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Backward Emission in Quasars

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Abstract. In the local Doppler theory of quasars the lack of observed blueshifts can be explained if quasars, ejected at high velocities from active galactic nuclei, radiate predominantly in a backward cone. An astrophysical single exhaust model has been proposed which not only explains why quasars emit radiation in the backward direction, but may also be able to account for some of their morphological features.

Key words: quasars—noncosmological redshifts—emission mechanisms

1. Introduction

In this Winter School we have seen excellent pictures of jets and beams in radio sources. I wish to describe a scenario where fast-moving quasars eject radiating material in the form of jets in the backward direction. The motivating idea is first described briefly.

From the early days of the discovery of quasars there have been several hypotheses concerning their redshifts. The most popular hypothesis known as the cosmological hypothesis (CH) interprets the redshift as due to the expansion of the universe. Other explanations come under the so-called noncosmological hypotheses (NCH) and include the Doppler redshift, the gravitational redshift and also other explanations involving variable masses, tired photons *etc*. (Terrell 1964; Hoyle & Burbidge 1966; Greenstein & Schmidt 1964; Bondi 1964; Hoyle & Fowler 1967; Das & Narlikar 1975; Das 1977; Narlikar & Das 1980; Narlikar & Edmunds 1981; Narlikar & Subramanian 1982; Pecker 1977). Burbidge has summarized the evidence suggesting the inadequacy of CH to account for the redshift phenomena in quasars. I will take it for granted that part of the redshift in a (high-redshift) quasar may well be of noncosmological origin. In particular I will explore the Doppler hypothesis further.

In the Doppler hypothesis it is assumed that quasars are ejected from explosions in active galactic nuclei (Hoyle & Burbidge 1966). In common with other NCH models it is presumed that most of the quasars now seen are comparatively nearby, at distances ranging from ~ 10 to ~ 100 Mpc. The Doppler redshift of a quasar ejected at speed V in a direction making an angle α with the line of sight away from the observer is given by

$$z = \frac{1 + (V/c)\cos\alpha}{(1 - V^2/c^2)^{1/2}} - 1. \tag{1}$$

Thus for example, for $\alpha = 0$ and $V = 0.8\,c$, we get $z = 2$. Here c = speed of light, and for a quasar of mass M, an ejection energy of γMc^2 $[\gamma = 1/(1 - V^2/c^2)^{1/2}]$ is needed. Thus the energy involved in the ejection of a quasar of $M \sim 10^6 M_\odot$ is $\sim 10^{60}$ erg. This is ~ 1 per cent of the energy commonly associated with active galactic nuclei.

The main problem with the Doppler theory is, however, with blueshifts. We should see quasars ejected towards us also, and these should exhibit large blueshifts. According to a calculation by Strittmatter (1967) if quasars are being ejected randomly in all directions and if a typical quasar radiates isotropically in its rest frame then in a flux-limited sample blueshifted quasars vastly predominate over the redshifted ones.

Strittmatter (1967) had sought a way out of this difficulty by arguing qualitatively that a typical quasar radiates, in its rest frame, in the backward direction. Hoyle (1980) has expressed the requirement more quantitatively as follows. In Fig. 1 we see a quasar Q moving with speed V in the direction of the arrow, relative to the intergalactic medium (IGM). The dotted cone in the backward direction has a semi-vertical angle θ_{H} given by

$$\cos \theta_{\mathrm{H}} = \frac{c - (c^2 - V^2)^{1/2}}{V}. \tag{2}$$

Then, provided the quasar emits all its radiation in this cone (in its rest frame), no observer at rest in the IGM will see it blueshifted.

Clearly an astrophysical explanation is needed to account for this emission property. Section 2 describes briefly the salient features of the model by Narlikar & Subramanian (1983).

2. The single-exhaust model

Our model is adapted from the original twin-exhaust model of Blandford & Rees (1974). In the Blandford-Rees (BR) model, a central engine ejects high-energy plasma which is collimated in two oppositely directed jets by a surrounding gas cloud which in turn is held together by the gravitational field of a massive matter distribution. To conserve momentum, two oppositely directed jets are necessary in the BR model.

The dynamical considerations are altered, however, when the object as a whole is moving rapidly through the IGM. The ram pressure exerted by the IGM can be considerable and may prevent a jet from emerging in the forward direction. The result is a single backward jet.

