Deeply Embedded Star Formation in Massive Clouds in the Central Molecular Zone

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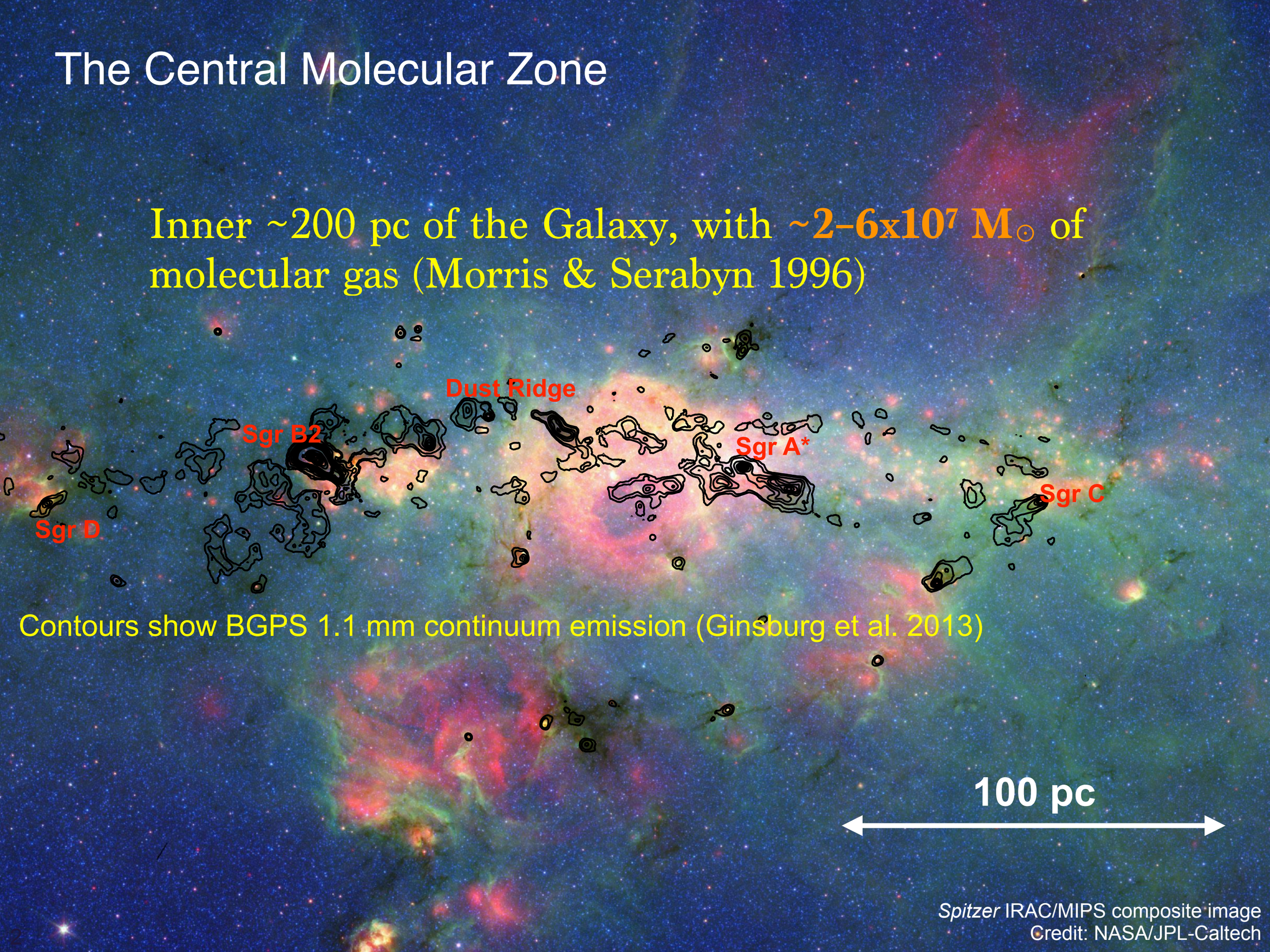
Spitzer IRAC/MIPS composite image
Credit: NASA/JPL-Caltech

The Central Molecular Zone

Inner ~200 pc of the Galaxy, with ~2–6x10^7 $M_\odot$ of molecular gas (Morris & Serabyn 1996)



Contours show BGPS 1.1 mm continuum emission (Ginsburg et al. 2013)

Spitzer IRAC/MIPS composite image
Credit: NASA/JPL-Caltech

Star formation in the Central Molecular Zone

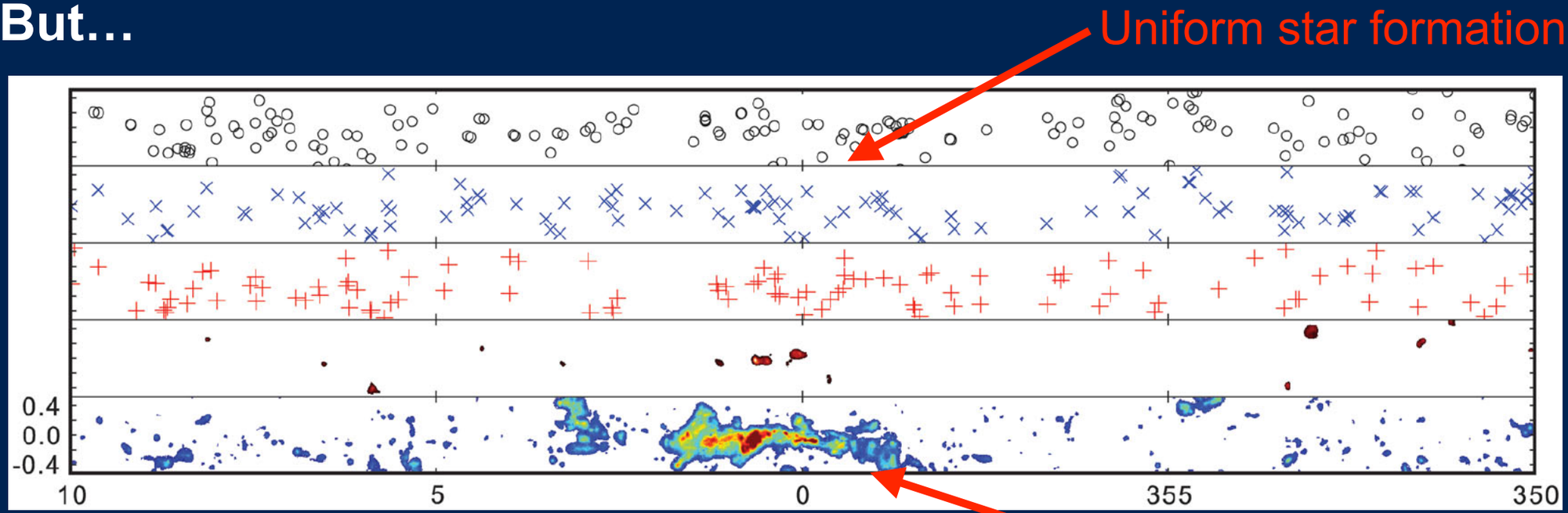
The dense gas SF law: more dense gas*, more star formation.

