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ON THE ORIGIN OF THE ABSORPTION SPECTRA OF QUASI-STELLAR AND BL LACERTAE OBJECTS

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ABSTRACT

Following a paper by Burbidge *et al.* (BORS), the authors reexamine the possibility that multiple absorption spectra of QSOs are due to gas in the disks, coronae, or halos of intervening galaxies. Using the same catalog and parameters as the previous authors did but assuming $\Lambda \approx \Lambda_c$ instead of $\Lambda = 0$ (as they did), we find that the discrepancy of several orders of magnitude between the predicted and observed multiplicities reported by BORS is drastically reduced and that the observed multiplicity distribution is theoretically obtainable. The intervening galaxy hypothesis cannot be rejected on the basis of this test.

Subject headings: BL Lacertae objects — cosmology — galaxies: structure — quasars

In a paper with the same title as this one, Burbidge *et al.* (1977, hereafter BORS), using the 1976 optical catalog of quasi-stellar objects (Burbidge, Crowne, and Smith 1977), have calculated the number of sources N expected to exhibit n redshift systems in their absorption spectra, assuming that absorption occurs every time the radiation on its way to the observer passes through a galactic disk, corona, or halo of a uniform distribution of galaxies. With the cosmological constant Λ equal to zero they found that the theoretical predictions are below the data (for $n \geq 2$) and by several orders of magnitude (for $n \geq 4$). The authors interpret their results as a clear indication that multiple absorptions cannot in general be ascribed to intervening galaxies.

We cannot concur with the uniqueness of such a conclusion: One can alternatively infer that the cosmological model employed was the culprit. Choosing $\Lambda = 0$ does not allow a particularly long travel time for light to encounter many galaxies. Using the same densities per Mpc^3 at $z = 0$ and the same QSO catalog as BORS did, the theoretical prediction can be greatly improved by taking $\Lambda \neq 0$ and, in particular, $\Lambda \approx \Lambda_c$, corresponding to the Lemaître or "dachshund" model characterized by a long coasting period during which time light travels in an almost unexpanding, constant-density universe, thereby having an increased chance of being absorbed. When $\Lambda \approx \Lambda_c$, the results are compatible with the data even at $n = 6$, where the BORS values are several orders of magnitude too small. In particular, our computations suggest two interesting features: (1) a minimum at $n = 5$–13 (depending on the particular model), while the data have minima at $n = 4$ and $n = 7$–11, and (2) a maximum at $n = 11$–16, while there is an isolated observation at $n = 12$.

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The details of the calculation are as follows:

The expected number of objects showing n redshift systems is (BORS)

$$N(n) = \sum_{i=1}^{637} \frac{\mu_i^{\,n} \exp(-\mu_i)}{n!}\,, \tag{1}$$

where the summation is over all sources in the catalog. With $\Lambda \neq 0$, the expression for μ_i,

$$\mu_i = X \int_0^{z_i} \frac{(1+z')^2 dz'}{[(1+z')^2(1+2\sigma_0 z') - (2+z')(\sigma_0 - q_0)z']^{1/2}}\,, \tag{2}$$

was integrated numerically from $z' = 0$ to the source emission redshift z_i. Here $X = D/l_0$ (Hubble radius divided by mean free path) is given the same values as in BORS, to wit, 0.025, 0.16, and 1 for galactic disks, coronae, and halos, respectively.

Once we have chosen a value for σ_0, the value of q_0 is obtained by solving the following relation:

$$\frac{\Lambda}{\Lambda_c} = \frac{27\sigma_0^2(\sigma_0 - q_0)}{(3\sigma_0 - q_0 - 1)^3} = 1 + \epsilon\,, \tag{3}$$

where ϵ is a free parameter.

Without any preconceived opinion about the value of ϵ, we computed several cases corresponding to $\epsilon < 0$, $\epsilon \approx 0$, and $\epsilon \geq 1$. Of all the results so obtained, only those corresponding to $0 < \epsilon \ll 1$ are acceptable. In Table 1 we present the detailed results for $\Lambda/\Lambda_c \approx 1$ and $\Lambda/\Lambda_c = 2$, as well as the BORS $\Lambda = 0$ case for halo, corona, and disk. For $n = 6$, the $\epsilon = 10^{-5}$ case predicts (for the most likely disk case) an $N(n)$ that is

