The TOP-SCOPE survey of Planck Galactic Cold Clumps

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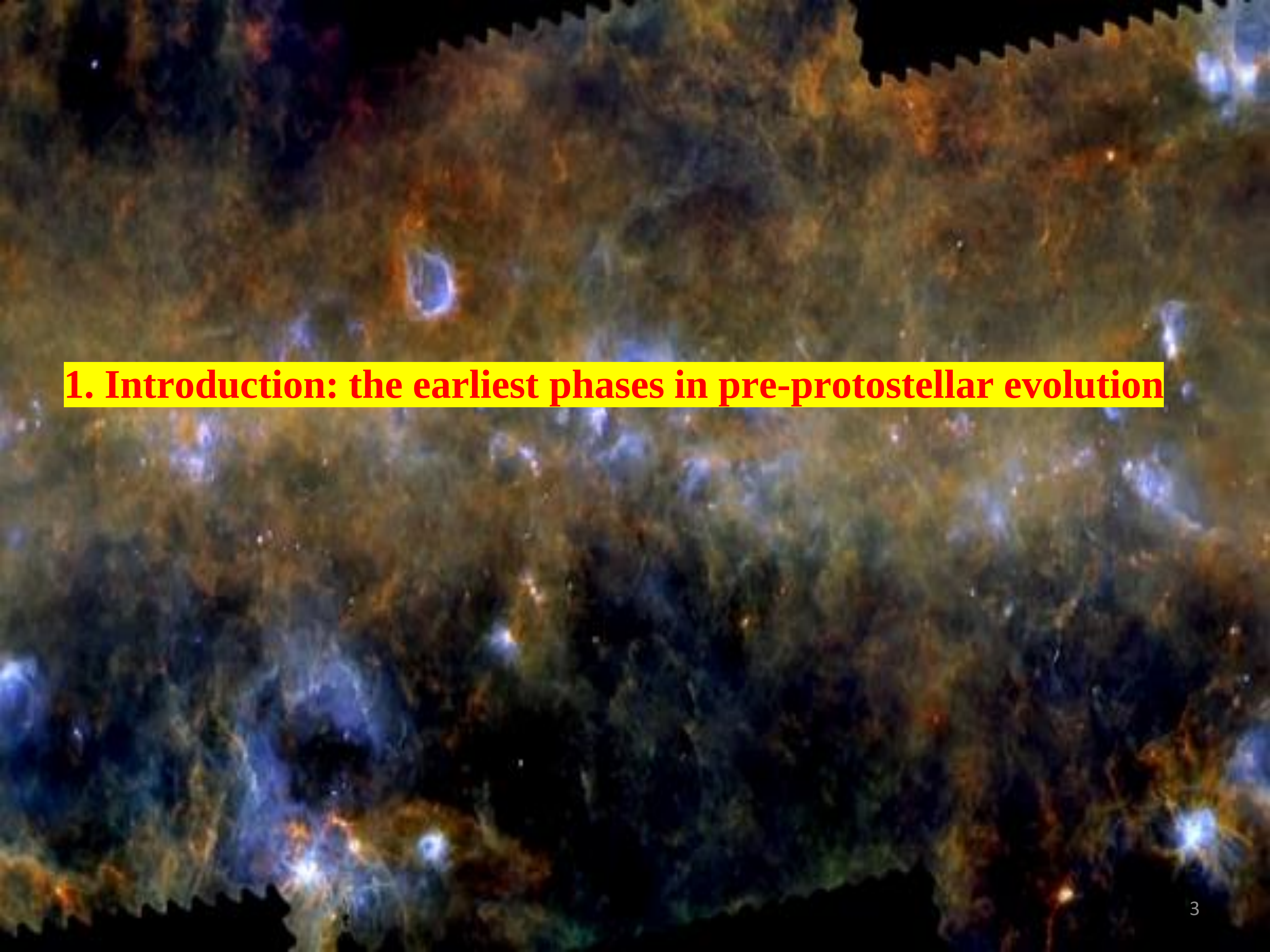
Image credit: Herschel/HiGAL

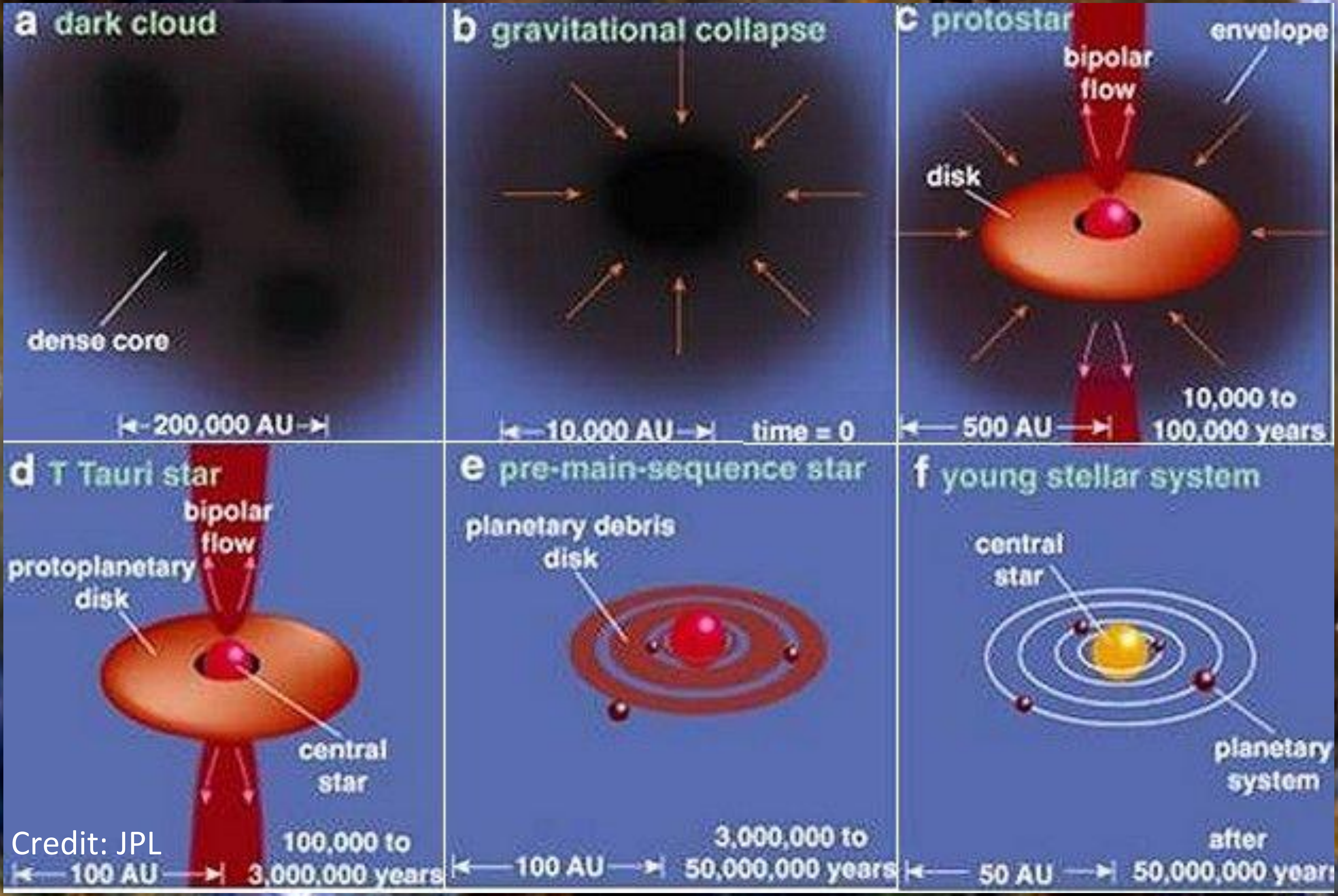
Outline

- 1. Introduction: the earliest phases in pre-protostellar evolution
- 2. The TOP-SCOPE Survey and follow-up observations of Planck Galactic Cold Clumps
- 3. Early results:
- Magnetic fields in massive filaments revealed by JCMT/POL-2
- ALMA follow-ups of 72 Orion cores
- 4. Summary

1. Introduction: the earliest phases in pre-protostellar evolution

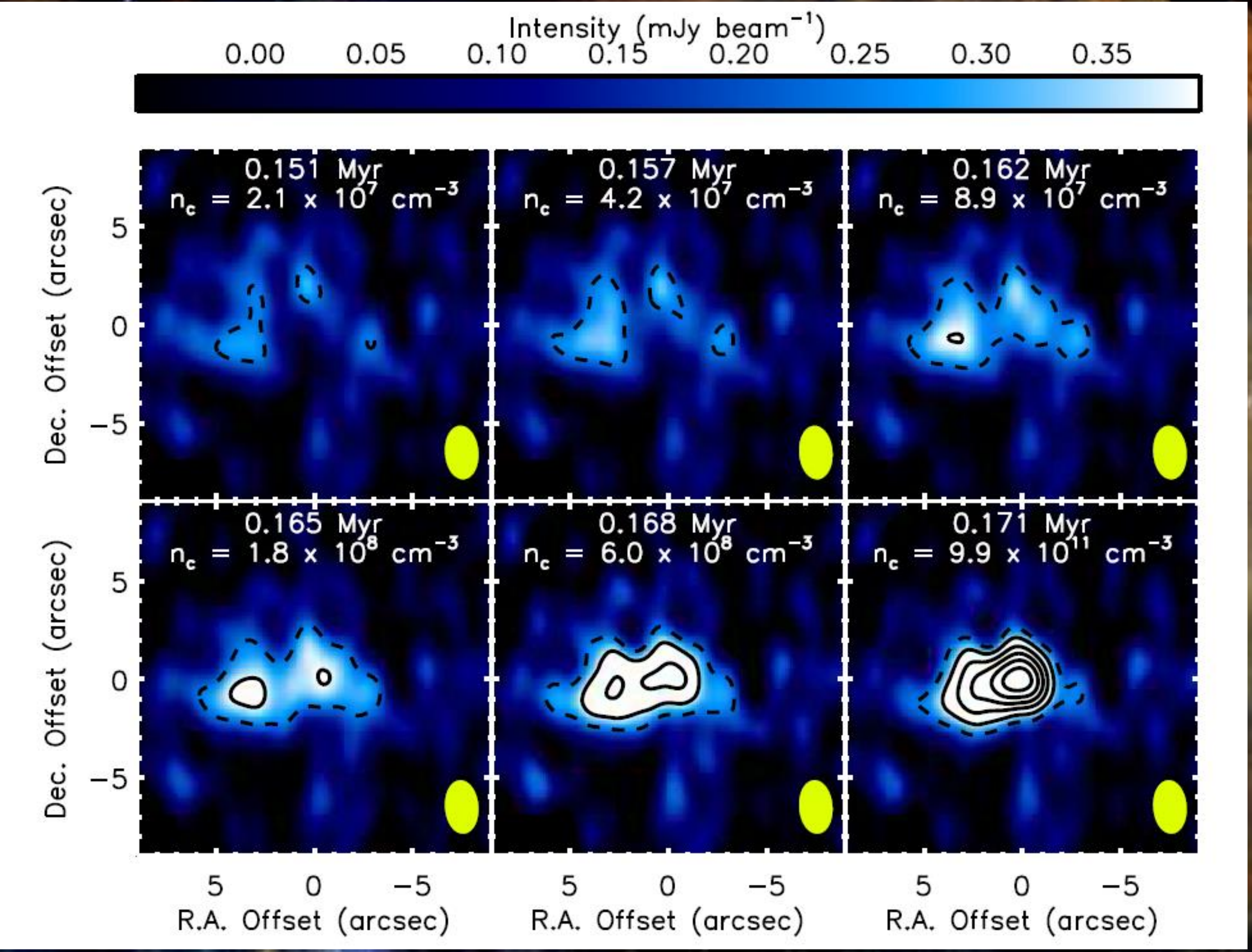


Low-mass star formation



Do high-mass stars and brown dwarfs form in the same way?

