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On the X-ray emission from M-type giants*

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Abstract. We have searched for X-ray emission from M-type giants and supergiants listed in the Bright Star Catalogue (BSC) in the data of the ROSAT all-sky survey (RASS). These stars lie to the far right of the X-ray dividing line and are thus not expected to be X-ray sources. Any X-ray detection would therefore violate the common paradigm of X-ray dark M-type giants beyond the X-ray dividing line. We found 11 BSC M-type giants and supergiants to coincide with RASS X-ray sources. While for 4 stars the X-ray emission is very likely related to their cataclysmic or symbiotic nature or can be attributed to a visual G-type companion, the other 7 stars are candidates for intrinsic X-ray emission. Of these objects, 3 have a rather large offset between optical and X-ray position, so their proper identification with late-type giants is at least questionable. For the remaining four stars, we obtained optical low-dispersion spectra in order to search for emission lines indicative of a possible symbiotic nature. None of these stars shows any bright emission lines, so they are probably quite normal M-type giants. We discuss possible origins of X-ray emission in these stars and the importance of evolutionary aspects.

Key words: stars: activity – stars: coronae – stars: late-type – X-rays: stars

1. Introduction

The occurrence of X-ray emission among cool giants is generally described by the so-called "X-ray dividing line" (XDL), which separates in the HR diagram stars with (to the "left") and without (to the "right") observable X-ray emission. Originally introduced by Linsky and Haisch (1979) on the basis of UV transition region emission lines and later extended to X-rays by Ayres et al. (1981) and Maggio et al. (1990), the XDL was at first thought to run from the early G Ib supergiants over the early K II stars to the mid K III stars.

A preliminary analysis of the comprehensive stellar X-ray data of the ROSAT all-sky survey (RASS) by Haisch et al. (1991, 1992) resulted in an XDL nearly vertical in the HR diagram at spectral type ∼K 3. While for the earlier stars a detection rate of 14% among all late-type giants listed in the Bright Star Catalogue (BSC; Hoffleit & Warren 1991) was derived, no stars of spectral types later than K 3 were detected. The only apparent exception, the star HR 4289 (K 5 III), was subsequently shown to be incorrectly identified, i.e., the X-ray emission can be shown to originate from a nearby X-ray bright galaxy (Hünsch et al. 1996b).

More sensitive X-ray observations in the pointing mode of ROSAT revealed a more complex picture of the X-ray properties of late-type giants: An investigation of a complete volume-limited sample of all late-type giants within 25 pc by Hünsch et al. (1996a) showed that essentially all G- and early K-type giants of luminosity class III are X-ray emitters with typical X-ray luminosities of a few 10^{27}erg s^{-1}. Since the cooler giants α Tau and β UMi could not be detected, this seems to confirm the XDL at least for the luminosity class III giants. However, among the brighter giants, there seems to be no conspicuous XDL. This specifically applies to the hybrid stars, which are characterized by the simultaneous presence of cool winds and hot transition regions and coronae. Reimers et al. (1996) reported the X-ray detection of almost all known hybrid stars, including at least one M-type and several K-type giants: A 9.2 ksec long pointing on μ UMa (M 0 III) revealed an X-ray source of $f_{\rm x} = 5 \times 10^{-14}$erg cm^{-2}s^{-1} corresponding to an X-ray luminosity of 3.5×10^{28}erg s^{-1} (taking into account the new distance from Hipparcos parallax measurements). A very similar object is γ Phe, variously classified as K 5 II (Reimers 1977a) or M 0-IIIa (BSC), with $L_{\rm x} = 3.6 \times 10^{28}$erg s^{-1}.

The detection of stellar X-ray emission beyond the dividing line is important since there is an ongoing discussion as to whether such giants are in principle not able to sustain stellar coronae. For possible theoretical explanations we refer to, e.g., Antiochos et al. (1986) and Rosner et al. (1991, 1995).

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* Based on observations by the ROSAT and Calar Alto Observatories

Recently, Hünsch and Schröder (1996) compared the observed X-ray properties of late-type giants with evolutionary tracks and suggested a scenario in which stellar activity decreases gradually as a star evolves into a red giant or supergiant. In fact, this revised XDL *does not cross* the evolutionary tracks any more, runs more or less parallel to them, and approximately coincides with a 1.2 $M_\odot$ track. There seems to be no sudden disappearance of coronae. Instead, one observes a gradual decrease of activity towards smaller masses and more advanced evolutionary stages, and the X-ray detection of any given giant is essentially a question of sensitivity. In view of a general trend of decreasing X-ray luminosities perpendicular to the evolutionary tracks for different masses, the average level of X-ray emission can be attributed to the different evolutionary history and, in particular, angular momentum evolution within different mass ranges.

