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Realistic Galaxy Models for Lensing Statistics

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Abstract.
The gravitational lensing rate in a well-defined sample of sources can place strong bounds on the cosmological constant, but only if the lensing optical depth is robustly calculated. Significant progress is likely to be achieved by employing more realistic models to describe the population of lens galaxies. Here we investigate the role of elliptical deflectors in lensing statistics, and their effect on cosmological constraints derived from the JVAS survey. We also evaluate the prospects for constraining the cosmological constant using the much larger CLASS data set.

1. Introduction

The expected number of gravitational lenses in a well-defined and homogeneously-selected sample of sources is sensitive to cosmological density parameters (Turner, Ostriker & Gott 1984), and in particular the cosmological constant Ω_Λ (Turner 1990). Lensing essentially probes the differential volume element – cosmologies with large Ω_Λ contain more volume out to a given redshift, which increases the probability that mass concentrations along the line of sight will lens background sources. Consequently, bounds can be placed on Ω_Λ by comparing an observed lensing rate with the predictions of various cosmologies (e.g. Kochanek 1996a).

The predicted lensing rate depends not only on cosmological parameters and source properties such as the redshift distribution and luminosity function, but also on various assumptions regarding the population of galaxies that act as potential lenses. While the sources may be investigated directly, questions still remain regarding how to accurately calculate the galaxy contribution to the lensing optical depth. Most previous lensing statistics analyses have represented galaxies as a distribution of isothermal spheres (Kochanek 1996a; Helbig et al. 1999). A wide variety of observational evidence does suggest that an isothermal mass profile is a good approximation to reality (Kochanek 1995). However the mass distributions of the elliptical galaxies that preferentially participate in lensing are, not surprisingly, elliptical in nature. Ellipticity clearly plays an important role in gravitational lensing, as it is necessary to account for the large number of four-image lens systems (which require a radially asymmetric potential) and construct mass models for even the simplest gravitational lenses.

In this talk we explore the effect of ellipticity on predicted lensing rates and constraints on the cosmological parameters.

2. Elliptical deflectors

We model the scaled projected surface density of galaxies as a singular isothermal ellipsoid (SIE):

$$\kappa(x_1, x_2) = \frac{b}{2} \frac{\eta(\epsilon)}{[(1-\epsilon)x_1^2 + (1+\epsilon)x_2^2]^{1/2}}$$

where ϵ is the ellipticity and $b = 4\pi(D_{ds}/D_s)(\sigma_v/c)^2$ is the Einstein radius of a singular isothermal sphere (SIS) with a one-dimensional dark matter velocity dispersion σ_v, and angular diameter distances D_s to the source and D_{ds} between the lens and source. Keeton, Kochanek & Seljak (1997) argue that for statistical purposes, the model should be normalized so that the line-of-sight stellar velocity dispersion $< v_{los}^2 >^{1/2}$ is fixed as ϵ is varied, and the factor $\eta(\epsilon)$ is introduced for this purpose. They go on to demonstrate that flattened mass distributions require larger normalizations to produce the same $< v_{los}^2 >^{1/2}$, and derive an approximation for $\eta(\epsilon)$ in the case of isothermal ellipsoids.

Only the total lensing cross-section produced by a deflector population is of concern when constraining Ω_Λ, as the distribution of image multiplicities contains no cosmological signal. However, the relative numbers of two and four-image lens systems may be an important cross-check on major assumptions (Rusin & Tegmark 2000). If $\eta(\epsilon) = 1$, the cross-section changes very little with ellipticity (e.g. Kochanek 1996b). By including the above dynamical normalization, however, the galaxy cross-sections are increased by the factor $\eta^2(\epsilon)$. We approximate this effect by assuming all galaxies are viewed edge-on (to avoid complex deprojection statistics). We then assume that mass-follows-light, and set the distribution of projected mass axial ratios of elliptical galaxies $n(\epsilon)$ to the distribution of surface brightness ellipticities for E/SO members of the Coma cluster (Jorgensen & Franx 1994). If the $\eta = 1$ SIE cross-section is $\sigma_i(\epsilon)$ and the magnification bias factor is $B_i(\epsilon)$ for the ith class of imaging (i=doubles, quads, naked cusps), the total biased cross-section for elliptical deflectors is increased by the factor

$$p = \frac{\sum_i \int [B_i(\epsilon)\sigma_i(\epsilon)\eta^2(\epsilon)n(\epsilon)d\epsilon]}{B(1)\sigma(1)} \sim 1.5$$

relative to the spherical-only case, using a bias model appropriate for compact radio sources.

The total optical depth can then be calculated by integrating over the galaxy population out to some source redshift. The method is outlined in Quast & Helbig (1999), and we use the same galaxy parameters they assume. We then reanalyzed the Jodrell-VLA Astrometric Survey (outlined in Helbig et al. 1999) using the distribution of SIE deflectors. We did not include core radii in our analysis, but the small cores currently favored by lensing and other observations (Kochanek 1996a) effect the lensing rate at only the few percent level. The results of a maximum likelihood analysis are displayed in Fig. 1. We find $\Omega_\Lambda < 0.57$ at 95% (flat cosmology), compared to $\Omega_\Lambda < 0.76$ at 95% for the SIS model

