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A DOPPLER INTERPRETATION FOR CLOSE PAIRS AND COMPACT GROUPS OF QUASARS

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ABSTRACT

We consider a Doppler model to account for (*a*) abnormal concentration of quasars in a given part of the sky and (*b*) the presence of two quasars with very nearly equal redshifts lying close to each other. The ejection parameters are explicitly determined and are shown to be reasonable for the nine quasars in the 1146+111 field. This example illustrates both (*a*) and (*b*). It is suggested that these calculations be carried out for quasars usually believed to be gravitationally lensed, as well as to other fields containing anomalously high concentration of quasars.

Subject heading: quasars

I. INTRODUCTION

Although most astronomers and astrophysicists take it for granted that the redshifts of quasars are of cosmological origin, there are grounds for doubting the universality of this assumption. Data showing apparent discrepancies with the cosmological hypothesis have accumulated over the years (for a review see Narlikar 1985; Arp 1987). Our purpose here is not to comment on the current controversy about quasar distances but simply to explore a noncosmological alternative further. We believe that in the light of such anomalies, a discussion of possible alternatives to the cosmological hypothesis is not only possible but necessary as well.

The hypothesis we wish to consider is the Doppler one, assuming that quasars are ejected at high speeds ($v \lesssim c$) from galaxies and that most quasars observed today have been ejected within a distance of ~ 100 Mpc. Kinematic applications of the Doppler effect to the anomalously redshifted triplets of quasars discovered by Arp and Hazard (1980) have been discussed in earlier papers (Narlikar and Edmunds 1981; Narlikar and Subramanian 1982). The observed lack of blueshifts in a Doppler model can be explained on the assumption that quasars preferentially emit their radiation backward as they travel through space (Strittmatter 1967; Hoyle 1980). An astrophysically viable model for such backward emission has also been given by Narlikar and Subramanian (1983).

A particular application of the Doppler ejection hypothesis could be to a quasar field containing an abnormally high concentration of quasars. Galaxies found in the field with low redshifts may be considered as prime candidates for ejection centers. Arp (1987) has already suggested several such examples. In the framework of the cosmological hypothesis it would be hard to understand (except as rather implausible chance coincidences) why low-redshift galaxies should be found near high-redshift quasars or why quasars of different redshifts should congregate together.

One of the arguments cited in favor of the cosmological hypothesis involves gravitational lensing. It is argued that quasar pairs like 0957+561A, B are two images of a single object lensed by an intervening mass distribution. Because the latter has a substantially large redshift (but less than that of the quasar) and is known unambiguously to be at a cosmological distance, so, it is argued, must be the lensed quasar.

While this interpretation is consistent with the cosmological hypothesis, it does not necessarily warrant it. The predicted time delays between the different light routes are only too greatly subject to model-dependent parameters and the vagaries of Hubble's constant to give an unambiguous proof of the lens hypothesis. On the other hand, there are certain difficulties with the simple lensing models that call for epicyclic assumptions or parameters. For example, in most cases an even number of images is observed, whereas the general theory of lensing predicts an odd number (see Subramanian and Cowling 1986). The lensing agents are not always easy to identify, and in most cases the (admittedly *a posteriori*) probability for the configuration turns out to be very small.

Where detailed structures are known, they have posed further problems for lensing models. For example, the VLA map of 0957+561A, B (Greenfield and Burke 1980) shows a curious and as yet unexplained feature first pointed out by Hoyle (private communication). The hot spots in radio lobes D and E are exactly aligned across the quasar image A. Such alignment is not expected in an image field that has been distorted by gravitational lensing.

It is therefore not inconsistent with the data to argue that some close quasar pairs with nearly identical redshifts are physically different objects. Indeed, such a conclusion was ultimately forced on the quasar pair in the region 1146+111. In this case the observed similarity of the spectra had initially led to the hypothesis that they were a lensed pair. The lensing mass required was very large ($\sim 10^{15}\ M_\odot$) in order to arrive at the observed separation of 157″. However, the view generally accepted at present is that these are two different quasars belonging to the same supercluster (see, e.g., Canizares 1987).

