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VLBI monitoring of the complex jet of Cygnus X-3 during the January 1991 outburst

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Abstract. We report on high sensitivity VLBI observations of Cygnus X-3 at 6 cm wavelength on four consecutive days during the large radio flaring event in January, 1991. Both total flux density evolution and visibility amplitudes indicate the presence of a complex jet. The superposition of flares however excludes unique modelling of the source structure and evolution. The minimum consistent interpretation requires at least five components of scattering size 16 milliarc-seconds (mas), resulting in a linear structure with a position angle of 180^o with an uncertainty estimate of $\pm 10^o$.

Key words: stars, individual: Cygnus X-3 – X-ray binaries – interferometry: VLBI – quasars – galaxies: jets – interstellar matter

1. Introduction

The radio counterpart of the Galactic X-ray binary system Cygnus X-3 has been shown to display structure in its radio emission that appears to be "jet like", resembling emission from a central source. Interferometric observations reported by Geldzahler et al. (1983), Spencer et al. (1986) and Schalinski et al. (1995) imply the existence of this emission on a scale of tens of milliarcseconds. These observations are complicated by extreme scattering which is probably due to the presence of an electron screen near the source. The large scattering size, 16 mas at 6 cm wavelength, makes it difficult to image Cygnus X-3 due to the lack of short baselines (of order 50 to 300 km at 6 cm). During large outbursts, however, the intensity of the signal makes it possible to observe this source on longer baselines which are available on Very Long Baseline Interferometry (VLBI) networks such as the European VLBI Network (EVN).

A large outburst in the flux density of Cygnus X-3 was observed with the Green Bank interferometer at 13.3 and 3.6 cm in January, 1991. An adhoc VLBI experiment was organized using antennas of the EVN. Successful observations were obtained on January 24-27, 1991. We describe the results of these observations here.

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2. Observations

An intense flare of radio emission of Cygnus X-3 was detected with the Green Bank Interferometer with a maximum of 15 Jy and 13 Jy on 1991 January 20 at 3.6 cm and 13.3 cm respectively, following a small outburst with amplitude of order 3 Jy at 3.6 cm on 1991 January 10. Whereas the maximum was reached within one day, the total duration of the flaring event was about 40 days, with at least four superimposed outbursts exceeding a flux density of 5 Jy.

The Green Bank Interferometer (GBI) monitoring data for this event are displayed in Fig. 1. The observational aspects of these data are described in Johnston et al. (1986), Fiedler et al. (1987), and Waltman et al. (1994), the latter describe the re-

Table 1. Observational parameters of the 1991 January adhoc VLBI-experiment on Cygnus X-3. *Notes:* I.H.A.: Interferometer Hour Angle; Telescopes: Effelsberg (Germany) 100 m (B), single 25 m antenna (W) of the Westerbork array (The Netherlands), and the 32 m antennas at Medicina (M) and Noto (N) (Italy). The MkIII system with a total bandwidth of 56 MHz was used (14 channels with 4 MHz bandwidth each, and sky-frequencies 4958.99 - 5010.99 MHz), with the lowest 7σ-detection limit (B-baselines) of 10 mJy. The angular resolution range of the baselines was 5 to 26 mas at 6 cm wavelength.

Date		Antennas				I.H.A.- Interval
1991 January	24	-	-	M	N	$-8 \ldots +4$ hours
	25	B	W	M	N	$-6 \ldots +3$ hours
	26	B	W	M	-	$+2 \ldots +10$ hours
	27	-	-	M	N	$-9 \ldots +3$ hours

lationship between very low flux densities ($\leq$ 30 mJy) at 2.25 and 8.3 GHz, which are observed prior to major flares, and the January 1991 flare. In summary Cygnus X-3 was observed simultaneously at 13.3 cm (2.25 GHz: S-band) and 3.6 cm (8.3 GHz: X-band) in two circular polarizations. The flux density scale is based on 3C286, which is assumed to have a flux density of 11.85 Jy and 5.27 Jy at 13.3 and 3.6 cm respectively. A detailed error analysis of GBI data is presented in Fiedler et al. (1987).

