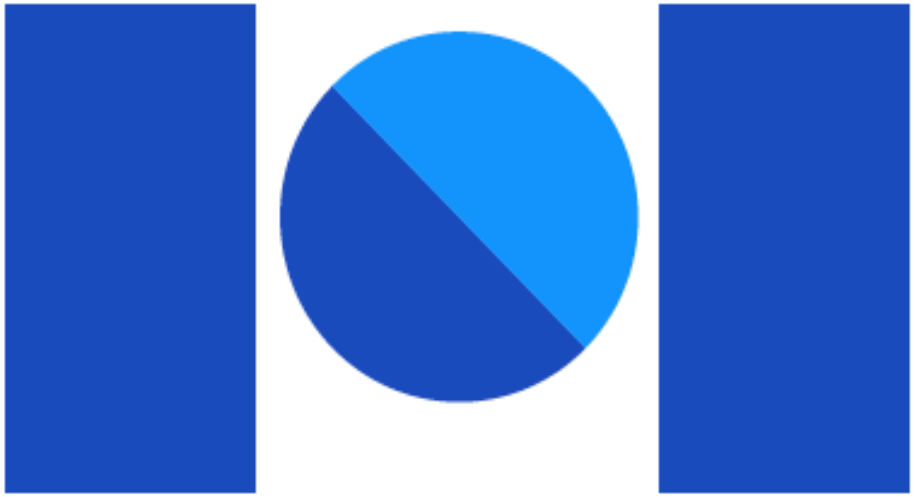
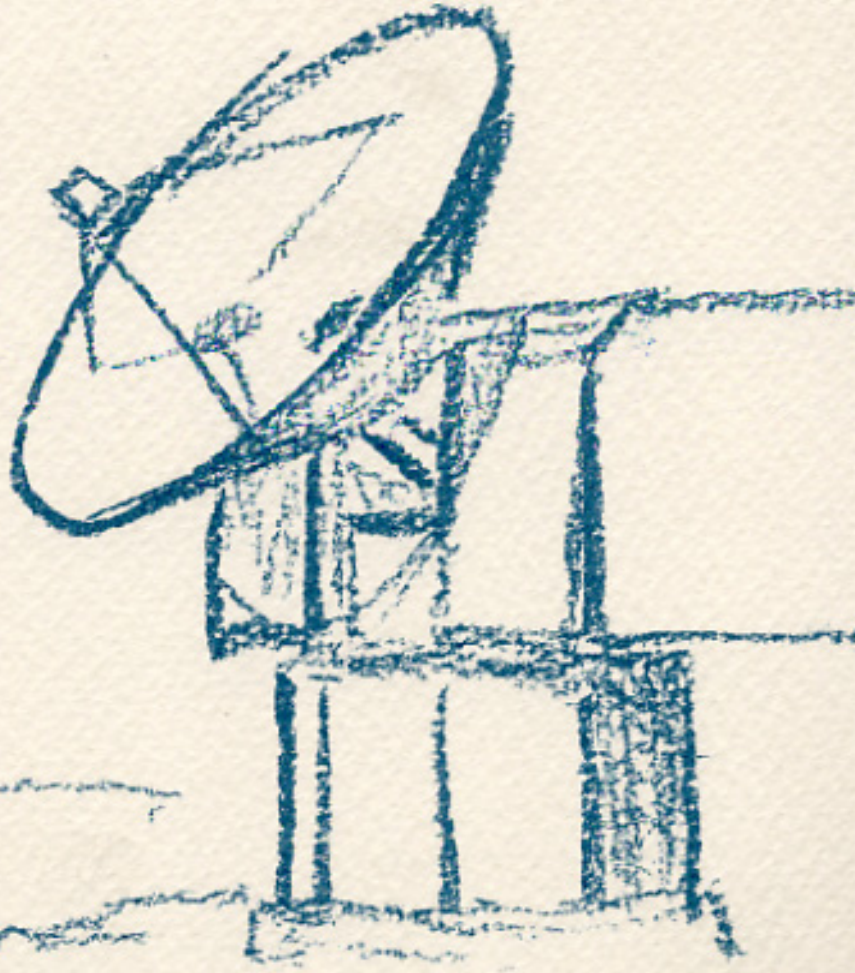


NANTEN

Submillimeter Observatory

Formation of super star clusters in galaxies



Yasuo Fukui

Nagoya University

A Lowell Observatory Workshop
Star Formation in Dwarf Galaxies **June 19-22, 2012** **Flagstaff**

Y. F.

Triggered formation of super star clusters

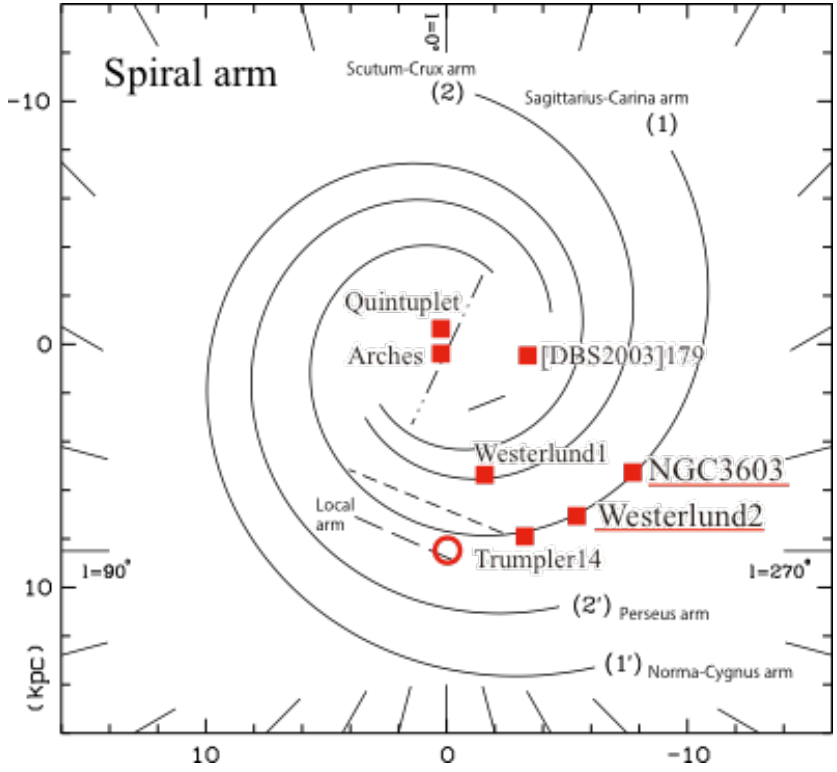
- Super star clusters [SSC] has 10^4 stars in 1pc radius, more than 10 O stars

