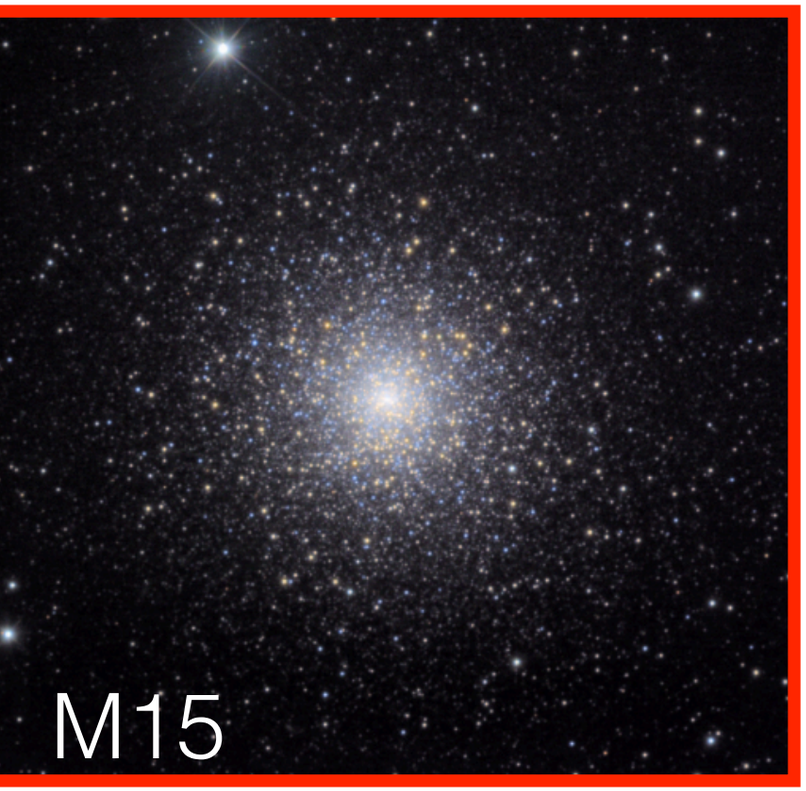
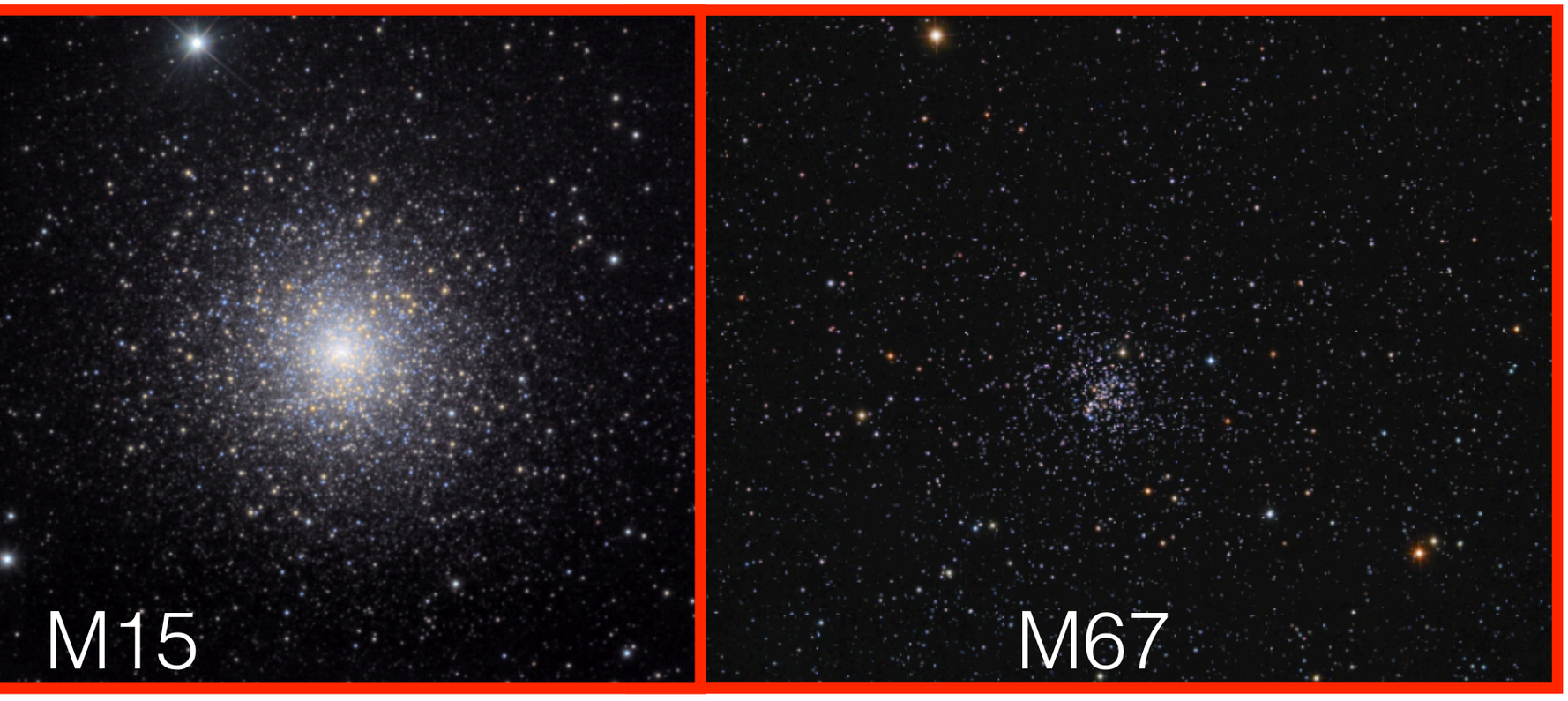
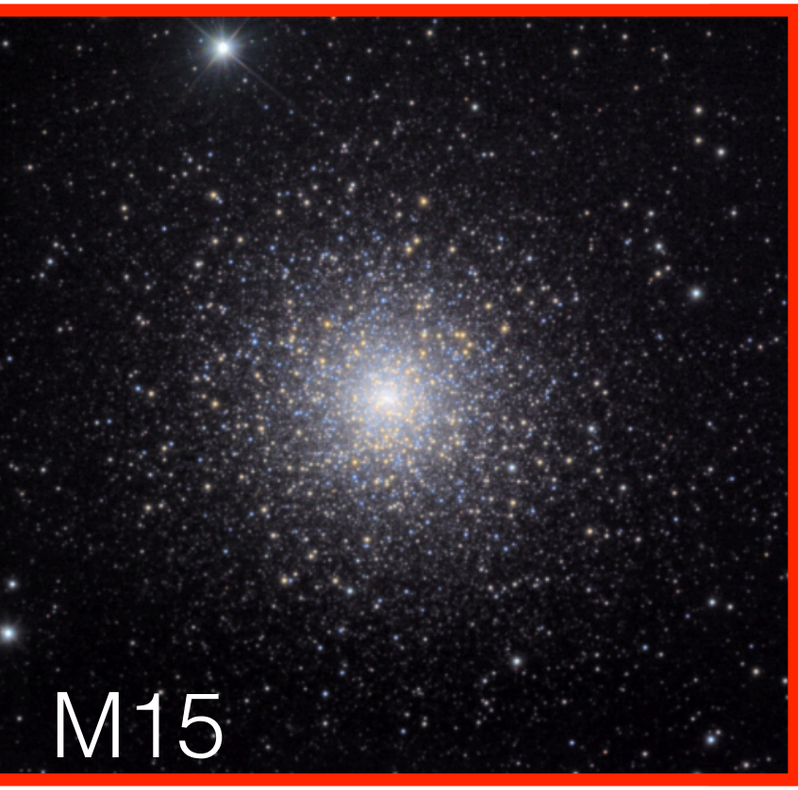
Amelia Stutz
UdeC Departamento de Astronomia

