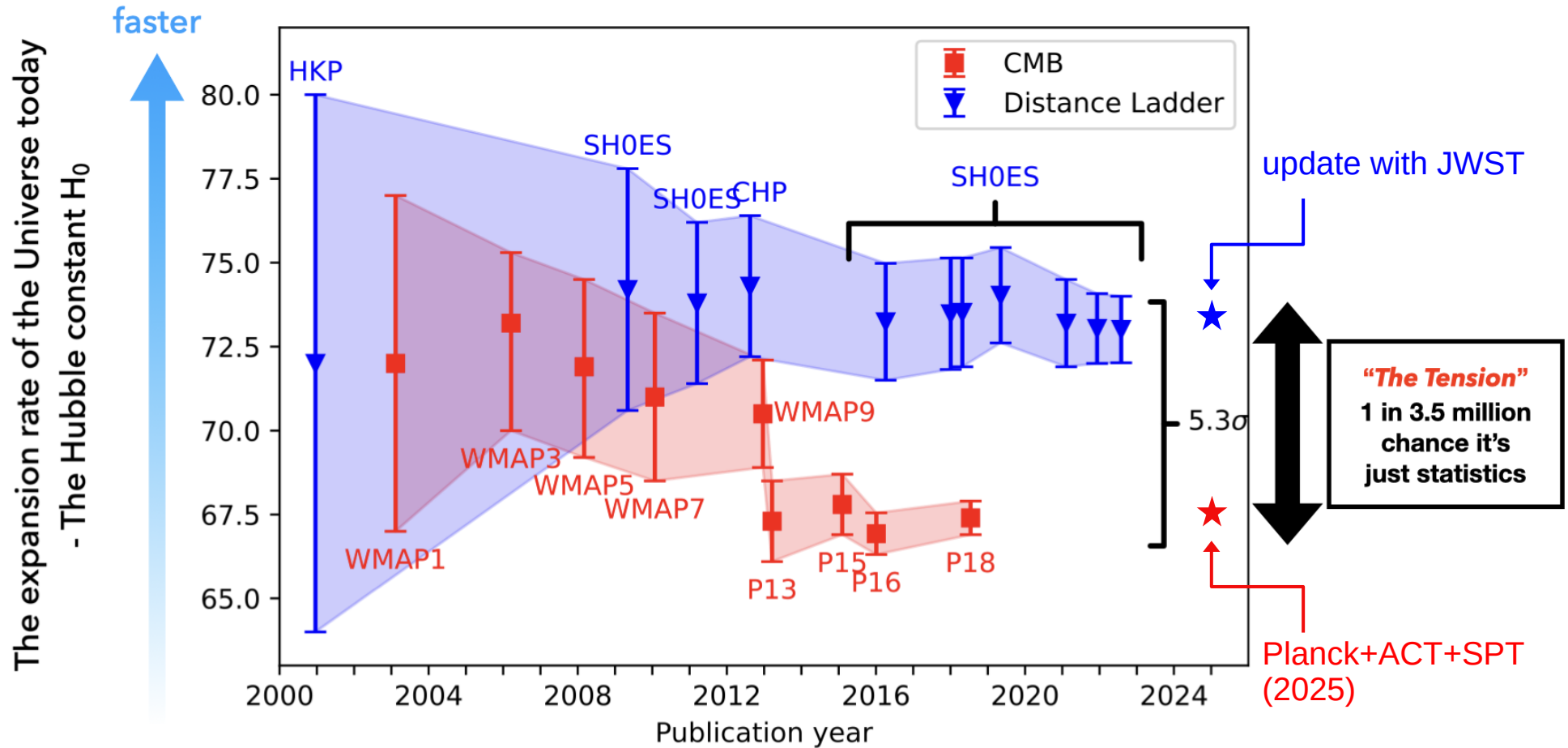# Tensions in Cosmology
CMB vs BAO vs SN

Lukas Tobias Hergt

Univers du pôle A2C

The "Hubble Tension"

Credit: D'arcy Kenworthy

Clustering Tension (a.k.a. σ_8 or S_8 tension):
Weak Lensing (WL) vs Cosmic Microwave Background (CMB)
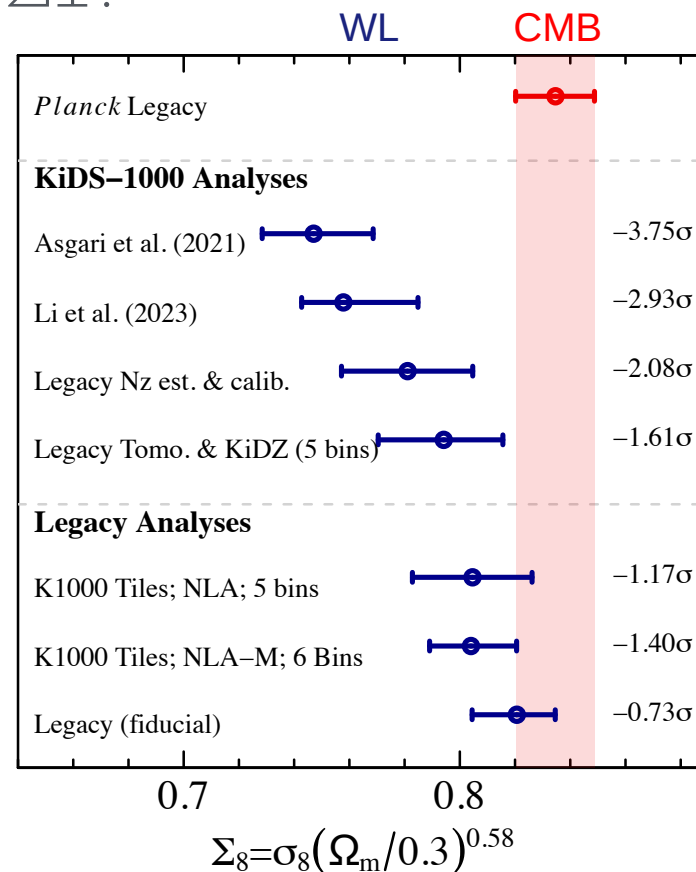
What changed since 2021?

Driving Factors

- New spectroscopic sample for $N(z)$ estimation

- Updated $N(z)$ calibration and estimation methods

- New imaging, new area

Further changes

- Revised scale cut
- New IA modelling
- New tomography
- New $P(k)$ emulation
- New sampler
- New analysis pipelines

Wright et al. (2025b)

	WL	CMB	
Planck Legacy		⊢○⊣	
KiDS–1000 Analyses			
Asgari et al. (2021)	⊢○⊣		−3.75σ
Li et al. (2023)	⊢○⊣		−2.93σ
Legacy Nz est. & calib.	⊢○⊣		−2.08σ
Legacy Tomo. & KiDZ (5 bins)	⊢○⊣		−1.61σ
Legacy Analyses			
K1000 Tiles; NLA; 5 bins	⊢○⊣		−1.17σ
K1000 Tiles; NLA–M; 6 Bins	⊢○⊣		−1.40σ
Legacy (fiducial)	⊢○⊣		−0.73σ

$$\Sigma_8 = \sigma_8(\Omega_m/0.3)^{0.58}$$

Cosmological Constant Tension ?

- Standard model of Cosmology:

  - ΛCDM with cosmological constant Λ

  - Corresponding equation-of-state parameters of Dark Energy:

    → $w_0 = -1$

    → $w_a = 0$

- CMB + BAO + SN:
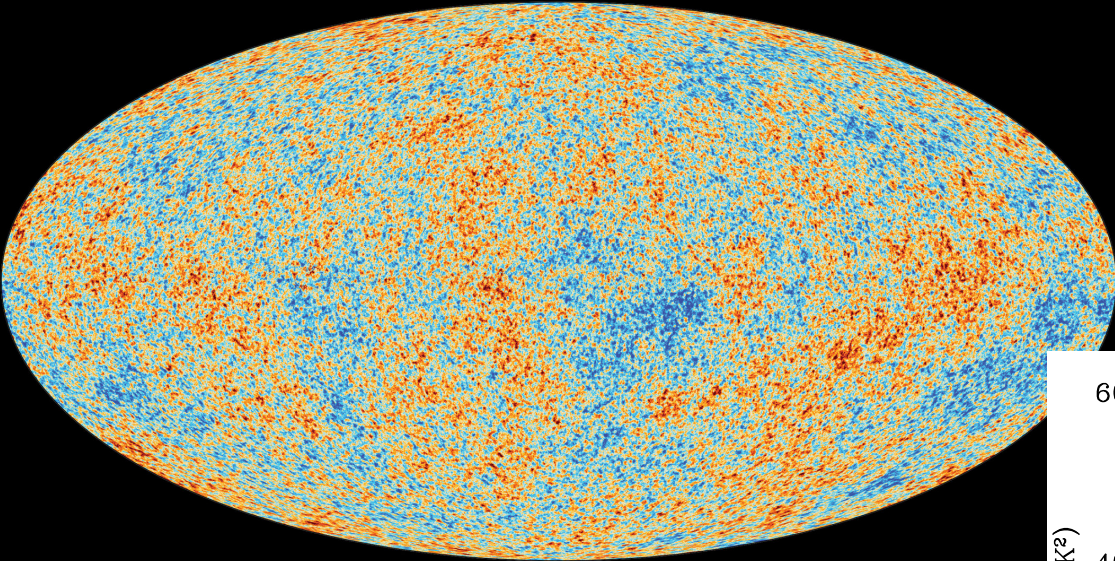 Preference for $w_0 w_a$CDM?
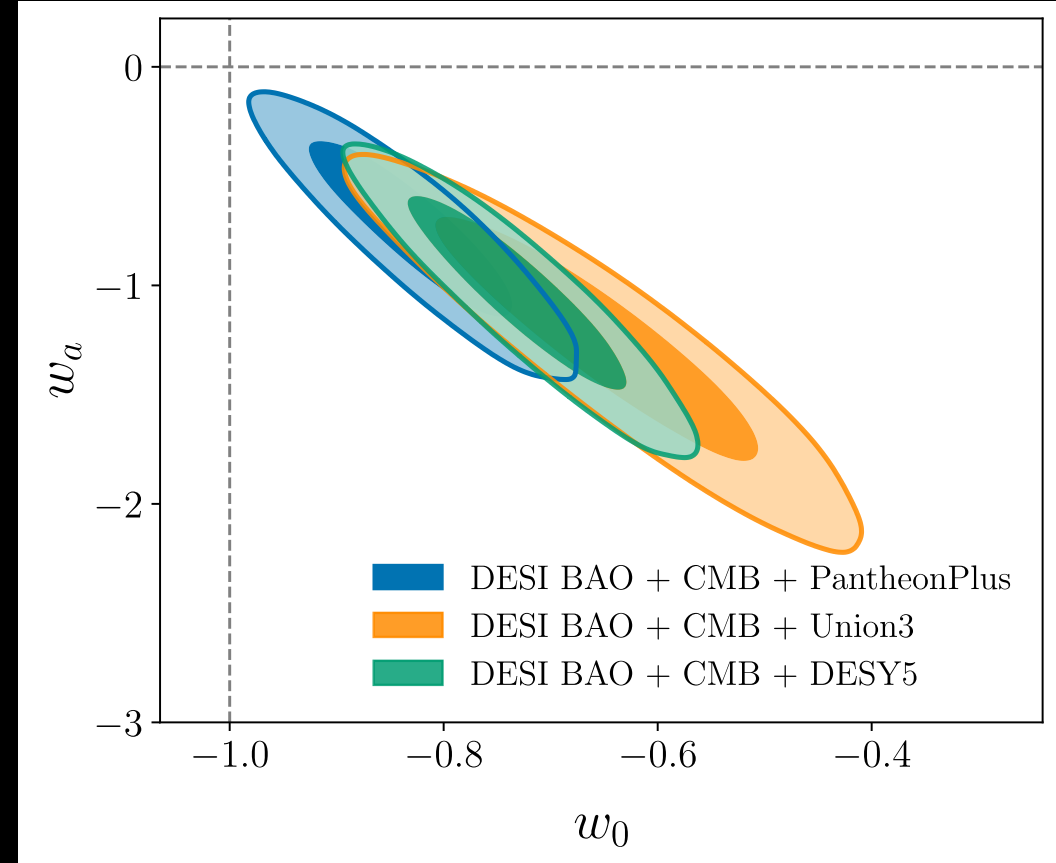
Credit: DESI Collaboration (2025)

The Cosmic Microwave Background (CMB)
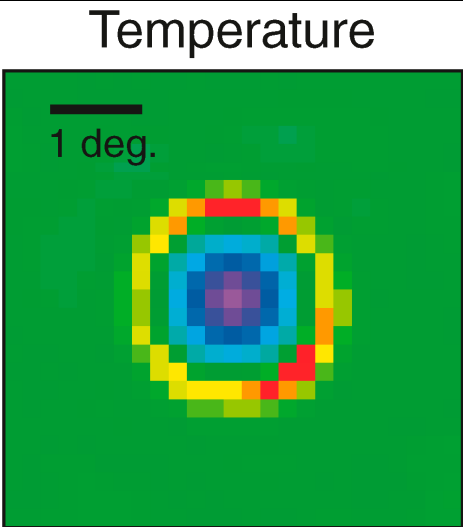
CMB = snapshot of anisotropies at recombination

Credit: ESA and Planck Collaboration
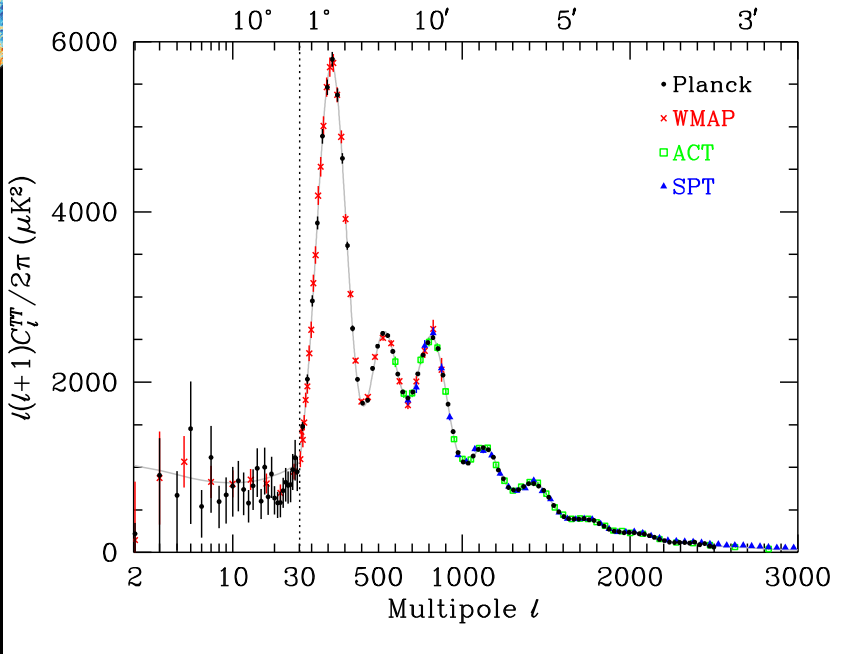
Temperature

Cold Spot WMAP Data

1 deg.

Credit: WMAP Collaboration

Stacking on
Cold Spots

Angular Power Spectrum
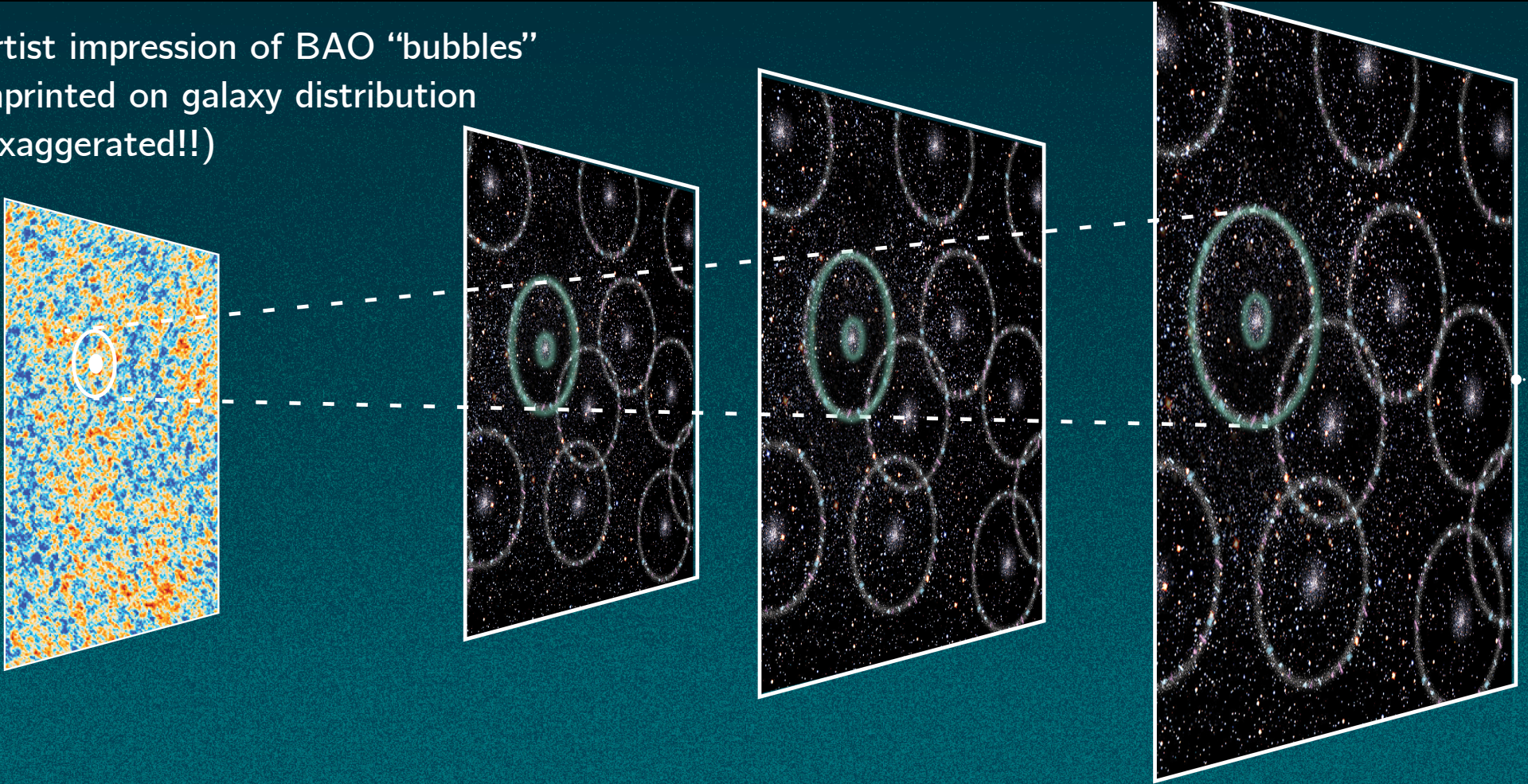("Fourier Transform" of
2-point correlation function)

Credit: Particle Data Group

Baryon Acoustic Oscillations (BAO)

