EVN Observations of an HI Disk in the FRI Radio Galaxy NGC4261

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High-resolution and high-sensitivity EVN observations of the 21cm HI line in the FRI radio galaxy NGC4261 locates the absorbing gas to be in front of the parsec-scale counterjet. This geometry is consistent with the orientation of the HST dust disk observed in this object. The absorbing gas is likely to reside in a thin (h = 1.3pc), atomic circumnuclear disk at r = 10pc which possibly feeds the central engine. The data presented here are the first published scientific project from the EVN MkIV data processor at JIVE (van Langevelde et al. 2000).

1. Introduction

One reason to study neutral gas in radio sources is to investigate and confirm unified schemes, in which an obscuring torus surrounds the central engine of the AGN. Such tori are thought to consist of large amounts of neutral gas and may have a significant atomic component. Moreover, the AGN is thought to be fueled by neutral gas that is removed from its host galaxy. Tracing the distribution and kinematics of neutral gas is therefore important in our understanding of AGN physics. By using the HI line in absorption we can trace the gas in front of the brightest radio components, which usually are in the core regions (on kpc-scales or less). To distinguish between the different origins of HI gas, we want to trace the distribution and also the kinematics of the gas on very small scales, which requires interferometry. VLBI observations probe phenomena on scales that are within the NLR, and are well suited for comparison with spectroscopic optical data of the NLR, or with HST images.

Both optical imaging and kinematical information exists for the target of the observations presented here, the FRI radio galaxy NGC 4261 (3C270), which harbours an HST dust disk of radius 240pc (Jaffe et al. 1996), with its major axis elongated more or less in the North-South direction. Ferrarese et al. (1996) determined the inclination of the disk to be 64 degrees, with the Eastern side of this disk tilted towards us. This agrees with the orientation of radio continuum images which show a symmetric core-jet structure with the Eastern side being assumed to be the counterjet (Jones & Wehrle 1997). The Eastern side of the dust disk would then cover the counterjet from our direct view. Consistently, in the 8GHz image from Jones & Wehrle (1997), a gap in the emission just to the East of the core is interpreted as free-free absorption due to a small radius ($\sim$ 0.2pc) ionised disk.

Weak (peak absorption depth 7mJy) HI absorption was earlier detected against the core region of NGC 4261 with the VLA (Jaffe & McNamara 1994). The aim of the EVN observations was to probe this gas on VLBI scales in order to see whether it had any connection to the HST disk.

2. Observations and Results

NGC 4261 was observed in February 1999 with 7 EVN telescopes for 10 hours. This experiment required extremely high sensitivity because of the weakness of the line detected at the VLA, so the inclusion of telescopes with large collecting areas were crucial. Unfortunately Effelsberg was lost due to snow, and data from Medicina was severely affected by radio frequency interference (RFI). The data was correlated on the EVN MkIV data processor at JIVE, and was the first scientific experiment carried out at this new facility. The line data was correlated with 128 channels which yielded a velocity resolution of 7 kms^{-1}. The data calibration followed the normal procedure in AIPS, where also imaging of the continuum was performed. For more details see van Langevelde et al. (2000).

The resulting 5 telescope EVN continuum image of NGC 4261 has an rms noise level of 0.35 mJy/beam (Fig. 1). This image displays the same East-West structure as is found in radio images at e.g. 1.6 and 8.4 GHz (Jones & Wehrle 1997). The simple continuum structure allow us to model the source with 3 Gaussian components; at the core, jet (Western side) and counterjet (Eastern side).

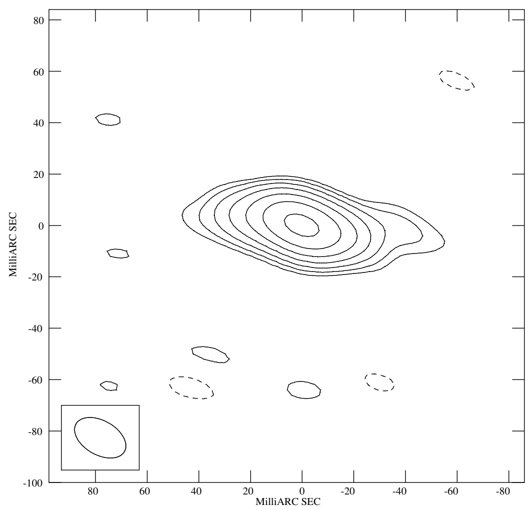

FIGURE 1. Continuum image of NGC 4261 at 21cm obtained with the EVN. The beam size is 21×15 mas. The contours are plotted at levels 1, 2, 4, 8, 16, 32 and 64 mJy/beam, with a map peak intensity of 79 mJy/beam. The East-West elongation of this source is consistent with earlier radio images at 1.6 and 8.4 GHz (Jones & Wehrle 1997).

3. Location of Absorbing Gas

Only the baseline between Jodrell Bank and WSRT provided enough sensitivity to unambiguously detect the absorption line. Figure 2 shows this resulting absorption spectra, plotted after continuum subtraction. The lower part of the spectrum plots amplitude versus channels, and the line FWHM is $\sim 130\ \mathrm{km\,s^{-1}}$. The upper part of Fig. 2 shows the phase, which provides information about the location of the absorbing gas. If the absorbing gas would cover the background continuum uniformly, we would in this plot expect the phase across the line to be 180 degrees. The thick horizontal line in the phase-panel marks 180 degrees. We find however, that the data shows that the phase is clearly offset from this line and thus indicates partial coverage. In order to better determine the location of the gas, we performed model-fitting of the spectral-line data.

