初代星･初代銀河研究会 2017 @ 呉
2018年2月10日(土)

銀河間潮汐相互作用が誘発する大質量星形成2：近傍の衝突/相互作用銀河

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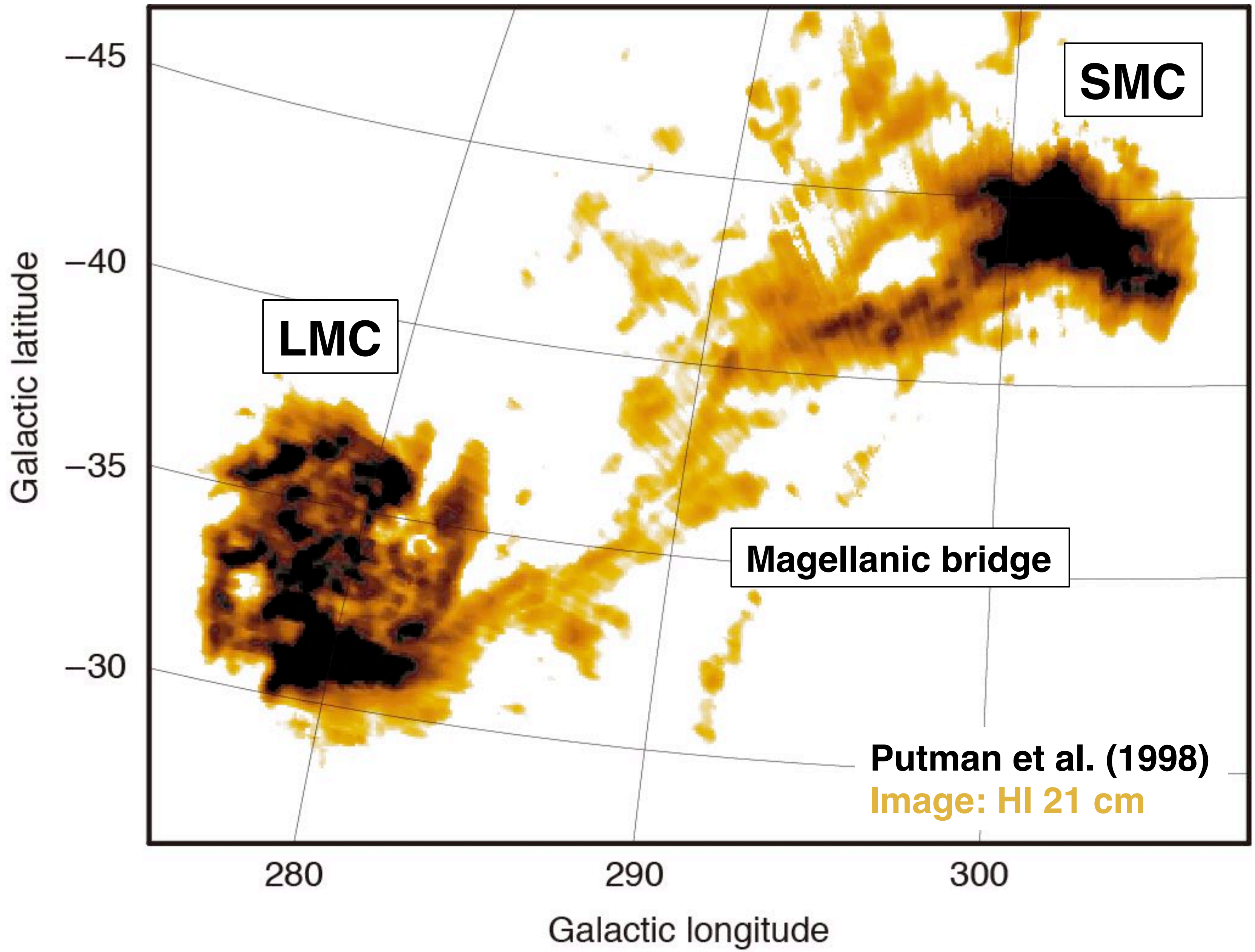
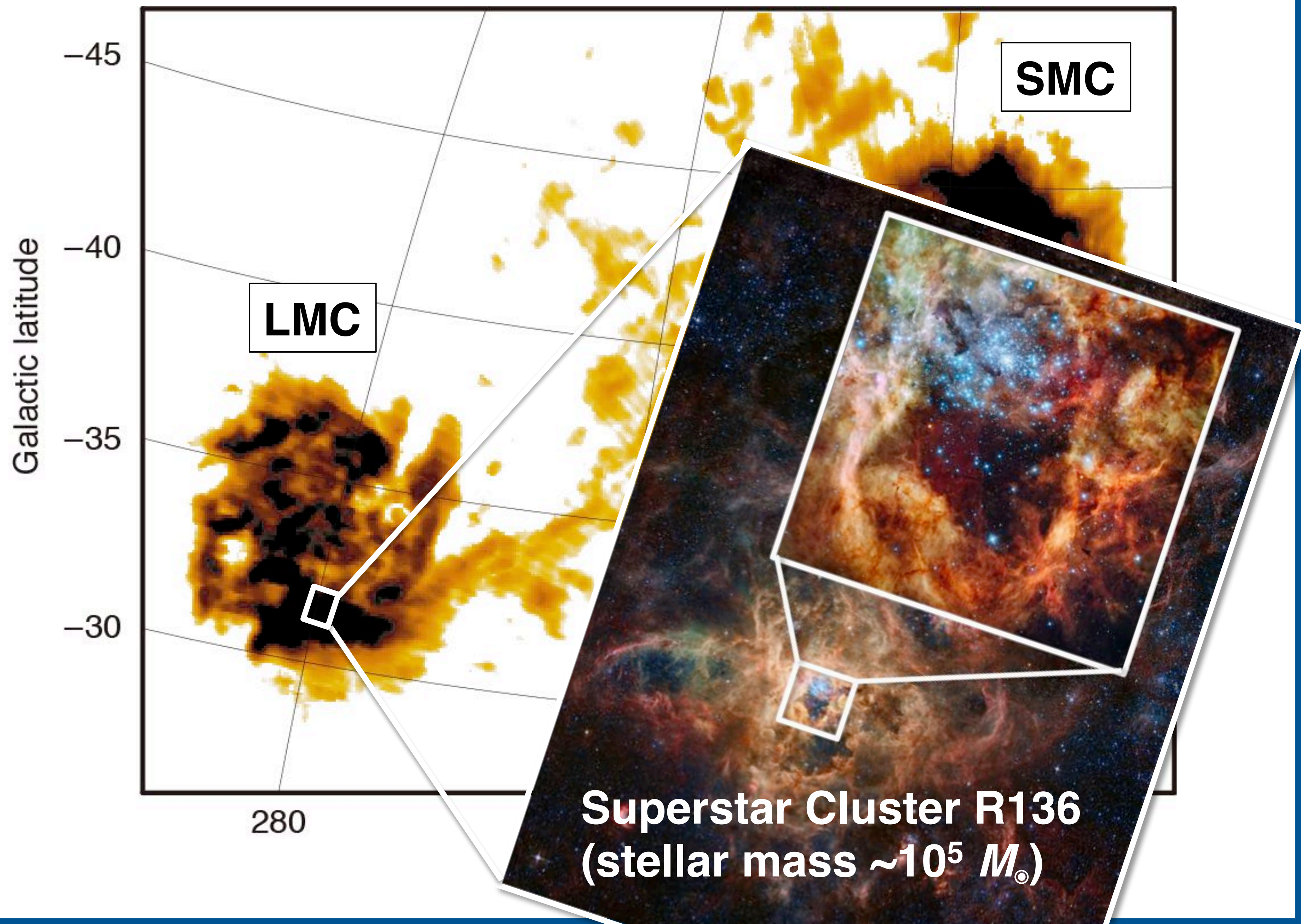
Outline

- **LMC-SMC 間潮汐相互作用が誘発する星形成**
  [Fukui, Tsuge, Sano al. 2017, PASJ, 69, 5]
  - LMC における HI ガス衝突
  - SMC HI ガスの2成分分離 [Tsuge et al. 2018 in prep.]
- **M33 における巨大星団形成**
  [Tachihara, Gratier, Sano et al. 2018 (arXiv: 1802.02310)]
  - M33-M31 潮汐相互作用
  - VLA HI の空間/速度構造
  - HI 衝突が誘発する大質量星形成と分子雲形成
- **アンテナ銀河における SSC 形成**
  [Fukui, Tsuge, Sano et al. 2018, in prep.]
  - overlap 領域における星形成
  - ALMA による CO 3-2 相補的分布と stellar feedback の影響
- **まとめ**

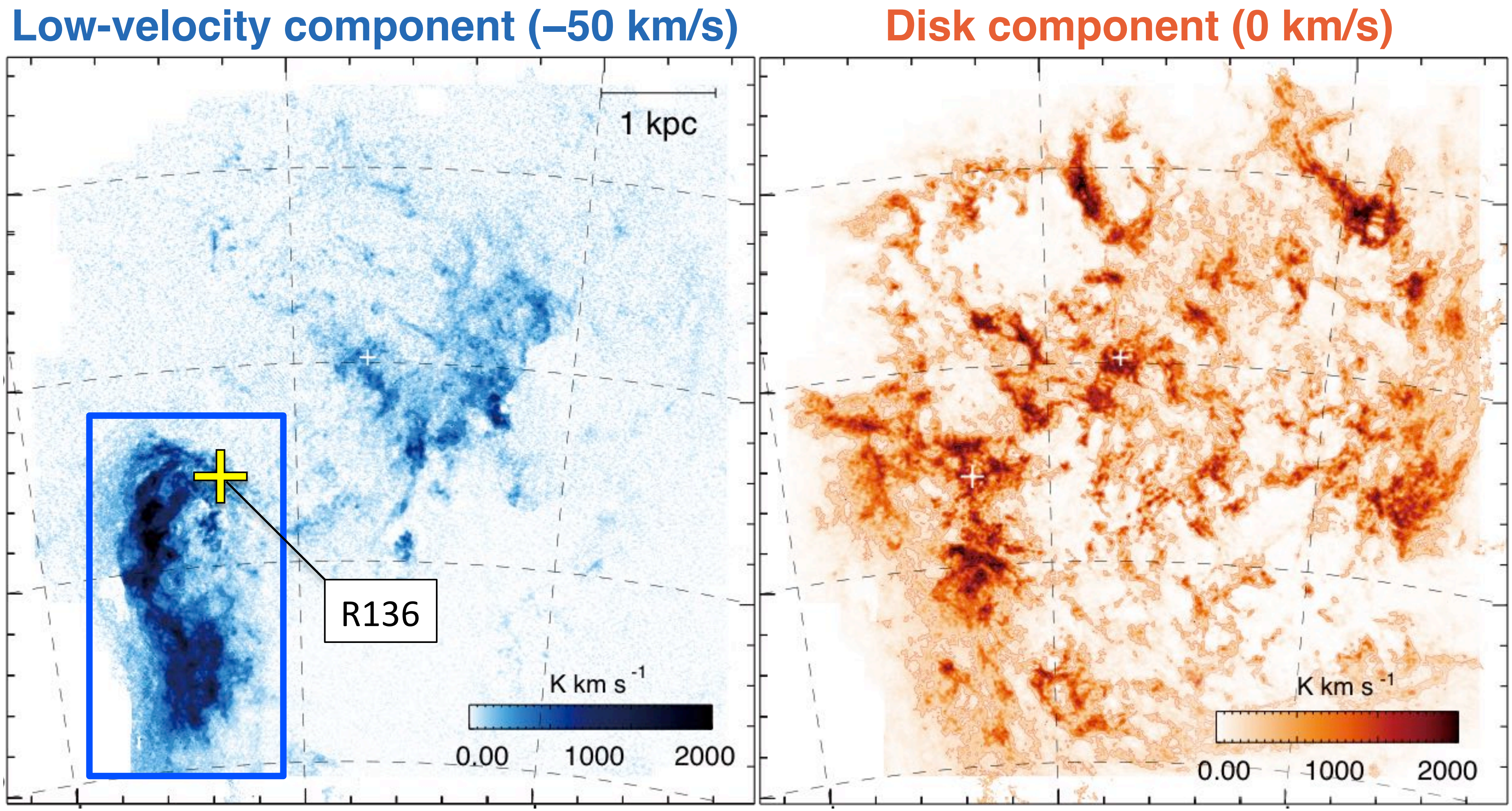
Tidal Interaction between the LMC and the SMC



