SPECTRAL SHIFTS IN QUASISTELLAR OBJECTS

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ABSTRACT

The hypothesis that Quasistellar Objects have been ejected with relativistic velocities from many comparatively nearby galaxies is considered. The expected frequency distribution of blueshifts and redshifts is calculated. If all members of a given group of objects with similar velocities could be observed, redshifts would be more numerous than blueshifts, but because the blueshifted objects are much brighter, they can be seen at much larger distances. If the groups are created at random through a Euclidean portion of space and a sample brighter than some limiting magnitude is examined, blueshifts should be far more numerous than redshifts. This appears contrary to observation.

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Terrell (1964), Burbidge and Hoyle (1966) and Arp (1966) have considered that the Quasistellar Objects (QSO) may not be at cosmological distances. In the first two papers this possibility is taken to imply that the redshifts are Doppler shifts associated with large velocities. Also in Arp's picture this interpretation seems difficult to avoid, since gravitational redshifts can be definitely ruled out because the forbidden line emission in these objects requires large volumes. No strong enough gravitational field can prevail in such large volumes (Greenstein and Schmidt, 1964). Terrell considered that all QSO had been ejected from our galaxy and thus no blueshifts would occur. This leads to difficulties with the total mass and energy involved (Setti and Woltjer, 1966). Thus it might be more likely with a local theory that many galaxies would have ejected QSO; this is of course explicitly suggested by Arp. In this paper we discuss the relative frequencies of redshifts and blueshifts to be expected within this kind of theory.

Let us suppose that we observe an isotropic explosion in which a large number of objects are ejected, all with the same speed $|\underset{\sim}{V}|$. If the angle between the line of sight and $\underset{\sim}{V}$ for an object is θ (in our reference frame) the relation between the frequencies ν of radiation observed by us and ν_0 of radiation emitted in the reference frame of the object is (Jackson, 1962)

$$\frac{1}{z+1} = \frac{1}{\zeta} = \frac{\nu}{\nu_0} = \frac{(1-\beta^2)^{1/2}}{1-\beta\cos\theta} \qquad (1)$$

where $\beta = V/c$, $z = \Delta\lambda/\lambda_0$, ζ is as defined, and $\theta = 0$ has been taken to correspond to approach. Since the explosion is isotropic $N(\theta)$, the number of objects ejected per unit interval in θ is $\frac{1}{2} N_0 \sin\theta \, d\theta$, with N_0 the total number of objects. For the distribution in ζ we then have

$$N(\zeta) = N(\theta)\frac{d\theta}{d\zeta} = \frac{1}{2} N_0 \frac{(1-\beta^2)^{1/2}}{\beta} \qquad (2)$$

for $\frac{1}{\rho} < \zeta < \rho$

with

$$\rho = \left(\frac{1+\beta}{1-\beta}\right)^{1/2}.$$

and $N(\zeta) = 0$ outside the stated interval for ζ. Thus <u>if</u> all objects are observed, more red-shifted than blue-shifted objects are found. If the QSO observed with $\zeta = 3.1$ correspond to the maximum ζ, about four times more red-shifted than blue-shifted objects would be found. If not all objects have the same velocity V, but if isotropy is maintained, we still have $N(\zeta) = N(\zeta^{-1})$ and the redshifts predominate since they extend over a larger interval in ζ.

Modifications are needed, however, when the lifetimes of the objects are taken into account. If the intrinsic lifetime of the objects is T_0, then the observed lifetime will be $T_0 \zeta$ (Noerdlinger, 1966). Thus the blue-shifted objects have the shortest lives and if we consider the result of one explosive event, equation (2) would overestimate the abundance of blue-shifted objects after enough time had elapsed for some of these to become unobservable.

If, however, we consider the more interesting case, where objects are observed from a large number of explosive events (distributed randomly in time) we clearly have

$$\langle N(\zeta)\rangle = \frac{1}{2} N_0 \frac{(1-\beta^2)^{1/2}}{\beta} \zeta \tag{3}$$

where the brackets indicate the time average and where N_o is now the number of objects produced per interval of time T_o (in our reference frame). The limits ρ and ρ^{-1} are the same as in equation (2). Integrating over the relevant range of ζ we have for the mean numbers R of red-shifted and B of blue-shifted objects

$$\langle R\rangle = \frac{1}{2} N_0 \rho \quad \text{and} \quad \langle B\rangle = \frac{1}{2} N_0 \rho^{-1} \tag{4}$$

the sum of which exceeds N_o because the average observed lifetime exceeds T_o. The mean values of ζ for the two classes of emitters (R and B) are obtained by multiplying equation (3) by ζ, integrating and dividing by the number of objects. We have

$$\langle\zeta\rangle_R = \frac{1-\beta}{3\beta}(\rho^3-1) \quad \text{and} \quad \langle\zeta\rangle_B = \frac{1+\beta}{3\beta}\left(1-\frac{1}{\rho^3}\right) \tag{5}$$

It is interesting to note that in the highly relativistic limit ($\beta \rightarrow 1$, $\rho \rightarrow \infty$) the mean blue shift tends to the value $\frac{2}{3}$, while the mean red shift is asymptotic to

$$(4/3)(1-\beta^2)^{-1/2}$$

The reason for the limit to the mean blue shift is that most of the blue-shifted objects have θ values in a small range near the point of zero redshift, on account of the larger solid angle available there. If all the objects are assumed to have the same velocity and we take $\rho^{-1} = 3.1$ as before, we now expect about ten times as many red shifts as blue shifts.

