Searching for Young Stellar Objects in CG4

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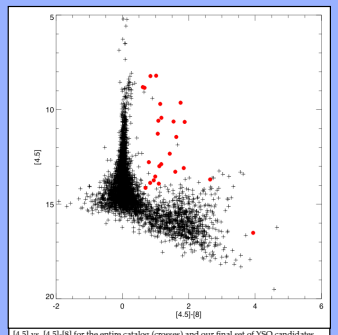
We used archival Spitzer Infrared Array Camera (IRAC) and Multiband Imaging Photometer for Spitzer (MIPS) data and Two Micron All-Sky Survey (2MASS) data, as well as optical data obtained by collaborators, to look for new young stellar objects (YSOs) in Cometary Globule 4 (CG4) in Puppis, one of many such star-forming structures in the Gum Nebula. These globules are generally pointing outward radially from the center of the Vela OB2 association, which are also forming stars. Focusing on infrared excesses, we settled on 25 YSO candidates. We independently rediscovered all 6 of the previously known YSOs. Of the 19 entirely new YSO candidates, 10 are reasonably high-confidence YSO candidates, 4 mid-grade and 5 low-grade confidence. This research was made possible through the NASA/IPAC Teacher Archive Research Project (NITARP) and was funded by NASA Astrophysics Data Program and Archive Outreach.

Background

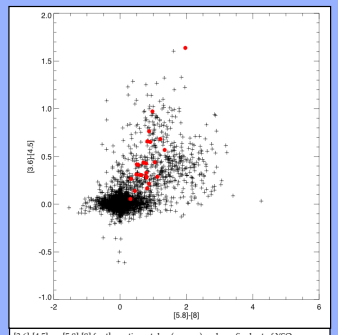
We chose to study the CG4/SA101 portion of the Gum Nebula because the area has some previously-identified young stars (Reipurth and Pettersson 1993), and because there is a lot of associated nebulosity, suggesting that additional stars could be forming. CG4/SA101 (α 07^h 32^m 45°, δ -46° 47′ 48″; ~1300 pc) and its immediate environs does appear to be actively forming stars. Using primarily Spitzer Space Telescope data (3.6-24 microns), we investigated the properties of previously known objects and looked for new candidate young stellar objects (YSOs) using infrared excesses.

One of the largest issues we faced is contamination from non-cluster members. With Spitzer, it is easy to confuse a foreground/background star or even a background galaxy with actual cluster members. Spitzer is so sensitive that it can see galaxies in just a few seconds of integration. Moreover, because this object is part of a very large HII region, contamination from other young clusters along the line of sight is likely. We investigated the properties of all our YSO candidates using all available data, including infrared excess, apparent age (if all of them are the same age, it is likely they are all members of the same cluster), brightness, bipolar outflows (if present), UV excess, spatial location, and association with nebulosity.

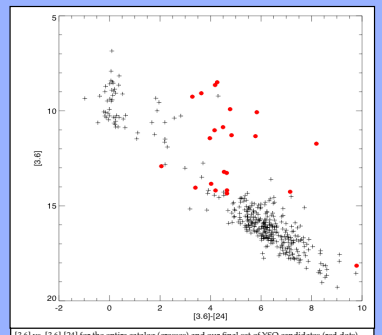
Future analysis will involve our attempt to characterize this young star population. We will compare the young star population, distribution, and age to other similar sites of star formation. We will also attempt to determine whether this is triggered star formation, which will help to determine the star formation efficiency locally. The presence of O & B stars, copious UV and gamma emitters, plus supernova remnants indicating violent interstellar explosions, suggest an energetic nebular environment in the larger Gum Nebula. Follow-up classification spectra will be required to confirm or reject our YSO candidates.



[4.5] vs. [4.5]-[8] for the entire catalog (crosses) and our final set of YSO candidates (red dots). Photospheres (e.g., stars without disks) are found near [4.5]-[8]~0, and galaxies are found at the red and faint (lower right) end of the plot. The lack of points in the extreme lower left is primarily an artifact of the survey itself – 4.5 μm reaches fainter objects than 8 μm. YSO candidates are red and bright, e.g., largely in the upper right of the diagram. Nearly all of our final YSO candidates are in this region of the diagram where other YSO candidates in other clusters are found. One of our candidates is quite faint, and may represent a faint legitimate YSO, or a background galaxy – follow-up spectroscopy is needed.



