Astrophysics and Cosmology with Galaxy Clusters

Session summary: Heidi Wu & Srini Raghunathan

Speakers: Vittorio Ghirardini, Sebastian Bocquet, Susmita Adhikari, Tesla Jeltema, Grant Tremblay, Eric Baxter, Daisuke Nagai, Erwin Lau, Han Aung.

Session notes: https://docs.google.com/document/d/1_YsZEJ8UIWulOtjDheZ8HofkCLi9OprtmAuKuhr9AXk/edit

Outline
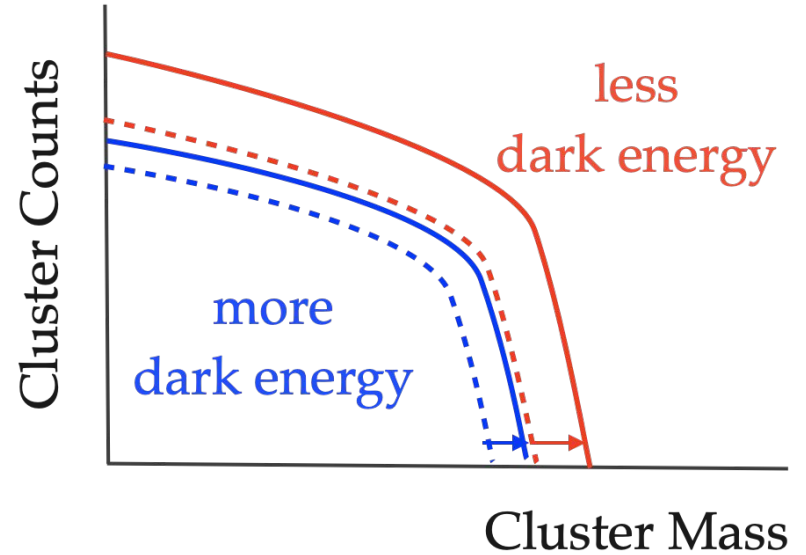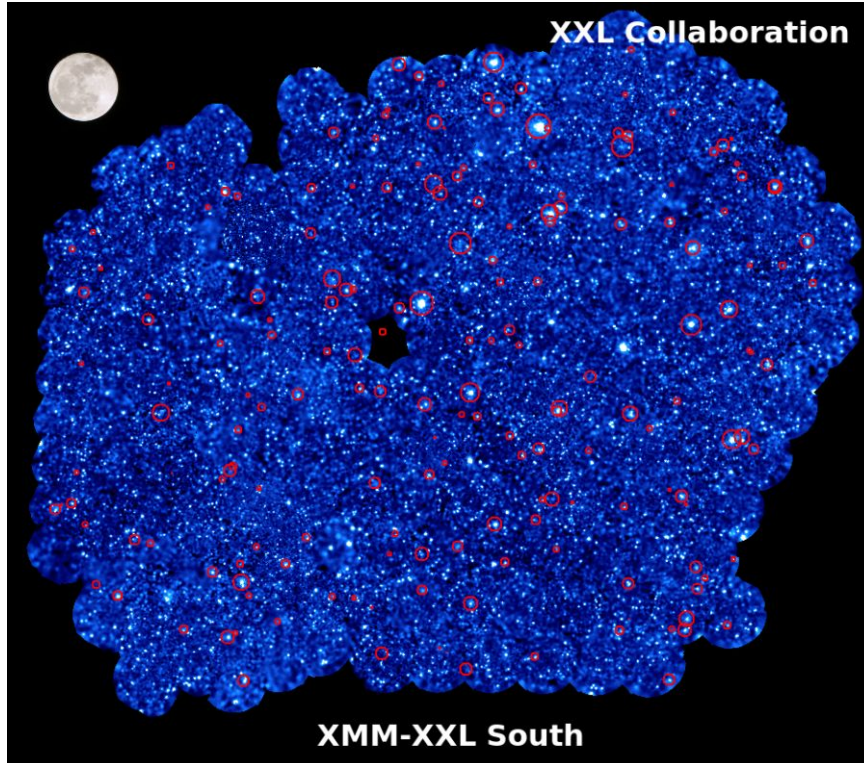
Part 1: Cluster cosmology

- galaxy cluster counts
  - CMB perspective
  - Optical perspective
  - X-ray perspective
- H_0 from galaxy clusters

Part 2: Cluster astrophysics

- Virialization mechanism
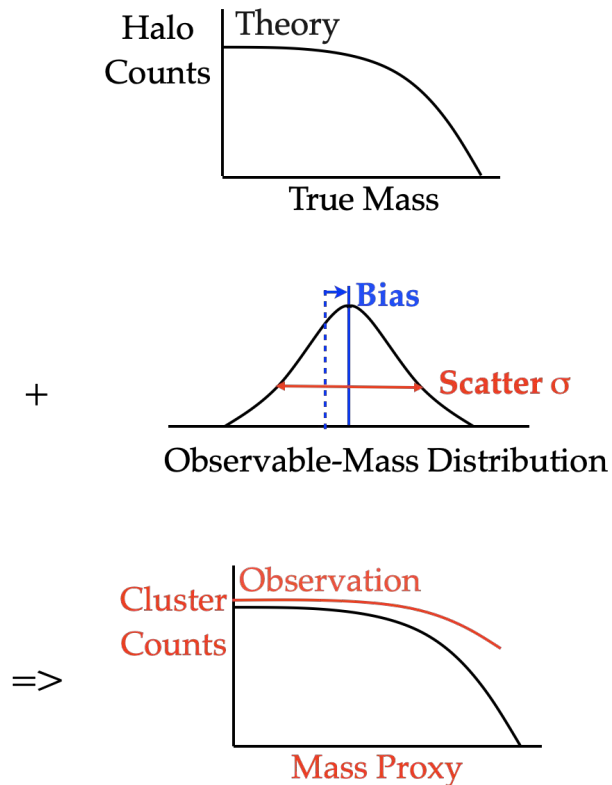- Splashback radius
- Shock feature
- Baryon pasting

Part 1: Cluster Cosmology

Cosmology with cluster number counts

Also: σ_8, Ω_M, neutrino mass, ...

Cosmology with cluster number counts

Halo Counts | Theory
True Mass

+

Bias
Scatter σ
Observable-Mass Distribution

=>

Cluster Counts | Observation
Mass Proxy

- Cluster sample selection
  - SZ
  - Optical
  - X-ray
- Mass calibration
  - Optical weak lensing
  - SZ
  - X-ray
  - CMB lensing

SZ perspective

SZ custers: current status (SPT, Sebastian Bocquet's talk)
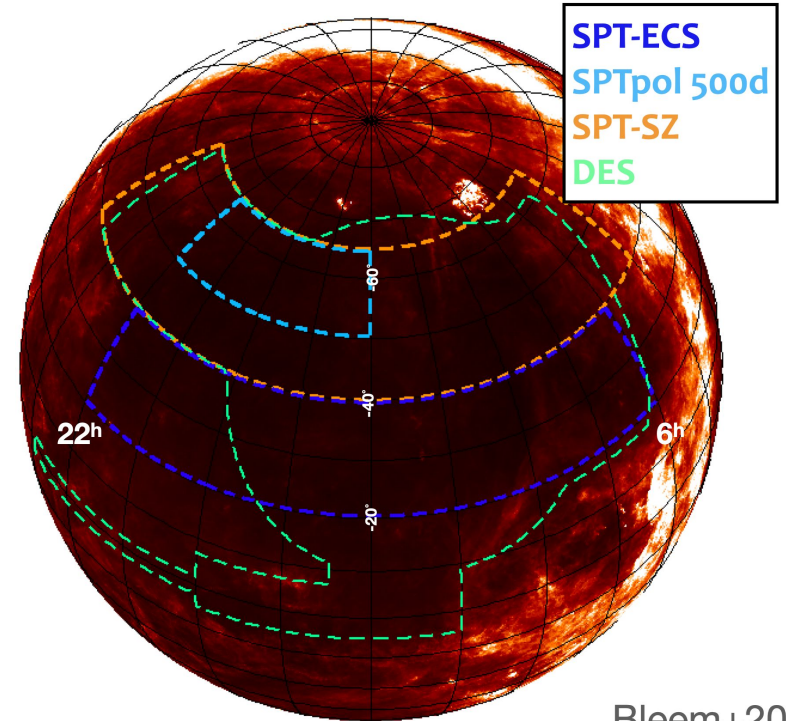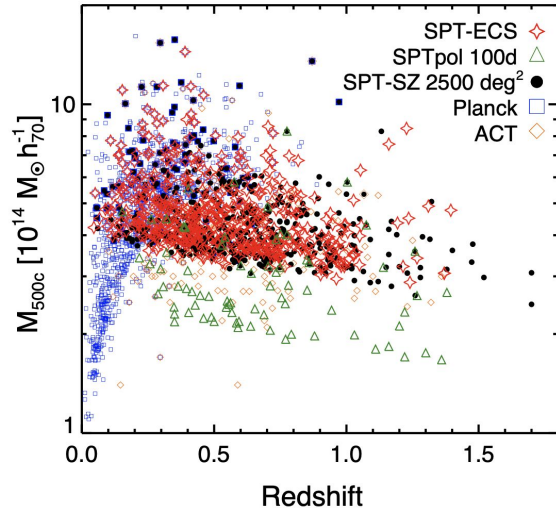
New cluster catalogs:
- Deep 100 square-degree SPTpol-100d survey (Huang+20)
- Wide 2700 square-degree SPTpol-ECS survey (Bleem,Bocquet+20)

~1000 clusters above detection SNR 4.5

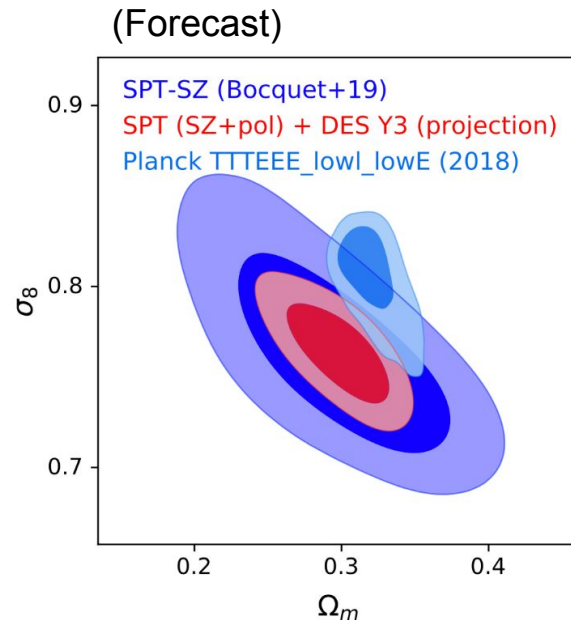Redshifts/optical confirmation mainly from Dark Energy Survey

Bleem+20

SZ custers: current status (SPT, Sebastian Bocquet's talk)

SPT-SZ + SPTpol + DES Year 3 weak-lensing
Bocquet et al. in prep.

