KiDS+ GAMA : constraints on Horndeski gravity from combined large-scale structure probes

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with F. Köhlinger, B. Joachimi *and others*

based on **Spurio Mancini et al., MNRAS 490, Dec. 2019**

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The idea

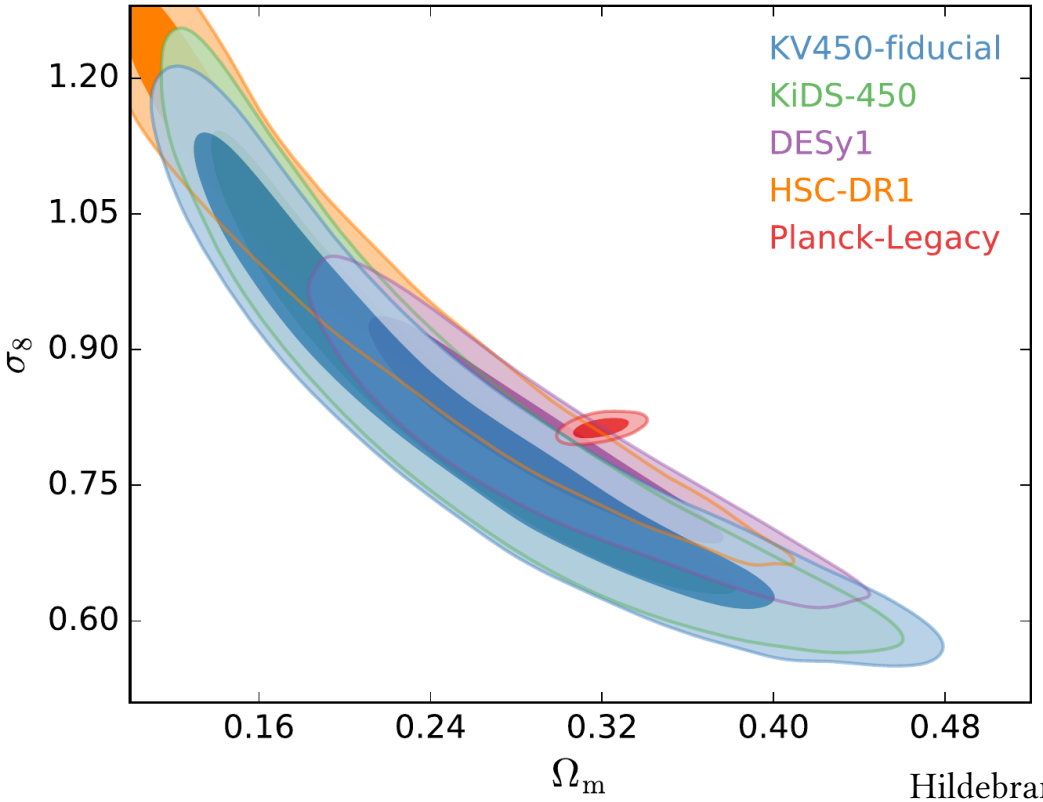
We constrain parameters describing **Horndeski** gravity

with a **3x2pt** cross-correlation analysis of
cosmic shear, **galaxy-galaxy lensing** and **galaxy clustering**
power spectra from the KiDS and GAMA surveys

→ First constraints on Horndeski gravity from cosmic shear!

ΛCDM and beyond

- **Cosmic acceleration**: Λ / DE / MG ?
- **Tensions**: (early vs late-time H_0) + CMB vs LSS Ω_m - σ_8



Hildebrandt et al. 2020

- Keep testing **gravity on cosmological scales!**

Introducing Horndeski Gravity

- Too many DE/MG models to test
- Horndeski Lagrangian: **most general** $g_{\mu\nu} + \phi + \text{local} + \text{Lorentz} + 4D$ with 2^{nd} order e.o.m.
- This covers the **majority of models** on the market: $f(R)$, quintessence, Brans-Dicke, Galileons, k-essence, Chameleons, etc...
- Avoids Ostrogradski's instabilities, i.e. ghost degrees of freedom
- First found by Horndeski 1974, then rediscovered by Deffayet et al. 2011

Constraining Horndeski Gravity

- **Four functions of time** describe linear perturbations in Horndeski gravity (Bellini & Sawicki 2014)

Cannot be constrained with LSS observables and uncorrelated with α_B , α_M , α_T

- $\alpha_K(\tau)$ — kineticity
- $\alpha_B(\tau)$ — braiding
- $\alpha_M(\tau)$ — Planck-mass run rate

Constraints from GW170817 + GRB170817A (see e.g. Baker et al. 2017)

- $\alpha_T(\tau)$ — tensor speed excess

- ΛCDM = { 0, 0, 0, 0 }

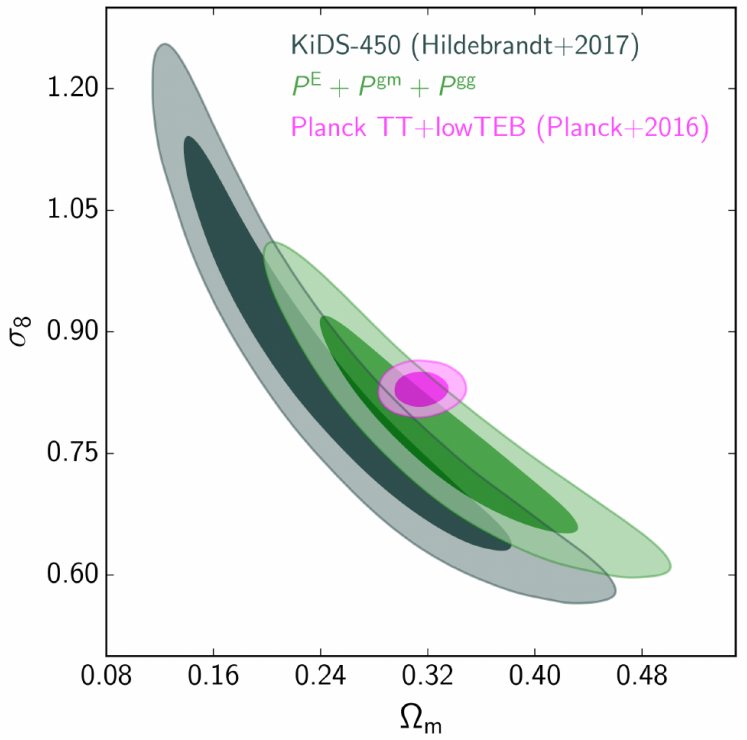
- Assume a time parameterization, e.g. $\alpha_B(\tau) = \hat{\alpha}_B\,\Omega_{\rm DE}(\tau), \quad \alpha_M(\tau) = \hat{\alpha}_M\,\Omega_{\rm DE}(\tau)$

