The TOP-SCOPE survey of Planck Cold Clumps

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1. Kee-Tae Kim will take the place of Tie Liu to coordinate Korean collaborators when Tie Liu leaves Korea in future.

Coordinators for Joint surveys:

Name	Affiliation	E-mail address	surveys
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M. Juvela	U. of Helsinki, FI	mika.juvela@helsinki.fi	Planck & Herschel

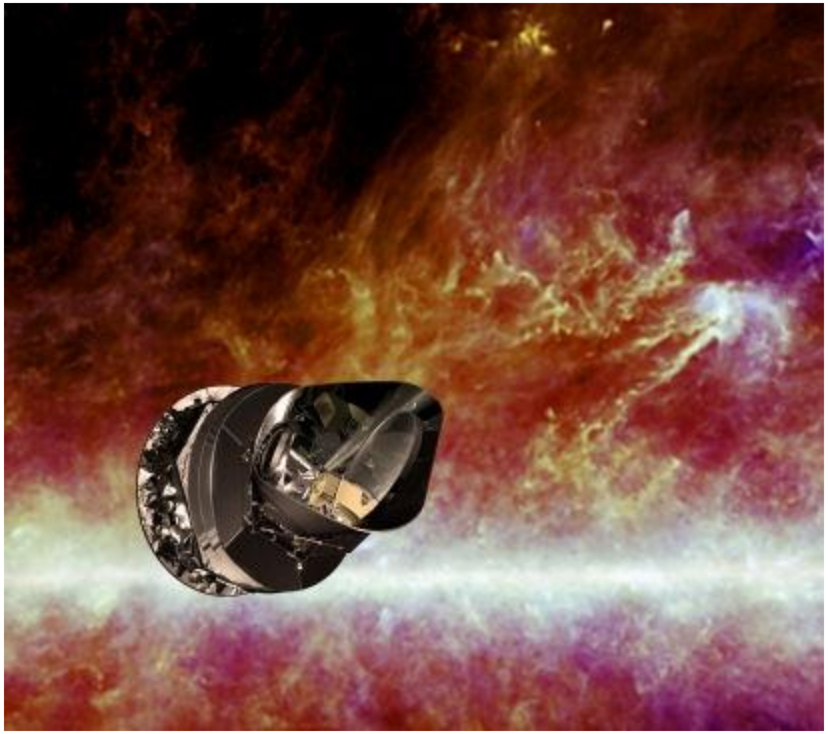
Including more than 150 members, new members are welcome!

Outline

1. Introduction of Planck Galactic Cold Clumps
2. Joint surveys and follow-up observations
3. Science Cases and Preliminary Results
4. Future plans and Summary

1. Introduction

What are Planck Galactic Cold Clumps?



Planck is a third generation space based cosmic microwave background experiment, operating at nine frequencies between 30 and 857 GHz

Planck Catalogue of Galactic Cold Clumps (PGCC), *13188 clumps*

The early cold core (ECC) sample: 915 sample Td<14 K, SNR>15

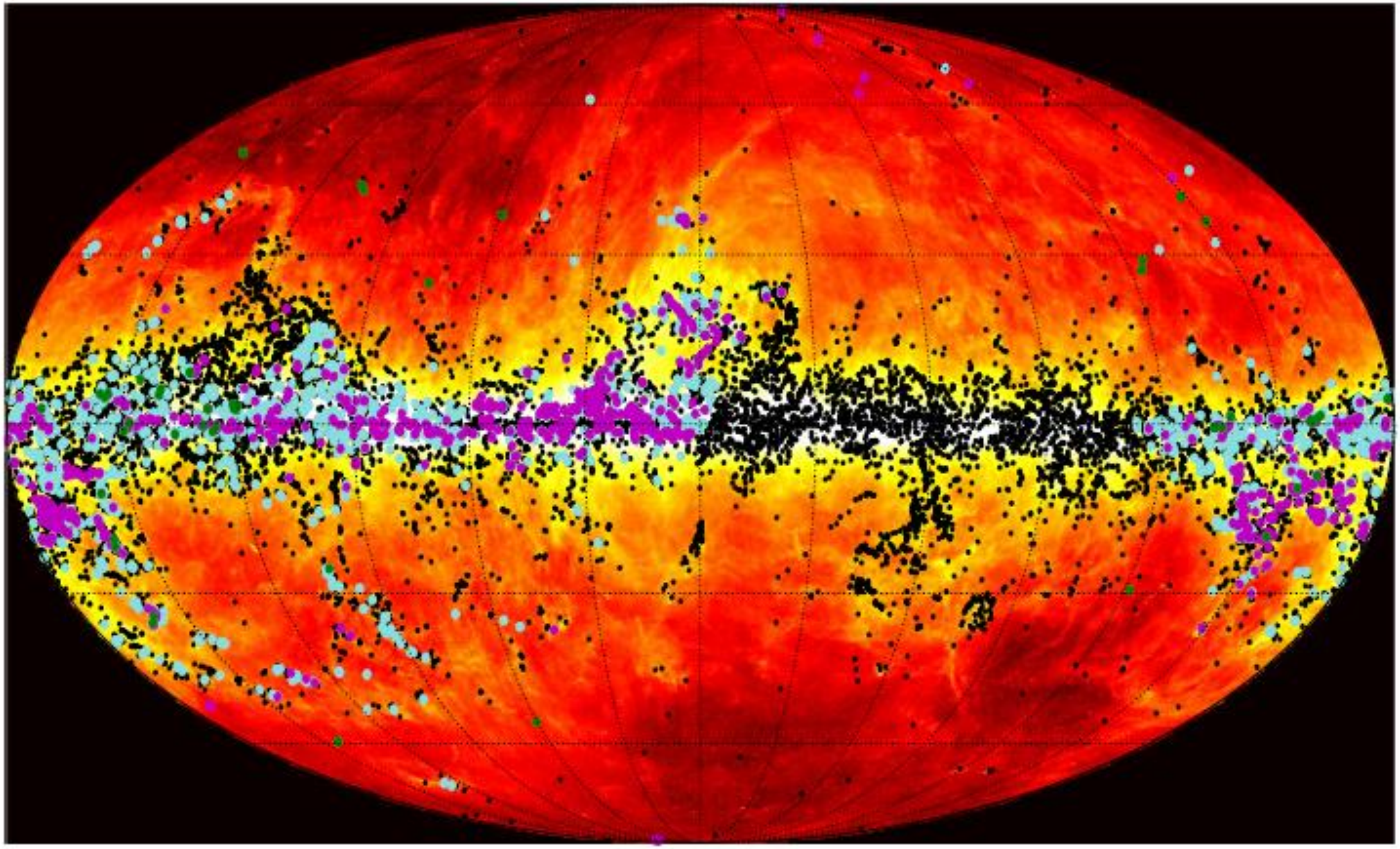
Driving science of follow-up surveys:

Summary from Planck collaborators et al. (2015)

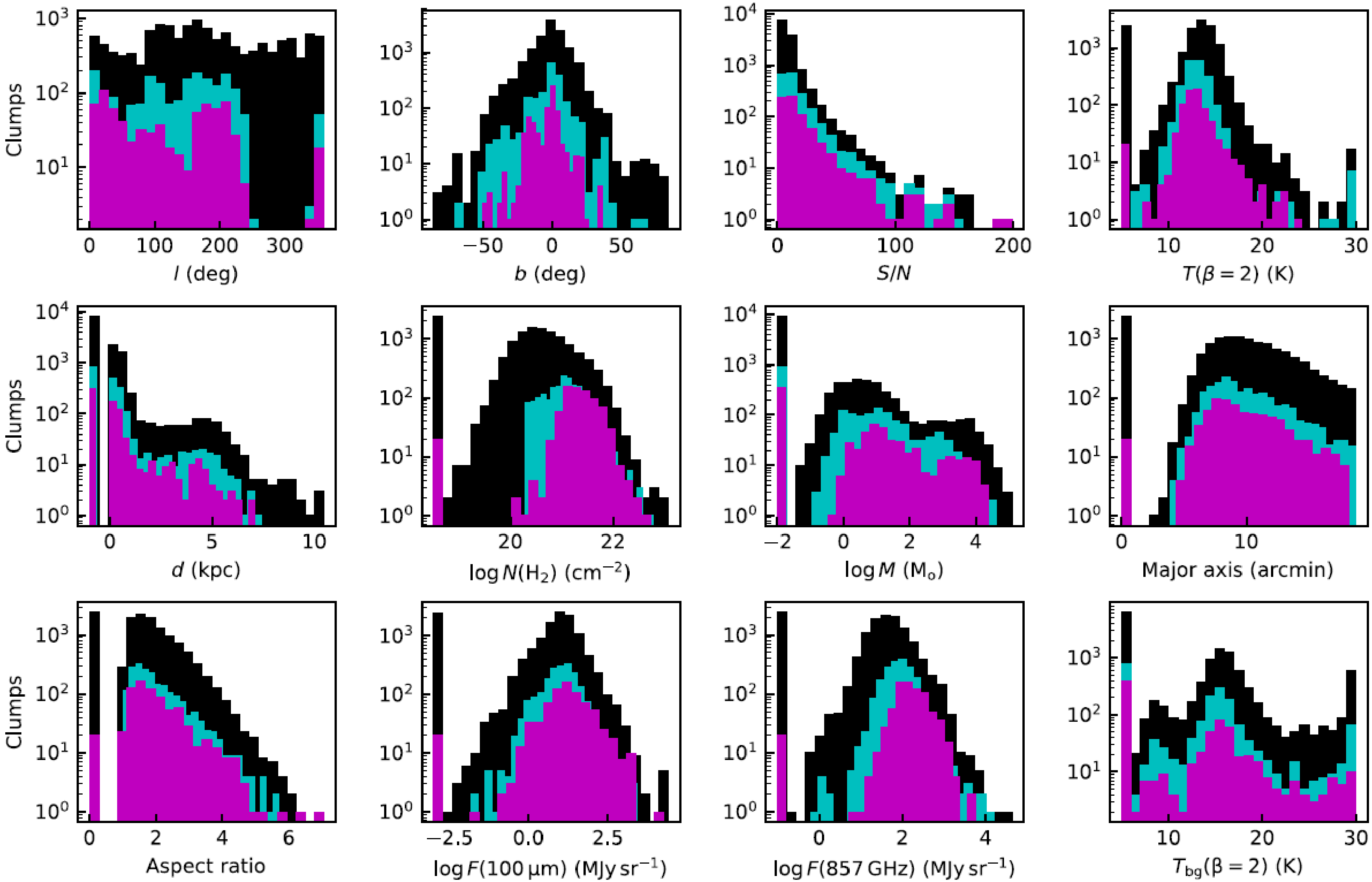
"We believe that the PGCC catalogue, covering the whole sky, hence probing wildly different environments, represents a real goldmine for investigations of the early phases of star formation. These include, but are not limited to: i) studies of the evolution from molecular clouds to cores and the influence of the local conditions; ii) analysis of the extreme cold sources, such as the most massive clumps or those located at relatively high latitude; iii) characterization of the dust emission law in dense regions and the role of the environment. "

2. Joint surveys and follow-up observations

Galactic distribution of targets



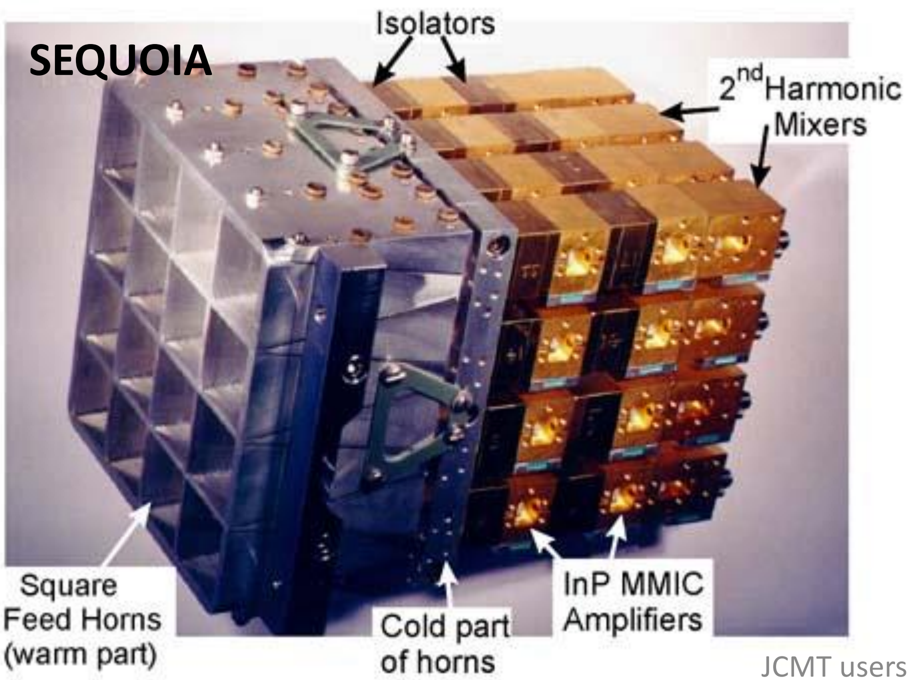
All-sky distribution of the 13188 PGCC sources (black dots), the 2000 PGCC sources selected for TOP (blue dots), and 1000 for SCOPE (pink dots) overlaid on the 857 GHz Planck map