- O(1000) SPT selected clusters

  - Optical confirmation (Lindsey Bleem, Matthias Klein)

- DES weak-lensing mass calibration up to z~0.85

- Code validation using mocks

- Blind analysis

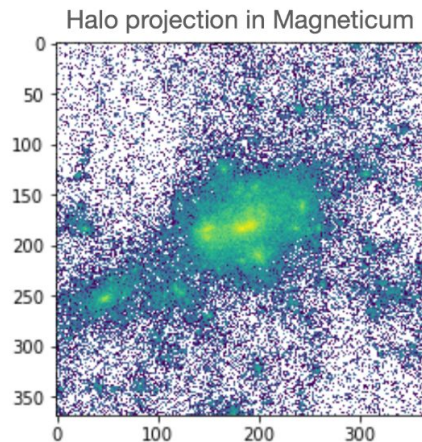(Forecast)

SPT-SZ (Bocquet+19)
SPT (SZ+pol) + DES Y3 (projection)
Planck TTTEEE_lowl_lowE (2018)

Full weak-lensing model
## Following Grandis,Bocquet+21

- Mass modeling (halo profiles, miscentering, uncorrelated LSS)

- Shear modeling (shear and photo-z calibration, cluster member contamination)

- Impact of baryonic effects on halo profiles by comparing Magneticum and Illustris TNG hydrodynamical simulations: 2% difference in mass

▸ Total systematic weak-lensing uncertainty: 3 — 6 % as function of cluster z

Halo projection in Magneticum

SZ cluster forecast: Raghunathan et al. (2107.10250)

SZ cluster forecast: Raghunathan et al. (2107.10250)

MODEL 2: $v(z) = A_v \ln(1+z) + B_v$

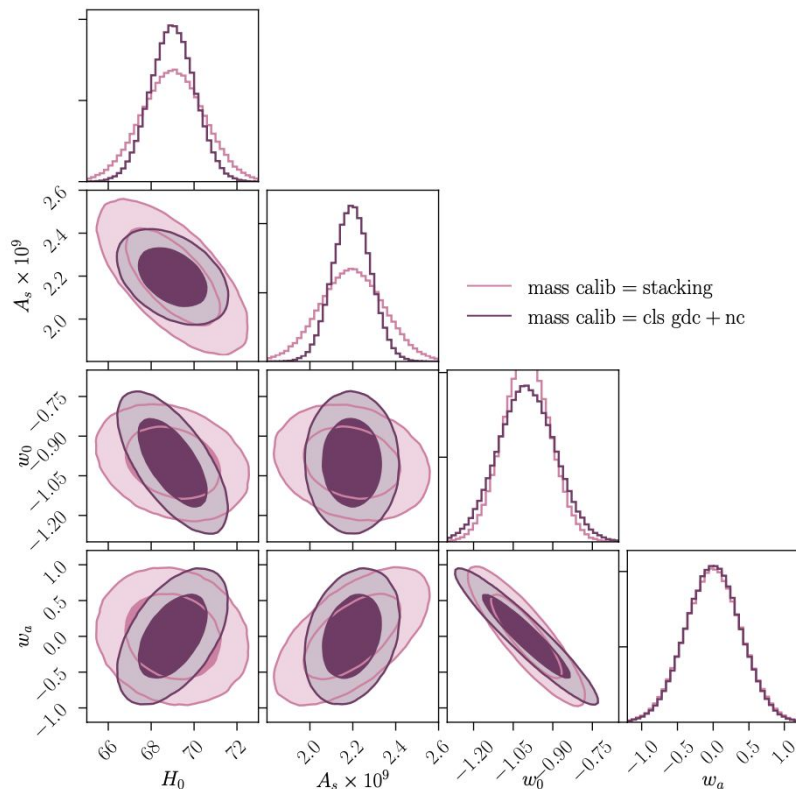MODEL 1: $v(z) = \eta_v(z)(1-b_{HSE})^{\alpha_Y}$
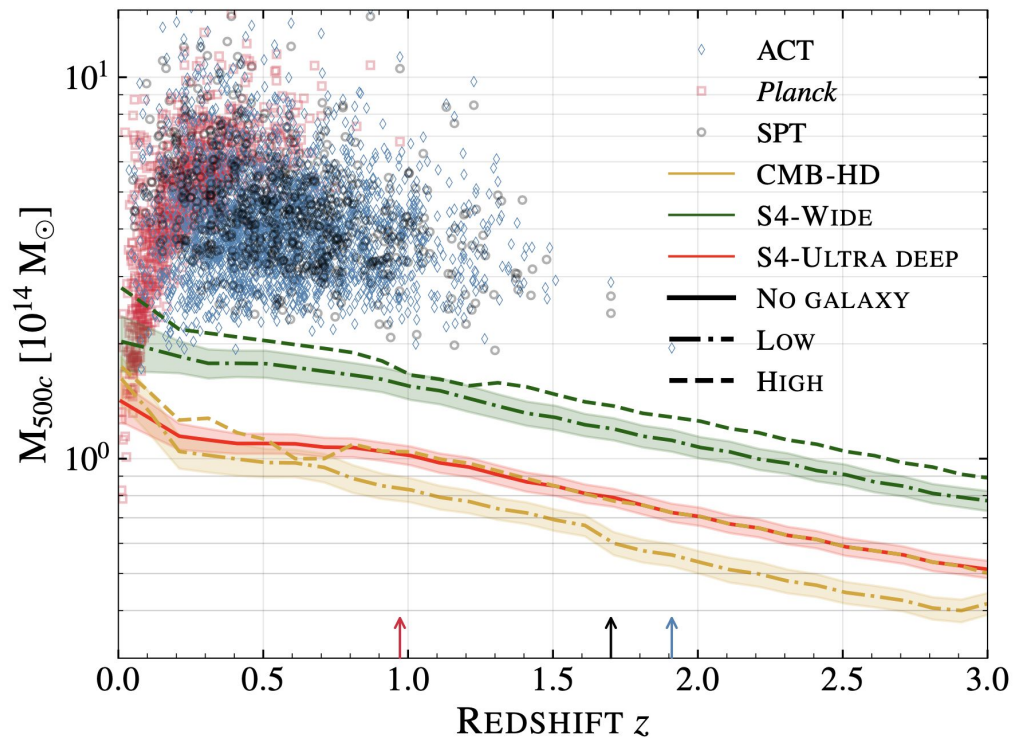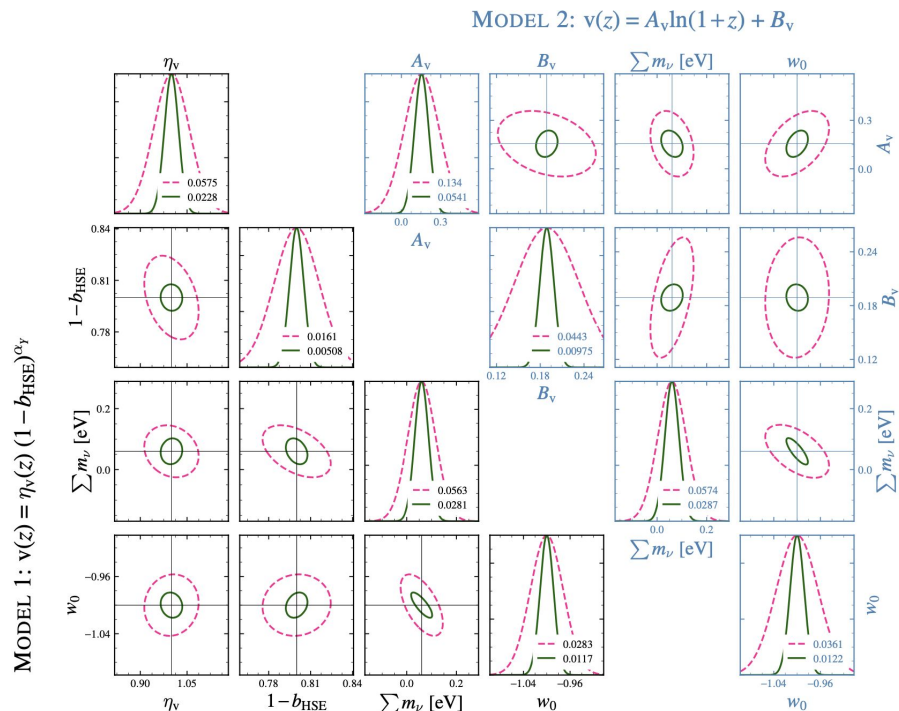
S4-WIDE: — — — NO CMB-CLUSTER LENSING — WITH CMB-CLUSTER LENSING (BASELINE)

15 z BINS: $z \in [0.1, 1.5]$ ($\Delta z = 0.1$) + $(1.5, 3.0)$; PRIOR(S): $\tau_{re} = 0.007$

S4 Wide: 14,000 clusters (10% are z > 2)
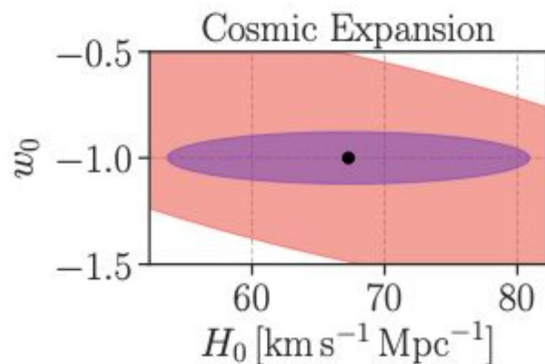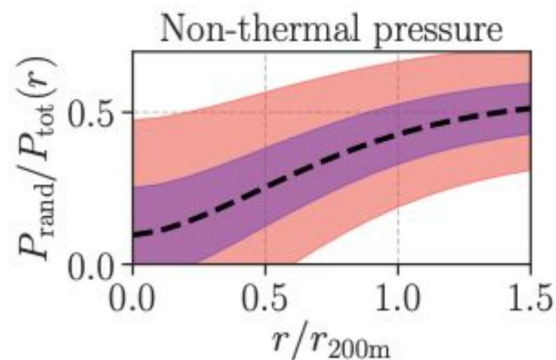CMB lensing mass calibration

