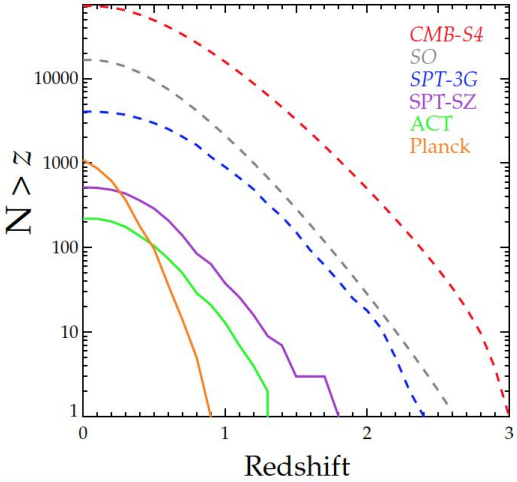
Cosmology and Astrophysics with Galaxy Clusters from CMB-S4

Session organisers: Hao-Yi (Heidi) Wu and Srinivasan Raghunathan



CMB-S4 DSR, arXiv:1907.04473

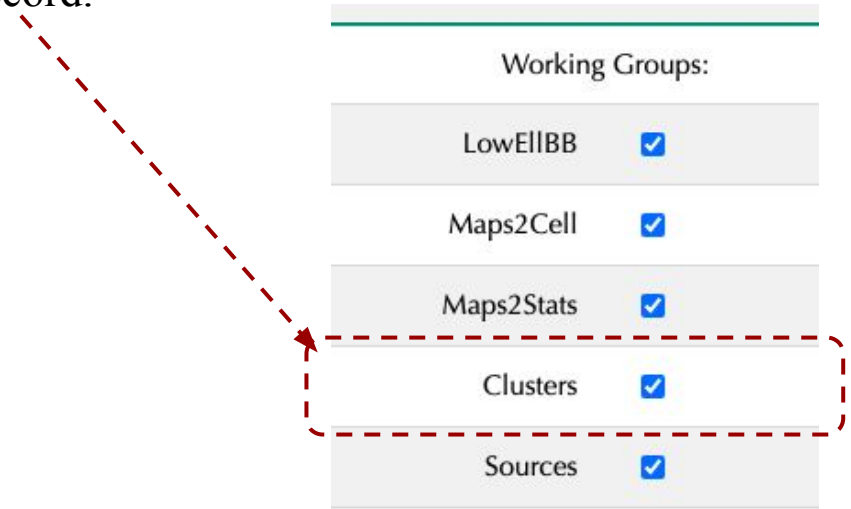
CMB-S4 summer collaboration meeting
12 August 2021

CMB-S4

New CMB-S4 clusters analysis working group

Jim Bartlett
(APC - U. of Paris)

- Co-coordinating along with Prof. Jim Bartlett.
- Goals: Clusters along with all possible SZ science including cross-correlations.
- **Next call: Aug 25, 2021 at 9 a.m. Pacific.**
- Please sign-up, if not done so already.
  - https://cmb-s4.org/ → https://cmb-s4.org/team-page/ → Your membership record.



Past parallel sessions

Secondary CMB anisotropies and their correlations with LSS:

ISW, lensing, kSZ, moving-lens (Birkinshaw-Gull), **tSZ**.

- Synergies of Large Scale Structure Surveys with CMB-S4 (Tuesday).
  - Andrina Nicola and Emmanuel (Manu) Schaan.
- Backlighting the Baryons with CMB-S4 (Wednesday).
  - Alexie Leauthaud and Simone Ferraro.

