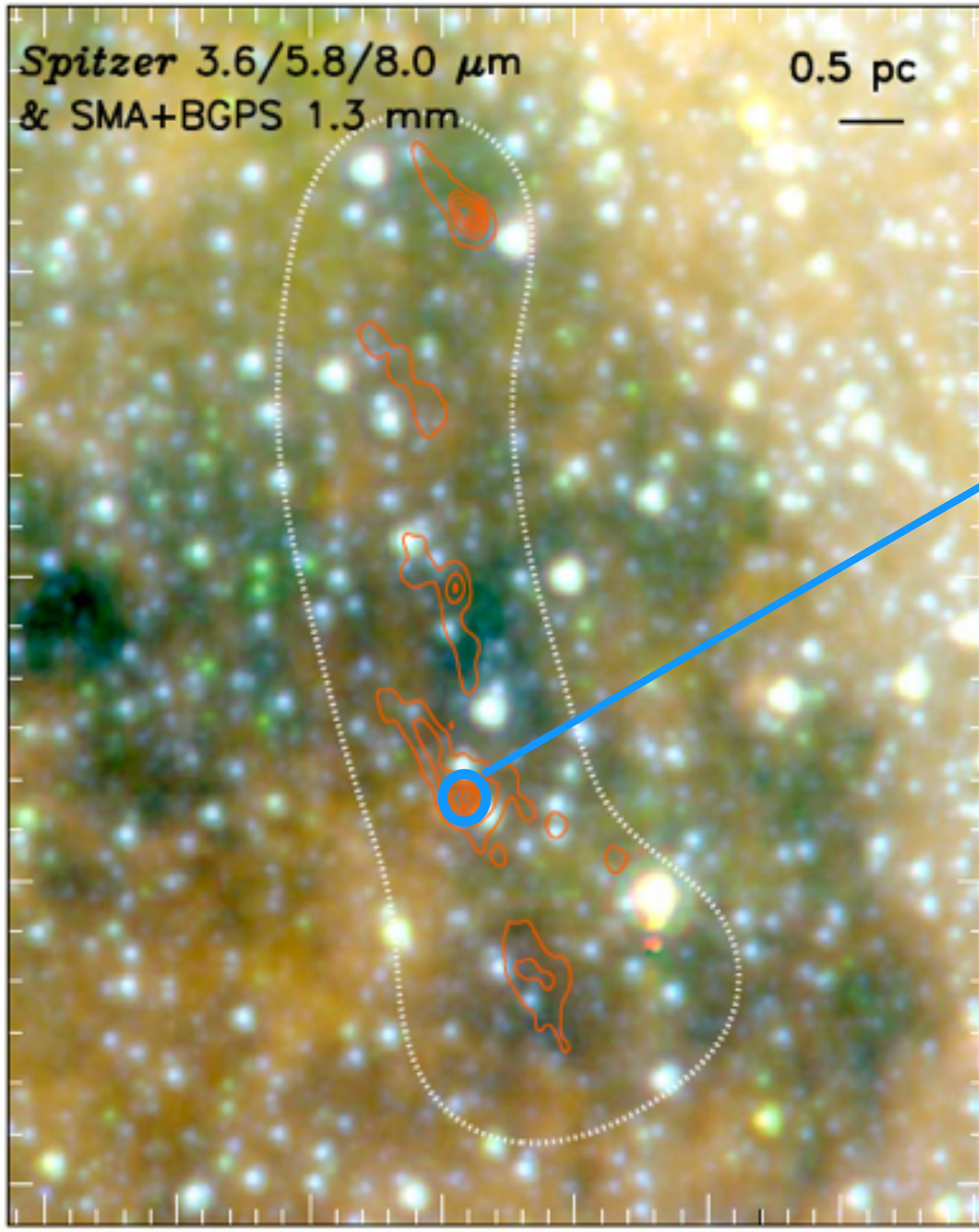
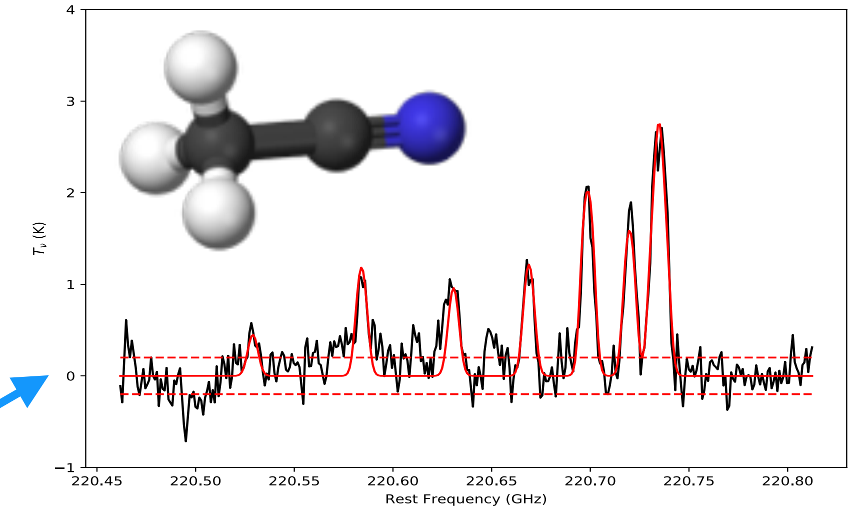




The molecular environment of star formation in the Central Molecular Zone

Xing "Walker" Lu
ALMA Project Fellow, NAOJ

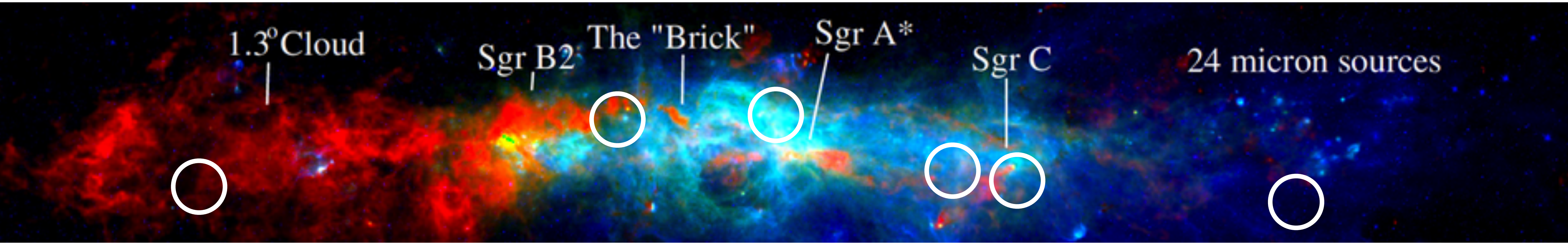
in collaboration with Qizhou Zhang (CfA), Jens Kauffmann (MPIfR), Thushara Pillai (MPIfR), Steve Longmore (LJMU), J. M. Diederik Kruijssen (ZAH), Cara Battersby (CfA), Hauyu Liu (ESO), Betsy Mills (SJSU), et al.