Marginalize over virilization models (thermal vs. non-thermal components)

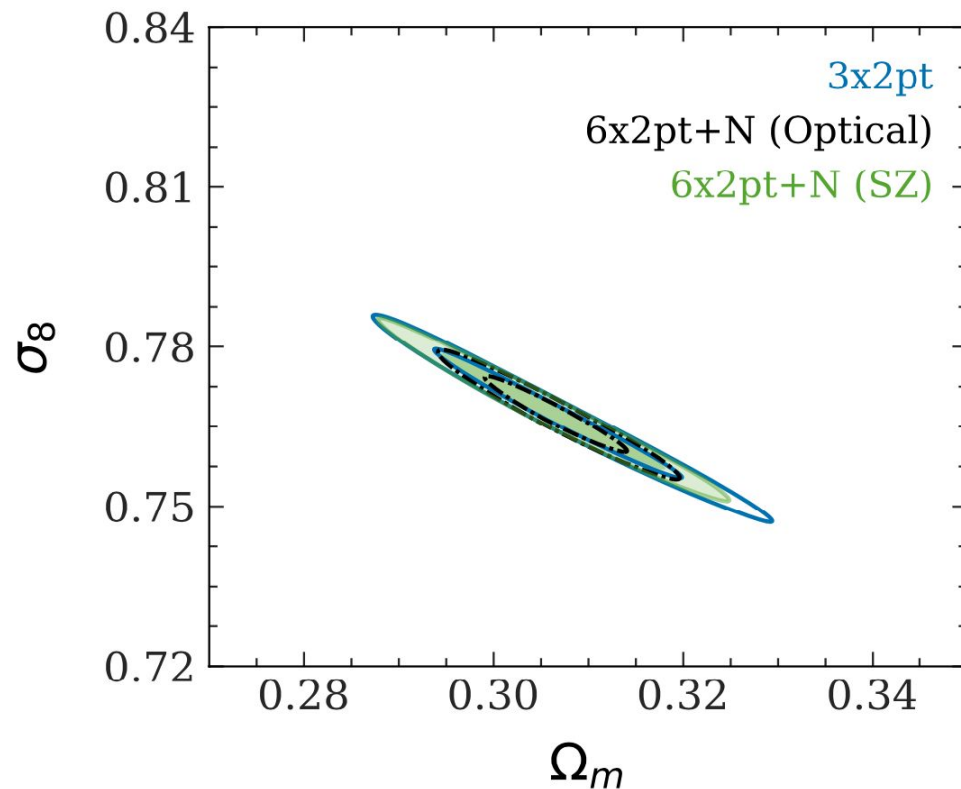# SZ cluster forecast: Nicola et al. (2021)

LSST + Simons Observatory
Cluster counts, cluster lensing, cosmic shear
Marginalized over Y-M relation
Using full C_ell give tighter constraint

CMB-S4+LSST+eROSITA forecast (Daisuke Nagai's talk)
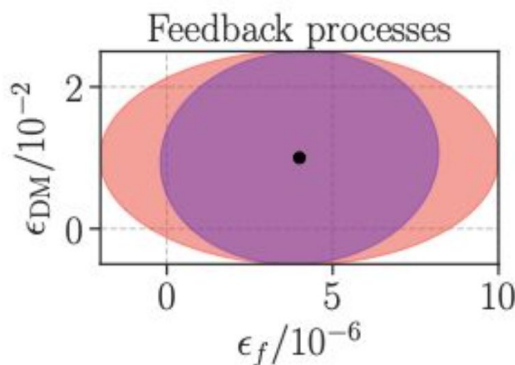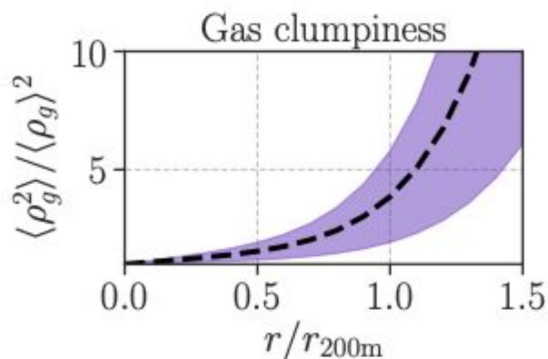
Shirasaki, Lau & Nagai (2020)
Marginalize over ICM parameters

SZ clusters + optical galaxy + lensing (To et al. in prep)

Cluster counts and
6x2pt (cluster x galaxy x shear)
Full MCMC forecast

Optical perspective

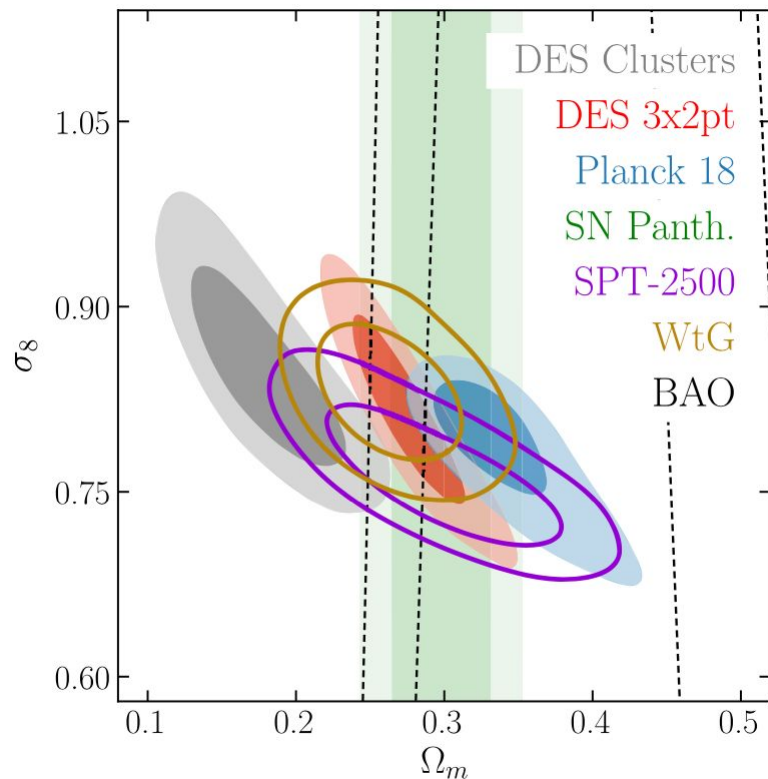# Current status of DES (Tesla Jeltema's talk)

5000 deg^2 footprint has been covered for 900 secs in griz and 450 sec in Y

Status:

