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On X-ray variability in ROSAT-PSPC observations of F7-K2 stars

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Abstract. We have analyzed the X-ray variability of dF7-dK2 stars in the solar neighborhood detected with the pointed ROSAT-PSPC observations. Our data base is the sample of all stars listed in the CNS3 catalog (Gliese & Jahreiβ 1991) having a $B-V$ color between 0.5 and 0.9; it includes 70 pointed observations of 40 distinct stars or multiple systems. We have applied the unbinned Kolmogorov-Smirnov test on all X-ray photon time series of our sample: only 10 observations relative to 8 distinct stars are variable at a confidence level greater than 99% and 4 of them belong to multiple systems. For the subsample of 9 stars observed both at the beginning and at the end of the mission, we can study the variability on time scale of years and compare amplitude variations at short and long time scales. Our analysis suggests that, for these stars, the X-ray variability is more likely on longer time scale. All the stars variable on long time scale, and not on short time scale, are relatively quiet and similar to the Sun, suggesting that the variations may be due to cycles. The comparison of our results with those previously obtained for dM stars shows that the amplitude of variability of X-ray emission from dF7-dK2 stars is smaller than that observed in dM stars.

Key words. stars: coronae – stars: late-type – X-rays: stars – galaxy: solar neighbourhood

1. Introduction

The Sun is the only star for which X-ray variability is extensively studied on virtually all time scales (e.g. Vaiana et al. 1973; Vaiana & Tucker 1974; Kreplin et al. 1977; Zombeck et al. 1978; Withbroe et al. 1985). The soft X-ray emission of the Sun is highly variable on time scales ranging from minutes to years. Moreover, observations of the Sun have high spatial, spectral and temporal resolution, and span a much longer time interval than stellar observations. Resolving the structure of the solar corona, presently down to ~700 km, allows us to identify directly the sources of X-ray emission and to relate variations of the global solar X-ray flux (e.g. Kreplin et al. 1977; Kahler & Kreplin 1991; Donnelly & Bouwer 1981; Peres et al. 2000; Orlando et al. 2001) to the originating structures on the Sun.

Since no equivalent studies are possible for other stars, X-ray variability studies provide a powerful tool to test the properties of coronae of late-type stars and to infer the presence of solar-like phenomena. We know that magnetic phenomena largely determine the level of solar coronal activity; by analogy, we expect the same to hold for solar-type stars. Solar observations are the benchmark against which to test dynamo models: these models are calibrated on the Sun. While the Sun offers unique observational details and it is a very fruitful test for theory, it suffers the difficulty that relevant stellar parameters that are supposed to affect model prediction cannot be varied. Hence comparing the Sun with late-type stars with different masses, rotation rates and evolutionary states will help us in understanding how the dynamo process depends on basic stellar parameters.

The systematic analysis of the X-ray variability of nearby dM stars as observed with ROSAT-PSPC (Marino et al. 2000, hereafter Paper I), showed that variability is a general property of these stars on all time scales we have explored. The amplitudes of these variations are independent from both stellar X-ray and visual luminosity. Compared to properties of solar X-ray variability our results suggest that the amplitude distribution of X-ray variability in dM stars is consistent with the analogous distribution for solar flares. The comparison of our data with those obtained with *Einstein* IPC showed that long term

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variability (on time scales longer than 10 years), if present, must be of smaller amplitudes than the short term variations observed in the ROSAT X-ray light curves (Paper I).

Coronal and chromospheric activity are known to be related (Schrijver et al. 1992). The observations of the Ca II H and K lines has allowed to monitor the chromospheric activity of solar-type stars in detail (Wilson 1978; Baliunas & Vaughan 1985; Baliunas et al. 1995). These data show a variety of behaviors which can be basically reduced to three different types: mostly old quiet stars like the Sun show a cyclic behavior, with periods ranging from about 3 to 15 years or more; young active stars usually show a chaotic behavior with no obvious periodicities; the remaining stars appear to be constant, with no indication at all of an activity cycle. The X-ray emission of the stars in the spectral range dF7-dG9 observed with EINSTEIN Observatory (Maggio et al. 1987) resulted well correlated with their cromospheric Ca II H-K line emission.

In this paper we present a study of X-ray variability of nearby dF7-dK2 stars detected with ROSAT-PSPC (Pfeffermann et al. 1987; Trümper 1992) pointed observations. Since, the sensitivity of ROSAT-PSPC is much higher than that of the *Einstein* IPC, we can study variability of smaller amplitudes and in more X-ray quiet stars. Furthermore, a better time coverage is reached since the typical observation live times with ROSAT are longer than with *Einstein.* ROSAT observations (similary to *Einstein* ones) are fragmented in time segments of typically a few thousand seconds.

Our paper is organized as follows: in Sect. 2 we present our sample of dF7-dK2 stars, the X-ray data, and their analysis. The basic results are given in Sect. 3. In Sect. 4, we draw our conclusions.

