On the resolved radio emission from AG Draconis: evidence for jet ejection?

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1 INTRODUCTION

AG Dra is the well-studied symbiotic binary consisting of a high-velocity, metal-poor, bright K-type giant and a hot white dwarf companion (e.g. Mikołajewska et al. 1995; Smith et al. 1996). The binary system has an orbital period of 549 days and a well-defined spectroscopic orbit (Fekel et al. 2001, and references therein). AG Dra is also among the most active symbiotic stars. Its optical light curve is characterized by a series of active (outbursts) and quiescent phases (e.g., Fig. 7 of Gális et al. 1999). Although the activity of AG Dra, and other classical symbiotic stars is still poorly understood, multifrequency observations covering a few whole activity cycles indicate that in AG Dra this activity is related to changes of both radius and temperature of the hot component (e.g. Mikołajewska et al. 1995; Greiner et al. 1997).

AG Dra is also one of 10 known galactic supersoft X-ray sources (Greiner et al. 1997).

Recently, the star has been searched, together with all the northern supersoft X-ray sources, for radio emission at 5 and 8.4 GHz (Ogley et al. 2002, hereafter O02). The observations by MERLIN telescope have confirmed previous VLA detections. Moreover, the source has been resolved at the milliarcsec scale into two components of nearly equal brightness, and combined flux of ∼1 mJy. O02 have also studied possible interpretations of this emission in terms of a wind environment from either the cool giant or the hot white dwarf. They have concluded that all their scenarios give the radio emission fluxes an order of amplitude lower than the observed value.

In the following we reanalyze a possible origin of the resolved radio emission from various wind environment, and show that it presumably arises from jet(s) ejected from the hot component during its recent series of outbursts.

2 RADIO EMISSION FROM AG DRA

2.1 Spherically symmetric steady outflow

We point out here that O02 have adopted unreasonably low values for both the cool giant wind and the hot component luminosity in their analysis. Below in this section, we provide a critical analysis of their assumptions and calculations.

The wind environment of AG Dra has been discussed in several papers, and estimates for the mass loss from both components are available. All these estimates have been based on the assumption of an isothermal, spherically symmetric steady flow. In particular, the mm-submm radio spectrum and K − [12] colour excess are both consistent with the cool giant mass-loss rate, $\dot{M}_g/v \sim 2.5 \times 10^{-8} (d/2.5 \text{ kpc})^{1/2} M_\odot \text{ yr}^{-1} / (\text{km s}^{-1})$ (Mikołajewska, Ivison & Omont 2002; Kenyon 1988), whereas the UV continuum and emission line analysis (Müri et al. 1991) gave $\dot{M}_g/v \gtrsim 4 \times 10^{-8} (d/2.5 \text{ kpc}) M_\odot \text{ yr}^{-1} / (\text{km s}^{-1})$, in all cases values two orders of magnitude larger than $\dot{M}_g/v \sim 5 \times 10^{-10} M_\odot \text{ yr}^{-1} / (\text{km s}^{-1})$ adopted by O02. Using the Wright & Barlow (1975) formula for completely ionized wind, the first estimate above gives a flux at 5 GHz of ∼0.5 mJy independent of the adopted distance. Thus, the cool component wind could, in principle, account for the observed intensity of the radio emission but not for the double structure.

We also find an error in the value of irradiation luminosity adopted by O02 in their estimate for the mass loss rate in the cool giant due to irradiation by its hot companion, $L_\text{h} = 1.4 \times 10^{36} \text{ erg s}^{-1}$ (or $L_{30} = 0.14$ in units of $10^{30} \text{ J s}^{-1}$; their Eq. (3) and Table 2). This error apparently stems from a mistake in rescaling results of Greiner (2000) to $d = 1.7 \text{ kpc}$ used by O02. The rescaling gives in fact $L_{30} = 0.44$. Using Eq.(3) of O02 with more realistic values, namely $L_{30} \sim 1$
Table 1. History of radio observations of AG Dra