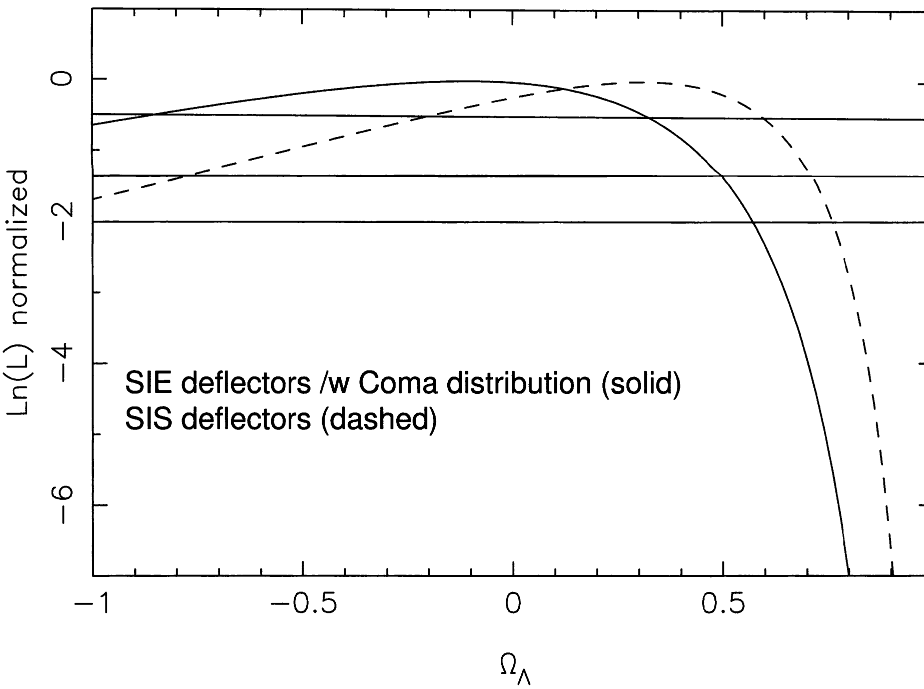

Figure 1. Likelihood analysis of Ω_Λ in flat models, using the JVAS lens sample. The 68%, 90% and 95% confidence limits are marked horizontally.

(compatible with the Helbig et al. results). The increased lensing rate due to SIE deflectors leads to a significant decrease in the upper bound on Ω_Λ.

3. Prospects for CLASS

Using more realistic mass models in lensing statistics will help us to fully exploit the data from new lens surveys such as the Cosmic Lens All-Sky Survey (CLASS; Myers et al. 1999), which has searched for lensing among flat-spectrum radio sources brighter than 30 mJy at 5 GHz. The size of the CLASS statistical sample is $\sim$ 5 times that of JVAS alone. Pushing down to a fainter sample presents new problems, such as determining the redshift distribution and number-flux relations of the unlensed and parent source populations. However, once these issues have been fully addressed through ongoing observational programs, CLASS will provide a large and clean sample that should set a new benchmark for lensing statistics.

How tightly can CLASS constrain cosmological parameters, if the galaxy and source populations are well-understood and realistically modeled? To investigate this we first produced fake JVAS and CLASS lens surveys for various flat cosmologies using the galaxy population parameters assumed by Helbig et al. (1999). We then performed a likelihood analysis on each fake survey using the same galaxy parameters and derived the 95% upper and lower limits on Ω_Λ. For

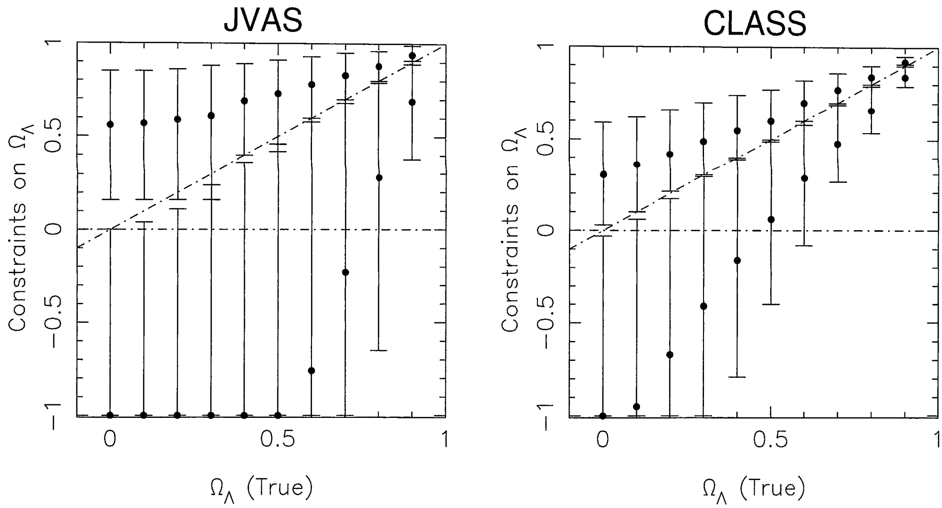

Figure 2. The prospects for constraining Ω_Λ using the CLASS sample, as opposed to JVAS. Filled circles mark the median 95% upper and lower bounds. Errors bars represent the typical range of these bounds.

each cosmology we calculated the median bounds, as well as the range containing 95% of these bounds. These are plotted in Fig. 2. Note the improvement of the expected CLASS constraints relative to JVAS. Not only do the upper bounds on Ω_Λ become tighter, but CLASS also has a good chance of deriving a positive lower limit on Ω_Λ, if the true $\Omega_\Lambda > 0.5$. Of course, poor representations of the galaxy population would introduce systematic uncertainties to the derived constraints. Consequently, it is essential to match the vastly improved CLASS data set with vastly improved models for the lensing optical depth.

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