Galaxy clusters and Dark Energy

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Based on work done in the CMB-S4 Clusters and Source Analysis Working Groups.

CMB-S4 Spring Collaboration Meeting
Snowmass Preparation session
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Galaxy clusters as probes of dark energy

- Given the number of clusters we observe today, we can note that ***clusters must form early in the Universe with (bottom) dark energy compared to the one without (top) dark energy***.
- However, note that the **distinction between the two panels becomes obvious only when we reach high redshifts**.
  - ***So the key is to detect high redshift clusters.***
- **CMB surveys,** using the ***redshift independent Sunyaev–Zeldovich (SZ) effect,*** facilitate the detection of distant clusters.

Galaxy clusters in (simulated) universes
with vs without dark energy

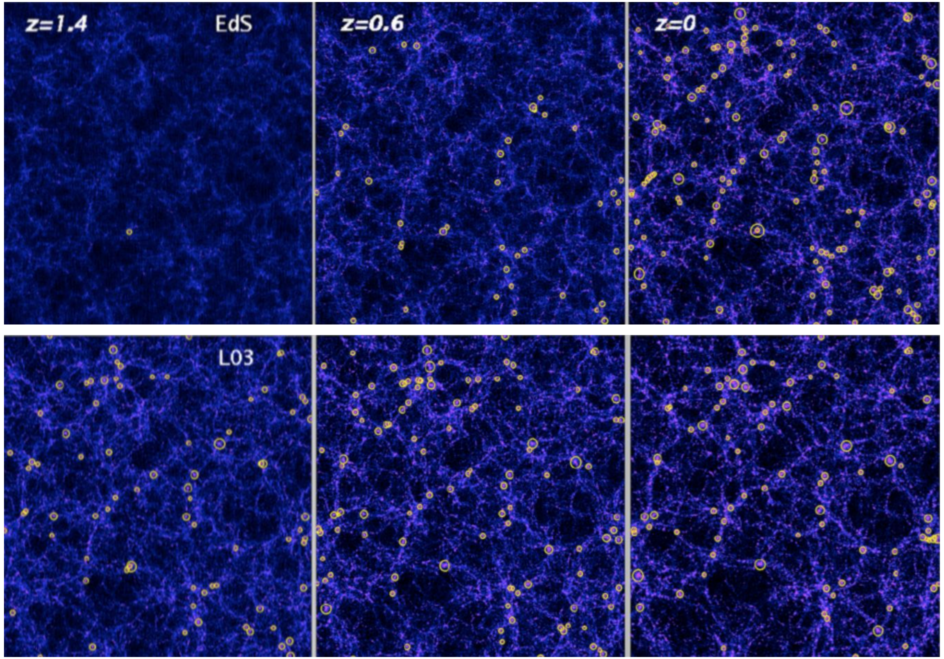
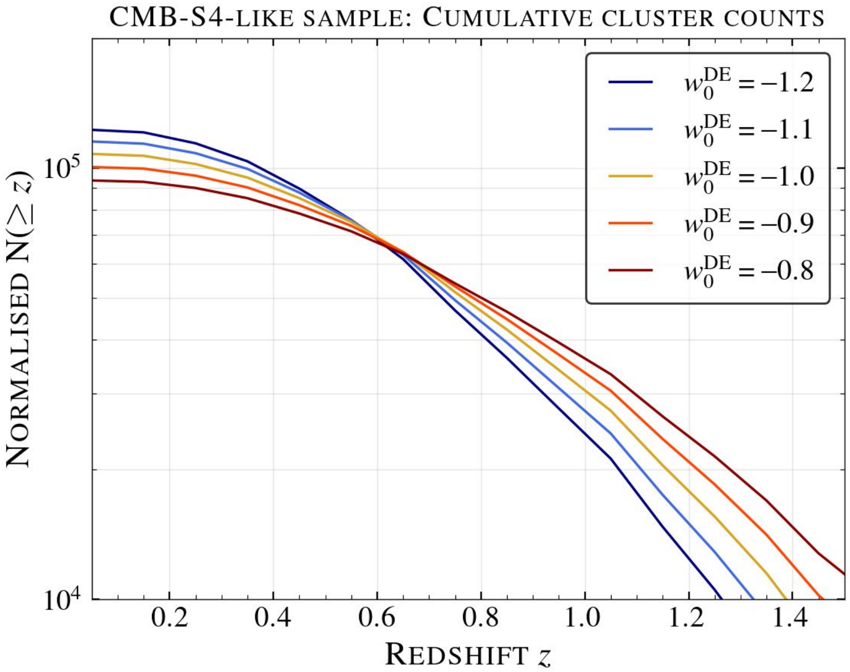


