Distributed Star Formation throughout the Galactic Center cloud Sgr B2

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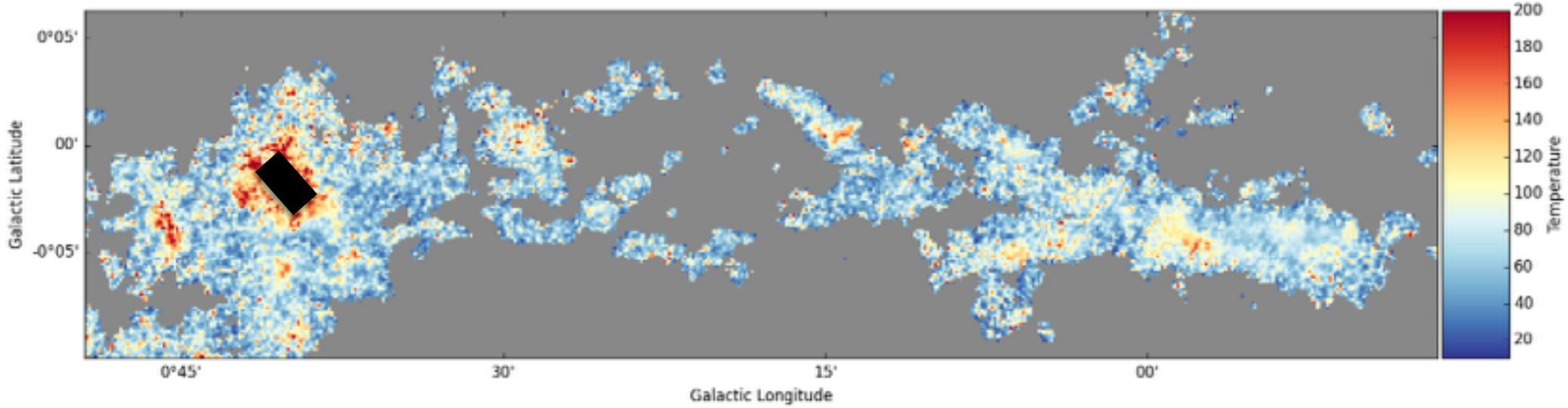
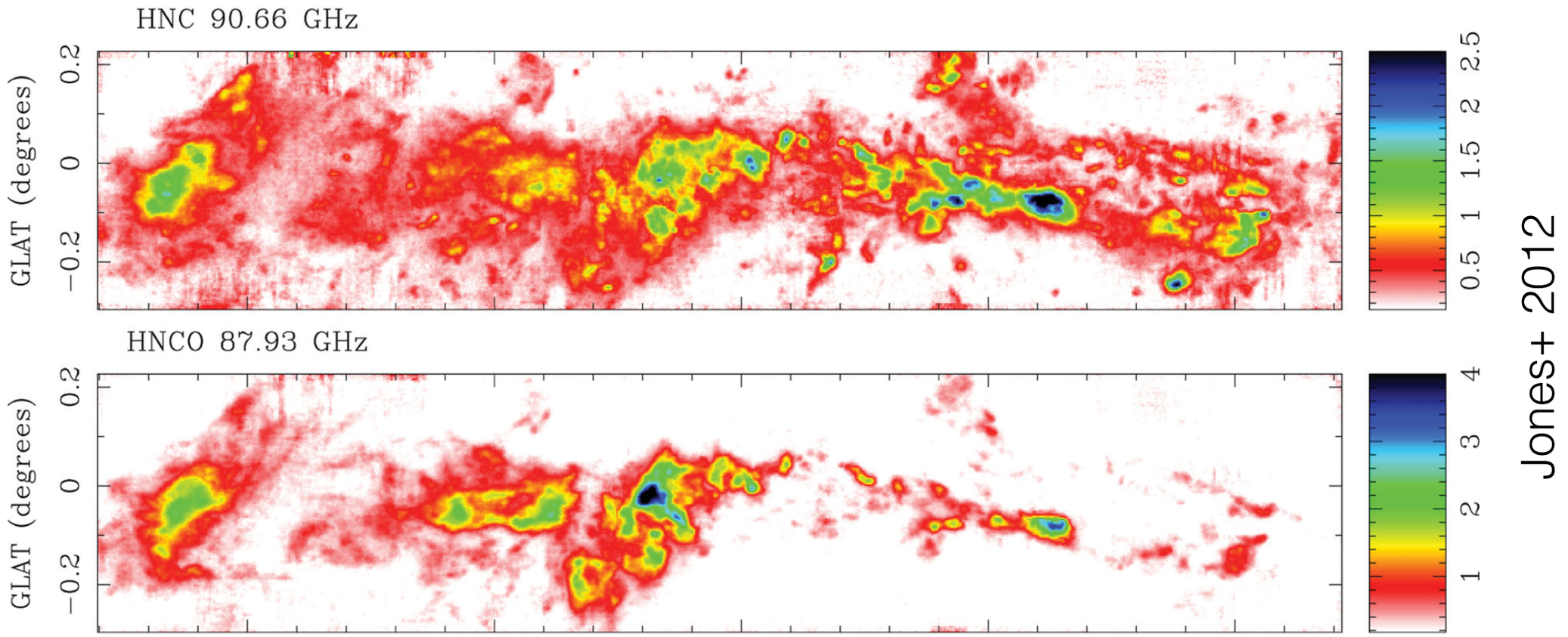
Gas in the CMZ is qualitatively different from gas in the disk



Ginsburg+ 2015

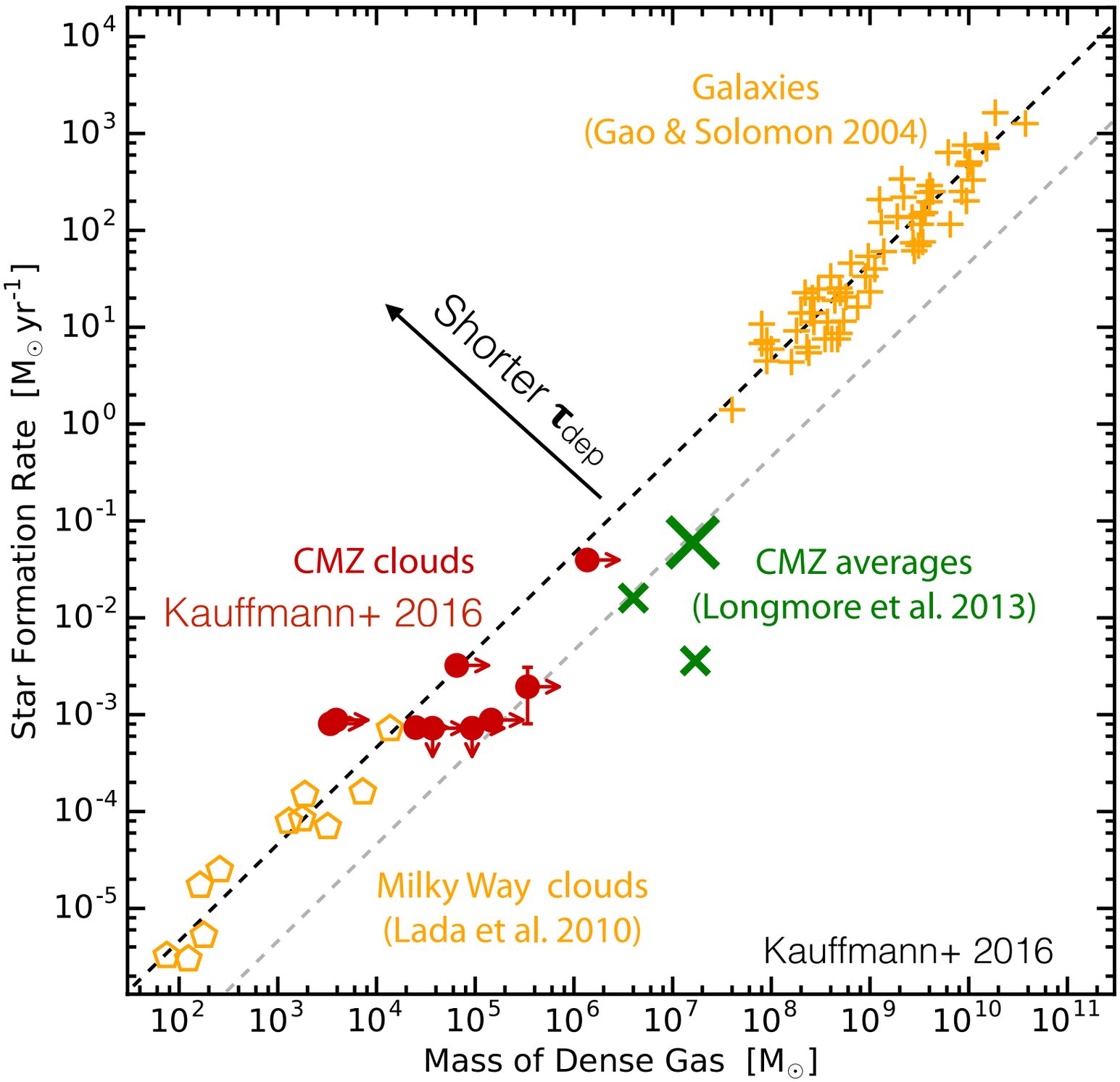
It is *warmer, denser,* and *more turbulent*.

It is also chemically rich (i.e., it has lots of molecules everywhere that usually aren't seen anywhere)



Jones+ 2012

Star formation in the Central Molecular Zone is lower than expected given its dense gas content



SFR in the CMZ

Yusef-Zadeh+ 2009: 0.14 $M_\odot$/yr
Koepferl+ 2014: >63% of Spitzer YSO candidates are not YSOs

Several other methods agree that SF is low:
Barnes+ 2017 summarizes, finding 0.06-0.12 $M_\odot$/yr

Background: Spitzer, Yusef-Zadeh+ 2009

Where has star formation been observed in the CMZ?

