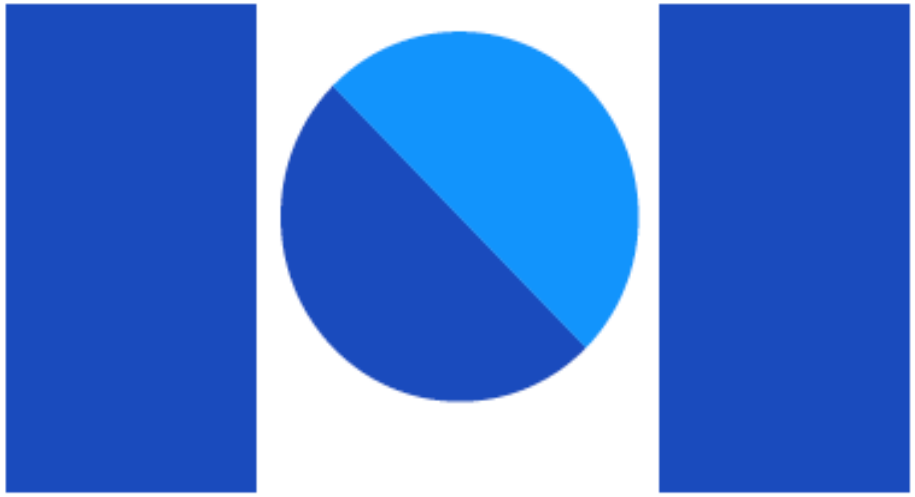
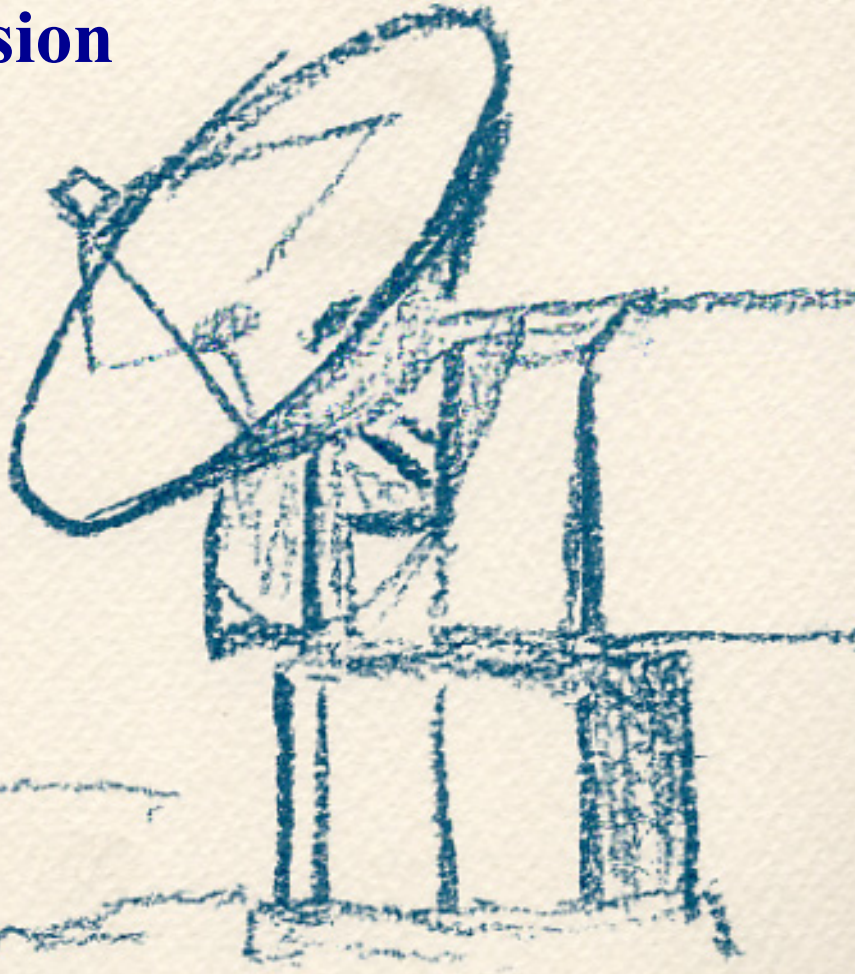


NANTEN

Submillimeter Observatory

Formation of super star clusters triggered by cloud-cloud collision



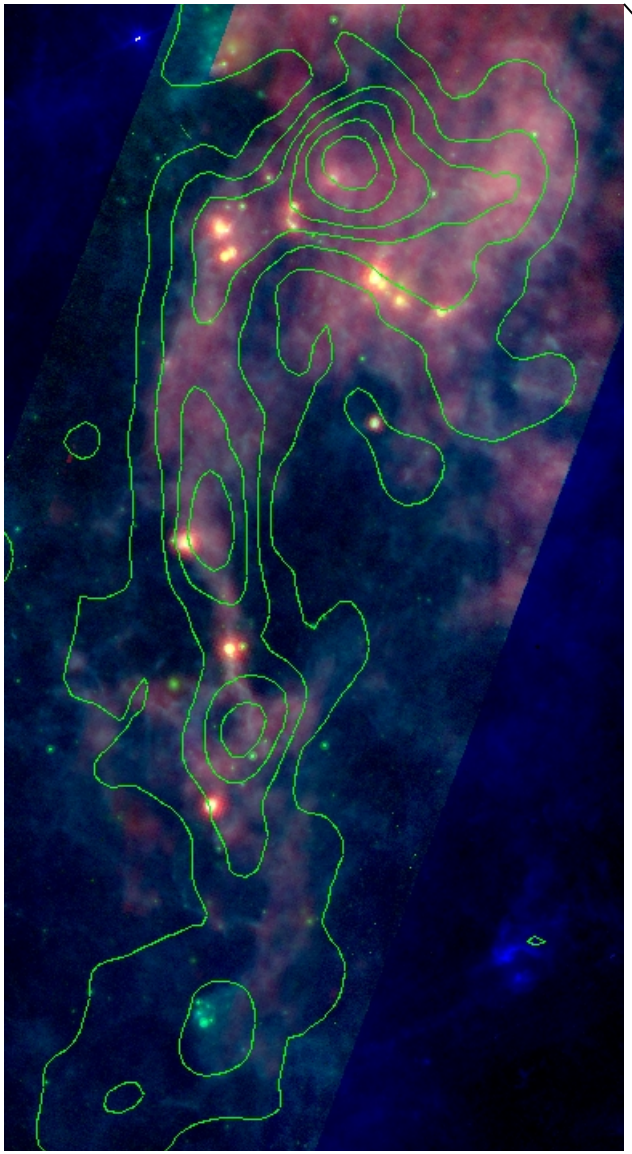
Yasuo Fukui

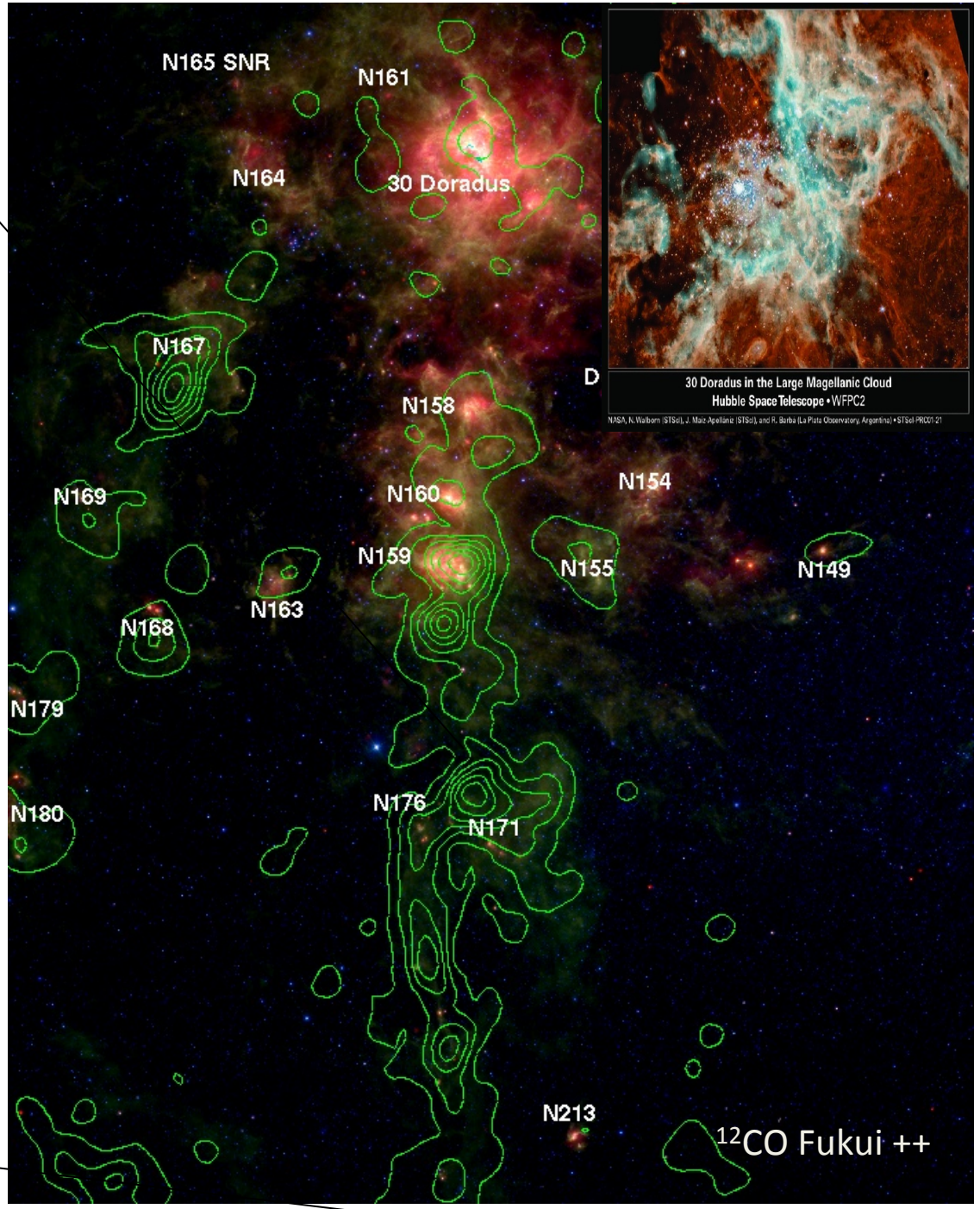
Nagoya University

28th New Mexico Symposium November 30, 2012 Socorro, NM

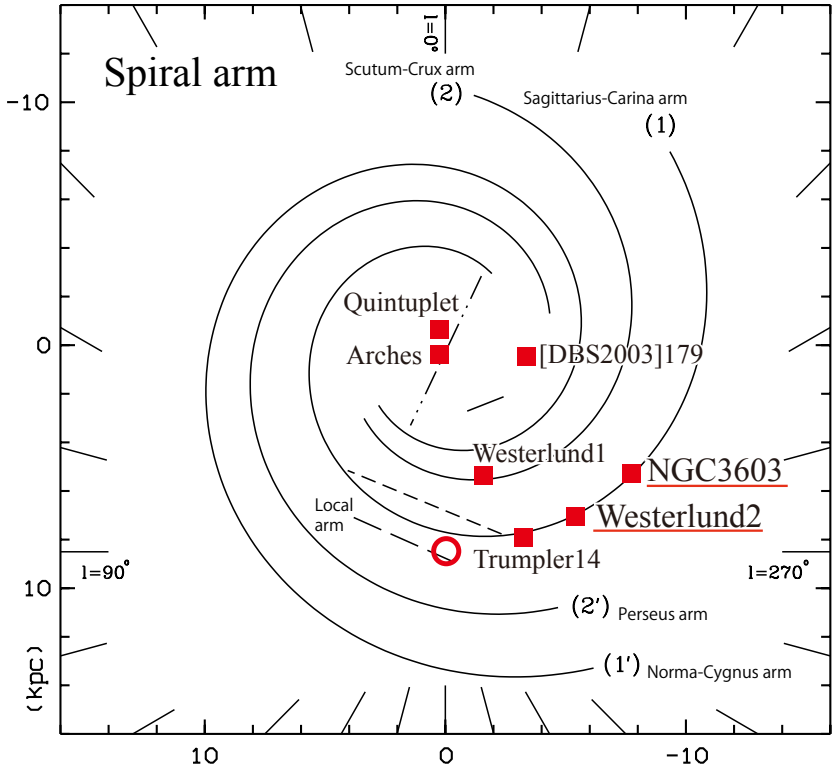
Y. F.

