The relation between dense molecular clouds cores and very young stellar clusters

Hongjun Ma

@JCMT 2/27/2019

Outline

- Background
  1) Clusters forming
  2） Environment of clusters forming
  3) Method of cluster forming
  4) Star formation law
- Next steps
- Data

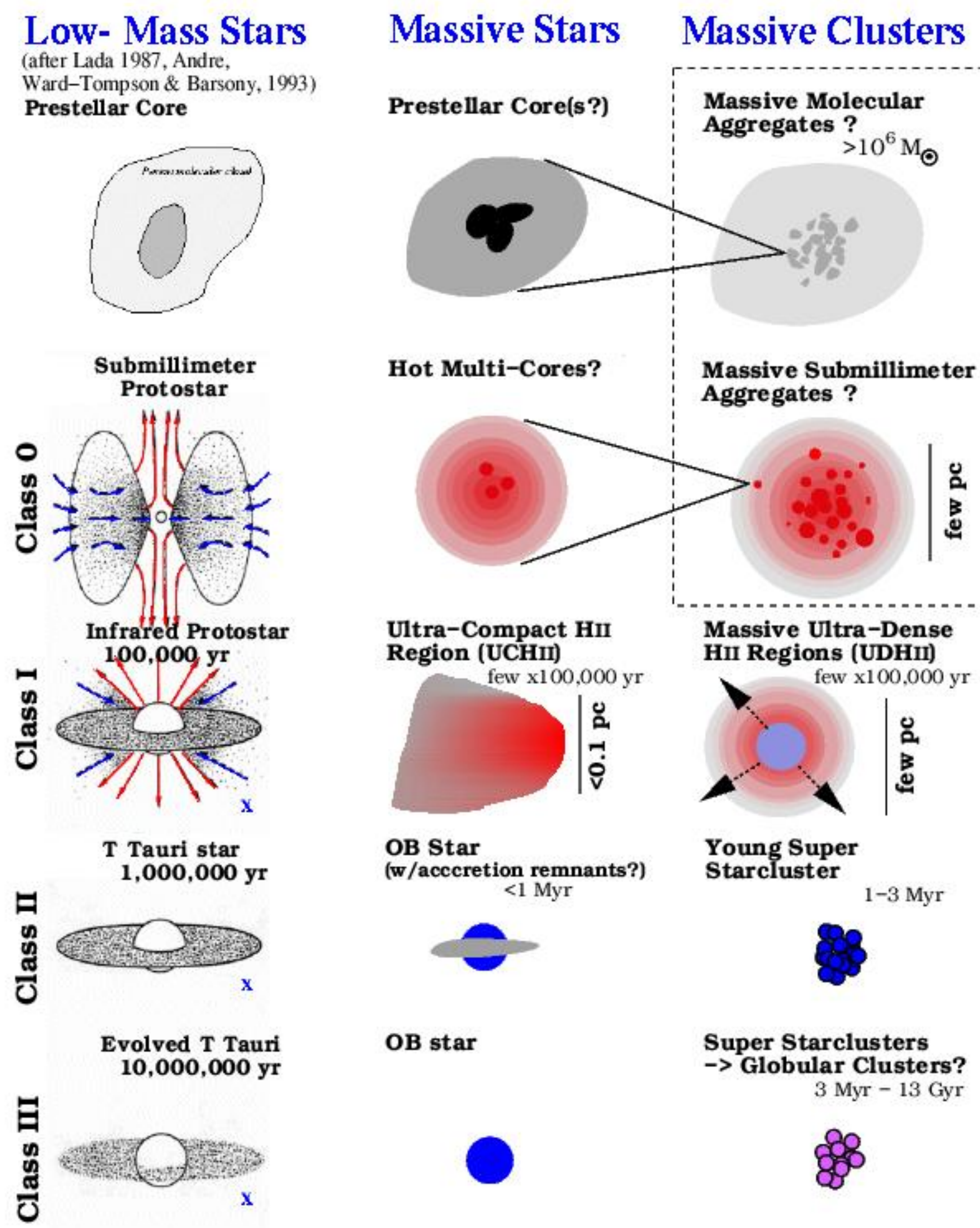
Background Clusters forming

Gies DR. 1987

Binary Frequency

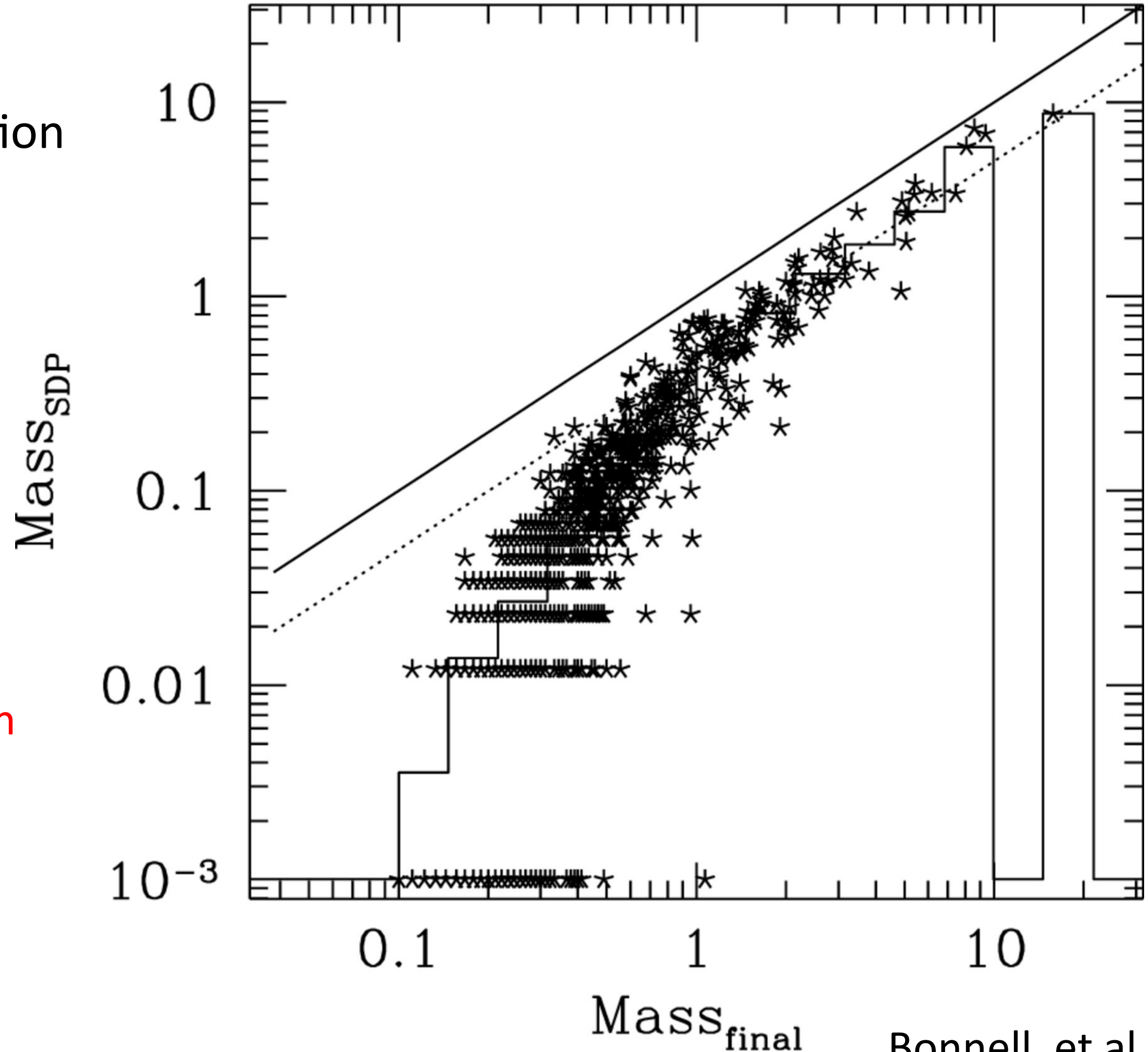
Type[a]	Cluster/Association	Field	Runaway
A. Visual Multiplicity			
VB	20	5	0
VMS	37	4	0
Total.....................	42%	21%	0%
OPT	4	4	0
S	75	30	16
Total.....................	58%	79%	100%

In the Milky Way Galaxy, for the global clustering of spectral O-type stars (Parker & Goodwin 2007), of which ~70% reside in young clusters or associations (Gies 1987) and ~50% of the remaining field population are directly identified as runaways (de Wit et al. 2005).



Method of cluster forming : fragmentation or accretion

Simulations of accretion in clusters containing 1000 stars result in mass spectra broadly consistent with these analytic estimates. The high-mass stars are confirmed to accumulate the majority of their mass in a stellar-dominated potential. Lastly, competitive accretion in clusters naturally results in mass segregation as the accretion rates are higher near the cluster centre during the gas-dominated phase.

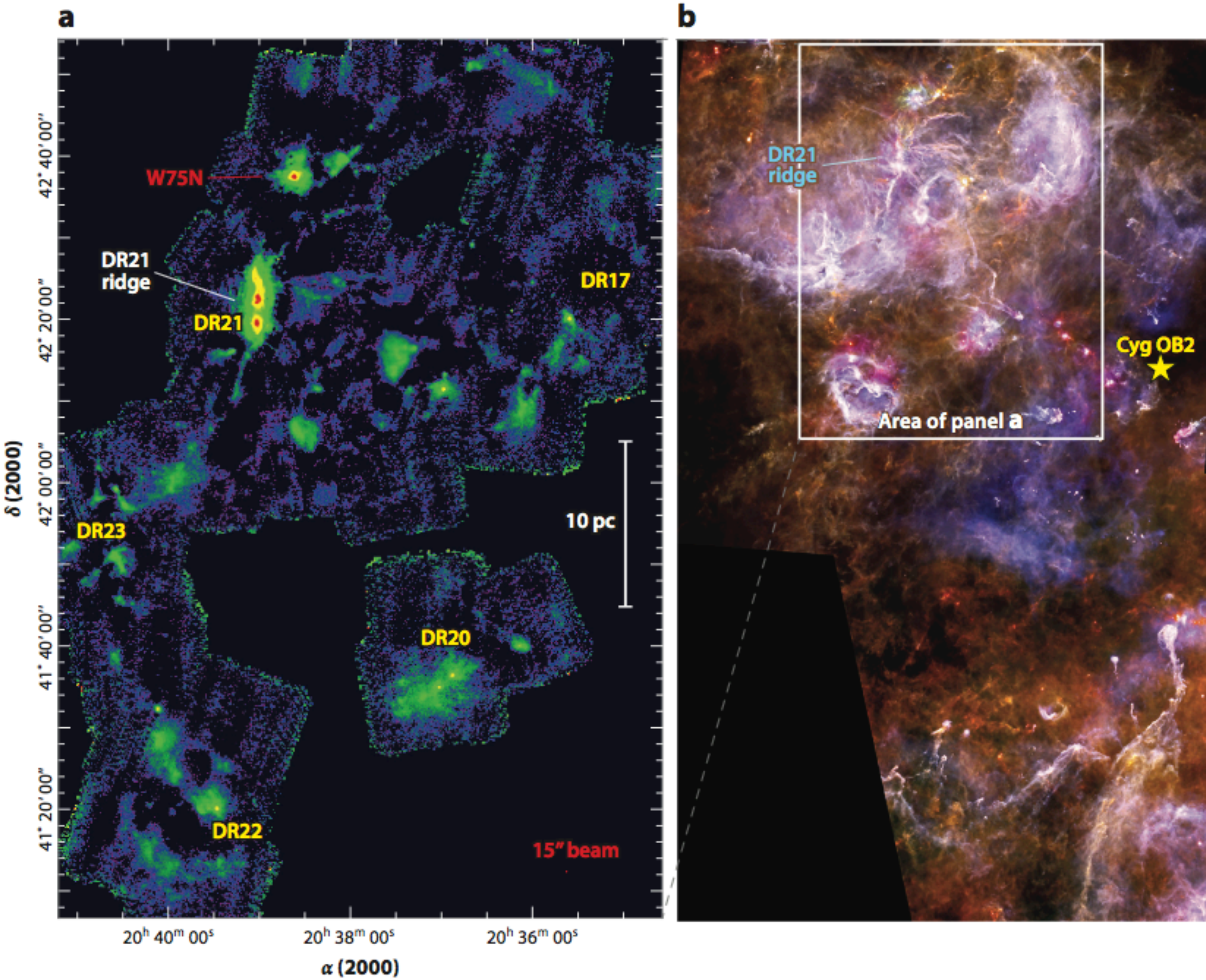


Bonnell, et al. 2001

The mass accreted during the stellar-dominated phase, $Mass_{SDP}$, plotted against total stellar mass

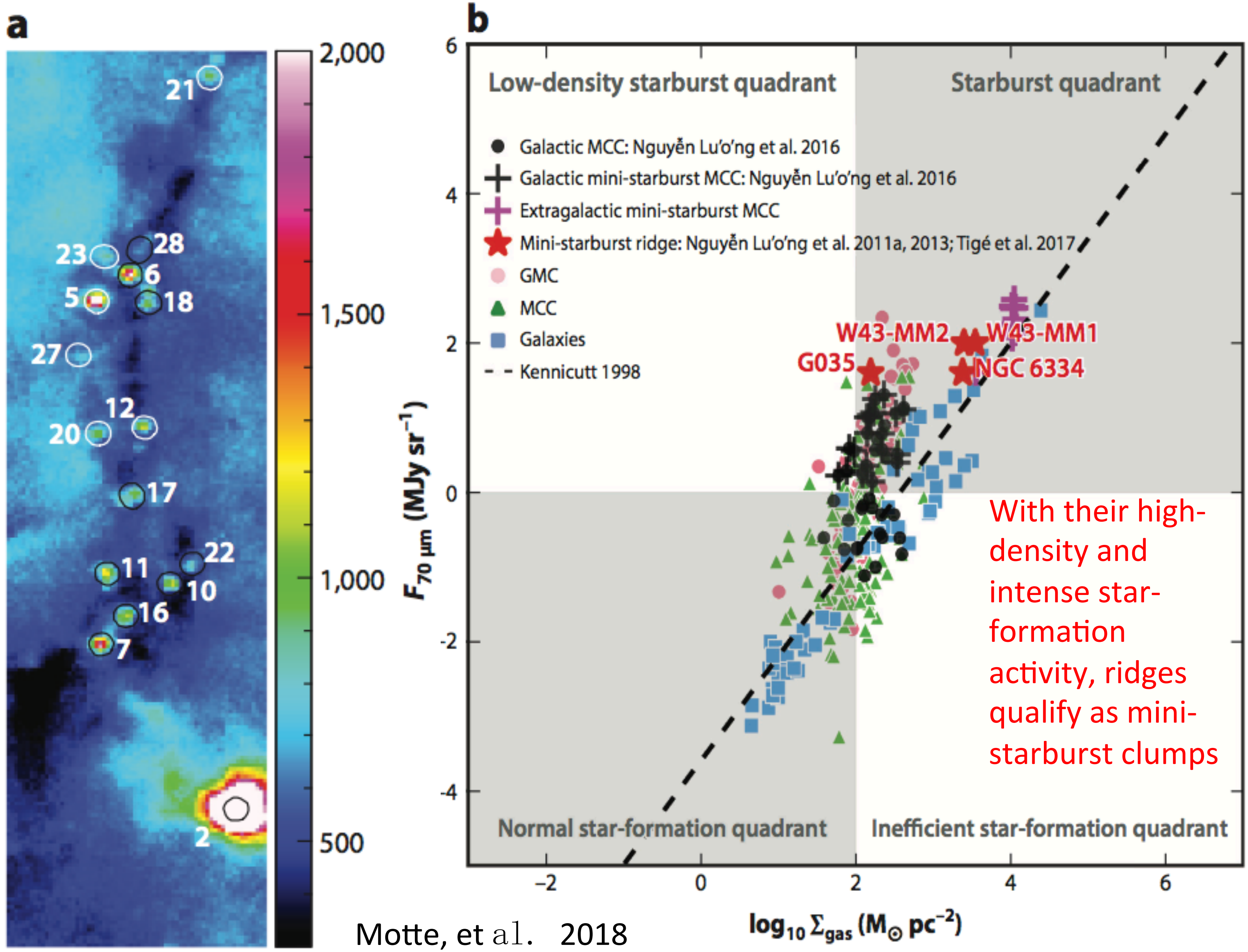
Monthly Notices of the Royal Astronomical Society, Volume 324, Issue 3, 21 June 2001, Pages 573–579, https://doi.org/10.1046/j.1365-8711.2001.04311.x

Environments of cluster forming



Motte, et al. 2018

The extreme characteristics of ridges and hubs, in terms of density and kinematics, could lead to atypical star-formation activity.



With their high-density and intense star-formation activity, ridges qualify as mini-starburst clumps

Motte, et al. 2018

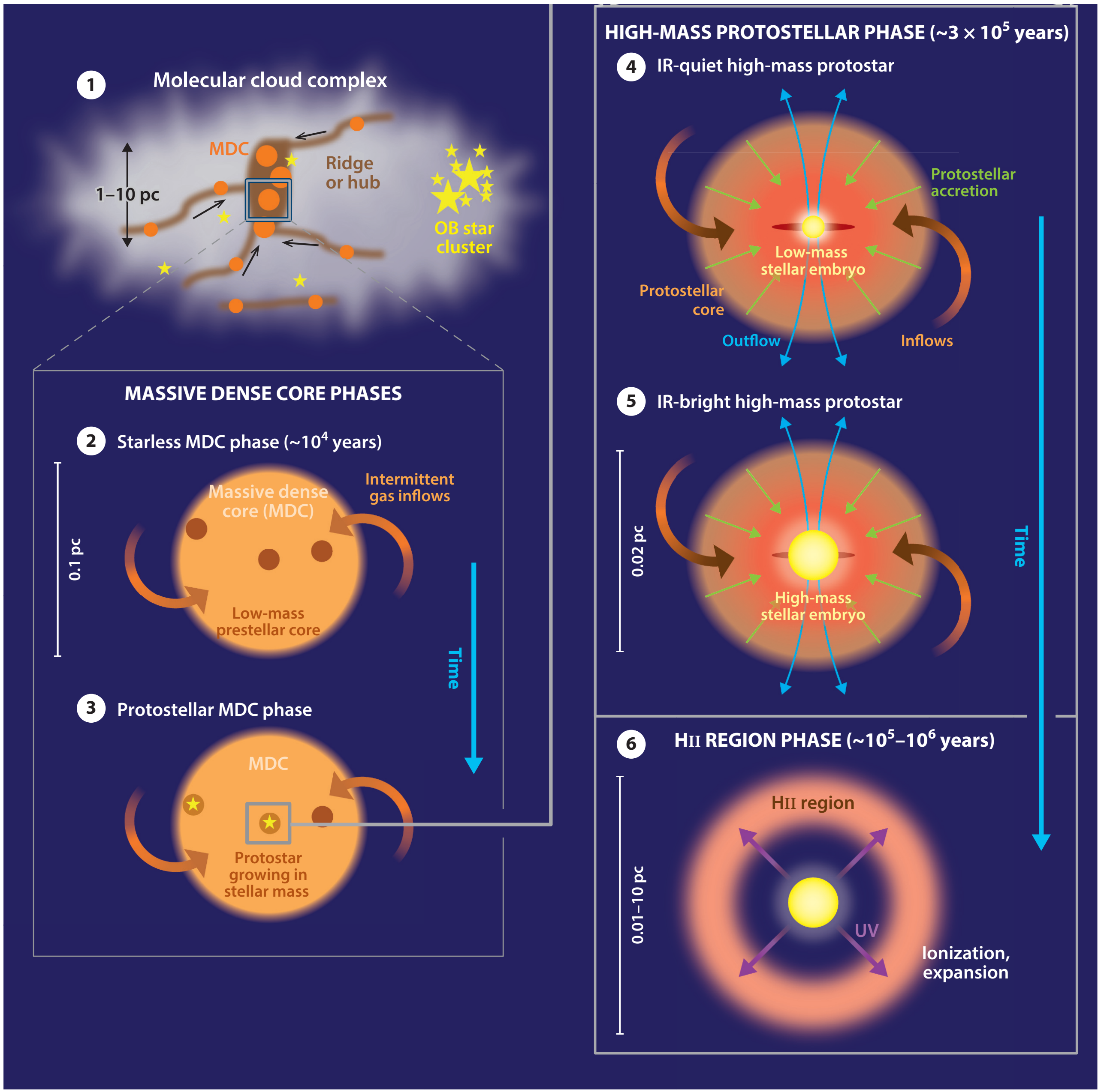


Figure 8

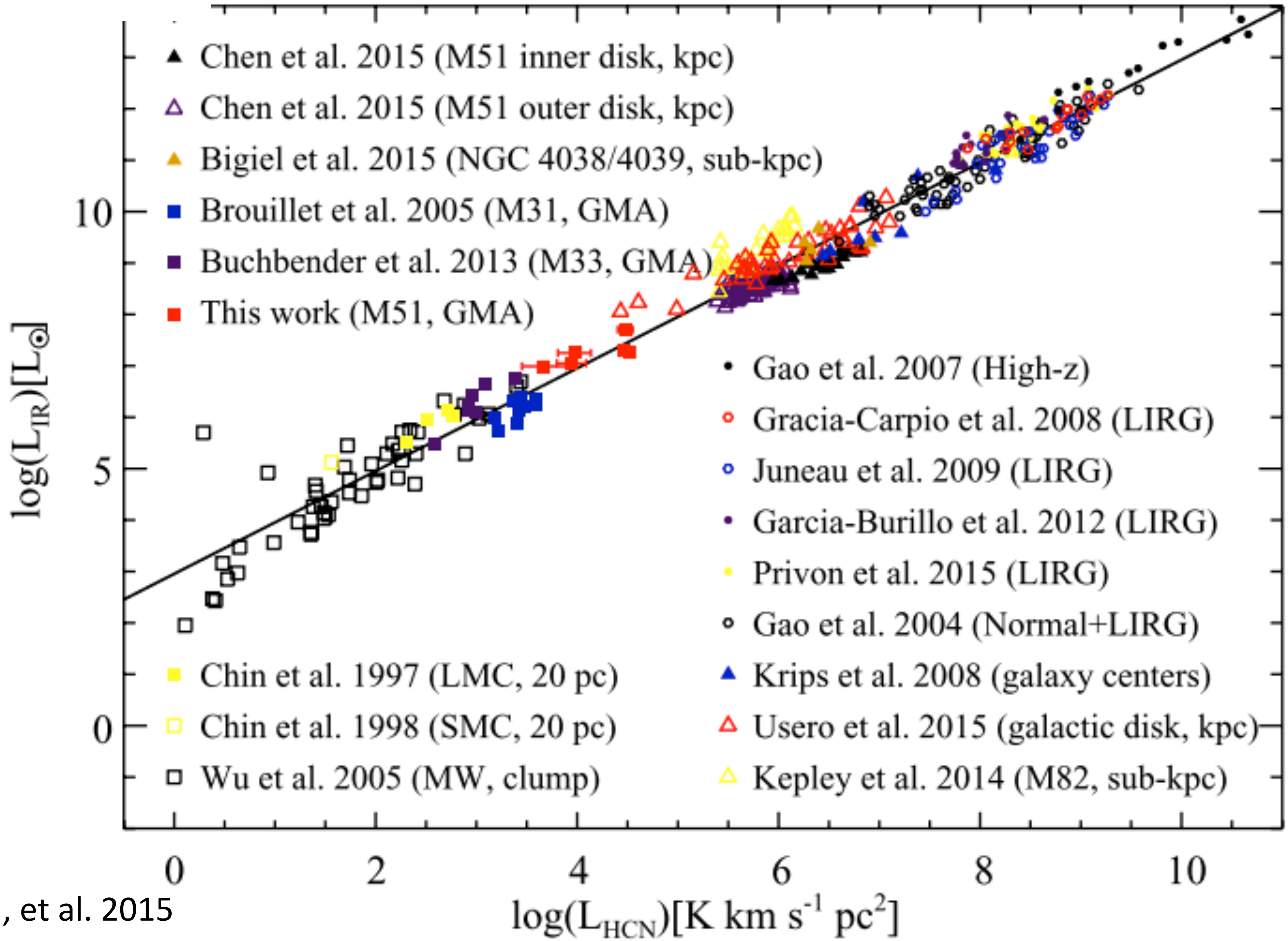
High-mass stars form in molecular complexes hosting massive clouds and often OB clusters. Parsec-scale massive clumps/clouds called ridges and hubs are the preferred, if not the only, sites for high-mass star formation. Their infall velocity and density structure suggest ridges/ hubs undergo a global but controlled collapse.

high-mass star formation develops simultaneously and in tight link with the formation of massive clouds and massive clusters

