HIPPARCOS, VLA, AND CCD OBSERVATIONS OF CYG OB2 No. 5

M.E. Contreras[1], **L.F. Rodriguez**[1], **M. Tapia**[2],
D. Cardini[3], **M. Badiali**[3], **A. Emanuele**[3], **P. Persi**[3]

[1]Instituto de Astronomía, UNAM, Apdo. Postal 70-264, 04510 México, D.F., México
[2]Instituto de Astronomía, UNAM, Apdo. Postal 877, Ensenada, México
[3]Istituto Astrofisica Spaziale, CNR, C.P. 67, 00044 Frascati, Italy

ABSTRACT

Cyg OB2 No. 5 (BD+40°4220; V729 Cyg) is known to be a contact binary system formed by two O-type stars. For this object a 6-cm radio emission has been detected at the optical position as well as an additional weak non-thermal radio source located at ~ 0.9 arcsec to the north east of the contact binary. It has been suggested that this radio component was possibly a third stellar object in the system. This was the first time that a radio companion was observed to be associated with the contact binary system. In this work we present new radio, CCD and Hipparcos observations that provide the basis for a plausible explanation of the origin of the non-thermal radiation emitted by the 'third' component of this system and its nature.

Key words: Radio continuum: general and stars; early-type stars.

1. INTRODUCTION

One of the more reliable methods for the determination of the mass loss rate in massive stars is via the observation of the free-free radiation emitted by their ionized winds at radio wavelengths. The first radio survey was carried out by Abbott et al. (1980). In this study they reported mass loss rate values for 15 O, B and A-Type stars observed at 6-cm. Later studies confirmed the detection of thermal radio emission at 2 and 6-cm (Abbott et al. 1981, 1984, 1986, Bieging et al. 1989) from OB stars. However, some early-type stars show time-variable, non-thermal emission of poorly understood origin (Abbott et al. 1984, Persi et al. 1985, Williams et al. 1990, Miralles et al. 1994). This synchrotron radiation can be comparable or even larger than the expected free-free emission and this non-thermal contamination limits the accuracy of the method.

Abbott et al. (1981) selected the most luminous stars in the Galaxy, most of their sample residing in the Cyg OB2 association. They reported 6-cm radio fluxes and mass loss values for 10 objects and determined accurate radio positions. In particular, their sample included Cyg OB2 No. 5 (BD+40°4220; V729 Cyg) which is known to be a contact binary system formed by two O7I stars (Torres-Dodgen et al. 1991). For this object they detected emission at the optical position as well as an additional weak radio source located at ~ 0.9 arcsec to the north east of the contact binary. They suggested that this radio component was possibly a third stellar object in the system. This was the first time that a radio companion was observed to be associated with the contact binary system.

Persi et al. (1985) reobserved this source at 2, 6 and 20 cm. They found that the 6-cm flux density had increased by a factor of 3, with respect to the 1980 observations made by Abbott et al. (1981), and have found a very flat spectral index of 0.2 $\pm$0.1.

Later, Persi et al. (1990) continued monitoring Cyg OB2 No. 5 and found again that the emision had changed, this time decreasing back to the 1981 levels. Persi et al. (1990) defined what they called the 'high' and 'low' states of emission. In the 'high' state the 6-cm measured flux density was of $\simeq$5 to 7 mJy with a spectral index of $\alpha_{2-6cm} \simeq 0.2$ while in the 'low' state the 6-cm flux was of $\simeq$1 to 2 mJy and the spectral index had increased and became consistent with the classical 0.6 value expected for a thermal wind. However, even in the low state of emission the spectral index derived from the 6 and 20-cm fluxes had a negative value indicating the presence of a non-thermal component. The presence of both thermal and non-thermal radio emitting components in Cyg OB2 No. 5 resembled the case of other Cyg OB2 association members (Cyg OB2 Nos. 8A, 9 and 12) and some Wolf-Rayet stars (WR 140 and WR 147).

Miralles et al. (1994) observed the source continuing the monitoring for about four more years. The source showed again its radio variations between the 'high' and 'low' states with flux densities and spectral indices similar to those found by Persi et al. (1990). The radio emission seems to switch between these two states in a period of about 7 years. They have modeled the emission as due to a synchrotron envelope created by a periodic production of relativistic electrons in the wind. Miralles et al. (1994) confirmed the coincidence between the radio maximum emission and the optical position for the binary system and rediscovered the weak radio companion at 3.6 and 6-cm. They determined a separation of $\sim 0.8 \pm 0.1$ arcsec to the NE of the main component and supported the idea that this source was a third component of the system and not a background object. The spectral index derived for the companion was $\alpha = -0.3 \pm 0.5$. However with such a large error it was not possible to establish if the radio companion was thermal or non-thermal. Herbig (1967) had reported a star of magnitude 13 or 14 located at about ~ 1.5 arcsec with a position angle of $60^\circ - 70^\circ$ from the optical position of the brightest component. Miralles et al. (1994) suggested the possibility that this could be the optical counterpart of the weak radio companion.

