Astron. Astrophys. 298, 482–488 (1995)

ASTRONOMY AND ASTROPHYSICS

The space density of active binaries from X-ray surveys

F. Favata[1], **G. Micela**[2], **and S. Sciortino**[2]

[1] Astrophysics Division - ESA/ESTEC, Postbus 299, NL-2200 AG Noordwijk, The Netherlands
e-mail: fabio.favata@astro.estec.esa.nl
[2] Istituto e Osservatorio Astronomico di Palermo, Piazza del Parlamento 1, I-90134 Palermo, Italy
e-mail: gmicela@oapa.astropa.unipa.it ssciortino@oapa.astropa.unipa.it

Received 30 August 1994 / Accepted 17 November 1994

Abstract. We review the currently available data on active binaries selected from *Einstein* observatory based X-ray surveys, and compare the inferred space density with the available estimates based on optically selected samples. It is shown that, in contrast to previous reports, no disagreement is present between the optical and X-ray based estimates, and that the space density of active binaries is likely to be smaller than previous estimates based on X-ray selected data. In particular, we show that of the 18 systems in the $\delta > -20$ deg subsample of the *Einstein* Extended Medium Sensitivity Survey previously classified as active binaries, 6 are not to be considered as such, while a further 5 have a somewhat doubtful status. The total space density we derive is $7.7 \cdot 10^{-5}$ pc^{-3} if the 5 doubtful systems are retained and $3.7 \cdot 10^{-5}$ pc^{-3} if they are excluded. Both values are substantially lower than the value of $4.5 \cdot 10^{-4}$ pc^{-3} originally derived from the same subsample of Extended Medium Sensitivity Survey fields. Also, the median X-ray luminosity of X-ray selected active binaries is found to be higher than previously reported, and again in contrast with previous reports, we find no disagreement between the X-ray luminosities of X-ray and optically selected samples. We briefly discuss the implication of the revised value of the space density on the contribution of active binaries to the soft X-ray background.

Key words: Galaxy: stellar content – binaries: close – X-rays: stars – stars: statistics

1. Introduction

Evolved close binaries have since long been recognized as systems in which all of the manifestations of stellar activity are greatly enhanced with respect to single stars of the same mass and evolutionary status. Given their high mean X-ray luminosity (up to L_X = 31.5 dex; all the X-ray luminosities in this paper are in units of log(erg s^{-1})), they can be detected at distances of up to a few kpc in typical *Einstein* or ROSAT exposures, and therefore can form an important contributor to both discrete source counts and the soft X-ray background. The level of contribution will of course strongly depend on the assumed spatial distribution of these systems. In particular the background flux will scale linearly with the assumed space density on the Galactic plane.

Send offprint requests to: F. Favata

Available density estimates for active binaries are based either on optical based surveys or on X-ray based surveys. Estimates based on the two methods differ widely both on the derived space density and on the derived X-ray activity levels. Most of the estimates based on optical surveys take as a starting point the catalog of active binaries of Strassmeier et al. (1993, hereafter CABS2) or its earlier version, Strassmeier et al. (1988, hereafter CABS), which is a collection of data on all currently known binary systems showing signs of stellar activity. Given that the various systems included in CABS2 have been discovered with different techniques, it is quite unclear what its completeness level is. However Morris & Mutel (1988), by assuming CABS to be complete out to 30 pc, infer a space density of about 10^{-4} pc^{-3}, while Drake et al. (1989, hereafter DSL89), starting from rather similar arguments, quote a value of $\approx 10^{-5}$ pc^{-3}.

On the other hand Fleming et al. (1989, hereafter FGM89) starting from the active binaries detected in the subsample of the 953 fields (kindly provided to us by T. Fleming) of the *Einstein* Extended Medium Sensitivity Survey (EMSS; Gioia et al. 1990) derive a spatial density for the active binaries of $4.5 \cdot 10^{-4}$ pc^{-3}, revised downwards by Fleming, as reported by Ottman & Schmitt (1992, hereafter OS92), to $(2.89 \pm 0.62) \cdot 10^{-4}$ pc^{-3}. OS92 also show that the median X-ray luminosity of the X-ray selected sample of FGM89 is about 0.3 dex *lower* than the median X-ray luminosity of the optically selected sample of DSL89 (which is essentially derived from CABS), a trend opposite to what would be expected given that the X-ray selected systems should be biased toward higher activity levels. They also show that, assuming that the X-ray luminosity function has a log-normal distribution and following the formalism of Schmitt & Snowden (1990), the true median X-ray luminosity of the X-ray selected sample is even lower (about 1 dex) than the true median X-ray luminosity of the optically selected sample.