The CMZ dust ridge:
Sgr B2 to The Brick

Brick:
Little-to-no SF
Longmore+ 2013
Rathborne+ 2014, 2015

20 km/s:
Some SF
Lu+ 2015

Sgr C:
Some SF
Kendrew+ 2013

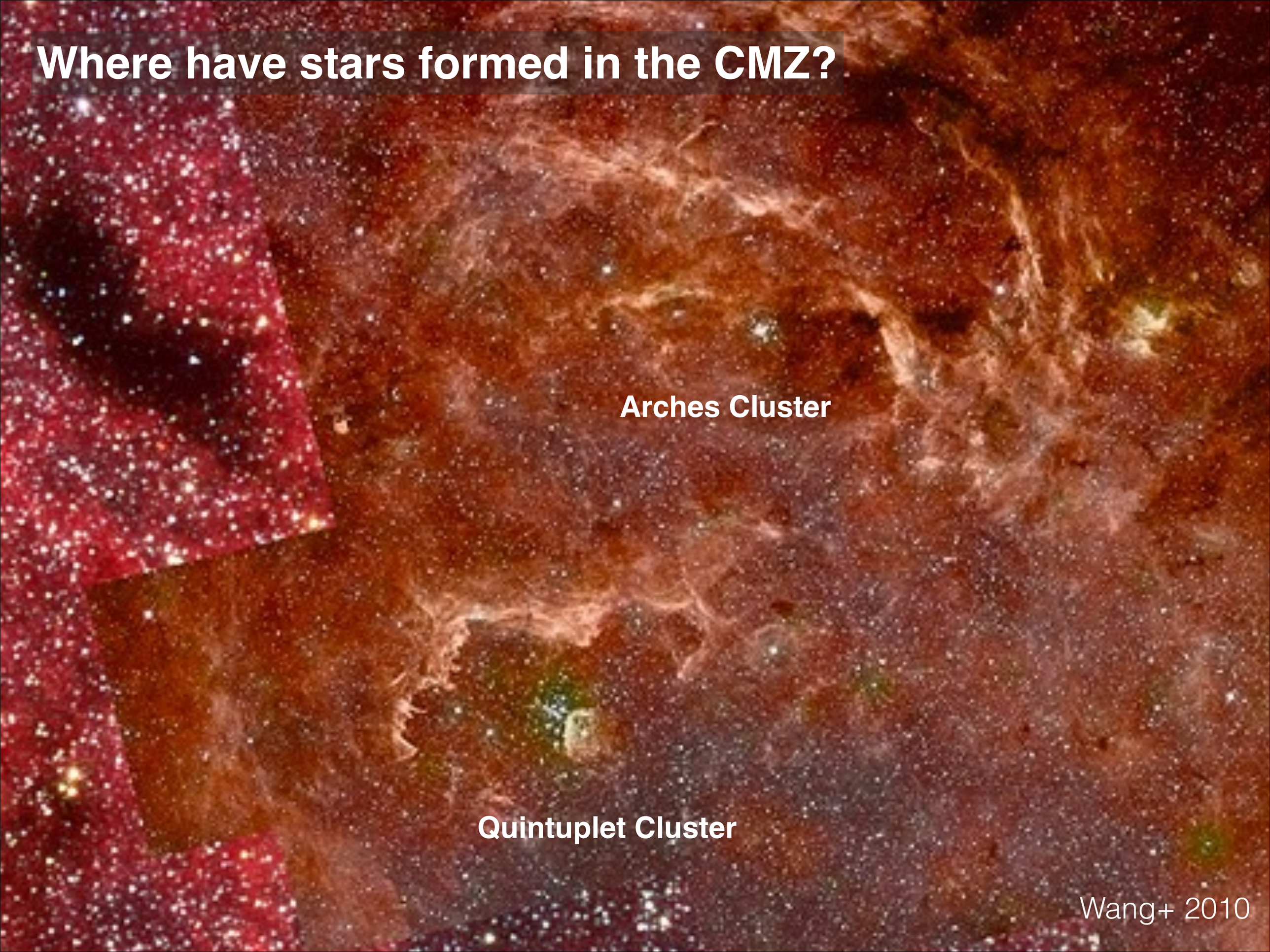
Sgr B2:
Star-forming
Schmiedeke+ 2016
Ginsburg+ 2017
De Pree+ 2014,2015

Sgr B1:
Stars formed

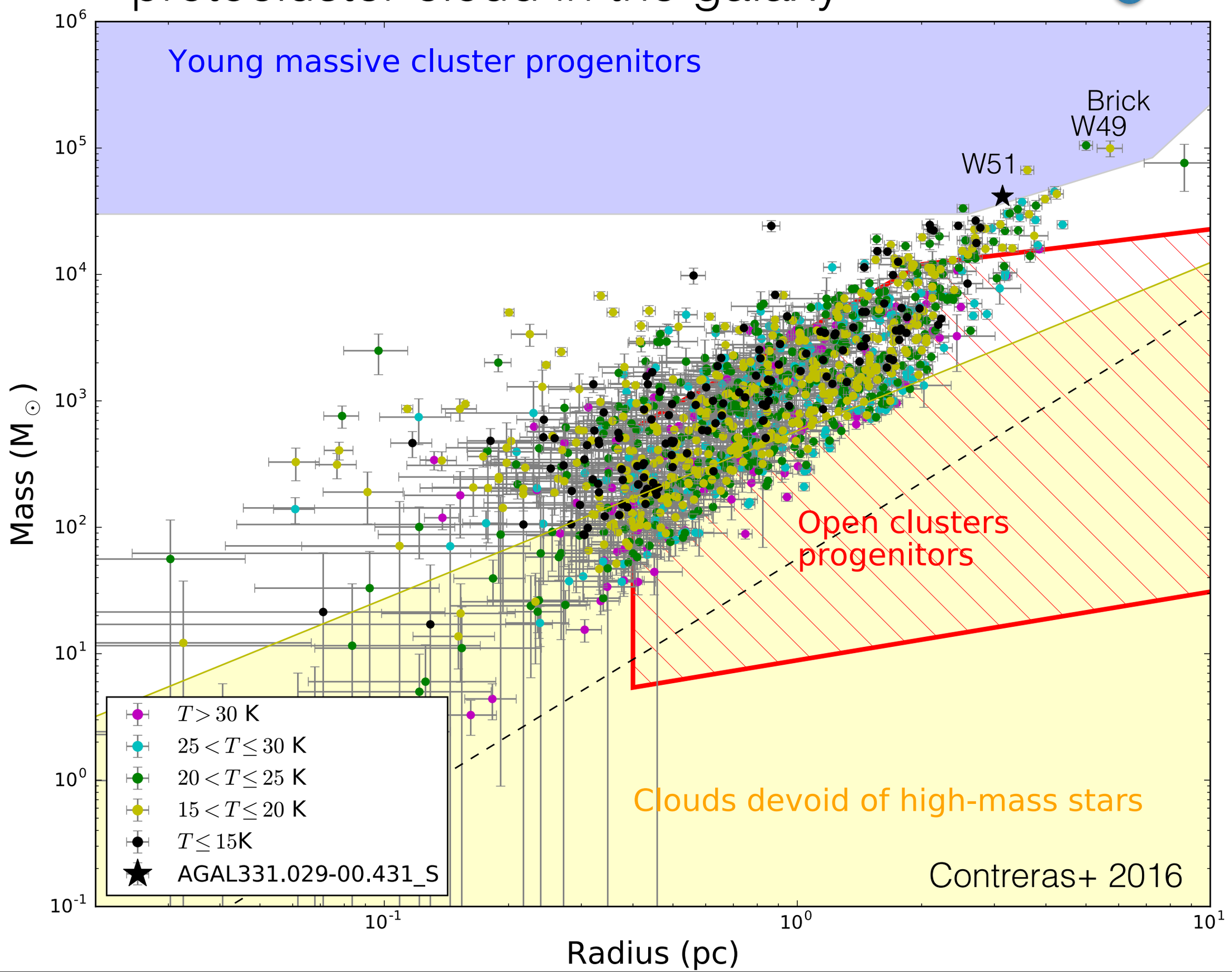
Clouds C/D/E:
Early signs of SF
Ginsburg+ 2015
Barnes+, Walker+ in prep

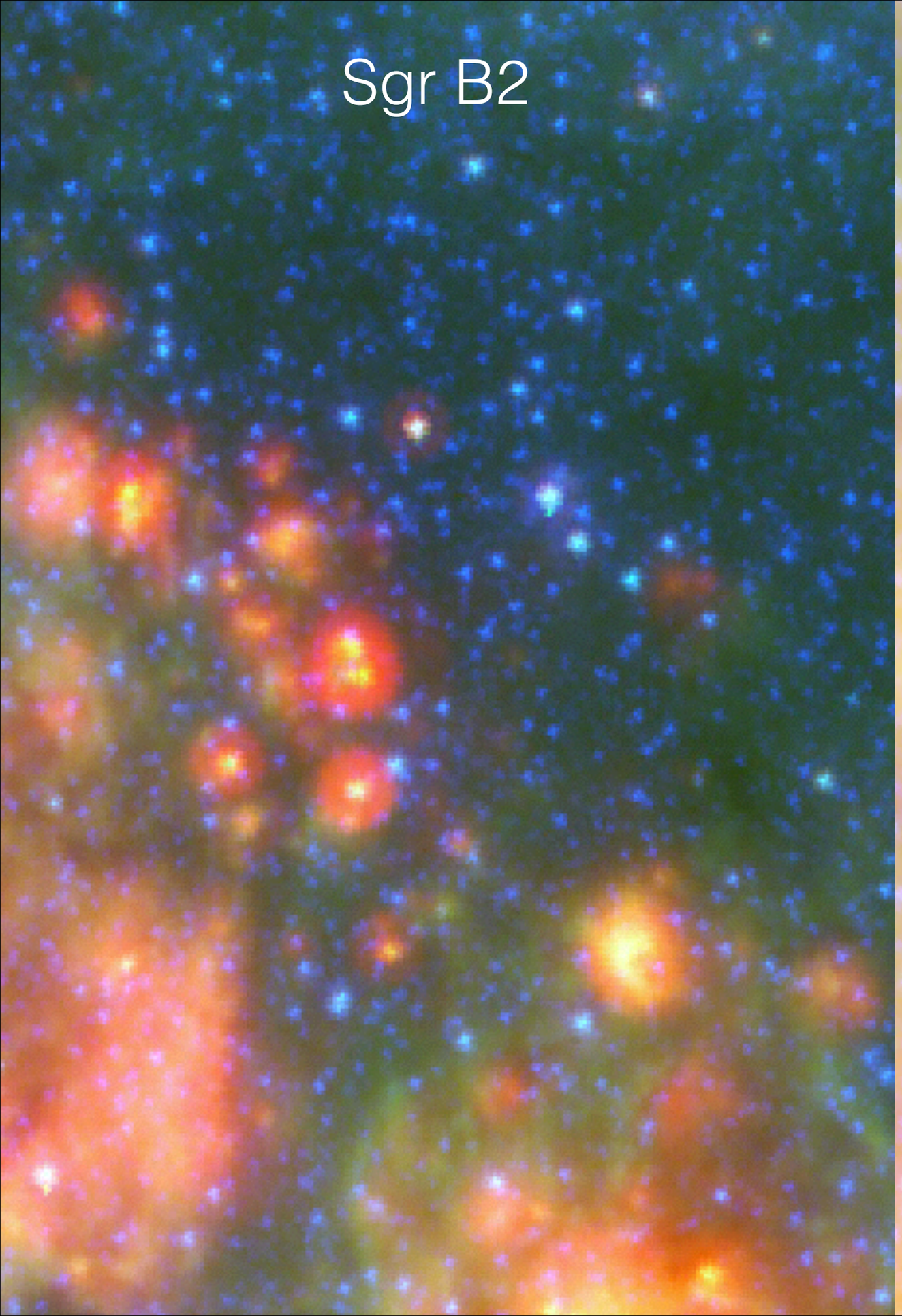
"TLP" / M10 / G10:
More SF from left to right
Battersby+ in prep
Butterfield+ in prep

