THEORETICAL PROPERTIES OF RADIO-GALAXIES

II. Luminosity and Energetics

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Abstract. In this paper we deduce, following a dimensional approach, the theoretical luminosity of a radio-galaxy and we make a confrontation with the observed one as deduced from a large sample of symmetric double radio-galaxies. Equalizing the two luminosities, we obtain the density and the energetics function of the intrinsic radio-luminosities.

List of symbols

\begin{itemize}
  \item \( W_{\text{m}} \) energy density of ambient magnetic field,
  \item \( W_{\text{tm}} \) energy density of magnetic turbulence,
  \item \( t_{\text{ins}} \) time-scale of K-H instabilities,
  \item \( t_{\text{cas}} \) time-scale of turbulent cascade,
  \item \( Q \) power reversed in the cascade,
  \item \( L \) observed luminosity,
  \item \( L_{\text{th}} \) theoretical luminosity,
  \item \( R \) jet radius,
  \item \( s \) sound velocity,
  \item \( B_{\text{eq}} \) magnetic field of equipartition,
  \item \( v_{\text{A}} \) Alfvén velocity,
  \item \( v_{\text{c}} \) corrected velocity of the jet,
  \item \( v_{\text{VLBI}} \) velocity in the VLBI jet,
  \item \( v_{\text{acc}} \) velocity in the accretion zone,
  \item \( \beta \) ratio between thermal and magnetic pressure,
  \item \( \beta_{\text{av}} \) average value of \( \beta \) of the sample,
  \item \( \rho \) mass density,
  \item \( \rho_{\text{c}} \) weighted mass density,
  \item \( n \) number of particles \( \text{cm}^{-3} \),
  \item \( n_{\text{acc}} \) number of particles in the accretion zone \( \text{cm}^{-3} \),
  \item \( N \) number of points of the sample = 180,
  \item \( t \) \( t \)-student variable,
  \item \( r \) degree of linear correlation,
  \item \( M \) mass flow,
  \item \( \dot{E} \) flux of kinetic energy,
  \item \( \dot{M}_{\text{acc}} \) critical accretion rate,
  \item \( M_{\text{cr}} \) critical mass,
  \item \( M_{\odot} \) 1 solar mass,
  \item \( \theta \) opening angle of the jet.
\end{itemize}
1. Introduction

The extragalactic radio-sources present, at the moment, many open problems of physics:

1. What physical mechanism is producing, in situ, acceleration of electrons with consequent radio-emission?
2. What is the energy reservoir able to produce the high luminosities observed?
3. What are the total masses and energies involved over the lifetime of the radio-sources?
4. What are the physical conditions in the VLBI jets and in the thick disk near the massive central object?

However, it is my purpose in this paper to explore the possibilities of the turbulent cascade approach, developed in a recent paper, but of which I give a synopsis below.

2. Turbulent Cascade

In a recent paper, Pelletier and Zaninetti (1984) investigated the contribution of hydrodynamic instabilities to the luminosity of extragalactic radio-jets assuming that most of the power of a turbulent cascade is absorbed by radiating particles. A simple formula for the expected theoretical luminosity $L_{th}$ can be deduced using equipartition arguments between ordered and turbulent magnetic field. The energy density in magnetic turbulence $W_{tm} = \frac{\delta B}{8\pi}$ and in the ordered magnetic field $W_m = \frac{B^2}{8\pi}$ is given by

$$ W_{tm} = W_m = \frac{(v_A)^2 \rho}{2} \quad (2.1) $$

where $B$ is the magnetic field strength, $\rho$ is the density of thermal particles, and $v_A$ is the Alfvén velocity which, under equipartition assumption with thermal particles, is equivalent to the generalized sound velocity $s = \frac{3}{2} v_A (3\beta)^{1/2}$.

The time-scale of instabilities that could trigger-off a cascade from large scales to small scales, where the acceleration is taking place, is of the same order of magnitude of the time-scale of formation of the turbulence: i.e.,

$$ t_{inst} \sim t_{cas} \sim \frac{R}{s} \quad (2.2) $$

where $R$ is the radius of the jet, then we can easily obtain the power $Q$ reversed in the cascade as

$$ Q \sim \frac{(\delta B)^2 s}{8\pi R} = 2v_A^3 \rho (3\beta)^{1/2}/6R \quad (2.3) $$

This last formula is in agreement with Equation (3.7) which Pelletier and Zaninetti (1984) have deduced in a more sophisticated manner. The maximum luminosity attainable in a cylindrical region of radius $R$ and length $R$ becomes

$$ L_{th} = v_A^3 \rho R^2 (3\beta)^{1/2} \quad (2.4) $$