ALMA community day event, March 22nd, 2019

ALMA Science highlights
Star cluster formation: Rosette and ALMA-IMF


M15

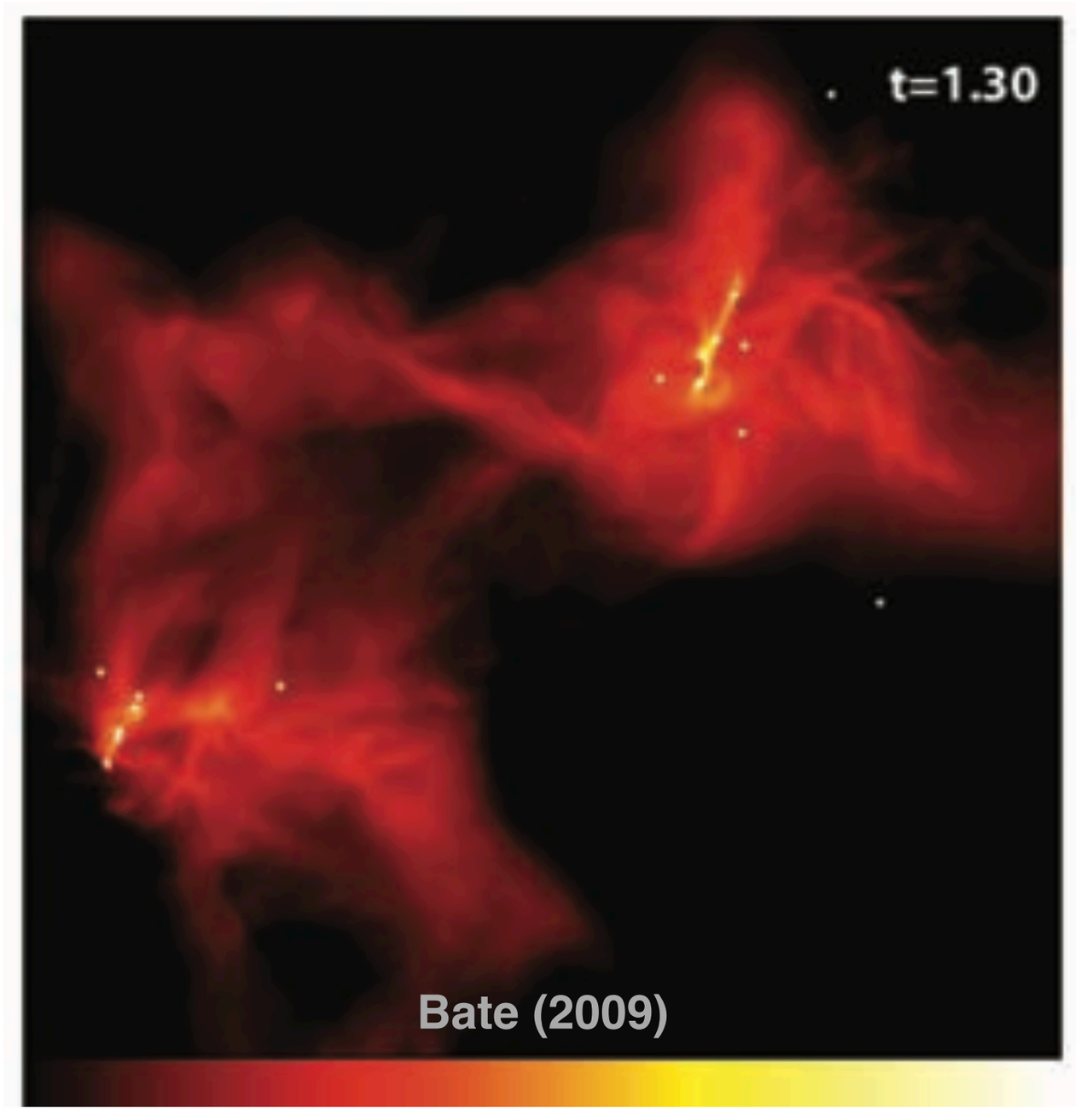

M15
M67

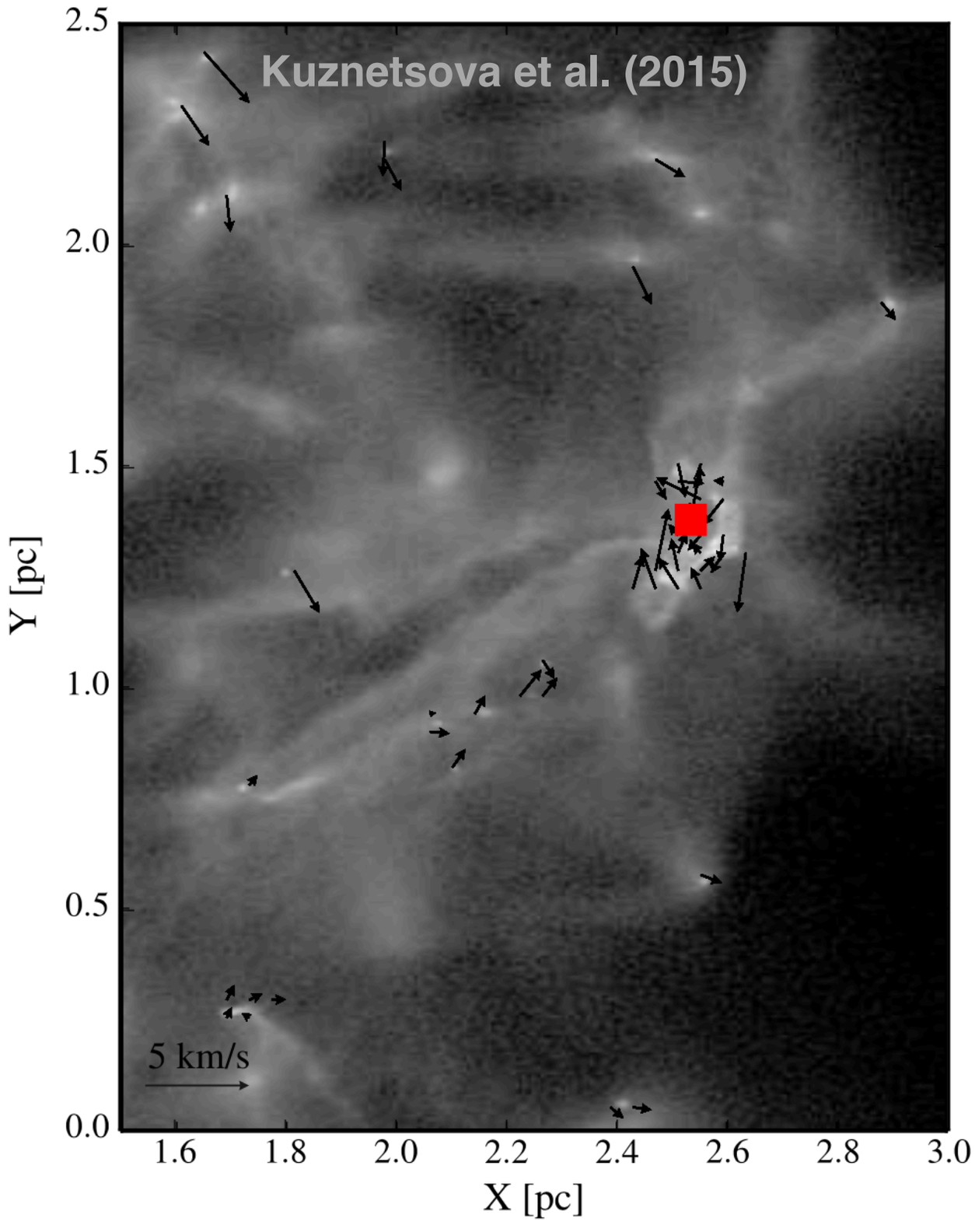

M15


M67

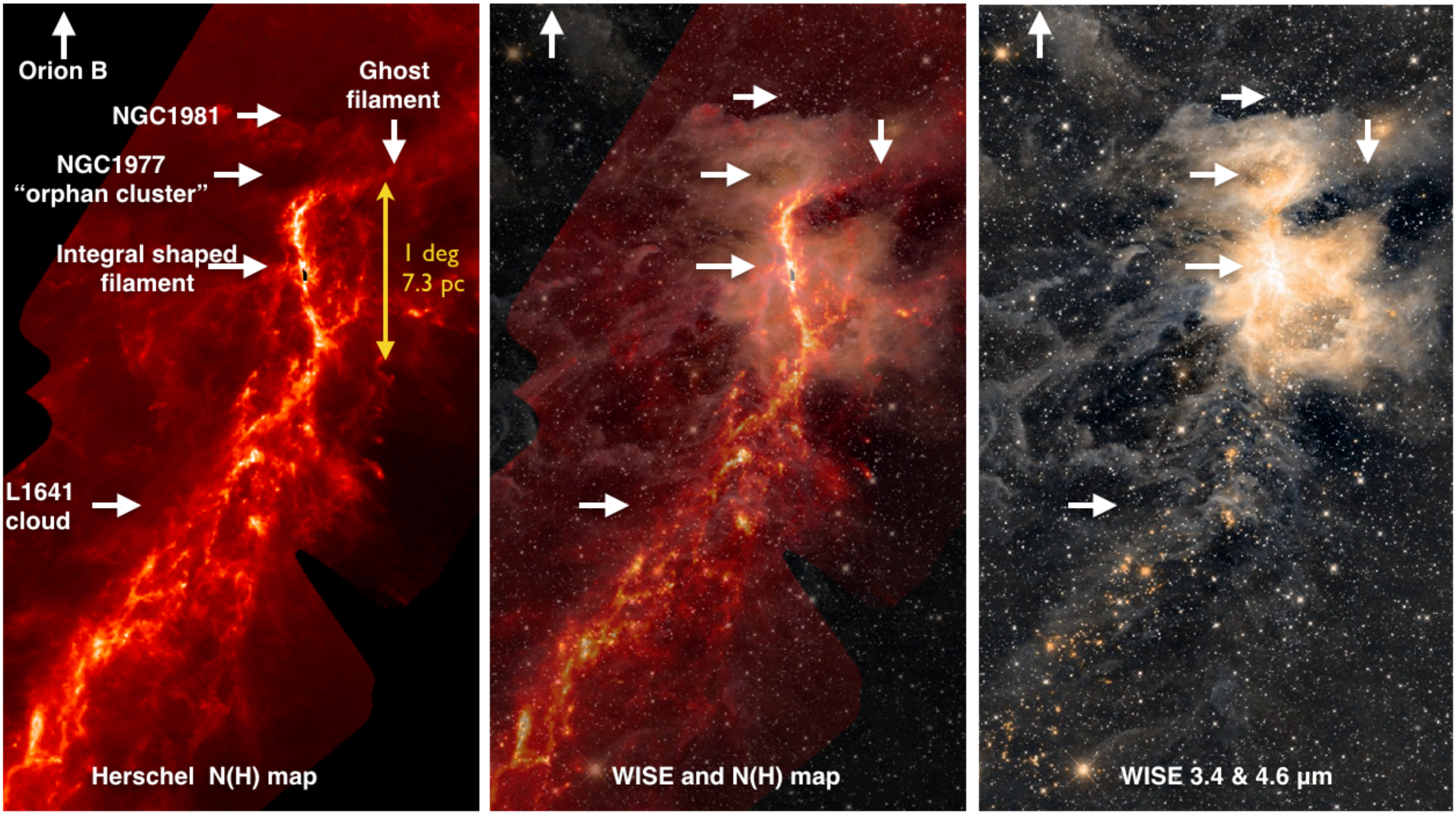

Pleiades

“Cold collapse”-like scenarios



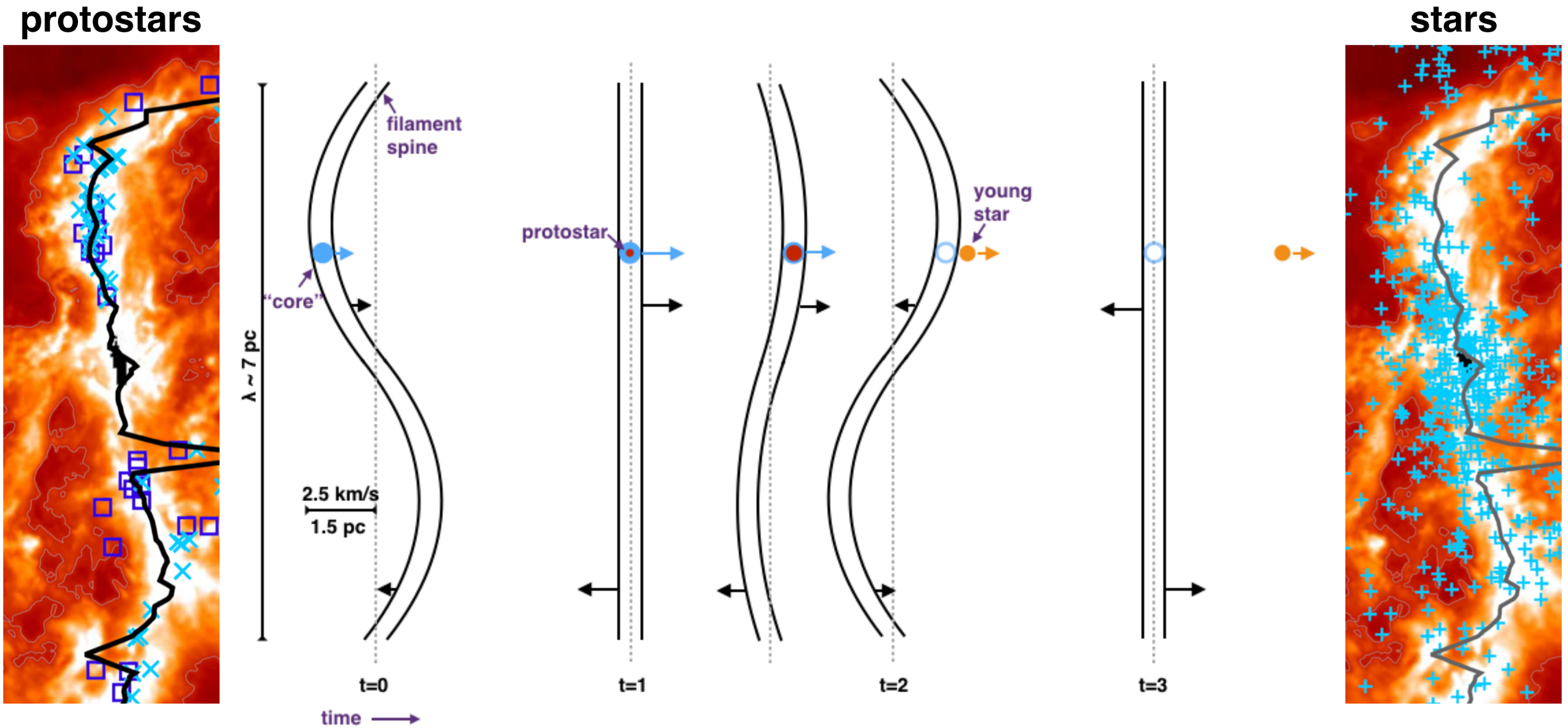


Evidence for a fundamentally different mode of cluster formation: Orion.

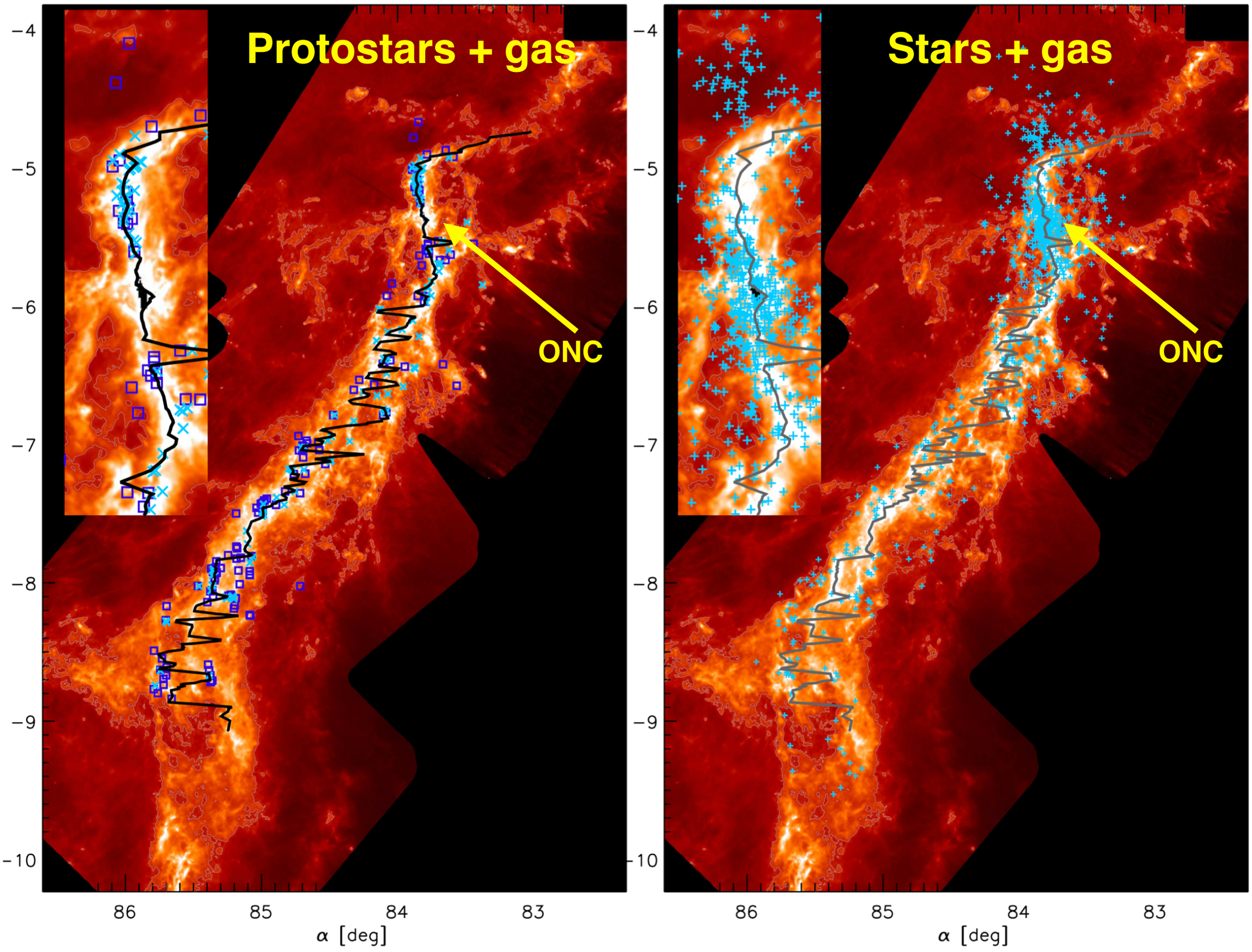


Stutz & Kainulainen (2015), Stutz & Gould (2016), Stutz (2018)

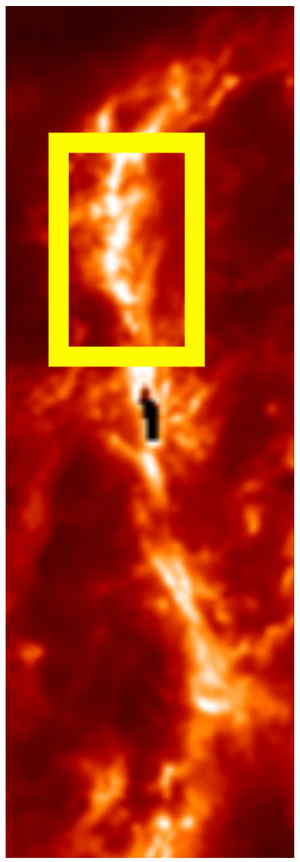
Slingshot: oscillating filament "ejects" stars



Protostars and stars

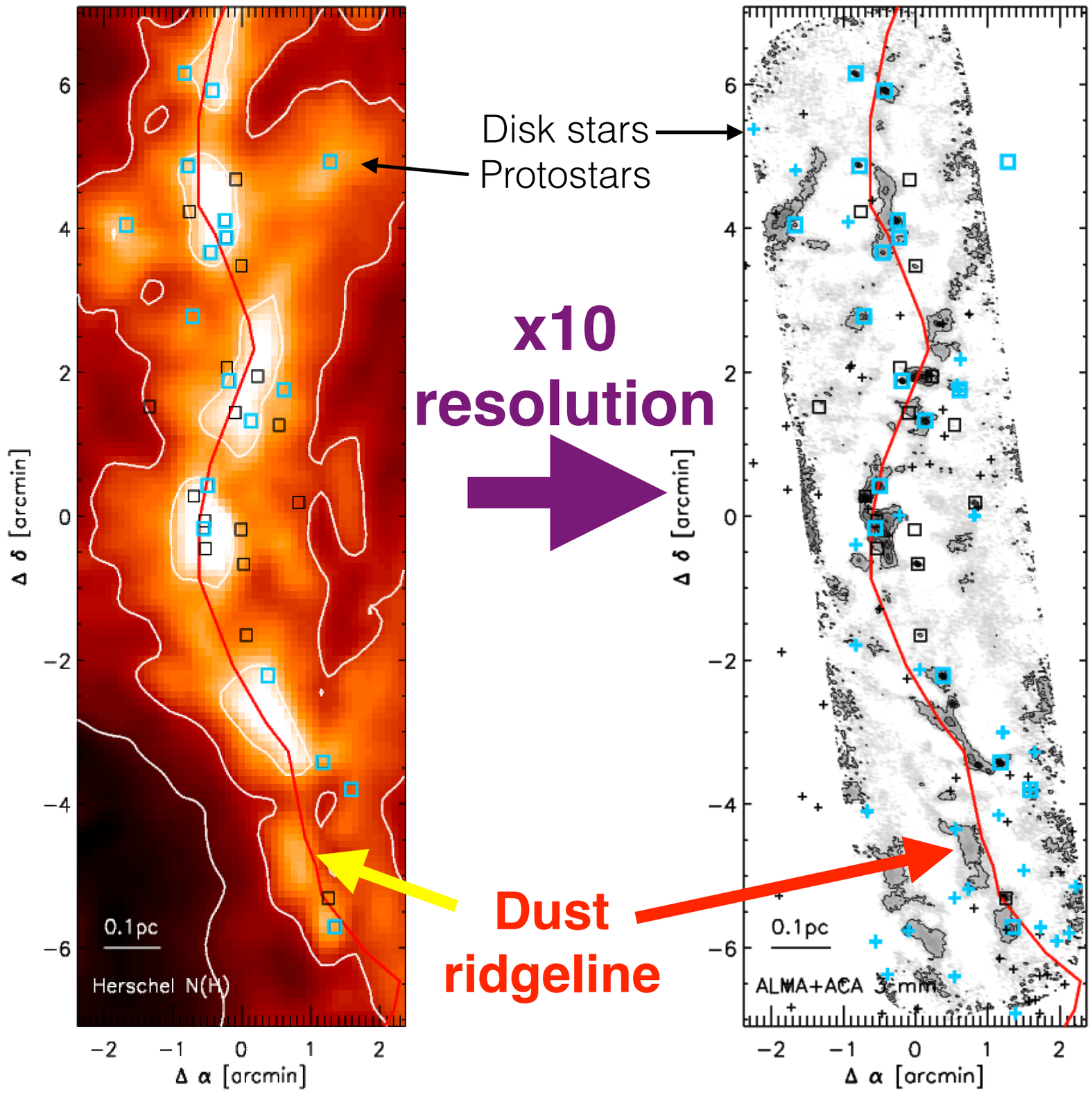


ALMA observations of the ISF: 3mm continuum



Herschel N(H)