- Y1 (1300 sq. deg, 40% depth)
  key results published
  ~ 7,000 clusters

- Y3 (4000 sq. deg, 50% depth)
  papers in progress
  ~ 21,000 clusters

- Y6 (full survey)
  Y6 Gold v2 complete

SPT-ECS
SPTpol 500d
SPT-SZ
DES
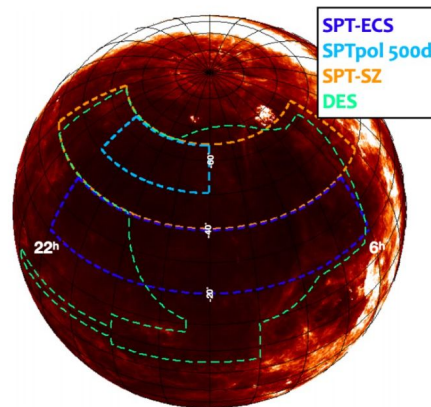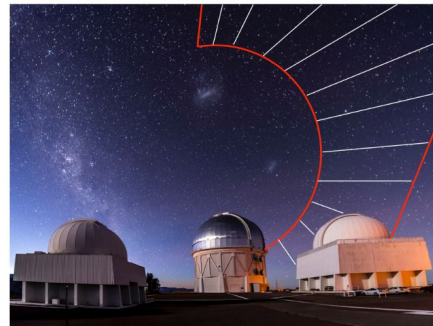
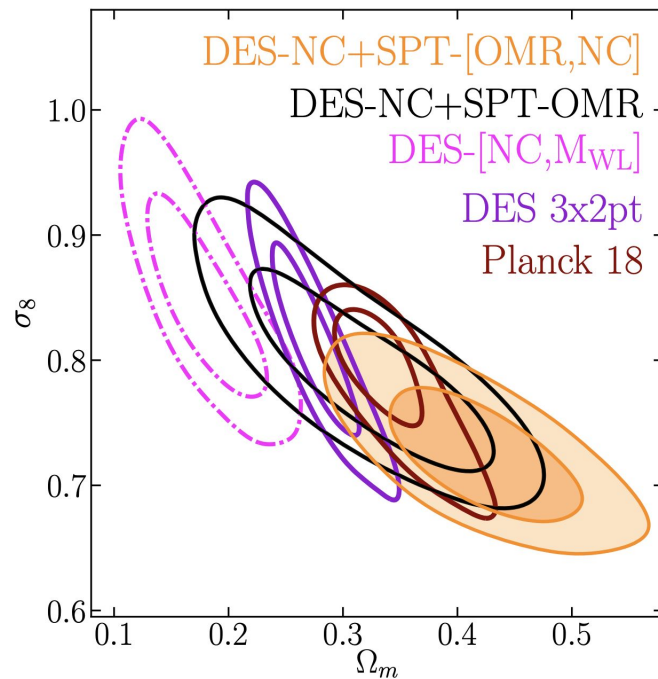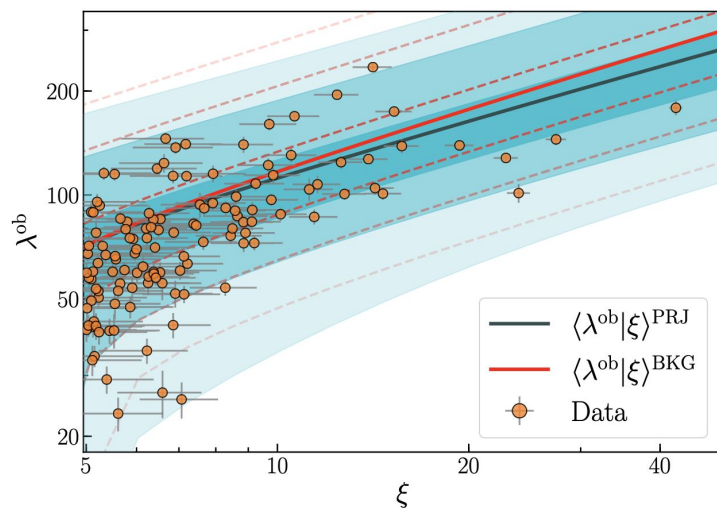# Current status of DES (Tesla Jeltema's talk)
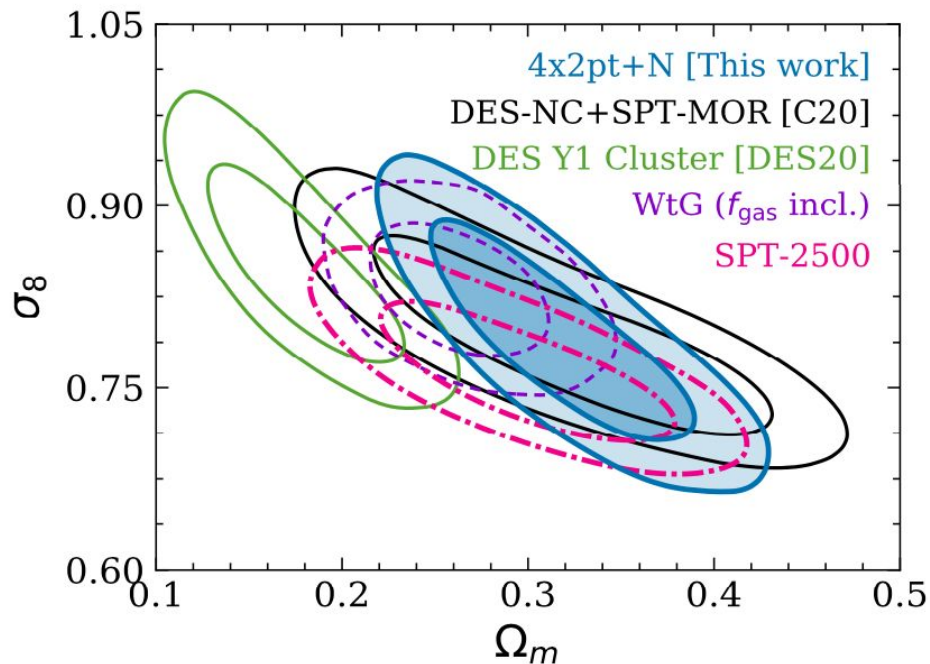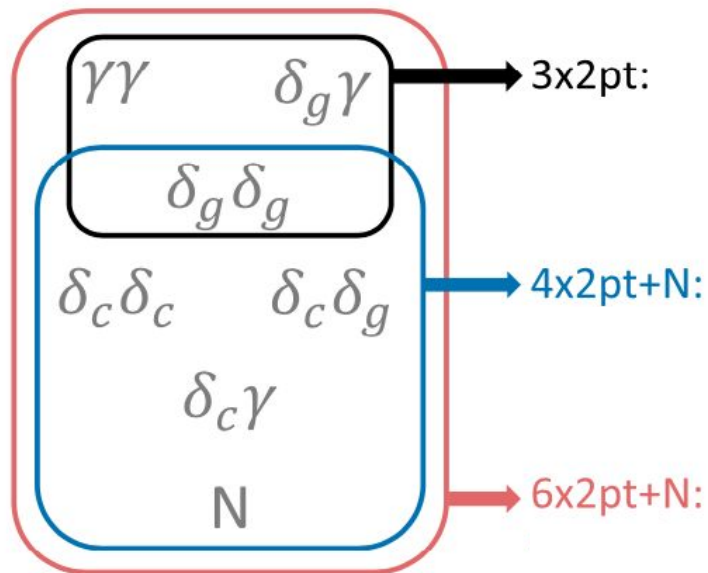

DES Y1
Cluster counts and lensing

Very low Ω_M caused by unexpected low lensing signal for low-richness clusters

DES counts + SPT mass-observable relation (Costanzi et al. 2020)

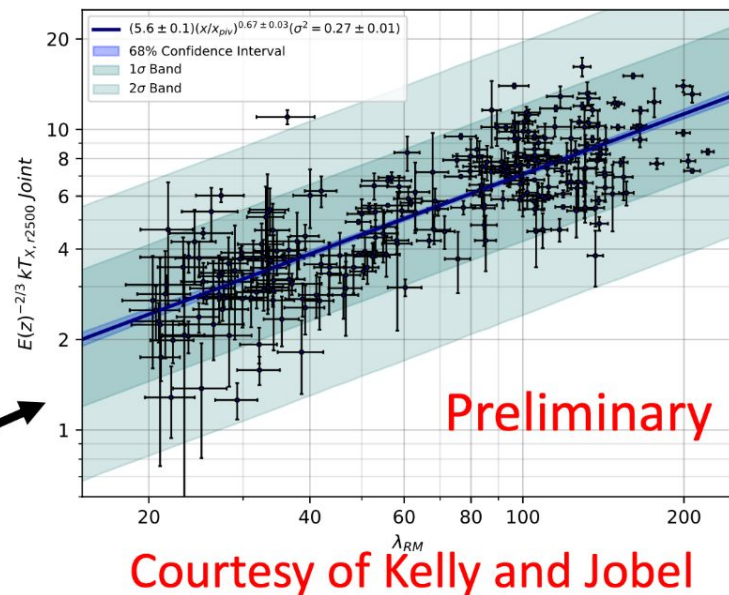# DES cluster counts + cluster x galaxy x shear (large-scale)
To et al. (2021)
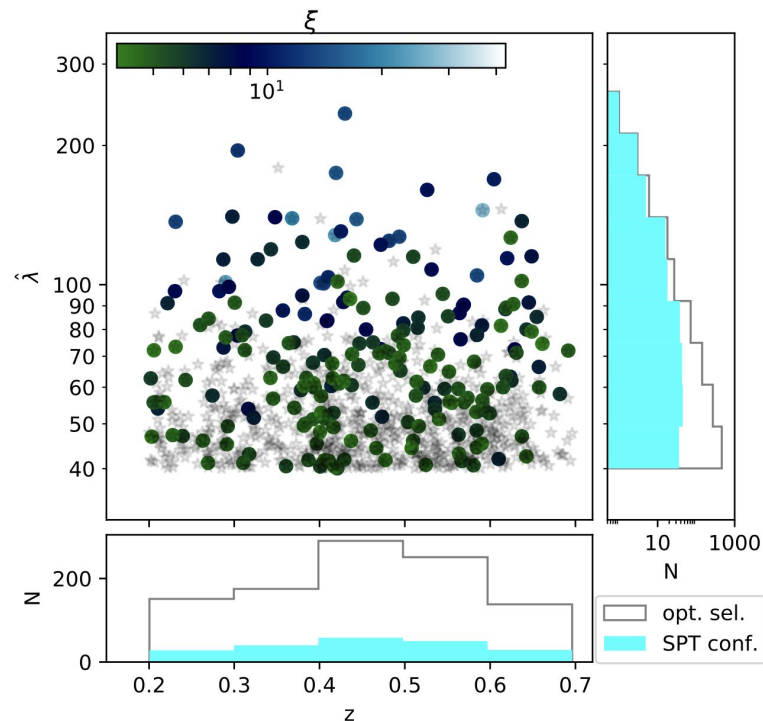
Synergy with SZ & X-ray (Tesla Jeltema's talk)

- X-ray and SZ calibration of
  miscentering and richness scatter

  Zhang+ 2019, Farahi+ 2019, Bleem+ 2020

  $Tx - \lambda$ Chandra + XMM
  for DES Y3 clusters →

Preliminary
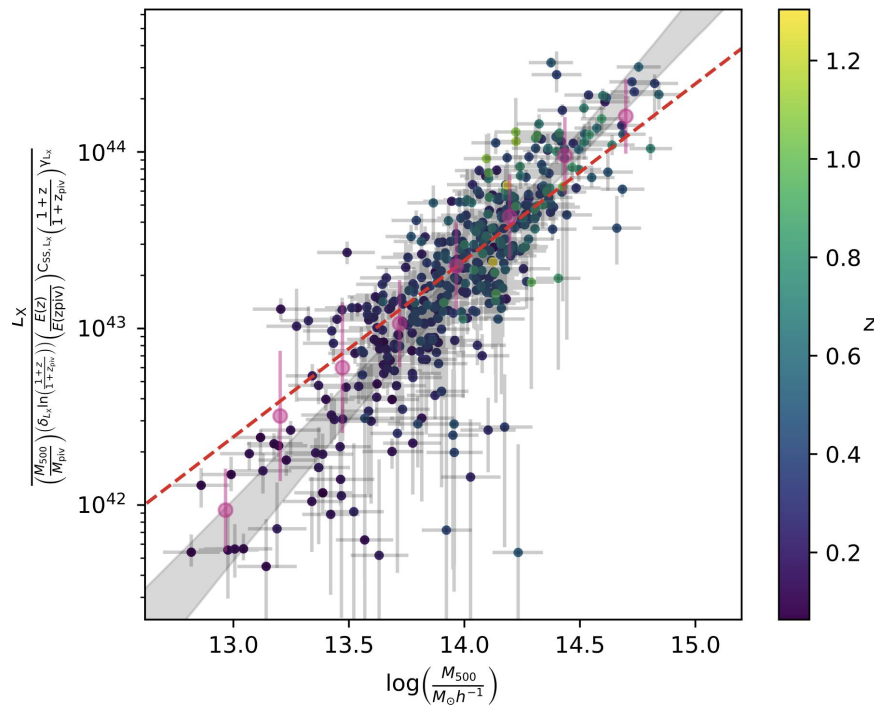
Courtesy of Kelly and Jobel
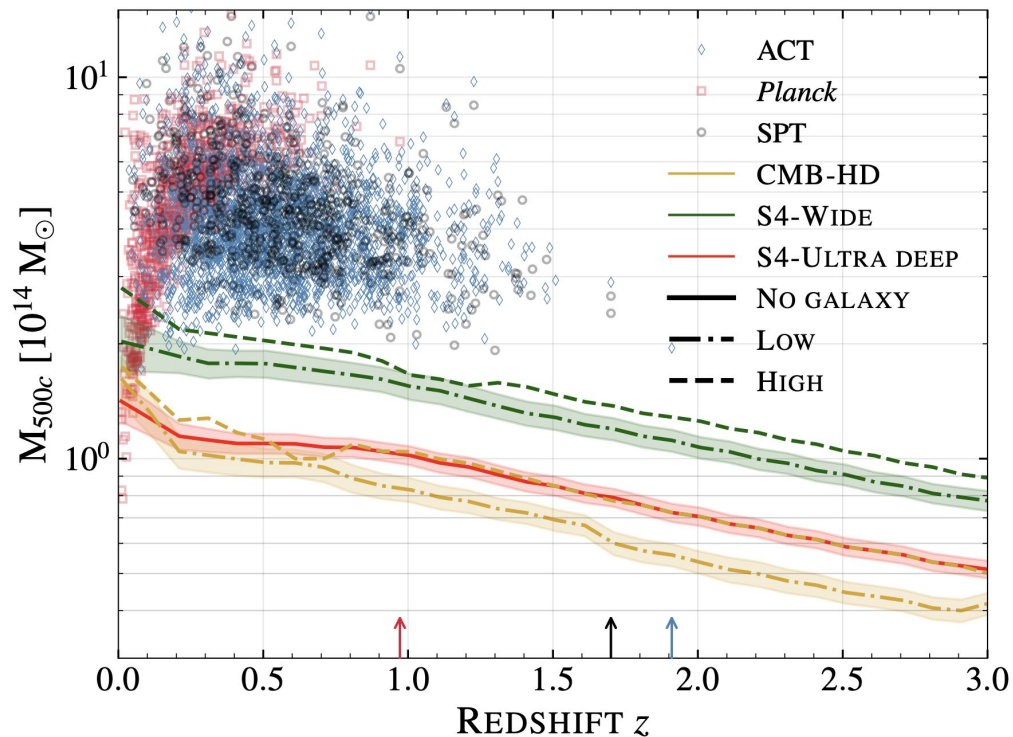
DES-SPT cluster cross validation

