RADIO CONTINUUM EMISSION FROM FS CMA STARS

Luis F. Rodríguez,[1,2] Alejandro Báez-Rubio,[1,3] and Anatoly S. Miroshnichenko[4]

RESUMEN

Las estrellas tipo FS CMa muestran espectros ópticos con líneas de emisión y fuertes excesos infrarrojos. Se sabe muy poco de sus características en ondas de radio. Hemos analizado datos de archivo del Very Large Array para buscar emisión de radiocontinuo en una muestra de ellas. Existen datos de buena calidad para siete de las aproximadamente 40 estrellas FS CMa conocidas. De estas siete estrellas, cinco resultan tener emisión de radio asociada. Dos de estas estrellas, CI Cam y MWC 300, han sido reportadas previamente en la literatura como emisoras de radio. Presentamos y discutimos brevemente la detección de las otras tres fuentes: FS CMa (el prototipo de la clase), AS 381, y MWC 922. La emisión de radio es muy probablemente libre-libre pero se requieren observaciones adicionales para caracterizarla mejor.

ABSTRACT

The FS CMa stars exhibit bright optical emission-line spectra and strong IR excesses. Very little is known of their radio characteristics. We analyzed archive Very Large Array data to search for radio continuum emission in a sample of them. There are good quality data for seven of the ∼40 known FS CMa stars. Of these seven stars, five turn out to have associated radio emission. Two of these stars, CI Cam and MWC 300, have been previously reported in the literature as radio emitters. We present and briefly discuss the radio detection of the other three sources: FS CMa (the prototype of the class), AS 381, and MWC 922. The radio emission is most probably of a free-free nature but additional observations are required to better characterize it.

Key Words: radio continuum: stars — stars: individual (FS CMa, AS 381, MWC 922)

1. INTRODUCTION

The B[e] phenomenon is associated with stars at different evolutionary stages, going from the pre-main sequence to the planetary nebula stage. This phenomenon is characterized by the simultaneous presence of low-excitation forbidden line emission and strong infrared excess in the spectra of early-type stars. The group of B[e] stars includes high- and low-mass evolved stars, intermediate-mass pre-main sequence stars and symbiotic objects. In more than 50% of the confirmed B[e] stars the evolutionary stage is still unknown. These objects are generally called unclassified B[e] stars (e.g., Miroshnichenko 2007; Borges Fernandes 2010). This lack of a classification is mostly caused by the limited knowledge regarding their physical parameters, in particular the distance and the geometry of their circumstellar matter.

Recently, Miroshnichenko (2007) has noted that most of the unclassified B[e] stars have unique observational properties that distinguish them with respect to the rest of the B[e] stars and he classified them within a new group: the FS CMa stars. Miroshnichenko (2007) has proposed that this group of stars could be binary systems that are currently undergoing or have recently undergone a phase of rapid mass exchange associated with strong mass loss stored in a circumbinary envelope. This scenario

---

[1]Centro de Radioastronomía y Astrofísica, Universidad Nacional Autónoma de México, Morelia, Michoacán, Mexico.
[2]Astronomy Department, Faculty of Science, King Abdulaziz University, P.O. Box 80203, Jeddah 21589, Saudi Arabia.
[3]Centro de Astrobiología (CSIC/INTA), Spain.
[4]Department of Physics and Astronomy, University of North Carolina at Greensboro, USA.

TABLE 1

FS CMA STARS WITH GOOD QUALITY VLA ARCHIVE OBSERVATIONS

	Position[a]		Flux	Wavelength	VLA	Project	Epoch of
Star	α(J2000)	δ(J2000)	Density (mJy)	(cm)	Conf.		Observation
FS CMa	06 28 17.39	-13 03 10.9	4.2 ± 0.4	1.3	DnC	AM570	1997 Sep 26
MWC 819	06 44 37.67	$+01$ 19 32.5	≤0.31[b]	6.0	B	AP116	1986 Jul 29
MWC 922	18 21 16.06	-13 01 25.7	10.8 ± 0.4	3.6	B	AL329	1994 Jul 09
AS 381	20 06 39.86	$+33$ 14 30.0	3.3 ± 0.7	20.0	C	AW271	1990 Nov 14
V669 Cep	22 26 38.71	$+61$ 13 31.6	≤0.57[b]	20.0	A	AM590	1998 Apr 04

[a]The position of MWC 819 is from Cutri et al. (2003) and the position of V669 Cep is from Hog et al. (2000). The positions of the other three stars are from the VLA images presented here.

