**MULTI-FREQUENCY VLBI OBSERVATIONS OF
PKS 1413+135: A VERY YOUNG RADIO GALAXY**

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ABSTRACT

We present high-dynamic range VLBA¹ maps of the radio galaxy/BL Lac object PKS 1413+135 at 3.6, 6, 13, and 18 cm. These observations reveal that PKS 1413+135 possesses complex, two-sided parsec-scale structure, similar to that of other Compact Symmetric Objects (CSOs). Its morphology appears to be that of a miniature wide-angle-tail (WAT) radio source, and its total power is at the upper extreme of that seen in WATs. Comparison of these maps with previous data reveals no evidence for superluminal motion, and supports the hypothesis that the milliarcsecond-scale structure of PKS 1413+135, unlike most BL Lacs and flat radio spectrum Quasars, is **not** a product of relativistic beaming. However, beaming is likely present within the core seen at 3.6 cm, due to its high brightness temperature. These new VLBA maps allow a more precise, but not completely unambiguous, interpretation of the various absorption data, suggesting that the $A_v > 30$ mag is due to a normal molecular cloud complex in the disk of the optical spiral galaxy at $z = 0.247$, $\gtrsim$ few kpc away from its nucleus. The absence of scatter broadening of the core source at 1.6 and 2.3 GHz and the lack of multiple images add to the evidence against the hypothesis (originally suggested by Stocke et al.) that PKS 1413+135 is background to the spiral galaxy at $z = 0.247$, in which the AGN appears centered. But if the AGN is within the spiral, the absence of reprocessed radiation (e.g. near-IR dust continuum and emission lines) remains difficult to understand, since the very high extinction is unlikely to cover the entire dust and line emitting regions. Whether within or background to the optical galaxy, PKS 1413+135 is similar to other CSOs in being a young radio source (of age $\lesssim 10^4$ years), with evidence for absorption along our line of sight.

1. Introduction

Since its discovery as a “red quasar” (Rieke et al. 1979), PKS 1413+135 has remained an enigma. Bregman et al. (1981) and Beichman et al (1981) originally classified it as a BL Lac object, since its optical

¹The Very Long Baseline Array (VLBA) is operated by the National Radio Astronomy Observatory, a facility of Associated Universities, Inc.

spectrum exhibits only stellar absorption features, and it is highly polarized ($16 \pm 3\%$) in K band (Stocke et al. 1992). PKS 1413+135 appears to lie within a spiral host (McHardy et al. 1991, Stocke et al. 1992, McHardy et al. 1994). By comparison, unified schemes for extragalactic radio sources (see Urry & Padovani 1995 for a review) associate quasars and BL Lacs with elliptical hosts, and very few exceptions have so far been found (Wurtz, Stocke & Yee 1996). Neither optical imaging nor spectroscopy reveal any evidence for a non-thermal continuum source, yet its near-IR continuum is variable, highly polarized (Stocke et al. 1992), and featureless in the H and K bands (Stocke et al. 1992, §5), indicating a synchrotron source in the core.

The obscuration of the AGN in the optical is just one of many pieces of evidence that there is a large absorbing column along this line of sight. Bregman et al. (1981) and Beichman et al. (1981) noted that the broadband spectrum of PKS 1413+135 declines exponentially shortward of the thermal infrared. Consistent with a near-IR cutoff due to $A_v > 30$ mag of foreground extinction, its soft X-ray spectrum yields a lower limit of $N(H) > 2 \times 10^{22} \text{ cm}^{-2}$ (Stocke et al. 1992). Redshifted 21 cm observations detected an HI column of $N(HI) = 1.3 \times 10^{19}(T_s/f_{HI}) \text{ cm}^{-2}$ (Carilli, Perlman & Stocke 1992), where T_s is the spin temperature, and f_{HI} the covering fraction of the absorbing gas. Also, molecular CO ($J = 1 \rightarrow 0$), HCO+ ($J = 2 \rightarrow 1, 3 \rightarrow 2$), and HCN ($J = 1 \rightarrow 2, 2 \rightarrow 3$) absorptions have been detected by Wiklind and Combes (1994, hereafter WC94; 1995).

Since there is evidence for much obscuration along our line of sight, one would ordinarily expect the absorbing gas to be heated and then emit reprocessed energy in either the thermal IR or in emission lines (as seen in Seyfert 2 galaxies and other AGN). However, these are not observed in PKS 1413+135. To solve this dilemma, Stocke et al. (1992) proposed that the AGN is background to the spiral galaxy seen at this location on optical images. The low intrinsic probability of such a superposition can be increased if the background source is brightened by gravitational lensing.

The radio structure of PKS 1413+135 is intriguing: a VLA map at 20 cm in A array reveals no kpc-scale structure to a dynamic range 9600:1 (Perlman et al. 1994; hereafter P94), yielding a 2σ lower limit on the core-to-extended power ratio $\gtrsim 5000$, considerably higher than for any other BL Lac known (Perlman & Stocke 1993, 1994). Unless its radio lobes are intrinsically $\lesssim 1$ kpc in size, such a high core dominance would indicate a high Lorentz factor. Yet initial VLBI maps (P94) have revealed two-sided structure, inconsistent with beaming.

In this paper, we present VLBA images of PKS 1413+135 at 3.6, 6, 13, and 18 cm from observations made on July 10-11, 1994. These images reveal a bent, two-sided morphology, and further establish that no double images due to microlensing exist, down to scales < 2 milliarcseconds (mas). The source is not scatter-broadened between 13 and 18 cm, as might be expected if the AGN is a background source. Its overall structure appears similar to classical wide-angle-tail (WAT) radio galaxies, but on much smaller scales. We therefore believe that PKS 1413+135, like several other Compact Symmetric Objects (CSOs; Wilkinson et al. 1994, Readhead et al. 1996a, b) is intrinsically small and probably quite young.

Throughout this paper, we assume a redshift of $z = 0.247$ for the optical galaxy associated with PKS 1413+135, as derived from the redshifted HI absorption observed by Carilli et al. (1992). We also assume $H_0 = 100 \text{ km s}^{-1} \text{ Mpc}^{-1}$ and $q_0 = 0.5$ throughout, which gives a map scale of $1 \text{ mas} = 2.43 \text{ pc}$.

In §2, we describe the observations, along with the data gathering and reduction procedures. In §3, we present single-frequency maps and spectral index maps, and discuss the morphology. In §4, we discuss the interpretation of this morphology. Included in this discussion is the relationship of this source to the class of CSOs, and the issue of beaming. In §5, we apply these VLBA data to the issue of the foreground absorptions. This discussion will include both the CO and HI absorption data (WC94, Carilli et al. 1992),

and also a reconsideration of whether dust and/or line emission could be hid by this absorbing gas. In §6, we return to the background source hypothesis, and discuss the impact of these data. Finally, in §7, we summarize our conclusions.