Motte, et al. 2018

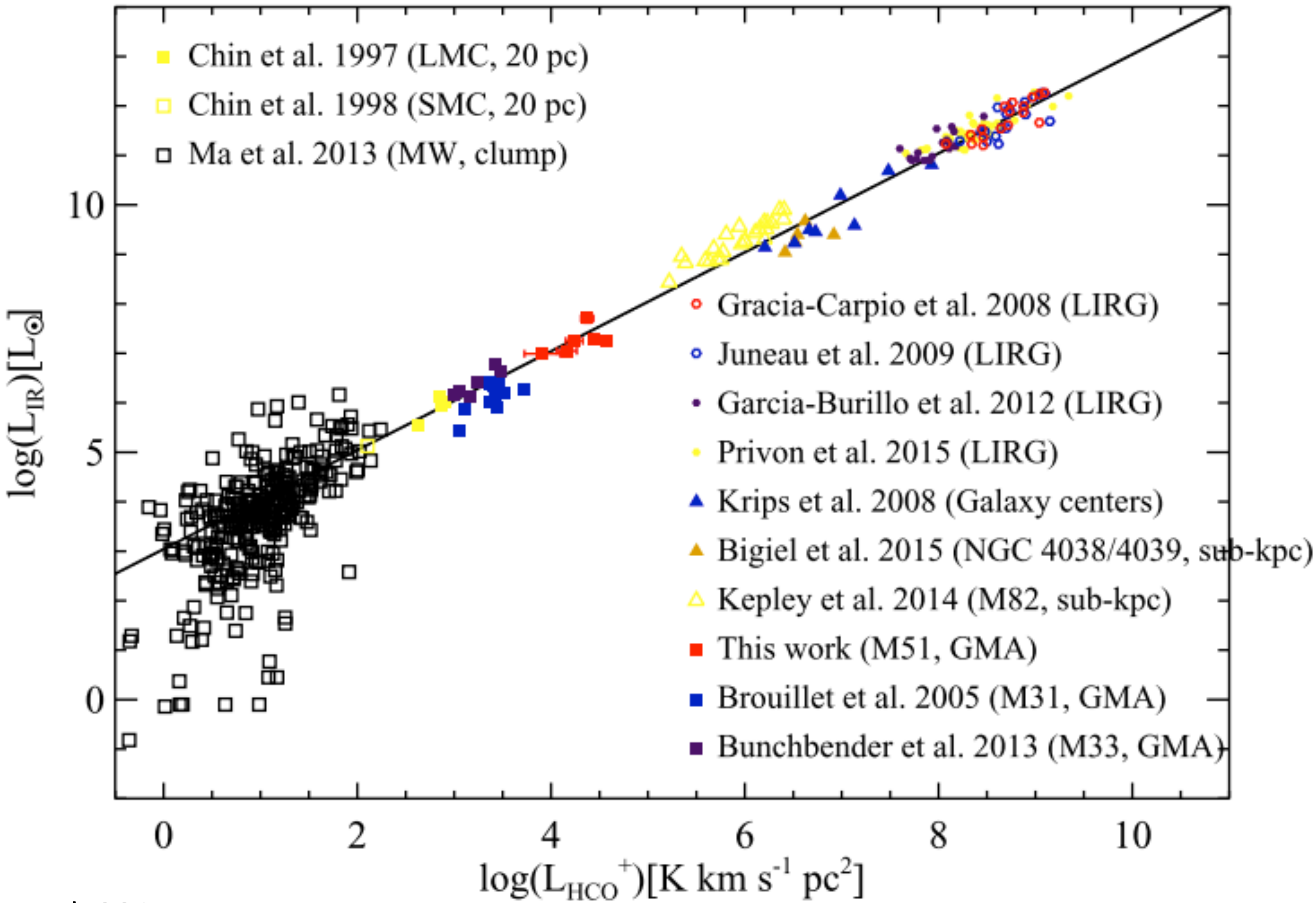
$$\Sigma_{SFR} \propto (\Sigma_{gas})^n$$

star formation law (SFL--KSL)



Chen, et al. 2015

star formation law



Chen, et al. 2015

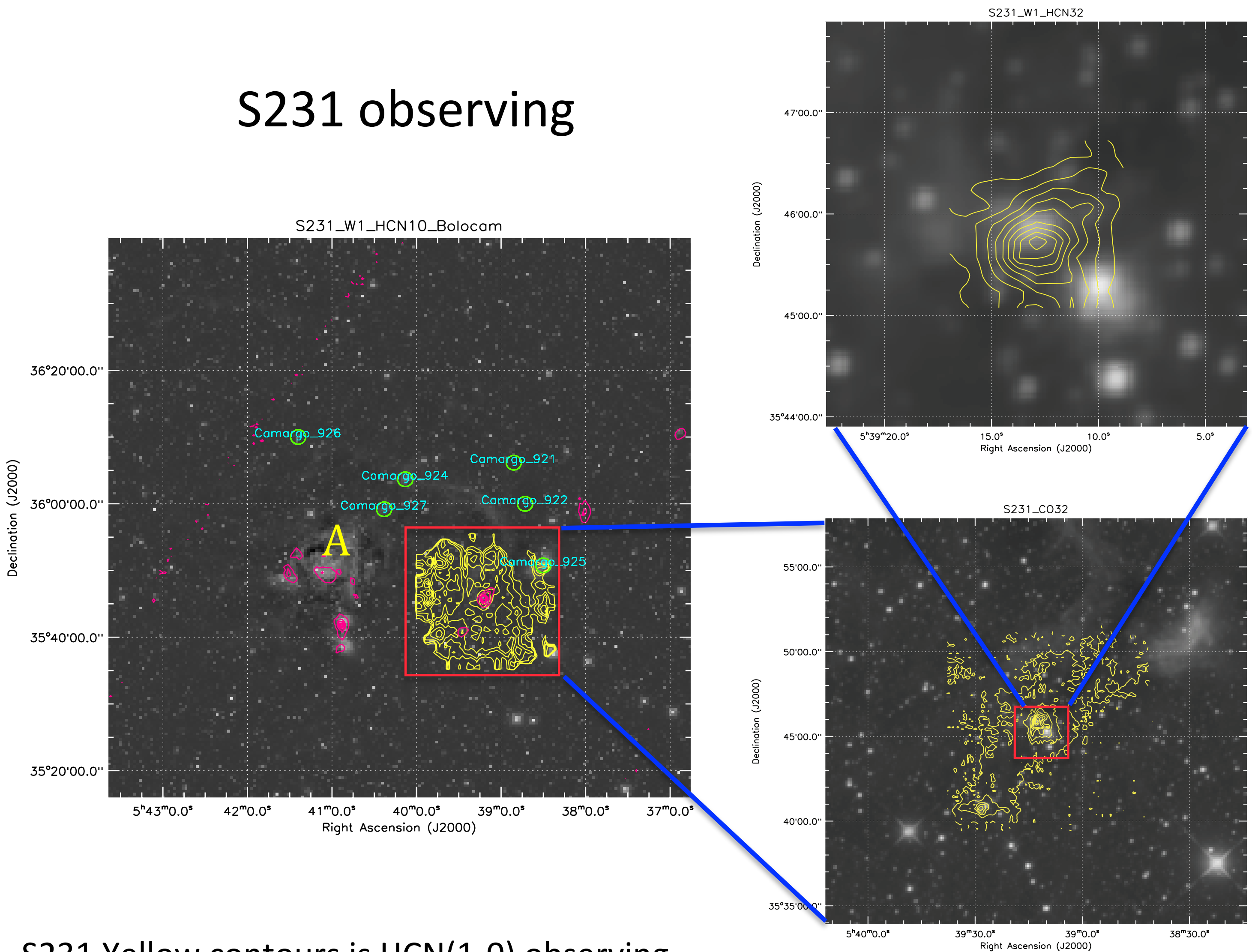
Our sample

- Wu et al. 2010 (82 molecular cloudy cores – massive star forming regions)
- Kharchenko et al. (2005) & Piskunov et al. (2008) —more than 3000 Galactic open clusters
- Camargo et al. (2011, 2015)—1089 embedded stellar clusters

About 40 molecular cloudy cores with young stellar clusters around

Sample: GMCs with young stellar clusters around

S231 observing



CSO HCN(3-2)

S231 pink is Bolocam 1.1 mm；

Cyan is Camargo et al. (2011, 2015) clusters

JCMT CO(3-2) contour map.

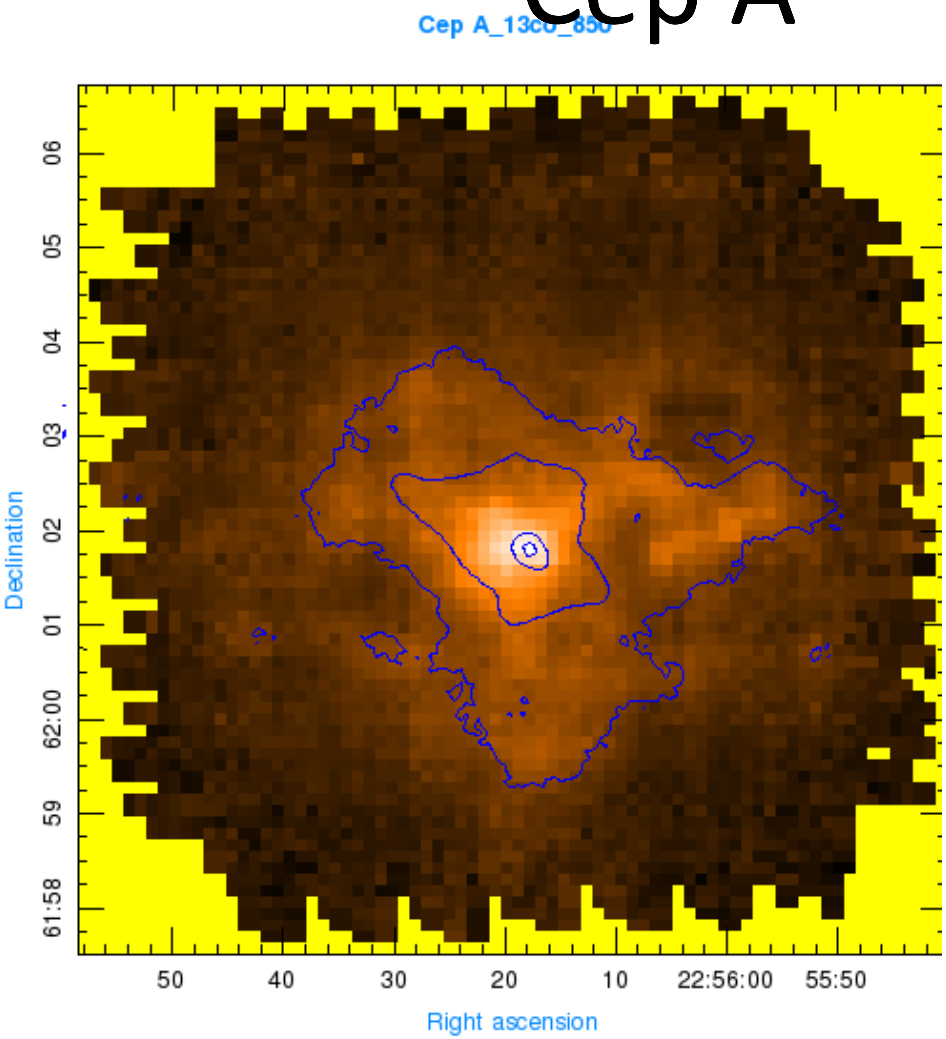
Background is WISE 3.4 micron band image.

S231 Yellow contours is HCN(1-0) observing with DLH telescope；

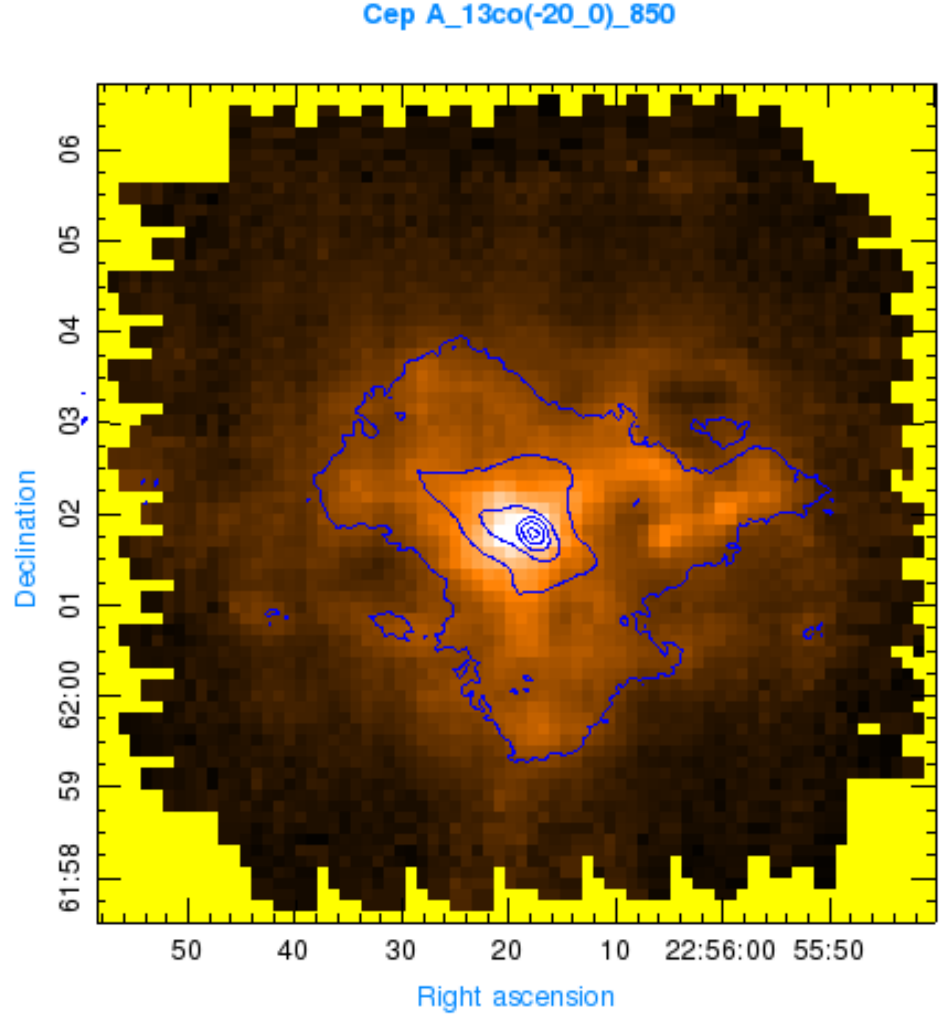
The sample with JCMT CO and Scuba-2 archive data available

# Name	RA	Dec	equ	Scanline	line2	project_1	850mic	project_2
W44	18:53:18.5	01:14:56.2	J2000	HCN(4-3	0	0	scuba-2	0
S106	20:27:25.7	37:22:51.8	J2000	HCN(4-3)	0	0	scuba-2	0
W3(OH)	02:27:04.7	61:52:25.5	J2000	13CO(3-2)	C18O(3-2)	M07BU16	scuba-2	S14BC01
NGC7538	23:13:44.85	61:26:50.67	J2000	13CO(3-2)	C18O(3-2)	M07BU16,	scuba-2	M16BP006
S158	23:13:44.9	61:26:50.6	J2000	13CO(3-2)	C18O(3-2)	M07BU16	scuba-2	M15BI059
S158A	23:13:45.4	61:28:11.7	J2000	13CO(3-2)	C18O(3-2)	M08AU19	scuba-2	M15BI059
NGC7538-IRS9	23:14:01.7	61:27:19.9	J2000	13CO(3-2)	C18O(3-2)	M07BU16	scuba-2	M15BI059
S157	23:16:04.4	60:01:40.6	J2000	13CO(3-2)	C18O(3-2)	M10BU08	scuba-2	M13AU03
W75N	20:38:36.9	42:37:37.5	J2000	13CO(3-2	C18O(3-2)	M08AU19	scuba-2	M11BEC30
W75(OH)	20:39:01.01	42:22:49.9	J2000	13CO(3-2)	C18O(3-2)	M08AU19	scuba-2	M11BEC30
S255	06:12:53.7	17:59:22.1	J2000	13CO(3-2)	C18O(3-2)	M08BU18	scuba-2	M11BD02
CEP_A	22:56:18.1	62:01:46.2	J2000	13CO(3-2)	C18O(3-2)	M08BU18	scuba-2	M13AU03
W51	19:23:04.16	14:36:25.90	J2000	13CO(3-2)	C18O(3-2)	M08AU06	scuba-2	M16AP046
W51W	19:23:11.0	14:26:38.1	J2000	13CO(3-2)	C18O(3-2)	M08AU06	scuba-2	M16AP046
W51M	19:23:43.9	14:30:29.4	J2000	13CO(3-2)	C18O(3-2)	M08AU06	scuba-2	M16AP046
w43North	18:47:36	-01:57:00	J2000	13CO(3-2)	C18O(3-2)	M10AC06	scuba-2	S13AU02
W43_Main3	18:47:47.2	-01:54:35.1	J2000	13CO(3-2)	C18O(3-2)	M10AC06	scuba-2	MJLSJ02
w43South	18:46:00	-02:42:00	J2000	13CO(3-2)	C18O(3-2)	M10AC06	scuba-2	MJLSJ02
S231	05:39:12.9	35:45:54	J2000	13CO(3-2)	C18O(3-2)	M11BN07	scuba-2	MJLSY02
W3(2)	02:25:40.6	62:05:51.1	J2000	13CO(3-2)	C18O(3-2)	M07BH45B	scuba-2	M13BC07
RCW142	17:50:14.7	-28:54:31.6	J2000	13CO(3-2)	C18O(3-2)	M15AI18	scuba-2	M12AJ01
W28A2(1)	18:00:30.4	-24:03:58.5	J2000	13CO(3-2)	C18O(3-2)	M09AU13	scuba-2	M12AJ01
W33cont	18:14:13.7	-17:55:25.2	J2000	13CO(3-2)	C18O(3-2)	M10BD02	scuba-2	MJLSJ02

Cep A



Range of velocity of CO (-20 _ 0)



Back ground grey map: ^{13}CO (3-2) observed with HARP;
contour map are 850 micron emission observed with SCUBA -2

850 micron emission contour level: 49.5037, 26.5168, 3.52986, 0.5

850 micron emission contour level: 50.7693, 39.3769, 27.9845, 16.5921, 5.19972, 0.5

Next steps

◆ Stellar clusters

1) to identify the new clusters with WISE data
2) check the age of all the clusters including the clusters published in literature

◆ Molecular cloudy core

1) getting the Mass of GMC cores with ^{13}CO (3-2) data
2) getting physical parameters of GMC cores with other dense gas tracers data

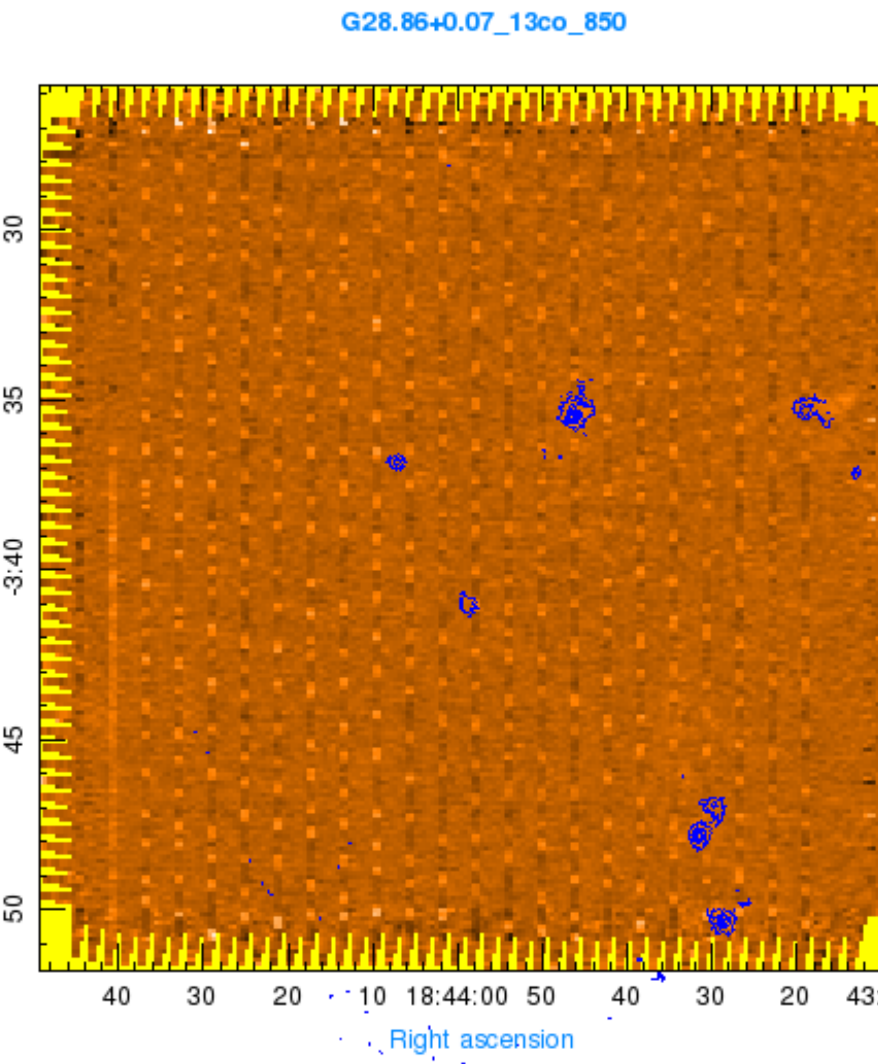
◆ Comparing the Initial Mass function (MF) of clusters with the MF of GMC cores

1) getting the mass function of GMC cores with simulation method
2) try to get more high resolved data to get the Mass function of GMC cores
3) try to get the Initial MF of clusters with optical and IR data.

◆ Checking SFL with star clusters

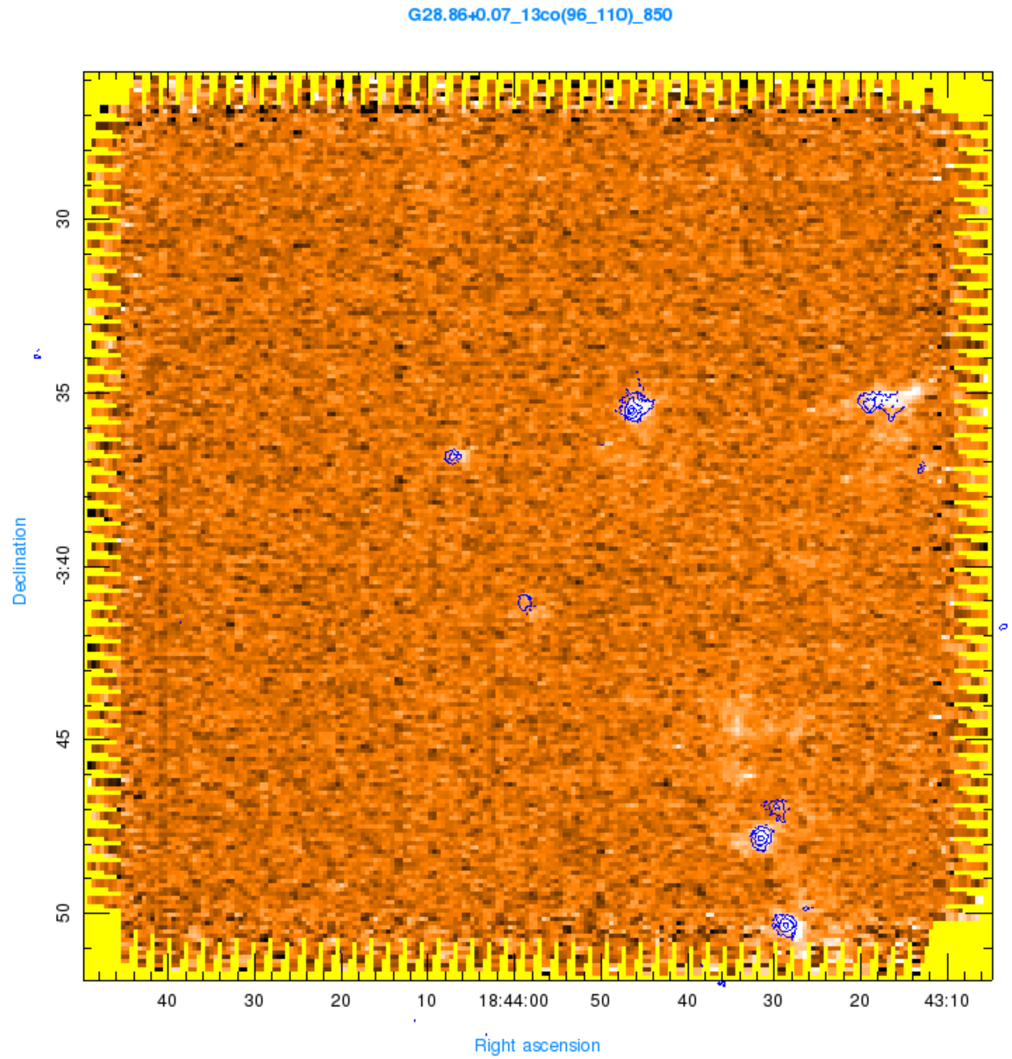
1) getting the luminosity of CO (3-2) of the molecular cloudy cores
2) identify the distance of clusters with gaia data to remove the front and back clusters
3) getting the mass of clusters to check the SFL

