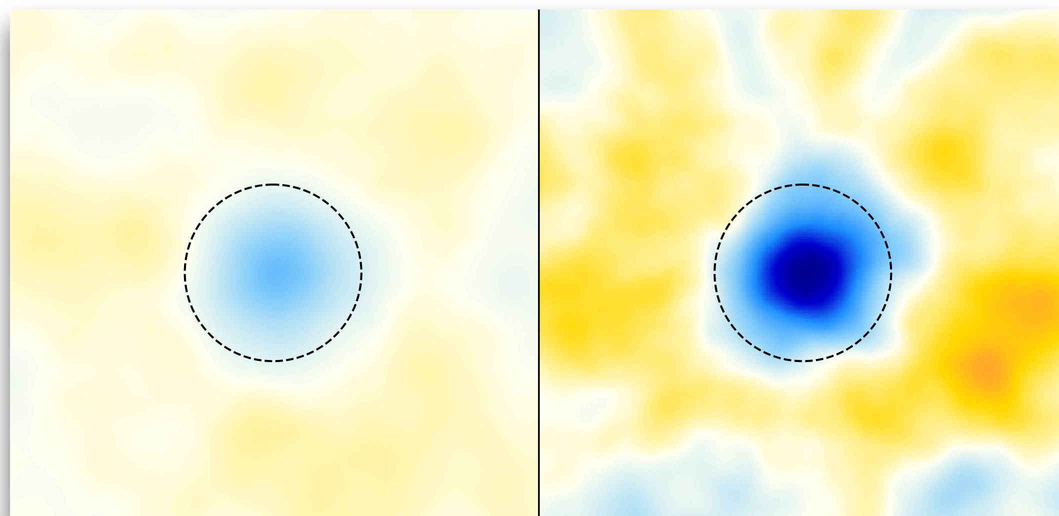
Impeaching Dark Energy

A common explanation of the Hubble tension and anomalous cold spots in the CMB



András Kovács (IAC)

Collaborators: Róbert Beck, István Szapudi, István Csabai, Gábor Rácz, László Dobos and the DES team for observational ISW results

arXiv:2004.02937

What is the problem with ISW?

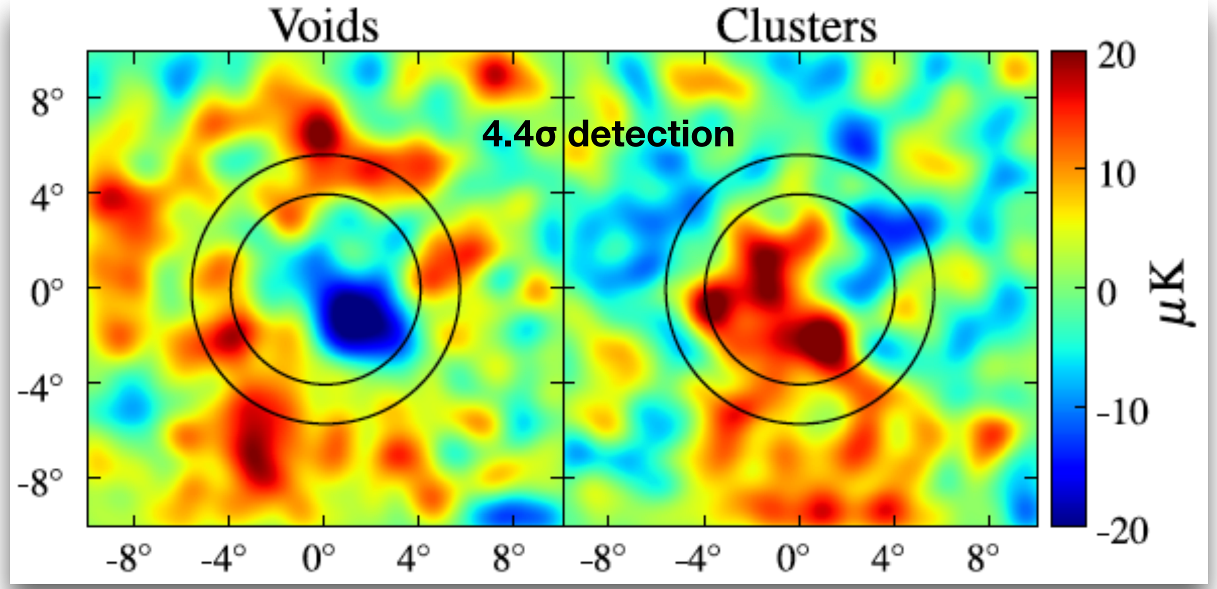
- **ISW: secondary CMB anisotropy due to the decay of the grav. potential at large scales**

- **Higher-than-expected ISW-like signal from SDSS super-structures**

- **If real, hard to interpret in ΛCDM given other precise constraints**

- **Not plausible to resolve with typical alternative cosmologies**

- **One should also see a real excess elsewhere in the sky**



The integrated Sachs-Wolfe imprint of cosmic superstructures: a problem for ΛCDM

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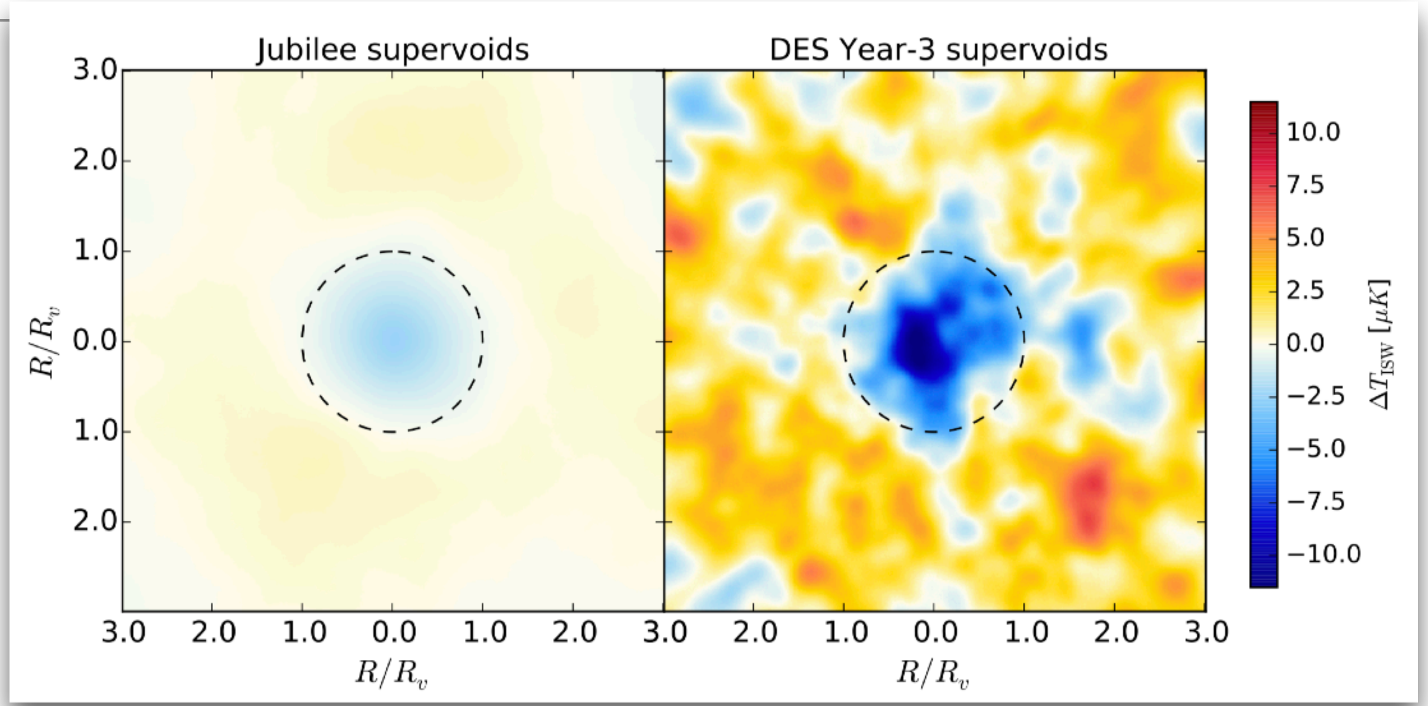
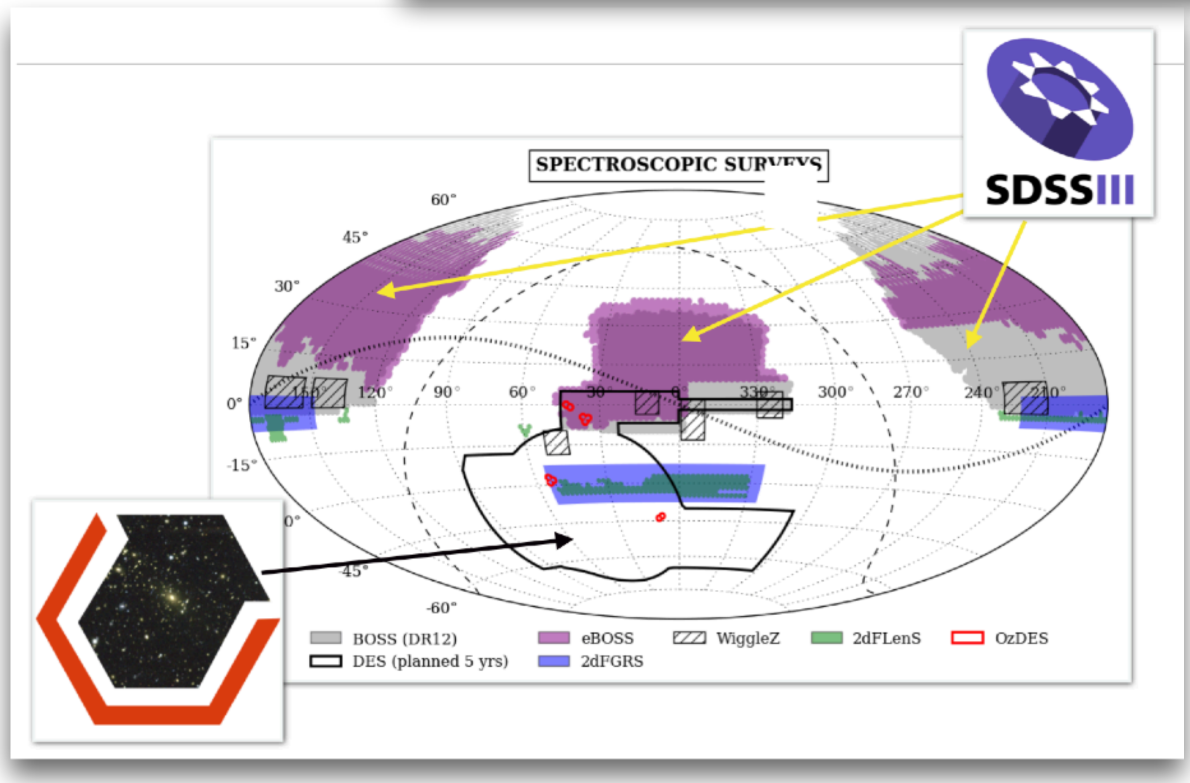
Abstract. A crucial diagnostic of the ΛCDM cosmological model is the integrated Sachs-Wolfe (ISW) effect of large-scale structure on the cosmic microwave background (CMB). The ISW imprint of superstructures of size $\sim 100\ h^{-1}$Mpc at redshift $z \sim 0.5$ has been detected with $> 4\sigma$ significance, however it has been noted that the signal is much larger than expected. We revisit the calculation using linear theory predictions in ΛCDM cosmology for the number density of superstructures and their radial density profile, and take possible selection effects into account. While our expected signal is larger than previous estimates, it is still inconsistent by $> 3\sigma$ with the observation. If the observed signal is indeed due to the ISW effect then huge, extremely underdense voids are far more common in the observed universe than predicted by ΛCDM.

