Follow-up surveys of Planck Galactic cold clumps with ground-based telescopes

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Outline

1. Motivation
2. Joint surveys and follow-up observations
3. Pilot observations and Preliminary results
4. Summary

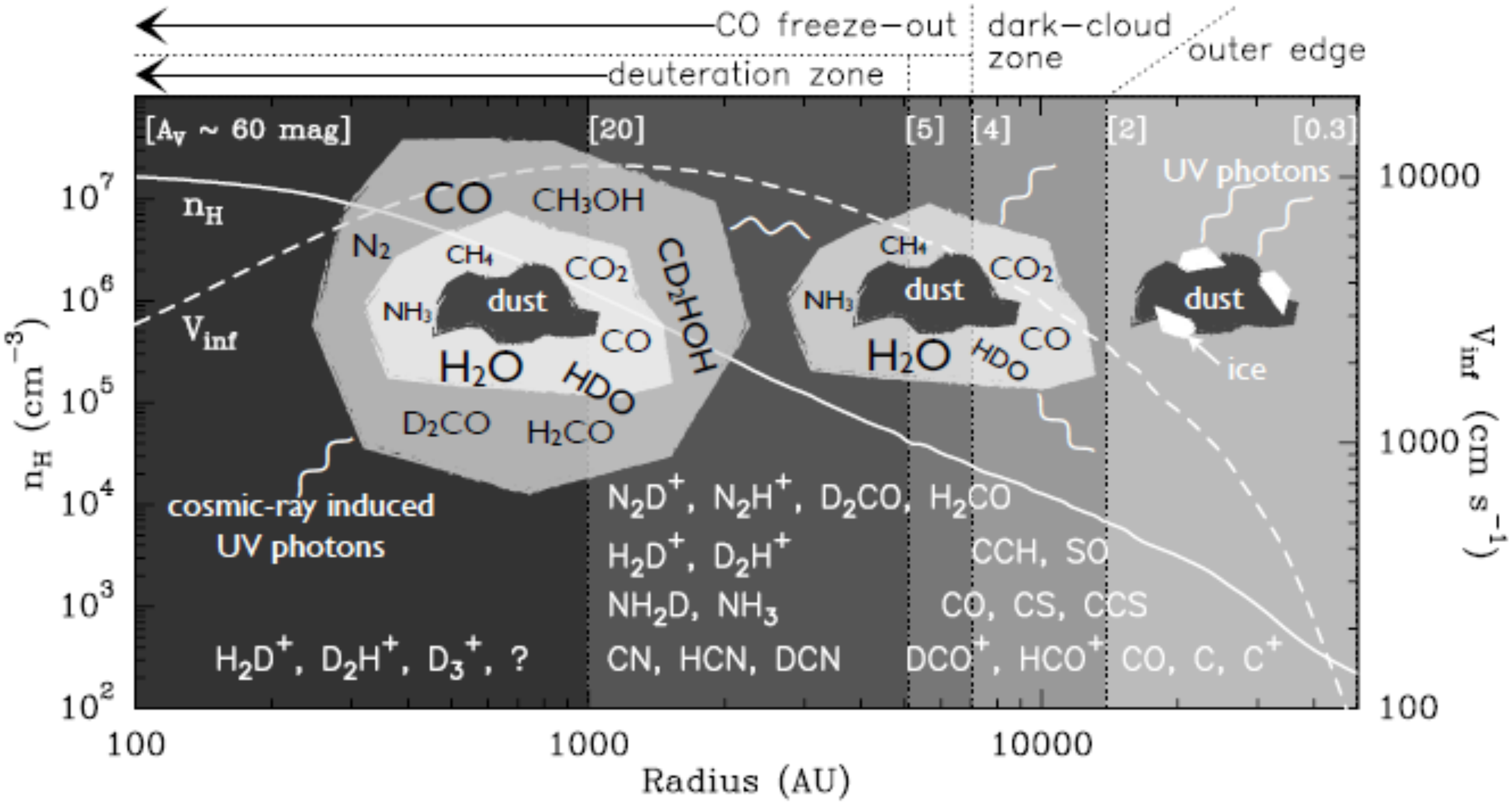
1. Motivation

- 1. Concerning the small scale, how and where do prestellar cores (i.e. future star forming sites) form? Specially, can prestellar cores form in less dense and metal poor high latitude clouds or short lived cloudlets? Is there really a "universal“ density threshold for core/star formation?

- 2. What is the interplay between turbulence, magnetic field, gravity, kinematics and external pressure in prestellar core formation and evolution in different environments (e.g. spiral arms, interarms, high latitude, expanding HII regions, supernova remnants)?

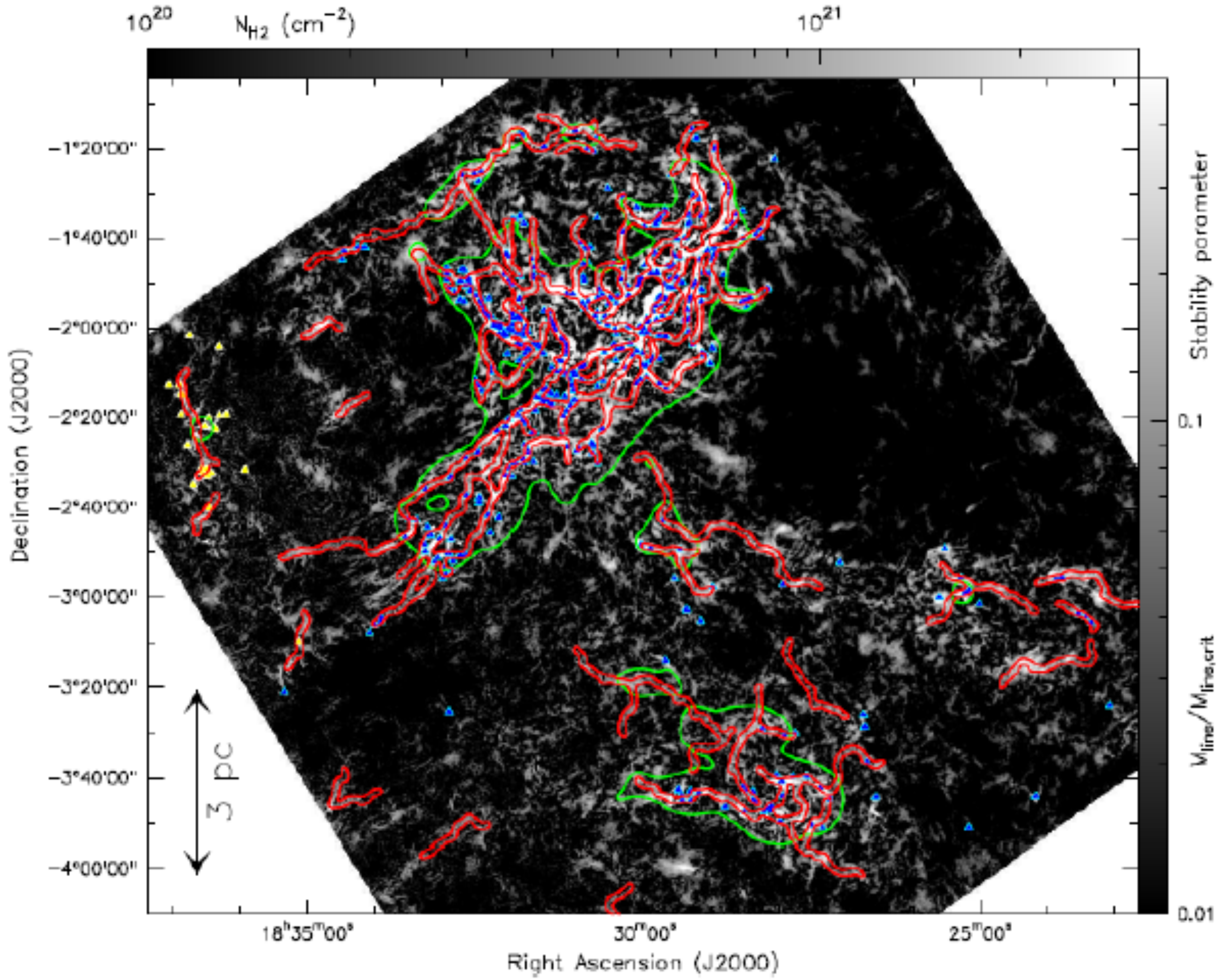
- 3. On the larger scale, what controls the formation of the hierarchical structures in molecular clouds? What are the roles of turbulence, magnetic field, and gravity in shaping molecular clouds? how common are filaments in molecular clouds? What is the role of filaments in generating prestellar cores?