  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 photo-ionization
- All the four have two parent molecular clouds, with 20 km/s velocity separation, gravitationally unbound
- Clouds are colliding with each other
- New observations suggest triggered formation of SSC by cloud collision
- Furukawa, Fukui+2009, Ohama, Fukui+ 2010, Torii, Fukui+2011[M20]

SSC catalog in the Milky way



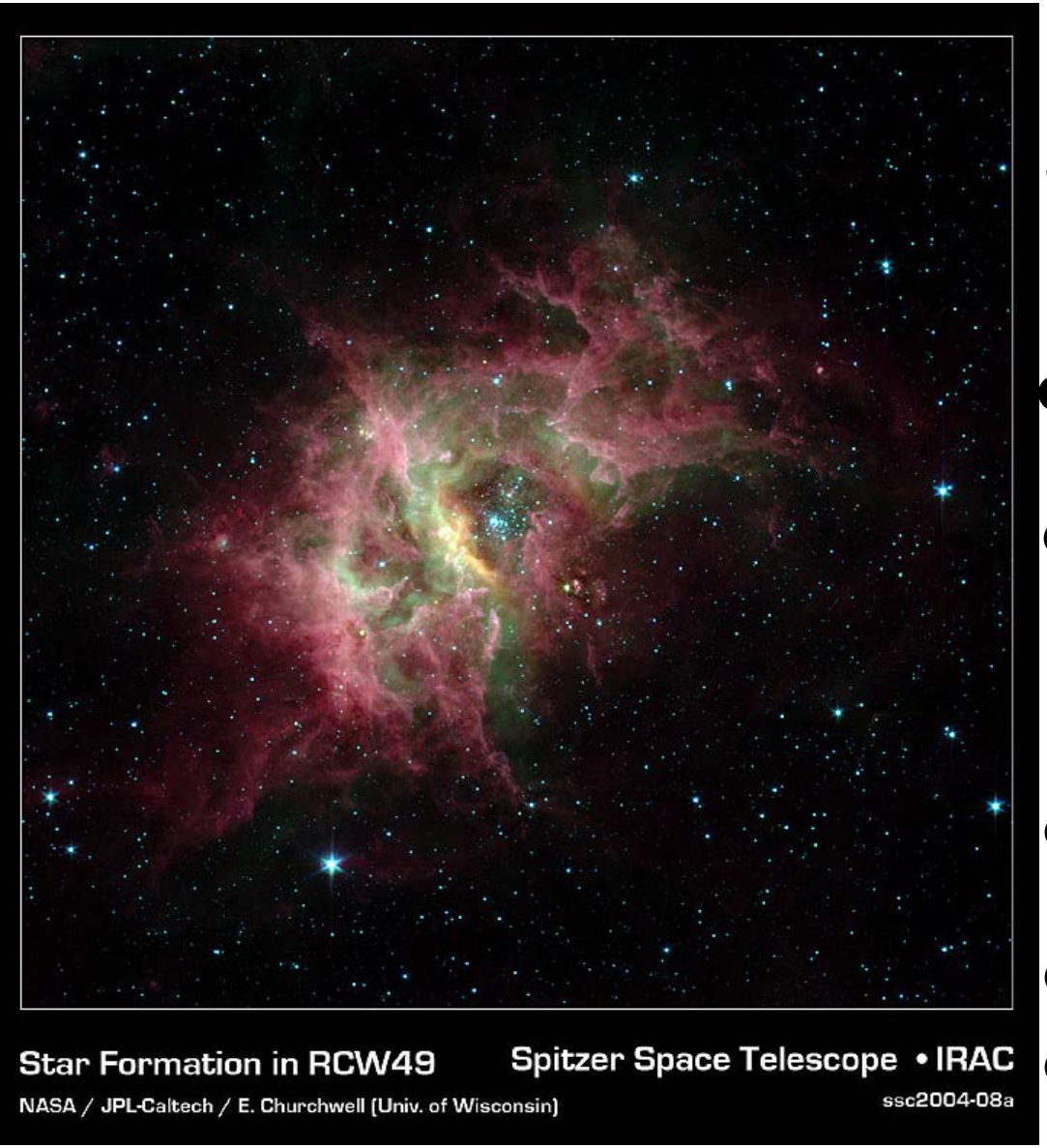
Distribution of SSC in the Milky way.
D.Russeil (2002)
Red circle is sun.

