

DEEP *ROSAT* HRI OBSERVATIONS OF THE ORION NEBULA REGION

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ABSTRACT

We present results from three deep *ROSAT* high-resolution imager observations of the Orion Nebula star-forming region. The X-ray images contain over 1500 cataloged stars in a roughly 0.8 deg^2 region centered on the Trapezium. In all, 389 distinct X-ray sources have been detected, at least two-thirds of which are associated with a single proper-motion cluster member. X-ray emission is detected from stars of all spectral types, from the massive O- and B-type components of the Trapezium to the coolest, low-mass pre-main-sequence (PMS) stars. In this paper we focus primarily on X-ray emission from the late-type PMS stars. Of the ~ 100 late-type cluster members with measured spectral types, approximately three-fourths have been detected; we have derived X-ray luminosity upper limits for the remaining stars. We found coronal X-ray emission turns on around spectral type F6, with the upper envelope of activity increasing with decreasing effective temperature. When plotted in an X-ray luminosity versus bolometric luminosity diagram, late-type PMS stars lie below a “saturation” line corresponding to $L_X/L_{\text{bol}} \sim 10^{-3}$. For approximately solar-mass PMS stars, we find a median X-ray luminosity $\sim 1 \times 10^{30} \text{ ergs s}^{-1}$. The late G, K, and M stars exhibit nearly a two order of magnitude spread in X-ray luminosity and in L_X/L_{bol} at a given effective temperature. Plots of X-ray activity versus $v \sin i$ rotational velocity and rotational period appear to show no clear dependence of activity on rotation. However, because only a small fraction of late-type PMS stars in the Orion Nebula have measured $v \sin i$ or P_{rot} and because of uncertainties in L_X and L_X/L_{bol} , we believe the data are not conclusive on this point. Light curves of the detected X-ray sources have revealed at least 10 strong X-ray flares with characteristic rise times $\gtrsim 1 \text{ hr}$ and decay times ranging from ~ 2 to 12 hr. All the flares have X-ray energies in excess of $3 \times 10^{35} \text{ ergs}$. Many of the X-ray sources associated with late-type cluster members have been observed in more than one *ROSAT* HRI exposure, allowing us to look for variability on the $\sim 1 \text{ yr}$ timescale between HRI observations. A statistical analysis of the resulting count rate ratios suggests that at least one-fourth of the late-type cluster stars are significantly variable on this timescale.

Subject headings: ISM: individual (Orion Nebula) — stars: pre-main-sequence — X-rays: stars

1. INTRODUCTION

The Orion Nebula region has been extensively studied in virtually all wavelength regimes because it possesses many features associated with star formation: a giant molecular cloud, an H II region, embedded infrared sources, Herbig-Haro objects, and a dense cluster containing O–B stars and hundreds of T Tauri stars. Open clusters and associations are excellent laboratories for studying stellar phenomena because they allow us to examine large samples of stars of a given age, chemical composition, and set of initial conditions. By comparing results for different clusters and associations, we can, in principle, begin to deconvolve the effects of age, metallicity, initial angular momentum, and circumstellar material on photospheric, chromospheric, and coronal activity indicators. In this paper we focus on X-ray emission in the 0.1–2.0 keV band from the cluster members within 1° of the Orion Nebula. For the late-type cluster stars we use X-ray emission as a coronal activity indicator and compare coronal activity with bolometric luminosity estimates, effective temperature, rotation rate, and accretion disk activity.

The Orion Nebula is an ideal target for imaging X-ray telescopes because of its relative proximity ($\sim 440 \text{ pc}$; Herbig & Terndrup 1986) and high density of late-type pre-main-

sequence (PMS) stars (cf. Cohen & Kuhn 1979; Herbig & Terndrup 1986; Jones & Walker 1988; McCaughrean & Stauffer 1994). Intermediate- and low-mass PMS stars detected by the *Einstein Observatory* have been shown to be vigorous X-ray emitters (cf. Gahm 1980; Feigelson & DeCampli 1981; Bouvier 1990; Montmerle et al. 1992), and X-ray surveys have proved to be an effective means of discovering previously unidentified PMS stars (cf. Montmerle et al. 1983; Walter 1986; Feigelson & Kriss 1989). In particular, the *Einstein Observatory* surveyed a 4.5 deg^2 region centered on the Orion Nebula, results of which have been reported by Ku & Chanan (1979), Pravdo & Marshall (1981), Ku, Righini-Cohen, & Simon (1982), Caillault & Zoonematkermani (1989), Strom et al. (1990), and Gagné & Caillault (1994, hereafter Paper I).

In this paper we report the general results of a new deep imaging survey which we have obtained as *ROSAT* guest observers. The increased collecting area of the *ROSAT* X-ray telescope and the improved quantum efficiency of the *ROSAT* high-resolution imager (HRI) combined with the long exposure times (in the range ~ 12 –47 ks) have provided a factor of 3 improvement in sensitivity over the *Einstein* survey of the Orion Nebula region. In addition, the excellent spatial resolution of the HRI (typically $\lesssim 5''$) has allowed us to unam-

biguously identify the vast majority of X-ray sources with a single optical counterpart. Initial results of this survey, pertaining only to observations of the O-, B-, and A-type stars in the survey region, have been presented by Caillault, Gagné, & Stauffer (1994, hereafter Paper I).

In Paper I we presented results based on a total of 23 exposures with both the *Einstein* imaging proportional counter (IPC) and the HRI; in all, 245 X-ray sources were detected, nearly half of which were associated with a single Orion Nebula cluster member. X-ray emission is detected from cluster stars in all mass and effective temperature ranges. The main-sequence O6–B5 stars are detected with X-ray activity levels comparable to O- and early B-type stars in the field (Chlebowski, Harnden, & Sciortino 1989; Grillo et al. 1992; Cassinelli et al. 1994). Also detected were four main-sequence B6–A5 stars that are not known to be components of binary systems. This is somewhat unexpected from a theoretical standpoint because, on the one hand, the strong stellar winds which drive X-ray emission in hotter stars are thought to be absent in the late B and early A stars and, on the other hand, the action of a magnetic dynamo which is thought to produce coronal X-rays in cool stars cannot operate in the late B and early A stars because these lack sufficiently deep outer convective envelopes to drive the magnetic dynamo. Although a number of theories have been proposed to explain X-ray emission from these stars (see Paper I and references therein), none can explain the observed X-ray luminosities, in excess of $\sim 3 \times 10^{30}$ ergs s⁻¹, of these otherwise normal, main-sequence B6–A5 stars. In Paper I we concluded that the detection fraction and the observed X-ray luminosity of these stars suggest that the emission probably arises in the corona of an unseen, late-type binary companion.

In Paper II we derived X-ray luminosities and upper limits for 21 O6–B5 stars and 27 main-sequence B6–A5 stars which fell into the field of view of at least one of the three *ROSAT* HRI fields. Of the O6–B5 stars, two-thirds were detected with X-ray luminosity in the range $10^{30} \lesssim L_X \lesssim 4 \times 10^{32}$ ergs s⁻¹. All of them have L_X/L_{bol} ratios similar to O-type and early B-type stars in the field, consistent with results obtained with *Einstein* and described in Paper I. Particularly noteworthy is the brightest component of the Trapezium, the O7 V star θ^1 C Ori, which exhibited a roughly 50% increase in L_X in the 11½ month period between individual *ROSAT* HRI observations. These variations were in phase with recently discovered periodic variations ($P \sim 15.4$ days) of the equivalent width of H α (Stahl et al. 1993). A 15.4 day period was also found in the *IUE* C IV $\lambda\lambda 1548, 1551$ wind profile of θ^1 C Ori during 1978–1983 (Walborn & Nichols 1994). Future time-critical *ROSAT* HRI observations of θ^1 C Ori will provide more complete phase coverage of the X-ray light curve and may determine whether or not the X-ray, H α , and C IV variations have the same physical origin.

Of the 27 main-sequence B6–A5 stars observed, 26 have proper-motion membership probabilities $P \geq 50\%$; of these, four are unambiguously identified with X-ray sources. In Paper II we examine several possible intrinsic X-ray emission mechanisms for late B and early A stars: most notably, the “wind-compressed disk” model of Bjorkman & Cassinelli (1993) and the “magnetic reconnection” model of Linsky, Drake, & Bastian (1992). Both of these models require stars that possess unusually strong surface magnetic fields, emission spectra, or chemically peculiar spectra; so far, none of the X-ray-detected B6–A5 stars in the Orion Nebula meet these

criteria. The detection fraction (at most $\frac{1}{3}$) and observed X-ray luminosity ($L_X \gtrsim 10^{30}$ ergs s⁻¹) of the B6–A5 stars observed by *ROSAT* suggest the presence of unseen, cool, PMS binary companions which give rise to the detected X-rays.

The vast majority of cataloged cluster stars in the Orion Nebula region are late-type PMS stars in the mass range ~ 0.2 – $2.0 M_\odot$, and over 100 of these have been detected by *Einstein*. Unfortunately, many of the fainter cluster members in Paper I do not have measured spectral types or rotational information. For those stars with measured spectral type, plots of L_X/L_{bol} versus effective temperature indicate that coronal X-ray emission turns on around spectral type F5 and increases in activity with decreasing T_{eff} to a peak level $L_X/L_{\text{bol}} \sim 2 \times 10^{-3}$. For spectral types later than roughly G7, there appears to be a nearly two order of magnitude spread in activity at a given mass or effective temperature. Whether this dispersion is real remains unclear, since there are large uncertainties in L_X and L_{bol} due to variability, uncertain extinction corrections, and uncertain spectral classifications. The spread in activity does not appear to be the result of the dispersion in rotational period or rotational velocity. Plots of L_X , L_X/L_{bol} , and F_X (X-ray surface flux) versus P_{rot} and $v \sin i$ show no correlation between activity and rotation rate. However, improved L_{bol} values and rotational periods for a greater number of stars are required to verify this result. An anticorrelation between rotational period and X-ray surface flux has been demonstrated for PMS stars in Taurus-Auriga by Bouvier (1990) and Strom & Strom (1994), while Feigelson et al. (1993) find no evidence of an activity-rotation connection in the Chamaeleon I cloud.

Thus, the results presented here focus primarily on X-ray emission from the late-type PMS cluster members. In § 2 we describe our database of stars, and in § 3 we explain our source detection scheme as well as our methods for determining short- and long-term X-ray variability among the late-type cluster stars. In § 4 we present our findings and discuss uncertainties and biases in the data. In § 5 we summarize our results, compare these to results obtained from other nearby star-forming regions, and suggest future avenues of investigation.

2. OPTICAL AND NEAR-INFRARED DATA

The morphology of the Orion Nebula region is unique among nearby star-forming regions (cf. Zinnecker, McCaughrean, & Wilking 1992). The nebular emission is powered by ionizing photons from the Trapezium O–B stars, and the Trapezium itself is at the core of an extremely dense cluster of stars, with central density in excess of 8000 stars pc⁻³ (McCaughrean & Stauffer 1994), containing dozens of young, high-mass main-sequence stars and hundreds of intermediate- and low-mass pre-main-sequence stars. The Trapezium cluster stars appear to be coeval, with $\tau_* \lesssim 10^6$ yr (Prosser et al. 1994; Herbig & Terndrup 1986). Recent 21 cm maps and H α and H β CCD imaging of the region within $\sim 5'$ of the Trapezium confirm the presence of a dense H II lid in the line of sight to the H II region (van der Werf & Goss 1989; O'Dell, Walter, & Dufour 1992). Outside the nebular emission region, the density of stars drops off considerably and the column density of hydrogen in the line of sight to most cluster stars becomes more moderate ($N_H \sim 5 \times 10^{20}$ cm⁻²). The stars in the outer portion of the cluster, referred to by Warren & Hesser (1977) as Orion 1d1 and Orion 1c, exhibit a greater spread in ages and may be older on average than the Trapezium cluster (Cohen & Kuhl 1979; van Altena et al. 1988). The entire complex of stars

and H I and H II regions lies in front of the Orion giant molecular cloud (L1641). The molecular cloud acts as an opaque screen to background starlight, thereby greatly facilitating the determination of proper-motion cluster membership.

Information for over 1500 stars in the region contained within our *ROSAT* HRI images has been assembled from published and unpublished sources into a single optical database. This database is essentially a subset of the catalog of stars put together for the larger region surveyed by *Einstein* and described fully in Paper I.

Figure 1 is a photograph of the POSS red plate of the Orion Nebula region. The three HRI fields have been drawn as white circles, each with a radius of $19'$. The survey area observed amounts to a little over 0.8 deg^2 and includes all of the Trapezium cluster (Orion 1d; Warren & Hesser 1977) and a portion of the more extended Orion Nebula cluster (Orion 1d1 and a part of Orion 1c). The catalog stars have been selected primarily from proper-motion surveys of the region, principally those of Parenago (1954) and Jones & Walker (1988). Positions and proper-motion membership probabilities from McNamara et al. (1989), Jones & Walker (1988), van Altena et al. (1988), and McNamara & Huels (1983), in order of preference, have been used whenever possible. We have also included 42 faint stars from the General Catalog of variable Stars (Kholopov et al. 1985) and five stars cataloged only by Herbig

& Terndrup (1986). The position accuracies of many stars outside the region of nebular emission have been improved to better than $1''$ from A Photometric Atlas of the Orion Nebula (Andrews 1981). Thus, the catalog contains high-probability cluster members, nonmembers, and stars of unknown membership.

The usefulness of this database of stars for the purpose of identifying X-ray sources can be estimated by comparing the limiting X-ray and *V*-band optical fluxes. The completeness of the optical database is described in detail in Paper I. The region within roughly $15'$ of the Trapezium has been surveyed by Jones & Walker (1988); their sample becomes significantly incomplete faintward of $I_C \sim 14.5$, and for faint, late-type cluster members with nominal reddening, $I_C \sim 14.5$ corresponds to a visual magnitude $V \sim 17$. In the region not surveyed by Jones & Walker (1988), the cataloged sample becomes incomplete faintward of $V \sim 15$.

We can estimate the limiting *V*-band flux from a source at the detection threshold of the *ROSAT* HRI observations by assuming a maximum ratio of X-ray to *V*-band flux, f_X/f_V . If we assume moderate absorption ($A_V \sim 0.25 \text{ mag}$) and a minimum detectable count rate of $8 \times 10^{-4} \text{ counts s}^{-1}$, we estimate the minimum unabsorbed X-ray flux to be $f_X \sim 4 \times 10^{-14} \text{ ergs cm}^{-2} \text{ s}^{-1}$. In a survey of X-ray-selected M-type dwarfs, Caillault et al. (1986) find that, generally, $\log(f_X/f_V) \leq -1$ and only

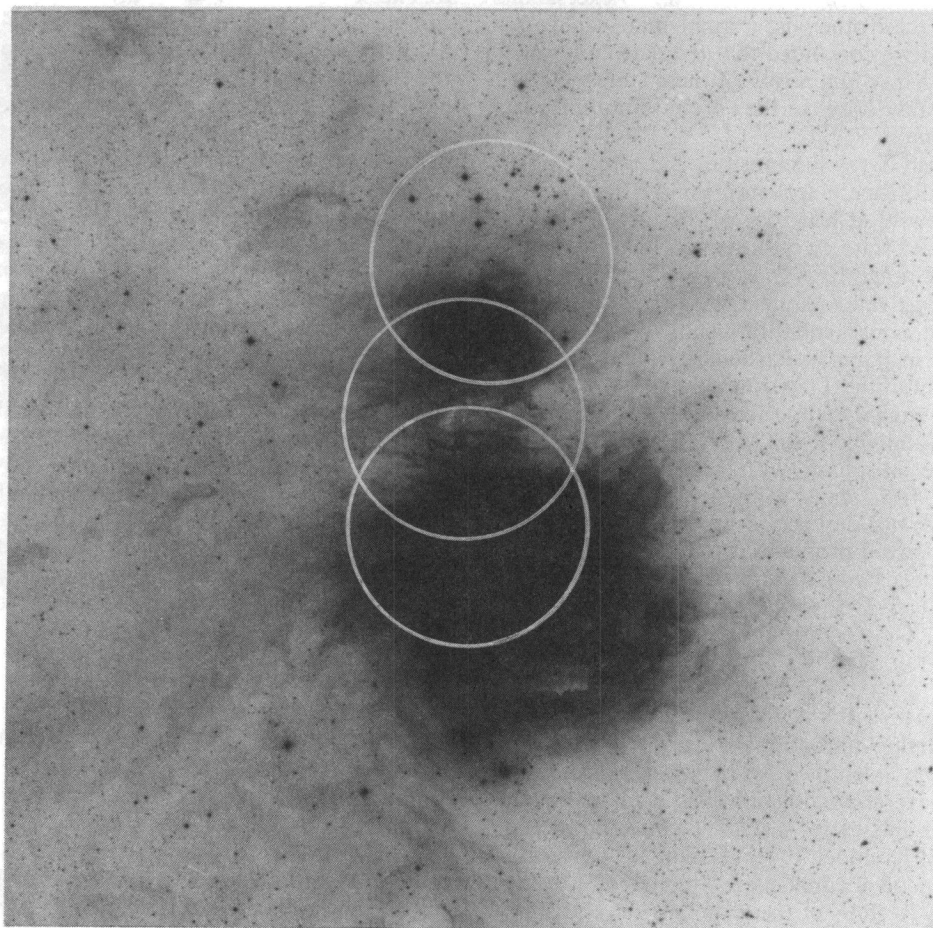


FIG. 1.—Outline of the three *ROSAT* HRI image areas projected onto the POSS red plate of the Orion Nebula region. North is up, and east is to the left. The circles each have radii $\sim 19'$, with a total observed area of $\sim 0.8 \text{ deg}^2$.

exceeds this value in rare cases of a strong X-ray flare. Thus, the unabsorbed optical flux of the faintest detectable star is $f_V \sim 4 \times 10^{-13}$ ergs cm $^{-2}$ s $^{-1}$. This corresponds to an unabsorbed apparent visual magnitude $V_0 \sim 17.5$ and, in the case of moderate absorption, an apparent visual magnitude $V \sim 17.8$.

Clearly, our optical database falls well short of being complete to this limiting magnitude, particularly outside the region surveyed by Jones & Walker. In the case of a deeply embedded source, the catalog is even less complete because, when observed through large column densities, V -band emission is more attenuated than X-ray emission (cf. Chlebowski et al. 1989). For example, if we consider an X-ray source at the same minimum detectable count rate with $A_V \sim 2.5$ mag, then the corresponding unabsorbed limiting X-ray and V -band fluxes are, respectively, $f_X \sim 1.5 \times 10^{-13}$ ergs cm $^{-2}$ s $^{-1}$ and $f_V \sim 1.5 \times 10^{-12}$ ergs cm $^{-2}$ s $^{-1}$. The corresponding apparent visual magnitude (with $A_V \sim 2.5$ mag) is $V \sim 18.6$.

Despite this apparent deficiency in our sample of cataloged stars, the vast majority of X-ray sources have at least one candidate counterpart in our optical database (see § 4 for a detailed description of the search procedure). We attribute this to three factors: first, nearly three-fourths of the X-ray sources detected lie in the Jones & Walker survey region; second, most stars outside the Trapezium cluster suffer only moderate extinction; third, the combined f_X/f_V distribution for G-, K-, and M-type dwarfs peaks near 10^{-2} (Stocke et al. 1991; Paper I). Therefore, we expect the optical flux distribution of faint sources to peak somewhere around $f_V \gtrsim 4 \times 10^{-12}$ ergs cm $^{-2}$ s $^{-1}$ and have apparent visual magnitude $V \lesssim 15.3$. For those sources with no candidate counterpart in our optical database, we have searched the Andrews (1981) atlas, which is fairly complete to $V \sim 16$ outside the region of nebular emission.

In addition to position and proper-motion membership information, the database contains, when available, spectral types, BVI_C magnitudes, rotational periods, and spectroscopic rotational velocities. Spectral types have been taken from the following sources, in order of preference: Edwards et al. (1993), Strom (1993), Duncan (1993), Abt, Wang, & Cardona (1991), van Altena et al. (1988), Kholopov et al. (1985), Walker (1983), Cohen & Kuhi (1979), Warren & Hesser (1977), Penston, Hunter, & O'Neill (1975), Penston (1973), and Walker (1969). Whenever possible, we have used BVI_C -band photometry from Prosser et al. (1994), Edwards et al. (1993), Duncan (1993), Attridge & Herbst (1992), McNamara et al. (1989), van Altena et al. (1988), Herbig & Terndrup (1986), Rydgren & Vrba (1984), Cohen & Kuhi (1979), Warren & Hesser (1977), Penston et al. (1975), Penston (1973), or Walker (1969). Otherwise, photographic magnitudes have been obtained from Jones & Walker (1988), Kholopov et al. (1985), Andrews (1981), Parnago (1954), or Brun (1935).

In the case of 96 stars in the ROSAT survey region, Strom (1993), Rydgren & Vrba (1984), and Cohen & Kuhi (1979) have derived visual absorption estimates and bolometric luminosities based on optical/near-infrared spectral energy distributions. For all other known cluster members with measured spectral type and apparent visual magnitude, we have estimated absorption and bolometric corrections to derive L_{bol} .

Extinction estimates are extremely important in order to determine both X-ray count-rate-to-flux conversion factors and bolometric luminosities. For cluster members in the region of nebular emission mapped by O'Dell et al. (1992), we have

used their $C_{H\beta}$ extinction maps to estimate the visual absorption using $A_\lambda = 2.5C_{H\beta}(1 + f_\lambda)$, where $\lambda = 5500$ Å and $f_{5500} = -0.094$ (D. K. Walter 1994, private communication). Using CCD images of the nebula taken with interference filters centered on H α and H β , point-by-point H α /H β ratios were used to derive the extinction along the line of sight to each pixel; $C_{H\beta}$ is the negative of the log of the extinction at 4861 Å.

For the components of θ^1 Ori, we have used $A_V \sim 1.0$ mag (Breger, Gehrz, & Hackwell 1981), and for stars outside the bright nebular emission region for which published extinction estimates or photometric $B-V$ colors are not available, we have assumed $A_V = 0.25$ mag and $N_H = 5 \times 10^{20}$ cm $^{-2}$. This value is somewhat higher than the median extinction $A_V \sim 0.17$ mag found by Warren & Hesser (1978), Breger et al. (1981), and Brown, de Geus, & de Zeeuw (1994) for O-, B-, A-, and F-type stars and by Rydgren & Vrba (1984) for G-type stars in Orion 1c. However, Raymond & Smith (1977) model fits to ROSAT position sensitive proportional counter (PSPC) spectra of X-ray-bright Orion Nebula cluster members (Geier 1993) indicate $N_H \geq 5 \times 10^{20}$ cm $^{-2}$; thus, we adopt $A_V \sim 0.25$ mag as our mean extinction outside the nebula.

For the late-type members observed by Strom (1993) and Rydgren & Vrba (1984), JHK photometry has been used to determine the level of near-infrared emission possibly arising from a circumstellar accretion disk.

In § 4 we compare X-ray activity indicators, namely, L_X and L_X/L_{bol} , with rotational period P_{rot} and rotational velocity $v \sin i$. P_{rot} values have been obtained for 39 cluster members in the ROSAT region by Attridge & Herbst (1994, 1992), Mandel & Herbst (1991), and Walker (1990), while rotational velocities for 51 cluster members have been taken from Strom (1993), Duncan (1993), Abt et al. (1991), Walker (1990), and Hartmann et al. (1986).

Finally, a wealth of observational data has been collected from H α objective-prism surveys and U -band photographic monitoring of flare stars over the past four decades (cf. Haro 1953; Herbig & Rao 1972; Haro 1976; Parsamian, Chavira, & González 1978; Parsamian & Chavira 1982; Herbig & Bell 1988; Wiramihardja et al. 1991; Chavira & Parsamian 1991; Parsamian, Chavira, & González 1993). In § 4 we examine X-ray activity and X-ray flaring in the context of H α emission and U -band flaring.

3. X-RAY DATA

Three ROSAT HRI observations were obtained for this program: the southernmost field centered on the Trapezium, a second field centered on the bright star P1905 approximately 20' north of the Trapezium, and a third field centered on the bright star P1795 approximately 45' north of the Trapezium. Table 1 provides a listing of the three pointing positions, the total net exposure times for each pointing, and the dates on which each integration was begun. The northernmost and southernmost field exposures were obtained during widely separated time periods spanning 6 months and 12 months, respectively. Although this delay was not our intention, the widely separated integrations, combined with the overlap of these two fields with the central field, have allowed us to look at variability of sources over timescales of 6–18 months.

