Massive star formation triggered by galactic tidal interaction in the LMC

Interstellar medium in the Nearby Universe

Bamberg, March 27

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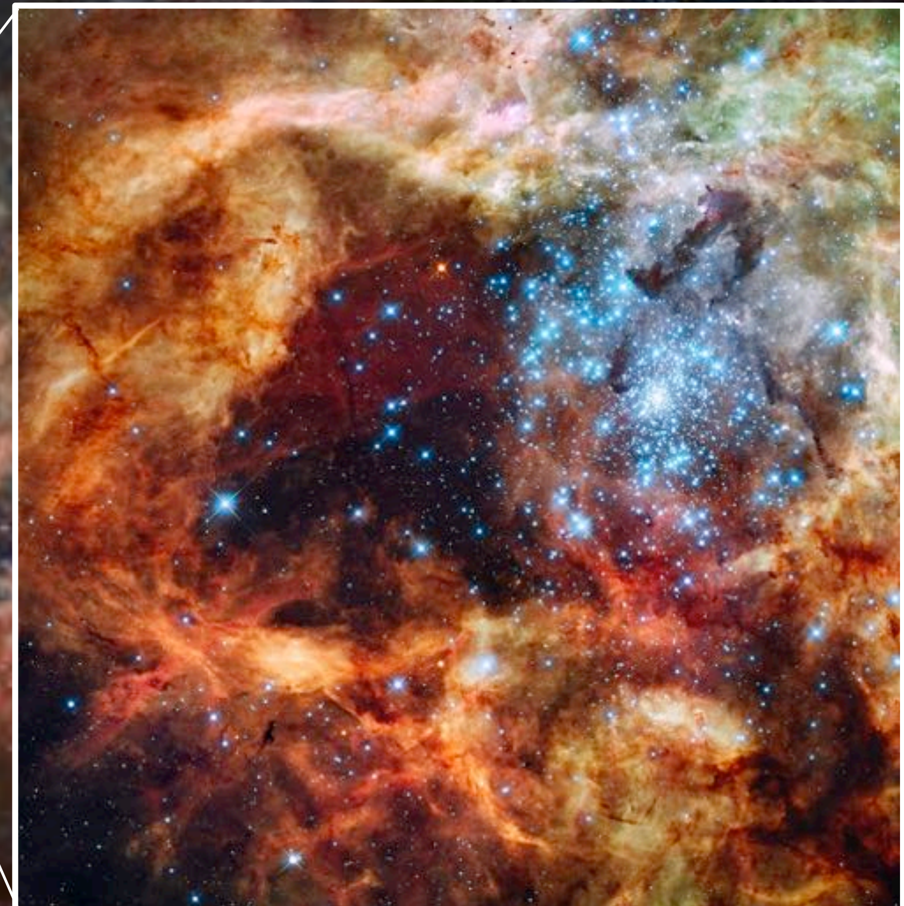
The Large Magellanic Cloud (LMC)

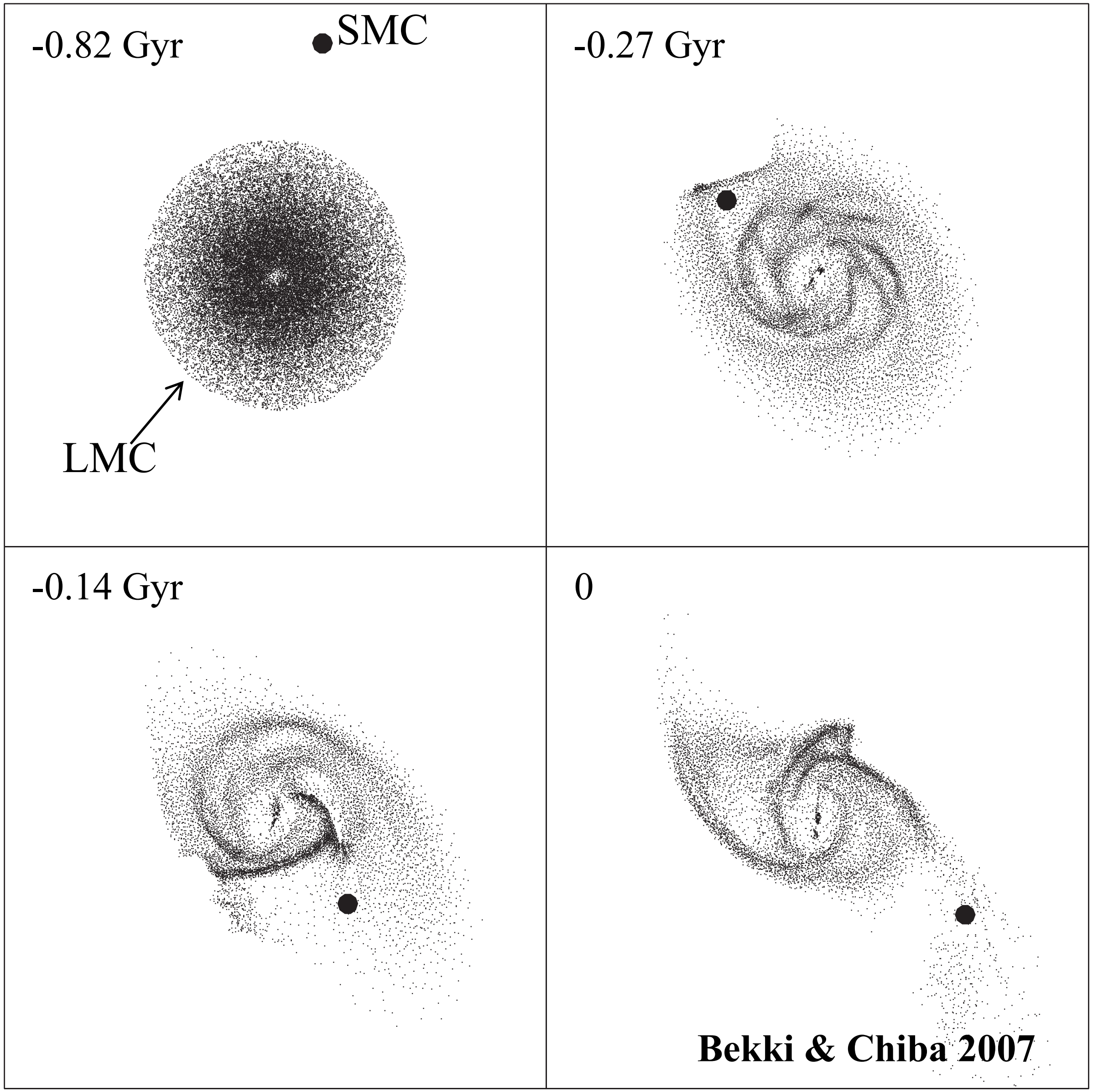
Distance: ~50 kpc



RMC 136 (R136)

- Age: ~1.5 Myr
- Mass: ~10^5 $M_\odot$
- The mass of R136 is ten times higher than that of the Milky Way SSC
- 385 O stars, ~30 WR stars (Doran et al.2013)
- The largest HII region in the Local group
- There are massive stars M >200 $M_\odot$ (Crowther et al. 2010)

Possibility of formation of massive cluster by tidal interaction



Fujimoto & Noguchi 1990 indicated the possibility of formation of massive cluster by galactic tidal interaction

- ~ 0.2 Gyr ago the LMC and SMC close encounter.
- LMC gas turbulence + Inflow of the SMC gas

