Flare Analysis for Multiple Stellar Cluster Data from ANCHORS Database.

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Abstract:
We present a progress report on a study of flares in young stellar clusters. We use 19 clusters from ANCHORS (An Archive of Chandra Observations of Regions of Star Formation) database and flare criteria derived previously from COUP. Most of the clusters have ages between 0.05 and 4 Myr and exhibit flaring behavior between 0 and 0.5 flares/day. Motivation: Stellar flares are strong disturbances in magnetic field structure in stellar atmospheres that result in violent outbursts of plasma and radiation. Identifying stars and young stellar objects that flare is important for studying their properties in understanding stellar magnetic field structures as well as evolution of proto-planetary disks and stellar environments. While COUP presents a large catalog of stars with extensive variability sampling from the Orion cloud region, ANCHORS offers a complementary sample from a variety of environments. As part of our ANCHORS database creation, we subject our sources’ light curves to Bayesian Blocks analysis, which allows us to search for flaring behavior.

COUP Flare Study and Mathematical Flare Definition:
From 9.7 days of effective exposure of the Orion Nebula Cluster, the COUP team has derived empirical constraints to quantify the length of a flaring structure. Wolk et al. (2005, ApJS, 160, 423) have selected criteria for flare identification from 41 flares in COUP data. Partitioning of the light curves in a maximum likelihood algorithm, similar to Bayesian Block method by Scargle (see above), these blocks are associated with constant brightness and identified the points at which there was a significant change, thus separating the curves into Maximum Likelihood Blocks (MLBs). These blocks represented the constant photometric count rate as they arrived to the detectors from each source. In order to differentiate stochastic behavior (random low-sigma fluctuations) from an abrupt change in brightness (orders of magnitude change indicating a flare), a characteristic “quiescent” count rate, \( R_{\text{block}} \), was defined by maximizing the number of blocks that fell within the range \( 0.5 \sigma < 1.5 \sigma \lesssim 1.2 R_{\text{block}} + 1.5 \sigma \), where \( R_{\text{block}} \) is the count rate of each block and \( \sigma \) is its significance. Slopes between consecutive blocks were defined as \( \Delta R \), where \( \Delta R = R_{\text{block}} - R_{\text{block-1}} = R_{\text{block}} - R_{\text{block+1}} \), and \( R_{\text{block-1}} \) was the length of the shorter block. A flare was then defined as a region on which at least one MLB had \( (1/R_{\text{characteristic rate}}) \cdot (\Delta R_{\text{block,i}}/\Delta t) > 10^{-4} \) sec\(^{-1}\).

ANChORS Flare Analysis Guidelines:
\[ (\text{block length}) \leq 1.2 R_{\text{characteristic rate}} + 2.5 \sigma \text{ (block length)} \] and
\[ (1/R_{\text{characteristic rate}}) \cdot (\text{block length}) > 10^{-4} \text{ sec}^{-1} \]
Identify a flare.

The first condition says that a Bayesian Block that indicates a flare should be higher than the characteristic rate (longest quiescent level block) as shown. The second condition says that the number of counts in a Bayesian Block should be greater than the rate by a factor of \( 10^{-4} \), i.e., the presence of a Bayesian Block.

Only blocks of greater than 1/4a duration were considered significant for flare identification.

Brief Description of ANCHORS Database as a Sample Page Output:

<table>
<thead>
<tr>
<th>ObsID</th>
<th>Obit</th>
<th>Flare Activity</th>
<th>Cluster</th>
</tr>
</thead>
<tbody>
<tr>
<td>5407</td>
<td></td>
<td>Young stars</td>
<td></td>
</tr>
<tr>
<td>2264</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1579</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2024</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2264</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The plot above shows 2MASS colors for flaring sources in select observations.

Comparison: Chandra observations are sensitive to flares and variability from very young clusters. On the plots above, there is a paucity of clusters with ages between \( \sim 15 \) Myr due to biases in Chandra’s target selection. In order to constrain the variability and flaring behavior of stars as a function of cluster age, this age needs to be filled in. Existing Chandra XMM data analysis should help as well as Chandra observations of older clusters.

Conclusion: There is no evidence in the data that any of the flaring stars are disk candidates.

2MASS Colors for Flaring Sources in Select Observations:

The plot above shows 2MASS colors for flaring sources in select observations.