Thermal Sunyaev-Zeldovich (SZ) effect

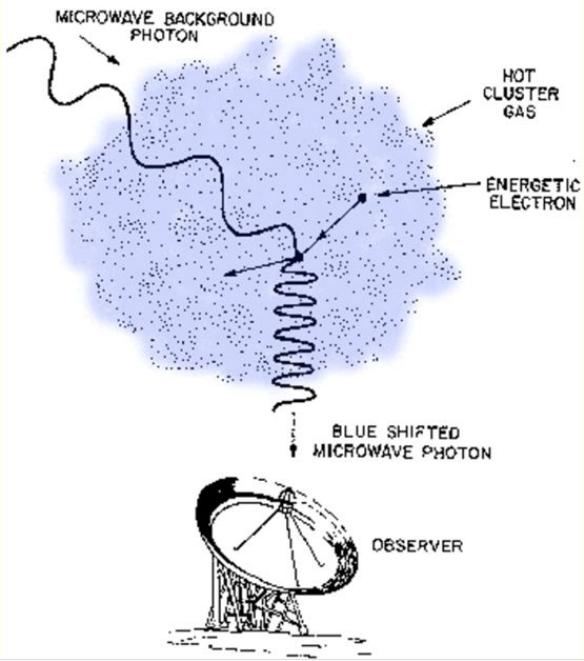
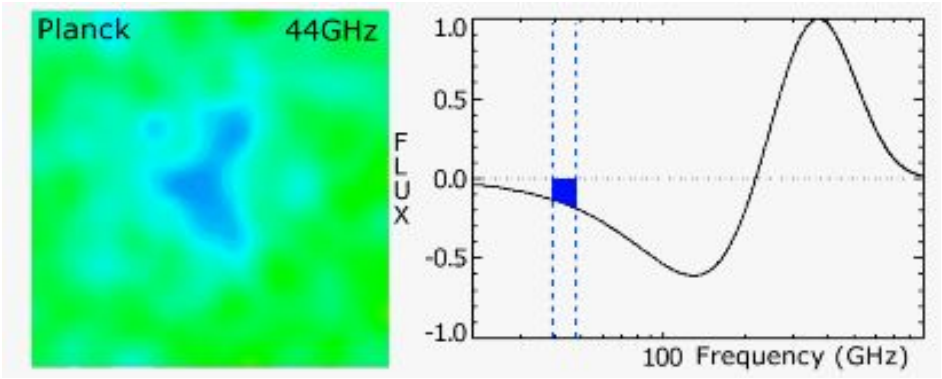


Image: L. Van Speybroeck

- Galaxy clusters contain hot gas (free electrons).
- CMB photons, that pass through clusters of galaxies, are inverse Compton scattered by free electrons in the intracluster medium (ICM).
- Used for blind detections of clusters in CMB surveys.
- ***SZ effect is redshift independent and hence allows us detect distant clusters.***
- Cluster abundance as a fn(M,z) is also an excellent probe of structure formation with different parameter degeneracies compared to primary CMB.



Frequency dependence of thermal SZ (Image: ESA)

CMB-S4 cluster forecasts

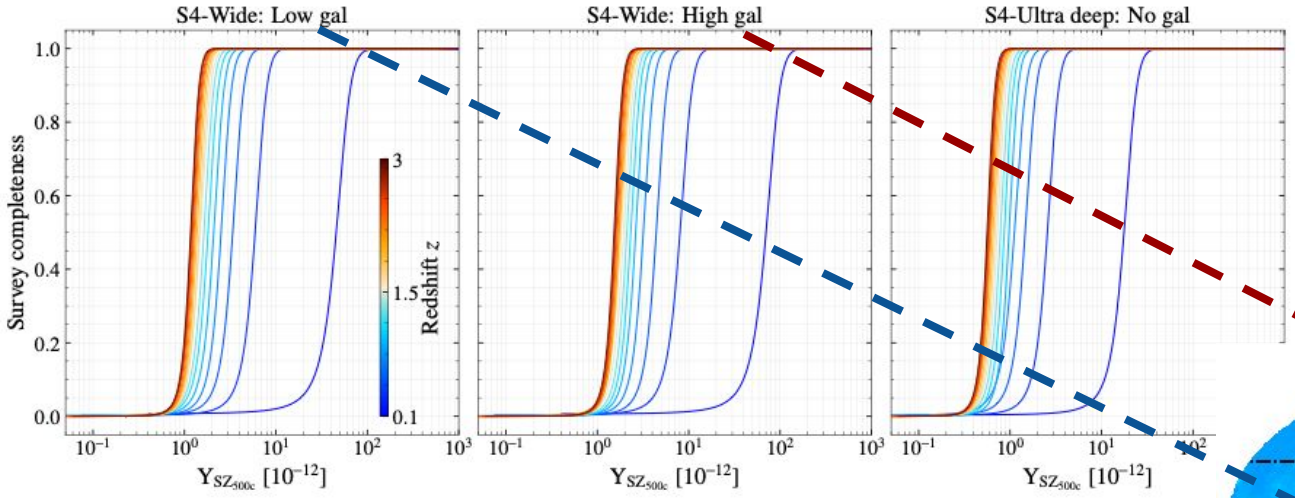
- **CMB-S4 cluster surveys:**
  - 6-metre telescopes → 1.4 arcmin beam at 145 GHz.
  - CMB-S4 Wide: Chilean survey: fsky = 67%.
  - CMB-S4 Ultra-deep: South Pole survey: fsky = 3%.

