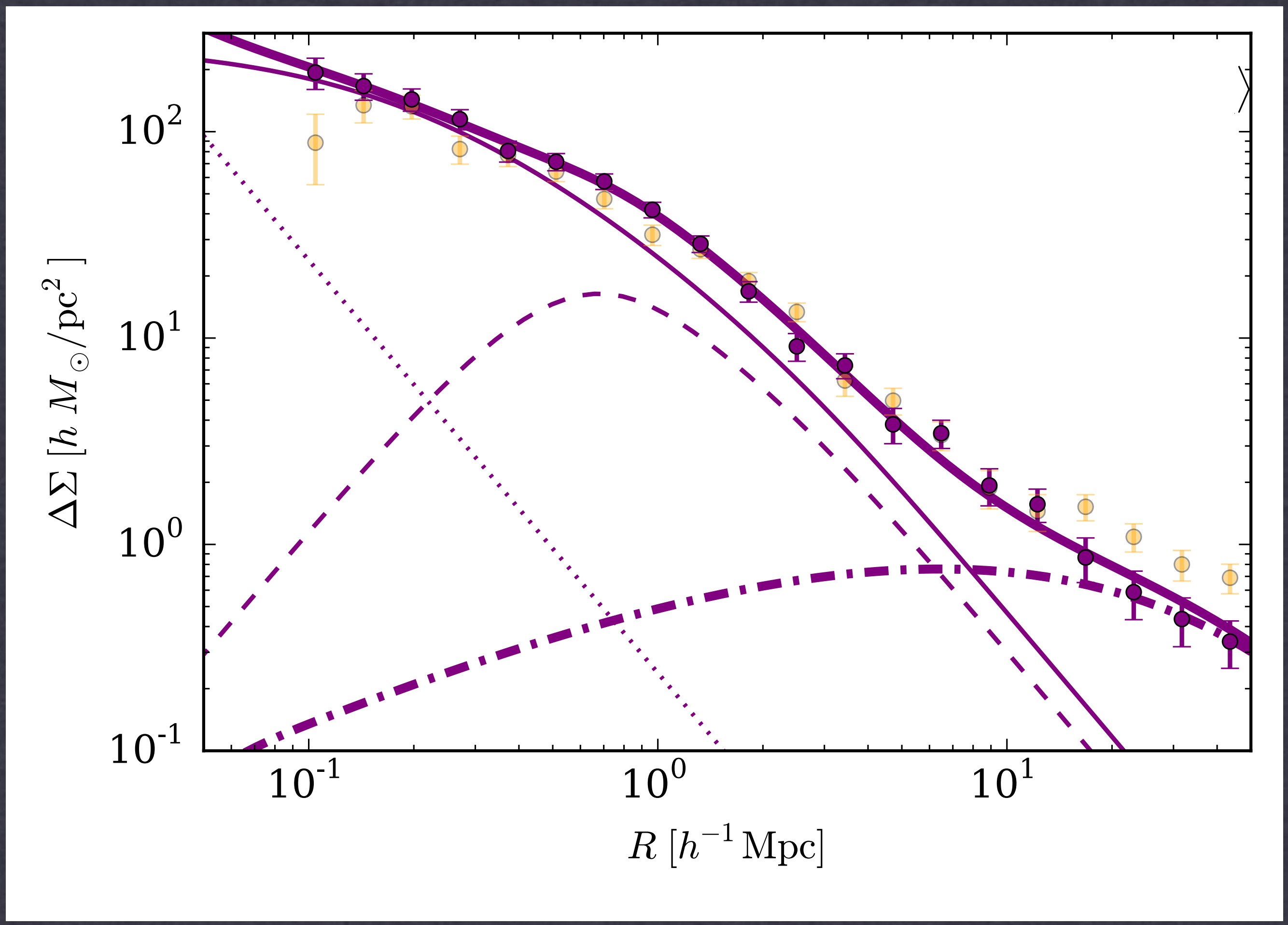


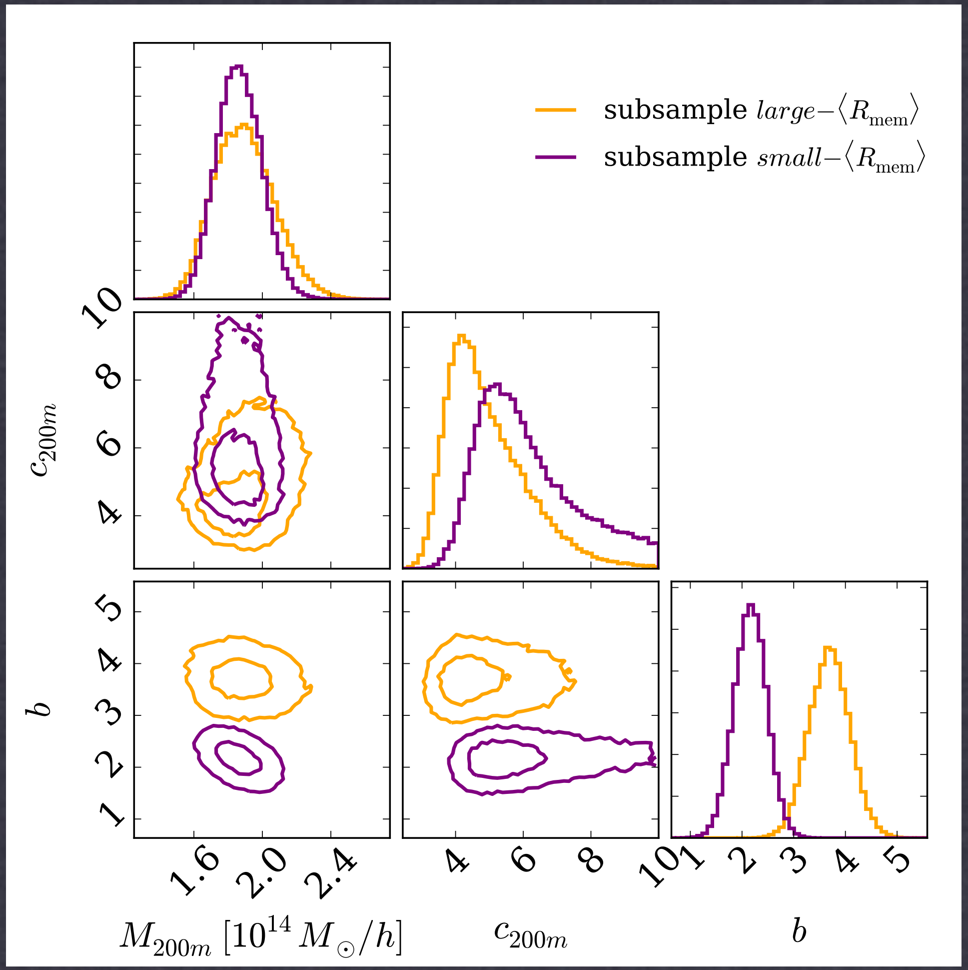
Less compact

More compact

- 8648 redMaPPer clusters: $z \in [0.1, 0.33]$
- Subsamples based upon the average cluster-centric distance of member galaxies, $\langle R_{mem}\rangle$
- Control for halo mass using the weak gravitational lensing signal

Weak gravitational lensing





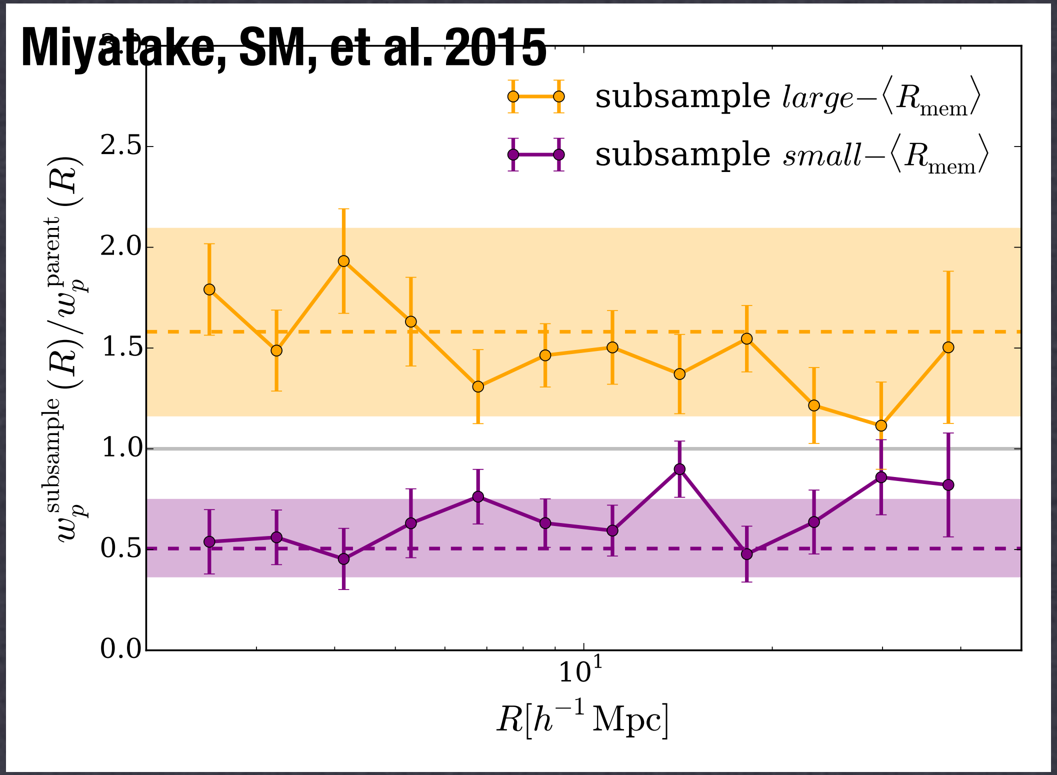
$$b^{\mathrm{large}-\langle R\rangle}/b^{\mathrm{small}-\langle R\rangle} = 1.64^{+0.31}_{-0.26}$$

- **Same average halo mass, different large scale bias.**
- **Bias difference due to mass difference is 1.1 in the extreme case.**

Miyatake, SM, et al. 2015

Clustering of galaxy clusters

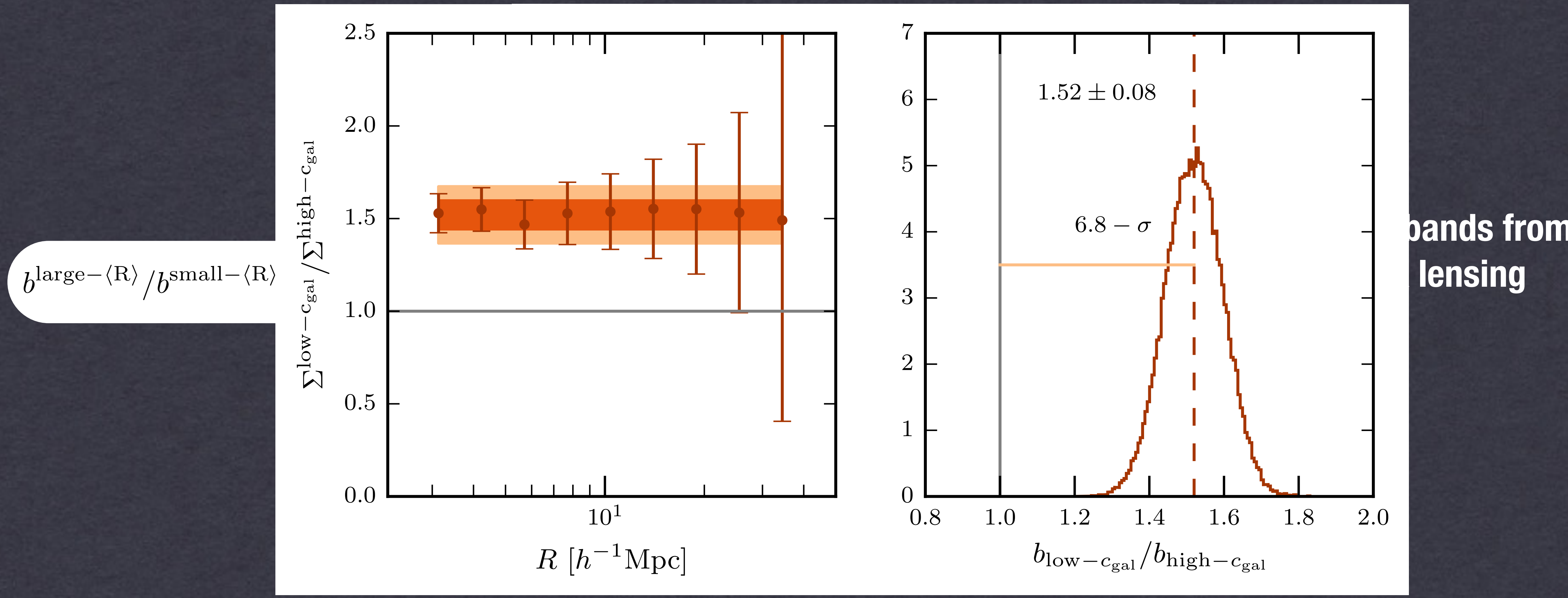
$$b^{\text{large}-\langle R\rangle}/b^{\text{small}-\langle R\rangle} = 1.40 \pm 0.09$$