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	○

Spitzer IRAC ;

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



Westerlund 2 (Wd2)

Super star cluster

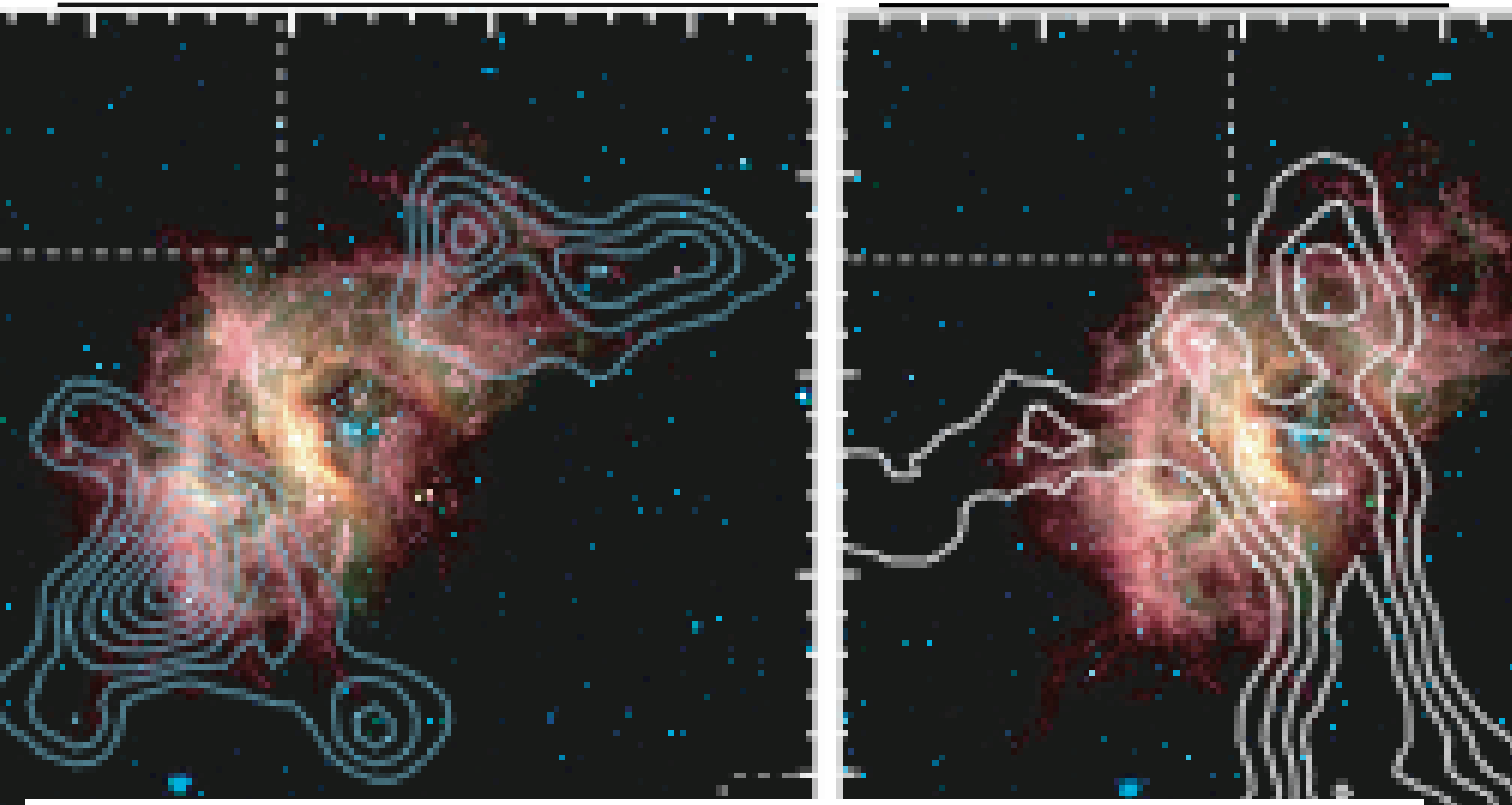
(l, b) = (284°.27, -0 °.33)

- 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)

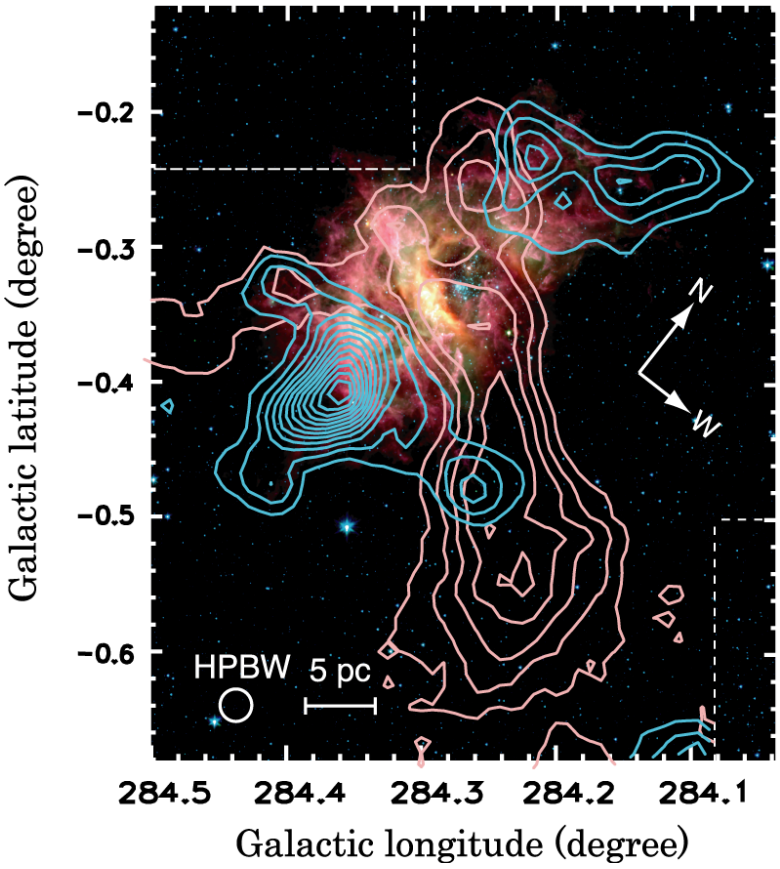
Spatial Distribution of ^{12}CO(J=2-1)