Tidal Interaction between the LMC and the SMC

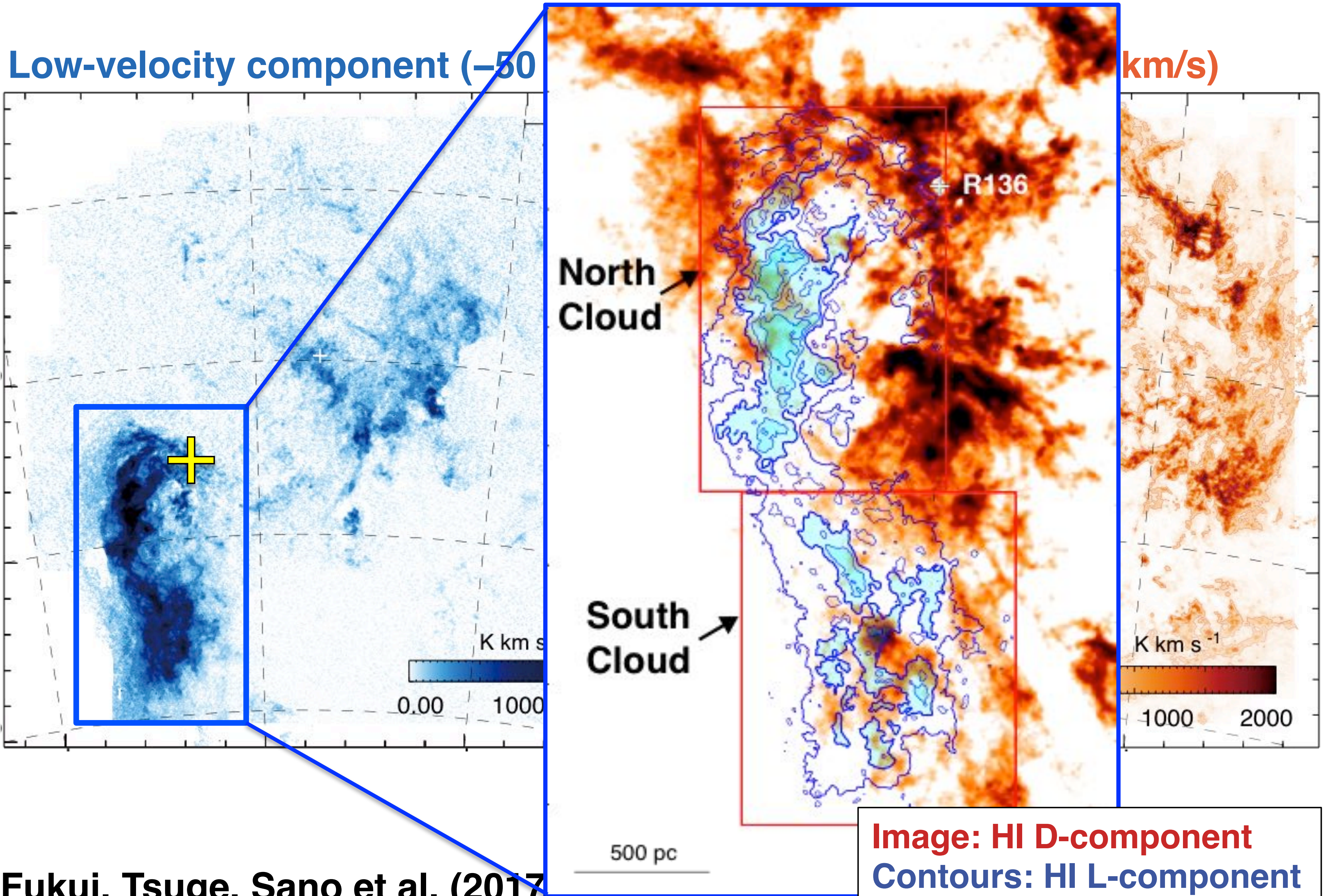


Massive cluster formation triggered by tidal interaction



Fukui, Tsuge, Sano et al. (2017), PASJ, 69, 5

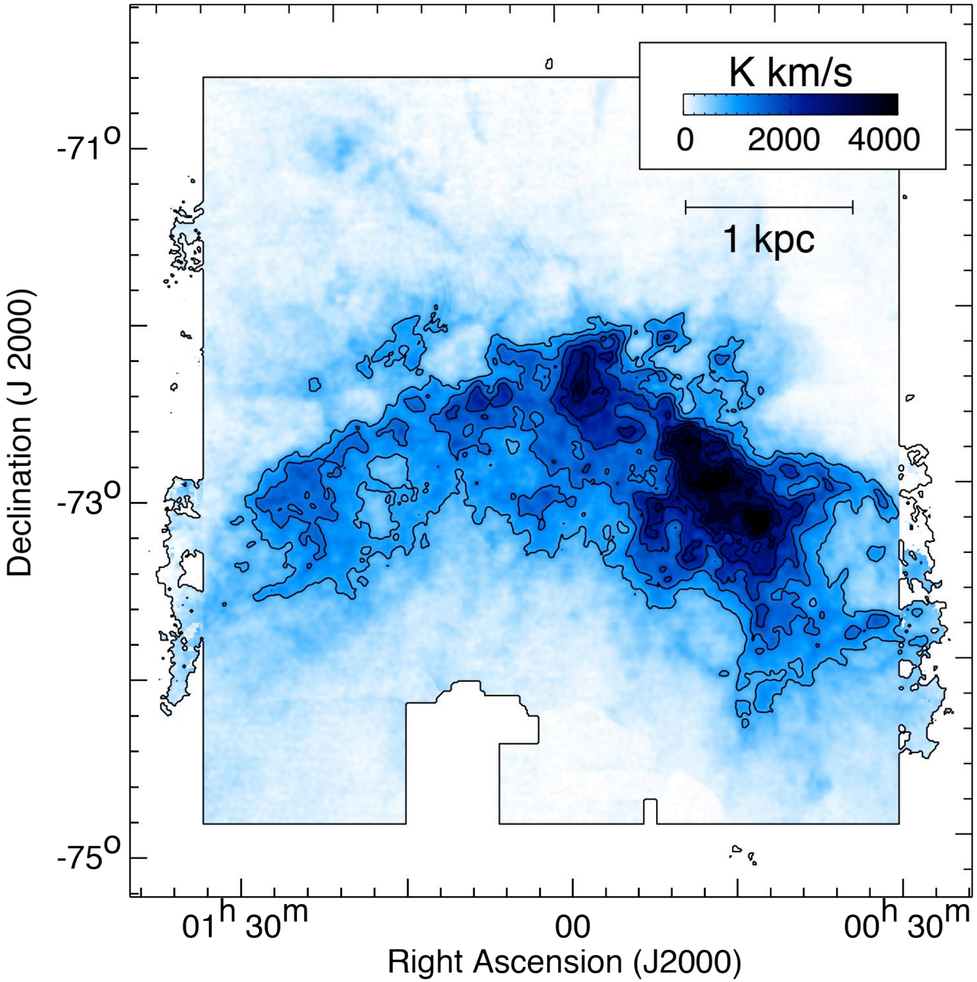
Massive cluster formation triggered by tidal interaction



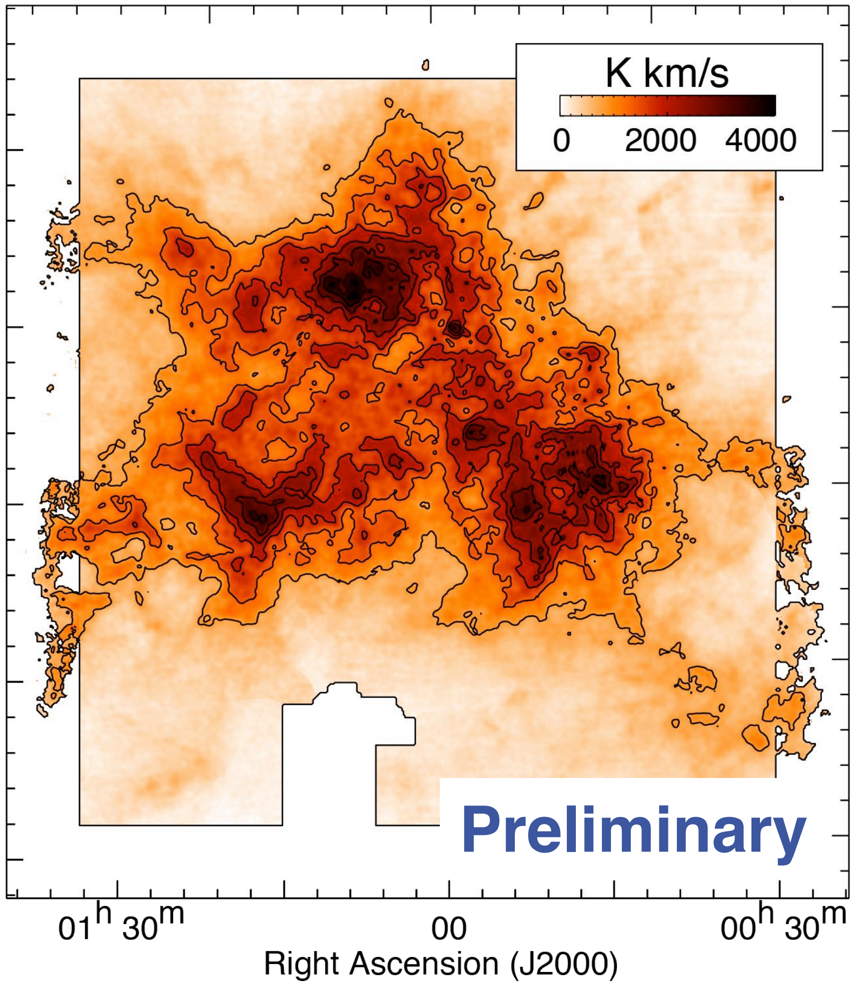
Fukui, Tsuge, Sano et al. (2017

Case 1: the Small Magellanic Cloud (SMC)

L-component (–100–-30 km/s)



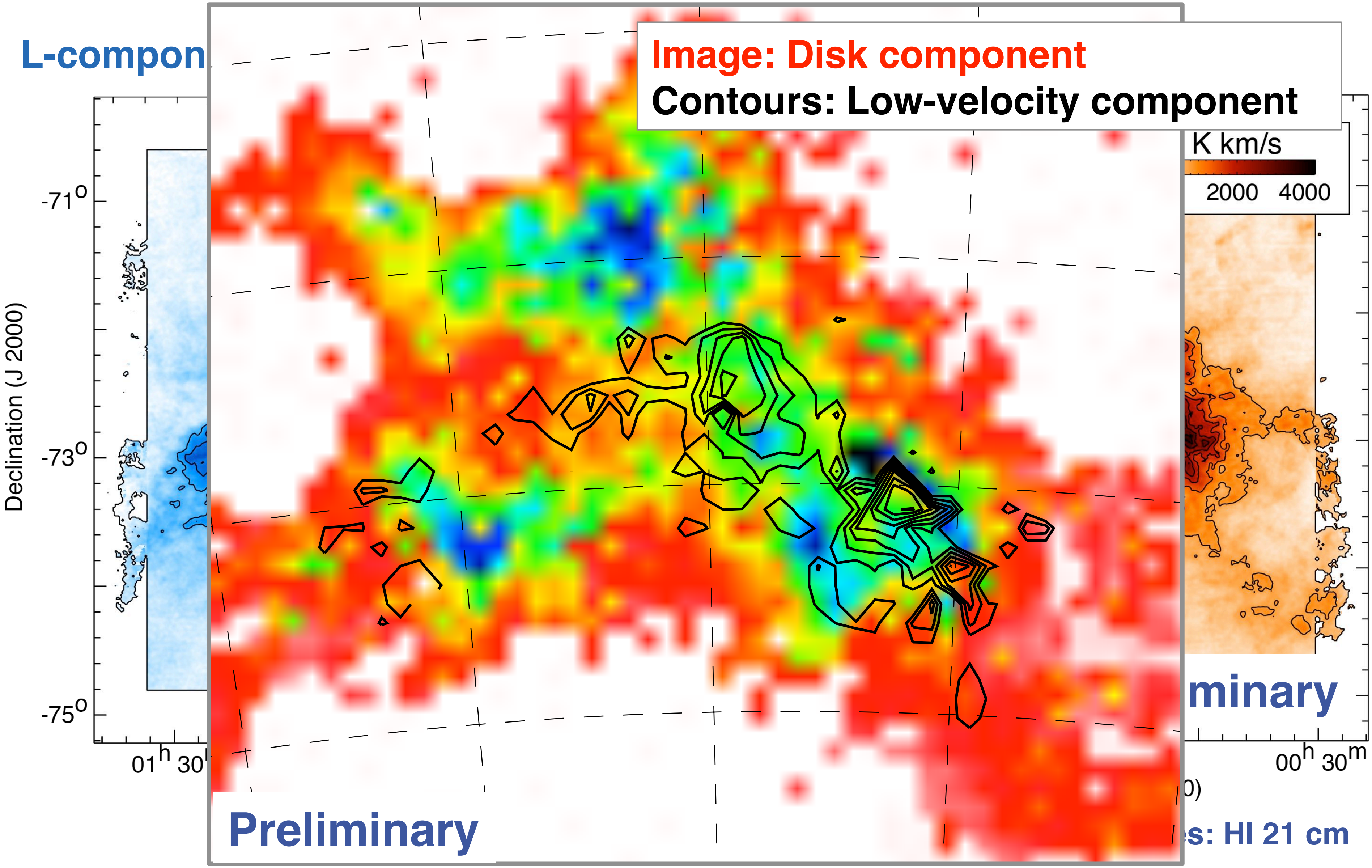
D-component (–30–+30 km/s)