Very little or perhaps no X-ray emission at all is expected to originate from M III-type giants since these stars have rather small masses ($\lesssim 2M_\odot$) and are probably relatively old ($\gtrsim 10^9$ yrs). They spent a long time on the main-sequence and their convective envelopes caused magnetic braking there, resulting in the loss of almost all of their stellar activity. At least the mid- and late-type M-giants are on the asymptotic giant branch (AGB). The nearest M-type giant, β And (M 0 III), has been observed by Hünsch et al. (1996a) in the course of a complete X-ray survey of all late-type giants within 25 pc. Taking into account the new distance of this star from Hipparcos measurements, the derived upper limit of now $L_x < 2.4 \times 10^{28}$ erg s^{-1} is not very stringent. More sensitive pointings on the slightly earlier stars α Tau (K 5 III) and β UMi (K 4 III) result now (using Hipparcos data) in upper limits of 7.7×10^{26} erg s^{-1} and 7.2×10^{26} erg s^{-1} respectively. This suggests that at least among luminosity class III stars the X-ray luminosity is considerably lower for stars later than K 3 when compared to earlier stars. On the other hand, X-ray emission from the similar hybrid star γ Dra (K 5 III) has been detected at a level of $L_x = 2.8 \times 10^{27}$ erg s^{-1} (Reimers et al. 1996; also adjusted to new distance from Hipparcos data).

The present paper addresses the question to what extent M-type giants can be intrinsic X-ray emitters or not. A key problem is, of course, whether any observed X-ray emission from such stars originates in companion stars, either late-type dwarfs or accreting white dwarfs and similar objects, or whether such emission can indeed be associated with the giant star itself. The ROSAT all-sky survey provides the largest, the most complete and the least biased sample of X-ray sources and therefore constitutes a natural sample to study the question whether M-type giants are X-ray sources or not.

2. Detection of M-type giants in the RASS

From July 1990 until January 1991 the ROSAT observatory performed its all-sky survey; additional survey observations were carried out in February and August 1991. The survey was performed by scanning the entire sky along great circles perpendicular to the direction to the Sun; details on the ROSAT observatory in general and the RASS can be found in Trümper et al. (1991). The effective exposure time at any point in the sky is mainly a function of ecliptic latitude and amounts to typically $\sim$400 sec in the ecliptic plane.

The all-sky survey resulted in the detection of $\sim$150 000 X-ray sources (with source existence likelihood ≥ 7, see below; W. Voges, priv. comm.), about one third of which are estimated to be of stellar origin, i.e., from coronae around cool stars.

We systematically analyzed the RASS data in order to perform a complete survey of X-ray emission from late-type giants and supergiants (Hünsch et al. 1997). In contrast to the earlier investigation by Haisch et al. (1991, 1992), we used the reprocessed version of the RASS data. In addition to an improved source detection algorithm, the re-processing software uses the merged data and therefore does utilize the increased sensitivity towards higher ecliptic latitudes because of the increasing exposure time. Since giants are intrinsically bright stars in the optical, we used the Bright Star Catalogue (Hoffleit & Warren 1991) as an input catalogue, which is complete down to a visual magnitude of $\sim$6.5. Thus, any giants (absolute magnitude $M_V \leq 1.5$) within 100 pc should be included in the BSC. We searched for matches between X-ray sources and BSC giants and used the positional coincidence as the main criterion for identification. As shown in more detail in Hünsch et al. (1997), the differential probability of a chance coincidence of a BSC star with a background (or foreground) X-ray source amounts to 50 percent at a given offset of 90 arcsec between optical and X-ray position, and decreases rapidly for smaller offset values. Therefore, 90 arcseconds are chosen as the cut-off offset for a match between an (optically selected) input position and an X-ray source. For the 482 entries in the BSC of spectral classes M I to M III (excluding composite spectral types) we found 10 M III-giants and one M-supergiant to coincide with RASS-detected X-ray sources. Since the integral search area amounts to $482 \times \pi(1.5^2)$ square arcminutes = 0.95 square degrees, and since there are about 150 000 detected RASS sources in the whole sky (41 253 square degrees) we expect 3.5 spurious identifications. In Table 1, we list the apparent magnitudes, colours, spectral types, distances, and absolute visual magnitudes of the matching stars. For the determination of distances and absolute magnitudes, we used the recently available Hipparcos parallaxes. Unfortunately, for two stars (15 Tri and R Aqr), the reported parallaxes do not match our quality criterion (i.e., $\pi > 3\sigma_\pi$). 15 Tri has even a negative Hipparcos parallax, however, the Tycho catalogue lists a value of 17.4±3.6 mas for 15 Tri, corresponding to a distance of 57 pc (but see Sect. 5.2). We note that for most of our M-type giants the Hipparcos measurements place the stars at larger distances than previous ground based measurements suggest.

