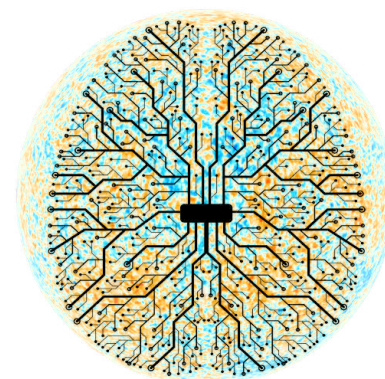


Torsion Condensation Cosmology: Hubble Tension & Curvature

Sinah Legner

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Astrophysics Group, Cavendish Laboratory, JJ Thomson Avenue, Cambridge CB3 0HE, UK
Kavli Institute for Cosmology, Madingley Road, Cambridge CB3 0HA, UK



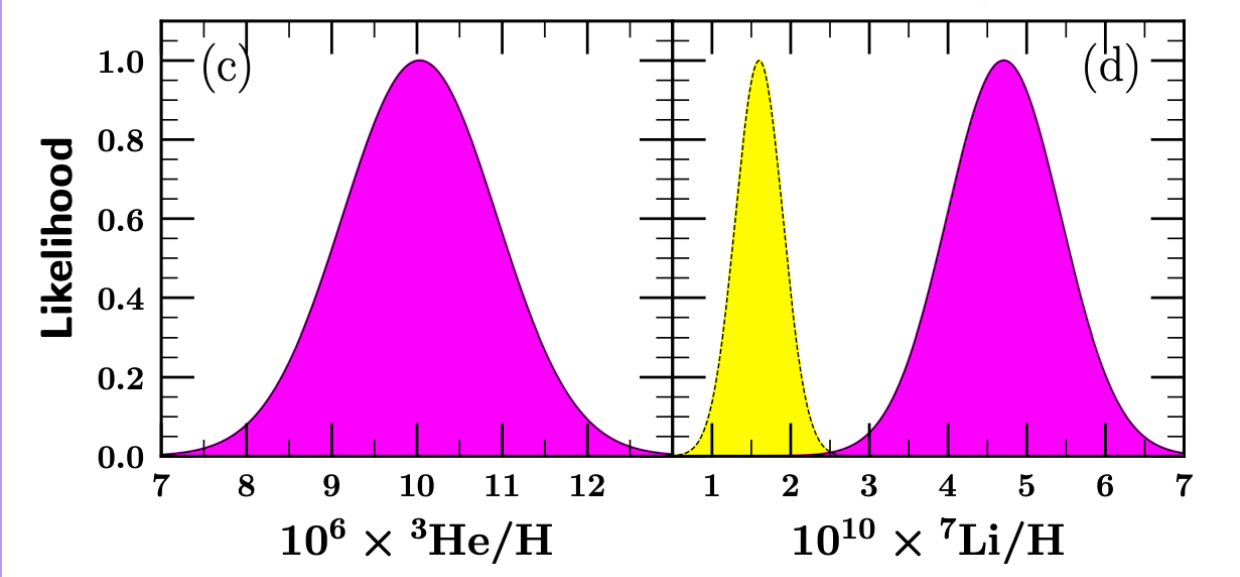
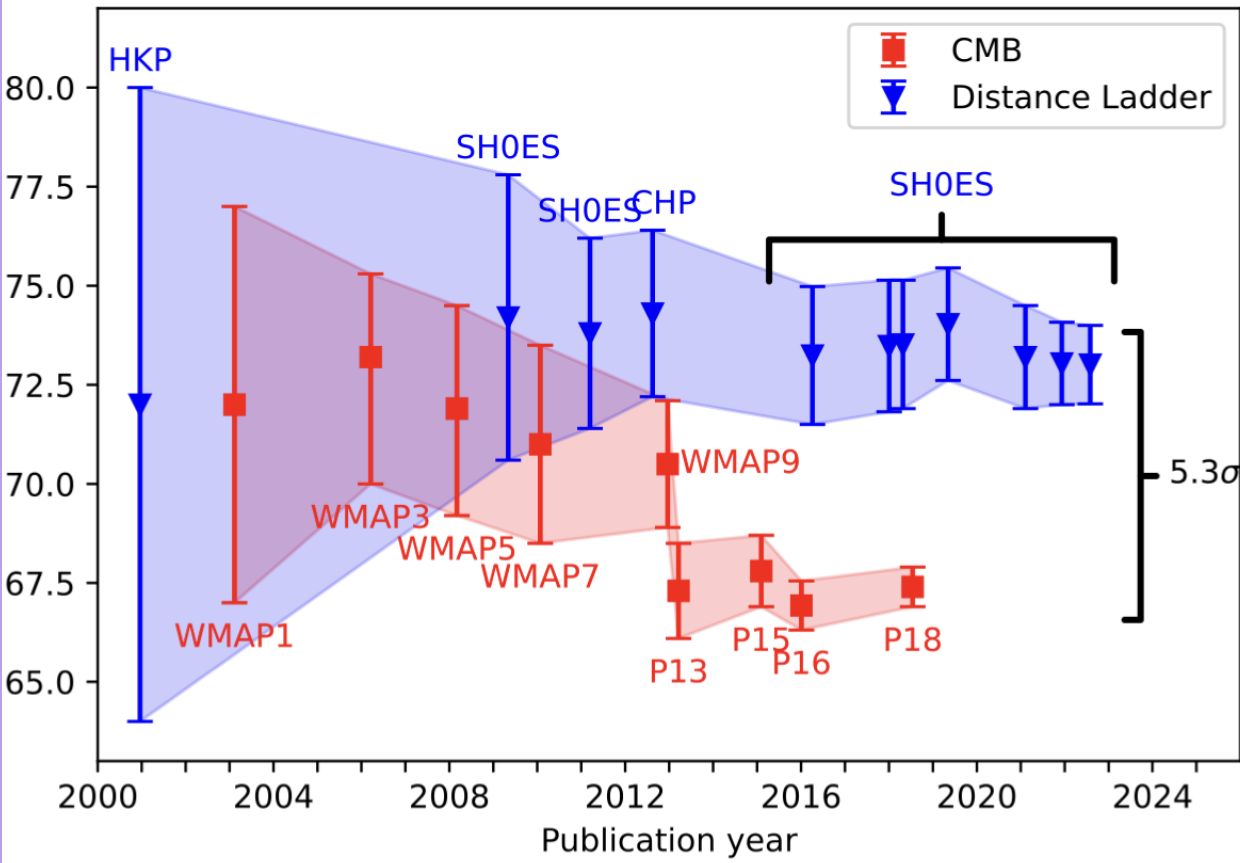
**UNIVERSITY OF
CAMBRIDGE**

Cavendish Laboratory
Department of Physics



Overview

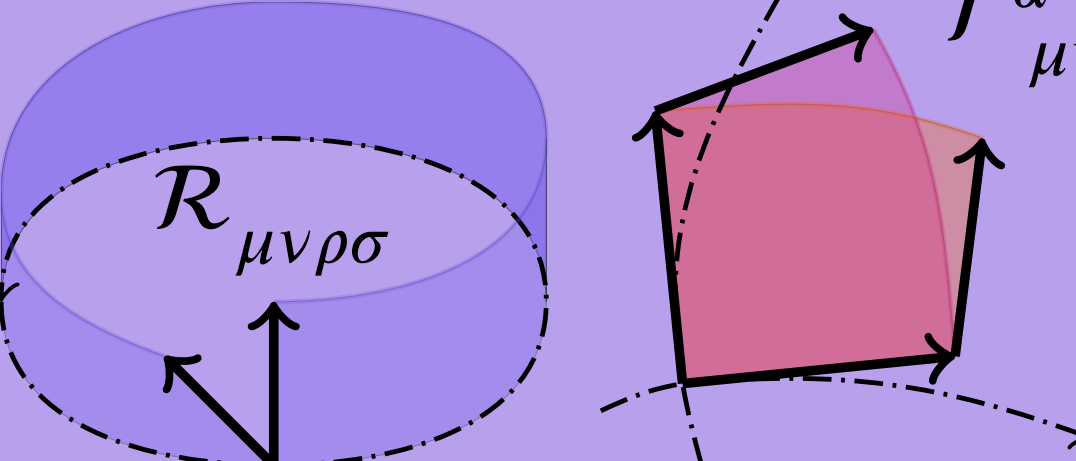
Cosmological Tensions



Exploration of different theory of gravity

Torsion Condensation (TorC)

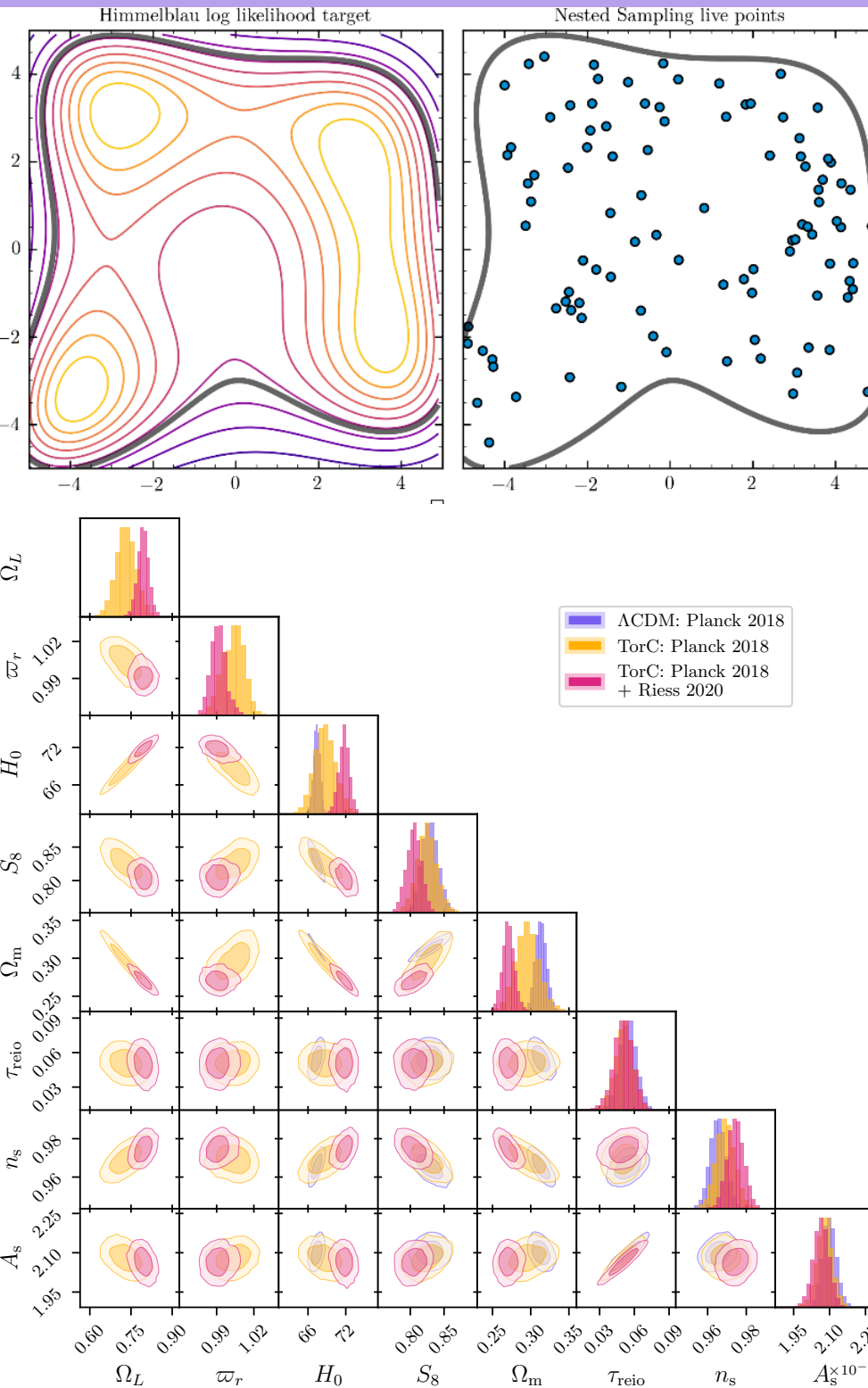
$$\mathcal{L} \propto R^2 + T^2 \quad [2003.02690]$$



Motivates

Analysis

Constraining TorC parameters



Comparison with Λ CDM and $k\Lambda$ CDM

Alleviate Tension?

Tension in Cosmology - Hubble Tension

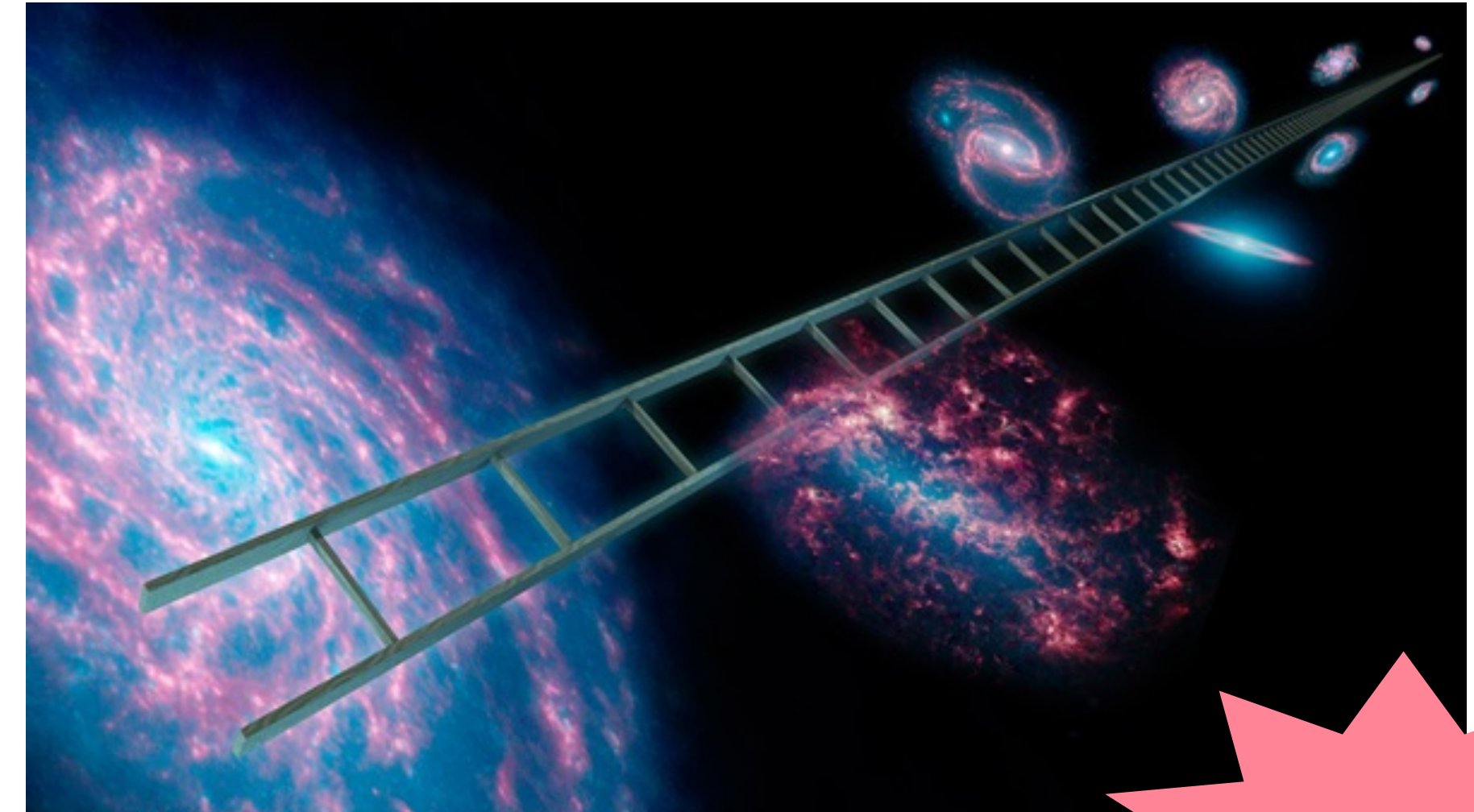
H_0 : Characterises Universe's expansion today.

SHOES(Cosmic Distance Ladder):

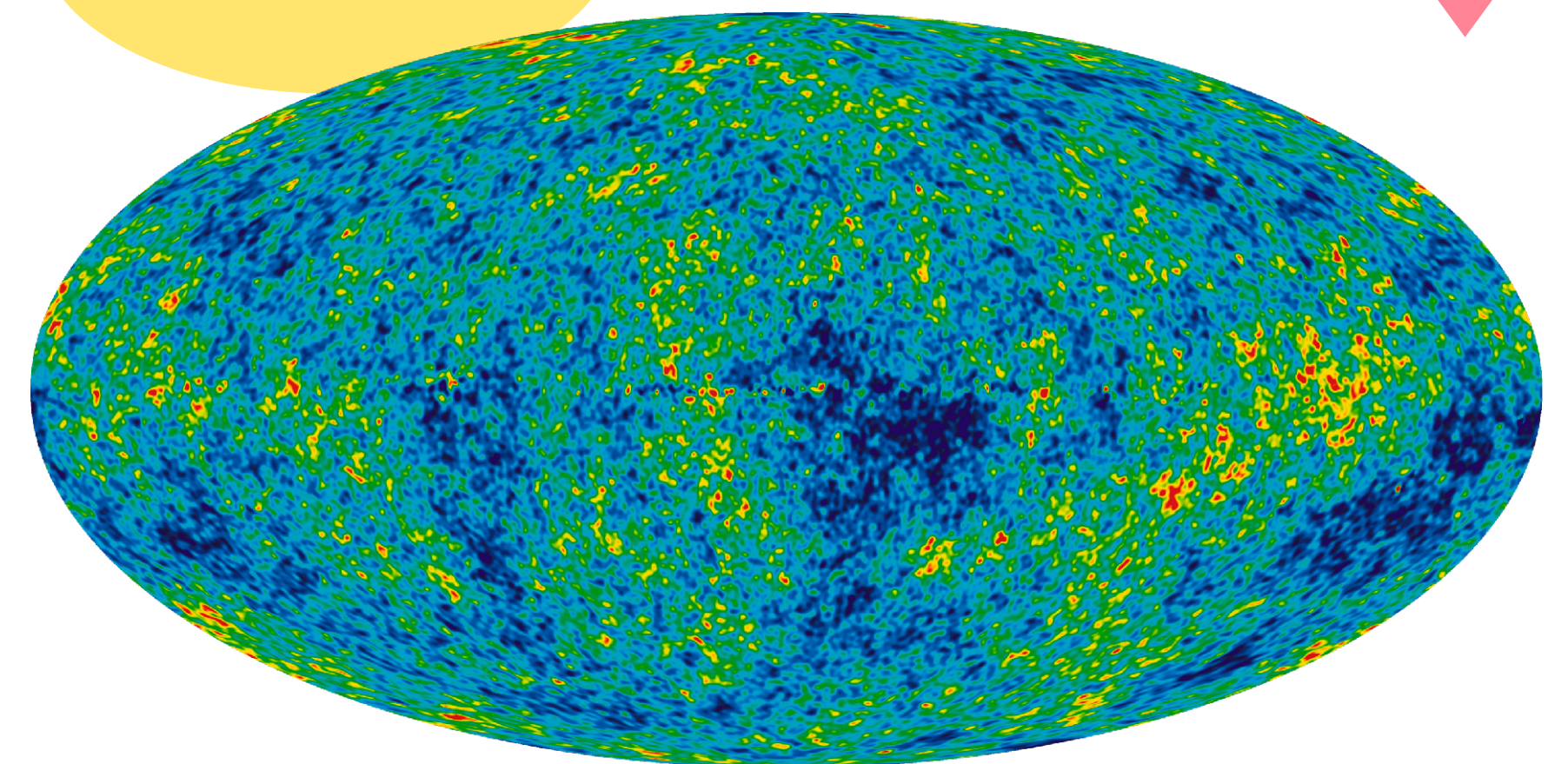
- $H_0 = 73.2 \pm 1.3$ km/s/Mpc. [[2112.04510](#)]
- Determined using Supernovae observations
- Challenges: Crowding, dust, metallicity, and calibration issues

Cosmic Microwave Background (CMB):

- $H_0 = 67.4 \pm 0.5$ km/s/Mpc. [[1807.06209](#)]
- CMB fluctuation data, fitted with Λ CDM model
- Measurement trusted, but Λ CDM assumptions are debated
- Tension at 5σ



