The structure of the quasar 3C 345 at λ49 cm and its relation to low-frequency variability

L.I. Matveenko¹, I.I.K. Pauliny-Toth², L.B. Báath³, D.A. Graham², W.A. Sherwood², and A.J. Kus⁵

¹ Space Research Institute, Profsojuznaja 84/32, Moscow 117810, Russia
² Max-Planck-Institute für Radioastronomie, Auf dem Hügel 69, D-53121 Bonn, Germany
³ Onsala Space Observatory, S-439 00 Onsala, Sweden
⁴ Center for Imaging Technologies, Halmstad University, Box 823, Halmstad, Sweden
⁵ Torun Radio Astronomy Observatory, Garagara 11, PL-87100 Torun, Poland

Received 27 June 1995 / Accepted 13 February 1996

Abstract. The structure of the quasar 3C 345 has been studied at λ49 cm with a global VLBI network. The core has a low-frequency cut-off in its spectrum, and is very weak at this wavelength. The most compact bright knot is the part of the jet nearest to the nucleus, with a size of ~ 5 × 4 mas and a brightness temperature of $T_b \sim 0.6 \cdot 10^{12}$ K. Its flux density and solid angle increased by a factor of ~ 2 during the period 1983.9 to 1990.8, but the brightness temperature did not change significantly. The emission at millimeter wavelengths decreased by a factor of ~ 2 during the same period, while the UV emission from the nucleus also decreased. We suggest that variations in the low-frequency emission are caused by changes in the absorption by a cocoon—the thermal plasma surrounding the jet. The electron density in the core region is $N_e \sim 10^4$ cm$^{-3}$ and the longitudinal component of the magnetic field is $\sim 40 \mu$G. The emission measure and the rotation measure vary with $r$, the distance from the nucleus, as $r^{-3}$. The data at λ49 cm indicate several components in and near the "hotspot" at the end of the arcsec jet.

Keywords: galaxies: jets – radio continuum: galaxies – quasars: 3C 345

1. Introduction

The radio source 3C 345 is identified with a 16th magnitude quasar at a redshift $z=0.595$. In the following we assume a Hubble constant $H_0 = 100$ km s$^{-1}$ Mpc$^{-1}$ and a deceleration parameter $q_0 = 0.05$, so that 1 milliarcsecond (mas) corresponds to 3.79 pc. Measurements of the fine structure of the quasar show that it contains a jet and a compact core which dominates the emission at short wavelengths.

The activity in the nucleus is accompanied by strong outbursts of radio emission which have a typical lifetime of a few months to one year. These outbursts appear first, and are strongest, at short (mm-cm) wavelengths, and then propagate to longer (dm) wavelengths while decreasing in amplitude. The lifetime of low energy electrons is much longer than that of high energy electrons, which leads to an accumulation of the former and a relative increase of the low frequency radio emission.

The outbursts of radio emission are presumably caused by the ejection of clouds of relativistic plasma from the nucleus, or by shock waves moving from the core down the jet. The apparent motions of the clouds (components or knots) in the jet exceed the velocity of light (Cohen et al., 1976, Wittels et al., 1976). The results of observations of 3C 345 at millimeter wavelengths (Báath et al., 1992, Krichbaum, 1990, Zensus, 1990) show that the compact components are ejected along P.A. between $\sim -90^\circ$ and $\sim -135^\circ$. This suggests that the relativistic plasma and the knots are initially ejected inside a cone having an apparent opening angle of ~ 40$^\circ$ with its axis along P.A. $\sim -110^\circ$, which corresponds to the orientation of the rotation axis.