>10^7 $M_\odot$ of molecular gas with mean densities ~10^4 cm^{-3} in the CMZ (>100 Orion GMC)

*** $n \gtrsim 10^4$ cm^{-3} (Lada et al. 2012)**

Longmore et al. 2013

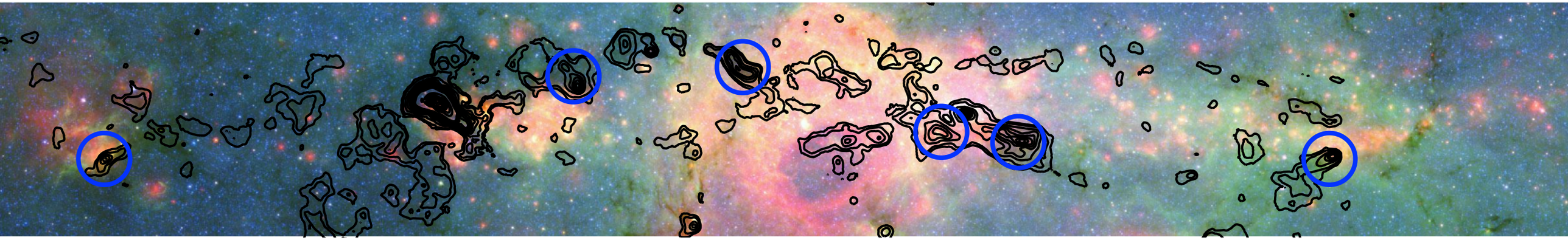
But…



Longmore et al. 2013

** Observed Star Formation Rate (SFR) is 10 times lower than expected from the SF law, both for the whole region and for individual clouds (Longmore et al. 2013; Barnes et al. 2017; Kauffmann et al. 2017).*

Missed star formation?



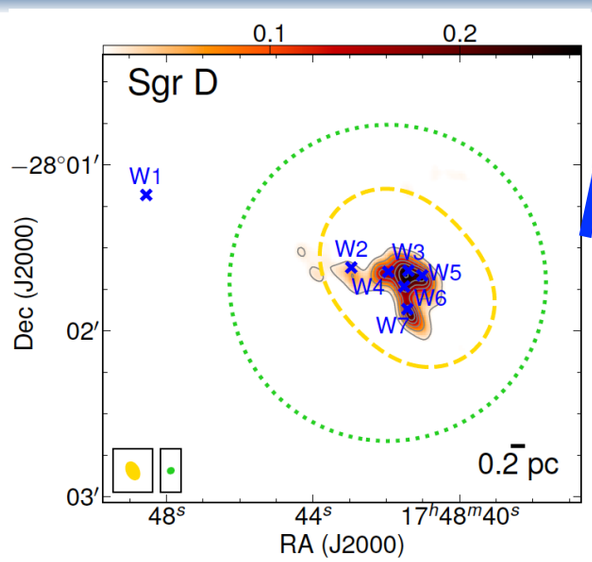
First of all…

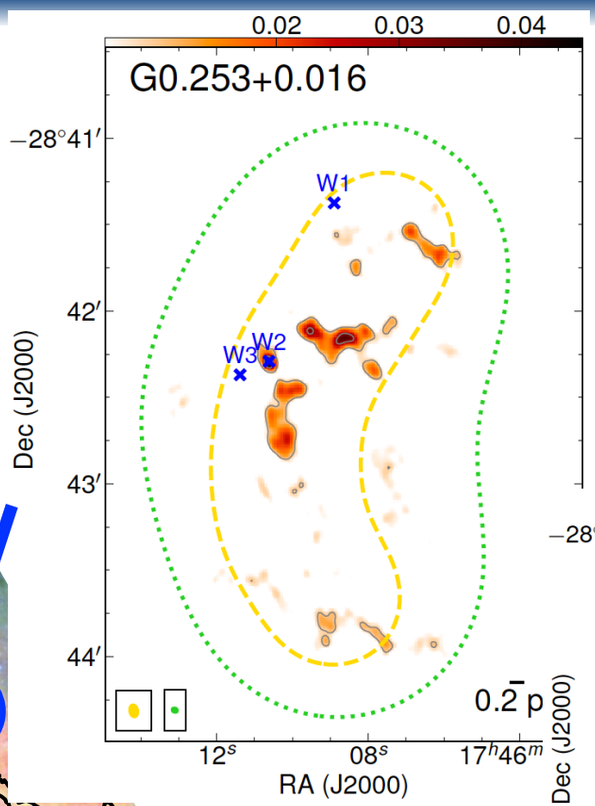
Did we miss anything?

Deeply embedded (very early phase) star formation?

- Previous studies use free-free or IR emission to characterize star formation at late evolutionary phase (Immer et al. 2012, Longmore et al. 2013, Yusef-Zadeh et al. 2013, Barnes et al. 2017), which may miss deeply embedded star formation.
- Time lags between dense gas and SF: current gas environment may not be directly related to SF several Myr ago (crossing time < 1 Myr).

