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Ejections of Quasars at Relativistic Speeds from Nearby Galaxies: Ejection Mechanism and Selection Effects

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Abstract. It has become part of the conventional wisdom of quasar research that quasars cannot be objects ejected from nearby galaxies. The reasons are summarized in Burbidge & Burbidge (1967) and they include: (1) in quasar spectra only redshifts, and no blueshifts, are observed, contrary to expectation in a local Doppler interpretation of quasar line shifts; (2) the energy requirements for relativistically moving quasars seem excessive and the ejection mechanism is unknown. In. this work we show that the first problem could be explained via some powerful selection effects, and that the second problem does not exist in the relativistic slingshot process of ejecting black holes. Consequently one cannot exclude the possibility that at least some of the quasar-galaxy associations of large redshift differentials discussed by Arp and Sulentic are real and that the redshift differences are due to high speeds of ejected quasars.

Key words: black holes—quasars

1. Introduction

One of the points of dispute in the so-called redshift controversy has been the claimed association of low redshift galaxies with high redshift quasars (Arp 1973). Even though it now appears well established that many quasars are at their redshift distances (Gunn 1971; Yee & Green 1984) there still remain many puzzling cases (Arp, Sulentic & di Tullio 1979; Arp & Sulentic 1979; Sulentic 1983; Arp & Burbidge 1990). In this paper we consider the possibility that some quasars are indeed ejected from centres of galaxies, and that the redshift difference is due to a Doppler shift. We do not attempt to replace the generally accepted hypothesis of cosmological redshifts, but rather consider ways in which a few exceptional associations could arise within the conventional cosmological theory. Gravitational lensing has been advanced as an explanation of some of the associations (*e.g.* Tyson 1986; Fugmann 1989). Here we consider an alternative to this hypothesis.

There are two fundamental objections which go against the ejection hypothesis. First, in the suggested quasar-galaxy associations the quasar has always the higher redshift, indicating that the ejection is always away from us. Secondly, the apparent velocity difference is often very large, a large fraction of the speed of light. What we argue in this paper is that the redshift (rather than blueshift) could be an observational selection effect, and that the ejection velocities could indeed be sufficiently high, if quasars are basically supermassive black holes, and the ejections happen by slingshot mechanism (Saslaw, Valtonen & Aarseth 1974).

The main requirement of detecting an appreciable blueshift is the availability of at least two reasonably strong emission lines in the observable window. For large blueshifts these lines obviously have to come from the infrared region. Possibilities of the existence of observational selection effects in discriminating against detection of QSOs with blueshifts were considered, although qualitatively, by Burbidge & Burbidge (1967). However, as Burbidge & Burbidge (1967) have mentioned there are actually very few emission lines in the infrared region of detectable strength. They tentatively concluded that it may not be possible to detect objects with blueshifts larger than 0.5. Furthermore, Strittmatter & Burbidge (1967) qualitatively discussed the probable effect of blueshift on colours of QSOs. However, as far as is known to us, there has not been any other analysis of observational selection effects concerning blueshift of emission lines of QSOs. We first investigate, in Sections 2 to 5, the possibility of observing blueshift and also the possibility of gaining and/or losing more QSOs as a consequence of blueshift. We shall then present, in Sections 6 and 7, our model based on ejections of supermassive black holes. Finally, several examples are discussed in Section 8 in the context of our model.

2. Availability of search lines for determination of blueshift

As has been mentioned above, at least two emission lines must be available for correctly determining the blueshift of an object. Although there are not many emission lines worth considering in the infrared region (Roche *et al.* 1984; Aitken & Roche 1985), the lines shown in Table 1 may be used as search lines for blueshift determination. We have included the infrared line of Paschen α (Grasdalen 1976; Cutri, Rieke & Lebofsky 1984) even though it is sometimes extremely weak (Puetter & Hubbard 1985), as well as Paschen β, He I λ10830 (Le Van *et al.* 1984) and [S III] λ9532. The table may not be complete in infrared, but it is balanced by the fact that we give a rather strong weight to those infrared lines which are known to occur at least in some quasars. The intensity and frequency of occurrence of the lines being different, the probability of observing them would obviously be different. Table 1 also gives 'weight' to the lines after the criteria defined by Basu (1973). The proper weights of the infrared lines are not known.

Each line enters and leaves the observable window 3300 Å to 6900 Å (Basu 1973), by being blueshifted by various amounts. A line would be available for identification only over the range of blueshifts for which it remains within the window. Fig. 1 shows the blueshift range over which each of the above lines remains within the observable window. The number of lines available for detection at any blueshift or any blueshift interval can be read off from this diagram. The total number of such lines with corresponding weights, at a blueshift, is defined as 'the availability of search lines' for measuring blueshift (A_{SB}). It is a measure of the probability of observing a blueshift and hence the 'detection probability' of a blueshifted QSO. Fig. 2 shows the distribution of A_{SB} at intervals of $\Delta z_{blue} = 0.05$. The detection probability is maximum at the smallest blueshift of 0.05 and falls off gradually up to $z_{blue} = 0.50$ when it starts falling off rapidly to zero at $z_{blue} = 0.85$. However, the Pβ λ12818 line actually leaves the observing

Table 1. List of search lines that can be used for identification of emission lines of QSOs and measurement of their blueshifts, with proper weight for each line.

Identification	Wavelength in Å	Weight
Pα	18751	1.0
Pβ	12818	1.0
He I	10830	1.0
[S III]	9532	1.0
[S II]	6724	0.5
[N II]	6584	1.5
Hα	6563	2.0
[O I]	6300	1.0
[O III]	5007	2.0
[O III]	4959	1.0
Hβ	4861	1.5
[O III]	4363	1.5
Hγ	4340	1.5
[Ne III]	3968	0.1
[Ne III]	3869	1.0
[O II]	3727	1.0
[Ne V]	3426	1.0

window at $z_{\rm blue}$ = 0.75 and the Pα λ18751 is the only line within the window for $z_{\rm blue}$>0.75 and a blueshift cannot be certainly confirmed with a single line. The detection probability of blueshifted QSOs therefore decreases at higher blueshift, with the probability rather small at $z_{\rm blue}$>0.5 and no QSO is expected to be confirmed at blueshift greater than 0.75.

Here we may also mention the problem of misidentification of spectral lines. The two lines which would be most easily available for strongly blueshifted quasars ($z \cong -0.7$) are Paschen α and Paschen β. The ratio of their wavelengths is 1.463. On the other hand, the two lines which are commonly used to determine redshifts around $z \cong 1$ are Mg II λ2798 and C III] λ1909. The ratio of their wavelengths is 1.466, identical to the Pα/Pβ wavelength ratio for most practical purposes. A search through the catalogue of 3681 quasars by Hewitt & Burbidge (1987) shows that the fraction of two-line identifications based on λ2798 and λ1909 is about 6 per cent of the sample. Thus there is a distinct possibility that blueshifted quasars have already been discovered but they are hiding among the redshift ~ 1 quasars in the catalogues. Similarly in the catalogue of optical spectra of BL Lac objects by Stickel, Fried & Kühr (1989) there exist several identifications based on the above mentioned two lines, or only on identifying one of them. It would be useful to study the above mentioned spectra over a wider range of wavelengths, and paying attention to other factors such as continuum shape, relative line intensities and equivalent widths, in order to search for a possible blueshifted quasar.

