High-mass star formation in the Central Molecular Zone

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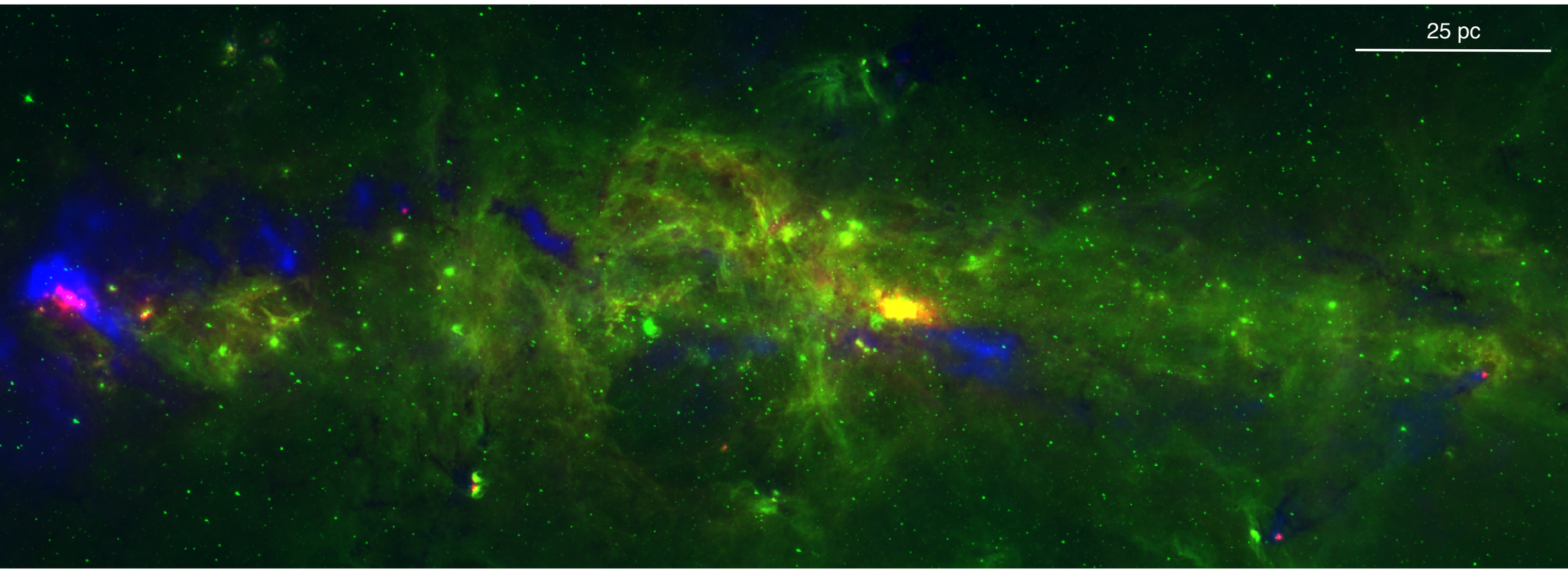
NAOJ / ALMA Fellow

Steve Longmore, Qizhou Zhang, Cara Battersby, Adam Ginsburg, Jonny Henshaw, Ashley Barnes, Diederik Kruijssen, Jens Kauffmann, Xing Lu, Betsy Mills, Thushara Pillai & many more!

Central Molecular Zone (CMZ)

Green — 8 μm (GLIMPSE)
Red — 70 μm (Herschel)
Blue — dust column (HiGAL)



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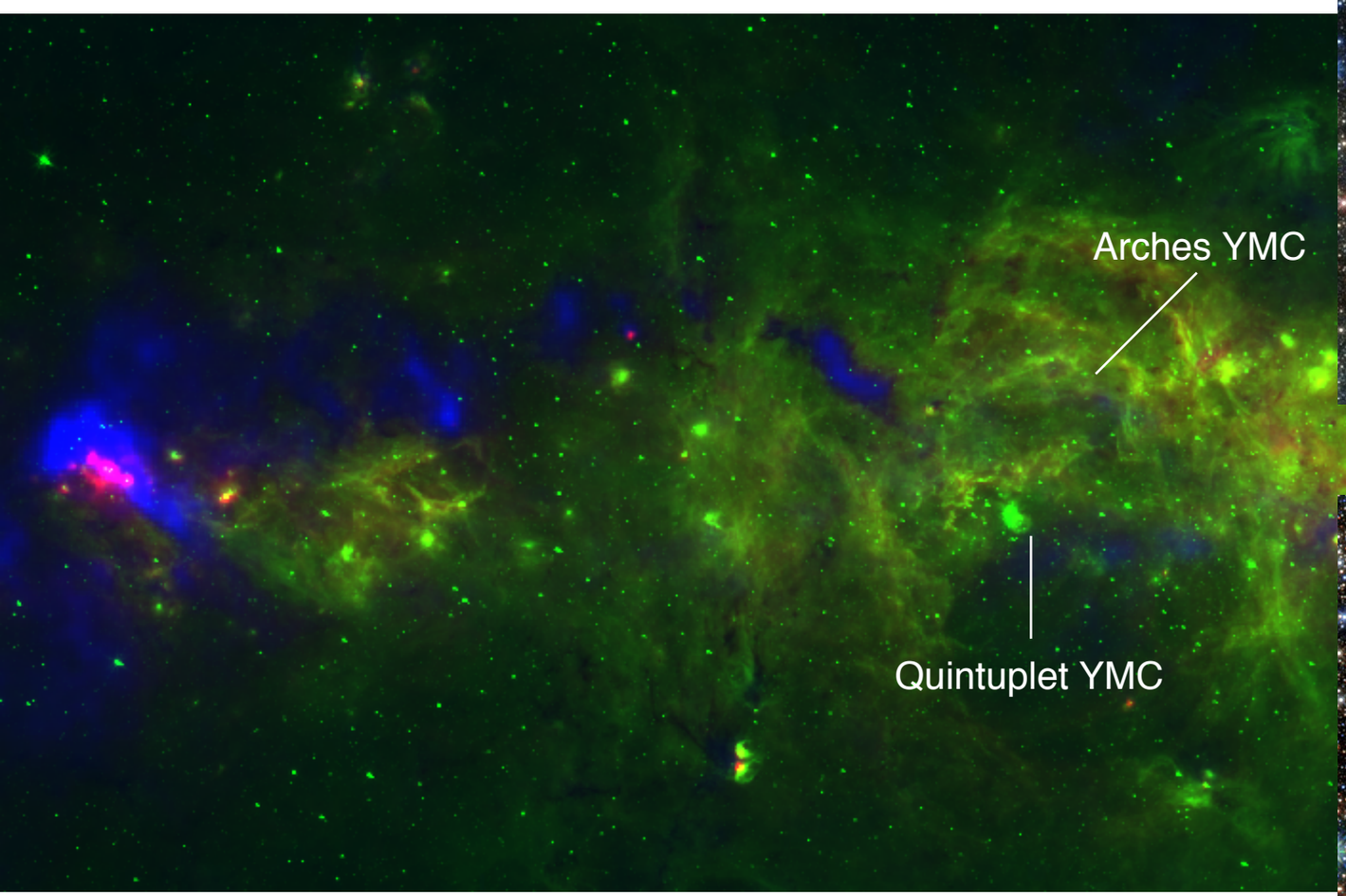

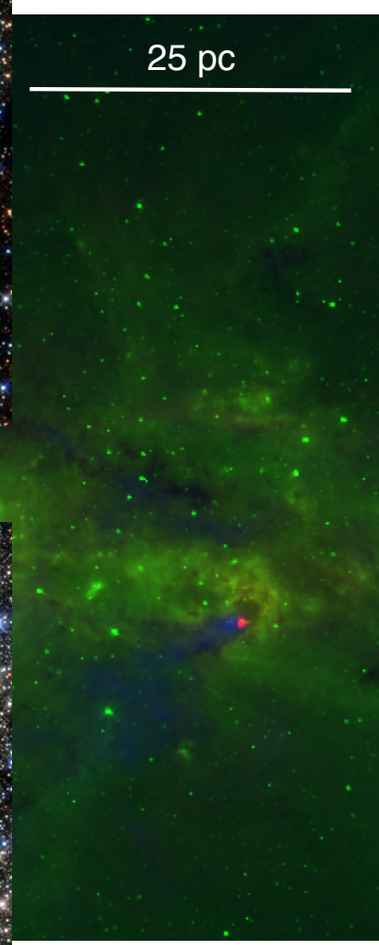

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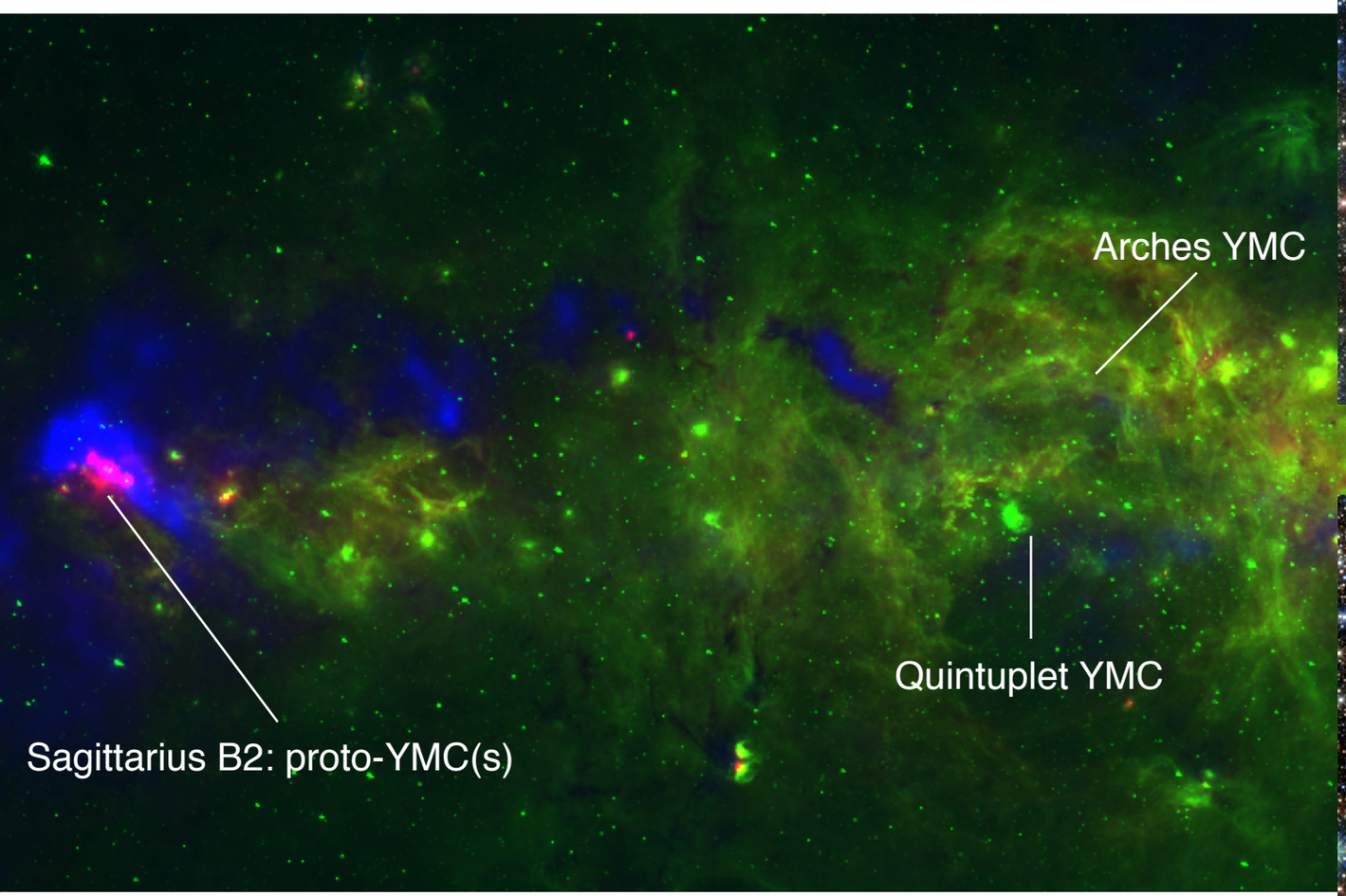