G28.86+0.07



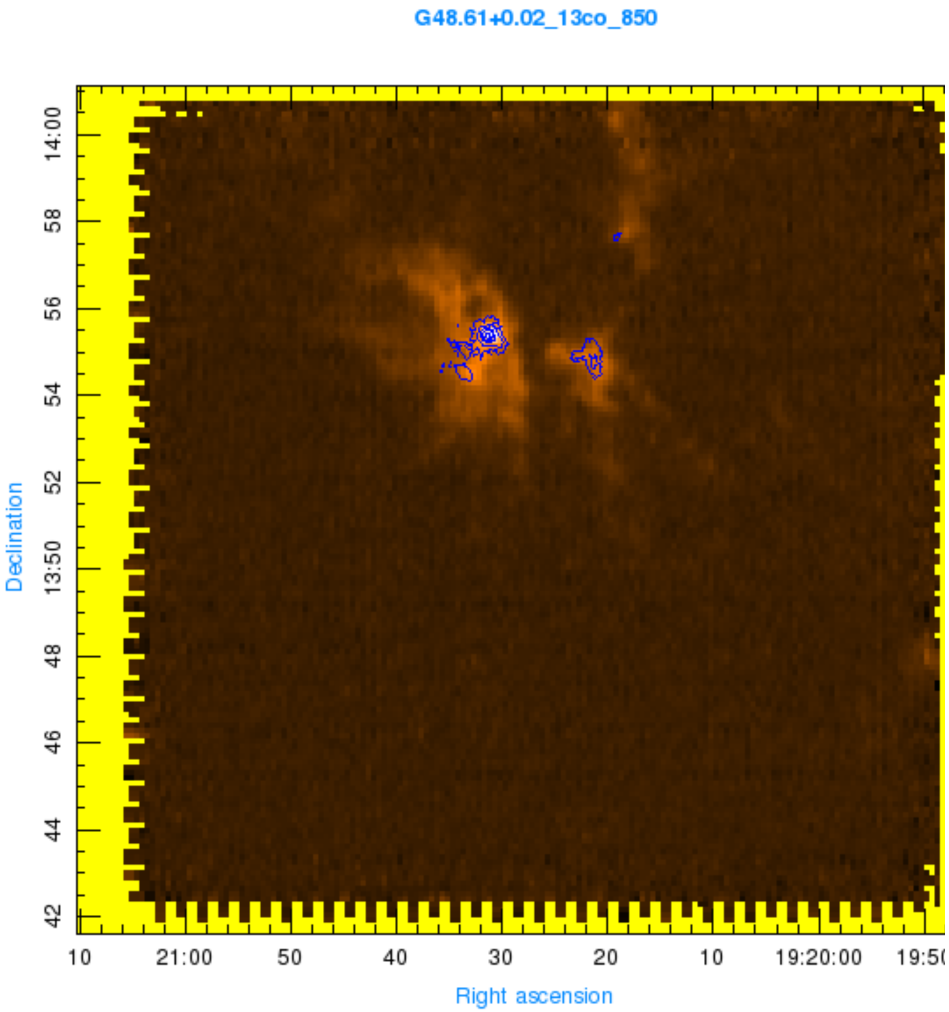
The contour level: 1.74429, 4.27113, 6.79797, 9.32482, 12

Range of velocity (96 _ 110)



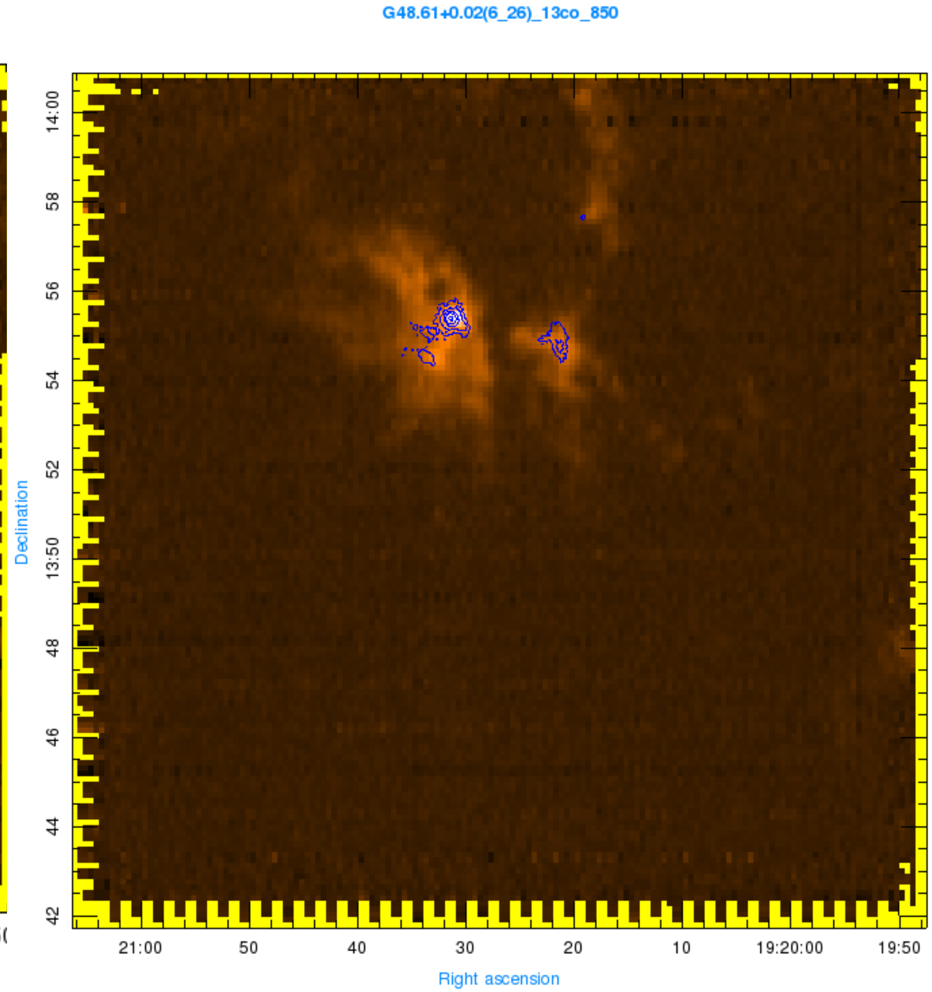
The contour level: 2, 4.27113, 9.32482,12

G48.61+0.02



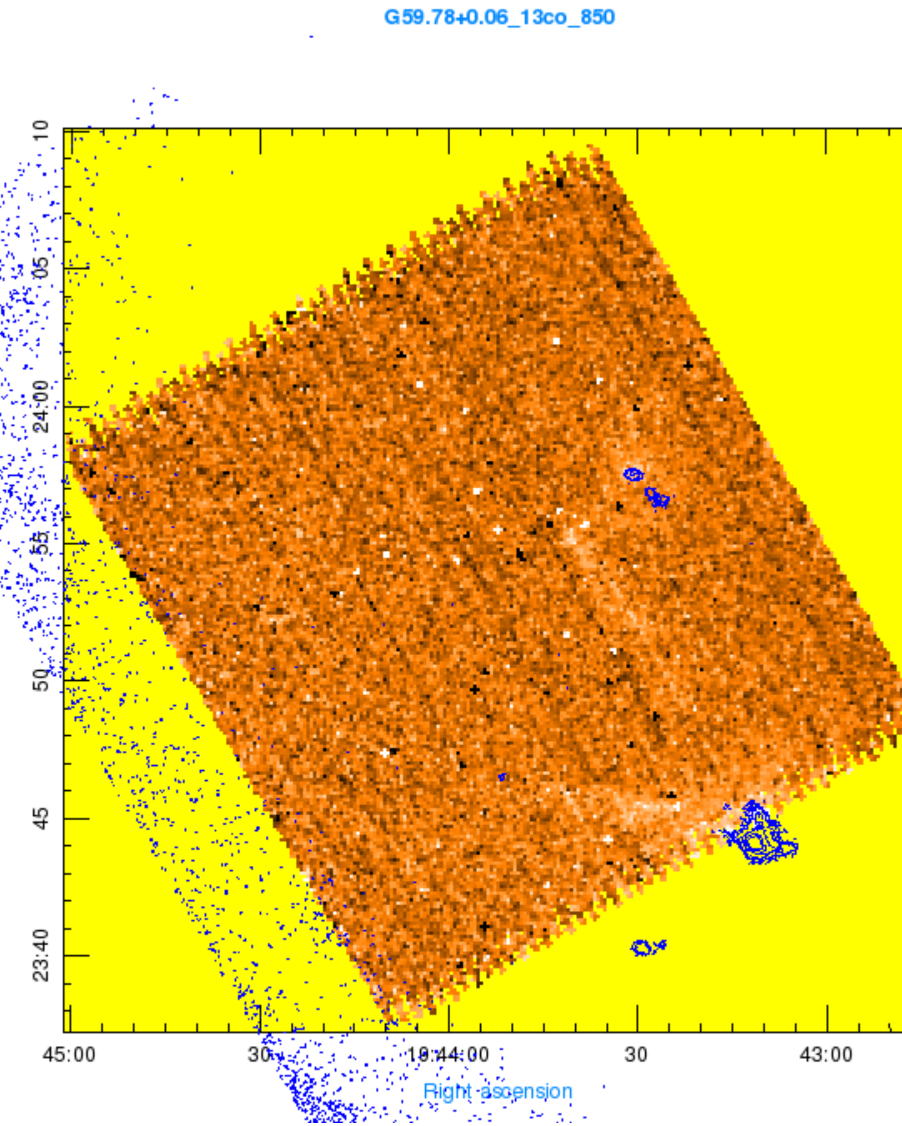
The contour level: 14, 10, 7, 4, 2.5

Range of velocity (6 _ 26)



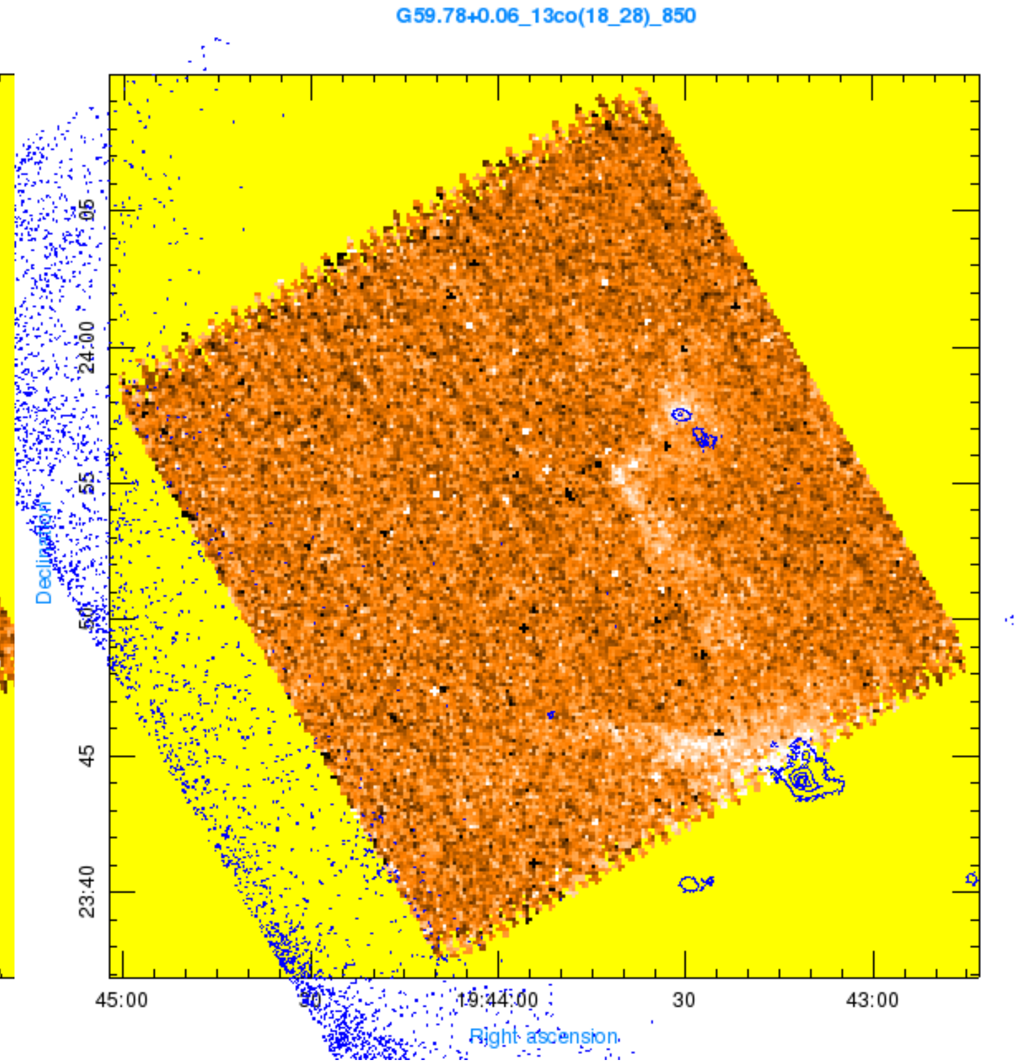
The contour level: 14, 10, 7, 4, 2.7132

G59.78+0.06



The contour level: 7, 5, 3, 1.5, 1

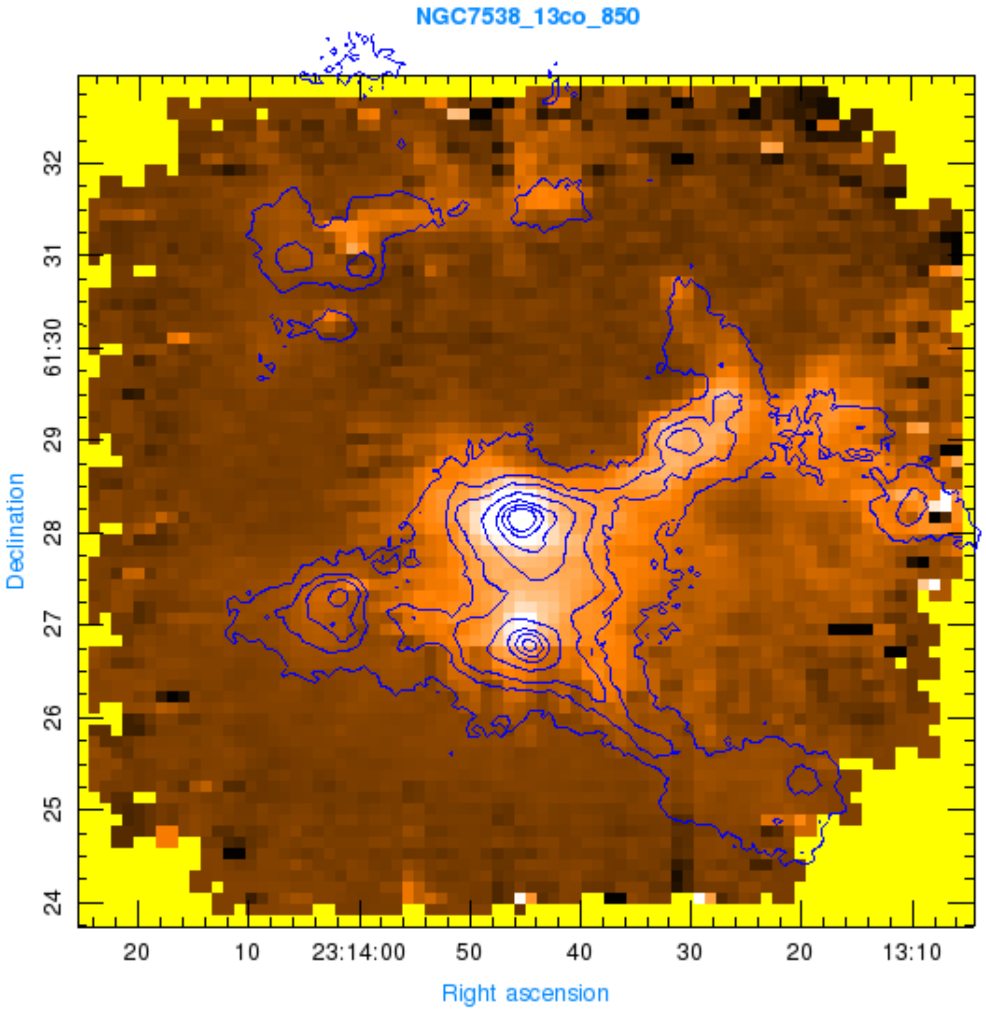
Range of velocity (18_28)

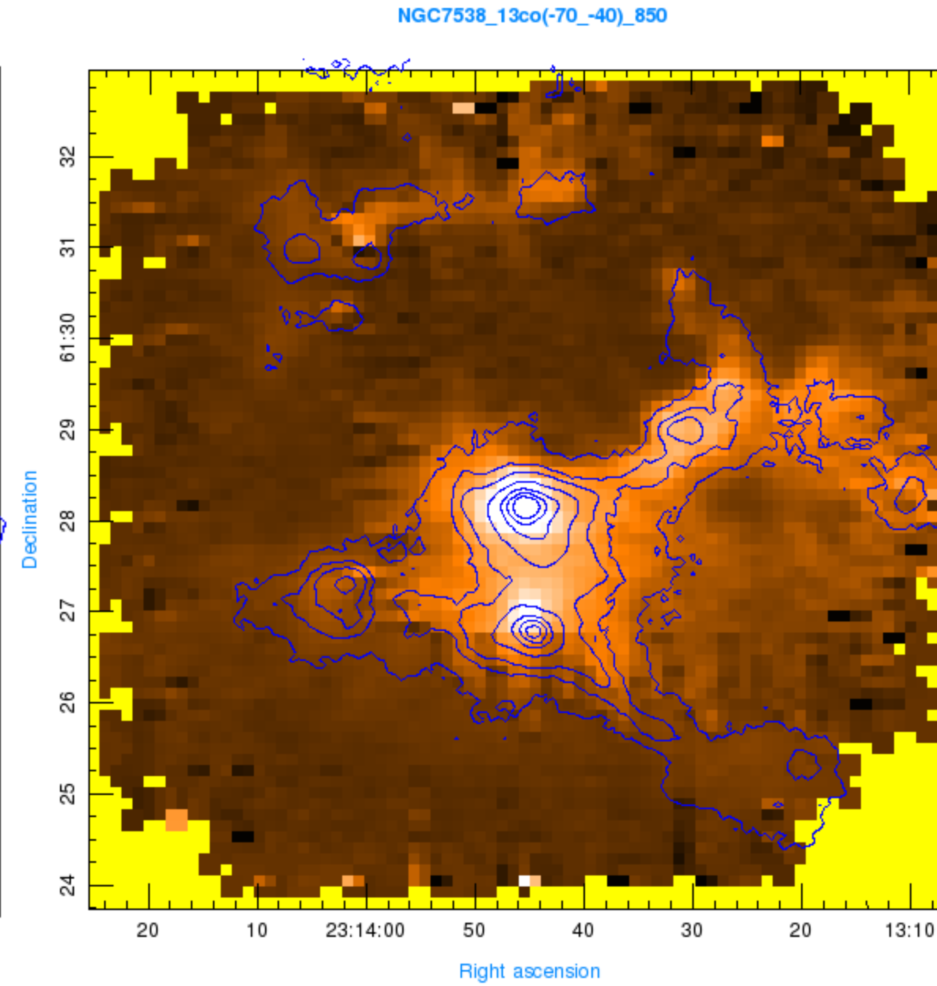


The contour level: 12.4829, 9. 42406, 6.38524, 3.34642, 1

NGC7538

Range of velocity (-70_ -40)

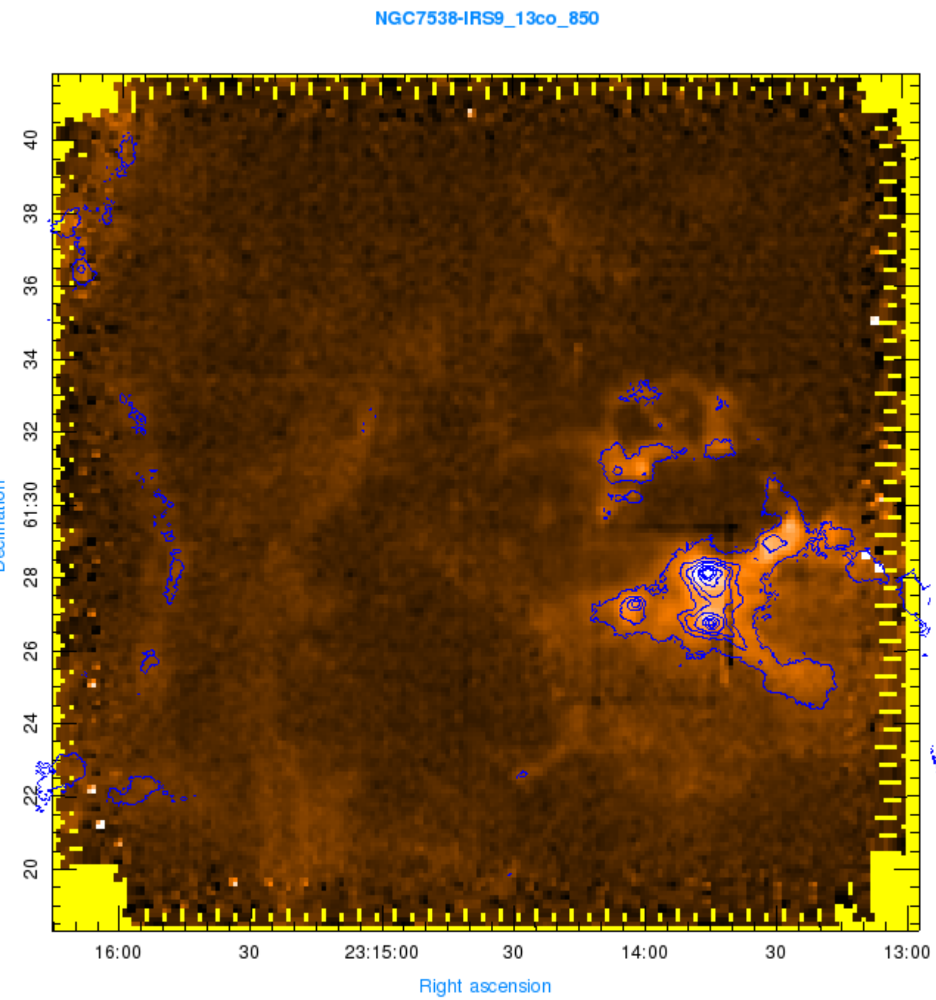


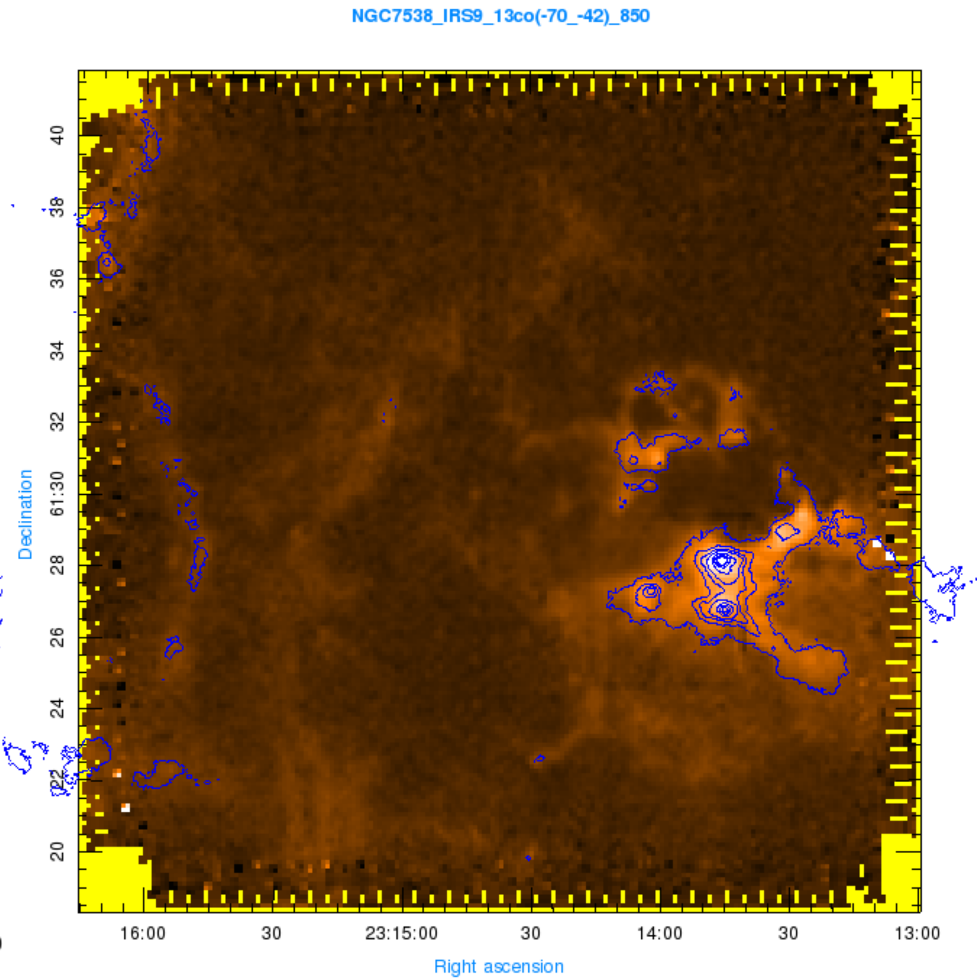


The contour level: 39.729, 29.8928, 20.0588, 10.2204, 5, 3, 1

NGC7538-IRS9

Range of velocity (-70 _ -42)