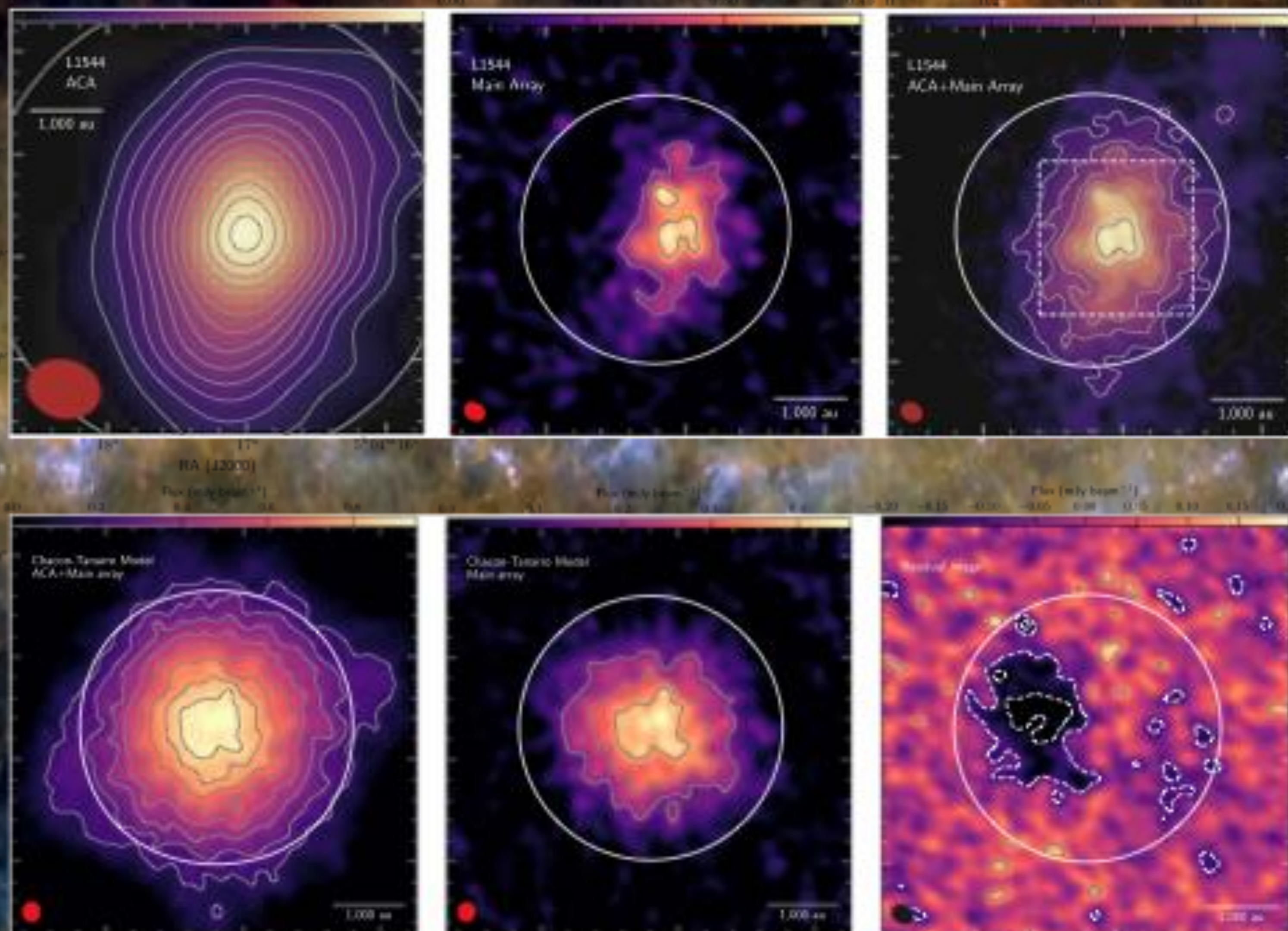
Fragmentation and substructures of starless cores in turbulent fragmentation



Synthetic ALMA 106 GHz continuum observations of the turbulent fragmentation simulation (Dunham+2016). ALMA is able to detect substructures for starless cores with peak density exceeding 9E7 cm^{-3}

The starless core non-detections (Schnee et al. 2010, 2012; Dunham et al. 2016; Kirk et al. 2017) indicate that either most of the starless cores are not collapsing, or that the starless cores are more accurately described by models that develop less substructure than predicted by the turbulent fragmentation scenario, such as Bonnor–Ebert spheres.

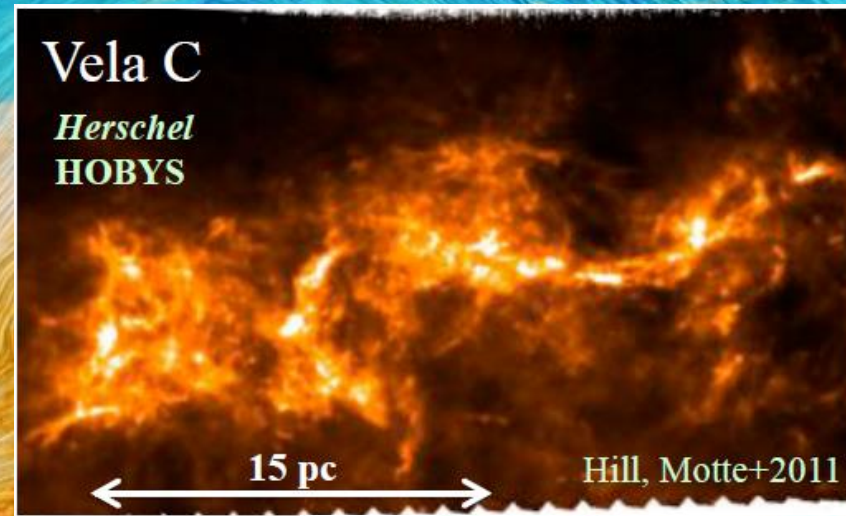
ALMA observations of L1544 (Caselli+2019)

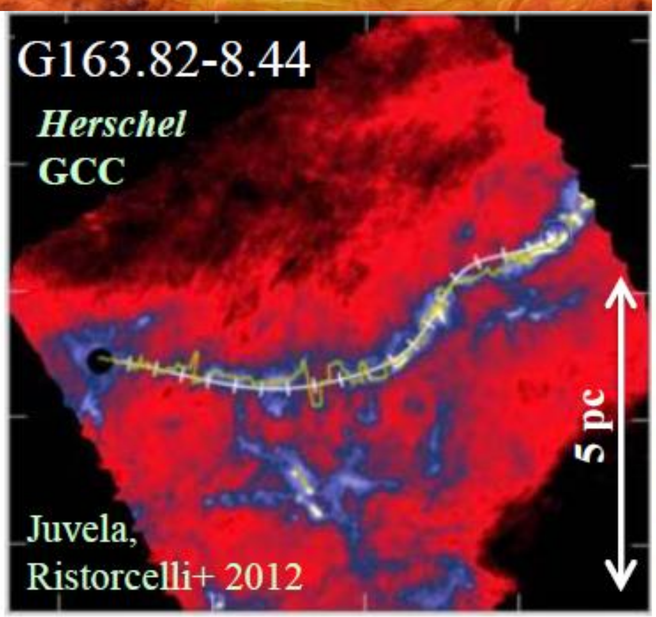


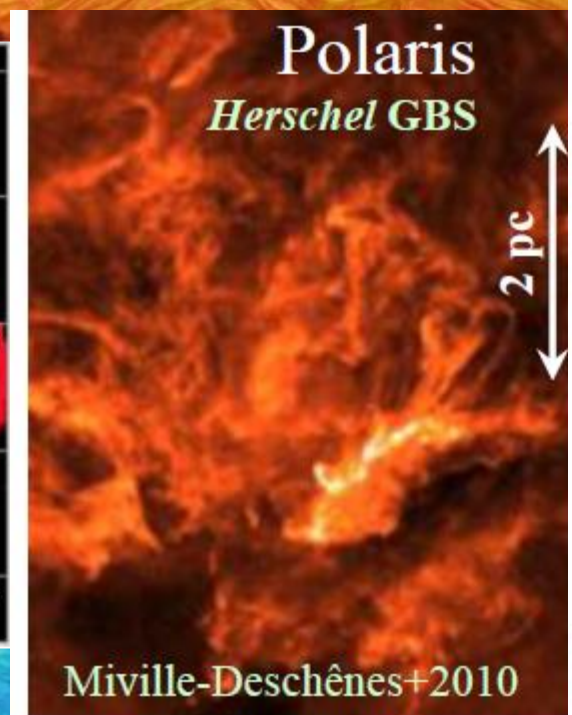
$$n(r) = \frac{n_0}{1 + (r/R_{\rm flat})^{\alpha}}$$