Table 2 contains the X-ray data for these sources, i.e., the exposure times, count rates and corresponding errors, likelihoods (defined as $-\ln(1-P)$, where P is the probability of source existence), offsets between optical and X-ray position and position angles (in direction of the X-ray source as seen from the optical position). Also given are the derived values for X-ray flux, ratio of X-ray flux to bolometric flux, and X-ray luminosity.

For the 482 entries of M-type giants in the BSC our formal detection rate is 2.1%. This rate has to be compared with the

Table 1. M-type giants and supergiants detected in the RASS. Data are from the BSC, parallaxes plx are from Hipparcos data (15 Tri: Tycho parallax); B: binary (separation <30 arcsec); SB: spectroscopic binary; CV: cataclysmic companion. Further details are given in Sect. 3.

HR	HD	name	spectral type	V	B–V	plx (mas)	d (pc)	M_V	remarks
750	16058	15 Tri	M 3 IIIa	5.35	1.66	17.4T±3.6T	57T	+1.56T	
2216	42995	η Gem	M 3 III	3.28v	1.60	9.34±1.99	107	–1.87	SB,B
3013	62898	π Gem	M 1 IIIa	5.14	1.60	5.80±0.81	172	–1.04	B
4765	108907	4 Dra	M 3 IIIa	4.95	1.62	5.61±0.51	178	–1.31	SB,CV
5512	130144	–	M 5 IIIab	5.63	1.57	3.59±0.86	279	–1.59	
5589	132813	RR UMi	M 4.5 III	4.60v	1.59	8.20±0.52	122	–0.83	SB
6200	150450	42 Her	M 2.5 IIIab	4.90	1.55	8.67±0.46	115	–0.41	B
6374	155035	–	M 1-2 III	5.84	1.84	3.93±0.91	254	–1.19	
6406	156014	α^1 Her	M 5 Ib-II	3.48v	1.44	8.53±2.80	117	–1.87	B
7547	187372	–	M 2 III	6.12	1.64	2.65±0.52	377	–1.76	SB
8992	222800	R Aqr	M 7 IIIpe	6.36v	1.58	5.07±3.15	(197)	(–0.12)	symbiotic

corresponding values for giants and supergiants of spectral type K (6.5%), G (21.3%), and F (31.5%) (cf. Hünsch & Schmitt 1997) and demonstrates the dramatic decrease of X-ray detectable giants towards later spectral types. However, since both our input sample (BSC giants) and our X-ray source sample are flux-limited, caution is required when interpreting these detection rates. M-type giants are generally brighter than $M_V \approx 0$. Therefore, our input sample completely covers a space volume of ≈200 pc radius around the Sun. At that distance, only X-ray sources of $L_x \gtrsim 5 \times 10^{29}$ erg s^{-1} are detectable in the RASS. In view of a typical X-ray luminosity of a few times 10^{27} erg s^{-1} for luminosity class III giants (Hünsch et al. 1996a), it is evident that the RASS is only sensitive to the "high luminosity tail" in the X-ray distribution function of the late-type giants.

An inspection of Table 1 shows that the detected M-giants are distributed over all subclasses between M 1 and M 5. Some stars are definitely binaries and are discussed below.

