RADIO EMISSION FROM *ROSAT* DISCOVERED YOUNG STARS IN AND AROUND TAURUS-AURIGA

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ABSTRACT. An 8.4 GHz VLA survey of 91 recently discovered lithium-rich late-type stars from the *ROSAT* All-Sky Survey and pointed observations is presented. These objects lie in the vicinity of the Taurus-Auriga star-forming region (d $\simeq$ 140 pc), however some are dispersed nearly 30° from known active star-forming cloud cores. This sample represents a spatially-complete, flux-limited population of X-ray bright young stars both within and away from the primary Tau-Aur stellar nurseries. Of the 91 sources, 29 are detected in this radio survey with a sensitivity limit of ~0.15 mJy. If they are at the distance of the star forming clouds, we find 32% of widely distributed young stars with $L_X \geq 5\times10^{28}$ ergs s^{-1} have radio luminosity densities in excess of 3.5×10^{15} erg s^{-1}Hz^{-1}. This detection rate, the ranges of radio and X-ray luminosities and L_R/L_X ratios are consistent with known young weak-lined T Tauri stars (ages $\sim 10^6$ yr) which reside *within* the Taurus molecular clouds, but is considerably higher than a zero-age main sequence population such as the Pleiades (age $\simeq 7\times10^7$ yr). The radio properties thus support the pre-main sequence classification of the stars. They roughly fit the empirical L_R vs. L_X relationship for active stars, implying that solar type gyro-synchrotron activity is the radio emission mechanism.

1. Introduction

Low mass pre-main sequence stars have long been known to produce strong and variable X-ray and radio emission. In nearby star forming regions, nonthermal radio emission has been detected in 10-30% of T Tauri stars. In Weak-lined T Tauri (WTT) stars both X-ray and radio emission are thought to be linked to the strong magnetic fields of T Tauri stars: X-rays from hot (10^7 K) plasma trapped in magnetic loops presumably anchored in the stellar photosphere, and radio waves from gyro-synchrotron emission produced by electrons spiraling in similar loop structures.

Recent data from the *ROSAT* All-Sky Survey (RASS) have revealed a population of lithium rich, X-ray bright stars up to 30 degrees distant from star forming clouds. These objects may be dispersed T Tauri stars of age $\sim$ 10 million years, or they may instead be zero age main sequence (ZAMS) stars of age $\sim$ 100 million years. The nature of these objects has important implications for galactic star formation and stellar evolution. Here we conduct a 3.6cm radio survey of a sample of 91 RASS stars in order to better classify them on the basis of their radio properties.

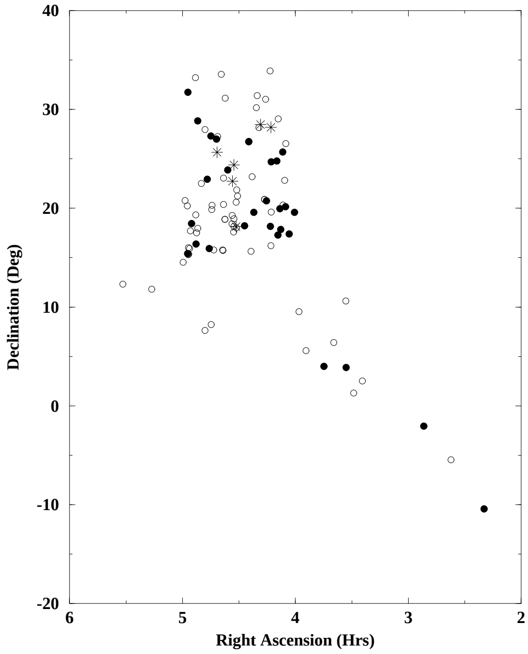

Fig. 1. Positions of T Tauri stars in and around the Taurus-Auriga region. Filled circles are radio detected sources, open circles are non-detections and asterisks (*) mark the locations of the six active star formation sites in Taurus-Auriga.

2. Sample, Observations and Results

Our sample consists of 91 lithium-rich ROSAT stars from recent studies of the Taurus-Auriga region (Neuhäuser *et al.* 1995 and Wichmann *et al.* 1996). Most of these stars are within a few degrees of active star forming clouds, but some are 20-30 degrees distant. The spatial distribution of our sample and the positions of the six active sites of star formation are shown in Figure 1.

The stars were observed in 89 fields with the Very Large Array (VLA) at 3.6cm in CnB configuration. Each field was observed for 14-15 minutes with a typical rms noise level of 50μJy. We detect 29 of 91 sources for a detection rate of 32%, which compares favorably with other surveys of T Tauri stars (e.g. O'Neal *et al.* 1990; Chiang *et al.* 1996). Detected flux levels range from 0.15-1.97 mJy or 3.5-46 $\times$ 10^{15} ergs s^{-1} Hz^{-1} if d=140pc.