The ROSAT HRI has been described in detail by Trümper et al. (1991), Pfeffermann et al. (1986), and Zombeck et al. (1990). The HRI has an on-axis spatial resolution of roughly 5" and is most sensitive to photons in the 0.2–2.0 keV energy range. Its field of view is 38' $\times$ 38', although it cannot detect

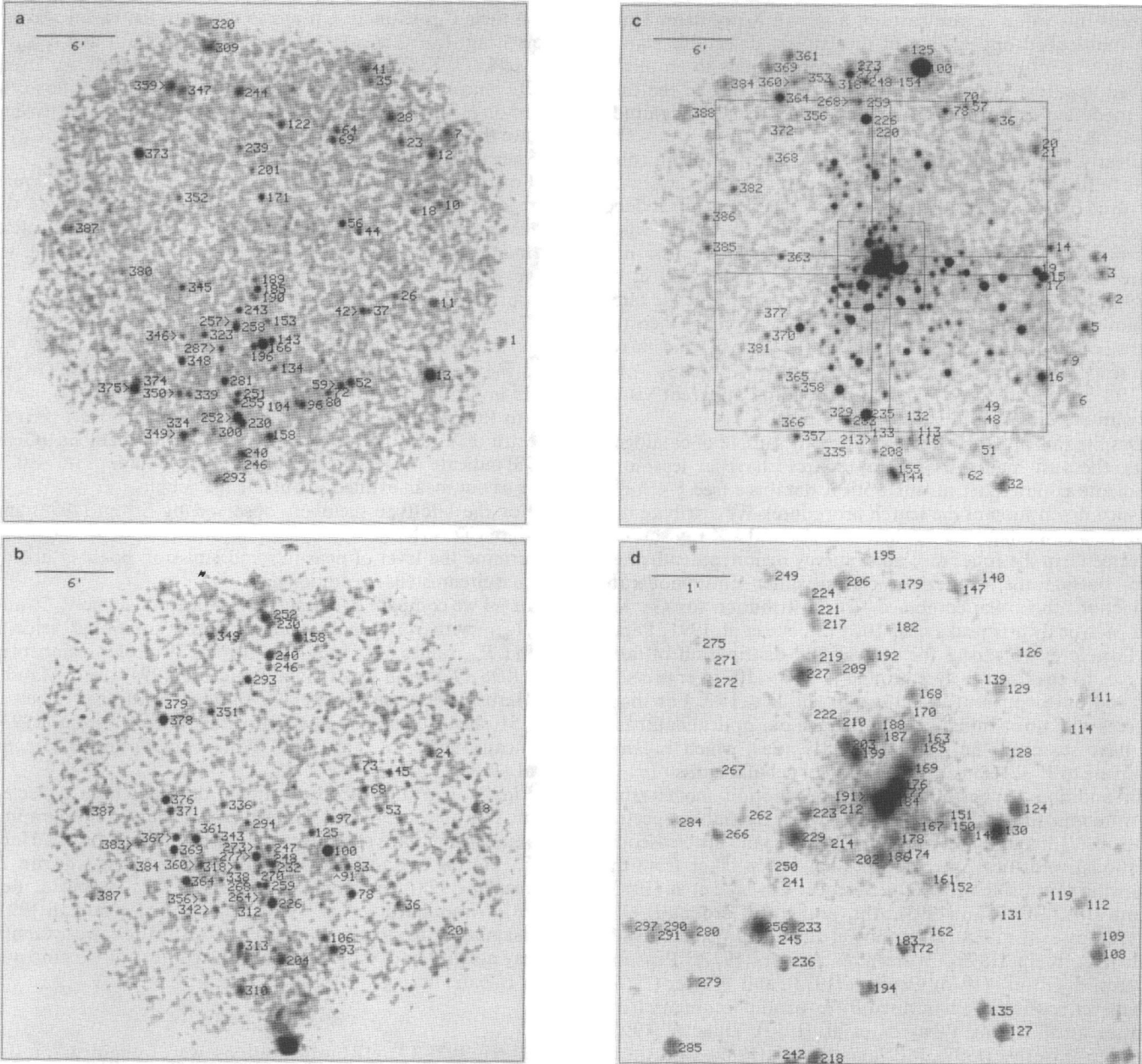


FIG. 2.—Soft X-ray ($\sim 0.2\text{--}2.0$ keV) *ROSAT* HRI images of the Orion Nebula region. In all these images, north is up and east is to the left. Pointing positions and exposure times are listed in Table 1. Source numbers are indicated to the immediate right of a detected source (see Table 2). (a–c) Full field of view of the north, central, and south exposures, respectively. The images have been Gaussian-smoothed with $\sigma = 9''$. The outlines in (c) indicate the location of images (d)–(h). (d) Inner $6'7$ (~ 0.9 pc) region of the Trapezium smoothed using $\sigma = 1''.5$. The bright central source is θ^1 C Ori. (e–h) The northeast, southeast, northwest, and southwest portions of the south field, smoothed using $\sigma = 3''$.

TABLE 1
ROSAT HRI OBSERVATIONS OF THE ORION NEBULA

IMAGE NAME	POINTING POSITION (J2000)		EXPOSURE TIME (s)	DATE OF OBSERVATION
	R.A.	Decl.		
P1795 (north)	5 ^h 35 ^m 14.3	−04°38'24"	2190	1991 Mar 22
	...	...	12240	1992 Mar 22
	...	...	13552	1992 Sep 14
P1905 (central)	5 35 24.0	−05 04 12	11411	1991 Mar 23
Trapezium (south)...	5 35 16.7	−05 23 24	28118	1991 Oct 2
	...	...	1032	1992 Mar 22
	...	...	18022	1992 Sep 14

photons in the four corners of the detector. Consequently, we have schematically represented the three fields as $19'$ radius circles in Figure 1. The optics of the *ROSAT* X-ray telescope suffer from vignetting and comatic aberration, and, as a result, sensitivity and spatial resolution degrade with increasing off-axis angle.

The HRI photon event data are tagged by the photon's position on the detector, its pulse-height channel, and its arrival time. We have filtered the HRI data to exclude photons detected during times of anomalously bright Earth (solar X-ray photons that have been backscattered into the detector by the Earth's upper atmosphere). These bright Earth times are easily seen in the data stream by the characteristic rise of the back-

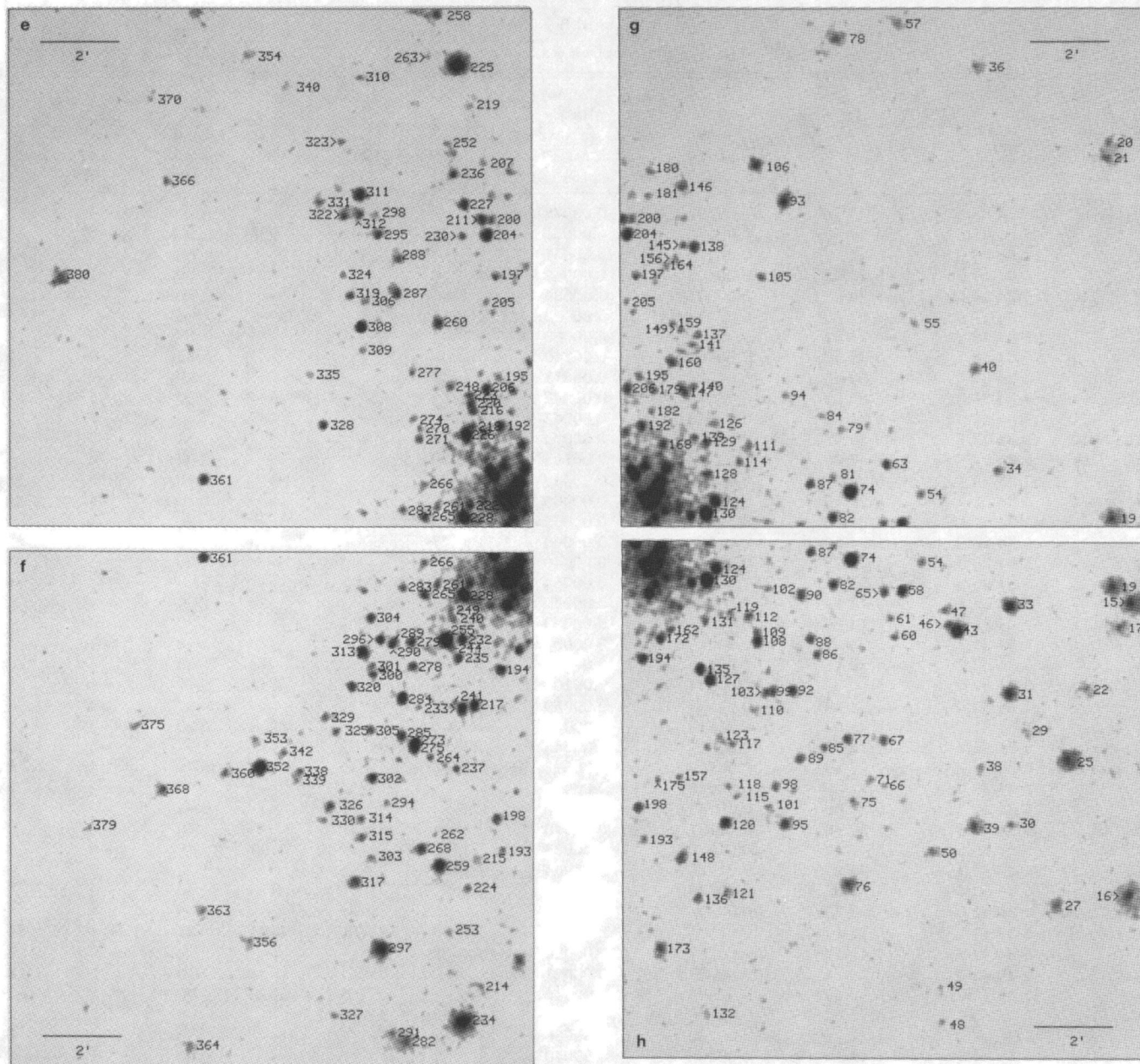


FIG. 2—Continued

ground light curve during the beginning or end of a given satellite orbit. In addition to analyzing the X-ray images spatially, the photon event data can be used to look for temporal variability and to generate X-ray spectra. The photon arrival times have been used to construct X-ray light curves for individual sources. However, because the energy resolution of the HRI is so poor, we have not been able to extract any relevant physical parameters from the pulse-height spectra.

In Figures 2a–2c we show the entire field of view of the north, central, and south HRI images. The images have been Gaussian-smoothed with $\sigma = 9''$; no background subtraction has been performed. Numbers indicate detected X-ray sources (see § 4 and Table 2). The outlines in Figure 2c represent the sections of the south image shown in Figures 2d–2h. Figure 2d is a Gaussian-smoothed image ($\sigma = 1''.5$) of the Trapezium. The

brightest source is θ^1 C Ori (No. 184) and nearby, barely resolved at this resolution, are θ^1 D Ori (No. 191) and θ^1 E Ori (Nos. 176 and 177). Figures 2e–2h show the northeast, northwest, and southwest portions of the south field. Again, these images have been Gaussian-smoothed, this time with $\sigma = 3''$. These images illustrate the high density of X-ray sources and the need for deep, high-resolution imaging to resolve emission from a large fraction of the cluster stars.

The HRI image analysis technique we have adopted is similar to the one described in Paper I. We employ an iterative procedure to detect X-ray sources and to determine background estimates, best positions, and net count rates and errors. The first step involves using two automated source-searching algorithms to construct an initial source list for each image: the first is the source list provided by the Standard

TABLE 2
ORION NEBULA X-RAY SOURCES

X-Ray Number (1)	Source Position (J2000)		Count Rate (counts s ⁻¹) (4)	Count Rate Error (counts s ⁻¹) (5)	Optical Candidate			Mem. Prob. (9)	Offset	
	R.A. (2)	Decl. (3)			Par. (6)	J&W (7)	Var. (8)		$\Delta\alpha$ (10)	$\Delta\delta$ (11)
1	5 ^m 34 ^h 00 ^s .8	-4°44'23"	0.00392	0.00079	...	...	...	...	...	...
2	5 34 06.6	-5 26 00	0.00593	0.00058	P1353	...	V395	93	-1"	-1"
3	5 34 09.0	-5 24 00	0.00591	0.00057	...	...	...	...	...	...
4	5 34 11.2	-5 22 48	0.00408	0.00052	P1374	...	...	99	1	7
5	5 34 14.1	-5 28 08	0.00831	0.00064	P1393	...	...	70	-6	8
6	5 34 17.6	-5 33 40	0.00383	0.00063	P1417	...	...	...	-6	-5
7	5 34 18.2	-4 28 31	0.00602	0.00083	P1408	...	...	89	0	4
8	5 34 18.5	-5 04 46	0.00610	0.00140	P1409	...	EZ	85	0	2
9	5 34 20.0	-5 30 40	0.00262	0.00051	P1428	...	V746	49	-7	9
10	5 34 21.2	-4 34 02	0.00194	0.00048	P1416	...	...	...	5	7
11	5 34 22.4	-4 41 36	0.00344	0.00053	...	...	V547	...	-7	3
12	5 34 23.3	-4 30 07	0.00626	0.00074	P1425	...	...	81	3	7
13	5 34 23.7	-4 47 06	0.02140	0.00105	P1440	...	...	88	-4	6
14	5 34 25.1	-5 22 00	0.00340	0.00042	P1455	...	...	98	3	6
15	5 34 26.7	-5 24 16	0.01515	0.00065	P1469	...	...	0	-9	6
16	5 34 27.4	-5 31 53	0.01317	0.00068	P1470	...	...	96	-1	2
17	5 34 28.0	-5 24 56	0.00343	0.00040	P1477	JW2	...	52	-7	2
18	5 34 28.4	-4 34 28	0.00165	0.00040	...	...	...	...	...	...
19	5 34 28.9	-5 23 52	0.00955	0.00054	P1484	JW5	...	0	-4	5
20	5 34 29.1	-5 14 12	0.00318	0.00042	P1482	JW3	...	0	1	3
21	5 34 29.4	-5 14 36	0.00305	0.00040	P1483	JW4	...	0	3	4
22	5 34 31.8	-5 26 32	0.00210	0.00034	...	JW20	...	99	-1	5
23	5 34 32.7	-4 29 11	0.00300	0.00056	P1491	...	...	86	4	6
24	5 34 32.9	-5 00 32	0.00544	0.00102	P1496	...	V652	...	-1	9
25	5 34 33.4	-5 28 24	0.01194	0.00059	P1510	JW27	...	97	-9	1
26	5 34 34.2	-4 41 03	0.00149	0.00036	P1500	...	V754	90	-3	8
27	5 34 34.7	-5 32 08	0.00316	0.00043	P1518	JW29	...	97	-6	3
28	5 34 35.7	-4 27 13	0.00752	0.00073	P1505	...	...	85	4	9
29	5 34 38.0	-5 27 36	0.00086	0.00027	...	JW39	...	99	-1	5
30	5 34 39.3	-5 30 00	0.00183	0.00032	*	*	*	...	...	...
31	5 34 39.6	-5 26 40	0.00727	0.00046	P1541	JW46	...	70	-4	2
32	5 34 39.6	-5 40 07	0.01389	0.00088	P1553	...	V398	86	-6	-2
33	5 34 39.7	-5 24 20	0.01112	0.00054	P1540	JW45	...	0	0	6
34	5 34 40.6	-5 22 36	0.00138	0.00026	P1552	JW50	...	89	-4	6
35	5 34 42.0	-4 24 23	0.00291	0.00063	...	...	...	...	...	...
36	5 34 42.1	-5 12 14	0.00305	0.00039	P1563	JW60	V473	81	-4	5
37	5 34 42.6	-4 42 12	0.00137	0.00031	A6862	...	...	...	0	3
38	5 34 42.7	-5 28 31	0.00085	0.00021	...	JW61	...	16	1	6
39	5 34 43.0	-5 30 08	0.00486	0.00040	...	JW65	...	99	-4	-1
40	5 34 43.1	-5 20 00	0.00193	0.00028	P1569	JW63	...	98	3	7
41	5 34 43.4	-4 23 28	0.00750	0.00086	P1546	...	...	38	4	5
42	5 34 44.3	-4 42 13	0.00306	0.00040	P1567	...	...	89	-1	2
43	5 34 45.1	-5 25 01	0.01529	0.00059	P1587	JW75	...	99	0	3
44	5 34 45.5	-4 36 04	0.00193	0.00033	P1573	...	V939	...	0	3
45	5 34 45.6	-5 02 00	0.00194	0.00058	P1584	...	V768	...	3	7
46	5 34 46.0	-5 24 51	0.00211	0.00024	P1595	JW77	...	99	3	4
47	5 34 46.3	-5 24 32	0.00137	0.00025	P1600	JW81	...	92	0	0
48	5 34 46.5	-5 35 12	0.00137	0.00039	P1606	JW88	...	96	-4	-3
49	5 34 46.8	-5 34 12	0.00133	0.00036	P1605	...	V372	88	-1	3
50	5 34 47.3	-5 30 48	0.00186	0.00030	P1604	JW91	...	99	-7	-1
51	5 34 47.6	-5 37 32	0.00215	0.00050	...	JW89	...	...	0	-6
52	5 34 48.0	-4 47 40	0.00565	0.00056	P1598	...	...	54	-3	0
53	5 34 48.2	-5 04 56	0.00196	0.00060	*	...	*	...	...	...
54	5 34 48.7	-5 23 15	0.00095	0.00022	...	JW99	V772	99	-1	3
55	5 34 48.9	-5 18 52	0.00065	0.00021	...	JW106	...	99	-4	4
56	5 34 50.6	-4 35 27	0.00474	0.00045	P1611	...	V773	87	0	6
57	5 34 50.6	-5 11 07	0.00226	0.00042	P1622	JW111	...	98	1	4
58	5 34 50.7	-5 23 59	0.00691	0.00042	P1633	JW116	...	99	1	3

TABLE 2—Continued

X-Ray Number (1)	Source Position (J2000)		Count Rate (counts s ⁻¹) (4)	Count Rate Error (counts s ⁻¹) (5)	Optical Candidate			Mem. Prob. (9)	Offset	
	R.A. (2)	Decl. (3)			Par. (6)	J&W (7)	Var. (8)		$\Delta\alpha$ (10)	$\Delta\delta$ (11)
59	5 34 51.0	-4 47 55	0.00477	0.00052	P1621	...	...	84	-3	2
60	5 34 51.4	-5 25 12	0.00097	0.00022	P1642	JW123	V401	99	-1	1
61	5 34 51.9	-5 24 43	0.00068	0.00021	...	JW127	...	99	-1	0
62	5 34 51.9	-5 39 28	0.00270	0.00054	...	...	...	...	...	...
63	5 34 52.2	-5 22 28	0.00265	0.00029	...	JW128	...	99	0	4
64	5 34 52.4	-4 28 11	0.00308	0.00046	A6221	...	...	...	4	0
65	5 34 52.4	-5 24 04	0.00234	0.00028	...	JW133	...	99	-1	0
66	5 34 52.6	-5 29 01	0.00102	0.00028	...	JW138	...	98	-3	-2
67	5 34 52.7	-5 27 52	0.00222	0.00028	...	*	*	...	...	...
68	5 34 52.9	-5 03 20	0.00351	0.00062	P1648	...	YZ	51	0	7
69	5 34 53.4	-4 28 57	0.00331	0.00045	P1631	...	...	...	7	8
70	5 34 53.5	-5 10 24	0.00162	0.00041	...	JW140	...	98	2	4
71	5 34 53.8	-5 28 56	0.00073	0.00020	...	JW148	...	99	-6	-2
72	5 34 54.8	-4 48 26	0.00264	0.00044	P1651	...	...	51	-4	1
73	5 34 55.4	-5 01 32	0.00124	0.00040	P1655	...	...	...	-3	9
74	5 34 55.6	-5 23 08	0.02248	0.00072	P1659	JW157	KM	99	-6	5
75	5 34 55.6	-5 29 28	0.00115	0.00024	...	*	*	...	...	...
76	5 34 56.2	-5 31 40	0.00630	0.00043	P1667	JW165	KO	97	-3	-4
77	5 34 56.3	-5 27 50	0.00231	0.00028	...	JW164	...	99	-3	1
78	5 34 56.4	-5 11 30	0.00580	0.00042	P1665	JW163	KN	98	-6	3
79	5 34 56.8	-5 21 34	0.00118	0.00028	...	JW167	...	99	0	2
80	5 34 57.3	-4 49 12	0.00133	0.00040	...	...	...	...	...	...
81	5 34 57.5	-5 22 44	0.00059	0.00018	...	JW175	V402	99	-4	7
82	5 34 57.7	-5 23 51	0.00403	0.00034	P1673	JW176	KQ	99	0	1
83	5 34 57.9	-5 09 24	0.00299	0.00061	P1656	JW178	V780	24	-3	3
84	5 34 58.9	-5 21 15	0.00054	0.00015	...	*	...	...	...	...
85	5 34 58.9	-5 28 04	0.00118	0.00023	...	JW188	...	99	0	-1
86	5 34 59.5	-5 25 39	0.00146	0.00023	P1686	JW192	...	99	-1	1
87	5 34 59.9	-5 23 00	0.00205	0.00027	P1684	JW193	KR	99	-1	3
88	5 35 00.2	-5 25 20	0.00170	0.00025	*	*	*	...	...	...
89	5 35 01.0	-5 28 20	0.00203	0.00026	...	JW211	...	99	-7	1
90	5 35 01.1	-5 24 07	0.00314	0.00031	*	*	...	...	...	...
91	5 35 01.2	-5 09 30	0.00194	0.00034	P1693	JW204	KV	97	-3	3
92	5 35 02.0	-5 26 35	0.00351	0.00032	*	*	...	...	...	...
93	5 35 02.6	-5 15 44	0.00863	0.00044	P1703	JW221	V403	99	4	5
94	5 35 02.6	-5 20 44	0.00051	0.00015	...	JW223	...	99	3	3
95	5 35 02.6	-5 30 04	0.00425	0.00035	P1727	JW232	KZ	76	-4	-2
96	5 35 02.9	-4 49 22	0.00431	0.00045	*	...	...	...	...	...
97	5 35 03.4	-5 05 38	0.00232	0.00048	P1712	...	...	99	0	3
98	5 35 03.7	-5 29 00	0.00122	0.00023	P1725	JW239	...	99	-1	4
99	5 35 03.9	-5 26 37	0.00203	0.00025	...	JW243	...	99	-1	0
100	5 35 04.1	-5 08 10	0.16090	0.00176	P1724	JW238	...	0	-3	3
101	5 35 04.2	-5 29 32	0.00078	0.00022	...	*	...	...	...	...
102	5 35 04.5	-5 23 58	0.00072	0.00020	P1737	JW249	...	99	1	-1
103	5 35 04.6	-5 26 38	0.00178	0.00024	...	JW258	...	99	-1	0
104	5 35 04.7	-4 49 13	0.00245	0.00043	P1721	...	...	...	-6	0
105	5 35 04.9	-5 17 40	0.00098	0.00022	...	JW253	...	99	1	3
106	5 35 05.0	-5 14 50	0.00534	0.00036	P1736	JW260	V479	99	-1	1
107	5 35 05.3	-5 09 32	0.00136	0.00045	P1735	...	...	...	0	5
108	5 35 05.6	-5 25 19	0.00506	0.00036	*	*	*	...	...	...
109	5 35 05.7	-5 25 05	0.00099	0.00020	P1745	JW275	...	99	1	1
110	5 35 05.9	-5 27 06	0.00109	0.00029	...	*	...	...	...	...
111	5 35 06.4	-5 22 01	0.00099	0.00022	*	*	*	...	...	...
112	5 35 06.5	-5 24 41	0.00167	0.00025	P1754	JW291	...	99	1	0
113	5 35 07.2	-5 36 16	0.00132	0.00034	P1763	JW308	SZ	1	-6	4
114	5 35 07.4	-5 22 26	0.00083	0.00018	...	*	...	...	...	...
115	5 35 07.4	-5 29 20	0.00062	0.00019	...	JW311	...	99	-6	-3
116	5 35 07.4	-5 36 48	0.00381	0.00042	...	JW315	...	99	-9	-1
117	5 35 08.2	-5 27 58	0.00082	0.00020	...	JW319	...	99	-1	-1
118	5 35 08.2	-5 29 00	0.00066	0.00019	...	JW326	...	99	-6	1
119	5 35 08.4	-5 24 34	0.00068	0.00021	...	JW317	...	99	3	1
120	5 35 08.8	-5 30 04	0.00564	0.00039	P1773	JW330	V356	99	-3	-5
121	5 35 08.8	-5 31 51	0.00113	0.00024	P1765	JW328	LM	99	0	-2

TABLE 2—Continued

X-Ray Number (1)	Source Position (J2000)		Count Rate (counts s ⁻¹) (4)	Count Rate Error (counts s ⁻¹) (5)	Optical Candidate			Mem. Prob. (9)	Offset	
	R.A. (2)	Decl. (3)			Par. (6)	J&W (7)	Var. (8)		$\Delta\alpha$ (10)	$\Delta\delta$ (11)
122	5 35 09.3	-4 27 45	0.00326	0.00045	P1752	...	V481	74	6	6
123	5 35 09.3	-5 27 50	0.00092	0.00020	P1772	...	LP	99	-7	3
124	5 35 09.7	-5 23 27	0.00897	0.00048	P1771	JW337	...	99	-1	0
125	5 35 09.8	-5 06 44	0.00311	0.00040	P1764	...	V355	...	0	3
126	5 35 10.0	-5 21 27	0.00079	0.00016	*	...	...	...	...	...
127	5 35 10.4	-5 26 18	0.00728	0.00042	P1785	JW348	LR	99	-1	0
128	5 35 10.5	-5 22 44	0.00115	0.00025	*	*	...	...	...	...
129	5 35 10.6	-5 21 55	0.00133	0.00024	P1782	JW347	...	99	0	1
130	5 35 10.7	-5 23 44	0.03853	0.00093	P1784	JW352	LQ	99	0	0
131	5 35 10.9	-5 24 49	0.00091	0.00029	...	JW356	...	99	0	-1
132	5 35 10.9	-5 34 55	0.00183	0.00047	...	JW362	...	99	-3	4
133	5 35 10.9	-5 36 52	0.00203	0.00039	P1802	JW363	...	98	-3	-1
134	5 35 11.3	-4 46 34	0.00165	0.00033	P1779	...	...	...	-5	-2
135	5 35 11.4	-5 26 03	0.00381	0.00032	P1800	JW365	LU	99	0	-1
136	5 35 11.4	-5 32 00	0.00128	0.00024	P1801	JW375	...	98	-7	-5
137	5 35 11.6	-5 19 09	0.00086	0.00017	...	JW361	...	99	4	3
138	5 35 11.8	-5 16 54	0.00269	0.00026	P1799	JW364	LT	99	3	4
139	5 35 11.8	-5 21 48	0.00079	0.00016	...	JW369	...	99	1	7
140	5 35 11.9	-5 20 30	0.00077	0.00019	...	JW373	...	99	0	3
141	5 35 12.0	-5 19 25	0.00076	0.00020	...	*	...	...	...	...
142	5 35 12.2	-5 23 48	0.00466	0.00038	P1808	JW378	...	99	0	0
143	5 35 12.3	-4 44 27	0.00366	0.00042	P1778	...	...	...	0	-2
144	5 35 12.5	-5 39 36	0.00928	0.00061	P1828	...	LX	85	-6	-1
145	5 35 12.8	-5 16 52	0.00090	0.00020	...	JW386	...	99	1	1
146	5 35 12.9	-5 15 22	0.00209	0.00028	...	JW388	...	99	1	2
147	5 35 12.9	-5 20 39	0.00281	0.00029	*	*	...	...	...	...
148	5 35 13.0	-5 30 56	0.00205	0.00027	*	*	*	...	...	...
149	5 35 13.2	-5 19 01	0.00061	0.00019	...	JW393	...	99	4	3
150	5 35 13.4	-5 23 41	0.00123	0.00019	P1824	JW409	...	98	0	0
151	5 35 13.5	-5 23 32	0.00290	0.00037	...	JW412	...	99	0	0
152	5 35 13.5	-5 24 27	0.00132	0.00027	...	JW417	...	98	0	-2
153	5 35 13.6	-4 42 58	0.00135	0.00029	P1797	...	...	...	4	3
154	5 35 13.6	-5 09 16	0.00156	0.00042	P1805	JW396	...	98	6	4
155	5 35 13.6	-5 39 08	0.00646	0.00053	P1846	JW433	LY	92	-3	2
156	5 35 13.7	-5 17 15	0.00072	0.00016	...	*	...	...	...	...
157	5 35 13.7	-5 28 48	0.00076	0.00019	...	JW422	...	99	0	-2
158	5 35 13.8	-4 51 40	0.00854	0.00059	P1798	...	...	91	7	4
159	5 35 14.1	-5 18 54	0.00122	0.00035	...	JW425	...	98	4	0
160	5 35 14.1	-5 19 53	0.00188	0.00026	P1836	JW429	...	99	1	0
161	5 35 14.3	-5 24 24	0.00111	0.00017	P1826	JW437	...	99	1	0
162	5 35 14.5	-5 25 02	0.00066	0.00015	...	JW443	...	99	1	1
163	5 35 14.7	-5 22 34	0.00424	0.00036	*	*	...	...	...	...
164	5 35 14.9	-5 17 22	0.00068	0.00019	...	JW439	...	99	7	3
165	5 35 14.9	-5 22 40	0.00403	0.00037	P1840	JW454	...	99	0	0
166	5 35 15.0	-4 44 43	0.03682	0.00117	P1817	...	...	87	-1	0
167	5 35 15.0	-5 23 41	0.00470	0.00044	P1844	JW456	...	7	1	-1
168	5 35 15.1	-5 21 59	0.00217	0.00029	P1837	JW457	...	93	3	1
169	5 35 15.3	-5 22 56	0.02077	0.00074	*	*	...	...	...	...
170	5 35 15.4	-5 22 13	0.00085	0.00025	...	JW470	...	99	1	3
171	5 35 15.5	-4 33 26	0.00353	0.00040	P1816	...	V487	51	3	1
172	5 35 15.5	-5 25 15	0.00234	0.00029	P1872	JW478	...	99	0	0
173	5 35 15.5	-5 33 15	0.00331	0.00034	P1874	JW501	MN	99	-4	-2
174	5 35 15.7	-5 24 03	0.00097	0.00015	P1871	JW480	...	99	3	0
175	5 35 15.7	-5 28 52	0.00109	0.00035	...	JW502	...	99	-1	1
176	5 35 15.8	-5 23 09	0.05998	0.00300	*	...	...	...	...	...
177	5 35 15.9	-5 23 12	0.07633	0.00382	*	...	...	...	...	...
178	5 35 16.0	-5 23 51	0.00582	0.00046	*	*	*	...	...	...
179	5 35 16.1	-5 20 35	0.00111	0.00023	P1859	JW504	...	99	1	2
180	5 35 16.3	-5 14 52	0.00096	0.00024	P1858	JW487	MM	99	6	8
181	5 35 16.3	-5 15 32	0.00155	0.00041	...	JW508	V489	99	0	7
182	5 35 16.3	-5 21 08	0.00069	0.00016	...	*	...	...	...	...
183	5 35 16.3	-5 25 09	0.00085	0.00017	...	JW516	...	99	0	1
184	5 35 16.5	-5 23 22	0.28338	0.00233	P1891	...	θ^1 C	99	0	1