Grandis et al. (2101.04984) joint-modeling for SZ scatter, optical scatter, correlation, and contaminant fraction

Need X-ray and SZ for group-size clusters!

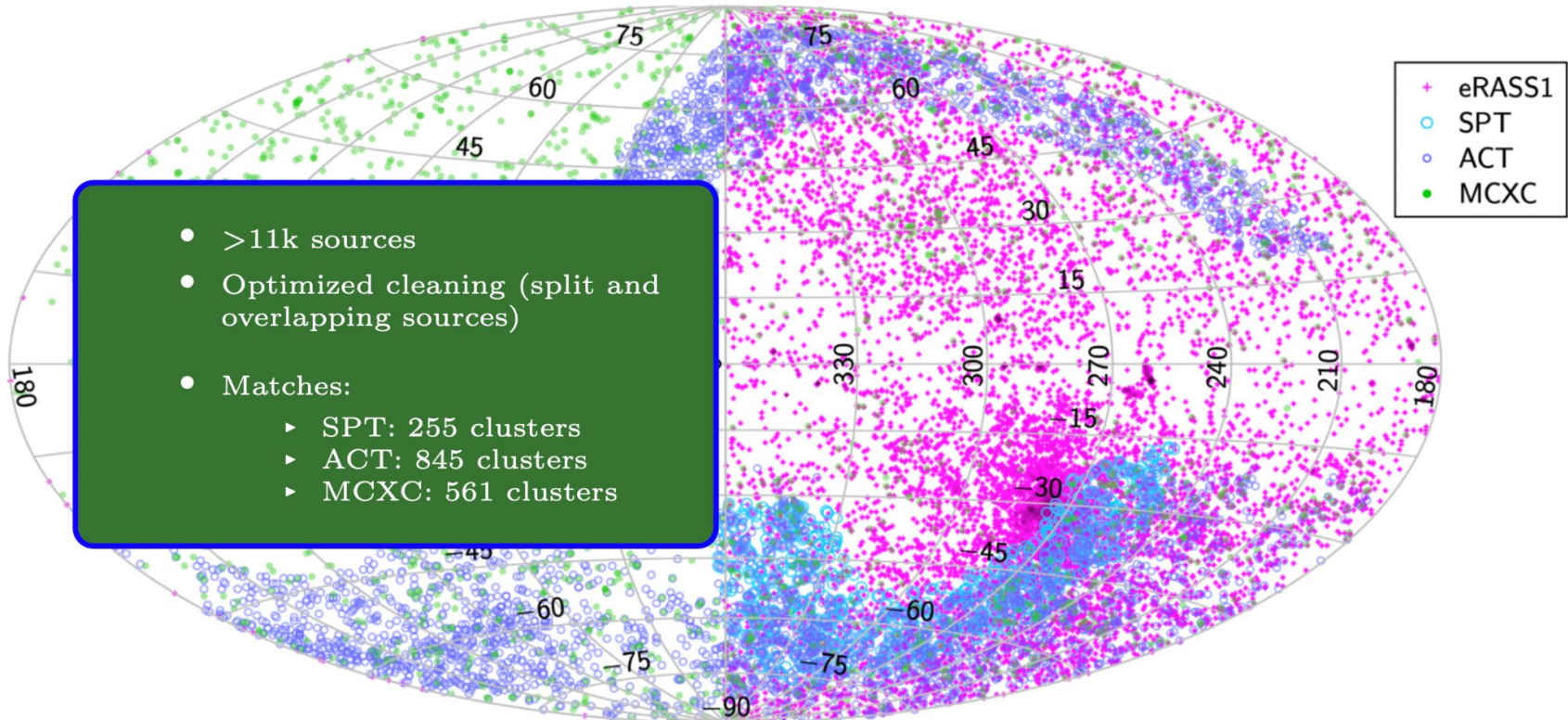eRosita results from Chiu+21
Also see Vittorio Ghirardini's
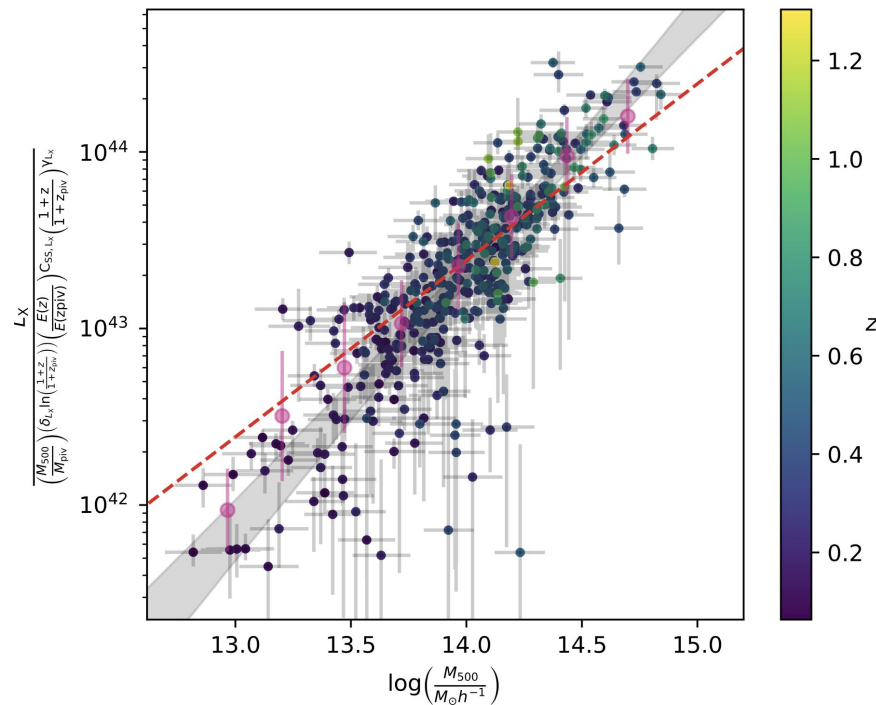talk

Need X-ray and SZ for group-size clusters!

Raghunathan et al. (2021)

X-ray perspective

eRosita status (Vittorio Ghirardini's talk)

- >11k sources
- Optimized cleaning (split and overlapping sources)

- Matches:
  - SPT: 255 clusters
  - ACT: 845 clusters
  - MCXC: 561 clusters

eRosita mass calibration (Vittorio Ghirardini's talk)

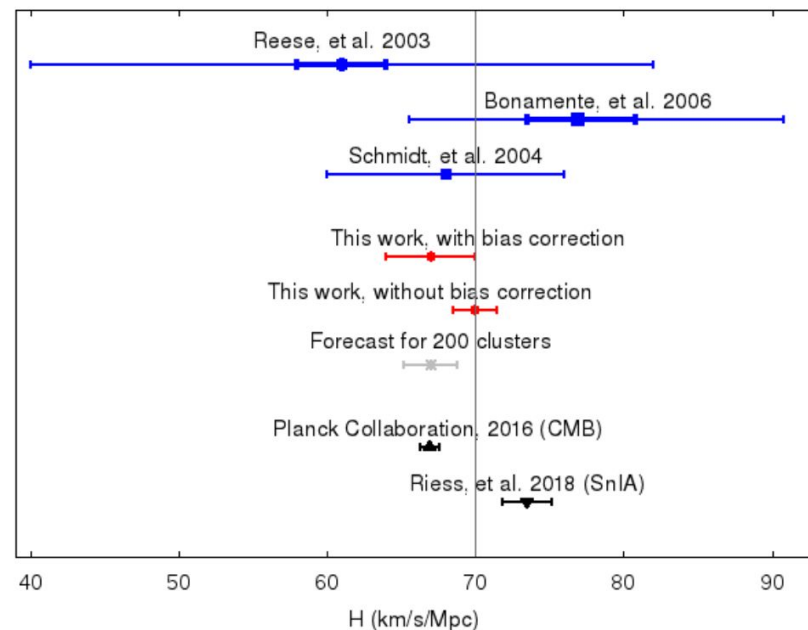eRosita results from Chiu+21

H_0 from combining SZ and X-ray (Vittorio Ghirardini's talk)