The ejected relativistic plasma generates a magnetic field which focuses the ejecta into a jet (Bisnovati-Kogan et al. 1969, Begelman et al., 1984), or into thin filaments which are twisted around the rotation axis, forming spirals (Shakura & Sunyaev, 1973, Lovelace & Berk, 1991, Wehrle & Unwin, 1991, Matveenko et al. 1992, Zensus et al., 1995). The individual components move along these spirals (Krichbaum et al., 1993, Zensus, 1990). A curvature of the jet (of helical form) may be due to a long-term precession of the rotation axis of the nucleus (Matveenko et al., 1985, Matveenko et al., 1990). At larger angular distances of ~3 arcsec from the nucleus, the P.A. of the jet is $\sim -30^\circ$ (Browne et al., 1982, Kollgaard et al., 1989) and the jet terminates in a bright "hotspot".

Many quasars, including 3C 345, show an increasing variability of flux density at low frequencies (Fanti et al. 1981, Padrielli, 1982, Padrielli et al. 1987, Gopal-Krishna et al. 1984, Mantovani et al., 1990), which is not expected for synchrotron emission from clouds of relativistic electrons. The time-scale,
of about one year, and the amplitude of the low frequency variations imply a brightness temperature for the emission region in excess of $10^{16} \text{K}$, a value much greater than the inverse Compton scattering limit of $10^{12} \text{K}$ (Kellermann & Pauliny-Toth, 1969).

If the low frequency variations are intrinsic to the source, and determined by Doppler effects, they require Lorentz factors $\geq 100$ for the emitting regions, i.e. much larger than those derived from the observed internal structural motions. Such high Lorentz factors would result in brightness temperatures at high frequencies much greater than those observed, so that such Lorentz factors can be ruled out. However, the low-frequency variability could be due to other, intrinsic mechanisms of radio emission, for example, amplification of the low frequency synchrotron emission determined by the narrow bunching of relativistic particles in the domain of the Razin-Tsytovich effect.

On the other hand, it has been suggested that the low-frequency variability arises outside the source – in the interstellar medium of our Galaxy (Shapirovskaia, 1978), or is due to changes in the absorption of the synchrotron emission in the ionized medium surrounding the quasar nucleus (Matveenko et al., 1982, Matveenko et al., 1985).

In either case, the radiation source must be compact, e.g. $\leq 1$ light-year, or the absorbing screen must be thin, $\leq 1$ light-year. However the observed brightness temperatures could differ by a few orders of magnitude in the two cases. In particular, collective radiation could give rise to brightness temperatures $\geq 10^{18} \text{K}$ (Benford, 1991). It is, therefore, important to measure directly the brightness temperature of compact components in the source at low frequencies.

In this paper we present the results of a study of the fine structure of 3C 345, obtained with the highest angular resolution achievable at 49 cm wavelength at that time. We also report on structure on arcsec scales, and discuss models of the low frequency variability.

2. Observations

We observed 3C 345 on October 4, 1986 at a wavelength of $\lambda 49\text{cm}$ with a global VLBI network consisting of the following antennas: 22m at Simeiz (R), 100m at Effelsberg (B), the Westerbork array (W), 76m at Jodrell Bank (J), 43m at Green Bank (G), 26m at North Liberty (N), and 40m at Owens Valley (O). The baselines in the VLBI array gave fringe spacings between 10 and 400 mas. The data were recorded with the Mk-2 system, which has a nominal bandwidth of 1.8 MHz and were processed with the Mk-2 correlator at the Max-Planck Institut für Radioastronomie in Bonn. The fringe amplitudes were calibrated using the measured values of the system noise temperatures at the antennas, and the known gains of the antennas (Cohen et al., 1975).

3. Results

We have investigated the structure of 3C 345 by model fitting of components with gaussian distributions of brightness to the visibilities and closure phases and by making maps using part, or all of the data. The beam of the entire array, using “natural” weighting, is $41 \times 10$ mas, P.A.$=-3^\circ$. Maps of the source, using various ranges/weighting of the $[u,v]$ plane are shown in Fig. 1.

