SPACE DISTRIBUTION OF QUASARS BASED ON OPTICALLY SELECTED SAMPLES

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Even though the number of known quasars is approaching 2000, relatively few belong to well defined complete samples which are needed to derive their space distribution. For many years, the Braccesi survey (Braccesi, Formiggini, and Gandolfi 1970) was the only published one – its limited spectroscopic coverage allowed construction of only a small complete sample of 19 quasars brighter than B = 18, over an area of 36 sq. deg.

A large-scale search for bright quasars was started in 1972. This survey for ultraviolet-excess stellar objects covers some 10,700 sq. deg. and is aimed to be complete, on the average, to B = 16.2. We undertook spectroscopic observations of all objects and produced a sample of over 100 quasars with redshifts and magnitudes that constitute the Palomar Bright Quasar Survey. We have used the results of this Survey, together with the Braccesi sample, two objective-prism quasar surveys discussed by Osmer and Smith (1980) and Osmer (1980), and a small, deep sample in SA 57 (Kron and Chiu 1981) to study the space distribution and optical luminosity function of quasars. This study will soon be submitted for publication, and we will summarize here some of the main results.

1. QUASAR DISTANCE SCALE

The slope of the cumulative counts with magnitude is very steep: d log N/dB = 0.93±0.06, or in the radio equivalent: d log N/d log S = -2.3±0.15. These slopes are significantly steeper than those (0.60, and -1.5, respectively) corresponding to a uniform distribution in Euclidean space. Hence, if quasars were local (and their redshifts non-cosmological) their space density would have to increase with distance (approximately as $r^{1.6}$).

In this case, we would be located in a unique position in the universe, namely in the central deep density minimum of the quasar cloud – a conclusion to be rejected on Copernican grounds. This argument only breaks down if quasar distances are so large that their travel time is a substantial fraction of the age of the universe.

D. S. Heeschen and C. M. Wade (eds.), Extragalactic Radio Sources, 437–440.

https://doi.org/10.1017/S0074180900028370 Published online by Cambridge University Press

This is precisely the distance scale corresponding to the cosmological interpretation of the redshifts.

Since the arguments given above are statistical in nature, we cannot use them to assert that every quasar must have a cosmological redshift. It may be shown that up to 2% of quasars at magnitude B = 20 can be local without violating the above arguments.

2. LUMINOSITY EVOLUTION

Pure luminosity evolution of quasars has been discussed recently by Mathez, by Braccesi and others. In this case it is assumed that the luminosity function of quasars at all cosmic epochs is the same, except for a time-dependent shift in luminosity. As a consequence, the total number of quasars is the same at all times.

We find that the observed number of quasars in the various surveys at redshifts less than around 2 can be well fitted by a shift in absolute magnitude $\Delta M_B = 7\tau$ mag. ($q_o = 0$), or $\Delta M_B = 5.5\tau$ mag. ($q_o = 1/2$), where τ is the light travel time expressed as a fraction of the age of the universe. It should be noted that this fit is achieved only if we assume that the nuclei of Seyfert galaxies are also subject to this luminosity evolution and hence, at larger redshifts, are all identified as quasars.

At redshifts larger than 2, however, the luminosity evolution models predict too few quasars. In particular, the $q_o = 1/2$ luminosity evolution model predicts only one third of the observed number of quasars brighter than B = 19.5 with redshifts in the range 1.8-3.1.

If luminosity evolution represents the evolution of individual objects all born at an early cosmic epoch, then their total radiated energy will be 10^{63}-10^{64} ergs. This excessive energy requirement is alleviated if quasars live less than 10^{10} years. If this is the case, then luminosity evolution does not represent the evolution of the luminosity of each individual object, but instead the statistical result of the births, light history and deaths of quasars on the luminosity function. In this case, there is no obvious reason why the luminosity function should have the same shape at all epochs and we discuss in the next section evolution models where this requirement is relinquished.

3. LUMINOSITY-DEPENDENT DENSITY EVOLUTION

The mean V/V_{max} of quasars in the Palomar Bright Quasar Survey shows a strong dependence on absolute optical luminosity. For quasars of highest luminosity it is close to 0.8, while for those of lowest luminosity it is not much larger than 0.5. This suggests that the increase in space density toward larger redshifts is luminosity dependent. This is confirmed by detailed comparison of the observed numbers in the different complete samples, as a function of absolute magnitude. Assuming that the space density in co-moving coordinates varies as $\exp(k\tau)$, we find that k is as large as 30 for the highest luminosities, and less than 10 for the lower luminosities.