3. Objective prism and other surveys

These surveys are carried out on low dispersion objective prism plates, and are concerned with the identification of an object as a possible QSO candidate rather than

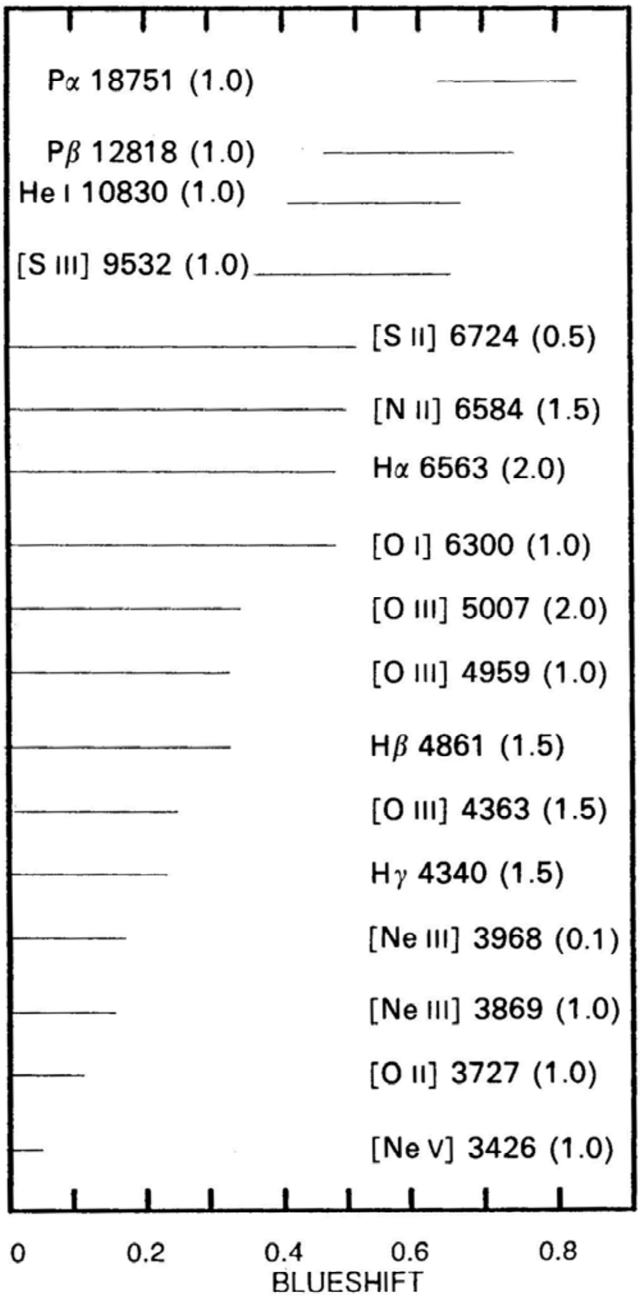

Figure 1. Blueshift range over which the spectral line is available within the observable window (3300–6900 Å) for measurement of blueshifts of QSOs.

with redshift determination. Very strong emission lines well above the continuum level must therefore be available within the observed wavelength interval. As such the two strong lines in Table 1, *viz.* Hα λ6563 and [O III] λ5007, blueshifted within the observable window (3300 Å to 6900 Å) may be used for identification of possible candidates for blueshifted QSOs.

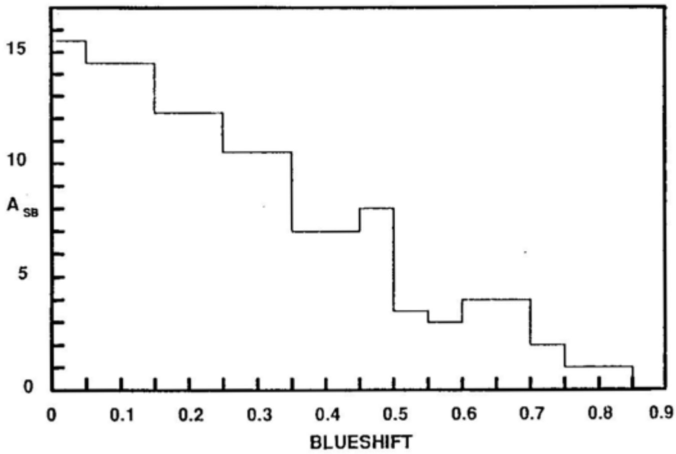

Figure 2. Distribution of 'availability of search lines' A_{SB} at intervals of Δz_{blue} = 0.05.

A separate function A'_{SB} was therefore constructed to investigate the effect of the objective prism survey on detection of possible blueshifted QSOs. In practice Hα λ6563 is much stronger and more important than [O III] λ5007, and objective prism surveys usually extend to 5400 Å (Osmer & Smith, 1980). A'_{SB} is similar to A_{SB} except that the above mentioned two lines are the only ones considered (instead of the seventeen lines in Table 1 for A_{SB}) with Hα λ6563 'weighing' 2.0 and [O III] λ5007 now 'weighing' 1.0, and the observing window now extending to 5400 Å (instead of 6900 Å as in the case of A_{SB}). The distribution of A'_{SB} is similar to $A_{SB,}$ except that it falls to zero at z_{blue} =0.4.

It is known that QSOs are discovered during routine optical identification of objects picked up from surveys at other wavelength bands, *viz.* radio, X-rays and other colours. It should be noted that these surveys are not carried out specifically for discovering QSOs. An object will be definitely identified as a QSO with its blueshift determined, only when at least two emission lines have been identified within the observable window and used for computing the blueshift. It is evident from Fig. 2 that the availability of search lines falls off to zero for blueshifts larger than 0.85, with only a single line available at z_{blue}>0.75. Thus even if possible candidates appear from surveys at radio and other colours, no blueshifts larger than 0.75 can be determined. Spectra of these objects will appear to be pure continuum, or with a single line. In either case, the object will not be identified as a QSO. Such objects have been observed, *e.g.* BL Lac objects.

4. Influence of blueshifted lines on *U, B, V* magnitudes

Presence of emission lines within any of the *U, B, V* filters may change the brightness of the QSO, thus increasing the probability of its detection (Basu 1987). In this section, we look into the effect of emission lines blueshifted to the *U, B, V* filters on the corresponding magnitudes.