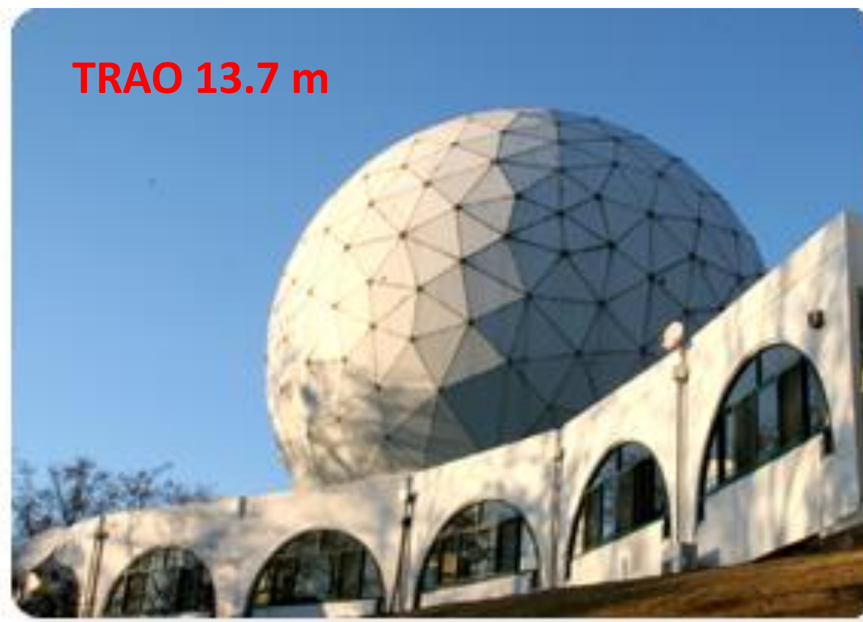


Black: All PGCCs; Blue: TOP; Pink: SCOPE


PMO 13.7 m


SMT


SEQUOIA
Isolators
2nd Harmonic Mixers
Square Feed Horns (warm part)
Cold part of horns
InP MMIC Amplifiers


TRAO 13.7 m

TOP: TRAO Observations of Planck cold clumps

- **Targets:** 2000 PGCCs
- **Tracers:** 12CO (1-0) and 13CO (1-0)

- **Telescope:** 13.7 m TRAO telescope (same as FCRAO, PMO)
- **Receiver:** SEQUOIA is a cryogenic focal plane array designed for the 85-115.6 GHz range.

  32 pixels are arranged in a dual-polarized 4x4 array.

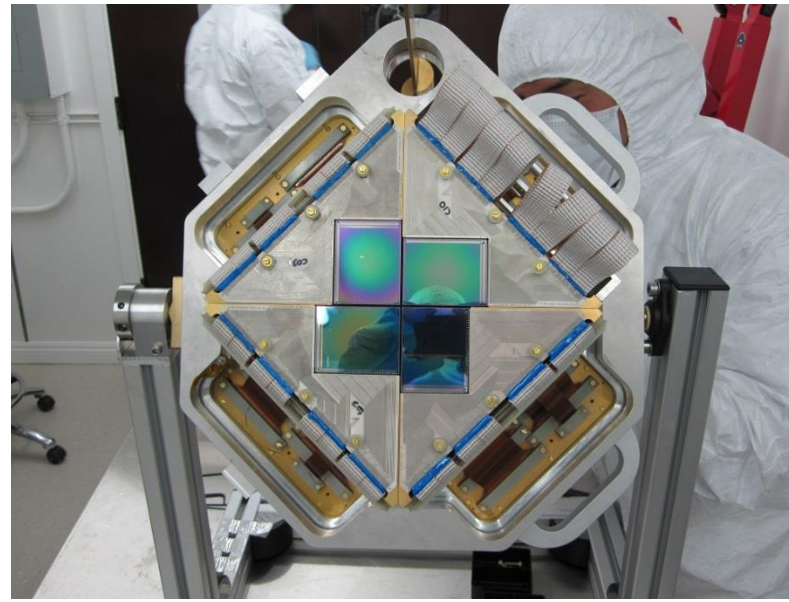
  The noise temperature ranges from 50-80K over most of the band.

  Tsys: ~250 K for 13CO (1-0) , ~500 K for 12CO (1-0)

- **Single pointing survey of all north sky PGCCs:**
- 3 minutes (on+off+cal) per source
- Rms: <0.15 K @ 0.3 km/s for 13CO (1-0), <0.3 K @0.3 km/s for 12CO
- **Otf Mapping survey of ~2000 PGCCs:**
- ~30 minutes per source for a 15arcmin*15arcmin map
- Rms: ~0.25 K @ 0.3 km/s for 13CO (1-0), <0.5 K @0.3 km/s for 12CO
- ~500 fields have been mapped

SCOPE: SCUBA-2 Continuum Observations of Pre-protostellar Evolution

Proposal for a JCMT legacy survey using 614 hrs of SCUBA-2 time to survey 2000 Planck galactic cold clumps (PGCCs) in 850 μm continuum under grade 3/4 weather condition with 225 GHz opacity between 0.1-0.15.



With a diameter of **15m** the James Clerk Maxwell Telescope (JCMT) **operated by EAO** is the largest astronomical telescope in the world designed specifically to operate in **the submillimeter wavelength** region of the spectrum.

SCUBA-2 (Submillimetre Common-User Bolometer Array 2) is a **10,000 pixel** bolometer camera operating simultaneously at **450 and 850 micron.** The camera has in total eight TES arrays, four at each wavelength band. With each array having 32×40 = 1280 bolometers there are in total 5120 bolometers per wavelength.

Summary of joint surveys/follow-ups

1. PMO/TRAO 13.7-m telescope survey in the J=1-0 transitions of CO isotopologues
   TRAO Observations of Planck cold clumps (TOP): (**PI: Tie Liu, 400hrs/yr for 3 years)**

Goals: large scale structure, CO gas abundance & kinematics

2. SMT 10-m telescope survey in the J=2-1 transitions of CO isotoplogues (**PI: Ke Wang, 600 hrs/3yrs**).

Goals: CO excitation, column density and depletion, kinematics

3. SCOPE: SCUBA-2 Continuum Observations of Pre-protostellar Evolution (**PI: Tie Liu, 300 hrs; completed**)

Goals: dense cores and filaments

4. KVN 21-m telescope survey in dense gas tracers (e.g. HCN, HCO+, N2H+) (**PI: Kee-Tae Kim, pilot survey done, 2016B & 2017A completed; large proposal to be submitted soon**)

Goals: chemistry & kinematics of dense cores

5. NH3 and carbon-chain lines follow-up survey with TianMa 65-m (**PI: Yuefang Wu, Mengyao Tang**)

Goals: kinetic temperature & turbulence

6. HI survey with Arecibo 300-m and FAST 500-m telescopes (**PI : Di Li**)

Goals: HI abundance and chemical evolution of molecular clouds

7. Follow-up observations with NRO 45-m (**PI: Ken Tatematsu, ~150 hrs in 2015B & 2016B; large proposal in preparation**)

Goals: Chemistry

8. Follow-up observations with the SMA (**five filler/standard proposals conducted**)

Goals: Chemistry and small scale structures/kinematics

9. **Three ALMA proposals accepted in cycle 4s/5**

10. **JCMT HARP and SCUBA-2/POL-2 follow-ups in 2017B (PI: Tie Liu)**

11. Joint large proposal toward 100 SCOPE dense cores accepted to NRO 45-m, and Effelsberg 100-m in 2018A semester

12. Two APEX proposal accepted in 2018A

3. Science cases and Preliminary Results

Publications

- Accepted papers:
- (1). “Planck Cold Clumps in the λ Orionis Complex. I. Discovery of an Extremely Young Class 0 Protostellar Object and a Proto-brown Dwarf Candidate in the Bright-rimmed Clump PGCC G192.32-11.88”
- Liu, Tie; Zhang, Qizhou; Kim, Kee-Tae; et al. 2016, ApJS, 222, 7
- (2). “Astrochemical Properties of Planck Cold Clumps”
- Tatematsu, Ken'ichi; Liu, Tie; Ohashi, Satoshi; et al. 2017, ApJS, 228, 12
- (3). “Star Formation Conditions in a Planck Galactic Cold Clump, G108.84-00.81”
- Kim, Jungha; Lee, Jeong-Eun; Liu, Tie; et al. 2017, ApJS, 231, 9
- (4). “The TOP-SCOPE survey of Planck Galactic Cold Clumps: Survey overview and results of an exemplar source, PGCC G26.53+0.17”
- Liu, Tie; Kim, Kee-Tae; Juvela, Mika; et al. 2017, ApJS in press
- (5). ”Herschel and SCUBA-2 observations of dust emission in a sample of Planck cold clumps”
- Juvela, Mika; He, Jinhua; Pattle, Katherine; et al. 2017, A&A in press

- Submitted papers:
- (6). ” THE PROPERTIES OF PLANCK GALACTIC COLD CLUMPS IN THE L1495 DARK CLOUD”
- Tang,Mengyao; Liu,Tie; Qin,Sheng-Li et al. 2018, submitted to ApJ
- (7). “The TOP-SCOPE survey of PGCCs: PMO and SCUBA-2 observations of 64 PGCCs in the 2nd Galactic Quadrant”
- Zhang,Chuanpeng; Liu,Tie; Yuan,Jianghua; et al., 2018, submitted to ApJ
- (8). “MAGNETIC FIELDS IN THE MASSIVE AND QUIESCENT CLOUD IRDC G035.39-00.33”
- Liu,Tie；Li,Pak-Shing;Juvela, Mika; et al. 2018, submitted to ApJ

