Bayesian constraints on dark matter halo properties using gravitationally-lensed supernovae

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Outline

Universe cake and standard candles

Cosmological inference

In using Type Ia supernovae (SNIa) as 'standardizable' candles to constrain cosmological parameters, one typically assumes that the universe is homogeneous and isotropic, and therefore one ignores gravitational lensing effects due to cosmic structure along the line-of-sight to each SNIa.

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DM halo parameters inference

One can perform a complementary analysis to cosmological parameter estimation by instead assuming a particular background cosmological model and using the observed distance moduli to constrain the nature of the cosmic structure along the line of sight to the SNa

Theoretically predicted distance modulus

Without lensing

$$\mu_0(\mathcal{C}, z) = 5 \log_{10} \left(\frac{D_{\rm L}}{\rm Mpc} \right) + 25, \tag{1}$$

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With lensing

$$\mu(z, \mathcal{C}, g, h) \approx \mu_0(z, \mathcal{C}) - 2.17[\kappa_{\rm los}(g, h) - \kappa_{\rm b}(h)], \tag{2}$$

Where,

$$g = \{z^1_{\rm gal}, \theta^1_{\rm gal}, M^1_B, \tau^1, \ldots, z^{N_{\rm gal}}_{\rm gal}, \theta^{N_{\rm gal}}_{\rm gal}, M^{N_{\rm gal}}_B, \tau^{N_{\rm gal}}\} \tag{3}$$

and h contains the parameters of the assumed dark matter halo model for these galaxies.

Scaling laws

The relationship between galaxy luminosity and velocity dispersion

$$\sigma = \sigma_* \left(\frac{L}{L_*} \right)^{\eta}, \tag{4}$$

In terms of absolute B-band magnitudes the scaling relation becomes

$$\sigma = \sigma_* 10^{-\eta(M_B - M_B^*)/2.5}, \tag{5}$$

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SIS halo parameters

$$h = \{\gamma, \eta, \sigma_*, r_*\}$$

Data

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All our foreground galaxies are REAL and taken from the SNLS galaxy catalogues in the deep CFHTLS fields.