Individual lines would enter and leave a filter by being blueshifted by different amounts. A particular line contaminates the filter and changes the brightness and hence the magnitude of the object as long as it remains within the filter. We assume

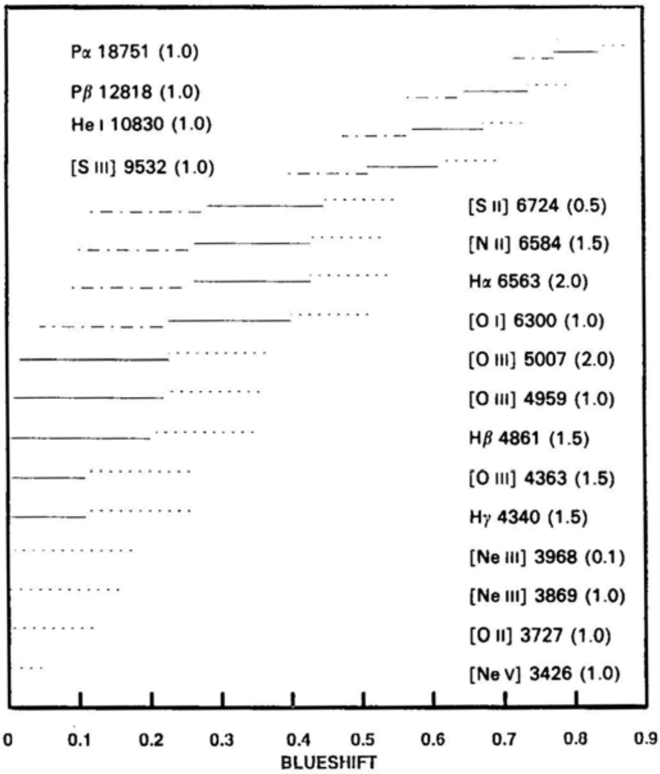

Figure 3. Blueshift range over which the spectral line remains within the observing window and hence influences the U (– – –), B(——) and V(–·– ·– ·) filters.

responses of U, B, V filters to be square wave, with half-power bandwidths of 600, 1000 and 1000 Å respectively, and with mean wavelengths of 3593 Å, 4408 Å and 5515 Å, respectively (Sandage 1966).

Fig. 3 shows the blueshift range over which each of the lines in Table 1 would remain within the particular filter. The number of lines influencing a particular filter at a certain blueshift or over a blueshift interval can be read off from this diagram. The total number of such lines with appropriate weights is a measure of the combined influence of all the emission lines at a particular filter and are denoted by U_{LB}, B_{LB} and V_{LB}. U_{LB}, B_{LB} and V_{LB} are then measures of changes in magnitudes in the sense that the higher their values, the brighter the object. Fig. 4 shows the distribution of these quantities at intervals of $\Delta z_{blue} = 0.05$.

It will be found that there is some effect of blueshifted emission lines in changing the brightness of the objects by varying amounts. Relatively more candidates are expected at $0.1 \leqslant z_{blue} \leqslant 0.5$ when observed with U filter, at $0.0 \leqslant z_{blue} \leqslant 0.45$ with B filter and $0.05 \leqslant z_{blue} \leqslant 0.25$ with V filter.

5. Effect of blueshift on colours of QSOs

The position of QSOs on the $(U - B)/(B - V)$ diagram is such that changes in either $(U - B)$ or$(B - V)$ or both may bring the QSO very close to the Main Sequence (MS)

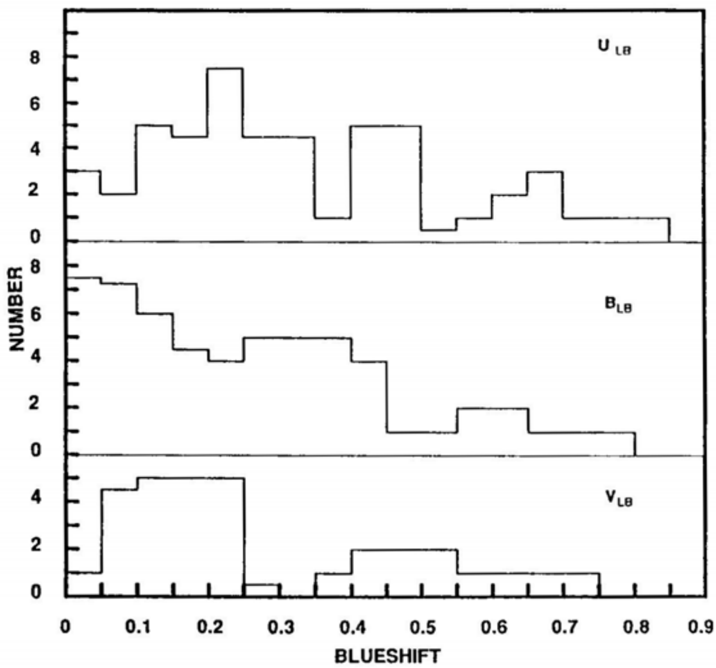

Figure 4. Blueshift distribution of U_{LB}, B_{LB}, and V_{LB} which are measures of changes in *U, B, V* magnitudes of QSOs due to influence of emission lines at the *U, B, V* filters.

band and the QSO may be mistaken for an MS star and thus lost (see *e.g.* Basu 1975). In this section we consider the possibility of such changes in colours due to the contamination of the *U, B, V* filters by blueshifted emission lines.

The influence of emission lines on individual filters has already been discussed in Section 4. The quantities $(U_{LB} - B_{LB}) = (U - B)_{LB}$ and $(B_{LB} - V_{LB}) = (B - V)_{LB}$ are therefore measures of contributions of the emission lines to the two colour indices. Fig. 5 shows the distribution of $(U - B)_{LB}$ and $(B - V)_{LB}$ with blueshift. Following the arguments of Basu (1975), it is obvious that emission lines blueshifted to the *U, B, V* filters would lead to misidentification of QSOs to MS stars as $(U - B)_{LB}$ becomes more negative making the objects drop down close to the MS band. Similarly, when $(B - V)_{LB}$ is more positive, the objects are removed away from the MS band to become more red and eventually lost, as the normal tendency for QSO search is to look for blue objects.

It is found in Fig. 5 that these situations arise for $0 \leqslant z_{blue} \leqslant 0.15$, $0.25 \leqslant z_{blue} \leqslant 0.45$, $0.50 \leqslant z_{blue} \leqslant 0.65$ and $0.75 \leqslant z_{blue} \leqslant 0.80$, thus covering the major part of the available blueshift spectrum.

There is now convincing evidence that the nonthermal continua of many QSOs extend through the visible well into the infrared, and the continua rise into the infrared as $\nu^{-1.2}$, typically with the peak around 10^{11} Hz (Rieke & Lebofsky 1979). It is clear that the peak flux, if blueshifted to the observing band, will produce some relatively bright objects, the apparent luminosities being greatly enhanced. However, it needs a blueshift of at least 1.0 to bring the peak flux from 10^{11} Hz ($= 3 \times 10^7$ Å) just entering the observing window at 6900 Å. At that wavelength the object would of course appear

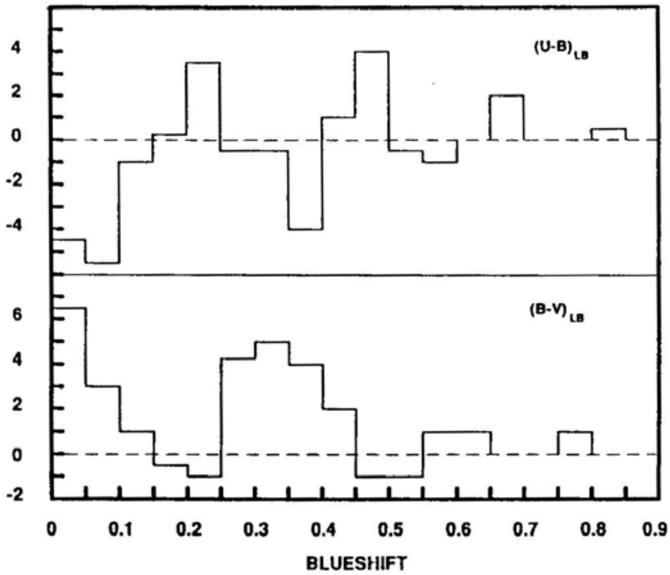

Figure 5. Blueshift distribution of $(U - B)_{\rm LB}$ and $(B - V)_{\rm LB}$ which are measures of the contributions of emission lines to the two colour indices.

very red, and as has been mentioned above, the normal tendency for QSO search being to look for blue objects, many of these objects are likely to be missed. More importantly, at $z_{\rm blue} > 1.0$ there will be no lines available within the observing window for identification and measurement of the blueshift (Fig. 2 and Section 2). Thus although a comparatively bright object may be observed, it cannot be identified as a QSO as its blueshift cannot be determined.