→ **constraints on parameters** $\hat{\alpha}_B, \hat{\alpha}_M$

KiDS+GAMA

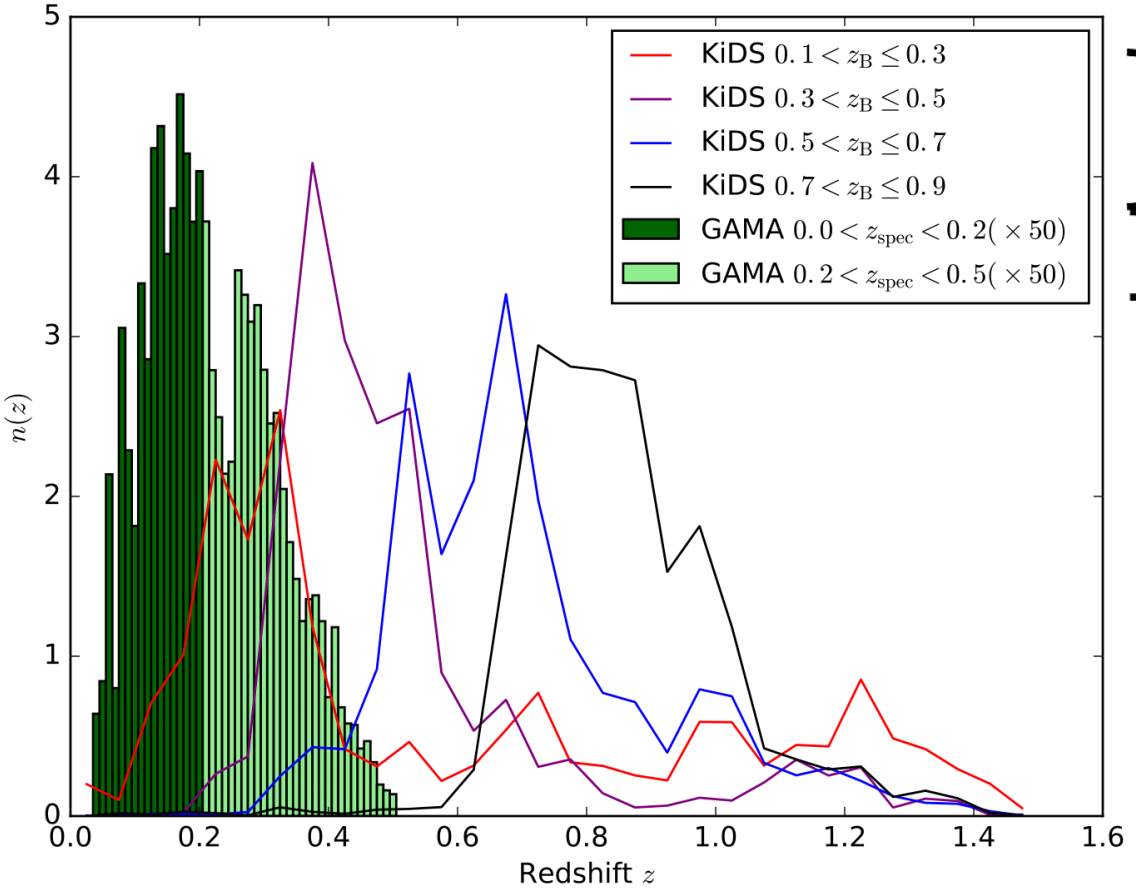
KiDS+GAMA: Cosmology constraints from a joint analysis of cosmic shear, galaxy-galaxy lensing and angular clustering

Edo van Uitert[1⋆], Benjamin Joachimi[1†], Shahab Joudaki[2,3,4], Catherine Heymans[5], Fabian Köhlinger[6,7], Marika Asgari[5], Chris Blake[2], Ami Choi[8], Thomas Erben[9], Daniel J. Farrow[10], Joachim Harnois-Déraps[5], Hendrik Hildebrandt[9], Henk Hoekstra[6], Thomas D. Kitching[11], Dominik Klaes[9], Konrad Kuijken[6], Julian Merten[4], Lance Miller[4], Reiko Nakajima[9], Peter Schneider[9], Edwin Valentijn[12], Massimo Viola[6]



