STAR FORMATION IN THE GUM NEBULA – COMETARY GLOBULES 31

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ABSTRACT. We report the initial results of our study of X-ray sources in the Gum nebula. For this presentation, we have concentrated on a region which includes cometary globule #31. We have found 6 X-ray sources in the 182 arcmin^2 region south of this globule. Photometric investigations find that most of the X-ray sources have a pre–main sequence (PMS) star within 10$''$. Further, these PMS stars all lie about a common locus indicating an age of less than a few million years.

We continue to carry out a more global study of the stellar colors across the globule. To date, photometry of over 1000 stars in this immediate vicinity has been carried out. We find a well defined main sequence for galactic stars beyond the fiducial distance of 450 pc. There is a small fraction (about 1%) of stars which lie significantly above the main sequence and are probably PMS stars. We are using these data to study star formation in the environment of small clouds.

1. Introduction to the Gum Nebula

The Gum Nebula (Gum 1952; Bruhweiler 1983) is the largest (apparent) HII region we can see, with a linear diameter of 125 pc at a distance of some 450 pc. The HII region is likely ionized by ζ Puppis and γ^2 Vela. The nebula may be an old supernova remnant (Leahy *et al.* 1992), a fossil Stromgren sphere, or a stellar wind bubble. The expansion age of the nebula is about 6 Myr. The interior of the nebula is home to at least 36 small dark clouds, or cometary globules, with a head-tail geometry. These globules are distributed over a span of more than 20 degrees on the sky. Here we focus on cometary globule 31 (CG31) and the area surrounding it. CG31 is part of a large complex of globules. It has 5 distinct components. Its tail merges with that of the CG30 and can be traced for over 25$'$. CG38 is just to the southeast.

2. X-Ray Observations

Using ROSAT we have observed this globule plus the region to the east. The X-ray images permit one to search for additional PMS stars associated with the globules. Previous X-ray studies have demonstrated that X-rays are an excellent means of selecting candidate low mass PMS stars. These stars are rapidly rotating and highly convective, two ingredients needed to generate solar-like coronal and chromospheric activity. X-ray studies (e.g., Walter *et al.* 1988) have shown that the majority of the low mass PMS stars

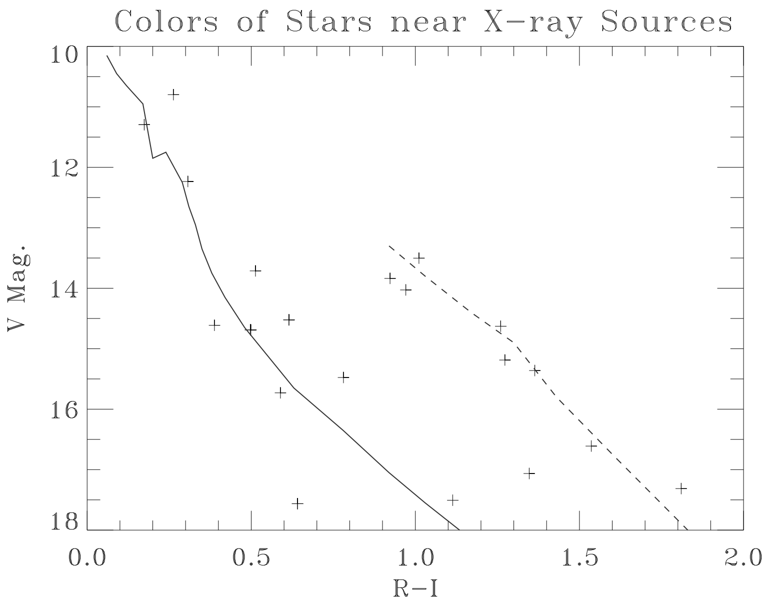

Fig. 1. Plot of the color and magnitude of stars within 10″ of an X-ray source. The solid line indicates a nominal main sequence at 450 pc, the dashed line is a fit to the 8 HRI sources associated with PMS stars.

are naked T Tauri stars, where the X-ray emission flux does not exceed the "saturation" level (Vilhu & Walter 1987).

Observations of the 3 square degrees near and east of CG31 using the ROSAT HRI have found about 30 X-Ray sources. The X-ray sources do not tend to be uniformly distributed over the HRI fields. Instead, most lie to the inside of the cometary globules. The densest region of X-ray sources is a concentration of 6 in a 200 arcmin^2 region near CG31. A simple interpretation is that star formation was triggered by initial passage of a shock through a cloud, which has subsequently evaporated away, leaving the stars behind.

3. Optical Photometry

In January 1996, we observed this field using the CTIO 0.9 meter telescope, a wide field CCD and UBVRI filters. Weather and seeing were very good providing 1% photometry at V of 16.5. The observed region included about 20 of the X-ray sources. Color and magnitude measurements of stars within 10″ of an X-ray source are shown in figure 1. The primary finding from these data is that the objects observed lie about 3 magnitudes above the main sequence for the assumed distance of 450 pc. These optical X-ray counterparts define a tight locus. We believe that these stars are $\approx$ 3 million year old PMS stars. However, a ZAMS star at 100 pc would be indistinguishable without spectra.