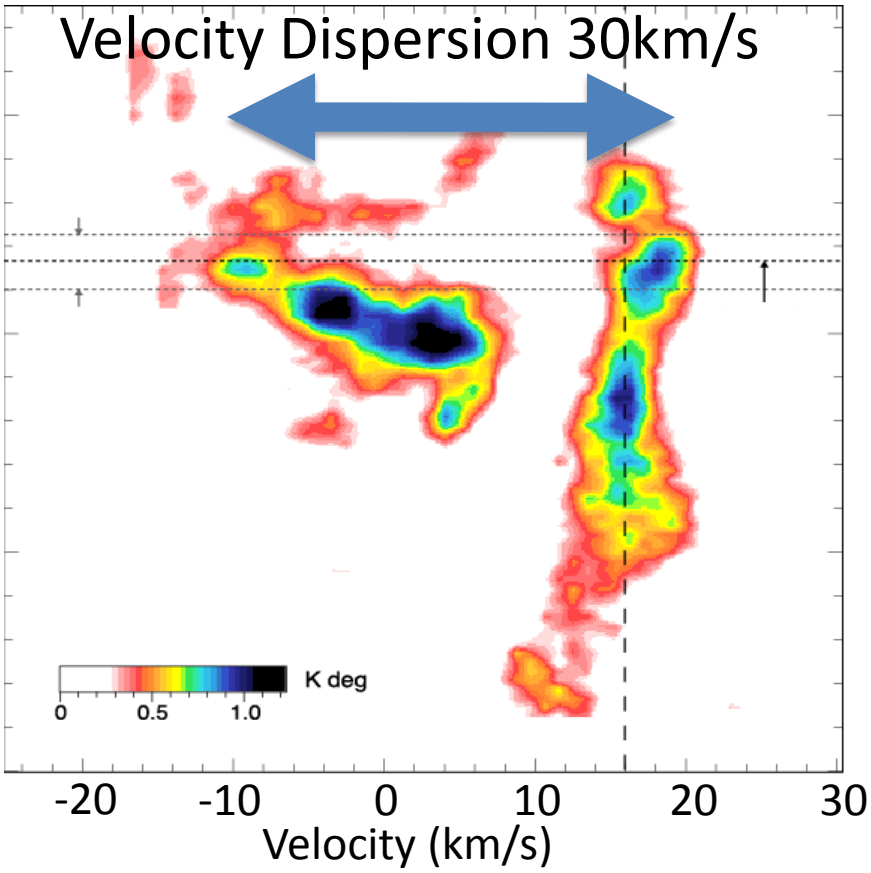


We suggested that molecular clouds are associated with HII region by the morphology.

Galactic latitude-Velocity Diagram

l = 284.2-284.4

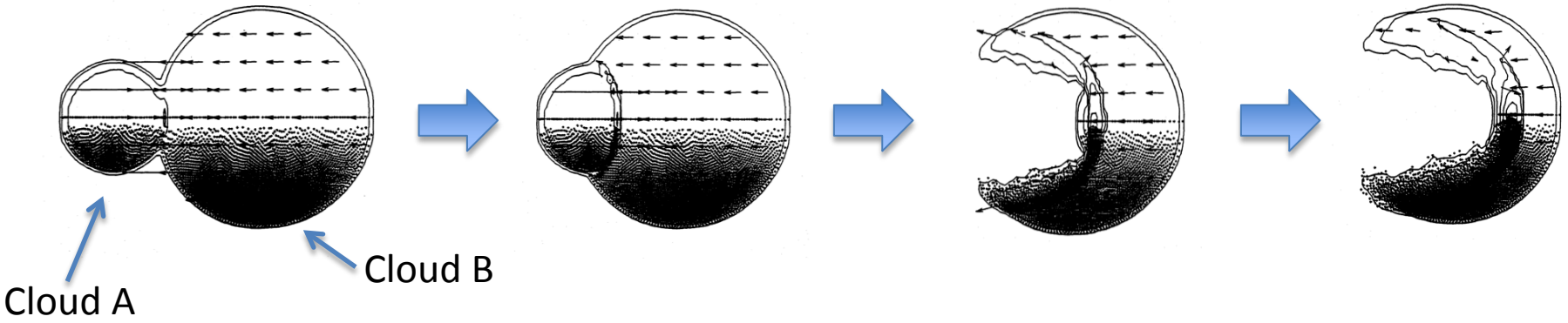




Two molecular clouds (10^5Mo) are not bound by gravity because of the large velocity separation 30 km/s

