Extended Star Formation in the Sgr B2 cloud

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Ginsburg et al 2018: tinyurl.com/SgrB2ALMA-2

radio-astro-tools

- radio-astro-tools.github.io
- spectral-cube, pvextractor, radio-beam
- built for general users, not just blackbelts
    - but for this audience, makes many tasks more convenient
- see also astroquery.alma, astroquery.nrao, astroquery.splatalogue

What gas conditions govern the star formation rate?

What gas conditions control the stellar initial mass function?

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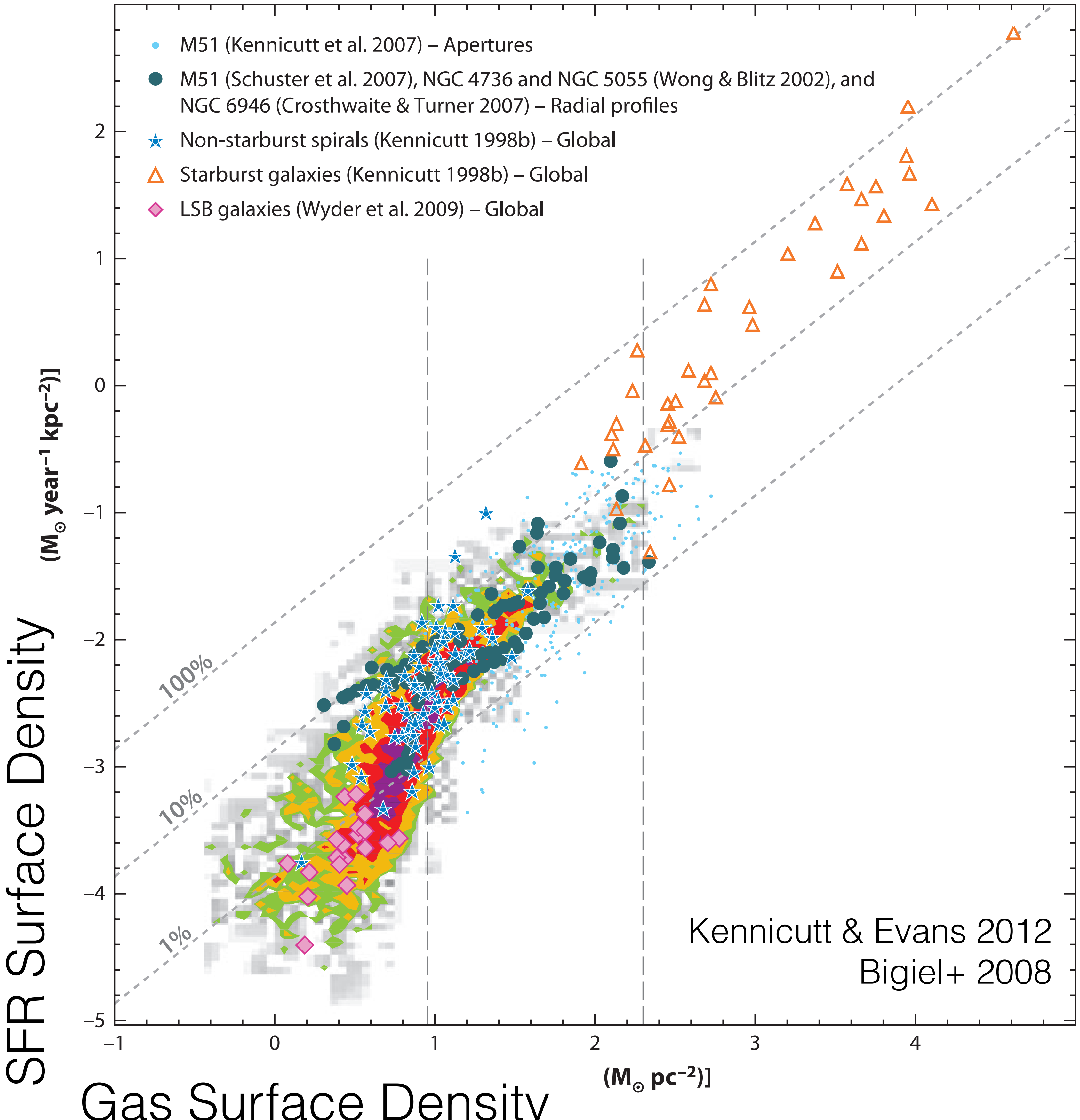
Transient, pulsar folks: You care because event rates are

$N \sim (N_{galaxies})\ (SFR)\ (\int IMF)$

Also, dust & gas modify observability of events,

so it's important where & when they occur

Star Formation in Galaxies

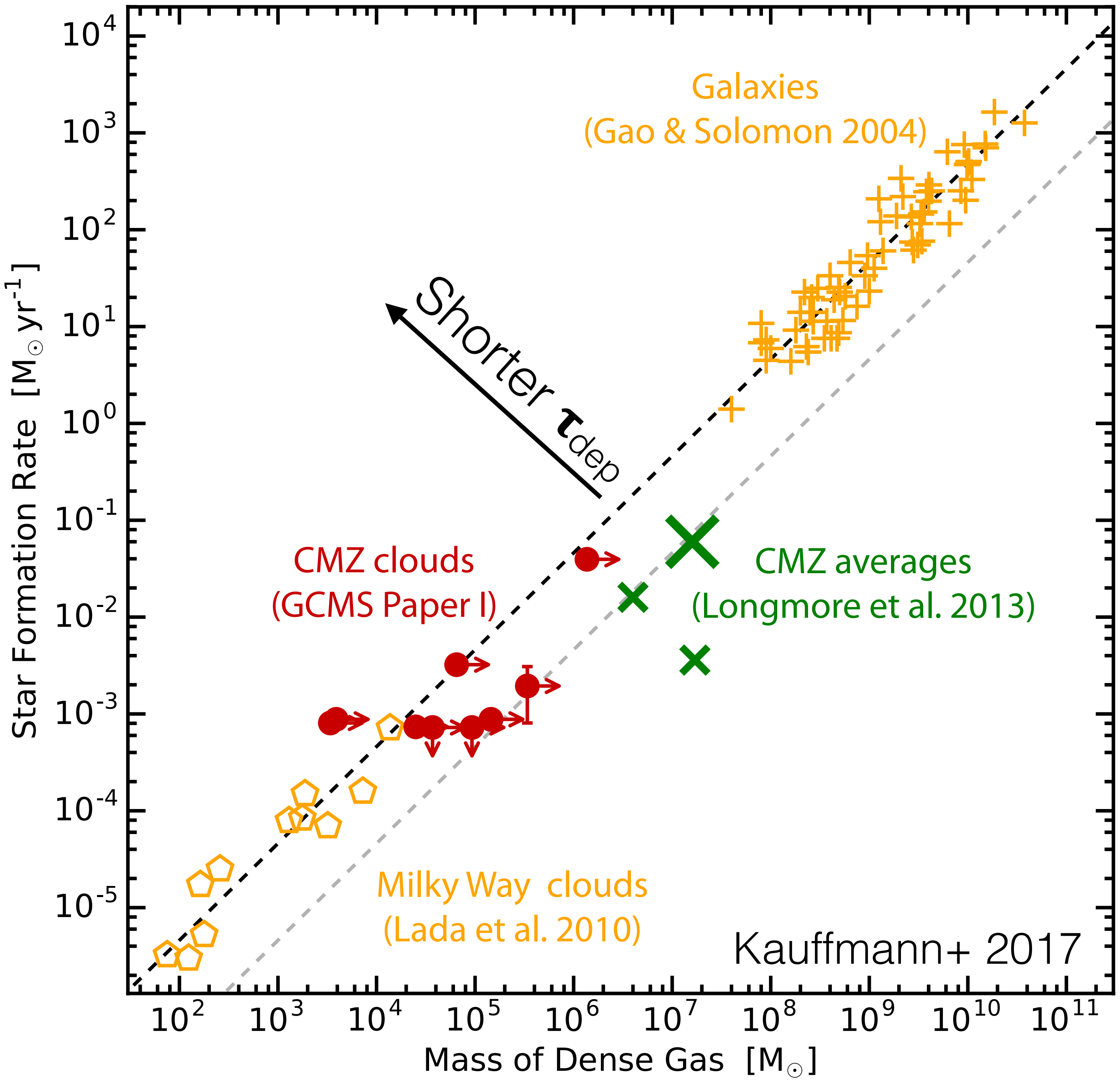


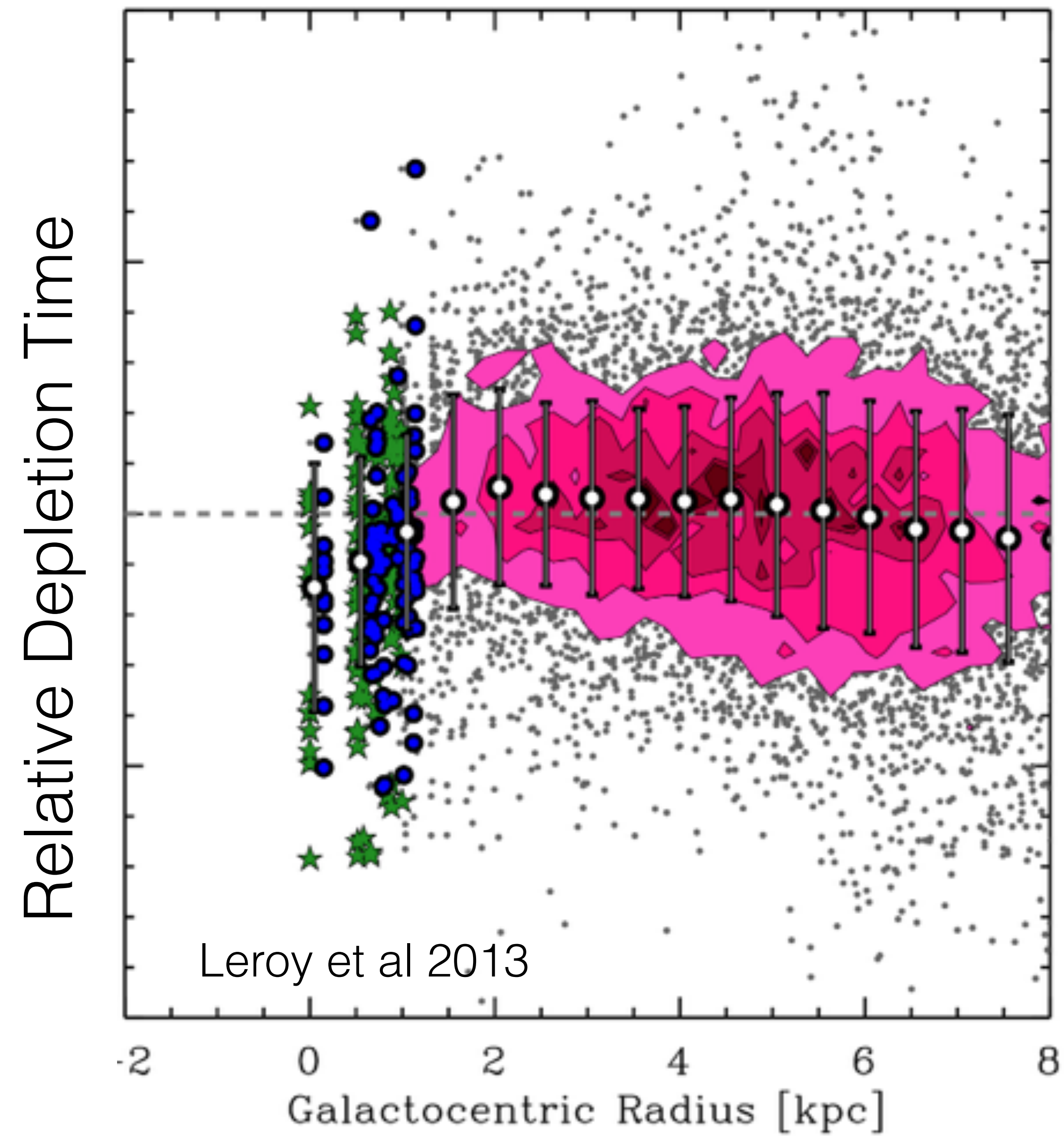
Generally follows the Kennicutt-Schmidt relation, but this is empirical & much of the scatter comes from local physical effects.

