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Nuclear Accretion and the FR I – FR II Dichotomy

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Abstract

In the radio – host galaxy optical luminosity plane FR I and FR II radio–galaxies are clearly divided. Using the host galaxy luminosity as an indicator of the mass of the central black hole, and the correlation between the radio power and the luminosity in narrow emission lines to estimate the ionising/accretion luminosity, we find that the FR I-FR II separation corresponds to a constant accretion rate, of about $\sim 10^{-2}$–10^{-3} the Eddington one. This value possibly determines the transition between different accretion modes and the consequent presence and characteristics of nuclear outflows.

1.1 Introduction

Among the strongest phenomenological clues on radio sources origin and physics is the recognition by Fanaroff & Riley (1974) that the majority of radio galaxies can be classified into two morphological types (FR I and FR II) according to where most of the luminosity is radiated, and that this division rather neatly corresponds to a separation in radio power (at about $L_{178} \simeq 2.5 \times 10^{33} h_{50}^{-2}$ erg s^{-1} Hz^{-1} at 178 MHz). This division has become even clearer and sharper when Ledlow & Owen (1994, 1996) found that the separating radio luminosity is a positive function of the optical luminosity of the host galaxy.

These pieces of evidence have prompted several physical interpretations, which invoke the interaction of the jet with the ambient medium (Bicknell 1995, Gopal–Krishna & Wiita 1988, 2001) or/and nuclear intrinsic properties of the accretion and jet formation processes (Baum et al. 1995, Reynolds et al. 1996, Meier 1999).

As amply discussed at this conference, it is possible to infer an estimate of the central black hole mass from both the luminosity of the bulge component (Kormendy & Richstone 1995, Magorrian et al. 1998) and the stellar velocity dispersion of the host galaxy (Ferrarese & Merrit 2000, Gebhardt et al. 2000). This powerful tool for tackling the long standing problem of the black hole/galaxy formation, also provides us with the possibility of estimating the combination of rate and radiative efficiency of accretion in active galaxies.

In particular we (Ghisellini & Celotti 2001) focused on the issue of the dichotomy between FR I vs FR II radio–galaxies, taking advantage of the information on the black hole mass and the indications of connections between the observed radio luminosity and the luminosity dissipated in the accreting flow. This allowed us to find that the separation between FR I and FR II corresponds to a critical value of the mass accretion rate.

1.2 Black Hole Masses

For the conversion of host galaxy optical magnitude into black hole mass $M_{\rm BH}$ we adopt the relation presented in McLure & Dunlop (2001), $\log(M_{\rm BH}/M_\odot) = -0.62(\pm 0.08) M_{\rm R} - 5.41(\pm 1.75)$, where $M_{\rm R}$ is the absolute R–band magnitude of the host.

The range of absolute magnitudes of the Ledlow & Owen (1996) sample can thus be re–expressed as a range of black hole masses. We report in Fig. 1.1 the plot from Ledlow & Owen (1996) with $M_{\rm BH}$ on the upper x–axis: the dividing radio power between FR I and FR II results to be a linear (within the errors) function of $M_{\rm BH}$ and, at a given radio luminosity, FR I are systematically associated with more massive black holes.

1.3 The Accretion Luminosity

We use the relation between the jet radio power the and intrinsic nuclear luminosity to derive the latter. This in turn corresponds, for a given assumed efficiency, to a mass accretion rate.

In particular, we adopt the established relation between the luminosity in narrow emission lines, believed to result from photoionization by the nuclear (accreting) radiation $L_{\rm ion}$, and the radio power (Saunders et al. 1989, Rawlings 1992, Willott et al. 1999). In Fig. 1.1 we report the result of converting radio luminosity into $L_{\rm ion}$ adopting the the relation reported by Willott et al. (1999), $L_{\rm ion} \sim 5 \times 10^3 L_{151}$. The division between FR I and FR II then turns out to be a separation at *constant* $L_{\rm ion}/M_{\rm BH}$, described by the relation $L_{\rm ion} \sim 6 \times 10^{-3} L_{\rm Edd}$.

1.4 Discussion and Conclusions

The separation of FR I and FR II in morphology and power appears to occur at a certain value of the luminosity over black hole mass ratio. Note that the significant dispersions of the assumed correlations would imply a fuzzier separation but would not alter the average behaviour.

One might thus speculate that the primary reason for the FR I–FR II dichotomy lies in the different nature of their accretion disks. If $L_{\rm ion}$ originates from the dissipation of the accretion power, the value of $L_{\rm ion}/L_{\rm Edd} \sim 6 \times 10^{-3}$ corresponds to an accretion rate (in Eddington units) $\dot{m} \sim 6 \times 10^{-2} \eta_{-1}^{-1}$, for a constant efficiency ~ 10 %. At this rate the accretion mode could change from a standard optically thick, geometrically thin, radiatively efficient Shakura–Sunyaev (1973) disk to a radiatively inefficient, optically thin flow, such as an ion supported torus (although it is not yet unanimously clear which process dominates the dynamics of the flow, Rees et al. 1982, Narayan, Garcia & McClintock 1997, Blandford & Begelman 1999, Narayan, Igumenshchev & Abramowicz 2000, Hawley & Balbus 2002). Note that, within the sample considered by Ledlow & Owen (1996), the radio galaxies span a wide range of $\dot{m}$, between $\dot{m} \sim 10^{-4}$ and ~ 10, and nevertheless such a physical transition would have to be rather sharp in order to produce such a well defined dividing line.