[b]Three-sigma upper limit.

explains the higher IR excesses due to circumstellar dust despite its lower mass-loss rate with respect to sgB[e] stars and the fact that FS CMa stars are not found in star forming regions.

As noted before, the determination of the geometry of the surrounding matter via high-angular resolution observations could provide valuable information on the nature of the unclassified B[e] stars. We have started a program to search for FS CMa stars with detectable radio continuum emission in unpublished archive data from the Very Large Array (VLA) of the NRAO[5]. The sources detected will be observed in the future to obtain high quality images with sub-arcsecond angular resolution using the ultrasensitive Expanded Very Large Array (EVLA) at centimeter wavelengths and the Plateau de Bure interferometer (PdBI) at millimeter wavelengths.

2. DATA REDUCTION

Of the $\sim$40 FS CMa stars and candidate stars reported by Miroshnichenko (2007), only seven have good quality VLA observations (that could provide a noise of order a few tenths of a mJy and a possible detection at the mJy level). Of these seven stars, CI Cam and MWC 300 have been previously reported as radio sources. CI Cam is a high-mass X-ray binary that has been observed extensively with the VLA, in particular after its 1998 outburst (e.g., Mioduszewski & Rupen 2004). MWC 300 has been observed on one occasion (1990 Feb 11) by Skinner, Brown, & Stewart (1993), who detected it with a flux density of 0.49 ± 0.03 mJy at 3.6 cm.
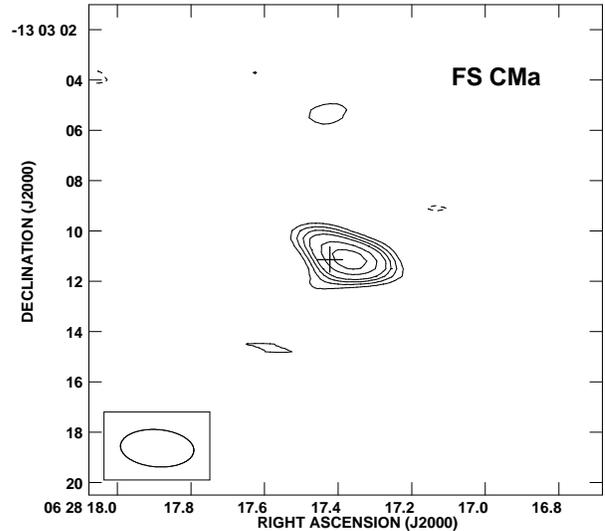
Fig. 1. VLA contour image of the 1.3-cm continuum emission toward FS CMa. Contours are -3, 3, 4, 5, 6, 8, and 10 times 0.36 mJy, the rms noise of the image. The synthesized beam, shown in the bottom left corner, has half power full width dimensions of $2\rlap{.}''92 \times 1\rlap{.}''48$, with the major axis at a position angle of $+86°$. The cross marks the optical position of FS CMa from Perryman et al. (1997).

The remaining five stars are listed in Table 1, with the parameters of their archive VLA observations. The archive data from the Very Large Array (VLA) of the NRAO were edited and calibrated using the software package Astronomical Image Processing System (AIPS) of NRAO.

3. DISCUSSION ON INDIVIDUAL SOURCES

For the stars MWC 819 and V669 Cep only upper limits were obtained. However, the other three stars,

TABLE 2

FLUX DENSITIES OF 0607-085 AND FS CMA
FOR 1997 SEPTEMBER 26

Frequency (GHz)	Flux Density 0607-085(Jy)[a]	Flux Density FS CMa(mJy)
4.86	2.424±0.004	0.87±0.05
8.46	2.240±0.008	1.46±0.03
14.94	2.051±0.024	2.71±0.12
22.46	1.776±0.036	4.21±0.36
43.34	2.551±0.210	8.60±1.43

