Spitzer-Selected Young Stellar Objects in Two Bright-Rimmed Clouds

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Found near the edges of HII regions, bright-rimmed clouds (BRCs) are thought to be home to triggered star formation. Using Spitzer Space Telescope archival data, we investigated two BRCs, BRC 27 and BRC 34, to search for previously known and new candidate young stellar objects (YSOs). BRC 27 is located in the molecular cloud Canis Majoris R1, a known site of star formation. BRC 34 has a variety of features worthy of deeper examination: dark nebulae, molecular clouds, emission stars, and infrared (IR) sources. Our team used archival Spitzer InfraRed Array Camera (IRAC) and Multiband Imaging Photometer for Spitzer (MIPS), combined with 2-Micron All-Sky Survey (2MASS) data. We investigated the IR properties of previously known YSOs and used IR colors to identify additional new candidate YSOs in these regions. 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 funds.

BACKGROUND

Bright Rimmed Clouds (BRCs) exist at the edge of HII regions. They are clouds that have experienced compression (and illumination) due to an external ionization shock from nearby massive stars, which served to focus the neutral gas into compact globules (Morgan et al. 2004, Valdetarro et al. 2008) and possibly trigger star formation. Additionally, Morgan (2004) reports that recombination with the ionized boundary layer allows the BRC to be seen at optical wavelengths, hence "bright rimmed." These clouds generally have a radius of less than 0.5 parsecs, with an average mass about 100 solar masses. Since the ionization front is compressing the gas and dust, the region near the boundary between neutral gas and gas ionized by incident photons is thought to be rich in potential sites for star formation.

BRC 27, located in the molecular cloud Canis Majoris R1, is a known site of star formation. BRC 34 has a variety of features worthy of deeper examination: dark nebulae, molecular clouds, emission stars, and IR sources. In a preliminary analysis, Allen et al. (2011) found both Class I and Class II YSOs in these BRCs; BRC 27 was studied primarily using JHK by Chauhan et al. (2009). Beyond that, these two BRCs had not been studied in detail until our analysis.

BRC 27 is a star-forming region located in the molecular cloud CMa R1 (07h 04m 07.8s -11d 16m 43s).

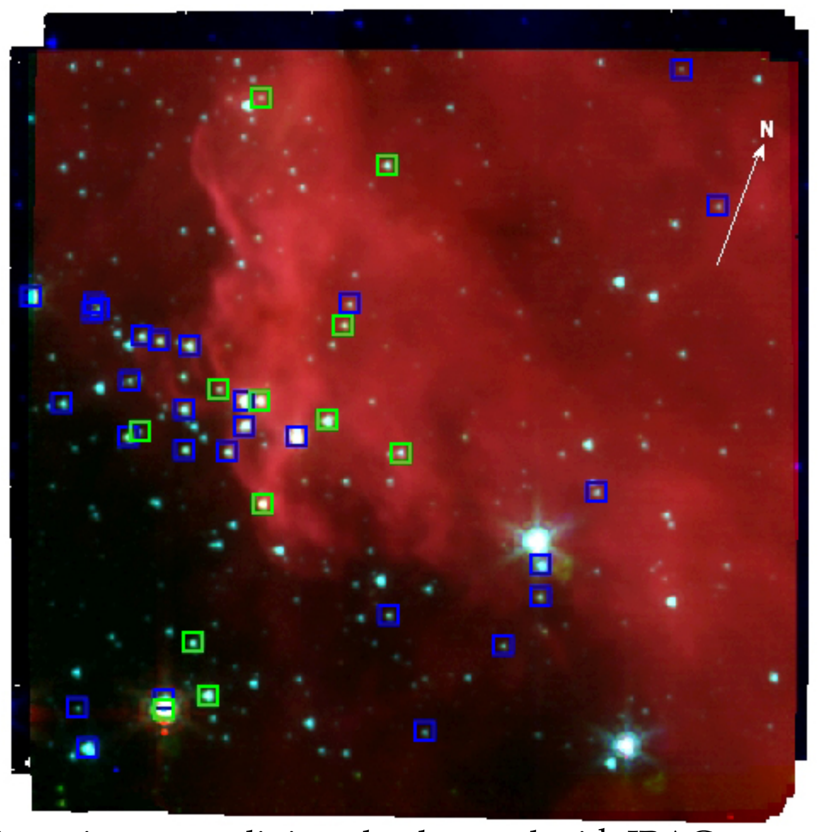
- The source of the shock front that triggered star formation in this region is still uncertain (Gregorio-Hetem et al. 2009).
- In a survey of this larger star-forming region, 179 Hα-emission stars were identified by Wiramihardja et al. (1986) using UBV photographic photometry. Sugitani et al. (1991) identified a star cluster associated with BRC 27 in their catalog of bright-rimmed clouds with IRAS point sources.
- Subsequent research by Sugitani et al. (1995) showed elongation of the distribution of cluster members suggesting that the star formation in BRC 27 was a triggered event.
- Using JHK_S photometry, Soares and Bica (2002, 2003) determined a distance of 1.2 kiloparsecs and an age of 1.5 Myr of the stars in BRC 27. This distance measurement was consistent with the findings of Shevchenko (1999) who placed the distance at 1.05 ± 0.15 kiloparsecs.
- Using BVI_C + JHK photometry, Chauhan et al. (2009) compared the ages of stars inside and outside the rims. As a result, they concluded that BRC 27 showed evidence of a radiation driven implosion. For completeness, we note here that Chauhan et al. analyzed the archival IRAC (but not MIPS) data for BRC 27, but selected their YSOs based on near-IR JHK colors.