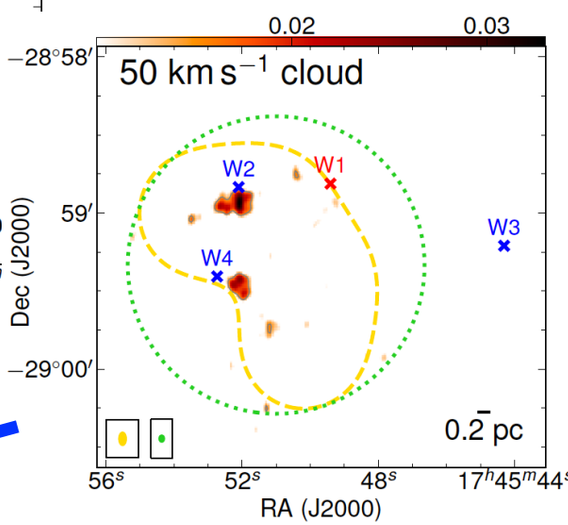
JVLA and SMA mini-survey of six clouds

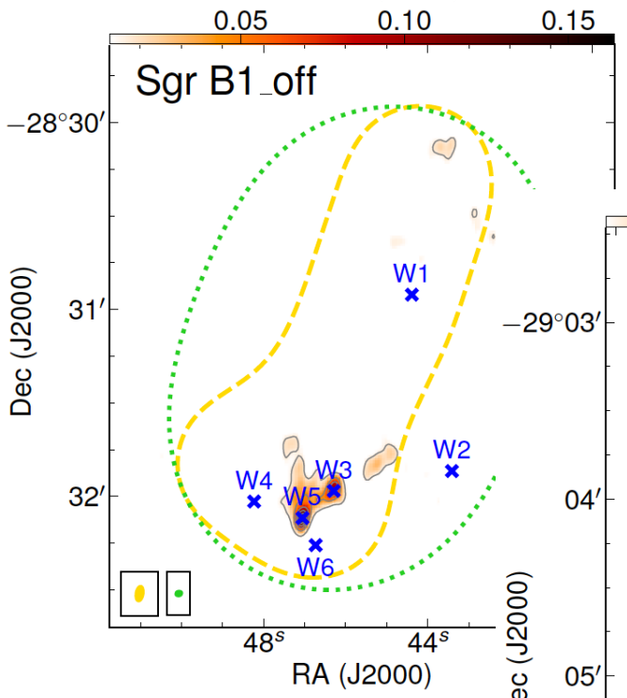


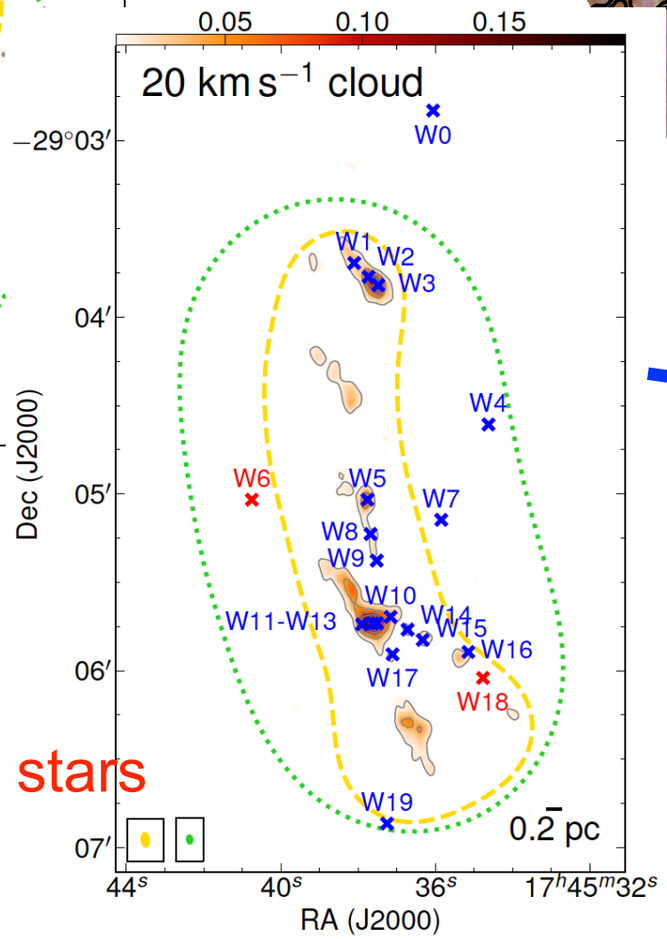


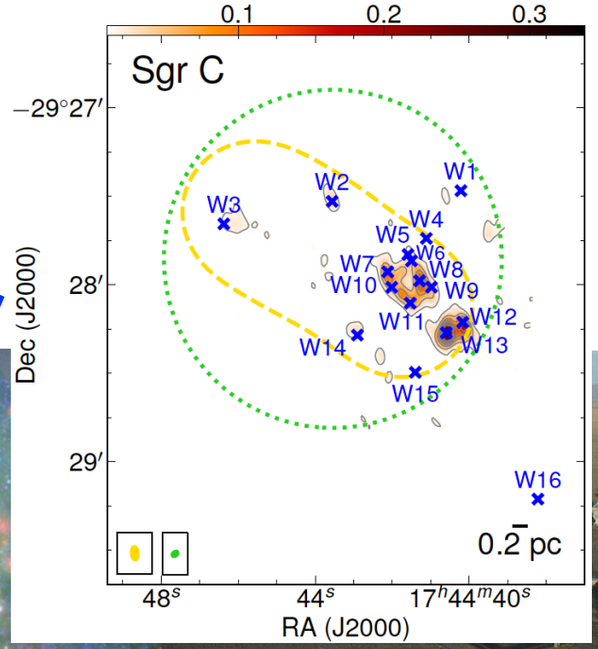
H_2O masers & UCHII regions associated with dense cores

Lu et al. 2015 & in prep.









'X': H_2O masers

'X': cataloged AGB stars

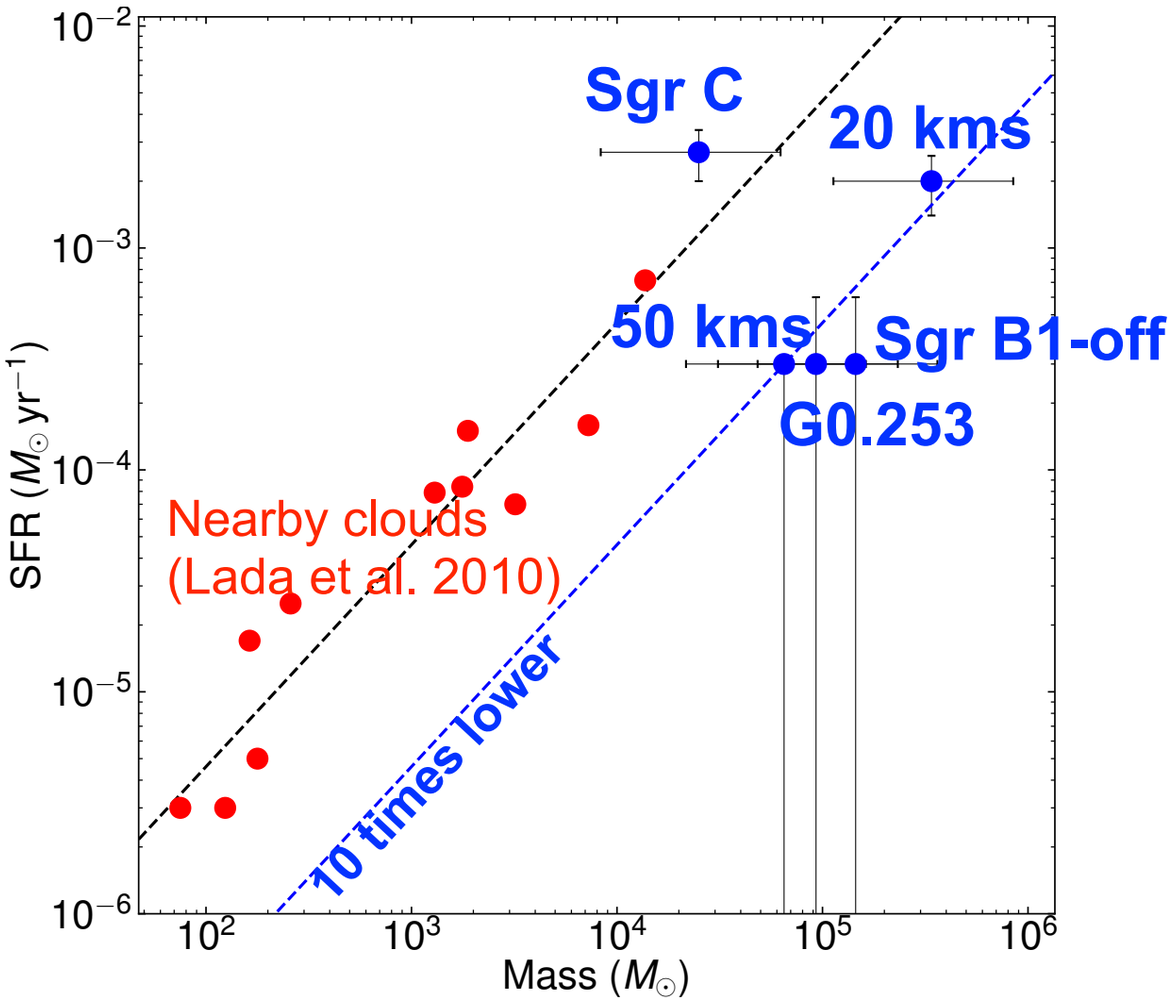
SFRs still 10 times lower than expected

Conclusion #1:

We found many new signatures of star formation (masers, UCHII regions), but...

