Baryon physics from the kinematic Sunyaev-Zel'dovich effect

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Nordita Advances in theoretical cosmology in light of data

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Collaborators

arXiv:1510.06442, arXiv:1705.05881

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Large-scale structure & baryons

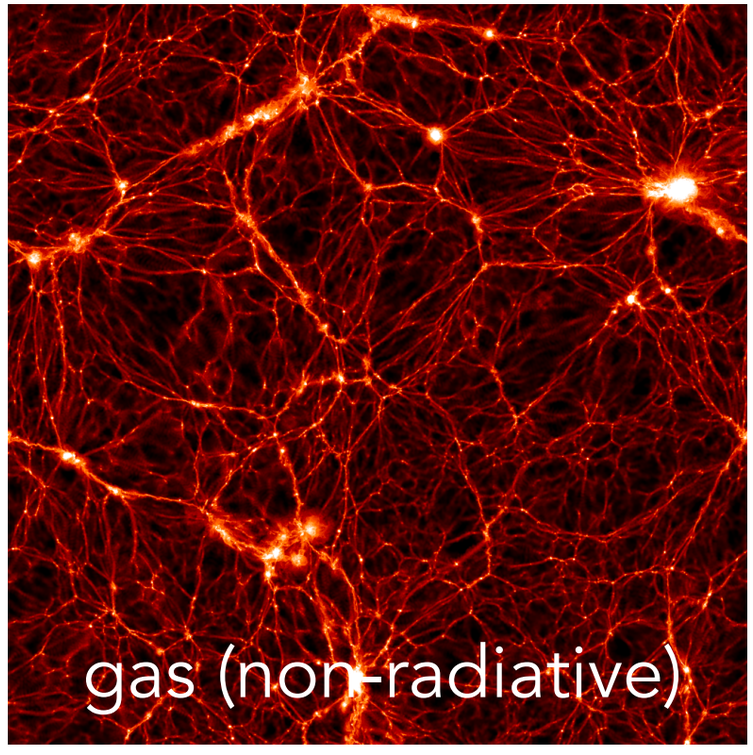
Statistics: volume vs area

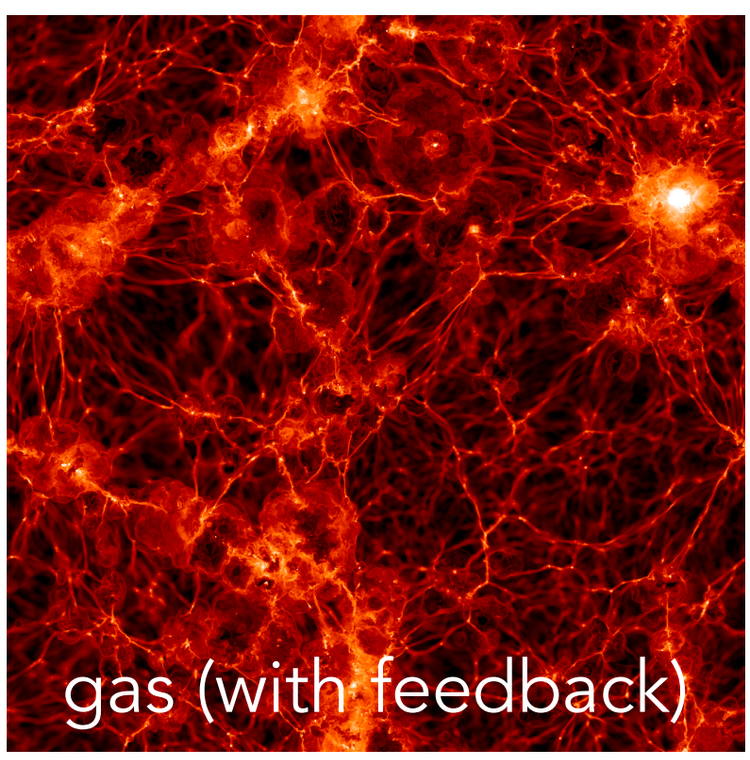
Probes dark energy, neutrino masses, non-Gaussianities

But **systematics**…
baryons, biasing, non-linear evolution, non-Gaussian statistics

Baryons ~15% total mass
→ largest uncertainty on the small-scale matter power spectrum

Can the CMB help?





