CMB-S4 Clusters
Science Requirements Messaging

CMB-S4 April 2023 Collaboration Meeting

6 April, 2023

CMB-S4 Cluster Science

PBDR Chapter 1 - Science Goals to Science Requirements

Goal 1: Test models of inflation by measuring or putting upper limits on r, the ratio of tensor fluctuations to scalar fluctuations.

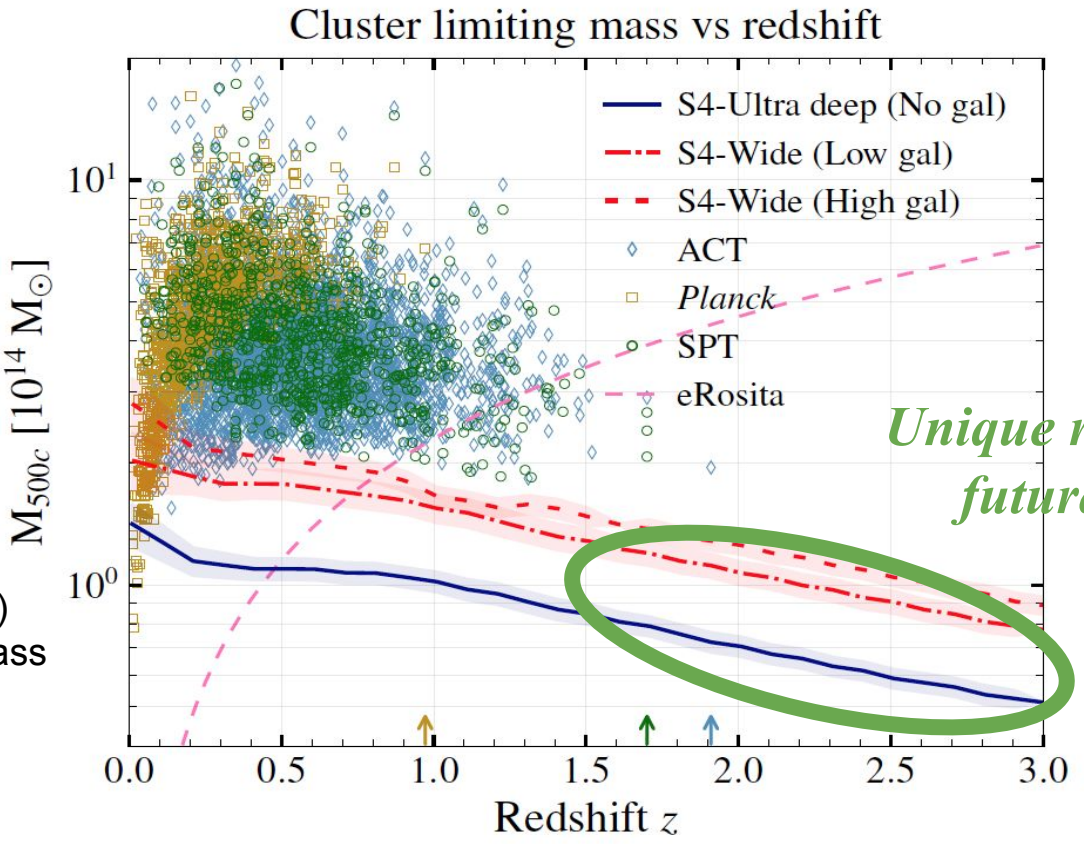
Goal 2: Determine the role of light relic particles in fundamental physics, and in the structure and evolution of the Universe.

Goal 3: Measure the emergence of galaxy clusters as we know them today. Quantify the formation and evolution of the clusters and the intracluster medium during the crucial early period of galaxy formation.

Goal 4: Explore the millimeter-wave transient sky. Measure the rate of mm-transients for the first time. Use the rate of mm-wave GRBs to constrain GRB mechanisms. Provide mm-wave variability and polarization measurements for stars and active galactic nuclei.

