XMM-NEWTON OBSERVATION OF THE α PERSEI CLUSTER

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Abstract

We report on the analysis of an archival observation of part of the α Persei cluster obtained with XMM-Newton. We detected 102 X-ray sources in the band 0.3–8.0 keV, of which 39 of them are associated with the cluster as evidenced by appropriate magnitudes and colors from Two Micron All Sky Survey photometry. We extend the X-ray luminosity distribution (XLD) for M dwarfs, to add to the XLD found for hotter dwarfs from spatially extensive surveys of the whole cluster by ROSAT. Some of the hotter stars are identified as a background, possible slightly older group of stars at a distance of approximately 500 pc.

Key words: open clusters and associations: individual (α Persei) – stars: activity – X-rays: stars

Online-only material: color figures, machine-readable and VO tables

1. INTRODUCTION

Open clusters have been a keystone in understanding stellar evolution because they contain stars at the same distance with similar reddening formed at the same time with the same chemical composition, at least to a first approximation. Their members display a range of masses, temperatures, luminosities, rotation rates, and multiplicity which can be explored. Comparison of cluster morphology provides an age sequence as a context for the evolution of stars. The well-known spin-down of low mass stars with age due to magnetic braking provides a good example of insight from clusters. This slowing of rotation results in the decrease of coronal X-rays due to their connection with stellar dynamos. Good summaries of the decrease in stellar activity as stars age for a range of masses are provided by Favata & Micela (2003) and Güdel (2004).

α Per is a young open cluster, found to be 50 Myr old from upper main sequence turnoff morphology (Meynet et al. 1993). More recently, Stauffer et al. (1999) have found an age of 90 Myr from the low mass lithium depletion boundary. Although there is some dispersion in the exact calibration of the age of the cluster, the sequence of age (increasing from the Orion Nebula Cluster (ONC) through the α Per cluster through the Pleiades) is generally agreed. Thus, studies find a range in age from 50 to 90 Myr. We will use the shorthand “50 Myr” for the age of the cluster.

This age makes it an excellent comparison for Cepheids and their companions. Indeed, α Per itself is a yellow supergiant, with similar parameters to Cepheids, except for its location at a temperature outside the instability strip. As an example of usage of the cluster, we have observed a number of Cepheids with the Hubble Space Telescope Wide Field Camera 3 to identify a population of resolved low-mass stars close to Cepheids which are probable physical companions. X-ray observations showing an activity level comparable to that of α Per dwarfs would confirm that they are young companions rather than chance alignments with old field stars (e.g., Evans et al. 2012). Another interesting aspect of a cluster of this age is that it is the period when young planets have just finished forming, and thus we gain insight into the X-ray environment during the early formation of atmospheres.

Because the cluster is nearby, it covers a wide area in the sky. It was observed with a raster of pointings by ROSAT (Randich et al. 1996). Essentially all the late F, G, and K members from the membership studies of Prosser (1992) were detected. Three deeper pointed ROSAT observations (22–25 ks) were subsequently made covering part of the cluster (Prosser et al. 1996). Two additional studies were made using near IR observations to try to identify counterparts of ROSAT sources (Prosser & Randich 1998; Prosser et al. 1998, PRS below). In the second of these, the authors identified a number of G and K stars with lower X-ray luminosity than expected for cluster members, which they termed “bad LX stars.” Finally, a deeper (60 ks) exposure of a small part of the cluster was made with XMM, which was described briefly by Pallavicini et al. (2004). This is the observation which we discuss here, which allows us to investigate fainter sources as well as the spectral properties of the sources. In addition to being relatively nearby (170 pc; Randich et al. 1996), the α Per cluster is also lightly reddened (E(B – V) = 0.09 mag; Meynet et al. 1993), making the data interpretation relatively robust.

The supergiant α Per itself was detected in the ROSAT observations (Prosser et al. 1996). However, recently Ayres (2011) has suggested that there is evidence that the X-rays might actually be produced by a low-mass X-ray active companion.

In this study we add the results of the deeper XMM image to the existing literature on the cluster. Specifically, in the sections that follow, we discuss the observations, the source detection and near IR matches, the source parameters (luminosity and spectra), the X-ray luminosity distribution (XLD), light curves, and the results. Of particular importance in deriving the cluster parameters (discussion section, Section 4) is a grouping of stars likely to be a cluster of young stars behind the α Per cluster.