TABLE 2—Continued

X-Ray Number (1)	Source Position (J2000)		Count Rate (counts s ⁻¹) (4)	Count Rate Error (counts s ⁻¹) (5)	Optical Candidate			Mem. Prob. (9)	Offset	
	R.A. (2)	Decl. (3)			Par. (6)	J&W (7)	Var. (8)		$\Delta\alpha$ (10)	$\Delta\delta$ (11)
185	5 35 16.7	-4 40 32	0.00416	0.00042	P1834	...	...	85	-1	4
186	5 35 16.7	-5 24 05	0.01021	0.00054	*	*	...	...	...	...
187	5 35 16.9	-5 22 32	0.00379	0.00047	P1887	JW536	...	99	-1	1
188	5 35 17.0	-5 22 23	0.00112	0.00016	P1886	JW529	...	99	1	0
189	5 35 17.1	-4 39 48	0.00100	0.00025	P1853	...	...	...	-6	3
190	5 35 17.1	-4 41 12	0.00101	0.00026	*	...	*	...	...	...
191	5 35 17.1	-5 23 18	0.04523	0.00109	P1889	...	θ^1 D	99	-1	-1
192	5 35 17.3	-5 21 30	0.00241	0.00030	P1884	JW544	AE	99	1	2
193	5 35 17.3	-5 30 28	0.00067	0.00021	...	JW556	...	99	-1	-2
194	5 35 17.4	-5 25 46	0.00300	0.00031	*	*	...	...	...	...
195	5 35 17.5	-5 20 13	0.00073	0.00021	...	JW547	...	97	3	2
196	5 35 17.7	-4 44 52	0.00347	0.00041	P1882	...	V559	51	-7	-3
197	5 35 17.9	-5 17 36	0.00084	0.00022	...	JW550	...	99	6	5
198	5 35 17.9	-5 29 32	0.00213	0.00027	...	JW576	...	99	0	3
199	5 35 18.0	-5 22 45	0.01647	0.00064	P1910	JW567	MT	99	1	1
200	5 35 18.2	-5 16 11	0.00116	0.00022	...	JW566	...	0	3	3
201	5 35 18.3	-4 31 18	0.00106	0.00028	...	...	...	...	...	...
202	5 35 18.3	-5 24 07	0.00095	0.00028	...	*	...	...	...	...
203	5 35 18.5	-5 22 38	0.00923	0.00051	P1925	JW589	...	99	3	0
204	5 35 18.6	-5 16 35	0.00823	0.00042	*	*	*	...	...	...
205	5 35 18.8	-5 18 19	0.00052	0.00017	...	JW592	...	99	4	2
206	5 35 18.8	-5 20 33	0.00314	0.00032	*	*	*	...	...	...
207	5 35 18.9	-5 14 44	0.00186	0.00047	...	JW597	...	0	1	3
208	5 35 18.9	-5 37 40	0.00276	0.00043	P1942	JW614	V412	0	-1	-3
209	5 35 19.0	-5 21 40	0.00136	0.00027	P1924	JW603	...	99	3	2
210	5 35 19.0	-5 22 21	0.00094	0.00025	...	JW617	...	...	-7	1
211	5 35 19.1	-5 16 12	0.00320	0.00031	P1921	JW601	MU	99	4	2
212	5 35 19.1	-5 23 27	0.00092	0.00031	P1928	JW610	...	99	0	0
213	5 35 19.2	-5 36 48	0.00145	0.00036	...	...	...	...	...	...
214	5 35 19.6	-5 23 55	0.00136	0.00030	...	JW620	...	99	1	2
215	5 35 19.6	-5 33 55	0.00144	0.00029	P1941	JW639	...	99	-6	-1
216	5 35 19.9	-5 30 39	0.00065	0.00021	*	*	*	...	...	...
217	5 35 20.0	-5 21 06	0.00212	0.00028	...	JW623	...	...	3	2
218	5 35 20.1	-5 26 40	0.00513	0.00036	P1962	JW641	...	99	0	-1
219	5 35 20.2	-5 21 31	0.00105	0.00023	P1939	JW637	...	99	1	3
220	5 35 20.3	-5 13 12	0.00112	0.00027	...	*	...	...	...	...
221	5 35 20.3	-5 20 55	0.00139	0.00019	P1937	JW640	TU	99	1	2
222	5 35 20.5	-5 22 15	0.00087	0.00026	P1959	JW645	...	99	1	-1
223	5 35 20.5	-5 23 31	0.00213	0.00031	P1960	JW648	...	99	0	-1
224	5 35 20.6	-5 20 42	0.00156	0.00025	...	JW651	...	99	1	2
225	5 35 20.8	-5 31 24	0.00092	0.00023	P1976	JW673	MZ	99	-1	-2
226	5 35 20.9	-5 12 14	0.02582	0.00071	P1955	JW670	...	98	-6	-1
227	5 35 20.9	-5 21 44	0.01046	0.00051	P1956	JW660	...	99	3	0
228	5 35 21.0	-5 15 48	0.00257	0.00027	...	JW655	...	99	4	1
229	5 35 21.1	-5 23 50	0.01488	0.00060	*	*	...	...	...	...
230	5 35 21.2	-4 50 46	0.00587	0.00052	P1935	...	MW	85	1	-4
231	5 35 21.2	-5 16 37	0.00084	0.00022	...	JW664	V493	99	4	1
232	5 35 21.3	-5 09 14	0.00349	0.00034	P1953	JW666	MX	99	1	2
233	5 35 21.3	-5 24 59	0.00354	0.00034	P1974	JW678	V377	99	1	-2
234	5 35 21.4	-5 26 46	0.00540	0.00037	*	*	...	...	...	...
235	5 35 21.5	-5 34 48	0.03191	0.00089	P1977	JW701	AG	99	-1	-1
236	5 35 21.6	-5 25 26	0.00101	0.00020	...	JW690	V495	92	0	0
237	5 35 21.9	-5 15 00	0.00150	0.00027	...	JW691	...	99	1	1
238	5 35 22.0	-5 28 17	0.00077	0.00016	...	JW704	...	99	0	-2
239	5 35 22.1	-4 29 35	0.00151	0.00033	P1933	...	V1046	56	4	3
240	5 35 22.1	-4 53 06	0.00848	0.00062	P1950	...	...	85	6	6
241	5 35 22.1	-5 24 25	0.00057	0.00018	P1992	JW707	V562	99	0	0
242	5 35 22.1	-5 26 37	0.00058	0.00019	P1994	JW709	...	99	-1	0
243	5 35 22.3	-4 42 08	0.00295	0.00037	P1948	...	CD	26	0	-1
244	5 35 22.3	-4 25 20	0.00774	0.00089	P1932	...	...	3	0	-7
245	5 35 22.3	-5 25 09	0.00088	0.00016	...	JW713	...	99	0	0
246	5 35 22.4	-4 54 00	0.00219	0.00059	P1951	...	V414	51	3	7
247	5 35 22.5	-5 08 00	0.00182	0.00028	...	*	...	...	...	...

TABLE 2—Continued

X-Ray Number (1)	Source Position (J2000)		Count Rate (counts s ⁻¹) (4)	Count Rate Error (counts s ⁻¹) (5)	Optical Candidate			Mem. Prob. (9)	Offset	
	R.A. (2)	Decl. (3)			Par. (6)	J&W (7)	Var. (8)		$\Delta\alpha$ (10)	$\Delta\delta$ (11)
248	5 35 22.5	-5 09 16	0.00180	0.00025	P1971	JW705	...	97	1	-5
249	5 35 22.5	-5 20 29	0.00111	0.00022	P1972	JW706	...	99	4	0
250	5 35 22.5	-5 24 13	0.00045	0.00014	...	JW710	...	99	-4	1
251	5 35 22.6	-4 48 31	0.00207	0.00040	P1968	...	...	51	-7	2
252	5 35 22.7	-4 50 22	0.01396	0.00074	P1970	...	...	31	-6	-4
253	5 35 22.7	-5 14 12	0.00078	0.00024	...	JW714	...	99	3	-1
254	5 35 22.7	-5 32 28	0.00073	0.00024	P1995	JW728	...	99	-3	1
255	5 35 22.9	-4 49 07	0.00351	0.00047	P1969	...	...	...	-3	-4
256	5 35 23.0	-5 24 59	0.03251	0.00086	P1993	...	$\theta^2 A$	80	3	-1
257	5 35 23.1	-4 43 03	0.00079	0.00024	P1966	...	...	...	-3	0
258	5 35 23.1	-4 43 26	0.00609	0.00051	P1967	...	...	44	-1	0
259	5 35 23.2	-5 10 54	0.00364	0.00035	P1988	JW731	...	93	-3	-2
260	5 35 23.6	-5 30 51	0.00939	0.00049	P2001	JW747	V358	98	-3	-4
261	5 35 23.7	-5 18 49	0.00274	0.00029	*	*	...	...	...	...
262	5 35 23.8	-5 23 33	0.00079	0.00026	...	*	...	...	...	...
263	5 35 24.2	-5 30 01	0.00052	0.00017	...	JW753	...	99	0	-4
264	5 35 24.3	-5 11 58	0.00174	0.00058	*	*	*	...	...	...
265	5 35 24.6	-5 28 01	0.00071	0.00018	...	...	...	...	...	...
266	5 35 25.0	-5 23 48	0.00211	0.00027	*	*	...	...	...	...
267	5 35 25.2	-5 22 58	0.00071	0.00020	...	JW766	...	99	3	0
268	5 35 25.3	-5 10 50	0.00239	0.00031	P2007	JW771	...	97	0	-2
269	5 35 25.5	-5 30 23	0.00366	0.00033	*	*	*	...	...	...
270	5 35 25.6	-5 09 24	0.00257	0.00043	P2005	JW765	...	98	6	4
271	5 35 25.6	-5 21 34	0.00047	0.00014	...	JW777	...	85	3	1
272	5 35 25.6	-5 21 51	0.00069	0.00019	...	...	V496	99	3	0
273	5 35 26.0	-5 07 58	0.00310	0.00044	*	*	...	...	...	...
274	5 35 26.1	-5 27 36	0.00863	0.00045	P2033	JW795	...	99	-1	0
275	5 35 26.2	-5 21 21	0.00054	0.00017	...	JW791	...	99	3	0
276	5 35 26.2	-5 27 44	0.00423	0.00034	...	JW798	...	99	-1	0
277	5 35 26.3	-5 08 40	0.01126	0.00053	*	*	*	...	...	...
278	5 35 26.4	-5 20 07	0.00072	0.00019	...	JW793	...	99	4	-1
279	5 35 26.4	-5 25 42	0.00127	0.00024	P2032	JW799	AK	99	1	-2
280	5 35 26.5	-5 25 03	0.00243	0.00029	P2031	...	...	99	1	-3
281	5 35 26.8	-4 47 32	0.00639	0.00052	P2017	...	...	94	-9	-5
282	5 35 26.9	-4 56 02	0.00157	0.00046	P2019	...	V563	51	-1	5
283	5 35 27.1	-5 35 20	0.00524	0.00043	P2048	JW818	...	98	-6	0
284	5 35 27.4	-5 23 39	0.00096	0.00021	...	JW810	...	99	1	-2
285	5 35 27.4	-5 26 32	0.00622	0.00040	P2047	JW813	...	99	0	-3
286	5 35 27.5	-5 27 28	0.00157	0.00029	...	JW815	...	99	0	-3
287	5 35 27.7	-4 45 06	0.00240	0.00036	P2027	...	...	51	-1	-3
288	5 35 27.8	-5 18 04	0.00275	0.00029	...	JW816	...	99	1	0
289	5 35 27.9	-5 17 05	0.00181	0.00026	...	*	...	...	...	...
290	5 35 28.2	-5 24 59	0.00087	0.00017	P2046	JW826	V420	94	1	-1
291	5 35 28.5	-5 25 06	0.00154	0.00022	...	JW830	...	99	3	-2
292	5 35 28.6	-5 35 08	0.00236	0.00034	...	JW835	...	99	-3	-1
293	5 35 29.0	-4 54 58	0.00719	0.00061	P2043	...	...	0	7	6
294	5 35 29.1	-5 06 04	0.00193	0.00043	P2057	...	...	80	-6	0
295	5 35 29.2	-5 29 12	0.00066	0.00016	...	JW836	...	99	3	-1
296	5 35 29.7	-5 16 34	0.00274	0.00028	...	JW837	...	99	4	0
297	5 35 29.7	-5 24 59	0.00245	0.00028	...	JW839	...	99	3	-2
298	5 35 29.7	-5 32 56	0.01485	0.00061	P2069	JW847	...	99	-1	-2
299	5 35 29.9	-5 16 00	0.00068	0.00021	...	...	...	...	...	...
300	5 35 30.1	-4 51 28	0.00230	0.00053	P2064	...	...	0	-7	3
301	5 35 30.4	-5 25 55	0.00092	0.00019	...	JW848	...	99	3	-3
302	5 35 30.5	-5 25 41	0.00075	0.00019	*	*	...	...	...	...
303	5 35 30.5	-5 28 34	0.00293	0.00031	...	JW855	...	99	0	-3
304	5 35 30.5	-5 30 36	0.00081	0.00022	...	JW863	...	99	-3	1
305	5 35 30.6	-5 24 25	0.00179	0.00025	*	*	...	...	...	...
306	5 35 30.7	-5 27 20	0.00129	0.00024	...	JW860	...	99	1	-3
307	5 35 31.0	-5 18 16	0.00072	0.00021	...	JW861	...	99	1	2
308	5 35 31.3	-5 23 41	0.00061	0.00017	...	JW868	...	99	1	-1
309	5 35 31.4	-4 21 49	0.01124	0.00100	P2054	...	...	13	4	2
310	5 35 31.4	-5 18 56	0.00629	0.00038	P2075	JW867	...	99	3	0

TABLE 2—Continued

X-Ray Number (1)	Source Position (J2000)		Count Rate (counts s ⁻¹) (4)	Count Rate Error (counts s ⁻¹) (5)	Optical Candidate			Mem. Prob. (9)	Offset	
	R.A. (2)	Decl. (3)			Par. (6)	J&W (7)	Var. (8)		$\Delta\alpha$ (10)	$\Delta\delta$ (11)
311	5 35 31.4	-5 19 32	0.00052	0.00014	...	...	...	...	...	...
312	5 35 31.5	-5 12 28	0.00111	0.00032	...	JW864	...	99	4	1
313	5 35 31.5	-5 15 28	0.00614	0.00038	P2073	JW866	...	98	4	6
314	5 35 31.5	-5 16 00	0.00222	0.00026	P2074	...	NU	99	1	3
315	5 35 31.5	-5 25 19	0.00543	0.00038	P2085	...	V361	99	1	-2
316	5 35 31.5	-5 29 36	0.00084	0.00022	...	JW880	...	99	-3	-2
317	5 35 31.5	-5 30 04	0.00138	0.00024	...	JW878	...	99	-1	0
318	5 35 32.0	-5 09 30	0.00365	0.00036	P2084	JW876	V360	81	1	-2
319	5 35 32.3	-5 31 16	0.00387	0.00035	P2100	JW887	...	98	0	-5
320	5 35 32.6	-4 19 58	0.00311	0.00084	...	...	V797	...	0	6
321	5 35 32.6	-5 18 04	0.00120	0.00022	...	JW883	...	99	4	4
322	5 35 32.6	-5 26 14	0.00192	0.00026	P2097	JW890	...	99	1	-3
323	5 35 32.9	-4 44 01	0.00280	0.00038	P2081	...	...	89	0	-2
324	5 35 33.1	-5 16 00	0.00244	0.00030	...	JW892	...	99	4	6
325	5 35 33.4	-5 14 08	0.00078	0.00025	...	JW893	...	99	4	3
326	5 35 33.4	-5 17 35	0.00046	0.00014	...	*	...	...	...	...
327	5 35 33.9	-5 27 20	0.00086	0.00021	...	JW901	...	99	-4	-2
328	5 35 34.5	-5 29 16	0.00182	0.00026	P2112	JW907	V803	10	-4	-2
329	5 35 34.5	-5 34 40	0.00077	0.00020	...	JW906	...	99	-1	-2
330	5 35 35.3	-5 21 29	0.00172	0.00024	*	*	*	...	...	...
331	5 35 35.3	-5 27 00	0.00124	0.00023	...	JW912	...	99	1	-5
332	5 35 35.3	-5 29 40	0.00070	0.00021	...	JW916	...	99	-3	-3
333	5 35 35.5	-5 15 44	0.00156	0.00026	...	JW914	V425	99	0	-1
334	5 35 35.7	-4 51 22	0.00166	0.00054	P2109	...	...	...	-4	1
335	5 35 36.4	-5 37 44	0.00191	0.00045	*	*	...	...	...	...
336	5 35 36.6	-5 04 38	0.00190	0.00043	P2117	...	...	...	1	3
337	5 35 36.7	-5 20 10	0.00058	0.00018	...	...	...	...	...	...
338	5 35 37.1	-5 10 28	0.00157	0.00044	...	JW925	...	98	0	2
339	5 35 37.7	-4 48 37	0.00212	0.00043	P2121	...	...	...	-6	-2
340	5 35 38.0	-5 28 23	0.00101	0.00024	...	JW933	...	99	0	-3
341	5 35 38.2	-5 28 32	0.00061	0.00019	...	*	...	...	...	...
342	5 35 38.6	-5 12 44	0.00211	0.00057	P2144	JW938	V426	99	-3	-2
343	5 35 39.0	-5 07 04	0.00118	0.00035	A5503	...	...	...	0	0
344	5 35 39.6	-5 27 52	0.00090	0.00023	...	JW944	...	99	0	-2
345	5 35 39.7	-4 40 25	0.00223	0.00034	...	...	...	...	...	...
346	5 35 39.7	-4 44 09	0.00119	0.00031	P2136	...	...	...	-9	-4
347	5 35 39.8	-4 25 10	0.00504	0.00063	P2128	...	...	89	4	3
348	5 35 39.9	-4 46 01	0.00409	0.00047	P2137	...	OO	...	-4	-6
349	5 35 40.1	-4 51 38	0.00593	0.00057	P2140	...	...	...	1	3
350	5 35 40.5	-4 48 33	0.00320	0.00048	P2145	...	...	97	-9	-3
351	5 35 40.5	-4 57 28	0.00405	0.00066	P2142	...	...	...	9	3
352	5 35 40.8	-4 33 30	0.00149	0.00031	A5551	...	...	...	3	-3
353	5 35 41.2	-5 09 00	0.00299	0.00046	P2148	JW949	V363	91	7	1
354	5 35 42.0	-5 28 16	0.01620	0.00062	P2167	JW959	AN	97	0	-3
355	5 35 42.2	-5 27 32	0.00098	0.00022	P2175	JW962	OQ	99	-3	2
356	5 35 42.6	-5 11 56	0.00139	0.00030	P2173	JW961	...	98	-1	-1
357	5 35 42.8	-5 36 32	0.00558	0.00052	P2185	JW971	OR	89	-6	-3
358	5 35 43.3	-5 32 48	0.00128	0.00031	P2184	JW972	V570	99	-1	-3
359	5 35 43.4	-4 24 51	0.00928	0.00084	P2152	...	BO	80	6	5
360	5 35 43.4	-5 09 20	0.00416	0.00040	P2172	JW968	V569	0	3	-3
361	5 35 45.0	-5 07 18	0.00956	0.00056	P2181	...	V500	89	3	-1
362	5 35 45.5	-5 28 24	0.00133	0.00025	...	JW984	...	97	-1	-1
363	5 35 47.7	-5 22 53	0.00320	0.00031	P2209	JW998	V427	99	4	-3
364	5 35 48.0	-5 10 36	0.01351	0.00059	P2216	JW999	...	36	4	-5
365	5 35 48.1	-5 32 00	0.00128	0.00031	...	JW1004	...	99	0	-4
366	5 35 49.2	-5 35 28	0.00209	0.00043	P2235	JW1008	V947	91	-4	-1
367	5 35 51.3	-5 07 14	0.00566	0.00077	P2243	...	V575	27	3	-5
368	5 35 51.5	-5 15 11	0.00099	0.00030	P2245	JW1017	V379	87	7	-2
369	5 35 51.7	-5 08 12	0.00867	0.00056	P2244	...	...	83	1	-3
370	5 35 52.2	-5 28 52	0.00257	0.00033	P2253	JW1020	AQ	99	3	-5
371	5 35 52.9	-5 05 08	0.00453	0.00068	P2252	...	V815	99	4	-3
372	5 35 52.9	-5 13 04	0.00109	0.00036	P2258	JW1021	OV	67	3	-5
373	5 35 53.0	-4 30 05	0.01315	0.00080	P2240	...	...	85	1	2

TABLE 2—Continued

X-Ray Number (1)	Source Position (J2000)		Count Rate (counts s ⁻¹) (4)	Count Rate Error (counts s ⁻¹) (5)	Optical Candidate			Mem. Prob. (9)	Offset	
	R.A. (2)	Decl. (3)			Par. (6)	J&W (7)	Var. (8)		$\Delta\alpha$ (10)	$\Delta\delta$ (11)
374	5 35 53.2	-4 47 35	0.00174	0.00046	P2251	...	...	84	-3	3
375	5 35 54.3	-4 48 09	0.01280	0.00082	P2257	...	...	86	-1	-5
376	5 35 54.4	-5 04 14	0.01242	0.00109	P2263	...	AR	95	6	1
377	5 35 54.8	-5 27 12	0.00091	0.00026	P2270	JW1030	OX	99	3	-4
378	5 35 54.9	-4 58 07	0.01707	0.00130	P2261	...	...	92	6	1
379	5 35 56.5	-4 56 52	0.00249	0.00066	P2268	...	...	89	7	3
380	5 35 57.8	-4 39 14	0.00117	0.00035	P2274	...	...	...	4	-6
381	5 35 59.7	-5 29 49	0.00083	0.00026	...	*	...	...	...	...
382	5 36 02.3	-5 17 36	0.00383	0.00041	P2305	JW1049	V578	97	7	1
383	5 36 02.6	-5 07 48	0.00239	0.00061	P2304	...	...	...	3	-9
384	5 36 05.0	-5 09 28	0.00621	0.00071	P2318	...	V655	0	9	1
385	5 36 10.4	-5 22 08	0.00423	0.00044	...	...	V391	...	6	-3
386	5 36 10.6	-5 19 48	0.00278	0.00043	P2347	...	V502	68	3	-3
387	5 36 14.4	-4 35 56	0.00212	0.00060	P2352	...	...	0	-3	-9
388	5 36 17.0	-5 11 43	0.00322	0.00073	P2368	...	AZ	89	1	-1
389	5 36 18.9	-5 05 10	0.00396	0.00105	P2372	...	V1075	92	6	-5

* Indicates multiple candidate optical counterparts. See Table 3.

Analysis Software System (SASS, *ROSAT*'s standard pipeline software), and the second is a "local detect" task provided with the PROS/IRAF software suite (PROS is distributed by the Harvard-Smithsonian Center for Astrophysics; IRAF is distributed by the National Optical Astronomy Observatories). Both algorithms use a maximum-likelihood estimator to determine best source positions. Source positions from the two lists are compared, and a merged list is created. This initial list serves as a starting point for our visual image analysis. For each potential source, either detected by one of the two automated routines or determined visually to be a region of enhanced emission, counts falling within a source circle and a concentric background annulus are determined.

We use 90% power-radius source circles and approximate the point response function of the telescope, the HRI detector, and the aspect solution using

$$r_{90} \sim 2.58r_{50} \sim 2.58 \frac{2.35}{2} [16.7 + (1.3 + 0.0205\theta^{2.35})^2]^{1/2}, \quad (1)$$

where r_{50} is the 50% power radius in arcseconds and θ is the off-axis angle in arcminutes (David et al. 1992).

In order not to overestimate the contribution of the local background by including counts from nearby sources, source regions are masked from the background statistics. In order to avoid overlapping source circles, i.e., incorrectly including counts in source cells as a result of other nearby sources, source regions have been adjusted using an algorithm which divides the overlap region equally between adjoining sources. Counts (B) falling within the background annulus (masked from nearby sources with area A_B) are scaled to the area of the source circle (A_S) and subtracted from the total counts (T) in the source cell, to give the net source counts (S). The 1σ error in the estimate of the net source counts is

$$\sigma_S = \left[T + \left(\frac{A_S}{A_B} \right)^2 B \right]^{1/2}. \quad (2)$$

The detection criterion we adopt is a signal-to-noise ratio $S/\sigma_S \geq 3.0$. Each potential source in the initial list is analyzed in this way, and a new source list for each image is produced. This new list is inspected visually: detected source positions are corrected when not centered on the emission peak and undetected regions of apparently enhanced emission are added to this list. A new background mask is generated, and net source counts and errors are reevaluated as before, with only 3σ sources being retained for the final source list.

