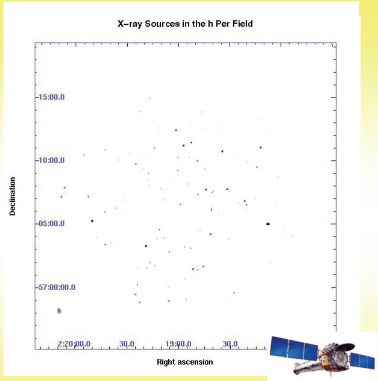
Chandra Observations of the Open Cluster h Per

N. R. Evans, S. J. Wolk, N. Bizunok, B. Spitzbart, F. Seward, S. Kenyon (CfA),
T. Barnes (U. Texas), and J. M. Pasachoff (Williams College)

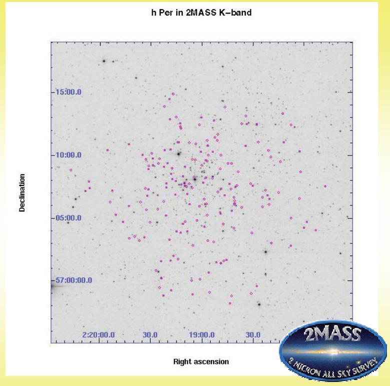
Abstract:

We are analyzing ~200 sources found in a 40 ksec observation of the open cluster h Per. The data are being processed with the ANCHORS pipeline which provides fluxes and low resolution X-ray spectra. For the stronger sources temperatures are derived from spectral fitting; for weaker sources interpretation is through quantiles. The luminosity distribution is discussed, including the effects of shallow sampling on the source population. The distribution of these properties on optical and infrared color magnitude diagrams is investigated for the cool pre-main sequence stars in this 10 Myr cluster.

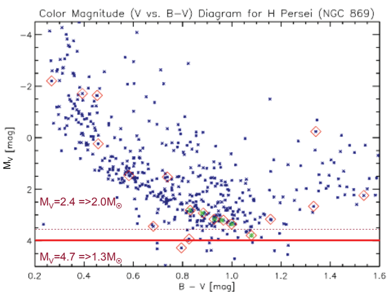
Motivation: In a ROSAT PSPC image of h and χ Per, Evans and Seward (2000, ApJ, 538, 777) found that the X-ray sources were not spatially correlated with B stars in the clusters. The sources in the shallow (11 ksec) image were brighter than solar mass stars in the Orion Nebula Cluster (ONC), which is surprising since the ONC is younger (4 x 10^6 years) than h and χ Per (14 x 10^6 years). Because of the low resolution of the ROSAT image, individual optical sources could not be identified with the X-ray sources.
Using the Chandra observation we can make these identifications, and see whether the X-ray luminosities are as expected at the age of the cluster, or whether, for instance, the unusually high rotation in the cluster affects the X-ray level.



X-ray observations of the h Per field. The image was obtained by binning the image by 4 and applying gaussian smoothing with r_{kernel}=3.



K-band 2MASS image of the h Per region. Locations of X-ray sources are indicated as magenta circles.



Optical Matches

Optical matches have been made between optical photometry from Keller, et al. (2001, AJ, 122, 248) and also 2MASS J, H, and K photometry. The figure shown above is converted from V and B for stars within 5' of the cluster center. Stars which are X-ray sources are marked with red diamonds.

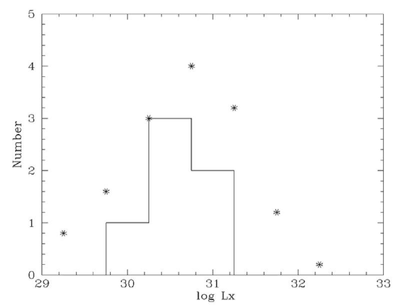
Optical photometry is only reliable to about 17th magnitude (the dotted line is at V=17.1mag, and the solid red line is at V=17.5mag). Approximately half the X-ray sources have optical matches. This is partly because we so far only have photometry as deep as F stars at the distance of h Per. We also expect that up to a quarter of the X-ray sources are background AGN.

In this figure, the absolute magnitude M_v is plotted, using a distance of 2410 pc, and an E(B-V) = 0.56 mag. The (B-V) color has NOT been corrected for reddening.

Stellar masses at MV=2.4mag and MV=4.7mag are indicated for an age of 10^7 years, according to the tracks of Siess, Dufour, and Forestini (2000).

