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## ROSAT X-RAY SPECTRAL PROPERTIES OF NEARBY YOUNG ASSOCIATIONS: TW HYDRAE, TUCANA-HOROLOGIUM, AND THE $\beta$ PICTORIS MOVING GROUP

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### ABSTRACT

We present archival *ROSAT* data for three recently identified, nearby ( $D < 70$  pc), young ( $\sim 10$ – $40$  Myr) stellar associations: the TW Hydrae association, the Tucana-Horologium association, and the  $\beta$  Pictoris moving group. The distributions of *ROSAT* X-ray hardness ratios (HR1, HR2) for these three groups, whose membership is dominated by low-mass, weak-lined T Tauri stars, are tightly clustered and very similar to one another. The value of HR1 for TW Hya itself—the only bona fide classical T Tauri star in any of the nearby groups—is clearly anomalous among these nearby young stars. We compare the hardness ratio distributions of stars in the three nearby groups with those of T Tauri stars, the Hyades, and main-sequence dwarfs in the field. This comparison demonstrates that the X-ray spectra of F through M stars soften with age and that F and G stars evolve more rapidly in X-ray spectral hardness than do K and M stars. It is as yet unclear whether this trend can be attributed to age-dependent changes in the intrinsic X-ray spectra of stars of type F and later, to a decrease in the column density of circumstellar gas (e.g., in residual protoplanetary disks), or to the diminishing contributions of star-disk interactions to X-ray emission. Regardless, these results demonstrate that analysis of archival *ROSAT* X-ray spectral data can help both to identify nearby, young associations and to ascertain the X-ray emission properties of members of known associations.

*Subject headings:* open clusters and associations: individual (TW Hydrae,  $\beta$  Pictoris moving group, Tucana) — stars: evolution — stars: individual (TW Hydrae) — X-rays: stars

### 1. INTRODUCTION

The recent discovery of several groups of young ( $\sim 5$ – $40$  Myr) stars within 100 pc of the Sun has given new direction to the field of star and planet formation (Jayawardhana & Greene 2001). The seminal, nearby, young stellar group is the TW Hydrae association (TWA), which lies only  $\sim 50$  pc from Earth (Kastner et al. 1997), is  $\sim 5$ – $10$  Myr old (Weintraub et al. 2000), and has  $\sim 20$  known member star systems (Webb et al. 1999; Zuckerman et al. 2001c, hereafter Zc). Several dozen additional, recently identified TWA candidate systems are listed in Makarov & Fabricius (2001) and Webb (2001). Other examples are the very nearby  $\beta$  Pictoris moving group (bPMG;  $D \sim 36$  pc, age  $\sim 12$  Myr; Zuckerman et al. 2001a, hereafter Za; Ortega et al. 2002), and the Tucana and Horologium associations (each  $D \sim 40$  pc, age  $\sim 30$  Myr; Torres et al. 2000; Zuckerman & Webb 2000; Zuckerman, Song, & Webb 2001b, hereafter Zb). Each of these groups consists of  $\sim 20$  known and candidate member star systems. Based on their adjacent positions and their similar distances, space motions, and ages, Zb and de la Reza et al. (2001) have proposed that the Tucana and Horologium associations constitute a single, young stellar group. We adopt this suggestion in the remainder of this paper, and we designate the combined group as the Tucana-Horologium association (T-HA).

In many respects systems such as the TWA, T-HA, and bPMG, though only recently identified and still in a rapid

state of flux, are better suited to detailed studies of star and planet formation than more distant, well-studied, star-forming regions like the Orion and Taurus molecular clouds. Unlike T Tauri stars in regions of active star formation, the nearby groups typically are not readily associated with parent molecular clouds and, as a result, there remains considerable uncertainty concerning their origin and evolutionary status (see reviews in Jayawardhana & Greene 2001). Indeed, the approximate age range of the TWA stars, and consequently the identification of this group as a nearby association, was initially ascertained by Kastner et al. (1997) largely through the strength of the stars' X-ray emission. The TWA's estimated age of about 10 Myr makes the association especially intriguing, since this age corresponds to the epoch of Jovian planet formation, according to present theory, and is a defining characteristic of post-T Tauri stars (Herbig 1978). The stars in the TWA and other nearby young associations, therefore, likely represent a long-sought missing link between the very young and well-studied T Tauri stage and the stellar main sequence (Jensen 2001).