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TABLE 1

EXPECTED NUMBER OF OBJECTS SHOWING *n* REDSHIFT SYSTEMS

		$\Lambda \approx \Lambda_c$	$\Lambda = 2\Lambda_c$	$\Lambda = 0$
σ_0		.05	.05	0
q_0		-1.299998	-1.197926	0
ϵ		10^{-5}	1	-1
D/ℓ_0	n	N(n)	N(n)	N(n)
0.025				
	1	.6848E+02	.6249E+02	.3109E+02
	2	.3221E+02	.7187E+01	.1333E+01
	3	.2481E+02	.7431E+00	.4930E-01
	4	.1851E+02	.6886E-01	.1618E-02
	5	.1192E+02	.5829E-02	.4843E-04
	6	.6606E+01	.4559E-03	.1343E-05
	7	.3199E+01	.3306E-04	.3472E-07
	8	.1376E+01	.2226E-05	.8381E-09
	9	.5332E+00	.1394E-06	.1890E-10
	10	.1881E+00	.8133E-08	.3981E-12
	11	.6098E-01	.4434E-09	.7849E-14
	12	.1830E-01	.2264E-10	.1450E-15
	13	.5120E-02	.1086E-11	.2517E-17
	14	.1342E-02	.4905E-13	.4112E-19
	15	.3308E-03	.2091E-14	.6336E-21
	16	.7708E-04	.8436E-16	.9230E-23
	17	.1703E-04	.3226E-17	.1274E-24
	18	.3577E-05	.1172E-18	.1670E-26
	19	.7164E-06	.4056E-20	.2082E-28
	T =	421.7	79.4	33.8
0.160				
	1	.1031E+03	.1456E+03	.1291E+03
	2	.4466E+02	.7008E+02	.3094E+02
	3	.2456E+02	.3394E+02	.6578E+01
	4	.1561E+02	.1534E+02	.1254E+01
	5	.1067E+02	.6460E+01	.2194E+00
	6	.7522E+01	.2575E+01	.3589E-01
	7	.5417E+01	.9815E+00	.5538E-02
	8	.4031E+01	.3589E+00	.8079E-03
	9	.3185E+01	.1257E+00	.1113E-03
	10	.2762E+01	.4202E+01	.1447E-04
	11	.2681E+01	.1338E-01	.1773E-05
	12	.2891E+01	.4054E-02	.2048E-06
	13	.3347E+01	.1169E-02	.2232E-07
	14	.3997E+01	.3207E-03	.2299E-08
	15	.4775E+01	.8383E-04	.2241E-09
	16	.5596E+01	.2089E-04	.2069E-10
	17	.6368E+01	.4967E-05	.1814E-11
	18	.7003E+01	.1128E-05	.1512E-12
	19	.7431E+01	.2449E-06	.1201E-13
	T =	2699.0	508.1	216
1.000				
	1	.8891E+02	.9671E+02	.1412E+03
	2	.5908E+02	.6702+02	.1001E+03
	3	.4128E+02	.4938E+02	.7203E+02
	4	.3038E+02	.3888E+02	.5142E+02
	5	.2343E+02	.3251E+02	.3528E+02
	6	.1881E+02	.2856E+02	.2297E+02
	7	.1551E+02	.2599E+02	.1422E+02
	8	.1293E+02	.2405E+02	.8455E+01
	9	.1078E+02	.2224E+02	.4884E+01
	10	.8996E+01	.2027E+02	.2766E+01
	11	.7567E+01	.1804E+02	.1543E+01
	12	.6489E+01	.1561E+02	.8480E+00
	13	.5719E+01	.1314E+02	.4582E+00
	14	.5186E+01	.1081E+02	.2425E+00
	15	.4809E+01	.8742E+01	.1253E+00
	16	.4518E+01	.7002E+01	.6310E-01
	17	.4262E+01	.5595E+01	.3087E-01
	18	.4011E+01	.4484E+01	.1465E-01
	19	.3756E+01	.3615E+01	.6735E-02
	T =	16867.9	3176.1	1352

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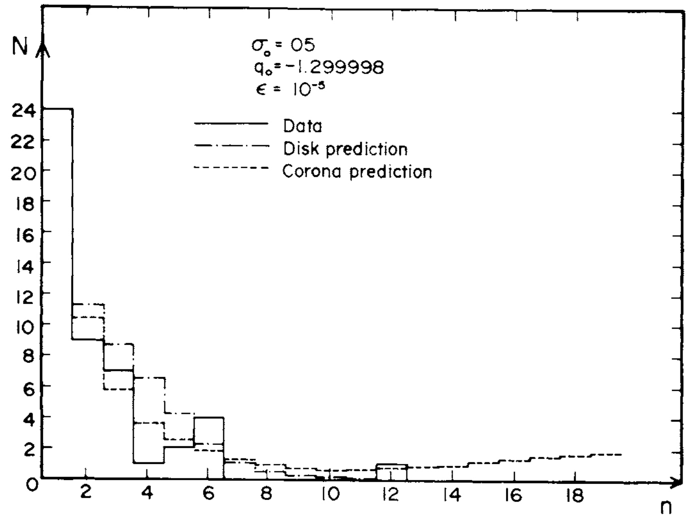