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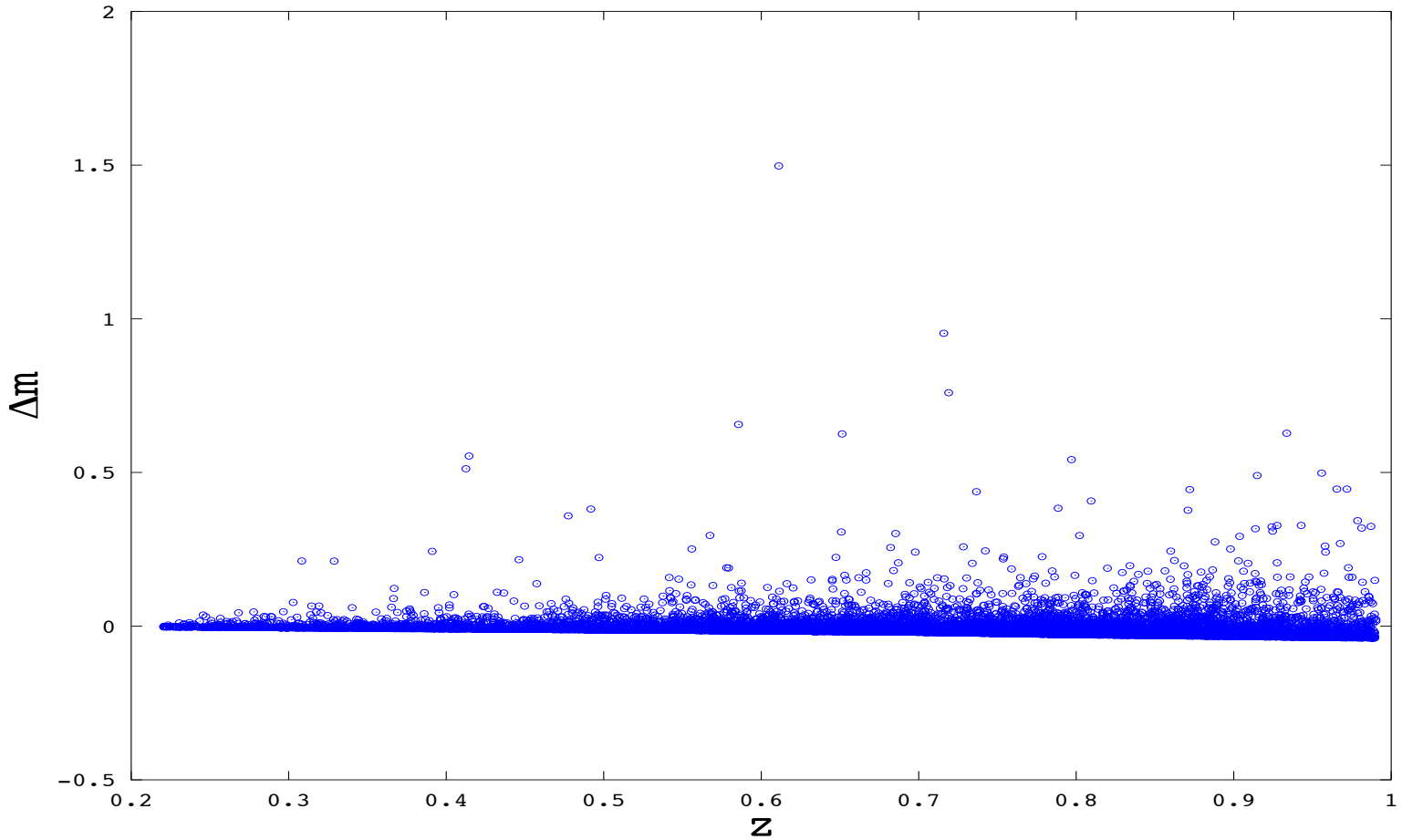
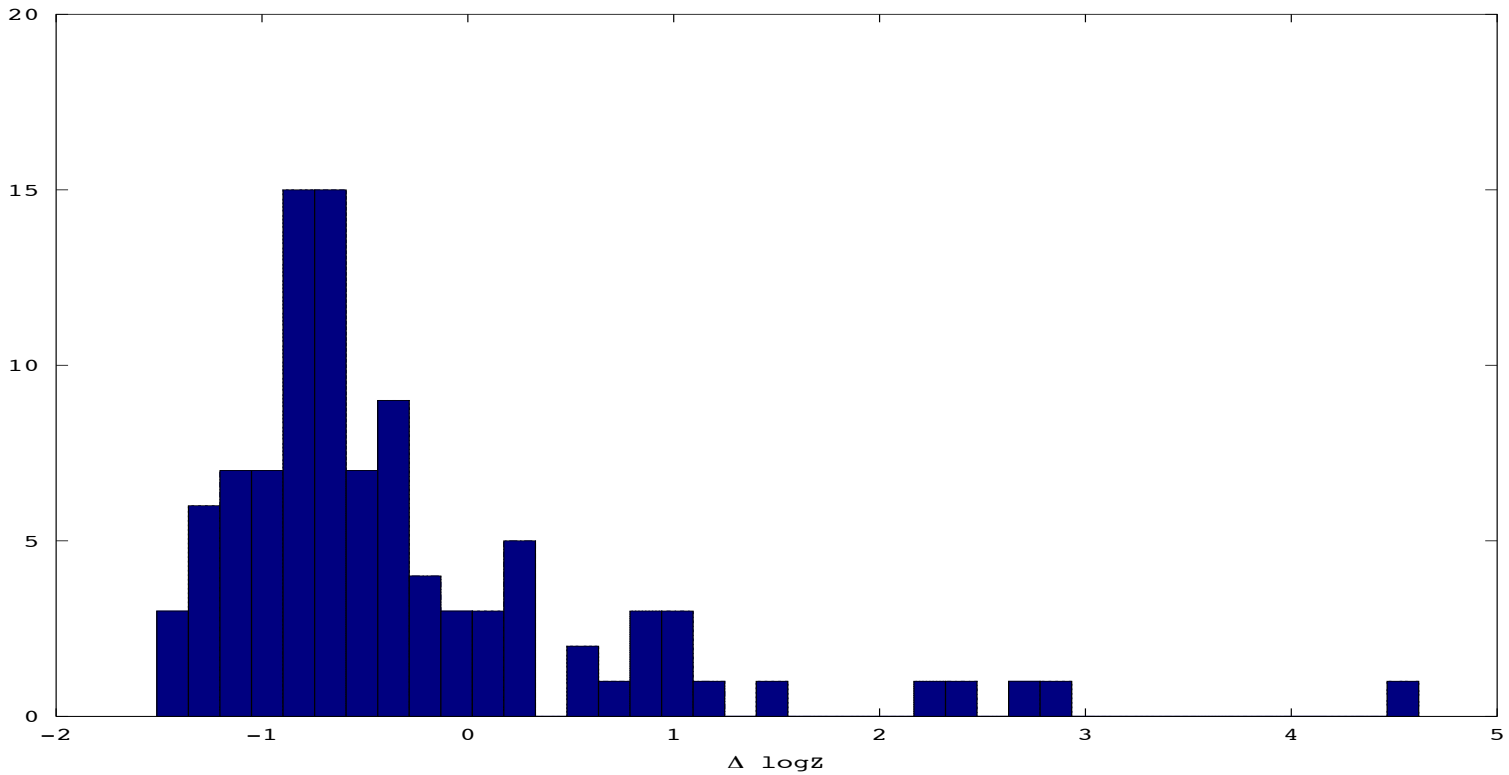
SNe

