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HOT ELECTRONS IN THE M87 JET

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INTRODUCTION

Hubble Space Telescope images of the M87 jet (Boksenberg et al. 1992) reveal that the optical/UV morphology is strikingly similar to that of the radio (Owen, Hardee and Cornwell 1989). This is at odds with naive considerations of synchrotron cooling, whether the radiating electrons are assumed to be accelerated in the nucleus or at the leading edges of the emitting knots. We discuss possible resolutions of this puzzle, and propose a definitive observational test.

MORPHOLOGY

As noted first from the radio data (Owen, Hardee and Cornwell, 1989), the M87 jet is limb-brightened in places and the coherent structure visible between knots 'A' and 'B' is suggestive of a magnetic filament which is wrapped around the jet. These authors also noted that the interior of the jet might be largely free of magnetic field and so could function as a low-loss conduit for a flow of relativistic particles. We suggest a modification of these ideas.

It is well known that magnetized jets tend to become dominated by internal magnetic stresses as adiabatic expansion proceeds, motivating the study of "force-free" configurations (e.g. Konigl and Choudhuri 1985). Such structures have little resistance to bending and are intrinsically floppy; bending occurs as a consequence of excess pressure. We therefore suggest a model of the M87 jet as a twisted-up, quasi force-free flux rope which carries all of the power emanating from the nucleus. The spatial structure which can be resolved in the jet is then interpreted as segments of the coiled rope, these being identified with the radio-optical filaments. The observed limb-brightening of the jet indicates that the rope tends to coil into a hollow configuration.

LOCAL OR NUCLEAR ACCELERATION

Estimates of the magnetic field strength in the M87 jet imply that the synchrotron lifetime of optically-emitting electrons is short. Local acceleration in the jet has therefore been invoked to account for the observed optical synchrotron emission, but it is difficult to reconcile the detailed optical/radio correlation with existing local acceleration models. If our proposed morphology is correct it may be that electrons are accelerated locally at shocks in the flux rope, and then radiate as they continue to stream out along the rope. The cooling length is then measured along the flux rope, not along the axis of the jet.

An alternative follows from the point that almost any scenario for generating a rope-like flow of energetic particles and magnetic field incorporates axial structure within the rope. For example, in the massive black hole plus accretion disk picture most of the power flows down the center of the rope, while most of the angular momentum is carried off by the outer parts of the rope. In particular there is no reason to suppose that the magnetic field is uniform across the rope: pressure balance merely requires that the total pressure vary slowly, while the magnetic and particle contributions may anticorrelate, giving rise to a magnetically confined low-loss flow. This means that particle acceleration in the nucleus is viable.

SPECTRA

The issue of local versus nuclear electron acceleration can be decided by measuring the high-energy spectrum of the jet. At energies above 10 keV the flux from knot A should be dominated by synchrotron self-Compton emission with spectral flux $F_\nu = C\,\nu^{-0.64}$ Jy (ν is in Hz), with $C \sim 100 - 4000$ for the case of nuclear acceleration, and $C \simeq 2$ for local acceleration. This difference between the models arises as follows. If the electrons are accelerated in the nucleus their radiating lifetime must be much longer than if they are accelerated locally in the jet, in order to account for the observed optical synchrotron emission. It follows that the average synchrotron power per electron is lower in the nuclear than in the local acceleration model. (The average synchrotron emissivity may be reduced by allowing a lower uniform magnetic field, or by having a strong field with a small filling factor.) Since the average synchrotron emissivity is lower for the nuclear acceleration model, more electrons are required to produce the observed synchrotron power and the flux due to inverse-Compton scattering is therefore much larger.

Some support for the nuclear acceleration model already exists. The observed X-ray/optical flux ratio decreases with increasing distance from the nucleus (Biretta, Stern and Harris 1991) and this is attributable to synchrotron spectral ageing. However, measurement of the broad-band spectral properties at higher energies would be the decisive test. For the most extreme nuclear acceleration model, which corresponds to a jet speed of $\beta_j \sim 0.1$, the expected flux from knot A at GeV energies is on the limit of detectability of the EGRET instrument on the Gamma-Ray Observatory; other models give lower fluxes. It might even be possible to detect knot A at TeV energies (via atmospheric Cerenkov) if the electrons are accelerated in the nucleus.

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