$$S_X \propto \int n_e^2 \Lambda_{ee} dl = \int n_e^2 \Lambda_{ee} D_A d\theta$$

$$\Delta T_{CMB} \propto \int n_e T_e dl = \int n_e T_e D_A d\theta$$
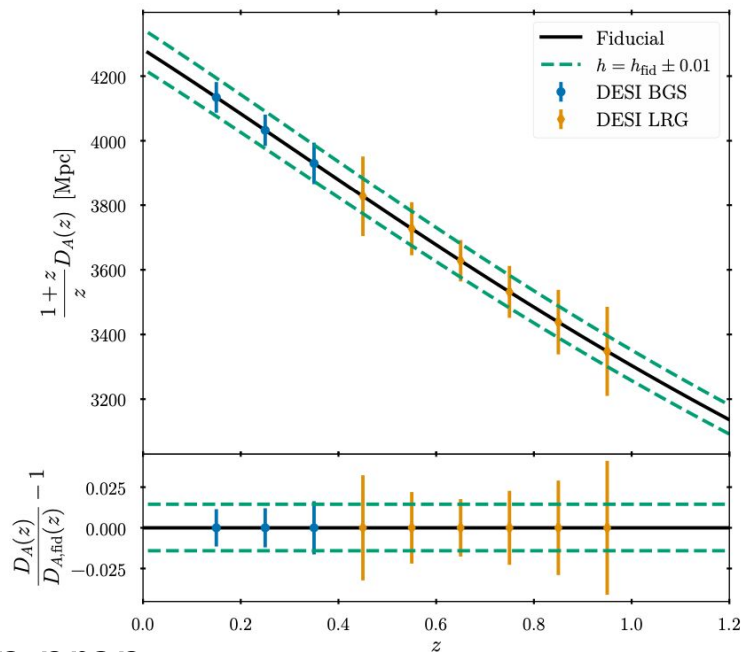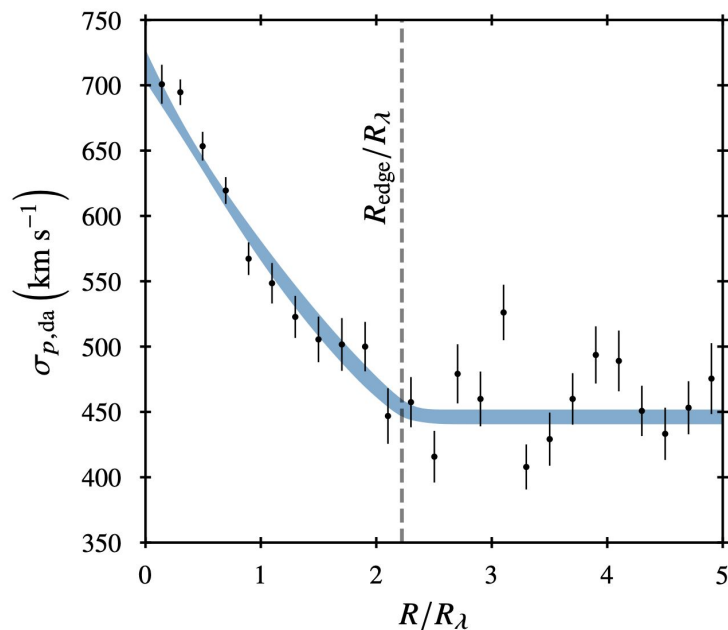
$$S_x / \Delta T_{CMB} \sim D_A$$
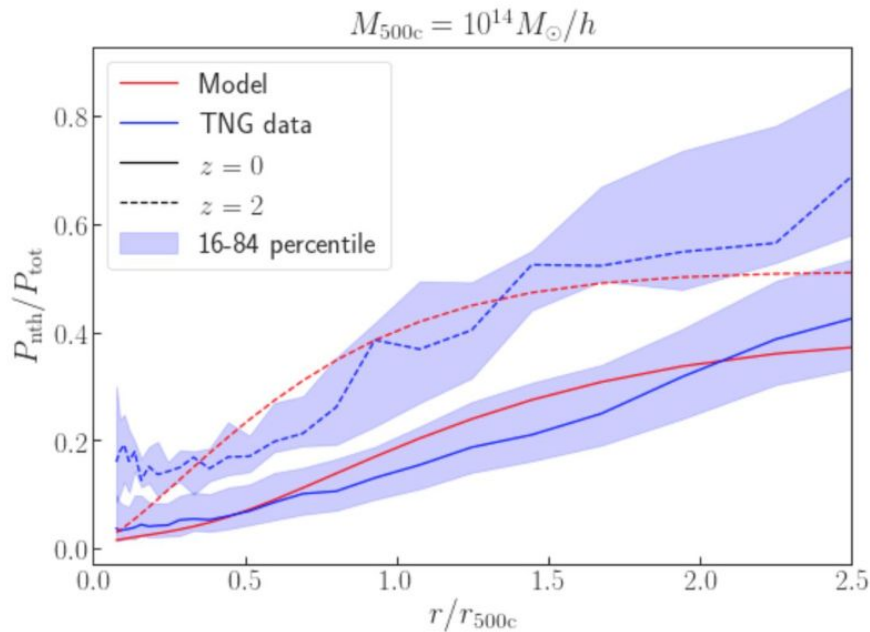
Bonamente 06

Kozmanyan 2019

H$_0$ from cluster edge
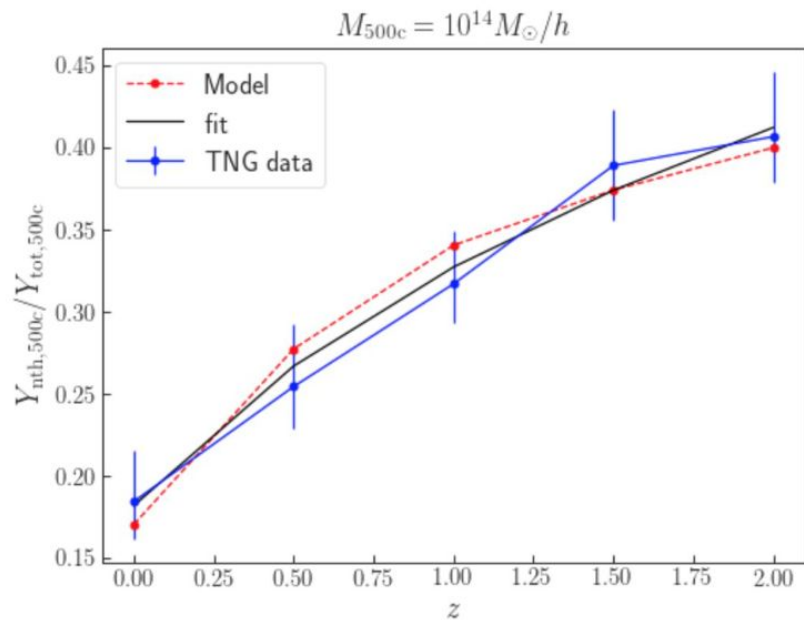
Velocity dispersion profile => physical cluster size.   Forecast for DESI

Wagoner et al. (2010.11324), Aung in prep

Part 2: Galaxy cluster astrophysics

Virialization mechanism (Han Aung's talk)

Non-thermal pressure caused by accretion and AGN feedback

Constraining the virialization mechanism for high-z clusters

v = 1 - Y_{nth}/Y_{tot} (thermal vs. nonthermal)

$$Y_{SZ_{500c}} = v(z) \; Y_* \left[\frac{h}{0.7} \right]^{-2+\alpha} \left[\frac{M_{500c}}{M_*} \right]^{\alpha} \left[\frac{D_A(z)}{100\text{Mpc}} \right]^{-2} E^{2/3}(z)$$
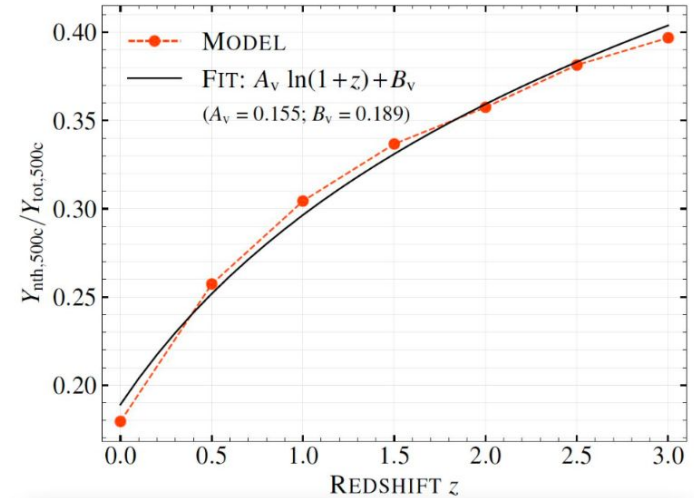
Planck Y_{SZ}- M scaling relation with a constant HSE bias.

Model 1: $v(z) = \eta_v(z) \, (1 - b_{HSE})^{\alpha}$
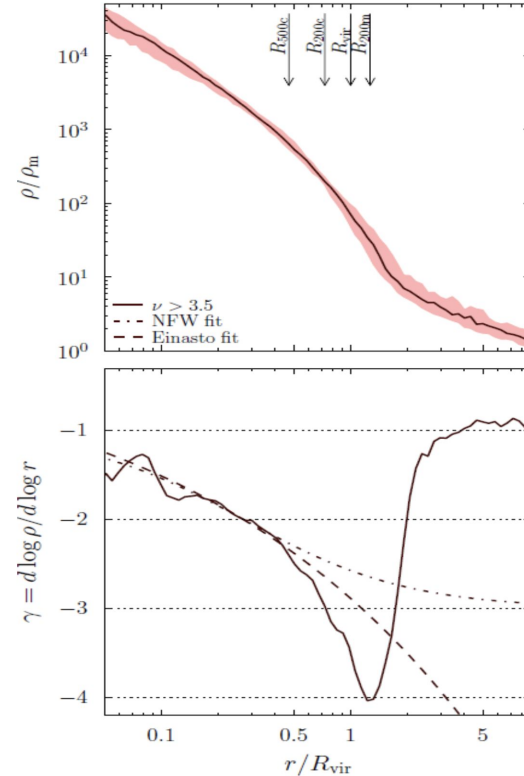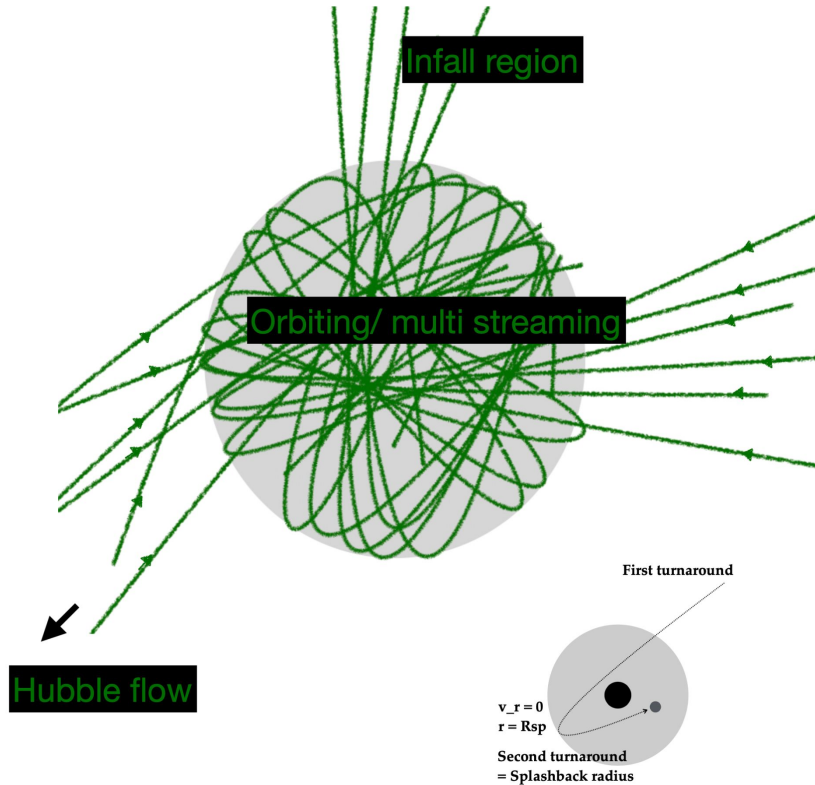
Simple linear scaling.

