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X-RAY STUDIES OF COEVAL STAR SAMPLES. II. THE PLEIADES CLUSTER AS OBSERVED WITH THE *EINSTEIN OBSERVATORY*

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ABSTRACT

We report the results of an extensive X-ray survey of the Pleiades cluster which improves upon previous studies by using refined X-ray source detection algorithms and the complete set of 14 *Einstein Observatory* Imaging Proportional Counter images (1° × 1° each) covering the Pleiades cluster region. Using an extensive compilation of Pleiades members, we detected 85 of 283 Pleiades stars falling in the surveyed region. Upper limits were computed for all nondetected stars, and maximum likelihood, integral X-ray luminosity functions for Pleiades stars in six selected color-index ranges were computed, using both detections and upper limits. The comparison of these newly derived X-ray luminosity functions for the Pleiades stars with analogous functions derived for other groups of stars of known age confirms the decreasing of X-ray emission level on increasing stellar age for solar-like stars, and indicates a dependence of X-ray luminosity from stellar age more complex than a simple power law. The absence of unidentified X-ray sources that could be related to faint uncataloged dM Pleiades stars implies that these stars (if in the cluster) must have an X-ray luminosity lower than 3×10^{29} ergs s^{-1}. Using our enlarged data sample we confirm that the X-ray luminosity of slow rotating Pleiades late-type stars scale with $(v \sin i)^2$, while the fast rotating dK stars do not follow this scaling law. However the fast rotating dK stars have a higher X-ray luminosity with respect to the slow rotating dK stars and are preferentially X-ray–detected. We have also searched for long-term variability of the stellar X-ray emission in this cluster and have established 3 σ upper bounds on such variability amplitude: these stars' X-ray luminosity varies by less than a factor of 3 on a typical time scale of a few days monitored by the *Einstein* observations of this cluster. X-ray luminosity variations smaller than those to which we are sensitive are compatible with the dispersions of the X-ray luminosity functions about their mean values. The absence of long-term variations shows that the single high-amplitude flarelike events observed once in the K star Hz 1136 has an occurrence rate significantly lower than the occurrence rate of X-ray flux variations of similar amplitude observed in several ρ Oph younger stellar objects.

Subject headings: clusters: open — stars: rotation — stars: X-rays

I. INTRODUCTION

The dependence of X-ray emission level on age and rotation for late-type stars is a well-established result (Pallavicini *et al.* 1981; Walter 1982, 1983; Vaiana 1983; Micela *et al.* 1985; Caillault and Helfand 1985; Maggio *et al.* 1987; Micela *et al.* 1988, hereafter Paper I). Open clusters have been used classically for studies of the age dependence of stellar parameters, with particular emphasis on studies of stellar activity in the early stages of life on the main sequence. The recent availability of the large data sample collected with the *Einstein Observatory* (Giacconi *et al.* 1979) Imaging Proportional Counter (IPC; Gorenstein, Harnden, and Fabricant 1981) has stimulated our systematic and homogeneous study of X-ray emission in all open clusters observed with *Einstein* (see our reports on the Hyades cluster, Paper I, and the Ursa Major stream, Schmitt *et al.* 1990, hereafter Paper III).

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Two previous X-ray surveys of the Pleiades cluster were based on more restricted data sets than the present. The first survey (Caillault and Helfand 1985) used five IPC images (*Einstein* sequence numbers 2296, 9916, 9917, 9918, and 9919) and one HRI image (*Einstein* sequence number 10408). Their analysis, based on the early IPC *Einstein* data processing system (the so-called REV-0 processing), detected a total of 38 Pleiades members, without any attempt to evaluate upper bounds for individual undetected stars; however, the authors did compute a mean "excess" of X-ray flux for undetected stars in each spectral type class. These mean excesses are generally compatible with the individual bounds derived in the present paper. The second survey was based on the final IPC data processing system (REV-1; Harnden *et al.* 1984), but also made use of only a small fraction of the data now available for the Pleiades region (i.e., only two of 14 IPC images, namely sequence numbers 5457 and 5458). This second survey detected 21 Pleiades members and reported individual upper bounds for members surveyed but undetected. Combined, these two surveys resulted in a total of 46 Pleiades-member detections.

The present survey improves upon these two previously published surveys by (1) using IPC data processed with the REV-1 system, (2) extending the number of IPC images analyzed to 14, and (3) using a more complete optical catalog of Pleiades members, assembled specifically for this project by extensively searching the published literature (Micela, Sciortino, and Serio 1990). The REV-1 data processing system, especially the Map detection algorithm (see § III and Paper I), permitted the detection of fainter X-ray sources and increased the number of Pleiades members detected as X-ray sources from 46 to 85. In addition, we have evaluated upper bounds for the remaining 198 Pleiades stars falling in the fields of view but which were not detected as X-ray sources.

Our paper is organized as follows: § II describes the selection procedures for compiling the optical catalog of Pleiades cluster members; § III presents the X-ray data analysis; § IV presents a discussion of our results; and § V summarizes the main conclusions.

II. CHARACTERISTICS OF THE OPTICAL CATALOG

The optical catalog used for our study is based on an extensive search of the published literature. It includes 500 stars classified as certain or probable Pleiades members (Micela, Sciortino, and Serio 1990). The major original catalogs used in the compilation are those of Hertzsprung (1947), Pels (quoted in van Leeuvwen 1983), Trumpler (1922), and van Maanen (1945). When available, Jones's (1973, 1981) membership attribution, based on proper motion criterion, has been used, retaining all those stars whose membership probability is greater than 20%. For those stars not included in the Jones investigation, our catalog uses the membership attributions of Johnson and Mitchell (1958) based on photoelectric criteria, those of Binnedijk (1946) based on proper motion criteria, and finally those of Ahmed, Lawrence, and Reddish (1965) based on photographic criteria. For the stars in the Pels list recently investigated by van Leeuwen (1983), his membership criterion based on proper motion studies has been used. Furthermore, the catalog adds five stars which are considered certain or probable members by Stauffer (1984).

The spatial distribution of cluster members in the final composed catalog is shown in Figure 1, and their magnitude distribution is shown in Figure 2 (*dotted line*).

The catalog is mainly based on the Hertzsprung (1947) catalog, which is believed to be complete up to 17th m_{pg} in a square region of 2°.5 × 2°.5 centered on Alcyone, the brightest Pleiades star. Pels's catalog covers a wider region, but with an inhomogeneous magnitude coverage. Hence we consider our catalog complete to the middle-K main-sequence spectral type in the region studied by Hertzsprung (1947). We further note that the full optical catalog we have assembled makes extensive use of previous studies of known flare stars in the Pleiades; this leads to a significant increase in the number of low-mass cluster members, as compared with previous catalogs assembled for studying X-ray emission of Pleiades members, but clearly does not ensure complete coverage of Pleiades members at the faint end of the main sequence. We have also searched the published literature (see references at end of Table 1) for other relevant optical data regarding stellar photometry (the fourth and sixth columns) and spectroscopy (the seventh column), rotational velocity (the ninth column), evidence for variability, and evidence for stars belonging to binary systems (the eleventh column); the data collected for stars considered in the present survey are listed in Table 1.

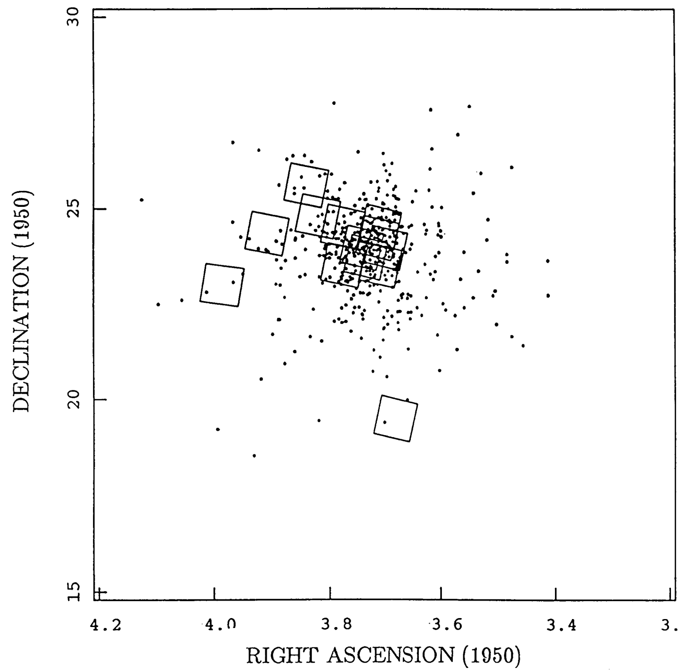

FIG. 1.—Spatial distribution of Pleiades stars listed in our optical compilation. Present survey coverage is indicated by the 14 IPC images 1° × 1° each. Note that the central 2° × 2° region has been observed more than once.

III. DATA SELECTION AND ANALYSIS

We have analyzed the 14 *Einstein Observatory* IPC images of the Pleiades region (each containing at least one cluster member); Table 2 summarizes the relevant characteristics of these exposures. The sky coverage of the present survey is shown in Figure 1; 283 Pleiades members are observed in the combined fields of view. The majority of X-ray observations are concentrated in the ~2° × 2° central region of cluster, where the optical catalog is more complete (see § II); in this central region, almost all stars have been observed more than once.

Table 1 summarizes the relevant optical data for the 283 cluster members present in our survey. The magnitude distributions of all Pleiades stars in our survey (*dashed line*) and of Pleiades stars detected as X-ray sources (*solid line*) are shown in Figure 2. The comparison between the magnitude distribution of the parent optical catalog (*dotted line*) and of the X-ray–surveyed sample (*dashed line*) shows that the X-ray–surveyed sample is dominated preferentially by faint stars; this can be explained simply by the fact that the bulk of X-ray observations covers the central region of the Pleiades, where intense scrutiny in the optical has led to a more complete knowledge of cluster membership at fainter magnitudes. In this respect, our survey tends to select out a stellar sample which has greater representation of optically faint stars than the original optical catalog.

a) *Detection Method*

We have adopted the final, standard IPC data processing system (REV-1) for the present Pleiades survey. This software system detects X-ray sources through independent application of Local and Map detection algorithms in three energy bands,

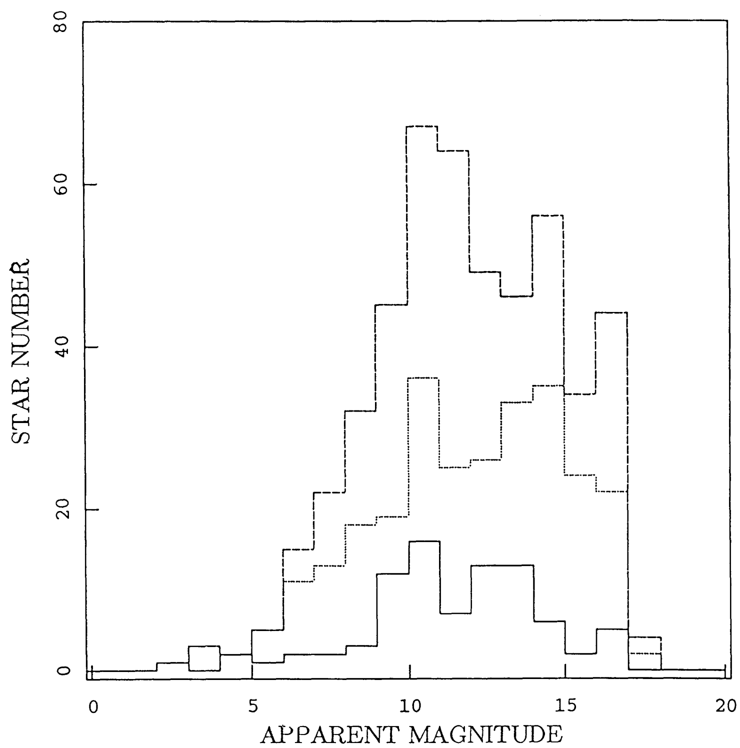

FIG. 2.—Apparent magnitude distributions for the Pleiades stars: *dotted line*, Pleiades members in our optical compilation; *dashed line*, Pleiades stars surveyed by *Einstein*; *solid line*, X-ray–detected Pleiades stars.

broad (0.16–3.5 keV), soft (0.16–0.8 keV), and hard (0.8–3.5 keV), and usually both the Local and Map detection algorithms were applied. In only two fields was the Map algorithm inhibited by the automated data processing system (because of enhanced background emission in these fields).

As for the Hyades survey (Paper I), we retained X-ray detections in the broad band, obtained either by the Local detect or Map detect algorithm. With this choice, we expect on statistical grounds about eight spurious detections out of a total of 151 detections in the present survey.

b) *Identification of Pleiades X-Ray Sources*

The final IPC data processing system looks for tentative identifications with cataloged celestial objects listed in the *Einstein* Master Catalog (Harris and Irwin 1984) within a 3′ radius of the X-ray detections. Moreover, we have supplemented the *Einstein* Master Catalog with the optical catalog of Micela, Sciortino, and Serio (1990) described in § II.

In the present survey we have adopted a more stringent identification criterion with respect to that implemented in the standard processing because the Pleiades region is quite crowded, and the probability of chance identification is relatively high. The number of Pleiades stars in each field, and the mean number of chance coincidences expected using identifications within a 1′, 2′, or 3′ radius circle, are summarized in Table 3. The expected number of chance identifications in each field is computed as $N_{\rm chance} = N_0 \times p$ where p is the probability for a mistaken identification[2] evaluated as

$$p = \frac{N_* r'^2 \pi}{3600}, \qquad (3.1)$$

[2] Mistaken identifications can occur when either a spurious detection or a real, unrelated source, appears near the position of a Pleiades star.

where N_* is the number of optical cataloged stars present in each field of view, $N_*/3600$ is the density of stars (expressed as the number of stars per square arcmin), and r' is the chosen radius of identification. N_0 is the number of expected (spurious and real) X-ray detections unrelated with Pleiades stars; namely N_0 is the sum of the expected spurious detections per field (0.6 per image), plus the number of expected extragalactic detections (0.63 per image), plus the number of field star detections (0.24 per image) for an expected total number of ∼21 X-ray detections unrelated with Pleiades stars in the entire survey. The computation of the indicated numbers is discussed in more detail in Paper I.

Because the Pleiades fields are very crowded, we have tailored our identification criteria to minimize the number of false identifications; in summary,

1. If the X-ray detection is uniquely identified within 1′ with a Pleiades star, this is assumed to be the correct identification. This criterion allow us to identify more than 100 detections, i.e., the majority of all the detections. In this sample we expect only one chance misidentification.

2. If the X-ray detection does not have identification within 1′ but does have only one identification within 2′ we adopt this identification as well; 10 cases meet this criterion. Because with a "2′ criterion" we expect four chance identifications in the overall survey (of 151 X-ray sources), we expect ∼0.3 additional chance identifications in this sample of 10 detections.