ALMA 3mm

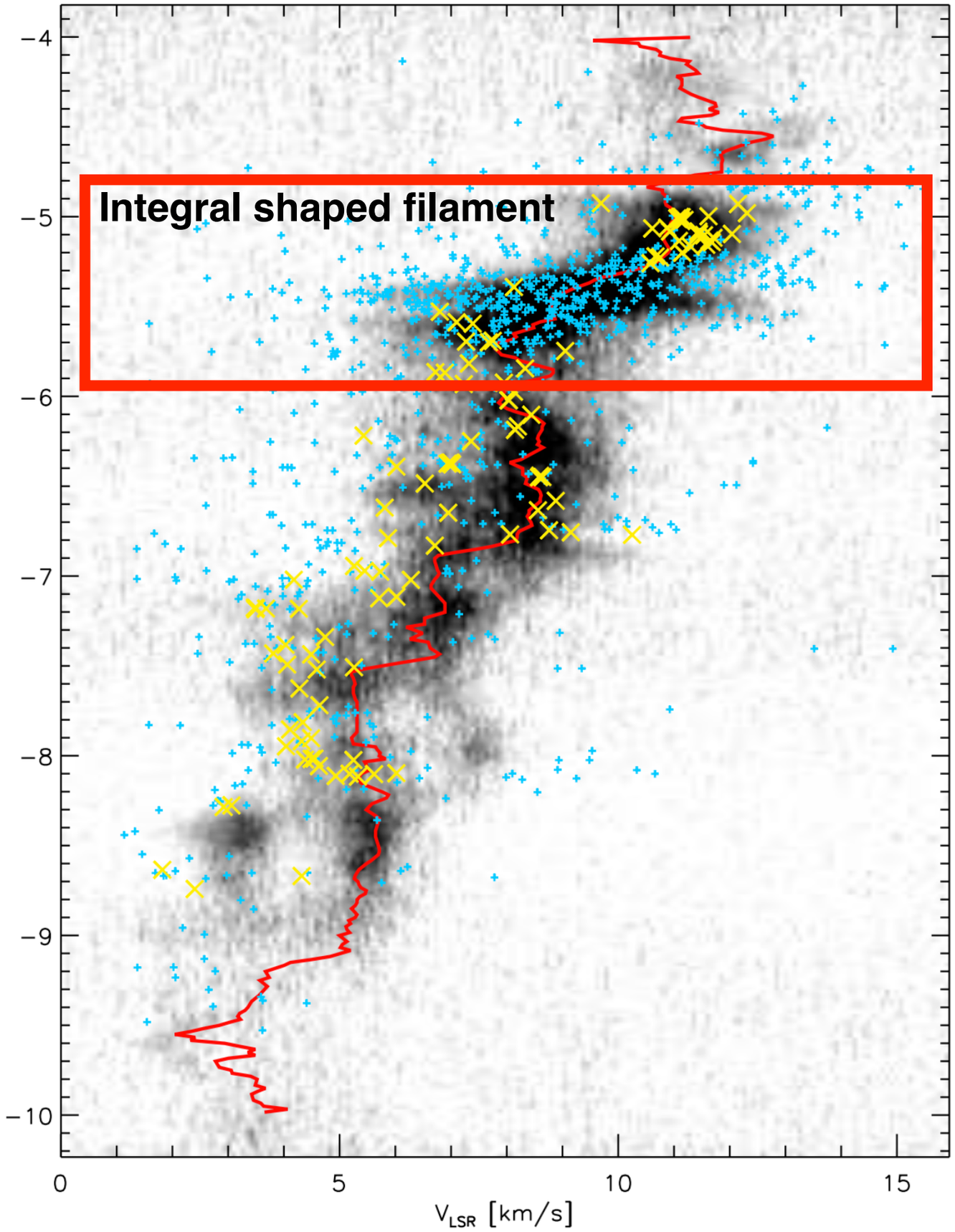


ALMA:

- sub-filaments on ridgeline
- protostars are on filaments
- disk stars are off filaments
- Kainulainen+2017:
  ➡confirmation of Slingshot
- Fragmentation properties (core spacings) not a stringent test of physical conditions

Kainulanen, Stutz et al. (2017)

Kinematics of gas, protostars, and stars



gas: ^{13}CO(2-1) (Nishimura+2015)

velocity ridgeline: line with maximum CO emission as a function of Dec.

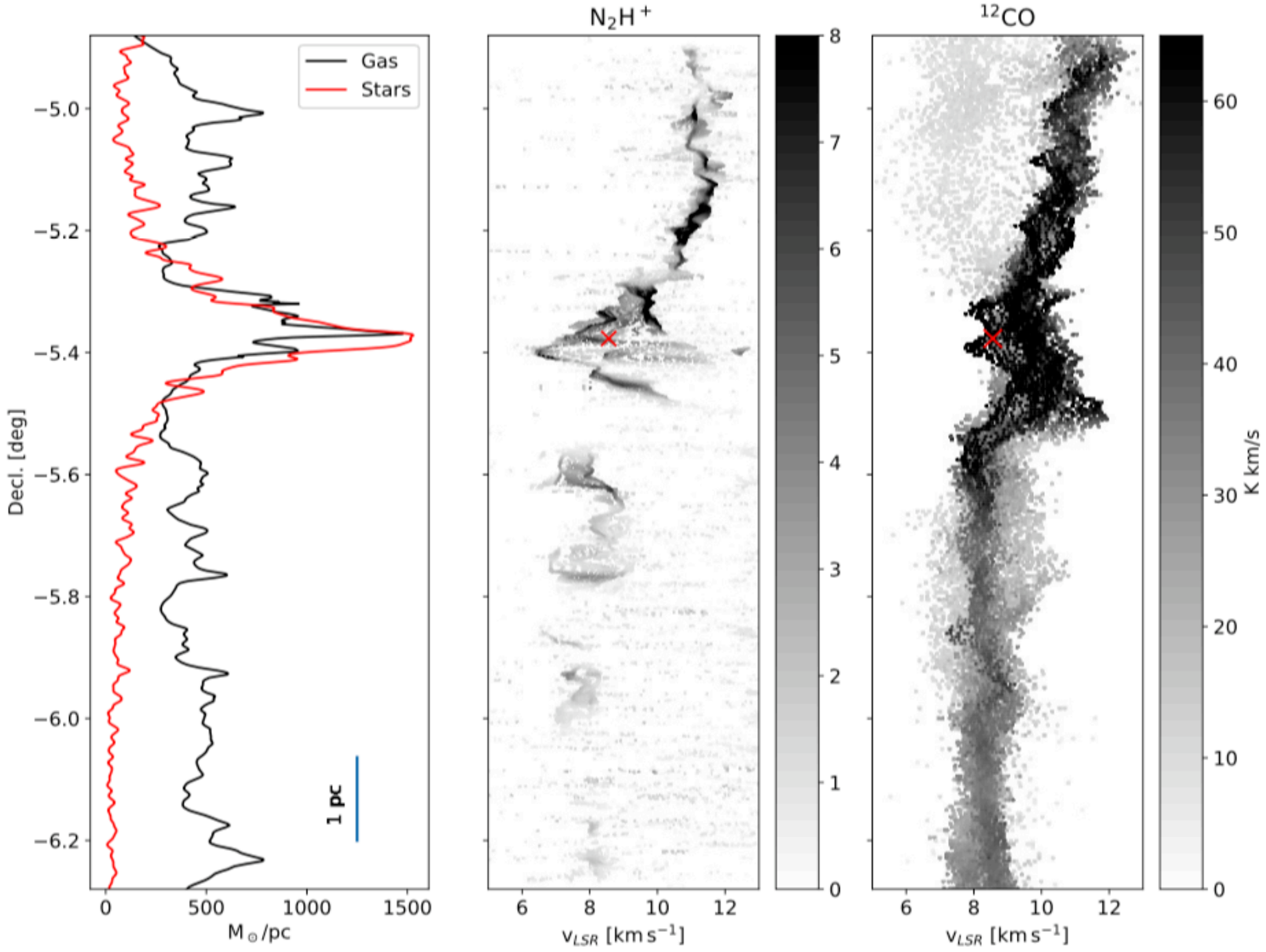
stars with disks: APOGEE near-IR spectroscopy

protostars: NH_3 (and HC_5N)

protostars — Spitzer & Herschel protostars from the Herschel Orion Protostar Survey (HOPS; **Furlan+2016, Stutz+2013**)

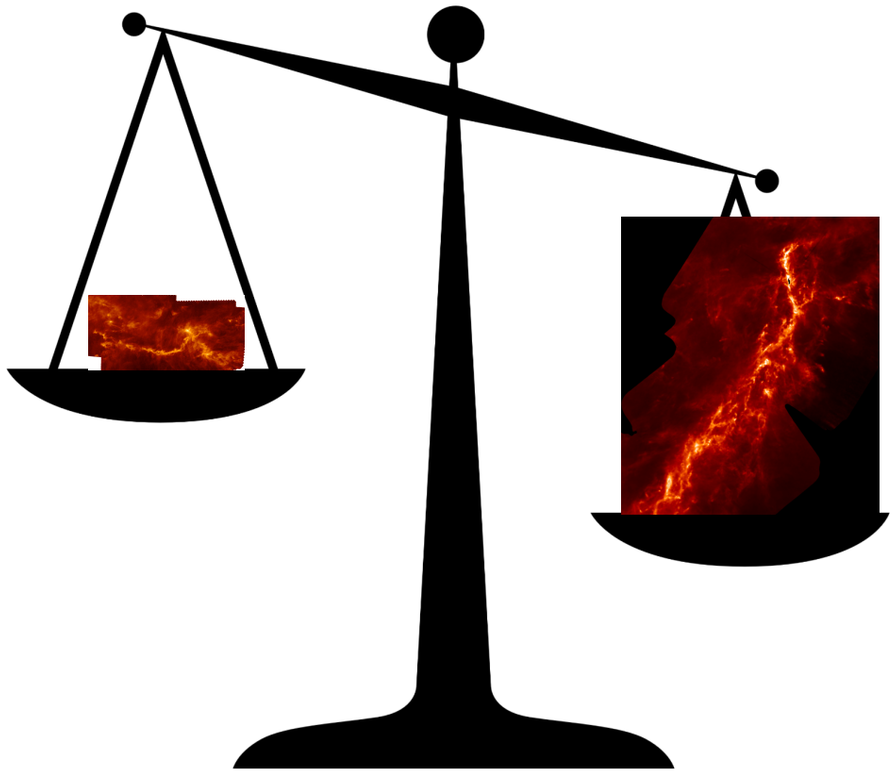
stars — Spitzer PMS stars with disks (from **Megeath+2012** catalog), so called “Class II Young Stellar Objects (YSOs)”. Da Rio+2016 for APOGEE spectroscopy.

Gas velocities: "twistings and turnings" and ripped filaments



Gonzalez-Lobos et al. (in prep.)

Cluster formation: key open questions

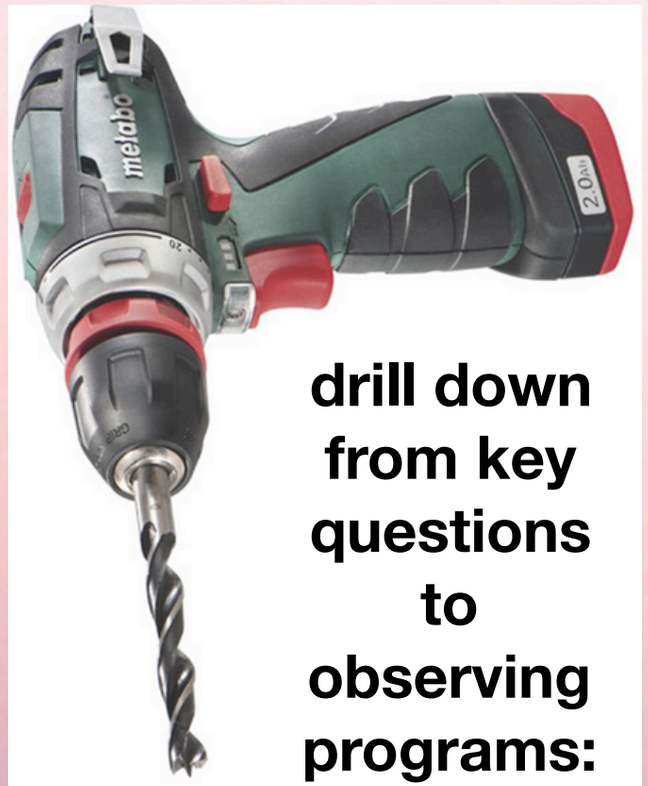


Mass

Does cluster outcome depend on parent cloud mass (larger clusters from larger clouds?)?
Does the IMF depend on cloud mass or other cloud characteristics?
Do the roles of turbulence, B-fields, and “feedback” change with cloud mass / gravitational potential?
Do more massive clouds have longer lifetimes?