August 7, 2017

Lu, X. et al. 2015, ApJL, 814, 18
Lu, X. et al. 2017, ApJ, 839, 1

Outline

1. What is going wrong? (Suppressed star formation in CMZ clouds)
2. Are there anything missing? (SMA+JVLA mini-survey of 6 clouds)
3. We found something! (The 20 km/s cloud: an outstanding case)
4. What are they? (ALMA+JVLA follow-ups)



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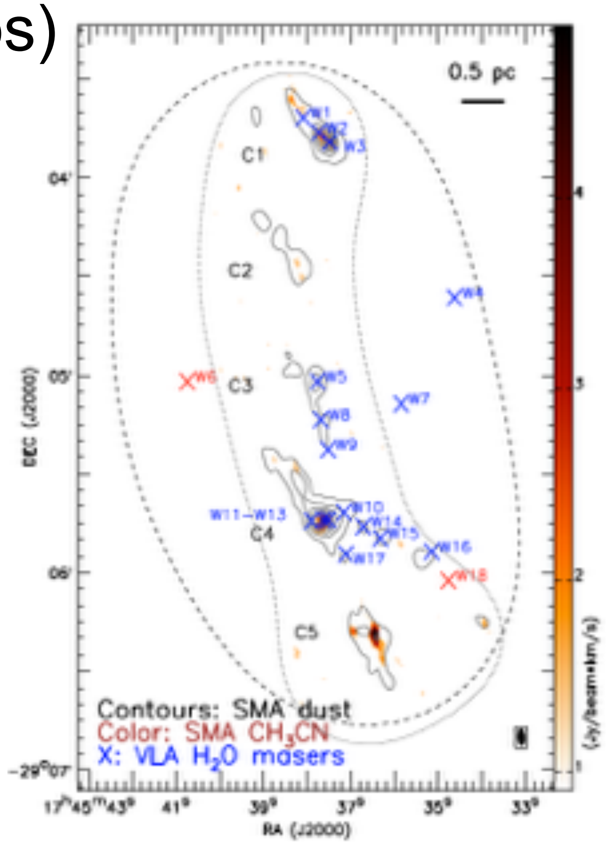
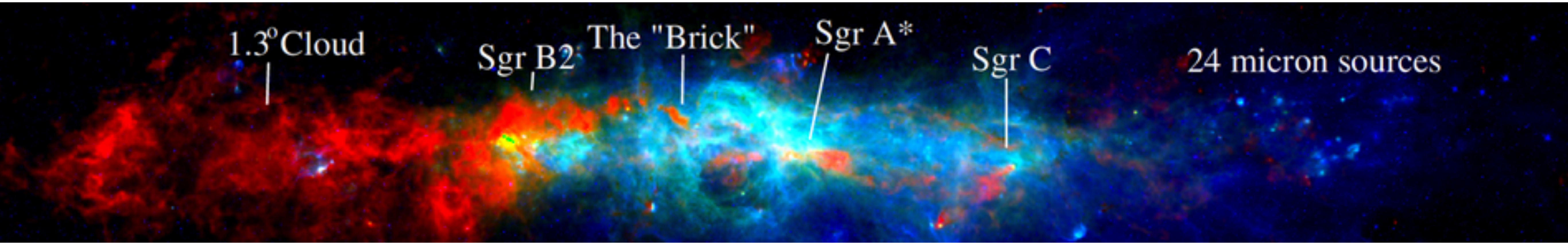


1. Suppressed star formation in the CMZ

The Central Molecular Zone (CMZ) — inner ~500 pc of the Galaxy, ~2–6x10^7 $M_\odot$, with unique properties (Morris & Serabyn 1996; Ferriere et al. 2007; Mills 2017).

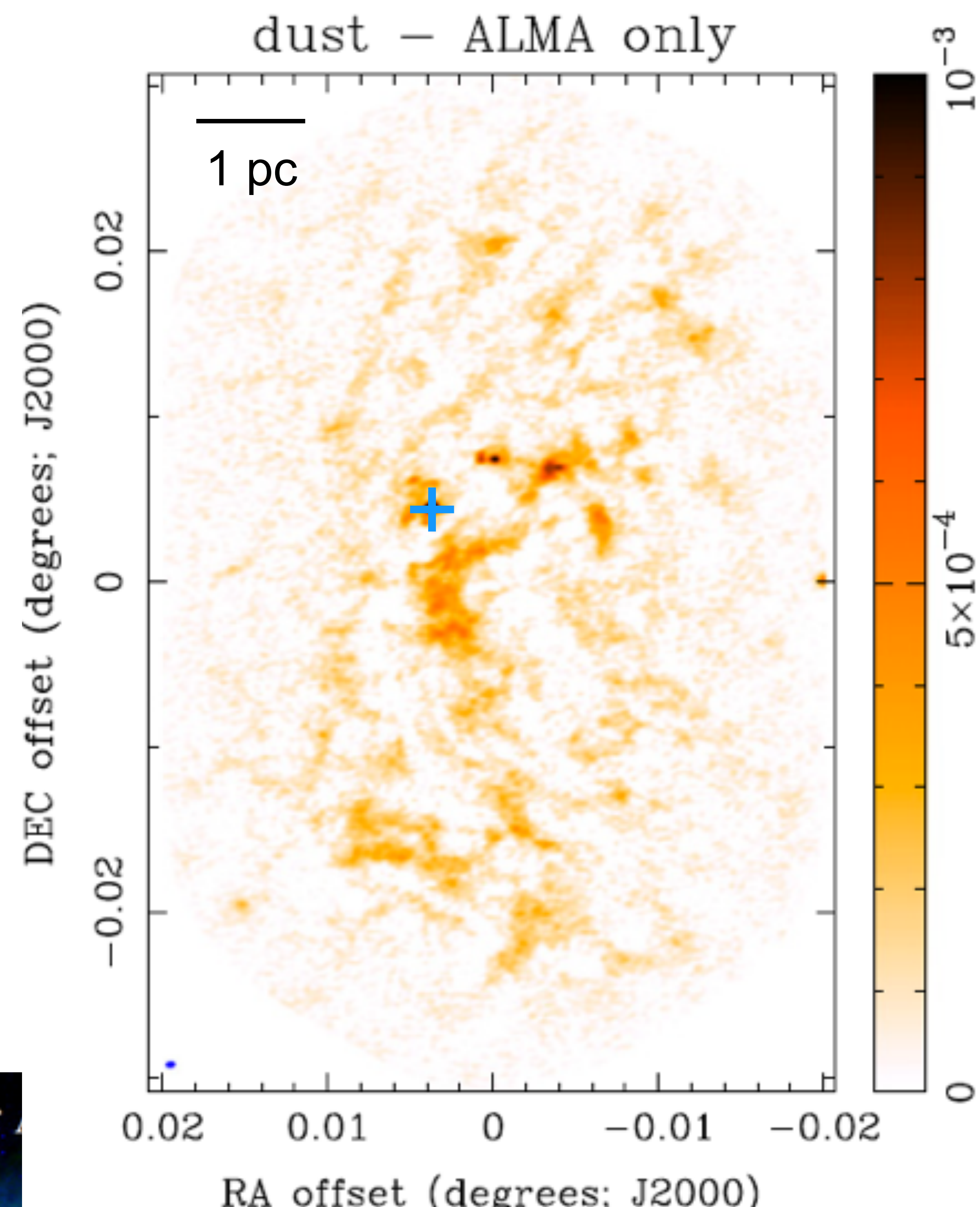
- Highly turbulent (FWHM~10–10^2 km s^{-1}).
- Large gas pressure (10^6–10^7 K cm^{-3}).
- Strong magnetic field (B ~ 1 mG).
- Asymmetric distribution of dense core/star formation…

