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# On the apparent superluminal separation of radio source components

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**Summary.** It is shown that the differential bending of radio waves by an intervening galaxy, or by any other clumpy material en route, can give rise to an apparent superluminal separation of the components of a radio source. The merits and demerits of this idea are briefly discussed.

## 1 Introduction

VLBI measurements (Kellermann 1978) have revealed several cases of radio sources with components in their nuclei apparently separating at speeds exceeding the speed of light $c$. If tachyons are excluded from the picture, two possibilities remain. The first is to argue that the distances of these radio sources are considerably smaller than is implied by Hubble's law. Since, with a sole exception, all cases of observed superluminal separation are of quasars (and the cosmological interpretation of QSO redshifts is still a controversial issue), this possibility cannot be discounted. The exception is the radio galaxy 3C 120, but here the identification with a normal galaxy has been questioned (Kellermann 1978).

The second possibility is of 'illusions', i.e. of special circumstances in which the observed effect is only an apparent one, while the real motions in the source (if any) are subluminal (McKee, Rees & Blandford 1977). At present it is difficult to assesss objectively how probable or plausible such cases are. Here we present a scenario which belongs to this second class of explanations. We suggest that the progressive bending of radio waves by a suitably located intervening clump of matter can produce the appearance of superluminal separation at the source. Although the gravitational lens has been advocated to account for other phenomena connected with the QSOs (e.g. Press & Gunn 1973; Gott & Gunn 1974; Barnothy 1975), the differential bending mechanism proposed here does not seem to have been used previously as an explanation of the observed superluminal separation. We first discuss the salient features of the mechanism and then consider its plausibility, merits and demerits.

## 2 Differential bending

We will use Newtonian gravitation to illustrate the idea. A detailed analysis using general relativity (to be published later) gives exactly twice the Newtonian effect in all the cases of

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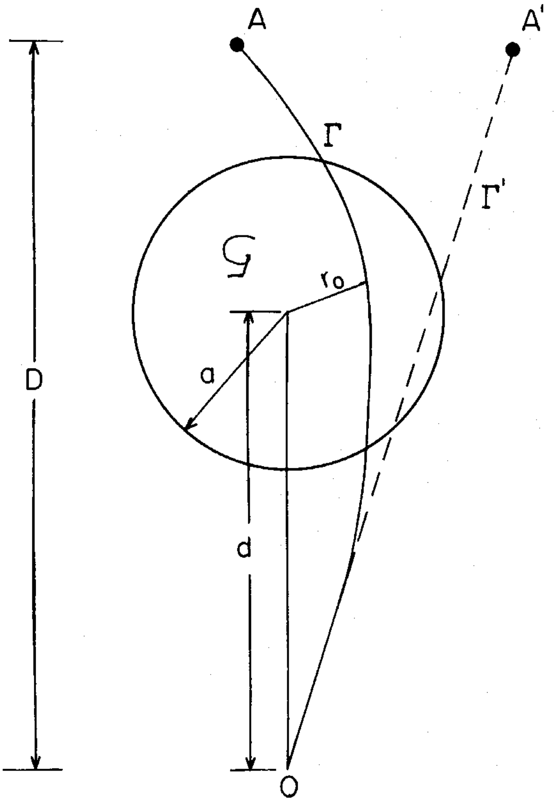

**Figure 1.** The gravitational bending of a ray of light produced by a spherical distribution $\mathscr{G}$ of matter is schematically displayed.

weak gravity. In Fig. 1 we have a spherical distribution $\mathscr{G}$ of matter with mass $M$, and a radial density profile $\rho(r)$ vanishing for $r \geqslant a$ (say). A ray $\Gamma$ passes through the distribution at an apsidal distance $r_0$ and reaches the remote observer O. If $r_0 > a$, the net gravitational bending at O is by an angle

$$\Delta(r_0) = 2GM/c^2 r_0. \tag{1}$$

For $r_0 < a$ the formula is more complicated. Write $m(r)$ for the fraction of mass interior to the sphere of radius $r$ concentric with $\mathscr{G}$ and define $\psi = \cos^{-1}(r_0/a)$. Then the bending angle is

$$\Delta(r_0) = \frac{2GM}{c^2 r_0}\left\{1 - \sin\psi + \int_0^{\psi} m(r_0 \sec\phi)\cos\phi \, d\phi\right\}. \tag{2}$$