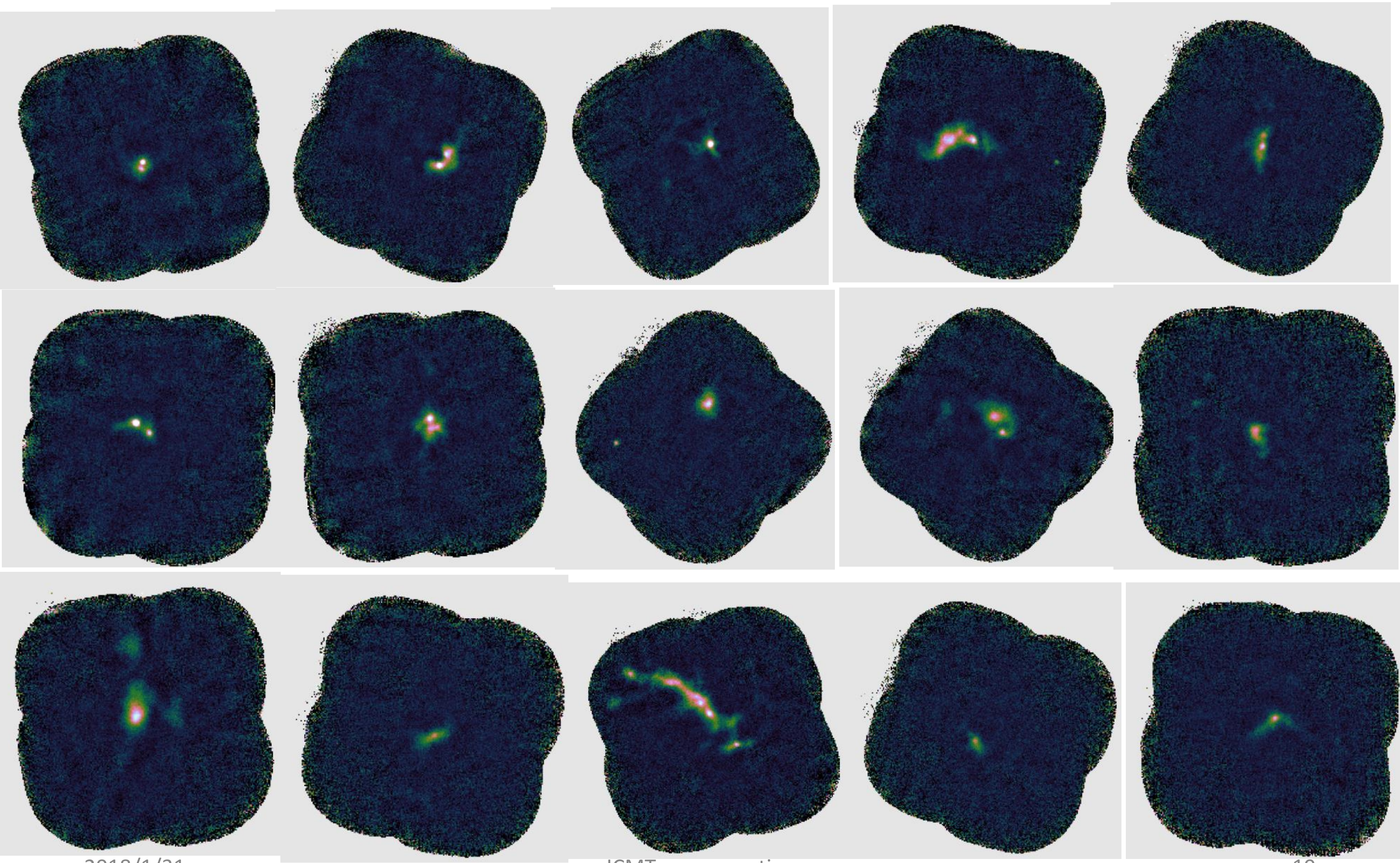
Working/planned papers

- (1) Core formation in different environments: Planck cold clumps in Lambda Orionis, Orion A and Orion B clouds (Heeweon Yi+)
- (2). Introduction of the SCOPE survey (David Eden+)
- (3). Multiple Molecular line analysis in the Planck cold clumps with KVN follow-up observations (SungJu Kang+)
- (4). The transition of HI-H2 in Planck cold clumps (Pei Zuo+)
- (5). Properties of Planck ECC sources (John Lopez+)
- (6). Filament formation due to cloud-cloud collision in G178.2-00.6 (Tianwei Zhang+)
- (7). Investigation of High latitude Planck cold clumps with molecular line and submillimeter continuum emission (Tie Liu+)
- (8). KVN observations of PGCCs in Orion complex (Heeweon Yi+)
- (9). SCOPE in 2016A semester (Sheng-Yuan Liu+)
- (10). Properties of SCOPE Galactic Plane sources (David Eden+)
- (11). Fragmentation and chemical properties of G207.3-19.8 (GuoYin Zhang+)
- (12). Filamentary accretion onto a stellar cluster: PLCKECC G074.1+00.11 (Jorma Harju+)
- (13). Chemical properties of Planck cold clump G163.32-8.41 (Viktor Toth+)
- (14). Discovery of a bright proto-cluster in Planck cold clump G133.4 (Gerardo Pech+)
- (15). SCOPE isolated cores (Dalei Li?)

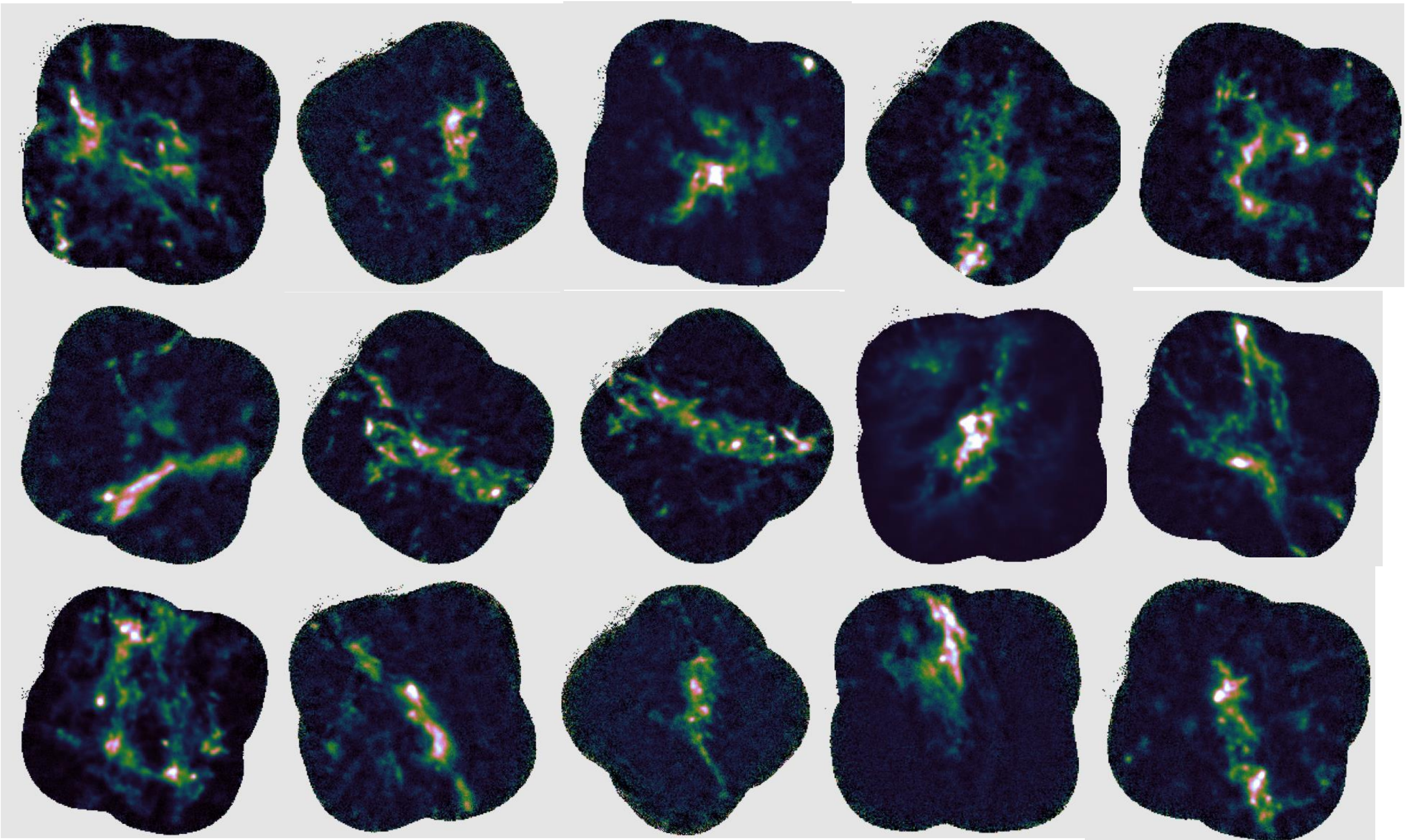
- (16). Astrochemistry modeling of Planck Cold clumps (Jixing Ge+)
- (17). NRO 45-m survey of SCOPE dense cores (Ken Tatematsu+)
- (18). Kinematic study of filament and PGCCs in Orion (Gwanjeong Kim)
- (19). Core stability and effect of external triggering in PGCCs (Gwanjeong Kim)
- (20). Investigation of sub-mm variability of the SCOPE clumps (Geumsook Park+)
- (21). SMA observations of 6 Lambda Orionis cores (Heeweon Yi+)
- (22). ALMA observations of 8 Lambda Orionis cores (Heeweon Yi+)
- (23). TRAO observations of 50 PGCCs in Lambda Orionis complex (Heeweon Yi+?)
- (24). JCMT sensitive survey of outflows in Orion cores (Heeweon Yi+?)
- (25). SCOPE filaments (Michel Fich?)
- (26). TOP 800 SCOPE cores? (Bingru Wang+)
- (27). TRAO single-pointing survey of 2000 PGCCs (Sungju Kang+)
- (28). Dust properties of G35 based on POL-2 observations (Juvela Mika+)
- (29). Herschel and SCUBA-2 observations of 100 SCOPE cores (Juvela Mika and his student+)
- (30). ALMA follow-ups of G204NE (Naomi Hirano+?)
- (31). NH3 survey of 100 SCOPE dense cores (Toth+)
- (32). ALMA ACA observations of two Orion cores close to the onset of star formation (Tatamatsu-san+)
- And more ……

