Bull. Astr. Soc. India (1996) **24,** 815–818

On the Hubble diagram of QSOs with cosmological redshifts

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Abstract. In this paper we study the Hubble Diagram of the QSOs whose redshifts are known to be cosmological in nature. These are the QSOs which lie close to bright galaxies and whose redshifts are nearly equal to those of the bright galaxies. These QSOs, being physically associated with the bright galaxies whose redshifts are known to be cosmological, have cosmological redshifts. We find that the Hubble Diagram of these QSOs can be used to test the cosmological nature of their redshifts only if Malmquist bias is properly taken into account.

1. Introduction

It is well known that the Hubble Diagram of the QSOs is a complete scatter diagram with a lack of any correlation between the redshifts and the apparent visual magnitudes of the QSOs. This has led to the controversy regarding the nature of the redshifts of the QSOs. The majority of the astronomers who believe that the redshifts of the QSOs are cosmological in nature interpret the scatter in the Hubble diagram as arising due to dispersion in absolute magnitudes of the QSOs whereas the minority of the astronomers who believe that the redshifts of the QSOs are generally non-cosmological in nature interpret the scatter as arising due to the fact that the redshifts of the QSOs have a large non-cosmological component. However, even those astronomers who believe that the redshifts of the QSOs are generally non-cosmological agree that the redshifts of these small number of QSOs, which lie close to the bright galaxies and whose redshifts are nearly equal to those of those of the bright galaxies, are cosmological in nature because such QSOs are physically associated with the bright galaxies whose redshifts are known to be cosmological. As a matter of fact this is the only sub-example of the QSOs available in the literature for which the " redshift controversy" does not exist. It would, therefore, be interesting to study the Hubble diagram of such QSOs with a view to test whether these QSOs obey the linear Hubble's law. In section 2, the data, analysis and results for the Hubble diagram of these QSOs are given and in section 3 the conclusions are discussed.

2. The data, analysis and results

From the catalogue of Burbridge *et al.* (1990) we find a sample of 21 QSOs (Table 1) lying close to bright galaxies with similar redshifts ($|Z_{\phi SO} - Z_{galaxy}| \leq 0.01$ so that the redshifts of the galaxies are within 3,000 kms^{-1} of the redshifts of the QSOs.)

The angular separations of the QSOs from their neighbouring galaxies in this sample range from 2 to 370 seconds of arc corresponding to the mean projected separation in the plane of the sky of about 290 kpc. Since the redshifts of the galaxies (and QSOs) in this sample $z \lesssim 0.5$ all standard Friedmann cosmological models predict a linear Hubble's law of the form

$$m_v = 5 \log (cz) + B, \tag{1}$$

where $B = M_v + 25 - \log H_o$, m_v is the apparent visual magnitude of the QSOs duly corrected for galactic absorption and the K-effect. When we plot the Hubble diagram for this sample of 21 QSOs (Fig.2) and test the Hubble's law for the sample in the form

$$m_v = A \log (cz) + B \tag{2}$$

we find that it is a scatter diagram and that the regression coefficient $A = 1.81 \pm 1.38$ and that the correlation coefficient $r = 0.29$. Though the correlation is statistically significant we find that the value of A is not consistent, at 95% confidence level, with the value $A = 5.0$ expected if the redshifts of these QSOs are cosmological in nature. Thus, though we known that this sample of 21 QSOs lie at the cosmological distances implied by their redshifts yet their Hubble diagram would lead us to the erroneous conclusion that their redshifts are not cosmological in nature ! Such a situation arises because the QSO sample, being magnitude limited, suffers from the well-known Malmquist bias (Fig.1). To minimise the effect of this bias we should consider only the brighter QSOs at each redshift. One way to obtain such a sub-set of the sample (Kembhavi & Kulkarni 1977) is to consider only those QSOs which lie to the brighter side of the best-fit line $m_v = 5 \log (cz) - 8.17$. We then obtain a sub-set of only 9 QSOs brighter than the limiting magnitude $m_v = 18.01$ for the sample. For this sample we find that $A = 3..25 \pm 1.82$ and $r = 0.56$. The value of A is now consistent, at 95% confidence level, with the value 5.0 expected if their redshifts are cosmological. Further, the correlation between m_v and log (cz) improves considerably and is statistically significant at 99% confidence level.

