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

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Outline

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2. Simulated Data
3. Real SNLS3 data
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1 Introduction

2 Simulated Data

3 Real SNLS3 data

4 Conclusions
Universe cake and standard candles

- dark energy
- dark matter
- gas
- stars, etc.

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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.
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.

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**

\[ \mu_0(C, z) = 5 \log_{10} \left( \frac{D_L}{\text{Mpc}} \right) + 25, \]  

(1)
### Theoretically predicted distance modulus

#### Without lensing

\[ \mu_0(C, z) = 5 \log_{10} \left( \frac{D_L}{\text{Mpc}} \right) + 25, \]  

(1)

#### With lensing

\[ \mu(z, C, g, h) \approx \mu_0(z, C) - 2.17[\kappa_{\text{los}}(g, h) - \kappa_{b}(h)], \]  

(2)

Where,  
\[ g = \{ z_{1\text{gal}}, \theta_{1\text{gal}}, M_{B1}, \tau_{1}, \ldots, z_{N\text{gal}}, \theta_{N\text{gal}}, M_{B}^{N\text{gal}}, \tau^{N\text{gal}} \} \]  

(3)

and \( h \) contains the parameters of the assumed dark matter halo model for these galaxies.
The relationship between galaxy luminosity and velocity dispersion

\[ \sigma = \sigma_\star \left( \frac{L}{L_\star} \right)^\eta, \quad (4) \]

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

\[ \sigma = \sigma_\star 10^{-\eta(M_B-M_\star^B)/2.5}, \quad (5) \]
Scaling laws

The relationship between galaxy luminosity and velocity dispersion

\[ \sigma = \sigma_\ast \left( \frac{L}{L_\ast} \right)^\eta, \]  
(4)

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

\[ \sigma = \sigma_\ast 10^{-\eta(M_B - M_B^\ast)/2.5}, \]  
(5)

The relationship between galaxy luminosity and truncation radius

\[ r_t = r_\ast \left( \frac{\sigma}{\sigma_\ast} \right)^\gamma = r_\ast \left( \frac{L}{L_\ast} \right)^{\eta\gamma}, \]  
(6)
The relationship between galaxy luminosity and velocity dispersion

\[ \sigma = \sigma_* \left( \frac{L}{L_*} \right)^{\eta} , \]  

(4)

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

\[ \sigma = \sigma_* 10^{-\eta(M_B - M_B^*)/2.5} , \]  

(5)

The relationship between galaxy luminosity and truncation radius

\[ r_t = r_* \left( \frac{\sigma}{\sigma_*} \right)^{\gamma} = r_* \left( \frac{L}{L_*} \right)^{\eta \gamma} , \]  

(6)

SIS halo parameters

\[ h = \{ \gamma, \eta, \sigma_*, r_* \} \]
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Galaxies

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

Galaxies

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SNe

10,000 SNANA SNLS3-like SNe.
Characteristics of the lensing signal: $\Delta m$ vs $z$ for 10,000 simulated SNe
Results for random samples of 162 supernovae

Histogram of the log-evidence difference $\Delta \ln Z$ 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
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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SNe
162 SNLS3 SNe
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\[ \Delta \ln Z = 0.2 \pm 0.2 \]
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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!