Fluctuation? We looked elsewhere with the Dark Energy Survey





Kovács et al. 2017 arXiv:1610.00637

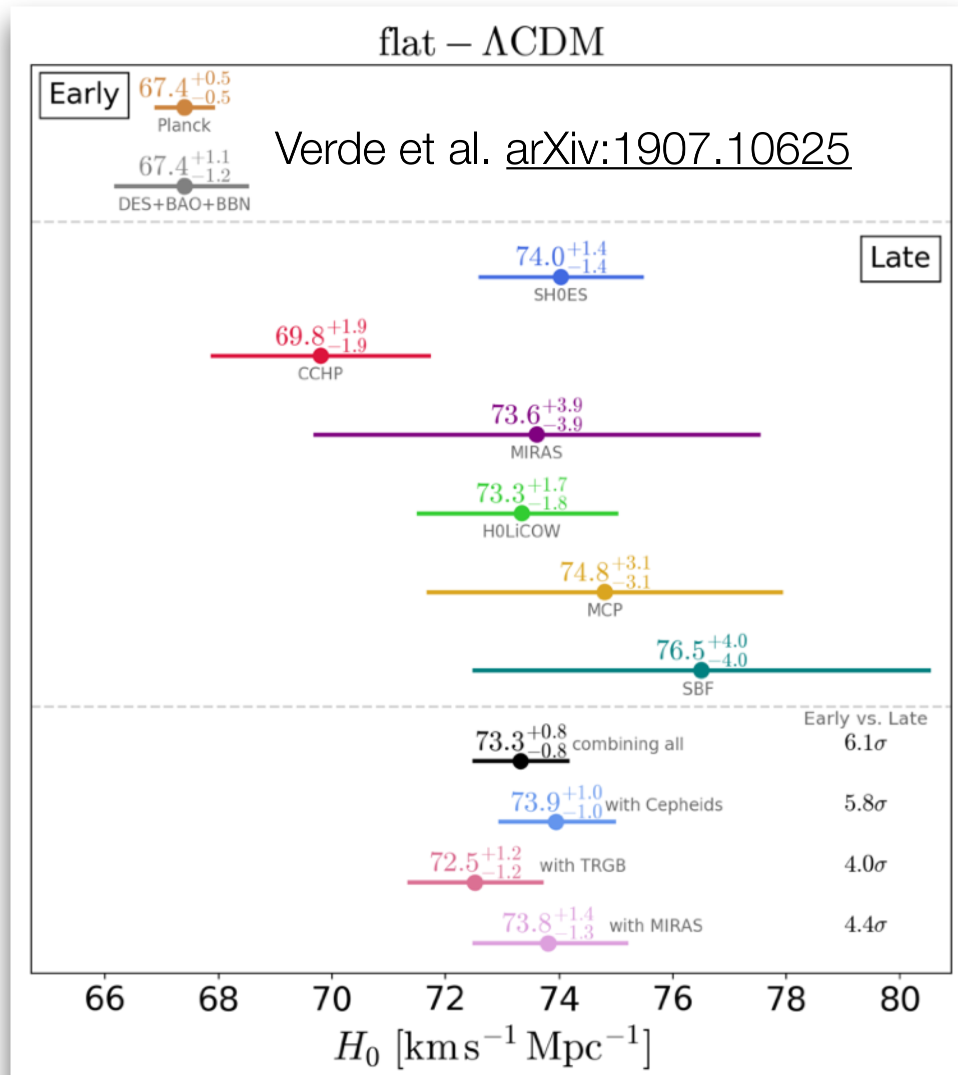
- **Dark Energy Survey Y1 data** 👍

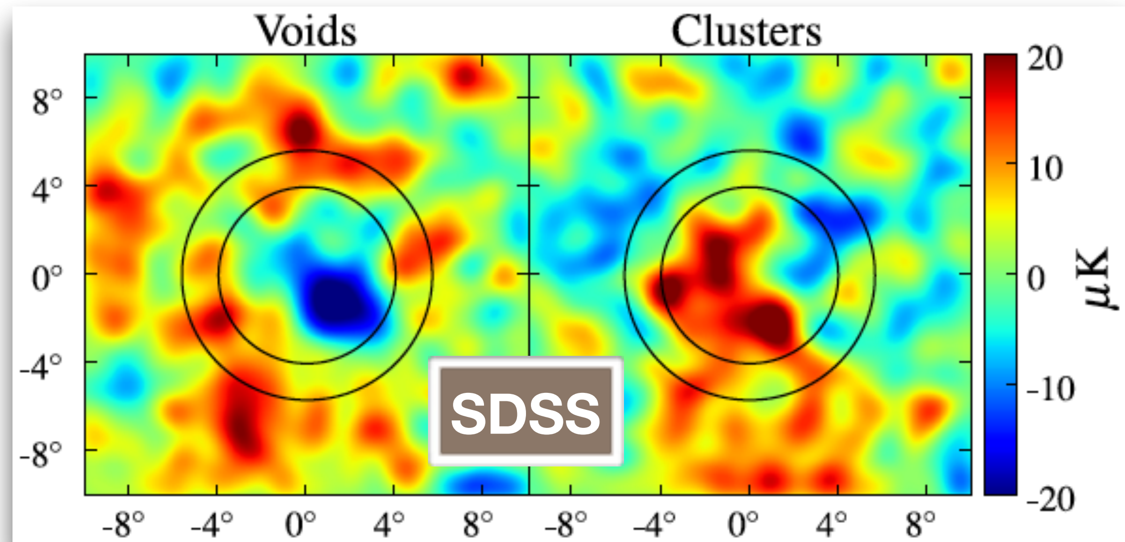
Kovács et al. 2019 arXiv:1811.07812

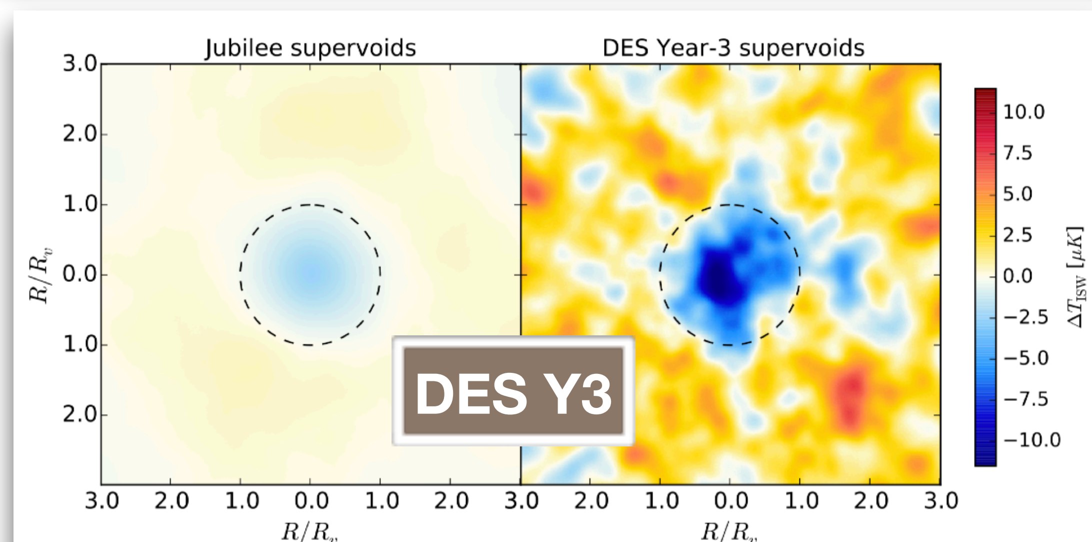
- **Dark Energy Survey Y3 data** 👍
- **BOSS DR12 CMASS and LOWZ data but using different (super)void definition** 👍
- **There is a problem with ISW from supervoids**

H_0 and ISW: related tensions from very different probes?