3. In two cases the identification criterion (1) is met by both a Pleiades star and non-Pleiades object: (i) In the first case, there is a Pleiades star (Hz 2366) and a Hyades star (Hz 2411) present within a circle of 1′ centered on the X-ray source. We cannot identify a single emitter in this case, and hence we consider the observed emission as an upper limit to the intrinsic emission of both stars. (ii) In the second case, one X-ray

TABLE 1

PLEIADES STARS IN OUR SURVEY

Star Name	RA h m s	DEC ° ' "	m_V	Ref.	B-V	Sp	Ref.	V	Ref.	Notes
T3/A112	3 39 42.1	23 49 52	15.70	1	1.45	...		...		...
T147	3 39 58.3	23 55 30	16.10	2	...	...		...		...
T148/B218	3 40 14.2	24 29 52	16.00	2	...	...		...		...
Hz81	3 40 21.1	23 42 11	13.55	3	0.92	G8V	4	...		...
Hz83	3 40 21.6	23 41 33	14.86	3	1.05	K0V	4	...		...
Hz97/T56b	3 40 27.3	24 50 13	12.65	5	1.08	K3V	5	<10,40	1,6	...
Hz120	3 40 34.1	23 31 03	10.79	7	0.70	G1	8	...		...
Hz129	3 40 36.4	23 36 19	11.47	7	0.88	G8	8	...		var.
Hz134	3 40 38.2	24 04 30	14.41	3	1.51	K7Ve	4	40	1	...
Hz133/T39b	3 40 38.3	24 14 12	14.32	1	1.35	K5.5Ve	4	19	1	...
Hz146	3 40 39.0	23 17 48	14.55	1	1.41	K7-M0Ve	4	...		...
Hz152	3 40 40.0	23 22 46	10.75	7	0.70	G1	8	...		...
MT41/T41	3 40 43.3	24 24 58	15.43	1	1.63	dM3	1	<12	1	...
Hz153	3 40 43.6	24 55 30	7.51	7	0.15	A2V	9	...		...
Hz157	3 40 43.6	23 29 35	7.90	7	0.34	A9V	10	100	11	bin?
Hz158	3 40 44.5	24 13 06	8.23	7	0.25	A7V	10	70	11	var.
Hz164	3 40 45.0	23 26 17	9.54	7	0.48	F5V	10	30	12	...
Hz174	3 40 48.8	24 50 54	11.62	7	0.85	...		...		var.
Hz186	3 40 50.1	23 03 19	10.49	5	0.79	...		...		bin?
Hz189	3 40 50.8	23 22 59	14.00	1	1.37	K5.5Ve	4	<10	1	var.
Hz193	3 40 52.2	24 05 29	11.29	7	0.81	...		...		...
Hz191/T7	3 40 52.9	24 41 05	14.53	1	1.35	K7V	13	...		var.
Hz212/T70	3 40 57.0	24 16 10	14.39	3	1.40	K7Ve	4	...		...
Hz220	3 40 57.7	23 31 50	...		...	...		...		...
JRS27	3 40 58.9	23 47 42	17.93	1	1.06	...		...		...
Hz233	3 41 00.7	23 43 37	9.66	7	0.52	F6V	10	80,<20	11,5	...
Hz232	3 41 01.3	24 24 04	8.06	7	0.20	A5V	10	20	11	Vel var?
T150	3 41 02.8	24 54 29	15.62	1	1.51	...		...		...
JRS26	3 41 03.6	23 42 22	17.22	1	1.95	...		...		...
Hz253	3 41 04.6	24 20 54	10.66	7	0.68	G1	8	...		...
Hz250	3 41 04.7	24 50 02	10.68	7	0.68	G1	8	...		...
Hz263	3 41 06.2	24 07 10	11.54	7	0.88	G8	8	...		...
T71/B283	3 41 11.6	22 55 24	15.43	1	1.42	...		...		...
Hz296	3 41 13.6	23 13 24	11.36	1	0.83	G8	8	17	1	var.
Hz298	3 41 14.4	23 52 34	10.86	7	0.88	...		...		bin?,Hz299 comp.
Hz299	3 41 14.7	23 52 30	10.86	7	0.88	...		...		bin?,Hz298 comp.
Hz293	3 41 14.7	24 37 26	10.80	7	0.70	G1	8	...		...
Hz303	3 41 16.2	23 56 47	10.48	7	0.88	...		...		bin?,red
Hz314	3 41 20.8	24 38 26	10.56	7	0.64	G1	8	...		var.
Hz320	3 41 21.2	24 37 02	11.04	7	0.88	G5	8	...		bin?
Hz324/A90	3 41 22.8	24 36 43	13.00	3	1.07	...		90,60	1,6	var.
Hz335	3 41 24.7	23 54 43	13.76	3	1.28	K5Ve	4	...		var.
Hz338	3 41 25.1	23 58 37	9.07	7	0.46	F2V	14	<40	11	...
T42b	3 41 25.7	24 36 43	15.42	1	1.55	...		15	1	...
B179	3 41 26.6	24 31 30	16.66	1	1.51	...		...		...
Hz344	3 41 26.9	24 14 21	8.17	7	0.27	A8V+	10	200	11	...
Hz345	3 41 27.2	24 26 03	11.65	3	0.85	G8	8	...		var.
Hz347	3 41 28.1	24 41 15	14.00	1	1.41	K5V-M1V	15,13	65	1	bin?,var
Hz357	3 41 29.5	24 00 55	13.34	1	1.22	dM0.5-dK4e	1,13	<10,50	1,6	var.
Hz370	3 41 33.8	23 43 12	14.56	7	1.18	...		...		Pg.
Hz390	3 41 37.1	23 50 45	14.40	7	1.16	...		...		...
A23/A57	3 41 38.6	23 20 49	16.55	1	1.57	...		...		...
Hz405	3 41 41.5	24 39 47	9.83	7	0.54	F5V	10	15	12	...
Hz430	3 41 45.3	24 04 33	11.37	1	0.82	G8	8	...		...
Hz447	3 41 49.5	24 08 04	5.46	7	-0.04	B7IV	10	260	11	bin,16 Tau
Hz451/T61b	3 41 50.7	24 45 22	13.44	1	1.19	dM0-K5Ve	1,4	<10	1	var.

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TABLE 1—*Continued*

Star Name	RA h m s	DEC ° ′ ″	m_V	Ref.	B-V	Sp	Ref.	V	Ref.	Notes
Hz470	3 41 53.7	23 06 48	8.95	7	0.39	F3V	10	<40	11	...
Hz468	3 41 54.0	23 57 29	3.71	7	-0.11	B6III	10	220	11	SB1,var,17 Tau
Hz476	3 41 55.6	23 45 58	10.78	1	0.80	F9V	14	...		bin?
Hz489	3 41 57.6	24 16 39	10.39	7	0.63	G0V	10	...		...
Hz513	3 42 01.3	23 14 02	13.84	3	1.31	K7Ve	4	...		...
Hz522	3 42 05.1	23 41 05	11.97	1	0.90	K2V	14	...		...
Hz530	3 42 07.2	23 32 52	8.95	7	0.39	F2V	10	<12	12	...
Hz531	3 42 07.9	24 06 31	8.58	7	0.34	Am?	10	75	11	...
P135	3 42 08	19 24 24	9.42	16	0.51	...		...		...
Hz541	3 42 10.4	24 41 03	5.65	7	-0.07	B8V	10	245	11	Vel Var, 18 Tau
Hz554	3 42 12.9	24 25 53	14.09	7	0.92	K5Ve	4	...		Pg.
Hz563	3 42 13.5	24 18 45	4.31	7	-0.11	B6V	10	135	11	SB1, 19 Tau
Hz559/T62b	3 42 13.9	24 56 00	13.33	1	1.11	...		...		var.
Hz566/A70	3 42 14.6	24 56 03	13.60	7	2.17	dK4	15	...		Pg.
MT57	3 42 16.6	24 57 18	...		...	...		...		...
A84/B196	3 42 17.6	24 25 13	16.18	1	1.57	...		...		...
Hz590/T45	3 42 18.6	24 56 39	14.34	5	1.37	...		...		...
Hz605	3 42 21.4	24 46 03	8.99	7	0.44	F3V	10	80	11	SB1
Hz625	3 42 23.1	23 34 23	12.57	7	1.10	K0V	14	>50,82	1,16	bin?,var
Hz624/B113	3 42 24.1	24 41 47	15.27	1	1.52	dM2.5	1	...		...
Hz636	3 42 24.4	23 19 02	12.48	7	1.06			<10	1	...
Hz627	3 42 24.6	24 43 54	9.68	7	0.50	F5V	10	25	12	...
Hz652	3 42 27.7	23 52 50	8.04	7	0.21	A3V	10	235	11	...
Hz673/MT59	3 42 31.5	24 09 29	15.46	7	1.47	dK7e	13	...		Pg.
Hz676/T162	3 42 31.5	23 36 19	13.64	1	1.30	K3.5Ve	4	<10	1	...
Hz686	3 42 34.2	24 08 53	13.38	5	1.27	K7Ve	13	150,90	1,16	var.
Hz697	3 42 35.5	24 18 32	8.60	7	0.35	A9V	10	75	11	var.
Hz708	3 42 36.9	23 55 44	10.13	7	0.62	F9V	10	70	12	...
B203	3 42 37.7	24 29 48	16.70	2						
Hz717	3 42 39.0	24 10 53	7.18	7	0.16	A1V	10	15	11	bin,Vel var?
Hz727	3 42 41.1	24 28 23	9.70	7	0.55	F9V	10	45	12	var.
Hz738	3 42 41.3	23 36 00	12.26	7	1.16	G9V	14	>60	1	bin?,var
Hz739	3 42 42.7	24 45 06	9.56	7	0.62	G0V	10	<12,16	12,1	bin?
Hz745	3 42 42.7	24 08 03	9.45	7	0.52	F5V	10	65	12	...
Hz746	3 42 42.9	24 16 38	11.27	7	0.92	G5	8	...		var.
Hz762/T63b	3 42 45.5	23 55 11	14.33	3	1.42	...		...		...
Hz761	3 42 45.7	24 03 58	10.55	7	0.67	G2V	14	...		...
Hz793/T46	3 42 50.7	23 41 52	14.31	1	1.47	M0-1V	13	<10	1	...
Hz785	3 42 50.8	24 12 49	3.88	7	-0.07	B7III	10	40	11	bin?,20 Tau
Hz799	3 42 52.2	23 43 12	13.70	1	1.34	K5V	14	<10	1	flare?
Hz804	3 42 53.2	23 53 05	7.85	7	0.20	A2V	10	170	11	...
Hz813	3 42 54.8	24 18 55	15.30	7	1.18	M1-2	18	...		Pg.
Hz817	3 42 55.4	24 24 02	5.76	7	-0.04	B8V	10	220	11	21 Tau
Hz859	3 43 03.9	24 22 26	6.43	7	-0.02	B9V	10	250	11	22 Tau
Hz870	3 43 04.7	23 35 00	12.68	16	1.26	G4.5V	14	...		bin?
Hz882	3 43 06.4	23 15 06	12.66	7	1.07	K3V	14	80,63	1,16	var.
Hz879	3 43 07.4	24 24 49	12.82	3	1.08	...		<10,35	1,6	var.
Hz883/T70b	3 43 07.9	24 24 29	13.05	3	1.15	...		40	6	var?
Hz885	3 43 08.3	24 42 47	12.05	7	1.01	K3	8	<10,40	1,6	...
Hz890/A121	3 43 08.6	24 13 14	14.80	7	1.33	M0Ve	4	...		Pg.
Hz915	3 43 10.6	23 11 37	13.62	7	1.23	K6Ve	4	...		...
Hz906	3 43 10.7	24 31 08	15.20	7	1.52	dM2e	13	...		bin?
Hz923	3 43 12.3	23 11 11	10.12	7	0.62	G1V	8	12	12	var
Hz916	3 43 12.6	24 28 07	11.71	7	0.87	G8V	8	...		...
Hz930/VM2	3 43 14.3	23 54 03	14.23	3	1.34	...		...		...
Hz956	3 43 17.3	24 02 10	7.96	7	0.32	A7V	10	150,150	11,17	bin?
Hz975	3 43 20.1	23 19 58	10.58	1	0.84	G0	8	...		bin?