As a consequence of the proximity of the TWA, X-ray observations of its members (and of TW Hya, in particular) have yielded new insight into the origin of high-energy emission from young stars. Archival data from the *Röntgen-Satellit* (*ROSAT*) demonstrate that the  $\sim 10$  Myr age of the TWA represents an especially X-ray-luminous epoch in the early evolution of solar-mass stars (Kastner et al. 1997), and X-ray (*ASCA* and *ROSAT*) spectral monitoring suggests the optical and X-ray variability of some classical T Tauri stars is due to a combination of short-term flaring and long-term variations in absorbing columns (Kastner et al. 1999). *Chandra*/HETGS (High Energy Transmission Grating Spectrograph) observations of TW Hya itself produced the first high-resolution X-ray spectrum of a T Tauri star (Kastner et al. 2002). The HETG spectra yield unexpected

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results for plasma density, temperature, and elemental abundances which, taken together, suggest that the X-ray emission from TW Hya may arise from accretion rather than from coronal activity. If so, this would suggest that many other X-ray luminous young stars derive part or most of their X-ray luminosity from accretion or other star-disk interactions, although coronal activity remains the widely accepted mechanism for such emission (e.g., Feigelson & Montmerle 1999).

Motivated by these results, we are conducting an archival study of *ROSAT* data that focuses on the TWA and other nearby stellar groups. Our goal is to establish the gross X-ray spectral properties of nearby post-T Tauri stars. Such data, when compared with similar results already available for T Tauri stars embedded in molecular clouds (e.g., Neuhauser et al. 1995) and for main-sequence field stars (e.g., Fleming, Schmitt, & Giampapa 1995), should offer clues to the evolutionary status of stars in nearby associations and, more generally, to the mechanism(s) responsible for the bright X-ray emission that appears ubiquitous among young (age  $\leq 100$  Myr), solar-mass stars. Here we present an analysis of *ROSAT* Position Sensitive Proportional Counter (PSPC) data available for the known members of the TWA, the TA, and the bPMG. These results strengthen the interpretation that the stars in these and other nearby, dispersed young associations constitute a transition stage between cloud-embedded T Tauri stars and main-sequence stars.

## 2. DATA

Data presented here consist of *ROSAT* PSPC X-ray hardness ratios, as cataloged in the *ROSAT* All-Sky Survey (RASS) Bright Source Catalog (BSC; Voges et al. 1999).<sup>4</sup> The *ROSAT* PSPC was sensitive from about 0.1 to 2.4 keV. Despite the limited spectral resolution of the PSPC ( $E/\Delta E \sim 1$ ), analysis of PSPC data, and hardness ratios in particular, has proved to be an effective means to understand the X-ray spectral properties of young stars (e.g., Neuhauser et al. 1995). As described in Neuhauser et al.,

<sup>4</sup> These *ROSAT* data were obtained through the High Energy Astrophysics Science Archive Research Center, a service of the Laboratory for High Energy Astrophysics at NASA/GSFC and the High Energy Astrophysics Division of the Smithsonian Astrophysical Observatory.

PSPC hardness ratios (hereafter HRs) are constructed from the integrated counts in three different PSPC energy bands (“soft,” “hard 1,” and “hard 2”), spanning the energy (channel) ranges 0.1–0.4 keV (11–41), 0.4–0.9 keV (52–90), and 0.9–2.0 keV (91–201), respectively. Denoting the counts in these three bands as S, H1, and H2, respectively, the two standard *ROSAT* PSPC HRs are then defined as

$$\text{HR1} = \frac{\text{H1} + \text{H2} - \text{S}}{\text{H1} + \text{H2} + \text{S}},$$

$$\text{HR2} = \frac{\text{H2} - \text{H1}}{\text{H2} + \text{H1}}.$$

## 3. RESULTS

### 3.1. Hardness Ratios of Local associations

In Figure 1a, we present PSPC HRs for established members of the TWA, as listed in Zc. With the exception of TW Hya itself, the PSPC HRs of the TWA stars are evidently rather tightly confined. It is apparent from Figure 1a that, while HR2 for TW Hya itself is typical of TWA stars, the value of HR1 for TW Hya is significantly different from the HR1 values of most other TWA members. This distinction in HR1 is consistent with the unusual ultraviolet-through-radio spectral properties of TW Hya. Indeed, TW Hya remains the only unambiguous example of a classical T Tauri star among the known TWA membership.