Fig. 2 illustrates our model qualitatively. C is the central source of fast-moving plasma. Although the plasma may initially come out isotropically, its flow pattern

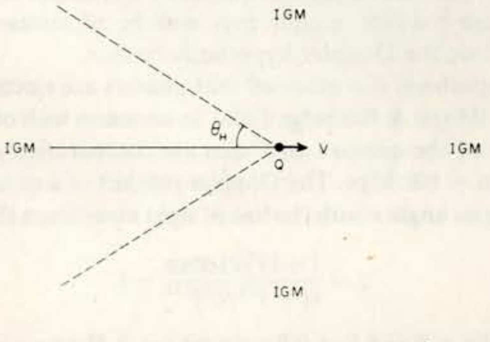

Figure 1. The permitted zone of backward emission is the dotted cone with semi-vertical angle θ_H. If quasars radiate (in their rest-frames) only within this cone, they are not seen blueshifted.

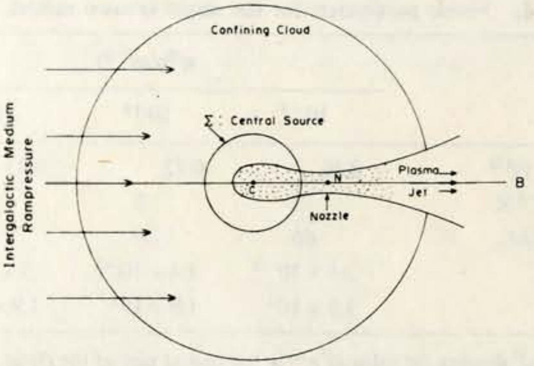

Figure 2. The components of the single-exhaust model where the gravitating mass is a compact object. The jet is in the backward direction. The dots denote emission-line clouds.

changes when it 'feels' the IGM ram pressure and selects the backward direction to come out since along there it encounters the least resistance. It carves out a channel in the backward direction CB, and forms a de Laval nozzle at N before emerging supersonically from the surrounding cloud. The cloud is held by a massive system, shown here as a compact object Σ, although as in the BR model it could also be in the form of a uniform distribution of stars. The optical and radio emission is supposed to come from the jet material. Forward emission is inhibited because (a) the jet as a source has a relativistic bulk motion in the backward direction and (b) a small fraction of dust in the surrounding cloud will absorb most of the forward (line and continuum) radiation.

These qualitative features need to be expressed in quantitative form. This can best be done through a discussion of various constraints on the model.

2.1 *Formation of Shocks*

The first question to be answered is whether any shocks are generated through collisions of the IGM with the enveloping cloud. Denoting by $n^{(c)}$ and $l^{(c)}$ the particle number density and linear size of the cloud and by σ the collision cross-section, the probability that an IGM particle collides with the cloud comes out to be

$$P \simeq n^{(c)} \sigma l^{(c)}. \tag{3}$$

For the typical model parameters (given later in Table 1) we find $P \ll 1$, for $\sigma \sim 10^{-24}\,\mathrm{cm}^2$. Thus IGM just flows through the cloud without generating shocks. However, if magnetic fields are present in the vicinity of the gas cloud, collisionless shock can form. This may have relevance to an observed feature of radio-loud quasars to be discussed later.

2.2 *Survival of the Gas Cloud*

Will the gas cloud be swept away by the IGM? The answer is 'no' if the gravitational binding of the system is sufficiently high. The survival requirement gives us the

Table 1. Viable parameters for the single exhaust model.

	$n^{(\mathrm{I})}(\mathrm{cm}^{-3})$		
	10^{-5}	10^{-4}	10^{-3}
$l^*_{\mathrm{pc}}(\gamma-1)^{1/2}$	2.26	0.72	0.23
$T \times 10^{-5}\,\mathrm{K}$	3	3	3
$M/10^5\,M_\odot$	60	20	6
K/K'	3.6×10^{-3}	1.4×10^{-2}	3×10^{-2}
$n_0^{(\mathrm{c})}$	1.9×10^2	1.9×10^3	1.9×10^4

Note: $n_0^{(\mathrm{c})}$ denotes the value of $n^{(\mathrm{c})}$ in the central part of the cloud.

inequality

$$\frac{GMm_{\mathrm{p}}n^{(\mathrm{c})}}{R^{(\mathrm{c})2}} > n^{(\mathrm{c})}n^{(\mathrm{I})}\sigma m_{\mathrm{p}}(\gamma^2-1)c^2. \tag{4}$$

Here m_{p} = proton mass (typical for cloud or IGM), $R^{(\mathrm{c})}$ = cloud radius, $n^{(\mathrm{I})}$ = particle number density in IGM. Parameters in Table 1 satisfy this inequality.

