Cosmology with the Kilo-Degree Survey

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LineA webinar
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KiDS

Optimised for weak lensing

- 1000 deg$^2$ analysed
- Full survey: 1350 deg$^2$

- 21 million galaxies

Overlap with VIKING

- 9 photometric bands
Cosmic probes

Cosmic shear
Cosmic probes

Cosmic shear

• correlation between galaxy shapes
Cosmic probes

Cosmic shear

• correlation between galaxy shapes

Galaxy-galaxy lensing

• correlation between galaxy positions and galaxy shapes
Gravitational lensing
Cosmic probes

Cosmic shear
- correlation between galaxy shapes

Galaxy-galaxy lensing
- correlation between galaxy positions and galaxy shapes

Galaxy clustering
- correlation between galaxy positions
Gravitational lensing
Cosmic probes

3x2pt

- Joint analysis of
  - Cosmic shear
  - Galaxy-galaxy lensing (GGL)
  - Galaxy clustering
Data

Cosmic shear
• Kilo-Degree Survey (KiDS-1000)

Galaxy-galaxy lensing
• Foreground galaxies
  • BOSS DR12
  • 2dFLenS
• Background shapes
  • KiDS-1000

Galaxy clustering
• BOSS DR12
Survey footprints

KiDS-N

KiDS-S

Joachimi, Lin+ 2021
KiDS-1000 core papers

Cosmic Shear Cosmology
• Asgari, Lin, Joachimi et al. (arXiv: 2007.15633)

Combined Probe Cosmology
• Heymans, Tröster et al. (arXiv: 2007.15632)

Beyond flat $\Lambda$CDM
• Tröster et al. (arXiv:2010.16416)

Methodology
• Joachimi, Lin, Asgari, Tröster, Heymans et al. (arXiv: 2007.01844)

Photometric Redshifts
• Hildebrandt, van den Busch, Wright et al. (arXiv: 2007.15635)

Shear Measurements
• Giblin, Heymans, Asgari et al. (arXiv: 2007.01845)
KiDS-1000 core papers

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Shear Measurements
• Giblin, Heymans, Asgari et al. (arXiv: 2007.01845)
5 tomographic bins

- $0.1 < z < 1.2$

3 two-point statistics

- Correlation functions
- COSEBIs
- Band powers ($C_l$)
Cosmic shear model

Baseline cosmological model

• Flat $\Lambda$CDM, fixed neutrino mass
• Nonlinear modelling with HMCode

Systematics

• Baryon feedback
• Intrinsic alignment
• Photometric redshift calibration uncertainty
• Shear calibration uncertainty
Cosmic shear band powers

![Cosmic shear band powers diagram](image)

The table below contains the cosmic shear band powers for various bin combinations. The values are given in units of $10^{-7}$.

<table>
<thead>
<tr>
<th>Bin Combination</th>
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<tr>
<td>1-1</td>
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<tr>
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<td>5-5</td>
<td>$10^3$</td>
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</tbody>
</table>

The null distribution of band powers is shown as a dotted line. The band powers are consistent with zero for both the full data vector and each bin combination.
Cosmic shear cosmology constraints

\[ S_8 = \sigma_8 \sqrt{\Omega_m / 0.3} \]
Baseline cosmological model

• Same as cosmic shear
• Full-shape perturbative model for BOSS galaxies

Systematics

• Same as cosmic shear +
  • Non-linear bias model
  • Redshift-space distortions
  • Magnification
BOSS DR12

$0.2 < z \leq 0.5$

$0.5 < z \leq 0.75$

KiDS-1000 x BOSS + 2dFLenS

Heymans, Tröster+ 2021
Galaxy clustering
Cosmic shear
KiDS-1000 3×2pt
Planck 2018 TTTEEE+lowE

The significance of the increase in sampling variance arising from the significant increase in the a reasonable statistical fluctuation in this parameter given the the two analyses. First, as the decrease in the e and photometric redshift calibrations, albeit at the expense of a and the probability to exceed (PTE) the measured value at the maximum of the posterior, the number of degrees of freedom (d.o.f.) of the data, the e

KiDS-1000 3×2pt result can also be compared to our previous KV450-BOSS 2pt analyses from KiDS-1000 with BOSS and 2dFLenS, 2pt analysis from DES Y1 (2021)

effective number density (see

matter fluctuations, we first concentrate on the parameter Hubble parameter,

accounting for the impact of priors and non-linear dependencies

3 as it is tightly constrained and only exhibits negli-

3, as illustrated in Fig.

Aiola et al.

6

i

Raveri & Hu

2021

1, meaning there is a 3

8

8

A&A 646, A140 (2021)

Heymans, Tröster+ 2021
(Dis)agreement with Planck?

Tension with Planck

- Same overall precision as Planck for the structure growth parameter $S_8$
- $S_8$ from KiDS is $8.3 \pm 2.6\%$ lower than Planck: $\sim 3\sigma$
- Full parameter space: $\sim 2\sigma$

Heymans, Tröster+ 2021
Standard model of cosmology

- Minimal neutrino mass
- Spatially flat Universe
- Cosmological constant
- General relativity
Massive neutrinos

$\nu \Lambda \text{CDM}$

- KiDS-1000 cosmic shear
- BOSS galaxy clustering
- 3 × 2pt
- Planck TTTEEE+lowE

$\Omega_m$, $\sigma_8$, $S_8$, $h$, $\sum m_\nu$
$o\Lambda$CDM

- KiDS-1000 cosmic shear
- BOSS galaxy clustering
- $3 \times 2\text{pt}$
- Planck TTTEEE+lowE

- $H_0$ priors matter!
Dark energy equation of state

$w_{\Lambda CDM}$

- KiDS-100 cosmic shear
- BOSS galaxy clustering
- $3 \times 2pt$
- Planck TTTEEE+lowE

- $H_0$ priors matter!
Modified gravity - $f(R)$

- Full non-linear modelling using reaction formalism

Tröster+ 2021
Summary

Data well described by a model of the Universe with

- Minimal neutrino mass
- Spatially flat
- Cosmological constant
- General relativity

Tension with Planck in $S_8$ persists*
Fix amplitude to Planck

Planck constrains amplitude of the matter power spectrum in the early Universe

- Parametrised by $A_s$

Lensing constrains $S_8 = \sigma_8 \sqrt{\Omega_m/0.3}$

- $\sigma_8$ is a complicated function of $A_s$ and other parameters
- Poor constraints on $A_s$
Fix amplitude

Cosmic shear, fiducial
3 × 2pt, fixed $A_s$
$Planck$ TTTEEE+lowE

Tröster+ 2021
Model selection

Do the data prefer any of the models?
Model selection criteria

Deviance information criterion (DIC)

• Compares improvement in best-fit $\chi^2$ with increase in model complexity

Watanabe-Akaike information criterion (WAIC)

• Similar to DIC
• Does not rely on point estimates

Evidence ratio

• Compares the Bayesian evidences
No indication for physics beyond flat $\Lambda$CDM

No preference for or against any of the models considered

$S_8$-tension with Planck remains at $\sim 3\sigma$
Thanks to KiDS and all our funders!