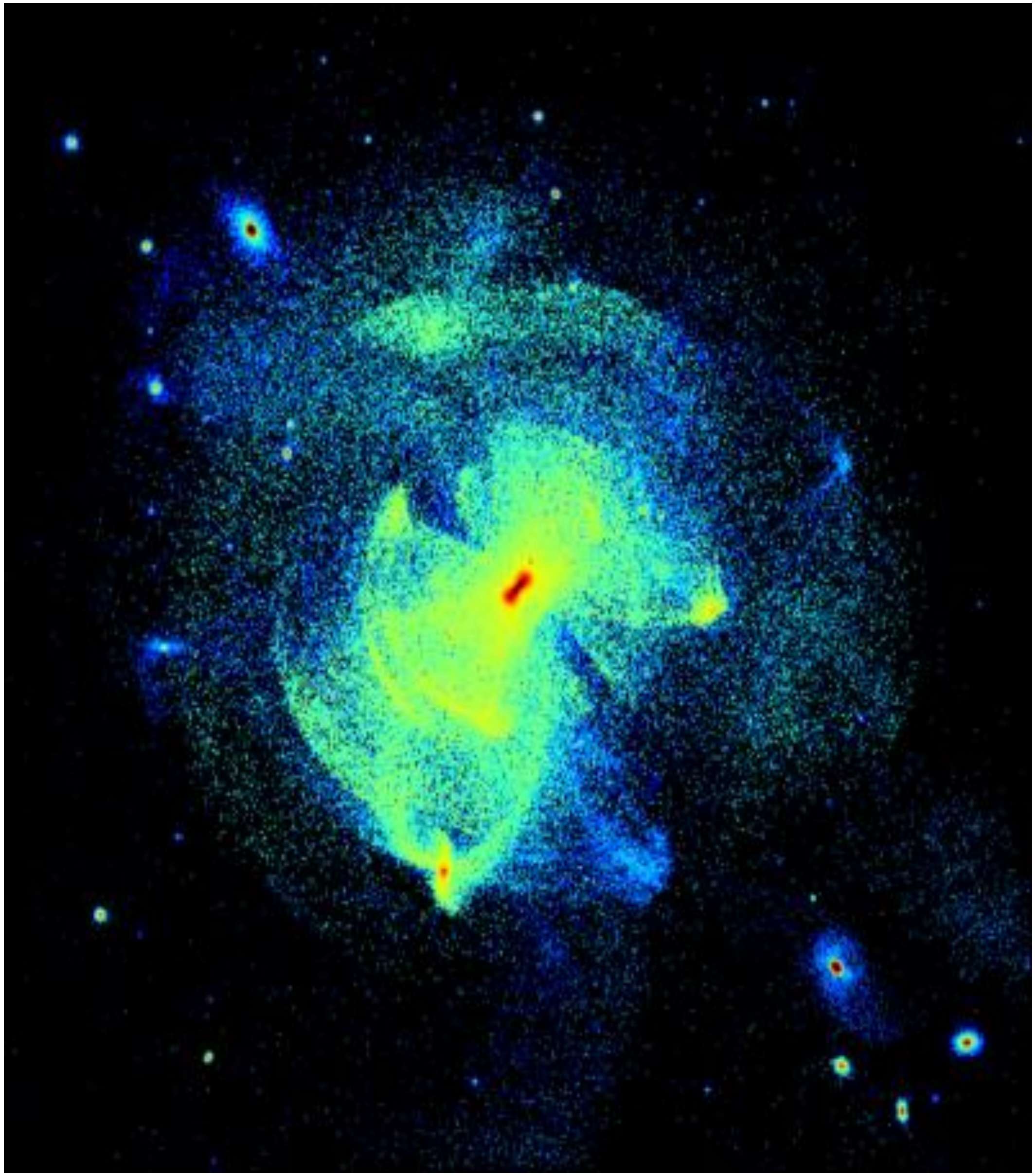


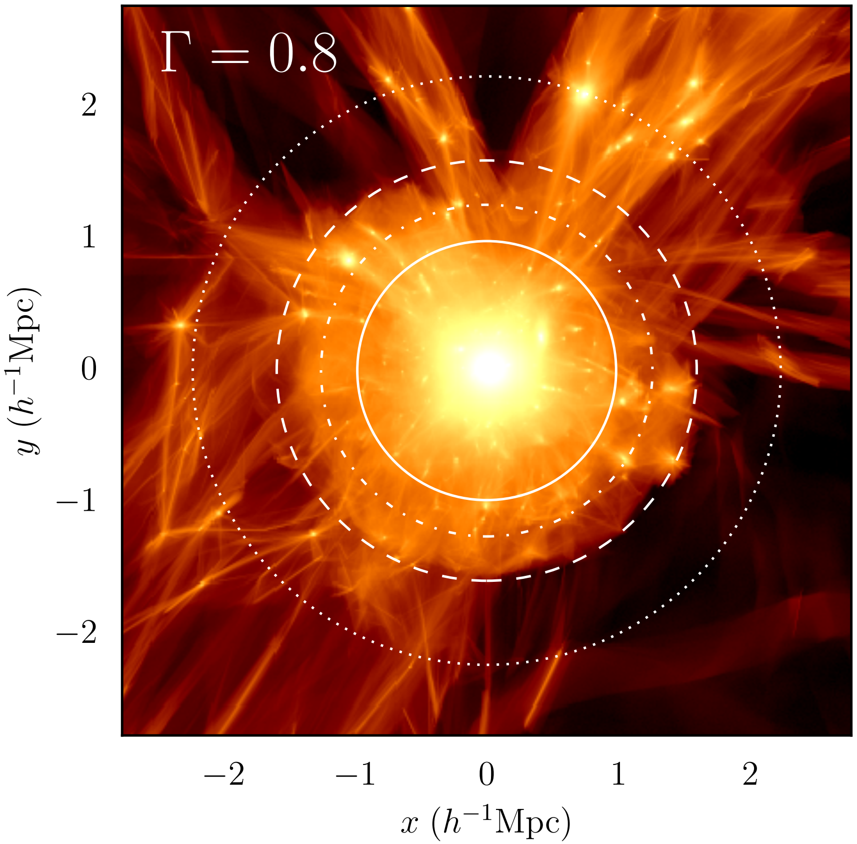
Splashback radius and current observational developments

With **Tae Hyeon-Shin**, Eric Baxter, Chihway Chang, Jeremy Sakstein, Bhuvnesh Jain, Neal Dalal, Baojiu Li and others

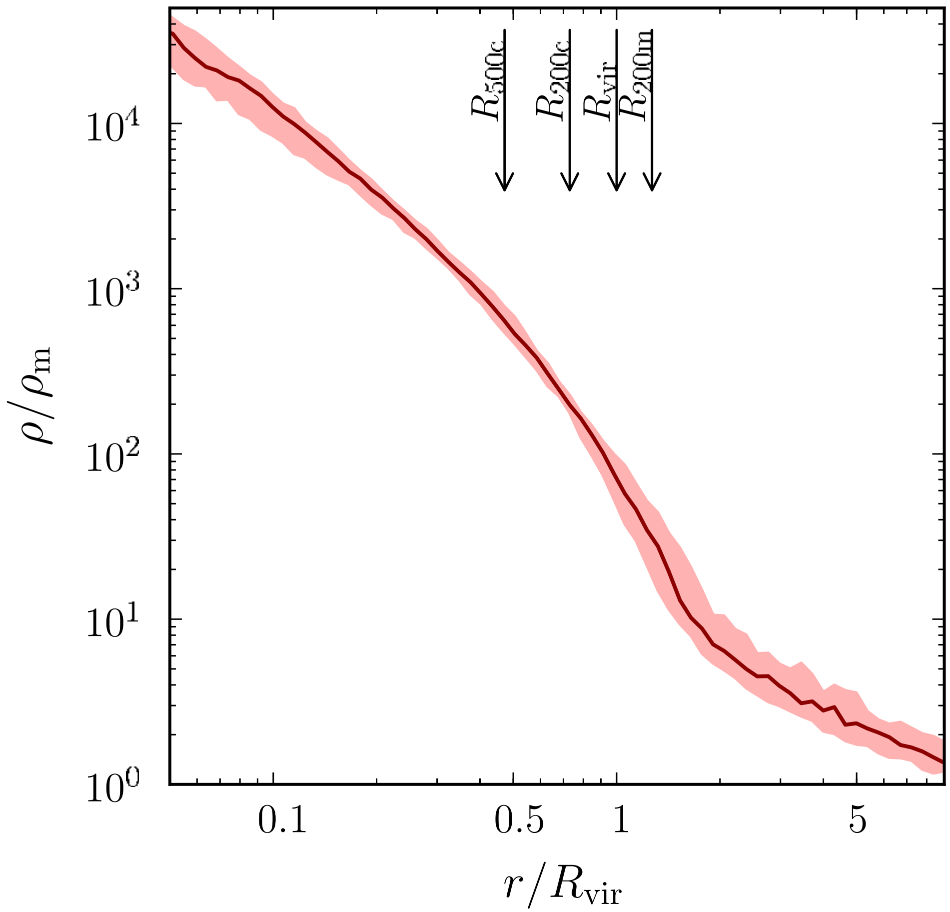
Susmita Adhikari
KIPAC Postdoctoral fellow

ICTS, Bangalore, 23rd January 2019

Where is the boundary of a halo?



