Gas contents of the local Universe from Sunyaev-Zel'dovich effect

Seunghwan Lim (5th-yr @ UMass)

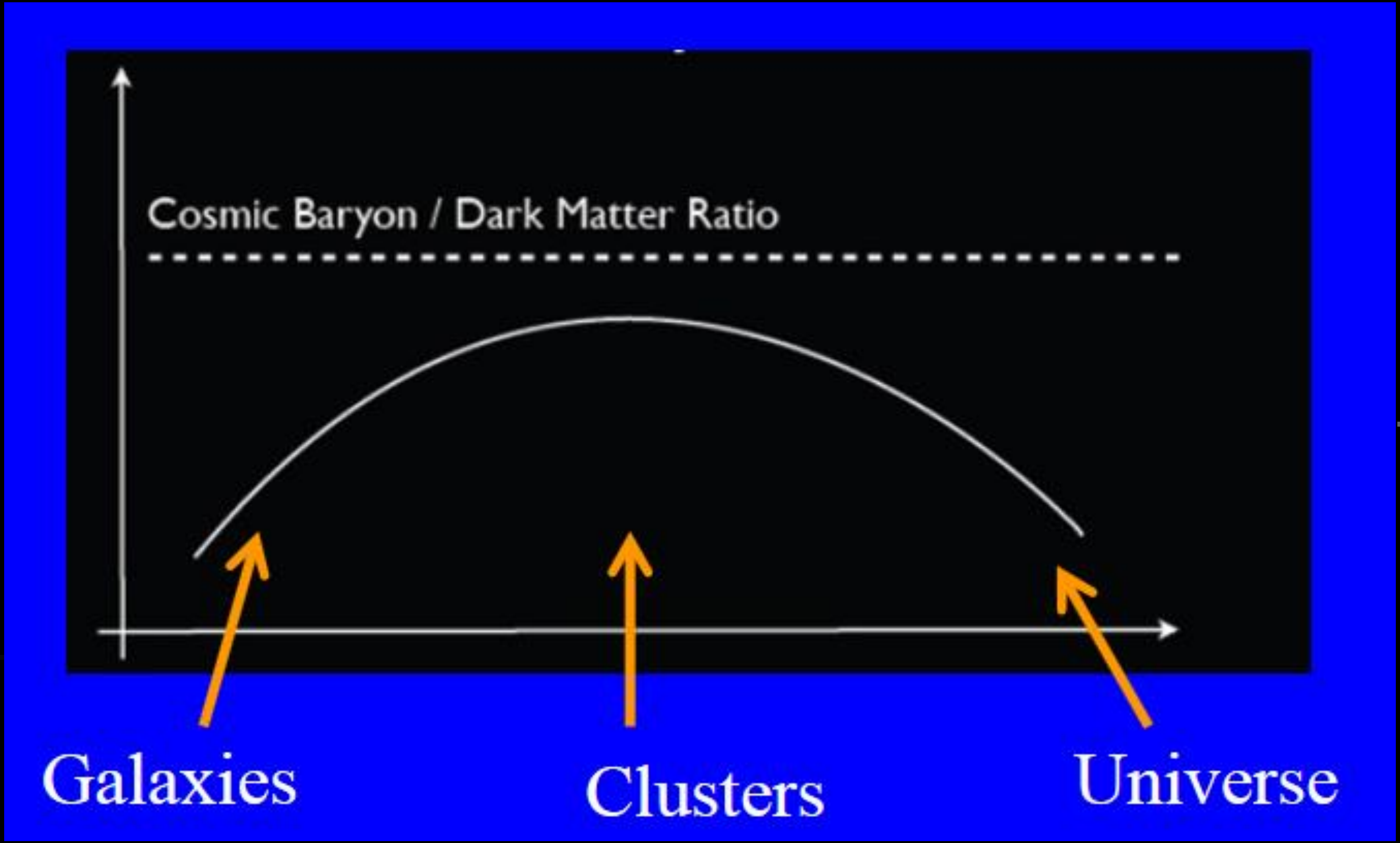
(main collaborators: Houjun Mo, Huiyuan Wang, Xiaohu Yang)

hot gas constrains galaxy model

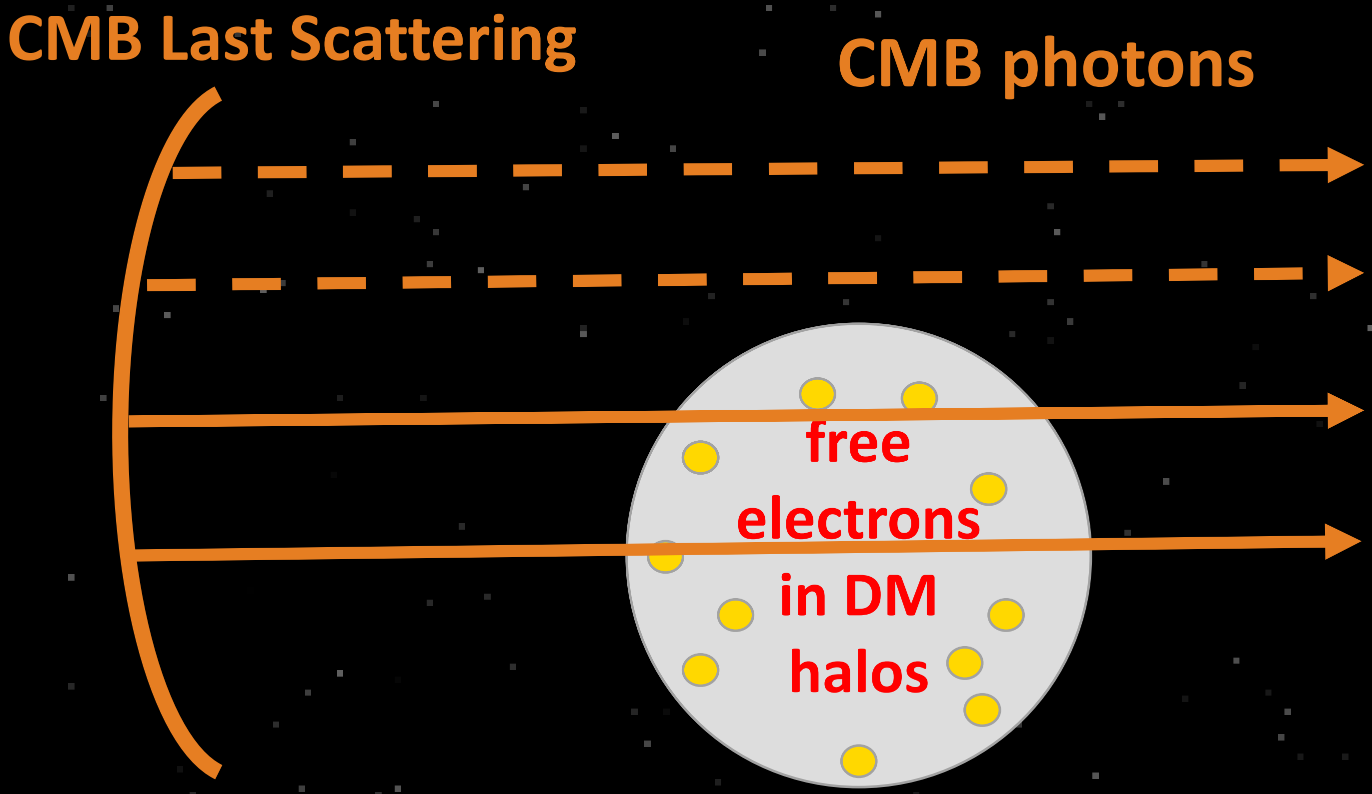
- when dark matter halo forms,
  baryons (cold gas) also falls into the potential.
  → 'belief': baryon fraction = cosmic mean fraction..
  → meanwhile, virial-shock heats cold gas to form hot gas halo