Haider+16, Illustris simulation

Halo imprints on the CMB

Key parameters: $\theta_{\rm lensing} \sim 1', \;\; \tau \sim 10^{-3}, \;\; \frac{v_{\rm thermal}}{c} \sim 0.1, \;\; \frac{v_{\rm bulk}}{c} \sim 10^{-3}$

→ Various observables with complementary information :

Halo lensing	$\propto \theta_{\rm lensing}$	→ Total density profile
Thermal SZ	$\propto \tau \left(\frac{v_{\rm thermal}}{c}\right)^2$	→ Thermal pressure profile
Kinematic SZ	$\propto \tau \left(\frac{v_{\rm bulk\ \parallel}}{c}\right)$	→ Gas density profile (but also velocities, reionization, ULSS)
Scattering	$\propto \tau \frac{\delta T}{T}$	→ Gas density profile
Polarized SZ	$\propto \tau Q, \; \tau \left(\frac{v_{\rm bulk\ \perp}}{c}\right)^2$	→ Gas density (but also ULSS)
Moving lens	$\propto \theta_{\rm lensing} \left(\frac{v_{\rm bulk\ \perp}}{c}\right)$	→ velocities
…		

Kinematic Sunyaev-Zel'dovich effect

$$\frac{\delta T}{T} = \int \mathrm{d}l \, n_e \sigma_T \frac{v}{c}$$

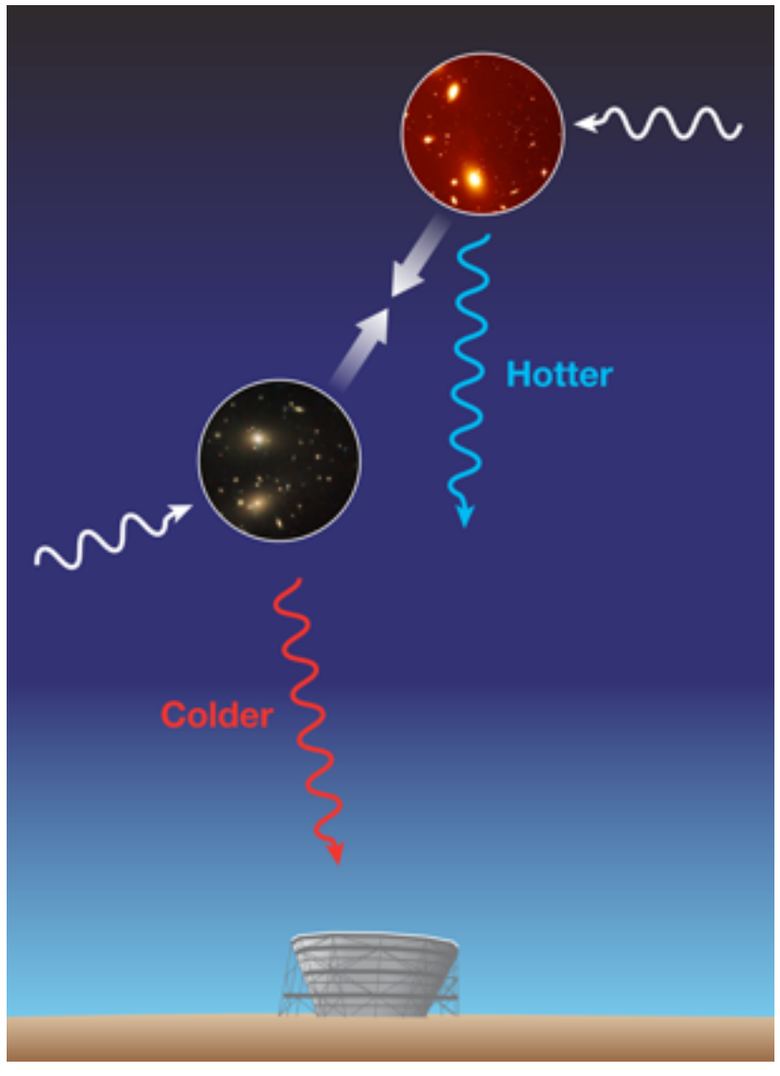
τ

Counts all free electrons

Lower mass halos at higher z

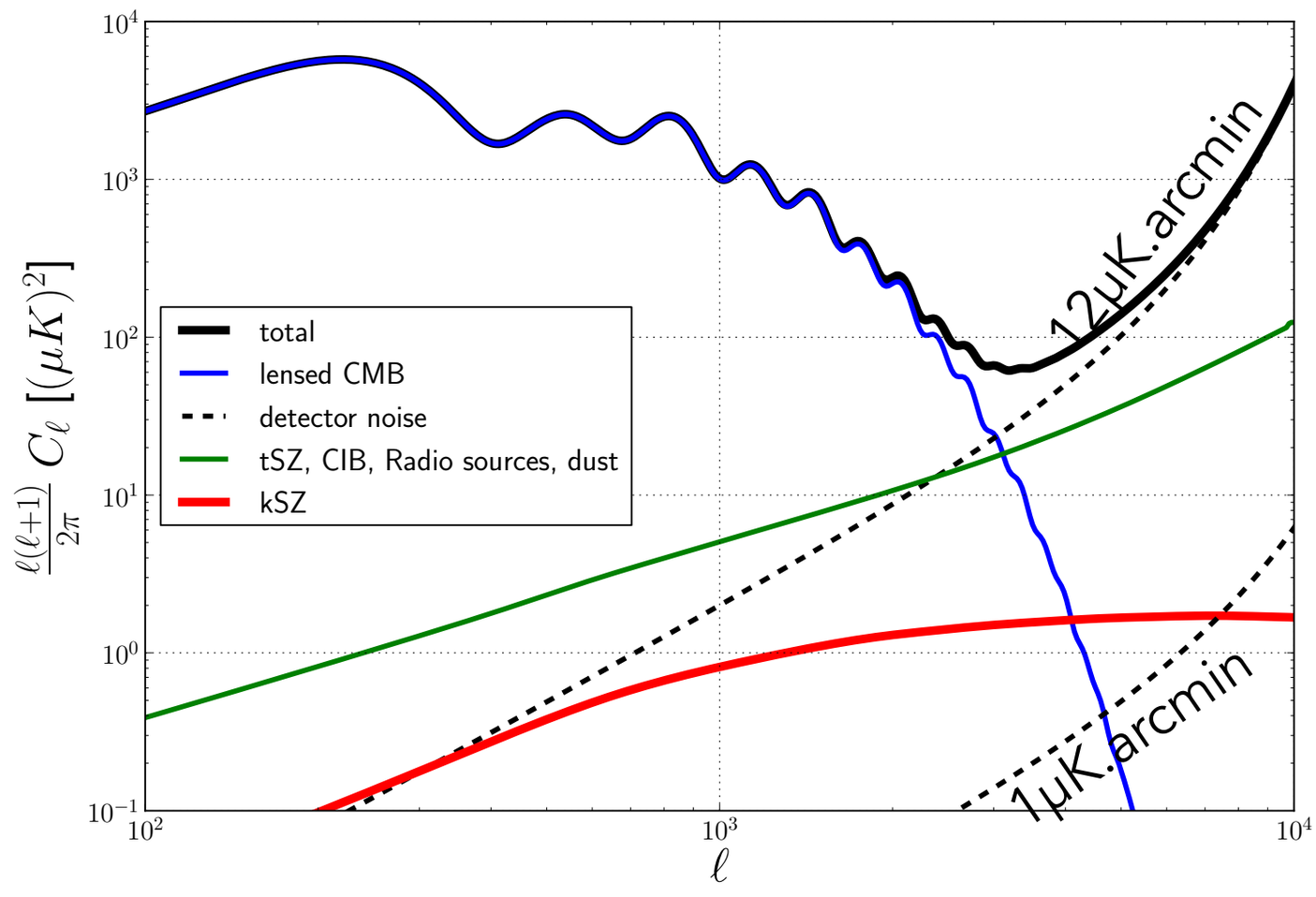
Small size: $\delta T_{\mathrm{kSZ}} \sim 0.1\mu\mathrm{K}, \delta T_{\mathrm{CMB}} = 110\mu\mathrm{K}$