The proposed model makes use of the fact that there are density distributions in galaxies and clusters for which $\Delta(r_0)$ increases outwards for an appreciable fraction $r_0/a$. In Fig. 2 we have taken as an example $\rho(r) \propto (1 + r^2/a^2)^{-5/2}$ for $r \leqslant a$. With this type of profile, suggested for galaxies by King (1958), $\Delta(r_0)$ increases for $r_0 \lesssim 3/4a$. Other density profiles give similar results. In most cases $\Delta'(r_0) > 0$ in the inner parts of $\mathscr{G}$ and $\Delta'(r_0) < 0$ in the outer parts.

We will now assume that the radio source consists of two components A and B in the nuclear region with a linear separation $l$ perpendicular to the line of sight to the observer O. Because of bending, the images of A and B are formed at A′ and B′, respectively. However, because $\Delta(r_0)$ is not a constant, the apparent separation (between A and B′) is different from the real separation. Two cases of interest arise. (1), we have A and B moving in opposite directions from a nucleus stationary with respect to $\mathscr{G}$ as seen by O. (2), A and B

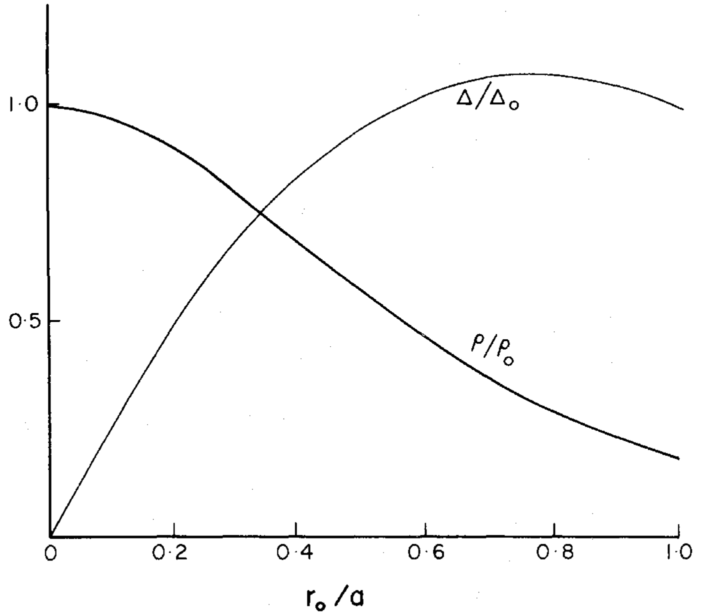

**Figure 2.** The density profile given by $\rho(r) \propto (1 + r^2/a^2)^{-5/2}$ and the bending produced at different radial distances from the centre. Here $\Delta_0 = \Delta(a)$. Similar curves may be obtained for other typical density profiles.

are fixed relative to the nucleus but the nucleus has a transverse motion relative to the line of sight from O through $\mathscr{G}$. We describe the cases below.

### *Case (1)*

Let $d$ be the distance of $\mathscr{G}$ from O, and $D$ the distance of the radio source from O. We will assume that $r_0 \ll d$, $r_0 \ll (D-d)$. Then a simple calculation using the optics of the situation shows that the apparent transverse separation is $l\xi$ where

$$\xi = \left[1 - \frac{d(D-d)}{D}\Delta'(r_0)\right]^{-1}. \tag{3}$$

Thus for $\Delta'(r_0) > 0$, the possibility exists that $\xi \gg 1$ if the expression in parentheses in equation (3) approaches zero. The factor $\xi$ also represents the ratio of the observed separation speed to the real speed (perpendicular to the line of sight).