The net source count rates and errors are calculated using the image live time and corrected for the off-axis decrease in telescope sensitivity using a vignetting function based on 1 keV photon calibration data,

$$f_{\text{vig}}(\theta) = 1.001 - 0.00149\theta - 0.000307\theta^2, \quad (3)$$

where the off-axis angle θ is expressed in arcminutes. It should be noted that out to $19'$, the vignetting correction is less than 15% at photon energies around 1 keV.

In this way, a total of 67, 60, and 297 X-ray sources have been detected in the north, central, and south images, respectively. Detections made in regions of image overlap and with position offsets of less than $\sim 8''$ have been considered to be a single X-ray source after visual verification of the HRI images. In those cases where a source has been detected in more than one field, the coordinates of the most on-axis detection have been assigned to the X-ray source. For each source detected in more than one image, an error-weighted mean count rate has been determined. In this manner we have derived positions, count rates, and errors for 389 distinct X-ray sources in the approximately 0.8 deg^2 *ROSAT* HRI survey region.

With the high spatial resolution of the HRI, particularly on-axis, and the long exposure time of the south (Trapezium) field, we have attempted to deconvolve X-ray emission from the five brightest components of θ^1 Ori. In the process of trying to achieve the best possible image resolution, we noticed that during two orbits the X-ray source positions were offset by approximately $2''.5$ in a northeast-southwest direction. We believe the offset was attributable to errors in the telescope

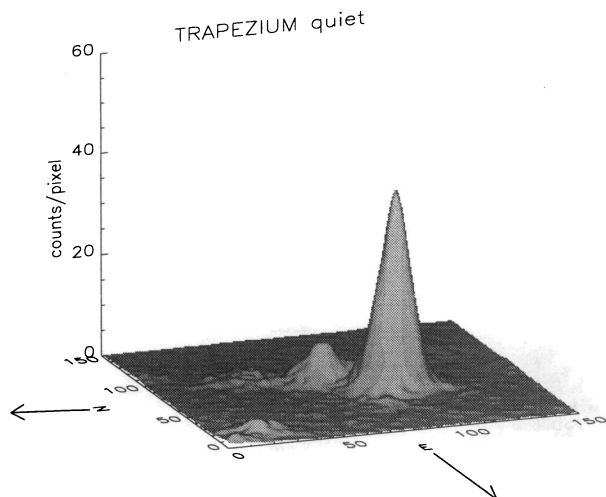


FIG. 3a

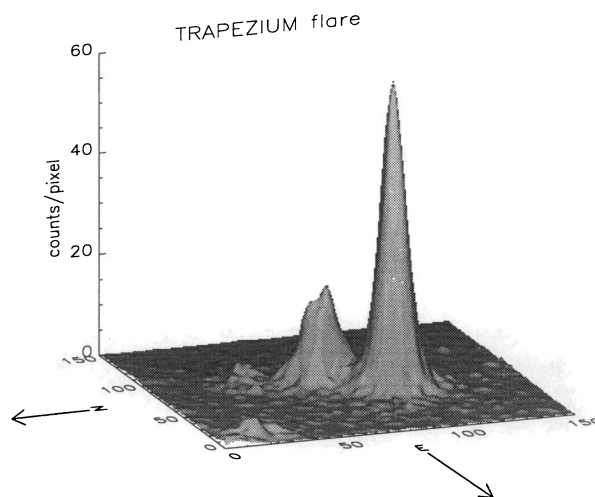


FIG. 3b

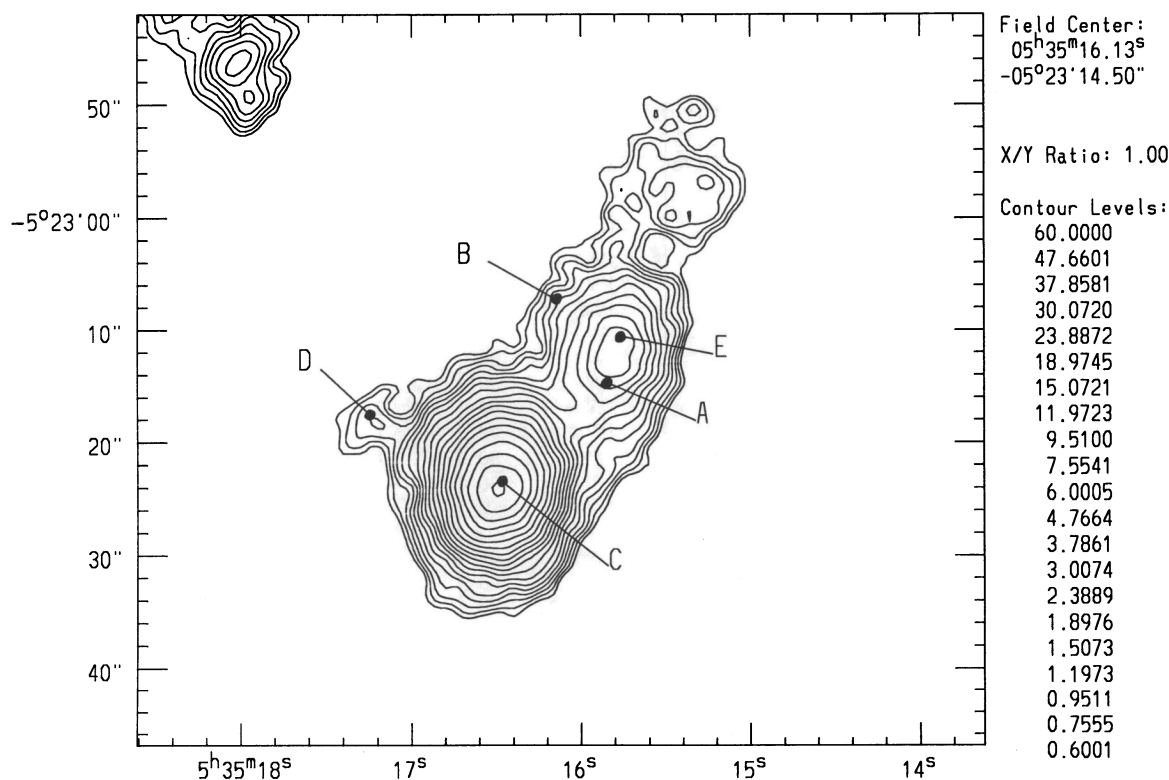


FIG. 3c

FIG. 3.— $1' \times 1'$ region centered on the Trapezium, Gaussian-smoothed with $\sigma = 1''$. The *ROSAT* HRI light curve for the blended source 176/177 indicated a strong X-ray flare on 1992 September 15. The photon events have been time-separated to create a quiet image and a flare image, normalized to the exposure time of the quiet image. Shaded surface plots of (a) the quiet image and (b) the flare image. The flare appears to be associated with the southernmost component of the blended source (176/177). (c) Contour plot of the quiet image indicating the optical positions of the five brightest components of θ^1 Ori. Optically, C is the brightest component, followed by A, D, B, and E.

aspect solution during those times, and the data have been corrected. We also detected a strong flare near source 176 (see Fig. 2d and the corresponding X-ray light curve, Fig. 11g). We have separated the photon events to create two images of θ^1 Ori: Figures 3a and 3b are shaded surface plots of the inner $75''$ of the Trapezium during quiescence and flare, respectively. Figure 3c is a contour plot of the quiescent image with optical star positions overlaid. The flare image has been normalized to

the exposure time of the quiescent image, and all three images have been smoothed with $\sigma = 1''$.

The brightest source is θ^1 C Ori, and visible to the northwest of it in Figure 3 is a strong, blended source. The flare is clearly visible in Figure 3b; it appears to be associated with the southern component of the blended source, source 177. Both X-ray peaks are very close to θ^1 E Ori and θ^1 A Ori, and, given the uncertainty both in the X-ray positions ($\gtrsim 2''$) and in the

optical position of θ^1 E Ori ($\sim 1''$), we do not know how much, if any, of the X-ray emission is attributable to either star. Consequently, we list both sources in Table 3. We have derived approximate count rates for sources 176 and 177 by scaling the total blended count rate by the relative counts in the inner $2''$ radius core of each peak. Also resolved is θ^1 D Ori, $\sim 13''$ to the east-northeast of θ^1 C Ori. Because of the limited spatial resolution of the HRI and the presence of the strong, blended

sources 176 and 177, we cannot assign any emission to the B0 V star θ^1 B Ori.

Also apparent in Figure 3 is an enhancement in the emission from θ^1 C Ori. The light curves for this source are presented in Paper II. During 1991 October and 1992 March, its count rate was nearly constant, $\sim 0.29 \pm 0.03$ counts s^{-1} . In 1992 September its count rate remained nearly constant, however, at $\sim 0.45 \pm 0.05$ counts s^{-1} . We have examined the possibility

TABLE 3
X-RAY SOURCES WITH MULTIPLE CANDIDATE OPTICAL COUNTERPARTS

X-Ray Number (1)	Optical Candidate			Offset		Optical Candidate			Offset		Optical Candidate			Offset	
	Par. (2)	J&W (3)	Mem. Prob. (4)	$\Delta\alpha$	$\Delta\delta$ (5)	Par. (6)	J&W (7)	Mem. Prob. (8)	$\Delta\alpha$	$\Delta\delta$ (9)	Par. (10)	J&W (11)	Mem. Prob. (12)	$\Delta\alpha$	$\Delta\delta$ (13)
30	P1542	JW47	96	-7"	7"	...	JW49	99	-9"	4"	...	...	...	...	...
53	P1599	...	51	-1	4	P1603	...	...	0	8	...	...	...	...	...
67	...	JW137	99	-1	1	...	JW136	99	-1	3	...	...	...	...	...
75	...	JW155	99	1	9	...	JW158	99	-4	-2	...	...	...	...	...
84	...	JW187	99	1	3	...	JW184	99	8	2	...	...	...	...	...
88	P1685	JW197	99	1	-3	...	JW198	99	-3	-5	...	...	...	...	...
90	P1694	JW206	98	0	0	...	JW201	99	3	4	...	JW212	99	-6"	4"
92	P1704	JW220	99	0	2	...	JW214	99	6	2	...	...	...	...	...
96	P1701	...	92	-3	-3	P1702	...	...	-3	-3	...	...	...	...	...
101	P1726	JW252	99	-3	6	P1739	JW256	99	-6	4	...	...	...	...	...
108	...	JW267	97	3	3	P1746	JW273	99	0	1	...	...	...	...	...
110	...	JW281	99	1	-4	...	JW283	99	0	3	...	JW290	99	-7	-1
111	...	JW286	99	1	2	...	JW287	99	0	7	...	...	...	...	...
114	...	JW300	99	1	1	...	JW302	99	0	3	...	...	...	...	...
126	...	JW332	99	4	-2	...	JW336	99	4	1	...	...	...	...	...
128	P1783	JW345	88	0	1	...	JW350	...	-1	0	...	...	...	...	...
141	...	JW370	99	3	1	...	JW374	...	0	0	...	...	...	...	...
147	...	JW389	89	3	-4	...	JW390	99	3	0	P1806	JW391	99	1	4
148	P1827	JW421	99	-7	2	...	JW416	99	-6	-7	...	...	...	...	...
156	...	JW406	99	4	-4	...	JW408	99	3	3	...	...	...	...	...
163	P1839	JW448	99	1	0	...	JW452	99	-1	-2	...	...	...	...	...
169	P1841	JW463	99	1	-1	P1842	JW468	99	1	1	...	...	...	...	...
176	P1865	θ^1 A	99	0	5	P1864	θ^1 E	96	1	1	...	...	...	...	...
177	P1865	θ^1 A	99	1	2	P1864	θ^1 E	96	2	-3	...	...	...	...	...
178	P1869	JW499	99	1	-1	P1870	JW503	0	1	2	...	...	...	...	...
182	...	JW497	99	6	2	...	JW506	...	3	3	...	...	...	...	...
186	P1896	JW526	98	0	0	...	JW521	85	3	1	...	...	...	...	...
190	P1854	...	95	-1	-2	P1855	...	...	0	5	...	...	...	...	...
194	...	JW551	99	1	-1	...	JW557	99	-1	-3	P1914	...	...	-4	-1
202	...	JW588	88	1	-2	H24	...	...	-1	0	...	...	...	...	...
204	P1906	JW585	99	3	3	...	JW574	99	6	0	...	JW593	99	1	1
206	P1922	JW595	99	3	1	...	JW602	...	0	-2	...	...	...	...	...
216	P1963	JW647	99	-4	0	...	JW628	99	3	-1	...	...	...	...	...
220	...	JW627	...	3	1	...	JW629	99	3	4	...	...	...	...	...
229	P1961	JW669	99	3	-1	...	JW681	99	-3	-4	...	...	...	...	...
234	P1975	JW683	99	0	-2	...	JW695	99	-4	-2	...	...	...	...	...
247	...	JW703	97	1	5	...	JW708	98	0	1	...	...	...	...	...
261	P1989	JW733	99	6	2	...	JW736	99	0	8	...	JW739	99	0	-9
262	...	JW738	99	3	-1	...	JW744	99	0	1	...	...	...	...	...
264	P2000	JW749	98	-1	0	...	JW754	99	-4	0	...	...	...	...	...
266	P2008	JW769	96	0	-2	P2009	JW768	99	0	6	...	...	...	...	...
269	P2022	JW787	99	-1	-3	...	JW784	...	0	-4	...	...	...	...	...
273	P2004	...	...	9	-1	...	JW774	80	6	-1	...	JW780	97	3	-2
277	P2020	JW790	94	1	0	...	JW785	98	4	-2	...	...	...	...	...
289	...	JW811	99	7	5	...	JW819	99	0	-7	...	...	...	...	...
302	P2077	JW850	99	3	-2	...	JW865	99	-6	3	...	...	...	...	...
305	P2076	JW852	99	3	-2	...	JW859	99	0	7	...	...	...	...	...
326	...	JW891	99	9	4	...	JW894	99	4	-1	...	...	...	...	...
330	P2111	JW911	99	1	-2	...	JW909	...	3	-5	...	...	...	...	...
335	P2134	JW926	97	-4	-2	...	JW927	99	-6	3	...	...	...	...	...
341	...	JW934	99	1	1	...	JW936	99	-1	2	...	...	...	...	...
381	...	JW1043	...	3	-5	...	JW1044	...	3	-4	...	JW1045	...	0	-5

that the observed variation may be the result of changes in the sensitivity of the HRI in the $11\frac{1}{2}$ month period between the first and third exposures of the south field. We have determined count rates for the ~ 180 sources with count rates $\geq 8 \times 10^{-4}$ counts s^{-1} detected in both the first and the third exposures, excluding the four brightest sources, i.e., those associated with P1724, θ^1 C Ori, θ^1 A Ori, and θ^1 E Ori. A linear regression on the count rates from the two exposures shows a systematic $7\% \pm 4\%$ count rate enhancement from the third exposure compared to the first. Similarly, the median count rates from the two exposures suggest an $\sim 10\%$ enhancement in the third exposure over the first. There is no evidence of detector gain variations either from the data stream or from the *ROSAT* short-term time line of observations on or before 1992 September 15. The count rates have not been corrected for quantum efficiency variations across the face of the detector. However, these variations are typically $\lesssim 5\%$ and do not exceed 10% (David et al. 1992). In any case, spatial variations in the detector quantum efficiency would not lead to a systematic change in count rates from a large sample of sources from different exposures. Since the third exposure represents less than two-fifths of the total 47 ks south exposure, the error in the count rate due to this enhancement is $\lesssim 4\%$ and is small compared to the statistical uncertainty in the count rate. Hence, we have not corrected for either possible quantum efficiency variations or the apparent count rate enhancement in the third exposure.

4. RESULTS

The positions of the detected X-ray sources have been compared to those of the more than 1500 stars in our optical database. Our search algorithm uses a variable search circle radius because of uncertainties in both the X-ray position (typically $\sim 8''$) and optical position (in the range $1''$ – $15''$). Since the density of stars within $5'$ of the Trapezium is high, X-ray contour diagrams were overlaid on the stellar finding charts of Parenago (1954) and Jones & Walker (1988) to determine the most likely optical counterpart in this region. Outside the core of the Trapezium cluster, all optical stars within the X-ray search radii were retained as candidate optical counterparts.

In columns (1)–(5) of Table 2, we list the X-ray source number, the right ascension and declination (J2000) of the best X-ray position, the corrected *ROSAT* HRI count rate, and the corresponding 1σ error. Columns (6)–(8) list the Parenago (1954), Jones & Walker (1988), and variable star designation (when applicable) of the candidate optical counterpart. In 52 cases, more than one optical candidate has been found; these sources are noted with asterisks (see Table 3). For the 324 sources with a single optical counterpart, the proper-motion membership probability and X-ray–optical right ascension and declination offsets (in arcseconds) are listed in columns (9)–(11). For the 52 sources with more than one candidate optical counterpart, we list in Table 3 the X-ray source number and the Parenago (1954) and Jones & Walker (1988) designations, membership probability, and right ascension and declination offsets of each candidate. Since the observed X-rays cannot be attributed to any one star, the count rate for that source (listed in Table 2) is considered an upper limit to each candidate's true count rate.

Table 4 presents a summary of the *ROSAT* HRI source identifications. Nearly 70% of detected sources are identified with a single, probable cluster member, while less than 4% have no candidate optical counterpart. Before we proceed, we must examine the meaningfulness of the X-ray to optical iden-

TABLE 4
IDENTIFICATION OF *ROSAT* HRI
SOURCES

Single optical counterpart:	
Members	261
Nonmembers	28
Unknown membership	35
Multiple optical counterparts	52
No optical counterpart	13
Total sources	389

tifications, particularly given the high density of stars in the survey region. In § 2 we addressed the question of completeness of the optical catalog for the purpose of identifying X-ray sources and concluded that, given the limiting X-ray flux of these observations, most stellar X-ray sources would be included in our optical database. Now we consider the reliability of the identifications listed in Table 2 and summarized in Table 4. In Paper I we simulated a sample of HRI source positions with the same spatial distribution as the sample of sources detected by the *Einstein* HRI by simply shifting the detected source positions $2'$ in right ascension and $2'$ in declination. More than 90% of the simulated positions have no optical counterpart within $8''$, with the number of random identifications increasing with increasing offset. Thus, we concluded in Paper I the HRI source identifications based on position offset $\lesssim 8''$ are probably reliable, while those based on larger offsets may be chance identifications.

The distribution of sources in the *ROSAT* HRI and *Einstein* HRI surveys are very similar, with the highest concentration of sources near the Trapezium and with most sources within the Jones & Walker (1988) survey area. Since the spatial resolution of the HRI is essentially the same on both observatories, we consider *ROSAT* identifications based on position offsets $\lesssim 8''$ to be reliable. Of the 326 sources detected by *ROSAT* with one candidate optical counterpart, only six have position offsets greater than $8''$, and none have offsets greater than $10''$. We conclude that most of the identifications in Table 2 are correct. However, because position uncertainties of up to $15''$ still exist for some stars, we feel we cannot eliminate candidates with large position offsets.

In Table 5 we present a breakdown of the cluster members by spectral type. Of the nearly 1100 stars with membership probability $\geq 50\%$ observed by the *ROSAT* HRI, only 147 have spectral classifications. As discussed in § 5, this dearth of optical information for the low-mass cluster population represents the greatest obstacle in interpreting these X-ray data. Roughly two-thirds of the X-ray–detected cluster members do not have measured spectral types, and, as a result, mass, effective temperature, or bolometric luminosity cannot be estimated for these stars. The distribution of V and I_C stellar magnitudes for typed and untyped stars (see Paper I) suggests that, of the 860 cataloged, untyped cluster members, fewer than 20 are in the spectral range O6–G5. That is, virtually all the untyped cluster members are late G-, K-, and M-type pre-main-sequence stars with mass $M \lesssim 2 M_\odot$. From Table 5 we thus see that as many as 247 (nearly 95%) of the 261 X-ray–detected cluster stars may be F6–M5 PMS stars.

Also indicated in Table 5 is the breakdown of “additional” stars, cluster members listed in Table 3 as one of multiple optical candidates. As stated above, these stars are not considered detected because we cannot assign X-ray emission to

TABLE 5
BREAKDOWN OF THE ORION NEBULA CLUSTER MEMBERS

Spectral Type	Number Observed	Number Detected	Additional Stars ^a	Detection Fraction
O6-B5	18	10	1	0.56
B6-A5	25	4	1	0.16
A6-F5	3	0	0	0.00
F6-G5	10	8	3	0.80
G6-K5	46	37	3	0.77
K6-M5	36	25	1	0.69
Untyped	860	177	84	0.21

^a Stars associated with sources with multiple candidate optical counterparts (see Table 3). These stars have not been included in the number observed or detected.

any one star; hence, these stars do not enter into our calculation of the X-ray detection fraction in Table 5. Over three-fourths of the known F6–M5 PMS stars are detected by *ROSAT*, a significant improvement over the two-fifths detected by *Einstein* (Paper I). Of particular note is that at least eight of 10 late F to early G stars were detected by *ROSAT*, whereas only three of the same 10 were detected by *Einstein*. Overall, only ~14% of the F6–G5 cluster stars observed in the *Einstein Observatory* survey of the Orion Nebula were detected.

Among the untyped stars, the *ROSAT* detection fraction is roughly $\frac{1}{3}$ as compared with less than $\frac{1}{20}$ for *Einstein*. When compared with the known late-type members, the substantially lower detection fraction of untyped members can be understood if we consider the mean stellar magnitudes of the typed and untyped stars. For example, among the members in the Jones & Walker (1988) sample, the known late-type stars have $\bar{I}_C \sim 11.2$ mag, whereas the untyped stars have $\bar{I}_C \sim 13.9$ mag. Assuming a similar distribution of ratios of X-ray to optical flux among the typed and untyped cluster stars, we expect many more optically bright stars to be detected, and, consequently, we expect many more typed stars to be detected.

We have divided the catalog of cluster stars observed by the HRI into two groups: group 1 consists of cluster stars with measured spectral type, spectroscopic rotational velocity, or spot-modulated photometric rotational period, while group 2 consists of all other cluster members. Since the stars in group 2 are so numerous (more than 900), we do not derive count rate upper limits for the undetected stars, nor do we present X-ray luminosities for the detected stars. Since the count rates in Table 2 have been corrected for vignetting, they can be used to derive approximate X-ray luminosities for the cluster members using an appropriate conversion factor. If we assume a cluster distance of 440 pc, an incident 1 keV Raymond & Smith (1977) thermal spectrum, and a moderate hydrogen column density $N_H \sim 5 \times 10^{20} \text{ cm}^{-2}$, ground and in-flight calibrations of the HRI imply a count rate to luminosity conversion factor of $\sim 2.6 \times 10^{33} \text{ ergs s}^{-1} (\text{counts s}^{-1})^{-1}$. For a column density $N_H \sim 5 \times 10^{21} \text{ cm}^{-2}$, the conversion factor is $\sim 7.9 \times 10^{33} \text{ ergs s}^{-1} (\text{counts s}^{-1})^{-1}$. Direct extinction measurements are not available for the majority of these sources; however, for most sources away from the bright nebular emission near the Trapezium, the lower column density is more appropriate (cf. Warren & Hesser 1977; O'Dell et al. 1992).

X-ray and optical data for the group 1 stars are presented in Table 6. Column (1) lists the primary designation of the star (see Table 2 for alternative designations), and column (2) lists the X-ray source number if detected. Columns (3) and (4) list the spectral type and corresponding T_{eff} , with uncertain spec-

tral types and effective temperatures denoted with a colon. We have used the PMS effective temperature scale of Cohen & Kuhn (1979). Columns (5)–(7) list the BVI_C stellar magnitudes. Photometric magnitudes are quoted to two decimal places; photographic magnitudes are quoted to a single decimal place. When accurate absorption values are available from published estimates, photometric $E(B-V)$ measurements, or the C_{HB} extinction map of the nebula, they are listed in column (8). Otherwise we assume moderate absorption ($A_V \sim 0.25$ mag) and indicate the value in parentheses. Spectroscopic rotational velocity and rotational period are listed in columns (9) and (10), respectively. The notes in column (13) describe the sources of the optical data. Listed in columns (11) and (12) are $\log L_X$ and $\log (L_X/L_{\text{bol}})$.

We have used the visual absorption values in Table 6 and assumed a constant conversion to hydrogen column density of $2 \times 10^{21} \text{ cm}^{-2}$ per magnitude of absorption (O'Dell et al. 1992) to derive a count rate to flux conversion factor for each star. For stars not identified as candidate optical counterparts in Table 2 or Table 3, we have derived 3σ count rate upper limits by determining a net error σ_S in the same manner described in § 3. For a handful of sources in the Trapezium region, a star has been eliminated as a candidate optical counterpart despite being within the source search circle because a more likely counterpart had a smaller position offset. In these cases, we have chosen half the source count rate or 3σ , whichever is highest, as the upper limit for that source. These stars are noted (with footnote N) in Table 6.

Statistical uncertainties in our estimate of $\log L_X$ scale as the Poisson error in the corrected count rate listed in Table 2 and are typically less than 0.1 in the log. The X-ray count rate to flux conversion factor is a greater source of uncertainty because of the wide range of hydrogen column densities: from the nominal interstellar value of $N_H \sim 4 \times 10^{20} \text{ cm}^{-2}$ for unembedded cluster members to $N_H \sim 10^{22} \text{ cm}^{-2}$ for the most deeply embedded stars. In this N_H range, the flux conversion factor increases by a factor of 6. For example, an absorption uncertainty in absorption of 0.5 mag. In this case, $\Delta \log L_{\text{bol}} \sim 0.25$. In the case of deeply embedded stars or stars with heavily veiled spectra, $\Delta \log L_{\text{bol}}$ could reach ~ 0.6 . The values in Table 6 are thus our best, albeit crude, estimates of $\log L_X$ and $\log L_{\text{bol}}$.

Errors in our estimates of L_{bol} stem from optical variability (about one-third of the late-type cluster members are variable), uncertain adsorption corrections, uncertain spectral classifications, and unknown infrared and ultraviolet excesses. To illustrate, we consider a mid-K-type variable star ($\Delta V \sim 0.2$) with a spectral-type uncertainty of two subclasses, and an uncertainty in absorption of 0.5 mag. In this case, $\Delta \log L_{\text{bol}} \sim 0.25$. In the case of deeply embedded stars or stars with heavily veiled spectra, $\Delta \log L_{\text{bol}}$ could reach ~ 0.6 . The values in Table 6 are thus our best, albeit crude, estimates of $\log L_X$ and $\log L_{\text{bol}}$.