Blackbody spectrum



Hand et al 2012

aps.org, ESO, ESA, Hubble, NASA



Detection methods

Individual (monster) cluster

Sayers+13, 14

Pairwise velocities

Hand+12, Planck15, Soergel Flender Story Bleem +16, de Bernardis+16

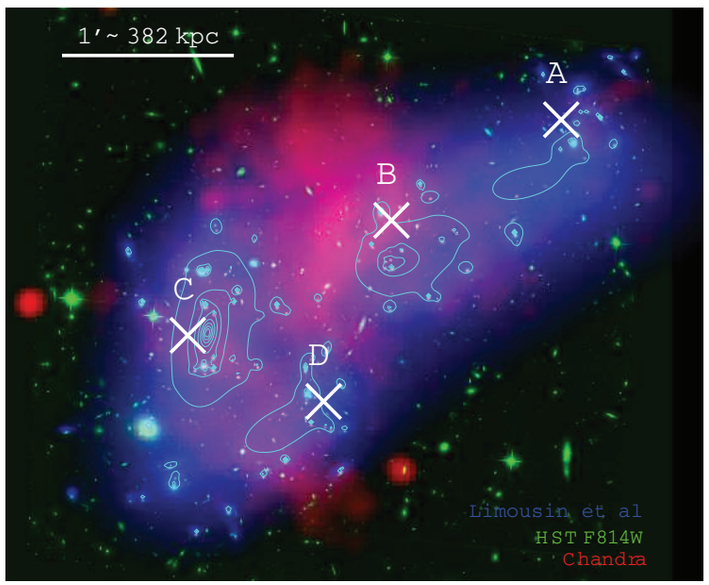
Velocity reconstruction

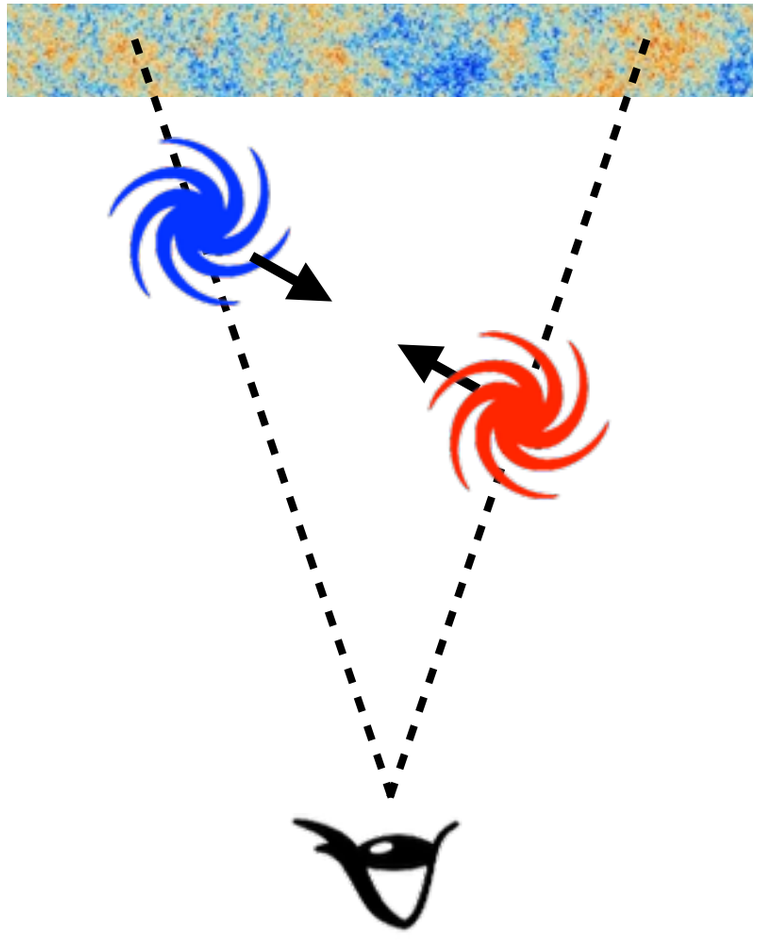
Planck15, Schaan Ferraro+15

<T^2 x tracer>, Hill+16, Ferraro+16, Planck17