Figure from Lindsey Bleem's presentation

Source: Borgani & Guzzo 2001

Galaxy clusters as probes of dark energy

Change in cluster counts with dark energy equation of state



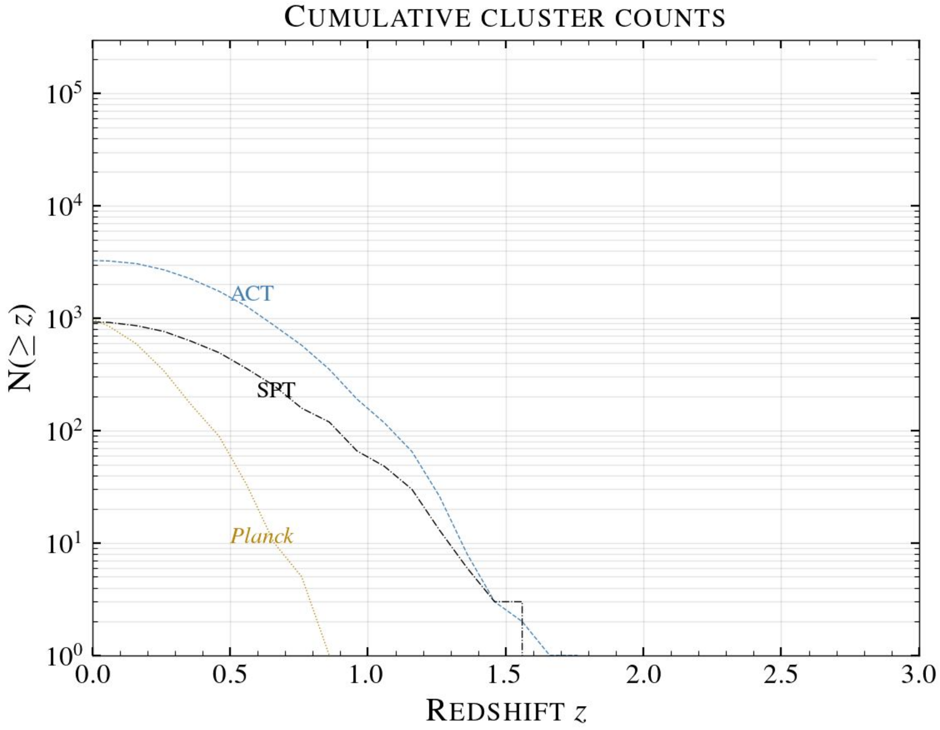
But the final constraints will be worse when we open the parameter space to constrain multiple parameters.

Galaxy clusters: SZ samples

Current SZ cluster samples:

- **Atacama Cosmology Telescope:**
  - Hilton et al. 2018, 2020 (arXiv: 1709.05600 and 2009.11043).
- ***Planck*:**
  - Planck Collaboration (arXiv: 1303.5089 and 1502.01597).
- **South Pole Telescope:**
  - Bleem et al. 2015 (arXiv: 1409.0850).
  - Bleem et al. 2020 (arXiv: 1910.04121).
  - Huang et al. 2020 (arXiv: 1907.09621).

