XMM-Newton view of eight young open star clusters

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Outline

- Introduction
- Sample Selection and classification
- Temporal and Spectral Analysis
- X-ray Characteristics: Massive, Intermediate and Low mass stars
- Conclusions
Introduction

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<th>Structure</th>
<th>X-ray</th>
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<tr>
<td>Massive ((M&gt; 10 , M_{\odot}))</td>
<td>Winds</td>
<td>(L_x \sim 10^{-7} , L_{\text{bol}})</td>
</tr>
<tr>
<td>O - B Stars</td>
<td>(L_x \sim V_{\text{rot}}^2)</td>
<td>???</td>
</tr>
<tr>
<td>Intermediate ((2&lt; M &lt; 10 , M_{\odot}))</td>
<td></td>
<td>(L_x) absent?</td>
</tr>
<tr>
<td>A Stars</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low mass ((M&lt; 2 , M_{\odot}))</td>
<td></td>
<td></td>
</tr>
<tr>
<td>F to M Stars</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Young Clusters (age < 100 Myr)

Yummy!
All this hydrogen keeps me HOT!!!!
Main-sequence

Young Clusters (age < 100 Myr)

Graph showing the evolution of young clusters with age, temperature, and luminosity. The graph includes lines for different masses: 15\(M_\odot\), 5\(M_\odot\), 2\(M_\odot\), 1\(M_\odot\), and 0.5\(M_\odot\). The graph also includes the main sequence and pre-main sequence phases.
Chandra Orion Ultra deep Project (COUP): 13 days nearly continuous observation in 2003

X-ray levels are roughly constant during Class I-II-III phases

but drop greatly on the main sequence
COUP (PMS) : \[ L_x \propto L_{bol}^{1.0} \]

NEXXUS (MS) : \[ L_x \propto L_{bol}^{0.4} \]

Schmitt & Liefke 2004

- PMS: no activity - rotation relation
  even slow rotators are highly active

MS : \[ L_x \propto P_{rot}^{-2} \]
  - saturation at \[ \log \left( \frac{L_x}{L_{bol}} \right) \sim -3 \]
  for \( P_{rot} \leq 3 \) days

Thomas Preibisch

http://www.mpifr-bonn.mpg.de/staff/tpreibis/3-02-preibisch.pdf
Low Mass Stars

- Not clear exactly at which stage of the PMS stellar evolution, low mass stars deviate from the X-ray saturation level.
- Which fundamental parameters govern their X-ray emission?
- Flare-disk interaction during 5 to 50 Myr?

Intermediate mass Stars

- Possible mechanism of X-ray emission.
- Companion Hypothesis or presence of magnetic fields?
Sample Selection and Classification

understand the X-ray emission properties of Young Stars

NGC 7380, Berkeley 86, Hogg 15 : 4-8 Myr

NGC 663, NGC 869, NGC 884 : 12 -15 Myr

Trumpler 18 : 15-30 Myr

IC 2602 : 40-50 Myr

4 – 50 Myr

FOV : 30’ x 30’

Science Analysis software (SAS).

XMM-Newton Mission
**Source Detection & Identification** (edetect_chain; 0.3-7.5 keV)

**Near Infrared** (Two micron all sky survey; 2MASS; Cutri et al. 2003)

<table>
<thead>
<tr>
<th></th>
<th>Name</th>
<th>X-ray Sources</th>
<th>NIR</th>
<th>Unidentified</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>NGC 663</td>
<td>85</td>
<td>48</td>
<td>36 (42%)</td>
</tr>
<tr>
<td>2.</td>
<td>NGC 869</td>
<td>183</td>
<td>130</td>
<td>70 (38%)</td>
</tr>
<tr>
<td>3.</td>
<td>NGC 884</td>
<td>147</td>
<td>61</td>
<td>67 (45%)</td>
</tr>
<tr>
<td>4.</td>
<td>NGC 7380</td>
<td>88</td>
<td>60</td>
<td>26 (29%)</td>
</tr>
<tr>
<td>5.</td>
<td>Be 86</td>
<td>95</td>
<td>82</td>
<td>8 (8%)</td>
</tr>
<tr>
<td>6.</td>
<td>IC 2602</td>
<td>95</td>
<td>55</td>
<td>39 (41%)</td>
</tr>
<tr>
<td>7.</td>
<td>Hogg 15</td>
<td>124</td>
<td>88</td>
<td>34 (27%)</td>
</tr>
<tr>
<td>8.</td>
<td>Trumpler 18</td>
<td>208</td>
<td>167</td>
<td>38 (18%)</td>
</tr>
</tbody>
</table>
Color-magnitude diagrams: Classification

