SHOCKWAVES IN EXTENDED NEAR-RELATIVISTIC JETS

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ABSTRACT. The origin of the sharp near infrared cutoff in the continuous energy distribution of many compact non-thermal sources (active nuclei or knots in jets) is considered under the assumption that particle acceleration takes place in shockwaves. Energy losses due to synchrotron emission and Compton interactions set upper limits to both electron and proton energies. In this case the upstream disturbance of the flow is dominated by the most energetic protons which are postulated, by analogy with the solar wind, to excite a turbulent wave spectrum of Kolmogorov type in this region. We predict for near relativistic flows a spectral cutoff near 3 10^{14} Hz independent of magnetic field. The observation of a sharp spectral cutoff near 3 10^{14} Hz is thus independent evidence for near-relativistic flows in jets.

1. INTRODUCTION

Emission regions in certain jets as well as compact sources (BL Lac's, OVV's and red quasars) quite frequently show evidence of a sharp cutoff in the continuous spectrum near 3 10^{14} Hz (e.g. Meisenheimer and Röser 1986). We interpret this cutoff spectrum as synchrotron emission from an electron population with a sharp upper limit to the electron energies.

Within the framework of diffusive shock acceleration (e.g. Drury 1983) we discuss here the acceleration of both protons and electrons subject to synchrotron losses. Due to their lower losses the protons reach much higher energies, and thus go much further upstream than the electrons. We postulate that they excite the dominant turbulence spectrum which determines the resonant scattering of particles at lower than the maximal energy. By analogy with the solar wind plasma (e.g. Goldstein et al 1984) we assume that the spectrum of this turbulence is of Kolmogorov type.

In section 2 we derive the spectral cutoff frequency and in section 3 some consequences. A fuller account, including Compton interactions, neutrino emission and variability is being published elsewhere (Biermann and Strittmatter 1987).

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2. THE MODEL

In order to determine the energy and spatial scale we first derive the maximal particle energy for protons by setting acceleration and loss time equal to each other. This yields a maximal proton energy $E_{p,max}$ of

$$E_{p,max} = 5.6\ 10^{10}\ (b/B)^{1/2}\ U/c \quad GeV$$

where U is the upstream velocity, B the magnetic field strength and c the speed of light. b is the fraction of magnetic energy residing in the turbulence. Thus given the scale the analysis can be repeated for electrons from which we derive an upper limit so the synchrotron emission frequency ν^* of

$$\nu^* = 3\ 10^{14}\ (3b\ (U/c)^2)\ Hz.$$

On dynamical grounds it appears likely that $b \lessapprox 1$; particle acceleration becomes inefficient for $(U/c)^2 \gtrapprox 1/3$ (Webb 1985). Hence, 3 10^{14} Hz appears to be a strong upper limit. A generalized version of this model is discussed in Biermann and Strittmatter (1987).

3. CONSEQUENCES

Observations of jets (Eckart et al 1986, Johnston et al 1987, Biermann et al 1987), compact and extended if measured in kpc, demonstrate that a large fraction of jets have near-relativistic or relativistic velocities. Associated shockwaves should also be near-relativistic (or relativistic). Our model predicts that the emission knots in jets, interpreted as shock waves, should show a sharp spectral cutoff near 3 10^{14} Hz. We thus have an aspect-independent means to find relativistic motion.

For the outermost knot in a jet, which has near relativistic motion, magnetic fields of order 10^{-4} Gauss are inferred. Our model then predicts maximal proton energies of order 10^{12} GeV in accord with the highest energies observed in cosmic rays. We note that escaping high energy particles suffer very much less adiabatic losses than during an escape from a compact region near to an active nucleus itself. We thus may have identified with observations such as given by Meisenheimer and Röser (1986) the sources of very high energy cosmic rays.

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