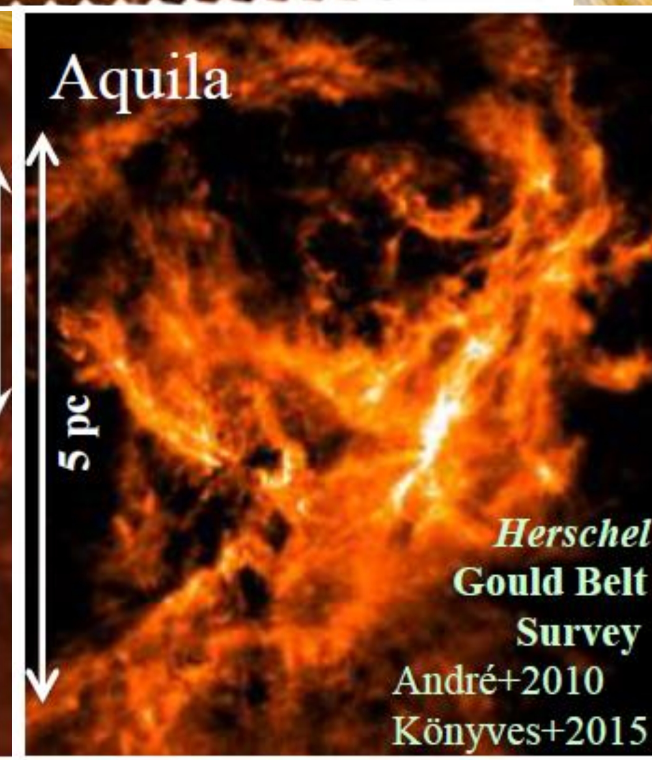
$n_0 = 1.6 \times 10^6\ \mathrm{cm^{-3}}$, $R_{\rm flat} = 17\farcs3$ (≡2336 au), and $\alpha = 2.6$

Herschel has revealed 'universal' filamentary structures in the cold ISM









Open questions on the earliest phases of pre-protostellar evolution

- ***1. Filaments in molecular clouds***
- How common are filaments in molecular clouds and how do they form?
- What is the role of filament in dense core or star formation?

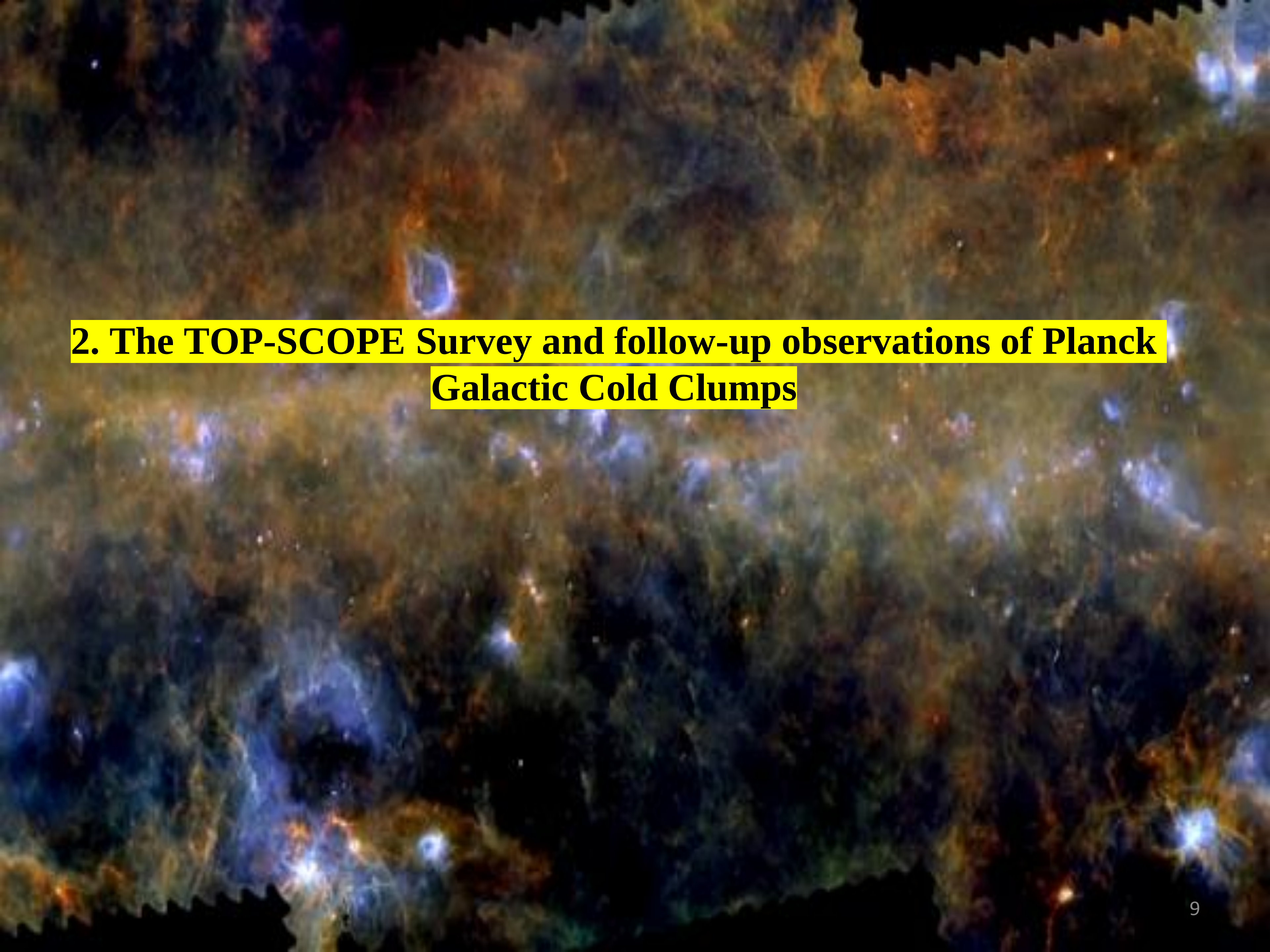
- ***2. Low-mass star formation***
- Substructure and fragmentation of starless cores
- Do first hydrostatic cores exist?
- Disk formation at Class 0 phase

- ***3. High-mass star formation***
- Do massive starless cores exist?
- Are massive pre-clusters undergoing global collapse?

- ***4. Very low-mass star (brown-dwarf) formation***
- Do they formed in the same way as their low-mass counterparts? Or do they form with other mechanisms?

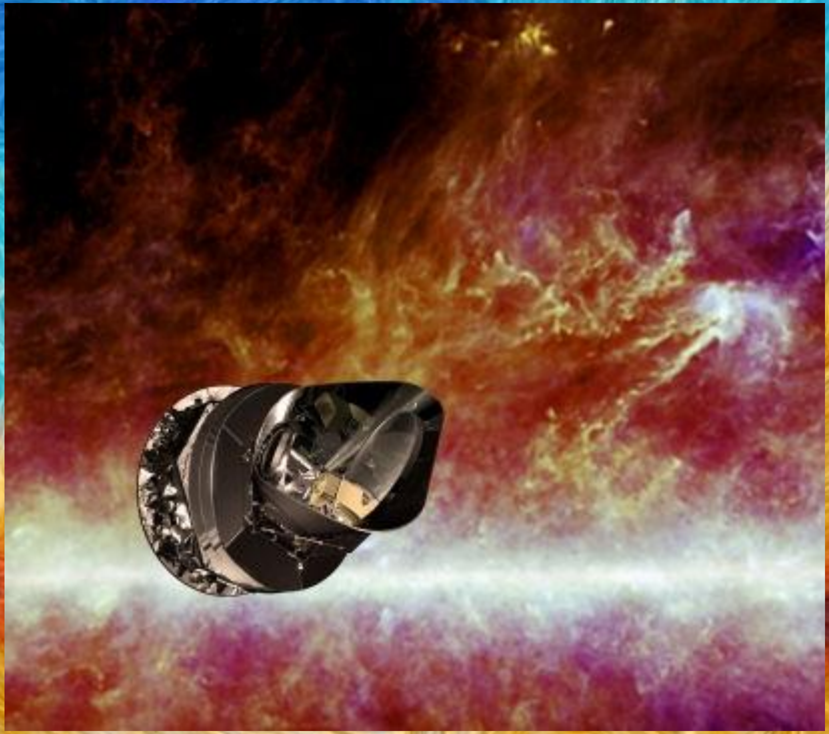
- ***5. Environmental effect on star formation***
- Is there a universal star formation law in different kinds (metallicity; UV radiation; density; temperature…) of clouds?

- ***We need a large sample of cold clumps/cores that represent the very initial conditions of star formation and are located in widely different environments.***



2. The TOP-SCOPE Survey and follow-up observations of Planck Galactic Cold Clumps

Surveys of Planck Galactic Cold Clumps

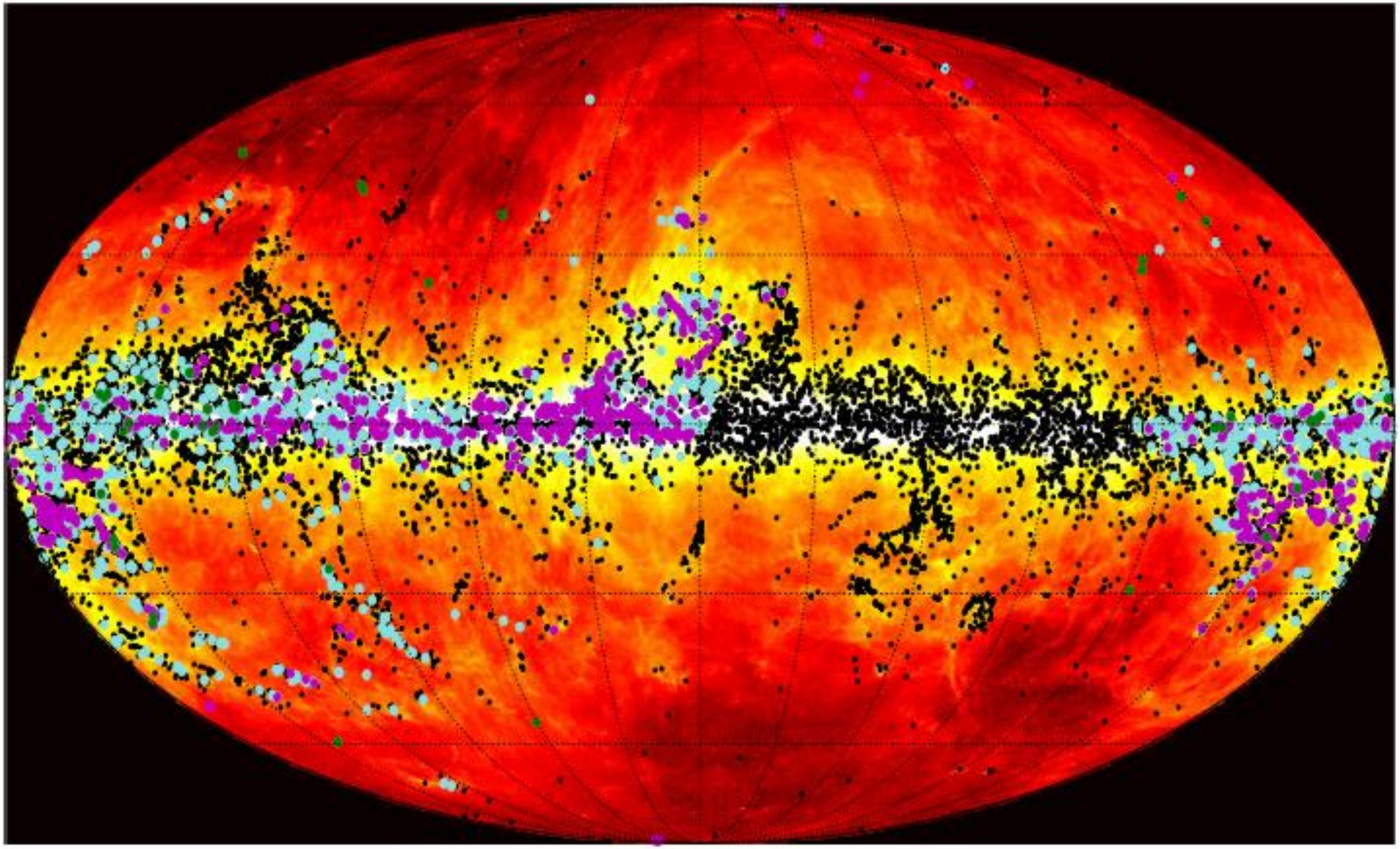


Planck is a third generation space based cosmic microwave background experiment, operating at nine frequencies between 30 and 857 GHz