Artist impression of BAO "bubbles" imprinted on galaxy distribution (exaggerated!!)
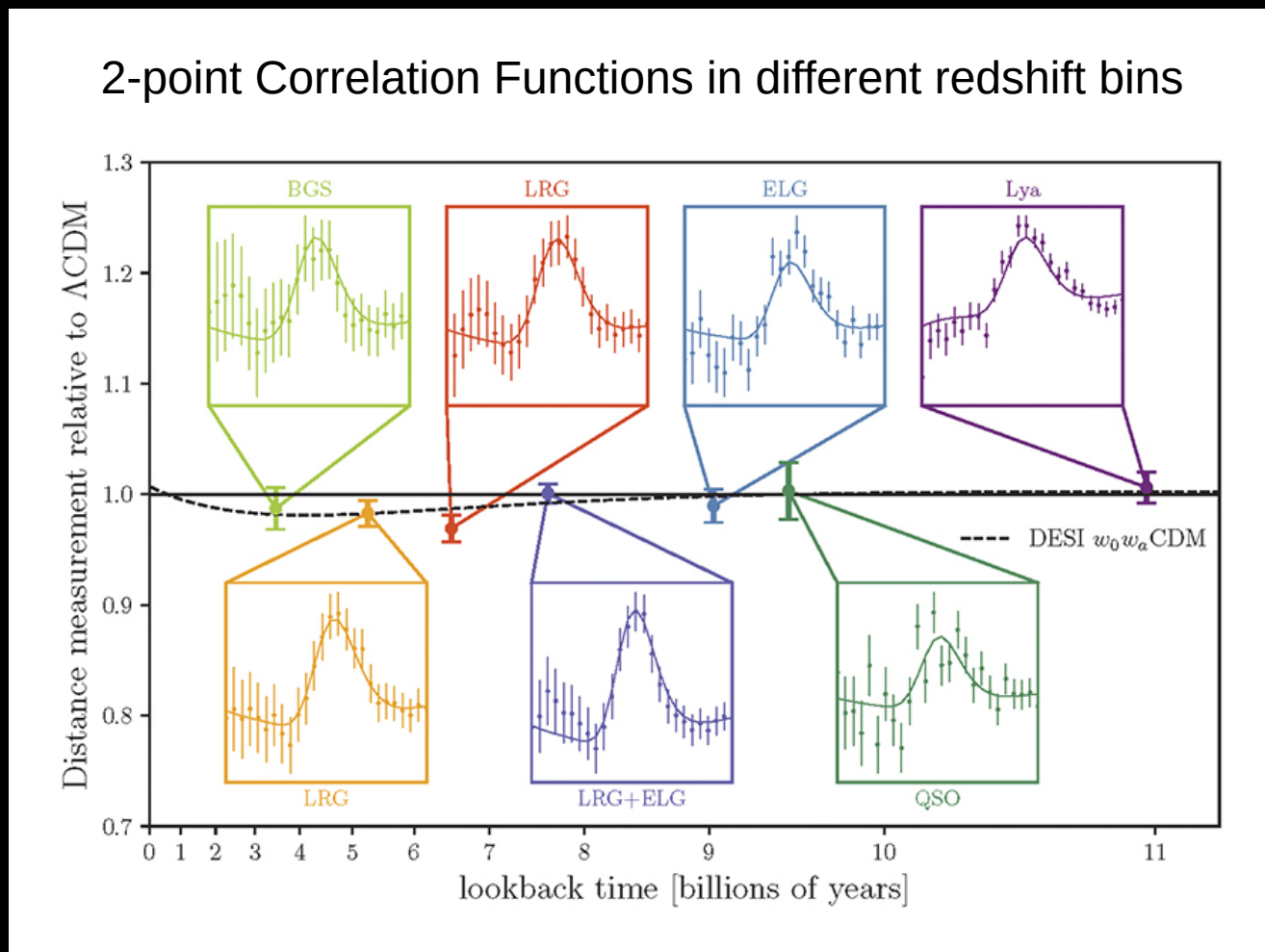

Source: ESA and the Planck Collaboration / Gabriela Secara / Perimeter Institute
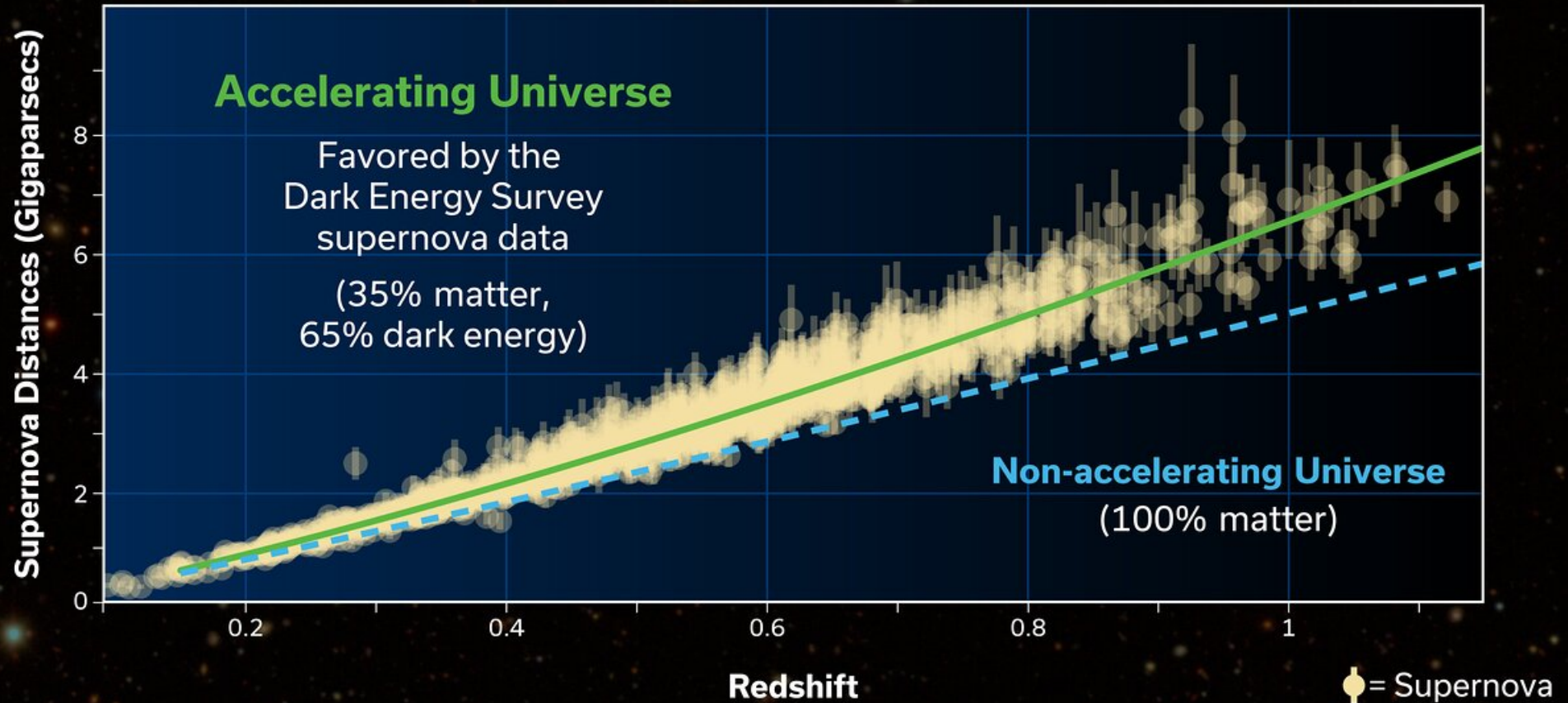
Baryon Acoustic Oscillations (BAO)

- Interplay between gravity and photon-baryon-pressure in the early Universe

  → overdensities propagate as sound waves

- Waves freeze when Universe becomes neutral (at recombination)

  → characteristic length scale: sound horizon

  → Standard Ruler

2-point Correlation Functions in different redshift bins

Credit: DESI Collaboration (2024)

SUPERNOVA HUBBLE DIAGRAM

Accelerating Universe
Favored by the
Dark Energy Survey
supernova data
(35% matter,
65% dark energy)

Non-accelerating Universe
(100% matter)