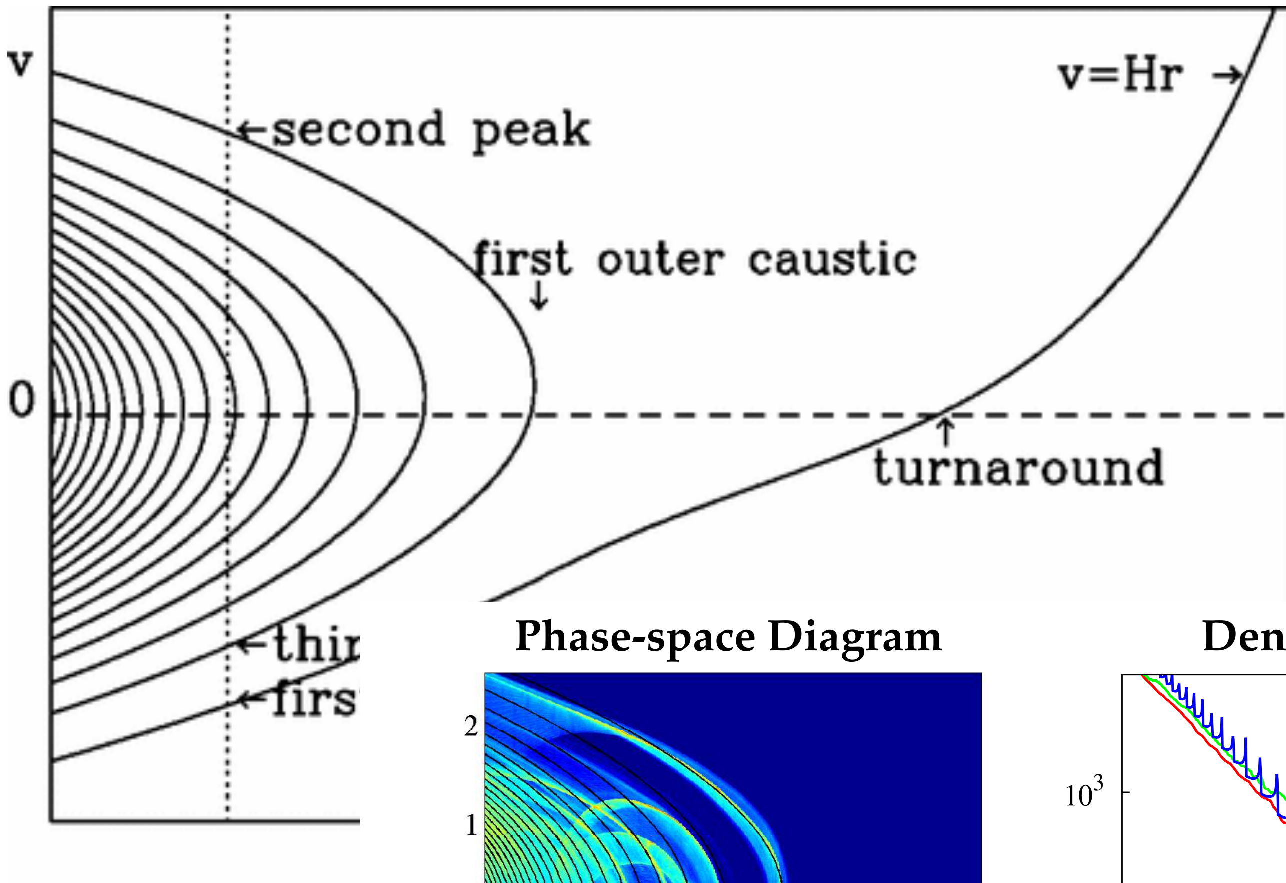
More et al. 2015

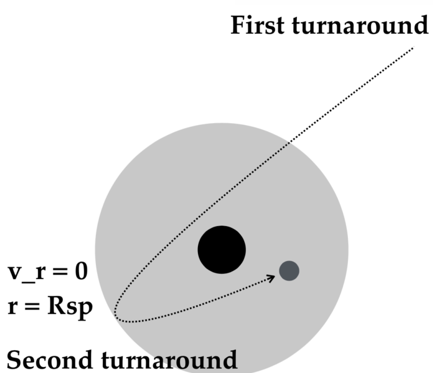


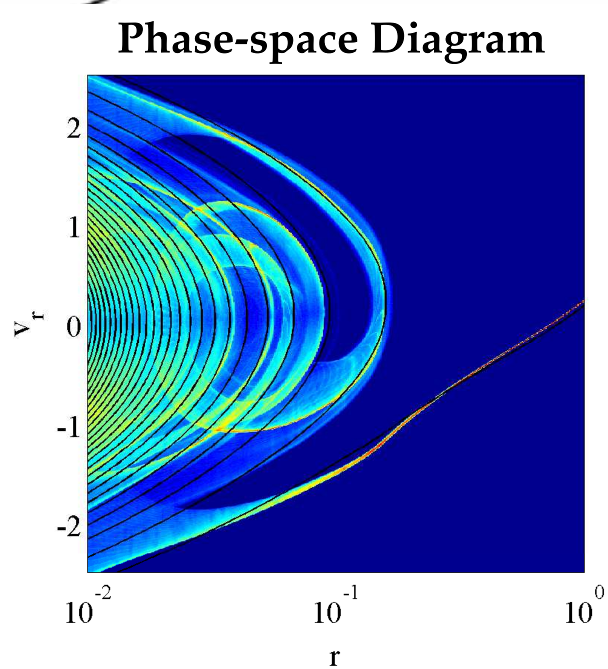
Diemer & Kravtsov 2014

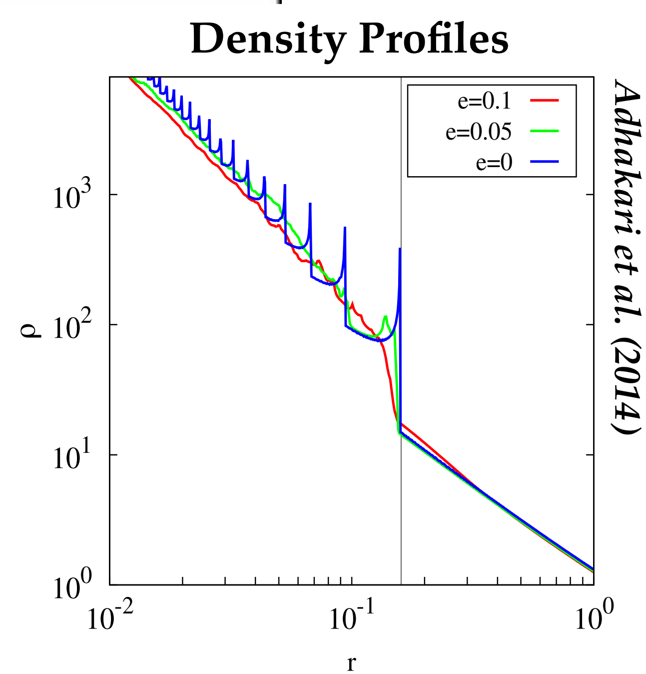
$$M_\Delta = \frac{4}{3}\pi R_\Delta^3 \Delta\rho_{ref}$$

