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Evidence for the class of the most luminous quasars

IV. Cosmological Malmquist bias and the Λ term

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Abstract. We study if the evidence for the optically luminous subclass of radio quasars (Teerikorpi 2000, 2001), depends on the Friedmann model used, especially on the presence or not of a Λ term. Previously this grouping, with distinct properties, was found at $M_V \approx -26.0 + 5\log h$ ($\Omega_m = 1$, $\Omega_\Lambda = 0$). The cosmological Malmquist bias approach shows that the member candidates, separated by an empty luminosity range from fainter quasars, as well or better appear in the currently favoured flat models with a non-zero Λ. We briefly illustrate the effect of Λ on the Malmquist bias, depending on the steeper volume derivative and longer luminosity distance in Λ models.

Key words. quasars: general – cosmology: observations

1. Introduction

This paper continues the study of the evidence for the optically luminous subclass of radio loud quasars, separated by a gap in the magnitude distribution from fainter quasars (Teerikorpi 1981, 2000, 2001, or Papers I–III). This class was suggested at redshifts 0.5–1.6 in Paper I. Paper II gave new evidence with the cosmological Malmquist bias approach (Teerikorpi 1998; or T98). Paper I noted a change in optical variability: the luminous "AI" quasars around $M_V = -26.0 + 5\log h$ are less active than those on the faint side of the gap. This property (without which groupings might go unnoticed) was confirmed by new data in Paper II, including optical polarization. Further evidence for a physically distinct class came from Paper III, from the size and morphology of double radio sources.

In Paper II the Friedmann model with $\Omega_m = 1$, $\Omega_\Lambda = 0$ was used. Here we study if the conclusion is affected when one goes to the now favoured lambda models. Type Ia supernovae (Riess et al. 1998; Perlmutter et al. 1999) and the measurements of the density parameter Ω from the angular power spectrum of the CBR (de Bernardis et al. 2000; Balbi et al. 2000; Jaffe et al. 2000) suggest that $\Omega = \Omega_m^0 + \Omega_\Lambda^0 = 1 \pm 0.05$ with $\Omega_\Lambda^0 \approx 0.7$.

2. The cosmological Malmquist bias

For a "standard candle" class one may predict the run of its average value of $\log z$ versus apparent magnitude m. This depends on the average absolute magnitude M_0, the dispersion σ_M, the K-correction, and the cosmological model (via luminosity distance and volume-element). It is not influenced by magnitude incompleteness, which sometimes can hamper the analysis made in the sense m vs. z (this was the reason for its implementation in Paper II). The difference between such a predicted average value $<\log z>(m)$ and the value given by the exact Mattig formula $z = z(m, M_0)$ is the Malmquist bias of the first kind in this cosmological context, as termed by Teerikorpi (1997). Now the bias is not constant for different apparent magnitudes, as classically found. Only for bright magnitudes does it have the familiar value $0.2 \times 1.382\sigma_M^2$ (for a uniform space distribution). The T98 recipe for calculating the bias was utilized in Paper II for the case of a zero cosmological constant. Calculations with a non-zero Λ require the expression of the normalized metric distance d_M (see e.g. Carroll & Press 1992):

$$d_M = \frac{1}{\sqrt{|\kappa|}} \sin n \times \left\{ \sqrt{|\kappa|} \int_0^z [\Omega_m(1+x)^3 + \Omega_\Lambda + \kappa(1+x)^2]^{-1/2} \mathrm{d}x \right\}. \quad (1)$$