BRC 34 is located at coordinates of 21h 32m 51.2s +58d08m43s and is thought to be at 0.75 kiloparsecs (Sugitani 1991).

- Using Hα grism spectroscopy and narrowband imaging, Ogura et al. (2002) found two Hα emission stars in BRC 34.
- This region has considerably less literature than BRC 27.

BRC 27

	Previously Known YSOs	Candidate YSOs	Total
Class I	6	11	17 (~30%)
Class II	13	1	14 (~25%)
Flat	4	5	9 (~16%)
Class III	14	2	16 (~29%)

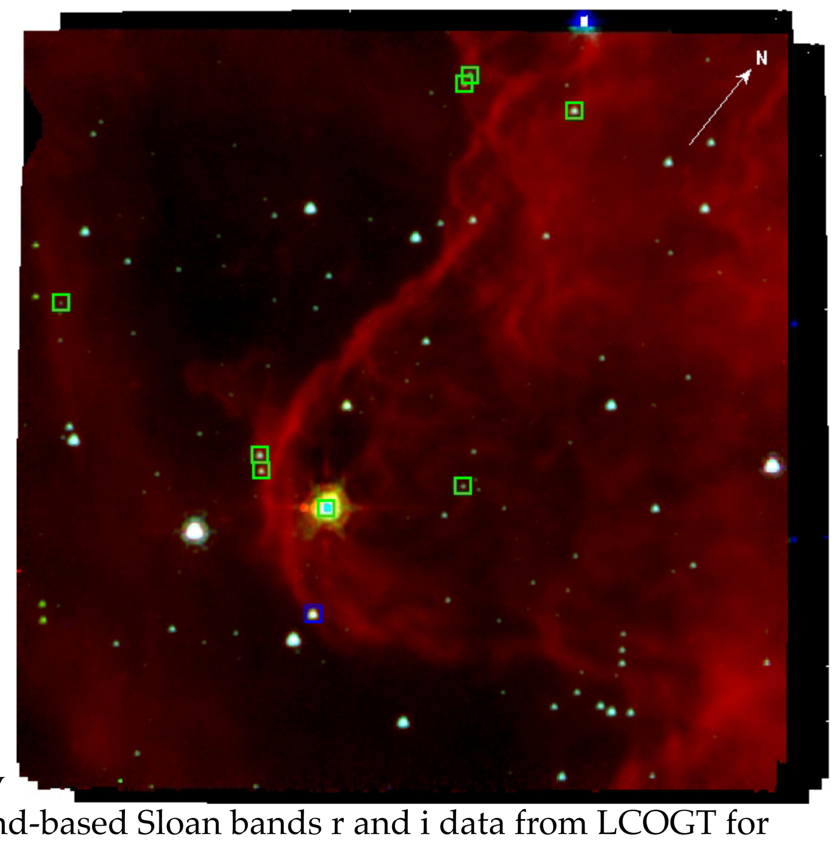


Previously known YSOs are indicated as blue squares. New candidate YSOs are green squares. Composite image made using IRAC-1 (3.6 μm) = blue, IRAC-2 (4.5 μm) = green; IRAC-4 (8 μm) = red.

This image is ~5 arcminutes on a side. MIPS 24 and 70 micron data exist in this region as well, though no point sources are seen at 70 microns. This region is also included in the publicly released WISE data. Some previously-known sources are off the edge of this image in regions serendipitously observed with IRAC; they have WISE plus only two bands of IRAC data available.

BRC 34

	Previously Known YSOs	Candidate YSOs	Total
Class I	0	1	1 (~11%)
Class II	1	1	2 (~22%)
Flat	0	6	6 (~67%)
Class III	0	0	0 (~0%)



Previously known YSOs are indicated as blue squares. New candidate YSOs as green squares. Composite image made using IRAC-1 (3.6 μm) = blue, IRAC-2 (4.5 μm) = green; IRAC-4 (8 μm) = red.

