FOUR YEARS OF MONITORING α ORIONIS WITH THE VLA: WHERE HAVE ALL THE FLARES GONE?

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ABSTRACT We observed this prototypical M supergiant using the VLA at centimeter wavelengths about once a month over a 4-year period from July 1986 to September 1990, resulting in a cumulative exposure time of about 120 hours. There is no evidence for radio flaring at any of the observing wavelengths. Low-level variability (≤ 25%) does appear to be present at the shorter wavelengths (2 and 3.6 cm) and may be also occurring at 6 cm, and is usually in the form of temporary decreases of the radio flux densities from their usual levels. The timescale for these radio dips is not well-determined by the present data set, but significant variability on a a timescale of ≤ 1 month is observed on occasion. There is no correlation between the variations observed at the different wavelengths.

Keywords: radio continuum observations; stellar winds and chromospheres; red supergiants

INTRODUCTION

One of the nearest M supergiants to the Sun is α Orionis (M1-2 Ia-Iab; D = 190 pc). It has been known for a number of years to be a centimeter radio source at the 1 to 10 mJy level, with a spectral index α ~ 1.32, where Sν ~ να (Newell and Hjellming 1982). Its radio continuum emission has been generally, but not universally, interpreted as free-free emission from the ionized component (~ 1%) of their stellar winds; however, the standard stellar wind models for radio emission (Wright and Barlow 1975) as have been extensively applied to
hot stars, predict a spectral index of $\alpha = 0.6$, that is much less than this observed value. The observed spectrum can be interpreted as being due to a steeper drop-off in ionized density than the standard $r^{-2}$ form: this, in turn, could be due to an accelerating stellar wind velocity or a decreasing ionization fraction with increasing radial distance from the star.

Newell and Hjellming (1982) gathered all the then-available radio data on $\alpha$ Ori - both single-dish and interferometric - to examine whether there was believable evidence for variability. They pointed out that most pre-VLA data on $\alpha$ Ori fitted with their VLA spectrum, but that 2 observations in 1977 and 1978 at 1.3 and 2 cm were a factor of 2 below ‘normal’ and that 2 measures at 2 and 2.8 cm were 12 to 50 times above the normal level, indicating that radio flaring may have occurred. They interpreted the below-normal measures as being most likely due to calibration errors in these single-dish observations.

From July 1986 to September 1990 we monitored $\alpha$ Ori at centimeter wavelengths using the VLA in order to confirm whether or not this variability is indeed intrinsic to $\alpha$ Ori, and, if so, whether such variability is periodic or irregular in nature and what the characteristic timescales $T_{\text{var}}$ for radio variability are. The radio observations were typically made at 1-month intervals, except during the third quarter of 1986 when the supposed periastron passage of the postulated close binary companion discovered by interferometry (Karovska et al. 1986) occurred, when the observations were made at roughly 2-week intervals. The initial sets of observations were made at 2 and 6 cm only: commencing in early 1988 regular observations were also made at 3.6 cm. Occasional measurements were also made at 1.3 and 20 cm. All data were reduced using standard NRAO software and procedures, and the flux densities were measured using AIPS tasks IMFIT and JMFIT, being generally taken to be the average of the peak and integrated values.

RESULTS AND DISCUSSION

About 90% of the radio observations have now been reduced. The average spectrum that can be constructed from these data is $S_\nu = 0.26$ mJy $\nu^{1.26}$, compared to $S_\nu = 0.23$ mJy $\nu^{1.33}$ found by Newell and Hjellming (1982), i.e., essentially the same. We note that, if we extrapolate our power law spectral fit to the mm region, we predict fluxes at 86 and 226 GHz of 72.5 and 246 mJy, respectively, compared to measured flux densities of 72.8 $\pm$ 5.5 and 353 $\pm$ 51 mJy (Altenhoff et al. 1986); thus, there is weak (2$\sigma$) evidence that the spectrum steepens between 86 and 226 GHz, but this should be confirmed by repeating the higher frequency measurement with a higher signal-to-noise.

The evidence for variability is strongest at 2 and 3.6 cm, where the standard deviations (s.d.) about the mean values are 6 and 7 times, respectively, the typical estimated rms errors of 0.16 mJy (2 cm) and 0.05 mJy (3.6 cm), while at 6 cm the s.d. is 0.16 mJy or 2.5 the typical rms error of a single measurement. At 2 cm, however, part of the apparent variability may be due to systematic errors: a combination of partial source resolution and bad atmospheric phases affecting the measurements in the A and B configurations, since the average 2-cm flux density in these arrays is only 89% of the average value found in the more compact C and D configurations, and the standard deviation of the A and B array measurements is 1.05 mJy compared to 0.61 mJy for the s.d. of the
C and D configurations. No such array-dependent effects are seen at 3.6 (or 6) cm, and thus the X-band (and possibly C-band) variations are almost certainly intrinsic to α Orionis.

There is no evidence for radio flaring (i.e., increases in flux density by large \( \geq 2 \) amounts) at any wavelength at any epoch! At 6 cm, the maximum flux density \( S_{\nu}^{\text{max}} \) measured is 22% above the mean, at 3.6 cm, \( S_{\nu}^{\text{max}} \) is 15% above the mean, and at 2 cm \( S_{\nu}^{\text{max}} \) is 21% above the mean value. This does not disprove the reality of the two radio ‘flares’ of α Ori observed in 1966 that involved increases in flux density of 1 or 2 orders of magnitude, but indicates that such events must be very rare, if real, and that even minor flares are very uncommon. As far as the postulated close companion is concerned, there is no evidence that the radio emission was enhanced during its proposed periastron in the summer of 1986, as might be expected by analogy with the radio properties of known interacting binaries. Thus, any increase in the volume and/or fraction of ionized material in the inner wind of the red supergiant primary due to the passage of this companion is apparently negligible.

The main type of variability seems to be small fluctuations about the mean levels, with drops to below-normal values slightly predominating. This behaviour is also apparent in the smaller and more inhomogeneous dataset assembled by Newell and Hjellming (1982). Clearly in A and B configurations poor phases and/or partial resolution of the source have sometimes led us to estimate the 2-cm flux density of α Ori by \( \sim 10\% \), but such effects are not evident at the longer wavelengths, and the apparent variability at 3.6 cm and (perhaps) 6 cm thus seems to be mostly intrinsic to the star.

The variability appears to be stochastic, there is no correlation between variations at different wavelengths (not surprising since the radio emission at different wavelengths comes from physically separated regions in the star’s wind), and a variety of different timescales appear to be present ranging from several months down to \(<1\) month (our sampling interval). A possible explanation for this behaviour given in Bookbinder et al. (1987) invokes the molecular catastrophe scenario of Muchmore et al. (1987): this hypothesis is explored in more detail in Drake et al. (1992).

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REFERENCES


