GRAVITATIONAL LENSES AND COSMOLOGICAL EVOLUTION

J.A. Peacock
Royal Observatory, Edinburgh

1. LENSING AND SELECTION EFFECTS

Empirical descriptions of cosmological evolution rely on an assumed relation between luminosity distance and redshift in order to derive the luminosity function and its epoch dependence. This relation is usually taken to be that of an idealised Friedmann cosmology, despite the obvious abundance of small-scale structure in the Universe. However, the assumption that the probability of a lensing event is negligible is now made less tenable with the discovery of the double and triple QSO's, both of which appear to have been magnified by factors of 10-15. With at least two events of this amplification in 1500 known quasars, it may be that a large fraction of observed QSO's have been magnified by significant amounts. Turner (1980) suggests that all evolutionary statistics (e.g. V/Vmax) may thus be misleading, although he considers only an illustrative model of the effect. The problem is that, even if the intrinsic probability of a lensing event is very low, the effect becomes important if the background density of faint sources rises sufficiently quickly. We must therefore calculate not only the intrinsic probability of a given amplification, but incorporate this with the luminosity function to see if lensing could be made dominant by selection effects.

2. THE LENS POPULATION

The first step is to identify the likely lenses: these are simply galaxies or groups/clusters of galaxies; in each case, we know the form of the optical luminosity function (Felten 1977; Bahcall 1979). We now model the mass distribution as that of a singular isothermal sphere, in which case the lensing effects depend only on the velocity dispersion, V. Using the relation $L \propto V^4$ (Faber & Jackson 1976), we can derive the space density of lenses of a given strength.

The probability distribution of amplification, f(A), is derived as follows: for a given A, we can calculate N, the expected number of interactions leading to an amplification greater than A. If N << 1, then differentiation yields f(A) directly. From this, and the condition

D. S. Heeschen and C. M. Wade (eds.), Extragalactic Radio Sources, 451–452.

https://doi.org/10.1017/S0074180900028394 Published online by Cambridge University Press

$\langle A \rangle = 1$ (flux conservation implies no amplification on average) we can construct realistic forms for f(A). The most important features of these distributions are:

i) For $A \gtrsim 2$ we have $f(A)=a/A^3$, where the constant a depends on redshift.

ii) f(A) has a cut-off at high A which depends both on redshift and on the physical size of the object being lensed.

Representative values for a 10-pc flat-spectrum radio source at z=1 are a=0.03, Amax=2500. Amax scales linearly with physical size, so lensing effects cannot be important for extended radio sources on scales $\gtrsim$kpc.

3. RESULTS

To find the observational effects of lensing we should take the luminosity function inferred in the standard manner and calculate the lensing correction (assuming this to be small). However, the luminosity function is not always uniquely defined (see Peacock & Gull 1981) and we shall be content for now with some simple illustrative calculations. If we take z=1 to be a representative redshift for QSO's and flat-spectrum sources (the constant a varies slowly with z in this range), then the importance of lensing depends on the slope of the source counts. For differential counts $dN \propto S^{-\beta}$, the distribution of amplifications at a given observed flux denisty is $f(A).A^{\beta-1}$; the probability of significant amplification can thus become very large if $\beta \gtrsim 3$. In practice, both radio and optical counts flatten at low flux densities, tending to slopes of $\beta = 1.5$ and 2.2 respectively; this implies that the probabilities of A>2 in the brightest observed flat-spectrum sources and optically selected quasars are about a and 3a respectively.

Lensing thus has a small effect on statistical conclusions based on samples of bright radio sources. For optically selected quasars, the effects are likely to be more important, since much smaller objects than galaxies may act as lenses. At z=1, a quasar continuum source of size $\sim 10^{-3}$ pc can be lensed by masses as low as $\sim 10^{-4} M_\odot$ whereas for radio emission of scale $\sim$10pc, the critical mass is $\sim 10^{5} M_\odot$. In principle, therefore, optically selected quasars could be magnified by large factors; this would help explain the high ratio of radio-quiet to radio-loud quasars.

We conclude that, while the effects of lensing do not invalidate cosmological conclusions based on radio samples, the phenomenon is not so rare as had been supposed: Arp's excess quasars near to bright galaxies and the extreme superluminal motions in 3C279 are two cases where lensing may well be dominant.

REFERENCES

Bahcall, N., 1979. Astrophys. J., 232, 689.
Felten, J.E., 1977. Astron. J., 82, 861.
Peacock, J.A. & Gull, S.F., 1981. Mon. Not. R. astr. Soc., 196, 611.
Turner, E.L., 1980. Astrophys. J., 242, L135.