No clusters in the LMC molecular ridge





SSC catalog in the Milky way



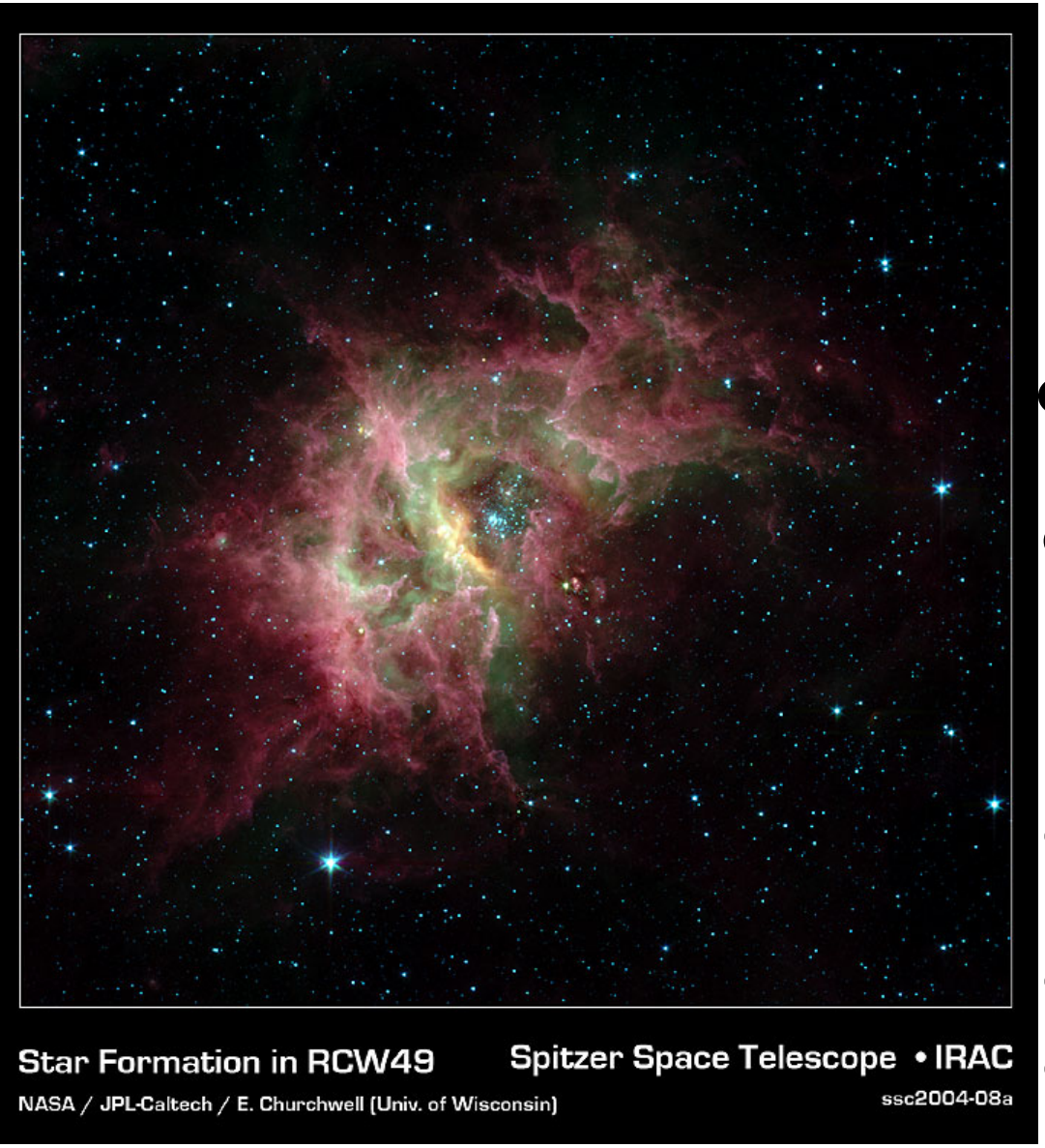
Distribution of SSC in the Milky way.
D.Russeil (2002)
Red circle is sun.

Portegies Zwart, McMillan & Giels (2010)

SSC	Age [Myr]	LogM_* [M_{sun}]	Size [pc]	Mole-cular cloud
NGC3603	2.0	4.1	0.7	○
Westerlund2	2.0	4.2	0.8	○
[DBS2003]179	3.5	3.8	1.2	○
Westerlund1	3.5	4.0	1.0	×
Trumpler 14	2.0	4.5	0.5	--
Arches	2.0	4.3	0.4	×
Quintuplet	4.0	4.0	2.0	×
RCW38	<1.0	--	0.8	○

Spitzer IRAC ;

3.5 (blue), 4.5 (green), 5.8 (orange), 8.0 (red) μm



Westerlund 2 (Wd2)

Super star cluster

(l, b) = (284°.27, -0 °.33)

- O Star 12
  WR Star 2
  WR20a, WR20b
- Total mass of stars 4500*Mo*
  (Rauw et al. 2007)
- Age 2-3 Myr (Piatti et al. 1998)

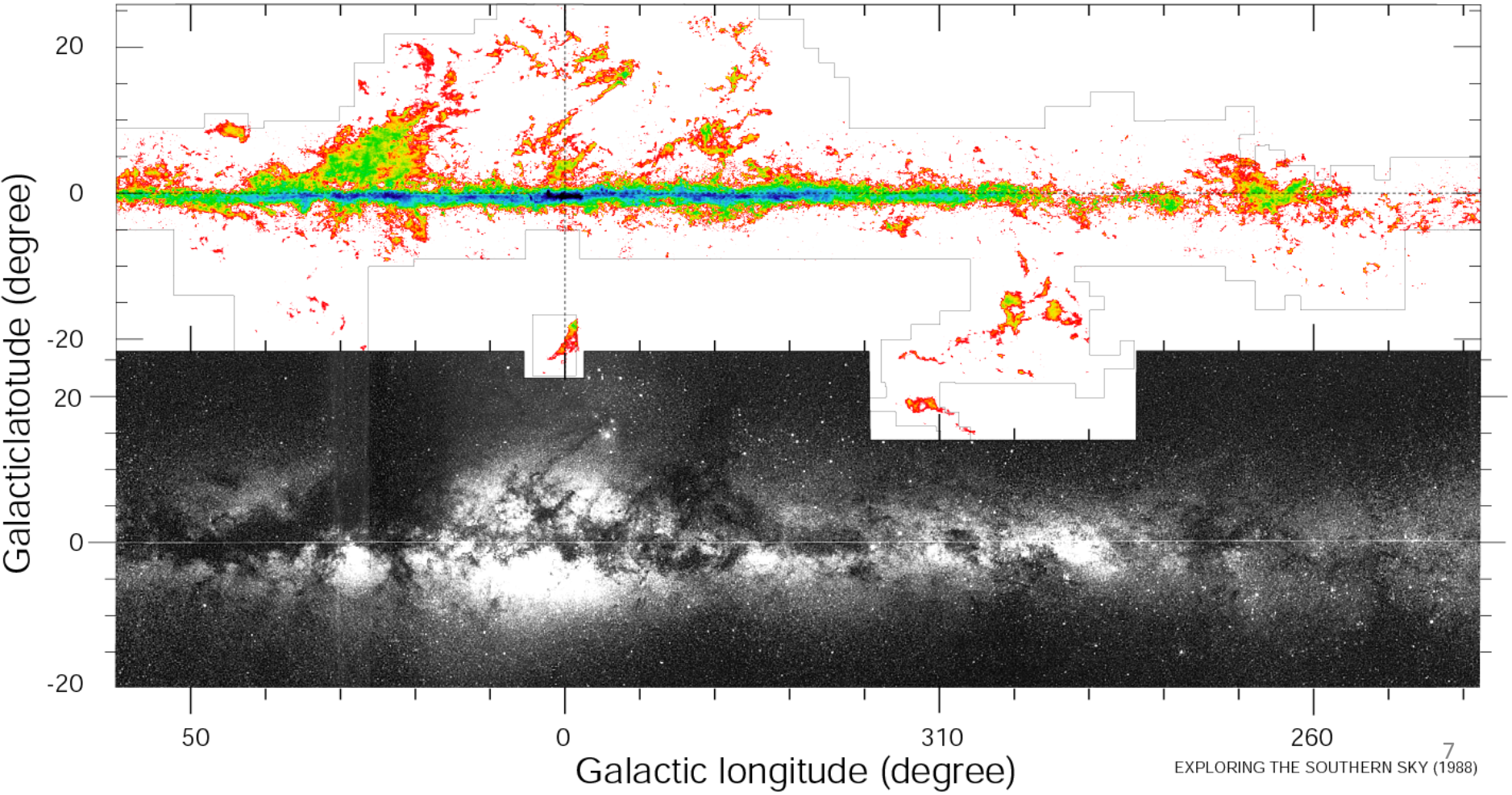
RCW 49

- Distribution of dust influenced by stars (Churchwell et al. 1998)
- Star formation in progress
- YSO 300 (Whitney et al. 2004)

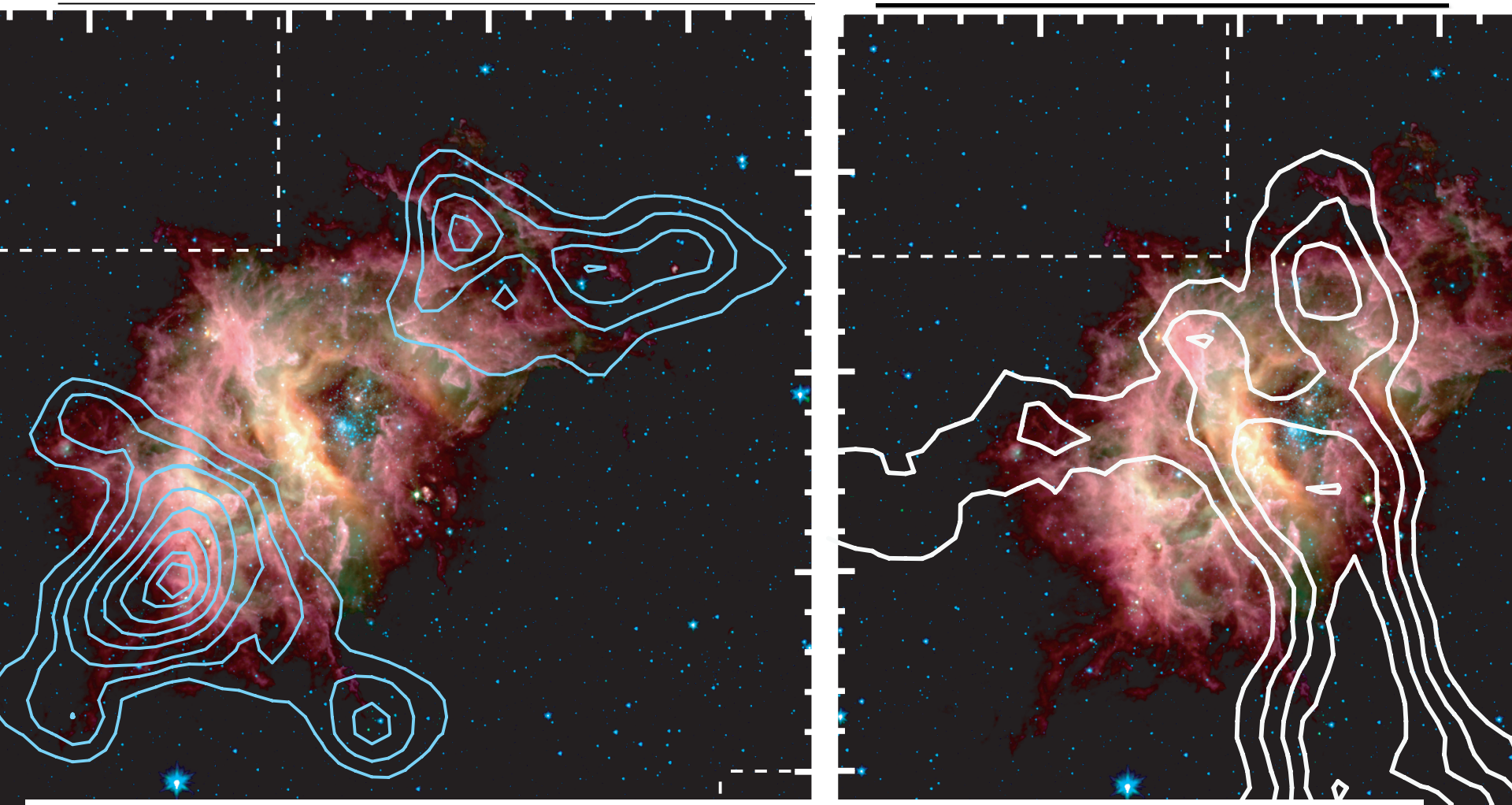

NANTEN2 4m sub-mm telescope

NANTEN Galactic Plane CO survey

^{12}CO(J=1–0),
Grid size ~ 4′ (|b| < 5°), 8′ (5° < |b| <10°), 2.’7 beam,
Integ. time (typ) ~ 5sec/point, ~1,000,000 observed points