Shaded bands from weak lensing

- Projected clustering of galaxy clusters shows a significant and consistent difference as well

Clustering of galaxy clusters



- Projected clustering of galaxy clusters shows a significant and consistent difference as well

Dark matter halos

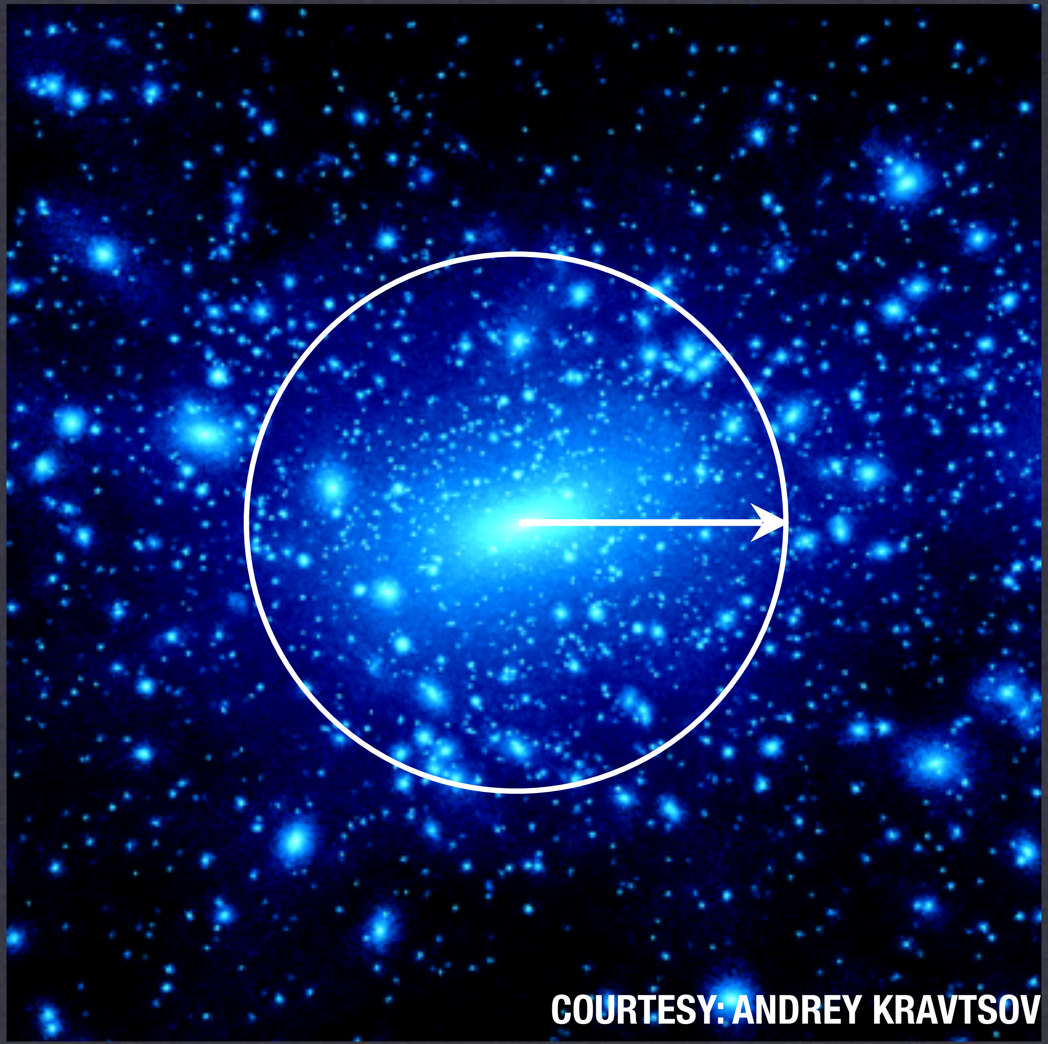
- Fundamental building block for structure in the Universe

- Near-universal density profile

$$\rho(r) \propto \left(\frac{r}{r_{\rm s}}\right)^{-1} \left(1 + \frac{r}{r_{\rm s}}\right)^{-2}$$

- Arbitrarily defined boundary

$$M_\Delta = \frac{4}{3}\pi R_\Delta^3 [\Delta \rho_{\rm ref}]$$



See Niikura et al. 2015 for observational evidence for NFW profile

Dark matter halos

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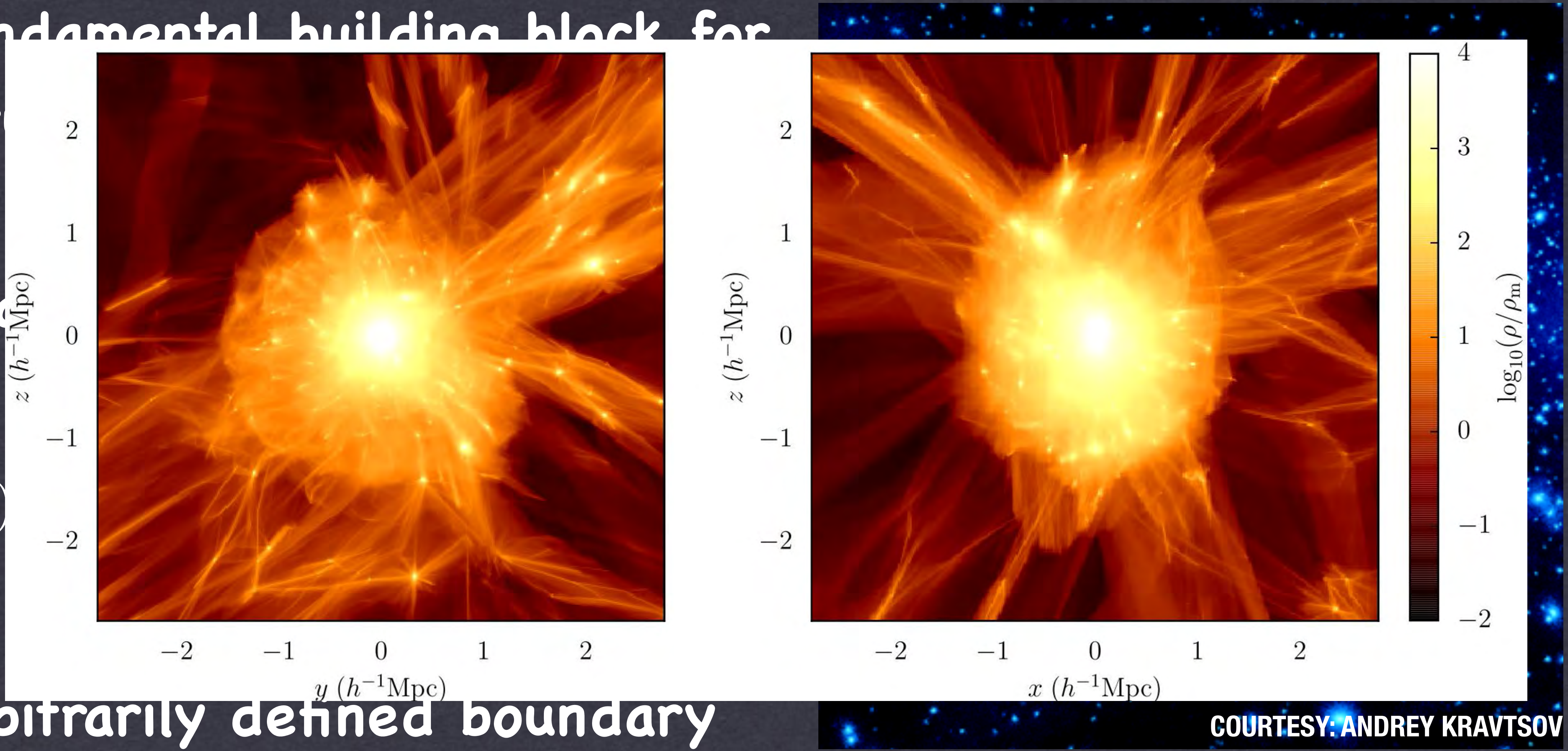
$\rho(r$



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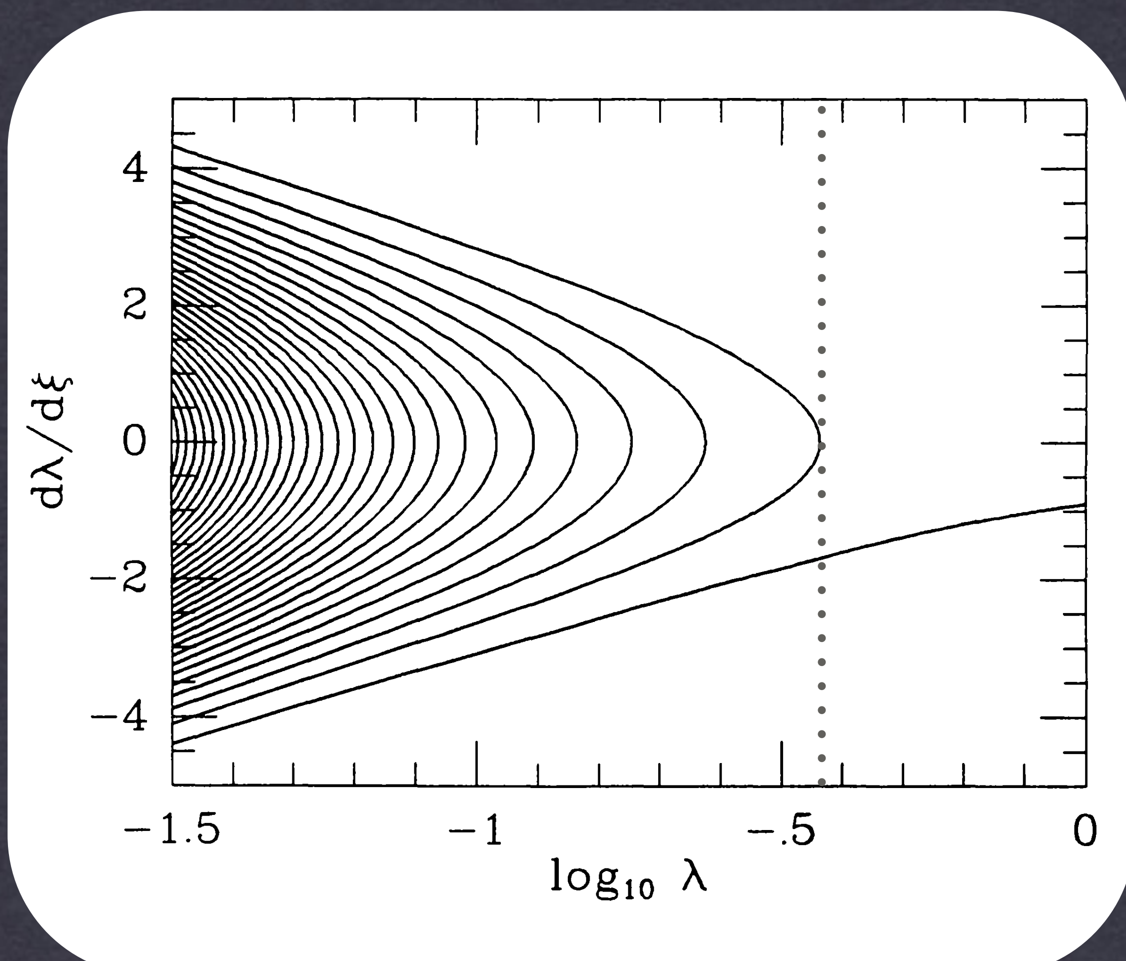
$$M_\Delta = \frac{4}{3}\pi R_\Delta^3 [\Delta \rho_{\rm ref}]$$