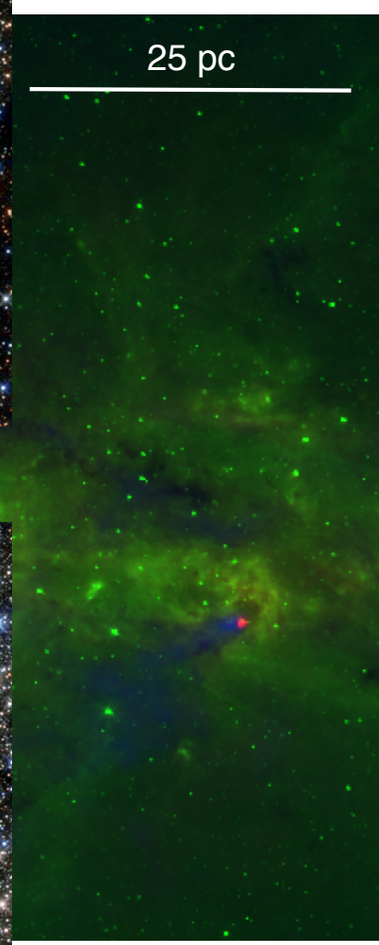

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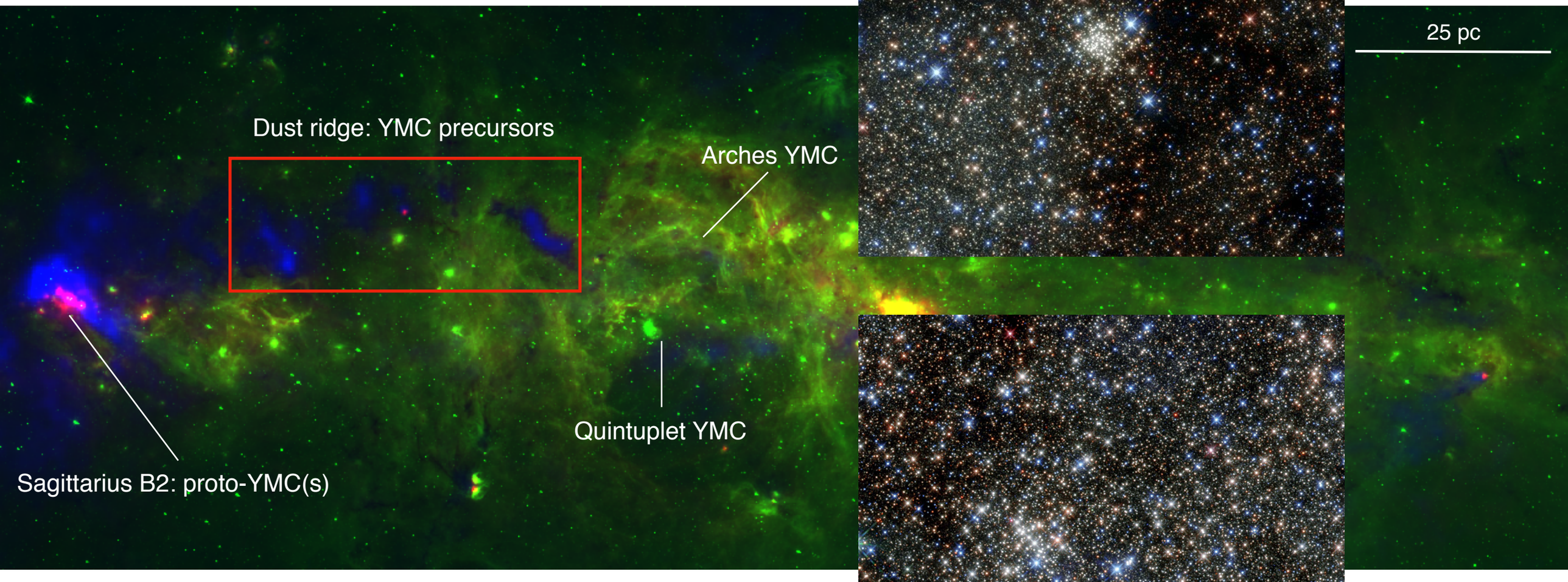

The ‘Dust Ridge’

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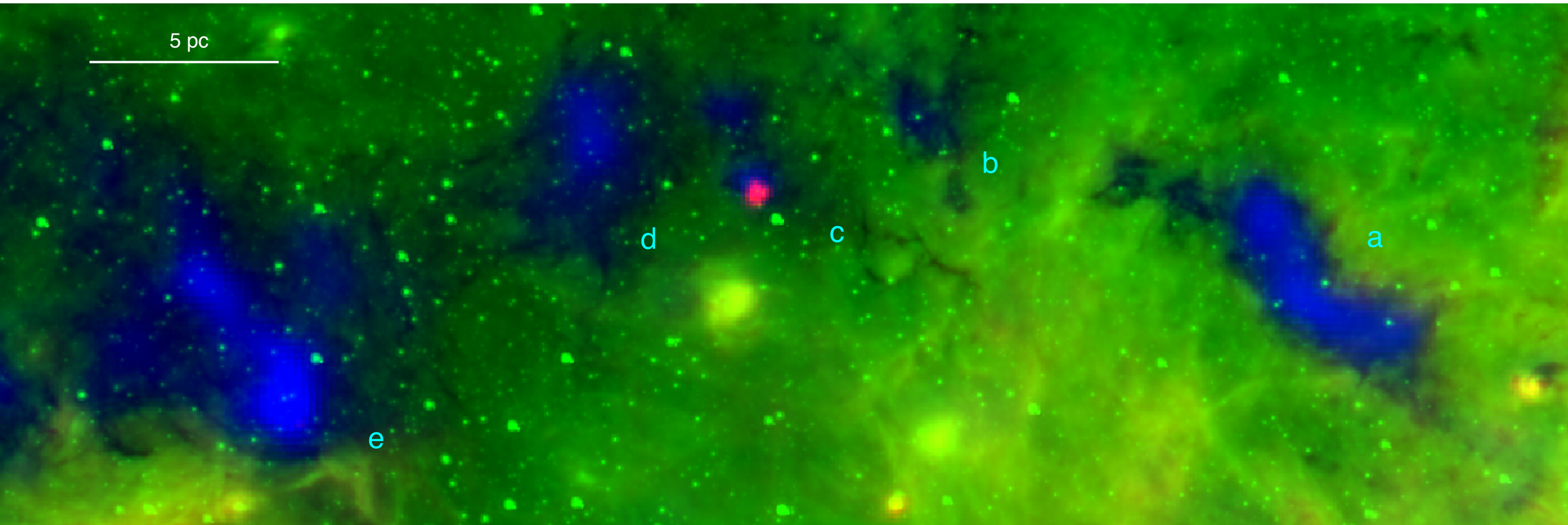
- 6 molecular clouds spanning ~ 0.25 deg (~ 40 pc)
  - M ~ $10^{4\text{-}5}\,M_{\odot}$
  - R ~ 2 - 3 pc
  - No widespread SF

→ Amongst the most massive and compact **quiescent** clouds known to exist in the Galaxy!



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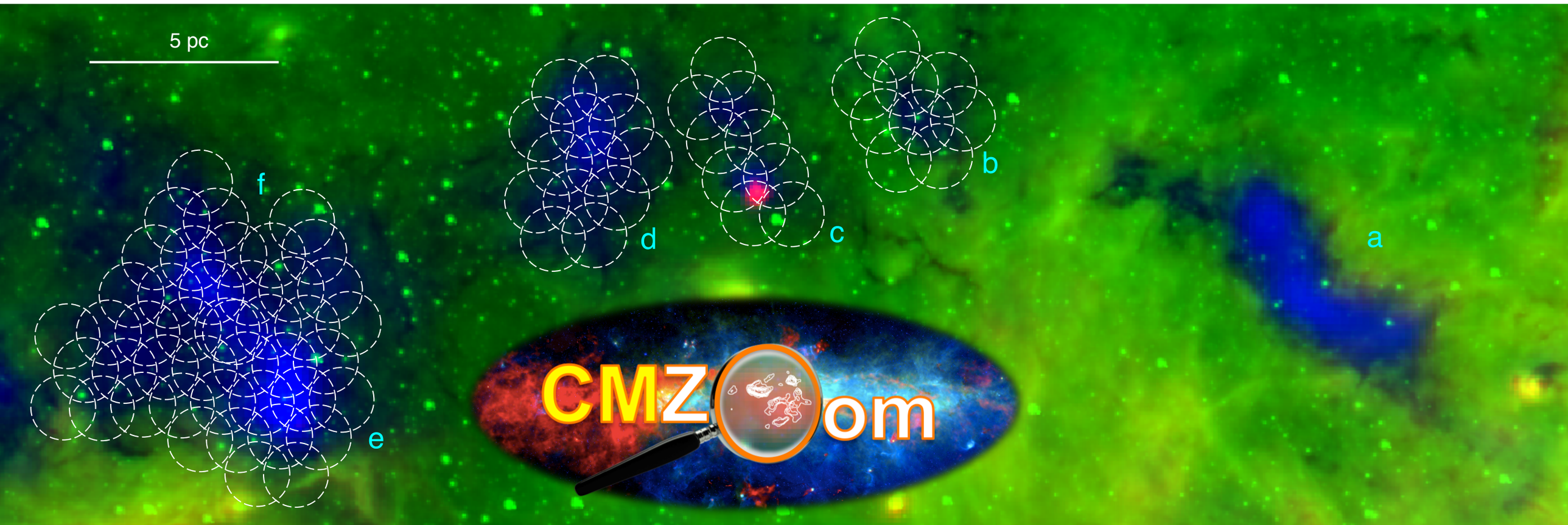

