Dark energy-independent constraints on curvature from upcoming surveys

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Curvature parameter

- Curvature parameter

$$\Omega_k = -k/(a_0 H_0)^2$$

- Question:To what extent can we constrain Ω_K?

Motivation:To test inflation models:

For example:

Slow-roll eternal inflation: $|\Omega_K| < 10^{-4}$

false-vacuum eternal inflation would be ruled out if $\Omega_K < -10^{-4}$

Current constraints on curvature come mainly from measurements of the Universe's geometry. BUT suffer severe degeneracy between curvature and dark energy.

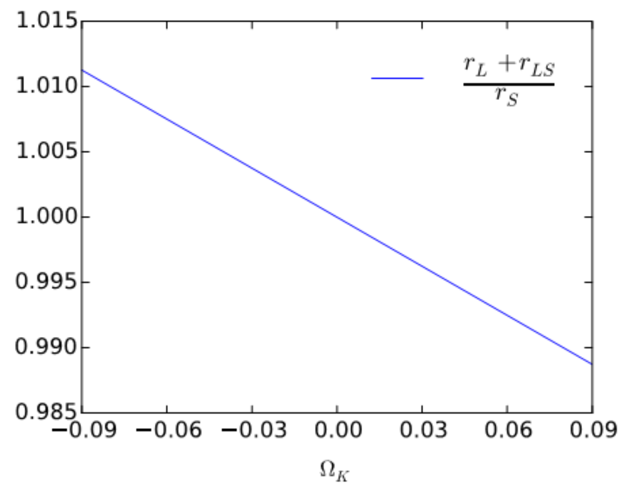
Our goal:to obtain constraints on curvature that are independent on the uncertainties in our knowledge about dark energy.

Methods

The observables we choose to constrain curvature geometrically:

- Type Ia supernovae magnitude(SN)
- Cross-correlation of galaxy with Type Ia supernovae magnification(gSN)
- Cross-correlation of galaxy with galaxy shear(gg)
- Cross-correlation of galaxy with CMB lensing(gκ)

Gravitational lensing uniquely probes the angular diameter distance from the lens to the source, the distances to the lens and to the source. The three distances altogether provide a pure metric probe for curvature.



Treatment of Dark Energy:

w is a binned function parameterized by its values in N equal-sized a(scale factor) bins.

Fisher matrix trick:

$$\boldsymbol{F}_{ij} \equiv \left\langle \frac{\partial^2 \mathcal{L}}{\partial \theta_i \partial \theta_j} \right\rangle,$$

$$\text{where } \mathcal{L} \equiv -\ln L$$

Cramer-Rao inequality:

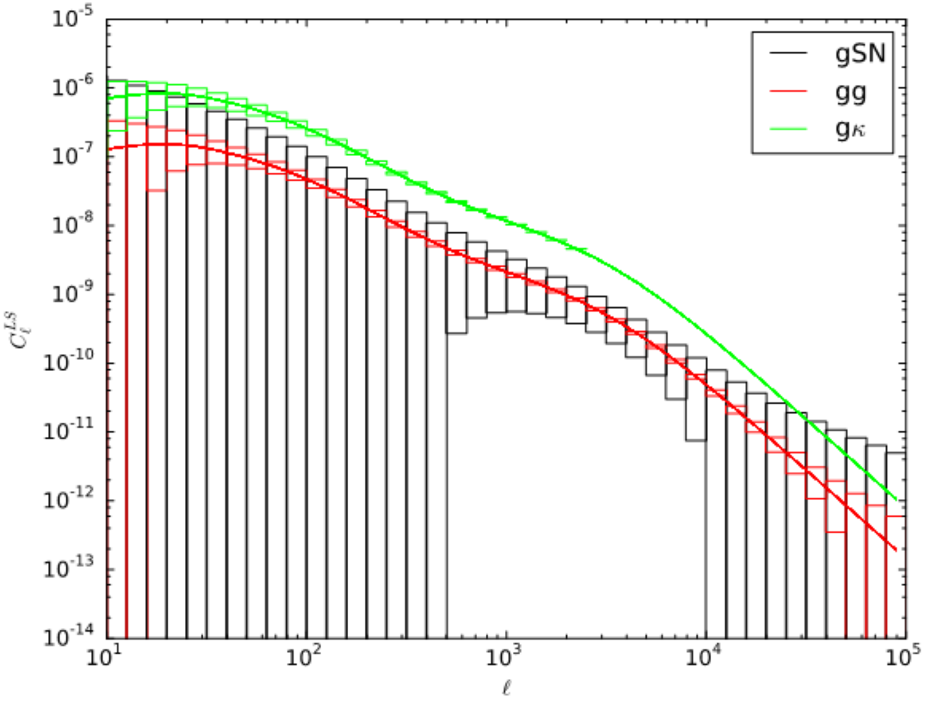
$$\Delta\theta_i = (\boldsymbol{F}^{-1})_{ii}^{1/2}$$