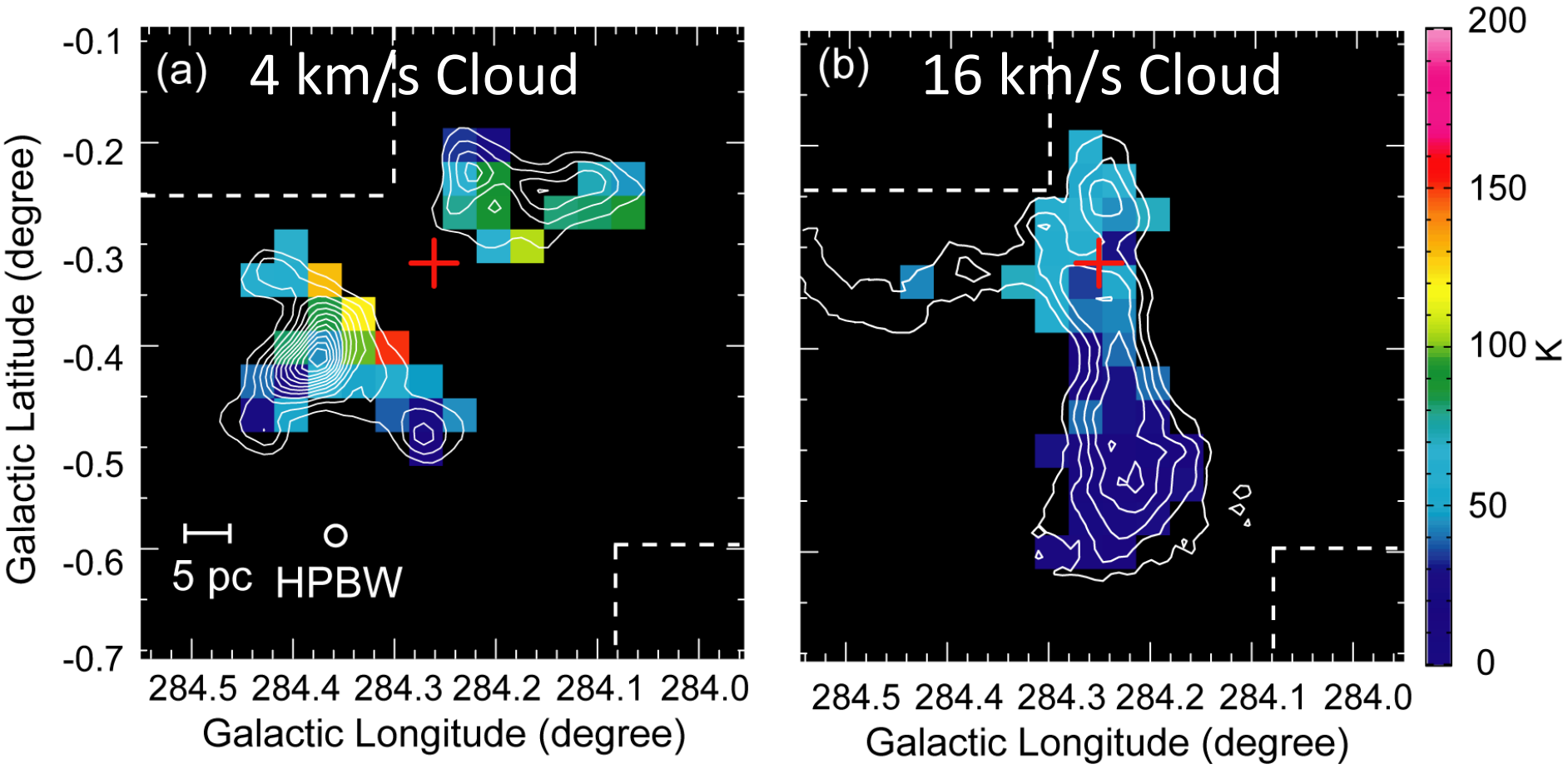
Spatial Distribution of ^{12}CO(J=2-1)



We suggested that molecular clouds are associated with HII region by the morphology.

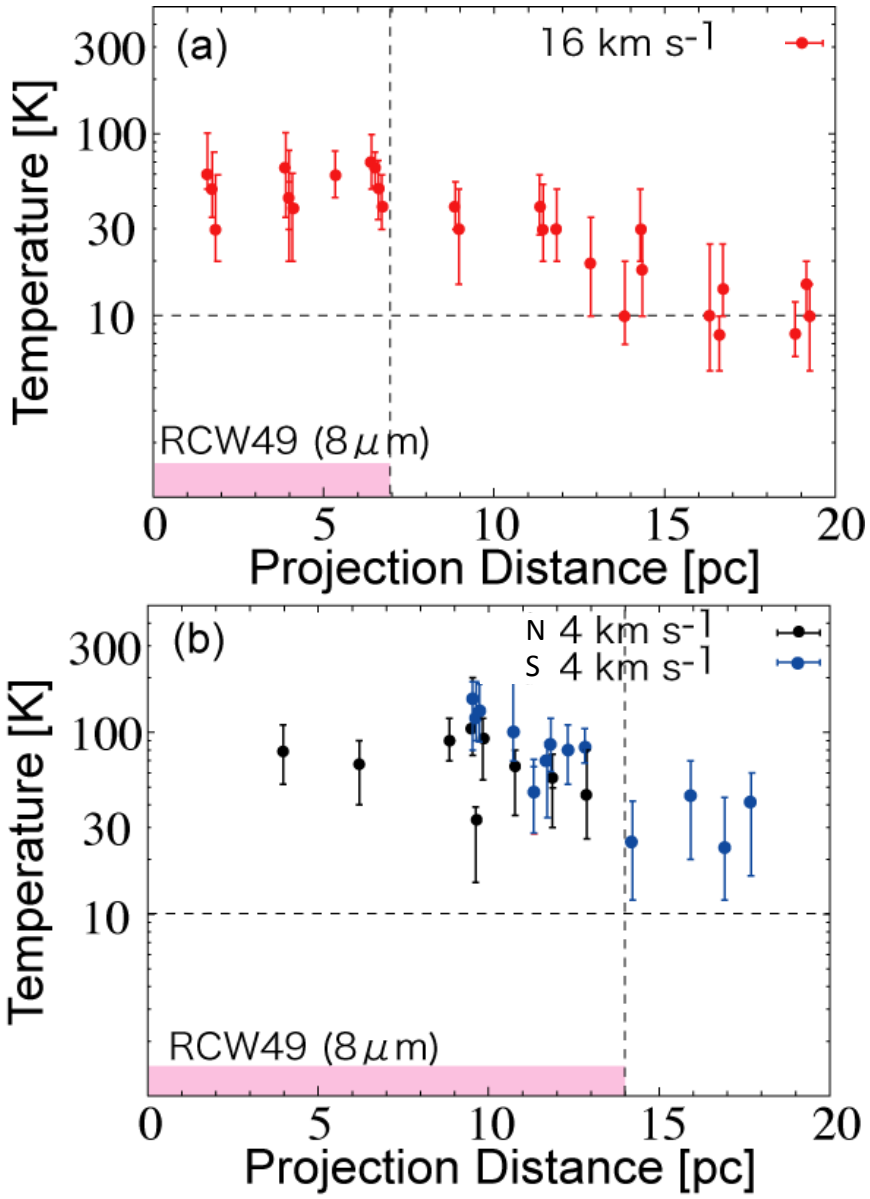
Temperature distribution of the molecular clouds

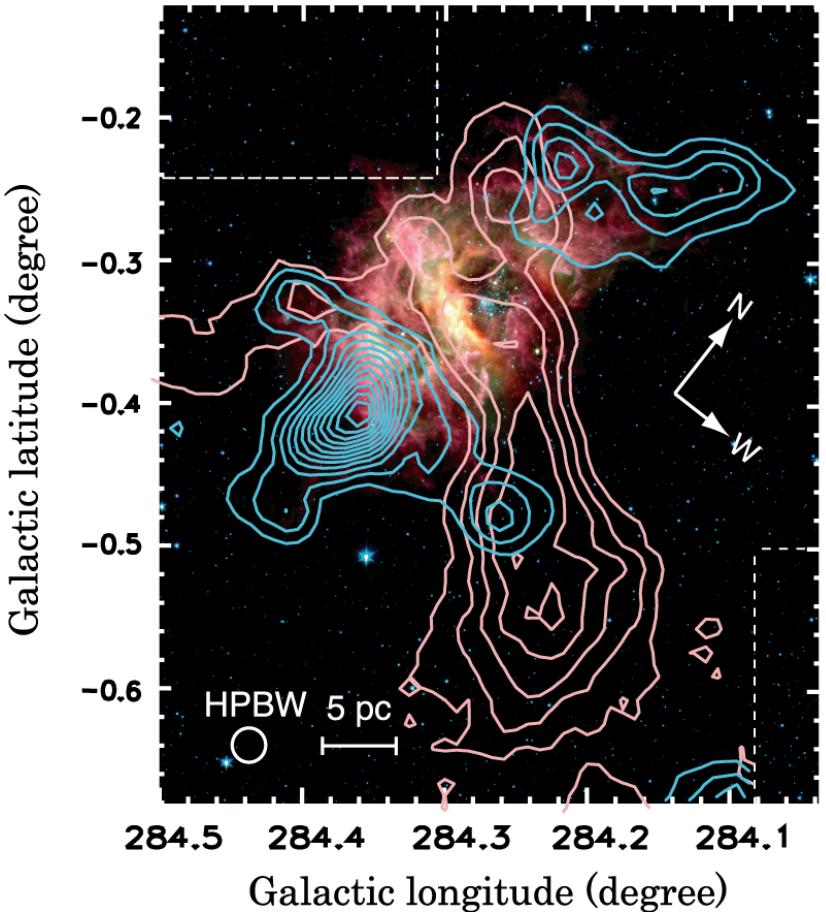
Image: Temperature, cont.:^{12}CO(2-1) red cross : Wd2



Suggesting gas is heated by the radiation from the cluster.

