Star Formation Activity in the Long Filamentary Infrared Dark Cloud IRDC G53.2

Hyun-Jeong Kim[1], Bon-Chul Koo[1] and Chris Davis[2]

[1] Dept. of Physics and Astronomy, Seoul National Univ., Rep. of Korea; [2] Astrophysics Research Institute, Liverpool John Moores Univ., United Kingdom

Abstract. Infrared dark clouds (IRDCs), seen silhouette against the bright Galactic background in mid-IR, are cold and very dense interstellar clouds with high column densities so that IRDCs are believed to be a probable site where massive stars are forming. In this study, we report star formation activity in the IRDC G53.2, a remarkable IRDC at (*l, b*)~(53.2, 0.0). The IRDC G53.2, which is well consistent with a CO cloud at *v*~23km/s (or at *d*~1.7 kpc), is long with its extent of ~30 pc and shows a number of reddened mid-IR sources distributed along its filamentary structure. We perform photometry of the Spitzer MIPSGAL 24 um data, merge with other published catalogs, and present a catalog of young stellar object (YSO) candidates in the IRDC. The classification of YSO candidates based on their spectral energy distributions and control field analysis to remove fore/background star contamination reveal an active star formation in the cloud with ~300 YSO candidates. We find that the evolutionary phases of the YSO candidates are rather earlier compared to other low-mass star forming regions with ~45% of Class I and Flat Class objects, most of which are concentrated in the region bright in far-IR and millimeter. Ubiquitous molecular hydrogen (H_2 at 2.122 um) outflows around the YSO candidates in the IRDC revealed by the UWISH2 data indicate that they are earlier class objects as well. Based on the catalog of YSO candidates, we discuss the population of the YSO candidates in different evolutionary phases, their spatial distribution, and the association with H_2 outflows in order to characterize star formation activity in the IRDC.

I. Introduction

Massive stars & Massive star formation

★ Importance of massive stars in understanding the evolution of galaxies
- providing ionizing photons, energy, and heavy elements into ISM

★ Insufficient knowledge on the formation of massive stars
- a scaled-up version of low-mass stars via accretion from circumstellar disks?

★ **Infrared dark clouds (IRDCs)**
- cold (< 25 K) and very dense ($n_{H2} > 10^5$ cm^{-3}) interstellar clouds
- a possible site where **massive star formation is occurring**

IRDC G53.2

★ Long (~30 pc) **IRDC at (*l, b*)~(53.2, 0.0)** with bright mid-IR stellar sources, coincident with 1.2mm continuum emissions along its filamentary structure

★ Well consistent with a CO cloud (^{13}CO J=1-0 map; GRS[1]) at ***v*~23.5 km/s** (or at ***d*~1.7 kpc**) clearly distinct from other velocity components (see ***Fig. 3***)

★ Previously identified as three separate IRDCs in the MSXDC catalog[2]

★ **H_2 (2.12μm) outflows** from UWISH2[3] (around earlier class YSOs; ***Fig 2***)