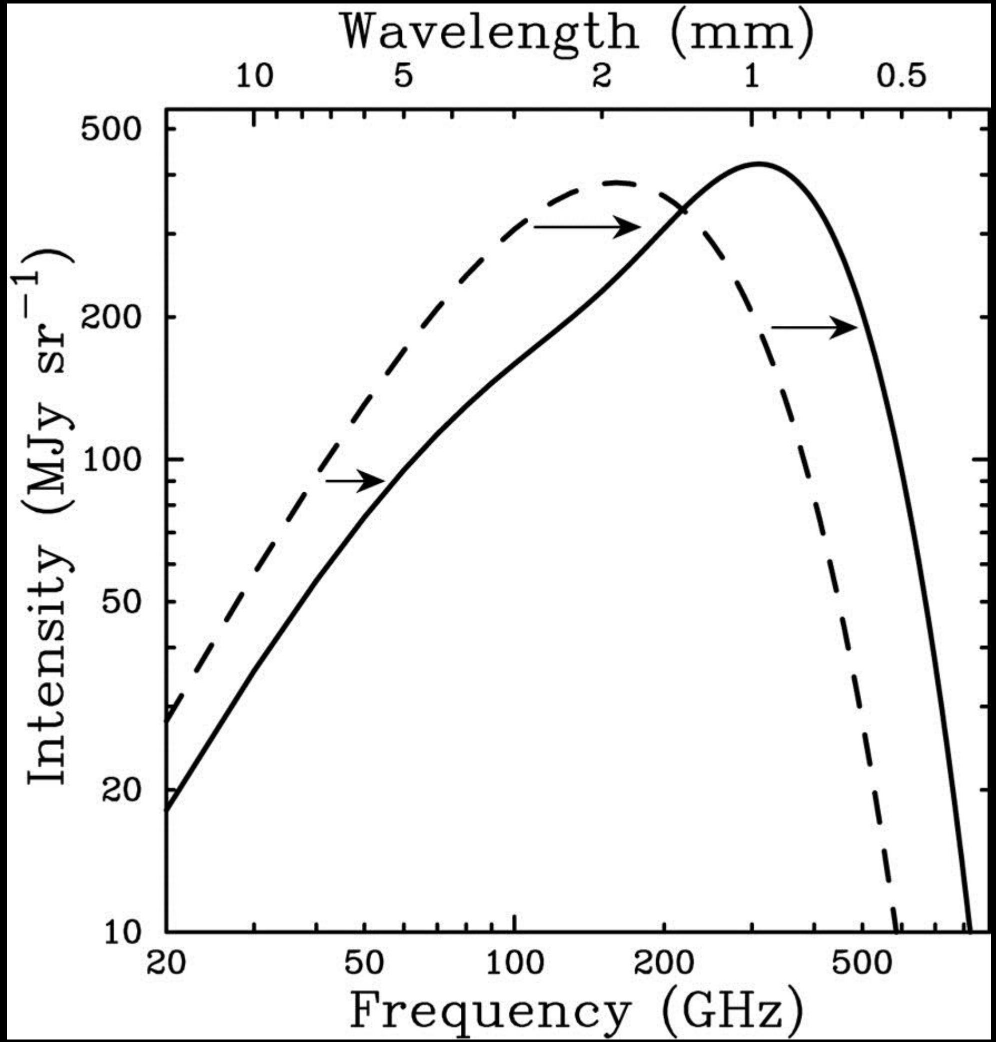
- If nothing further happens, all baryons will be found in hot gas..
  - reality, however: cooling, SF, feedbacks...
  → Thus, hot gas can constrain galaxy models

Is the hot gas where missing baryons are ?



CMB spectrum traces hot gas





Sunyaev-Zel'dovich effect (SZE): hot electrons scatter CMB photons off

there are two types of SZE

- **thermal SZ effect (tSZE;** due to thermal motion of electrons)

$$\left(\frac{\Delta T}{T_{\mathrm{CMB}}}\right)_{\mathrm{tSZ}}(\hat{r}) = g(x) y_{\mathrm{tSZ}}(\hat{r}) \equiv g(x) \frac{\sigma_{\mathrm{T}}}{m_{\mathrm{e}} c^2} \int P_{\mathrm{e}} \mathrm{d}l,$$

$P_{\mathrm{e}} = n_{\mathrm{e}} k_{\mathrm{B}} T_{\mathrm{e}}$ is electron pressure.

- **kinetic SZ effect (kSZE;** due to bulk motion of electrons)

$$k(\hat{r}) \equiv \left(\frac{\Delta T}{T_{\mathrm{CMB}}}\right)_{\mathrm{kSZ}}(\hat{r}) = -\frac{\sigma_{\mathrm{T}}}{c} \int n_{\mathrm{e}} (\boldsymbol{v} \cdot \hat{r}) \mathrm{d}l,$$

this talk is based on 4 papers:

Lim et al. (2017b) *Galaxy groups in the low-redshift Universe*

Lim et al. (2018a) *Gas contents of galaxy groups from thermal Sunyaev-Zeldovich effects*

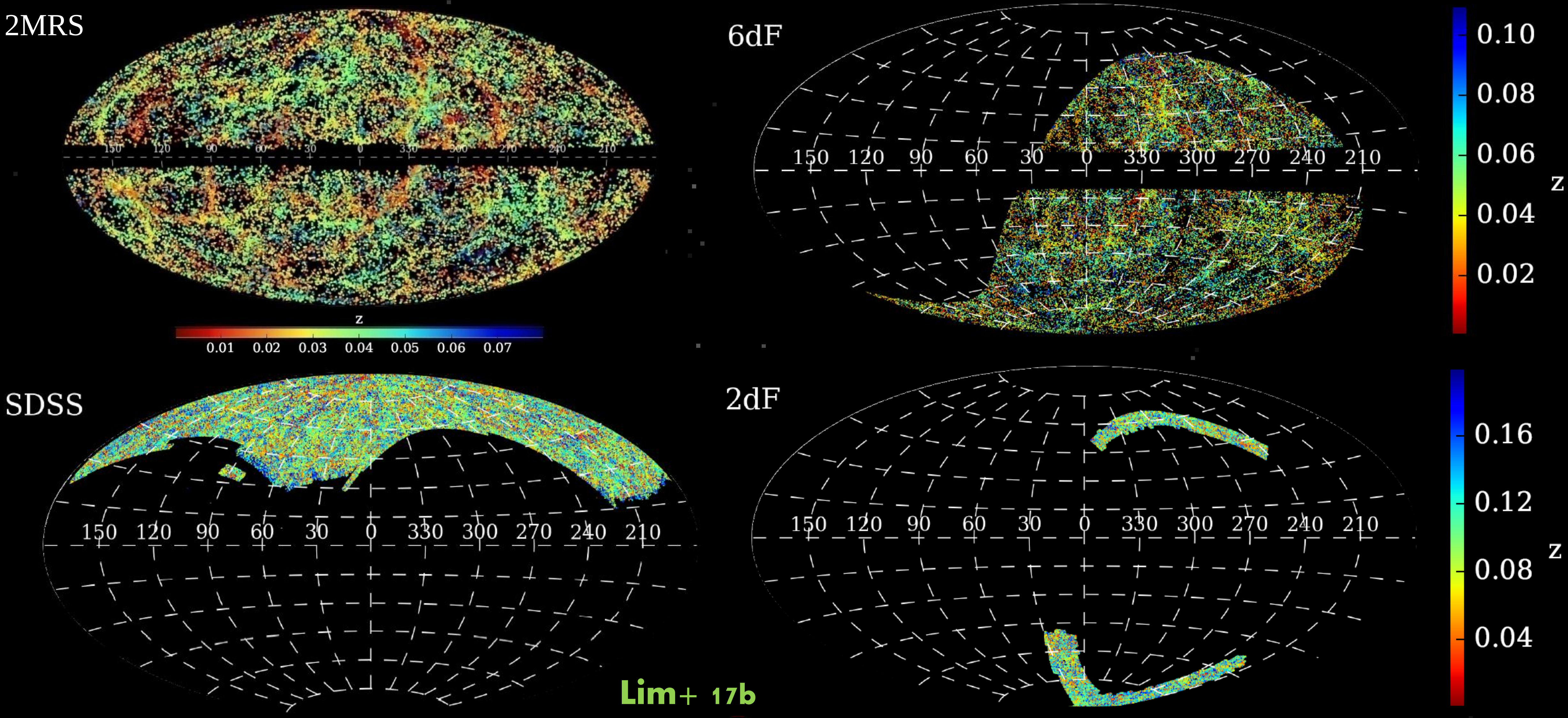
Lim et al. (2017c) *The detection of missing baryons in galaxy halos with kinetic Sunyaev-Zeldovich effect*

Lim et al. (2018b) *Exploring the thermal energy contents of the intergalactic medium with the Sunyaev-Zeldovich effect*

Gas in halos from SZE

(Lim et al. 2017b,c; 2018a)