2. Observations and Data Reduction

We observed PKS 1413+135 with the full VLBA on 10-11 July 1994, for a total of 12 hours, at four wavelengths: 3.6, 6, 13, and 18 cm. Critical to the success of these observations was the frequency agility of the VLBA, which enabled us to switch observing frequencies on very short timescales.

In order to obtain optimal Fourier spacing coverage and sensitivity within the observing time allotted, we alternated between frequencies every thirteen minutes. We received only left-hand circularly polarized data at each frequency. Each station used the VLBA recording system, which provided 16 MHz bandwidth in two IF channels, with 2 bit data sampling. The data were correlated at the VLBA correlator in Socorro, NM, and then fringe-fitted, calibrated and mapped within the AIPS software package, using a point source model for initial fringe fitting. *A priori* amplitude calibration was done using the gain and system temperatures for each station, yielding correlated flux densities. At each frequency, the hybrid mapping procedure was started using a point-source model for initial phase self-calibration. In subsequent iterations of self-calibration, we allowed first the phase and then both amplitude and phase to vary, taking care to restrict the range of (u, v) distances used for the solutions in each self-calibration iteration.

As these observations were among the first to have been correlated with the VLBA correlator in Socorro, the initial flux scaling was somewhat uncertain. To check the flux calibration, we compared the highest (one scan average) flux measured on our shortest baselines at 8.4 GHz (3.6 cm) and 5.0 GHz (6 cm) to data gathered from the University of Michigan Radio Astronomy Observatory (UMRAO) database at 8.0 GHz and 4.8 GHz. Although this comparison is subject to the assumption that no structure is resolved out at the lowest frequency for which this comparison is possible (5 GHz), we derive an approximate correction factor $b \approx 1.3$. We have multiplied all flux densities derived directly from the original maps by this factor to obtain the final maps and flux figures.

3. Results: Parsec-scale Morphology of PKS 1413+135

We used the procedure outlined in §2 to produce both naturally-weighted and uniformly-weighted maps at each frequency. Tapered maps were also made, but in general these did not reveal any new extended structure. The large bandwidth and high data quality delivered by the VLBA enabled us to make high-dynamic range maps (the dynamic range of the 3.6 cm map is $\approx 9000:1$), with off-source RMS noise levels within 50% of thermal noise at all frequencies. In Table 1, we show the beam sizes (FWHM), and RMS noise levels achieved in the naturally-weighted maps, which we show in Figure 1. We also produced spectral index maps (convolved to the resolution of the longer wavelength map in each case) between the 6-3.6 cm, 13-6, and 18-13 cm maps respectively. These maps are shown in Figure 2. Note that to date, very few spectral index maps have been constructed from simultaneous multi-frequency VLBI data.

It is useful to name the components on the 18 cm map, and then follow their structure on higher resolution maps through the 13, 6, and 3.6 cm maps. At 18 cm (Figure 1a), the source separates into eight components. We have labeled the non-nuclear components A-G. At this low frequency, the brightest

component is B, which coincides with a significant bend in the counterjet. This component appears at (0,0) on the 18 cm map, since the self-calibration process shifts the map center to correspond with the brightest flux component in the map. Two components appear on the 18 cm map which do not appear on any of the other maps (F and G). The remainder of these features all appear on the 13 cm map (Figure 1b), which in addition shows the curving of the jet from component D towards E. Somewhat greater detail is shown on a uniformly-weighted map at 13 cm (Figure 3), which begins to show separation of some of the components which are resolved in greater detail at the higher frequencies. In the 6 cm map (Figure 1c), each of the jet and counterjet components resolve into at least two knots. For example, A resolves into four knots, plus some diffuse emission; component D resolves into 3 knots, and components B and C resolve into 2 knots each. The 3.6 cm map (Figure 1d) reveals the greatest detail of all, and a few of the components reveal even smaller-scale structure. The structure near the VLBI core (component N; see below), i.e. from the bend at component B through component D, aligns along roughly $PA \approx 54^\circ$, quite close to the minor axis of the spiral galaxy ($PA = 56^\circ$; Stocke et al. 1992).

In order to extract all of the flux contained in each of the components at higher frequency, we produced tapered maps, and then convolved those maps to the beam produced in the full-resolution 18 cm map. This procedure was chosen because we believe that the full-resolution, naturally-weighted 18 cm map is at the minimum resolution required to separate the components adequately. We then determined the integrated flux within each component by enclosing it in a multi-verticed region using the AIPS task TVSTAT. These values are listed in Table 2. Except where noted, we have assumed 5% errors based upon estimates of errors in the flux bootstrapping procedure. This procedure required us to take considerable care in determining the flux of components C, and D. To find the flux of component D, we found the combined flux of components N+D by using TVSTAT, and then subtracted off the maximum, which was fit to component N using JMFIT. To find the flux of component C, we enclosed both B+C in a multi-verticed region, and then subtracted off the flux previously found for component B using TVSTAT. Given the extra uncertainty involved in this procedure, all errors quoted for these fluxes in Table 2 are 10% of the integrated flux.

Our maps firmly establish the location of the core as the component labeled ‘N’. Component N has an extremely inverted spectrum (well-fit by a power law of index $\alpha = +1.7$, where $S_\nu \propto \nu^\alpha$; see Figure 4), and is the most compact component. It is also the site of variability ($\sim 10\%$) between epochs 1992 (P94) and 1994 (this paper). Under the usual interpretation (e.g. Miley 1980), its inverted spectrum implies that N is synchrotron self-absorbed, implying a small component size and large magnetic fields. An alternate hypothesis is that of free-free absorption (P94). This latter hypothesis is now effectively refuted, since the fitted core spectrum (Figure 4) indicates a turnover frequency > 8 GHz, which would require $\tau_{ff} \gtrsim 30$ at 18 cm. In such a case the core would not be visible at all on the 13 cm and 18 cm maps. However, we cannot rule out a free-free screen which partially covers the core source. The identification of component N as the core had been preliminarily made by P94 on the basis of lower-resolution and lower-dynamic range data. The location of the core firmly establishes the two-sided nature of this source. We define a “jet” and “counterjet” side, as shown on the 3.6 cm map (Figure 1d).