Following the report of the radio outburst on January 18 an adhoc VLBI campaign on four consecutive days using telescopes of the European VLBI network at 6 cm wavelength was organized. Data were taken with the 32 m telescopes at Medicina and Noto (Italy) on January 24. On January 25 and 26 the 100 m telescope at Effelsberg (Germany), one 25 m antenna of the Westerbork array (The Netherlands) and the 32 m telescopes at Medicina and Noto (the latter only on January 25) were used, and on January 27 the antennas at Medicina and Noto observed the source. The wideband MkIII recording system (Rogers et al., 1983) was used at a bandwidth of 56 MHz (in Mode A: 4958.99 - 5010.99 MHz), the angular resolution of the baselines was in the range of 5 to 26 mas. The observational details are summarized in Table 1. The VLBI scans on Cygnus X-3 were of 780 s duration. Every hour one 780 s block was split to record 480 s data on the quasar 2005+403, which serves as structural calibrator, and the remaining 300 s were observed on Cygnus X-3 again.

The data were correlated at the MkIII correlator of the Max-Planck- Institut für Radioastronomie, Bonn (Germany). In order to improve the signal-to- noise ratio on the weaker baselines and reduce the noise on the closure phases, the data were refringed with narrow windows making use of closure relations to determine and fix the delays and delay rates (Alef & Porcas 1986). The results obtained for Cygnus X-3 especially on the "weak" baselines were cross-checked with those obtained for the structural calibrator 2005+403, which was well detected on all baselines. The calibration of the amplitudes was performed by applying the system temperatures recorded between VLBI scans and the reported gain curves for each telescope. The flux density scale was obtained by performing cross scans with the 100 m telescope on 3C295, adopting a flux density of 6.74 ± 0.03 Jy at 6 cm wavelength from Ott et al. (1994). As a further check of the consistency, the flux densities of Cygnus X-3 and 2005+403 have been interpolated from the Green Bank Interferometer flux density measurements at 13.3 and 3.6 cm wavelength and compare well with those obtained using 3C295.

3. Results

In order to calibrate the VLBI scans on Cygnus X-3, the quasar 2005+405 was observed with sufficient sampling to allow a model reconstruction of its structure. A two-component model yielded a good fit to the data of 2005+403 at the four epochs; details will be presented elsewhere. The analysis shows that in contrast to Cygnus X-3, the radio source 2005+405 did not display significant variability during the observations or image broadening due to interstellar scattering on scales larger than 5 mas, so that the data could be used for calibrating the visibility amplitudes of Cygnus X-3.

Fig. 2 shows the visibility amplitudes for the observations of Cygnus X-3 obtained between January 24 and January 27. Observations were made with all available telescopes. Unfortunately, there are large gaps in the data due to the difficulty of scheduling telescopes with very short leadtimes. Table 1 lists the dates and telescopes for which observations were made. Fig. 1 shows that the radio flaring event is characterized by multiple outbursts. The flaring event is preceded by an initial flare of order 3 Jy detected on 1991 January 10 (c. Waltman et al., 1994). A flare with maximum flux density of 14.8 Jy at 3.6 cm occurs on January 21.5 (denoted Max 1 in Fig. 1) and is followed by secondary maxima of almost equal amplitude on January 24.8 (7.0 Jy, Max 2) and January 27.8 (7.1 Jy, Max 3), and at least six distinct peaks $\leq$ 4 Jy during the 30 following days. (see Fig. 1b). The profile of the lightcurve may be described by one peak and three consecutive plateaus of average (maximum) flux densities of order 7 Jy, 3.5 Jy, and 1.5 Jy in the time intervals 7 - 12, 12 - 22, and 22 - 34 days after the onset of the flaring event on January 18.

The occurrence of multiple flares is reflected in the spectral index distribution ($S_\nu \propto \nu^{+\alpha}$): after the steep rise during the first maximum $\alpha_{3.6cm}^{13.3cm}$ drops to -0.4 at the first minimum (c. Fig. 1c). The average spectral index, not including the time of the outburst, is -0.4 indicating a mixture of steep ($\sim$ 0.7) and inverted ($\geq$ 0) component spectra as expected by the blending of consecutive flares. The presence of two components in the total spectrum may also explain that the flares Max 2 and Max 3 occurr simultaneously at 3.6 and 13.3 cm (c. Fig. 1a,b), whereas the large flare Max 1 displays a timelag: the peak at the shorter wavelength preceeds the one at the longer wavelength by 0.4 days.