Star Formation in the Galactic Center

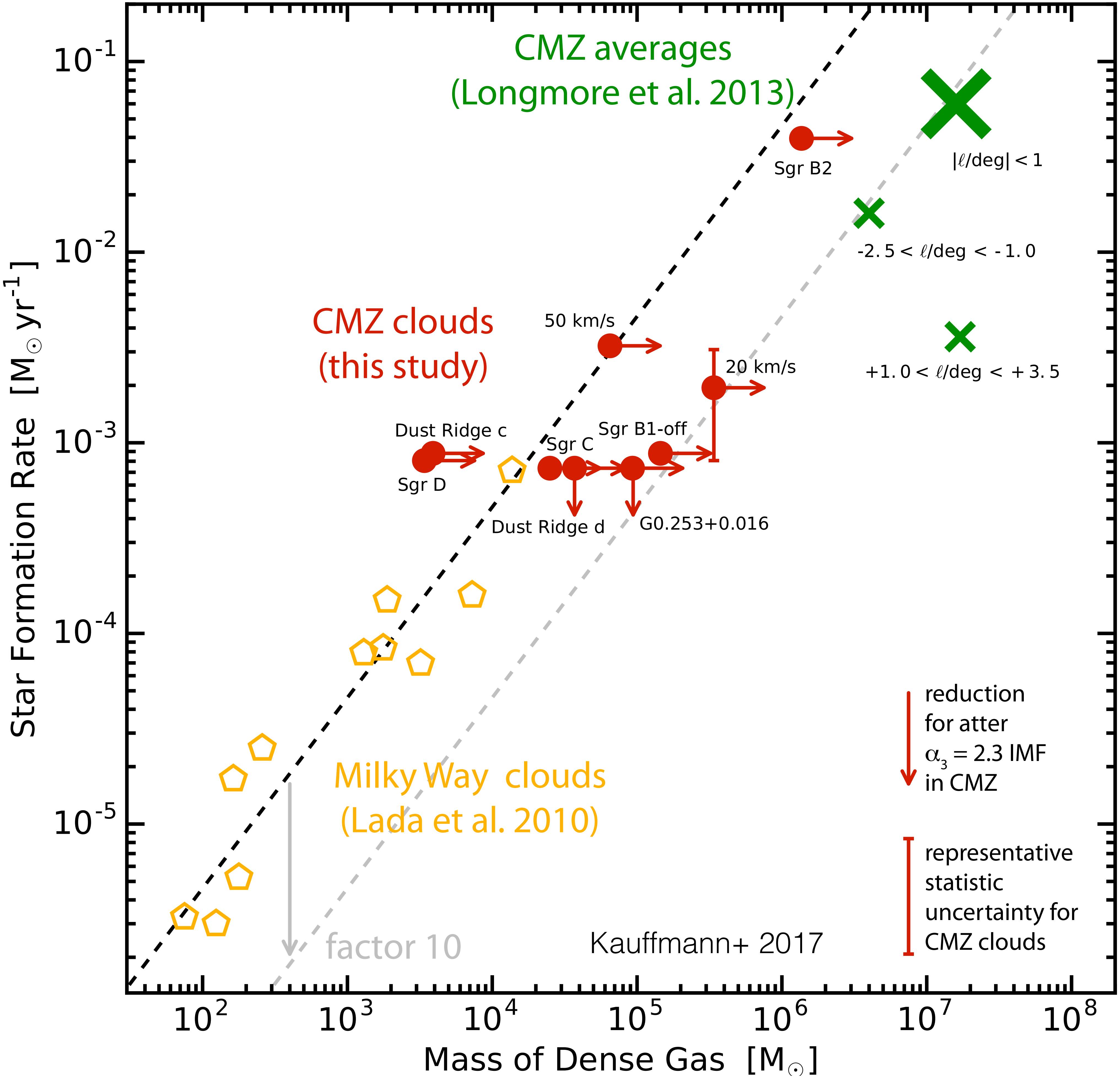
Our Galactic center has a low SFR per dense gas mass
(a long apparent depletion timescale $\tau_{dep} \sim M_{gas}/SFR$)

Galaxy centers have shorter τ_{dep} (but higher variance in τ_{dep})





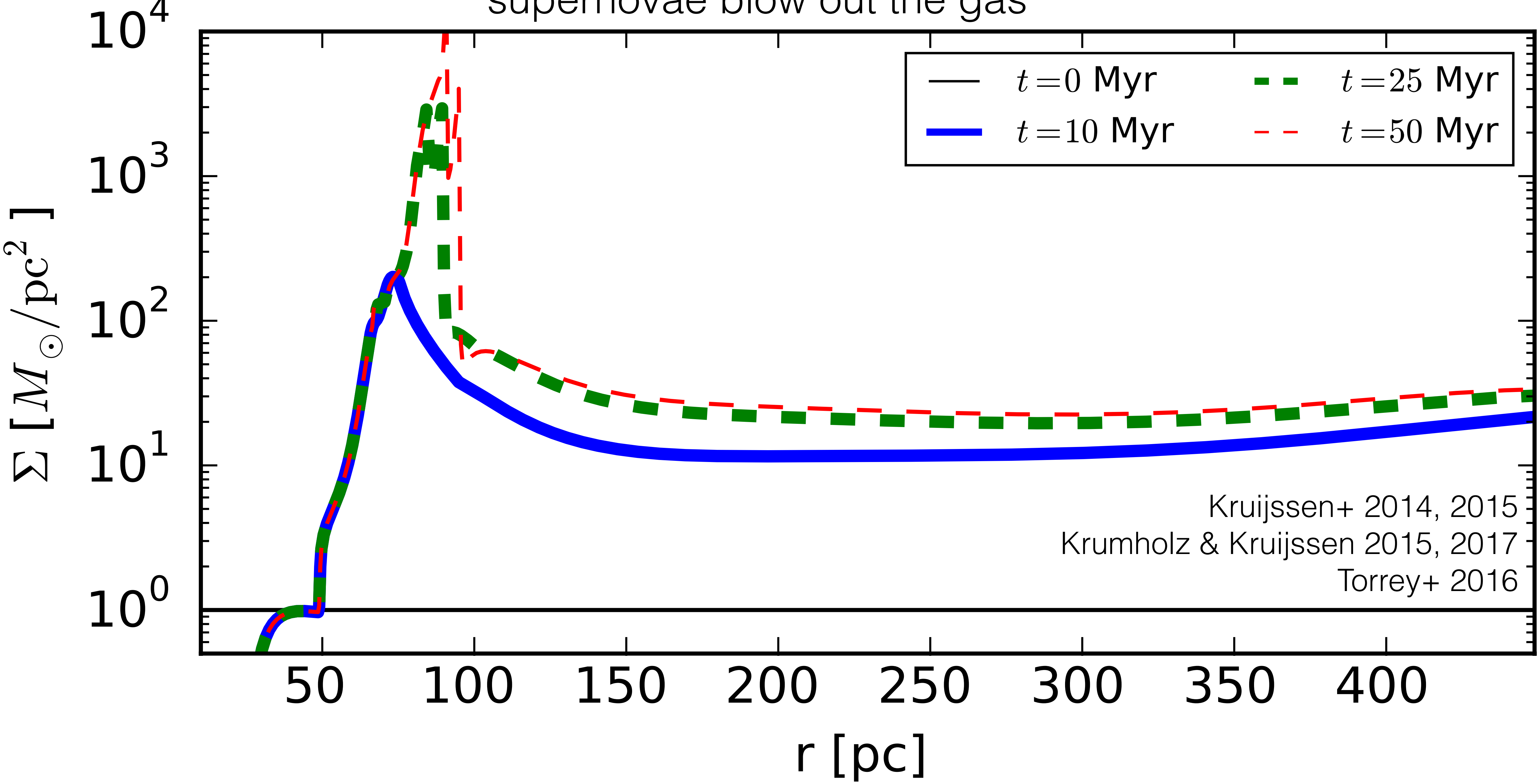
The discrepancy occurs on both global and local scales