The conclusion of OS92 is that the FGM89 and DSL89 samples are not derived from the same population, and they are unable to provide an explanation for this evident discrepancy. We believe that the explanation lies in the different sample selection criteria, and in particular in the different definition of active binary used by different authors. We have re-analyzed the data of the same subsample of the EMSS considered by FGM89 using the definition of active binary discussed in Sect. 2 and show that by doing so, no discrepancy is present between X-ray selected and optically selected samples.

2. The definition of active binary

The existence of a number of late-type binary stars with greatly enhanced levels of CaII H&K line emission with respect to single stars of similar mass and luminosity class has been recognized for 40 years (see Bidelman 1954), and the first phenomenological classification of the "active binary" stars is perhaps the one of Hall (1976). Since then, different authors have been using different criteria to define different samples of active binaries to be studied using different techniques, often resulting in highly non-homogeneous samples which can hardly be compared with each other.

In the context of the present work, we define an active binary as a binary stellar system in which the activity level is significantly enhanced as a consequence of it being a binary with respect to the level which is typical for single stars of the same mass and evolutionary state. The mechanism through which the activity is enhanced is not relevant here, although it is most likely to be due to the tidal locking between rotational and orbital period, which inhibits angular momentum shedding and therefore maintains the rotational velocity at a higher value than the typical value for the object's mass and age.

The present definition is more constraining than other previously used definitions in that it requires a system to be both binary and to show an enhanced activity level for its age and mass. This differs from the criteria which have often been adopted by other authors, who have often classified all the (close) binaries found in an active star sample as active binaries, regardless of their age and evolutionary state, and regardless of whether they were more active than otherwise similar single stars. Given that about half of the normal stellar systems are multiple, many of the young binary systems would be classified as active binaries, thus greatly increasing the estimates of their density. This is well exemplified in the Pleiades whose stars have a generally high X-ray activity level (most likely due to their being young) and often large rotational velocities. Binary systems in the Pleiades show no increase in their X-ray activity level with respect to the components taken individually. Yet, a Pleiades binary system found in the field would be classified as an active binary if age is not considered. It should however be noted that the situation might be different already at the age of the Hyades: Pye et al. (1994) report that, in their recent ROSAT survey of the Hyades, dK binaries consistently have a higher X-ray luminosity than single dK stars. Their result is somewhat puzzling in the present context given that all the binaries in their samples are long-period ones, with periods ranging between 1 yr and more than 10 yr. Such long periods surely rule out tidal locking as the cause of the enhanced activity.

None of the available measurements can be used, alone, to deterministically date an individual star. We have therefore used, for each system considered, all the available age indicators, including spectral type and luminosity class, kinematics, lithium abundance and activity level. Many of the original definitions of active binaries of the RS CVn type required one of the component to be evolved, thus implicitly setting an age criterion. Active binaries with unevolved late type companions have often been grouped under the BY Dra class, with extensions to subclasses such as the early-type BY Dra of Fekel et al. (1986). Different authors have for example been discussing whether short-period RS CVn type systems should not be classified as early-type BY Dra (Collier 1982). We feel that, in the present context, also given the small size of the available sample, no distinction is necessary between the different types of active binaries, and therefore all of the derived quantities will refer to the integrated sample of all systems whose activity is driven up by tidal locking, covering both evolved and main sequence systems.

Two classes of systems in particular are likely to be incorrectly classified as active binaries: pre-main sequence (PMS) and Pop II close binaries. PMS close binaries are likely to be very active because of their young age, and will often have a luminosity class of IV or III if they have not yet reached the main sequence. Therefore they can easily be confused with an active binary, except that their lithium abundance usually allows to discriminate them. A typical example of this class is HD 155555 (Pasquini et al. 1991, from which the following data are taken): it is a close binary with a circular orbit and a period of 1.68 d, the two components have about solar masses, and $T_{\rm eff}$ of about 5500 and 5000 K. The X-ray luminosity is about 30 dex, and the optical spectra show strong CaII H&K emission cores and Hα fill-up. On the basis of the observed colors and spectral types the two components are not main sequence objects, and have a surface gravity compatible with their being sub-giants. HD 155555 therefore has all the characteristics for being considered an active binary system. On the other hand the system has a quite high lithium abundance, and a space motion typical of very young systems, and it has an optical companion which is a very active dMe star, also very likely a young object. Note that the high X-ray luminosity is compatible *both* with its being an active binary and with its being a PMS object, as is the low surface gravity. Pasquini et al. (1991) therefore consider this object much more likely to be a PMS binary than an evolved active binary.

Short period Pop II binaries (period less than about 10 d) show enhanced rotation and activity levels, very similarly to what happens to "normal" Pop I binaries (Pasquini & Lindgren 1994), and are therefore by all means "active binaries". However, one should be careful not to include them in density or luminosity estimates for Pop I objects. A very good example of this is present in the sample studied here, SAO 91772. As reported by Pasquini & Lindgren (1994), this G5 star has a binary period of 1.84 d, with an almost circular orbit ($e = 0.007$), and it displays strong chromospheric activity in both CaII H&K and Hα. Its X-ray luminosity is relatively high for its spectral class (29.54 dex from FGM89). It would therefore easily be classified as a normal Pop I active binary. Its very low metallicity, on the other hand ($\left[\mathrm{Fe/H}\right] = -2.12$) clearly qualifies it as a Pop II object.