The boundary of halos in phase space



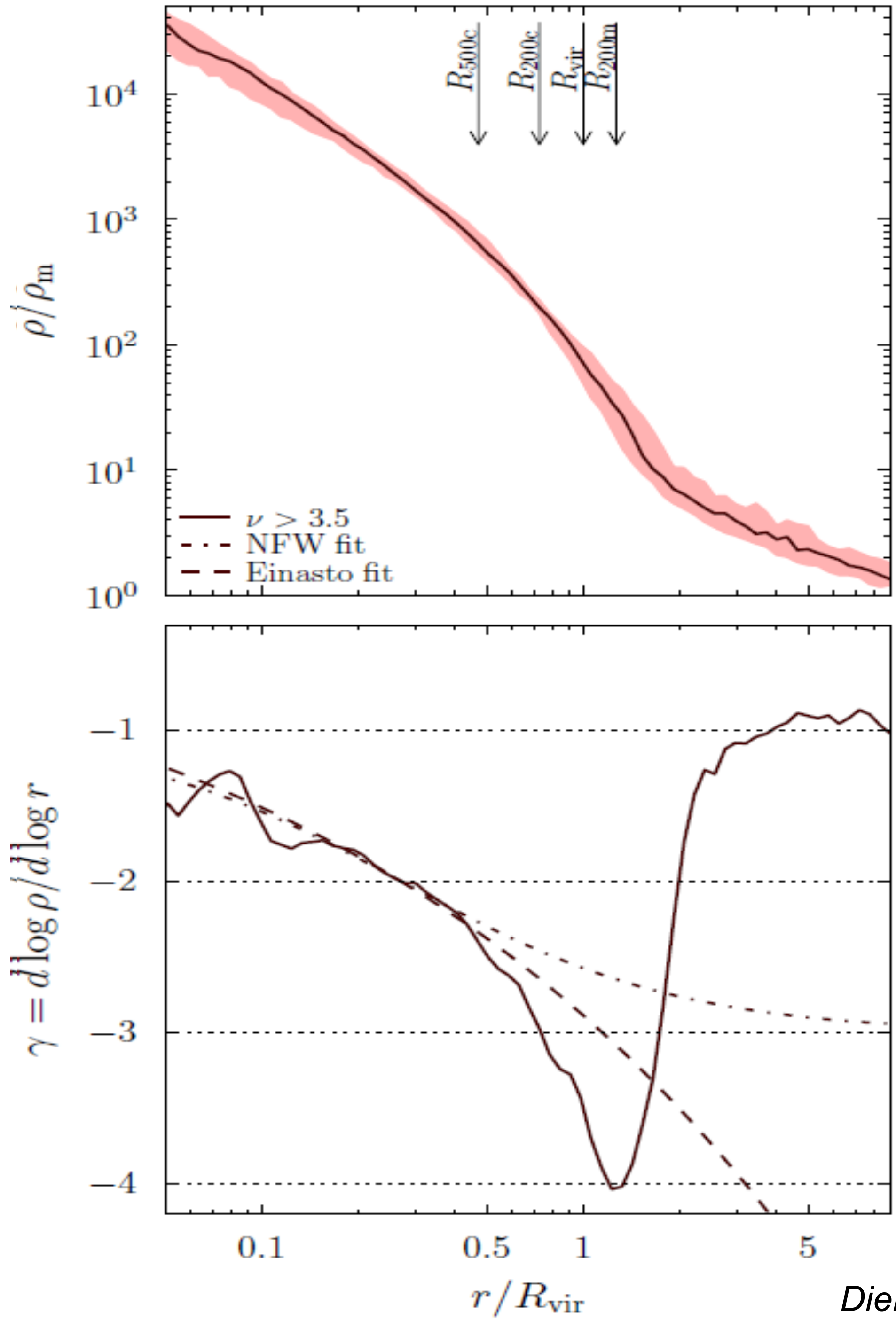






The first turnaround of the most recently accreted material

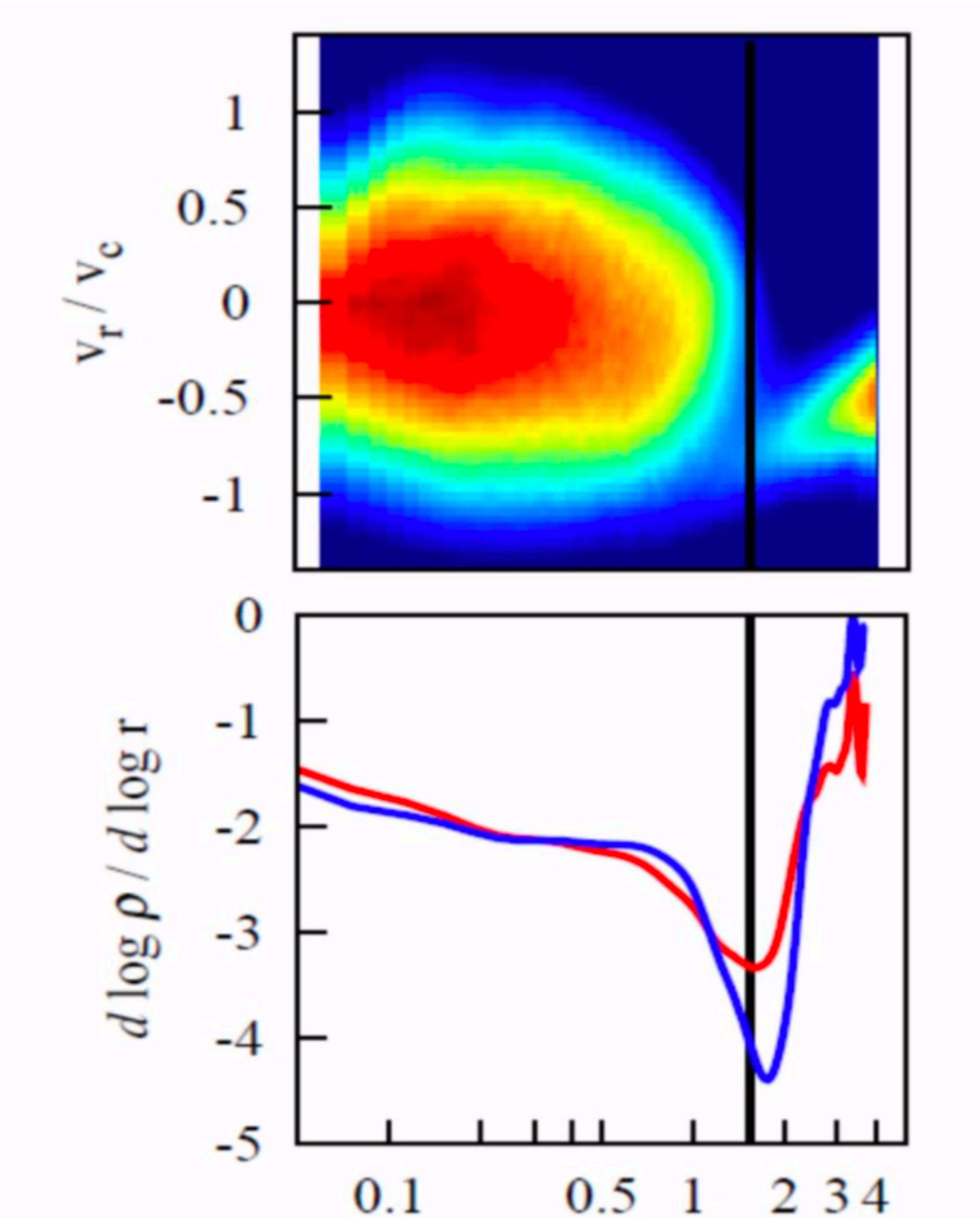
Outer density profiles of Dark Matter Halos

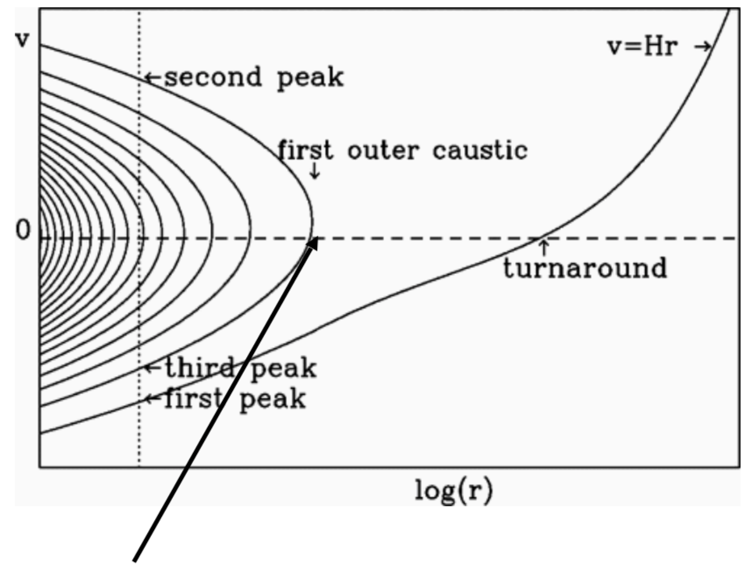


- Deviation from NFW and Einasto profile in the outer regions of the halo
- Slope of the local density deviates in a narrow confined region

Diemer & Kravtsov 2014

Phase space boundary separates multi-streaming region from infall region

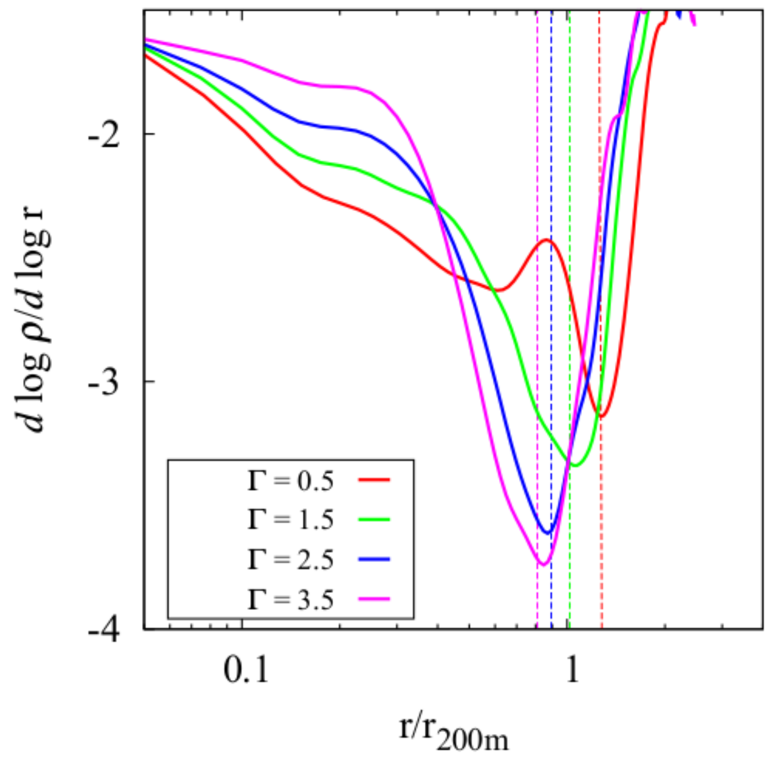




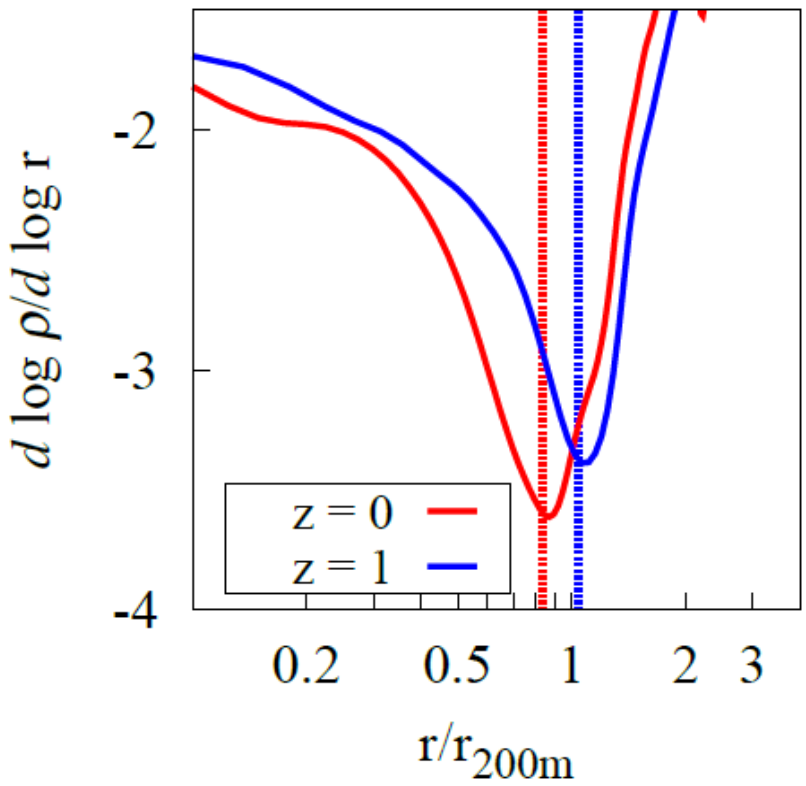
Splashback - corresponds to first apoapses passage after collapse

Adhikari et al. 2014

Location of the splashback radius



Accretion rate dependence

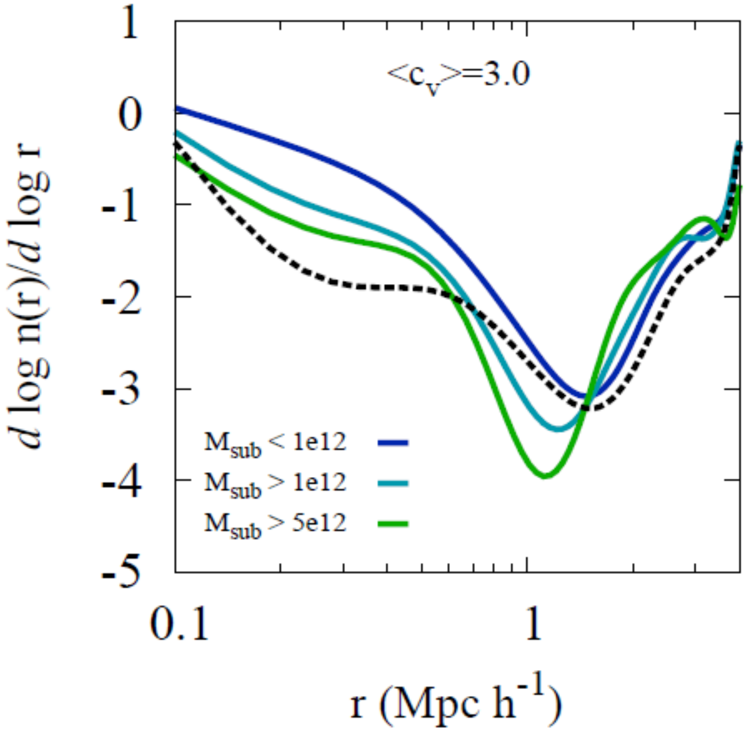


Redshift dependence

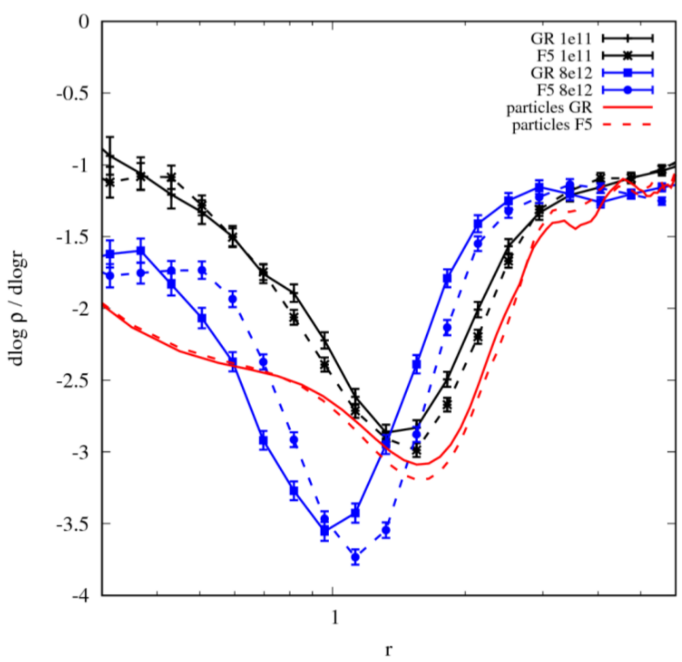
Adhikari et al. 2014, Diemer & Kravtsov 2014, Shi et al. 2015

Splashback in Subhalos

Subhalos follow the same dynamics as dark matter particles but are effected by dynamical friction



Adhikari et al. 2016



Sensitive to Cosmology .
Models of modified gravity predict different splashback.