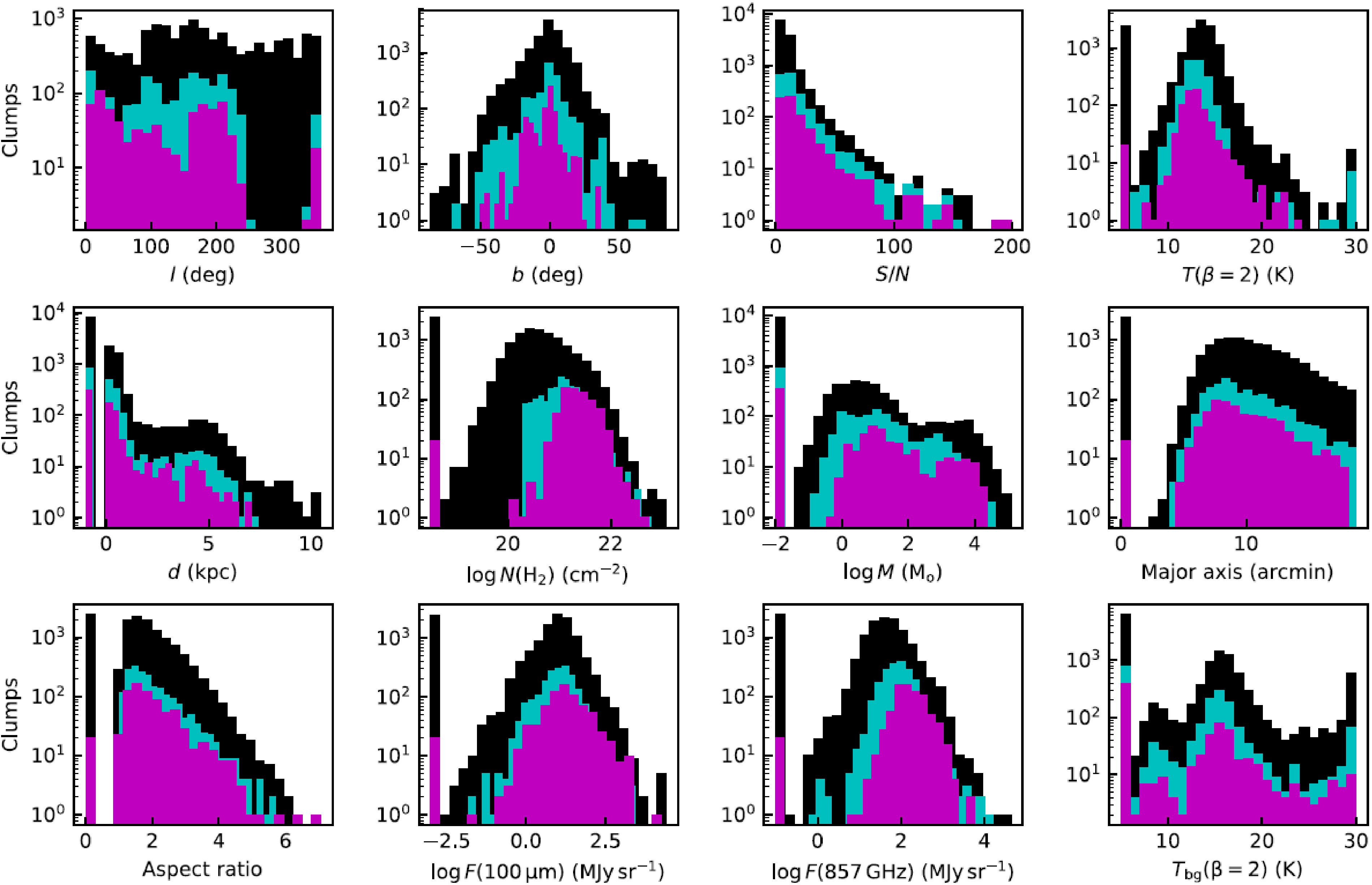
Planck Catalogue of Galactic Cold Clumps (PGCC), *13188 clumps*

The PGCCs are cold (T_d~14 K) clumps and thus represent the very initial conditions of star formation and molecular cloud evolution

We have an international team that includes more than **150 experts** all over the word (China; Japan, S. Korea, U.K., Taiwan, U.S., Canada, France, Finland…) to follow-up observe **1000-2000** PGCCs with multiple state-of-the-art telescopes (**TRAO 13.7-m, PMO 13.7-m, JCMT 15-m, NRO 45-m, SMT 10-m, KVN, IRAM 30-m, SMA, ALMA**, **SOFIA**, **BLAST-TNG**, **Effelsberg 100-m, TianMa 65-m, FAST 500m**…) in order ***to investigate the initial conditions of star formation in widely different environments and to address the questions raised in the introduction part***.

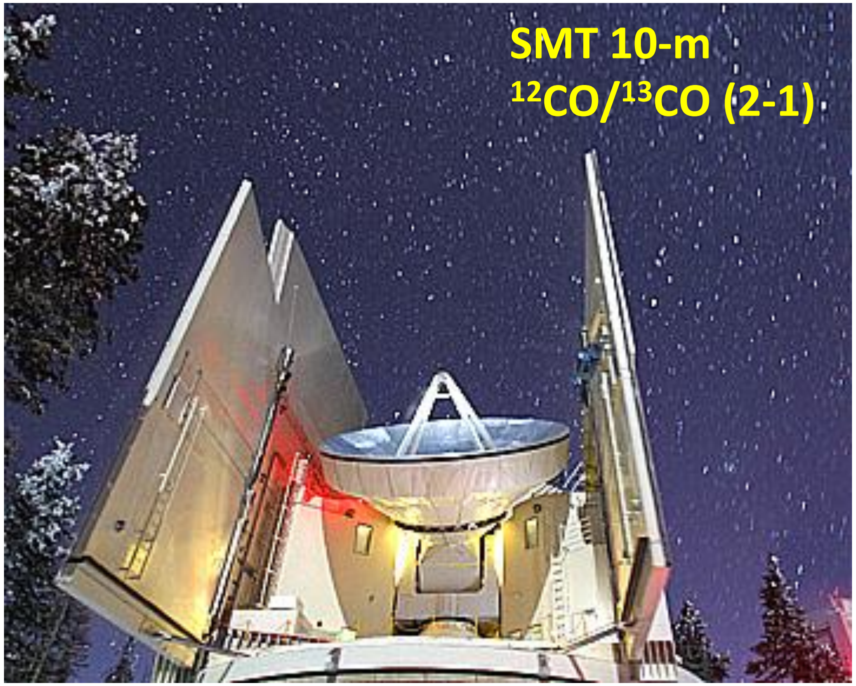


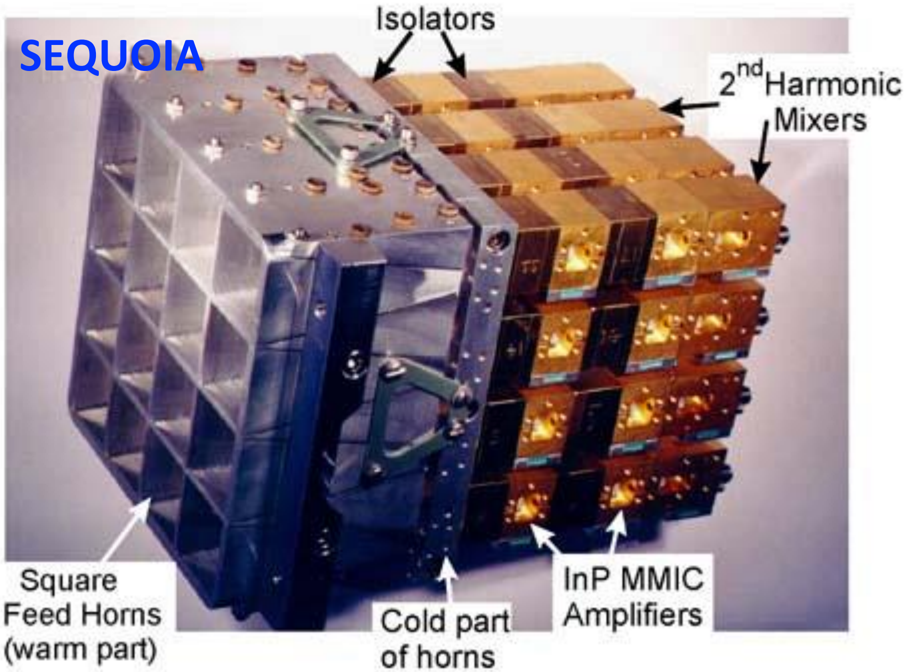
All-sky distribution of the 13188 PGCC sources (black dots), the 2000 PGCC sources selected for TOP (blue dots), and 1000 for SCOPE (pink dots) overlaid on the 857 GHz Planck map (Liu et al. 2018, ApJS, 234, 28)

