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A deep Chandra X-ray observation of NGC 2362

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Abstract. We present a deep Chandra ACIS-I imaging observation of the very young cluster NGC 2362. This cluster, only 5 Myr old, has already cleared most of its inter- and circumstellar dust, and with its small and uniform reddening offers a unique opportunity of studying its pre-main-sequence stellar population with minimal disturbance from a dense interstellar medium. We detect almost 400 X-ray sources, and identify most of them with low-mass pre-main-sequence stars. The quiescent X-ray emission of low-mass cluster stars is found to be rather strictly correlated with the stellar bolometric luminosity, with a spread much smaller (a factor of 2 rms) than that found in other young clusters. Such a small spread in the correlation puts a tight upper bound on the amplitude of X-ray variability, on timescales longer than one day (e.g., activity cycles) in very young coronal sources.

Key words. Stars: activity – Stars: coronae – Stars: pre-main sequence – Open clusters and associations: NGC 2362 – X-rays: stars

1. Introduction

NGC 2362 is a star cluster (of age 5 Myr, and distance 1.5 kpc, Moitinho et al. 2001), which unlike most clusters of the same age has already dissipated most of the residual dust from the star formation process. Its stars have a low and uniform reddening ($E(B-V) = 0.1$, Moitinho et al. 2001). There is also very little evidence of circumstellar material (dust disks), from the almost complete lack of excess emission in the near IR. Therefore, it is an ideal laboratory for early stellar evolution studies, free of the many uncertainties introduced by intra-cluster and circumstellar dust and gas.

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We present here new, high spatial resolution X-ray data on this cluster, obtained with the *Chandra* X-ray Observatory. NGC 2362 was already observed in X-rays with the ROSAT PSPC, but its dense central region remained unresolved (Figure 1). The bright X-ray source near cluster center is the massive star τ CMa (O9.5 I).

2. The high-resolution *Chandra* data and the color-magnitude diagram

Figure 2 shows the (100 ks) *Chandra* ACIS-I image, where 387 point X-ray sources have been detected, resolving the cluster population even in its densest inner parts, near τ CMa.

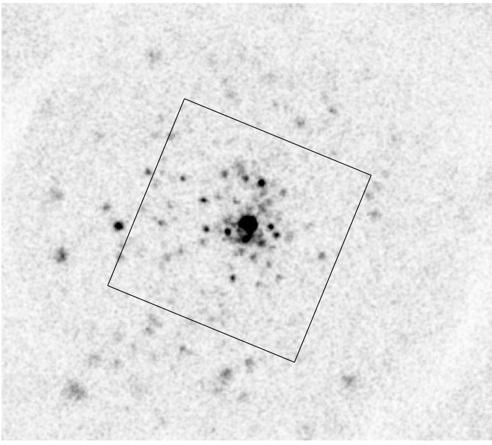

Fig. 1. The ROSAT/PSPC image of NGC 2362, with outlined the field of view (16.9′ × 16.9′) of the new *Chandra* ACIS-I observation.

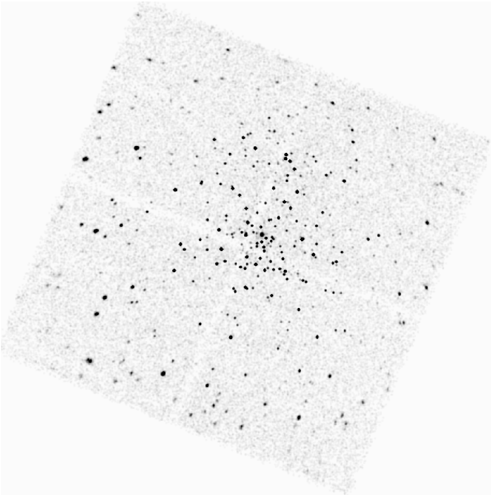

Fig. 2. *Chandra* ACIS-I image of NGC 2362.

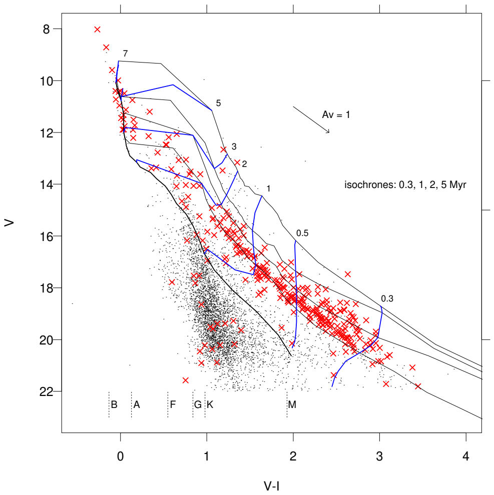

Fig. 3. ($V, V - I$) diagram of NGC 2362.

The obvious clustering of X-ray sources in the ROSAT and *Chandra* images implies that most X-ray sources are indeed cluster members.

Figure 3 shows a ($V, V - I$) diagram of NGC 2362. Optical photometry is from Moitinho et al. (2001). Crosses are stars detected in X-rays with *Chandra*. Evolutionary tracks and isochrones from Siess et al. (2000) are also shown.