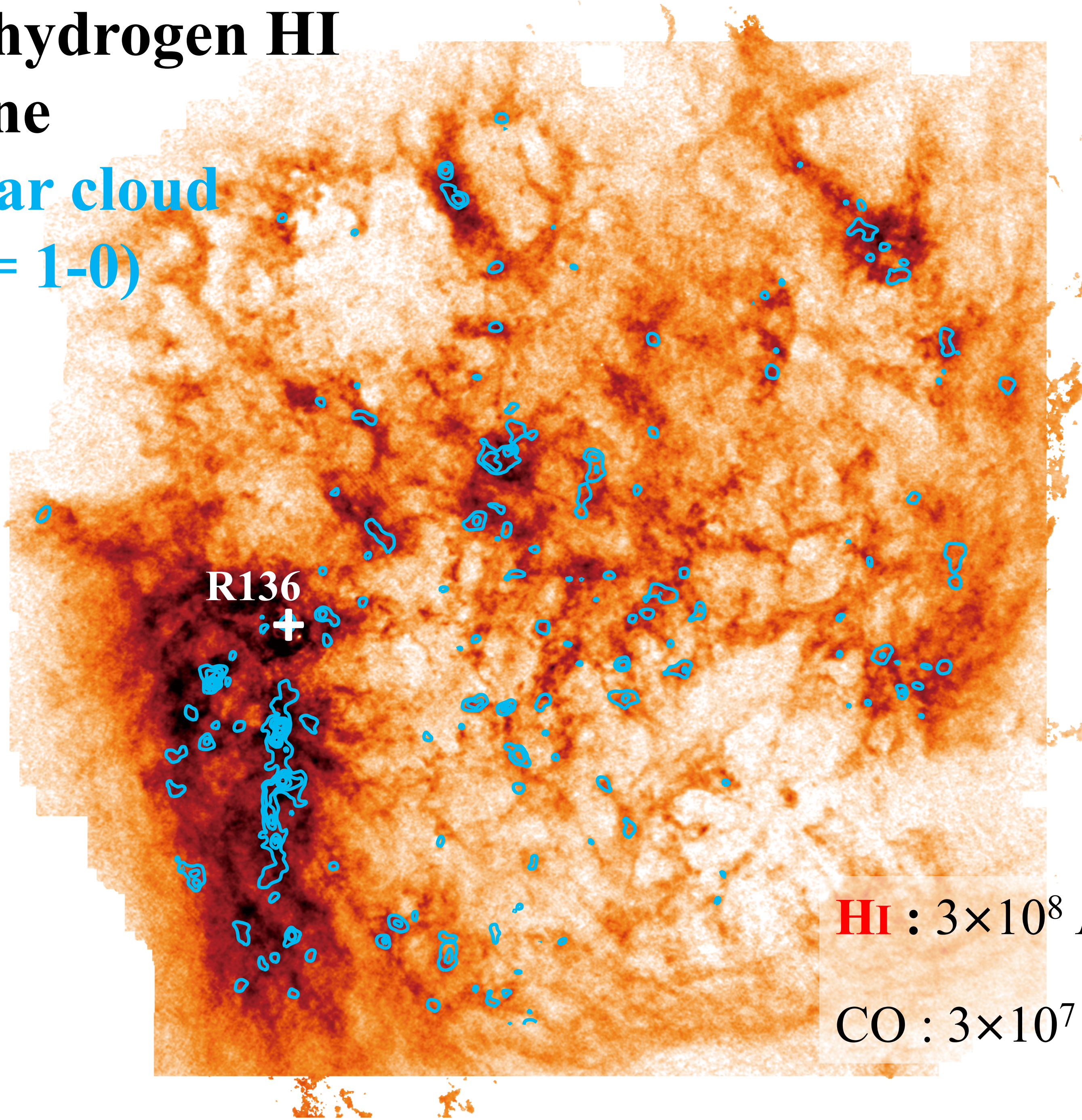
↓

The collision of gas triggered formation of massive cluster

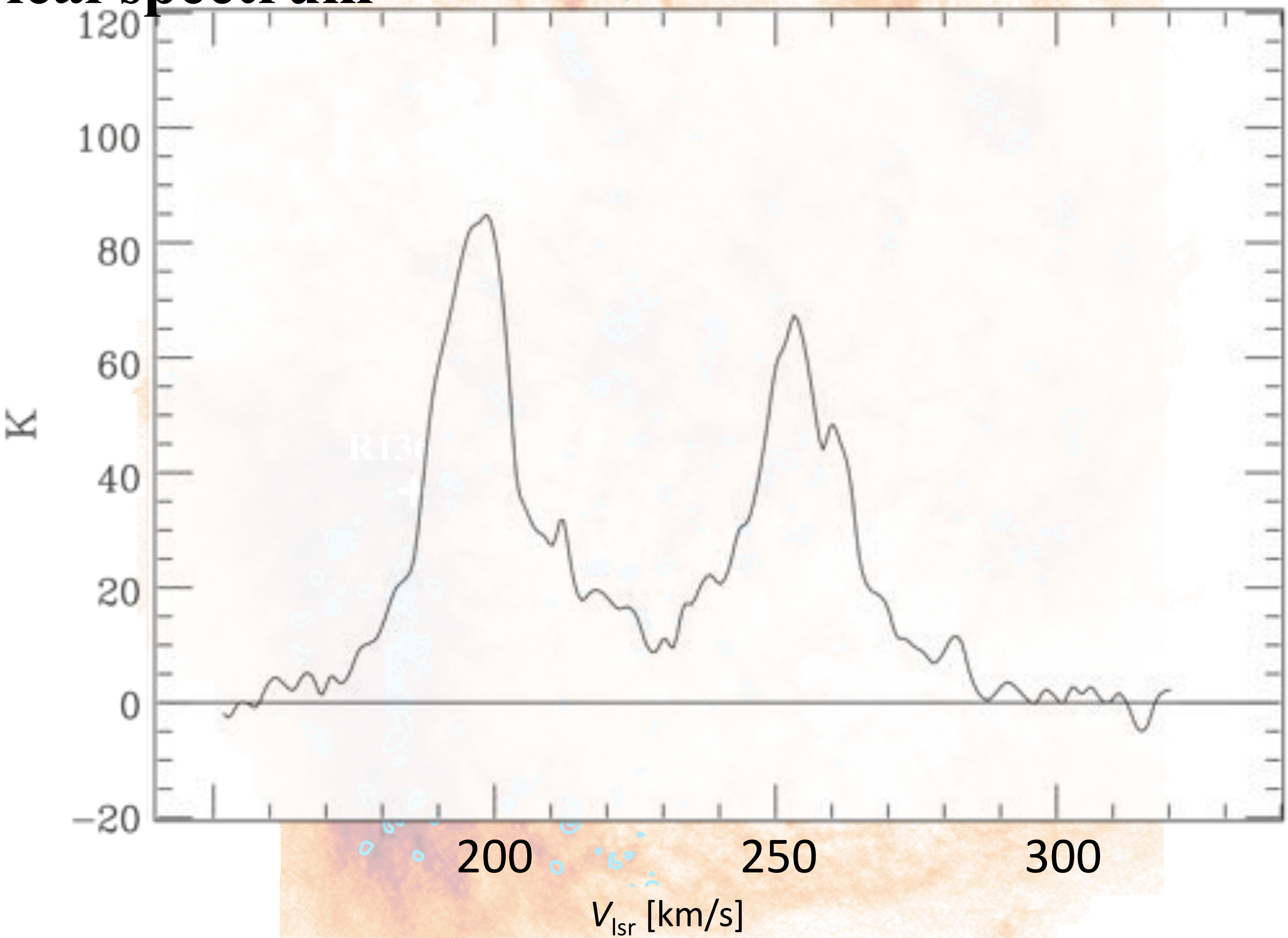
Bekki & Chiba 2007 supported this scenario.

This model has not been observationally verified

Atomic hydrogen HI
21 cm line
Molecular cloud
^{12}CO(J = 1-0)



HI 21 cm line
Typical spectrum



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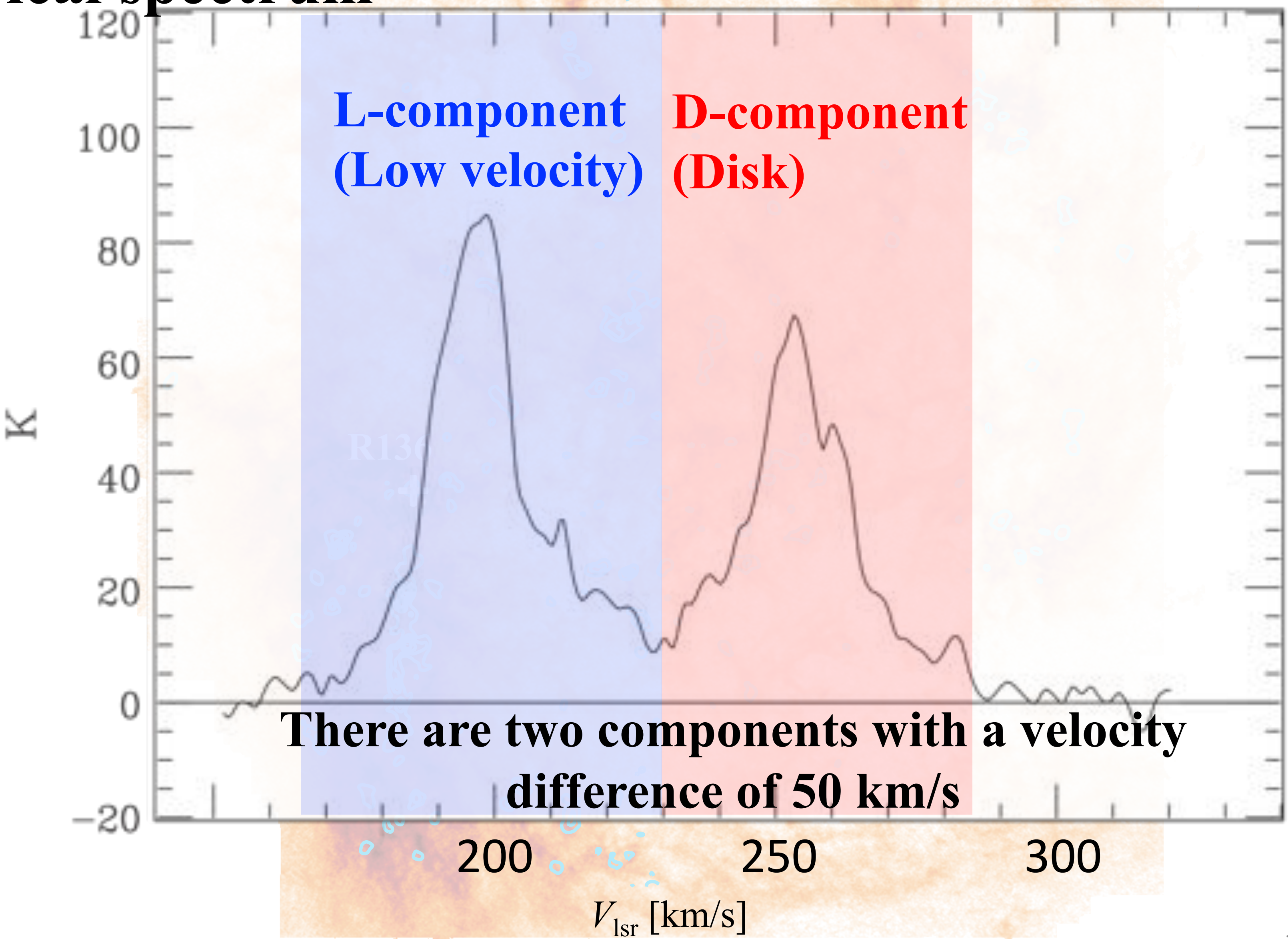


Purpose of the study

To observationally verify that gas turbulence, inflow and collision due to tidal interaction between the LMC and SMC are related to formation of massive clusters.