3.1. The fine structure

Model fitting of compact components with gaussian brightness distributions to the correlated flux densities and closure phases on the longest and intermediate baselines shows that the brightest region has an angular size of $5.1 \times 4.1$ mas, a flux density $S = 2.0 \text{ Jy}$ and P.A. = 16$^\circ$. The brightness temperature $T_B = 0.43 \cdot 10^{12} \text{ K}$. Similar results have been obtained by (Padielli et al., 1991) at $\lambda 49\text{cm}$ at epoch 1988.5. They derived a size of $5 \times \leq 8$ mas, $S = 3.7 \text{ Jy}$ and a brightness temperature $T_B \geq 0.4 \cdot 10^{12} \text{ K}$.

The measured angular size is somewhat larger than that expected for a point source affected by interstellar scattering. The scattering angle is 3.0 mas for the galactic latitude (b=40$^\circ$) of 3C 345 (Matveenko, 1984). If we correct the angular size of this component for the scattering angle, the derived intrinsic size becomes $4.1 \times 2.8$ mas and the brightness temperature is $T_B = 0.8 \cdot 10^{12} \text{ K}$. This value roughly corresponds to the Compton limit, and is much smaller than $T_B = 10^{16} \text{ K}$, as determined from low frequency flux density variations (Gopal-Krishna et al., 1984).

One problem with the identification of components of the fine structure at different frequencies is finding a reference feature. At higher frequencies, the reference feature is the bright core, with a flat spectrum (Readhead et al., 1978, Biretta et al., 1986). At decimeter wavelengths, the emission of the core can be very weak, owing to synchrotron self-absorption, or absorption by the surrounding ionized medium, and the brightest component then corresponds to nearby parts of the jet, but not to the nucleus.

For the identification of the low and the high-frequency fine structures we took the $\delta$-functions at $\lambda 49\text{cm}$ that fit the visibilities and closure phases on the longest and intermediate baselines. These are shown, restored with a circular beam of $FWHM 5 \text{mas}$, in Fig. 1a, and $FWHM 15 \text{mas}$, Fig. 1b. Apart from the brightest component, there are other components, located along the jet: a component with a brightness temperature $T_B \sim 0.2 \cdot T_{\text{peak}}$ located at a distance of 10 mas from the peak, at P.A.$=-70^\circ$; with a brightness temperature of 0.01 $T_{\text{peak}}$, and at a distance of 30 mas, P.A.$=-67^\circ$ ($T_{\text{peak}}$ is the peak brightness temperature). A strip brightness distribution along the jet, derived by convolving the $\delta$-functions of the map (Fig.1a) with a fan-beam of $200 \times 3$ mas is shown in Fig. 2. Position ‘0’ corresponds to the brightest feature in the jet.

The positions of the compact components in the jet are probably frequency-dependent, which makes their registration difficult from one frequency to another. However, the jet also has transverse structures on larger scales, the location of which should be fairly stable, or move relatively slowly ($\leq 0.4 \text{ mas/yr}$) (Unwin & Wehrle, 1992, Unwin, 1992). We can estimate the position of the nucleus from these transverse features, which are located at distances of $\sim -5, \sim 15$, and $\sim 30$ mas from...
the peak brightness temperature at $\lambda49$ cm, Fig. 1a. The same transverse features are observed at 3.6 and 6 cm wavelengths (Readhead et al., 1978, Unwin et al., 1983, Zensus, 1991) and $\lambda18$ cm and are located at 4, 10 and 19 mas from the peak of the brightest component. A weak compact region corresponds to the core in the $\lambda6$ cm maps and is located 2 mas East of the peak (Wehrle & Unwin, 1991). Within the experimental errors, a weak compact component is also found in this region at $\lambda13$ cm (Bartel et al., 1986) and at $\lambda18$ cm (Matveenko et al., 1985, Rantakyrö et al., 1992).

We can therefore identify the nucleus (i.e. the core) at $\lambda49$ cm with the compact component located at $\sim 16$ mas, P.A. $=95^\circ$ from the brightest feature in Fig. 1a. The brightness temperature of the core at $\lambda49$ cm is about $0.01 \cdot T_{\text{peak}}$ (Fig. 1a).