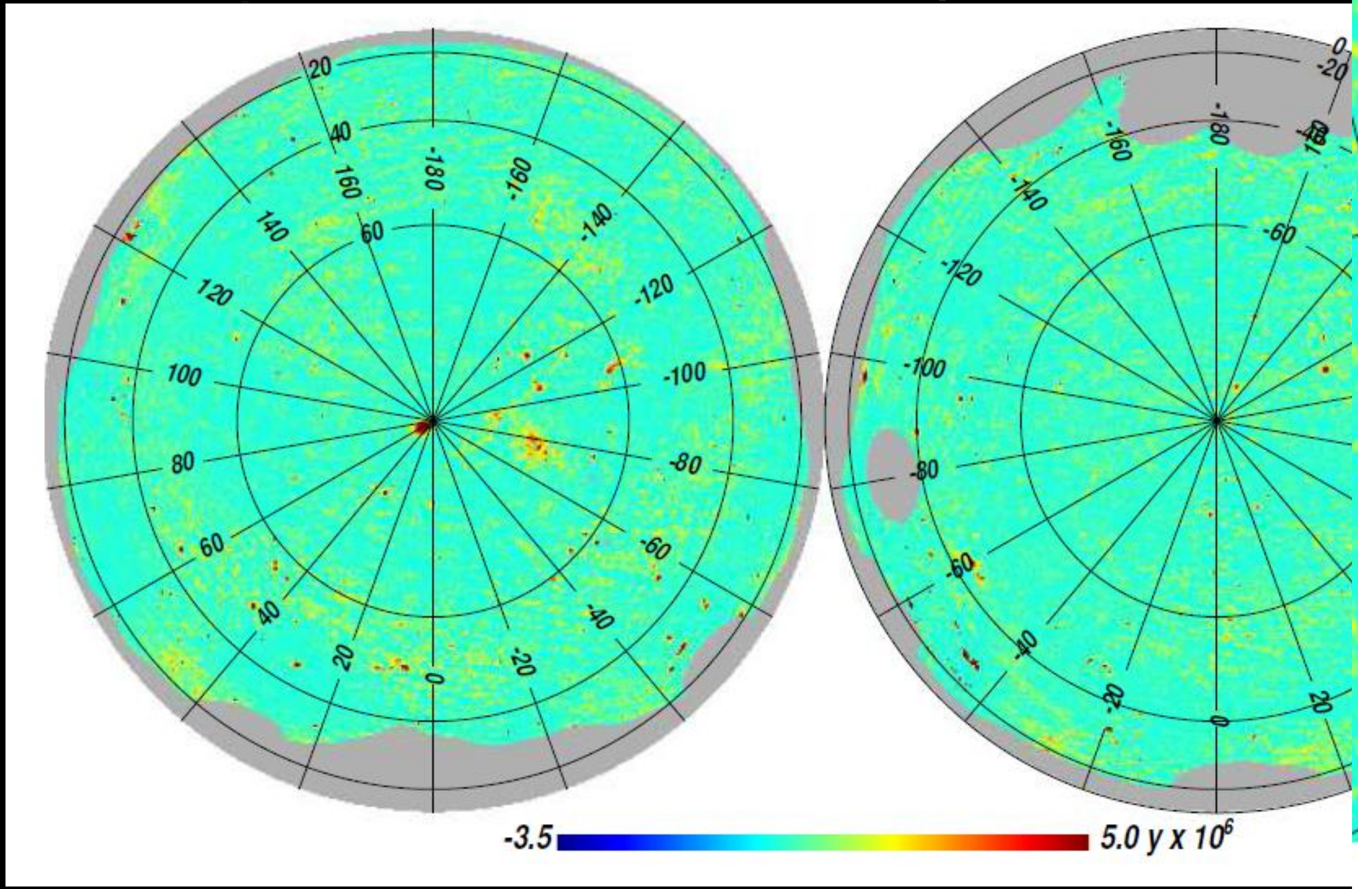
halos are from all-sky group catalog of Lim+17b

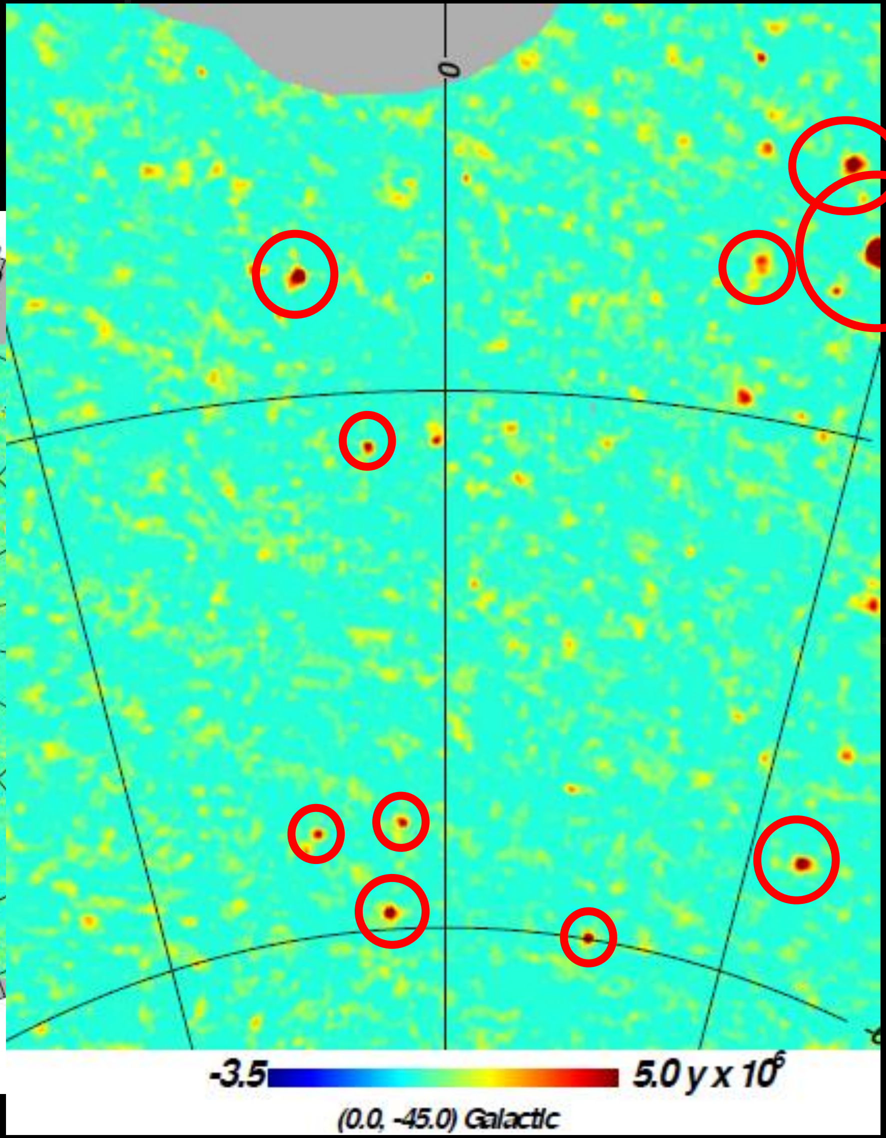


Lim+ 17b

SZE can probe gas contents in halos

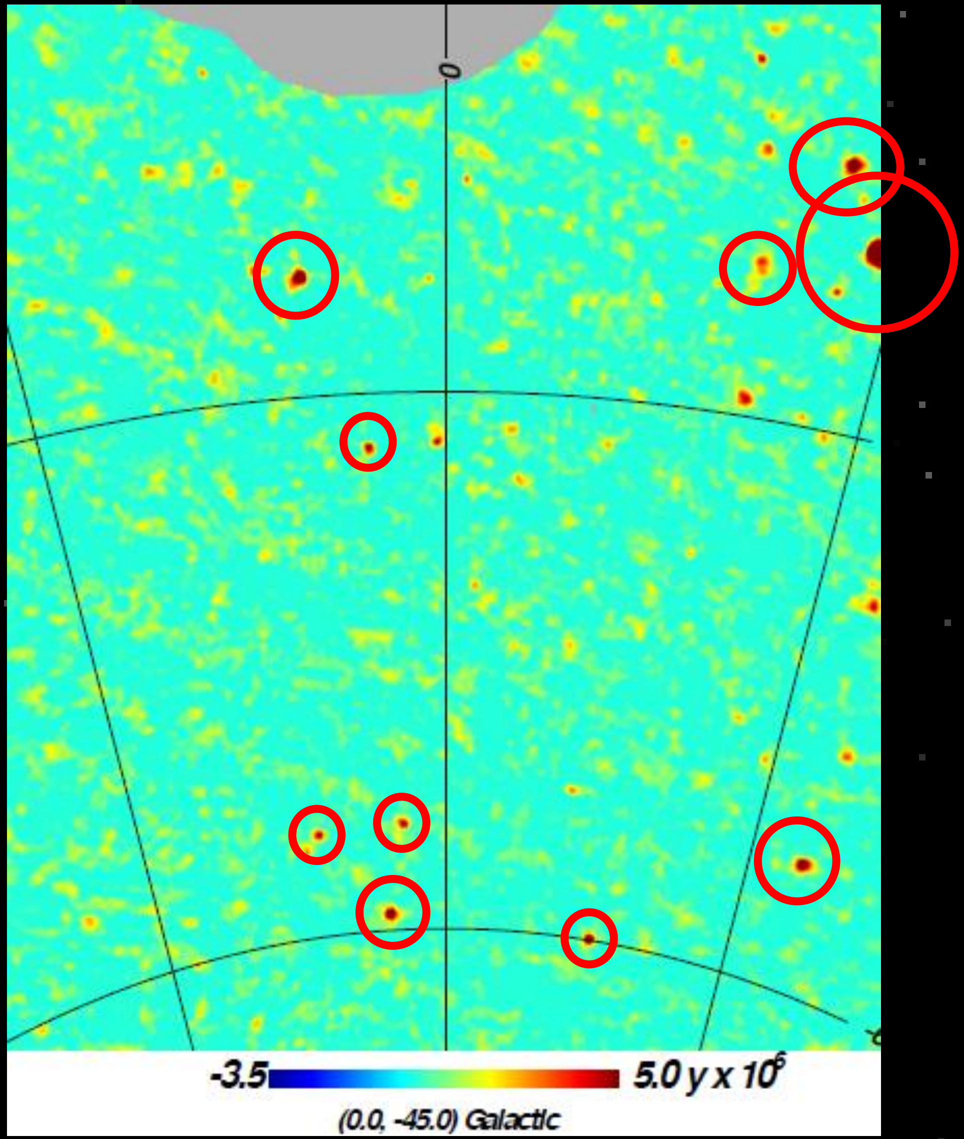
- **Data**
  - Planck all-sky **CMB map**