- **Revealing the detailed spatial- and velocity-structures of HI gas in the LMC**

  - Separation of two velocity components

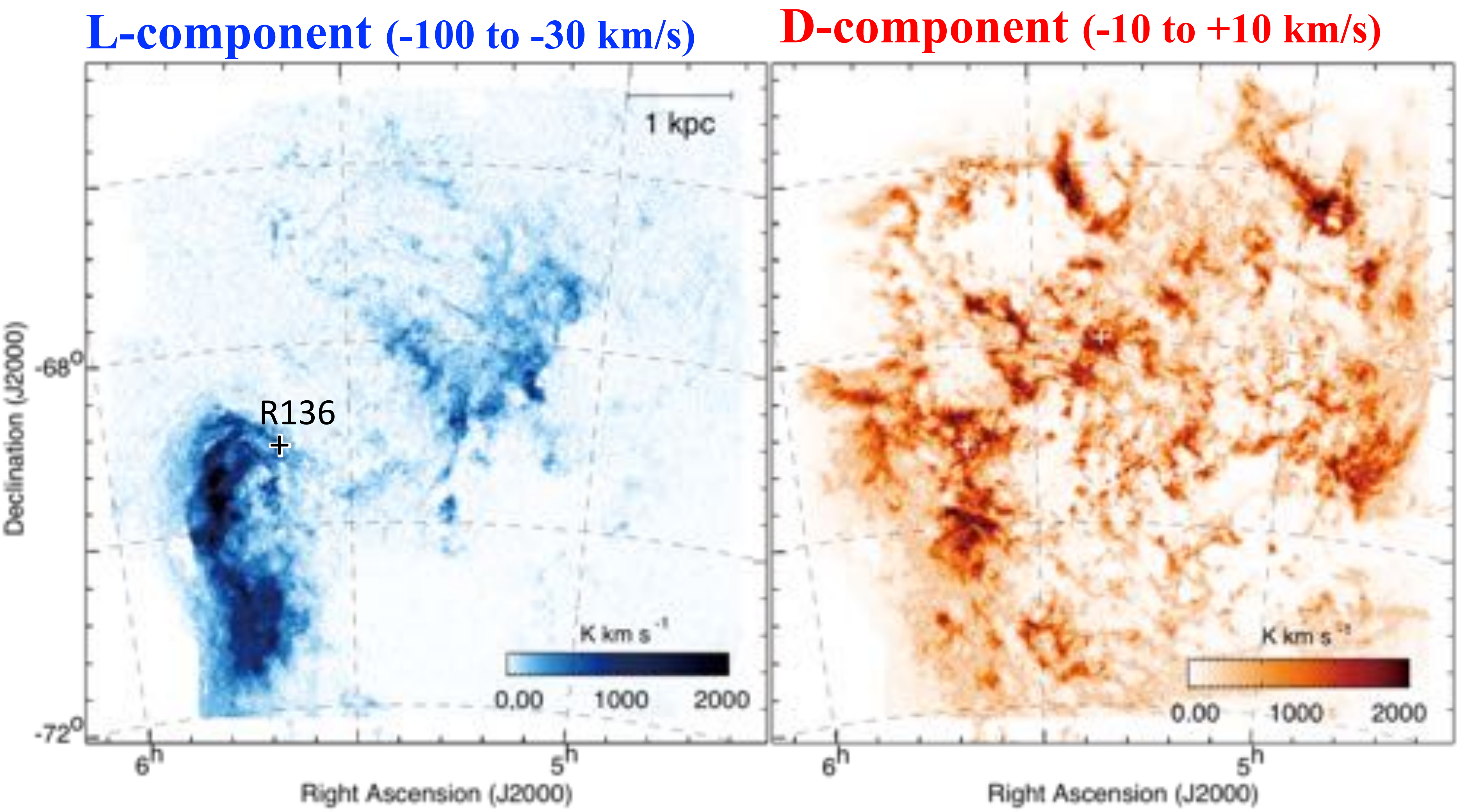
  Check the evidence of collision

  - The complementary distribution
  - Bridge features in the velocity space

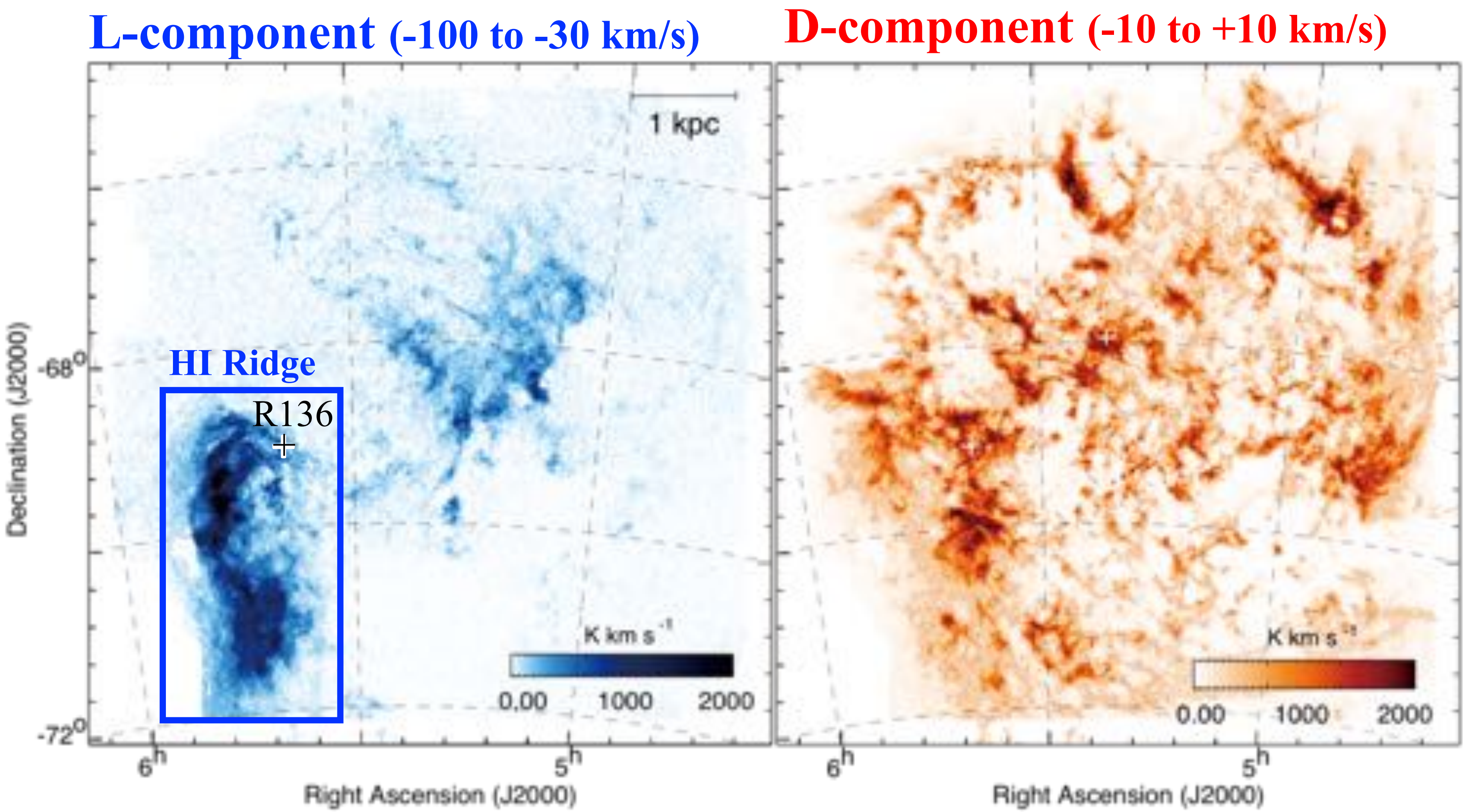
- **Investigating gas inflow from the SMC due to tidal interaction**

  - The metallicity of the SMC is 1/5 that of the LMC
  - An amount of metal decreases if the metal poor gas inflow from the SMC.

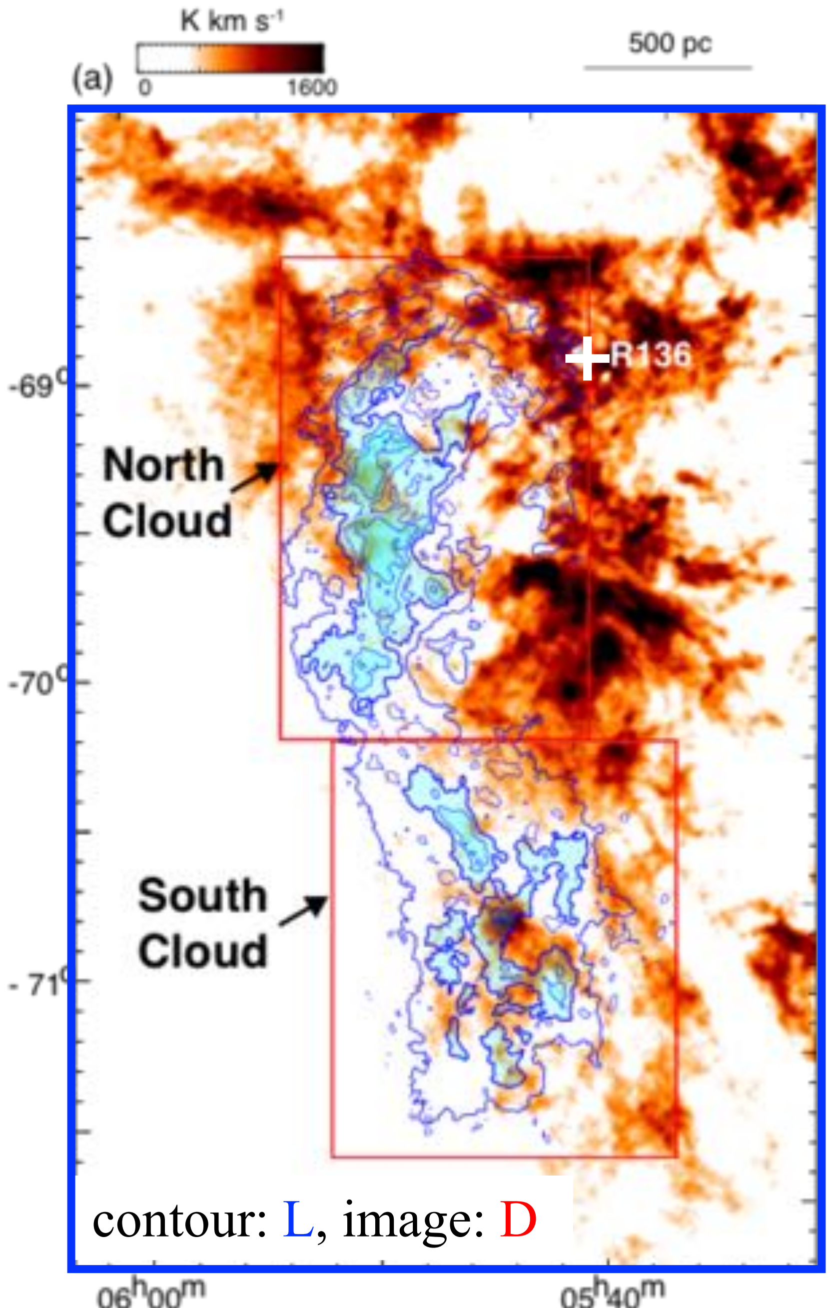
Spatial distributions of L- & D



- The L-component mainly consists of two extended clumps.
- Consistent with Luks & Rohlfs 1992