10,000 SNANA SNLS3-like SNe.

Characteristics of the lensing signal: Δm vs z for 10,000 simulated SNe



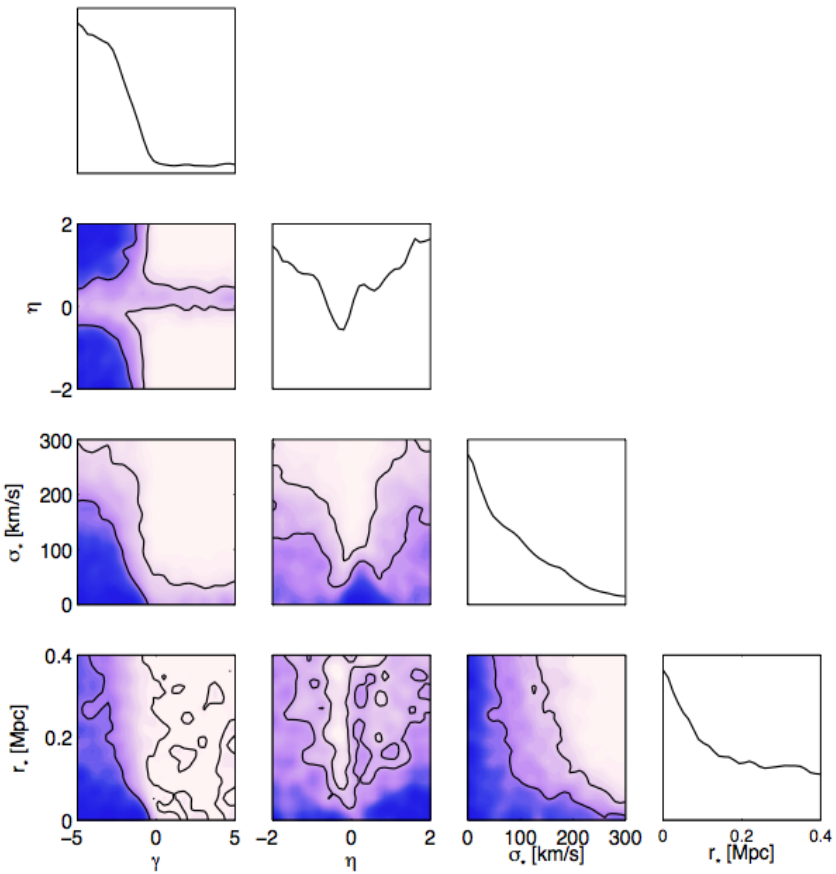
Results for random samples of 162 supernovae