Structure of a prestellar core



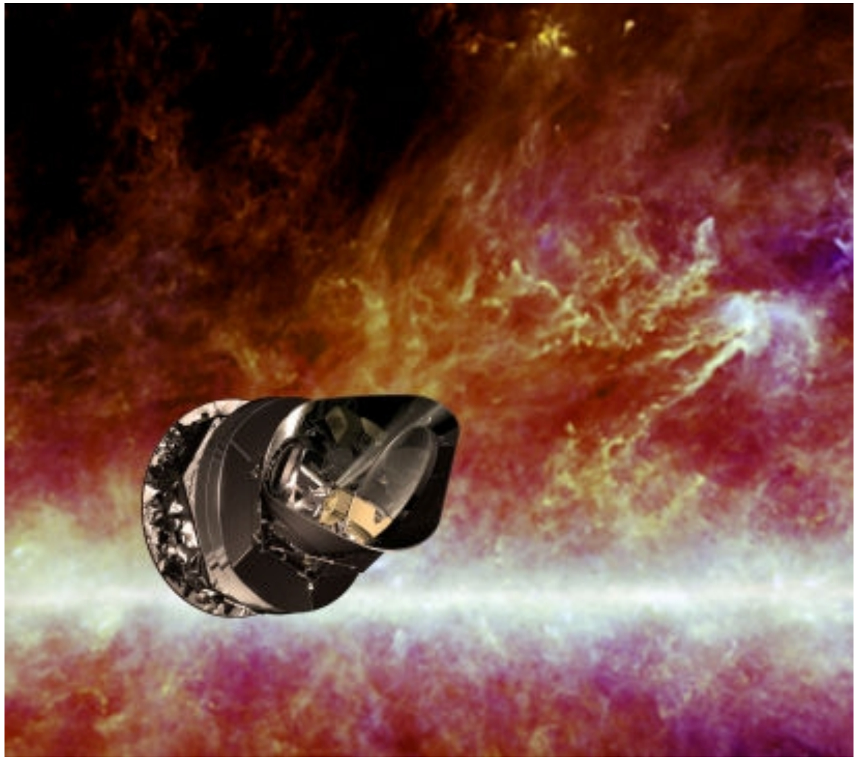
Radial slice of L1544, indicating the number density (nH), infall velocity (Vinf) proles, the visual extinction Av , the main molecular diagnostic tools in the various zones and a rough summary of dust grain evolution within the pre-stellar core (see Caselli 2011, Caselli and Ceccarelli, 2012).

Filaments and prestellar cores



Comparison of the spatial distribution of the prestellar core population with the footprints of all the filaments in **the Aquila cloud complex** **(**Könyves et al. 2015**)**.

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

a blackbody at T = 6K, the coldest dust temperature found inside Galactic dense cores, peaks at 850 GHz

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

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

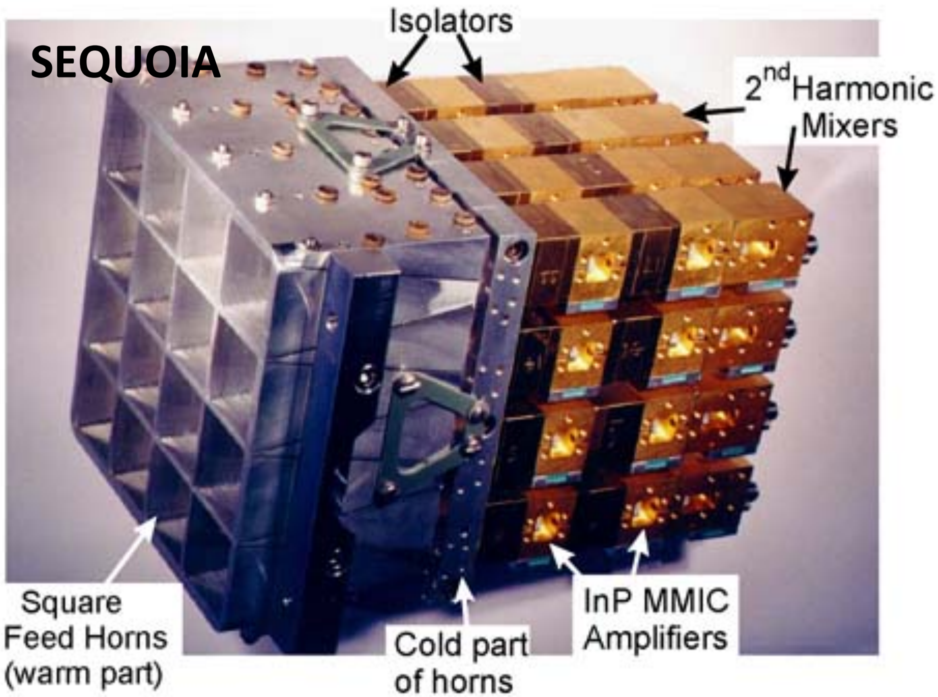
Summary from Planck collaborators et al. (2015)

"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


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

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.

Table 1: **List of most representative (sub)millimeter continuum surveys in the Galaxy**

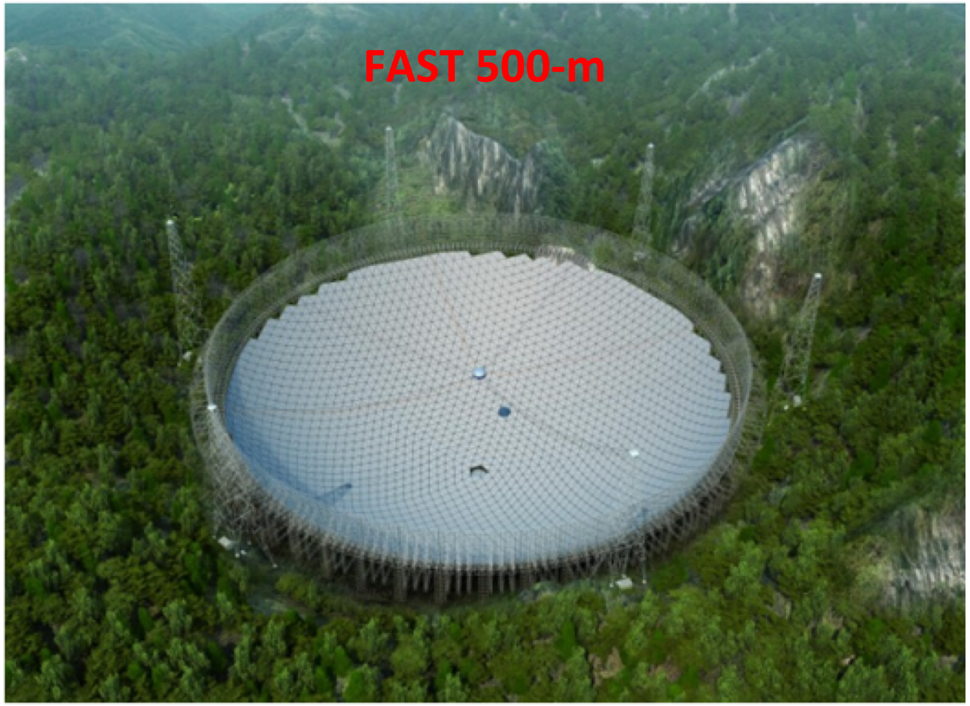
Survey	Bands	Angular resolution	Survey region (°)	Sky Coverage
BGPS/CSO	1.1 mm	$33''$	$-10.5 < l < 90.5, \lvert b\rvert < 0.5 - 1.5$	170 deg.^{2}
ATLASGAL/APEX	870 μm	$17''.5$	$-80 < l < 60, \lvert b\rvert < 1 - 2$	~400 deg.^{2}
Hi-GAL/Herschel	70-500 μm	$5''$-$35''$	$-180 < l < 180, \lvert b\rvert < 1$	~720 deg.^{2}
GBS/Herschel	70-500 μm	$5''$-$35''$	Gould Belt clouds	~160 deg.^{2}
SASSy/JCMT	850 μm	$14''.5$	$60 < l < 240, \lvert b\rvert < 1.2 - 3$	~846 deg.^{2}
JPS/JCMT	450-850 μm	$7''.5$-$14''.5$	$10 < l < 65, 102.5 < l < 141.5, \lvert b\rvert < 1$	~180 deg.^{2}
GBS/JCMT	450-850 μm	$7''.5$-$14''.5$	Gould Belt clouds	~24 deg.^{2}
Planck	0.35-10 mm	$\sim 5'$	All sky	~41253 deg.^{2}