3.1 Dense core formation across the Galaxy

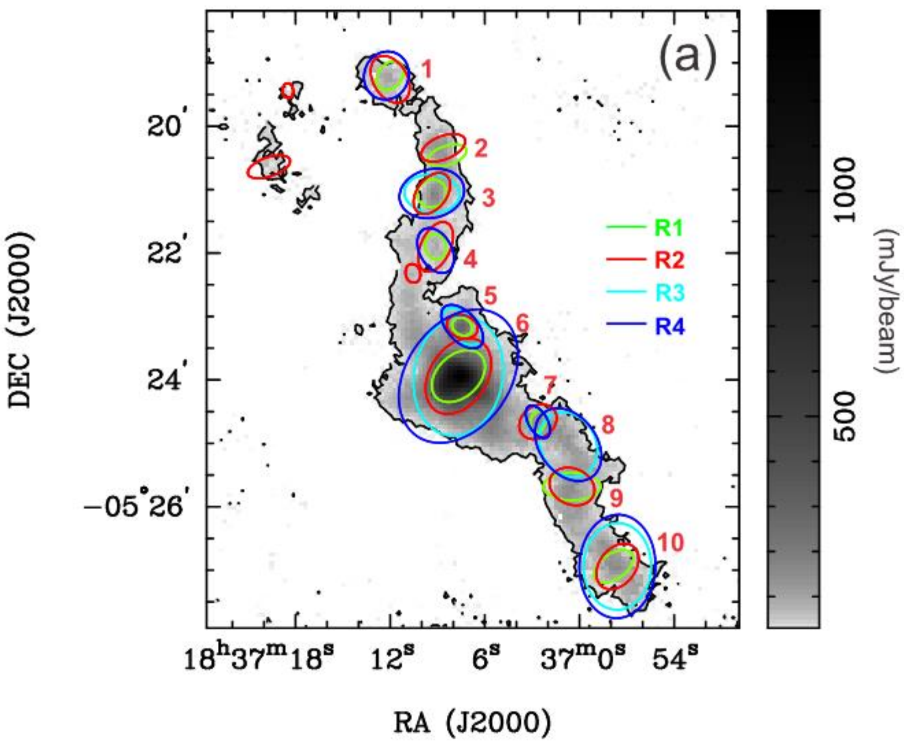
SCOPE objects above the Galactic Plane

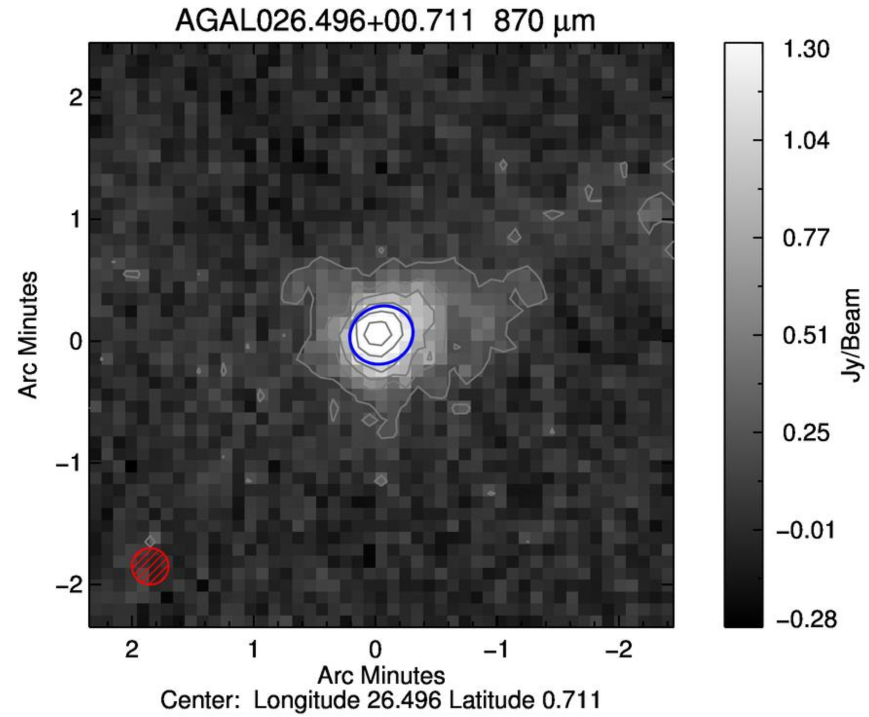


SCOPE objects at the Galactic Plane

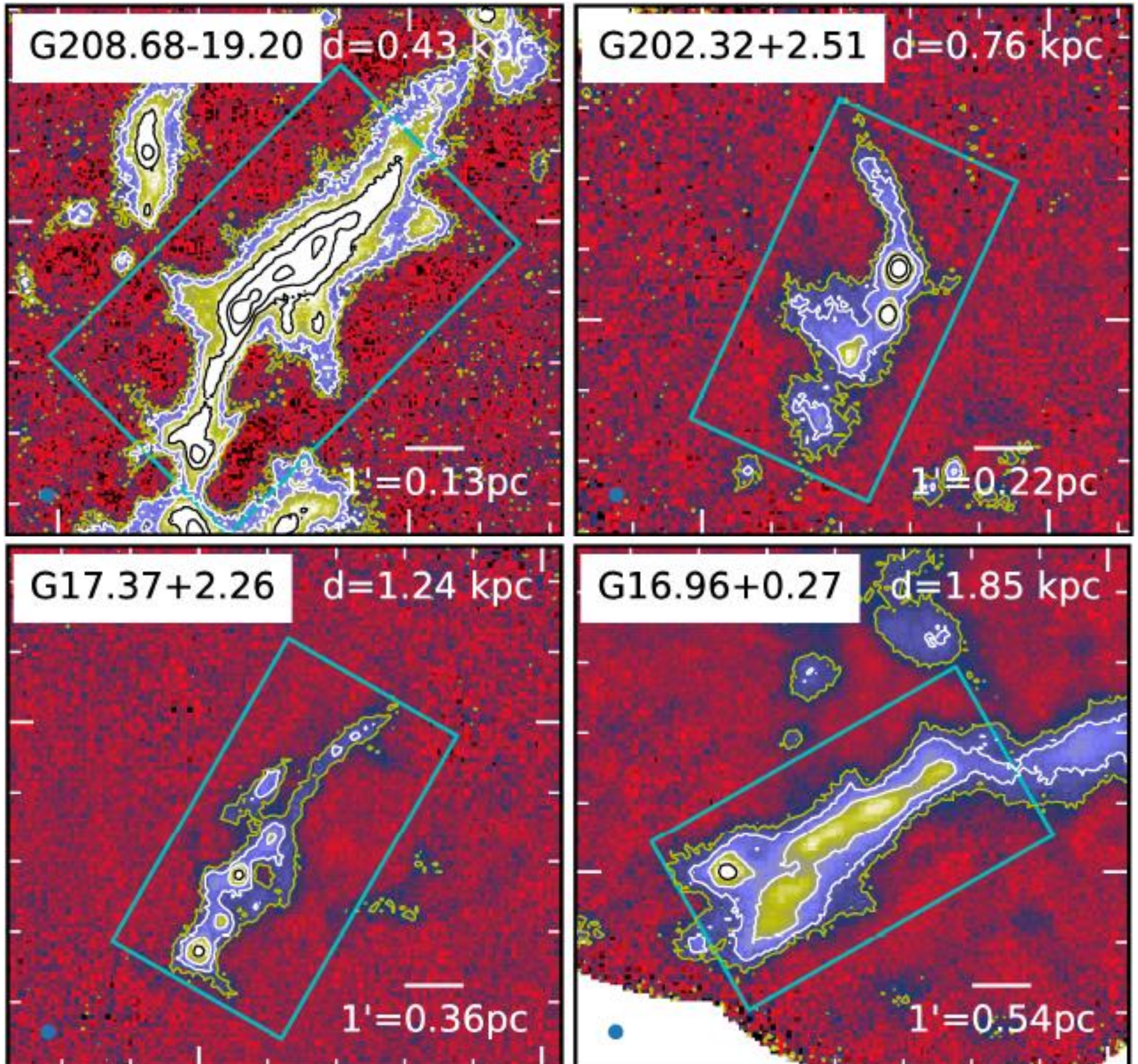


JCMT/SCOPE vs APEX/ATLASGAL



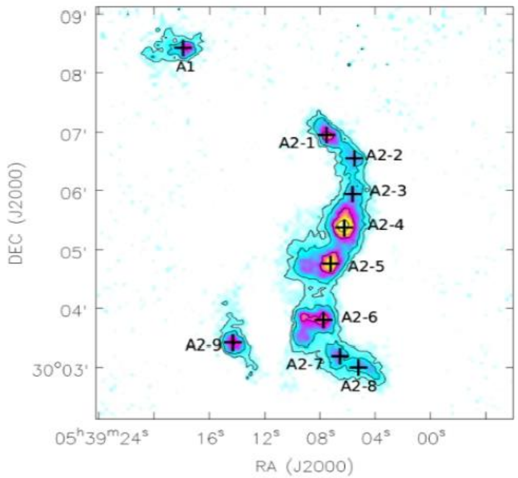


3.2 SCOPE filaments

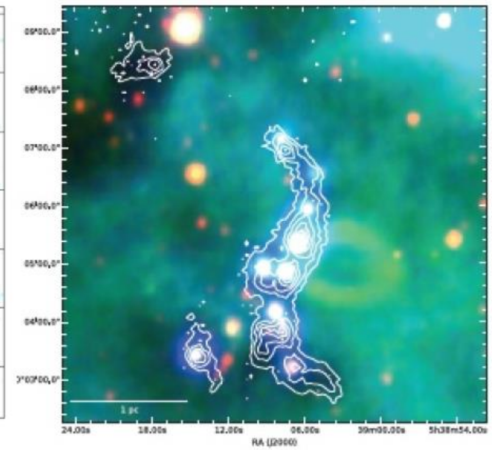


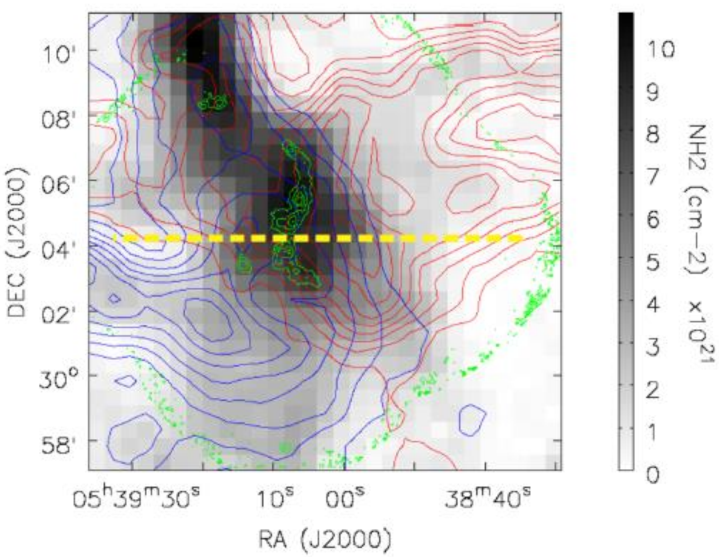
Filament formation due to Cloud-cloud collision