Images: HI 21 cm

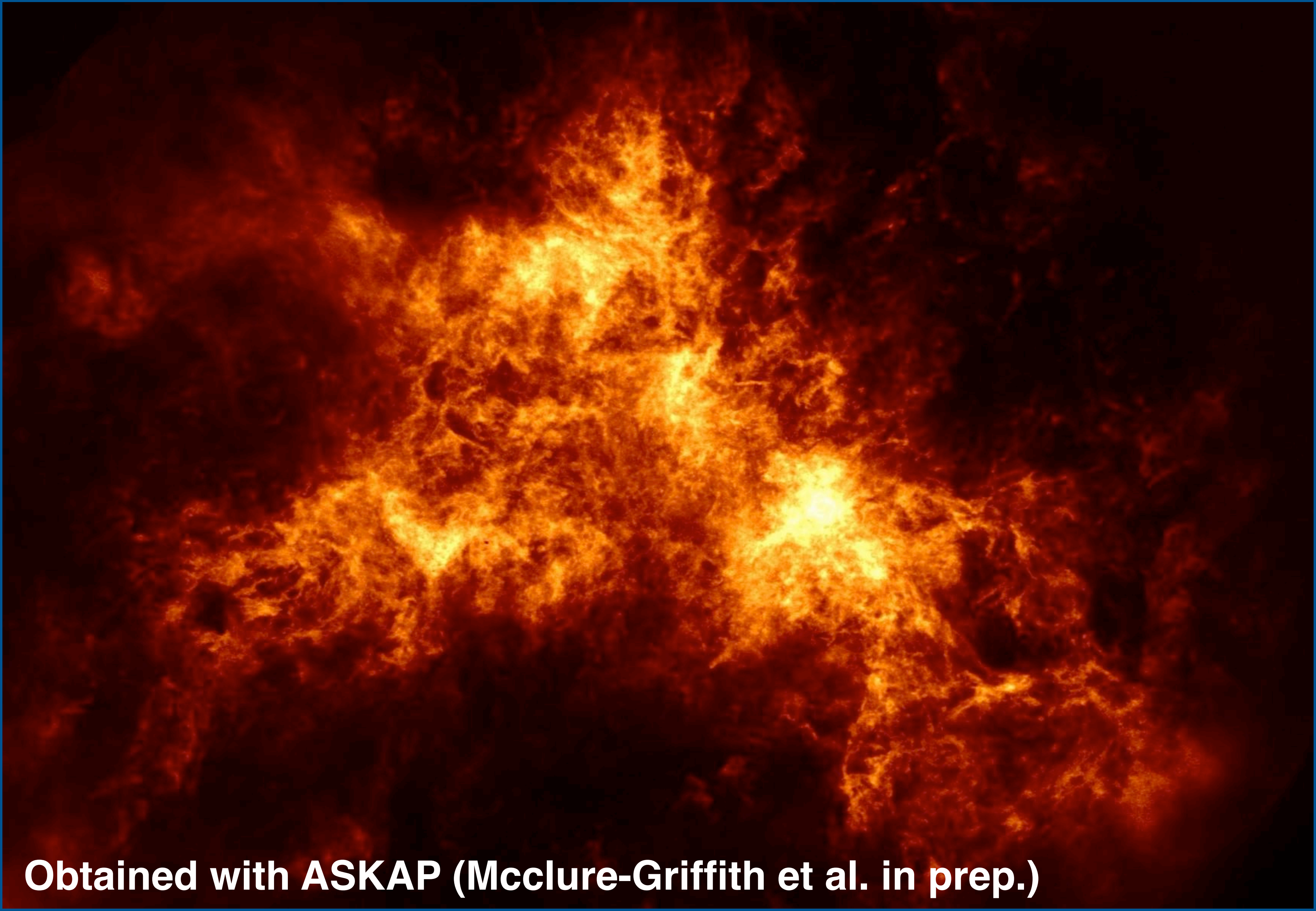
Tsuge et al. (2018) in preparation

Case 1: the Small Magellanic Cloud (SMC)



Tsuge et al. (2018) in preparation

Case 1: the Small Magellanic Cloud (SMC)



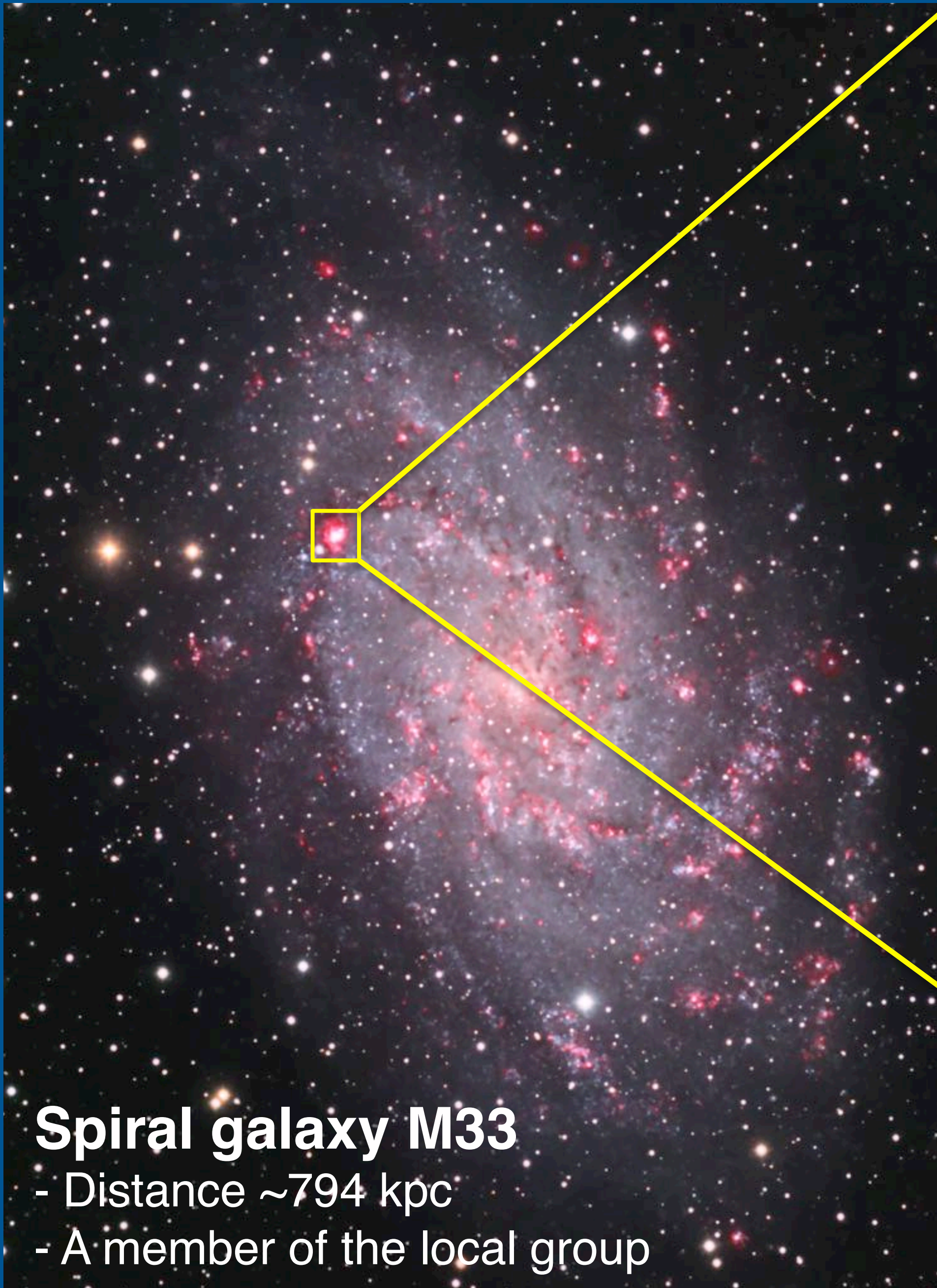
Obtained with ASKAP (Mcclure-Griffith et al. in prep.)