Supernova Distances (Gigaparsecs)
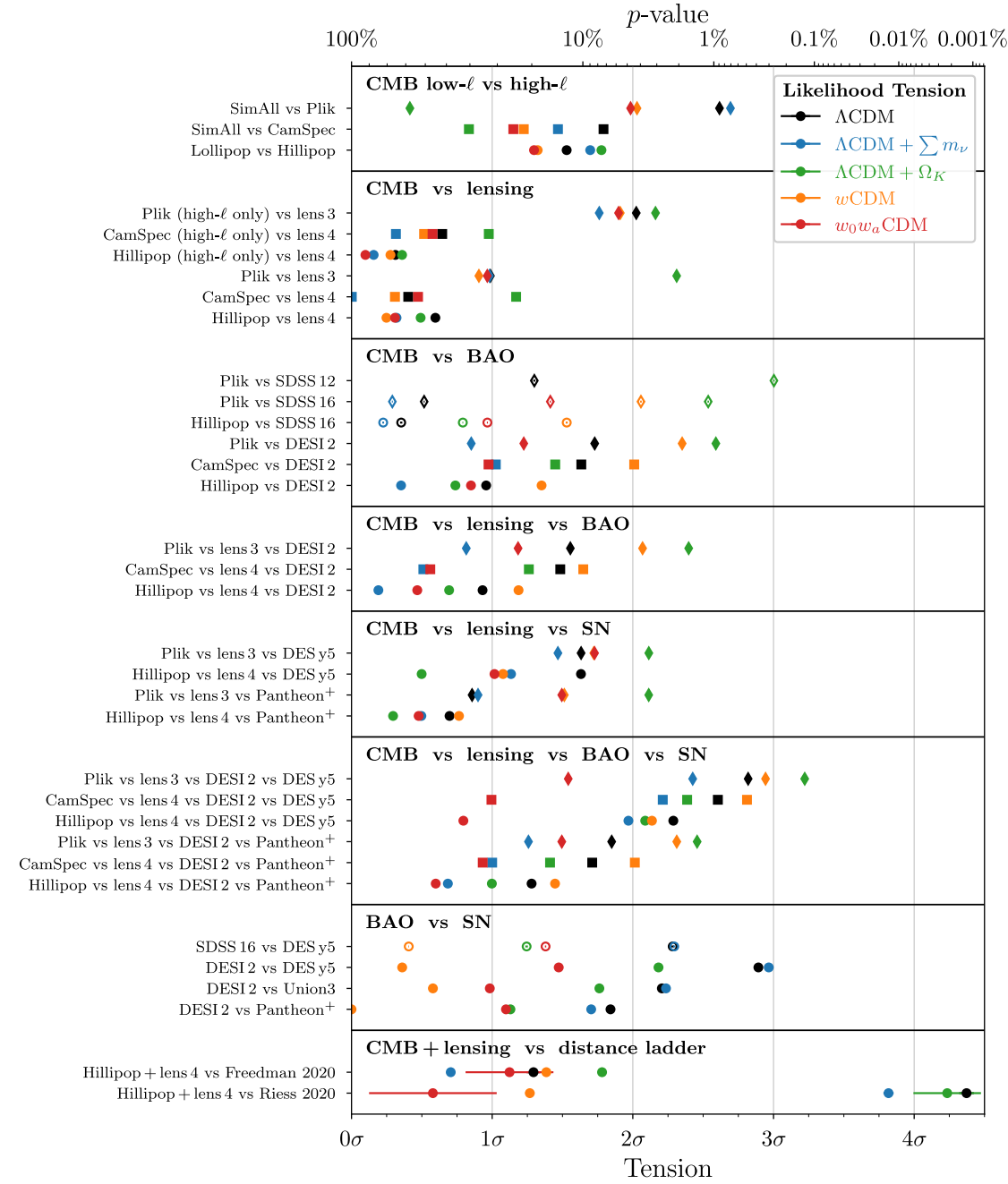
Redshift

= Supernova

Credit: DES Collaboration
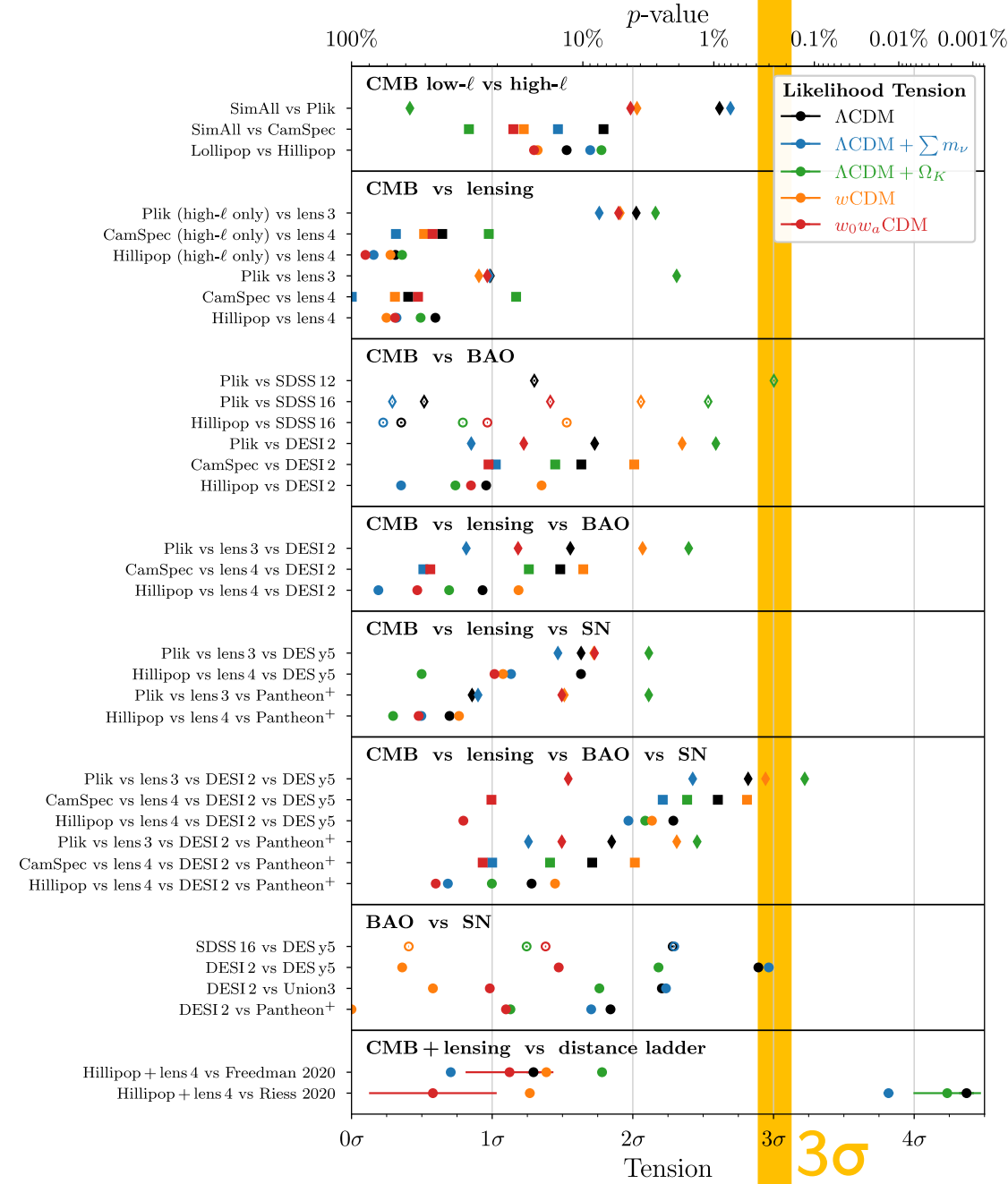
Lukas T. Hergt   8

Slightly overwhelming overview

Range of dataset combinations

- **CMB:** Planck PR3 and PR4
  - low-ℓ: SimAll, Lollipop
  - high-ℓ: Plik, CamSpec, Hillipop