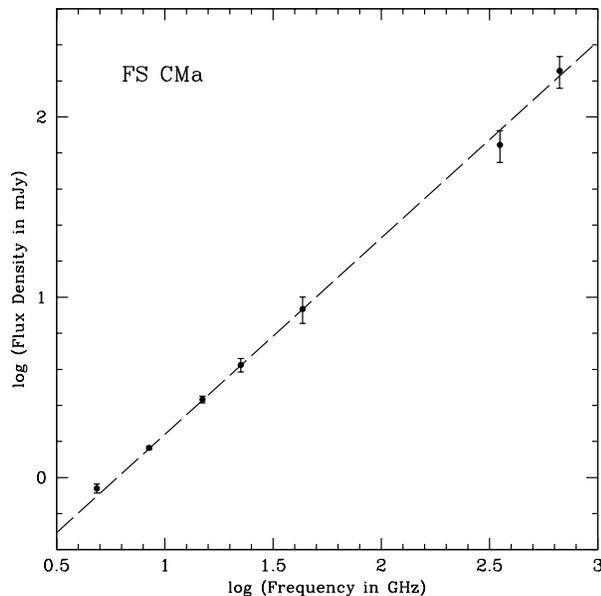[a]The phase calibrator for all observations was 0607-085.

Fig. 2. Radio spectrum of the star FS CMa. The five lower frequency data points are reported here while the two higher frequency data points are from Di Francesco et al. (2008). The dashed line marks the least-squares best fit to the data, given by $(S_\nu/\mathrm{mJy}) = 0.141 \pm 0.020 \; (\nu/\mathrm{GHz})^{1.09\pm0.03}$.

FS CMa, MWC 922, and AS 381 have associated radio continuum emission and we discuss them in what follows.

3.1. FS CMa

This star is the prototype of the class and we find it is associated with a radio continuum source (see Figure 1). This source was observed at 6.0, 3.6, 2.0, 1.3 and 0.7 cm in the same observing session (1997 September 26) and the observed flux densities are given in Table 2. Di Francesco et al. (2008) re-
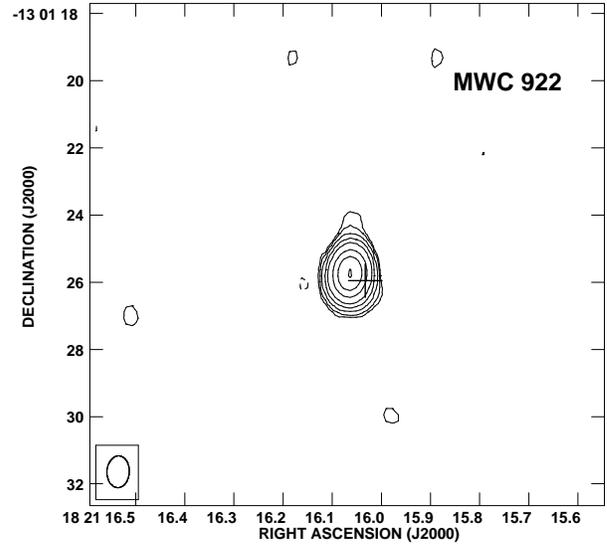

Fig. 3. VLA contour image of the 3.6-cm continuum emission toward MWC 922. Contours are −3, 3, 5, 10, 20, 40, 100, 200, and 400 times 24 μJy, the rms noise of the image. The synthesized beam, shown in the bottom left corner, has half power full width dimensions of $0.''95 \times 0.''66$, with the major axis at a position angle of $-3°$. The cross marks the position of MWC 922 derived from the average of the 2MASS H, J and K images.

port flux densities for FS CMa of 0.070±0.014 and 0.180±0.036 Jy at 850 and 450 μm, respectively. These seven data points allow the analysis of its spectrum as shown in Figure 2. Remarkably, the spectrum is well described over two decades of frequency by a power-law of the form

$$\left[\frac{S_\nu}{\mathrm{mJy}}\right] = (0.141 \pm 0.020)\left[\frac{\nu}{\mathrm{GHz}}\right]^{1.09\pm0.03}.$$

