DO QUASARS EVOLVE OVER COSMOLOGICAL TIME SCALES?

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ABSTRACT. Systematic biases that are redshift dependent can influence the optical discovery of quasars and the evolution laws derived from counts of quasars. New data and their interpretation for quasars brighter than $M_B = -24$ in the Palomar Bright Quasar Survey (BQS) (Schmidt and Green, 1983) are consistent with no evolution. A comparison of BQS quasars with the brightest quasars from the CTIO Schmidt Telescope Survey (Osmer and Smith, 1980) shows that if q_o is near zero, the co-moving density of bright quasars in a Friedmann cosmology is about 15 times higher for the CTIO survey quasars (mean $z \approx 2.8$) than for the BQS quasars (mean $z \approx 1.8$). In this case spectral evolution is also required since the CTIO quasars have stronger CIV λ1548 lines than the BQS quasars of similar luminosity. Alternatively, if q_o is taken to be near 1, the CTIO survey quasars would then have lower luminosity than the BQS quasars and these data would be consistent with no evolution. Strong CIV λ1548 lines for the CTIO quasars would then fit the general correlation between absolute quasar luminosity and emission line strength (Wampler, Gaskell, Burke and Baldwin, 1984).

1. INTRODUCTION

Much of the material given in this talk will soon be published in the Astrophysical Journal (Wampler and Ponz, 1985). Here we summarize the main points of that article and give a comparison of the scanner IDS magnitudes with broad band blue magnitudes obtained by Peter Allan and William Keel using the Mark II computer controlled photometer at the 1.3-m telescope on Kitt Peak. These data provide an important check on the IDS photometric system and were kindly provided by W. Keel prior to publication.

2. BIASES THAT COULD AFFECT QUASAR STATISTICS

1.1. Line Emission: In the ultraviolet Ly-α λ1215 and CIV λ1548 can become very strong. For quasars with absolute continuum magnitudes of

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about -24 at λ1550 these two lines can have a combined equivalent width of nearly 600 Å in the quasar rest frame. For brighter quasars the equivalent width is much less. This rough anti-correlation between equivalent width and quasar luminosity is called the Baldwin effect (Baldwin, 1977; Wampler et al., 1984). At a redshift of 2, quasars with λ1550 continuum magnitudes of -24 have apparent magnitudes (which depend on the exact cosmological model) near mag 21. At this redshift both strong emission lines are in the UV-blue spectral region and can increase the apparent magnitude of the blue continuum of faint quasars on blue survey plates. To the red, strong FeII emission can also substantially increase the apparent brightness of the continuum magnitude (Wills, Netzer and Wills, 1984; Wampler, 1986). These effects would not be important if samples of quasars were actually observed at a given rest wavelength and a careful correction were made for the effects of line emission. Unfortunately this has not usually been the case. The steep increase in the space density of quasars with decreasing luminosity can result in substantial redshift dependent errors in determining the space density of the objects.

1.2. Photometric Errors: Accurate photometry exists for only a few "complete samples" of quasars. And for those observed with broad band filters the published magnitudes are affected in an unknown way by the line emission described above. Two types of photometric errors exist: accidental errors and systematic errors. The accidental errors usually increase with decreasing apparent magnitude. Also several surveys seem to be affected by systematic errors that result in faint quasars being assigned a magnitude that is too bright (Wampler et al., 1984; Wampler and Ponz, 1985). Both of these effects result in a steepening of the log(N)-log(mag) curve. Since, roughly, the fainter quasars have a higher z this effect results in the high z quasars being assigned a magnitude that is actually too bright.

1.3. Survey Incompleteness: All surveys are incomplete in some sense. If the characteristics of the survey are well understood this incompleteness can be taken into account and corrections made for the errors that develop when working near the survey limit. But often the characteristics of a survey are rather poorly understood and redshift dependent effects are usually not correctly addressed. Most biases seem to favor the discovery of high redshift quasars over those of low redshift. Great care must be taken to ensure that all the lower redshift quasars that correspond to the identified high redshift ones have in fact been discovered.