In a recent study Contreras et al. (1996) reported two sets of observations for Cyg OB2 No. 5 obtained in 1994 and 1995. They found that the flux densities appeared to be increasing between the two observing runs at the different frequencies observed, 6, 3.5 and 0.7 cm. This tendency and the fact that the spectral indices derived were decreasing was indicative of the onset of the 'high' emission state predicted to occur in 1996 by Miralles et al. (1994). Besides, in their 1994 observations they detected the radio companion at 6-cm and 3.6-cm. With these two observed fluxes they derived an upper limit value for the spectral index, $\alpha = -2.4 \pm 0.6$, indicating beyond doubt that the companion source was clearly non-thermal at least during that epoch. The separation between the main component and the companion was 0.8 ± 0.1 arcsec.

Hence, separation values determined in the radio by different authors (Abbott et al. 1981, Miralles et al. 1994, Contreras et al. 1996) indicated that the separation between the two components was less than 1.0 arcsec, apparently smaller than the value reported by Herbig (1967) in the optical. In this work we present new radio and optical observations that determine this separation accurately and provide the basis for a plausible explanation of the origin of the non-thermal radiation emitted by the 'third' component of this system and its nature.

2. OBSERVATIONS

2.1. Very Large Array Observations

New 3.6 and 6-cm observations were made with the Very Large Array (VLA) of NRAO[1]. The 3.6-cm observations were made during 1996 December 27 and 28, while the 6-cm observations were made during 1997 January 4. During both observing runs the array was in the A configuration giving resolutions of ~ 0.2 arcsec and ~ 0.3 arcsec, at 3.6 and 6-cm, respectively. The amplitude calibrator was 1328+307 and the phase calibrator 2005+403 in both cases. The bootstrapped flux densities of 2005+403 were 2.98±0.01 and 3.24±0.01 Jy at 3.6 and 6-cm, respectively. Editing, calibration, imaging, and analysis of the data was performed using the AIPS software of NRAO. Cleaned maps made from self-calibrated uv data at 3.6 and 6-cm are shown in Figures 1 and 2.

[1]NRAO is operated by Associated Universities, Inc., under cooperative agreement with the National Science Foundation.

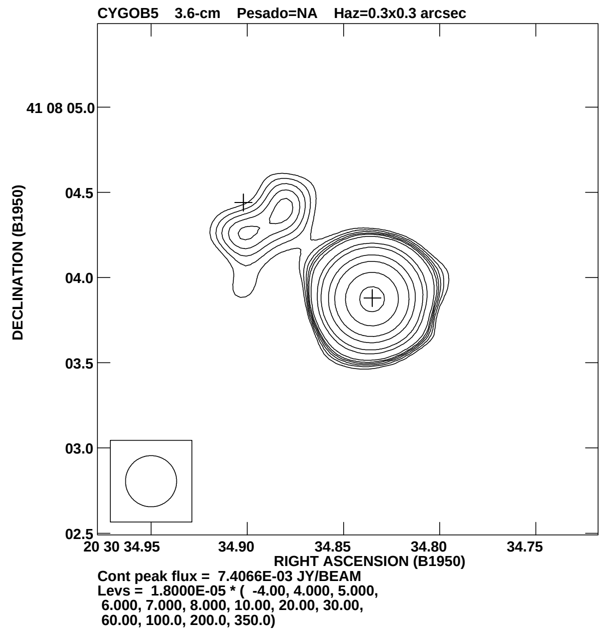

Figure 1. Cleaned, natural-weight map of Cyg OB2 No. 5 from self-calibrated uv data at 3.6 cm. The crosses mark the position of the optical stars (see text).

2.2. CCD Observations

CCD images were obtained through the broad-band filters B, V and R Tek4 800×800 CCD on the 1-m Johannes Kepler Telescope (JKT) at the Observatorio Roque de los Muchachos in La Palma, Canarias, Spain, on the nights 6/7 and 15/16 November 1994 as part of the Service Observing program. The plate scale was 0.33 arcsec/pixel and the mean seeing was around one arcsec during both nights. The exposure times were between 1–10 s but even with the shortest exposure, Cyg OB2 No. 5 was saturated in the I frames.

A Gaussian Point Spread Function was fitted to isolated stars on each frame and was then subtracted, after scaling, from the spot centred on Cyg OB2 No. 5. The residual image clearly showed the fainter isolated companion star. Its relative position was measured on all frames with an average value for the separation to primary binary of 0.98 ± 0.06 arcsec and position angle 61 ± 7 degrees. The differential photometry (Cyg OB2 No. 5 minus companion) yielded $\Delta V = -3.96$ and $\Delta(B-V) = 0.11$.

Assuming the values of the photometry for the composite system to be those given by Torres-Dodgen et al. (1991), the individual colours of the spectroscopic binary Cyg OB2 No. 5 are $V = 9.18$ and $(B-V) = 1.81$, while those of the stellar companion are $V = 13.14$ and $(B-V) = 1.70$. As the star was saturated, no photometry was performed in the I band.