Note that while neither PMS binaries nor Pop II binaries are expected to be very common, at least one example of each object is present in the active binary sample of FGM89. Given the small size of FGM89's sample (18 objects altogether) they represent a sizable fraction of the total.

3. The revised sample of active binaries

The original sample of FGM89 is shown in the top part of Table 1, which gives, in column 6, the relative contribution of each system to the total space density, in units of 10^{-3} pc^{-3}. We have added to our sample four systems (four bottom rows of Table 1) which are not in the original FGM89 RS CVn sample, but which are classified as either RS CVn or BY Dra by Stocke et al. (1991). These systems are otherwise very similar to the ones included in the sample of FGM89. The spectral type reported in the table is the one reported by FGM89 or by Stocke et al. (1991). We have also reported in Table 1, when available, the recent measurements of orbital period and eccentricity which Baker et al. (1994, hereafter BSMLN94) have done on several binary systems from the EMSS.

The contribution of each system to the space density has been computed according to Schmidt (1968) and Avni & Bahcall (1980). The flux sensitivity of the subsample of the EMSS IPC fields we have used spans approximately a decade, mainly because of the range of exposure times. Moreover the limiting sensitivity varies across each individual IPC field because of mirrors vignetting. In determining the distribution of limiting sensitivities we have considered both effects as described by Sciortino et al. (1994). This is a crucial issue since the derived density can be affected by a too coarse limiting sensitivity distribution.

The last column of Table 1 indicates whether or not the system satisfies the present definition of active binary. We have flagged with y the stars we consider "bona fide" active binaries (in the following we refer to this subsample as "certain sample"), with y? stars that have some characteristics consistent with those of the active binaries, but that need to be studied in more detail to be confirmed as "certain" active binaries (heretofore "possible sample"), and with n the stars we have excluded from our sample. Each individual system and the reasons for its inclusion/exclusion are discussed in the appendix. We have assumed a typical error of 49% and 28% in distance for spectroscopic and photometric parallaxes respectively, as given by FGM89. In the table are also reported the values of the assumed scale height (according to FGM89) for each star.

It is immediately apparent by inspection that the active binary sample of FGM89 contains a relatively large fraction of early type (F5 or earlier) systems (3 out of 14), and these three systems alone account for $3.1 \cdot 10^{-4}$ pc^{-3}, or about 75% of the total space density. This fraction of early type systems contrasts with CABS2, in which only 15 out of the total 206 system listed which have a spectral type available have a component of spectral type F5 or earlier, and all of these have evolved later type companions, showing an important discrepancy between FGM89's sample and the optically selected sample of CABS2. As detailed in the discussion on individual systems in the Appendix, all but one of the earlier type active binary candidates of FGM89 are not distinguishable from normal main sequence F stars of comparable mass and age. Therefore, only one of the early type systems is present in the revised sample, which is mostly composed of solar-type system, with a spectral type distribution much closer to the one of CABS2.

To test the spatial uniformity of our samples we have applied the V'_e/V'_a test, as defined by Avni & Bahcall (1980) and modified by FGM89 to account for the effect of stellar scale heights. If our sample is uniformly distributed in space one expects $< V'_e/V'_a > = 0.5 \pm 1/\sqrt{12 \cdot N}$, where N is the number of stars present in our samples. We find $< V'_e/V'_a > = 0.42$ and 0.39 for the entire retained and for the certain sample, with uncertainties of 0.08 and 0.11, respectively. Both samples are therefore marginally consistent with an uniform distribution. Discrepancies from uniformity could be due to incorrect estimate of scale heights or of stellar distances.

4. Results

On the basis of Table 1 we have re-computed the space density of X-ray selected active binaries, finding it to be $7.7 \cdot 10^{-5}$ pc^{-3} and $3.7 \cdot 10^{-5}$ pc^{-3} for the entire retained sample ("certain + possible") and for the "certain" sample, respectively. In both cases we found a value significantly lower than the value reported by FGM89. We note that, about half of the density for the entire retained sample is contributed by the four stars we have added to the original FGM89 sample. We have also recomputed the median of $\log L_x$ for our samples, obtaining 29.97 dex ($-0.16, +0.06$) and 30.07 ($-0.06, +0.31$) for the retained and certain sample respectively, higher than the one for the total FGM89 sample. Errors indicated in parenthesis represent the sampling errors at 68% in the median determination estimated by the bootstrap procedure described in the following. The X-ray luminosity functions for the three sub-samples are shown in Fig. 1, from which it is evident that our revised samples cut away the low luminosity tail of FGM89's sample.