van Uitert et al. 2018

Analysis setup



cosmic shear

clustering

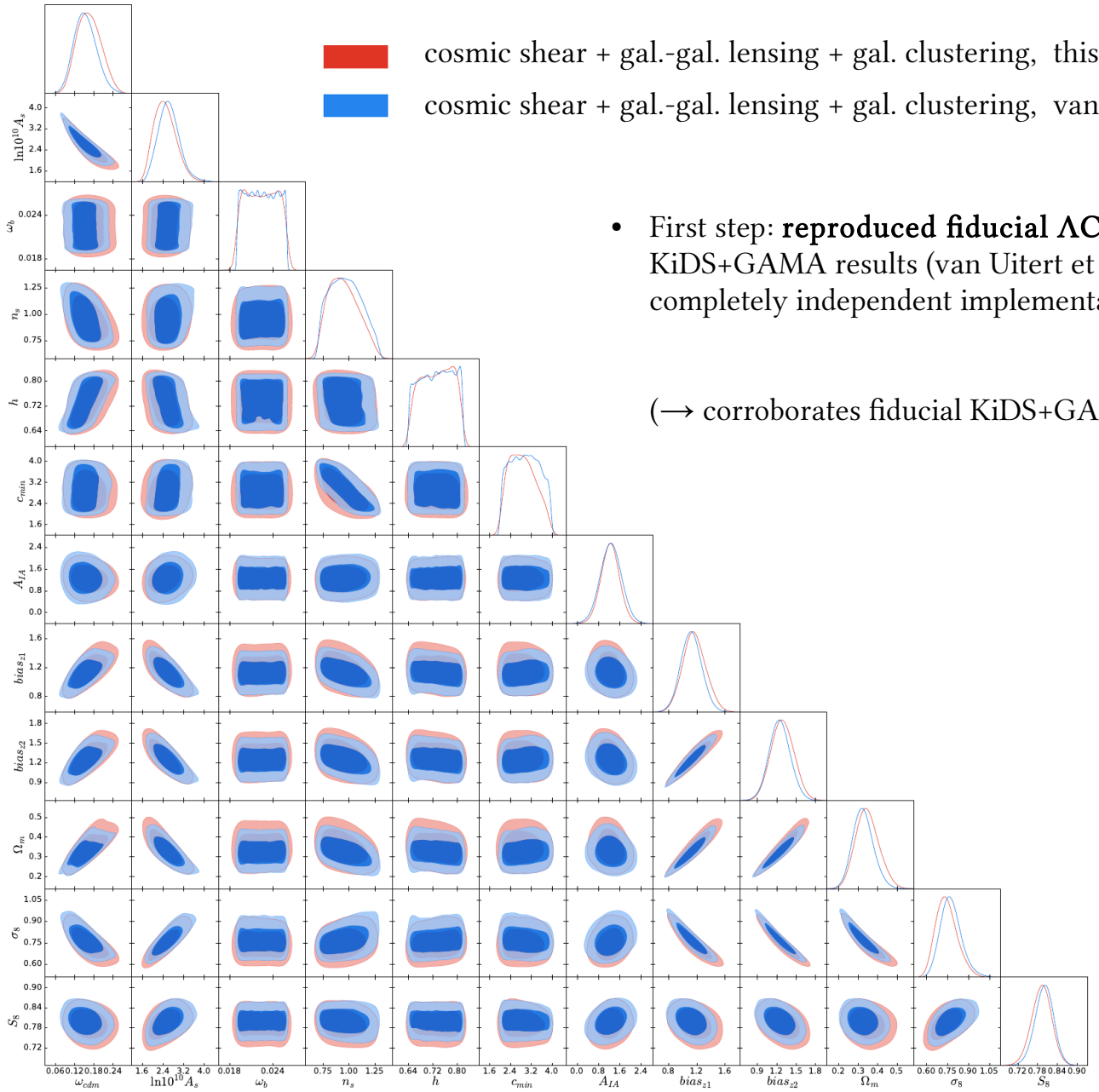
galaxy-galaxy lensing

Modelling

Developed a new likelihood module for MontePython, including:

- linear matter power spectrum from **HiClass** (Zumalacarregui et al. 2017), i.e. **Class** for Horndeski. Nonlinear corrections from **HMcode**, including one parameter to account for baryon feedback
- intrinsic alignments: tidal model (for all galaxies) including non-linear extension with free amplitude
- linear effective galaxy bias for each spectroscopic sample
- screening mechanism: GR recovered in small scales/high density environments (e.g. Solar System). Implemented as phenomenological scale-dependent filter with screening scale

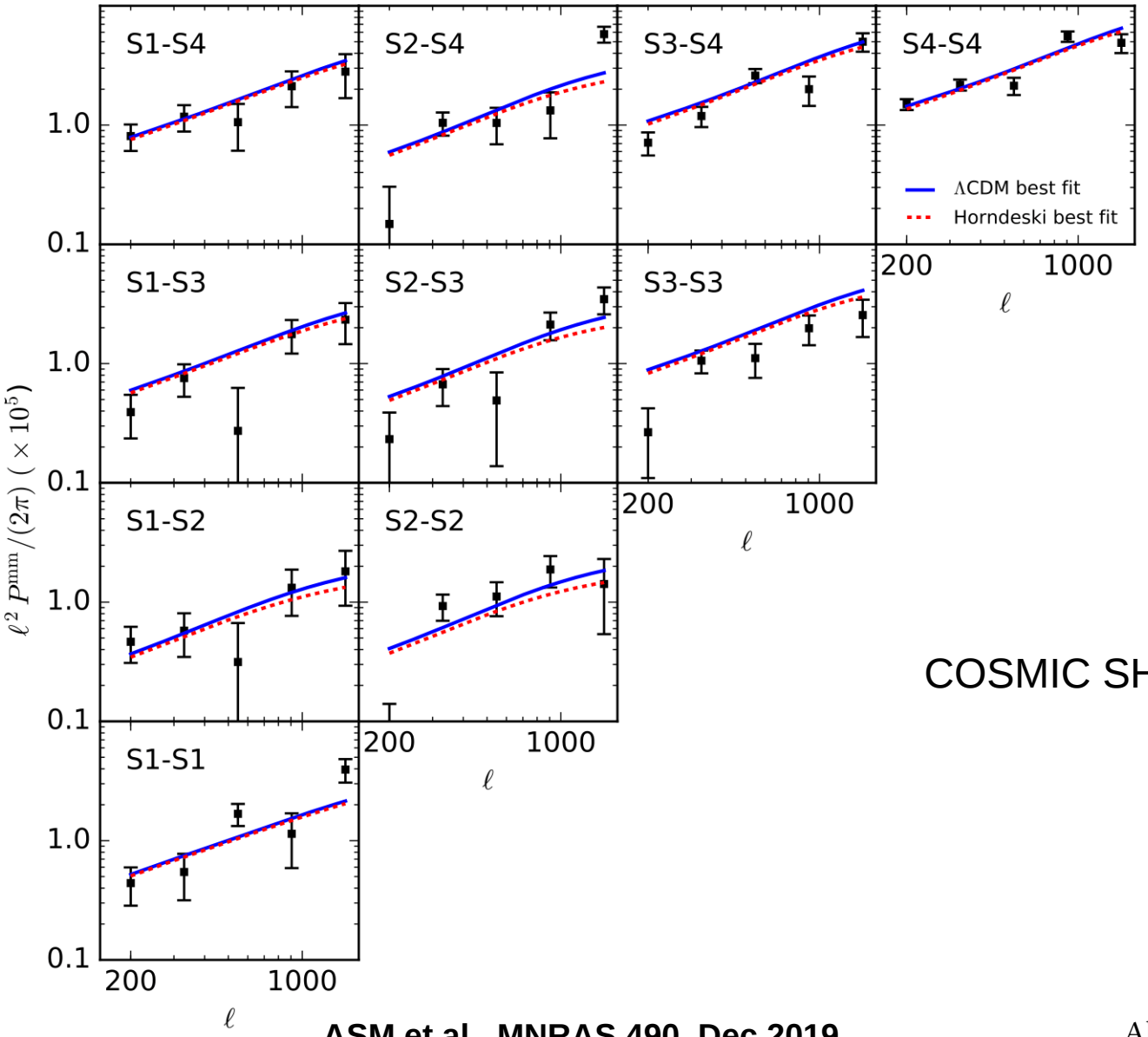
Comparison with van Uitert et al. (2018) in ΛCDM