2. Observations and data analysis

2.1. The sample

Our sample contains all stars in the spectral range dF7-dK2, listed in the CNS3 catalog, having a $(B-V)$ color between 0.5 and 0.9, detected in ROSAT-PSPC pointed observations. Among these, we have selected all stars detected with more than 40 net counts and having an off-axis angle from the center of the field of view less than 48 arcmin. Our sample consists of 40 stars, for a total of 70 distinct observations. Fifteen of these stars were multiply observed with the ROSAT-PSPC at time intervals typically separated by months; in these cases we can explore variability up to these time scales. Table 1 summarizes the optical characteristics of our sample stars. Columns 1 and 2 provide the stellar names according to the catalogs by Gliese & Jahreiss (1991), Woolley and HD number, while more common names are given in Col. 8. The distances in Col. 5 are from the Hipparcos catalogue (Perryman et al. 1997) for all the stars having Hipparcos measurements, for the only one (GL 663) without Hipparcos measurement we report the CNS3 distance. The other optical data are taken from the CNS3 catalog or SIMBAD database.

Table 1. Optical properties of the selected sample.

Name	HD	Sp. Type	$B-V$	Dist. (pc)	Single B./T.	Other name
GL5	166	K0 Ve	0.75	13.70	S	
GL17	1581	F9 V	0.58	8.59	S	ζ Tuc
GL17.3	1835	G2 V	0.66	20.39	S	BE Cet
GL19	2151	G2 IV	0.57	7.47	S	β Hyi
GL41	5015	F8 V	0.53	18.57	S	
GL68	10476	K1 V	0.84	7.47	S	107 Psc
GL86	13445	K0 V	0.82	10.91	S	
GL117	17925	K2 V	0.87	10.38	S	EP Eri
GL124	19373	G0 V	0.60	10.53	S	τ Per
GL137	20630	G5 Ve	0.68	9.16	S	κ Cet
GL139	20794	G5 V	0.71	6.06	S	82 Eri
Wo9158	28946	K1	0.79	26.79	S	
GL189	33262	F7 V	0.52	11.65	S	ζ Dor
GL211	37394	K1 Ve	0.84	12.24	S	
Wo9189	39091	G1 V	0.60	18.21	S	
GL231	43834	G5 V	0.72	10.15	S	$\propto$ Men
GL311	72905	G1 V	0.62	14.27	S	π^1 UMa
GL434	101501	G8 Ve	0.72	9.54	S	61 UMa
GL449	102870	F9 V	0.55	10.90	S	β Vir
GL3715	106156	G8 V	0.79	30.96	S	
GL475	109358	G0 V	0.59	8.37	SB	β CVn
GL502	114710	G0 V	0.57	9.15	S	β Com
GL506	115617	G6 V	0.71	8.53	S	61 Vir
GL559A	128620	G2e V	0.64	1.35	B	α^1 Cen
GL559B	128621	K0 V	0.84	1.35	B	α^2 Cen
GL559.1	129333	dG0 e	0.61	33.94	S	EK Dra
GL566A	131156	G8 Ve	0.73	6.70	B	ξ Boo A
GL566B	131156	K4 Ve	1.16	6.70	B	ξ Boo B
GL567	131511	K2 V	0.84	11.54	S	DE Boo
GL575A	133640	F9 V	0.65	12.76	B	44 Boo A
GL575B		G2		12.76	B	44 Boo B
GL598	141004	G0 V	0.60	11.75	S	λ Ser
GL620.1A	147513	G3/5 V	0.63	12.87	B	
GL635A	150680	G0 IV	0.65	10.79	B	ζ Her A
GL635B		K0 V	0.75	10.79	B	ζ Her B
GL641	152391	G8 V	0.76	16.94	S	
GL663A	155886	K1 Ve	0.85	5.33	B	36 OphA
GL663B	155885	K1 Ve	0.86	5.33	B	36 OphB
GL691	160691	G5 V	0.70	15.28	S	μ Ara
GL732.1	175225	G9 IVa	0.84	26.10	S	
GL744	177565	G5 IV	0.71	17.17	S	
GL764	185144	K0 V	0.79	5.77	S	σ Dra
GL779	190406	G1 V	0.61	17.67	S	15 Sge
GJ1255	197433	K0 V	0.86	27.65	B	VW Cep
GL882	217014	G4 V	0.67	15.36	S	51 Peg

2.2. X-ray observations

Table 2 provides a journal of the ROSAT-PSPC observations in our study. Column 1 gives the star's name (as in Table 1), the ROSAT Observation Request (ROR) is listed in Col. 2, and the date of the observation in Col. 5; the esposure-time for each observation is given in Col. 3, while in Col. 4 we provide the total time spanned by the observation. In Col. 6 we give the hardness ratio, defined as $HR = \frac{H-S}{H+S}$, S being the number of photons measured in channels 3–10 (0.11–0.42) keV and H the number of

Table 2. Journal of ROSAT PSPC observations. Asterisks indicate stars observed over at least four temporal segments having more than 30 counts each. In Col. 9, K-S results “-” indicate a Confidence Level ≤90%.