TABLE 1—*Continued*

Star Name	RA h m s	DEC ° ′ ″	m_V	Ref.	B-V	Sp	Ref.	V	Ref.	Notes
Hz974	3 43 21.1	24 37 55	13.96	1	1.34	K7Ve	4	...		...
Hz980	3 43 21.1	23 47 41	4.18	7	-0.06	B6IVn	10	275	11	bin?,23 Tau
Hz996	3 43 23.5	24 25 00	10.42	7	0.64	G0V	10	...		var?
VM6/A2	3 43 26.8	24 00 21	15.77	7	1.32	...		...		Pg.,bin?
Hz1028	3 43 28.5	24 06 06	7.35	7	0.10	A2V	10	110	11	Vel var?
Hz1029/B212	3 43 29.3	24 36 17	14.34	1	1.39	...		...		...
Hz1032/VM8	3 43 29.4	24 16 50	11.10	1	0.75	G8	8	...		var
Hz1039/A148	3 43 29.8	23 26 18	13.07	5	1.23	K2V	5,28	10,16	1	var,bin
Hz1061	3 43 32.6	23 57 47	14.23	1	1.39	K5V	15	<10	1	...
Hz1081	3 43 35.2	23 09 07	14.61	1	1.42	K7Ve	4	...		...
Hz1084	3 43 36.2	23 28 14	8.11	7	0.36	A0V	10	150	11	red
Hz1094	3 43 37.5	23 48 49	14.02	7	1.40	...		...		Pg.
Hz1103/T151	3 43 37.6	23 15 27	14.77	1	1.48	K7Ve	4	...		...
Hz1095	3 43 38.4	24 35 40	11.92	7	0.88	K0	8	...		...
Hz1100	3 43 38.5	24 11 22	12.25	1	1.10	K3V	15	<10<30	1,6	bin?
Hz1117	3 43 39.5	23 38 04	10.22	14	0.71	G6V	14	...		bin?
Hz1110/VM12	3 43 39.8	24 22 01	13.41	5	1.23	K6.5Ve	4	...		...
Hz1122	3 43 40.7	23 57 00	9.29	7	0.46	F4V	10	28	12	...
Hz1124/VM14	3 43 40.8	23 52 35	12.12	7	0.92	K2V	14	<10,48	1,16	var
Hz1136	3 43 42.3	23 20 40	12.02	7	0.99	G8V	14	...		var,bin?
VM15	3 43 44.9	23 50 27	16.07	7	0.99	...		...		Pg.
Hz1173	3 43 50.1	24 26 46	15.10	1	1.56	dM2	1	<10	1	...
Hz1200	3 43 53.0	23 05 09	9.90	7	0.54	F6V	12	<20	12	...
MT72/VM16	3 43 54.8	24 08 01	16.09	7	1.12	dM1-2e	13	...		Pg; var
Hz1207	3 43 55.4	24 38 36	10.47	7	0.62	G1	8	...		var?
Hz1215	3 43 55.7	23 25 50	10.52	7	0.65	G0V	10	<30	6	...
A33	3 43 55.8	25 03 21	16.40	2	...	...		...		...
A40	3 43 59.5	23 05 48	15.50	2	...	...		...		...
Hz1234	3 44 00.2	24 22 02	6.82	7	0.02	B9.5V	10	260	11	...
Hz1275	3 44 03.5	23 20 31	11.45	1	0.83	K0V	14	10	1	...
Hz1266	3 44 04.1	24 40 01	8.28	7	0.36	A9V	10	95,50	11,17	bin?,var
Hz1280	3 44 04.9	24 00 21	14.55	3	1.37	dK7-M0	15	...		...
Hz1284	3 44 05.7	23 50 32	8.37	7	0.30	A9V	10	100	11	...
Hz1286/T16	3 44 05.8	23 27 45	15.34	1	1.68	dM2.5	1	...		bin?
Hz1298	3 44 08.6	23 33 44	12.18	7	1.02		10	1		...
Hz1306/T17	3 44 10.4	23 33 26	13.45	1	1.31	K5Ve	15	<30	6	flare
Hz1309	3 44 11.2	24 07 26	9.46	7	0.47	F6V	10	85	12	...
Hz1321/T28b	3 44 11.2	23 35 22	15.22	1	1.47	dM3	1	17	1	bin?
Hz1332	3 44 15.3	23 33 42	12.53	1	1.02	K4V	14	<10,<30	1,6	var
B363	3 44 15.4	23 40 41	15.78	1	1.35	...		...		...
Hz1338	3 44 17.9	23 58 32	8.69	7	0.46	F3V	10	110	11	bin?
Hz1348	3 44 19.0	24 14 18	12.75	1	1.15	K5	15	<10	1	bin?
Hz1355/T45b	3 44 19.6	23 52 59	14.07	1	1.40	dM1.5	1	<10	1	bin?
Hz1362	3 44 20.6	23 59 12	8.25	7	0.26	A7V	10	<12	11	var
Hz1375	3 44 22.4	23 57 49	6.29	7	0.02	A0V	10	160	11	bin
Hz1380	3 44 22.6	23 39 02	6.99	7	0.03	A1V	10	235		...
Hz1384	3 44 24.8	24 26 09	7.66	7	0.21	A4V	10	215	11	...
Hz1392	3 44 25.5	23 45 43	10.36	9		F9V	12	<20	12	...
Hz1397	3 44 26.0	23 45 43	7.26	7	0.05	A2Vm+G5V	9	<10	11	bin,Vel var?
Hz1425	3 44 28.6	23 31 33	7.77	7	0.15	A3V	10	185	11	var
Hz1432	3 44 30.4	23 57 09	2.87	7	-0.09	B7III	10	220	11	25 η Tau
Hz1431	3 44 30.6	24 08 09	6.81	7	0.06	A0V	10	40	11	SB2
Hz1454/T57b	3 44 34.3	24 31 54	12.87	5	1.12	K3V	5	<10	1	
MT78/T105	3 44 35.3	23 32 21	15.73	1	1.45	dM3e	10	...		bin?
Hz1491/B347	3 44 39.0	24 34 51	15.9	2	...	...		...		...
Hz1512	3 44 40.1	23 18 56	13.50	7	1.37	K6	15	...		var
Hz1514	3 44 41.4	24 12 44	10.48	7	0.64	G5	20	...		...

TABLE 1—*Continued*

Star Name	RA h m s	DEC ° ′ ″	m_V	Ref.	B-V	Sp	Ref.	V	Ref.	Notes
Hz1516/T64b	3 44 41.4	24 08 58	13.97	1	1.34	...		...		...
Hz1531	3 44 43.0	23 49 08	13.41	5	1.22	(K7-M0)Ve	13	50,73	1,16	var
Hz1532/B270	3 44 43.0	23 35 14	13.90	3	1.29	...		...		...
ALR513	3 44 48.1	23 53 38	11.11	alr	1.23	...		...		...
Hz1593	3 44 50.4	23 03 57	11.11	3	0.86	G6V	14	...		...
A60/B240	3 44 51.8	24 21 08	16.10	2	...	...		...		...
ALR929	3 44 52.7	24 21 12	16.16	1	1.56	...		...		...
Hz1613	3 44 54.0	23 47 21	9.88	7	0.54	F8V	10	18	12	var?
ALR928	3 44 57.9	24 22 32	13.77	3	1.03	...		...		...
Hz1653/T21	3 45 00.4	24 34 43	13.49	1	1.21	K4.5Ve,K7V	4,13	30	1	var
Hz1695/VM38	3 45 05.5	23 54 51	15.45	7	1.43	...		...		Pg
Hz1726	3 45 08.4	23 59 25	9.25	7	0.55	F7V	14	<12	12	bin?,var?
Hz1756	3 45 13.0	23 21 18	14.11	3	1.37	...		...		...
Hz1762	3 45 14.6	24 10 00	8.27	7	0.36	A9V	10	180	11	...
Hz1776	3 45 17.8	24 53 47	10.91	7	0.72	G5V	14	<10	1	...
Hz1785	3 45 18.2	24 21 07	14.29	3	1.40	...		...		...
Hz1794/VM42	3 45 18.7	23 44 19	13.36	7	0.64	...		...		VM43 comp.
Hz1805/VM43	3 45 19.5	23 44 23	13.36	7	0.64	...		...		VM42 comp.
Hz1797	3 45 18.7	23 29 06	10.11	7	0.56	F9V	10	15	12	var
Hz1823	3 45 22.9	23 16 11	5.45	7	-0.07	B8V	10	270	11	...
Hz1827/T51	3 45 24.3	23 49 13	14.87	1	1.47	...		...		bin?
Hz1856	3 45 27.5	23 53 49	10.02	7	0.56	F8V	10	12	12	...
Hz1876	3 45 31.0	24 11 38	6.95	7	0.12	A1V	10	105	11	bin?
VM46/T156	3 45 32.4	24 07 20	16.01	1	1.59	dM3	1	...		...
Hz1912	3 45 36.0	24 01 47	9.05	7	0.49	F4V	10	75	11	bin?
Hz1924	3 45 36.5	23 17 00	10.33	7	0.62	G0V	10	<20	12	var?
B207	3 45 42.4	24 51 21	16.61	1	1.63	...		...		...
Hz1993	3 45 46.0	23 06 31	8.37	7	0.29	A8V	10	85	11	...
Hz2016	3 45 47.5	23 11 15	13.61	1	1.22	dK7	13	...		...
Hz2027	3 45 50.0	24 06 58	10.91	7	0.86	K0	20	...		bin?,var
Hz2034	3 45 50.8	23 49 31	12.51	5	1.04	K2.5V	5	75,100	1,6	var
ALR728	3 45 52.3	24 02 54	16.09	1	1.46	...		...		...
Hz2106	3 46 00.7	23 03 00	11.53	7	0.86	K0	8	...		var?
Hz2126	3 46 04.5	23 06 05	11.64	7	0.86	K0	8	<10	1	var?
ALR715	3 46 04.8	24 09 43	15.08	3	0.95	...		...		...
Hz2144/T157	3 46 07.6	23 35 17	15.31	1	1.45	...		...		bin?
Hz2147	3 46 07.6	23 37 49	10.83	7	0.80	K0V	14	...		bin?,var
ALR1381	3 46 07.7	23 35 21	15.34	3	1.54	...		...		...
Hz2168	3 46 11.1	23 54 10	3.64	7	-0.08	B8III	10	215	11	SB1,bin
Hz2172	3 46 12.2	24 29 09	10.44	7	0.62	G0	8	<20	12	...
Hz2181	3 46 12.3	23 59 10	5.09	7	-0.08	B8p	10	340	11	28 Tau, var
Hz2193/T88	3 46 13.2	23 24 13	14.18	5	1.47	K6Ve	4	...		...
Hz2195	3 46 13.7	23 44 10	8.12	7	0.22	A7V	10	160	11	Vel var?
Hz2209	3 46 14.5	23 04 39	14.38	7	1.47	K6.5Ve	4	...		...
Hz2208	3 46 16.1	24 20 57	14.46	1	1.36	K6Ve	4	...		...
Hz2220	3 46 17.7	24 14 44	7.52	7	0.10	A2V	10	240	11	...
Hz2244/T51b	3 46 21.1	24 37 31	12.63	1	0.99	K2.5	5	50	1,6	...
Hz2263	3 46 22.6	24 13 49	6.60	7	-0.03	B9.7V	10	90	11	...
Hz2284/VM57	3 46 25.5	23 41 19	11.35	7	0.78	...		...		var
Hz2278	3 46 26.0	24 47 14	10.92	1	0.88	...		<10	1	bin?,var
Hz2289	3 46 27.0	24 05 50	7.97	7	0.18	A3V	10	165	11	var?
Hz2311/VM59	3 46 30.4	23 33 43	11.35	1	0.82	...		<10	1	var
Hz2323	3 46 33.1	24 28 30	...		...	...		...		...
T90	3 46 33.8	24 22 58	16.58	1	1.52	...		...		...
Hz2345	3 46 34.6	23 13 48	9.10	7	0.44	F3V	10	130	11	...
Hz2341	3 46 34.7	23 38 41	10.87	7	0.71	G4V	14	...		...
Hz2368	3 46 36.9	23 18 13	14.02	5	1.34	...		...		...

TABLE 1—*Continued*

Star Name	RA h m s	DEC ° ' "	m_V	Ref.	B-V	Sp	Ref.	V	Ref.	Notes
Hz2366/VM61	3 46 37.5	24 08 44	11.53	7	0.82	...		...		...
Hz2406	3 46 41.5	23 08 23	11.10	7	0.76	...		...		var
Hz2407/VM62	3 46 43.1	24 18 46	12.28	5	0.98	K3	15	<10	1	var
Hz2425	3 46 45.2	23 33 42	6.17	7	-0.05	B9V	10	310	11	...
Hz2462/VM64	3 46 52.0	23 33 19	11.49	1	0.84	...		...		...
T92	3 46 56.2	24 35 28	16.26	1	1.48	...		...		...
Hz2506	3 46 58.6	23 04 06	10.27	7	0.60	G0	8	20	12	...
Hz2500	3 46 58.8	23 41 52	10.95	9		F9.5V	9	...		Hz2507 comp.
Hz2507	3 46 59.5	23 41 55	6.74	7	0.06	A0V	10	15,30	11,12	Hz2500 comp.
Hz2503	3 46 59.3	23 41 53	...		...	...		...		...
Hz2548/VM69	3 47 06.2	23 58 27	14.02	1	1.33	K5.5Ve	4	...		...
T28	3 47 12.6	23 46 39	16.50	2	...	...		...		...
Hz2588	3 47 13.1	24 22 57	13.25	3	1.16	K3Ve?	4	<10	1	var
Hz2602/T93	3 47 13.6	23 50 43	15.49	1	1.63	dM3	1	<15	1	bin?
Hz2644/VM71	3 47 21.6	24 19 02	11.07	3	0.74	...		...		...
Hz2655	3 47 22.0	23 25 21	15.46	1	1.29	K4	15	...		Pg.
Hz2741	3 47 35.2	24 21 30	12.69	1	1.01	...		10	1	...
Hz2786	3 47 41.3	23 47 01	10.31	7	0.60	...		...		...
Hz2870	3 47 53.4	23 10 48	12.45	7	1.07	...		<10	1	...
Hz2866	3 47 53.7	23 48 45	6.93	7	0.09	A2V	10	155	11	bin?
Hz2881	3 47 55.7	23 41 09	11.56	1	0.98	K2	8	12	1	bin?
Hz2880	3 47 56.0	24 02 55	11.75	7	0.86	...		...		...
Hz2908/T166	3 48 02.3	24 54 20	13.41	5	1.15	K3Ve	4	...		...
Hz2927/T109	3 48 06.0	24 35 14	13.80	5	1.34	K4Ve	4	...		...
Hz2940/Tov3	3 48 07.9	24 19 56	13.98	1	1.32	M0-1	15	...		...
A18	3 48 12.3	24 14 15	16.10	2	...	...		...		...
Hz2966	3 48 13.4	23 47 02	14.90	1	1.50	dM2-K7	1,15	...		...
T95	3 48 17.9	23 07 58	14.84	1	1.43	...		...		...
Hz2984	3 48 18.2	23 40 40	12.37	7	1.00	...		<10	1	...
A54/B238	3 48 26.2	24 38 41	16.30	2	...	...		...		...
Hz3030/T30	3 48 26.7	23 44 24	14.02	5	1.35	K7V	15	...		...
Hz3031	3 48 27.7	24 22 14	8.83	7	0.38	F2V	10	230	11	...
Hz3063/T55b	3 48 31.3	23 45 00	13.60	1	1.17	...		28	1	...
Hz3096	3 48 39.8	24 24 02	12.15	7	1.00	...		...		...
Hz3097	3 48 40.4	24 50 06	10.97	7	0.74	...		...		var
Hz3163	3 48 54.1	24 14 20	12.69	7	0.98	...		60,75	1,6	var
P74/TS165	3 48 56	25 51 00	7.64	7	0.16	...		...		...
Hz3187	3 48 59.2	23 11 28	13.12	7	1.16	K4.5Ve	4	...		...
Hz3197/T59b	3 49 02.7	24 30 52	12.04	5	1.15	K3V	5	40	6	bin?
LB1497	3 49 06.0	24 47 12	16.52	9	0.20	D A wk	19	...		...
T159	3 49 21.1	24 25 02	15.44	1	1.49	...		...		...
P70/TR60	3 49 54	24 34 06	9.44	7	0.48	...		...		...
TS177	3 50 33.4	25 32 08	6.36	7	0.12	A2V	9	...		...
P83	3 50 49	25 49 12	11.09	16	0.75	...		...		var
B127	3 51 32.6	25 31 57	14.72	1	1.47	...		...		bin?
P159	3 51 33	25 23 18	10.80	16	0.73	...		...		...
A141	3 52 51.7	24 03 21	16.40	2	...	...		...		...
P115	3 53 00	24 24 36	12.68	16	1.13	...		...		...
MT124	3 53 26.8	24 08 14	...		...	...		...		...
A113	3 53 30.9	24 08 40	16.10	2	...	...		...		...
P116	3 54 18	23 52 00	12.26	16	0.97	...		...		var
P162	3 54 34	23 54 42	12.11	16	0.99	...		...		...
P163/TS194	3 55 21	23 56 24	7.19	7	0.04	A0V	9	...		...
P117	3 56 19	24 12 18	13.10	16	1.12	...		...		...
P173	3 57 59	23 03 42	9.60	16	0.46	...		...		...
P174	4 00 46	22 48 30	9.67	16	0.60	...		...		...

