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IS THE SUPERLUMINAL MOTION OF COMPACT SOURCES A CONSEQUENCE OF THE DYNAMICS OF PROPAGATION OF THERMAL INSTABILITITIES?

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RESUMEN. Mapas VLBI de fuentes como 3C273 y 3C345 muestran que estas fuentes contienen un rasgo difuso semejante a un chorro en el cual están encajados nudos con movimientos aparentes superluminales. Durante los últimos años, la evidencia contra el modelo estándar relativista de 'beaming' para explicar el movimiento superluminal ha aumentado. En estos modelos se requieren flujos extremadamente relativistas con cocientes de velocidad de $\beta_J^2 \equiv V_J^2/c^2 \approx 0.84$-$0.99$. Examinamos un model básicamente no relativista en donde los nudos se forman por inestabilidad térmica (ITS) de radiación sincrotónica. Investigamos la posibilidad de que el movimiento aparente superluminal es fruto de la dinámica de propagación de la inestabilidad y mostramos que los nudos con una velocidad aparente $V_{Ap} \equiv \Delta\ell_{max}/\Delta_{max}$ mayor que c puede producirse en un chorro con $V_J < c$, en donde Δt_{max} es la diferencia de tiempo en la formación de emisividad máxima (producida por ITS entre dos regiones perturbadas (simultáneamente) a lo largo del chorro separadas por una distancia $\Delta\ell_{max}$. Suponiendo condiciones físicas razonables para el chorro, encontramos que con $\beta_J^2 \leq 0.7$ y $\delta_1(0)$ ($\equiv U_e/U_M$) ≤ 0.2 y $\delta_2(0)$ ($\equiv U_{ph}/U_M$) $\lesssim 0.3$ (en donde U_e, U_M y U_{ph} son las densidades de energía de los electrones relativistas del campo magnético y de la radiación, respectivamente), se crean condensaciones no lineales por inestabilidades térmicas sincrotónicas a distancias de unos pocos parsecs del centro, produciendo velocidades aparentes $V_{Ap}/c \sim 3$.

ABSTRACT. VLBI maps of such sources as 3C273 and 3C345 show that these sources contain a diffuse jet-like feature in which are embedded knots with apparent superluminal motion. Over the last few years, evidence has increased against the standard beaming relativistic model for explaining superluminal motion. In these models, extremely relativistic flows with velocity ratios $\beta_J^2 \equiv V_J^2/c^2 \approx 0.84$-$0.99$ are required. We examine here a basically nonrelativistic model where the knots are formed by a synchrotron radiation thermal instability (STI). We investigate the possibility that the apparent superluminal motion is a fruit of the dynamics of propagation of the instability and show that knots with an apparent velocity $V_{Ap} \equiv \Delta\ell_{max}/\Delta t_{max}$ greater than c may be produced in a jet with $V_J < c$, where Δt_{max} is the time difference of the formation of maximum emissivity (produced by STI) between two (simultaneously) perturbed regions along the jet separated by a distance $\Delta\ell_{max}$. Assuming reasonable physical conditions for the jet, we find that with $\beta_J^2 \leq 0.7$ and $\delta_1(0)$ ($\equiv U_e/U_M$) ≤ 0.2 and $\delta_2(0)$ ($\equiv U_{ph}/U_M$) $\lesssim 0.3$ (where U_e, U_M and U_{ph} are the energy densities of the relativistic electrons, magnetic field, and radiation, respectively), nonlinear condensations by synchrotron thermal instabilities are created in distances of a few parsecs from the core, producing apparent velocities $V_{Ap}/c \sim 3$.

Key words: GALAXIES-ACTIVE — HYDRODYNAMICS

I. INTRODUCTION

Superluminal motion is now established as a common phenomenon in active galactic nuclei (Zensus and Pearson 1987). There are now more than 23 radio sources in which superluminal motion has been detected with typical apparent velocities in the range $1 < V_{Ap}/c < 10h^{-1}$ ($H_o = 100h$ kms^{-1} M_{pc}^{-1}).