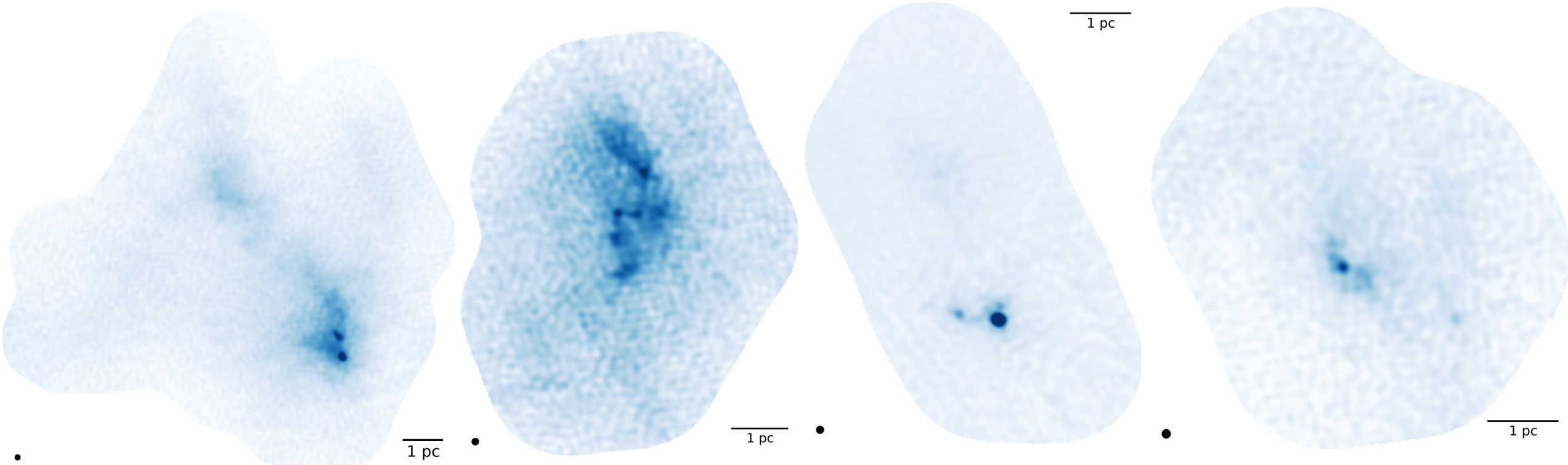

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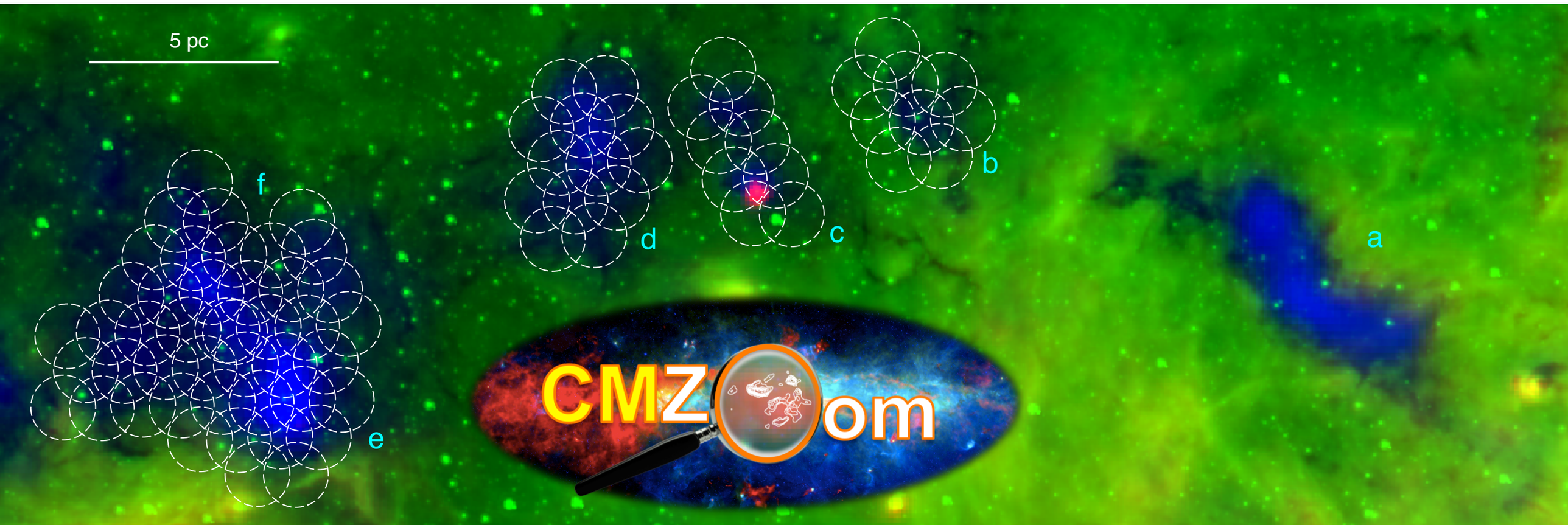
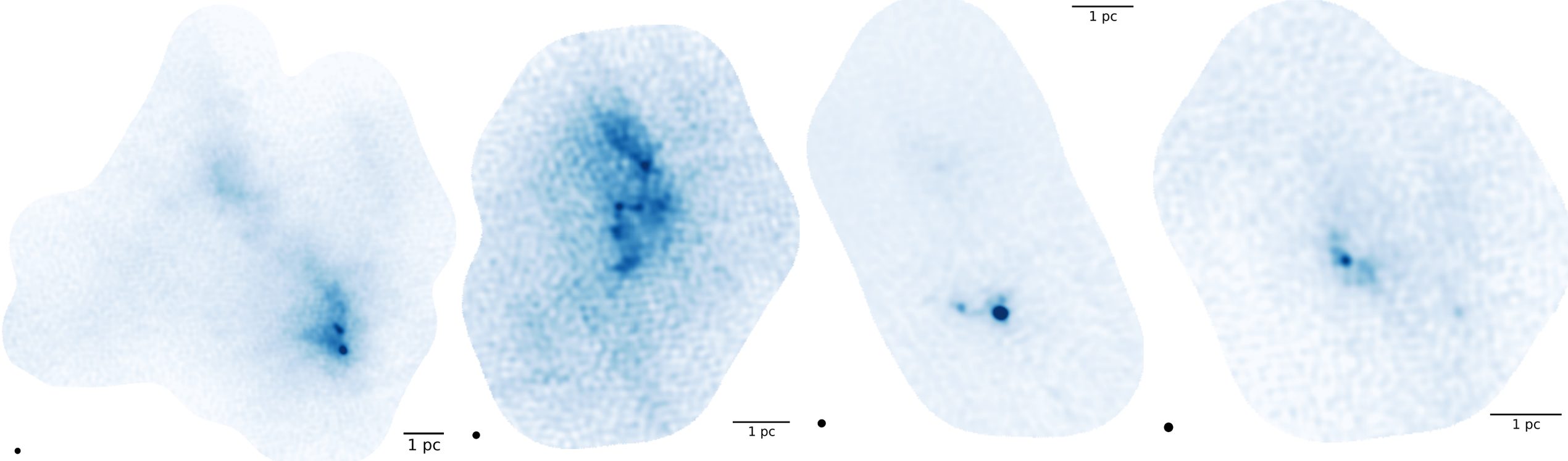
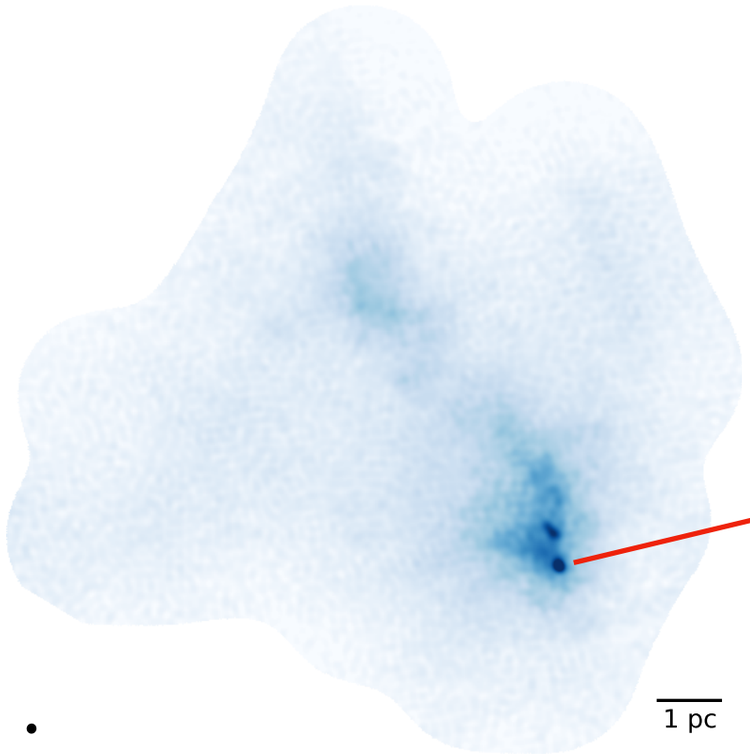
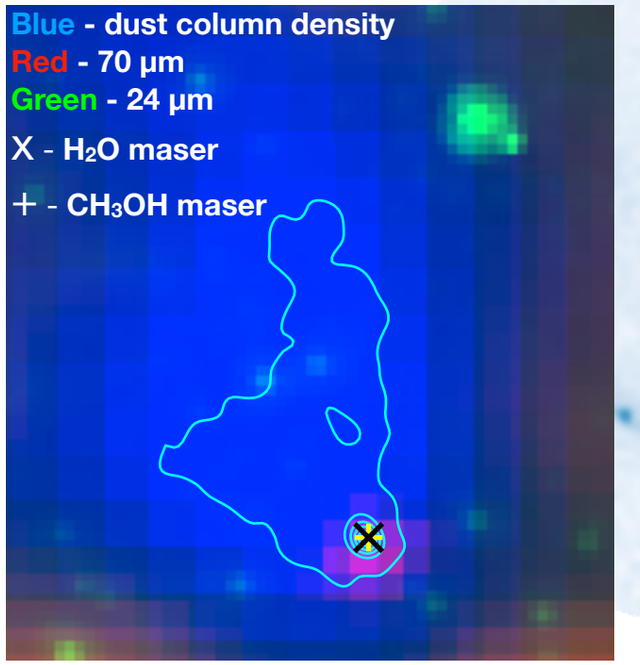


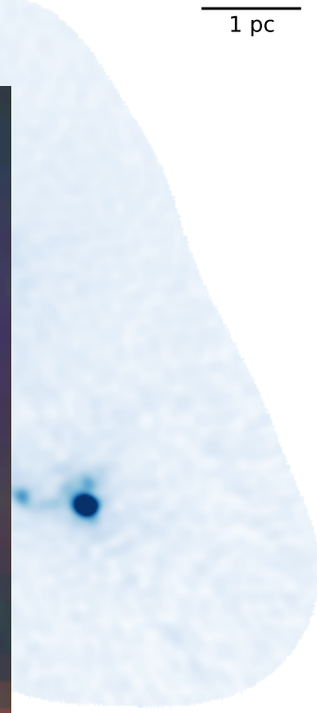


- Detected a robust sample of 15 cores with **R ~ 0.1 - 0.25 pc** and **M ~ 50 - > 1000 $M_\odot$**
- ΔV ~ 5 km/s
  - Majority of cores appear to be super-virial
  - Pressure-bounded equilibrium requires $P/k \sim 10^8$ K cm^{-3}, consistent with measurements in the CMZ
- Only **2** of the **15** cores show signatures of embedded star formation, despite all being **> 10^6 cm^{-3}**
  - *Further evidence for a heightened critical density threshold for SF in the CMZ*

Walker et al. (2018)



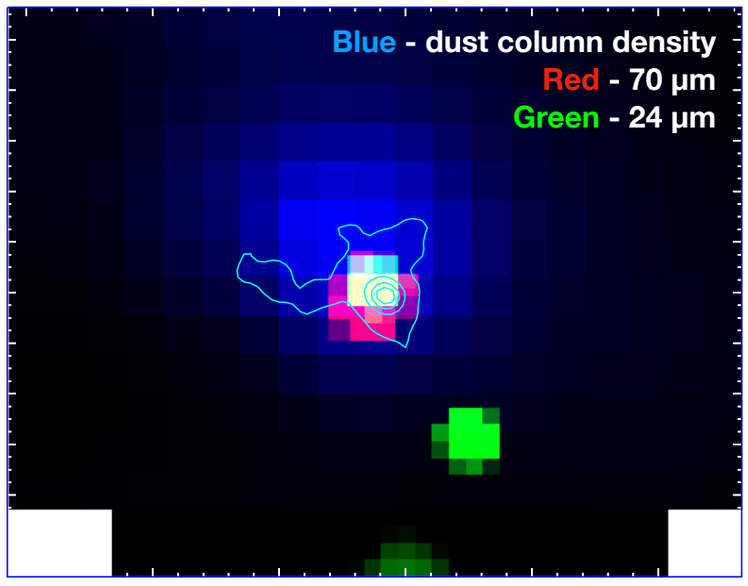


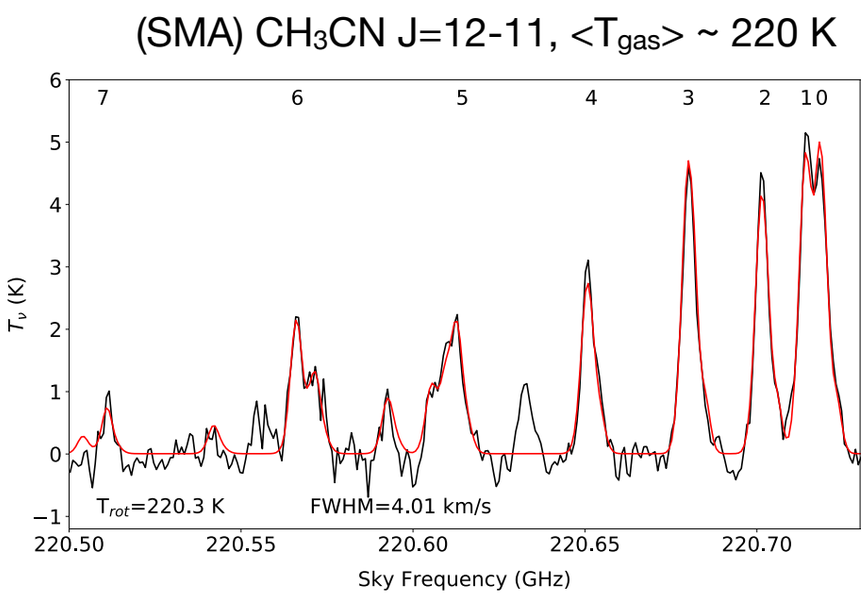


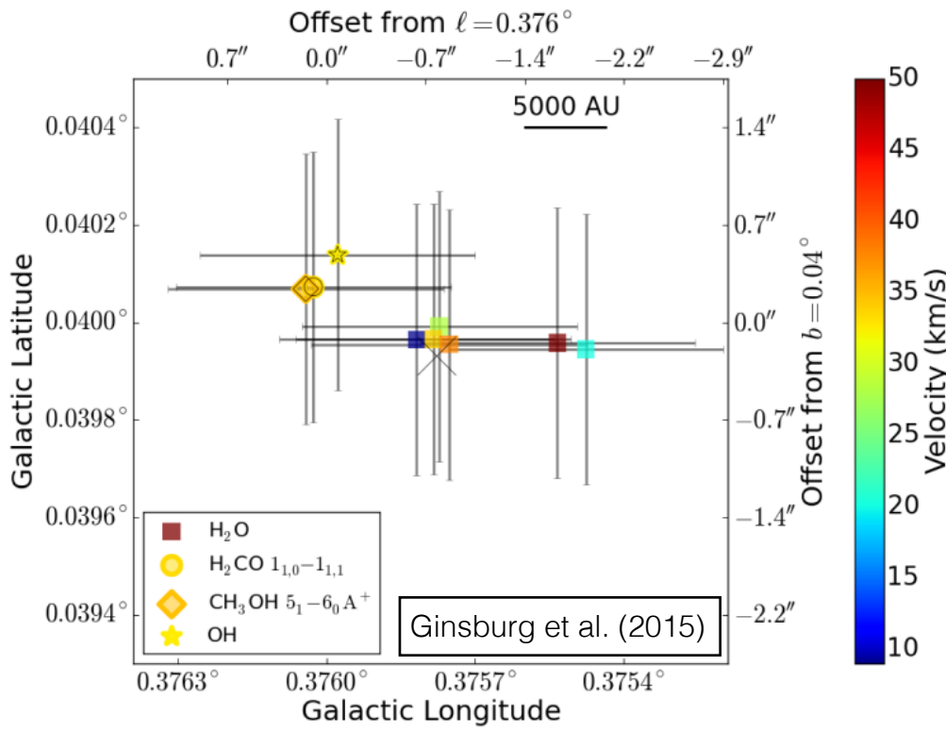
e

c

Two newly discovered high-mass star-forming regions in the dust ridge!