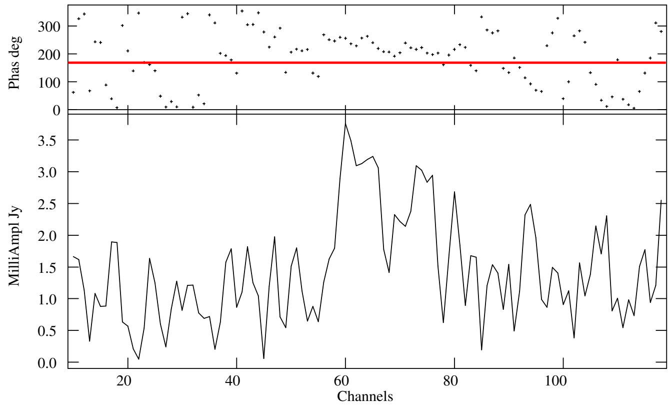

FIGURE 2. Lower part: Amplitude of absorbed flux density for the Jodrell Bank – Westerbork baseline integrated 18 mas to the East of the map centre, i.e. at the counterjet side. The continuum has been subtracted and one spectral channel corresponds to 7 km/s. Upper part: The phase on the absorption line is offset from 180 degrees (horizontal line), indicating non-uniform gas coverage.

For the modelfitting we used the continuum model described above with two jet components and one compact core component. In the modelfitting the positions of these 3 components were fixed, while the amount of absorbed flux were allowed to vary. Two different absorption models are shown in Fig. 3, where the upper parts of the plots are amplitude versus time, and phase versus time in the lower parts. In the left panel, we have the absorption against the western jet component only, and looking at the phase the model is far off the data points. But if we instead let the absorption be over the counterjet and the core, there is a good agreement in the phase between the model and the data (see the right panel). Thus, with this modelfitting we can show that the absorption is found against the counterjet. The best χ^2 fit is achieved for a counterjet opacity of 0.1 and a core opacity of 0.01.

4. Conclusions

The main result of this project is that we are able to place the bulk of the HI in front of the counter-jet, with the modeled absorption component at a deprojected distance of 6 pc from the core. Moreover, we can estimate an HI column density of 2.5×10^{21} cm^{-2}, assuming a spin temperature of 100 K. Consequently, there is 10 times less HI column density towards the core. The amount of gas in front of the core can be compared with results from X-ray observations of FRI radio sources, made for example by Worrall and Birkinshaw (1994). For NGC4261, they show that the total X-ray absorption can be explained by mere Galactic absorption, so we have an upper limit to the total column density towards the core of $N_H \leq 4 \times 10^{20}$ cm^{-2}, which is consistent with our results. Moreover, our results fits well with the free-free absorption on 0.2pc, which would be inside the HI.

Using optical spectroscopy Ferrarese et al. (1996) have estimated the mass of the central object to $M_{BH} = 5 \times 10^8 M_\odot$. In our observations we could not map the velocity distribution, but using the results from Ferrarese et al. (1996) we will assume that the HI lies in a Keplerian disk rotating around the central mass. Given this, the thin disk relation (e.g. Pringle 1981) can be used to estimate a disk-height of 1.3pc. Moreover, assuming a uniform disk a simple mass estimate gives $M_{HI} = 2 \times 10^3 M_\odot$. Given that

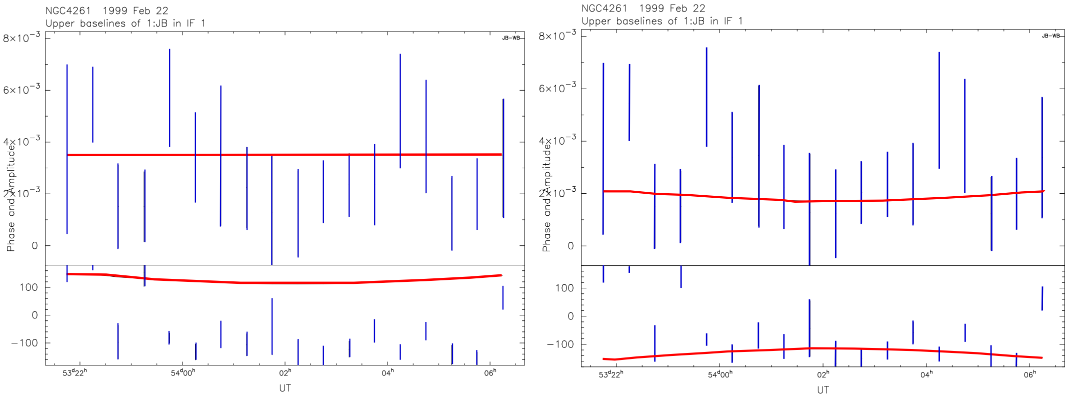

FIGURE 3. Two models of the absorption location. The upper parts plots amplitude versus time, while the lower parts plots the phase versus time. The lines represents the model and vertical lines the data with error bars. In the left panel, the absorption has been placed against the jet, and the modeled phase is clearly offset from the data. If the bulk of the absorption instead is located on the counterjet, the modeled phase agrees well with the data, which is shown in the right panel.

we know the radio source luminosity of NGC4261 (Ferrarese et al. 1996) and that the expected age of radio sources is $\sim 10^8$ years (Parma et al. 1999), such a mass is barely enough to fuel the source. Possibly the gas we observe is part of a continous accretion process.

Summarising, our data is consistent with earlier results on NGC4261 - for example the orientation of the dust disk and the occurrence of free-free absorption on sub-pc scales. It therefore appears like NGC4261 harbours a disk structure with an increasing state of excitation, going from molecular on HST scales down to the small ionised part in the centre. It is likely, that this thin disk has a role in the feeding of the AGN. Higher sensitivity observations are needed to trace the velocity distribution of the gas across the continuum, which could confirm the estimate of the enclosed mass given by optical spectroscopy.

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