The Doppler model provides a natural explanation for such close pairs with nearly the same redshift. In the Doppler hypothesis it is possible to argue that these were two objects ejected with the same velocity in very close directions, or that a single ejected object split into two bits that remained in close physical neighborhood.

In this paper we explore this idea further and also discuss how the observed positions and redshifts of quasars in a close group can be related to a possible ejecting galaxy in the field. In § II we develop the general kinematical results, while in § III we apply them to the specific quasar field 1146+111. In the concluding section (§ IV) we outline possible ways of testing our hypothesis.

II. THE KINEMATICS OF EJECTION

a) *The Model*

Consider the scenario illustrated in Figure 1 where we have a group of quasars $Q_1, Q_2, \ldots, Q_i, \ldots Q_N$ distributed in a compact group on a photographic plate. Let their respective redshifts be $z_1, z_2 \ldots, z_i, \ldots, z_N$. The plate may also contain some galaxies in the field. In Figure 1 we have selected galaxy G as a possible center of ejection. Let $\theta_1, \theta_2, \ldots, \theta_N$ be the angular separations of G from $Q_1, Q_2, \ldots, Q_N$, respectively, as viewed from Earth. In view of our interest in close pairs, we will assume that there is one such pair, (Q_1, Q_2), in this group.

Figure 2 illustrates the scenario as seen by an Earth-bound observer O in the Doppler model. In this model, the typical quasar Q_i is ejected in a direction making an angle ϕ_i with the line of sight from O to G. Let $v_i = c \sin \psi_i$ (ψ_i real) be the speed of ejection of the quasar, where c is the speed of light. If z_G is the (cosmological) redshift of G, then the Doppler shift Z_i of Q_i is given by

$$1 + Z_i = \frac{1 + z_i}{1 + z_G} = \frac{1 + \sin \psi_i \cos \phi_i}{\cos \psi_i} . \tag{1}$$

Let OG = d.

We will assume that all quasars were ejected at the same epoch, which we denote by $t = 0$. The quasar Q_i travels a distance $R_i = v_i t_i$ when its light leaves it in order to be received by the observer O at time $T + d/c$. We will assume that $d \gg R_i$.

Then we get

$$t_i + \frac{v_i t_i \cos \phi_i}{c} = T ,$$

i.e.,

$$t_i(1 + \sin \psi_i \cos \phi_i) = T . \tag{2}$$

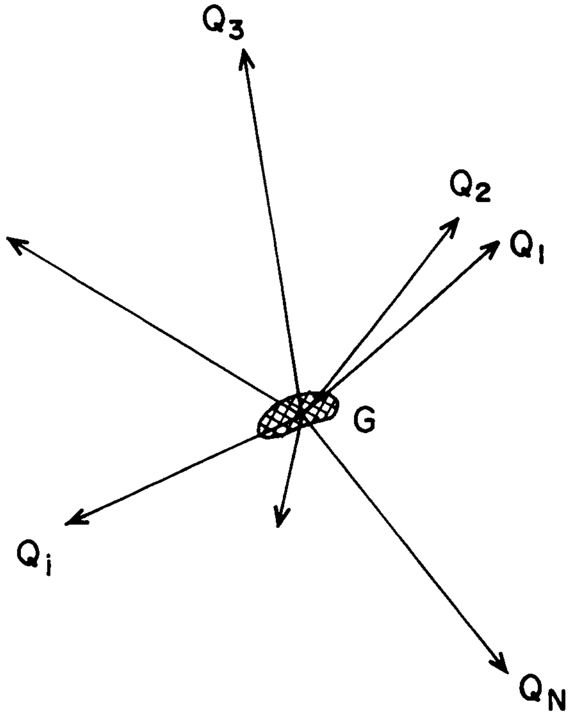

FIG. 1.—Typical quasar concentration $Q_1, Q_2, \ldots, Q_i, \ldots, Q_N$ arising from ejection from a galactic source G