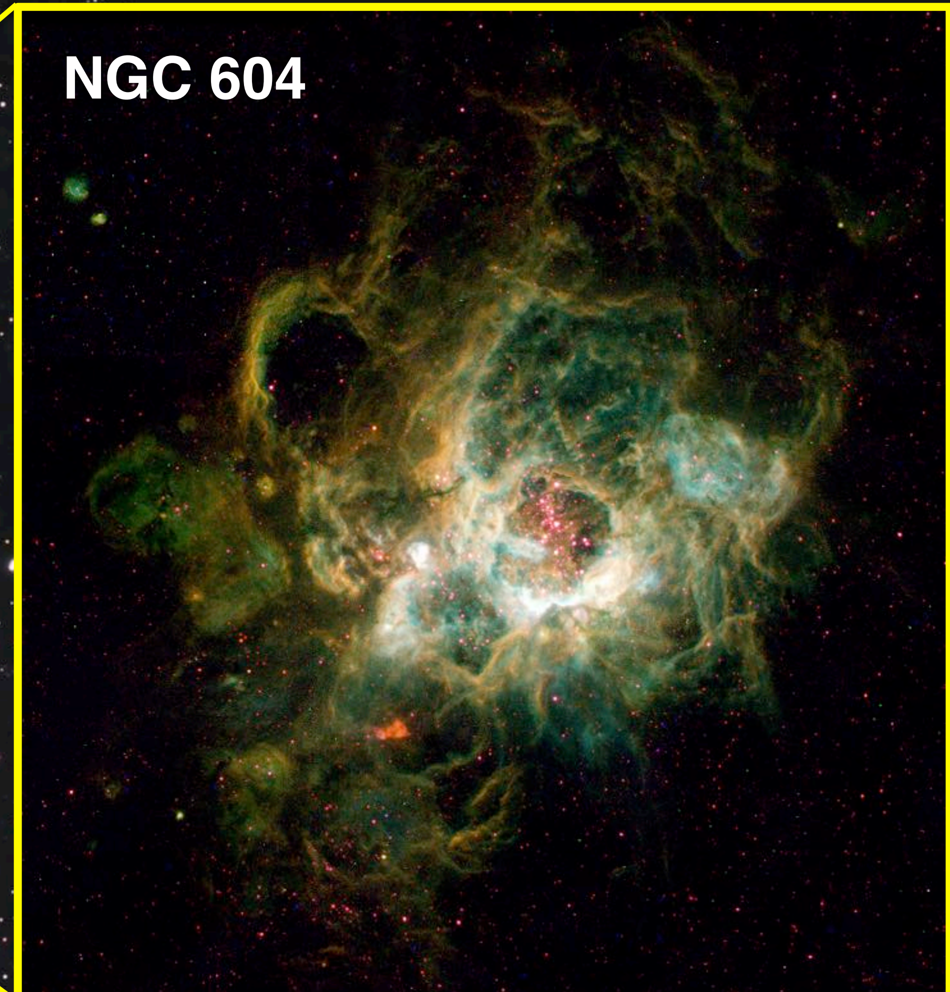
Case 2: M33

Spiral galaxy M33

- Distance ~794 kpc
- A member of the local group

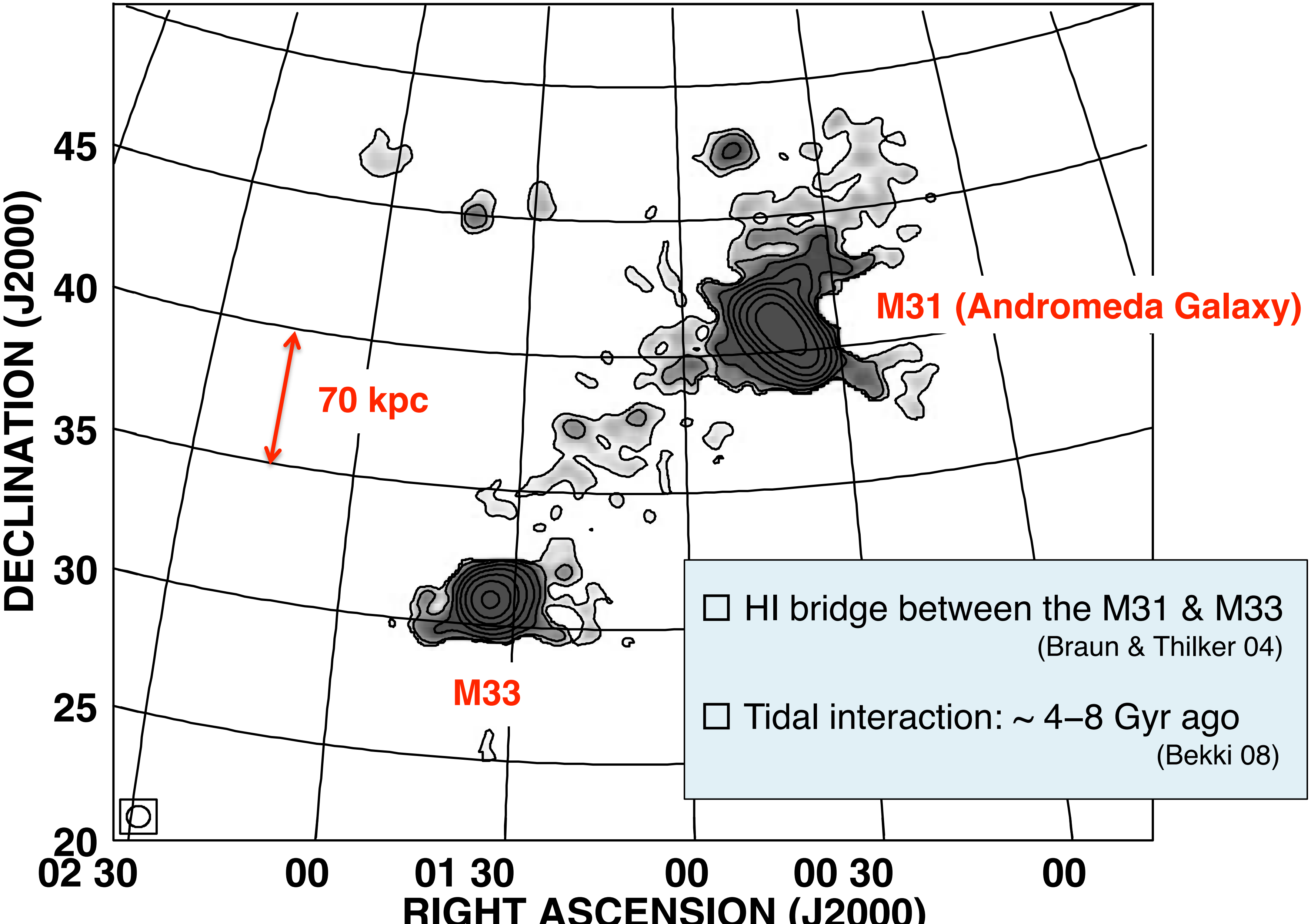
Case 2: M33 (Young massive star cluster NGC 604)





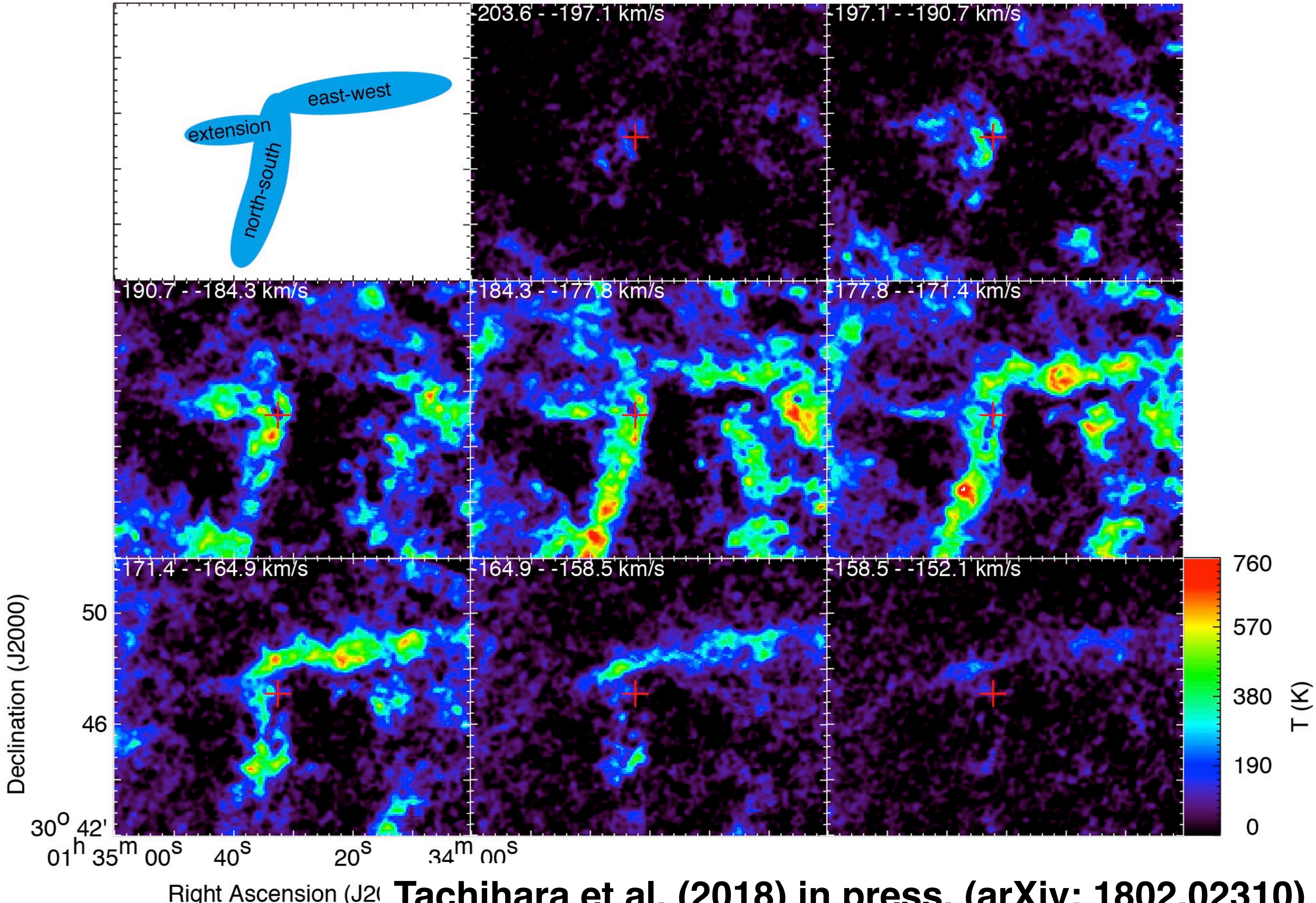
- ☐ 2nd largest HII region in the local group
- ☐ Number of OB stars: ~ 200
- ☐ Stellar mass: ~ $4 \times 10^5\ M_\odot$ (Eldridge & Relano 11)
- ☐ Age: ~ 3–5 Myr (e.g., Relano & Kennicutt 09)

Case 2: M33 (The M31–M33 HI bridge)



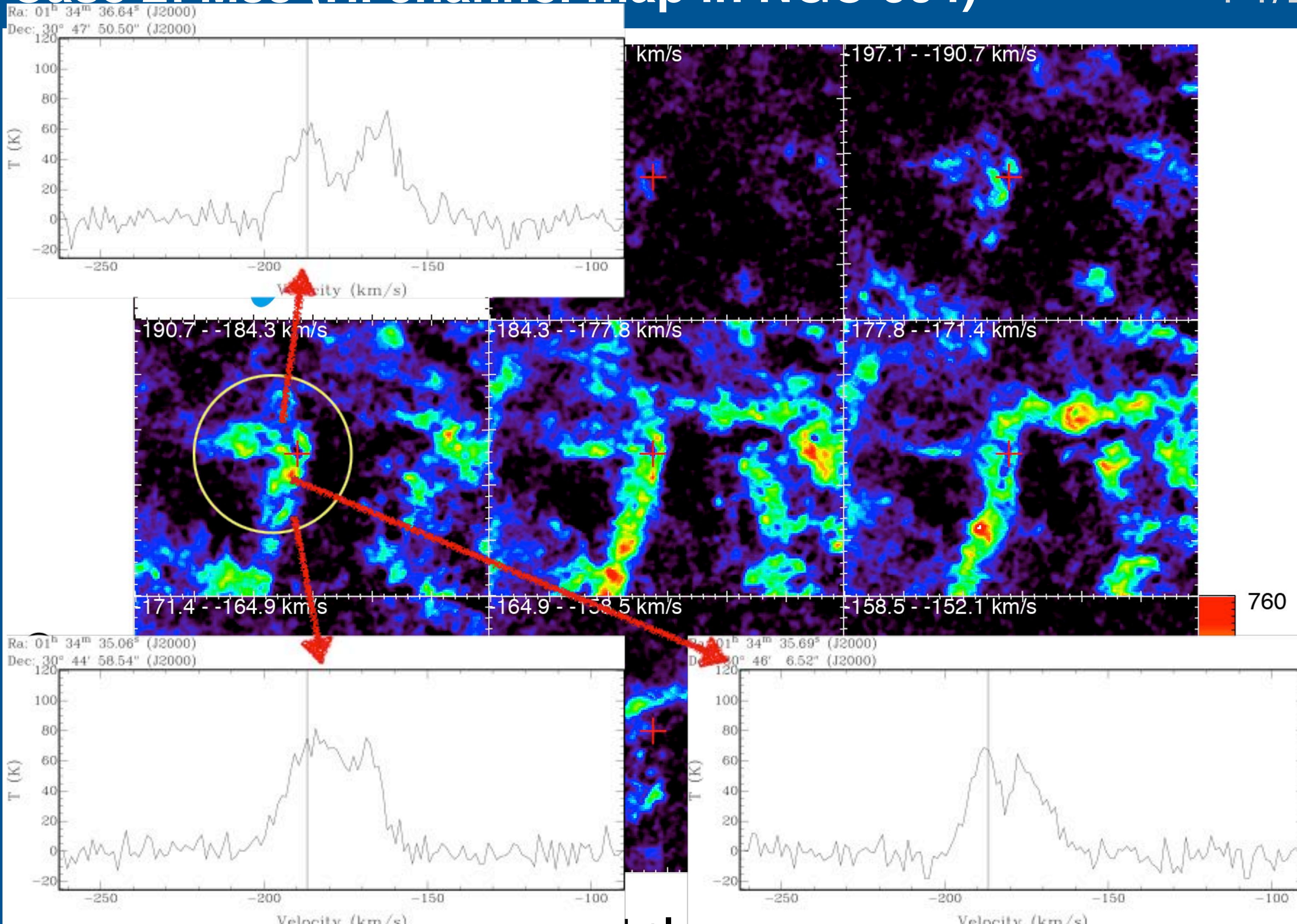
- ☐ HI bridge between the M31 & M33 (Braun & Thilker 04)
- ☐ Tidal interaction: ~ 4–8 Gyr ago (Bekki 08)

Case 2: M33 (HI channel map in NGC 604)



Tachihara et al. (2018) in press. (arXiv: 1802.02310)