While the majority of the extended structure shown in these maps is very steep-spectrum ($\alpha \leq -1$; see Figure 2) there is considerable variation in the spectral index structure. Several of the knots and bends are somewhat flatter spectrum regions, indicative of reacceleration and/or recollimation at these points. The most far-flung components are the steepest, with power-law indices approaching $\alpha = -2$. Such spectra are much steeper than average for most kiloparsec-scale lobes in radio galaxies, which tend to have spectra of $\alpha \sim -0.8$ (e.g. Cygnus A, Carilli et al. 1991; note that little is known regarding the spectral index structure of most AGN on parsec scales). The steep spectral index could be due to synchrotron losses (e.g. Jaffe &

Perola 1973) by the relativistic electrons. For example, the expected synchrotron break frequency for the electrons in this region is 7 GHz, assuming a source age and minimum energy fields as derived in §4.

These maps are broadly consistent with earlier-epoch maps of PKS 1413+135 presented by P94 at 3.6 and 18 cm. At 3.6 cm, those maps showed the core (labeled ‘B’ in P94), component B (labeled ‘A’ in P94), some of component C (originally thought to be due to false symmetrization in P94), as well as D (labeled ‘C’ in P94). However, our original interpretation of the 18 cm structure in the 1991 map must be revised, as those data were inadequate to fully resolve the components. For example, component B in the 18 cm map in P94 was originally thought to be associated with the core; however, inspection of the higher-resolution maps we present here reveals that it is associated with knot B (corresponding to the $\sim 60^\circ$ bend in the counterjet).

There is undoubtedly some structure resolved out in each map. For the higher frequency maps (Figures 1b-1d), this can most easily be seen by comparison with the 18 cm map (Figure 1a). There is evidence of extended structure resolved out by the 18 cm map as well: the total integrated flux of the structure shown in Figure 1a is 820 mJy; by comparison, the integrated flux of the structure seen on the (lower-resolution) 18 cm map presented by P94 is 988 mJy, with over 800 mJy in the extended structure. We are obtaining MERLIN observations at 20 cm to probe the outer structure of PKS 1413+135, which must have a maximum extent $\lesssim 2$ kpc given its lack of arcsecond-scale extended structure (Perlman & Stocke 1994).

4. Interpretation of the Morphology

The morphology revealed by these observations is fascinating, and confirms the close relationship of PKS 1413+135 to the class of CSOs (Wilkinson et al. 1994), first suggested by P94. If indeed this bent, somewhat arcuate structure is not a projection effect (which remains a possibility since the VLBI core is likely beamed (§4.3)), two interpretations are possible. The first possibility, which we will explore in §4.1, is that large-scale nuclear gas motions are responsible. The second possibility is that the source is bent by gravitational lensing. Since our re-interpretation of the absorption data also has some bearing on this question, we will delay discussion of this question to §6. In §4.2, we will discuss the relationship of PKS 1413+135 to the class of CSOs. This will be followed by a discussion of beaming issues (§4.3).

4.1. A Miniature Wide-Angle Tail?

Morphologically, the overall structure of PKS 1413+135 appears similar to wide-angle-tail radio galaxies (compare, for example, with the kpc-scale structure of 2236-176; O’Donoghue, Owen & Eilek 1991). However, the physical extent of the two lobes is only ~ 240 pc (100 mas at $z = .247$), 2-3 orders of magnitude smaller than the typical WAT. The sharp “bends” in WAT structures are thought to be caused by interactions with a hot intergalactic medium surrounding the host galaxy. Therefore, if this source is not gravitationally lensed (see §6), it is likely that the sharp bend in the counterjet (knot B) is produced by interaction with a nuclear interstellar medium which is undergoing large-scale gas motions at that point.

Since there is evidence for beaming within the core (§4.3), it is also possible that the “bend” seen at B is a projection effect. However, the morphology observed herein rules out a helical model similar to that proposed for 4C39.25 by Alberdi et al. (1993), where the “hot-spots” are locations where the trajectory of a misaligned, bent jet is more closely aligned with our line of sight. A helical model would require the

counter-jet to be approaching in order to produce a brightening at (B). However, if one assumes that the observed jet to counterjet flux ratio is a product of Doppler boosting of the jet, one is forced to conclude that the counter-jet is receding (§4.3).

The counter-jet also contains smaller-scale wiggles, which are particularly evident on the 6 cm map (within component A, and between A and B). These are unlikely to be the product of gravitational lensing, and therefore must be regarded as intrinsic. This, along with the steep spectral indices present in the furthest-flung parts of the lobes, is evidence for a fairly dense nuclear medium.

Our data provide no information on scales $\lesssim 2$ mas, hence we can only make some very general comments regarding this region. First of all, we measure a line-of-sight separation angle of 172° between the “jet” and “counterjet”. It is therefore likely that modest submilliarcsecond bends are present (which are not uncommon; e.g. PKS 0735+178, Zhang & Bååth 1991). In addition, we may obtain some constraints on the core size of PKS 1413+135 by inspecting single-dish variability data gathered by the University of Michigan Radio Observatory. We show radio fluxes gathered from the publicly available UMRAO database for PKS 1413+135 since September 1, 1993, in Figure 5. These data show violent variability; the shortest-timescale variation during that time period was the $\sim 30\%$ increase within ~ 30 days near day 200. This sets an upper limit on the core size of .024 pc ($10\mu\text{as}$), so that on higher resolution maps we may expect jet structure down to this size scale. Even more violent variability is shown at higher frequencies (22-375 GHz, where the spectrum of PKS 1413+135 is roughly flat), and on similar timescales by the data of Stevens et al. (1994). It is important to note that if relativistic beaming (§4.3) is present, a larger core size is possible, since in that case the intrinsic timescale of the core would be compressed.

4.2. Relationship to the Compact Symmetric Objects

Compact Symmetric Objects (CSOs) are a class of extragalactic radio sources with physical extents $\lesssim 1$ kpc and two-sided parsec-scale structure (Wilkinson et al. 1994, Readhead et al. 1996a). Closely related classes of objects include the GigaHertz Peaked Spectrum (GPS; see O’Dea et al. 1991) sources, and the compact steep-spectrum (CSS; see Fanti et al. 1990) sources. Both of these classes exhibit radio structures considerably smaller than classical double-lobed radio galaxies. Recently Readhead et al. (1996b) has proposed re-classifying powerful extragalactic radio sources into three categories, solely based upon size. Readhead et al. group all sources of size ≤ 1 kpc into the CSO class; sources of extent 1 – 15 kpc comprise the MSO, or medium symmetric object, class; the remainder (≥ 15 kpc) are called LSOs (large symmetric objects).