The spectral index is inverted prior to the large outburst on January 18 ($\alpha_{3.6cm}^{13.3cm}$ = +1.8). An analysis of the flaring events from the Green Bank Interferometer longterm monitoring has to show if the occurence of an inverted spectral index of the quiescent component prior to the large flares is significant and may serve as pre-indicator of these events.

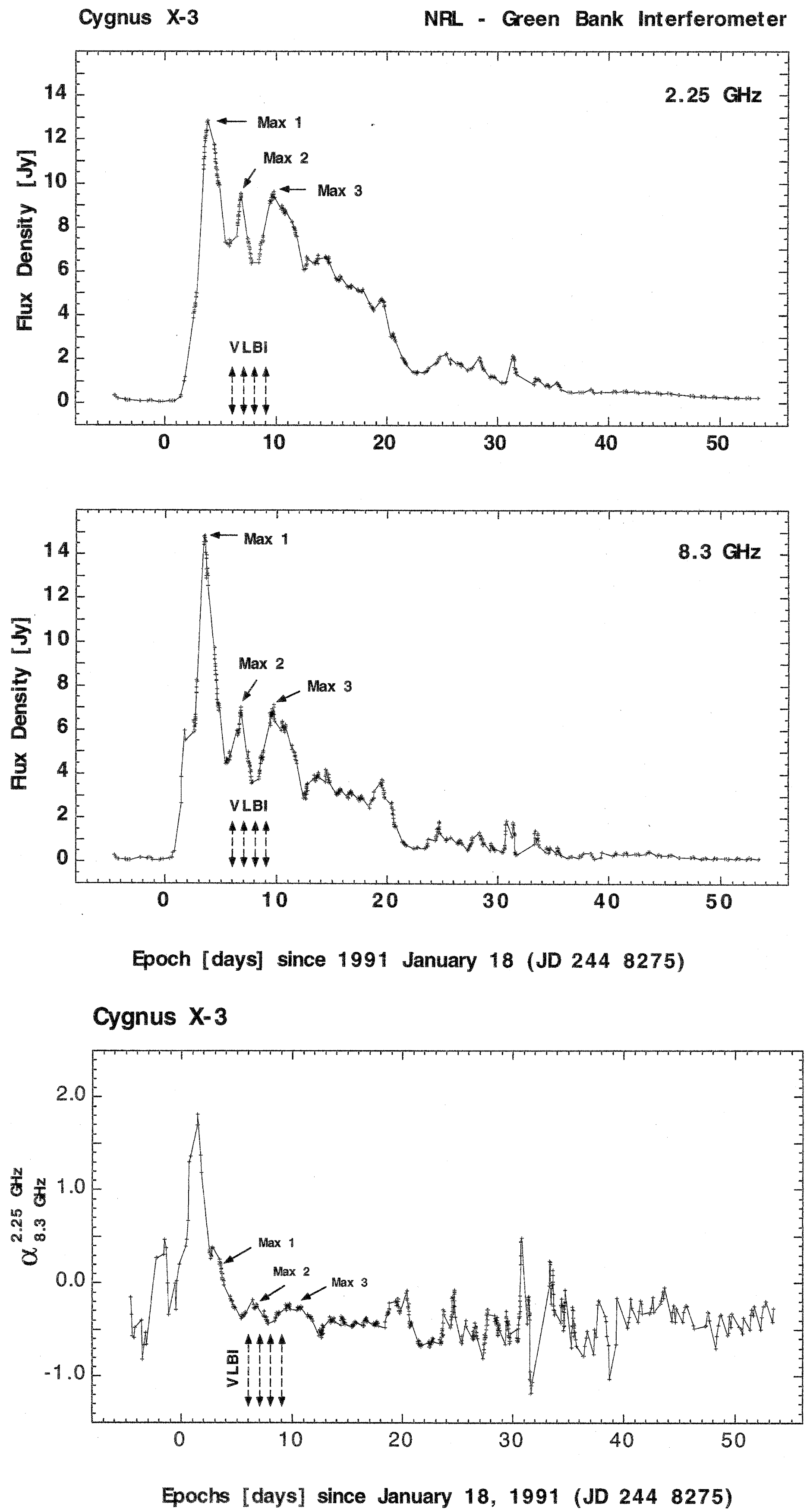

Fig. 1a–c. The lightcurves at 13.3 cm (2.25 GHz) (**a**) and 3.6 cm (8.3 GHz) (**b**) of Cygnus X-3 during the outburst of January 1991 measured by the NRL - Green Bank Interferometer, along with the spectral indices $\alpha^{13.3cm}_{3.6cm}$ (**c**). All epochs are referred to the onset of the outburst (at 3.6 cm wavelength) on 1991 January 18 (JD 2448275), as discussed in the text.