Concerning the X-ray data as given in Table 2 we find that the objects can be divided into two subclasses. Eight stars (15 Tri, η Gem, 4 Dra, HR 5512, 42 Her, α^1 Her, HR 7547, R Aqr) show a good agreement between optical and X-ray position while for the other three objects (π Gem, RR UMi, HR 6374) the offset is about 80 arcseconds, casting doubt on a proper identification of the X-ray sources.

We refrain from deducing formal errors to the derived X-ray luminosities. While formal errors are quoted for the distances (parallax errors) and count rates, this is impossible for the energy-conversion factor, which is probably the main source of uncertainty. The conversion factor depends on the coronal temperture and the interstellar hydrogen column density, both of which are not well known for the M-type giants. Nevertheless, information on these parameters is contained in the hardness ratio hr, and we therefore used a hr-dependent relation for the conversion of count rates to X-ray fluxes; for details see Hünsch et al. (1997). We estimate the uncertainty in the conversion factor to be within a factor of 2. Given the errors in distances and count rates, which are each at most 40%, the overall error in L_x is most likely within a factor of 3.

The low count rates of the sources close to M-type giants prevent us from constructing light curves for variability studies. Nevertheless, for four stars (15 Tri, HR 5512, 42 Her, HR 7547), we checked the arrival times of the individual photons and confirmed that they are more or less evenly distributed over all scans (i.e., over a time interval of $\sim$ 2 days). Therefore, it is unlikely that the detection of these sources did occur only because of enhanced count rates resulting from flares.

3. Notes on individual objects

15 Tri: An A 5-type companion of 4.2 magnitude exists in 141 arcseconds distance, which is probably an optical companion (BSC).

η Gem: is a triple system. The primary is classified as M 3.5 Ib-II by Abt (1985), which better agrees with the Wilson-Bappu magnitude. A visual companion, classified as G 0 III by Baize & Petit (1989), lies 1.5 arcseconds close to the primary. A long-period orbit is known for this physical companion (Baize 1980). Furthermore, the primary is itself a spectroscopic binary of 2983 d period. Evidence for eclipses has already been reported by McLaughlin & van Dijke (1944) but remains doubtful. Deutsch (1961) assumed the spectroscopic companion to be an M-type giant of even later spectral subtype. The X-ray detection of η Gem, which lies at the rim of the supernova remnant IC 443, was already reported by Maggio et al. (1990).

π Gem: A visual companion of 11th magnitude and unknown type exists at 21 arcseconds distance and 214° position angle.

4 Dra: is a triple system. The M-type giant forms a long-period spectroscopic binary with a cataclysmic secondary, probably consisting of a late-type dwarf and a magnetic white dwarf (cf. Reimers et al. 1988).

RR UMi: is a spectroscopic binary with a nearly circular orbit of 750 d period (Batten 1986). No information on the secondary is available. A 3 ksec long ROSAT PSPC pointing exists (WG400164p), in which RR UMi is in the field of view at an off-axis angle of 23.6 arcminutes. The count rate and especially the rather large positional offset between X-ray and optical position is very similar to the corresponding values from RASS observations.

Table 2. X-ray properties of the sources close to the M-giants of Table 1. hr is the hardness ratio as defined by $H–S/H+S$, where H and S denote the counts in the hard and soft ROSAT PSPC passbands, respectively. The X-ray luminosities in the last column are derived by using the distances as given in Table 1.

HR	Exp. time (sec)	Count rate (sec^{-1})	±err (sec^{-1})	Likeli.	Offset (arcsec)	Pos. angle (°)	hr	$f_x(\times10^{-13}$ erg cm^{-2}s^{-1})	log $\frac{f_x}{f_{bol}}$	log L_x
750	162	0.097	0.028	37	17	120	1.00	13.6	–5.91	29.72T
2216	389	0.052	0.014	23	24	135	0.04	4.7	–7.20	29.80
3013	393	0.034	0.012	19	77	340	0.31	3.5	–6.40	30.10
4765	689	0.033	0.008	31	16	106	1.00	4.6	–6.53	30.24
5512	382	0.024	0.010	14	12	116	0.04	2.2	–6.84	30.30
5589	1283	0.091	0.009	181	81	140	–0.15	7.2	–6.67	30.11
6200	1038	0.017	0.006	11	14	250	0.12	1.6	–6.97	29.41
6374	276	0.030	0.013	8	86	140	–0.24	2.2	–6.37	30.23
6406	546	0.293	0.035	194	9	117	0.68	36.1	–5.87	30.77
7547	791	0.018	0.006	16	18	140	1.00	2.6	–6.23	30.64
8992	207	0.121	0.028	34	25	71	–0.87	4.9	–6.39	(30.36)

42 Her: A visual companion of 42 Her is of magnitude 11.8 and lies at 25.6 arcseconds distance and 92° position angle. According to the BSC, this is an optical companion. Eaton et al. (1990) have found an increase of the continuum towards longer wavelengths in IUE-LWP UV spectra, which they interpret as evidence for a G-type star in the 42 Her system.