- First step: **reproduced fiducial ΛCDM 3x2pt** KiDS+GAMA results (van Uitert et al. 2018), with completely independent implementation

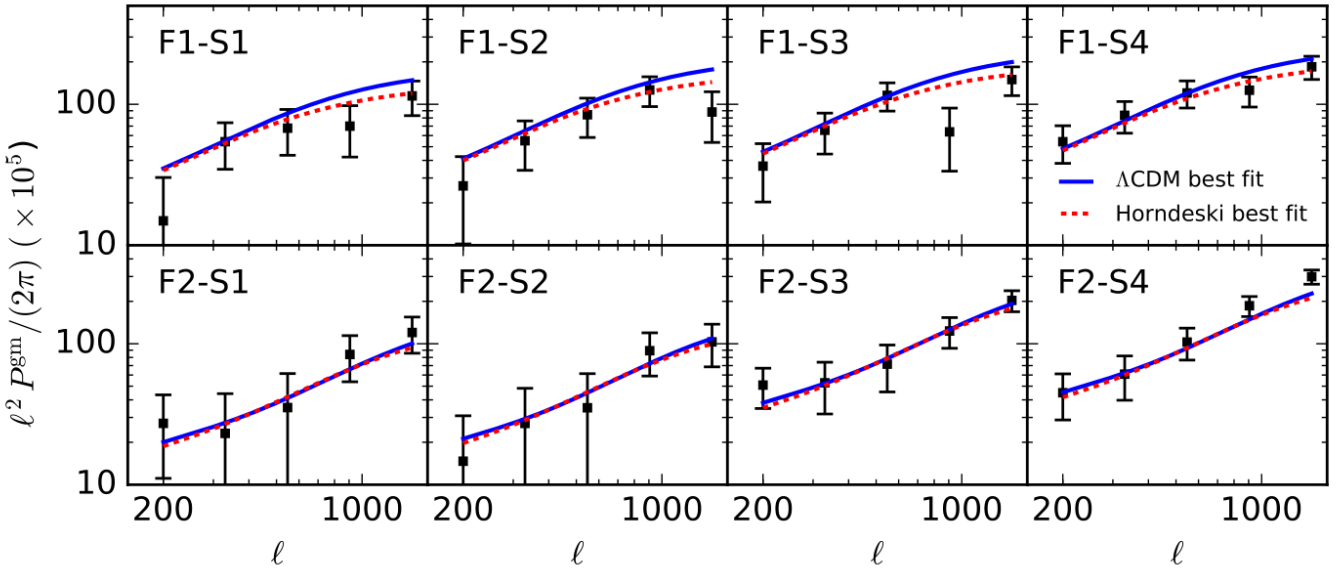
(⟶ corroborates fiducial KiDS+GAMA analysis!)