T Power spectrum, George Reichardt+14

T^2 power spectrum, Smith Ferraro 16





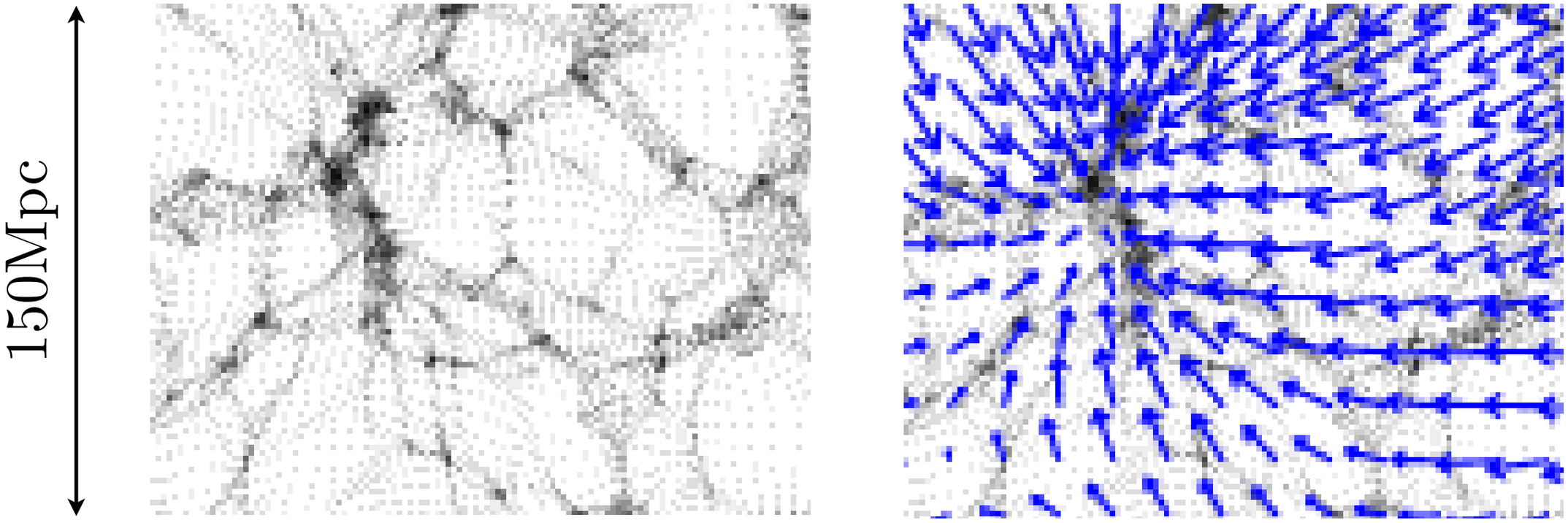
Velocity reconstruction

Peculiar velocity $\vec{v} = \dfrac{d\vec{r}}{dt} - H_{(t)}\vec{r} = \dfrac{d\vec{x}}{d\eta}$

Mass conservation + linear approx.

$$\dot{\delta} + \vec{\nabla}\cdot\vec{v} = 0 \;\Rightarrow\quad \vec{v} = -aHf\;\vec{\nabla}\Delta^{-1}\delta$$