We use $\log (L_X/L_{\text{bol}})$ as an X-ray activity indicator throughout this section, and we consider the effect of uncertainties in A_V on this ratio. We have performed a quadratic fit to the HRI flux conversion factors in the *ROSAT* Mission Description (1991) for an incident 1 keV Raymond & Smith (1977) spectrum as a function of N_H . Following Chlebowski et al. (1989), we plot the change in $\log (L_X/L_{\text{bol}})$ against A_V in Figure 4. We have assumed the same absorption to hydrogen column density conversion factor as above and have chosen the zero point to correspond to $N_H = 5 \times 10^{20} \text{ cm}^{-2}$, corresponding to our nominal value $A_V = 0.25$ mag. From Figure 4, we see that

TABLE 6
OPTICAL AND X-RAY DATA FOR GROUP I STARS

Star Name (1)	X-ray Num (2)	Spectral Type (3)	$\log T_{\text{eff}}$ (K) (4)	B (mag) (5)	V (mag) (6)	I_C (mag) (7)	A_V (mag) (8)	$v \sin i$ (km s ⁻¹) (9)	P_{rot} (days) (10)	$\log L_X$ (ergs s ⁻¹) (11)	$\log \frac{L_X}{L_{\text{bol}}}$ (12)	Notes (13)	
P1322		...	G8	3.736	12.55	11.70	...	(0.25)	70	...	<30.03	< -4.37	afuH
P1360		...	G8V:	3.736:	14.82	13.90	...	0.56	15	...	<30.54	< -3.01:	dktI
P1374		4	F6IV	3.798	10.31	9.75	...	(0.25)	77	...	30.72	-4.09	afuH
P1379		...	...	...	13.69	12.90	...	(0.25)	23	...	<30.36	...	atI
P1393		5	K0	3.719	13.02	12.16	...	(0.25)	<20	...	31.03	-3.04	afuI
P1391		...	F6IV	3.788	11.12	10.63	...	(0.25)	<20	...	<30.81	< -3.83	afuH
P1408		7	K5	3.643	13.65	14.40	...	(0.25)	21	...	30.89	-2.51	afuH
P1409		8	G4Ve	3.719	12.44	11.60	10.59	0.57	29	1.50	30.92	-3.46	afwGH
P1425		12	G7	3.742	12.91	12.00	...	(0.25)	26	...	30.91	-3.47	aftH
P1440		13	K0Ve	3.643	13.65	12.70	...	(0.25)	<20	...	31.44	-2.62	afuH
P1455		14	G0V	3.778	10.89	10.25	...	0.12	21	...	30.64	-3.97	afuH
P1477		17	K5Ve(SB)	3.643	14.9	14.0	12.6	(0.25)	...	...	30.65	-2.91:	bgty
P1491		23	B8V	4.025	7.36	7.43	...	0.09	...	...	30.59	-5.42	afo
P1510		25	K2	3.695	13.65	12.40	10.9	(0.25)	38	...	31.19	-3.29	bfuyH
P1507		...	A7Vm	3.917	10.06	9.90	...	(0.25)	136	...	<30.45	< -4.46	afoH
P1518		27	K2IV	3.695	14.6	13.8	11.8	(0.25)	38	...	30.61	-2.91	bgtyH
P1505		28	K2	3.695	13.65	12.78	...	(0.25)	<20	...	30.99	-2.86	aftH
P1541		31	K0IVe	3.710	13.57	12.58	11.30	(0.25)	<20	...	30.97	-3.16	bfotyH
P1539		...	B8	4.053	11.43	10.73	9.30	2.39	250	...	<30.45	< -5.26	bfvyH
P1553		32	K2e:	3.695:	13.76	12.40	...	(0.25)	28	...	31.25	-3.36:	afuH
P1552		34	Ke	...	14.72	13.72	12.5	0.49	15	...	30.27	...	bptyH
P1562		...	A0V	3.993	9.71	9.70	...	0.22	200	...	<30.35	< -4.91	afuH
P1563		36	M1e:	3.566:	15.2	13.8	11.7	(0.25)	<20	...	30.59	-3.31:	bjuy
P1587		43	K2	3.695	14.44	12.60	11.4	0.35	<20	...	31.30	-3.16	bfyuH
P1605		49	B9.5+A0.5	3.933	8.11	7.94	7.42	0.50	127	...	30.26	-5.46	ahlH
P1623		...	A2Vp	3.930	10.13	9.56	9.30	0.58	171	...	<29.79	< -5.58	dhuyzH
P1648		68	K5e	3.643	...	13.9	...	0.24	...	...	30.65	-2.94	dm
JW145		...	...	...	...	14.40	0.51	...	12.15	<29.81	...	...	byE
P1660		...	B8-B9V	4.053	8.98	9.00	9.10	0.47	275	...	<29.92	< -5.59	bfoyH
P1659		74	K1	3.695	...	12.0	10.5	0.52	<20	17.25	31.48	-3.26	bfyEH
P1654		...	B8	4.025	8.56	8.58	...	0.54	...	...	<30.08	< -5.53	afoH
P1665		78	K6e	3.623	14.21	13.60	12.3	(0.25)	...	...	30.87	-2.89:	bmuy
P1664		...	B5V	4.253	7.46	7.59	...	(0.25)	...	...	<30.50	< -6.15	afo
JW191		...	M4	3.509	...	...	14.2	0.68	...	4.33	<29.81	< -3.22:	beyD
P1671		...	A7V	3.917	9.91	9.65	...	(0.25)	...	...	<29.94	< -5.19	afo
P1684		87	K6e	3.623	...	13.5	12.0	0.60	...	...	30.45	-3.32	bmy
P1685		88	A1Vn+Am	4.025	10.32	10.17	10.1	0.70	201	...	30.38	-4.79	bhnyH
P1683		...	A1	3.980	9.79	9.73	...	0.97	...	...	<30.14	< -4.96	afo
P1712		97	B9	4.025	11.01	10.45	...	1.88	75	...	30.58	-5.00	afoH
P1698		...	A1V	3.980	8.93	8.87	...	0.09	...	...	<30.40	< -5.02	afo
P1725		98	M4:	3.509:	15.9	15.04	12.79	0.37	...	4.46	30.21	...	beBD
JW248		...	M3	3.526	...	...	13.4	0.82	...	6.86	<29.87	< -3.57:	beyE
P1708		...	B3V	4.140	7.25	7.34	...	(0.25)	...	...	<29.90	< -6.53	afn
P1736		106	G5	3.753	12.26	11.01	10.24	1.77	41	...	30.94	-4.21	bfwH
P1746		108	A0V+K0IVe	3.719	12.74	11.66	10.5	0.81	36	...	<30.86	...	bfyCHM
P1744		...	B4V	4.140	7.79	7.80	8.12	(0.25)	75	...	<30.03	< -6.15	ahuH
JW311		115	M5	3.494	...	...	14.4	0.43	...	6.14	29.92	-2.91:	beE
P1752		122	...	...	14.0	12.9	...	(0.25)	21	...	30.62	...	atH
P1773		120	K6	3.679	14.20	13.26	11.87	(0.25)	...	1.57	30.86	-3.05	betE
JW338		...	M3	3.526	...	...	14.1	0.61	...	6.62	<29.93	< -3.20:	beyD
P1772		123	B2V	4.290	8.55	8.45	7.92	0.65	80	...	30.11	-6.58	chvyH
P1760		...	K2-3e	3.679	...	14.2	...	(0.25)	...	...	<29.87	< -3.92	am
P1785		127	K0	3.719	...	11.9	11.5	1.05	<20	...	31.03	-3.35	bfyBH
P1782		129	M2:	3.544:	...	13.6	12.8	1.05	...	7.32	30.30	...	beyBF
P1784		130	K2-M1V:	...	...	12.46	10.36	1.03	...	7.99	31.76	...	bseF
P1799		138	K0IV-Vn	3.766	13.79	12.64	11.2	(0.25)	123	0.50	30.54	-3.95	bfyGH
JW373		140	K3	3.679	...	16.85	13.48	0.97	...	9.57	30.05	-4.17	beqF

TABLE 6—Continued

Star Name (1)	X-ray Num (2)	Spectral Type (3)	$\log T_{\text{eff}}$ (K) (4)	B (mag) (5)	V (mag) (6)	I_C (mag) (7)	A_V (mag) (8)	$v \sin i$ (km s ⁻¹) (9)	P_{rot} (days) (10)	$\log L_X$ (ergs s ⁻¹) (11)	$\log \frac{L_X}{L_{\text{bol}}}$ (12)	Notes (13)
JW379	...	...	...	...	...	14.4	(0.25)	...	5.65	<29.76	...	byE
P1808	142	...	...	...	15.00	12.89	1.07	...	9.01	30.84	...	bqF
P1807	142	K1V	3.708	...	12.64	11.02	1.01	...	...	<30.54	< -3.73	bqsN
JW383	...	...	...	...	...	14.1	(0.25)	...	7.14	<29.83	...	beyD
JW388	146	M1	3.566	...	16.32	13.68	1.70	...	9.08	30.53	-3.04	beE
P1828	144	K3e	3.680	13.58	12.44	...	0.69	29	...	31.11	-3.16	amlH
P1795	...	B9V	4.025	8.99	9.00	...	0.16	...	...	<29.90	< -5.55	afo
P1798	158	B3	4.253	7.67	7.85	...	2.78	50	...	31.19	-5.32	aouH
P1840	165	K7	3.602	...	13.96	11.86	1.53	...	8.69	30.81	-3.38	beqD
JW466	...	...	...	...	...	13.9	(0.25)	...	6.17	<30.15	...	byE
P1817	166	K2(SB)	3.695	12.09	11.16	10.60	0.32	35	...	31.68	-2.92	dgwH
P1862	169	...	...	...	12.77	10.97	1.52	...	8.74	<31.22	...	bqEN
P1864	176	G0-5+B5-8	3.771	...	11.4	...	(0.25)	...	...	<32.00	...	dpBC
P1865	177	O9V(SB)	4.531	6.75	6.73	6.19	1.68	135	...	<32.00	< -5.90	cfvH
P1869	178	G5:	3.753:	...	13.79	11.45	1.75	...	...	<30.98	< -3.06:	bsM
P1863	176	B0V+A7IV	4.490	8.17	7.95	8.00	1.68	320	...	<31.96	< -5.56:	civJ
P1891	184	O7V	4.580	5.13	5.14	4.72	1.68	140	...	32.66	-5.93	bnvyJ
P1856	...	K1e:	3.708:	12.05	11.06	...	1.08	...	...	<29.99	< -4.03:	bo
P1896	186	K6	3.623	...	13.77	11.87	1.59	...	1.68	<31.21	< -3.03	beqEM
P1892	184	B8	4.053	...	11.0	...	1.68	...	...	<32.36	< -3.00:	dpBN
P1885	...	A2	3.930	10.89	10.47	9.99	1.63	...	...	<29.93	< -5.22:	bnqs
P1854	190	A0	3.993	...	10.08	...	(0.25)	...	...	<30.11	< -4.72	doM
P1884	192	K7	3.602	...	13.04	10.82	0.84	...	3.43	30.58	-3.71	beqE
P1889	191	B0V	4.490	...	6.70	6.19	1.68	145	...	31.86	-6.16	civJ
P1852	...	...	...	13.76	12.60	...	(0.25)	<12	...	<29.99	...	auI
P1881	...	A0	3.993	10.2	9.8	...	1.24	...	...	<29.92	< -5.36	afu
JW571	...	...	...	...	...	14.3	(0.25)	...	2.50	<29.82	...	beyD
P1910	199	K3-4:	3.679:	...	11.39	9.66	1.60	...	8.53	31.42	-3.41:	beqF
P1905	...	A0IV	3.993	9.42	9.38	...	0.12	177	...	<30.10	< -5.15	afoH
P1925	203	M0:	3.593:	...	13.42	11.30	1.00	...	14.32	31.17	-3.11:	beqF
JW592	205	M4	3.509	...	...	14.2	(0.25)	...	7.80	29.83	-3.06:	beyD
P1922	206	F8n:	3.778:	...	12.23	10.56	1.32	...	...	<30.69	< -3.78:	bsM
P1921	211	K5	3.643	...	13.66	12.45	(0.25)	...	2.22	30.62	-3.08	beE
P1923	206	A5:	3.917:	13.20	11.89	11.25	1.25	125	...	<30.38	< -3.83:	bfsBHN
P1937	221	G0Vn:	3.771:	13.22	12.22	10.80	1.41	...	...	30.34	-4.17:	bsu
P1956	227	B2V:	4.253:	9.66	10.00	9.40	1.75	200	6.15	31.23	-5.13:	bfsxFH
JW664	231	K7:	3.602:	...	...	14.0	(0.25)	...	7.20	30.03	-3.01:	beyE
P1953	232	F9IV	3.766	11.32	10.60	8.8	0.36	31	...	30.66	-4.41	bfoyH
P1955	226	G0-2III:	3.736:	12.14	10.99	10.32	(0.25)	109	...	31.52	-3.50:	bfwH
P1977	235	K6e	3.623	...	15.4	13.0	0.82	...	...	31.66	-1.54	bmy
P1950	240	G8	3.736	13.14	...	...	(0.25)	27	...	31.04	-3.03:	afuH
JW695	234	...	...	...	...	14.3	0.87	...	11.53	<30.89	...	byEN
P1933	239	B2Vp	4.312	6.27	6.45	...	(0.25)	85	...	30.29	-6.94	aho
JW691	237	...	...	...	...	14.2	(0.25)	...	6.34	30.29	...	byE
P1972	249	K3	3.679	...	12.62	11.80	0.93	<20	...	30.21	-4.08	bsE
JW715	...	M5	3.494	...	...	14.3	(0.25)	...	4.46	<29.86	< -2.98:	beyD
P1990	...	M0	3.593	...	15.20	13.12	1.31	...	11.37	<29.96	< -3.81	beD
P1946	...	M0.5e	3.580	...	15.0	...	(0.25)	...	...	<30.04	< -3.43	dm
P1993	256	O9.5V(SB)	4.490	...	5.10	5.37	1.03	145	...	31.68	-6.67	chvJ
P1988	259	M0:	3.593:	...	14.04	12.31	(0.25)	...	7.63	30.67	-3.13:	beD
P2001	260	K0	3.719	13.57	13.57	11.3	(0.25)	<20	...	31.08	-2.66	bfvyD
JW758	...	M4	3.509	...	...	14.0	0.70	...	2.51	<29.85	< -3.27:	beyE
P2007	268	...	...	...	13.61	12.48	(0.25)	...	7.88	30.49	...	beD
JW789	...	...	...	...	...	14.3	(0.25)	...	3.26	<29.65	...	beyD
P2006	...	K0IV-V	3.719	13.88	12.88	12.10	0.60	28	...	<30.01	< -3.97	blpBI
JW786	...	M0	3.593	...	14.22	12.37	0.50	...	8.79	<29.84	< -3.99	beD
JW792	279	...	...	...	...	13.9	0.51	...	10.33	<29.99	...	byEN

TABLE 6—Continued

Star Name (1)	X-ray Num (2)	Spectral Type (3)	$\log T_{\text{eff}}$ (K) (4)	B (mag) (5)	V (mag) (6)	I_C (mag) (7)	A_V (mag) (8)	$v \sin i$ (km s ⁻¹) (9)	P_{rot} (days) (10)	$\log L_X$ (ergs s ⁻¹) (11)	$\log \frac{L_X}{L_{\text{bol}}}$ (12)	Notes (13)
P2020	277	K2	3.695	12.91	11.98	10.88	(0.25)	36	2.74	<31.16	< -3.12	befTEHM
P2033	274	K0	3.719	12.64	11.75	10.63	0.44	56	1.56	31.06	-3.32	beEH
P2032	279	G5	3.753	...	12.9	10.9	0.46	...	...	30.23	-3.65:	bjy
P2031	280	B1V	4.354	6.31	6.40	6.53	0.54	50	...	30.52	-6.92	cfvH
P2029	...	G3e:	3.758:	14.07	12.26	11.3	2.50	...	...	<30.14	< -4.80:	bly
P2047	285	M0	3.593	14.90	14.22	12.37	0.41	12	2.85	30.92	-2.88	beBH
JW815	286	...	...	...	...	13.9	(0.25)	...	6.45	30.31	...	byE
P2027	287	...	...	14.8	14.1	...	(0.25)	<15	...	30.49	...	atI
JW823	...	...	...	...	16.96	13.90	(0.25)	...	9.00	<29.73	...	beD
JW830	291	M4	3.509	...	...	13.4	0.43	...	9.26	30.31	-2.99:	beyE
P2058	...	B9.5V	3.993	9.60	9.55	9.6	0.31	170	...	<29.74	< -5.43	bfnyI
JW837	296	M1	3.566	...	15.07	13.19	(0.25)	...	10.32	30.55	-2.94	beE
P2057	294	K1IV-Ve	3.708	15.03	14.09	...	(0.25)	...	...	30.40	-2.98	dko
JW839	297	...	...	...	...	13.6	0.41	...	7.55	30.51	...	byE
JW843	...	...	...	...	...	13.8	(0.25)	...	10.88	<29.83	...	byD
P2069	298	K3	3.679	13.32	12.30	10.8	(0.25)	38	...	31.28	-2.90	bfuyH
JW842	...	...	...	...	...	13.8	(0.25)	...	8.56	<30.10	...	byE
JW848	301	...	...	...	...	13.9	0.31	...	4.93	30.08	...	byD
P2077	302	...	...	...	14.1	13.5	0.31	...	7.78	<29.99	...	byBDM
JW855	303	...	...	...	...	14.1	(0.25)	...	7.02	30.58	...	byE
JW860	306	M4:	3.509:	...	16.56	14.14	(0.25)	...	6.31	30.22	-2.98:	beE
JW863	304	...	...	...	16.62	14.14	(0.25)	...	7.95	30.02	...	beD
P2066	...	K7-M0Ve:	3.598:	16.26	14.99	...	0.58	...	...	<30.25	< -3.34:	dko
P2065	...	B8	4.025	9.07	9.08	...	(0.25)	180	...	<30.27	< -5.15	afoH
P2073	313	...	...	...	13.82	11.77	(0.25)	...	6.77	30.90	...	beyBE
P2074	314	B1V(SB)	4.312	7.10	6.84	6.21	2.30	225	...	30.58	-7.04	dhloH
P2085	315	B4V	4.140	...	8.20	8.02	0.37	50	...	30.85	-5.36	bfvyH
P2086	...	F2III-Ve	3.806	10.38	9.90	8.9	(0.25)	72	...	<29.93	< -4.98	bfoyH
P2084	318	K4-M0IVe	3.680	13.80	12.49	10.6	0.97	<20	...	30.73	-3.73	bfoyH
P2100	319	G9eIV-V	3.719	11.8	10.8	10.4	1.26	72	...	30.77	-3.64	bftyH
JW892	324	...	...	...	15.63	12.26	(0.25)	...	7.71	30.50	...	beD
P2083	...	B2Vp	4.200	7.17	7.32	...	(0.25)	50	...	<30.29	< -6.30	ajnuH
P2102	...	A0V	3.993	9.40	9.36	...	0.12	250	...	<29.97	< -5.28	ajoH
P2111	330	K4e	3.661	...	13.8	13.2	0.10	...	...	<30.34	< -2.96	bmyM
JW914	333	M3	3.526	16.5	...	13.4	(0.25)	...	7.71	30.30	-3.03:	beyD
P2118	...	A0V	3.980	10.11	10.00	9.6	0.34	400	...	<30.08	< -4.96	bfuyJ
P2143	...	M3e	3.526	15.07	13.95	11.9	(0.25)	...	...	<30.11	...	boy
P2148	353	M1:	3.566:	16.50	14.56	11.68	1.43	...	...	30.68	-3.43:	blyD
P2167	354	K1IVe	3.719	12.41	11.39	9.92	(0.25)	57	...	31.32	-3.36	bflH
P2152	359	K5ne	3.661	15.41	14.02	...	0.12	...	...	31.07	-2.86	ako
P2181	361	K2Ve:	3.695:	13.75	12.62	...	0.68	...	...	31.13	-3.03:	aou
P2203	...	K5e	3.643	...	16.2	...	1.22	...	...	<30.25	< -3.21	dm
P2248	...	F6IV	4.197	11.91	11.26	10.72	4.08	...	...	<30.60	< -5.37	ciw
P2247	...	A3Vep	3.930	11.24	10.82	9.4	0.99	140	...	<29.89	< -5.33	bfuyH
P2246	...	K5e	3.643	...	13.0	13.6	0.84	...	...	<30.03	< -4.16	bmy
P2245	368	K7	3.598	15.2	...	13.4	(0.25)	...	...	30.11	-3.18:	bjy
P2244	369	K1-2Vne	3.680	13.60	12.35	...	1.27	51	2.46	31.12	-3.33	aftGH
P2253	370	K0:	3.719:	...	14.4	13.0	(0.25)	...	...	30.52	-3.01:	bkyA
P2252	371	K1IVe	3.736	12.34	11.52	11.02	(0.25)	33	...	30.77	-3.71	afwH
P2263	376	K7-M0e	3.598	...	14.3	...	(0.25)	...	...	31.20	-2.71	dm
P2271	...	B5Vne	4.111	6.84	6.95	7.11	(0.25)	260	...	<30.37	< -6.06	afu
P2257	375	K0	3.719	13.08	12.21	...	(0.25)	47	...	31.22	-2.94	afoH
P2284	...	B8Vp	4.000	9.03	9.03	9.1	0.28	180	...	<29.96	< -5.41	afoyH
P2282	...	K3Ve-M1e	3.566	...	15.1	...	0.11	...	...	<30.31	< -2.99	dm
P2305	382	...	...	14.7	13.3	11.9	(0.25)	<12	...	30.69	...	byBI
P2303	...	K2V	3.695	14.34	13.66	...	(0.25)	...	...	<30.44	< -3.13	agt
P2302	...	B9	4.025	10.13	9.94	...	1.00	...	...	<30.37	< -5.03	ao

TABLE 6—Continued

Star Name (1)	X-ray Num (2)	Spectral Type (3)	$\log T_{\text{eff}}$ (K) (4)	B (mag) (5)	V (mag) (6)	I_C (mag) (7)	A_V (mag) (8)	$v \sin i$ (km s ⁻¹) (9)	P_{rot} (days) (10)	$\log L_X$ (ergs s ⁻¹) (11)	$\log \frac{L_X}{L_{\text{bol}}}$ (12)	Notes (13)
P2314	...	B2V	4.312	...	7.2	...	(0.25)	...	...	<30.60	< -6.33	anu
P2347	386	K1e:	3.708:	15.1	14.0	...	0.74	...	...	30.59	-3.02:	ajz
P2368	388	K4eIV-V	3.661	14.26	13.10	...	0.44	47	...	30.63	-3.29	amuL
P2387	...	B9V	3.993	9.21	9.22	...	0.16	125	...	<30.31	< -4.93	afoH

NOTE.—Footnotes below are referenced by the letters listed in col. (13).

^a Position and proper-motion membership probability from McNamara et al. 1989.

^b Position and proper-motion membership probability from Jones & Walker 1988.

^c Position and proper-motion membership probability from van Altena et al. 1988.

^d Proper-motion membership probability from McNamara & Huels 1983.

^e Spectral type, V - and I_C -band photometry from Edwards et al. 1993.

^f Spectral type from Strom 1993.

^g Spectral type, B - and V -band photometry from Duncan 1993.

^h Spectral type from Abt, Wang, & Cardona 1991.

ⁱ Spectral type from van Altena et al. 1988.

^j Spectral type from the General Catalog of Variable Stars (Kholopov et al. 1985).

^k Spectral type from Walker 1983.

^l Spectral type, B or V -band photometry from Penston et al. 1975 or Penston 1973.

^m Spectral type and V -band photometry from Cohen & Kuhl 1979.

ⁿ Spectral type from Warren & Hesser 1977.

^o Spectral type, B - and V -band photometry from Walker 1969.

^p Spectral type from Parenago 1954.

^q V - and I_C -band photometry from Prosser et al. 1994.

^r V - and I_C -band photometry from Attridge & Herbst 1992.

^s Position or spectral type, V - and I_C -band photometry from Herbig & Terndrup 1986.

^t B - and V -band photometry from Duncan 1993.

^u B - and V -band photometry from McNamara et al. 1989.

^v B - and V -band photometry from van Altena et al. 1988.

^w B -, V -, and I_C -band photometry from Rydgren & Vrba 1984.

^x B - and V -band photometry from Warren & Hesser 1977.

^y I_C photographic magnitude from Jones & Walker 1988.

^z Position, B and V photographic magnitudes from Andrews 1981.

^A V photographic magnitude from Brun (1935).

^B Position, B photographic or V photovisual magnitude from Parenago 1954.

^C The bolometric luminosity of the late-type secondary cannot be determined.

^D Rotational period from Attridge & Herbst 1994.

^E Rotational period from Attridge & Herbst 1992.

^F Rotational period from Mandel & Herbst 1991.

^G Rotational period from Walker 1990.

^H Spectroscopic rotational velocity from Strom 1993.

^I Spectroscopic rotational velocity from Duncan 1993.

^J Spectroscopic rotational velocity from Abt et al. 1991.

^K Spectroscopic rotational velocity from Walker 1990.

^L Spectroscopic rotational velocity from Hartmann et al. 1986.

^M One of two candidate optical counterparts. Upper limit corresponds to source flux.

^N Possible blend. Upper limit corresponds to half of source flux.

for moderate absorption values, $0.2 \text{ mag} \leq A_V < 1.3 \text{ mag}$, the resulting change in L_X/L_{bol} is only ± 0.05 in the log. On the other hand, for deeply embedded stars, a large underestimation of A_V would lead to a large overestimation of L_X/L_{bol} .

4.1. The Late-Type PMS Stars

Figure 5 is an H-R diagram of the detected (*filled circles*) and undetected (*open circles*) late-type cluster members for which $\log L_{\text{bol}}$ can be calculated. Stars with uncertain bolometric luminosities (noted with a colon in col. [12] of Table 6) are indicated with smaller symbols in Figure 5 as well as in Figures 6–10 (see below). Plotted are the ZAMS (*solid line*), 10^7 yr (*long-dashed line*) and 10^6 yr (*short-dashed line*) isochrones, along with 1.4, 1.0, and $0.7 M_{\odot}$ evolutionary tracks of D'Antona & Mazzitelli (1994), calculated using the Alexander opacities and the Canuto & Mazzitelli convection formulation. Also plotted is the birthline (*dot-dashed line*) at which PMS stars emerge from their natal circumstellar cloud of gas and

dust and become visible at optical and near-infrared wavelengths (Palla & Stahler 1990).