- **Signal-to-noise threshold:** 5σ.

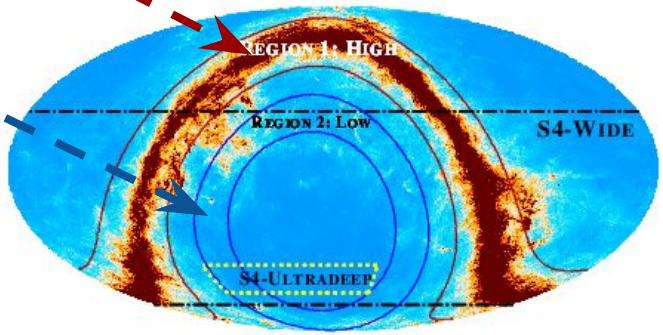
- **Observable:**

CMB-S4 shall detect (at 5σ) all galaxy clusters with an integrated Compton $Y_{SZ} \geq XX$ *at* $z \geq 1.5$ *over the large area survey footprint (*$f_{sky} = 67\%$*). Furthermore, it shall detect (at 5 sigma) all galaxy clusters with an integrated Compton* $Y_{SZ} \geq YY$ *at* $z \geq 1.5$ *over the de-lensing survey footprint (*$f_{sky} = 3\%$*).*

CMB-S4 cluster survey completeness



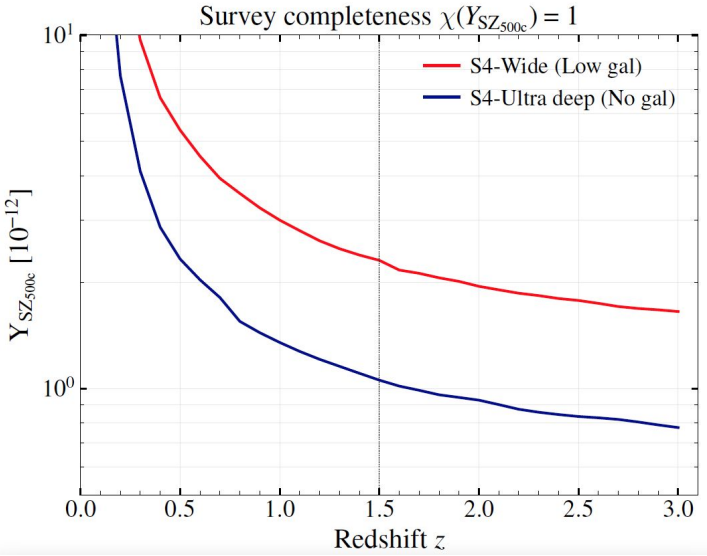
CMB-S4 PBDR (in prep.)