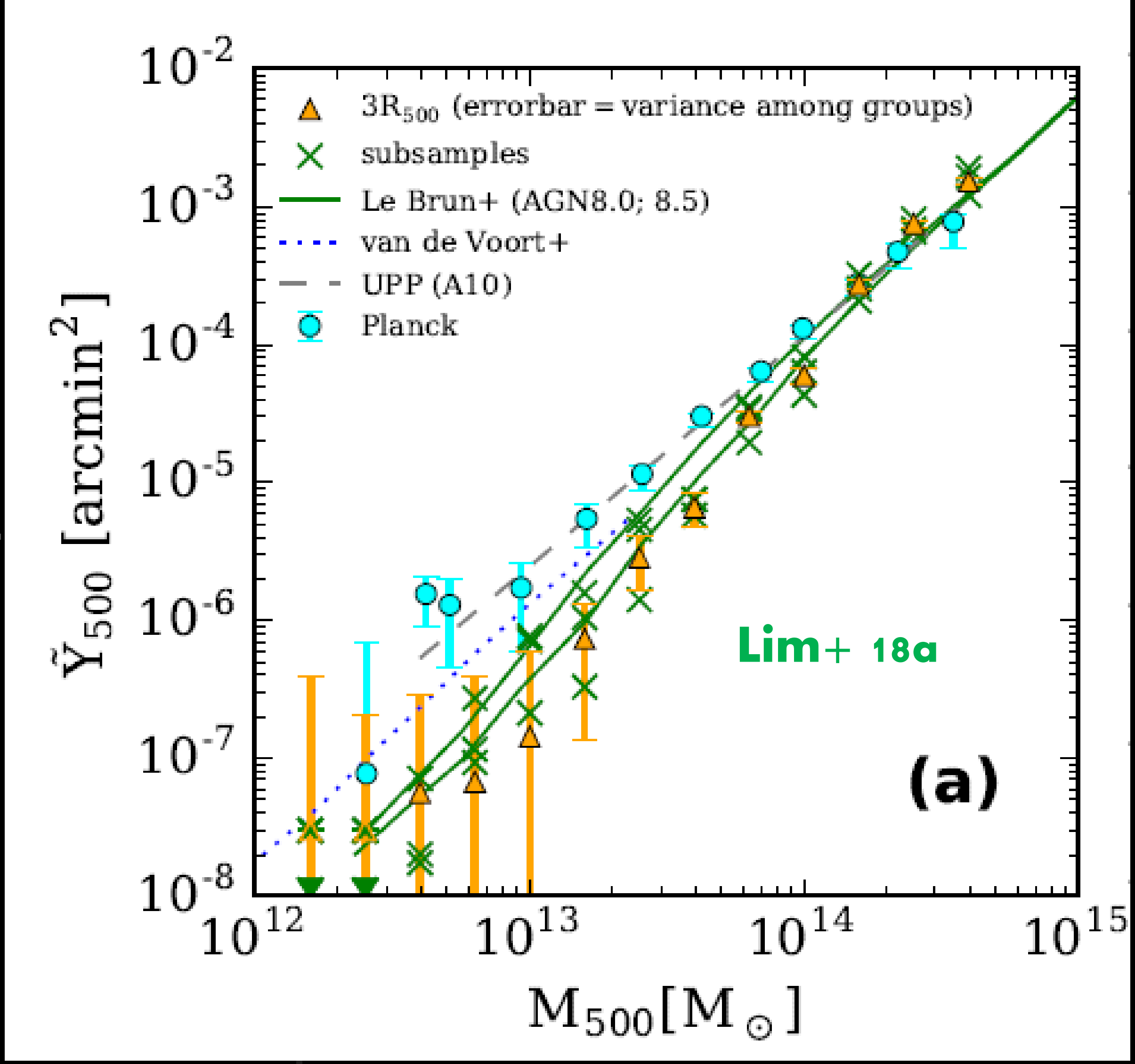


SZE can probe gas contents in halos

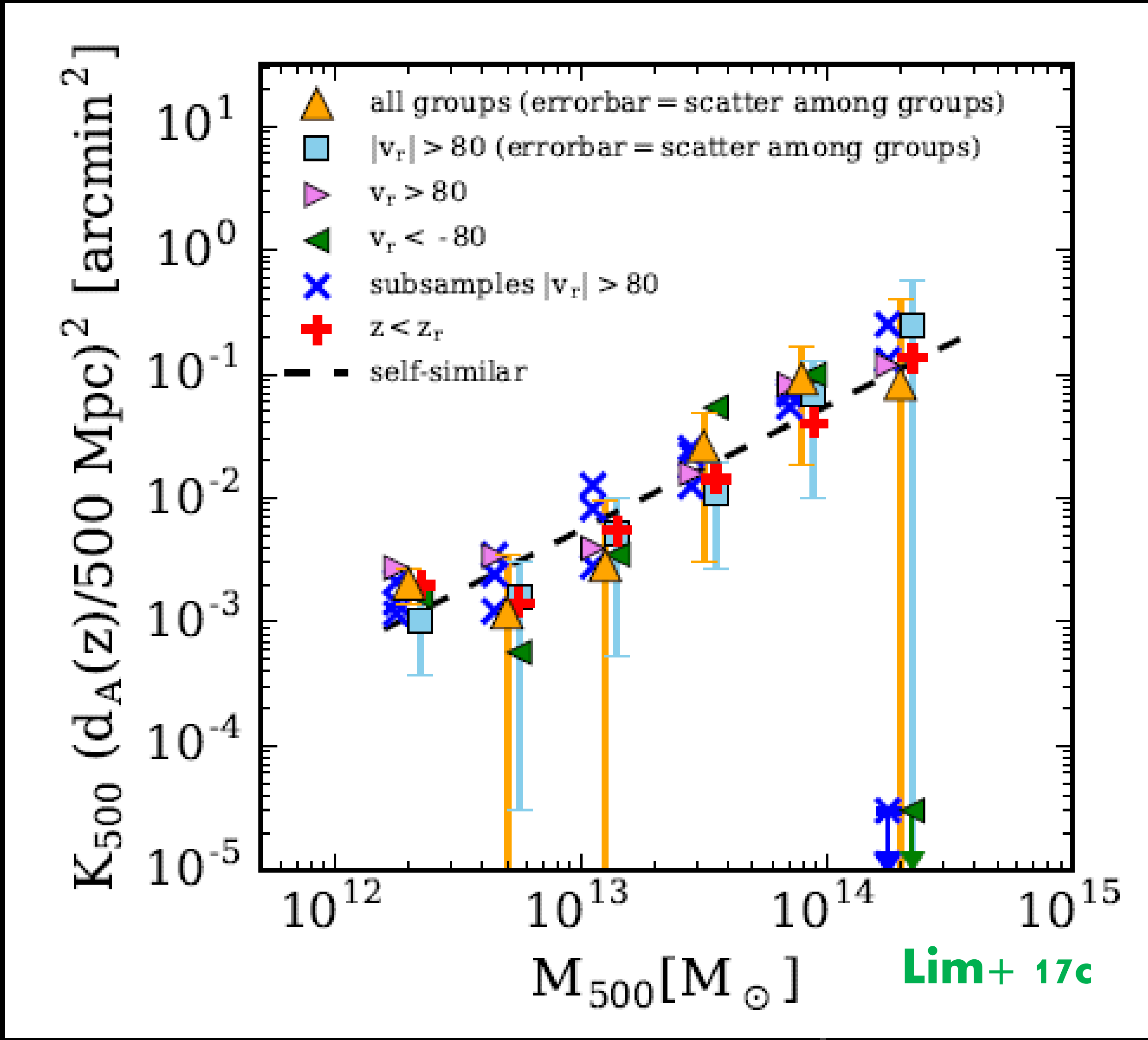
- flux extraction
  1. matched filter:
     - maximize S/N for given data
     - fixed filter shape to determine amplitude (shape: Arnaud+10 (tSZ)
       beta-profile (kSZ)
  2. simultaneous matching
     : automatically accounts for contamination along line-of-sight



