Unraveling the evolutionary process of molecular clouds in the Milky Way galaxy from temperature profiles of dense gas

SE-26P



Yosuke SHIBATA (Nagoya Univ.)

Kengo TACHIHARA, Fumika DEMACHI (Nagoya Univ.), Rin YAMADA(NAOJ), Toshihiro HANDA(Kogakuin Univ.), Takeru MURASE(Gifu Univ.), Rina KASAI, Hiroshi IMAI(Kagoshima Univ.), Ren MATSUSAKA(Tokyo Univ.), Shinji FUJITA(The Institute of Statistical Mathmatics)

Abstract

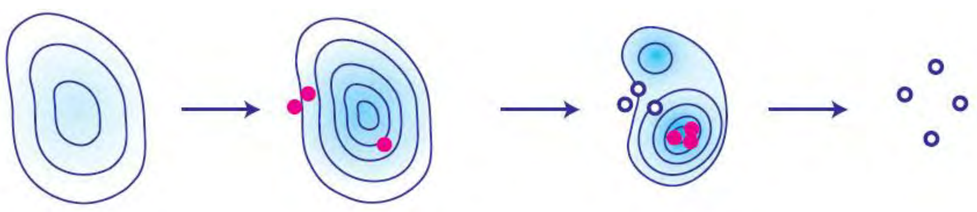
Models of molecular cloud evolution using star formation activity as an indicator have been studied through extragalactic observations (e.g., Fukui et al., 1999), but their spatial resolution is insufficient to resolve internal structures. A promising alternative is statistical surveys of well-resolved molecular clouds in the Milky Way. Conventional tracers such as Hα and mid-infrared continuum are ineffective for estimating star formation activity across the Galactic plane.

In this study, we used NH_3 emission lines to derive dense gas temperatures in 29 molecular clouds and estimate star formation activity with Mid-Infrared. Clouds were classified into two stages: a pre-star formation stage with low-temperature (~10 K) gas and no mid-infrared emission, and a star-forming stage with high-temperature (~30–40 K) gas associated with mid-infrared emission. A positive correlation was found between dense gas temperature and mid-infrared luminosity. Radial temperature profiles revealed heating regions larger than those reported for isolated high-mass star-forming regions (< 3 pc; Rumble+2021), often corresponding to multiple MIR peaks. These results suggest that dense gas temperature profiles are good indicators of star formation activity. Future work will incorporate CO data from the Nobeyama 45 m Telescope.

Introduction

GMC evolution process

- Whole galaxy survey on LMC with CO Line emission: special resolution ~ 40 pc (Fukui+1999, Kawamura+2009)



Type I: No massive star formation

Type II: Only HII region

Type III: HII region and young clusters

Only young cluster

The evolutionary processes in molecular clouds remain unclear

- **How does the internal structure of molecular cloud gas evolve?**
- **How does dense gas relate to the evolutionary process?**

Dataset

Milkyway(MW) Star-forming Regions: 29, Distance: 300-5500 pc

	NH_3 (J,K) = (1,1), (2,2)	Mid-Infrared
Frequency, Wavelwngth	23 GHz	21.3 μm
Telescope	Greenbank 100 m Radio Telescope	Midcourse Space Experiment
Beam size	32 arcsec (0.05-0.85 pc)	18.3 arcsec (0.03–0.49 pc)

Dense gas tracer & Derived Physical quantities: NH_3

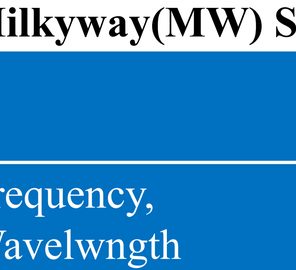
- critical density(n_{H_2}): $10^{3\text{-}4}$ cm^{-3})

Star Formation tracer: Mid Infrared continuum(MIR)

- Good correlation to Star Formation rate (Calzetti+2007)

Analysis

η_{ff}: Beam filling factor



NH_3 (I_{22} , I_{11} : NH_3 observation intensity)