2.3 *Deformation of the Cloud*

The cloud will be significantly deformed by the IGM if the pressure scale height K is large compared to the distance K' over which the effect of IGM ram pressure is felt. We have

$$K = \frac{GMm_{\mathrm{p}}}{2kT}, \quad K = \frac{2kT}{n^{(\mathrm{I})}m_{\mathrm{p}}\sigma c^2(\gamma^2-1)}, \tag{5}$$

where T = temperature of the isothermal cloud. For the parameter values in Table 1, $K \ll K'$ so that the cloud is *not* significantly deformed from its spherical shape.

2.4 *Physical Parameters of the Model*

The key quantity which determines the viable dimensions is the ram pressure exerted by the IGM on the object. This is given by

$$P^{(\mathrm{I})} = n^{(\mathrm{I})}m_{\mathrm{p}}c^2(\gamma^2-1). \tag{6}$$

The central pressure p_0 at the origin of the jet cannot exceed the above value, if the forward jet is to be effectively suppressed. We therefore set $p_0 \simeq P^{(\mathrm{I})}$. Then from the analysis given by BR, the nozzle radius l^* is given by

$$l^* = (3\sqrt{3}/8\pi)^{1/2}(L/p_0c)^{1/2}, \tag{7}$$

where L is the quasar energy output from the jet. In NCH, L is typically in the range 10^{40}–10^{41} erg s^{-1}. We have assumed that the distance CN in Fig. 2 is $\sim 4l^*$. This is a compromise between the linear approximation CN $\gtrsim 10\,l^*$ of BR and the 'fat-jet' calculations of Norman *et al.* (1981) suggesting CN $\sim 2l^*$.

Since the cloud must be large enough to form the nozzle, the above considerations put a lower bound on M. Table 1 gives the ranges of viable parameters subject to such constraints. For details see the paper by Narlikar & Subramanian (1983).

3. Radiative features

We consider radiation in two forms: continuum and in lines, both taking place in the backward jet.

3.1 *Continuum Radiation*

Detailed calculations (Narlikar & Subramanian 1983) show that the most likely and energetically viable mechanism for continuum emission is the synchroton process. The characteristic magnetic field strength is $\sim 10^{-4}$ G, the electron density $n_e \sim 10^{-6}\,\mathrm{cm}^{-3}$ with relativistic γ-factor $\sim 10^6$. The characteristic lifetime for such energetic electrons is $\sim 10^2$–10^3 yr. This suggests that some *in situ* re-acceleration of electrons might be needed since the characteristic lifetime for these quasars ($\simeq$ time taken by the electrons to come out of the parent active galaxy) is expected to be $\sim 10^4$ yr.

Spectral analysis of the emitted radiation shows that a quasar is more powerful in optical and ultraviolet wavelengths than in radio. To be able to pick out a radio quasar one has to be preferentially located more or less along the direction of the backward jet. This may explain why radio-selected quasars are comparatively few.

A second mystery is the presence of only one radio jet in quasars. In twin-exhaust models it is difficult to explain why *all* radio quasars are seen with one jet only. In the present model this observation finds a natural explanation.

How is it then that ~ 40 per cent of all radio quasars show double lobes? The backward jet should form a radio lobe in the backward direction. To understand the possibility of forming the second lobe we recall the models with collisionless shocks. As shown in Fig. 3, a bow shock is formed in the forward direction. A weak forward jet develops which is stopped by the ram pressure of the IGM which has already been shocked this way. This weak jet may form the second lobe in the forward direction.

3.2 *Line Radiation*

Line radiation in the jet comes from emission-line clouds of characteristic mass $\sim 10^{-2} M_\odot$ and characteristic radius $\sim 5 \times 10^{-4}$ pc. These clouds can be driven forward (by ram pressure of the jet plasma) and backward (by gravity of the main object) so that their exact location in the jet may change. Some clouds may be driven away altogether.

Can the emission lines be seen in the forward direction? The cloud is optically thin unless it also contains dust. Calculations show that with dust forming only 10^{-3} of the cloud mass the radiation is absorbed over a distance of ~ 20 pc. Thus emission lines will not be seen unless we are viewing from the backward direction as explained in Fig. 4.