2. OBSERVATIONS AND DATA ANALYSIS

A fraction of the α Per cluster was observed by XMM-Newton as part of the Mission Scientist Guaranteed Time (Pallavicini et al. 2004). A 60 ks observation was obtained in

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Figure 1. Composite PN Mos 1 Mos 2 XMM-Newton image within the α Per field. The bands used are: red = 0.3–1.0 keV, green = 1.0–2.5 keV, blue = 2.5–8.0 keV. (A color version of this figure is available in the online journal.)

2000 September 5 using EPIC MOS and PN cameras on board XMM-Newton with a pointing at R.A.: 3°26′16″ and decl.: 48°50′29″. Figure 1 shows the composite PN, MOS 1 and MOS 2 image of the EPIC field within the α Per cluster.

We carried out Data Analysis similar to that in Pillitteri et al. (2004). We used the standard tasks of SAS v10.0 to reduce the Observation Data Files and obtain event tables calibrated in arrival time, energy and astrometry. First the events were filtered to be within the band 0.3–8.0 keV, appropriate for the coronal emission we want to investigate. Good time intervals were filtered out after inspecting the light curve of events at energies higher than 10 keV and removing high background intervals (with rate thresholds of >2.5 counts s⁻¹ for PN and >0.5 counts s⁻¹ for MOS). This optimizes the event lists for the detection of faint X-ray sources.

2.1. Source Detection

Source detection was performed using the algorithm based on wavelet convolution described in Damiani et al. (1997a, 1997b) and optimized for XMM-Newton (Pillitteri et al. 2004). The threshold used for positive detection of sources was 4.8σ above local background fluctuations.

The full list of source parameters is provided in Table 1 in the online journal. The first few entries are provided in the hardcopy illustrate the content. The columns of the table list the source number, right ascension, declination, distance off axis, source count rate, and effective exposure time (for the summed MOS and PN detectors, assuming a PN–MOS conversion factor of 3.1). We detected 102 sources in 0.3–8.0 keV band.

See http://xmm.esac.esa.int/sas/current/documentation/threads/EPIC_filterbackground.shtml

Table 1
List of X-Ray Sources Detected in EPIC-XMM-Newton Image

| ID | R.A. (J2000) | Decl. (J2000) | Offaxis (′) | Significance (σbkg) | Rate (counts ks⁻¹) | Exp. Time (ks) |
|----|--------------|---------------|------------|---------------------|-------------------|---------------|
| 1  | 03:26:37.9   | 48:37:28.9    | 15         | 15.7                | 5.55              | 48.3          |
| 2  | 03:25:43.7   | 48:38:32.4    | 14         | 7.76                | 1.63              | 50.7          |
| 3  | 03:26:43.6   | 48:38:47.1    | 14         | 6.75                | 1.66              | 57.3          |
| 4  | 03:26:01.3   | 48:39:10.1    | 12         | 21.7                | 4.83              | 59.9          |
| 5  | 03:25:50.9   | 48:39:22.2    | 13         | 29.4                | 7.41              | 57.4          |

This table is available in its entirety in machine-readable and Virtual Observatory (VO) forms in the online journal. A portion is shown here for guidance regarding its form and content.

2.2. Optical Catalogs

We have cross-correlated the positions of X-ray sources with the optical catalogs of Prosser (1992), Randich et al. (1996) and Deacon & Hambly (2004) with a match radius of 5″. Only one object of the catalog by Prosser is in the main field of view of XMM but was not detected. Another object from that catalog is on the edge of the XMM field and was also undetected. Two objects of the Deacon and Hambly catalog are detected in X-rays, and four stars from the Randich et al. catalog are matched with X-ray sources. We have used the Two Micron All Sky Survey (2MASS) catalog (Cutri et al. 2003) to find near IR counterparts to the X-ray sources, finding 39 matches (Figure 2). X-ray sources detected on the image (Figure 1) are a mixture of active young stars from the α Per cluster and background objects. Any star more massive than M5 would have a K magnitude ≤13.6 at the age and distance of α Per (Siess et al. 2000). Therefore, we assume that sources without counterparts in the 2MASS catalog are distant active galactic nuclei which are...
Figure 2. The combined PN, MOS1 and MOS2 XMM image with the 2MASS sources indicated in red; the stars from the Prosser catalog are in green. (A color version of this figure is available in the online journal.)