Temperature with Distance from Wd2



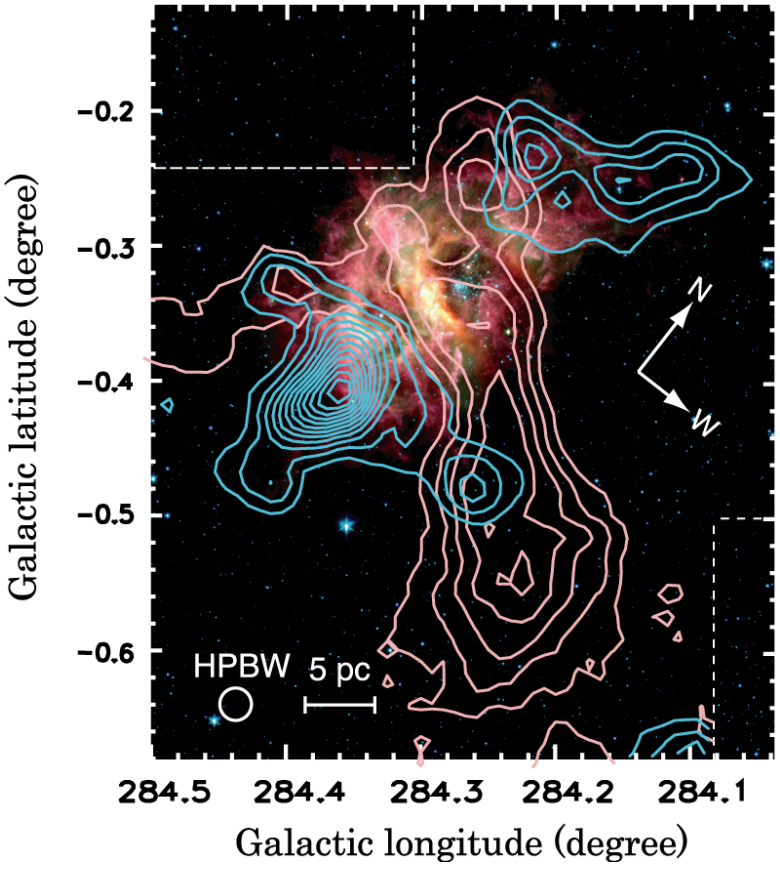


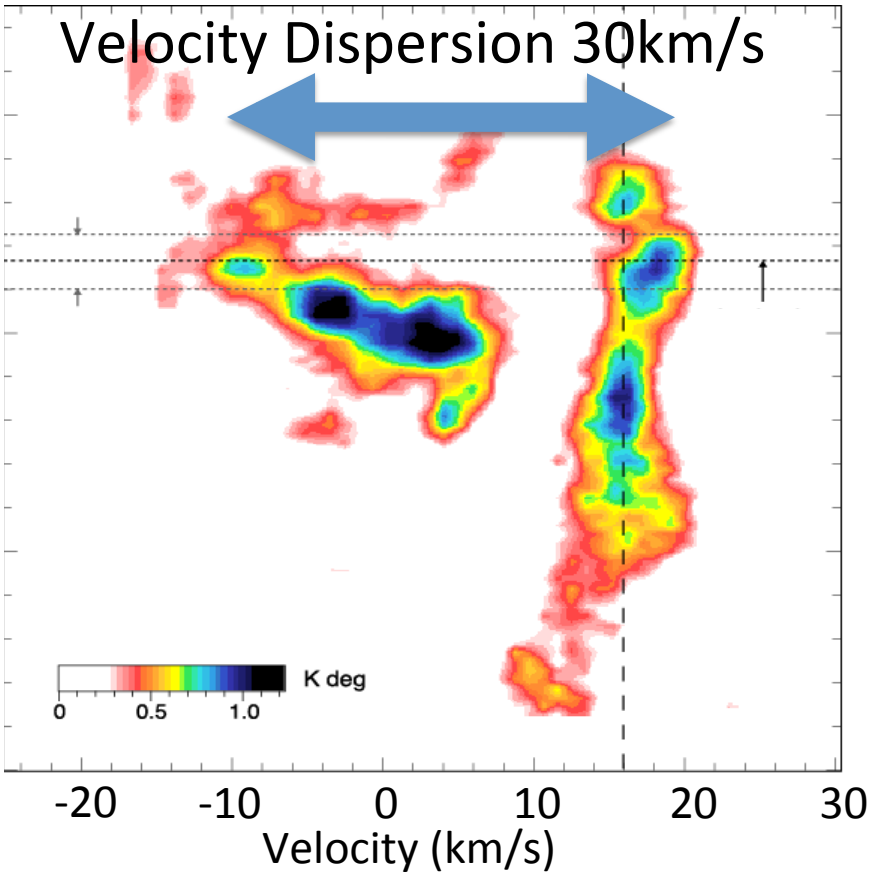
Molecular clouds are associated
With the cluster and HII region

Ohama et al. 2010, ApJ 709, 975

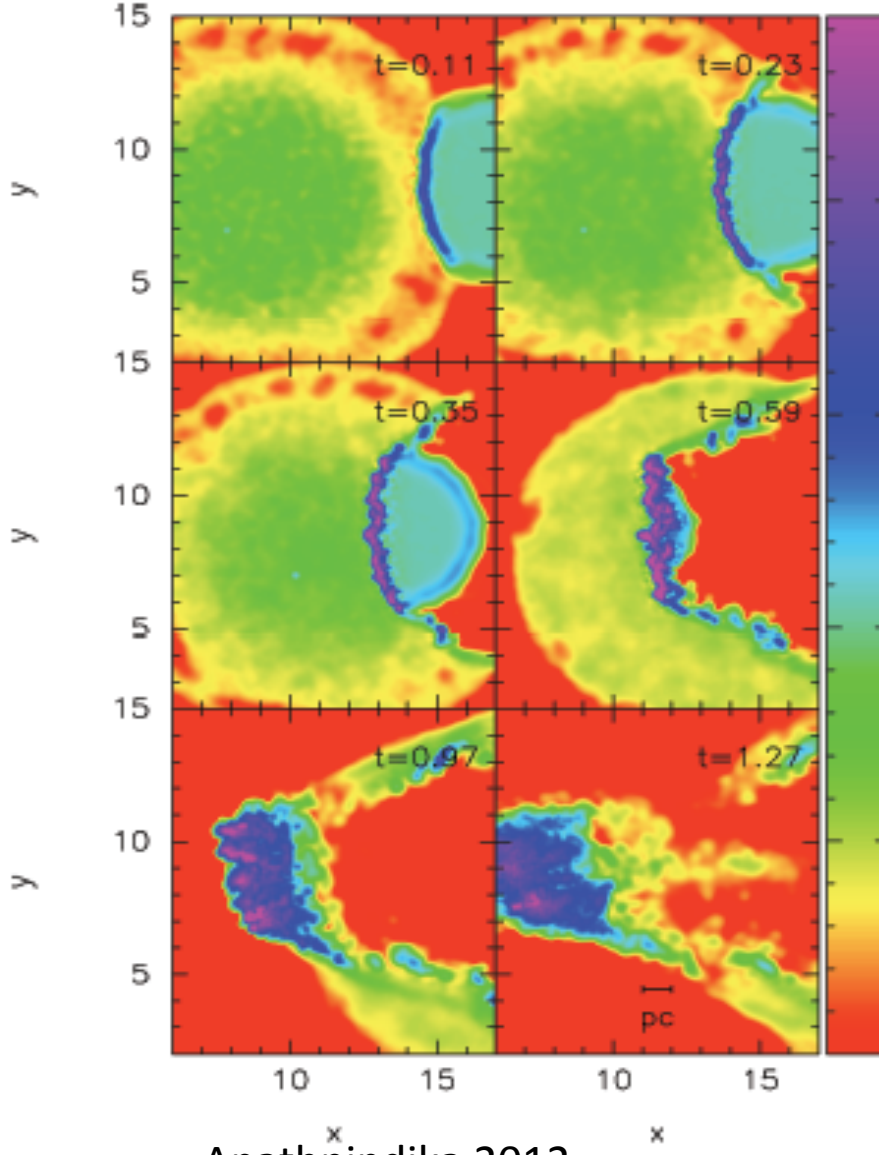
Galactic latitude-Velocity Diagram

l = 284.2-284.4





Two molecular clouds (10^5Mo) are not bound by gravity because of the large velocity separation 30 km/s



Anathpindika 2012,
Habe&Ohta 1992

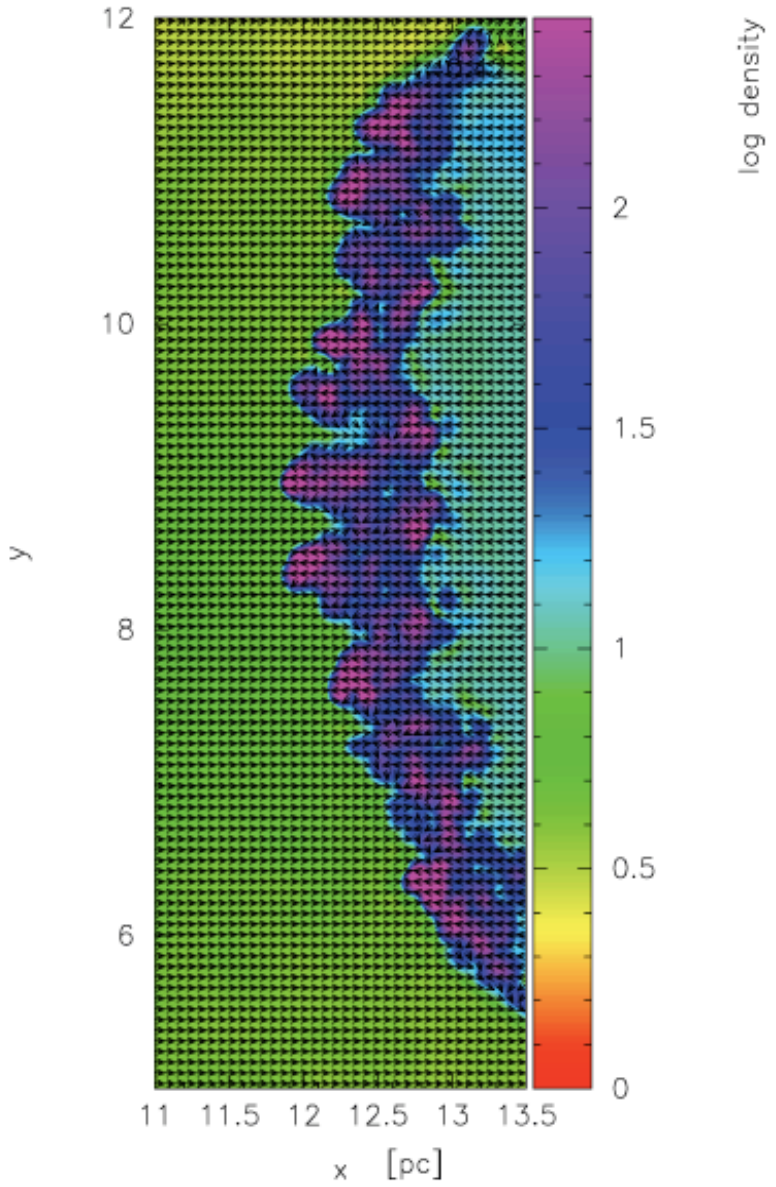
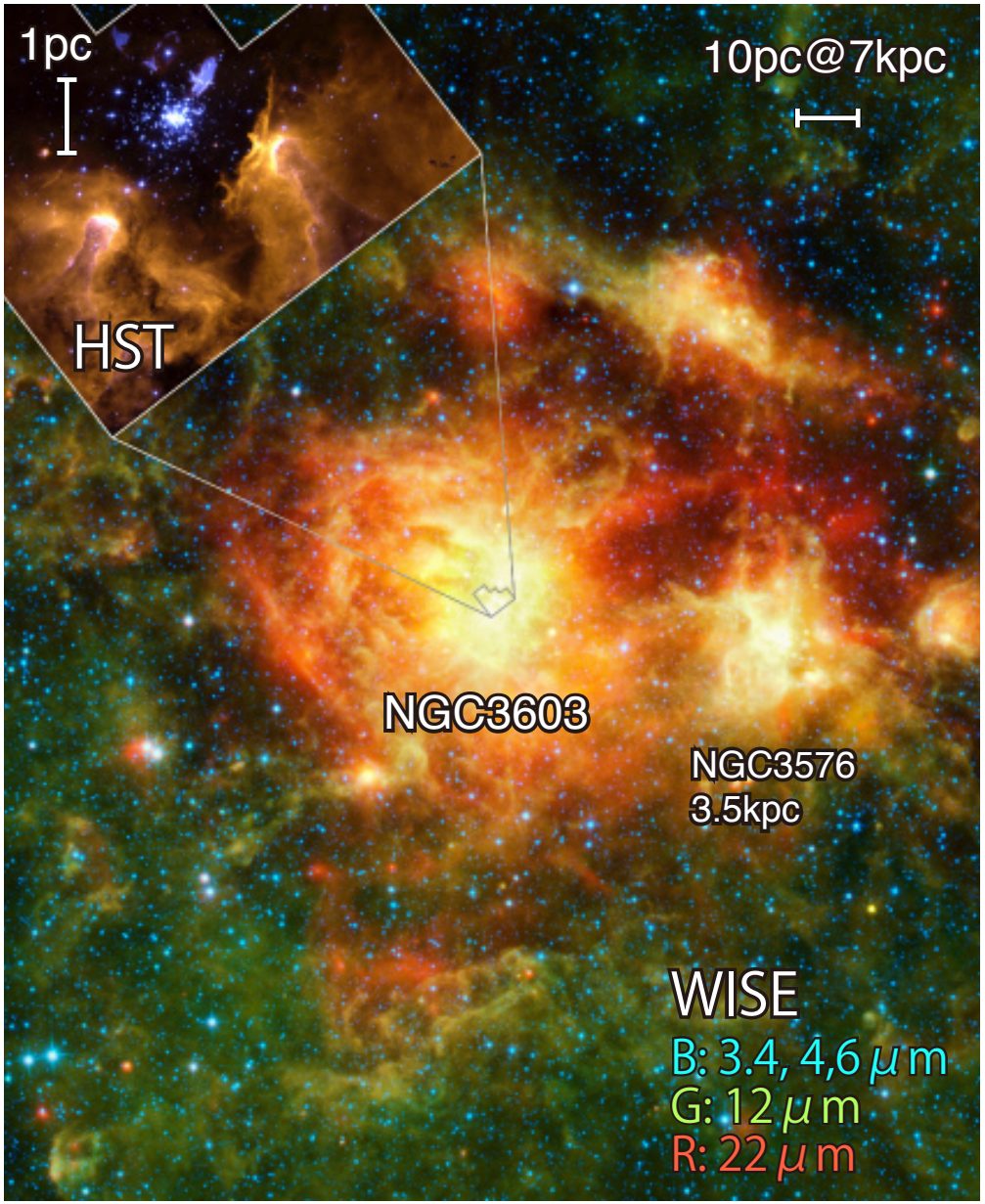


Figure 4. Plot showing a cross-section of the bow-shock from the case with the highest resolution with the velocity vectors (depicting direction only) overlaid on the column density. Turbulence within the interiors of the shell, and the accumulation of material in the convex and concave regions of the perturbed slab are evident from these vectors.