Name	Obs. seq.	Exposure (s)	Elapsed Time Time (s)	Observing Dates	HR	Rate ± Err. [cnt/s]	L_x [erg/s]	Results of the K-S test
GL5	200645N00	2575	6308	91/12/20	−0.19	0.859 ± 0.018	29.13	≥99%
GL17	201138N00	2385	1 600 708	93/05/09–27	−0.85	0.029 ± 0.003	27.03	-
GL17.3*	201470N00	5388	201 731	93/06/16–18	−0.17	0.408 ± 0.009	29.15	-
GL19	200071A01	2668	965 914	92/11/17–29	−1.00	0.043 ± 0.004	26.98	-
GL19	200071N00	1743	1819	91/04/21–91/05/11	−0.65	0.111 ± 0.008	27.63	-
GL41*	400379N00	5587	65 137	93/07/16–17	−0.61	0.059 ± 0.003	28.16	≥99%
GL68	201768N00	3968	24 912	93/07/14	−0.54	0.029 ± 0.003	27.09	-
GL86*	701156N00	1723	6464	93/06/09	−0.60	0.097 ± 0.008	27.92	-
GL86*	701157N00	1995	6640	93/06/08	−0.67	0.113 ± 0.008	27.97	-
GL86*	701158N00	1914	6732	93/06/07	−0.57	0.127 ± 0.008	28.04	-
GL86*	701159N00	2400	14 822	93/05/28	−0.65	0.098 ± 0.008	27.91	-
GL86*	701160N00	3587	7764	93/05/29	−0.55	0.117 ± 0.006	28.02	-
GL86*	701161N00	1621	1811	93/05/30	−0.54	0.143 ± 0.009	28.11	-
GL86*	701162N00	1335	1472	93/05/31	−0.65	0.129 ± 0.010	28.03	-
GL86*	701163N00	2449	41 037	93/06/01	−0.50	0.143 ± 0.008	28.11	-
GL86*	701164N00	1589	1780	93/06/02	−0.53	0.130 ± 0.009	28.07	-
GL86*	701166N00	1036	1154	93/06/04	−0.48	0.111 ± 0.010	28.01	-
GL86*	701167N00	2373	6856	93/06/05	−0.52	0.128 ± 0.007	28.06	-
GL86*	701168N00	2251	6722	93/06/06	−0.49	0.136 ± 0.008	28.09	-
GL117	150055N00	3880	247 597	90/07/20–23	−0.19	1.107 ± 0.017	29.00	≥99%
GL124	180169N00	1821	1962	97/02/23	−0.67	0.068 ± 0.006	27.71	-
GL137	201473N00	1588	1676	93/07/27	−0.39	1.115 ± 0.026	28.87	-
GL139	201139N00	1738	333 240	92/08/13–17	−0.83	0.024 ± 0.004	26.67	90%–95%
GL189	200644N00	500	529	92/01/30	−0.20	1.476 ± 0.054	29.22	-
GL211	201509N00	5498	224 831	92/03/11–12	−0.43	0.432 ± 0.009	28.71	-
GL231*	180172N00	2660	574 955	97/02/23–97/03/02	−0.75	0.032 ± 0.003	27.31	-
GL231*	201142N00	2573	29 266	92/11/06	−0.84	0.077 ± 0.005	27.62	-
GL311*	200654N00	21 730	186 681	92/04/25–27	−0.25	0.847 ± 0.006	29.15	95%–99%
GL311*	201472N00	4756	402 169	93/10/05–10	−0.19	0.884 ± 0.014	29.18	90%–95%
GL434	201120N00	1956	52 782	93/05/18–19	−0.41	0.428 ± 0.015	28.49	-
GL449*	200813N00	7433	99 760	92/06/02–03	−0.51	0.449 ± 0.008	28.61	-
GL475*	201141N00	2690	526 766	93/05/22–28	−0.89	0.048 ± 0.004	27.19	-
GL475*	900137N00	20 537	85 622	91/06/01–02	−0.80	0.076 ± 0.002	27.48	≥99%
GL502*	110309N00	904	35 777	90/06/28	−0.49	0.384 ± 0.021	28.39	-
GL502*	110315N00	775	46 445	90/06/28	−0.51	0.402 ± 0.023	28.41	-
GL502*	110342N00	1217	34 744	90/06/27	−0.60	0.476 ± 0.020	28.46	90%–95%
GL502*	140315N00	432	629	90/07/08–09	−0.63	0.364 ± 0.029	28.33	-
GL502*	140316N00	1205	12 719	90/07/09	−0.61	0.439 ± 0.019	28.42	-
GL502*	201471N00	8135	71 257	93/06/17–18	−0.70	0.359 ± 0.007	28.30	-
GL506	201144N00	3113	506 395	92/07/23–29	−0.94	0.021 ± 0.003	26.80	95%–99%
GL559AB*	180025N00	357	374	93/09/14	−0.54	9.958 ± 0.167	28.13	-
GL559AB*	201119N00	3260	98 824	92/09/02–03	−0.85	4.693 ± 0.038	27.64	≥99%
GL559.1*	200069N00	7136	26 020	91/05/09	0.06	1.290 ± 0.013	30.17	≥99%
GL559.1*	150015A01	5673	108 940	93/04/15–16	0.004	0.909 ± 0.013	29.95	≥99%
GL559.1*	201474N00	4891	14 552	93/10/19	0.01	0.869 ± 0.013	29.97	≥99%
GL566AB	150090N00	464	486	90/07/22–23	−0.30	2.482 ± 0.073	28.96	90%–95%
GL567	150090N00	391	486	90/07/22–23	−0.52	0.414 ± 0.033	28.62	-
GL567	800294N00	2650	82 858	92/08/08–09	−0.46	0.476 ± 0.013	28.69	90%–95%
GL575AB	200841N00	2166	2286	92/06/15	−0.13	3.915 ± 0.043	29.73	-
GL598	180174N00	2726	75 869	97/02/21	−0.91	0.091 ± 0.006	27.75	-
GL620.1A	200588A01	1234	1316	93/03/05–06	−0.27	0.816 ± 0.026	29.05	-
GL620.1A	200588N00	1724	1857	92/02/26	−0.24	0.758 ± 0.021	29.02	-
GL635AB	180173N00	1841	1984	97/02/23	−0.86	0.098 ± 0.007	27.76	-
GL635AB	201136N00	7752	9129	94/09/08	−0.72	0.185 ± 0.005	28.14	-
GL641	201371N00	1956	18 620	92/09/08	−0.33	0.260 ± 0.012	28.78	-

