A VLBI Search for Compact Nonthermal Emission from the Herbig Be Star MWC 297

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Abstract. Intermediate mass pre-main-sequence stars ("Herbig Ae/Be stars") show unusual behavior such as rapid spectroscopic variability that may be of magnetic origin. If magnetic fields are present in these early-type stars, they could give rise to compact, high brightness temperature ($T_b \geq 10^{7.5}$ K) gyromagnetic radio emission. We have conducted a 3.6 cm VLA/VLBI observation of the Herbig Be star MWC 297 to search for such emission. Although the star was clearly detected with the VLA at a peak flux density of 5.2 mJy, it was not detected on any of the VLBI baselines. The derived upper limit on the 3.6 cm brightness temperature is $T_b \leq 3 \times 10^6$ K which, along with other evidence, implies that MWC 297 is an extended *thermal* radio source whose emission is most likely wind-related.

1. Introduction

The presence of magnetic fields in low mass ($\leq 2\ M_\odot$) pre-main-sequence stars is now firmly established. The radio evidence for magnetic activity is particularly convincing for weak-lined *T* Tauri stars. Their centimeter radio emission is in some cases circularly polarized (WHITE *et al.*, 1992; SKINNER, 1993) and VLBI observations give typical radio brightness temperatures $T_b \geq 10^{7.5}$ K (PHILLIPS *et al.*, 1991). These brightness temperatures are too high for thermal processes such as free-free wind emission.

The evidence for magnetic activity in intermediate mass (2–20 $M_\odot$) premain-sequence stars, the "Herbig Ae/Be stars", is somewhat less convincing. However, some objects of this type such as AB Aur show short-term (~days) spectroscopic variability that could be of magnetic origin (PRADERIE *et al.*, 1986; CATALA *et al.*, 1987). Since Herbig Ae/Be stars are quite young (~10^6 years), the hypothesized magnetic fields could be primordial (DUDOROV and GORBENKO, 1991) or perhaps sustained by outer convection zones that result from subsurface deuterium burning (PALLA and STAHLER, 1990).

A high-sensitivity radio survey of 57 Herbig Ae/Be stars using the Very Large Array (VLA) and Australia Telescope (AT) was recently completed by SKINNER *et al.* (1993) (hereafter SBS93). One of its objectives was to search for radio evidence of magnetic nonthermal activity such as circular polarization or rapid flux variability. Generally, such evidence was *not* detected and these authors concluded that the radio emission of Herbig Ae/Be stars is predominantly thermal and in many cases wind-related. However, the VLA/AT observations were not of sufficient angular resolution to place tight constraints on T_b, which is the most reliable discriminator between thermal and nonthermal emission. Hence, we have conducted the first VLBI observation of a Herbig Be star, MWC 297, in order to tightly constrain T_b and search for compact emission confined to angular scales of a few milli-arcseconds that is typical of gyromagnetic processes (e.g. gyrosynchrotron radiation). MWC 297 lies at a distance of 530 pc and is of spectral type B0 (BERGNER *et al.*, 1988). It had the highest 3.6 cm flux density (8.8 mJy) of any Herbig star detected in the VLA/AT survey, and is the only such star that is bright enough at radio wavelengths to warrant a VLBI observation.

2. VLBI Observations

We observed MWC 297 on 1992 Nov 9 at 8435 MHz (3.6 cm) with a VLBI network consisting of antennas of the partially-completed U.S. Very Long Baseline Array (VLBA), the NASA DSN 70 m antenna at Goldstone, and the phase-linked VLA in "A" configuration. On-source time for the VLBI observation was limited by Mark IIIa tape capacity to $\approx$600 s. The detection threshold on the most sensitive VLA-Goldstone baseline was 1.4 mJy (6σ), with a baseline length $2.2 \times 10^7\ \lambda$. On-source time with the VLA was 28 minutes, giving a VLA detection threshold of 0.15 mJy (3σ).

Data were correlated with the Haystack Mark IIIa VLBI processor, and the fringe search was conducted with the maximum likelihood algorithm FRNGE. Scans on the quasar 2134 + 004 indicated that all stations were operating normally. Absolute flux calibration and phase referencing for the VLA were achieved by observing 3C 48 and 1821 + 107, respectively. The VLA data were calibrated and imaged with the AIPS software package.