ALMA follow-up observations … but first …

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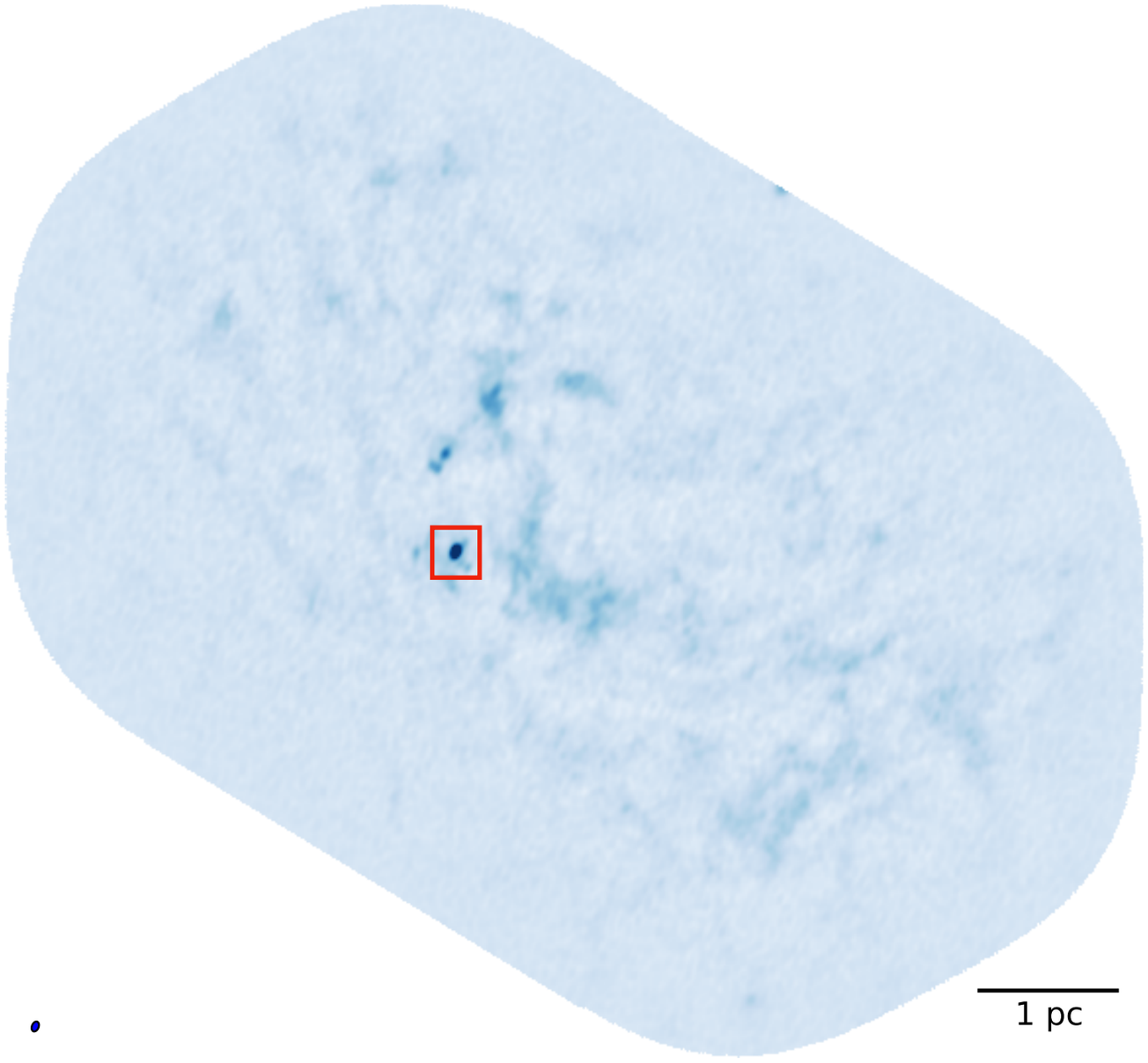
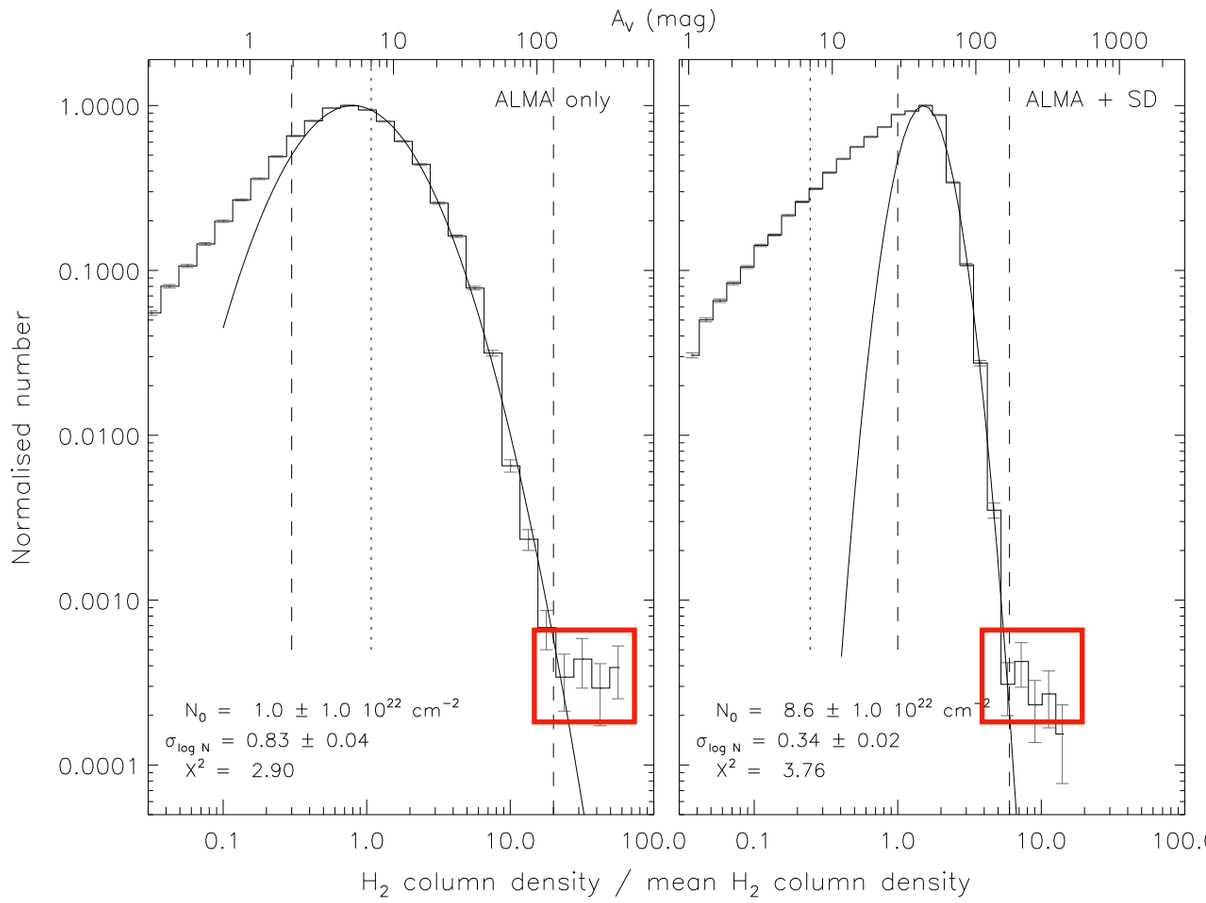
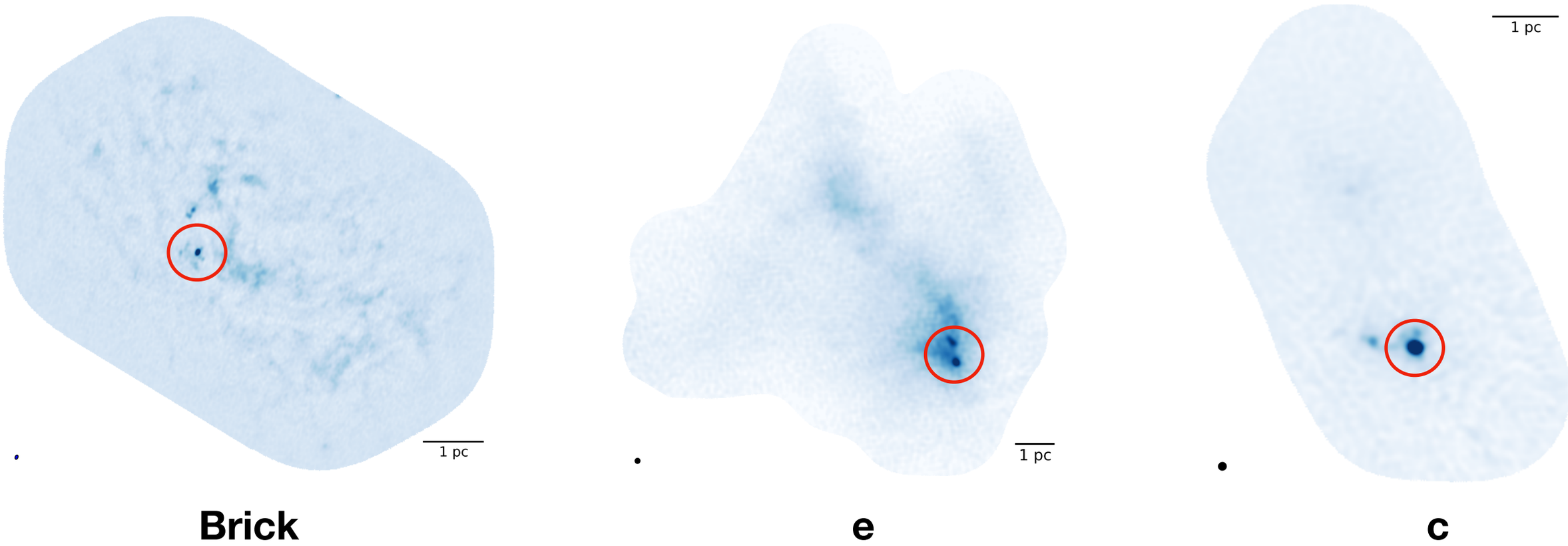




Mass ~ 100 $M_\odot$ and coincides with water maser emission → potential site of (massive) star formation in the Brick

Rathborne et al. (2014)

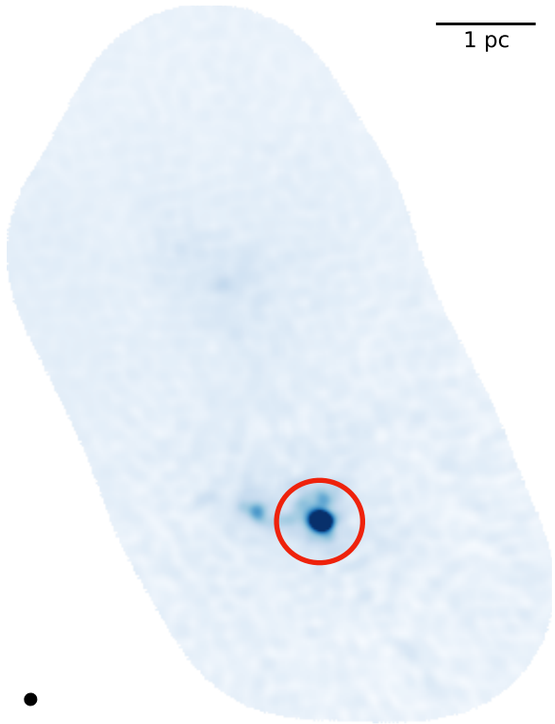
ALMA follow-up observations



- Observed with ALMA in band 6 (~ 230 GHz)
  - Angular resolution ~ 0.13′′ (1000 AU)
  - Velocity resolution ~ 0.7 km/s, targeting CH_3CN, SiO, H_2CO, ^{13}CO & many more

- Also observed dust ridge cloud **c** in band 3 at ~ 0.07′′ (600 AU)

ALMA follow-up observations — dust ridge cloud C



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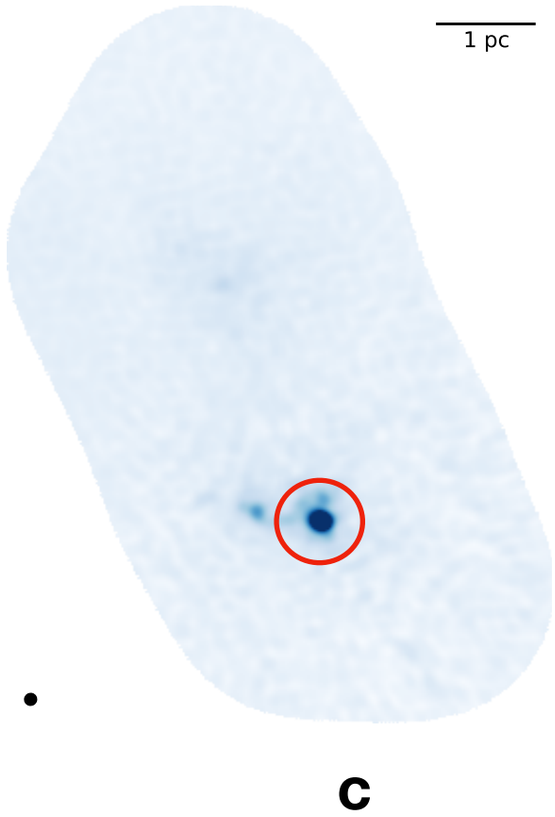