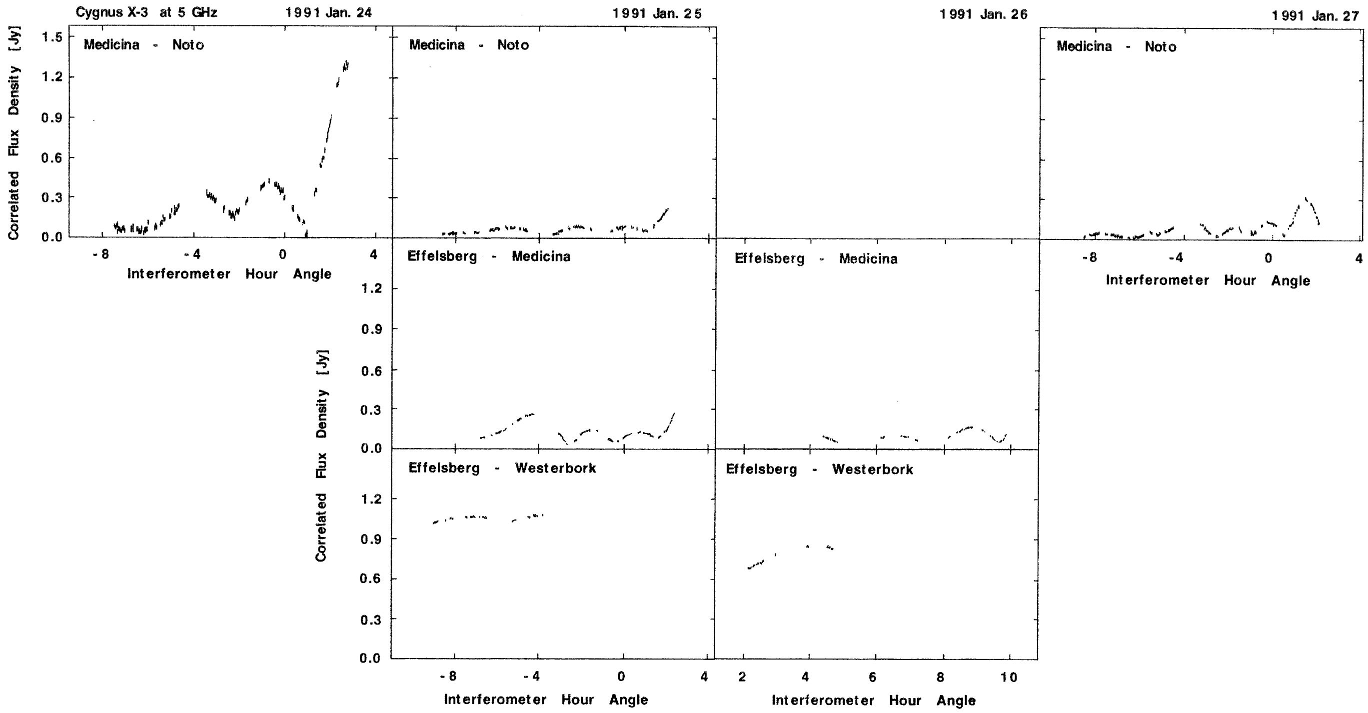

Fig. 2. Visibility amplitudes of Cygnus X-3 on 1991 January 24 - 27. Note that the visibilities are all plotted on the same scale. The visibilities on the shortest baseline, Effelsberg - Westerbork, do not reach unity, indicating that the source displays significant spatial structure on scales exceeding the 6 cm scattering size of 16 mas.

The four VLBI observations separated by one day each have been performed between Max 1 and Max 3 . In addition to the total flux densities at the VLBI epochs the values of the three peaks Max 1, Max 2 and Max 3 and the onset of the outburst (ZERO) are shown in Table 2.