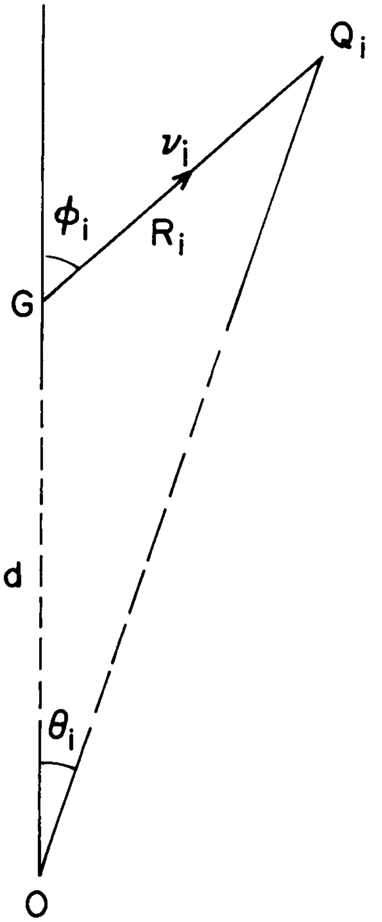

FIG. 2.—Geometry of the ejection scenario as seen by a terrestrial observer O. Here Q_i is a typical quasar ejected from G in an event of the kind illustrated in Fig. 1.

Note that in order to maintain simultaneity of observation of all Q_i by the observer, T has to be independent of i.

The geometry of Figure 1 also gives us the relation

$$\frac{c t_i \sin \psi_i}{d} = \frac{\sin \theta_i}{\sin (\phi_i - \theta_i)} . \tag{3}$$

Each Q_i is accompanied by three unknowns, ψ_i, ϕ_i, and t_i. There are three equations to solve in terms of d, θ_i, Z_i, and T. The parameters are thus fully determined, provided T is known.

b) *The Solution*

We now show that it is possible to determine T, provided the compact group contains a close pair of quasars with very nearly the same redshift. We will identify such a pair by Q_1, Q_2. Thus we have $\psi_1 = \psi_2$. In a Doppler model a pair of this kind might easily arise if a single ejected object broke up into two parts which continue moving with nearly the same speed.

The above six equations for the two quasars Q_1, Q_2 then contain just enough information to be able to determine the six unknowns $\phi_1, \phi_2, t_1, t_2, \psi_1 (= \psi_2)$ and T.

We illustrate how, using the above assumption for the close pair (Q_1, Q_2), these equations can be solved for T analytically.

Let us assume that the redshift of G, z_G, is small compared to unity so that we can use the linear Hubble law to write $d = c z_G / H$, where H is Hubble's constant. In practice, unless

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the quasars are beamed away from the observer, $\phi_i \gg \theta_i$. Thus, dropping the suffix $i = 1$ for Q_1, we transform equations (1)–(3) to eliminate t and write

$$1 + Z = \sec \psi + \tan \psi \cos \phi \,, \tag{4}$$

$$\frac{z_G(1 + Z)\theta}{HT} = \sin \phi \tan \psi \,. \tag{5}$$

Here we have used $\sin \theta \approx \theta$. Eliminating ϕ, we then get

$$\sec \psi = \frac{1}{2}\left(1 + Z + \frac{1}{1 + Z}\right) + \frac{1}{2}\left(\frac{z_G \theta}{HT}\right)^2 (1 + Z) \,. \tag{6}$$

Suppose that for Q_2 the corresponding values are $Z + \Delta Z$, $\theta + \Delta\theta$, respectively, while ψ is the same. Differentiation of equation (6) then gives

$$\Delta Z\left[1 - \frac{1}{(1 + Z)^2} + \left(\frac{z_G \theta}{HT}\right)^2\right] + 2(1 + Z)\left(\frac{z_G}{HT}\right)^2 \theta \, \Delta\theta = 0;$$

i.e.,

$$T = H^{-1} z_G \theta (1 + Z)\left\{\frac{-1}{Z(Z + 2)}\left[1 + \frac{2(1 + Z)}{\theta}\frac{\Delta\theta}{\Delta Z}\right]\right\}^{1/2} . \tag{7}$$

Knowing $\Delta\theta$, ΔZ, θ, Z, z_G, and H from observations, T can be calculated.