Table 2

| ID | R.A. J2000 | Decl. J2000 | 2MASS ID | J (mag) | H (mag) | K (mag) | kT (keV) | E.M. (cm⁻³) | log fX (erg s⁻¹ cm⁻²) | log LX (erg s⁻¹) |
|----|------------|-------------|----------|--------|--------|--------|--------|-----------|-----------------|----------------|
| 4  | 03:26:01.3 | 48:39:09.7  | 03260131+4839097 | 12.60  | 11.92  | 11.69  | 0.76   | 51.7      | −13.8           | 28.8           |
| 10 | 03:26:14.2 | 48:42:38.3  | 03261419+4842382 | 12.48  | 11.80  | 11.56  | 0.89   | 51.9      | −13.6           | 29             |
| 19 | 03:26:22.7 | 48:44:20.1  | 03262270+4844201 | 12.77  | 12.31  | 12.20  | 0.86   | 50.7      | −14.9           | 27.7           |
| 22 | 03:26:52.6 | 48:44:37.9  | 03265263+4844378 | 11.10  | 10.77  | 10.76  | 0.88   | 51.1      | −14.4           | 28.1           |
| 42 | 03:24:58.8 | 48:48:14.7  | 03245884+4848147 | 16.47  | 15.69  | 14.52  | ⋯      | ⋯         | ⋯              | ⋯              |

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too faint in the IR. Table 2 provides IR photometry for sources identified as stars within 5″ of the position of X-ray sources, with source number, coordinates, 2MASS ID, and J, H, and K magnitudes in successive columns. Parameters derived from fitting (kT, emission measure, and luminosity) are discussed below in Section 3.2. Note that in Table 2, X-ray luminosities have been computed from X-ray fluxes assuming the sources are at the distance of α Per. This is probably not true for the “bad LX” sequence (discussed in Sections 3.1 and 4 below).

3. RESULTS

3.1. The X-Ray Luminosity

The color–magnitude diagram from the 2MASS photometry is shown in Figure 3. In it, the sources are numbered with the X-ray source ID (Table 1). The size of the circle is proportional to the X-ray luminosity, which is derived from the count rate using a conversion factor from PIMMS derived from a 1-T APEC spectrum with kT = 1 keV and NH = 10²⁰ cm⁻³. Overlaid in the figure is the isochrone from Siess et al. (2000) for an age of 50 Myr and solar metallicity. The figure shows the well-known decrease in X-ray luminosity with bolometric luminosity along the main sequence. The Siess tracks allow us to infer masses (see Section 3.3).

A second sequence below the main cluster sequence is present, near the shifted isochrone (dotted line) in Figure 3. This sequence is made up of sources 19, 22, 25, 39, 58, 59, 62, 63, 67, and 87 in Table 2. For stars fainter than J ≳ 14 mag, the distinction between the two sequences is more ambiguous. However, referring to the morphology of the color–magnitude diagram in Lodieu et al. (2012; Figure 6) the main sequence is nearly vertical, and we accept the fainter stars as predominantly belonging to the cluster itself. The lower sequence appears to correspond to sources labeled “bad LX,” in PRS’s Figure 5. These sources have a lower X-ray luminosity than the sequence of cluster members. We draw attention to the low-lying sequence in the near IR data (Figure 3), and will discuss the characteristics of these stars in the succeeding sections. It is possible, of course, that some of the stars near the isochrone of the cluster are not in fact cluster members. Star 71 could for instance be a foreground star.
Figure 3. The 2MASS $J-(J-K)_0$ color magnitude diagram for the stellar X-ray sources. The circles are proportional to the strength of the X-ray signal. Spectral types for the $(J-K)_0$ colors are indicated on the top axis. The top upper solid line is the isochrone for 50 Myr age from Siess et al. (2000) for the distance of $\alpha$ Per. The dashed line just below that is the isochrone for 90 Myr. The solid line at the bottom is the same isochrone shifted by 2.5 mag to match the “bad LX” sequence.

(A color version of this figure is available in the online journal.)

Figure 4. The log of the count rate as a function of $J$ magnitude. Symbols are as follows: F–G stars: *; K-early M stars: triangles; late M stars: x; “bad LX” stars: squares. To emphasize the location of the “bad LX” stars, they have been connected in order of magnitude. Two distinct sequences are seen, merging at the faintest stars. $J$ is in magnitudes, count rate is counts per ks.