Superluminal expansion and related phenomena have found a more or less satisfactory explanation assuming relativistic motion of emitting regions directed nearly along the line of sight (i.e. the standard beam model)(cf. Blandford and Konigl 1979). However, the evidence against the simple beam model has increased over the last few years. For example: 1) several core-domianted superluminal sources have exceedingly large deprojected linear sizes; 2) several objects, such as BL Lac, require extremely small angles with respect to the line-of-sight to explain the data (e.g. $\Delta\theta < 1.5^o$ with a probability for selecting such an object at random < 0.03%) (e.g. Barthel 1987; Hough and Readhead 1987). The standard relativistic models require extremely relativistic flows, V_J, with typical Lorentz factors $\Gamma = (1-\beta^2)^{-1/2} \sim 2.5 - 10$,imlying flow velocities $\beta_J{}^2 \equiv V_J{}^2/c^2 \gtrsim 0.84 - 0.99$ (e.g. Bridle 1985).

In the present analysis, we drop the requirement of alignment of the source axis to the line of sight. We examine a model in which the superluminal knots are formed by a Synchrotron - Inverse-Compton Thermal Instability (STI) in an expanding jet which is not extremely relativistic (with $\beta_J{}^2 \lesssim 0.7$ or $\Gamma_J \lesssim 1.8$) and examine the possibility that the apparent superluminal motion is a consequence of the dynamics of propagation of the instability.

Simon and Axford (1967) first considered synchrotron-driven thermal instabilities in relativistic flows. Recently, we performed linear and nonlinear analysis of the formation of the observed filamentary structure in galactic and extragalactic radio sources (Gouveia Dal Pino and Opher 1989a - GOI; 1989b - GOII; and 1989c - GOIII) by a synchrotron-plus inverse Compton-thermal instability. In the case of the superluminal sources, we found that for jets with $\beta_J{}^2 \leq 0.7$ and $\delta_1(0)$ $(\equiv U_e/U_M) \leq 0.2$ and δ_2 (0) $(\equiv U_{ph}/U_M) \lesssim 0.3$ (where U_e, U_M and U_{ph} are the energy densities of the relativistic electrons, magnetic field, and radiation, respectively), condensations by synchrotron-inverse-Compton thermal instabilities are created in a few parsecs from the core (GOIII).

II. THE BASIC ASSUMPTIONS

In the present work, we consider an expanding jet with an optically thin plasma in which the major part of the internal energy of the system is due to the relativistic electrons emitting synchrotron and inverse Compton radiation. The magnetic field lines are assumed to be parallel to the z-axis of the jet. The border of the jet describes a cone of constant half-opening angle θ. As in GOI (see also GOIV, this conference), we take for the volume element of plasma to be perturbed a field-aligned cylinder moving with the expanding jet and restrict the analysis to transverse perturbations to the magnetic field, since the growth of longitudinal perturbations tends to be inhibited by the thermal conductivity of the relativistic particles , which is very large parallel to the magnetic field. We separate out the ambient (or equilibrium) and the perturbed quantities which we designate with subscript "o" and "1", respectively. The MHD equations which describe the nonlinear evolution of the perturbation according to the scenario above are given in GOIII.

III. THE APPARENT SUPERLUMINAL MOTION

In order to examine the possibility that the apparent superluminal motion is a consequence of the dynamics of propagation of the instability, we consider a jet having a velocity $V_J < c$ and suppose that at a time t=0, two (or more) distinct regions in the jet, separated by a distance $\Delta\ell$, are simultaneously perturbed, as in Fig. 1. We suggest that a magnetosonic standing wave in the ambient plasma at the border of the jet, can compress the jet approximately simultaneously over a small distance, which initiates the synchrotron-inverse-Compton radiation thermal instability (STI) over the region (GOIII). At a time t_{max1}, the density and the emissivity of the perturbed propagating region (1) reach their maximum (see Fig. 1).The perturbed propagating region (2), reaches the maximum at a time t_{max2} later, when the emissivity in region (1) is no longer relevant, as shown in Fig. 1. It is easy to show from Fig.1, that the maximum emissivity (i.e. "knot") moved an apparent distance $\Delta\ell_{max}$ in a time $\Delta t_{max}=t_{max2}-t_{max1}$ with an apparent velocity:

$$V_{Ap} \equiv \frac{\Delta\ell_{max}}{\Delta t_{max}} = V_J + \frac{\Delta\ell}{\Delta t_{max}} \qquad (1)$$