For the rest of the quasars in the field, T is taken as known, and the three equations (1)–(3) for each quasar can be used to find ψ_i, ϕ_i, and t_i. Note that the position of an ejected quasar at a specific epoch is uniquely determined in terms of the above three variables together with the azimuthal angle ξ_i. Since the azimuthal angle of the quasar is the same at the ejecting galaxy and as it is at the observer, ξ_i is given by

$$\xi_i \simeq \xi_0 + \tan^{-1} \frac{\delta_i - \delta_G}{(\cos \delta_G)(\alpha_i - \alpha_G)} \tag{8}$$

where α_i, α_G are the right ascensions and δ_i, δ_G are the declinations of the quasars and the galaxy, respectively, and ξ_0 is a reference angle.

This problem can be solved numerically. A solution is not always guaranteed, since the condition $v_i < c$ must be satisfied for all ψ_i; thus all ψ_i must be real. If no solution is found, then the Doppler model with the galaxy G as the ejecting source has to be rejected. Thus the model is in principle capable of being tested by the available data.

III. THE 1146+111 FIELD

For the purpose of illustration we consider the quasar field discovered by Arp and Hazard (1980). This has nine quasars in the neighborhood of R.A. = 11^h46^m and $\delta = 11°11'$. Earlier, Hazard, Arp, and Morton (1979) had noticed the presence of four galaxies in the neighborhood, at redshifts 0.080–0.082. We have considered all four galaxies as likely sources. The details of the parameters θ, ϕ, v, T, and ξ are given in the case of the galaxy (see Huchra 1986) at R.A. = $11^h46^m7^s.7$ and $\delta = +11°05'15''$ in Table 1. The reference angle ξ_0 is chosen such that $\xi = 0$ for the first quasar 1146+111A. No consistent model is possible for the other three galaxies in the plate.

Although the redshifts and positions of the quasars are given in the Hewitt-Burbidge catalog (1986), it is preferable to measure the θ_i values directly from the plate given by Arp and Hazard (1980). These are given in Table 1.

Note that the computed values of v_i range from $0.505c$ to $0.854c$, while the ϕ_i values range from 1°45′ to 50°0′. The two quasars with nearly identical redshifts are the ones listed first in the Table 1. They have a separation of $2'.6$ from each other.

The fact that the ϕ_i values range over almost 1 rad and ξ_i values are spread randomly over the range of 0 to 2π tells us that the explosion was over a wide solid angle. Had the solid angle turned out to be small, it would have meant a special situation with respect to the observer, i.e., ejection in a thin solid angle away from the observer. In other words, the probability of a quasar lying in the part of space within the solid angle is ~ 0.2. Since no solution exists in the other three cases, the model has the merit of identifying a unique galaxy as the center of explosion.

We have selected the 1146+111 field for its richness of quasars and because it includes two of them with nearly the same redshift and small angular separation. The ejection time $t \sim 3.4 \times 10^7$ yr corresponds to an overall physical size of the exploded system of 6 Mpc at the time of observation. This may be compared with the galaxy distance $d = 480$ Mpc ($H_0 = 50$ km s^{-1} Mpc^{-1}). Our assumption $R_i \ll d$ is therefore justified.

