CHANDRA OBSERVATIONS OF YOUNG OPEN CLUSTERS

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ABSTRACT

We review the X-ray aspects of our ongoing *Chandra/Spitzer* study of regions of star formation. Here we focus on three clusters. RCW 38 - one of the most massive clusters within 2 kpc, RCW 108 - a more modest O star cluster at a little more than 1 kpc away and NGC1579 a relatively nearby cluster of low mass stars surrounding the Be star LkHα101. A common thread among the fields is that they are embedded with a minimum of 3 optical magnitudes of extinction.

1. RCW 38

Originally discovered as a radio source, early near and mid-IR studies discovered 2 embedded sources (IRS1/2) - one is a possible protostar, while the other is the exciting source of the HII region (Frogel & Perrson (1974). JHK imaging resolves the exciting source into at least 5 sources. Images of the core region from 8-13 μm, resolves the main exciting source as an O5-O5.5 star T_{eff}~ 44,000K (Smith et al. 1999). The protostar candidate is embedded within a very complex ridge with four additional 10 μm protostar candidates within 10".

In a 100ks observation, we detect over 450 sources within the primary *Chandra* field of view. About 200 of these are in the central 2' (1 pc). We use the X-ray colors observed in the central region to discriminate cluster members from foreground and background objects. Using this method we ascertain that about 360 of the X-ray sources are cluster members. Due to the ~2 kpc distance of this cluster and our sensitivity, only the top 15% of the mass function is sampled (Feigelson et 2005). This implies a total cluster membership of over 2000 sources.

We have IR detections of about 300 of the cluster members and find the fraction of X-ray sources with K-band emission indicative of disks is about 20%. As a control, we also imaged the region with the VLT and find over 50% of the cluster members not detected in X-rays do indeed show evidence for disks. This is more in line with the disk fraction expected for such a young cluster. Thus we identify that X-ray selection is strongly biased against disks at our level of completeness.

We use the near-IR data to calculate dust extinction to each star. We use the absorption column determined using X-ray spectral fits to break the degeneracy intrinsic to using JHK to measure N_H. We then fit the observed dust extinction to the observed Hydrogen column and find $N_H=2.0xA_vx10^{21}$. There are a few outliers in the fit with much larger N_H than expected based on the observed A_v. This could be the result of particular lines of sight to a disk along which the dust has grey opacity due to, for example, large particles.

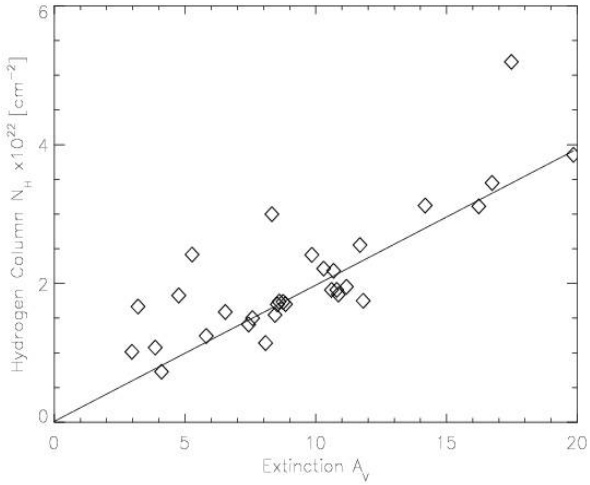

Fig 1. The Hydrogen column as derived by X-ray spectral fits plotted versus dust extinction. The line is the best fit passing through the origin: $N_H=2.0xA_vx10^{21}$.

2. RCW 108

This cluster contains a deeply embedded young cluster lying in a dark cloud to the west of the young open cluster NGC 6193 (excited by two early O stars). The cluster is obscured by A_v ~20 and at a distance of 1.3 kpc (Straw 1987) and so is more embedded and closer than RCW 38. The exciting source of the IRAS cluster is ~O6-8. At 8-20 μm, the Midcourse Space Experiment Galactic Plane Survey data shows a ridge of warm dust passing through the eastern edge of the emission peak and traversing 15 minutes in a north-south ridge parallel but west of the optical ridge. Our SEST mm continuum observations show this dust ridge as well. The far infrared luminosity suggests that there is more than one significant heating source, i.e., OB

stars and/or intermediate mass protostars. The colors and luminosities of the infrared sources imply an associated cluster of low mass T Tauri stars. The extended infrared nebulosity to the east of the main cluster is due to emission and not reflection, suggesting a break-out of radiation in this direction.

We detected 250 X-ray sources in our 100 ks observation. The morphology is striking. The region is dominated by unabsorbed sources to the east. Theses are associated with the older cluster NGC 6193. The sources associated with RCW 108 proper seem to sit in the middle of a void. This is indicative of a dense cloud of neutral gas. Several specific sites of star formation are found within that cloud complex. These align with some, but not all, the 8 μm peaks in the MSX data. There are several sites within the warm dust cloud containing 1-10 stars. The overall trigger appears to be compressive.