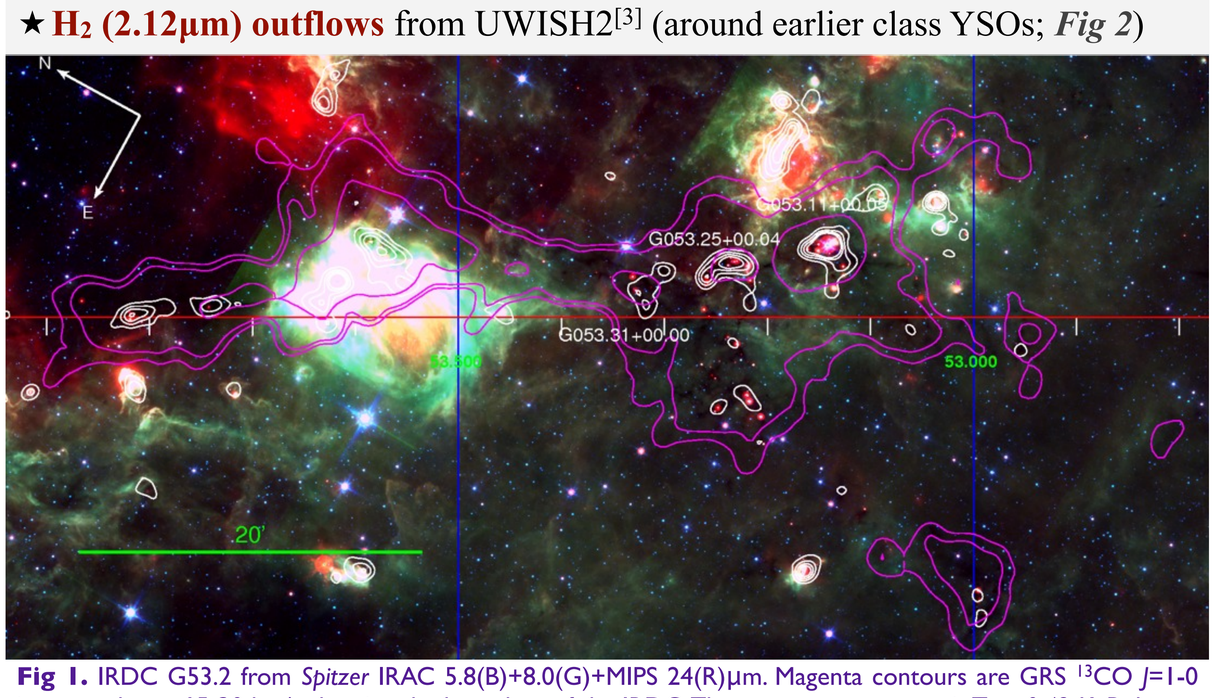


Fig 1. IRDC G53.2 from *Spitzer* IRAC 5.8(B)+8.0(G)+MIPS 24(R)μm. Magenta contours are GRS ^{13}CO *J*=1-0 integrated at *v*=15-30 km/s showing the boundary of the IRDC. The outermost contour is T_b = 0.42 K. Bolocam GPS 1.2 mm contours are overlaid in white. Previously identified 3 IRDCs in MSXDC catalog are marked.

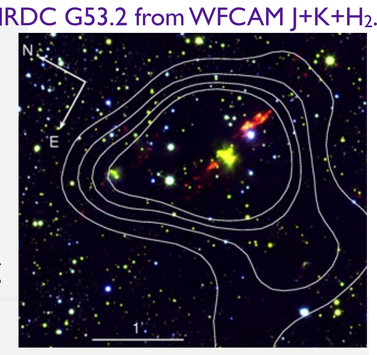
II. Data & Analysis

Point source catalog of the IRDC G53.2

- PRF-fitting Photometry of **MIPSGAL[4] 24μm**
- GLIMPSEI[5] Catalog & Archive (v2.0)
- 2MASS PSC; MSX PSC for MIPS saturated sources

➡ **373 sources** with 24μm limiting mag of ~7.8 mag

Fig 2. Prominent H_2 outflow in the IRDC G53.2 from WFCAM J+K+H_2.



YSO classification

- Spectral index α = d log(λS(λ)) / d log(λ) from 2-24μm[6,7]

➡ **78 Class I (21%), 66 Flat (18%), 135 Class II (17%), 62 Class III (17%), 26 photospheric (7%)** (+6 No class)

Contamination

- Few extragalactic contamination
  - located in Galactic plane
- Removal field star contamination using control fields w/o CO cloud (***Fig. 3***)

➡ **77 Class I (25%), 63 Flat (20%), 129 Class II (42%), 33 Class III (11%)** (+6 No class)

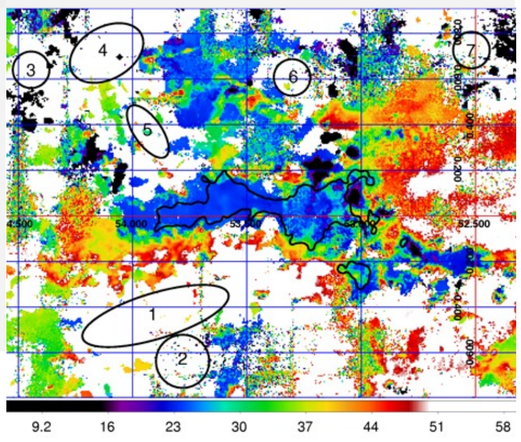


Fig 3. GRS ^{13}CO *J*=1-0 velocity moment map. The colors indicate velocities of clouds. 7 control fields are with numbers. Blue cloud encompassed by contour is the IRDC G53.2.

IV. Discussion

YSO population in the IRDC G53.2 vs. other star forming regions

❖ c2d clouds: 5 nearby (*d* < 0.3 kpc) molecular clouds[8]

❖ Vul OB1: active star forming region at the Galactic plane (*d*~2.3 kpc)[9]

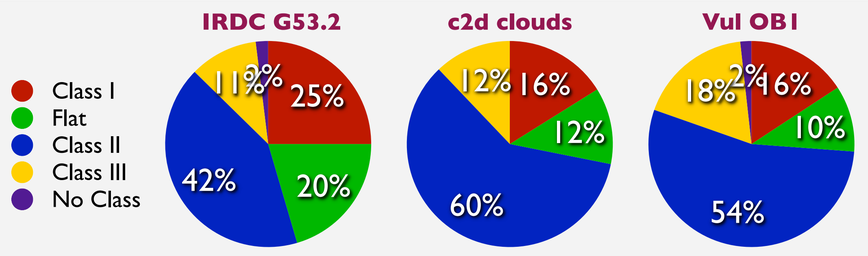


Fig 4. YSO population of the IRDC G53.2 after removing contamination and other star forming regions

★ **More Class I & Flat and fewer Class II in the IRDC**
- **IRDC in earlier evolutionary phase** than other star forming regions

cf) highly-reddened Class II in Class I? uncertainty in classification of Flat?