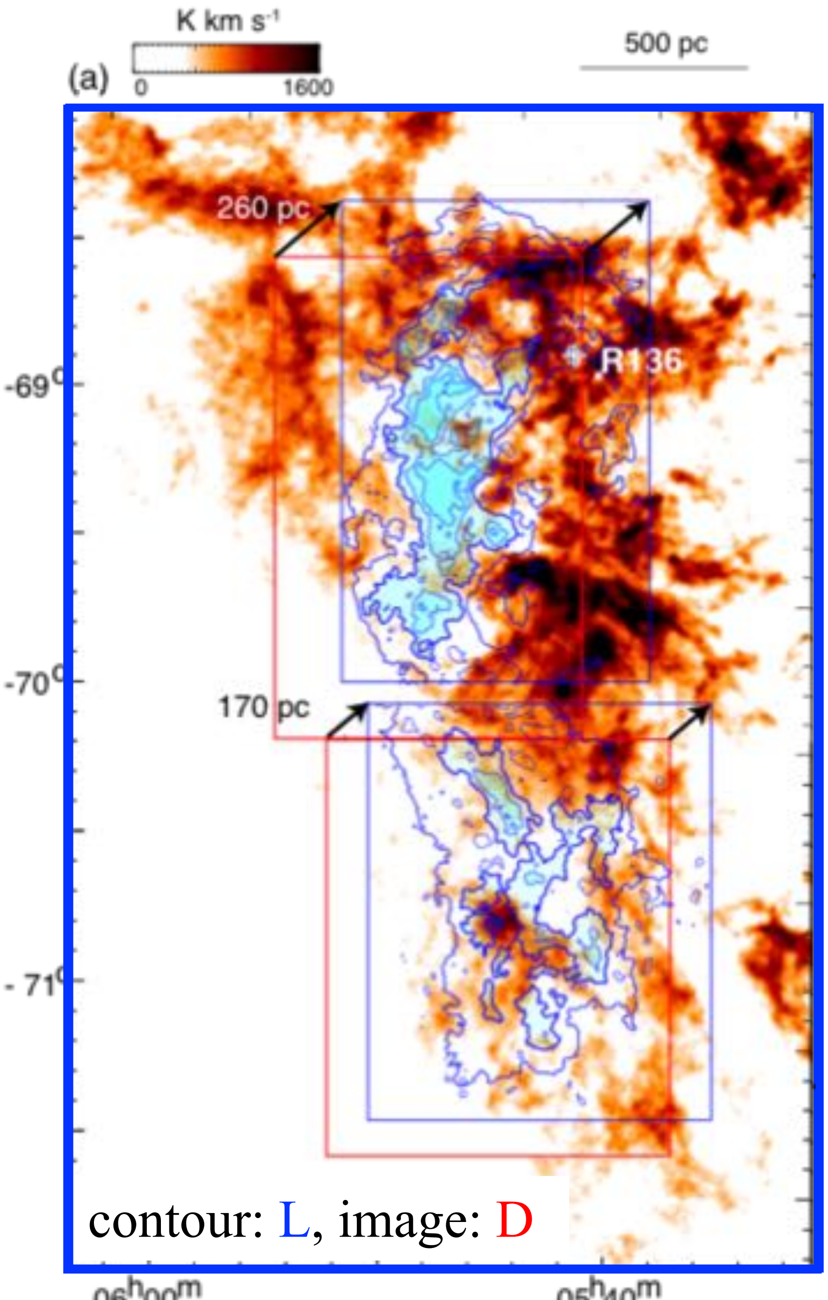


We focus on the HI Ridge region including the young star forming region R136



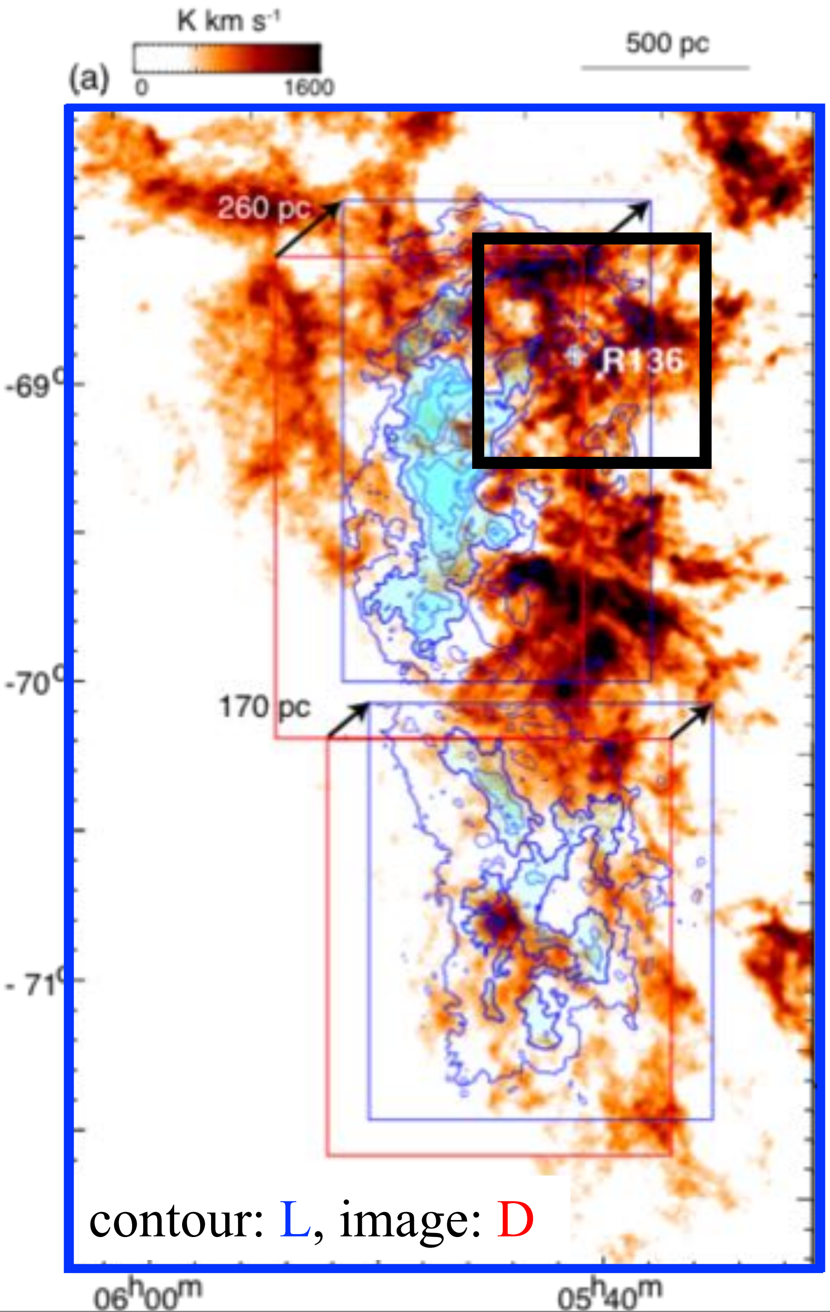
Complementary distributions of the L- & D-components

Spatial ditributions of L- & D (kpc pc scale)

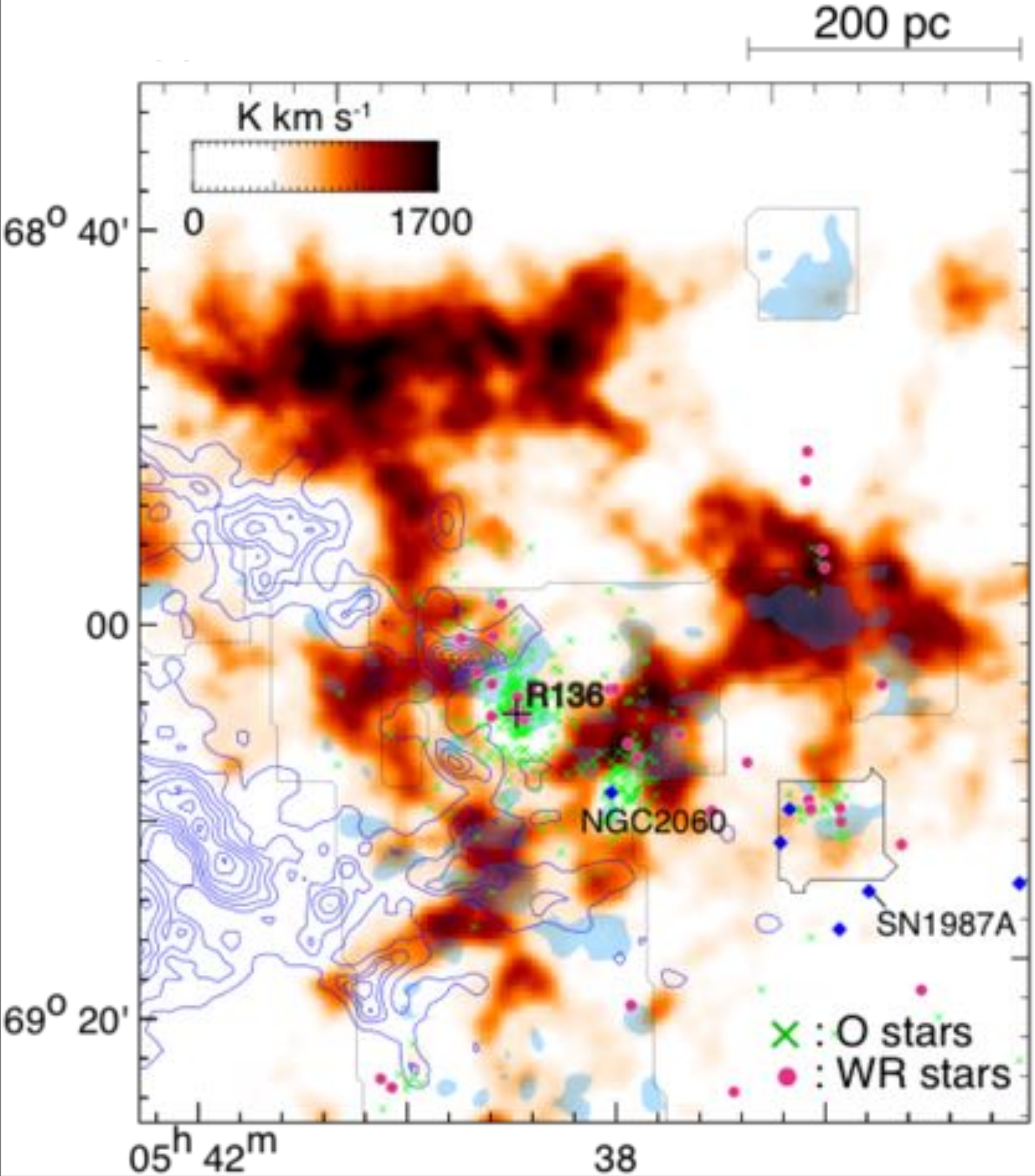


Complementary distributions of the L- & D-components with displacement ~ 200 to 300 pc