Dark energy to blame?





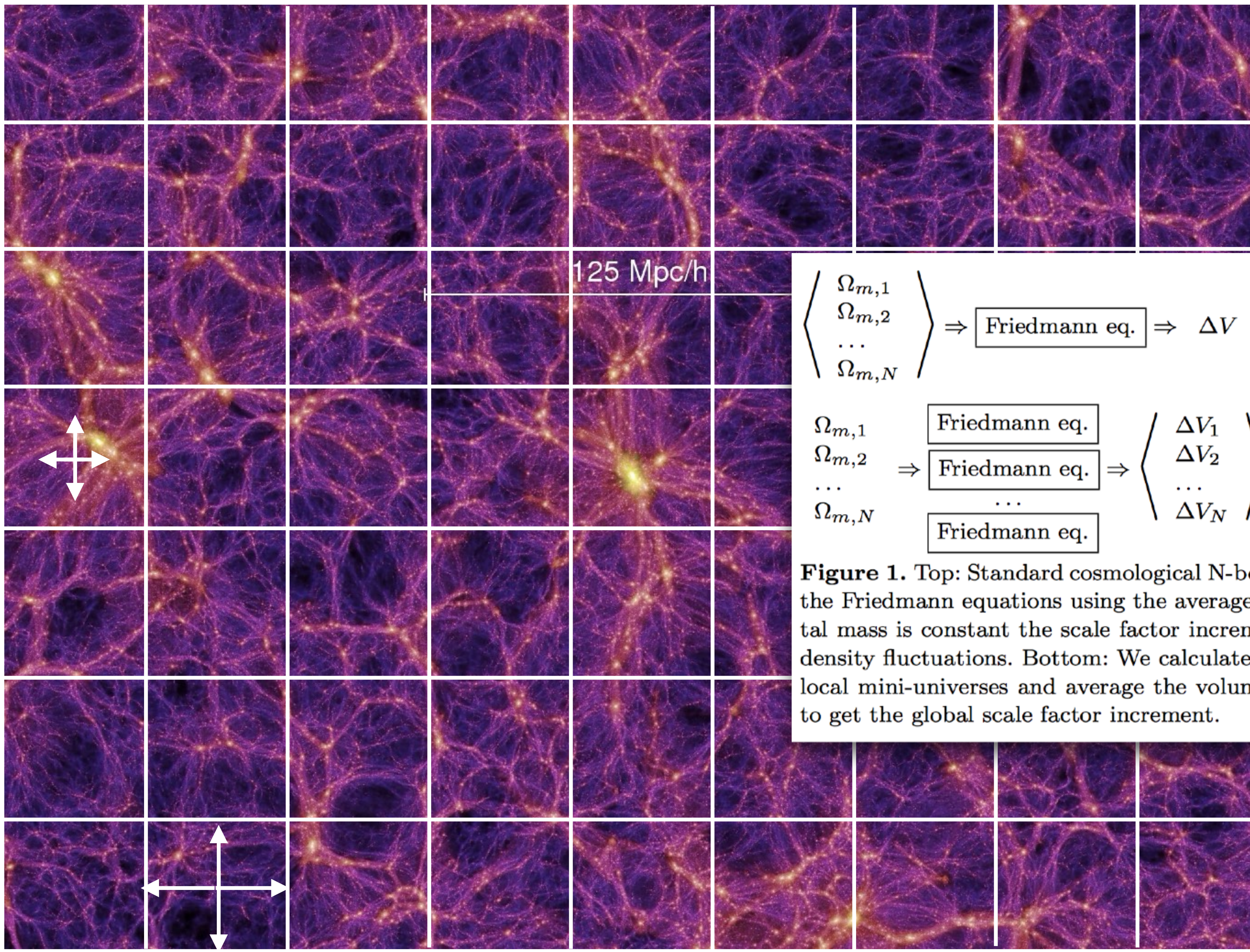


~4-5σ tension

~3-4σ tension

AvERA: average expansion rate approximation

a late-time solution



$$\begin{pmatrix} \Omega_{m,1} \\ \Omega_{m,2} \\ \cdots \\ \Omega_{m,N} \end{pmatrix} \Rightarrow \boxed{\text{Friedmann eq.}} \Rightarrow \Delta V \Rightarrow a(t+\delta t) \qquad (1)$$

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Figure 1. Top: Standard cosmological N-body simulations evolve the Friedmann equations using the average density. Since the total mass is constant the scale factor increment is independent of density fluctuations. Bottom: We calculate the expansion rate of local mini-universes and average the volume increment spatially to get the global scale factor increment.

See also Räsänen 2010 https://arxiv.org/pdf/1012.0784.pdf

Effect of inhomogeneities?

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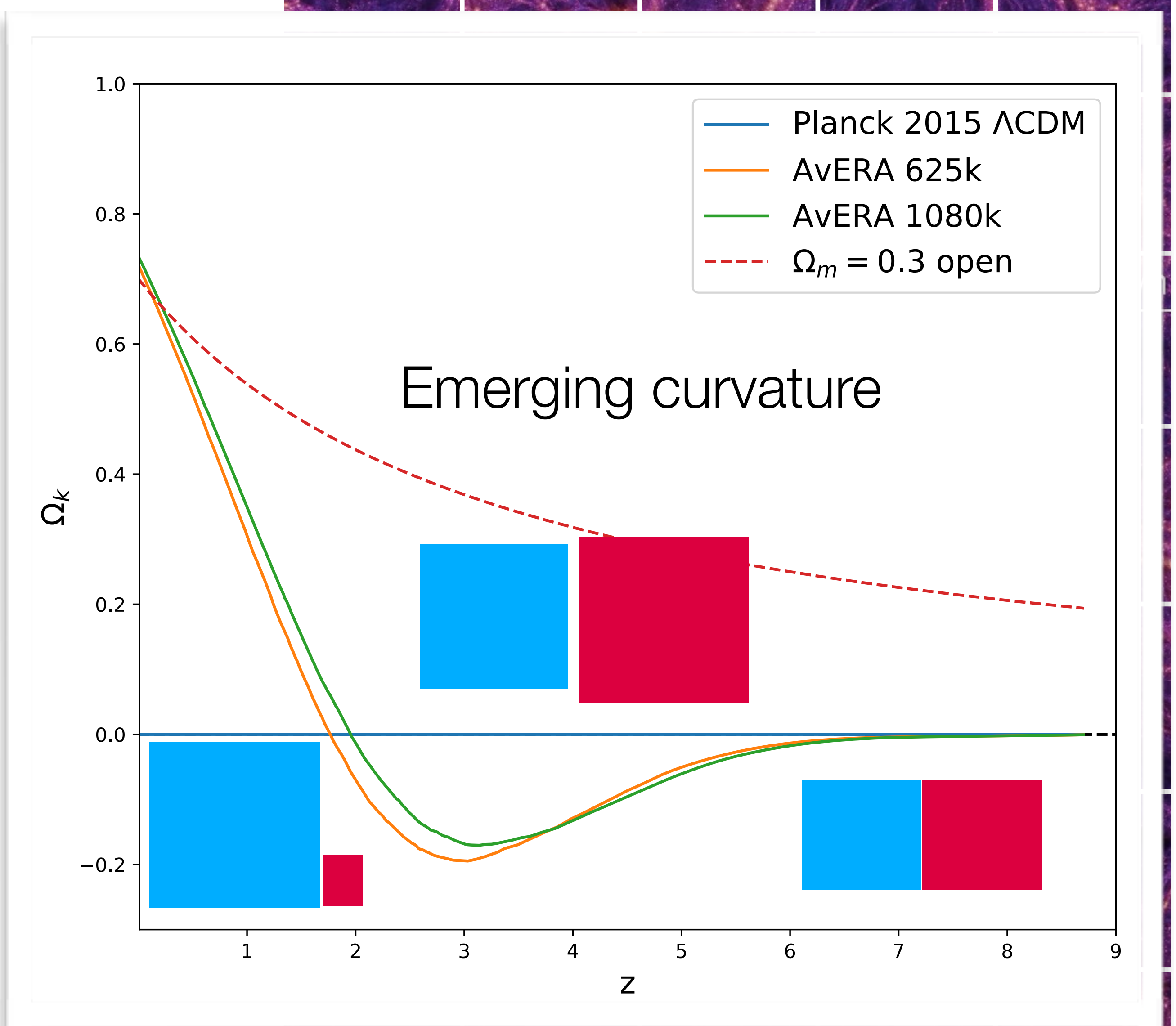