KVN연세대
KVN울산
KVN제주도
KVN연세대
KVN제주
KVN울산

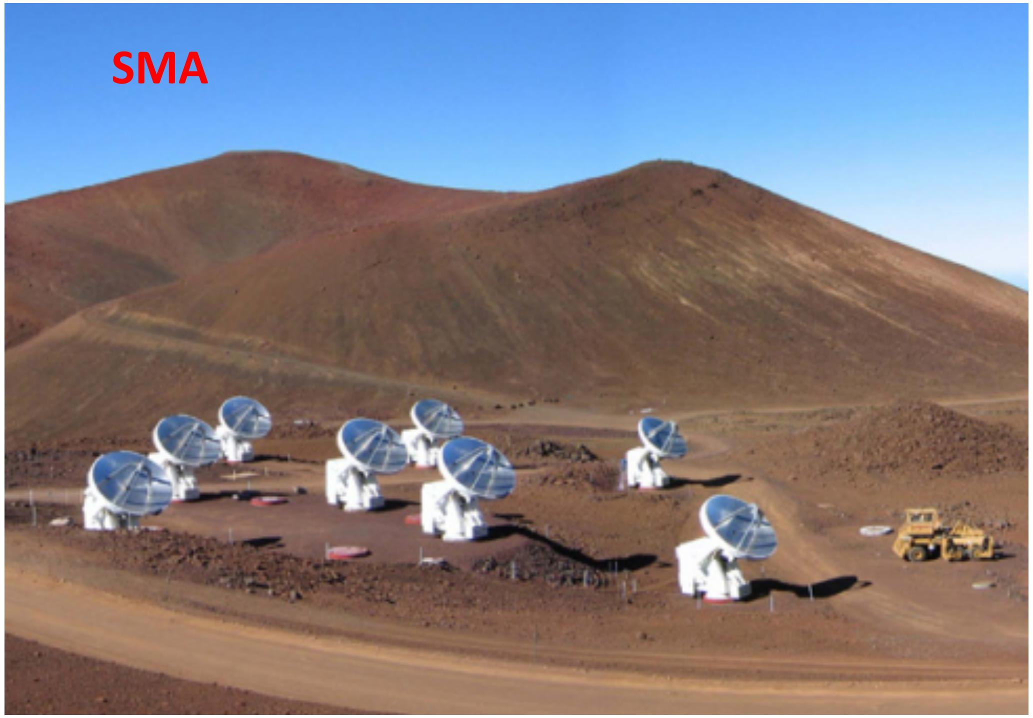

Effelsberg 100-m


TianMa 65-m


Arecibo 300-m


FAST 500-m


NRO 45-m


SMA

Summary of planned surveys

1. PMO/TRAO 13.7-m telescope survey in the J=1-0 transitions of CO isotopologues

Goals: large scale structure & kinematics

2. SMT 10-m telescope survey in the J=2-1 transitions of CO isotoplogues.

Goals: CO excitation, column density and depletion, kinematics

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

Goals: dense cores and filaments

4. KVN 21-m telescope survey in dense gas tracers (e.g. HCN, HCO+, N2H+)

Goals: chemistry

5. NH3 follow-up survey with Effelsverg 100-m and TianMa 65-m

Goals: kinetic temperature & turbulence

6. HI survey with Arecibo 300-m and future FAST 500-m telescopes

Goals: HI abundance and chemical evolution of molecular clouds

7. Follow-up observations with NRO 45-m

Goals: Chemistry

8. Follow-up observations with the SMA

Goals: Fragmentation

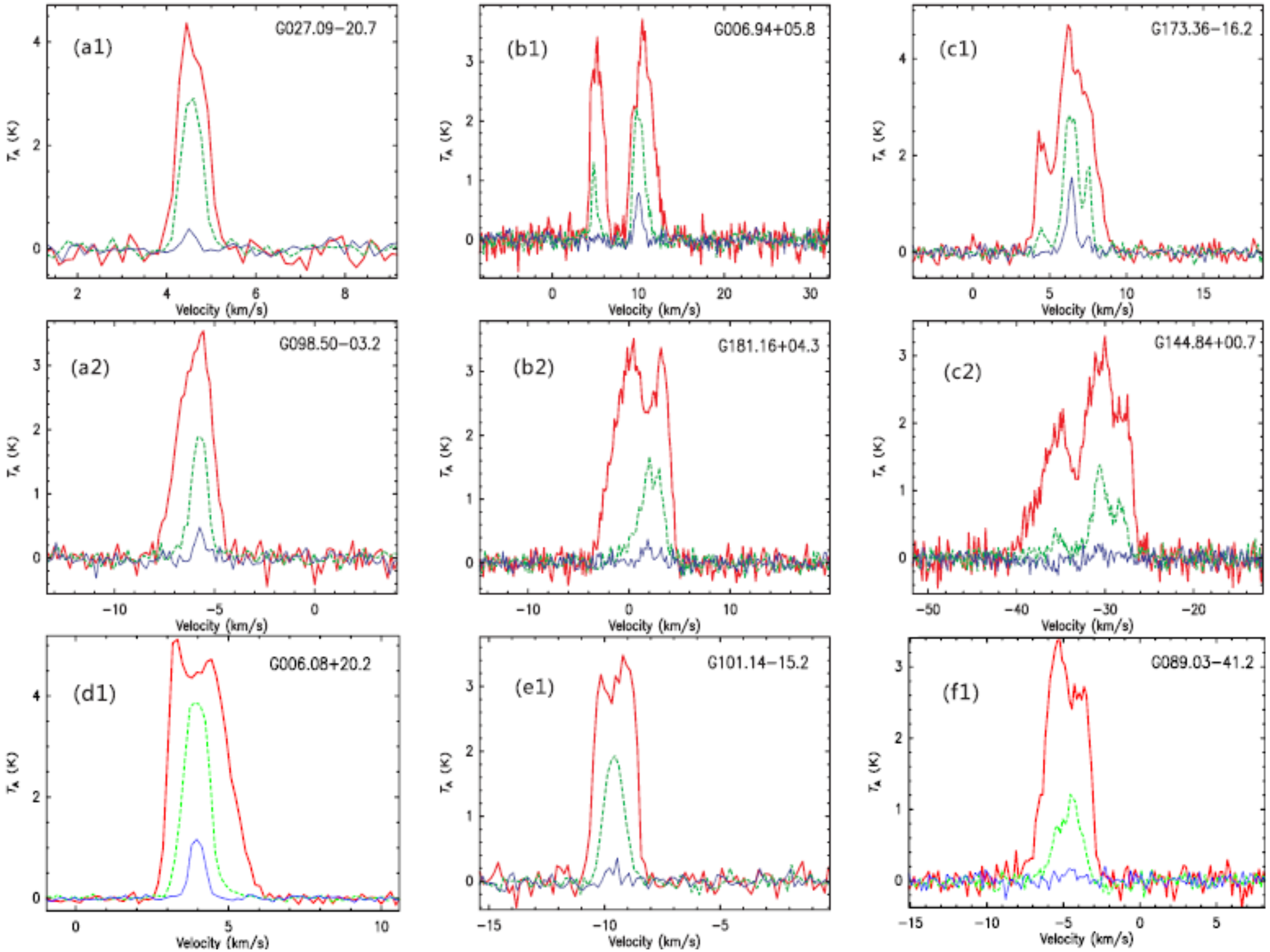
3. Pilot observations and Preliminary results

Pilot Observations

- **1. PMO 14 m**
  Line tracers: 12CO/13CO/C18O (1-0), HCN/HCO+ (1-0)
  Status: ~1000 hrs awarded. 672 PCCs suveyed in single pointing. ~500 mapped in an area of 22arcmin*22arcmin, ~700 dense clumps detected, one third of which HCN/HCO+ (1-0)
- **2. CSO**
  Line tracers: 12CO/13CO/C18O (2-1), 12CO (4-3), CI (492 GHz)
  Status: 5 nights awarded, 20 PCCs mapped
- **3. IRAM 30 m**
  Line tracers: 12CO/13CO/C18O (2-1) & HCN (1-0), HCO+ (1-0), N2H+ (1-0)
  Status: 30 hrs awarded. 24 PCCs mapped
- **4. Effellsberg 100 m**
  Line tracers: NH3 (1,1) & (2,2)
  Status: 27 hrs awarded, 6 PCCs mapped
- **5. Mopra 22 m**
  Line tracers: N2H+ (1-0), N2D+ (1-0), and so on
  Status: 54 hrs awarded. 30 PCCs observed
- **6. APEX**
  Line tracers: 12CO/13CO/C18O (2-1) & HCN (3-2)
  Status: one proposal approved (30 hrs),10 PCCs observed
- **7. JCMT/SCUBA-2**
  SASSy+Pilot: 80 PCCs mapped
- **8. SMA**
  PGCC G192.32-11.88 mapped
- **9. NANTEN2**
  Line tracers: 12CO (4-3) & (7-6)
  Status: 30 hrs awarded, observations canceled
- **10. JCMT/SCUBA-2**
  Standard Proposal in 2015B has been approved. 100 PGCCs will be observed

PMO 13.7-m observations

Red: 12CO (1-0)
Green: 13CO (1-0)
Blue: C18O (1-0)