Here $\kappa = 1 - \Omega_m - \Omega_\Lambda$ and $\sin n(y)$ stands for $\sin h(y)$, y, $\sin(y)$, respectively for the curvature factor $\kappa >, =$ or < 0. The luminosity distance is $\mathrm{d}_L = (1+z)\mathrm{d}_M$. The volume element $\mathrm{d}V$ gives the derivative $\mathrm{d}V/\mathrm{d}z$ for the comoving volume, needed to calculate the survey volumes and the average $<\log z>$ for a standard candle viewed through a magnitude window $m \pm \frac{1}{2}\mathrm{d}m$:

$$\mathrm{d}V = ((c/H_0)^3 \mathrm{d}_M^2/[1 + \kappa \mathrm{d}_M^2]^{1/2})\mathrm{d}(\mathrm{d}_M)\mathrm{d}\Omega. \quad (2)$$

3. The influence of Λ on the Malmquist bias

In an analysis of $\log z$ versus m the Malmquist bias approach may lead to more accurate conclusions on the cosmological

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Table 1. The models, the best M_0, and the standard deviations $\sigma_{\Delta \log z}$ for the AI candidates (for $\sigma_M = 0.15$ mag).

model	Ω_m	Ω_Λ	$M_0 - 5 \log h$	$\sigma_{\Delta \log z}$
"closed"	1.5	0	−25.69	0.0274
E–deS	1	0	−25.81	0.0259
lambda1	0.5	0.5	−26.17	0.0247
lambda2	0.3	0.7	−26.36	0.0246
lambda3	0.15	0.85	−26.58	0.0297
"vacuum"	0	1	−26.99	0.0328

model, in comparison with the usual habit of using the exact Mattig relation and putting the K correction either into the apparent magnitude or to the Mattig curve (T98; see also Bigot & Triay 1990a, 1990b).

The ratio of the comoving volumes from which the bright and faint wings of the Gaussian LF are visible at $m \pm \frac{1}{2}\mathrm{d}m$ is smaller than classically found (T98) and generally causes a smaller Malmquist bias. Figure 1 shows the comoving volume derivative $\mathrm{d}V/\mathrm{d}z$ versus luminosity distance for the E-deS and two flat lambda models, up to $z = 2$. For lambda models, $\mathrm{d}V/\mathrm{d}z$ is steeper, while the luminosity distance is larger than in the E-deS model, so the influence of Λ on the Malmquist bias is not immediately clear. To illustrate this, we show in Fig. 2 the cosmological Malmquist bias in $<\log z>$ at different apparent magnitudes using the dispersion $\sigma_M = 0.5$ mag. In this example, the absolute magnitude $M_0 = -26.0 + 5 \log h$, and we take the K correction to be zero.

At bright magnitudes (small distances) the cosmological bias → the classical one, as expected. The curves show how much the bias makes the data points differ from the exact Mattig curve. The detailed run of the curves for the E-deS and Λ models reflects the behaviour of the luminosity distance and the volume derivative as functions of redshift. Also, a fixed apparent magnitude corresponds to different redshifts within different models.

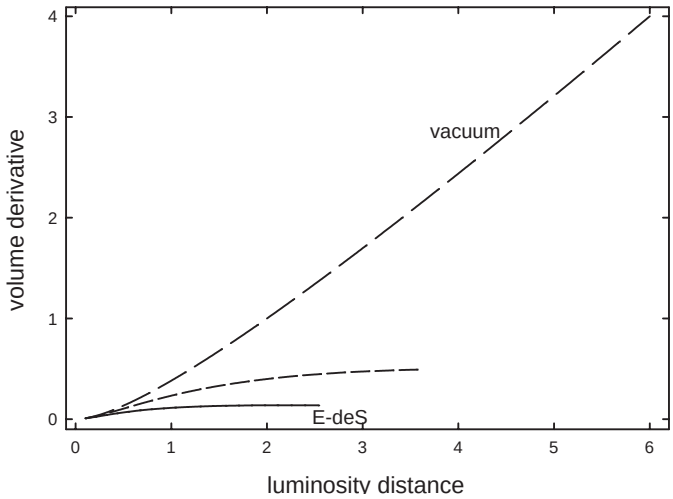

Fig. 1. The derivative of the comoving volume versus the luminosity distance for the Einstein-de Sitter model and for flat lambda models: $\Omega_\Lambda = 0.7$, $= 1$, when z goes from 0.1 to 2.0.