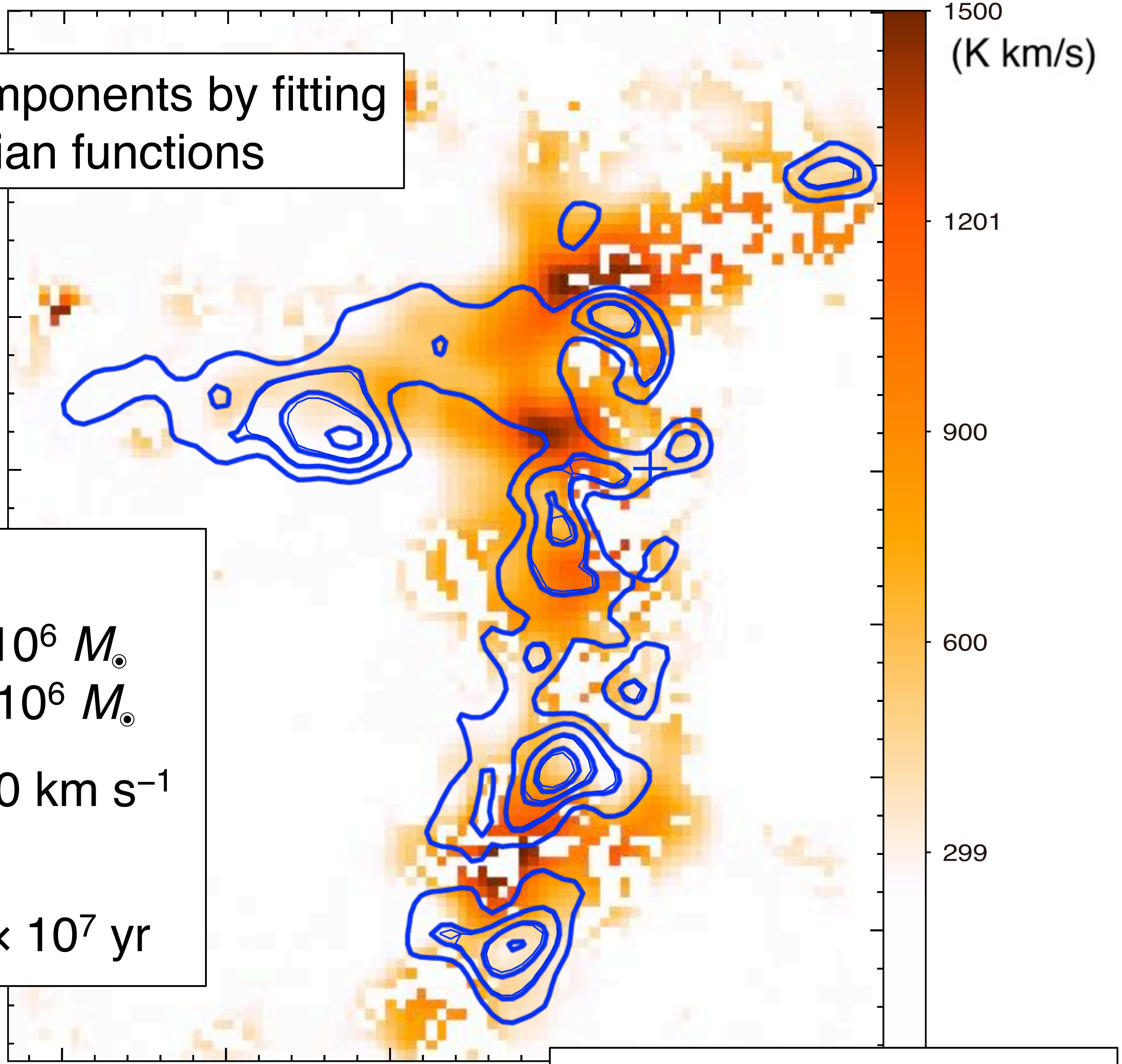
Case 2: M33 (HI channel map in NGC 604)



Tachihara et al. (2018) in press. (arXiv: 1802.02310)

Case 2: M33 (Complementary spatial distribution)

Separate the 2 velocity components by fitting to the 2-component Gaussian functions



- ☐ Cloud mass
- Red-shifted cloud: ~ 9 × 10^6 $M_{\odot}$
- Blue-shifted cloud: ~ 6 × 10^6 $M_{\odot}$

☐ Typical V separation ~20 km s^{-1}

☐ Dynamical time scale
200 pc / 20 km s^{-1} ~ 3 × 10^7 yr

Tachihara et al. (2018) in press. (arXiv:1802.02310)

Case 2: M33 (Discussion & Summary)

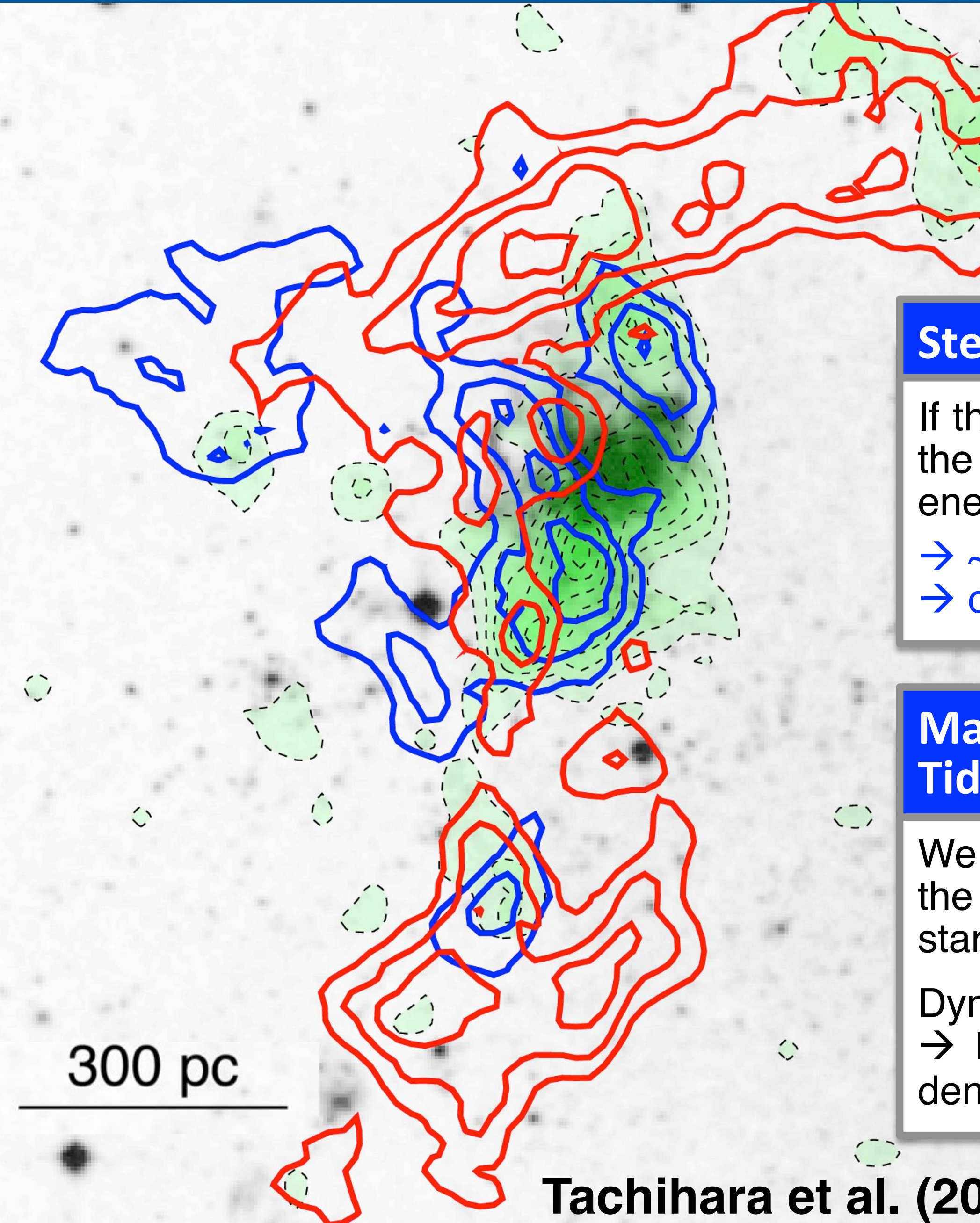


Image: Optical
Red contours: Red-shifted HI cloud
Blue contours: Blue-shifted HI cloud
Green image: Molecular cloud

Stellar feedback → unreasonable

If the blue- & red-shifted HI clouds are due to the expanding motion ~10 km/s, the kinetic energy of the clouds are to be $\sim 6 \times 10^{51}$ erg.

→ ~100 SNe are needed (5% efficiency, Kruijssen+12)
→ cluster mass > 10^6 $M_\odot$ is needed

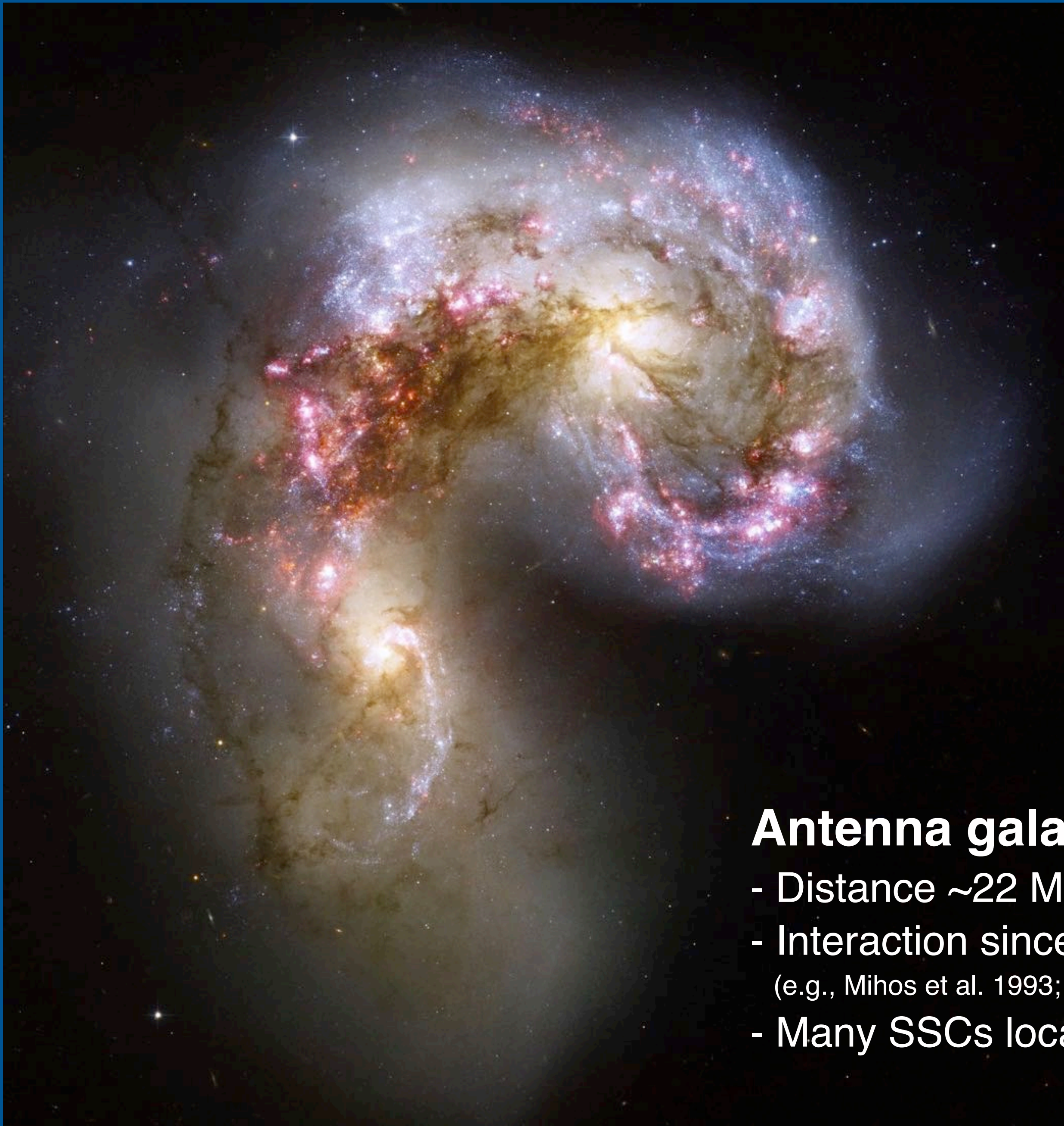
Massive cluster formation triggered by Tidally driven HI collisions

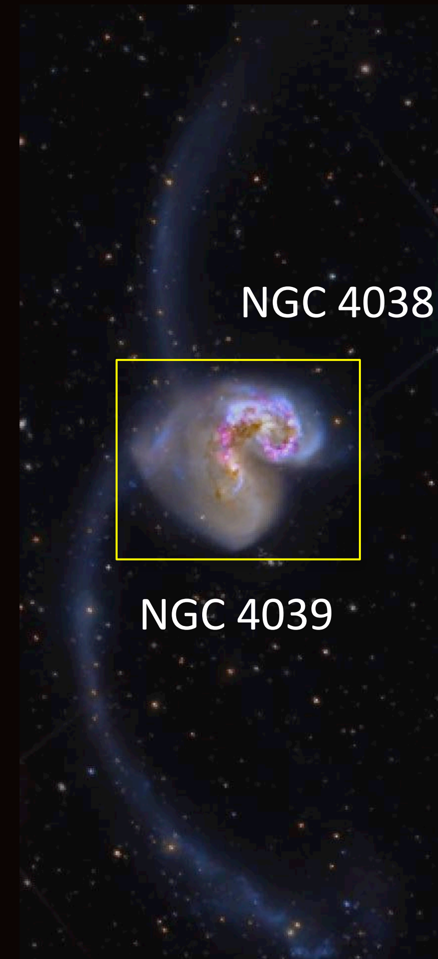
We propose a gas accretion scenario onto the spiral arm of the disk, that triggered active star formation of NGC 604.