Λ CDM



$\sim 5\sigma$

Tension in Cosmology - Hubble Tension

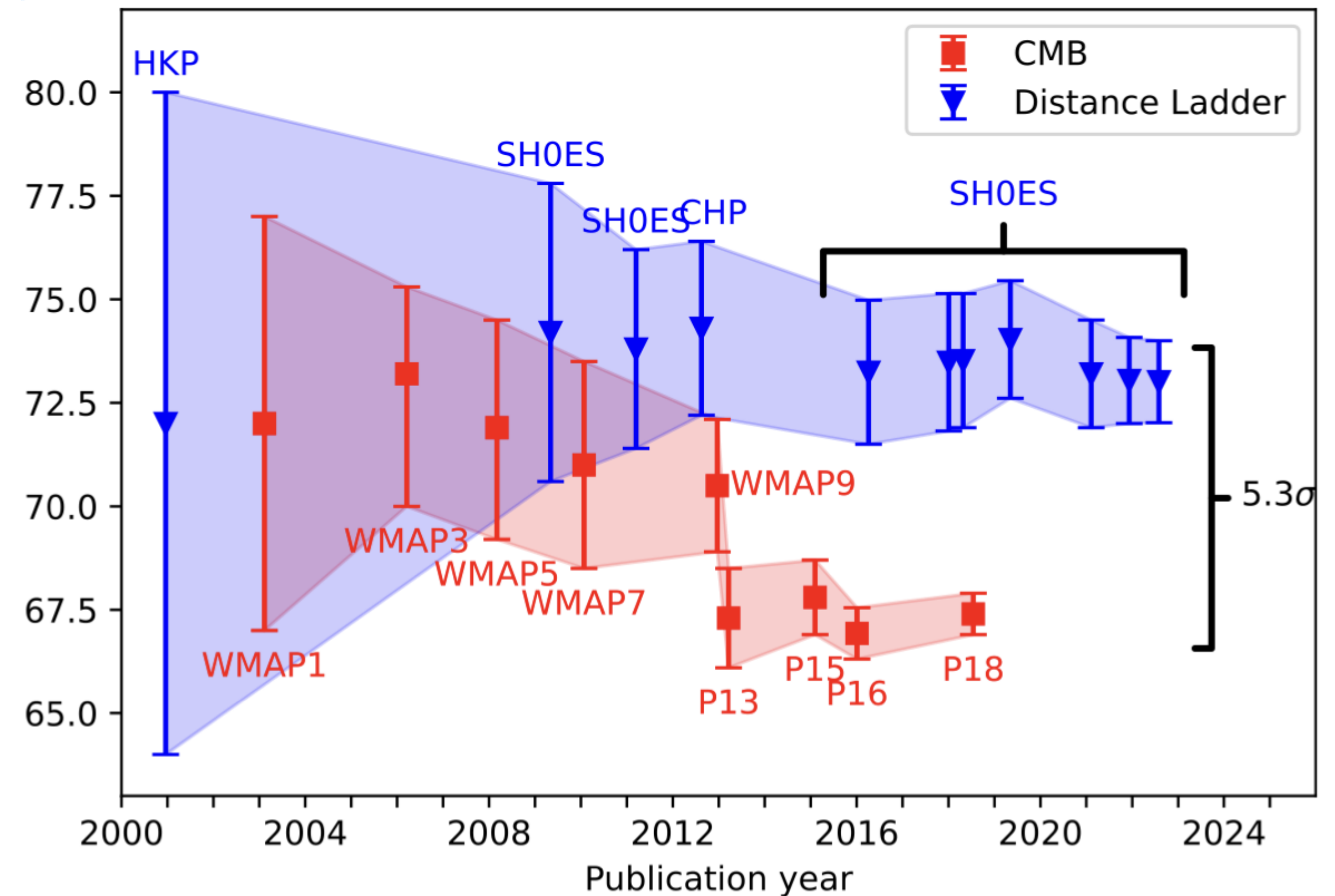
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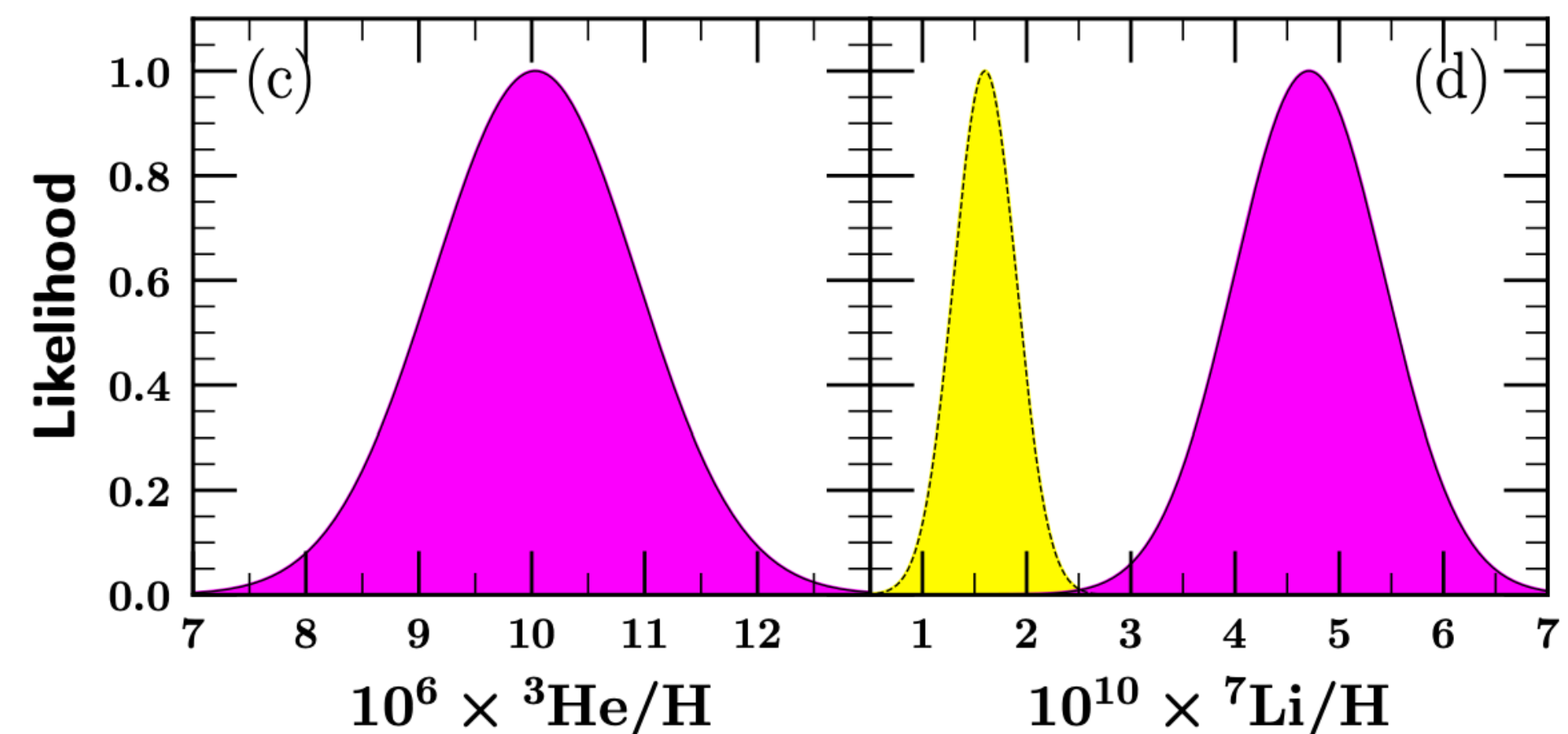
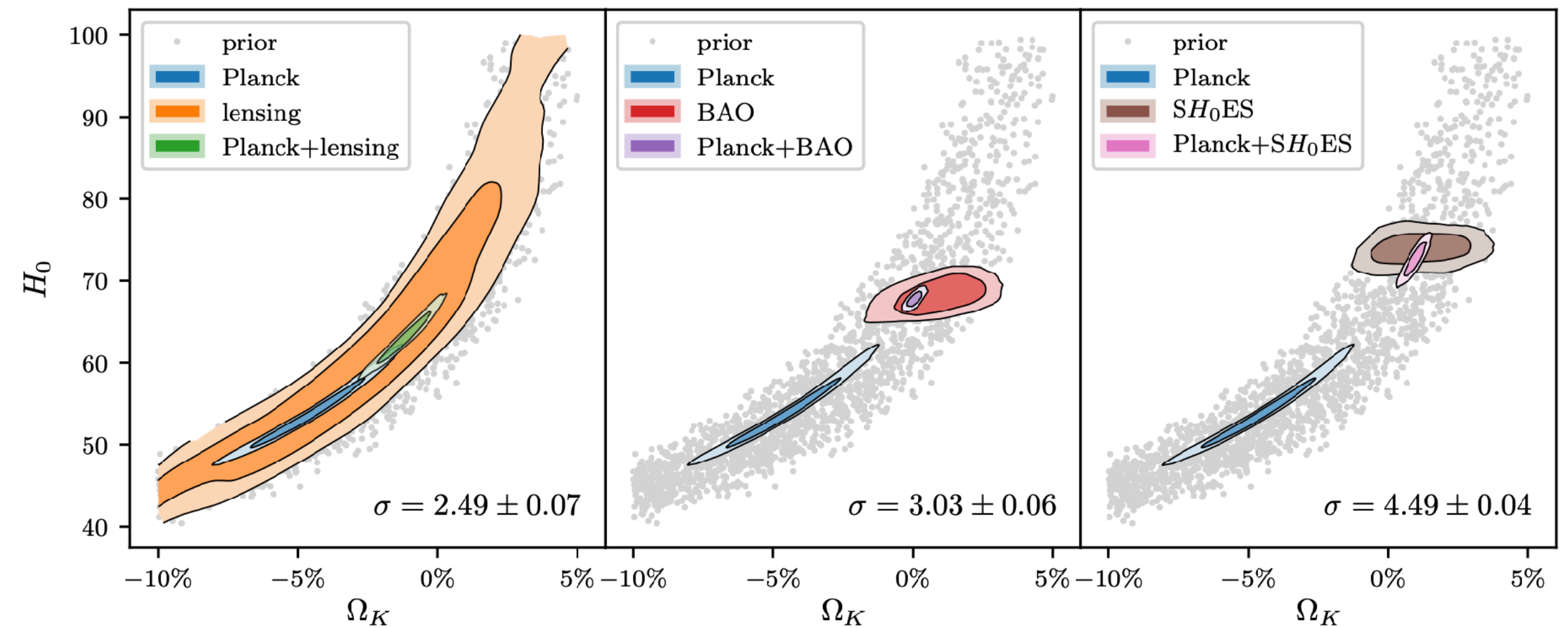
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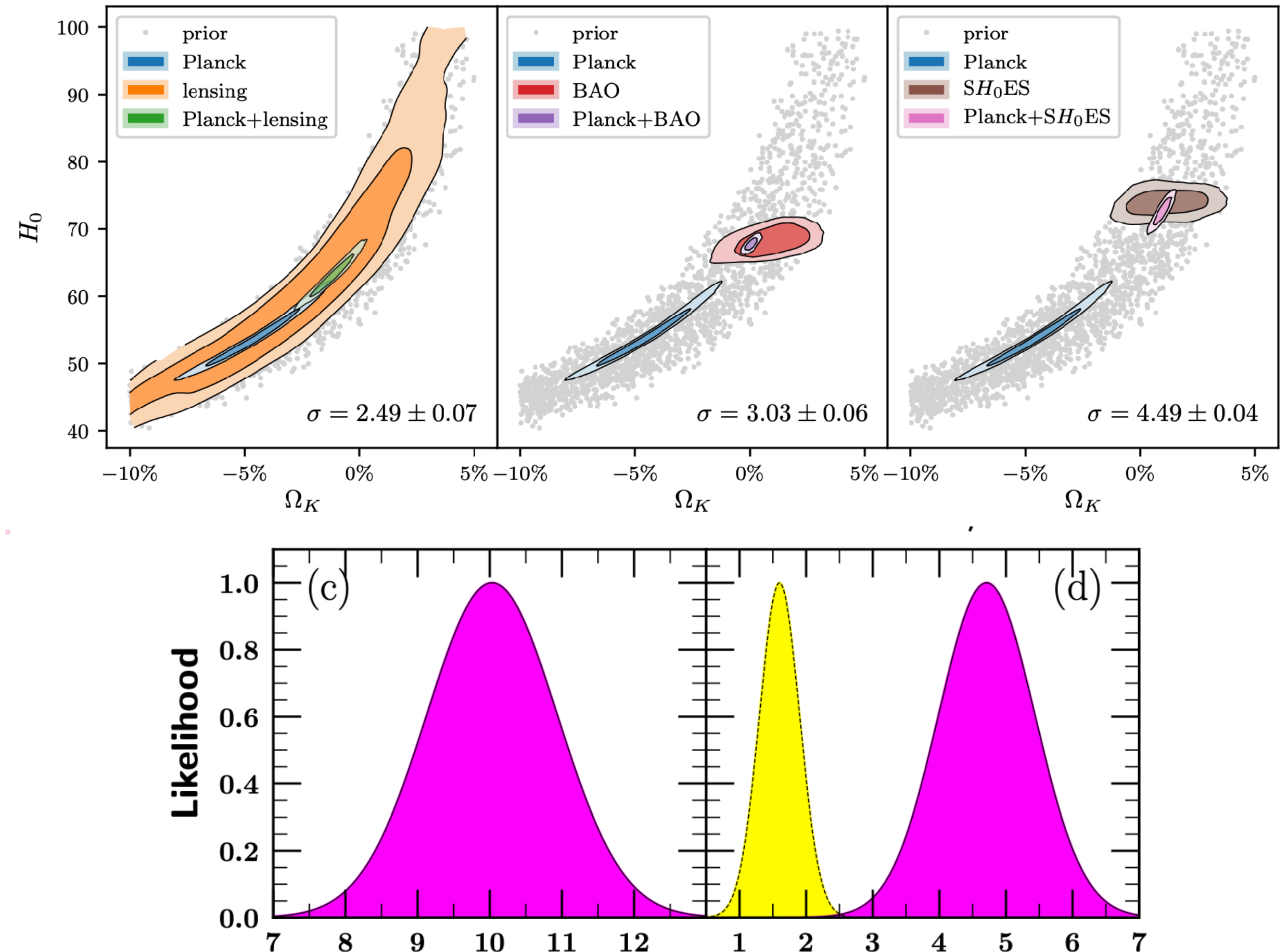
Tension in Cosmology - other tensions

- **Curvature Tension:** CMB data (Planck) prefers closed universe [[1908.09139](#)]
- **CMB hemispherical power asymmetry:** Challenging isotropy [[1510.07929](#)]
- **BBN:** Discrepancy in light element abundance, Lithium problem [[1912.01132](#)]
- And others...



Tension in Cosmology - other tensions

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- And others...



If not systematics — need new theory to replace Λ CDM

The Gauge Approach to Gravity: PGT

Poincaré group

- Four spacetime translation
- Lorentz group: Three spatial rotation and three Lorentz boosts

Poincaré gauge theory (PGT)

- Gauge fields correspond to translations and Lorentz rotations of the Poincaré group
- Lagrangian is constructed from field strengths, identified as **torsion** T and **curvature** R , up to quadratic order

- $\mathcal{L} \propto R + R^2 + T^2$

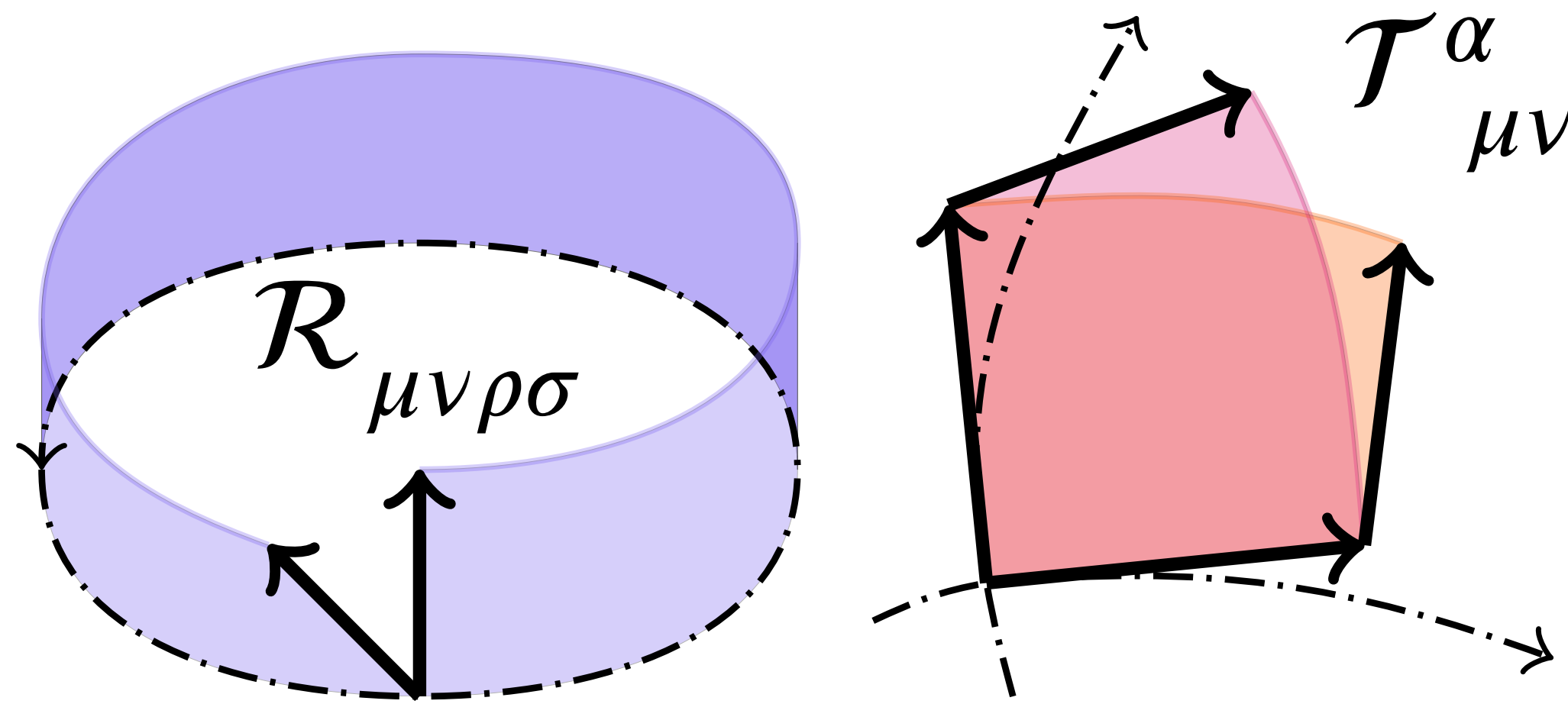
$$\mathcal{L} = h^{-1} [L_{R^2} + \kappa^{-1} (L_R + L_{T^2} + L_\Lambda) + L_m]$$

$$L_R = -\frac{1}{2} \alpha_0 R$$

$$L_{R^2} = \alpha_1 R^2 + \alpha_2 R_{ab} R^{ab} + \alpha_3 R_{ab} R^{ba} + \alpha_4 R_{abcd} R^{abcd} + \alpha_5 R_{abcd} R^{acbd} + \alpha_6 R_{abcd} R^{cdab}$$

$$L_{T^2} = \beta_1 T_{abc} T^{abc} + \beta_2 T_{abc} T^{bac} + \beta_3 T_a T^a$$

$$L_\Lambda = -\Lambda$$





450 critical cases of PGT
[1812.02675]

- Ghost-free
- Tachyon-free

58 cases [1910.14197]

- Power-counting renormalisable

★ **Torsion condensation:**

$$\mathcal{L} \propto R^2 + T^2$$

Under a homogeneous and isotropic background, torsion has a unique form: $T \propto \{\phi, \varpi\}$

Properties of TorC:

- Ghost-free, Tachyon-free, Power-counting renormalisable
- Has a Einsteinian limit
- Screened from curvature: the coupling choice completely removes k from the system
- Field equation shows ϕ can be expressed in terms of other fields



TorC Lagrangian

$$\begin{aligned}\mathcal{L}_{\text{TorC}} = & -\frac{4M_{\text{P}}^2}{9}T_{\mu}T^{\mu} \\ & -\frac{\mu}{6}\left[\lambda T_{\mu\nu\sigma}\left(T^{\mu\nu\sigma} - 2T^{\nu\mu\sigma}\right)\right. \\ & +R_{\mu\nu}\left(R^{[\mu\nu]} - 12R^{\mu\nu}\right) \\ & \left.-2R_{\mu\nu\sigma\rho}\left(R^{\mu\nu\sigma\rho} - 4R^{\mu\sigma\nu\rho} - 5R^{\sigma\rho\mu\nu}\right)\right] \\ & +2\nu R_{[\mu\nu]}R^{[\mu\nu]} - M_{\text{P}}^2\Lambda + \mathcal{L}_{\text{M}}\end{aligned}$$