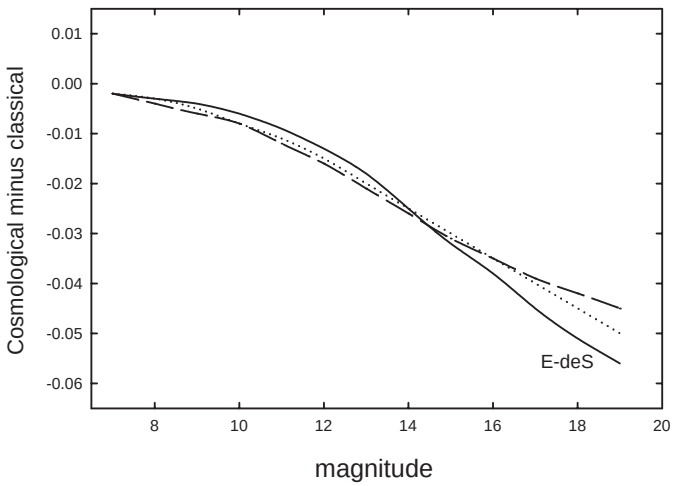

Fig. 2. The cosmological Malmquist bias in $<\log z>$ minus the classical bias for the E-deS model (the solid curve) and for two flat lambda models: $\Omega_\Lambda = 0.7$ (dots), $=1$ (dashes), when the dispersion $\sigma = 0.5$ mag and the absolute magnitude M_0 is typical for luminous quasars. At bright magnitudes (small distances) the bias is close to the classical one, as expected.

4. The $\Delta \log z$ vs. m diagrams

We use the K_V and reddening corrections as in Paper II, and restrict the data to quasars with moderate or good variability information (var > 1 in Table 1 of Paper II) and having the optical amplitude $\Delta m < 1.2$ mag. This leaves in the sample 15 AI candidates (the filled circles in Figs. 4, 5 of Paper II), and the gap is clearly visible. The "base brightness" $V_{\min}$ magnitude is used as before.

Table 1 lists the cosmological models used for the calculations. They include as extreme cases a "closed" and a "vacuum" model, then the Einstein–de Sitter model, and three flat lambda models. We are interested in what happens when one goes from the E-dS model (used in Paper II) to the now favoured lambda-models.

We note that we fix here $h = 1$, as in Paper II, and let the average (volume-limited) M_0 vary until in the $\Delta \log z = \log z - <\log z>_{\mathrm{pred}}$ vs. m diagram the AI candidates settle at $\Delta \log z \approx 0$. There is no independent value for M_0, i.e. no low-redshift "calibrators". Recall from T98 and Paper II that the K_V correction is put into the bias calculation and the apparent magnitude V in the $\Delta \log z$ vs. m diagram contains the reddening correction only. Because the original sample is limited below $z = 1.65$, we integrate in the bias calculation only up to $z = 1.7$.

In Fig. 3 we illustrate the method using the extreme "closed" and "vacuum" models from Table 1 to calculate the expected $<\log z>$. We adopt $\sigma_M = 0.15$ as in Paper II. For the first model one must take $M_0 = -25.69$ and for the second one $=-26.99$ in order to have $<\Delta \log z> = 0$ for AI. Note that the data points have clearly non-zero slopes, in different senses. If AI were a standard candle, this would suggest that the correct model is somewhere between these ones. With the current understanding that $\Omega \approx 1$, we show in Fig. 4 similar diagrams for other such flat models from Table 1. Now the AI groupings are more horizontal.