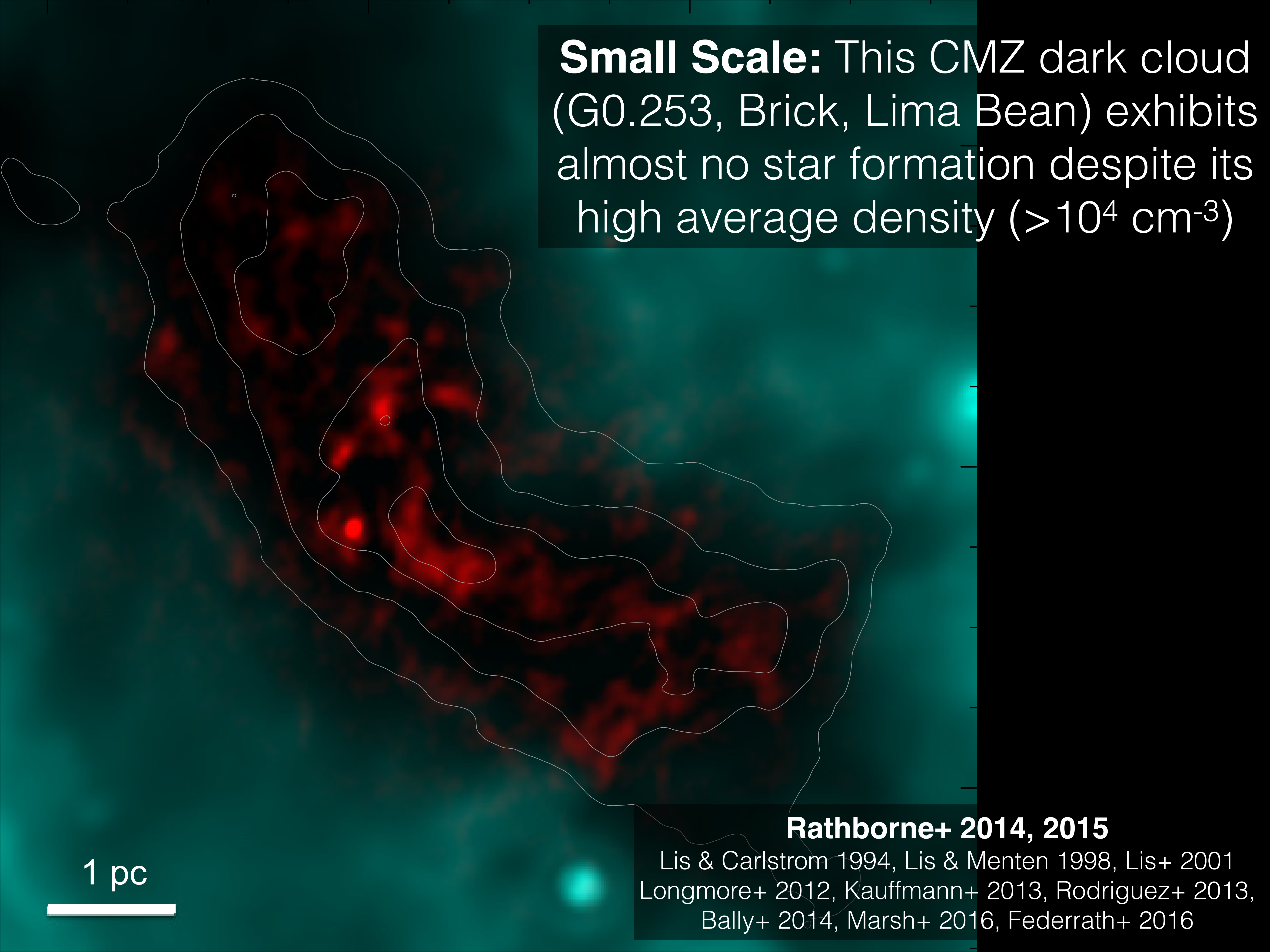


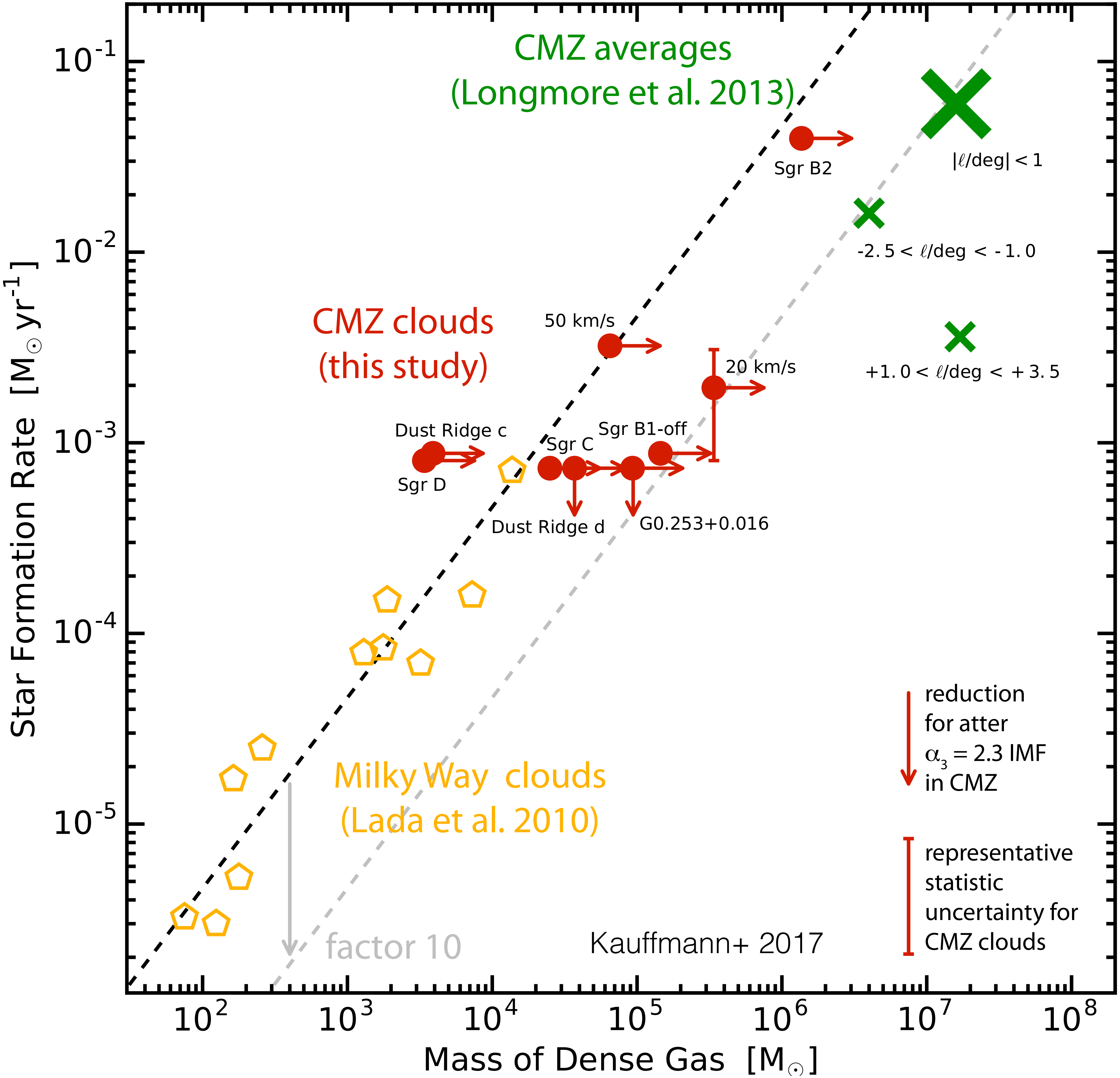
Large-scale:
CMZ SFR is low because star formation is bursty

Gas is fed into the CMZ “ring” by the Galactic bar.
Accreted gas is highly turbulent.

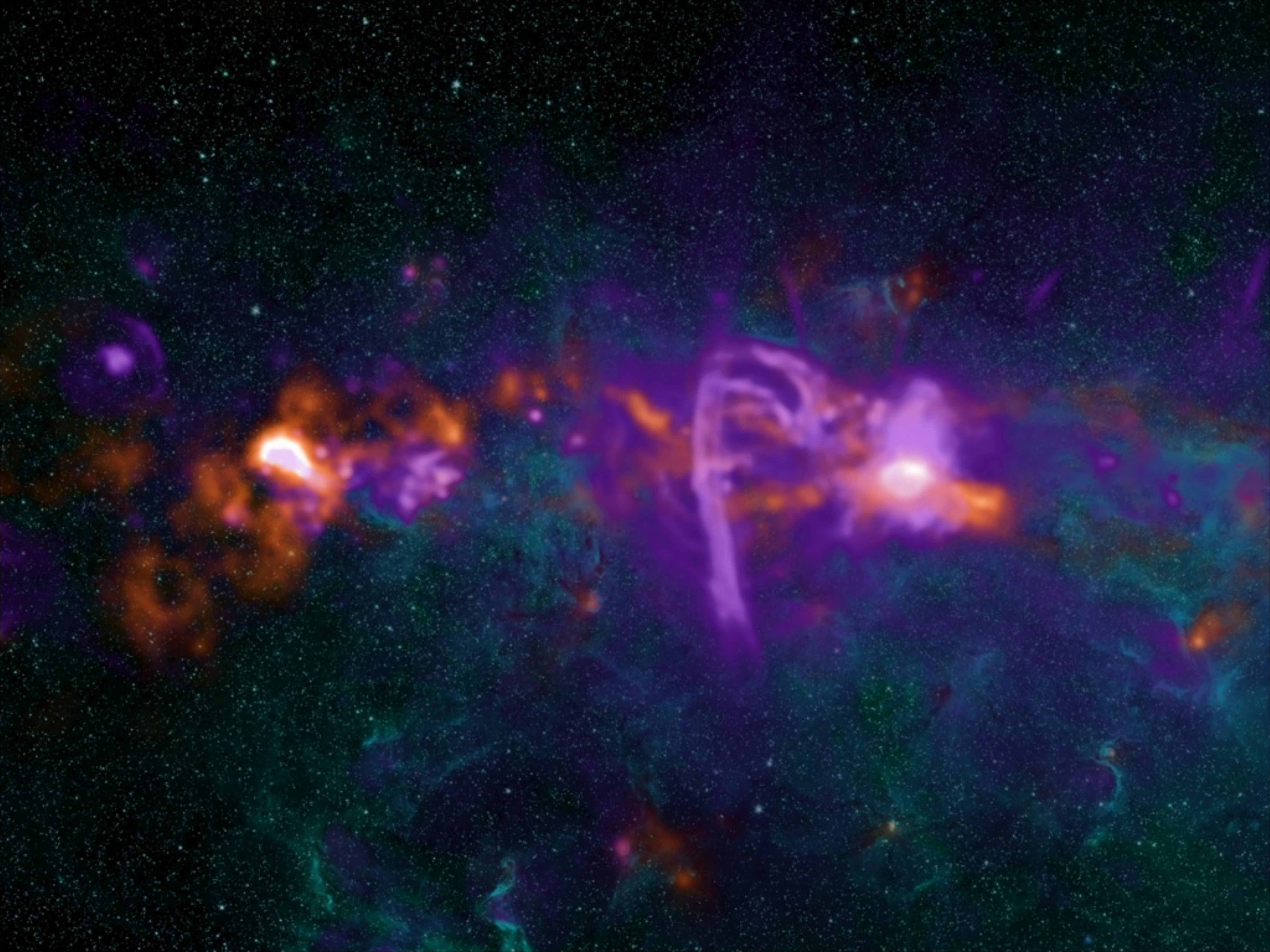
Once enough gas is in the ring, starbursts occur and radiation and supernovae blow out the gas