[2507.09228]

Under a homogeneous and isotropic background, torsion has a unique form: $T \propto \{\phi, \varpi\}$

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TorC Lagrangian

$$\mathcal{L}_{\text{TorC}}^{\text{ST}} = M_{\text{P}}^2 \left[-\frac{2}{3} \left(1 - \frac{\varpi^2}{4} \right) R + g^{\mu\nu} \partial_{\mu} \varpi \partial_{\nu} \varpi \right. \\ \left. - \frac{4}{3} \sqrt{|J_{\mu} J^{\mu}|} - \phi^2 + \phi^2 \varpi^2 \right] \\ - M_{\text{P}}^2 \Lambda + \mathcal{L}_{\text{M}}$$

$$J_{\mu} \equiv 4\varpi^3 \partial_{\mu} (\phi / \varpi) + \partial_{\mu} \phi$$

- **Bi-scalar-tensor equivalent**

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TorC Cosmological Parameters

- H_0 - Hubble parameter today
 - Ω_b - Density of baryonic matter
 - Ω_c - Density of cold dark matter
 - τ_{reio} - Optical depth due to reionisation
 - n_s - Scalar spectral index
 - A_s - Amplitude of the primordial scalar power spectrum
-
- ϖ_r - Initial value of the torsion scalar field ϖ
 - Ω_L - Bare dark energy density parameter

Λ CDM parameters

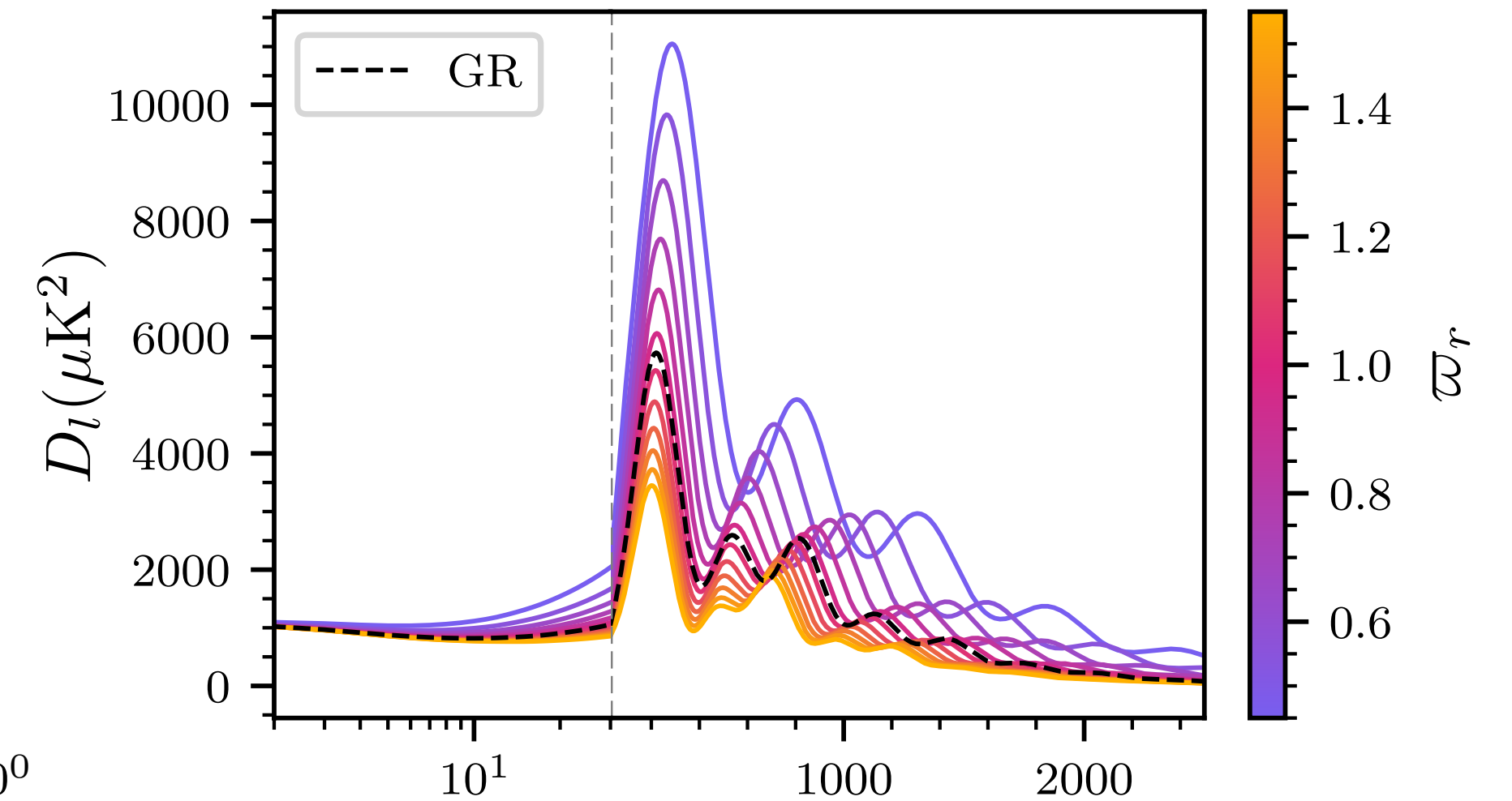
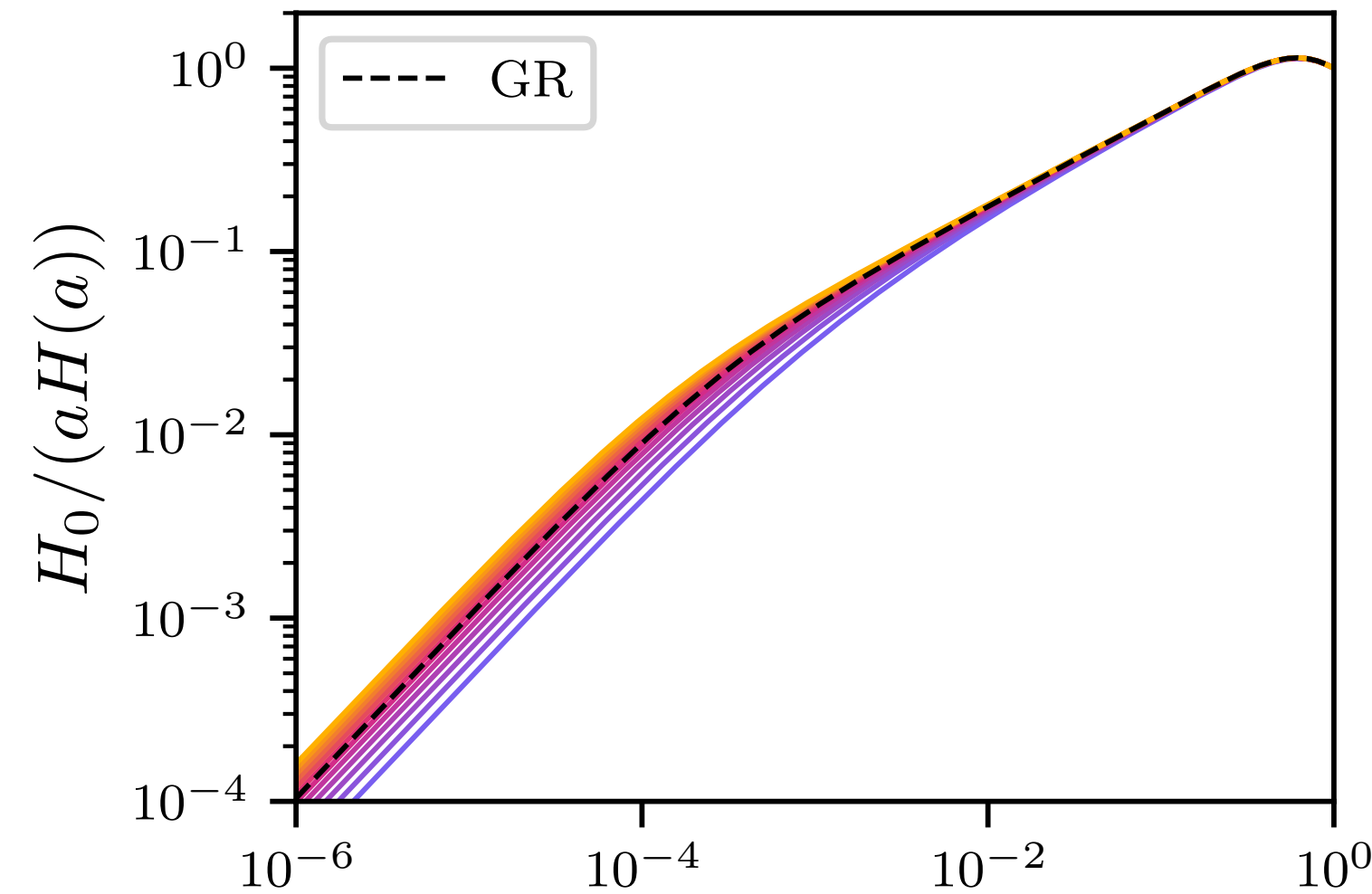
$$\varpi_r \rightarrow 1$$
$$\Omega_L \rightarrow \Omega_{\Lambda}^{\Lambda\text{CDM}}$$

TorC parameters

How the New Parameters Affect Cosmology

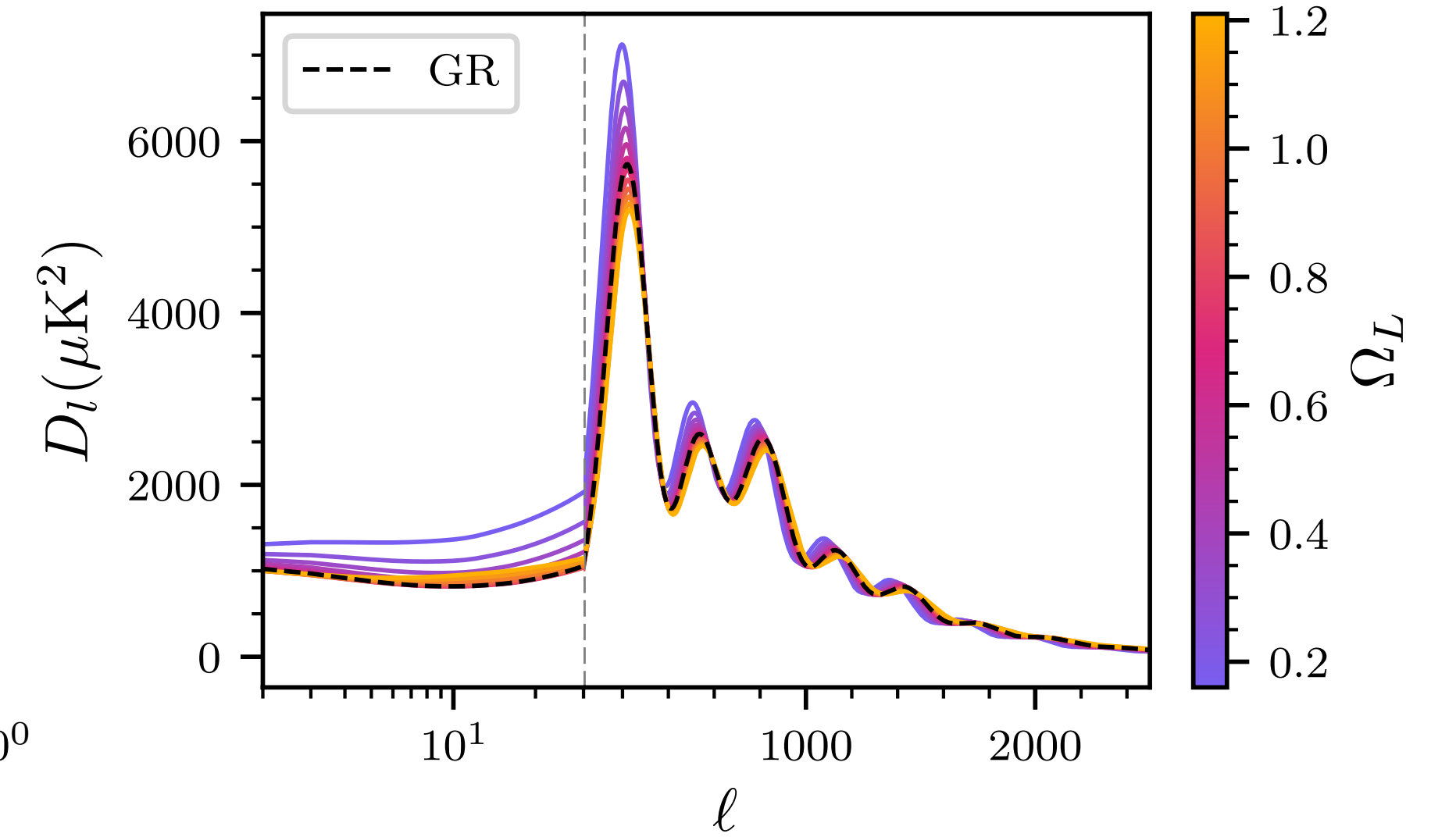
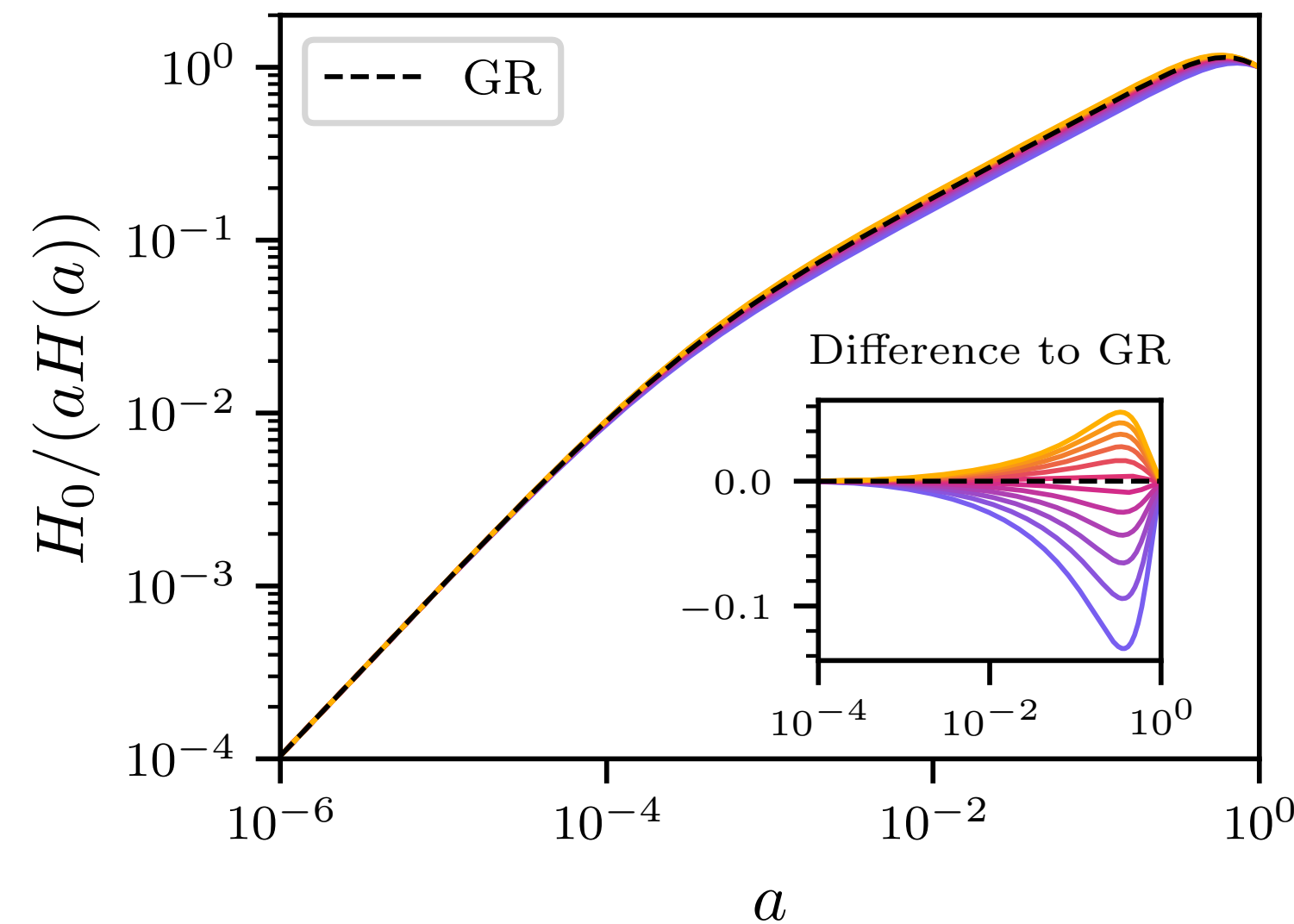
$$\varpi_r$$

- Smaller ϖ_r reduces the Hubble horizon in early Universe



$$\Omega_L$$

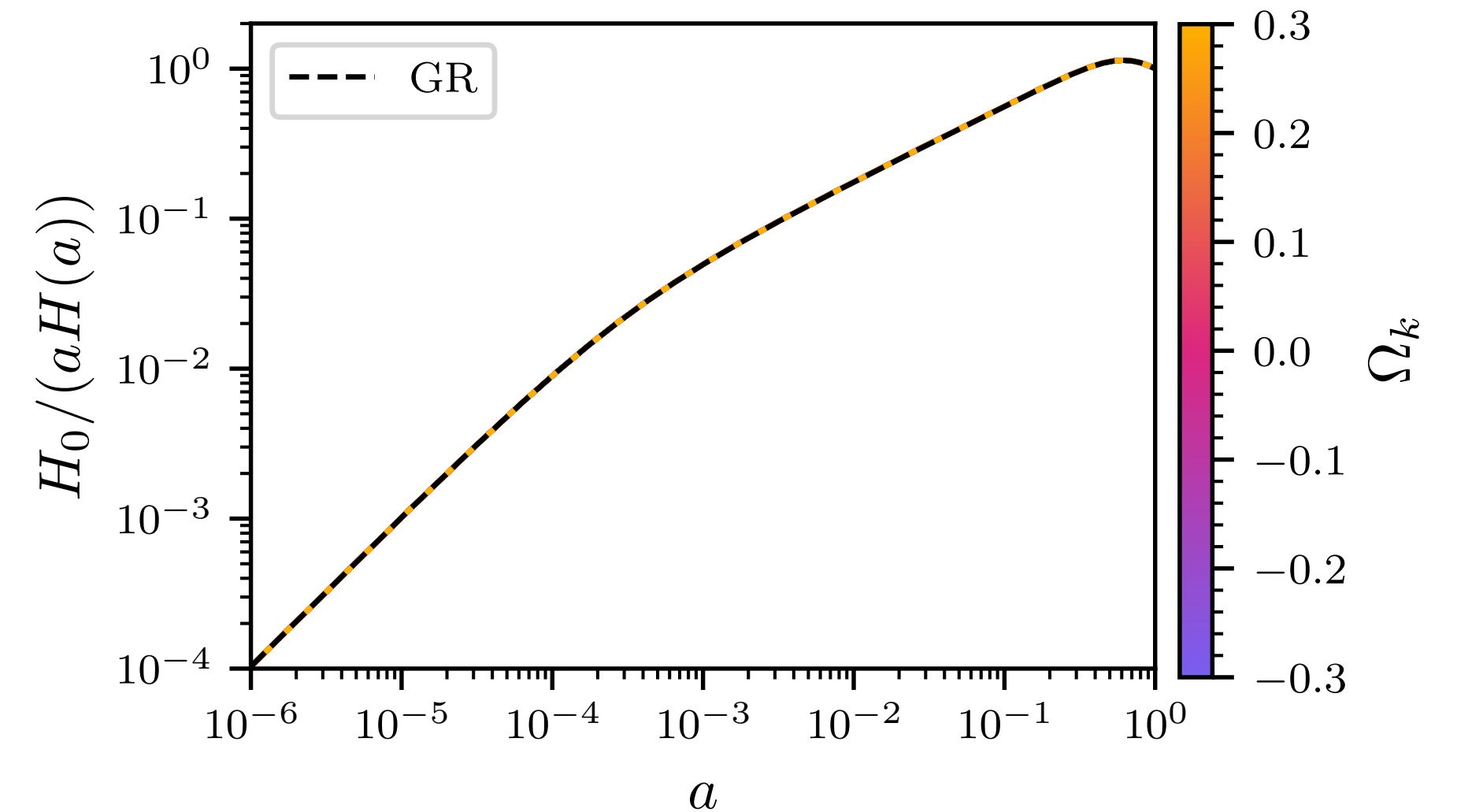
- Ω_L influences the late-time expansion, most significant in late-matter dominated epoch



