Triggered Star Formation in the Isolated Cluster CB 34?

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Bok globules, optically opaque small dark clouds, are classical examples of isolated star formation. However, the collapse mechanism for these cold, dense clouds of gas and dust is not well understood. Observations of Bok globules include some which appear to be starless while others harbor single stars, binaries and even small groups of forming stars. One example of a Bok globule forming a group of stars is CB 34, which was observed with a Spitzer guaranteed time observation with IRAC and MIPS as part of the Young Cluster Survey. Based on initial analysis using Two Micron All Sky Survey (2MASS) photometry in addition to the four channel IRAC photometry, 8 Class 0/I and 14 Class II sources are detected within the small, 4.5' x 4.5' region encompassing CB 34. This unusually high number of protostars compared with Class II sources is intriguing because it implies a high rate of star formation. Therefore we have begun a larger study of this region in order to determine why and how CB 34 started forming stars at such a high rate. Is CB 34 embedded within a larger HII region which may have triggered its collapse or does it appear to have collapsed in isolation from outside influences?

1. CB 34: A Young Cluster

- First detected by Clemens & Barvainis (1988); one IRAS point source within its optical extent
- Alves & Yun (1995) detected 50 sources within 4′.5 × 4′.5 in J, H, and K bands with 12 sources showing large $H-K$ colors, indicating that they are likely to be young members of the aggregate
- Four Herbig-Haro objects were discovered by Moreira & Yun (1995) in narrowband S II and Hα imaging and shock emission features were seen in H_2 imaging

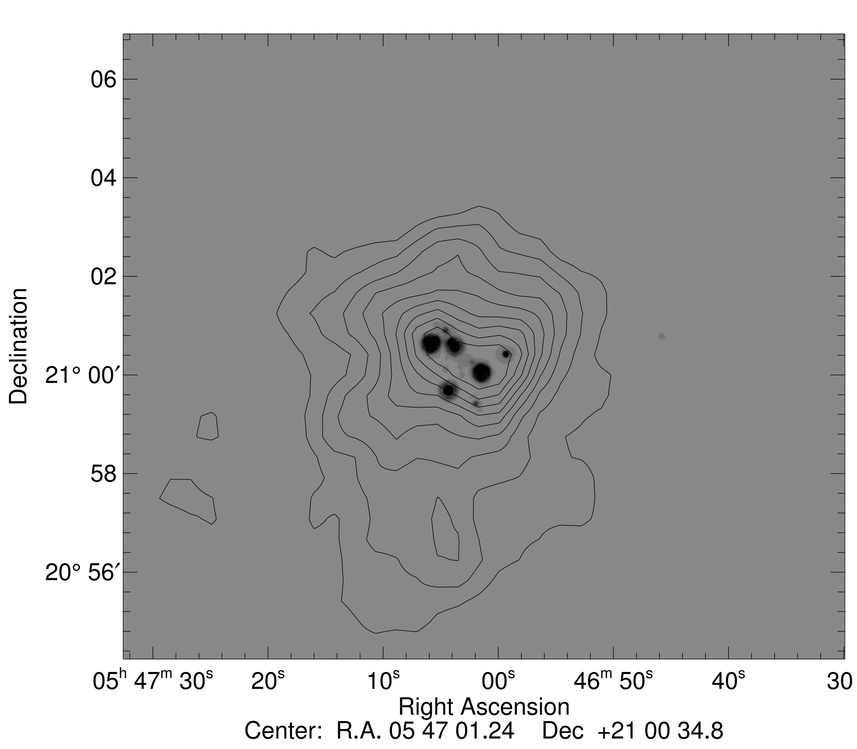


Fig. 1: Spitzer image of CB 34: inverse scale 24 μm MIPS map with ^{13}CO contours overlaid. The ^{13}CO map was obtained at FCRAO (Ridge et al. 2003). Based on the ^{13}CO and $C^{18}O$ observations, CB 34 was determined by Ridge et al. (2003) to have a compact core with 1 "significant peak."