6. Ejections of supermassive black holes at relativistic speeds from centres of galaxies

Let us assume that supermassive black holes can appear as quasars (Rees 1986) even when they are ejected from centres of galaxies. We will discuss this assumption in the next section. Is it possible to eject black holes fast enough, at relativistic speeds, so that some apparent high redshift quasar—nearby galaxy pairs could be real associations?

6.1 *General Considerations*

The ejection of black holes can happen via the so-called slingshot mechanism (Saslaw, Valtonen & Aarseth 1974). When galaxies merge, their central black holes first form binaries (Valtaoja, Valtonen & Byrd 1989) and subsequent mergers lead to ejections (Mikkola & Valtonen 1990). When black hole masses are similar to each other, ejections happen in opposite pairs, but when they are unequal the ejections consist of single black holes. The limiting ejection speed for black hole pairs is about 10 000 km s^{-1} (Mikkola & Valtonen 1990). How fast can single black holes be ejected?

Valtonen (1976) has discussed the slingshot process at the relativistic limit. The study was limited to the interaction between an equal mass binary, $m_1 = m_2 = 1/2$ and a third body of mass $m_3 = 1$. It was found that there were large numbers of escapers even when the binary speed was $c/4$ (c = speed of light). Higher binary speeds were not studied. Since the ejection speed is typically some fraction of, and at most about equal to the binary speed, it is important to ask how high the binary speed can be before the slingshot process becomes impossible. Gravitational radiation will destroy binaries and will prohibit ejections at some limit of binary speed.

To get an idea of the time scales involved in the gravitational radiation process, we quote the binary lifetime T_m by Peters (1964):

$$T_m = 2.4 \cdot 10^6 \text{ yr} \, (m_1 + m_2) \frac{(m_1 + m_2)^2}{m_1 m_2} \left(\frac{V}{10\,000 \text{ km s}^{-1}} \right)^{-8} \tag{1}$$

where m_1 and m_2 are the component masses in units of 10^9 solar mass and V is the orbital velocity in a circular orbit. This may be compared with the orbital period

$$T_{\text{orb}} = 25 \text{ yr} \, (m_1 + m_2) \left(\frac{V}{10\,000 \text{ km s}^{-1}} \right)^{-3}. \tag{2}$$

We see that equal mass supermassive binaries live of the order of 10^5 orbital periods, and unequal binaries even longer, at orbital speed of V=10 000 km s^{-1}. Thus there should be plenty of opportunities for ejections below this speed.

At the highly relativistic regime, if we put *e.g.* V=100 000 km s^{-1}, equal mass systems are destroyed almost immediately. However, unequal mass systems live about m_1/m_2 orbital periods ($m_1 > m_2$). Thus it is possible to have ejections even at these speeds, but they are more likely asymmetric.

The next question is the likelihood of such an ejection. Are there processes in nature which might bring a relativistic supermassive binary to interact with another supermassive black hole?

Initially the binary should be wide in order to survive the mean interval of time between collisions of galaxies, which may be about 10^9 yr in groups of galaxies. With an approach to another supermassive body the binary tends to become eccentric Gravitational radiation circularizes the orbit such that the pericentre distance becomes the new semi-major axis of the binary. This results in a dramatic reduction in the expected lifetime of the binary, typically by two orders of magnitude per encounter.

When the orbital speeds become of the order of 10 000 km s^{-1}, escapes of black holes from the galaxy become possible. However, they do not necessarily happen at this stage yet, instead the system may become more compact and speeds higher before escapes take place. We are dealing with a random process which has many possible outcomes, among them ejections at speeds up to 100 000 km s^{-1}.

Let us consider this chain of events in greater detail in order to estimate the probability of very high speed ejections. Initially we have a stable binary in the nucleus of a galaxy with orbital speed ~ 3000 km s^{-1} (Valtaoja, Valtonen & Byrd 1989). In a merger with another galaxy a third black hole is brought into the system. During subsequent evolution the black holes have such close encounters that sooner or later they form a binary whose lifetime is of the order of the crossing time of the three-body system. This requirement means that the binary orbital speed has to be ~ 40000 km s^{-1}.

In order that such a close binary is formed, the encounter distance has to be about 1 % of the orbital size of the initial binary. The probability of the encounter is about 1 % during one crossing time. Since the galactic potential prevents escapes, sooner or later such a close encounter must take place.

To get a close triple system we require that the third body comes within about one orbital radius of the centre of the binary during the next crossing time. The probability for this is $P_1 \sim 10^{-2}$. The triple system may either break up through an escape, or it may evolve further via close encounters. Let us consider the latter case, and assume that a close encounter between two black holes again takes place such that a new tight binary is formed whose lifetime is of the order of the crossing time of the triple system. The orbital velocity of the new binary has to be ~ 100 000 km s^{-1}. The probability of such an encounter is $P_2 \sim 0.2$ during one crossing time and since the system is likely to live through several crossing times, the probability of formation of the binary is close to unity. The probability of another close triple interaction is P_2. It either results in an escape or further close encounters. However, any subsequent close encounters would mean mergers of black holes. The probability of an escape may be $P_3 \sim 0.5$.

Therefore the whole chain of events leading to a relativistic escape has the likelihood of $P_1 \cdot P_2 \cdot P_3 \sim 10^{-3}$. Even though low, it is not exceedingly low. Moreover, this is only one possible channel of evolution. Since we are dealing with chaotic dynamics, there are many other possible scenarios which could lead to the same final result.

In systems of black holes of comparable mass it is difficult to have ejection speeds greater than about $c/3$. Most ejections would take place close to the escape velocity from the galaxy and only the tail of the distribution would extend from 10 000 km s^{-1} upwards (Mikkola & Valtonen 1990). If we want to discuss even higher ejection speeds, we have to turn to another process.

As mentioned above, binaries of large mass ratios can have high orbital speeds and still survive a considerable length of time. When the mass ratio exceeds 100, the ejection speeds could, in principle, reach very close to the speed of light. Below we will discuss one possible process where this may be achieved.