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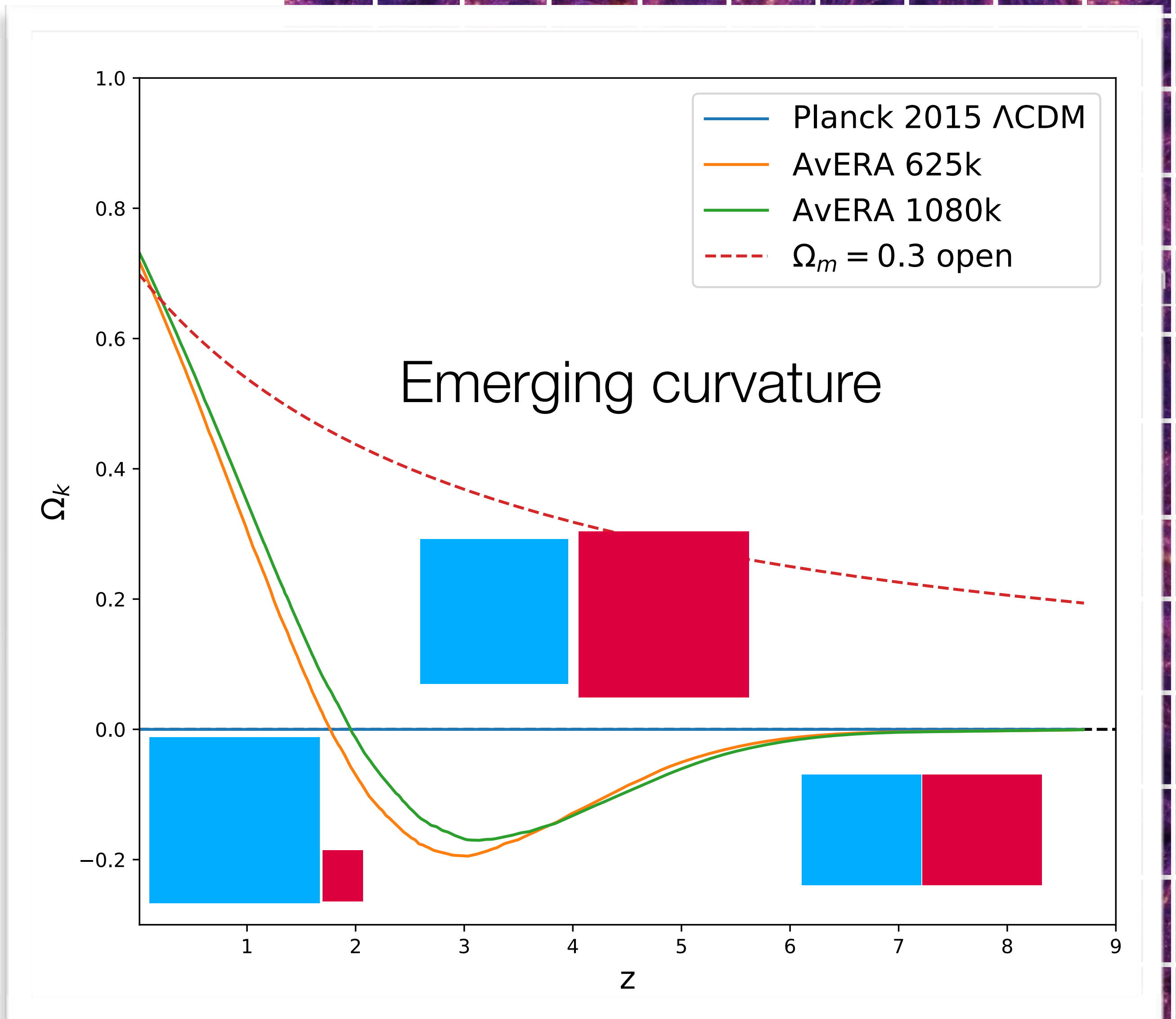
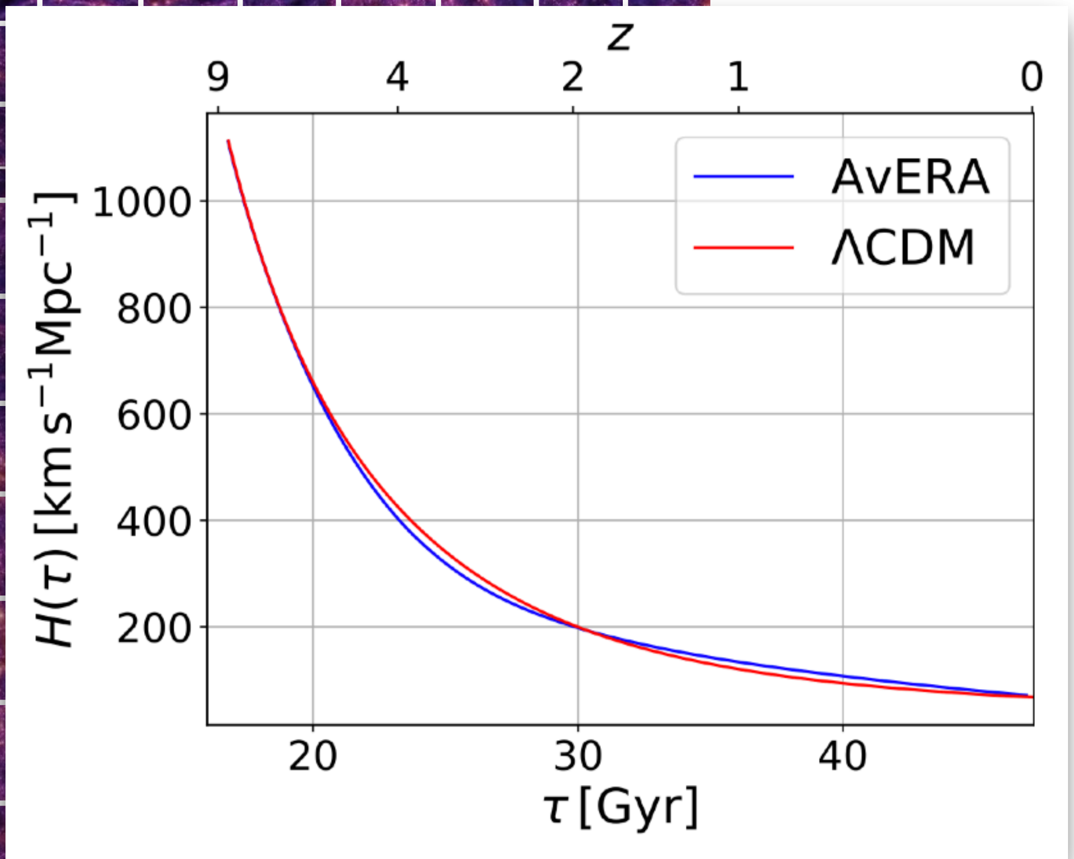
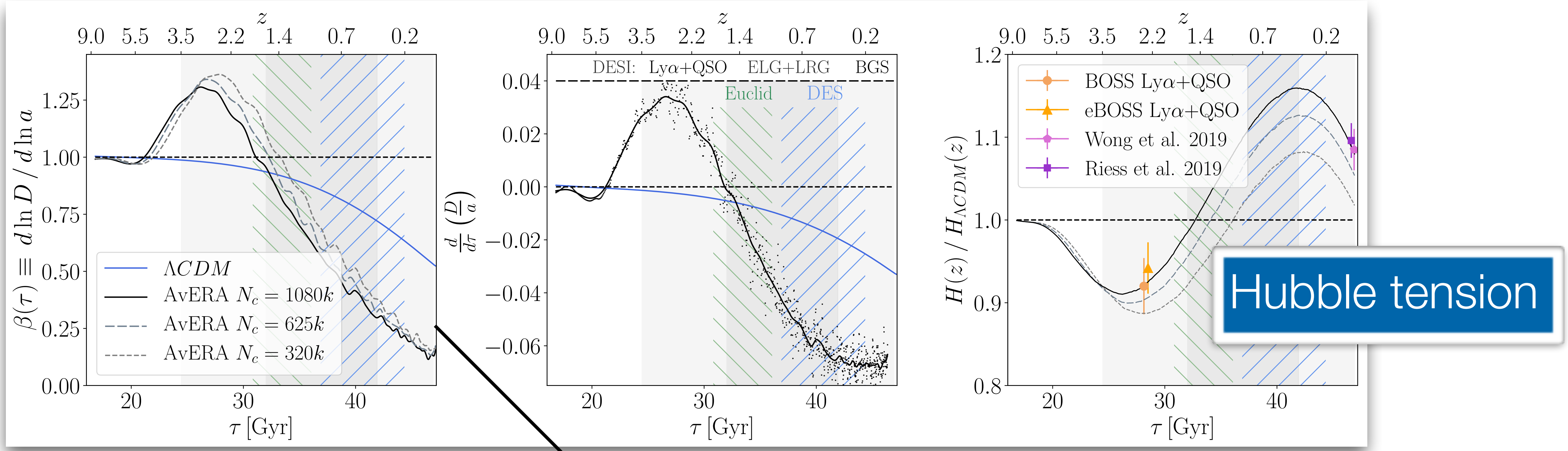




Rácz et al. arXiv:1607.08797

What else can be tested within the AvERA model?