- **CMB lensing:**
  - Planck PR3 and PR4

- **BAO:**
  - SDSS DR12 and DR16
  - DESI DR2

- **SN:**
  - Pantheon+
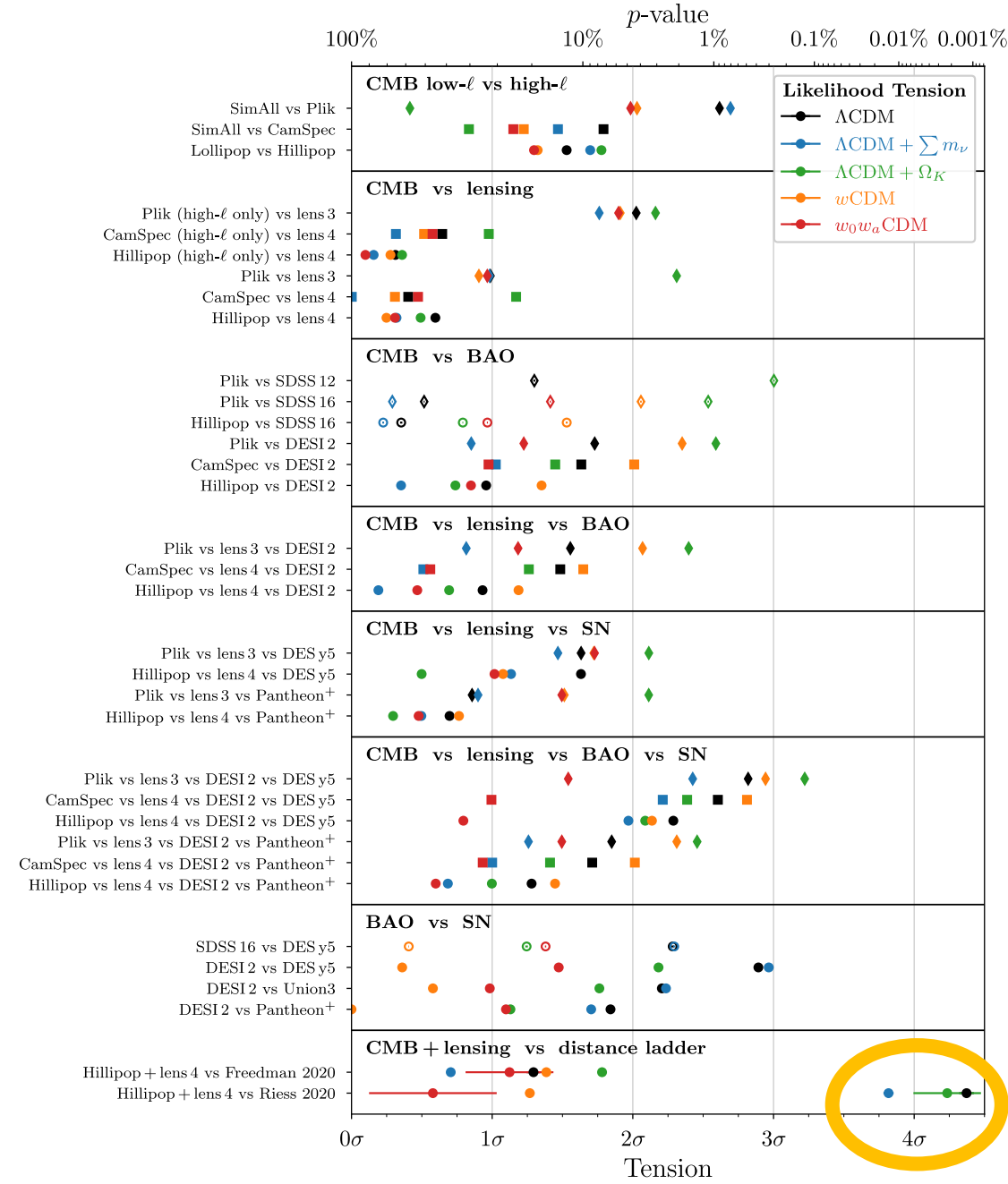 - DES year-5

Lukas T. Hergt

Slightly overwhelming overview

Remark 1:
Allmost all points below 3σ line.
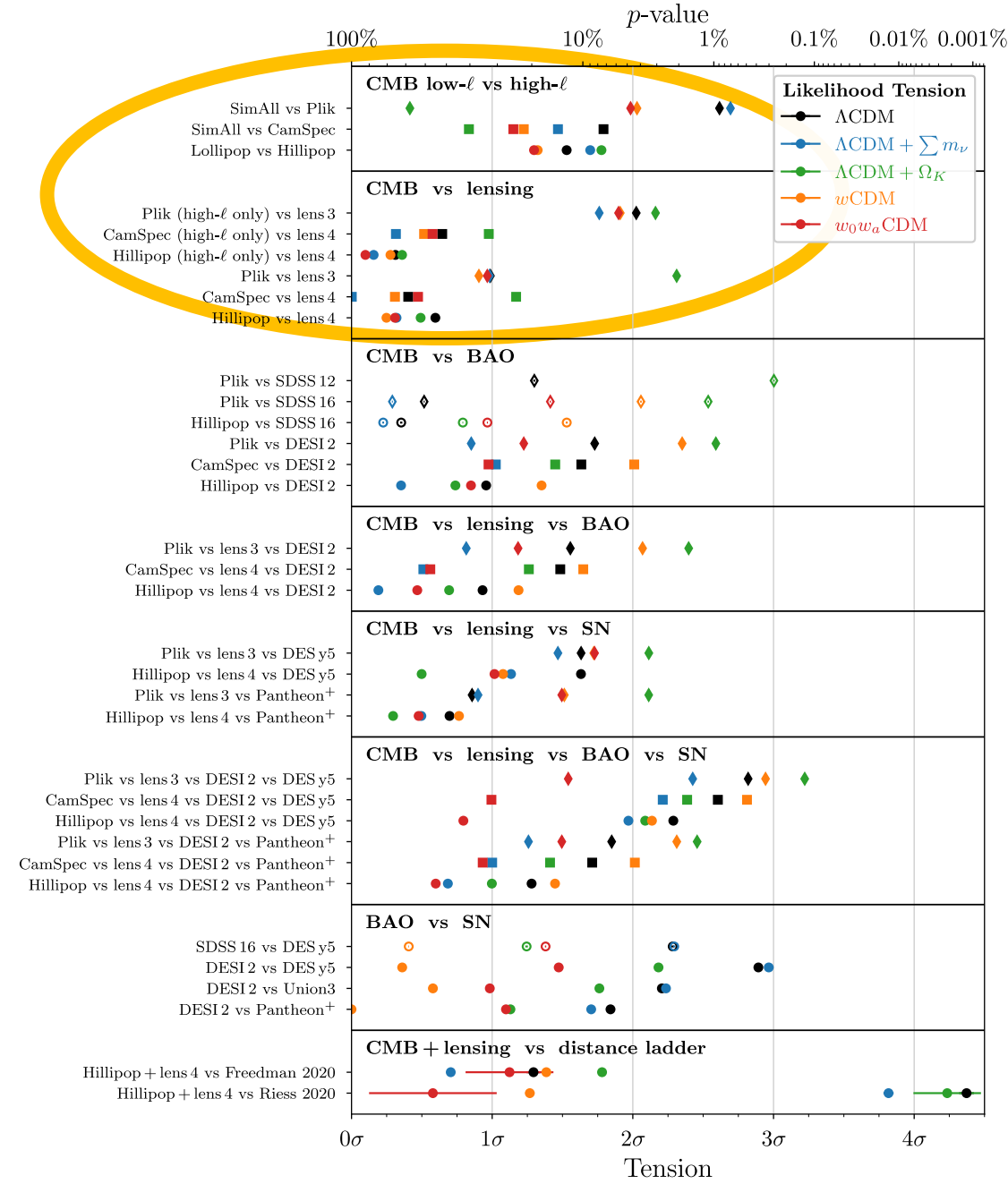
Lukas T. Hergt

Slightly overwhelming overview

Remark 2:
Hubble Tension clearly strongest.

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Slightly overwhelming overview
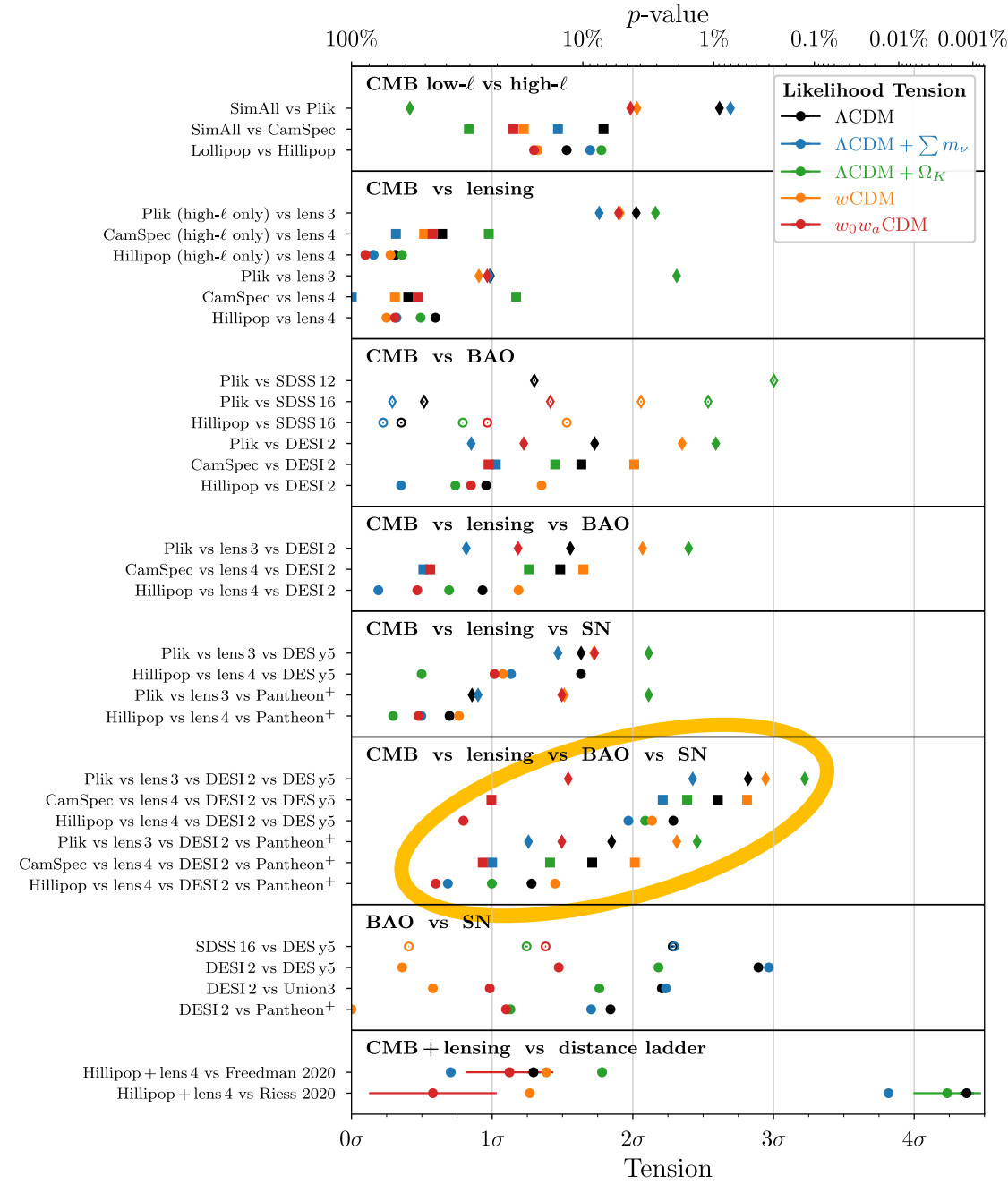
Remark 3:
CMB internal tensions have also reached beyond 2σ in the past.

Slightly overwhelming overview

Remark 4:
Highly variable tension statistics dependent on dataset choices for CMB vs BAO vs SN.
(Independent of theory model!)