Comparison of Fig. 1 with Fig. 2 shows that the source is heavily resolved even on the shortest baseline (B-W), with maxima of $\sim$ 20% (also M-N at epoch I), and $\leq$ 5% of the total flux densities at 6 cm for the others (see Table 2). A similar characteristic has been independently found during the October 1985 outburst at the two epochs with data for the Effelsberg to Westerbork and Effelsberg to Medicina baselines (Schalinski et al. 1995), with different levels of the total flux density (10 and 2 Jy at 6 cm wavelength, respectively).

The large reduction of visibility amplitudes can in principle be fitted by two classes of models:

(1) many compact components with sizes on the order of the interferometer beam or less of similar flux density and spatially blended together, or

(2) component sizes larger than the fringe spacing on the longest baseline and with flux densities adding up to the total source flux density.

However, a source representation on the basis of incomplete uv-data is ambiguous, because a mixture of these two types of models is likely, and the occurrence of different flaring events blending with each other will result in a superposition of component flux densities. Another complication for these observations is that Schalinski et al. (1995) have shown that individual components will have scattering sizes of order 16 mas at 6 cm wavelength. The interferometer for these observations is not very sensitive to structures on these size scales with the exception of the Bonn - Westerbork baseline. If there were a single large flare, the interferometer would be easily capable of measuring the evolution of this flare. However given multiple flares, this interferometer can only give evidence of multiple events and give a general description of the geometry of the radio emission associated with them. Given the flux density variability at the four VLBI epochs a possible influence on the source structure has to be considered. Since the variations of the visibility amplitudes appear not to be correlated with the variations of the overall intensity we estimate any effects on the source structure to be negligible for the study presented here.

To derive structural information and determine a preferred position angle from the current VLBI observations many possible image representations were investigated through simulations (varying source component parameters and generating continuous tracks with four stations) and subsequent modelfitting using the CalTech-Package (Pearson & Readhead, 1988). The simplest model adopted for the start of the simulations was three components of scattering size 16 mas, a total flux density of 6.6 Jy, angular separations exceeding 30 mas, along position angles $90^o - 270^o$. The results may be summarized as follows:

1) The visibility amplitudes show multiple (at least six) maxima and minima below a correlated flux density of 1 Jy except for the shortest baseline (Effelsberg to Westerbork, 270 km). The maximum flux density obtained from the model fits rises up to

Table 2. Total flux densities at 3.6 cm and 13.3 cm wavelength (cols. 3,4) of Cygnus X-3 at selected epochs (cols. 1,2) obtained with the NRL-Green Bank Interferometer, along with the corresponding flux densities at 6 cm wavelength (col. 6), interpolated from the spectral index $\alpha_{3.6cm}^{13.3cm}$ (col. 5). *Notes:* Cols. 7-9 list the maximum correlated flux densities on the baselines B-W, B-M and M-N during the four VLBI - observations (labelled I-IV in Col. 1) at 6 cm wavelength (in % of the total flux density) a: $S_{corr}^{max}/S_{tot}^{5GHz}[B-W]$, b: $S_{corr}^{max}/S_{tot}^{5GHz}[B-M]$, and c: $S_{corr}^{max}/S_{tot}^{5GHz}[M-N]$. All epochs are referred to the onset of the outburst (at 3.6 cm wavelength) on 1991 January 18 (JD 244 8275).

EVENT	Epoch [days]	$S_{3.6cm}$ [Jy]	$S_{13.3cm}$ [Jy]	$\alpha_{3.6cm}^{13.3cm}$	S_{6cm} [Jy]	a [%]	b [%]	c [%]
$\mathrm{ZERO}_{of outburst}^{January 18}$	0	0.10	0.07	0.27	0.09			
Max $1_{3.6cm}$	3.5	14.8		0.20				
Max 1_{6cm}	3.6			0.15	13.5			
Max $1_{13.3cm}$	3.9		12.9	0				
VLBI I	6.5	5.8	8.2	-0.27	6.6			20
Max 2	6.8	7.0	9.5	-0.23	7.9			
VLBI II	7.5	4.6	7.3	-0.35	5.5	20	5	4
VLBI III	8.5	4.1	6.8	-0.39	4.9	18	4	
VLBI IV	9.5	6.6	9.2	-0.25	7.5			5
Max 3	9.8	7.1	9.6	-0.23	8			

4 Jy (80% of the total flux density) on the Bonn to Medicina baseline, and is less on the other baselines due to the limited visibility.