α^1 Her: α Her forms a triple system. The M-type supergiant primary has a visual companion at 4.9 arcseconds distance, which is itself a spectroscopic binary. The spectral types are given by Thiering & Reimers (1993) as M 5 II, G 8 III and A 9 IV-V. The visual companion shines through the extended circumstellar envelope of the primary and has extensively been investigated to study the phenomenon of mass loss from red giants.

HR 7547: The BSC lists this star as a spectroscopic binary, but no details are given.

R Aqr: A well-known symbiotic star. The Mira-type primary forms a binary with an accreting white dwarf and has an extended, optically visible bipolar outflow. X-ray emission from R Aqr has already been detected with the *Einstein*-Observatory (Jura & Helfand 1984).

4. Optical observations

For the four M-type giants 15 Tri, HR 5512, 42 Her, and HR 7547 there is good agreement between optical and X-ray position and the nature of possible companions is not definitively known. In order to check whether the X-ray emission can be explained by a symbiotic or cataclysmic nature, we obtained optical medium-resolution spectra with the 2.2 m telescope on Calar Alto Observatory, Spain. The observations were obtained in September 1996 with the CAFOS spectrometer, which was equipped with a LORAL CCD chip (2048 × 2048, 15μm pixel). For each star, two exposures in different wavelength ranges (3500 to 5500 Å and 4800 to 7400 Å) were taken. The linear dispersion of the spectra was 88 Å mm^{-1} in both wavelength ranges. With a 0.7″ slit the resulting spectral resolution was about 3 Å. The exposure times ranged between 2 sec and 30 sec. Wavelength calibration and flat-fielding were achieved by exposing built-in HeHgCd and continuum lamps, respectively. The spectra were reduced using standard MIDAS (version 95NOV) software available at MPE.

All of the four stars show normal M-type spectra with their characteristic TiO bands. No emission lines, neither the Balmer lines nor lines of He II 4686 Å or He I 4026, 4471, or 5876 Å are discernible. We therefore conclude that there is no evidence for any of these four giants being a symbiotic star. However, our low-resolution spectra do of course not exclude the possible presence of optically fainter late-type (probably main-sequence) companion, which could in principle be responsible for the observed X-ray emission.

We also note that cataclysmic companions as in the case of 4 Dra would hardly be detectable in our low-resolution spectra. However, 4 Dra is probably a very rare case of a triple system (cf. Reimers et al. 1988), and a similar configuration in the other four M-type giants is rather unlikely.

5. Discussion

5.1. Origin of X-ray emission

Possible mechanisms for X-ray production in M-type giants, can be divided into two subclasses: a) non-intrinsic origin, b) intrinsic origin.

a) Non-intrinsic mechanisms have the X-ray emission originate in a companion star of the giant. This companion can be either an active main-sequence star or even an optically fainter evolved star, or it may be a degenerate object like a white dwarf. White dwarfs can be quite strong X-ray sources, but the total number of white dwarfs detected in the RASS data is quite small ($\ll$ 1 percent of the total number of X-ray sources). Further, the X-ray emitting white dwarfs tend to have extremely soft X-ray spectra, which makes them subject to substantial interstellar absorption especially in the galactic plane. Instead, a far more likely X-ray emission process involving an M-giant and white dwarf binary would have the white dwarf accrete matter from the cool wind of the giant through an accretion disk, where temperatures eventually become sufficiently high for significant X-ray emission. Indeed, cataclysmic variables and symbiotic stars are a well known class of X-ray sources.