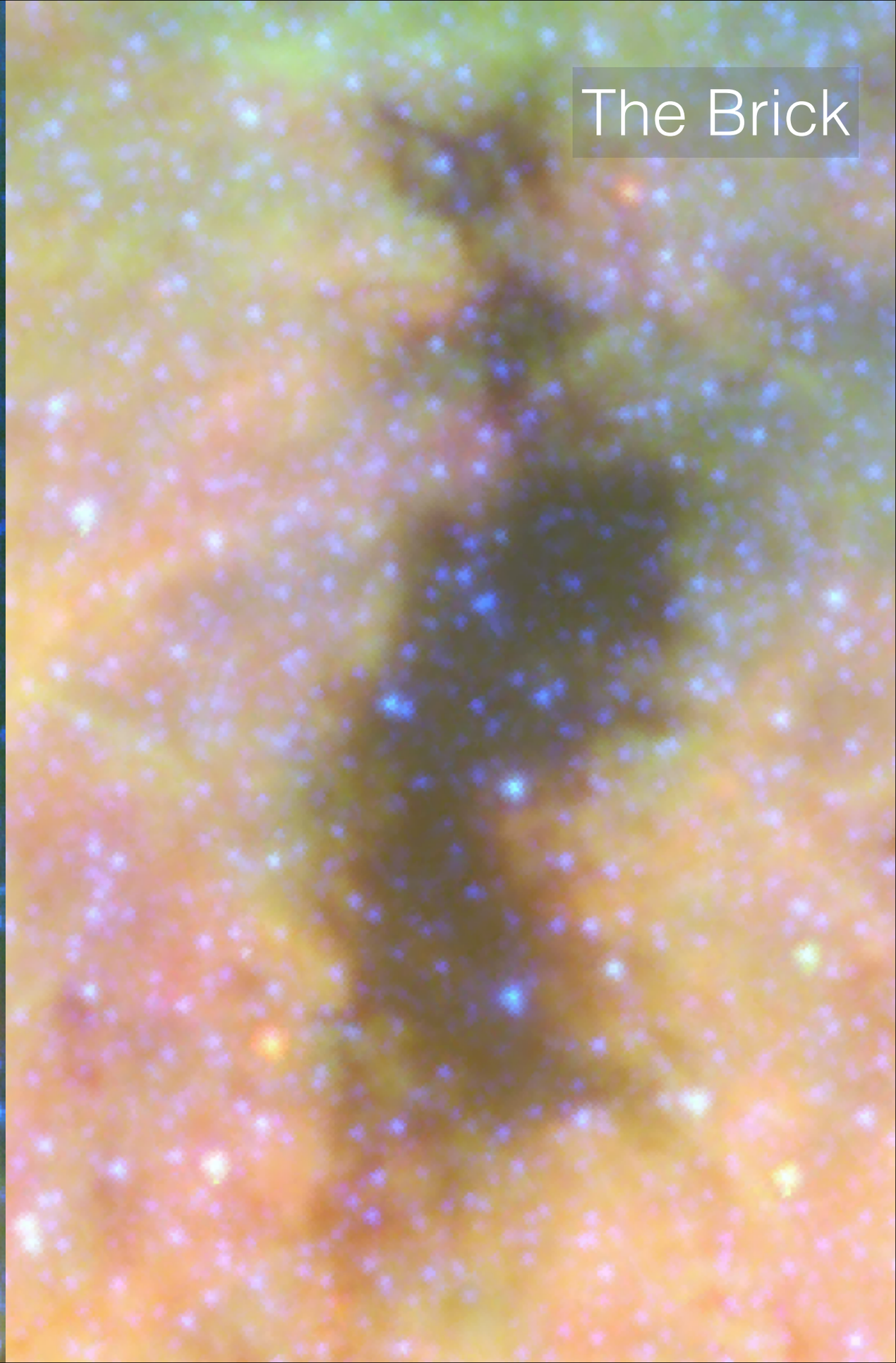
Where have stars formed in the CMZ?

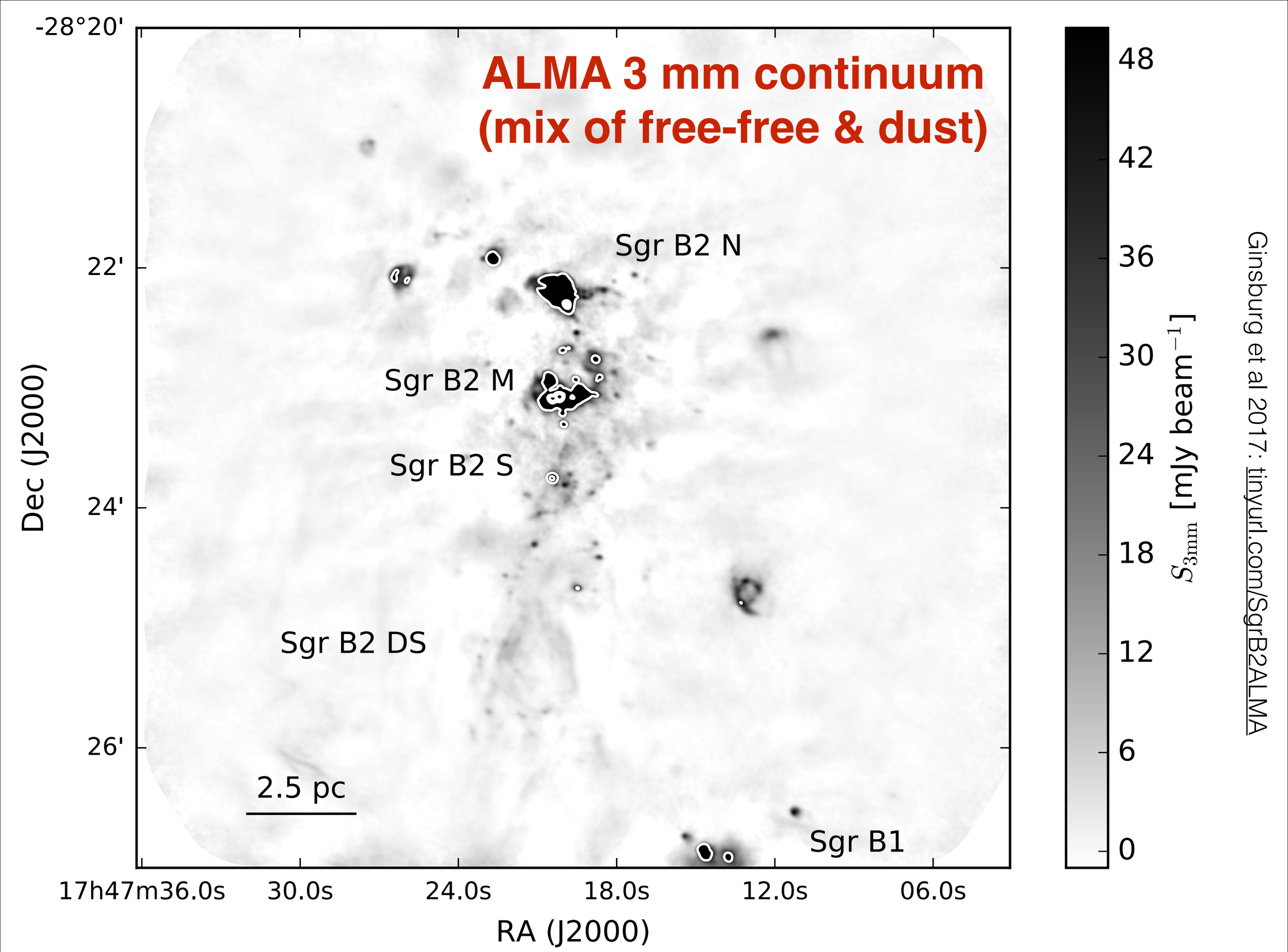


Sgr B2 is the most massive protocluster cloud in the galaxy




Sgr B2


The Brick


ALMA 3 mm continuum
(mix of free-free & dust)
Sgr B2 N
Sgr B2 M
Sgr B2 S
Sgr B2 DS
Sgr B1
2.5 pc
-28°20'
22'
24'
26'
Dec (J2000)
17h47m36.0s
30.0s
24.0s
18.0s
12.0s
06.0s
RA (J2000)
48
42
36
30
24
18
12
6
0
S_{3mm} [mJy beam^{-1}]
Ginsburg et al 2017: tinyurl.com/SgrB2ALMA

ALMA 3 mm continuum
(mix of free-free & dust)

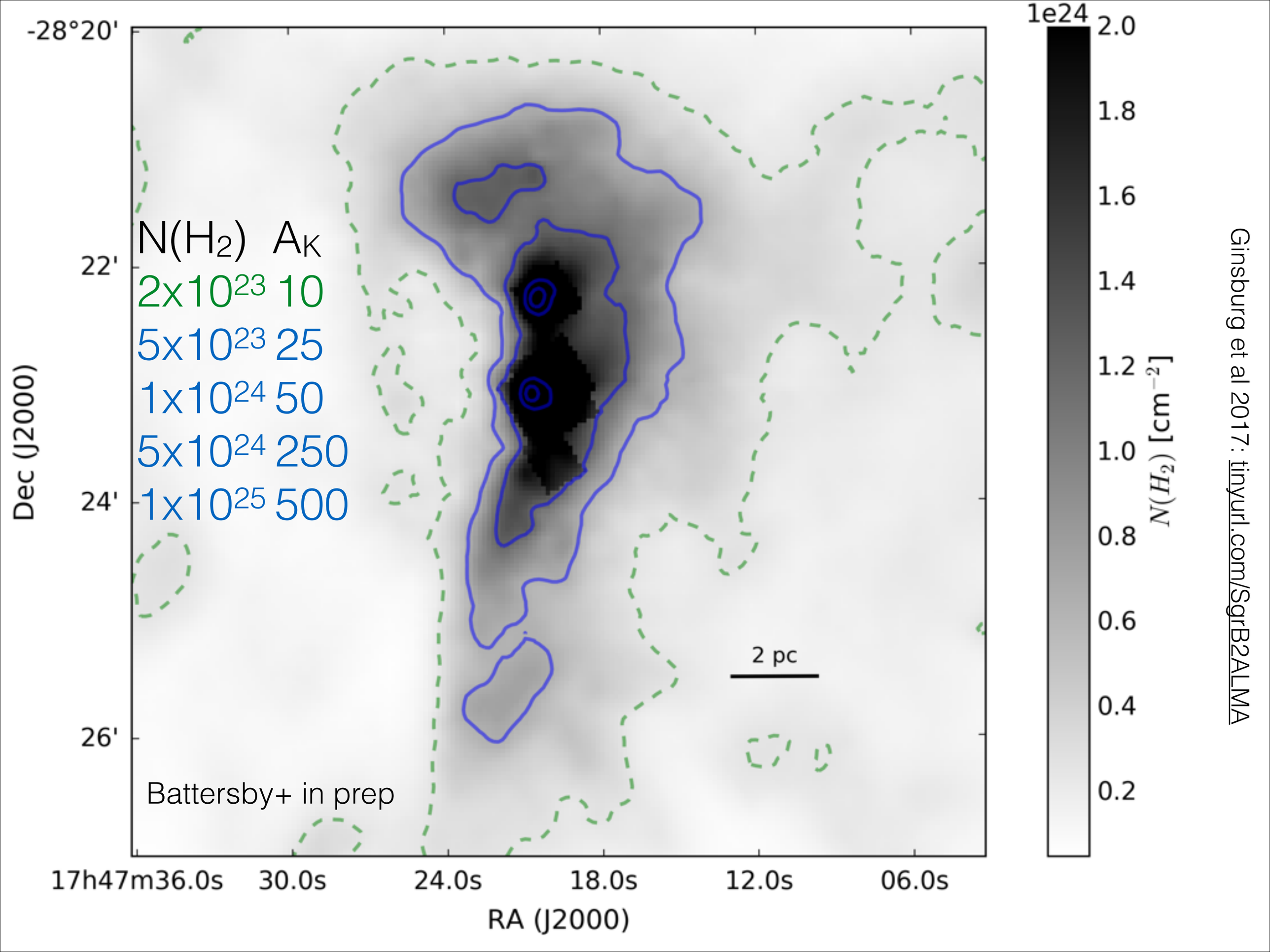
-28°20'
22'
24'
26'
Dec (J2000)