Timescales

When is the IMF established? In the core phase?
Is the IMF time-variant? Do high mass stars form first?
What is the role of “feedback” in destroying clouds?
What are the dynamical evolution timescales for the gas and forming stars?
How quickly does turbulence “disipate” at the bottom of dense gas potentials that are forming clusters?



drill down from key questions to observing programs:

Two ALMA programs:

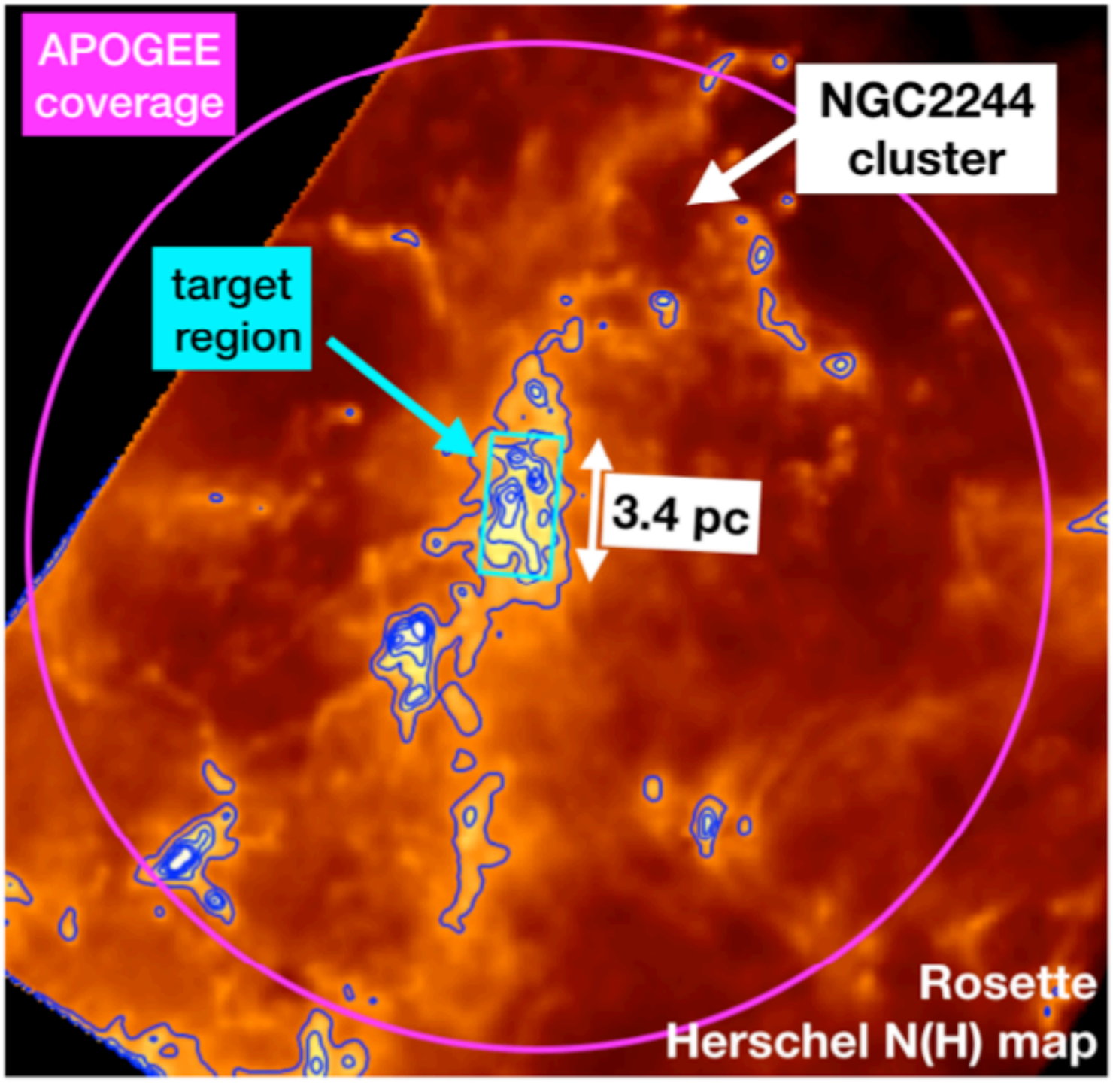
1. **The Rosette protocluster (P.I. Stutz)**
2. **ALMA-IMF Large Program (P.I. Motte)**

The Rosette protocluster

Image credit: Jean-Charles Cuillandre (CFHT) & Giovanni Anselmi (Coelum), MegaPrime Camera

Detail of the Rosette:
Submm Herschel color composite

The Rosette protocluster



Summary: measure the dense gas distribution and radial velocities (RV) in the Rosette young embedded protocluster (d=1.4 kpc).

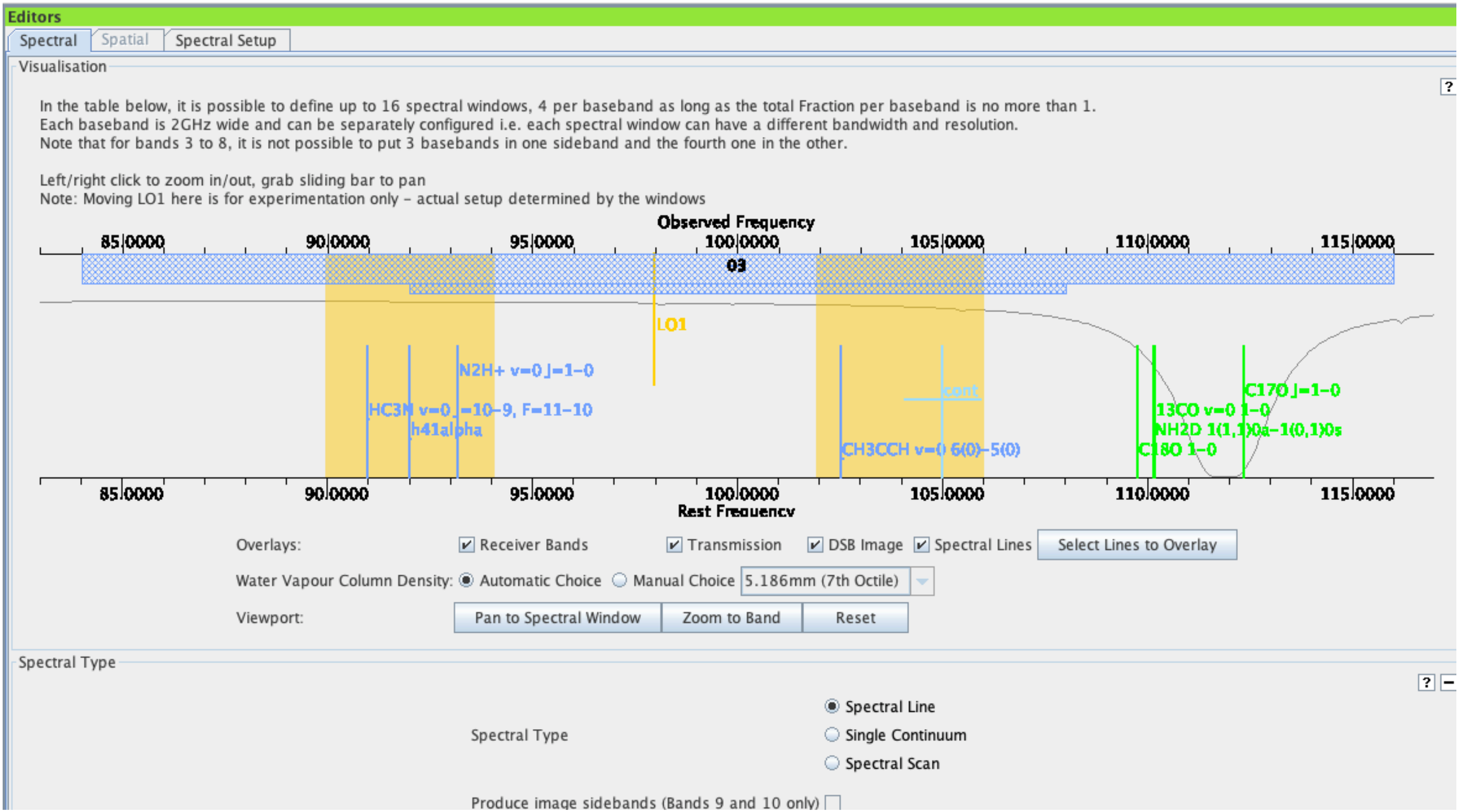
Observed **N_2H^+ (1-0) ACA+TP in Band 3 (1 mm) down to a physical resolution of ~ 0.084 pc (~ 18 kAU or 12.5")** over an area of 1.7 × 3.4 pc^2 (250" × 500").

Our proposed observations trace high N(H) regions. In combination with our multi-wavelength data-set, including APOGEE2-S near-IR spectroscopy of young stars, our goal is to use the N_2H^+ line emission in this embedded protocluster to ultimately distinguish between several radically different theoretical scenarios proposed to explain star cluster formation.

The Rosette Band 3 setups

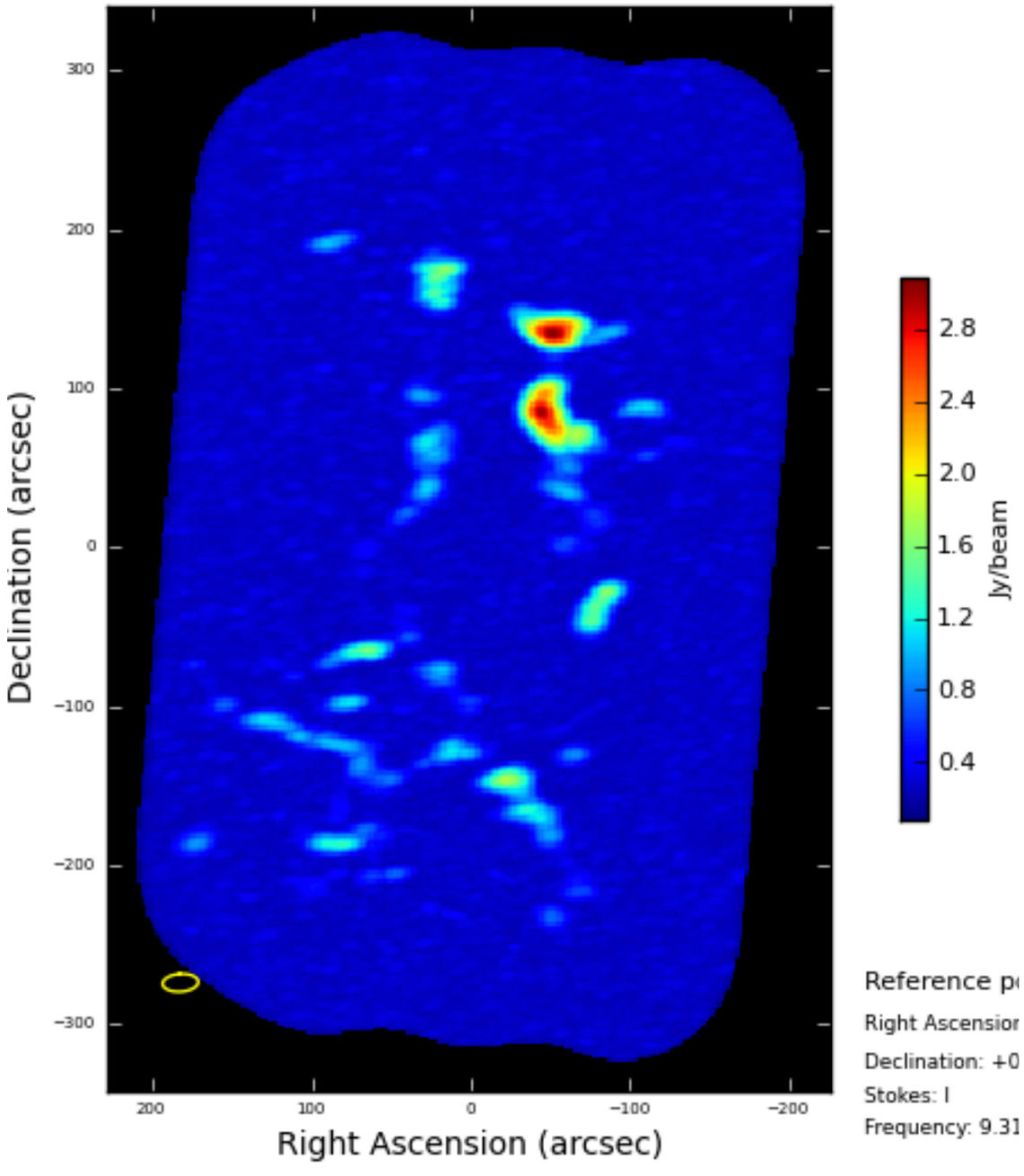
Real ID	Virtual ID	Name	Type	Frequency (TOPO)			Bandwidth (TOPO)	Transitions
				Start	Centre	End		
16	16	X428912546#ALMA_RB_03#BB_1#SW-01	FDM	93.131 GHz	93.162 GHz	93.194 GHz	62.500 MHz	N2H__v_0_J_1_0(ID=3925982)
18	18	X428912546#ALMA_RB_03#BB_2#SW-01	FDM	91.968 GHz	91.999 GHz	92.030 GHz	62.500 MHz	h41alpha(ID=0)
20	20	X428912546#ALMA_RB_03#BB_2#SW-02	FDM	90.937 GHz	90.968 GHz	91.000 GHz	62.500 MHz	HC3N_v_0_J_10_9__F_11_10(ID=4095046)
22	22	X428912546#ALMA_RB_03#BB_3#SW-01	FDM	102.473 GHz	102.536 GHz	102.598 GHz	125.000 MHz	CH3CCH_v_0_6_0__5_0_(ID=4192430)
24	24	X428912546#ALMA_RB_03#BB_4#SW-01	TDM	103.988 GHz	104.988 GHz	105.988 GHz	2.000 GHz	cont(ID=0)