b) Intrinsic mechanisms of X-ray emission can be attributed to the M-type giant itself, i.e., thermal emission from coronal plasma in the atmosphere of the giant. The occurrence of activity usually requires sufficiently rapid rotation. In the presence of a short-period ($\lesssim$100 d) binary companion, tidal interaction could force the giant to co-rotate and thus rotate with a higher velocity than usual for single stars. This would result in an enhanced level of magnetic activity and is a well known phenomenon in the case of the RS CVn systems. However, RS CVn systems mostly contain a G- or K-type giant or subgiant and a main-sequence or subgiant late-type companion. Until present, no M-type giant is known to be a member of a RS CVn system. Since these binaries are always detached, the minimum orbital rotation period (which is assumed to be synchronized with the rotational period) depends on the radius of the primary. Therefore, an M-type giant of typically $R \gtrsim 50 R_\odot$ and a mass of 2 $M_\odot$ in a binary (and a companion mass of, say, 1 $M_\odot$) would result in an orbital rotation period of $P \gtrsim 25$ d, which is quite large compared to the typical periods observed in RS CVn stars.

If, on the other hand, the X-ray emitting giant is a single star (or if a distant companion can be assumed to be X-ray dark for other reasons), we are dealing with a hybrid star by definition, since all M-type giants and supergiants are known to possess cool stellar winds (cf. Reimers 1977b; Reimers et al. 1996). Until present, the coolest known hybrid stars are μ UMa (M 0 III) and γ Phe (K 5 II – M 0 III), which incidentally are both spectroscopic binaries. Although most known hybrid stars are of earlier spectral type, the region in the Hertzsprung-Russell diagram occupied by hybrids is not well-defined and there is in principle no reason why such stars should not populate the whole cooler part of the HR diagram.

5.2. Masses and evolutionary status of the M-type giants

For the determination of individual masses and ages of the M-type giants, we calculated various evolutionary tracks with the Eggleton code as described in Pols et al. (1995) and Schröder et al. (1997). The Eggleton code employs an adaptive mesh and uses latest opacities, nuclear reaction rates and a modified mixing length approach. The parameters for mixing length and overshooting were calibrated and discussed empirically (Schröder et al. 1997, Pols et al. 1997), which was achieved with eclipsing binaries, including some giant primaries in He-burning stages. Further tests of the lower mass models have been obtained from cluster isochrones (Pols et al. 1998) and the population of the Hertzsprung gap (Schröder 1997). Both methods show a fading-out of the overshooting effects around 1.8 $M_\odot$.

This semi-empirical approach removes the uncertainties from the otherwise ambiguous choice of the two free parameters in mixing length theory. A grid of such evolutionary tracks, including different metallicities, is given by Pols et al. (1998). For our computations we assumed solar-like abundances ($Y = 0.28, Z = 0.02$) and adopted a fading-out of the overshooting as suggested by Schröder (1997): between 1.6 and 2.2 $M_\odot$.

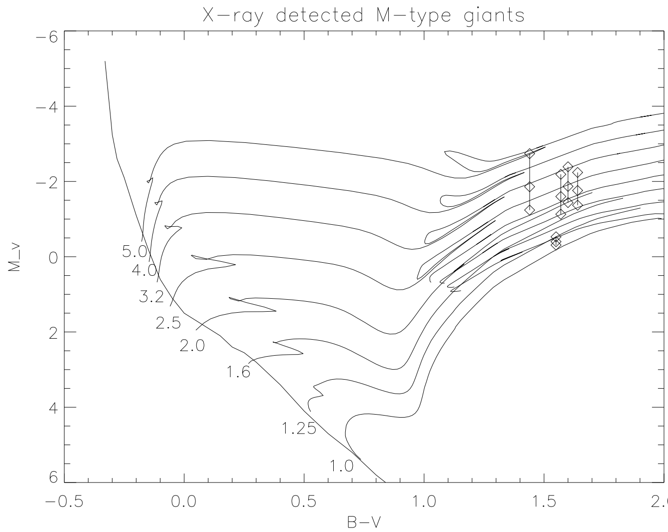

Fig. 1. HR diagram with evolutionary tracks for different stellar masses (given in solar masses). Overplotted are the positions of the M-type giants (from left to right): α^1 Her, 42 Her, HR 5512, η Gem, and HR 7547. Each star is plotted as a bar, representing the range in absolute magnitude according to the uncertainty in the Hipparcos parallaxes. The diamond in the middle of each bar gives the best estimate (cf. Sect. 5.2 and Table 3).