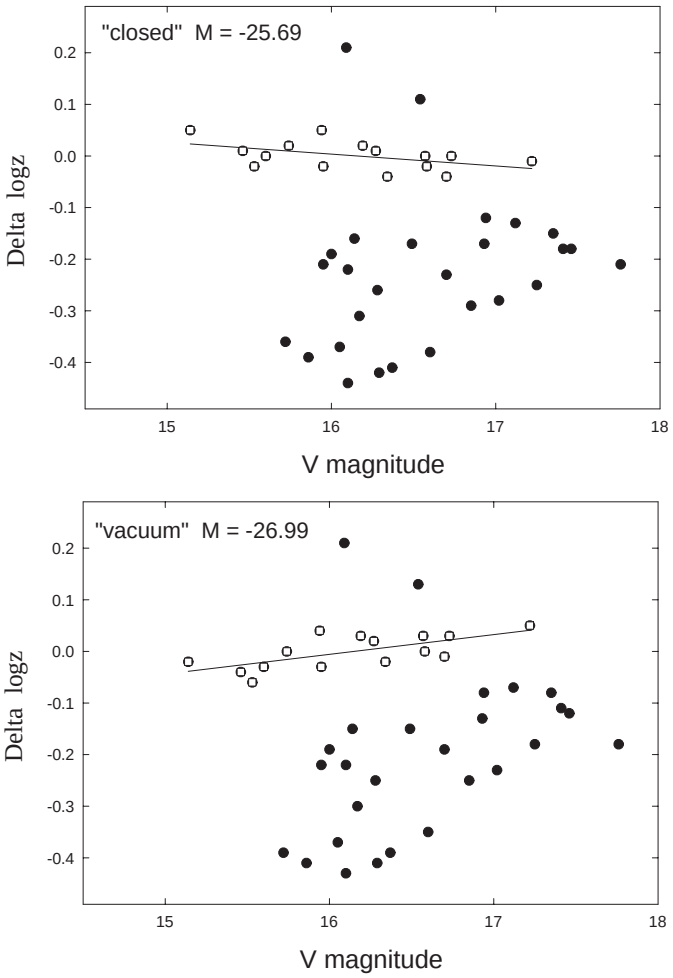

Fig. 3. The $\Delta \log z$ vs. V for the extreme models in Table 1, with M_0 adjusted so that the AI candidates (open circels) have the average $\Delta \log z = 0$. The non-zero slopes show that AI is best visible in some model between these extreme ones.

