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Evidence for a Circumnuclear Atomic Disk and Massive Black Hole in the Hidden Quasar Cygnus A

J. E. Conway
Onsala Space Observatory, Sweden

Abstract. We present evidence for a compact ($\approx$ 50pc scale) rotating H I disk or torus in Cygnus A, which may represent part of the structure which hides the quasar nucleus.

Cygnus A is the closest strong FR II radio galaxy and is therefore a key object for studying the proposed quasar/FR II radio galaxy unification by orientation. Optical spectropolarimetry observations (Cohen et al., these Proceedings, p. 81) argue that there is indeed a hidden quasar in Cygnus A; furthermore there is considerable evidence for a large obscuring column of gas (e. g., Ueno et al. 1994) which blocks our direct view of this quasar nucleus. Despite this no molecular absorption has been detected against the strong millimeter continuum from the nucleus (Drinkwater, Combes, & Wiklind 1996). However, Conway & Blanco (1995) did find significant broad H I absorption. The simplest interpretation of these results is that the majority of the obscuring column density is in the form of atomic gas (Conway & Blanco 1995). This is plausible given the expected heating from the central hard X-ray source in Cygnus A (Maloney 1996).

To more exactly locate the H I absorption we made VLBA plus phased VLA observations, the results of which are shown in Figure 1. Because of the low galactic latitude of Cygnus A the effective resolution is limited by foreground interstellar scattering. Both the 22cm data and a few scans included at 6cm were phase-referenced to a nearby compact calibrator, so that we could determine that the peak of the 22cm continuum brightness occurs within about 10 mas of the core seen in our 1 mas resolution 6cm map. The spectral line data was processed in a standard way and the continuum removed using UVLIN. As shown in Figure 1 the H I opacity peaks on the counterjet side of the source, with the maximum opacities of around 1 occurring about 20mas North and South of the jet axis. The centroid absorption velocity in this high opacity region shows a gradient across the jet axis ranging from -30 km/s to the North to +30 km/s in the South (see Fig. 1, right). In contrast as we move further out along the jet to the low ($\approx$ 0.05) opacity gas that covers the continuum peak the centroid velocity is increasingly redshifted reaching approximately +100 km/s.

We interpret the high opacity component of the H I absorption as being due to a flattened distribution of gas with significant H I content rotating around the jet axis. This could represent the dense midplane of the "obscuring torus" which absorbs and shadows ionizing radiation and gives rise to the bi-cones seen in optical continuum and spectral lines. This interpretation for the high opacity H I is consistent with it occurring against the continuum emission on the counterjet side. We know from 6cm images that the synchrotron emitting counterjet in Cygnus A (Sorathia et al. 1996) is quite narrow, $<$ 5pc, and therefore absorption against this feature cannot account for either the off-axis locations of the peak opacities or the observed North-South velocity gradient (see Fig. 1, right). The absorbed continuum must instead come from another more extended component, hints of which are seen in the continuum images. The required brightness temperature of this component is 5×10^6 K and it could be due to thermally emitting ionized gas evaporated from the inner edge of a torus or disk (as ob-

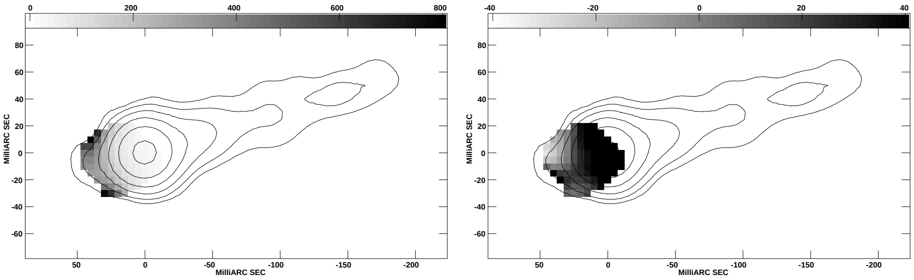

Figure 1. Left. Greyscale shows H I opacity averaged over a velocity range of 320 km/s covering the whole absorption line, resolution is 25 mas FWHM circular. Black is opacity of 0.8. Contours show the 1340 MHz continuum image of Cygnus A, resolution 25 mas circular, contours at 4,8,16,32,64,128 mJy/beam. Right. Greyscale shows centroid of absorption velocity, white is -40 km/s and black is 40 km/s

served in NGC 1068, Gallimore, Baum, & O'Dea 1997). Alternatively the diffuse component might be Thompson scattered synchrotron radiation. This is plausible even if the free electron column within the circumnuclear torus is only a few percent of the estimated column density along the line of sight to the nucleus. This is because for a jet with $\gamma > 3$ and oriented at 60° to the line of sight the free electrons will see synchrotron radio emission which is > 10 times brighter than that which we see directly.

We can use the observed North-South velocity gradient within the high opacity H I (Figure 1, right) to set limits on the enclosed mass; the exact value depends on the jet angle to the line of sight and the detailed geometry of the obscuring gas. However in order to explain the large N-S gradient in opacity we need a relatively compact ring or annulus of high opacity H I of inner radius $40\mathrm{h}^{-1}$pc whose normal (the jet axis) is inclined $\approx 60°$ to the line of sight. In this case the enclosed mass is $1.3 \times 10^8 \mathrm{h}^{-1} \mathrm{M}_\odot$. A black hole of this mass accreting at 10% of its Eddington rate is enough to supply the bolometric luminosity of Cygnus A.

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