This spectral index is consistent with partially optically-thick free-free emission. It is significantly steeper than the spectrum from ionized winds expanding at constant velocity, which behaves as $S_\nu \propto \nu^{0.6}$ (i.e. Panagia & Felli 1975). The Herbig B[e] star MWC 297 (Cidale, Zorec, & Morrell 2000) also shows a spectral index of ~1 from the radio to the sub-mm (Sandell, Weintraub, & Hamidouche 2011). A spectral index of the order of 1 is also frequently found in hypercompact H II regions (Ignace & Churchwell 2004). This departure from the expected value of 0.6 most probably indicates that the outflow has velocity, temperature, or ionization fraction gradients with radius. For example, assuming a constant velocity and electron temperature in the outflow and following Olnon (1975) and Panagia & Felli (1975), the observed spectral index of ~1.1 implies an elec-
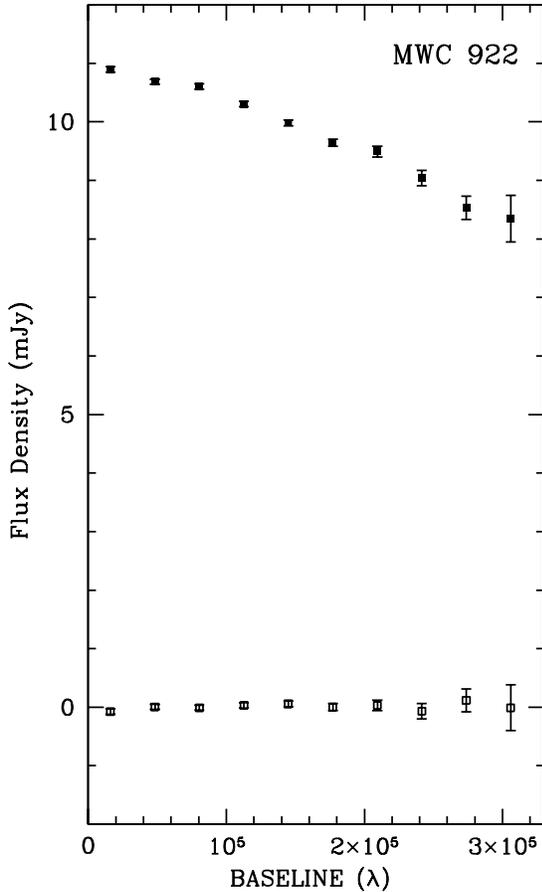
Fig. 4. Real (filled squares) and imaginary (empty squares) components (given in mJy) of the emission from MWC 922 at 8.46 GHz as a function of baseline (given in wavelengths). The real component decreases with increasing baseline, indicating that the source is slightly resolved in these observations. The imaginary component is consistent with zero, indicating that the source is symmetric about the phase center (the origin of the visibility plane) and has no significant structure on these spatial scales.

tron density gradient of $n_e \propto r^{-2.8}$, steeper than the gradient of $n_e \propto r^{-2.0}$ expected for a constant ionization fraction.

3.2. *MWC 922*

The radio source associated with this star (Figure 3) is quite bright at 3.6 cm. Unfortunately, there are no observations at other frequencies that could allow the determination of its spectral index. The source is angularly resolved, as can be seen in the behavior of its amplitude as a function of baseline (Figure 4). Analysis of the source with the task JMFIT of AIPS gives deconvolved dimensions of
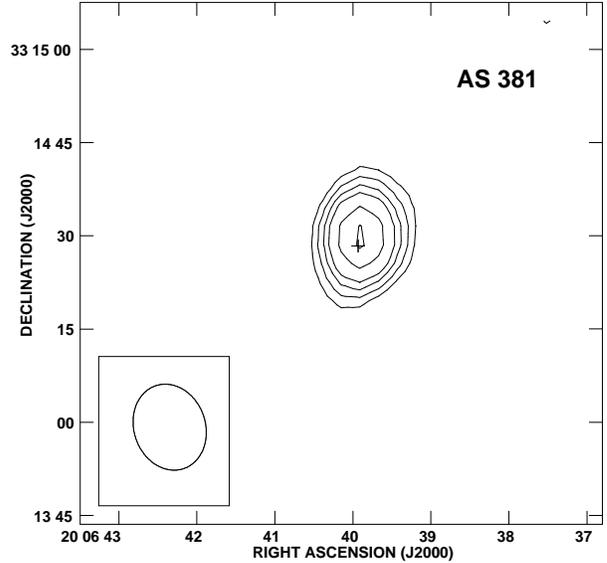

Fig. 5. VLA contour image of the 20-cm continuum emission toward AS 381. Contours are −3, 3, 4, 5, 6, 8, and 10 times 0.32 mJy, the rms noise of the image. The synthesized beam, shown in the bottom left corner, has half power full width dimensions of $14''1 \times 11''5$, with the major axis at a position angle of $+19°$. The cross marks the position of AS 381 derived from the average of the 2MASS H, J and K images.