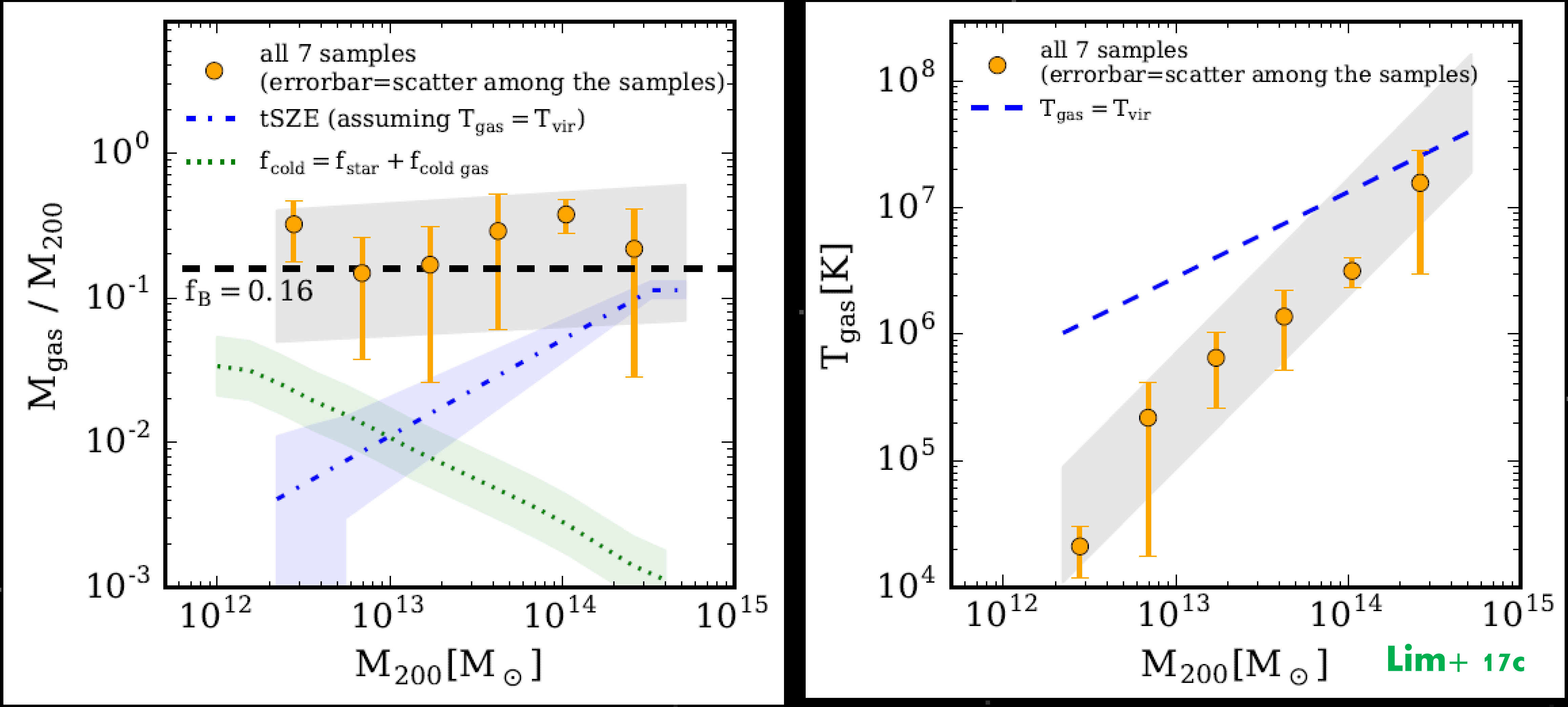
tSZ result don't follow self-similar case



kSZ result indicate no missing baryon



Combining tSZ & kSZ, baryons are there, but at low temperature



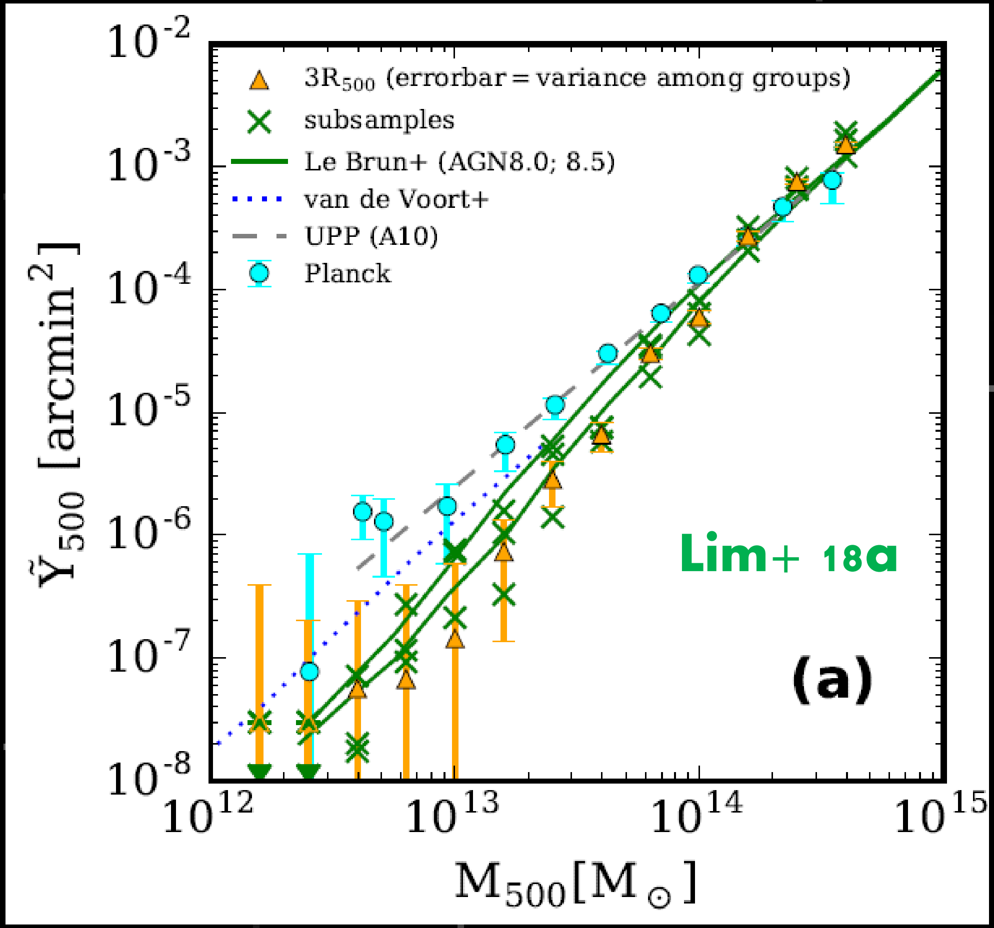
Lim+ 17c

But, how robust against methods?