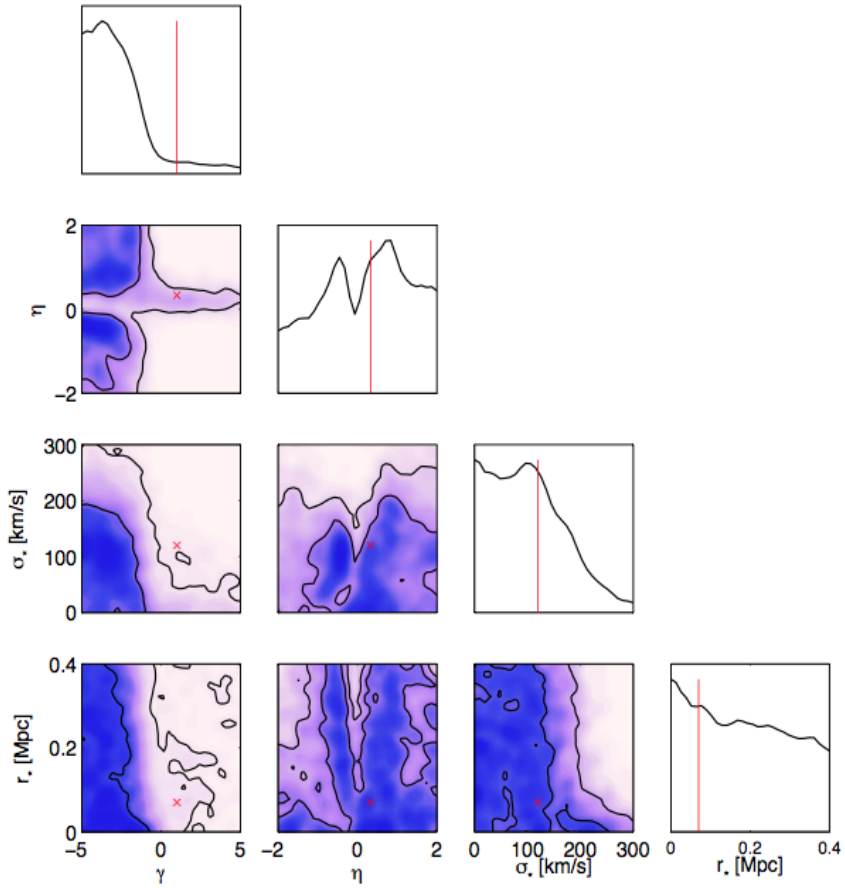
Histogram of the log-evidence difference $\Delta \ln \mathcal{Z}$ between the SIS halo model and the null (no-lensing) model obtained from the analysis of one hundred random samples of 162 SNIa.