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

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

CMB-S4 cluster survey completeness



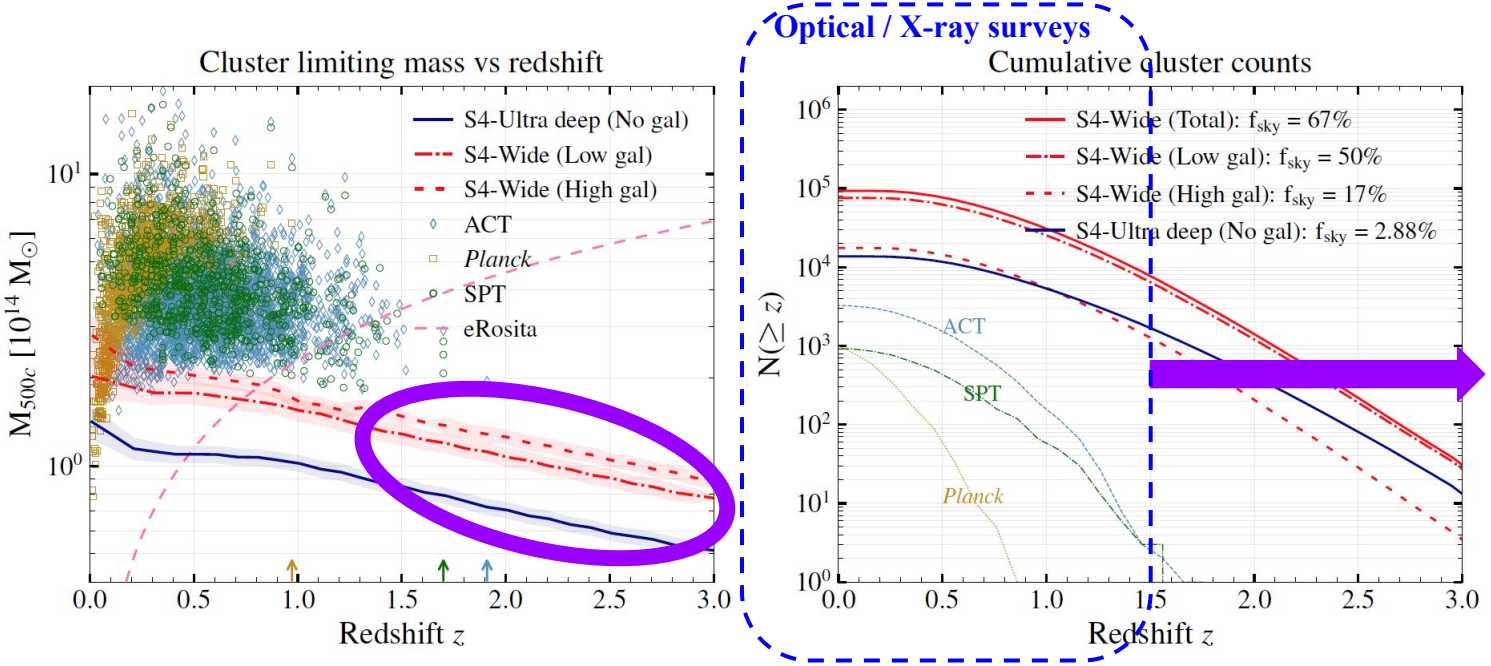
CMB-S4 PBDR (in prep.)

Science requirement:

CMB-S4 shall detect (at 5σ) all galaxy clusters with an integrated Compton $Y_{SZ} \geq 2x10^{-12}$ *sr* ***at $z \geq 1.5$ over the large area survey footprint (f_{sky} = ~~65%~~ 50%)***. *Furthermore, it shall detect (at 5σ) all galaxy clusters with an integrated Compton* $Y_{SZ} \geq 10^{-12}$ *sr* ***at $z \geq 1.5$ over the de-lensing survey footprint (f_{sky} = 3%)***.

CMB-S4 cluster sensitivity / counts

- **S4-Wide:** Contains clusters from low (f_{sky} = 0.5) + high (f_{sky} = 0.15) galactic emission regions. Removing high galactic emission region reduces ~20% objects.
- **High-z (z>=2) clusters:** S4-Wide → ~1000 clusters; S4-Ultra deep → ~350 clusters.