From Figure 5 we have selected stars in the mass range $0.7 M_{\odot} \lesssim M \lesssim 1.4 M_{\odot}$ to compare with solar-mass stars in other clusters and associations. In Figure 6 we plot the cumulative X-ray luminosity function of solar-mass stars in the survey with those of main-sequence G-type dwarfs in the Pleiades, the Hyades, and the field (Rosner, Golub, & Vaiana 1985) and with late-type PMS stars in the Chamaeleon I region (Feigelson & Kriss 1989). We have used the Kaplan-Meier estimator in ASURV (Isobe, Feigelson, & Nelson 1986) in order to incorporate upper limits in the Orion Nebula sample. We also present the cumulative X-ray luminosity function for solar-mass stars in the Orion Nebula determined in Paper I.

The *Einstein* and *ROSAT* luminosity functions both suggest a median X-ray luminosity of $\sim 5 \times 10^{30} \text{ ergs s}^{-1}$. However, the distributions have somewhat different slopes as a result of the improved sensitivity of the *ROSAT* observations below

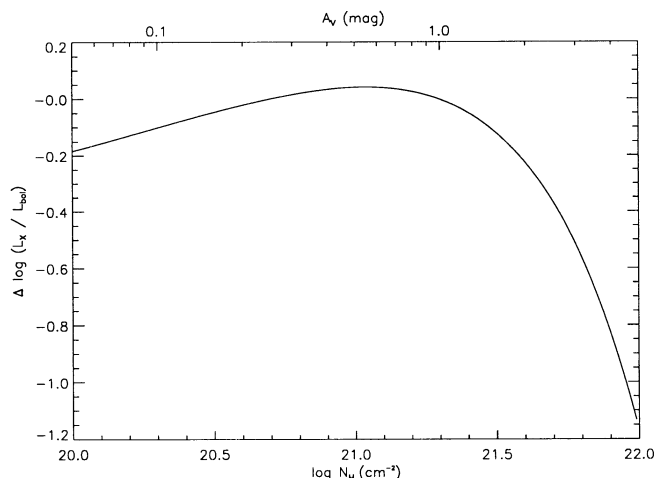


FIG. 4.—Change in $\log(L_X/L_{bol})$ as a function of $\log N_H$ and A_V assuming $2 \times 10^{21} \text{ cm}^{-2}$ per magnitude of visual absorption. The zero point has been chosen to correspond to $\log N_H \sim 20.7$ and to our nominal absorption value $A_V \sim 0.25 \text{ mag}$.

$\sim 3 \times 10^{30} \text{ ergs s}^{-1}$. Among the main-sequence G-type dwarfs, the Pleiades stars are the most X-ray-active, presumably because of their relatively large rotation rates when compared to older dwarfs (Stauffer et al. 1994). The distributions suggest a one order of magnitude decline in L_X from the age of the Orion Nebula to the age of the Pleiades ($\sim 70 \text{ Myr}$); however, this difference is partly the result of the increased surface area of PMS stars. When, instead, we compare L_X/L_{bol} values for late-type stars in the Pleiades (Stauffer et al. 1994) with those listed in Table 6, we find the same range of activity in both clusters, i.e., $3 \times 10^{-5} < L_X/L_{bol} < 3 \times 10^{-3}$, with most stars below $L_X/L_{bol} \sim 10^{-3}$.

As discussed in the previous section, the sample of stars with

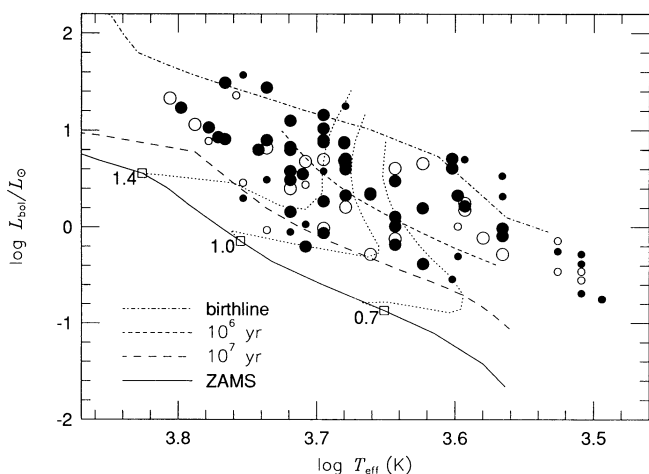


FIG. 5.—H-R diagram of the late-type Orion Nebula cluster members for which bolometric luminosities and effective temperatures have been determined (see Table 6). *ROSAT* detections are indicated with filled circles, and nondetections with open circles. Smaller circles indicate stars for which L_{bol} or T_{eff} determinations are uncertain. All of the stars lie near to or below the birth line of Palla & Stahler (1990) (dot-dash line). Also plotted are the ZAMS (solid line) and the 10^6 yr (long-dashed line) and 10^7 yr (short-dashed line) isochrones, and 1.4, 1.0, and $0.7 M_{\odot}$ evolutionary tracks (dotted lines) of D'Antona & Mazzitelli (1994). The open squares indicate the positions of ZAMS 1.4, 1.0, and $0.7 M_{\odot}$ stars in the H-R diagram. Stars in this diagram have an approximate mass range $0.4\text{--}2.5 M_{\odot}$.

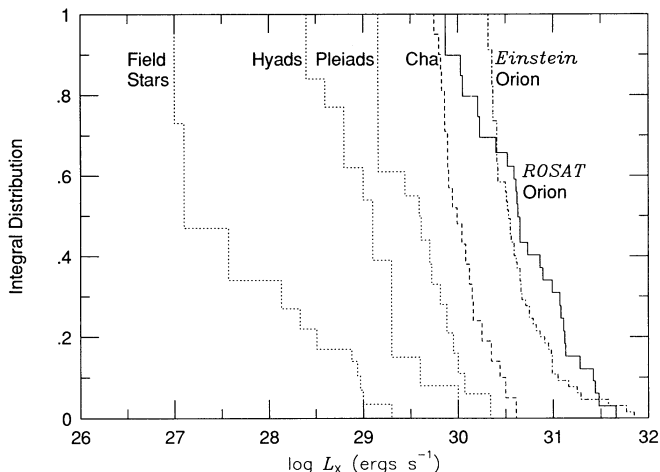


FIG. 6.—Cumulative X-ray luminosity functions for solar-mass cluster members using the Kaplan-Meier estimator based on these *ROSAT* HRI data (solid line) and based on the *Einstein* survey of the Orion Nebula region (dot-dash line). Also shown are the cumulative X-ray luminosity functions for late-type pre-main-sequence stars in the Chamaeleon I star-forming region (dashed line) adapted from Feigelson & Kriss (1989), and main-sequence G-type dwarfs (dotted lines) in the Pleiades, the Hyades, and the field adapted from Rosner, Golub, & Vaiana (1985).

known spectral types, and hence with known bolometric luminosities, is heavily biased toward more luminous stars, with an approximately 2.5 mag difference in $\bar{L}_C$ between late-type and untyped stars. As a result, the cumulative distribution functions in Figure 6 may not be representative of the solar-mass cluster population as a whole.

In order to estimate the mean X-ray luminosity of solar-mass stars in this survey, we follow a procedure outlined in Paper I. Of the 33 approximately solar-mass stars plotted in Figures 5 and 6, 26 are detected with a mean X-ray luminosity $\bar{L}_X \sim 1.0 \times 10^{31} \text{ ergs s}^{-1}$. We wish to estimate the number of stars among the ~ 430 untyped cluster members brighter than $V \lesssim 15.5$ or $I \lesssim 14.0$ that are in the mass range $0.7\text{--}1.4 M_{\odot}$. Assuming the stellar initial mass function in the Orion Nebula is like the field initial mass function (IMF) of Scalo (1986), then $\sim 30\%$ of the 430 untyped stars have masses of approximately $1 M_{\odot}$, i.e., roughly 130. Since the detection fraction of untyped cluster members is $\sim 20\%$, then ~ 26 of these stars will have been detected. The mean count rate for untyped cluster members listed in Table 2 is $\sim 10^{-3} \text{ counts s}^{-1}$, implying $\bar{L}_X \sim 2.6 \times 10^{30} \text{ ergs s}^{-1}$. Although these estimates are somewhat crude, we can use them to determine upper and lower limits to $\bar{L}_X$ for all solar-mass cluster members (both typed and untyped), following the method outlined by Caillaud & Helfand (1985). We derive a lower limit by assuming the ~ 11 undetected stars (seven typed and $130 - 26 = 104$ untyped) emit no X-rays. We derive an upper limit by assuming that the undetected stars all emit at $\bar{L}_X \sim 1.0 \times 10^{30} \text{ ergs s}^{-1}$. We find $2.0 \times 10^{30} \text{ ergs s}^{-1} < \bar{L}_X < 2.9 \times 10^{30} \text{ ergs s}^{-1}$. Since only ~ 52 of the ~ 137 solar-mass stars are detected, the median X-ray luminosity occurs below our detection threshold, that is, $L_X < 1.0 \times 10^{30} \text{ ergs s}^{-1}$. Comparing with results from *Einstein*, in Paper I we find $1.6 \times 10^{30} \text{ ergs s}^{-1} < \bar{L}_X < 3.6 \times 10^{30} \text{ ergs s}^{-1}$ and a median X-ray luminosity well below $L_X \sim 2.5 \times 10^{30} \text{ ergs s}^{-1}$, the *Einstein* survey detection threshold. Thus, the *ROSAT* results place tighter constraints on the mean and median X-ray luminosity of the solar-mass PMS stars.

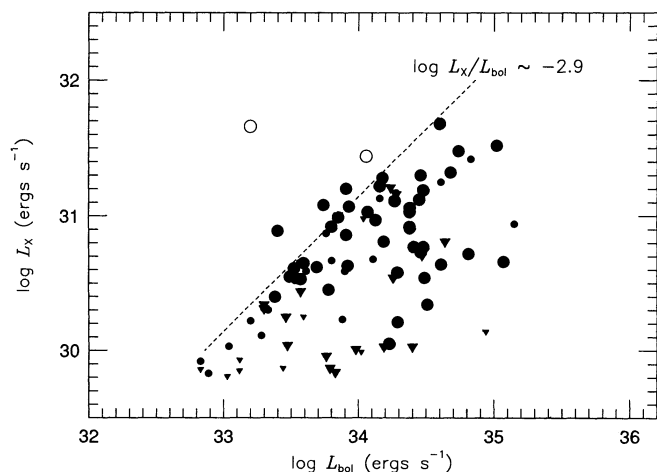


FIG. 7.—X-ray luminosity vs. bolometric luminosity for stars with measured L_{bol} (see Table 6). Downward-pointing triangles indicate X-ray upper limits, smaller symbols indicate uncertain L_{bol} determinations, and open circles indicate that strong X-ray flares were detected on these stars (see Table 7). Most stars appear very close to or below the saturation line corresponding to $\log(L_X/L_{\text{bol}}) \sim -2.9$.

We use L_X/L_{bol} as a coronal activity indicator because both the number of X-ray-emitting regions and the bolometric luminosity should scale with the area of the photosphere, hence the ratio measures coronal activity, independently of stellar radius. In Figure 7 we plot $\log L_X$ versus $\log L_{\text{bol}}$ for the late-type stars with values in column (12) of Table 6; we have indicated the flare stars (see § 4.2) with open symbols and L_X upper limits with downward pointing triangles. As in Figure 5, smaller symbols indicate stars for which our L_{bol} determination is uncertain. With the exception of five stars, all late-type PMS stars lie below a line corresponding to $\log(L_X/L_{\text{bol}}) \sim -2.9$, with many stars lying close to this “saturation” line. Of the five stars lying above the saturation line (P1408, P1440, P1977, P2001, P2263), strong X-ray flares have been detected on P1440 and P1977 (see Table 7 and § 4.2). This saturation line has been observed in other clusters, most notably in the Pleiades (Stauffer et al. 1994), where late G, K, and M dwarfs show a sharp increase in activity with increasing rotational

TABLE 7
X-RAY FLARE STARS

X-RAY NUMBER (1)	STAR NAME (2)	MEMBERSHIP PROBABILITY (3)	$\log L_X$ (ergs s ⁻¹)		DURATION (10 ³ s)	
			Quiet (4)	Flare (5)	Rise (6)	Decay (7)
13	P1440	88	31.0	32.2	...	>4
21	P1483	0	...	...	5	25
39	JW 65	99	30.5	31.5	...	14
63	JW 128	99	30.3	31.3	<1	>12
100	P1724	0	...	...	...	>30
155	P1846	92	30.6	31.1	9	35
176	$\theta^1\text{A}/\theta^1\text{E}$	96	31.7	32.0	>6	>24
235	P1977	99	30.5	32.0	8	43
303	JW 855	99	<30.0	31.5	...	>14
373	P2240	85	31.1	32.0	...	>10

velocity at low $v \sin i$ and saturated activity ($L_X/L_{\text{bol}} \sim 10^{-3}$) at $v \sin i \gtrsim 15 \text{ km s}^{-1}$.

In Figures 8a and 8b we plot L_X and L_X/L_{bol} , respectively, versus T_{eff} for group 1 stars with measured spectral type. We have used the same symbol definitions as for Figure 7. The dashed lines separate stars into spectral types O6–B5, B6–A5, and F6–M5. Among the very hottest stars in the first category, there is a sharp increase in L_X and a more moderate increase in L_X/L_{bol} with increasing T_{eff} . For the mid-B- to early A-type stars, $L_X/L_{\text{bol}} \sim 10^{-5}$. In Papers I and II we argue that the X-ray luminosity and detection fraction for these stars support the hypothesis that the observed X-rays are not produced in the late B and early A atmospheres but rather in the coronae of hitherto unseen, late-type PMS binary companions. Among the late-type cluster members, X-ray emission turns on around spectral type F6, with the upper envelope of activity increasing sharply from mid-F to late G. As for the late G, K, and M PMS stars, Figures 8a and 8b illustrate the roughly 1.5 order of magnitude dispersion in L_X and L_X/L_{bol} at a given effective temperature.

In the Pleiades cluster, the dispersion in X-ray activity at a given color or effective temperature is shown to be largely the result of the dispersion in rotational velocity among the mid-G

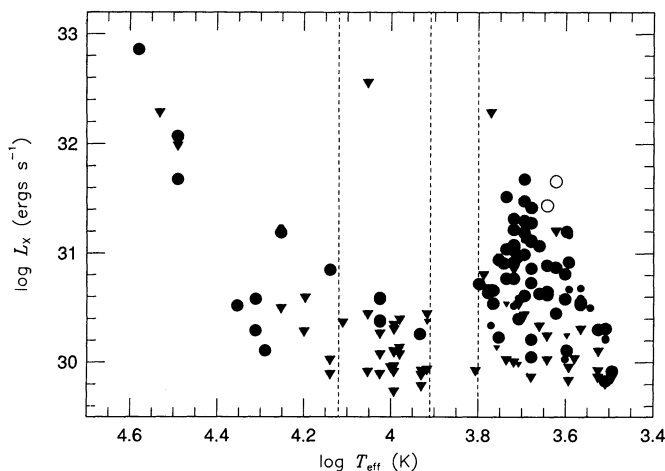


FIG. 8a

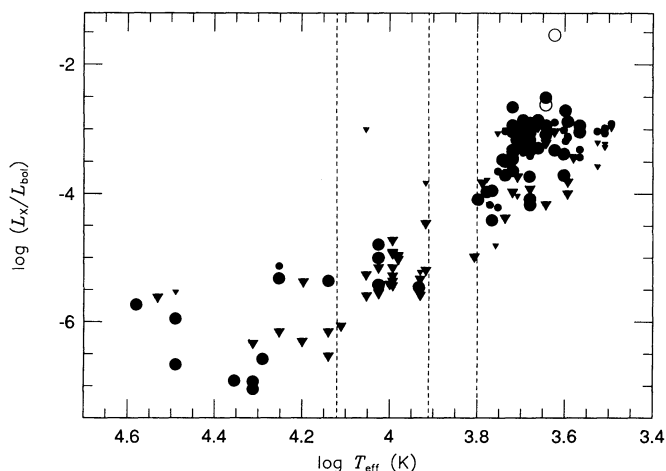


FIG. 8b

FIG. 8.—Plots of (a) $\log L_X$ and (b) $\log(L_X/L_{\text{bol}})$ vs. effective temperature of stars with measured spectral types in Table 6. The dashed lines separate O6–B5, B6–A5, A6–F5, and F6–M5 stars. See Fig. 7 for symbol definitions.

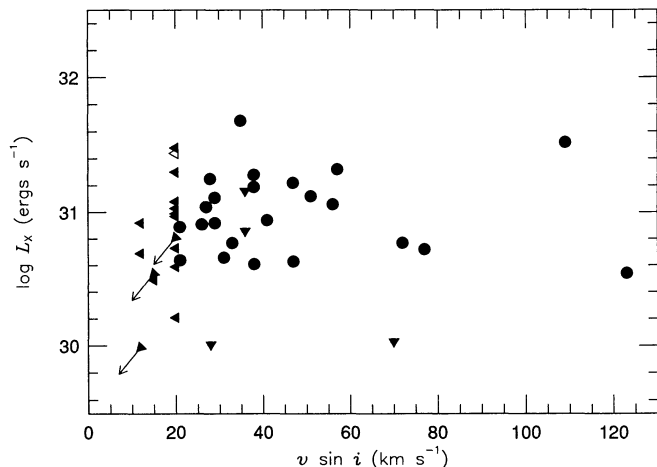


FIG. 9a

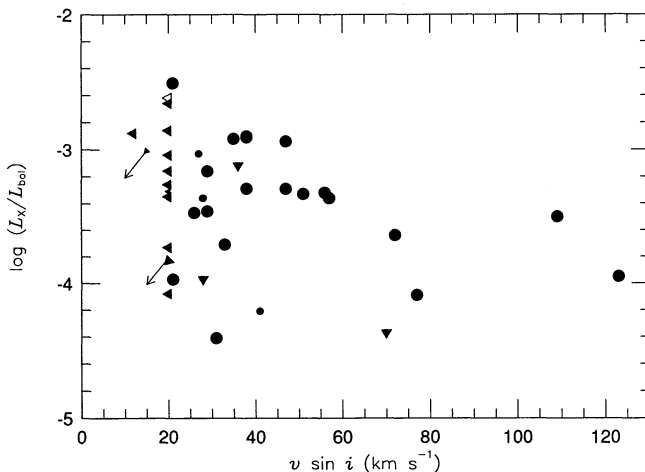


FIG. 9b

FIG. 9.—Plots of (a) $\log L_X$ and (b) $\log (L_X/L_{bol})$ vs. $v \sin i$ for stars with measured spectroscopic rotational velocities (see Table 6). Open symbols represent strong X-ray flares, smaller symbols represent stars with uncertain $\log (L_X/L_{bol})$, leftward-pointing triangles represent stars with $v \sin i$ upper limits, and downward-pointing triangles represent X-ray upper limits. Stars with both X-ray and rotational velocity upper limits are indicated with arrows.

to M Pleiades stars (Stauffer et al. 1994). We wish to look for a similar X-ray activity-rotation connection in the Orion Nebula. Unfortunately, our sample of late-type cluster stars with measured rotational velocities is biased toward more luminous stars (as was the sample with measured spectral types), and toward rapid rotators as well, because of the relatively high $v \sin i \sim 20 \text{ km s}^{-1}$ upper limits. Rotational period is the ideal measure of stellar rotation because it does not contain an unknown geometric factor ($\sin i$), it can be measured over a broader, more critical range of rotation rates, and it can be obtained for a fainter sample of stars, thereby removing some of the bias discussed above. Of the stars in Table 6, 58 have measured P_{rot} .

In Figures 9a and 9b, we plot $\log L_X$ and $\log (L_X/L_{bol})$, respectively, against $v \sin i$. No clear activity-rotation correlation is apparent. In Figures 10a and 10b we plot these same two X-ray activity indicators against P_{rot} ; again, there is no apparent correlation with rotation. What is most striking in Figures 9b and 10b is that many stars, spanning the entire range of measured rotation rates, show signs of saturated or

near-saturated activity, i.e., $\log (L_X/L_{bol}) \gtrsim -3.5$. Figures 9a and 10b also suggest an order-of-magnitude spread in $\log (L_X/L_{bol})$ at a given rotation rate. This dispersion is larger than our estimate of the error in L_X/L_{bol} . However, given the biases in the optical sample, the relatively high $v \sin i$ upper limits, and the relatively high X-ray luminosity threshold of these observations ($L_X \sim 10^{30} \text{ ergs s}^{-1}$), very little can be said about the fainter stars or the truly slow rotators because few or no useful X-ray or optical data are available. In particular, we cannot rule out the possibility of an activity-rotation correlation. We return to the discussion of activity and rotation in § 5.

4.2. X-Ray Flaring

For each of the 389 X-ray sources in Table 2, we have used the photon arrival times to construct a set of light curves with 500, 1000, and 2000 s bins for each field and for each time segment in Table 1 during which the source has been detected. The light curves have been generated in precisely the same manner as that described in § 3.1 for the count rate determi-

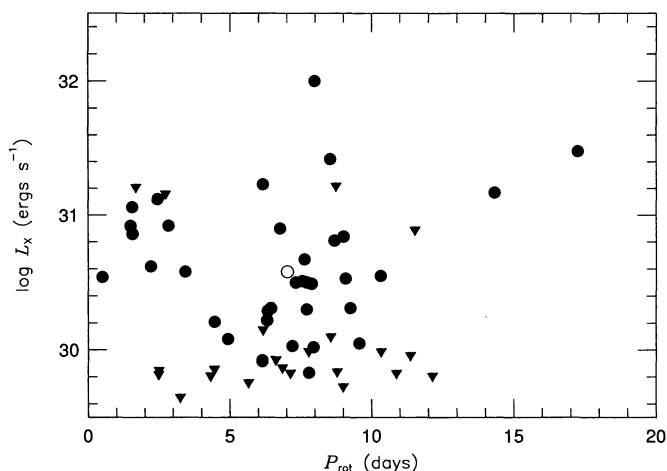


FIG. 10a

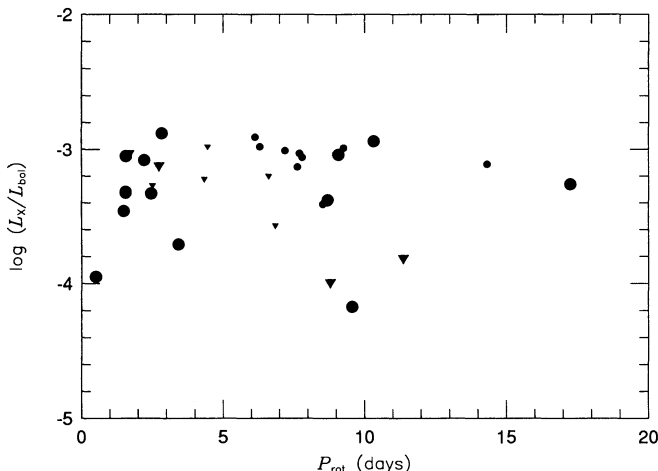


FIG. 10b

FIG. 10.—Plots of (a) $\log L_X$ and (b) $\log (L_X/L_{bol})$ vs. P_{rot} for stars with measured rotational periods (see Table 6). See Fig. 7 for symbol definitions.

nation: in each time bin, background counts from a concentric annulus have been subtracted from source counts in a 90% power-radius circle. Since the median source count rate is $\sim 10^{-3}$ counts s^{-1} , the typical light curve has only a few photons in each time bin. Consequently, the only short-term variability we can detect from a typical source is a strong, short-duration flare. Each light curve has been visually inspected for evidence of flaring.

In order to test each light curve for statistical variability, a mean rate has been determined and the binned data have been tested against the hypothesis of a constant count rate. We have computed χ^2_ν for each light curve and consider a source variable if we can reject the constant count rate hypothesis at the 99% confidence level. Only 10 sources meet both our χ^2_ν and our visual inspection criteria for short-term variability: light curves for these are shown in Figures 11a–11j. Of these, eight are associated with a single late-type (or untyped) cluster member.

The flares in Figure 11 have rise times in the range $(1-9) \times 10^3$ s and decay times in the range $(12-43) \times 10^3$ s. In the case of two flares (sources 63 and 303) the end of the flare decay was not observed, while in five cases (sources 13, 39, 100, 303, and 373) the rise of the flare was not observed. We list the source number, star name, proper-motion membership probability, quiescent and flare X-ray luminosities, and rise and decay times for the 10 flares in Table 7. The most energetic flare is associated with the K6 cluster member P1977 (AG Ori), with a total flare duration in excess of 4×10^4 s, a rise time to decay time ratio $\lesssim \frac{1}{5}$, and a total incident energy in excess of 2×10^{36} ergs.

Another notable flare merits a separate discussion. As was discussed in the previous section, we have attempted to derive count rates for sources 176 and 177 by estimating the counts attributable to each. Although the presence of at least two sources is apparent from Figure 3, we cannot deconvolve the photon events. Consequently, the combined light curve contains emission from both sources. The flare event is evident in Figure 11g, and its association with source 176 can be seen in Figure 3b. The blended sources 176 and 177 were observed in the south field to have a steady combined count rate ~ 0.08 counts s^{-1} during the entire 1991 October and 1992 March exposures and partway through the 1992 September exposure. On 1992 September 15, the count rate rose by a factor of 3 and decayed to its quiescent level over a roughly 11 hr period. We estimate that over 1200 photons associated with the flare were detected, implying a flare energy $\sim 2 \times 10^{36}$ ergs.

Variability in the U band and in $H\alpha$ has been monitored among classical T Tauri stars for many years, and the amplitudes, characteristic timescales, and patterns of the fluctuations not only are vastly different from star to star but can undergo drastic changes with time on a single star. The rapid optical variability associated with flare stars may originate, for example, in solar-like flares or in instabilities in a hot boundary layer between an accretion disk and the photosphere (cf. Montmerle et al. 1992; Gahm 1988). The short-term variability observed in the *ROSAT* HRI data have amplitudes and rise and decay times characteristic of very powerful, solar-like flares. These X-ray flares are very similar to flares observed on late-type, main-sequence dwarfs in the Pleiades (Gagné et al. 1994).

Of the 10 X-ray flare stars listed in Table 7, only one, P2240, has been detected as a U -band flare star (Parsamian et al. 1978) in the half-dozen or so surveys we have examined (see § 2 for

references). The P2240 U -band flare occurred 1977 January 26 with $U_{\max} \sim 15.6$ mag and $\Delta U \sim 1.6$ mag; no $H\alpha$ feature was detected at the time of flare. Two X-ray flare stars have been found to have large optical variability ($\Delta V \geq 1.6$ mag) and strong, variable $H\alpha$ intensity in the objective-prism survey of Parsamian & Chavira (1982); P1846 (LY Ori) and P1977 (AG Ori).