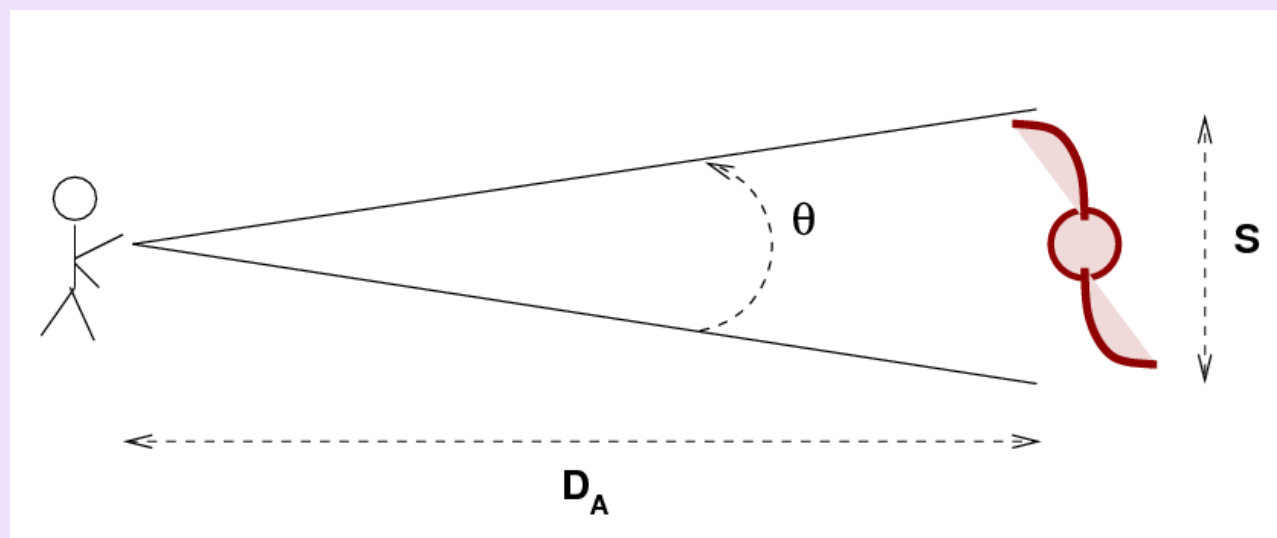
How curvature behaves in TorC

Curvature affects expansion history

- Comes from the geometry of the FLRW metric, as an effective energy component
- $H^2(a) = H_0^2 [\Omega_r a^{-4} + \Omega_m a^{-3} + \Omega_k a^{-2} + \Omega_\Lambda]$

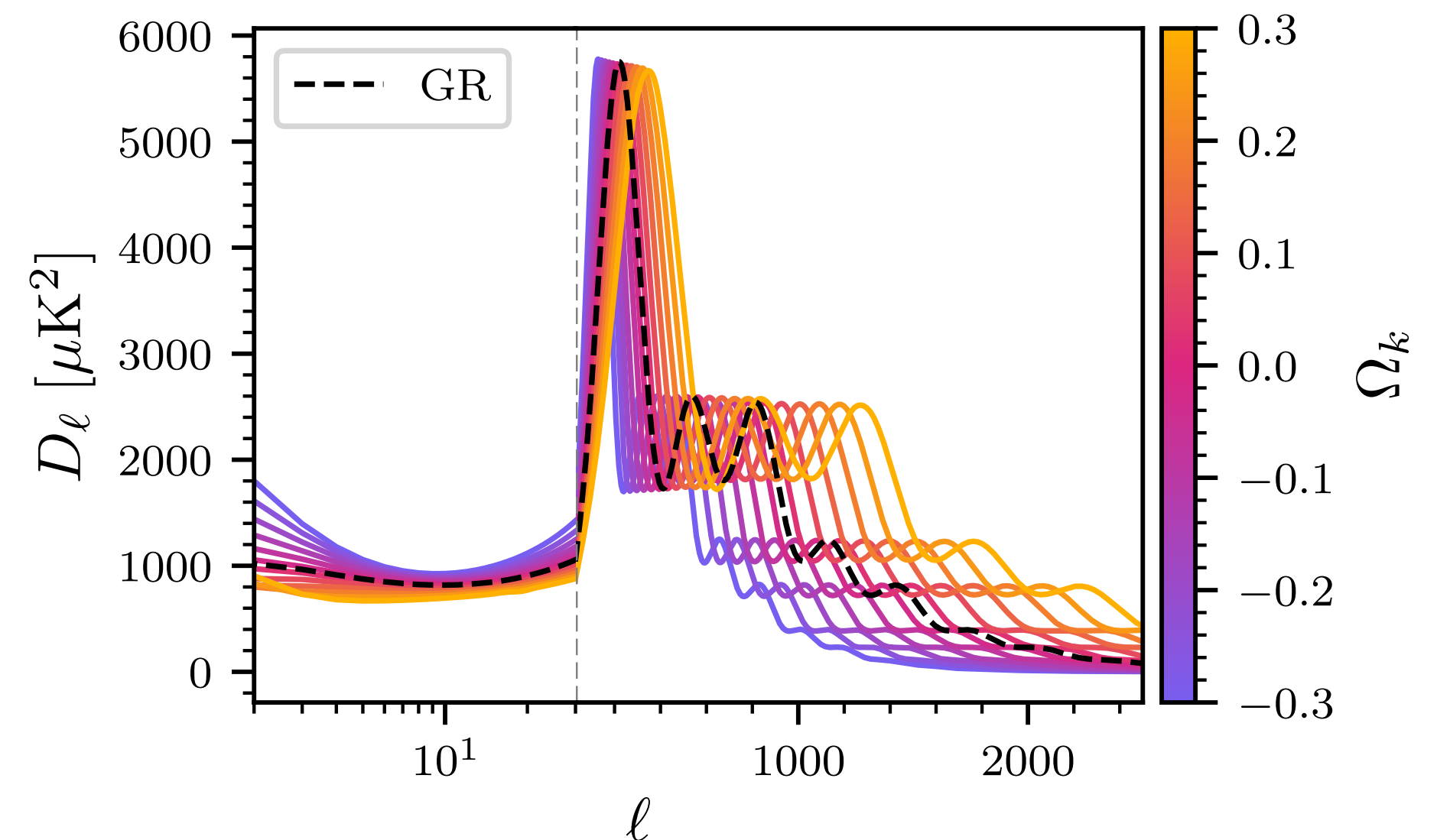


Curvature affects propagation of light



$$D_A(z^*) \equiv \frac{\sin\left(\sqrt{-\Omega_k} \int_0^{z^*} \frac{H_0 dz}{H(z)}\right)}{H_0 \sqrt{-\Omega_k}}$$

- Angular diameter distance is affected



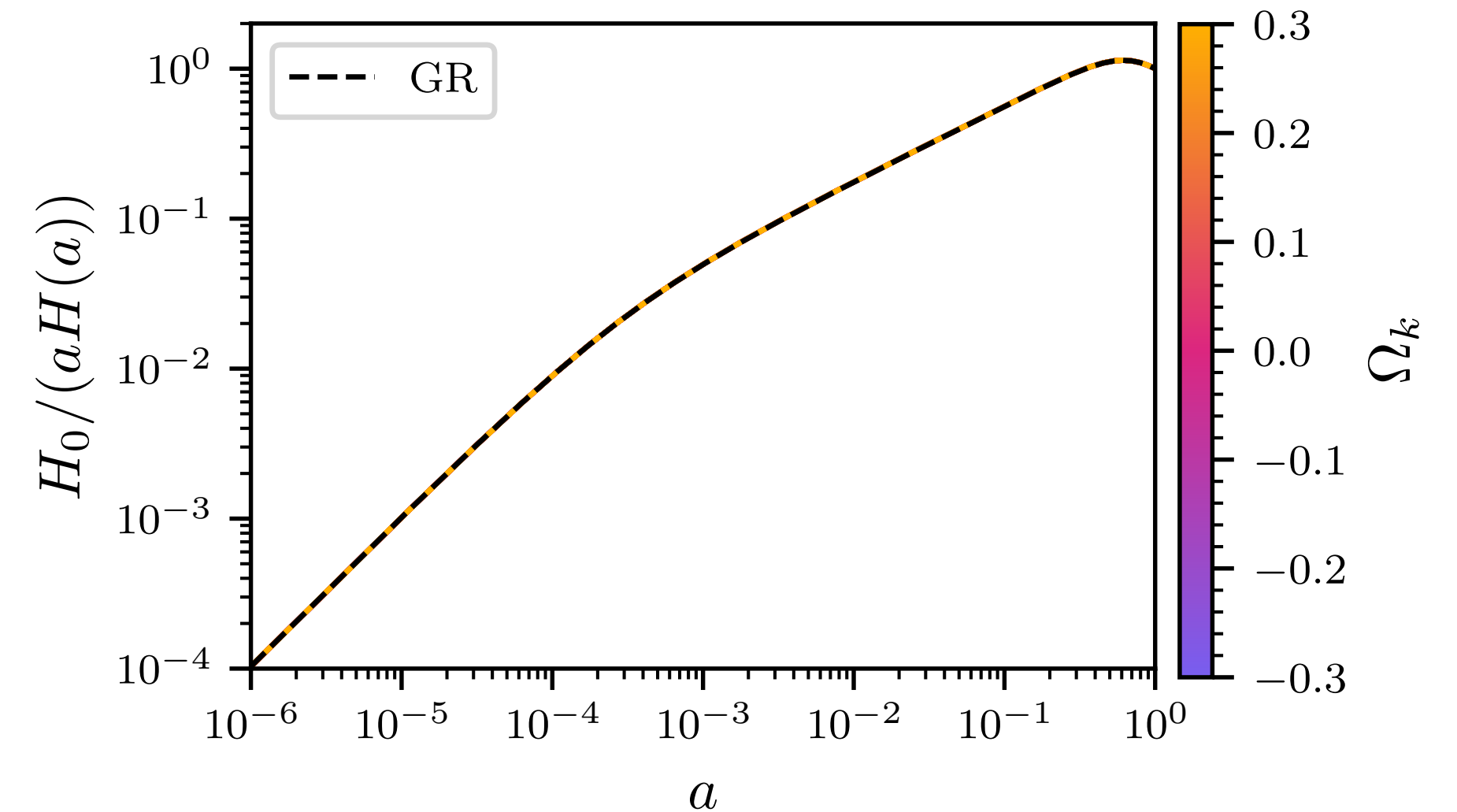
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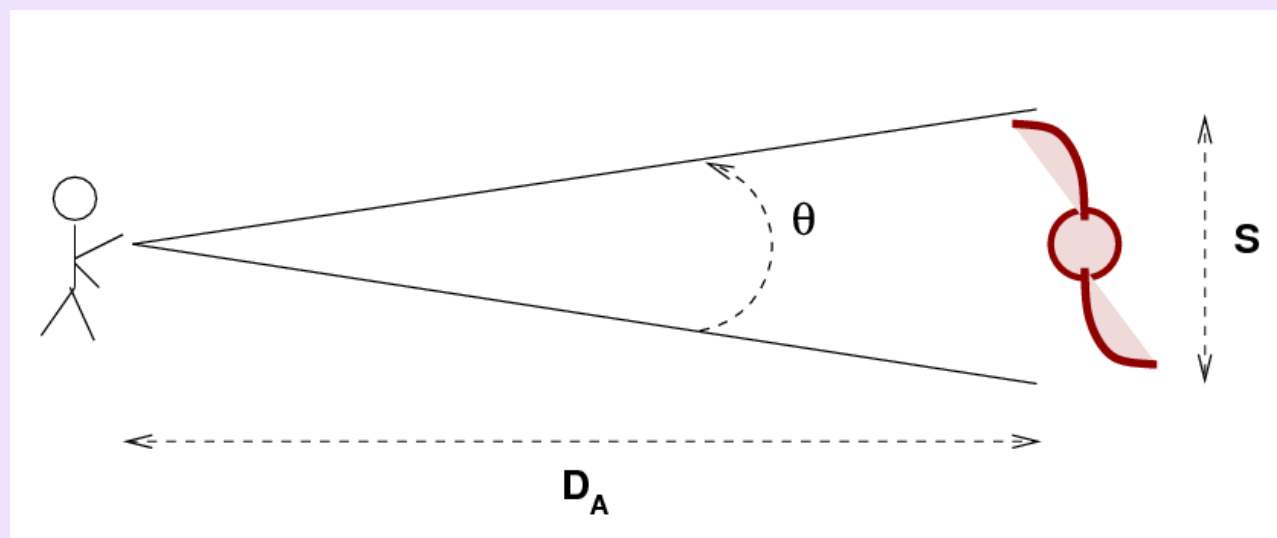
- Comes from the geometry of the FLRW metric, as an effective energy component

- $H^2(a) = H_0^2 [\Omega_r a^{-4} + \Omega_m a^{-3} + \Omega_k a^{-2} + \dots]$

kTorC:

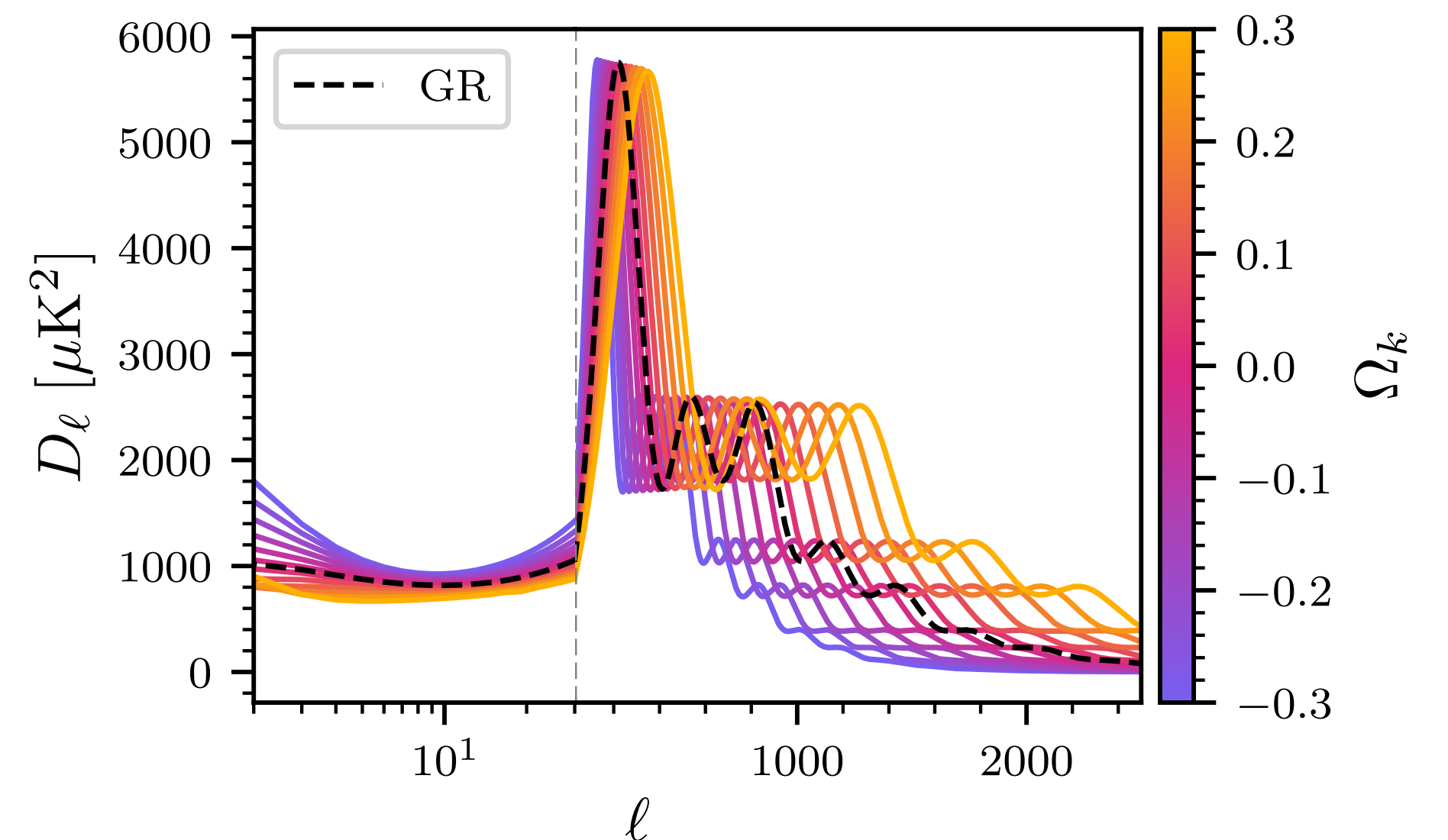


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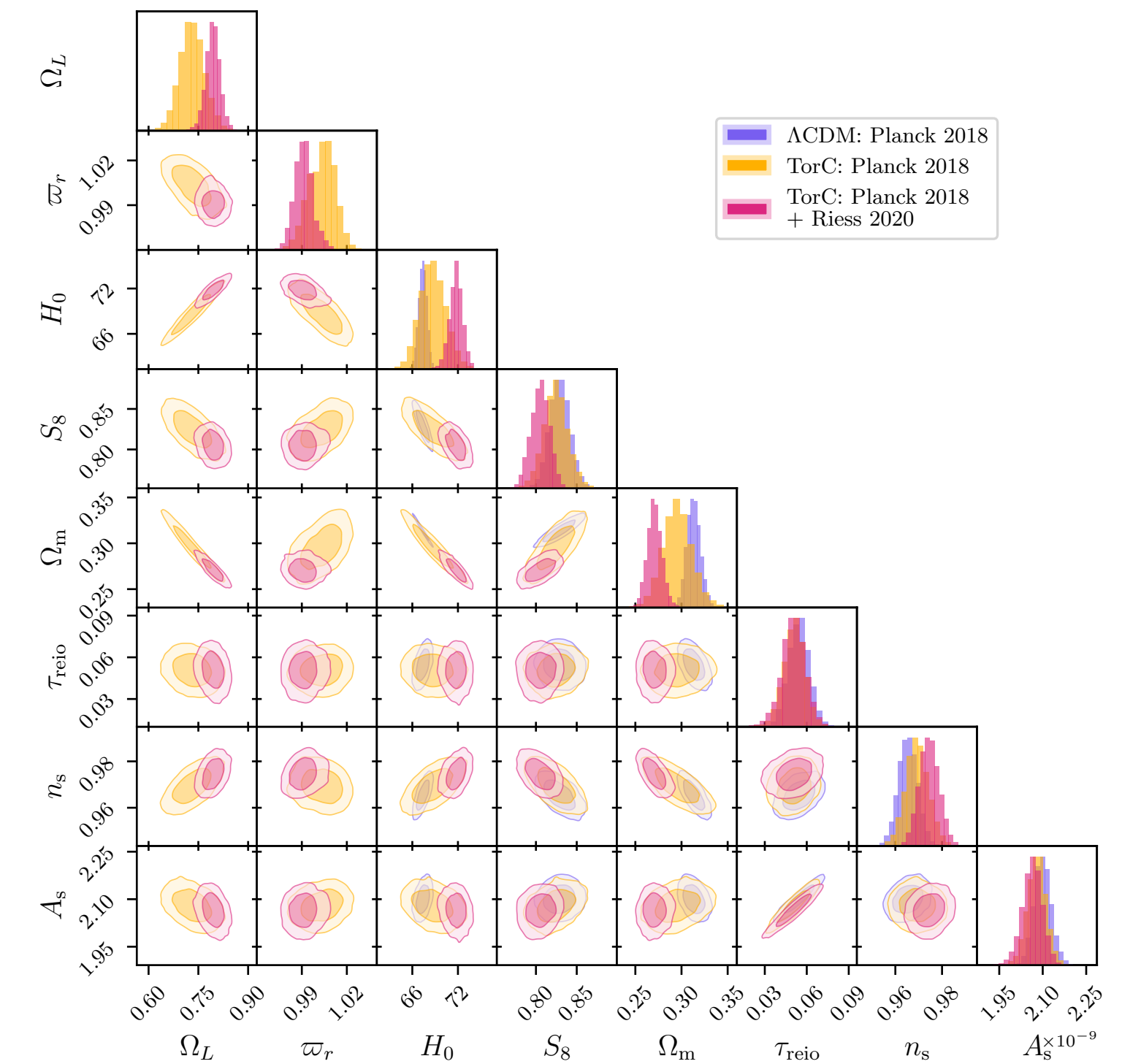
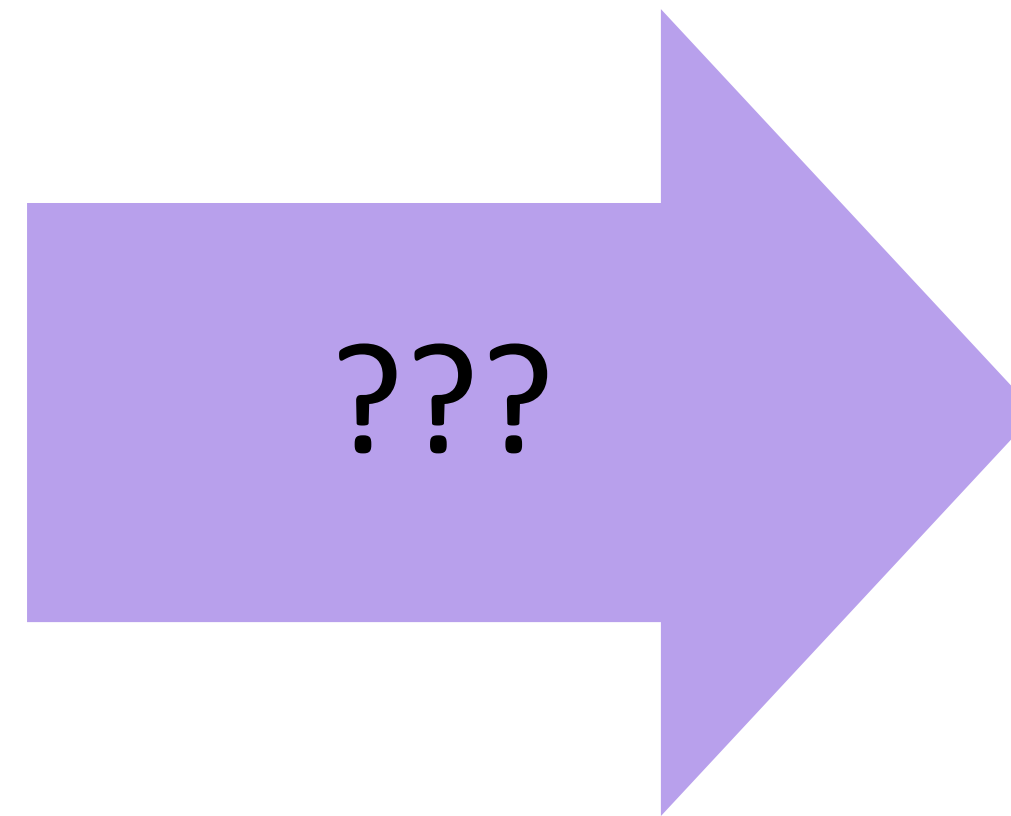
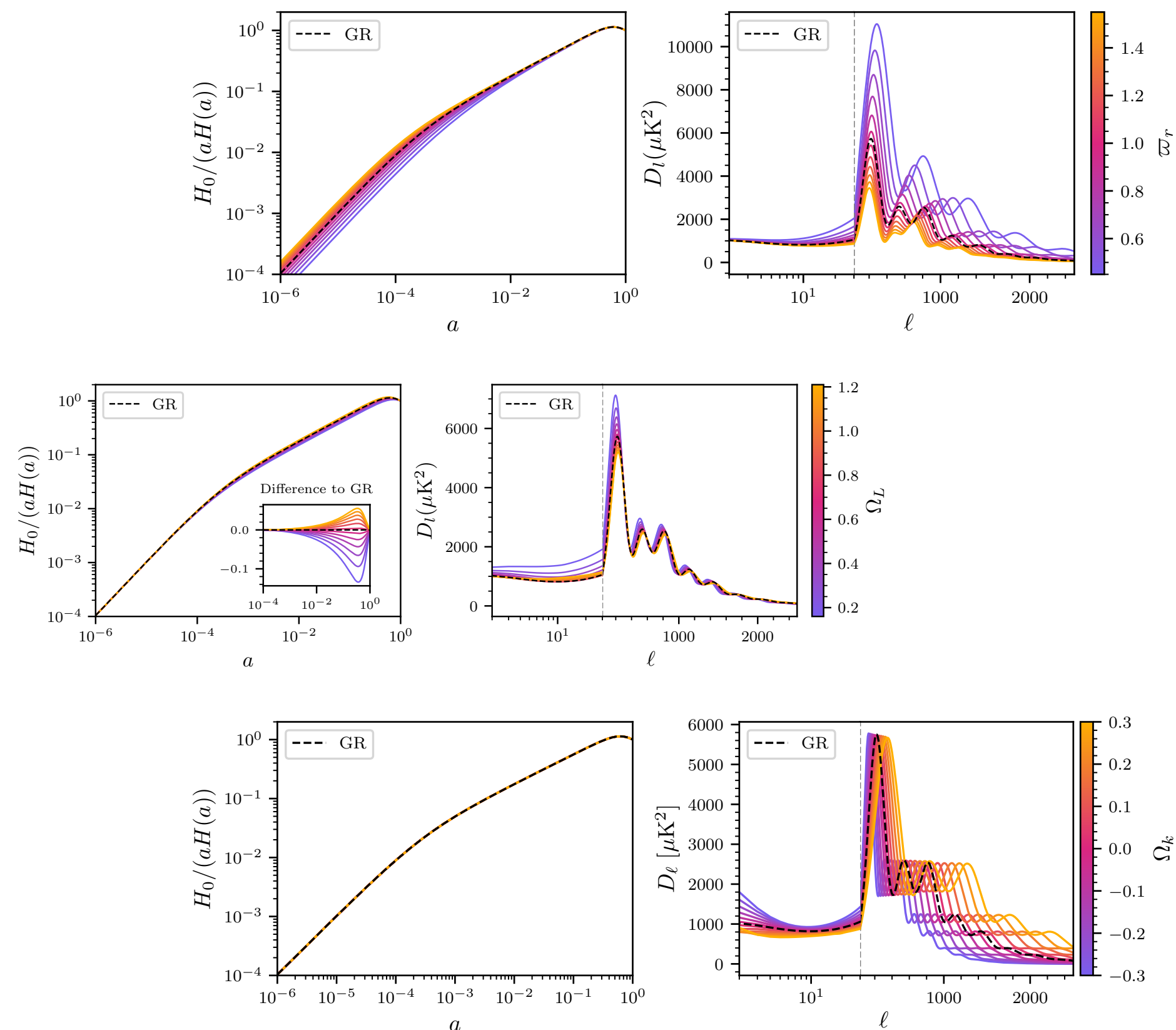
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Method

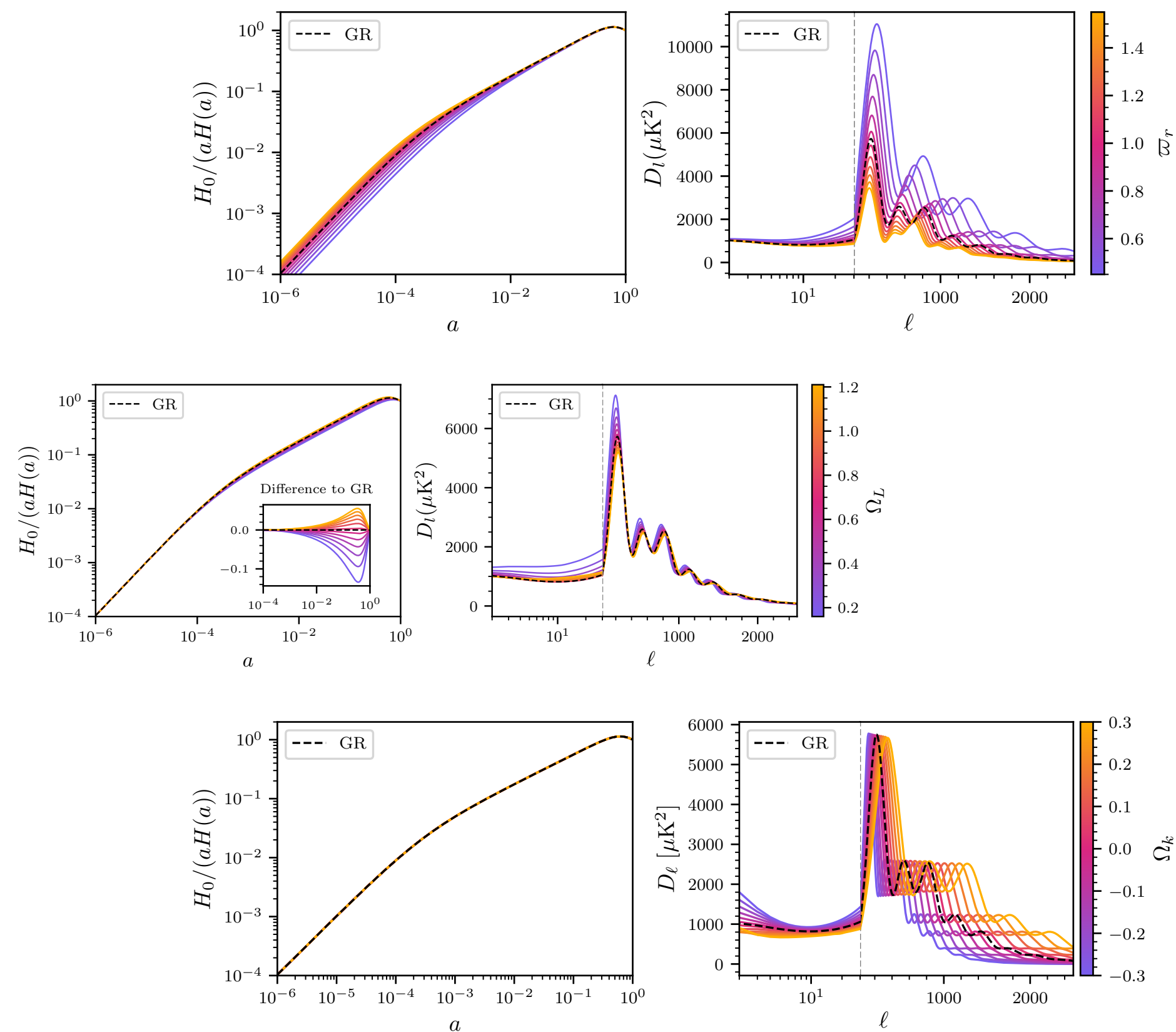
How does TorC Compare to Λ CDM and $k\Lambda$ CDM?



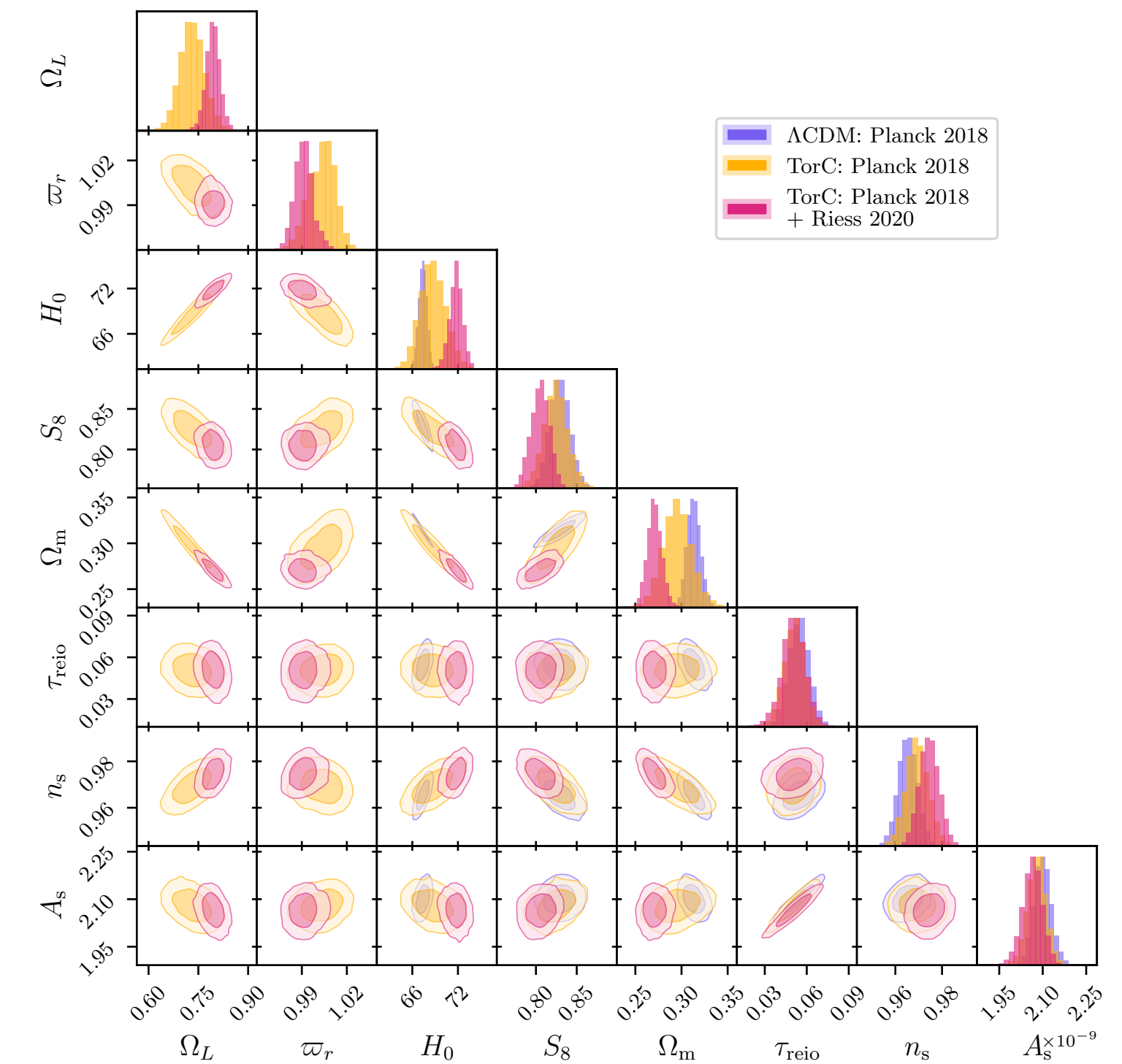
what does data tell us about the cosmological parameters?

Method

How does TorC Compare to Λ CDM and $k\Lambda$ CDM?



Nested Sampling



what does data tell us about the cosmological parameters?

Bayesian Inference and Nested Sampling



David Yallup



Will Handley

Parameter Estimation:

- What does data tell us about parameters?

$$P(\theta | D, M) = \frac{P(D | \theta, M)P(\theta | M)}{P(D | M)}$$

P - posterior
L - likelihood
 π - prior
Z - evidence

Model Comparison:

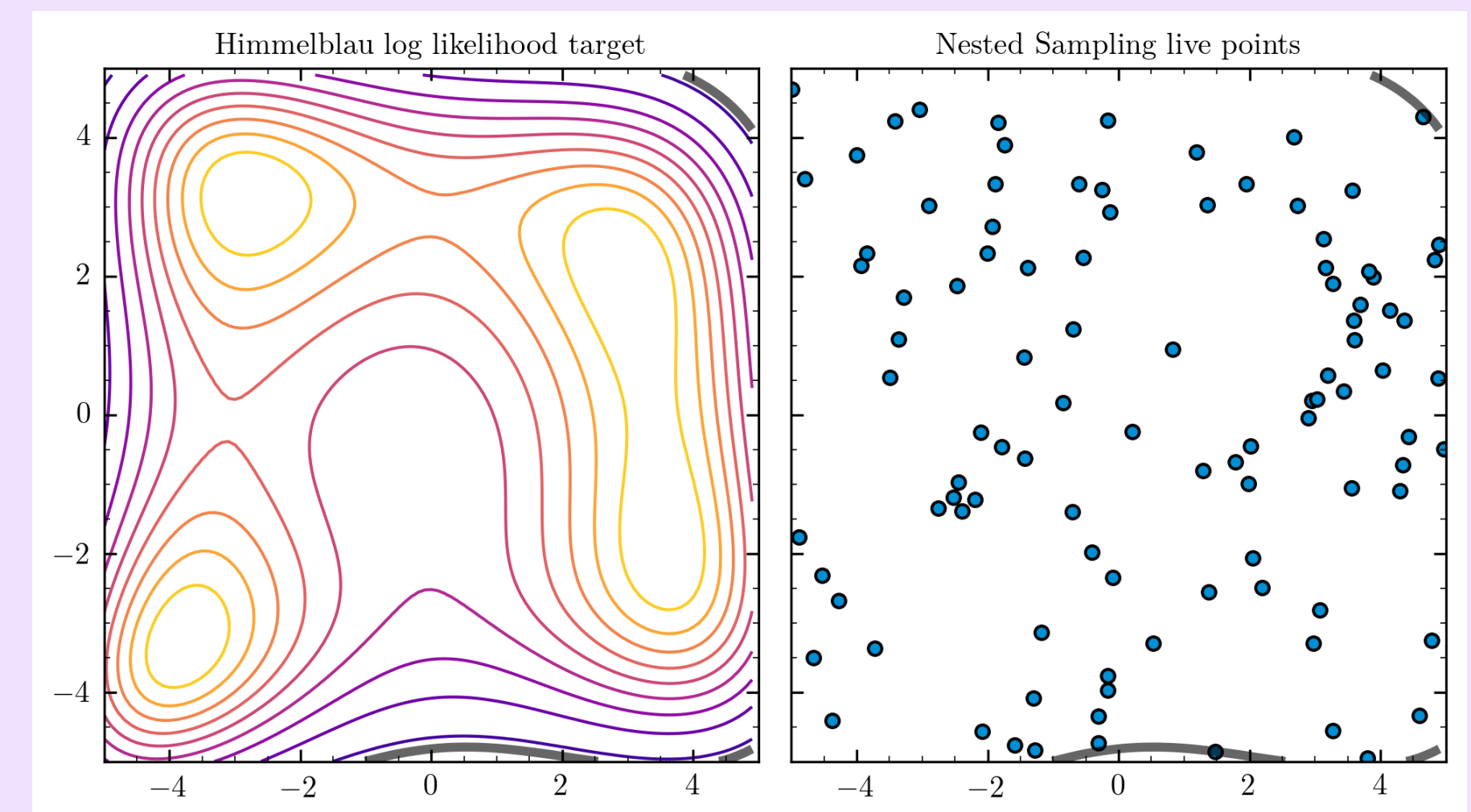
- How much does data support the model?

$$P(M | D) = \frac{P(D | M)P(M)}{P(D)}$$

- Higher evidence favours a model
- Penalises complexity

Nested Sampling:

- Computes evidence directly
- Handles multimodal posteriors



Gif from David Yallup

- **Polychord**: nested sampling algorithm tailored for high-dimensional parameter spaces. [[1506.00171](#)]

Method: The Analysis Pipeline — Cobaya

Cobaya - code for **bayesian** analysis [[2005.05290](#)]

- A framework for sampling and statistical modelling, providing interfaces to cosmological theory codes and likelihoods from cosmological experiments.

Cobaya:

- Sets up cosmological model

likelihoods:

- Planck 2018
- SHOES 2020

CAMB:

- Computes CMB Power spectrum for each parameter set.