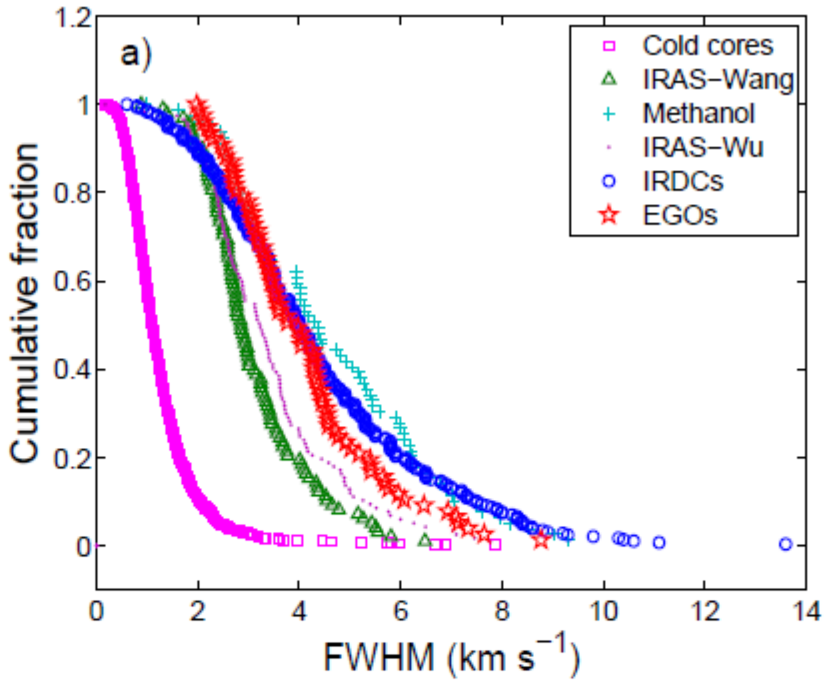


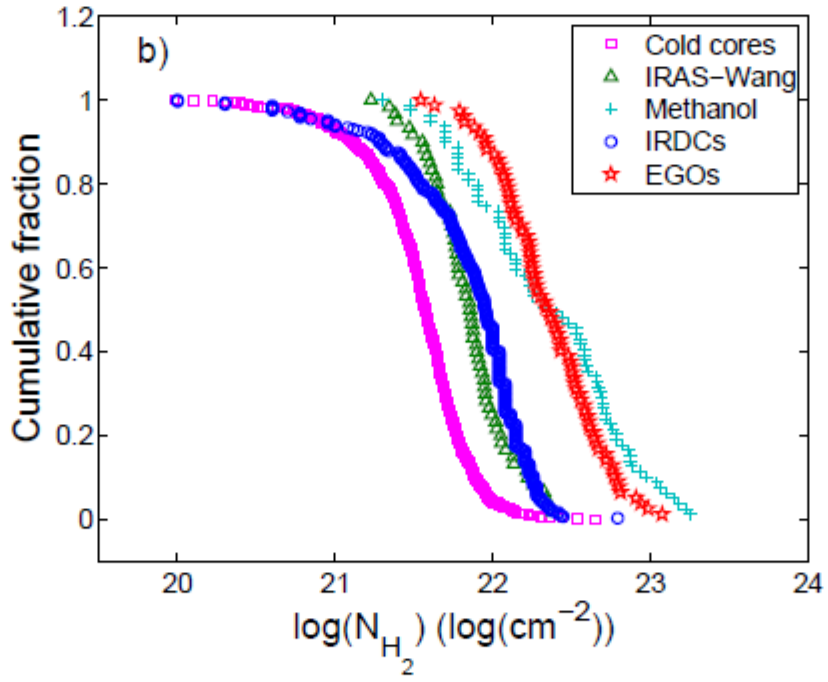
(Wu et al.2012)

Stat	N_{H_2} (10^{21} cm^{-2})	T_{ex} (K)	$\tau(13)$	X_{13}/X_{18}	σ_{NT} (km s^{-1})	σ_{Therm} (km s^{-1})	σ_{3D} (km s^{-1})	$\sigma_{NT}/\sigma_{Therm}$
Number[a]	782	782	782	437	782	782	782	782
Mean	4.4	10.1	0.93	7.0	0.53	0.17	0.98	3.09
std	3.6	2.6	0.56	3.8	0.31	0.02	0.51	1.83

Region	l [°,°]	b [°,°]	Number	N_{H_2} (10^{21} cm^{-2})	T_{ex} (K)	$\tau(13)$	X_{13}/X_{18}	σ_{NT} (km s^{-1})	σ_{Therm} (km s^{-1})	σ_{3D} (km s^{-1})
First quad	[12,100]	[−10,10]	84	5.7(5.1)	9.4(2.4)	1.1(0.9)	5.6(3.3)	0.75(0.60)	0.17(0.02)	1.34(1.02)
Second quad	[98,180]	[−4,10]	70	4.5(3.4)	9.5(2.1)	0.9(0.5)	7.6(3.3)	0.62(0.29)	0.17(0.02)	1.13(0.49)
Third quad	[180,279]	[−4,10]	43	4.7(2.6)	9.1(2.0)	0.7(0.3)	7.0(2.9)	0.73(0.28)	0.17(0.02)	1.31(0.47)
Fourth quad and ctr	[300,15]	[−8,8]	6	4.2(2.6)	9.5(0.9)	0.8(0.4)	4.4(2.3)	0.77(0.83)	0.17(0.01)	1.39(1.42)
Anticenter	[175,210]	[−9,7]	16	4.7(2.1)	9.3(1.7)	0.9(0.3)	7.6(1.1)	0.67(0.24)	0.17(0.02)	1.20(0.39)
Aquila South	[27,40]	[−21,−10]	2	3.1(0.4)	12.8(1.3)	0.9(0.1)	9.0(0.2)	0.24(0.04)	0.20(0.01)	0.54(0.05)
Cephens	[99,143]	[8,22]	87	3.5(1.9)	8.8(1.8)	1.0(0.5)	5.4(2.1)	0.48(0.18)	0.16(0.02)	0.88(0.30)
High Glat		$\|b\| \geqslant 25$	41	3.0(2.0)	10.5(2.0)	0.8(0.5)	11.6(5.5)	0.37(0.17)	0.18(0.02)	0.72(0.26)
Oph-Sgr	[8,40]	[9,24]	9	3.0(1.6)	10.2(2.7)	0.9(0.5)	6.1(2.9)	0.34(0.13)	0.18(0.02)	0.67(0.20)
Ophiuchus	[344,4]	[7,25]	6	5.9(2.0)	15.0(1.2)	1.1(0.1)	7.0(5.6)	0.29(0.07)	0.21(0.01)	0.63(0.10)
Orion	[180,225]	[−25,5]	82	5.8(5.3)	11.1(4.0)	1.0(0.6)	8.1(5.1)	0.55(0.23)	0.18(0.03)	1.02(0.38)
Taurus	[152,180]	[−25,−3]	153	4.2(2.9)	10.3(2.6)	1.0(0.7)	6.2(3.4)	0.45(0.18)	0.18(0.02)	0.85(0.29)
Other			75	3.4(2.4)	10.5(3.3)	0.9(0.7)	7.4(4.4)	0.38(0.20)	0.18(0.03)	0.75(0.31)

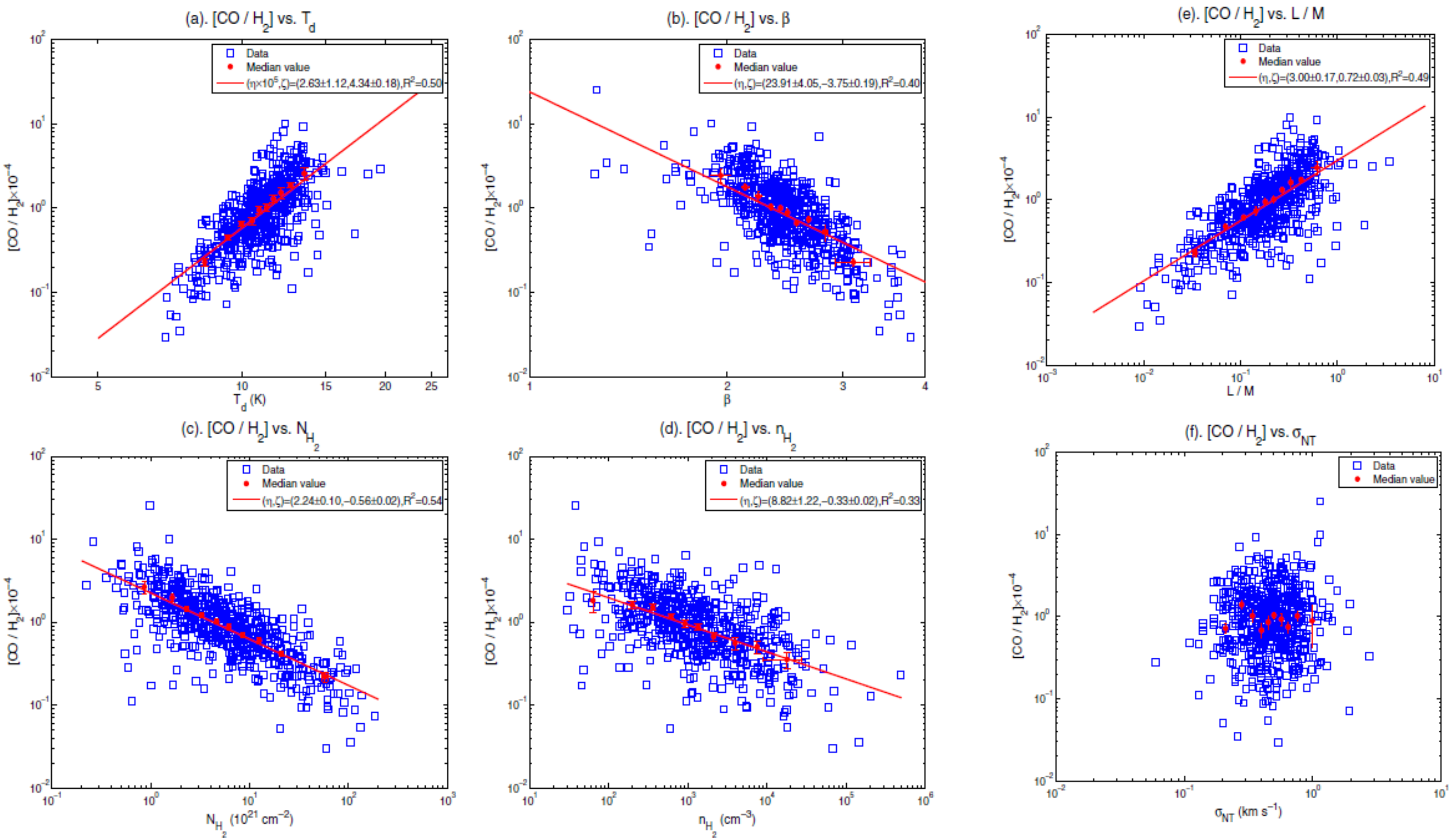
Comparing with other Star forming regions