The membership of the T-HA remains subject to debate. Here we adopt the membership proposed by Zb and Za. Specifically, we include all Tucana candidate members in Tables 1 and 2 of Zb except for HIP 92024, which was subsumed into the bPMG by Za, and all but five Horologium candidate members listed in Table 5 of Torres et al. (2000). The rejected five stars (ERX 14, 16, 45, 49, and 5) were judged by Zb to be too distant to be part of the T-HA; including these five stars in our HR sample would not significantly change the results described below. Seven additional T-HA candidate members proposed by Torres et al. and Zb, including the infrared-excess object HD 10647, were not detected in the RASS. Most of these stars are of sufficiently early type (F5 and earlier) that they may be intrinsically X-ray-faint (see below). The lack of a RASS X-ray counterpart to the F9 star HD 10647 casts some doubt on its membership in the T-HA, however, given the RASS

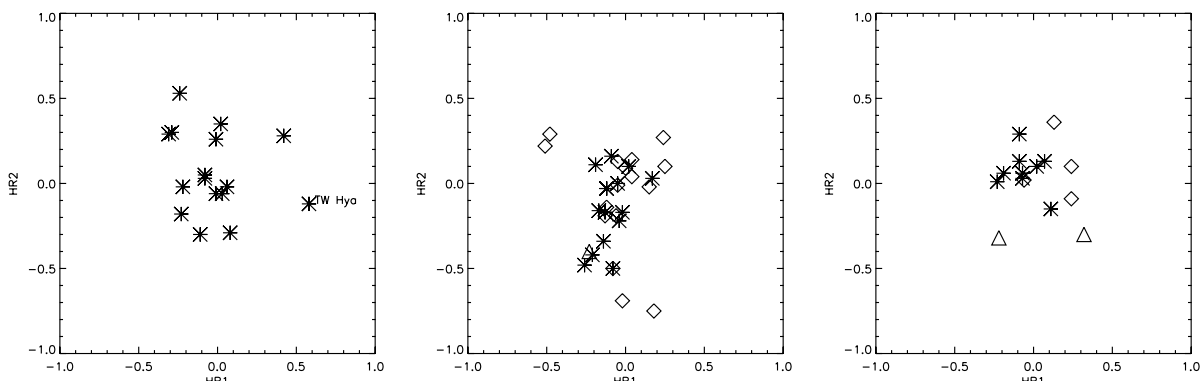


FIG. 1.—*ROSAT* PSPC hardness ratios for presently established members of the TW Hya association (*left*), the Tucana-Horologium association (*center*), and the  $\beta$  Pic moving group (*right*). The position of TW Hya is indicated in the left panel. In each panel, K and M stars are indicated as asterisks, F and G stars as diamonds, and A stars as triangles. Typical uncertainties in HRs range from  $\pm 0.05$  to  $\pm 0.2$ .

TABLE 1  
MEAN *ROSAT* PSPC HARDNESS RATIOS

Sample <sup>a</sup>	X-Ray-emitting Stars <sup>b</sup>	HR1	HR2
ALL STARS			
Taurus T Tauri.....	64	0.833 ± 0.033	0.289 ± 0.043
TW Hya association.....	16	0.040 ± 0.070	0.025 ± 0.047
$\beta$ Pic moving group.....	15	-0.060 ± 0.025	0.054 ± 0.016
Tuc-Hor association.....	32	-0.008 ± 0.025	0.015 ± 0.034
Hyades.....	93	-0.234 ± 0.027	-0.048 ± 0.028
Nearby field stars.....	74	-0.710 ± 0.045	-0.129 ± 0.018
K AND M STARS			
TW Hya association.....	16	0.040 ± 0.070	0.025 ± 0.047
$\beta$ Pic moving group.....	9	-0.081 ± 0.021	0.062 ± 0.015
Tuc-Hor association.....	15	-0.057 ± 0.024	-0.054 ± 0.043
Hyades.....	31	-0.104 ± 0.027	-0.011 ± 0.033
Nearby field stars.....	61	-0.544 ± 0.042	-0.083 ± 0.021
F AND G STARS			
$\beta$ Pic moving group.....	4	0.104 ± 0.074	0.009 ± 0.045
Tuc-Hor association.....	16	0.029 ± 0.040	0.059 ± 0.047
Hyades.....	62	-0.313 ± 0.035	-0.044 ± 0.039
Nearby field stars.....	13	-0.928 ± 0.050	-0.375 ± 0.011

<sup>a</sup> See text for definitions and references.

<sup>b</sup> Number of X-ray-emitting stars included in calculations of means and errors on the means.

detections of several other T-HA and bPMG stars of similar spectral type.

With its membership thus defined, the distribution of HRs for the T-HA is quite well confined, and the locus of HRs for the T-HA lies very near that of the TWA (Fig. 1*b*). The same is true for the bPMG (Fig. 1*c*), for which we include all probable and possible members identified by Za.