Current SZ cluster samples



CMB-S4

Galaxy clusters: SZ samples

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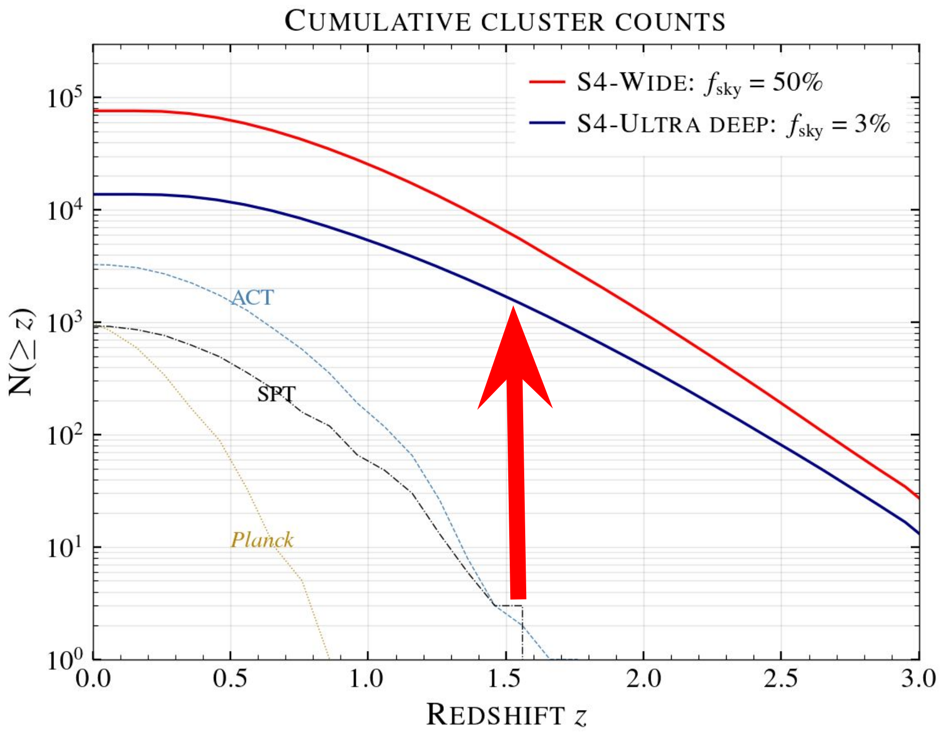
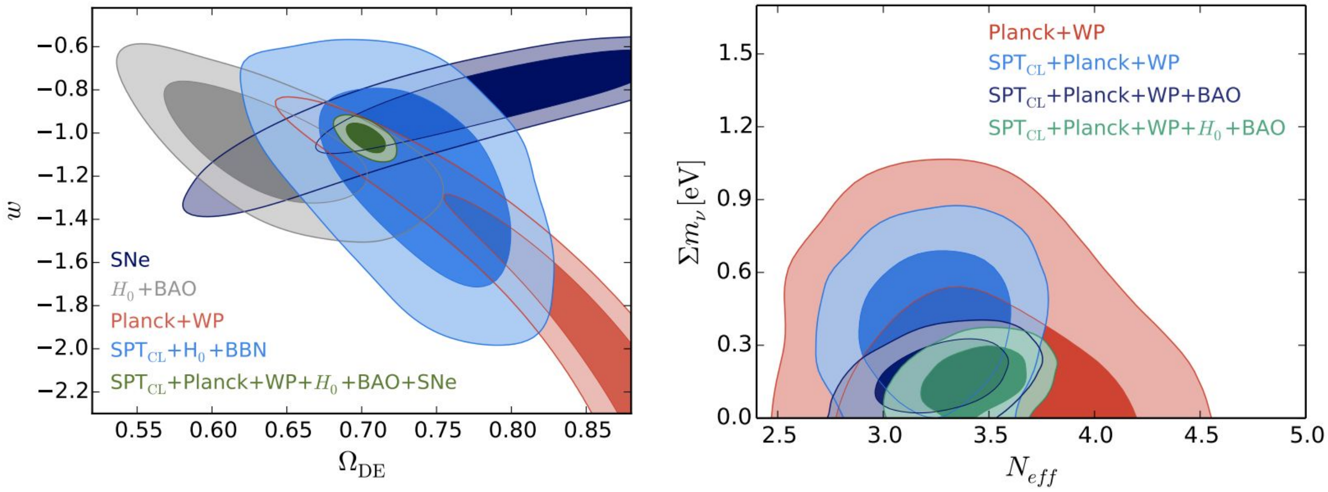
But we must rely on other surveys to obtain redshifts.