These results are valid only if all objects are observable during their lifetime. However, if we consider that the objects will be found at different distances and that in practice we can only observe spectral shifts down to some limiting magnitude, further discussion of the expected brightness of the objects is needed. If we assume that the emission of the objects is isotropic in the object's rest frame, the radiative flux emitted at angles between θ_0 and $\theta_0 + d\,\theta_0$ with respect to the velocity vector of the object and per unit frequency interval at frequency ν_0 is given by

$$F_0(\theta_0, \nu_0)\,d\theta_0\,d\nu_0 = \frac{1}{2}\,F_0(\nu_0)\,\sin\theta_0\,d\theta_0\,d\nu_0 \qquad (6)$$

The observer sees the radiation at frequency $\nu = \nu_0/\zeta$ and at an angle θ given by (Jackson, 1962)

$$\tan\theta = \frac{(1-\beta^2)^{1/2}\sin\theta_0}{\beta + \cos\theta_0} \tag{7}$$

Since the energy density per unit frequency interval in an electromagnetic wave transforms as the frequency and since the solid angle into which the radiation is emitted transforms as ν^2, from equations (1) and (7) we have for the flux in the observer's frame (also see Robertson, 1938 and Hoyle, 1962)

$$F(\theta,\nu)\,d\theta\,d\nu = \frac{F_0(\nu\zeta)}{\zeta^3}\sin\theta\,d\theta\,d\nu \tag{8}$$

Thus taking a typical spectrum for a quasistellar object of the form $F_0(\nu_0) = Q_0\,\nu_0^{-\alpha}$ we have

$$F(\theta,\nu) = \tfrac{1}{2}\,Q_0\,\zeta^{-(3+\alpha)}\,\nu^{-\alpha}\sin\theta = \tfrac{1}{2}\,Q\,\nu^{-\alpha}\sin\theta \tag{9}$$

so that the observed flux at some frequency for a set of objects at the same distance with the same intrinsic spectrum varies as $\zeta^{-(3+\alpha)}$. For typical QSO α appears to be near zero or slightly positive and thus the blue-shifted objects should be quite bright. If many explosion centers are now distributed randomly through a locally Euclidean portion of the universe, the brighter objects will be observed from a larger volume if the intrinsic brightness of all objects is the same. Thus if $N(m, \varsigma)$ is the number of objects per unit ς which are brighter than a limiting magnitude m we will have (again with β the same for all objects)

$$N(m,\varsigma) \propto \frac{(1-\beta^2)^{1/2}}{\beta}\, \varsigma^{-\frac{7}{2}-\frac{3}{2}\alpha}\, 10^{0.6m} \tag{10}$$

between the appropriate limits (ρ and ρ^{-1}) of ς. For the ratio of the numbers of blue and red-shifted objects we now have

$$\frac{\langle B\rangle}{\langle R\rangle} = \frac{\rho^{\frac{5}{2}+\frac{3}{2}\alpha}-1}{1-\rho^{-\frac{5}{2}-\frac{3}{2}\alpha}} \tag{11}$$

with $\rho = 3.1$, corresponding to the largest red shifts observed in QSO we have $\langle B\rangle / \langle R\rangle = 16.9$ for $\alpha = 0$, which corresponds to the optical continuum in 3 C 273 and $\langle B\rangle / \langle R\rangle = 39.6$ for $\alpha = 0.5$. This is to be contrasted with the case where all objects are observable when we would have from equation (4) $\langle B\rangle / \langle R\rangle = \rho^{-2} = 0.10$. The brightening of the blue-shifted objects and the relevance of blue-shifted objects to a local theory have been pointed out also by B. Hoffman (1964).

Expression (11) has been derived under the assumption that all objects have the same velocity. If this is not the case, the results would have to be somewhat modified, but the ratio $N(m, \zeta) / N(m, \zeta^{-1})$ would remain unchanged from that found from equation (10). Thus if we take the observed distribution of redshifts for the QSO as observed by Schmidt and others and reported in the literature before the middle of April, 1966, we can calculate the expected distribution of blue shifts. The results are given in Table I.

Insert Table I here

It would appear that the last case considered should represent the situation if the QSO are not associated with our galaxy, but still are located at distances where the cosmological red shift is not yet large. The disagreement with observation is striking already, but can be further enhanced by consideration of the mean red and blue shifts to be expected in this model. The mean values of ζ for the two classes of observable emitters, based on Eq. (10) are now

$$\langle \zeta \rangle_R = A \frac{1 - \rho^{-\frac{3}{2} - \frac{3}{2}\alpha}}{1 - \rho^{-\frac{5}{2} - \frac{3}{2}\alpha}} \quad \text{and} \quad \langle \zeta \rangle_B = A \frac{\rho^{\frac{3}{2} + \frac{3}{2}\alpha} - 1}{\rho^{\frac{5}{2} + \frac{3}{2}\alpha} - 1} \tag{12}$$

where $A = \dfrac{5 + 3\alpha}{3 + 3\alpha}$.

