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活动星系和类星体中的喷流 (II)

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摘　　要

喷流的研究是天文学和天体物理学中最使人感兴趣的课题之一。在本文中，陈述了河外射电源中喷流在现阶段的观测状态，讨论了某些典型的高能天体中喷流的特性。第一部分所涉及的内容包括喷流的定义、产生和传播；也包括喷流的不对称性和统一的解释模式的讨论。在这部分将详细地讨论喷流的形态和不规则性；详细地描述用高分辨率射电望远镜，特别是在高频段的高分辨率 VLBI 观测所得到的图像。在文章的最后部分，阐述了射电源的结合阵数据的图像处理结果对喷流的研究带来的好处。

关 键 词　星系：活动星系 — 星系：喷流 — 类星体：一般 — 技术：干涉 — 射电连续辐射：星系

Jets in Active Galaxies and Quasars (II)

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Abstract

The study of jets presents one of fascinating and intriguing aspects of astronomy and astrophysics. In our paper, we review the current observational status of jets in powerful extragalactic radio sources and discuss the properties of some prototype energetic objects. Part I is concerned in the content including the definition, the production and propagation of jets, the jet asymmetries and unified schemes. Part II will give us the details about the features related to jets, the irregularities in cosmic jet including wiggly jets and distorted jets. High

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resolution imaging of jets with high resolution telescopes, in particular, the case for VLBI at higher frequencies and high angular resolution will be discussed. At the end of part II we will highlight the immense benefit of combined–array imaging of radio sources.

Key words galaxies: active—galaxies: jets—quasars: general—techniques: interferometric—radio continuum: galaxies

1 Features related to jets

1.1 Lobes, hot spots and cocoons

In the classical radio sources, the jets terminate in large, diffuse "lobes" which also radiate synchrotron emission[1]. Why are the lobes at the distance we find them? What makes the jet stop and material spill out?

Very often the end point of the jet corresponds to a local brightening or 'hot spot', which is usually close to the edge of the associated radio lobe. Hot spots are believed to be a shock region where the jet material collides with the intergalactic medium, accelerating particles to relativistic energies. The diffuse lobes are then formed by material 'processed' in this shock flowing back towards the nucleus.

There are several cases, such as 3C9, 3C280.1[2], 1857+566[3], 0800+608[4,5] (Figure 1), 1150+497[6] where the jets are relatively bright out do not end in obvious hot spots. One suggestion is that these jets lose much of their bulk kinetic energy through internal shocks or instabilities or collisions with dense clumps of materials and hence cannot form bright hot spots[6]. Then there are "naked" jets; in 0800+608 and 1150+497 there is no lobe on the jet side and in both cases there is a counter lobe which does not have any hotspot. There is a faint cocoon surrounding the jets of both sources. Are sources with no lobes too young to have produced them, or are these typical cases of disrupting jets?

In some sources the high resolution features are dominated by a large scale cocoon or halo, particularly prominent at low frequencies. These halos are thought to be the superposition of the twin radio lobes seen at a small projection angle. A typical example is the cocoon surrounding the quasar 3C380 (Figure 2).

There are two main reasons for which jets can be disrupted; they may collide with dense clumps of gas in the ambient medium, or they may disrupted by different sorts of hydrodynamic instability. In the collision scenario, a jet can be disrupted if the pressure in the clumps is comparable to the ram pressure in the jet. We can usually estimate conservatively the jet ram pressure as the internal energy of the brightest knot in it. The gas presssure in the surrounding medium is given by $P = nkT \cdot \mathrm{Nm}^{-2}$. In many jets sources calculated thermal pressures in the medium are usually high enough to disrupt the jets. This is particularly true for jets in compact steep spectrum sources, e.g. 3C138[8]. But in the wiggly jets of 1150+497, it is found that the pressure in the medium could hardly affect the jet[6].

Also numerical simulation[12,13,14,15] have shown that jets propagating through a uniform medium and have comparable densities as the medium are more susceptible to Kelvin–Helmholtz (Hydrodynamic) instabilities. Such instabilities usually grow as wiggles in the jet. Estimates of the resonant frequency come from simulations of jet response to small perturbations in a direction very close to the core. The resonant wavelength is given by[9]