Polychord:

- Explore parameter space with nested sampling

Result:

- Posterior distribution for cosmological parameters
- Compare models through evidence (Z)

Method: Comparison Metrics

Tension Quantification [1902.04029]

- Assess the level of agreement between two datasets. (e.g. Planck & SH0ES)
- R-statistic: measures relative confidence in dataset A given dataset B, compared to its self-consistency.
 - $R \gg 1$: indicates that B strengthen confidence in A by a factor of R
 - $R \ll 1$: indicates tension
- For each model, given datasets A and B :

$$R = \frac{Z_{AB}}{Z_A Z_B} = \frac{P(A, B)}{P(A)P(B)} = \frac{P(A | B)}{P(A)} = \frac{P(B | A)}{P(B)}$$

Bayesian Evidence

- Compare the overall viability of models
- Naturally incorporates ‘Occam’s razor’:

$$\log Z = \langle \log L(\theta) \rangle_P - D_{\text{KL}}$$

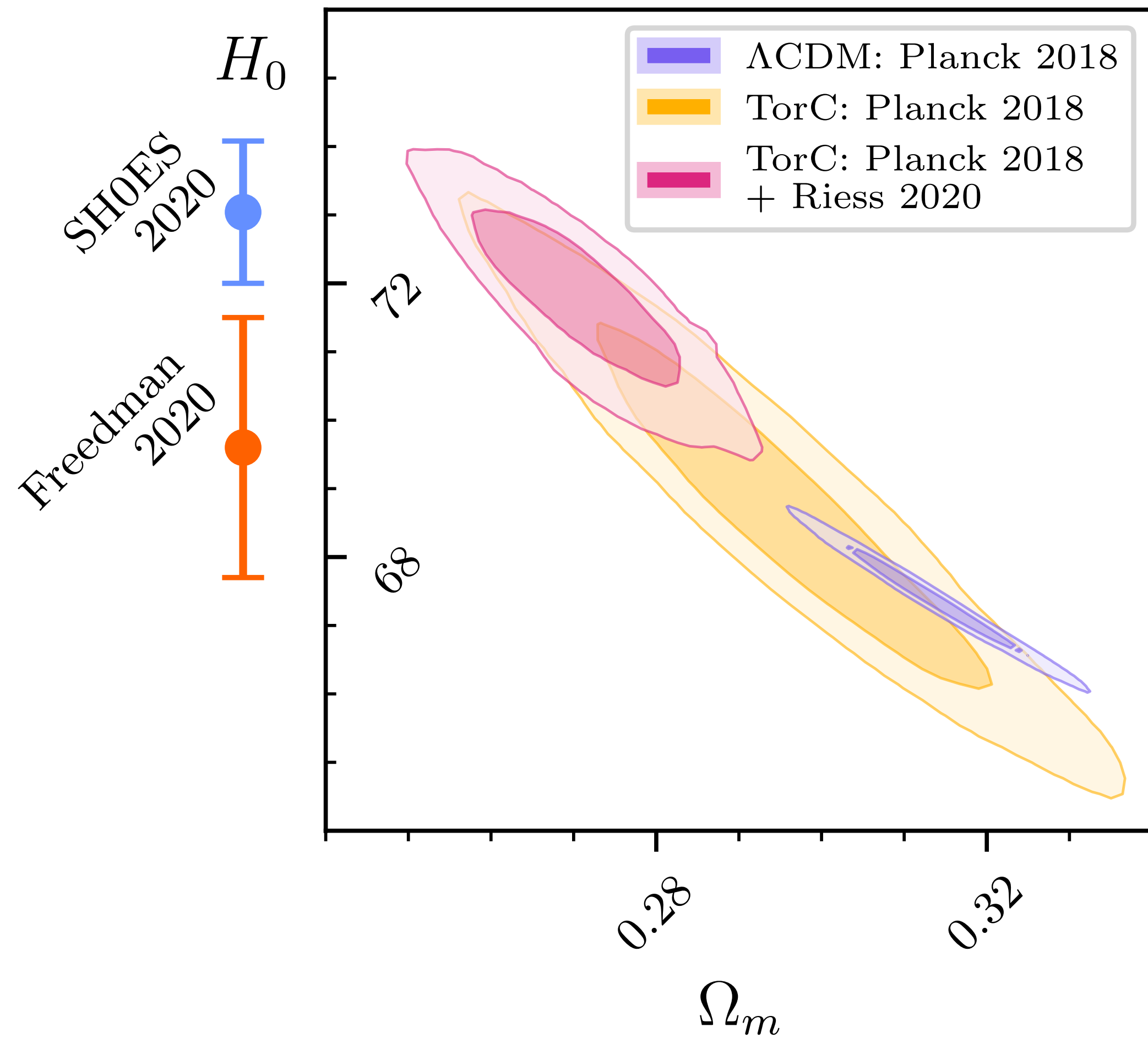
$\langle \log L(\theta) \rangle_P$ - how well the model fits the data, averaged over the posterior

D_{KL} - complexity penalty

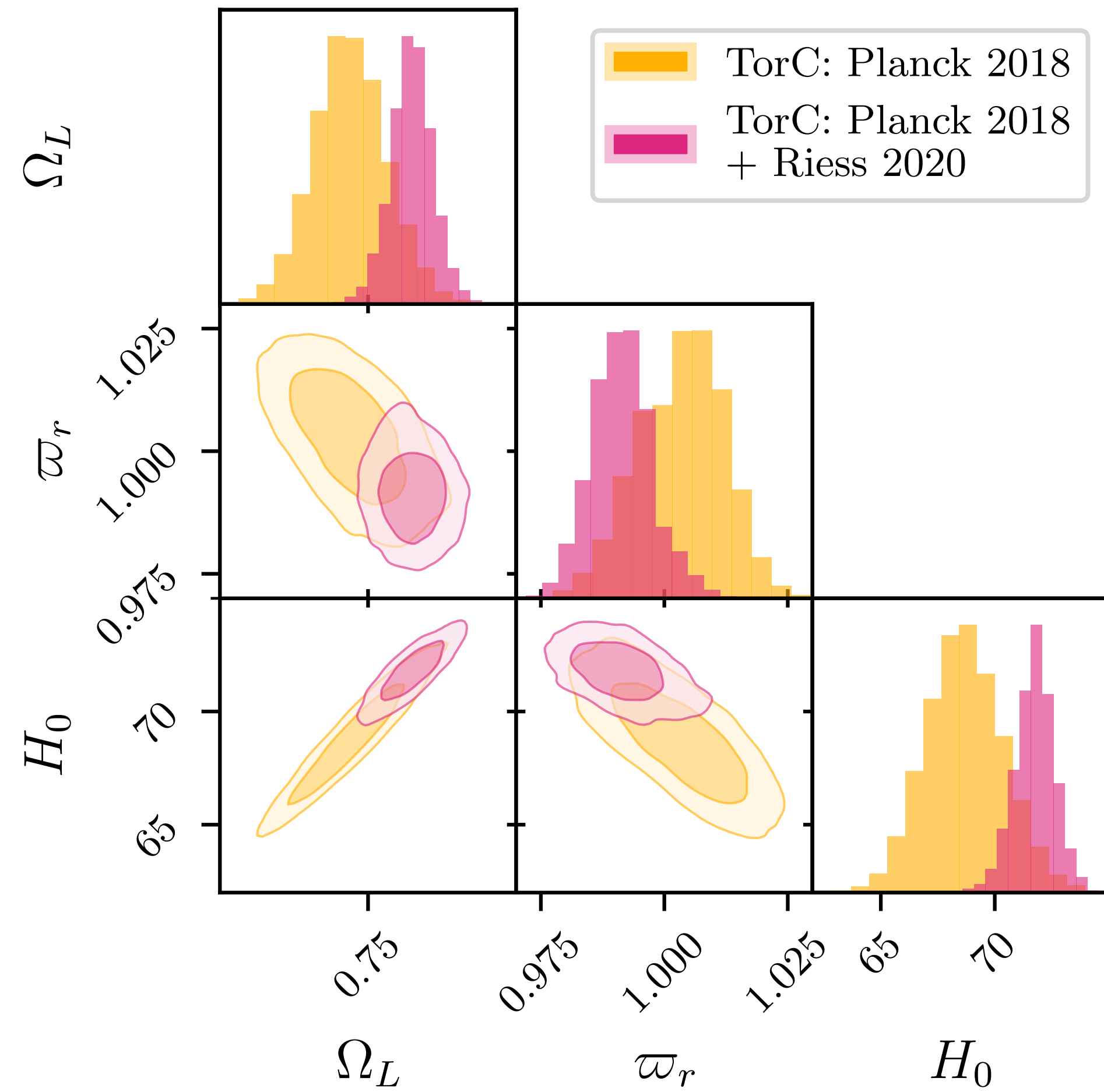
- Given uniform prior for two models, they can be compared using Bayes factor

$$\begin{aligned} \Delta \log Z &= \log Z_1 - \log Z_2 \\ &= \Delta \langle \log L(\theta) \rangle_P - \Delta D_{\text{KL}} \end{aligned}$$

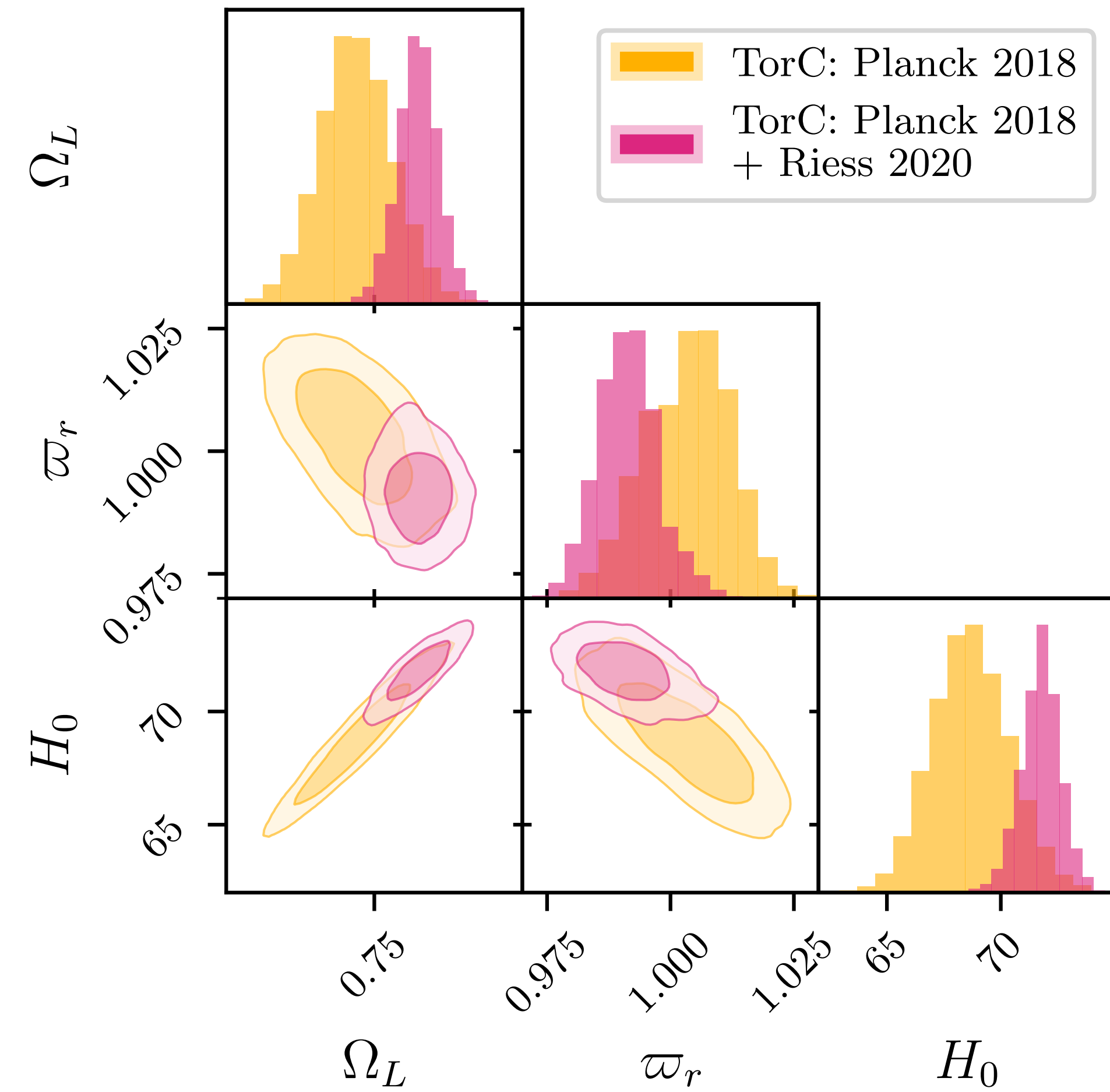
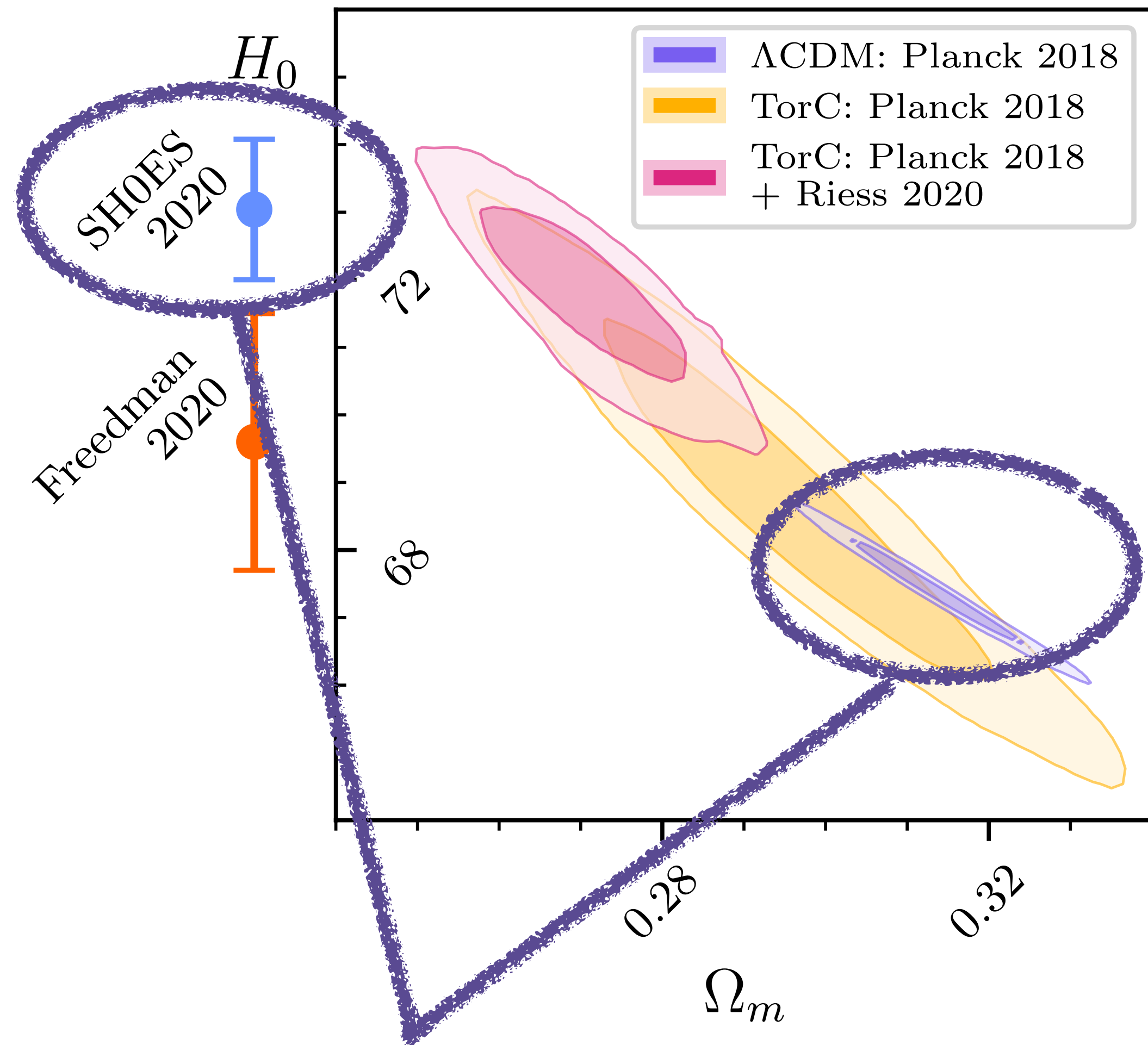
Flat TorC posterior result



[2507.09228]

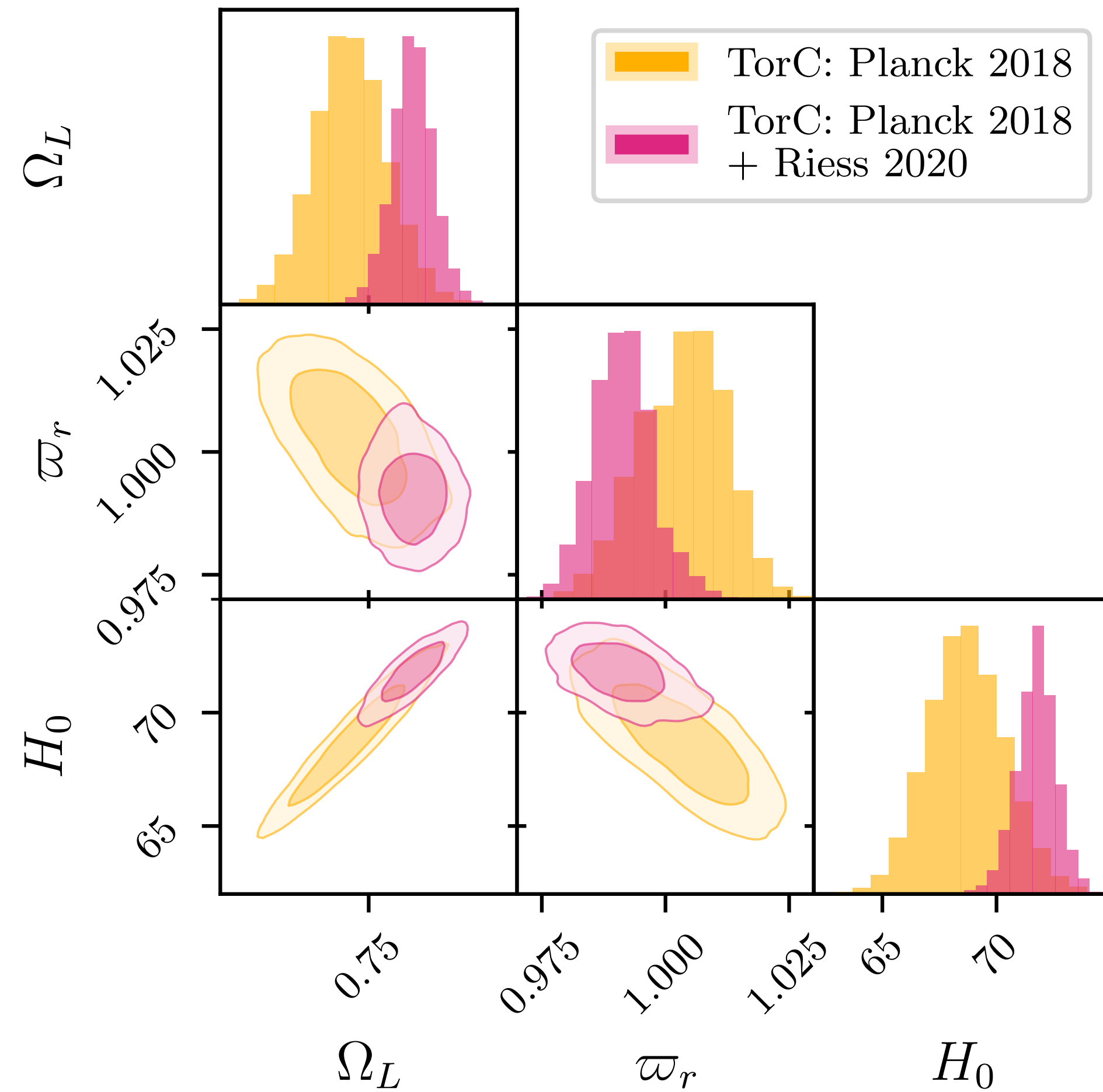
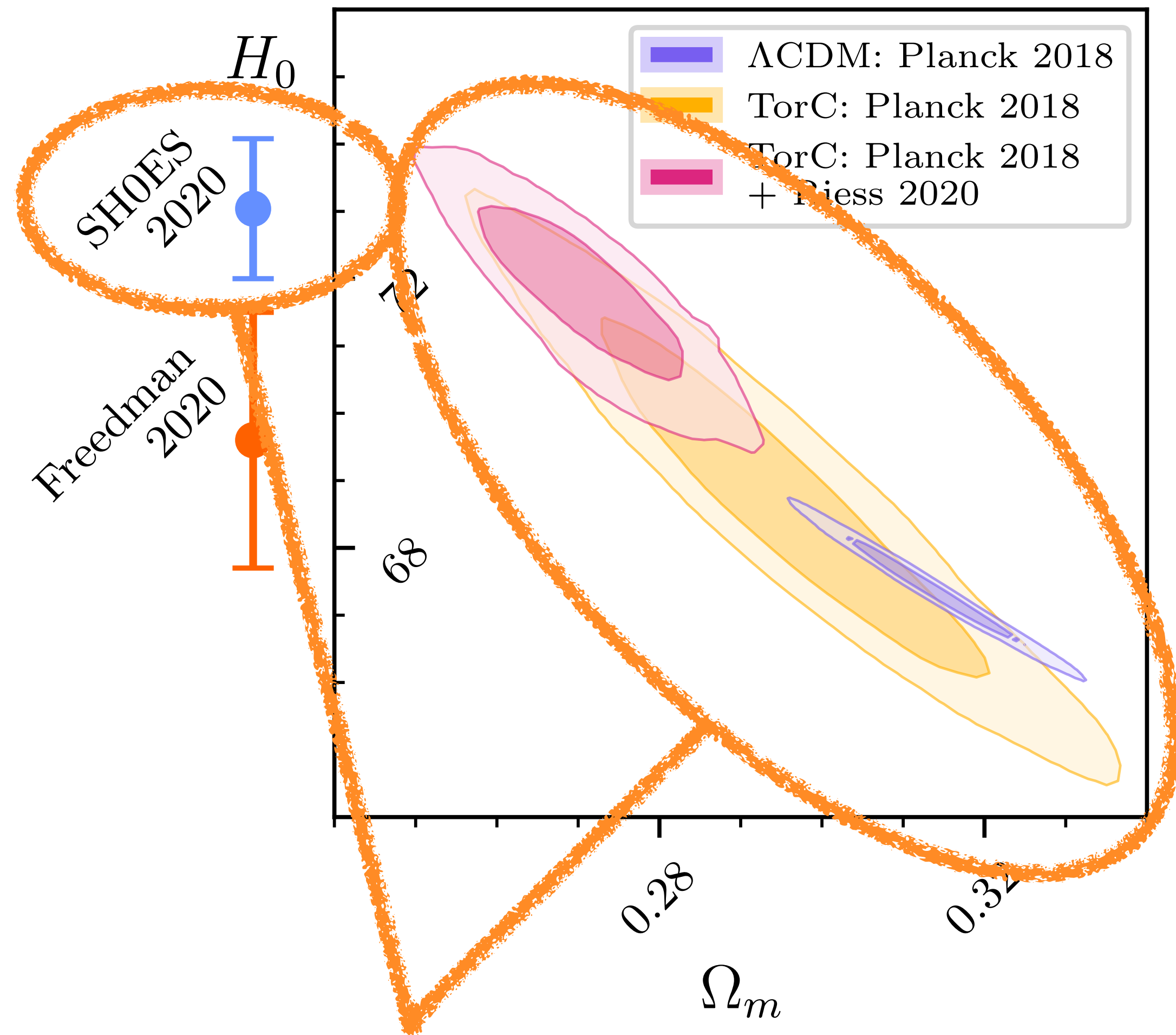