| JD      | Frequency | Flux  | Reference |
|---------|-----------|-------|-----------|
| 2400000+| [GHz]     | [mJy] |           |
| 45006   | 4.9       | < 0.41| ST90      |
| 46515   | 4.9       | 0.60 ± 0.21 | ST90     |
| 46611   | 4.9       | ≥ 0.5  | TC87      |
| 46646   | 4.9       | 0.36 ± 0.08| ST90     |
| 46646   | 14.9      | 0.77 ± 0.23| ST90     |
| 48290   | 8.3       | < 0.17 | SKT93     |
| 51622-30| 5.0       | ~ 1    | O02       |

ST90 – Seaquist & Taylor 1990; SKT93 – Seaguist et al. 1993; TC87 – Torbett & Campbell 1987.

(e.g. Greiner et al. 1997), \( r_2 \sim 80 \, R_\odot \), and \( d \sim 2.5 \, \text{kpc} \) (Miko\l ajewska et al. 1995), we find the mass loss rate for the evaporated wind, \( M_k \sim 1.2 \times 10^{-7} \, \text{M}_\odot \, \text{yr}^{-1} \), and the predicted quiescent 5 GHz flux of \( \sim 0.1 \, (d/2.5 \, \text{kpc})^{-2/3} \, \text{mJy} \). This radio flux can be further increased by increasing the hot component luminosity (e.g. Miko\l ajewska et al. 1995) found an order of magnitude increase in \( L_h \) due to activity, however, this model still does not account for the double source structure.

Concluding this section, the resolved radio emission from AG Dra detected by MERLIN cannot be interpreted in terms of the spherically symmetric steady wind from the cool giant. We note, however, that the Hipparcos position of AG Dra (Perryman et al. 1997) practically coincides with that of the N1 component in the MERLIN image. This indicates that the N1 component can, in principle, originate in the cool giant wind.

2.2 Episodic flow

The active phases of AG Dra are characterized by an increase of the emission line widths and marked P Cyg structure of high ionization UV lines (e.g. N \( \text{v} \)), which indicate outflow velocities of 200–300 km s\(^{-1}\) (Miko\l ajewska et al. 1995, and references therein), while the optical He II and H \( \text{I} \) Balmer lines develop broad emission wings (e.g. Tomova & Tomov 1999). This behaviour suggests that the hot component develops a significant wind in outburst. Tomova & Tomov (1999) estimated the wind velocity of \( \sim 800 \, \text{km s}^{-1} \) and the mass loss rate of \( \sim 2 \times 10^{-7} \, \text{M}_\odot \, \text{yr}^{-1} \) from the broad wings of H\( \alpha \) and H\( \beta \) profiles observed during the 1995 outburst. Their estimate made use of the distance-dependent estimate for the hot component radius of Miko\l ajewska et al. (1995), and thus it corresponds to \( d \approx 2.5 \, \text{kpc} \). It was also based on the assumption of the spherically symmetric steady wind which is probably not true for the hot component wind developed during the outburst. Anyway, applying the Wright & Barlow formula (1975), such a wind should give rise to the radio flux of \( \sim 5 \, \mu \text{Jy} \) at 5 GHz, again much lower than the flux observed by O02.

Although only a few attempts have been made to observe AG Dra at radio wavelengths, it seems that the radio emission may be variable, and possibly related to the hot component activity (Table 1). AG Dra was not detected at 4.9 GHz on JD 2 445 006 (Seaquist & Taylor 1990) when the star was at maximum of a large eruption (see the light curves in Miko\l ajewska et al. 1995, and Gális et al. 1999), whereas it was detected at 3 epochs (Torbett & Campbell 1987; Seaquist & Taylor 1990) during less pronounced burst and its decline a few years later. It is particularly important that AG Dra was not detected on JD 2 448 290, when the star was in quiescent phase, by the highly sensitive VLA survey at 8.3 GHz (Seaquist et al. 1993), and the 3 \( \sigma \) upper limit for the 8.3 GHz flux of \( \leq 0.17 \, \text{mJy} \) was much lower than the 5 GHz fluxes of any of the two radio components detected by O02.