Another critical point is the conversion from a theoretical HR diagram ($T_{\rm eff}$, log$L$) into B–V and M_V. We used the colour (and bolometric correction) tables computed by Kurucz (1991) for solar abundances. These agree fairly well with the colours of the few K and M-type giants, for which empirical $T_{\rm eff}$ exist (Di Benedetto 1993), within the uncertainties for log g. The cool end of the Kurucz grid (3500 K) is less than 0.15 mag different from the models of Bessell et al. (1989), who computed, e.g., V–K and R–I specifically for M-type giants. We therefore estimate the uncertainties in B–V and M_V to be of the order of 0.1, which corresponds to only about 10% error in the deduced stellar masses from the conversion alone.

By comparison of the star's locations in the HR diagram with the theoretical evolutionary tracks (cf. Fig. 1), we derived masses and ages as given in Table 3. We also give error ranges corresponding to the uncertainties in the Hipparcos parallaxes. There may also be a (presumably small) error in B–V, and, additionally, a larger and systematic error may result from interstellar reddening. However, the uncertainty in colour has a rather small effect on the derived masses and ages in comparison to the effect of the uncertainty in M_V.

As is evident from Table 3, three of the M-type giants most likely have masses between 2.0 and 2.5 solar masses and ages of $\sim 10^9$ yrs. Even within the uncertainty in M_V, they are at least of the age of the Hyades cluster, i.e., $\sim 7 \times 10^8$ yrs). Only α^1 Her seems to be more massive and younger, while 42 Her is probably only slightly more massive than the Sun and has a much larger

Table 3. Estimated masses M (in solar masses) and ages τ (in Gyrs) for some X-ray detected M-type giants (cf. Sect. 5.2). Also given are lower and upper limits resulting from the uncertainty in the Hipparcos parallaxes.

Name	M	$M_{\rm min}$	$M_{\rm max}$	τ	$\tau_{\rm min}$	$\tau_{\rm max}$
η Gem	**2.5**	2.0	3.2	**0.81**	0.4	1.1
HR 5512	**2.2**	1.8	3.1	**1.1**	0.43	1.6
42 Her	**1.15**	1.05	1.25	**10**	7	13
α^1 Her	**3.2**	2.3	5.0	**0.4**	0.1	1.05
HR 7547	**2.2**	1.8	2.7	**1.1**	0.65	1.6

age of $\sim 10^{10}$ yrs. We further note that the quoted Tycho parallax for 15 Tri must be in serious error since its according location in the HR diagram lies much below a 1.0 $M_\odot$ track. Such low-mass stars cannot have evolved into giants yet, and we assume – especially in the absence of a reliable Hipparcos parallax – this star to be much more distant and luminous.

5.3. The possibility of X-ray bright companions to the M-type giants

Given the masses and ages of the M-type giants as given in Table 3 we now address the issue whether the observed X-ray emission from the M-type giants could have its origin in yet unknown X-ray bright but optically faint companions. While giant-type companions would have a brightness difference of at most 2 to 3 magnitudes and would thus hardly escaped detection in the optical range (see for example the visual companions to η Gem and α^1 Her), a late-type main-sequence companion may be difficult to detect in the vicinity of a bright M-type giant. Radial velocity measurements have to be carried out with great accuracy to distinguish orbital motion from stellar pulsations, which are known to occur in almost every M-type giant.

We restrict this discussion to those stars only, where the identification of the X-ray source with an M-type giant is reasonable, i.e., we exclude π Gem, RR UMi, and HR 6374. First, we have the obvious cases of 4 Dra and R Aqr, where degenerate companions are already known, which provide a plausible origin for the X-ray emission (cataclysmic or symbiotic nature). Of the six remaining stars, little can be said on 15 Tri since its mass and age is not known (cf. previous subsection).

