TWO-FLOW MODEL FOR EXTRAGALACTIC RADIO JETS

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Different models of extragalactic jet formation have been proposed in the litterature. They usually considered only one population of particles, ascribing one typical bulk velocity to the jet. However from the point of view of plasma physics it seems very likely that beams of particles with different velocity will be generated in the surroundings of the central engine by any kind of jet acceleration mechanism. This can lead to a typical beam-plasma configuration with a slow ambient plasma pervaded by energetic beams which constitute a population inversion and are a potential source of energy and of instability.

To investigate the role of the beam-plasma instability in the physics of astrophysicals jets, we considered the simplest scenario with a beam-plasma configuration but still consistent with the current knowledge on extragalactic jets. This includes three components :

(i) a relativistic beam of electrons and positrons, related to the VLBI jets, with a bulk Lorentz factor deduced from the observed superluminal motion,
(ii) a longitudinal magnetic field, as inferred from VLBI polarization maps and also from theoretical studies of black hole magnetosphere evolution,
(iii) and a slow ambient plasma of electrons and protons due to the accreted interstellar medium and to a wind from the accretion disk.

The presence of a relativistic beam and of a longitudinal magnetic field is directly grounded on observational facts. The presence of a slow ambient plasma has no direct observational signature yet. However it seems hard to avoid especially in the vicinity of the central engine. It might be responsible for a part of the X-ray emission of the active galactic nuclei and play a role in the confinement of broad and narrow emission line clouds. Evidence of this ambient plasma and estimates of its density can be expected from further Faraday depolarization data which up to now provide only upper

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limits.

Assuming given a relativistic beam, a wind from the accretion disk and a longitudinal magnetic field, we studied the strong Langmuir turbulence excited by the beam-plasma interaction and the development of the self-modulation instability (the quasilinear theory is not expected to apply for high values of γ, the Lorentz factor of the beam). Under simplifying assumptions such as small transverse wavenumber $k_\perp$ and small thermal velocity v_{th} in the ambient wind, we deduced the evolution of the Langmuir waves packets. Following the perturbation method developed by Karpman and Maslov (1978) and Kaup and Newell (1978) we found that they are stable against transverse perturbations for high values of the magnetic field, namely when the cyclotron frequency $\omega_c = eB/m_e c$ is greater than the plasma frequency $\omega_p = \left(\frac{4\pi n_p e^2}{m_e}\right)^{1/2}$. Conversely, for weak magnetic field, when $\omega_c < \omega_p$, we found that the Langmuir waves packets are unstable and collapse towards small scales (Pelletier et al, 1988). Then qualitative arguments about the detuning of the beam-plasma interaction due to large density fluctuations in the strong field zone lead to the idea that the beam itself is stable and can propagate as long as the magnetic field is strong enough ($\omega_c > \omega_p$). However when the beam reaches the weak magnetic field zone it starts losing its energy. The beam-plasma interaction generates Langmuir waves in the ambient wind which evolue through the self-modulation instability and collapse towards the Debye's sphere where they transmit their energy to the ambient wind through Landau effect. Energy is then transferred from the beam to the ambient wind, which induces the destruction of the beam after some relaxation length.

Using a self-similar solution for the collapse of the Langmuir waves packets and under the assumption that all the energy of the beam goes through such a mechanism we obtain an estimate of the beam relaxation length

$$z_R = \gamma^{14/3} \left(\frac{m_e c^2}{T}\right)^{5/3} \left(\frac{n_b}{n_p}\right)^{1/9} \frac{c}{\omega_p}$$

The value of the relaxation length is thus very dependent on the Lorentz factor of the beam. We can adopt for γ a conservative value of the order of 10 or less, as deduced from the standard model of superluminal sources. The beam to ambient plasma density ratio n_b/n_p does not have a great influence on the relaxation length. We assume it of the order of 0.01. Up to now, observational data do not provide direct information on the density and temperature of the ambient plasma. All we can say is that in a realistic range of density and temperature, for instance n_p between 10^{-3} cm^{-3} and 10^2cm^{-3} and T between 10^4K and 10^8K, the relaxation length is always much smaller than typical lengths of VLBI jets. It is also smaller than the relaxation length due to other dissipation effects such as relativistic bremsstrahlung, diffusion on turbulent Alfven waves, ionization losses, electron-positron annihilation, synchrotron losses or inverse Compton effect at some parsecs from the central engine (Sol et al, 1988). The dynamics of the beam seem therefore controlled by the magnetic field strength. The beam propagates for a magnetic field larger than a critical value $B_c = 3.2 \times 10^{-3} \sqrt{n_p}$ and is rapidly destroyed as soon as $B < B_c$. The problem is then to have an estimate of the relative importance of the magnetic field.