Add: cosmic ecosystem - galaxy/gas interactions - around “cosmic noon”

CMB-S4 Cluster Sensitivity



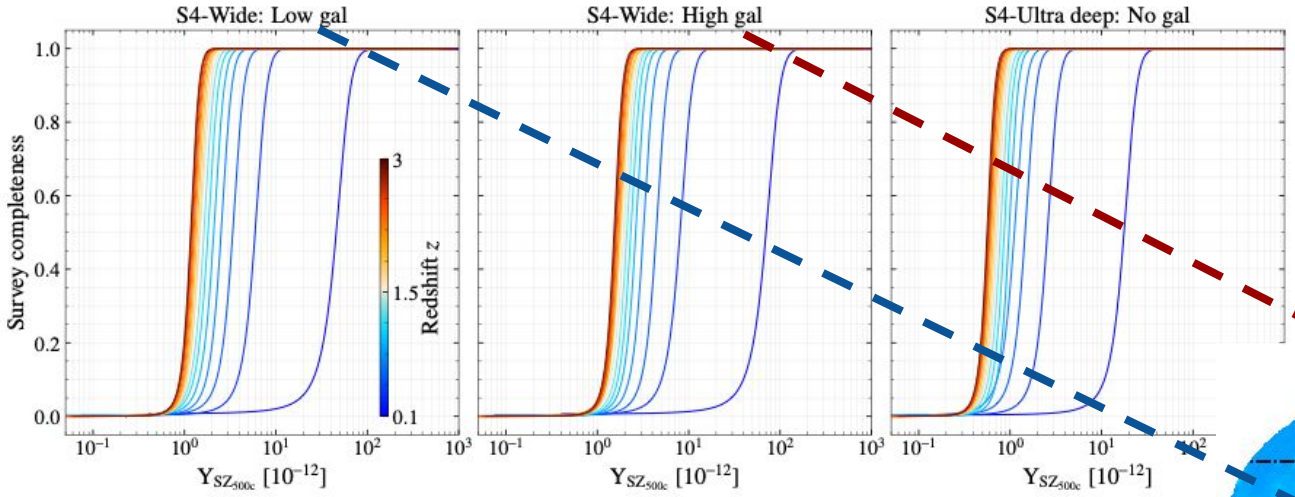
Unique region probed by future SZ surveys.

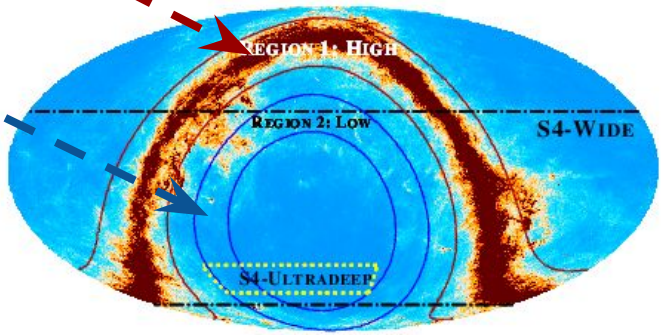
Use $Y^{true}SZ$ (M500c, z) relation to translate mass target into true YSZ target values.

Key objects: galaxy groups around cosmic noon.

CMB-S4 PBDR (in prep.)

CMB-S4 Cluster Survey Completeness



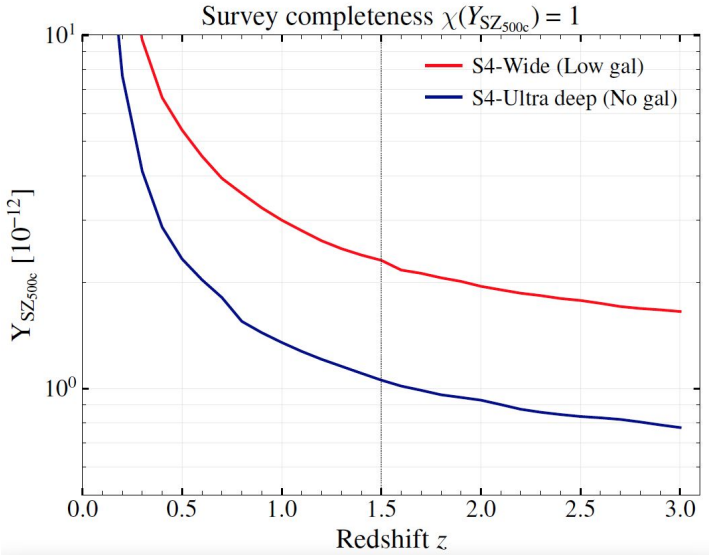


CMB-S4 PBDR (in prep.)