Surveys

We make forecast for fiducial survey mimicking the LSST and CMB Stage 4 experiment

- total number of supernovae : 400,000.
- rms of SN intrinsic brightness variance : 0.1
- average galaxy angular number density: 50 arcmin^{-2}, and 30 of them can be used for shear measurement.
- rms of shear variance has a redshift-independent value of 0.28
- For CMB experiment, assume a 1 arcmin beam and 1μK arcmin noise.
- Cosmological parameters: Planck 2018.

- The galaxy-supernovae , galaxy-galaxy lensing and galaxy-CMB lensing power spectrum .



- Parameter constraints ,From top to bottom section, for (1). w=-1, (2). w=const, (3). $w = w_0 + w_a(1 - a)$; the last three sections assume w is a binned function parameterized by its values in N bins from a=0 to a=1, with N=10, 20, 50 respectively.

parameters	SN	SN+gSN	SN+gg	SN+gg+gκ
Ω_K	0.00815	0.00815	0.00659	0.00166
Ω_Λ	0.00568	0.00568	0.00463	0.00142
Ω_K	0.0701	0.0698	0.00874	0.00200
Ω_Λ	0.0720	0.0717	0.00882	0.00396
w	0.0825	0.0822	0.0123	0.0101
Ω_K	0.408	0.356	0.0151	0.00214
Ω_Λ	0.517	0.451	0.00886	0.00792
w_0	0.515	0.449	0.0156	0.0101
w_a	1.28	1.12	0.173	0.107
Ω_K	1.16	0.614	0.0359	0.0343
Ω_Λ	1.30	0.702	0.0735	0.0709
Ω_K	8.22	0.722	0.0407	0.0389
Ω_Λ	9.19	1.32	0.175	0.170
Ω_K	9.72	0.723	0.0417	0.0400
Ω_Λ	8.68	2.35	0.391	0.384

- Tighten the constraints further with other geometrical probes.

- CMB anisotropies can probe the angular size extended by the sound horizon at recombination , hence the angular diameter distance to recombination $r_*(= s/\theta_*)$

- Late-time BAO measurements can also probe the sound horizon. Its extensions in the transverse direction $\delta\theta = s/r$ and the line-of-sight direction $\delta z = sH$ probe the late-time angular diameter distance r and Hubble expansion rate H respectively.

- Parameter constraints , for w a binned function parameterized by its values in 10,20,50 bins from a=0 to a=1.

parameters	BAO+CMB	SN+gg+gκ+BAO+CMB
Ω_K	0.00149	0.000658
Ω_Λ	0.173	0.00506
Ω_K	0.00174	0.000771
Ω_Λ	0.194	0.00330
Ω_K	0.0227	0.00130
Ω_Λ	0.264	0.00315

- Parameter constraints , for supernovae redshift distribution tracing the LSST galaxies up to z = 2 and z = 3.(N=50)

parameters	SN	SN+gg+gκ	SN+gg+gκ+BAO+CMB
Ω_K	1.12	0.00926	0.00103
Ω_Λ	0.736	0.248	0.0202
Ω_K	0.728	0.00541	0.00102
Ω_Λ	0.543	0.201	0.0214

SUMMARY

1. For robust test of inflation models, require constraints on curvature independent of DE.

2. We study the constraining power of galaxy-magnification , galaxy-shear and galaxy-CMB lensing cross-correlations on curvature.

3. Combine five probes , we obtain constraint of 0.0013 from" SN + gg + gκ + BAO + CMB". Tighter constraints if better knowledge about DE.

Thank You

DISCUSSION

Systematics:

1. photometric redshift errors . $\sigma/(1+z)$ within 0.02
2. shear calibration uncertainty.
3. thin redshift bin width assumption.
4. intrinsic alignments (IA).