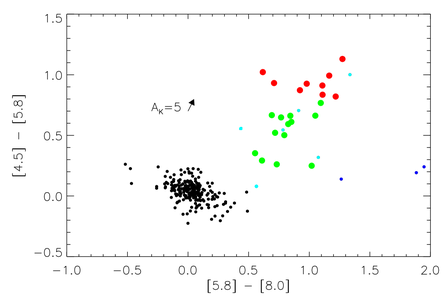
Table 1: CB 34 Properties

IRAS source	Distance (kpc)	FIR Luminosity ($L_\odot$)	Core mass ($M_\odot$)	Virial mass ($M_\odot$)	V_{LSR} (km s^{-1})
05440+2059	1.5	86.25	343.75	510	0.6

Far-IR luminosity and mass estimates from Ridge et al. (2003) scaled to 1.5 kpc. Masses are based on ^{13}CO measurements. V_{LSR} from Kawamura et al. (1998).

Spitzer Observations

- Observed with a *Spitzer* guaranteed time observation as part of the Young Cluster Survey
- IRAC observations obtained March 8, 2004 and MIPS on March 15, 2004.
- 265 point sources detected in all 4 IRAC bands in the 15′ x 15′ field around CB 34



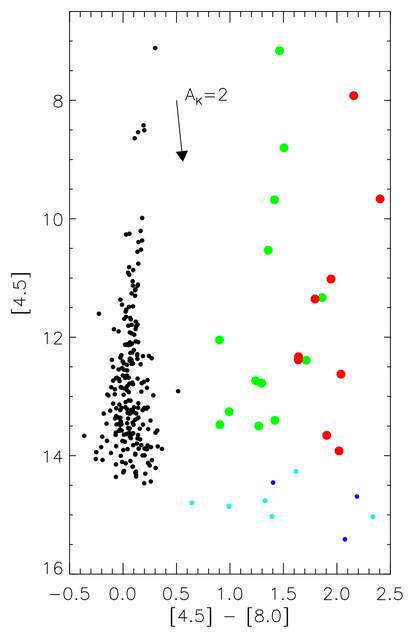


Fig. 2: Spitzer IRAC color-color and color-magnitude diagrams for CB 34 showing the selection of Class I (red dots) and Class II sources (green dots) as well as those deemed outlying galaxies (PAH, dark blue dots; AGN, cyan dots). Selection method used from Gutermuth et al. (2006, in prep) and reddening law from Flaherty et al. (2006, in prep).

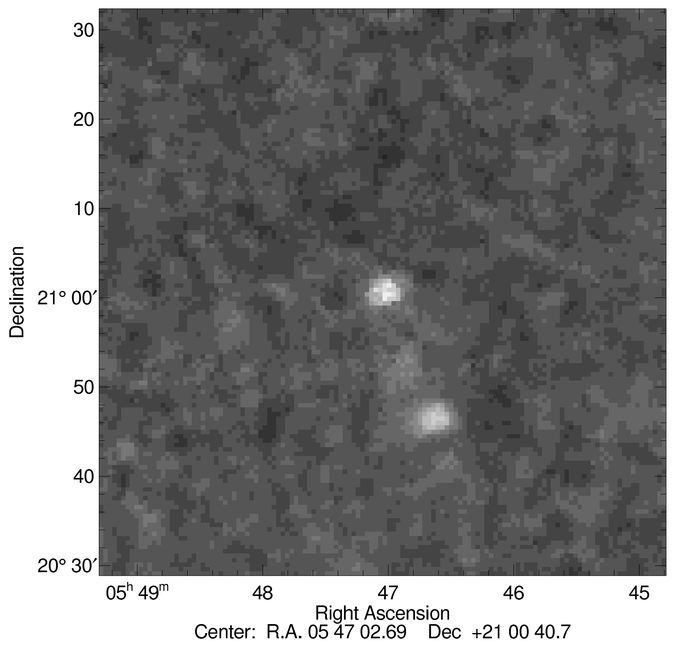


Fig. 3: Extinction map of a 1°x1° FoV around CB 34; note dark cloud CB 33 to the south. Created using a nearest neighbor method using H-K colors from 2MASS data (Gutermuth et al. 2005). Linear scale, gray implies A_V=0, white implies A_V=9

2. Spitzer Identified Class I and Class II Sources

Based on analysis of the CB 34 *Spitzer* data and using Two Micron All Sky Survey (2MASS) JHK in addition to the 4 channel IRAC photometry, we select:

- 9 Class 0/I sources
- 14 Class II sources

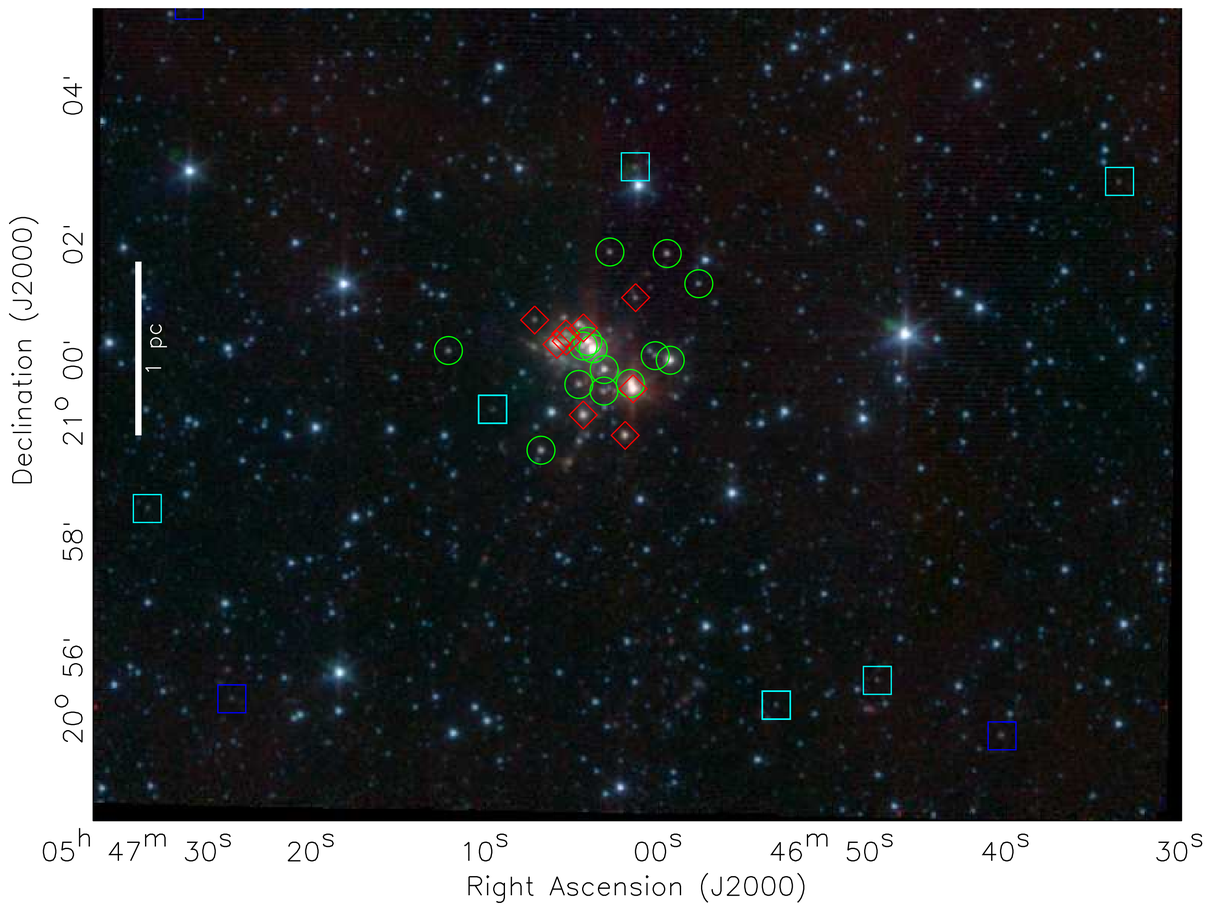


Fig. 4: Spitzer 3.6 μm (blue), 4.5 μm (green), and 8.0 μm (red) image showing the locations of the 23 young stellar objects (YSOs) in CB 34. Class I = red diamonds, Class II = green circles, "galaxies/PAH" = blue squares, "galaxies/AGN" = cyan squares (color code matches that of Figure 2). Selection of these sources is described in detail in Gutermuth et al. (2006, in prep).