Adhikari et al. 2018

Observations of Splashback radius

DETECTION OF THE SPLASHBACK RADIUS AND HALO ASSEMBLY BIAS OF MASSIVE GALAXY CLUSTERS

Surhud More[1], Hironao Miyatake[1,2,3], Masahiro Takada[1], Benedikt Diemer[4], Andrey V. Kravtsov[5,6,7], Neal K. Dalal[1,8], Anupreeta More[1], Ryoma Murata[1,9], Rachel Mandelbaum[10], Eduardo Rozo[11], Eli S. Rykoff[12], Masamune Oguri[1,9,13], and David N. Spergel[1,3]

The Halo Boundary of Galaxy Clusters in the SDSS

Eric Baxter[1⋆], Chihway Chang[2], Bhuvnesh Jain[1], Susmita Adhikari[3], Neal Dalal[3,4], Andrey Kravtsov[2,5,6], Surhud More[7], Eduardo Rozo[8], Eli Rykoff[9,10], Ravi K. Sheth[1,11]

THE SPLASHBACK FEATURE AROUND DES GALAXY CLUSTERS: GALAXY DENSITY AND WEAK LENSING PROFILES

C. Chang,[1] E. Baxter,[2] B. Jain,[2] C. Sánchez,[2,3] S. Adhikari,[4,5] T. N. Varga,[6,7] Y. Fang,[2] E. Rozo,[8] E. S. Rykoff,[5,9] A. Kravtsov,[10,11,12] D. Gruen,[5,9] W. Hartley,[13] E. M. Huff,[14] M. Jarvis,[2] A. G. Kim,[15] J. Prat,[3] N. MacCrann,[16,17] T. McClintock,[8] A. Palmese,[13] D. Rapetti,[18,19] R. P. Rollins,[20] S. Samuroff,[20] E. Sheldon,[21] M. A. Troxel,[16,17] R. H. Wechsler,[5,9,22] Y. Zhang,[23] J. Zuntz,[24] T. M. C. Abbott,[25] F. B. Abdalla,[13,26] S. Allam,[23] J. Annis,[23] K. Bechtol,[27] A. Benoit-Lévy,[13,28,29] G. M. Bernstein,[2] D. Brooks,[13] E. Buckley-Geer,[23] A. Carnero Rosell,[30,31] M. Carrasco Kind,[32,33] J. Carretero,[3] C. B. D'Andrea,[2] L. N. da Costa,[30,31] C. Davis,[5] S. Desai,[34] H. T. Diehl,[23] J. P. Dietrich,[35,36] A. Drlica-Wagner,[23] T. F. Eifler,[14,37] B. Flaugher,[23] P. Fosalba,[38] J. Frieman,[1,23] J. García-Bellido,[39] E. Gaztanaga,[38] D. W. Gerdes,[40,41] R. A. Gruendl,[32,33] J. Gschwend,[30,31] G. Gutierrez,[23] K. Honscheid,[16,17] D. J. James,[42] T. Jeltema,[43] E. Krause,[5] K. Kuehn,[44] O. Lahav,[13] M. Lima,[30,45] M. March,[2] J. L. Marshall,[46] P. Martini,[16,47] P. Melchior,[48] F. Menanteau,[32,33] R. Miquel,[3,49] J. J. Mohr,[7,35,36] B. Nord,[23] R. L. C. Ogando,[30,31] A. A. Plazas,[14] E. Sanchez,[50] V. Scarpine,[23] R. Schindler,[9] M. Schubnell,[41] I. Sevilla-Noarbe,[50] M. Smith,[51] R. C. Smith,[25] M. Soares-Santos,[23] F. Sobreira,[30,52] E. Suchyta,[53] M. E. C. Swanson,[33] G. Tarle,[41] and J. Weller[6,7,35]
(DES Collaboration)

RedMaPPer Cluster catalog

Cluster - galaxy cross correlation

Measurement - Number density of galaxy in projection as a function of radius

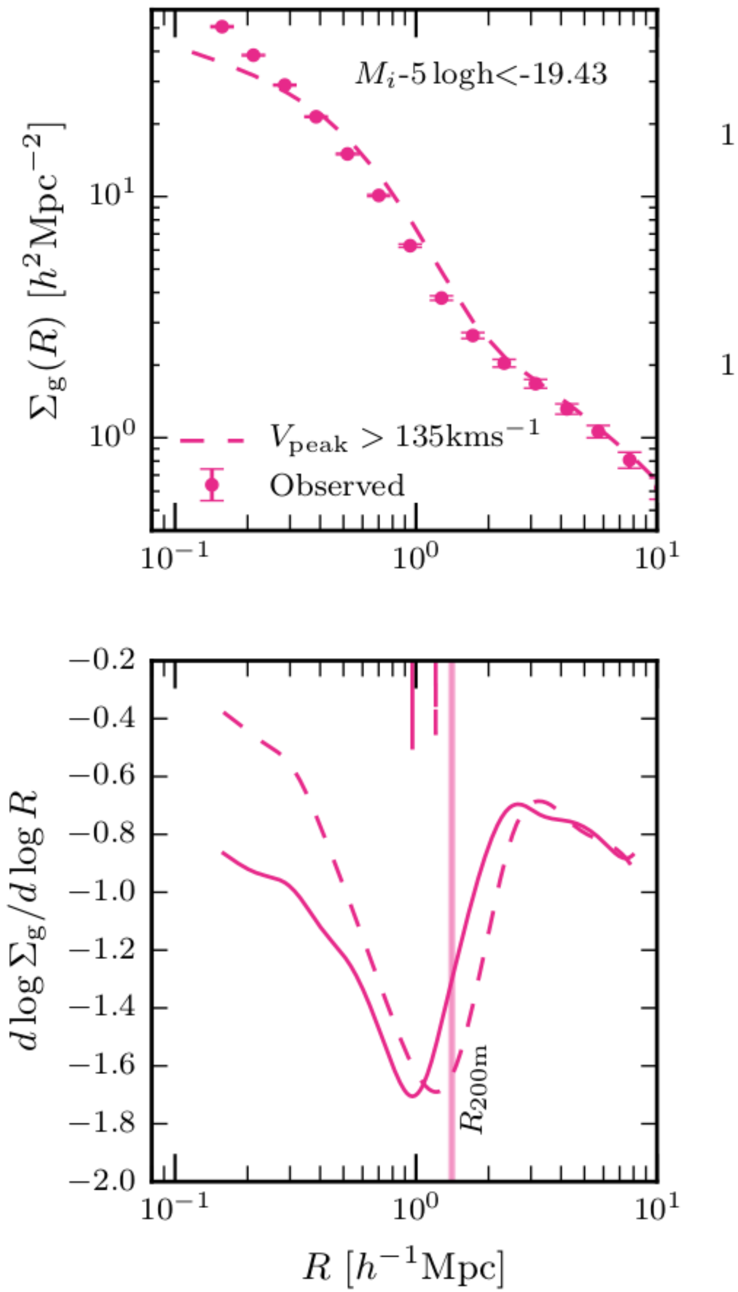
$$\Sigma(R) = \int_{-h_{\max}}^{h_{\max}} dh\, \rho(\sqrt{R^2 + h^2})$$

$$\begin{aligned}
\rho(r) &= \rho^{\rm coll}(r) + \rho^{\rm infall}(r), \\
\rho^{\rm coll}(r) &= \rho^{\rm Ein}(r) f_{\rm trans}(r) \\
\rho^{\rm Ein}(r) &= \rho_s \exp\left(-\frac{2}{\alpha}\left[\left(\frac{r}{r_s}\right)^{\alpha} - 1\right]\right) \\
f_{\rm trans}(r) &= \left[1 + \left(\frac{r}{r_t}\right)^{\beta}\right]^{-\gamma/\beta}, \\
\rho^{\rm infall}(r) &= \rho_0 \left(\frac{r}{r_0}\right)^{-s_e},
\end{aligned}$$