If the jet was homogeneous, STI would grow simultaneously along the jet and regions (1) and (2)

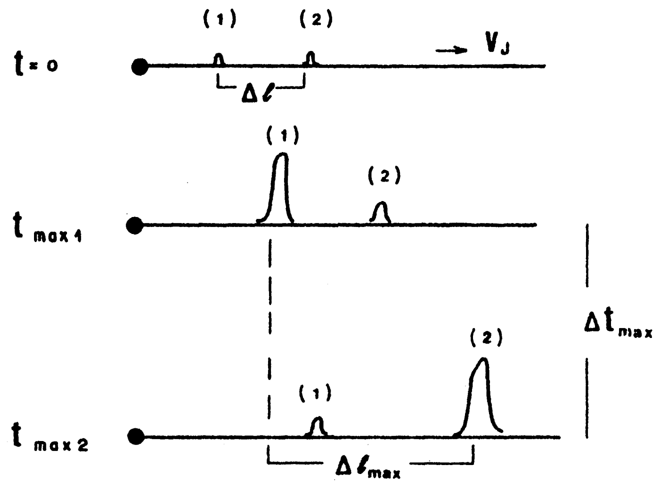


Fig. 1: We suppose that at a time t=0, two distinct regions, (1) and (2), are simultaneously perturbed. At a time t_{max1}, the emissivity of the perturbed propagating region (1) reaches its maximum. The perturbed propagating region (2), reaches the maximum at a tim t_{max2} later.

would brighten simultaneously, i.e., $\Delta t_{max} = t_{max2} - t_{max1} = 0$ and $V_{Ap} \to \infty$. Since the jet densit and the magnetic field decrease outward, STI propagates outward and the inner region (1) (closer to the nucleus than region (2)) attains the maximum emissivity before region (2) thus leading t finite velocities V_{Ap}. If the apparent velocity $V_{Ap} = \Delta\ell_{max}/\Delta t_{max}$ is > c, we say that the "knot moves superluminally.

IV. RESULTS

In order to obtain reasonable initial values for the ambient parameters, we used as a data base the values obtained from observational data of the superluminal source BL Lac 0735 178 for which Bregman et al. (1984) obtained simultaneous spectra covering the radio through th X-ray regimes.

As an example, Fig. 2 shows the nonlinear evolution of the density contrast between the perturbed and the ambient regions $\rho_p/\rho_o = (\rho_1+\rho_o)/\rho_o$ (with an initial density perturbation $\rho_1(o)/\rho_o(o) = 0.1$) for the family of models based on model (b2). Fig. 3 shows the corresponding contrasts between the electronic pressure of the perturbed and the ambient regio Model b2 was taken as the reference model. The four regions (b2(I),b2(II),b2,and b2(III)) were simultaneously compressed at t=0. The initial displacement $\Delta\ell$ of each region relative to b2 is

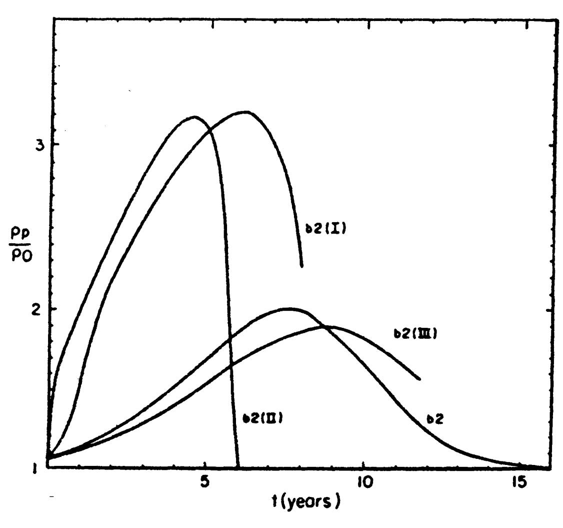
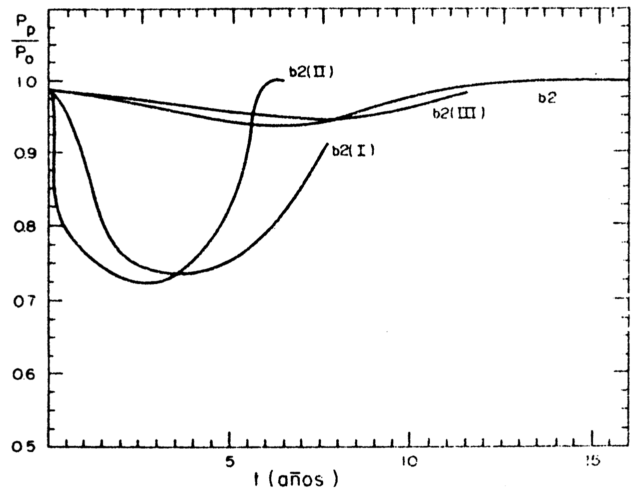