- **Different methods**
  - aperture photometry vs. matched filter
  - how to identify halos
  - simultaneous vs. individual matching
  - different profiles adopted
  - resolutions of surveys
  - … led to different conclusions

→ while visiting MPA,

: test the methods using simulations



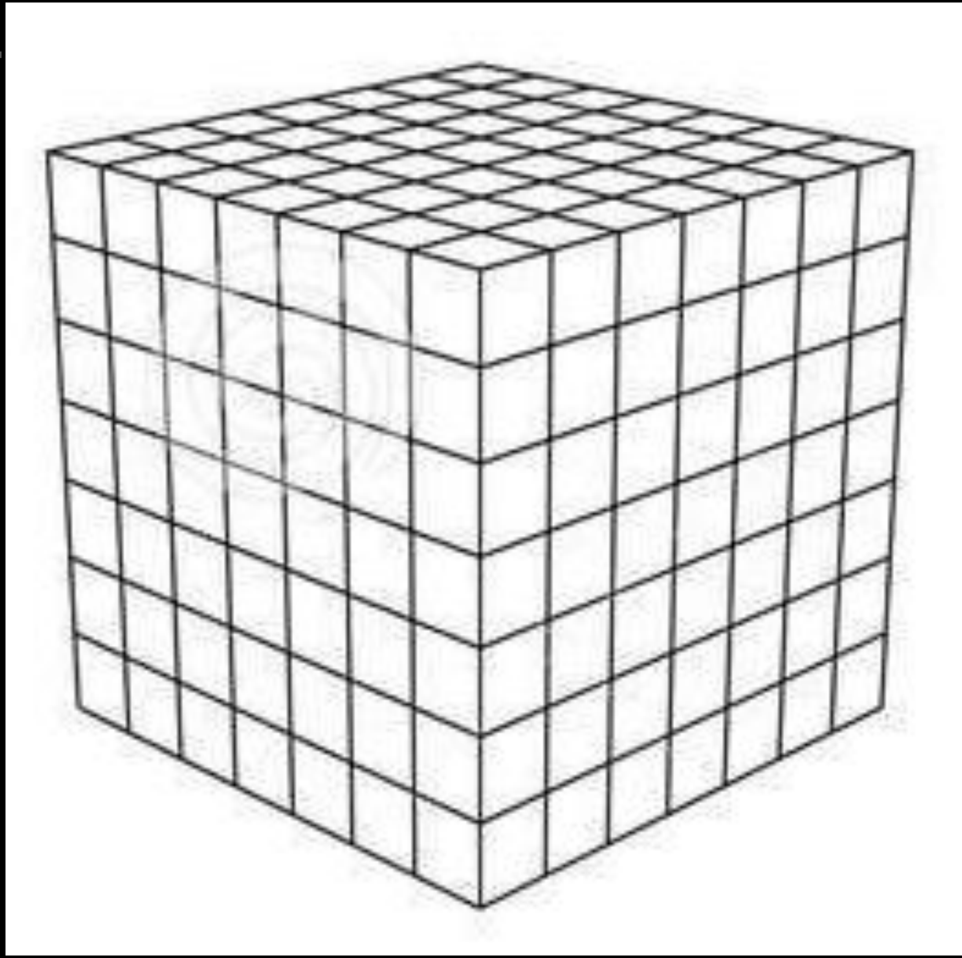
Extension to gas outside halo

(Lim et al. 2018b)

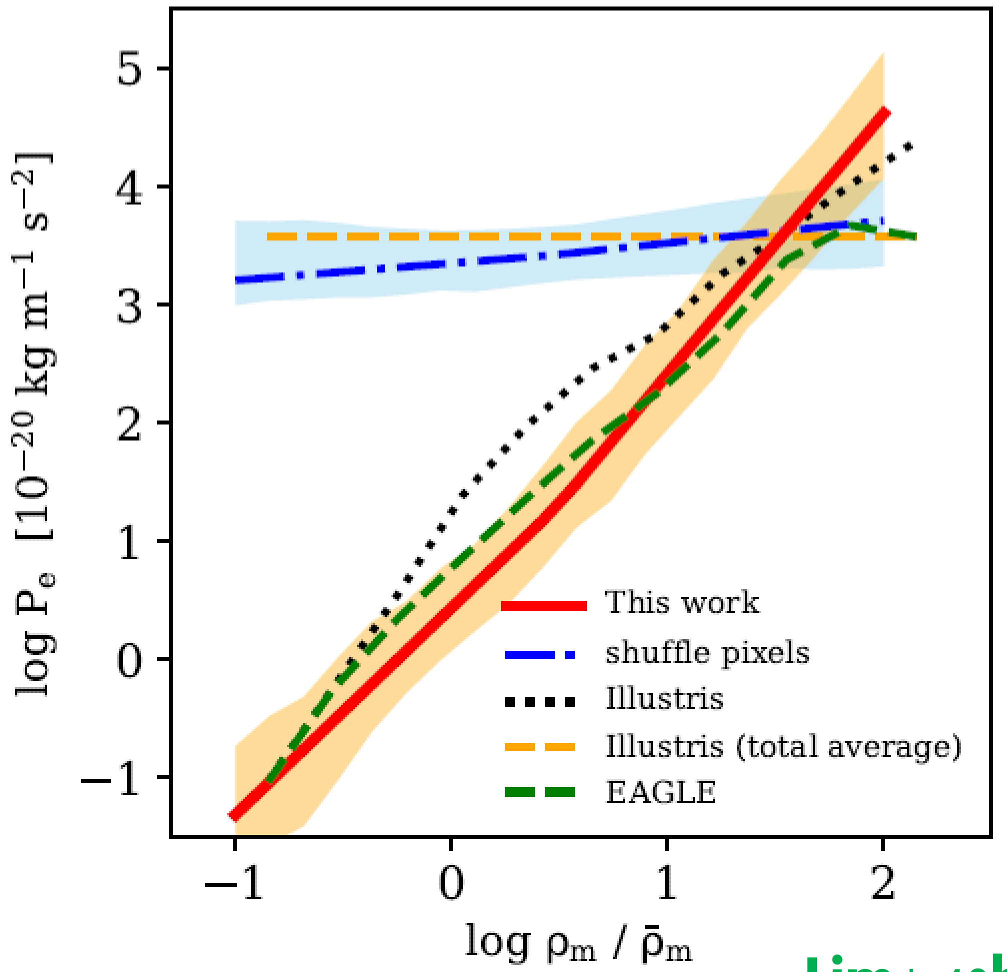
Probing IGM with tSZ and density field

- **Pressure – density relation**
  1. SDSS volume into (1Mpc/h)^3 cells
  2. density of cells reconstructed
     using group catalog & halo profiles
  3. assume power-law P-rho to assign P
  4. smooth and integrate P to obtain y
  5. seek for power-law that best-matches
     observed y-map