This image is ~5 arcminutes on a side. MIPS 24 and 70 micron data exist in this region as well; the bright point source in the lower middle of the frame is the only source seen at 70 microns. We obtained additional ground-based Sloan bands r and i data from LCOGT for this region.

METHODS

In each cloud, properties of previously known YSOs (selected from the literature) were examined and compared to other objects in the frame to look for new YSOs.

Data sources included Spitzer archival data from IRAC and MIPS; additional data came from the Two-Micron All-Sky Survey (2MASS), and the Wide-field Infrared Survey Explorer (WISE); new original ground-based optical photometry in the Sloan bands was gathered for BRC 34 using the 2-m Las Cumbres Observatory Global Telescope (LCOGT) on Haleakala (thanks to JD Armstrong). **Source matching** between our sources and the extant literature provided some additional optical data for BRC 27, in particular. Due to source confusion and limited accuracy of previously-reported coordinates, some previously-known sources could not be matched to individual sources in our data.

For our **new photometry**, we used a combination of MOPEX and the Aperture Photometry Tool (APT). We applied a Gutermuth-style color cut method to select sources exhibiting infrared excess. We collected the photometry in spreadsheets, which facilitated conversion between flux densities and magnitudes and the generation of color-color and color-magnitude diagrams, and spectral energy diagrams (SEDs).

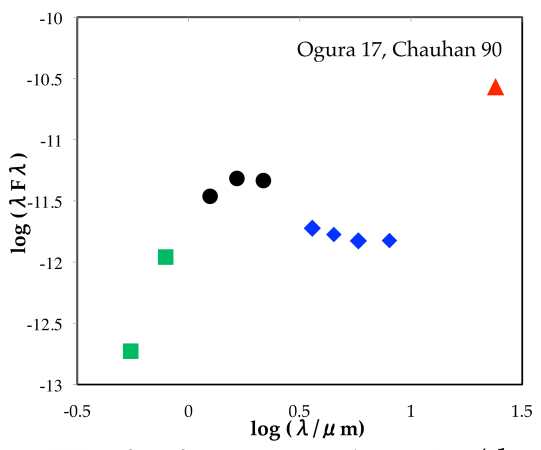
RESULTS and CONCLUSIONS

These two regions are rich in YSOs. Of the 35 previously-known sources in **BRC 27,** we recovered all but 12 as having IR excesses and identified 19 new YSO candidates based on apparent IR excesses. In **BRC 34,** where there is little literature, the one previously-known YSO has an excess, and there are 8 new YSO candidates.

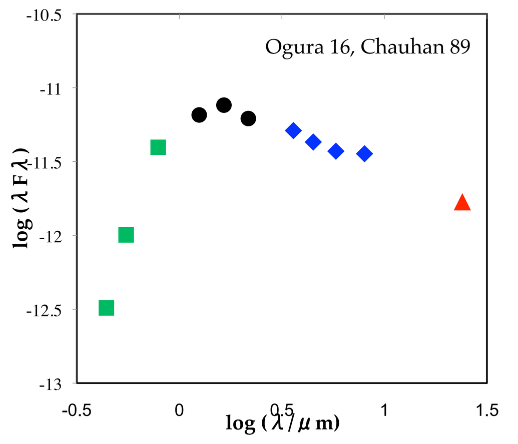
While follow-up spectra are critical for assuring that these are young stars (and not background AGB stars), we will assume, for now, that they are all legitimate young stars. There are significantly more YSOs in BRC 27 than BRC 34; since the objects are at approximately the same distance, the source density in BRC 27 does seem to be significantly higher (~1.6 per arcmin² in BRC 27 vs. ~0.4 in BRC 34). Since we are looking for IR excesses, our sample of Class III YSOs is guaranteed to be incomplete, but most of the identified BRC 27 sources are Class I (~30%) or II (~25%); by comparison, most of the BRC 34 sources are Class Flat (~67%). We, therefore, suspect that BRC 34 is slightly older than BRC 27. A previous NITARP project (Johnson et al. 2011, Rebull et al. 2011) studied the CG4+Sa101 region which, based on similar source fractions, might be intermediate in age between BRC 27 and BRC 34.

