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2006 J. Phys.: Conf. Ser. 31 201

(http://iopscience.iop.org/1742-6596/31/1/053)

Institute of Physics Publishing
Journal of Physics: Conference Series **31** (2006) 201–202
doi:10.1088/1742-6596/31/1/053
The Third 21COE Symposium: Astrophysics as Interdisciplinary Science

Estimate of the total power and age of FRII radio galactic jets

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Abstract. By using analytical model of cocoon expansion, we examine the total power and age of jets in five FRII radio galaxies. The estimated total power is quite larger than those estimated in previous works based on observation of non-thermal emission from electrons. This might imply that the amount of unobservable particles (e.g. protons and thermal component) can not be ignored when considering jet dynamics.

1. Introduction

Relativistic jets in powerful radio galaxy forms a cocoon configuration filled with shocked jet matter via interaction with intra-cluster medium (ICM) (see Fig. 1). Recently, Kino & Kawakatu 2005 (hereafter KK05) proposed an analytical model which describes cocoon evolution. By comparing the observed shape of cocoon and the analytical model, the power and the age of the jet can be estimated. In this paper, by using the identical model used in KK05 (with a little modification), we examine five FRII radio galaxies which are Cygnus A, 3C223, 3C284, 3C263, and 3C219.

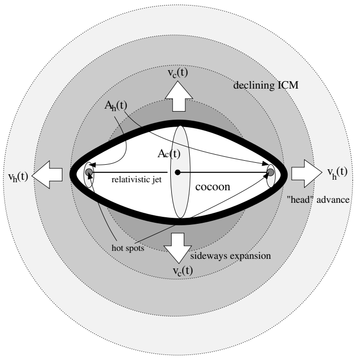

Figure 1. Schematic picture of the interaction of the ambient medium and the relativistic jet in FR II radio galaxy. Most of the kinetic energy and mass of jet is deposited in overpressured cocoon with cross sectional area of body (A_c). The sideway expansion speed of cocoon is (v_c). The reverse shocked region is identified as a hot spot. The forward shock is identified as a bow shock. The area of the radio lobe at the position of hot spots (A_h) is larger than that of hot spots. The area of bow shock expands into the ambient medium with speed (v_h).

Table 1. Estimated total power and age of 5 FRII radio galaxies

Name	$t_{age}(Myr)$	$L_j(erg/s)$	L_j/L_{Edd}
Cygnus A	18 - 42	1.0×10^{46} - 5.2×10^{46}	0.029 - 0.16
3C223	260 - 528	4.7×10^{45} - 1.9×10^{46}	0.25 - 1.0
3C284	220 - 510	2.0×10^{45} - 1.1×10^{46}	
3C263	94 - 230	1.9×10^{46} - 1.1×10^{47}	0.071 - 0.42
3C219	100 - 180	4.5×10^{46} - 1.4×10^{47}	2.1 - 6.8

2. Analysis using cocoon model

We consider 2-dimensional model, and our basic assumptions are as follows; (1) Jet is relativistic among large scale ($v_j \sim c$), (2) Power of jet L_j is constant in time, (3) Cocoon is overpressured against ICM. Basic equations in our model are the equation of motion along the jet axis, the equation of motion of sideway expansion, and the energy conservation in the cocoon which are given as

$$\frac{L_{\rm j}}{v_{\rm j}} = \rho_{\rm a}(r_{\rm h}) v_{\rm h}^2(t) A_{\rm h}(t), \tag{1}$$

$$P_{\rm c}(t) = \rho_{\rm a}(r_{\rm c})\ v_{\rm c}(t)^2, \tag{2}$$

$$\frac{P_{\rm c}(t)V_{\rm c}(t)}{\hat{\gamma}_{\rm c} - 1} + \int_{t_{min}}^{t} P_c(t^{'})\frac{dV_c(t^{'})}{dt^{'}}dt^{'} \simeq 2L_{\rm j}t, \tag{3}$$

where $\hat{\gamma}_{\rm c}$, $r_{\rm h}$, $r_{\rm c}$, $V_{\rm c}$, and $P_{\rm c}$ are the specific heat ratio, the length of the cocoon, the width of the cocoon, the volume of the cocoon, and the pressure of the cocoon, The other quantities are defined in the caption of Fig. 1. The only difference with the KK05 is the inclusion of work done by cocoon in eq. (3). Results obtained by comparing the observed cocoon shape and the analytical model are summarized in Table 1. For the sources which the central black hole mass is estimated from observation, the ratio between power and Eddington luminosity are listed.

3. Discussions and Conclusion

The quantity L_j/L_{Edd} indicates the required minimum mass accretion rate onto central black hole normalized by the corresponding Eddington mass accretion rate. This gives a constraint on central region activity. Comparing with the previous works (e.g. Rawlings & Saunders 1991), obtained power in present paper is quite larger (∼one order or more). Their estimates of power are based on the observed radiation from the non-thermal electrons. Thus, our results might imply that the amount of unobservable particles (e.g. protons and thermal component) can not be ignored when considering jet dynamics. The particle content of the jets is an open question and is a future work (see Ref. [3]).

Acknowledgments

This work was partially supported by the Grants-in-Aid for the Scientific Research (17540267, 14079202) the Ministry of Education, Science and Culture of Japan and by Grants-in-Aid for the 21th century COE program “Holistic Research and Education Center for Physics of Self-organizing Systems”.

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