### 3.2. The large scale structure

The peculiar structure of the jet of 3C 345 also has features transverse to the jet at longer distances: 55, 70, 140, 250 mas and more from the core (Fig. 1a,b,c). On a larger scale, an extension some 6 arcsec in length, perpendicular to the jet is seen in the VLA map (Kollgaard et al., 1989) at $\lambda6$ cm.

In order to represent the structure on arcsec scales, we resorted to model fitting to the amplitudes and closure phases on the shortest baselines: for the stations B-W-J, at least ten gaussian components are required. Weak components lie at distances of 2.8 to 4.4 arcsec from the peak of the emission, in P.A. between $-32^\circ$ and $-41^\circ$. The component orientations are perpendicular to the arcsec jet and their brightness temperature is $\sim 10^7$K. They coincide with the brightest features in the “hotspot” in the

---

**Fig. 1a-c.** The radio brightness distribution of 3C 345 at $\lambda49$ cm. a restored with a circular beam of 5 mas. The contours are at 0.5, 1.0, 2.5, 5, 10, 20, ...,90 % of the peak brightness of 2.07 Jy/beam. b restored with a circular beam of 15 mas. The contours are at 0.25, 0.5, 1.0, 2.5, 5, 10, 20, ...,90 % of the peak brightness of 3.2 Jy/beam. c restored with a circular beam of 120 mas. The contours are at 0.05, 0.10, 0.25, 0.5, 1.0, 2.5, 5, 10, 20, ...,90 % of the maximum brightness of 4.9 Jy/beam.
arcsec jet, as seen in the MERLIN (Browne et al., 1982) and VLA (Kollgaard et al., 1989) maps at 6 and 18 cm.

A map (Fig. 1c) derived from the data on the baselines with lengths up to 8 Mλ, restored with a beam of 120 mas, shows a similar structure. Maps of higher resolution are shown in Fig. 1a and 1b, corresponding to different weighting in the [u,v] plane and restored with beams of 5 and 15 mas respectively. The flux density in all the features is 6.2 Jy, compared to the total flux density of 9.0 Jy. We attribute the difference to emission on large scales (in the arcsec jet and halo) (Schilizzi & de Bruyn, 1983), which is resolved out by our interferometer. Any large scale "counter-jet" in our maps is below a level of 0.1 percent of the peak brightness.

4. Discussion

The overall structure of 3C 345 consists of a core, a jet and a 22 × 15 arcsec halo, P.A. ~ 30° (Schilizzi & de Bruyn, 1983). The variability of the high frequency synchrotron emission is directly determined by the activity in the core. Here we will discuss the structure of 3C 345 in connection with the activity of the nucleus and the low frequency variability.

4.1. Spectrum of the radio emission of 3C 345

The continuum emission, including UV, the high frequency radio emission of the core and of the compact jet components arises from relativistic plasma ejected from the nucleus. Changes in the continuum emission were observed simultaneously at several frequencies at epochs 1980-1993 (Schramm et al., 1993, Zensus et al., 1995). These changes were accompanied by variations of the polarized emission. The polarized emission increased simultaneously with the increase of the total emission, and reached a maximum before decreasing. When the total emission began to decrease, the polarized flux increased again, reached the previous maximum and then decreased in step with the total intensity. The polarized flux appears to increase with distance from the core and reaches a maximum about 4.5 mas from the core (Browne et al., 1994). The position angle of the polarized emission also changes with time.