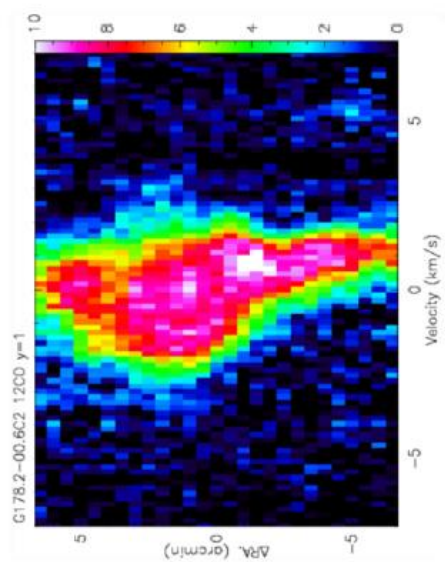
JCMT 850 micron

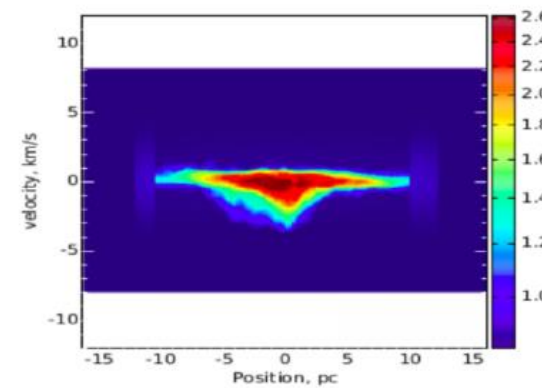


WISE 2/3/4 band RGB image, overlaid with 850 micron contour



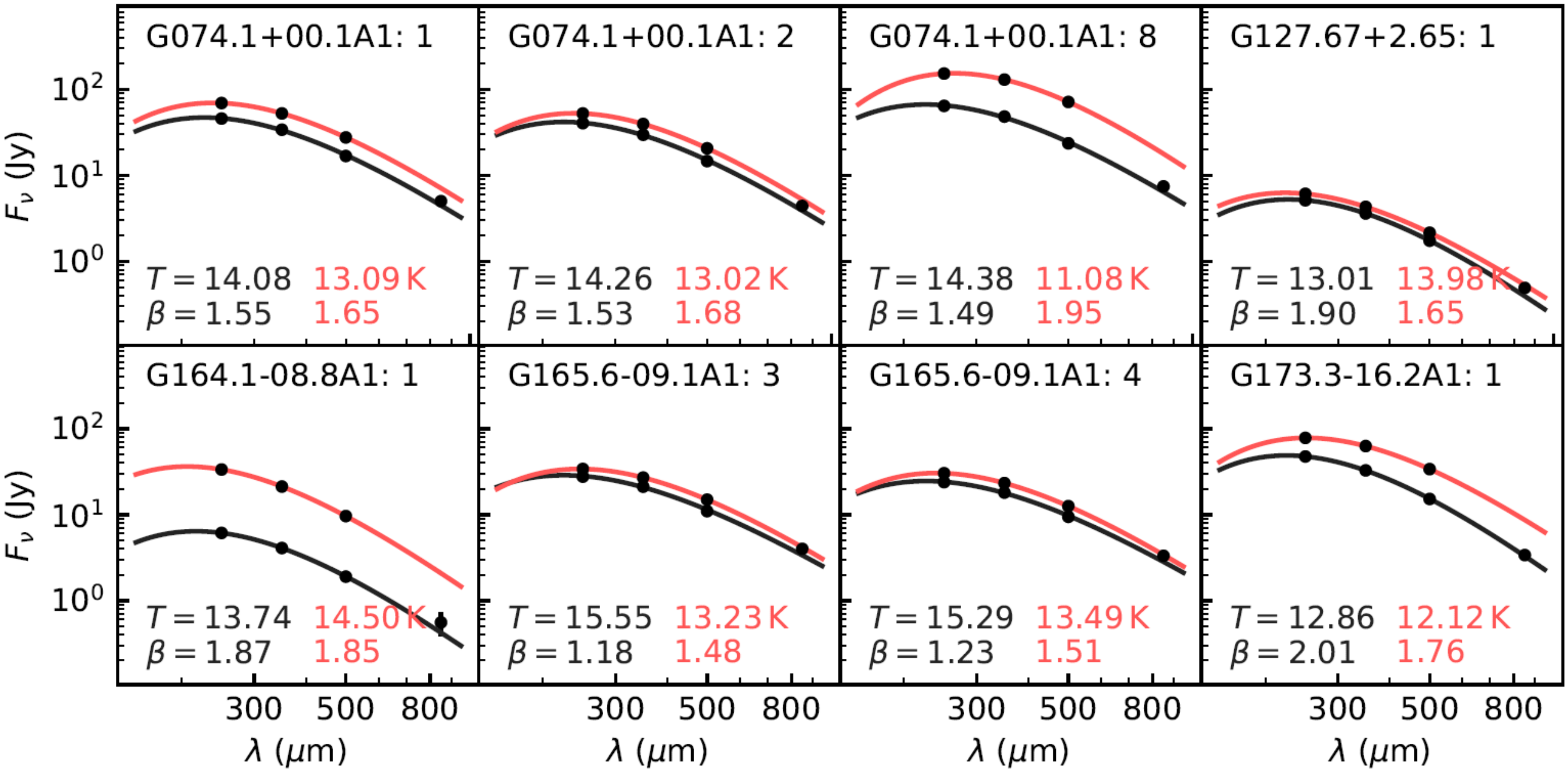






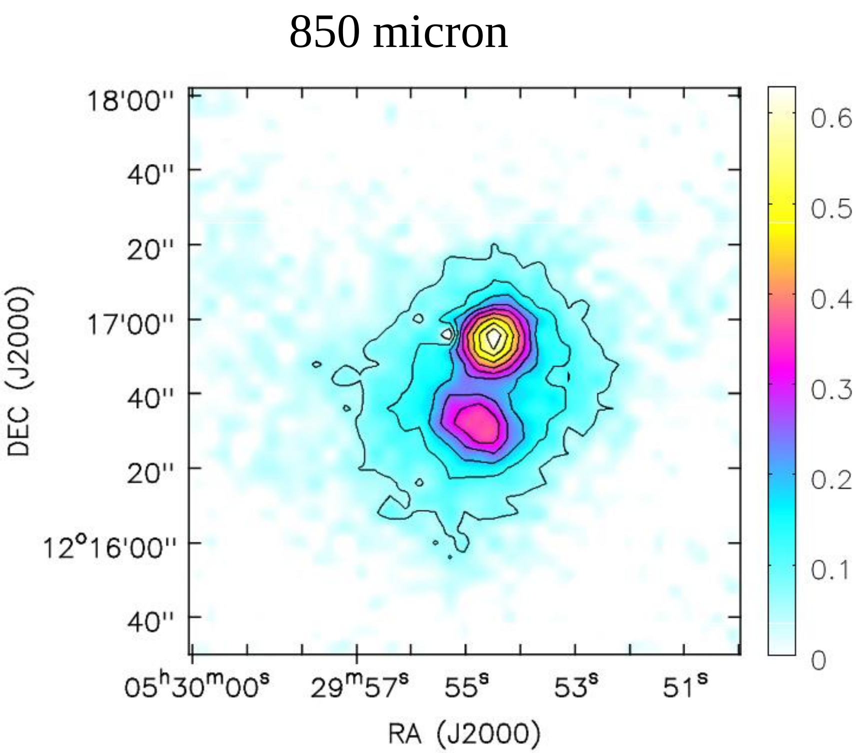
 (Zhang et al. 2017, in preparation)

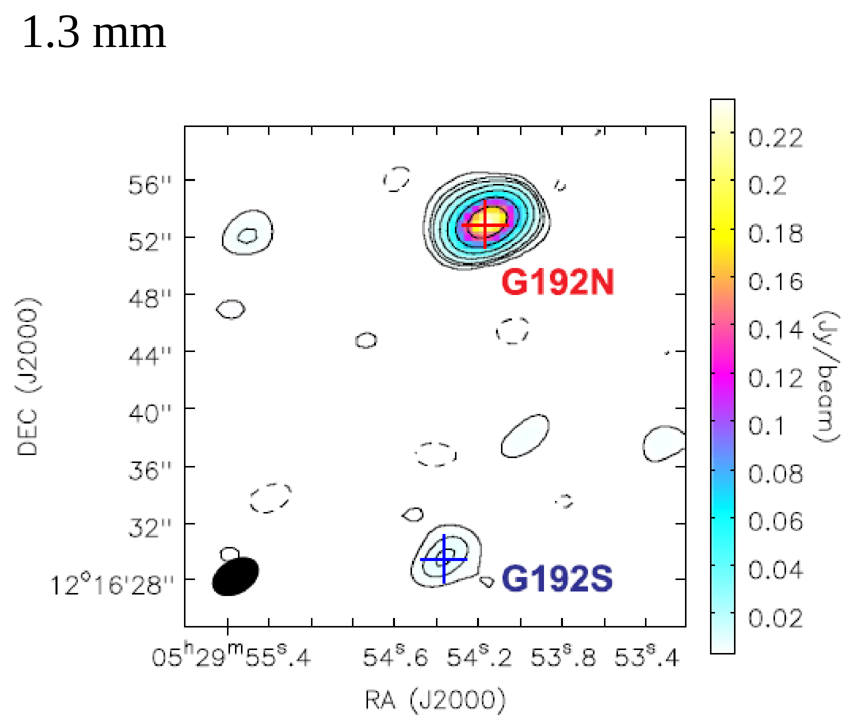
3.3. Dust properties (Juvela+2017)



The typical submillimetre opacity spectral index of cold clumps is found to be 1.7. This is above the values of diffuse clouds and even general molecular clouds but lower than in some previous studies of dense clumps. There is only tentative evidence for values decreasing at millimetre wavelengths

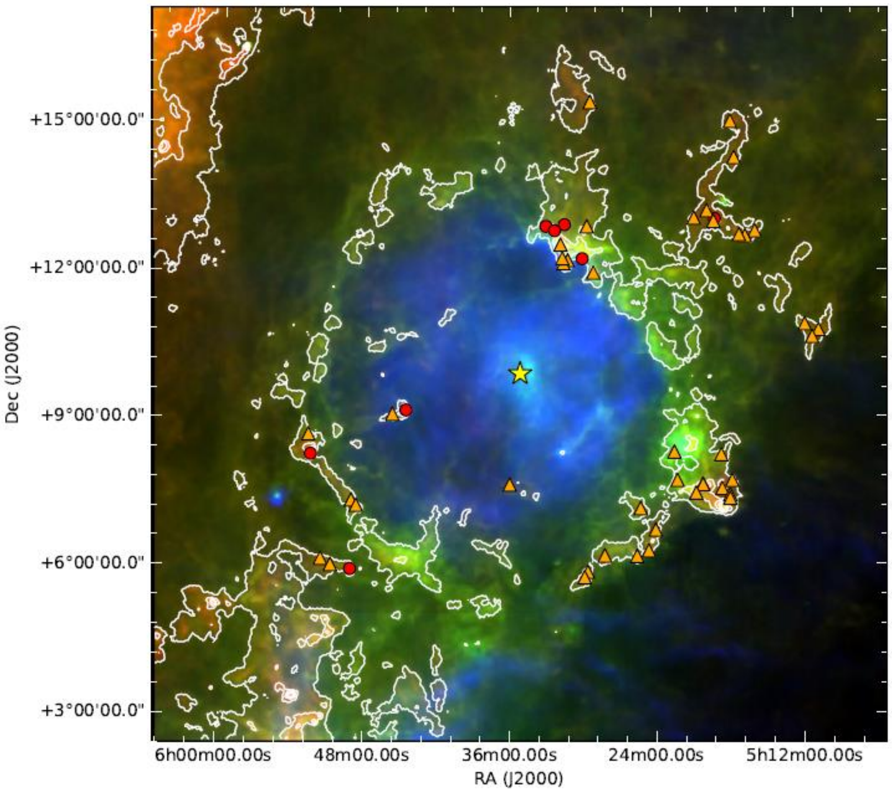
3.3. Proto-brown dwarfs and very low mass protostars (Liu+2016)





Extremely young Class 0:
G192N: M=0.43 Msun (JCMT); M=0.38 Msun (SMA); Lint=~0.2 Lsun
Proto-brown dwarf:
G192S: M=0.23 Msun (JCMT); M=0.02 Msun (SMA); Lint=~0.08 Lsun

3.4. Stellar feedback on core/star formation (Yi et al.)



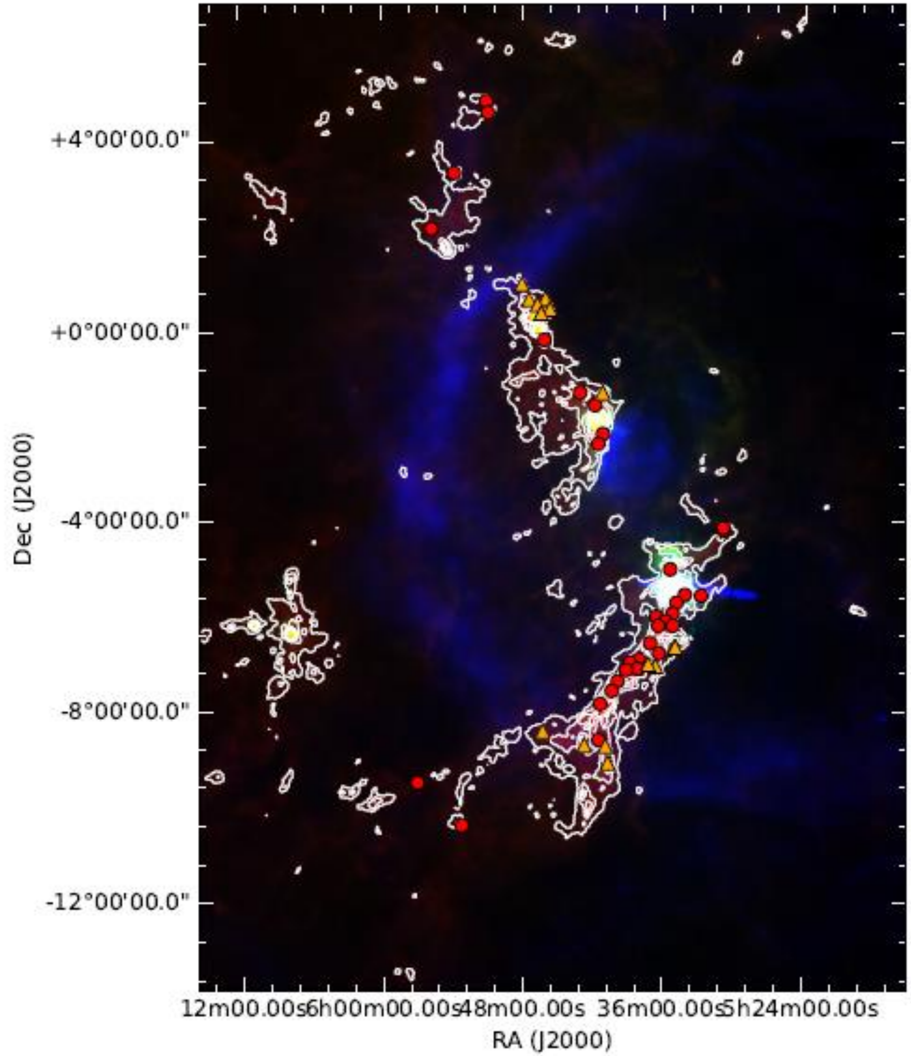
Lambda Orionis complex

Red and contours: Planck 353 GHz

Green: IRAS 100 micron

Blue: Halpha

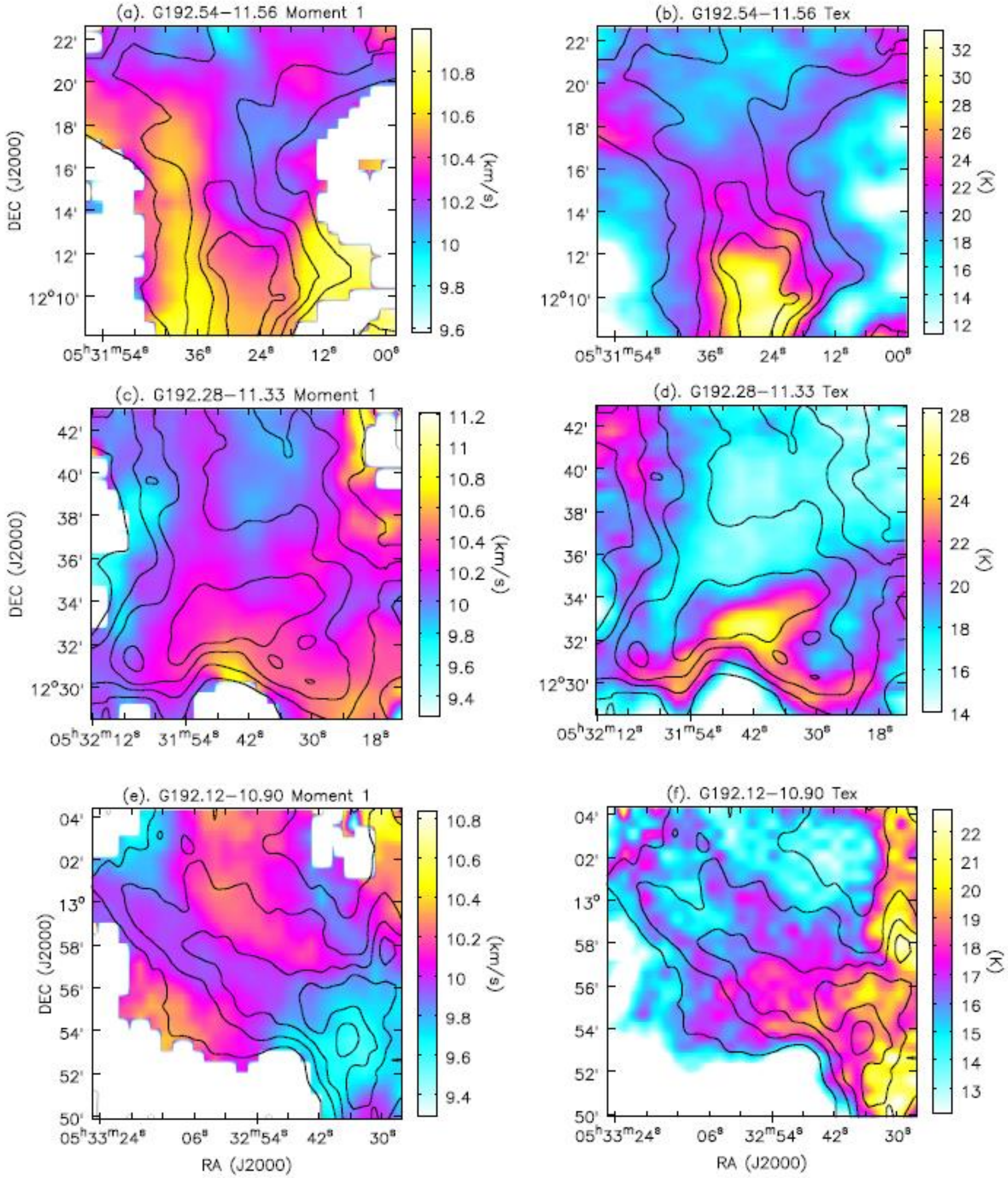
Circles: SCOPE cores; triangles: non detection