Numerical Simulations

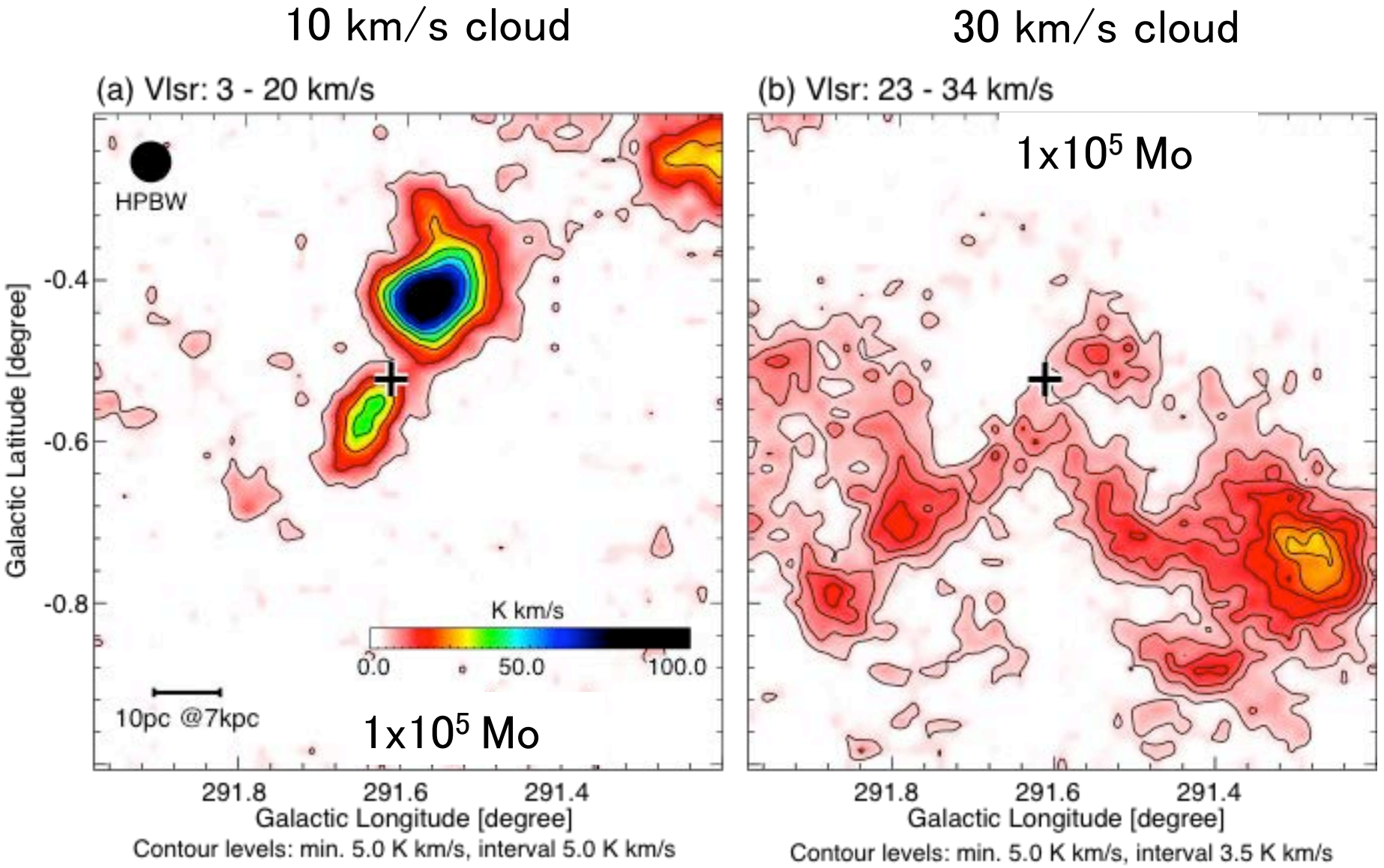
■ Collision between uneven clouds (Habe & Ohta 1992）



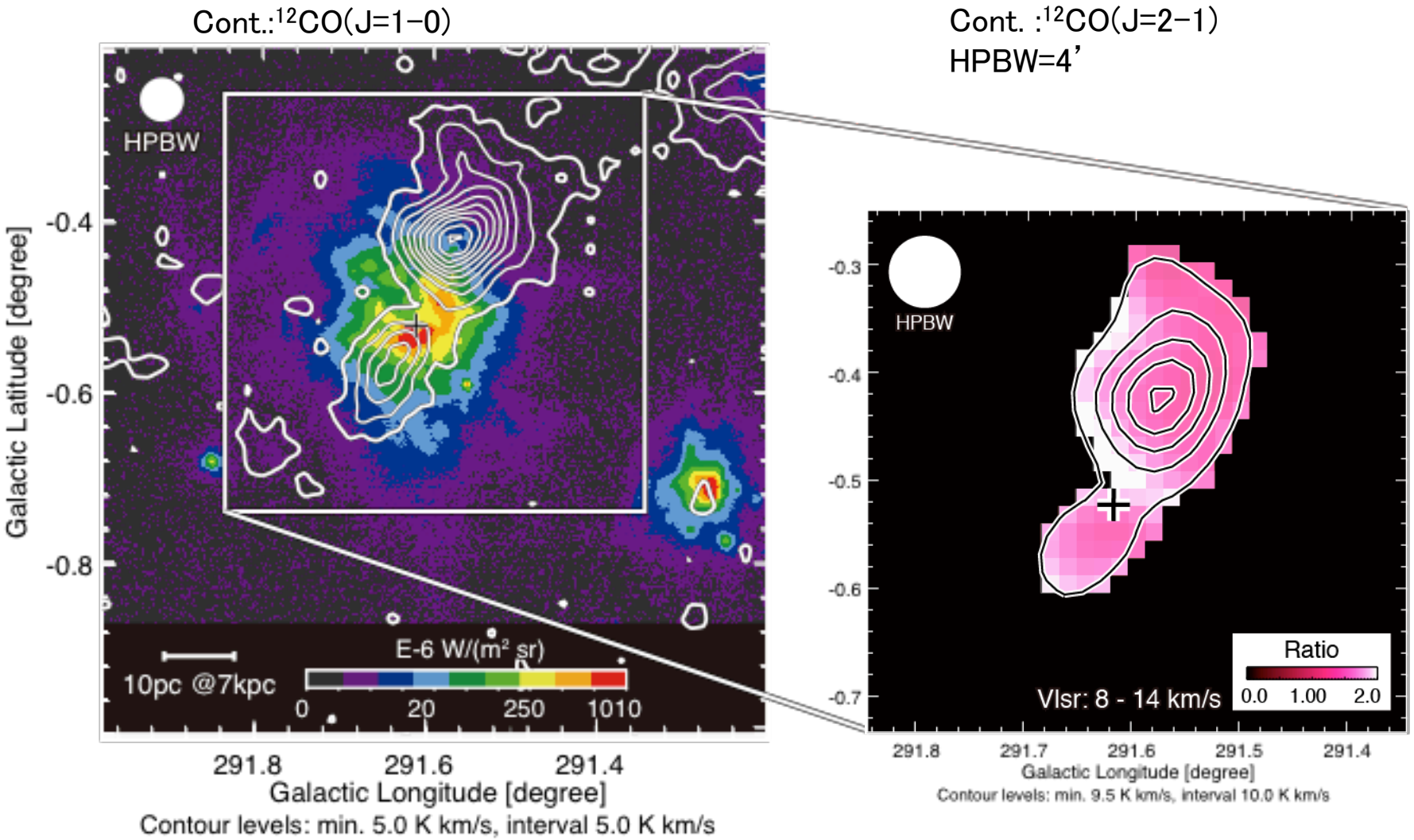
– The compact dense cloud disrupts the large diffuse cloud
– The shock triggers star formation