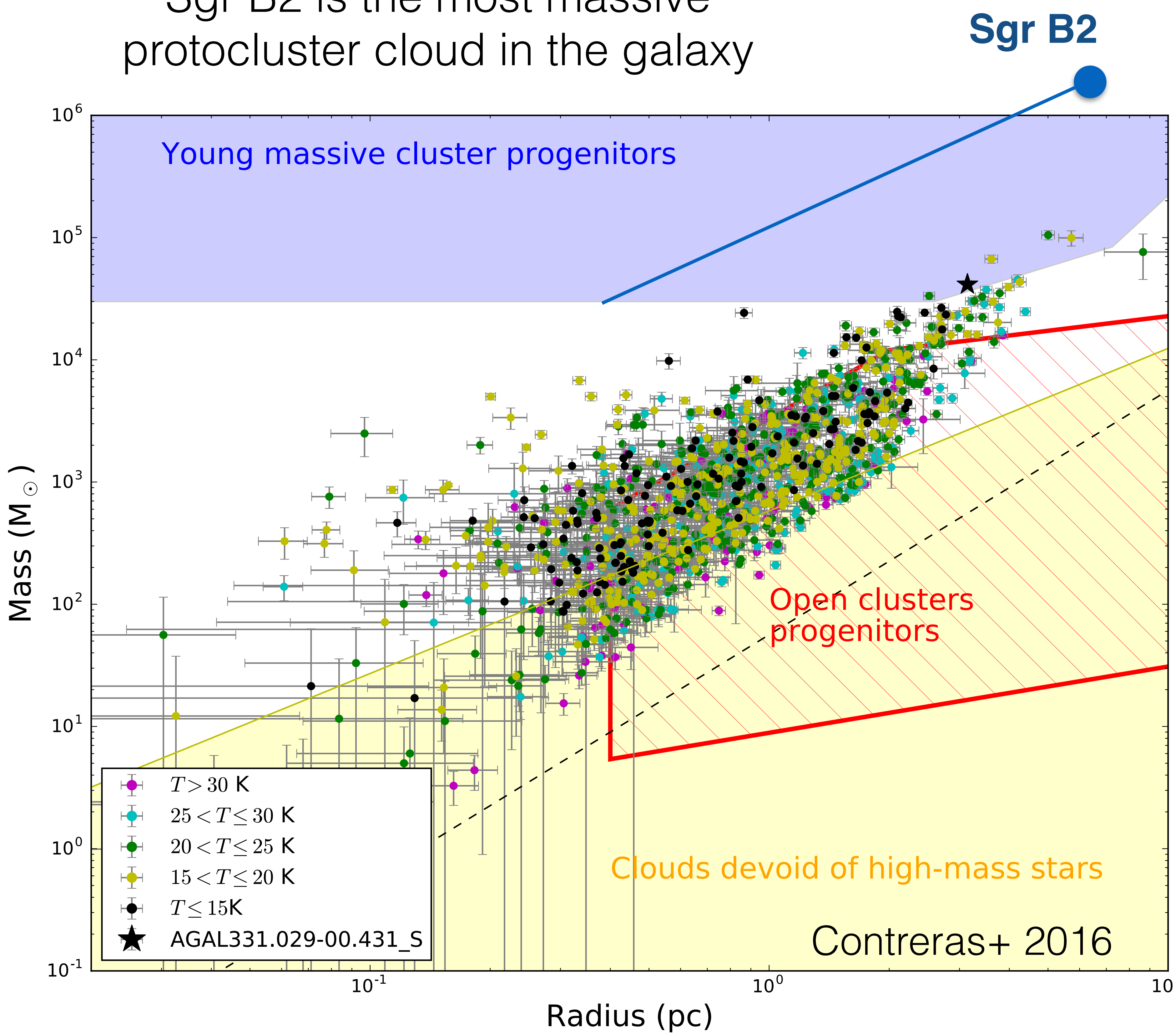

Small Scale: This CMZ dark cloud (G0.253, Brick, Lima Bean) exhibits almost no star formation despite its high average density ($>10^4$ cm^{-3})
Rathborne+ 2014, 2015
Lis & Carlstrom 1994, Lis & Menten 1998, Lis+ 2001
Longmore+ 2012, Kauffmann+ 2013, Rodriguez+ 2013,
Bally+ 2014, Marsh+ 2016, Federrath+ 2016
1 pc

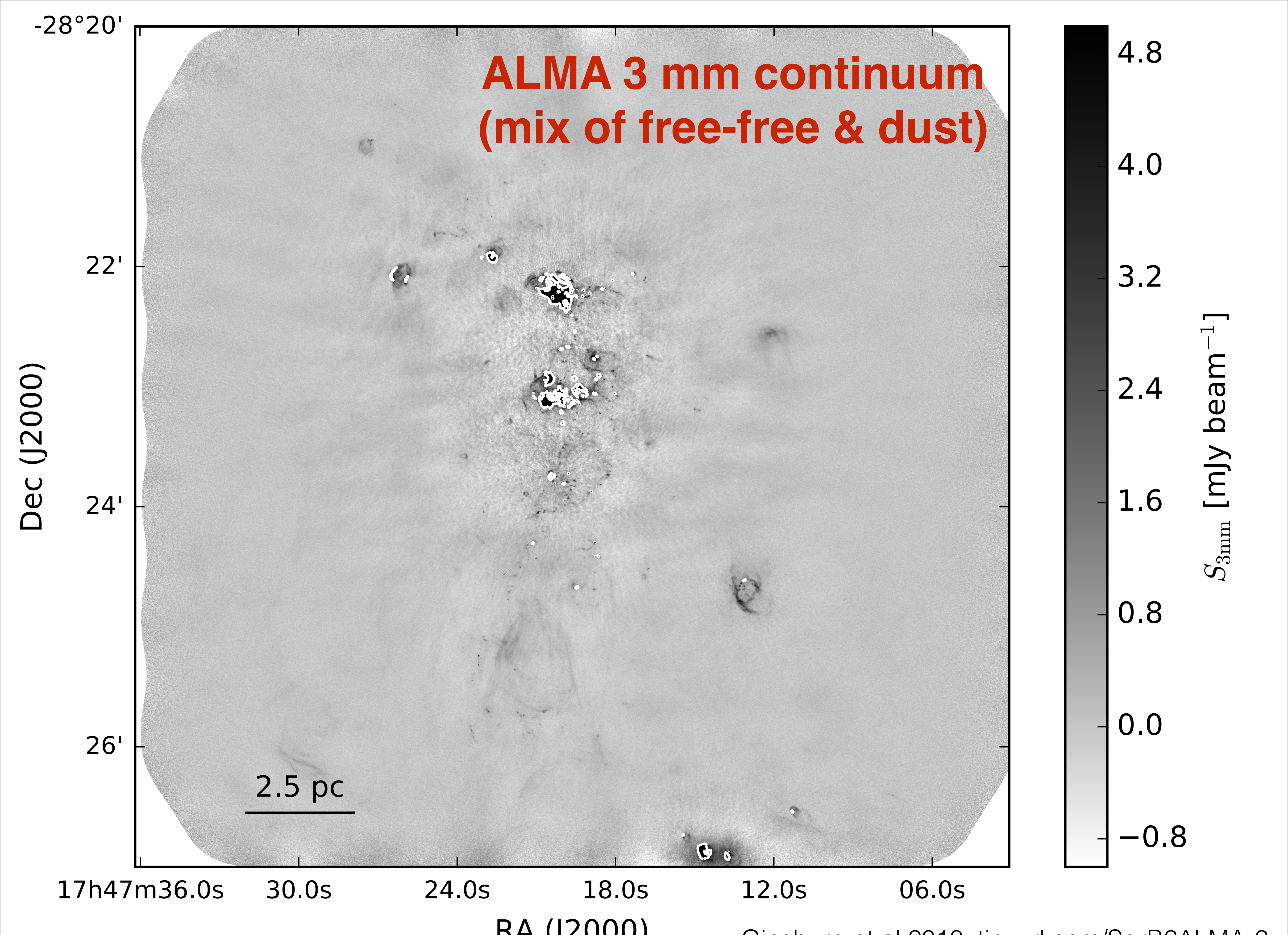


CMZ averages
(Longmore et al. 2013)
CMZ clouds
(this study)
Milky Way clouds
(Lada et al. 2010)
Sgr B2
|ℓ/deg| < 1
-2.5 < ℓ/deg < -1.0
+1.0 < ℓ/deg < +3.5
50 km/s
20 km/s
Dust Ridge c
Sgr D
Sgr C
Sgr B1-off
Dust Ridge d
G0.253+0.016
reduction
for atter
$\alpha_3 = 2.3$ IMF
in CMZ
representative
statistic
uncertainty for
CMZ clouds
factor 10
Kauffmann+ 2017
Star Formation Rate [$M_\odot$ yr^{-1}]
Mass of Dense Gas [$M_\odot$]
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{2}
10^{3}
10^{4}
10^{5}
10^{6}
10^{7}
10^{8}