Signals



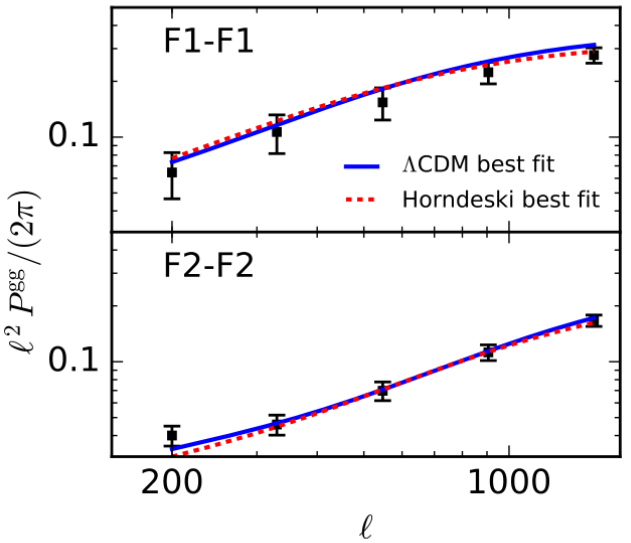
COSMIC SHEAR

Signals



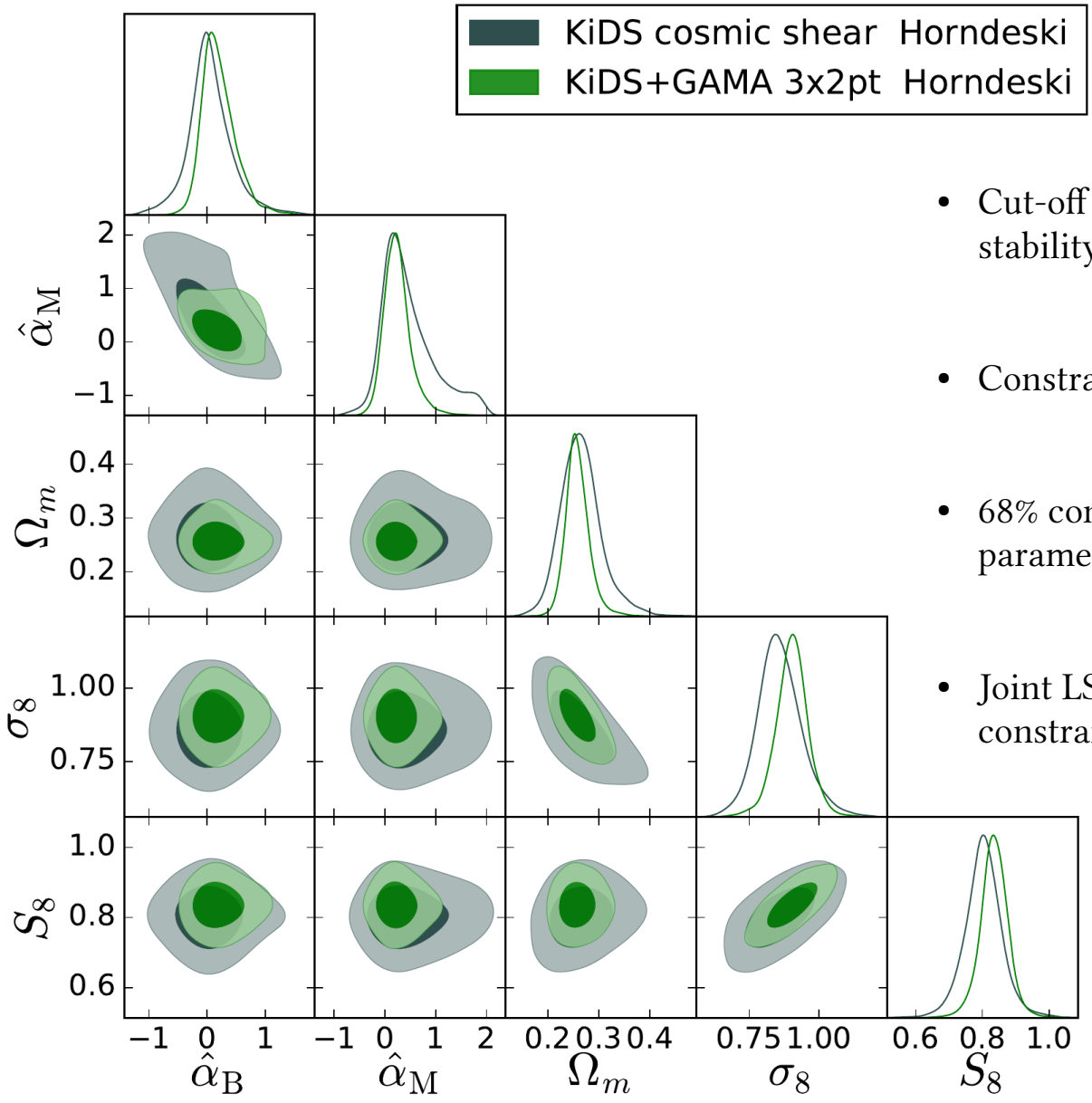
GALAXY-GALAXY LENSING

GALAXY CLUSTERING



- Suppression of signal at small angular scales in Horndeski gravity
- Similar χ^2 for Horndeski and ΛCDM