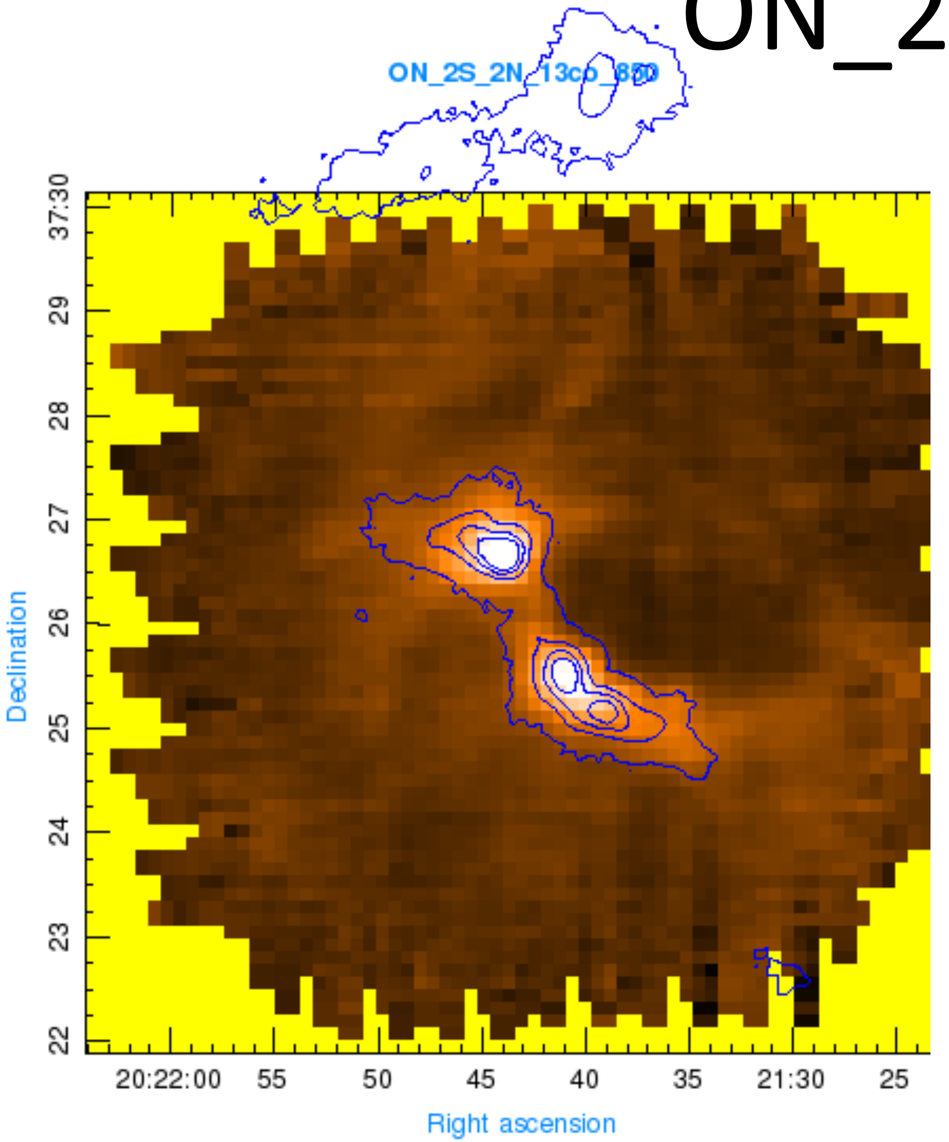


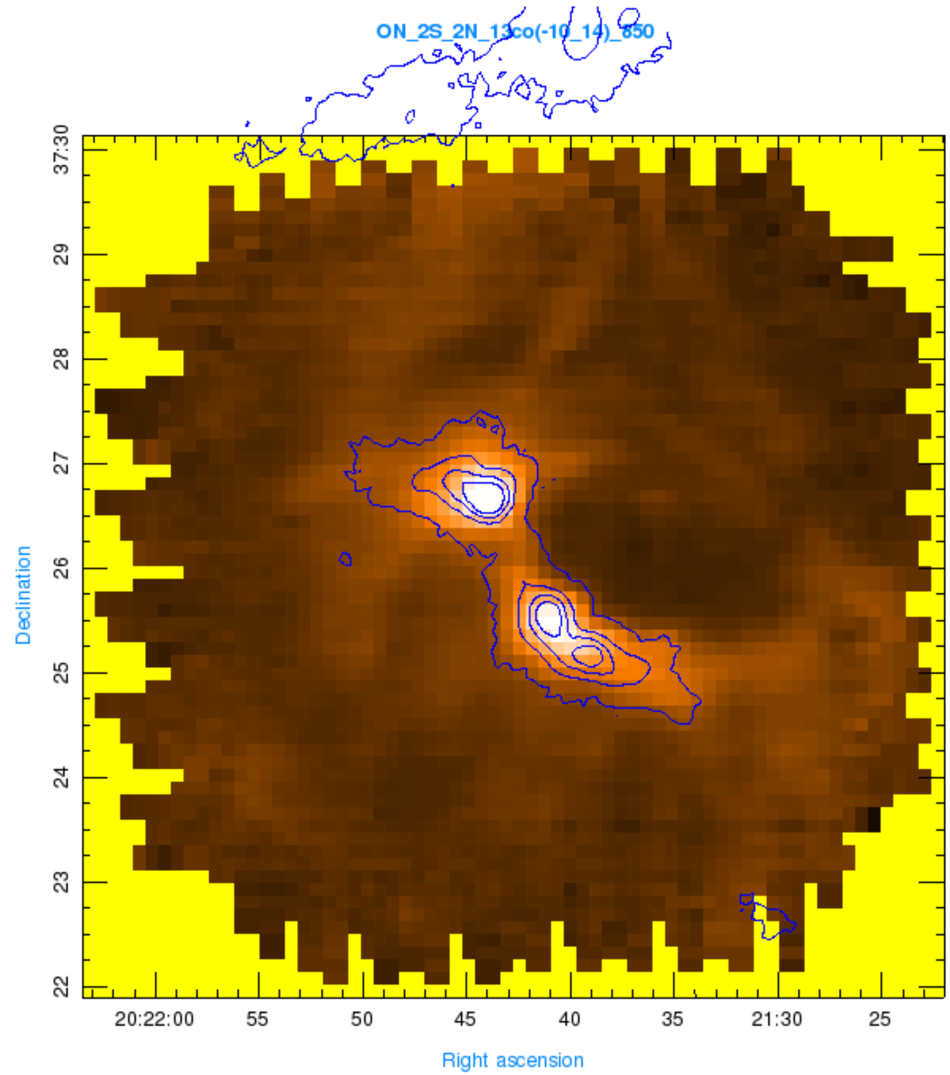
The contour level: 39.729, 29.8928, 20.0588, 10.2204, 5, 3, 1

The contour level: 39.729, 29.8928, 20.0588, 10.2204, 7, 4, 1

ON_2S_2N

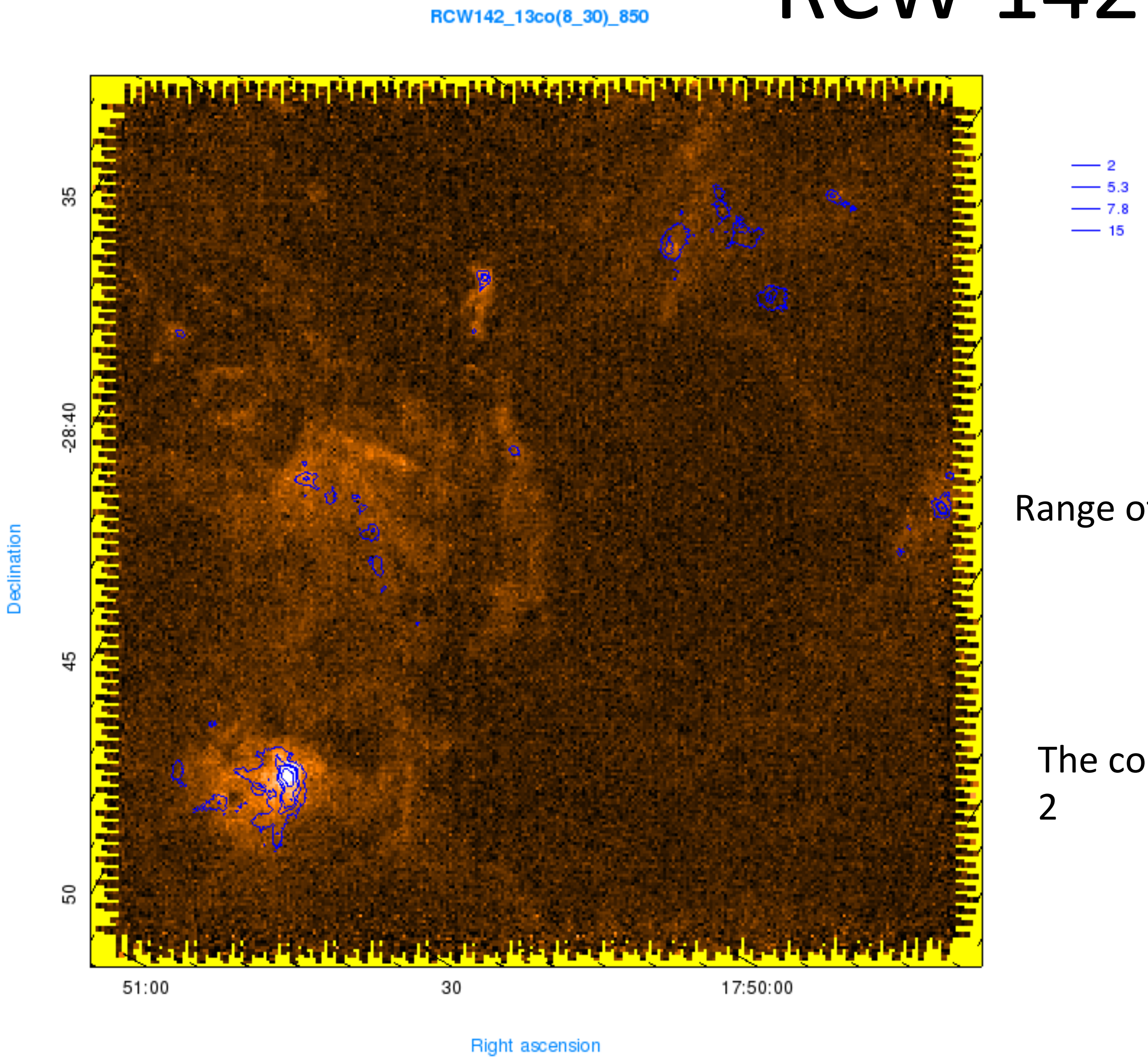
Range of velocity (-10 _ 14)





The contour level: 14.479, 10.233, 5.98703, 1.74102

RCW 142

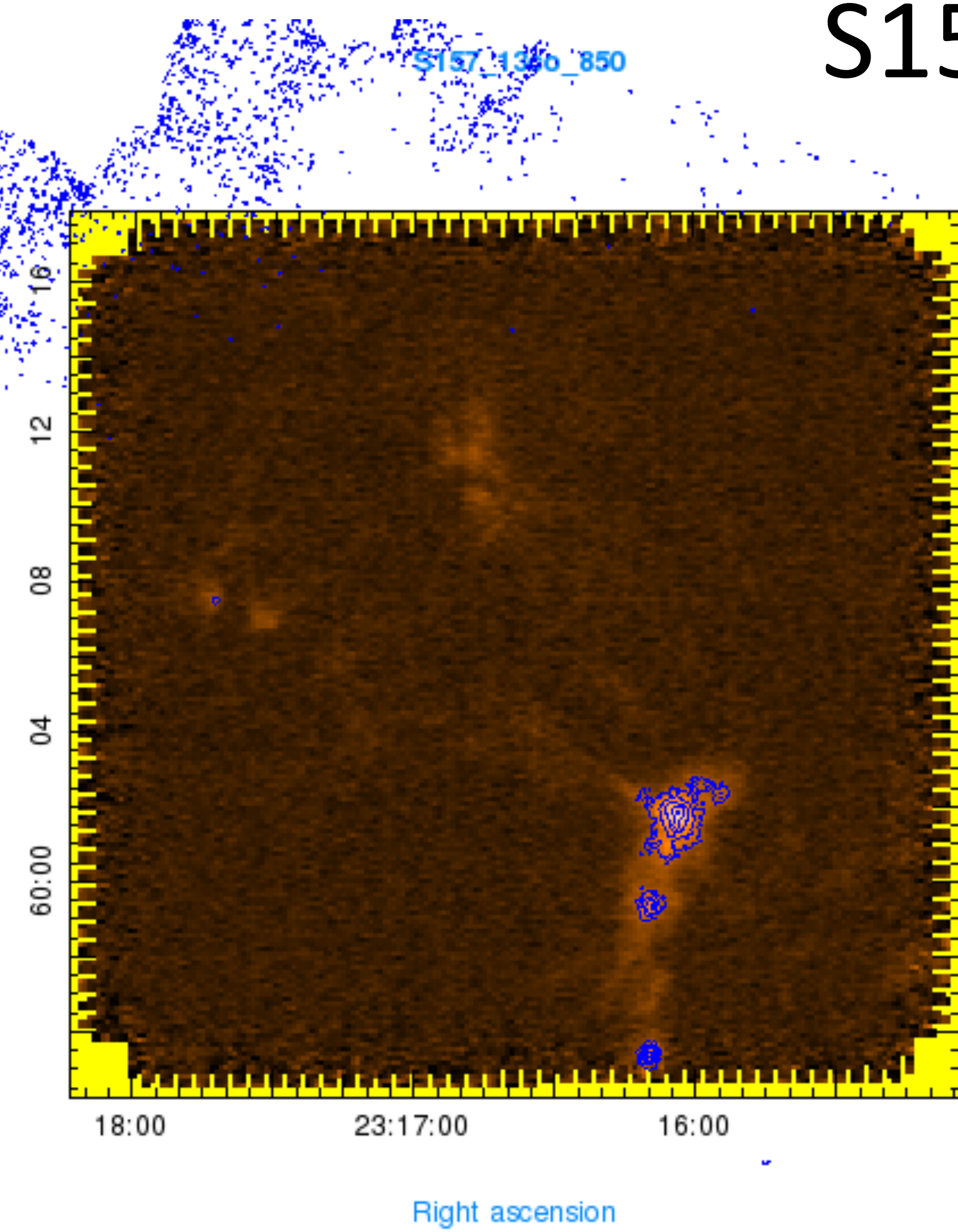


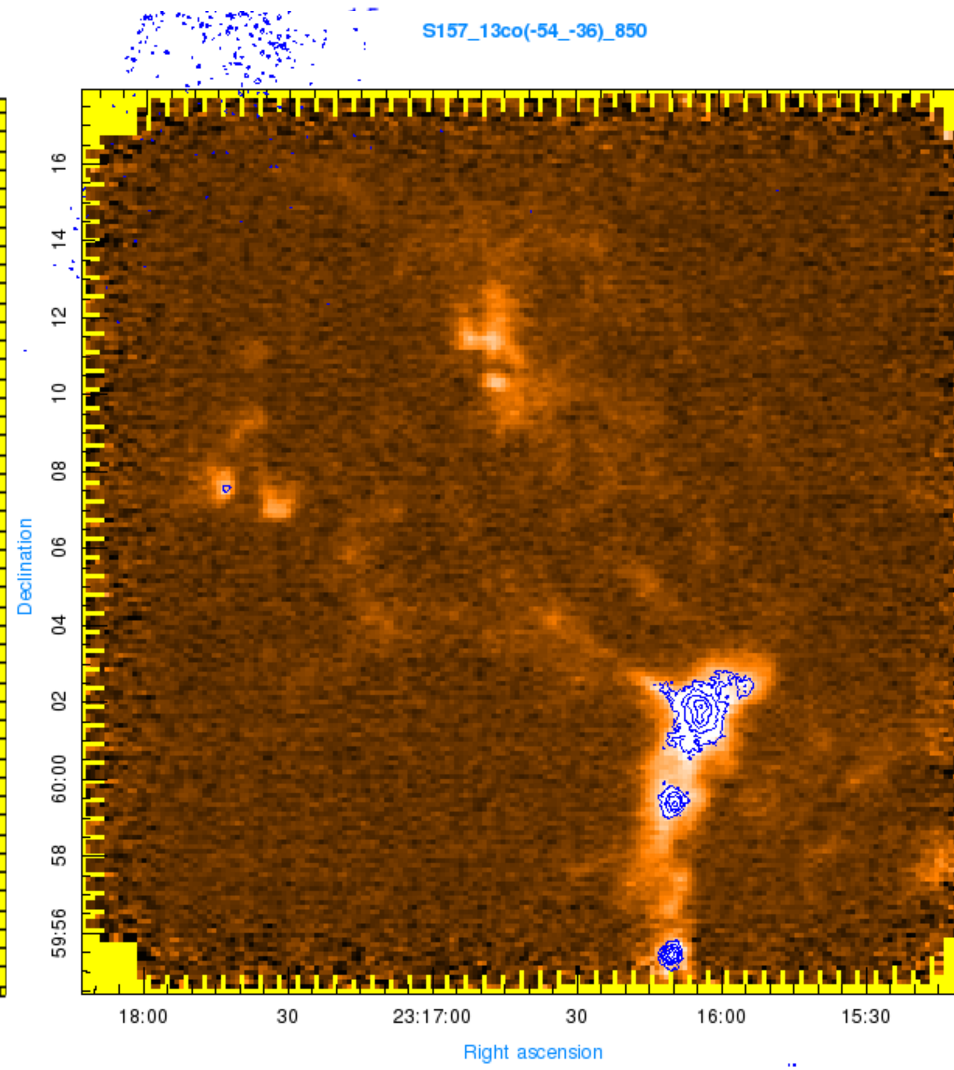
Range of velocity (8 _ 30)

The contour level: 15, 7.8, 5.3, 2

S157

Range of velocity (-54 _ 36)

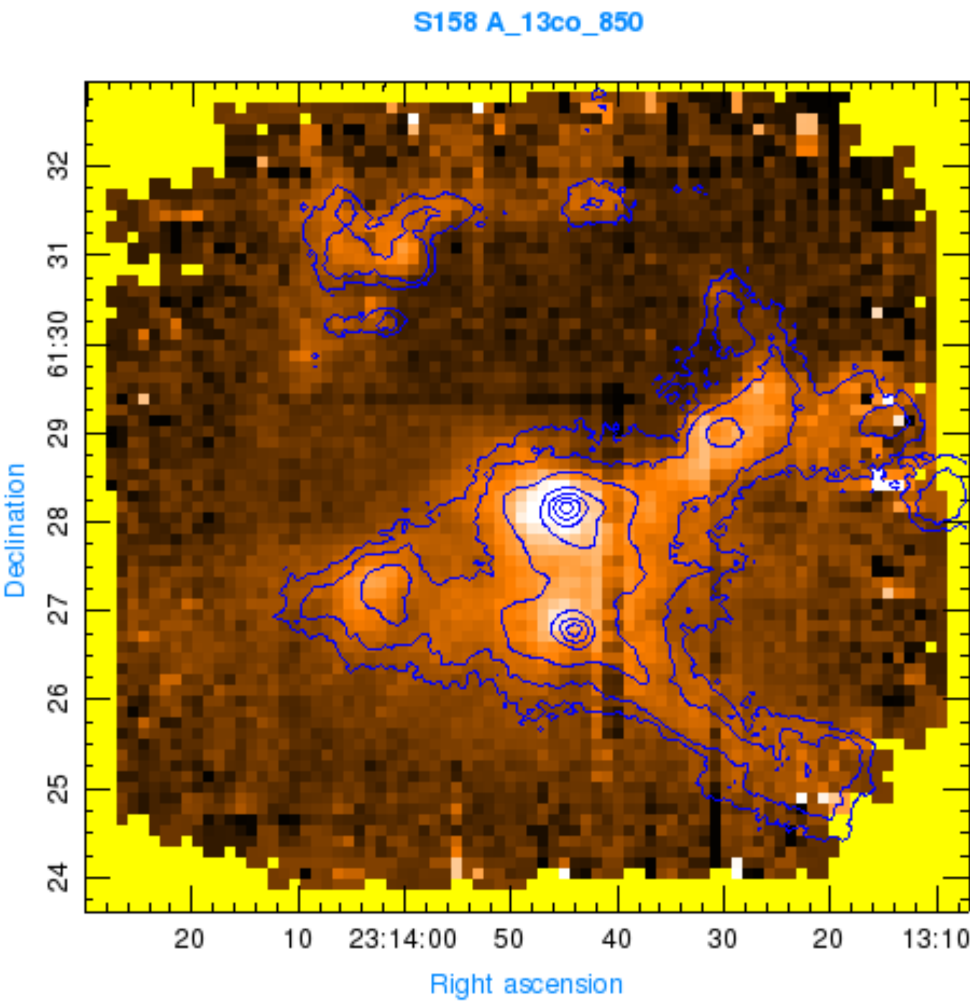


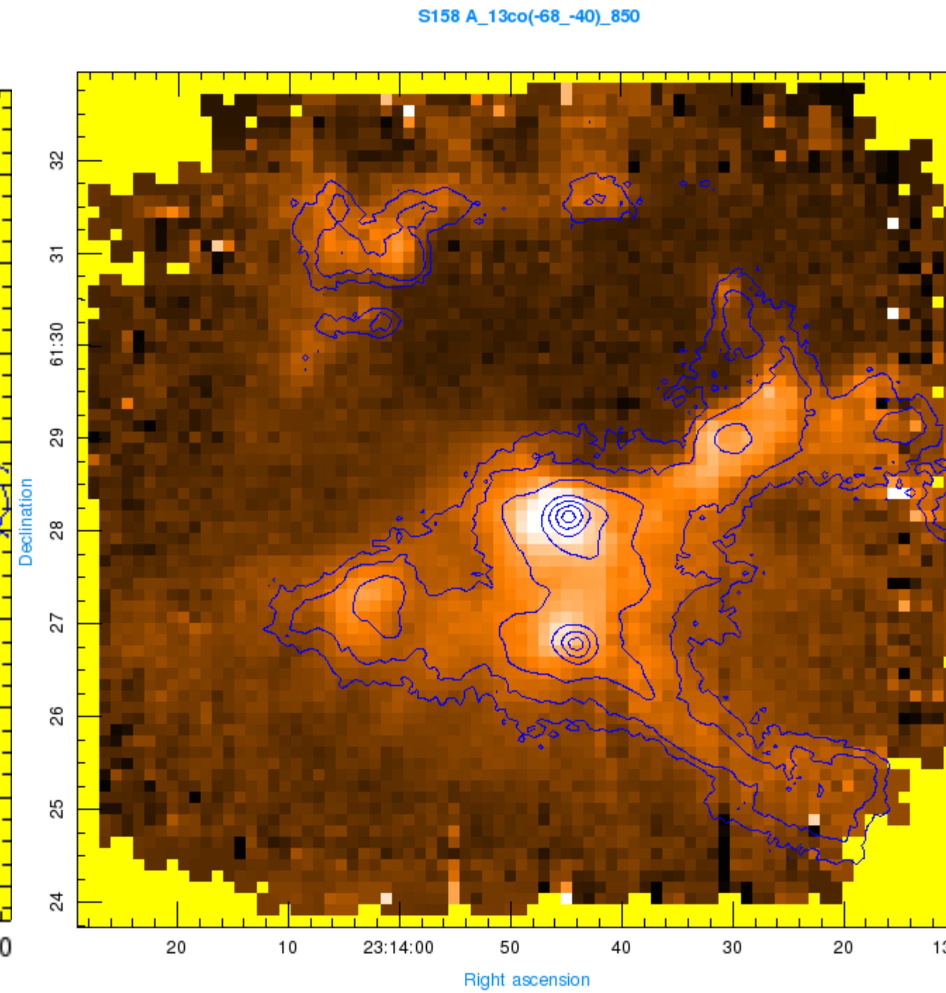


The contour level: 10, 9.61619, 6.15754, 2.69889, 4,1.5

S158A

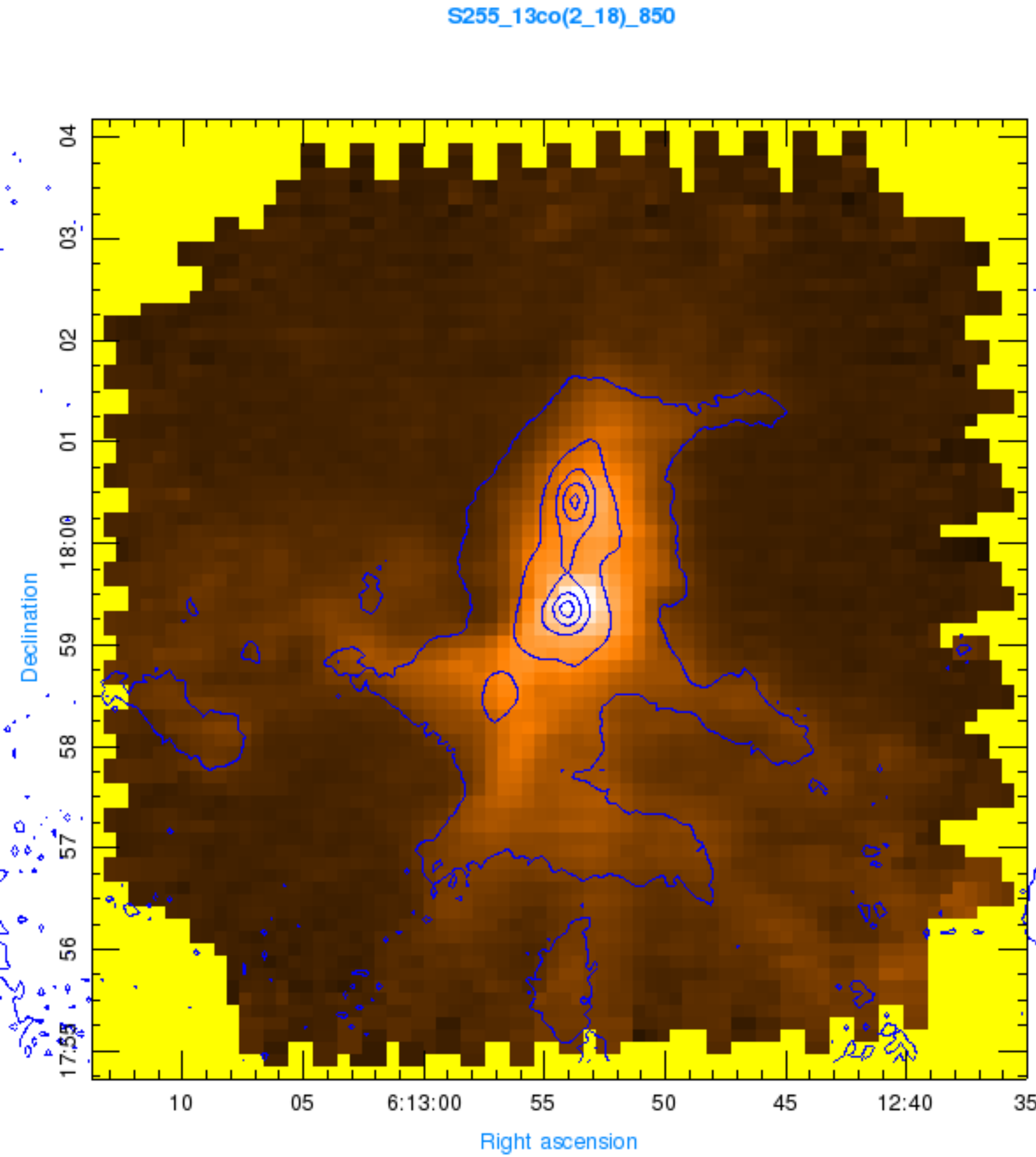
Range of velocity (-68 _ -40)