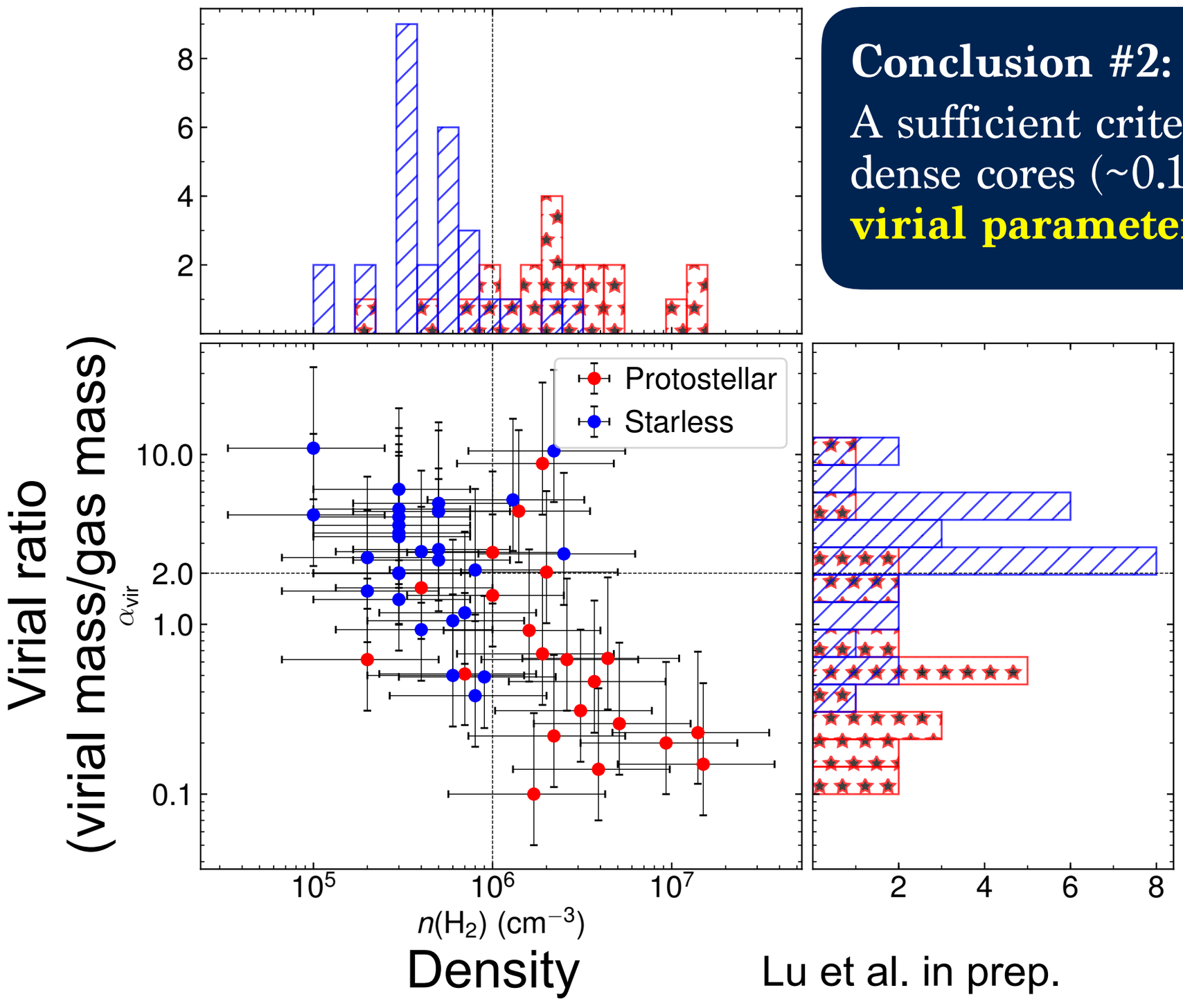
SFRs are still ~10 times lower than expected (except Sgr C).

SFRs are estimated using UCHII regions and H_2O masers associated with dense cores, which characterize SF in a time scale of ~0.3 Myr (comparable to the crossing time).



Lu et al. in prep.
(also see Kauffmann et al. 2017)

A higher density threshold for star formation?



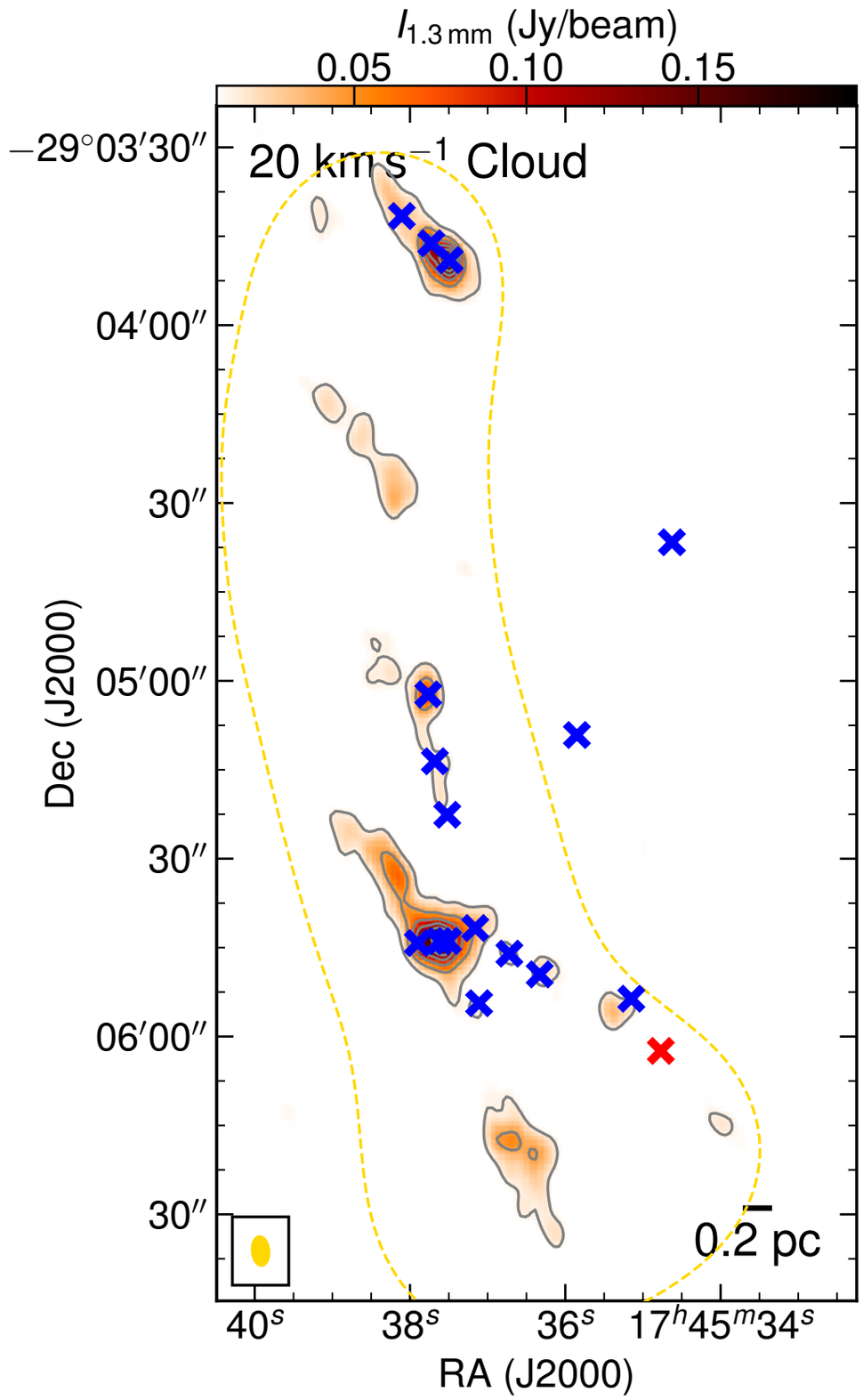
Conclusion #2:

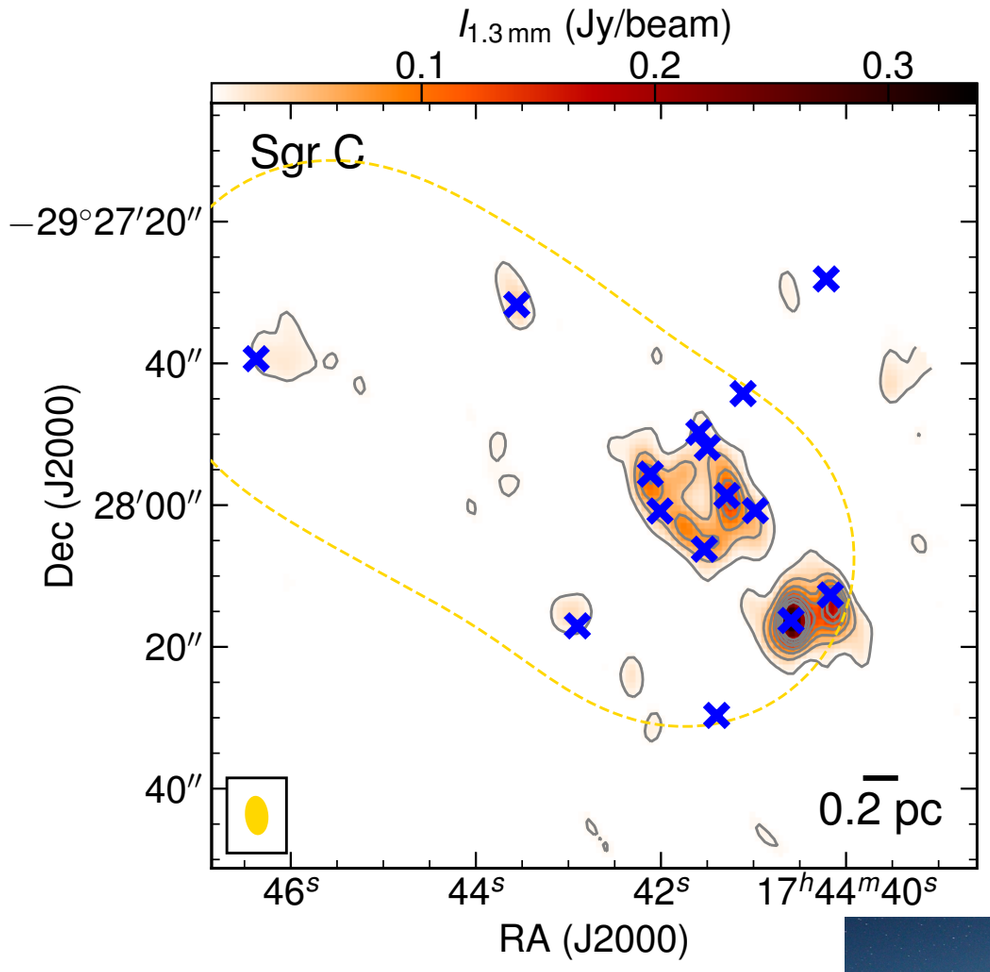
A sufficient criterion for star formation in dense cores (~0.1 pc scales) in the CMZ: **virial parameter < 2** & **density ≳ 10^6 cm^{-3}**

Protostellar cores are those associated with UCHII or H_2O masers.

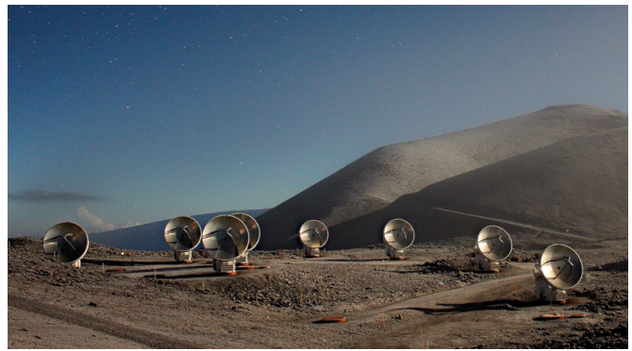
Lu et al. in prep.