$$\int_{q\sigma_{Y_{SZ}}}^{\infty} dY_{SZ}\; P(Y_{SZ}\,|\,Y_{SZ}^{true}) = 0.5\left(1+\mathrm{erf}\left[\frac{Y_{SZ}^{true}-q\sigma_{Y_{SZ}}}{\sqrt{2}\sigma_{Y_{SZ}}}\right]\right)$$

Planck collaboration 2014 XX, arXiv: 1303.5080
Alonso, Louis, Bull et al. 2016, arXiv: 1604.01382

CMB-S4 Cluster Survey Completeness

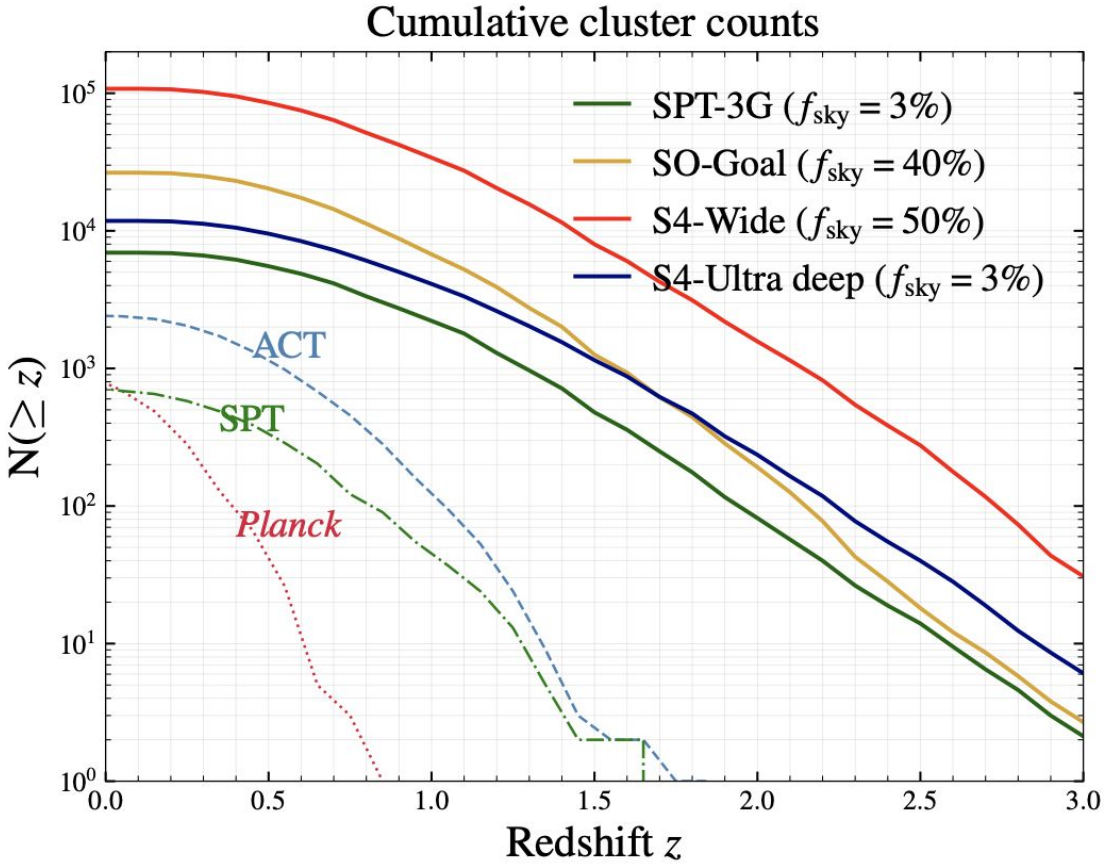


CMB-S4 PBDR (in prep.)