Dynamical timescale of collision $\sim 3 \times 10^7$ yr.
→ Molecular gas formation is feasible if the density is high enough (Goldsmith et al.2007)

Tachihara et al. (2018) in press. (arXiv: 1802.02310)

Case 3: Antenna galaxies

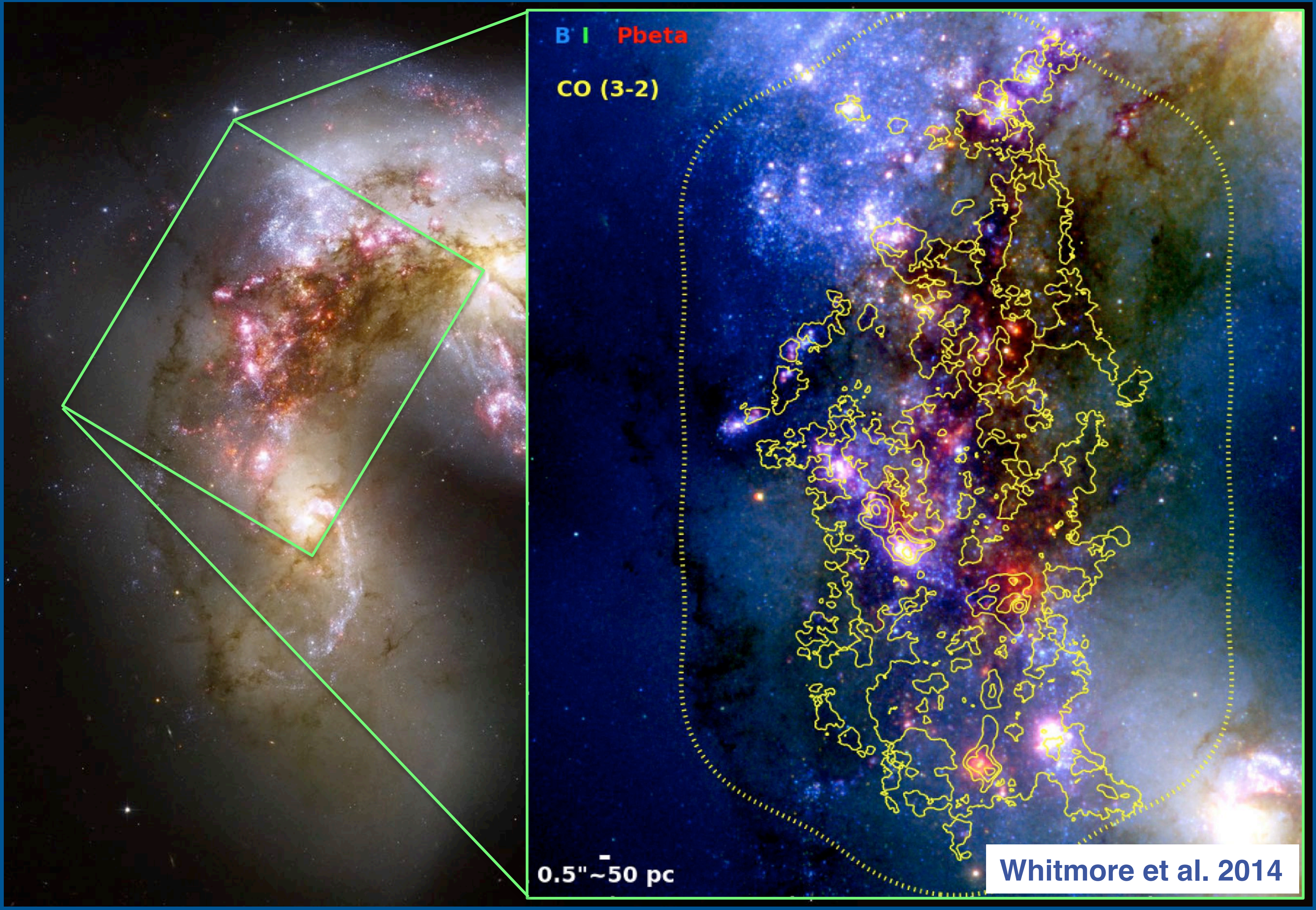




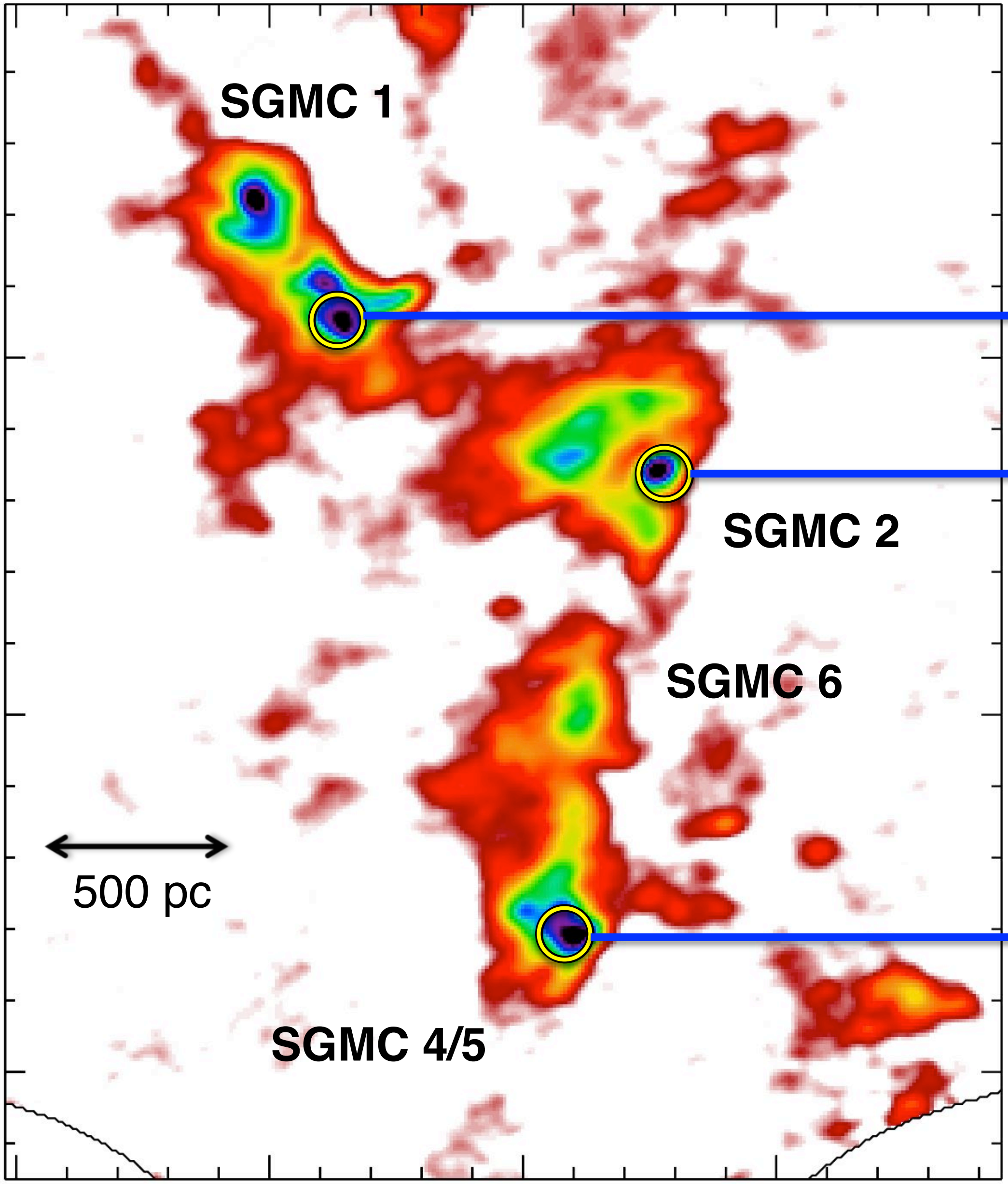
Antenna galaxies

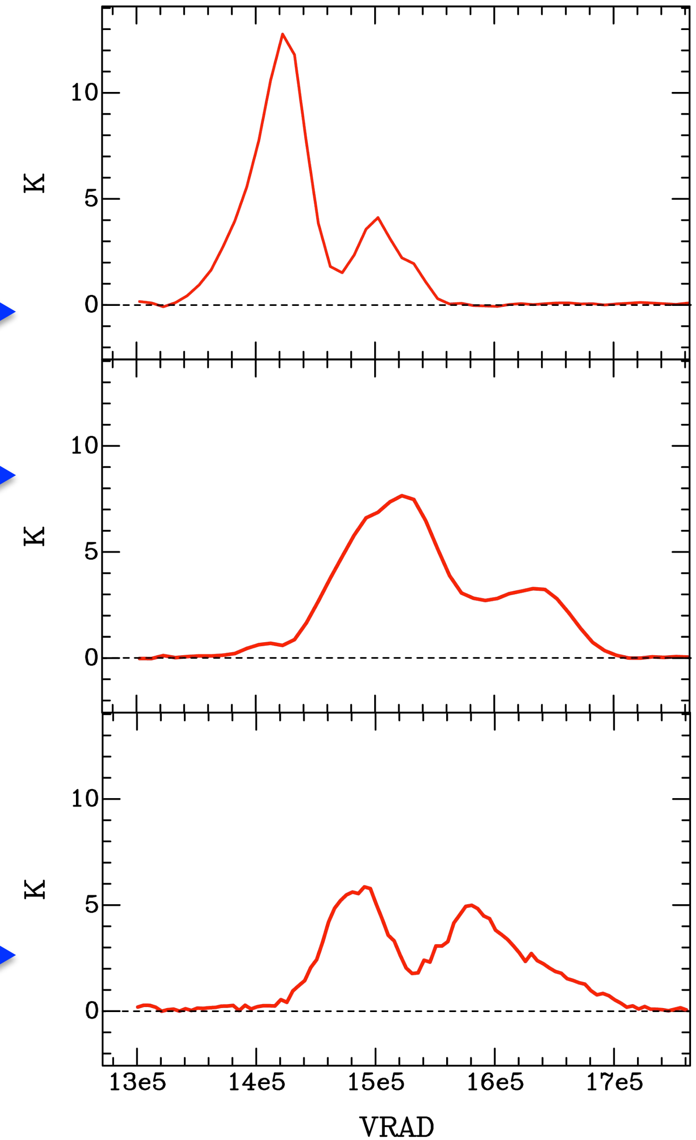
- Distance ~22 Mpc (Schweizer et al. 2008)
- Interaction since a few Myrs ago
  (e.g., Mihos et al. 1993; Karl et al. 2010, Renaud et al. 2009)
- Many SSCs located at the overlap region

Case 3: Antenna galaxies (ALMA CO)



Case 3: Antenna galaxies (Two velocity components)