To fix ideas we may take $d = fD$, where $0 < f < 1$. If $z$ is the redshift of the radio source, $D \approx 2z \times 10^{28}$ cm for a Hubble constant $\approx 50\,\mathrm{km\,s^{-1}\,Mpc^{-1}}$. $\Delta'(r_0)$ is of the order of $2GM/c^2a^2$ in general, where $a$ is the characteristic dimension within which most of the mass of $\mathscr{G}$ is contained. For an elliptical galaxy $a$ is much smaller than the optical radius. Taking $a \sim 3$ kpc, we get

$$\eta \equiv \frac{d(D-d)}{D}\Delta'(r_0) \sim \alpha z\left[\frac{M}{10^{11}M_\odot}\right]\left[\frac{3\,\mathrm{kpc}}{a}\right]^2, \tag{4}$$

where $\alpha$ is the $a$ fraction $\sim 1$. Thus, if there is an intervening galaxy, it is possible to have $\eta$ close to unity and $\xi$ correspondingly large.

If $\eta$ exceeds unity, the source lies behind the conjugate point for the optical system $\mathscr{G}$. In this case the images are inverted and the magnification is small for $\Delta'(r_0) > 0$.

*Case (2)*

The transverse motion of the nucleus in this case is $u$ (say), while the separation $l$ between A and B is constant. However, as the source moves across $\mathscr{G}$, rays from A and B encounter different distributions of bending matter, and so the apparent separation between A$'$ and B$'$ will change. The apparent speed of separation is given by

$$V = l(d/D)^2(D-d)\,\xi^3\,\Delta''(r_0)\,u. \tag{5}$$

This effect is small for galaxies but will be higher for more compact objects with large values of $\xi$ and $\Delta''(r_0)$. Its main interest lies in the fact that a finite apparent separation-velocity results from a real separation-velocity of zero.

## 3 Discussion

We discuss here case (1) in more detail. To begin with, how probable are large values of $\xi$ in equation (3)? The chance of there being an intervening galaxy en route to the radio source has been estimated (*cf.* Bahcall & Spitzer 1969) to be fairly high, perhaps as high as 10 per cent in the present case. However, the chance for $\mathscr{G}$ to be so located as to produce a large value of $\xi$ must be considerably less than this, whereas the observed fraction of superluminal-separation cases appears to be much higher. But a selection effect which works the opposite way must be taken into account. The images formed are usually brighter in intensity (Press & Gunn 1973) and thus the source is more likely to be picked up in a survey of sources down to a given flux density limit. (Secondary images, or sources with $\xi < 1$, are less likely to be detected.) It is hard to estimate, on the basis of the handful of cases of superluminal separation, whether the proposed explanation generates sufficient numbers.

There is a serious difficulty of alignment which also needs observational study. In the cases of superluminal separation, the inner separating components A and B in the nucleus are very often found to be aligned with the outer components of the radio source. This alignment may be due to a linear ejection from the nucleus of the outer as well as the inner components. In the bending process the direction $\overrightarrow{A'B'}$ is not necessarily the same as $\overrightarrow{AB}$. so one would have to argue that the alignment seen is fortuitous.

The effective optical depth of the intervening material turns out to be small enough (*cf.* Gunn & Peterson 1965; Bahcall & Salpeter 1965) not to cause any significant attenuation of the radio waves. In fact the variation of $\xi$ with time can be seen to provide us with information about $\Delta(r_0)$ and hence about the density profile of $\mathscr{G}$. Any irregularities in the density distribution will be reflected in $\xi$, causing a 'wobble' in the separation velocity. It is interesting that the VLBI measurements do show such fluctuations (Kellermann 1978). These are difficult to account for in the purely kinematic models of superluminal separation.

Finally, it is tempting to suggest that the bending may occur *in situ*, in the dense nuclear region of the radio source itself. However, calculations show that, so far as weak gravity is concerned, the effects are too small to be of interest. In the case of strong gravitational fields, one may have to simulate the explosion in the nucleus by a white hole. As shown by the calculations of Narlikar & Kapoor (1978), superluminal effects can arise in the early stages of separation, although to sustain them for a few years would require impossibly large nuclear masses ($\sim 10^{14} M_\odot$).

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