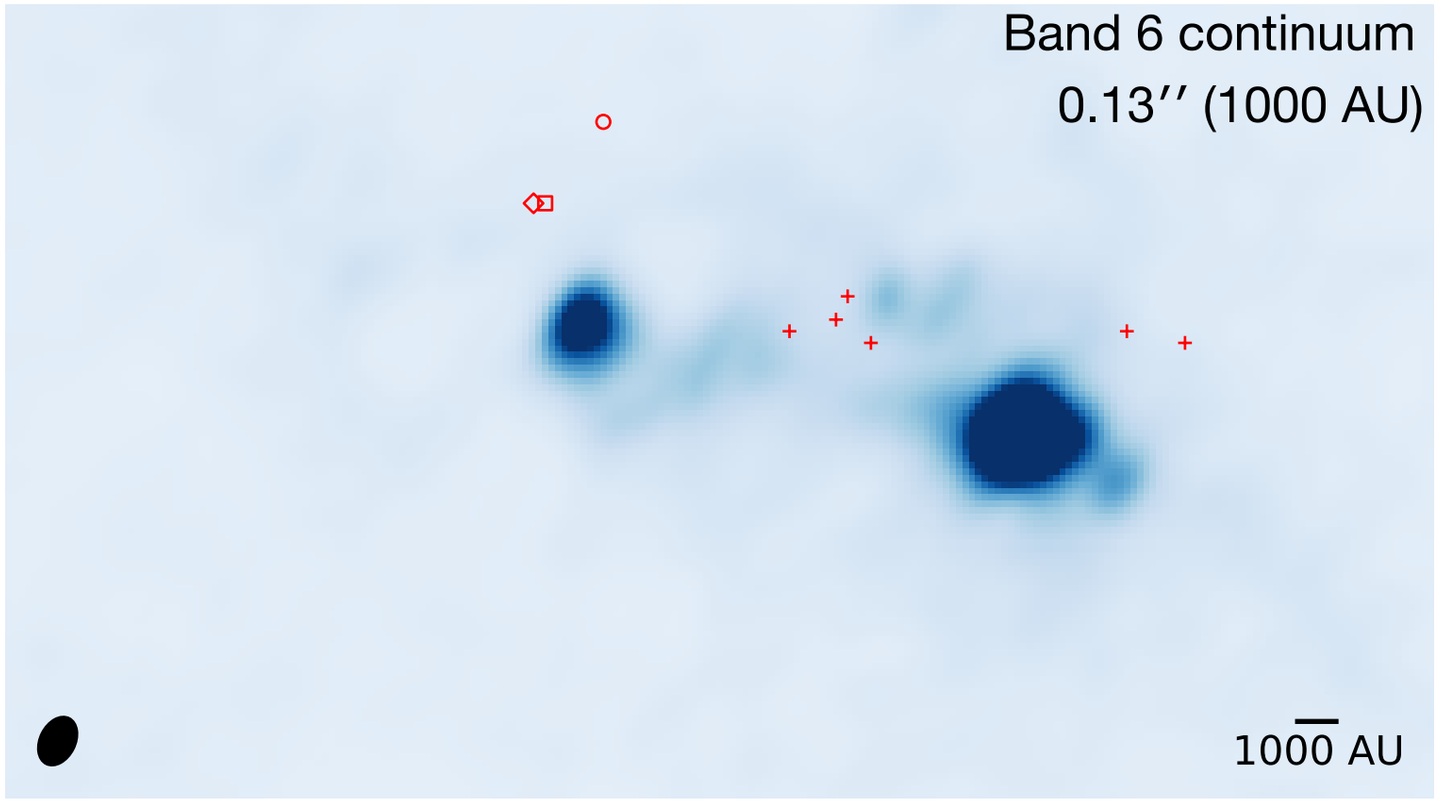

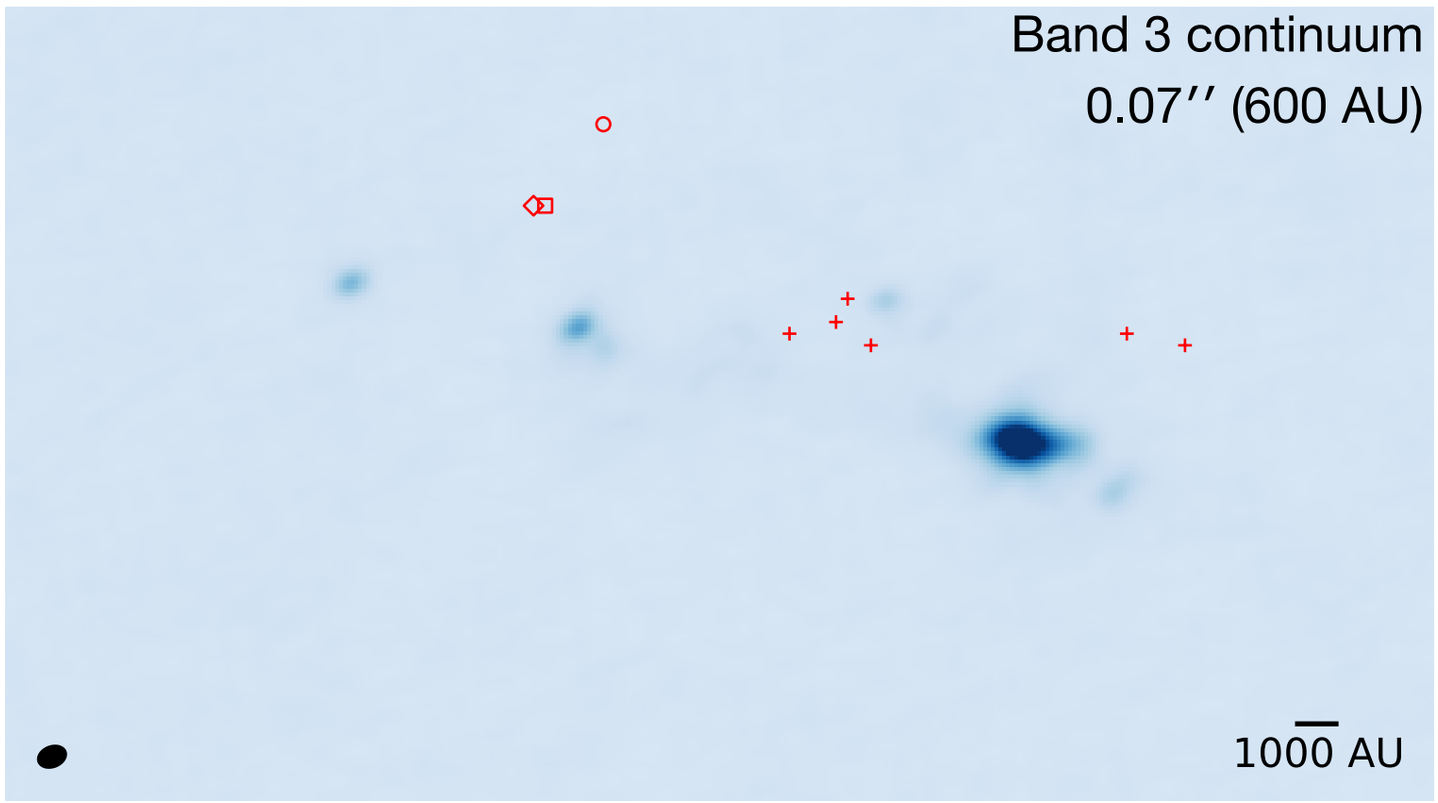

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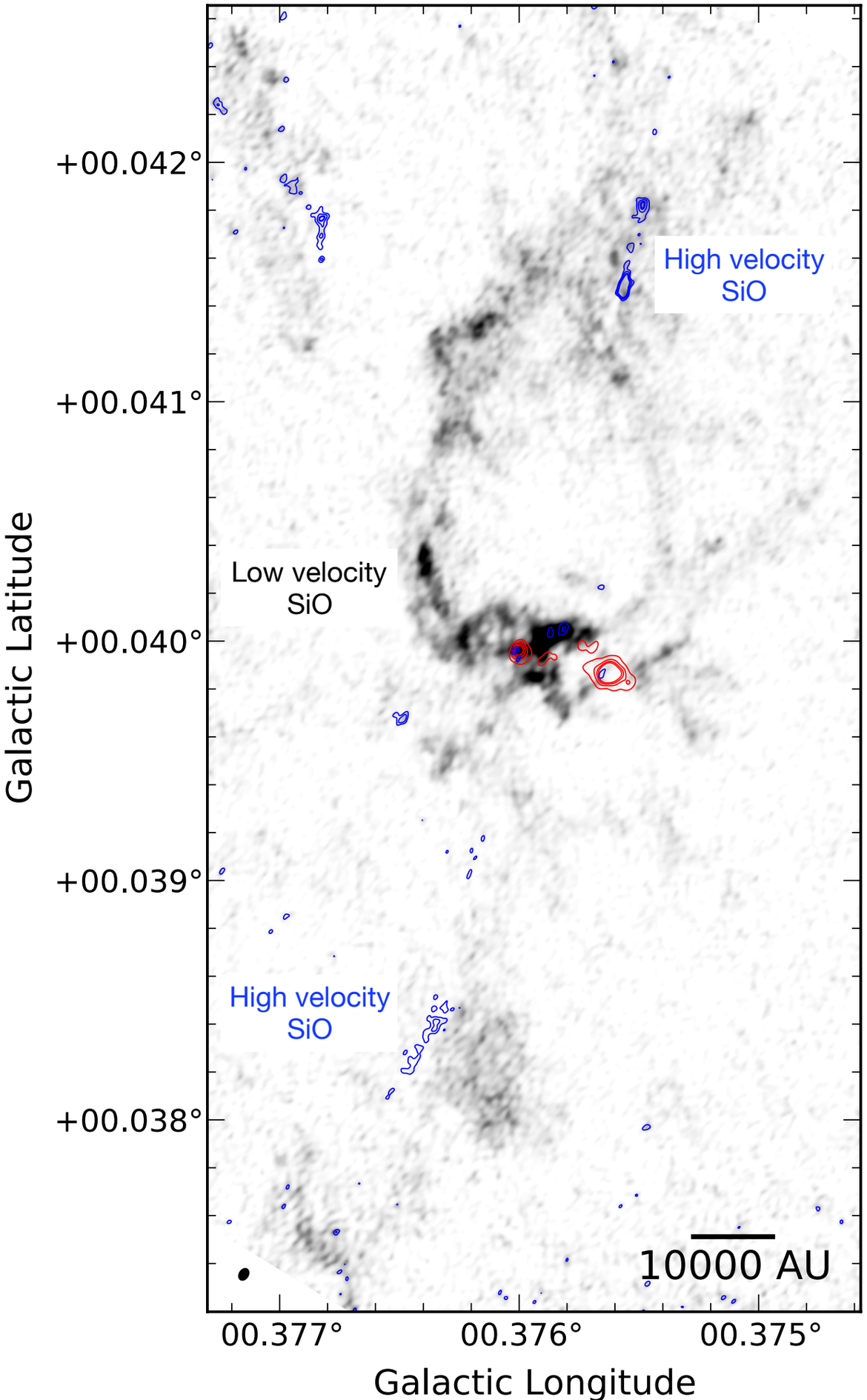
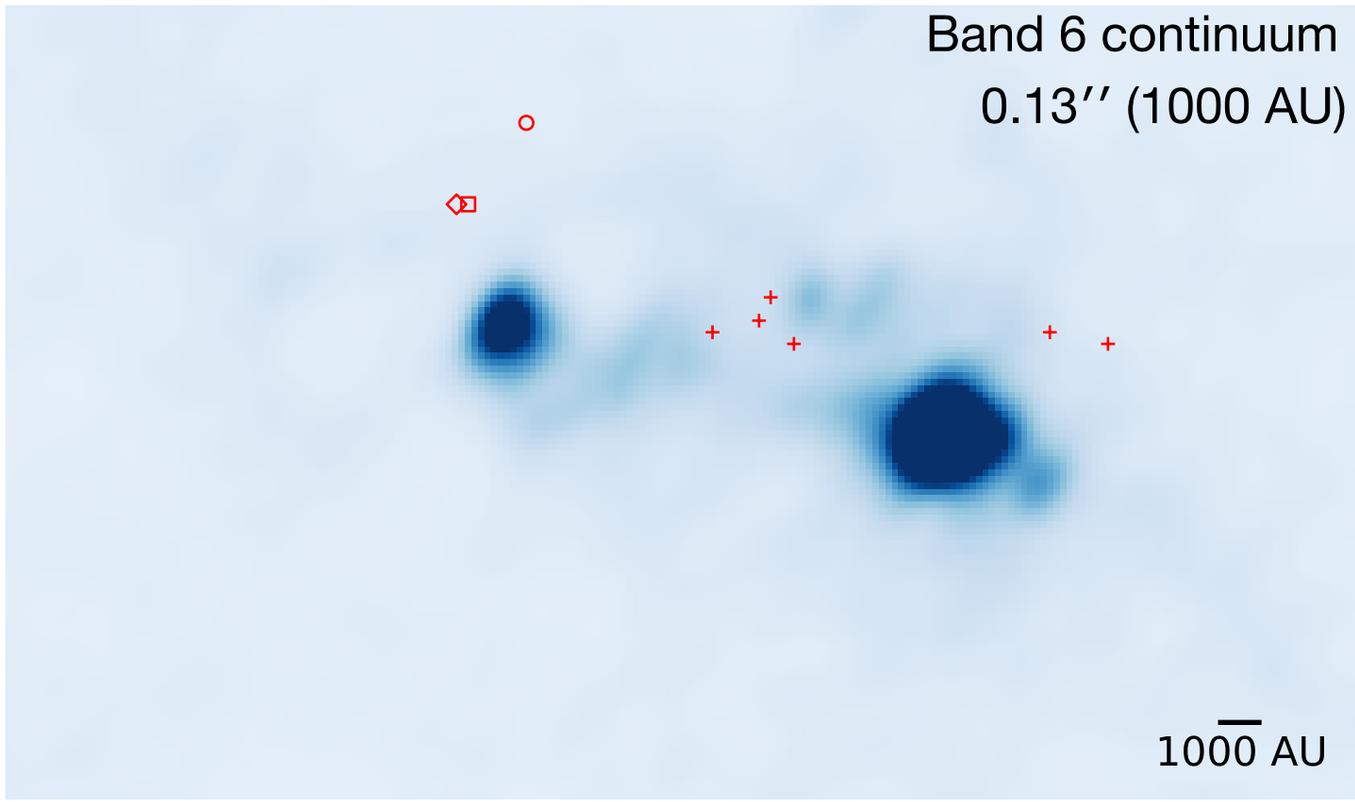
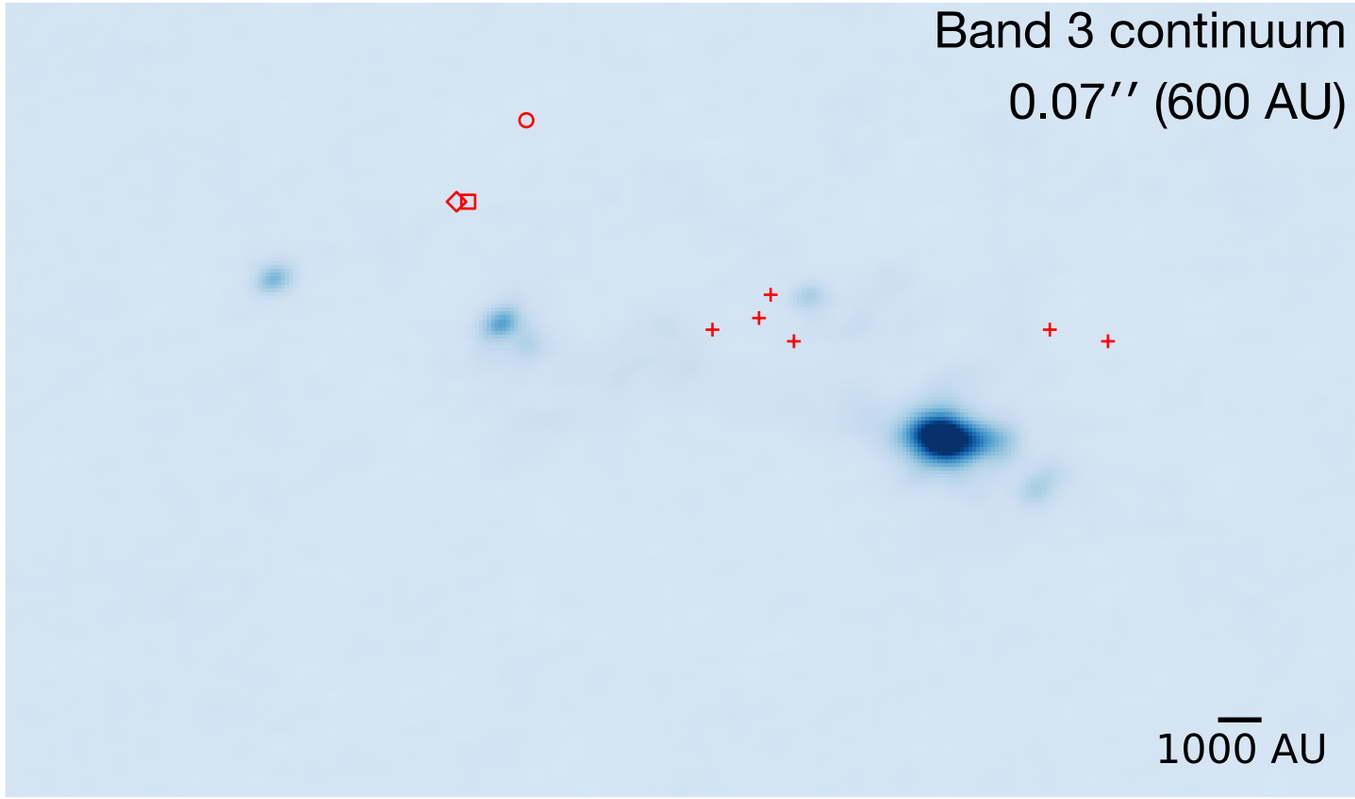
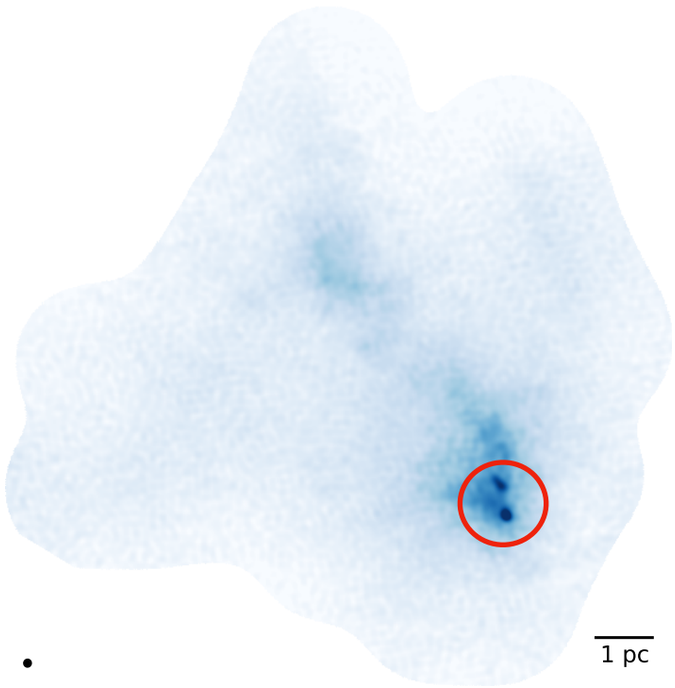






