

**A STUDY OF STELLAR FLARES IN ANCHORS STAR CLUSTER DATABASE.** N. S. Bizunok<sup>1</sup> (*nbizunok@cfa.harvard.edu*), S. J. Wolk<sup>1</sup>, and B. D. Spitzbart<sup>1</sup>, <sup>1</sup>*Harvard-Smithsonian Center for Astrophysics, Cambridge MA 02138, USA.*

**Introduction:** Among topics of great interest in stellar astronomy are stellar flares that are defined by exceptionally energetic outbursts in stellar luminosity and temperature due to the breaking of magnetic loop structures. Evolutionary studies of protoplanetary disks, for example, require knowledge of stellar flare history and rate. A powerful flare may greatly disturb a disk region with a planet in its early formation stages. Knowing a flare’s geometry can help in constraining the underlying stellar magnetic field structure and consequently allow for modeling of internal mechanisms creating the field. X-ray observations of stellar flares are excellent for tracking stellar behavior at high energies present in a flare, and data obtained with *Chandra* X-ray observatory are particularly suited for this task due to the telescope’s high spectral and spatial resolution. Ideally, a very large sample of flaring stars is needed to classify flare properties. Existing X-ray studies of flares limit themselves to single clusters, thus limiting what may be learned about the influence of location on flaring stars. A notable exception is *Chandra* Orion Ultradeep Project (COUP) [1], a 13.2 day observation of about 1400 young stars in the Orion star cluster. While the duration and depth of the COUP survey are excellent for a detailed study of flares, we offer a different approach to sampling potential flaring candidates with ANCHORS (An archive of *Chandra* Observations of Regions of Star Formation). We present our findings and compare them to the information obtained by COUP.

**ANCHORS Overview:** We process cluster data for ANCHORS in a uniform manner for each cluster on our list (around 50 *Chandra* fields and thousands of point sources). We reprocess level2 *Chandra* event files of observations where necessary, detect point sources in three energy bands with *wavdetect* from *Chandra* X-ray Center CIAO package [2], fit Raymond-Smith thermal plasma models to spectra of members of the final source lists, calculate x-ray colors through quantile analysis [3], break up source light curves into blocks of uniform count rate with Bayesian Blocks scripts [4] (based on Bayesian statistics), conduct photometry matching to 2MASS, and output all of the results on the web in an interactive interface [5]. (For a detailed description of ANCHORS, please see poster by B. D. Spitzbart).

**COUP Flare Study:** From 9.7 days of effective exposure on The of Orion Nebula Cluster, the COUP team has derived empirical constraints to quantify the length of a flaring structure. Wolk et al. [6] 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 [4], they searched for the periods of 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 behavior of photon 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,  $R_{\text{char}}$ , was defined by maximizing the number of blocks that fell within the range  $R_{\text{block}}/2 - 1.5\sigma \leq R_{\text{char}} \leq R_{\text{block}} * 1.2 + 1.5\sigma$ , where  $R_{\text{block}}$  is the count rate of each block and  $\sigma$  is its significance. Slopes between consecutive blocks were defined as  $dR/dt$ , where  $dR$  was the change in count rate and  $dt$  was the length of the shorter block. A flare was then defined as a region on which at least one MLB had  $dR/dt$ , normalized by  $R_{\text{char}}$ , greater than  $10^{-4} \text{ s}^{-1}$ . Favata et al. [7] study of COUP sources concentrated on 32 sources with very bright flares conducted uniform cooling loop modeling in which they defined the length of the flaring structure as  $L = \tau_{\text{lc}} \sqrt{T_{\text{pk}}} \div 3.7 \times 10^{-4} F(\zeta)$ , where  $\tau_{\text{lc}}$  is the observed light curve decay time,  $T$  is the peak temperature in the flaring loop, and  $F(\zeta)$  is the ratio between the intrinsic and observed decay times ( $\zeta$  is the slope of the flare decay on a temperature-electron density logarithmic plot). Loop volume was then defined and plasma density approximated, and, finally, the minimum magnetic field required to produce the flare was estimated as  $B \approx (8\pi k n T)^{-2}$ , where  $n$  is the plasma density.

**ANCHORS Flares:** We use Bayesian Blocks analysis to subdivide X-ray light curves into maximum likelihood blocks as a part of our standard processing routine for each cluster we work with. The results are scanned for flares using the same criteria as described above for determining a characteristic count rate and identifying all blocks with normalized count rate derivative greater than  $10^{-4} \text{ s}^{-1}$  and find the duration of the flares. An example of a light curve analyzed with

flares. An example of a light curve analyzed with Bayesian Blocks script is shown below:

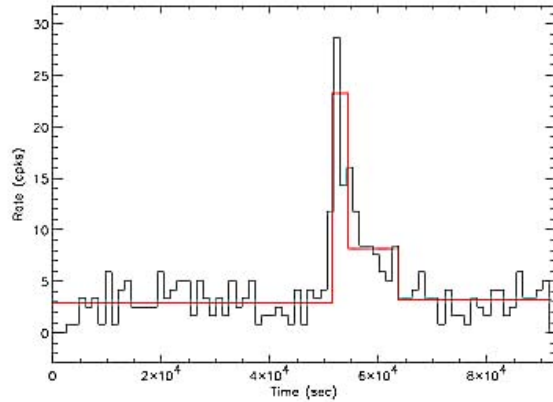


Figure 1. a source from OMC 2-3 X-ray data exhibiting a flaring pattern.

We then apply the loop structure equations from the COUP analysis to our flare sample and obtain physical characteristics. Because spectral fitting is also a routine part in ANCHORS, nearly every bright source has either a 1 or 2-temperature Raymond-Smith thermal plasma model fit to it, depending on the number of source counts. 2MASS J, H, and K photometry, matched to our x-ray sources wherever possible, provides infrared properties of flaring stars and quantile analysis yields their complimentary x-ray “photometry”. Literature search for each cluster gives cluster masses, ages, extinctions, and other important characteristics, as well as, in some cases, individual stellar masses and properties.

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**References:** [1] Getman K. V., Flaccomio E. et al. (2005) *ApJS* in press. [2] <http://cxc.harvard.edu/ciao/>. [3] <http://space.mit.edu/ChaMPlane/quantile/>. [4] <http://hea-www.harvard.edu/ChaMPlane/quantile/> [5] <http://cxc.harvard.edu/ANCHORS/>. [6] Wolk S. J. et al. (2005) in press (arXv:astro-ph/0.507151 v1) [7] Favata F. et al. (2005) *ApJS*, in press.