In Table 1 we list the mean HRs (and errors on the means) for the TWA, the T-HA, and the bPMG. Aside from HR 4796A (whose M-type companion, HR 4796B, is most likely the X-ray source in this binary system; Jura et al. 1998), the known membership of the TWA consists exclusively of K and M stars. The T-HA and bPMG membership includes a larger proportion of earlier type stars, and for these two associations we also list separately in Table 1 the mean HRs for K and M stars and for earlier types. In calculating the mean HRs for the earlier type stars, we have omitted the handful of A stars that are associated with X-ray sources, since it is likely that the X-rays from such systems originate from later type companions (e.g., Daniel, Linsky, & Gagne 2002).

It is clear from Figure 1 and Table 1 that all three nearby, young stellar groups considered here display very similar X-ray spectral properties in the RASS data. There appears to be a weak tendency, moreover, for the earlier type (F and G) stars in these young associations to exhibit harder X-ray emission, as measured by HR1, than the later type (K and M) stars.

### 3.2. Comparison with T Tauri Stars, the Hyades, and Field Main-Sequence Stars

In Figure 2 we compare the HRs of the TWA, T-HA, and bPMG members with the HRs of classical T Tauri stars (cTTSs) and weak-lined T Tauri stars (wTTSs) in Taurus (Neuhauser et al. 1995), with Hyades members detected in the RASS (Stern, Schmitt, & Kahabka 1995) for which data

are available in the BSC, and with nearby field main-sequence stars. The last sample consists of the K and M dwarfs studied by Fleming et al. (1995;  $D < 7$  pc, ages  $\gtrsim 1$  Gyr) and all single F and G stars within 14 pc for which data are available in the BSC.<sup>5</sup> Aside from  $\pi^1$  UMa, which likely is a member of the Ursa Major moving group (age 300 Myr; e.g., Messina & Guinan 2002), the stars in the nearby F–G sample likely have ages of at least 2 Gyr (e.g., Habing et al. 2001). In Table 1 and Figure 3 we display the mean HRs for the Taurus TTS, local association, Hyades, and field star samples; in calculating these means and their formal errors, we use as weights the inverse squared uncertainties in HR1 and HR2.

It is readily apparent from Figures 2 and 3 that the typical HRs for the TWA, T-HA, and bPMG, which cluster in the vicinity of HR1 = 0, HR2 = 0, differ significantly from the HRs of cTTSs and wTTSs associated with the Taurus star-forming clouds and from the field dwarf population. The cloud TTSs have larger values of both HR1 and HR2 than the TWA, T-HA, and bPMG stars. The wTTSs in Taurus display HR1 in the range 0.8–1.0, while the cTTSs in Taurus all display HR1 = 1.0. The hardness ratios of field dwarfs, on the other hand, are centered well to the left of and somewhat below the hardness ratios of the nearby associations; all of these stars have negative values of HR1, and the vast majority have negative values of HR2. Thus, although there is some overlap between the three populations (Fig. 2)—cloud TTS, nearby young association, and field main-sequence—Figures 2 and 3 indicate that they represent a sequence of decreasing HRs.

The distinction between the HR distributions of the members of nearby young associations and the Hyades is more subtle (Figs. 2 and 3). There is substantial overlap between

<sup>5</sup> As determined through a search of the Nstars database, available at <http://nstars.arc.nasa.gov/index.cfm>.

