A NEW GEOMETRY FOR SUPERLUMINAL MOTIONS +

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ABSTRACT

In the context of superluminal motions, the statistical difficulties intrinsic to the canonical jet geometry are alleviated if the relativistic flows occur on a plane screen, orthogonal to the source axis. The strongest superluminal effects should be detected when the source lies in the plane of the sky, rather than pointing at the observer. The polarization properties, the simplest deviations from the basic geometry, and the connection with other non-thermal phenomena are also indicated.

Jets have proved to be a powerful, unifying concept in the interpretation of extragalactic radio sources. The global schemes proposed by Scheuer and Readhead (1979) and Orr and Browne (1982) suggest that randomly oriented jets and their anisotropic emission can explain major morphological differences as well as short-time-scale phenomena. In particular, the superluminal motions detected with VLBI (Cohen and Unwin, 1982; Phillips and Mutel, 1982) offer the most direct evidence of relativistic flows, and the information conveyed by their kinematics is more straightforward to interpret than dynamics or radiation transfer. A proper modelling of this specific phenomenon would then help in assessing the soundness of the general picture.

The most obvious difficulty which jets have to face - and which is relevant to a broader context than just superluminal motions - is the very tight alignment between line of sight and jet axis, required for strong light-travel-time effects and large differences with respect to the classical case. The alignment would entail peculiar statistical properties, easy to recognize even in the limited sample of sources which can be used to this purpose: the expectations, however, are not met in practice. The most evident inconsistency is provided by 3C 273 (Cohen and Unwin, 1982), at whose redshift one should observe several tens of radio quiet optical analogues. Further arguments are derived from the extended radio structure associated with superluminal sources. Deprojection with the angle implied by the apparent velocity would systematically put these

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sources at the upper end of the known size distribution (Schilizzi and de Bruyn, 1983). Reversing the argument, one would not expect superluminal motions in classical extended doubles, while a neat counterexample has been discovered by Porcas (1981).

The suggestion which can be deduced from these discrepancies, together with the simplicity and attractiveness inherent in the idea of relativistic flows, is one of changing the geometry and retaining the basic mechanism. The purpose of this paper is to describe and discuss - and to some extent to provide with a physical background - a non-canonical configuration where the relativistic motion occurs on a two-dimensional screen instead of a one-dimensional jet; thus the solid angle of the "useful" lines of sight, down which the desired effects are observable, is increased substantially.

In the configuration which we envisage, a standard, relativistic jet impinges on a screen which is approximately orthogonal to the flow direction. The distance from the impact point to the jet's origin is of the order of several m.a.s.; hence a possible outer jet and - a fortiori - a possible extended lobe are far downstream, and their existence depends on the jet's ability to drill its way out. At any rate, even if a tunnel is established through the screen, a certain level of "steady" interaction and emission is expected at the intersection point. We identify this emission as the steady radio core, with respect to which outbursts and motions are measured. The screen itself is an important ingredient of our model; for the time being, we can picture it as a cloud, or a collection of clouds, whose upstream boundary is somehow sharply defined. A basic requirement for superluminal effects is that the generalized sound speed for waves along this boundary be very close to the speed of light; hence the volume inside the screen must be filled with an anisotropic relativistic fluid, which dominates dynamically the first and thinnest layers of screen material. A possible scenario has a toroidal magnetic field associated with the jet (Rees, 1982).

Now suppose that a perturbation occurs, for instance, an extra lump of matter is expelled together with the jet, or the flow properties are subject to some modification which the screen can "sense"; if extra energy is deposited at the jet-screen intersection, a circular wave is excited which sweeps the screen's boundary at a speed βc, $\beta \simeq 1$. We propose that radio emission from the tip of such waves is responsible for the superluminal phenomena. Let ϕ be the angle between line of sight (observer to source) and jet axis (quasar to lobe); then, as long as $1-\beta \ll 1-\sin\phi$, the light-travel-time effects and the projection effects conspire to produce on the sky the image of a superluminally expanding ring. At the oberver's time t, the ring diameter is $2ct/\cos\phi$, and the steady core is projected excentrically, at a distance $ct(1-\sin\phi)/\cos\phi$ from the receding edge. The brightness distribution along the ring can be evaluated under simple assumptions about the perturbation decay. If the particles are isotropic, notwithstanding the strong anisotropy of the field an almost flat distribution is obtained, which contrasts with the very collimated structures observed in real life. Material outflow at a speed comparable to the perturbation speed would only produce radian-wide collimation angles, as it happens in the context of canonical, freely expanding jets; in both configurations the most straightforward remedy is to assume a strong internal anisotropy; narrow images are obtained of jets if their opening angle << $1/\Gamma$, and of circular waves if the particle pitch angle distribution << $\cos\psi$. In effect, in the proposed scenario one cannot invoke turbulence and field reconnection as the source of particle energy, since the field is dominant and very regular. One can expect, however, a radial compression of the field, which implies induced electric fields and accelerated particles only in the meridian planes. If kinetic instabilities are not fast enough to isotropize the particle velocities during a wave transit time, from a given line of sight one should observe only the intersections of the full ring with the plane containing that line of sight and the jet axis. A final remark is in order about the possible values of $\cos\psi$: we have tacitly assumed that it be small and positive, i.e., that we are looking at the screen from the inside. In this case the putative VLBI jet would extend from the core in the same direction as the outer jet, in accordance with the observations. But a priori one would expect an equal number of cases where $\cos\psi$ is small and negative, and the VLBI jet points in the opposite direction. We must therefore assume that the screen is opaque, at least in the region around the jet-screen intersection where the superluminal phenomena occur.

If our picture has any bearing to reality, the fastest motions should be observed when $\cos\psi \simeq 0$, i.e., in those sources which lie in the plane of the sky. It is impossible to distinguish superluminal sources by means of their extended emission, and classical doubles have - if anything - a larger than average chance of showing the effect. The role of the Doppler enhancement is drastically reduced: in particular, the one-sidedness of jets must be taken as a real one-sidedness, which, at a distance of several kpc from the center, is perhaps more acceptable than the "Doppler favouritism" hypothesis (Rees, 1982). Note also that the a priori probability of a one-jet source showing superluminal velocities in excess of nc is $1/n$, to be compared with $1/2n^2$ of the canonical configuration; thus, with a conservative choice of H_o, 3C 273 becomes unlikely to just the 20% level. The fate of our model will of course depend on the agreement with the very detailed measurements which are now becoming feasible. Roberts (1984) reported the first polarization studies at m.a.s. resolution, and modern VLBI techniques allow a model-free monitoring of position angle and separation of the individual knots as a function of time (Moore, 1984). We can anticipate that, apart from small scale irregularities due to the unevenness of the screen surface, accelerated motions are expected because of the concave shape of the screen looked at from the inside. Also, changes in position angle with separation are easily explained with a small helicoidal, distance-dependent twist of the field lines; the intrinsic bending would then be amplified by projection effects as in the canonical case. The crucial tests will be provided by polarimetry; we definitely expect a strong linear polarization. On a m.a.s. scale the magnetic field direction should be independent of the bending, and orthogonal to the large-scale jet axis. More generally, our model relies heavily on the properties of the magnetic field in accounting for the superluminal motions; it is tempting to identify this feature - rather than the Doppler enhancement - as the link between superluminal effects and other extreme non-thermal manifestations, which has been pointed out by Dennison et al. (1981) on empirical grounds.

Much physics, and many constraints and/or information, underlie the properties of the screen which we have just postulated; a model of these properties consistent with current ideas on the environment of quasars is beyond the scope of this paper, and will be tackled elsewhere.

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