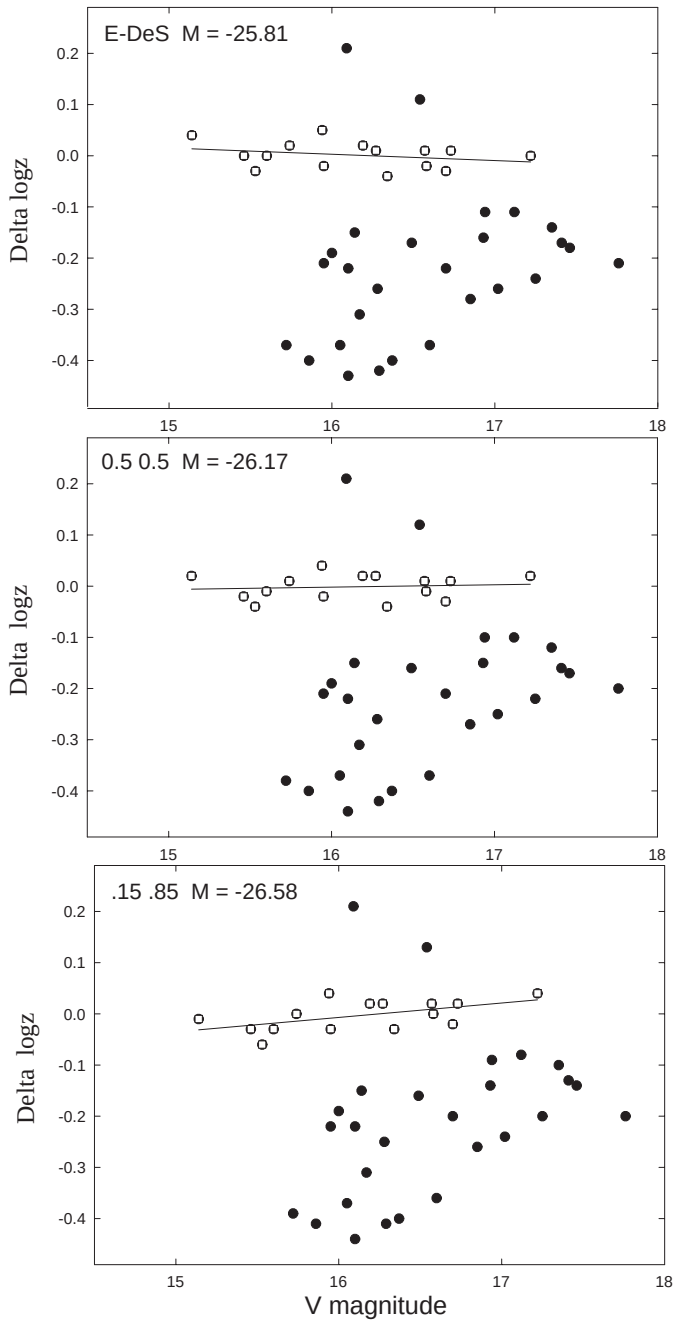

Fig. 4. The $\Delta \log z$ vs. V for three flat models in Table 1. Note that in these cases the slope is closer to horizontal, reaching zero for the model with $\Omega_\Lambda = 0.5$.

Recall that the calculation of $\Delta \log z$ refers to the (Gaussian) standard candle class and has little meaning for other quasars, e.g. those fainter than the optical gap. So it is an artifact that the bright edge of the fainter population is not horizontal (see the Discussion), while their lower envelope just reflects a cut at $M = -24.0 + 5 \log h$ (for E-deS).

Figure 5 shows the standard deviation from zero of $\Delta \log z = (\log z)_{\rm obs} - (\log z)_{\rm pred})$ for these models. A (broad) minimum is reached around $\Omega_\Lambda = 0.7$, the currently favoured value. We do not put much weight on this result as such, but rather note that it shows that the support for AI (Papers II, III) does not rely on the old "standard" model. But if looked at as a test, this approach is rather sensitive to values of Ω_Λ approaching 1.

5. Discussion

We have also experimented with a looser selection criterion, including quasars with poor variability information (var = 1 in Paper II). We show the result in Fig. 6 for the flat $\Omega_\Lambda = 0.5$ model. In this diagram we have also made a separate Malmquist bias calculation for the fainter population, using for them $M = M_0 + 0.8$ which corresponds to the bright envelope, and making a shift of $-0.8/5 = -0.16$ in $\Delta \log z$ (this is for convenience, otherwise the envelope would also lie at $\Delta \log z = 0$, as AI). Note that now also the envelope becomes horizontal, as expected if the width of the gap in magnitudes is constant.

The present results show that the existence of the AI plus optical gap structure does not depend on our previous choice of the cosmological model. It appears best within the currently favoured flat Λ models. This is interesting, but we do not know