ALMA follow-up observations — dust ridge cloud E



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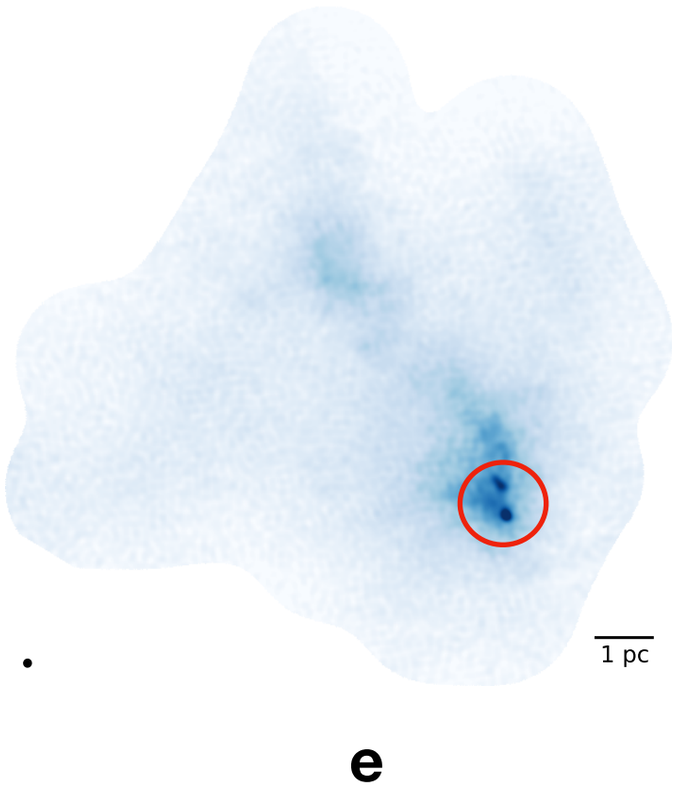

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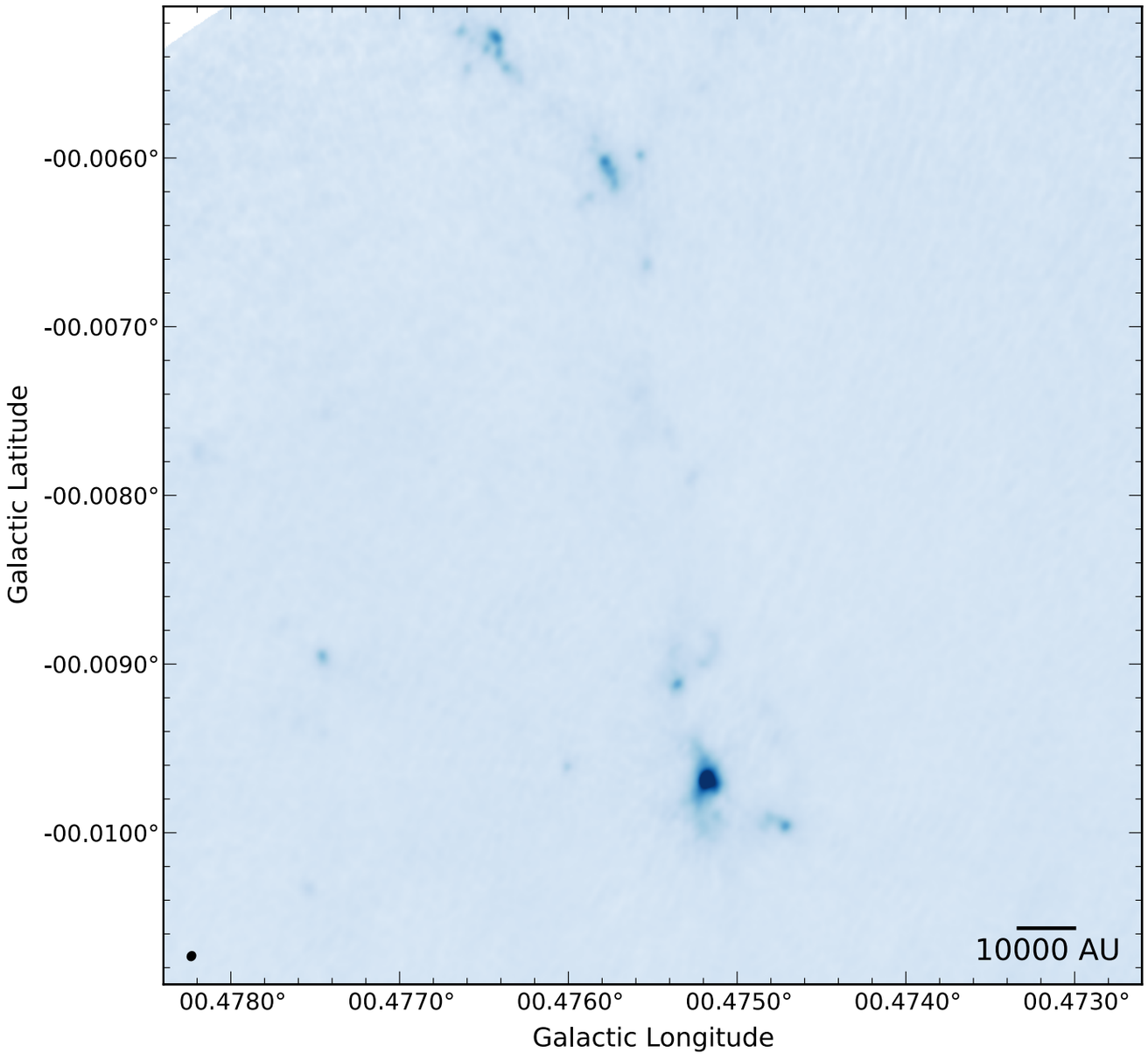

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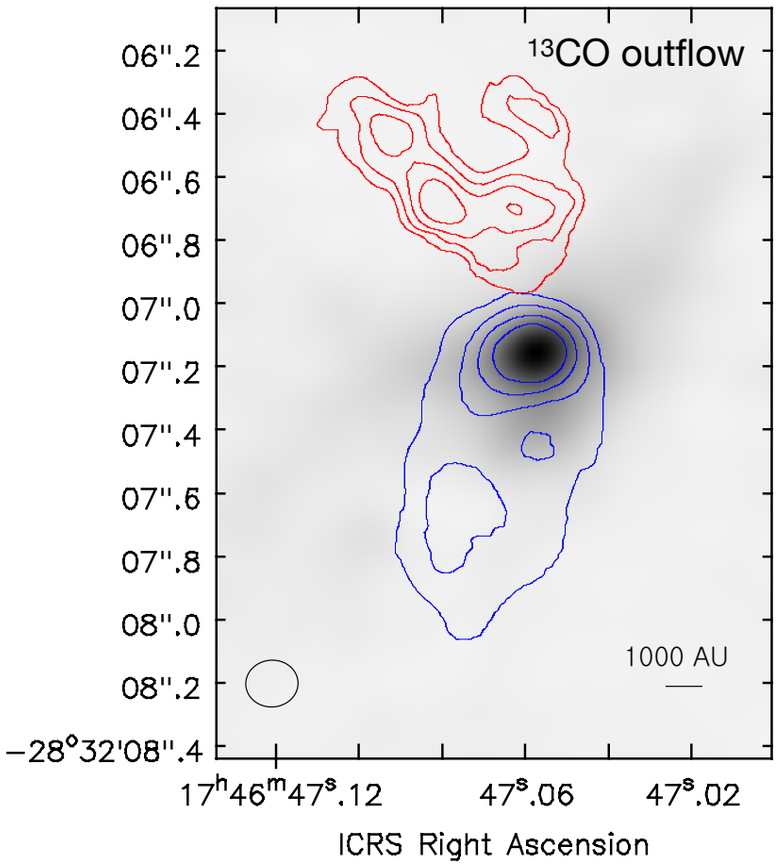

