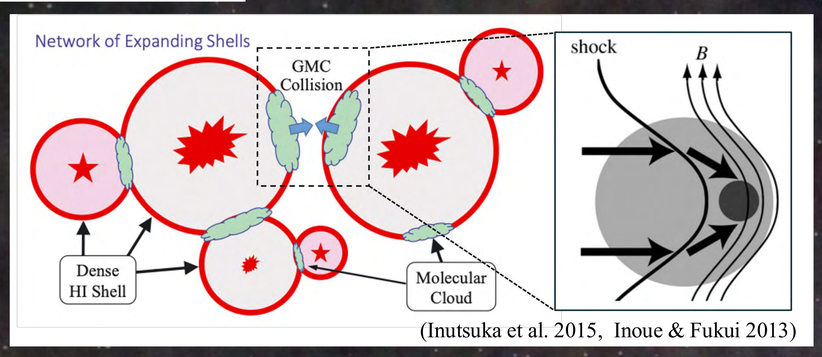
# Filament and star formation in the Perseus cloud revealed by Nobeyama 45m telescope

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## Abstract

Filamentary molecular clouds are sites of star formation, and understanding their formation processes is crucial. Recent theoretical studies suggest that shock waves are essential for filament formation. However, observational confirmations remain limited. To investigate filament formation triggered by cloud-cloud collisions (CCC), we focused on the Perseus molecular cloud at a distance of 300 pc. The Perseus cloud is attached to the surface of the expanding HI shell with a diameter of 150 pc. It contains two low-mass cluster-forming regions, NGC1333 and IC348, and previous studies have proposed a CCC in NGC1333. Furthermore, Herschel observations have revealed filamentary structures in the Perseus cloud, making it an ideal target for this study. Although filaments are thought to have a wide range of densities, previous high-resolution observations have been limited to dense gas tracers. Therefore, we conducted high-resolution observations of three CO isotopologue lines toward NGC1333 and IC348 using the Nobeyama 45m telescope. The velocity structure of the 13CO shows evidence of CCC in both regions. From the C18O peak intensity maps, we identified 40 and 20 filamentary structures in NGC1333 and IC348, respectively. These filaments exhibit a wide range of line masses, 4-250 Mo/pc in NGC1333 and 4-125 Mo/pc in IC 348. High line mass filaments concentrated in areas where the two colliding clouds overlap. The filaments exhibit velocity offsets of ~0.5 km/s relative to the surrounding gas and display V-shaped structures in P–V diagrams perpendicular to the filaments. Furthermore, we analyzed the motions of young stars using GaiaDR3 and APOGEE-2 data. The proper motions show radially outward motions from the shell center, while the radial velocities are distributed in the intermediate velocity of the two colliding clouds. These results suggest that filament and star formation in NGC1333 and IC348 are triggered by CCC driven by the expanding shell.

## 1. Introduction




(Inutsuka et al. 2015, Inoue & Fukui 2013)

Fig1:*Schematic view of filament formation driven by expanding shells*

- Filamentary molecular clouds are site of star formation
  - Filament formation needs shock waves (e.g., Inoue et al. 2018)
  - Shock waves are driven by multiple expanding shells? (Inutsuka et al. 2015)

→ **Observational evidences are limited**

## 2. Perseus cloud

- Distance: ~ 300 pc
- Filamentary structure (e.g., Hacar et al. 2017)
- Cluster-forming regions, NGC 1333 and IC 348

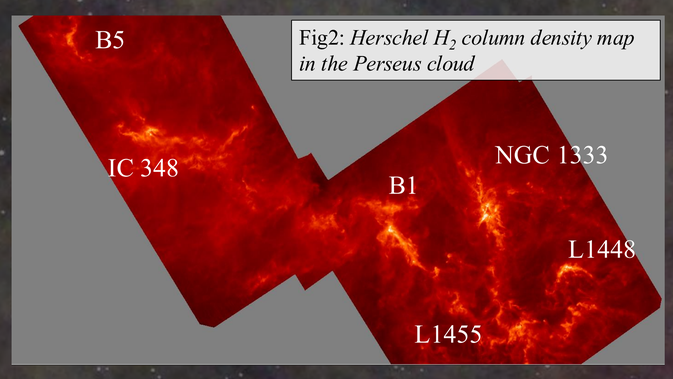



Fig2: *Herschel $H_2$ column density map in the Perseus cloud*

- Associated with the Per-Tau shell with a diameter of 150 pc identified by the 3D dust extinction map obtained from Gaia (Bialy et al. 2021)

## 3. Dataset

- CO observation by Nobeyama 45m Telescope
- YSO catalog by Spitzer and 2MASS (Gutermuth et al. 2008, 2009)
- Proper motion and distance of stars by Gaia DR3
- Radial velocity of stars by APOGEE-2

| Telescope | Nobeyama 45m | Nobeyama 45m |
|---|---|---|
| object | NGC 1333 | IC 348 |
| Lines | $^{12,13}$CO, C$^{18}$O (J=1-0) | $^{12,13}$CO, C$^{18}$O (J=1-0) |
| Resolution | 14” | 14” |
| Sensitivity | ~0.15 K (dv = 0.16 km/s) | ~0.15 K (dv = 0.16 km/s) |
| Date | 2022-2023 Regular program | 2024-2025 CSV program |

## 4. Result

- Two velocity components (Red:8.5-11.8 km/s, Blue:3.4-7.0 km/s)
- YSOs are localized in the overlap region
- V-shape in the large-scale P-V diagram
- The cloud-cloud collision (CCC) triggers star formation
- A similar result is obtained in IC 348.



