THE LENS-REDSHIFT TEST REVISITED

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Kochanek[1] suggested that the redshifts of gravitational lens galaxies rule out a large cosmological constant. This result was questioned by Helbig & Kayser[2], who pointed out that selection effects related to the brightness of the lens can bias the results of this test against a high λ_0 value; however, we did not claim that the observations *favoured* a high λ_0 value, merely that current observational data were not sufficient to say either way, using the test as proposed by Kochanek[1] but corrected for selection effects. Kochanek[3] pointed out that an additional observable, namely, the fraction of measured lens redshifts, provides additional information which restores the sensitivity of the test to the cosmological model, at least somewhat. Here, I consider three aspects. First, I discuss the appropriateness of the correction to the test proposed by Kochanek (1996a). Second, I briefly mention the slightly different statistical methods which have been used in connection with this test. Third, I discuss what results can be obtained today now that more and better-defined observations are available.

1 Introduction

The optical depth for gravitational lensing depends on the cosmological model, the Faber-Jackson and Tully-Fisher relations, lens-galaxy type (or the morphological mix), the luminosity function of lens galaxies and the S-z relation of the source population (e.g. Kochanek[1], Helbig & Kayser[2]). There is an obvious problem with simply measuring the integrated optical depth, i.e. the number of lens systems (according to some useful definition): There is a degeneracy between various parameters such that quite different combinations can result in the same number of lenses. While it is possible to break this degeneracy somewhat, this requires a careful survey and cannot be done with a sample of lenses 'from the literature'. Kochanek[1] pointed out that one could use the *shape* of the optical-depth function $\mathrm{d}\tau/\mathrm{d}z$ as a probe of the cosmological model. The advantage of this approach is that it does not depend on the overall normalisation, as counting the number of lenses obviously does. Also, it is quite sensitive to the cosmological model, with the dependence on the cosmological model of a) the combination of angular size distances and b) the volume element, both of which appear in $d\tau/dz$, reinforcing one another. In other words, the redshifts of lens galaxies can be used as a probe of the cosmological model which is relatively little affected by our ignorance of other factors which determine the total optical depth.

2 History

Kochanek[1] used a sample of 4 gravitational lens systems from the literature (estimating the lens redshift from absorption lines if unknown) and found that the Einstein-de Sitter model was 5–10 times more likely than a flat model dominated by a cosmological constant. Helbig & Kayser[2] pointed out that this is potentially subject to a strong bias: It could be that most known lens redshifts are low not because we live in a universe in which this is more probable, but since we could not have measured them if they were higher. To correct for this effect, we suggested comparing the shape of $d\tau/dz$ not over the whole range $[0,z_s]$ (in practice, the value of this function is negligible before z_s is reached), but rather only out to that redshift where a lens redshift could have been measured, assuming some realistic limiting magnitude (at this redshift, $d\tau/dz$ usually still has a non-negligible value) and found that no interesting constraints could be obtained from then-current data (using 6 systems, all with measured, not estimated, lens redshifts), even if many more such systems were found, and that this conclusion did not depend on the precise value assumed for the limiting magnitude.

Kochanek[3] then pointed out that one can use an additional observable to restore cosmological sensitivity to the lens-redshift test: the fraction of lens systems with measured redshifts. If a strong bias were present such that only low lens redshifts could be measured, then there should be many lens systems with unmeasured redshifts. While true, this misses the point of Helbig & Kayser[2]: Our claim was not that the observations supported a large value of the cosmological constant (nor the opposite), but rather that the conclusion of Kochanek[1] did not follow from the sample used (or our sample) since the lens-brightness bias had not been taken into account. Also, the correction proposed in Kochanek[1] assumes that unknown lens redshifts are unknown only because they are faint; in practice, there can be many other reasons why some lens redshifts have not yet been measured (e.g. the maximum declination accessible from UKIRT).

Various different statistical measures have been used to compare the observed and predicted lens-redshift distributions. Here, I only consider the maximum-likelihood method (e.g. Kochanek[3]), which I consider to be most appropriate. However, results from using the binning method of Helbig & Kayser[2] or a Kolmogorov-Smirnov test (Helbig, unpublished) give qualitatively similar results.

3 Using CLASS

The whole issue of unknown lens redshifts and their possible causes can be avoided if one has a sample which is complete with respect to lens redshifts. CLASS (e.g. Helbig[4]) is close to this goal, and the JVAS subset of CLASS (more exactly, the JVAS lens systems in CLASS which are also part of the statistically complete lens-survey sample; see Helbig[4] for more details) is actually complete. While only consisting of four systems, this is the same number used in Kochanek[1], so the time is ripe to revisit this topic. (The last JVAS lens redshift was obtained by Kochanek & Tonry[5].)