Given the large uncertainties, we expect the distance determination to be the largest contributor to the final uncertainty on the derived spatial density. To evaluate this effect we have used a bootstrap procedure, by generating for each stellar system 200 realizations of its distance assuming a uniform distribution in the range $(d - \Delta d, d + \Delta d)$. From each of the 200 samples we have computed the value of the medians of $\log L_X$, of individual contribution to the density and of the overall spatial density.

Table 1. The active binary sample of FGM89 (top part of the table) and the additional systems from Stocke et al. (1991) (4 bottom rows of the table). The quoted X-ray luminosity from FGM89 is in log(erg s^{-1}), while column ($1/V_a'$) gives the contribution of each system to the total space density, in units of 10^{-3} pc^{-3}. A flag after the distance indicates photometric (p) or spectroscopic (s) parallax. The columns P and e report, when available, the orbital period in days and the eccentricity from Baker et al. (1994). The last column indicates whether a system has been included in our revised sample

1E	Other Name	log L_X	Sp.	Scale Height	d(pc)	$1/V_a'$	P (d)	e	inc.?
1E0002.8+1602	SAO 91772	29.54	G5	340	32p	0.0179	1.844	0.006	n
1E0105.2+3144	HD 6680	28.96	F5	190	49p	0.1307			n
1E0244.8-0024	SAO 130113	29.63	G9	340	55p	0.0134	2.634	0.012	y
1E0315.8-1955		29.67	K5	350	72p	0.0117			n
1E0505.0-0527		30.38	G9	340	55p	0.0013	8.816	0.006	y
1E1022.6+1121		30.01	G6	340	112p	0.0040	1.371	0.015	y
1E1049.5-0849		30.07	G7	340	149s	0.0034	0.805	0.031	y
1E1127.8-1502	HD 100022	29.97	G0	340	95s	0.0046	2.296	0.007	y?
1E1208.6+3924	HD 105881	28.97	F5	190	76p	0.1265			n
1E1213.9+3809		31.99	G2	340	2980s	0.0000			y
1E1222.5+2548	HD 108102	29.81	F7	190	63p	0.0092			n
1E1440.4+5213	HD 129674	29.24	F3	190	86s	0.0531			n
1E1520.7-0625	GX Lib	30.80	K0	350	277s	0.0004	11.135	0.0	y
1E2116.7-1042		29.86	G2	340	231p	0.0065	4.796	0.505	y?
1E0011.6+0840		29.60	K0	350	81p	0.0146	0.959	0.014	y
1E0730.3+6546		29.81	F6	190	103p	0.0092	2.337	0.002	y?
1E1533.0+0919		29.57	K4	350	75p	0.0160	2.941	0.036	y?
1E1548.7+1125		30.03	K5	350	125p	0.0038	6.616	0.025	y?

In Table 2 we report these median values, together with their 10% – 90% quantiles. Given the cubic dependence of the volume on distance, the distribution of $1/V_a'$ is highly asymmetric, explaining why the spatial density derived from the nominal values corresponds to a quite low quantile of the distribution of possible density values when one takes into account distance uncertainties as we have done.

Using our sample of X-ray selected active binaries we therefore find that the discrepancy between the properties of X-ray selected and optically selected active binaries discussed by OS92 is no longer present. In particular, the spatial density is brought back to a value which is fully compatible with the range of values obtained from optical surveys quoted by DSL89 (who give a range from $3 \cdot 10^{-6}$ pc^{-3} to $\approx 1 \cdot 10^{-4}$ pc^{-3}). Also the median X-ray luminosity of the sample is now compatible with the value obtained for the DSL89 sample by OS92, specially when considering that our sample contains a small number of systems, and is therefore subject to a relatively large sampling error. Therefore, we find no reason to conclude that the X-ray and optical selected samples are inconsistent and cannot therefore be considered to be derived from the same parent population.

The space density of active binaries has also been used for computing their expected contribution to the soft X-ray background, and in particular their contribution to the Galactic ridge. While admittedly one would want to know what the total contribution of coronal sources is, rather than the contribution of a single class, the contribution of the active binaries to the Galactic ridge is of interest in itself. Their high X-ray luminosity coupled with the low space density tends to produce an emission strongly concentrated in the Galactic plane, and their relatively hard X-ray spectrum (Schmitt et al. 1990b) together with the observed Fe line emission at 6.7 keV (as it has been seen in UX