Orion A+B

Velocity

Gas Temperature



Lambda Orionis clouds

On the properties of Class 0/I protostellar cores in the Lambda Orionis molecular complex

2017.1.01320.S

ABSTRACT

Stellar feedback (e.g. photoionization, stellar winds and supernova explosions) may shut star formation down or trigger new star formation in different Galactic environments. However, how the stellar feedback influences the new star formation is still unclear. We propose to observe eight Class 0/I protostellar cores located in the Planck cold clumps in Lambda Orionis complex in order to study the influence of stellar feedback on new star formation with the ALMA 12-m array in band 3. We aim to: (1). Study their dust emissivity spectral indices; (2). Investigate whether the envelopes are still in collapse; (3). Study outflow properties (4). Study PDR-like chemistry.

The proposed high-resolution (1 arcsec or ~400 AU) observations will shed light on how the properties of dense cores and star formation therein are influenced by radiation feedback from HII regions. The total requested 12-m array time is 2.8 hrs.

PI NAME:	Kee-Tae Kim	**SCIENCE CATEGORY:**	ISM, star formation and astrochemistry
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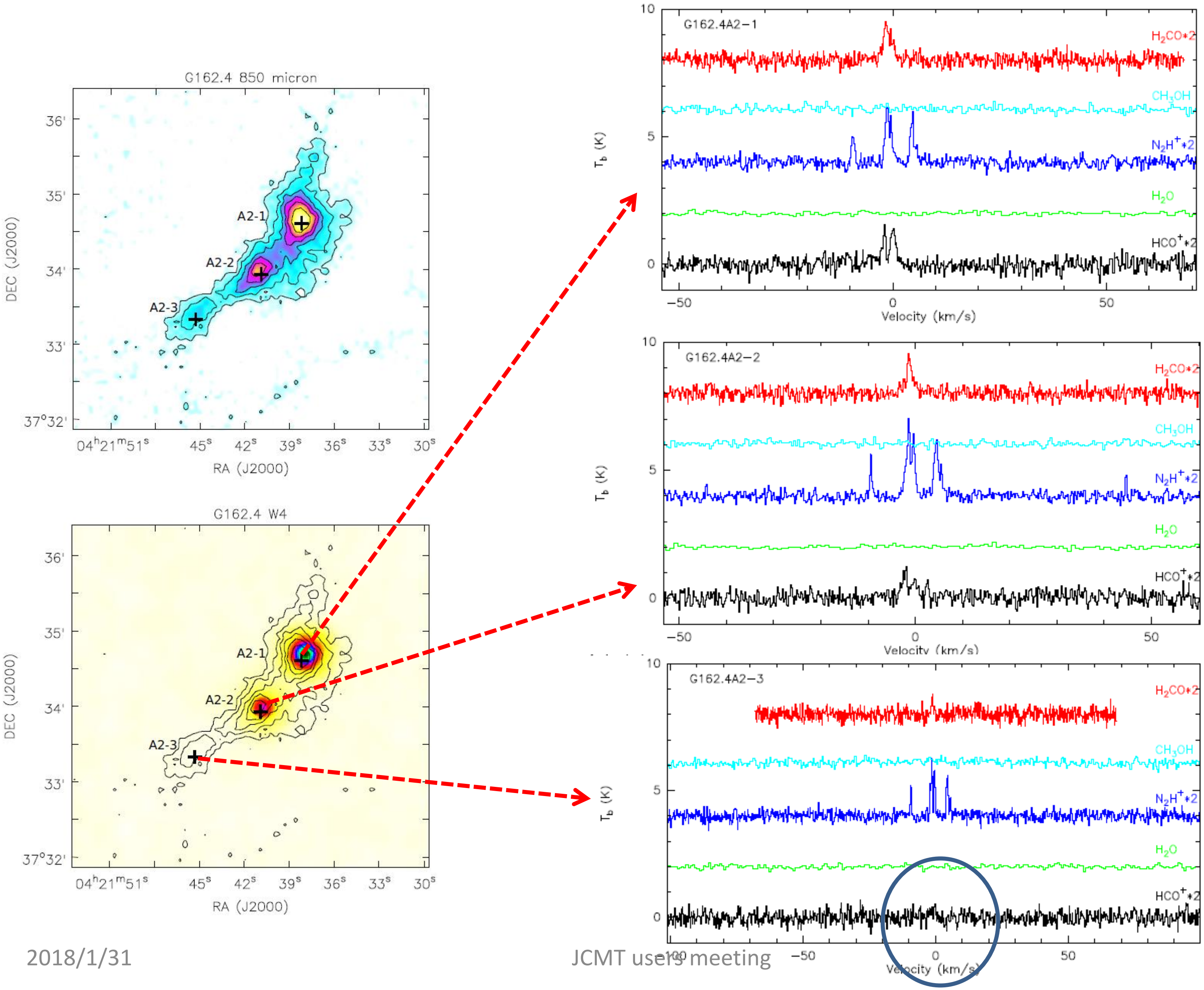
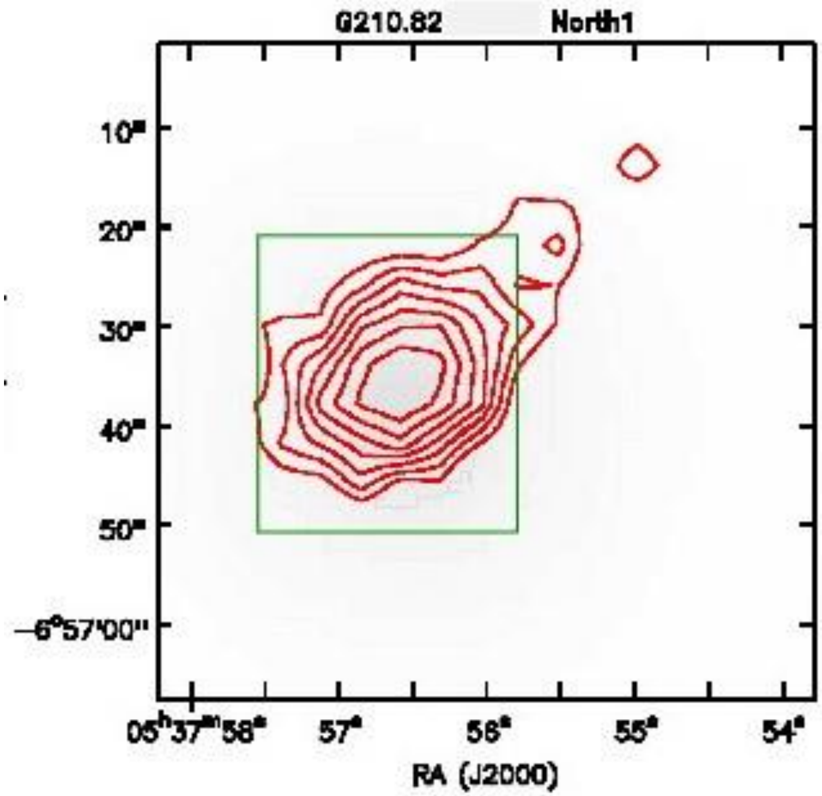
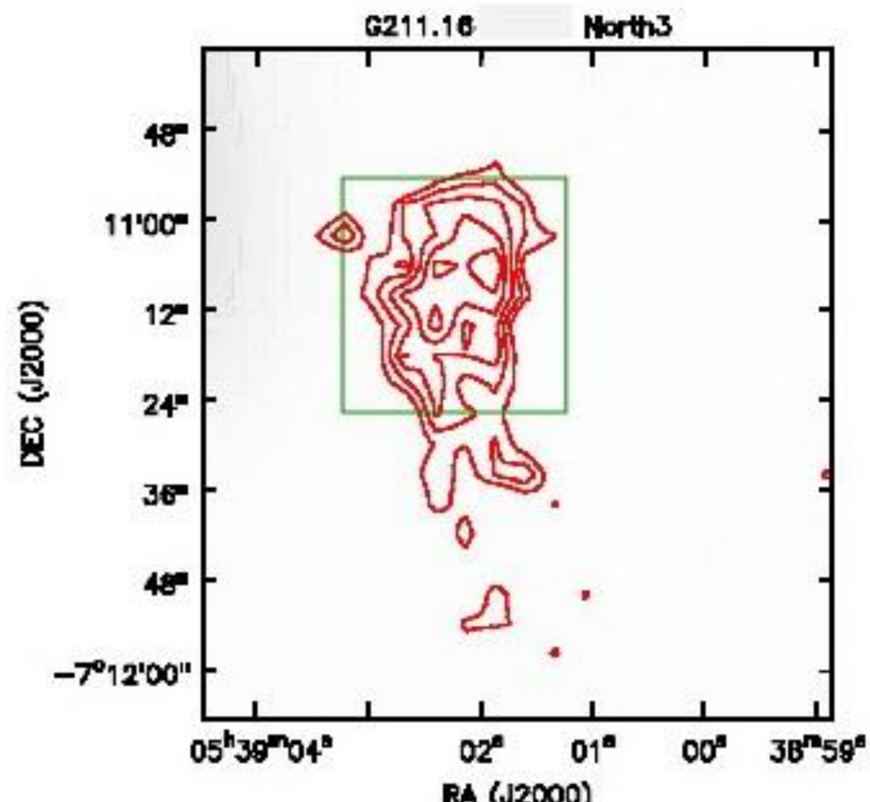
3.5. Evolution of dense cores



No HCO+!!!