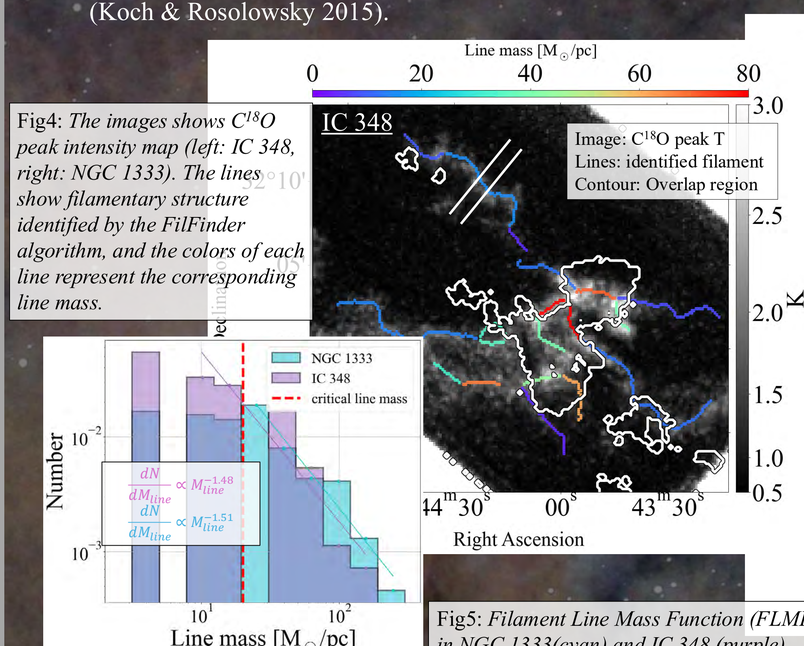




Fig3.:*(Top) First-moment map of $^{13}$CO. The red and blue contours represent the Red cloud and Blue cloud, respectively. Star markers indicate Class 0/I YSOs.*
*(Left) Position–velocity diagram taken along the black line in the top panel. The red, blue, and green shaded regions denote the velocity ranges of the Red cloud, Blue cloud, and intermediate-velocity component, respectively.*

## Filament identification

- 20 and 54 filamentary structures identified by *FilFinder* (Koch & Rosolowsky 2015).



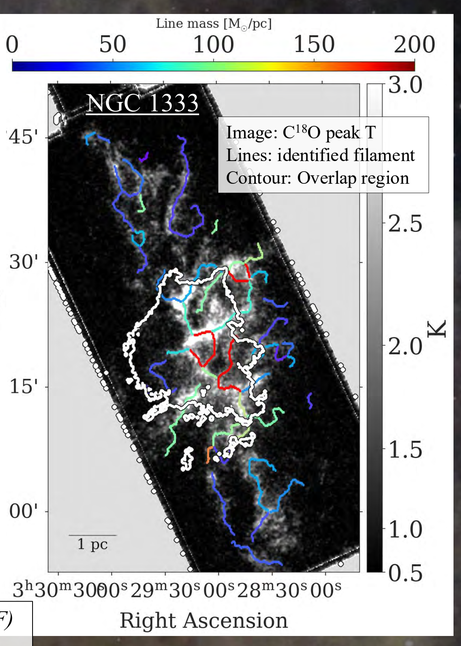




Fig4: *The images shows C$^{18}$O peak intensity map (left: IC 348, right: NGC 1333). The lines show filamentary structure identified by the FilFinder algorithm, and the colors of each line represent the corresponding line mass.*




Fig5: *Filament Line Mass Function (FLMF) in NGC 1333(cyan) and IC 348 (purple)*

- Massive filaments are concentrated in the overlap region.
- The slopes of FLMF are consistent with IMF and CMF, but the maximum value differs by a factor of two.