Perlman et al. (1994) first noticed the overall similarity of PKS 1413+135 to the CSOs (Wilkinson et al. 1994). These VLBI maps confirm beyond any doubt that the radio source PKS 1413+135 is indeed a CSO. Importantly, this classification is *independent* of the location of the AGN (i.e., background to, or within, the optical spiral), since even if the radio source is at $z > 1$ its physical extent must be < 1 kpc. Besides its compact radio morphology, PKS 1413+135 shares a number of characteristics with CSOs and MSOs:

- (1) While all CSOs have two-sided radio structures, in all cases the jet is considerably brighter than the counterjet. This is also the case for PKS 1413+135 (§4.3), and may indicate bulk relativistic motion in the jets (Readhead et al. 1996a).
- (2) None of the CSOs show any evidence of superluminal motion (Conway et al. 1994).

(3) Large near-IR excesses have been found in some CSOs (compared to normal elliptical galaxies; O’Dea et al. 1994).

(4) A much higher incidence of strong HI absorption in CSOs (Conway et al. 1996) compared to radio-loud ellipticals in general (van Gorkom et al. 1989).

(5) Little or no evidence for AGN-like optical continua (Stanghellini, O’Dea & Baum 1993; O’Dea, Baum & Morris 1990a; Readhead et al. 1996a).

(6) Unambiguous disk host galaxies for at least 2 GPS sources (0914+114 and 1323+321), and evidence for significant reddening in both some MSOs and CSOs (Stanghellini et al. 1993).

(7) Other evidence of significant absorption, for example large Balmer decrements (Fosbury et al. 1987, Bartel et al. 1984), and either very low ($< 0.5\%$) polarization or, where polarization is $> 1\%$, very high Faraday rotations (O’Dea et al. 1990b; Mantovani et al. 1994).

(8) Large absorbing columns for some GPS sources in ROSAT PSPC spectra (Elvis et al. 1994).

However, PKS 1413+135 is also different from all other CSOs in the following ways:

(1) The nucleus (N) comprises $> 90\%$ of the flux at 8 GHz, and $> 70\%$ of the flux at 5 GHz. Thus PKS 1413+135 is by far the most core-dominated of all CSOs.

(2) The radio emission of PKS 1413+135 is far more variable (Figure 5) than that of any other CSO (Readhead et al. 1996a).

It has been argued that CSO, GPS and CSS sources are young, and began ejecting their radio jets $\lesssim 10^6$ years ago (DeYoung 1993, Gopal-Krishna & Wiita 1991). An alternate hypothesis, proposed by Baum et al. (1990), is that these sources have been “smothered” as a result of gaseous infall towards the nucleus. A third possibility is that CSOs and MSOs are ‘frustrated’ radio galaxies, the growth of which has been limited by dense nuclear gas (e.g., O’Dea et al. 1991). Below, we explore the applicability of these scenarios to PKS 1413+135 and, by extension, other CSOs.

It is likely that the outer components of PKS 1413+135, like those of other CSOs, are ‘minilobes’, which are quasi-stationary, and are where the jets terminate. From the 18 cm map (Figure 1d), we derive a total flux of 238 mJy and a size of 12.6×8.9 mas for component A, the most far-flung knot. By assuming minimum-energy conditions (e.g. Miley 1980 and sources therein), we may then obtain a first-order estimate of the magnetic field, advance speed, and approximate age of this source. Assuming a spectral index of $\alpha = -1.5$ (based on the spectral index maps), we derive a minimum-energy magnetic field of $B_{me} \approx 11$ mG, which corresponds to a pressure of $P_{me} = 3.6 \times 10^{-6}$ dyne cm^{-2} . We then assume ram pressure balance, which allows us to calculate the mean advance speed, i.e. $v = (P_{me}/m_p n)^{0.5}$, where n is the density of the surrounding nuclear medium. Thus we obtain $v \approx 1.5 \times 10^9 n^{-0.5}$ cm s^{-1} . Assuming a constant advance speed over the lifetime of the source, this translates into a source age of $t \approx 7000 n^{0.5}$ years. Even if the AGN PKS 1413+135 is at $z \gg .247$, the lobes cannot be much larger than a few hundred parsecs. Therefore, regardless of whether the AGN is within, or behind, the optical galaxy, our data favor the “young” radio galaxy hypothesis for PKS 1413+135.

Alternative hypotheses are not feasible. Readhead et al. (1994) calculated that to pressure-confine the jets of 2352+495, another CSO, would require $n \approx 10^5 \text{ cm}^{-3}$, which translates into a nuclear mass of $\sim 10^{11} M_\odot$ within the inner 100 pc. Readhead et al. show that in order to achieve the hydrostatic pressure necessary to prevent its gravitational collapse (which would otherwise cause it to collapse in $\sim 10^5$

years), a temperature $\sim 10^7 K$ would be required. This would ionize the nuclear ISM and quench the radio source below a few GHz (which is not observed). The simulations of DeYoung (1993) show that even a fairly dense ($\sim 1 - 10 \text{ cm}^{-3}$) nuclear ISM can only confine radio jets of power comparable to those seen in powerful radio sources for $\lesssim 10^7$ years; therefore, despite suggestions that CSS sources (MSOs) may possess denser-than-average nuclear ISMs, it remains likely that these sources must also be relatively young. We also do not consider the Baum et al. (1990) hypothesis (that the AGN has been “frustrated” as a result of gaseous infall towards the nucleus) reasonable for PKS 1413+135, since no kpc-structure is observed. Begelman (1996) has come to similar conclusions for the class of CSOs.

It is therefore likely that the CSO and MSO classes represent early stages in the lifetimes of powerful radio galaxies. Recently, Readhead et al. (1996b) have proposed that the CSO $\rightarrow$ MSO $\rightarrow$ LSO sequence is, in fact, an evolutionary sequence; i.e., radio galaxies begin their active “lives” as CSOs, then evolve into MSOs, and then LSOs. In addition to the advantages cited by Readhead et al. (1996b), we suggest that there is another persuasive argument favoring this model. If indeed the MSOs are at a later evolutionary stage than CSOs, one would expect the nuclear media of CSOs to be denser than their larger cousins, since the ram pressure of the jets, combined with radiation pressure from the AGN, should thin the nuclear medium as time progresses. This would explain the larger near-IR excesses found for CSOs than MSOs (O’Dea et al. 1994).