Thus an entirely reasonable picture emerges in which the quasars are seen to derive the bulk of their redshift from Doppler effect, with the two quasars 1146+111A, C forming a close pair possessing equal ejection speed. It should be noted that the plate from which the quasars were selected covers an area of $\sim 52 \times 43$ (arcmin)^2. The theoretical maximum value of the ejection angle ϕ for a redshifted quasar to be seen on this

TABLE 1

PHYSICAL AND GEOMETRICAL PARAMETERS FOR THE QUASARS IN THE 1146+111 FIELD

Quasar Catalog Number	Redshift (z)	Apparent Separation from G (θ)	Angle of Ejection (ϕ)	Speed of Ejection (v)	Azimuthal Angle of Ejection (ξ)
1146+111A	1.013	49″	1°45′	$0.553c$	0°
C	1.012	110	3 55	0.553	161
H	1.930	678	19 37	0.771	108
J	1.670	1114	32 25	0.751	−166
K	2.220	1905	50 0	0.854	47
P	1.89	1607	44 06	0.807	175
B	1.10	84	2 53	0.582	−39
MC2	0.863	393	14 48	0.505	127
D	2.120	139	4 09	0.786	47

NOTE.—Ejector galaxy G at R.A. = $11^h46^m7^s.7$, $\delta = +11°5'15''$, $z_G = 0.08$; time of explosion $T = 3.4 \times 10^7$ yr.

plate is ~ 2 rad, against the value of ~ 1 rad observed for 1146+111K. Thus the model does not require special conditions like beaming.

IV. CONCLUSION

The Doppler ejection hypothesis is thus able to explain the presence of a large concentration of quasars including a close pair of identical redshifts. The above calculation could in principle be applied to the gravitational lens candidates as well as other quasar concentrations reported by Arp (1987) and others. For example, the gravitational lens models for the systems 2345+007 (Weedman *et al.* 1982) or 0023+171 (Hewitt *et al.* 1987) have some unsatisfactory features. In spite of deep surveys, the lensing agent for the system 2345+007 has been elusive. The wide disparity in the intensity ratio between the images in radio continuum and the optical spectral line fluxes in the object 0023+171 is not natural in a lens model. Djorgovski *et al.* (1987) argue that the quasar pair PKS 1145−071 they have resolved recently is likely to be two distinct quasars of redshift 1.345 separated by 4″.12 in projection, rather than a lensed system. However, the chance projection of two quasars of identical redshift is more plausible in a Doppler model like ours than under cosmological hypothesis. Such cases suggest that the Doppler option proposed here should not be ruled out as a possible explanation. More so, because our understanding of the quasar phenomenon cannot be considered complete at this stage.

It would be worth noting that even in the confirmed lens cases (known until mid-1987, say), it is a fact that consistent lens models are available even if the redshifts of the quasars were halved. This curious circumstance allows a substantial noncosmological component in the redshift of such quasars. A similar latitude is not available in the cases where the lensed background source is a galaxy, as in the observed giant arches; there it appears that the redshift of the background source must be entirely cosmological. Thus, the present statistics of gravitational lensing of quasars seem to support a model like ours.

We emphasize that our approach is fully able to calculate all the geometrical and dynamical parameters of ejection for a dense quasar field, only when it happens to contain a close pair with nearly equal redshifts. Without the near equality of redshifts it would not be correct to assume the same v_i for even the close pairs since what we observe is a two-dimensional projection of a three-dimensional configuration.

Our example suggests that the source galaxy and its environment should be carefully examined morphologically and spectroscopically for any possible indications of a past explosion.

The 1146+111 field might contain quasars with blueshifts also, but, according to the model proposed by Narlikar and Subramanian (1983), they may be faint. It is therefore worthwhile searching for possible blueshifted objects in this field. If there are no familiar lines that could be blueshifted into the visual spectrum, such objects may appear lineless.

Another prediction of the Narlikar and Subramanian model that can be tested is the anticorrelation between the size of the fuzz around a quasar and its velocity through intergalactic space. Table 1 illustrates that large redshift does not automatically imply large velocity. For example, the velocity ($0.81c$) of the quasar with $z = 1.89$ is greater than that ($0.79c$) of the quasar with $z = 2.12$. The nebulosities around quasars in this field, if and when discovered, can be compared with their velocities as given in Table 1. The sizes of nebulosities should turn out to be inversely correlated with these velocities.

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