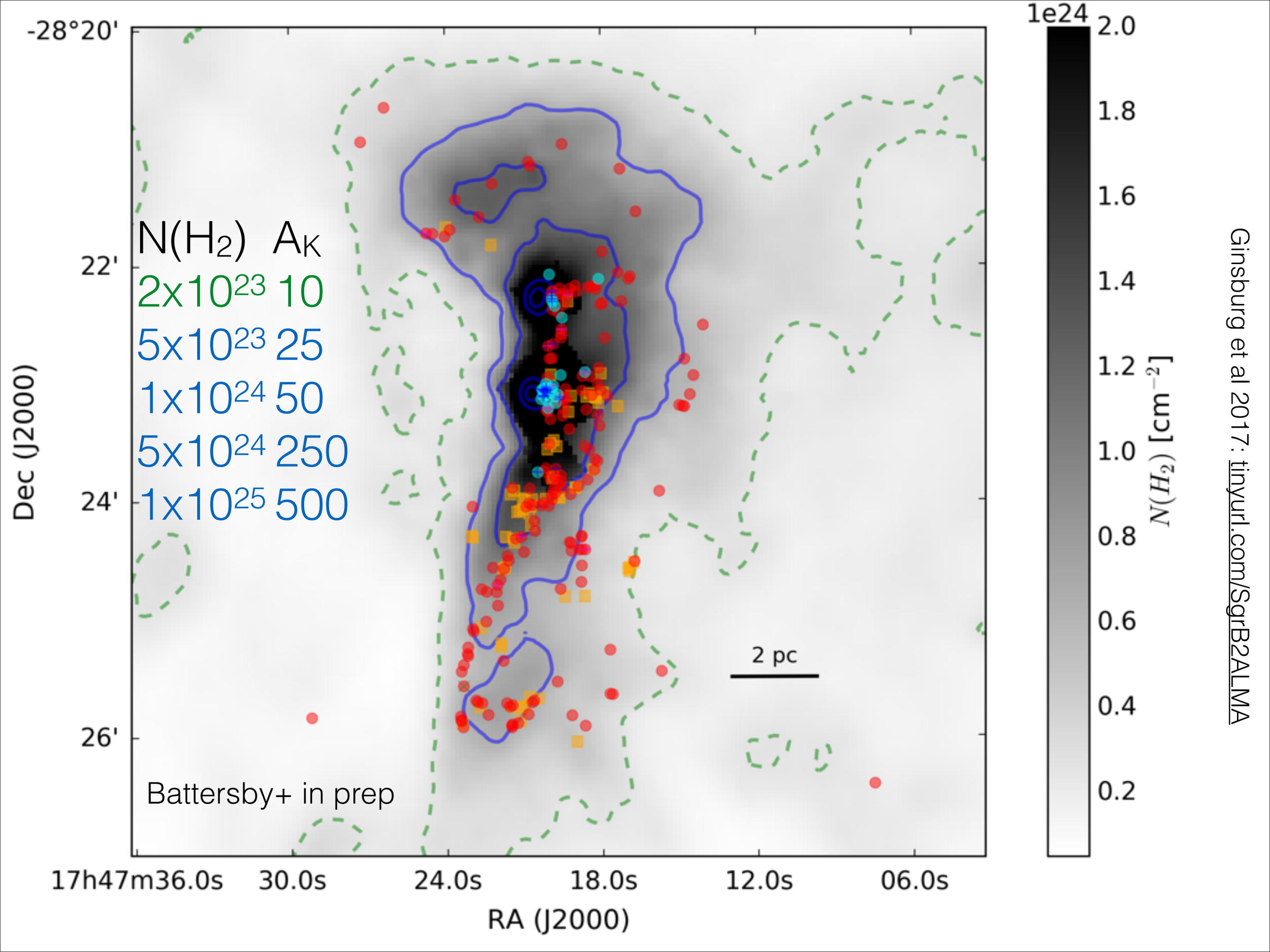
2.5 pc

17h47m36.0s
30.0s
24.0s
18.0s
12.0s
06.0s
RA (J2000)

4.8
4.0
3.2
2.4
1.6
0.8
0.0
−0.8
S_{3mm} [mJy beam^{-1}]

Ginsburg et al 2017: tinyurl.com/SgrB2ALMA


-28°20'
22'
24'
26'
Dec (J2000)
17h47m36.0s
30.0s
24.0s
18.0s
12.0s
06.0s
RA (J2000)
N(H2) AK
2x10^23 10
5x10^23 25
1x10^24 50
5x10^24 250
1x10^25 500
2 pc
Battersby+ in prep
1e24
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
N(H2) [cm^-2]
Ginsburg et al 2017: tinyurl.com/SgrB2ALMA


-28°20'
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N(H2) AK
2x10^23 10
5x10^23 25
1x10^24 50
5x10^24 250
1x10^25 500
2 pc
Battersby+ in prep
1e24
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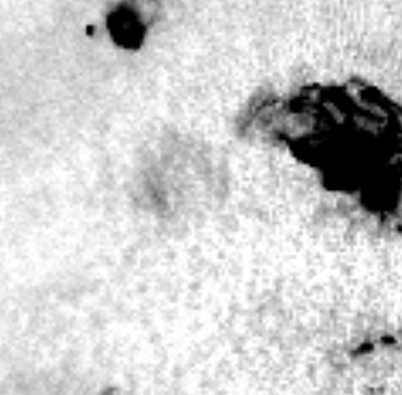
1.4
1.2
1.0
0.8
0.6
0.4
0.2
N(H2) [cm^-2]
Ginsburg et al 2017: tinyurl.com/SgrB2ALMA

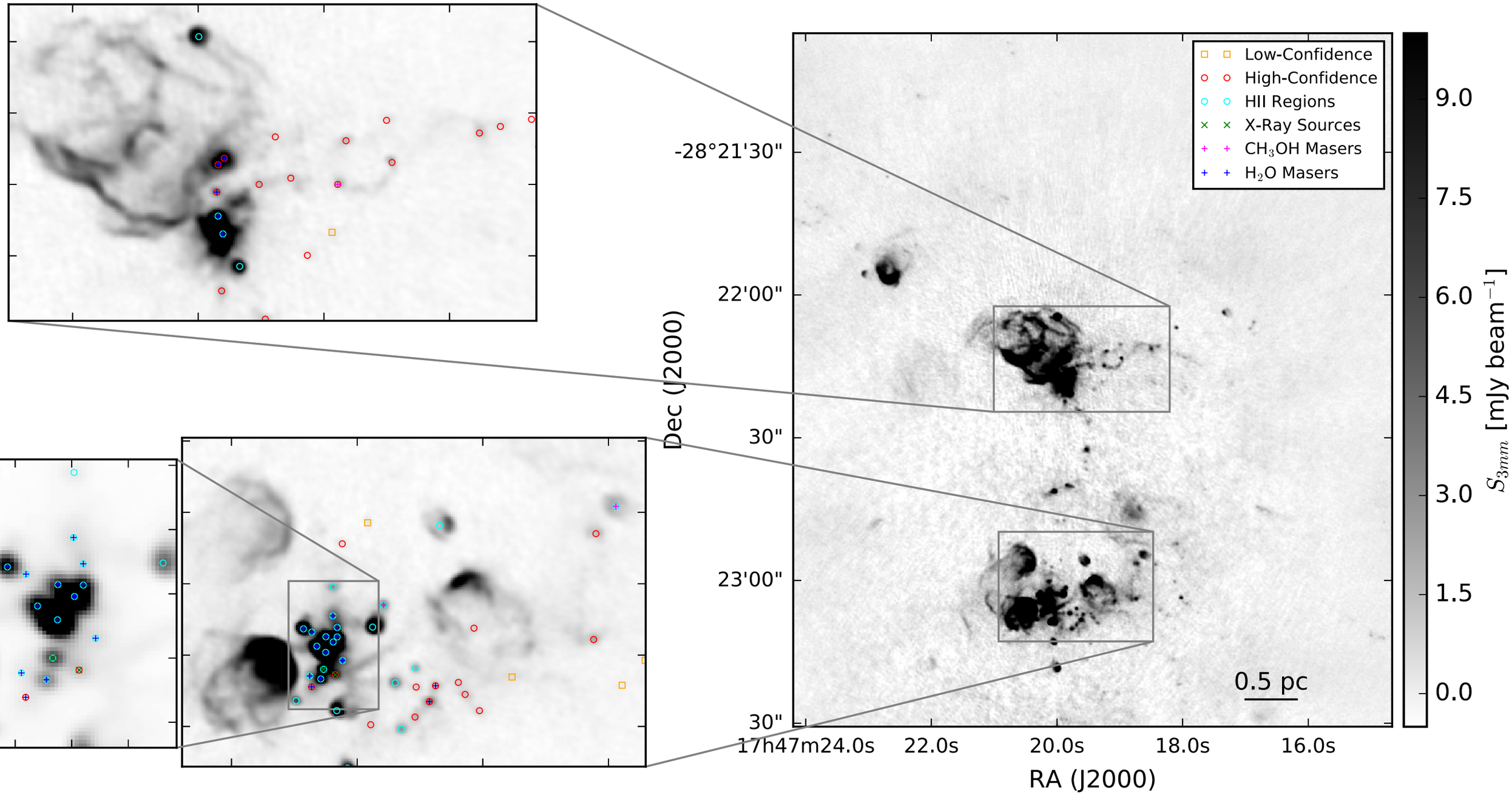
ALMA 3mm Continuum



ALMA 3mm Continuum

ALMA 3mm Continuum

A visual sample of the clustered regions



Ginsburg et al 2017: tinyurl.com/SgrB2ALMA

VLA 1.3 cm

Low-Confidence
High-Confidence
HII Regions
X-Ray Sources
CH_3OH Masers
H_2O Masers