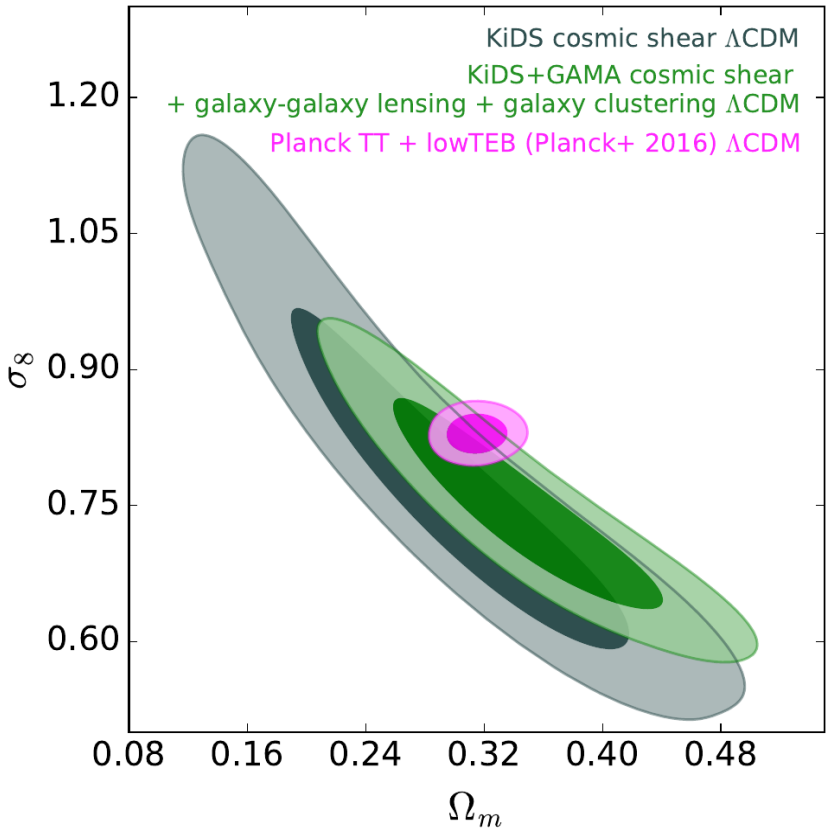
Constraints from LSS



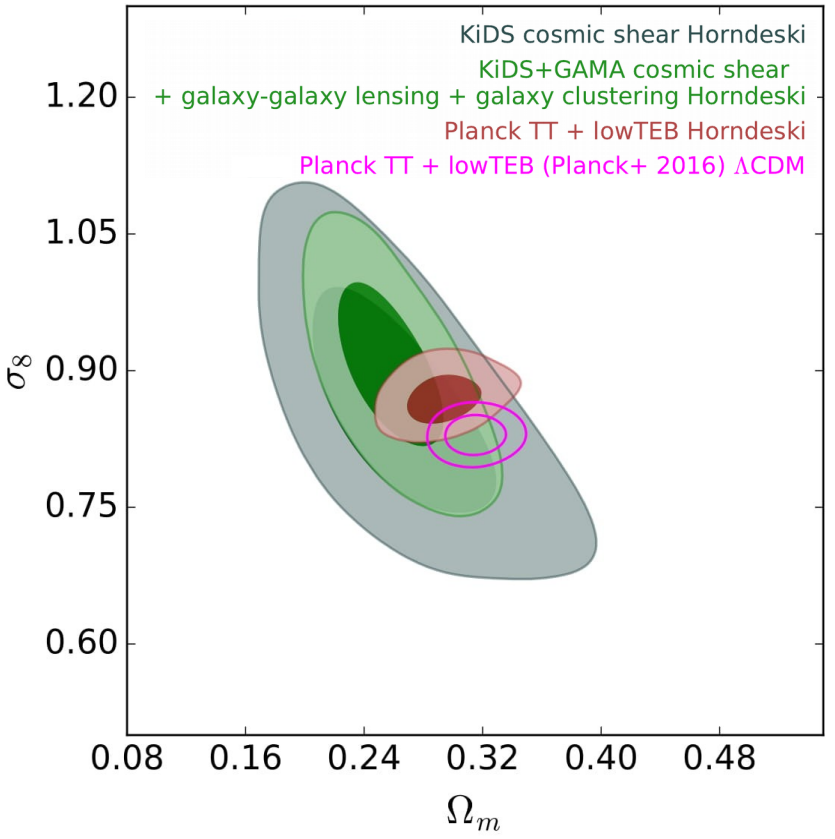
- Cut-off in $\hat{\alpha}_B - \hat{\alpha}_M$ plane determined by stability conditions applied by **HiClass**
- Constraints **compatible with ΛCDM**
- 68% contours shrink from 11% to 6% of allowed parameter space in $\hat{\alpha}_B - \hat{\alpha}_M$ plane
- Joint LSS analysis tightens in particular constraints on nuisance parameters, e.g. $A_{\rm IA}$

Comparison of constraints from LSS and CMB

ΛCDM



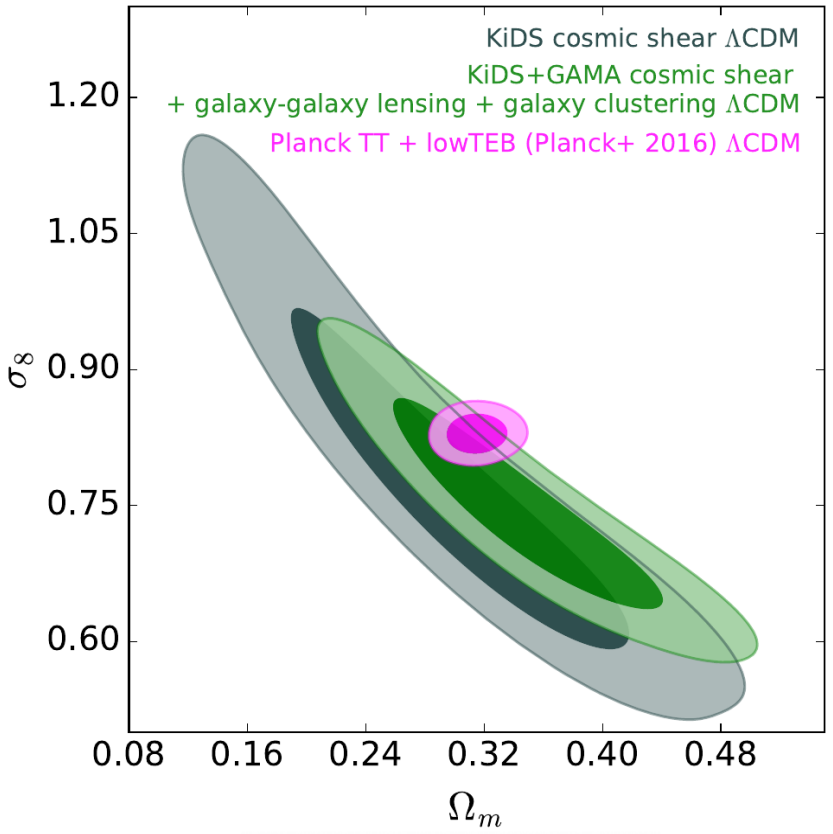
Horndeski



Larger parameter space and shift of best fit values reduce LSS-CMB tension

Comparison of constraints from LSS and CMB

ΛCDM



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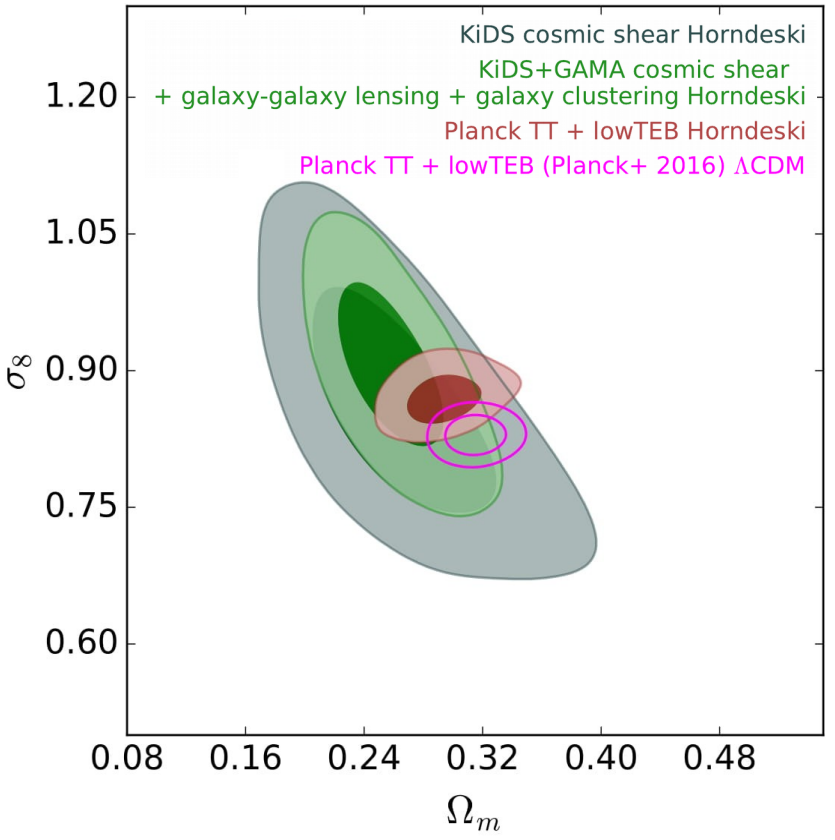