The contour level: 53.5301, 41.4752, 29.4203, 17.3654, 5.31045, 2, 1

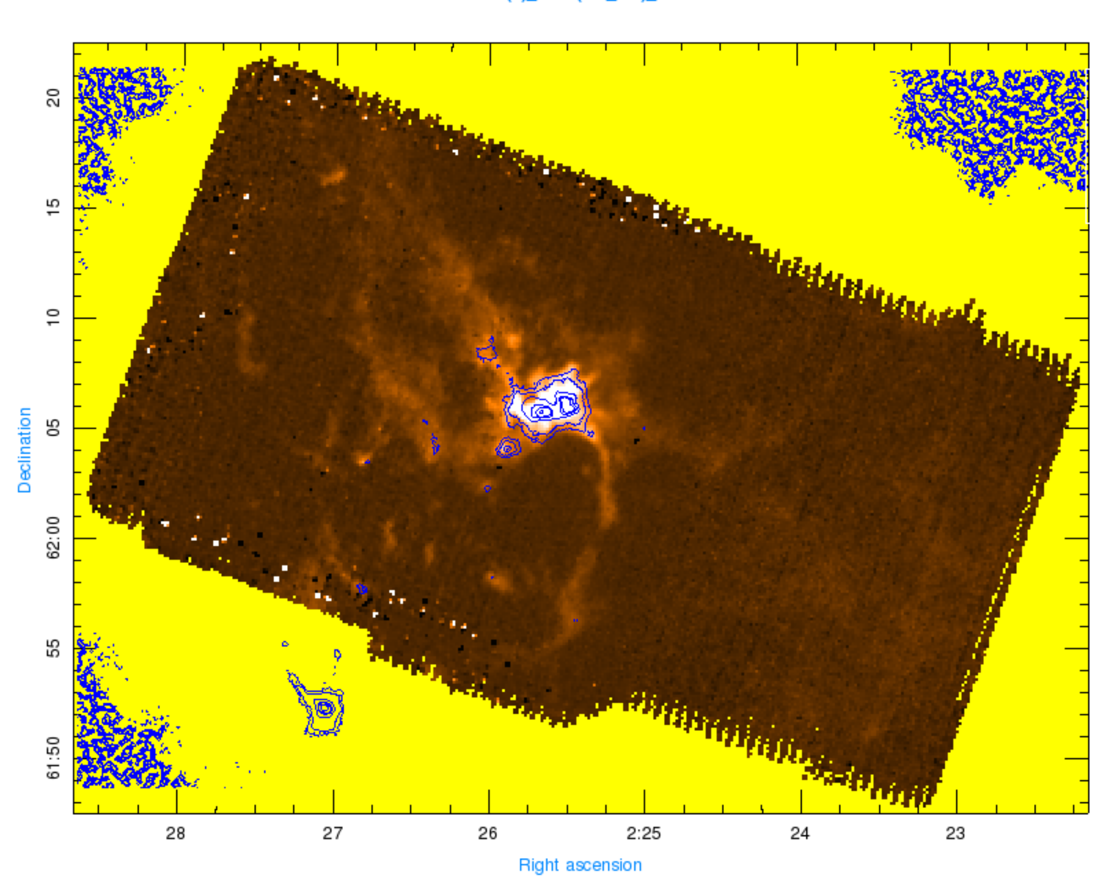
S255



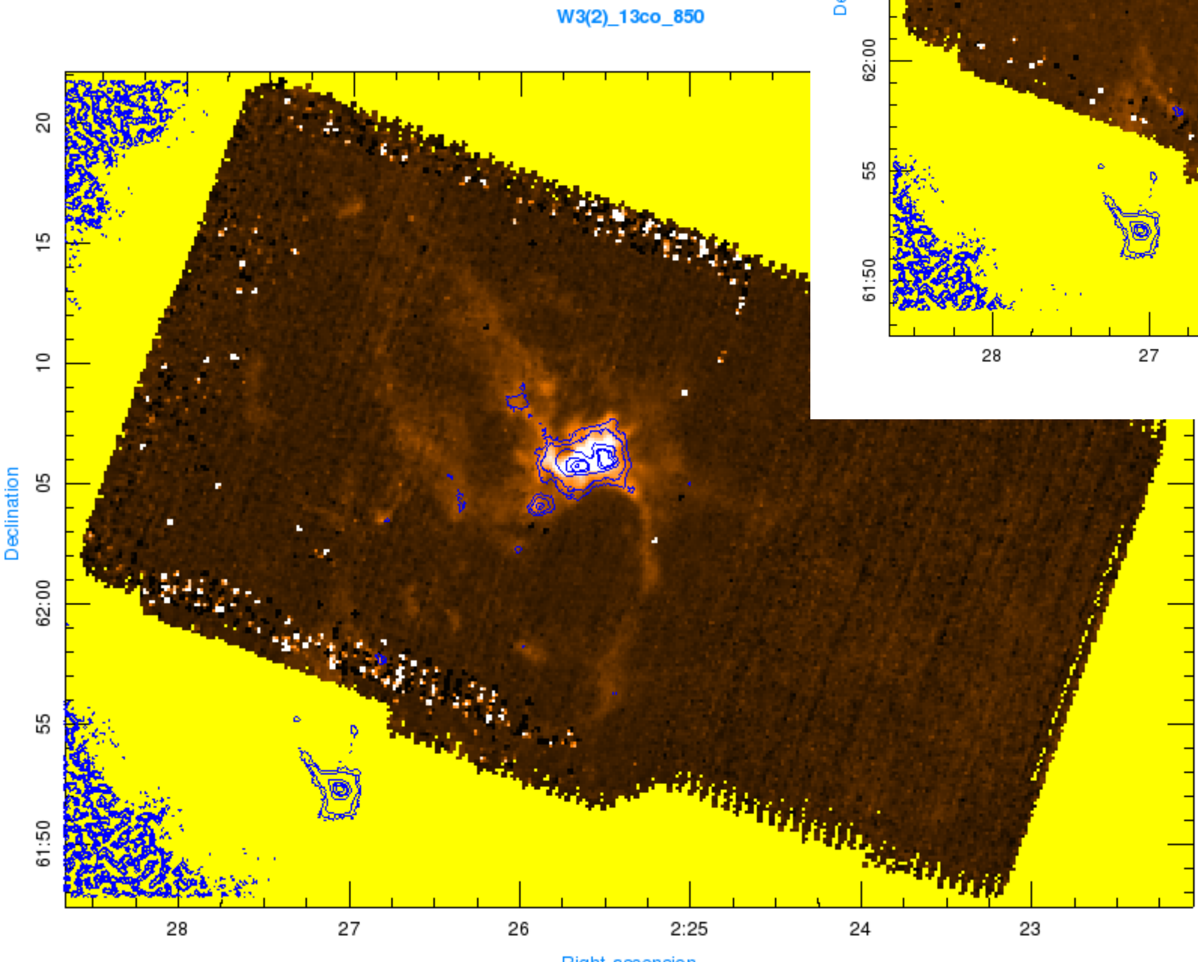
Range of velocity (2 _ 18)

The contour level:
4066.66, 2957.39, 1848.18, 738.978, 50

W3(2)

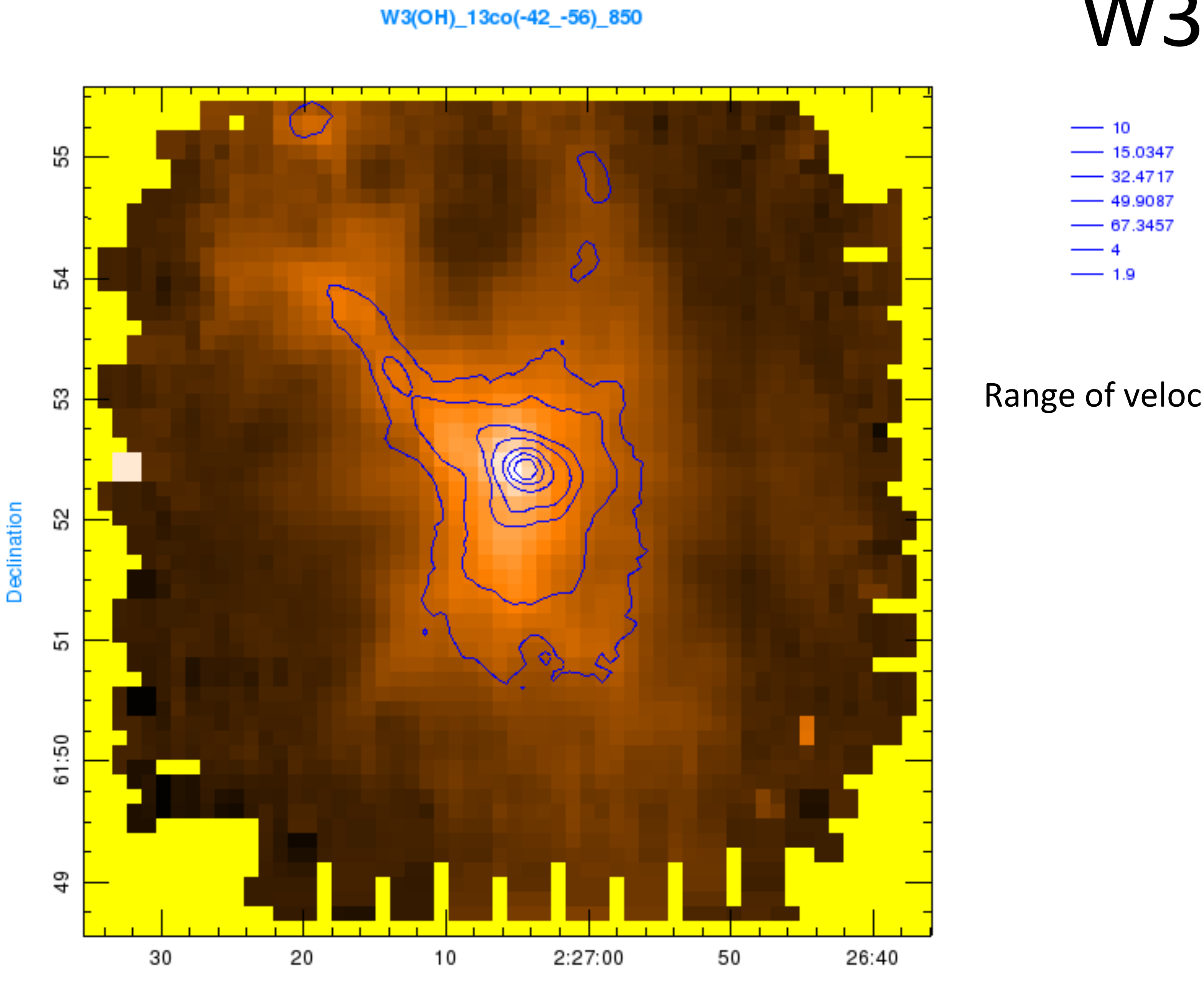


Range of velocity (-48 _ -30)



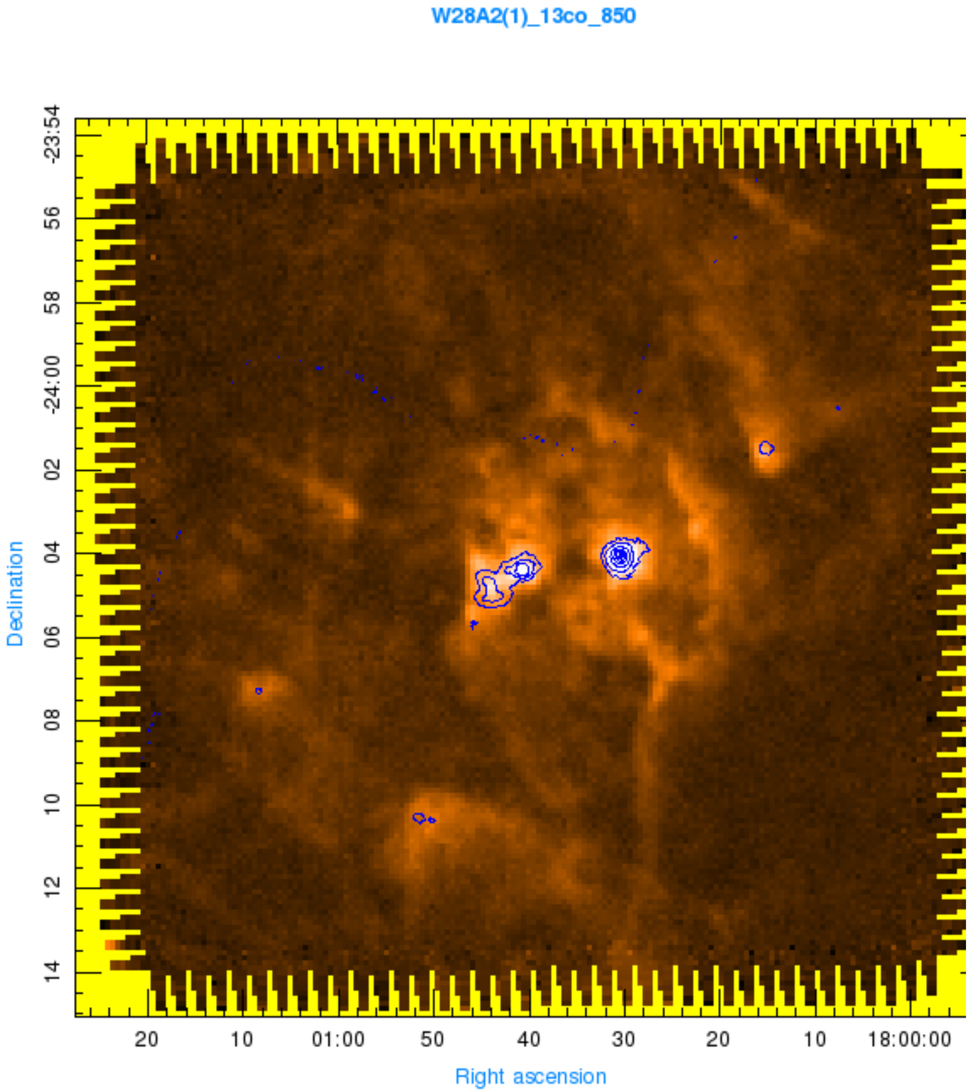
The contour level: 45, 20, 15, 9, 3, 1.7

W3OH

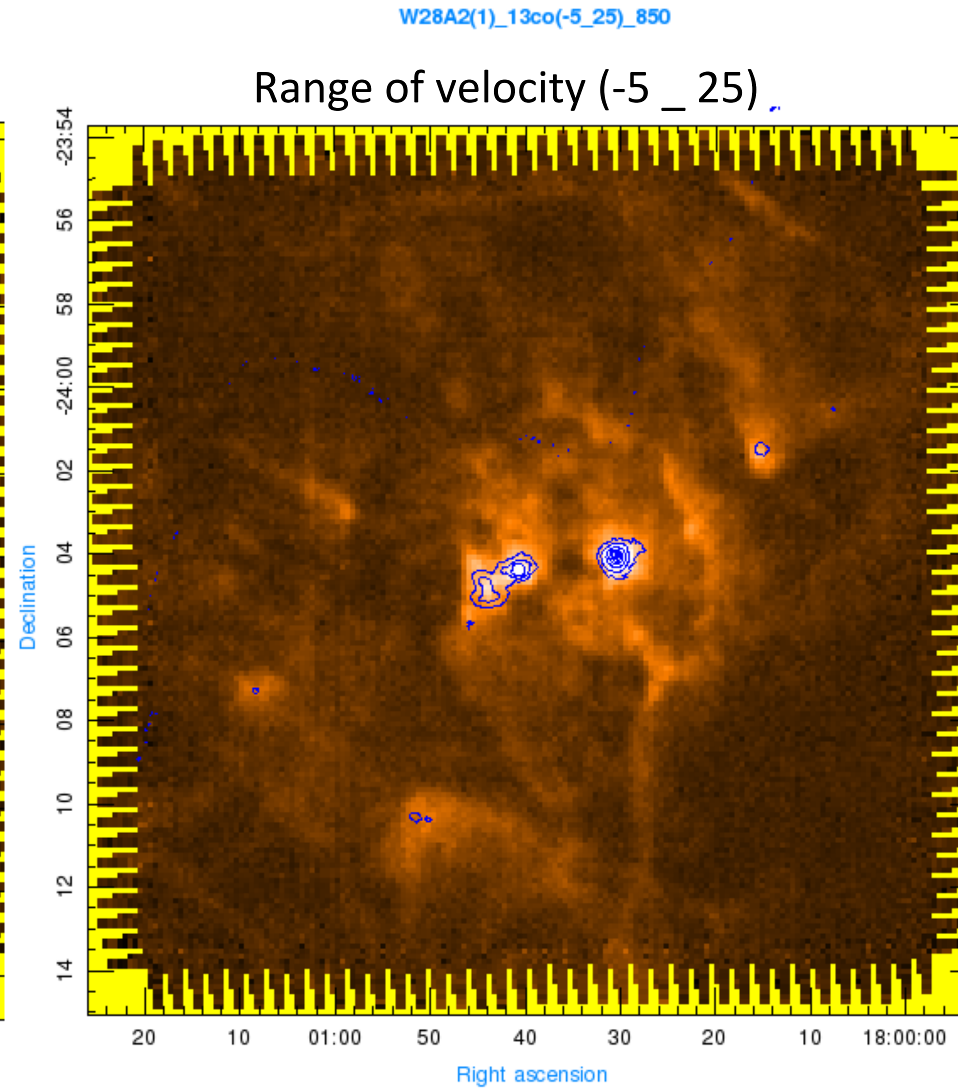


Range of velocity (-42 _ 56)

W28a

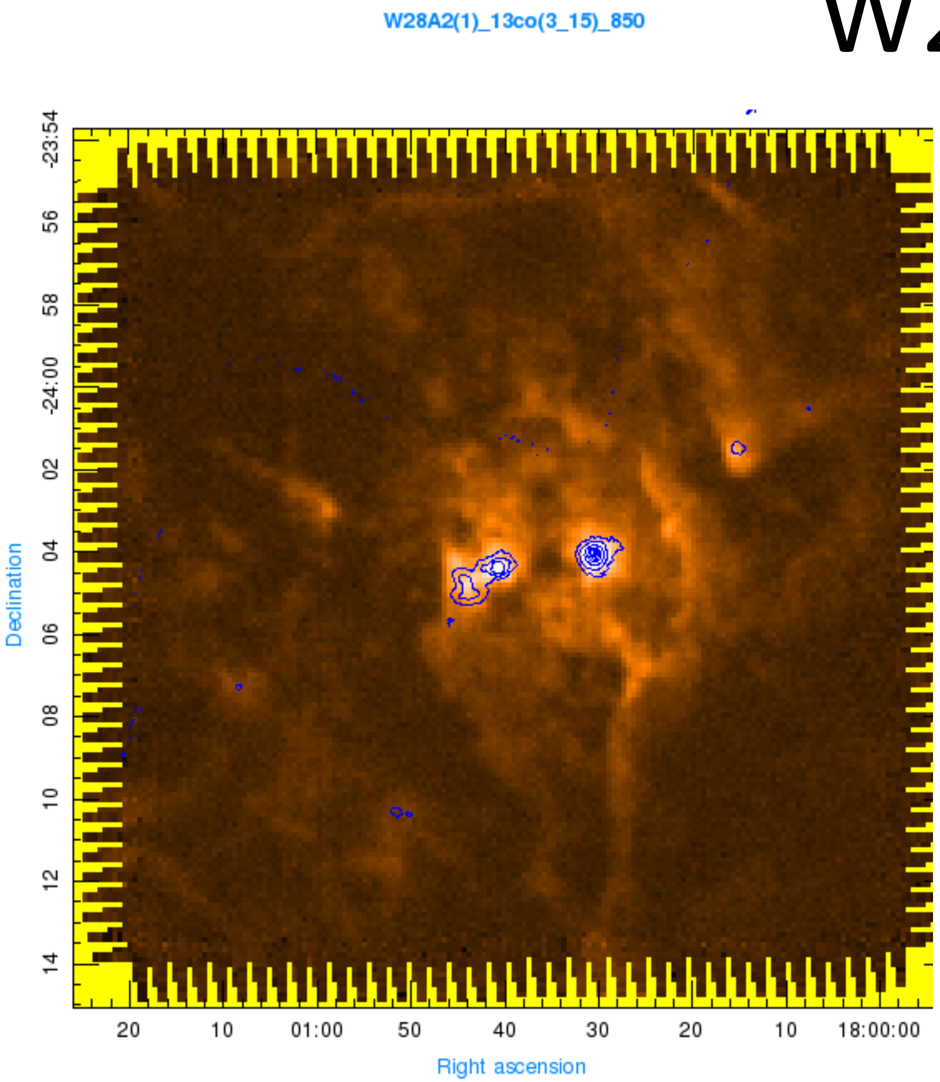


Range of velocity (-5 _ 25)

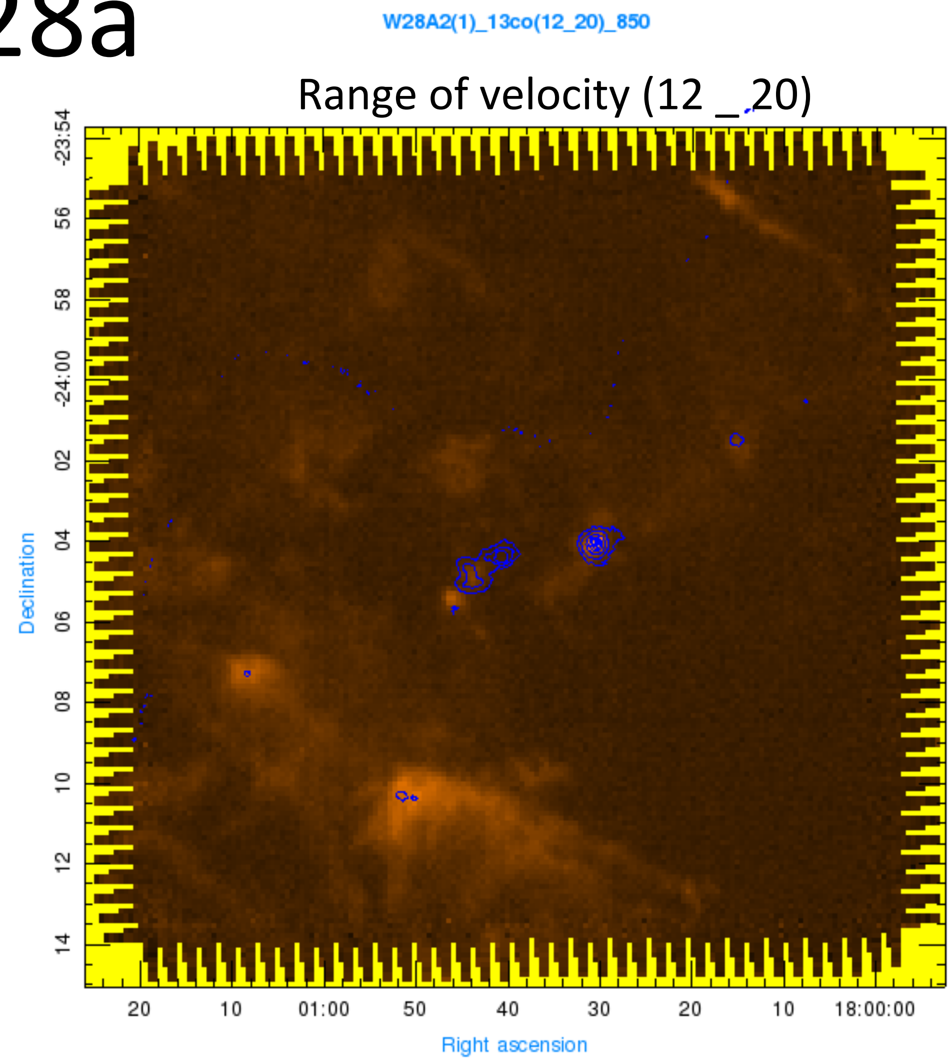


The contour level: 92.5437, 69.025, 45.5062, 21.9875, 10, 5

W28a

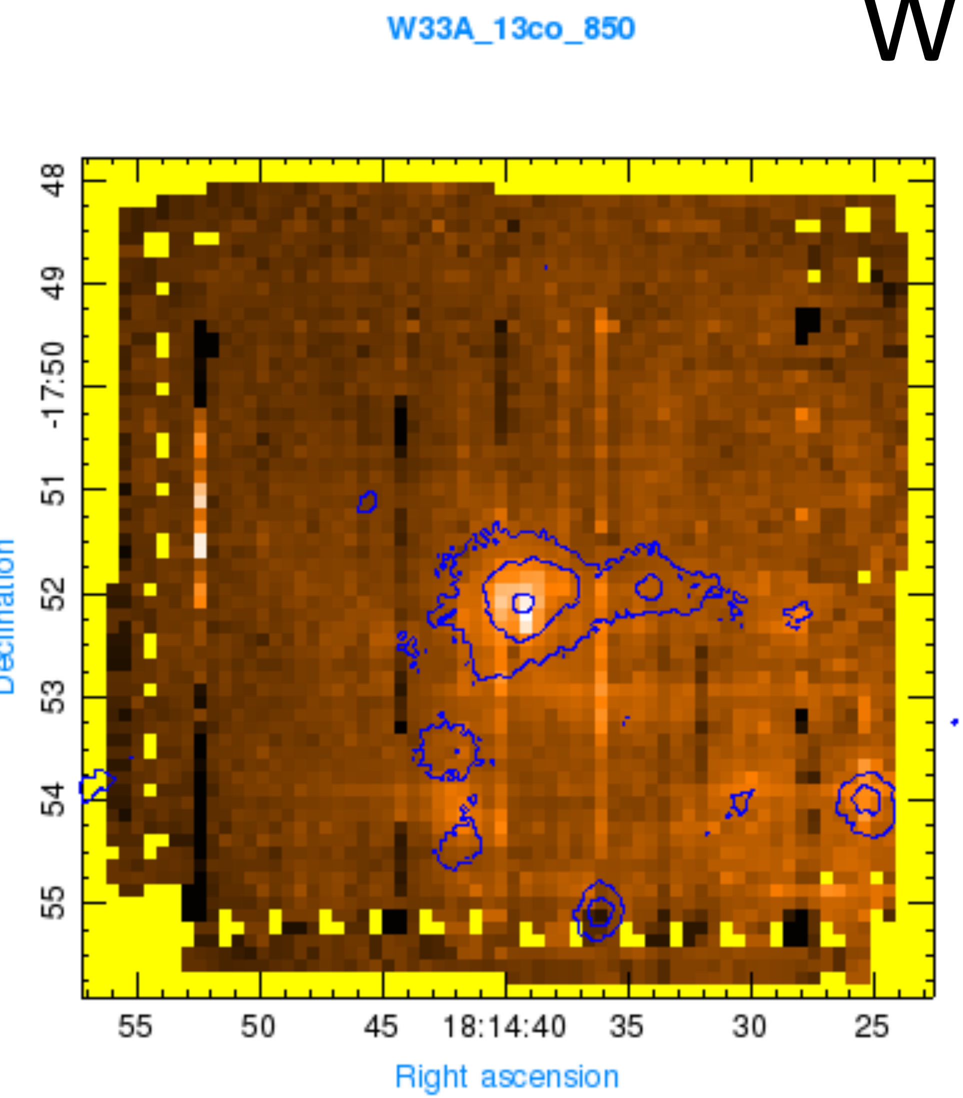


Range of velocity (12 _ 20)