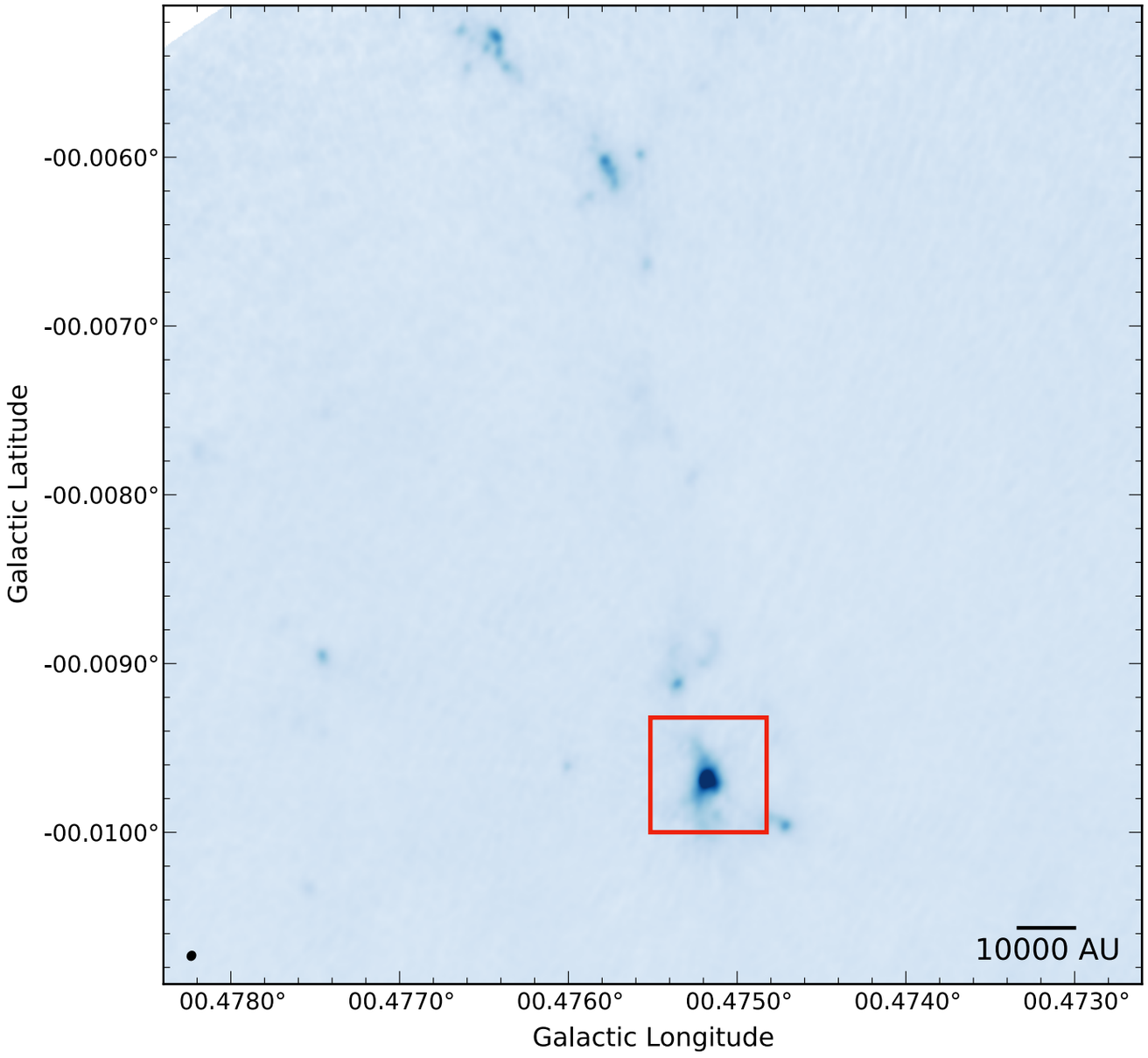

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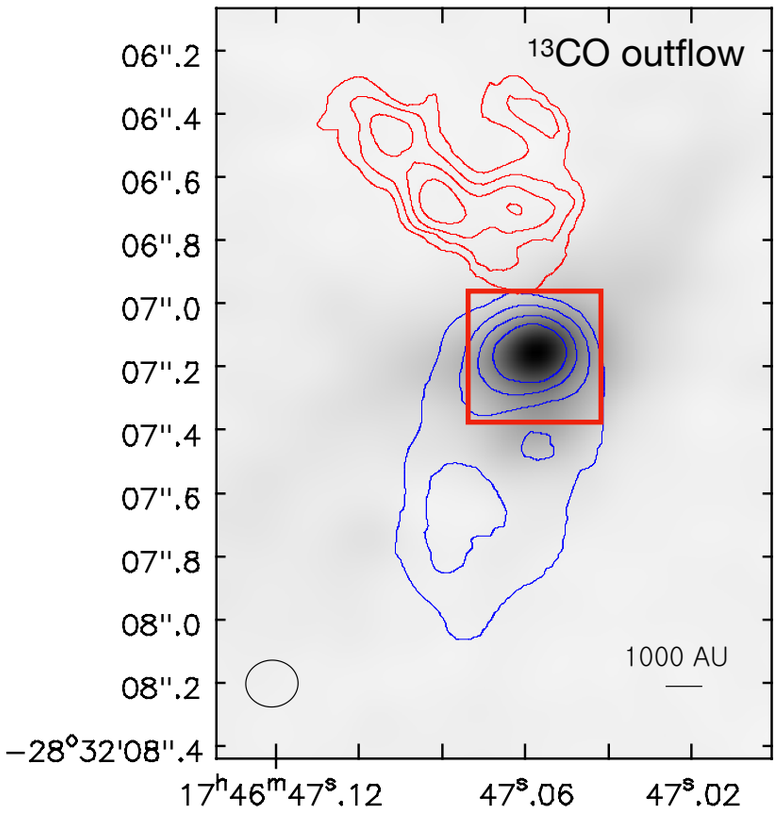
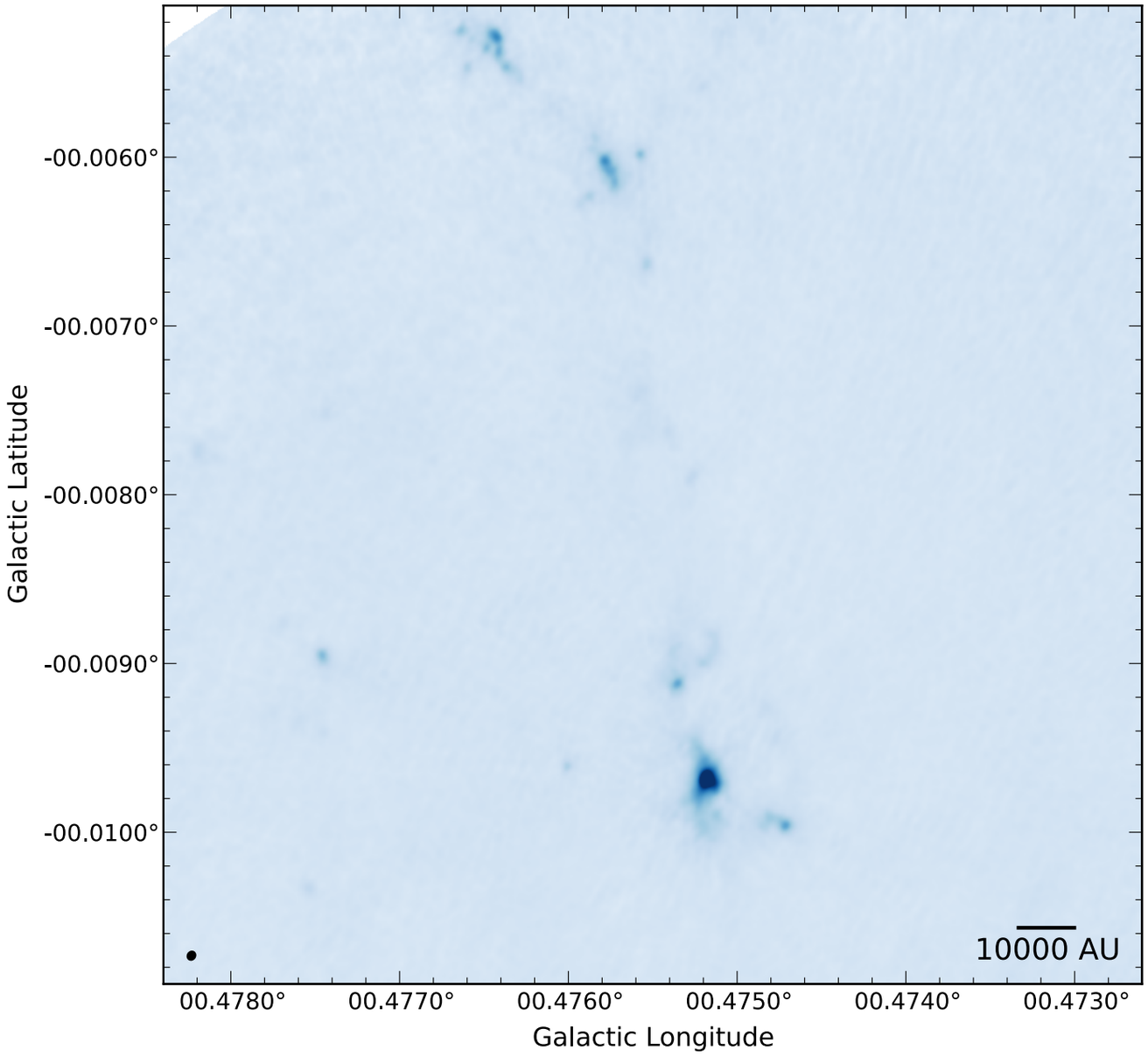
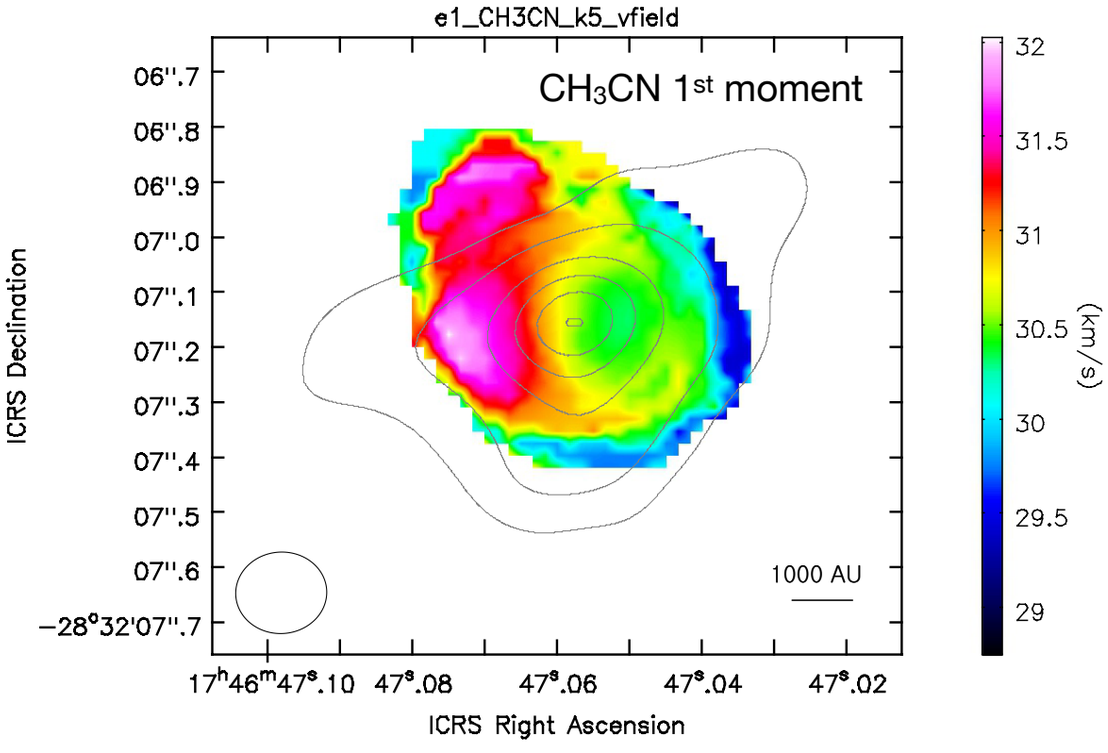
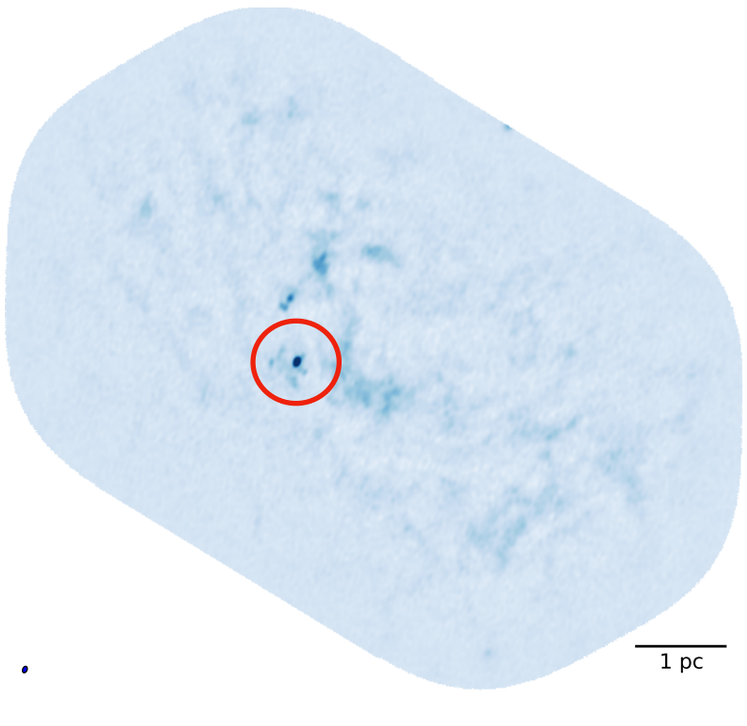






Potential disc & associated outflow around a high-mass protostar?