3. THE PALOMAR BRIGHT QUASAR SURVEY

Because the Palomar Bright Quasar Survey (BQS) was one of the most carefully determined complete surveys of quasars and because the objects in it are bright and easy to observe we decided to re-examine the survey to assess the extent to which the possible errors listed above might have affected the conclusions of Schmidt and Green (1983).

Image Dissector (IDS) scans were obtained for 67 of the 69 BQS quasars which Schmidt and Green give absolute magnitudes brighter than -24. The two unobserved quasars are both low redshift, low luminosity objects and their neglect does not affect the conclusions reached here. From these scans U,B,V Blue magnitudes were constructed using the B filter response and a computer program due to Jack Baldwin. These Blue magnitudes were compared to the observed magnitudes listed by Schmidt and Green (1983). A systematic effect seems to be present in the comparison of these two sets of data. For the fainter quasars the magnitudes listed by Schmidt and Green (1983) are about 0.5 mag brighter than the B magnitudes found from the IDS scans. IDS magnitudes of faint white dwarf stars with broad band filter photometry by Eggen (1968) showed a slight non-linearity in the IDS system but this was corrected for in the photometry published by Wampler and Ponz (1985) (see also Wampler, 1985). Fortunately, after this work was completed, Peter Allan and William Keel (private communication) sent us filter photometry magnitudes obtained from observations at KPNO for many of the BQS quasars we observed. In general their results agree rather well with ours although there is a systematic seasonal effect of a few tenths of a magnitude (see Fig. 1).

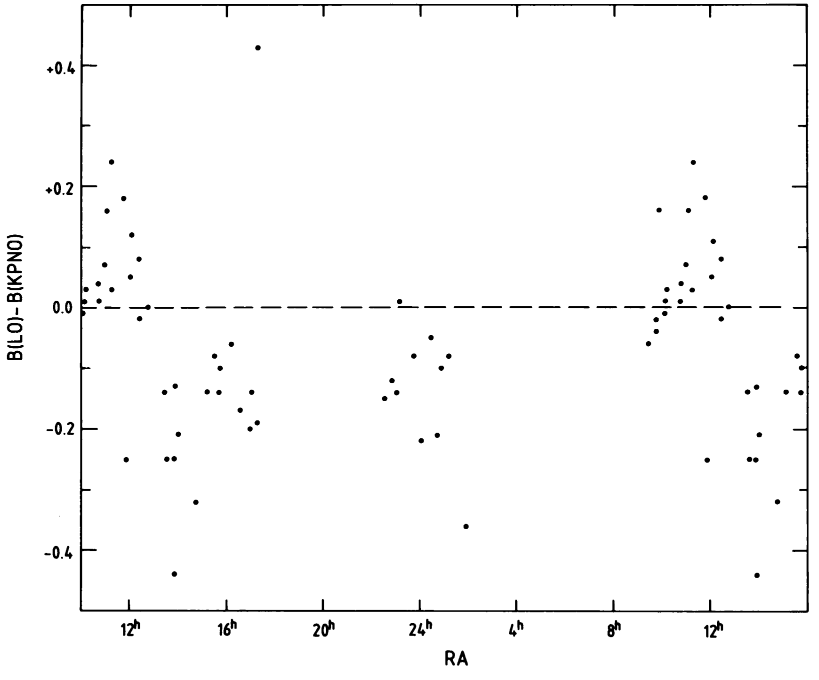

Fig. 1. - The difference between the blue magnitudes obtained at Lick Observatory (LO) with the IDS scanner and those obtained at Kitt Peak National Observatory (KPNO) using a broad band filter photometer. The comparison is shown as a function of right ascension.

After the Lick Observatory data was corrected for this seasonal effect the Lick and the KPNO photometry are in satisfactory agreement (see Fig. 2). In particular there is no systematic effect with magnitude similar to that seen in the comparison with BQS data.