Wilson & Colbert (1995) have recently proposed a model for AGN formation based upon the mergers of supermassive black holes at the nuclei of merging galaxies. This model argues (following, e.g., Toomre & Toomre 1972) that elliptical galaxies result from mergers of spiral galaxies, and predicts AGN-like activity from these mergers, with radio-loud AGN caused by the mergers of already active, radio-quiet galaxies (i.e. Seyferts). This model is supported by the observation that the only powerful radio sources found within disk galaxies are very young, so that their host galaxies have yet to evolve into ellipticals following the merger which (under the Wilson & Colbert model) triggered the formation of their radio jets. However, other observational facts may violate this appealing scenario. For example, the host galaxy of PKS 1413+135 (McHardy et al. 1994) does not show obvious signs of recent interaction; nor does it appear to be within an overdense environment (Wurtz, Stocke & Yee 1996).

4.3. Beaming?

We can use these data in concert with our earlier VLBI observations (P94) to decide whether PKS 1413+135 fits within the standard unified scheme for core-dominated radio sources, i.e. that they are produced by viewing relativistic jets at small angles with respect to the beaming axis (e.g. Urry & Padovani 1995). We first attempt to constrain the range of (β, θ) parameter space within which PKS 1413+135 may lie. The two-sided nature of this source makes it difficult to decide which (if either) of the jets is pointing in our general direction. To compute the jet to counterjet ratio, R , we first subtracted out a Gaussian fit to the core component ‘N’ on our 1994 July 10 8.4 GHz map. We then rotated the map so that the “jet” was at PA 0° , and enclosed both the “jet” and “counterjet” structures in rectangular boxes measuring 12×7.5 mas. After integrating the fluxes thus obtained, we measured the RMS and total flux in identical boxes above and below each structure, as well as at rotations of 60, 90 and 120 degrees, to estimate the error in this procedure. We obtain a value of $R = 14.5 \pm 2.2$.

To search for proper motion between the two epochs in hand, we first convolved the 8.4 GHz map to the resolution of the uniformly-weighted map made from our 1992 Jun 25 dataset (2.5×2.3 mas in PA

18°). These maps are shown in Figure 6. Given the significantly greater dynamic range of the 1994 Jul 10 map compared to the 1992 Jun 25 map (8800:1 compared to 2000:1), it is difficult to directly infer motion of any component from this comparison. However, we may set an upper limit of $\beta_{app} < 0.8$ based upon the identification of the leading edge of component C in the 1992 June map with the leading edge of component D in the 1994 July map.

We recall that a relativistic jet moving with velocity $v = \beta c$ has an apparent velocity $v_{app} = \frac{v \sin \theta}{1 - \beta \cos \theta}$. Such a jet has an observed jet to counterjet ratio of $R(\theta) = R_0[(1 + \beta \cos \theta)/(1 - \beta \cos \theta)]^p$, where $p = -(2 + \alpha)$ for a simple jet morphology, and $p = -(3 + \alpha)$ for an optically thin spherical knot (Scheuer & Readhead 1979). Assuming $R_0 = 1$ and $p = -(3 + \alpha)$, and applying these formulae (valid for 180° opposing jets) to our values of β_{app} , α , and R yields Figure 7. Since the allowed region is on or below both lines in Figure 7, we can place fairly strong upper limits of $\beta \leq 0.65$ and $\theta \leq 60^\circ$. Indeed, if the source is seen close to the jet axis, $\beta \approx 0.5$. Therefore, relativistic boosting is unlikely to play a major role in producing the observed morphology.

We stress that this analysis does not eliminate the possibility that the nucleus seen at 3.6 cm is relativistically beamed. Indeed, this is highly likely, since the 14.5 GHz variability data (Figure 5) set a lower limit on the brightness temperature of $T_B \gtrsim 3.4 \times 10^{13}$ K, which is considerably in excess of the limiting temperature for the inverse-Compton catastrophe ($\sim 10^{12}$ K; Scott & Readhead 1977). This translates into a lower limit of $\Gamma \gtrsim 1.6$ (see Qian et al. 1991 with regard to translating brightness temperature limits into limits upon bulk relativistic motion). It is therefore likely that higher resolution maps will reveal superluminal structure. We have obtained third-epoch VLBA data at 6, 3.6, 2 and 0.7 cm data in order to test the above hypotheses further.

5. The Foreground Absorbing Screen

Ample evidence for a substantial foreground absorbing screen is seen in the radio, IR and X-ray spectra of PKS 1413+135, which our new VLBA maps help to interpret. From the observed soft X-ray absorption a somewhat uncertain lower limit of $N(H_{tot}) > 2 \times 10^{22} \text{ cm}^{-2}$ and $A_v > 30 \text{ mag}$ is obtained towards the AGN core (Stocke et al. 1992). Better X-ray spectroscopy with ASCA will allow a more accurate determination of this total column.

The observed H I redshifted 21 cm absorption line has $N(HI) = 1.3 \times 10^{19}(T_s/f_{HI})\text{cm}^{-2}$ (Carilli et al. 1992). It is quite likely that $f_{HI} \sim 1$ since the flux at 18 cm (Table 2) is rather evenly distributed between several components, none of which is sufficient to account for the entire depth of the observed H I line. In particular, the extrapolated core flux at 1.1 GHz (see Figure 4) is $< 10\%$ of the total, so that the cloud which creates the molecular absorptions against the core observed at shorter wavelengths can only account for a tiny fraction of the observed H I. The H I velocity width ($\text{FWHM} = 18 \text{ km s}^{-1}$) is typical of a random sightline through our own Galactic disk, and suggests that $T_s \sim 300 \text{ K}$ is appropriate yielding a mean (i.e. source averaged) $N(HI) = 4 \times 10^{21} \text{ cm}^{-2}$ but with significant deviations expected across the source. VLBA mapping in the redshifted 21 cm line should reveal interesting, extended morphology of this gas.

Three narrow ($\text{FWHM} \lesssim 1 \text{ km s}^{-1}$) CO absorption lines (WC94) and other molecular species (Wiklind & Combes 1995) have also been detected at high frequencies where the continuum flux is dominated by the core (see Table 2). Using an $N(CO)/N(H_2) = 2 \times 10^{-4}$ (Lacy et al. 1994), we infer $N(H_2) \sim 1.3 \times 10^{21}(1/f_{CO})(T_x/10K)^2 \text{ cm}^{-2}$, where T_x is the excitation temperature. The depth of the CO absorptions suggest $f_{CO} \sim 1$ (this is further elaborated upon by WC94). The narrowness of the lines

further suggests that these cores must be fairly compact and at $T_x \sim 10$ K. The combination of the large filling factor with the compactness of the radio core from the radio variability database (Fig. 5) places a lower limit of $\gtrsim .024$ pc on the size of these regions, consistent with the observed sizes of molecular cores in our own Galaxy (Goldsmith 1987). The low T_x implies that these molecular absorptions arise in a cloud core quite distant (3-10 kpc) from the nucleus of the spiral rather than in a nuclear torus, where much hotter temperatures ($\sim 50 - 100$ K; Maloney 1990) are expected. The velocity offset between two of the molecular lines and the H I absorption line center (-11 km/s; see Fig. 3 of WC94) suggests that the majority of H I is not directly related to the molecular cloud core. Further the two lines at -11 km/s may to share a common envelope (WC94), suggesting that they are part of a larger GMC complex containing several such cores (e.g., Orion; Green & Padman 1993).