The Rosette Band 3 Spectral setup

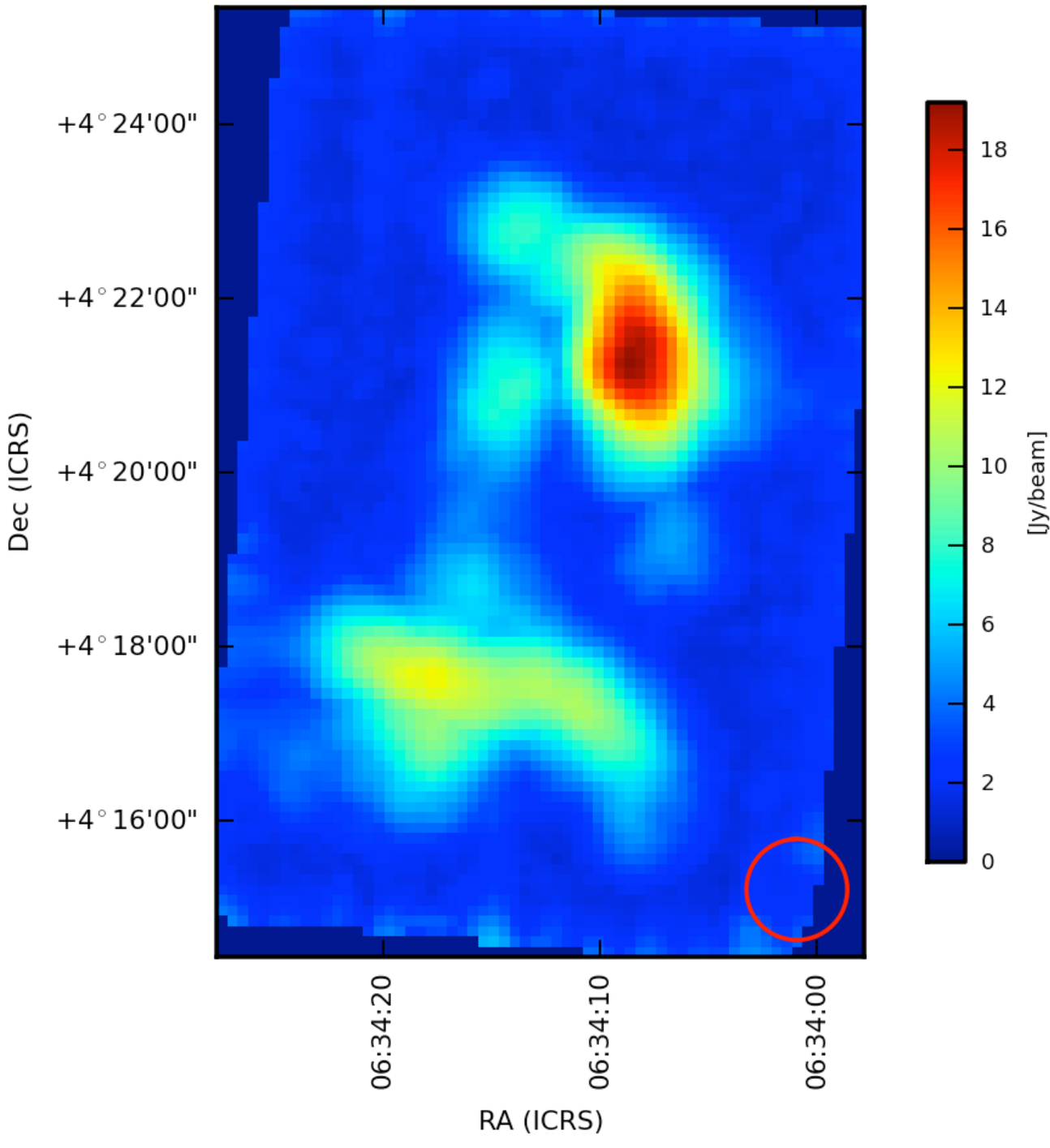


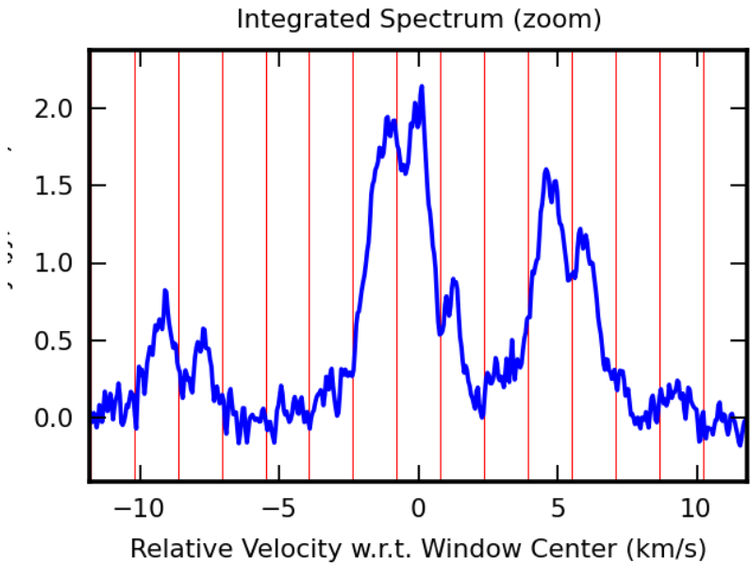
The Rosette Band 3 N2H+

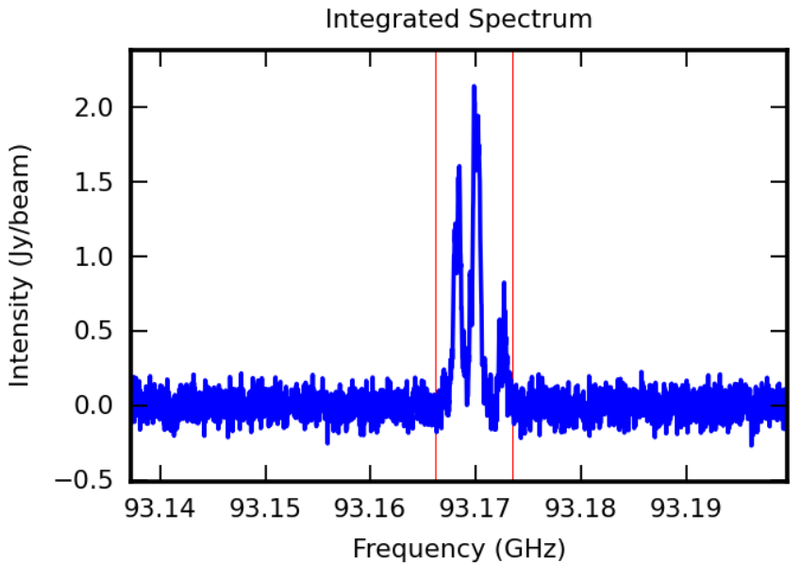
ACA

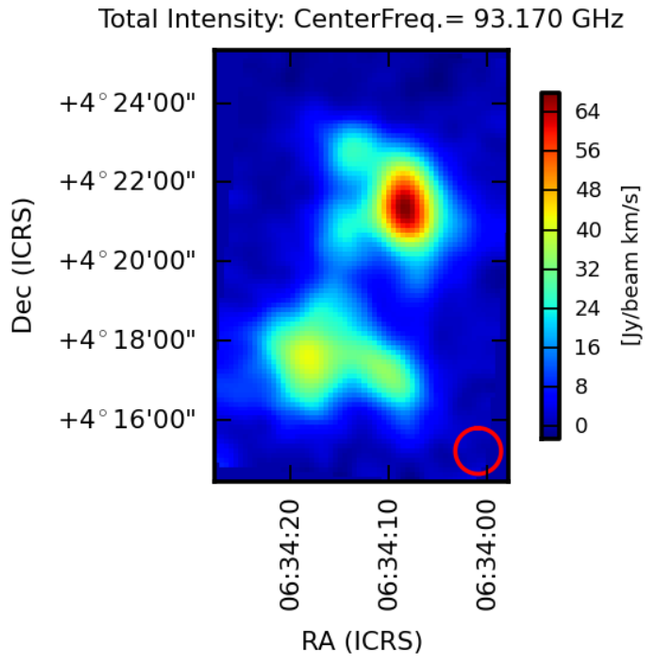


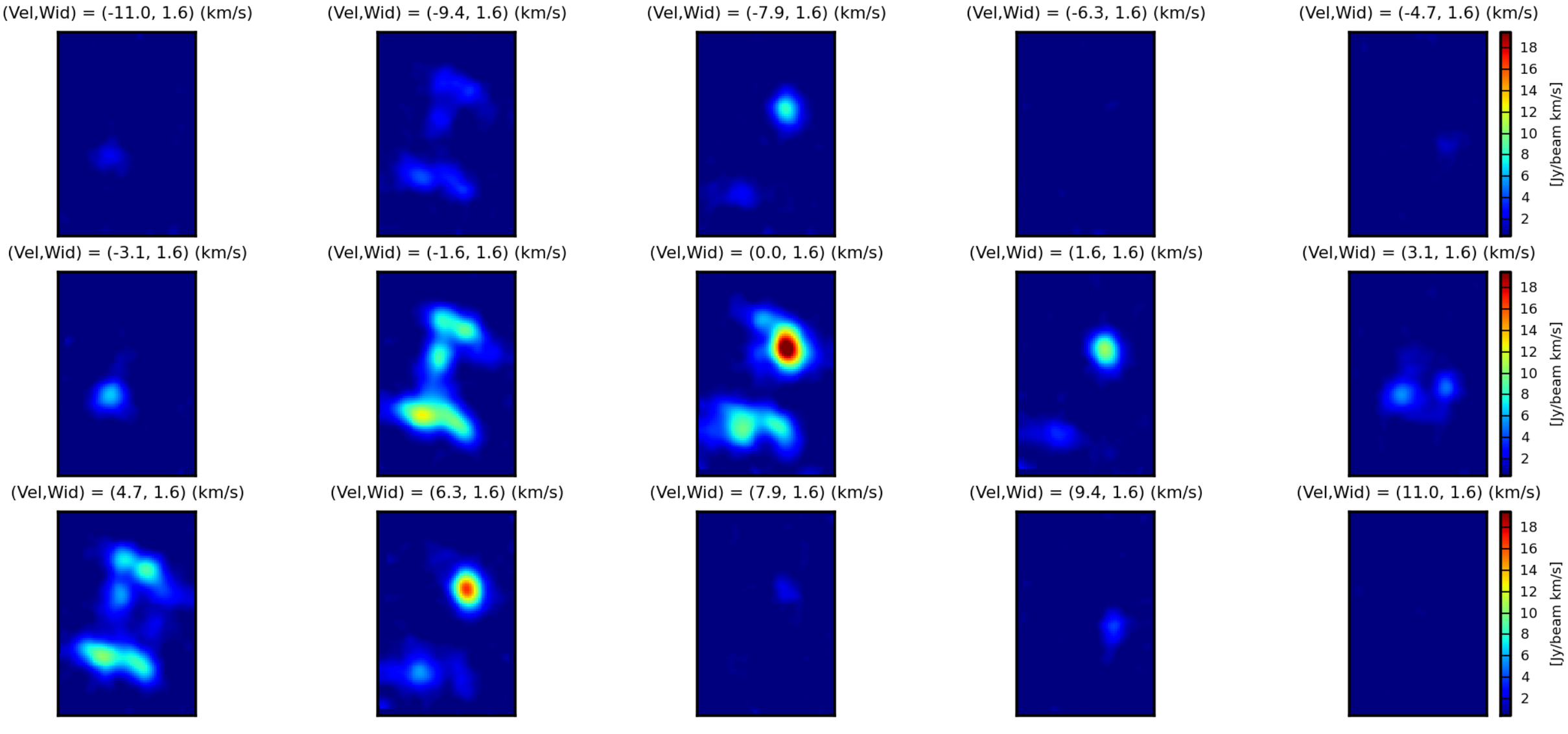
TP



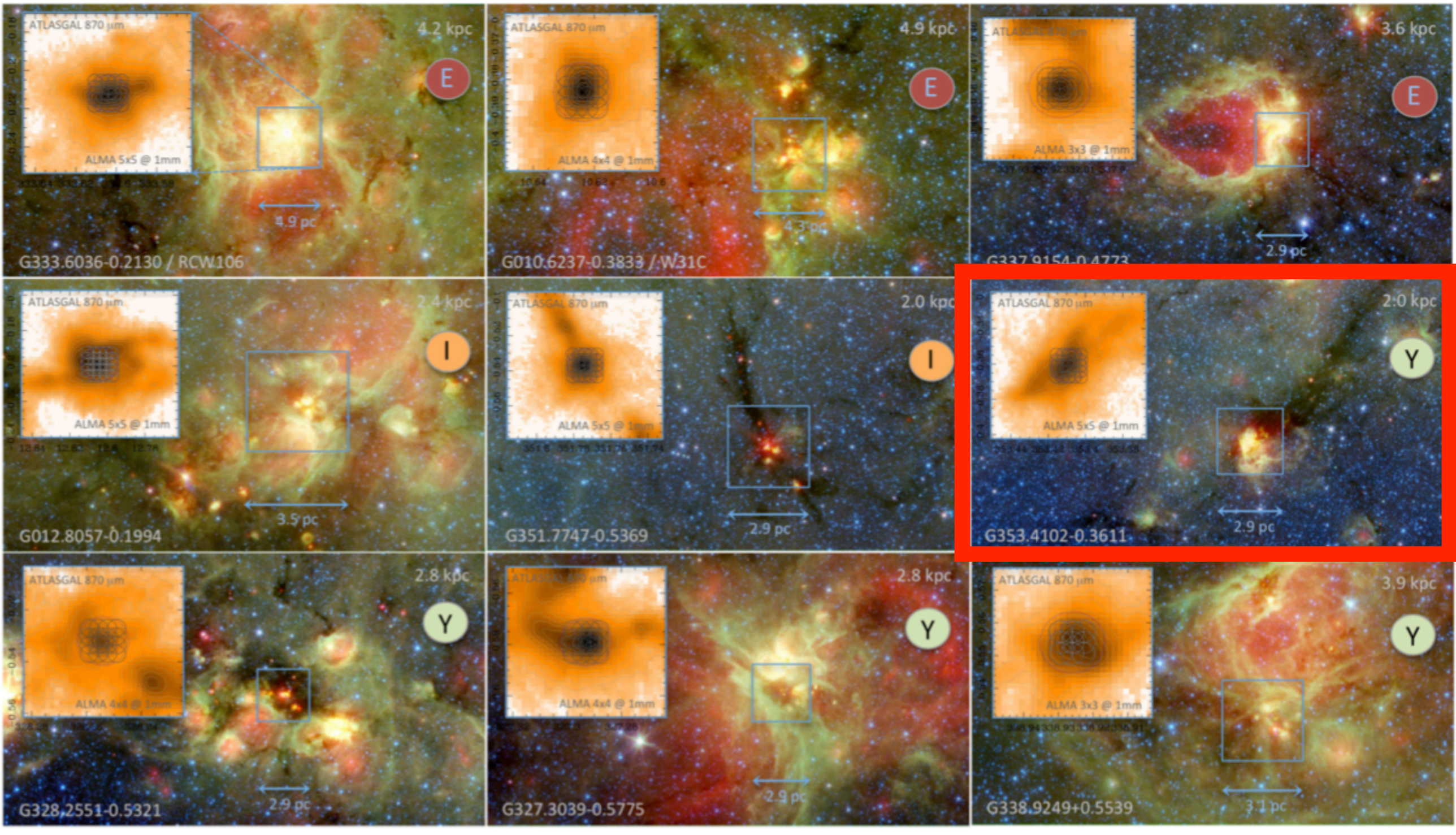

Integrated Spectrum (zoom)
2.0
1.5
1.0
0.5
0.0
−10
−5
0
5
10
Relative Velocity w.r.t. Window Center (km/s)


Integrated Spectrum
Intensity (Jy/beam)
2.0
1.5
1.0
0.5
0.0
−0.5
93.14
93.15
93.16
93.17
93.18
93.19
Frequency (GHz)

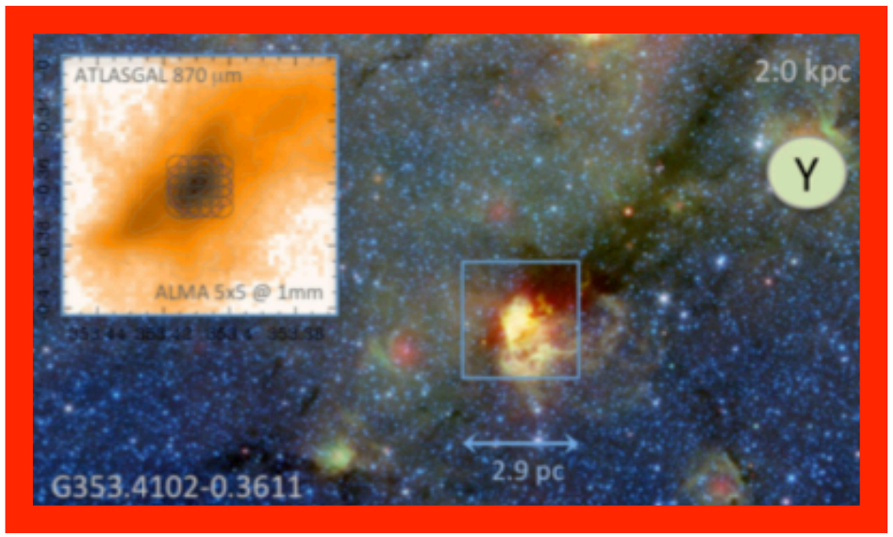

Total Intensity: CenterFreq.= 93.170 GHz
Dec (ICRS)
+4°24'00"
+4°22'00"
+4°20'00"
+4°18'00"
+4°16'00"
06:34:20
06:34:10
06:34:00
RA (ICRS)
64
56
48
40
32
24
16
8
0
[Jy/beam km/s]