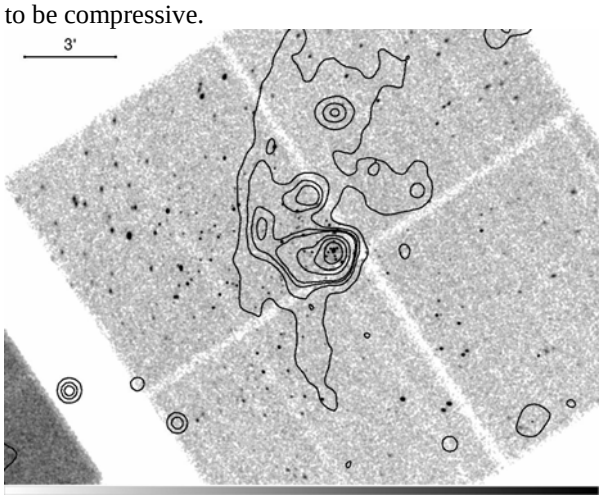

Fig 2*: Chandra* image of RCW 108. The image is about 15' on a side and smoothed to about 4" resolution. The contour overlay is 8μm emission as measured by MSX. Note the large gap between the sources to the east (left) and the central cluster. The bright source in the middle is the HII region associated with the cluster.

3. NGC 1579

LkHα 101 is a luminous, ~$5x10^3 L_\odot$, Herbig Be star with a strong wind, an associated HII region (Sharpless-222) and a reflection nebula (NGC 1579). The visual extinction in the extended area is about 1 magnitude. IRAS data show 100μm emission extending 30' around the star. Recent observations (Tuthill et al. 2001) have discovered that this star possesses a disk which is nearly face on, and show evidence of a secondary star.

The cluster was first identified by Becker & White (1988) as they detected 9 point sources at 6 cm using the VLA. Aspin & Barsony (1994) found 51 sources (K<16.8) within 40" of LkHα 101. Extinction of these sources is moderate (3-20 A_v) and one-third of the stars show infrared excesses consistent with disks. These 51 sources do not represent the entire cluster as Aspin & Barsony found sources 2 magnitudes fainter than the 2MASS limit. At an estimated 340 pc, the limiting K magnitude of 2MASS corresponds to about 0.3 $M_\odot$.

In two 40 ks integrations, we detect about 190 X-ray sources in the ACIS I field of view. Based on sensitivity estimates, we expect this to include about 75% of the cluster members including almost all the stars down to 0.5 $M_\odot$. About 35 of the X-ray sources are bright enough for spectral fits. We find the mean plasma temperature of these sources is about 2.1 KeV, which is about the value expected for young stars < 1 Myr old. The mean column, N_H, is about $4.6x10^{21}$ cm^{-2} or A_V ~ 2.25. 120 of the 192 X-rays sources are detected by *Spitzer*/IRAC, 37 of these have excesses indicative of a disk. The disk nature of the remainder has yet to be determined.

The Be Star itself, LkHα 101, is well fit by an absorbed (N_H~$2.4x10^{22}$) very cool (kT~830eV) plasma. The luminosity (log L_x/L_{bol}~-6) and temperature are consistent with the weak wind expected from a mid B star. Absorption along the line of sight is about 5 times the cluster mean which is perhaps indicative of neutral gas above the disk plane or dusty environs surrounding the star which is thought to possess a face on disk.

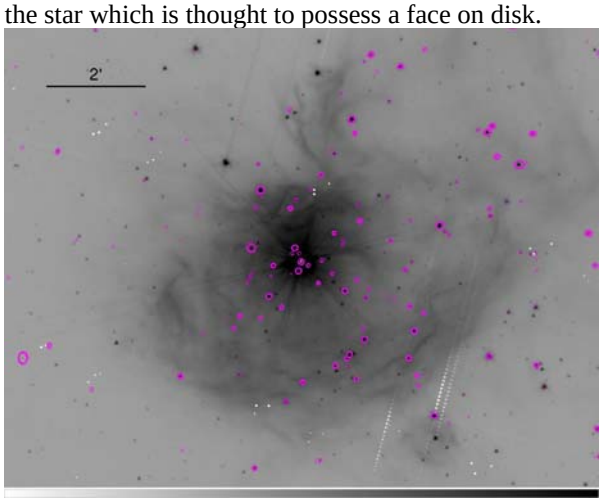

Fig3. The central 12' of the *SPITZER* image (IRAC band 1= 3.5μm) of NGC 1579. X-ray contours from 40 ks of *Chandra* data are overlaid.

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4. REFERENCES

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