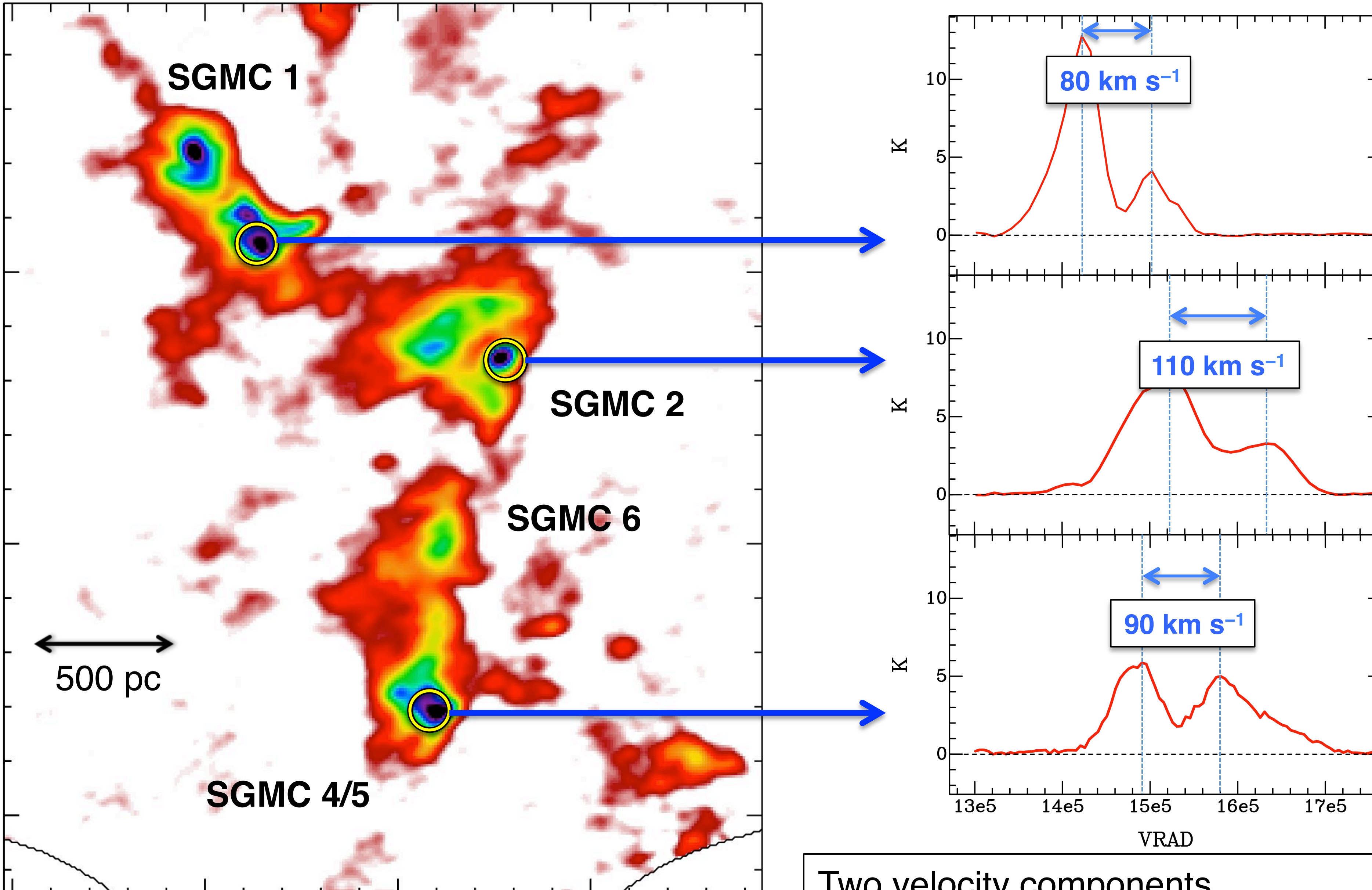




Fukui, Tsuge, Sano et al. in preparation

Two velocity components
→ Stellar feedback? (e.g., Herrera+2017)

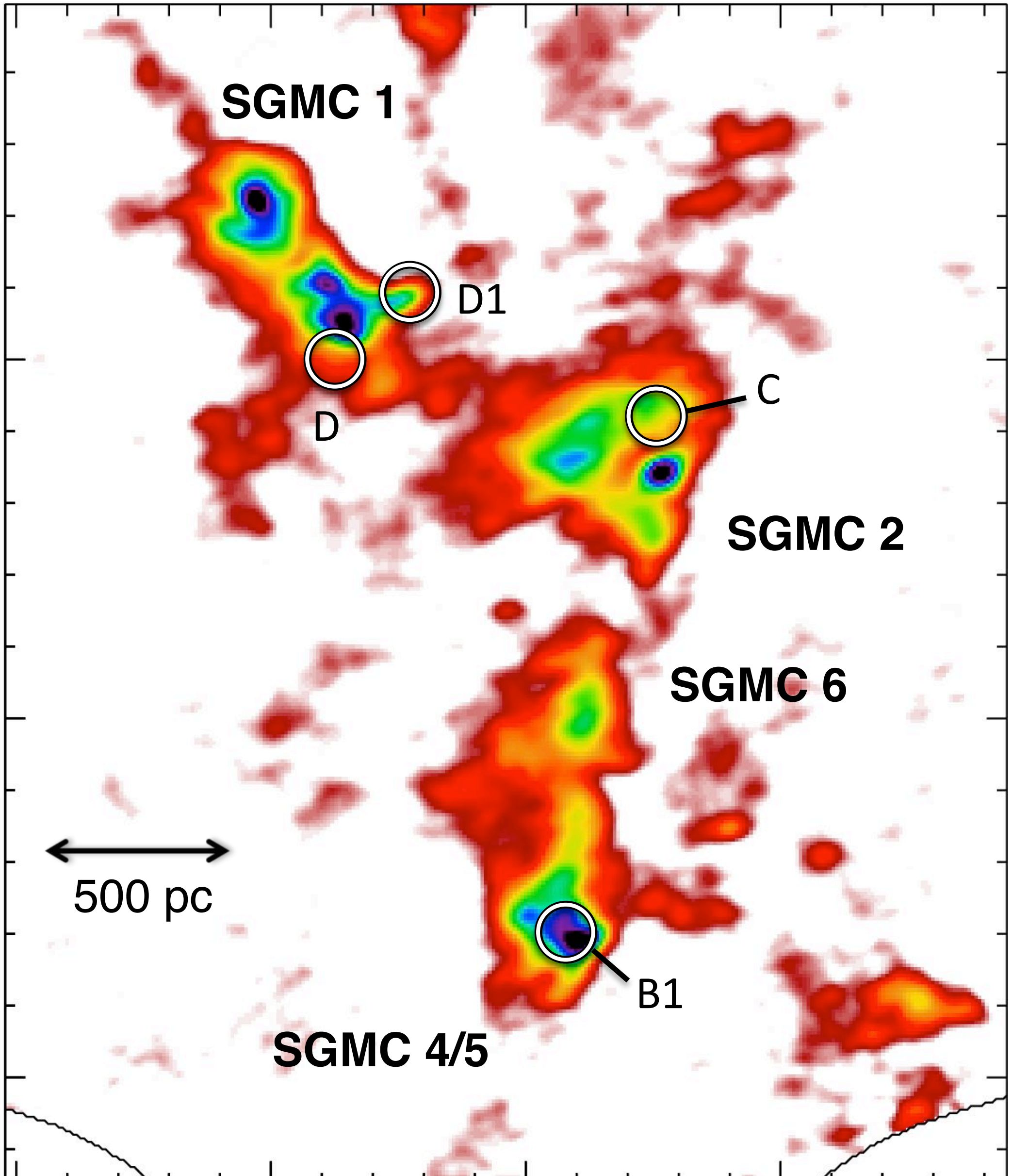
Case 3: Antenna galaxies (Two velocity components)



Fukui, Tsuge, Sano et al. in preparation

Two velocity components
→ Stellar feedback? (e.g., Herrera+2017)

Case 3: Antenna galaxies (Young SSCs)

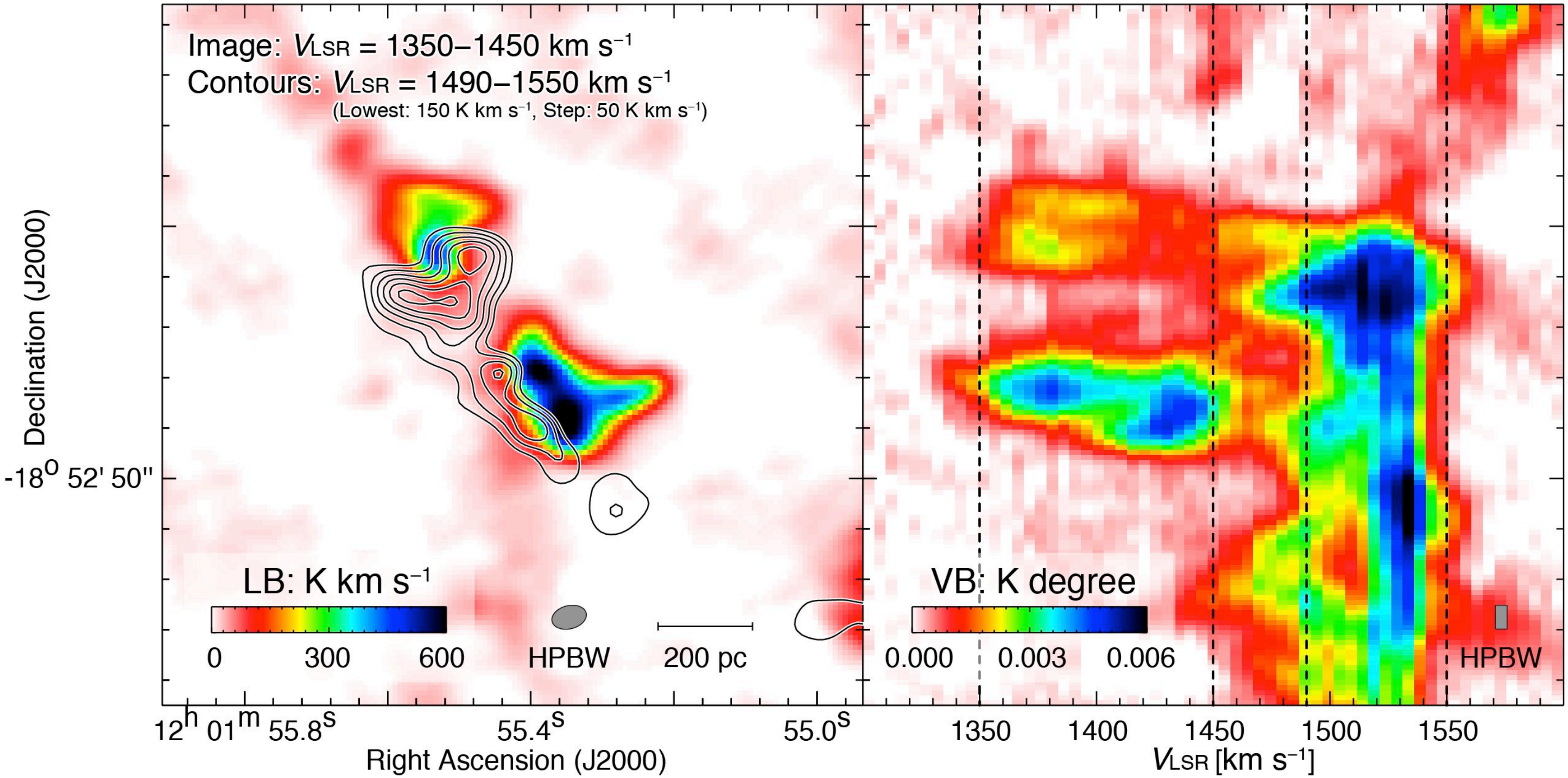


Fukui, Tsuge, Sano et al. in preparation

SSC ID	Age[a] Myr	Mass 10^6 $M_\odot$	Ref.[b]	Flux H_2 erg s^{-1} cm^{-2}	Flux Brγ erg s^{-1} cm^{-2}
D	3.9	1.4	[1]	$<2.9\times10^{-16}$	$2.1\pm0.1\times10^{-15}$
30	1.45	0.32	[2]		
D1	6.1	1.6	[1]	$<1.1\times10^{-16}$	$<1.5\times10^{-16}$
3	–	–	[2]		
D2	5.4	0.8	[1]	$<1.1\times10^{-16}$	$6.7\pm0.3\times10^{-16}$
C	5.7	4.1	[1]	$<1.0\times10^{-16}$	$<9.9\times10^{-17}$
28	4.8	1.2	[2]		
B1[c]	3.5	4.2	[1]	$2.9\pm0.2\times10^{-15}$	$2.2\pm0.1\times10^{-14}$
16	1	6.8	[2]		

Fluxes are not corrected for extinction.
[a] Errors in ages estimated by Gilbert & Graham (2007) are derived from Starburst99 fits to the Brγ EW and are typically below 0.1 Myr. Cluster D2 has a larger error on the Brγ EW, the error on the mass is $5.4^{+0.4}_{-1.4}$.
[b] [1] Gilbert & Graham (2007), [2] Table 8 in Whitmore et al. (2010). Masses estimated by Gilbert & Graham (2007) are not corrected by extinction.
[c] SSC first identified by Whitmore & Schweizer (1995) as WS80.