For a tentative model based on $q_o = 0$ and $H_o = 100$ km s^{-1} Mpc^{-1} we find the following results. The space density of quasars rises from 360 Gpc^{-3} at z = 0 to 30,000 Gpc^{-3} at z = 3. The space density of Seyfert nuclei, which we assume not to evolve, is around 13,000 Gpc^{-3}. The model predicts that there should be some 20 quasars brighter than B = 20.5 with z = 3.7 - 4.7 in an area of 5 sq. deg. Osmer (1981) found none in a survey designed to detect such quasars, suggesting strongly that there is a significant deficiency of quasars with such redshifts. This may reflect the turn-on time of the earliest quasars, or the effect of dust as suggested by Ostriker and Cowie (1981).

The total number of quasars ever formed can be derived once an assumption is made about the lifetime of quasars. Assuming that the lifetime is inversely proportional to the quasar luminosity, we find a space density of dead quasars of $10^{-3}\left(\frac{10^{61}\text{ergs}}{E_{rad}}\right)$ Mpc^{-3} where E_{rad} is the total energy radiated by a quasar during its lifetime. Depending on E_{rad} it seems that the space density of dead quasars could be a substantial fraction of that of galaxies.

The apparent birth rate of quasars out to a redshift of 3.4 is $10^{-1}\left(\frac{10^{61}\text{ergs}}{E_{rad}}\right)$ yr^{-1}. If the birth of a quasar is signaled by a gravitational collapse, then the detection of such an event within a century, would require $E_{rad} < 10^{62}$ ergs.

This research was supported in part by the National Science Foundation under grant AST 77-22615.

REFERENCES

Braccesi, A., Formiggini, L., and Gandolfi, E.: 1970, Astron. Astrophys. 5, pp. 264-279.
Kron, R. G., and Chiu, L. G.: 1981, preprint.
Osmer, P. S.: 1980, Astrophys. J. Suppl., 42, pp. 523-540.
Osmer, P. S.: 1981, preprint.
Osmer, P. S., and Smith, M. G.: 1980, Astrophys. J. Suppl., 42, pp. 333-349.
Ostriker, J. P., and Cowie, L. L.: 1981, Astrophys. J. (Letters) 243, pp. L127-131.

DISCUSSION

SHAPIRO: The absence of quasars with z > 3.5 found by Osmer in his search for redshifted Ly-α emission lines may be the effect of Ly-α absorption by intergalactic neutral hydrogen. The absence of such absorption in the spectra of quasars with z < 3.5 then requires that the H atoms be ionized by roughly this redshift. In order to explain the absence of partially absorbed quasars in the redshift range corresponding to the transition of the absorbing gas from neutral to ionized, it may be necessary that the space distribution of absorbing gas be patchy on large scales during this epoch (V. Trimble, private communication). Since the absorbing gas is likely to be transparent to X-rays, at least those above a few keV, these high z Ly-α-obscured quasars may be identifiable as X-ray sources whose optical spectra show intergalactic absorption troughs.

BARNOTHY: Do you think that the space distribution of quasars and the possibility of quasar evolution would be affected if a significant percentage of quasars were gravitational lens intensified nuclei of Seyfert galaxies? (J. M. Barnothy 1965, A. J. 70, 666). Due to the circumstance that not only the number of objects, but also the number of potential gravitational lenses, and the intensification through the lens increases with increasing distance of the object, the number of lensed quasars should, in a first approximation, increase as the fifth power of z, and simulate a rapid increase in the number of observable quasars per unit volume. (J. M. Barnothy, 1966, Observatory 86, 115). The V/V_m ratio is about the same for a luminosity evolution, or gravitational lens without evolution. (J. M. Barnothy 1975 Ap. J. 201, 287). A further modification in the explanation of quasar distribution could occur, should the universe correspond to the modified static solution of the Friedmann equations, in which latter the luminosity distance has the form sin ln (1+z). (J. M. Barnothy, IAU Symp. No. 44).

SCHMIDT: J. Ostriker (private communication) has stated that lensing of quasars would yield a quasar luminosity function proportional to L^{-3} dL at the bright end. Observations show $L^{-3.5}$ dL or L^{-4} dL, suggesting that lensing has no major effect on the luminosity function. An independent argument is provided by the space density increase of steep radio spectrum 3CR quasars, which can be derived from radio statistical evidence only. In this case, most of the radio sources are so large that they should be little affected by galaxies acting as gravitational lenses.

TERRELL: It seems to me that your lnN-lnS argument against local quasars clearly does not apply to very local quasars, ejected by our own galaxy.

SCHMIDT: You are entirely correct. Since the ejection you postulate is precisely centered on our own galaxy, no Copernican arguments can be used in this case.