The radio outbursts correspond to increased emission from the ejected relativistic plasma clouds. Measurements show that an activity of the core in 1981.5 - 1982.5 was accompanied by strong radio outbursts in the frequency range 8 - 89.6 GHz. The outbursts occur first at high frequencies and later, with lower amplitude, at lower frequencies: e.g. at 4.8 GHz, the outburst emission was smaller than at higher frequencies. The spectra from these data are shown in Fig. 3. Curve "a" represents the 1981.6 outburst spectrum, which lasted about half a year. The "b" curve spectrum of the total flux density represents the same time. The outburst spectrum has a low frequency cut off and the spectral index at low frequencies is $\alpha = 2.8 \pm 0.2$. The spectrum of the compact core from VLBI observations in 1981, curve "c", also has a steep low frequency slope $\alpha = 3.0 \pm 0.2$ (Matveenko et al., 1982). The total emission (1979.0-1979.8) before the outburst had a flat spectrum, shown as "d". In 1984.5, after the period of high activity, the spectrum was again flat, but the radio emission was stronger than before (Fig.3, "e"). We suggest that a decrease in the UV emission of the nucleus at this time (1979.0 – 1984.5) decreased the ionization of the surrounding medium and that the radio emission, including that at low frequencies, became less absorbed. Simultaneously, there was an accumulation of the relativistic plasma, connected with the active period of the core. The duration of the high radio emission (the period of high radio activity) was about 3 years.

We suggest that the steep cutoff in the spectrum is determined by absorption at low frequencies. The absorption inside a relativistic plasma (synchrotron self-absorption) gives a spectral index $\alpha_{\text{c}} \leq 2.5$ in the optically thick part of the spectrum. However, as shown by (Razin, 1960), the spectral index for synchrotron radio emission from relativistic electrons distributed in an ionized medium is $\alpha = \alpha_{\text{c}} + 2.1$, where the 2.1 term corresponds to absorption of the emission by the thermal electrons. But the synchrotron radio emission decreases catastrophically at frequencies $f \leq f_{\text{c}}$, where $f_{\text{c}} = 20N_{e}/B$. From polarization measurements the thermal electron density is less than 0.01 cm$^{-3}$ and its influence on the synchrotron radio emission is negligible (Begelman et al., 1984).

The synchrotron emission crossing an external ionized medium is decreased exponentially and the resulting spectral index is $\alpha = \alpha_{\text{c}} + 2.6$, for an optical depth of the thermal plasma $0.7 \leq \tau \leq 2$ (Razin, 1960). The low frequency part of the spectrum during the outburst has $\alpha \sim 2.8$, which suggests absorption of the emission from relativistic electron emission by an external ionized medium. Nuclear activity, accompanied by increased UV emission, increases the ionization of the medium, the optical depth of which becomes large even at 4.8 GHz, Fig. 3a. The absorption at low frequencies is larger than before and we observe a "negative" low frequency outburst. This phenomenon has also been observed in the object 0954+658 at
2.6 GHz (Fiedler et al., 1987). However, a general increase of the low frequency radio emission at 408 MHz occurs some 3 to 4 years later than at the higher frequencies (Bregman et al., 1986, Spangler et al., 1989).

4.2. Surrounding medium

Optical studies of quasars, including 3C 345, show that their nuclei are surrounded by an ionized medium, which radiates the broad and the narrow emission lines. The size of the broad line region is typically \( \sim 10^{18.5} L_{46} \) cm with typical electron density \( \sim 10^{10} \text{ cm}^{-3} \), where \( L_{46} \) is the optical-UV luminosity in units of \( 10^{46} \text{ erg s}^{-1} \). The narrow line region has dimensions \( \sim 10^{21} L_{46} \) cm and densities \( \sim 10^{4-6} \text{ cm}^{-3} \), (Netzer, 1987). The luminosity of the quasar 3C 345 is \( \sim 10^{45} \text{ erg s}^{-1} \), (Bregman et al., 1986) and the size of the ionized medium is \( \sim 10^{20} \text{ cm}, (\sim 33 \text{ pc or } \sim 8 \text{ mas}) \). The temperature of the ionized region is \( T_e = 2 \times 10^{4} \text{K} \), (Netzer, 1987). The UV emission of the nucleus ionizes the surrounding gas and variations in this radiation change the ionization of the medium and the strength of the emission lines. However, the intensity of the emission lines and of the IR emission decreases with increasing UV emission, corresponding to the “negative” outbursts (Bregman et al., 1986).