G210 and G211 SCUBA-2 850um map star-forming vs starless

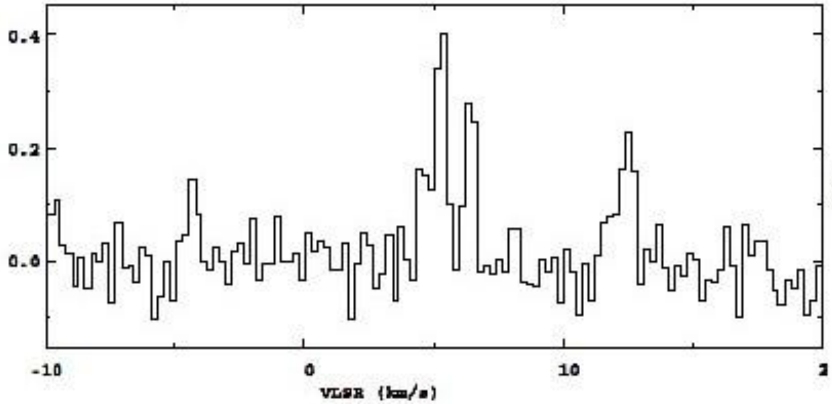


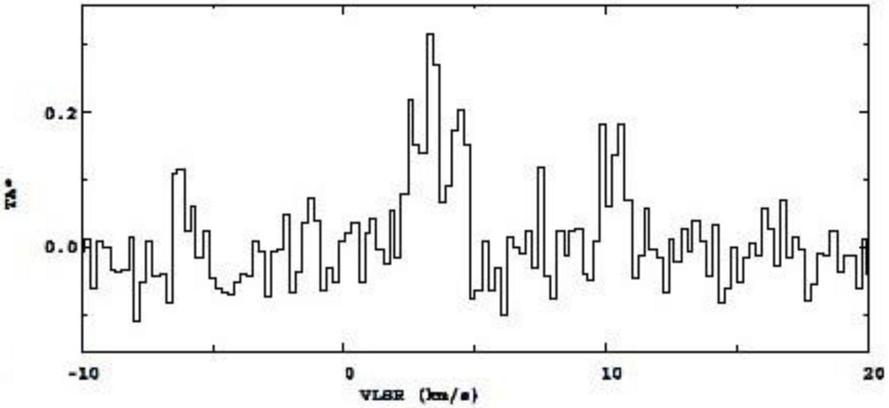


Green box: ALMA 7m observing regions

N2D+ obtained with Nobeyama 45m toward G210 and G211

Star forming vs starless





It is known that D/H increases during starless phase, and decreases after the onset of star formation (for gas-phase molecules such as N2D+, DNC). High D/H will mean that the cores are very close to the onset. (Tatematsu+2018, see his poster)

PHYSICAL AND CHEMICAL PROPERTIES OF COLD ORION CORES VERY CLOSE TO THE ONSET OF STAR FORMATION

2016.2.00058.S

ABSTRACT

The initial condition is a key for star formation studies. We have successfully identified two very attractive cores in the Orion GMC: one is a candidate of starless cores on the verge of star formation, and the other is a star forming core probably at the earliest stage. These core were detected in DNC and N2D+ with Nobeyama 45 m telescope in the follow-up observation to JCMT/SCUBA-2 legacy program SCOPE for Planck cold clumps. The N2D+ linewidth is as narrow as 0.45 km/s in both cores. We can assume that they are cores just before and after the onset of star formation in almost the same environment. We will investigate (A) Mechanism of the onset of star formation: turbulence dissipation or accretion?, (B) Core dynamics: infall or oscillation?, (C) Chemical evolution status within the cores. This observation tackles the basic question: how star formation starts?

PI NAME:	Ken'ichi Tatematsu	**SCIENCE CATEGORY:**	ISM, star formation and astrochemistry
PI E-MAIL:	k.tatematsu@nao.ac.jp	**PI INSTITUTE:**	Chile Observatory, National Astronomical Observatory of Japan

ESTIMATED 12M TIME:	**0.0 h**	**ESTIMATED ACA TIME:**	**11.7 h**	**ESTIMATED NON-STANDARD MODE TIME (12-M):**	**0.0 h**

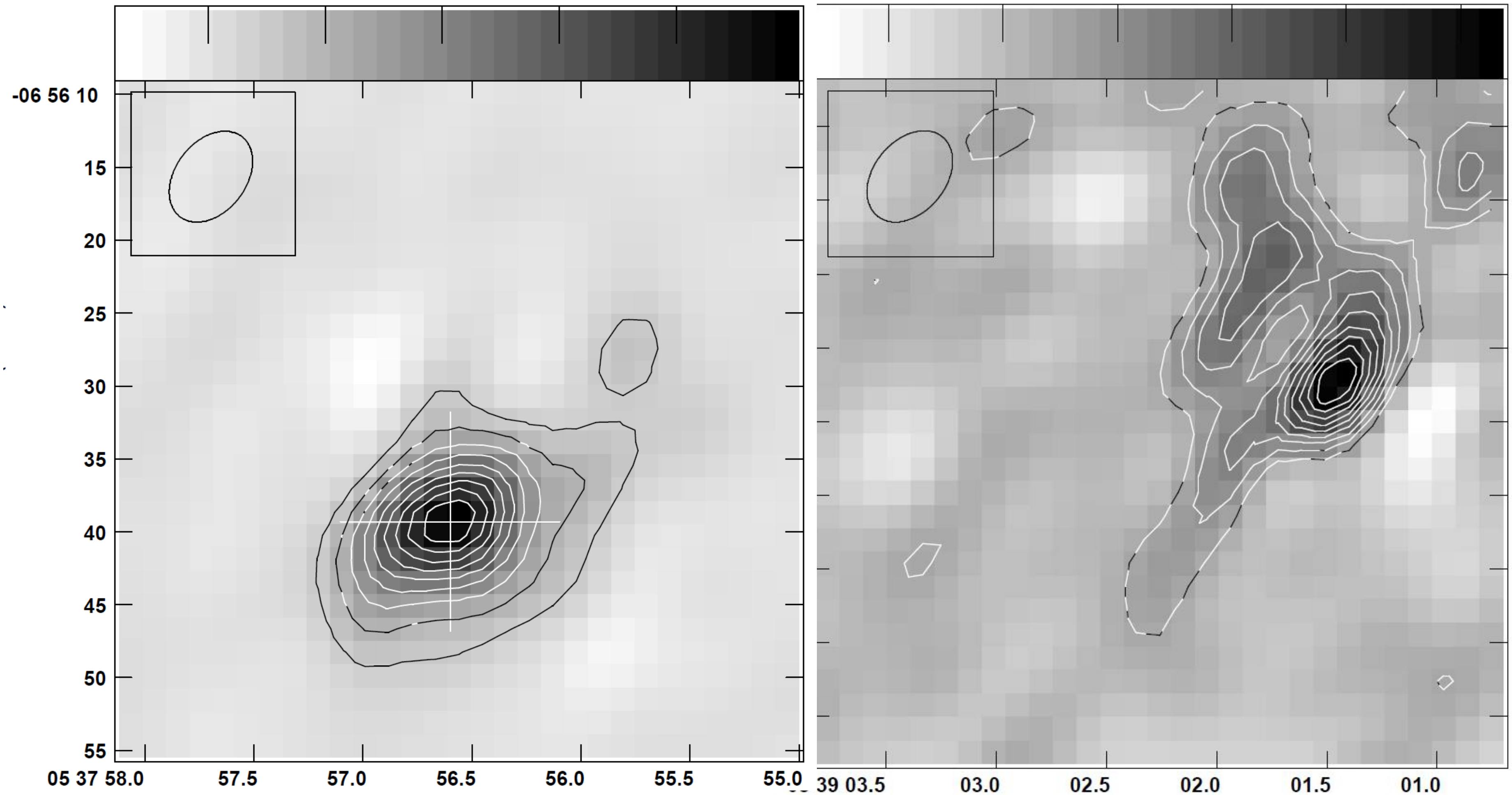
Detected, not detected
ALMA Band 6

- G211 (starless) DCO+, HCO+, CO, N_2D^+, DNC, DCN, DCO^+, HCO^+, $H^{13}CN$, $H^{13}CO^+$, CS, CO, $C^{18}O$
- G210 (star forming) N_2D^+, DNC, DCN, DCO^+, HCO^+, $H^{13}CN$, $H^{13}CO^+$, CS, CO, $C^{18}O$

- DCO^+, HCO^+, and CO were detected in both
- $C^{18}O$ was not detected in either of them

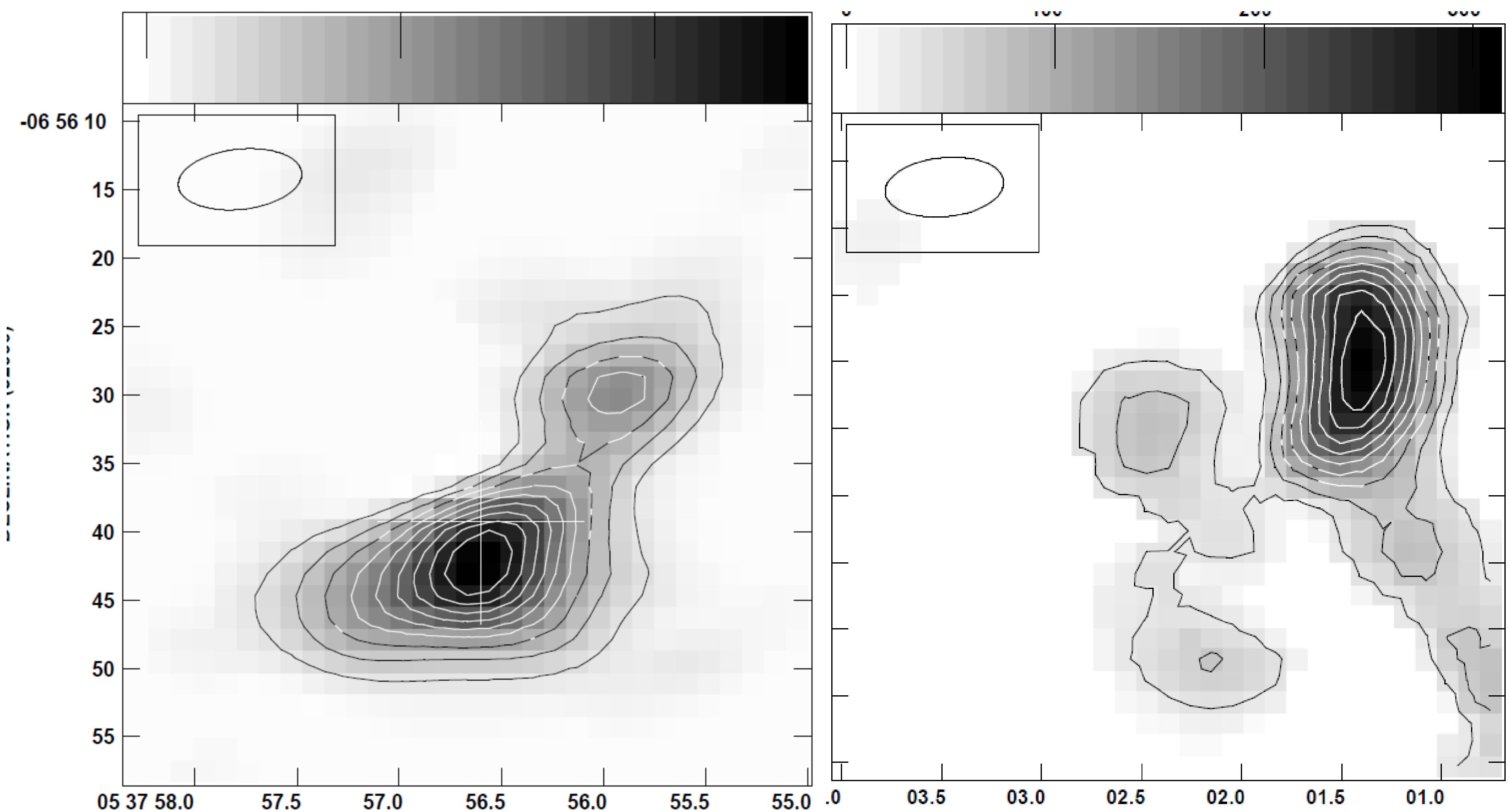
(Tatematsu+2018 in preparation, see his poster)

CONTINUUM
G210 (star-forming) G211 (starless)



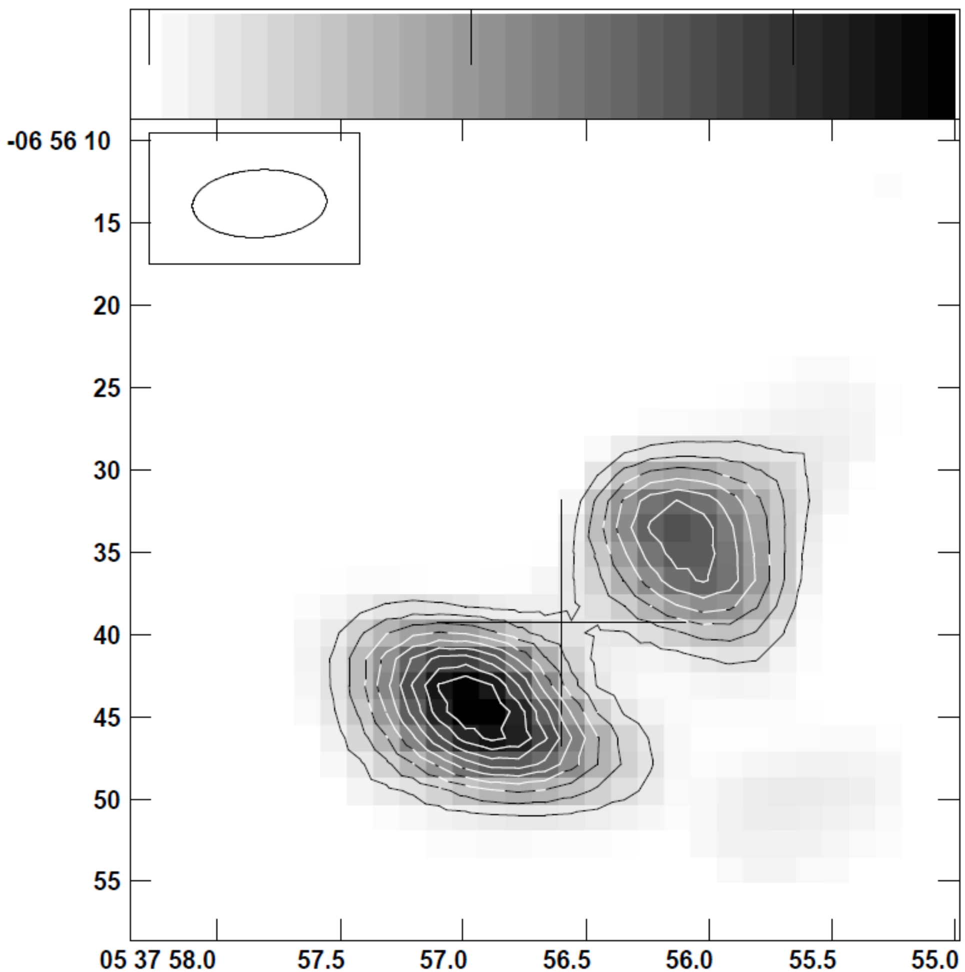
(Tatematsu+2018 in preparation, see his poster)

