A model-independent test of gravity from the Weyl potential evolution

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How can we test modified gravity?
Possibility 1

1. Pick a modified gravity model →
2. Data analysis with additional parameters →
3. Obtain constraints for one model

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Repeat for each model!

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Identify model-independent observable → Obtain observable from data → Check which theory fits the measurement

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Model-independent observable for gravitational lensing?

Lensing is sensitive to the perturbed geometry of the Universe:

Lensing $\propto$ $\Psi_W = (\Phi + \Psi)/2$ ⟶ Weyl potential

Weyl potential in General Relativity:

$$\Psi_W \propto D_1(z)\,\Omega_m(z)$$

$D_1(z)$: Growth of matter perturbations

$\Omega_m(z)$: Matter content in the Universe

Model-independent observable for gravitational lensing?

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Lensing $\propto$ $\Psi_W = (\Phi + \Psi)/2$ ⟶ Weyl potential

Weyl potential in ~~General Relativity:~~ **any gravity theory:**

$$\Psi_W \propto \sout{D_1(z)\,\Omega_m(z)}\ J(z)$$

Growth of matter perturbations

Matter content in the Universe

I. Tutusaus, D. Sobral-Blanco & C. Bonvin (2022), arXiv:2209.08987

Galaxy-galaxy lensing angular power spectrum

$$C_\ell^{\Delta\kappa}(z_i, z_j) = \frac{3}{2}\int \mathrm{d}z\, n_i(z)\mathcal{H}^2(z)\boxed{\hat{b}_i(z)\hat{J}(z)}B\left(k_\ell, \chi\right)\frac{P_{\delta\delta}^{\mathrm{lin}}\left(k_\ell, z_*\right)}{\sigma_8^2(z_*)}\int \mathrm{d}z' n_j(z')\frac{\chi'(z') - \chi(z)}{\chi(z)\chi'(z')}$$

lens bin → z_i; source bin → z_j

$$\hat{J}(z) \equiv \frac{J(z)\sigma_8(z)}{D_1(z)} \quad \text{(Weyl evolution)}, \qquad \hat{b}_i(z) \equiv b_i(z)\sigma_8(z)\,.$$

Galaxy clustering: Depends on $\hat{b}_i(z)\hat{b}_j(z)$

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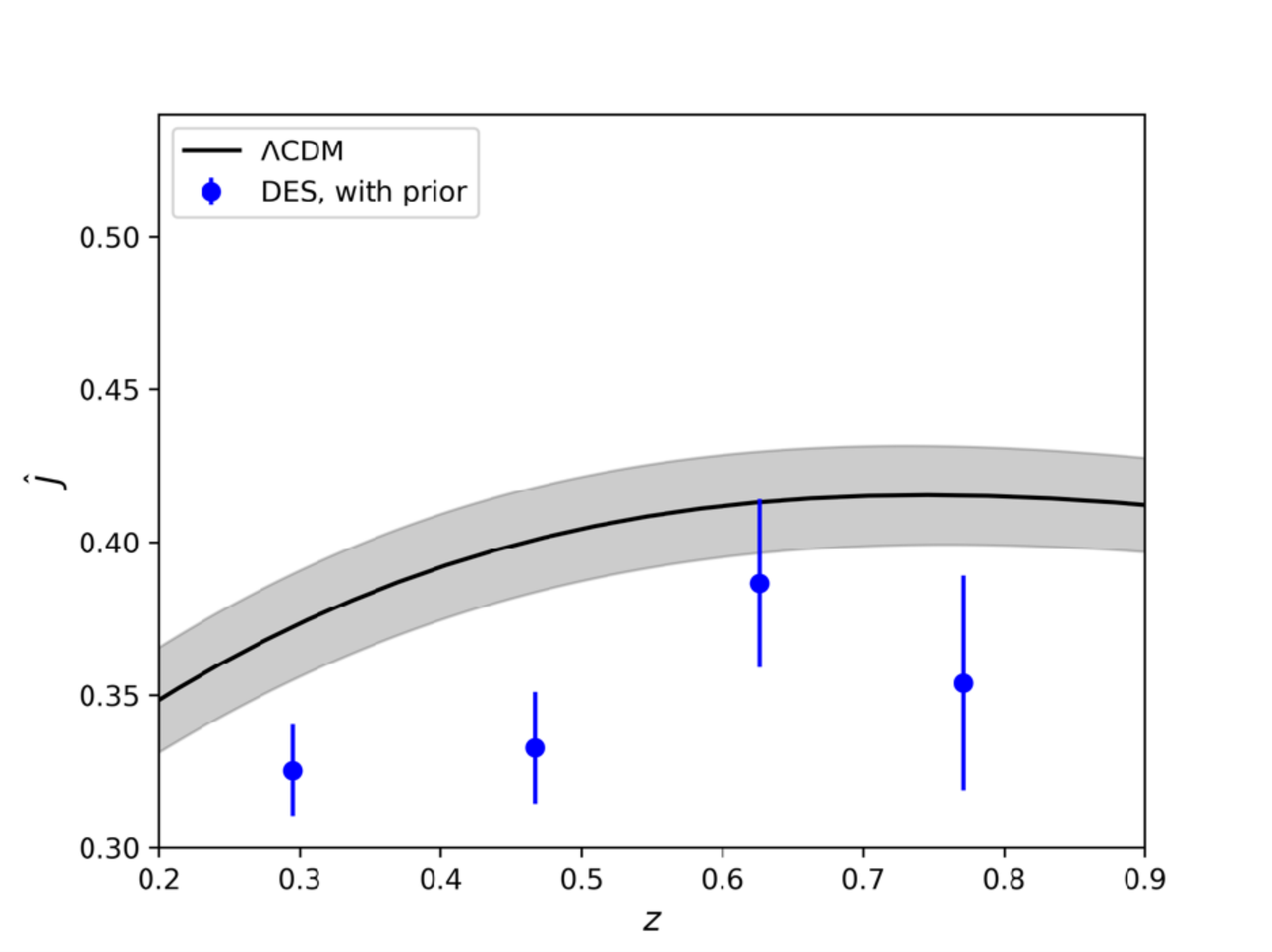
Combining galaxy-galaxy lensing and galaxy clustering → Measurement of $\hat{J}(z)$