$0''28 \pm 0''0.01 \times 0''20 \pm 0''0.01$ with a position angle of $169° \pm 7°$. From the measured flux density and these angular dimensions, we obtain a brightness temperature of $\sim 3.3 \times 10^4$ K, suggestive of partially optically thick free-free emission from photoionized gas.

Recently, Tuthill & Lloyd (2007) reported the detection of a biconical "Red Square" nebula surrounding MWC 922 in the near-infrared. This nebula extends for about $5''$. The radio continuum emission probably traces the very inner part of this structure.

3.3. *AS 381*

AS 381 is a binary system with a spectrum that indicates the presence of both a hot (early B-type) star and a cool (K-type) star (Miroshnichenko et al. 2002). Of the three stars with radio continuum reported here, this is the only one whose membership is under debate since it has also been proposed as a possible galactic supergiant candidate (sgB[e]; Miroshnichenko 2007). The characteristics of AS 381 allow to classify it as an evolved object with an initial mass of about 20 solar masses (Miroshnichenko et al. 2002).

As can be seen in Figure 5, this source is angularly unresolved, but given the modest angular reso-

lution of the observations ($\sim 13''$) this does not provide additional information.

4. CONCLUSIONS

Using VLA archive data, we report the detection of radio continuum emission toward three FS CMa stars: FS CMa, MWC 922, and AS 381. Given that we only found good quality data for five stars, these results suggest that detectable radio continuum emission could be common in FS CMa stars.

In the case of FS CMa, we combined the VLA data with JCMT/SCUBA observations to show that its radio continuum spectrum is well described by a single power law over two decades in frequency.

Although the data do not have sufficient frequency coverage and angular resolution to provide important new insight into this type of stars, the flux densities detected are relatively high and will allow in the future a detailed radio study of the spectrum and morphology of the sources.

REFERENCES

Borges Fernandes, M. 2010, RevMexAA (SC), 38, 98
Cidale, L., Zorec, J., & Morrell, N. 2000, ASP Conf. Ser. 214, The Be Phenomenon in Early-Type Stars, ed. M. A. Smith, H. F. Henrichs, & J. Fabregat (San Francisco: ASP), 472
Cutri, R. M., et al. 2003, The IRSA 2MASS All-Sky Point Source Catalog of Point Sources, NASA/IPAC Infrared Science Archive
Di Francesco, J., Johnstone, D., Kirk, H., MacKenzie, T., & Ledwosinska, E. 2008, ApJS, 175, 277
Høg, E., et al. 2000, A&A, 355, L27
Ignace, R., & Churchwell, E. 2004, ApJ, 610, 351
Mioduszewski, A. J., & Rupen, M. P. 2004, ApJ, 615, 432
Miroshnichenko, A. S. 2007, ApJ, 667, 497
Miroshnichenko, A. S., et al. 2002, A&A, 383, 171
Olnon, F. M. 1975, A&A, 39, 217
Panagia, N., & Felli, M. 1975, A&A, 39, 1
Perryman, M. A. C., et al. 1997, A&A, 323, L49
Sandell, G., Weintraub, D. A., & Hamidouche, M. 2011, ApJ, 727, 26
Skinner, S. L., Brown, A., & Stewart, R. T. 1993, ApJS, 87, 217
Tuthill, P. G., & Lloyd, J. P. 2007, Science, 316, 247

Luis F. Rodríguez: Centro de Radiostronomía y Astrofísica, Universidad Nacional Autónoma de México, Apdo. Postal 3-72, (Xangari), 58089 Morelia, Michoacán, Mexico (l.rodriguez@crya.unam.mx).
Alejandro Báez-Rubio: Centro de Astrobiología (CSIC/INTA), Ctra. de Torrejón a Ajalvir km 4, 28850 Torrejón de Ardoz, Madrid, Spain (baezra@cab.inta-csic.es).
Anatoly S. Miroshnichenko: Department of Physics and Astronomy, University of North Carolina, Greensboro, NC 27402 USA (a_mirosh@uncg.edu).