6.2 *Relativistic Ejection Model*

One of the ideas about dark matter halos in galaxies is that they consist of intermediate mass ($< 10^6\ M_\odot$) black holes (Carr 1978; Carr, Bond & Arnett 1984). Such black holes would very slowly accrete toward the centre of the galaxy over the Hubble timescale. If the total number of the intermediate mass black holes is large, say millions, then a fair number of them, say thousands, would be expected to lie in the central few parsecs of the galaxy. There they would form a satellite system around the more massive ($\sim 10^8\ M_\odot$) central supermassive black hole.

Let us assume that two galaxies merge and each galaxy possesses a massive central black hole of mass M, (say, $M \sim 10^8\ M_\odot$) and N smaller satellite black holes of mass m (say, $m \sim 10^5\ M_\odot$). We call the typical mass ratio $\eta \equiv m/M$.

The two primary black holes approach each other because they scatter stars of the nuclear region and lose orbital energy in the process. A binary is formed which is stable over the Hubble time, assuming that no further galaxy mergers take place, if the binary mass $\gtrsim 10^7\ M_\odot$ (Valtaoja, Valtonen & Byrd 1989). Otherwise the black hole binary coalesces because of gravitational radiation energy losses. The binary may be pushed over to the range where gravitational radiation dominates either by an approaching third black hole, or by encounters with stars if the binary is light enough. One way or the other, quite often the supermassive binaries collapse, and in the process their satellites are ejected.

A satellite system is stable against gravitational radiation over the time span Δt if the typical satellite orbital speed V_s is (Equation 1)

$$V_s \cong \left[\frac{2.4 \cdot 10^5\,\mathrm{yr}}{\Delta t} \left(\frac{M}{10^8 M_\odot} \right) \eta^{-1} \right]^{1/8} \cdot 10^4\,\mathrm{km\,s^{-1}}. \tag{3}$$

In order to be of interest to us, the satellite systems must survive over the mean interval between galaxy mergers, say $\Delta t \sim 10^9$ yr. Thus typically $V_s \cong 10^4$ km s^{-1}. Fig. 6a illustrates two such satellite systems coming together in a merger of galaxies.

When the merger of the primaries proceeds, the secondary satellites form a halo around them (Fig. 6b). Some of the satellites will be ejected at speeds below V_s, others obtain eccentric orbits about the massive binary. A certain fraction of satellite orbits become so eccentric that they pass close to one of the primary members, and due to gravitational radiation losses, become tightly bound satellites of them. These tightly bound satellites can be ejected at relativistic speeds in the final stages of the merger of the primaries.

"Tightly bound" means here that in its new orbit the satellite should merge with the primary at about the same time when the primaries merge together. In this way very compact three-body systems form. By Equation 1 this condition requires that the orbital speed V_s^1 of the satellite in its new (circular) orbit should be

$$V_s^1 \cong V(8\,\eta)^{-1/8} \tag{4}$$

Here V is the orbital speed of the primary at the time of ejections. In order that such a tight binary forms, the eccentricity e of the original satellite orbit must be

$$1 - e \cong (V_s/V_s^1)^2 \cong (8\,\eta)^{1/4}\,(V_s/V)^2. \tag{5}$$

We may assume that the eccentricities of the satellite orbits are distributed as $f(e) = 2e$ after the binary has perturbed the cloud of satellites (*e.g.* Heggie 1975; Valtonen 1988). Some of the high eccentricity orbits lead to almost an immediate merger between the primary and the satellite. When these two factors are taken into account, the probability P for forming the tight orbits (lasting over the timescale T_m) is

$$P \cong 0.5\,(1 - e^2) \cong 1 - e \cong (8\,\eta)^{1/4}\,(V_s/V)^2. \tag{6}$$

For example, $\eta = 10^{-3}$, $V, = 2 \cdot 10^5$ km s^{-1} and V_s=10^4 km s^{-1} give us $P \cong 10^{-3}$. With N satellites, the probability of a relativistic ejection is of the order of 10^{-3} N. Generally we expect that $N < \eta^{-1}$, which means that the number of relativistic ejections cannot be much greater than one in any single merger event. And accompanying the few relativistic ejections there should always be many more subrelativistic ejections, most of them only barely above the escape speed from the galaxy.

7. Ejected supermassive black hole as a quasar

We now come back to the question whether a moving supermassive black hole could appear as a quasar. By itself the black hole is hardly observable. However, the black

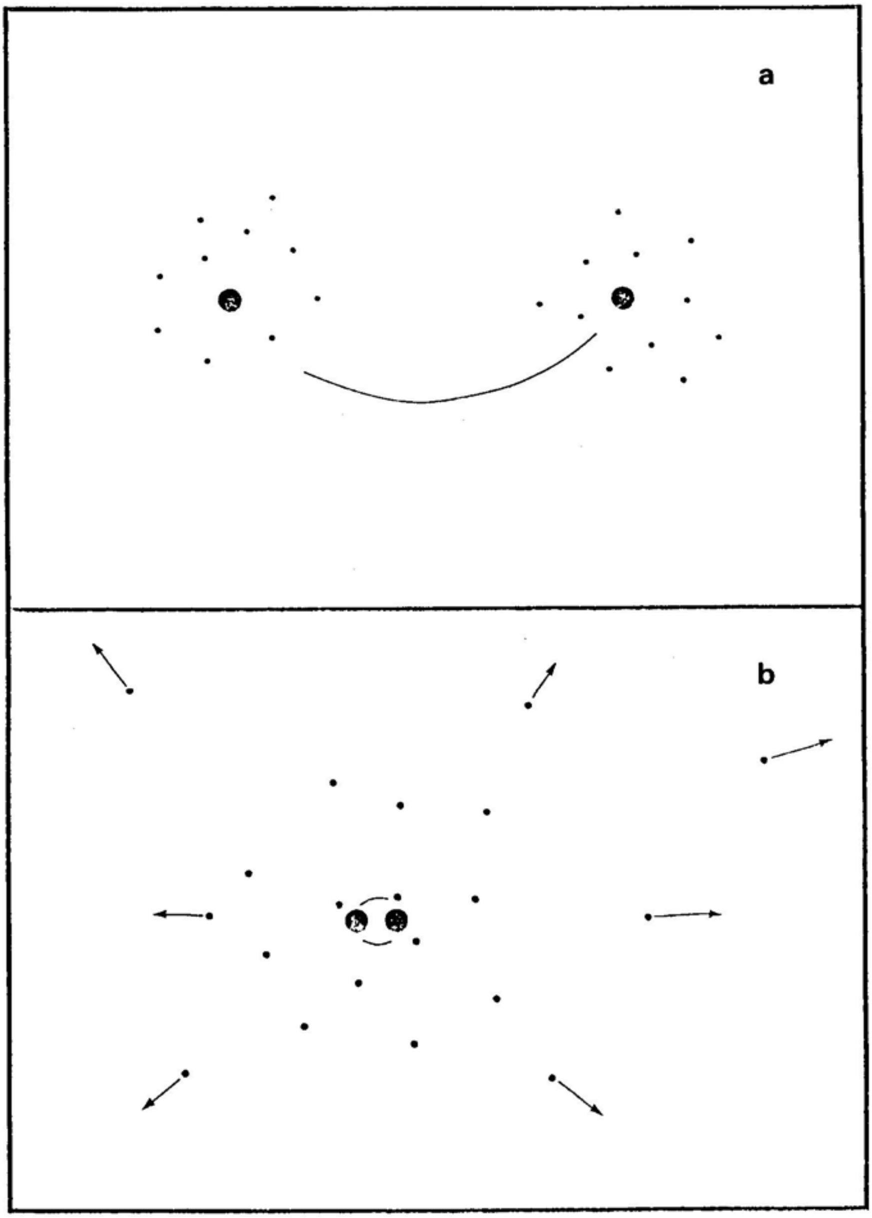

Figure 6. An illustration of the scenario of ejecting black holes at relativistic speeds, (a) Two primary black holes approach each other with their satellite black holes, (b) The primary black holes merge together and in the process eject satellite black holes, some of them at relativistic speed.