Case 3: Antenna galaxies (SGMC 1)

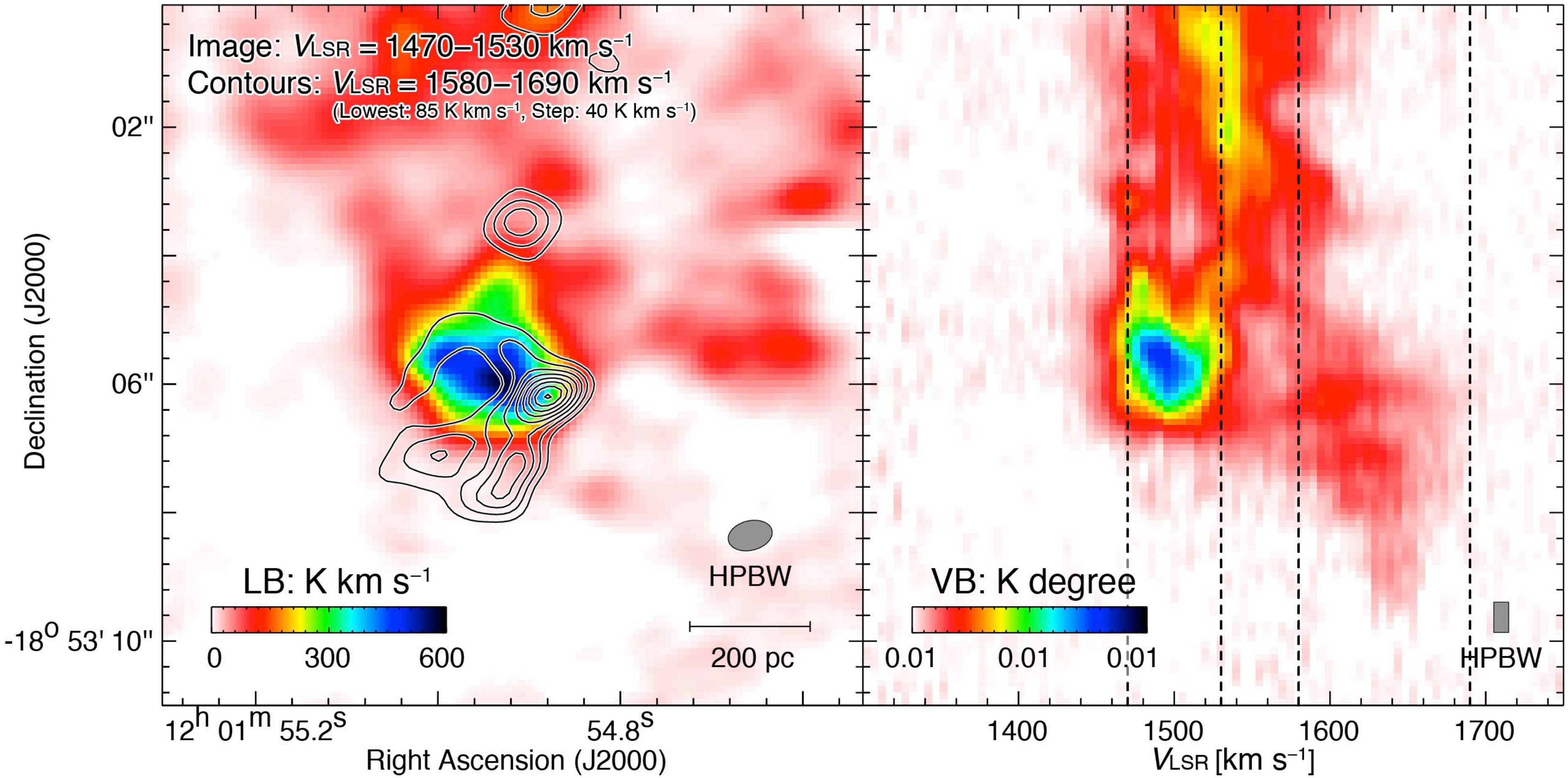


Low–velocity cloud (image): ~ $5 \times 10^7\ M_\odot$

High–velocity cloud (contours): ~ $9 \times 10^7\ M_\odot$

Fukui, Tsuge, Sano et al. in preparation

Case 3: Antenna galaxies (SGMC 4/5)

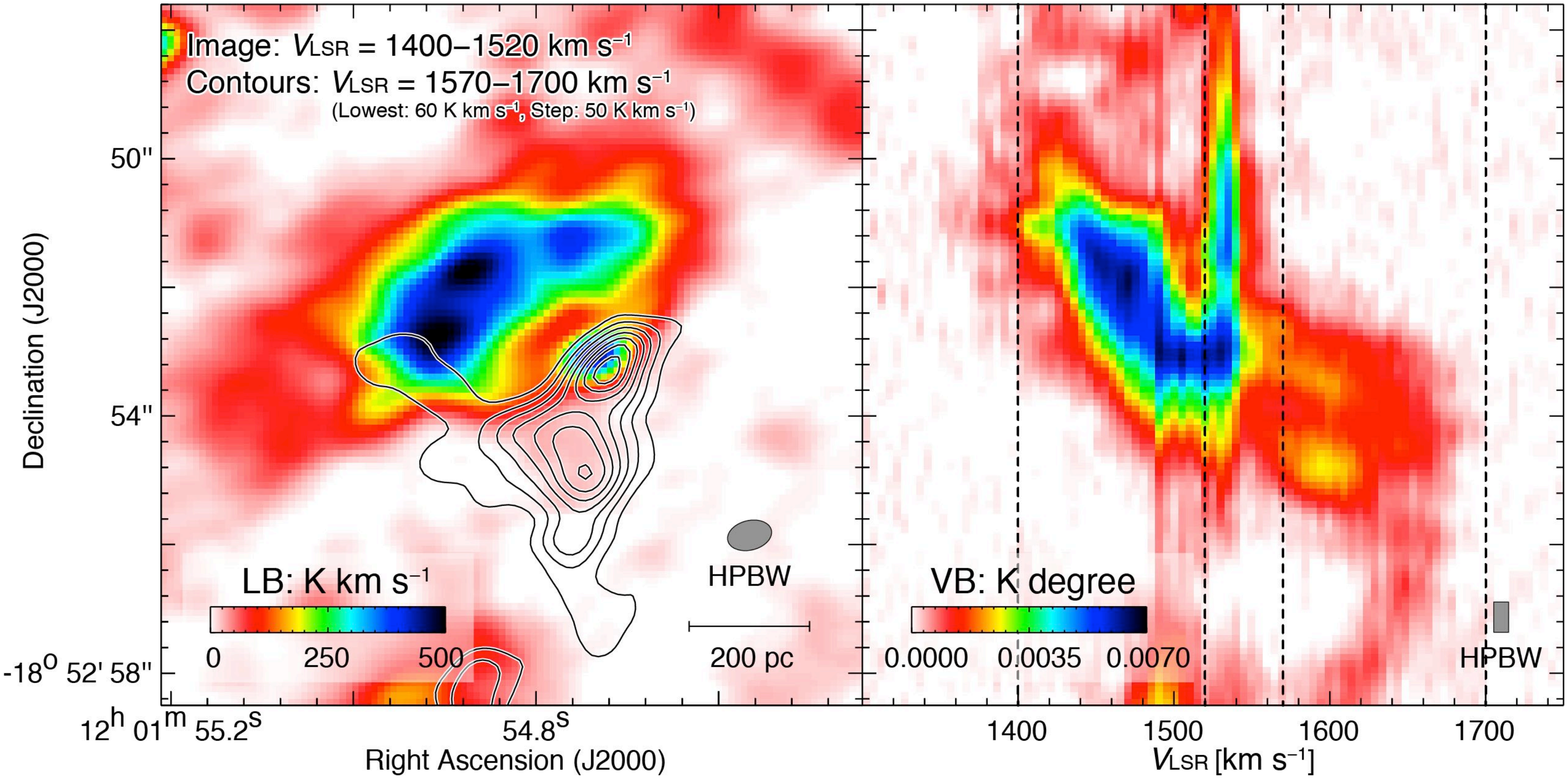


Low–velocity cloud (image): ~ $5 \times 10^7\ M_\odot$

High–velocity cloud (contours): ~ $3 \times 10^7\ M_\odot$

Fukui, Tsuge, Sano et al. in preparation

Case 3: Antenna galaxies (SGMC 2)



Low–velocity cloud (image): $\sim 9 \times 10^7\ M_\odot$

High–velocity cloud (contours): $\sim 4 \times 10^7\ M_\odot$

Fukui, Tsuge, Sano et al. in preparation

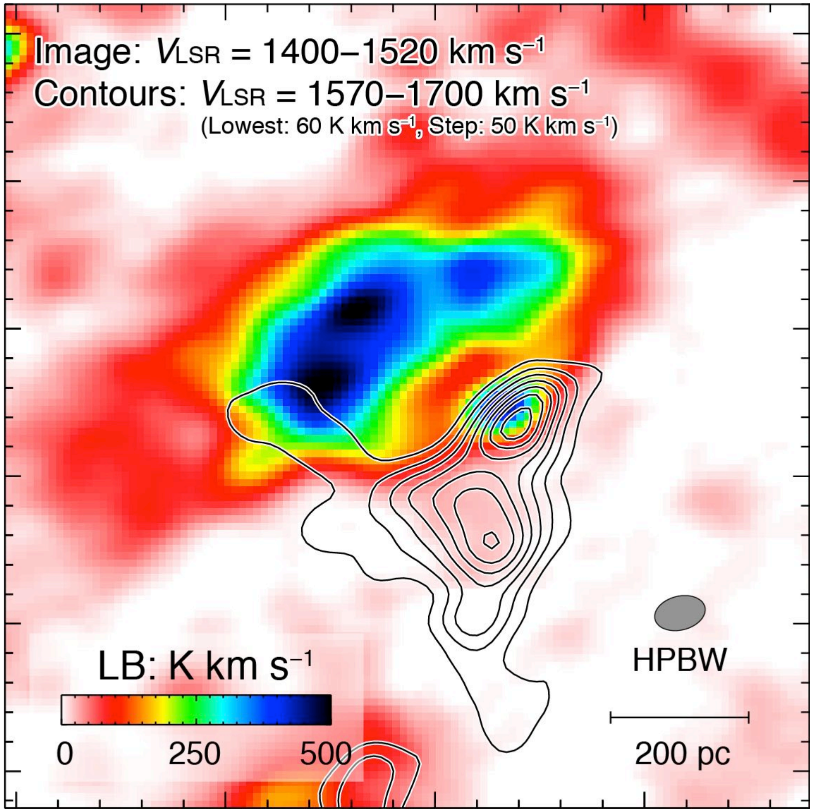
Case 3: Antenna galaxies (Stellar feedback in SGMC 2)

- The total mechanical luminosity from the stellar wind is assumed to be ~ 5×10^{53} erg (~4×10^{6} $M_\odot$, Gilbert & Graham 2007) (Westerlund 2: ~ 3.6×10^{51} erg @ ~3×10^{4} $M_\odot$, Rauw et al. 2007)

- Kinematic energy of SGMC 2

  - Total mass: 1.3×10^{8} $M_\odot$
  - ΔV : ~ 68 km s^{-1}

  → ~ 6×10^{54} erg



In ideal adiabatic wind bubbles 20% of the wind luminosity is transferred to the expanding gas shell (Weaver et al. 1977).

→ The gas motion cannot be explained by the stellar feedback

Fukui, Tsuge, Sano et al. in preparation

Summary

■ **LMC-SMC 間潮汐相互作用が誘発する星形成**
[Fukui, Tsuge, Sano al. 2017, PASJ, 69, 5]

- □ LMC における HI ガス衝突
- □ SMC HI ガスの相補的分布 [Tsuge et al. 2018 in prep.]

■ **M33 における巨大星団形成**
[Tachihara, Gratier, Sano et al. 2018 (arXiv: 1802.02310)]

- □ M33-M31 潮汐相互作用
- □ VLA HI の空間/速度構造解析により2つの速度成分が存在
- □ HI 衝突が誘発する大質量星形成と分子雲形成

■ **アンテナ銀河における SSC 形成**
[Fukui, Tsuge, Sano et al. 2018, in prep.]

- □ overlap 領域において分子雲の相補的分布＋ブリッジ構造
- □ stellar feedback のみでは、2つの速度差は説明できなさそう

■ **まとめ**