Measurement of $\hat{J}(z)$ from Dark Energy Survey data



I. Tutusaus, C. Bonvin & NG, arXiv:2312.06434

Measurement in 4 bins of the MagLim sample, with 3σ Planck priors

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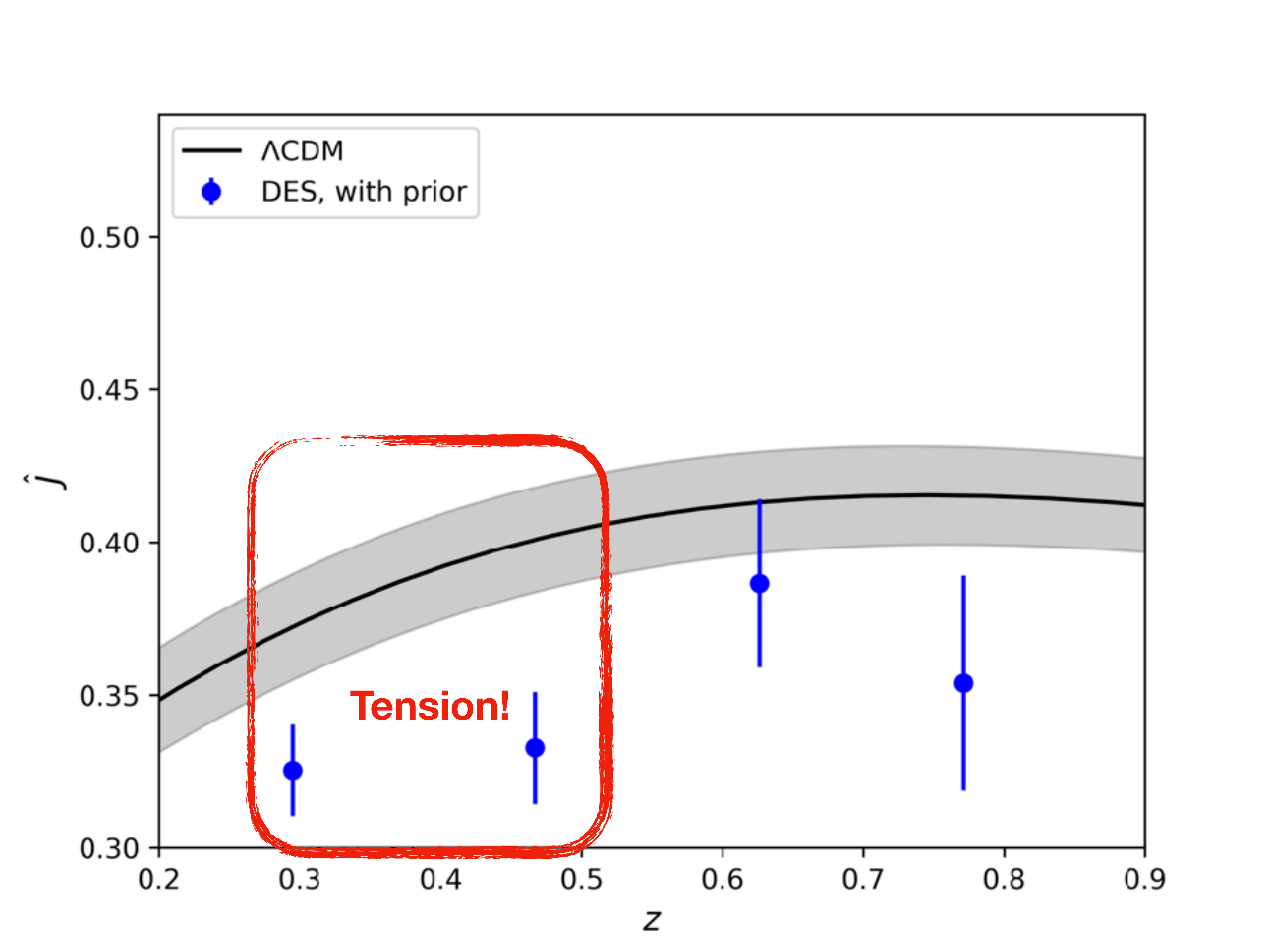