FIG. 1.—Number of sources N out of 637 observed manifesting n absorption redshift systems, normalized to $N(1) = 24$

10^6 times larger than the BORS predictions. Even though the $\epsilon = 1$ case does better than the $\Lambda = 0$ case, the resulting $N(n = 6)$ is still far below the data. In Figure 1 we present $N(n)$ versus n for $\epsilon = 10^{-5}$ and see that the overall fit is satisfactory, and more data analysis is expected to increase the experimental $N(n)$, as already noted by BORS. Detailed features such as the position and width of the minimum and maximum can be modified by a judicious choice of q_0 and σ_0, with only slight changes in ϵ.

The total number of intersected galaxies

$$T = \sum_{i=1}^{637} \mu_i$$

is also given in Table 1 and is seen to be much larger than the BORS results. When nonzero Λ values not near Λ_c were used, the values of T were of the same order as those of BORS.

It is also instructive to display the data differently, by plotting the distribution of absorption redshifts $N(z_{\rm abs})$. In Figure 2 we present such a plot for $\Lambda/\Lambda_c =$ 0, 2, 1.006, and 1.0006. The superiority of the two cases near 1 is evident; while the fit is not perfect, neither are the data complete nor is the membership of all 136 entities of the sample in the same species assured. The two cases near 1 illustrate how a small variation of parameters within the Lemaître class can be used to adjust predictions for a more detailed fit when a better sample is available.

A Lemaître model would also predict that the absorption redshifts (instead of having a fairly flat distribution for $z < z_{\rm em}$, as calculated by Weymann *et al.* 1977 for a limited sample in an Einstein–de Sitter $q_0 = \frac{1}{2}$ universe) would tend to be close to the emission redshifts. This is indeed observed (J. Perry 1977, private communication).

Since we have found that a discrepancy of a factor of more than a million between the data and the $\Lambda = 0$ cosmology is resolved if we adopt $\epsilon \ll 1$, corresponding to the Lemaître model, it is appropriate to inquire how the same model fares with respect to other tests. The most comprehensive reviews have been presented by Petrosian (1974) and Gunn and Tinsley (1975). Tinsley has emphasized the possible existence of age problems since $H_0 t_0 > 1$. All models at some point

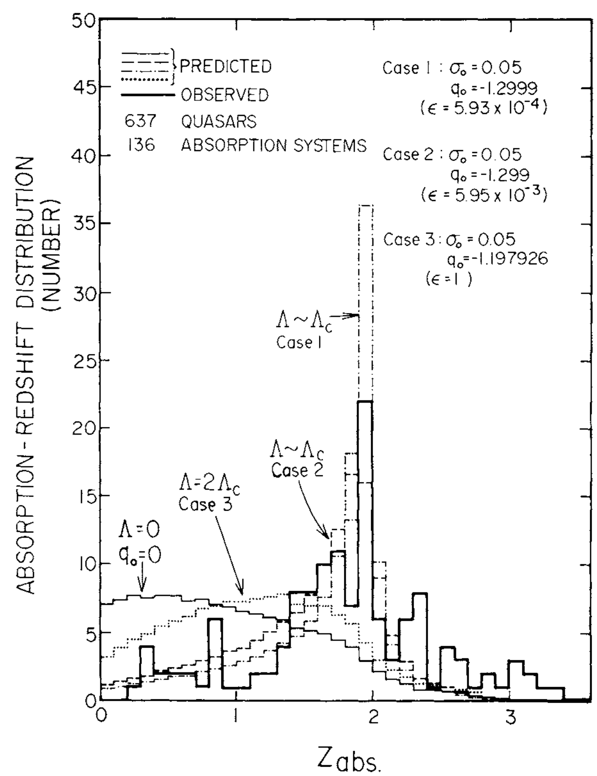

FIG. 2.—Number of quasars manifesting a redshift system $z_{\rm abs}$. Area under each curve is normalized to 136.

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require the choosing of particular parameters (radio luminosity function and α) or evolutionary models. We should not for this reason reject the Lemaître models and not others. Especially as a nonzero Λ is gaining wider acceptance, there should have to be particular reasons for objecting to particular values near Λ_c and even stronger arguments for throwing out the intervening galaxy explanation of absorption redshifts whose success or failure is so model-dependent.

We are very grateful to Drs. G. Burbidge and S. O'Dell for pointing out the advantages of the $N(z_{\rm abs})$ graph and for their provocative comments; we also thank Dr. V. Petrosian, with whom we discussed the present status of the Lemaître tests.

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