TABLE 2

CHARACTERISTICS OF OBSERVATIONS

Sequence Number	R.A. (1950)	Decl. (1950)	Observation Date	Live Time (ks)	Original Observer
I2296......	$3^h44^m06^s$	23°41′49″	1980 Feb 19/20	14.2	CAL
I3175......	3 49 06	24 47 00	1979 Aug 13	1.3	Bowyer
I4546......	3 59 09	22 59 41	1980 Mar 1	1.5	Wilson
I5457......	3 41 54	23 57 28	1981 Feb 7	2.9	CfA
I5458......	3 42 51	24 12 47	1981 Feb 8	4.5	CfA
I6003......	3 44 30	23 57 30	1980 Feb 16/17	2.5	CAL
I7408......	3 50 20	23 36 00	1981 Feb 10	2.4	GSFC
I9257......	3 54 26	24 20 00	1981 Feb 9	1.7	CAL
I9258......	3 40 55	19 30 00	1981 Feb 1	2.5	CAL
I9916......	3 42 30	24 30 00	1981 Feb 7	4.7	CAL
I9917......	3 46 30	24 30 00	1981 Feb 8	6.1	CAL
I9918......	3 42 30	23 30 00	1981 Feb 8	5.7	CAL
I9919......	3 46 30	23 30 00	1981 Feb 7/8	5.8	CAL
I10132.....	3 43 00	24 12 47	1981 Feb 8	1.9	Cash and Snow

source has been detected in three distinct exposures; in each exposure, the error circle contains an A7 Pleiades star (Hz 956) and a foreground early K SAO star. We assume that the K star is responsible for the emission and also consider the observed flux as an upper limit to the emission of the A7 Pelaides star; this is the same assumption as in Micela *et al.* (1985), and is based on our present best knowledge of X-ray luminosity functions of dK and dA stars.

4. In nine cases there are pairs of Pleiades stars that meet criterion (1). For eight X-ray sources we cannot determine the "true" emitter, and, because the possible counterparts are of similar spectral type, we attribute half of the observed X-ray emission to each star.[3] In one case, the X-ray source has as possible counterparts an F9 and an A2 star; in this case we attribute the X-ray emission to the F9 star, and consider this emission to be an upper limit to the emission of the A2 star. Again this decision is based on our present knowledge of X-ray luminosity function for solar-like and dA stars.

By adopting the criteria indicated above and considering the

[3] There is an HRI observation covering one of these sources, but the two optical candidates are too close together to be resolved even by the HRI.

TABLE 3

MISIDENTIFICATION ESTIMATES

IPC Field Sequence Number	Number of Pleiades Stars in Field	Expected Number of Chance Coincidences		
		1′	2′	3′
2296	86	0.11	0.44	0.99
3175	9	0.01	0.05	0.10
4546	2	3.(−3)	0.01	0.02
5457	80	0.10	0.41	0.92
5458	89	0.11	0.46	1.03
6003	85	0.11	0.44	0.98
7408	5	6.(−3)	0.03	0.06
9257	8	0.01	0.05	0.09
9258	1	1.(−3)	5.(−3)	0.01
9916	76	0.10	0.39	0.88
9917	42	0.05	0.22	0.48
9918	69	0.09	0.35	0.80
9919	61	0.08	0.31	0.70
10132	84	0.11	0.43	0.97
Entire survey......		~1	~4	~9

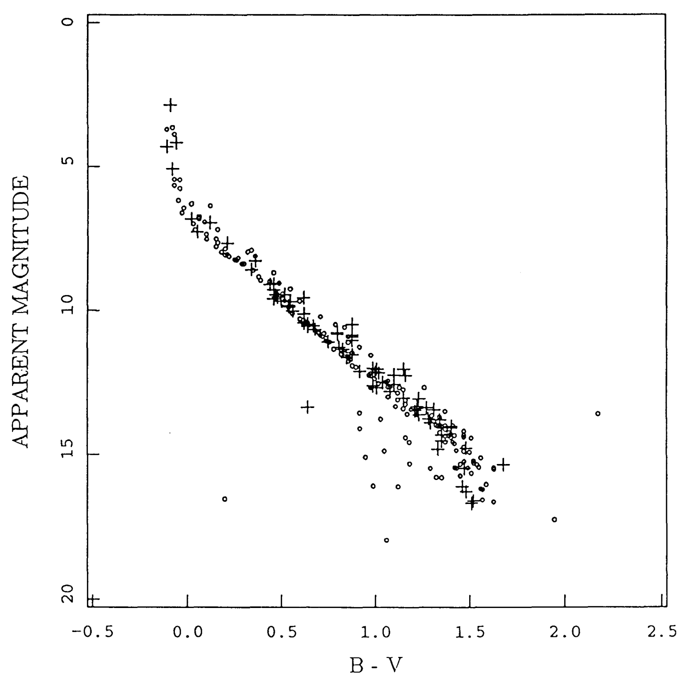


FIG. 3.—H-R diagram of the Pleiades stars surveyed, with undetected stars shown as circles, and detections, as crosses. For membership criteria see § II. For the effect of potential interlopers below the main sequence see comments in the text (§ III*b* and § IV *a*[iii]). The majority of detected B type stars, and many of the A type stars are members of binary systems.

NOTE.—The stars names are coded according to the following conventions: A: Asiago observatory flare stars. ALR: Ahmed, Lawrence, and Reddish 1965. B: Byurakan observatory flare stars. Hz: Hertzsprung 1947. JRS: Stauffer 1984. MT: McCarthy and Treanor 1964. P: Pels (quoted in van Leeuwen 1983). T: Tonantzintla flare stars. VM: van Maanen 1945.

REFERENCES.—(1) Stauffer 1980, 1982, 1984; Stauffer *et al.* 1984; (2) Jones 1970, 1973, 1981; (3) Landolt 1979; (4) Kraft and Greenstein 1969; (5) Iriarte 1967; (6) Soderblom 1983; (7) Johnson and Mitchell 1958; (8) Wilson 1963; (9) Buscombe 1977, 1980, 1981; (10) Mendoza 1956, 1967; (11) Anderson, Stoeckly, and Kraft 1966; (12) Kraft 1967; (13) McCarthy 1969; (14) Breger 1972; (15) Herbig 1962; (16) van Leeuwen 1983; van Leeuwen and Alphenaar 1982; (17) Smith and Struve 1944; (18) Pesch 1962; (19) Eggen and Greenstein 1965; (20) Danzinger and Conti 1966.

result listed in Table 3, we expect one or two mistaken identifications of X-ray sources with Pleiades stars.

In summary, we have identified 128 X-ray detections with 85 distinct Pleiades stars. In addition, there are five detections identified from IPC standard processing (i.e., inside 3′) with cataloged field objects, and 18 unidentified detections. These latter two numbers (five and eighteen) compare well with the expected number of extragalactic, field stellar and spurious X-ray detections (21 sources).

We show the H-R diagram of the 283 cluster stars in the present survey in Figure 3 and a breakdown into spectral types of detected main sequence Pleiades stars in Figure 4.

We note that in the H-R diagram of the surveyed Pleiades stars there is a group of stars which lie significantly below the main sequence; probably these stars are not true members. However, we have preferred to retain them in our optical sample with the explicit purpose of applying an homogeneous selection criteria to the entire sample (see § II). The inclusion of these possible interlopers does not affect any of the following results and conclusions, because these stars are less than 10% of the total number of stars in the same $B-V$ range (see § IV*a*).

c) *Count Rate, Flux, and Luminosity*

The effective broad-band count rate for X-ray detections has been evaluated by taking into account vignetting, detection cell efficiency, and potential shadowing by the IPC entrance-aperture support structure or edges, following the procedure given in Paper I. In the Appendix of that paper we showed that, for stellar X-ray detections, a significant fraction of photons fall outside the standard detection cell; however, in the present survey we are forced to evaluate X-ray count rates from the standard (2.′4 × 2.′4) cell count rate because the counts collected in a circle of 3′ radius centered on the X-ray detection (that would contain ~100% of photons of the X-ray sources) are affected for the majority of Pleiades sources by the presence of nearby (<3′), interfering, source detections; that is, the sources are too crowded in the field to allow us the freedom of enlarging the region from which the count rate is determined to the optimal point. In order to take proper account of the photons falling outside the standard detection cell, and so to correct for this unavoidable difficulty, we have applied a further correction factor of 1.14 with respect to that routinely applied in the final IPC data processing system (see Appendix B of Paper I). This value of the correction factor was determined from 17 detections unaffected by the presence of nearby detections and not obscured by entrance-aperture supports or edges. We note here that the value of the correction factor we have derived for Pleiades stars is somewhat less than the value adopted in the Hyades survey (1.24); this is consistent with the expected spectral dependence of this factor, which should decrease with the hardening of the X-ray spectrum due to the reduction of number of soft photons scattered out of the detection cell. In fact, the Pleiades region is characterized by a larger value of hydrogen column, which selectively absorbs softer ($\lesssim 1$ keV) X-ray photons and hence reduces the overall fraction of photons displaced from the standard detection cell.

To compute the source count rate, we apply the same procedure as described in Appendix A of Paper I; we note that information about entrance-aperture support and edge shadowing is retained by the standard processing in the so-called RECO (Ribs and Edge Code), which equals 0 only for completely unobscured detections:

a. For multiple detections, we take a wighted-mean count rate of all observations having RECO equal to 0, weighted by the inverse square of the statistical error.[4] If there are only obscured observations for a given source, then measurements having RECO different from 0 are used. If there is only one observation, we take the rate computed with the Map algorithm if the source has been detected with this method; otherwise, we take the value computed by the Local method.

b. For upper bounds, we use the lowest available value measured with RECO equal to 0. If only values with RECO different from 0 are available, we conservatively retain the largest such value. We note that upper bounds are always evaluated with the Local algorithm.

The use of a unique value of X-ray luminosity for each given star is justified because none of the observed stars show significant (at the 3 σ level) long-term variability in X-ray emission between different exposures (cf. § IV*g*).

We have converted from count rates, evaluated as described above, to X-ray fluxes in the 0.16–4.0 keV energy band using a constant conversion factor of 2.2×10^{-11} ergs count^{-1} cm^{-2}. This value has been obtained by assuming a source temperature of $\sim 3 \times 10^6$ K and a hydrogen column density of $N_H = 2.0 \times 10^{20}$ cm^{-2}; the value of N_H has been computed according to Bohlin, Savage, and Drake (1978) using a reddening of $E(B-V) \sim 0.04$ (Crawford and Perry 1976); these

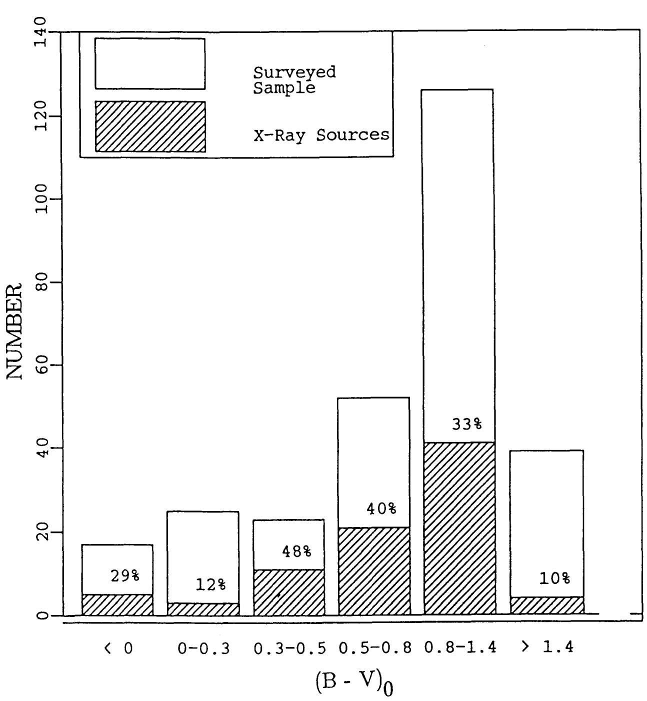


FIG. 4.—Color-index breakdown for the Pleiades survey. The color distribution of the entire surveyed sample (white area of bars) is compared with that of stars detected as X-ray sources (*dashed area*). Percentage number of detected stars is indicated in each range of $(B-V)_0$. Note the small number of detected dA and dM stars.

[4] We use a weighted mean to evaluate the X-ray source flux, as in the Hyades survey (Paper I), rather than adopting a maximum likelihood estimate of flux as done by Chlebowsky, Harnden, and Sciortino (1989) for a survey of O stars. It is noteworthy that both these methods make the assumption of an underlying constant source. We have checked that, for our sources, the weighted mean computed fluxes are within 20%–25% of the maximum likelihood computed fluxes.

"mean" corrected $B-V$ values will be referred as $(B-V)_0$ in the following discussion. With a common distance of 127 pc for all cluster members, the total conversion factor from count rate measured in the detection cell to X-ray luminosity is then 4.85×10^{31} ergs count^{-1}. The deduced X-ray luminosities are listed in Table 4.

The estimated overall uncertainty in derived X-ray luminosities is $\sim 60\%$ and consists of statistical errors (less than 40%), systematic errors in instrumental calibrations ($\leq 10\%$; Harnden *et al.* 1984), errors due to individual cluster member distance ($< 15\%$), and systematic errors in converting count to flux due to the assumed source temperature ($\leq 40\%$).

Note that an apparent discrepancy between our luminosities and those of Caillault and Helfand (1985) is likely due to the combination of two effects: those authors used a conversion factor of 2.5×10^{-11} ergs count^{-1} cm^{-2} versus 2.2×10^{-11} ergs count^{-1} cm^{-2} used here, and their count collection technique differed from ours. Since the REV-1 software was not available at the time they did their work, Caillault and Helfand would have had to collect counts from the images using pulse-height (PH) bins instead of the Pulse-height Invariant (PI; cf. Harnden *et al.* 1984) bins used here. For example, if they had used PH bins 1–10 (on a scale of 0–15), they would have gotten 5% more counts than did we by extracting PI bins 2–10 (0–15 scale) from the same images. (This factor was derived from 22 sources found in the five IPC fields they studied.) The product of these two factors (1.19) is quite close to the mean value of 1.17 for the ratio of their fluxes to ours.

IV. X-RAY SOURCES IDENTIFIED WITH PLEIADES CLUSTER MEMBERS

a) *Main-Sequence-Star Luminosity Functions*

In the following, for ease of comparison with Paper I, we consider subsamples of main-sequence stars with spectral type later than A, in four distinct color intervals, namely $(B-V)_0 =$ 0.0–0.5, dA and early dF stars; $(B-V)_0 = 0.51$–0.80, solar-like stars; $(B-V)_0 = 0.81$–1.45, dK stars; and $(B-V)_0 > 1.45$, dM stars, according to the $B-V$ color index subdivision used in Paper I. Due to reddening in the Pleiades cluster region, we have corrected measured $B-V$ values with a mean reddening $E(B-V)$ equal to 0.04 (Crawford and Perry 1976); discussion of effects of differential reddening is deferred to § IV*c*. Our statistical analysis is based on techniques developed for censored data samples (Avni *et al.* 1980; Schmitt 1985; Feigelson and Nelson 1985) and uses bootstrap techniques with repetitions to evaluate mean values and estimates of their errors (Schmitt 1985).