Forecasts for CMB-S4



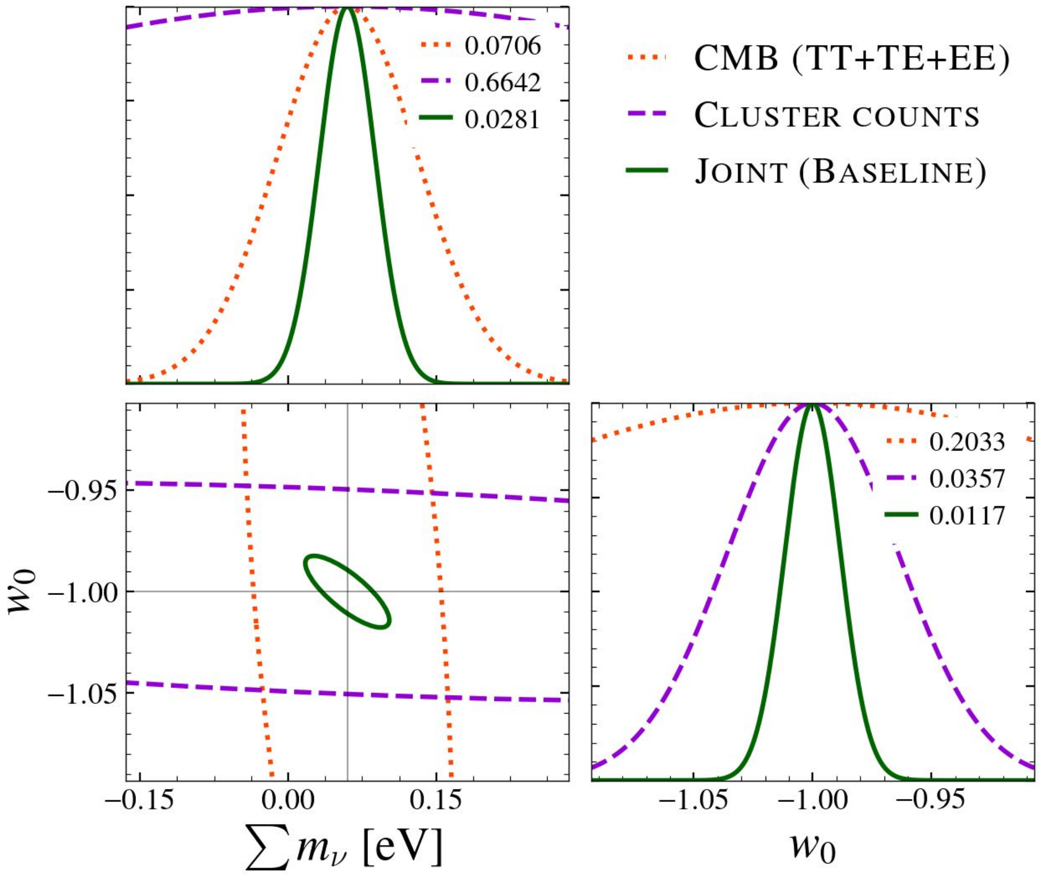
Clusters: Probes of dark energy and neutrino masses

- The degeneracy directions between dark energy and neutrino masses are different for **primary CMB power spectra** and **cluster abundance** measurements.
- *CMB lensing power spectra is also an excellent probe of structure formation (next talk by Alexander van Engelen).*
  - However, there are degeneracies between parameters and cluster abundance measurements, with multiple redshift bin information, will help break degeneracies.



SPT: De Haan et al. 2016, arXiv:1603.06522. Also see Bocquet et al. 2019, arXiv: 1812.01679.

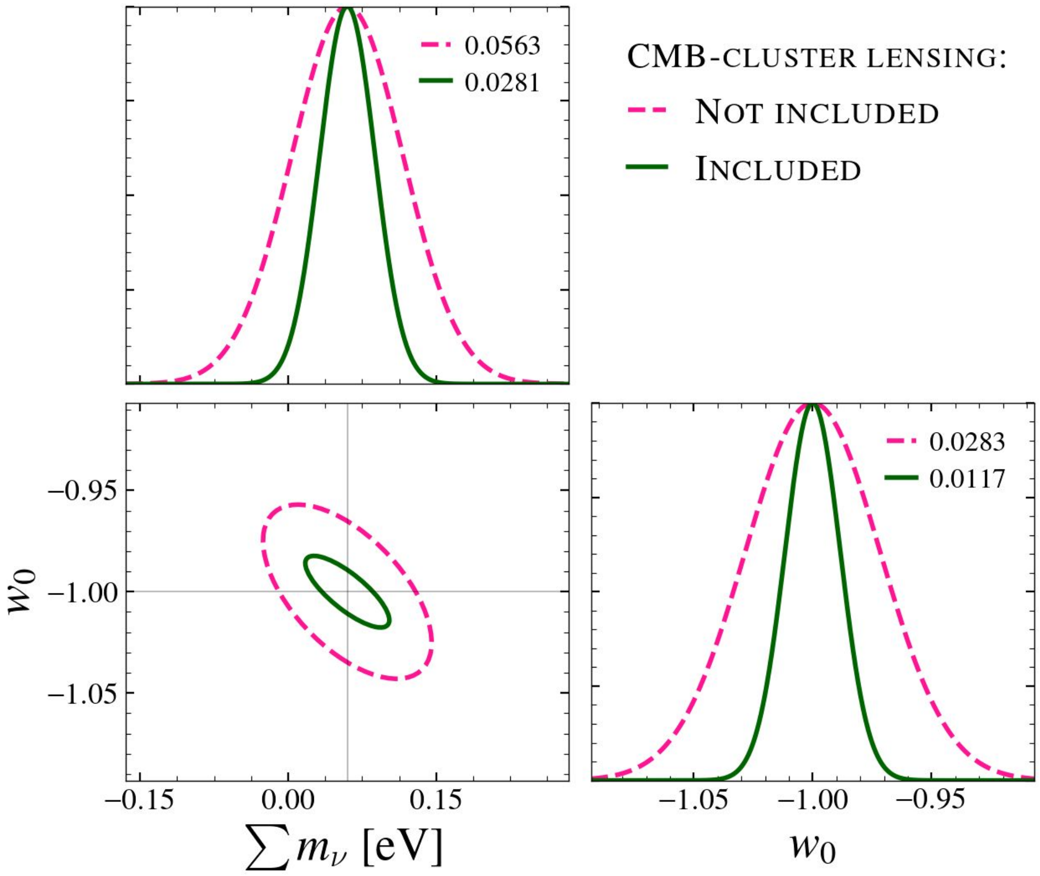
Clusters: Probes of dark energy and neutrino masses