Based on a similar analysis of the *Einstein* data, only two X-ray flares, associated with cluster members P1470 and JW 315, were tentatively reported in Paper I. Both of these were detected by *ROSAT*, with $L_X \sim 10^{31}$ and $\sim 3 \times 10^{31}$ ergs s^{-1} , respectively. *ROSAT* light curves for both sources show some evidence of variability, but the characteristic rise and decay of a flare were not observed. All 10 sources associated with strong *ROSAT* flares were observed by *Einstein*, although none were seen flaring in those data. In fact, P1483, JW 65, and P1977 were not even detected in the *Einstein* survey. Given the X-ray energies of the detected flares, i.e., $\gtrsim 3 \times 10^{35}$ ergs, we may be seeing only a handful of very powerful, low-probability events. Future, more sensitive X-ray detectors may reveal many more lower energy flares in the Orion Nebula.

4.3. Long-Term X-Ray Variability

The north and south field exposures were divided into large ($t > 12$ ks) time segments separated by roughly 6 and 12 months, respectively (see Table 1). Together, these two images contain 243 distinct X-ray sources associated with a single late-type or untyped proper-motion cluster member. In addition, 24 of these sources were observed in the central field. This has allowed us to examine X-ray source variability on timescales of 6–18 months. We can thus compare 291 ($243 + 2 \times 24 = 291$) pairs of count rates or upper limits associated with a single late-type or untyped cluster member.

For each pair of observations, we have computed a count rate ratio, $r \equiv \eta_1/\eta_2$, where η_1 and η_2 are the count rate or upper limit from the earlier and later observations, respectively. Since some sources detected in one exposure are observed but not detected in others, the count rate ratios consist of some upper and lower limits. (In 32 cases, both count rates η_1 and η_2 were upper limits; in these cases, the ratios were not used.)

The set of r -values for all observations are doubly censored univariate data, and we follow the procedure used in Paper I to estimate the “true” distribution of count rate ratios. We have binned the three sets of $\log r$ values (count rate ratios, upper limits, and lower limits) into three distributions: n_i , u_i , and l_i , where $i = 1, N$. In our case, the $\lambda = 259 \log r$ values have been divided into $N = 64$ bins of length 0.05, where the total number of $\log r$ values is simply

$$\lambda = \sum_{i=1}^N (n_i + u_i + l_i). \quad (4)$$

We estimate the “true” count rate ratio distribution function iteratively using the maximum-likelihood estimator of Schmitt et al. (1993).

The cumulative distribution function is plotted as the solid histogram in Figure 12. The error bars in Figure 12 have been generated by adding and subtracting 1σ uncertainties in the count rate ratios and recomputing the count rate ratio distribution function as before. Hence, the error bars represent $\pm 1 \sigma$ uncertainties in the cumulative distribution function. The spread in the observed distribution of count rate ratios

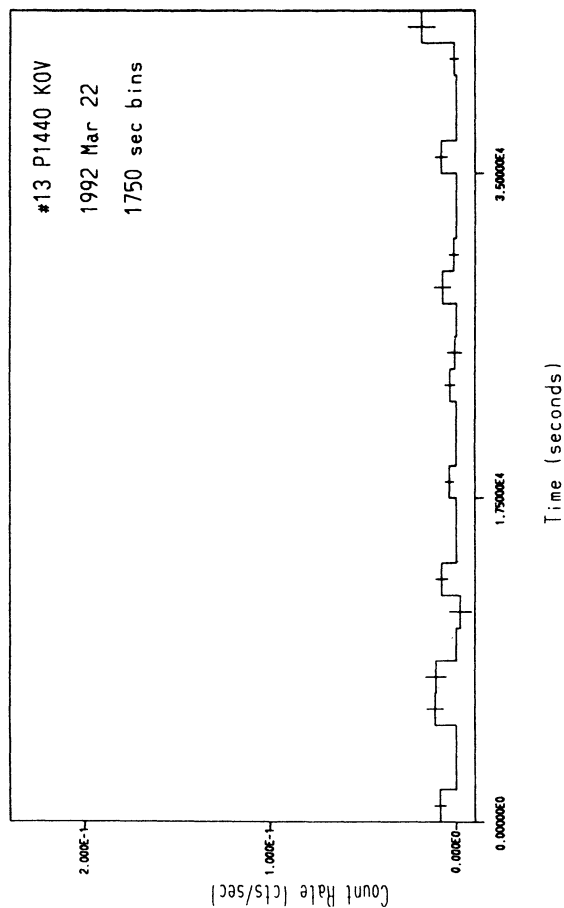


FIG. 11a

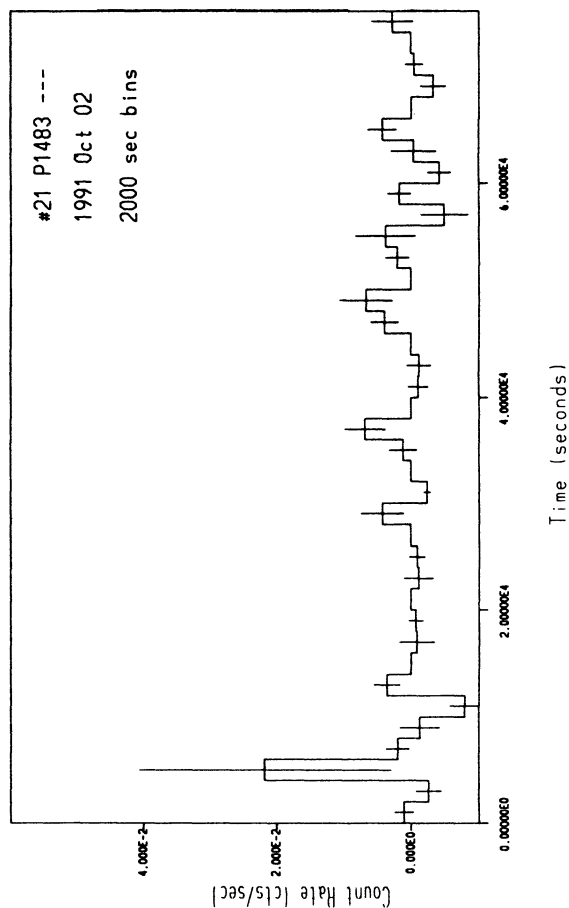
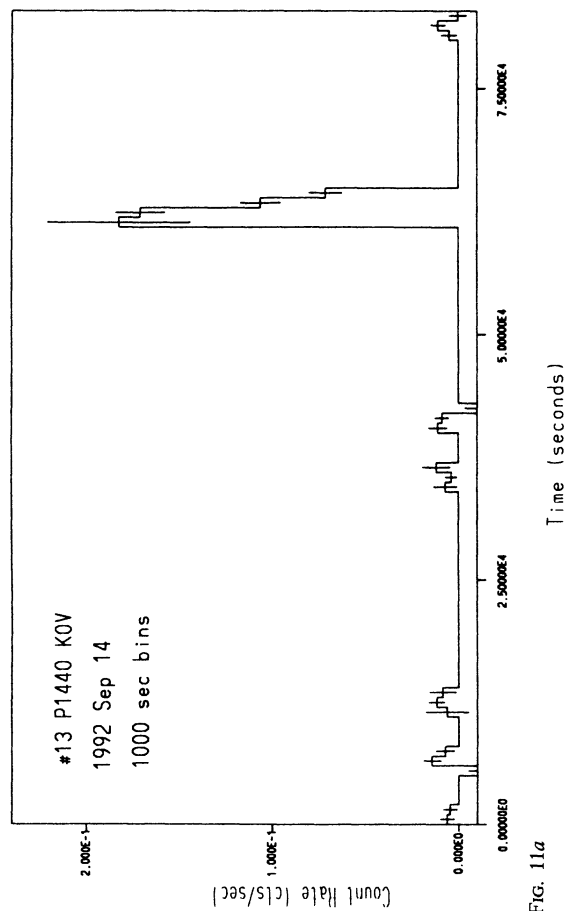


FIG. 11b

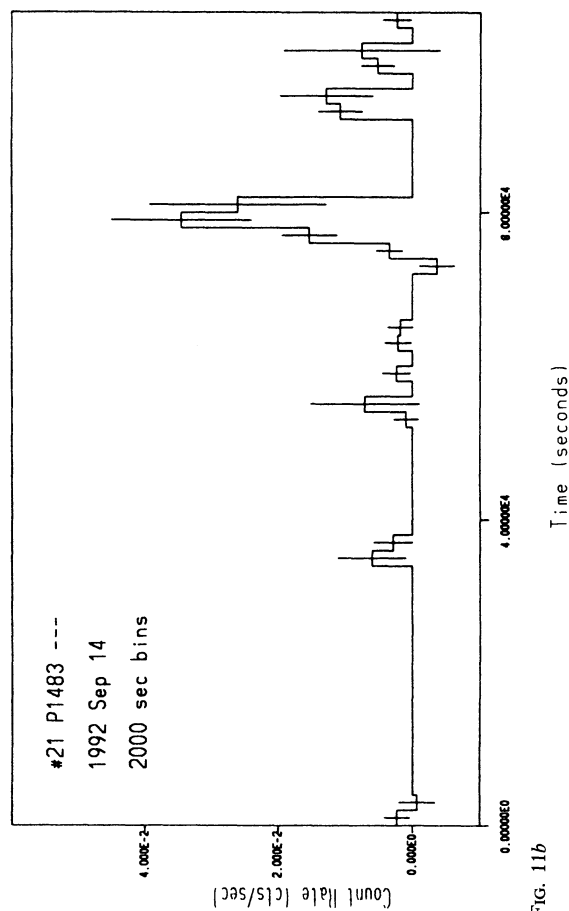


FIG. 11.—*ROSAT* HRI light curves of 10 X-ray flares. For each pair of light curves, the X-ray source number, the name and spectral type of the candidate optical counterpart(s), the observation date, and the size of the light-curve bins are indicated. Plotted in each X-ray light curve is the net count rate vs. time relative to the start of the observation. These count rates have not been corrected for telescope vignetting. Large error bars generally indicate time bins with little effective exposure time and, hence, highly uncertain count rates. The characteristics of each flare are summarized in Table 7. Negative count rates indicate that more background counts than source counts were detected in that bin.

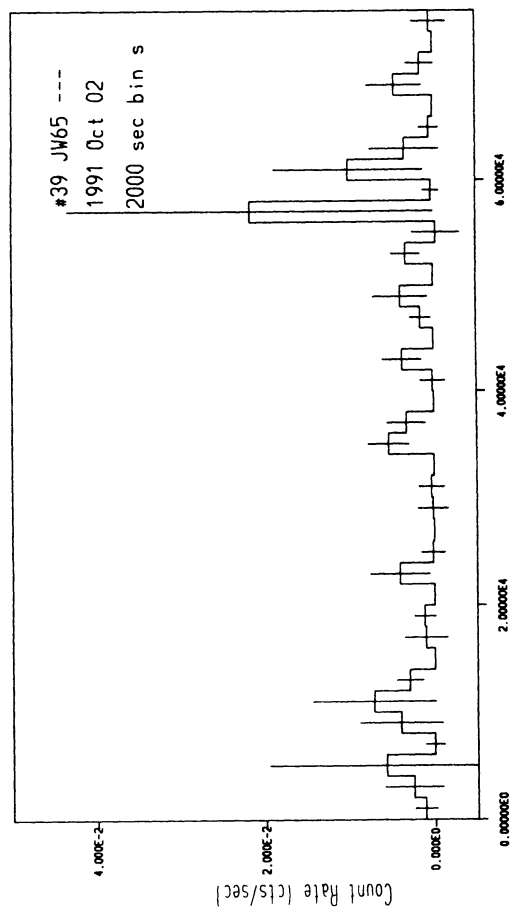


FIG. 11c

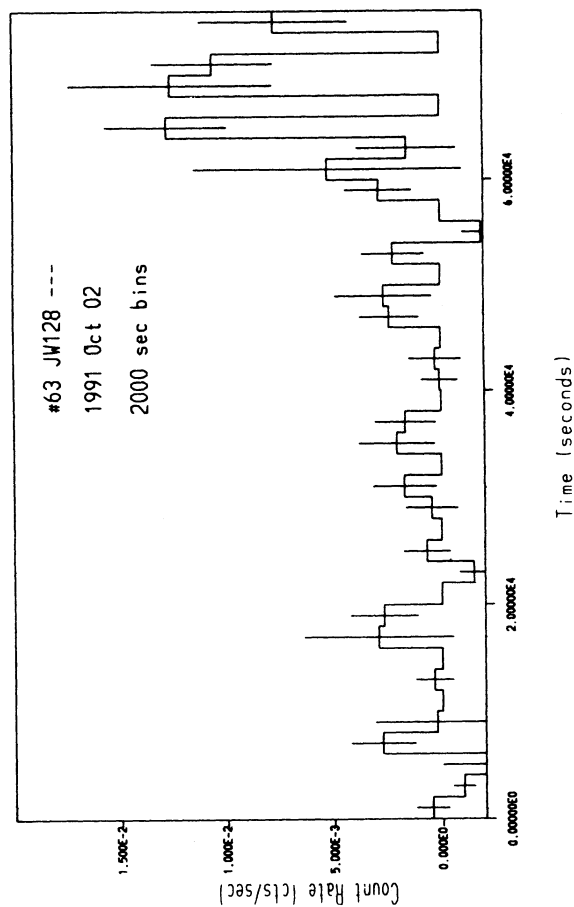


FIG. 11d

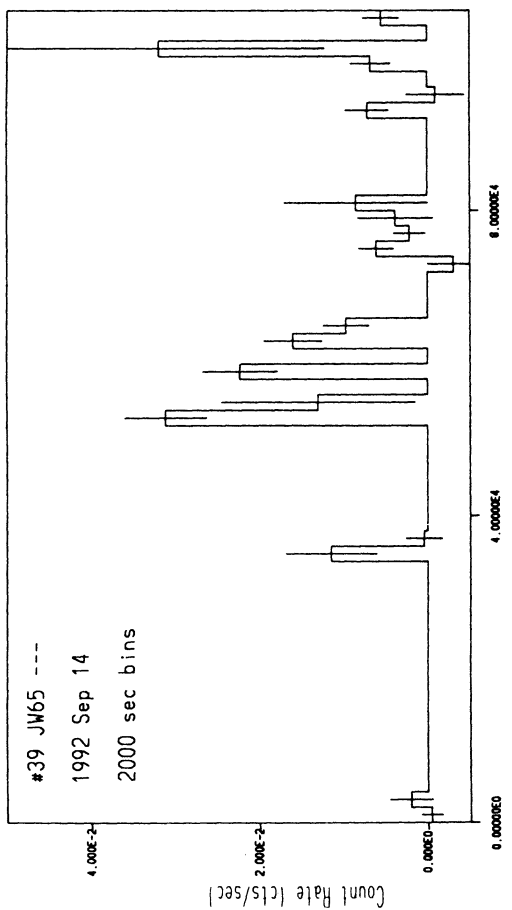


FIG. 11e

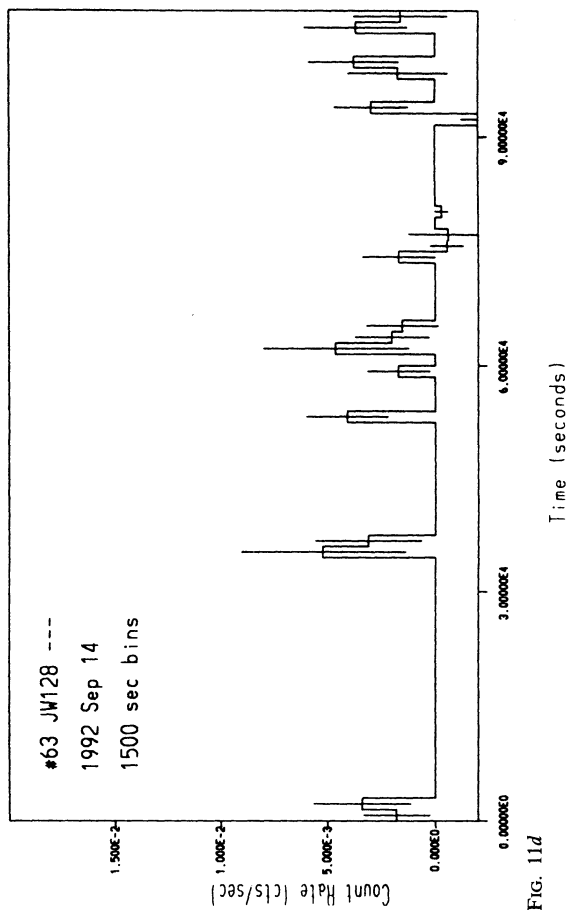


FIG. 11f

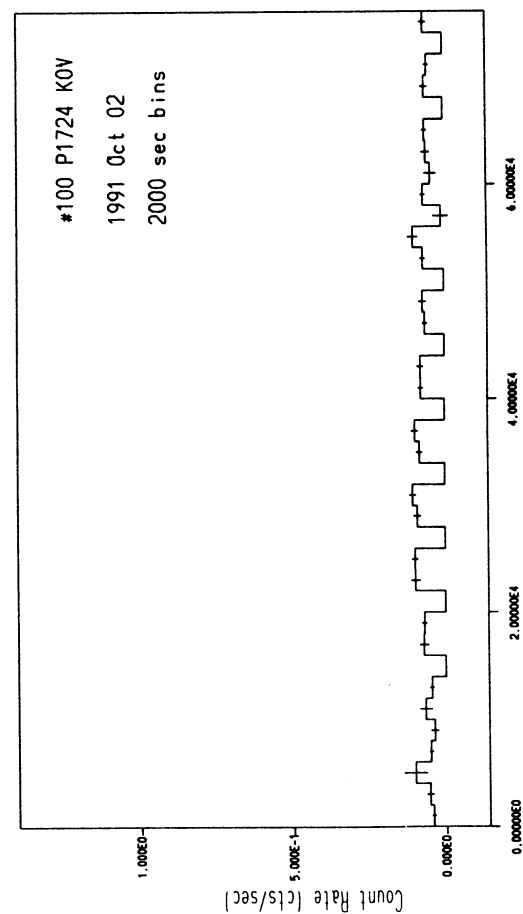


Fig. 11e

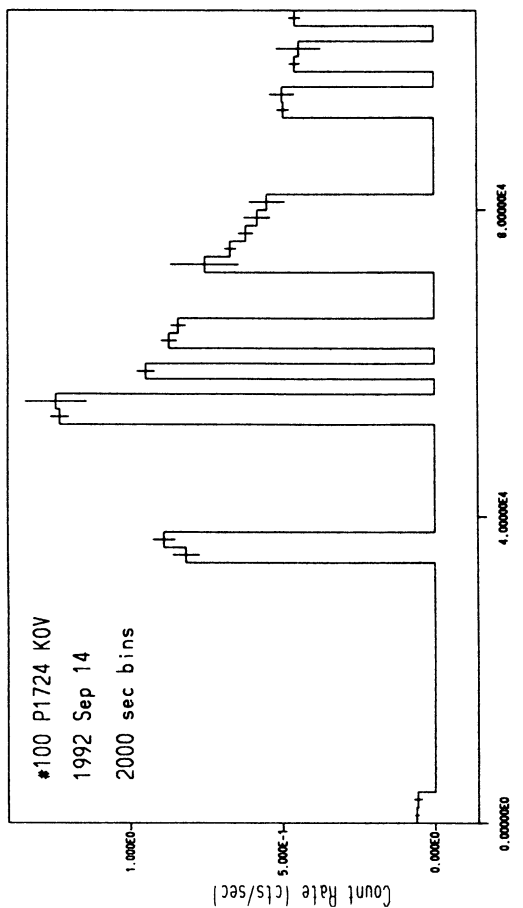


Fig. 11f

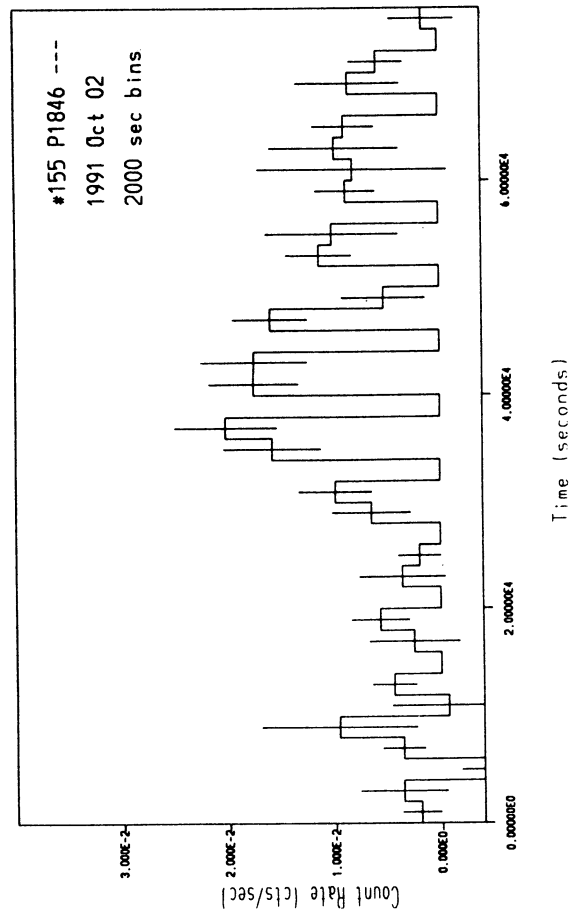
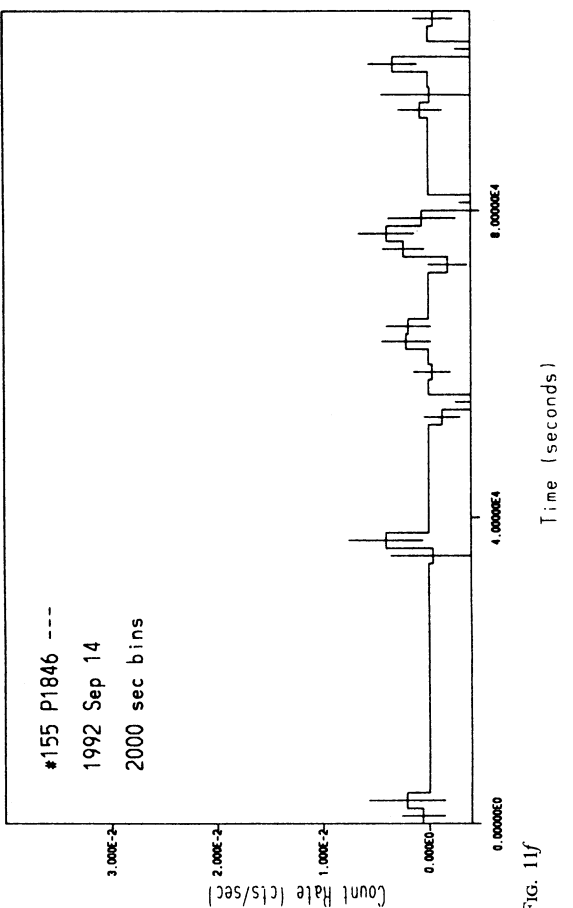