Alternative growth rate of structure

↓

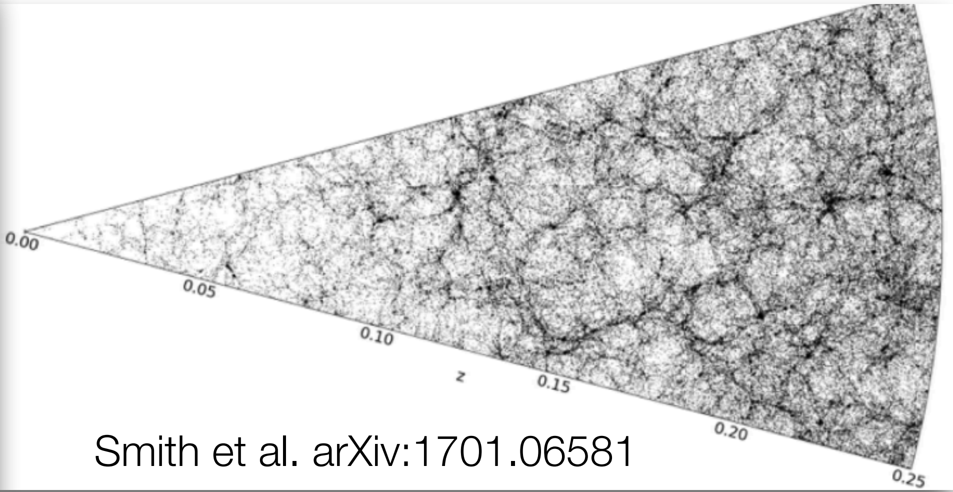
ISW and other dynamical probes of late-time cosmic acceleration

Angulo et al. arXiv:1203.3216

New stuff: ISW in the Millennium XXL, AvERA vs. ΛCDM

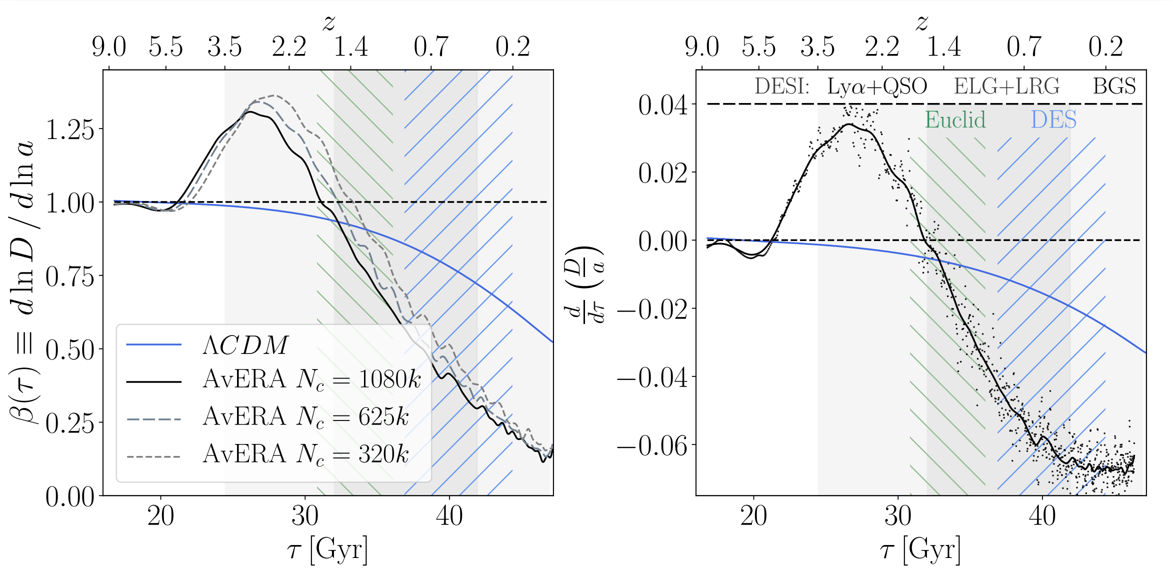
- **MXXL halo mock on a lightcone out to z=2.2 (Smith et al. 2017)**
- **Beck et al. 2018 constructed a ray-traced ISW map for this simulation (but using a different starting point)**
- **New idea: use the lightcone mock's center for the ISW ray tracing**
- **Prune data to have LRG-like tracers**
- **Then find supervoids and stack**

- WMAP1 cosmology (Ω_m=0.25, Ω_Λ=0.75, σ_8=0.9, h=0.73)
- Box size 3Gpc/h
- Particle mass 8.456e9 $M_\odot$
- 20 particle halo mass resolution
- Merger trees for SUBFIND subhaloes



Smith et al. arXiv:1701.06581

Approximation: linear growth was used to evolve the z=9 MXXL density field (ΛCDM) to get AvERA ISW



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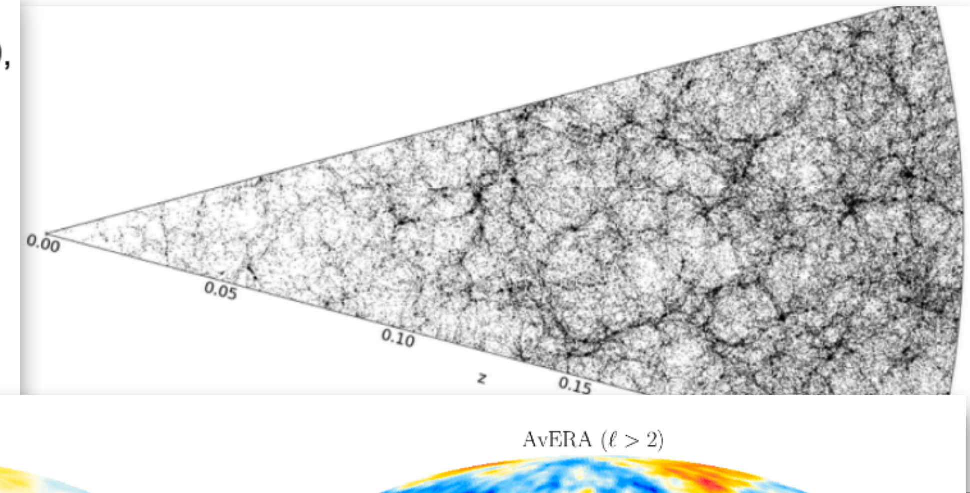
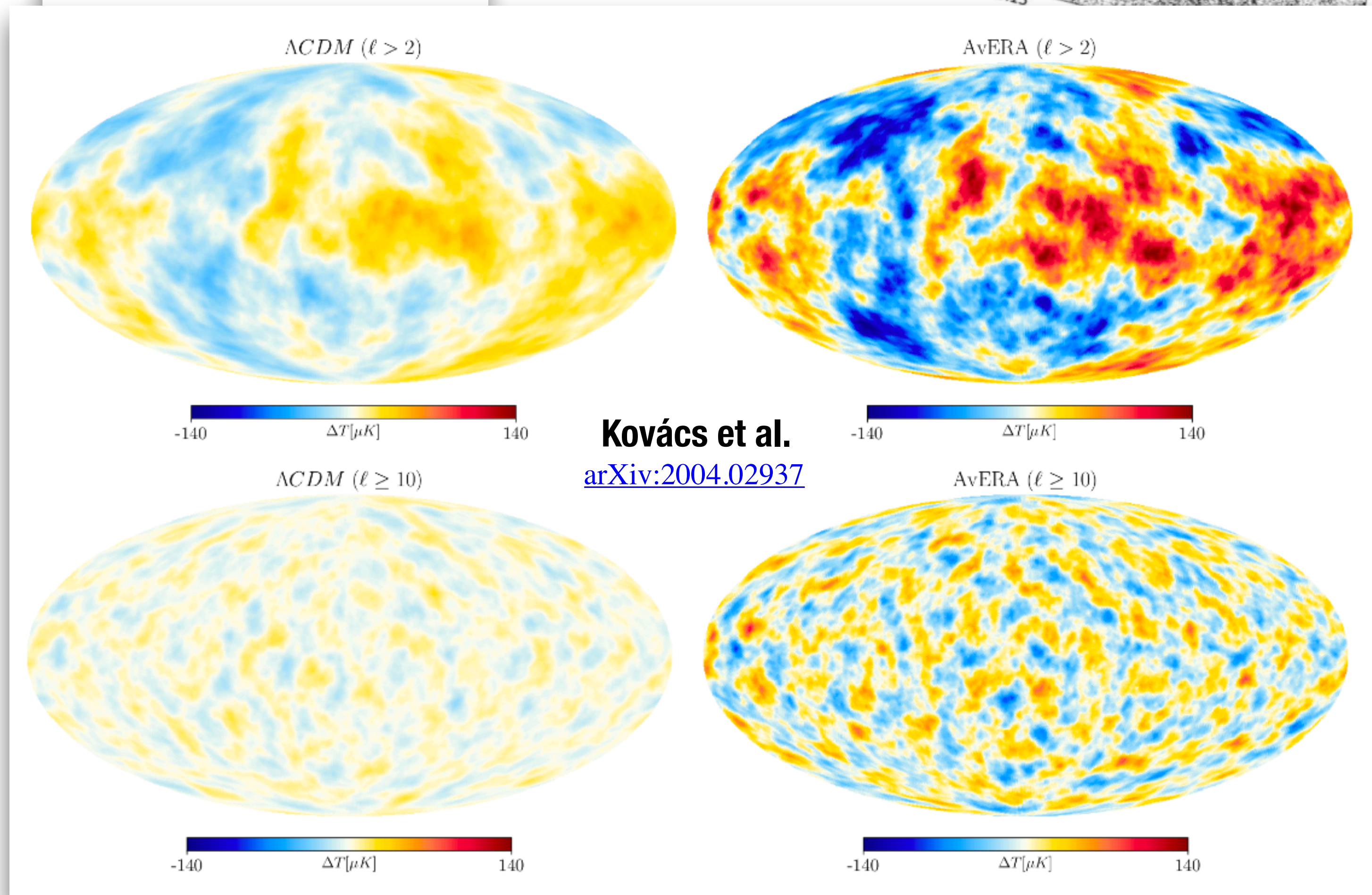
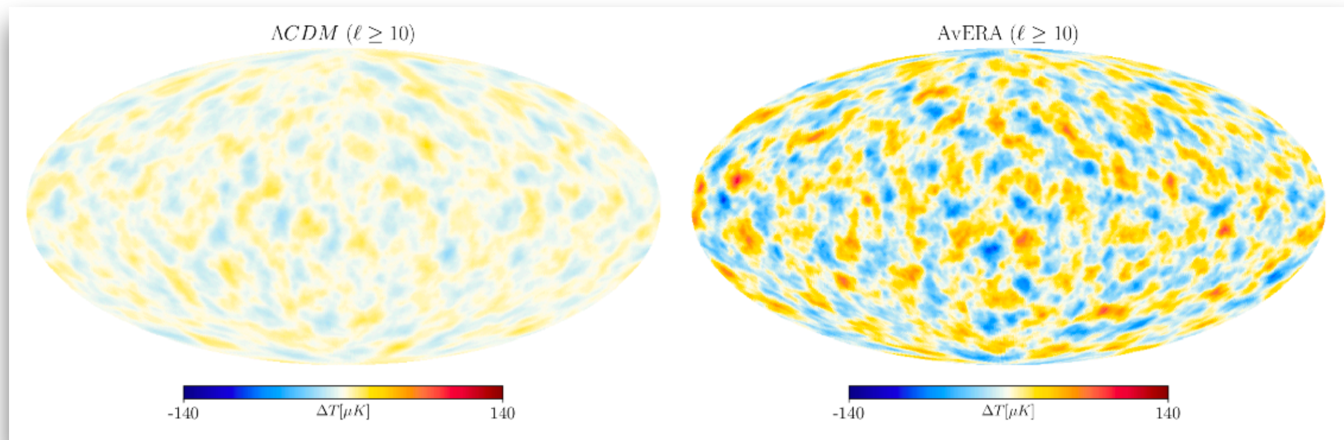
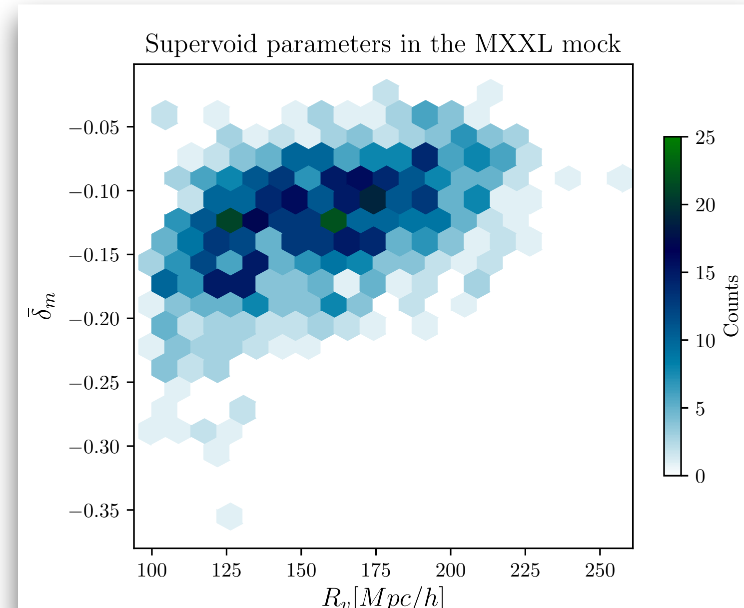