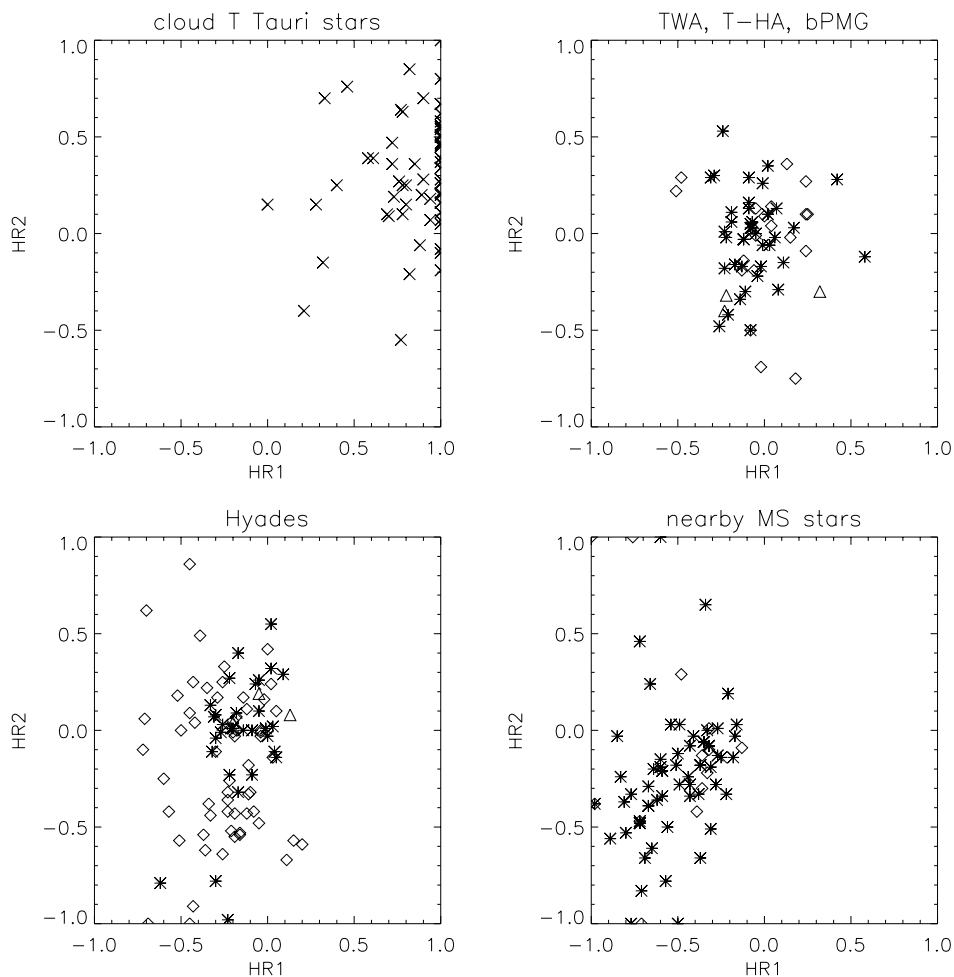


FIG. 2.—*Top left*: HRs for T Tauri stars in Taurus (Neuhauser et al. 1995). The points at the extreme right of the plot are predominantly cTTs, all of which display  $HR1 = 1.0$ . *Top right*: HRs for established members of all three local associations (TWA, T-HA, and bPMG). *Bottom left*: HRs for Hyades members (Stern et al. 1995). *Bottom right*: HRs for nearby ( $D < 7$  pc) field K and M dwarfs (Fleming et al. 1995) and for single F and G stars within 14 pc. Symbols are as in Fig. 1. Typical uncertainties in HRs range from  $\pm 0.05$  to  $\pm 0.2$ .

the HR distributions of these two samples (Fig. 2). The 93 Hyades members in the RASS are all confined to  $HR1 < 0.2$ , however, whereas seven of 53 (13%) known members of nearby young associations display  $HR1 > 0.2$ . Consistent with this observation, the means of both  $HR1$

and  $HR2$  for the Hyades stars are significantly more negative than the means of the members of nearby young associations (Fig. 3, *left panel*). It is apparent, however, that these distinctions are primarily the result of the sharp distinction between the mean HRs of the F and G stars in the young

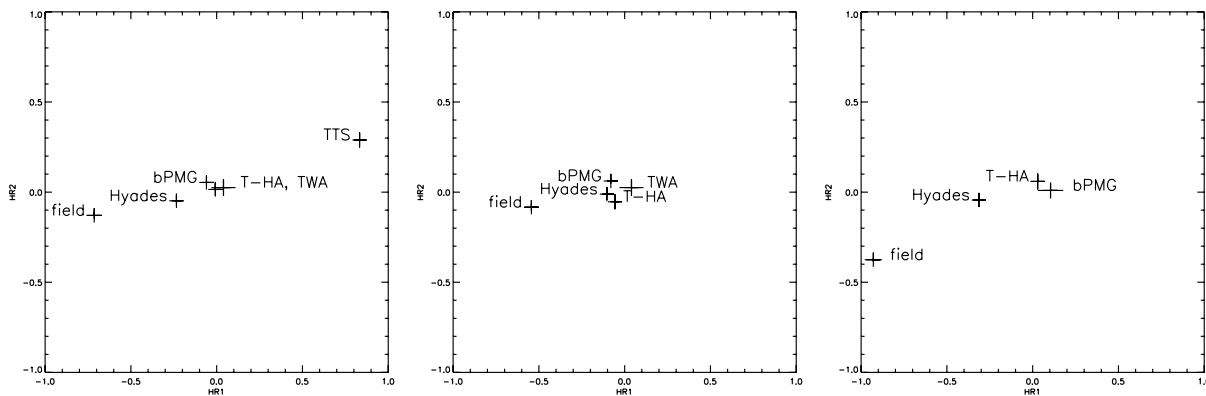


FIG. 3.—Means and errors on the mean for the hardness ratios of Taurus TTSs, members of the TWA, the T-HA, and the bPMG, and field stars. The left panel illustrates the mean HRs for all stars, the center panel for K and M stars, and the right panel for F and G stars.



association and Hyades samples (Fig. 3, *right panel*). For K and M stars, there is no statistical difference between the HRs of members of nearby, young associations and those of the Hyades members (Fig. 3, *center panel*).