NGC3603(RCW57B)



◇one of SSC in the Milky Way

◇Carina arm
(l, b) = (291.6, -0.5)

◇Distance: 6-8 kpc
(e.g. Russeil 2003)

◇Total mass of stars: > 10^4 M_{sun}
(Harayama et al. 2008)

◇Age :1-3 Myr
(e.g. Sung & Bessell 2004)

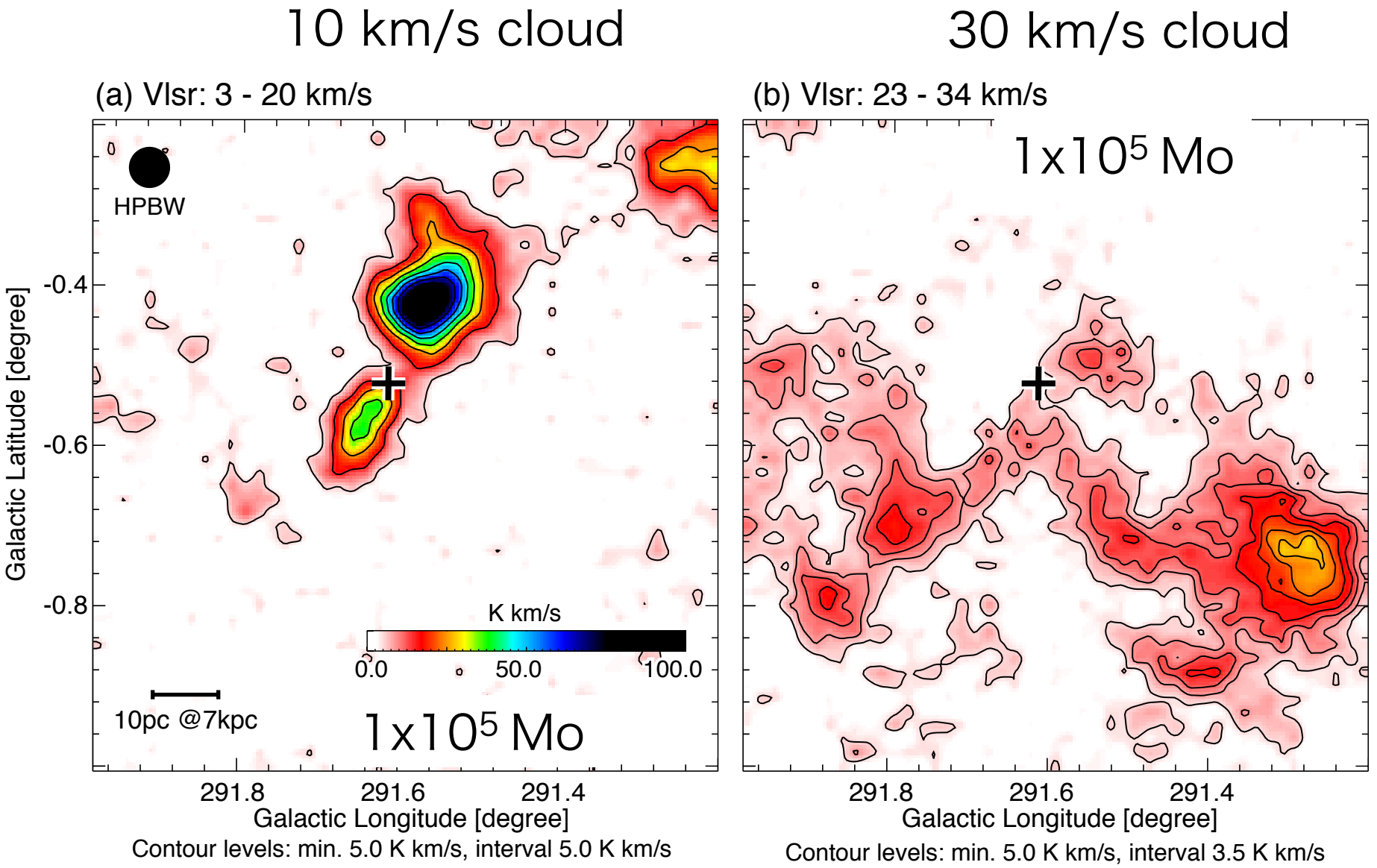
◇O type Star: more than 30
(Moffat et al. 2004)

◇WR:1-4 (Schmutz W. et al. 1999)

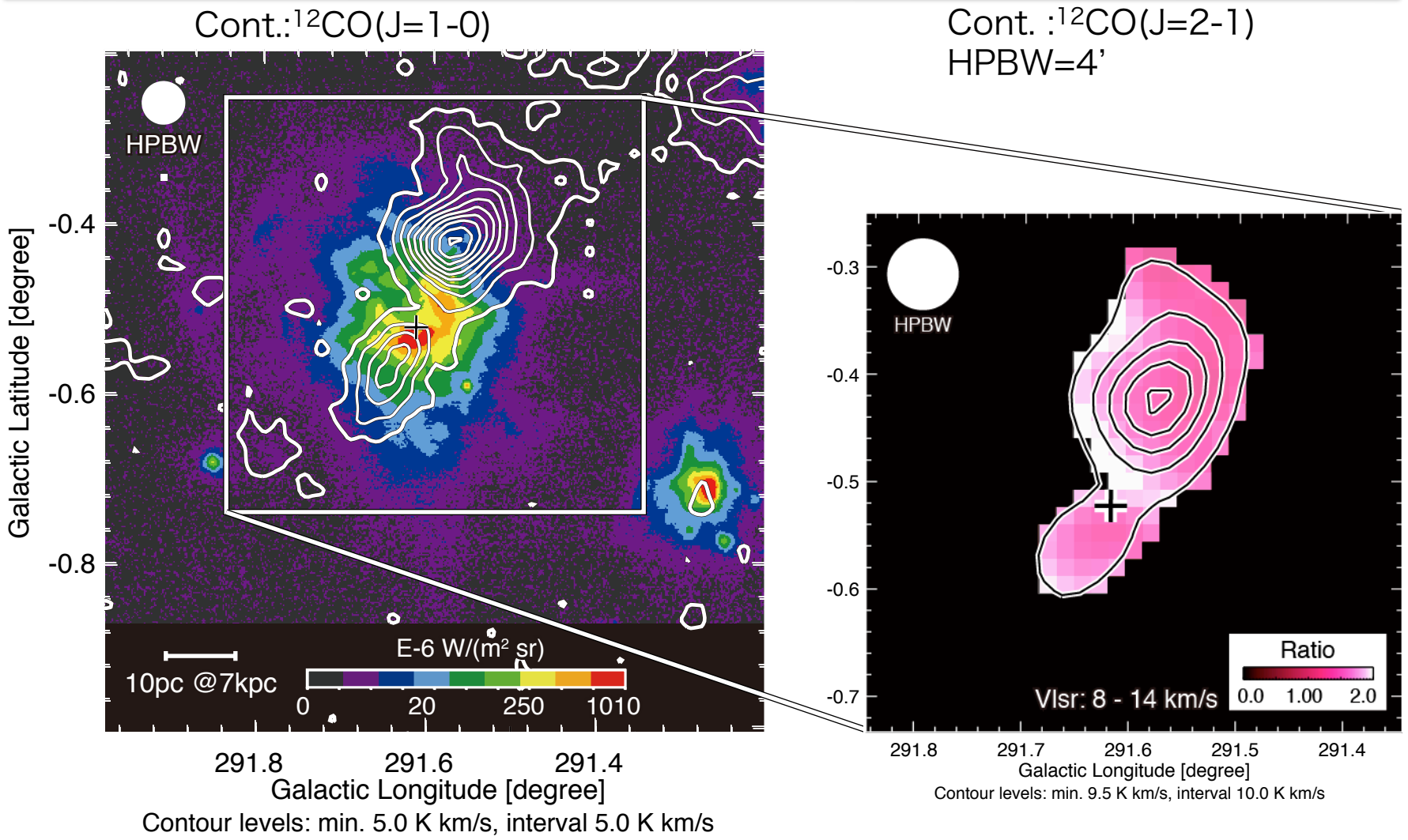
◇Star formation in progress
(Stolte et al.2004)

WISE&HST credit: NASA/JPL-Caltech/UCLA

Spatial Distribution of ^{12}CO(J=1-0)



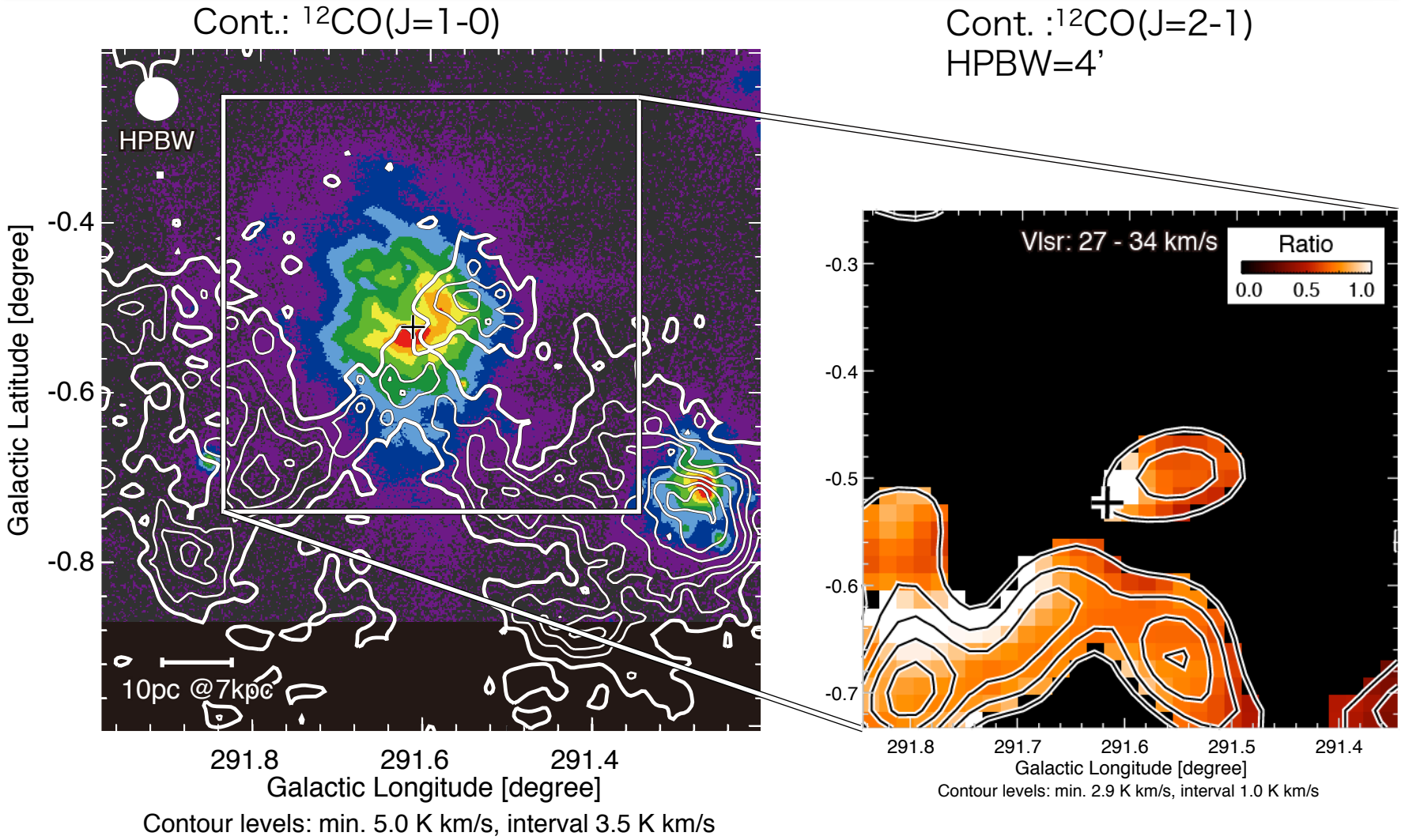
Intensity Radio ^{12}CO(2-1/1-0) of 10km/s



◇Typical ratio is less than 0.5. The ratio doesn't have a gradient. (Sakamoto et al. 1993)