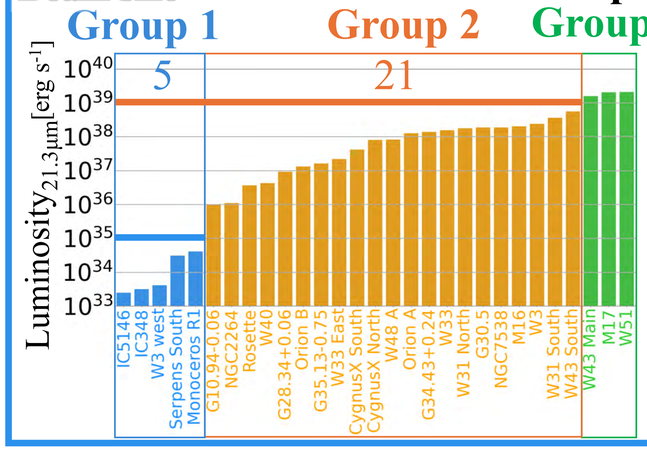
Observed Excitation temperature($T_{ex,obs}$) $= \eta_{ff} T_{ex} \propto I_{11}$

Rotational temperature(T_{rot}) $\propto I_{22}/I_{11}$

LTE: $T_{rot} = T_{ex}$

$T_{ex,obs} / T_{rot} = \eta_{ff}$

Gas temperature(T_{gas}) derived from T_{rot}



Classification using MIR

➤**Previous method difficult to adapt MW**

Reference value:

Group 1 ~ B0.5 Star

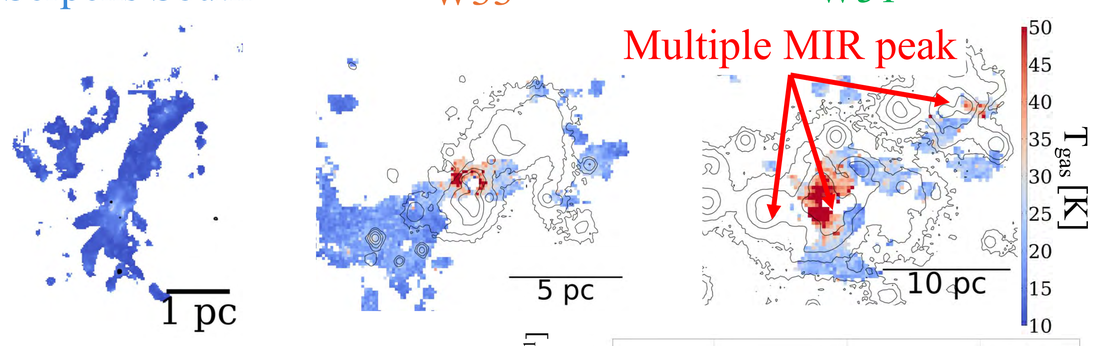
Group 2 ~ 1- 10 O Star

Group 3 ~ over 10 O Star

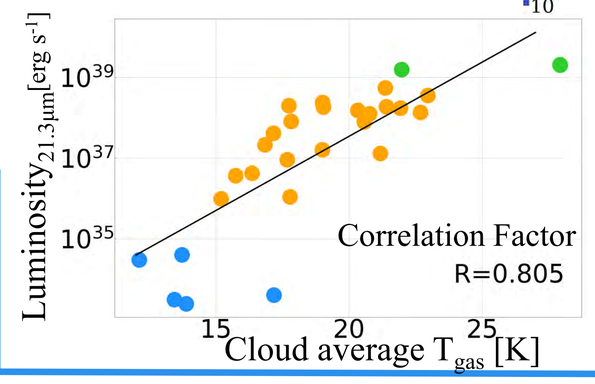
Result

contour: 21.3μm (5σ, 10σ, 30σ, 100σ, 1σ~same value)