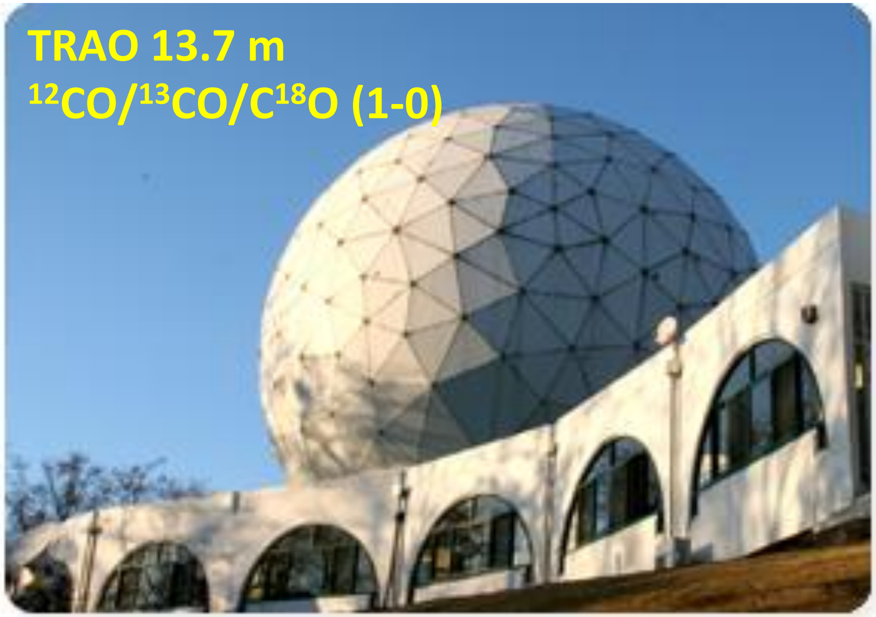


Black: All PGCCs; Blue: TOP; Pink: SCOPE (Liu et al. 2018, ApJS, 234, 28)


PMO 13.7 m
12CO/13CO/C18O (1-0)

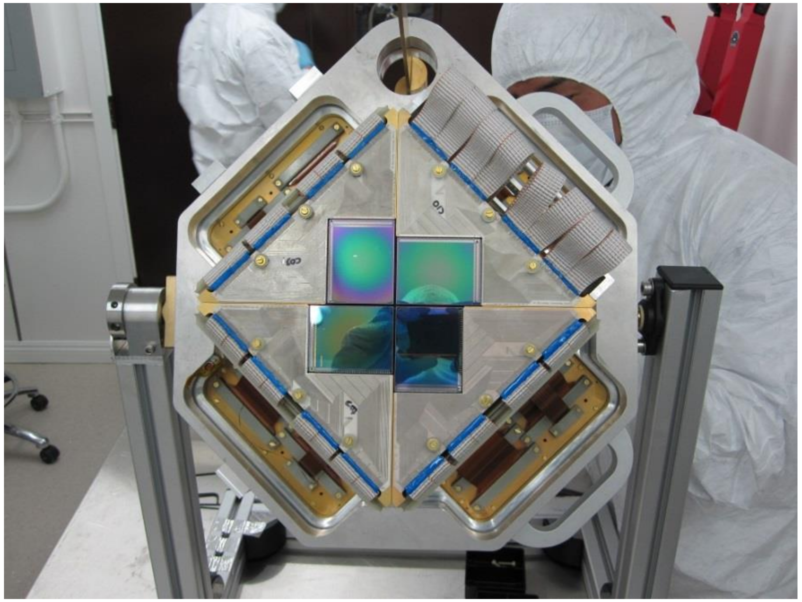

SMT 10-m
12CO/13CO (2-1)


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


TRAO 13.7 m
12CO/13CO/C18O (1-0)

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

A JCMT legacy survey using ~400 hrs of SCUBA-2 time to observe ~1300 Planck Galactic Cold Clumps (PGCCs) in 850 micron continuum



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, 1400hrs for 3 years)

2**. SCOPE: SCUBA-2 Continuum Observations of Pre-protostellar Evolution (PI: Tie Liu, 400 hrs; completed)**

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

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**)

5. Carbon chain molecular lines follow-up survey with Effelsberg 100-m and TianMa 65-m (**PIs: Yuefang Wu; Mengyao Tang**)

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

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

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

9. **Three ALMA proposals accepted in cycle 4s/5; one in cycle 6, one in cycle7 (PI: Tie Liu)**

10. **JCMT HARP and POL-2 follow-ups in 2017B, 2018B,2019A (PIs: Tie Liu; Archana Soam)**

11. Joint large proposal toward ~200 SCOPE dense cores accepted to NRO 45-m and Effelsberg 100-m in 2018A, 2019A semester (PIs: Ken Tatematsu; Victor Toth)

12. Two APEX proposal accepted in 2018A (PI: Mika Juvela)

13. Three SOFIA proposals accepted in 2018A,2019A

14. Four IRAM 30-m proposals accepted in 2018A, 2019A

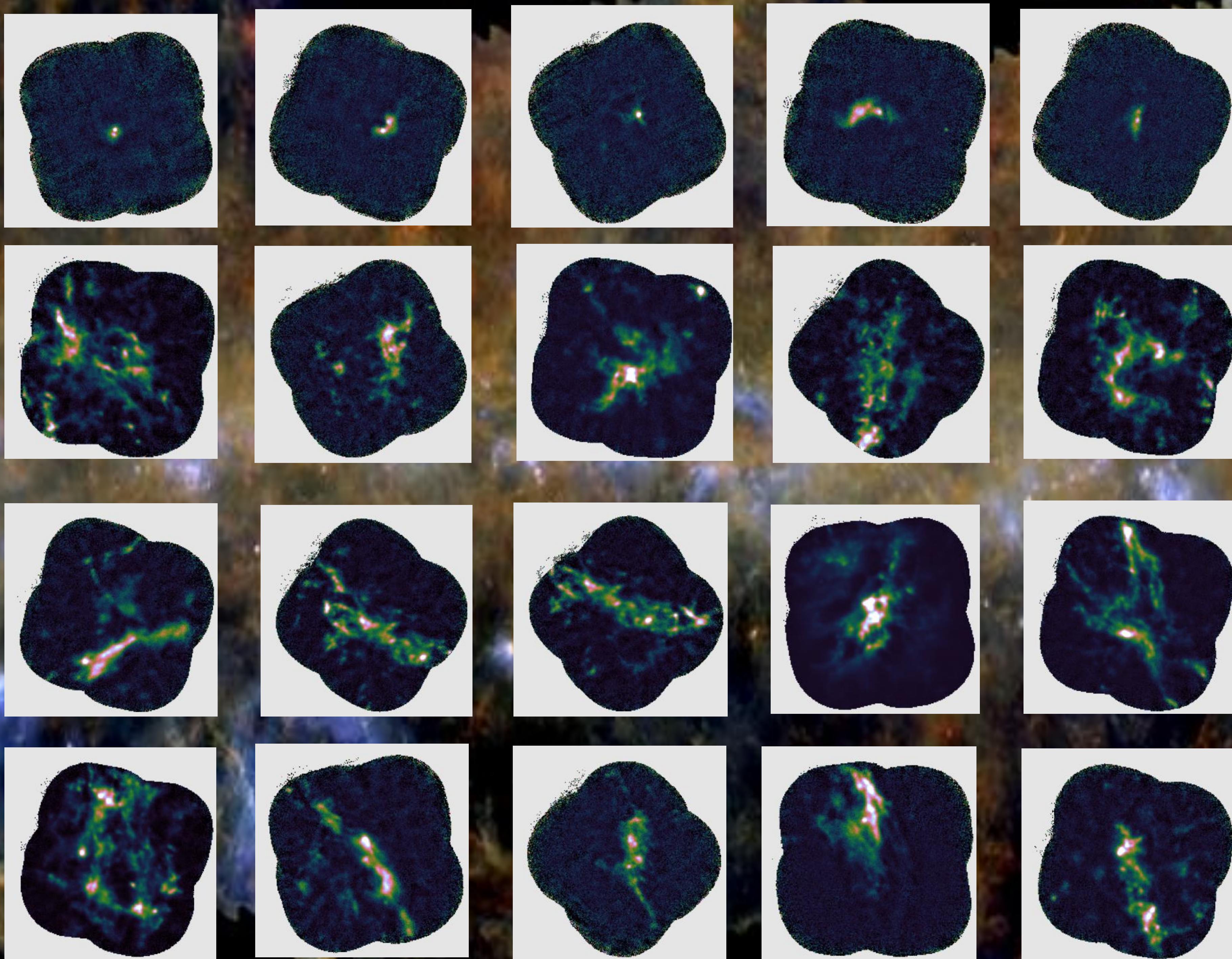
15. Three Effelsberg 100-m proposals accepted in 2018B, 2019A