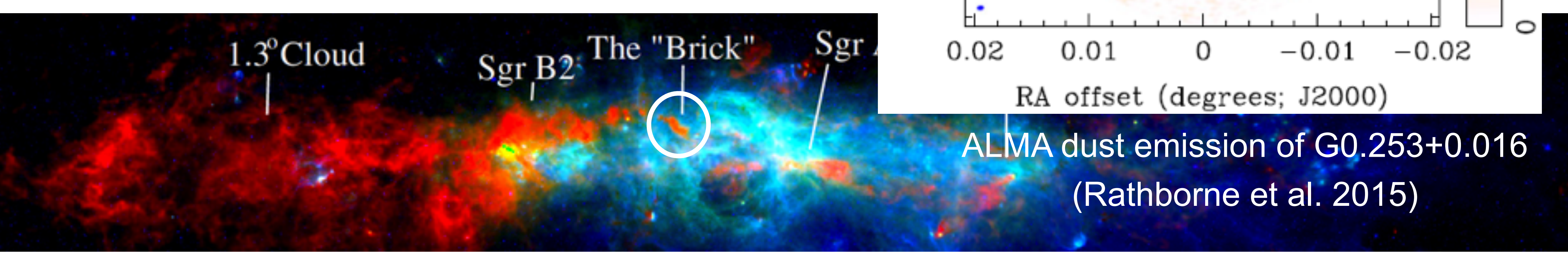


$N(H_2)$+70 μm+8 μm, made by C. Battersby,
from the SMA CMZoom website, https://www.cfa.harvard.edu/sma/LargeScale/CMZ/

1. Suppressed star formation in the CMZ

- Observed SFR is **10 times lower** than expected from SF-gas relations (Longmore et al. 2013; Kauffmann et al. 2016).
- Most clouds are quiescent in **current** star formation (Immer et al. 2012; Mills et al. 2015; Kauffmann et al. 2016).
- G0.253+0.016, 10^5 $M_\odot$ of dense molecular gas, but…
  - **Only one SF site**: one weak H_2O maser in one dense core (Lis et al. 1994; Kauffmann et al. 2013; Johnstone et al. 2014; Rathborne et al. 2014, 2015; Mills et al. 2015).



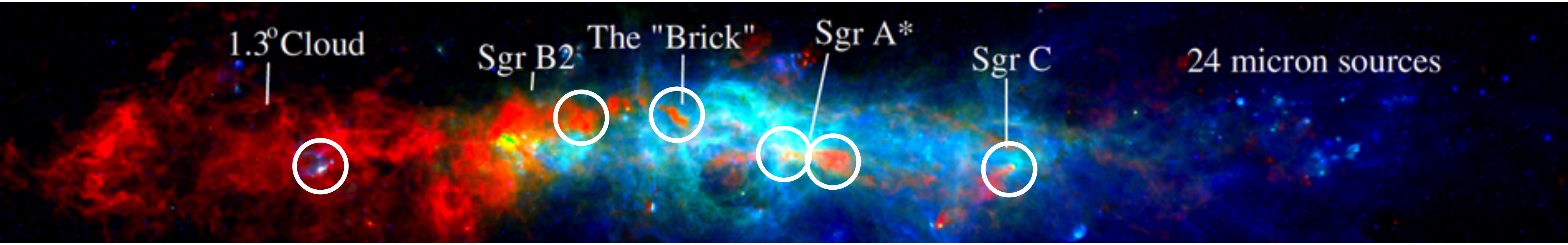


ALMA dust emission of G0.253+0.016 (Rathborne et al. 2015)

1. Suppressed star formation in the CMZ

- Do other massive clouds in the CMZ have similar internal structures to G0.253+0.016 (a lack of dense cores)?
- If they instead present more dense cores, how is the star formation in them?

2. Deeply embedded star formation



The Submillimeter Array (SMA)

- Dust continuum (3 mJy@4” beam)
- 1.3 mm lines (CH_3CN, H_2CO, CH_3OH, SiO, …; 0.1 Jy@4” beam&1 km/s)

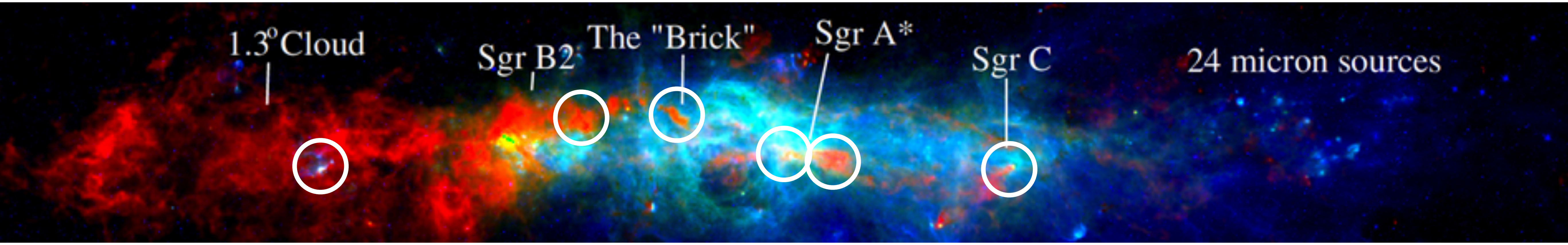
Atacama Large Millimeter/submm Array (ALMA)

- Dust continuum (0.06 mJy@0.3” beam)
- 1.3 mm lines (CH_3CN, H_2CO, CH_3OH, SiO, …; 5 mJy@0.3” beam&1 km/s)

Very Large Array (VLA)

- 1.3 cm continuum (30 μJy@3” beam).
- NH_3 (1,1)-(5,5), H_2O maser (6 mJy@3” beam&0.2 km/s).
- 6 cm continuum (20 μJy@1.4” beam)
- RRLs, Class II CH_3OH maser (10 mJy@1.4” beam&0.2 km/s)

2. Deeply embedded star formation



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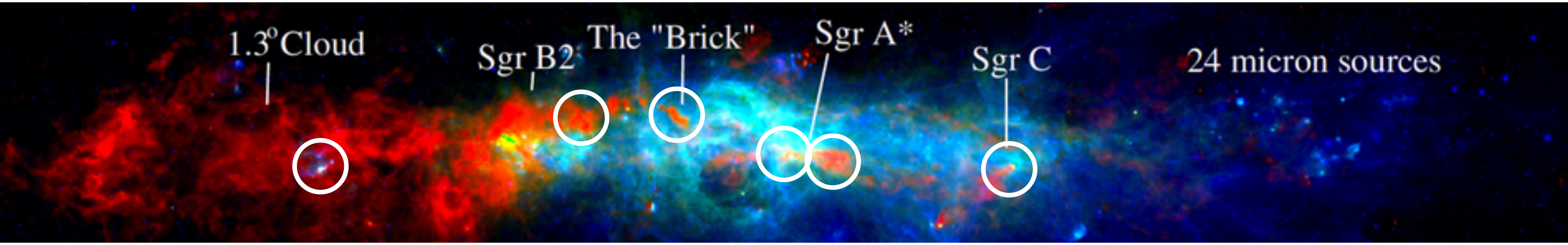