From SMA…

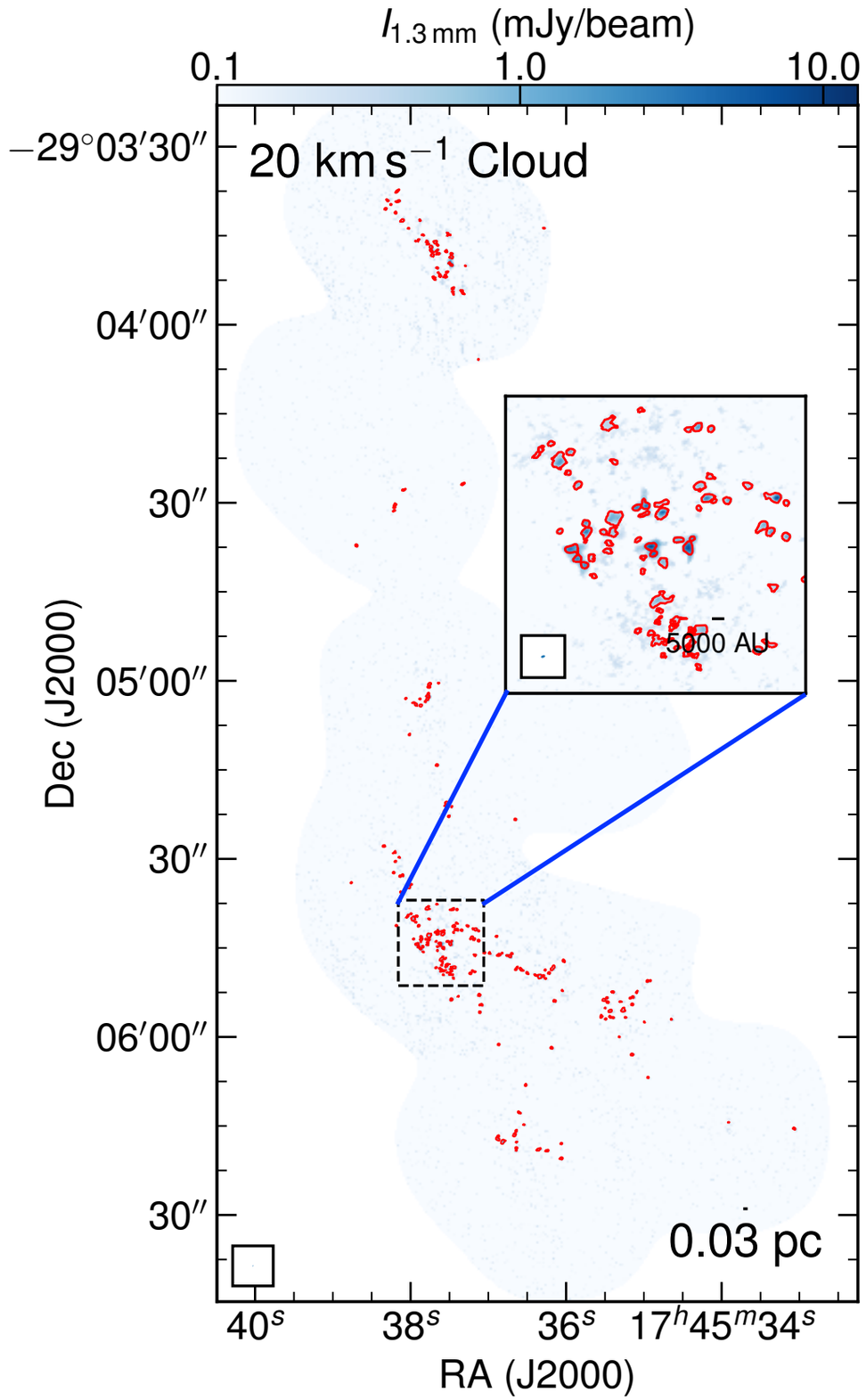




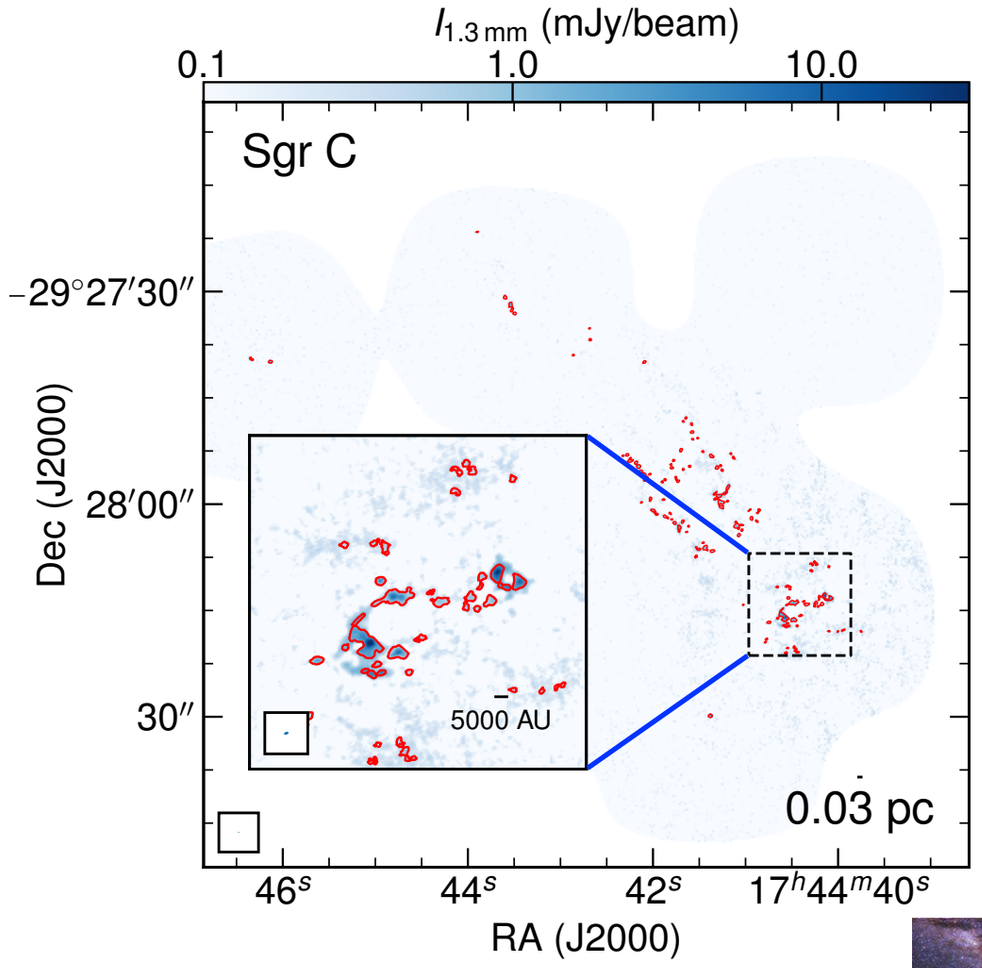
Lu et al. 2015 & in prep.