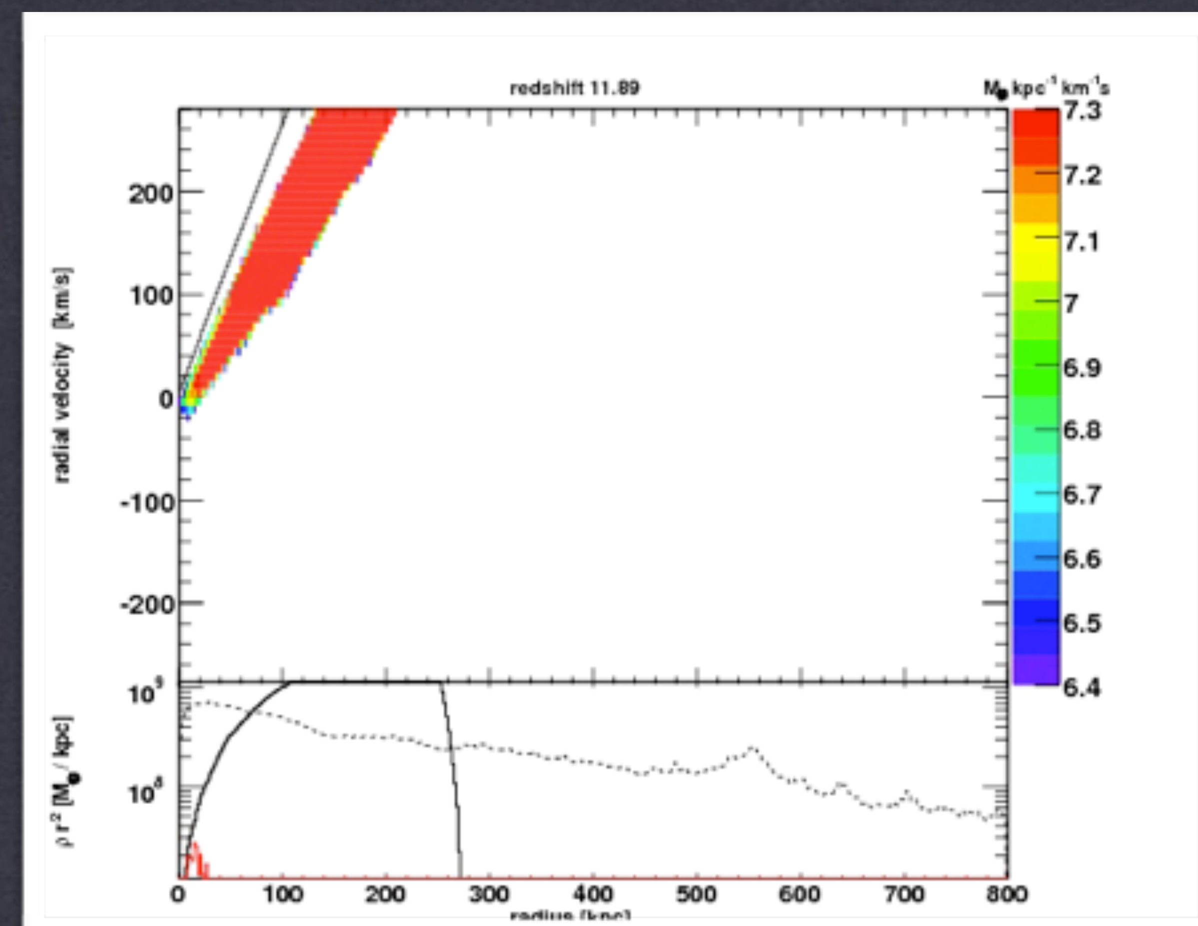
Visualization based on a technique developed by Kaehler, Hahn and Abel 2013

Self-similar secondary infall

LAST CAUSTIC

VELOCITY





DISTANCE

DISTANCE

FILLMORE AND GOLDREICH 1984
BERTSCHINGER 1985

VIA LACTEA I
DIEMAND ET AL 2008

Self-similar secondary infall

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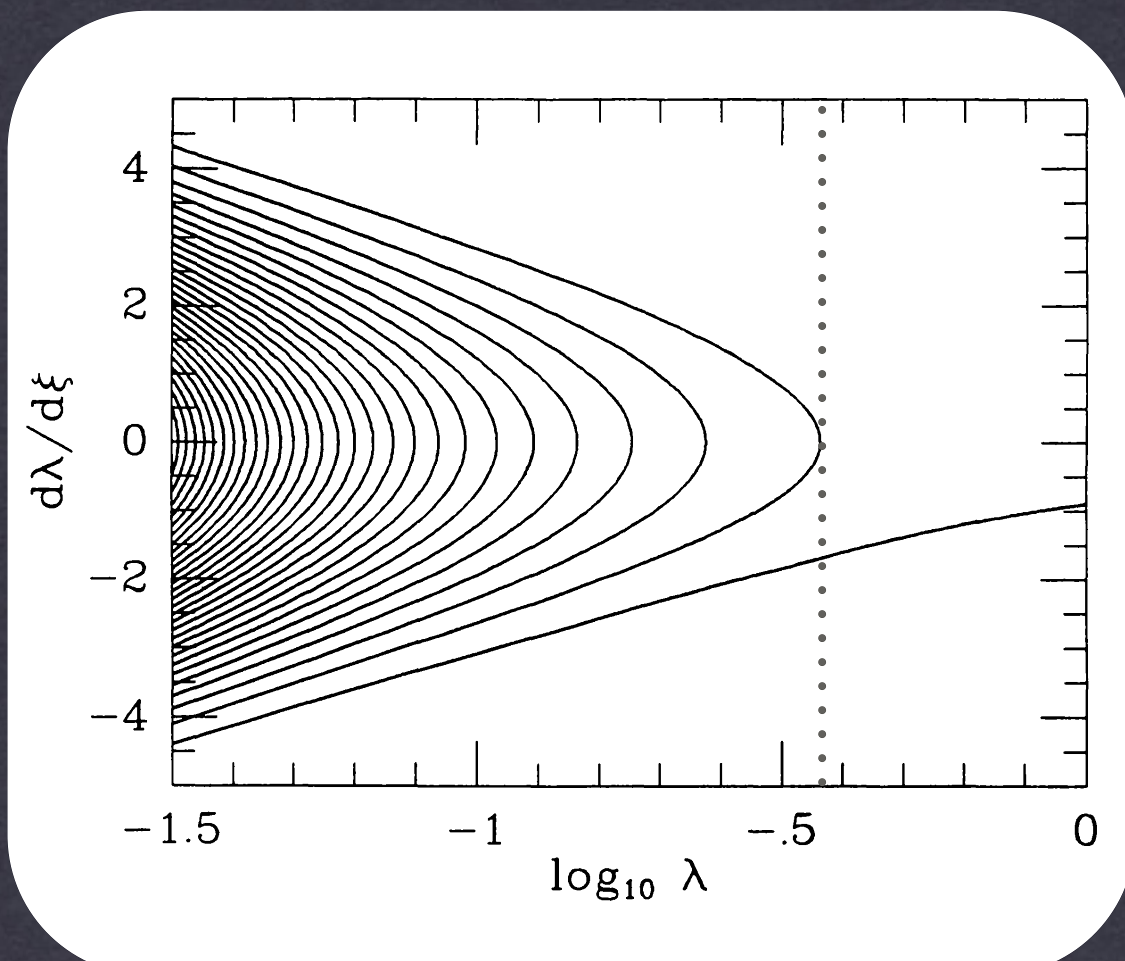