holes in galactic nuclei are probably surrounded by gaseous discs. Even though details are still quite unclear, it is generally believed that the interaction of the gaseous disc and the black hole with their surroundings is somehow able to generate the phenomena which we call a quasar (*e.g.* Rees 1986, Osterbrock & Mathews 1986). In the absence of a widely accepted theory of quasars, we are clearly not in a position to say definitely in what way a supermassive black hole moving outside the galaxy would differ from one which is stationary in the nucleus.

The first steps in discussing this problem have been taken by Rees & Saslaw (1975), Lin & Saslaw (1977), De Young (1977) and Narlikar & Subramanian (1983). These authors point out that (1) ejected black holes will be surrounded by gaseous discs. The masses of the discs could be a fair fraction of the masses of the black holes, and in principle they could generate power at a rate which is similar to the power of active galactic nuclei. (2) Just as in the case of galactic nuclei, jets of relativistic plasma could be flowing away from the black hole perpendicular to the disc. The continuum emission of the quasar could be associated with the jet, while there are several alternatives for the origin of the line emission (*e.g.* Krolik & Vrtilek 1984; Carroll & Kwan 1985). Narlikar & Subramanian (1983) also point out a further interesting and rather obvious fact that (3) the jet from the moving black hole is likely to be one-sided and pointing opposite to the direction of motion. Then there could be several further selection effects, *e.g.* Doppler boosting, which work against detecting blueshifted quasars (Narlikar & Edmunds 1981; Narlikar & Subramanian 1982).

In spite of the many uncertainties of quasar models, both when the quasar is at its cosmological distance and when it is nearby, we attempt to sketch a model of ä high speed quasar. At the heart of the quasar is the black hole. It is surrounded by a gaseous disc and a relativistic wind is thought to blow out from the central region. As a first approximation we may estimate that the pressure in the wind P_w goes down as the square of the distance d from the black hole: $P_w \alpha d^{-2}$ (*e.g.* Carroll & Kwan 1985). We have a handle on the pressure at the distance d_B of the broad-line region. The pressure is $P_B \cong 10^{13–14}$ K cm^{-3}, and the distance is $d_B \sim 10^{18}$ cm in (cosmological) quasars and $d_B \sim 10^{17}$ cm in Seyfert galaxies (Osterbrock & Mathews 1986). Since we are discussing local quasars, scaled down versions of Seyfert nuclei, we may take $d_B \sim 10^{16}$ cm. Thus we could say that

$$P_w \cong 10^{13.5}\,(d/10^{16}\text{ cm})^{-2}\text{ K cm}^{-3}. \tag{7}$$

At some distance d_0 in the forward direction this is balanced by the ram pressure P_0 of the external medium. It is given by $P_0 \cong nm_pc^2\,(\gamma^2 - 1)$ where m_p is the mass of a proton, and $\gamma = [1-(V^2/c^2)]^{-1/2}$, if V is the speed of the quasar.

The number density of interstellar matter varies with distance r from the centre of the galaxy as well as from one galaxy to another. To make matters concrete, we use models by Mathews & Baker (1971) and Mathews & Loewenstein (1986) to describe the variation of number density with radial distance r:

$$n \cong 10^{-2}\,(r/\text{kpc})^{-2}\text{ cm}^{-3}. \tag{8}$$

The ram pressure in the forward direction is

$$P_0 \cong 10^{11}\,(r/\text{kpc})^{-2}\,\gamma^2\,(V/c)^2\text{ K cm}^{-3}. \tag{9}$$

Equating (7) and (9) we obtain

$$d_0 \cong 0.017\,\gamma^{-1}\left(\frac{V}{c}\right)^{-1} r. \tag{10}$$

De Young (1977) performs numerical simulations of a hot plasma sphere moving through the interstellar medium with a high speed. In this simulation (case a) a relativistic jet forms at the back of the plasma sphere. For example, the experiment may be scaled such that the speed of the quasar $V = 0.1\ c$ and the pressure of the sphere is $7 \cdot 10^6$ K cm^{-3}. According to Equation 7 this pressure is obtained at $d \cong 7$ pc and the corresponding ram pressure occurs at $r \cong 12$ kpc. The length of the backward pointing jet is a few tens of parsecs.

Unfortunately numerical simulations are not available for the range of parameters which would cover all the different ejection speeds V and ambient densities n. For every ejection speed V we can scale De Young's model such that it applies with a given value of n. This value is obtained somewhere on the way out of, the galaxy. Thus the model is applicable at least at some point in the galaxy. This model is illustrated in Fig. 7.

However, there is a problem with very slow quasars. Confinement and therefore the jet formation is poor if $d_0 > 10^{-1}\ r$, or by Equation 10 if V/c<0.2. Consequently we do

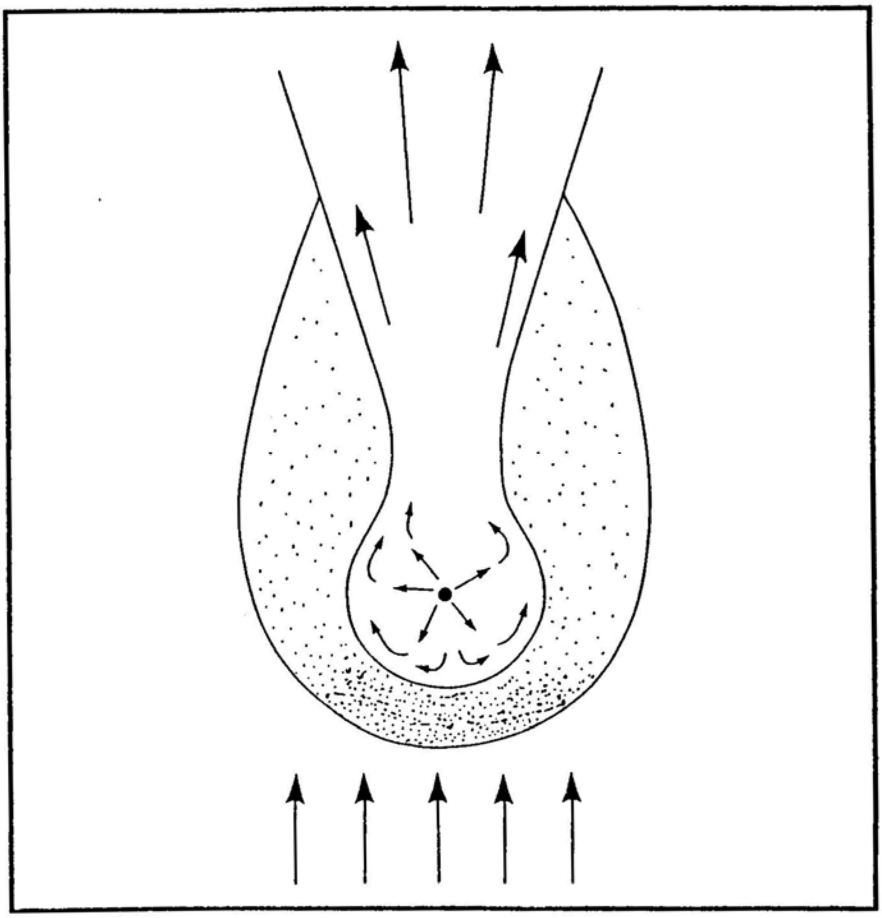

Figure 7. An illustration of the fast moving quasar model. A supermassive black hole (black dot) moves from right to left and encounters the ram pressure of the ambient medium. As a result, the more or less isotropic relativistic wind from the black hole is redirected to a single backward jet.