$$S_8 = \sigma_8 \sqrt{\Omega_{\rm m}/0.3}$$

COSMIC SHEAR

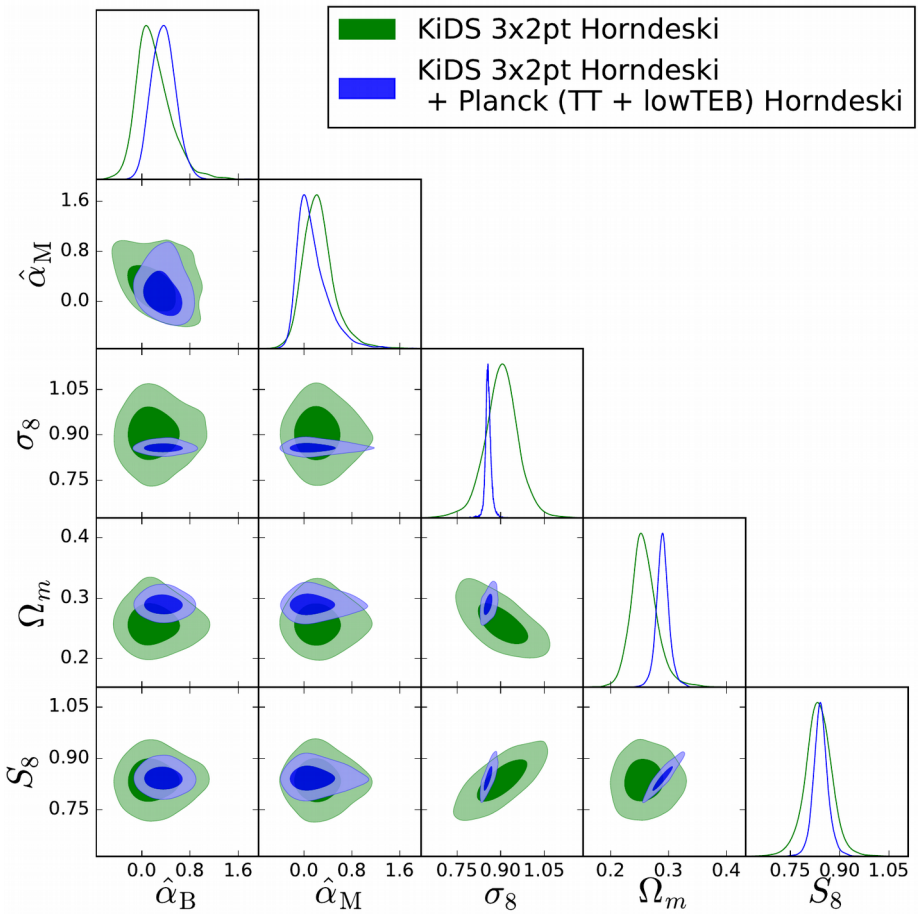
$$\begin{cases} \Delta S_8 = 0.091^{+0.046}_{-0.045}\ \Lambda\text{CDM} \\ \Delta S_8 = 0.048^{+0.059}_{-0.056}\ \text{Horndeski} \end{cases}$$

JOINT LSS

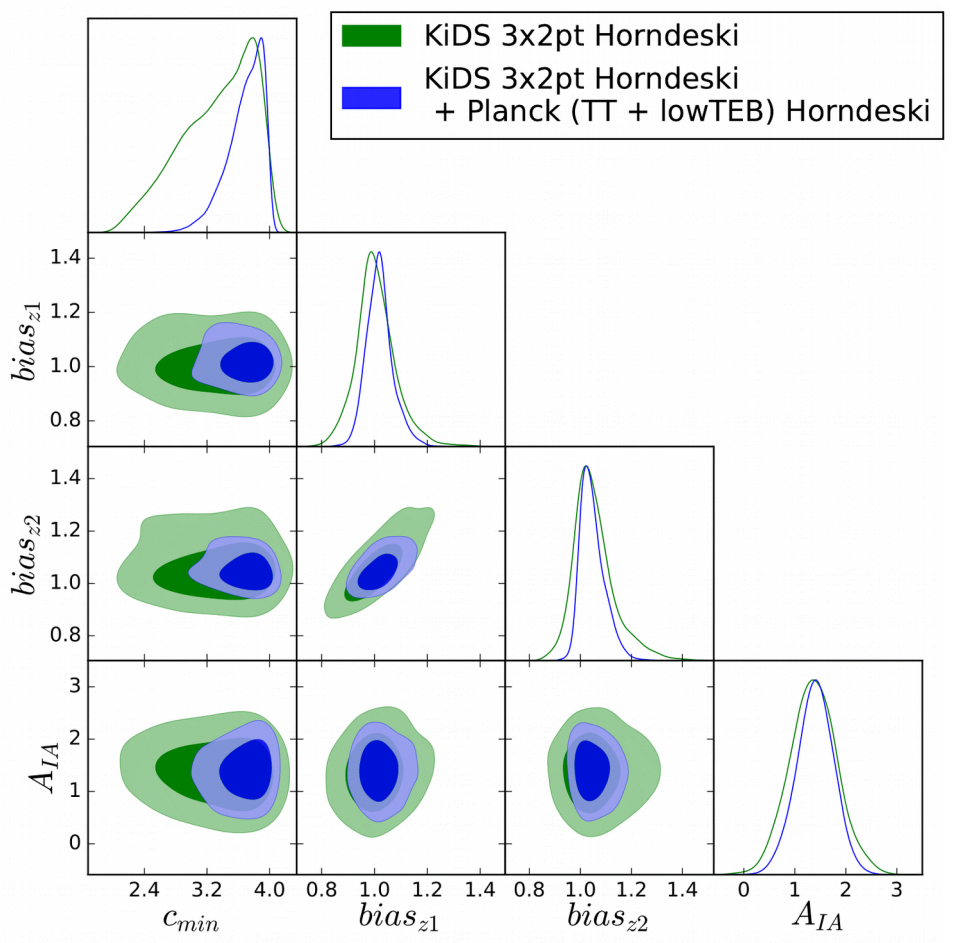
$$\begin{cases} \Delta S_8 = 0.059^{+0.040}_{-0.039}\ \Lambda\text{CDM} \\ \Delta S_8 = 0.016^{+0.048}_{-0.046}\ \text{Horndeski} \end{cases}$$