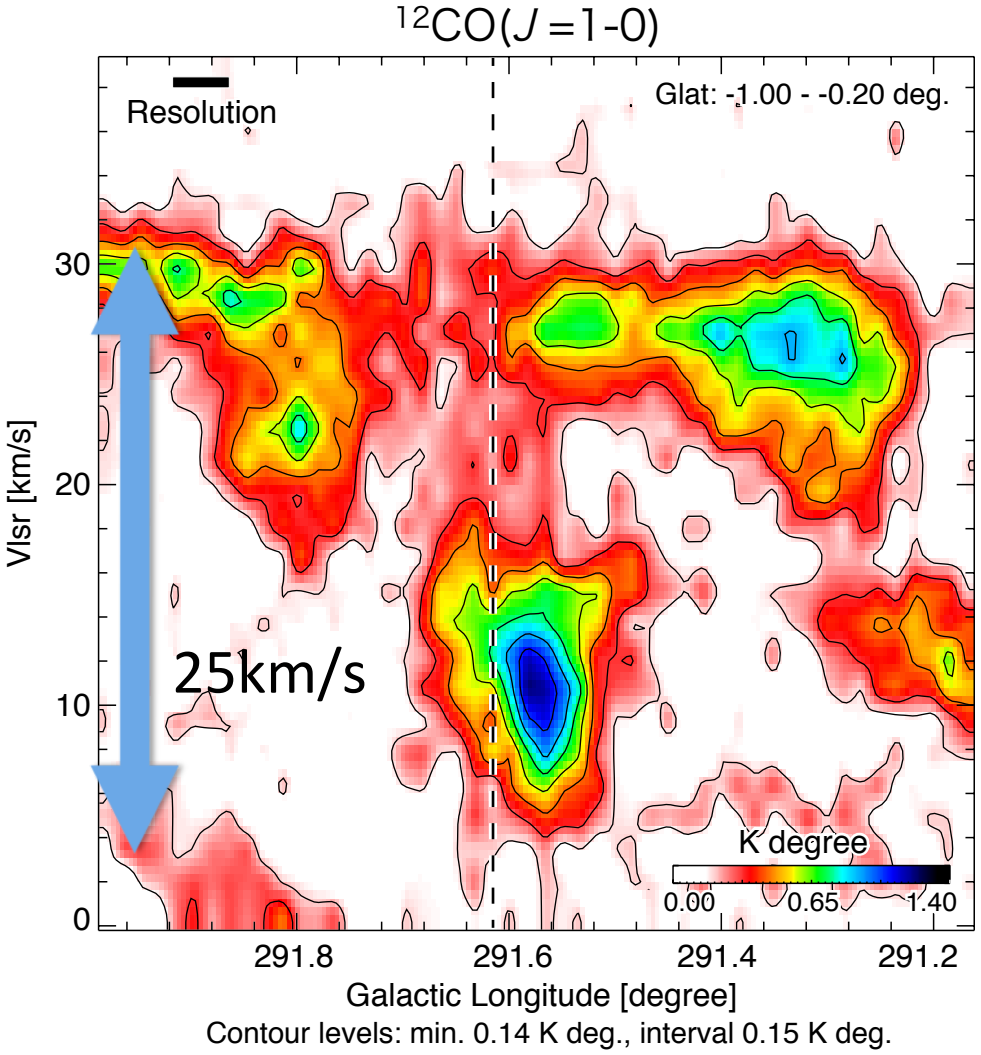
◇There is high ratio near the cluster ⇒ MC associated with the cluster

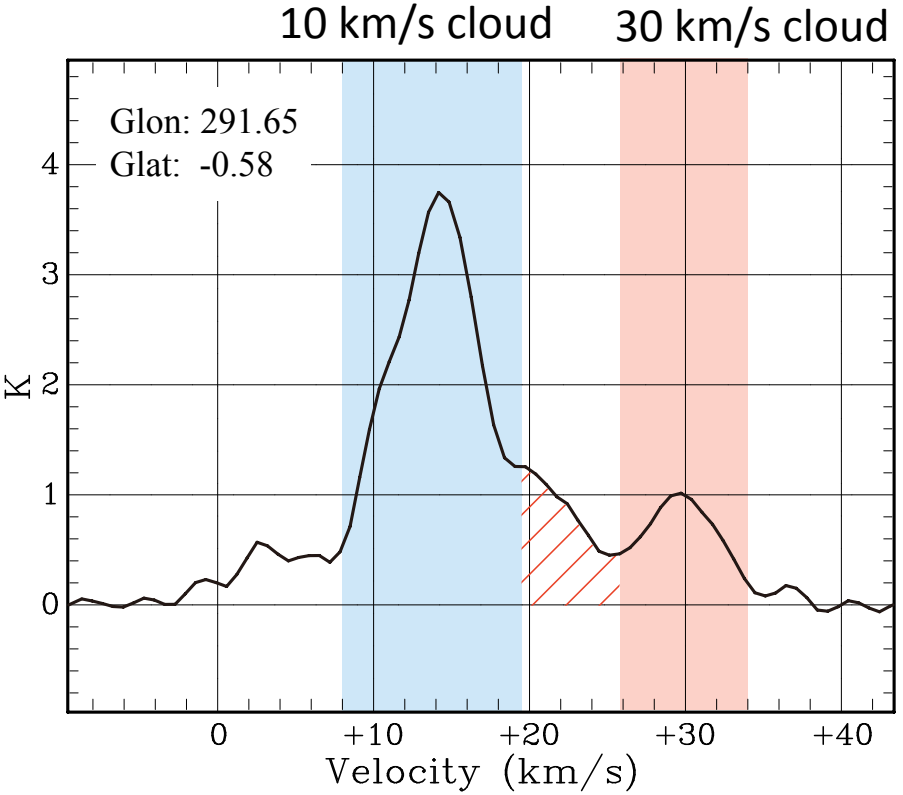
Intensity Radio ^{12}CO(2-1/1-0) of 30km/s



◇Typical ratio is less than 0.5. The ratio doesn't have a gradient. (Sakamoto et al. 1993)
◇There is high ratio near the cluster ⇒ MC associated with the cluster

Position vs. Velocity Diagram toward Molecular cloud





profile of ^{12}CO(J=1-0)

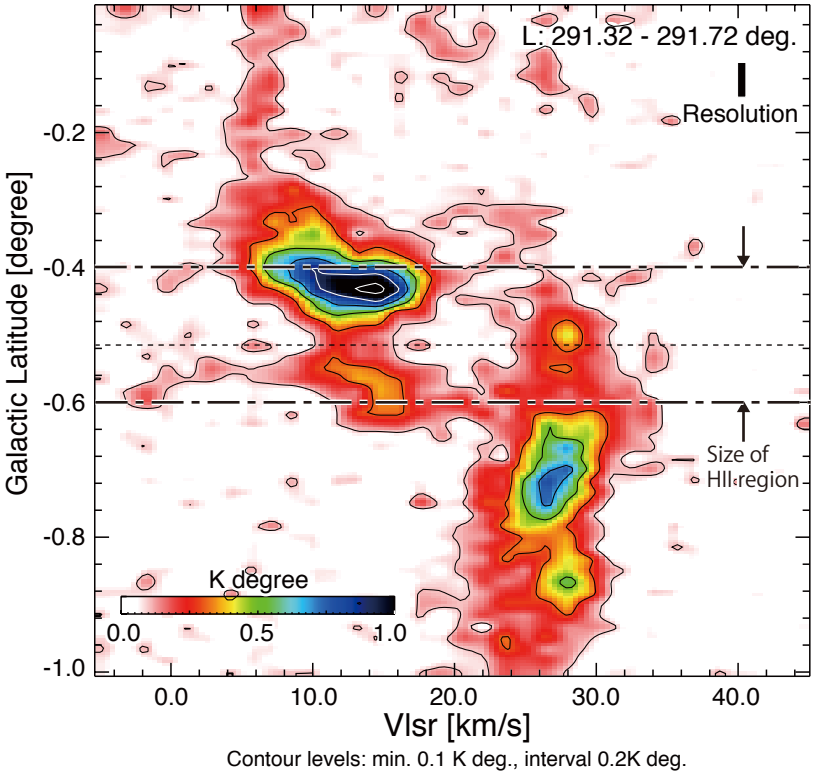
There is a bridge structure of molecular cloud between 10 km/s cloud and 30 km/s cloud toward NGC3603

Position vs. Velocity Diagram NGC3603 & Wd2

◇Separation beteween Blue shift (ΔV=20km/s) & Red shift (ΔV=10km/s)

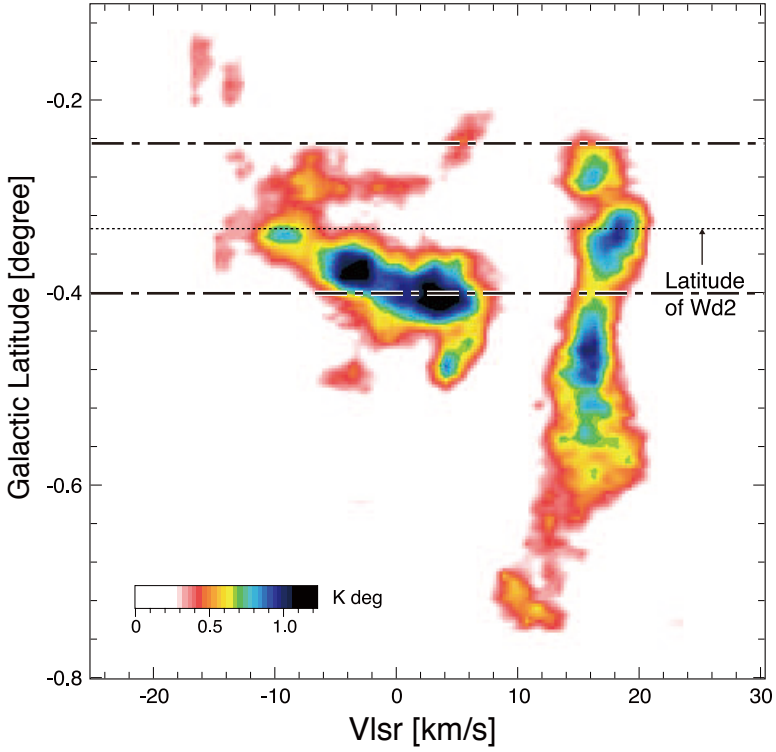
◇cavity of molecular clouds corresponds the expanse of HII region

NGC3603 This work, ^{12}CO(J=1-0)



Contour levels: min. 0.1 K deg., interval 0.2K deg.

Westerlund2 Furukawa et al. (2009), ^{12}CO(J=2-1)

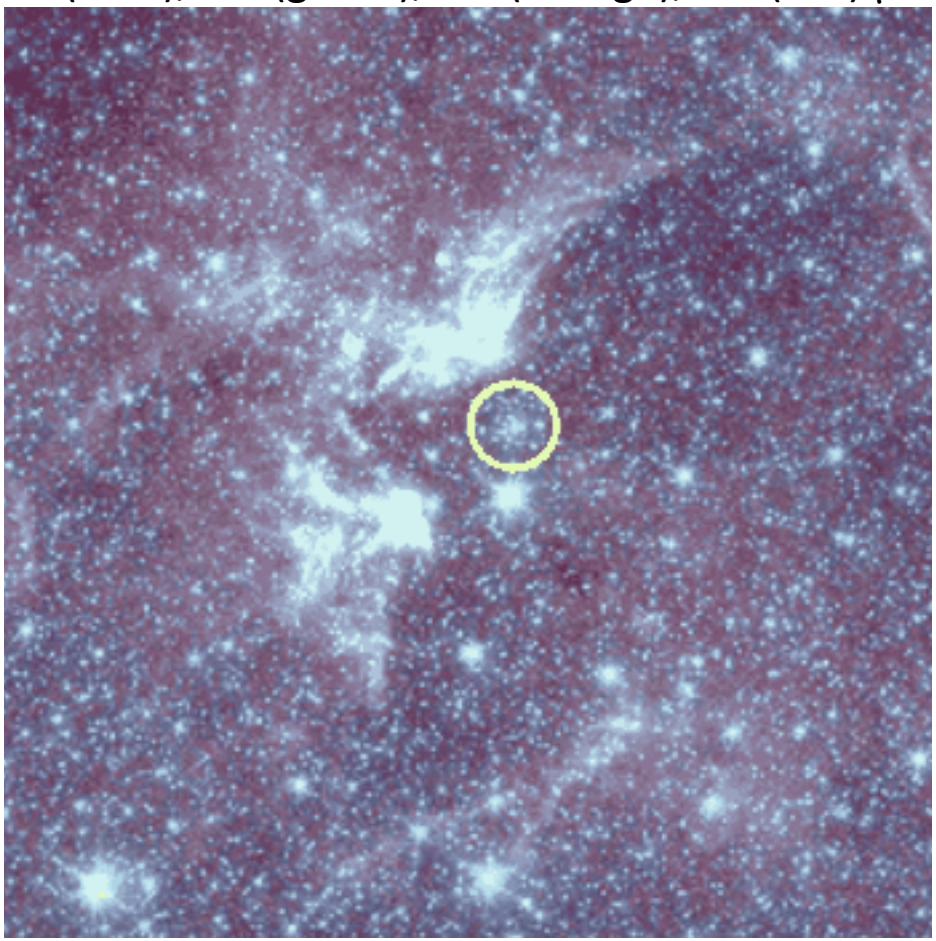


NGC3603

[DBS2003]179

Spitzer IRAC ;