Spatial ditributions of L- & D (kpc pc scale)



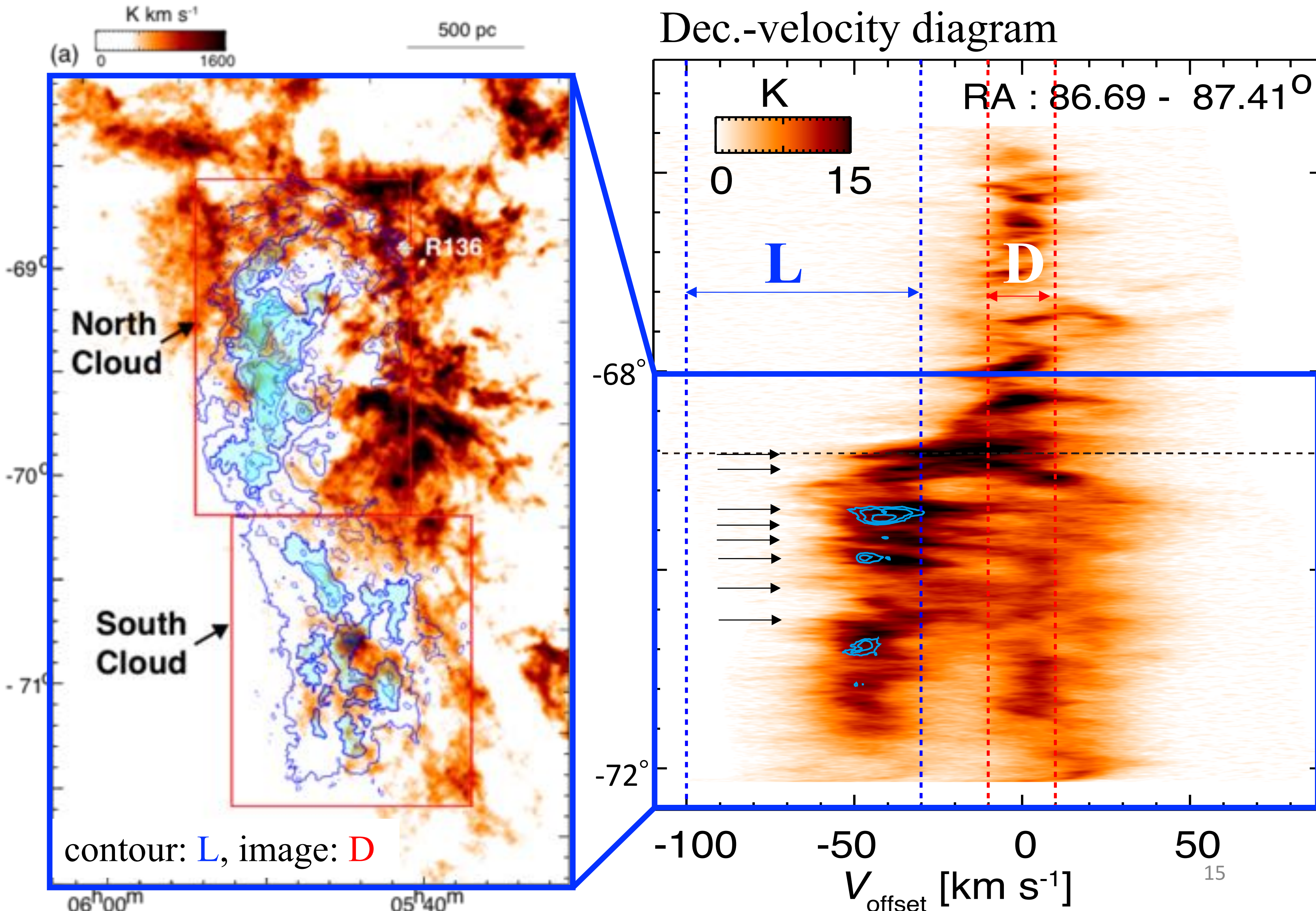
Spatial ditributions of L- & D (100 pc scale)