Fig. 11g



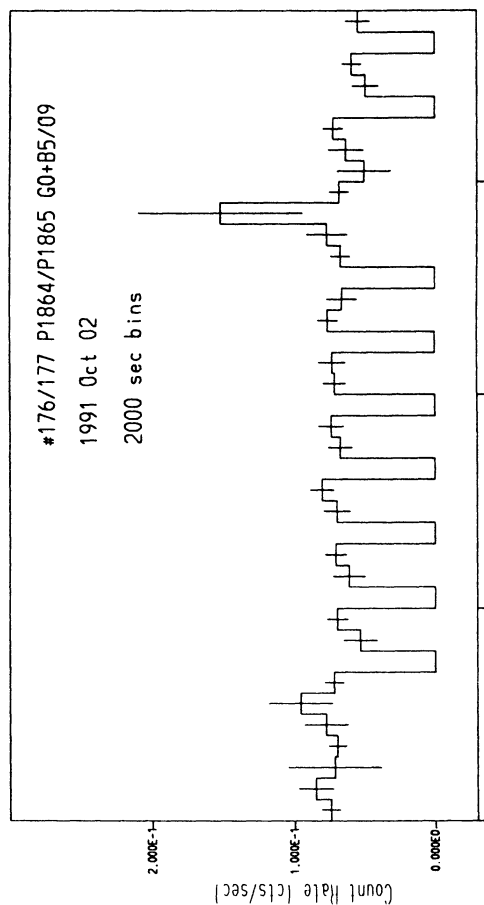


Fig. 11g

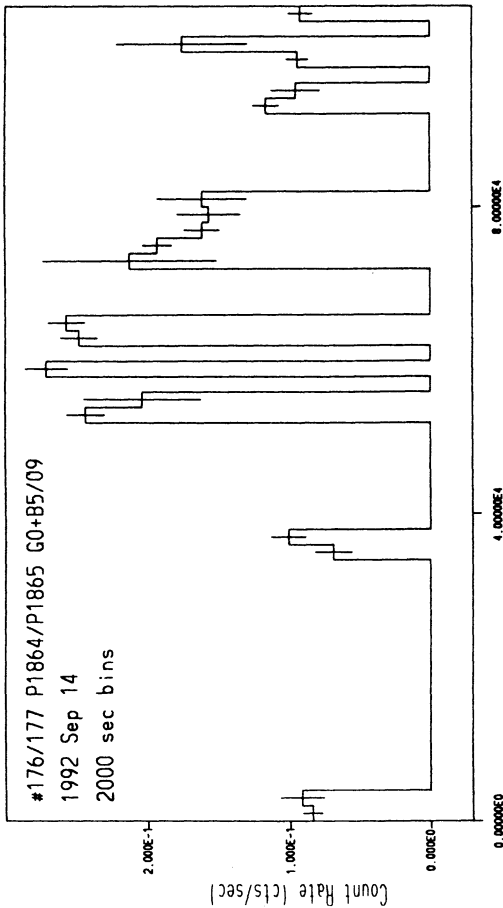


Fig. 11h

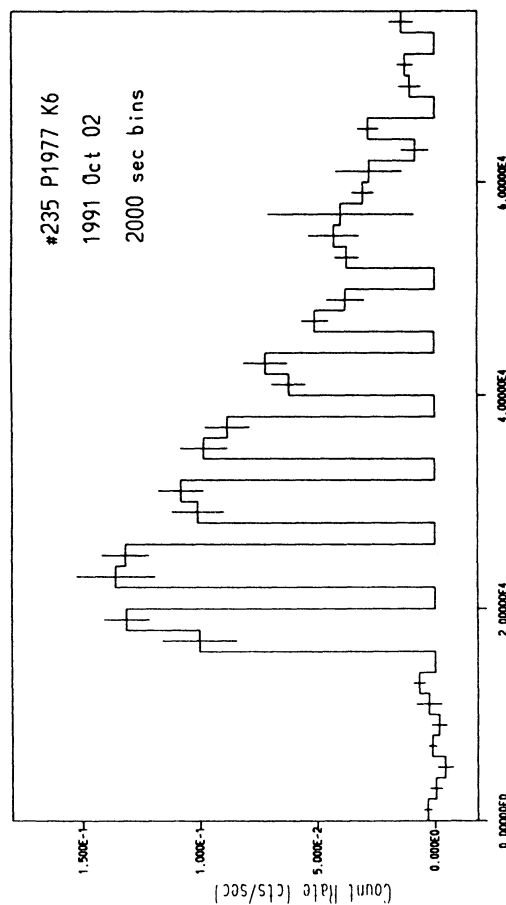


Fig. 11i

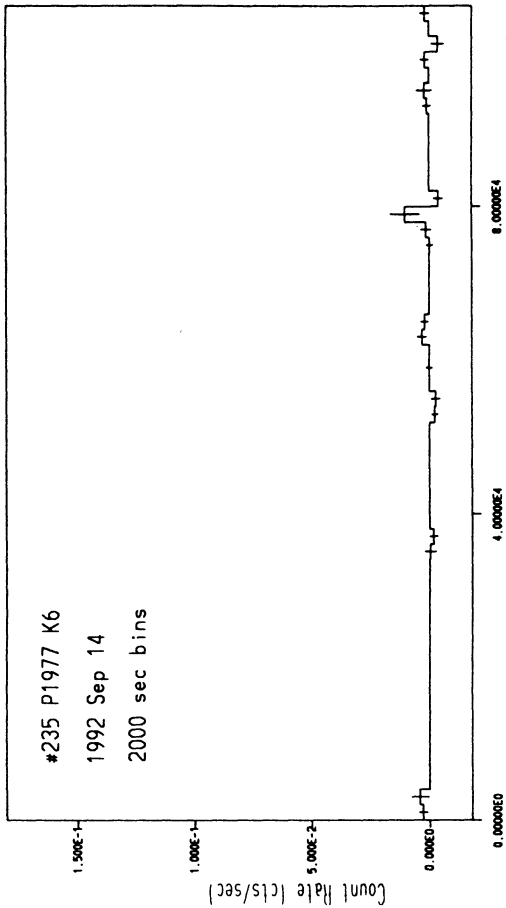


Fig. 11j

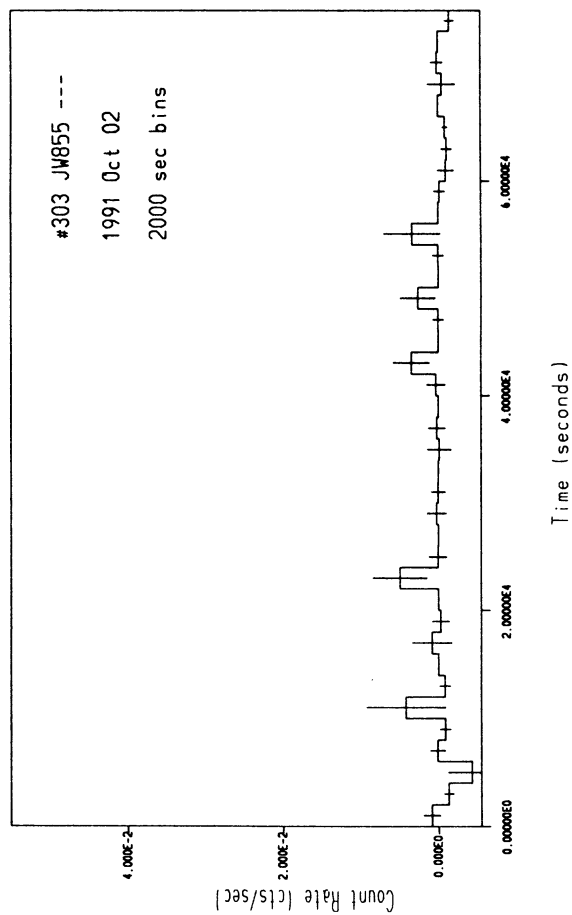


Fig. 11i

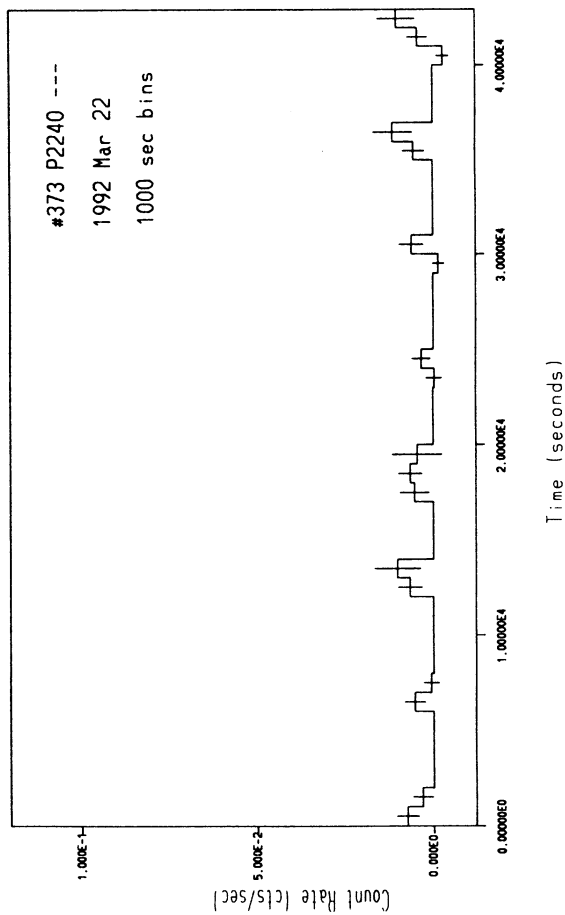
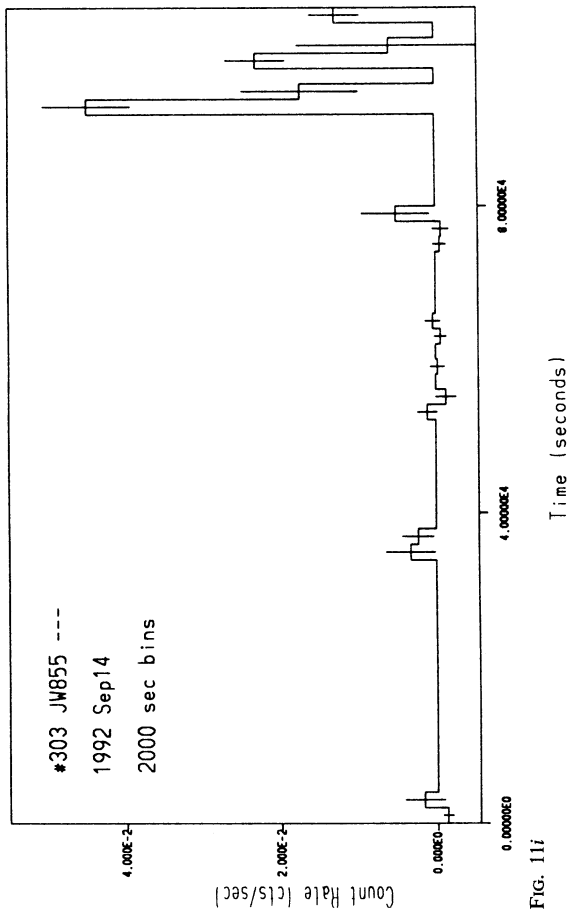
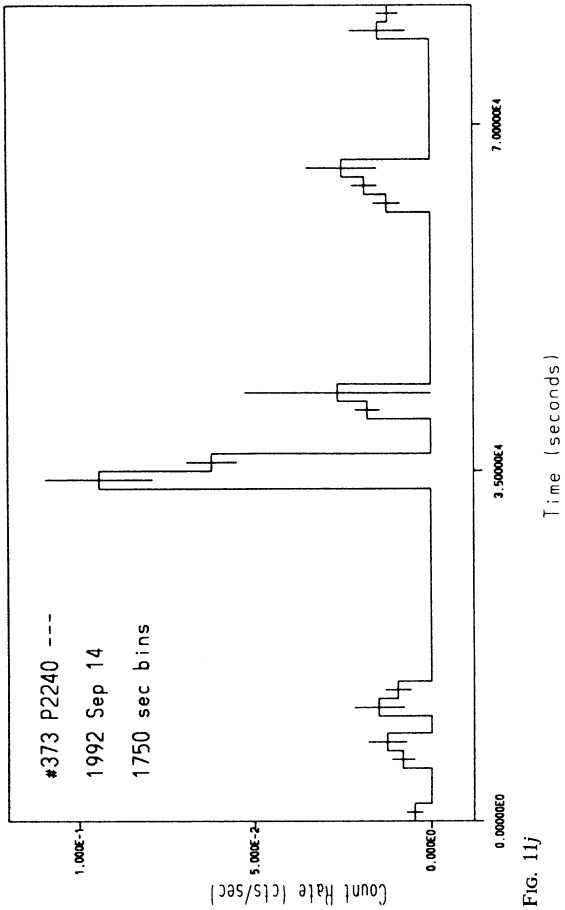


Fig. 11j



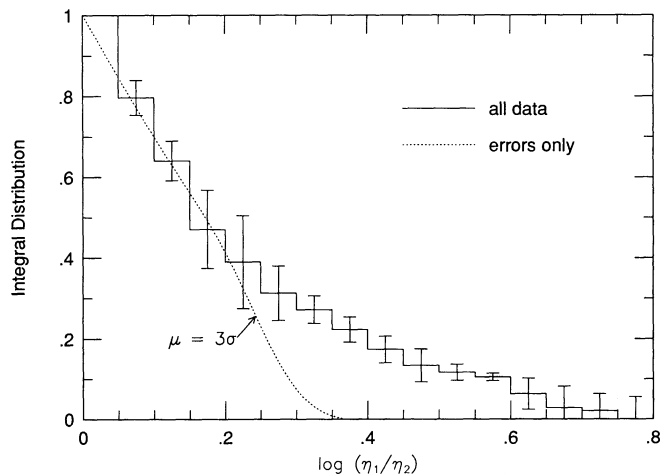


FIG. 12.—Count rate ratio histogram for sources associated with late-type and untyped cluster members. The histogram (solid line) represents the cumulative maximum-likelihood count rate ratio distribution for detections and upper limits using the estimator for doubly biased univariate data described by Schmitt et al. (1993). The dotted line indicates the cumulative count rate distribution we expect as the result of statistical fluctuations alone in the observed data in the case of a faint source with an intrinsic mean count rate $\mu = 3\sigma$. The difference between the two distributions represents a lower limit to the true variability of the X-ray sources. As an ensemble, at least one-fourth of the PMS stars are significantly variable.

suggest significant long-term X-ray variability among the late-type cluster members. This is somewhat misleading in that repeated observations of an intrinsically constant source will produce a broad distribution of count rate ratios as the result of measurement errors alone. This effect is particularly pronounced for sources near the 3σ detection threshold.

We want to estimate how much of the observed variability is intrinsic and how much is the result of statistical fluctuations alone. Although the fluctuations from a photon counter like the HRI are, strictly speaking, Poisson distributed, all the sources in this survey have been detected with at least 20 net photons; thus, we assume that a Poisson error distribution can be accurately approximated by an appropriate normal distribution. We consider the extreme case of a source with a constant intrinsic count rate $\mu = 3\sigma$, the source detection threshold. In this case, the probability of obtaining an upper limit is 0.5, and variations due to statistical fluctuations alone will result in count rate ratios as well as some upper and lower limits. The resulting (n_i, u_i, l_i) distribution is used to calculate a maximum-likelihood distribution as before; the dotted curve in Figure 12 represents this cumulative distribution function. The difference between the solid and dotted curves represents a lower limit to the intrinsic variability.

Our results suggest that at least one-fourth of the sources associated with late-type or untyped cluster members are significantly variable on timescales of ~ 1 yr with individual sources varying by factors of ~ 2 –6. These results are entirely consistent with the X-ray variability observed in the Orion Nebula with the *Einstein* IPC (Paper I). Despite the factor of 3 improvement in sensitivity of these *ROSAT* data over the *Einstein* data presented in Paper I, the distance of the Orion Nebula means that only the brighter, more active late-type stars are being detected ($L_X \geq 10^{30}$ ergs s $^{-1}$). Among the PMS stars in the ρ Ophiuchus cloud observed by *Einstein*, X-ray luminosities range from $(0.5$ – $25) \times 10^{30}$ ergs s $^{-1}$ (Bouvier 1990), and individual sources are seen to vary by factors of

2–20 (Montmerle et al. 1983). In addition, a powerful ($\geq 8 \times 10^{35}$ ergs) X-ray flare, associated with ROX 20, was observed in the *Einstein* data. The very young stars in the Orion Nebula and in ρ Oph have comparable mean X-ray luminosities and exhibit significant variability on timescales ranging from a few hours to many months.

5. SUMMARY AND DISCUSSION

We present results from three deep *ROSAT* HRI observations of an approximately 0.8 deg ^{2} region centered on the Orion Nebula. We have detected a total of 389 soft X-ray sources for which we have derived accurate positions and count rates. We have constructed an extensive optical database from published and unpublished sources to search for optical counterparts to the X-ray sources; this database contains positions, proper-motion membership probabilities, spectral types, BVI_C stellar magnitudes, and rotational periods and velocities, when available, for over 1500 stars in the *ROSAT* HRI survey area. Of the detected X-ray sources, over two-thirds are associated with a single proper-motion cluster member. Of the X-ray–detected cluster stars, 95% are late-type, pre-main-sequence stars.

X-ray emission is detected in virtually all mass and effective temperature ranges, from the very hot, massive components of the Trapezium to the coolest, low-mass PMS stars. Results from observations of the 50 or so O6–A5 stars have been presented in Paper II; in this contribution, we have focused primarily on the late-type PMS stars. Most (at least three-fourths) of the known or probable cluster members in our optical catalog do not have measured spectral types, photometric stellar magnitudes, rotational periods, or rotational velocities; hence, we know little about the physical nature of these stars, i.e., we cannot derive masses, effective temperatures, bolometric luminosities, or rotation rates for them. For these stars, we estimate a count rate to X-ray luminosity conversion factor by making assumptions about the distance to the cluster (440 pc), the incident spectrum of the X-ray–emitting plasma (1 keV; Raymond & Smith 1977), and the hydrogen column density in the line of sight to the star (for most stars more than $\sim 5'$ from the Trapezium, $N_H \sim 5 \times 10^{20}$ cm $^{-2}$). The count rates in Table 2 can thus be used to determine L_X for the X-ray–detected cluster members. Individual upper limits have not been calculated for the more than 700 undetected cluster members, presumably late-type PMS stars, for which little optical information is available. However, we estimate the sensitivity of these observations at the distance to Orion to be $L_X \sim 10^{30}$ ergs s $^{-1}$ at the 3σ level.

We have determined a mean X-ray luminosity of no less than $\bar{L}_X \sim 2.0 \times 10^{30}$ ergs s $^{-1}$ for the approximately solar-mass cluster members and a median X-ray luminosity below the survey threshold, i.e., $\lesssim 1.0 \times 10^{30}$ ergs s $^{-1}$. By comparison, the solar-mass PMS stars in Chamaeleon I have a mean X-ray luminosity $\bar{L}_X \sim 7 \times 10^{29}$ ergs s $^{-1}$ (Feigelson et al. 1993) while those in Taurus-Auriga have $\bar{L}_X \sim 1.4 \times 10^{30}$ ergs s $^{-1}$ (Strom & Strom 1994). Based on *ROSAT* all-sky survey observations of Taurus-Auriga, Neuhäuser et al. (1994) find a median X-ray luminosity of $L_X \sim 1.0 \times 10^{30}$ ergs s $^{-1}$, like that obtained in the Orion Nebula.

As discussed in Paper I, the higher mean X-ray luminosities in the Orion Nebula and in Taurus-Auriga may be an indication of the extreme youth of both these complexes 10^5 yr $< \tau_* < 10^7$ yr as compared to Chamaeleon I. The ρ Oph cloud is another important nearby star-forming region because of its

extreme youth ($\tau_* < 10^6$ yr). The low-mass stars in ρ Oph are extremely variable and appear to be as active as the PMS stars in the Orion Nebula (Montmerle et al. 1983). However, X-ray luminosities have been derived for only a handful of *Einstein*-detected ρ Oph members (Bouvier 1990).

For the 127 late-type cluster members with measured spectral types, rotational periods, or velocities (so-called group 1 stars), we have estimated T_{eff} , A_V , and bolometric corrections to obtain L_{bol} values, whenever possible. We discuss the optical data used in these estimates and consider uncertainties in the determination of L_{bol} and L_X/L_{bol} . Plots of both these X-ray activity indicators versus effective temperature indicate that strong X-ray emission in late-type PMS stars turns on around spectral type F6, with the upper envelope of activity rising sharply with decreasing effective temperature, peaking around spectral type G8. For late G, K, and M cluster stars, there is a 1.5 order of magnitude dispersion in L_X and L_X/L_{bol} at a given effective temperature. This spread is much larger than our uncertainties in either X-ray activity indicator. We thus conclude that most of the spread in activity is indicative of a real dispersion in the level of coronal X-ray emission, at least for the sample of stars in group 1.

From a theoretical standpoint, we expect such a dispersion in coronal X-ray activity in convective-envelope stars like the late G, K, and M PMS stars in the Orion Nebula, because the efficiency of the magnetic dynamo which drives the X-ray emission should depend on the depth of the outer convective envelope and its rotation rate. The efficiency of the dynamo is often parameterized in terms of the inverse Rossby number, defined as $R_0 \equiv P_{\text{rot}}/\tau_c$, where τ_c is the convective turnover time. One complicating factor in PMS stars is that the depth of the outer convective envelope is not simply a function of effective temperature. We feel that a meaningful estimate of τ_c and, hence, R_0 , requires accurate photospheric bolometric luminosities and effective temperatures combined with an appropriate theoretical model of pre-main-sequence evolution. Given the uncertainties in the empirical data, we have examined X-ray activity as a function of rotation rate only. Plots of L_X and L_X/L_{bol} versus $v \sin i$ and P_{rot} indicate no clear correlation between X-ray activity and rotation.

In § 4 we discuss biases in the sample of stars with measured P_{rot} and $v \sin i$. On the one hand, stars with measured $v \sin i$ are strongly biased toward more luminous stars (because the sample of stars with high-dispersion spectra is limited to stars brighter than $V \sim 12$) and toward rapid rotators (because these spectra have a resolution $\sim 20 \text{ km s}^{-1}$). On the other hand, many stars with measured P_{rot} are not detected in these observations. The relatively high L_X upper limits and the relatively uncertain bolometric luminosities we have determined for these stars do not sufficiently constrain L_X/L_{bol} to decisively rule out a possible correlation between activity and rotation. Because rotational period determinations are not subject to the severe biases associated with spectroscopic rotational velocity measurements in Orion, P_{rot} is the ideal measure of stellar rotation for late-type PMS stars.

Two important issues merit attention in our discussion of these *ROSAT* X-ray data: binarity and circumstellar accretion disks. Binarity may account for some of the spread in L_X , e.g., in Figures 8a, 9a, and 10a, because both components of a binary system may contribute to the observed X-ray emission, while only the effective temperature, rotational velocity, or rotational period of the primary is measured. While the radial velocity study of Abt et al. (1991) has identified a number of

spectroscopic binaries in Orion, the handful of late-type systems observed do not allow the frequency of binarity among late-type stars in Orion to be estimated. Based on direct imaging of the Trapezium cluster with the *HST* Planetary Camera, Prosser et al. (1994) determine a binary frequency consistent with the roughly 60% binary frequency found by Duquennoy & Mayor (1991) for G-type stars in the field. If we extrapolate the Prosser et al. results to the entire Orion Nebula cluster, over half the stars plotted in Figures 8, 9, and 10 are binaries. Of course, our implicit assumption that the cluster stars are single-star systems can, at most, only account for a factor of 2 error in our determination of L_X .

Circumstellar accretion disks around some late-type PMS stars are important for two reasons. First, blue emission from a disk-boundary layer and near-infrared emission from the disk itself may lead to a substantial overestimate of the photospheric bolometric luminosity; for this reason, we have used the bolometric luminosity estimates of Strom (1993) whenever possible because these are based on *J*-band near-infrared magnitudes (spectral energy distributions of late-type PMS stars suggest that nearly all of the emission in the *J* band is photospheric; Strom & Strom 1994). Second, the presence of an accretion disk and the timescale for disk dissipation may be very important in determining the angular momentum evolution of a star on its convective Hayashi track and may ultimately decide which stars become rapid and slow rotators on the ZAMS. Edwards et al. (1993) have shown that the presence of accretion disks directly regulates the rate of surface rotation on low-mass PMS stars. Moreover, Strom (1994) has shown that disk-regulated rotation is only observed in PMS stars with spectral type later than $\sim F5$. This is precisely the point at which strong coronal X-ray emission emerges in these stars. If X-ray emission is a tracer of magnetic activity, then the mechanism for disk regulation would appear to be related to the presence of strong surface magnetic fields. One model originally proposed by Königl (1991) and discussed by Edwards et al. (1993) to explain the rotational periods of stars with massive accretion disks is that the stellar photosphere is connected to disk material beyond the corotation radius by way of extended magnetic field lines, thereby effectively preventing the photosphere from rapidly rotating. If strong, extended magnetic field lines do exist on the surface of late-type stars with disks, i.e., slow rotators, the question arises as to how these fields are generated within the context of standard magnetic dynamo theory.

Only 36 stars with *JHK* photometry were observed in our *ROSAT* HRI images. We use an infrared excess color $\Delta(H-K) \geq 0.1$ as an indicator of a massive accretion disk (Edwards et al. 1993). Of the 10 late-type cluster members with $\Delta(H-K) \geq 0.1$, eight were detected as X-ray sources. Including upper limits, these stars have median $L_X \sim (5.9 \pm 2.4) \times 10^{30} \text{ ergs s}^{-1}$ and $L_X/L_{\text{bol}} \sim (2.0 \pm 1.5) \times 10^{-4}$. Of the 26 late-type cluster members with $\Delta(H-K) < 0.1$, 23 were detected as X-ray sources. Including upper limits, these stars have median $L_X \sim (1.1 \pm 0.2) \times 10^{31} \text{ ergs s}^{-1}$ and $L_X/L_{\text{bol}} \sim (5.0 \pm 0.6) \times 10^{-4}$. While the number of stars with *JHK* photometry is small and biased toward optically luminous stars, these results suggest slightly lower median L_X and L_X/L_{bol} values for stars with massive accretion disks, i.e., classical T Tauri (CTT) stars.

Similarly, in the Chamaeleon I cloud, Feigelson et al. (1993) find that their sample of CTT stars have slightly lower X-ray luminosities than their sample of weak-line T Tauri (WTT)

stars; however, they caution that this result is probably a selection effect in the WTT sample. We point out that Damiani, Micela, & Vaiana (1991) find that, for a sample of 53 T Tauri stars detected by *Einstein*, WTT stars have slightly higher X-ray activity levels than CTT stars. Similarly, Neuhauser et al. (1994) find that WTT and CTT stars in Taurus-Auriga have X-ray luminosities $\sim 10^{30}$ and 3×10^{29} ergs s $^{-1}$, respectively. They attribute the higher mean X-ray luminosity of WTT stars to the fact that WTT stars are generally more rapidly rotating. In order to discern a difference in activity levels between T Tauri stars with and without massive accretion disks in the Orion Nebula, *JHK*-band CCD photometry must be obtained for a larger, magnitude-limited sample of stars.

With these considerations in mind, we conclude that our plots of X-ray activity versus rotational velocity and rotational period for late-type stars indicate (a) that approximately three-fourths of the stars with measured rotation rate have $\log(L_X/L_{\text{bol}}) \geq -3.5$, possibly indicating saturated activity, and (b) that $\log L_X$ and $\log(L_X/L_{\text{bol}})$ do not appear to be clearly related to rotation rate. The upper envelope of X-ray activity does, however, appear to depend on effective temperature and bolometric luminosity. In addition, for the handful of late-type stars with measured infrared excesses, the data suggest that stars with circumstellar accretion disks may have lower levels of X-ray activity.

In most respects, our findings based on these *ROSAT* HRI data and the *Einstein* data reported in Paper I are essentially the same. Similarly, Feigelson et al. (1993) find that X-ray luminosity is correlated with bolometric luminosity, mass, radius, and effective temperature; they find no evidence of an activity-rotation correlation in the Chamaeleon I *ROSAT* data. In contrast, the results of Stauffer et al. (1994) and Micela et al. (1994) for main-sequence dwarfs in the Pleiades and of Bouvier (1990), Damiani et al. (1994), Strom & Strom (1994), and Neuhauser et al. (1994) for late-type PMS stars in Taurus-Auriga all point to increased coronal activity with increased rotation rate. For example, among the low-mass dwarfs in the Pleiades, Stauffer et al. (1994) find saturation-type relations, i.e., X-ray activity increasing with rotation rate at low rotational velocities and saturated activity at higher rotational velocities. For PMS stars in Taurus-Auriga, Damiani et al. (1994) demonstrate a monotonic increase in L_X with decreasing P_{rot} over a wide range of rotational periods, with no evidence of saturation, even among stars with rotational period 1 day $< P_{\text{rot}} < 2$ days. Clearly, to what extent rotation determines coronal X-ray activity and how angular momentum and coronal activ-

ity evolve as pre-main-sequence stars contract and dissipate circumstellar material remain open questions.

Although we see no evidence of an X-ray activity-rotation correlation in these *ROSAT* HRI observations of late-type stars in the Orion Nebula, we only have rotation rates for a small, biased sample of stars, and the X-ray and bolometric luminosity determinations are uncertain. We feel the data cannot be more conclusive on this point without more accurate extinction estimates, spectral classifications, bolometric luminosities, and rotation periods for a less biased sample of low-mass stars. In particular, very little is known about the truly slow rotators in Orion.

One notable difference between X-ray observations of the Orion Nebula and those of other nearby clusters and associations is the relatively low detection fraction of intermediate- and low-mass Orion Nebula cluster members. Although the *ROSAT* detection fraction ($\sim 25\%$) is somewhat higher than the *Einstein* detection fraction ($\lesssim 10\%$) (Paper I), the observed count rates are only instantaneous snapshots of sources active enough to be detectable. Future high-sensitivity, high spatial resolution X-ray observations of the Trapezium would provide X-ray luminosities for a larger fraction of low-mass PMS stars, while accurate CCD photometry and classification spectra for a larger, less biased sample of cluster stars would provide better estimates of mass, effective temperature, extinction, and bolometric luminosity.

In addition, the *ROSAT* HRI observations have allowed us to examine both short- and long-term variability of the X-ray sources. X-ray light curves of individual sources have identified at least 10 strong X-ray flares with flare energies in excess of 3×10^{35} ergs. We have looked at the variability of the ensemble of X-ray sources associated with late-type cluster members on the timescale of ~ 1 yr and find that least a fourth of the sources to be significantly variable. This result is similar to the X-ray variability observed in the Orion Nebula a decade before by *Einstein* (Paper I).

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