Table 2. continued.

Name	Obs. seq.	Live-time (s)	Elapsed Time (s)	Observing Dates	HR	Rate ± Err. [cnt/s]	L_x [erg/s]	Results of the K-S test
GL663AB	201373N00	1783	80 796	92/09/21	-0.43	1.233 ± 0.026	28.44	$\geq$99%
GL691	201147N00	2894	7346	92/10/04	-0.69	0.023 ± 0.003	27.80	-
GL732.1	200976N00	1842	1983	92/11/01	-0.08	0.916 ± 0.022	29.72	-
GL732.1	201021N00	2110	3597	92/11/28	-0.19	0.584 ± 0.017	29.52	90%–95%
GL744	200494A00	1734	17 539	91/10/22	-0.77	0.041 ± 0.005	27.86	-
GL744	200494A01	2891	162 161	92/04/15–17	-0.91	0.022 ± 0.003	27.47	-
GL764*	180170N00	1647	2228	97/02/24	-0.74	0.407 ± 0.016	27.93	-
GL764*	201125N00	2684	2916	92/11/03	-0.77	0.189 ± 0.008	27.57	-
GL779	201475N00	5634	77 300	93/11/15–16	-0.69	0.064 ± 0.003	28.13	-
GL882	201282N00	11 983	100 323	92/12/28–29	-1.00	0.008 ± 0.001	26.84	-
GL1255*	201763N00	18 523	98 300	92/12/28–29	0.00	1.758 ± 0.010	30.06	$\geq$99%
GL3715	700079A00	1966	52 925	91/12/16–17	-0.43	0.031 ± 0.004	28.37	95%–99%
Wo9158	700916N00	2905	7161	93/09/02	-0.72	0.018 ± 0.003	27.93	-
Wo9158	700945N00	2331	2516	93/03/06	-0.83	0.018 ± 0.003	27.84	-
Wo9189	999998A01	7107	526 765	91/03/05–91/04/24	-0.90	0.016 ± 0.001	27.38	-

Table 3. Variability on longer time scale: here we use multiple ROSAT observations separed by at least 6 months. As in Table 2, a "-" in K-S results means a Confidence Level $\leq$90%.

name	HD	$<L_\mathrm{x}>$ range [erg/s]	K-S results on short-time scale	K-S results on long-time scale	Elapsed time of each obs. [hours]	Elapsed time of all obs. [months]
GL19	2151	26.98–27.63	-	$\geq$99%	0.5–268	18
GL231	43834	27.31–27.62	-	$\geq$99%	8–160	52
GL559	128620/1	27.64–28.13	$\leq$90%–$\geq$99%	$\geq$99%	0.1–27	12
GL559.1	129333	29.95–30.17	$\geq$99%	$\geq$99%	4–7–30	30
GL620.1	147513	29.02–29.05	-	-	0.4–0.5	12
GL635	150680	27.76–28.14	-	$\geq$99%	0.6–2.5	30
GL744	177565	27.47–27.86	-	$\geq$99%	5–45	6
GL764	185144	27.57–27.93	-	$\geq$99%	0.6–0.8	50
Wo9158	28946	27.84–27.93	-	-	0.7–2	6

photons recorded in channels 11–30 (0.42–2.4) keV. In Col. 7 we report the count rate in the (0.1–2.4) keV range. The mean X-ray luminosity, computed as explained below, is given in Col. 8 and the results of the Kolmogorov-Smirnov test discussed in Sect. 3 (e.g. Eadie et al. 1971; Siegel 1956) are presented in Col. 9.

For each star we evaluated the number of photon counts in a circular region centered on the average position of the observed photons in the (0.1–2.4) keV range and with a radius R, ranging from 2 arcmin for sources positioned on the optical axis, up to 5 arcmin, for sources at large off-axis positions. Count rates of the off-axis sources were corrected for vignetting. The radius R has been determined as described in Paper I.