The inside of the shell is ionized (HII region).
The compressed layer becomes ring-like star formation.
The two velocity components or the residual one may be observed.
Spitzer bubbles are good candidates of such triggering.

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



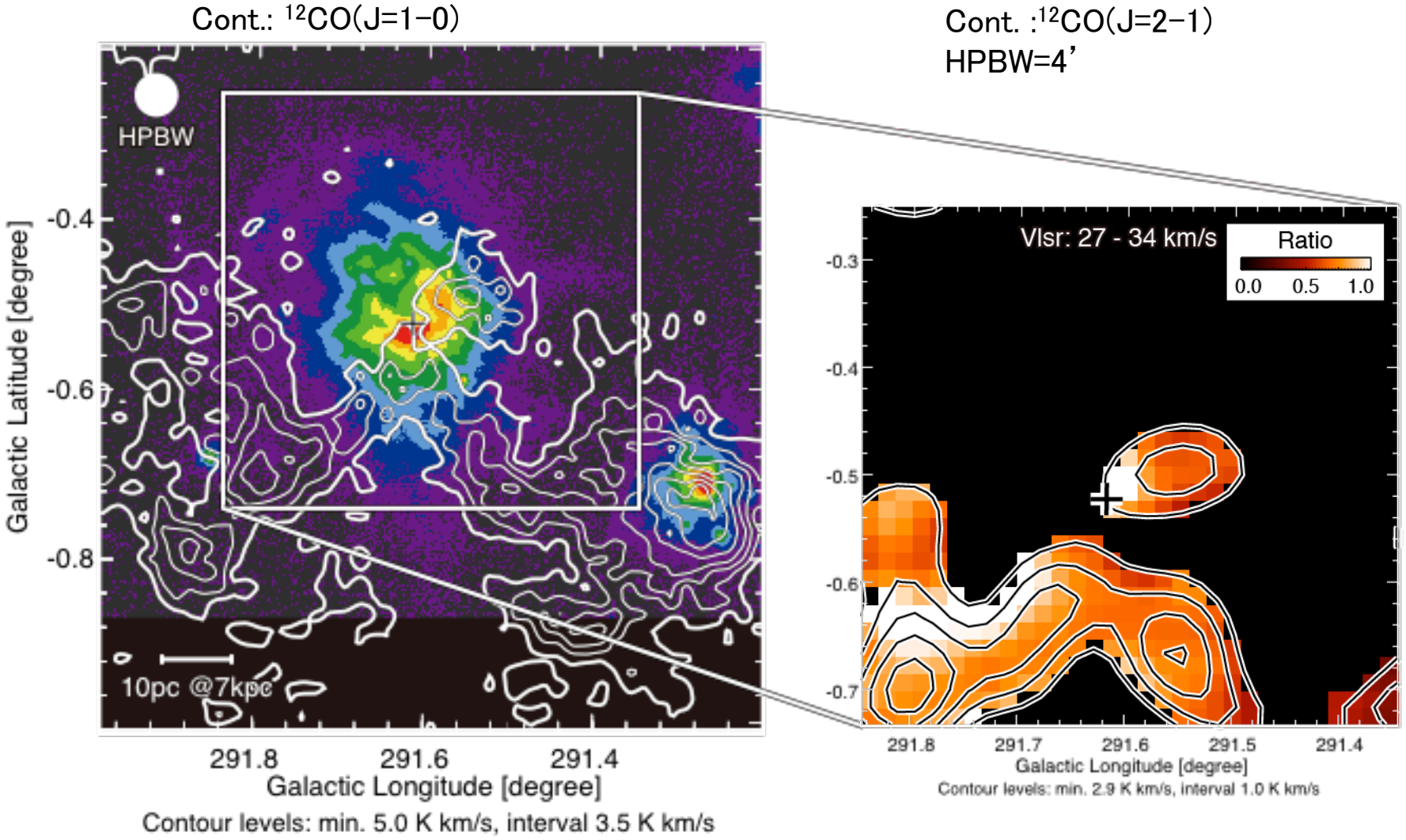
Intensity Radio ^{12}CO(2-1/1-0) of 10km/s