Sample Spectral Energy Diagrams (SEDs)

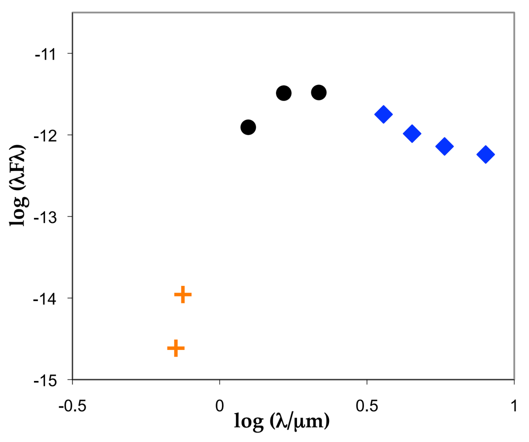
BRC 27 070406.0-112315 (class I)



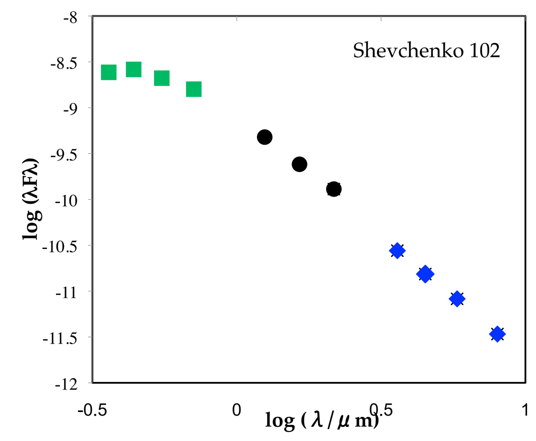
BRC 27 070405.9-112358 (class II)



BRC 34 213340.8+580631 (flat)

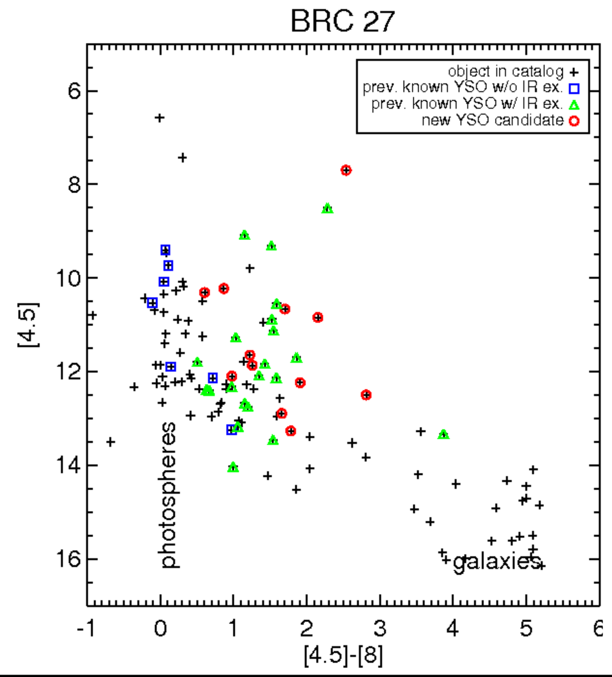


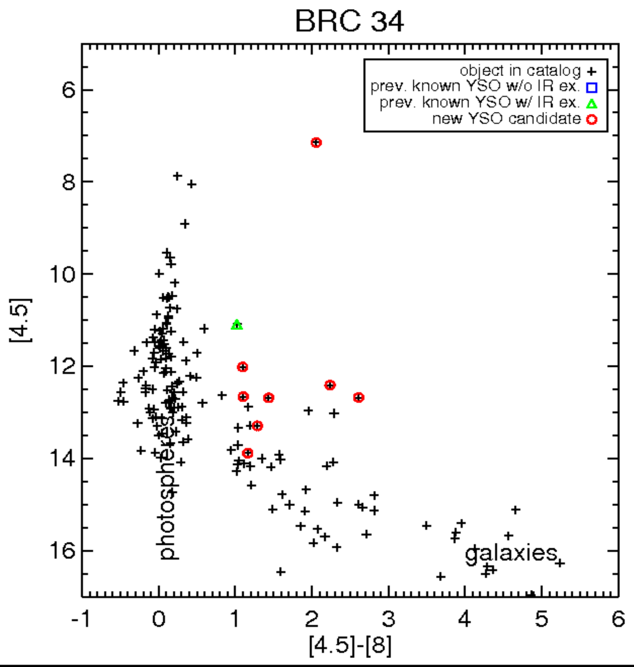
BRC 27 070403.9-112609 (class III)



SEDs for four example YSOs (three previously known and one new). In all figures, λFλ is in ergs/s/cm², and λ is in microns; green squares are optical data from the literature, orange crosses are new LCOGT data, black circles are 2MASS data, blue diamonds are IRAC data, and red triangles are MIPS-24 data.

Color-Color and Color-Magnitude Diagrams





Photospheres (e.g., foreground/background stars without disks) are expected to have [4.5]-[8]~0 and galaxies are expected to be red and faint. Some of the previously known YSOs in BRC 27 do not appear to have significant IR excesses (they have [4.5]-[8]~0). All of the new YSO candidates are red and relatively bright, as expected.

*See companion poster (**Linahan, et al. 350.04: The Effect of an Authentic Science Research Experience on Teachers and Students through NITARP**) for an analysis of the educational effect of this project.*