0.5 pc

18.0s
16.0s

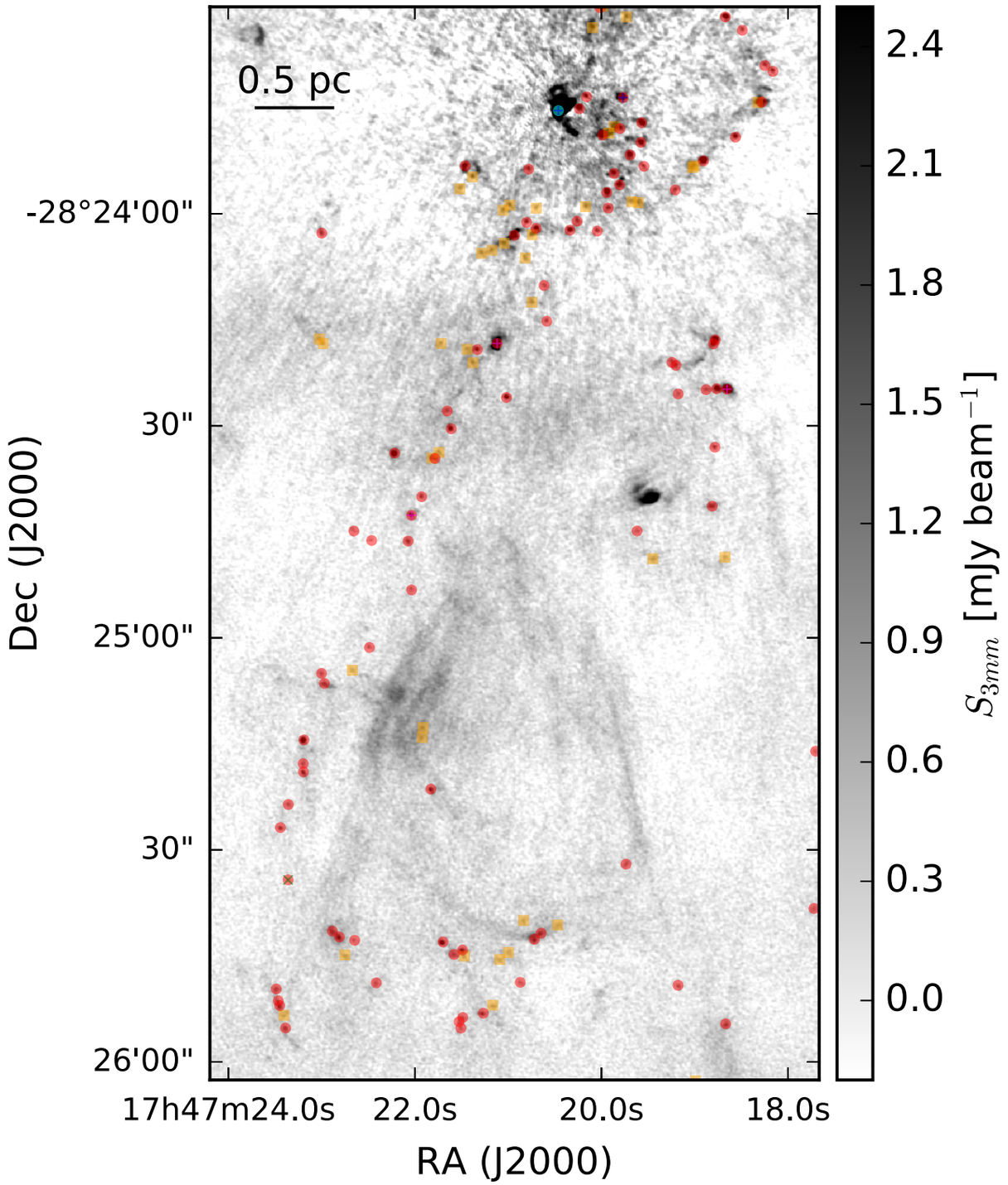
00)

9.0
7.5
6.0
4.5
3.0
1.5
0.0

S_{3mm} [mJy beam^{-1}]

Ginsburg et al 2017: tinyurl.com/SgrB2ALMA

…and the unclustered



This population is newly discovered, and is the first clear sign of star formation in the CMZ outside of dense clusters

Ginsburg et al 2017: tinyurl.com/SgrB2ALMA

Sgr B2 high-confidence
Sgr B2 low-confidence
Sgr B2 HII

We have a catalog of sources with only 3mm detections.

Are they YSOs?

$N(cores)$

S_{3mm} (Jy)

1. Age estimate for the distributed population in DS

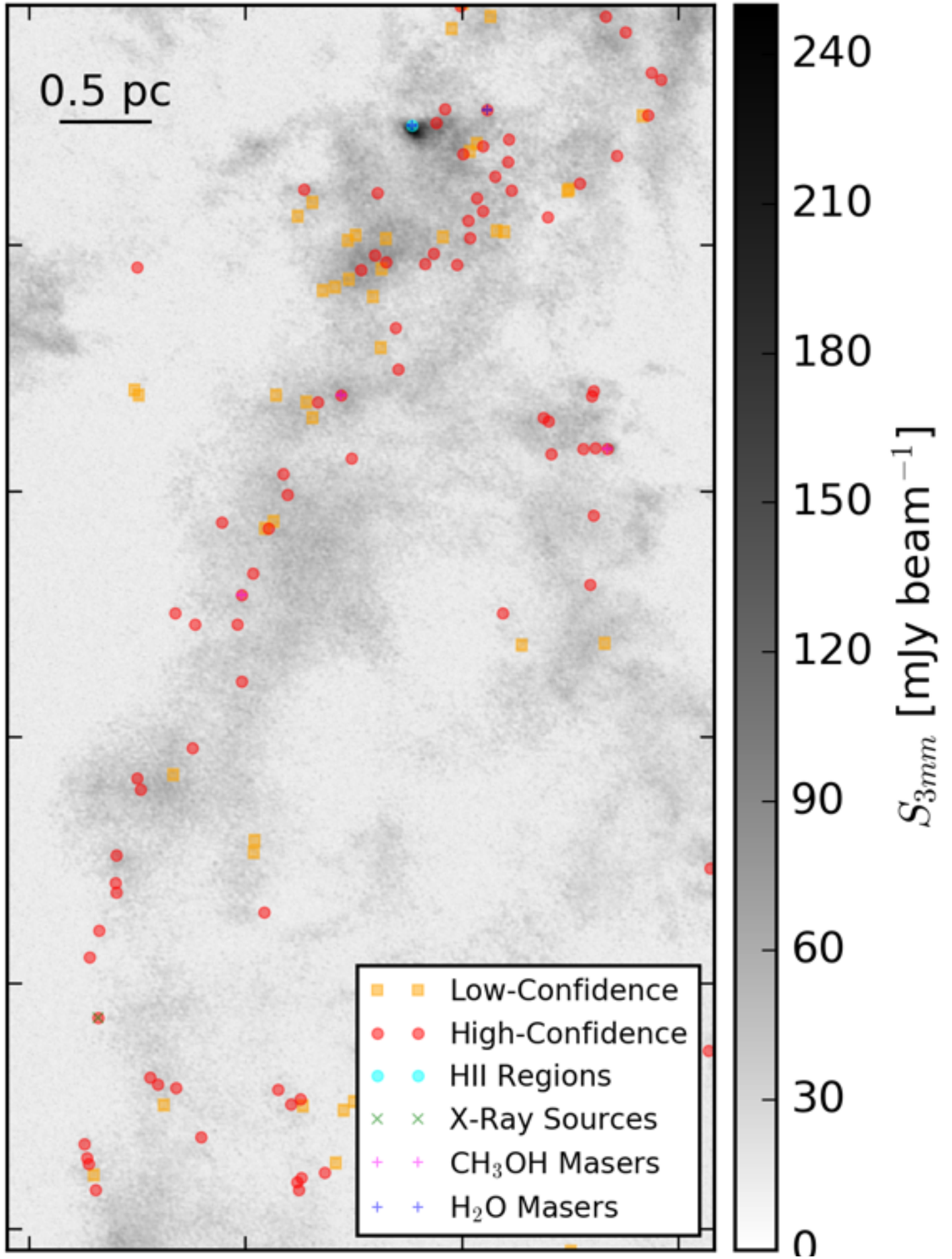
Gas σ_v ~ 10 km/s

"Ridge" width r~0.5 pc

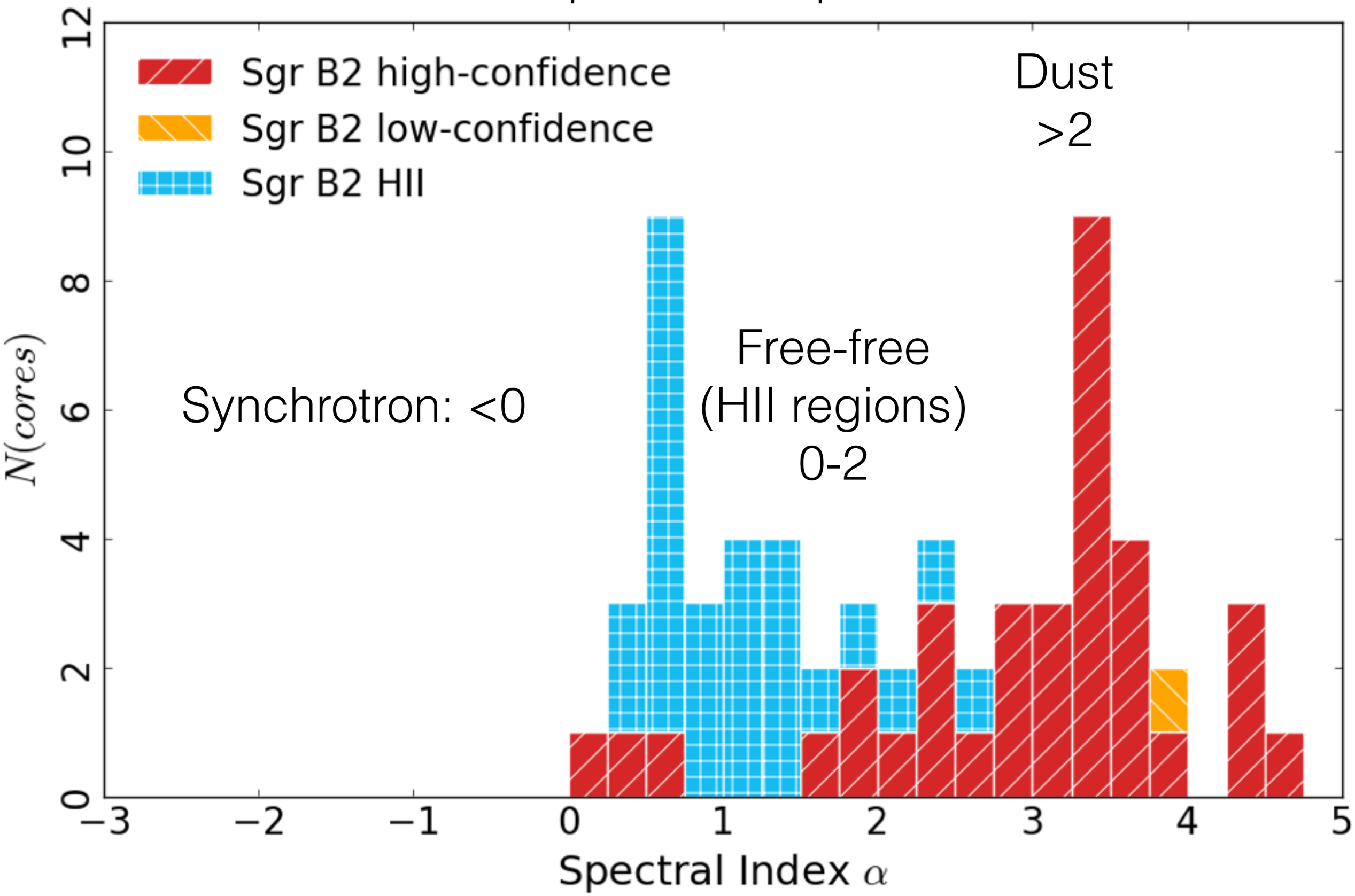
Most sources within 0.5 pc of the ridge

Diffusion (dispersion) timescale
$t = r / \sigma_v = 5x10^4$ yr

(sims suggest $t = 5\ (r/\sigma_v) = 2.5x10^5$ yr
Offner+2009)