2.3. Flux and luminosity determination

The conversion factor from count rate to X-ray flux depends on the instrumental properties, on the interstellar hydrogen column along the line of sight, and on the source spectrum. The X-ray emission was assumed to be produced by a single temperature plasma described by a Raymond-Smith model spectrum (Raymond & Smith 1977). Interstellar absorption has not been included since this effect is negligible in the case of our sample of nearby stars. For these conditions we modeled a conversion factor [erg cm^{-2}/count] as a function of the observed Hardness Ratio HR (as also described in Sect. 2.3 and Fig. 1 of the Paper I).

We computed X-ray luminosities from the obtained fluxes and the distances reported in Table 1. Since each observation consists of a set of temporal segments typically obtained during different satellite orbits we estimated count rate, HR, flux and X-ray luminosity for each temporal segment with at least 30 counts. In Fig. 1 we show the scatter diagram of X-ray luminosity versus $B-V$. The segments connecting symbols indicate multiple observations of the same star, filled diamonds mark the 10 short-term variable observations with a confidence level >99%, filled circles mark the observations showing variability with confidence level between 90% and 99%, the position of the Sun is also shown (square symbol), with the range of expected solar luminosities between periods of minimum and maximum activity indicated by

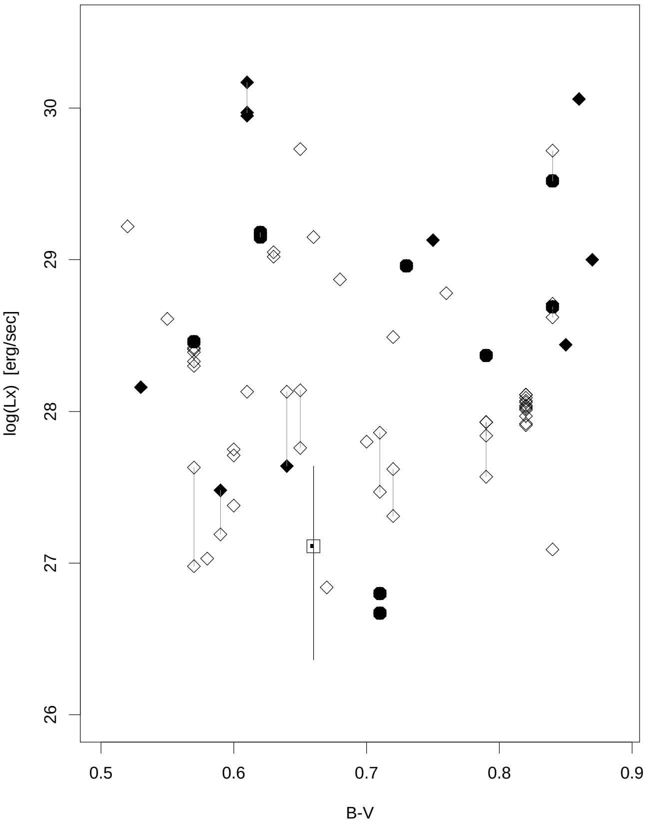

Fig. 1. Scatter plot of X-ray luminosities vs. $B-V$. The segments connecting symbols indicate multiple observations of the same star, filled diamonds mark the 10 short-term variable observations with confidence level >99%, filled circles mark observations showing variability with a confidence level between 90% and 99%, the position and the luminosity variation of the Sun over the solar cycle, is also shown (square symbol). The (statistical) errors of the measured X-ray luminosities are typically ~15%.

a vertical line. There are very few sources with X-ray luminosity similar to that of the solar minimum. This is due to a selection effect because of our choice of selecting the sample as described in Sect. 2.1.

3. Results

3.1. Time variability

For each star in our sample, we obtained light curves in the (0.11–2.4) keV band.

In order to have a statistical evaluation of the X-ray variability we applied the unbinned Kolmogorov-Smirnov (K-S) test on all X-ray photon time series of our sample stars. We used the procedure implemented in the pros.xtiming package of IRAF after having removed data gaps. This method does not allow us to distinguish stochastic variability, or other forms of variability, from periodic ones (see also Collura et al. 1987; Haisch & Schmitt 1994 for a more sophisticated treatment of the gaps), but it can detect variability of any kind.

Table 4. Results of the K-S test.

Results of the K-S	Number of observations
>99%	**10**
95%–99%	3
90%–95%	6
≤90%	**51**

For each observation, we ran the K-S test on the source counts as well as on the counts detected in the background regions, the latter being carried out to monitor possible background variability. In three cases the background is variable with Confidence Level (CL) >99%; GL 231 (Obs. seq. 180172N00), GL 475 (Obs. seq. 900137N00), GL 1255) however, in these cases, the number of counts in the variable background is much lower than the counts attributed to the source, hence we assume that the test results for these sources are reliable. In Col. 9 of Table 2 we report the results in terms of the confidence level at which we can reject the hypothesis that the source in the given observation is constant. In Table 4 we present a summary of K-S test results. Only during 10 observations relative to 8 distinct stars we have found the emission to be variable at a CL greater than 99%. This finding suggests that X-ray variability on short time scale is not common among these stars.