DCO+ (3-2)
G210 (star-forming) G211 (starless)



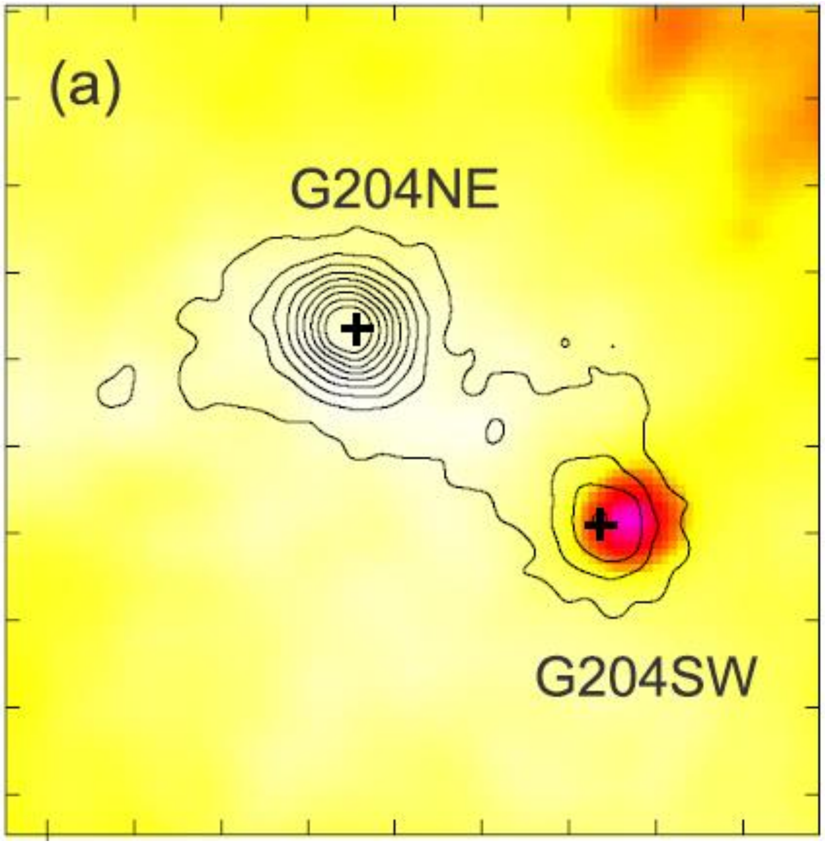
(Tatematsu+2018 in preparation, see his poster)

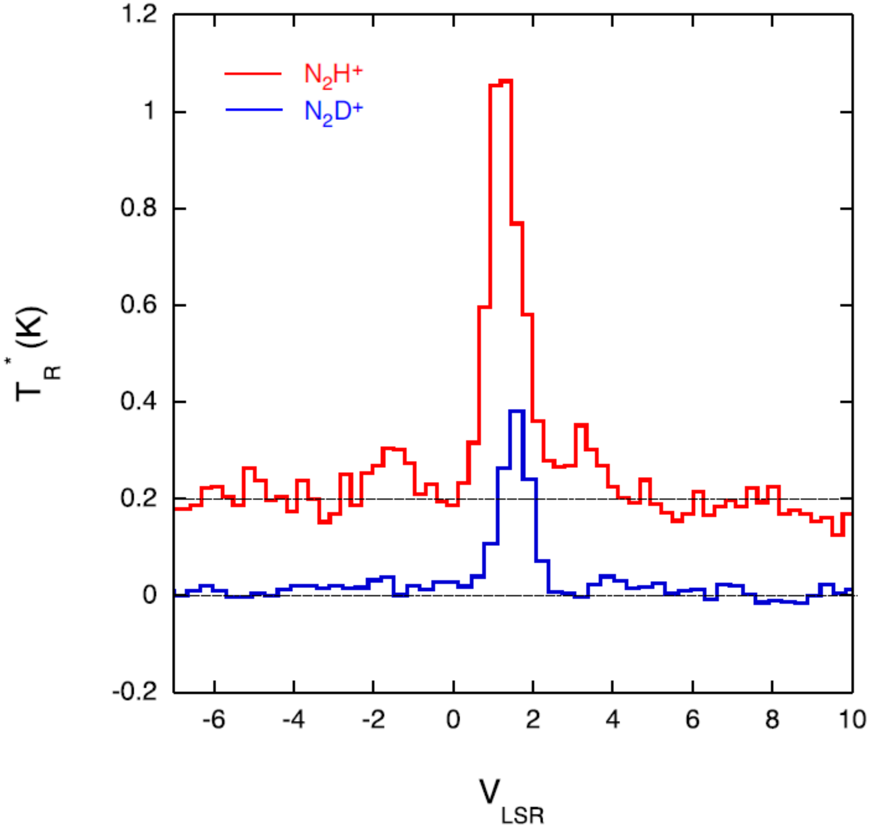
N_2D^+ (3-2)
G210 (star-forming)



(Tatematsu+2018 in preparation, see his poster)

First hydrostatic core candidates





Unveiling the nature of the very-low luminosity source in the Planck cold clump G204NE

2017.1.00707.S

ABSTRACT

Our high resolution (0.26" x 0.16") ALMA Cycle-4 observations have successfully detected very compact (60-120 AU in radius) CO evaporation areas around the first core candidate sources B1-bN and B1-bS. Our results imply that the CO evaporation radius can be a good indicator for the evolutionary stage of extreme young objects prior to Class 0. Here, we propose to examine nature of the very-low luminosity (0.027 L_sun) object in the Planck cold clump G204.4-11.3 NE.(G204 NE) Since this core has enough mass (3.2 M_sun) to form a low-mass protostar, we hypothesize that the source has a very-low luminosity because it is in the very early evolutionary stage. In order to test this hypothesis, we plan to observe the C18O, CO, N2D+, and H2CO lines in Band 6 at an angular resolution of 0.13" (= 55 AU at 420 pc). For a comparison, another Class0/I source, G204SW, in the same clump is also observed. The C18O and N2D+ lines will be used to determine the CO evaporation radius. The CO and H2CO lines will be used to study the properties of the outflow. The observed chemical and physical properties of the source in G204 NE will be compared with those of the FHSC candidate soures, B1-bN and B1-bS.

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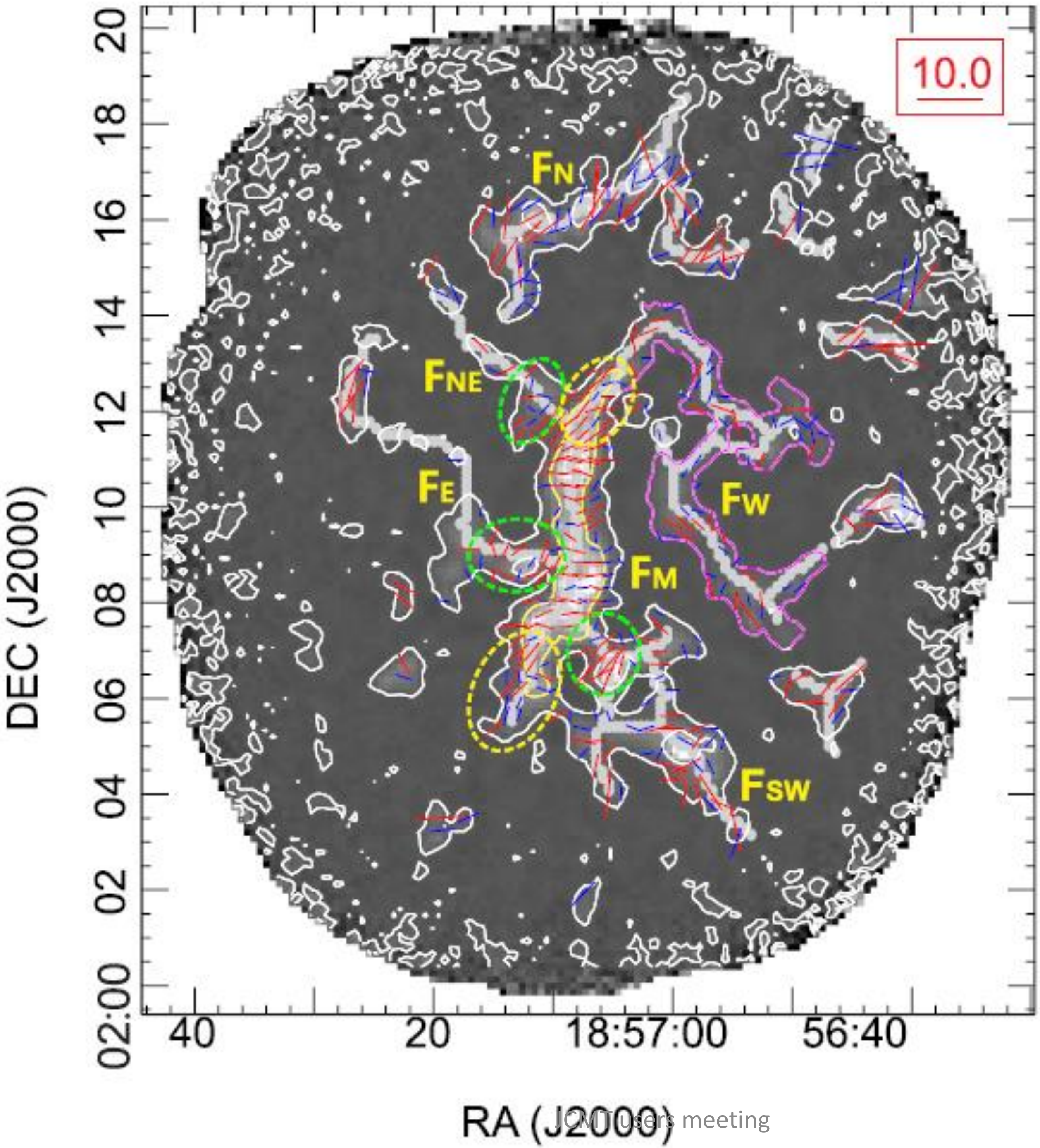
ESTIMATED 12M TIME:	**6.4 h**	**ESTIMATED ACA TIME:**	**0.0 h**	**ESTIMATED NON-STANDARD MODE TIME (12-M):**	**0.0 h**

4. Future plans and Summary

- 1. Publish catalogue papers in 2018
- 2. Follow-ups with other telescopes (e.g., NRO 45-m; see Tatematsu-san's poster)
- 3. Propose more interesting objects in ALMA cycle 6
- 4. POL-2 follow-ups of SCOPE quiescent filaments and isolated cores



POL-2 map of G35
(Liu+2018; Juvela+2018)

Summary

- 1. The PGCC catalog represents a real goldmine for investigations of the early phases of star formation.
- 2. We are conducting a joint survey (**"TOP-SCOPE"**) towards PGCCs. We are also actively developing follow-up observation towards the SCUBA-2 cores detected in "SCOPE" with other ground-based telescopes (e.g. SMT 10-m, KVN 21-m, NRO 45-m, TianMa 65-m, Effelsberg 100-m, FAST 500-m, Arecibo 300-m, IRAM 30-m, and SMA).
- 3. Future molecular line and/or dust polarization follow-up observations with both single dishes and interferometers toward SCOPE objects are crucially needed for understanding the initial conditions of star formation in different Galactic environments.

Thanks!