Figure 5. The log of the count rate as a function of $J-K$ color. Symbols are the same as Figure 4. The “bad LX” stars clearly have lower count rates than cluster main sequence stars of the same color. $J-K$ is in magnitudes, count rate is counts per ks.

We have divided the stars in Figure 3 in a straightforward way to examine the dependencies of $L_X$. There is a significant gap between the cluster main sequence, and the lower sequence, the stars classified “bad LX.” Within the cluster sequence, stars have been grouped into “F–G,” “K-early M,” and “late M” according to gaps in the magnitude distribution. Figure 4 shows the count rate as a function of $J$ magnitude. The F–G stars (asterisks) and the K–M stars (triangles) show the well known progression to lower count rates for cooler stars. The exceptions are a few of the hottest F–G stars, suggesting that their convective envelopes and X-ray production are just becoming established. The bad $L_X$ stars occur in a separate location, with lower count rates and fainter magnitudes, except that the faintest stars in both sequences which are mixed in the figure. Note that this is despite the fact that Figure 3 shows that the “bad $L_X$” stars are in general bluer than the K–M stars in the $\alpha$ Per sequence. Similarly, Figure 5 shows the log count rate as a function of color. The “bad $L_X$” stars clearly have lower count rates than cluster main sequence stars of comparable colors. Thus low count rate
Figure 6. The temperature $kT$ (keV) as a function of the $J - K$ color. Symbols are the same as in Figure 4, except that the “bad $L_X$” stars are linked in order of $kT$. $J - K$ is in magnitudes, $kT$ is keV.

Table 3
Two Temperature Fits for the α Per Cluster

| Src | $kT_1$ (keV) | $kT_2$ (keV) | Off Ax (arc) | Cts |
|-----|-------------|-------------|-------------|-----|
| 4   | 0.18        | 0.88        | 12          | 289 |
| 36  | 0.5         | 0.86        | 8.1         | 7030|
| 41  | 0.46        | 0.9         | 3.5         | 10200|
| 52  | 0.24        | 0.98        | 1.8         | 3170 |
| 68  | 0.77        | 1.42        | 13          | 2100 |
| 74  | 0.81        | 1.48        | 13          | 2380 |
| 85  | 0.74        | 1.52        | 9           | 651  |
| 90  | 0.81        | 2.6         | 12          | 279  |
| 96  | 0.57        | 1.24        | 11          | 2520 |

“bad $L_X$ stars” have properties distinct from cluster members in both near IR photometry (Figure 3) and in X-rays.

3.2. Spectra

One of the most important parameters to examine for the cluster stars is the temperature derived from the X-ray spectra. In order to use temperature from a large number of sources, we have made 1 temperature fits of APEC models to the spectra with XSPEC software (version 12.6). These temperatures are listed in Table 2. For low count rates, we did not fit spectra, and the temperature, emission measure, flux and luminosity columns in Table 2 are blank. These sources are omitted from figures. (Luminosities in Figure 3 were derived as in Section 3.1 assuming $kT = 1$ keV.) Figure 6 shows the temperatures for the groups of stars as a function of the $J - K$ color. The late M stars in Figures 4 and 5 are all too weak to have a reliable temperature determination. All groups (the F–G stars, the K–M stars and the bad $L_X$ stars) have a range to temperatures. However the mean X-ray temperature $kT$ for the bad $L_X$ stars (0.57 keV) is lower than the mean for the other two groups (0.80 keV). Figure 7 shows the X-ray temperature as a function of luminosity for all groups. The F–G and K–M stars show a range of temperatures along with the well-known decrease in X-ray luminosity for the lower mass stars. These two groups exhibit minimal overlap in the figure and a large dispersion. The dotted line indicates the upper envelope of the bad $L_X$ stars, which do not in general reach the highest luminosities of the other groups.