A very narrow cluster sequence for K-M stars is obvious in the ($V, V - I$) diagram. The age of stars in this sequence, from Siess et al. tracks, is about 5 Myr, in agreement with Moitinho et al. (2001). Stars in the upper envelope above this sequence might be either binaries, or younger stars, suggesting non-instantaneous star formation in the cluster. Also remarkable is the spread at $V - I \sim 0.6$ (age spread?), where no defined sequence is seen, despite small observing errors.

3. X-ray properties of NGC 2362 stars

Figure 4 is a plot of the X-ray luminosity L_X vs. the stellar bolometric luminosity L_{bol}, for candidate pre-main-sequence (PMS) members of NGC 2362. Big dots are stars falling in the narrow cluster sequence of Figure 3 (most plausible members); crosses are stars falling above that sequence (possible binaries, or younger stars); small dots are cluster stars with $V - I < 1$. For stars with X-ray flares, the quiescent X-ray luminosity was used here. To convert X-ray count rates to fluxes, conversion factors were derived from spectral fits with 2 or 3 temperatures. The two dotted lines correspond to $L_X = 10^{-3} L_{bol}$ and $L_X = 10^{-4} L_{bol}$. Note the very narrow correlation, compared to other star-formation regions.

Comparing the X-ray luminosity functions of NGC 2362 with the younger Orion Nebula

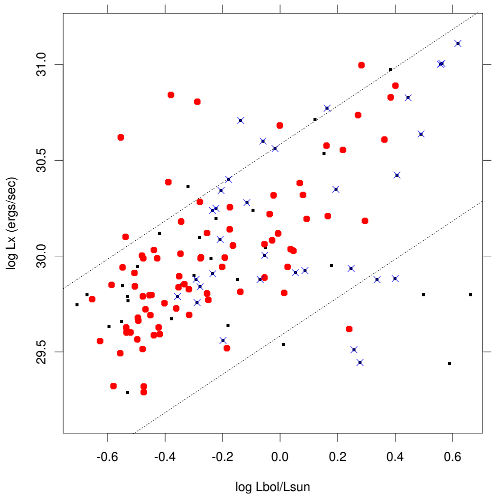

Fig. 4. L_X vs. L_{bol} for PMS cluster members.

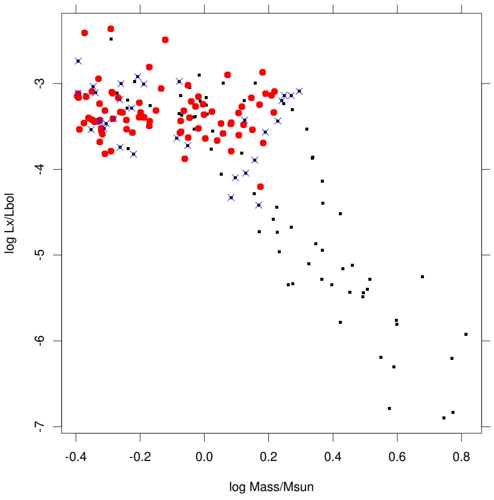

Fig. 5. L_X/L_{bol} vs. mass for PMS cluster members (symbols are as in Fig.4).

Cluster (Flaccomio et al. 2003), we find a small decrease of median X-ray luminosities of NGC 2362 stars with mass $< 2M_\odot$, but a much more drastic reduction for stars in the range $2-3M_\odot$. This can be ascribed to the rapid crossing of these stars in the HR diagram, leading them from K stars with developed convection zones, to A-F stars with shallow or absent convection zones. This agrees well with the older age of NGC 2362 with respect to the Orion Cluster.

Figure 5 is a plot of the ratio L_X/L_{bol} vs. the stellar mass. For late-type stars (less massive than $\sim 2M_\odot$), there is a relatively small spread in the L_X/L_{bol} ratio (0.33 dex rms, or a factor of 2.2), if compared to e.g. the Orion Nebula Cluster (Flaccomio et al. 2003). This does not include short-term variability (flares), but puts severe constraints on any long-term variability (e.g., cycles), whose amplitude cannot thus exceed a factor $\sim$ 2. The average L_X/L_{bol} of low-mass stars in NGC 2362 is indicative of 'saturated' emission, and is very similar to that found for *non-accreting* stars in Orion.

Finally, Figure 6 shows cumulative distributions of masses of (PMS) cluster stars, within a radius of $3'$ (1.3 pc) from τ CMa (solid), and outside of this radius (dashed). Mass segregation is already present in NGC 2362, at an age of only 5 Myr.

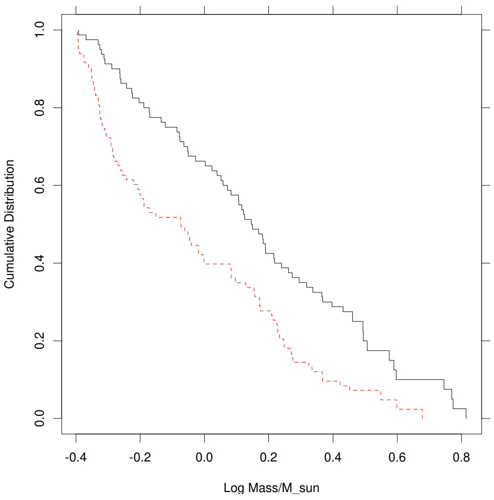

Fig. 6. Mass distributions in different distance ranges from cluster center.

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