We compare the Pleiades results with analogous results from surveys of nearby field stars and Hyades stars. For nearby stars with which to draw comparisons, we use as reference the following volume-limited samples: Schmitt *et al.* (1985), for dA and early dF stars; Maggio *et al.* (1987), for solar-like stars; and Bookbinder (1985), for dK and dM stars. In this last group we have discriminated between kinematically old and young disk stars, which Bookbinder (1985) has shown to have different X-ray luminosity levels. For the Hyades stars, we draw comparisons with Paper I. We note that because of the different ranges of stellar distances for the samples we have compared, the distributions of the X-ray luminosity thresholds are different. In such a case of "censored data," the use of the permutational variance in applying nonparametric two sample tests is strictly speaking not correct (Feigelson and Nelson 1985). To overcome this problem in performing comparisons between different samples, we use the Peto-Prentice generalized Wilcoxon test, using the functional form for the variance as derived by Latta (1981) (see also discussion in Paper I). The Pleiades-Hyades comparisons given here differ slightly from those reported in Paper I, for which the Pleiades data were limited to only two (i.e., those of Micels *et al.* 1985) of the 14 Pleiades fields considered here; however, the main conclusions presented in Paper I remain unchanged and are now based on a larger sample of Pleiades members.

i) *dA and Early dF Stars*

As in Paper I, we consider separately stars with $0.0 \leq (B-V)_0 < 0.3$ and stars with $0.3 \leq (B-V) < 0.05$. In the combined fields of view there are 25 stars belonging to the first group; three were detected by the IPC, and 3 σ upper limits were derived for the remaining 22 stars. Figure 5*a* shows the maximum likelihood integral X-ray luminosity distribution based both on detections and upper bounds. The available number of detections and the distribution of upper limits do not allow to sample the X-ray luminosity function up to the median value. In such a case, while the "formal" mean value of $\log L_X$ results equal to 29.15, the determination of its errors via a "bootstrap" technique is unreliable. A further constraint is set by an upper bound to the median of $\log L_X$ equal to 29.5, evaluated as the median of the values of both detections and 3 σ upper bounds.

We have compared this sample with analogous samples of field stars and Hyades stars, using the nonparametric generalized Peto-Prentice Wilcoxon test, but find their luminosity functions to be indistinguishable (confidence levels for rejecting the null hypotheses that those samples and the Pleiades sample are drawn from the same parent population are 58% and 77%, respectively). Of the three Pleiades stars detected, two (Hz 1397 and Hz 1876) are binary stars: both have later spectral-type companions (F and G5, respectively) which may well be responsible for the observed emission, as suggested by the observation of nearby dA field stars of Schmitt *et al.* (1985). The remaining A4 V star (Hz 1384) is a very intense emitter ($\log L_X = 30.20$), as previously reported by Caillault and Helfand (1985) and by Micela *et al.* (1985). As it has been remarked previously (Micela *et al.* 1985), Abt *et al.* (1965) found no evidence that Hz 1384 is a spectroscopic binary; but on the other hand, this star's X-ray luminosity would be too intense even for a comparison star of later spectral type (i.e., an unseen optical companion). Hence, the high X-ray luminosity of this star remains an enigma. Indeed, we note that while in general X-ray–detected dA stars in the solar neighborhood are in binary systems (Schmitt *et al.* 1985), peculiary high X-ray luminosities have also been observed in other cases, such as in 71 Tau ($\log L_X = 30.11$), a late dA Hyades star (Stern *et al.* 1981; Paper I) with a dG companion (where the measured X-ray luminosity is too high to be easily explained by emission from the G star); and in an apparently single Ursa Major stream dA star, HR 1666 (Paper III), whose X-ray luminosity ($\log L_X = 28.90$) is an order of magnitude less than that of Hz 1384 but still substantially higher than that of nearby dA stars.

In the range $0.3 \leq (B-V)_0 < 0.5$ our sample consists of 23 stars, of which 11 were detected as X-ray emitters. The maximum likelihood integral X-ray luminosity function is shown in Figure 5*b*, and the mean value of $\log L_X$ is 29.40 ($+0.06$, -0.05), where the indicated 1 σ errors are evaluated with the use of bootstrap with replications (Schmitt 1985).

TABLE 4

X-Ray Luminosity of Pleiades Members

Star Name	$Log(L_X)$ erg/sec	Percentage error	Flux Flag[a]	RECO[b]
T3	< 30.19		LB	Y
T147	< 29.73		LB	
T148	< 29.71		LB	Y
Hz81	< 29.77		LB	Y
Hz83	< 29.73		LB	Y
Hz97	< 29.71		LB	Y
Hz120	< 30.24		LB	Y
Hz129	< 29.79		LB	Y
Hz134	< 29.55		LB	
Hz133	29.63	35.2	MB	Y
Hz146	< 29.55		LB	
Hz152	< 30.55		LB	Y
MT41	< 29.89		LB	Y
Hz153	< 30.11		LB	Y
Hz157	< 29.67		LB	Y
Hz158	< 29.63		LB	
Hz164	29.49	32.8	MB	Y
Hz174	30.10	17.1	MB	Y
Hz186	< 29.88		LB	Y
Hz189	< 29.67		LB	Y
Hz193	29.86	23.2	MB	
Hz191	29.58	31.6	MB	Y
Hz212	< 29.85		LB	Y
Hz220	< 29.76		LB	Y
JRS27	< 29.66		LB	
Hz233	< 29.52		LB	
Hz232	< 29.71		LB	Y
T150	< 29.58		LB	Y
JRS26	< 29.46		LB	
Hz253	30.40	13.3	MB	
Hz250	< 29.48		LB	Y
Hz263	29.72	27.8	MB	
T71	< 30.09		LB	Y
Hz296	29.58	26.9	MB	Y
Hz298	29.29	22.5	WM	
Hz299	29.29	22.5	WM	
Hz293	< 29.72		LB	
Hz303	29.83	22.9	MB	
Hz314	29.97	10.8	MB	
Hz320	29.97	10.8	MB	
Hz324	< 29.80		LB	
Hz335	29.53	35.7	MB	
Hz338	29.69	28.0	MB	
T42b	< 29.77		LB	
B179	29.61	26.2	MB	
Hz344	< 29.62		LB	Y
Hz345	30.19	9.9	WM	
Hz347	< 29.55		LB	
Hz357	29.60	28.0	MB	
Hz370	< 29.30		LB	
Hz390	< 29.37		LB	
A23	< 29.31		LB	
Hz405	29.56	28.0	MB	
Hz430	< 29.42		LB	
Hz447	< 29.37		LB	
Hz451	< 29.46		LB	Y
Hz470	< 29.53		LB	Y
Hz468	< 29.38		LB	
Hz476	29.36	38.3	MB	Y
Hz489	< 29.46		LB	
Hz513	< 29.28		LB	
Hz522	< 29.28		LB	
Hz530	< 29.30		LB	
Hz531	29.50	33.8	MB	
P135	< 29.88		LB	
Hz541	< 29.39		LB	
Hz554	< 29.38		LB	
Hz563	29.59	18.5	WM	
Hz559	< 29.60		LB	
Hz566	< 29.60		LB	
MT57	< 29.52		LB	
A84	< 29.38		LB	
Hz590	< 29.59		LB	
Hz605	< 29.41		LB	
Hz625	29.76	15.3	WM	
Hz624	< 29.46		LB	
Hz636	< 29.37		LB	
Hz627	29.46	32.2	MB	
Hz652	< 29.51		LB	
Hz673	29.27	21.1	MB	
Hz676	< 29.38		LB	
Hz686	29.27	21.1	MB	
Hz697	< 29.38		LB	
Hz708	29.73	21.4	MB	
B203	< 29.53		LB	
Hz717	< 29.44		LB	
Hz727	29.91	10.8	WM	
Hz738	29.80	11.5	WM	
Hz739	30.31	10.7	MB	
Hz745	29.61	34.5	MB	
Hz746	< 29.40		LB	
Hz762	< 29.43		LB	
Hz761	29.60	13.3	WM	
Hz793	< 29.15		LB	
Hz785	< 29.43		LB	
Hz799	< 29.12		LB	
Hz804	< 29.18		LB	
Hz813	< 29.19		LB	
Hz817	< 29.45		LB	
Hz859	< 29.37		LB	
Hz870	< 29.22		LB	
Hz882	< 29.58		LB	Y
Hz879	29.22	26.5	MB	
Hz883	29.22	26.5	MB	
Hz885	29.40	34.6	MB	
Hz890	29.79	30.2	MB	
Hz915	29.20	18.5	WM	Y
Hz906	< 29.47		LB	
Hz923	29.20	18.5	WM	Y
Hz916	< 29.42		LB	
Hz930	< 29.22		LB	
Hz956	< 29.60		LB	

TABLE 4—*Continued*

Star Name	Log(L_x) erg/sec	Percentage error	Flux Flag[a]	RECO[b]
Hz975	< 29.42		LB	
Hz974	< 29.42		LB	
Hz980	29.71	11.4	WM	
Hz996	< 29.48		LB	
VM6	< 29.49		LB	
Hz1028	< 29.19		LB	
Hz1029	< 29.41		LB	Y
Hz1032	29.95	12.1	WM	
Hz1039	29.30	22.0	WM	
Hz1061	< 29.61		LB	
Hz1081	< 29.50		LB	
Hz1084	< 29.13		LB	
Hz1094	29.42	20.4	MB	
Hz1103	29.52	29.0	MB	
Hz1095	< 29.68		LB	Y
Hz1100	29.39	35.3	MB	
Hz1117	< 29.18		LB	
Hz1110	< 29.38		LB	
Hz1122	29.24	27.8	MB	
Hz1124	29.74	23.0	MB	
Hz1136	31.27	3.0	MB	Y
VM15	< 29.18		LB	
Hz1173	< 30.03		LB	Y
Hz1200	< 29.64		LB	Y
MT72	< 29.29		LB	
Hz1207	< 30.05		LB	Y
Hz1215	< 29.81		LB	Y
A33	< 29.77		LB	Y
A40	< 29.81		LB	Y
Hz1234	29.73	35.7	MB	
Hz1275	< 29.40		LB	Y
Hz1266	29.71	25.5	MB	
Hz1280	< 29.56		LB	
Hz1284	< 29.12		LB	
Hz1286	29.30	24.4	MB	
Hz1298	29.26	13.3	WM	
Hz1306	29.26	13.3	WM	
Hz1309	29.50	20.0	WM	
Hz1321	< 29.25		LB	
Hz1332	< 29.28		LB	
B363	< 29.10		LB	
Hz1338	< 29.19		LB	
Hz1348	< 29.78		LB	Y
Hz1355	29.29	22.5	WM	
Hz1362	< 29.20		LB	
Hz1375	< 29.18		LB	
Hz1380	< 29.05		LB	
Hz1384	30.20	8.8	WM	
Hz1392	29.05	21.7	MB	
Hz1397	29.05	21.7	MB	
Hz1425	< 29.15		LB	
Hz1432	29.60	36.1	MB	
Hz1431	< 29.55		LB	
Hz1454	< 29.57		LB	
MT78	< 29.19		LB	
Hz1491	< 29.58		LB	Y
Hz1512	< 29.20		LB	
Hz1514	29.79	23.4	MB	
Hz1516	< 29.64		LB	
Hz1531	29.48	17.7	MB	
Hz1532	29.31	23.8	MB	
ALR513	< 29.20		LB	
Hz1593	< 29.93		LB	Y
A60	< 29.87		LB	Y
ALR929	< 30.09		LB	Y
Hz1613	29.60	36.1	MB	
ALR928	< 29.77		LB	Y
Hz1653	29.40	34.6	MB	Y
Hz1695	< 29.39		LB	
Hz1726	< 29.63		LB	
Hz1756	< 29.24		LB	
Hz1762	29.72	29.9	MB	
Hz1776	< 29.51		LB	
Hz1785	< 29.34		LB	Y
Hz1794	29.29	37.5	MB	
Hz1805	29.29	37.5	MB	
Hz1797	< 29.45		LB	
Hz1823	< 29.48		LB	Y
Hz1827	< 29.65		LB	
Hz1856	29.24	30.6	MB	
Hz1876	29.45	32.8	MB	Y
VM46	< 29.74		LB	Y
Hz1912	< 29.32		LB	
Hz1924	< 29.51		LB	
B207	< 29.64		LB	Y
Hz1993	< 29.60		LB	Y
Hz2016	< 29.56		LB	Y
Hz2027	< 29.92		LB	Y
Hz2034	29.45	24.1	MB	
ALR728	29.46	35.0	MB	
Hz2106	< 29.64		LB	
Hz2126	< 29.52		LB	Y
ALR715	< 29.83		LB	
Hz2144	< 29.49		LB	
Hz2147	30.36	5.3	WM	
ALR1381	< 29.51		LB	
Hz2168	< 29.76		LB	Y
Hz2172	29.25	37.8	MB	
Hz2181	29.51	36.4	MB	
Hz2193	< 29.42		LB	
Hz2195	< 29.32		LB	
Hz2209	< 29.54		LB	
Hz2208	< 29.27		LB	
Hz2220	< 29.36		LB	
Hz2244	29.55	23.3	MB	
Hz2263	< 29.86		LB	Y
Hz2284	< 29.35		LB	
Hz2278	29.51	26.9	MB	Y
Hz2289	< 29.44		LB	
Hz2311	< 29.29		LB	
Hz2323	< 29.39		LB	
T90	29.49	25.0	MB	

TABLE 4—*Continued*

Star Name	$\log(L_x)$ erg/sec	Percentage error	Flux Flag[a]	RECO[b]	Star Name	$\log(L_x)$ erg/sec	Percentage error	Flux Flag[a]	RECO[b]
Hz2368	< 29.51		LB		Hz2984	< 29.58		LB	
Hz2366	< 29.62		LB	Y	A54	30.26	11.4	MB	
Hz2406	< 29.55		LB	Y	Hz3030	< 29.81		LB	Y
Hz2407	< 29.37		LB		Hz3031	< 29.47		LB	
Hz2425	< 29.33		LB		Hz3063	< 30.02		LB	Y
Hz2462	< 29.36		LB		Hz3096	29.54	33.8	MB	Y
T92	29.39	29.4	LB		Hz3097	< 29.75		LB	
Hz2506	< 29.64		LB		Hz3163	< 29.78		LB	Y
Hz2500	30.22	11.6	LB	P74	< 29.73		LB	Y	
Hz2507	< 30.22		LB		Hz3187	< 30.00		LB	Y
Hz2503	< 30.22		LB		Hz3197	30.02	26.3	MB	
Hz2548	< 29.52		LB		LB1497	< 29.57		LB	
T28	< 29.49		LB		T159	< 30.23		LB	Y
Hz2588	< 29.45		LB		P70	< 29.80		LB	
Hz2602	< 29.59		LB	Y	TS177	< 29.36		LB	
Hz2644	< 29.40		LB		P83	< 29.56		LB	
Hz2655	< 29.38		LB		B127	< 29.70		LB	Y
Hz2741	29.43	30.9	MB		P159	< 29.72		LB	Y
Hz2786	< 29.73		LB	Y	A141	< 29.80		LB	Y
Hz2870	< 29.57		LB	Y	P115	< 29.76		LB	Y
Hz2866	< 29.59		LB		MT124	< 29.75		LB	
Hz2881	< 29.61		LB	Y	A113	< 29.73		LB	
Hz2880	< 29.73		LB		P116	< 29.80		LB	
Hz2908	< 29.76		LB		P162	< 29.70		LB	
Hz2927	29.73	21.6	MB		P163	< 29.72		LB	
Hz2940	< 29.64		LB	Y	P117	< 29.88		LB	
A18	< 29.83		LB	Y	P173	29.73	36.6	MB	
Hz2966	< 29.49		LB		P174	< 29.96		LB	Y
T95	< 29.68		LB	Y					

[a] Flag indicating how the X-ray is evaluated (cf. § III): MB = from the "Map" cell count rate; LB = from "Local" cell count rate; WM = weighted mean for source observed more than once.