     → P - rho anywhere in the volume

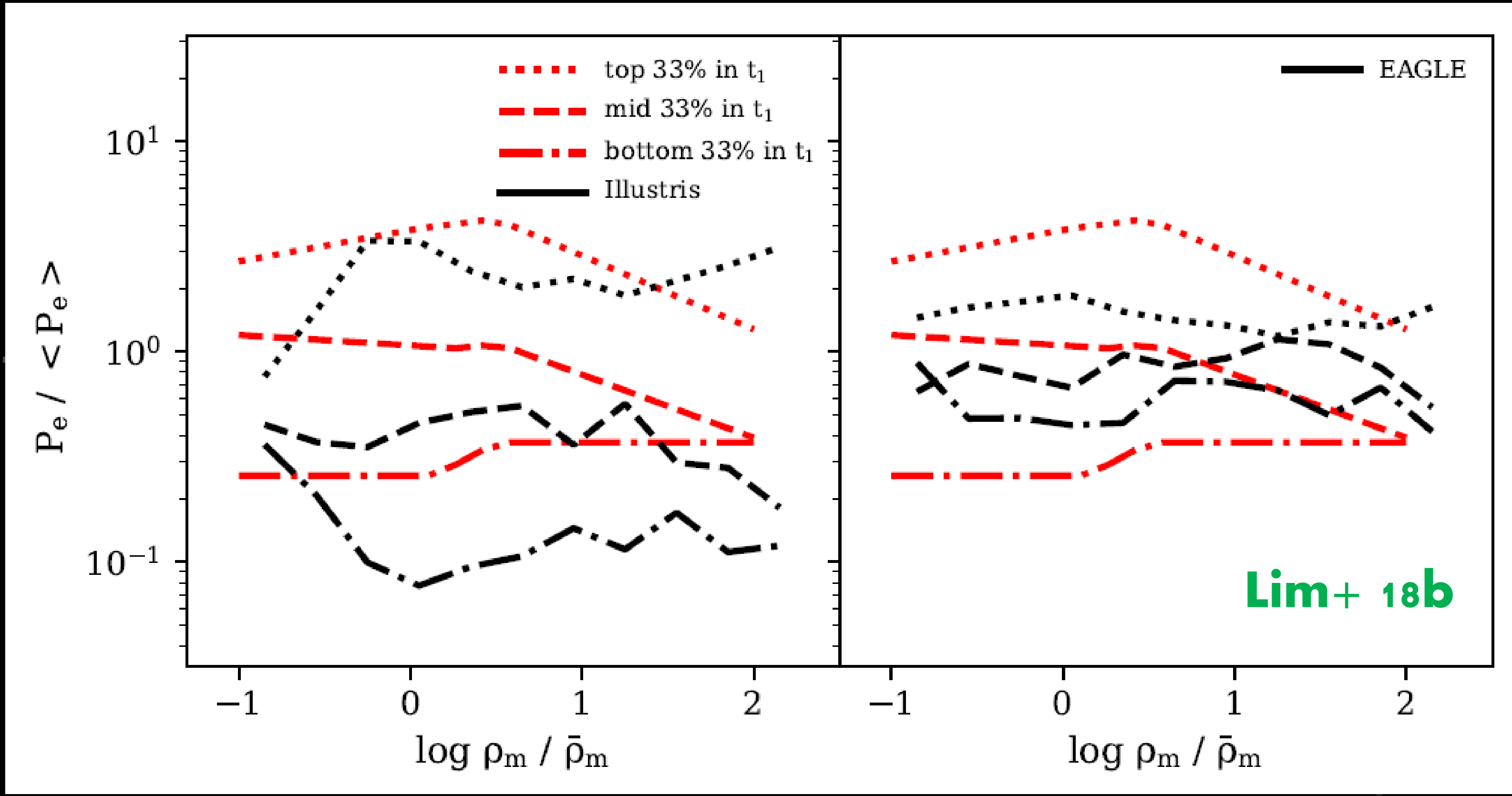


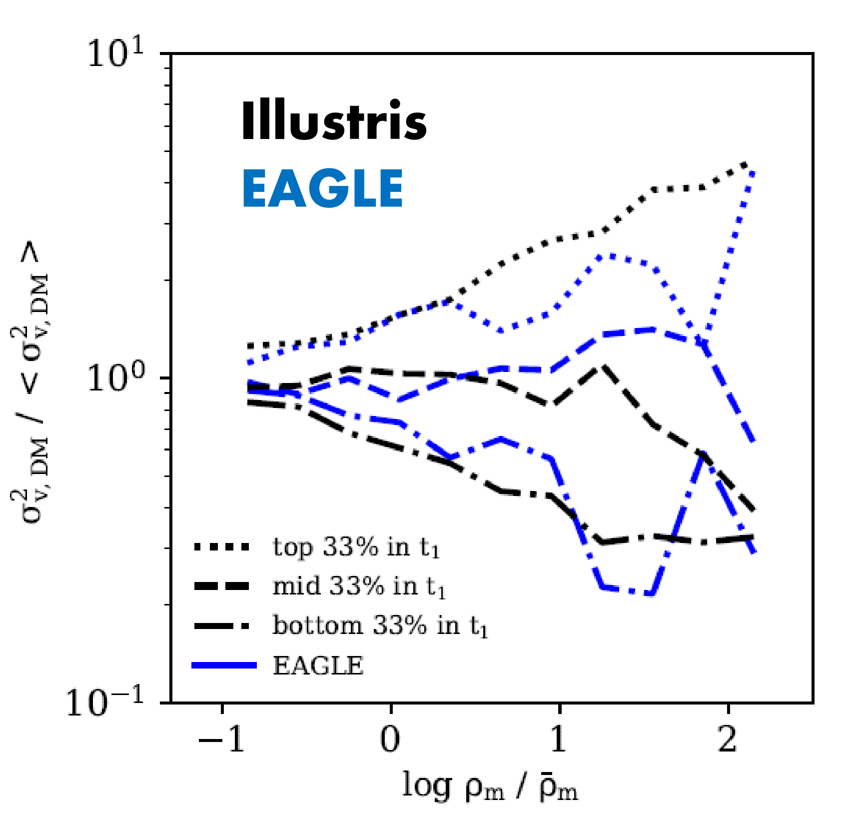
IGM roughly follows adiabatic EOS



Lim+ 18b

tidal field dependence is due to AGN feedback?





Summary

Gas in halos from SZE

: **no missing baryon in halos** but in low temperature

: signals from low-mass halos are **yet method-sensitive**

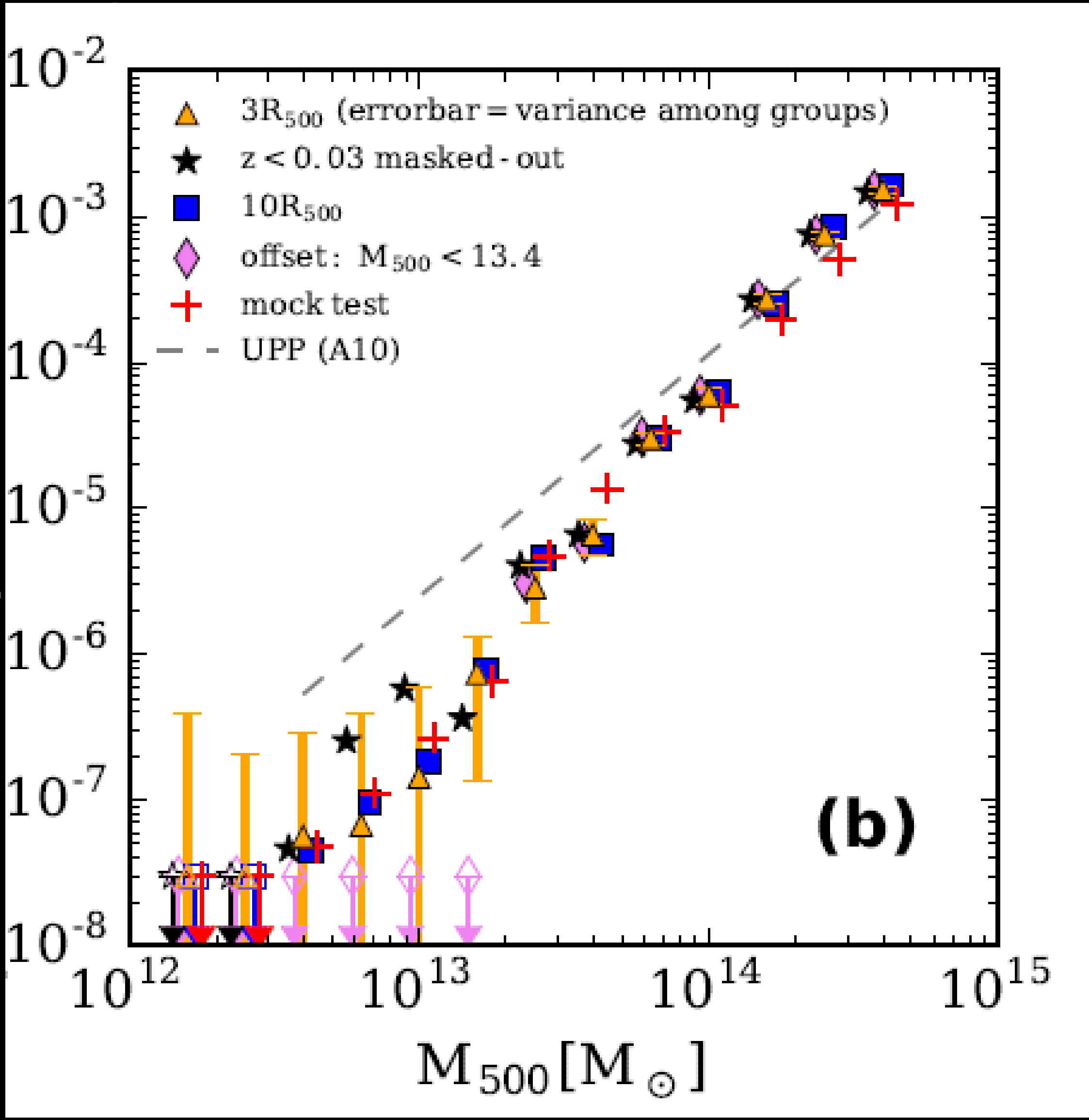
Gas in from halos to diffuse regions from tSZE

: pressure – density relation over three orders of magnitude in density (roughly follows adiabatic EOS)