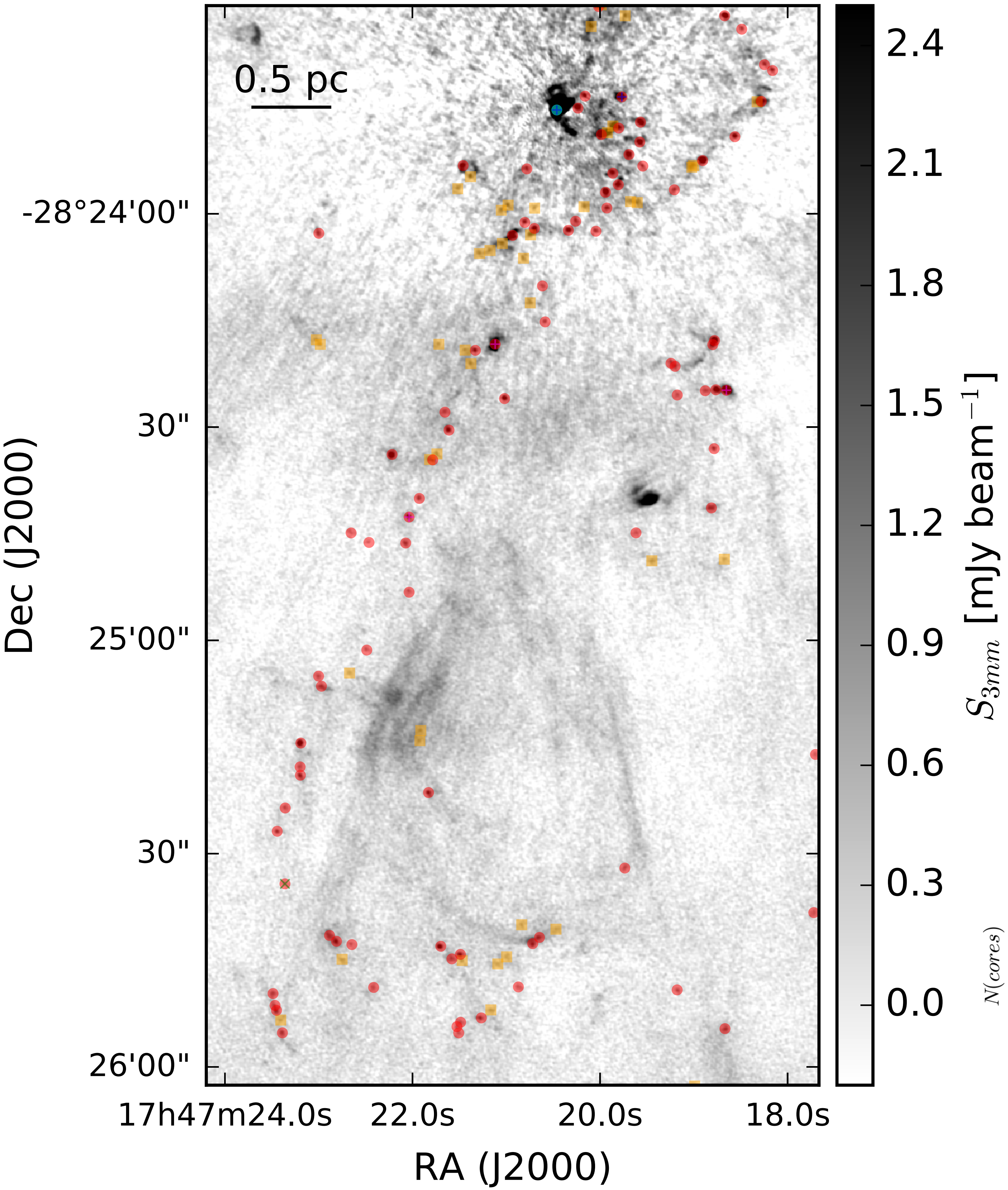


Sgr B2 is the most massive protocluster cloud in the galaxy





Ginsburg et al 2018: tinyurl.com/SgrB2ALMA-2



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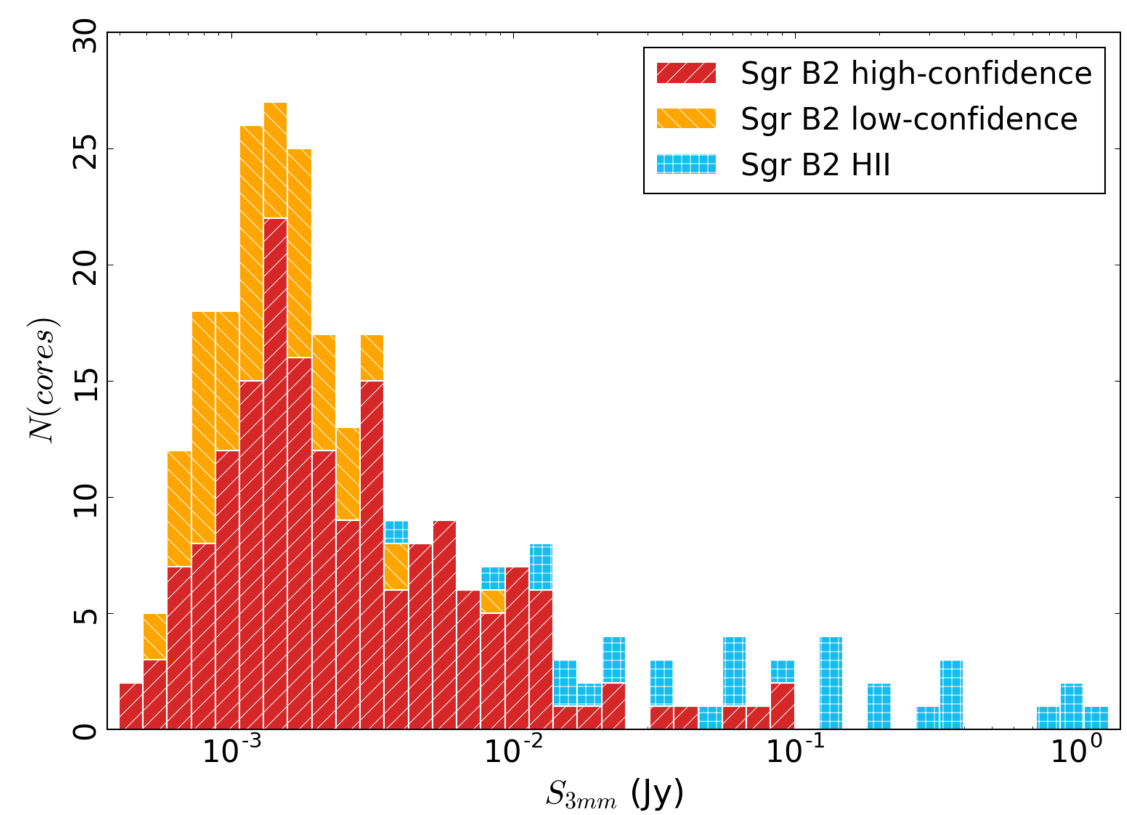
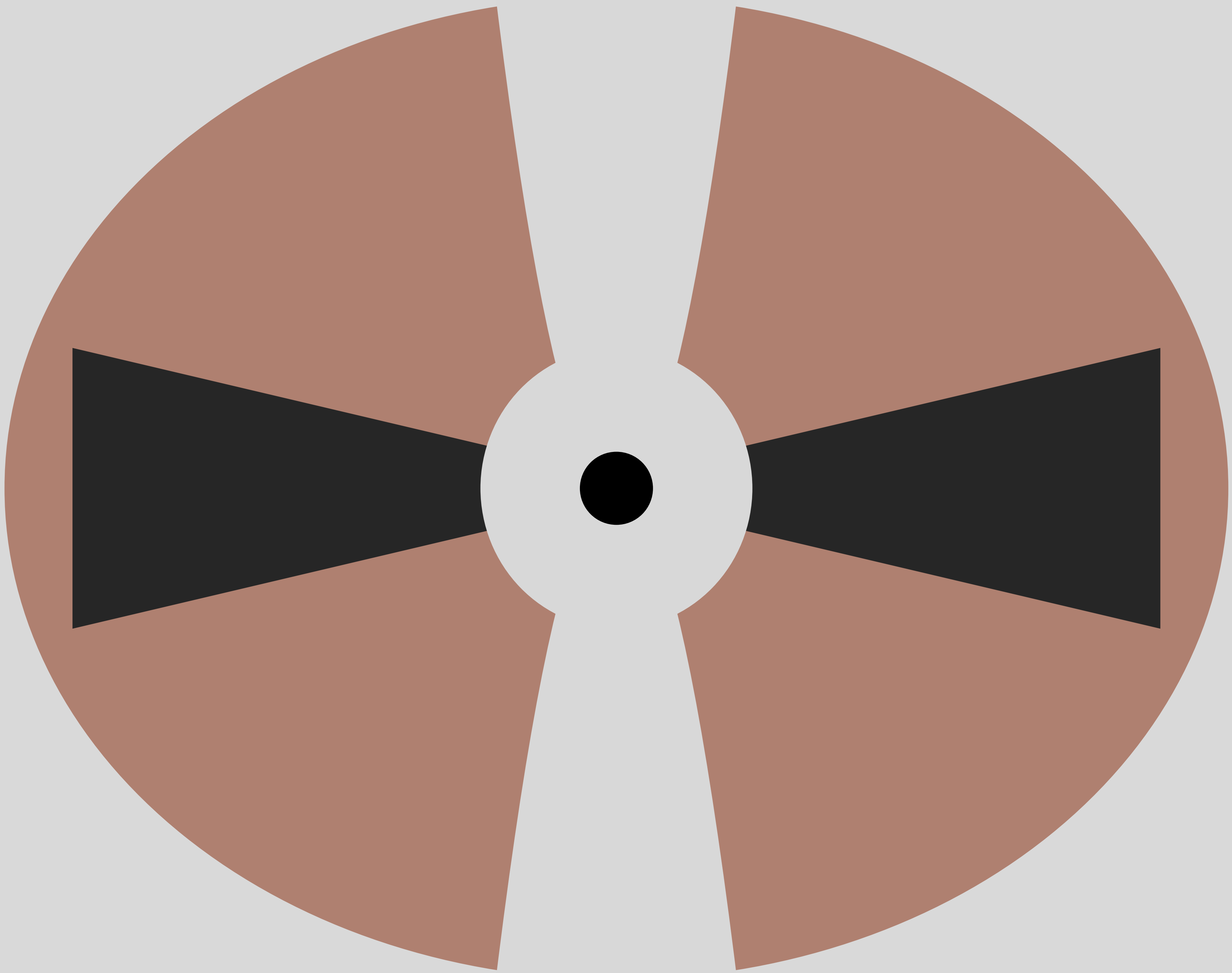
ALMA enables YSO counting in massive SFRs