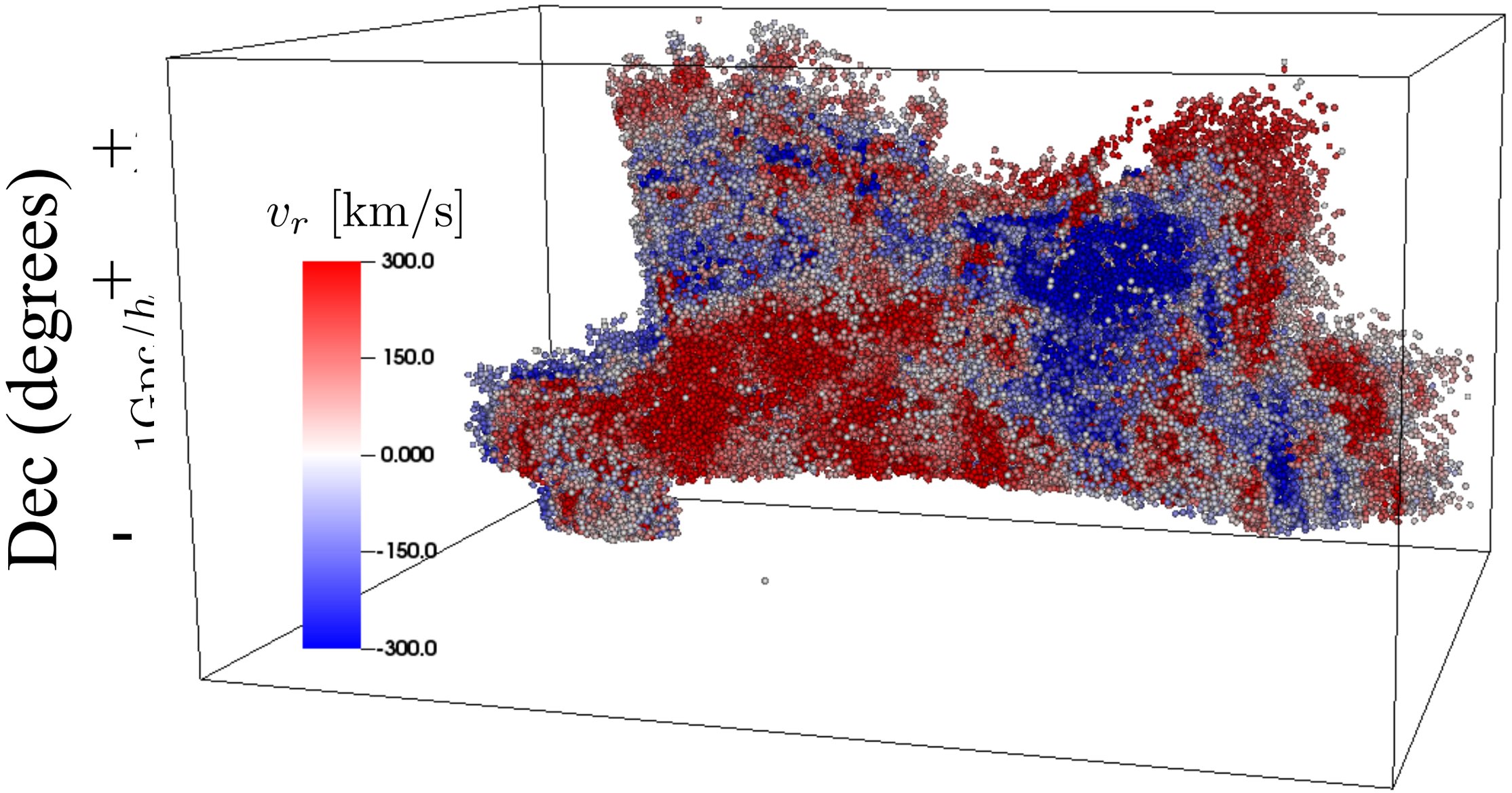
$$\rightarrow v_{\mathrm{rms\ 1d}} \sim 300\ \mathrm{km/s}$$



Eisenstein+07, Padmanabhan+12,14

Velocity reconstruction

$$\vec{v} = -aHf\,\vec{\nabla}\Delta^{-1}\delta$$



Velocity data from Smith, Vargas-Magaña, BOSS

BOSS CMASS South DR11 footprint (sdss.org)

Gas profile of CMASS halos

3 σ measurement (for now)

Already useful profile information

Future is exciting:

$$\frac{S}{N} \sim (1 \text{ or } 2) \left(\frac{M_h}{10^{13} M_\odot} \right) \sqrt{\frac{N_{\rm obj}}{10^4}}$$