16. One BLAST proposals accepted in 2018B (PI: Mika Juvela)

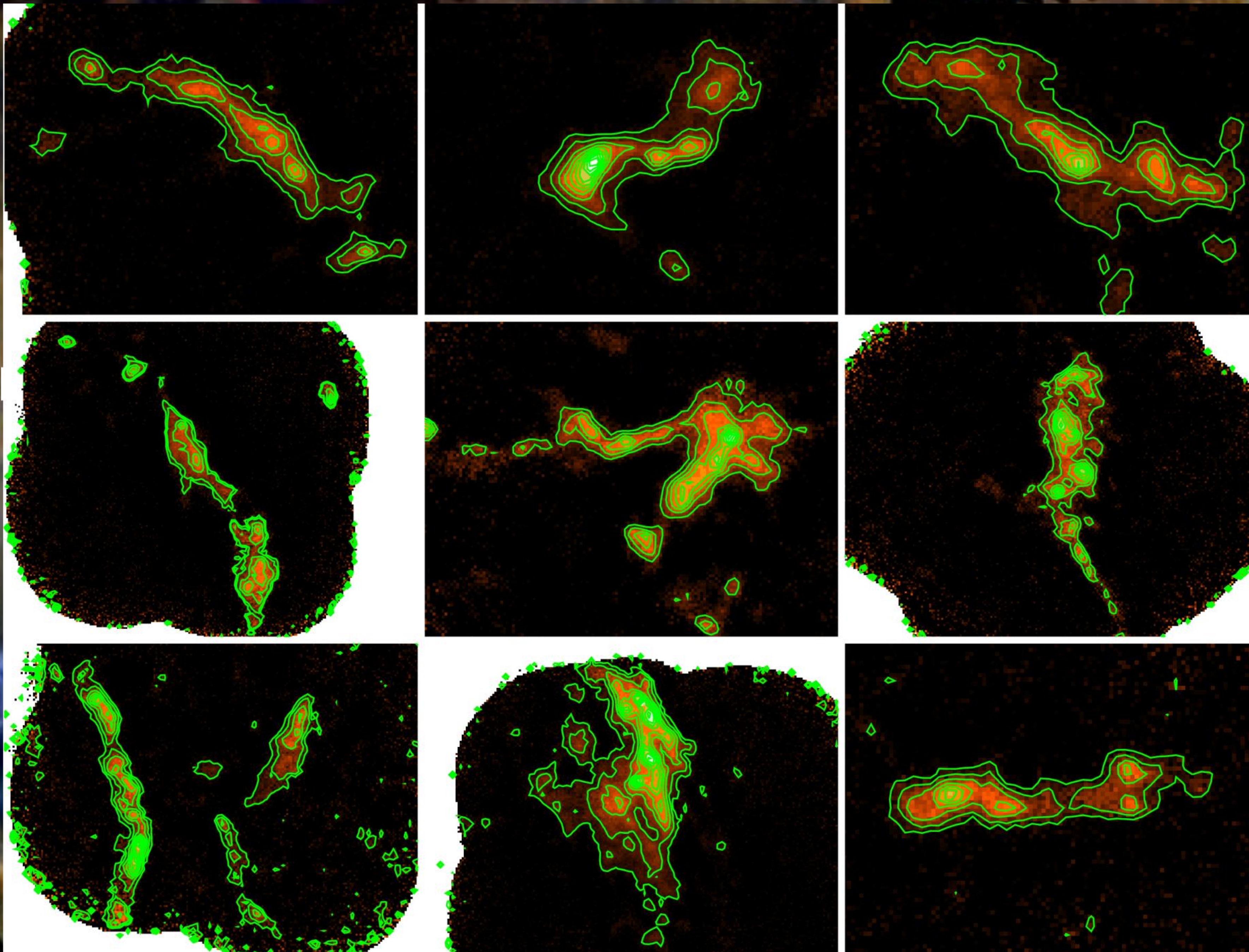
Publications

- *(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. 2018, ApJS, 234, 28
- *(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, 612, 71
- *(6).* ” THE PROPERTIES OF PLANCK GALACTIC COLD CLUMPS IN THE L1495 DARK CLOUD”
- Tang,Mengyao; Liu,Tie; Qin,Sheng-Li et al. 2018, ApJ, 856, 141
- *(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, ApJS, 236, 49
- *(8).* “A Holistic Perspective on the Dynamics of G035.39-00.33: The Interplay between Gas and Magnetic Fields”
- Liu,Tie； Li,Pak-Shing;Juvela, Mika; et al. 2018, ApJ, 859, 151
- *(9)* “Planck cold clumps in the Lambda Orionis complex. II. Environmental effects on core formation”
- Yi, Hee-weon; Lee, Jeong-Eun; Liu, Tie; et al. 2018, ApJS, 236, 51
- *(10).”*Dust spectrum and polarization I the massive star-forming filamentary cloud G035.39-0.33”
- Juvela, Mika; Guillet, Vincent; Liu,Tie; et al. 2018, A&A, 620, 26
- *(11)* “SCOPE: SCUBA-2 Continuum Observations of Pre-protostellar Evolution - survey description and compact source catalogue”
- Eden, David; Liu,Tie; Kim, Kee-Tae; et al. 2019, MNRAS, 485, 2895
- *(12)* Submillimeter Continuum Variability in Planck Galactic Cold Clumps
- Park, Geumsook; Kim, Kee-Tae; Johnstone, Doug; et al., 2019, ApJS, 242, 27
- *(13)* Sequential star formation in the filamentary structures of the Planck Galactic cold clump G181.84+0.31
- Yuan, Lixia; Zhu, Ming; Liu, Tie; et al., 2019, MNRAS, 487, 1315
- *(14)* Magnetic Fields in the Infrared Dark Cloud G34.43+0.24
- Soam, Archana; Liu, Tie; Andersson, B. -G., et al., 2019, ApJ, 883, 95
- *(15)* Cloud G074.11+00.11: a stellar cluster in formation
- Saajasto, Mika; Harju, Jorma; Juvela, Mika; et al. 2019, A&A, 630, 69

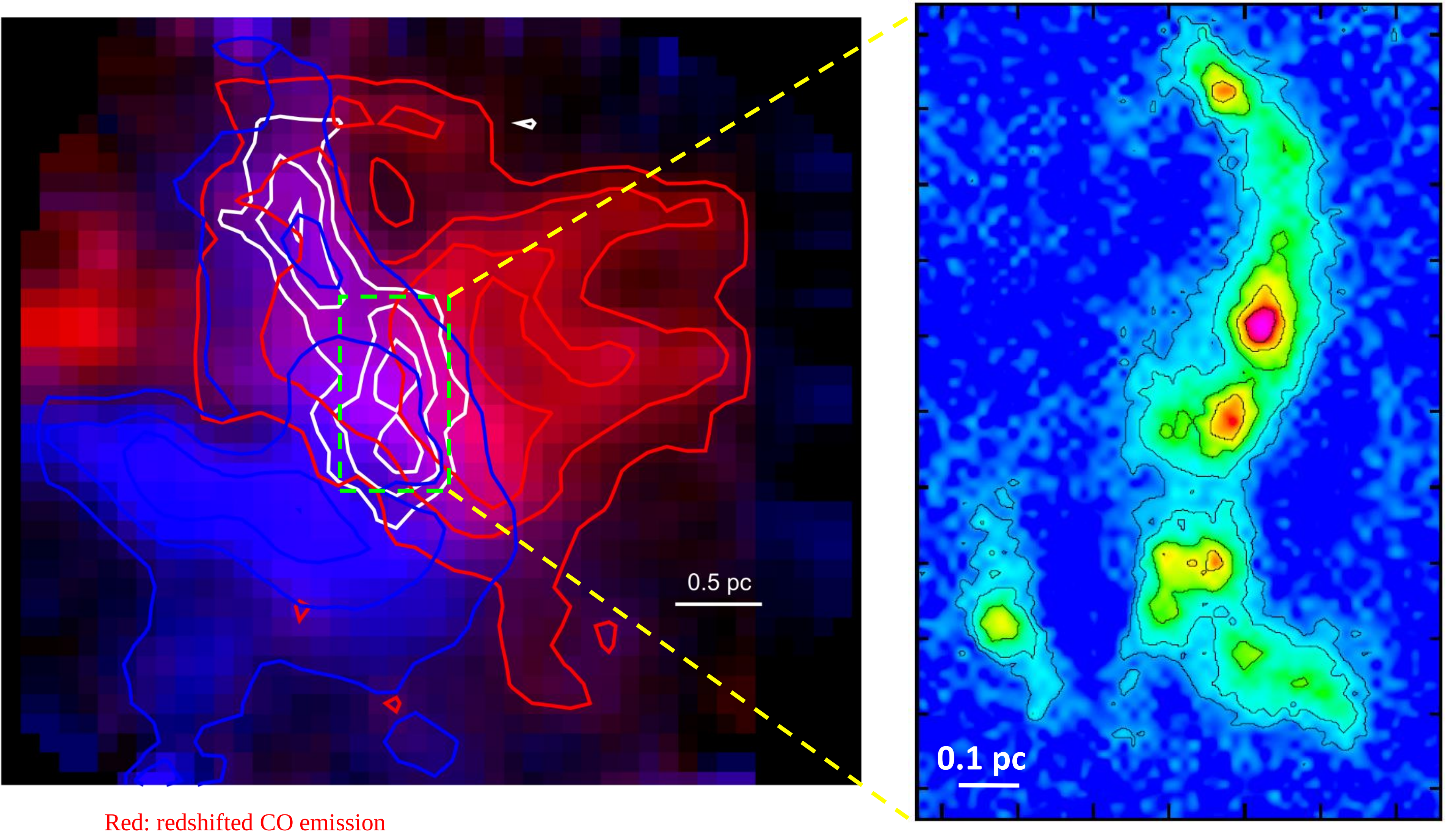
3 Early results



Filaments in the TOP-SCOPE survey



Filaments formed due to cloud-cloud collision

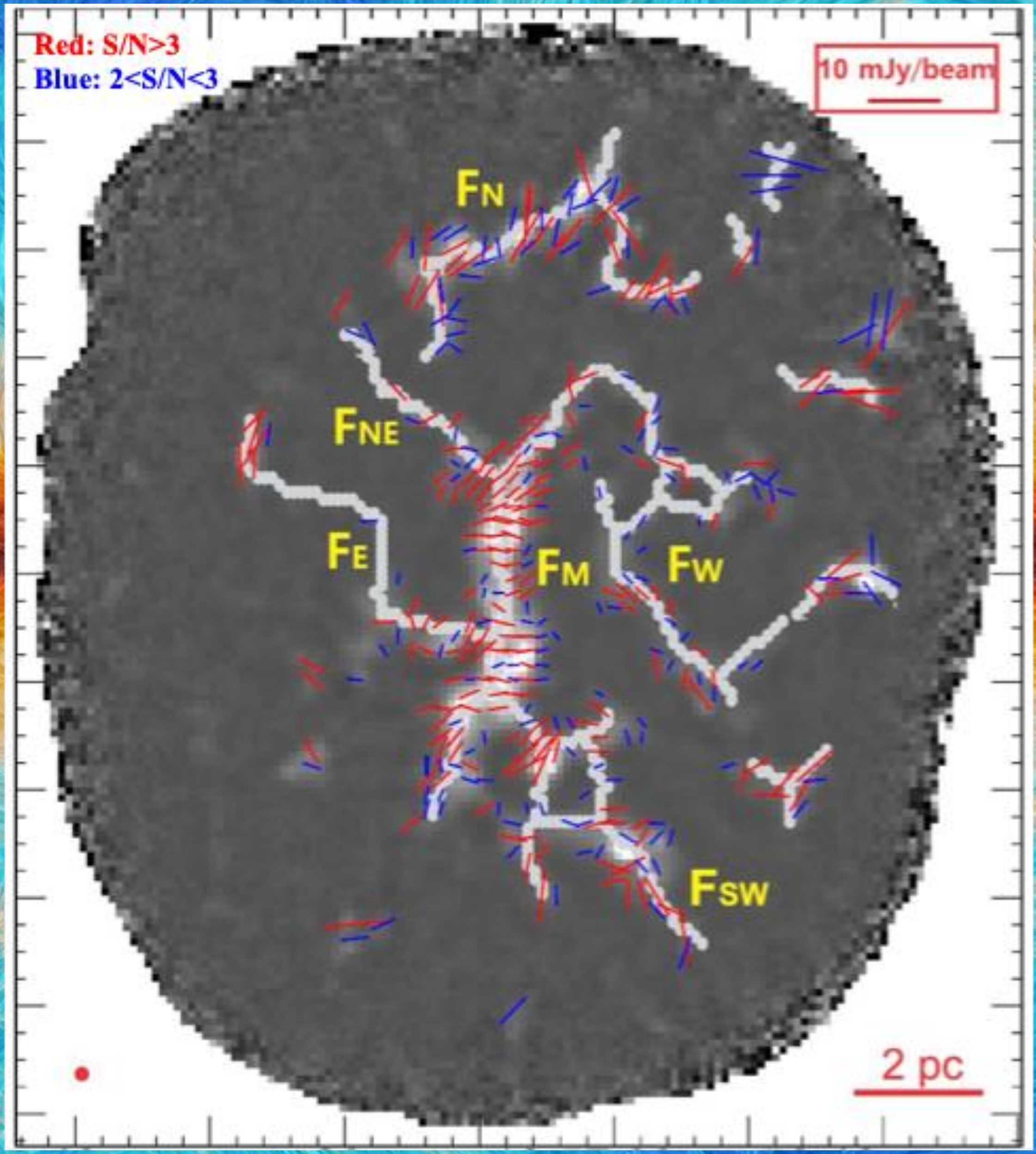


Red: redshifted CO emission
Blue: blueshifted CO emission
White: $C^{18}O$ emission