★ Fewer Class III in the IRDC
- deeper photometry of c2d clouds ➔ if eliminating fainter sources ([24] > 7.8 mag) from the c2d clouds, Class III in both the IRDC & c2d clouds ~ 10%
- field star contamination in Vul OB1 ➔ comparable Class III fraction between the IRDC before removing contamination & Vul OB1 (~18%)

Spatial distribution of YSOs

★ YSO distribution along dark filaments in MIR
- **central part of the CO cloud** with high column density

★ **Clustering and concentration**
- well consistent with **far-IR/mm continuum** (e.g. *Herschel* 500μm; ***Fig. 5***)
- **the earlier class (e.g.Class I), the higher degree of clustering/concentration**
  - nearest neighbor (NN) distance at which 80% of each class object included

➡ Class I=0.48; Flat=0.75; Class II=0.68; Class III=0.98 [pc] (***Fig. 6***)

cf) statistically no significant difference bet. Class II & Flat (with K-S test of >10%)
- as decreasing 500μm intensity, earlier class ⬇ & later class ⬆ (***Fig. 7***)

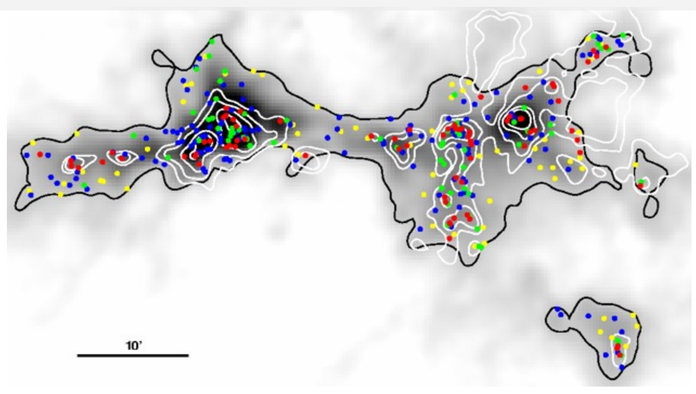


Fig 5. YSO distribution on the column density map from GRS. White contours: *Herschel* 500μm intensities (2, 3, 5, 8 Jy/beam); Black contour: the IRDC boundary; Symbols: **Class I**, **Flat**, **Class II**, **Class III**

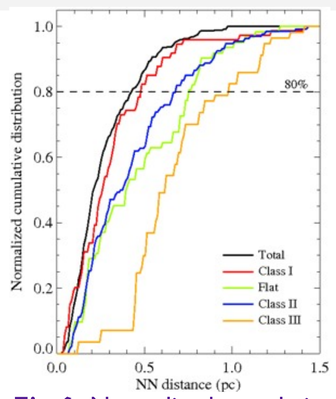


Fig 6. Normalized cumulative distribution of nearest neighbor distances of each class of YSOs

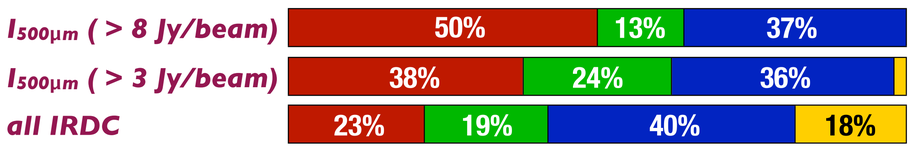


Fig 7. Fraction of YSO class (except photospheric objects) in 500μm contours. **Class I**, **Flat**, **Class II**, **Class III**

V. Summary

★ We investigate the **star formation activity in the IRDC G53.2**.

★ Our YSO candidates catalog shows **the IRDC is rather in earlier evolutionary phase** compared to other star forming regions.

★ YSOs in the IRDC have a good spatial correlation with far-IR/mm and denser part of the CO cloud. **Earlier class shows higher degree of clustering/concentration**.

★ Detailed study on individual YSOs (e.g. SED modeling) and comparison to other star forming regions will be necessary to examine the characteristics of star formation in the IRDC G53.2.

References. [1] Jackson et al. 2006, ApJS, 163, 145; [2] Simon et al. 2006, ApJ, 639, 227; [3] Froebrich et al. 2011, MNRAS, 413, 480; [4] Carey et al. 2009, PASP, 121, 76; [5] Benjamin et al. 2003, PASP, 115, 953; [6] Lada 1987, IAUS, 115,1L; [7] Greene et al. 1994, ApJ, 434, 614; [8] Billot et al. 2010, ApJ, 712, 797 [9] Evans et al. 2009, ApJS, 181, 321

hjkim@astro.snu.ac.kr