Flat TorC posterior result



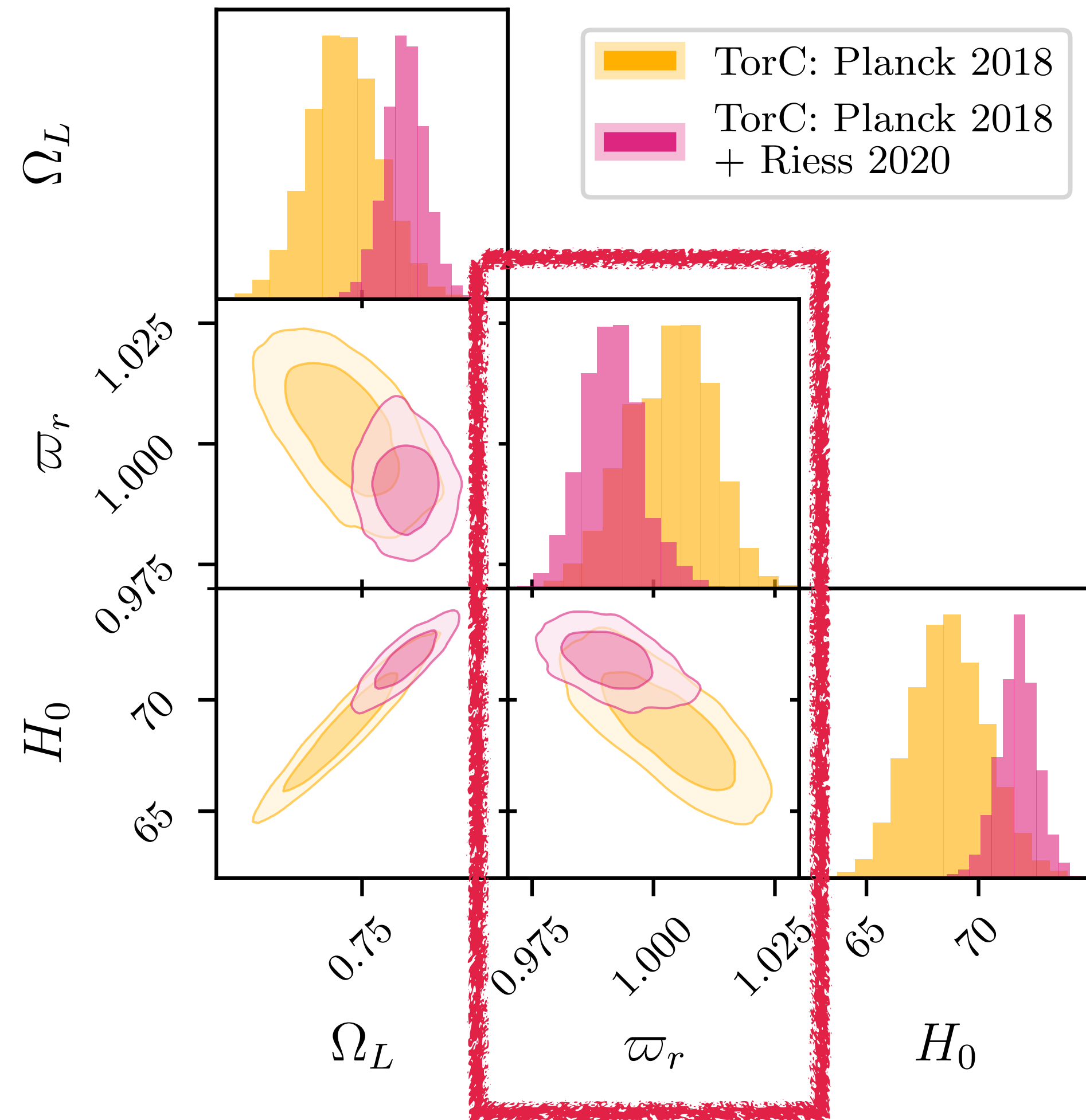
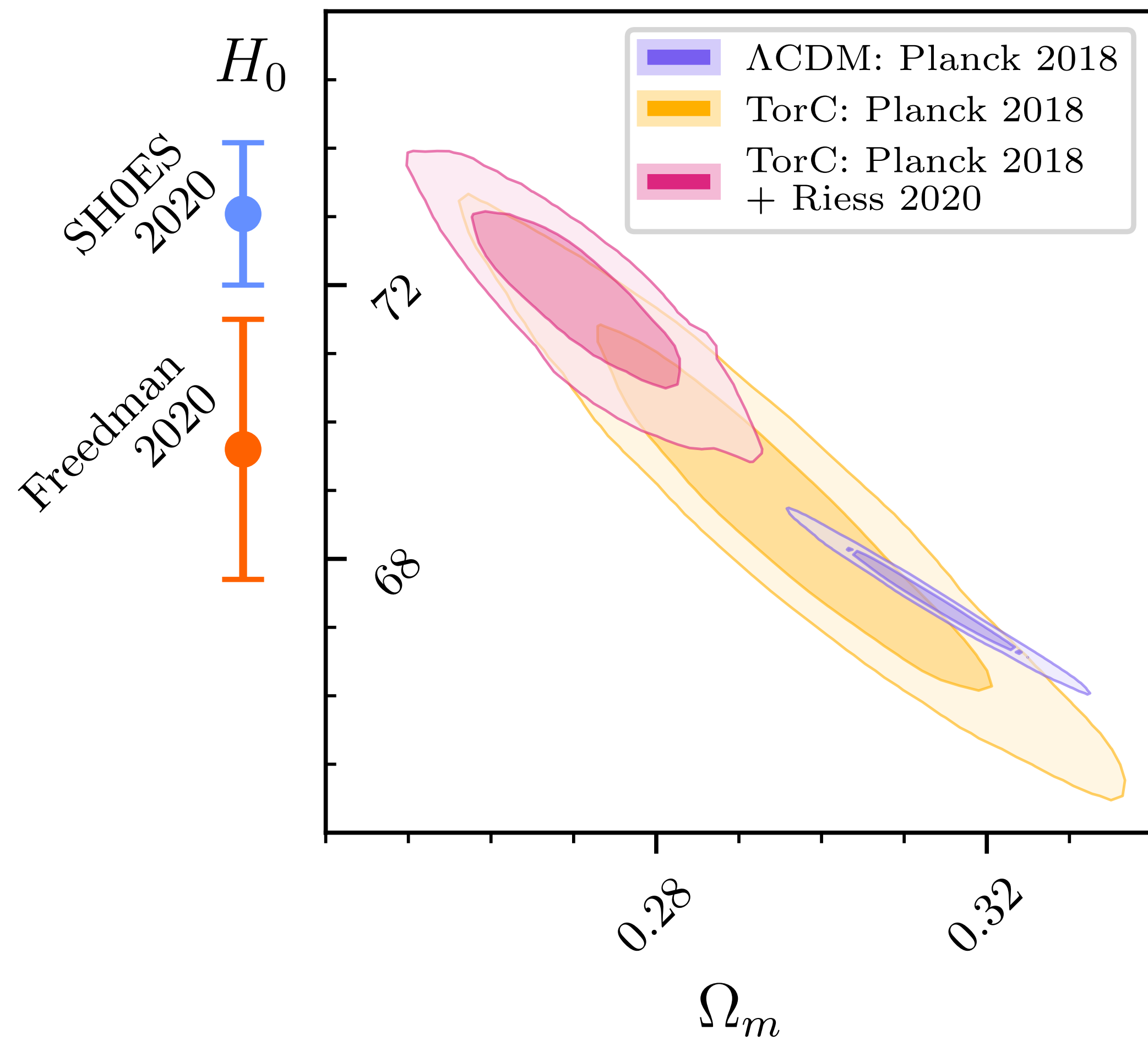
Λ CDM: SHOES 2020 & Planck 2018 data in tension

Flat TorC posterior result



TorC: Planck 2018 data is consistent with SHOES

Flat TorC posterior result



Consistent with Λ CDM, but allows higher H_0 through presence of torsion

Flat TorC Tension Quantification

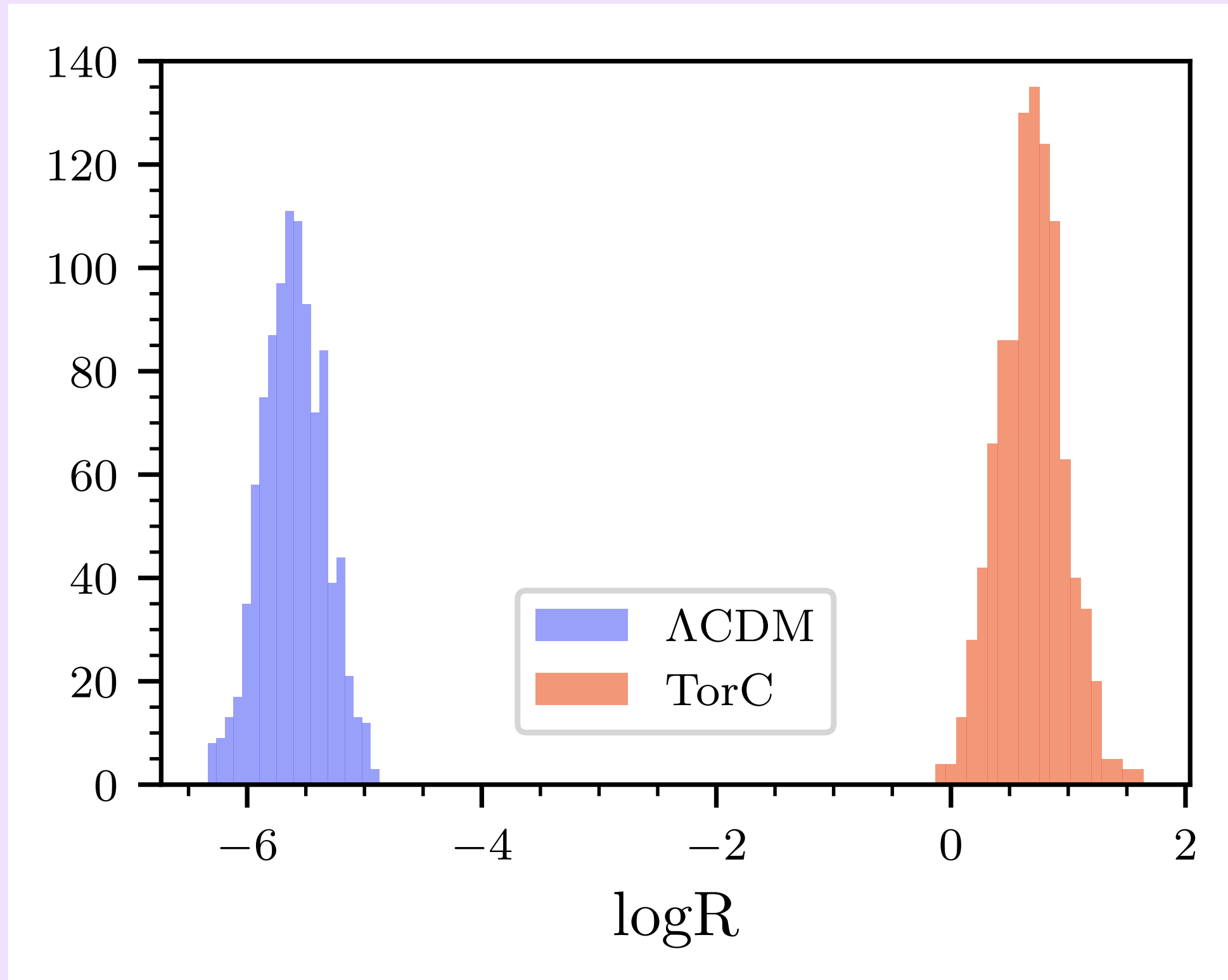
For Λ CDM and flat TorC models.

Assess the level of agreement between two datasets for each model:

- Planck 2018
- SHOES 2020

Λ CDM: $\log R \ll 0$ - Significant tension between the two datasets

TorC: $\log R > 0$ - Improved consistency between the two datasets



Flat TorC Tension Quantification

For Λ CDM and flat TorC models.

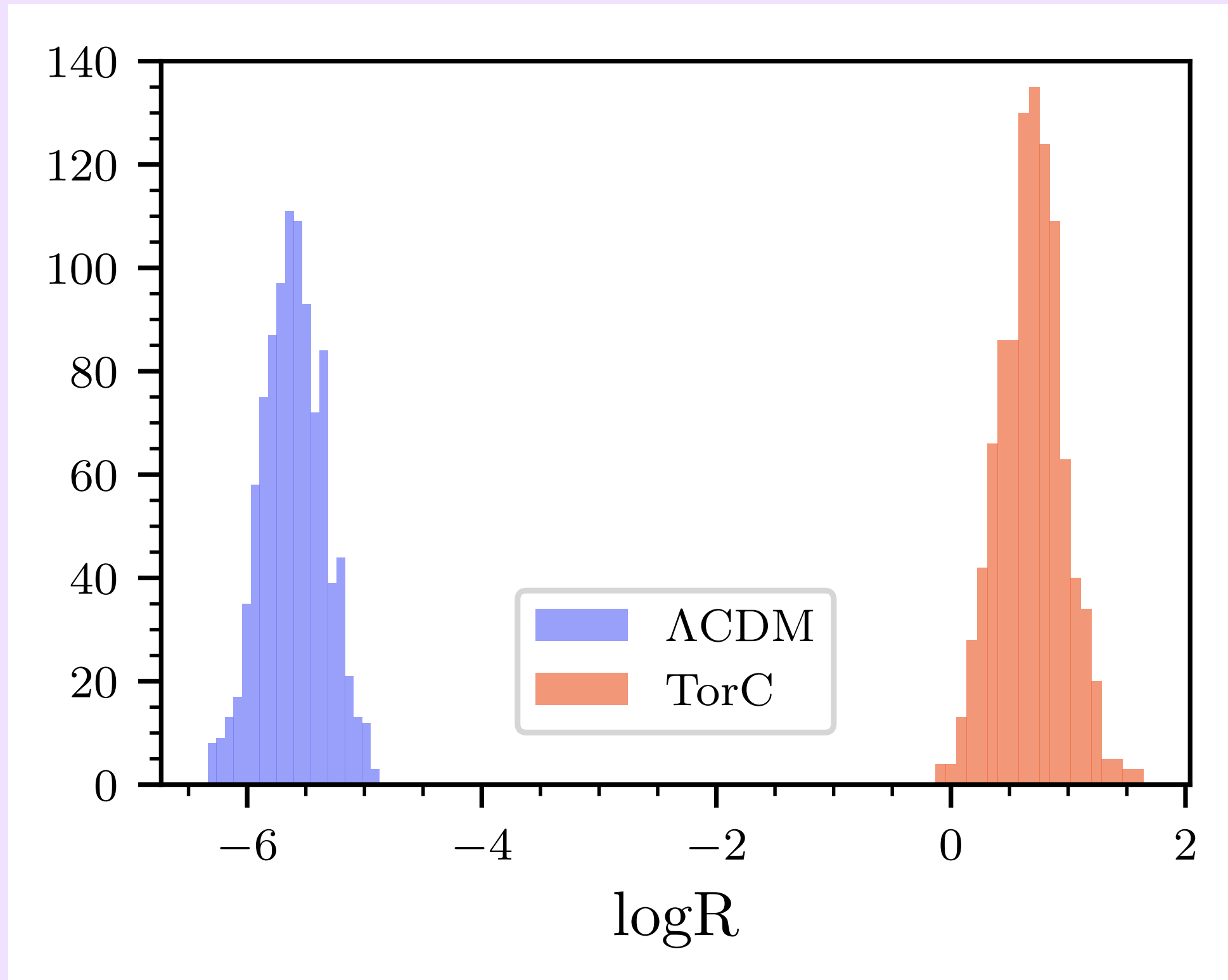
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Tension Alleviated??



TorC Model Comparison

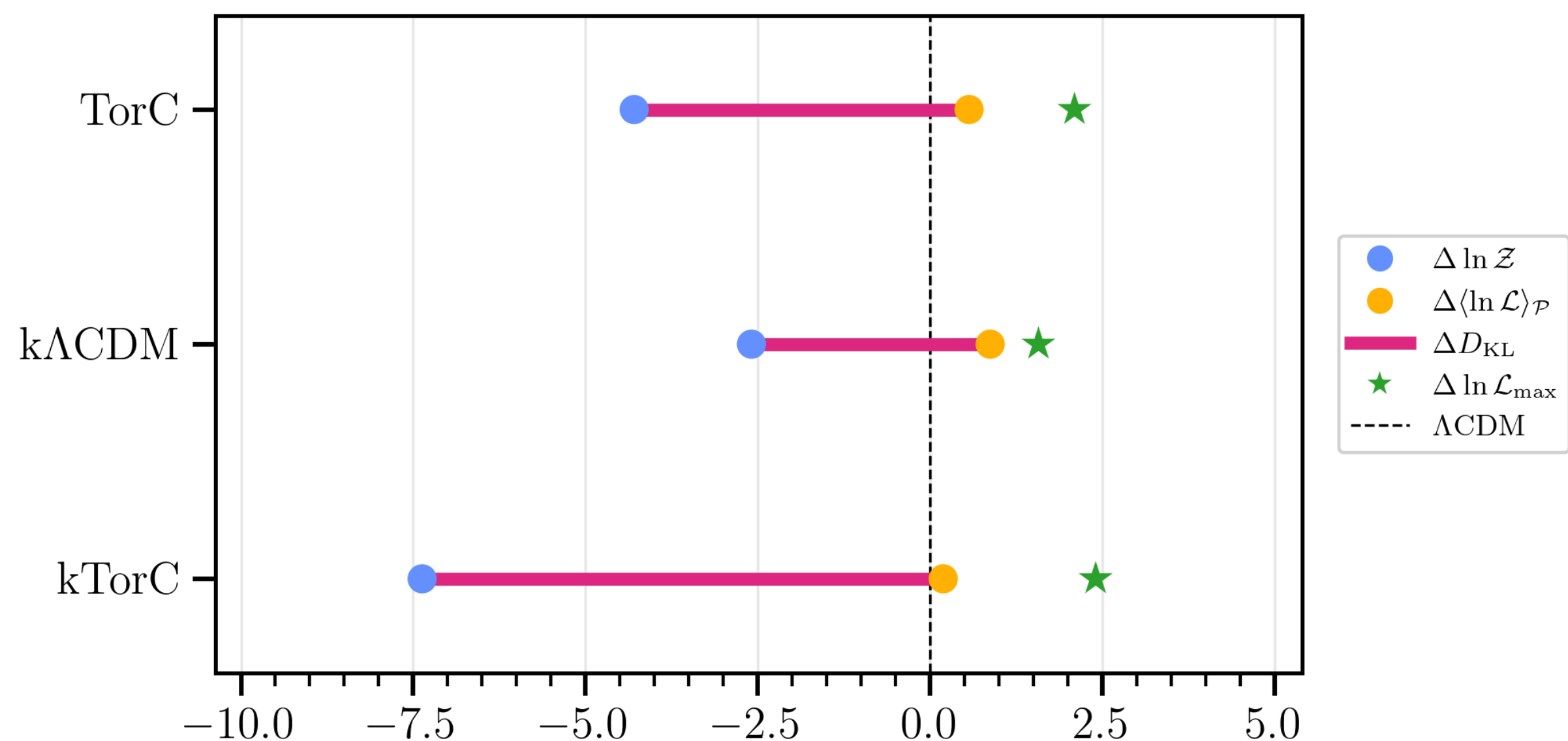
Given data, compare the overall viability of models: TorC, kTorC, Λ CDM, k Λ CDM