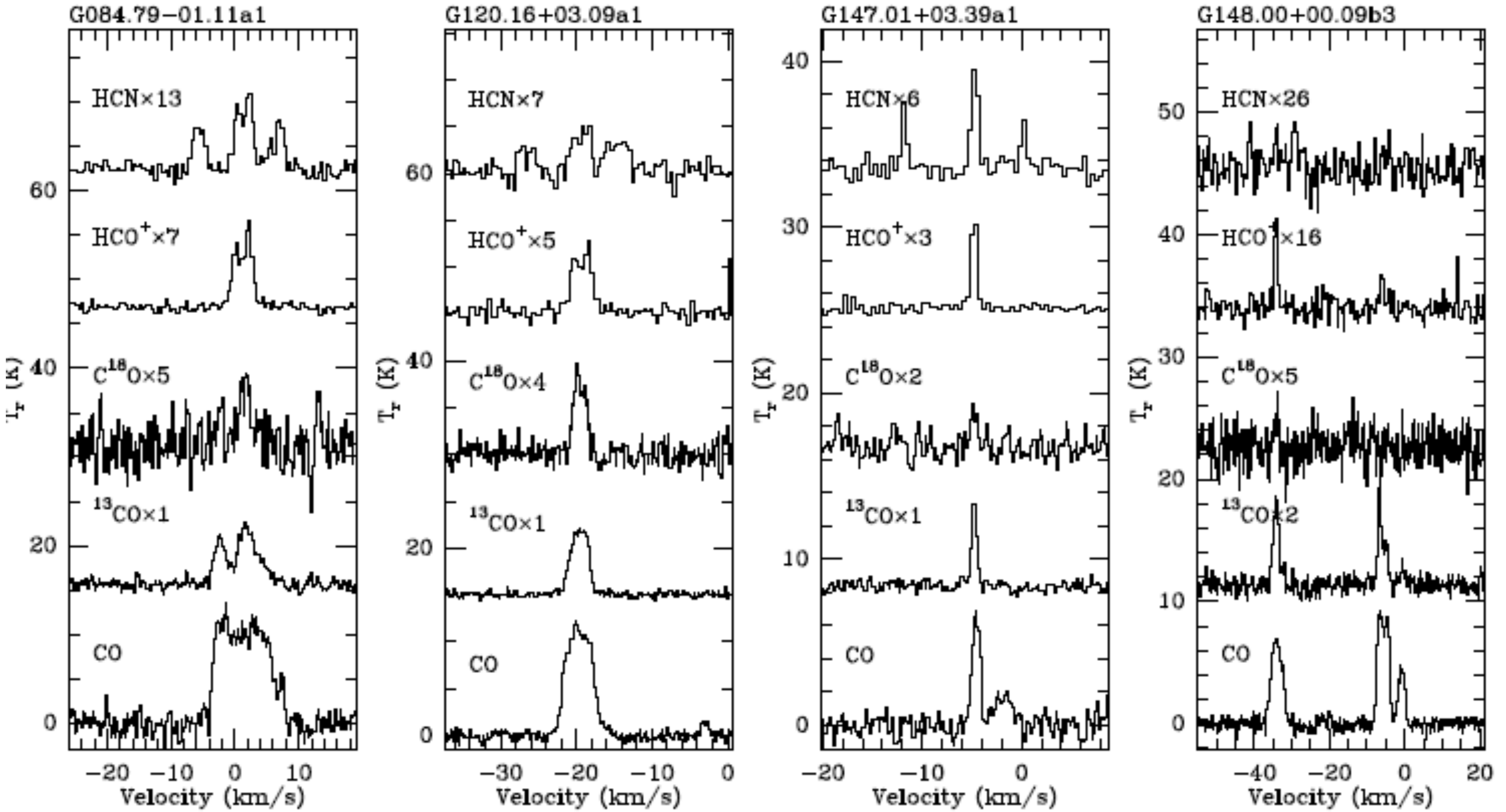
(Wu et al. 2012)

CO abundance as an evolutionary tracer

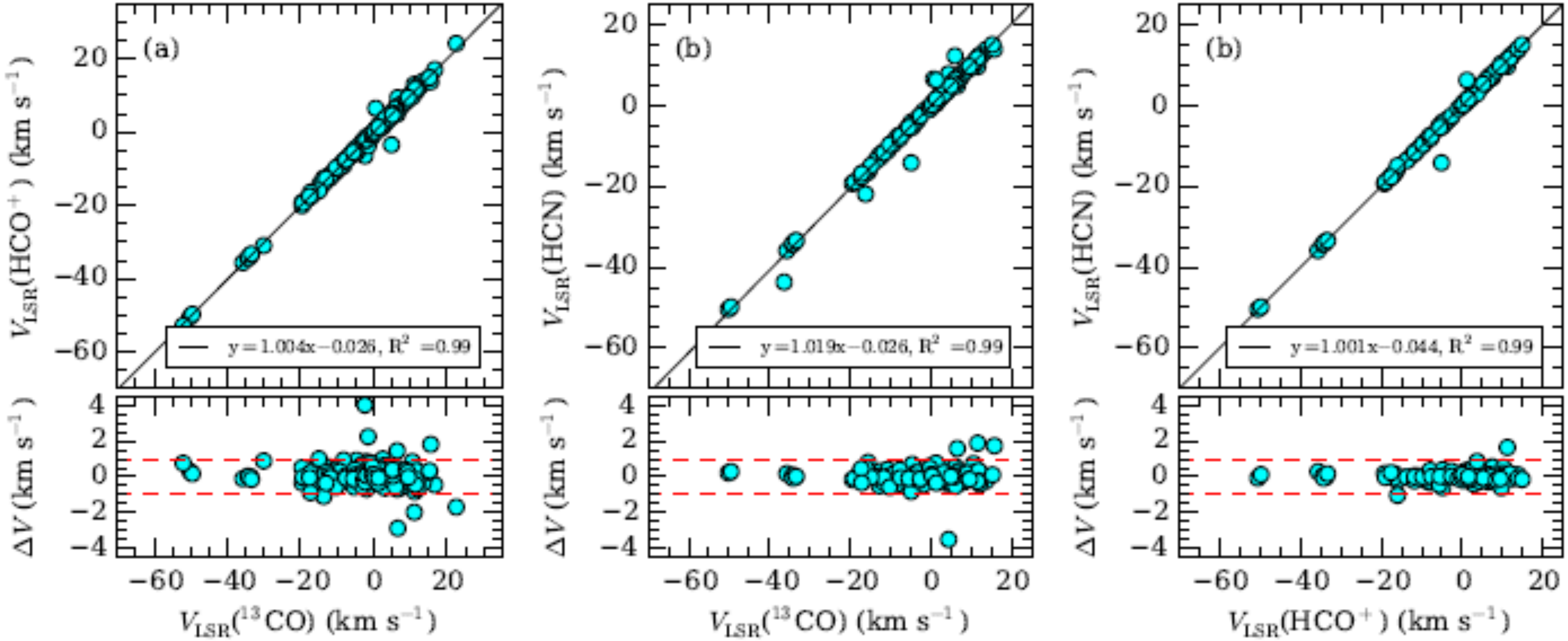


(Liu et al. 2013)

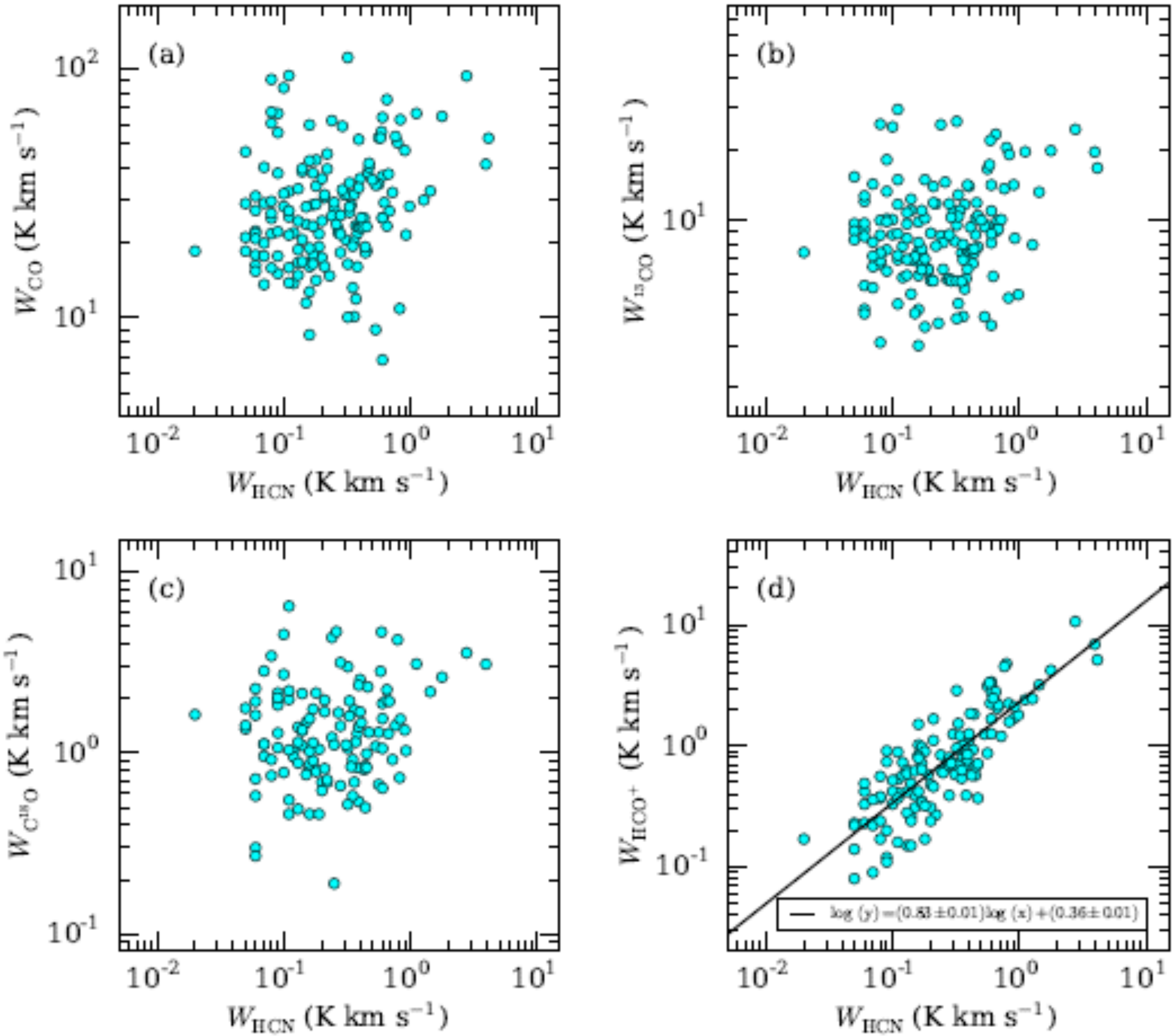
Dense gas in PGCCs (Yuan et al. 2015, in prep)