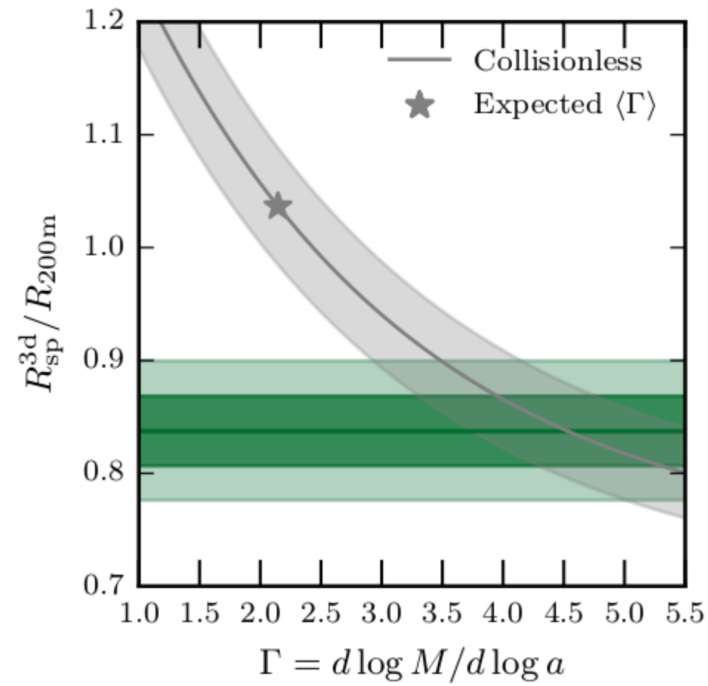
Stack clusters based on richness

richness > 20
M > 1e14 M_{sun} h^{-1}

Observation of the splashback feature in Galaxy density profiles

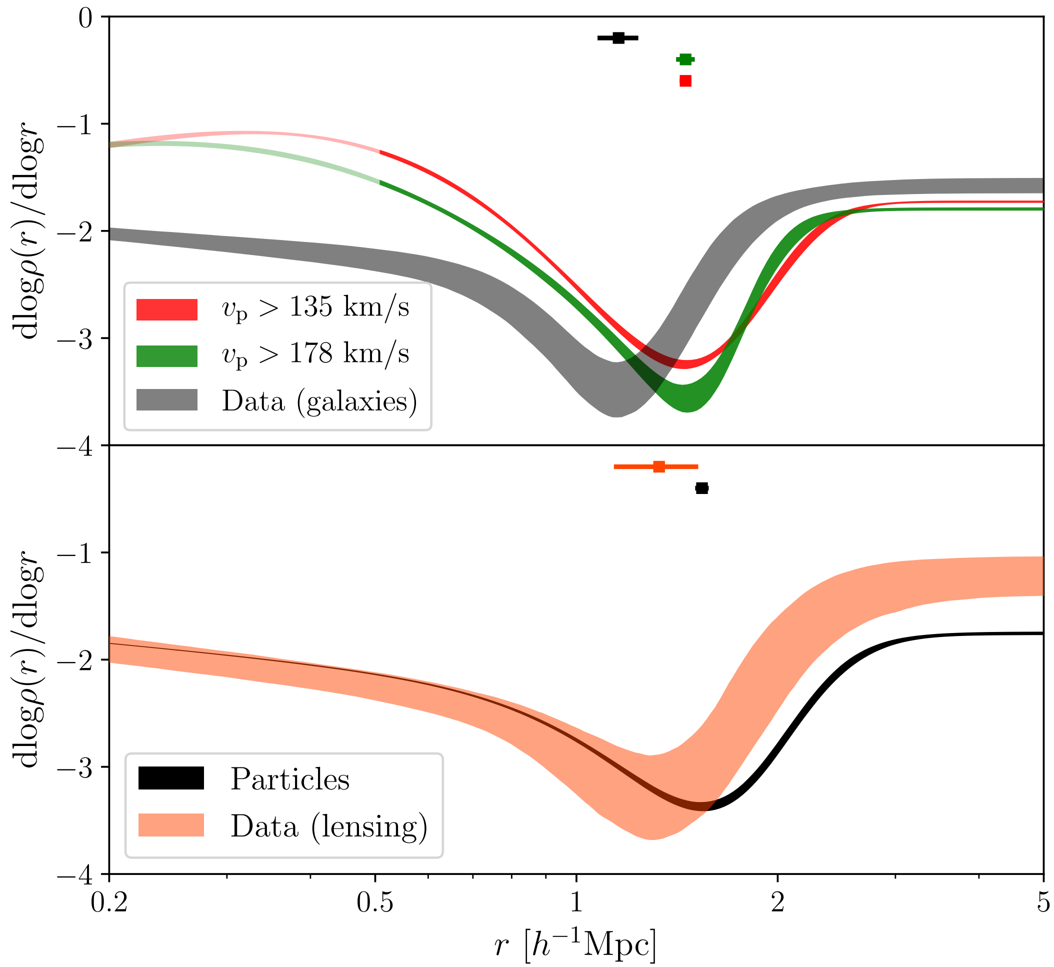


More et al. 2016



- 20% offset in the position of splashback

Splashback radius in DES Y1 results



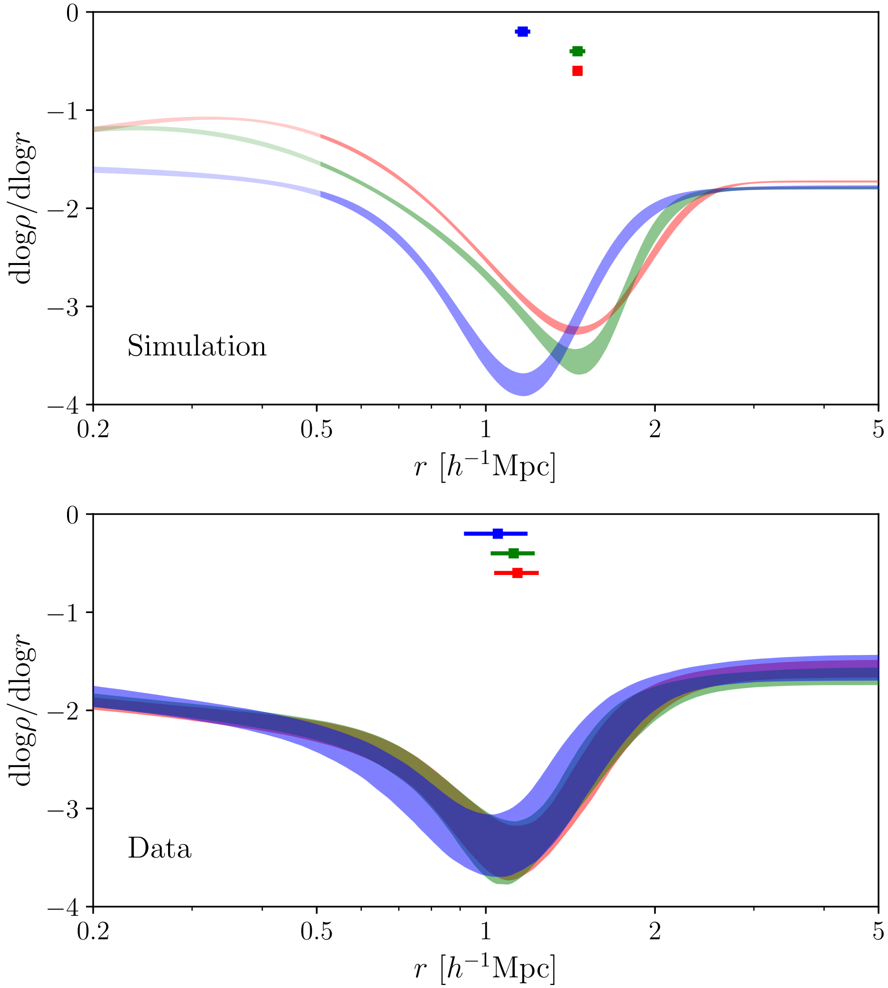
Galaxy number density

Weak lensing around clusters

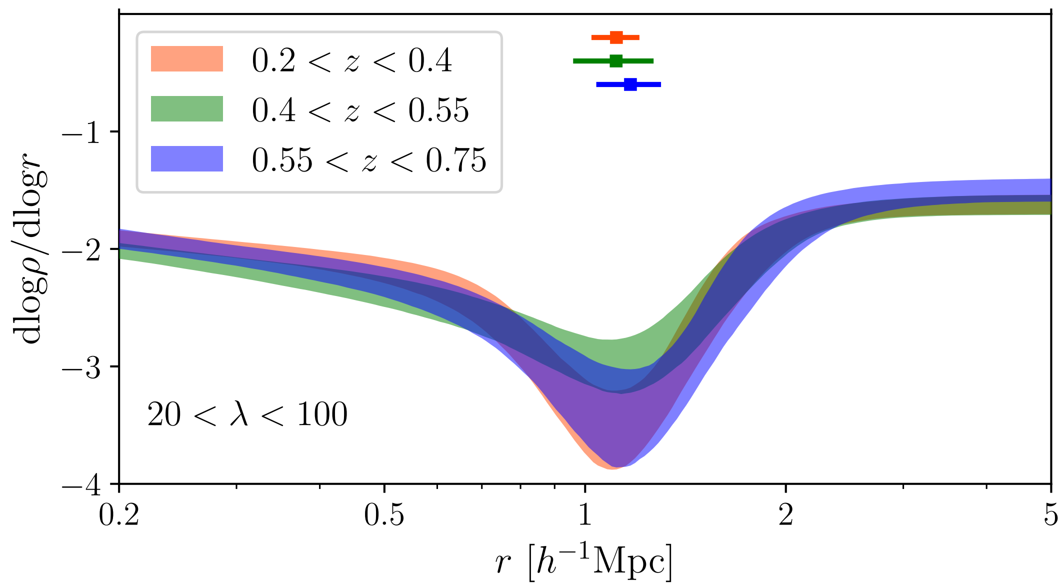
Chang, Baxter, Jain, Sanchez, ***Adhikari*** *et al.2017*

Discrepancy persists in the lensing splashback radius as well

Outstanding issues



No movement with galaxy magnitude



Chang, Baxter, Jain, Sanchez, ***Adhikari*** *et al.2017*

No movement with redshift of host cluster

Why is splashback discrepant with simulations?

a) Dynamical Friction?

b) New Physics?

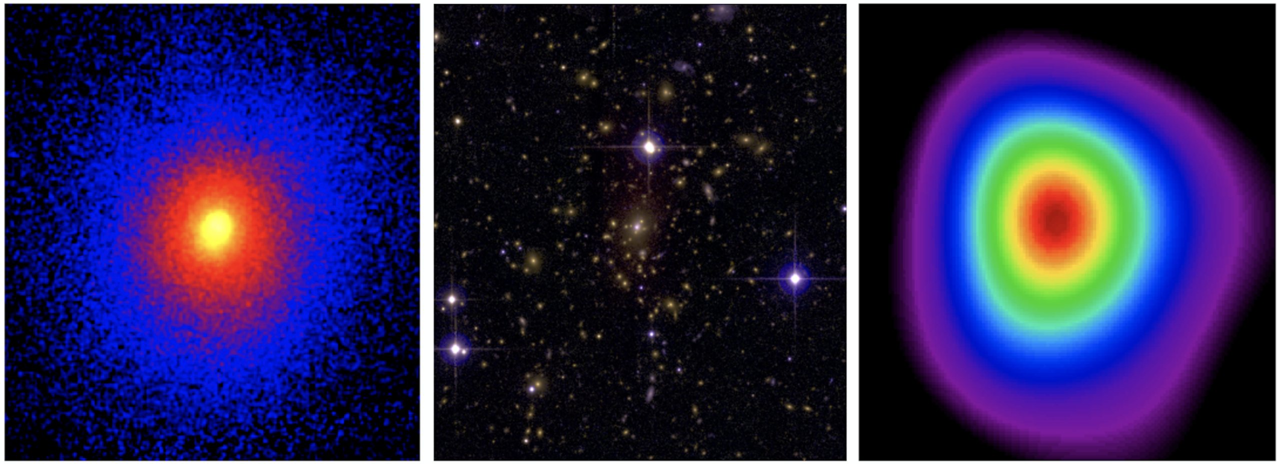
c) Observational bias?

Cluster selection?