Figure 1 shows the likelihood as a function of λ_0 and Ω_0 for the sample from Kochanek[1] while Fig. 2 shows the same for the JVAS lens systems B0218+357, MG0414+054, B1030+074 and B1422+231. It is obvious that the Kochanek[1] sample indicates that the Einstein-de Sitter model is more likely than a flat model dominated by a cosmological constant. The JVAS sample tells a different story. Probably, part of the difference, in particular, the low probability of models

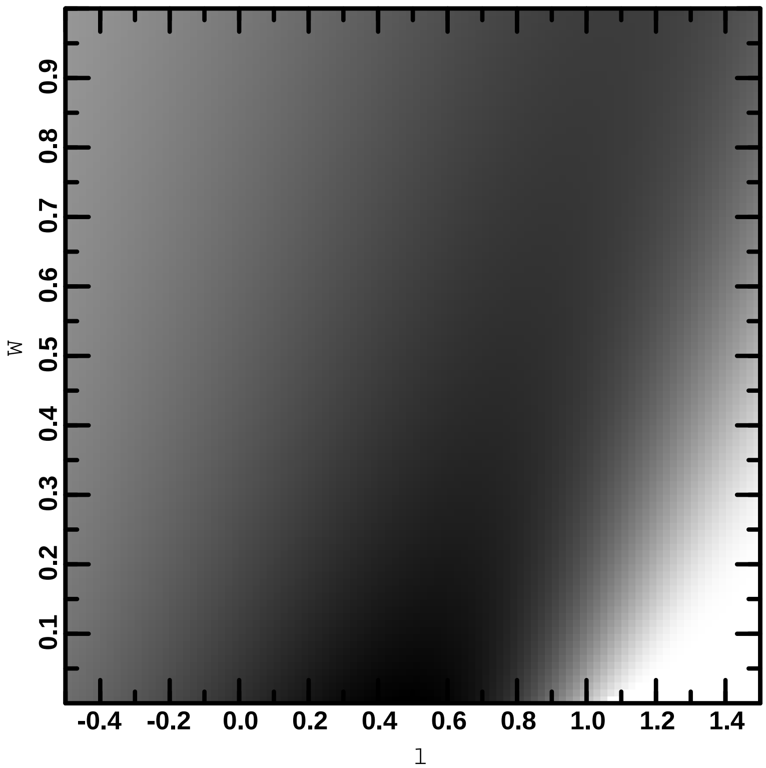

Figure 1: Likelihood as a function of λ_0 and Ω_0 using the Kochanek sample; darker means higher likelihood.

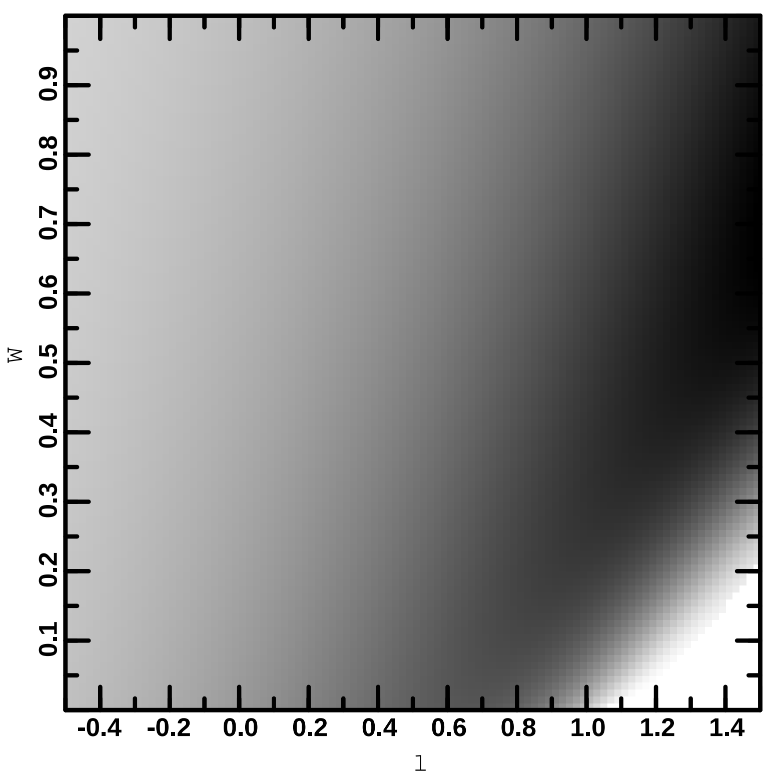

Figure 2: Likelihood as a function of λ_0 and Ω_0 using the JVAS sample; darker means higher likelihood.

near the white area to the lower right (which corresponds to no-big-bang models and is excluded *a priori*) can be explained by the bias noted in Helbig & Kayser[2], while part can be explained by small-number statistics. This will be explored in more detail in Helbig & Rusin[6]. (It should be noted that the results for the Kochanek[1] sample presented here do not correspond exactly to those in Kochanek[1] since there (as in Helbig & Kayser[2]), the now-known-to-be-erroneous $(3/2)^{\frac{1}{2}}$ factor for elliptical galaxies was used. Including this factor increases the relative likelihood of the Einstein-de Sitter model for the Kochanek[1] sample while its effect on the JVAS sample is less pronounced.)

4 Conclusions and Future Prospects

It is obvious that the conclusion of Kochanek[1] was premature: using a better-defined and in particular bias-free (since complete) sample, the lens-redshift test does not disfavour cosmological-constant dominated models, although the significance of this is not yet clear. Since the publication of Kochanek[1], of course, the cosmological constant has become popular again and, although more detailed lens-statistics analyses are not incompatible with this (e.g. Helbig[7]), it is not yet clear whether systematic effects, such as our lack of sufficient information about the S-z plane of the source population (e.g. Kochanek[8]), make current estimates of λ_0 from the analysis of lens surveys unreliable. It is at least interesting that the lens-redshift test does not seem to favour an Einstein-de Sitter universe over a model (flat or not) dominated by a cosmological constant. When the much larger CLASS sample is complete with respect to lens redshifts, the time will be ripe to revisit this topic once again.

Acknowledgments

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