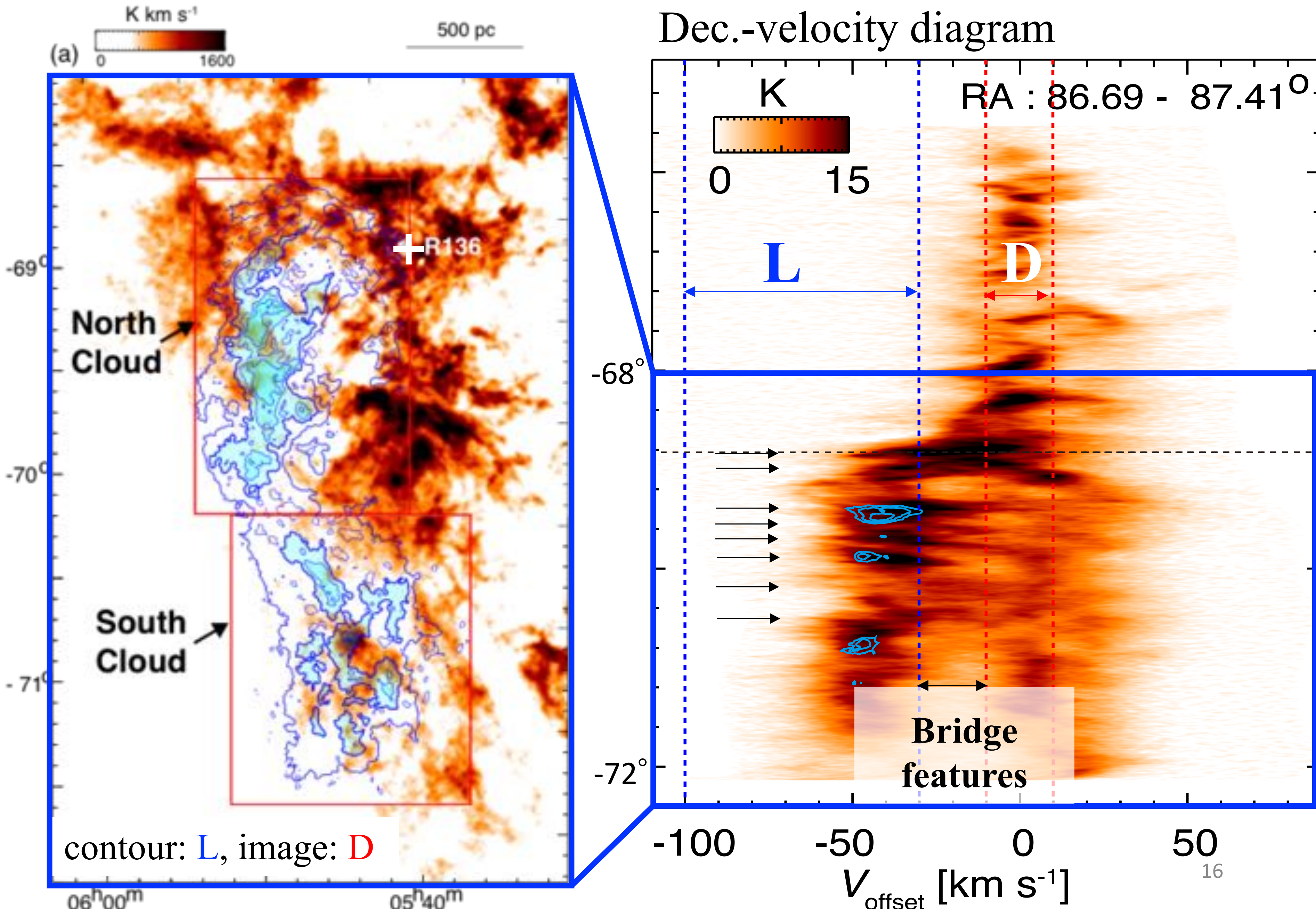
Complementary distribution toward R136

image: D-component
contour: L-component
■ : CO

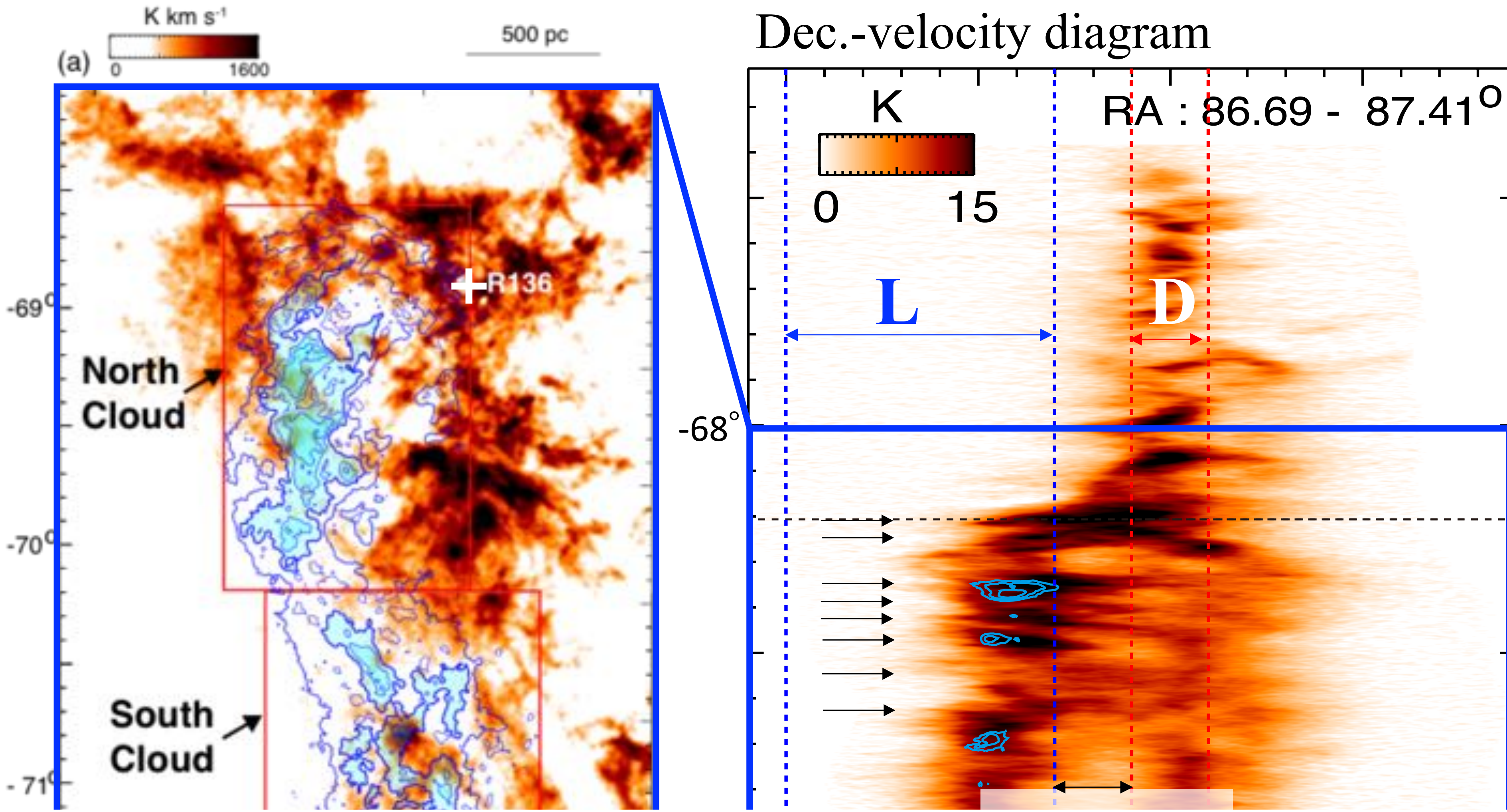
Velocity structure : HI Ridge



Velocity structure : HI Ridge

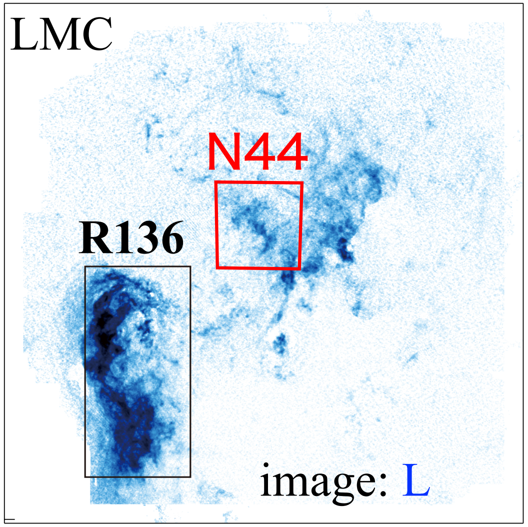


Velocity structure : HI Ridge

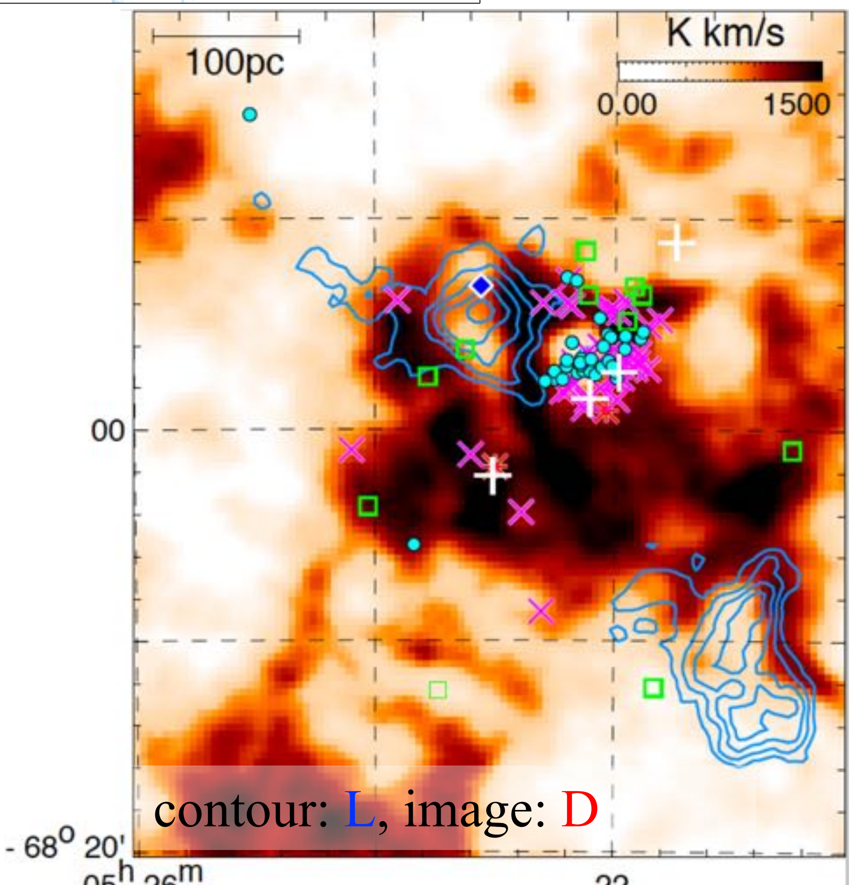


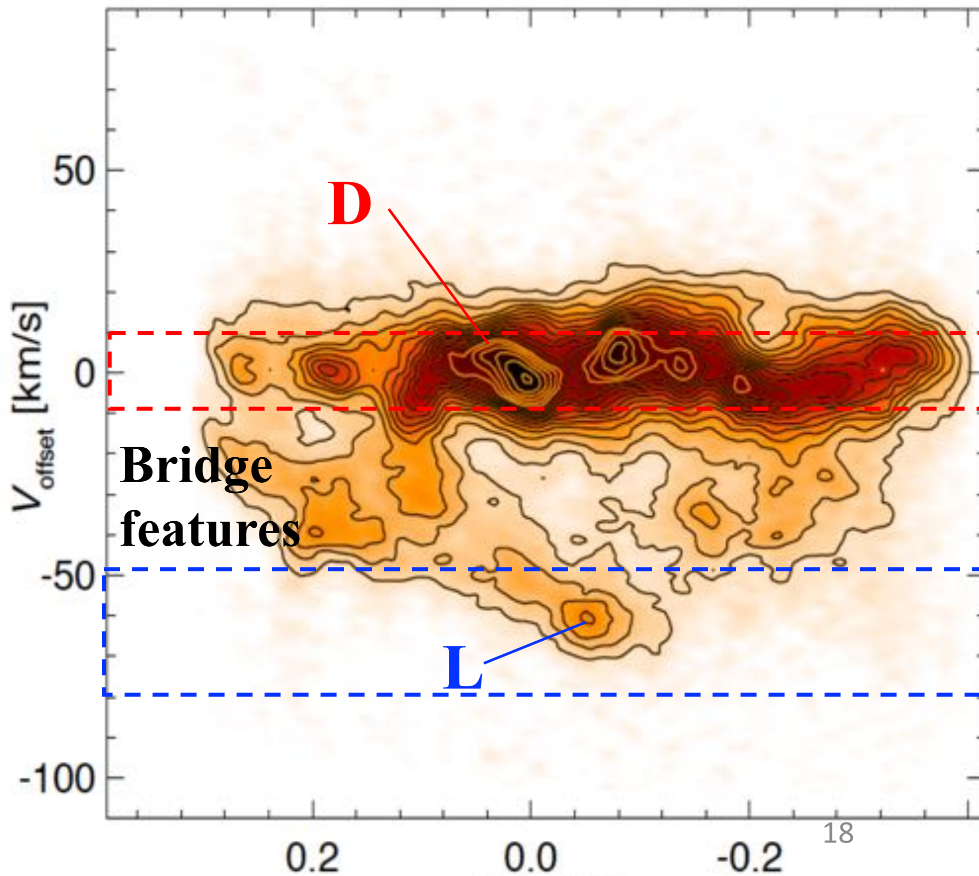
In order to understand the 3D structure of the collision, we are comparing the HI data with X-ray data.

(Collaborators: J. Knies, M. Sasaki, F. Harberl)