◇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



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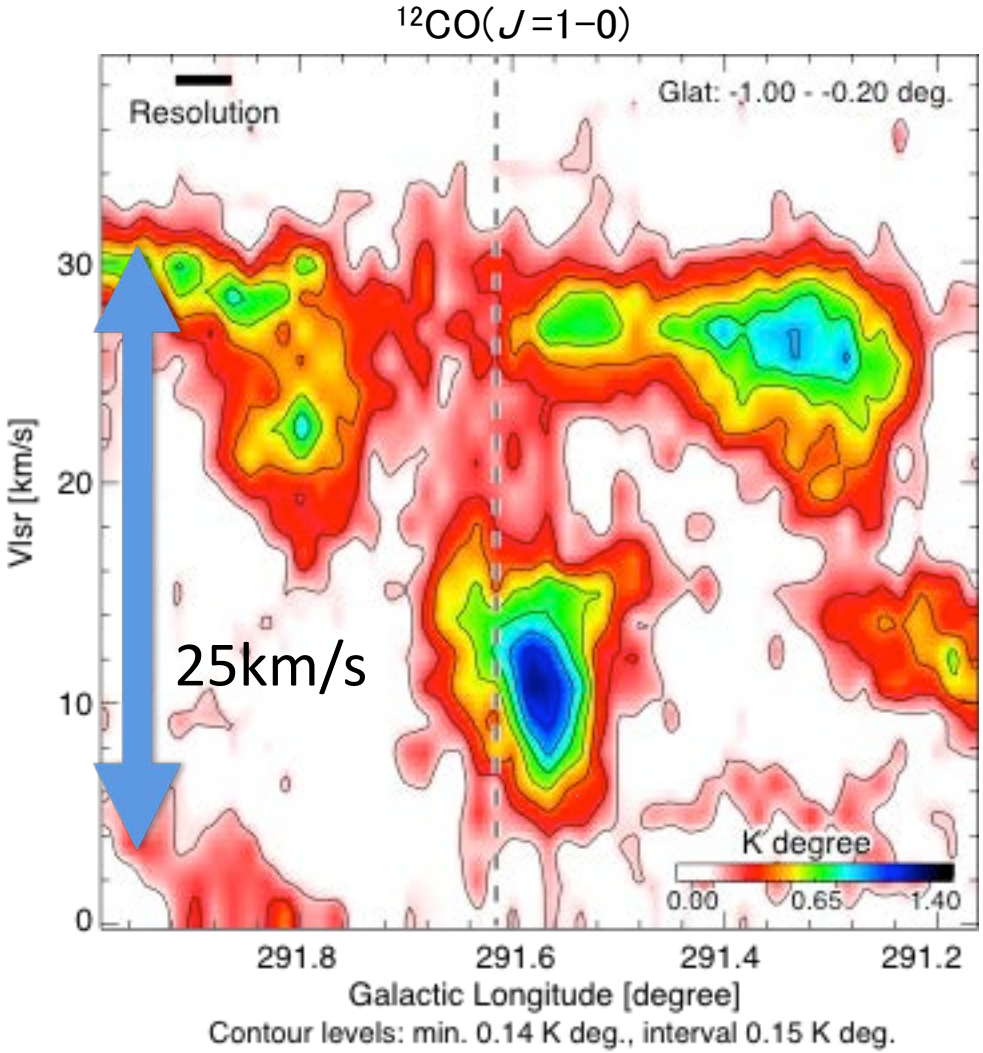
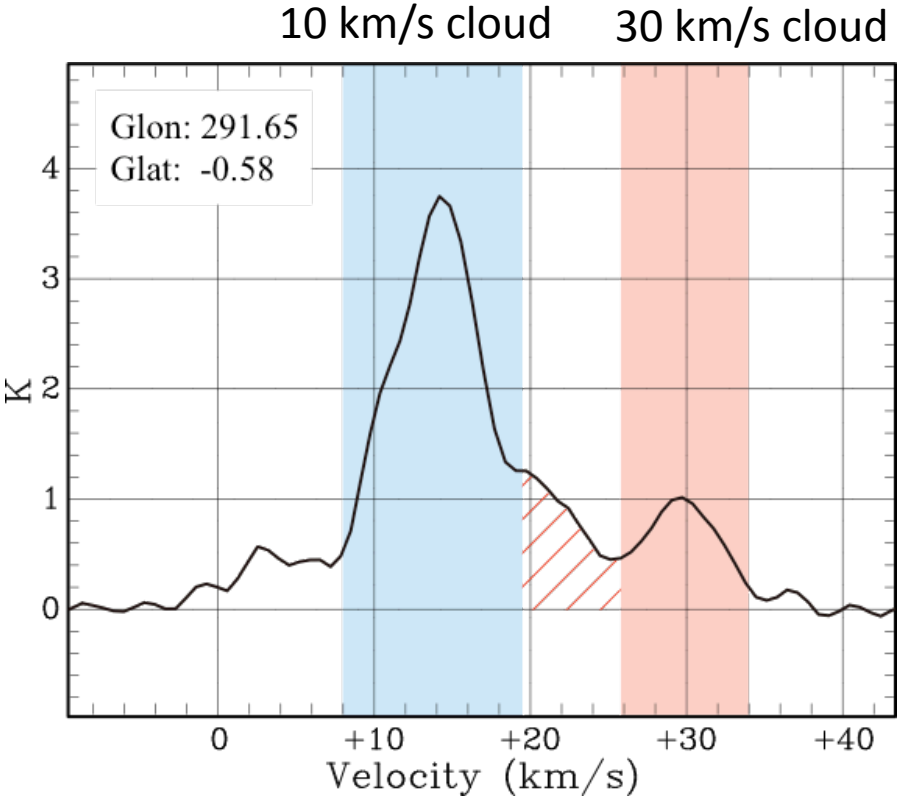
Position vs. Velocity Diagram toward Molecular cloud