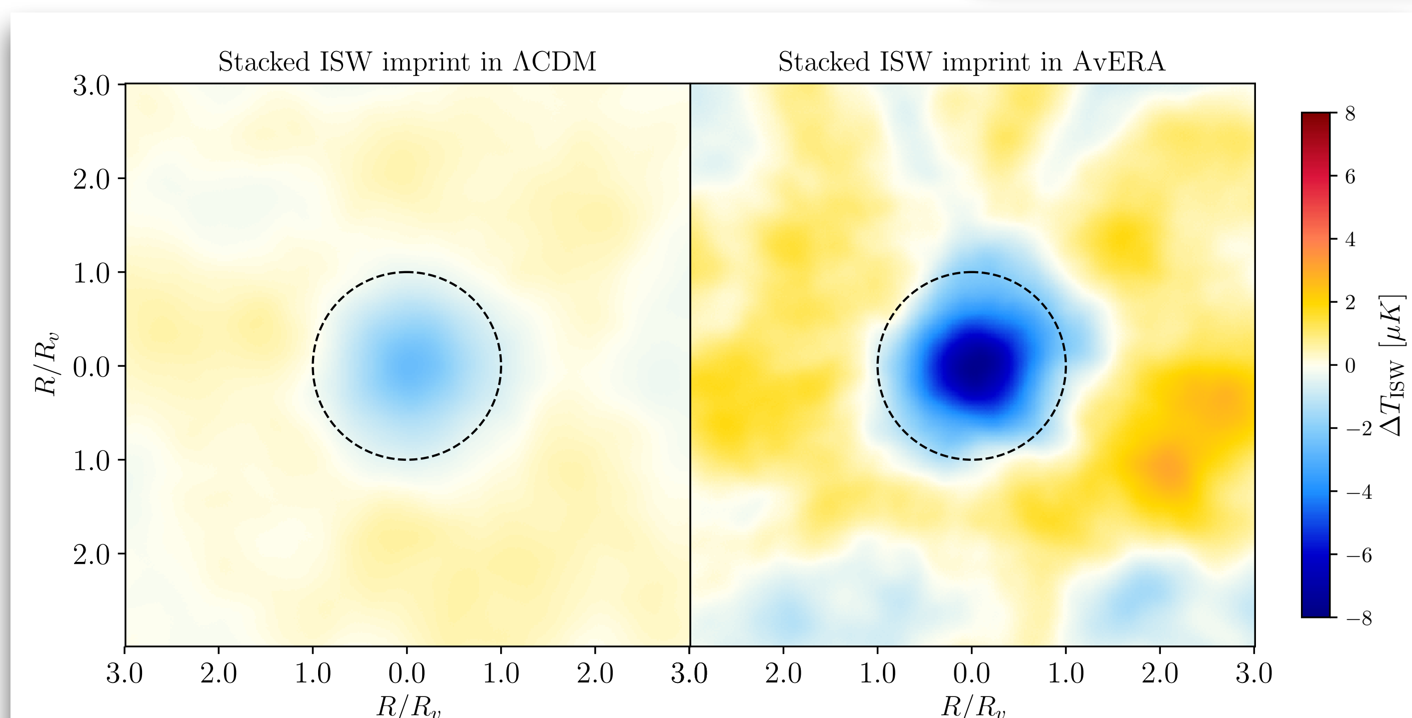


The stacked imprint of Millennium XXL supervoids



X



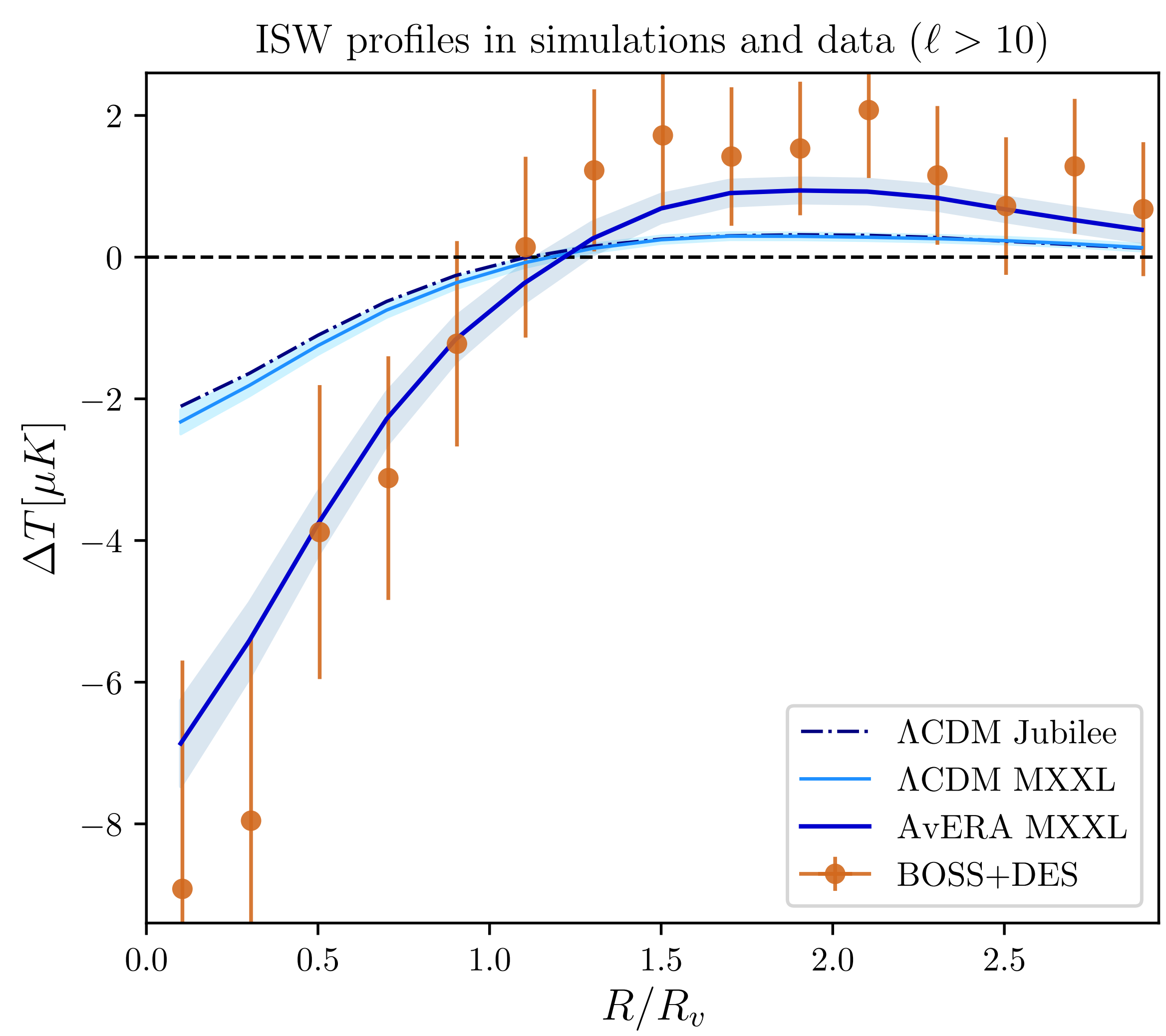


The stacked imprint of Millennium XXL supervoids

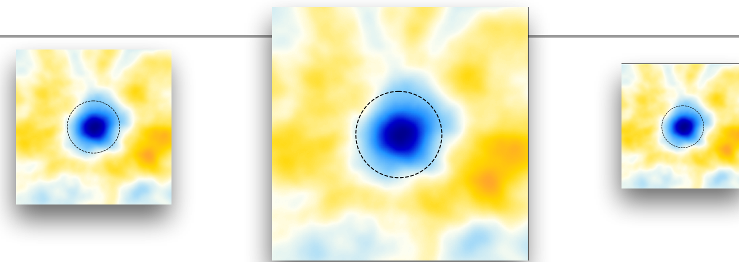
- **AvERA results closely match BOSS+DES Y3 observations**
- **Not fit to data, same AvERA model as in the Hubble tension problem**
- **Cross-check in ΛCDM: the Jubilee ISW simulation that we used before to estimate this signal is in good agreement with our MXXL ΛCDM result**
- **Already an important finding but there is more**

$$\frac{d\Phi\left(\vec{k}(\tau),\tau\right)}{d\tau} = \frac{3}{2}\frac{H_0^2}{k^2}\Omega_m\left[H(\tau)\delta\left(\vec{k},\tau\right)\underline{(1-\beta(\tau))}\right]$$