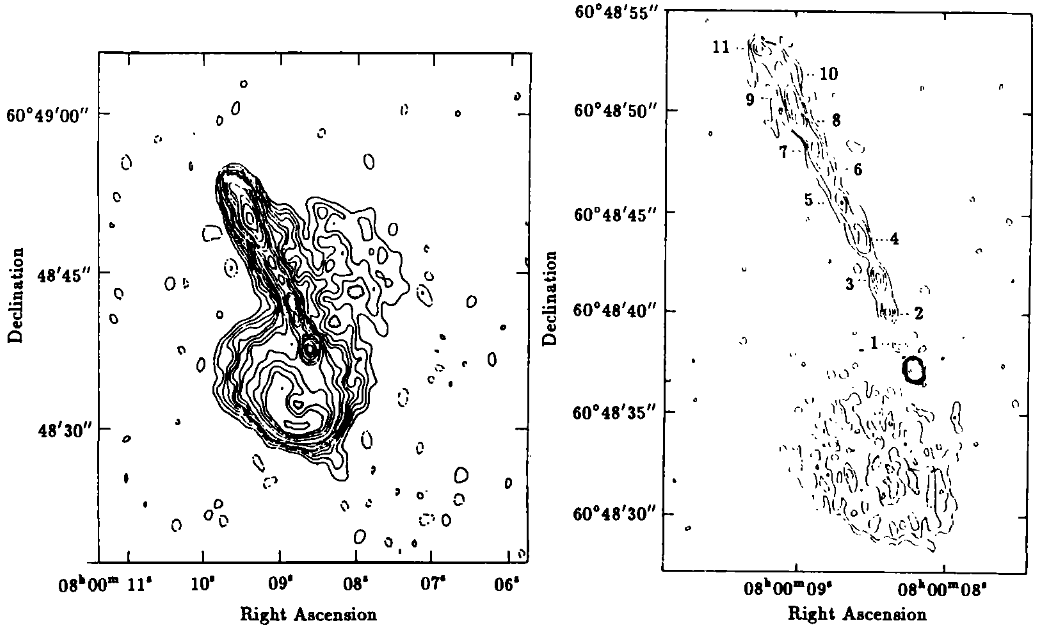


Figure 1 20cm (left) and 6cm (right) VLA maps of the one–sided 'hotspotless' jet in the quasar 0800+608[4].

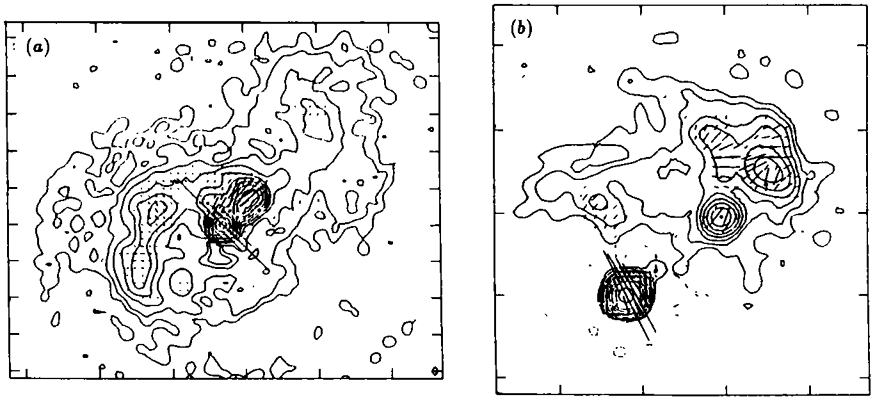


Figure 2 Halo in the bright quasar 3C380. Left: VLA map at 5 GHz with polarized intensity E-vectors superposed. Right: VLA map at 15 GHz with polarized intensity E-vectors superposed[7].

$$\lambda \approx \frac{2Mr_J}{m(1+n^{1/2})} \tag{1}$$

where r_J is the jet radius, n is the ratio of jet to ambient density, m is the mode and M is the Mach number; for $m = 1$ (fundamental mode) we usually expect a resonant wavelength $\lambda/r_{\rm J} \sim M$. For example, in the quasar 1150+497 we obtain $\lambda/r_{\rm J} \sim M \sim 10$ whcih gives a jet velocity of $\sim 10^4 {\rm km \cdot s^{-1}}$ if the jet is assumed to be in pressure equilibrium with a surrounding halo of gas at 10^7 K. Such jets, which from numerical calculations should have a characteristic disruption length of a few times λ do not produce hot spots but end in diffuse emission produced by large oscillations in the direction of the jet. This fits well with the observed features of 1150+497 and has also been used to explain the peculiar radio structures of 0800+608, another prototype hotspotless jet[4,5].

1.2 Active galaxies without jets?

If the radio lobes are being supplied by jets, why do some twin–lobed radio galaxies and quasars show no jets at all? A prominent example is the powerful quasar 3C196[10] (Figure 3) and the powerful galaxy 3C295 [11] in which high dynamic range maps have revealed no jets. In radio galaxies, such as, 3C295, there could be a natural explanation in the absence of relativistic effects; the jet may be very weak as the core is also very weak, possibly also reflecting a weak central engine. But in powerful quasars like 3C196 the absence of jets is more difficult to understand. Brown[10] proposed a model of very low speeds in 3C196 and similar sources which makes such jets visible only as X–ray sources.

Also some sources with milliarcsecond(mas) double or triple structure have no jets[16]. Could these sources be very young and at the same time develop twin components/lobes or are they on their death (throes)? Could there be periodic ejection of double components in some circumstances?

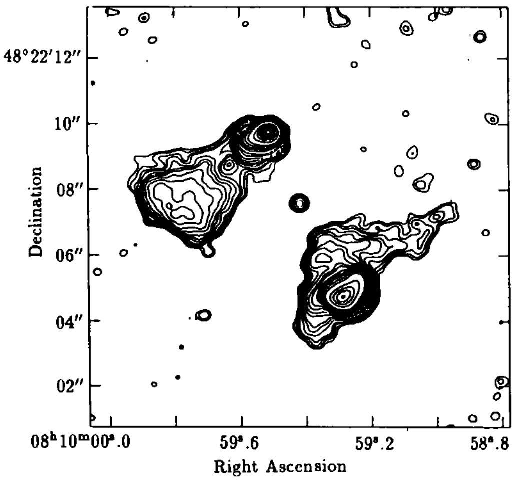


Figure 3 VLA image at 5 GHz of the twin lobed QSO 3C196 in which no jet has been found[10]

1.3 Jets in ‘optically quiet quasars’

In the last few years attention has been drawn to a class of powerful extragalactic radio sources with compact radio structures and flat spectrum radio cores usually associated with quasars but are faint optically[17]; they are identified with ‘empty fields’ or very faint optical objects, $m_v \geq 20$, and are called ‘optically quiet quasars’ (OQQ). One support for thier distinct nature comes from polarization studies which show that mean fractional polarization of OQQ cores at short wavelengths is 1.8%, which is different from quasars (2.4%).