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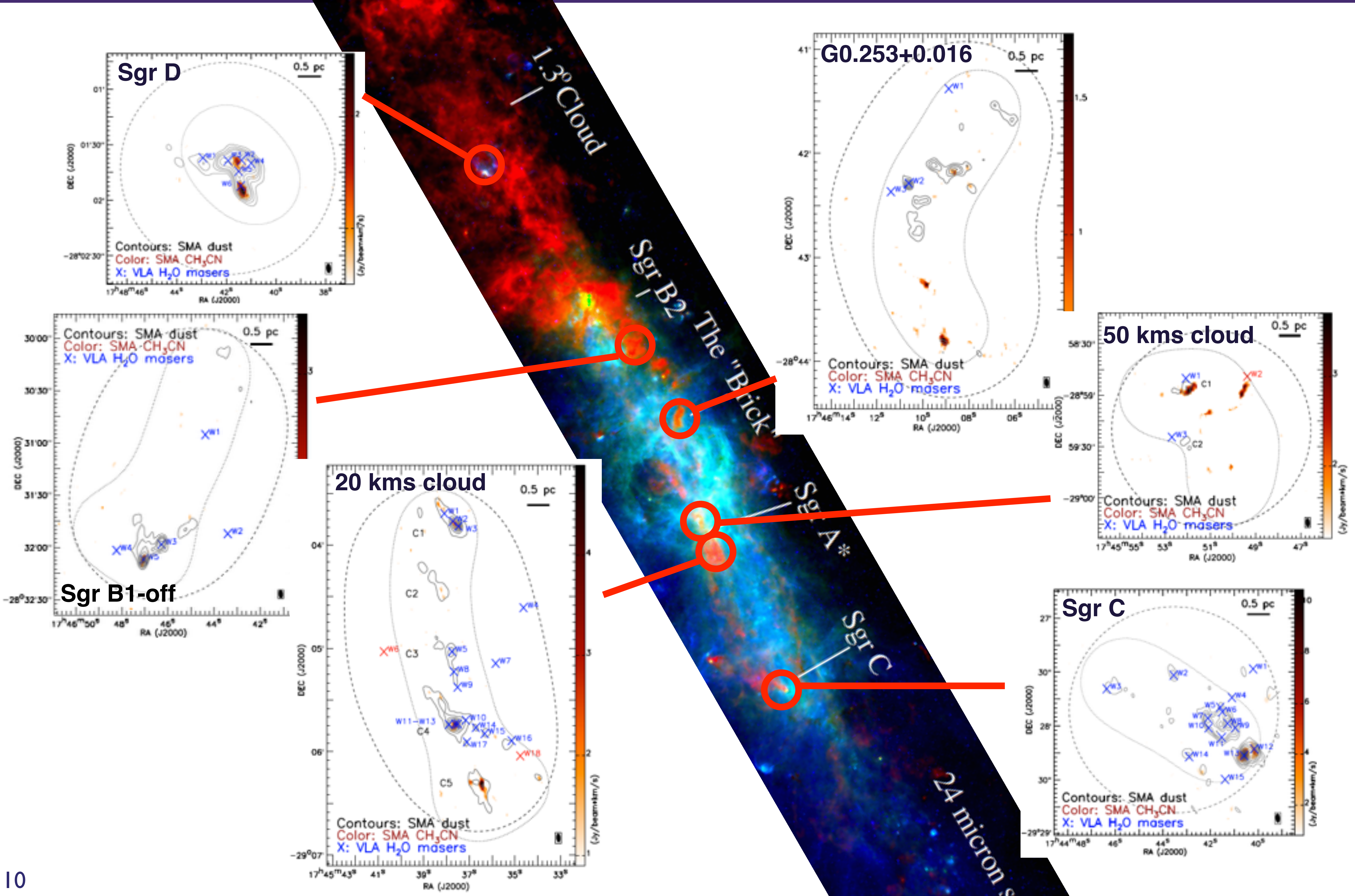
1. Dense cores traced by dust emission.
2. Star formation traced by H_2O masers.
3. Star formation traced by free-free emission.
4. Dense gas environment of dense cores (chemistry, temperature).