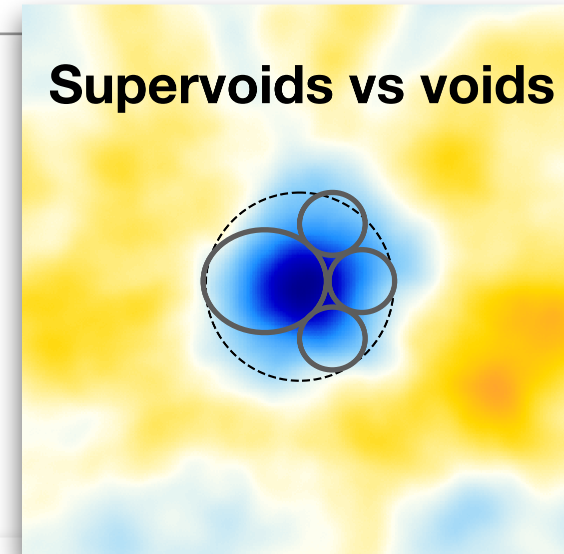
Growth rate

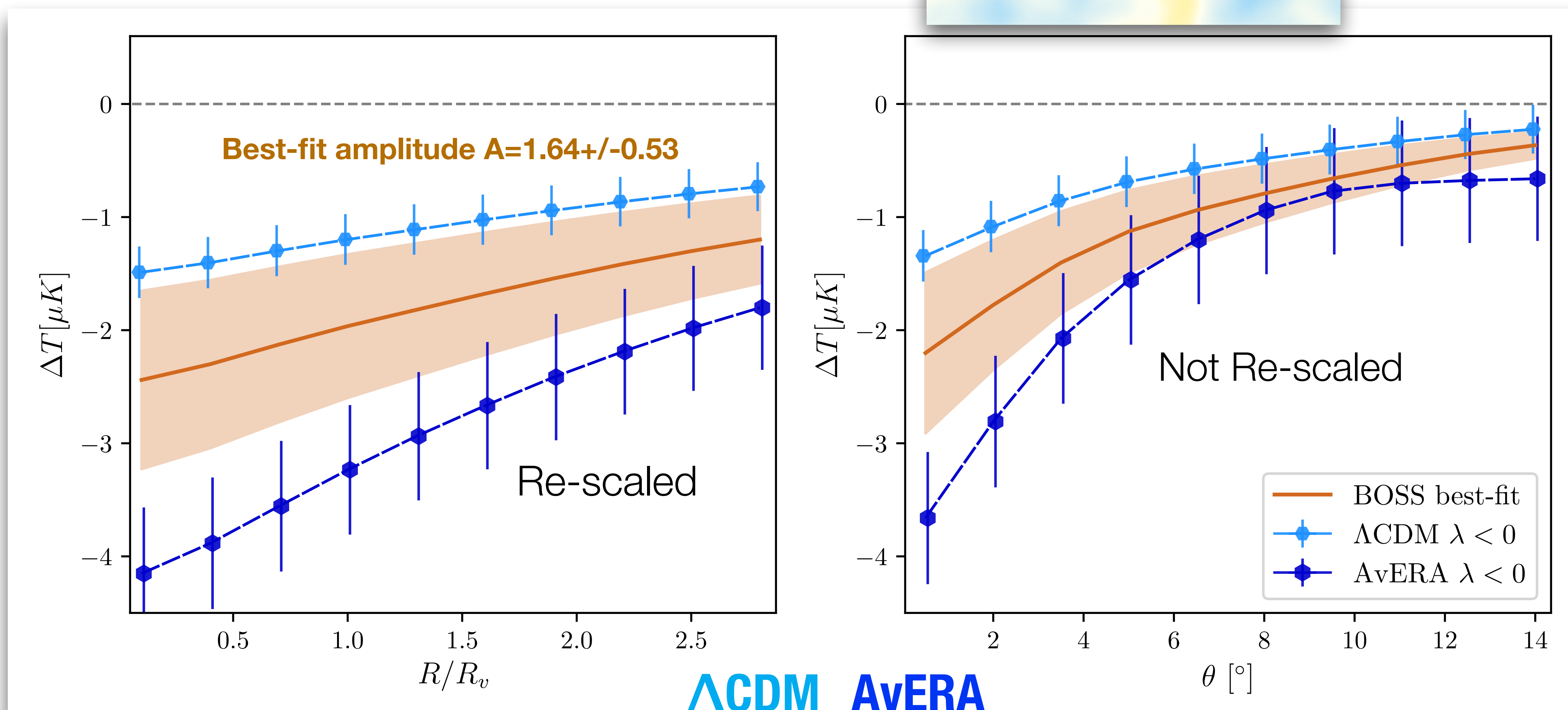


Checking up on the Nadathur & Crittenden results



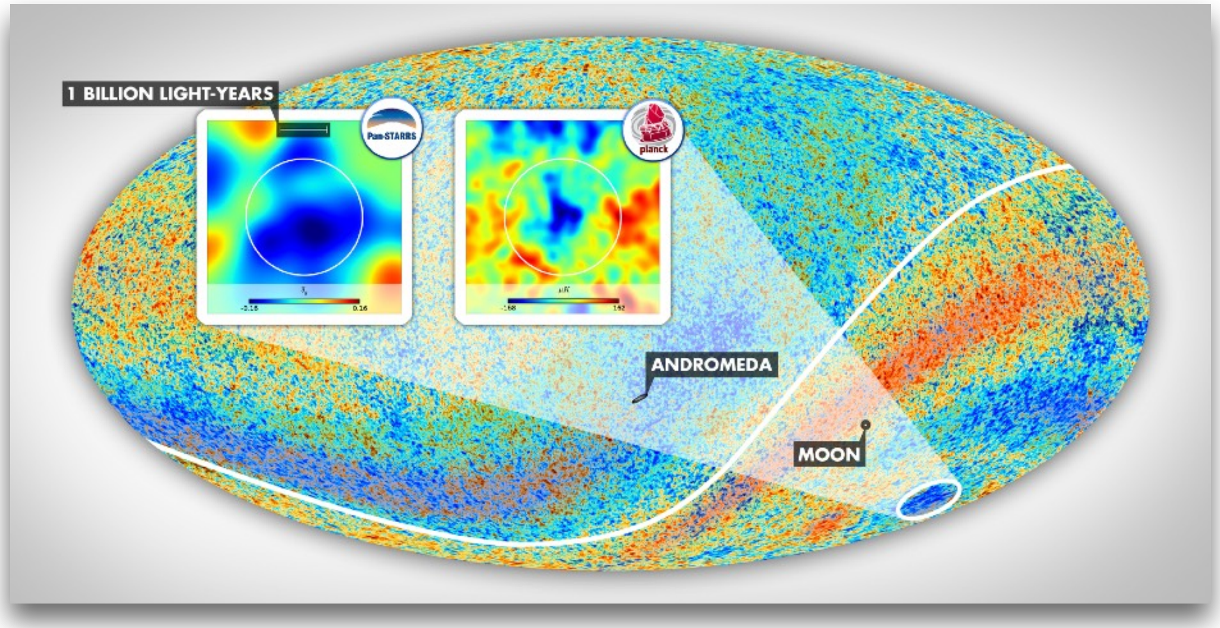
The AvERA signal can remain *hidden* with their analysis





AvERA and the CMB Cold Spot - a bonus

- Evidence for a low-z supervoid aligned with the Cold Spot
- Galaxy density field, cosmic flows, etc all suggest a supervoid that has at least 3-4 sub-voids
- debate if the CMB Cold Spot and the Eridanus supervoid are in causal relation
- Same problem: ΛCDM models predict 4-5 times smaller signal than the observed CMB profile



Can a supervoid explain the Cold Spot?

