PHYSICAL PARAMETERS IN RELATIVISTIC JETS FROM COMPACT SYMMETRIC OBJECTS

M. PERUCHO AND J.M. MARTÍ
Dpt. Astronomia i Astrofísica, Universitat de València
46100 Burjassot (València), SPAIN

Abstract. Compact symmetric objects conform a class of sources characterized by high luminosity radio emission located symmetrically on both sides of the active galactic nucleus on linear scales of less than 1 kpc. Given their small size, the hot spots of the jets in CSOs provide a unique laboratory for the study of the physics of relativistic jets and their environment close to the central engine. We present a simple model for the hot spots in CSOs assuming synchrotron emission, minimum energy and ram pressure equilibrium with the external medium. Further comparison of our model with observational data allows us to constrain the physical parameters in the hot spots and the jets feeding them, and the density profile of the external medium.

1. Introduction

In the early eighties Phillips and Mutel (1982) first detected compact radio sources with double structure, known as compact doubles. Later on, compact symmetric objects (CSOs) were defined by Wilkinson et al. (1994) as core-detected sources with double sided emission and total linear size smaller than 1 kpc. They present a typical synchrotron spectrum at high radio frequencies, with a peak due to absorption, around the GHz, i.e., they are also included within a class of objects known as gigahertz peaked spectrum sources.

The main controversy about the nature of CSOs has been if they are old, confined sources (van Breugel et al. 1984; Carvalho 1998) or the young precursors of large Faranoff-Riley II (Owsianik et al. 1998; Taylor et al. 2000). The study of this class of compact sources is thus very interesting as a family of objects on their own, and they provide a scenario to probe jet properties close to the active nucleus.
In this contribution, we present results for the physical conditions in the jets and hot spots in a sample of CSOs and summarize the main conclusions of a simple evolution model, trying to discern between the proposed scenarios by comparing the model with observational data. All the quantities have been calculated assuming synchrotron emission, minimum energy and ram pressure equilibrium with the external medium. Calculations are performed assuming the Universe is described by the standard Friedmann-Robertson-Walker model with Hubble constant \( H_0 = 70 \text{ km s}^{-1} \text{ Mpc}^{-1} \) and deceleration parameter \( q_0 = 0.5 \).

Sources have been selected from the GPS samples of Stanghellini et al. (1998), Snellen et al. (1998), and Peck et al. (2000). We have chosen those sources with double morphology and already classified in the literature as CSOs and also those whose components can be safely interpreted as hot spots even though the central core has not been yet identified. Moreover, sources possibly affected by orientation effects (beaming, spectral distortion), like quasars and core-jet sources, have not been considered. The resulting sample is formed by 20 sources which are listed, along with the data relevant for our study, in Perucho & Martí (2001).

2. Physical parameters of hot spots and jets

Panels (a) and (b) display hot spot radius \( r_{hs} \) and hot spot luminosity \( L_{hs} \), respectively, versus source linear size \( L_S \). These quantities are directly obtained from the corresponding angular sizes and the formulas for cosmological distance. A selfsimilar evolution for the hot spot \( r_{hs} \propto L_S \) is clearly observed. The hot spot luminosity seems to be independent of the source linear size, with only a weak tendency to grow with \( L_S \).

We have also estimated the internal energy and pressure in the hot spots assuming that the magnetic field strength and the particle energy distribution arrange in the most efficient way to produce the estimated (synchrotron) luminosity. These minimum energy conditions are reached near the equipartition conditions in which magnetic field and particle energy have the same values. Finally, the number density of relativistic particles within the hot spots is estimated assuming that there is no thermal (leptonic nor barionic) component. Panels (c) and (d) show the distribution of pressures and number densities of relativistic particles in the hot spots, \( p_{hs} \) and \( n_{hs} \), respectively, as a function of \( L_S \). We refer the interested reader to the Appendix in Perucho & Martí (2001) for details on our model.

