Extragalactic jets: trends and correlations[1]

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The systematic properties of jets from active extragalactic objects are reviewed and related to models of confined jet propagation. The debate about jet velocities and the origin of one-sidedness is outlined, and some important future observations are listed.

On présente une revue des propriétés systématiques des jets provenant d'objets extragalactiques et ces propriétés sont reliées aux modèles de propagation confinée des jets. On expose les grandes lignes du débat concernant les vitesses des jets et l'origine de l'unilatéralité, et on donne une liste de certaines observations futures importantes.

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1. Introduction

I have been asked to review the observed properties of jets emanating from active galactic nuclei (AGNs), which I shall take to mean radio galaxies and quasi-stellar objects (QSOs). In his review on outflows from star-forming regions, Lada defined a jet as "a collimated stream or flow." I wish that those of us studying AGNs could do the same. Most of our statements about flow velocities in our putative jets rest not on the bedrock of Doppler-shifted emission lines and proper motions but on rickety piles of assumptions and model-building. For us, a jet is a feature that *looks* as if it *might* be a collimated stream or flow emanating from the center of an AGN. Still, active galaxies form a large part of the agenda of this "Jets" meeting because *so many* of them contain long, narrow radio features. Section 2 discusses this ubiquity of jetlike features from AGNs. Section 3 outlines how their properties correlate with power and identifies two basic "flavors" of extragalactic jet. Section 4 considers their collimation and Sect. 5 their brightness properties. Section 6 argues that the two jet flavors parallel the two principal instability regimes of confined supersonic jet propagation. Section 7 reviews the current debate about jet velocities and sidedness, and Sect. 8 lists some problems to challenge jet observers at all wavelengths. More detailed reviews of extragalactic jet data and models can be found in refs. 1–3.

2. The ubiquity of extragalactic jets

I know of 136 extragalactic sources with measured red shifts and radio features that meet my three empirical criteria for jethood; namely, the feature is

(i) at least four times as long as it is wide (after deconvolving the instrumental response from the image),

(ii) separable at high resolution from other extended structure (if any) either by brightness contrast or spatially (e.g., it should be a narrow ridge that runs through more diffuse emission or a narrow feature in the inner part of a source that enters more extended emission in the outer part), and

(iii) aligned with the nucleus of the parent object where it is closest to it. (The nuclei of sources with clear radio jets are always marked by compact radio "cores," so I use core and nucleus interchangeably here in practice. My criterion does, however, admit the *possibility* of a so-far unobserved class—coreless radio jets.)

The 136 sources with clear morphological jets and known red shifts are at distances ranging from 5 Mpc (Cen A) to 10.2 Gpc (a quasi-stellar radio source (QSR) with $z = 2.594$; I assume $H_0 = 100\,\mathrm{km \cdot s^{-1} \cdot Mpc^{-1}}$ and $q_0 = 0.5$ in this paper). Their total powers $P_{\mathrm{tot}}^{1.4}$ at 1.4 GHz range from $10^{21.6}$ to $10^{28.4}$ $\mathrm{W \cdot Hz^{-1}}$, and their core powers P_{core}^{5} at 5 GHz range from $10^{20.4}$ to $10^{28.2}\,\mathrm{W \cdot Hz^{-1}}$. The total jet lengths range from a few tens of parsec (those detected only by very long baseline interferometry (VLBI) jets) to several hundred kiloparsec (jets in giant radio galaxies and QSRs). Jets from AGNs are evidently not confined to any subrange of red shifts, powers, or size scales.

Jets are also found in large *fractions* of complete samples of both weak radio galaxies and extended QSRs imaged at the Very Large Array (VLA) with good sensitivity, dynamic range, and relative resolution (many beam widths across the extended lobes). Definite jets are detected in at least 12 of the 22 radio galaxies with $z < 0.05$ in the rerevised 3C sample ($3CR^2$ (4)), whose median $P_{\mathrm{tot}}^{1.4} = 10^{24.43}\,\mathrm{W \cdot Hz^{-1}}$. Definite jets are also detected in 11 (and possible jets in 4 more) of the 21 *lobe-dominated* $3CR^2$ QSRs with angular diameters $\geq 10''$ that have been imaged by self-calibrated 20- or 6-cm observations $\geq$ 30 min long with the VLA's highest resolution. The median 1.4-GHz total power of these 21 QSRs is $P_{\mathrm{tot}}^{1.4} = 10^{27.39}\,\mathrm{W \cdot Hz^{-1}}$.

In contrast, definite jets are detected in only two of a complete sample of 42 $3CR^2$ radio galaxies with $z \geq 0.4$. The median power ($P_{\mathrm{tot}}^{1.4} = 10^{27.36}\,\mathrm{W \cdot Hz^{-1}}$), angular size, and brightness of these strong $3CR^2$ galaxies are all similar to those of the extended $3CR^2$ QSRs, and both groups have been imaged at the VLA with similar sensitivities, dynamic ranges, and relative resolution. The differing jet-detection rates are thus not merely an instrumental bias; the jets in most strong $3CR^2$ galaxies emit smaller fractions of the total radio flux density than those in the extended $3CR^2$ QSRs. (The large-scale jet in Cyg A emits only about 0.25% of the total luminosity at 1.4 GHz and was found only in VLA images of much higher quality than those available for most other strong radio galaxies.) The differing prominence of the jets in strong radio galaxies and QSRs may also be related to the differing prominence of their nuclear regions at both radio and optical wavelengths. The median value of $f_C = S_{\mathrm{core}}^{5}/S_{\mathrm{tot}}^{1.4}$ for the 21 extended $3CR^2$ QSRs observed at the VLA is 0.017, while for the strong $3CR^2$ galaxies, it is only 0.0005. The two $3CR^2$ radio galaxies with $z > 0.4$ and definite radio jets are 3C200 (with an unusually high f_C = 0.018) and 3C341 ($f_C = 0.0005$).

The ubiquity of radio jets in extragalactic sources and the morphological and statistical connections between jets and cores suggest that jet production is a universal aspect of AGNs.

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