While the core is heavily extinguished ($A_v \gtrsim 30$ mag; Stocke et al. 1992), what can we infer about the total extinction between us and the rest of the radio source and thus between us and any potential broad and narrow emission-line regions? Even if the observed cloud cores are part of a much larger GMC complex containing several such compact cores, the resulting high extinction would be quite patchy (and certainly could not extend across $\gtrsim 1$ kpc, as would be required to cover both the putative broad-line and narrow-line regions). If we then assume that the large majority of the total hydrogen column density is due to atomic, rather than molecular hydrogen and the majority of the radio source would be obscured only by $A_v \sim 2.5$ mag ($A_K \sim 0.25$ mag), a value estimated from the $\langle N(HI) \rangle$ obtained from the 21 cm line plus the standard conversion ratio of $N(HI)/E(B - V) = 5.2 \times 10^{21} \text{ mag}^{-1} \text{ cm}^{-2}$ (Shull & Van Steenberg 1985). While this amount could effectively hide some optical emission lines, near IR emission lines would be reduced by only 20-25%. Stocke et al. (1992) reported that the infrared H & K band spectra of PKS 1413+135 are featureless to modest limits ($W_\lambda < 100$ and $50 \text{ \AA}$ respectively) and more recent spectra set even tighter limits of $W_\lambda < 5$ and $10 \text{ \AA}$ respectively. The new H-band and K-band spectra of PKS 1413+135 are shown in Figure 8; Paschen α should appear at 2.37μ . Given that the K-band continuum luminosity of PKS 1413+135 is $\sim 10^{10} L_\odot$, the above limits require that the $P\alpha$ line luminosity is $< 10^7 L_\odot$. By comparison the $B\Gamma$ line luminosity of NGC 1068 is $\sim 5 \times 10^6 L_\odot$ (Thompson, Lebofsky & Rieke 1978), which converts to an expected $P\alpha$ luminosity for NGC 1068 of $\sim 6 \times 10^7 L_\odot$. Further the $B\Gamma$ line emission region in NGC 1068 is resolved and comparable in size to the optical narrow-line region (Rotaciuc et al. 1991). Thus, the expected $P\alpha$ emission region in PKS 1413+135 is too luminous and too extended to remain undetected, if the above inferences about patchy high extinction are correct.

If indeed the AGN is resident within the optical spiral, it would be possible to avoid the necessity of observing emission lines if the ionizing radiation is highly beamed, so that it illuminates only a very small solid angle, comparable to that occupied by that foreground GMC core (see above), so that the ionizing luminosity of the nucleus reduces to that of $\lesssim 1$ O star. While previous arguments (§4.3) have already concluded that the core is likely beamed, this model would require a jet Γ considerably higher than the lower limit we can set from the variability data ($\Gamma \geq 1.6$; see §4.3). Further VLBI observations are required to test the viability of this model.

Perhaps the most likely reason for the lack of observed emission lines is that the ionizing continuum of this object is too soft to create a luminous emission line region. Guilbert, Fabian & McCray (1983) originally proposed that BL Lacs, as a class, lack strong emission lines due to their extremely steep X-ray spectra, which are too soft to create a stable two-phase medium (warm emission clouds embedded in a hot substrate); instead, a single hot phase at $T \sim 10^5$ K is created which emits minimal line emission. Recently Perlman et al. (1996b) have updated the Guilbert, Fabian & McCray (1983) model based upon a viewing angle dependent model in which soft (synchrotron) X-rays are emitted into a significantly broader

cone than the inverse Compton hard X-rays. This would cause the gas conditions in the putative (nuclear) line emitting regions to be controlled primarily by the soft X-ray continuum and cause them to emit little line radiation. But this may not explain the absence of narrow emission lines, since the non-thermal continuum may not control the temperature in the narrow-line region. The current X-ray observations of PKS 1413+135 (*Einstein* IPC only; Stocke et al. 1992) do not constrain the pre-absorbed X-ray spectral index at all. ASCA observations are needed to constrain the presence, or lack thereof, of a hard inverse Compton component in the X-ray spectrum of this source.

Near- and far-IR emission from AGN-heated dust also would be expected to be present in PKS 1413+135. Since the HI absorption found in PKS 1413+135 is $\sim 10\times$ higher in optical depth than that found for e.g. 3C236 and 4C31.04 by van Gorkom et al. (1989), we can scale the rough correlation found in Figure 9 of Knapp (1990) up by that factor to obtain an order-of-magnitude estimate of the dust luminosity at $60\ \mu$ for PKS 1413+135. This procedure predicts $F_{60\mu} \sim 0.5$ Jy at $z = 0.247$ for PKS 1413+135, very close to the sensitivity limit of the IRAS point source catalog. Indeed, as noted by Beichmann et al. (1981), the observed IR spectrum of PKS 1413+135 does not preclude the possibility of IR emission by dust grains at $T \lesssim 100$ K, as would be expected for an AGN within a dust rich galaxy (e.g. NGC 1068, which emits $\sim 10^{11} L_{\odot}$ of resolved dust emission in the near-IR; Telesco et al. 1984; Tresch-Feinberg et al. 1987). But previous observations (with IRAS by Beichman et al. 1981 and ground-based telescopes by Rieke et al. 1978; Bregman et al. 1981; and Stocke et al. 1992) found the near-IR and far-IR continuum of PKS 1413+135 to be variable and the near-IR highly polarized suggesting that any dust emission must be small compared to the continuum emission from the AGN. If this is correct, it is hard to imagine a sensible geometry that would hide the circum-nuclear emission line region without hiding the continuum source.

While the above estimate suggests that the far-IR dust emission could be hidden by the unobscured AGN core continuum, hot dust emission would be more difficult to hide beneath the non-thermal core emission simply because the core is already slightly obscured at K-band. However, the interpretation of the K-band polarimetry may be ambiguous, since it is consistent with constant P and θ to within somewhat large errors (Stocke et al. 1992) as would be expected for dust scattering from a flattened geometry. Thus, the observed K-band variability could be due not to variable emission, but to variable absorption. An $A_v > 30$ mag covering the entire inner 100 pc of this galaxy cannot be unambiguously excluded by the present data; however, the compactness of the CO lines argues against this hypothesis. Given such substantial columns obscuring the entire radio continuum source, radio recombination lines and perhaps even OH maser emission would be expected from this source. We have obtained VLA data to test this idea (Carilli et al. in preparation).