Furthermore, we have analyzed the K-S results for stars of different X-ray luminosities (see Table 5). The Table suggests that the X-ray variabilty changes with X-ray luminosity level, and in particular that a larger fraction of variable stars are more X-ray luminous. However we show below that this result is very likely due to the different count statistics distribution in the two samples. Indeed, to explore the possible presence of a bias due to the statistics of photon counts in our results, in Fig. 2 we show the cumulative X-ray luminosity functions for variable ($CL > 99\%$) and not variable ($CL < 90\%$) stars with at least 500 counts. Figure 2 suggests that the high luminosity stars are more variable than the low luminosity ones, but the K-S two-sample test is unable to distinguish the two distributions[1] This result allows us to study the variability of our sample assuming that all nearby dF7-dK2 stars belong to the same population as far as X-ray variability is concerned (Fig. 3, dashed line). We derive the cumulative Time amplitude X-ray Luminosity Distribution (Time XLD) for these stars (dashed line Fig. 3) defined as the cumulative distribution of the ratio between the "instantaneous" $L_{\rm x}$ and the minimum value observed for each observation. The Time XLD gives the fraction of time that an dF7-dK2 star spends in a state at flux larger than a given factor of its minimum value.

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[1] The null hypothesis that the two samples are drawn from the same parent distribution can only be rejected at the 12.3% confidence level. If some difference is present, the statistics does not allow to observe it, and therefore the variability does not depend on X-ray luminosity for $L_{\rm x} > 27.5$, that is the luminosity range explored in this test.

Table 5. K-S test results for different ranges of $\log(L_{\rm x})$.

CL	$\log(L_{\rm x})$ [erg/s]			
	$\leq$27.5	27.5–28.5	28.5–29.5	>29.5
>99%	**1**	**3**	**2**	**4**
95%–99%	1	1	1	0
90%–95%	1	1	3	1
$\leq$90%	**8**	**32**	**9**	**2**

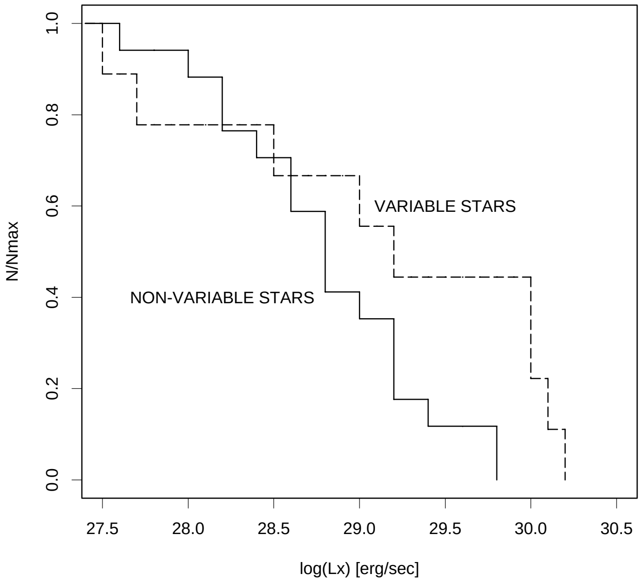

Fig. 2. The cumulative X-ray luminosity functions for variable ($CL > 99\%$; dashed line) and non variable ($CL < 90\%$; solid line) stars, having at least 500 counts. The two luminosity functions are indistinguishable, according to a K-S two sample test, suggesting that variability is independent on X-ray luminosity.

In Fig. 3 we also compare the Time XLD for our sample, having $L_{\rm x} > 27.5$, with the distribution obtained for dM stars (Fig. 4, Paper I). Using K-S two-sample test, we have tested the null hypothesis that the M XLD and the dF7-dK2 XLD are drawn from the same population, finding that, the two distribution are different, with dM stars more variable than dF7-dK2 ($CL > 99\%$). This finding may be a strong indication that magnetic activity on dM stars and solar type stars is due to different processes, as it appears to be the case, for example, in Brown Dwarfs as suggested by Berger et al. (2001).

3.2. X-ray variability on longer time scale

Nine stars of our sample were multiply observed with a similar off-axis, and with a time separation of at least six months. Using a procedure implemented in the pros.xdataio package of IRAF, we applied the K-S test on all available data for each star, just appending the various observations one after the other.

We find indications that the variability increases with the time scales. Five stars, not variable ($CL < 90\%$) on time scales ranging from a few hours to less than 1 week, result variable ($CL > 99\%$) on time scales of months (see Table 3). We note that the only two stars, out of the nine stars multiply observed, that show short term variability are: EK Dra, the most active star of our sample, and α Cen, the one observed with the highest statistics. On the contrary the stars that do not show long term variability are Wo9158, observed over a time scale of only 6 months, and GL 620.1, the only star, together with EK Dra, of the subsample observed on long time scale, having $L_{\rm x} > 10^{29}$ erg/s. Below we discuss the evidence that very X-ray luminous G-type stars do not appear variable on longer time scale. The amplitude of the variations ranges between a factor ~2 and ~4 for variable stars on long time scales.