$$\log Z = \langle \log L(\theta) \rangle_P - D_{\text{KL}}$$

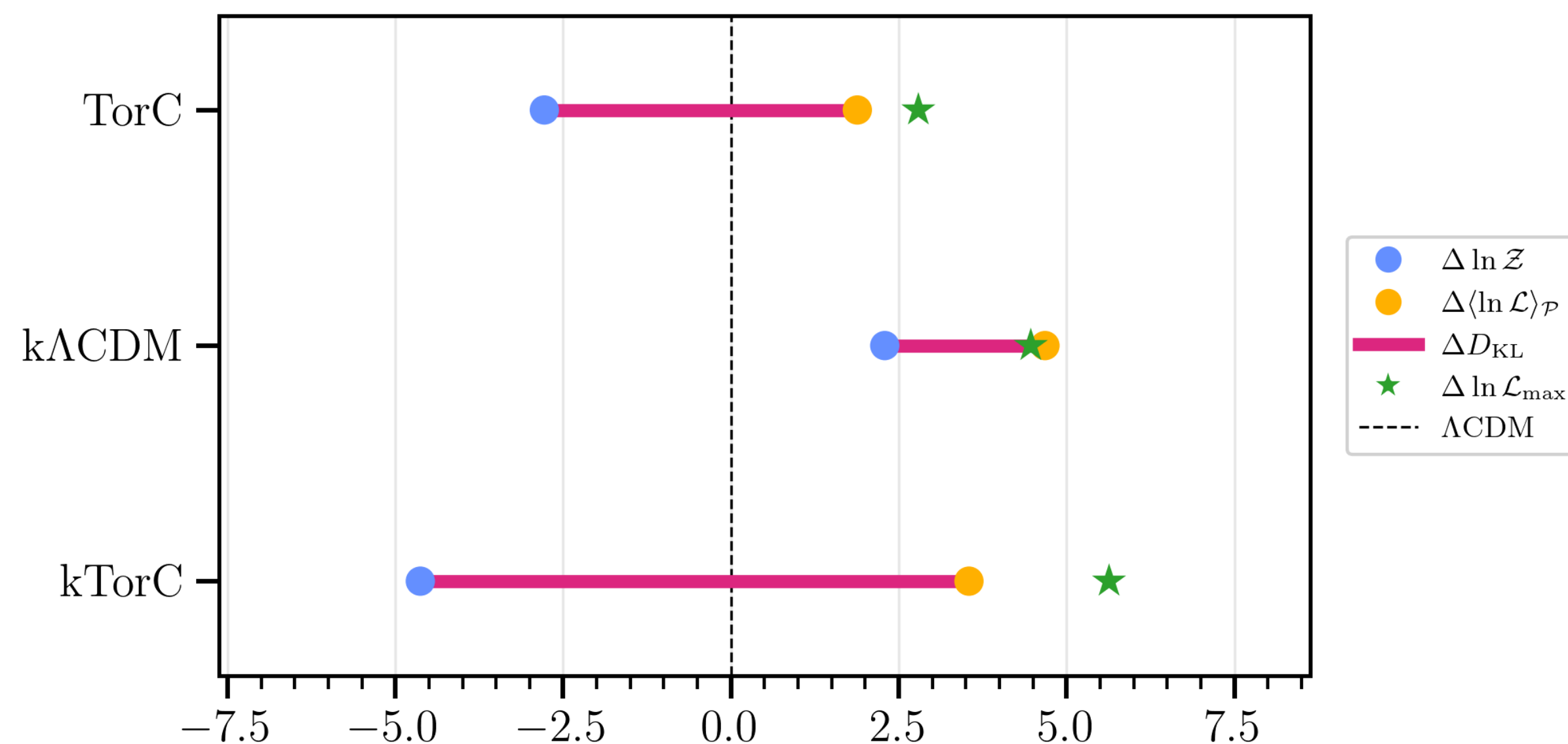
$\langle \log L(\theta) \rangle_P$ - how well the model fits the data, averaged over the posterior

D_{KL} - complexity penalty

Lensing

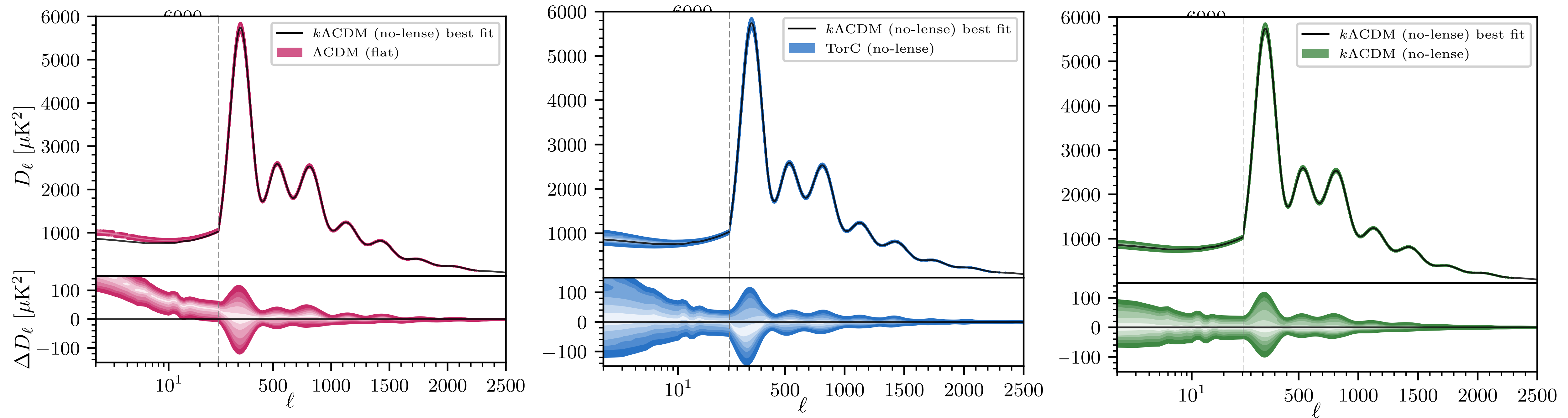


No-Lensing



Curved TorC Model Comparison

Posterior power spectrum in comparison with best fit no-screen $k\Lambda$ CDM result (Highest evidence)



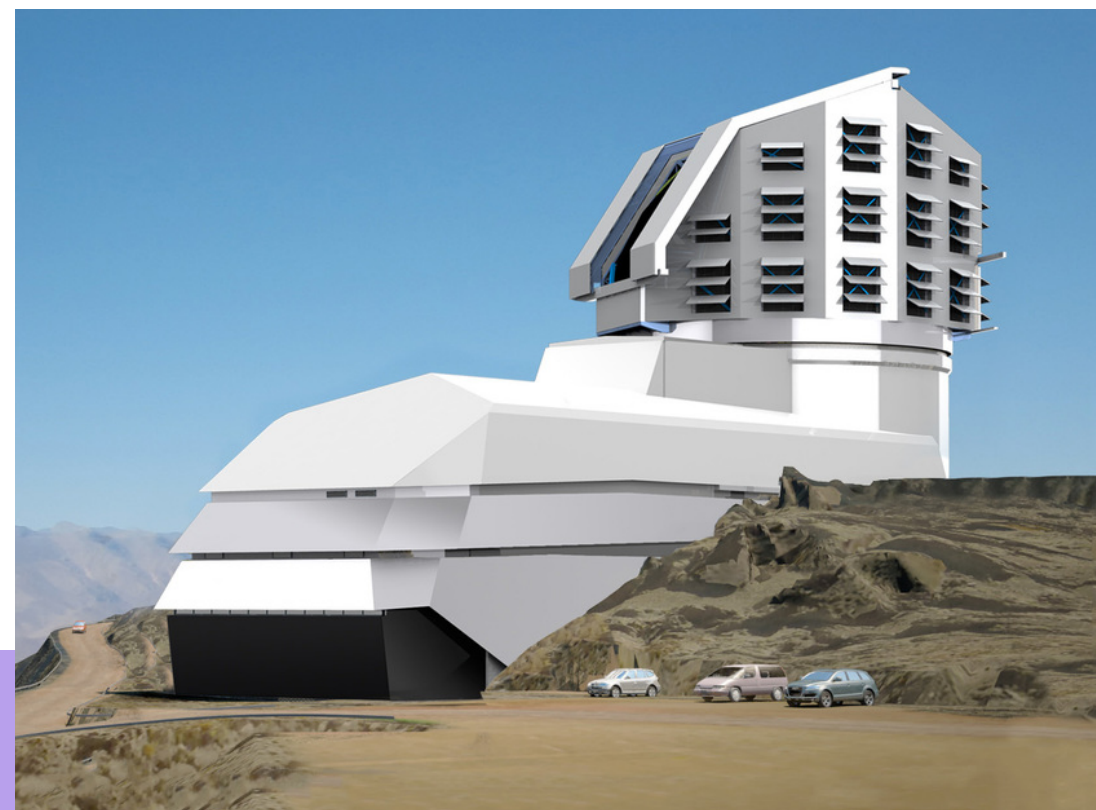
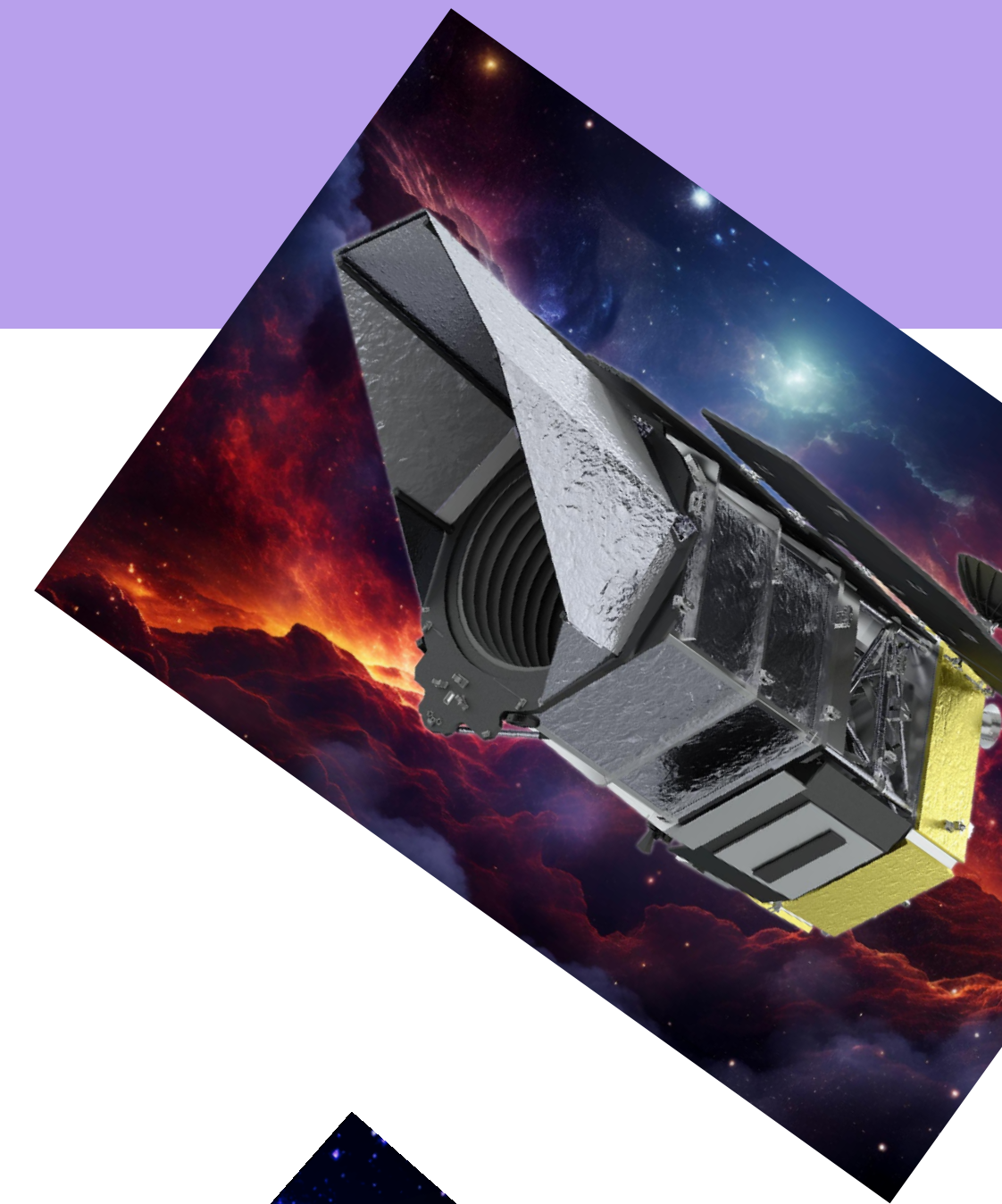
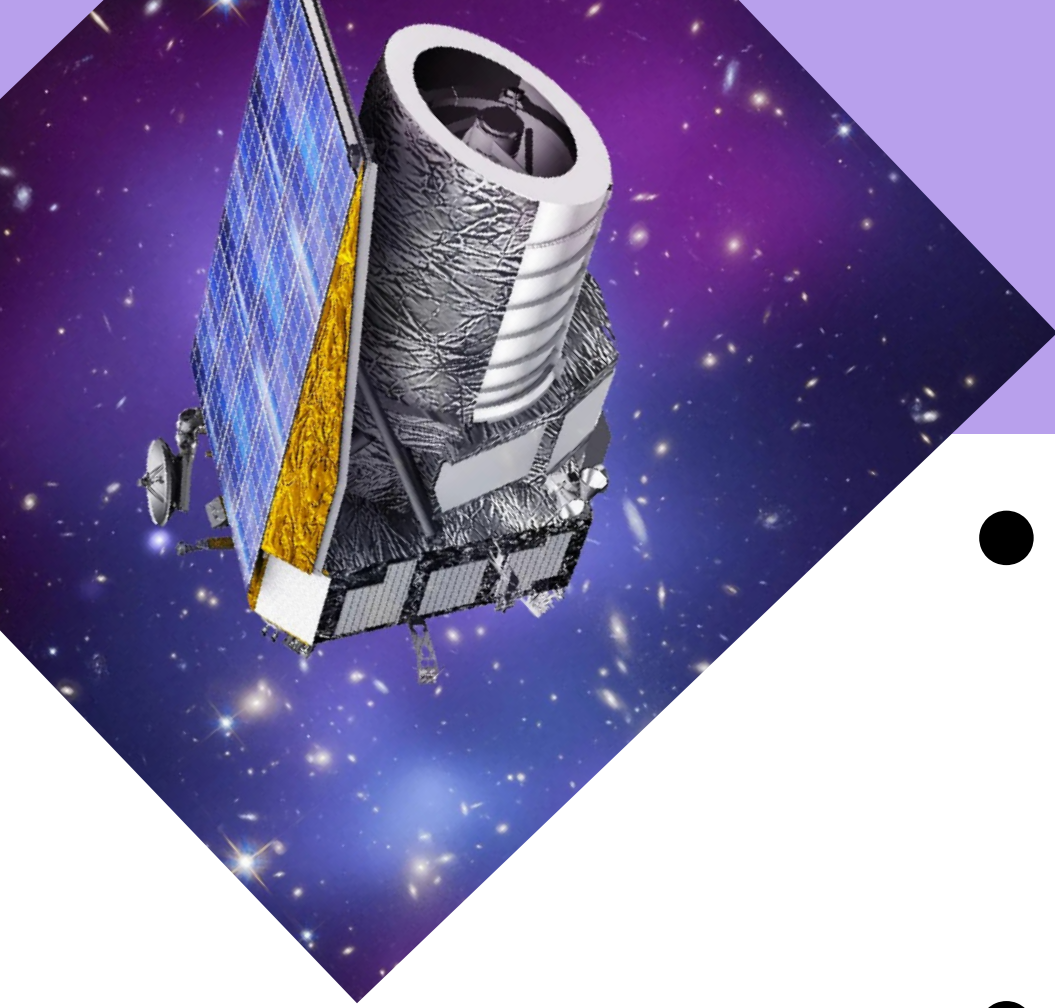
$k\Lambda$ CDM and Λ CDM show different behaviour for fit

k TorC fits $k\Lambda$ CDM, but it predicts a broader distribution at low multipoles, leading to a lower evidence

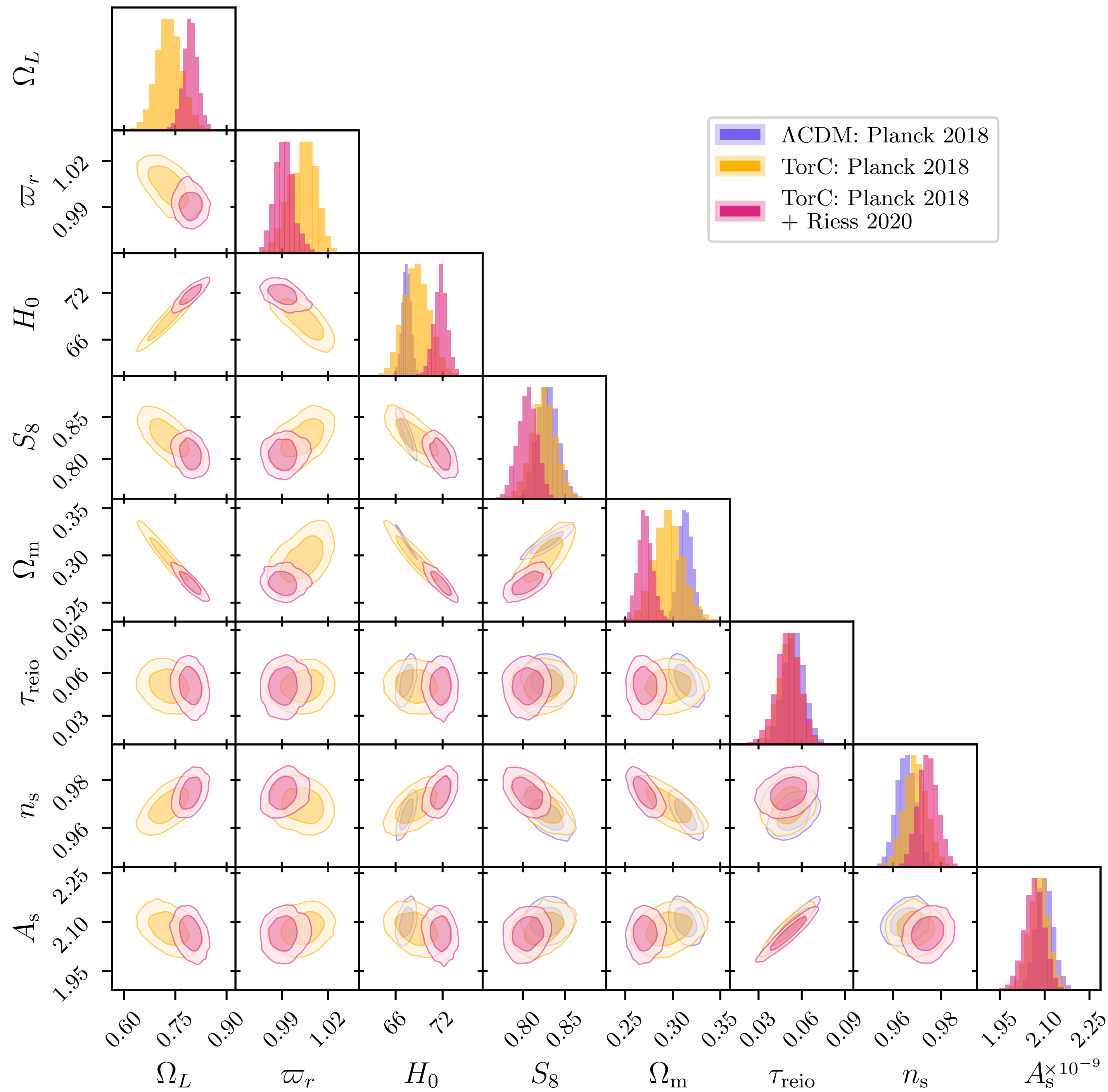
Fgivenx [[1908.01711](#)]

Conclusions

- Studied TorC as an extension of Λ CDM model with two extra cosmological parameters (ϖ_r & Ω_Λ) and its k-screening property
- Using Cobaya, constrained parameters with PolyChord + CAMB, using Planck 2018 & SH0ES data.
- R-statistic: Planck–SH0ES tension reduced under flat TorC.
- Bayes factors: TorC not decisively favoured over Λ CDM.
- Current & upcoming surveys will critically test models like TorC, making this a pivotal time for gravity theories!



Thank you!



Posterior