There is also a significant difference between the mean HR1 values of the Hyades and main-sequence field populations, for both F and G and K and M stars. However, the weighted mean of HR1 for the field star F and G sample is strongly influenced by the nearest G star,  $\alpha$  Cen, because the uncertainties in its HR values ( $\pm 0.01$ ) are much smaller than those of the remainder of the field F and G star sample (which range from about  $\pm 0.05$  to about  $\pm 0.2$ ). Excluding this star, whose values of HR1 =  $-0.98$ , HR2 =  $-0.38$  place it at the extreme left of the field star HR distribution, the F and G star HR distributions of the Hyades and the field stars appear quite similar (Fig. 2).

#### 4. DISCUSSION

##### 4.1. Does X-Ray Emission Soften with Stellar Age?

Figures 2 and 3 suggest that X-ray emission softens monotonically (toward smaller values of HR1 and, to a lesser extent, HR2) as stars evolve from cloud T associations to sparse, cloudless T associations (as represented by the TWA, T-HA, and bPMG stars), then again from cloudless T association to aging cluster (Hyades) and, finally, from cluster to the field. Such a trend of softening X-ray radiation with stellar age has been noted by previous investigators, based on observations of TTSS and open clusters (including the Hyades; e.g., Neuhauser 1997). This trend is much more clearly demonstrated herein—through the inclusion of the newly identified local associations—than in the previous work. We now consider the possible origin and interpretations of such a trend.

##### 4.1.1. Distance, Absorption, and Hardness Ratio

The Hyades ( $D \sim 45$  pc; e.g., Gunn et al. 1988) and the local associations lie at very similar distances, such that any systematic differences in *ROSAT* HRs most likely are not due to differences in intervening interstellar absorption. We must consider, however, whether the trend evident in Figures 2 and 3 partly represents monotonically decreasing interstellar absorption, from the most distant sample (cloud TTSS) to the least distant sample (nearby, field main-sequence stars). One does expect objects of a given X-ray emission temperature ( $T_X$ ) to move almost directly to the right (increasing HR1) in the hardness ratio diagram as the absorbing column ( $N_H$ ) increases (see Fig. 4 of Neuhauser et al. 1995). However, for  $T_X \sim 25$  MK, HR1 only increases from  $\sim 0.2$  to  $\sim 0.5$  as  $N_H$  increases by 2 orders of magnitude (from  $10^{18}$  to  $10^{20}$   $\text{cm}^{-2}$ ), while HR2 remains roughly constant (Neuhauser et al. 1995). Thus, while the typical extinction (and hence  $N_H$ ) toward stars in local associations remains to be determined,<sup>6</sup> it is likely that the local ISM gas column densities are not large enough to explain the differences in mean HR1 between local, older (age  $\gtrsim 2$  Gyr) field stars and the younger stars in the Hyades and in local groups such as the TWA, T-HA, and bPMG. Furthermore, we find no statistical difference between the HRs of TWA members recently identified by Zc and those of the “origi-

nal” TWA members identified by Kastner et al. (1997) and Webb et al. (1999), despite the fact that the former stars are generally more distant than the latter (Zc). The trend apparent in Figure 2 therefore is caused predominantly by age and/or circumstellar environment (§ 5).

The situation may be somewhat more complicated for samples that lie as distant as Taurus ( $D \approx 140$  pc), since at such distances interstellar gas may have a significant affect on HR1. Indeed, the effects of interstellar absorption may explain the positions of Pleiades stars in a plot of HR1 versus HR2; these  $\sim 100$  Myr old stars are clustered near HR1  $\sim 0.5$  (see Fig. 6 of Neuhauser 1997); i.e., their *ROSAT* X-ray spectra are softer than those of cloud TTSS but are somewhat harder, on average, than those of the TWA, T-HA, and bPMG members, particularly in HR1. The typical reddening toward Pleiades members,  $E(B-V) \approx 0.04$  (Breger 1986), implies typical column densities of  $N_H \approx 2 \times 10^{20}$   $\text{cm}^{-2}$  (Neuhauser et al. 1995), so this difference in mean HR1 can be explained as partly due to extinction, suggesting that the intrinsic HRs of the Pleiades stars are similar to those of the younger TWA and other local groups.