3. Evidence for Triggering?

The immediate vicinity around CB 34 is fairly empty (see Figure 3). Possible triggerers were searched for within a 3^o radius around CB 34. Within that region on the sky includes:

- NGC 2129 (young, 10 Myr, open cluster; d=2.2 kpc; V_r=17.5 km s^{-1}; Carraro, Chaboyer, & Perencevich 2006)
- star forming region GGD 4 (d=1 kpc; V_r=2.1 km s^{-1}; Kawamura et al. 1998)
- western edge of the Gemini OB 1 association (d=1.5 kpc; V_r=3.8 km s^{-1}; Carpenter, Snell, & Schloerb 1995)

Approximately 7^o away from CB 34 is IC 443 (the Jellyfish Nebula), a supernova remnant which is too young ($\sim 10^3$ years old) to have triggered CB 34.

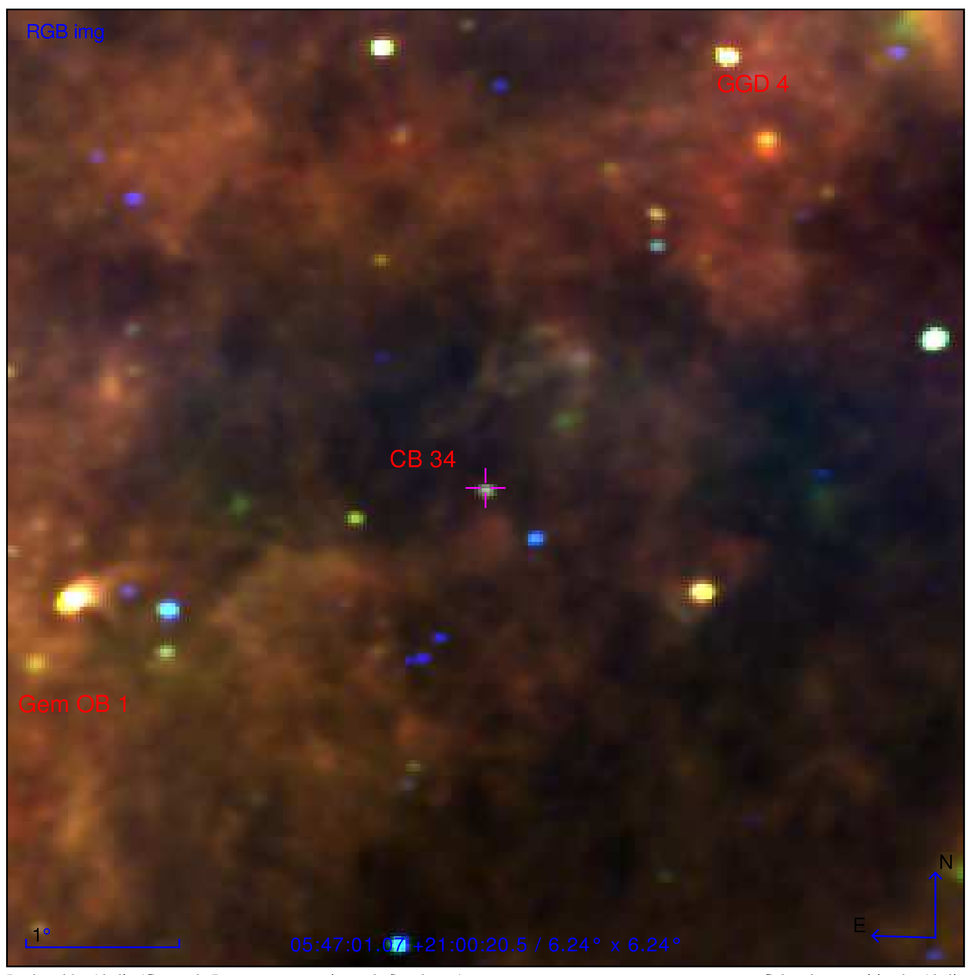


Fig. 5: IRAS 25 μm (blue), 60 μm (green), and 100 μm (red) image of a 3^o radius around CB 34. CB 34 is quite isolated, with only another dark cloud, CB 33, nearby. However, at slightly further distances there is the star forming region GGD 4 to the northwest and the western edge of the Gemini OB 1 association to the east.

Conclusion

The high star formation efficiency in CB 34 is interesting, particularly because the region is so isolated. If star formation in CB 34 has been triggered, it is likely due to activity from the nearby Gemini OB 1 association.

References

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