Observations of cores of OQQs[17] show that they are associated with mas scale jets as well compact double structures as in other flat, spectrum sources. It is therefore not certain why they are faint optically. A small fraction may be quasars at high redshifts, others may be a population of young radio sources in early stages of evolution which will become stronger optically at a future epoch. They could be associated with optical emission that is obscured by dust or some peculiar geometry of the central active region.

1.4 Irregularities in jet structures

Features which we may think of as "anomalous", such as knots, kinks, wiggles and sharp bends, are becoming more common as we gain the means and know-how to make better and more detailed images. Far from being pathological, these features may be essential characteristics of the jet phenomenon that we are only now beginning to discern. If we could look closely enough, would we see such things in all jets? Are they due to shocks and turbulent flow? Or are they the scars of past disruptions of the outflow, related to the radio outbursts observed in many sources, particularly BL Lacs and OVVs (Optically Violently Variable sources).

1.4.1 Wiggly jets

Some jets, like the one in M87, have a wavy structure as if material is issuing in a corkscrew fashion. Figure 4 shows the superb image of the nuclear jet in M87, which has a dynamic range of 2200:1. Analysis of this image shows that the jet oscillates from side to side and that it is limb-brightened at distances beyound 50 mas. Furthermore, greyscale images show clearly that between 40 and 90 mas there are sinous, sometime multiple, filaments[18,19,20]. This may be evidence that the black hole in its core is precessing, or wobbling on its axis, somewhat like a rotating lawn sprinkler. For this to happen requires the presence of a nearby massive object, such as a second black hole or a nearby galaxy.

Some theorists argue that a double black hole may be a more plausible energy source than a single hole, and could arise from the collision and merger of two massive elliptical galaxies. Indeed, some sources, such as the famous dumbell galaxy 3C75, clearly have two nuclei, each with their own twin jets.

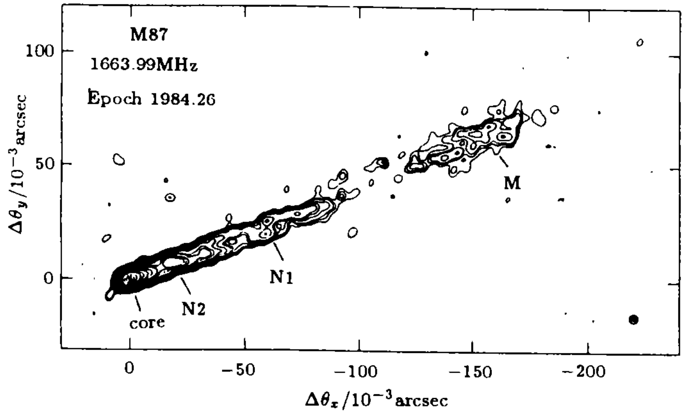


Figure 4 High dynamic range map of the small-scale jet in M87 showing both limb-brightening and an oscillating ridge line[20].

1.4.2 Knots, kinks, grossly distorded jets

In many sources we see jets that seem to have been distorted or disrupted on a vastly larger scale than can be explained by processes within the jets themselves. Often the jets are swept back like plumes of smoke, as if they being blown by some intergalactic wind.

In others, the jet is suddenly disrupted as if it has collided with an object far outside the core. VLBI observations of the quasar 3C48 reveal a most convoluted jet structure, which is thought to be the result of a collision with a cloud of gas about 150 parsecs from the core.

In 3C119 the jet appears to be disrupted (see Figure 5: left)[22]; while in 3C380 there is a tangle of emission beyond a short arcsec jet beneath which is a parsec scale jet with peculiar structure (see Figure 5: right)[23]. In addition to superluminal motion this jet shows recent brightening at a bend, which could be a second nucleus[21]. But sharp bends in milli-arcsec scale jets accompanied by bright knots is common in CSS sources and may be a line of sight effect or a result of interaction between the radio beams and dense interstellar gas clumps — which radio astronomers call "cosmological equivalent of brink walls". Evidence for this ubiquitous gas has not been found (in CSS) beyond the measurement of high O[III] luminosity[24]. There were hopes that HST would spatially resolve the gas if present.

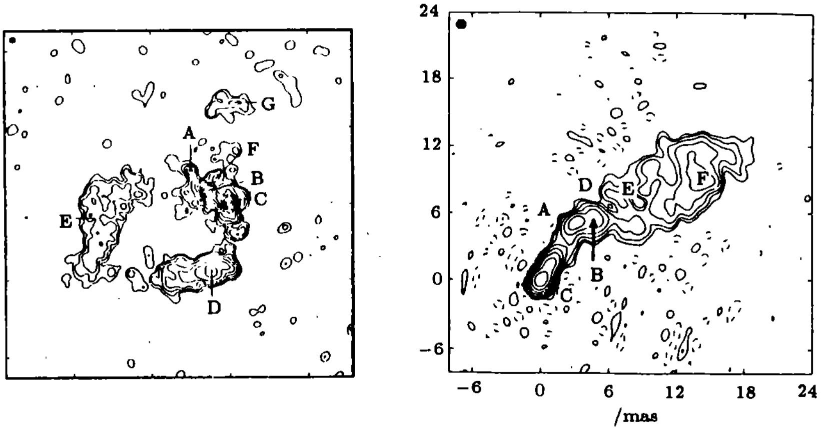


Figure 5 Left: VLBI image of 3C111 at 18 cm[22]. Right: VLBI image of 3C380 at 5 GHz[23].