Science requirement:

CMB-S4 shall detect (at 5σ) all galaxy clusters with an integrated Compton $Y_{SZ} \geq 2x10^{-12}$ *sr or* $2.4\ x10^{-5}$ *arcmin*^{2} ***at*** $z \geq 1.5$ ***over the large area survey footprint*** ($f_{sky} = 50\%$). *Furthermore, it shall detect (at 5σ) all galaxy clusters with an integrated Compton* $Y_{SZ} \geq 10^{-12}$ *sr or* $1.2\ x10^{-5}$ *arcmin*^{2} ***at*** $z \geq 1.5$ ***over the de-lensing survey footprint*** ($f_{sky} = 3\%$).

CMB-S4 Cluster yield with SPT and SO



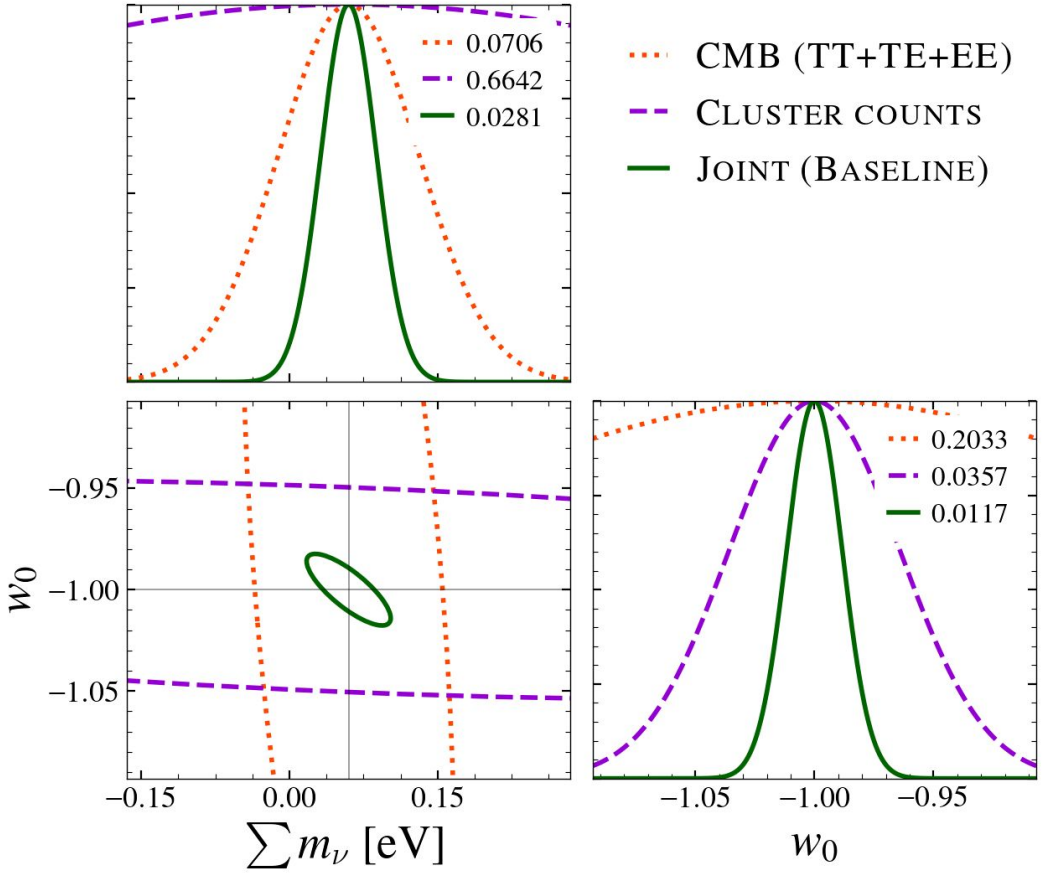
CMB-cluster lensing Mass Estimates

CMB lensing mass calibration: **Average mass of the sample**

Survey	f_{sky}	Cluster counts		Median mass M500c [10^{14} Msol]		Lensing mass error M500c [10^{14} Msol]	
		Total	z>=2	Total	z>=2	Total	z>=2
S4-Wide	0.5	75701	992	1.6	0.8	0.02	0.31
S4-Ultra deep	0.03	13699	341	1.0	0.6	0.05	0.55