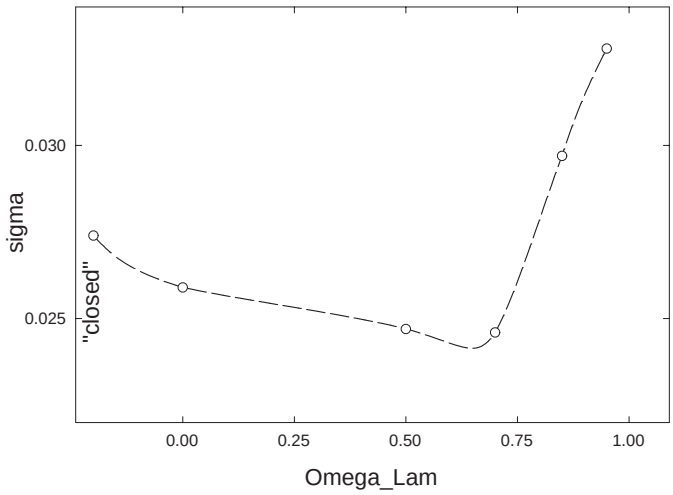

Fig. 5. The standard deviation $\sigma_{\Delta \log z}$ versus Ω_Λ for the AI candidates, as calculated within the flat $\Omega = 1$ models (the leftmost circle refers to the "closed" model in Table 1).

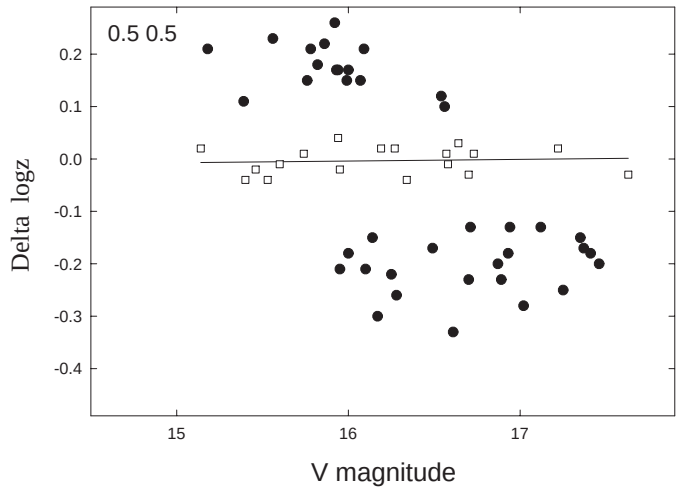

Fig. 6. The $\Delta \log z$ vs. V for the flat $\Omega_\Lambda = 0.5$ model, now with a looser selection criterion, and the envelope of the fainter population normalized to $V \approx 16$, now visible as horizontal. The points scattered above the AI candidates are mostly with poor variability information. These may also include truly overluminous or gravitationally lensed objects (Paper II).

if the AI luminosities do not evolve[1] (even with the evidence for a physically distinct class in Papers II–III) and one also needs to analyze better the K- and reddening corrections.

One problem is that one cannot assign to these quasars low-z "calibrators" as e.g. the supernovae SNIa have, so in Figs. 3, 4 the available magnitude range is not wide and we cannot fix M_0 independently. This in fact explains the visibility of AI within different Friedmann models. On the other hand, the present sample extends about as deep as the record distant ($z = 1.7$) SNIa supernova reported by Riess et al. (2001) and covers the region ($1 < z < 1.7$) within which few supernovae have been thus far detected. This makes further studies of this standard candle candidate especially interesting.

6. Conclusions

We summarize the conclusions:

* In a flat Λ universe the cosmological Malmquist bias, affecting $<\log z>$ at constant m, is influenced by an interplay between the steeper comoving volume derivative and longer luminosity distance as compared with the E-deS model, and by the fact that an apparent magnitude corresponds to different redshifts in different models. At bright bolometric magnitudes the bias is slightly smaller than in the E-deS model, then at fainter magnitudes becomes larger, for a luminous quasar standard candle with fixed M_0.
* The AI candidates are as well or even slightly better seen, via the cosmological Malmquist bias approach, for the flat lambda models than for the E-deS model.
* The slope of the AI grouping in the $\Delta \log z$ vs. magnitude diagram, reaches the zero value around $\Omega_\Lambda = 0.5$ for flat models. This result is interesting, but formally the present data statistics permit a range of Ω_Λ on the 2σ level from 0 to 0.8. And of course, it is early to claim that the AI quasars form a genuine non-evolving standard candle class.

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[1] The observed correlation between the central black hole mass and the host galaxy mass suggests that quasars arising in a narrow galaxy class could lie in a narrow luminosity range.