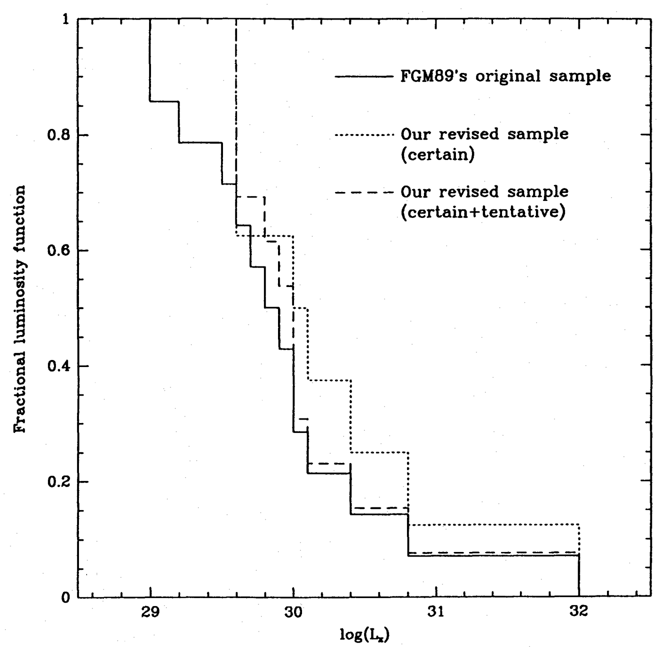

Fig. 1. The apparent X-ray luminosity functions for FGM89's original sample and for our revised samples

Table 2. The values of 10%, 50%, and 90% quantiles of $\log L_x$ and $1/V'_a$ obtained from a bootstrap procedure taking into account distance uncertainties

Name	$\log L_X$			$1/V'_a$ 10^{-3} pc^{-3}		
	10%	50%	90%	10%	50%	90%
SAO 91772	29.38	29.54	29.77	0.0099	0.0160	0.0394
HD 6680	28.78	28.98	29.16	0.0745	0.1307	0.2759
SAO 130113	29.46	29.62	29.85	0.0079	0.0148	0.0261
1E0315.8-1955	29.51	29.67	29.89	0.0067	0.0107	0.0237
1E0505.0-0527	30.20	30.36	30.61	0.0008	0.0014	0.0026
1E1022.6+1121	29.84	30.00	30.23	0.0024	0.0042	0.0064
1E1049.5-0849	29.78	30.06	30.52	0.0015	0.0037	0.0126
HD 100022	29.70	29.95	30.38	0.0020	0.0055	0.0154
HD 105881	28.78	28.96	29.19	0.0705	0.1161	0.2546
1E1213.9+3809	31.70	31.96	32.41	0.0000	0.0000	0.0001
HD 108102	29.63	29.80	30.04	0.0055	0.0091	0.0172
HD 129674	28.96	29.22	29.66	0.0209	0.0534	0.2290
GX Lib	30.52	30.82	31.21	0.0002	0.0004	0.0013
1E2116.7-1042	29.69	29.84	30.08	0.0036	0.0063	0.0126
1E0011.6+0840	29.43	29.61	29.81	0.0084	0.0137	0.0297
1E0730.3+6546	29.54	29.80	30.24	0.0041	0.0104	0.0341
1E1533.0+0919	29.40	29.57	29.78	0.0090	0.0157	0.0307
1E1548.7+1125	29.85	30.00	30.22	0.0023	0.0038	0.0077
Entire Retained Sample	29.59	29.99	31.16	0.0763	0.0938	0.1223
Certain Sample	29.61	30.07	31.75	0.0314	0.0439	0.0603

Ari, cf. Pasquini et al. 1989) makes them attractive candidates to explain the observed spectral characteristics of the ridge. OS92 have assumed, for their computation of the contribution of active binaries to the soft X-ray background and to the Galactic ridge, a density of $5.7 \cdot 10^{-5}$ pc^{-3} and a mean X-ray luminosity of 30.62 dex. This results in a total emissivity (cf. Eq. 2 of OS92) of $1.9 \cdot 10^{25}$ erg sec^{-1}. By instead considering our two samples we derive a total emissivity of 1.77 (+0.15, −0.12) $\cdot 10^{24}$ erg sec^{-1} and 3.30 (+0.24, −0.20) $\cdot 10^{24}$ erg sec^{-1}, for the "certain" and "possible" samples, respectively. Errors in parenthesis represent the 10% and 90% quantiles obtained from the same bootstrap procedure described above. Hence our newly deduced values are at least one order of magnitude lower than OS92's value. Assuming that the total contribution of active binaries scales linearly with emissivity, OS92's calculations would therefore largely over-estimate the contribution of active binaries to the X-ray background. In other word, our re-estimate of the active binaries density show that they cannot explain the majority of the diffuse emission in the Galactic ridge.

On the other hand, X-ray fainter and softer sources, such as dMe stars, while probably contributing to the soft X-ray background, are expected to produce a more isotropic contribution (cf. Schmitt & Snowden 1990; Kashyap et al. 1992). However as suggested by Micela et al. (1991), if one accounts for the age-dependence of scale heights and X-ray luminosity levels the contribution of young active late-type stars becomes an alternative explanation to the origin of the Galactic ridge. A preliminary calculation (Micela 1991) supports this view, and a detailed report of the full set of calculation will appear in a forthcoming paper.