SCUBA-2 850 micron continuum

(Zhang et al. 2019; more examples in Dana et al. 2019; Liu et al. 2018b, ApJ, 859, 151)

JCMT/POL2 observations of a magnetically “supercritical” IRDC G035.49-00.33



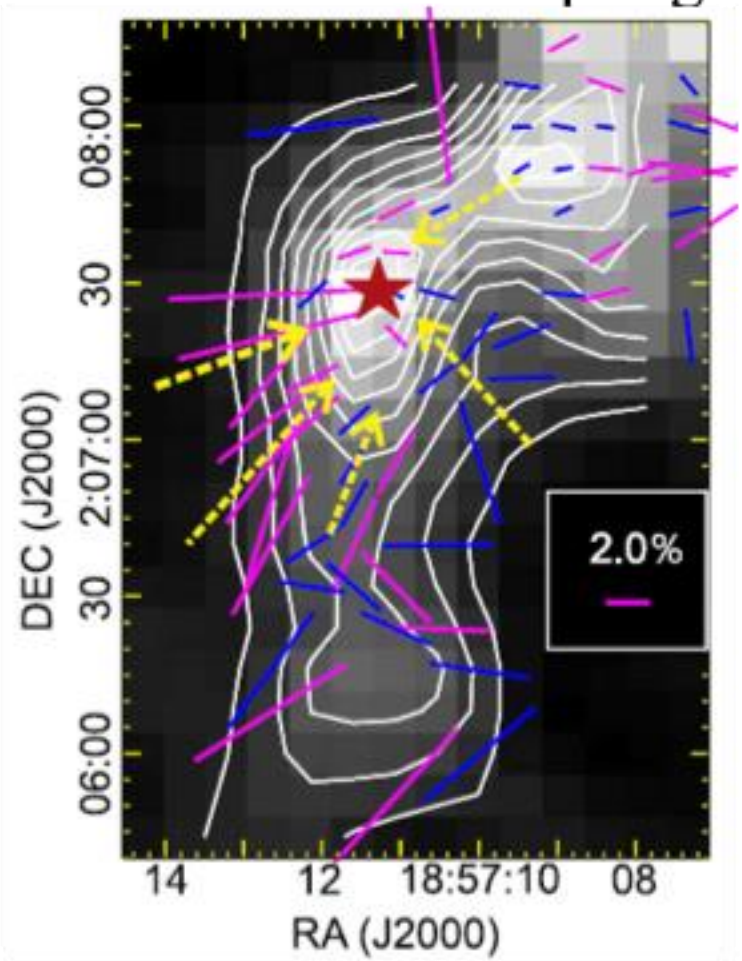
POL-2 observations reveal a network of filaments and an ordered magnetic field

Clouds are highly structured with a network of filaments

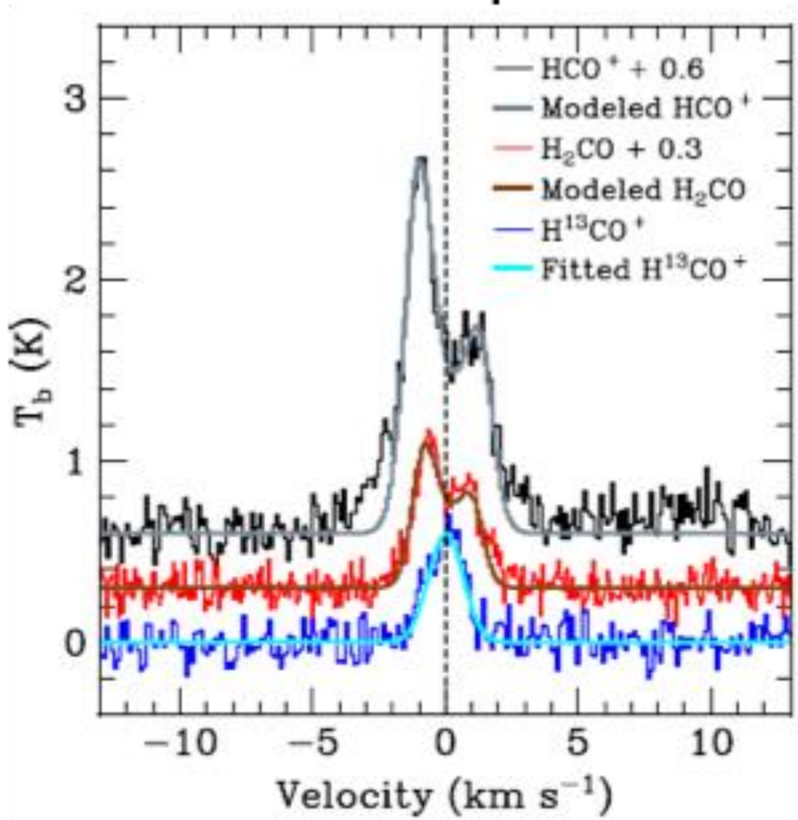
Magnetic fields inside filaments are ordered but not strong enough to support filaments or cores against gravitational collapse

Liu et al. 2018, ApJ, 859, 151

A collapsing high-mass starless clump



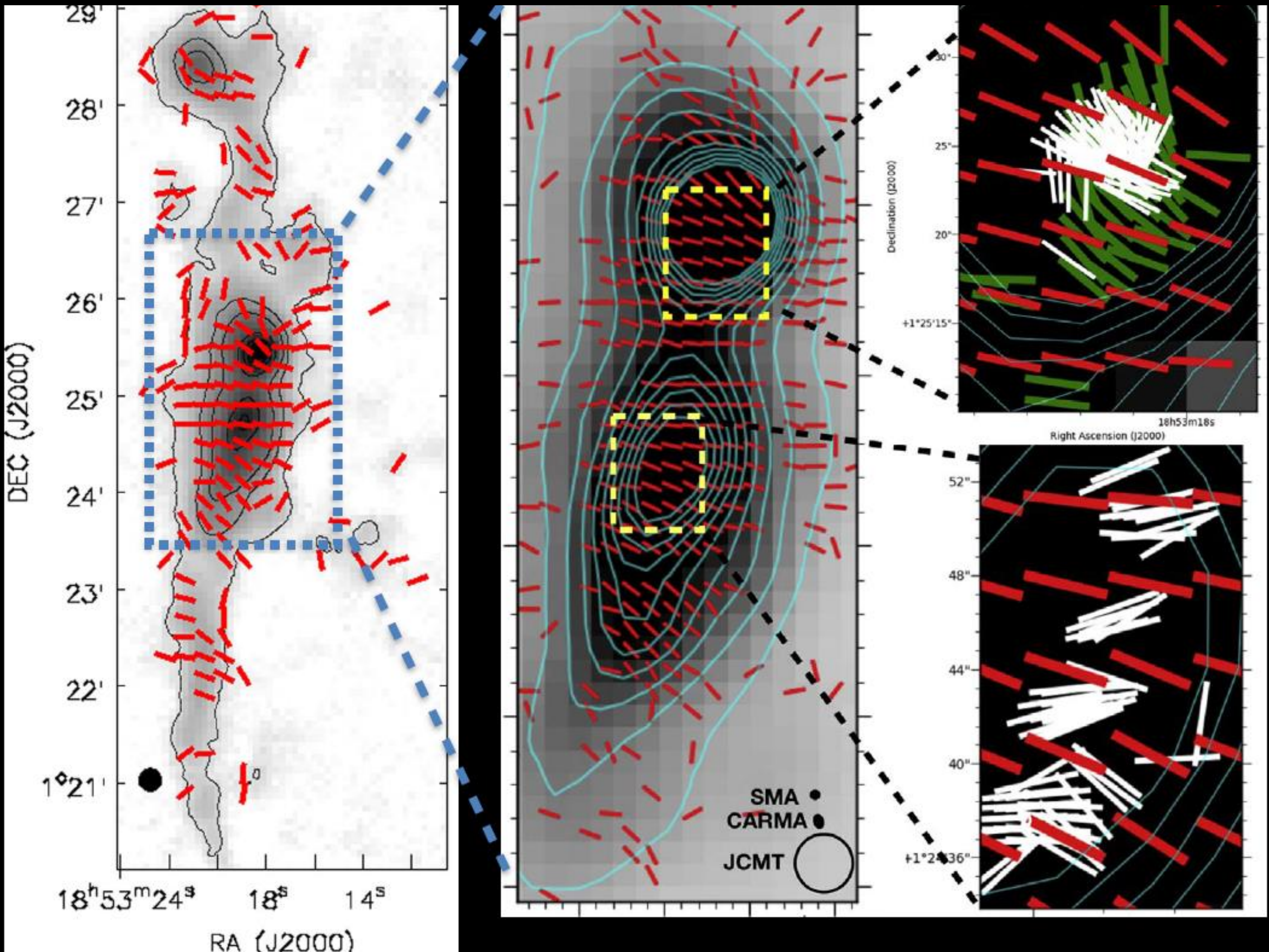
Pinched magnetic field hinting for accretion flows?