Mean sample of 162 supernovae

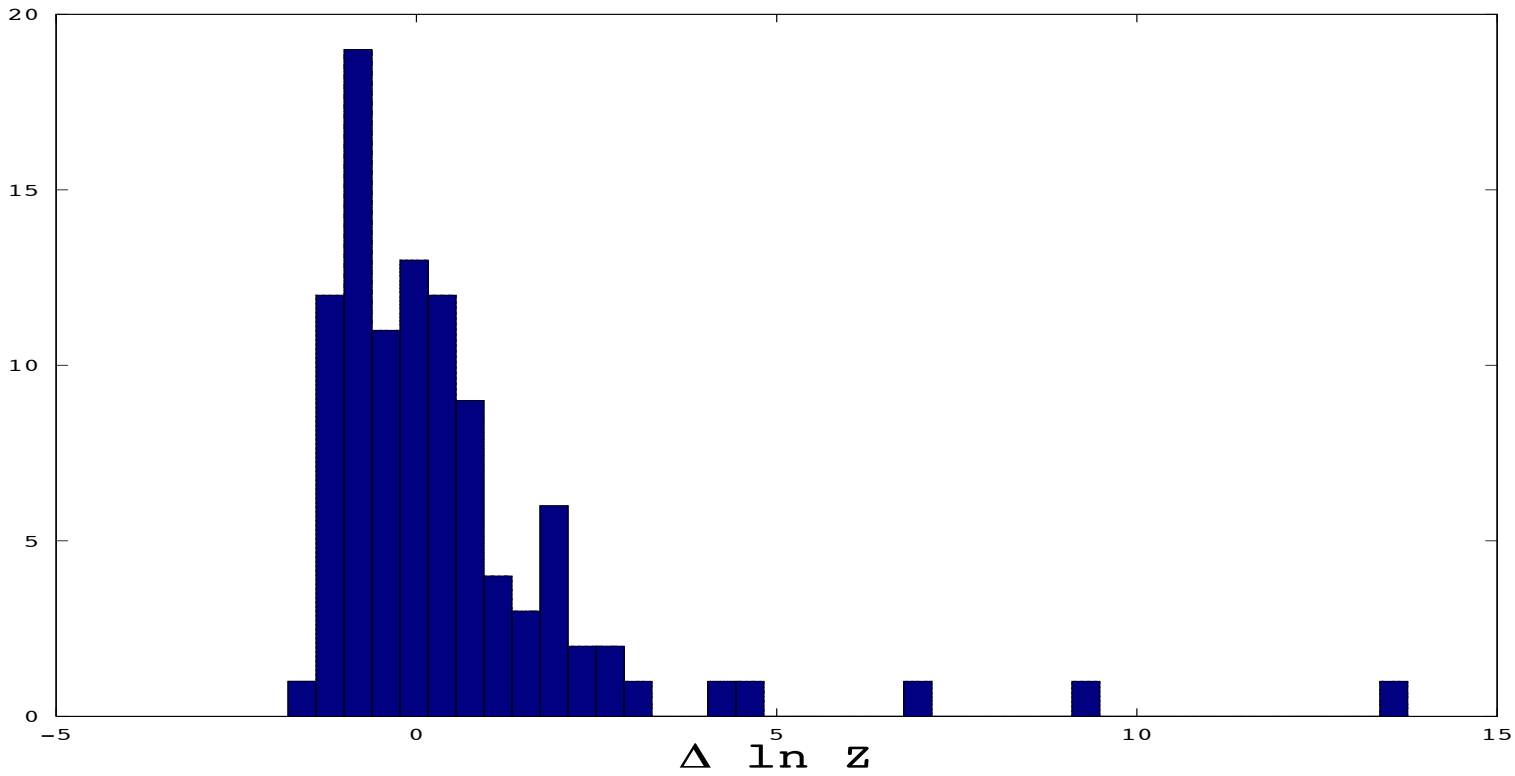
No Lensing



Truncated SIS model



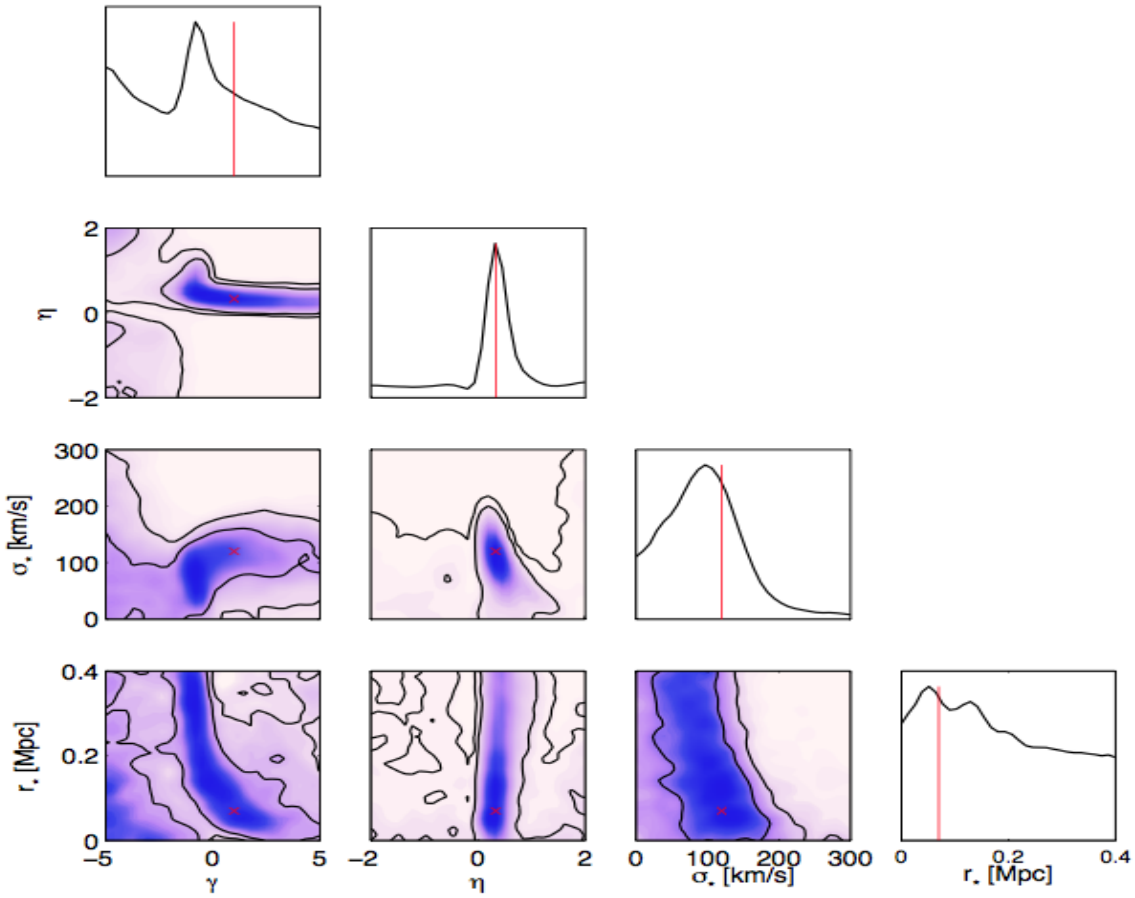
Results for random samples of 500 supernovae