It will of course be quite interesting to compare, in the future, these results, derived from a relatively small sample, with the results on the space densities of active binaries which will come from the ROSAT All Sky Survey (RASS). This will unfortunately not be possible until the source list is available. Also, optical counterparts need to be identified, for a sample complete down to a certain limiting flux level, at a reasonable level of confidence, and the detailed limiting sensitivity sky map of the RASS will also be needed. Works such as Dempsey et al. (1993) are in this regard of no help, being based on lists of previously identified active binaries (in particular CABS2), and therefore not saying anything about the number of yet unidentified active binaries present in the X-ray source list and about the volume of space actually sampled.

Finally we note that the range of deduced density values for the active binaries confirm the findings of Sciortino et al. (1994) and Favata et al. (1994) that the active binaries cannot account for the excess of yellow stars observed in the EMSS.

Appendix A: notes on individual objects

- **SAO 91772**: classified as an RS CVn type system by Stocke et al. (1991), this system actually appears to be an active Pop II binary, as reported by Pasquini & Lindgren (1994). It does satisfy in a sense our definition of active binary, in that the rotational velocity and therefore the activity level are strongly increased by the tidal locking with respect to normal Pop II objects. However, by virtue of its being a Pop II object, it should not be included in the density estimates of Pop I active binaries.

- **HD 6680**: a early type system (F5), classified in the literature as luminosity class IV (Cowley 1976). Eggen (1970) considers it a member of the Hyades moving group, which would imply an age of about 800 My. Neither its rotational velocity nor its X-ray luminosity are peculiar when compared to single normal stars of the same mass and age. Actually, its X-ray luminosity (28.96 dex) lies below the median X-ray luminosity for F stars in the Hyades (Micela et al. 1988). It therefore does not satisfy our criteria for an active binary.
- **SAO 130113**: this object, also observed by EXOSAT, has been studied in detail by Tagliaferri et al. (1994), who classify it as G6V+K6V or K2IV+F7V, on the basis of photometric data. They also derive a higher distance than FGM89, which increases the X-ray luminosity of the system by at least 0.5 dex. If we use this luminosity the contribution of this star to the spatial density of active binaries decreases by a factor $\sim$ 5. The orbital period from BSMLN94 is 2.634 days, with $e = 0.012$. Tagliaferri et al. (1994) report two spectra to be visible, with equal rotational velocity (18 km/s), high for its mass and indicative of a locked binary. A bona fide active binary. Its lithium abundance (Favata et al. 1993, hereafter FBMS93; Tagliaferri et al. 1994) is within the normal range observed in active binaries.
- **1E0315.8-1955**: the high lithium abundance, close to the Pop I cosmic abundance, as reported by FBMS93, make this a PMS system. Its X-ray luminosity (29.67 dex) is not at all exceptional for very young K dwarfs (Micela et al. 1990). This system does not therefore satisfy our definition of active binary.
- **1E0505.0-0527**: the presence of an evolved component (luminosity class IV), together with the high rotational velocity, the low eccentricity ($e = 0.006$ for a period of 8.816 days) reported by BSMLN94 and X-ray luminosity make this a bona fide active binary. Lithium from FBMS93 is compatible with values typical of active binaries.
- **1E1022.6+1121**: fast rotator for its spectral type G6 (58 km/s from FGM89), its X-ray luminosity (30.01 dex) is also high with respect to field stars of the same type, although it would be not untypical for a very young system. On the other hand the lack of detectable lithium (FBMS93) together with the short period and low eccentricity ($P = 1.371, e = 0.015$) points against its being young, and we therefore consider it a bona fide active binary.
- **1E1049.5-0849**: the same considerations apply as for 1E1022.6+1121, with $P = 0.805, e = 0.031$. Also a bona fide active binary.
- **HD 100022**: the rotational velocity of this system (21 km/s) is relatively high for its G0 spectral type, which is reported as G2V in Simbad. Also the X-ray luminosity (29.97 dex) is rather high for the spectral type. Given that FGM89 report an orbital period of 2.3 d, and BSMLN94 report a low eccentricity ($e = 0.007$), the system satisfies our definition of active binary. No lithium measurements are unfortunately available for this system, for this reason we include this star in the "possible" sample.
- **HD 105881**: classified as F3V by Seto & Kuji (1990), an age of 9.3 Gy is derived for this system by Hill et al. (1976), who additionally find no radial velocity variations for the system. Given that FGM89 report only two radial velocity measurements for this system, which differ by about 14 km/s, if it is a binary it is unlikely to have a short period. The rotational velocity is reported as variable by FGM89. The X-ray luminosity (28.97 dex) is normal for a field dF star, and therefore we find no evidence to support its classification as an active binary.
- **1E1213.9+3809**: FGM89 report two radial velocity measurements, differing by about 11 km/s, and a rotational velocity of 11 km/s, with no luminosity class. The inferred X-ray luminosity (31.99 dex), exceptional even for a very young solar-type star, votes in favor of this system being an active binary.
- **HD 108102**: this is a member of the Coma cluster, and has been studied by Boesgaard (1987) who measured the lithium abundance and the rotational velocity in a set of A-F dwarfs in Coma. Although a relatively fast rotator (35 km/s), its $v\,\sin(i)$ is by no means exceptional for F stars in Coma. Its lithium abundance is normal, and also the X-ray luminosity reported by FGM89 (29.81 dex) although relatively high, is well within the normal values for young late F-early G dwarfs (Micela et al. 1990, 1994; Stauffer et al. 1994). Finally Huisong & Xuefu (1987) show that the system is not tidally locked. Therefore we see no reason to classify it as an active binary, and consider it rather a normal young, active F-type star.
- **HD 129674**: included in CABS2 on the basis of its being reported as active binary by FGM89, but with the comment "most likely too early in spectral type to be chromospherically active". It is a fast rotator (FGM89 report 70 km/s), with an X-ray luminosity of 29.24 dex. Neither the rotation nor the X-ray luminosity (Schmitt et al. 1985) are really exceptional for its early spectral type. The presence of the companion does not appear therefore to influence the rotation or the activity, and therefore this system does not satisfy our criteria for an active binary.
- **GX Lib**: a well known active binary, listed as K1III by Randich et al. (1993).
- **1E2116.7-1042**: FGM89 report it as a fast rotator (60 km/s) with relatively large radial velocity variations (about 40 km/s over two observations). Its X-ray luminosity is high (29.86 dex) for its spectral class. BSMLN94 give $P = 4.796, e = 0.505$. The strong eccentricity is indicative of a non-synchronized orbit, perhaps indicative of young age. Lithium observations and kinematics would help exclude the possibility of its being a young system. We include this star in the "possible" active binary sample.