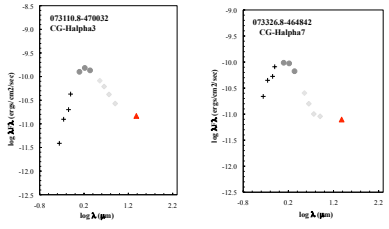
[3.6]-[4.5] vs. [5.8]-[8] for the entire catalog (crosses) and our final set of YSO candidates (red dots). Photospheres (e.g., stars without disks) are found near a color of 0 on both axes. YSOs are generally red on both axes. All of our YSO candidates fall in this regime. The rest of the objects that fall in this regime have colors in other bands strongly suggesting that they are contaminants, not YSO candidates.



[3.6] vs. [3.6]-[24] for the entire catalog (crosses) and our final set of YSO candidates (red dots). Photospheres (e.g., stars without disks) are found near [3.6]-[24]~0, and galaxies are found at the red and faint (lower right) end of the plot. The structure of the overall distribution going from upper left to lower right is primarily an artifact of the mis-matched depth of the survey (3.6 μm reaches substantially fainter sources than 24 μm). YSO candidates are red and bright, e.g., largely in the upper right of the diagram. Nearly all of our final YSO candidates are in this region of the diagram where (in similar plots) other YSO candidates in other clusters are found. One of our candidates is quite faint, and may represent a faint legitimate YSO, or a background galaxy. Follow-up spectroscopy is needed.

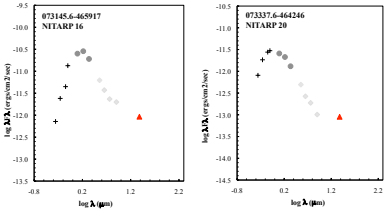
SEDs of two reconfirmed YSOs

Black crosses indicate optical data (B, V, R, I), grey circles indicate 2-MASS data (1.25, 1.65 and 2.17 μm); diamonds indicate Spitzer IRAC data (3.6, 4.5, 5.8, and 8.0 μm), and the red triangle indicates Spitzer MIPS data (24 μm). There are four more reconfirmed YSOs in our final list of YSO candidates.



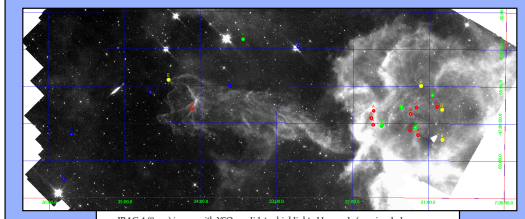
SEDs of two new YSO candidates

Black crosses indicate optical data (B, V, R, I), grey circles indicate 2-MASS data (1.25, 1.65 and 2.17 μm); diamonds indicate Spitzer IRAC data (3.6, 4.5, 5.8, and 8.0 μm), and the red triangle indicates Spitzer MIPS data (24 μm). There are 17 more new YSO candidates in our final list of YSO candidates.



Methods and Conclusions

We used archival Spitzer IRAC and MIPS data (from programs 202, 462, 20714). Via collaboration with J. S. Kim (Univ. of Arizona), we were able to access already-reduced optical data in BVRI filters from the CTIO 0.9-m. These data cover a roughly 40′x40′ region including CG4 and SA101. The primary property that we used to find new YSOs is the near- and mid-infrared excess emission coming from the matter around a newly forming star. Spitzer data is especially well suited to finding these excesses, as well as any bipolar outflows that may be present. We performed a Gutermuth et al. (2008, 2009) IRAC-based color selection to identify an initial sample of YSO candidates with infrared excesses, and then investigated each of these objects using all of our available data, U-band through 24 microns. We used MOPEX (Makovoz & Marleau 2004) to create the mosaics and SAO DS9 to investigate them. We did photometry using APT (Laher et al. 2010, IDL, and MOPEX. We constructed color-color and color-magnitude diagrams, as well as spectral energy distributions (SEDs). We rediscovered all 6 of the previously known YSOs (Reipurth and Pettersson 1993) with Spitzer data. **Our final results suggest 25 YSO candidates, 19 of which are completely new! Among these 19 new YSO candidates, there are 10 of reasonably high-confidence, 4 mid-grade confidence, and 5 low-grade confidence. Of the completes set of 25, there are 4 Class I candidates, 16 Class II candidates, 4 flat candidates, and 1 class III candidate.**



IRAC-4 (8 μm) image with YSO candidates highlighted by grade (previously known YSO = "Y", then A, B, C in order from highest to lowest confidence).

References

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