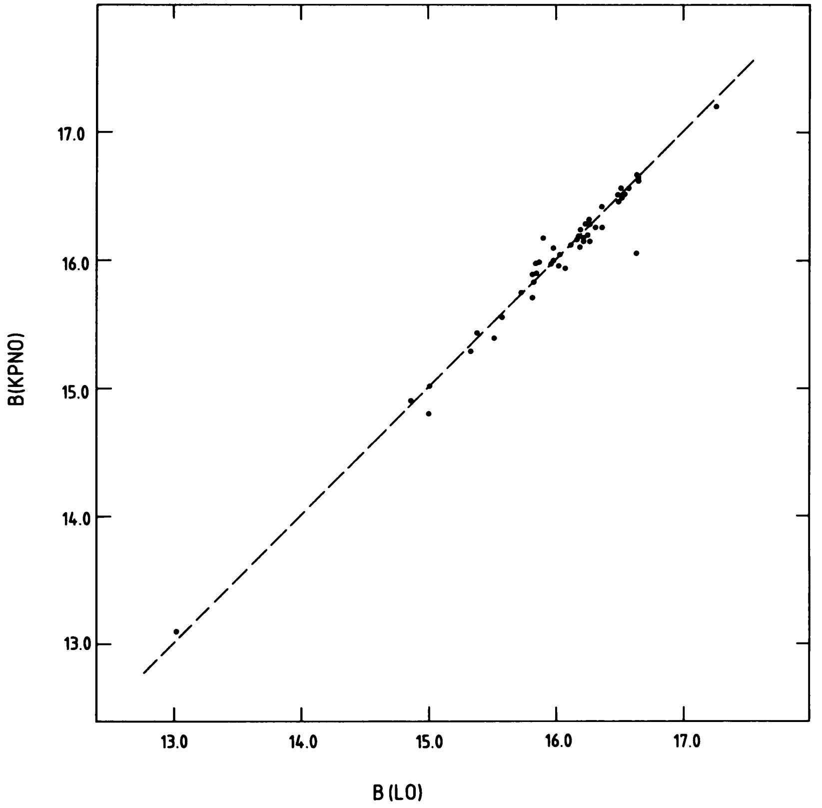

Fig. 2. - A comparison of the LO and KPNO Blue magnitudes after correction for the systematic seasonal effects shown in Fig. 1.

Rather than convert the measured Blue magnitude to a magnitude at some fixed rest wavelength it was decided to actually measure the continuum magnitude near λ2800, a wavelength that is accessible, or nearly so, to the IDS system for all of the quasars in the survey. In the process of obtaining these scans it was found that two of the quasars in the BQS that has listed redshifts near z = 0.5 in fact had redshifts near 1.0. This change accentuates the decrease of sensitivity of the BQS that was noted by Schmidt and Green (1983) for quasars with redshifts near 0.5. The drop in the survey sensitivity near z = 0.5 is caused by the appearance of the MgII λ2798 line and strong FeII bands in the blue filter. This causes the quasar candidates to appear redder than normal and apparently resulted in their elimination from the survey.

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The result of all these changes is that for the brightest quasars in the survey there is no strong evidence for evolution. This conclusion, which differs very markedly from that of Schmidt and Green (1983), mostly results from differences in the interpretation of the data although differences in the measured magnitudes and the correction of the redshift for two objects contribute to this different conclusion.

4. COMPARISON WITH OTHER SURVEYS

The only other survey of radio quiet quasars with accurate monochromatic magnitudes is a CTIO objective prism survey (Osmer and Smith, 1980). Most of these objects have redshifts greater than the $z = 2.05$ cut-off in the BQS that is occasioned by the presence of Ly-α in the Blue filter passband for quasars with redshifts slightly greater than 2.05. Therefore a comparison of these two surveys requires a cosmological model. It was found that in Friedmann universes with $q_o = 0$ the space density of the bright CTIO survey quasars was about 15 times the space density of BQS quasars with similar luminosity. However if this model is chosen, then for the same luminosity the bright CTIO survey quasars have about twice the CIV equivalent width as the BQS quasars. Also the CTIO survey quasars now no longer fit the relationship Baldwin (1977) found between absolute luminosity and CIV line strength.