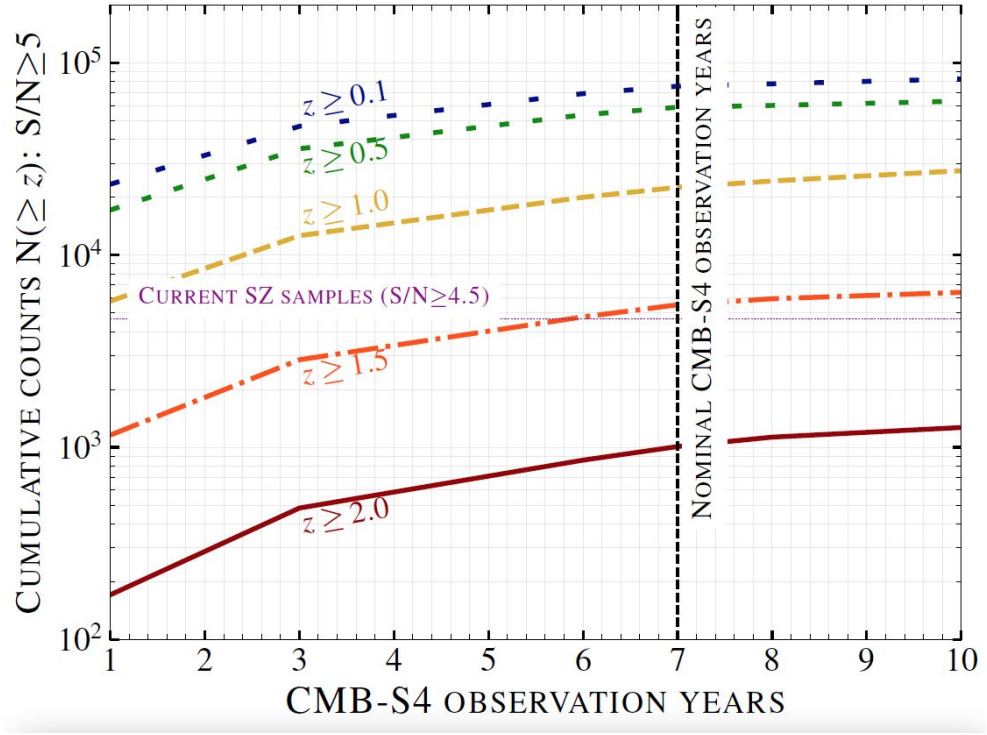


Talks in the parallel session:

Vittorio Ghirardini, Tesla Jeltema, and Grant

CMB-S4 PBDR (in prep.)

CMB-S4 cluster forecasts: Expected counts

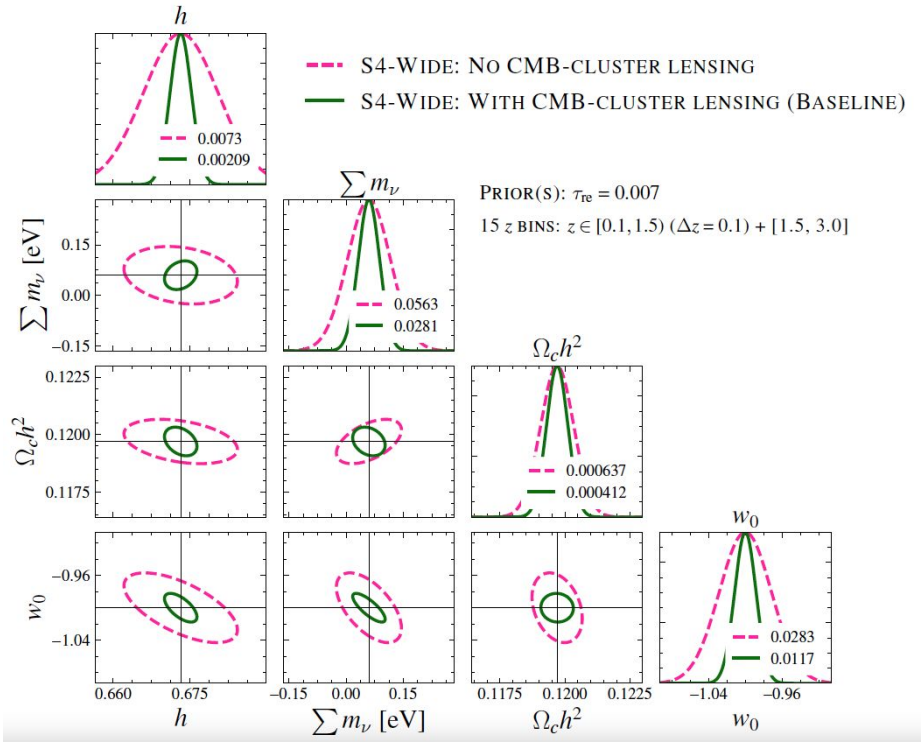


Work done with *Marcelo* ***Alvarez***, *Han* ***Aung***, *Nick* ***Battaglia***, *Gil* ***Holder***, *Daisuke* ***Nagai***, *Elena* ***Pierpaoli*** *and Nathan* ***Whitehorn***.