Three of the M-type giants (η Gem, HR 5512, HR 7547) have at least ages comparable to the Hyades (i.e., 0.7 Gyrs), yet their X-ray luminosities are close to (η Gem) or considerably in excess of 10^{30}erg s^{-1}. From the well-established X-ray luminosity distribution functions of the Hyades (Stern et al. 1995) we note that only three stars in the Hyades have X-ray luminosities in excess of 10^{30}erg s^{-1}: the peculiar binaries V 471 Tau (dK + WD) and vB 141=71 Tau (unusually rapidly rotating F 0 V star with G 4 V companion) and the K 0 IIIb giant θ^1 Tau (=vB 71). Four additional stars (γ Tau = vB 28, vB 50, BD 22° 669, BD 23° 675; all binaries) have $L_{\rm x} > 5 \times 10^{29}$ erg s^{-1}, and for the large sample of Hyades dK/dM stars studied by Pye et al. (1994) we find $L_{\rm x} < 4 \times 10^{29}$ erg s^{-1}, regardless if they are binaries or single stars. While η Gem has about the same X-ray luminosity as γ Tau and thus its known G-type giant companion may be a good candidate for the X-ray source, the X-ray luminosities of HR 5512 and HR 7547 exceed the brightest non-peculiar and non-giant Hyades by a factor of 2.5 and 5.5, respectively. We further note that the coeval Praesepe cluster members have generally lower X-ray luminosities (Randich & Schmitt 1995), and that the Hyades age is a lower limit for the age of HR 5512 and HR 7547. We therefore conclude that any suspected main-sequence companions of both stars are very likely not able to produce the observed X-ray emission.

The same argument applies to 42 Her, which has a lower X-ray luminosity of 2.5×10^{29}erg s^{-1}. Yet, it is about twice as old as the Sun, much older than any known open cluster. From X-ray studies of M 67, one of the oldest open clusters (age $\sim$ 5 Gyrs) it is known that even at that old age binaries can have X-ray luminosities in excess of 10^{30}erg s^{-1} (Belloni et al. 1993). The X-ray detected binaries in M 67, however, resemble the properties of RS CVn systems very closely. In particular, all of them are rather short period ($P < 50$ d) binaries.

Finally, only α^1 Her remains as a probably more massive and hence younger M-type giant (in fact, it is almost a supergiant). Its age is most likely between those of the Pleiades and Hyades clusters. However, for α Her, the known G-type giant companion, which is itself a spectroscopic binary, provides a more plausible explanation for the observed X-ray emission.

6. Conclusions

In summary, we have detected X-ray emission at the locations of 11 out of 482 stars classified as M-type giants of luminosity class I to III.

In the cases of 4 Dra and R Aqr, the X-ray emission is almost certainly related to the cataclysmic or symbiotic nature of these objects, i.e., the existence of an accretion disk.

Little can be stated about intrinsic X-ray emission from the M-type primaries of η Gem and α Her since both stars have close G-type secondaries (and a third A- or F-star in α Her), which are likely candidates for the source of observed X-ray emission. However, this does not rule out the M-type giants as X-ray sources, yet due to the small angular separation of these visual binaries, a proper attribution of the X-ray emission to the individual components is not possible with ROSAT and requires observations with higher spatial resolution as achieved by, e.g., the AXAF observatory.

Among the remaining seven stars, three have rather large offsets between optical and X-ray position. In one case (RR UMi), this also holds for a serendipitous pointed ROSAT observation, strongly suggesting that the X-ray source is not related to RR UMi. Since we statistically expect 3.5 spurious identifications within our input sample, and to be on the safe side, we do not assume that these stars are actually X-ray sources.

We thus retain four stars (15 Tri, HR 5512, 42 Her, HR 7547) as candidates for intrinsically X-ray bright M-type giants. Optical low-resolution spectra of these stars have been obtained and examined for bright emission lines, but none were found, suggesting that these four objects are not symbiotic stars. While 42 Her has a moderately close visual (and perhaps also a spectroscopic) companion, and HR 7547 is possibly also a spectroscopic binary, no evidence for binarity yet exists for 15 Tri and HR 5512. However, even if these stars do have main-sequence companions, the X-ray emission cannot easily be attributed to those companions alone. Except for 15 Tri, whose exact position in the HR diagram is not known, the estimated evolutionary ages of the stars (i.e., at least Hyades-like age) do not correspond to the observed high levels of X-ray emission.

It therefore appears that the observed X-ray emission from these four stars is indeed quite unusual. Either one has to invoke peculiar configurations such as triple systems involving BY Dra-like binaries or cataclysmic variables, for which there is no evidence (yet), or one has to attribute the X-ray emission to the M-type giants themselves – which is the physically more interesting case – either as RS CVn-like systems containing an M-type giant or even as a single star, both of which possibilities would be quite extraordinary. It is obvious that these systems require further study until a final decision can be made.

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