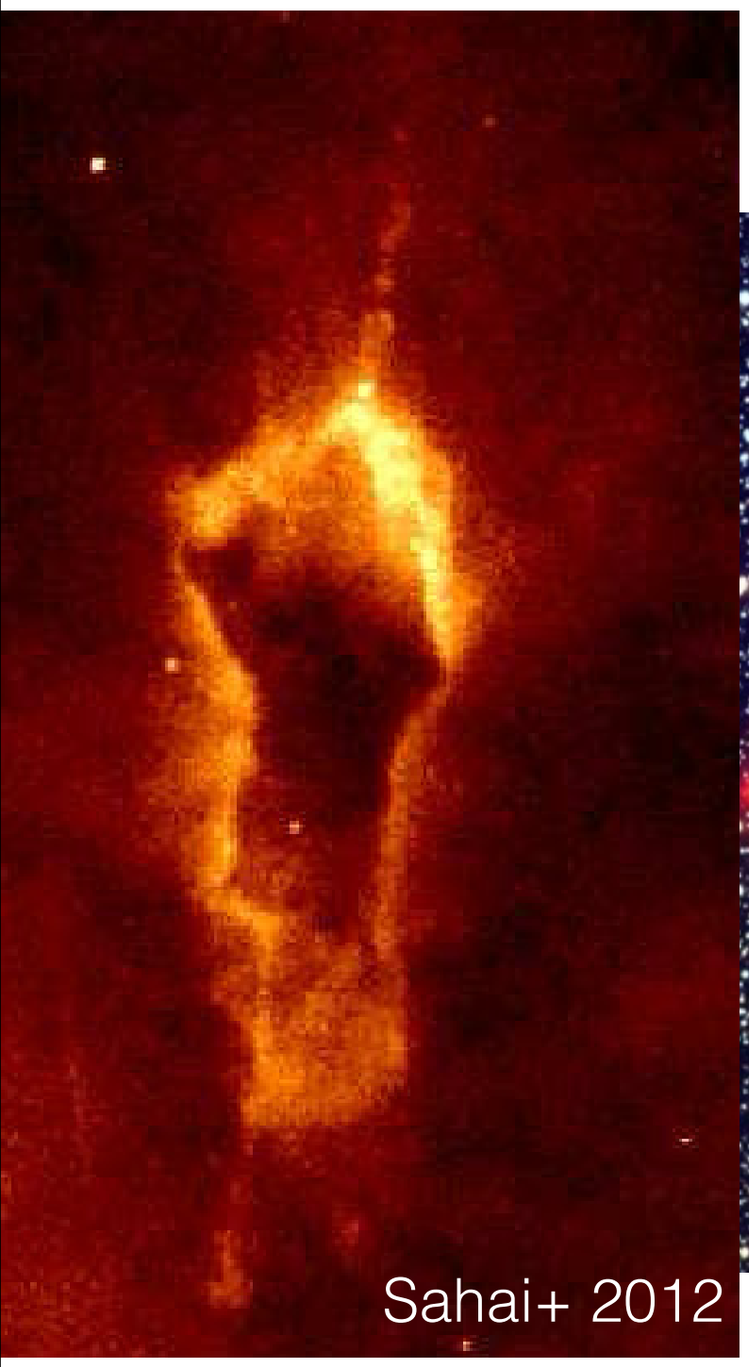


2. Spectral Shape



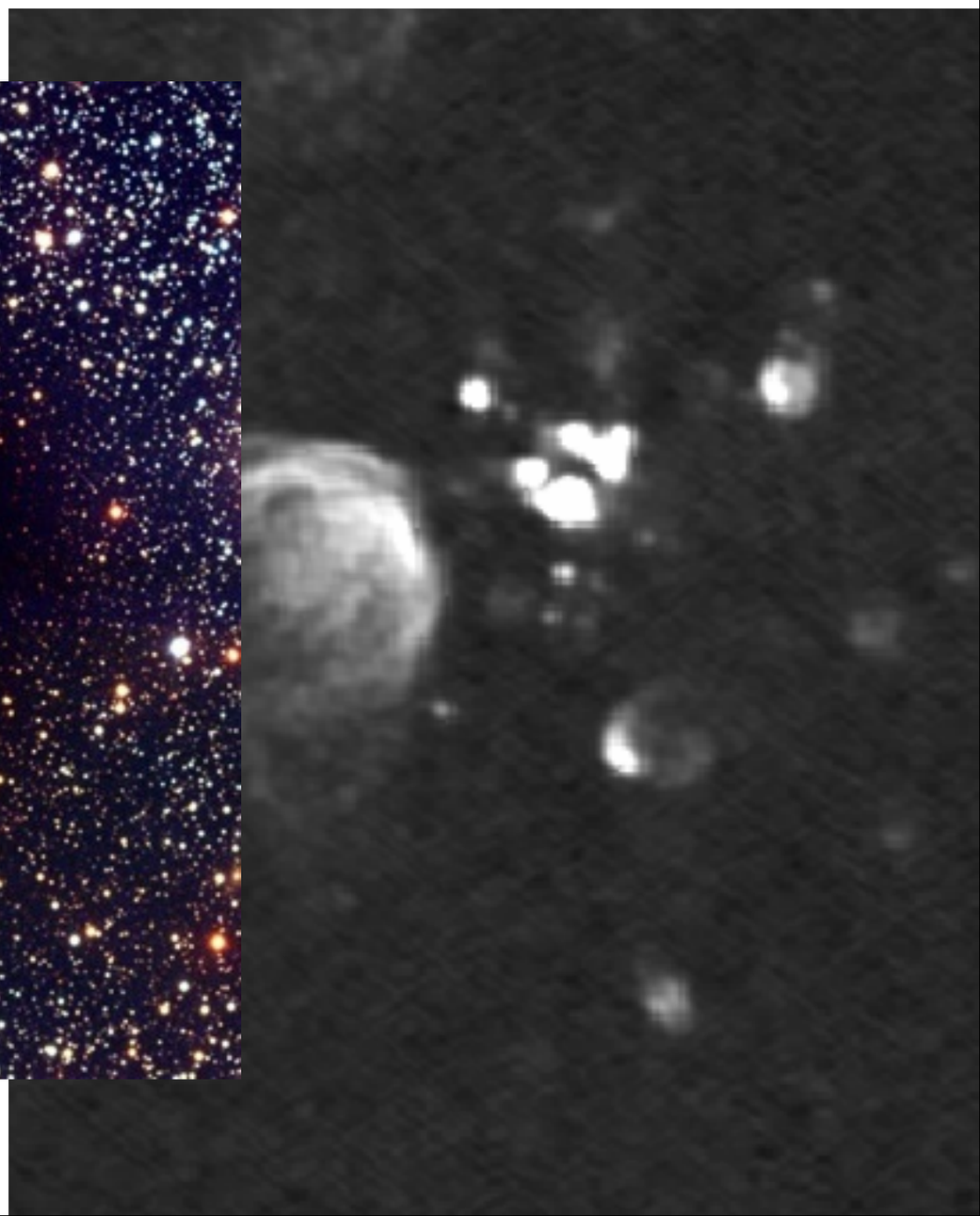
3. Rule out alternatives

frEGGs:
Too compact, wrong locations

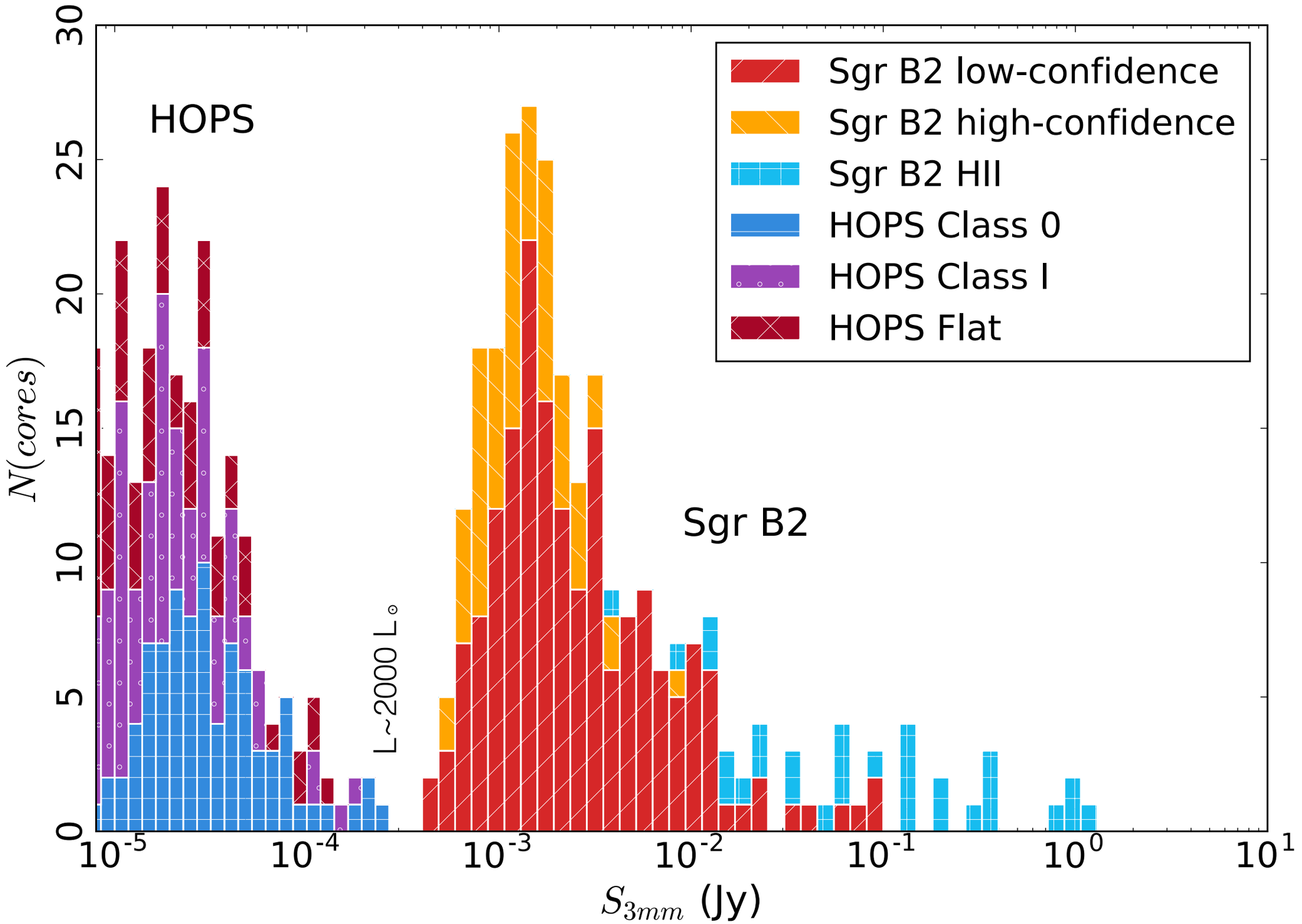


Prestellar Cores:
Too bright, implied mass too large