2.3. Hipparcos Observations

A complete, detailed description of the Hipparcos mission and of the derivation of the astrometric parameters is given in the Hipparcos Catalogue (ESA 1997). During the 37 months of the Hipparcos mission, the object Cyg OB2 No. 5, identified by the Hipparcos Catalogue number HIP 101341, fell 113 times in the field of view of the rotating telescope, each time performing an apparent transit through the modulating grid of its focal plane. By analysing this set of signals with a processing algorithm described in Mignard et al. (1995), it has been possible to obtain the separation (0.948 ± 0.043 arcsec) and the position angle ($54° \pm 3°$). These data are in good agreement with those of the CCD measurements.

3. DISCUSSION

In Figures 1 and 2 we have superposed the optical positions for the primary and secondary optical components, as determined by Hipparcos, onto the radio maps. For this we have assumed that the brightest optical component coincides in position with the brightest radio component. As can be clearly seen, the radio 'companion' is located in between the two optical positions, although closer to the secondary optical component. While at 6-cm the separation between components is 0.79 ± 0.03 arcsec, the separation measured by Hipparcos is 0.948 ± 0.0043 arcsec.

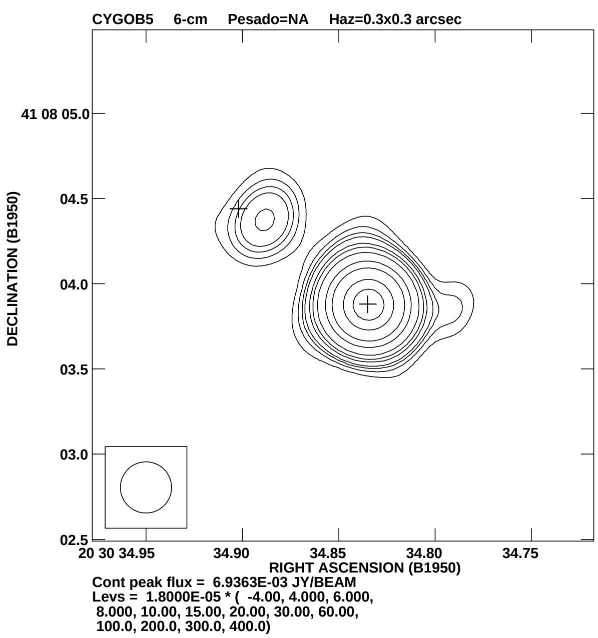

Figure 2. Cleaned, uniform-weight map of Cyg OB2 No. 5 from self-calibrated uv data at 6-cm. The crosses mark the position of the optical stars (see text).

These results indicate that the radio 'companion' is not a star, but most likely a bow shock produced at the position where the winds of the contact binary and the secondary star collide. Acceleration of electrons to relativistic speeds can take place in strong shocks, giving rise to the observed synchrotron (non-thermal) radiation.

Assuming the absolute V magnitude and intrinsic $(B-V)$ colour of two O7Ia stars for the contact binary primary and the same distance and reddening (Torres-Dodgen et al. 1991), then we inferred a spectral type B2V for the companion star.

A very similar situation has been recently found for WR 147 by Williams et al. (1997).

REFERENCES

Abbott, D.C., Bieging, J.H., Churchwell, E., Cassinelli, J.P. 1980, ApJ, 238, 196

Abbott, D.C., Bieging, J.H., Churchwell, E. 1981, ApJ, 250, 645

Abbott, D.C., Bieging, J.H., Churchwell, E. 1984, ApJ, 280, 671

Abbott, D.C., Bieging, J.H., Churchwell, E. Torres, A.V. 1986, ApJ, 303, 239

Bieging, J.H., Abbott, D.C., Churchwell, E. 1989, ApJ, 340, 518

Contreras, M.E., Rodríguez, L.F., Gómez, Y. Velázquez, A. 1996, ApJ, 469, 329

ESA, 1997, The Hipparcos and Tycho Catalogues, ESA SP–1200

Herbig, G.H. 1967, PASP, 79, 502

Mignard, F., Soderhjelm, S., Bernstein H. et al 1995, A&A, 304,94

Miralles, M.P., Rodríguez, L.F., Tapia, M., Roth, M., Persi, P., Ferrari-Toniolo, M., Curiel, S. 1994, A&A, 282, 547

Persi, P., Ferrari-Toniolo, M., Tapia, M., Roth, M., Rodríguez, L.F. 1985, A&A, 142, 263

Persi, P., Tapia, M., Rodríguez, L.F., Ferrari-Toniolo, M. Roth, M. 1990, A&A, 240, 93

Torres-Dodgen, A.V., Tapia, M. Carroll, M. 1991, MNRAS, 249, 1

Williams, P.M., van der Hucht, K.A., Pollock, A.M.T., et al. 1990, MNRAS, 243, 662

Williams, P.M., Dougherty, S.M., Davis, R.J., van der Hucht, K.A., Bode, M.F., Gunawan, D.Y.A.S. , MNRAS, submitted