Fig. 2: Time development of the density contrasts ρ_p/ρ_o for models b2(I), b2(II), and b2(III) compared with model b2.



.g. 3: Time development of the electronic pressure contrast P_p/P_o for models b2(I), b2(II),and b2(III) compared with model b2.

.ven in Table 1. In Table 1 is also given the radius of the jet at t=0, R(0), the distance $_{ax}$ $(=V_J\ t_{max} + R(o)/\tan\theta)$ of the peak of the condensation from the core of the source for ıch model and the apparent velocity $V_{Ap} = \Delta\ell_{max}/\Delta t_{max}$, for the peak of each derived model :lative to the peak of the reference model (or vice-versa).

A Lorentz correction F_{COR} was made to the above evaluated V_{Ap}.The thermal instability ıd its time evolution is evaluated in the plasma frame. Since $\Delta\ell$ is in the inertial frame

TABLE 1: Models b2: $\theta = 0.05$ $\beta_J 2 = 0.7$ $\delta_1(o) = 0.1$ and $\delta_2(o) = 0.2$.

MODEL	$\Delta\ell$ (pc)	R(0) (cm)	t_{max} (anos)	ℓ_{max} (cm)	V_{Ap}/c
b2	0	4.35(17)	7.3	1.44(19)	-
b2(I)	-0.5	3.60(17)	5.6	1.16(19)	1.74(2.49)
b2(II)	-1.0	2.85(17)	4.4	9.17(18)	1.91(2.80)
b2(III)	+0.5	5.1 (17)	8.4	1.68(19)	2.31(3.53)

$_{COR} = 1 + (\Gamma_J - 1)(1 - f_J)$, where $f_J \equiv V_J/V_{Ap}$ and $\Gamma_J \equiv (1 - \beta_J{}^2)^{-1/2}$(GOIII). The Lorentz corrected ›parent velocity for an inertial observer, $F_{COR}(V_{Ap}/c)$, is noted in parenthesis in the column ›r V_{Ap}/c in Table 1.

CONCLUSIONS AND DISCUSSION

For BL Lac 0735-178, whose basic data we have used, we obtained $V_{Ap}/c \sim 3$. This ꞉sult is in close agreement with observations, which indicate for BL Lac 0735+178 $V_{Ap}/c \approx 2.8$ 3aath, 1984).

The principle conclusions of this work can be summarized as follows: 1) Superluminal ›parent velocities can be produced in jets with $\beta_J{}^2 \leq 0.7$ in separation distances $\sim$ (0.5-1.0 pc); ׀ The jet can be randomly oriented; 3) The size, R, of the emitting region is relatively large ›ut smaller than the present VLBI resolution). R is not limited by the condition $R < c\tau$ imposed ׳ flux variability and light-travel-time arguments (where τ is the characteristic time of ıriability) since the formation of the condensation propagates with a velocity $V_{Ap} > c$. Our ›del is consistent with present observations and predicts: a) Deprojected linear sizes for the ›urces which are not excessively large; and b) high probability for a sample of sources, with ındom distribution of angles between the source (i.e. jet) axis and the line of sight, to have ›parent superluminal motion. The model is thus an interesting possible alternative to the :andard beaming model for explaining apparent superluminal motion and related phenomena.

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