Table 4
Two Temperature Fits for the ONC (XMM)

| ObsID    | Src | $kT_1$ (keV) | $kT_2$ (keV) |
|----------|-----|--------------|--------------|
| 0212480301 | 304 | 0.97         | 2.49         |
| 0093000101 | 281 | 0.78         | 1.86         |
| 0212480301 | 221 | 0.30         | 1.58         |
| 0212480301 | 237 | 0.51         | 1.33         |
| 0212480301 | 280 | 0.81         | 1.57         |
| 0093000101 | 281 | 0.78         | 1.86         |
| 0093000101 | 229 | 0.84         | 1.76         |
| 0093000101 | 200 | 0.73         | 1.86         |
| 0093000101 | 194 | 0.96         | 2.14         |
| 0093000101 | 196 | 0.25         | 1.30         |
| 0093000101 | 309 | 0.20         | 0.99         |
| 0093000101 | 132 | 1.04         | 3.71         |
| 0093000101 | 158 | 0.25         | 1.02         |

To illustrate the effects of different source temperatures, Figure 8 shows the spectra of two strong sources, Src 68 and Src 36. Src 68 is an F star ($J = 9.2$ mag) with a single temperature fit (Table 2) $kT = 0.64$. Src 68 has $J = 10.11$ mag, and $kT = 0.9$. The softer spectrum of Src 36 is clearly apparent in Figure 8.

For about half the strong sources, the $\chi^2$ was satisfactory for a single temperature fit. For the other sources, Table 3 lists the temperatures for two temperature fits, together with the off-axis distance and source counts. Source counts include all three cameras (MOS1, MOS2, and PN), taking into account the different effective areas of the three cameras. Figure 9 shows the results. A correlation between the two temperatures is present, as found by Wolk et al. (2005) and Briggs & Pye (2003). In order to investigate this relation as a function of age, Figure 9 includes data from the 1–3 Myr ONC COUP project (Wolk et al. 2005), the 100 Myr Pleiades (Briggs & Pye 2003) and 30 Myr NGC 2547 (Jeffries et al. 2006) as well as fits to XMM ONC sources (Table 4) to explore this with XMM and Chandra data. ONC Chandra data were taken from Wolk et al. for the “characteristic flux” (their Table 4), omitting the data for the four stars flagged as poor fits. Their fit to that data ($kT_2 = 2.14 \times kT_1 + 0.660$ keV) is also included in Figure 9. Data for the Pleiades were taken from the XMM observations of Briggs & Pye (2003), using the two temperatures from the PN (their Table 3), since only one source had determinations for several instruments,
and they are all similar.\footnote{Daniel et al. (2002) also fit Chandra spectra of several sources, but $kT_2$ was fixed in their solutions.} We also include nine sources from the 30 Myr cluster NGC 2547 (Jeffries et al. 2006). Data for NGC 2547 is taken from the two temperature fits in Jeffries et al. (2006, their Table 5), omitting sources where $kT_2$ is described as unconstrained in the fits. Sources which are late B stars (7 and 8) were also omitted. However, their two temperatures match those of the cool stars very well, confirming that the X-rays from these sources come from a low-mass companion.

Figure 9 shows that both the $kT_1$ and $kT_2$ temperatures are smaller on average for the 50 Myr $\alpha$ Per stars than for the younger ONC stars (1–3 Myr; Megeath et al. 2012). This is expected as a result of the decrease in stellar activity as stars age. (The single point for $\alpha$ Per with $kT_2 > 2$ is for a source which is both weak compared to the others and off axis, and hence has a significant systematic error in addition to the measurement error.) The Pleiades stars (100 Myr) fall among the $\alpha$ Per stars, but the hottest of both $kT_1$ and $kT_2$ for Pleiades stars is cooler than those for the $\alpha$ Per stars. Similarly, the NGC 2547 stars (30 Myr) largely overlap the $\alpha$ Per stars. The lines at the bottom of Figure 9 indicate the range of $kT_1$ values ordered from the youngest cluster (ONC) to the oldest (the Pleiades). This shows the decrease in stellar activity as stars age. Once on the zero-age main sequence (ZAMS), rotation and hence dynamo activity decreases as stars spin down. Jeffries et al. discuss activity at 30 Myr in NGC 2547 for G, K, and M stars. At this age, solar mass stars have just contracted to the ZAMS. They argue that coronal temperatures decrease up to this point as gravity increases. The decrease in the harder component in solar mass stars was previously noted by Güdel et al. (1997) and subsequently by Telleschi et al. (2005).