Comparison of Planck Likelihoods

- ## Plik:
  - Planck PR3 (2018)

- ## CamSpec:
  - Planck PR4 (2020)
  - pre-cleaning of galactic dust
  - fitting of foreground residuals

- ## Hillipop:
  - Planck PR4 (2020)
  - fitting of foreground spectra
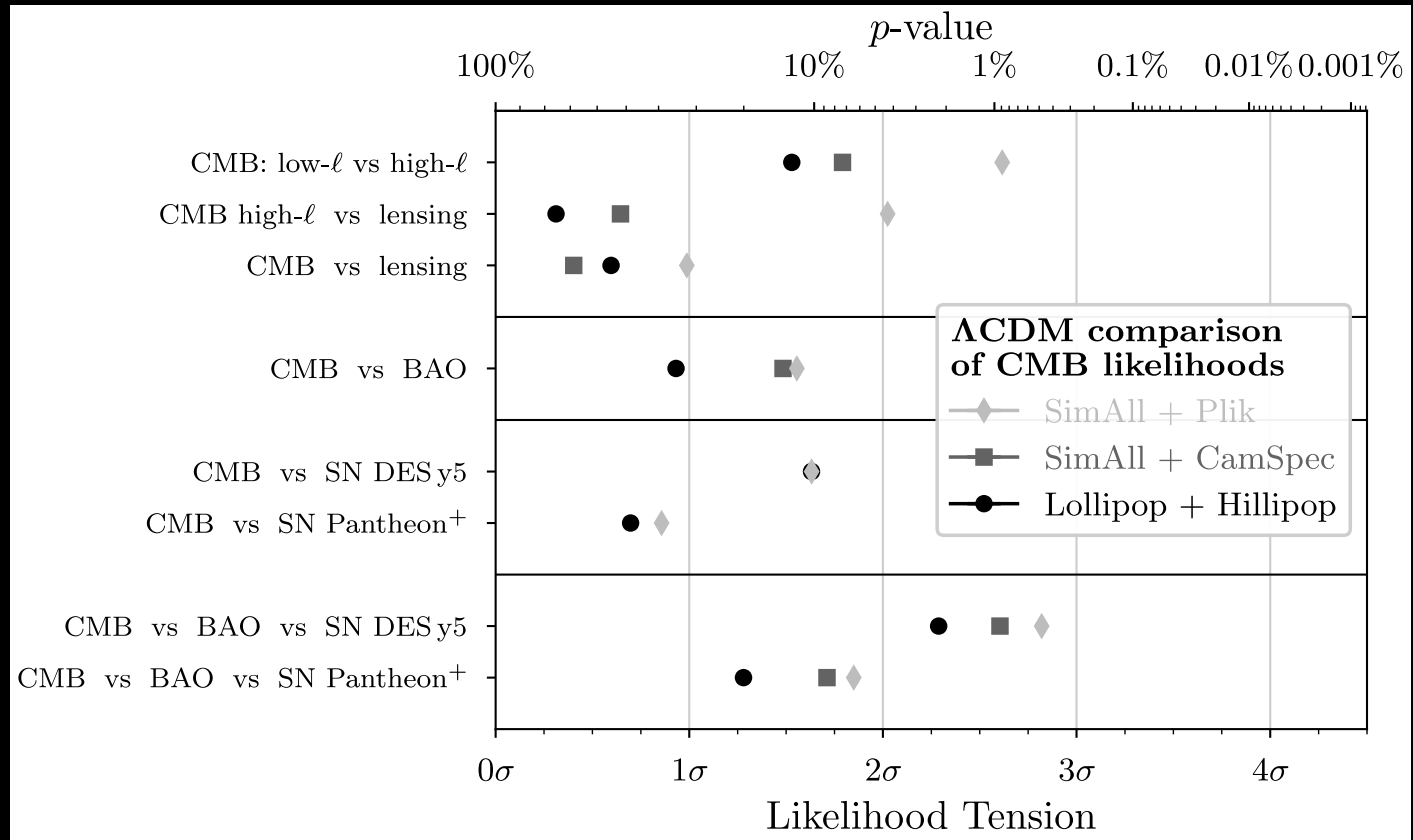
Takeaway:
Big shifts in tension statistics from choice of CMB likelihood pipeline (for the same data!)
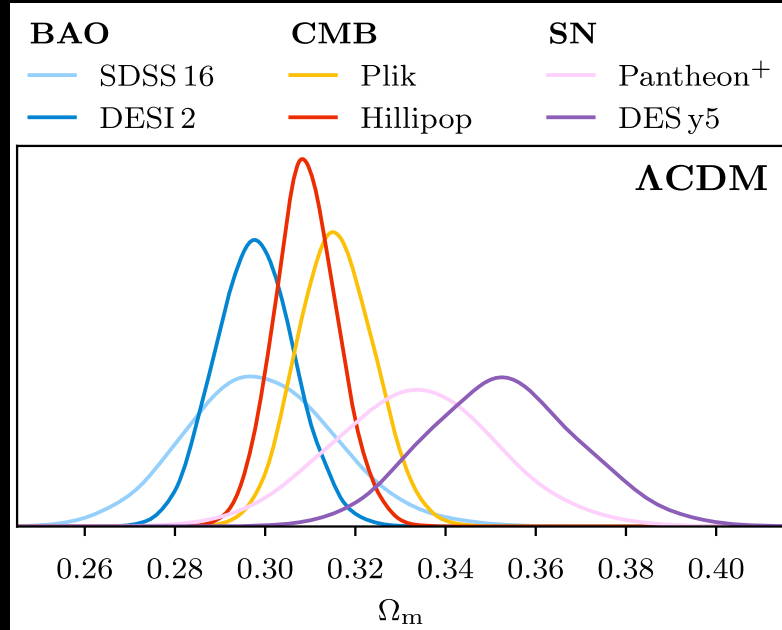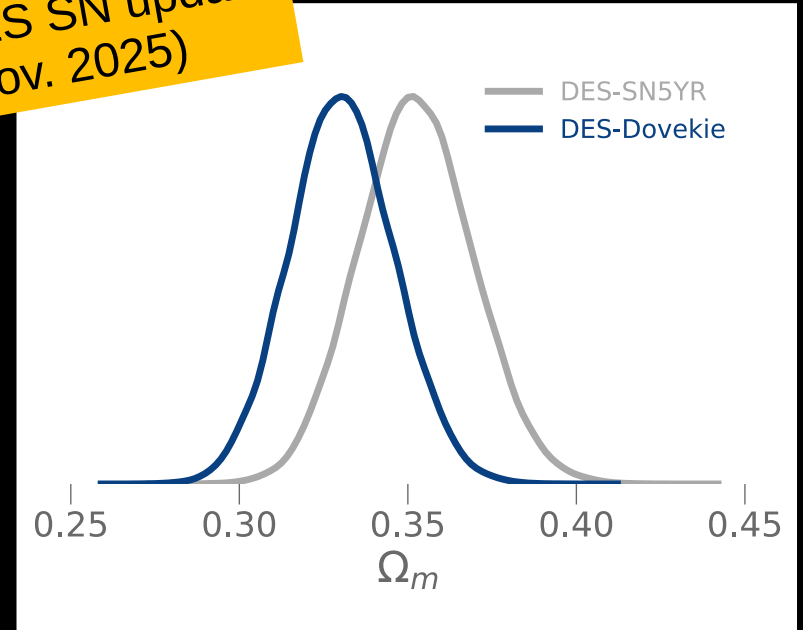
Comparison of Supernovae Likelihoods
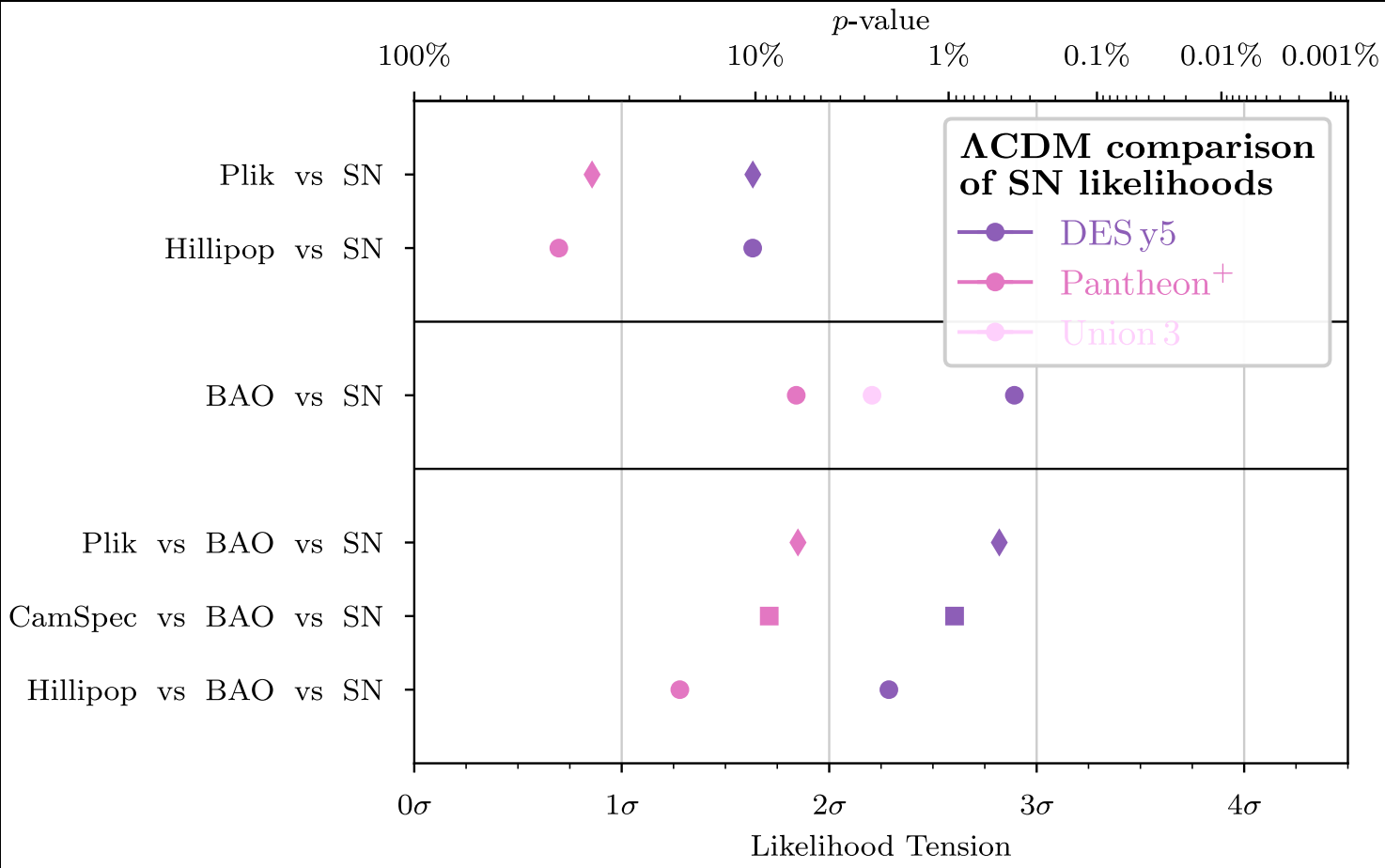
Takeaway:
Big shifts in tension statistics from choice of SN likelihood.