2) In case of similar component sizes and intensities, the minima are close to zero (here at the detection limit of VLBI data). The location of the minima defines, unaffected by residual amplitude calibration errors, a preferential position angle of the structure. A p.a. change of 30^o changes the location of minima significantly and also reduces the amplitude of the main maximum significantly - from 4 Jy to 0.6 Jy for the tested data sets.

3) On longer baselines (Effelsberg to Noto), or adopting larger component sizes and separations, the contrast between main maximum and secondary minima is enhanced. Thus only minimal component sizes can be derived.

In order to constrain a preferred position angle of the structure, we plotted the correlated flux densities of the January 25 data as a function of projected baseline, and varied the position angle of the projection. Even for complex data the minima of different baselines will appear at the same uv-locations, if the baseline p.a. equals the position angle of the structure. A significant match of visibility amplitude minima in the data set of January 25 could be only found in the small range of position angles of $180^o - 190^o$.

Using the above additional constraints on any representation of the source on January 25, we performed multiple modelfits to this data set. A five component model (with parameters listed in Table 3) appears to be the minimum requirement but non-unique solution to fit the visibility amplitudes, with evidence for more complex structure. Since the minima are well defined on the baselines, we only assume the position angles of component orientations with respect to a central component to be reliable for interpretation: starting from $0^o/180^o$ these values tend to vary up to $-10^o/+170^o$. With the value obtained from the projected baseline plots we thus determine the p.a. to be in the range of $170^o - 190^o$. Multiple modelfits for the other epochs, especially for the Medicina to Noto baseline of January 24 and 25 also indicate, that more than three components are required to fit the visibility amplitudes.

Table 3. Typical modelfit to the Cygnus X-3 6 cm VLBI data of 1991 January 25. *Notes:* S: flux density, R: separation from central component, with corresponding position angle Θ; MAX: major axis, MIN: minor axis of elliptical components; Φ: position angle of major axis. Due to the visibility fine structure and the poor uv-coverage the solution is not unique, and only gives a representative fit with least complexity (at least five components). Error analysis of VLBI modelfits of Cygnus X-3 see Schalinski et al. (1995).

S [Jy]	R [mas]	Θ [deg.]	MAX [mas]	MIN [mas]	Φ [deg.]
0.51	0	0	19	12:	51:
1.53	15	-2	33	14:	44:
1.42	15	180	23	14:	65:
0.98	28	-2	23	16:	118:
0.84	32	179	15	13:	52:
Error estimates:					
±15 %	±5 mas	$\pm 10^0$	±10 mas	±10 mas	$\geq 10^0$

4. Discussion

The data of the 1991 outburst are different from previous VLBI observations of Cygnus X-3 in two ways: First, the total intensities at radio wavelengths are dominated by a superposition or blending of multiple flares, preventing a unique identification of single events. Second, the first high sensitivity VLBI data on this source show that considerable structure is contained in the low amplitude part of the visibility curves.

The investigation of the October 1985 flare (Schalinski et al. 1995) has shown evidence for "jet-like" radio emission on milliarcsecond scales, confined to a compact core and extended emission (30 mas) along a position angle of about 180^o. The analysis presented here contains evidence for the structure of Cygnus X-3 during the 1991 flare to be much more complex. Although a five component model is the least complex representation of the data, the real source structure is likely to be more complicated. This also applies to the analysis of the other epochs, especially to the single baseline observations of January 24 and 27. These modelfits, however, are all non-unique solutions, and not considered as reliable representations of the structure. On the other hand the well-defined minima of the visibility amplitudes, although low, allow the p.a. of the structure of the January 25 data to be constrained in the range of $170^o - 190^o$. The data show that the emission is confined to jets rather than a simple spherical expansion. A multiple component representation is best explained as a continuous outflow from Cygnus X-3. On the basis of these data it is however not possible to decide, whether this outflow is two sided or alternating.