3. Age

In order to better determine the age of our sample we have compared its L_X, L_R, and L_R/L_X distributions with those of known T Tauri stars, Pleiades ZAMS stars and active main sequence stars. The luminosity comparisons depend on the assumption of d = 140 pc for the RASS stars, while the luminosity ratio is independent of distance.

• **T Tauri Stars** We have compared our sample to the 3.6cm survey of 28 Taurus-Auriga T Tauri stars of Chiang *et al.* (1996). According to two-sample tests, the populations are compatible in L_X, L_R, and L_R/L_X at the P=80-90% level. The L_R/L_X comparison is shown in Figure 2.

• **Main Sequence Stars** We have used two different main sequence samples for comparison. The Pleiades are the best studied ZAMS cluster, yet only a few its members have been detected at radio wavelengths. Our comparisons with the Bastian, Dulk & Slee (1988) and Lim & White (1995) Pleiad samples produce a compatibility probability of P=1-2% (Figure 2).

We have also made a comparison to the active main sequence sample of Güdel (1992) and Güdel *et al.* (1995). These are nearby main sequence stars selected on the basis of strong coronal activity (including X-ray emission). On the basis of L_R, and L_R/L_X comparisons there is a compatibility probability of P<1% (Figure 2).

The current sample of Li-rich RASS-selected stars has X-ray and radio properties similar to non-dispersed Taurus-Auriga weak-lined T Tauri stars, but incompatible with Pleiades and magnetically active main sequence stars. The RASS sample is consistent with the ZAMS population only if one or more extreme conditions are met: (1) these objects are 2-3.5 times closer than 140 pc, which is inconsistent with observed X-ray hardness ratios and incompatible with the quantitative star formation model of Briceño *et al.* (1997); (2) magnetic activity in field ZAMS stars is qualitatively different than in open cluster ZAMS stars, producing more gyrosynchrotron emission per unit X-ray emitting plasma while surface rotation rate is far below that of Pleiad Ultra Fast Rotators; and/or (3) a large population of radio-luminous main sequence stars with $L_R \sim 10^{15} - 10^{16}$ ergs s^{-1} Hz^{-1} has escaped discovery despite considerable observational effort.

4. Emission Mechanism

If X-ray and radio emission both scale with magnetic flux emerging from the stellar surface, emission in the two bands should be correlated in stellar samples with a range of magnetic activity. A correlation between X-ray luminosity and radio luminosity has been shown to exist for a wide variety of active stars (Benz & Güdel 1994). Our sample is roughly consistent with the empirical relationship for stellar solar-type magnetic activity from Benz & Güdel (1994), and indicates that the mechanism for radio and X-ray emission is enhanced solar-type magnetic activity. The RASS stars may be overluminous at radio wavelengths for their levels of X-ray emission.

5. Conclusions

• We have detected 29 of 91 (32%) young X-ray emitting stars in and around the Taurus-Auriga region at 3.6cm. This is a significant increase in the number of known radio emitting young stars.

• We have compared our sample with other stellar groups in order to better quantify its age. Two-sample statistical tests of the radio luminosity functions and the distance-independent L_R/L_X ratios indicate that our sample and non-dispersed T Tauri stars

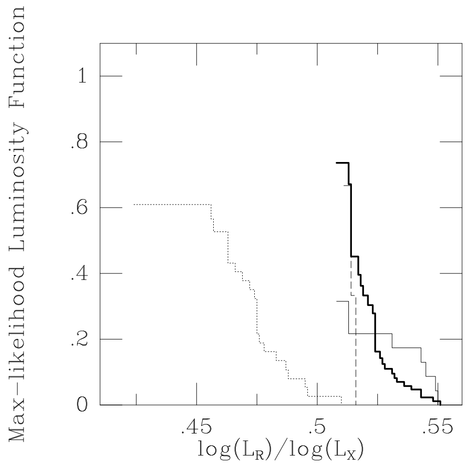

Fig. 2. Kaplan-Meier maximum-likelihood L_R/L_X function. Our RASS-VLA sample is the thick solid line, the Chiang *et al.* (1996) sample is the thin solid line, the active main sequence sample of Güdel (1992) and Güdel *et al.* (1995) is the dotted line and the Bastian, Dulk & Slee (1988) Pleiades sample is the dashed line.

are similar, and that our sample differs significantly from both Pleiades ZAMS stars and magnetically active main sequence stars. These results support the identification of most dispersed lithium-rich RASS stars as genuine weak-lined T Tauri stars rather than ZAMS stars.

• The X-ray/radio luminosity distribution of the sample is roughly consistent with the empirical relationship found by Benz & Güdel (1994) for a wide range of X-ray and radio emitting stars, indicating that the mechanism for both X-ray and radio emission is probably solar-type magnetic activity.

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