(Vel,Wid) = (-11.0, 1.6) (km/s)
(Vel,Wid) = (-9.4, 1.6) (km/s)
(Vel,Wid) = (-7.9, 1.6) (km/s)
(Vel,Wid) = (-6.3, 1.6) (km/s)
(Vel,Wid) = (-4.7, 1.6) (km/s)
(Vel,Wid) = (-3.1, 1.6) (km/s)
(Vel,Wid) = (-1.6, 1.6) (km/s)
(Vel,Wid) = (0.0, 1.6) (km/s)
(Vel,Wid) = (1.6, 1.6) (km/s)
(Vel,Wid) = (3.1, 1.6) (km/s)
(Vel,Wid) = (4.7, 1.6) (km/s)
(Vel,Wid) = (6.3, 1.6) (km/s)
(Vel,Wid) = (7.9, 1.6) (km/s)
(Vel,Wid) = (9.4, 1.6) (km/s)
(Vel,Wid) = (11.0, 1.6) (km/s)
18
16
14
12
10
8
6
4
2
[Jy/beam km/s]

ALMA-IMF Large Program



ALMA-IMF Large Program



Aims: **determine how young protocluster CMFs evolve both in time and as a function of parent cloud mass**

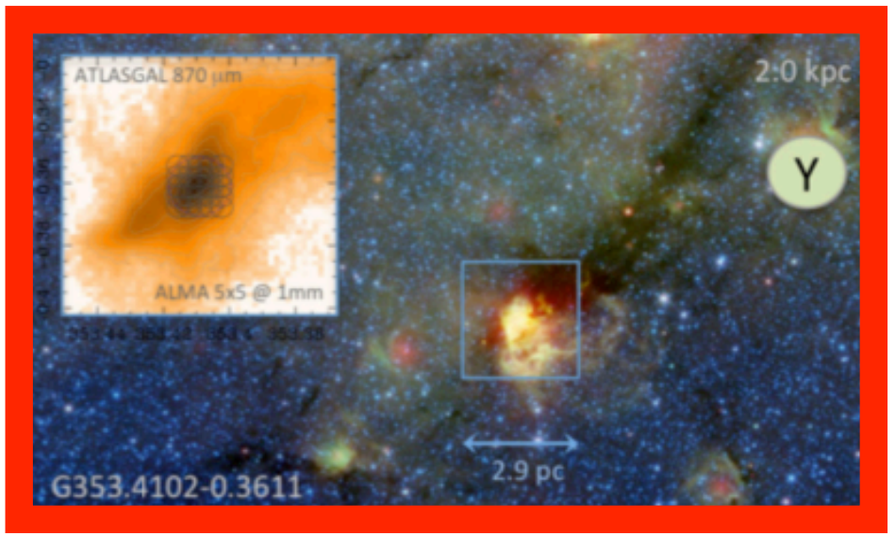
ALMA-IMF will investigate the CMF evolution of **massive protoclusters with the 15 most massive pc^2 clouds at d < 6 kpc**. We will focus on

1) investigating the distribution of **0.5-200 Msun cores** at 1~mm and 3~mm at the 2000~AU core size;

2) characterizing the core mass evolution through gas **inflows** toward individual cores and gas **outflows** driven by protostars; and

3) comparing massive protocluster CMFs to the IMF and determine which variables, such as inflows, outflows, or **forming filaments,** might be correlated with CMF evolution toward the IMF shape.

ALMA-IMF Large Program



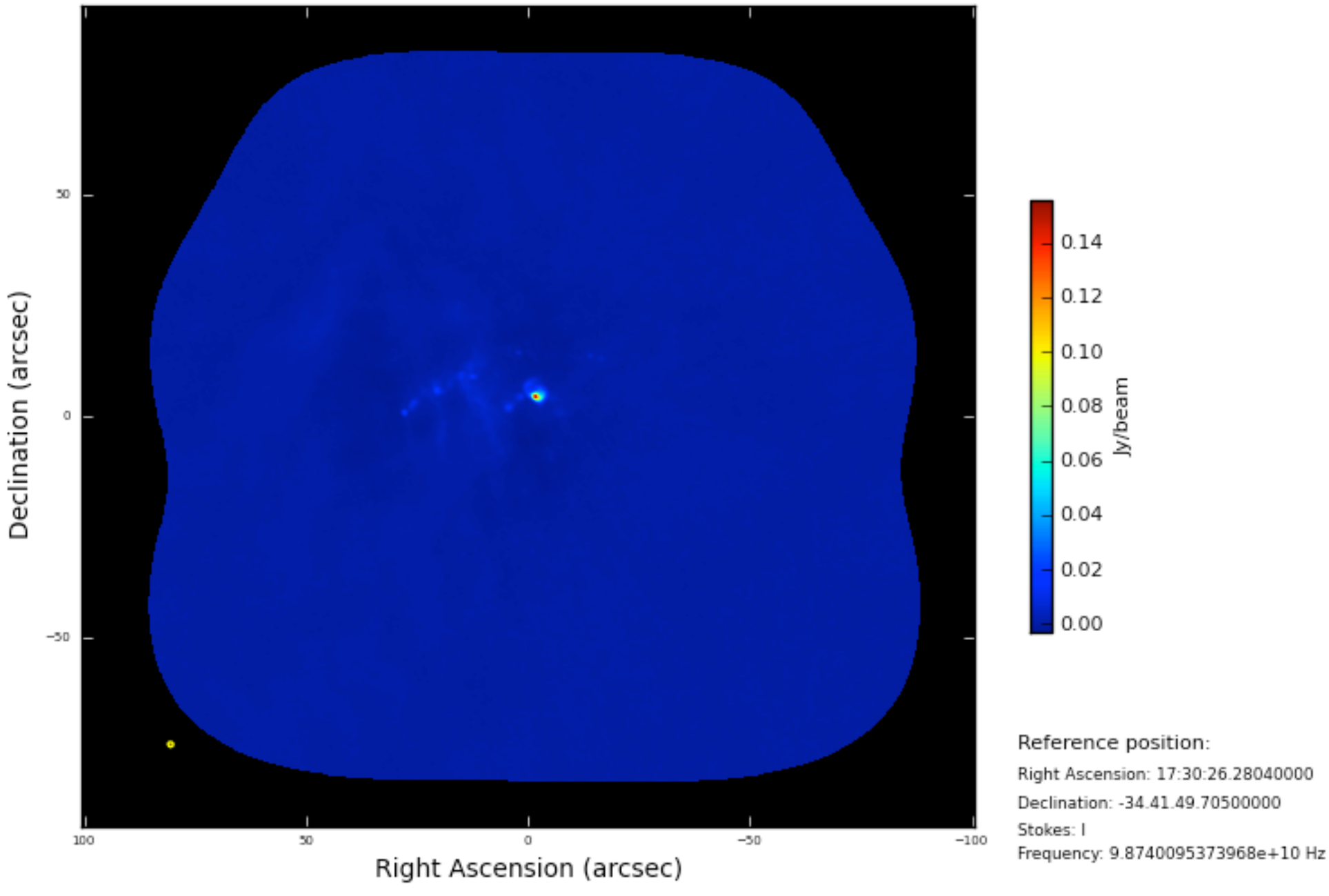
1 mm and 3 mm (bands 6 & 3) spectral bands, main lines:

^{12}CO(2-1) and **N_2H^+(1-0) to measure gas mass outflows and inflows,** and

^{13}CS and N_2D^+ to estimate core turbulence levels, the H41α recombination line to identify HII regions, and CH_3OH, CH_3CN, and CH_3CCH to probe gas temperature.

Band3/TM1/continuum @ ~100 GHz

type:image display:mean field:G353.41 spw:25,27,29,31 iter:1



Reference position:

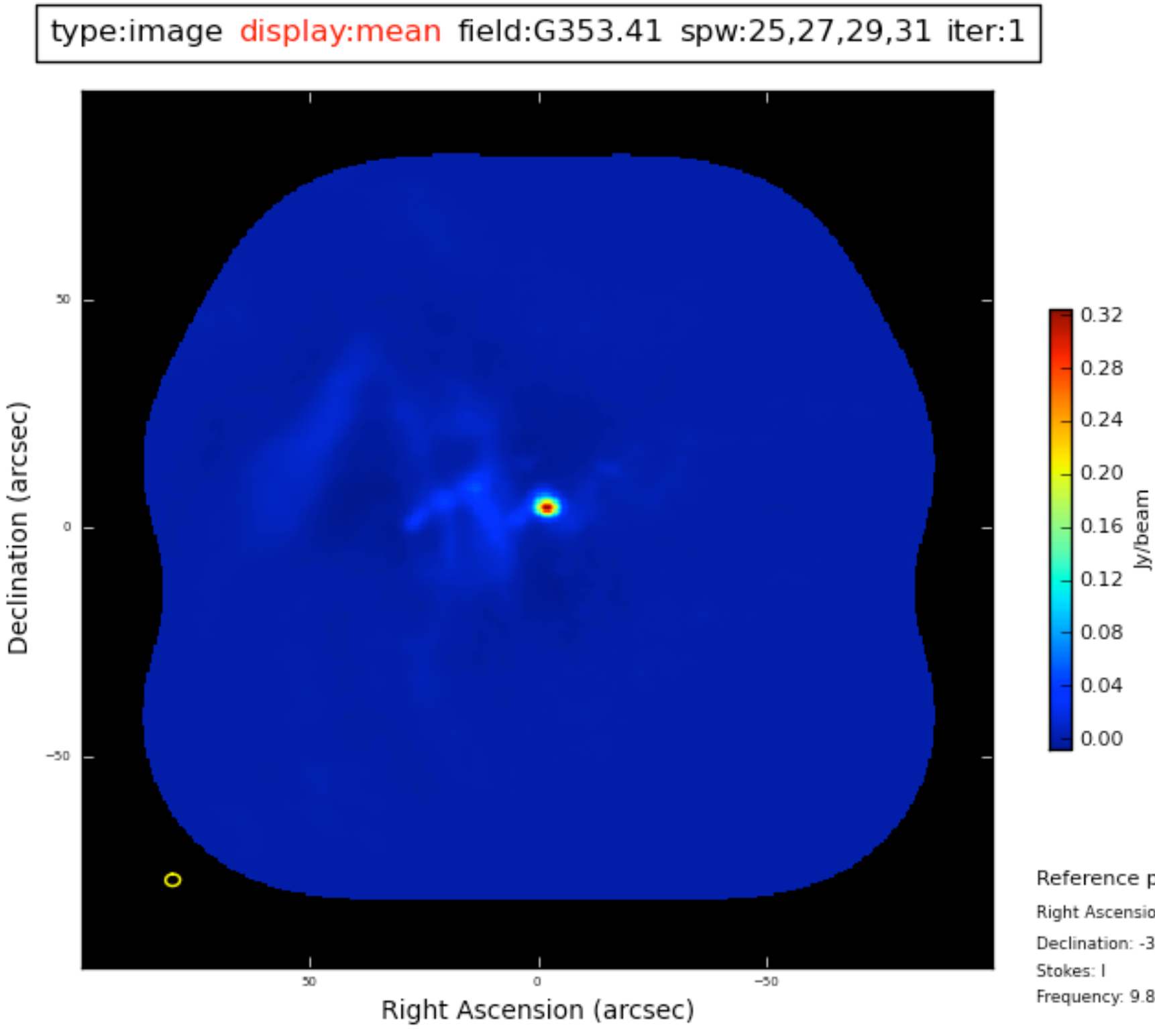
Right Ascension: 17:30:26.28040000

Declination: -34.41.49.70500000

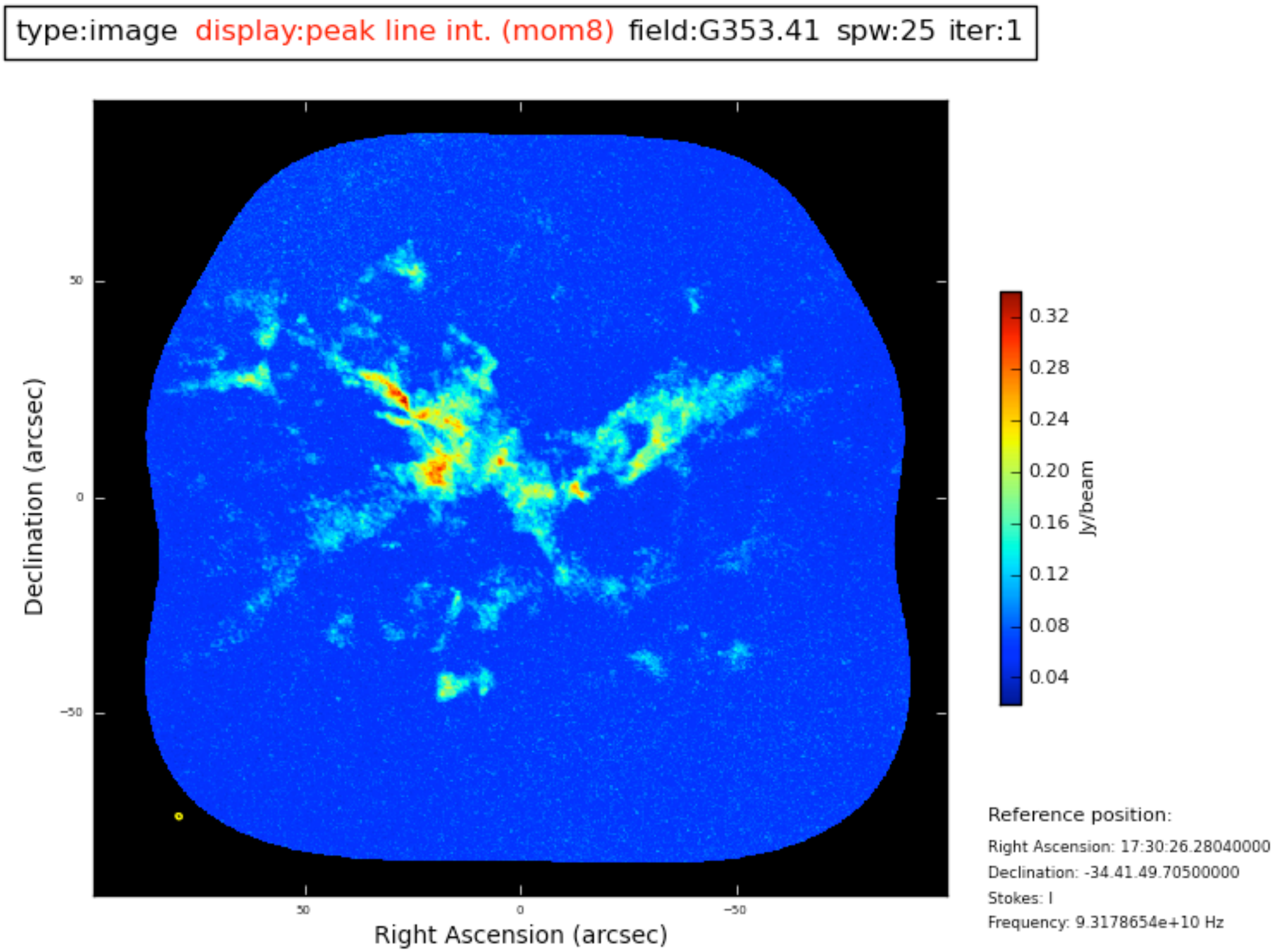
Stokes: I

Frequency: 9.8740095373968e+10 Hz

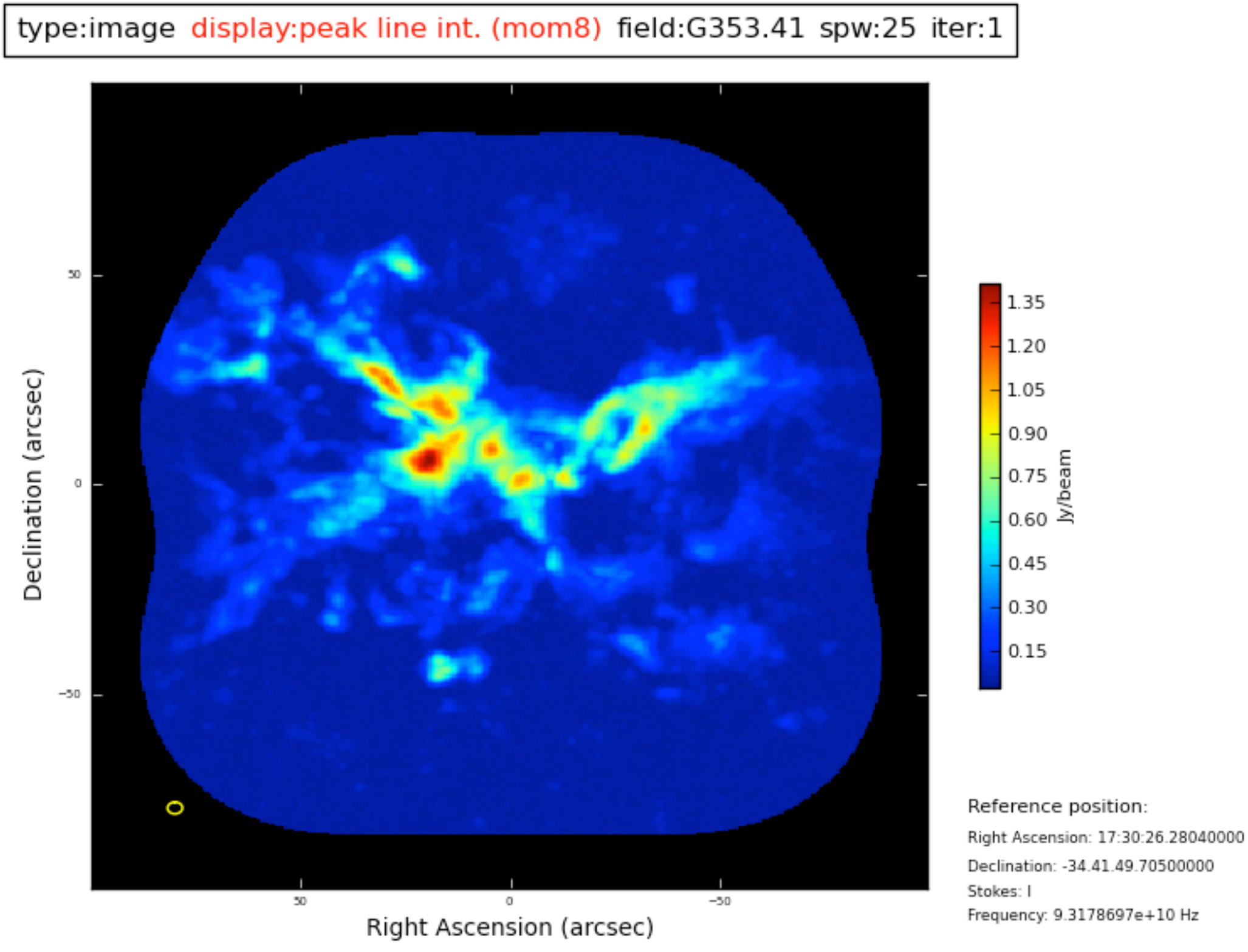
Band3/TM2/continuum @ ~100 GHz



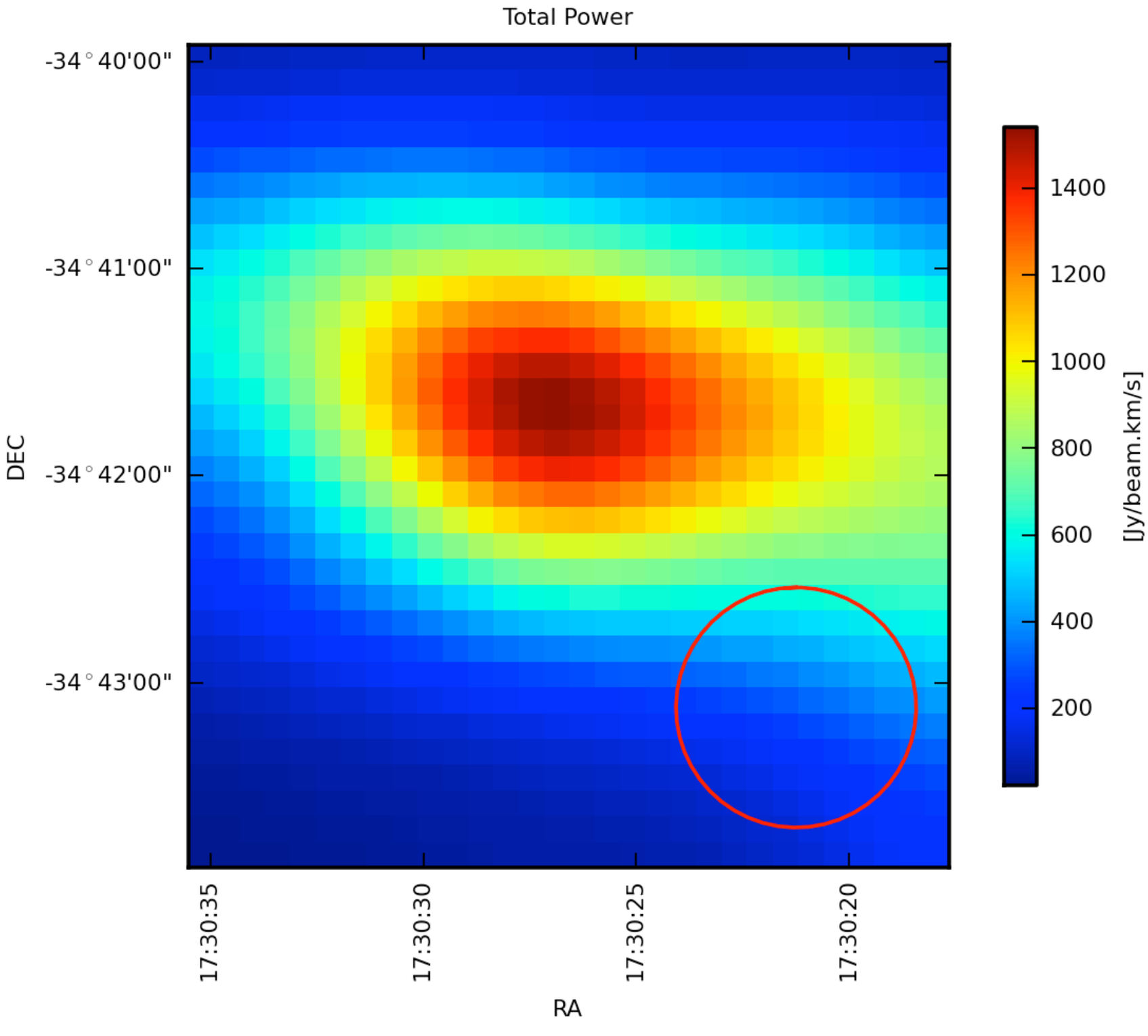
Band3/TM1/N2H+(1-0)



Band3/TM2/N2H+(1-0)



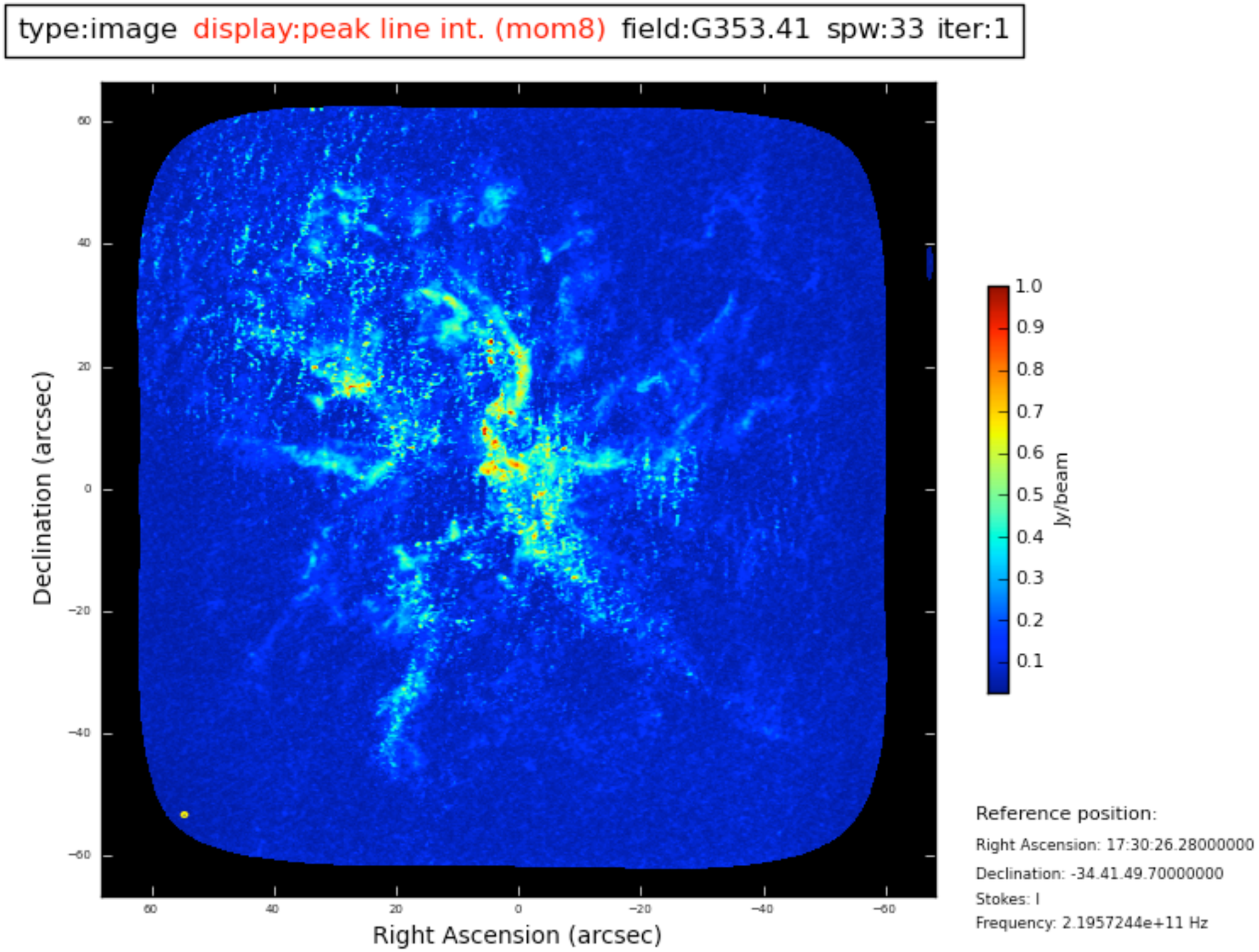
B3/TP/N2H+(1-0)


Total Power
-34°40'00"
-34°41'00"
-34°42'00"
-34°43'00"
DEC
17:30:35
17:30:30
17:30:25
17:30:20
RA
1400
1200
1000
800
600
400
200
[Jy/beam.km/s]