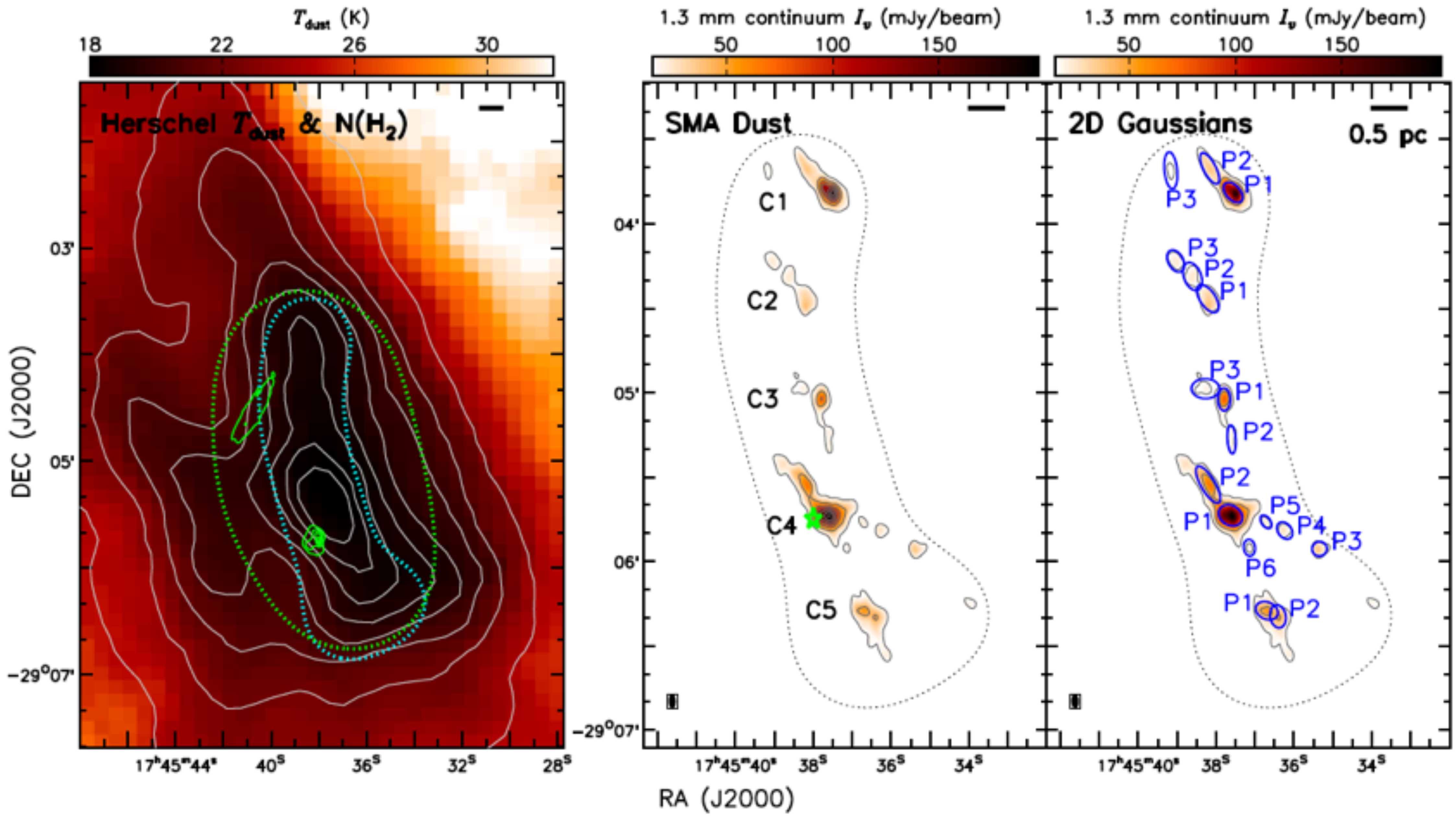
2. Deeply embedded star formation



3. Star formation in the 20 km/s cloud

SMA dust emission ➤

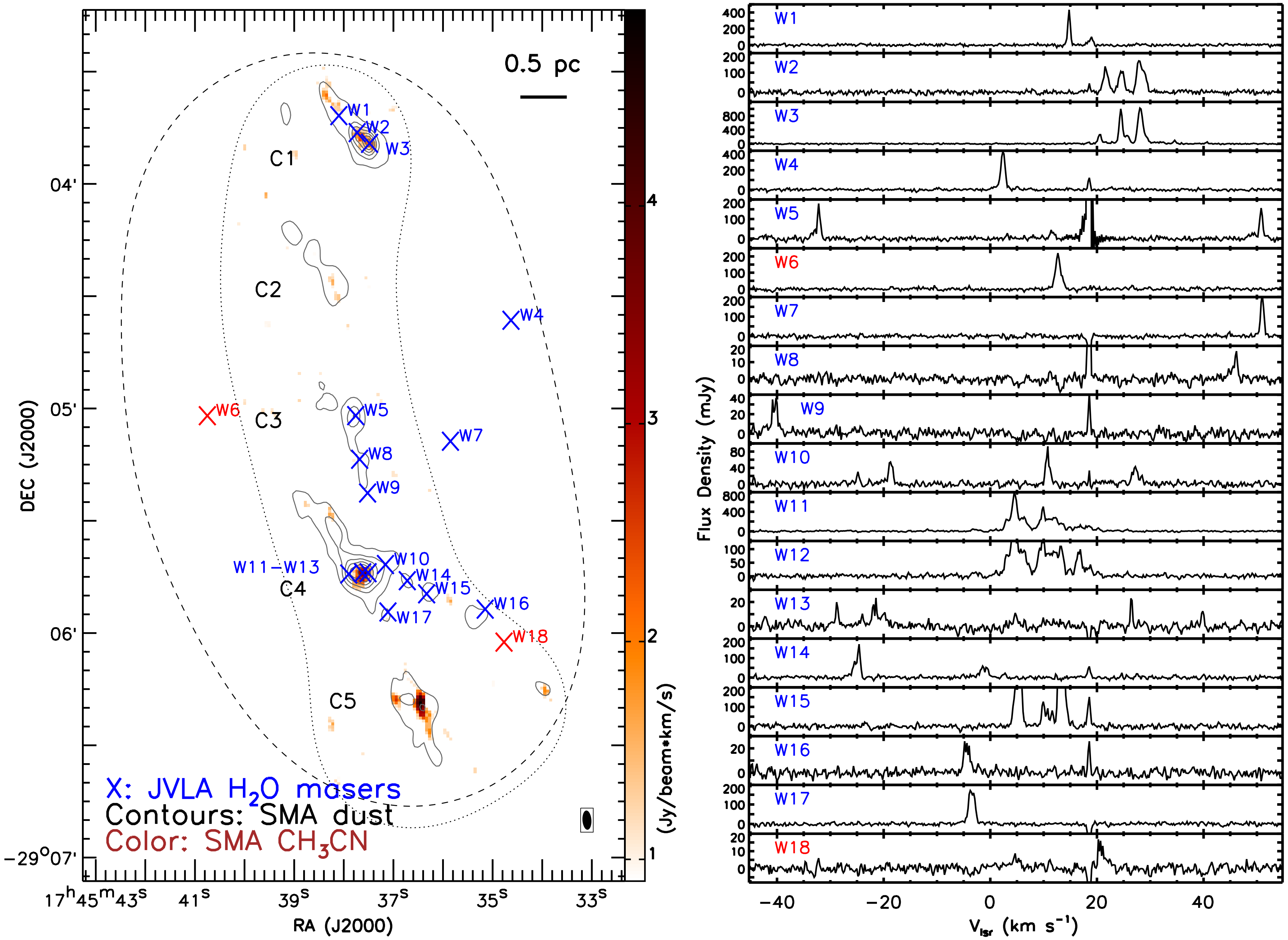
- 12 gravitationally bound dense cores (Lu et al. 2015).