not expect to find very slowly moving ejected quasars. The slow ejections have a rather large cross-section for interaction with the interstellar medium, which may result in mixing of thermal plasma into the flow at the interface. Such models are probably close to the case *b* models of De Young (1977) which have a resemblance to the continuum radiosource components.

If we consider the quasar all the way in the nucleus, say at $r \cong 1$ pc, its radius becomes $d_0 \cong 0.02 - 0.1$ pc depending on the ejection speed. The Schwarzschild radius of a black hole of mass M_6, in units of $10^6\ M_{\odot}$, is $\cong 10^{-7}\ M_6$ pc. The accretion disc around it may be $\sim \eta^{-1}$ times larger and still survive the ejection. We see that even for $\eta = 10^{-3}$ the accretion disc is well below the quasar radius d_0, and it is not affected by ram pressure on the way out of the galaxy. It is thus able to replenish the gas clouds which at least in some quasar models are convected outwards with the wind and cause the line emission of the quasar.

The radiation emitted in the direction of a jet is greater than the radiation in the backward direction by a factor $\lambda = ((c + V_j)/(c - V_j))^{2.5}$ where V_j is the bulk flow speed in the jet. It should be at least $V_j \cong c/\sqrt{3}$, which gives $\lambda \cong 27$ (Narlikar & Subramanian 1983), and could be even higher than $V_j \cong 0.99$ c (Biretta, Moore & Cohen 1986) which corresponds to $\lambda \approx 10^6$. This means that if an ejected quasar is detected, it is highly unlikely to be seen from any other direction except from behind, i.e. it should almost always show a redshift relative to its local environment.

8. Discussion

It would appear from Section 2 through 5 as well as from the discussion of the previous section that powerful selection effects are really present to make blueshifted QSOs being observed very difficult. Although various surveys (*viz.* objective prism, radio, and other colours) may produce possible candidates for blueshifted QSOs, a QSO will not be confirmed at a blueshift larger than 0.75, which corresponds to a line-of-sight velocity of 0.6 *c*. Also the continuum radiation, if it is jet-dominated, may be so weak that blueshifted quasars hardly ever enter the surveys.

The presence of blueshifted lines in the *U, B, V* filters will result in losing QSOs owing to their being misidentified as Main Sequence stars and/or being too red. There is, however, some possibility of enhancement in brightening of QSOs due to the effect of blueshifted lines to *U, B, V* filters, at rather low values of blueshift ($0.05 \leqslant z_{\rm blue} \leqslant 0.25$) at *V* magnitude, which is the most important among the three (*U, B, V*) from an observational point of view.

The large infrared continuum flux may also increase the apparent luminosities of QSOs in the visible (red) region at $z_{\rm blue} > 1.0$. However, being too red, again, they are likely to be missed and at that blueshift there will be again no lines available for identification and blueshift measurement.

We will now consider a few examples of proposed quasar—galaxy associations.

Quasars aligned across NGC 3384. NGC 3384 is an S0 galaxy in a group of galaxies. Thus it could possibly result from a number of mergers, and could have been an accumulation point of supermassive black holes. Arp, Sulentic & di Tullio (1979) associate with it six quasars which are not far from a straight line through the centre of the galaxy. The interpretation of their redshifts in terms of ejection velocities gives ejection speeds around 0.6 *c*.

In the context of the present theory we would then have to say that there should be about six quasars with corresponding blueshifts about this galaxy also. The alignment of quasars could come about as follows: two major galaxies merge, each containing a massive central black hole binary and a number of smaller satellite black holes. The satellite systems are stable as long as they are separate, but when the two massive black holes come close to each other, ejections follow. They happen dominantly in the plane of the binary formed by the two major black holes (Saslaw, Valtonen & Aarseth 1974), and a line of ejected objects is seen if the observer happens to be close to the binary plane. In the last stages of the collapse the binary orbital speed is close to the speed of light and so should also be the ejection speeds of the smaller supermassive black holes.

We should also consider the possibility that the quasar spectral lines are wrongly identified. The redshifts of all the six quasars are determined from only two lines Mg II λ2798 and C III] λ1909, which could be, in the absence of further information, just as well Paschen α and Paschen β (Section 2). Then the six quasars could be approaching us with the speed ~ 0.5 *c*. A certain degree of ejection symmetry would be restored by the two additional quasars which also lie in the same line of quasars (Arp, Sulentic & di Tullio 1979), and whose redshifts indicate escape away from us with the speed of ~ 0.4 *c*. This hypothesis could be tested by improved spectral observations of the quasars in question.

Markarian 205 and NGC 4319. Here the evidence of physical association is based on a luminous connection (Sulentic 1983). A counter-argument for a real physical association is the fact that the quasar Markarian 205 is even much closer to another galaxy which has essentially the same redshift as the quasar (Stockton, Wyckoff & Wehinger 1979). The redshift difference between NGC 4319 and Markarian 205 when interpreted as a Doppler velocity difference is rather small, less than 20 000 km s^{-1} (perhaps even so small as to be problematic, see Section 7). In this case the corresponding ejection to the opposite direction is not out of question, as suggested by Sulentic & Arp (1987a, b). Here we should look for the quasar which is coming toward us.

Quasars near companion galaxies. Arp (1981) claims that there is a high probability of finding a quasar near a companion galaxy of a major galaxy. This could be understood if the companion galaxy was initially the centre of a small group of galaxies, and the approach of the major galaxy triggered a coalescence of this group. Then black hole clusters may have resulted and ejections of some of the black holes. A nearby example of this type of association is in the M81–M82 system (Burbidge *et al.* 1980).

Compact groups of quasars. Arp & Hazard (1980) discovered a field of nine quasars in the area of R.A. 11^h46^m and δ =11°11′, in the neighbourhood of four galaxies which have much lower redshifts than the quasars. Narasimha & Narlikar (1989) applied a Doppler interpretation to this group and derived ejection velocities in the range of 0.5 c to 0.85 *c*. All ejections were calculated to be away from us, so that corresponding numbers of quasars coming toward us should also exist. In a nearby field Arp & Hazard (1980) pointed out two very well aligned quasar triplets. For them Narlikar & Edmunds (1981) derived ejection velocities between 0.8 c and 0.93 *c*, assuming that the central quasar at its cosmological redshift distance had ejected an opposite pair of quasars. These ejection speeds are far too high for the symmetric slingshot mechanism.

