A dichotomy in radio jet orientations

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Abstract

We examine the relative orientations of radio jets, central dust and stars in low-power (i.e., FR I and FR I/II) radio galaxies. We use the position angles of jet and dust to constrain the three-dimensional angle $\theta_{DJ}$ between jet and dust. For galaxies with filamentary dust 'lanes' (which tend to be misaligned with the galaxy major axis) the jet is approximately perpendicular to the dust structure, while for galaxies with elliptical dust distributions (typically aligned with the galaxy major axis) there is a much wider distribution of $\theta_{DJ}$. The dust ellipses are consistent with being nearly circular thin disks viewed at random viewing angles. The lanes are likely warped, unsettled dust structures. We consider two scenarios to explain the dust/jet orientation dichotomy.

Key words:

1. Introductory remarks

Since the late 1970s, many studies have found the position angles (PA) of jets in dusty radio galaxies to be roughly perpendicular to the PA of the longest axis of the dust structures (e.g., Kotanyi & Ekers 1979; Möllenhoff, Hummel & Bender 1992; van Dokkum & Franx 1995; de Koff et al. 2000; de Ruiter et al. 2002). Capetti & Celotti (1999) and Sparks et al. (2000) reported that also the intrinsic, i.e., three-dimensional, orientation of radio jets is roughly perpendicular to the dust in samples of radio galaxies with regular dust disks. In contrast, Schmitt et al. (2002) found in a sample of 20 radio galaxies with regular dust disks that the jets are not roughly perpendicular to the disks in three-dimensional space.

Here we summarize our analysis of the intrinsic orientation of dust and jets in 47 FR-I and FR-I/II radio galaxies using HST/WFPC2 broadband imaging to explore the cause of the conflicting results on the dust-jet orientation. A detailed analysis is presented in Verdoes Kleijn & de Zeeuw (2005). This paper also compares the dust properties of radio galaxies and quiescent ellipticals.
2. Dust and jets: projected properties

The PA of the dust axis (PA_D) is defined as the PA of the largest linear extent of the dust feature. The PA of the stellar isophotal major axis (PA_G) is measured just outside the radius of the main dust distribution. The jet axis defines the PA_J for the radio component. Figure 1 shows three special features in the relative orientation of the three axes. First, no radio jets are observed close to the dust axis (i.e., ∆PA_{DJ} < 20°). Second, the data points are distributed roughly along two regions forming a mirrored 'L' shape. Dust structures in region E are roughly aligned with the galaxy major axis (∆PA_{DG} < 20°) and have a wide distribution in relative angles with the radio jet (∆PA_{DJ} ∼ [20° − 90°]). In contrast, dust features in region L are misaligned from the galaxy major axis (∆PA_{DG} > 20°) and have a narrow distribution in PA differences with the radio jets (∆PA_{DJ} ∼ [60° − 90°]). These dust structures, while misaligned with the galaxy, are in a very rough sense perpendicular to the radio jets. Third, dust morphology correlates with these distinct classes of relative orientations. The appearance of dust structures in the radio galaxy sample varies from regular elliptical shapes – evoking the idea of inclined disks – via filamentary dust 'lanes' to highly irregular structures – suggesting unsettled dust (Verdoes Kleijn et al. 1999; 2005). The dust ellipses tend to fall in region E and the dust lanes in region L.

3. Intrinsic dust-jet orientations

The relative intrinsic orientation between jet and dust is characterized by the 'misalignment angle' θ_{DJ} which is the angle between the jet and dust disk rotation axis. We have analysed the distribution of θ_{DJ} separately for dust ellipses and lanes. The reason is that, besides the difference in ∆PA_{DG}, there are various other pieces of evidence that filamentary dust lanes are not simply the edge-on counterparts of dust ellipses (Verdoes Kleijn et al. 2005).

For dust ellipses, four of the 16 galaxies with measured ∆PA_{DJ} require minimal θ_{DJ}^{min} > 40°. In other words, significant misalignments occur.

Given the small number of observations, we constrain the distribution of misalignment angles P_{DJ}(θ_{DJ}) further by exploring three parameterizations for P_{DJ} instead of attempting a parameter-free recovery. In model A, P_{DJ} is assumed to be a single step-function to test the hypothesis that the distribution of θ_{DJ} peaks at small or large angles. Model B assumes it to be a two-step function to test for peaks at intermediate misalignment angles (i.e., θ_{DJ} = 45°). Lastly we explore model C.
which assumes a Gaussian distribution truncated to the physically allowed region $0^\circ \leq \theta_{DJ} \leq 90^\circ$ to explore arbitrary peaks and widths. These models are fitted to the observed relative orientations of dust and jets using Maximum Likelihood optimization and results are shown in Figure 2.

The jet misalignment angle distribution in galaxies with dust ellipses is consistent with having a peak around $\theta_{DJ} \sim 45^\circ$. The width of this peak is not well constrained. The limited data set cannot rule out a spherically random distribution of misalignment angles or a very narrow peak at more than 95% confidence. These conclusions do not depend critically on either the assumed parameterization for $P_{DJ}$ or the assumed thickness or ellipticity of the disk. Regardless of the assumed model, typically at least half of the radio jets make an angle of 45° or more with the symmetry axis of the dust disks.

To constrain the three models for dust lanes, we assume that the lanes are exactly edge-on systems to obtain an upper-limit on the typical $\theta_{DJ}$. Figure 2 shows that the upper limit to the median misalignment angle for dust lane radio galaxies is smaller than the median angle for dust disk radio galaxies. The fact that dust lanes seem to be viewed close to edge-on prompts the question: where are the relatively face-on dust lanes? We conclude from further analysis that the dust classified as either irregular or intermediate between ellipse and lane most likely represent the close to face-on counterparts of the edge-on lanes (Verdoes Kleijn & de Zeeuw 2005).

There are two scenarios to explain the dust-galaxy-jet orientation dichotomy for radio galaxies. Scenario I: the radio jets exert a torque on the nuclear dust in active galaxies which in some cases overcomes the gravitational torque forcing the nuclear dust in a plane perpendicular to the jets. This scenario does not explain why the dust/galaxy misalignment is also seen in galaxies without radio jets. Scenario II: the angular momentum vector of unsettled nuclear dust is initially aligned with the radio jet in active galaxies but this alignment is lost as dust settles in an equilibrium plane of the galaxy. A weakness of this scenario is that the settling time-scales of the dust seem short compared to the age of the radio sources. In conclusion, the
analysis establishes a dichotomy in jet orientations related to distinct dust morphologies, but the current data set is too small to distinguish between scenarios explaining the phenomenon.

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