In 3C345 the appearance of new VLBI components have been linked to radio outbursts implying that spectral evolution might indeed be related to the physical evolution of radio sources[25,26]. In 4C39.25 there is superluminal component moving between two stationary components[27,28]. In 3C395 similar motion reported earlier is reported to have stopped. In 3C273 all the components — about 8 over about 20 years have the same proper motion[29,30], in 3C345 and 3C120 this is not so, the different components have different speeds. There are jet wiggles off ridge lines as seen in some large scale jets.

2 High resolution imaging

High resolution radio images of galaxies and quasars have been made possible by the technique of "aperture synthesis" developed by Martin Ryle and his colleagues at Cambridge University in the 1950s. The angular resolution of a radio telescope, a measure of the fineness of detail it can see, depends upon the diameter, d of its reflecting dish or 'aperture' and is given by λ/d radians, λ is the operating wavelength. In aperture synthesis, several small telescopes are linked by cables to operate as a single instrument. Their combined signals are processed by computer to make an image. The angular resolution then depends not on the size of the individual telescopes, but on their maximum separation or "baseline", which then becomes the 'effective' diameter determining its resolution. The longer the baseline, and the shorter the wavelength, the more details can be seen.

2.1 High resolution telescopes

The first successful aperture synthesis telescope, the Cambridge One–Mile Telescope, began work in 1964 and has since been followed by several others, notably the 2.8km array at Westerbork in the Netherlands and the 4.6km Ryle telescope at Cambridge. Array like these can achieve typical resolutions of a few arcseconds.

Some of the finest and high sensitive images published yet by radio astronomers come from the most celebrated of all synthesis telescopes, The Very Large Array (VLA) of 27 dishes in New Mexico, USA[31]. With a maximum baseline of 36 km, the VLA can achieve sub-arcsecond resolution at high frequencies and is responsible for some of the best images available in radio astronomy. Still larger arrays can be built by linking telescopes by radio beams rather than cables. In Britain, Jodrell Bank's MERLIN array[32] of eight telescopes (with the addition of a new 32m dish sited at Cambridge) now stretches 220 km across central England, achieving a resolution of 0.05 arcsecond or better at short wavelengths.

New arrays include the 6km Compact Array of Australia Telescope (AT) in Narrabi, which is now in operation, and the Giant Meterwave Radio Telescope (GMRT) of 30 dishes over a 25km baseline, under construction at Poona in India.

2.2 Very Long Baseline Interferometry

Even higher resolutions can be achieved by VLBI—Very Long Baseline Interferometry—in which independent observatories agree to observe the same objects at the same time and record the radio signals on magnetic tapes[33]. The tapes are later played back together and the signals combined as if coming live from the telescopes. Observatories all around the world now routinely take part in VLBI sessions, and the very long baselines—up to the diameter of the Earth—allow astronomers to achieve resolutions as fine as 0.001 arcseconds. Both the USA and Australia are creating dedicated VLBI arrays over continental-size baselines. The US VLBI Array (VLBA), already in operation, consists of ten 25m antennas, spread over the US and controlled remotely from Socorro, New Maxico. In the European VLBI Network (EVN) most of the European radio antennas participate with other telescopes in Russia, China, etc to form an array. Global VLBI observations including telescopes in both arrays are also a routine.

Even with these powerful techniques we are still far from penetrating the innermost parts of active galaxies. A resolution of 0.001 arcsecond corresponds to distances as small as 0.25 parsec in nearby radio sources to about 4 parsecs in the most distannt galaxies and quasars that can readily be observed with VLBI. (interstellar distances are typically a few parsecs.) The size of the outer "narrow line region" of galactic nuclei is typically about 100 parsecs, the size of the "broad line region" is about 1 parsec and the Schwarzschild radius of a billion solar mass black hole is around 10^{-4} parsec (3 billion kilometres). So at present we can only resolve the broad line region.

We should be able to do much better with the proposed International VLBI Satellite. This will be a radio telescope in an elliptical orbit around the Earth, operating with an array of telescopes on the ground. Baselines will be at least several times longer than Earth-bound VLBI, with correspondingly better resolution at cm wavelengths. With all these efforts we may still be far from resolving the "central engine" of active galaxies but definitely not far from interpreting its signatures.

2.3 Millimeter and submillimeter wave VLBI

Our knowledge of active galactic nuclei comes from indirect observations, such as high resolution imaging of the radio jets or the intensity fluctuation observed in the radio, optical, UV and X–ray bands. Observations with VLBI at mm wavelengths is currently our only possibility to make images of the cores of active galactic nuclei. The resolution we can now obtain with such instruments is 40μas (microarcsecond) or better, resulting in linear resolution of 10^{15}—10^{17} cm, a resolution equivalent to that of a 2km diameter optical telescope which is diffraction limited.

Although interest in mm– and submm–wave astronomy germinated in the late 1960s, its recent application in interferometry and VLBI is a direct result of the improvements of the 1980s in receiver sensitivity and the construction of antennas of high surface accuracy. The first operational mm–wave antenna was NRAOs telescope at Kitt Peak in Arizona (USA) but other high precision antennas have since been built. mm– and submm–wave astronomy was hitherto mainly confined to the investigation of intensity and velocity distribution of molecules associated with interstellar gas and dust. Such studies have led to the detection of a wide range of radicals and molecules, ranging from carbon monoxide (CO) and the hydroxyl radical (OH) to complex organic molecules such as ethanol (CH_3CH_2OH). This effort which certainly improved our knowledge of the planets, the Sun and our galaxy also gave rise to the new field of science — the chemistry of the cosmos, Astrochemistry.