Using automated software we have obtained colors and positions for about 1000

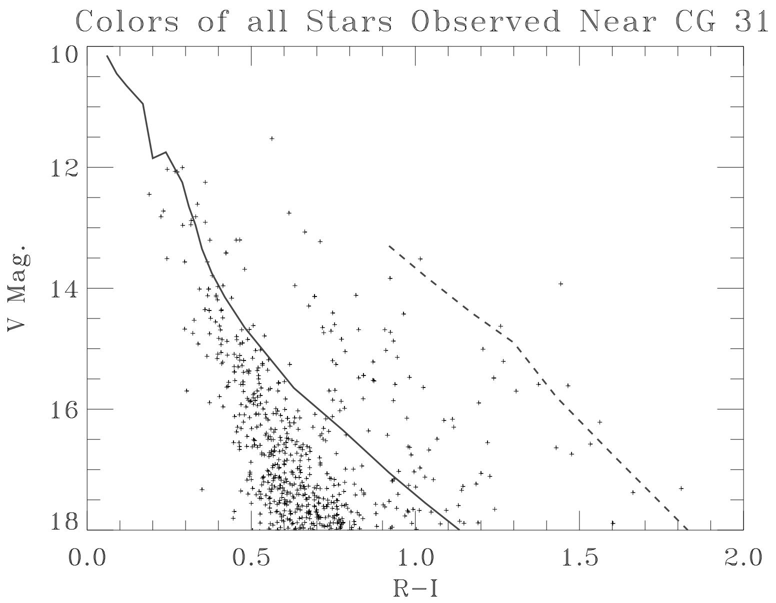

Fig. 2. Plot of the color and magnitude of about 1000 stars in the region of CG31. One $13.5' \times 13.5'$ pointing was used. The solid and dashed lines are the same as the previous figure.

stars in the and area of $13.5' \times 13.5'$ which encompasses the 6 X-ray sources. The color magnitude diagram shown as figure 2 summarizes all the optical results.

The overall color-magnitude diagram shows that most of the stars lie below the main sequence if they are all 450 pc away. We interpret this to mean that they are background objects. A few score lie above this 450 pc main sequence. Very few, less than 20, lie nearly on the fit to the PMS stars shown in figure 1. The reddening vector in this diagram runs roughly parallel to the main sequence. This means that reddening does not effect the perceived spectral class of a star.

There are three populations of stars, one at or below the main sequence, one about a magnitude above, and a third about three magnitudes above the fiducial main sequence. We can immediately make the some qualitative comments. The largest group of objects appear to be main sequence stars along the line of sight. The second group seems to consist of giant branch stars. In fact, one can see below V of 16 the "giant branch" seems to run into the "main sequence" body. The brightest group of stars shows no connection to the other branches. However, the stars in the brightest group align very tightly to the PMS locus defined in figure 1. We suspect the stars in this group of being PMS. This region contained 6 X-ray sources, 4 of which were identified with PMS stars. Photometry indicate the existence of 17 stars in this region which could be coeval with the X-ray identified PMS candidates.

To put these data on more quantitative footing, we fit a symmetric Gaussian distribution centered on the core of the the observed distribution. There is indeed an excess of bright stars which indicates a residual of about 70 stars which are brighter than the Gaussian distribution would have expected. The bulk of these may be background giants. Stars with $M_V \approx 11$ and R$-$I $\approx$ 0.6 and those immediately below are definitely of this category. We fit a second Gaussian profile to this distribution. There is an excess of sources even when a second Gaussian profile is removed. The total excess is about 20 $\pm$5 stars. The distribution of these excess stars is centered near the locus derived from the HRI sources with PMS colors. We suspect these stars of being PMS stars, many of which were not detected by our ROSAT observations either due to the fact that the stars were quiescent during the observation or are very late type and simply do not have a large enough surface area to emit a detectable quantity of X-rays.

4. Tentative Conclusions

The discussion presented here is a preliminary analysis of the X-ray and photometric data regarding star formation near cometary globule #31 of the Gum nebula. The main findings can be summarized as:

- Six X-ray sources with optical counterparts are found in about 180 square arc minutes of the Gum nebula.
- The distribution of the X-ray sources is *not* uniform. Most of the X-ray sources are not found in the clouds, but interior to them.
- Optical photometry of the X-ray sources indicates about most of them are PMS stars still on their radiative tracks.
- Analysis of about 1000 optical sources along the same line of sight as the X-ray sources indicate that there may be as many as 20 PMS stars in near this cometary globule.

While young stellar objects are seen in cometary globules (e.g. CG30), the X-ray sources are not. The X-ray sources and stars with similar photometric colors are interior to them. We feel that this is indicative of star formation having been ongoing in the Gum nebula probably for several million years. The X-ray sources and cometary globules represent only a subset of the PMS populations. The interior of the Gum nebula may be host to thousands of low–mass PMS stars.

References

Bruhweiler, F.C. 1983, Comments Astrophys., **10,** 1.
Gum, C.S. 1952, Observatory **72,** 151.
Leahy, D.A., Nousek, J., & Garmire, G. 1992, *Astrophys. J.* **385**, 561.
Vilhu, O., & Walter, F.M. 1987, *Astrophys. J.* **321**, 958.
Walter, F.M., Brown, A., Mathieu, R.D., Myers, P.C., & Vrba, F.J. 1988, *Astron. J.* **96**, 297.