RADIO OBSERVATIONS OF WEAK-LINED T TAURI STARS

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ABSTRACT  We report the results of a search for radio-continuum emission from weak-lined T Tauri stars selected on the basis of a range of criteria. A correlation is found with strong X-ray emission and with youth. All the stars in the survey older than about 20 million years were not detected as radio sources. A flare was seen on one of the survey targets, with a rise time of several hours. Circular polarization was also seen in two of the targets, providing the first direct confirmation of the presence of magnetic fields on these stars.

1. THE SURVEY

Weak-lined T Tauri stars are low-mass pre-main-sequence stars which do not have the strong Hα emission line of classical T Tauri stars. They are known to be strong X-ray sources, and display solar-like activity thought to be characteristic of PMS stars. PMS stars probably spend a significant fraction of their contraction time in this state.

In this survey we look for continuum radio emission among samples of these stars chosen on the basis of a number of criteria. Many of these stars are already known to be radio sources (Bieging et al. 1984; Kutner et al. 1986; André et al. 1987; Stine et al. 1988; O’Neal et al. 1990). Rather than trying to completely sample the population of PMS stars in a young star-forming region, as most previous surveys have done, our survey was intended to try to identify a number of new sources suitable for further study of the nature of radio emission from these stars. We therefore chose most of the targets on the basis of known high activity levels, and particularly of strong X-ray fluxes. For comparison we included a number of stars known to be radio sources from the observations described above. However, we also included 8 targets chosen because they are late-type stars occurring in visual binaries with an early-type primary, and are therefore likely to be young stars. Such PMS stars, which are away from star forming regions, have not previously been studied in radio observations, and we feel it would be of interest to compare their radio properties with those of other PMS stars in the survey. The observations were carried out at 5 GHz with the Very Large Array in “A”-configuration, on 1990 Feb. 18 and 19. The typical 3σ detection threshold was 0.12 mJy. In the following subsections we describe the survey results.
Visual binaries with a young early-type primary. We observed 9 stars in this class: 8 chosen from Lindroos (1986), plus HD 28867 from Walter et al. (1988). Nearly all the targets from Lindroos (1986) consist of a late-type B dwarf and an F, G or K dwarf; all are in wide binaries, ensuring that the two components have evolved independently and are not Algol systems. From the large list in Lindroos (1986) we choose a small sample to include some of the closest of the Lindroos (1986) stars, with distances ranging from 23 to 157 pc. We also selected on the basis of other indicators of youth and/or activity. The primaries in all these systems should not have strong winds and are unlikely to be radio sources, and indeed none were detected. None of the eight young-dwarf companions from Lindroos (1986) were detected. The only detection in this category is HD 28867, which was chosen on the basis of its X-ray flux (Walter et al. 1988). Both known components of HD 28867 are probably B stars. Normal main-sequence single B dwarf stars are not generally detected as radio sources. We believe that either HD 28867 is a Herbig Be star, or that there is an undiscovered pre-main-sequence component in the system which produces the radio emission.

Post T Tauri candidates from the original list by Herbig (1978). Three were observed, and two (V410 Tau and HD 283447, both in Taurus–Auriga) were detected. Both are short-period spotted stars (1.9 days for V410 Tau, 3.4 days for HD 283447) and had been previously detected as radio sources, and both are known to be variable. The distant K binary FK Ser was not detected, although it is otherwise known as a very active star.

Naked T Tauri candidates in Taurus–Auriga. We observed 12 sources identified as X-ray sources by Walter et al. (1988), ranging in spectral type from G5 to M0, with most being K stars. Their X-ray luminosities range from $10^{29.6}$ to $10^{31.3}$ ergs s$^{-1}$. We detected 5 of the 12 targets: the rapidly-rotating G star HDE 283572 (period 1.5 days), the spectroscopic K binary V826 Tau (period 3.9 days); and three stars previously undetected as radio sources, the M2 star 040234+2143, the K5 star 045226+3013 and the K7 star 045251+3016.

Post T Tauri candidates in Ophiuchus. We observed Oph 1 – 4, identified in an X-ray survey of Ophiuchus by Walter (1986), and detected all four stars at fluxes of 0.2 – 0.6 mJy. Oph 1 – 3 are early K-type stars with strong Lithium absorption, and with a Strontium line indicating subgiant luminosity class. Given the results of the rest of the survey, it is remarkable that all four of these stars should prove to be radio sources, when they seem otherwise undistinguished.