[b] Y means that X-ray luminosity is derived in presence of partial shadowing of source by the IPC entrance-aperture support structure (cf. § III).

Again, we are unable to distinguish the luminosity function of early dF stars in this sample from those in the field and in the Hyades samples (null hypotheses rejection confidence levels of 95.5% and 96.4%, respectively).

The result of nonparametric Wilcoxon test allow us to reject (confidence level 99.5%) the null hypothesis that the X-ray luminosities of the Pleiades stars in the range $0.0 \leq (B-V)_0 < 0.3$ and in the range $0.3 \leq (B-V)_0 < 0.5$ are drawn from the same parent population. We conclude that the Pleiades cluster members show a real rise of the X-ray luminosity from dA stars to early dF stars, extending to younger stars the previous finding of Schmitt *et al.* (1985) based on analysis of field star data.

ii) *Solar-like Stars*

The sample of the solar-like stars $[0.5 \leq (B-V)_0 < 0.8]$ consists of 52 stars, of which 21 have been detected as X-ray sources. The luminosity function shown in Figure 5*c* corresponds to a mean log L_X value of 29.43 (+0.06, −0.05), evaluated as described in the previous section. Comparing the Pleiades star sample with that of nearby field stars, we do find their luminosity functions to be different, with the Pleiades being stronger emitters than the nearby field stars (null hypothesis rejection possible at the 99.8% confidence level), but a similar comparison with the solar-like stars in the Hyades shows no significant difference (null hypothesis rejection only at 95.1% confidence level). We were also unable to distinguish the solar-like Pleiades stars from the early-dF Pleiades stars, notwithstanding the more pronounced, high-luminosity tail present in the X-ray luminosity function of the Pleiades dG star sample (see Fig. 5*c*).

iii) *dK Stars*

We have observed 126 dK Pleiades stars, 41 of which were detected as X-ray sources. The integral maximum likelihood X-ray luminosity function is shown in Figure 5*d*, and the mean value of log L_X is 29.34 (+0.03, −0.03). The luminosity function of the Pleiades dK stars clearly shows that these stars are significantly more X-ray luminous than the field dK stars (null hypothesis rejection at a confidence level greater than 99.99%). This result is obtained regardless of whether we consider the old and young disk field star samples separately. With similar confidence, we find that the Pleiades dK star sample also differs from that of the Hyades, the Pleiades stars being more luminous than the Hyades stars.

The rejection of stars which lie many magnitude below the main sequence, hence with questionable membership, does not affect the present analysis; the overall effects is to increase the

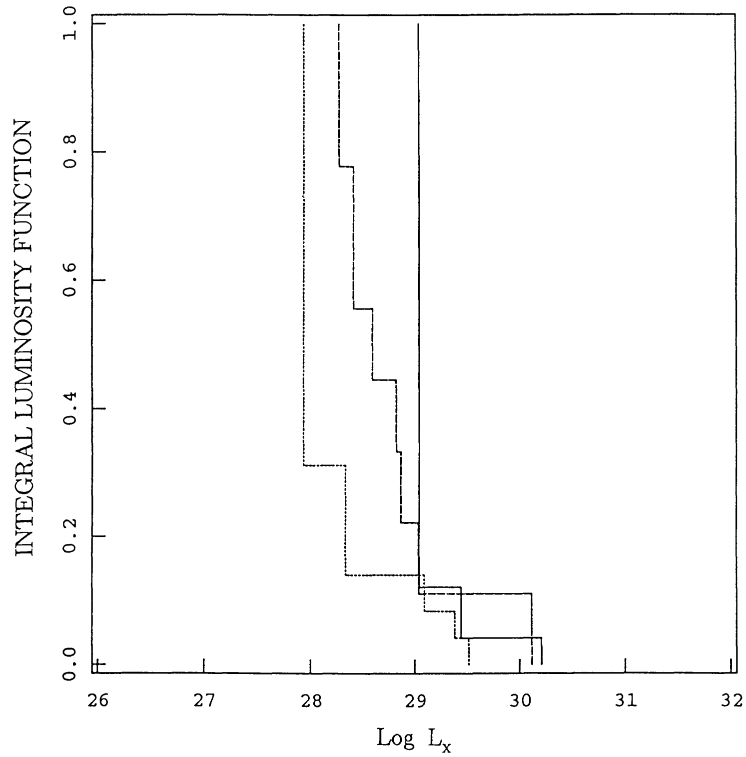


FIG. 5*a*

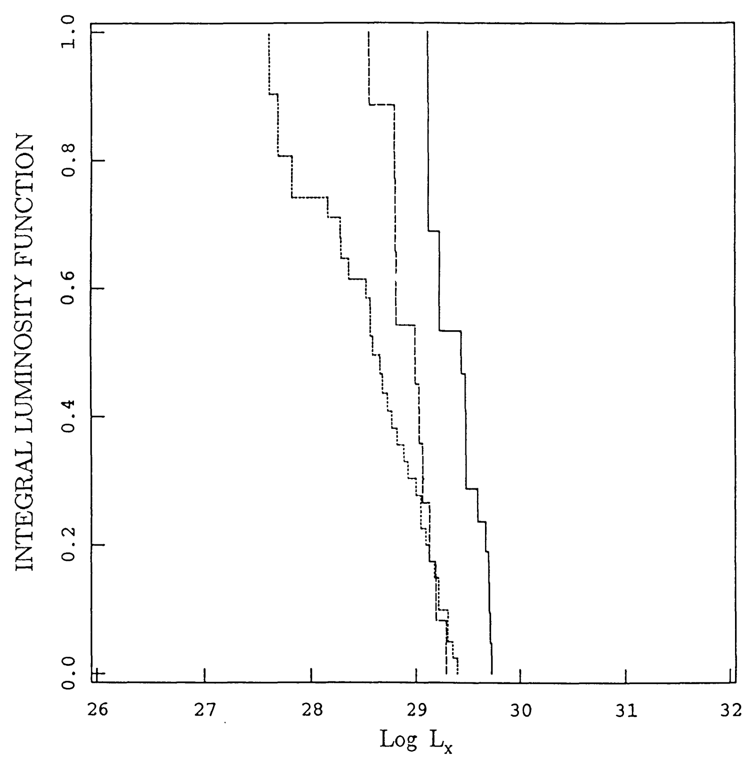
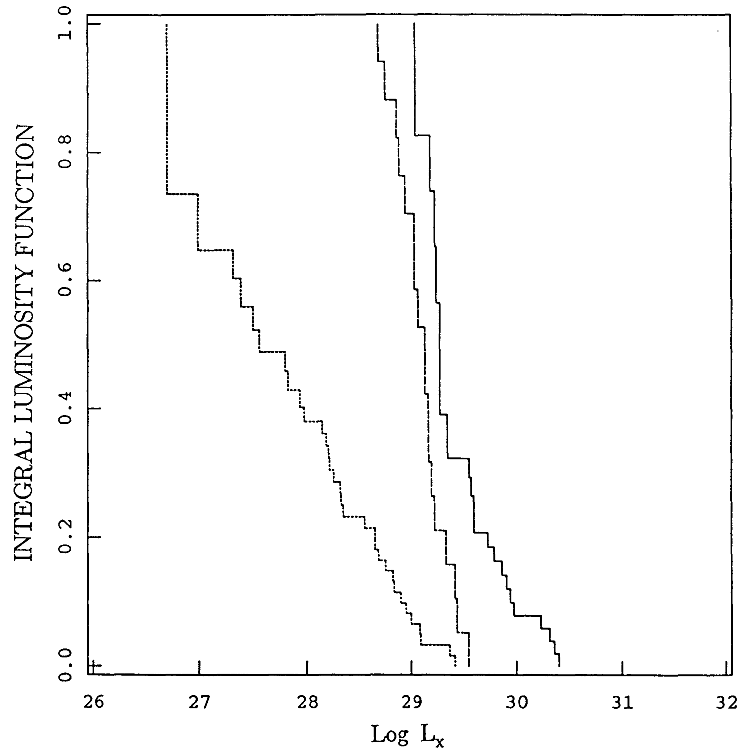


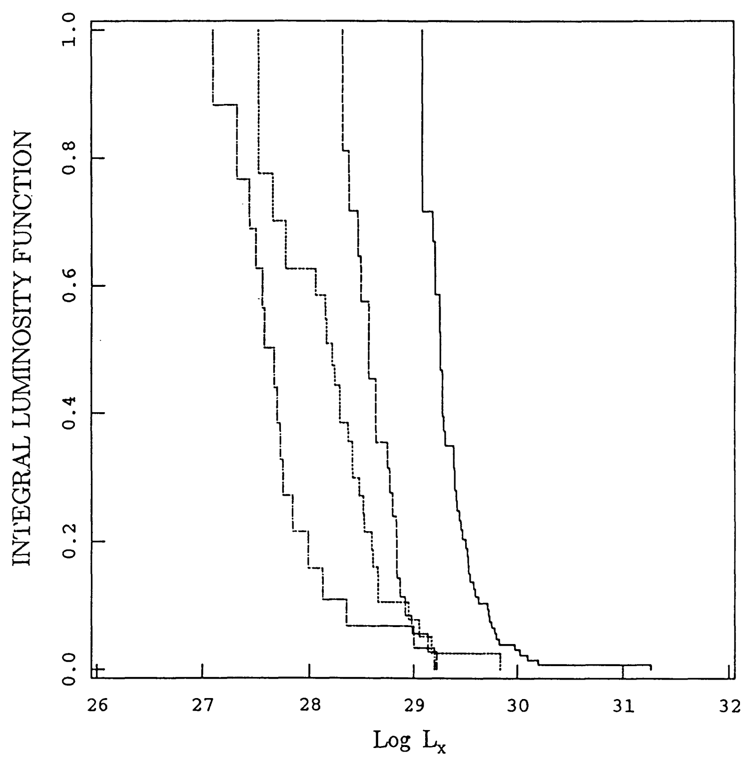
FIG. 5*b*

FIG. 5.—Maximum likelihood X-ray luminosity function for (*a*) the dA $[0 \leq (B-V)_0 < 0.3]$ stars of the Pleiades (*solid line*), the Hyades (from Paper I; *dashed line*), the nearby field stars (data from Schmitt *et al.* 1985; *dotted line*); (*b*) the early dF stars $[0.3 \leq (B-V)_0 < 0.5]$ of the Pleiades (*solid line*), the Hyades (from Paper I; *dashed line*), the nearby field stars (data from Schmitt *et al.* 1985; *dotted line*); (*c*) the solar-like stars $[0.5 \leq (B-V)_0 < 0.8]$ of the Pleiades (*solid line*), the Haydes (from Paper I; *dashed line*), the nearby field stars (data from Maggio *et al.* 1987; *dotted line*); (*d*) the dK stars $[0.8 \leq (B-V)_0 < 1.4]$ of the Pleiades (*solid line*), the Hyades (from Paper I; *dashed line*), the young disk nearby population (data from Bookbinder 1985; *dotted line*), the old disk nearby population (data from Bookbinder 1985; *dashed-dotted line*); (*e*) the dM $[1.4 \leq (B-V)_0]$ stars of the Pleiades (*solid line*), the Hyades (from Paper I; *dashed line*), the young disk nearby population (data from Bookbinder 1985; *dotted line*), the old disk nearby population (data from Bookbinder 1985; *dashed-dotted line*).



INTEGRAL LUMINOSITY FUNCTION
0.0
0.2
0.4
0.6
0.8
1.0
26
27
28
29
30
31
32
Log L_x

FIG. 5c



INTEGRAL LUMINOSITY FUNCTION
0.0
0.2
0.4
0.6
0.8
1.0
26
27
28
29
30
31
32
Log L_x

FIG. 5d

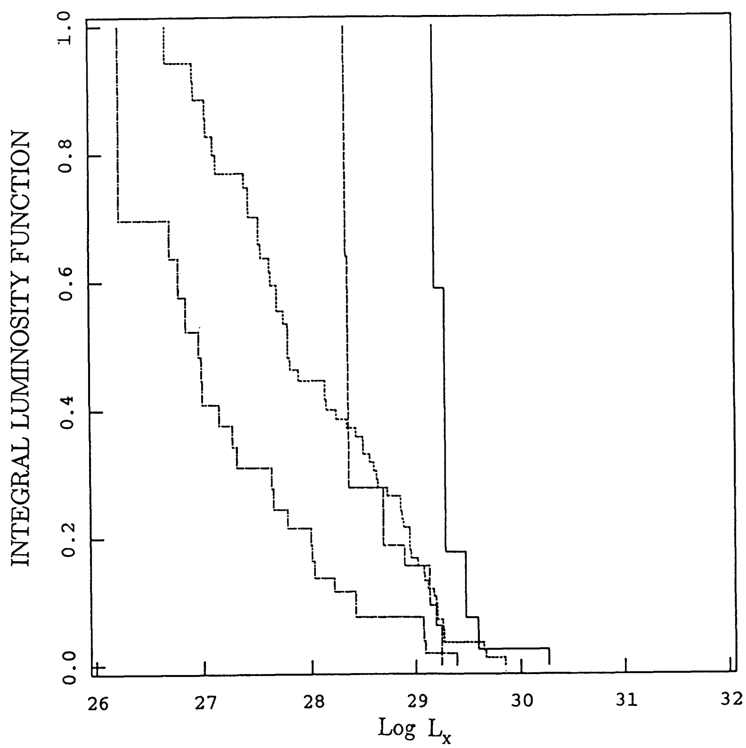


FIG. 5e

mean of log L_X from 29.34 to 29.38. The inclusion of these possible interlopers does not change the characteristics of the coronal emission of Pleiades K stars.

The star Hz 1136, the most luminous X-ray source in the Pleiades, was observed during a period of "flaring" activity, as already discovered by Caillault and Helfand (1985). The reddening of this star is quite high because it is embedded in a CO molecular cloud; hence this star has been included in the K star sample while indeed it is classified as a dG8 star (see also discussion in § IV*d*).

iv) *dM Stars*

We detected four out of 39 Pleiades dM stars observed by *Einstein*; the resulting maximum likelihood integral X-ray luminosity function is shown in Figure 5*e*. In this case we have no detection below the median value. The mean value of log L_X is 29.32, but error estimates using bootstrap cannot reliably be evaluated; the upper bound to the median of log L_X is 29.61. Application of nonparametric tests to distinguish the Pleiades dM star sample from that of the Hyades dM stars and the young and old disk dM stars failed to demonstrate any differences (null hypothesis rejections are less than 60% confidence in all cases). We want to point out that the above results do not allow us to state that the Pleiades dM stars are drawn from the *same* parent population of the Hyades dM stars, or the field dM stars; in fact we can state only that we cannot reject at high confidence level the null hypothesis of the samples being drawn from the same parent population.