To ALMA

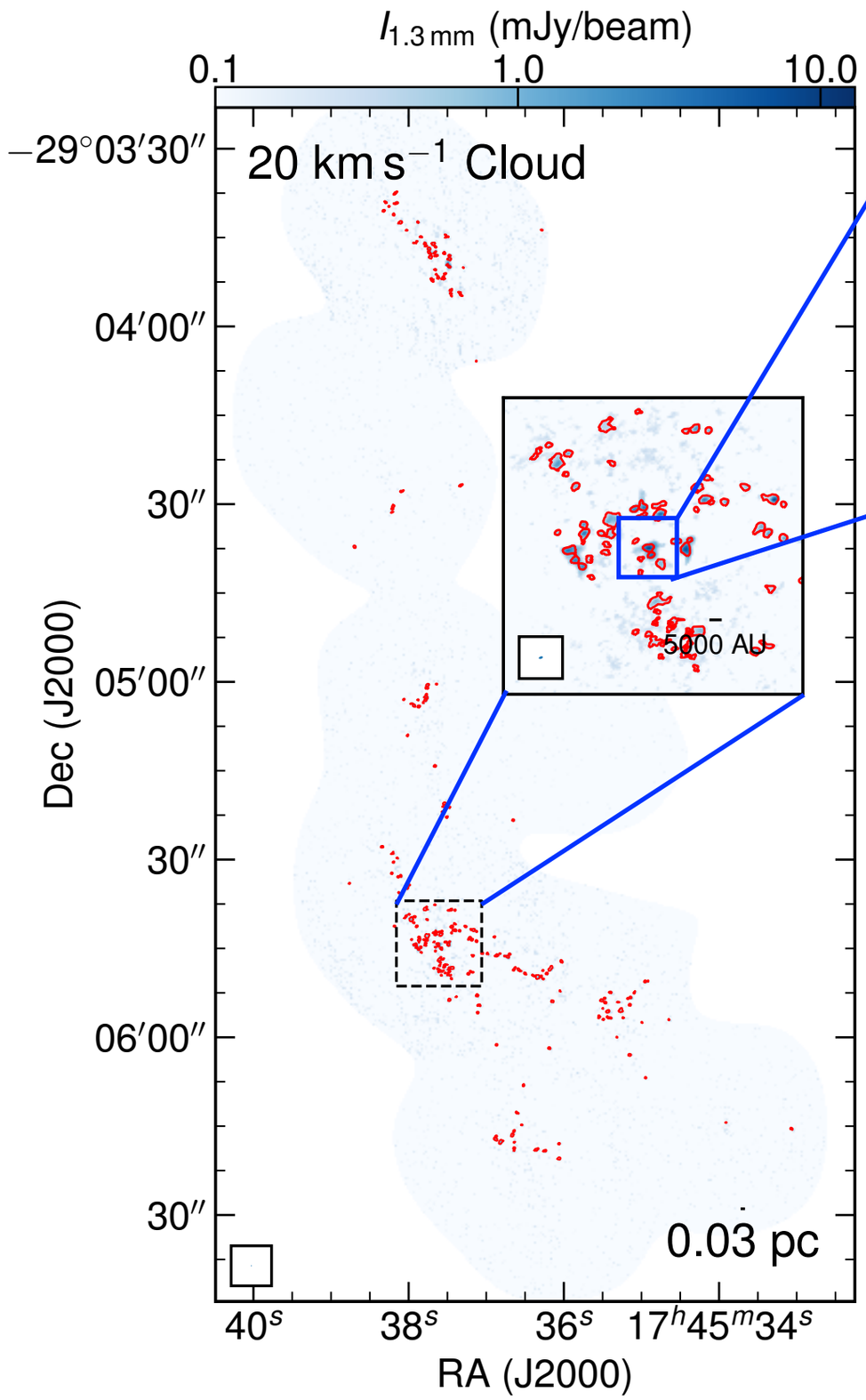


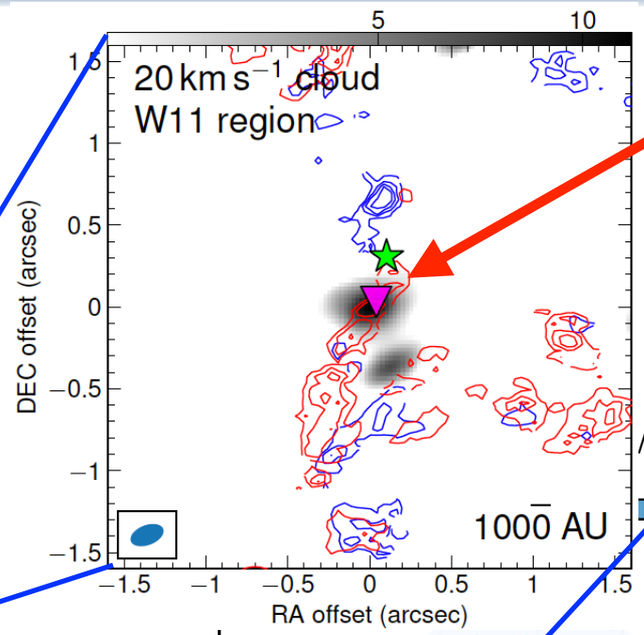
ALMA resolves cores down to 2000 AU, reveals ~10 times more ‘cores’ of **thermal Jeans masses** (1-10 $M_\odot$)



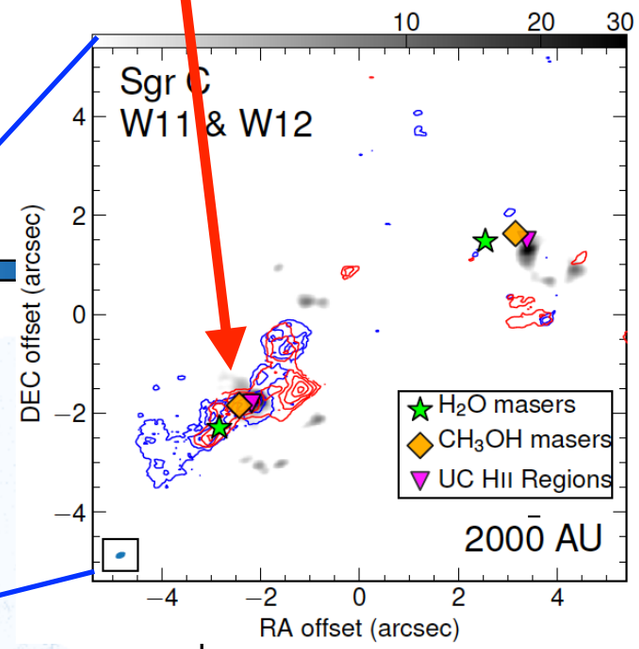
Lu et al. in prep.

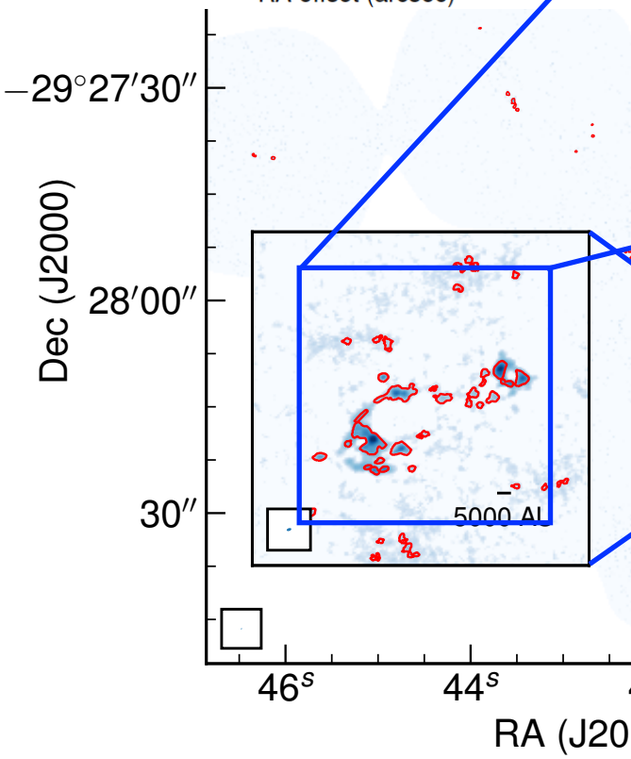
Massive outflows





SiO outflows around 100 $M_\odot$ cores?