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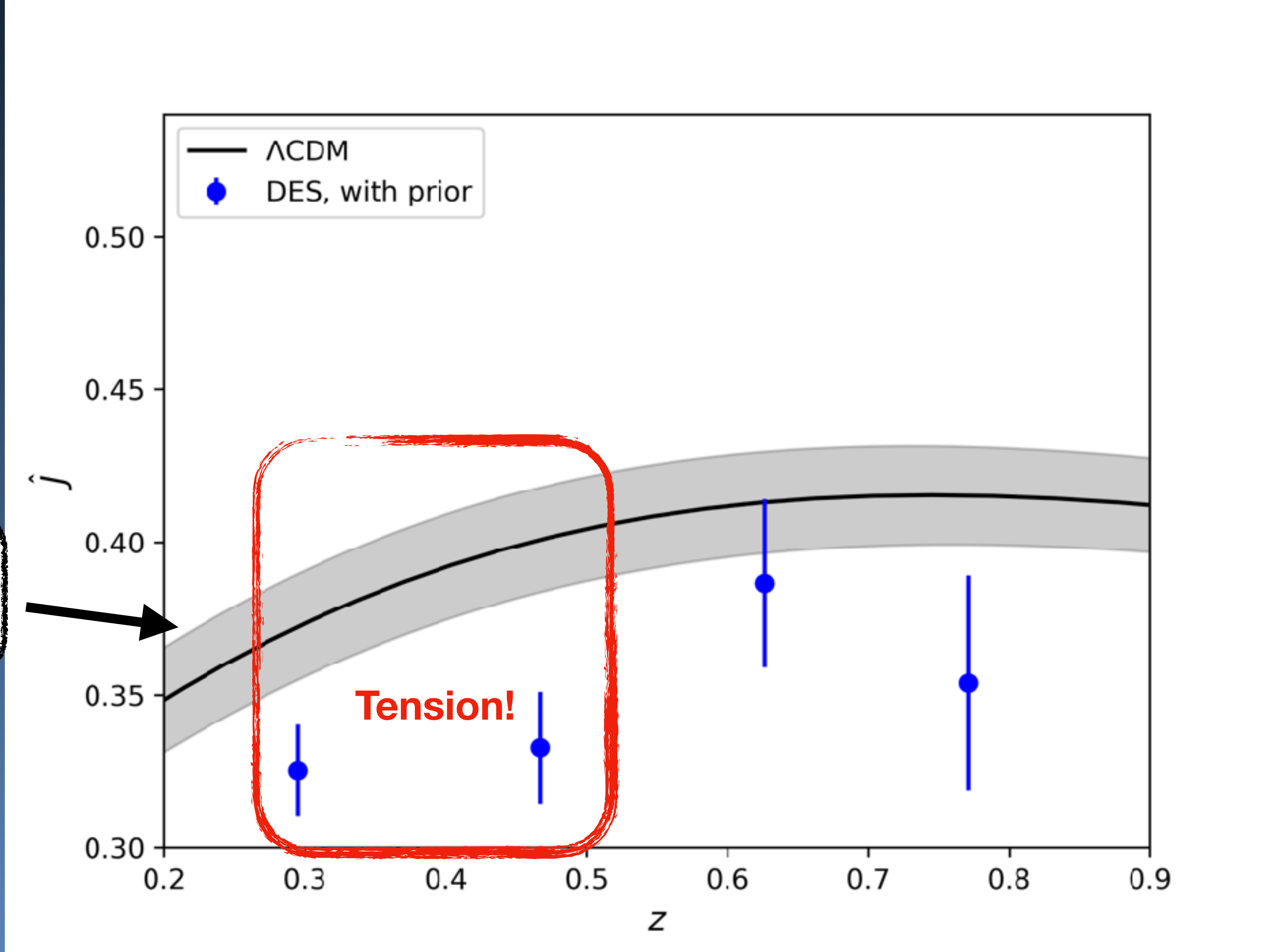

