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Gravitational Lensing as Probe of Large Scale Structure of the Universe

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Abstract. We apply gravitational lensing statistics to: (1) place a limit on the cosmological constant (Ω_Λ); (2) place a limit on the average red-shift ($< z >$) of gamma-ray bursters (GRBs); (3) investigate models of galaxy evolution to see how compatible these models are with lensing statistics. We also point out the sources of uncertainty in lensing statistics, leading to uncertainty in the results.

1. Introduction

We assume the lensing galaxies to be single isothermal spheres and assume the universe to be flat ($\Omega_M + \Omega_\Lambda = 1$). The expressions for differential probability $d\tau$, cross section σ and angular diameter distances have been derived in Turner, Ostriker & Gott (1984). The dispersion velocity v is related to the luminosity of the galaxy by the Faber-Jackson relation $L \propto v^\gamma$. The luminosity function for galaxies is the usual Schecter function modified for high z by Rocca-Volmerange & Guiderdoni (1990) to include evolution of galaxies assuming that the present day galaxies result from a number of building blocks whose comoving number changes with z:

$$\Phi(L, z)dL = (1 + z)^{2\eta}\Phi(L(1 + z)^\eta, 0)dL. \tag{1}$$

The value $\eta = 1.5$ gives a good fit to the data on high z galaxies. We get

$$d\tau = F_*(1 + z_L)^3(1 + z_L)^{\eta(1-\frac{4}{\gamma})} \left(\frac{D_{OL}D_{LS}}{R_0 D_{OS}}\right)^2 \frac{1}{R_0}\frac{cdt}{dz_L}dz_L, \tag{2}$$

$$F = \frac{16\pi^3}{cH_0^3}\phi_* v_*^4 \Gamma\left(\alpha + \frac{4}{\gamma} + 1\right) \tag{3}$$

Clearly, when $\gamma = 4$, the effect of evolution is masked.

2. The cosmological Constant

We calculate (Jain et al. 1998; Jain et al. 2000) the number of lensed quasars for the HST Snapshot Survey taking the average bias factor due to magnification caused by lensing as 9.76 (as estimated by the survey). With Schecter parameters given in Nakamura & Suto (1997) and in the context of an evolutionary mode the comparison with the observed lenses gives $\Omega_\Lambda <\sim 0.68$. This value is to be compared with the value 0.73 inferred from observations of distant SNe Ia. However, there are many uncertainties associated with the method using lensing statistics, such as the correct values of Schecter parameters, the correct distance formula to be used, and whether or not to use SIS approximation with core. These issues have been discussed in Jain et al. (1998).

3. Average red-shift of GRBs

If GRBs are cosmological objects, they must be lensed. However, BATSE has not detected any lensed GRB, implying an upper limit on $< z >$ for these objects. We have calculated (Jain et al. 1999) upper limit on $< z >$ for the following scenarios of galaxy evolution:
(i) *Fast merging* (Broadhurst, Ellis & Glazebrook 1992), (ii) *Slow merging* (in these two models the comoving number density of lenses changes with the look-back time), and (iii) *Mass accretion* where comoving density remains unchanged but the mass of galaxies increases with time. We calculate the number of image pairs for the BATSE 4B catalogue (1802 entries) following Holz, Miller & Quashnock (1999) in the SIS approximation using reasonable Schecter parameters and infer an upper limit on $< z >$. However, the uncertainties discussed above do not allow yet to reach a definitive conclusion.

4. Lensing Statistics and Models of Galaxy Evolution

From $d\tau$ we have derived $\frac{d^2\tau}{dz_L d\phi} d\phi dz_L$, the differential optical depth for angular separation between ϕ and $\phi + d\phi$, for various evolutionary models. We have then calculated (Jain et al. 2000) the angular separation distribution $\frac{dN}{d\Delta\theta}$ by integrating over z_L for reasonable Schecter parameters and average bias factor:

$$\frac{dN}{d\Delta\theta} =< B > \sum \int_0^{z_S} \frac{d^2\tau}{dz_L d\Delta\theta} dz_L. \tag{4}$$

For a flat Ω_Λ - universe, Schecter parameters given in Loveday et al. (1992) seem to favour the mass accretion model and, to a lesser extent, the non-merging evolutionary model. These results can be put on a firm footing when an agreed set of Schecter parameters are available.

We give below only key references. The detailed list is in Jain et al. (2000).

References

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