Look into arXiv:2107.10250 for more details.

Cosmological constraints

CMB-S4 Wide: CMB (TT/EE/TE) with Cluster counts using CMB-cluster lensing mass calibration.



Including information from galaxy weak lensing will further strengthen the constraints and also offer an important systematic check.

Data:

To et al. 2021, arXiv: 2010.01138
DES collaboration 2020, arXiv: 2002.11124
Bocqet et al. 2019, arXiv: 1812.01679
Zubeldia & Challinor 2019, arXiv: 1904.07887

Talks in the parallel session:
Sebastian Bocquet and Tesla Jeltema.

Look into arXiv:2107.10250 for more details.
Also see Louis & Alonso 2017, arXiv: 1609.03997; Madhavacheril, Battaglia & Miyatake 2017, arXiv: 1708.07502.

What about cluster astrophysics?

CMB-S4 STM

DOE & NAS SCIENCE GOALS (P5* Strategic Plan; New Worlds New Horizons 2010)	CMB-S4 SCIENCE GOAL
Witnessing the emergence of the Intracluster Medium (ICM)	Measure the emergence of galaxy clusters as we know them today. Quantify the formation and evolution of the clusters and the ICM during this crucial period in galaxy formation.

Talks in the parallel session:

Susmita Adhikari, Eric Baxter, Han Aung/Daisuke Nagai/Erwin Lau and Grant Tremblay.

Virialisation mechanism of distant clusters

What about the virialisation process of high-z clusters?

- **Observations:** Only one cluster at z~2. Mantz et al. 2014, 2018 (arXiv: 1401.2087, 1703.08221) find the properties of this cluster to be consistent with low-z clusters.
- CMB-S4 will make a giant leap in the field of cluster science.

$$Y_{\mathrm{SZ}_{500c}} = \mathrm{v}(z)\ Y_* \left[\frac{h}{0.7}\right]^{-2+\alpha} \left[\frac{M_{500c}}{M_*}\right]^{\alpha} \left[\frac{D_A(z)}{100\mathrm{Mpc}}\right]^{-2} E^{2/3}(z)$$

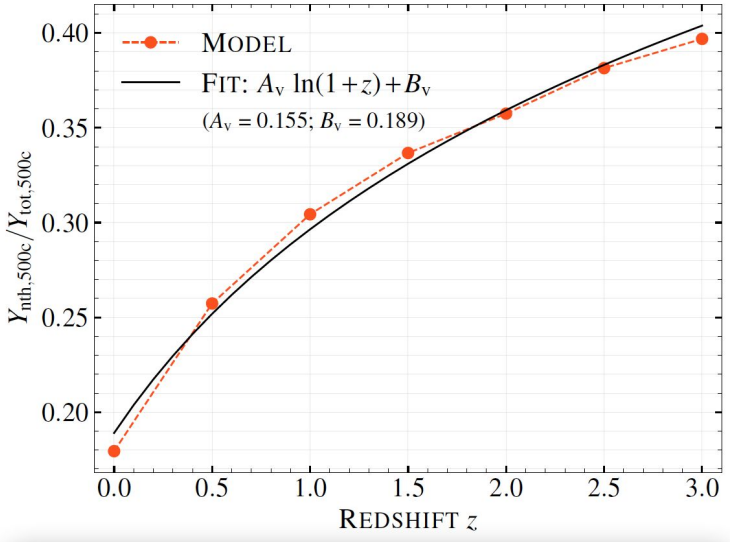
Planck Y_{SZ}- M scaling relation with a constant HSE bias.

Model 1: $\mathrm{v}(z) = \eta_{\mathrm{v}}(z)\ (1 - b_{\mathrm{HSE}})^{\alpha}$

Simple linear scaling.