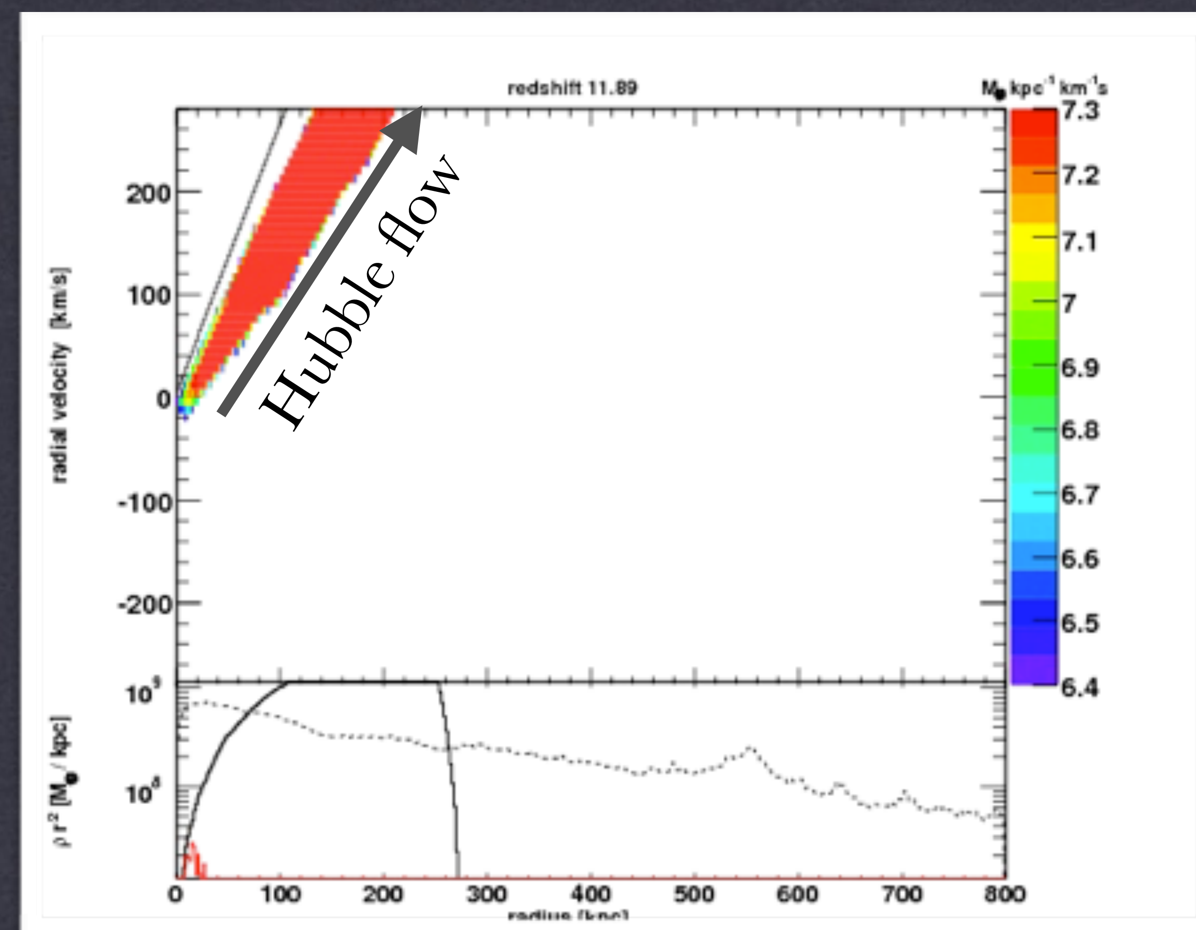

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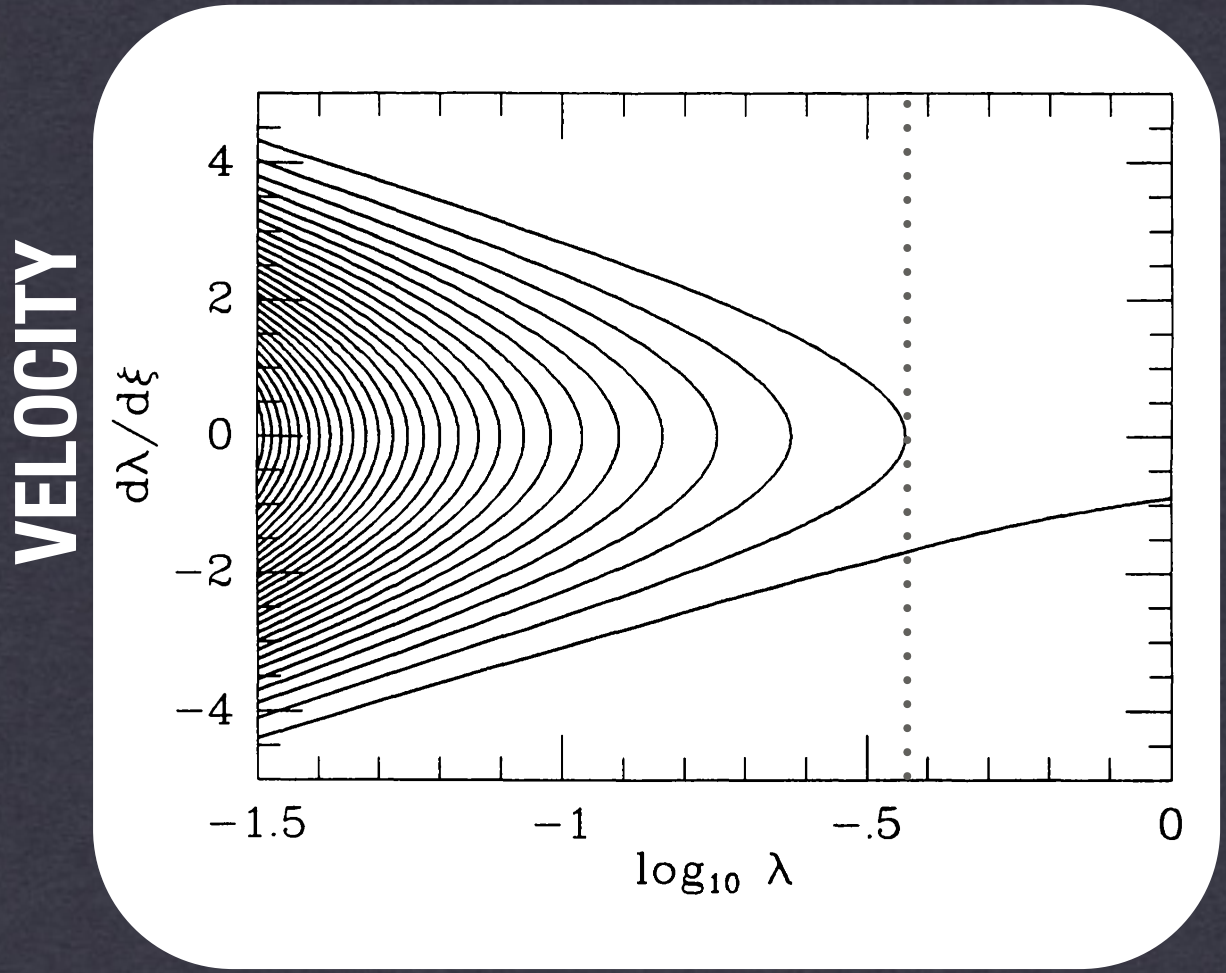

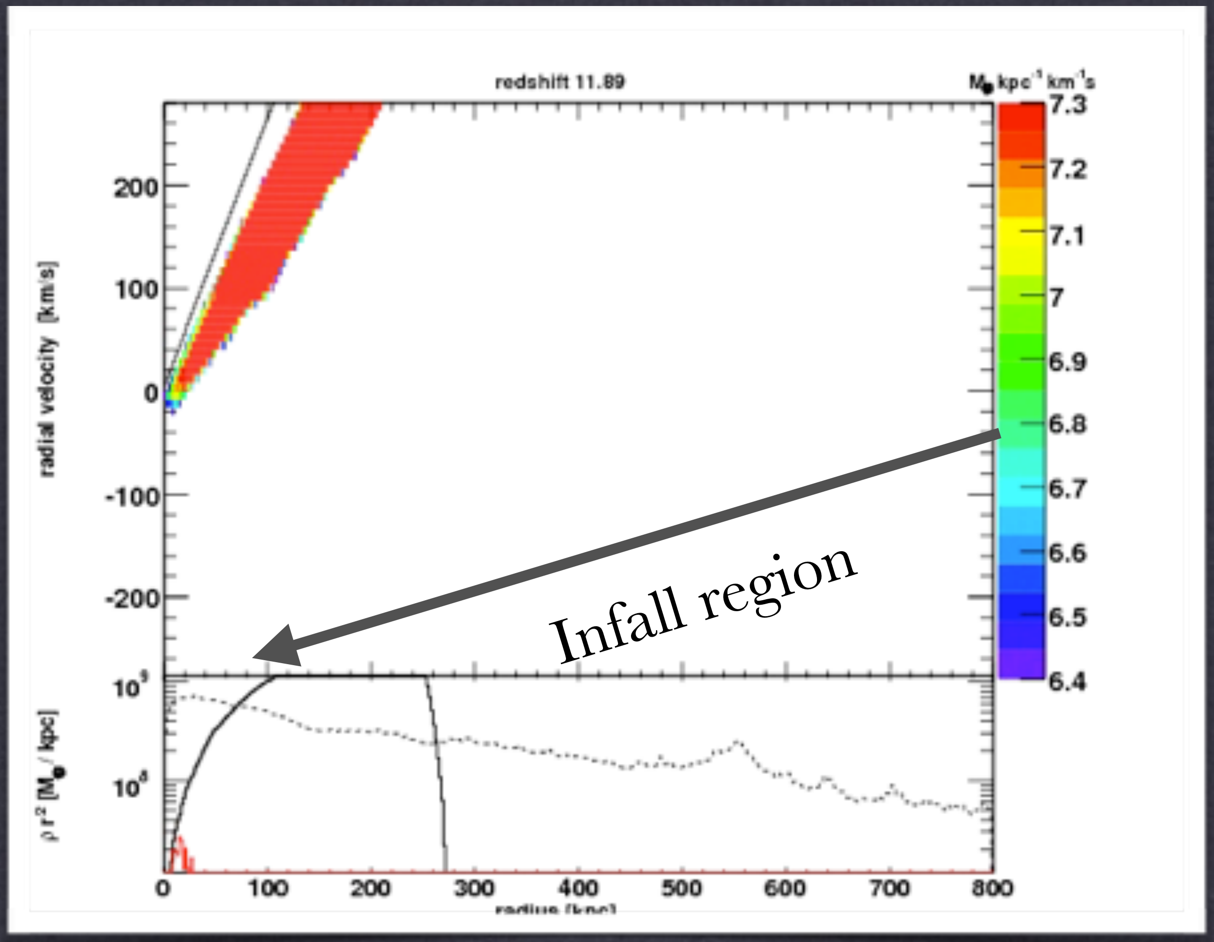

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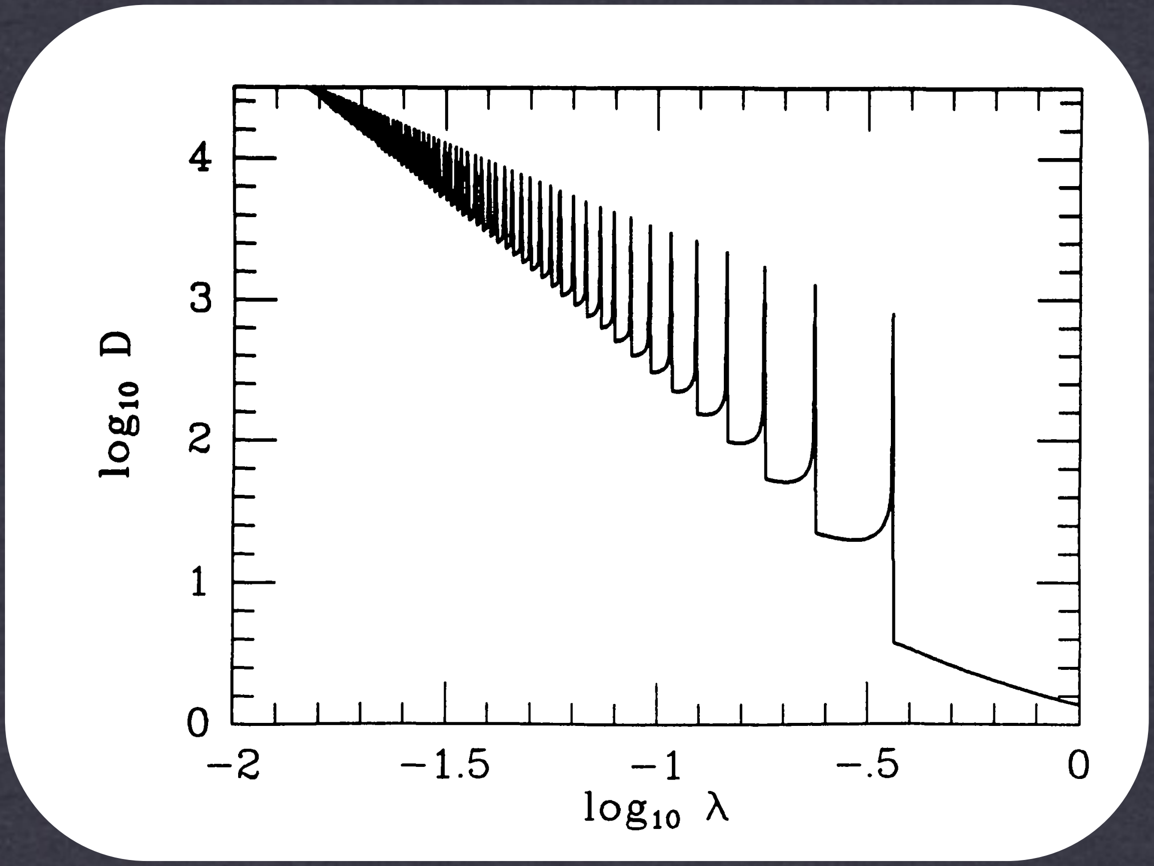
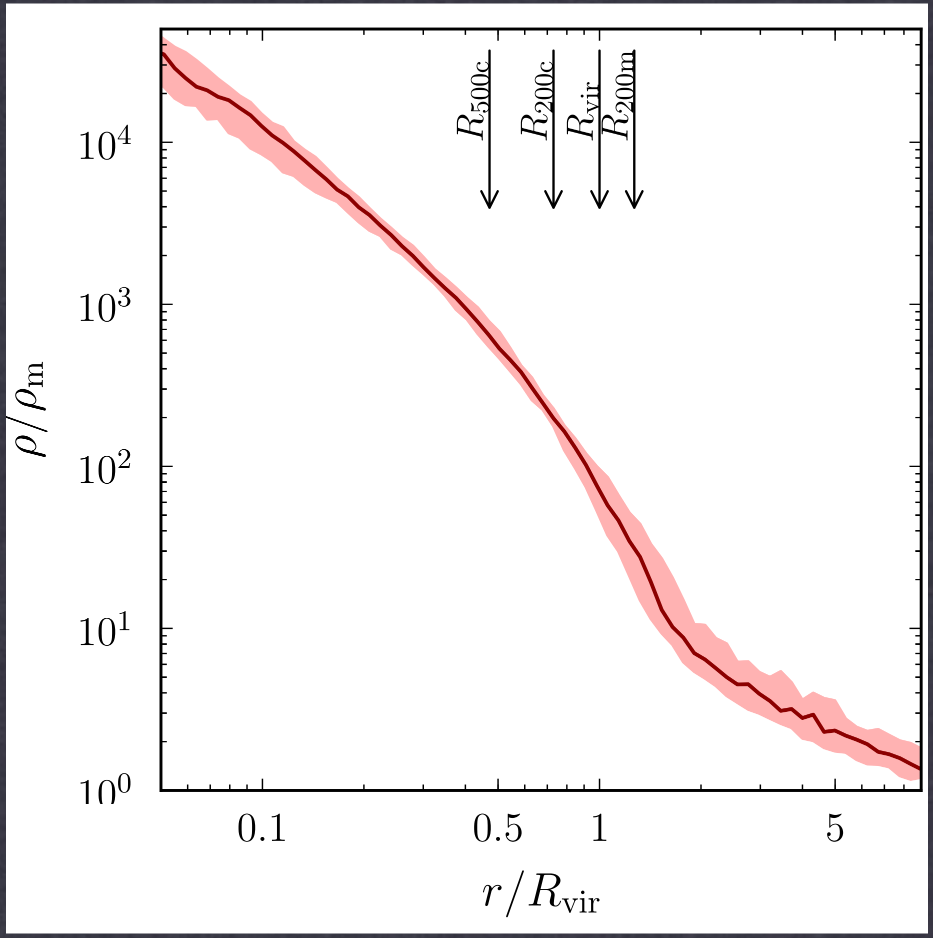
Last caustic in the density profile