Group 1 Serpens South | Group 2 W33 | Group 3 W51



Cloud average T_{gas} and $L_{21.3}$ is good correlation

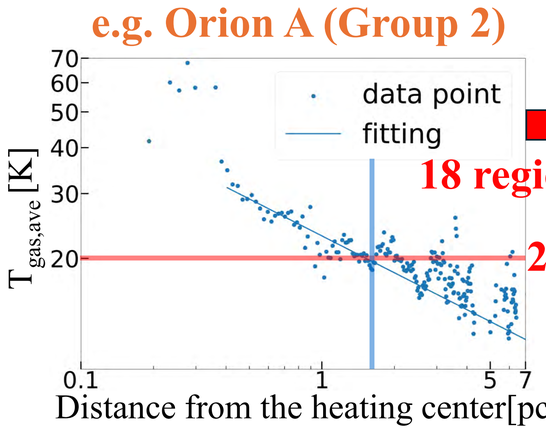


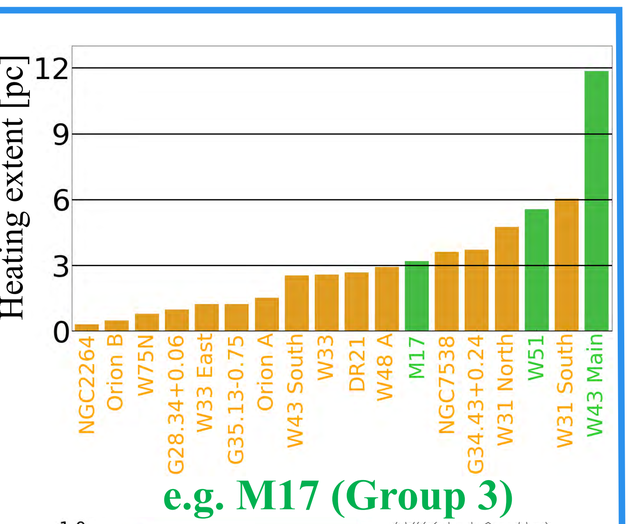
Discussion

Temperature Profile

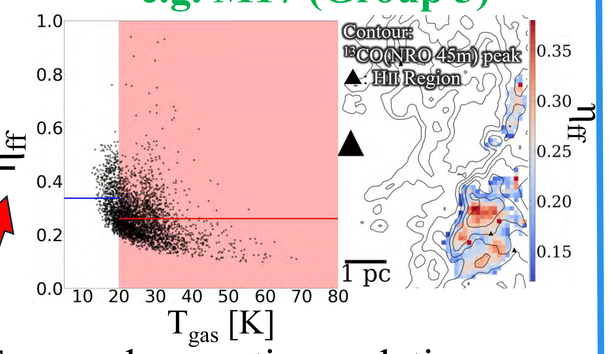
Heating extent: Intersection of the fitting line and 20K

e.g. Orion A (Group 2)





e.g. M17 (Group 3)



Heating center: MIR Peak or HII Region(WISE: Underson+2014)

The heating extent clearly exceeding 3pc (isolated HM star: Rumble+2021)

➤**Created by multiple heating sources (e.g. W51, W43)**

How can dense gas heated to few pc?

➤ **Fine dense gas structure investigate with η_{ff}**

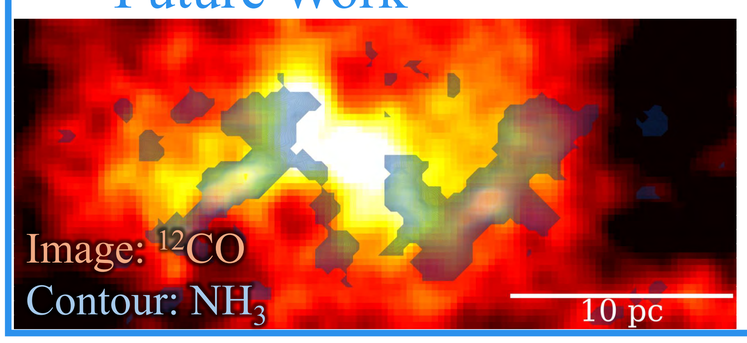
T_{gas}-η_{ff} show anti-correlation: Warm gas have smaller structures

Warm gas shielding not effective

Compare diffuse gas(^{13}CO) data

➤^{13}CO and η_{ff} show similar distribution

Future Work



Using NRO45m data:

CO gas temperature distribution obtained by LVG analysis

➤Comparing dense gas distribution