Model 2: $v(z) = A_v \ln(1 + z) + B_v$

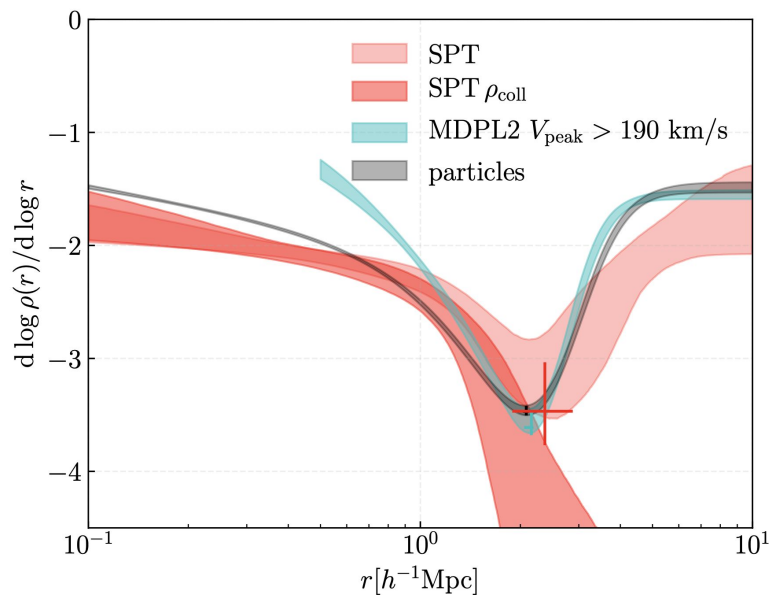*Analytic model tested using simulations.*

Srini Raghunathan's talk

Splashback radius (Susmita Adhikari's talk)

Infall region

Orbiting/ multi streaming

Hubble flow

First turnaround

v_r = 0
r = Rsp

Second turnaround
= Splashback radius

ρ/ρ_{m}

R_{500c}
R_{200c}
R_{vir}
R_{200m}

$\nu > 3.5$
NFW fit
Einasto fit

$\gamma = d\log\rho/d\log r$

r/R_{vir}

Dimmer & Kravtsov 2014

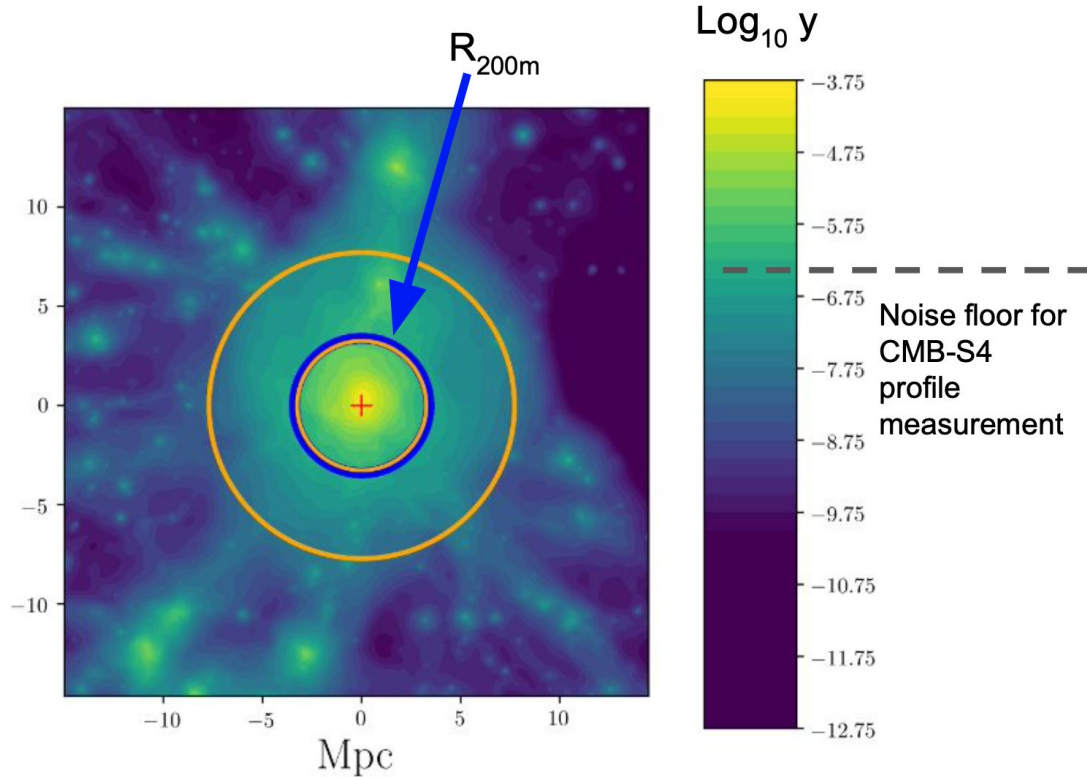# Splashback radius: mystery solved with SZ selection

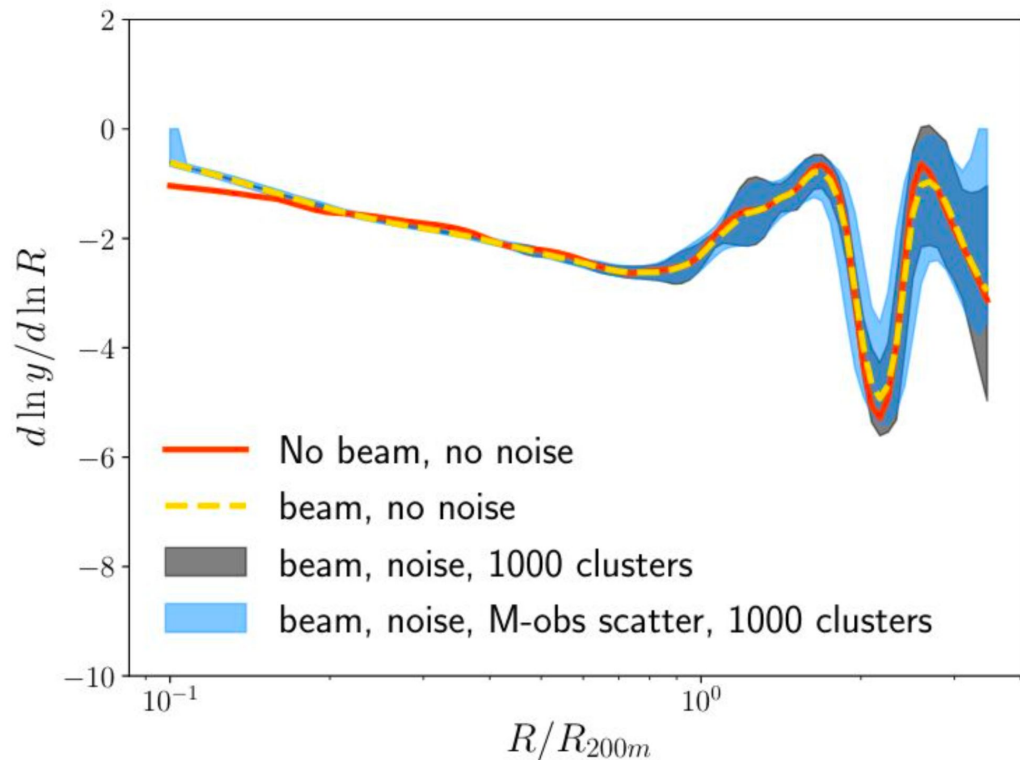Optical clusters: splashback radius smaller than simulations