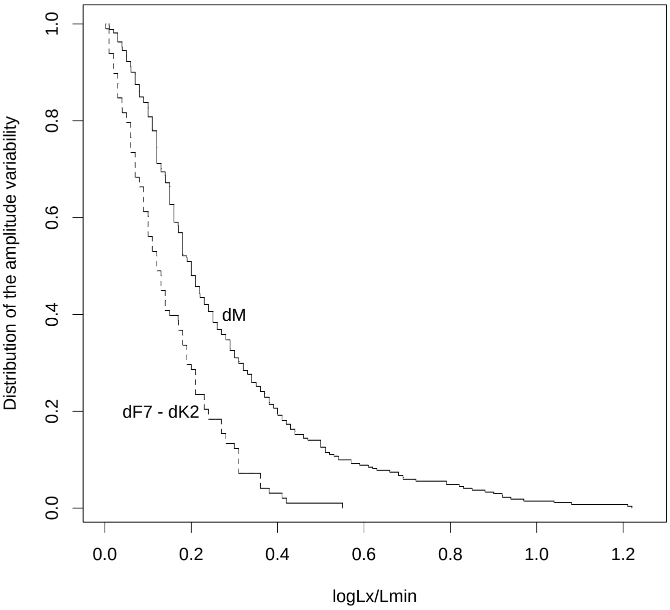

Fig. 3. The dashed line shows the cumulative time X-ray luminosity distribution for dF7-dK2 stars having more than 500 counts and $\log(L_{\rm x}) \geq 27.5$; the solid line shows the cumulative time amplitude X-ray luminosity distribution for dM stars with more than 500 counts.

A few stars in our sample have been observed with *Einstein*-IPC in 1978–1981 allowing the study of possible variability on a time scale comparable with that of the solar cycle. We show in Fig. 4 the $\log(L_{\rm x})$ measured with the PSPC (one value for each observing time interval) versus $\log(L_{\rm x})$ measured with the IPC (one value averaged on the IPC observation (Maggio et al. 1987; Barbera et al. 1993). We excluded the upper limit IPC observations consistent with the PSPC observation and the PSPC observations spanning less than 500 s because in this case it is very difficult to disintangle flare emission from quiescent emission. Given the difference of the two instruments and the cross calibration uncertainties, we do not consider as significant any variability within a factor two i.e. inside the region of the plot enclosed by the dotted lines. Long term variability seems to exist for three stars of our sample (GL 86, GL 124, GL 598); we note that these stars

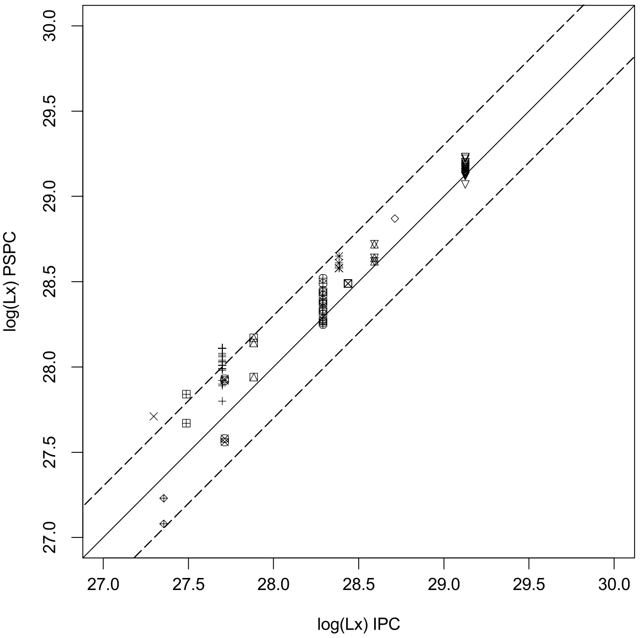

Fig. 4. Scatter plot of $\log(L_{\mathrm{x}})$ observed by *Einstein*-IPC (corrected using hipparcos distances) and ROSAT-PSPC. The solid line represents the line of equality and the dashed line represents variation of factors two.

have X-ray luminosity similar to the solar one. In literature we found information on cyclic variability only for one of these three stars (GL 598), it is found to have a cyclic period >30 yr (Baliunas et al. 1995). Saar & Brandenburg (1999) find for GL 598 a cyclic period >25 yr.

It is worth noting that stars variable on longer time scales have a solar-like X-ray luminosity, while for the two more luminous stars of our sample there is no long term variability. Studies of stellar X-ray emission at different epochs based on Einstein and ROSAT observations of stars in open clusters (Stern et al. 1995; Gagnè et al. 1995; Micela et al. 1996) as well as of field stars (Schmitt et al. 1995; Fleming et al. 1995) suggest that at least the most active stars do not show long term variability. Some authors have suggested that the lack of strong cyclic activity in active stars indicates that small-scale turbulent magnetic field generation is strongly dominant over the large-scale dynamo that accounts for the Sun's magnetic cycle.

4. X-ray and chromospheric emission

The Ca II H-K fluxes are closely related to magnetic activity in late-type stars (Schrijver et al. 1992) suggesting a common origin for the activity. On the Sun, the Ca II emission varies significantly on several time scales: about 27 days due to rotational modulation; weeks to months due to the growth and decay of active regions; 11 yr due to the activity cycle and longer periods may also modulate the activity cycle. From solar minimum in 1975, to solar maximum in 1980, the intensity of Ca II K_3 central emission increased by 30%, while the emission within a 1 A window centered on the K line increased by 18% (White & Livingston 1981).