Projection effects? (*Busch & White 2017*)
Orientation bias?
Aperture selection? (*Busch & White 2017*)

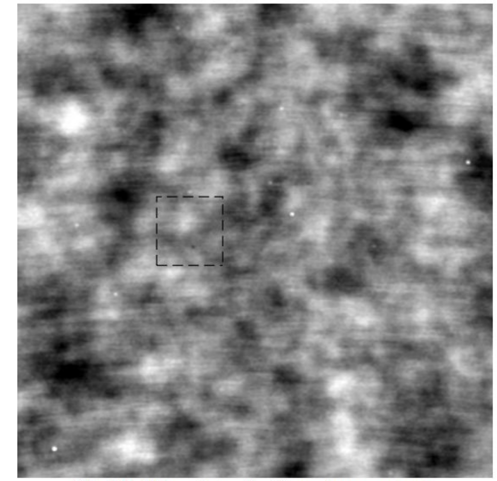
Different cluster selection method - SZ selected clusters

Splashback radius in SZ-selected clusters with DES, SPT and ACT

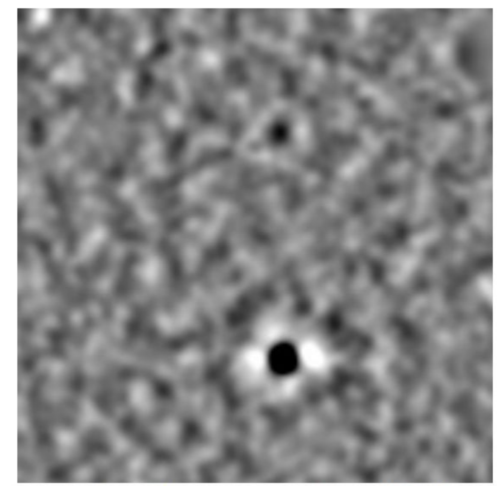


X-ray Optical tSZ

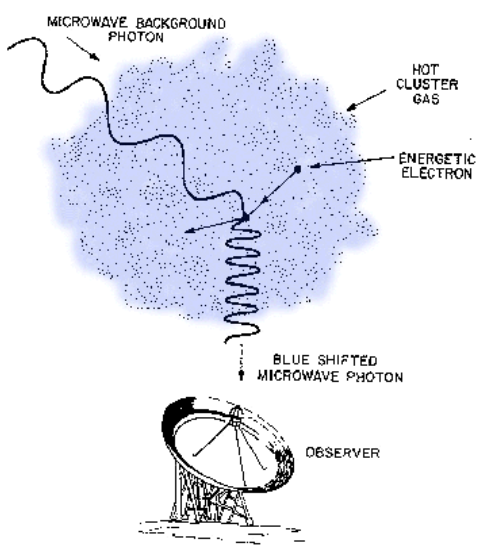
Allen et al. 2011



(b) 150 GHz minimally filtered map cutout



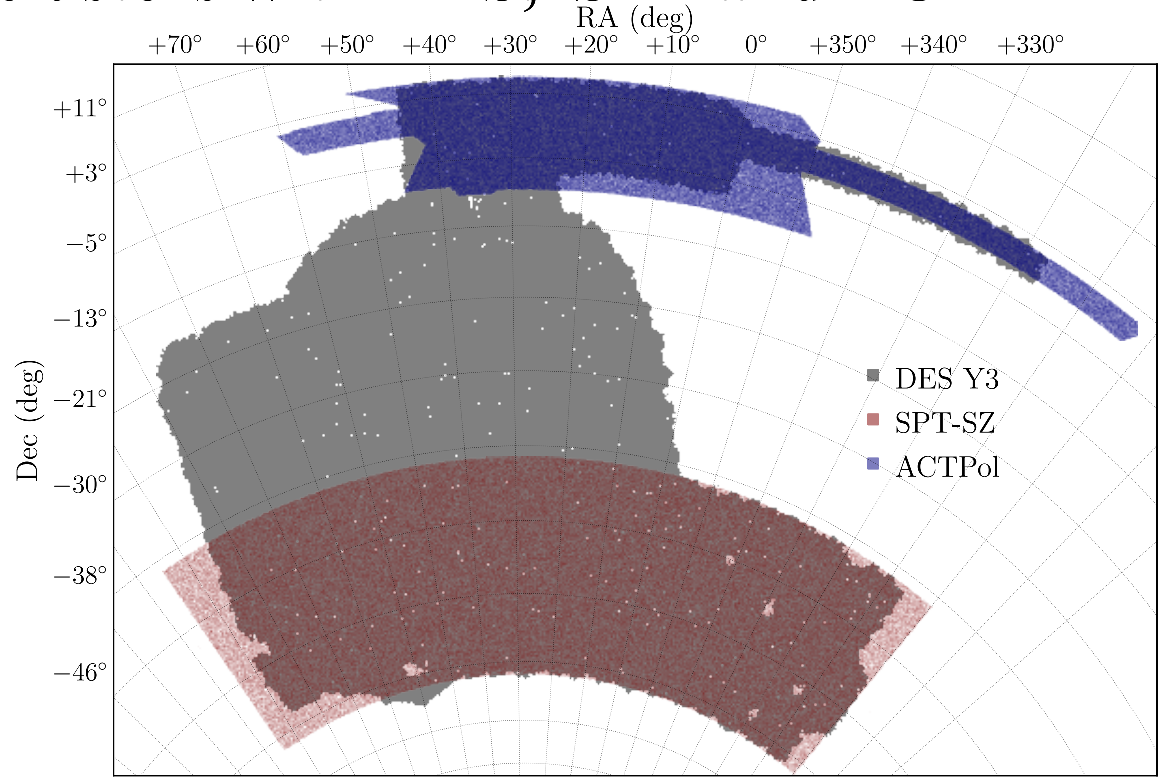
Clusters seen as a temperature decrement in CMB

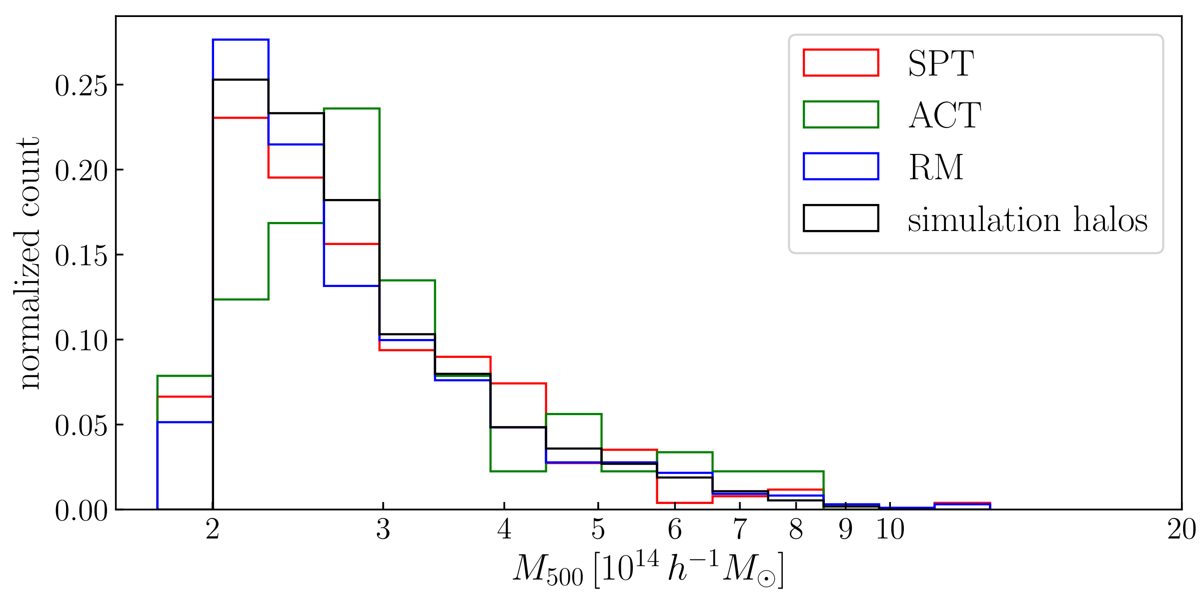


Splashback radius in SZ clusters with DES, SPT and ACT

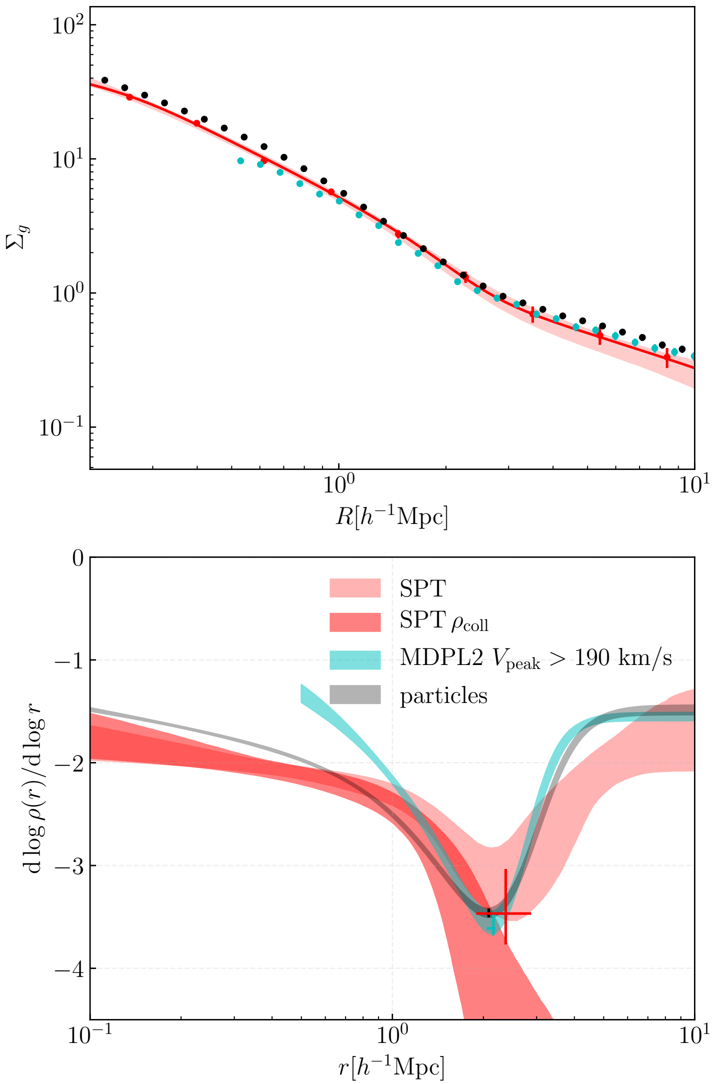
SPT
315 clusters
0.25 < z < 0.7
$\langle M_{500c} \rangle = 3.0e14\ M_{sun}$