However if a Friedmann model with $q_o = 1$ is chosen the CTIO survey quasars fit the Baldwin relationship and are sufficiently fainter than the BQS quasars that their increased space density is consistent with the steep quasars' luminosity functions that have been determined from other observations. Thus the CTIO and BQS data are consistent with no evolution of quasar density from $z \approx 3.2$ to the present if q_o is taken to be near 1. This value of q_o is in agreement with other indications that $q_o \approx 1$ (Wampler et al., 1984).

5. CONCLUSIONS

Even the most carefully studied complete samples of quasars seem to have sufficient discrepancies as to throw into doubt the assertion that they show strong quasar evolution over cosmic time scales. In fact it is possible to assert that the quasar data show no evidence for evolution and favor a high value for q_o. This high value (close to the Euclidean result) and the apparent lack of evolution is not understood in the context of popular cosmological theories.

We would like to thank Drs. Allen and Keel for supplying their BQS blue magnitudes to us prior to publication.

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DISCUSSION

Shanks : In terms of answering the question of whether QSOs evolve or not, I think if both the bright and faint surveys are taken together there is stronger evidence for evolution than taking any survey individually; for example in the steep slope of the QSO number counts found brighter than B = 19.5 mag. So although the effects you have discussed must be considered, in my opinion the evidence for evolution may be too strong to be explained away.

Wampler : You may well be right ! I have only compared the CTIO survey with the BQS. Because the CTIO survey may be incomplete, even for bright quasars, other surveys may be better. But it is important to prove that the two surveys are on the same photometric system and that the redshift or luminosity difference in the populations are properly accounted for.

Veron : You said that the photometric errors have an important effect on the log N/B curve because the slope of this curve is so steep. But if you accept this high slope, does not that mean that you accept evolution ?

Wampler : There are two slopes that are important: the luminosity function and the intrinsic log N/B curve. If strong emission lines from many faint, high redshift quasars overpopulate the fiant end of the log N/B curve then its observed slope would be steeper than the unevolving slope even in a non-evolving Universe. Photometric errors that increase with magnitude increase this slope even more. I think it is in general dangerous to use B magnitudes to derive cosmological parameters. The "K" corrections are large and, in my view, uncertain.

Kapahi : Since the radio luminosity function is well known to evolve strongly with epoch, wouldn't the absence of evolution in the optical luminosity function imply a strong epoch dependence of the radio emission from optically selected quasars, contrary to observations ?

Wampler : First, I'm not sure how tightly the observations constrain the

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ratio $R = P_{opt}/P_{radio}$. But I am willing to accept the working hypothesis that R is independent of z. I have been told that the observed evolution of the radio luminosity function is somewhat uncertain. In any case it seems that now people believe that the evolution is not as strong as was first reported.

Green : I disagree with your statement that the higher luminosity objects show less evolution than those of lower luminosity. Taking the data in my figure at face value, the lower luminosity objects show an increase in number density of a few hundred, while the higher luminosities increase by more than 2000. Marshall's formal statistical test showed a 5σ difference in the density evolution rate for the lower and higher luminosity quasars.

Wampler : I had intended only to say that it seems to me that your current figure is not in very good agreement with Fig. 4 of Schmidt and Green (1983). In that figure there was little evolution of quasars fainter than about -25 but there was rapid evolution of bright ($M_B \sim -30$) quasars. Also for the bright quasars the evolution for $0 < z \leq 0.5$ is comparable to that for $0.5 < z < 2.5$. In the figure you just gave the low luminosity quasars have substantial evolution and there is little evolution for the high luminosity quasars until $z \sim 1$. I think that these different results only reflect the fact that these evolution "laws" are not well constrained statistically, or perhaps changing sample biases are affecting the results. Are your new curves statistically compatible with the old ones or do they only appear different ?

" .... despite some tantalizing possible inhomogeneities in some quasar surveys, there is as yet no evidence based on carefully calibrated, quantitative searches for significant large-scale anisotropies in the distribution of quasars."

- Patrick Osmer (p.451)