LAST CAUSTIC



FILLMORE AND GOLDREICH 1984, BERTSCHINGER 1985



DIEMER & KRAVTSOV 2014

- Steepening of density profile at the last caustic

SEE ADHIKARI, DALAL AND CHAMBERLAIN 2014 FOR A SIMPLE SPHERICAL MODEL

Last caustic in the density profile

- Depends upon the mass accretion rate
  - Faster accreting halos have smaller splash back radius

See also: Vogelsberger et al. 2011, Diemer & Kravtsov 2014, Adhikari, Dalal & Chamberlain 2014

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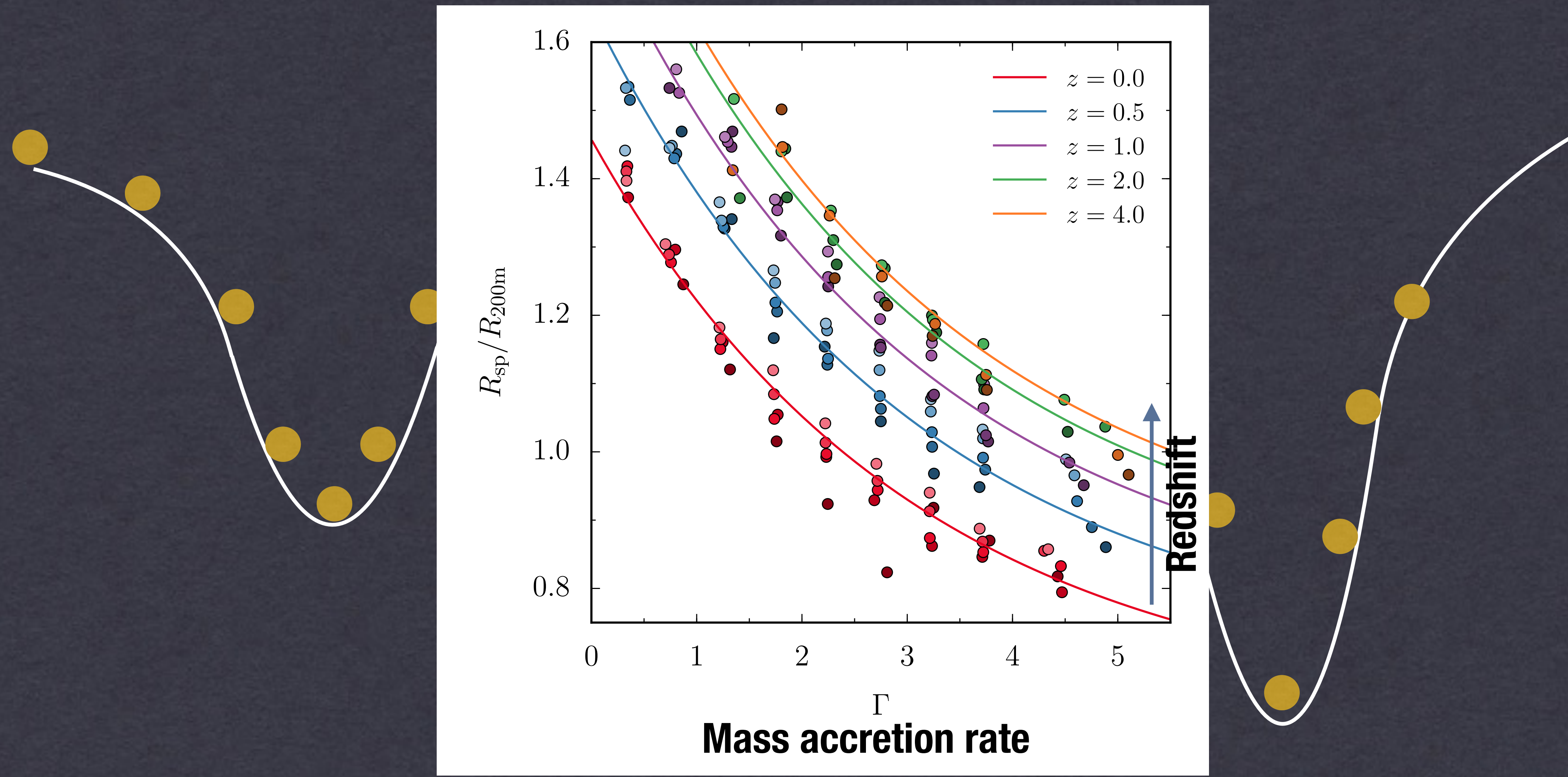

SM, DIEMER & KRAVTSOV 2015

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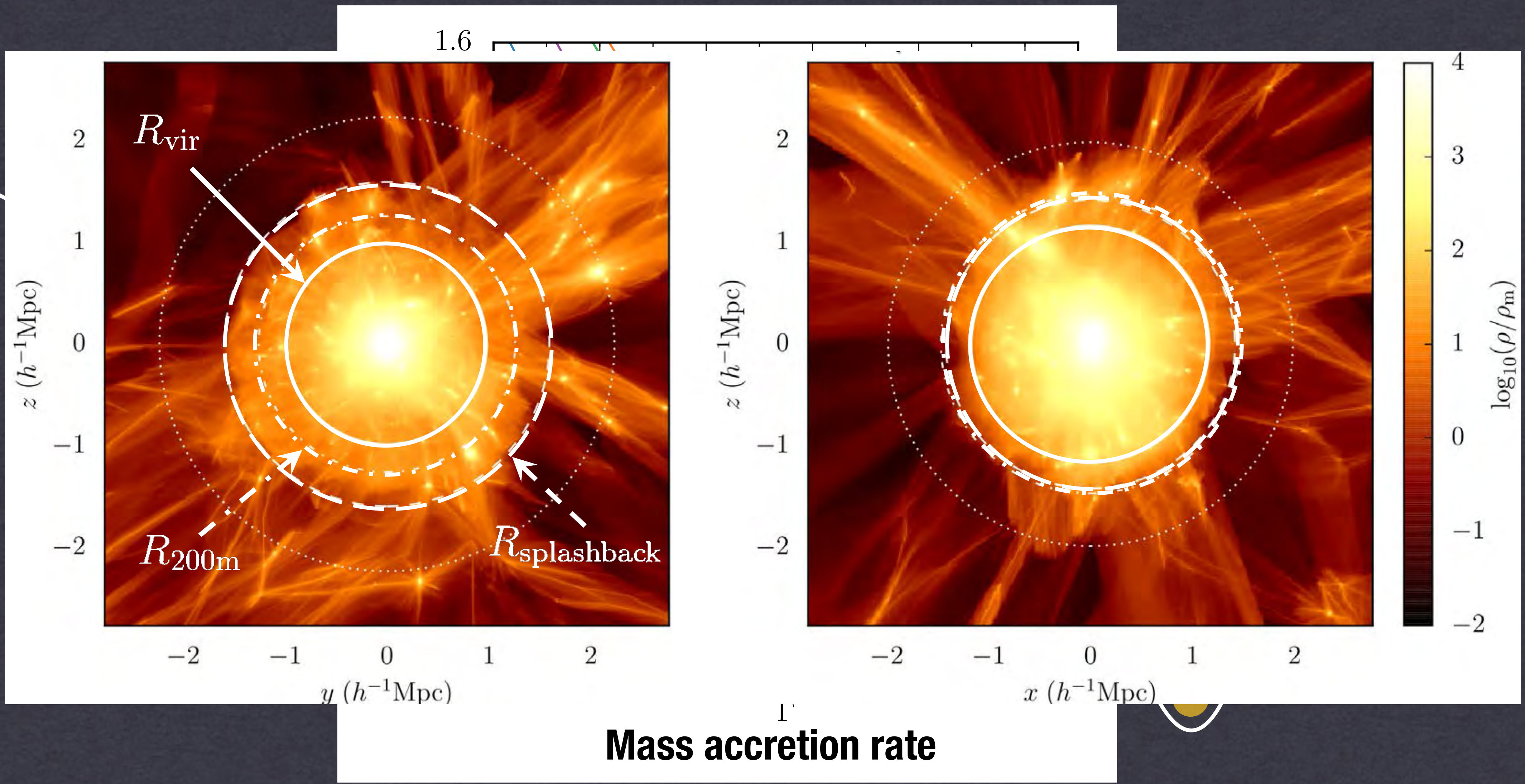