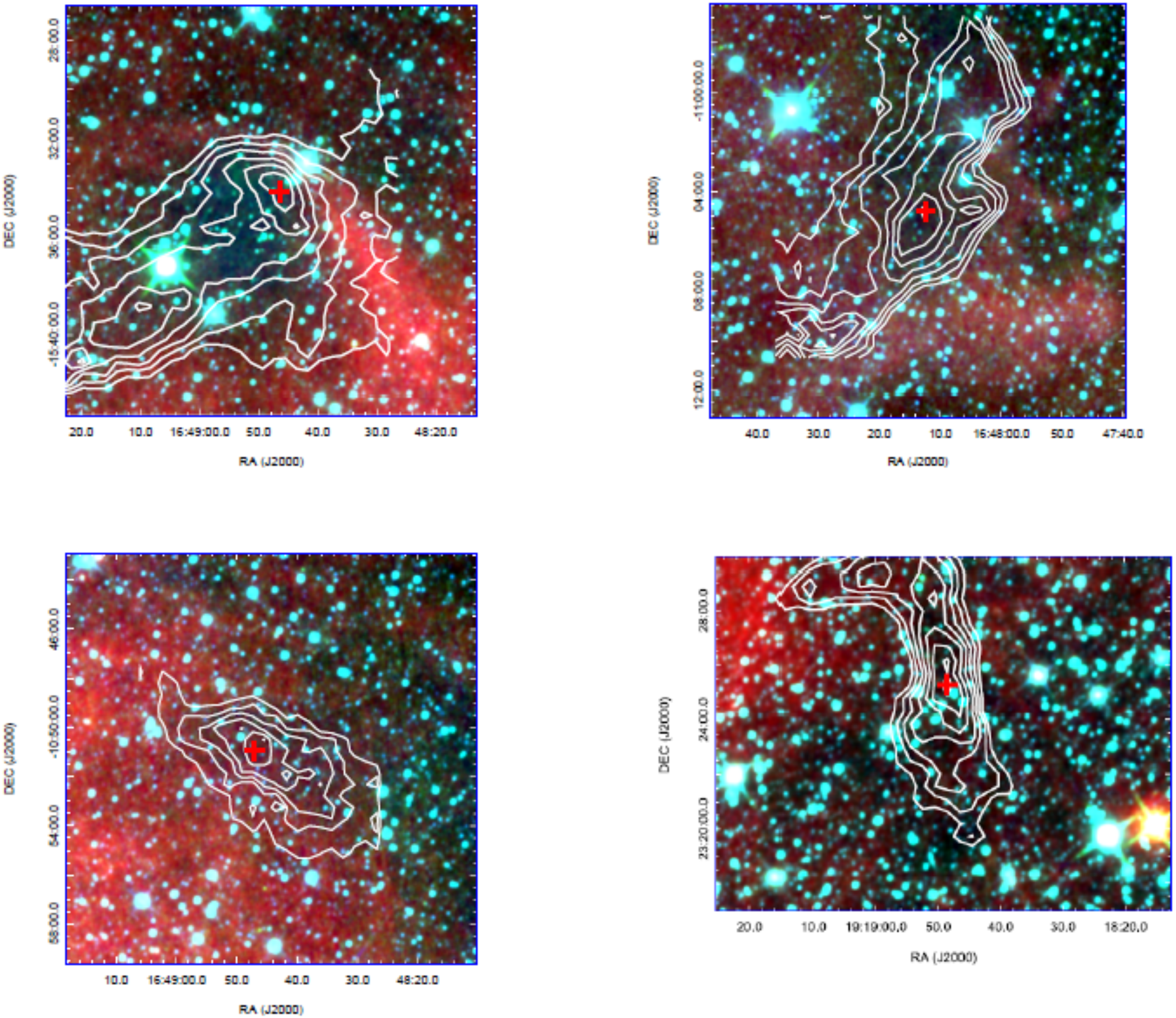
Dense gas in PGCCs (Yuan et al. 2015, in prep)



Dense gas in PGCCs (Yuan et al. 2015, in prep)