A.1. Systems originally not in FGM89

The following four systems are not listed in FGM89, although they satisfy all the criteria set forth in FGM89.

- **1E0011.6+0840**: a BY Dra candidate from Stocke et al. (1991). Listed as a binary system in Fleming (1988), who also report a K0Ve spectral type, with a maximum radial velocity difference of about 50 km/s. BSMLN94 give $P = 0.959, e = 0.014$, and the $v \sin(i)$ of about 22 km/s is compatible with rotational locking. FBMS93 find a lithium abundance (N(Li)=1.75) on the upper range of the values found in active binaries, and definitely below the values found in very young EMSS stars. We therefore include it in the "extended" active binary sample.
- **1E0730.3+6546**: an RS CVn candidate from Stocke et al. (1991). It is listed as a binary system in Fleming (1988), with a rotational velocity of 17 km/s. BSMLN94 give $P = 2.337, e = 0.002$, with an almost circular orbit and a $v \sin(i)$ compatible with being a locked binary. This system has been studied by Silva et al. (1987), who classify it as G0, and who report an upper limit to the 6 cm radio flux from this system of 0.8 mJ. Its X-ray luminosity (29.8 dex) lies on the upper range for early G stars, but it is not exceptional for a young early G star. Its kinematics (U, V, W = (-16, +23, -21)) are not typical of young active solar-type stars (Soderblom 1990), and we therefore include it in the "possible" active binary sample.
- **1E1533.0+0919**: a BY Dra candidate from Stocke et al. (1991). Listed as a binary system in Fleming (1988), who also report a K0Ve spectral type, and a $v \sin(i)$ of about 30 km/s. Its X-ray luminosity is 29.6 dex, relatively high but not exceptional for a young system. The period from BSMLN94 is $P = 2.941, e = 0.036$, with a relatively high eccentricity. Unfortunately no lithium abundances are available for it, and we cannot therefore discriminate whether it is a bona fide active binary or rather a young system similar to 1E0315.8-1955. We include it in the "possible" active binary sample.
- **1E1548.7+1125**: a BY Dra candidate from Stocke et al. (1991), who report $v \sin(i) = 30$ km/s. Silva et al. (1985) report CaII H&K emission and no visible Balmer series emission at 1 Å resolution. Its f_X/f_v is quite high (-1.3 dex), as it is the X-ray luminosity (30.0 dex). The period from BSMLN94 is $P = 6.616, e = 0.025$. Unfortunately no lithium abundances are available for it, and we cannot therefore discriminate whether it is a bona fide active binary or rather a young system similar to 1E0315.8-1955. We include it in the "possible" active binary sample.