The first mm–wave VLBI experiments were made in late 1981, but the first observations aimed at obtaining hybrid maps of powerful sources had to wait until 1984[34] and since 1988 mm– wave VLBI are being down routinely at 100 GHz (λ3mm) with telescopes in Japan, Sweden, and United States, and observations are being extended to 230 GHz and 350 GHz[35]. These observations at 100 GHz yield incredibly high resolutions of about 40—50 μas corresponding to about 10^{16} cm in the nearest sources; this is equivalent to resolving a golf ball on the lunar surface. These images when fully appreciated should provide direct clues to the structure of galactic nuclei on the scale of the broad–line region and better—perhaps close to the accretion disc. One of the significant results from these obserevations is the image of the core of the powerful quasar 3C273[35], which have revealed structural changes within the core and their association with recent radio outbursts.

Observations with mm–wave VLBI sofar have shown that the radio cores of the AGN's are very small, on the order 10^{16} – –10^{17}cm, which is only 5–500 times larger than the Schwarzchild radius of a $10^9 M_\odot (4 \times 10^8$cm) black hole and of the same size scale as the nonthermal source. It is, therefore, possible that radiation pressure from the central region is still a viable source of energy for the relativistic plasma within the radio jet.

The structure we observe at these sub–milliarcsecond scales is usually also more complicated and more curved than what is observed at larger scales. Especially the curvature observed with cm–wave VLBI seems to continue, but further enhanced, closer to the core. All our images sofar are in very good agreement with extrapolation of the images made at cm wavelengths. In this context it is important to stress the necessity of VLBI observations at intermediate wavelengths. Especially observations at λ7mm are important in order to tie the images made with mm–wave VLBI to the larger scale structure of the jet observed with conventional VLBI.

The structural changes observed on these scales are very small and slow in some cases. In 3C84, for example, a component is observed moving southward from the core, down along the "northern ridge"[36]. This component moves with an apparent velocity of only 21000 km · s^{-1}. In contrast to this, a new component in 3C273 was observed only 60 days after a major outburst in 1988. Comparision with a later VLBI experiment at λ7mm shows that this component moves at about 800μas · yr^{-1}, an apparent velocity similar to that observed further out in the jet. One can, therefore expect faster, similar, or slower velocities on μas scales. Figure 6 shows the VLBI images of 3C273 observed at the frequencies of 5, 43 and 100 GHz seperatively.

Indeed, there are indications that the curvature of the jet increases towards the core and with more compact (at early stages) components, then it would also be expected to observe much larger apparent velovities in some cases due to the larger energies involved and to the higher chance of having the jet flow in a favourable viewing angle.

2.4 The physics of active galactic nuclei from mm–VLBI

The nature of radio jets have been carefully studied with connected interferometers such as MERLIN and the VLA. These images, however, show the cumulative effects of thousands to millions of years of nuclear activity. Images from VLBI at cm wavelengths on the other hand show the effects of more immediate activity, often only about one to two years after the activity first was detected as an increase in intensity. Observations with such instruments have increased our knowledge about the properties of radio jets, but we still know less about the central power house. What we do know is that it must have a small linear extent and that it must be able to sustain a high efficiency over a very long time period, in some cases a significant fraction of the Hubble time. Observations with a mm–wave VLBI instrument are aimed at observing closer to the Active Galactic Nuclei than ever before, at the very start of the radio jets.

One of the few opinions about quasars where the concensus has been steady since the quasar discovery in 1963 is that the energy is gravitational in origin. The primary reason to involk collapsed objects is that any gravitationally bound source which releases more than 1% of its rest mass must contract unstoppable; and a collapsed object, once formed, offers a more powerful and efficient power source than any precursor system. The massive object in the center of AGN's is suggested to have a mass of $10^8 - 10^9 M_\odot$ and a size of about $10^{14} - 10^{15}$ cm[42]. No radio emission will come from this part, unless a coherent mechanism is operative.

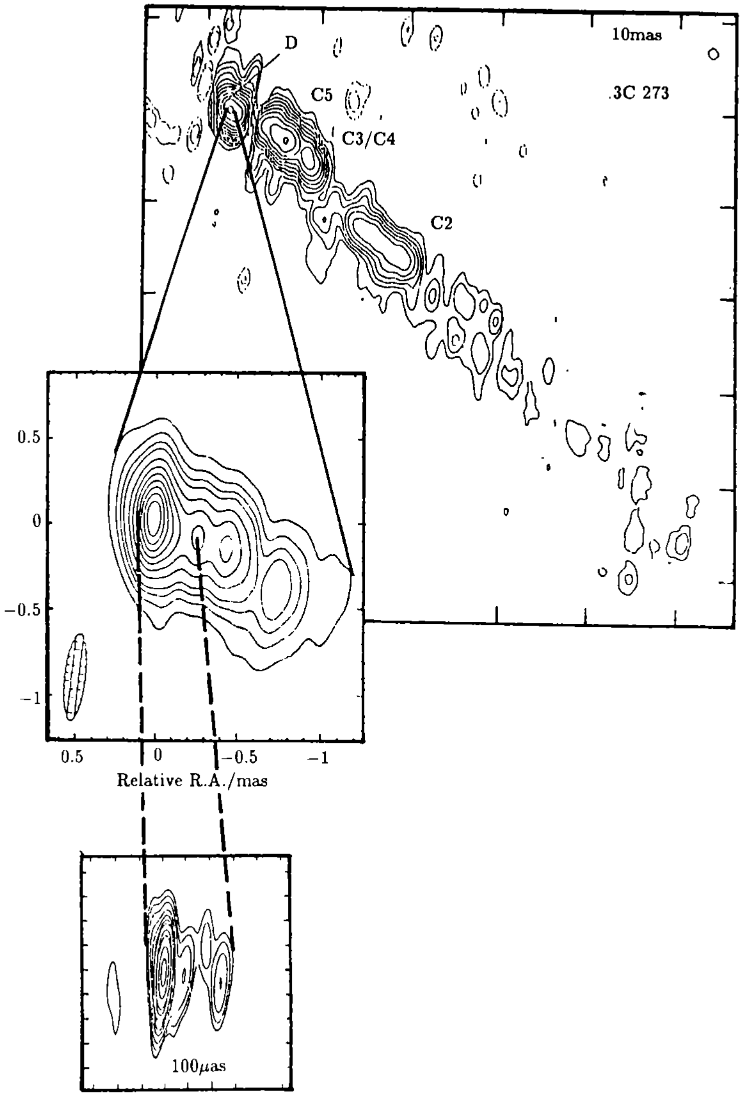


Figure 6 VLBI images of the QSO 3C273.