ACT
89 clusters
0.25 < z < 0.7
$\langle M_{500c} \rangle = 3.26e14\ M_{sun}$





Splashback radius in SPT SZ clusters, DES galaxies

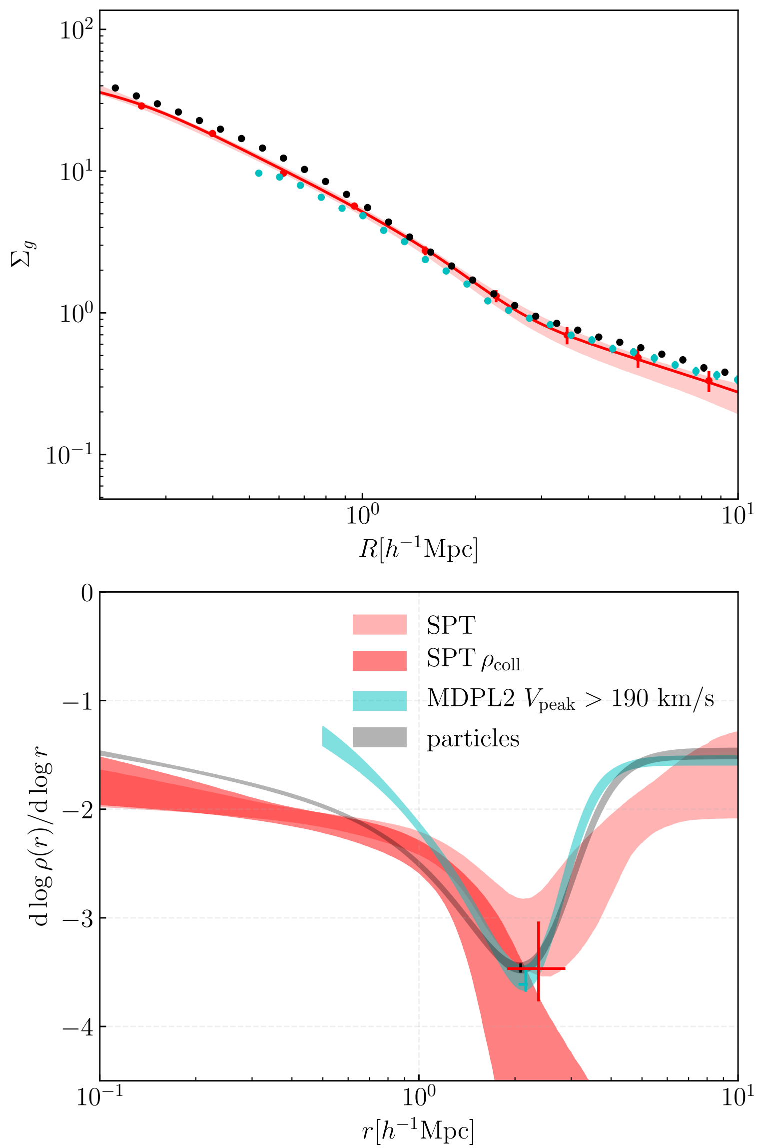


Splashback radius SZ clusters are statistically consistent with simulations

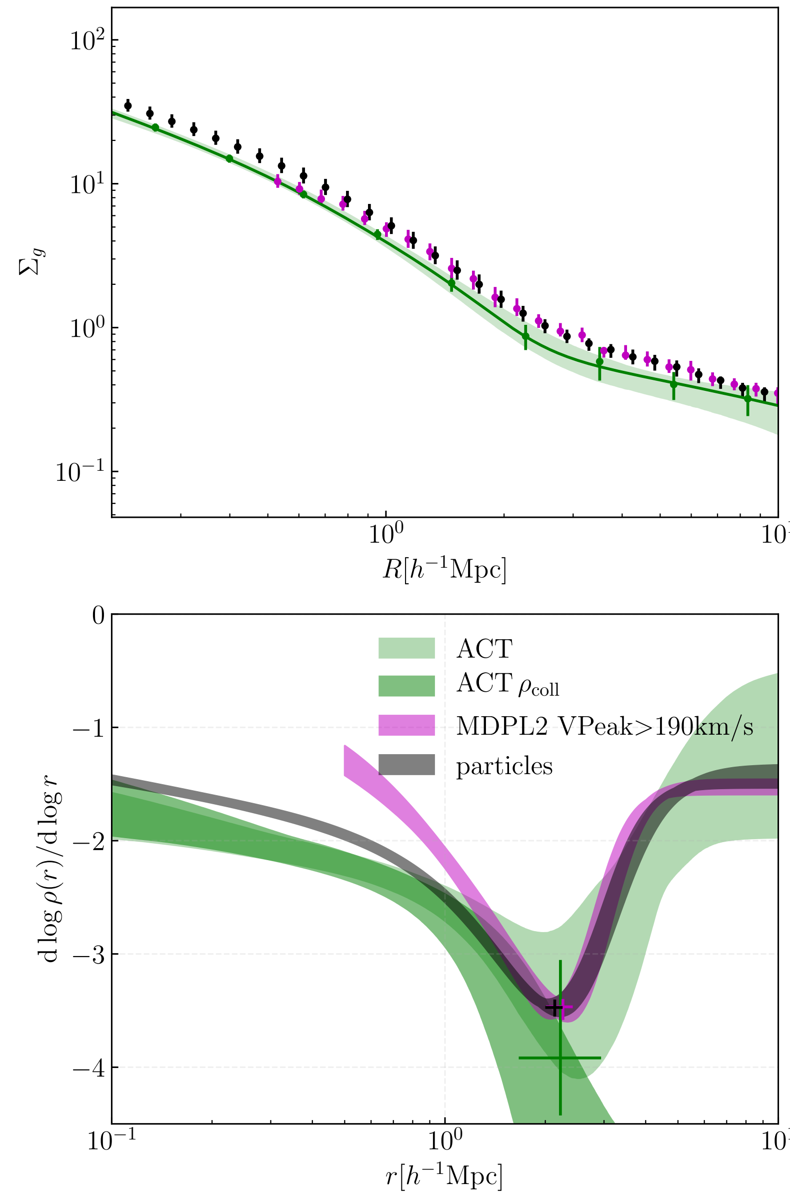
Pink - Slope of the fitted density profile
Black- Particles from MDPL2
Blue - Subhalos abundance matched

Hyeon-Shin, Adhikari et al. 2018

SPT



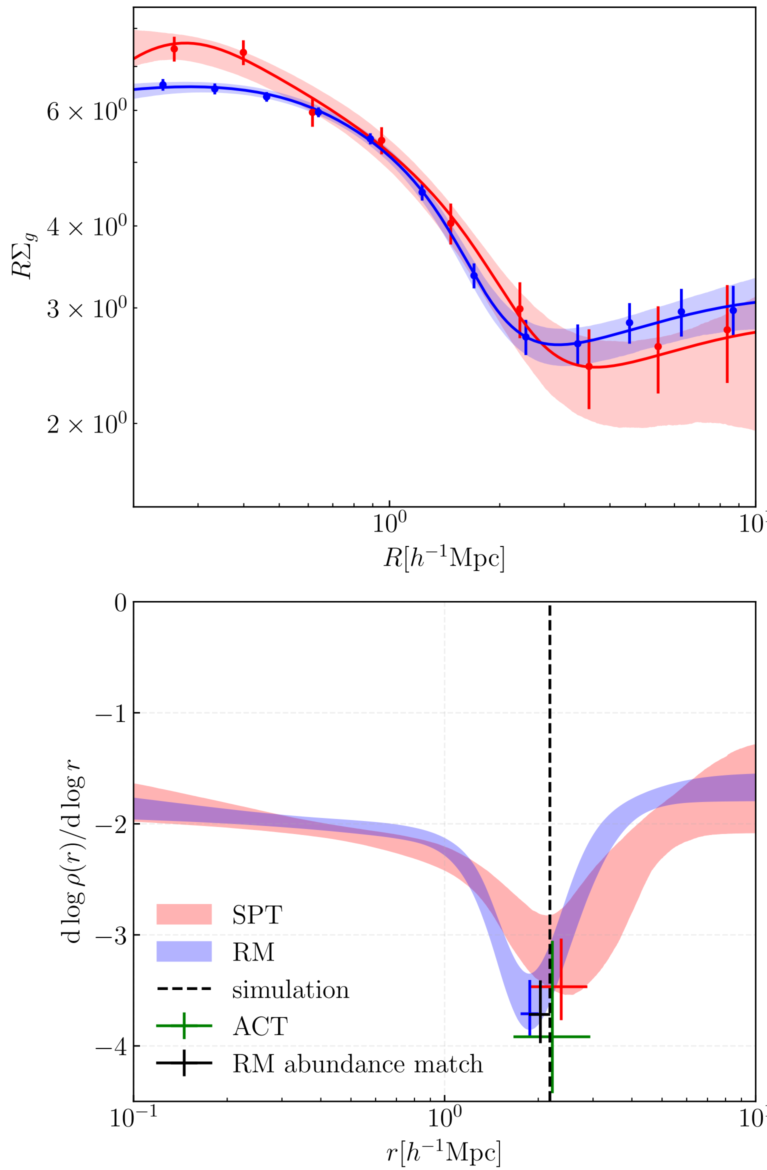
ACT



Hyeon-Shin, Adhikari et al. 2018

SPT and ACT are both consistent with simulations

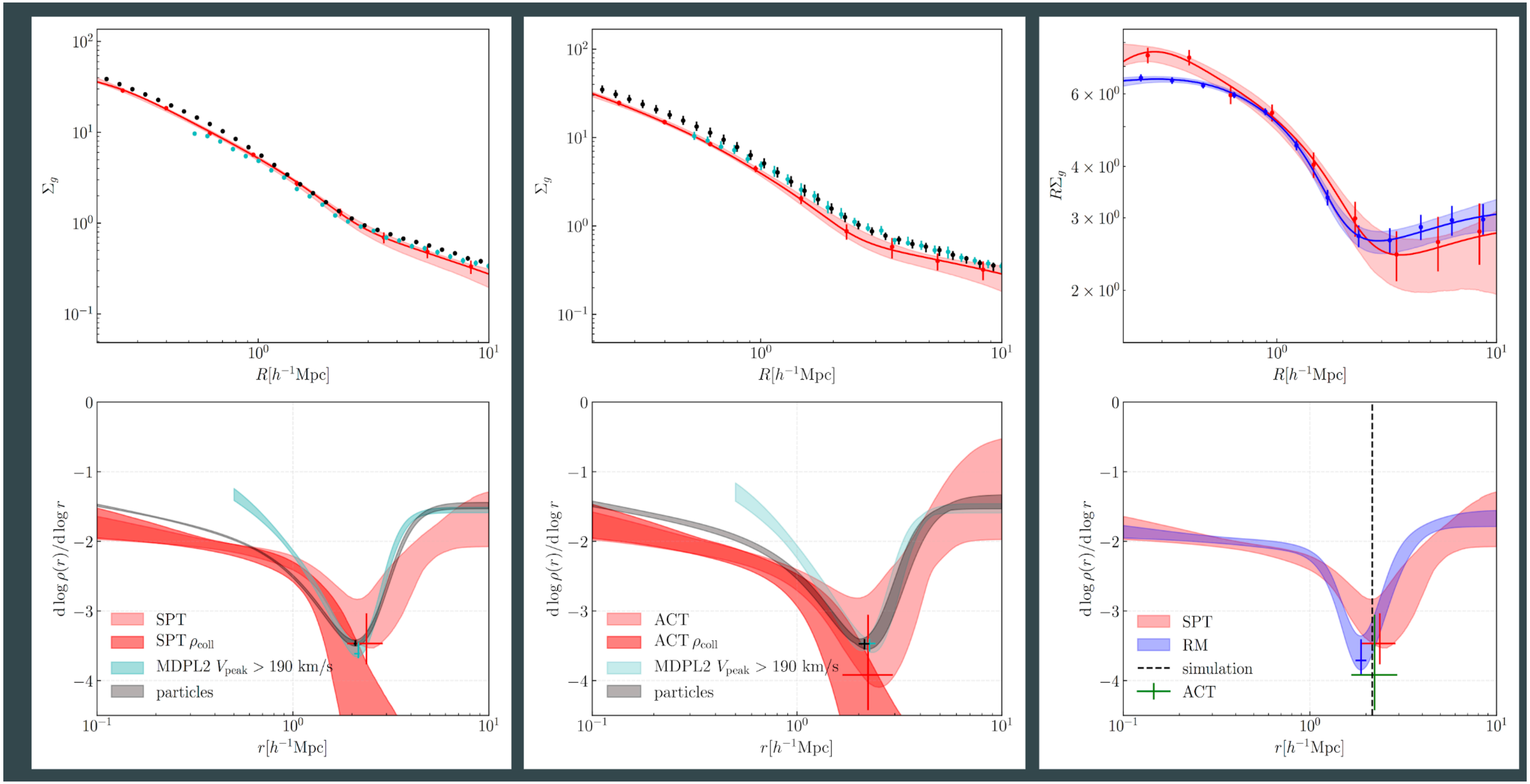
Comparison with RedMaPPer



Hyeon-Shin, Adhikari et al. 2018

RM and SPT are consistent within 1 sigma, but RM is inconsistent with sims.