While these new VLBA maps aid in the interpretation of the absorption data, few firm conclusions are possible and the observable properties of PKS 1413+135 remain frustratingly difficult to understand. The most straightforward interpretation of the absorption data seem to require that the $A_v \sim 30$ mag extinction covers only the compact radio core so that any near-IR emission line and dust emission regions would not be heavily obscured. Therefore, the absence of this emission remains a difficulty in understanding this source, if it is within the nucleus of the $z = 0.247$ spiral.

6. The Background Source Hypothesis

If PKS 1413+135 is a background source to the observed $z=0.247$ spiral, then gravitational lensing could affect its observed properties including: selective amplification of compact structures, distortion, or

even doubling, of source structures and two redshift systems, one for the lens and one for the source. To date only the compact radio morphology has been observed and this could be an intrinsic source property as discussed at length in §6.

McHardy et al. (1994) use the lack of arcsec-scale multiple images to argue against the background source hypothesis for PKS 1413+135. However, this same difficulty arises in the case of AO 0235+164, where the large difference between emission and absorption redshifts makes the background source hypothesis more obviously convincing than here. To address the problem of the absence of multiple images for AO 0235+164 and other BL Lacs, Narayan & Schneider (1990) show that if a lensing galaxy has a scale-length $\gtrsim 2$ kpc (i.e. unusually diffuse), it is possible to avoid multiply-imaging a background source, even at small impact parameters. The measured disk scale-length for the PKS 1413+135 spiral is 6.9 kpc (Wurtz, Stocke & Yee 1996). At least one other BL Lac (MS 0205+351; Stocke, Wurtz & Perlman 1995) is similar to AO 0235+164 and PKS 1413+135 in this respect. And a fourth, 1 Jy 0218+357 (“the smallest Einstein ring”; O’Dea et al 1992; Patnaik et al. 1993) shows evidence for gravitationally-lensed imaged structure only at subarcsec scales. These four cases have led Stocke, Wurtz & Perlman (1995) to suggest that at least some of the classical BL Lac properties might be produced by the alignment between a relatively normal background quasar and a foreground, diffuse or low luminosity spiral galaxy.

Our VLBA maps show that the overall morphology of PKS 1413+135 may be somewhat arcuate, reminiscent of the arcsec-scale structure of 0957+561 (Greenfield, Roberts & Burke 1985). While this bending could be produced dynamically by large-scale nuclear gas motions (§4.1), if we proceed along the lines of the lensing hypothesis, we derive a radius of curvature of 135 ± 10 mas from the 18 cm map. The uncertainty reflects the relative inadequacy of any single circle in fitting the observed radio structure. Thus, if the curved radio structure is a product of gravitational lensing, the spiral’s center of mass is $\gtrsim 135$ mas from the radio core; this does not contradict the limit on decentering of the core relative to the galaxy centroid in H-band ($0.1''$; Stocke et al. 1992). This amount of curvature requires a mass interior to this radius of $\sim 10^9 M_\odot$, comparable to dynamical mass estimates for the central 200 pc of our own Galaxy (Blitz et al. 1991)

Under this hypothesis, a second image of the source might be expected at a location along this radius at 130-300 mas from the source structure displayed in Figure 1. We have searched for such a structure using our 6, 13 and 18 cm data but find no secondary images to a surface brightness limit of 0.45 mJy/beam (3σ at 6 cm), corresponding to a flux ratio of 1:1100 from the core source. Nor do our data show evidence for other possible secondary images, down to a scale of ~ 2 mas. If indeed the AGN is gravitationally lensed and multiply imaged, this translates into a lower limit upon the amplification factor, and commensurately stringent constraints upon the lensing geometry. But importantly, the diffuse morphology of the optical galaxy leaves open the possibility of lensing without multiple images. Thus, while the absence of multiple images does not support the background source hypothesis, it does not doom the idea completely.

Since the sightline for the AGN PKS 1413+135 through the optical galaxy appears similar to sightlines through our Galaxy at $|b| < 5^\circ$, we would also expect to observe scatter broadening at long wavelengths ($\lambda \gtrsim 20$ cm) due to interstellar scintillation. Fey et al. (1989) observed such an effect for 5 of 6 compact radio sources with $|b| < 5^\circ$. The signature of scatter-broadening is source size $\propto \lambda^2$ (e.g. Spitzer 1978, Rickett 1990). By comparison, synchrotron self-absorption implies source size $\propto \lambda$ longward of the turnover. To test for the presence of scatter broadening, we computed the sizes of the deconvolved core Gaussians (i.e. component N) in each map. These values are shown in Table 3. At 3.6 cm and 6 cm, the core is essentially unresolved. However, at 13 cm and 18 cm, the core is resolved, and we are able to perform this test. The ratio of the core sizes at 18 and 13 cm is $1.38 \pm .25$ perpendicular to the jet, and $1.41 \pm .03$ parallel to the

jet. By comparison, the self-absorption model predicts a size ratio of 1.36, while the scatter-broadening model predicts a size ratio of 1.86. Therefore, there is no evidence for significant scatter broadening in this source at $\lambda \leq 20$ cm; however, observations at longer wavelengths are required to be more definitive on this point.

In order for scatter broadening from within the host galaxy to be observable at ~ 1 GHz, the core would need to be $\lesssim 1$ mas in angular size *at the location of the absorbing screen*. (Rickett 1990). By comparison, the radio core would have an angular size $\theta \sim 5d_{kpc}^{-1}$ arcseconds (from the single-dish variability data) at the location of the absorber, where d_{kpc} is the distance from the core to the absorber, in kpc. Thus scatter broadening is likely only if the AGN is far in the background of the $z = .247$ spiral galaxy.

We now summarize the evidence in favor of, and against, the background source hypothesis. The arguments in its favor are (1) that we see no evidence for reprocessed radiation, (2) that the observed host galaxy is quite unusual for BL Lac (and indeed all radio galaxy) hosts (Wurtz, Stocke & Yee 1996), and (3) that the arcuate shape of the mas radio structure is suggestive of gravitational lensing by the foreground core of the spiral. The arguments against the background source hypothesis are more persuasive, but not decisive. (1) The AGN core and galaxy centroid are coincident in the infrared to within $0.1''$, where light from both can be seen (Stocke et al. 1992), indicating a very low probability of a chance superposition ($\sim 10^{-10}$; Carilli et al. 1992). (2) While not a strong constraint we note that the milliarcsecond structure ($PA = 54^\circ$) aligns well with the minor axis of the spiral galaxy ($PA = 56^\circ$). (3) No multiple images are observed to 2 mas resolution, as might be expected if the arcuate structure were a product of lensing. (4) Scatter broadening, which might be expected if the source were background, is not observed.