Acknowledgements. GM and SS acknowledge financial support from MURST (Ministero della Università e della Ricerca Scientifica e Tecnologica), and GNA-CNR. We have extensively used the Simbad database to prepare this paper. We would also like to thank the referee, K. Strassmeier, for the helpful comments and the very careful reading of the manuscript.

References

Avni, Y., Bahcall, J. N. 1980, ApJ, 235, 694
Baker, A.J., Stefanik, R.P., Marschall, L.A., Latham, D.W., Nations, H.L. 1994, in Cool Stars, Stellar Systems and the Sun, J.P. Caillault ed., ASP Conference Series Vol. 64, p. 551
Bidelman, W.P. 1954, ApJS 1, 175
Boesgaard, A.M. 1987, ApJ 321, 967
Collier, A.C., 1976, PhD Thesis, Univ. of Canterbury, NZ
Cowley, A.P. 1976, PASP 88, 95
Dempsey, R.C, Linsky, J.L., Fleming, T.A., Schmitt, J.H.M.M. 1993, ApJS 86, 559
Drake, S.A., Simon, T. and Linsky, J.L. 1989, ApJS 71, 905
Eggen, O.J. 1970, PASP 82, 99
Favata, F., Barbera, M., Micela, G., Sciortino, S. 1994, A&A in press
Favata, F., Barbera, M., Micela, G., Sciortino, S. 1993, A&A 277, 428 (FBMS93)
Fekel, F.C., Moffett, T.J. and Henry, G.W. 1986, ApJS 60, 551
Fleming, T.A. 1988, Ph.D. Thesis, Univ. of Arizona
Fleming, T.A., Gioia, I., Maccacaro, T. 1989, AJ 98, 2, 692 (FGM89)
Gioia, I.M., Maccacaro, T., Schild, R.E. et al. 1990, ApJS, 72, 567
Hall, D.S. 1976, in *IAU Colloquium 29, Multiply Periodic Phenomena in Variable Stars*, ed. W.S. Fitch (Dordrecht, Reidel), p. 287
Hill G., Allison A., Fisher W.A. et al. 1976, MNRAS 82, 69
Huisong, T., Xuefu, L. 1987, A&A 172, 74
Kashyap, V., Rosner, R., Micela et al. 1992, ApJ, 391, 667.
Micela, G., Sciortino, S., Vaiana, G.S. et al. 1988, ApJ 325, 798
Micela, G., Sciortino, S., Vaiana, G.S. et al. 1990, ApJ 348, 557
Micela, G., Harnden, F.R., R. Rosner, R. et al. 1991, ApJ 380, 495
Micela, G. 1991, Ph. D. Thesis, University of Palermo
Micela, G., Sciortino, S., Kashyap, V. et al. 1994, ApJ submitted
Morris, D.H., Mutel, R.L. 1988, AJ 95, 204
Ottman, R., Schmitt, J.H.M.M. 1992, A&A 256, 421 (OS92)
Pasquini, L., Schmitt, J.H.M.M., Pallavicini, R. 1989, A&A 225, 225
Pasquini, L., Cutispoto, G., Gratton, R. et al. 1991, A&A 248, 72
Pasquini, L., Lindgren, H. 1994, A&A 283, 179
Pye, J.P., Hodgkin, S.T., Stern, R.A., Stauffer, J.R. 1994, MNRAS 266, 798
Randich, S., Gratton, R., Pallavicini, R. 1993, A&A 273, 194
Schmidt, M. 1968, ApJ, 151, 393
Schmitt, J.H.M.M., Snowden, S.L. 1990, ApJ 365, 704
Schmitt, J.H.M.M., Collura, A., Sciortino, S. et al. 1990b, ApJ 361, 207
Schmitt, J.H.M.M., Golub, L., Harnden, F.R. et al. 1985, ApJ 290, 307
Sciortino, S., Favata, F., Micela, M. 1994, A&A in press (SFM)
Seto K., Kuji S. 1990, A&AS 85, 1069
Silva, D.R., Gioia, I.M., Maccacaro, T., Mereghetti, S., Stocke, J.T. 1987, AJ 93, 869
Silva, D.R., Liebert, J., Stocke, J.T., Aaronson, M. 1985, PASP 97, 1096
Soderblom, D.R. 1990, AJ, 100, 204
Stauffer, J., R., Caillault, J.-P., Gagne, M., Prosser, C.F., & Hartmann, L.W., 1994, ApJS, 91, 625
Stocke, J.T., Morris, S.L., Gioia, I.M. et al. 1991, ApJS, 76, 813, 218
Strassmeier, K.G., Hall, D.S., Fekel, F.C., Scheck, M. 1993, A&AS 100, 173 (CABS2)
Strassmeier, K.G., Hall, D.S., Zeilik, M. et al. 1988, A&AS 72, 291 (CABS)
Tagliaferri, G., Cutispoto, G., Pallavicini, R. et al. 1994, A&A 285, 272