Upper: observed at 5 GHz[37]. Middle: observed at 43 GHz[38]. Lower: observed at 100 GHz[35].

The radio jets observed with VLBI at cm wavelengths are in the volume $10^{18} - 10^{20}$ cm from this nucleus. This region is just outside the Broad Line Region (BLR) and is likely to include clouds and filaments which have an impact on the radio jet structures. However, the radio jets probably originate on smaller size scales, inside the BLR, within $10^{15} - 10^{18}$ cm from the nucleus.

This volume must have a complex structure and is dominated by the gravitational field of the massive central object. Rees and others have suggested a multiphase structure to form here: optically thick and hot clouds at $10^4 - 10^5$ K, embedded in a plasma where all the electrons may be marginally relativistic[42]. Processes on these length scales may be crucial in determining the emergent continuum emission and establishing the collimation of radio jets. For these reasons it is important to try to answer some very specific questions concerning this volume:

1. What is the spatial configuration? Is the gas in an approximately spherical distribution, or is it in a thick disc, or in a jet–like outflow?

2. What are the kinematics? Is the gas flowing out in the wind, and if so what pushes it?

3. How does this multiphase structure form radio jets? What is the relation between the gas flow in this region and the collimation of radio jets?

4. How does the BLR affect the radio jet?

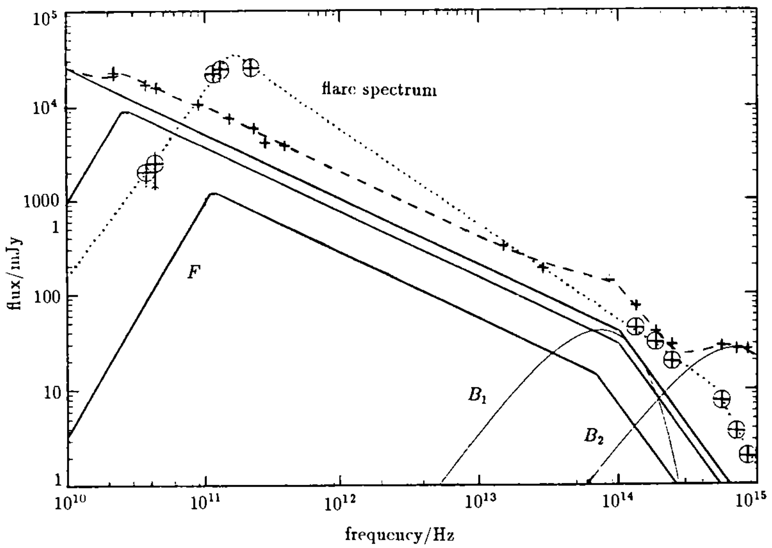


Figure 7 The electromagnetic spectrum of the quasar 3C273[35,40].

It has been suggested that the components observed with VLBI are the results of the interference between two reflecting mode shocks caused by Kelvin–Helmholz instabilities by having a plasma of lower density flow through a medium of higher density. If this is true, then one would expect the multiphase structure inside the BLR to have a severe impact on the structure of the observed radio jet there. Similarly, the difference in structure of the radio jet between this region and the outer region can be used to deduce the difference in the structure of the medium through which the plasma propagates. Other explanations for the VLBI components include shocks formed in the very central regions[34]. In such cases it is very important to be able to study such shocks at the very earliest stages of development. The volume inside the BLR is presumably where the radio jets are formed and collimated, and direct observations of this region will eventually give a clue to many important astrophysical questions, e.g. to whether the jets are formed one–sided or whether the one sided jets are simply a matter of viewing angle. A long time study over many years of epochs at mm–wave VLBI will tell not only how new components are being born and developed, but also about the gas near the central massive object and, in the longer perspective, its velocity field. Such observations will, with time, give direct and conclusive clues to the very nature of the Active Galactic Nuclei phenomenon.

2.5 The case for VLBI at higher frequencies and high angular resolution

Figure 7 shows the electromagnetic spectrum of 3C273, broken down into the overall spectrum of the quasar in a quiet state (broken line), a flare spectrum (dotted line), and various sub–components: B1 and B2 represent the blackbody radiation spectra of the inner and outer parts of the accretion disc and F represents the self–absorbed synchrotron spectrum of the high–frequency radio core. It is clear from the spectrum of F that this part of the source will be self–absorbed at cm–wavelengths and not accessible to any interferometer working at these wavelengths. Therefore, any global VLBI network will not be able to observe and make images of this core region, no matter how much the baselines are increased using satellite platforms. This very region is where the activity is believed to start and it is therefore of uttermost importance to study. VLBI at mm wavelengths (λ3mm and shorter) is the *only* means to do this.