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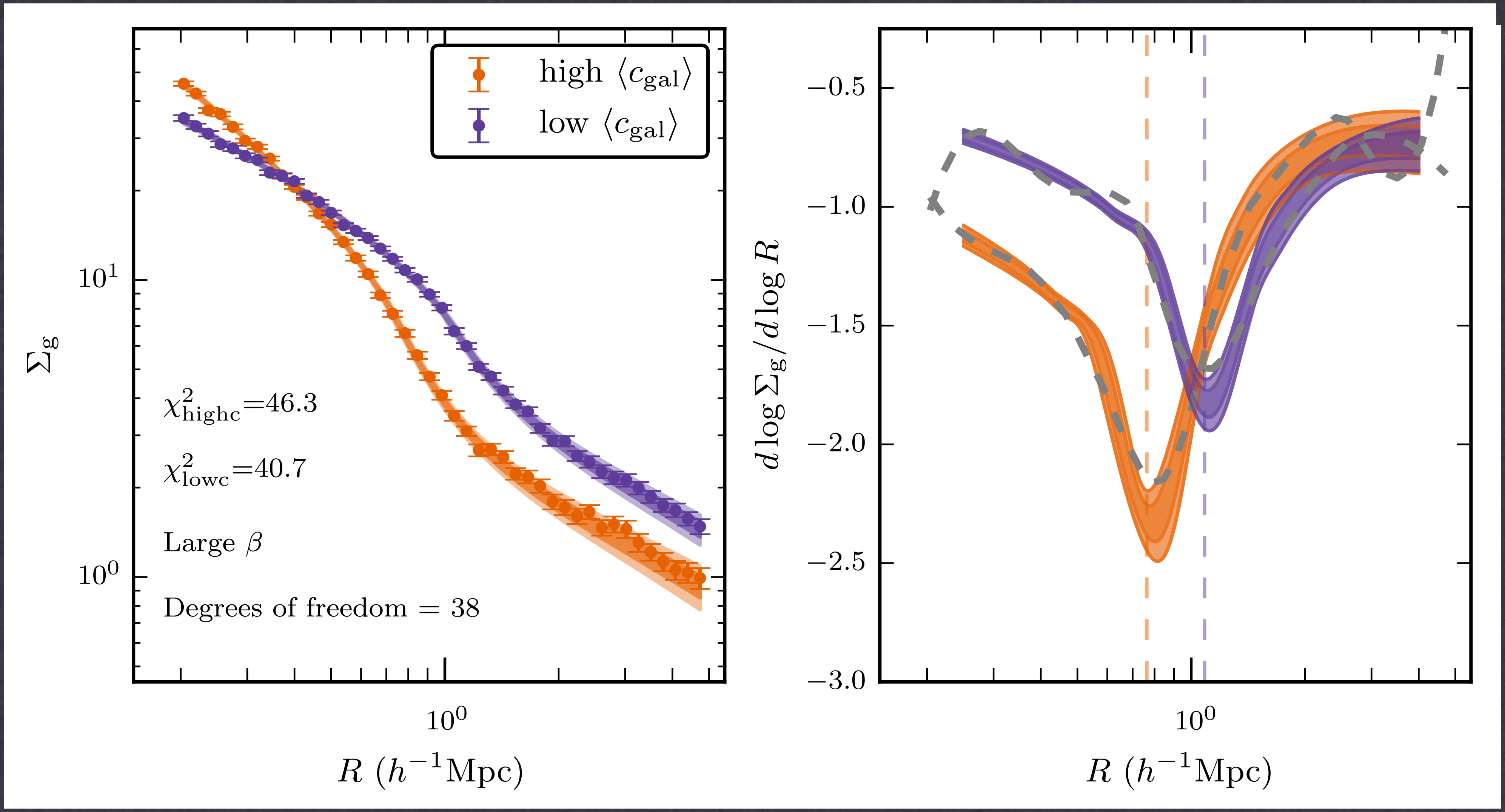
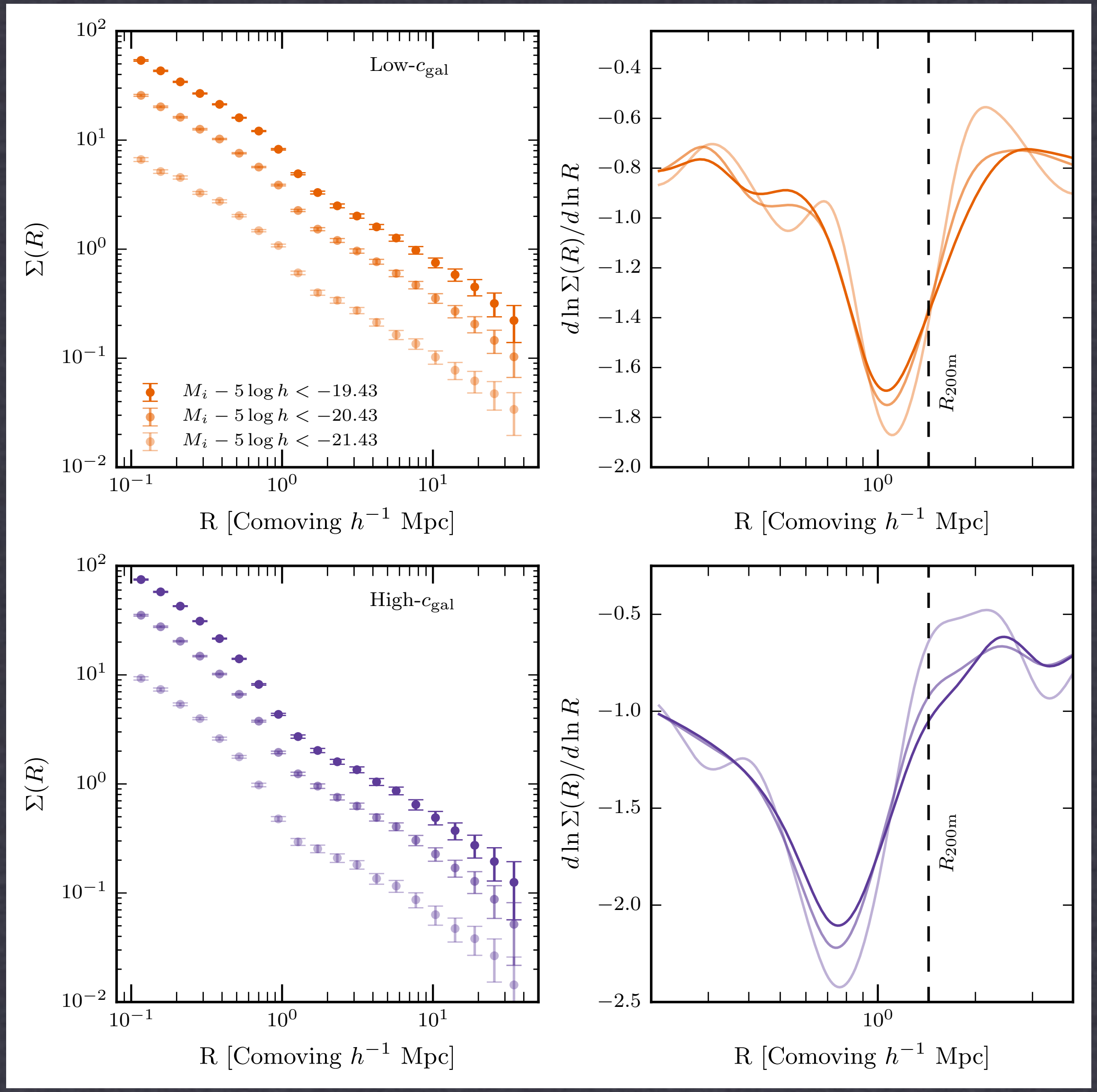
Splashback radius



- Use photometric galaxies with M_i-5 log h <-21.42 (assuming cluster redshift)
- Surface number density of such galaxies as a function of radius

SM, et al. 2015 (in preparation)

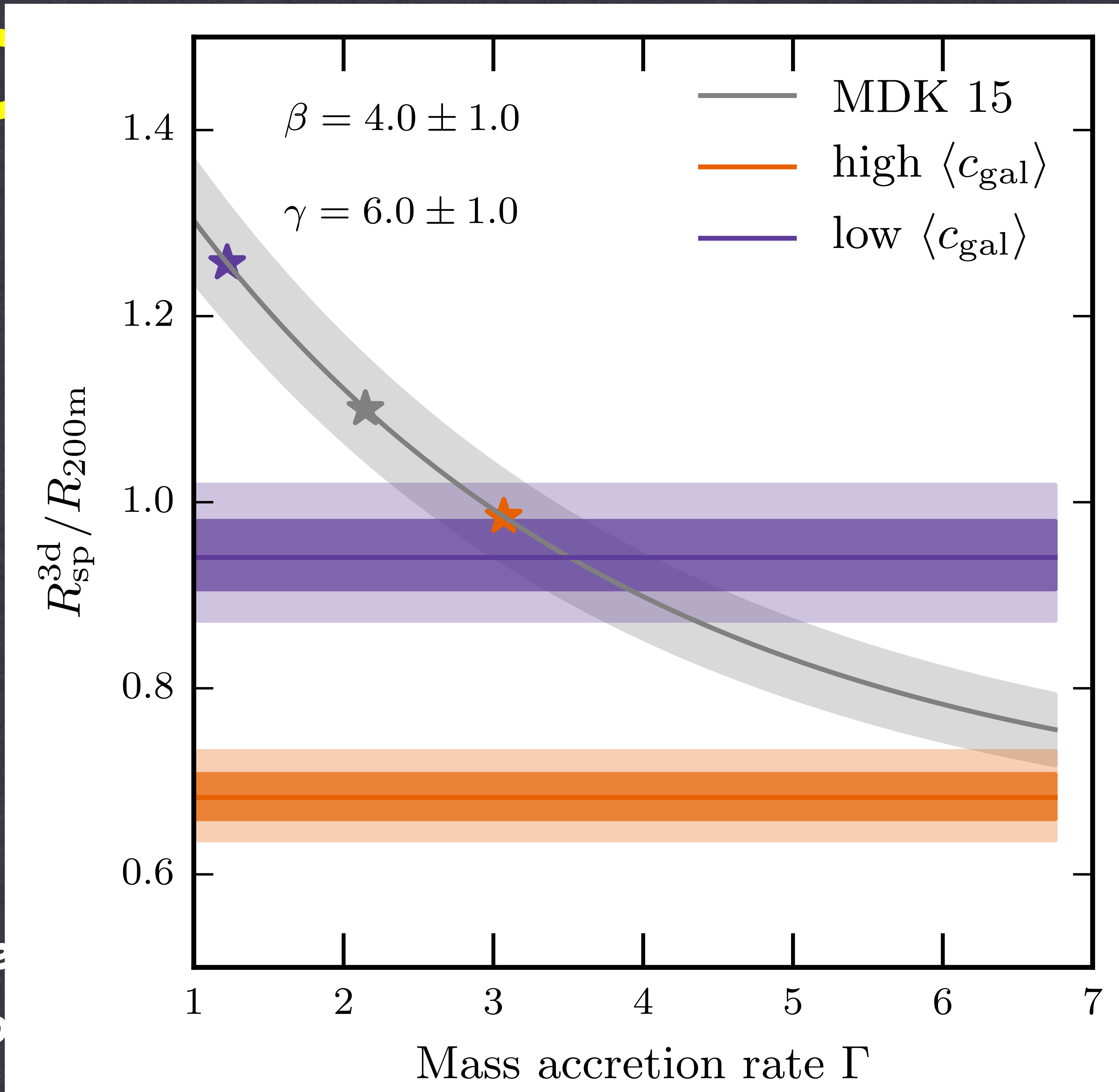
Dynamical friction ?!



- Does not appear to depend upon the magnitude of photometric galaxies used.

SM, et al. 2015 (in preparation)

D ?!



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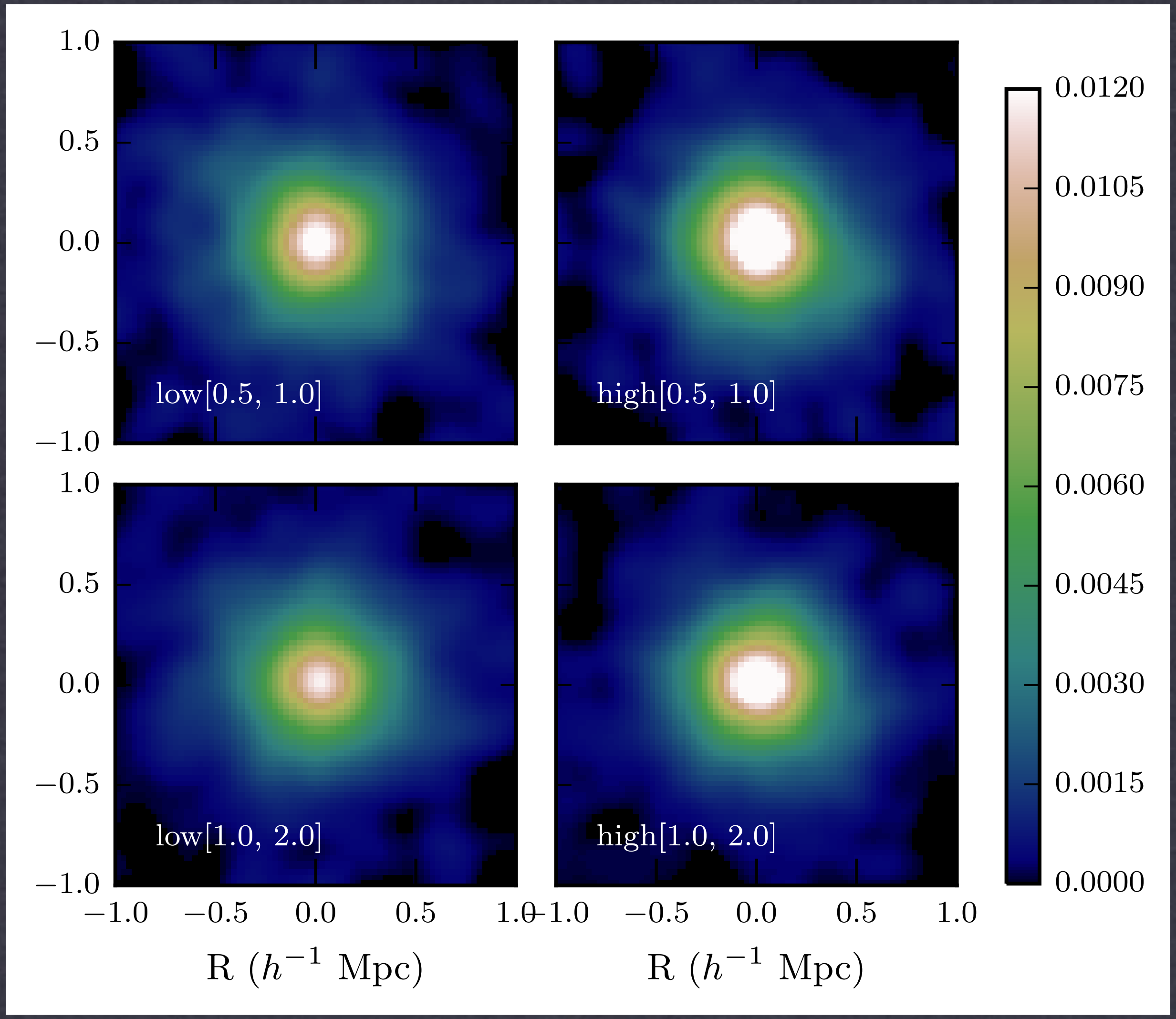
SM, et al. 2015 (in preparation)