Variability of the Balmer line profiles shows that the medium is not uniform (Pronik, 1972). The time scale of the variations is from a few days to a few years for different objects. The broad line region consists of dense clouds of ionized gas, distributed in an ionized medium of low density. Usually, the dense clouds fill only a small part of its volume, so that most of the radiation from the continuum source can escape freely.

The variability of 3C 345 at 408 MHz (Padrielli, 1982, Spangler et al., 1989) also has the character of “negative” outbursts with a typical time-scale of one year, similar to that of the long-term optical variability. The low-frequency variations appear, in general, to be anti-correlated with those at high frequencies (Aller & Aller, 1982), and uncorrelated for quasars located close together in the sky (Spangler et al., 1981, Spangler et al., 1989). These can be explained in terms of the absorption of the synchrotron emission by the ionized medium surrounding the nucleus.

4.3. Visible size of the core

The distribution of the magnetic field, energy and density of the relativistic electrons with distance from the nucleus determines the visible size of the radio core – a bright compact component. Also, the observed size of the core depends on the transparency of the ionized medium, which, in turn, depends on the frequency.

The absorption (transparency) of the ionized medium \( e^{-\tau} \) depends on the optical depth \( \tau \), which is (Lang, 1974)

\[
\tau = 0.08 \times T_e^{-1.35} \times (1 + z)^{-2.1} \times f^{-2.1} \int N_e^2(l)dl, \tag{1}
\]

where \( f \) is the observed frequency in GHz, \( T_e \) – the electron temperature of the ionized gas in Kelvin, \( l \) – the path length in pc and \( N_e(l) \) – the distribution of electron density in \( \text{cm}^{-3} \).

The measured size of the core is given by (2), and corresponds to

\[
R(f) = 1.05 f^{-0.54} \text{ [pc]} \tag{5}
\]

From equation (4) and (5) we then have \( \beta = 2.44 \).

The electron density at the visible depth (\( \tau = 1 \)) from (3) and (5) is given by

\[
N_e(f) \propto f^{1.3} \text{ [cm}^{-3}] \tag{6}
\]

A lower limit to the electron density is set by the recombination time of the ionized medium. This time can not exceed the time scale of the variability of the radio emission. The recombination time \( t_r \) is (Netzer, 1987)

\[
t_r \sim 10^5 N_e^{-1} \text{ [years]} \tag{7}
\]

The time scale of the low-frequency (0.4 GHz) variability is typically about 1 year, which corresponds to an electron density \( N_e \sim 10^5 \text{ cm}^{-3} \) and

\[
N_e(f) \sim 3.6 \times 10^5 f^{1.3} \text{ [cm}^{-3}] \tag{8}
\]

In this case the minimum time scale of the low-frequency variability depends on the frequency as \( t = 0.3 \times f^{-1.3} \text{ years} \). The larger time scales are determined by the UV variations.

4.4. Brightness temperature of the core

The brightness temperature of the core at high frequencies is \( T_b \sim 10^{13} \text{K} \), which is larger than the inverse Compton limit. This excess value can be due to a non-uniform distribution of the magnetic field and relativistic electrons, or more realistically by a non-stationary process – the ejection or acceleration of relativistic electrons, or the beaming effect of the moving relativistic plasma. The size of the core at millimeter wavelengths is about 0.05 pc and the mechanism of acceleration must be very effective, in order to operate over so short a distance. At low frequencies the maximum brightness temperature is \( \sim 10^{12} \text{K} \).
4.5. Core

But what is meant by the quasar “core” [25]? According to models of black holes (Shakura & Sunyaev, 1973, Begelman et al., 1984), an accretion disk in the azimuth plane of the hole implies a surrounding medium, leaving a relatively free space in the direction of the axis of rotation. Acceleration of a plasma takes place in the region of the accretion disk and the relativistic plasma is then ejected along the rotation axis, within an angle of less than 1 radian. The plasma flow generates a magnetic field which focuses the plasma into thin filaments. The rotation of the black hole (the ejector) twists the filaments into a spindle form (shank). The ejector of the relativistic plasma is the source of the synchrotron emission i.e. what we call the “core” (Blandford & König, 1979).