Histogram of the log-evidence difference $\Delta \ln \mathcal{Z}$ between the SIS halo model and the null (no-lensing) model obtained from the analysis of one hundred random samples of 500 SNIa.

Mean sample of 500 supernovae

Truncated SIS model



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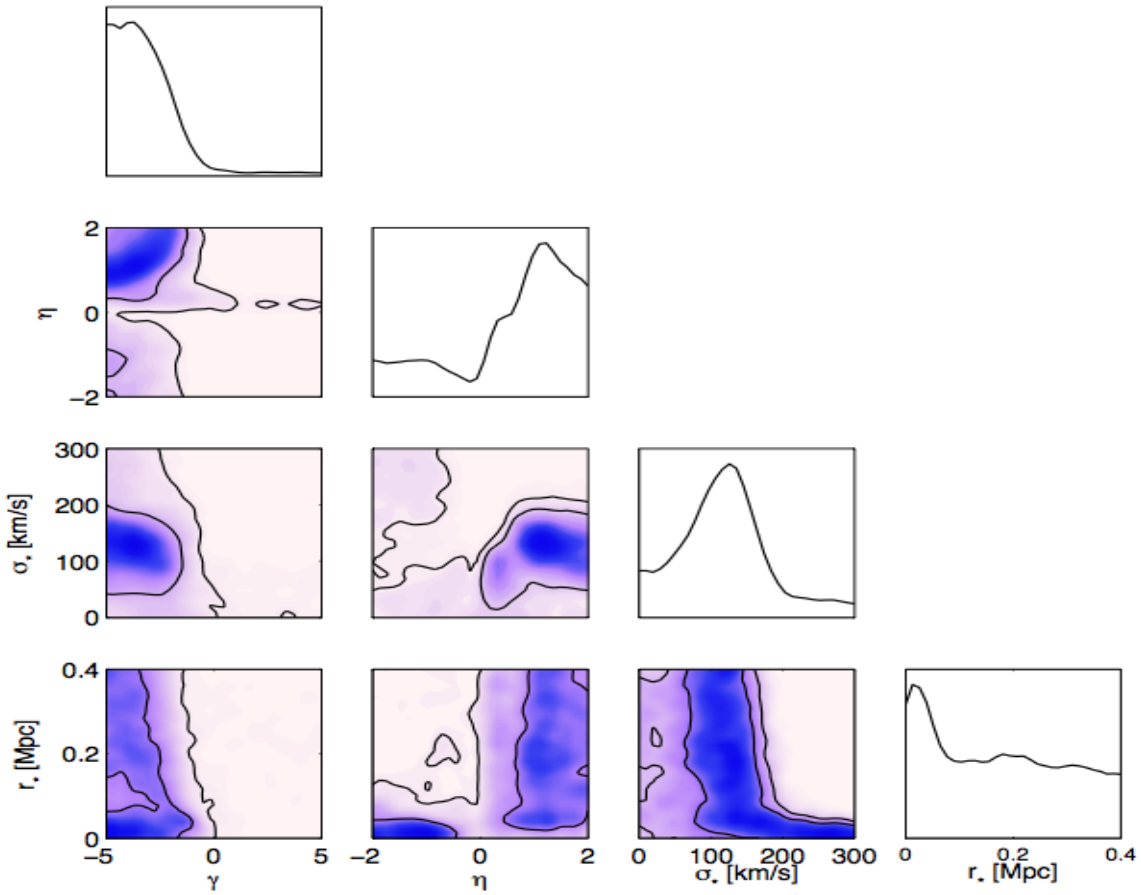
162 SNLS3 SNe