7. Conclusions

Despite the plethora of data which now exist, the radio source PKS 1413+135 remains a puzzle. The VLBA maps we have presented have, for the first time, allowed us a high-resolution and high dynamic range glimpse of its inner ($\lesssim 1$ kpc) regions. These maps reveal a bent, two-sided structure, which appears to be a miniature wide-angle tail radio source. However, the current data cannot completely discriminate between the competing possibilities that this bent structure is a product of gravitational lensing, or a product of interactions with a dense medium in the nucleus of the optical spiral. The nature of the absorbing screen in front of the AGN similarly remains in doubt, although these data have resolved some of the questions posed by Carilli et al. (1992) and Wiklind & Combes (1994) with respect to its nature.

Regardless of whether the AGN is within the spiral galaxy at $z = .247$ or in the background, the observed morphology strengthens the similarities between PKS 1413+135 and the compact symmetric objects, which make up $\sim 10\%$ of the Pearson & Readhead (1988) sample. However, 1413+135 is unusual among CSOs in that its jet is likely oriented close to the line of sight. Properties inferred from these observations suggest an age of 10^{3-4} years for PKS 1413+135. This leads us to join Readhead et al. (1996b) in contending that CSO sources similar to 1413+135 represent the earliest stages in a double radio source's active lifespan. The study of such sources may enable us to probe the initial stages of powerful radio galaxies. In exploring this scenario, it will be important to resolve the question of whether CSOs show evidence for relativistic bulk motion, for which there is evidence in nearly all other varieties of radio-loud AGN. From two epochs of VLBI mapping of PKS 1413+135, we find no evidence for superluminal motion, and set an upper limit of $\beta > 0.65$ on scales $\gtrsim 2$ mas. However, it is quite likely that the core itself is beamed, due to the high lower limit we set on the core brightness temperature.

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TABLE 1
MAP STATISTICS

λ (cm)	θ_{FWHM} (mas)	Beam PA	RMS noise (mJy/beam)
18	10.98×6.33	-8°	.22
13	8.02×5.19	-1°	.25
6	3.60×2.14	-4°	.20
3.6	2.22×1.19	-8°	.14

TABLE 2
COMPONENT FLUXES

Component	Flux @ 18 cm (mJy)	Flux @ 13 cm (mJy)	Flux @ 6 cm (mJy)	Flux @ 3.6 cm (mJy)
A	238 ± 12	187 ± 9	39 ± 2	$5.7 \pm .3$
B	243 ± 12	185 ± 9	60 ± 3	17 ± 1
C	86 ± 9	52 ± 10	15 ± 2	3 ± 1
N	83 ± 4	112 ± 6	547 ± 27	1183 ± 59
D	173 ± 17	84 ± 8	64 ± 6	59 ± 6
E	11 ± 1	5 ± 1		
F	$3 \pm .5$			
G	$.5 \pm 1$			

TABLE 3
CORE GAUSSIAN SIZE

λ (cm)	$\theta_{core}(mas)$	Core PA
18	$11.64 \pm .04 \times 2.24 \pm .15$	$67^\circ \pm 3^\circ$
13	$8.25 \pm .10 \times 1.61 \pm .30$	$67^\circ \pm 3^\circ$
6	$< 1.04 \times < 0.15$	67°
3.6	$< 0.28 \times < 0.01$	63°

Figure Captions

Figure 1. Naturally weighted VLBA images of PKS 1413+135 at 18, 13, 6, and 3.6 cm. The map contours are at $(-2, -1.4, -1, 1, 1.4, 2, 2.8, 4, 5.7, 8, 11, 16, 22, 32, 45, 64, 91, 128, 182, 256, 512, 1024) \times C$. The panels and C values are: (a) 18 cm, $C = 6 \times 10^{-4}$ Jy/beam; (b) 13 cm, $C = 6 \times 10^{-4}$ Jy/beam; (c) 6 cm, $C = 6 \times 10^{-4}$ Jy/beam; and (d) 3.6 cm, $C = 4 \times 10^{-4}$ Jy/beam.

Figure 2. Spectral index maps between our naturally weighted images at (a) 18-13 cm, (b) 13-6 cm, and (c) 6-3.6 cm. In each case, the greyscale is as indicated, and we have placed contours at $\alpha = -2.5, -2, -1.5, -1, -0.5, 0, 0.5, 1, 1.5, 2$, and 2.5.

Figure 3. Uniformly weighted VLBA image of PKS 1413+135 at 13 cm. This image shows some of the separation into individual components seen more clearly by the higher-resolution, short-wavelength data. Contours are at $(-2, -1.4, -1, 1, 1.4, 2, 2.8, 4, 5.7, 8, 11, 16, 22, 32, 45, 64, 91, 128, 182, 256, 512, 1024) \times 5 \times 10^{-4}$ Jy/beam.

Figure 4. Spectrum of Component N, which we believe is the core, derived from these data.

Figure 5. Flux variability of PKS 1413+135 (total intensity) since September 1, 1993, taken from the public UMRAO database.

Figure 6. Two epochs of VLBI maps of the inner 30 mas of PKS 1413+135 at 3.6 cm. These images show the vast improvement that use of the full VLBA can give over previous arrays. In addition, these images show no evidence for superluminal motion. In each case, we have placed contours at $(-2, -1.4, -1, 1, 1.4, 2, 2.8, 4, 5.7, 8, 11, 16, 22, 32, 45, 64, 91, 128, 182, 256, 512, 1024) \times C$. The panels and C values are: (a) Map taken July 10-11, 1994, with the full VLBA; $C = 6 \times 10^{-4}$ Jy/beam; (b) Map taken June 25, 1994, with 7 dishes of the VLBA; $C = 2 \times 10^{-3}$ Jy/beam.

Figure 7. (β, θ) plot for PKS 1413+135. Given that the value we derive for β_{app} is an upper limit, the permissible range of (β, θ) is that below both curves.

Figure 8. H & K band grism spectra obtained with the KPNO 2.1m + Cryogenic Optical Bench on 14 April 1994. Both spectra are quite featureless, and it is difficult to explain the absence of Pa α (see §5) at $\lambda = 2.37\mu$. A full description of the near-IR spectra presented here will be presented with similar data on other sources at a later time (Perlman et al., in preparation).

PKS 1413+135, H band

PKS 1413+135, K band