The relativistic plasma flow is surrounded by thermal plasma in the form of a cocoon, which the synchrotron emission must penetrate. The electron density of the cocoon wall decreases with increasing distance from the core (the ejector) so that the ejecta from the core are observed earlier at the high frequencies.

The thickness of the wall must be thin for the following reason. The time scale of the low-frequency variability is \( t \sim 1 \) yr. This means that the recombination time of the thermal plasma must be around one year or less. The recombination time is \( t_r = 10^5 \cdot N_e^{-1} \) yr (eq. 7) and the electron density must be \( N_e \sim 10^5 \) cm\(^{-3}\). We take the optical depth of the cocoon as \( \tau \sim 1 \). From these conditions, and Eq. 1, the thickness \( l \sim 10^{-3} \) pc. It is much less than one light year and does not smear out the low-frequency variations. The pressure in the jet varies with density as \( P_j \sim \rho^2 \) and with distance as \( r^{-2} \), (Begelman et al., 1984). In this case \( N_e \sim r^{-2} \). The wall thickness increases with distance from the nucleus and the total number of thermal electrons in a column \( N_e \cdot l \) varies more slowly than \( r^{-2} \). The transparency of the wall is determined by the emission measure EM which is proportional to \( N_e^2 \) and varies as \( \sim r^{-3} \). The rotation measure \( RM = 8.1 \cdot 10^9 N_e \cdot B_{||} \cdot l \), where \( B_{||} \) is the longitudinal component of the magnetic field. This component varies as \( \sim r^{-2} \) and the rotation measure \( RM \sim r^{-3} \).

We identified the core with the compact component located about 16 mas from the brightness peak in our maps. The brightness temperature of the core at \( \lambda 49 \) cm is \( \sim 0.01 \) of the peak or \( T_b \sim 10^{10} \) K. The brightness temperature of the core at the higher frequencies is \( T_b \sim 10^{12} \) K. This means that the absorption of the core radio emission at \( \lambda 49 \) cm is \( \sim 100 \) and the optical depth \( \tau \sim 5 \). By comparison, at 6 cm, the absorption by the cocoon wall will be only \( \sim 20 \% \), i.e. the wall is practically transparent at cm-mm wavelengths.

The compact components are distributed along the nearest part of the jet in the region \( \sim 6 \) mas from the core (Zensus et al., 1995, Browne et al., 1994) and are visible through the cocoon, the transparency of which varies with the distance from the nucleus and with time. At low frequencies, the screen merges the emission from the compact components into one bright region, the observed size and brightness of which vary with time. At high frequencies, the screen is transparent and does not affect the observed structure.

However, the screen does change the observed polarization of the high frequency emission. According to VLA measurements with a beam size \( \sim 5 \) arcsec (Rudnick & Jones, 1983), the rotation measure at wavelengths between 18-21 cm is \( RM \sim 28 \) rad m\(^{-2}\) and the degree of polarization is \( \sim 4 \% \). The main emission region at 18 cm corresponds to the part of the jet nearest to the core. This region has a size \( \sim 5 \) mas, (Matveenko et al., 1985). In the same region are located the components which give rise to most of the polarization at \( \lambda 6 \) cm. The maximum polarized emission arises from \( \sim 5 \) mas from the core. We propose that the polarized emission at 18 cm arises from this same region. The polarization position angle, corrected for the Faraday rotation of 28 rad m\(^{-2}\), corresponds to a position angle of a magnetic field of \(-70^\circ\). The magnetic field orientation, (Browne et al., 1994), taking the jet curvature into account (Matveenko et al., 1992), is parallel to the local jet orientation. At the distance \( \sim 5 \) mas the jet orientation has the same position angle, i.e. \(-70^\circ\). This means that the rotation measure \( RM = 28 \) rad m\(^{-2}\) corresponds to a distance of 5 mas from the core. The \( RM \propto r^{-3} \) and will be 3500 rad m\(^{-2}\) at the position of the core.