SZ clusters: splashback consistent with simulations

Shin et al. (1811.06081) & Susmita Adhikari's talk

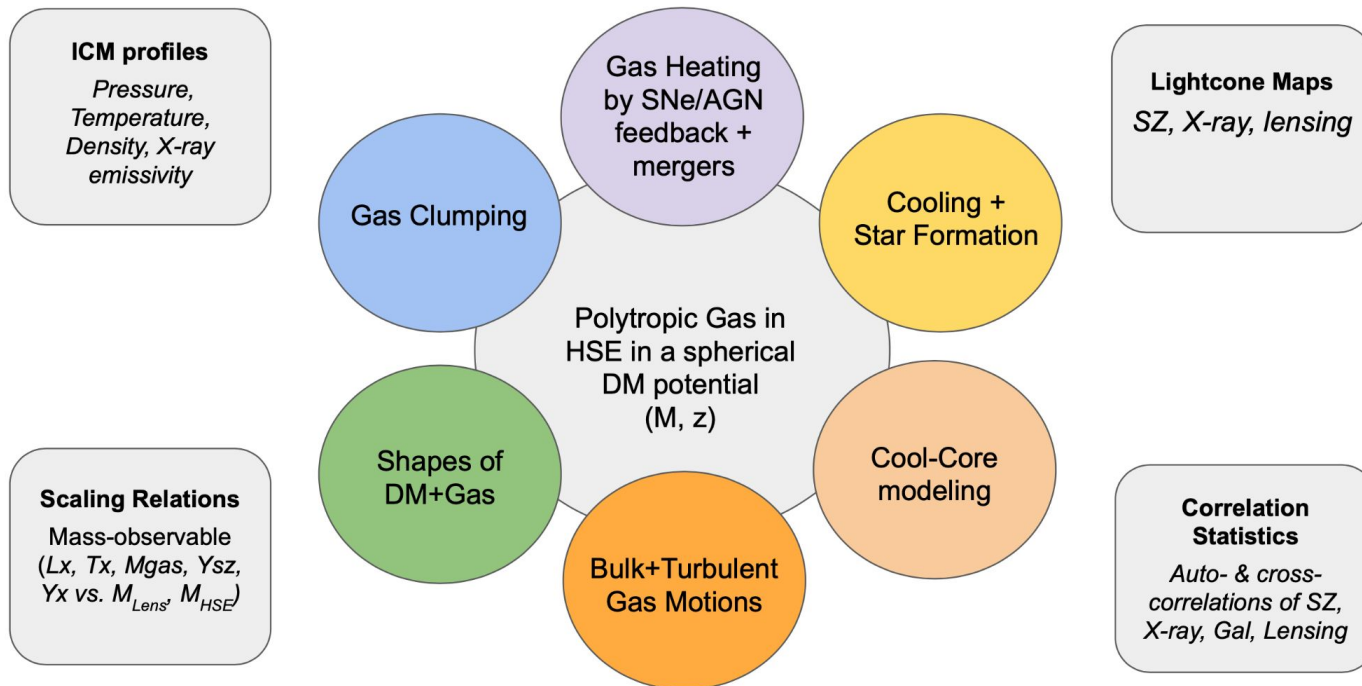# Probing cluster edge with CMB-S4 (Eric Baxter's talk)
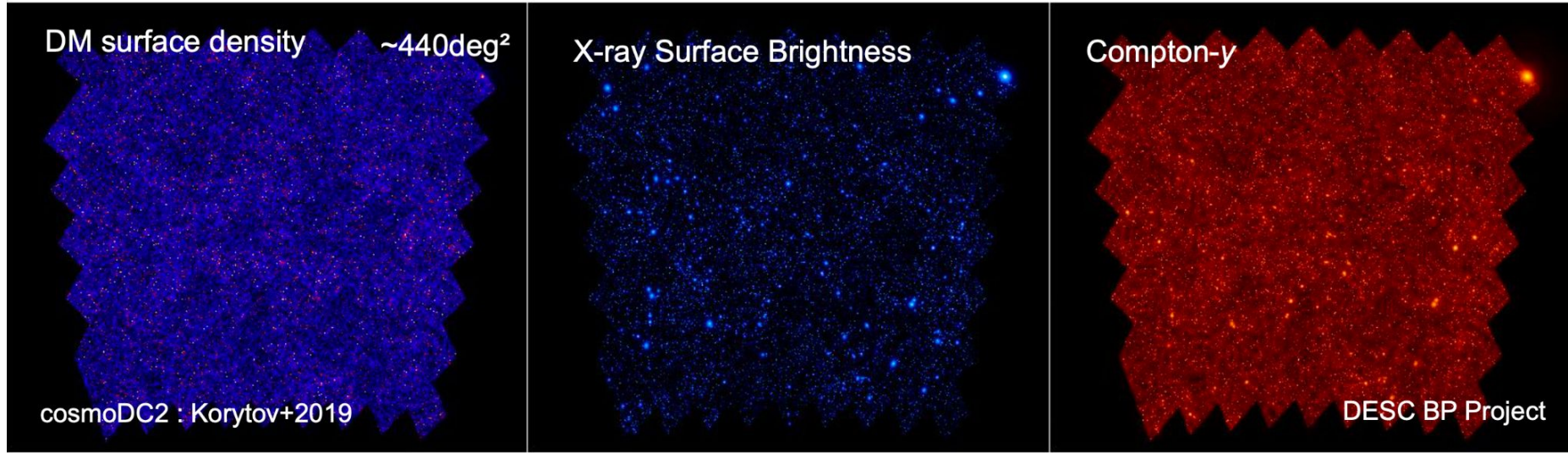
Shock should be detectable in stacked CMB-S4 profiles

(Eric Baxter's talk)
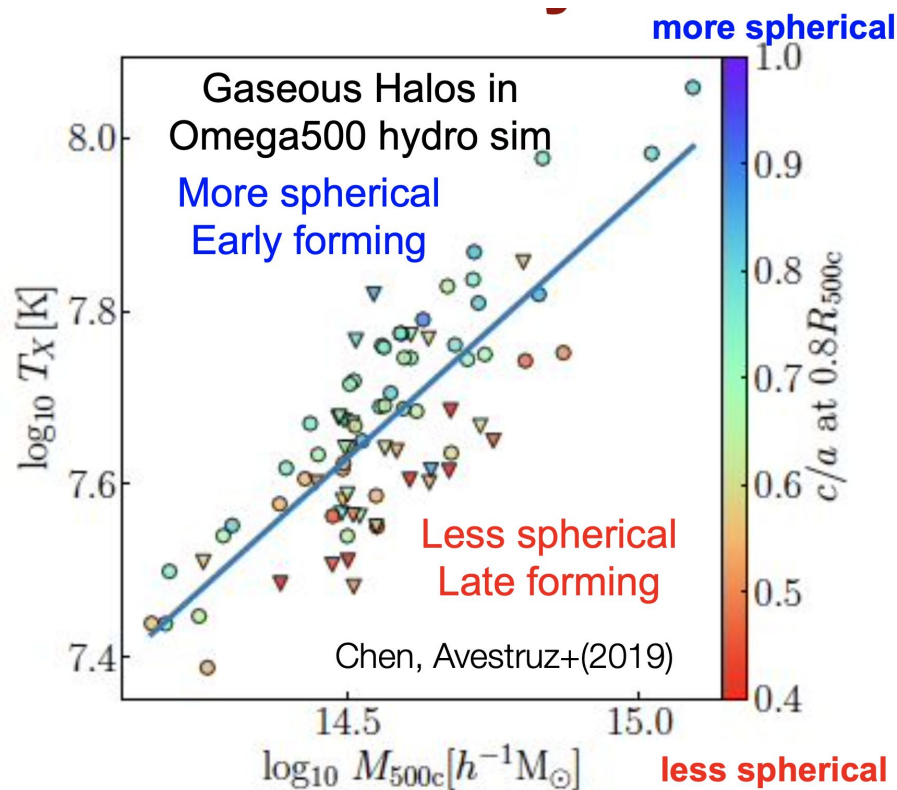
Baryon Pasting (Daisuke Nagai, Erwin Lau, Han Aung)

BP Gas Model

Multi-wavelength maps (Daisuke Nagai's talk)

DM surface density ~440deg²
cosmoDC2 : Korytov+2019

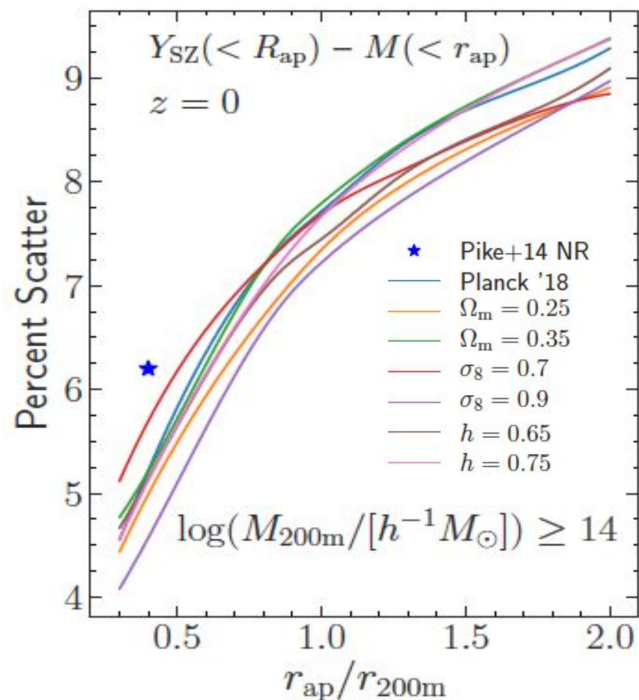X-ray Surface Brightness

Compton-y
DESC BP Project

Modeling the scatter due to gas shape/formation history
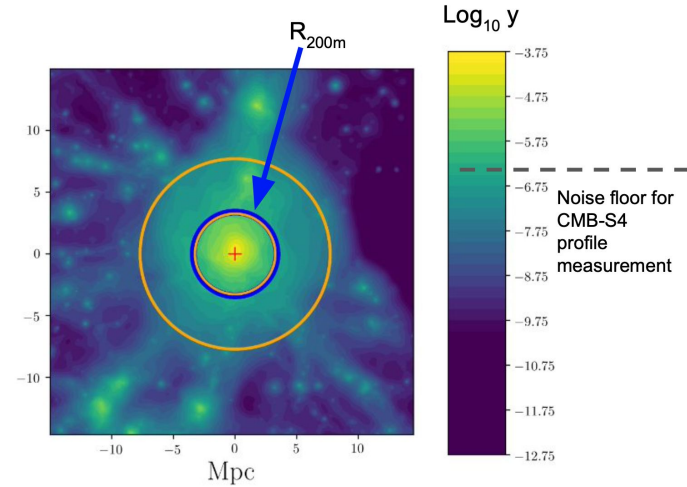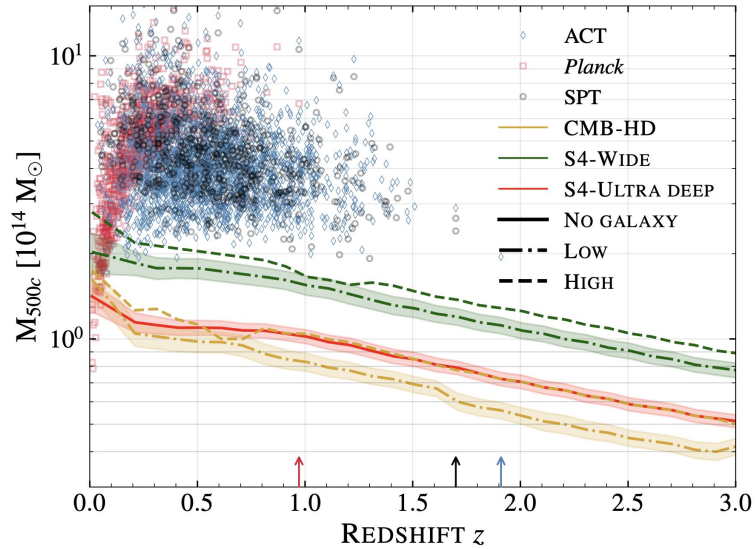

Erwin Lau and Han Aung's talk

Modeling the scatter due to non-thermal pressure

Modeling scatter in the Ysz-M relation generated by bulk and turbulent gas motions in cluster outskirts (Green+20)

Erwin Lau and Han Aung's talk

Summary

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