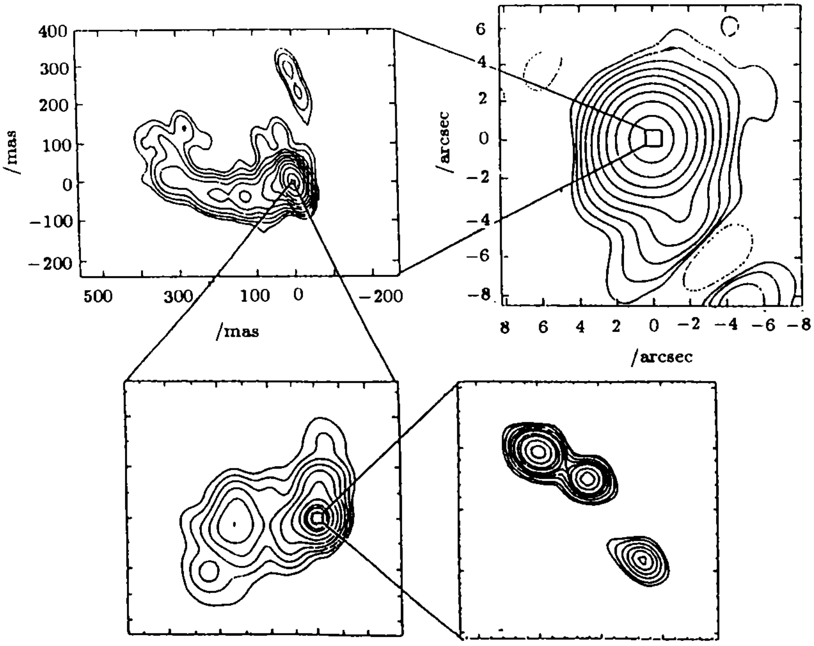


Figure 8 3C446 observed with interferometers[44].

upper right: VLA at λ22cm (tick marks at 2as); upper left: MERLIN at λ6cm (tick marks at 100mas); lower left: VLBI at λ6cm (tick marks at 1mas); and lower right: VLBI at λ3mm (tick marks at 20μas).

Furthermore, observations at very high frequencies make it possible to observe VLBI (compact) components very close in time after their birth. Outbursts have been shown to coincide with the birth of a new component which later can be observed in VLBI maps at cm wavelengths. Typical for outbursts is that they first start by a rapid increase in intensity simultaneously at optical–IR–and high radio frequencies (100 GHz and higher). This has been explained[30] by a thin shock which is formed close to the central engine and then moves down the jet. After some time the shock will expand adiabatically and the spectral turnover (due to synchrotron self–absorption) will move towards lower frequencies. The outburst will therefore be observed at lower frequencies first after the expansion has started! Observations of the shocks at their very early stages of development are fundamemtal to our understanding how they are formed, how they emerge from the core, and how they develop on their way through the radio jet. It must be emphasized that such observations can only be done with very high resolution at high frequencies. The mm–wave VLBI observations of the remarkable quasar 3C273 only 60 days after the start of an outburst show the new component to be thin along the jet and elonged across the jet as $(56 \times 5) \cdot 10^{16}$ cm. This suggests a compactness along the jet of about 10:1 which is in very good agreement with the thin shock model by Marscher and Gear[39,40]. Again, VLBI at the very highest possible frequencies is necessary to fully observe such shocks in their first stages.

2.6 Comparing sources at different Hubble distances

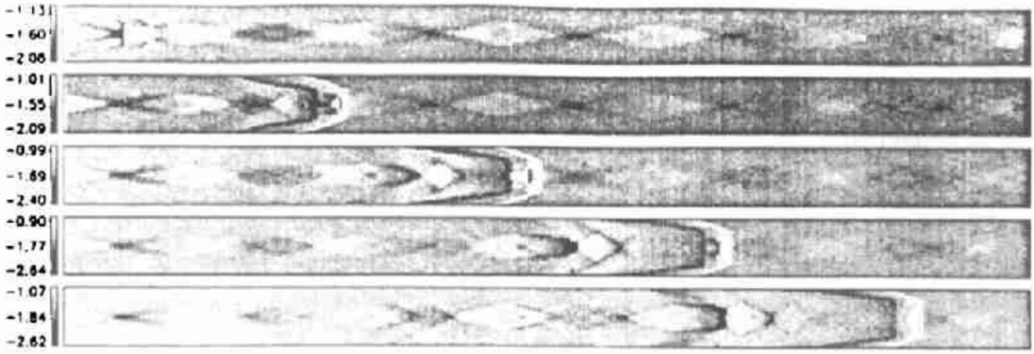
A superb image of the nuclear jet in M87 is shown in Figure 4. A comparison between the radio sources M87 and 3C345 in the same linear scale has been made. There are two points which have to be emphasised.

- mm–wave VLBI can yield images of quasars with the same linear resolution as is possible with the best global VLBI interferometer observing nearby AGN’s at cm wavelengths.
- The radio jet on mas/sub–mas scales look substantially different in the two sources. The jet of M87 is much more straight than that in 3C345. We are of course looking at different parts of the source because of the difference in observing frequency, but the large curvature seen in 3C345 cannot be hidden inside the jet of M87.