##### 4.1.2. Spectral Type and Hardness Ratio

Figure 3 and Table 1 indicate that earlier type (F and G) stars evolve more rapidly in HR than do late-type (K and M) stars. Specifically, it would appear that at the age of the local associations ( $\sim 10$ – $30$  Myr), F and G stars display somewhat harder X-ray emission than do K and M stars, while by the Hyades’ age (700 Myr) the situation is reversed. A recent *Chandra* study of the Pleiades (Daniel et al. 2002) suggests that F and G types already display softer X-ray spectra than K and M types by the time such stars are  $\sim 100$  Myr old. The relatively rapid X-ray evolution of F and G stars (relative to K and M types) is consistent with the result that K and M stars reach the X-ray “saturation” level ( $\log L_X/L_{\text{bol}} \sim -3$ ) at  $\sim 100$  Myr (Kastner et al. 1997), much later than F and G stars (e.g., Randich et al. 1995). While Figure 3 indicates that K and M stars evolve very little in X-ray spectral hardness between  $\sim 10$  and 700 Myr, K and M stars do become softer X-ray sources after several Gyr.

##### 4.2. ROSAT Hardness Ratios of Candidate TWA Members

Based on an optical spectral survey of TWA candidate stars identified by Makarov & Fabricius (2001, hereafter MF), Song, Bessell, & Zuckerman (2002, hereafter SBZ) conclude that 20 of these 23 candidates are not TWA members. Many or most of the MF stars appear to be  $\sim 100$  Myr old, based on their positions in theoretical pre-main-sequence isochrones (Fig. 2 of SBZ) and, to a lesser extent, on the strengths of their Li  $\lambda 6708$  absorption lines (Fig. 1 of SBZ). Figure 4 demonstrates that the HRs of most of the MF stars follow the HR distribution of the “established” TWA as defined by Zc. If the results of SBZ are correct, therefore, Figure 4 further indicates that there is little evolution in the X-ray spectral properties of late-type stars between  $\sim 10$  Myr and  $\sim 100$  Myr.

The only three Makarov & Fabricius (2001) TWA candidates whose spectral properties are consistent with TWA membership, according to SBZ, display somewhat anomalous (TW Hya-like) HRs in Figure 4. The absence of strong H $\alpha$  emission in the SBZ spectra of these three stars (TYC 7760 0835 1, TYC 8238 1462 1, and TYC 8234 2856 1)

<sup>6</sup> Rucinski & Krautter (1983) noted that foreground extinction is negligible in the general direction of TW Hya itself.

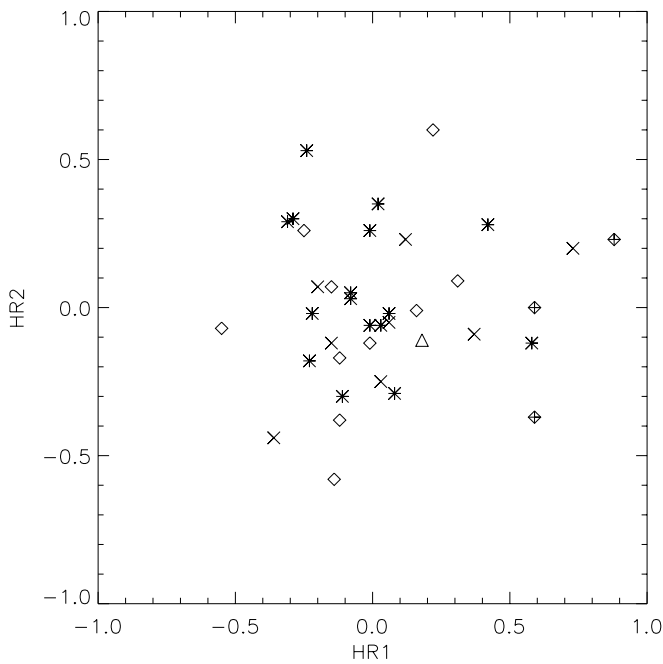


FIG. 4.—HRs for known TWA members (*asterisks*) and for candidate TWA members identified by Makarov & Fabricius (2001). For the Makarov & Fabricius stars, crosses indicate K and M stars, diamonds F and G stars, and the triangle is an A star (where we infer these spectral types from  $B-V$  colors as listed in Song et al. 2002). The only three Makarov & Fabricius candidate stars that Song et al. (2002) tentatively confirmed as TWA members are the three rightmost F and G stars in the diagram (*plus signs*).