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.***

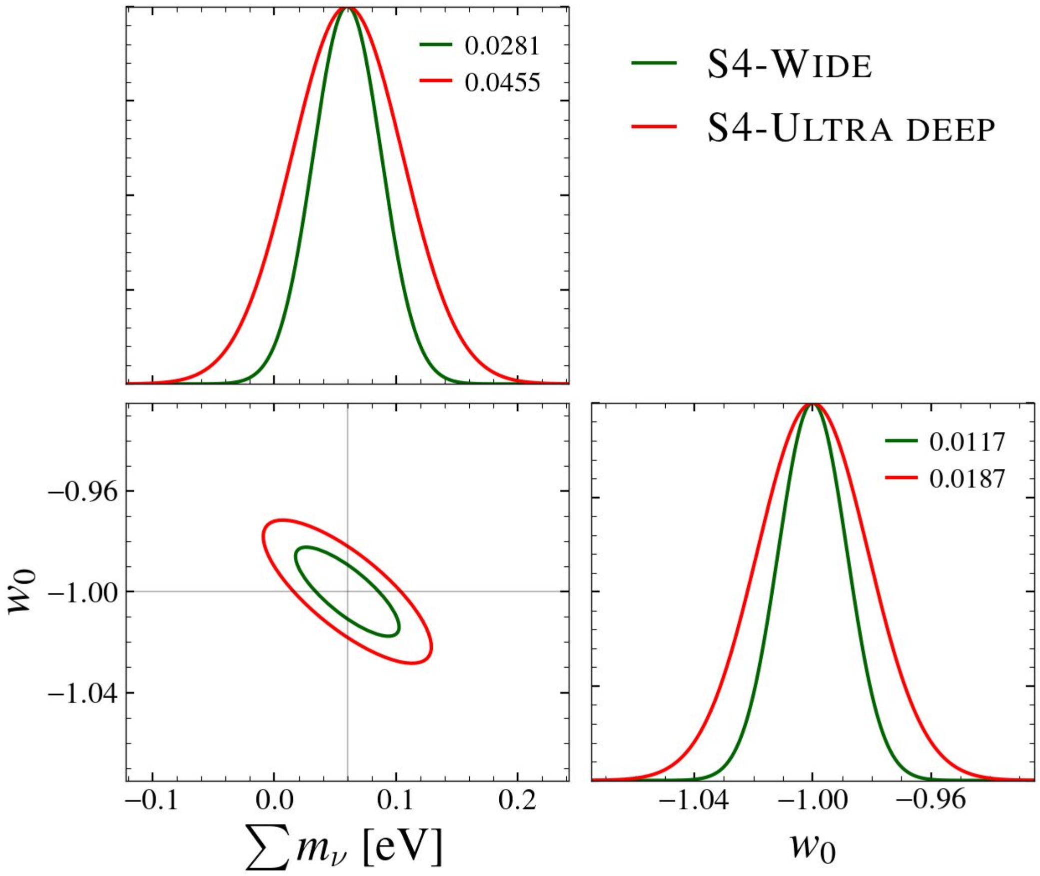
Clusters: Probes of dark energy and neutrino masses



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.*

Clusters: Probes of dark energy and neutrino masses



CMB-S4 Wide/Ultra-deep surveys:

- ***~1 per cent constraint on $\sigma(w_{DE})$.***
- ***2.5-3σ detection of the sum of neutrino masses.***
- Constraints obtained by combining primary CMB (TT/EE/TE) power spectra with cluster abundance measurements.
- CMB-lensing masses are included.

References:

- CMB-S4 DSR, arXiv: 1907.04473 ;
- arXiv: 2112.07656; arXiv: 2112.07656;
- Madhavacheril, Battaglia & Miyatake 2017, arXiv: 1708.07502;
- Louis & Alonso 2017, arXiv: 1609.03997.