We note that the threshold of the present survey was not sensitive enough to permit the detection of dM stars having emission levels comparable to typical young dM disk stars, although the more X-ray luminous stars, i.e., those in the tail of X-ray luminosity distribution, could have been detected and indeed were. The lack of unidentified X-ray sources cf. § III*b*) that could be related to faint uncataloged dM Pleiades stars possibly present in the surveyed area demonstrates that the X-ray luminosity of these stars, if present in the cluster, must be below the limiting sensitivity of the present survey, namely these stars must have $L_X \lesssim 3 \times 10^{29}$ ergs s^{-1}.

b) The B Stars

In our survey, five of 17 surveyed stars with $(B-V)_0 < 0$ were detected; the maximum likelihood integral X-ray luminosity function shown in Figure 6 corresponds to a mean log L_X value of 29.28 (+0.10, −0.11). This luminosity function is statistically indistinguishable from those of Pleiades stars of all other spectral types; hence, we cannot rule out the hypothesis that the emission is due to late-type companions of the B stars, indeed the large majority of the B stars (and in particular four of the five detected B stars) are members of a binary or suspected binary system. On the other hand the $F_X/F_{\rm bol}$ ratio is of the same order of magnitude (10^{-6} to 10^{-7}) as that of the OB stars (Pallavicini *et al.* 1981; Chlebowsky, Harnden, and Sciortino 1989). Only for the star Hz 1234, that is one of the latest B stars in this sample, is this ratio higher ($F_X/F_{\rm bol} = -5.32$). We note that, due to the X-ray sensitivity threshold of the present survey, the range of log L_X is significantly smaller than that of log $F_X/F_{\rm bol}$ (see Fig. 6).

c) The White Dwarf

The only known Pleiades white dwarf, DA wk (LB 1497/EG25), found by Luyten (1958) in his extensive search for white dwarfs in the Pleiades, was not detected in X-rays. Its X-ray luminosity upper limit, log $L_X \leq 29.57$, is quite similar to upper limits for Hyades white dwarfs[5] (Paper I), and to X-ray

[5] Note that the correct values for the X-ray luminosity and upper bounds on X-ray emission from white dwarfs in the Hyades are reported in Table 4 of Paper I; the values quoted in the text itself are given as one order of magnitude greater than the correct values, due to typographical errors.

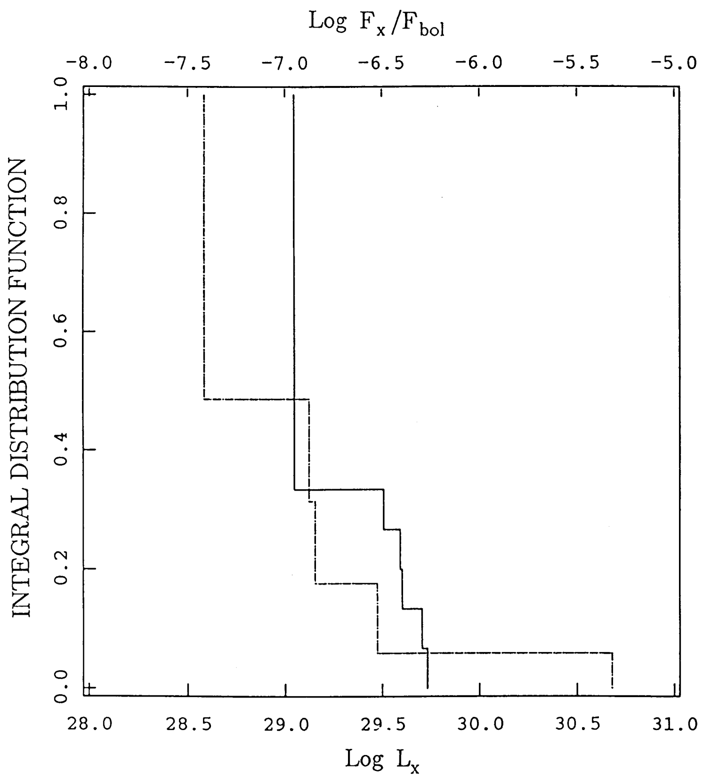


FIG. 6.—Maximum-likelihood integral X-ray luminosity function (*solid line*) for Pleiades B-type stars and maximum-likelihood F_X/F_{bol} integral distribution function (*dashed-dotted line*) for the same sample; note that almost all these stars are members of binary (or suspected binary) systems. The range of log F_X/F_{bol} is larger than the range of log L_X due to the sensitivity threshold of the present survey.

luminosities for other white dwarfs (Vaiana *et al.* 1981; Fontaine, Montmerle, and Michaud 1982).

d) Effects of Differential Reddening

The patchy distribution of the many, small-sized dust clouds in the Pleiades region results in differential reddening for stars in different regions of the cluster (van Leeuwen 1983 and references therein). The reddening may be particularly high for stars located in the direction of a CO molecular cloud detected near the B star 23 Tau in the southwestern region of the cluster. Breger (1987) has measured individual extinction and reddening for stars in this region; his largest values of reddening are ~0.3, i.e., an order of magnitude larger than the mean value (0.04) derived for the Pleiades cluster by Crawford and Perry (1976).

This finding suggests the following, more detailed considerations of the effects of reddening, especially for the more reddened stars:

1. Because we have subdivided cluster members according to observed $B-V$, corrected for *mean* reddening, it is appropriate to ask whether stars would shift to a bluer subdivision with the application of individual reddening corrections. Three stars suffer this effect: Hz 1084, an A star which shifts from the $B-V = 0.3$–0.5 sample to the $B-V = 0$–0.3 sample; Hz 1136 (the X-ray flare star) shifts from dK to a more solar-like group; and Hz 1286 shifts from the dM to the dK sample. These changes do not in any respect modify the conclusions of § IV*a*.

2. We have used the mean value of N_H (derived from mean reddening) for evaluating the conversion factor from count rate to X-ray flux; in this process we underestimate individual N_H values for those stars embedded in the molecular cloud, possibly up to a factor ~5; a similar increase in N_H corresponds to an increase of ~20% in the conversion factor, and hence in the derived X-ray luminosity.

e) Correlation with Rotation for Late-Type Stars

It is known that an important parameter in determining the level of X-ray emission in late-type stars is the rotational velocity (Pallavicini *et al.* 1981, 1982; Walter 1982, 1983; Maggio *et al.* 1987), and has been suggested that the relationship $L_X \propto (v \sin i)^2$ derived from the nearby star sample holds for normal stars with equatorial rotational velocities larger than ~10 km s^{-1}. However, when we extrapolate the relation to the typical rotation rates of rapidly-rotating Pleiades dK stars, the observed L_X are systematically lower than those predicted from the above relation, as indicated in Figure 7, where we have plotted X-ray luminosity (distinguished by spectral type) for those stars for which we have measurements of projected rotational velocity. Stauffer and Hartmann (1987) noted that in the Pleiades dK star sample, the rapidly rotating stars generally seem to be preferentially detected as X-ray sources when compared to the more slowly rotating stars. Our enlarged sample consists of 75 dK stars having both X-ray luminosity and rotational velocity measurements and allows us to verify those authors' suggestion; indeed, we find that the fraction of X-ray emitters is greater for rapid rotators (16 out of 28, or ~60%) than for slow rotators (13 out of 47, or ~30%). In order to quantify this result, we have applied the analysis procedure given by Gehrels (1986) for establishing confidence limits when comparing ratios derived from relatively small samples. The ratio for dK stars surveyed by the two samples is 0.596 (28/47), while the ratio for stars detected is 1.230 (16/13),

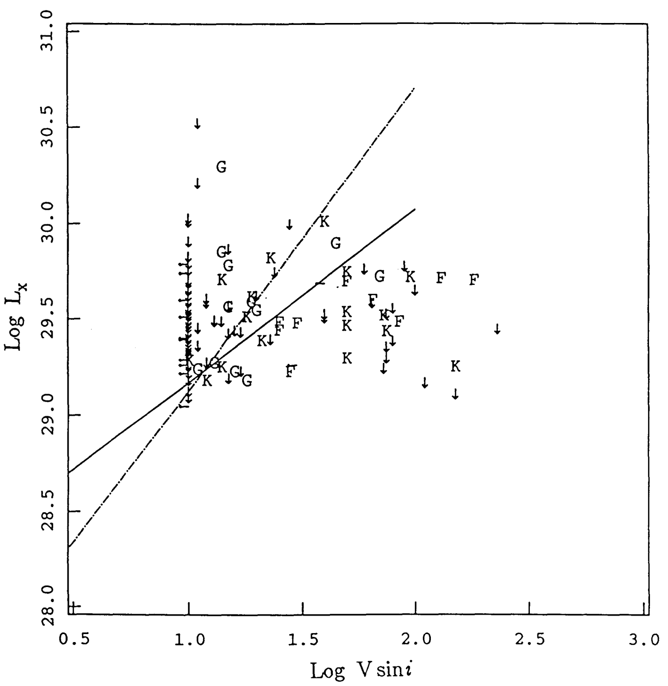


FIG. 7.—Log-log scatter plot of L_X vs. (v sin i) for late-type Pleiades stars. The Pallavicini *et al.* (1981) result connecting rotation rate to the X-ray emission level is also indicated (*dashed line*). Stars with measurements in both axes are plotted with single letter codes indicating spectral type; points with an upper limit in one axis are denoted simply with an appropriate arrow (and no indication of spectral type). The solid line shows the result of a formal correlation analysis between log L_X and log (v sin i) including present Pleiades data and data for nearby solar-like stars taken from Maggio *et al.* (1987). Note that the inclusion of the Pleiades data reduce the slope of the resulting relation.

but the formal procedure fails to distinguish between the two ratios (the confidence level for rejecting the null hypothesis that these two ratios are equal is only 96%). While this test fails to provide a statistically significant result (because of the limited sample size), it is certainly consistent with the suggestion of Stauffer and Hartmann (1987).

On the other hand, there is a trend for rapidly rotating late-type stars to be more active than more slowly rotating stars, although the relation between coronal activity, as measured by X-ray luminosity, and rotation for rapidly rotating stars is less steep than that derived from nearby solar-type stars (Maggio *et al.* 1987). The formal regression (solid line in Fig. 7) between log L_X and log (v sin i) evaluated taking into account both late-type Pleiades stars and solar-like nearby stars data results in a slope of 1.20 [1.07, 1.33] with a correlation coefficient $r = 0.76$ [0.74, 0.79], where the 1 σ error bars are evaluated via bootstrap with replications (Schmitt 1985). The scatter of the Pleiades solar-type star data around the mean relation between X-ray luminosity and rotational velocity is about one order of magnitude, similar to the scatter observed in the nearby solar-like stars data (from which the relation indicated with the dashed line in Fig. 7 has been derived); however, none of the Pleiades solar-like stars has a rotational velocity comparable to that of rapidly rotating dK Pleiades stars. In fact, the nearby sample and the solar-like Pleiades star sample do not allow us to explore rotational velocities greater than $\sim$10–15 km s^{-1} (excluding the well-known RS CVn stars); hence, we do not know whether the Pleiades dK stars have "peculiar" X-ray emission levels just because they are late-type "normal" stars with exceptionally high rotational velocity. In other words, the above data do not allow one to discriminate whether the apparent saturation in the level of the X-ray emission that we observe for these stars is a general phenomenon, or whether it is a peculiar behavior of the Pleiades dK stars. Recently Fleming *et al.* (1989) have studied a sample of X-ray–selected single normal late-type stars. This sample, drawn from the Extended Medium Sensitivity Survey, is by definition representative of the highest level of X-ray activity and indeed contains a rather high number of dwarf late-type stars with rotational velocity comparable to those of the Pleiades fast rotating dK stars. The analysis of Fleming *et al.* (1989) shows that the X-ray luminosity in their sample of strong emitters is approximately linearly proportional to (v sin i) and provides plausible evidence for rotationally saturated levels of stellar coronal activity.

f) Age Dependence

The dependence of the X-ray emission levels of solar-type stars on age in the range of 10^7 to $\sim 10^{9.5}$ yr has been reported elsewhere (Vaiana 1983; Caillault and Helfand 1985; Micela *et al.* 1985; Maggio *et al.* 1987; Paper I). Figure 8*a* shows the scatter plot of log L_X versus $(B-V)_0$ for Pleiades stars; Figure 8*b* shows the mean values of log L_X versus $(B-V)_0$ for samples of different age.

In Figure 9 we show the scatter plot of log L_X versus age using the cluster age for both Pleiades and Hyades stars, and the lithium age for individual field stars. Hyades and Pleiades data are represented by mean log L_X values for each spectral type. The plot suggests, albeit with a large scatter, that the X-ray luminosity slowly decays with stellar age for $\sim 10^{7.7}$–10^9 yr, and then undergoes a rapid decay for ages greater than 10^9 yr. Caillault and Helfand (1985) using a somewhat smaller data sample of late-type stars have suggested that this behavior can be described by an exponential decay law. However, the data are so scattered (see Fig. 9) that it is difficult to draw any definite conclusions on the actual shape of the decay law. If we use the mean log L_X value for field stars, we find decay laws (L_X vs. age) of different functional shape for each distinct spectral type; this behavior is masked if we use the individual values, as can be seen from Figure 9. We conclude that the scatter is so dominant that some further parameter—other than age and/or rotational velocity—must also influence the level of stellar X-ray emission.

g) Time Variability

For the stars observed more than once, with typical separation times largely of a few days, and with at least two X-ray observations unaffected by shadowing of the IPC entrance-aperture support structure, we have examined the X-ray fluxes for variations between different observations. We have applied a new technique that assumes Poisson statistics for the observed counts in different observations of the same objects and uses a maximum likelihood estimate for the expected counts, under the hypothesis of constant source emission (Sciortino, Micela, and Vaiana 1990) using both X-ray detections and upper limits for each given object. This technique allow us *for each observation* to evaluate, or set upper bounds on, the amplitude of the variability with respect to the maximum likelihood source rate to a given level of significance (increasing and decreasing variations can be separately evaluated). In analogy with techniques used for X-ray luminosity data, we have computed maximum likelihood integral

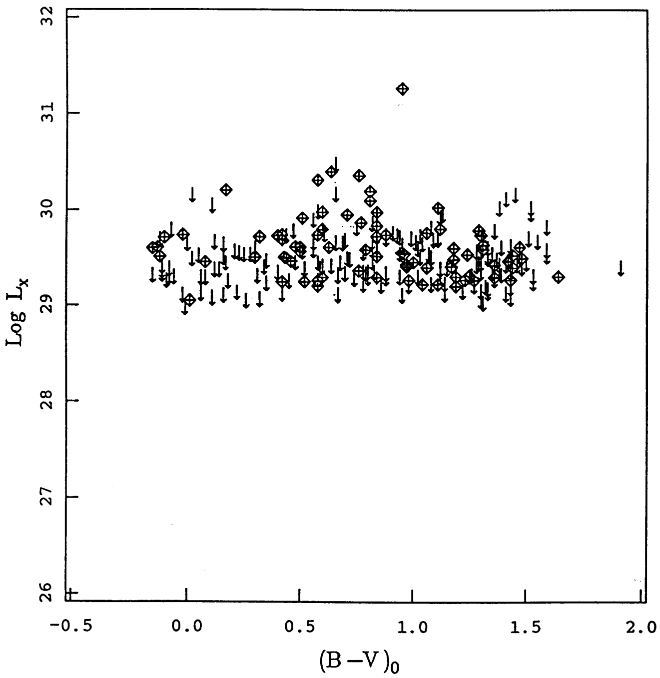


FIG. 8*a*.