3. Star formation in the 20 km/s cloud

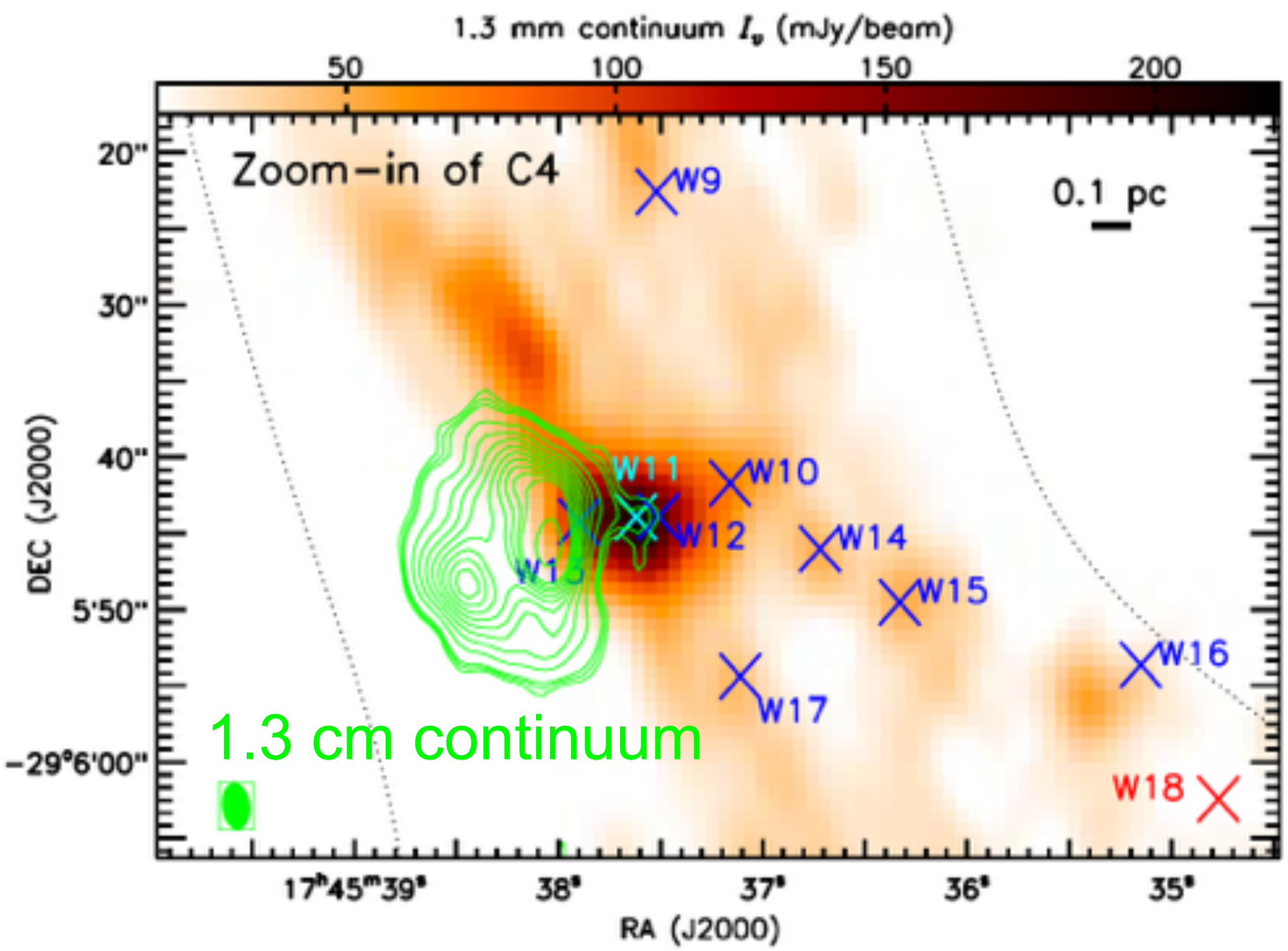
VLA H_2O masers ➤

- 16 H_2O masers without known AGB start counterparts (Lu et al. 2015).



3. Star formation in the 20 km/s cloud

VLA 1.3 cm continuum ➤
- An ultra(hyper)-compact HII region (Lu et al. 2017).



Ionizing photo rate = 1.1×10^{46} s^{-1}
➤ a B0.5 star

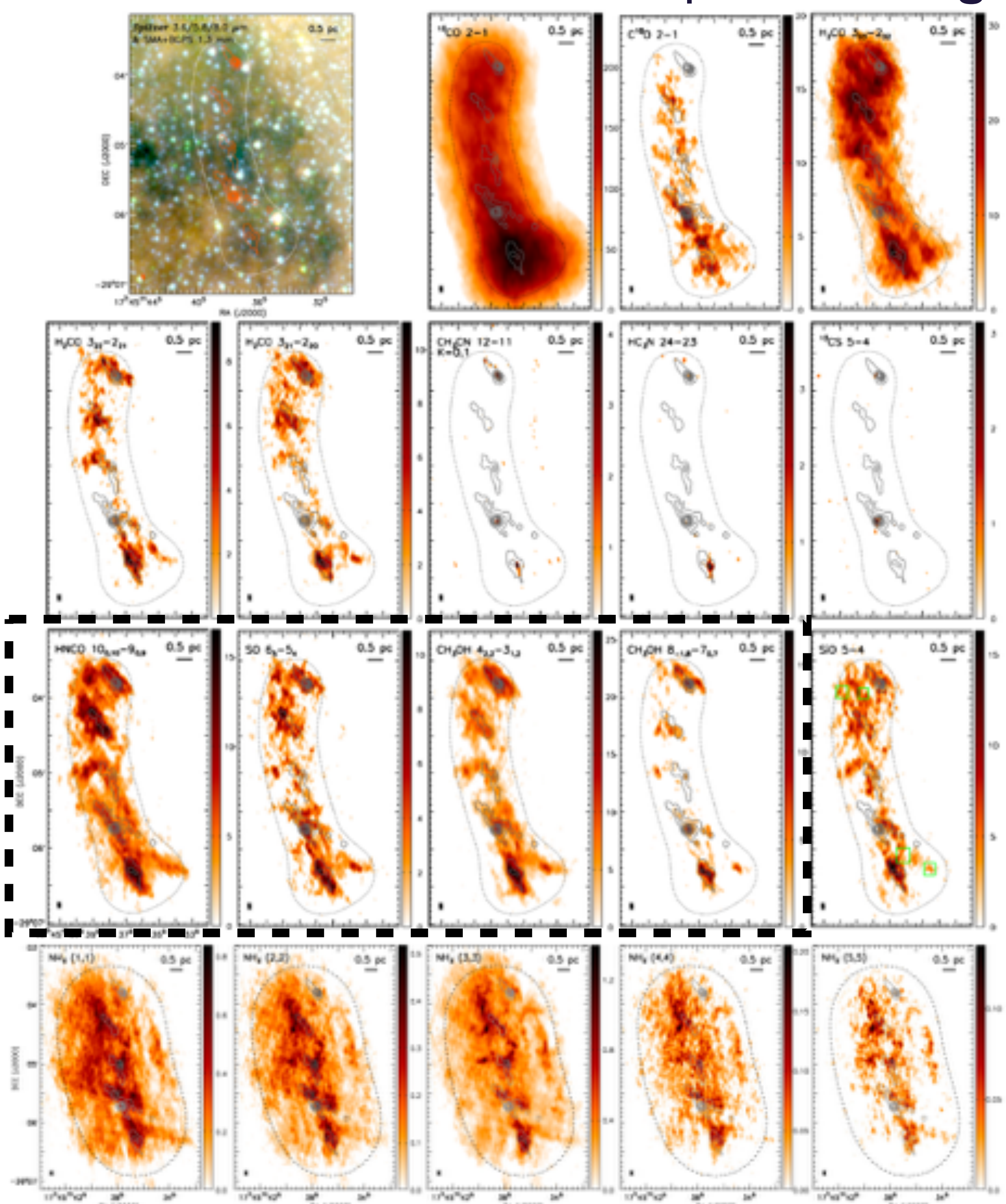
3. Star formation in the 20 km/s cloud

SMA/VLA molecular lines ➤

- Star formation has an impact on the **gas chemistry** (Lu et al. 2017).