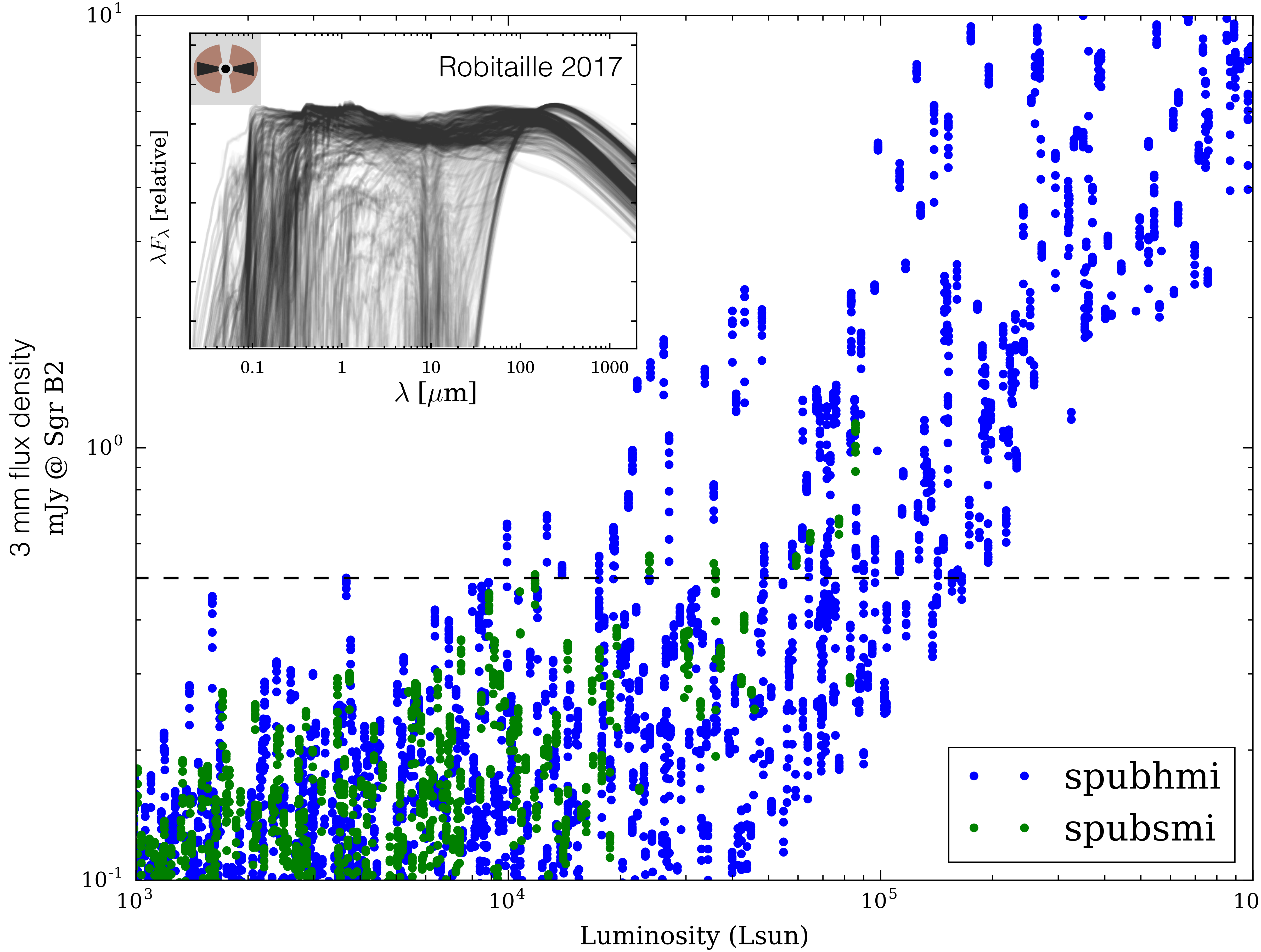
Discovered 271 point(ish) sources, most of which are new



Class 0/I YSO: an accreting star with a gas & dust envelope
may have a disk and an outflow