## Proper motion of YSOs

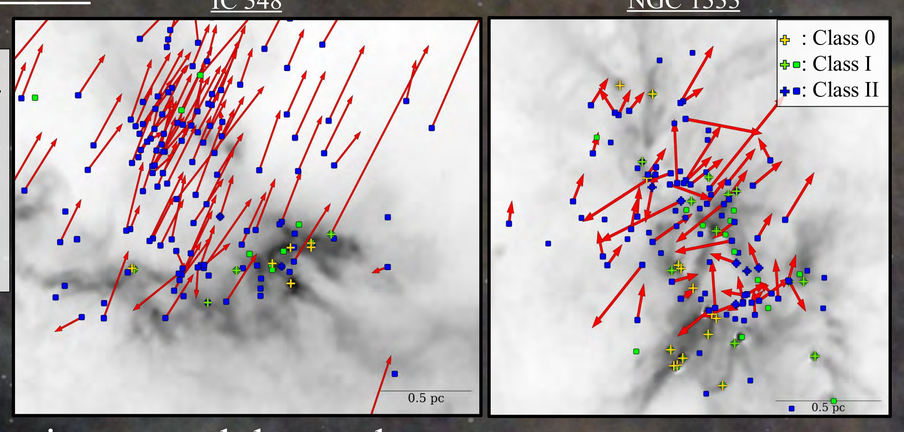



Fig6: *Proper motions of YSOs with respect to the LSR are illustrated by the arrows superposed on the N(H2) map by Herschel in IC 348 (left) and NGC 1333 (right). Position of YSOs from the VANDAM survey (Tobin et al. 2016) and catalog by Spitzer and 2MASS (Gutermuth et al. 2008, 2009) are marked by crosses and squares, respectively.*

- YSOs are co-moving toward the northwest

## 5. Discussion

### Formation mechanism of filaments

- V-shaped in the P–V diagrams around filaments suggest diffuse gas accretion onto filaments triggered by shock waves

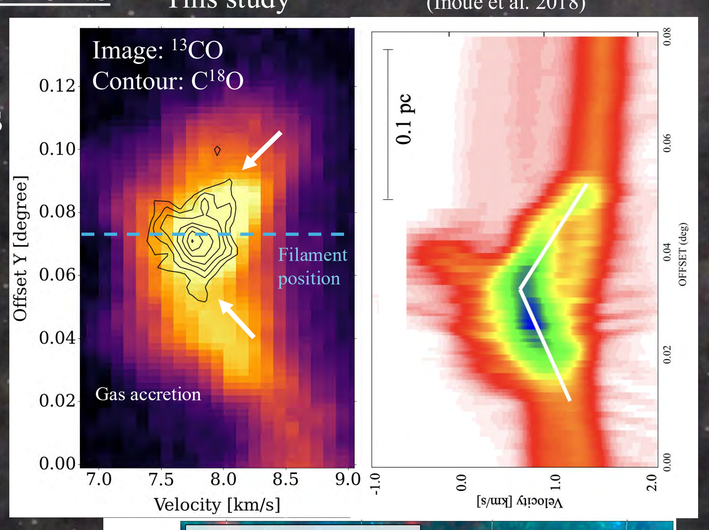



Fig6: *(Left) P-V diagram taken perpendicular to the filament indicated by the white line in the left panel of Figure 4. The image shows $^{13}$CO and the contours show C$^{18}$O.*
*(Right) P-V diagram perpendicular to a filament in MHD simulations of shock-induced filament formation (Inoue et al. 2018).*

### What drive CCC?

- YSOs are moving radially outward from the center of the Per-Tau shell.
- The CCC was driven by the expansion of the Per-Tau shell

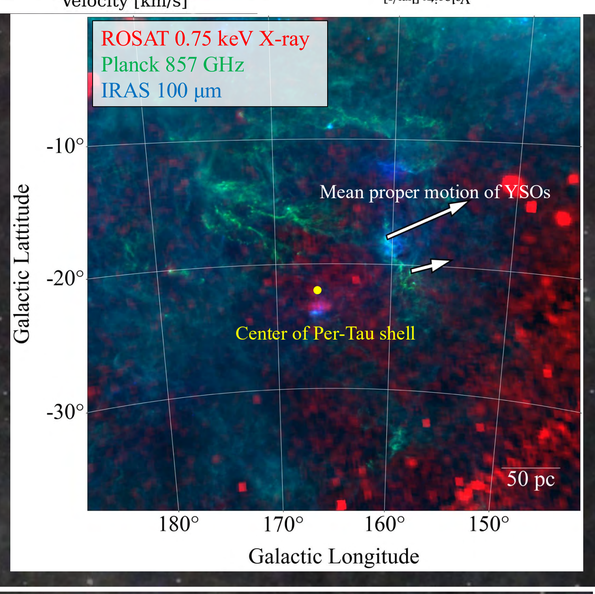



Fig6: *Three-color composite image of the Perseus region, Arrows indicate the mean proper-motion vectors of YSOs in NGC 1333 and IC 348, and the yellow circle marks the center of the Per–Tau shell.*

## 6. Conclusion

- Filamentary clouds in the Perseus cloud are formed by diffuse gas accretion triggered by cloud-cloud collision
- CCC in the Perseus cloud are driven by expansion of Per-Tau shell

*Background photo by Mitsuru Hoshi*