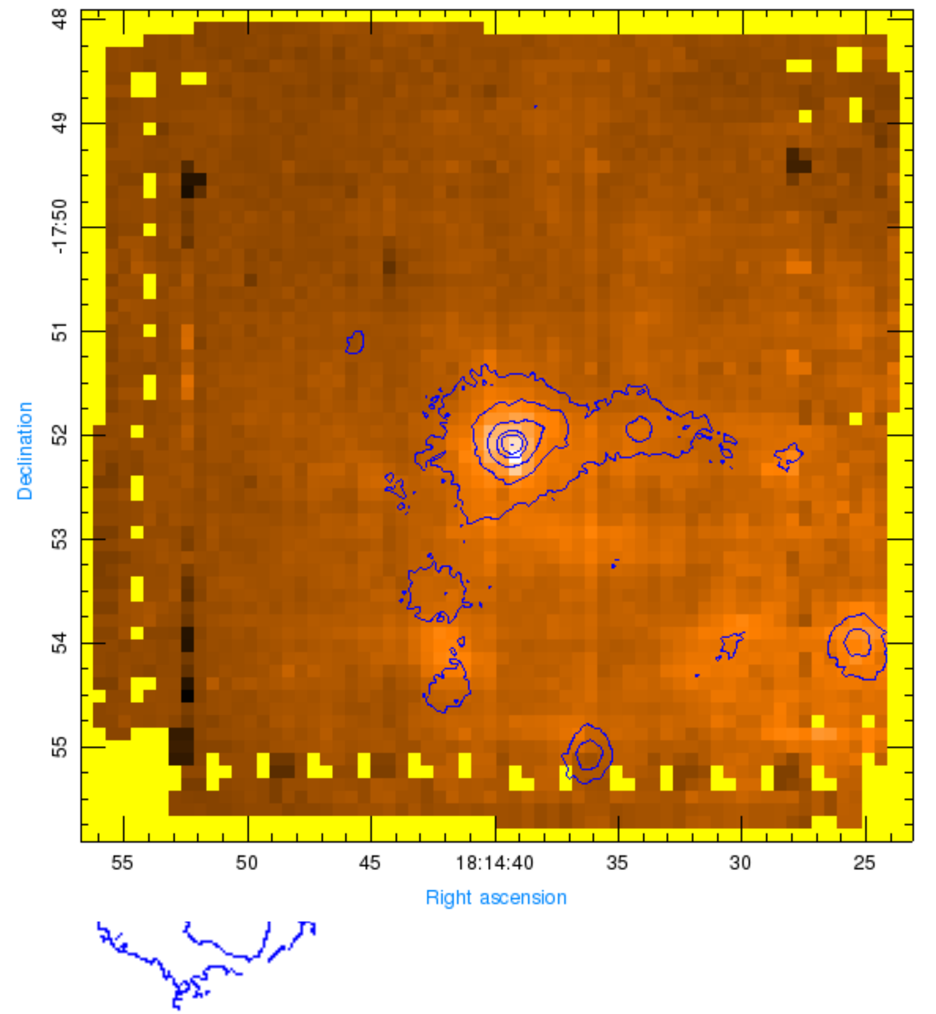


The contour level: 10, 9.61619, 6.15754, 2.69889, 4,1.5

W33A



Range of velocity (25 _ 50)

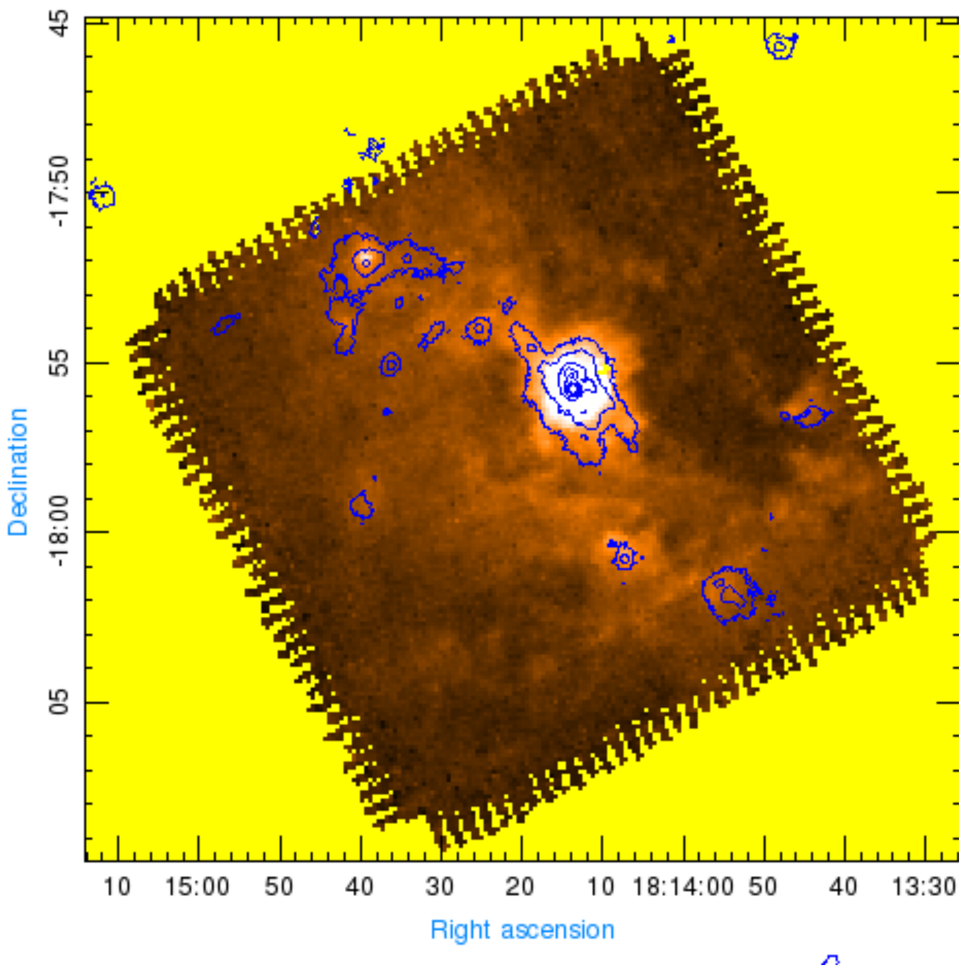


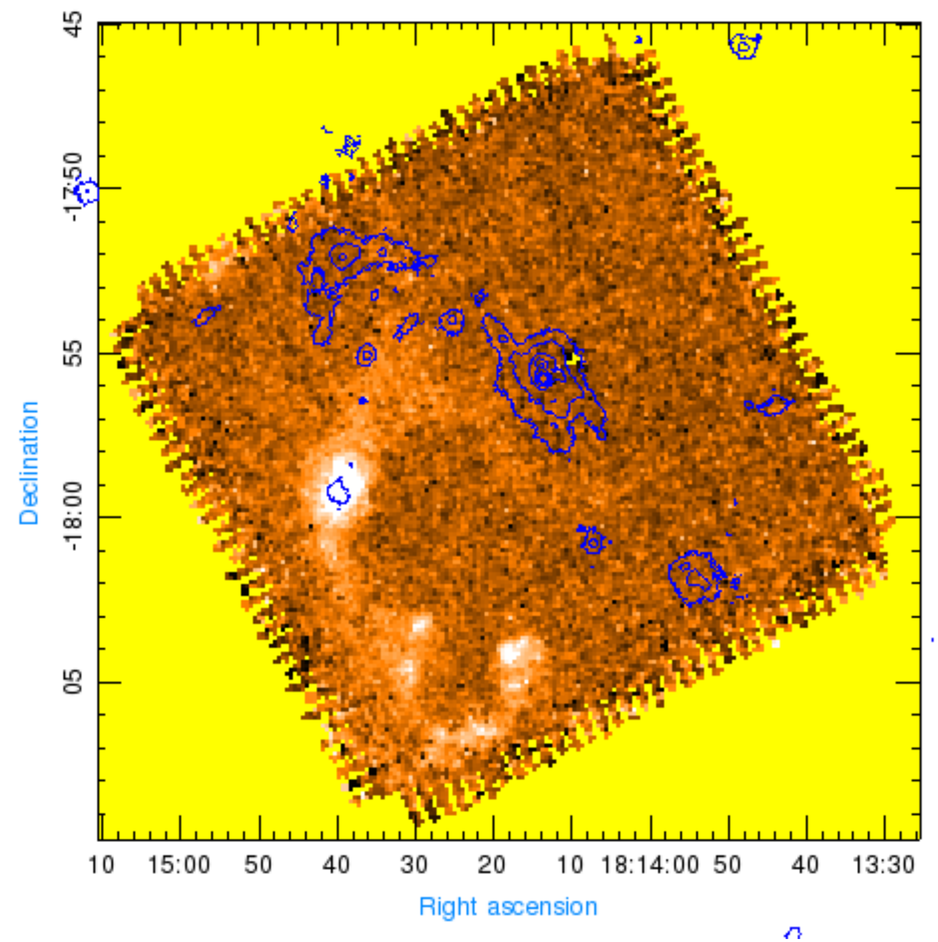
The contour level: 76.3796, 50.0402, 41.6829, 24.3255, 6.96819, 3

The contour level: 30, 24.3255, 20, 12, 6.96819, 3

W33cont

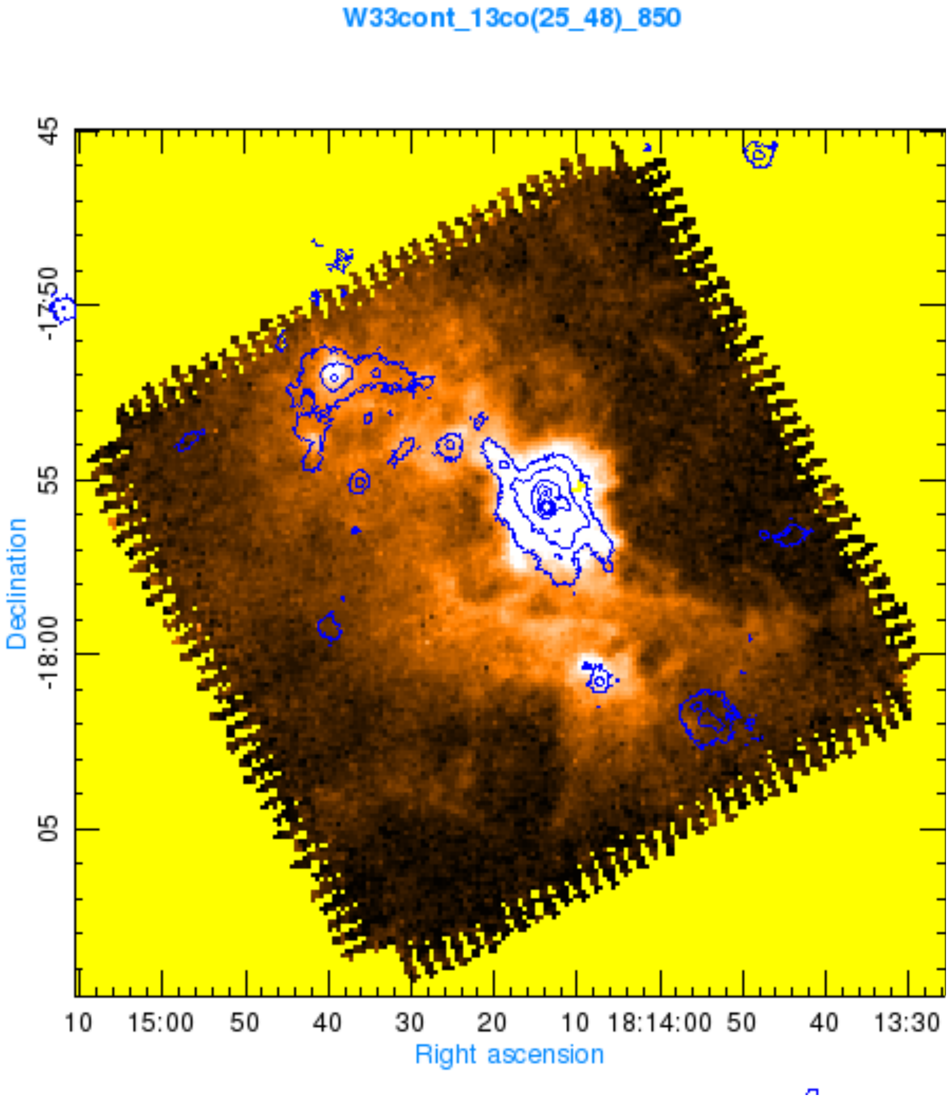
Range of velocity (8 _ 20)



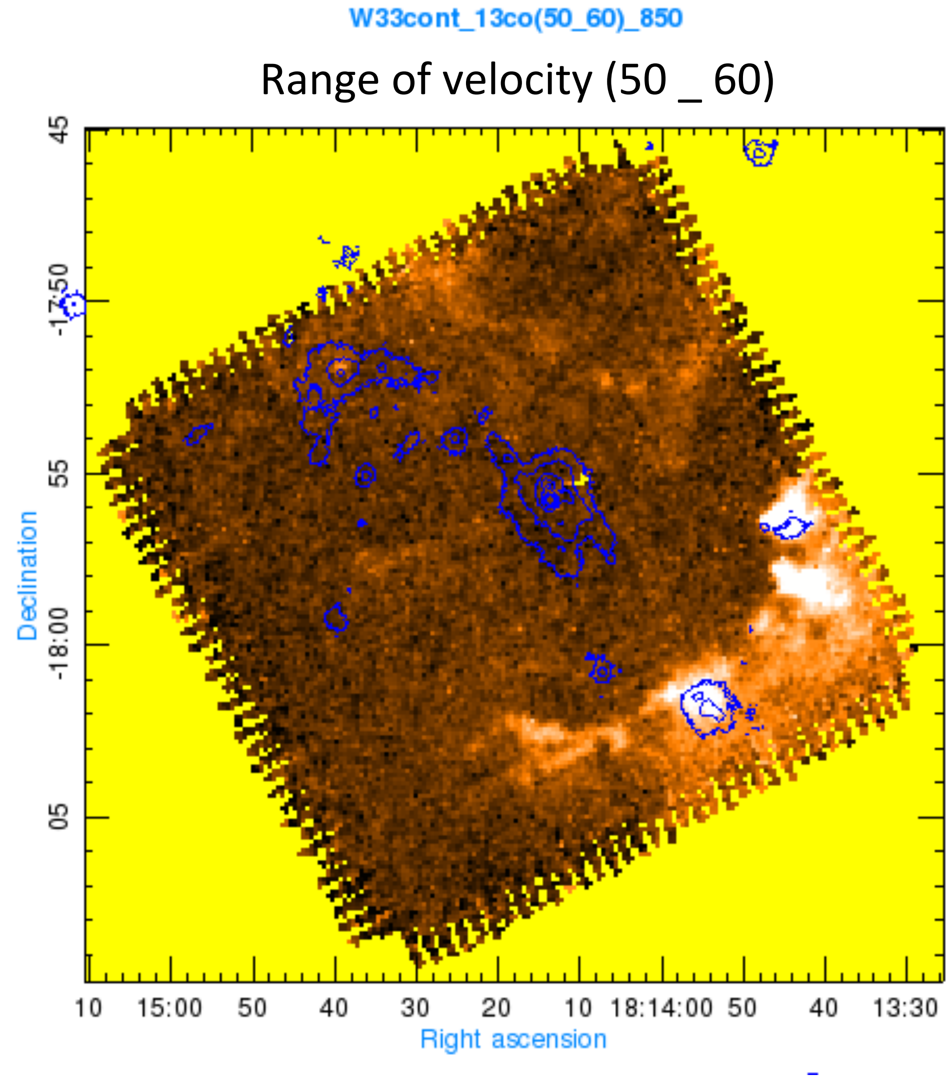


The contour level: 76.3796, 50.0402, 41.6829, 24.3255, 6.96819, 2

W33cont

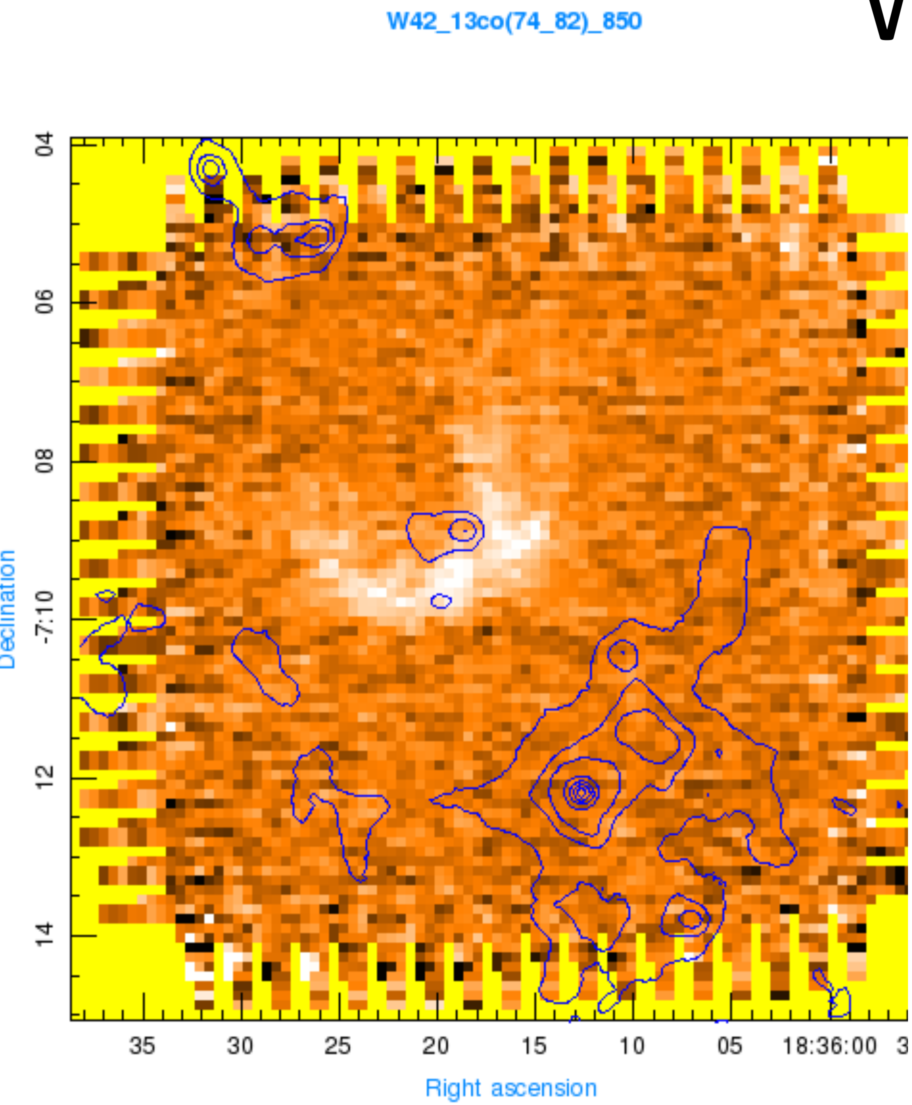


Range of velocity (50 _ 60)



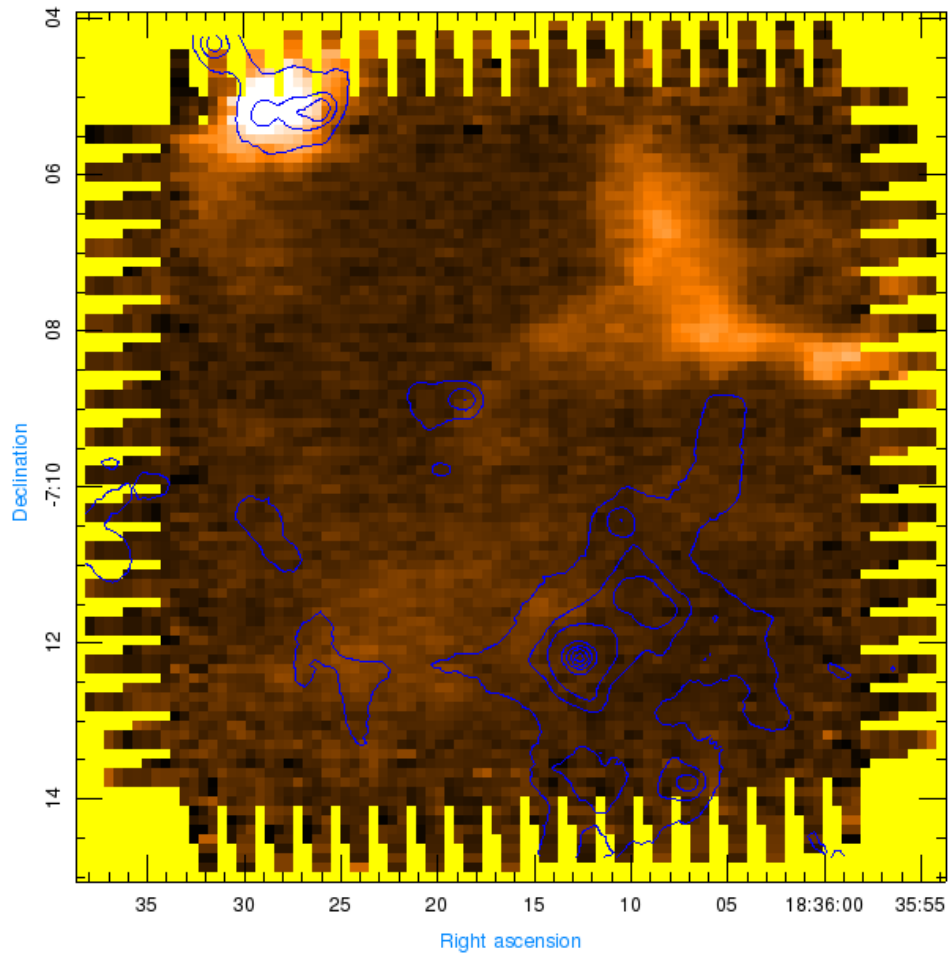
The contour level: 76.3796, 50.0402, 41.6829, 24.3255, 6.96819, 2

W42



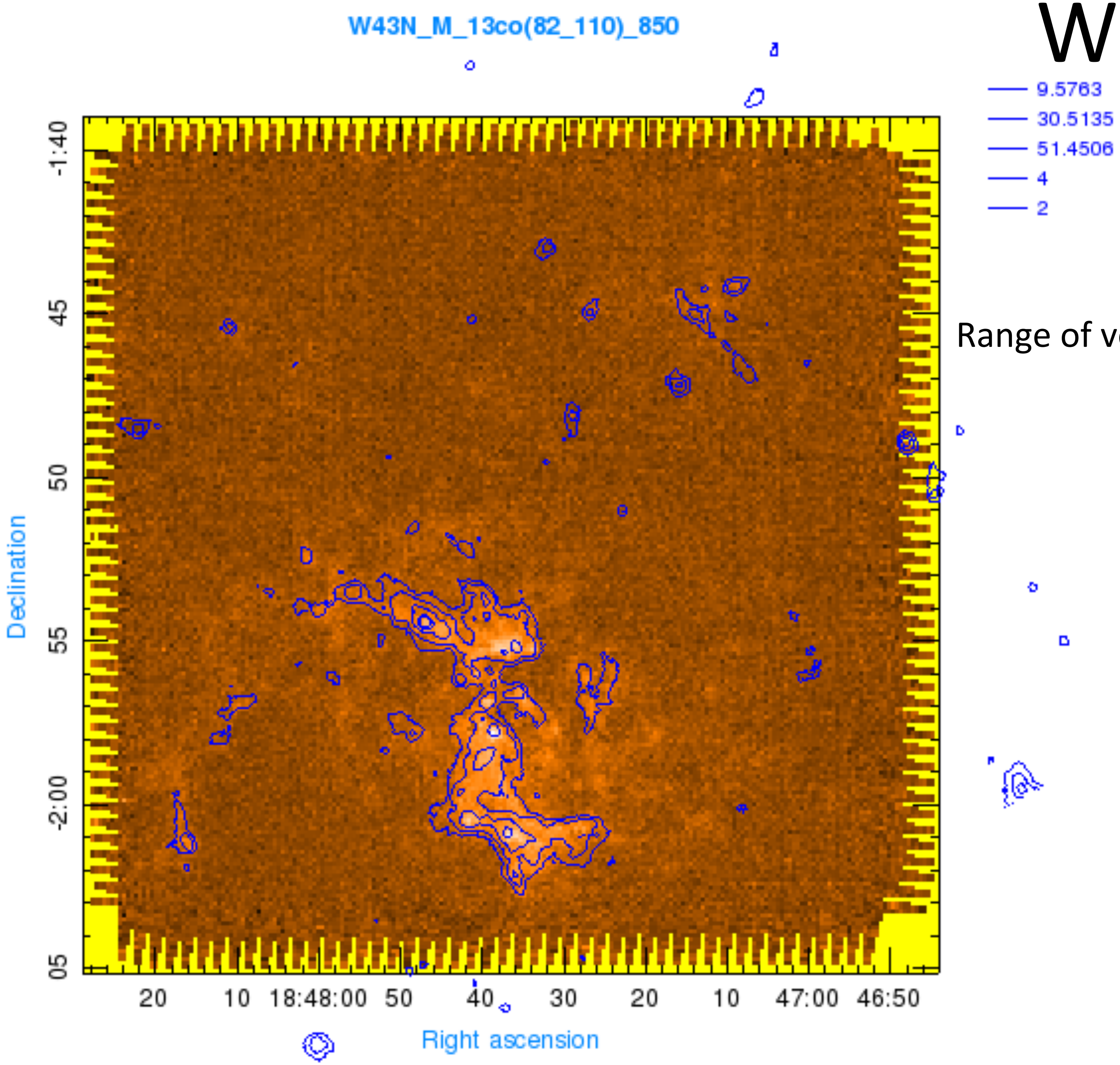
W42_13co(43_48)_850

Range of velocity (43 _ 48)