3.5 (blue), 4.5 (green), 5.8 (orange), 8.0 (red) μm



Object [DSB2003]179

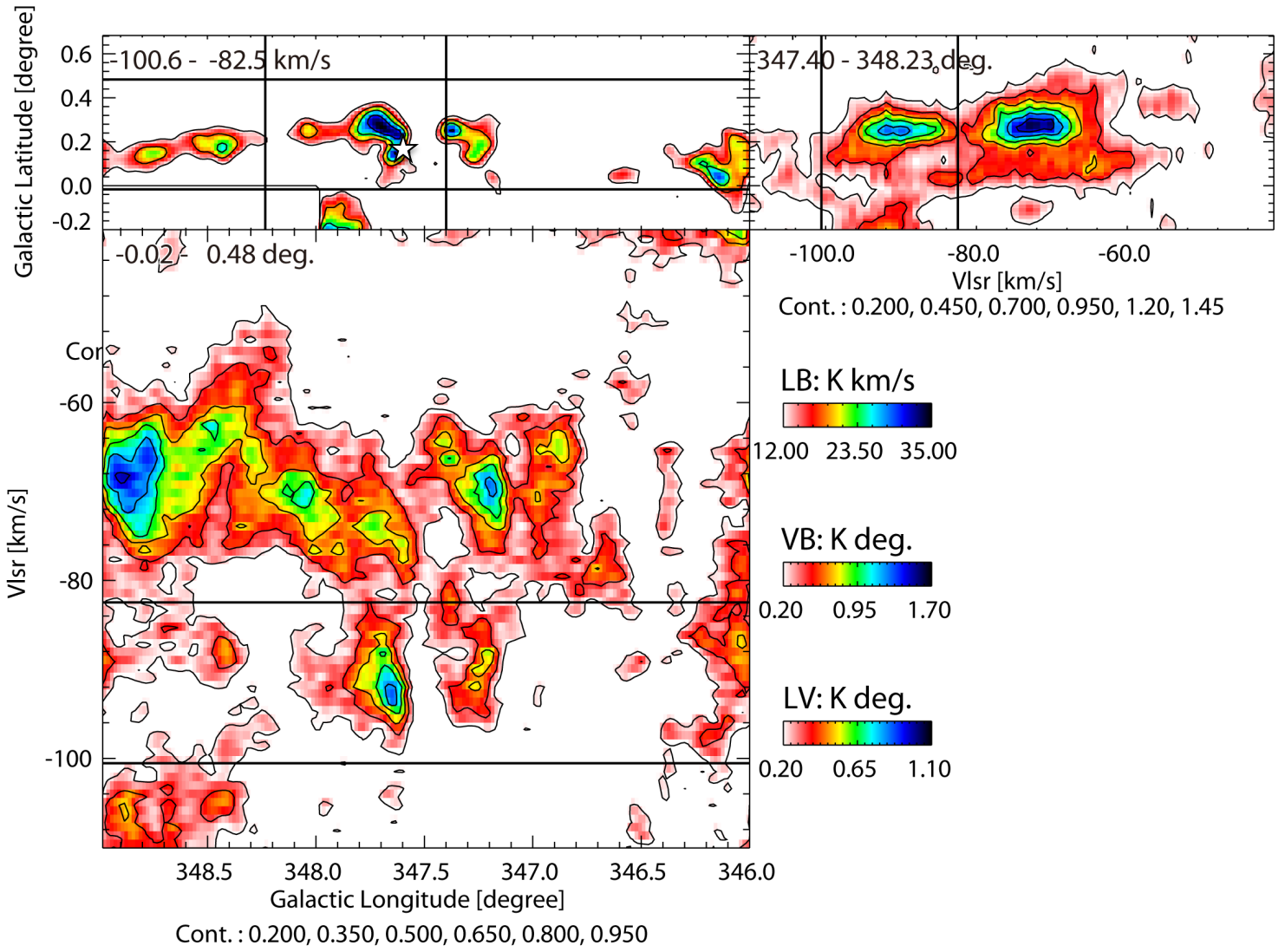
Position (l,b) = (347.6°,0.2°)

Distance 7.9 Kpc

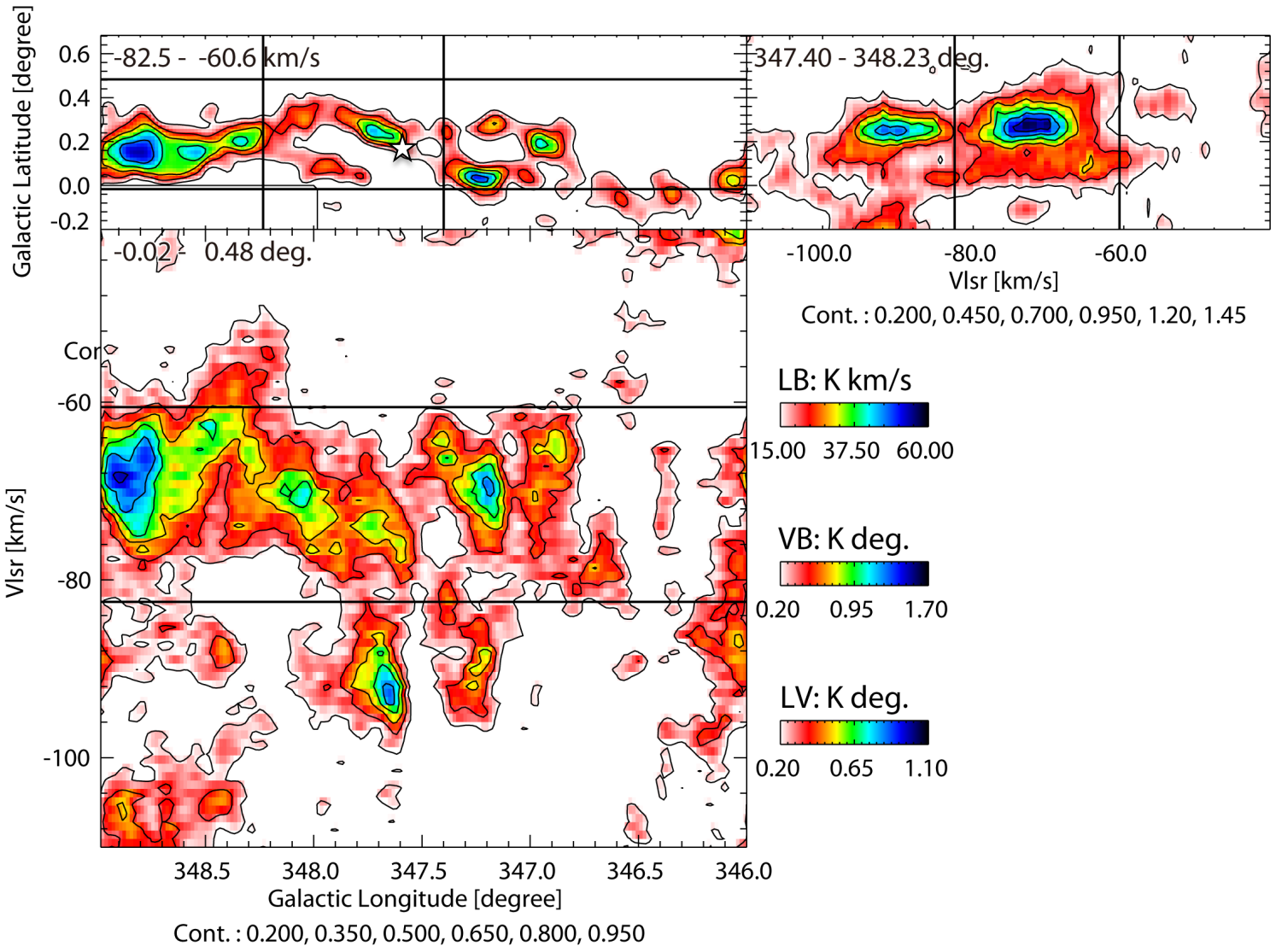
Age 2 - 5 Myr

Total mass of stars 0.7×10^4 Mo

(Borissova et al.2008)

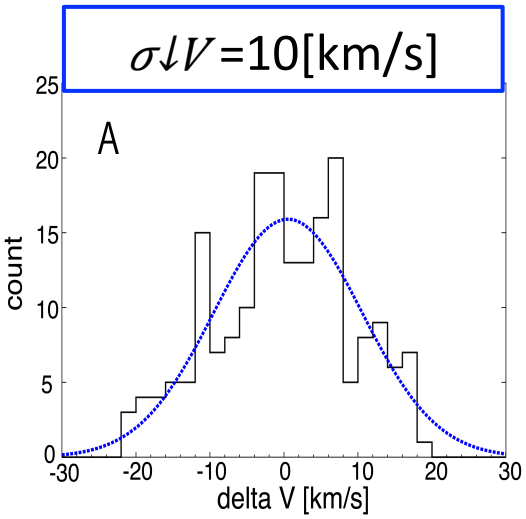


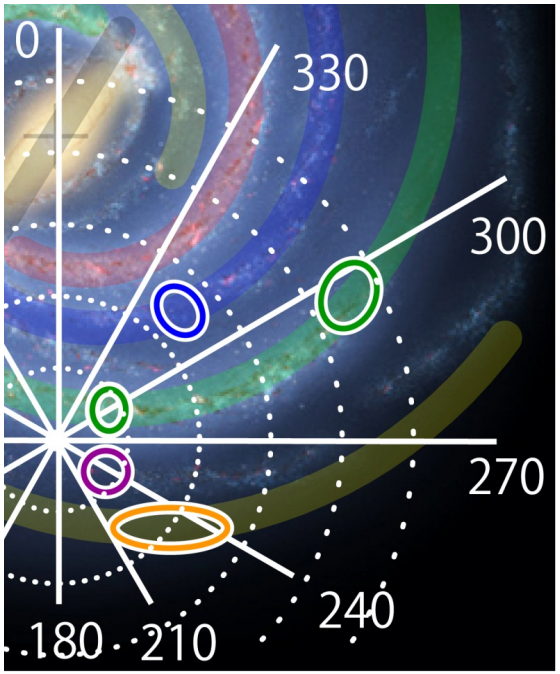
☆... [DBS2003]179 (l=347.6°,b=0.2°)

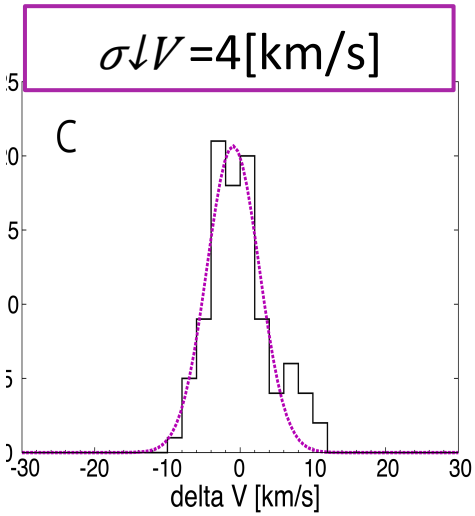


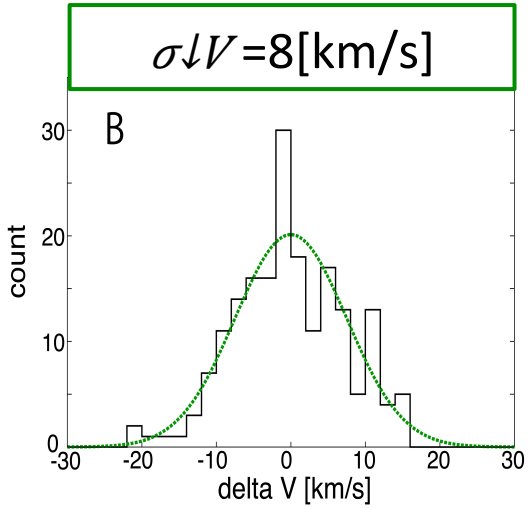
☆... [DBS2003]179 (l=347.6°,b=0.2°)