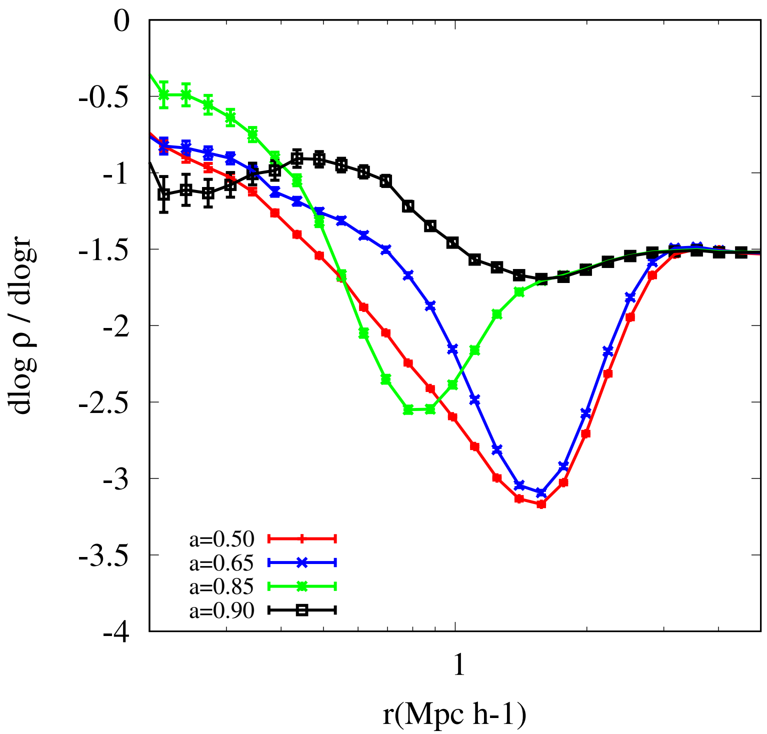
Splashback in galaxy clusters

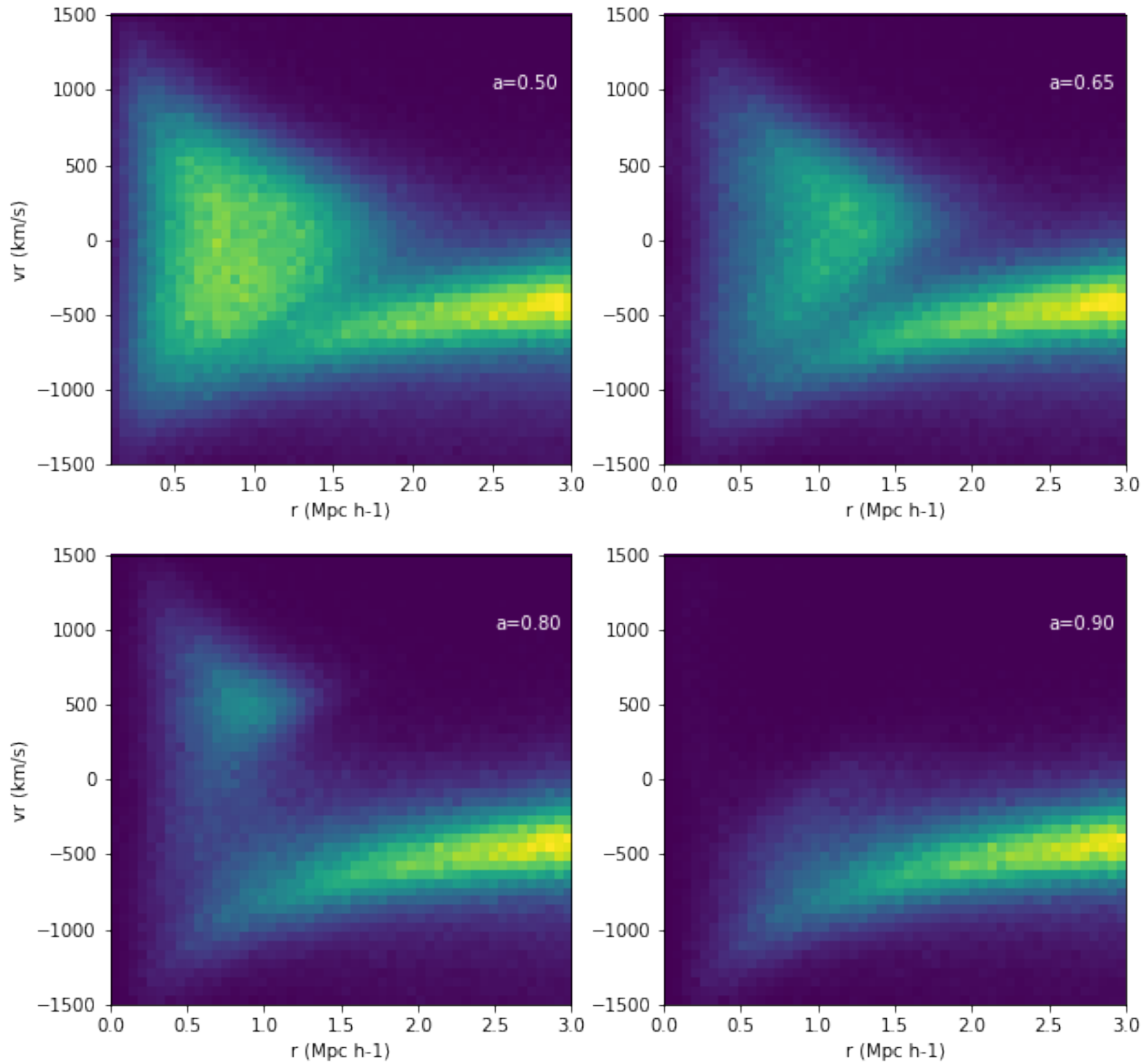


Hyeon-Shin, Adhikari et al. 2018

- Slope profile of clusters closer to particles than subhalos - expected
- The inner regions are significantly steeper than profiles expected from simulations.
- See also ***Zuercher and More 2018*** (measurements with Planck clusters) - Our results are consistent.

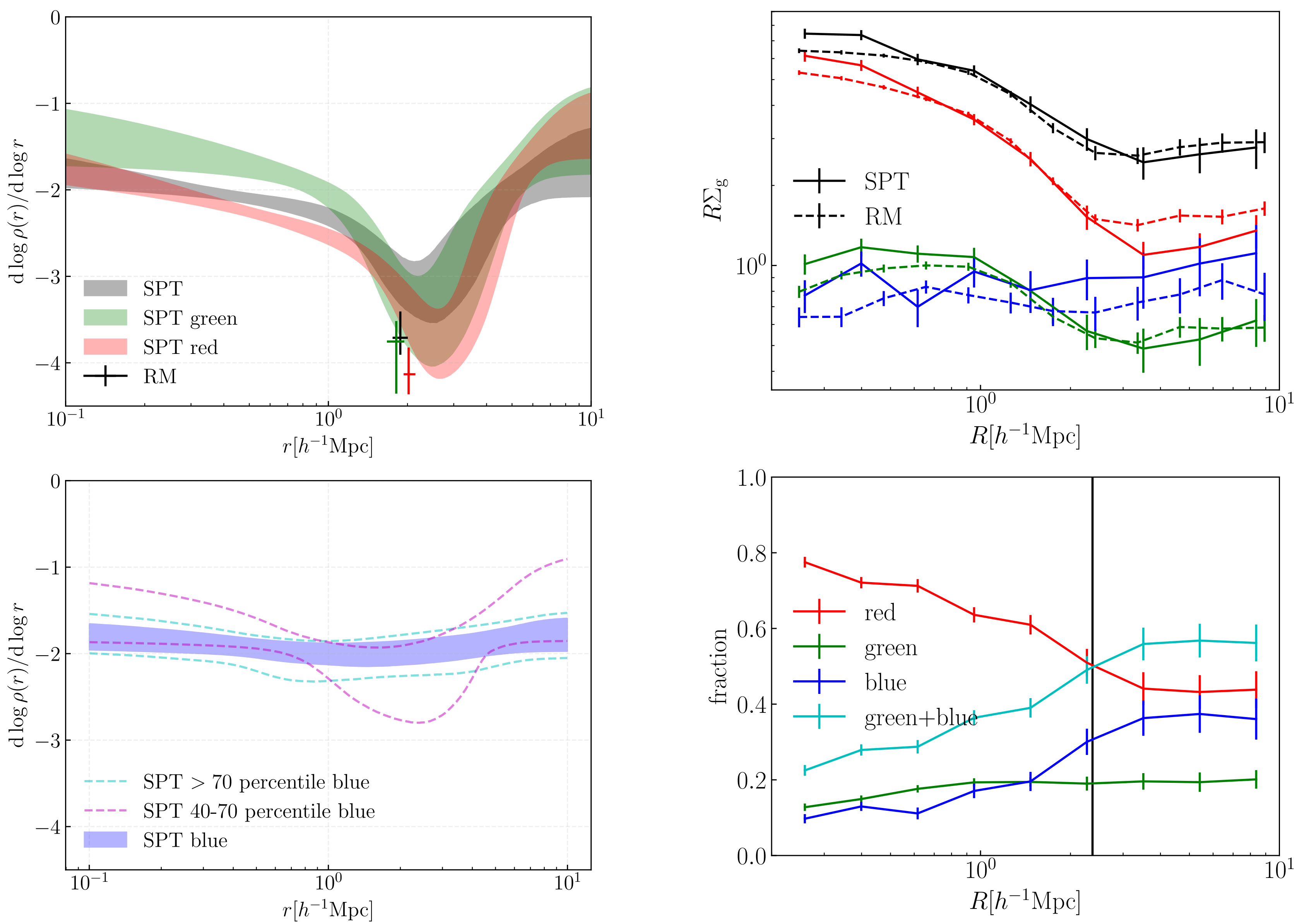
Splashback radius as a clock - Splashback as a function of galaxy color





Phase space diagram of subhalos around clusters

Splashback as a function of galaxy color



Hyeon-Shin, Adhikari et al. 2018

Conclusion

- Splashback radius can be used as probe for halo history, dynamical friction
- The location of splashback is sensitive to Cosmology, difference in splashback of massive subhalos in clusters
- Observations of splashback radius are consistent with simulations when SZ selected clusters are used.
- systematic effects in RedMaPPer may be making splashback biased.
- Splashback radius as a function of color can give dynamical information about galaxy quenching.

Thank you!