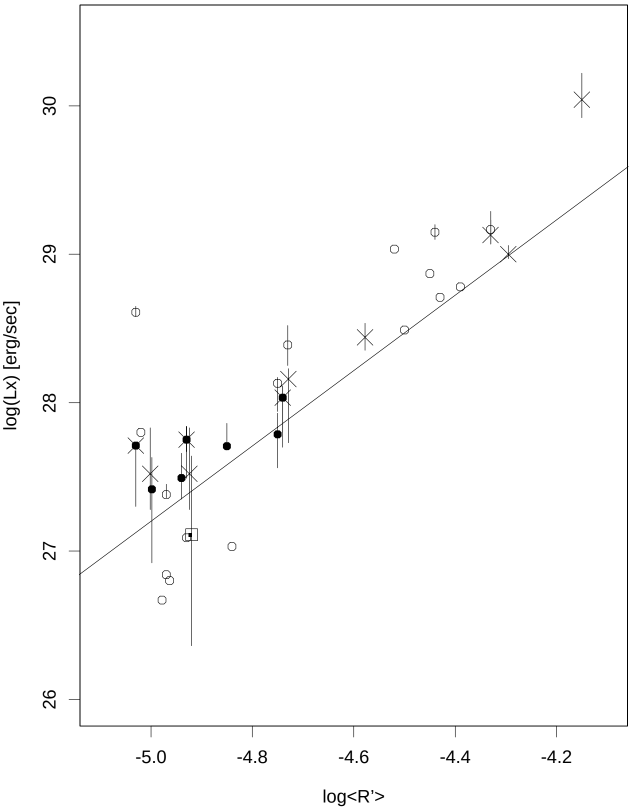

Fig. 5. Scatter plot of X-ray luminosity vs. the Ca II R'_{HK} emission index (Henry et al. 1996; Soderblom 1985; Radick et al. 1998) for the stars in our sample quoted in the same papers. Filled symbols are the stars variable on long time scale but not on short time scale, vertical lines show the range of luminosity spanned by stars having more than one temporal segment, among them the filled crossed symbols are the three stars variable between IPC and PSPC observations and not variable on short term scale (for them, the vertical lines indicate variations between IPC and PSPC observations). Crosses indicate the stars variable on short time scale with a $CL \geq 99\%$, the Sun is shown as a square symbol. For the Sun vertical line spans the luminosity variation over the solar cycle (Peres et al. 2000).

Stellar magnetic cycles manifest themselves in a long term variability of their chromospheric (Wilson 1978; Baliunas et al. 1995) and possibly also coronal emission (Hempelmann et al. 1996). We therefore studied the relation between X-ray luminosity and Ca II H-K emission as parameterized by the Ca II R'_{HK} index (R'_{HK} measures the intensity of the line corrected for the contribution of the photospheric continuum and scaled for the bolometric flux). Using the Ca II data published by Henry et al. (1996), taken between 1992–1993, integrated with data from Soderblom (1985) and Radick et al. (1998), we show in Fig. 5 the scatter plot of $\log(L_{\mathrm{x}})$ versus R'_{HK} for the stars in our sample mentioned in the same papers. Figure 5 also shows the best fit power-law relation obtained by

Maggio et al. (1987). Our data are in good agreement with this relation. The Ca II and X-ray data are not taken symultaneonsly, introducing some spread in the relation; in particular the star GL 449 (see Fig. 5) shows an anomalous value of Ca H-K. In Fig 5 vertical segments show also the spread introduced by X-ray variability Our data indicate that at least at low activity levels ($L_\mathrm{x} \leq 10^{28}$) long-term variability can also account for the observed spread.

We have searched information on cyclic variability (Wilson 1978; Baliunas et al. 1995) of the stars in our sample. Chromospheric observations of GL 137 and GL 663 analyzed by Wilson (1978) indicate cyclic variations while GL 434 and GL 502 do not seem to show any cyclical behavior. Baliunas et al. (1995) find indication of long term variations (on time scales longer than about 20 yr) for GL 17.3, GL 137, GL 434, GL 663A; GL 502 analyzed by Baliunas et al. (1995) presents a 16.6 yr activity cycle superposed on a 9.6 yr cycle. GL 598 has rotation and mass similar to the Sun, but weak chromospheric activity and a variation in activity that appears to be longer than 30 yr. Data are too sparse to compare the time scales of variations in calcium and X-ray.

5. Summary and conclusions

- We studied the X-ray variability of nearby dF7-dK2 stars observed with ROSAT-PSPC. The sample includes 70 pointed observations of 40 distinct stars.
- The Kolmogorov–Smirnov test indicate that only 10 observations are variable at a confidence level greater than 99%: X-ray variability is not a common feature for these stars.
- The short term amplitude variations of X-ray emission of dF7-dK2 stars are smaller than those observed in dM stars.
- Nine stars of our sample observed over time intervals longer than 6 months suggest that X-ray variability is more likely to occur over longer time scales. It is worth noting that stars variable only on time scales >6 months have a solar-like X-ray luminosity level. This finding is not in contrast with the hypothesis that the X-ray variability may be due to a cyclic behavior of relatively quiet stars.

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