Collision of HI gases occurs similarly to the case of R136



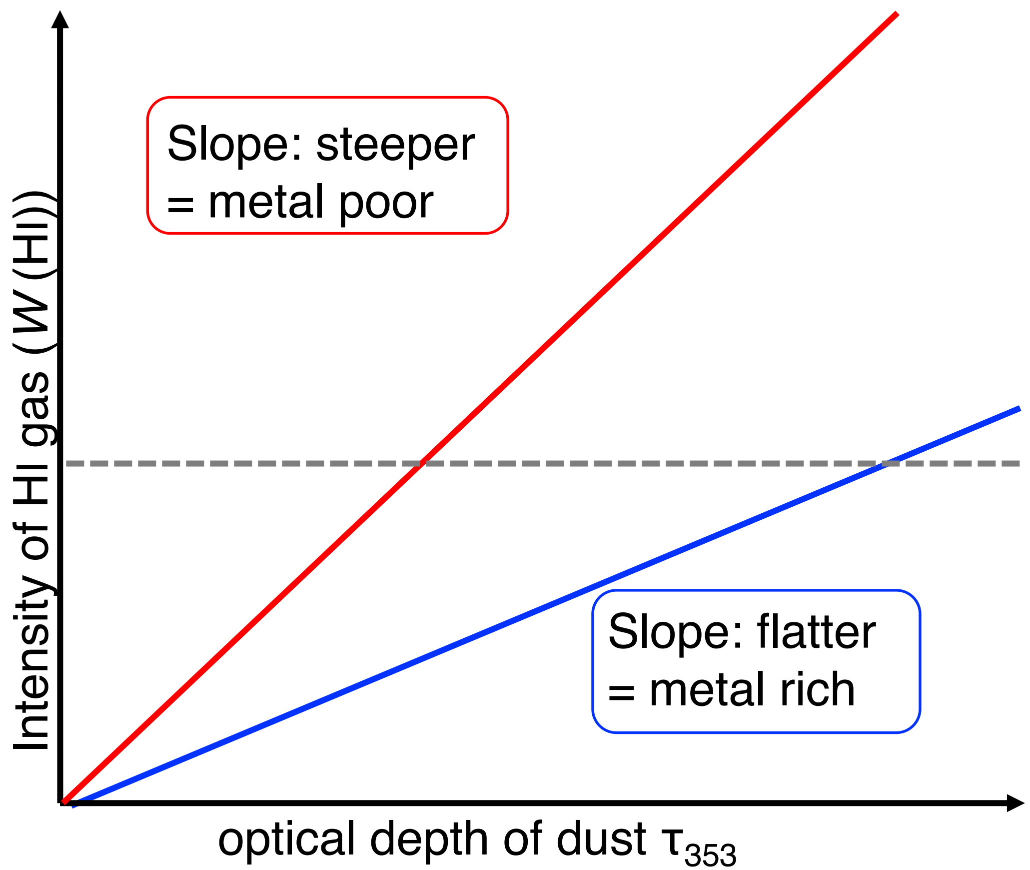


Comparison of metallicity by using the dust data

About half of the heavy element exists as dust

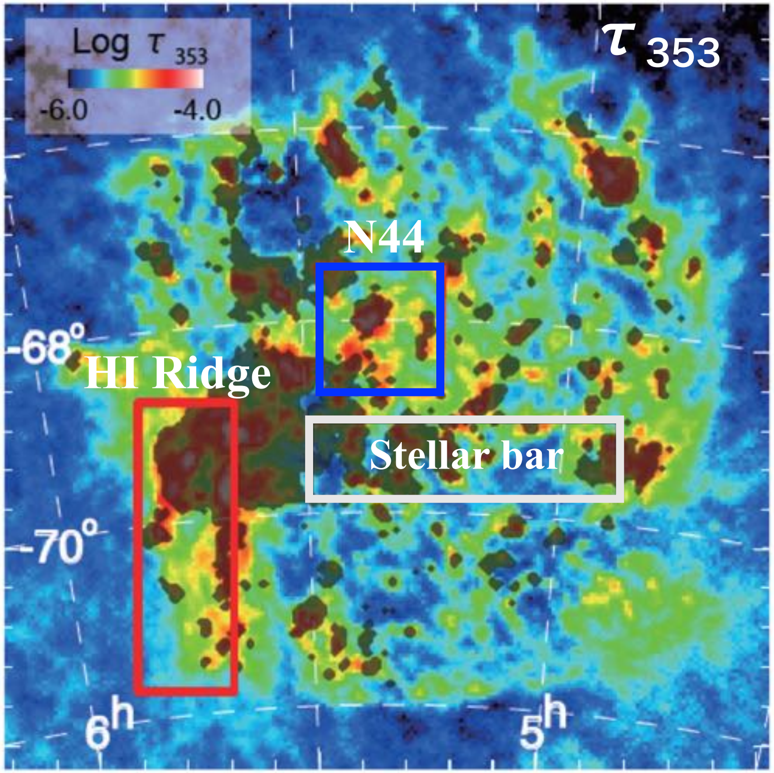
gas/dust ratio = indicator of metallicity

- ■ The amount of dust
  - optical depth at 353 GHz (τ_{353}) by *Planck/IRAS* telescope
- ■ The amount of gas
  - HI integrated intensity (W(HI))
- ■ *W*(HI) /τ_{353} (slope of scatter plot) indicate gas/dust ratio

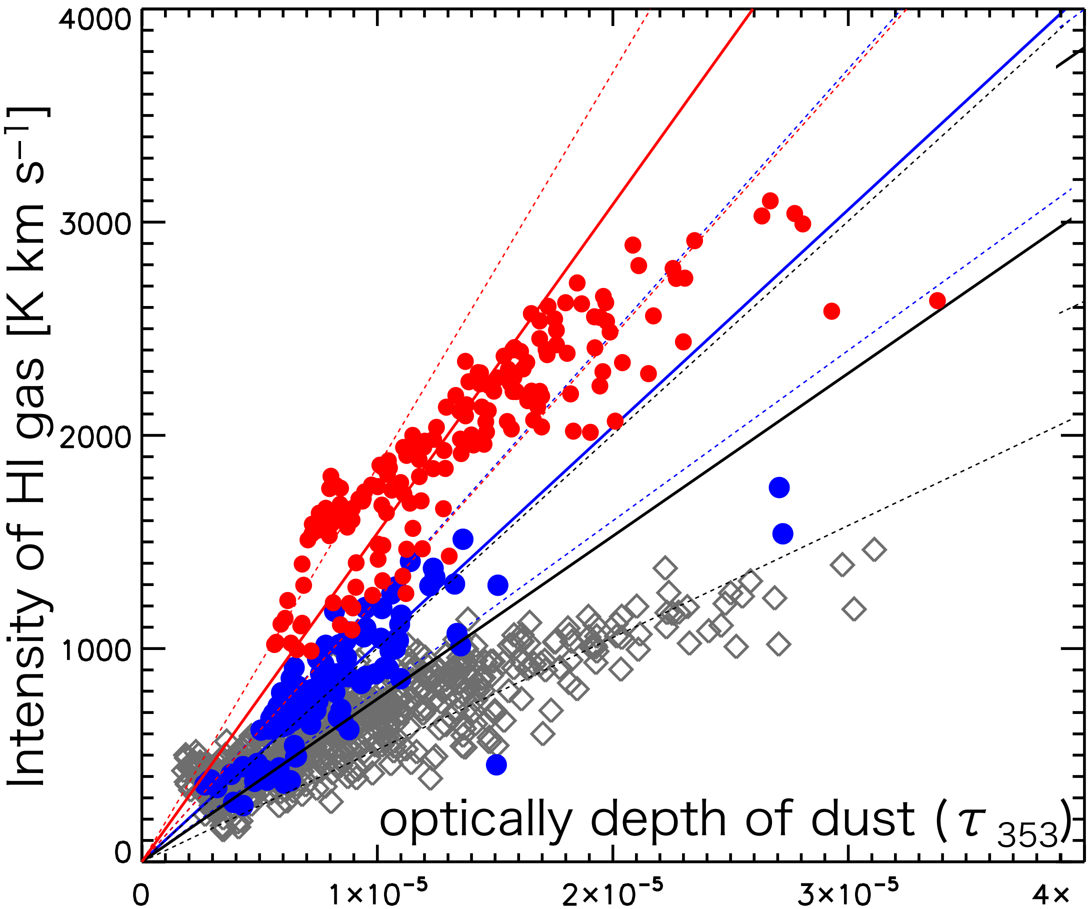


We made a scatter plot between τ_{353} and *W*(HI)

Scatter plot between τ_{353} and W(HI)



mask: CO > 1σ, Hα > 30R



	Stellar bar	N44	HI Ridge
Slope [10^8 K km/s]	0.75 ± 0.24	1.0 ± 0.2	1.5 ± 0.3

Slope: **Stellar bar < N44 < HI Ridge**

Metal rich ⟷ Metal poor

Inflow of the SMC gas (the origin of HI gas collision)

We compared the dust/gas ratio between the regions based on the value of stellar bar

	region	dust/gas ratio (metallicity)	Mass ratio of the SMC and LMC
Not collision	Stellar bar (LMC)	1	----
collision	N44	0.8	3 : 7
collision	HI Ridge	0.5	1 : 1
	SMC = 1/5 LMC	0.2	----

R_{SMC} : ratio of the SMC gas, R_{LMC} : ratio of the LMC gas

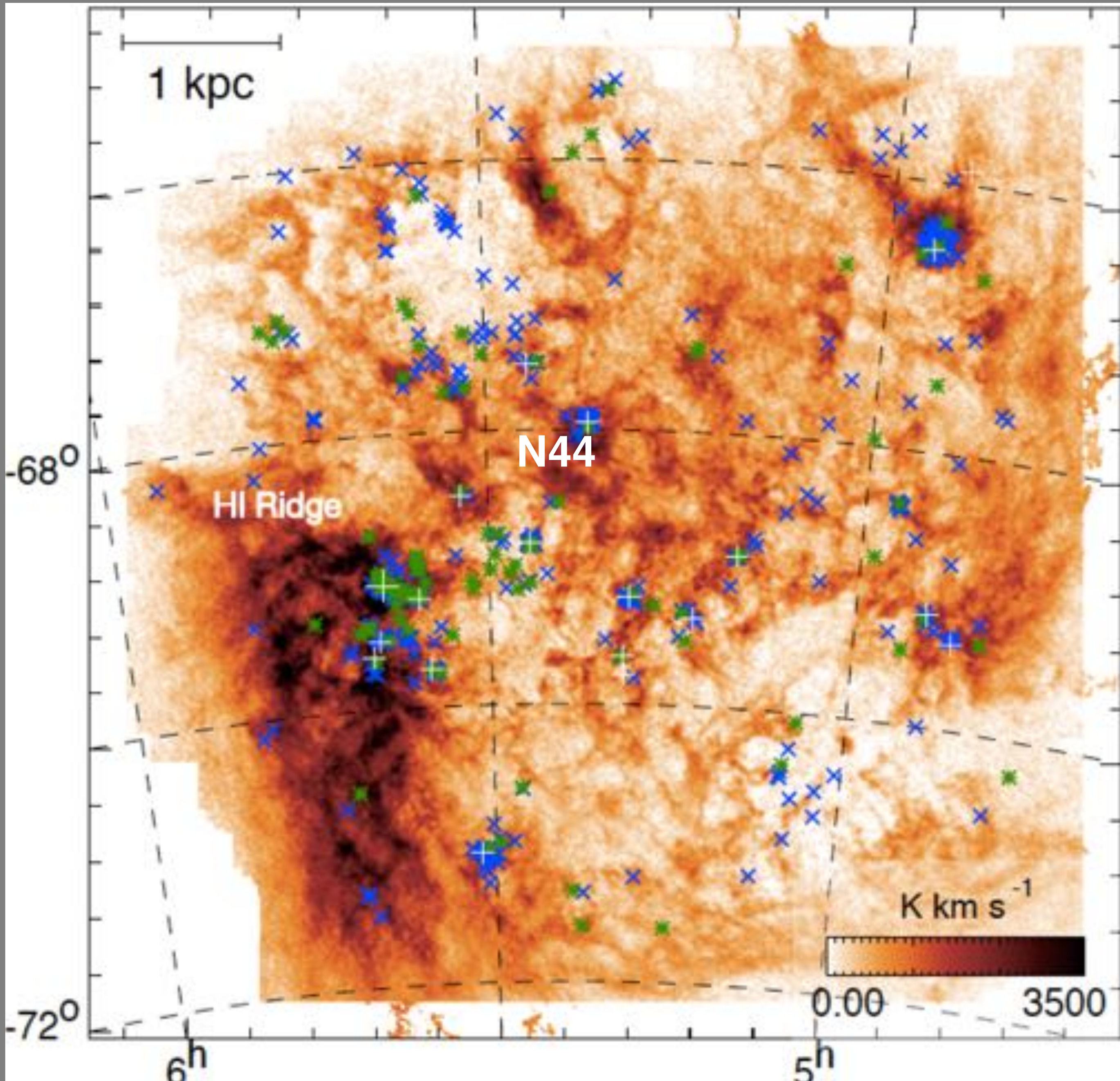
$R_{SMC} + R_{LMC} = 1$

$R_{SMC} \times 0.2 + R_{LMC} \times 1 = 0.8$ or 0.5

=> Gas inflow from the SMC into the colliding region.