Previous observations during outburst (e.g. Geldzahler et al. 1983; Spencer et al. 1986; Schalinski et al. 1995) and quiescent stages (Molnar et al. 1988) have shown evidence for outflow of the source with a velocity of 0.3c. Again the complexity of these data along with the sparse uv-coverage does not allow an unambiguous kinematic analysis. An estimate of the duration of the large flare, assuming that the lightcurve in later stages is a superposition of multiple outbursts, may be determined from inspection of Fig. 1 to be on the order of three days. This is similar to the timescales involved in previous flares (e.g. Johnston et al. 1986; Schalinski et al. 1995), and let us thus speculate that the kinematics involved may be similar. The five component modelfit of Table 3 is consistent with a total source size of at least 60 mas, and puts a lower limit to an expansion rate of 0.25c. The flux density constraints from the lightcurves (Fig. 1), requiring almost equal flux density contained in extended structure and "core", are also roughly consistent with the above model fit, showing about 3 Jy in a central region of about 30 mas, and about 2 Jy at core separations of 60 mas.

The low visibility amplitudes indicate sizes of components exceeding the beamsize of the array of about 5 mas. The modelfits show minimum sizes of about 16 mas. This is consistent with the compact components being dominated by image broadening most likely due to electron inhomogeneities along the line of sight towards the source. The Cygnus region has been shown to be subject to enhanced interstellar scattering on the basis of pulsar timing, interplanetary scintillation and VLBI measurements (e.g. Cordes et al. 1984; Fey et al. 1989). Schalinski et al. (1995) on the basis of two VLBI observations at 6 cm during the October 1985 flare derive compact component sizes of 16 mas. They also find a wavelength dependence of -2.02 on frequency consistent with refractive interstellar scattering with powerlaw index α = 3.7. This is slightly in excess of the Kolmogorov value for neutral turbulence, suggesting lengthscales of 10^{14} cm. Image broadening is most likely responsible for the strong resolution effects visible in the 1991 data. To obtain structural information on smaller scales and determine individual outbursts short wavelength VLBI observations with high sensitivity are required.

The September 1972 radio outburst (Gregory et al. 1972) has been modeled as particle injection into twin jets (Marti et al. 1992), extending the spherical solution of Marscher & Brown (1975) to confined jets. The data presented here give supporting evidence for jet emission, with emphasis on a continuous outflow. It is interesting to relate these radio flaring events to the X-Ray emission of the source.

Smale et al. (1993) report observations with the Broad Band X- Ray Telescope onboard the Space Shuttle Columbia showing Cygnus X-3 in an "ultrahigh", soft X-Ray state on December 5, 1990, prior to the large radio flare, with a luminosity of $\sim$2 x 10^{38} ergs s^{-1} (1-10 keV, at an assumed distance of 10 kpc). More general, from quasi-simultaneous radio and X-Ray measurements during a 4.5-year interval with Ginga and the GBI, Watanabe et al. (1994) find that during seven radio flaring events with flux densities exceeding 5 Jy Cygnus X-3 displayed X-ray flux densities corresponding to a high state with a luminosity of about 10^{38} ergs sec^{-1}, but no correlation with X-Ray variability.

They argue that, although a high accretion rate, as suggested by the high X-Ray state, might cause jets, the absence of simultaneous X-Ray outbursts requires additional physical processes to be relevant for the radio flares, such as large mass transfer from the companion star, and a sudden relaxation of magnetic field wound up by accreting matter. As can be seen from Fig. 4 in Watanabe et al. (1994) compared to other epochs the softness ratio displays a steep gradient prior to the large flaring event of January 1991. A confirmation of a possible correlation of X-Ray softness ratio and radio flaring events from simultaneous X-Ray and VLB-interferometric monitoring during outburst should help to understand the underlying mechanisms in detail.

In order to obtain a reasonable analysis of flaring events of Cygnus X-3 the individual flares must be identified. This can be accomplished by observing the flaring event as soon to initial onset as possible at 1.3 cm wavelength using an array with a minimum resolution of 1 mas which is sensitive to structure on size scales 1 - 20 mas. Scattering at 1.3 cm is expected to be 0.5 mas. Continuous monitoring at 1.3 cm with this resolution could identify each individual flare and confirm that the Cygnus X-3 jet emission is ballistic in nature. Further with instruments such as the VLBA, the evolution of the flaring event and emergence of a jet could be confirmed by studies at 3.6 and 6 cm wavelength (with sensitivity to spatial structure on scales 5 - 60 mas), as the 1.3 cm emission will probably decay below detectable limits.