In most examples of suggested quasar ejection we notice the general trend that ejection velocities are relativistic. On the other hand the slingshot process works best at subrelativistic speeds and only the tail end of the velocity distributions should extend to the relativistic regime. Where are the quasars ejected at low speeds?

Within the context of the present paper we would have to say that ejections of black holes indeed happen at different speeds, mostly at low speeds. For one reason or another, the optical spectral lines should become visible only when the ejection speed is in the area of ~ 0.5 *c*. In the model of Section 7 the confining pressure causing the backward flowing jet comes from the interaction between the interstellar medium and the hot plasma. If the velocity of the black hole is too small, the confining pressure is not sufficient and the single jet structure does not arise. The object will perhaps be a continuum radiosource.

In conclusion, there exist scenarios in which mergers of galaxies can lead to the ejection of some black holes at relativistic speeds, as well as scenarios where the ejected black holes may have the appearance of quasars. Since black hole ejections occur with equal probability toward us and away from us, the question arises why all the proposed quasar ejections are directed away from us, or more generally, why we do not see blueshifted quasars. We suggest several reasons for this. First, there may not be suitable spectral lines to identify a blueshift greater than 0.75. Second, the probability of identification goes down already before this limit, and there is serious problem of misidentification of lines near blueshift 0.7. Thus the major question is then why the blueshift range $-0.5 < z < 0$ is not observed.

There are several possible answers to this. One is that at least in some ejected quasar models large ram pressures are required which are not realized outside the galaxies except at relativistic ejection. This can be tested by searching for low speed ejections inside the galaxy images. Secondly, the quasar envelope ("narrow-line region") may be dusty (Rudy 1984), which limits the view to the broad-line region to the narrow jet cone at the back of the quasar (Narlikar & Subramanian 1983). If the broad emission lines are missing, and the narrow lines reduced in strength in blueshifted quasars, their discovery may become difficult, especially when the continuum Doppler boost factor works in favour of redshifted quasars. This description of spectral line properties is not too far off in case of many BL Lac objects (Stickel, Fried & Kühr 1989), even though as a rule a redshift has been determined for them, sometimes based on only a single spectral line.

A theory of quasars may be developed in two ways by starting from the active nucleus in Seyferts. Either one scales up the processes, masses, energies, *etc.* and takes the galaxy far away, in which case quite a plausible quasar model is achieved. Associations of quasars with galaxies of practically identical redshifts provides a good argument in favour of this idea (*e.g.* Stockton, Wyckoff & Wehinger 1979). The other line of argument frees the active nucleus from its galactic hold and lets it run through the intergalactic space. Also this provides a quasar model, and with the advantage of not having to scale up the processes of activity. Rather, a considerable scaling down appears to be required. If the typical Seyfert nuclei are about 1 per cent of the brightness of the galaxy, and the masses of the ejected black holes are about 1 per cent of the nuclear black hole mass, then the ejected quasars should be about 10 magnitudes fainter than their parent galaxies. Also this idea of quasars has been supported by reasons of association with galaxies (*e.g.* Arp 1973, 1990).

The scaling down of the quasar energies' and distances could be beneficial in the interpretation of certain observations such as the rapid periodic variations in the quasar OJ 287 (Valtaoja *et al.* 1985; De Diego & Kidger 1990). The jet of OJ 287 lies at the position angle of P.A. = – 100° to P.A.= – 115° (Gabuzda, Wardle & Roberts 1989), the same as the direction of the brightest galaxy in our nearest neighbouring galaxy group, the Sculptor group (NGC 253 at P.A. = –107°). This galaxy is also a strong radio and infrared (IRAS) source. Thus we could offer as an alternative to the cosmological redshift an ejection of OJ 287 from the Sculptor group about 10^8 yr ago approximately toward us. By now the quasar would be beyond us at a distance of ~ 10 Mpc, and escaping with high speed of $V \cong 0.25\ c$ (assuming that the measured redshift z =0.3 is correct). Its luminosity would be ~10^{42} ergs^{-1} instead of ~ 10^{47} ergs^{-1}, and its mass down to something like $10^6\ M_\odot$. It would not be surprising to find flux variations in timescales of a few minutes in such an object (Bassani, Dean & Sembay 1983), while in cosmological quasars theoretical problems arise (Elliot & Shapiro 1974). The local model of OJ 287 is illustrated in Fig. 8. This model may be tested by searching for a proper motion in OJ 287, which should show up at 10^{-4} arcsec/yr level.

Another test case for an ejected quasar could be 3C 273. It lies almost opposite to NGC 253 in the sky (angular separation 156.3°) and its famous jet lies in the position angle of 220° while NGC 253 is found in the position angle of 190.5° relative to 3C 273. Along the line of the jet one finds also a neutral hydrogen cloud, the most dense part of which is at the position angle of 217° (Arp & Burbidge 1990). This dense part coincides

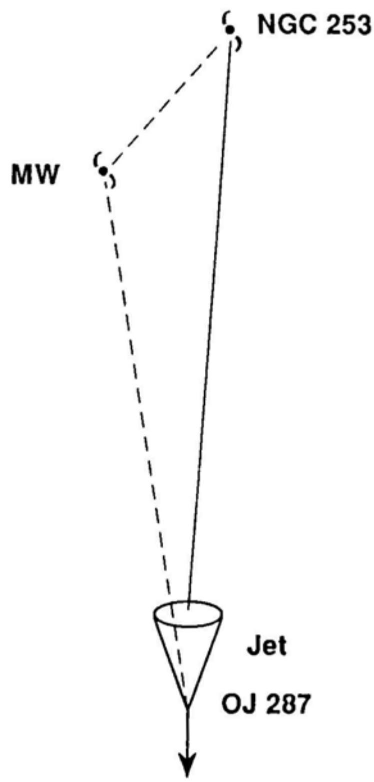

Figure 8. A sketch of OJ 287 as an ejected local quasar. The near by galaxy NGC 253 ejects a black hole of mass ~ $10^6\ M_\odot$. After ~ 10^8 yr it is seen receding away from us (MW), while its single jet points close to our direction. The length of the jet is greatly exaggerated.

with an irregular galaxy (Impey *et al.* 1990). In the black hole ejection scenario the quasar 3C 273 could have interacted with the galaxy on the way from NGC 253in which case the quasar and galaxy distances should be similar, even though presently 3C 273 would be behind the galaxy. The redshift of the hydrogen cloud is z = 0.0042 (Giovanelli & Haynes 1989) while the redshift of 3C 273 is z = 0.158 (Schmidt 1963). In the cosmological scenario 3C 273 with its surrounding "fuzz" is an exceptionally large galaxy with a diameter of 184 kpc (Wyckoff, Wehinger & Gehren 1981). It has at least one companion with a redshift identical within the measurement errors to the redshift of 3C 273 (Stockton 1978).

At present neither the cosmological interpretation nor the local theory can be totally excluded, and it would be exciting if both kinds of quasars could be proven to exist.

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