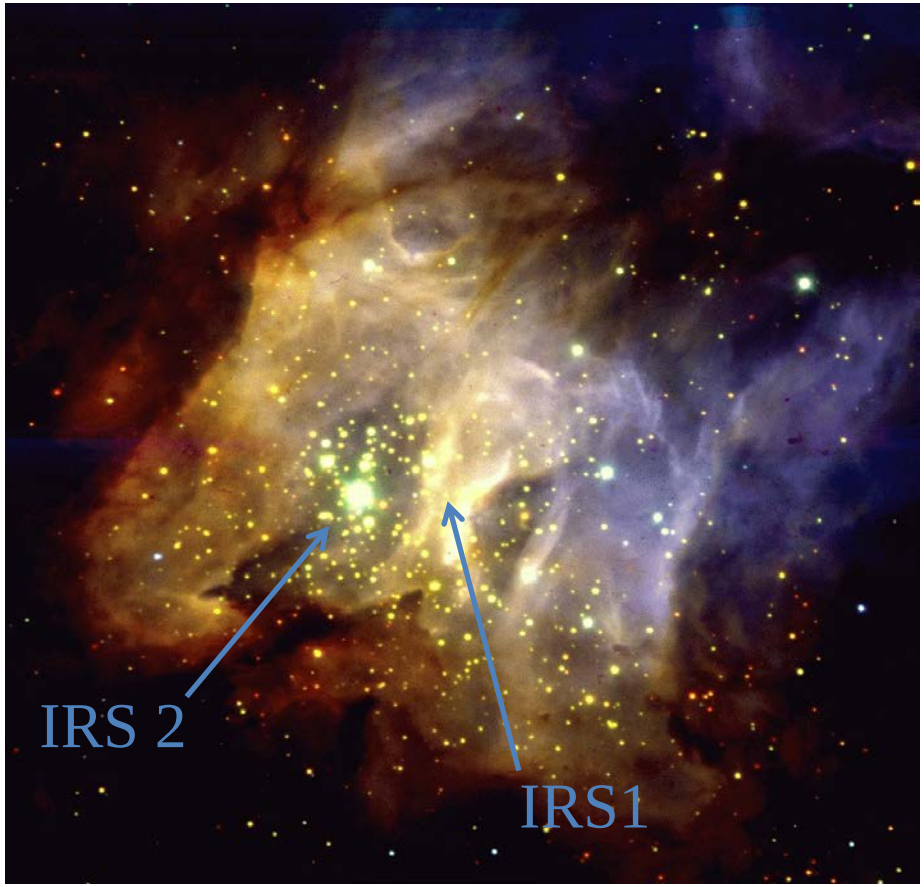




profile of ^{12}CO(J=1–0)

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

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)

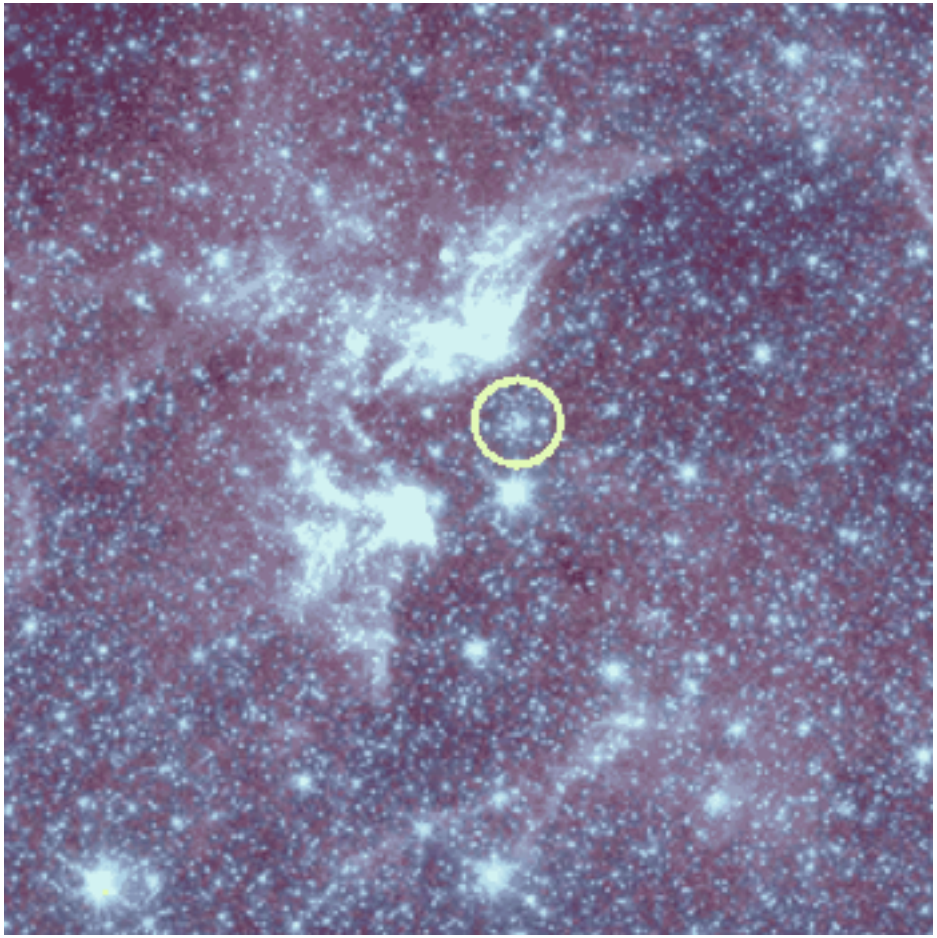
- Two bright mid-IR sources IRS 1 and IRS2
  (Frogel & Persson; 1974; Smith et al. 1999; DeRose et al. 2009)

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.

[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)

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