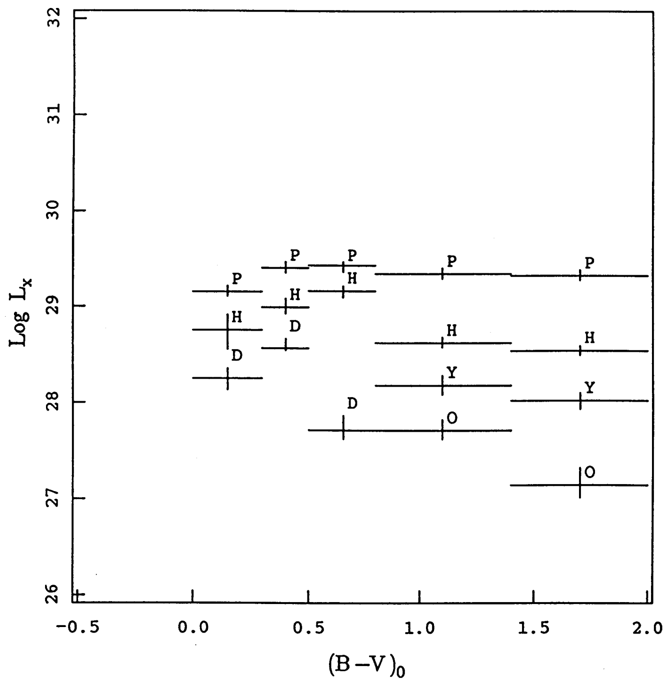


FIG. 8*b*.

FIG. 8.—(*a*) Scatter plot of log L_X vs. $(B-V)_0$ color index for surveyed Pleiades stars: *diamonds*, X-ray detections; *arrows*, upper limits. (*b*) Mean values of log L_X vs. color index, for different groups of stars, as labeled: *P*, present Pleiades survey; H, Hyades (Paper I); D, disk field stars (dA and dF from Schmitt *et al.* 1985, dG from Maggio *et al.* 1987); Y, young (and O, old) K and M disk stars (Bookbinder 1985). Horizontal bars indicate the range of color index over which the mean value was computed, and vertical bars indicate formal bootstrap errors on the means.

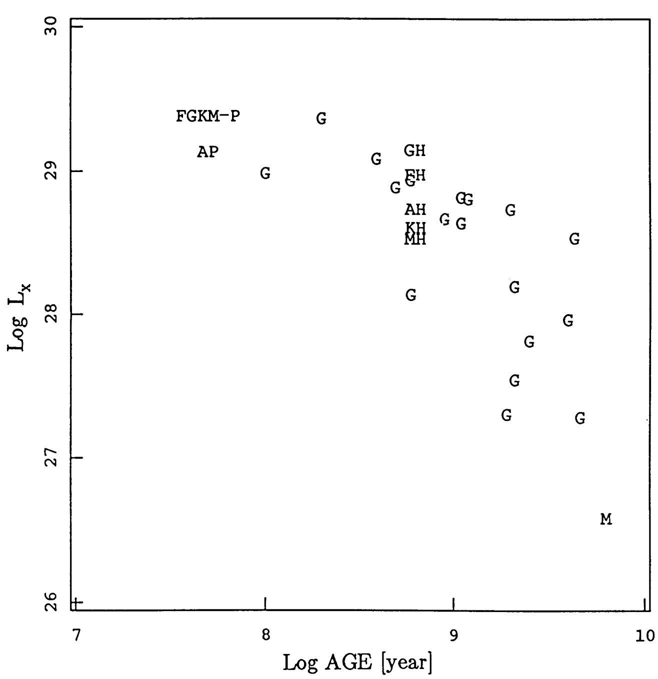


FIG. 9.—L_X vs. stellar age for main-sequence stars, plotted log-log with two-letter symbols indicating spectral type (first letter) and cluster membership (second letter: H, Hyades; P, Pleiades), or with single-letter symbols indicating individual field stars whose ages have been derived from lithium abundance. For clusters, we plot mean X-ray luminosity values for each spectral type, while for individual stars we report the best estimate of their X-ray luminosity values (typical uncertainties less than a factor of 2).

"variability-amplitude" distributions and, for specified confidence level, "variability-threshold" distributions.

We have applied this analysis to 18 Pleiades members, largely of spectral type dG and dK, usually observed twice, with X-ray luminosities greater than 3×10^{29} ergs s^{-1} (the present survey limiting sensitivity). Our analysis rules out the presence of long-term variations with amplitudes greater than a factor ~ 3. We note that the two stars Hz 708 and Hz 1514 reported as long-term X-ray variable by Caillault and Helfand (1985) have not been recognized as variable by present analysis because we have rejected the observations in which these stars were partially shadowed by the IPC entrance-aperture support structure. In the remaining analyzed observations these stars do not meet our 3 σ criterion for being considered X-ray–variable. We want also to point out the star Hz 303 reported as variable by Sciortino *et al.* (1983) has not been included in the present analysis because only one of the five available observations was unaffected by partial shadowing. Although we have not detected significant ($>3\ \sigma$) X-ray variability in Pleiades stars on the explored time scales, our sensitivity to such variability was limited due to the low IPC count rate of a typical Pleiades star and typical exposure time; that is, for $\sim 90\%$ of the Pleiades stars we could detect intensity changes greater than a factor of 3 and for $\sim 50\%$ intensity changes greater than a factor of 1.5, compared with the positive detections of greater than a factor of 1.5 variability amplitude in $\sim 10\%$ of the Hyades members (Micela *et al.* 1990). We show in Figure 10 (*solid line*) the integral distribution of variability thresholds for all Pleiades stars we have included in our analysis. The distribution has been computed taking into account variations in excess with respect to the maximum likelihood source count rate; thresholds have been evaluated at 3 σ confidence level assuming Poisson distributions for the observed counts and

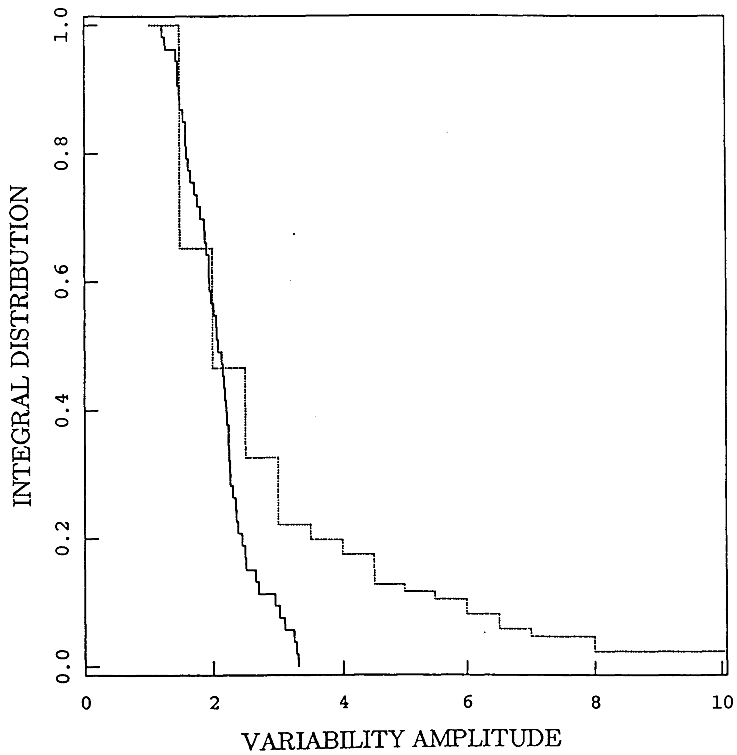


FIG. 10.—Integral distribution of the threshold variability for Pleiades stars observed more than once without shadowing from the IPC entrance-aperture support structure of edges (*solid line*; see § IV*g*). The distribution has been computed for Pleiades stars with $L_X \gtrsim 3 \times 10^{29}$ and gives the fraction of stars studied for which we are unable, due to the sensitivity of the present survey, to detect excess variability whose amplitude is smaller than a given factor. For comparison we show the integral distribution of X-ray flux variability for ρ Oph stars (*dotted line*; data from Montmerle *et al.* 1983) at the same L_X limiting sensitivity of the Pleiades data. It is evident the incompatibility of Pleiades distribution threshold with the variability amplitude observed in the ρ Oph younger stars.

adopting confidence levels from Gehrels (1986). We note that present survey variability threshold distribution does not allow us to exclude that the width of the X-ray luminosity function could be partly explained in terms of low-amplitude X-ray variations, such as those implied by rotational modulation.

We want to point out that the Pleiades dK members are well-known optical variable stars (Robinson and Kraft 1974; van Leeuwen 1983; Stauffer *et al.* 1984). Robinson and Kraft (1984) have suggested that the observed optical variability is of BY Dra type, i.e., they suggested that in the photosphere of these stars are present large, long-living spots of reduced optical emission. In a recent work, Butler *et al.* (1987) report evidence for the existence of "plage-type" regions at chromospheric level overlying photospheric spots in BY Dra stars. These structures can be explained with the presence of magnetic confined structure (loops) above the photospheric spots. These authors argue that the lack of strong rotational modulation of the UV emission and the intensity of UV emission itself can be explained in terms of magnetic confined emitting regions visible for quite long time due to their physical dimensions. A similar explanation, with several regions of enhanced X-ray emission visible for sizable fraction of rotational period, could account for the lack of strong variations of dK Pleiades star' X-ray emission and is compatible with present evidence of rotational saturation of their X-ray emission (cf. § IV*e*).

Phenomena such as the large flare detected on Hz 1136 (see Caillault and Helfand 1985), a normal dK star observed only once, during which the luminosity increased by a factor larger than 10, are rare events if compared with the rate of similar amplitude variations seen in X-ray–detected younger stellar objects in the ρ Oph cloud (Montemerle *et al.* 1983), as can be seen by considering the following. In the present survey, there were a total of some 300 observations of G and K stars (counting repetitions) with a mean exposure time of 4500 s, and we can assume that these stars could show similar flaring activity (that has not been detected). Hence the total exposure time is $\sim 1.3 \times 10^6$ s during which only a single large flare has been seen implying a "superflare" occurrence rate of $\sim 10^{-6}$ s^{-1}, i.e., one "superflare" would occur approximately every 15 days on each star. This fact is consistent with the shape of the G and K star X-ray luminosity functions (Figs. 5*a* and 5*d*), where the high-luminosity tail, present only in the K sample, is due entirely to the Hz 1136's "superflare.") We note also that a large flare (i.e., with an increase of the "mean" X-ray luminosity of a factor larger than ~ 3 with respect to the quiescent level) would have a duration of the order of few thousand seconds, i.e., comparable with a typical IPC exposure time. The occurrence of so large a variation in the luminosity level of a given star could be detected also by the "long-term" variability analysis in $\sim 90\%$ of the Pleiades stars, but it has not been detected. Hence a higher flare rate is ruled out also by the lack of "long-term" variability detections.

A comparison of the Pleiades star variability threshold distribution (Fig. 10, *solid line*) with the integral distribution of X-ray flux variations (Fig. 10, *dotted line*) derived from data of the ρ Oph stars (Montemerle *et al.* 1983; see their Fig. 5), detected above the same limiting sensitivity of the present Pleiades survey, shows that X-ray detected ρ Oph stars are more intense X-ray variable then Pleiades stars do. This result suggests that, if strong X-ray variability is a general signature of very young stellar objects, the amplitude of variations decays to quite low value even at Pleiades age.

V. SUMMARY AND CONCLUSIONS

We have investigated coronal X-ray emission of the Pleiades stars, have computed maximum likelihood, integral X-ray luminosity functions for Pleiades members in selected color-index ranges, and have undertaken a detailed search for long-term variability in the X-ray emission of those stars observed more than once. An overall comparison of the results of this survey with those of two previous surveys, which were based on smaller sets of IPC images, confirms the ubiquity of X-ray emission in the Pleiades cluster stars and its higher rate of emission with respect to older stars.

Our analysis of the X-ray emission from the Pleiades members allow us to draw the following major conclusions:

1. The X-ray emission from dA and early dF stars cannot be proven to be dissimilar to that of Hyades and field stars of same spectral type. The Pleiades cluster members show a real rise of the X-ray luminosity from dA stars to early dF stars. The Pleiades A4V star 1384, which appears to be single, has an extremely high (and therefore puzzling) X-ray emission level.

2. X-ray emission for the young, solar like (dG) Pleiades stars is approximately two orders of magnitude more intense than for the nearby solar-like stars. We have also shown that Pleiades dK stars have X-ray emission one order of magnitude stronger than Hyades dK stars, and two orders of magnitude stronger than field dK stars.

3. Using a significantly larger data set, we confirm the previous findings (Caillault and Helfand 1985; Micela *et al.* 1985; Micela, Sciortino, and Serio 1985) that the rapidly rotating Pleiades dK stars, as a group, have X-ray emission levels lower than those expected from the extrapolation of the relationship between L_X and rotation rate derived from the nearby samples (Pallavicini *et al.* 1981; Maggio *et al.* 1987). The fraction of X-ray emitters seems to be larger in the rapidly rotating dK stars than in the more slowly rotating ones, although a formal analysis yields only 96% confidence for such an effect.

4. Five X-ray detections have been identified with Pleiades B stars; however, the majority of these stars are known members of binary systems. From present data, we cannot distinguish between the hypothesis that X-ray emission is due to the later spectral type companions or to intrinsic X-ray emission from the B stars.

5. Only a small fraction of the dM stars have been detected as soft X-ray emitters above present survey sensitivity, notwithstanding the fact that Pleiades dM stars are optically well-known flare stars. Our results are in agreement with the lack of radio flare detections on a recent extensive VLA radio survey (Bastian, Dulk, and Slee 1988). The lack of X-ray detections that could be related to faint uncataloged dM Pleiades stars demonstrates that if these stars are present in the cluster their X-ray luminosity is lower than 3×10^{29} ergs s^{-1}.

6. We report the first detailed analysis of temporal variations in the X-ray emission of Pleiades stars: long-term variability (from days to a year) at levels above a factor of 3 was *not* detected. Integral maximum likelihood distributions of X-ray variability threshold, as well as dispersions around maximum likelihood mean X-ray luminosities (for each spectral type), strongly constrain the number of large (greater than a factor $\sim$2-3) amplitude fluctuations in the X-ray emission levels of Pleiades members, and indicate that the "superflare" observed from one of the Pleiades stars (Hz 1136) must be a rather rare event even in stars as young as the Pleiades if compared with the rate of similar amplitude variations observed in the sample of detected ρ Oph younger stellar objects.

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