According to (Browne et al., 1994) the polarization position angle of the core varies with time by \( \sim 1 \) rad. This corresponds to a changing \( \Delta RM = \Delta \chi \cdot \lambda^{-2} \) or 300 rad m\(^{-2}\). This value corresponds to only \( \sim 10 \% \) of the previous one and is realistic. In this case, the magnetic field in the core region, \( B_{||} \sim 40 \mu G \).

Other possibilities, however, cannot be excluded. The relativistic plasma is ejected within a cone angle \( \sim 40^\circ \) and the different position angles of the polarization of the core could be determined by different directions of the component motions. Or, changes in the opacity of the core could occur. In an opaque source, the polarization is parallel to the magnetic field and the degree of polarization is \( \leq 10 \% \). In the transparent case the polarization is perpendicular to the magnetic field and is of order of 70 \% (Kellermann, 1974).

5. Conclusion

The study of the low-frequency structure of the quasar 3C 345 shows that the emission of the radio core is weak at \( \lambda 49 \) cm. The brightest feature observed corresponds to nearby parts of the jet, where the high frequency compact components are located. In the period 1983.9-1990.8 the observed brightness temperature of the brightest component was \( T_b \sim (0.4-0.6) \times 10^{12} \) K and did not change significantly. The flux density of the compact component and its solid angle increased by a factor of \( \sim 2 \) during the same period. Simultaneously, the millimeter band emission slowly decreased from \( \sim 13 \) to \( \sim 6 \) Jy, (Valtaojai, 1992). In general the high-frequency radio emission is correlated with the UV-emission. Therefore the UV-emission probably also decreased and the ionized medium became more transparent to low frequency radiation. This, in turn, suggests that the low-frequency variability in 3C 345 is determined by a varying transparency of the ionized medium surrounding the nucleus – the cocoon and synchrotron emission of relativistic plasma. We suggest that a high activity of the nucleus is accompanied by ejection of rel-
ativistic plasma, high UV-emission and increased ionization of the surrounding medium which absorbs radio emission at frequencies up to ~ 4.8 GHz. The electron density of this medium is ~ $10^5$ cm$^{-3}$ and the longitudinal component of the magnetic field $B_l ~ 40$ $\mu$ G.

The large scale structure of the quasar 3C 345 at $\lambda 49$ cm contains weak, elongated components distributed along, and oriented perpendicular to, the jet, in the region of the "hotspot" seen at lower resolutions. The direction of elongation of these features suggests that they are connected with the interaction of the jet relativistic plasma with the intergalactic medium. Their brightness temperatures lie in the range $T_b ~ 10^5$ - $10^6$K. The data from the shortest baselines also show that extended structure, transverse to the jet, is present near the active nucleus. No large scale counter-jet above a level of 0.1% has been detected, even on the shortest baselines.

Acknowledgements. In closing, we wish to thank the participating observatories for providing facilities needed to carry out the observations and to process the data. I.I.Matveenko thanks the MPIfR and Onsala Space Observatory for hospitality, and the Soros’s International Science Foundation for financial support, Grant MFP000. We also wish to thank Dr. K. I. Kellerman for his helpful comments in refereeing this paper. Onsala Space Observatory at Chalmers University of Technology is the Swedish National Facility for Radioastronomy.

References


Matveenko, I.I.: 1984, Proc. of "Workshop on QUASAT", (Gr.Enzendorf), Austria, 18-22 June, p.119


Pronik, I.I.: 1972, AZh 49, 768, (SVa 16, 628)


Razin, V.A.: 1960, Radiofizika 3, 584


Shapirovskaya, N.Ya.: 1978, AZh 55, 953, (SVa 22, 544)


Valttaoja, E.: 1992, Private communication


This article was processed by the author using Springer-Verlag LaTeX A&A style file version 3.