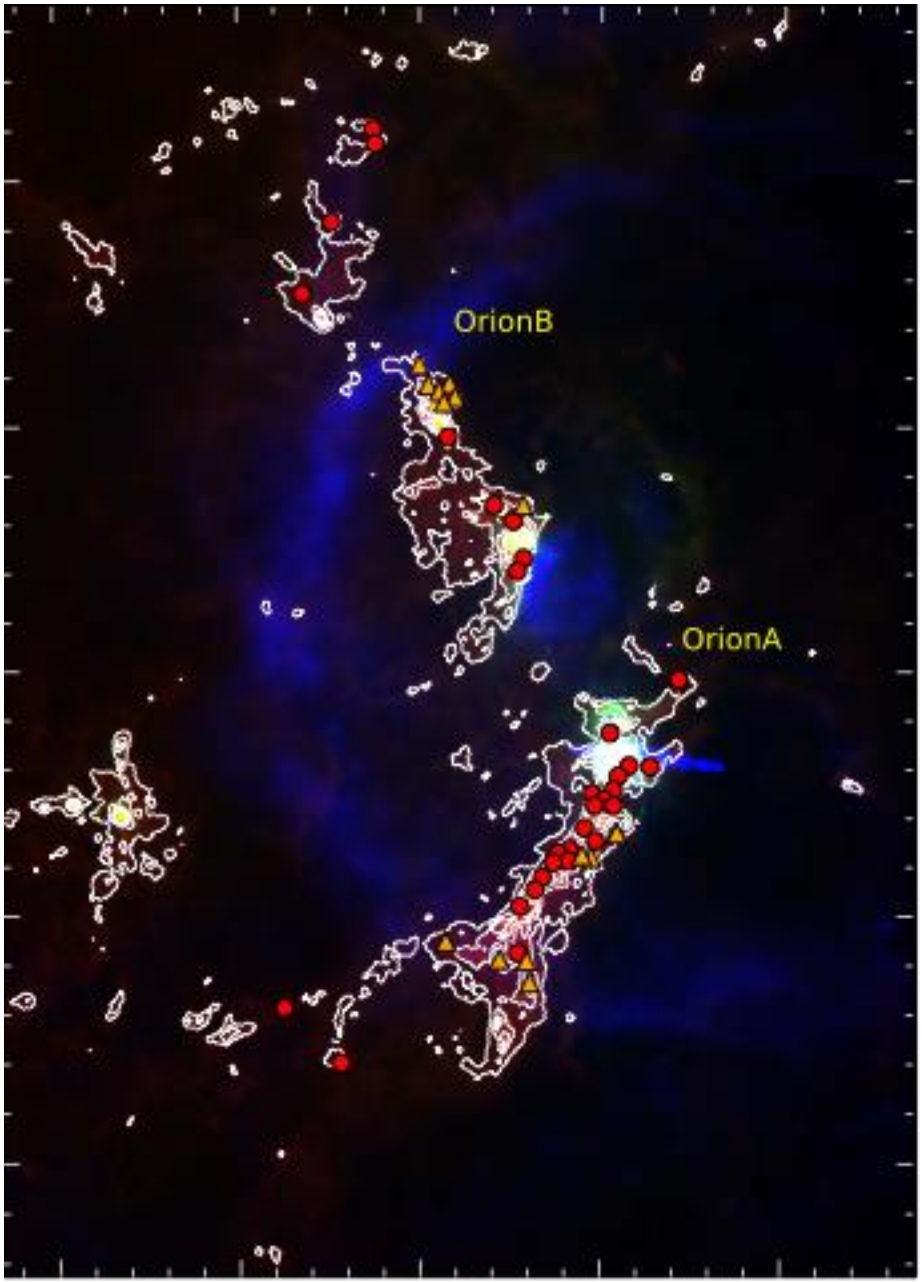
Collapsing signature in lines

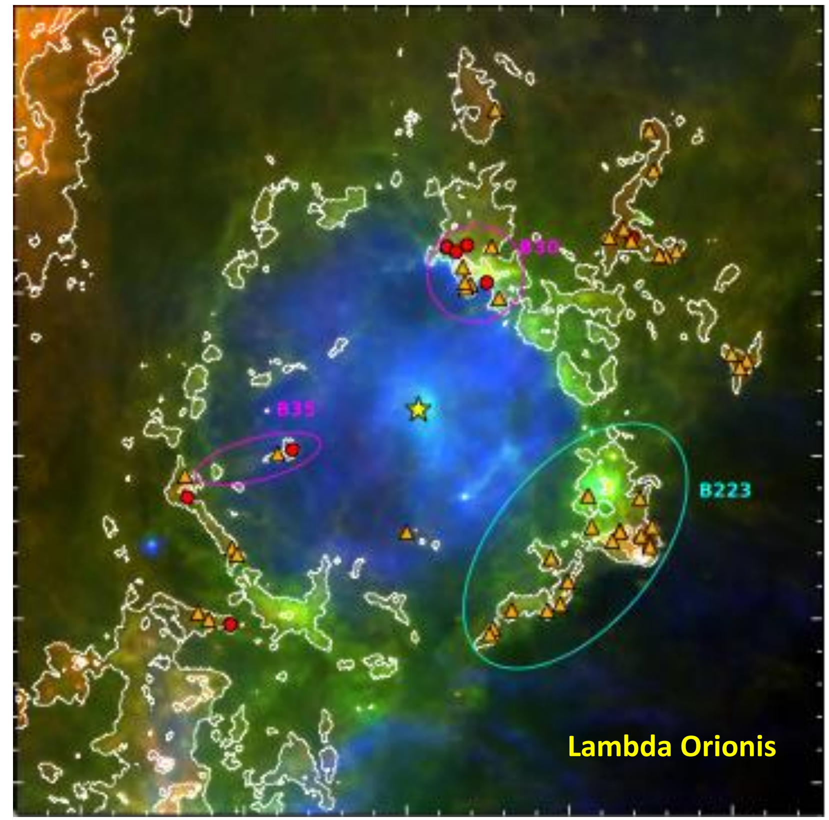
We firstly report a collapsing high-mass starless clump with pinched magnetic field:
R~0.3 pc, M~ 200 $M_\odot$, V_{in}~0.3 km/s; Mass infall rate: 4*10^{-4} $M_\odot$/yr

JCMT/POL-2 observations of a magnetically “critical” cloud G34.43+0.24 (Soam,Liu+2019)



An ALMA band 6 survey of 72 Orion cores down to 100 AU



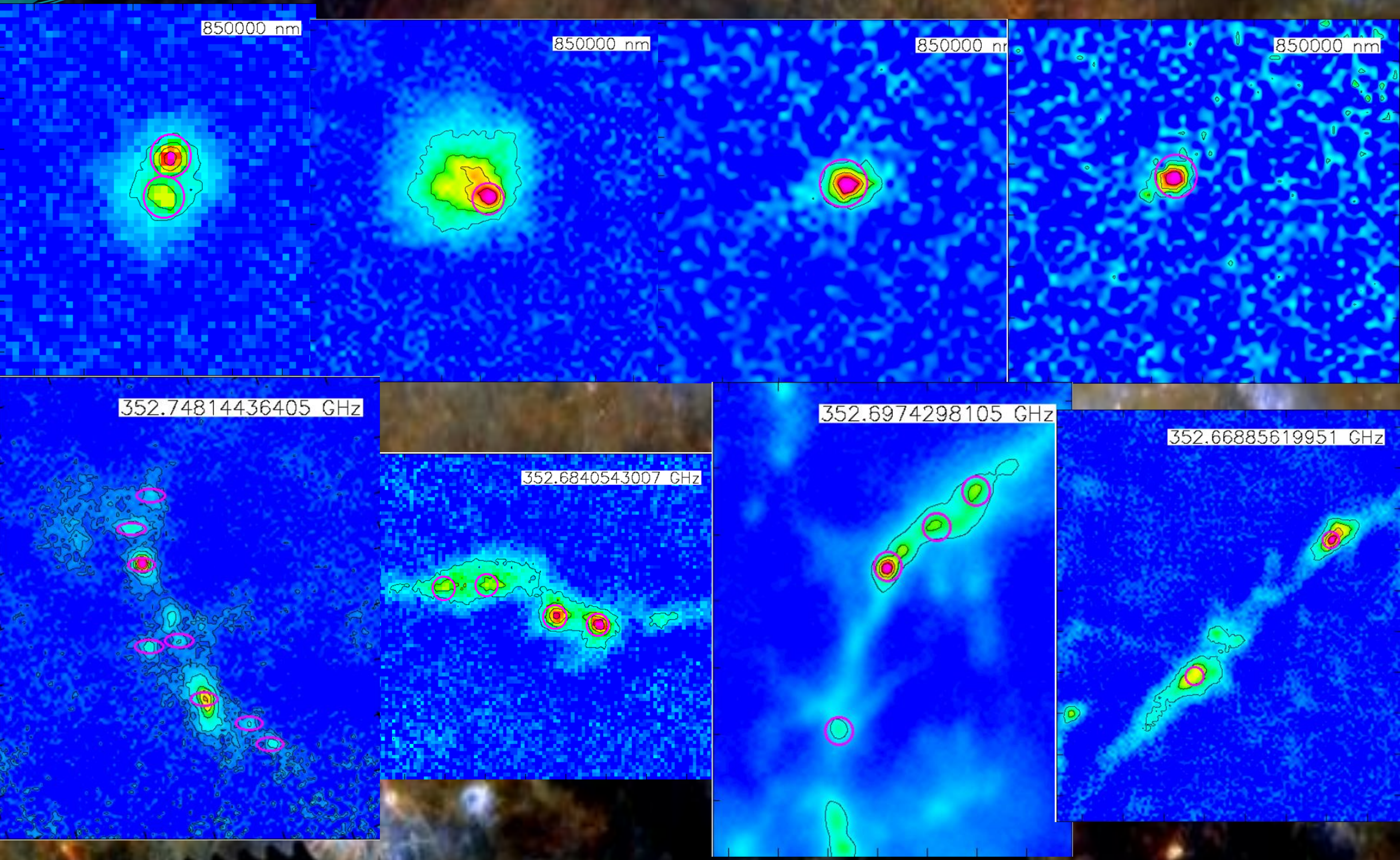


Blue: Halpha

Green: IRAS 100 micron

Red: Planck 353 GHz continuum

An ALMA band 6 survey of 72 Orion cores down to 100 AU



JCMT/SCUBA-2 850 micron continuum

Summary

- The TOP-SCOPE survey has observed 1000-2000 PGCCs and detected a large sample of cold filaments and dense cores that probes wildly different environments, and thus represents a real goldmine for investigations of the early phases of star formation.

- Magnetic fields are ordered inside massive filaments and are as important as turbulence and gravity for star formation. Gas accretion along filaments can inject momenta into cores, causing core rotation. Core rotation can drag magnetic fields into spiral-like shape.

- ALMA follow-ups of 72 Orion cold cores reveal profound sub-structures inside starless cores and very collimated outflows in Class 0 protostellar cores. Prestellar cores in filaments may be not centrally peaked and may not collapse from center as relatively isolated cores (e.g. L1544). Need more sample!

- # Thanks!