Observationally, high values of the bulk Lorentz factor Γ ($\sim$ 10–15) are required to account for the spectral energy distribution of high energy peak BL Lac objects – which are believed to be FR I whose jet is aligned with the line of sight – (Ghisellini et al. 1998, Tavecchio et al. 1998). Furthermore, the parsec scale jets of FR I and FR II appear to have similar velocities (e.g. Giovannini et al. 2001). On the other hand, on the kpc scale FR I jets have velocities typically smaller than the FR II ones (e.g. Begelman 1982, Bicknell 1984, Laing 1993), and indeed mildly relativistic transonic jets could be more subject to Kelvin–Helmholtz instabilities, leading to the typical FR I morphology. Therefore R I jets

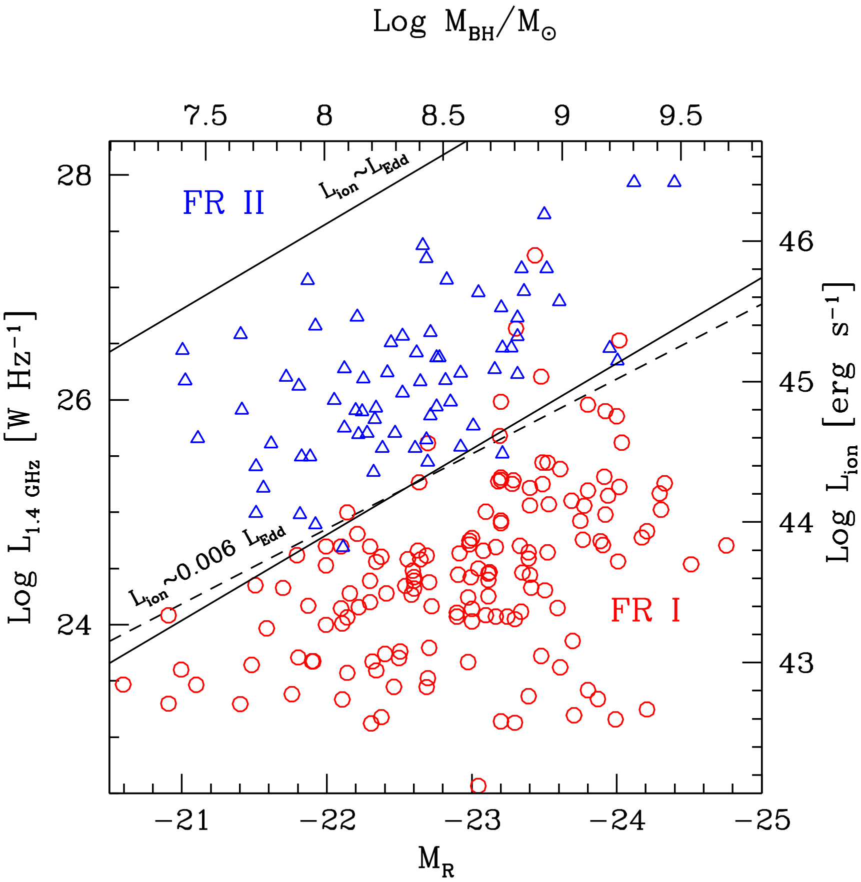

Fig. 1.1. The radio jet power – host magnitude plane with the line dividing FR I from FR II (dashed line, from Ledlow & Owen 1996). According to established correlations this is equivalent to an accretion power vs black hole mass plane (right and upper axis). The central diagonal line represents $L_{\rm ion} \sim 6 \times 10^{-3} L_{\rm Edd}$.

start highly relativistic and decelerate between the sub-pc/pc and the kpc scales. And in fact this is a crucial ingredient in the model proposed by Bicknell (1995), who points to the environment and the consequent deceleration as the main cause of the FR I–FR II dichotomy.

Our findings suggest that the FR I–FR II dichotomy could be controlled by the properties of the underlying accretion process more than (or in addition to) a different environment. It might be also that the accretion process itself plays a role in the deceleration by affecting the pc–kpc scale environment. Although at this point it might be premature to single out a consistent model, one could tentatively attribute the effect of accretion to the presence of a wind – produced by the disk itself and interacting and slowing down the relativistic jet – becoming more important for lower accretion rates, as indeed predicted by some accretion scenarios (see Blandford & Begelman 1999, Merloni & Fabian 2002 and also numerical simulations by Hawley & Balbus 2002). We can only speculate about the expected signatures of the interaction of a wind and a relativistic jet, which might lead to the formation of shocks and the conversion of the bulk kinetic energy into radiation. FR I radio galaxies – and BL Lacs – could therefore be more efficient radiators than FR II radio galaxies and emission line blazars (although with a smaller absolute power).

Since the accretion luminosity in low radiative efficiency flows is expected to decrease fast with the accretion rate this scenario can account for the lack of intense broad emission lines in FR I sources and BL Lac objects (although allowing some sources to show broad but weak lines), being due to the low intensity of the ionising continuum (and not to obscuration).

Note also that this picture is consistent with an evolutionary scenario: as FR I have, on average, larger black hole masses, they might be older or have accreted at a greater rate in the past. It is then conceivable to argue that at least a fraction of them were FR II radio–galaxies in the past. This might account for the different evolution properties of the two classes (see e.g. Urry & Padovani 1995).

We are testing the robustness of our finding of a critical and constant accretion rate being responsible for the FR I-FR II dichotomy, via both the accurate measure of the black hole masses of a sub-sample of sources with similar radio luminosity (see Marchesini, Celotti & Ferrarese, these proc.) and the estimate of the nuclear accretion rate through the measure of the optical nuclear luminosity (Marchesini, Celotti & Ferrarese 2004).

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