SNLS3


2
0
−2
η
300
200
100
0
σ. [km/s]
0.4
0.2
0
r. [Mpc]
−5
0
5
γ
−2
0
2
η
0
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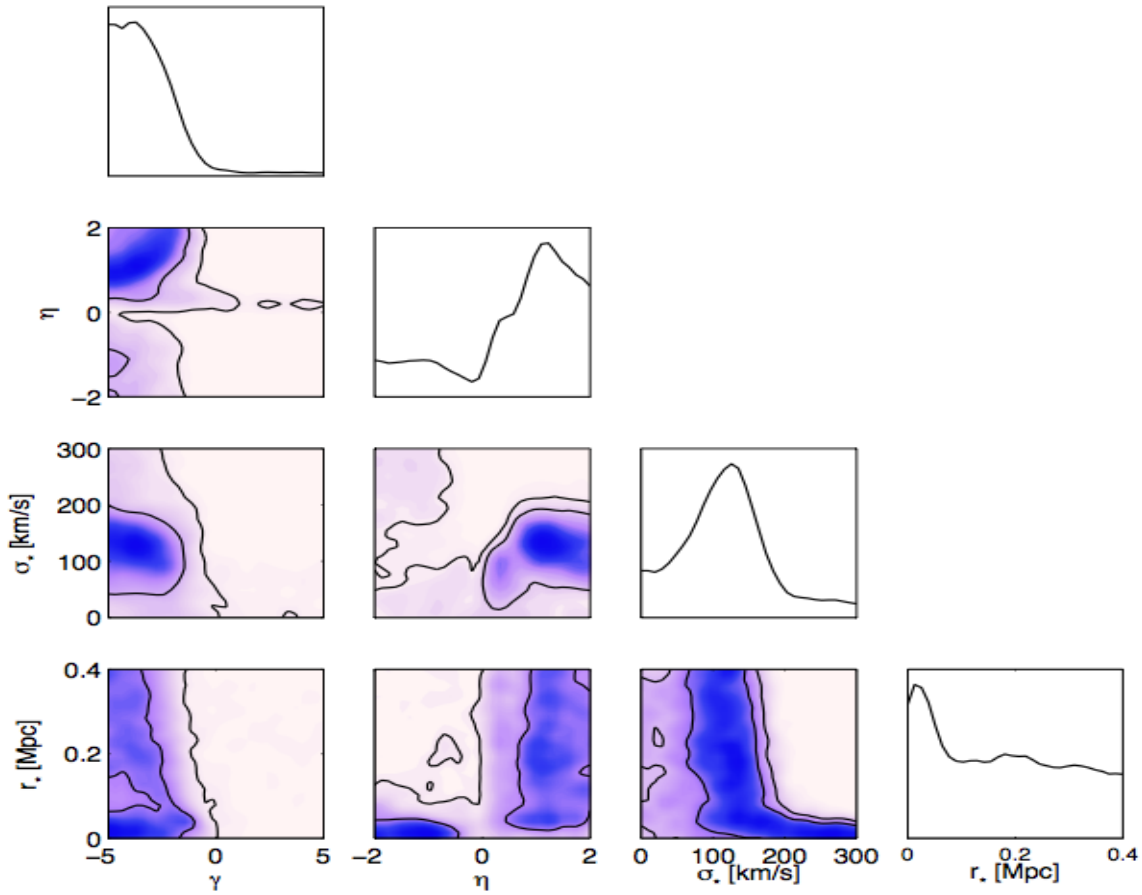
SNLS3



$$\Delta \ln \mathcal{Z} = 0.2 \pm 0.2$$

Conclusions

- Our simulations show that our method works!
- But real SNLS data show no evidence of lensing by dark matter haloes :(
- Our simulations suggest that future surveys should yield a clear detection of the effect :)
- Watch this space!