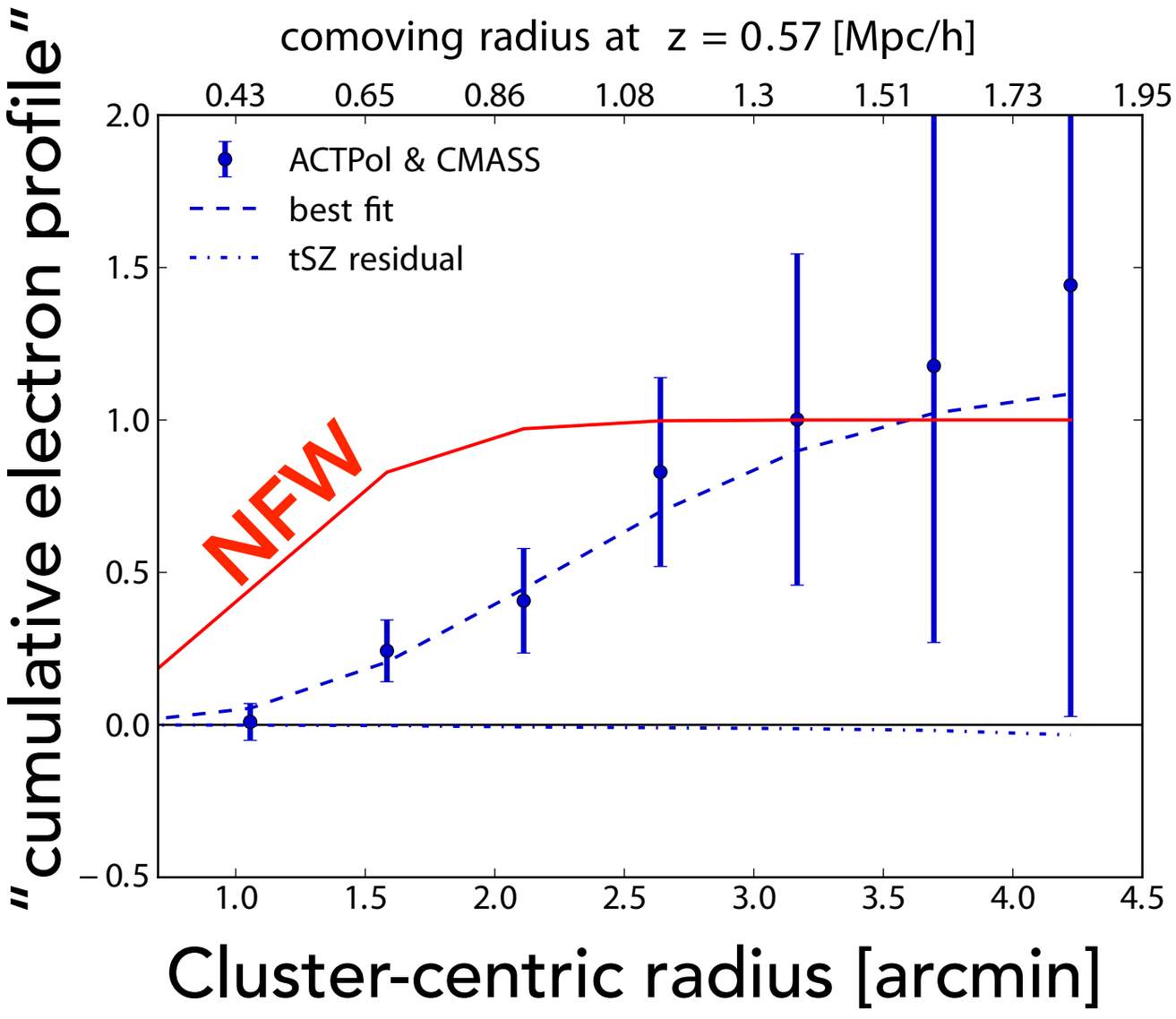
BOSS & new ACTPol: area x 25

PFS/DESI: S/N x ~30 from N_{obj}

SO/CMB S4: S/N x few from sensitivity,

x few from tSZ removal

→ S/N~100



Schaan Ferraro +15

Gas energetics from kSZ/tSZ

Measure 1-halo / 2-halo term → diffuse gas
Bin in redshift
Split populations
SZ from quasars

Gralla+14, Verdier+15, Crichton+15, Chowdhurry+17

Virial theorem for gas:

$$\underbrace{\frac{1}{3}\Phi_{\rm gas}}_{\substack{\text{from kSZ}\\ \text{\&mass profile}}} + \underbrace{\int P_{\rm th}\mathrm{d}V}_{\text{from tSZ}} + \underbrace{\int P_{\rm Nth}\mathrm{d}V}_{\rightarrow\text{inferred}} \propto P_{\rm Surface}$$

→ **Constrain $P_{\text{non-th}}$ as a function of radius, hydro mass bias**
→ **Constrain energy injected through feedback**

Battaglia Ferraro Schaan Spergel +15

Summary: kSZ & gas physics in clusters

- Evidence for kSZ with ACTPol and velocity reconstruction from BOSS arXiv:1510.06442
- KSZ powerful baryometer: abundance, profile
- Constrain non-thermal pressure and energy injection with kSZ & tSZ
- CMB S4 and DESI will increase the S/N to ~100
  → bin in mass/type/color
- Requires large aperture CMB telescope

Thank you!