- Foregrounds (tSZ/kSZ) in temperature-based lensing reconstruction are not an issue because we have multiple fancy estimators now.
  - Inpainted-gradient QE: **Raghunathan, Holder, Bartlett et al. 2019, JCAP (arXiv: 1904.13392)**.
- Polarised CMB-cluster lensing is also detected with SPTpolxDES: **Raghunathan, Patil, Baxter et al. 2019, PRL (arXiv: 1907.08605)**.
- S4-Ultra deep lensing is dominated by polarisation.
- *Combing T and P, we can measure the average mass of z≥2 clusters at 18-20 per cent level with S4-Wide or S4-Ultra deep.*

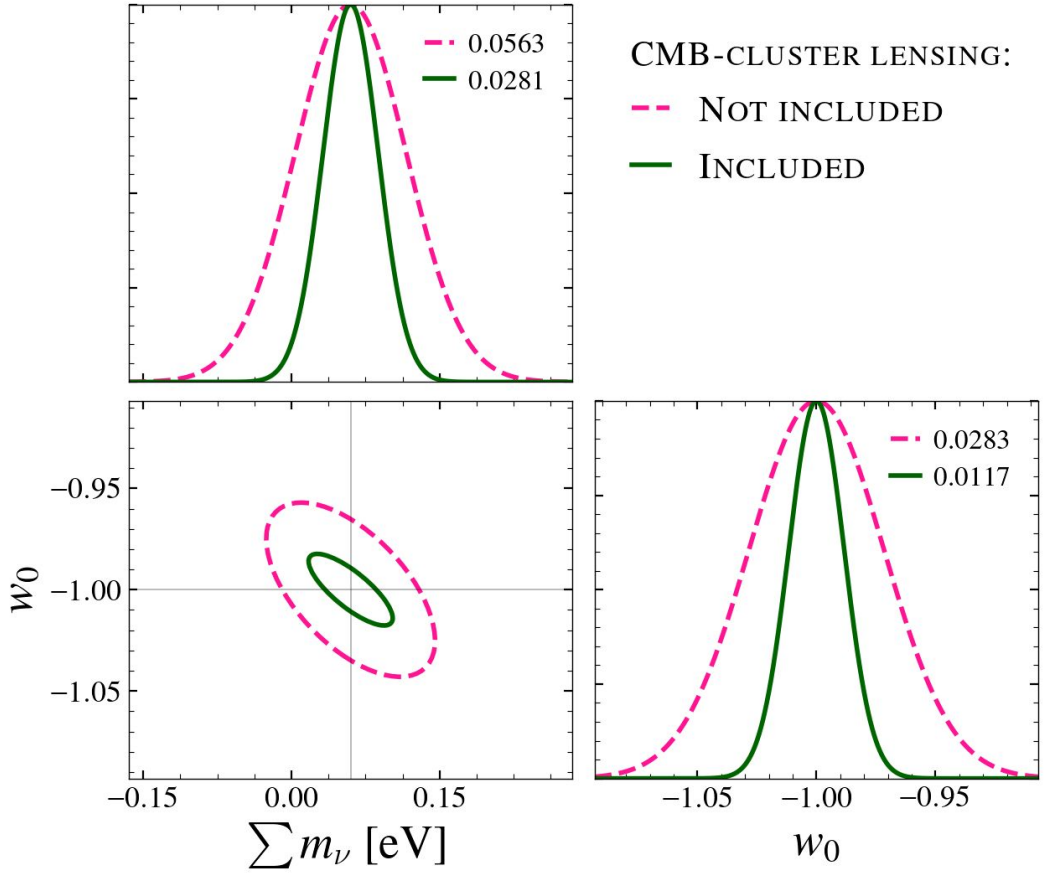
Clusters: Probes of dark energy and neutrino masses



CMB-S4 Wide survey:

- The degeneracy directions between dark energy and neutrino masses are different for **primary CMB power spectra** and **cluster abundance** measurements.
- ***Joint constraints are remarkable for CMB-S4.***
- **Mass calibration:** Performed using CMB lensing. Optical weak-lensing measurements can add further information and help remove systematics.

Importance of CMB-cluster lensing



CMB-S4 Wide survey:

- CMB-lensing based mass calibration is important.
- Excluding CMB-lensing degrades constraints by more than x2.
- *Optical weak lensing measurements from Rubin Observatory can add more constraining power.*

CMB-S4 Cluster yield with multiple SO configurations