ALMA follow-up observations — the Brick ‘maser core’



Brick

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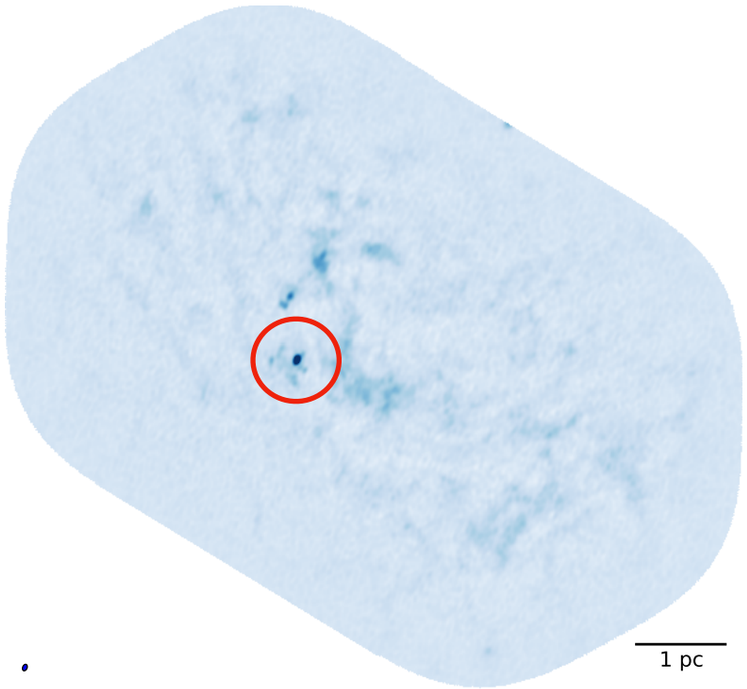

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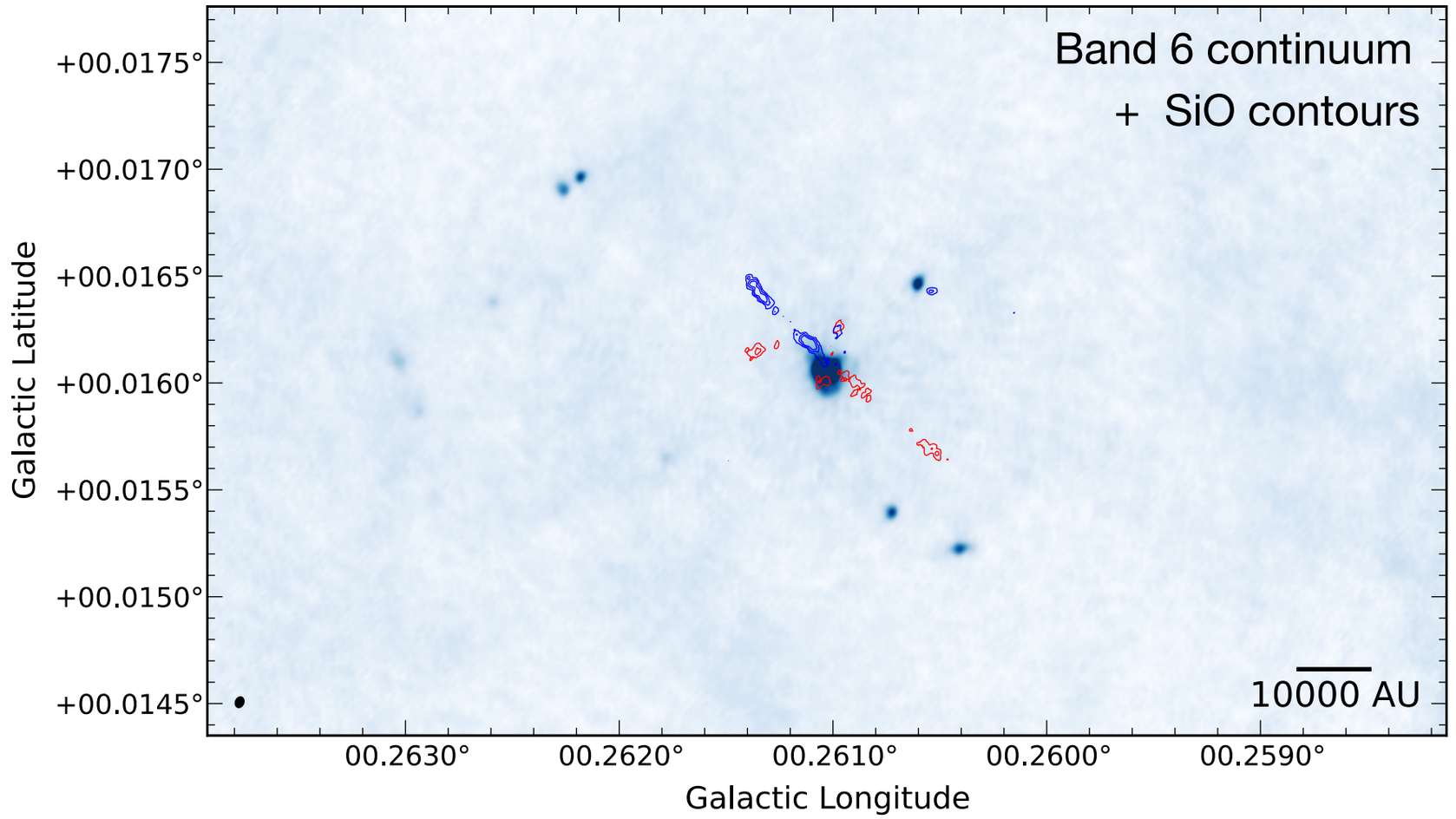

Masses ~ 1 - 5 $M_\odot$
Central source is ~ 60 $M_\odot$

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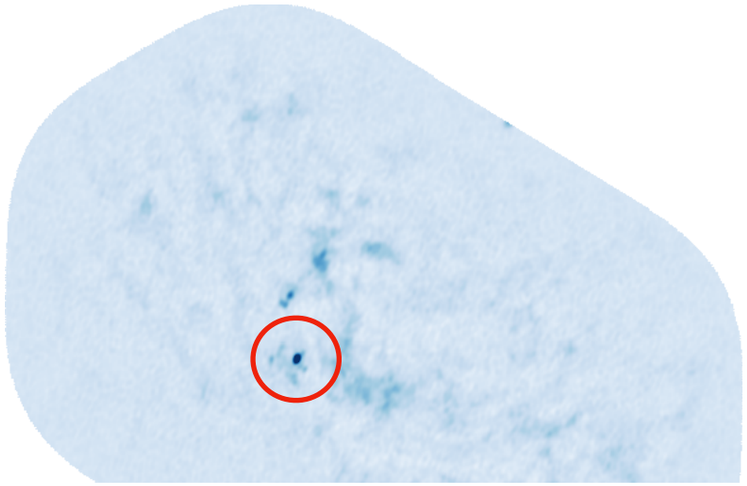

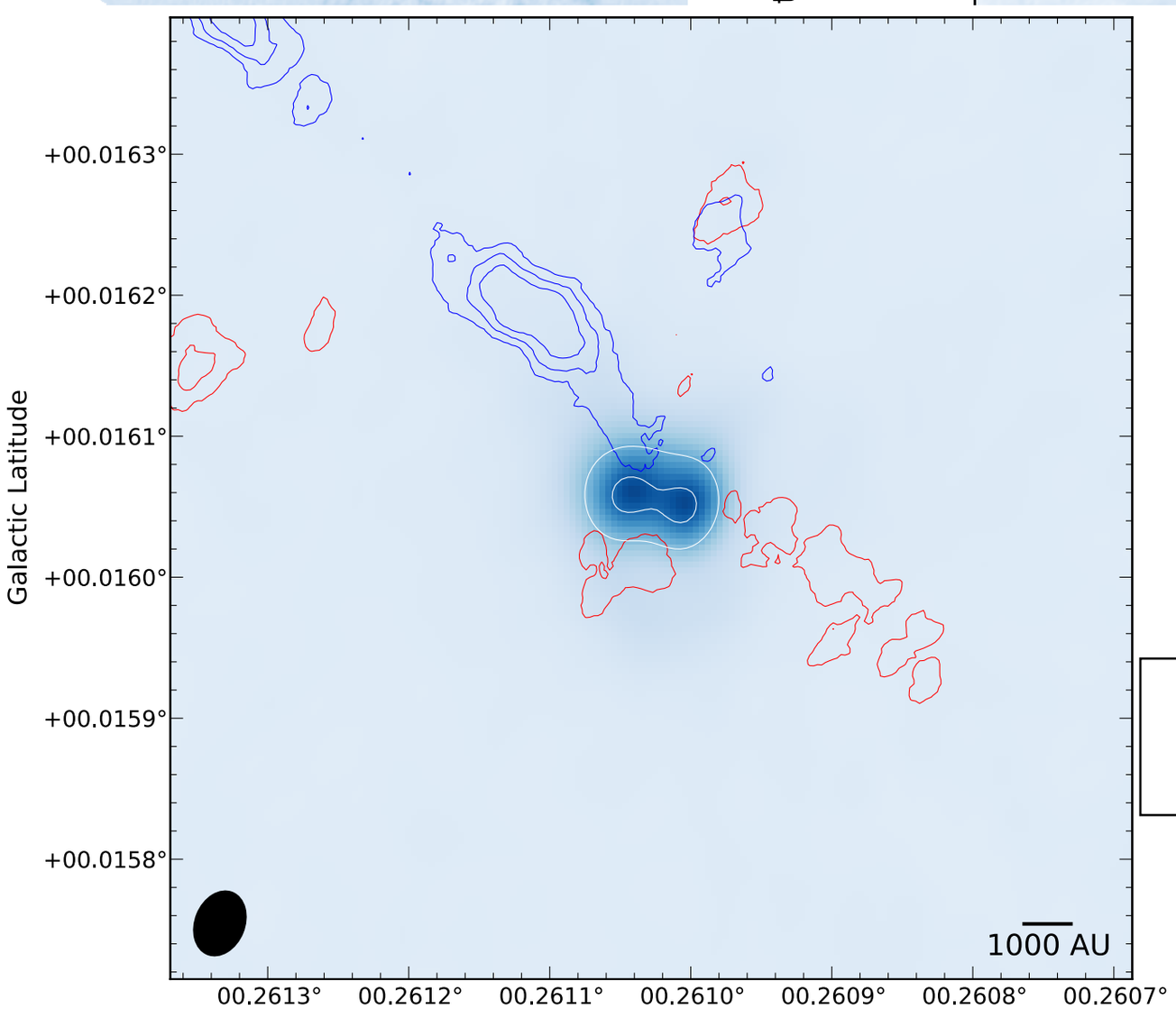

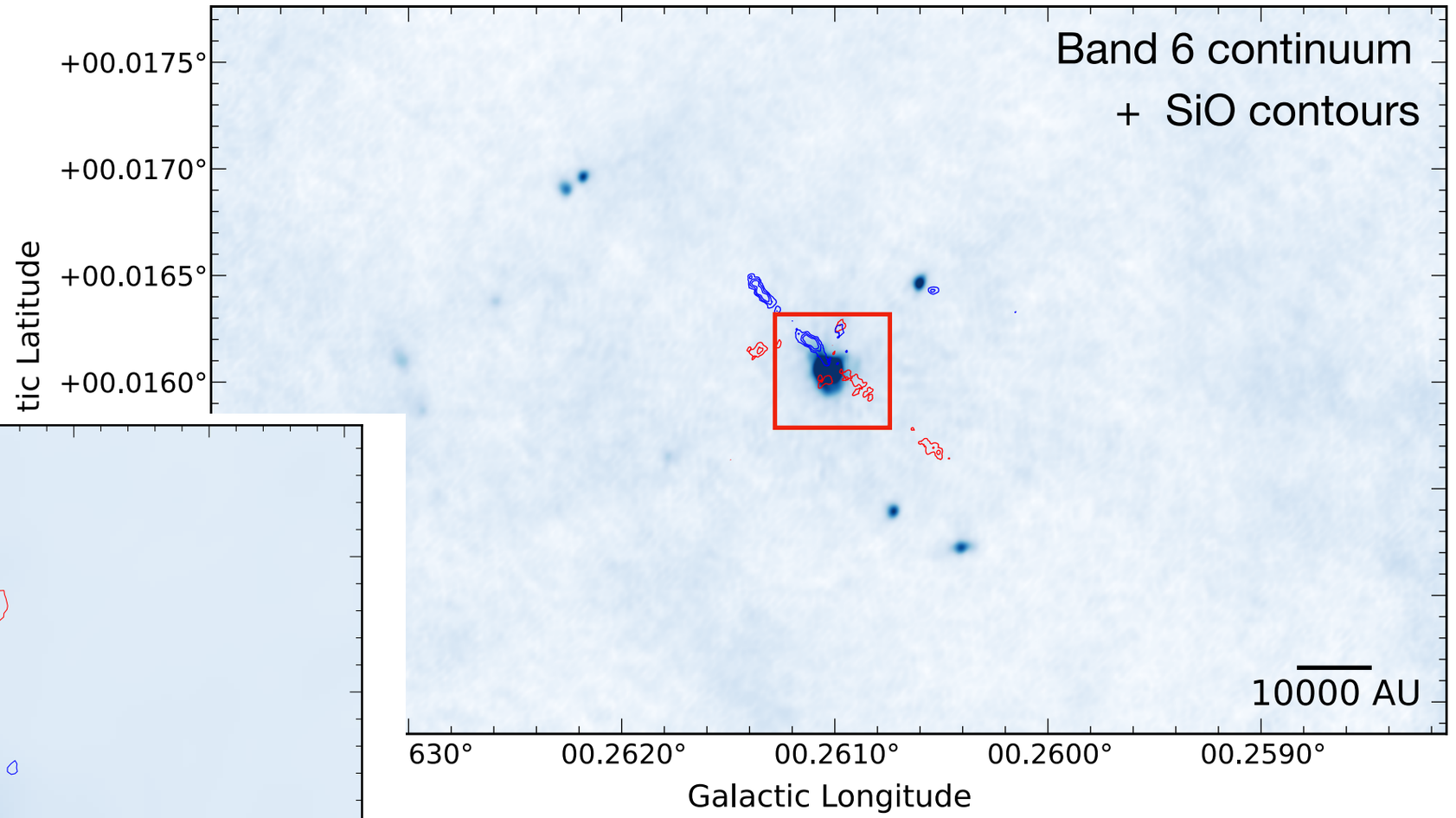

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Central source(s) is(are) ~ 60 $M_\odot$

Summary

- SMA *CMZoom* observations find a population of embedded dense cores in the Galactic centre dust ridge —
    - > 80% of the cores are quiescent, despite densities > 10^6 cm^{-3}
    - Further evidence for environmentally-dependent critical density threshold for SF
    - Two new sites of embedded high-mass star formation
- Follow-up ALMA observations reveal detailed sub-structure on < 1000 AU scales, showing significant fragmentation, suggesting that the low- and high-mass sources are forming simultaneously
- All 3 targeted massive cores are driving bipolar outflows in SiO and ^{13}CO — this is the first direct evidence of outflows in the CMZ in young (pre-UCHII) protostars
- One source in cloud E shows tantalising evidence of disc-like kinematic structure — if confirmed, this would be the first direct detection of a (massive) disc in the CMZ