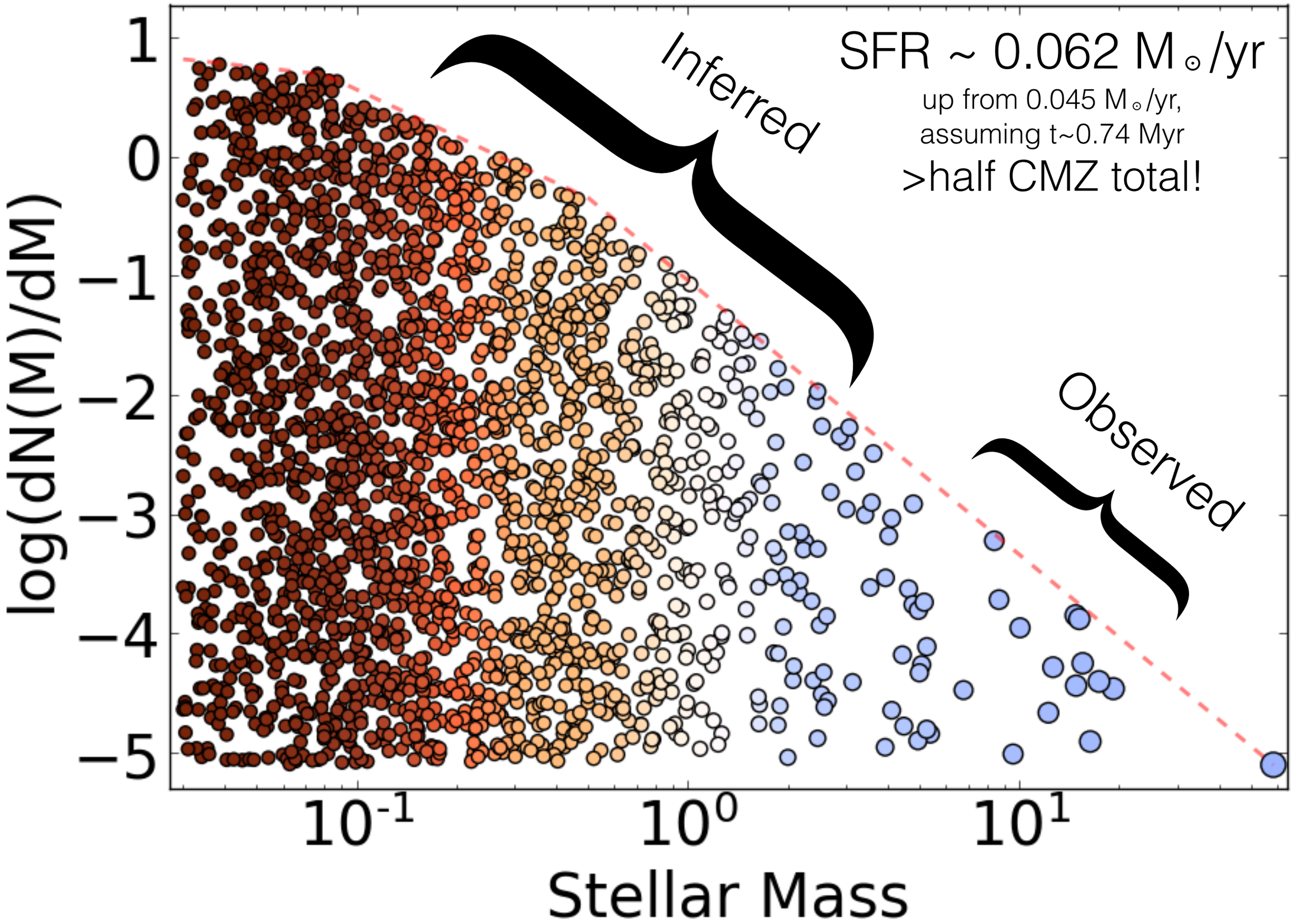
Compact HII regions:
Can explain some, but not most

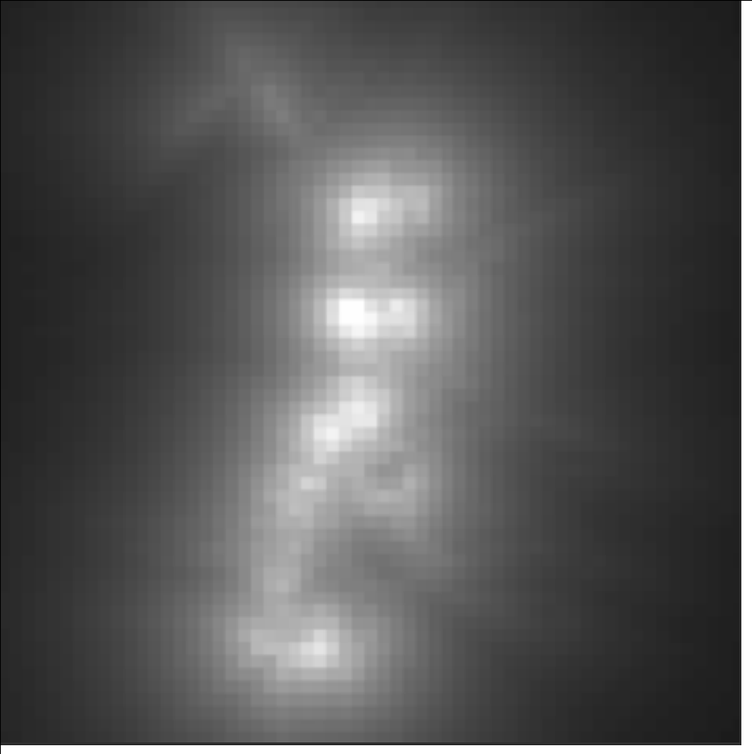


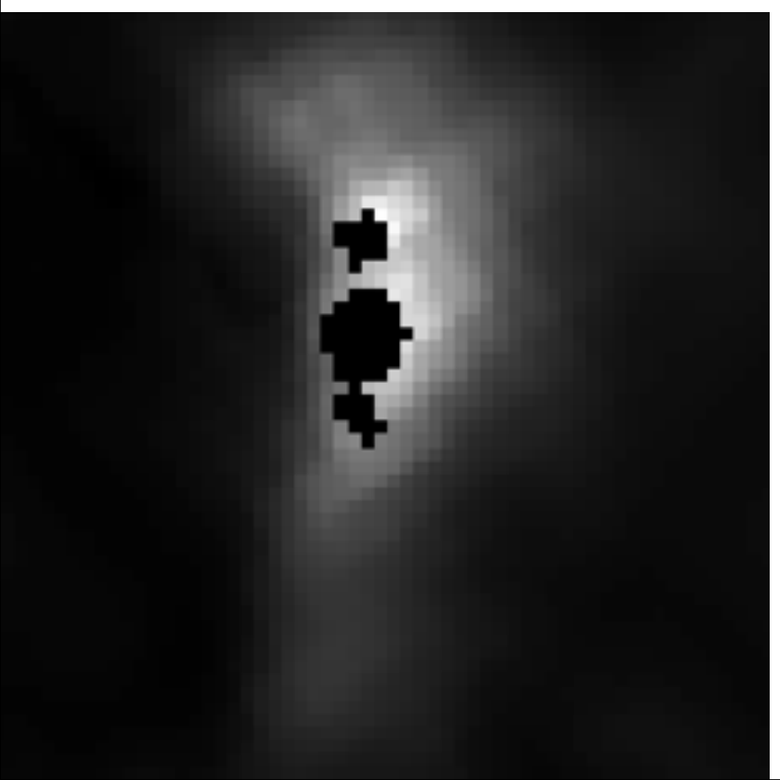
Young, Dust-dominated:
Most are HMYSOs. Some are HCHIIs.
All will likely form massive stars.