Green asterisks indicate a tight sequence of X-ray sources, corresponding to F stars, with optical matches. *(see discussion about those stars in the next figure on the right)*

Future work: We (TGB) are obtaining deeper optical photometry to determine the optical properties of X-ray sources which are cooler pre-Main Sequence stars. This will also be important in confirming those suspected of being background AGN: those which have a very large X-ray to optical ratio.



Luminosity Distribution

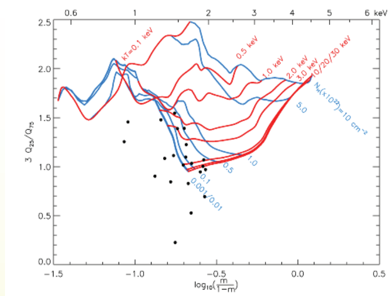
This luminosity histogram is for the F star sequence shown by the green asterisks in the figure on the left. Note that in this case, we do not expect further optical identifications, since the photometry for this group is already in hand.

Using the formula from Feigelson, et al. (2005, ApJS, 160, 379), the image of h Per is only complete to a luminosity of log L_x = 30.3 ergs/s. The asterisks show the luminosity distribution for 1 to 3 $M_\odot$ stars from the ultradeep exposure on the Orion Nebula Cluster (ONC; Feigelson, et al. 2005, Fig. 5), which will be complete for the entire luminosity range on this figure. (For comparison purposes, the frequency of the ONC sources has been divided by 5.) Thus, the lower luminosity side of the distribution is complete for the ONC, but not for the much shallower observation of h Per.

As would be expected, the younger ONC (~4 Myr) has more luminous sources than the 14 Myr h Per cluster (right side of the luminosity distribution.) The lowest luminosity bin of the distribution for h Per, however, is incomplete. If the distribution of luminosities is similar to that of the ONC, it is also below the peak of the distribution for F stars. A deeper exposure is required to confirm this.

Future work: One remaining question for the high luminosity F stars is that the 1 to 3 solar mass group in Feigelson, et al. (2005) contains some higher mass stars than our sequence. We plan to subdivide the mass range in the ONC results to check whether the higher luminosity ONC stars are really higher mass stars.

The comparison of luminosity distributions will also be extended to cooler stars when deeper optical photometry is obtained.



Quantile Analysis

- For ***strong sources*** (greater than 50 counts) we are fitting spectral models to the counts using Raymond-Smith models in the CIAO *Sherpa* software.
- For ***sources*** for which either a suspiciously *high temperature* or a *very faint optical source* (or upper limit) indicates that they **are probably AGN**, we refit with a power law spectrum. In addition we are exploring the use of quantiles to derive the parameters of the X-ray spectra or colors. This approach was developed by Hong, Schlegel, and Grindlay (2004, ApJ, 614, 508) as an alternative to pre-specified X-ray color divisions which frequently result in empty bins with no information. The quantile approach works with median (50%) energy and quartiles (25% and 75%):

$$Q_x = (E_{x\%} - E_{lo}) / (E_{up} - E_{lo})$$

The figure above is derived from the median (m = Q_{50}) and the ratio of Q_{25} and Q_{75}. For comparison, a grid of predictions is shown for Raymond-Smith models for a range of H column densities and kT.

h Per is a particularly useful cluster to begin an exploration of quantiles, since for cluster members, the extinction is relatively uniform. A hydrogen column density of 3.3 x 10^{21} is inferred from the E(B-V).

We have restricted our X-ray sources to those with more than 30 count sources in order to have reasonable statistics. Furthermore, we have omitted sources which have kT greater than 40 keV from preliminary spectral fitting, and also those which do not have optical identifications. (For identifications alone, we have used photometry down to 19 mag, since we are inferring nothing further from the rather inaccurate colors.) In this way, we expect that the sources will be almost exclusively stars, relatively uncontaminated by AGN.

The figure above shows that most of the sources, indeed, do fall in the range of approximately the right NH, and reasonable temperatures. However, there are still a few sources which have an improbably high temperature and/or an improbably small H column density.

Future work: We are exploring questions such as: How few counts provide a reasonable values of NH and kT from quantiles? Do the spectral fits agree with the quantiles and median temperatures? How well can quantiles be used to identify background AGN? Is there a correlation between the X-ray spectral results and stellar photospheric parameters (especially when we have deeper photometry)?

If you have any questions or comments, please contact Nancy Evans at nevans@head.cfa.harvard.edu