The hot component entered another large outburst in 1995, which was followed by a series of more or less prominent bursts of activity till at least the end of 1999. It is interesting that there are two kinds of outbursts: stronger, cool outbursts during which the hot component temperature decreases, and fainter, hot outbursts during which it increases (González-Riestra et al. 1999; Miko\l ajewska et al. 1995). The temperature decrease during the strong cool outbursts is very likely due to slow expansion of the hot component to about 2–3 times its original size (Miko\l ajewska et al. 1995; Greiner et al. 1997) and possible development of an optically thick wind. All the previous radio detections were made during hot outbursts. Moreover, in 1997 and 1998, AG Dra was detected at 1.3 and 0.85 mm by the IRAM and JMCT telescopes, respectively (Miko\l ajewska et al. 2002). At the time of both detections AG Dra was at the hot activity stage.

The fact that the radio emission is resolved into two compact components raises an interesting possibility that it originates in jets ejected from AG Dra. Bipolar jets have been detected in a few symbiotic systems, e.g. in V694 Mon, CH Cyg, Hen 3-1341 and STHA 190 (Belczyński et al. 2000, and references therein; Tomov, Munari & Maresse 2000; Munari et al. 2001), and in all cases they have been associated with the hot component outbursts and an appearance of a high-velocity stellar wind. A relation between the radio emission and the hot component activity stage has been also found in another symbiotic binary, CI Cyg. The cm-submm spectrum of CI Cyg is inconsistent with predictions of any model involving spherically symmetric wind(s), and the radio emission most likely originates from a bipolar outflow (Miko\l ajewska & Ivison 2001).

Figure 1 shows the relationship between the binary geometry and the resolved MERLIN image of AG Dra. From the data in Table 1 of O02, we have estimated a separation of the components, \( \alpha \sim 0.4 \pm 0.1 \, \text{arcsec} \), and a position angle of the whole structure, \( PA_{\text{rad}} \approx 35 \pm 20 ^\circ \). From spectropolarimetry we know the binary orbit orientation, \( \Omega = 150 \pm 20 ^\circ \), as well as the orbit inclination, \( i = 120 \pm 20 ^\circ \) (Schmid & Schilt 1997). Thus the two radio components are within the observational errors aligned.

\(^1\) Parenthetically, we also point out that the values of \( d = 1.7 \, \text{kpc} \) and \( r_2 = 30 \, \text{R}_\odot \), adopted by O02 from Tomov, Tomova & Ivanova (2000) are mutually inconsistent given the observed near IR magnitudes, colours and spectral classification of the giant. Namely, if we accept \( r_2 = 30 \, \text{R}_\odot \), we obtain (using the Barnes-Evans relation, Cahn 1980, with the surface brightness appropriate for a mid K-type giant and the observed \( K \approx 6.2 \), e.g. Belczyński et al. 2000) \( d \approx 1 \, \text{kpc} \), even more discrepant with our preferred value of \( d = 2.5 \, \text{kpc} \).
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3 CONCLUSIONS

The major results and conclusions of this paper can be summarised as follows:

(i) The radio emission from the symbiotic binary AG Dra seems to be variable, and probably related to the hot component activity.

(ii) The cool component wind can, in principle, account for the intensity of the N1 component (O02), which position practically coincides with the Hipparcos position of AG Dra.

(iii) The two radio components resolved by MERLIN (O02) are practically aligned with the binary axis of AG Dra. The possible extended radio emission reported by Torbett & Campbell (1987) has similar orientation. The resolved radio emission presumably originates in jets ejected from the binary system.

(iv) Assuming that the jet velocity is of order of the escape velocity of the hot component, the separation between the two radio sources indicates that the ejection took place \( \sim 3\) yr earlier, and it was associated with the recent series of outbursts.

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