Constraints from LSS + CMB

Cosmological parameters

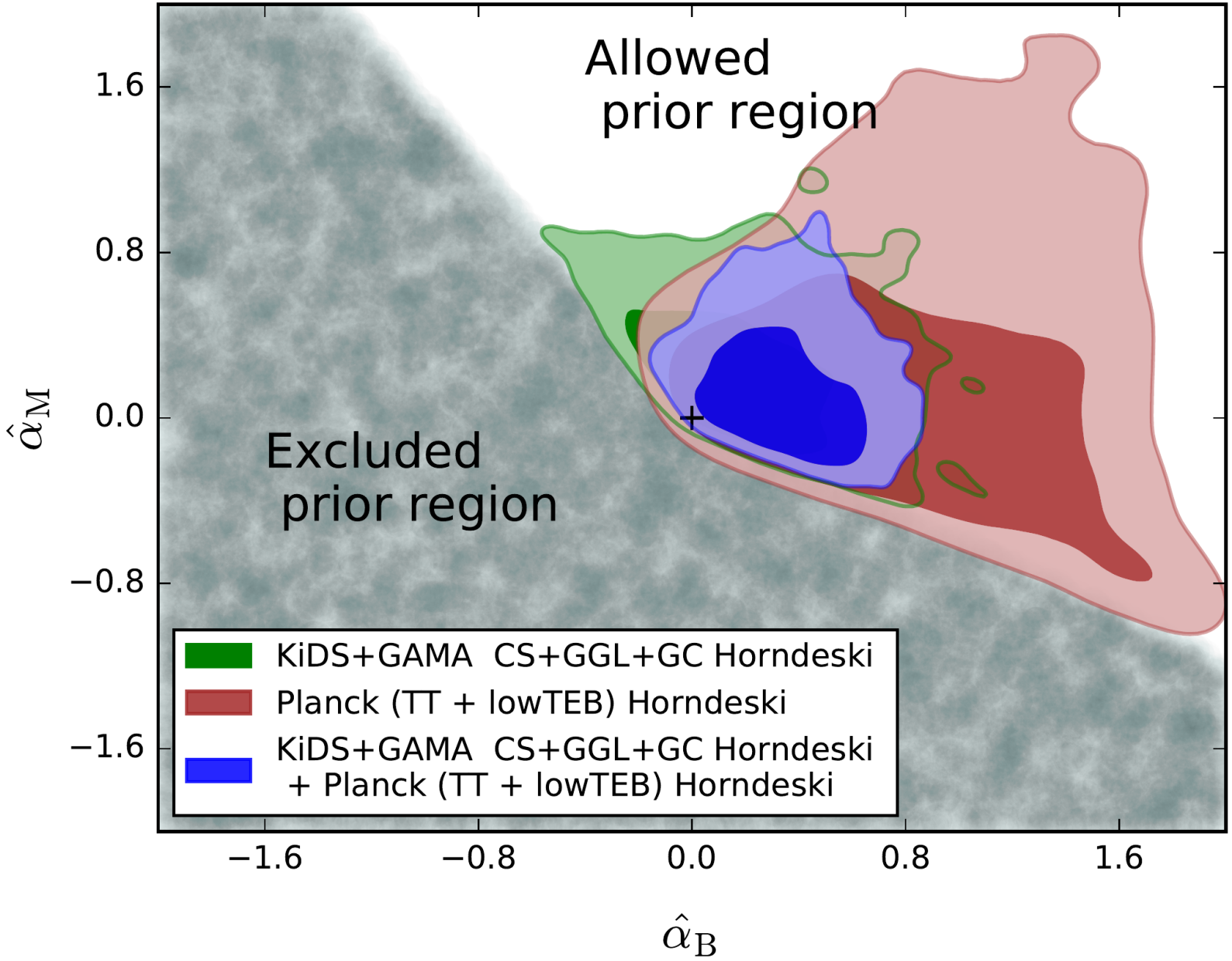


Astrophysical parameters



- Tension reduced ⟶ run together LSS and CMB MCMC chains in Horndeski gravity
- Contours (in particular for standard cosmological parameters) shrink noticeably due to CMB constraining power

Constraints on Horndeski parameters from CMB, LSS and CMB+LSS



Conclusions

- **3x2pt** analysis of **KiDS + GAMA** to constrain **Horndeski gravity** (majority of DE/MG models). First constraints on Horndeski gravity from cosmic shear
- Constraints on Horndeski parameters **compatible with ΛCDM**
- **Reduced tension in** $\Omega_{\rm m} - \sigma_8$ plane in Horndeski gravity
- Modelling of baryon feedback, intrinsic alignments, galaxy bias, screening mechanism. **Likelihood code available** at

  `github.com/alessiospuriomancini/KiDSHorndeski`

  → can be used with future KiDS data releases or Stage IV surveys data
- Need improved DE/MG prescriptions for non-linearities (see e.g. Giblin et al. 2019)

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Thank you!

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