3. Conclusion

We thus conclude that the Hubble diagram for the QSOs, though a scatter diagram, can be used to test the cosmological nature of the redshifts of the QSOs provided Malmquist bias is properly taken into account. Our study clearly shows that if Malmquist bias is not taken into account then the Hubble diagram of even those QSOs whose redshifts are already known to be cosmological would lead us to the erroneous conclusion that the redshifts of such QSOs are not cosmological in nature !

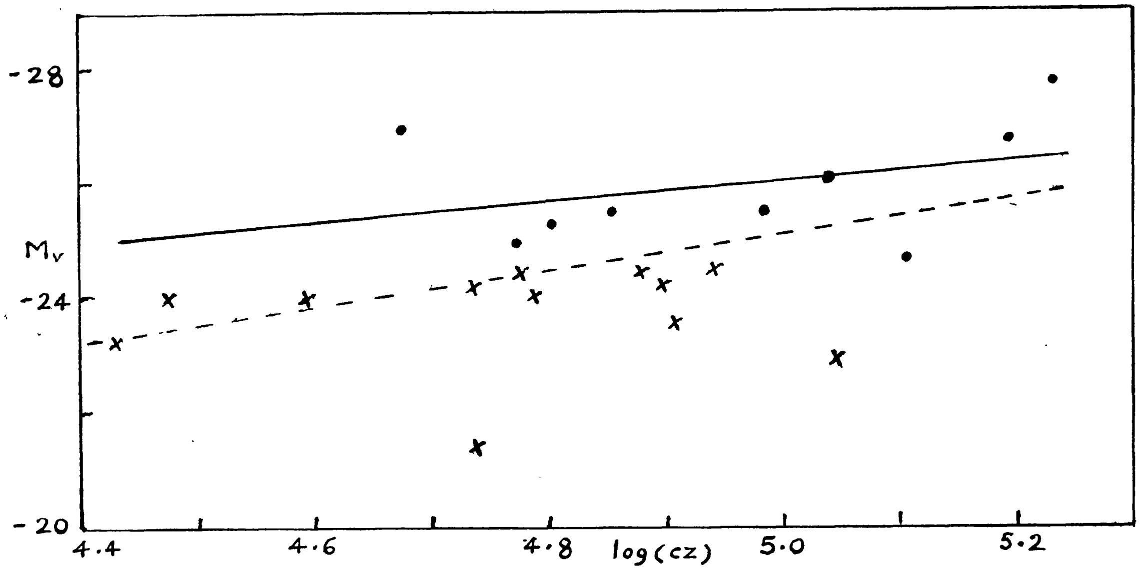

FIG. 1.

Figure 1. Plot of absolute magnitude against log (cz) for the sample of 21 QSOs lying close to galaxies with similar redshifts (shown by crosses and filled circles). Presence of Malmquist bias (decrease in absolute magnitude with increase in redshift) is clearly seen. Filled circles represent a sub-sample of the brightest 9 QSOs left after minimising the effects of Malmquist bias (see text).