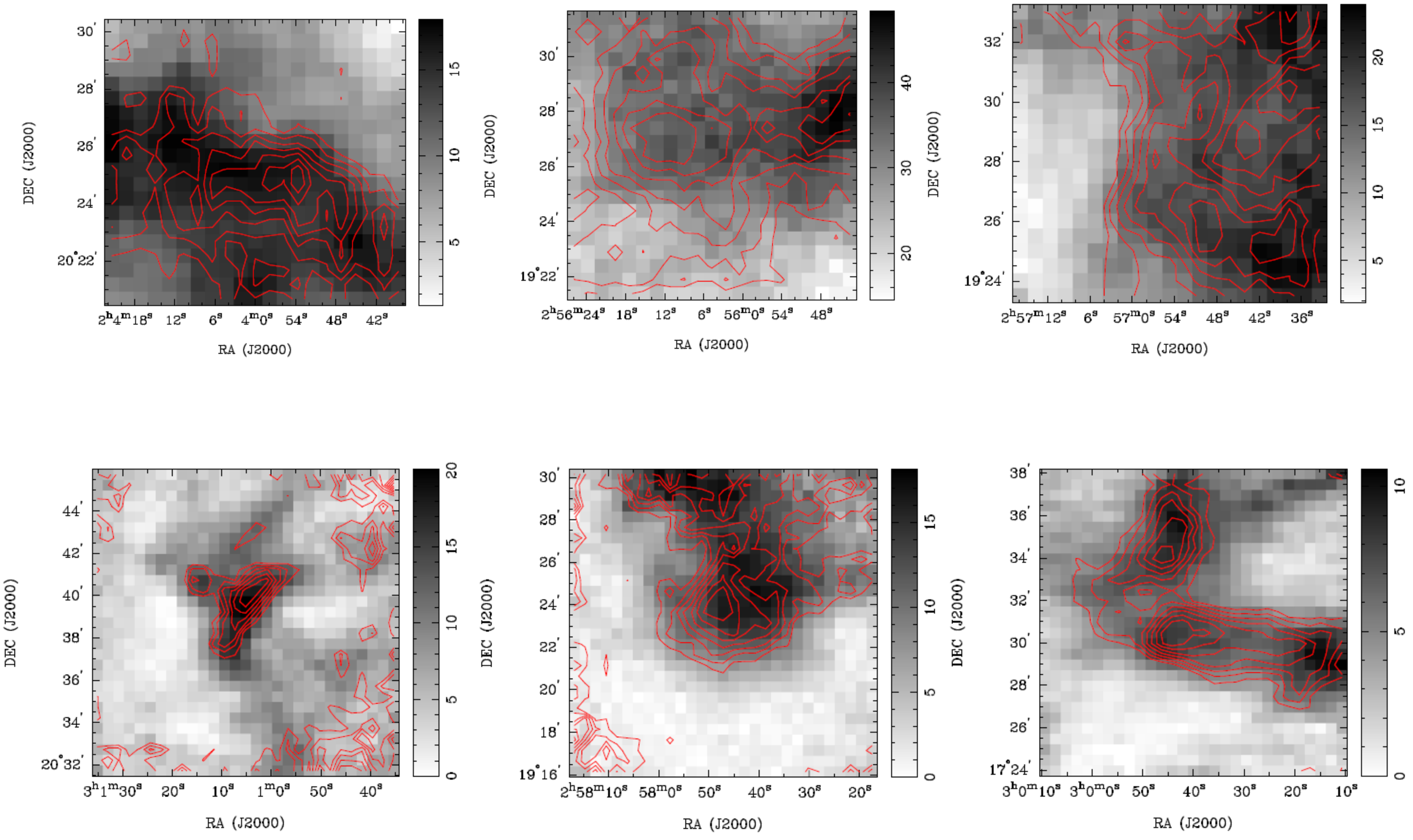


Quiescent clouds

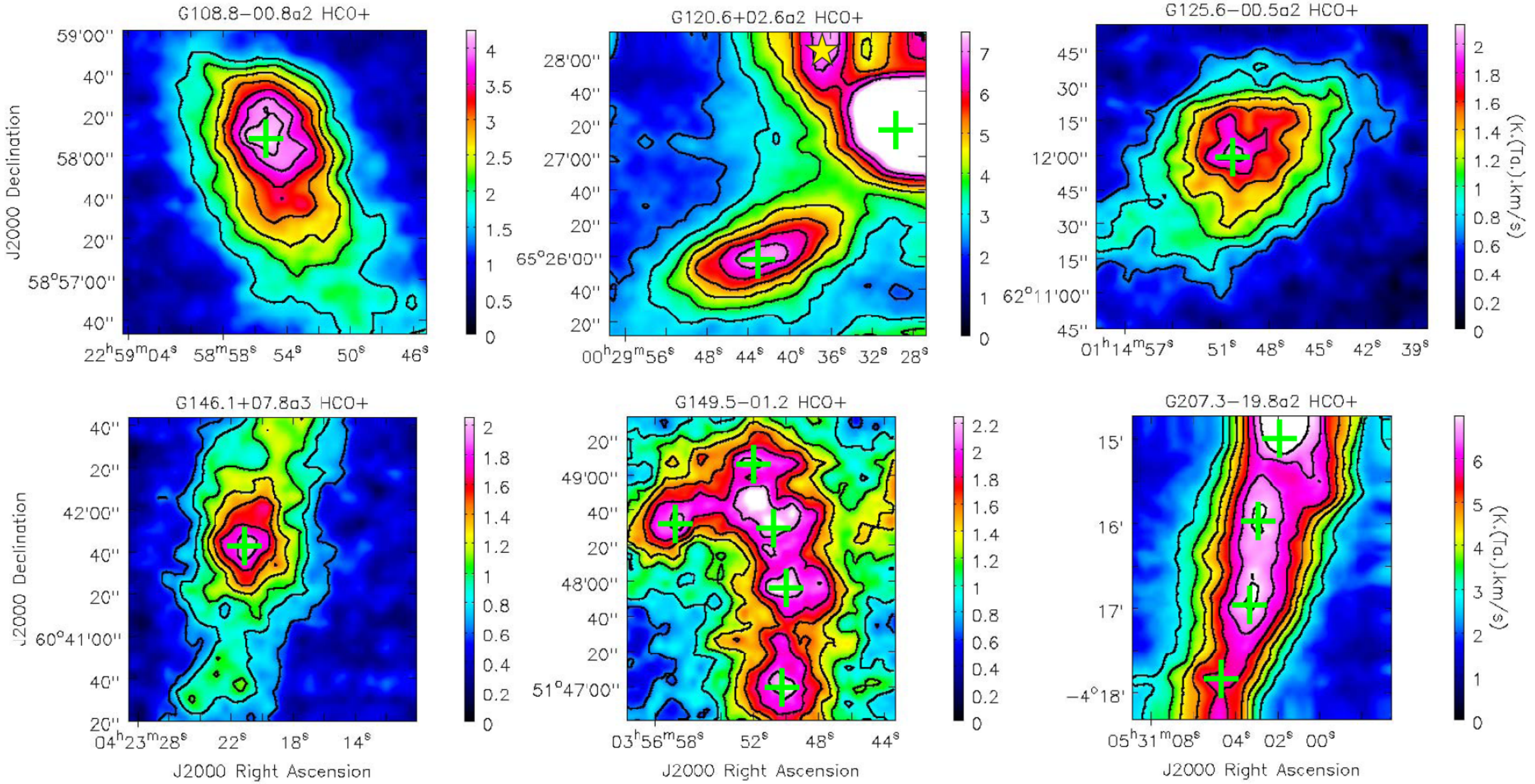


G108

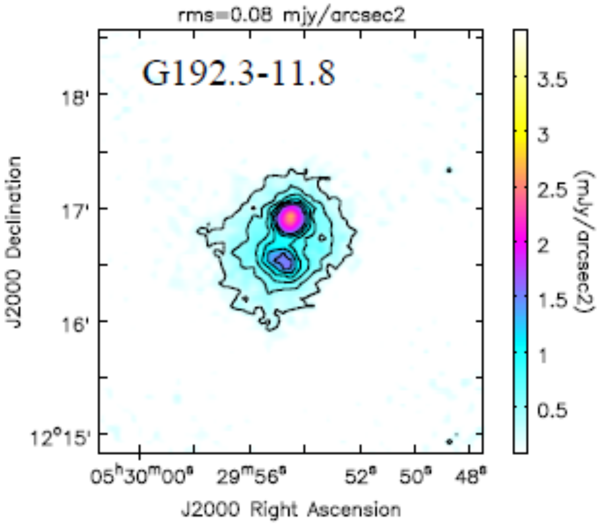
High-Latitude clouds (|b|>30 deg.)