indicates that (unlike TW Hya) these stars are not classical TTSs. If these stars are indeed roughly coeval with and have HRs similar to those of the TWA, then their rightward positions, relative to previously established TWA members, in Figure 4 may be due in part to their relatively early spectral types; all three stars have  $B-V$  colors that suggest they are earlier than spectral type K. We may also view these stars through a larger column density of interstellar absorbing material than most other TWA members (§ 4.1). With regard to the latter possibility, we note that SBZ derive photometric distances of  $\sim 130$  pc to TYC 7760 0835 1, TYC 8238 1462 1, and TYC 8234 2856 1—i.e., these stars are roughly twice as distant as the “established” TWA membership (Zc).

## 5. CONCLUSIONS

Our analysis of the *ROSAT* PSPC hardness ratios of local associations, cloud T Tauri stars, and field main-sequence stars, indicates that X-ray spectral hardness decreases monotonically with increasing stellar age (Figs. 2 and 3 and Table 1), with the trend stronger for F and G stars than for K and M stars. There are three alternative interpretations of this trend:

1. The intrinsic X-ray spectrum of a star of spectral type F or later softens with age (Fleming, Schmitt, & Giampapa 1995; Neuhauser 1997). Such a trend could be due to decreasing X-ray emission temperature and/or to age-dependent changes in X-ray-emitting region abundances that modulate the strengths of the brightest emission lines in the *ROSAT* band.

2. The column density of X-ray-absorbing material associated with the environments of young stars declines monotonically as these objects evolve. For Taurus TTSs, the X-ray-absorbing gas and dust may consist of both circumstellar and molecular cloud material, whereas for the older, nearby stellar groups like the TWA, T-HA, and bPMG, we expect residual circumstellar material to dominate. This would suggest that PSPC hardness ratios of the members of local associations can be used to examine the evolution of gaseous circumstellar disks around young stars.

3. Contributions to X-ray emission from star-disk interactions in general, and accretion in particular, decline as stars evolve from the T Tauri phase toward the main sequence. Such contributions may arise in star-disk magnetic field reconnection events (e.g., Shu et al. 1997) or in energetic shocks along accretion columns (Kastner et al. 2002). In either model, the emitting region temperature would be in excess of  $\sim 10^6$  K and therefore should contribute a relatively hard excess X-ray emission component that diminishes with age as the disk disperses.

For F and G stars—which continue to evolve in HR from the T Tauri through post-T Tauri through early main-sequence stages—we cannot distinguish, at present, between these alternative explanations. Given that TW Hya is surrounded by a disk viewed nearly pole-on (e.g., Kastner et al. 2002 and references therein), the anomalous position of this K7 star in Figure 1 offers support for the third interpretation (declining star-disk interactions) in the case of young ( $\lesssim 10$  Myr), low-mass stars. The first interpretation (changing intrinsic stellar X-ray emission properties) best explains the continuing X-ray spectral evolution of K and M stars beyond the age of the Hyades, however. We are analyzing archival PSPC spectra of individual stars to determine whether further progress can be made from the available *ROSAT* data (J. H. Kastner & L. Crigger 2003, in preparation). However, high-resolution *Chandra* and *XMM-Newton* X-ray spectroscopy of representative objects—from which precise X-ray-emitting region temperatures, densities, and elemental abundances can be determined (e.g., Kastner et al. 2002)—will no doubt be required to establish the mechanism(s) responsible for the softening of X-ray emission with stellar age.

Regardless of the correct interpretation of the observed trend, Figures 2 and 3 demonstrate that analysis of *ROSAT* HRs can help discriminate between X-ray-emitting T Tauri stars, post-T Tauri stars, and both young (Hyades- and Pleiades-age) and older (age  $\lesssim 1$  Gyr) main-sequence stars in the field. *ROSAT* HRs evidently are a particularly useful tool for assessing the ages of samples that consist mostly of F and G stars, while for spectral types of K and later, *ROSAT* HRs can effectively isolate peculiar cases (e.g., TW Hya). The results presented here suggest, therefore, that candidate members of young associations can be identified partly on the basis of *ROSAT* PSPC hardness ratios, particularly if other age-related X-ray emission discriminants are applied (such as the ratio of X-ray luminosity to bolometric luminosity; Kastner et al. 1997).

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