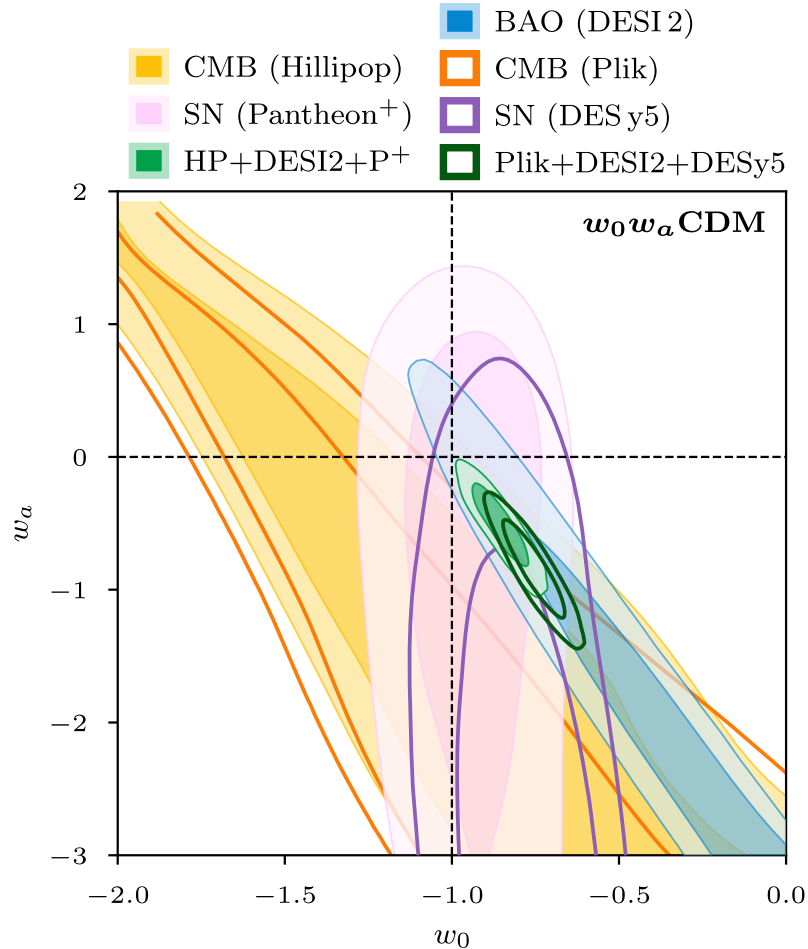# Tension driving parameter: Matter density Ω_m

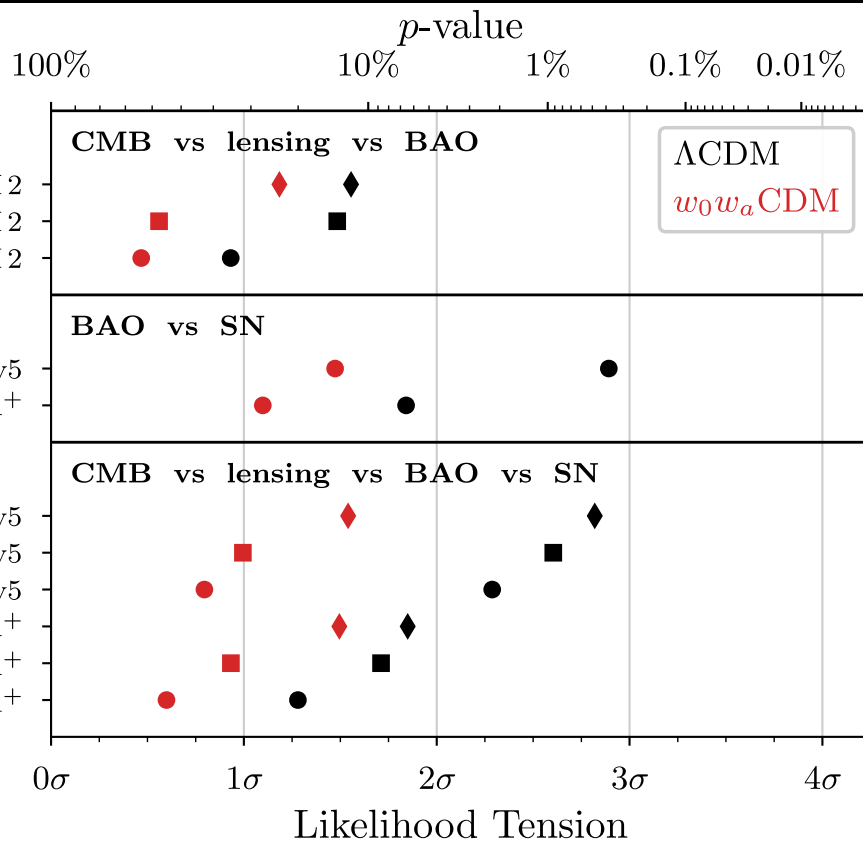DES SN update (Nov. 2025)

CMB vs BAO vs SN

Takeaway:
Cosmologic Constant Tension highly dependent on choice of dataset combination.

Conclusion

- Hubble Tension the only one clearly over 3σ threshold.

  - Still persisting after first JWST updates.

- Many tensions have reduced over time with analysis updates:

  - Clustering tension between Weak Lensing and CMB.

  - CMB low-ℓ vs high-ℓ or CMB vs lensing with updates PR3 → PR4.

  - SN update DES-y5 → DES-Dovekie.

- Tensions vary with choice of CMB likelihood:

  - 0.5σ to 1.5σ.

  - Trend: tensions reduce from Plik → CamSpec → Hillipop

  - Note: tensions might tighten for ACT & SPT

- Tensions vary with choice of SN likelihood:

  - −1σ going from DES-y5 → Pantheon+

- Cosmological Constant Tension and preference for w_0w_aCDM highly dependent on dataset combination:

  - Only specifically for Plik + DESI + DES-y5

 - Gone with Hillipop + DESI + Pantheon+

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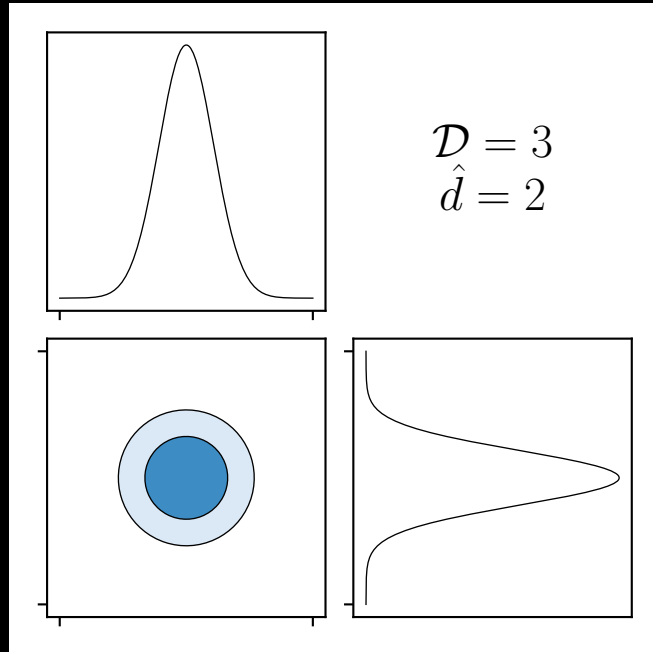 - Gone with Hillipop + DESI + Pantheon+