Sample:

Low mass Stars
(<2M_{\text{sun}}): 152

Intermediate mass stars
(2-10 M_{\text{sun}}): 36

Massive stars
(>10 M_{\text{sun}}): 16
Analysis

Timing (for all the stars)

Flares from 6 stars

Intermediate mass: LAV 796 (B7)
LAV 1174 (B9)

Low mass PMS: SHM2002 3734 (A7)
V553 Car (M4)
V557 Car (G0)
2MASS02191082+5707324 (K5)

Spectral (counts > 40)

The stars with different masses

1T Apec model

$N_H$ is fixed to the extinction for the open cluster.

Massive Stars:

$\log(L_x) = 31-35 \text{ erg s}^{-1}$

$\log(L_x/L_{bol}) = -6.9 \pm 0.3$
Low mass stars

Quiescent state

Plasma temperatures: 0.2 – 3.0 keV

Appears to be constant during 4 to 46 Myr (median value ~1.3 keV)

Decrease after 15 Myr
Low mass stars

Quiescent state

Come out from saturation before 4 Myr

Log(Lx/Lbol) = -3.6 ± 0.4

Integral Distribution

Constant during 4 to 46 Myr

Log Age
Low mass stars

Quiescent state

$L_x/L_{bol} \propto L_{bol}^{-0.48 \pm 0.05}$

All stars

$L_x/L_{bol} \propto L_{bol}^{-0.83 \pm 0.05}$

For 4 to 14 Myr

$L_x/L_{bol} \propto L_{bol}^{-0.36 \pm 0.17}$

For 46 Myr

$L_x/L_{bol}$ depends upon $L_{bol}$.

As low mass stars evolve to MS, their effective temperatures eventually increase and the depth of their convective envelopes reduce, therefore their $L_{bol}$ changes.

During 4 Myr to 46 Myr, the $L_{bol}$ increases nearly three times.

This increase in $L_{bol}$ can produce a decrease of nearly one third in $(L_x/L_{bol})$ (0.5 dex in log scale).

Such a variation cannot be distinguished using present data because the standard deviation in log$(L_x/L_{bol})$ is comparable with the decrease of 0.5 dex.
Intermediate mass stars

If intermediate mass stars themselves emit X-rays, they possess weaker dynamo
Timing Analysis : Flares

**NGC869 #67 (Bin Time=800s)**
- $\chi^2=84$
- dof=29
- $P_{var}>99.999\%$
- $F_{var}=0.89\pm0.17$

**NGC869 #140 (Bin Time=800s)**
- $\chi^2=59$
- dof=36
- $P_{var}=99\%$
- $F_{var}=0.72\pm0.14$

**NGC869 #42 (Bin Time=600s)**
- $\chi^2=162$
- dof=54
- $P_{var}>99.999\%$
- $F_{var}=0.47\pm0.09$

**IC2602 #6 (Bin Time=400s)**
- $\chi^2=571$
- dof=49
- $P_{var}>99.999\%$
- $F_{var}=0.64\pm0.09$

**IC2602 #48 (Bin Time=400s)**
- $\chi^2=5948$
- dof=82
- $P_{var}>99.999\%$
- $F_{var}=0.30\pm0.02$

The function $c(t) = A_0 e^{-t/t_d} + q$ is used to describe the timing analysis.
### X-ray flare characteristics