Xray properties

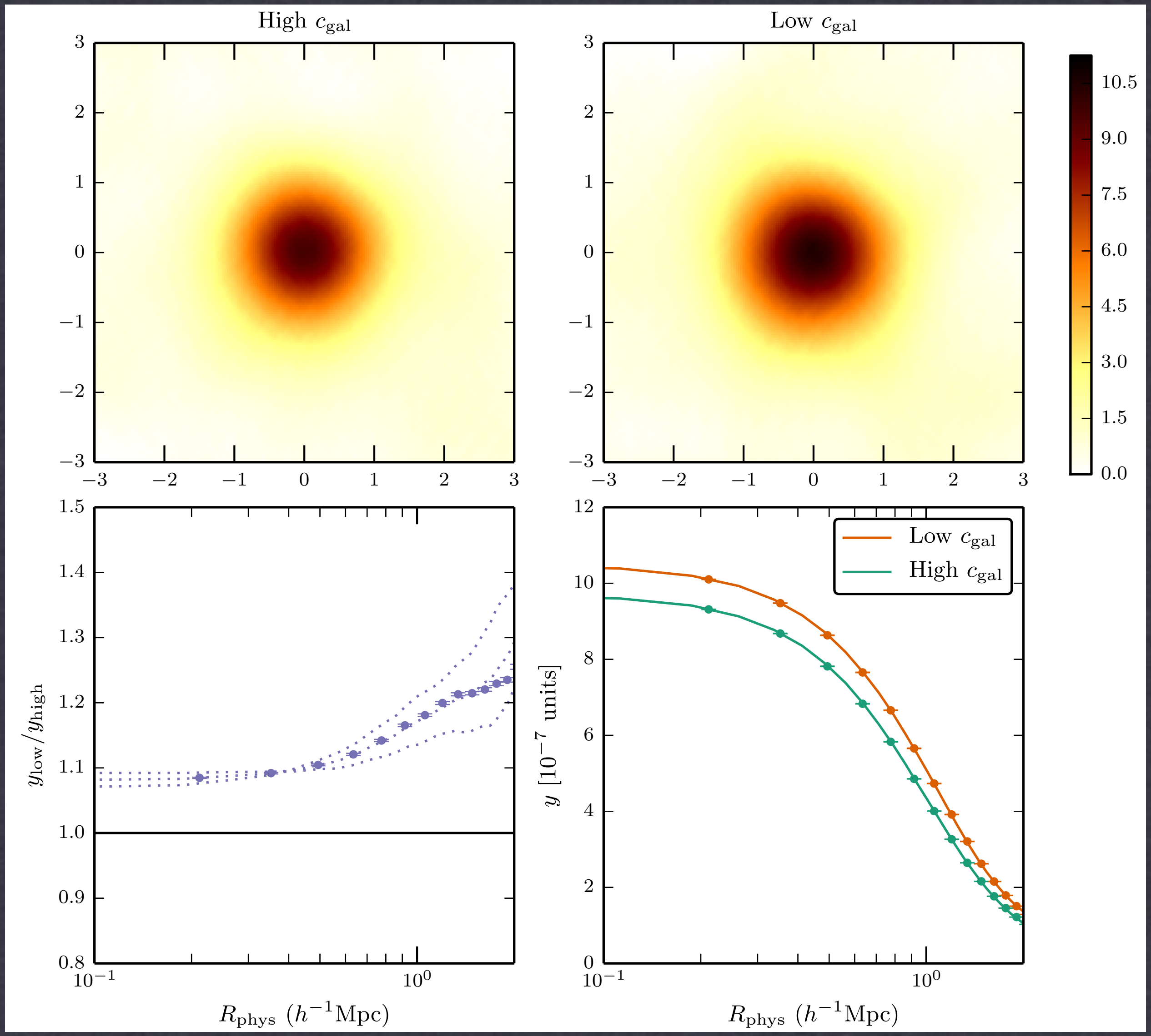


- Stacked ROSAT all sky survey data

- Differences in the inner regions (perhaps different from theoretical expectations).

SZ properties

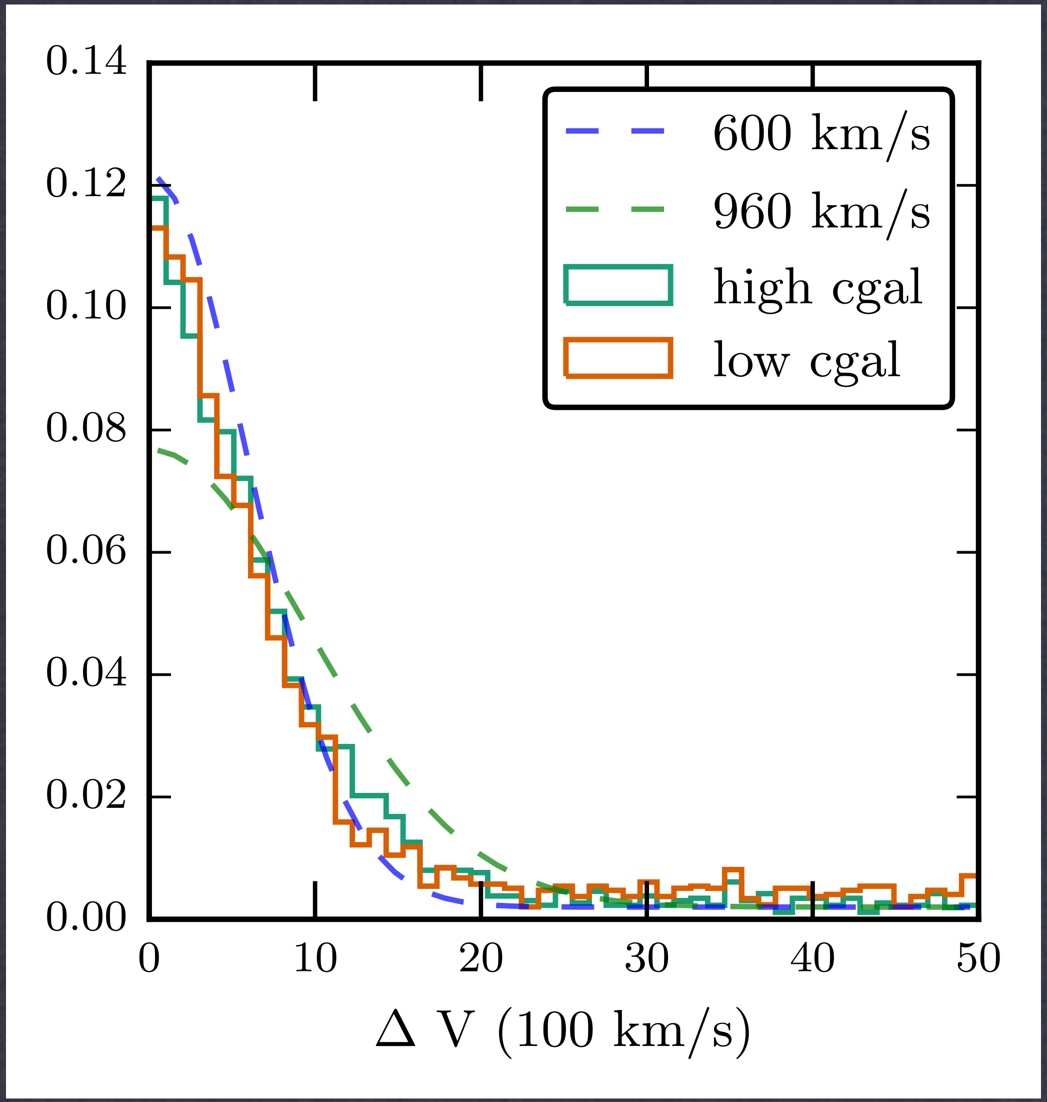
- Stacked Planck Compton y-maps



- Differences in the outer regions (similar to theoretical expectations).

See e.g., Lau et al. 2014

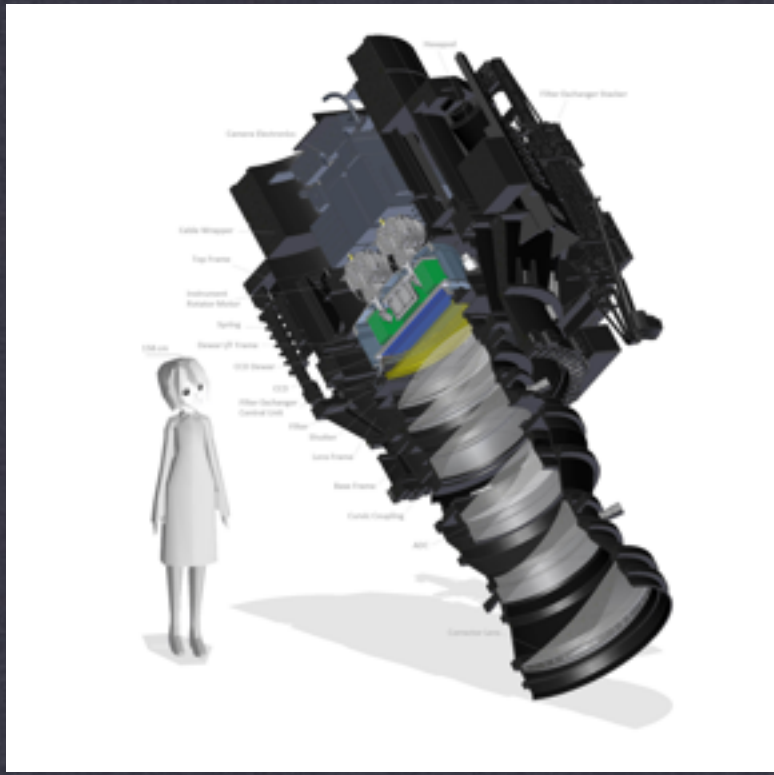
Weak lensing systematics ???