This study would require dedicated use of the VLBA and EVN networks for a continuous period of thirty to forty days. At the present time this is probably impossible due to the scheduling of these networks for other programs, such as the study of jets associated with extragalactic sources. However Cygnus X-3 allows us to determine the evolution of jet-like structure from the beginning to its disappearance, i.e. "birth to death". Such an opportunity with its associated contribution to understanding jet like radio emission is certainly worth the observing time when we consider all the observations of extragalactic sources displaying jets so the morphology of these sources may be understood.

5. Conclusions

Cygnus X-3 has been observed with high sensitivity and spatial resolution at 6 cm wavelength on four consecutive days during a major flare in January 1991. The visibility amplitudes are low, in the range of 5-20% of the total flux density of the source, with minima down to the 7σ-detection limit of 10 mJy. The Green Bank Interferometer lightcurves at 13.3 and 3.6 cm show consecutive outbursts following a large flare starting on January 18, 1991 and, as can be also seen in the spectral index distribution, contain evidence that the apparent slow decay of the large flare is due to blending of continuous outbursts. Since the visibility amplitudes are low, a unique model cannot be derived from these observations. The best model representation of the data is of an almost continuous emission of length 60 mas along a position angle of $170^0 - 190^0$.

We argue that the complex structure of the visibility amplitudes and the lightcurve is caused by a superposition of multiple flares forming a quasi-continous outflow of the source. Our data analysis shows that adequate modelling of the complex outflow characteristics of the radio emission of Cygnus X-3 during outburst requires continuous multi-wavelength monitoring, especially at short wavelengths. The VLBA with it's multi-wavelength capability should have enough flexibility to perform monitoring of the source immediately following a reported large flare. It is important to observe the peak of the flare with VLBI as early as possible, in order to follow (and be able to distinguish) multiple outbursts, which we have shown here to be likely to occurr. Short wavelength observations at 1.3 cm (or at 7 mm, depending on sensitivity, see Schalinski et al. in prep.) are less affected by scattering, and should allow to determine the ejection of new components close to the core, whereas observations at longer wavelengths, e.g. at 3.6 cm and 6 cm, are sensitive to the evolution of the complex jet. The complex outburst structure requires a sampling of at least two days, although continuous monitoring for at least 14 days would be preferred. Complementary interferometric studies of Cygnus X-3 during "quiescent" stages (c. the total flux density monitoring by Waltman et al. 1994) should reveal whether there is continuous outflow via jets.

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References

Alef W., Porcas R.W., 1986, A&A 168, 365
Cordes J. M., Ananthakrishnan S., Dennison B., 1984, Nature 309, 689
Fey A. L., Spangler S.R., Mutel R.L., 1989, ApJ 337, 730
Fiedler R.L., Waltman E.B., Spencer J.H., et al., 1987, ApJS 65, 319
Geldzahler B.J., Johnston K.J., Spencer J.H., et al., 1983, ApJ 273, L65
Gregory P.C., Kronberg P.P., Seaquist E.R., et al., 1972, Nature 239, 440
Johnston K.J., Spencer J.H., Simon R.S., et al., 1986, ApJ 309, 707
Marscher A.P., Brown R.L., 1975, ApJ 200, 719
Marti J., Paredes J.M., Estalella R., 1992, A&A 258, 309
Molnar L.A., Reid M.J., Grindlay J.E., 1988, ApJ 331, 494
Ott M., Witzel A., Quirrenbach A., et al., 1994, A&A 284, 331
Pearson T.J., Readhead A.C.S., 1988, ApJ 328, 114
Rogers A.E.E., Cappalo R.J., Hinteregger H.F., et al., 1983, *Science*, 219, 51
Schalinski C.J., Johnston K.J., Witzel A., et al., 1995, ApJ 447, 752
Smale A.P., Mushotzky R.F., Schlegel E.M., et al., 1993, ApJ 418, 894
Spencer R.E., Swinney R.W., Johnston K.J., Hjellming R.M., 1986, ApJ 309, 694
Waltman E.B., Fiedler R. L., Johnston K.J., Ghigo F.D., 1994, AJ 108, 179
Watanabe H., Kitamoto S., Miyamoto S., et al., 1994, ApJ 433, 350.

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