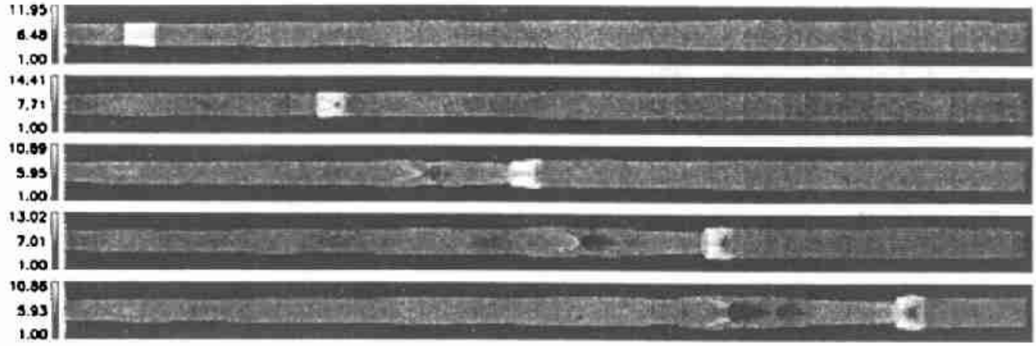
It is just one out of many comparisons that can be made between AGN’s at different Hubble distances. The questions arising from such comparison are whether the differences is due to that one of the objects is a more powerful AGN, or, does the difference reflect the difference in the surrounding media at another Hubble time or in a denser cluster? Such questions are fundamental to our understanding of AGN’s and their role in the fabric of the Universe. We will need all possible tools to our disposal to answer these, and mm–wave VLBI is certainly one of these tools, especially in combination with network VLBI observations at cm wavelengths. An example is the difference in the structure and orientation of the core jet observed at cm and mm wavelengths in quasar 446 (Figure 8).

3 Conclusion

The study of jets presents one of fascinating and intriguing aspects of astronomy and astrophysics. Despite the abundance of observation data at radio frequencies a lot of the physical processes associated with its origin and propagation are far from being clearly understood. There may be a number of reasons for this; for example, the prodigious amount of data obtained at radio frequencies have not been matched at other frequencies due to lack of resolution. Some workers believe that theoretical explanations also seem to lag behind availability of observational data. Also attempts to model relativistic MHD jets have not been very successful and when magnetic fields are introduced in numerical simulations of jets, we get oscillations which do not look like the observed jets. Figure 9 & 10 are obtained recently and show an example of a simulated compact, relativistic jet.



Evolution of the logarithm of the pressure

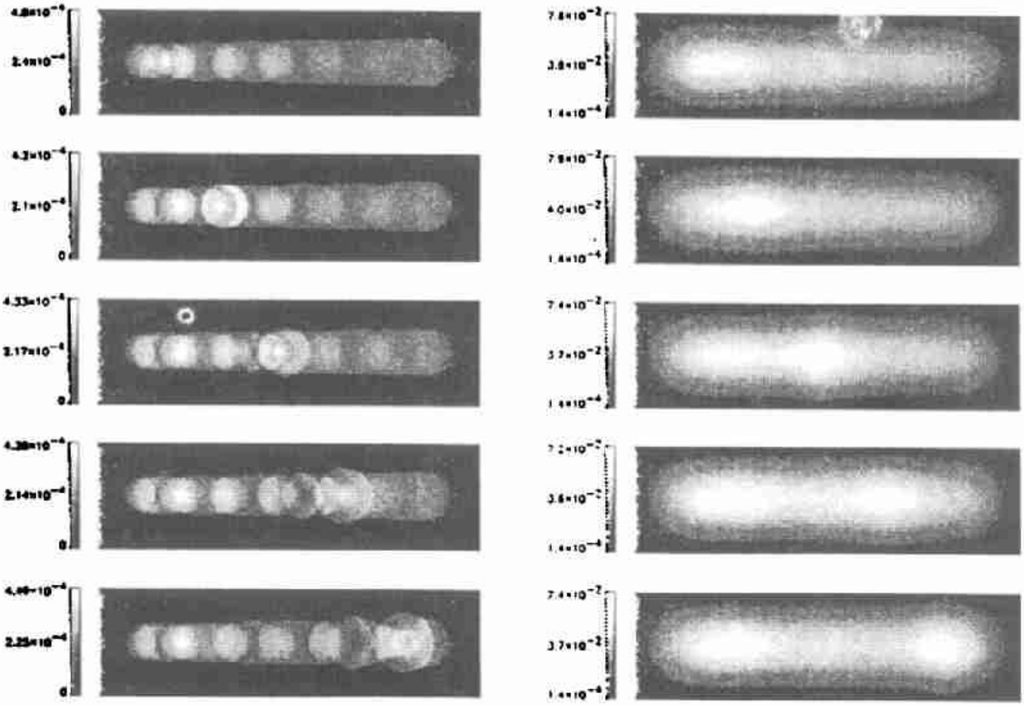


Evolution of the Lorentz factor

Figure 9 Maps of the pressure and Lorentz factor of the jet as a function of time for a jet that has been perturbed by a temporary increase in flow Lorentz factor at the injection point (A.P. Marscher & J.L. Gomez 1996, unpublished).

When every source seems to be showing superluminal motion, including the weak nuclear jets in double–lobed quasars which, in the context of the 'unified scheme' should represent the "unbeamed" parent population of core–dominated sources, astronomers are extending the 'unified scheme' to include all quasars–meaning that galaxies could be "unprojected" quasars. But we remain comfortable as long as the few galaxies, like 3C120 showing superluminal expansion are peculiar ones.

In the next few years, as even better high–resolution radio telescopes become available, we can expect a mass of new data about active galaxies and their jets. But it remains to be seen whether our theoretical understanding of jets can keep pace with our ability to do more sensitive and even higher resolution observations.



Total intensity maps at 5 epochs

Figure 10 Simulated images of the synchrotron radiation as a function of time for the model jet shown in figure 9. Left: At high resolution, as would be observed with a VLBI array incorporating VLBI spacecraft. Right: Convolved with a lower-resolution beam, as would be observed with a ground-based array (A.P. Marscher & J.L. Gomez 1996, unpublished).

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