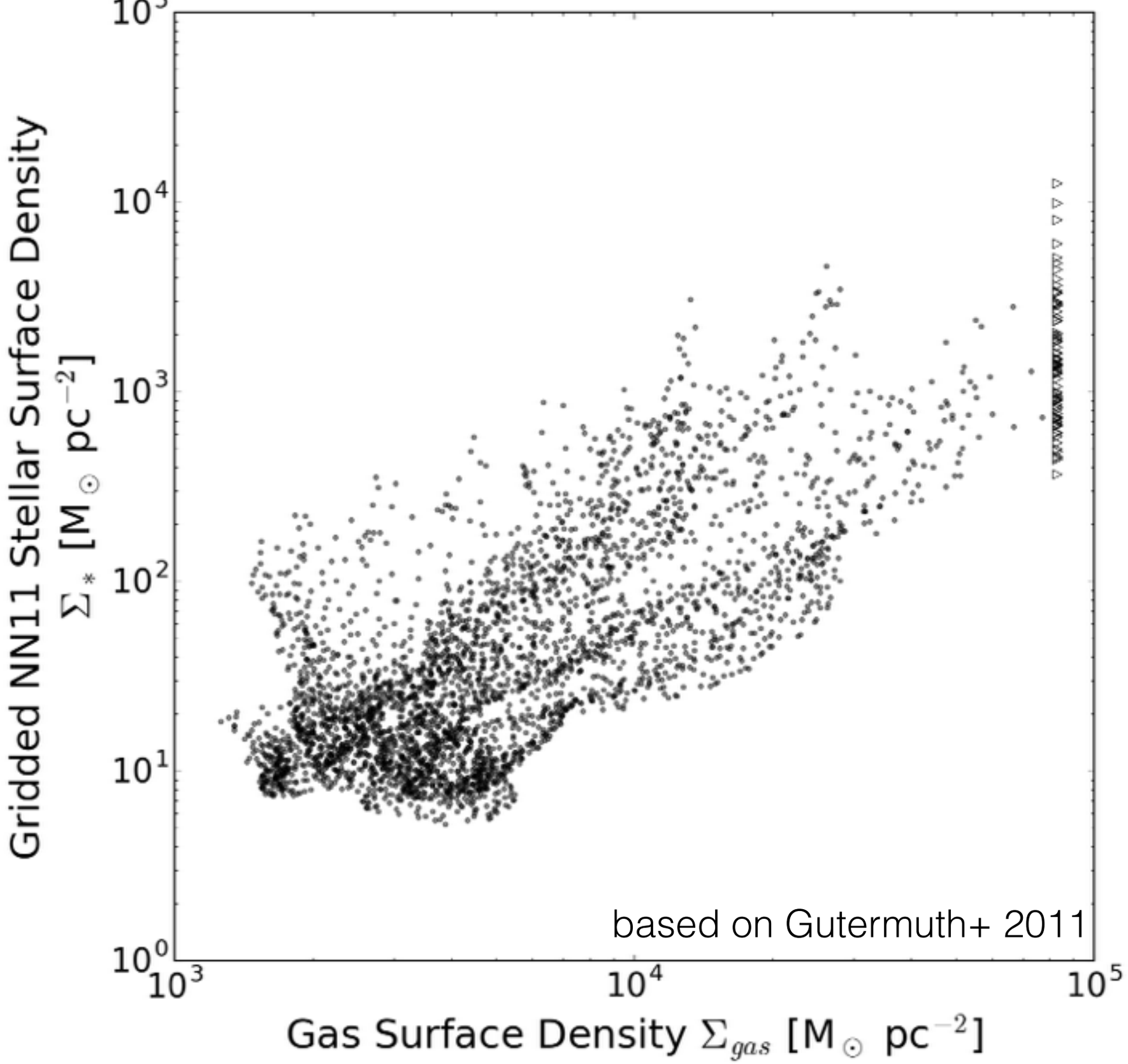


Estimate total (proto)stellar mass using an assumed IMF

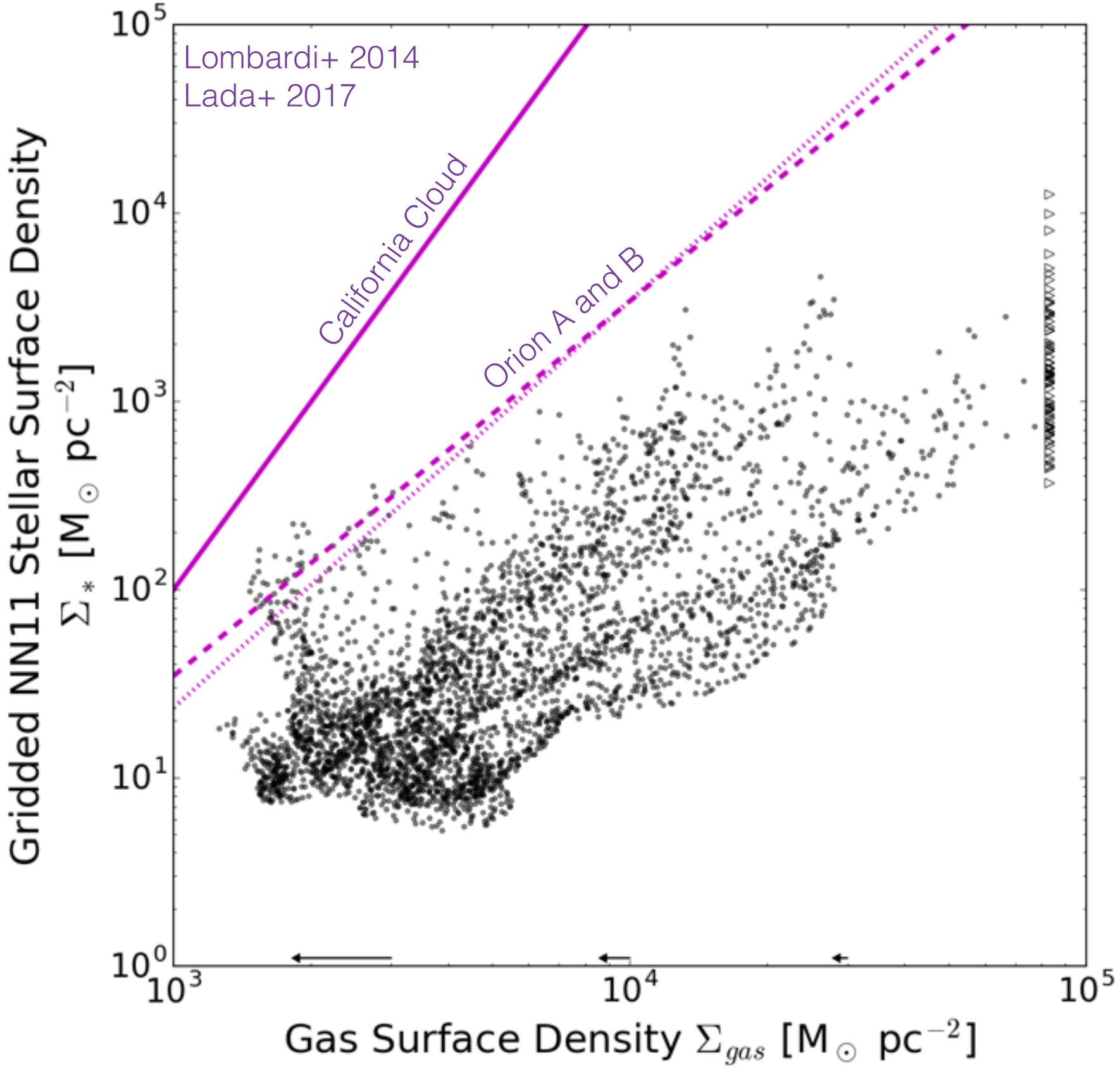








Ginsburg et al 2017: tinyurl.com/SgrB2ALMA



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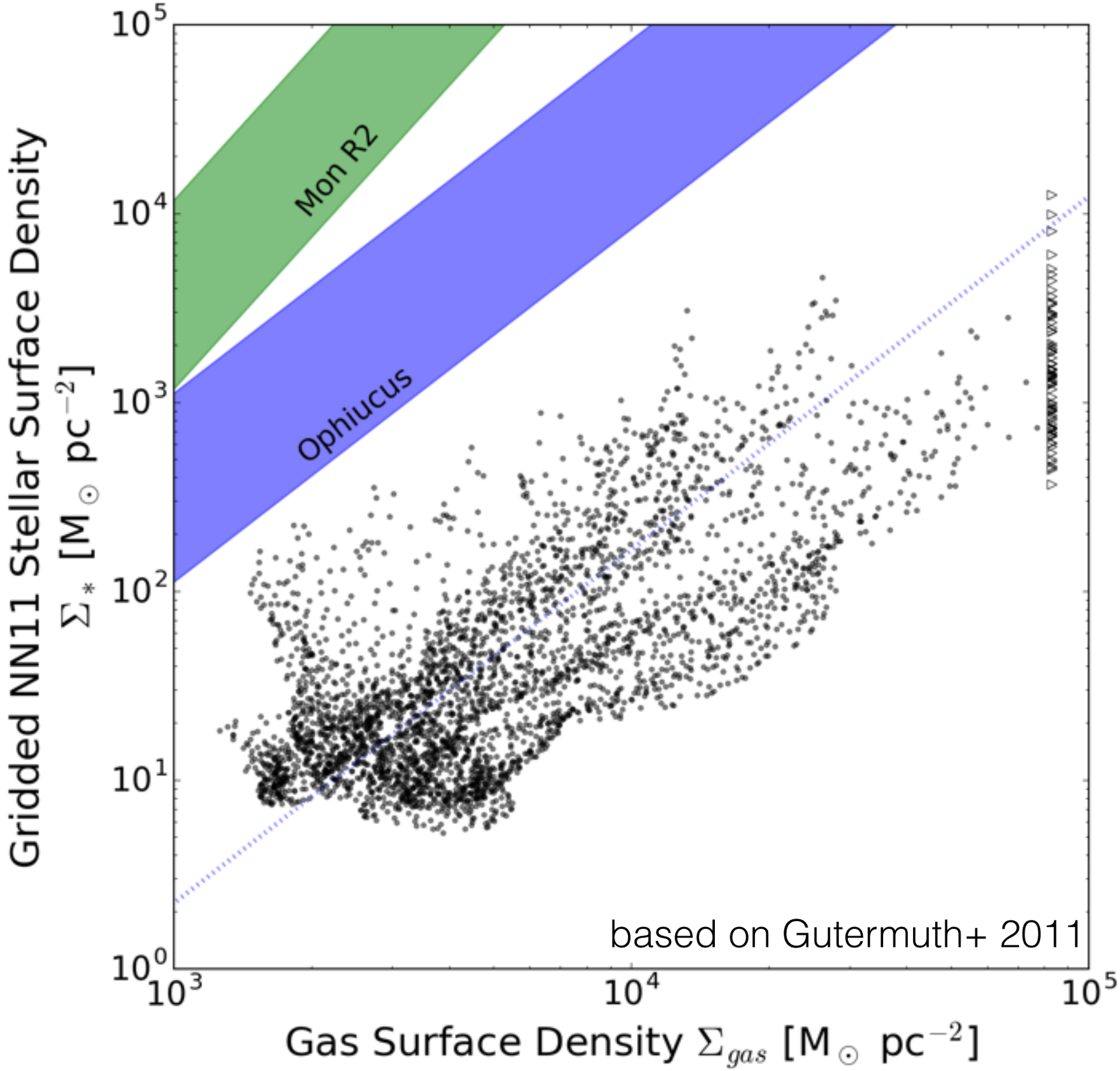
Sgr B2 does not fit on Σ_{gas}-Σ_{star} relations extrapolated from local clouds



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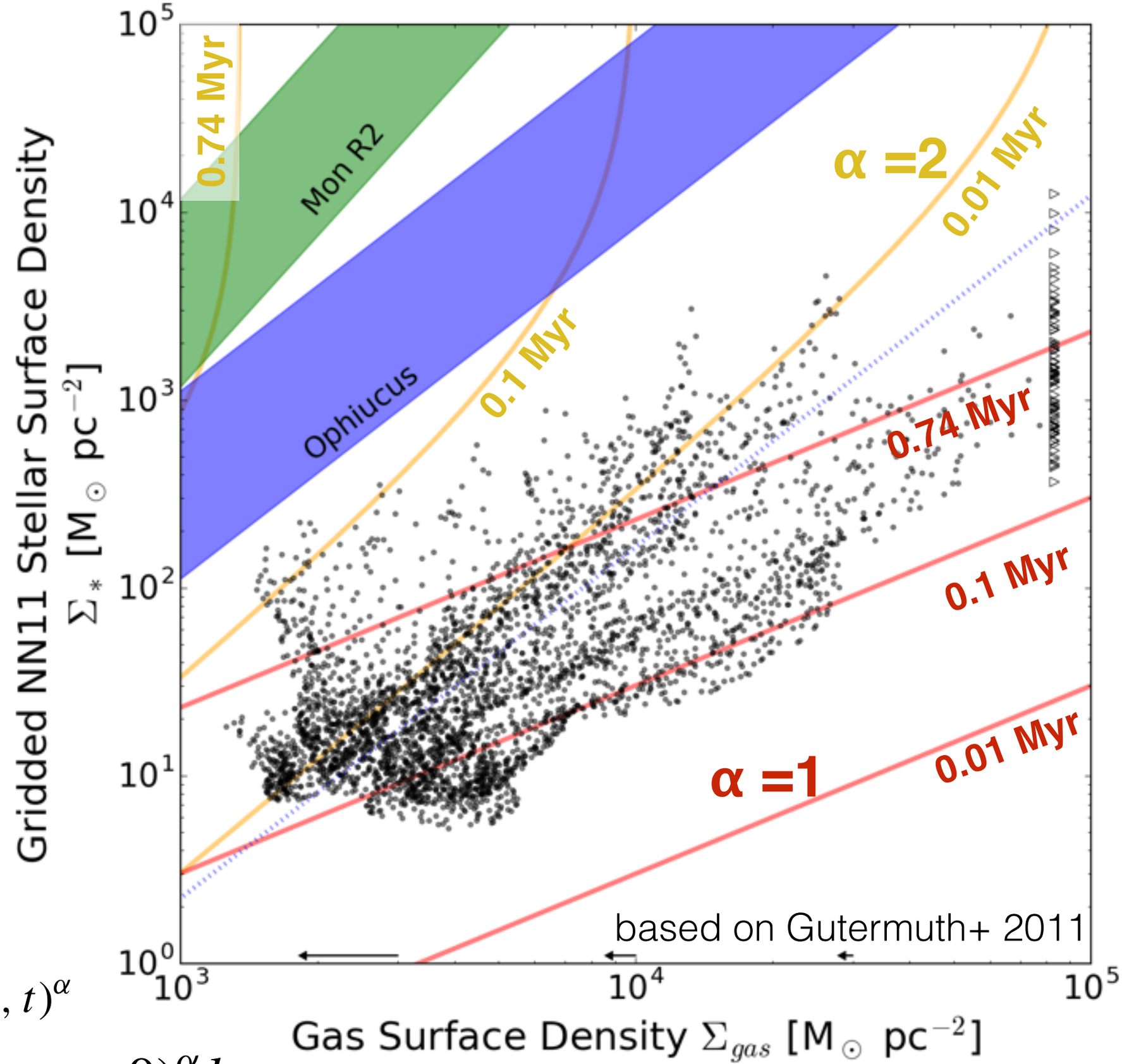
Sgr B2 does not fit on Σ_{gas}-Σ_{star} relations extrapolated from local clouds

A linear relation fits the Sgr B2 data, but not the local



$$\frac{\partial \Sigma_\star(x,\,y,\,t)}{\partial t} = ck\Sigma_{\rm gas}(x,\,y,\,t)^\alpha$$

$$\Sigma_\star(x,\,y,\,t) = c\Sigma_{\rm gas}(x,\,y,\,0)^\alpha kt$$

Ginsburg et al 2017: tinyurl.com/SgrB2ALMA

SF in the CMZ is lower than predicted and allows us to test SF relations.
Sgr B2 is vigorously forming stars, and not just in the main protoclusters

Surface-density star formation relations can't fit both Sgr B2 and local clouds.
The critical density for SF is higher in CMZ clouds