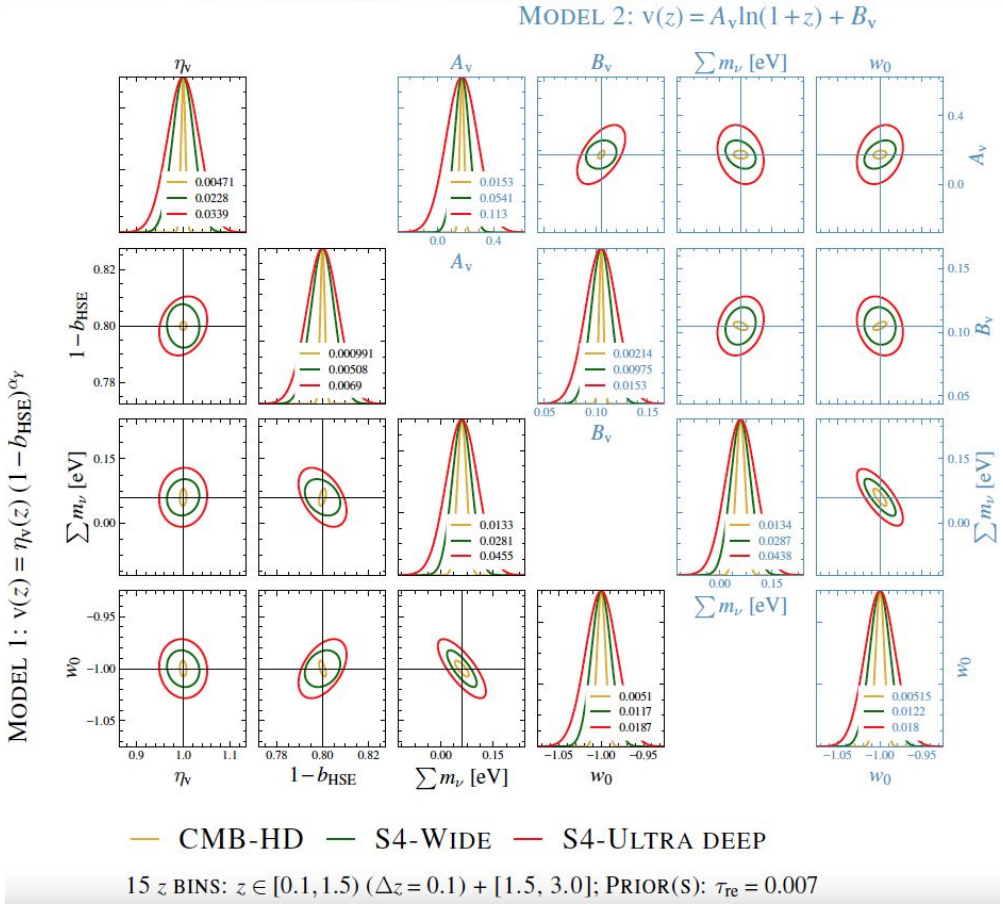
Model 2: $\mathrm{v}(z) = A_{\mathrm{v}} \ln(1+z) + B_{\mathrm{v}}$

Analytic model tested using simulations.



Talks in the parallel session: *Han Aung/Daisuke Nagai/Erwin Lau.*

Constraining astrophysics and cosmology with clusters



- **Model 1:**
  - 2-4 per cent on cluster virialisation parameter.
  - Sub-percent constraint on (constant) HSE bias.
- **Model 2:**
  - <5 per cent on B_v and ~30 per cent on redshift evolution A_v.
- Swapping cluster virialisation model 1 to model 2 does not affect cosmological constraints significantly.

Look into arXiv:2107.10250 for more details.

Details about parallel session

- Status of eROSITA - **Vittorio *Ghirardini***.
- SPT/DES Cluster Cosmology - **Sebastian *Bocquet***.
- Understanding the mass and galaxy distribution in Clusters: A perspective from the edge of DM halos - **Susmita *Adhikari***.
- Synergy between optical, SZ, and X-ray: Lessons learned from DES Cluster Cosmology - **Tesla *Jeltema***.
    - Discussion/Break.
- Cluster science using the synergy between CMB-S4 and Lynx - **Grant *Tremblay***.
- Gas in the outskirts of galaxy clusters - **Eric *Baxter***.
- Baryon pasting + high-z cluster virialization models - **Han *Aung*, Erwin *Lau*, and Daisuke *Nagai***.
    - Discussion/Close.