We can use the values of the pressure and particle number density within the hot spots to estimate the fluxes of momentum (thrust), energy and particles in the relativistic jets feeding them. Ram pressure equilibrium between the jet and hot spot leads to \( F_j = P_{hs} A_{hs} \), for the jet thrust \( F_j \),
Figure 1. Mean radius (panel a), radio luminosity (b), pressure (c) and electron density (d) of hot spots versus linear size. Solid lines correspond to the best linear log-log fits. Results are $\log(r_{hs}) \propto (1.0 \pm 0.3) \log(LS)$ ($r = 0.8$), $\log(L_{hs}) \propto (0.4 \pm 0.5) \log(LS)$ ($r = 0.2$), $\log(P_{hs}) \propto (1.7 \pm 0.4) \log(LS)$ ($r = -0.75$), and $\log(n_{hs}) \propto (2.3 \pm 1.3) \log(LS)$ ($r = -0.75$). $r$ stands for the regression coefficient of the corresponding fits. Error bars correspond to 15% errors in angular size and measured radio flux and are just indicative.

where $A_{hs}$ stands for the hot spot cross section ($\simeq \pi r_{hs}^2$). Taking mean values for $P_{hs}$ and $r_{hs}$ from our sample we get $F_j \simeq 8.3 \times 10^{34}$ dyn. In a similar way, the particle flux in the jet, $R_{hs}$, can be estimated from the total number of particles in the hot spot, $n_{hs}V_{hs}$ ($V_{hs}$ is the hot spot volume, $\simeq 4\pi r_{hs}^3/3$) and the source lifetime, $\simeq v_{hs}/LS$, where $v_{hs}$ is the hot spot advance speed (assumed constant and $\simeq 0.2c$; see below). According to this, $R_j = n_{hs}V_{hs}v_{hs}/LS \simeq 1.3 \times 10^{49}$ e$^{+/−}$ s$^{-1}$. Finally, a lower bound for the jet power, $Q_j$, can be estimated considering that, in a relativistic jet, $Q_j = (F_j/v_j)c^2$. Hence, for given $F_j$ and taking $v_j = c$, we have $Q_{j,\text{min}} = F_jc = P_{hs}A_{hs}c = 2.5 \times 10^{45}$ erg s$^{-1}$. It is interesting to note that the lower bound for the jet power is consistent with the one obtained by Rawlings & Saunders (1991) for FRII radio galaxies ($10^{44}$ erg s$^{-1}$) supporting the idea of CSOs being the early phases of FRIIs. Also, the flux of particles inferred in the jet is consistent with accretion rates of barionic plasma of the order $0.35M_{\odot}$ y$^{-1}$, implying a highly efficient conversion of accretion energy at the Eddington limit into ejection (or a leptonic composition of jets).
3. An evolution model for CSOs

The results presented in Sect. 2 admit an evolutive interpretation assuming the linear size of the source (LS) is related with time by means of the hot spot advance speed ($v_{hs}$). According to this, we have developed a model (Perucho & Martí 2001) for the evolution of CSOs within the first kpc assuming that the advance speed is determined by ram-pressure equilibrium between the relativistic jet and the external medium and consistent with the self-similar character of the source growth. The linear fits shown in Fig. 1 together with the assumption of an almost constant advance speed (Owsianik et al. 1998, Taylor et al. 2000), allow us to determine the values of the parameters in our model. Results show that, in order to maintain increasing luminosity and constant advance speed, it is required to invest increasing power with time which can lead to severe energy problems. On the other hand, fixing a constant jet power supply, keeping constant advance speed requires decreasing luminosity, and viceversa: when luminosity is kept increasing with linear size, external density has a less steep gradient, turning out in a less steeply decreasing internal pressure, and a decreasing advance speed; on the other hand, keeping speed constant, external density has to decrease faster, causing a fast expansion of the hot spot and a decrease in luminosity.

Finally, our results allow us to estimate the ages and speeds of the sources at one kpc from the central engine. Considering a (constant) advance speed of 0.2c, the age is $1.6 \times 10^4$ y. If we allow for a decrease in the advance speed (as suggested by one of our models), the age of a source which starts to decelerate at 10 pc (100 pc) will be of $10^5$ y ($3.5 \times 10^4$ y) at 1 kpc. These results support the young source scenario for CSOs. Moreover, the speeds of the hot spots at the end of the first kpc (0.02 – 0.06c) are consistent with the terminal speeds inferred for FRIIs.

Much more conclusive answers could be given if there was a larger sample of CSOs with i) measured advance speeds, and ii) measured luminosities.

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