3. Results

Table 1 summarizes the results of the observations. MWC 297 was clearly detected with the VLA at a peak flux density of 5.2 mJy, but was not detected on any of the VLBI baselines. The failure to detect circular polarization down to low levels confirms previous VLA results, which gave an upper limit on circular polarization of $\leq$2% (3σ) (SBS93).

The upper limit $T_b \leq 3 \times 10^6$ K is an order of magnitude below that expected for nonthermal emission, and provides convincing evidence that MWC 297 is a thermal radio source. The lower limit on the source angular diameter $\theta_s \geq 7$ mas implies a source radius $R_s \geq 40\ R_*$, assuming a stellar radius $R_* \approx 10\ R_\odot$. The possible presence of P-Cygni line profiles (HERBIG, 1960) and the evidence from previous observations that its radio flux increases with frequency (SBS93) suggest that the emission originates in an ionized wind. An ionized mass loss rate of $\sim 10^{-6}\ M_\odot\ \mathrm{yr}^{-1}$ is required to account for the observed 3.6 cm flux, assuming a spherical constant-velocity wind (SBS93).

Table 1. Radio properties of MWC 297 (8.435 GHz)*.

Peak flux	5.24 ± 0.15 mJy
Circular polarization	$\leq 3.4\%$ ($3\ \sigma$)
Brightness temperature	$\leq 3 \times 10^6$ K
Source angular diameter	≥ 7 mas

*Data are from observations on 1992 Nov. 9.

4. Discussion

The existing data for this Herbig Be star show no evidence for gyromagnetic emission either in the form of circular polarization or a compact high T_b core. However, the radio observations alone do not rule out the presence of weak magnetic fields. Fields weaker than ~30 G in the radio-emitting region could not produce 3.6 cm gyrosynchrotron emission from harmonics $s \leq 100$ of the electron cyclotron frequency.

The cooler Herbig Ae stars such as AB Aur (A0 Ve) are perhaps the more interesting members of the class in view of their spectroscopic variability. Unfortunately, the Ae stars have weak 3.6 cm fluxes of ≈0.1–0.5 mJy, which are well below current VLBI detection limits. Thus, VLBI searches for high T_b nonthermal cores in cooler Herbig Ae stars are not yet feasible and must await improvements in sensitivity.

The radio properties of Herbig Ae/Be stars stand in sharp contrast to those of the chemically-peculiar magnetic Ap/Bp stars, which show convincing radio evidence for magnetic fields (LINSKY *et al.*, 1992) and which have been detected in VLBI experiments (PHILLIPS and LESTRADE, 1988). It is now believed that the radio emission detected in Ap/Bp stars is gyrosynchrotron radiation originating in a wind-fed magnetosphere. It is of interest to note that radio continuum emission is rarely detected from either magnetic Ap/Bp stars or Herbig Ae/Be stars later than spectral type ≈A2. The point at which the detection cutoff occurs is somewhat uncertain due to ambiguities in spectral types. However, in both cases it is believed that the low detection rate among later A-type stars is due to the rapid decrease in wind ionization toward lower effective temperatures. Thus, the radio emission of these two classes of A/B stars, which shows such striking qualitative differences, ultimately owes its existence to the electrons produced in an ionized wind.

In terms of radio properties, the Herbig Ae/Be stars seem to more closely resemble the classical Ae/Be stars than they do the magnetic Ap/Bp stars. Some classical Ae/Be stars such as ψ Per and β CMi show radio fluxes that increase with frequency, which has been interpreted as thermal (free-free) emission originating in extended circumstellar envelopes (DOUGHERTY *et al.*, 1991). PALLA and STAHLER (1990) have argued on the basis of angular momentum considerations that Herbig Ae/Be stars may evolve into classical Ae/Be stars. Traditionally, it has been thought that classical Ae/Be stars are main-sequence objects undergoing mass loss. However, recent optical and infrared studies of the young cluster NGC 6611 (HILLENBRAND *et al.*, 1993) reveal a large number of apparently young stars with properties quite similar to those of classical Ae/Be stars. These new results suggest that a closer comparison between Herbig Ae/Be stars and classical Ae/Be stars at all wavelengths, including the radio, would be worthwhile.

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