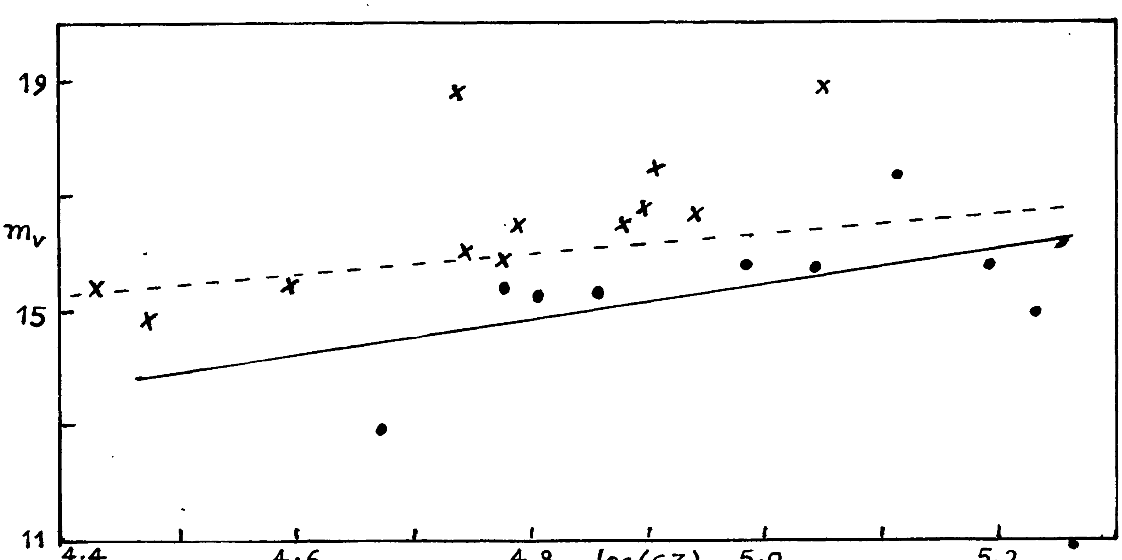

FIG. 2.

Figure 2. The Hubble diagram for the sample of 21 QSOs of Fig. 1. The dotted line is the best-fit line $m_v = 1.81 \log (cz) + 7.31$ for the data whereas the continuous line $m_v = 3.25 \log (cz) - 0.76$ represents the best-fit line for the sub-sample of the brightest 9 QSOs left after minimising the effects of Malmquist bias (see text).

Table 1. A sample of 21 QSOs lying close to galaxies with similar redshifts.

Coordinates of QSOs	Redshift Z	Apparent Magnitude m_v	Log (cz)	Corrected m_v	Absolute magnitude m_v**	Angular/ projected separation θ"/kpc
0147 + 089	0.27	17.40	4.908	17.51	- 23.535	4/28
0154 + 316	0.373	18.90	5.049	18.88	- 22.870	4/42
0405 – 123	0.574	14.82	5.236	14.98*	- 27.705	13/188
0804 + 761	0.100	15.15	4.479	14.90	- 23.990	24/70
0837 – 120	0.198	15.76	4.773	15.43*	- 24.940	10/52
0947 + 396	0.206	16.40	4.791	16.45	- 24.010	8/48
1012 + 008	0.185	16.00	4.744	16.01	- 24.215	3/12
0235 + 164	0.524	15.50	5.196	15.71*	- 26.775	2/30
0007 + 106	0.089	15.40	4.426	15.45	- 23.185	50/124
0210 + 860	0.184	19.00	4.742	18.79	- 21.425	12/3
1004 + 130	0.241	15.15	4.857	15.26*	- 25.530	34/237
1128 + 315	0.289	16.60	4.938	16.74	- 24.455	7/59
1512 + 376	0.371	15.50	5.046	15.67*	- 26.065	75/345
1525 + 227	0.253	16.39	4.880	16.51	- 24.395	33/240
1548 + 114	0.436	17.23	5.116	17.39*	- 24.695	9/113
2135 = 147	0.200	15.91	4.778	15.95	- 24.445	6/35
2141 + 175	0.213	15.50	4.805	15.33*	- 25.200	38/221
2251 + 113	0.323	15.77	4.986	15.90*	- 25.535	28/260
1226 + 023	0.158	12.86	4.675	12.94*	- 26.940	75/345
1545 + 210	0.264	16.69	4.898	16.82	- 24.175	370/2906
1612 + 262	0.131	15.41	4.594	15.44	- 24.035	210/764

** For Friedmann model with $q_0 = +1$ and $H_0 = 50$ kms^{-1} Mpc^{-1}

* 9 Brighter QSOs left after minimising the effects of Malmquist bias (see text).

References

Burbidge G., Narlikar J.V., Hevitt A., Das Gupta P., 1990, ApJS, 74, 675.

Kembhavi A.K., Kulkarni V.K., 1977, MNRAS, 181, 19 P.