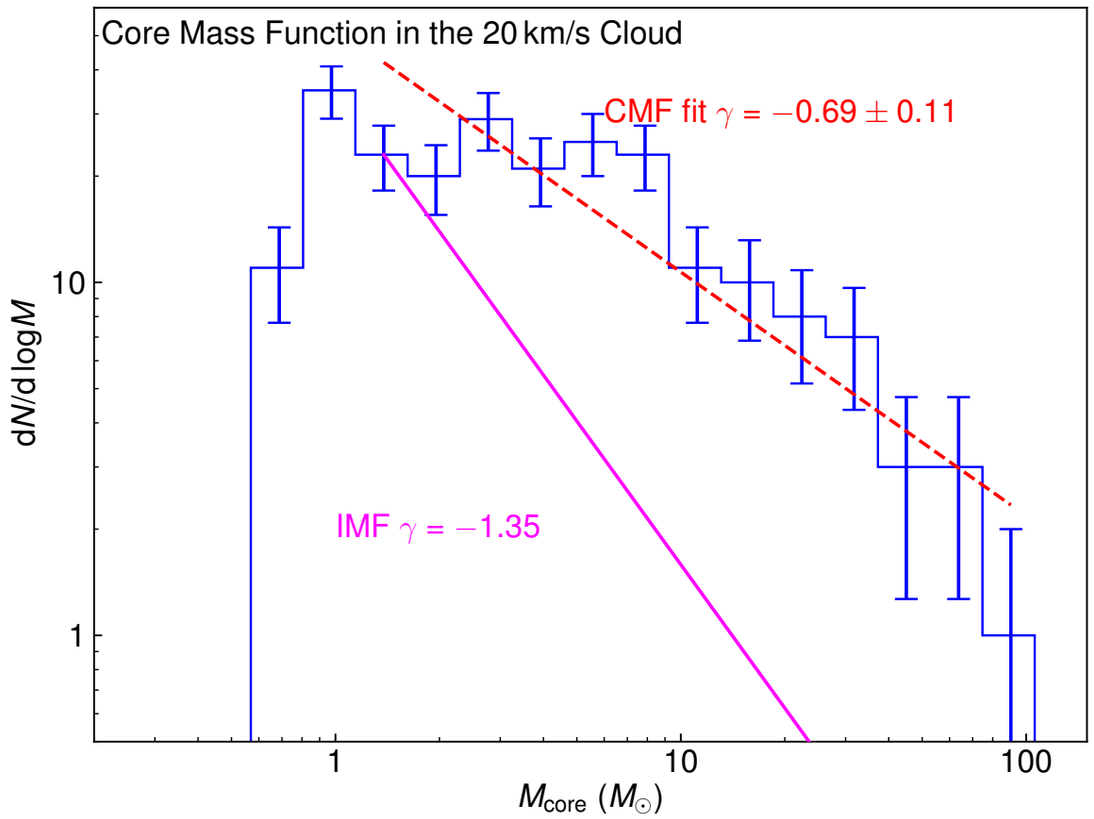


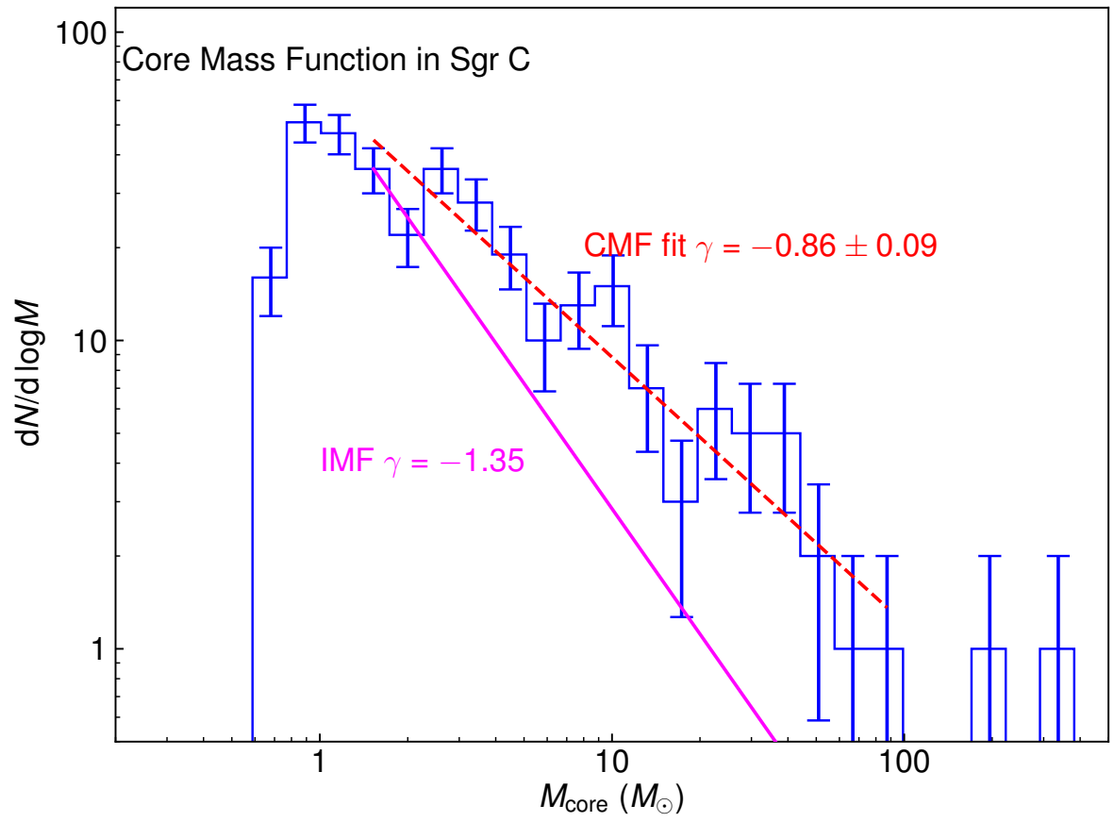


Lu et al. in prep.

Core Mass Functions

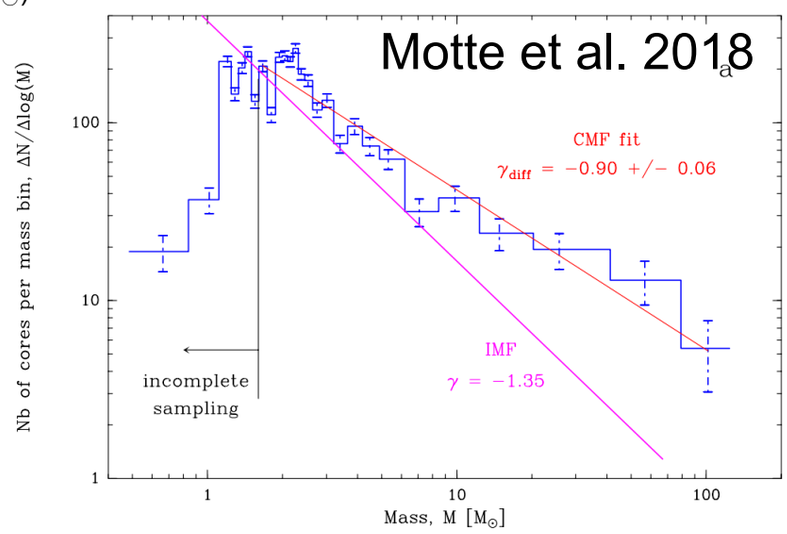
Core Mass Functions (CMFs) are shallower than the canonical IMF?





Lu et al. in prep.

CMF in a Galactic mini-starburst W43-MM1



Summary

- SFRs at very early evolutionary phases (~0.3 Myr) in the CMZ clouds are likely ~10 times lower than expected from the dense gas SF law, suggesting constantly low SFRs in the last several Myr.
- A sufficient (but not necessary) criterion for star formation in CMZ dense cores is virial parameter < 2 AND $n \gtrsim 10^6$ cm^{-3}.
- Jeans fragmentation, bipolar outflows (with disks), etc. may suggest SF processes in gravitationally bound regions similar to Galactic disk clouds.
- To be explored: high-mass protostellar disks? Robust CMFs? Comparison with Galactic disk clouds?

Check my poster! (#12)



Thanks!

11/16/2017 @ALMA AOS, Chile