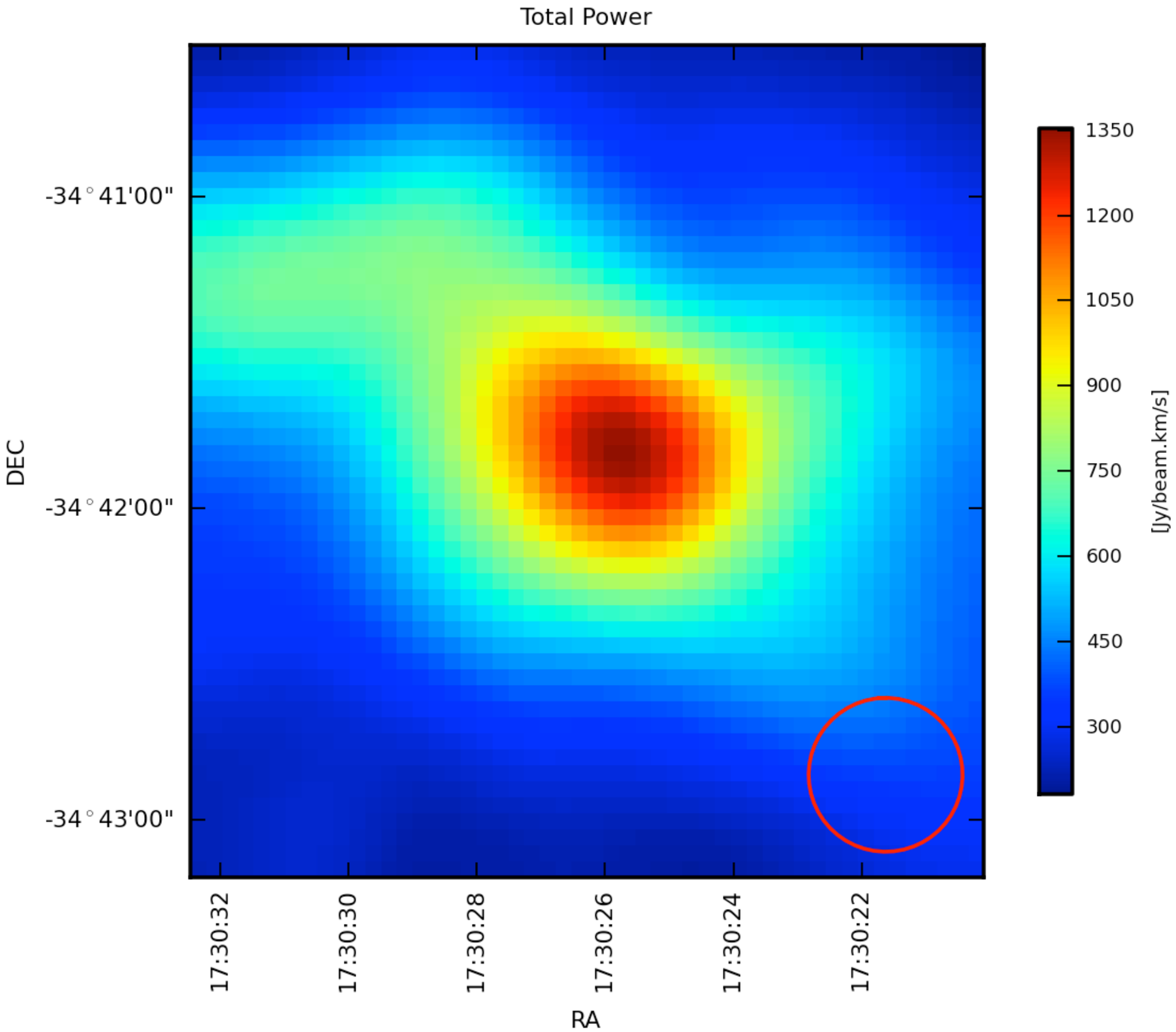
ALMA-IMF Band 6 spectral setup

Real ID	Virtual ID	Name	Type	Frequency (TOPO)			Bandwidth (TOPO)	Transitions
				Start	Centre	End		
16	16	X96246849#ALMA_RB_06#BB_1#SW-01	FDM	216.106 GHz	216.231 GHz	216.356 GHz	250.000 MHz	DCO_3_2(ID=0)
18	18	X96246849#ALMA_RB_06#BB_1#SW-02	FDM	217.055 GHz	217.180 GHz	217.305 GHz	250.000 MHz	SiO5_4_DCN(ID=0)
20	20	X96246849#ALMA_RB_06#BB_2#SW-01	FDM	219.913 GHz	219.975 GHz	220.038 GHz	125.000 MHz	SO_HNCO(ID=0)
22	22	X96246849#ALMA_RB_06#BB_2#SW-02	FDM	218.135 GHz	218.260 GHz	218.385 GHz	250.000 MHz	H2C0218_2(ID=0)
24	24	X96246849#ALMA_RB_06#BB_2#SW-03	FDM	219.528 GHz	219.591 GHz	219.653 GHz	125.000 MHz	C18O2_1(ID=0)
26	26	X96246849#ALMA_RB_06#BB_3#SW-01	FDM	230.312 GHz	230.562 GHz	230.812 GHz	500.000 MHz	CO2_1(ID=0)
28	28	X96246849#ALMA_RB_06#BB_3#SW-02	FDM	231.062 GHz	231.312 GHz	231.562 GHz	500.000 MHz	13CS_N2D_(ID=0)
30	30	X96246849#ALMA_RB_06#BB_4#SW-01	FDM	231.476 GHz	232.476 GHz	233.476 GHz	2.000 GHz	continuum(ID=0)

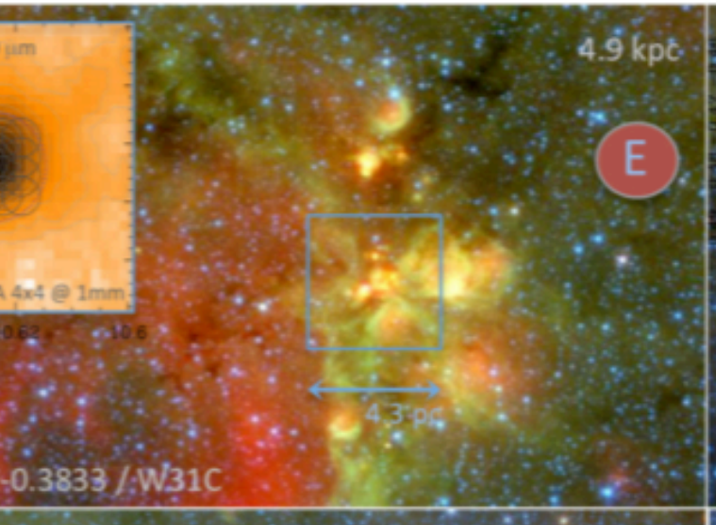
B6/TM1/C18O(2-1)

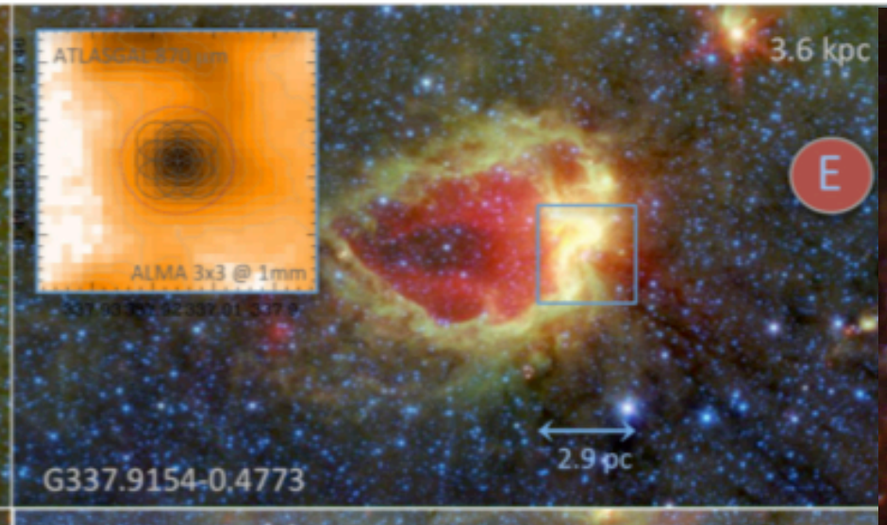


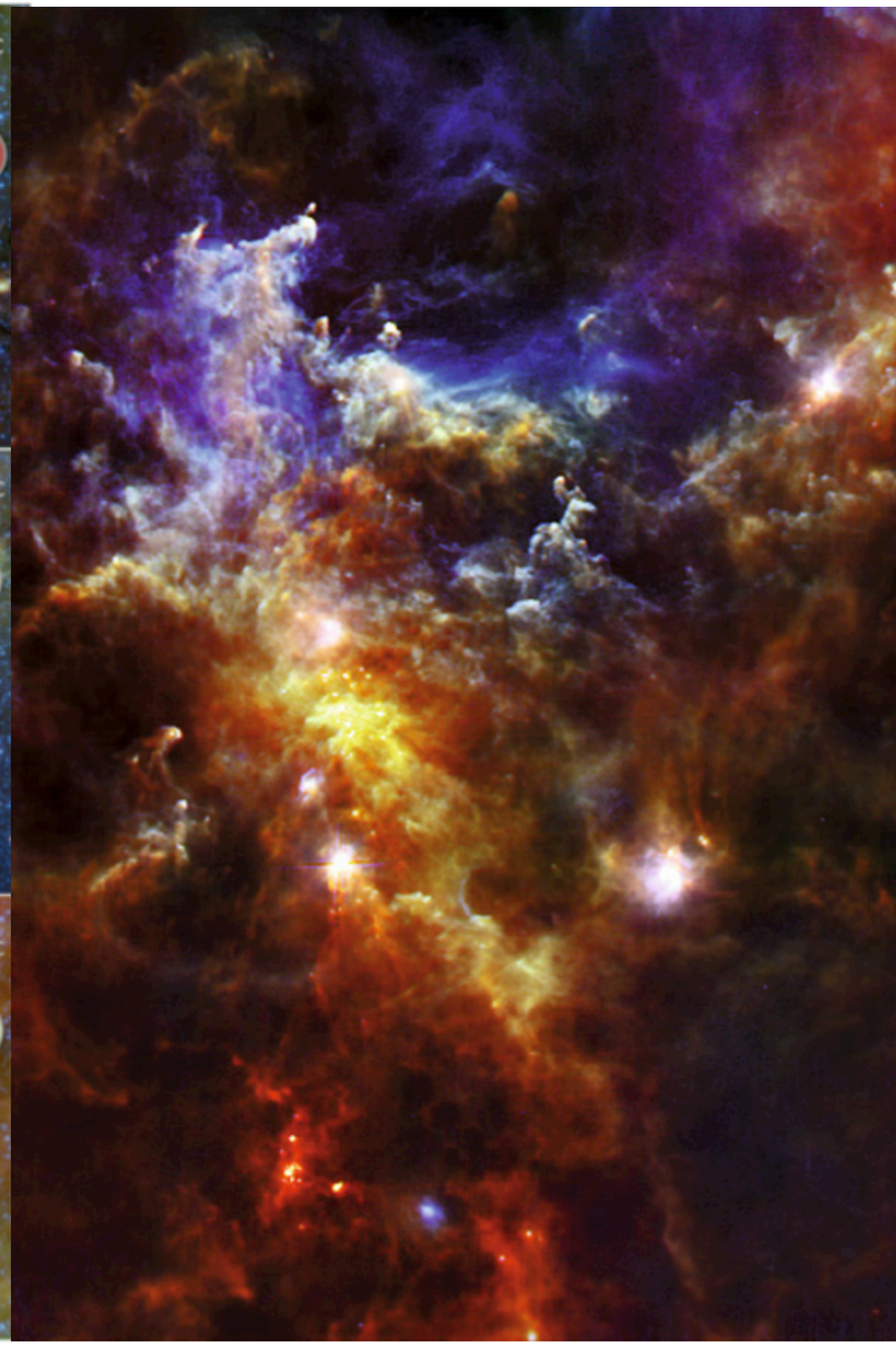
B6/TP/C18O(2-1)

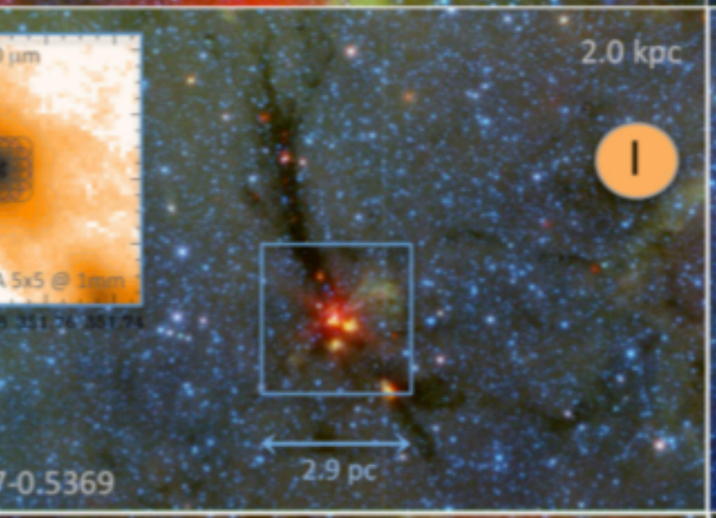

Total Power
DEC
-34°41'00"
-34°42'00"
-34°43'00"
17:30:32
17:30:30
17:30:28
17:30:26
17:30:24
17:30:22
RA
1350
1200
1050
900
750
600
450
300
[Jy/beam.km/s]

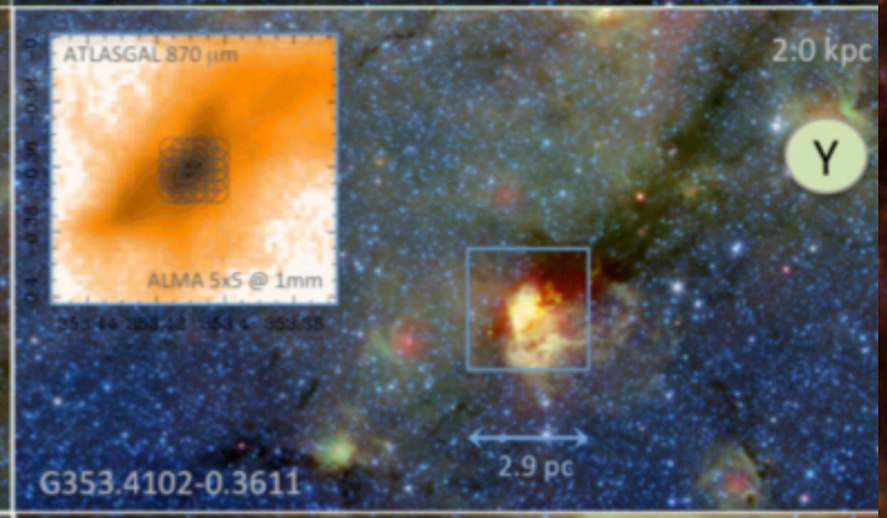
ALMA: Rosette and ALMA-IMF

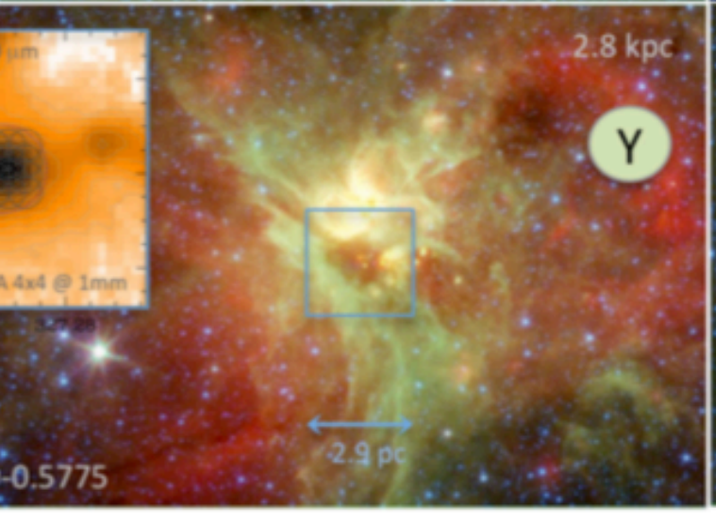


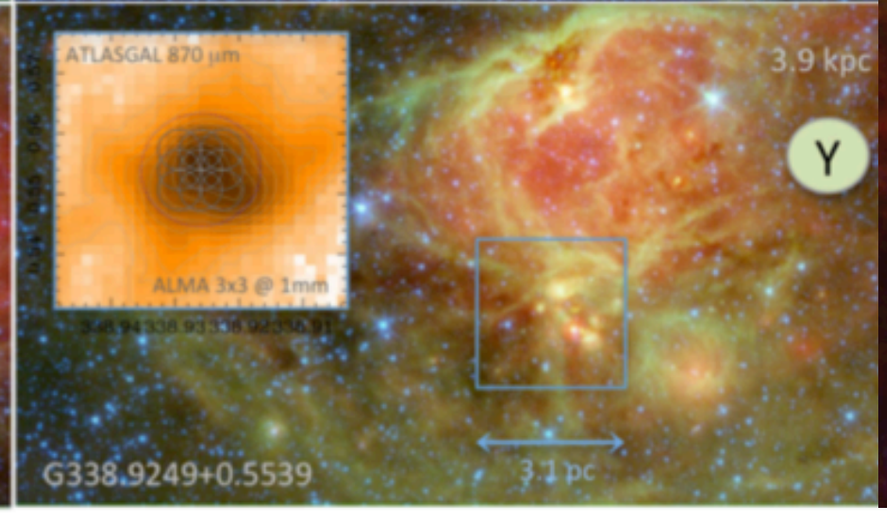












Thank you!