<table>
<thead>
<tr>
<th>Cluster</th>
<th>ID</th>
<th>Name</th>
<th>FN</th>
<th>Start Time (ks)</th>
<th>Duration (ks)</th>
<th>$T_r$ (ks)</th>
<th>$T_d$ (ks)</th>
<th>Quiescent (cts s(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>NGC 869</td>
<td>67</td>
<td>LAV 796</td>
<td>F1</td>
<td>27.0</td>
<td>11.0</td>
<td>2.3±0.5</td>
<td>1.6±0.4</td>
<td>0.002± 0.001</td>
</tr>
<tr>
<td>NGC 869</td>
<td>140</td>
<td>LAV 1174</td>
<td>F2</td>
<td>0.0</td>
<td>10.0</td>
<td>1.7±0.7</td>
<td>1.0±0.3</td>
<td>0.003± 0.002</td>
</tr>
<tr>
<td>NGC 869</td>
<td>42</td>
<td>SMH2002 3734</td>
<td>F3</td>
<td>0.0</td>
<td>25.0</td>
<td>2.0±0.7</td>
<td>4.6± 0.6</td>
<td>0.004± 0.003</td>
</tr>
<tr>
<td>NGC 869</td>
<td>111</td>
<td>2MASS 02191082+5707324</td>
<td>F4</td>
<td>16.0</td>
<td>21.0</td>
<td>0.8±0.1</td>
<td>3.0± 0.9</td>
<td>0.003± 0.002</td>
</tr>
<tr>
<td>IC 2602</td>
<td>6</td>
<td>V553 Car</td>
<td>F5</td>
<td>24.8</td>
<td>13.2</td>
<td>0.6±0.1</td>
<td>5.3± 1.7</td>
<td>0.014± 0.007</td>
</tr>
<tr>
<td>IC 2602</td>
<td>48</td>
<td>V557 Car</td>
<td>F6</td>
<td>18.4</td>
<td>9.6</td>
<td>1.1±0.2</td>
<td>2.7± 0.2</td>
<td>0.349± 0.036</td>
</tr>
<tr>
<td>IC 2602</td>
<td>48</td>
<td>V557 Car</td>
<td>F7</td>
<td>28.0</td>
<td>8.0</td>
<td>2.3±1.1</td>
<td>1.1± 0.9</td>
<td>0.349± 0.036</td>
</tr>
</tbody>
</table>

- Rise time in the range of 10-40 minutes
- Decay time in the range of 20-90 minutes
Temperature increases during flaring state.

Flaring state:
- Temperature: 1.5 – 7.5 keV
- Luminosity: 30.0 – 31.7

Quiescent state:
- Temperature: 0.5 – 1.3 keV
- Luminosity: 29.2 – 31.0

An increase of nearly 5 times in X-ray luminosity. Maximum increase: 16.6 times in F4 flare.

These flares are more powerful than those observed from field stars but equally powerful as the flares from PMS stars in Orion (Getman et al. 2008).
Loop Parameters:

- Semi Loop lengths: 2 – 4 \(10^{10}\) cm
- Pressure: 1.5 – 87 \(10^3\) dyne cm\(^{-2}\)
- Density: 0.5 – 15 \(10^{11}\) cm\(^{-3}\)
- Loop Volume: 1.3 – 570 \(10^{30}\) cm\(^3\)
- Magnetic field: 100 – 1200 (G)
- Heating rate per unit volume: 0.3 – 92 erg s\(^{-1}\) cm\(^{-3}\) (at flare peak)

Using the spectral parameters during flaring state and estimated values of rising and decay times.

- X-ray flares from young stars are enhanced analogs of eruptive solar Flares
- Can interact with Disk around stars
- No significant difference in loop parameters of intermediate & low mass stars.
Conclusions

**PMS Low mass**

(a) Plasma temperatures in the range of 0.2-3 keV, irrespective of their ages.

(b) The observed XLFs of low mass stars from 4 to 14 Myr appear to be similar. The decrease in Lx may occur during 14 to 100 Myr.

(c) Nearly 85% of the stellar population deviate from the saturation level, deviation of low mass stars from X-ray saturation may occur before the age of 4-8 Myr.

(d) The \(L_x/L_{bol}\) correlate with their \(L_{bol}\), shows its dependence on the internal structure of stars.

(e) Semi loop lengths of coronal structure are found to be of order of \(10^{10}\) cm, which may interact with the disk around the PMS stars and may affect the planet formation process during 4 to 50 Myr.

**Intermediate mass stars**

(a) No statistically significant difference in Lx from intermediate mass and low mass PMS stars.

(b) The observed \(L_x/L_{bol}\) for intermediate mass stars are found to be significantly lower than that of low mass stars.

(c) But, the possibility of companion hypothesis can not be examined because of the limited resolution of XMM-Newton.

(d) Coronal loops which are involved for the X-ray flares from intermediate mass stars are similar to that of low mass stars.
Thanks
This work is recently published in

(1) Himali Bhatt et al., 2013 Journal of Astrophysics & Astronomy, vol. 34, 393-429

(2) Himali Bhatt et al., 2014 Journal of Astrophysics & Astronomy, vol. 35, 39-54