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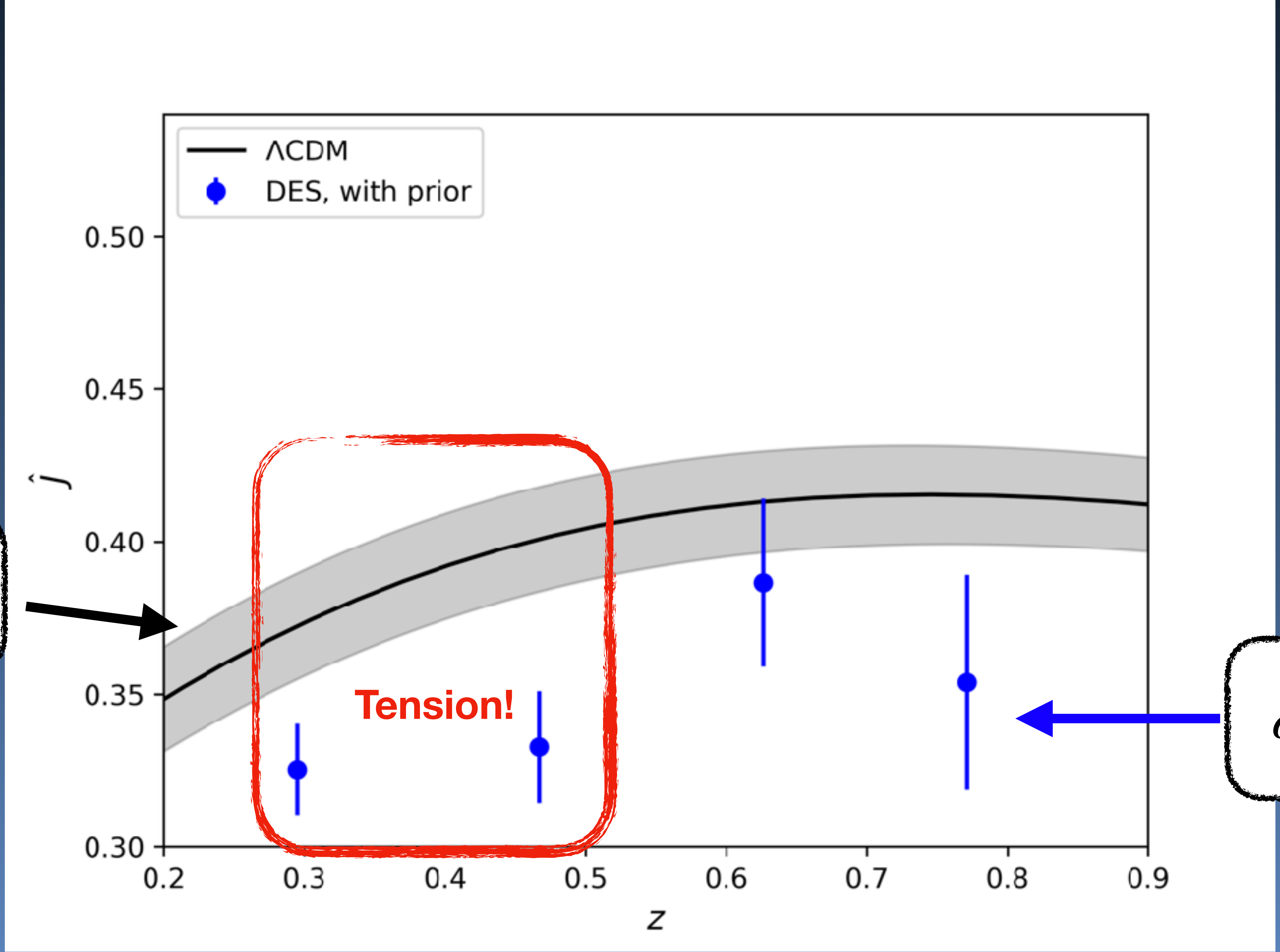

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$\sigma_8(z=0) = 0.85 \pm 0.03$

$\sigma_8(z=0) = 0.74 \pm 0.04$

Measurement in 4 bins of the MagLim sample, with 3σ Planck priors

Conclusion & additional work

- DES data already gives us measurements of $\hat{J}$ with $5 - 10$ % precision.
  $\Rightarrow 2.8\sigma$ tension with ΛCDM at $z = 0.49$.

- Further application: Combination of $\hat{J}$ with galaxy velocities allows to reconstruct the E_G statistic, $E_G(z) \propto \hat{J}(z)/\big(f(z)\sigma_8(z)\big)$, see arXiv:2403.13709 (NG, C. Bonvin & I. Tutusaus).

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