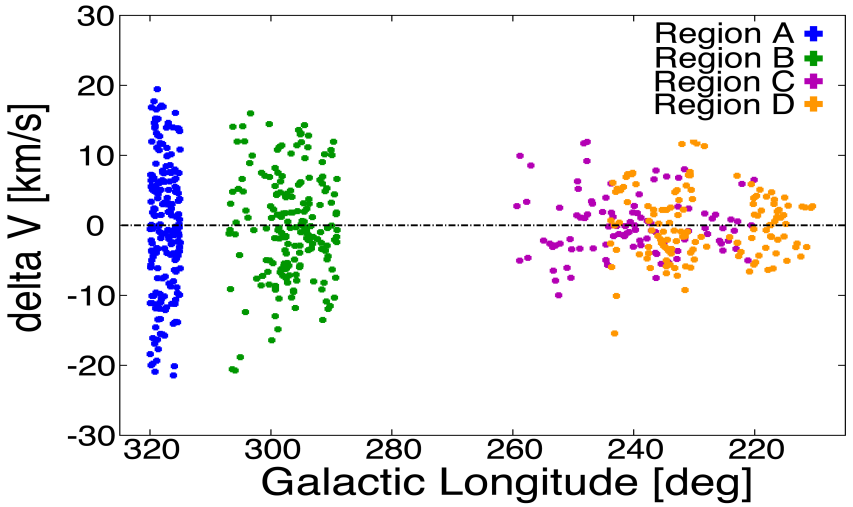
CO clouds velocity dispersion

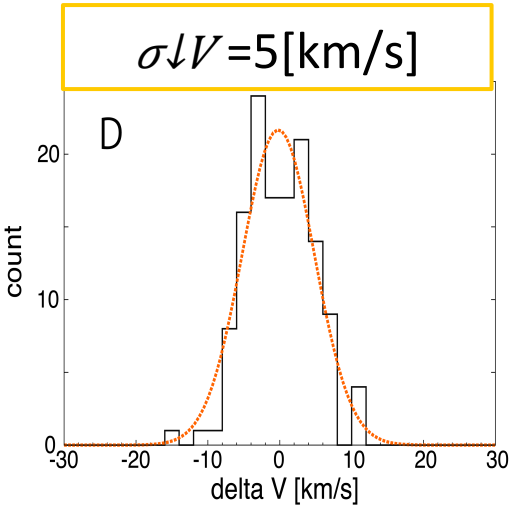




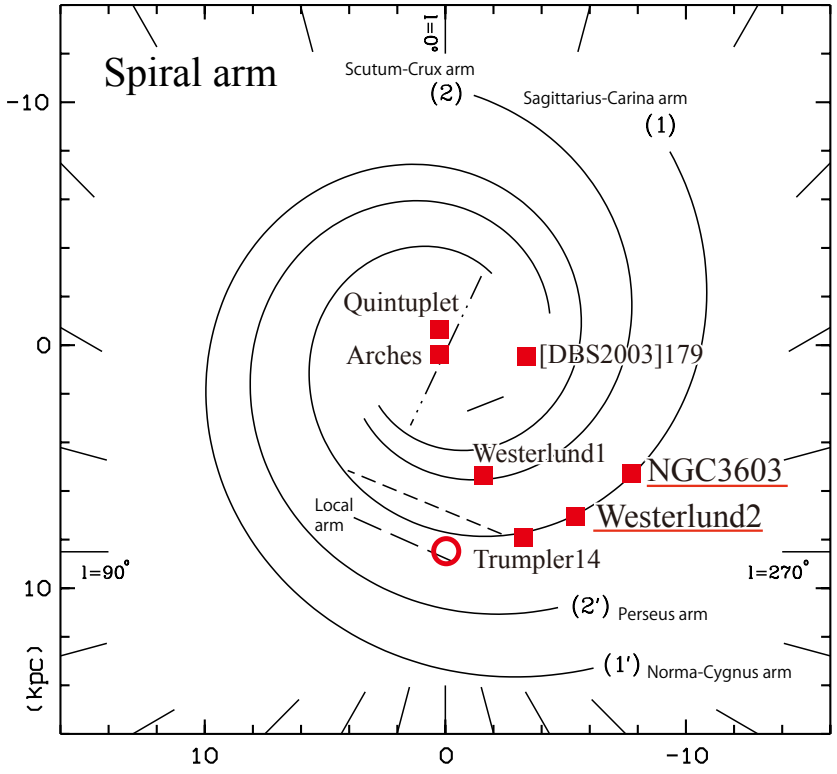








SSC catalog in the Milky way



Distribution of SSC in the Milky way.
D.Russeil (2002)
Red circle is sun.

Portegies Zwart, McMillan & Giels (2010)

SSC	Age [Myr]	LogM_* [M_{sun}]	size[pc]	Molecular cloud
NGC3603	2.0	4.1	0.7	○
Westerlund2	2.0	4.2	0.8	○
[DBS2003]179	3.5	3.8	1.2	○
Westerlund1	3.5	4.0	1.0	×
Trumpler 14	2.0	4.5	0.5	--
Arches	2.0	4.3	0.4	×
Quintuplet	4.0	4.0	2.0	×
RCW38	<1.0	--	0.8	○

Triggered formation of super star clusters

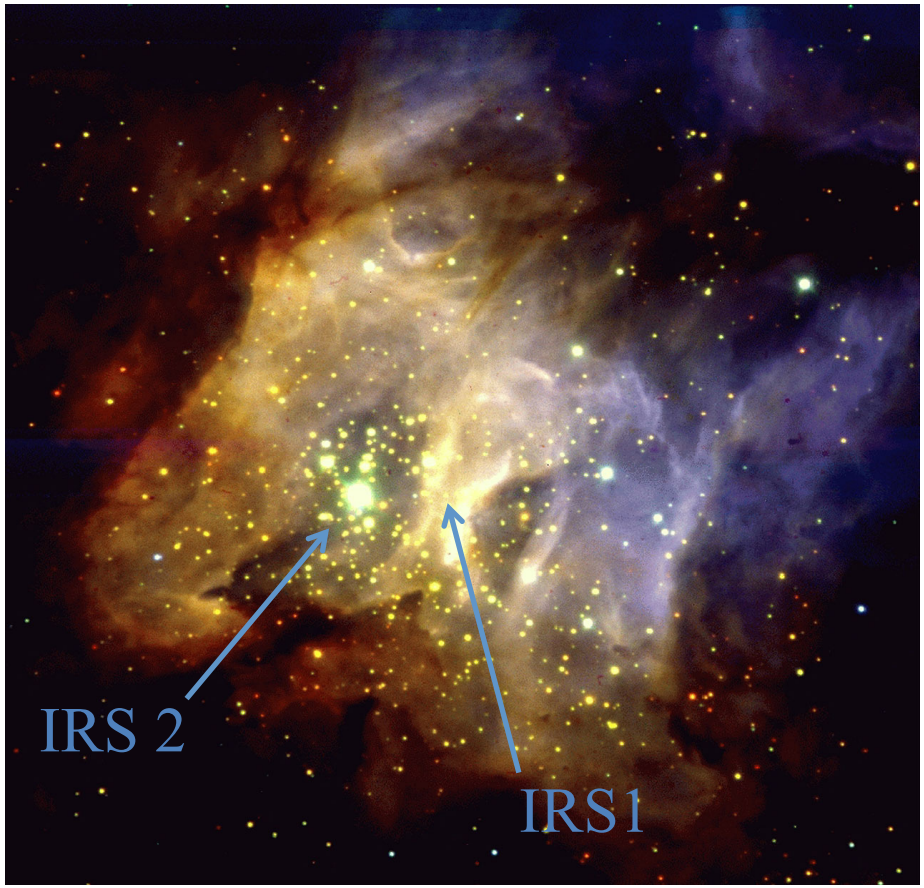
- Super star clusters [SSC] has 10^4 stars in 1pc radius, more than 10 O stars

  R136 etc, in LMC and dwarfs
- Only four SSCs in the Milky Way have parent molecular clouds

  Westerlund 2, NGC3603, RCW38, [DBS2003]179

  - the rest has no cloud due to ionization
- All the four have two parent molecular clouds, with 20 km/s velocity separation, collision creates strong turbulence
- New observations suggest triggered formation by cloud collision
- Furukawa, Fuku+2009, Ohama, Fukui+ 2010, Torii, Fukui+2011[M20]

Star-Forming Region RCW38



- High mass star-forming region
- Bright HII region
  (Rodgers, Campbell & Whiteoak, 1960)

- Position: (l, b) = (268°, -1°)
- Age: < 1Myr (young cluster)
- Distance: 1.7 kpc (Rodgers 1960)
- Number of stars: 10^3–10^4 (O-star:~30)
  (Wolk et al. 2006; Winston et al. 2011)

- Two bright mid-IR sources
  IRS 1 and IRS2
  (Frogel & Persson; 1974; Smith et al. 1999;
  DeRose et al. 2009)

A close-up of the central 2.5' (~1.2 pc) of RCW 38 (Wolk et al. 2006; credit ESO).
In this VLT image, Z band data are printed as blue, H band data are green and K band are red.

Spatial Distribution of ^{12}CO(J=1-0)

HPBW grid RCW38 5pc

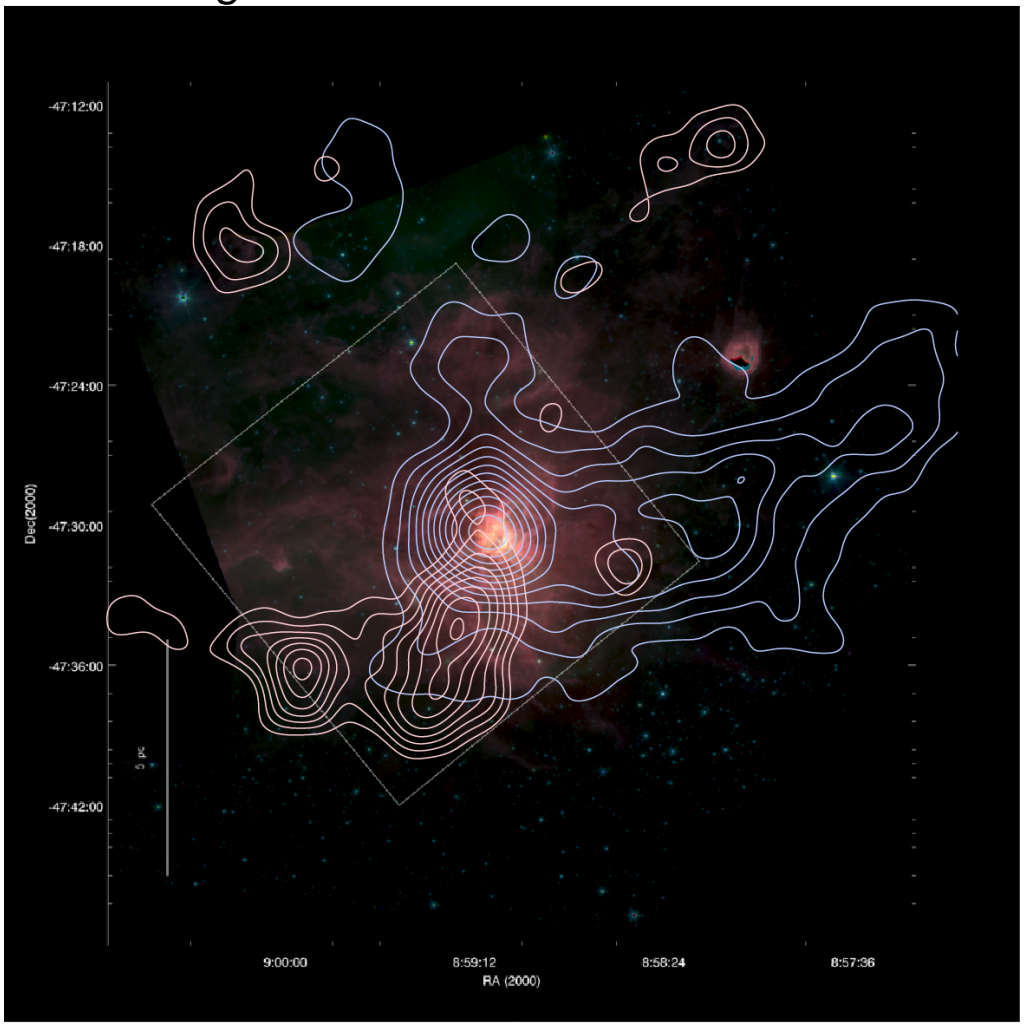


image: Sptizer (Blue 3.6 μm, green 4.5 μm, red 8.0 μm)
cont.: 12CO(1-0)

blue cloud Vlsr: -3.0 - 7.9 km/s
Cont. : 24.2, 31.2, 38.2, 45.2, 52.2

red cloud Vlsr: 7.9 - 14.8 km/s
Cont. : 8.0. 10, 12, 14, 16, 18, 20