Seshadri Nadathur,[1] Mikko Lavinto,[1] Shaun Hotchkiss,[2] and Syksy Räsänen[1]

[1] *Physics Department, University of Helsinki and Helsinki Institute of Physics, P.O. Box 64, FIN-00014, Helsinki, Finland*
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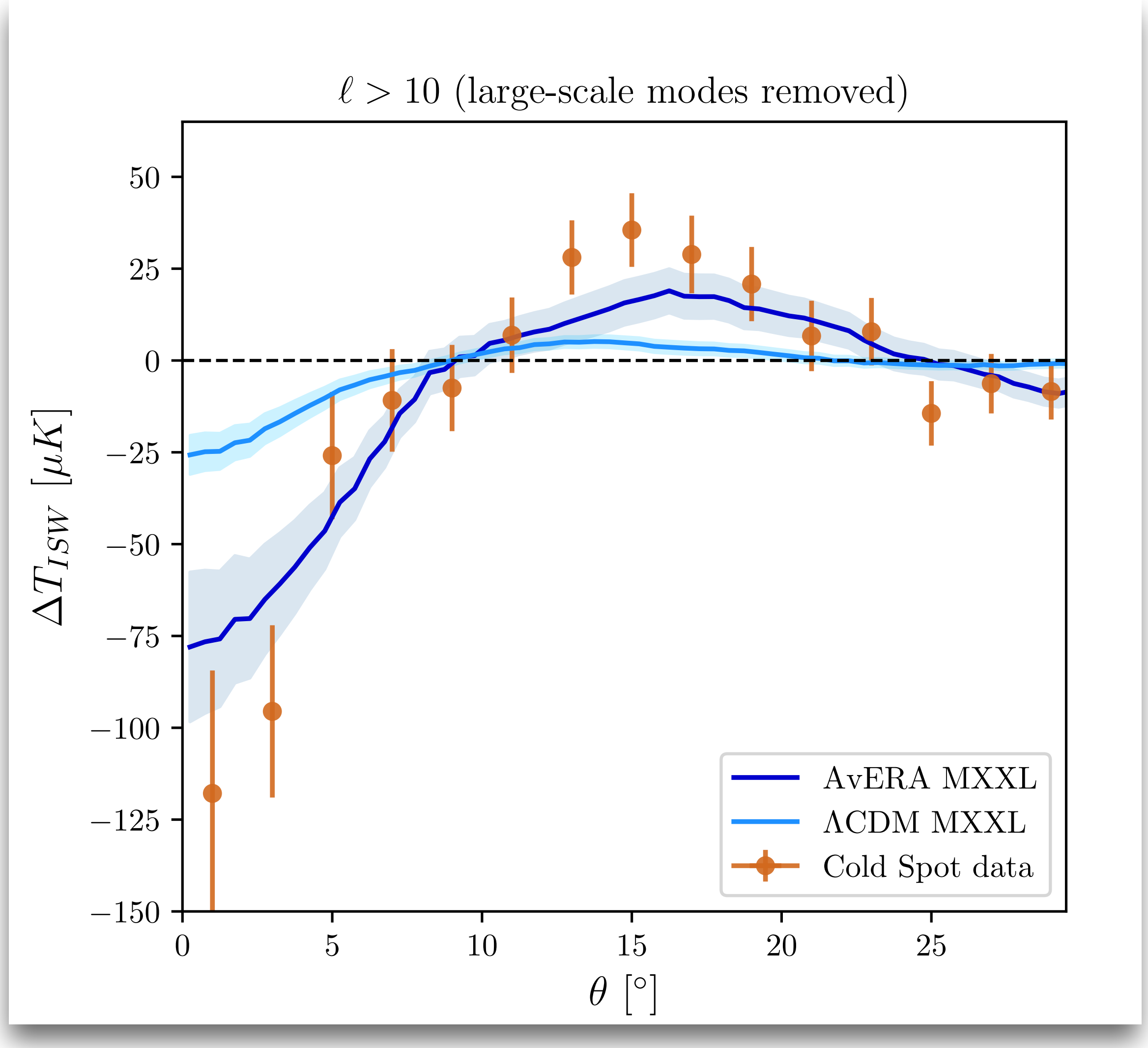
(Dated: September 10, 2018)

The discovery of a void of size $\sim 200\ h^{-1}$Mpc and average density contrast of ~ -0.1 aligned with the Cold Spot direction has been recently reported. It has been argued that, although the first-order integrated Sachs-Wolfe (ISW) effect of such a void on the CMB is small, the second-order Rees-Sciama (RS) contribution exceeds this by an order of magnitude and can entirely explain the observed Cold Spot temperature profile. In this paper we examine this surprising claim using both an exact calculation with the spherically symmetric Lemaître–Tolman–Bondi metric, and perturbation theory about a background Friedmann–Robertson–Walker (FRW) metric. We show that both approaches agree well with each other, and both show that the dominant temperature contribution of the postulated void is an unobservable dipole anisotropy. If this dipole is subtracted, we find that the remaining temperature anisotropy is dominated by the linear ISW signal, which is orders of magnitude larger than the second-order RS effect, and that the total magnitude is too small to explain the observed Cold Spot profile. We calculate the density and size of a void that would be required to explain the Cold Spot, and show that the probability of existence of such a void is essentially zero in ΛCDM. We identify the importance of *a posteriori* selection effects in the identification of the Cold Spot, but argue that even after accounting for them, a supervoid explanation of the Cold Spot is always disfavoured relative to a random statistical fluctuation on the last scattering surface.

Coldest Spots in AvERA vs in ΛCDM versions of MXXL

1. Filter the CMB temperature map with a SMHW (as in data)
2. Choose the coldest region as the one with strongest response

- **The AvERA prediction is again in great agreement with observed data**
- **Other ΛCDM simulations with slightly different cosmology and mapmaking pipeline give a similar answer**
- **The starting point of the ray-tracing or a slightly different filter scale makes no difference**



The main findings in our MXXL ISW analysis

1. The excess ISW signals can be explained by the AvERA model

2. We presented evidence for the importance of seemingly trivial ISW analysis choices that may cover up the true signal

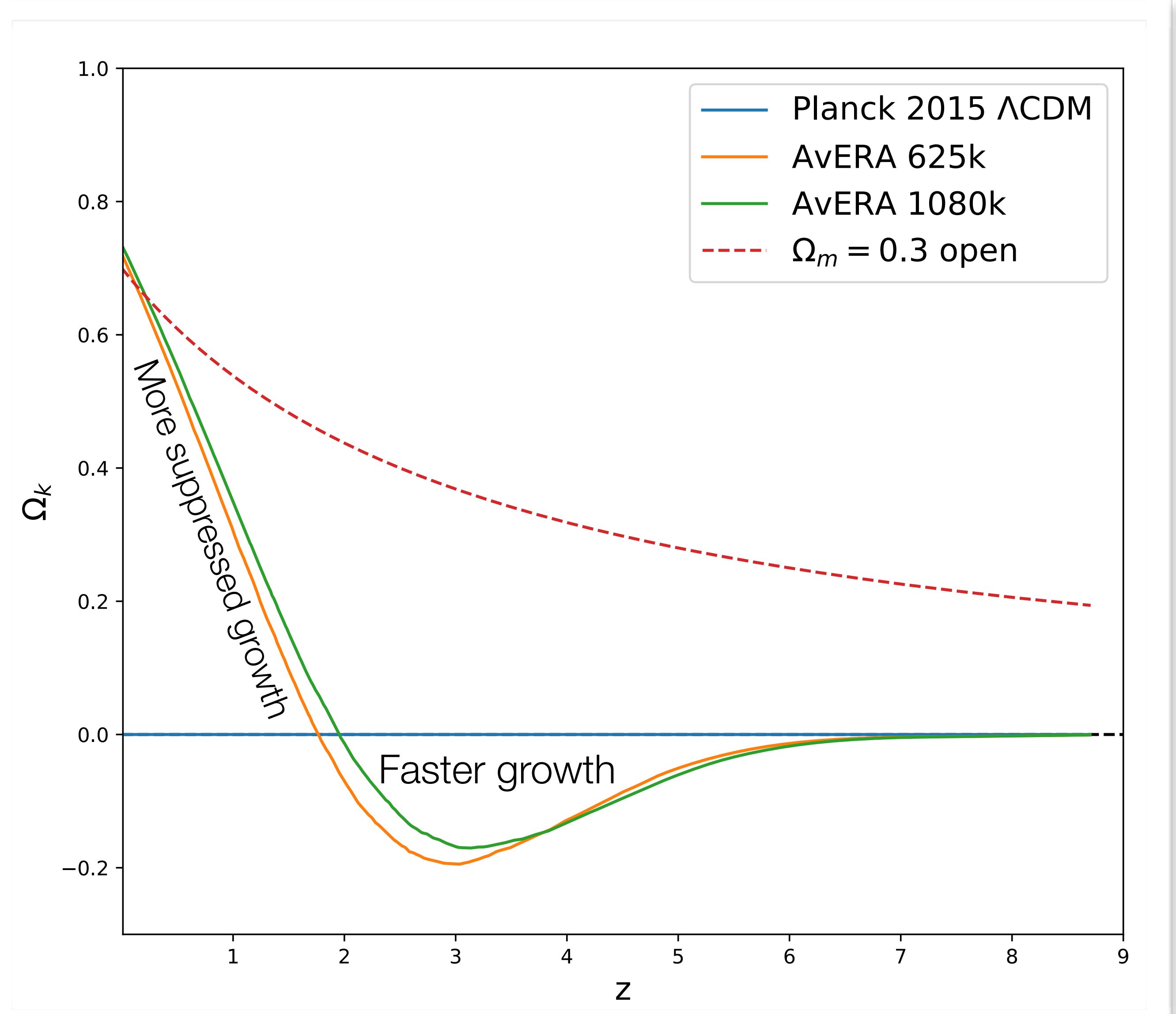
3. The ISW tension is plausibly related to *the* Cold Spot anomaly

The price to pay is to introduce emerging curvature and abandon Λ and FLRW

Summary

See Kovács et al. for further information
arXiv:2004.02937

- **the DES Y3 data probed the ISW effect in a new window and confirmed previous excess signals in SDSS/BOSS**
- **MXXL simulation results indicate that the ISW tension is plausibly related to the Hubble tension**
- **To be understood in AvERA: BAO with emerging curvature, growth rate constraints, galaxy bias, etc.**
- **Future: opposite-sign ISW at z>1.4 in AvERA (eBOSS, DESI, Euclid)**



See e.g. Heinesen & Buchert https://arxiv.org/abs/2002.10831