SMA+CSO/APEX
1.3 mm lines

JVLA+GBT
NH_3 lines

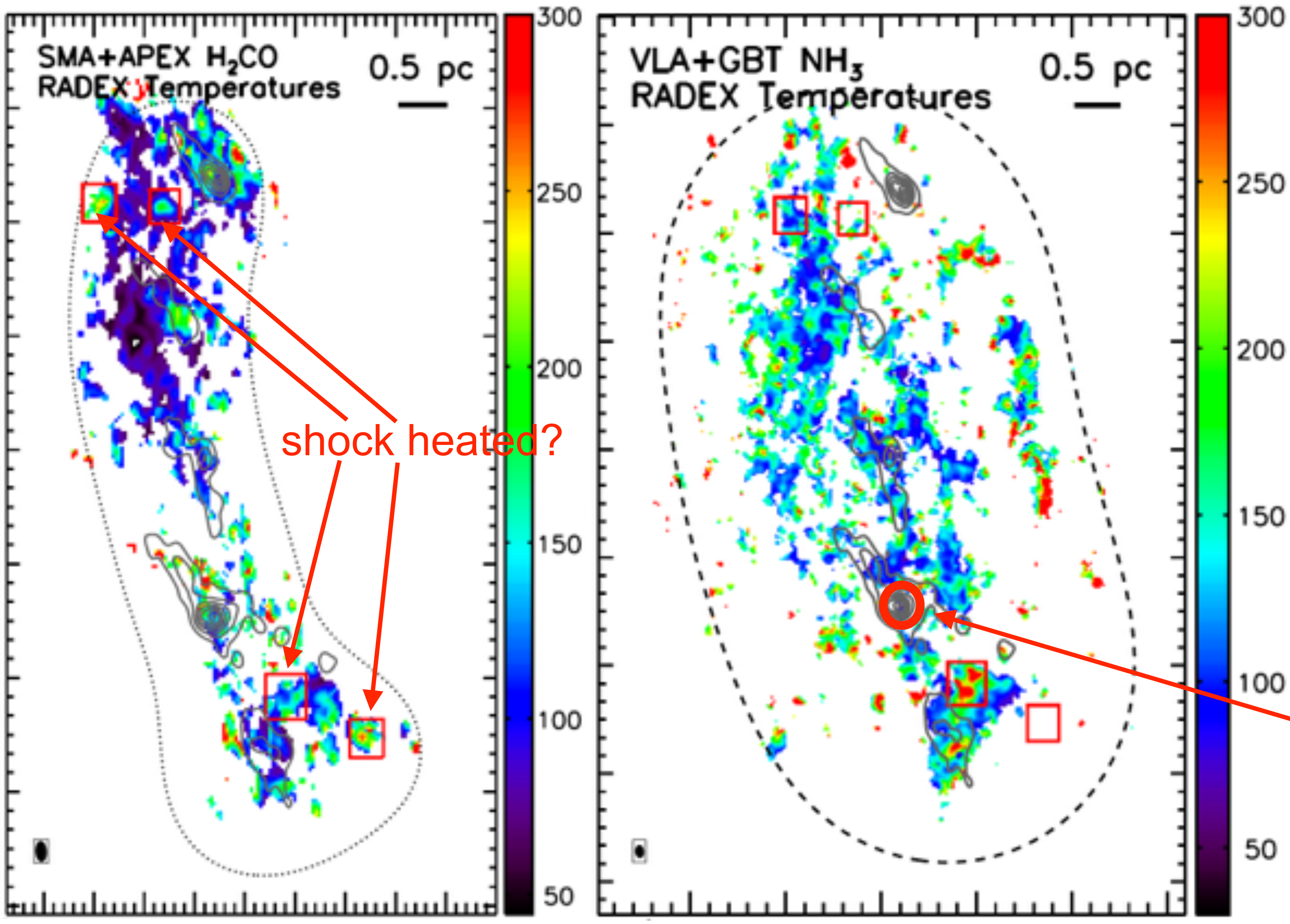


CH_3OH/SO/HNCO are spatially correlated with dust emission (2D cross-correlation ≳ 0.5)
➤ Star-formation-induced enhancement?

3. Star formation in the 20 km/s cloud

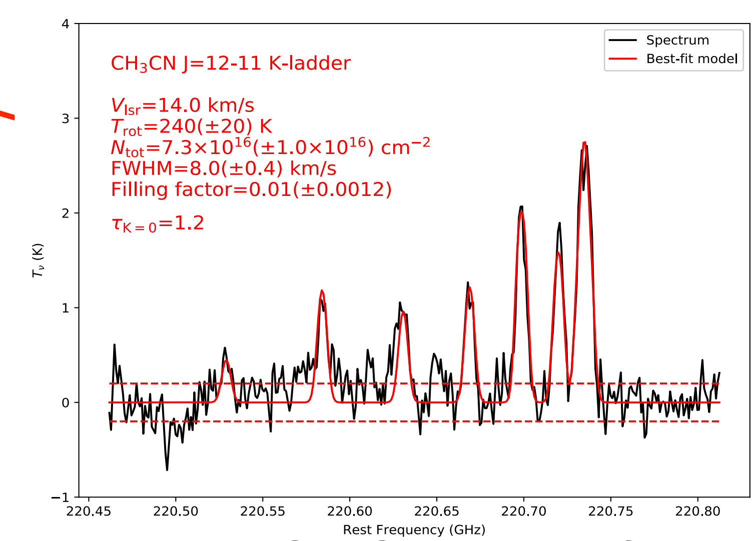
SMA/VLA molecular lines ➤

- Star formation has an impact on the **gas temperatures** (Lu et al. 2017).



At 0.1-pc scale, both **star formation** and **shocks** are important.