Provided $\alpha > -1$, $\langle \zeta \rangle_B \to 0$ as $\rho \to \infty$ (unbounded mean blueshift) but $\langle \zeta \rangle_R \to A$ as $\rho \to \infty$. Since $\langle \zeta \rangle_R$ <u>never</u> exceeds A (unless $\alpha < -1$) one cannot possibly fit the mean value $\langle \zeta \rangle_R = 1.93$ found from the observed values in Table I unless $\alpha < -.28$. Unless α is rather less than $-.28$, ρ must also be taken very large. Negative values of α do not correspond to observation at all except in the very low frequency radio region ($<$ 100 Mc/s). The relevance of this region will be discussed presently, but for now we may note that if optical observability is the criterion for detection, no fit to the data is possible without the unreasonable assumption that $\alpha < -.3$. This conclusion would hold even if none of the blue-shifted objects were observable!

Before accepting the conclusion that an excessively large number of blue-shifted objects should have been observed among the QSO some possible selection effects must be noted. First of all, most QSO have been found by identification of 3C radio sources. The 3C catalog should be a reasonably complete catalog of the brighter radio sources at 159 Mc/s. Since at low frequencies many QSO show a decrease of flux with decreasing frequency, corresponding to negative α, there would be a tendency to miss some of the blue-shifted objects. It is difficult to estimate the importance of this effect, but we do not think it could be large, since for at least several sources the maximum of the spectrum occurs well below 100 Mc/s. If the effect were large, sources with large blue shifts should be found in great numbers in surveys at higher frequencies. The available data do not seem to indicate this. For example, in a survey at 1421 Mc/s, Kellermann and Read (1965) found 28 sources brighter than 2 flux units, of which 22 had already been included in the 3C catalog. Thus no strong discrimination abainst finding blueshifted objects arises from the radio frequency spectrum. It is conceivable, of course, that some mechanism ascertainable only on the basis of a detailed model could inhibit radio emission in the direction of motion; this would suppress the detection of blueshifted objects, since for large ρ the emitters are redshifted unless seen nearly head on.

A more intriguing possibility is related to the strong infrared emission in 3C273. If the source had a blue shift corresponding to $\rho = 0.5$ it would no longer be a blue object. Since QSO have frequently been discovered by searches for blue objects, this might mean that many blue-shifted objects could have been missed. In this case the assumption $\alpha = 0$ is rather conservative and the number of blueshifted QSO with red appearance should be quite large. It appears unlikely, however, that there are enough unidentified small-diameter radio sources in the 3C catalog for this interpretation to be possible. Thus unless a significant fraction of the red shifts is incorrect -- which appears unlikely*, though not impossible, since many red shifts are based on only two lines -- a generalized local theory appears to encounter difficulties.

Of course, if the blue-shifted objects were so distant that the cosmological red shift were important, the fraction of blue-shifted objects would again be less than indicated in Table I. However, cosmological redshifts should be relatively minor out to 500 Mpc distance or more. Even if only the five QSO identified by Arp as nearby (< 100 Mpc) are taken as our red-shifted sample, the accessible volume for the blue-shifted objects within 500 Mpc would be 100 times

* We have actually attempted to interpret the spectra of 3C9, 3C245, 3C287, and CTA 102 by blueshifting the stronger lines that are observed in the red and infrared in planetaries; although some reasonable fits (with lines of [OII] , [OIII], and [SII] could be obtained, except in 3C9, the absence of some expected lines like H_α makes this interpretation implausible.

as large, and we should expect to see about 50 such objects. In fact, if Arp's proposal is correct, one would expect many of the 23 observed objects in Table I to be within 100 Mpc, bringing the count of blue-shifted objects within 500 Mpc close to the values in the last column. The fit of the theory to the data seems so poor that cosmological effects do not merit further discussion at this time.

As an aside, we remark that the dimming of approaching objects receding at relativistic speeds might conceivably lead to an apparent asymmetry in the ejection of jets in radio sources. For example, in 3C273, if the jet is approaching us an identical jet located symmetrically but receding might be too faint for observation.

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Table 1

Observed redshift frequency distribution for QSO and the predicted frequency distribution for blueshifts, first for the unrealistic case where all objects are observed and then for a fully local theory where sources are observed down to some limiting magnitude in a homogeneous Euclidean portion of the universe.

	n		All Objects Observed	Objects to Limiting Magnitude ($\alpha = 0$)
3.33 - 2.50	7	0.30 - 0.40	0.1	1400
2.50 - 2.00	8	0.40 - 0.50	0.3	450
2.00 - 1.67	5	0.50 - 0.60	0.5	100
1.67 - 1.33	8	0.60 - 0.75	1.6	59
1.33 - 1.00	3	0.75 - 1.00	1.7	6
3.33 - 1.00	31	0.30 - 1.00	4	$\approx$ 2000