Jet deceleration: the case of PKS 1136-135

F. Tavecchio¹, L. Maraschi¹ and R.M. Sambruna²

¹ INAF-OAB, via Brera 28, 20121 Milano, Italy
² NASA/GSFC, Code 661, Greenbelt, MD, 20771, USA

1 Introduction

Despite decades of intense efforts, the present knowledge of the physical processes acting in relativistic jets is still rather poor and basic questions are awaiting answers (e.g. Blandford 2001). Among these problems, one of the most fundamental concerns the speed of the flow and the processes leading to deceleration. The present evidence suggests that FRI jets decelerate, becoming trans-relativistic, quite early, within few kiloparsecs (e.g. Bridle & Perley 1984), while the situation for FRII jets appears more ambiguous. The interpretation of multiwavelength observations of extended jets in QSOs points toward highly relativistic speeds (Γ ~ 10) even at very large scales (~ 100 kpc; Tavecchio et al. 2000, Celotti et al. 2001; see Stawarz et al. 2004 and Atoyan & Dermer 2004 for some criticisms to the model). In the same sources, recent multiwavelength observations suggest that also these jets undergo deceleration close to their terminal hot spots. This (model-dependent) conclusion is based on the observed increase of the radio to X-ray flux along the jet, which, interpreted in the framework of the synchrotron-IC/CMB emission model, uniquely implies deceleration.

The possibility of “observing” the gradual slowing-down of a jet could in principle provide precious information on the physical processes at work. This approach was successfully developed in great detail for a few FRI jets where the morphology could be well studied thanks to the large angular scale (e.g. Laing & Bridle 2002). Here we report on the analysis performed on the FRII jet of the quasar PKS 1136-135, for which the excellent data (Sambruna et al. 2006), allow us to apply a similar (but less detailed) approach. More details can be found in Tavecchio et al. (2006).
2 Modelling deceleration

The profiles of the interesting physical quantities of the jet (the bulk Lorentz factor, $\Gamma$, the intensity of the magnetic field, $B$, and the density of the non-thermal electrons, $K$) can be derived by applying the IC/CMB emission model to the measured radio and X-ray fluxes at different emission knots along the jet. The derived values for different regions in the jet are shown in Fig. 1. The errorbars take into account as much as possible all the uncertainties (associated to the measurements and the modelling) affecting the derivation of the parameters. Clearly, the Lorentz factor appears to decrease along the jet, going from $\Gamma \sim 6$ at B to $\Gamma \sim 2.5$ at F. At the same time, the inferred magnetic field and the particle density increase, as expected in the case of deceleration (Georganopoulos & Kazanas 2004).

Fig. 1. Left Panel: profiles of the relevant quantities ($\Gamma$, top panel, $B$ and $K$, lower panel) for regions B–F of the jet of PKS 1136-135 estimated from the radiative model. Right Panel: the pressure inside the jet as a function of the Lorentz factor of the jet, calculated with the momentum and energy flux conservation laws (Bicknell 1994), assuming the initial conditions inferred for knot C. The solid line refers to the case in which the initial pressure of protons is negligible, while the dashed line is calculated assuming an initial pressure in protons ten times that supported by the non-thermal component (relativistic electrons and magnetic field). Crosses indicate the value of the non-thermal pressure (provided by magnetic field and non-thermal electrons) calculated through the modelling of the observed emission (both plots are adapted from Tavecchio et al. 2006).
In the case in which the jet inertia is dominated by protons (as supported by several indications, e.g. Maraschi & Tavecchio 2003), we explored the possibility that entrainment of external gas is effective in decelerating the jet. Basically, deceleration through entrainment can be understood to happen through a continuous series of inelastic collisions between the moving plasma and the external gas at rest. As a result of the collision, part of the kinetic energy is dissipated and converted into internal energy of the jet, thus increasing the internal pressure. We applied the hydrodynamical treatment, based on the use of energy and momentum conservation, developed by Bicknell (1994) to describe the deceleration of the jet of 1136-135 in order to discuss the plausibility of the entrainment mechanism for this particular case. The predicted run of the pressure is reported in Fig. 1.

3 Discussion

The proposed scenario can explain in a plausible way the deceleration inferred for the jet of 1136-135 (and possibly in the other sources showing the same radio-to-X-rays increasing trend). A more detailed understanding of the processes at work and the comparison with the observed properties of jets necessarily involves several still poorly-known physical issues. An important feature of the entrainment-induced deceleration is that the jet starts to slow down significantly when the mass of collected gas is of the order of \(1/\Gamma\) of the mass transported by the jet. In this framework, jets characterized by different mass fluxes will experience different behaviours. Large mass fluxes will assure that, under the same conditions of external gas density and entrainment rate, the jet will reach its hotspot almost unperturbed. On the other hand, jets with a small mass flux will be decelerated soon. It is tempting to further speculate along these lines, associating the FRII morphology to jets with large mass flux and FRI objects to jets characterized by small mass fluxes.

References

1. Atoyan, A. & Dermer, C.D: ApJ, 613, 151 (2004)
2. Bicknell, G. V.: ApJ, 422, 542 (1994)
3. Blandford, R. D.: ASP Conf. Ser. 250, 487 (2001)
4. Bridle, A. H., & Perley, R. A.: ARAA, 22, 319 (1984)
5. Celotti, A., Ghisellini, G., & Chiaberge, M.: MNRAS, 321, L1 (2001)
6. Georganopoulos, M., & Kazanas, D.: ApJ, 604, L81 (2004)
7. Laing, R. A., & Bridle, A. H.: MNRAS, 336, 1161 (2002)
8. Maraschi, L., & Tavecchio, F.: ApJ, 593, 667 (2003)
9. Sambruna, R. M., et al.: ApJ, in press (astro-ph/0511459) (2006)
10. Stawarz, L. et al: ApJ, 608, 95 (2004)
11. Tavecchio, F. et al.: ApJ, 544, L23 (2000)
12. Tavecchio, F. et al.: ApJ, in press (astro-ph/0512389) (2006)