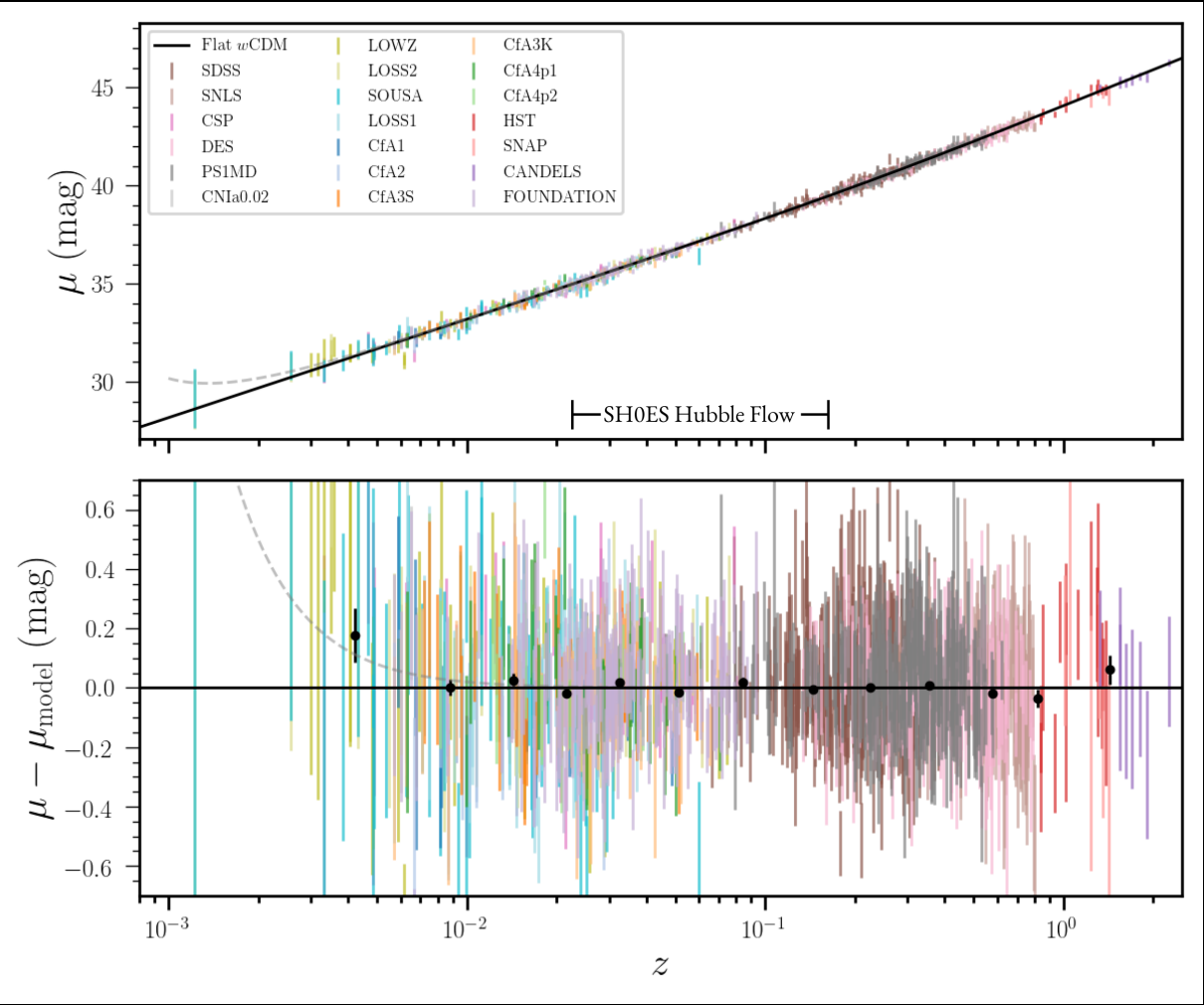# Tensions can be hidden in 2d projections
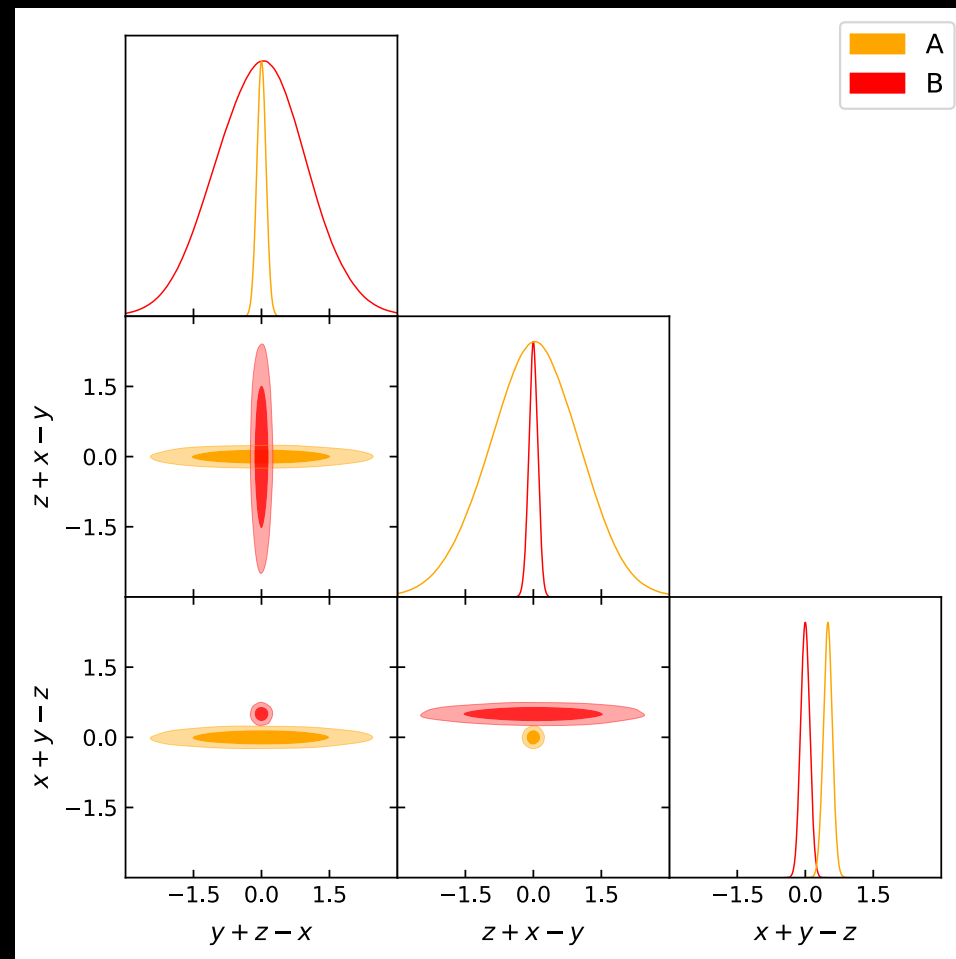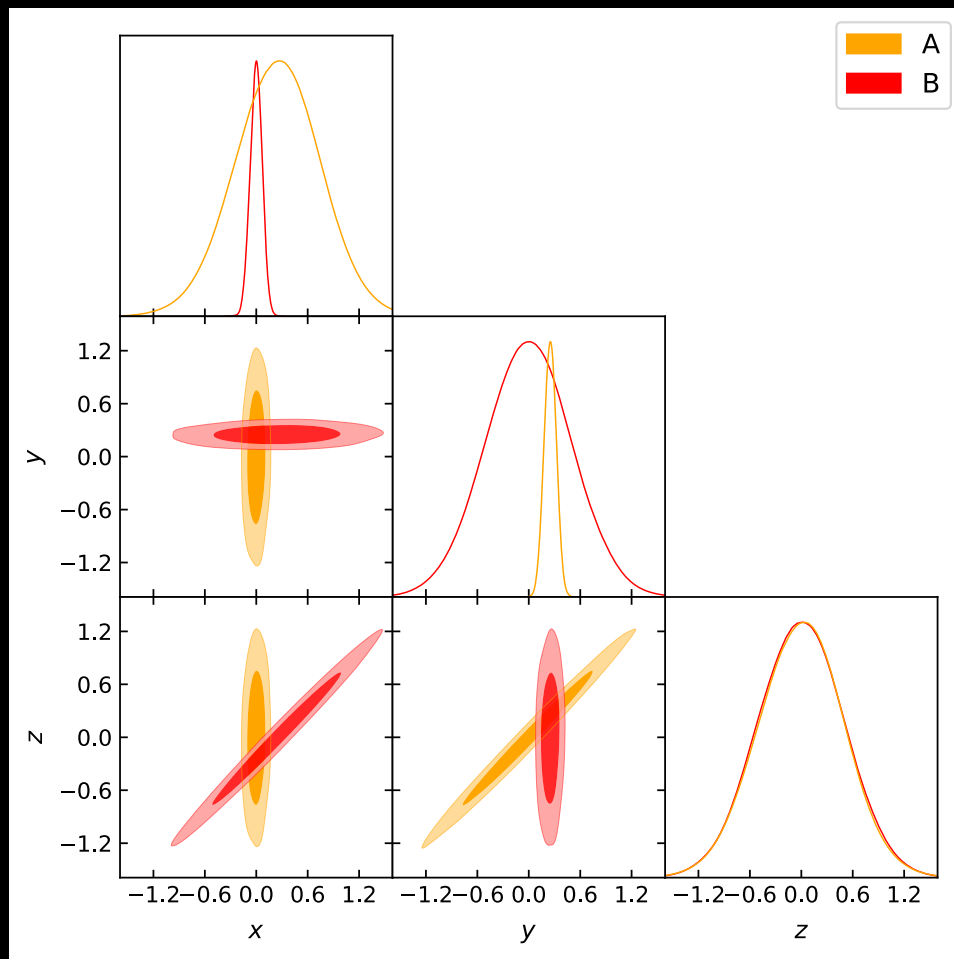
Parameter Dimensionality

$$\mathcal{D} = 3$$
$$\hat{d} = 2$$

$$\mathcal{D} = 3$$
$$\hat{d} = 1$$
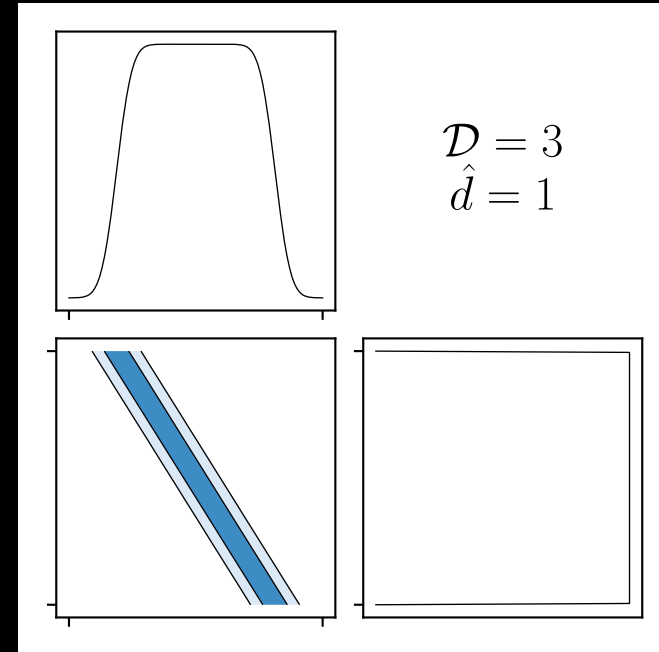
Supernovae Cosmology

"Hubble Diagram"
of Supernovae (Pantheon+)

Credit: Pantheon+ (2022)