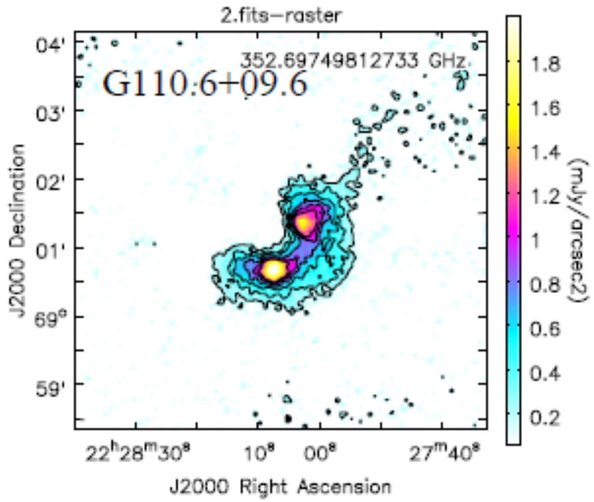


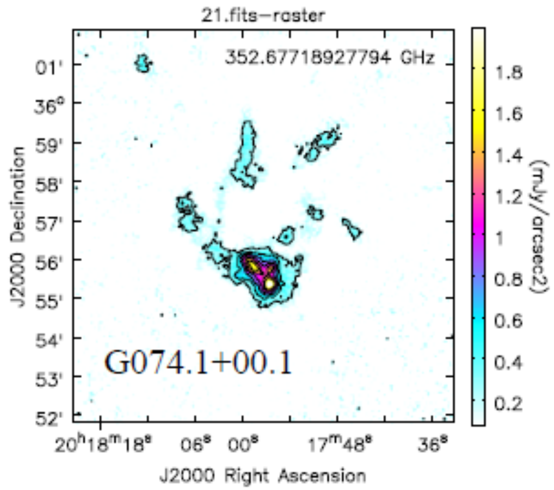
IRAM 30-m observations

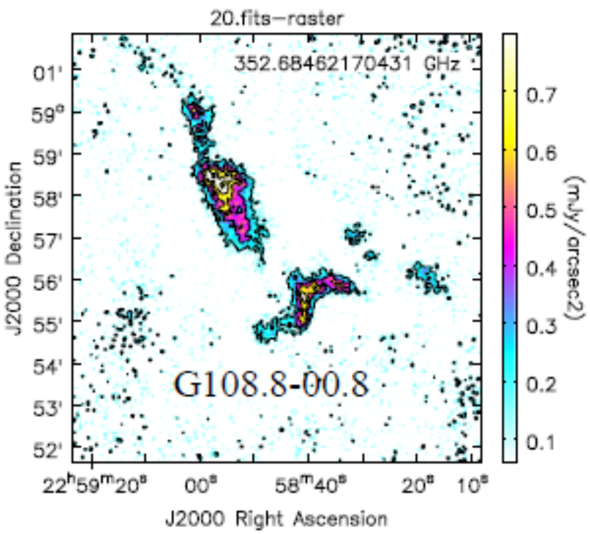


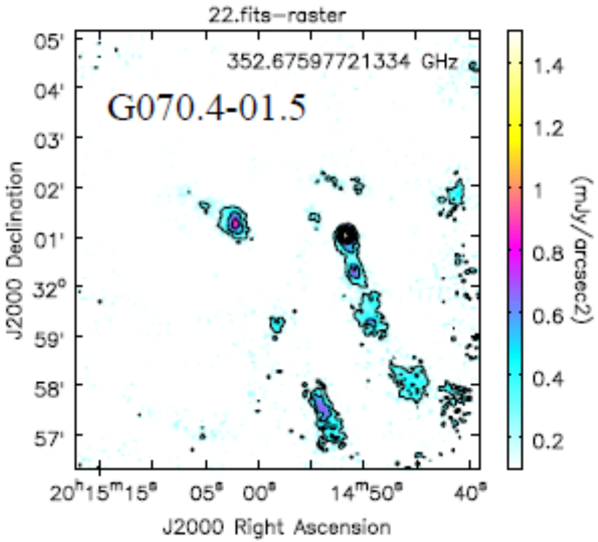
JCMT pilot observations

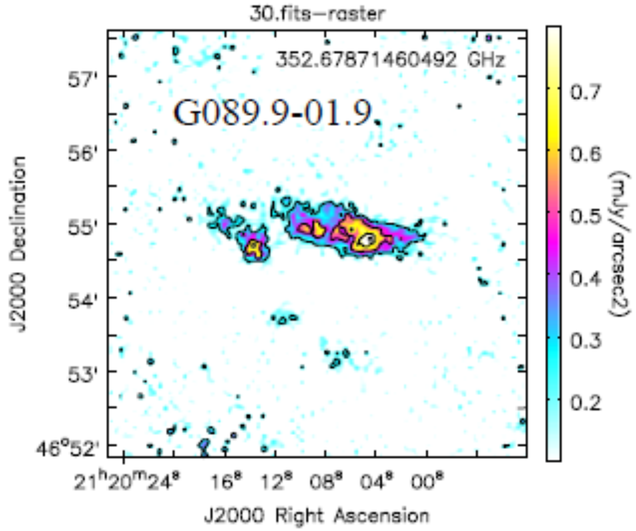




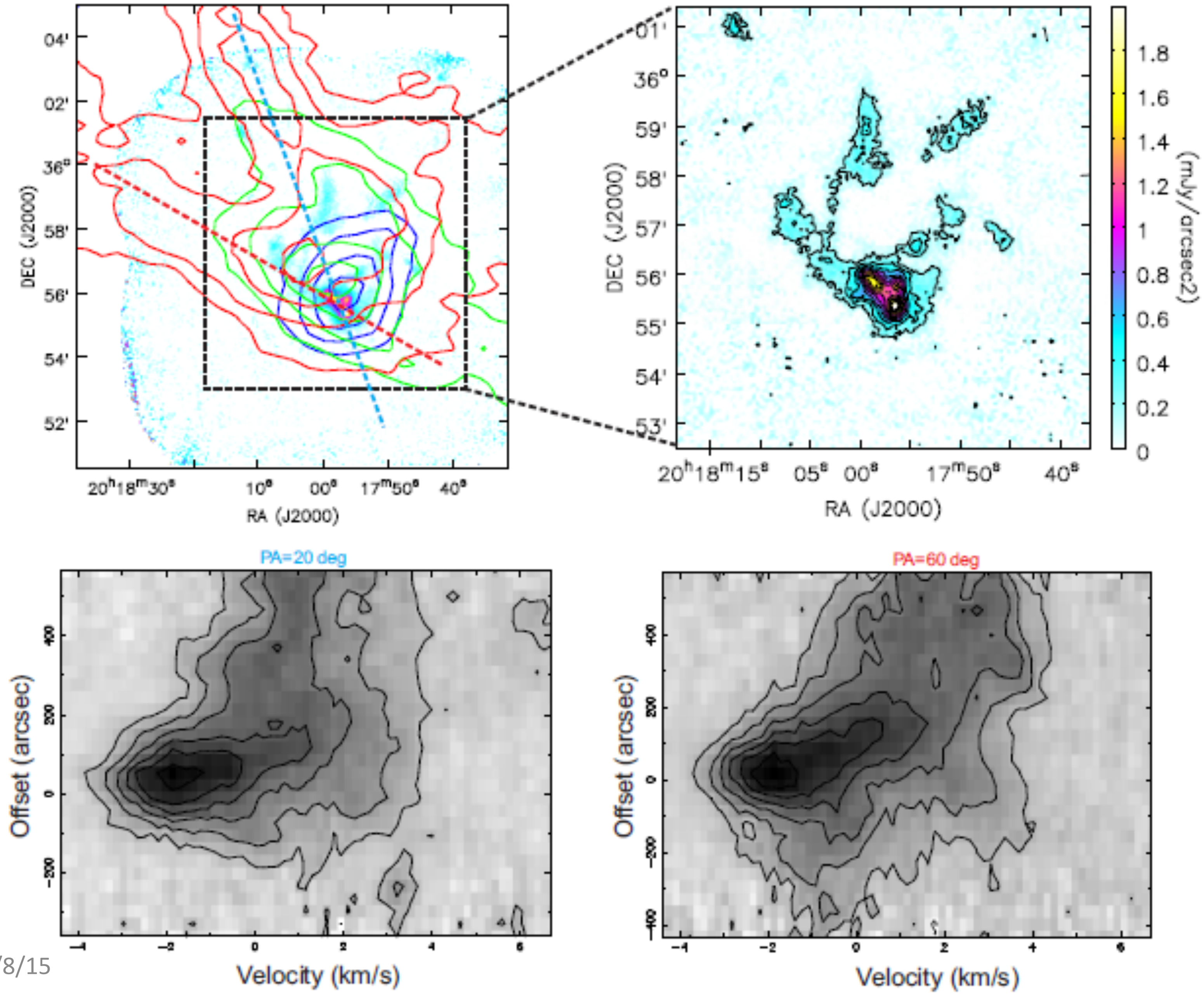




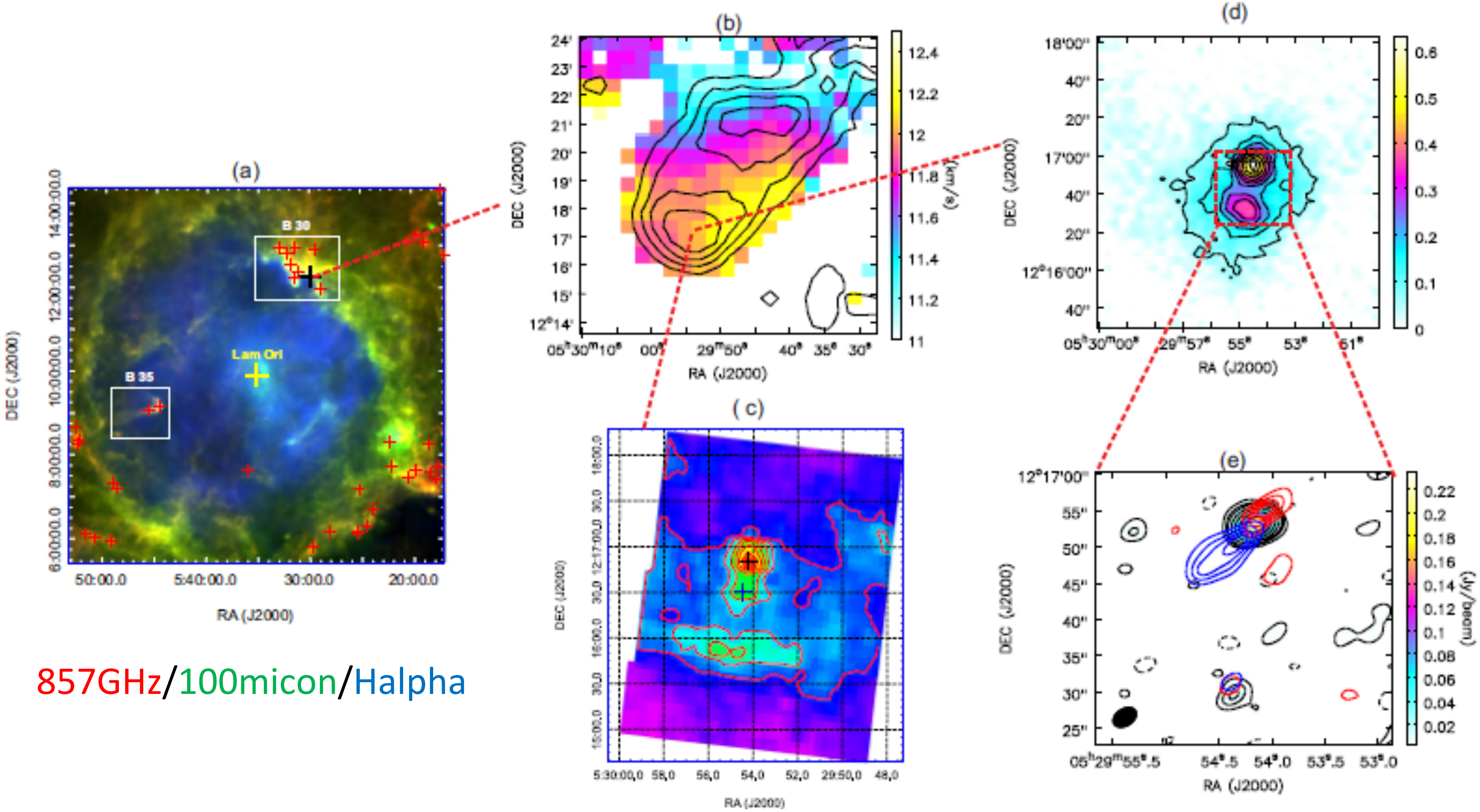




Highlight 1: filament-filament collision



Highlight 2: Stellar feedback



857GHz/100micon/Halpha

Highlight 3: initial fragmentation of filaments and core evolution

Table 1: *Parameters of clumps and cores*

Name	R (pc)	n (10^4 cm^{-3})	M ($M_\odot$)	M_{vir} ($M_\odot$)	M_{Jeans} ($M_\odot$)
			clumps		
HH58	0.19	1.9	37	45	3.5
G207N1	0.23	1.5	54	31	4.0
G207N2	0.24	1.1	44	32	4.6
G207S	0.43	0.6	132	37	6.3
			cores in G207S		
G207S1	0.05	8.6	3.7	4	1.7
G207S2	0.04	13.0	1.9	3	1.3
G207S3	0.02	33.2	1.2	2	0.8
G207S4	0.07	4.7	5.3	6	2.2
G207S5	0.08	4.2	5.0	7	2.4

Summary

- Planck cold clumps correspond to the coldest portion of the ISM where stars form, and can be used to characterize the earliest stages of star formation. In order to make significant progress in understanding the early evolution of molecular clouds and dense cores in a wide range of Galactic environments, we have been proposed a series of surveys with ground-based telescopes.
- Our pilot observations have proved that Planck cold clumps are really suitable and interesting for studies of initial conditions of star formation at their earliest evolutionary stages.

Thanks!