Collision of HI gas was possibly caused by galactic tidal interaction

O/WR star formation of the whole LMC



- Total number of O/WR stars ~ **700** (SAGE Meixner et al. 2006)
- O –type star ~ 600
- WR star ~ 100
- We analyzed 20 star forming regions

× : O-type star

✱ : WR star

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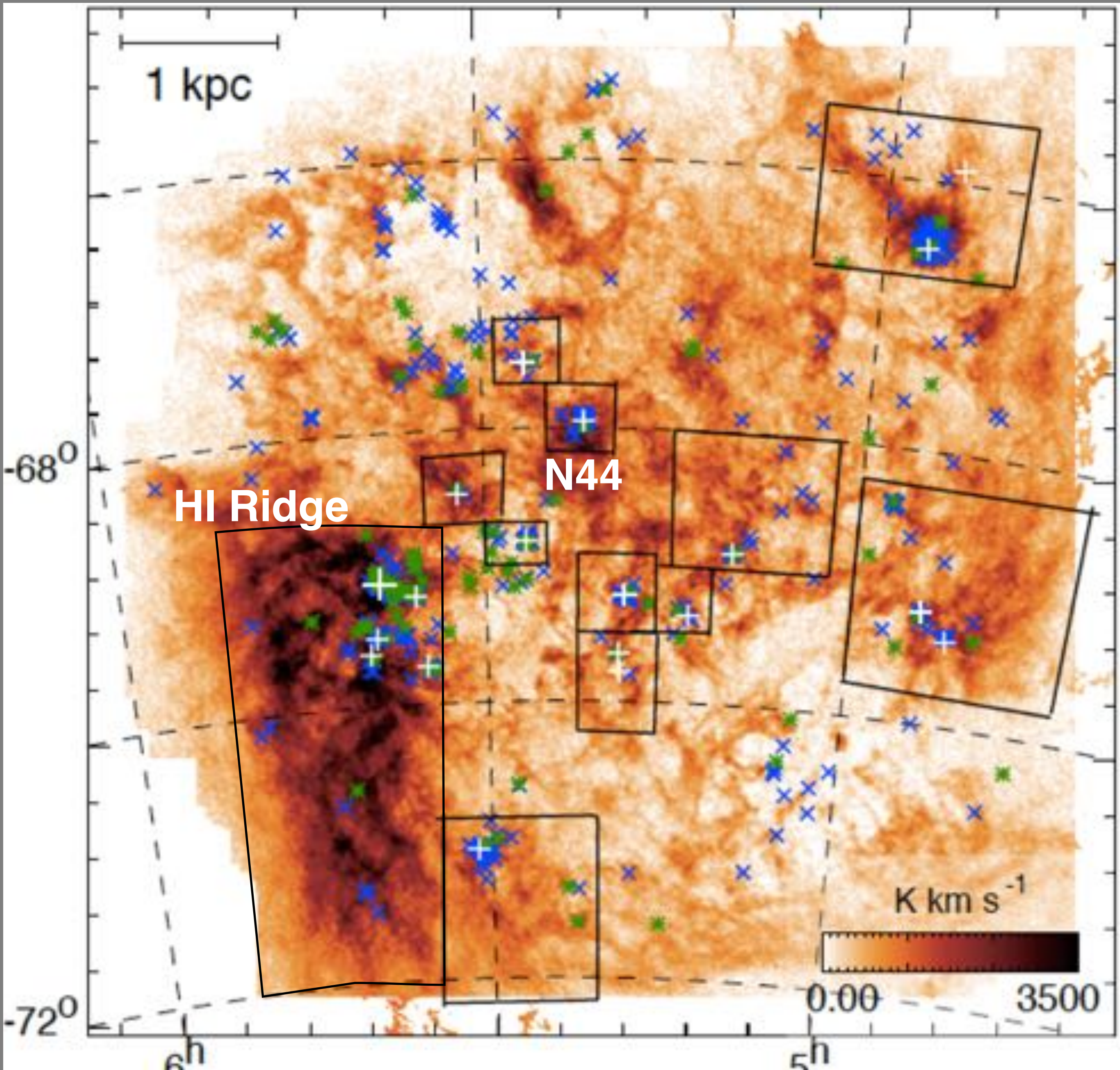

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- **~ 560 O/WR stars** are possibly formed by the collision of HI flows caused by tidal interaction between the SMC and LMC.

× : O-type star
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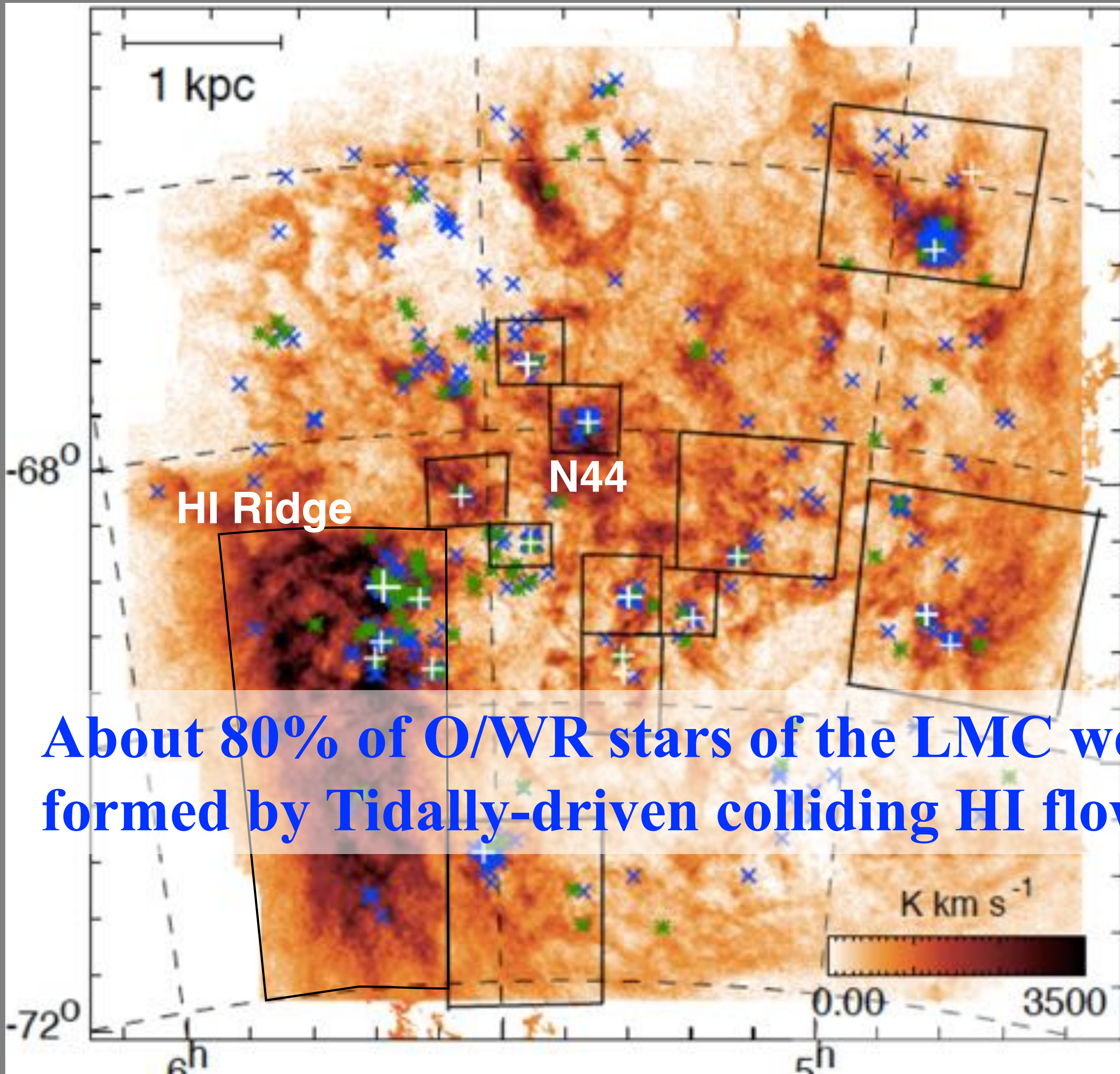

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- We analyzed 20 star forming regions
- **~ 560 O/WR stars** are possibly formed by the collision of HI flows caused by tidal interaction between the SMC and LMC.

About 80% of O/WR stars of the LMC were possibly formed by Tidally-driven colliding HI flows at least.

× : O-type star

∗ : WR star

Summary

- **We revealed the spatial- and velocity structures of the LMC by using high spatial resolution HI data**
  - ✓ We reveal the three evidence of the HI gas collision toward the star forming regions.
  - ✓ The collision of HI gas possibly triggered the 80% of massive star formation at least.

- **Comparison of the intensity of HI and optical depth of dust at 353 GHz**
  - Gas/dust ratio is indicator of the metallicity
  - Metallicity : Stellar bar > N44 > HI Ridge (including R136)
  - Metal poor gas inflow from the SMC into the colliding region
  - The collision of HI gas was possibly caused by galactic tidal interaction.

Galactic tidal interaction is important for Massive star formation of the LMC