There is a correlation between $kT_1$ and $kT_2$ in Figure 9, particularly for $\alpha$ Per and the ONC. There is a suggestion, however, that the relation for $\alpha$ Per is less steep than for the ONC. That is, even for the same soft component temperature $kT_1$, the hard component decreases as stars age. The Pleiades stars (100 Myr) cluster among the $\alpha$ Per stars, although the coronae appear generally cooler than the $\alpha$ Per sample and there appears to be much less differentiation among the individual stars, with five of the eight being well described as $kT_1 = 0.35 \pm 0.050$ keV and $kT_2 = 0.950 \pm 0.100$ keV. Due to this clustering no slope can be determined for the Pleiades stars. In fact the concept may no longer be relevant at that age if the hot component is gone.
Typically older cool stars have a corona that is dominated by a one-temperature cool plasma. If the cool component at 100 Myr has already reached this asymptotic minimum, then these stars may be best described merely a single temperature which is a function of time.

This discussion, of course, is produced from a sample for all clusters that is biased in the sense that the two temperature fits are only possible for the strongest X-ray sources. In addition, in the α Per cluster, a number of strong sources are satisfactorily fit with one temperature. Furthermore, the samples from different clusters may contain a different distribution of spectral types, again creating possible bias.

3.3. X-Ray Luminosity Distribution (XLD)

Although the XMM field covers only a small part of the α Per cluster, the exposure is deeper than the ROSAT images. We derive an XLD to compare with the ROSAT results for the full cluster area using the ASURV software package. As discussed in Section 2.2, there are two sequences. The brighter sequence is from the cluster itself. There is also a fainter sequence, corresponding to the “bad $L_X$” stars, which will be discussed further in Section 4. The XLD is derived from the upper cluster sequence. Figure 3 shows that it contains a natural divide in the $J/(J-K)_0$ diagram, with a gap in both color and magnitude. The sources 32, 36, 41, 52, 65, 68, 71, 74, 85, and 96 in Table 2 belong to the earlier side of the low-mass main sequence stars (G–K stars). Others in that sequence are assigned to the cooler low-mass star group (M stars). The division in $(J-K)_0$ comes at the end of the K dwarf color, so the first group contains F, G, and K stars. Since the number of sources in the part of the cluster we are sampling is small, we are not able to subdivide this group further. The cooler group contains M stars. Since we do not have a list of authenticated faint cluster members, we do not have upper limits for nondetections of faint members. Figure 10 provides the results. The luminosity distribution for the F, G, and K stars is similar to the results from Randich et al. (1996) for the full cluster. For instance, the mean log $L_X$ from that study is 29.63 erg s$^{-1}$ (F dwarfs), 29.74 erg s$^{-1}$ (G dwarfs), and 29.56 erg s$^{-1}$ (K dwarfs), comparable to the blue line in Figure 10. For the M dwarfs, the deeper XMM data provide a distribution that continues more smoothly to lower luminosities than the Randich et al. distribution which has a mean log $L_X$ of 28.96 erg s$^{-1}$. For completeness, we derive an XLD for the “bad $L_X$” distribution as though it were at the same distance as the cluster even though this is likely an incorrect assumption (see Section 4). Thus, the XMM results for the α Per cluster are in agreement with the previous ROSAT results for the XLD for F, G, and K stars, but they extend the XLD to fainter sources for M stars. Figure 10, for instance provides a basis for inferring the properties of possible low-mass companions of Cepheids (Evans et al. 2012), necessary for calculating X-ray exposure times.

3.4. X-Ray Time Variability

We have examined the light curves of the sources to look for time variability, since flares are expected at the young age of the α Persei cluster. However because most of the sources have relatively low counts and 60 ks is a short interval, we discuss here only six bright sources that show possible variability in inspection by eye. Figure 11 shows the PN light curves of these bright sources, all of which belong to the “cluster” sequence. Source 36 shows a smooth rise of about 1σ level and a flare-like event at 43 ks. The flare has peak rate 50% larger than the pre-flare rate and a significance >2σ. The duration is 3–4 ks. Other possible small flares are visible at about the 1σ level. Sources 41, 68, and 96 are largely constant, with possible variability at the 1σ level. Source 74 shows a possible sequence of flares, the first at ≃13 ks with a duration of 8 ks and peak rate about 80% larger than minimum observed rate. Source 90 is interesting because it has a very low count-rate in the first half of the observation, then a slow increase and a steeper fall within 10 ks. The peak rate in this event is about eight times the quiescent rate. In summary, in the brief window of the observation, several sources show evidence of low level variability, but only one has a significant flare.