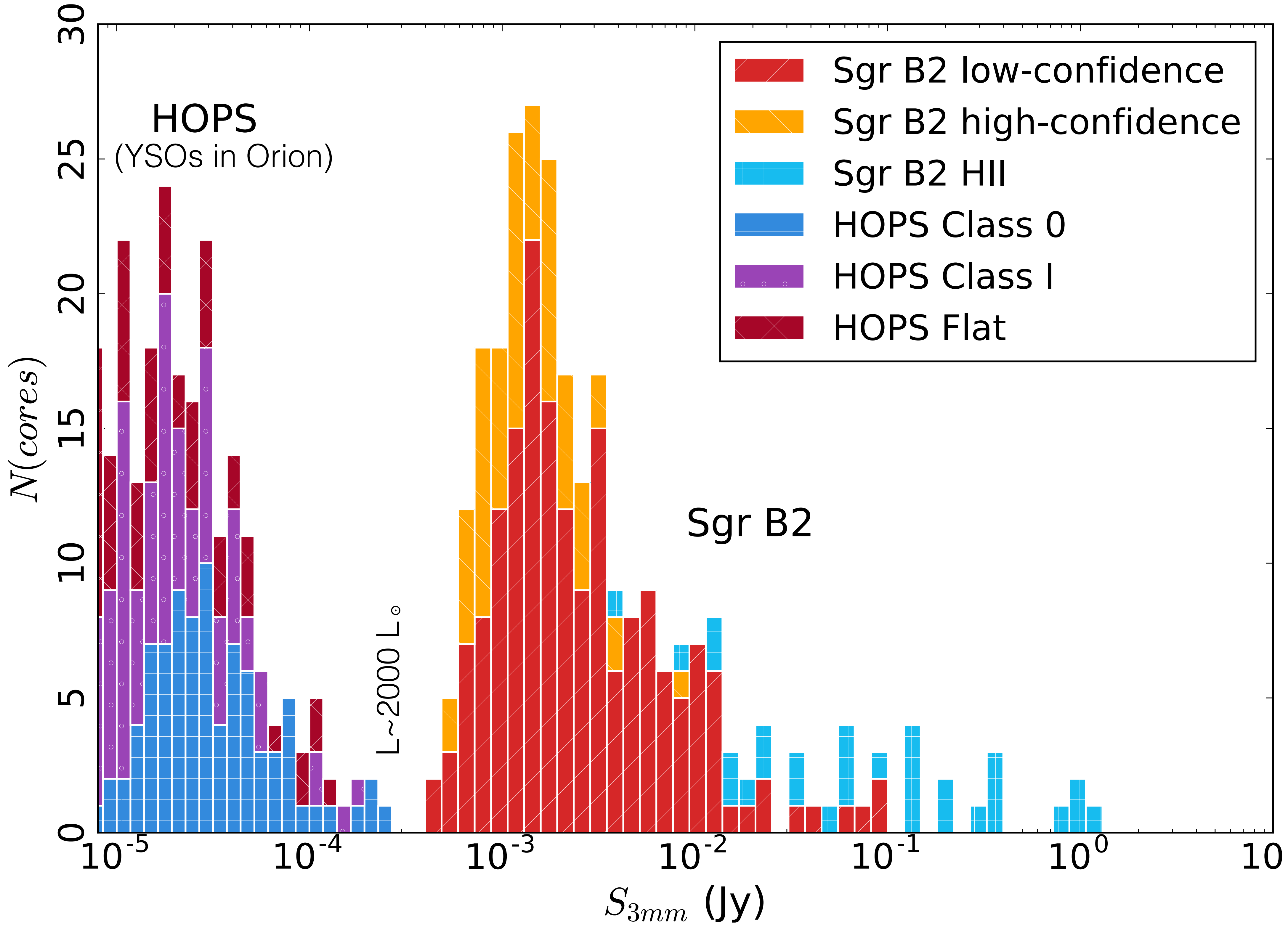


Class 0/I YSO SED



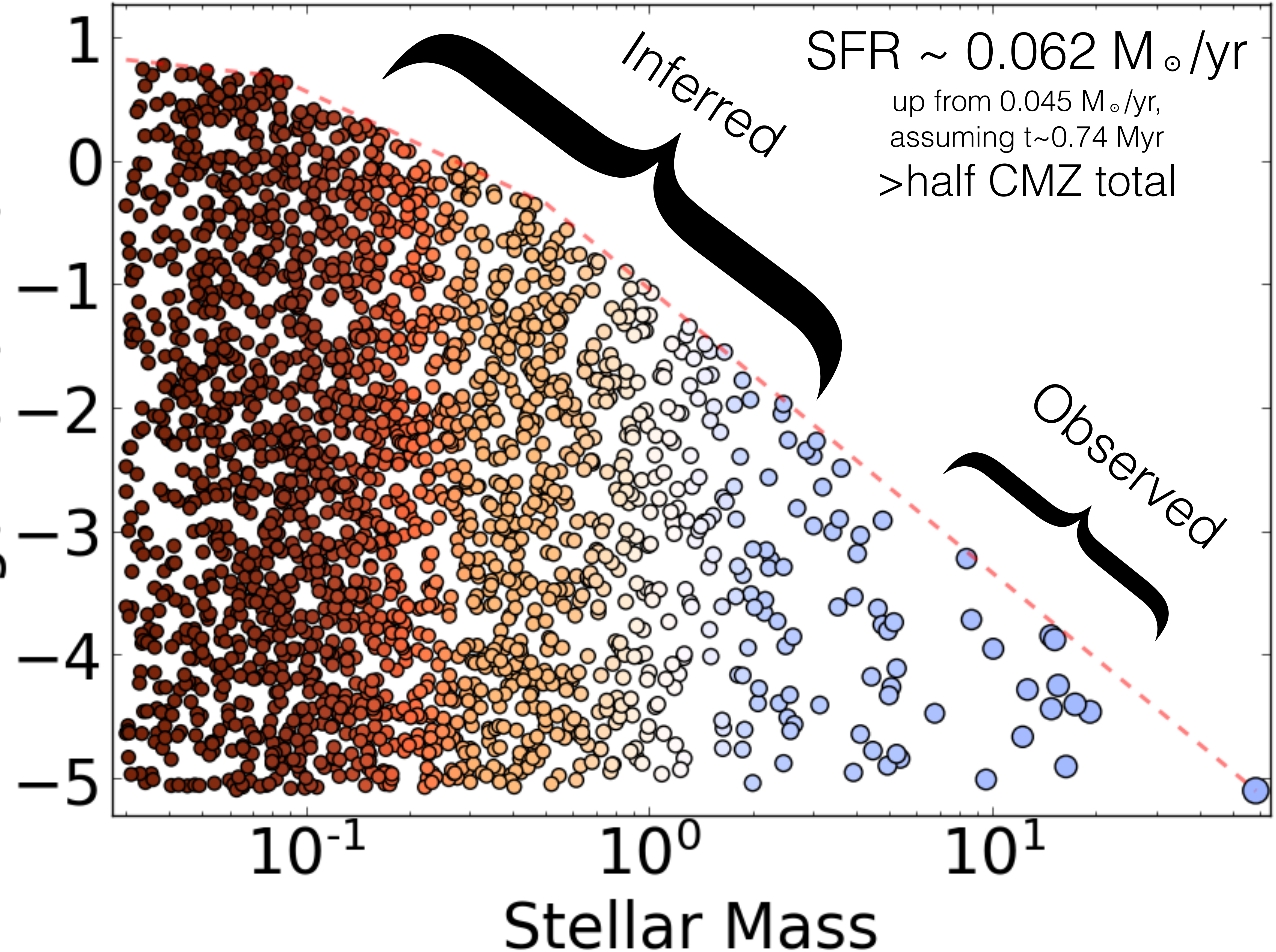
3 mm source classification

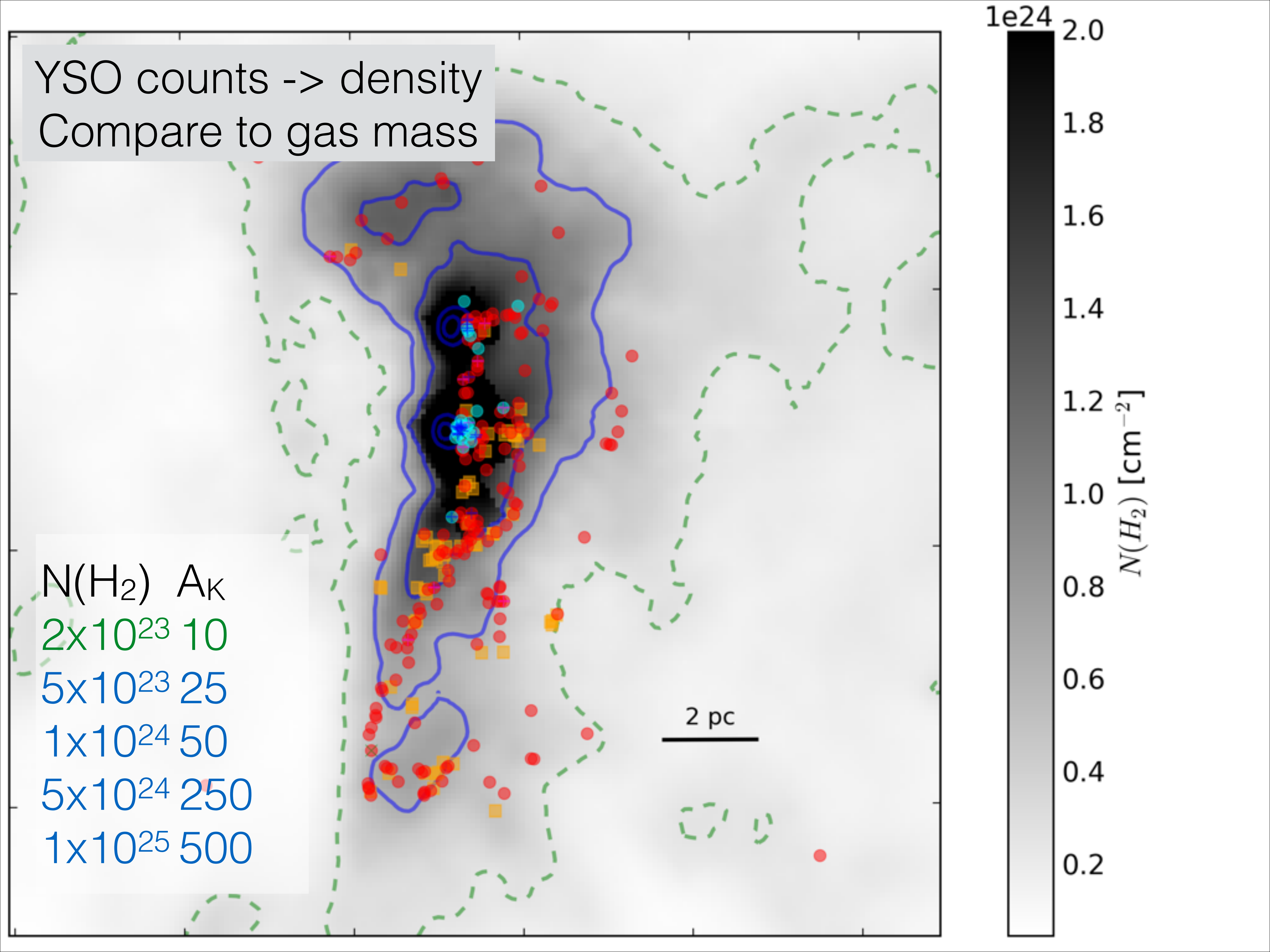
Most are HMYSOs. Some are HCHIIs.
All will likely form massive stars.



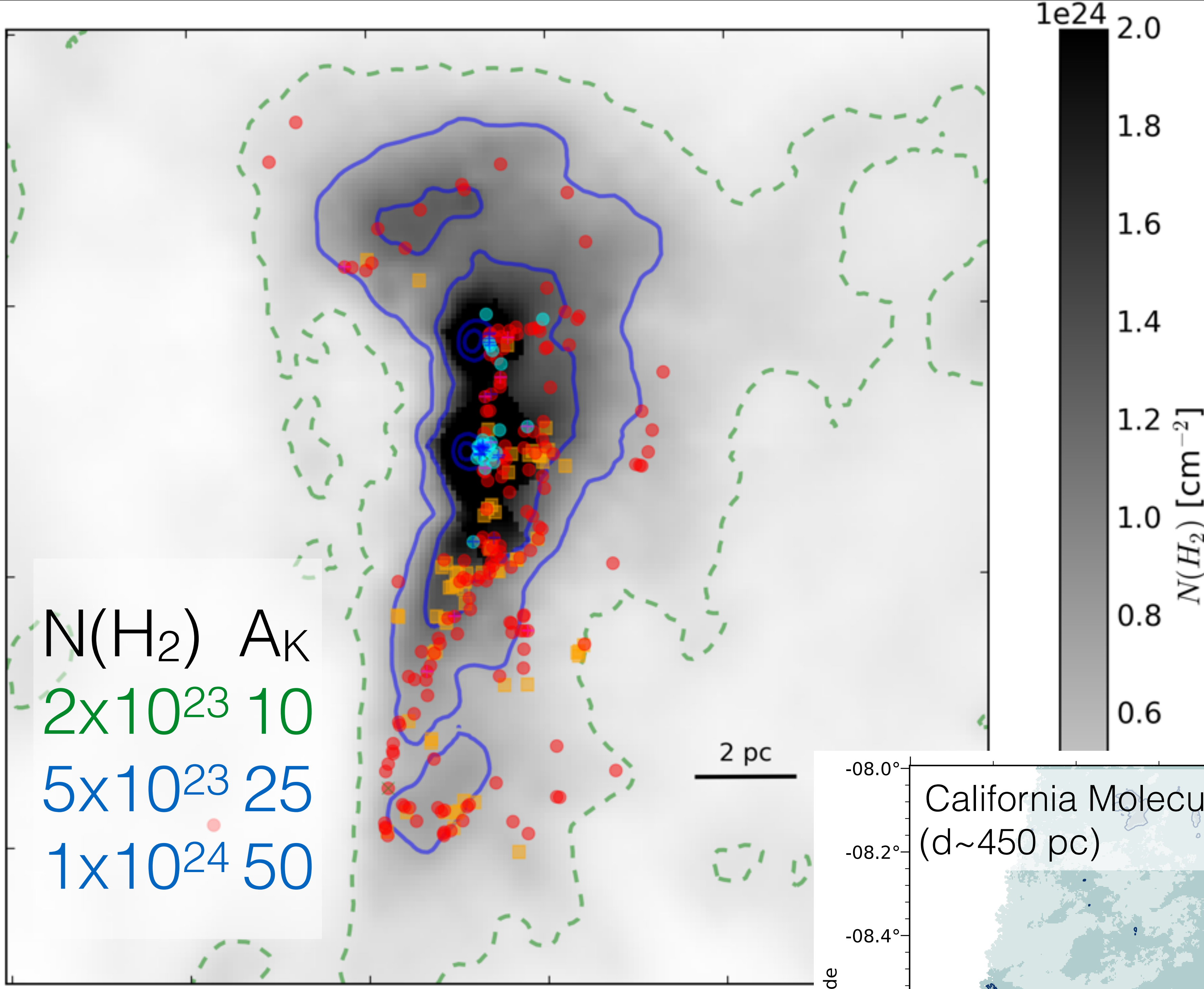
Estimate total (proto)stellar mass using an assumed IMF