Thus the blueshift catastrophe mentioned earlier is resolved. First, quasars selected

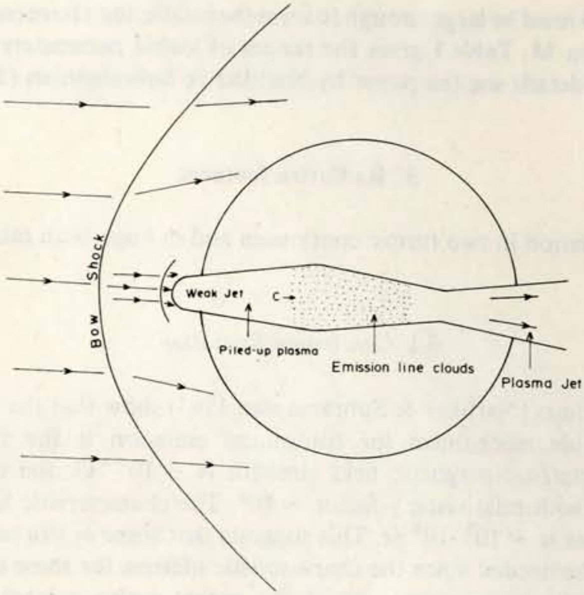

Figure 3. The formation of a collisionless bow shock allows the formation of a weak forward jet. The emission-line clouds are, however, prevented from entering the forward portion of the jet by the piled up plasma.

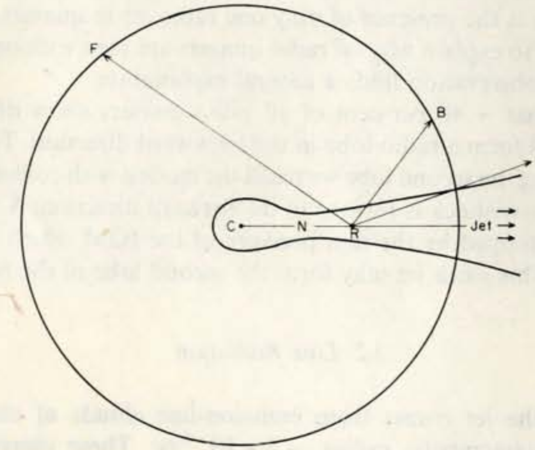

Figure 4. Because of ready absorption by dust in the cloud, emission lines are not seen in the forward direction like RF, but may be seen in the backward direction like RB through the cloud, or like RJ through the dust-free jet.

from their continuum radiation will have to be viewed from the backward direction. Second, even if some are bright enough to be seen from the forward direction they would appear as lineless objects. In an earlier paper (Narlikar & Edmunds 1981) the suggestion was made that BL Lacs may be such objects.

4. Observational tests

Besides the observation of single-jet quasars and the explanation of paucity of radio-loud quasars, the model makes further testable predictions:

(1) Proper motions of the order of 0.5–5 milliarcsec yr^{-1} should be seen. These could be detected by VLBI techniques if they can measure absolute movement across the sky.

(2) If proper motions are found they should be in a direction opposite to the observed jet.

(3) The cloud around the quasar could be detected as a fuzz. Since ram pressure is small for low-speed quasars, these should have a larger fuzz. Thus the size of the fuzz should be inversely correlated with the Doppler redshift.

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Discussion

Porcas: Quasars in your model must show appreciable proper motion. VLBI measurements of the proper motion between the quasar pair 1038 + 52 A, B, which have different redshifts, give stringent upper limits to such motion.

Narlikar: The proper motion expected to be observed in a quasar of distance d_{Mpc} from us is $\sim 60\, d_{\mathrm{Mpc}}^{-1}$ milliarcsec yr^{-1}. VLBI techniques should be able to detect such motions provided it is ensured that we are measuring motion relative to the IGM and not relative to separations between two moving objects. Naturally the model gets discredited if observations of a number of quasars show no proper motions.

Laing: Why, in your model, are radio sources in quasars double? One would expect extreme asymmetries if the jets pointing towards us are much stronger. Secondly, why are the radio structures of galaxies (presumed stationary) and quasars (moving relativistically) so similar?

Narlikar: The possibility of a weak forward jet may give rise to a lobe in the forward direction also. I gather that less than 50 per cent of all quasars have double lobes. Regarding the second question, so far all radio quasars seem to have one jet while radio galaxies usually have two jets. This difference could be due to Doppler effect and ram pressure in the case of quasars.

van Speybroeck: How do absorption line systems occur in your model?

Narlikar: The absorption lines have to originate in the quasar, probably in the surrounding cloud. We have not investigated this as yet.