T(CH_3CN) = 240 K
T(H_2CO) = 120 K
T(NH_3) = 70 K



ALMA CH_3CN spectra fitting

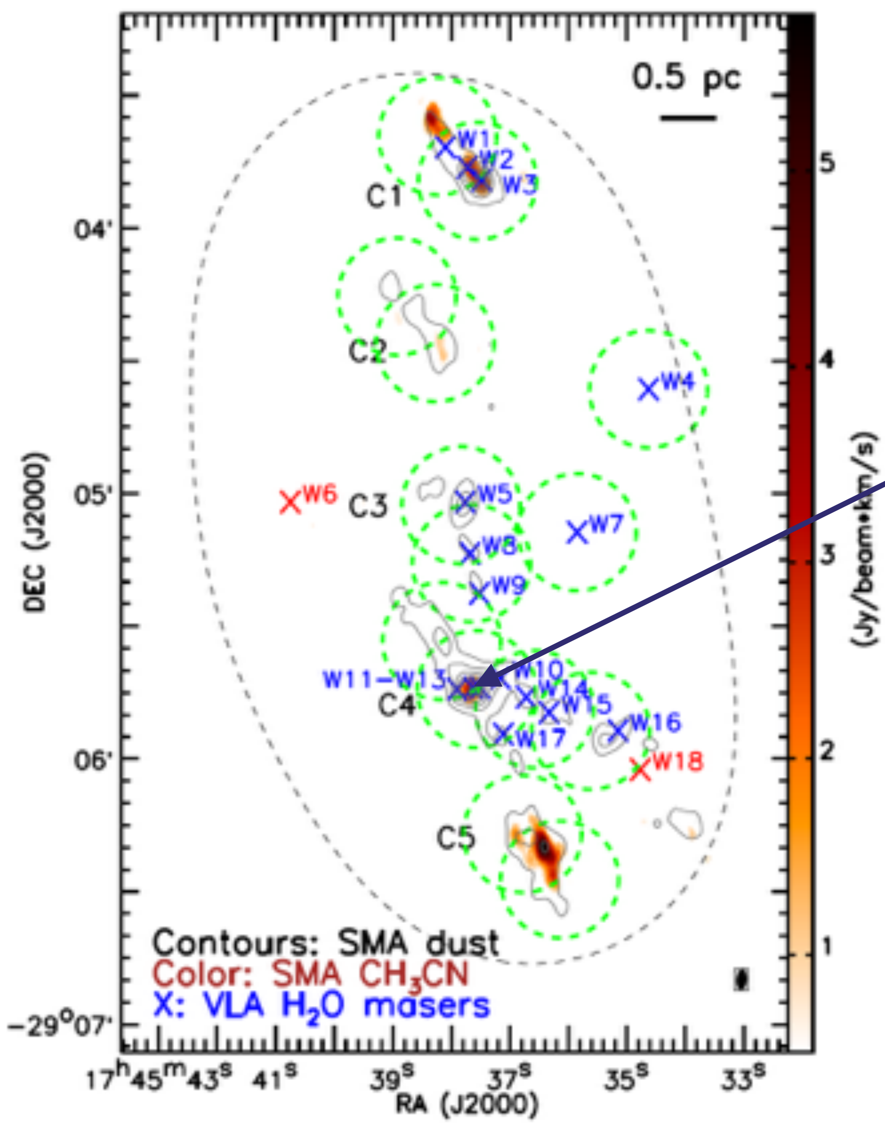
3. Star formation in the 20 km/s cloud

Conclusions

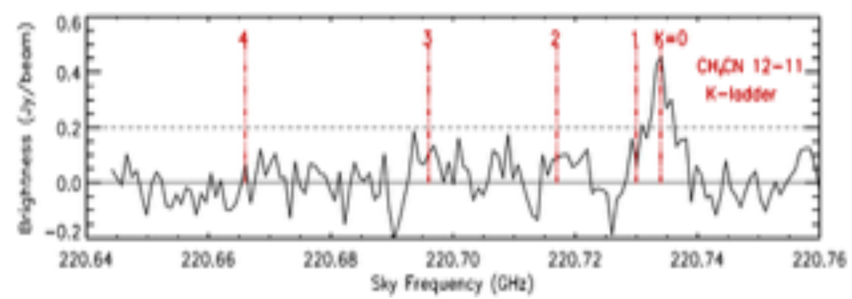
- In the 20 km/s cloud, dense cores, H_2O masers, UCHII regions, internal heating, chemical enhancement, all point to **more active star formation** missed by previous observations.
- The six clouds are in three states: Sgr B1_off and G0.253+0.016 are quiescent; the 20 km/s cloud and Sgr C are actively forming stars; the 50 km/s cloud and Sgr D are dominated by HII regions.
- **If these protostellar candidates were all high-mass (M > 8 $M_\odot$) protostars, the SFR of the star-forming clouds would become consistent with SF relations.**
  (e.g., for 20kms: ~0.8×10^{-2} $M_\odot$/yr vs. 1.4×10^{-2} $M_\odot$/yr)

4. JVLA+ALMA followups

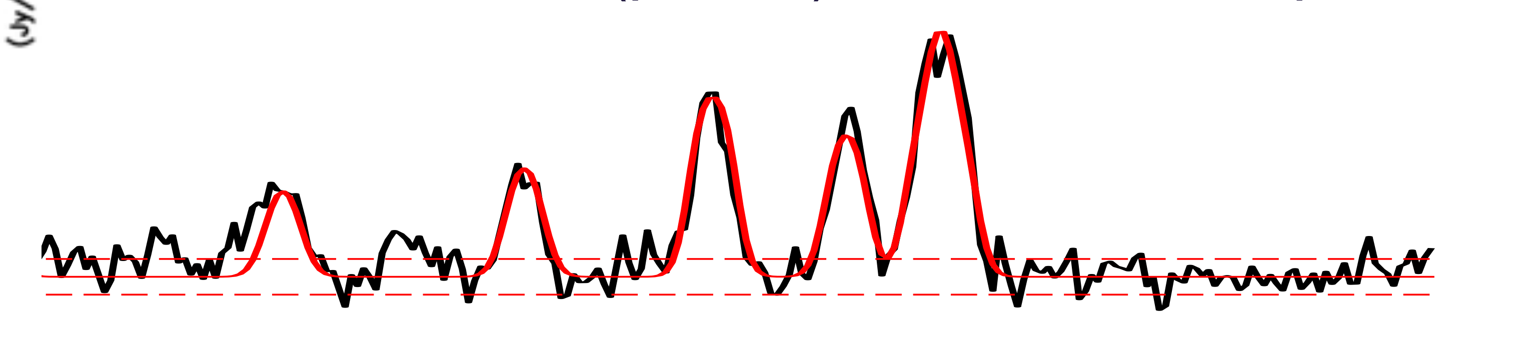
- ALMA cycle 4 project: pointed observations of protostellar candidates found by the SMA/JVLA in four clouds.
- The key objective is to confirm existence of hot cores using CH_3CN lines.



SMA CH_3CN spectra

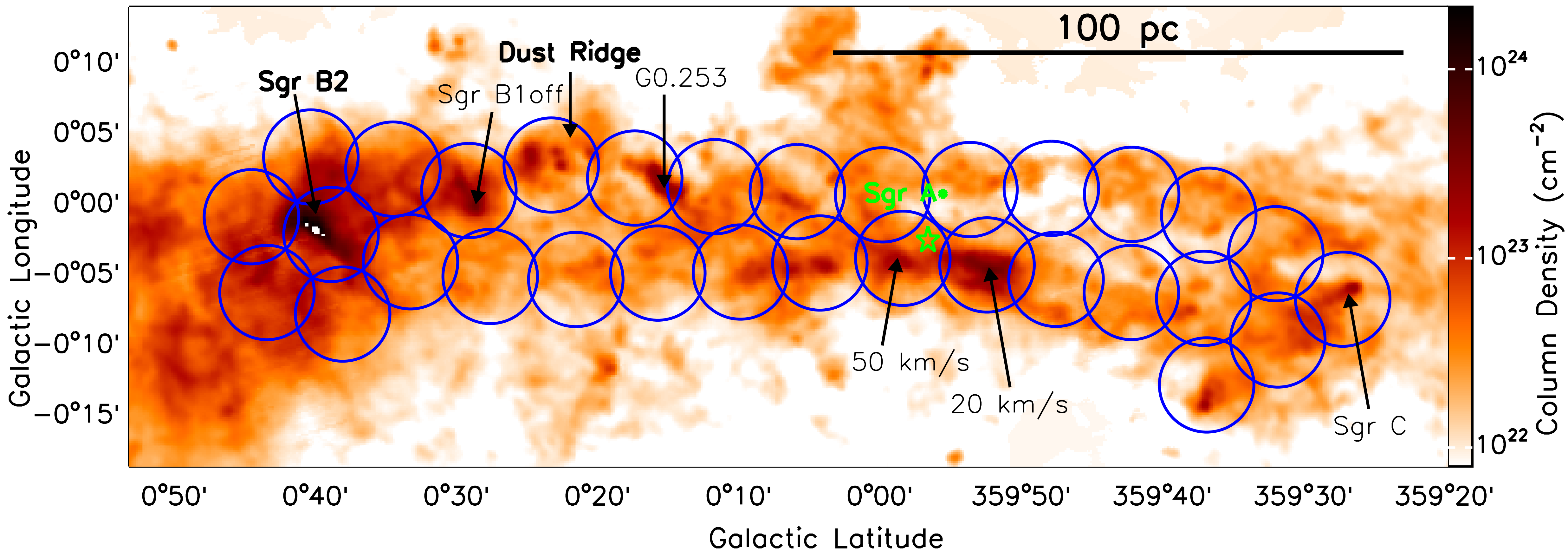


(part of) ALMA CH_3CN spectra



4. JVLA+ALMA followups

- JVLA C-band (6.7 GHz CH_3OH maser, RRL, 6 cm continuum) survey, to confirm high-mass star formation.
  (data delivered, analysis underway)



Thanks!