For the fiducial values given by Rees (1984), we obtain a ratio $B/B_c \simeq 40$ close to the active galactic nuclei which is consistent with the beam extraction and propagation from the vicinity of the central engine.A simple flux conservation model leads to a ratio B/B_c inversely proportional to $\sqrt{S}$, (S is the cross-sectional area of the jet). This corresponds to a decrease of B/B_c with the distance from the central engine, if the jet widens out. When B/B_c reaches unity the beam enters its relaxation zone and is destroyed , with a subsequent heating and entrainment of the wind. The heating likely induces a local enhancement of the radio emission. Acceleration of the wind can be described by the equations of hydrodynamics for two coupled fluids. We showed the possibility to have regular solutions with no shocks for the flow and to reach wind asymptotic velocities larger than 2c/5 (Sol et al, 1988). If the wind is identified with the jets observed at the kiloparsec scale, such midly relativistic values for the speed are high enough to explain the one-sidedness of large scale jets by a Doppler beaming effect.

Combining VLBI and VLA observations, Walker and cowokers (1987) obtained very detailed data on the radio galaxy 3C120. In particular, they derived under the usual minimum-energy assumption the variation of the magnetic field along the jet $B = 4.1 \times 10^{-5} r^{-0.97}$ G, where r is the measured full width at half maximum (FWHM) of the jet in arcseconds. The absence of any significant Faraday rotation gives an upper limit on the ambient plasma density inside the emitting jet $n_p \lesssim 9.9 \times 10^{-4}\ r^{-0.03}$ cm^{-3}, assuming a uniform magnetic field mainly oriented along the line of sight. With these values the ratio B/B_c reaches unity at $r \gtrsim 180$ pc which corresponds to a minimal distance of about 1.4 kpc from the central engine. This is amazingly close to the location of the 4"-radio knot, a "rather curious structure" described by Walker et al (1987). We propose to interpret this peculiar 4"-knot as the beam relaxation zone. The relativistic beam then survive for the first 4" from the nucleus and starts to be dissipated when it reaches the 4"-knot where $B/B_c = 1$. This picture is quite coherent with recent results of Benson et al (1988) and Walker et al (1988) which show some evidence for superluminal motion on kiloparsec scales in 3C120. Several properties of this curious 4"-knot can find a natural explanation in this context. Especially the morphology of the jet can suggest a change in the flow regime at the location of the 4"-knot, which would correspond here to the beam (respectively the wind) being mainly responsible of the radio emission before (respectively beyond) the 4"-knot.

Our two-flow model is not drastically different from the usual scenario for extragalactic jets. It introduces a new realistic latitude with allows qualitative explanations of the different types of extragalactic radio sources, according to the relative importance of the relativistic beam and of the slower ambient wind. It also allows high bulk Lorentz factor in the first part of the jets where superluminal motion are detected and midly relativistic bulk velocity on larger scales, without inducing any strong discontinuity in the jet structure. Moreover only a small fraction of the jet particles needs to reach very high bulk Lorentz factor, which can help to solve the problem of jet formation. Different steps in our study rely on simplifying assumptions or qualitative arguments required to progress further. This brings about uncertainties in the scenario. However there are several possible observational tests such as other estimates of the magnetic field and ambient plasma density in 3C120 and other superluminal radio sources showing peculiar knots somewhat reminiscent of the 3C120 4"-knot (NRAO 140, 4C39.25, 3C279, 3C345, 3C454.3, 3C245, 1642+690, 1928+738). Generally speaking, any direct evidence of a slow wind from the active galactic nuclei, for instance from positive Faraday depolarization measures or from detection of very faint non superluminal radio emission at VLBI scale in superluminal sources, would be an important clue in favour of two-flow models.

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