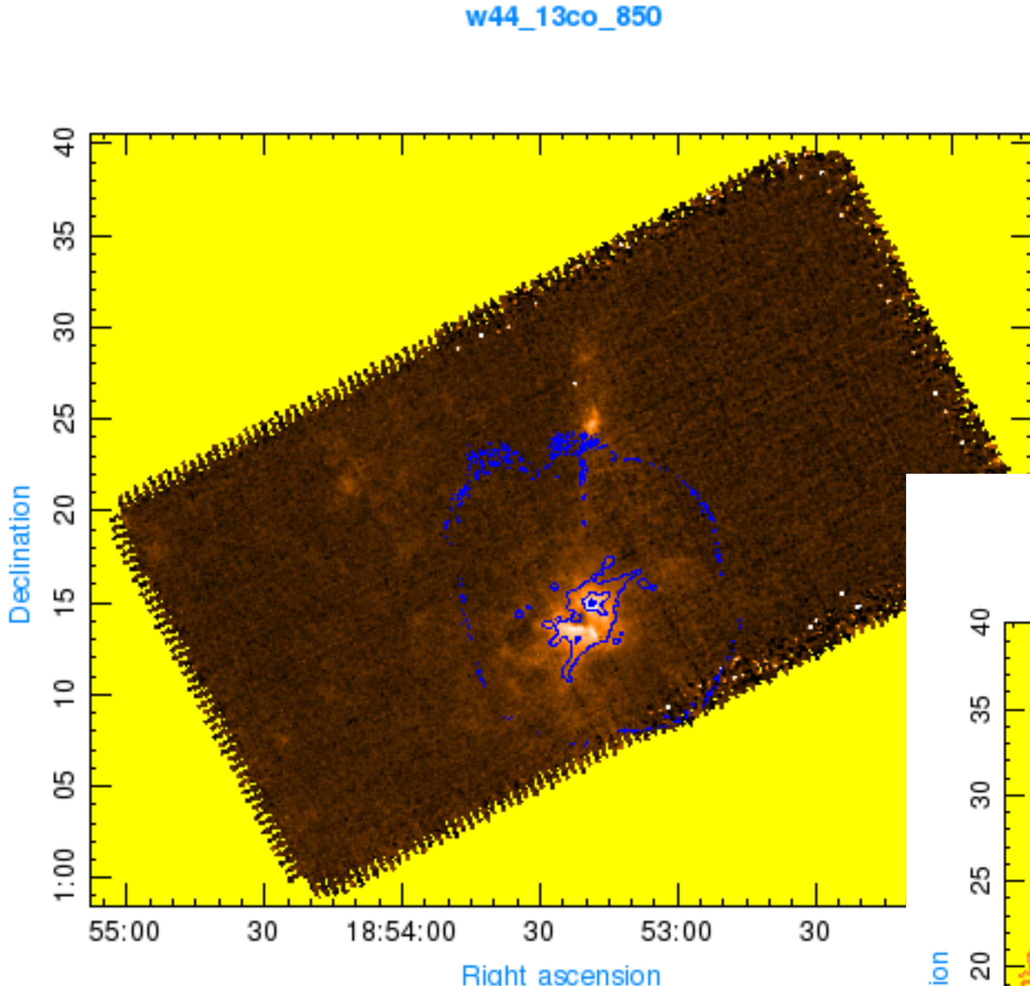
The contour level: 51.3875, 39.9231, 28.4586, 16.9941, 5.52966, 3, 1

W43N_M

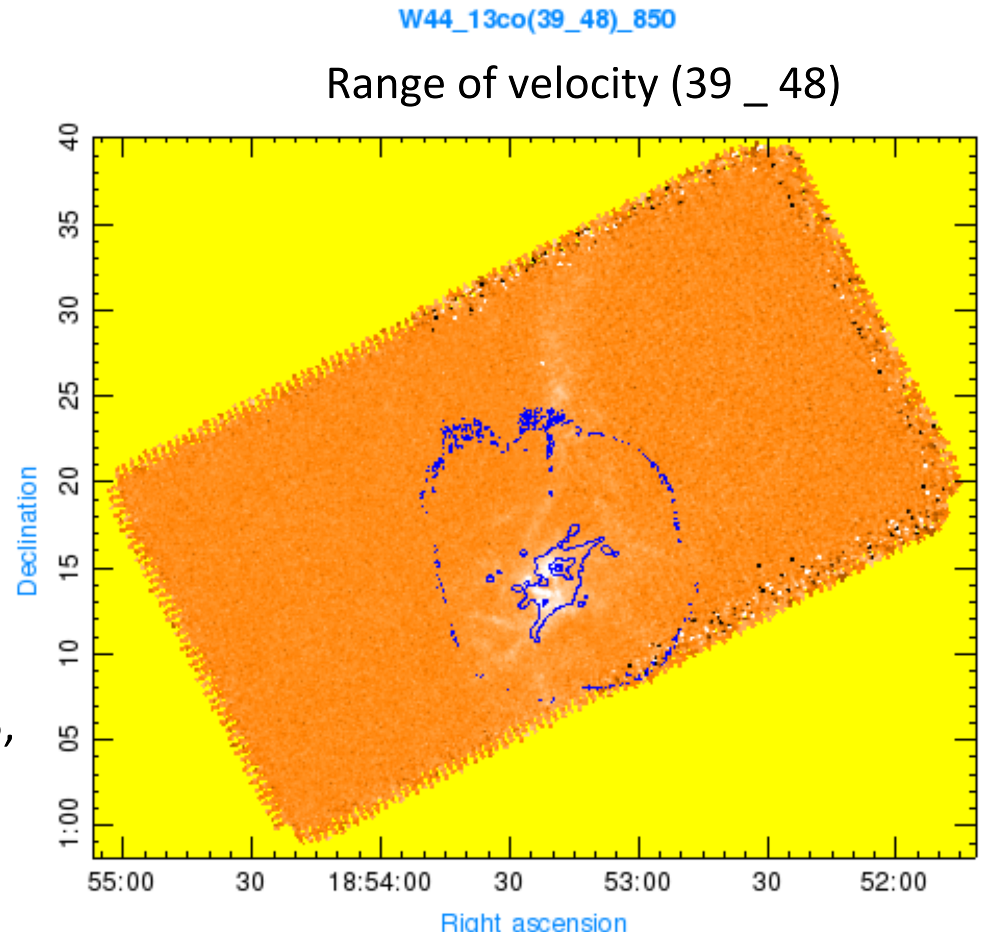


Range of velocity (82 _ 110)

W44

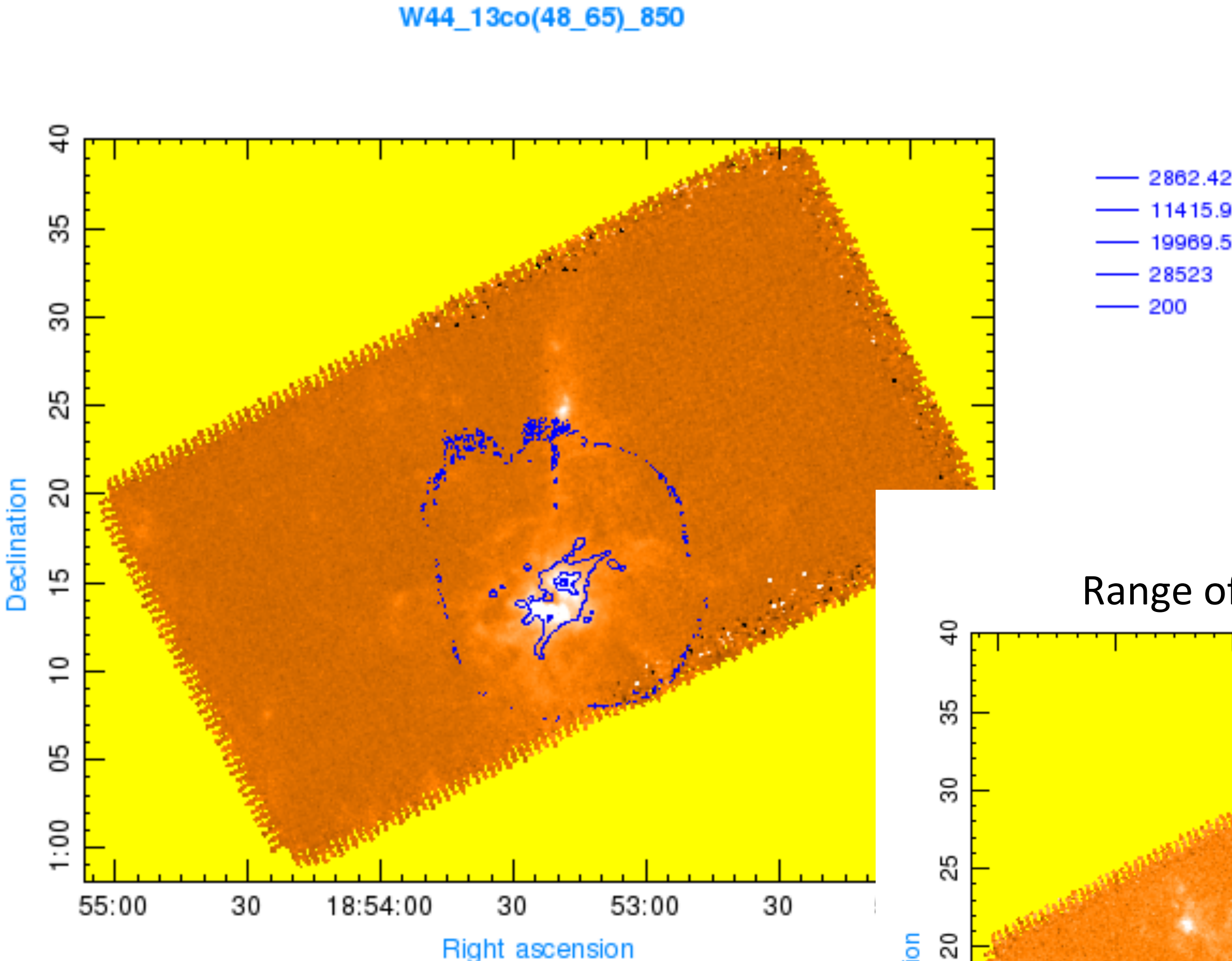


Range of velocity (39 _ 48)

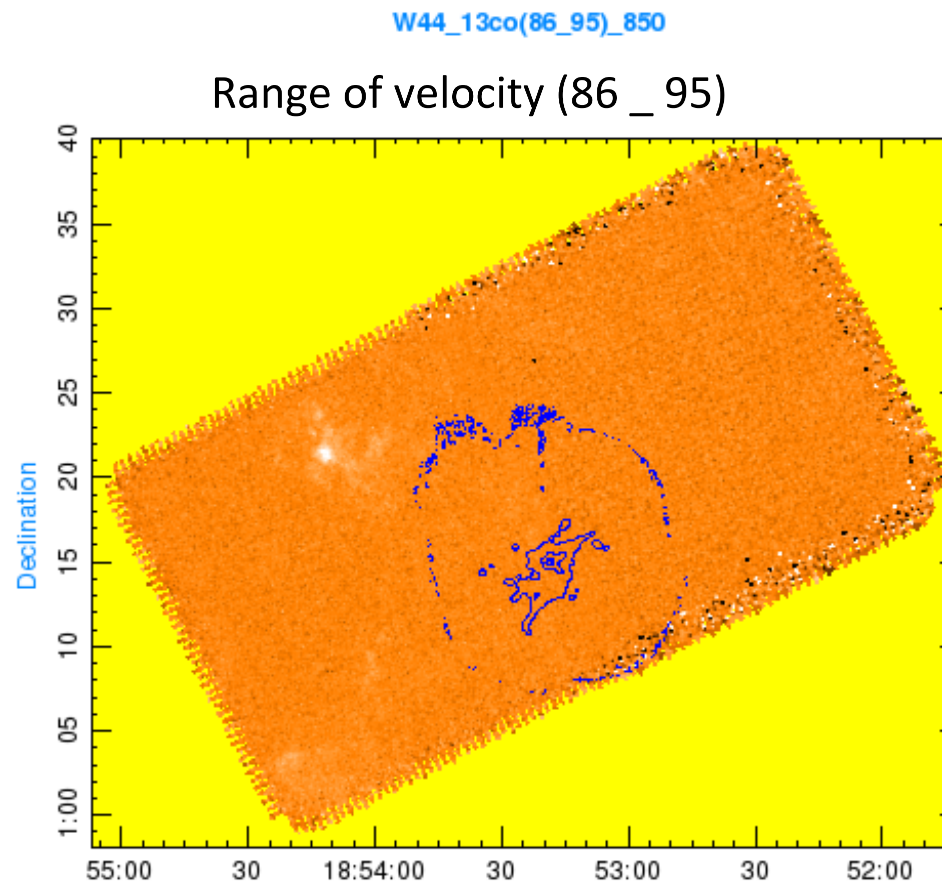


The contour level: 37076.5, 28523, 19969.5, 2862.42, 200

W44



Range of velocity (86 _ 95)

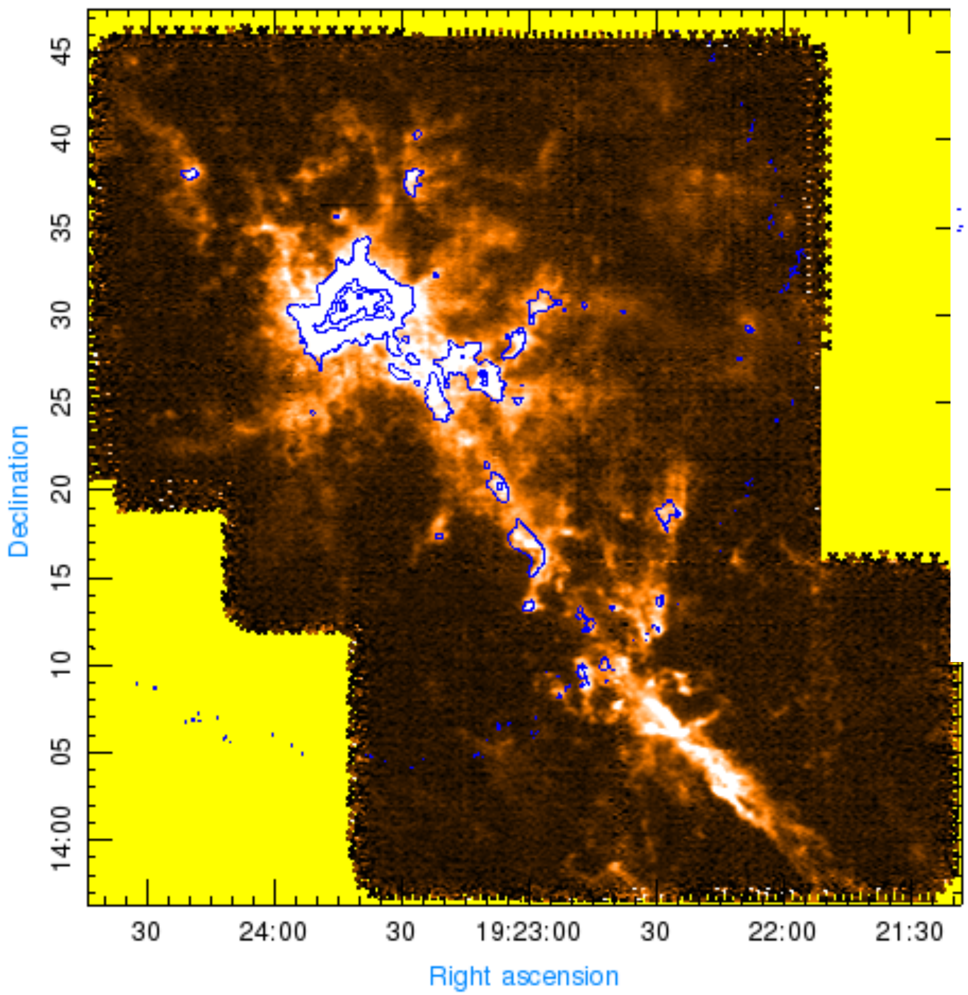


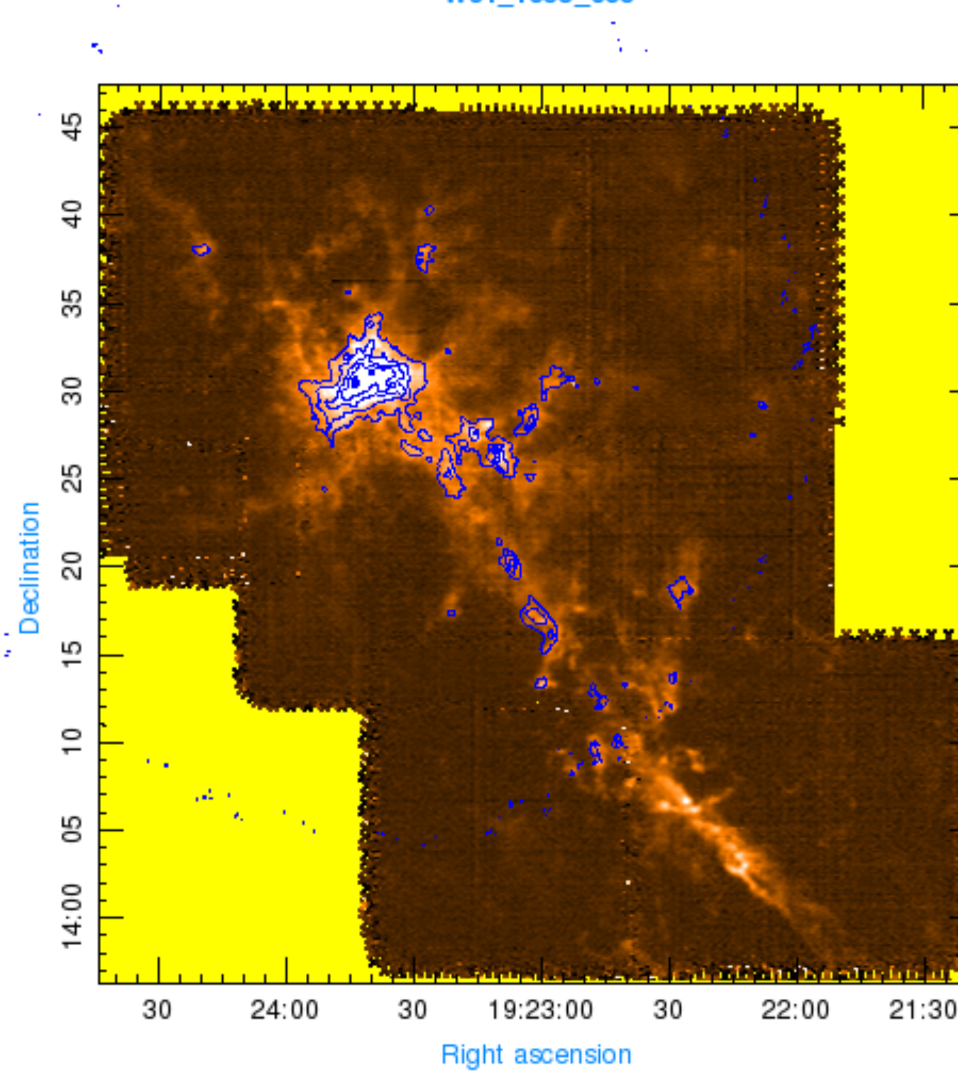
The contour level: 37076.5, 28523, 19969.5, 2862.42, 200

W51

W51_13co(44_76)_850

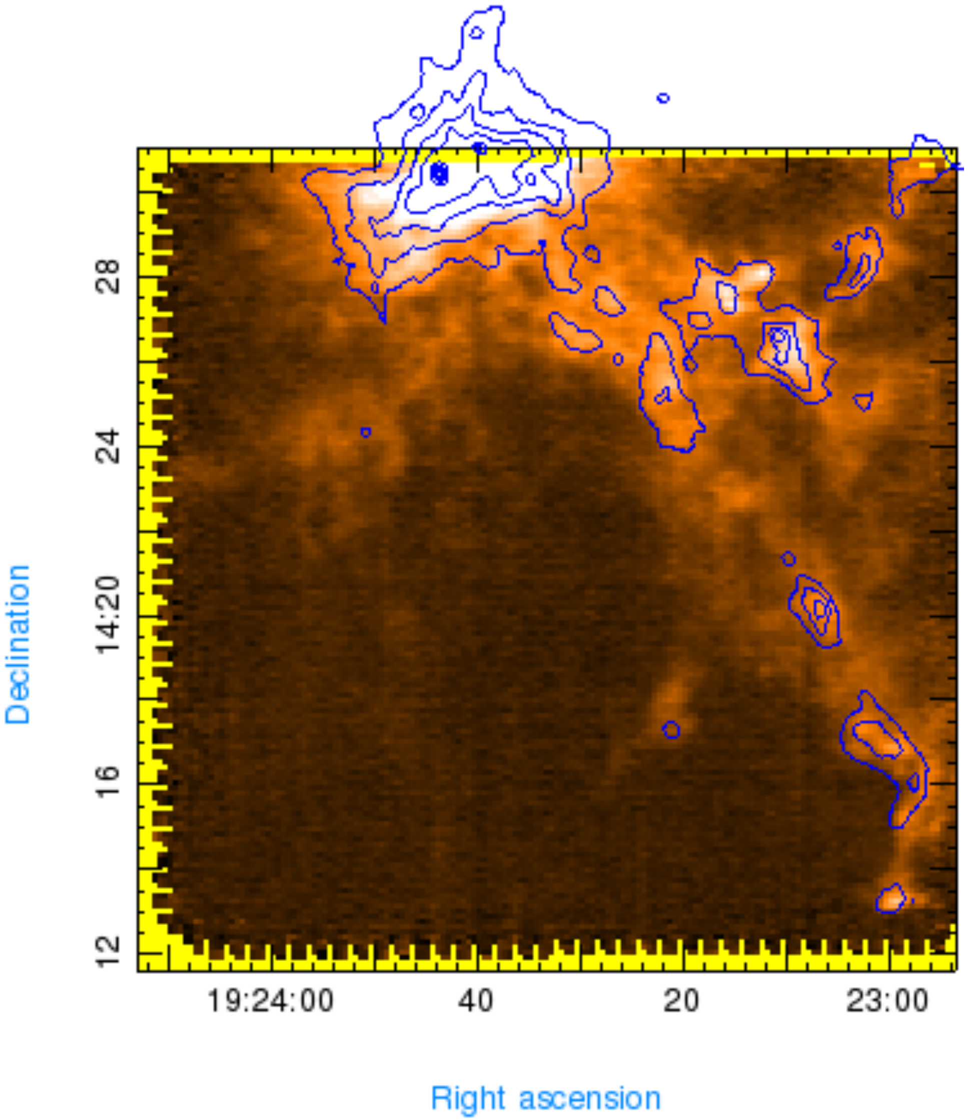
Range of velocity (44 _ 76)