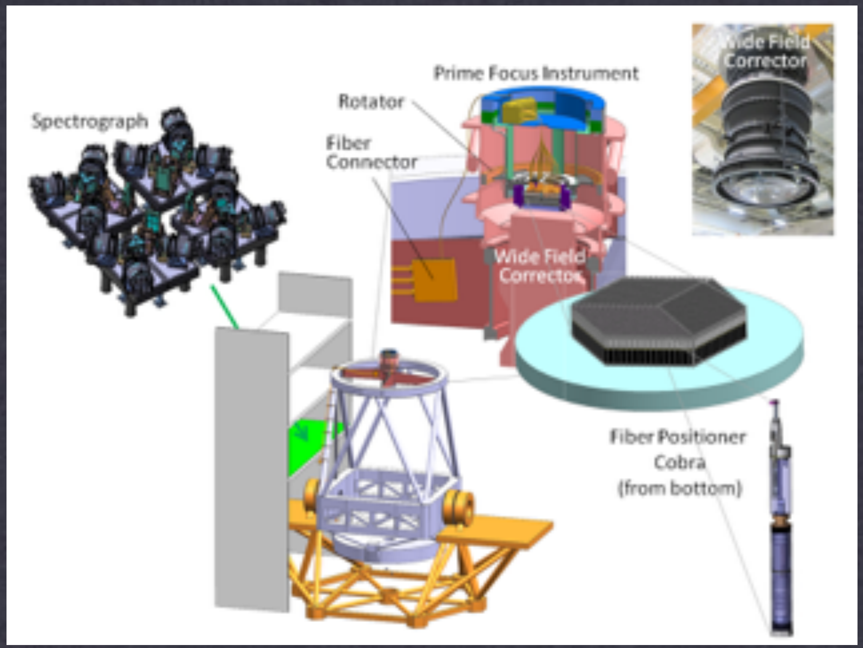


- **Kinematics of member galaxies around the redMaPPer clusters (using spectra from SDSS DR12 BOSS)**

SM, et al. 2015 (in preparation)

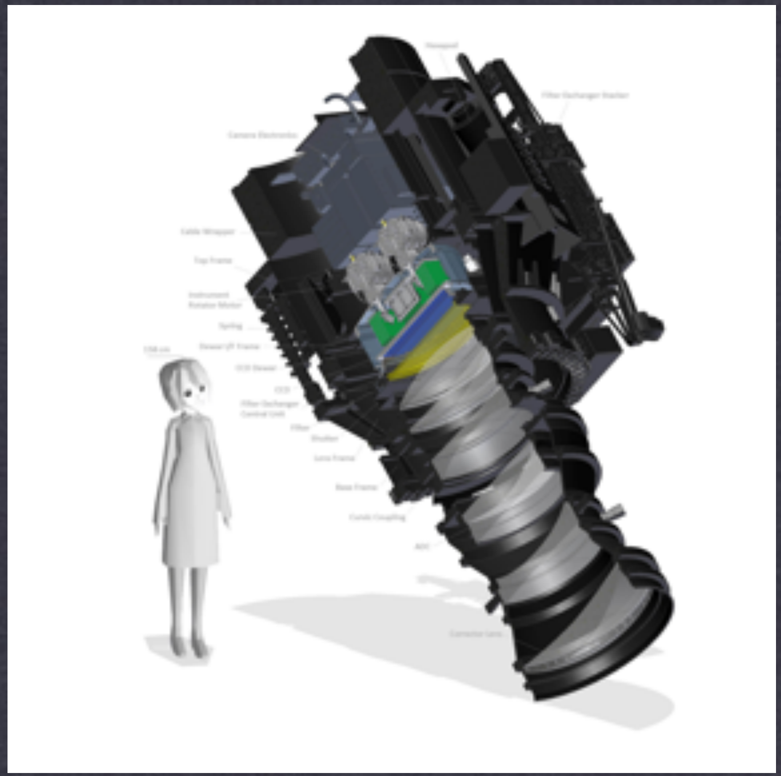
SuMIRe: Subaru Measurements of Images and Redshift Survey

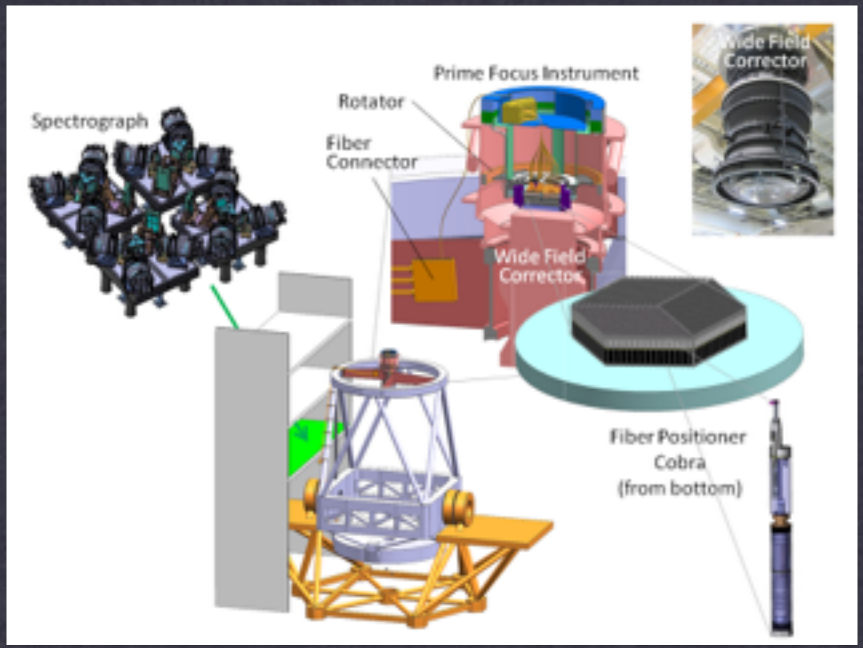




SuMIRe: Subaru Measurements of Images and Redshift Survey

- Hyper Suprime-cam:
  - 0.9 Gpixel camera
  - 5 bands: g,r,i,z,y
  - r band limit: 26 (Wide)
  - Wide angle (1.77 sq deg.)
- Prime Focus Spectrograph:
  - 2400 optical fibers per field of view
  - Real time fiber positioning adjustments





SuMIRe: Subaru Measurements of Images and Redshift Survey

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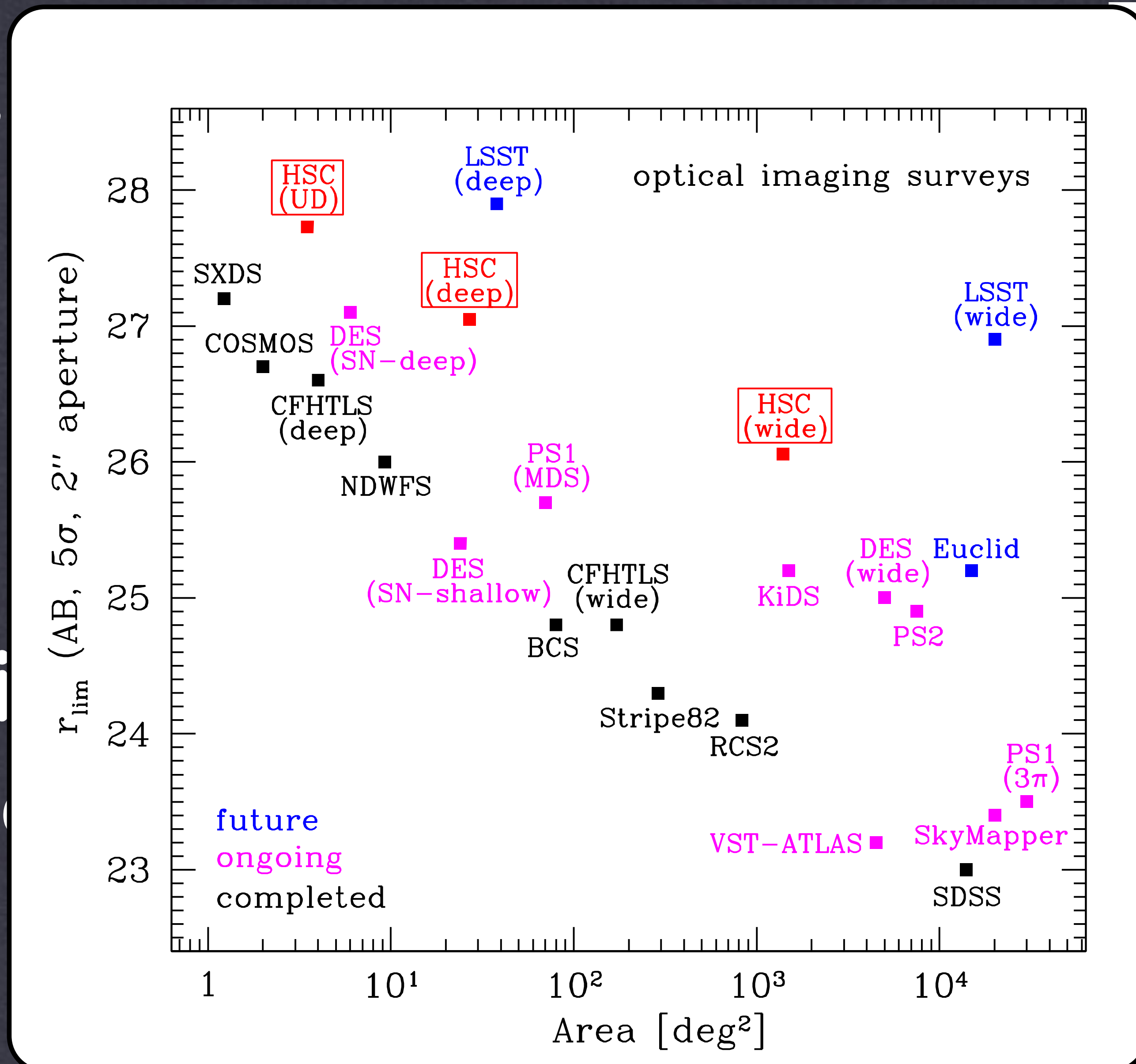

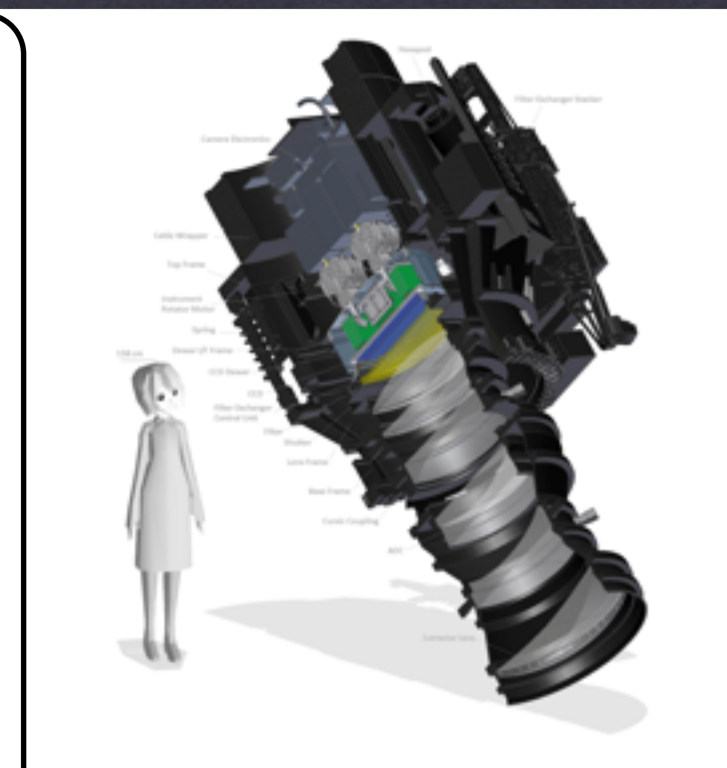

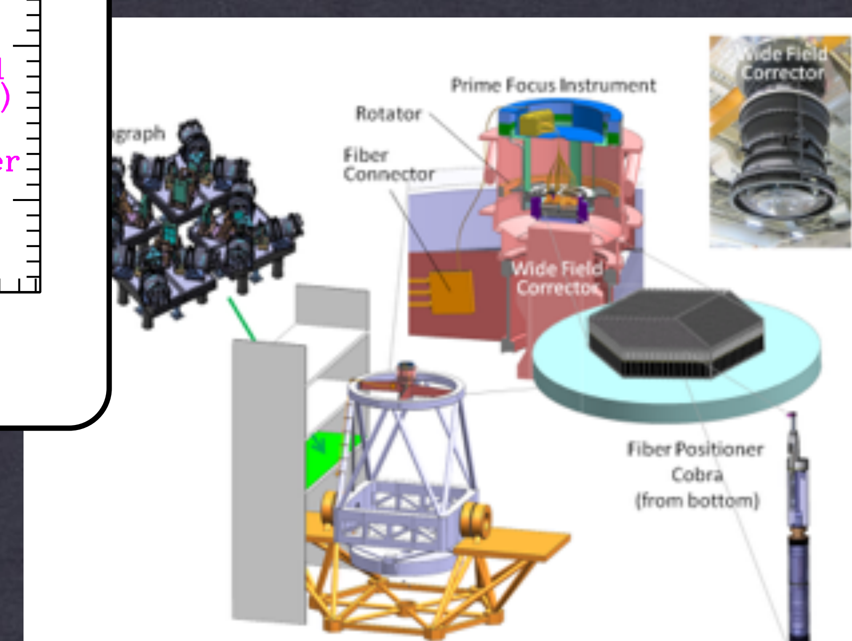

  - Real time fiber positioning adjustments

Conclusions

- Detection of halo assembly bias and the splash back radius on cluster scales !!!
- The strength of the assembly bias effect seems to be larger than naive expectations.
- The splash back radius is smaller than expected.

Thank you!!!