Known radio-emitting weak-lined T Tauri’s in ρ Ophiuchi. We observed the well-known radio star DoAr 21, as well as three X-ray-selected targets known to be radio sources: ROX 31, ROX 39 and a source near ROX 43 (Stine et al. 1988). We detected sources near the center of all four fields, but find that the ROX 43 source (which is about 40″ away from the original stellar candidate for the optical counterpart to the X-ray source; the star was not detected) is an extended jet source, and therefore confirm the speculation by Stine et al. (1988) that it is probably extragalactic.
2. FLARES AND CIRCULAR POLARIZATION

Previous radio observations of the weak-lined T Tauri stars have not detected circular polarization. This has been regarded as peculiar, since the activity on these stars seems to be magnetic (i.e., solar-like) in nature, and on all other classes of stars which show similar activity (e.g., the RS CVn binaries and the dMe dwarfs), circularly-polarized radio emission has been detected. We have now detected circular polarization in the radio emission of the two strongest radio sources amongst our sample of weak-lined T Tauri stars. This is direct confirmation of the presence of magnetic fields in the coronae of these stars. The degree of polarization is small ($\sim 2 - 4\%$), consistent with previous observations which did not find measurable polarization.

We also saw a flare on one of our targets (HD 283447), which rose in flux by a factor of about eight in three hours. This is one of the few reported radio flares from this class of stars, although variability on timescales longer than weeks is well-established. The timescale is relatively long for stellar flares, and suggests a large source size. It is well established that the radio emission from WTT stars must be nonthermal, and VLBI observations have now directly confirmed this (Phillips, Lonsdale and Feigelson 1991). The presence of circular polarization confirms that the emission mechanism must be nonthermal gyrosynchrotron emission; this can be optically thick or optically thin.

There is some evidence on the spectrum of the radio emission, at least for those stars which seem to be in outburst. We deduced a spectral index of $+0.8$ at 5 GHz for the radio emission from our strongest source by comparing the upper and lower sidebands, and values of $+0.5$ to $+1.2$ seem to be characteristic (Feigelson and Montmerle 1985; Bieging et al. 1984; Garay et al. 1987). This suggests optically thick emission, in which case the rise time can be interpreted as associated with the expansion of an optically thick source.

3. DISCUSSION

We have detected 15 of the 32 targets in our survey, including 8 new detections but excluding one of the detected sources that appears to be extragalactic. Altogether some 22 weak-lined T Tauri stars are now known as radio sources: the 14 detected here (excluding HD 28867), plus Parenago 1910 (MT Ori) and 1925 in Orion, HP Tau/G2 and HP Tau/G3, Herbig's Anon 1, Hubble 4, and Elias 12 in Taurus–Auiga, and probably AB Doradus. HD 28867 should be added to this list if the radio emission comes from an unseen late-type companion. Of the radio-detected WTT stars for which we can find spectral types (all except the Parenago stars in Orion), 3 are G stars, 15 are K stars and 2 are M stars. Most known Hα–emission stars in star–forming regions are of late-K spectral type (Cohen and Kuhf 1979) and the distribution of radio stars amongst spectral type appears consistent with this.

Our survey is not complete in any sense, since it was biased in favour of stars already known to be active optically, in X-rays, or in radio. However, we can do some simple comparisons between the stars detected in our survey and those
which were not. The mean log of the X-ray flux (ergs s$^{-1}$) of the detected stars was $30.5 \pm 0.5$ (sample of 13), compared with $30.2 \pm 0.4$ for the undetected stars. We have used the Student $t$ statistic for populations of unequal variance to test the significance of the difference between the two means, and find that there is only a 5% chance that the radio-detected and radio-undetected stars actually have the same distribution of X-ray fluxes.

Ages are given for the subsample of survey stars in the Taurus–Aurigae region by both Walter et al. (1988) and Skrutskie et al. (1990). Using the Walter et al. ages, we find that the mean log of the age of the detected stars was $6.0 \pm 0.3$, while that of the undetected stars was $6.5 \pm 0.6$. There is an 11% probability that these two means could arise in samples from a single distribution of ages. However if we use the Skrutskie et al. values we find that the mean log of the age of the detected stars was $6.2 \pm 0.3$, while that of the undetected stars was $6.8 \pm 0.4$; the probability that these two means come from samples from a single distribution of ages is only 0.5%. The Lindroos (1986) stars are nearly all much older than 20 million years, and our failure to detect any of them may be further evidence of an age effect. The survey results are discussed in detail by White et al. (1992a,b).

While most of the weak-lined T Tauri stars show little evidence for circumstellar material, others do. The most notable case is HD 283447, one of the most active nonthermal radio sources. While showing no evidence of an extended circumstellar Hα-emitting envelope of the type which characterizes classical T Tauri stars, it does have strong infrared and millimeter emission, indicating the presence of a dust disk around the star. However the disk is probably a considerable distance from the star, and need not interact with the nonthermal corona close to the star, whose existence is implied by the radio emission.

REFERENCES

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