4. DISCUSSION: BAD $L_X$ SOURCES

We have used the deep XMM exposure of the α Per cluster to sample the XLD of a section of the cluster. In particular we have added a sample of M stars to the previous work. This confirms that the distribution fits nicely between the youngest clusters (e.g., the ONC) and the older Pleiades.

An unusual feature of both the ROSAT and the XMM images of the cluster is the additional sequence, dubbed the “bad $L_X$” stars by PRS. It was first identified in the ROSAT images, however it is clearly evident in the near IR color–magnitude data of the XMM X-ray sources (Figure 3) as well. The simplest explanation is the geometric one, that the “bad $L_X$” sequence comes from a more distant grouping behind the α Per cluster. Interpreting Figure 3 in this way, the sequence is 2.5 mag fainter than the α Per sequence as shown by the shifted isochrone in Figure 3, which translates into a factor of three farther in the distance, making it about 500 pc away. This ignores possible additional reddening at that distance. However, the faintest pair of stars in the “bad $L_X$” sequence are in the late-K and M region where the main sequence in Figure 3 is nearly vertical. Their $(J-K)_0$ is not consistent with significant additional reddening as compared
with the cluster sequence. The increase in the “bad $L_X$” distance of 3 implies an addition of 1 to the log $L_X$ or log count rate. Figure 5 provides a good check on this possibility. Even if the log count rate were adjusted by this amount, it would still fall a little below the $\alpha$ Per sequence for the same $J - K$. This suggests that the grouping may also be a little older than the 50 Myr $\alpha$ Per cluster. There is evidence for this in Figure 6, in that the average $kT$ (in the relevant $J - K$ band) is a little smaller than for the $\alpha$ Per stars with the same colors. Thus there is a suggestion in Figure 6 that the “bad $L_X$” stars may be slightly older than the $\alpha$ Per stars. However there are only eight stars and several parameters involved (distance, reddening, age/temperature) so this is not a conclusion, rather a possible interpretation of the available data. For a second comparison, in Figure 10, if the estimated addition to the “bad $L_X$” of 1. is subtracted from the log $L_X$ of the F–G–K stars of the cluster (blue line), it would be moved nearly to the log $L_X$ XLD (dotted line). It is not surprising from Figure 3 that faint M stars are not detected at the distance of the “bad $L_X$,” and hence the F–G–K stars (blue line) are the best comparison at that distance. While the small number of “bad $L_X$” stars preclude firm conclusions, we at least offer a plausible interpretation of a group about the same age as the $\alpha$ Per cluster or possibly a little older.

PRS remarked that the “bad $L_X$” stars are frequently classified as nonmembers of the $\alpha$ Per cluster on the basis of radial velocities. Of the seven “bad $L_X$” in their Table 4 with radial velocities, five are listed as nonmembers on the basis of radial velocities, and for the other two, the membership status is questionable.

There is one restriction on the distance of the “bad $L_X$” stars, which is that they cover a large part of the $\alpha$ Per area surveyed by PRS. That is, it cannot be so much farther behind that it

![Figure 11. Light Curves for a selection of brighter sources. See text for discussion.](image-url)
covers only a small fraction of $\alpha$ Per cluster area, which is quite extended on the sky. However, $\alpha$ Per cluster members have been found in ground-based studies in an area on the sky about twice as wide at the PRS ROSAT observations (Prosser 1992). Thus a grouping about twice as far away as the $\alpha$ Per cluster is consistent with the spread of “bad $L_X$” stars on the sky.

In summary, a grouping behind the $\alpha$ Per cluster is a plausible explanation for the “bad $L_X$” sequence. This interpretation is key to deriving an XLD appropriate for the 50 Myr stars in the $\alpha$ Per cluster itself.

5. SUMMARY

We have investigated an archival XMM-Newton image of part of the $\alpha$ Per cluster, partly because the age of this cluster makes it appropriate for comparison with low-mass companions of Cepheids. In particular, this data adds observations of X-ray faint M stars to the wider but shallower observations of the whole cluster area by ROSAT. The count rate sequence for the M stars continues the sequence for hotter dwarfs in both $J$ magnitude and $J-K$ color. XLDs have been derived for both the hotter dwarfs, and also the M stars. The “bad $L_X$” sequence identified by PRS is appears to be a background grouping at a distance of about 500 pc and an age similar (or slightly older) than the $\alpha$ Per cluster, as shown by near IR magnitudes and colors, as well as X-ray luminosities and temperatures.

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