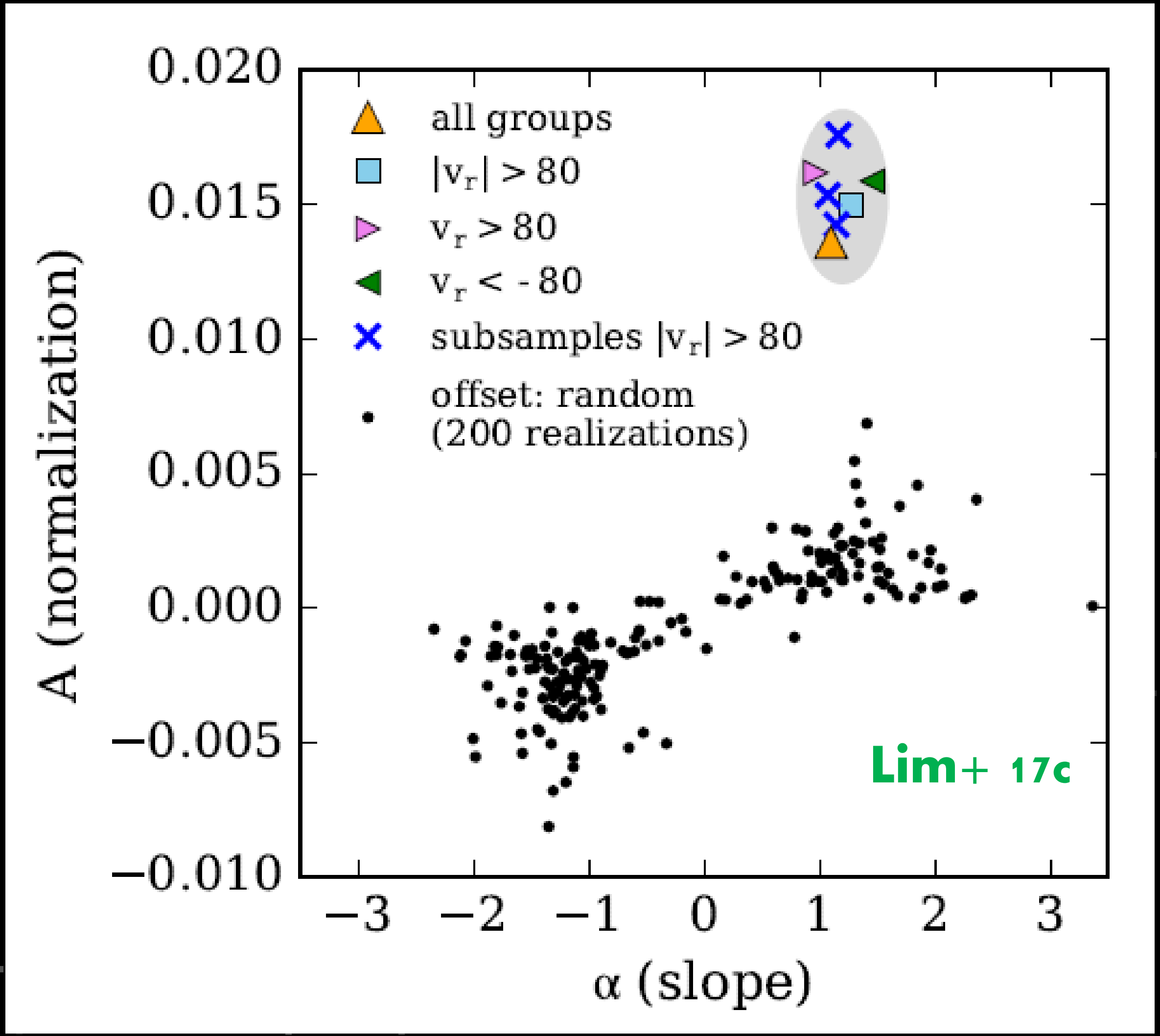
: regions of **higher tidal field** show **higher thermal energy** possibly due to AGN feedback → can provide constraint

Supplements

tSZ results are robust for log Mh>13



kSZ detections are at 4-5 sigma level

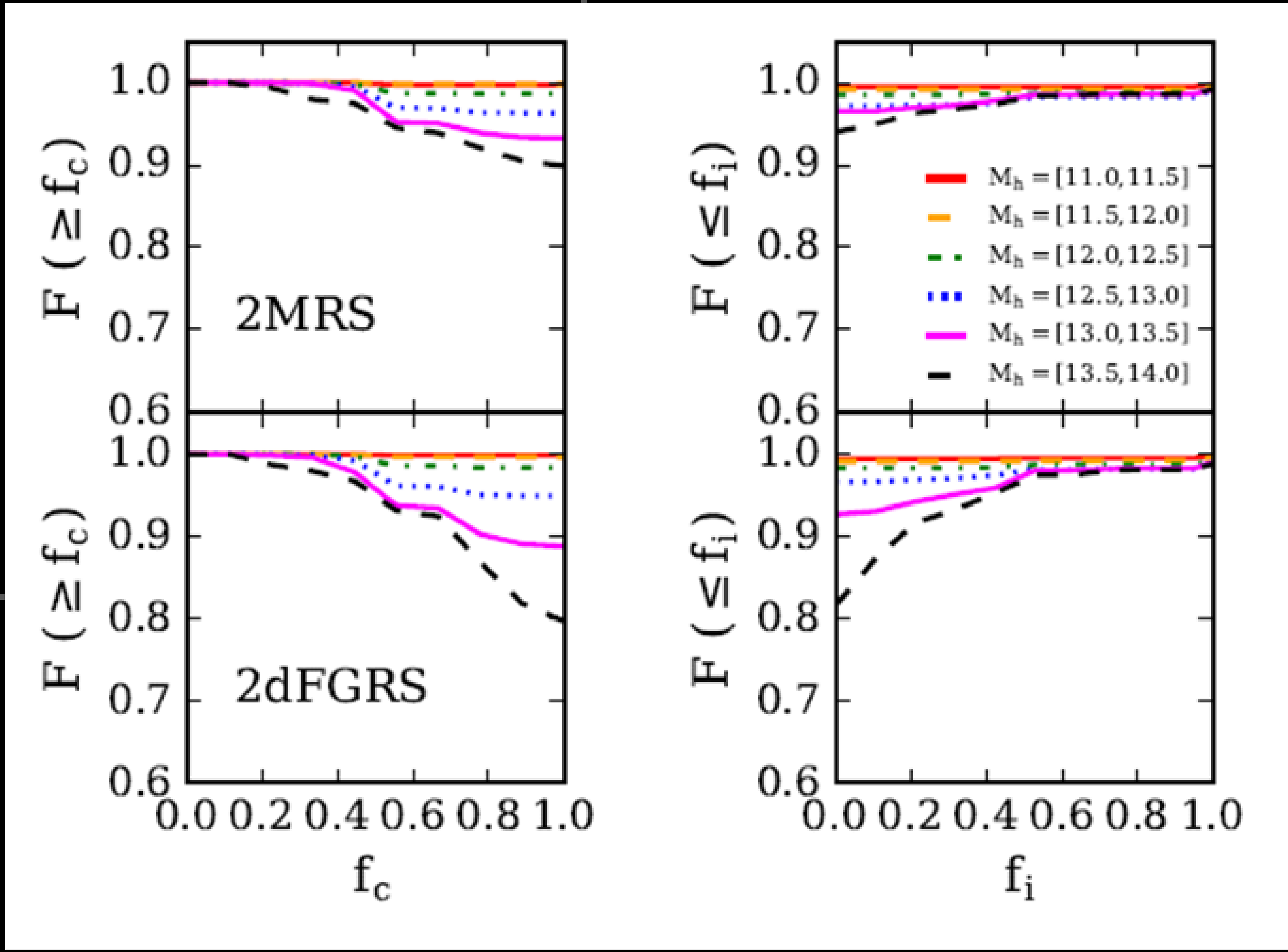


Mock groups

Membership assignment

$f_c = N_{true} / N_{tot}$

$f_i = N_{non\text{-}true} / N_{tot}$



Lim+ in prep

Group census

Table 3. A summary of group catalogs.

Catalog	Total galaxies	Total groups[a]	Total groups with mass	$N^b = 1$	$N \geqslant 2$	$M_h \geqslant 10^{14} M_\odot/h$	$M_h \geqslant 10^{13} M_\odot/h$
2MRS(L)	43,249	30,937	18,650	13,311	5,339	982	6,836
2MRS(M)	43,249	31,752	19,224	13,913	5,311	1,016	7,156
2MRS+(L)	44,310	31,804	18,731	13,275	5,456	984	6,877
2MRS+(M)	44,310	32,693	19,307	13,923	5,384	1,014	7,211
6dFGS(L)	62,987	46,676	17,907	11,126	6,781	1,004	6,919
6dFGS(M)	62,987	47,176	18,555	11,789	6,766	1,045	7,291
6dFGS+(L)	73,386	59,515	21,481	14,168	7,313	1,154	8,030
6dFGS+(M)	73,386	59,512	22,223	15,278	6,945	1,191	8,459
SDSS(L)	586,025	446,495	165,538	112,444	53,094	3,757	39,565
SDSS(M)	586,025	421,715	167,638	105,979	61,659	3,780	43,880
SDSS+(L)	600,458	453,927	164,694	107,066	57,528	3,712	39,464
SDSS+(M)	600,458	426,932	166,999	101,518	65,481	3,760	43,649
2dFGRS(L)	180,967	144,965	77,423	62,101	15,322	606	8,526
2dFGRS(M)	180,967	145,756	77,365	61,309	16,056	632	9,116
2dFGRS+(L)	189,101	147,757	77,861	59,606	18,255	634	8,553
2dFGRS+(M)	189,101	148,290	77,757	58,909	18,848	638	9,099

Notes.

a This includes groups without halo mass assigned because halo mass is not complete at given redshift.
b The number of member galaxies in a group. This excludes groups without halo mass assignment.