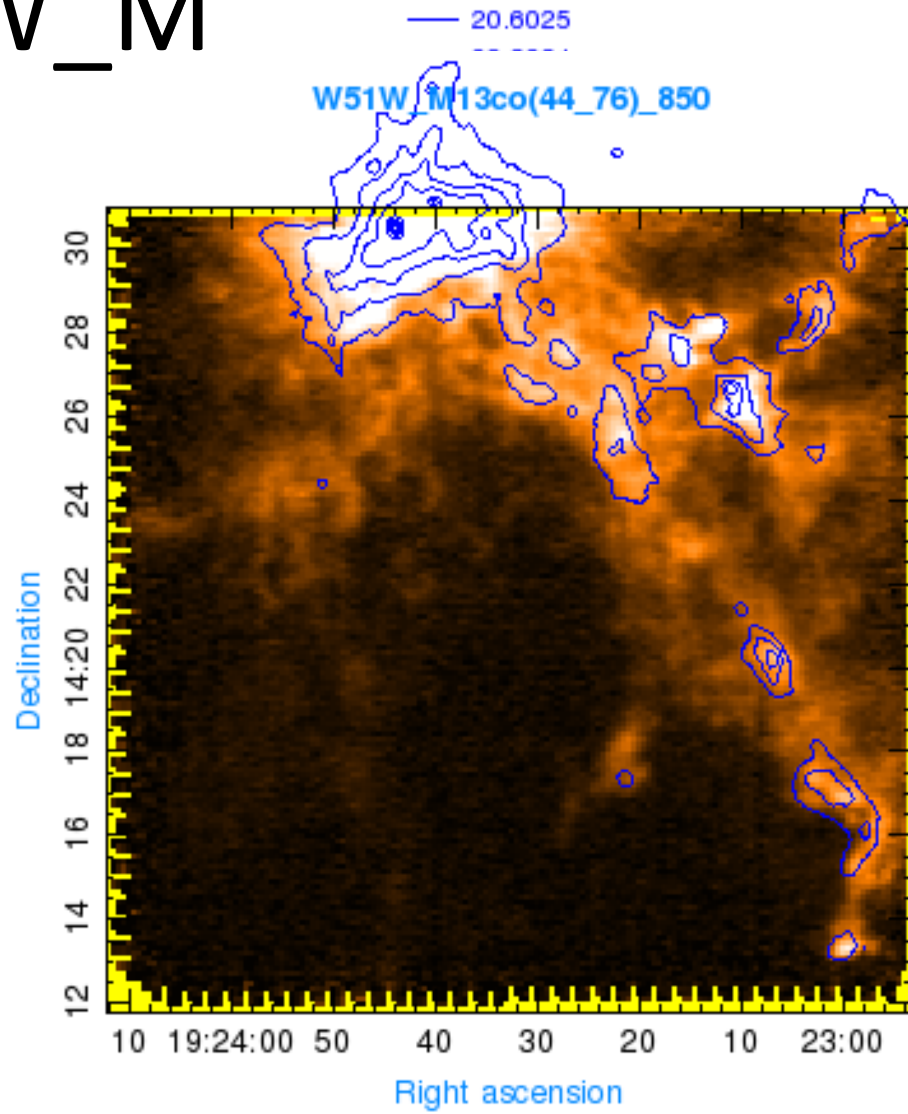




The contour level: 214.07, 165.58, 117.05, 68.5399, 20.0299, 10, 5, 2

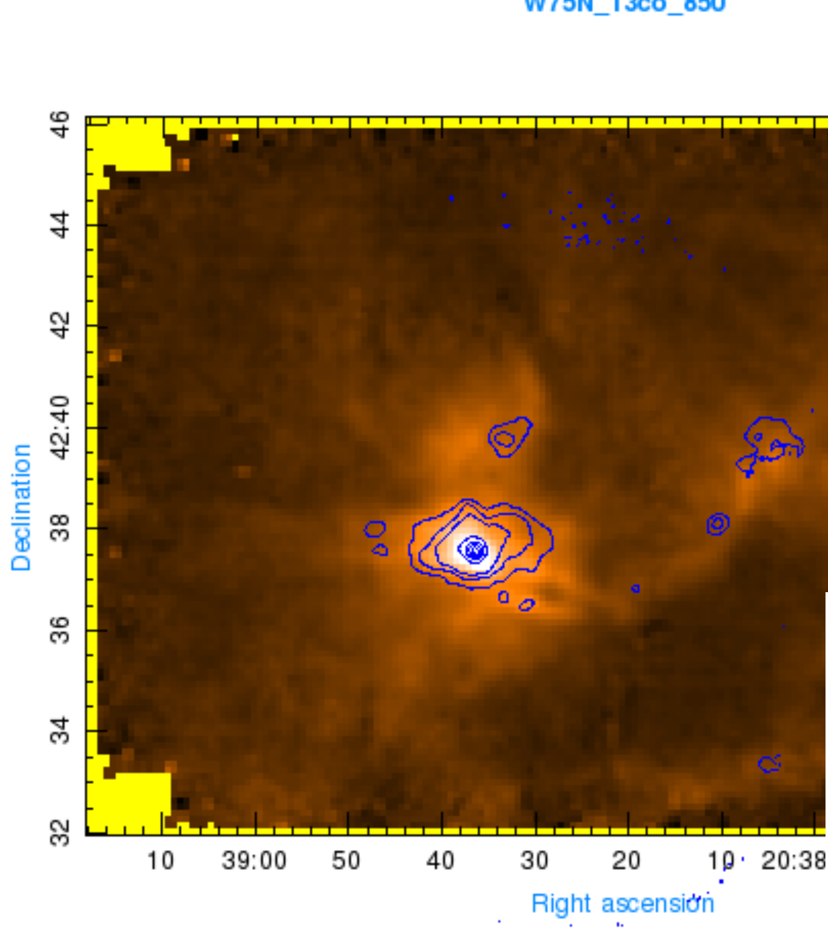
W51W_M



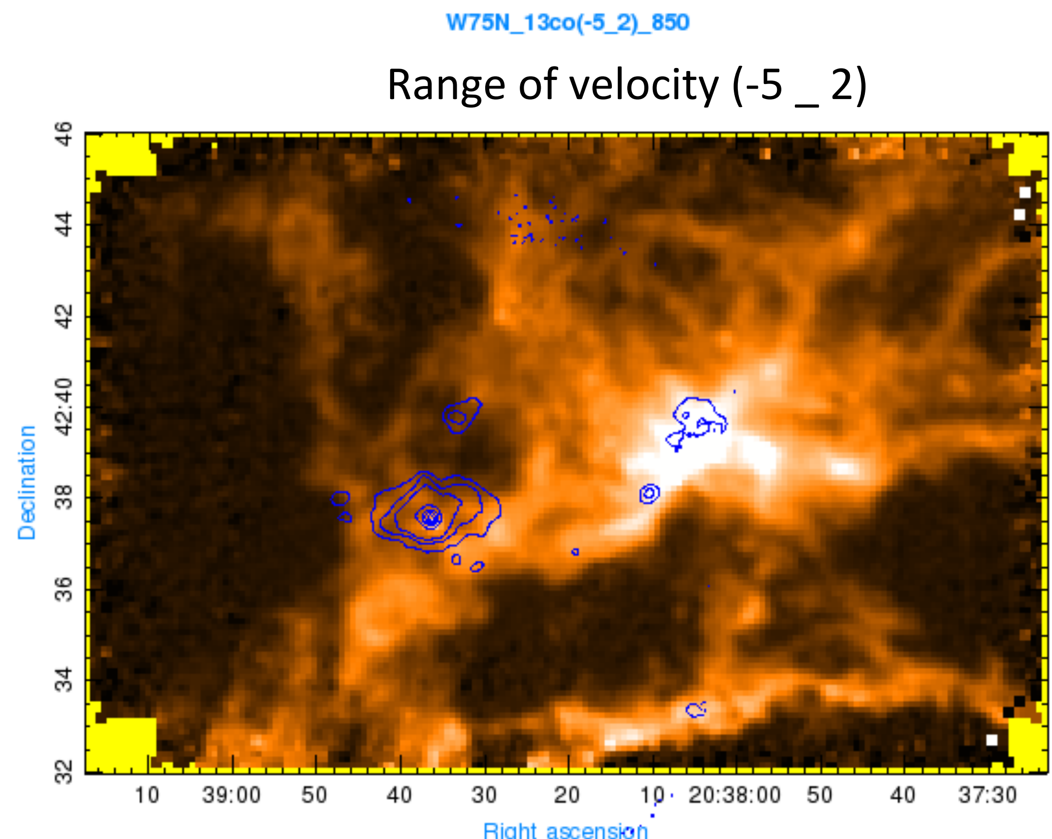


The contour level: 214.07, 165.58, 117.05, 68.5399, 20.0299, 10, 5, 2

W75N

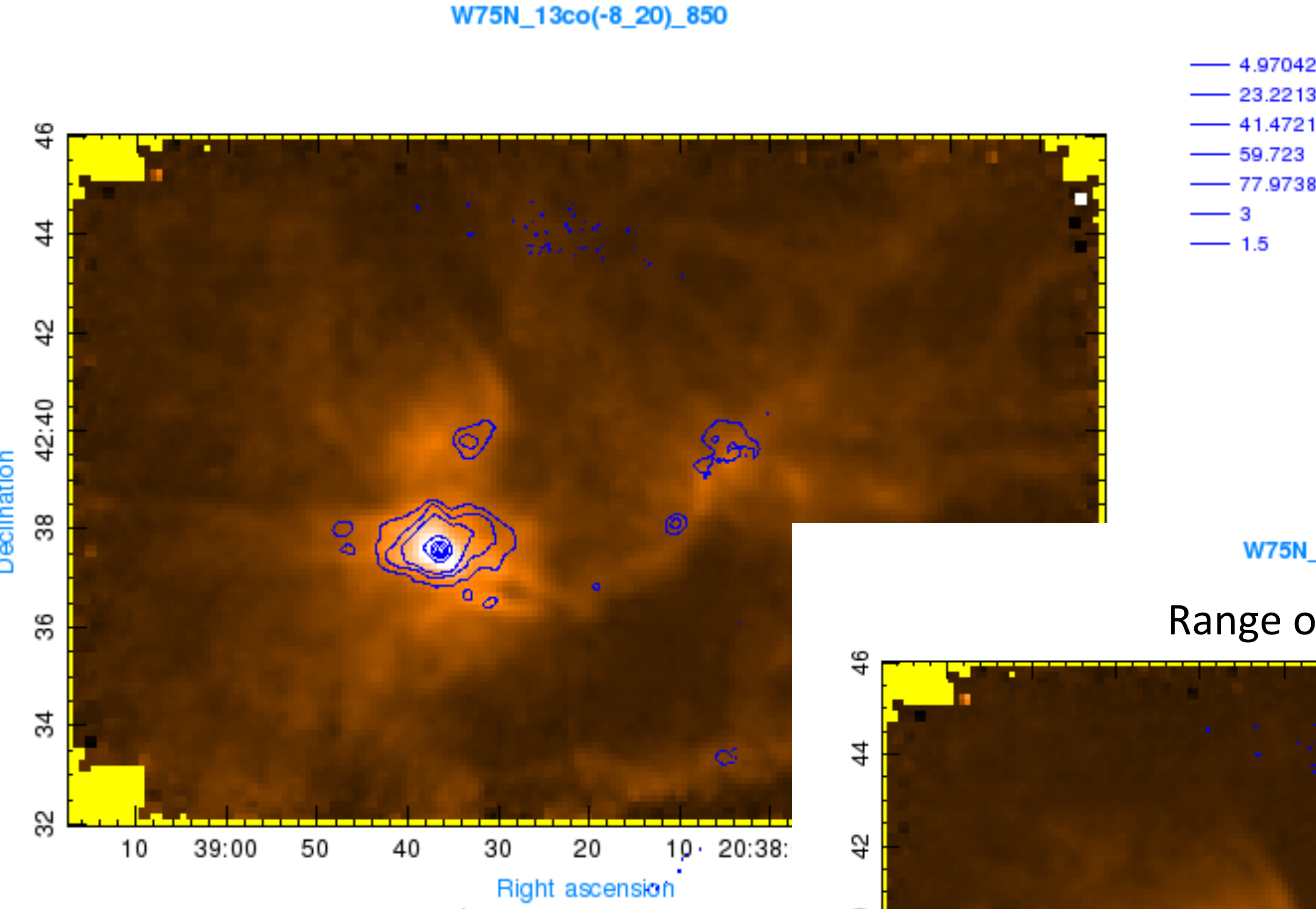


Range of velocity (-5 _ 2)

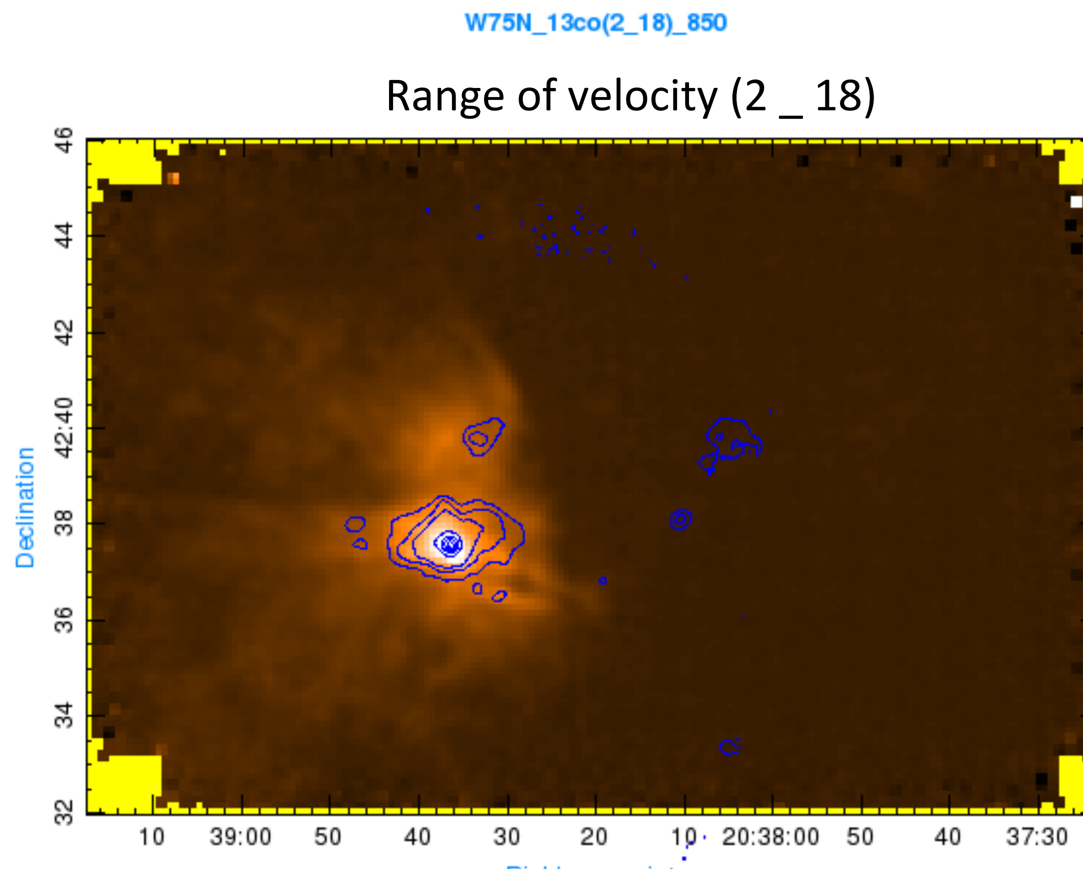


The contour level: 77.9738, 59.723, 41.4721, 23.2213, 4.97042, 3, 1.5

W75N

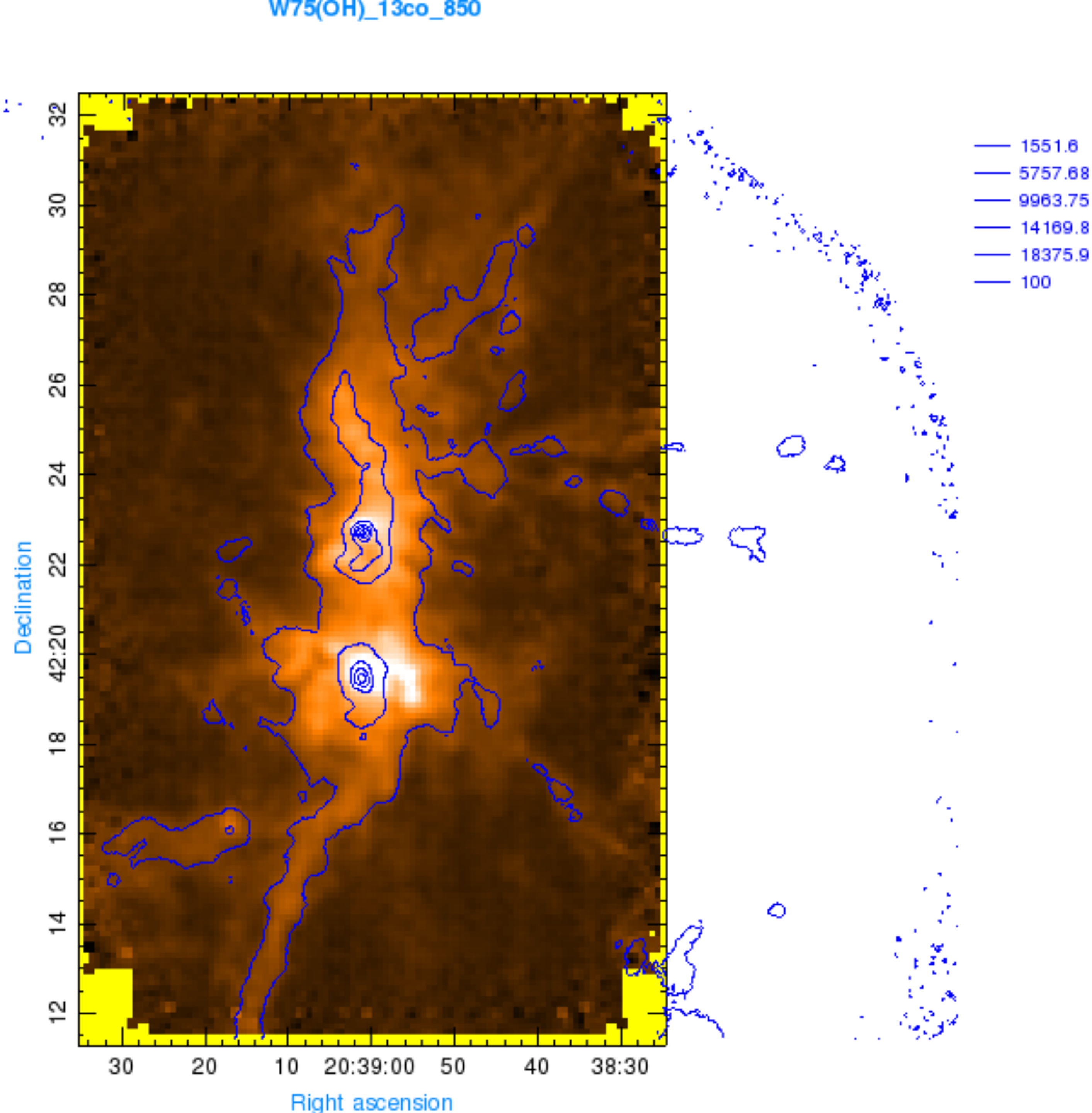


Range of velocity (2 _ 18)



The contour level: 77.9738, 59.723, 41.4721, 23.2213, 4.97042, 3, 1.5

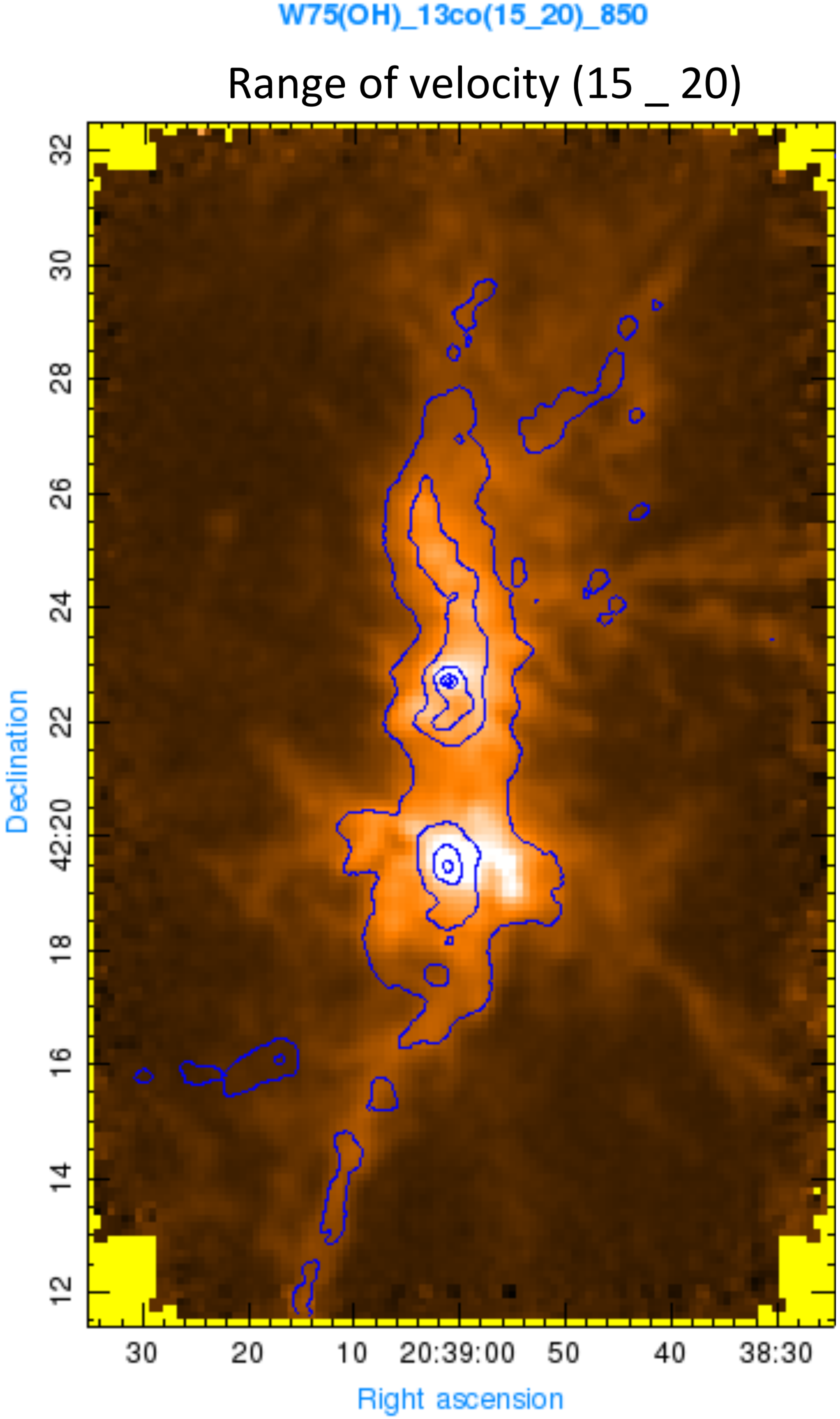
W75OH



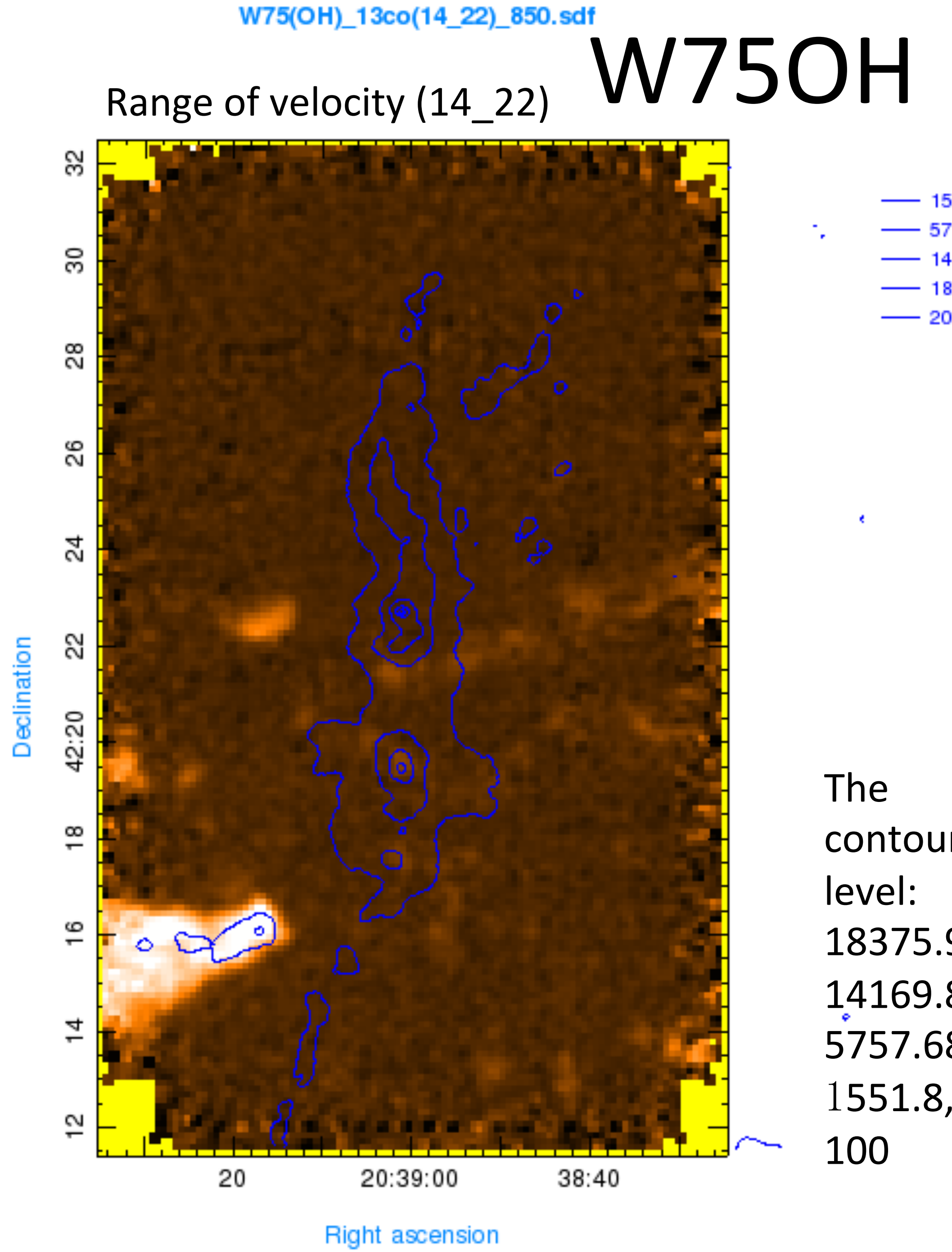
The contour level: 18375.9, 14169.8, 9963.75, 5757.68, 1551.8, 100

W75OH

Range of velocity (15 _ 20)



Range of velocity (14_22)



The contour level: 18375.9 14169.8 5757.68 1551.8, 100