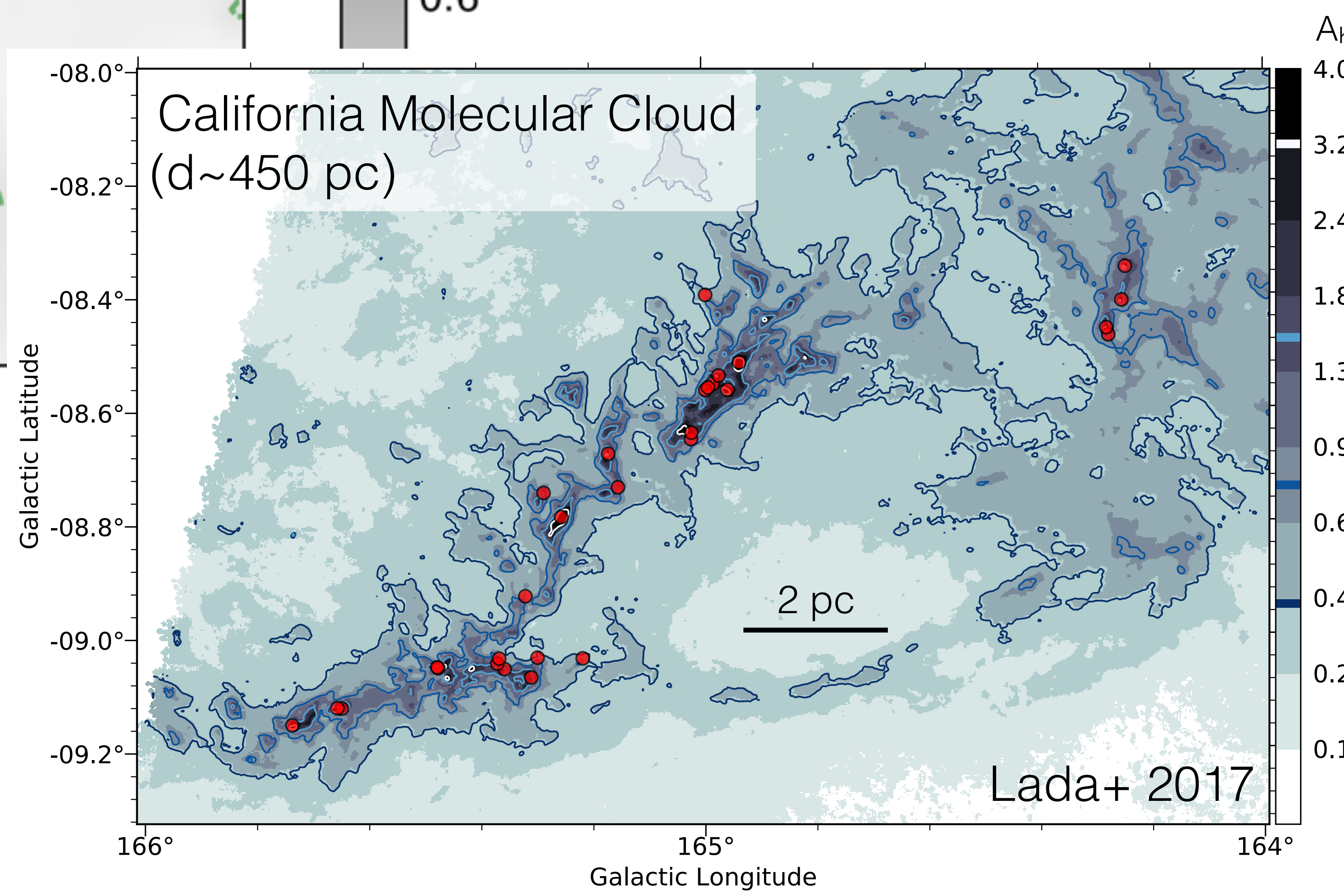
each observed ~10 $M_\odot$ source implies the presence of ~100 $M_\odot$ of lower-mass stars



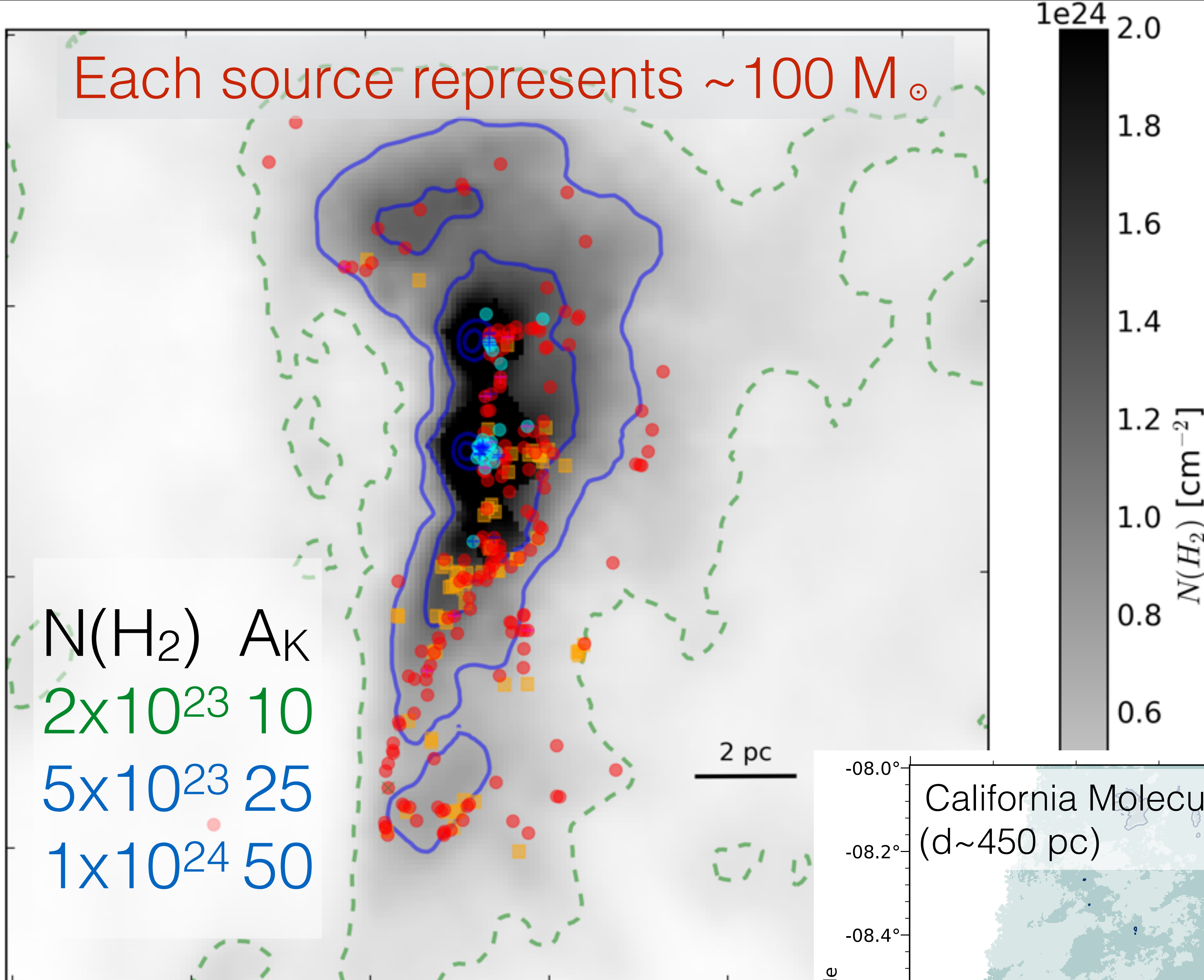

YSO counts -> density
Compare to gas mass
N(H2) AK
2x10^23 10
5x10^23 25
1x10^24 50
5x10^24 250
1x10^25 500
2 pc
1e24
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
N(H2) [cm^-2]

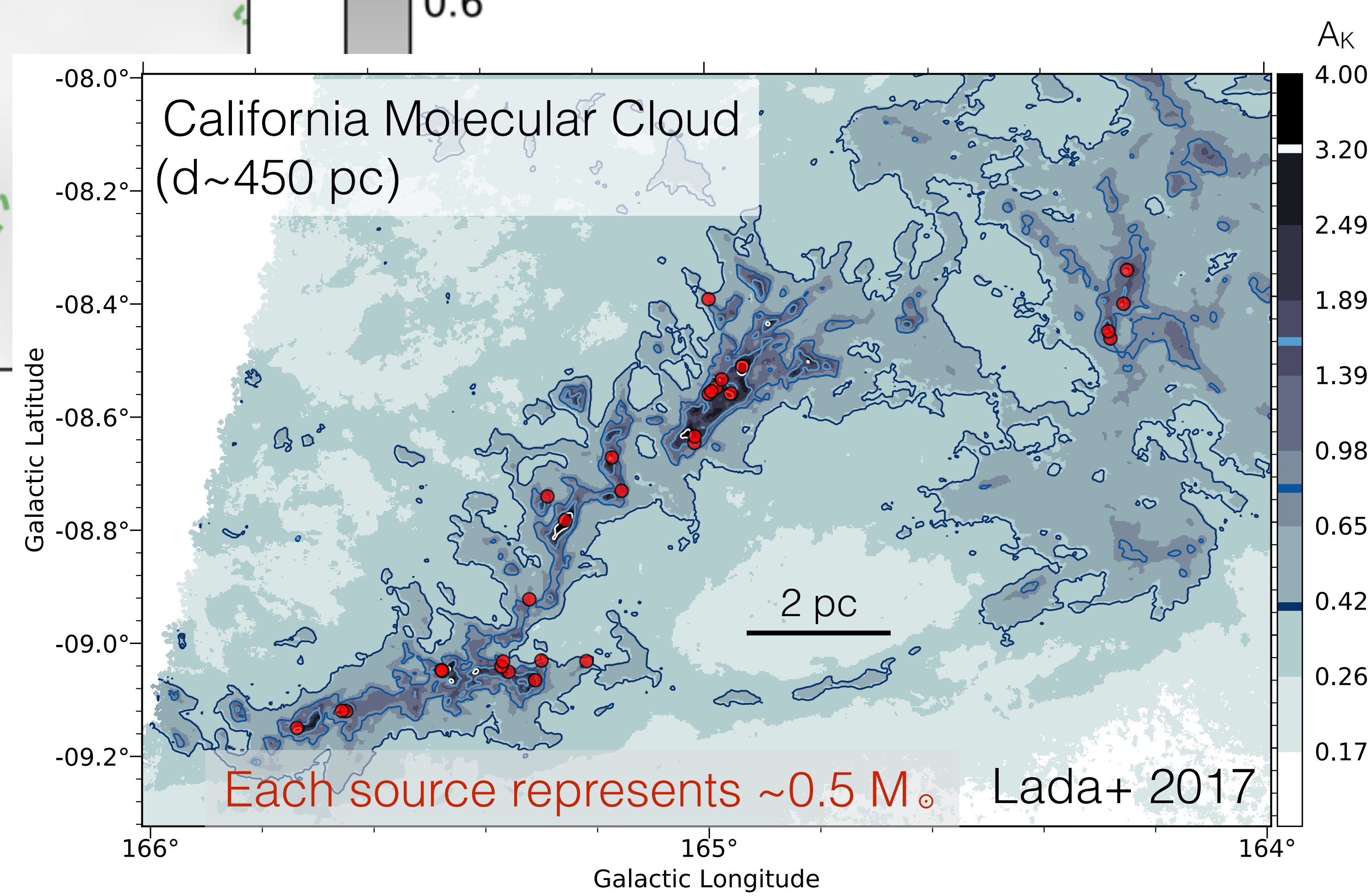
Local Cloud Comparison





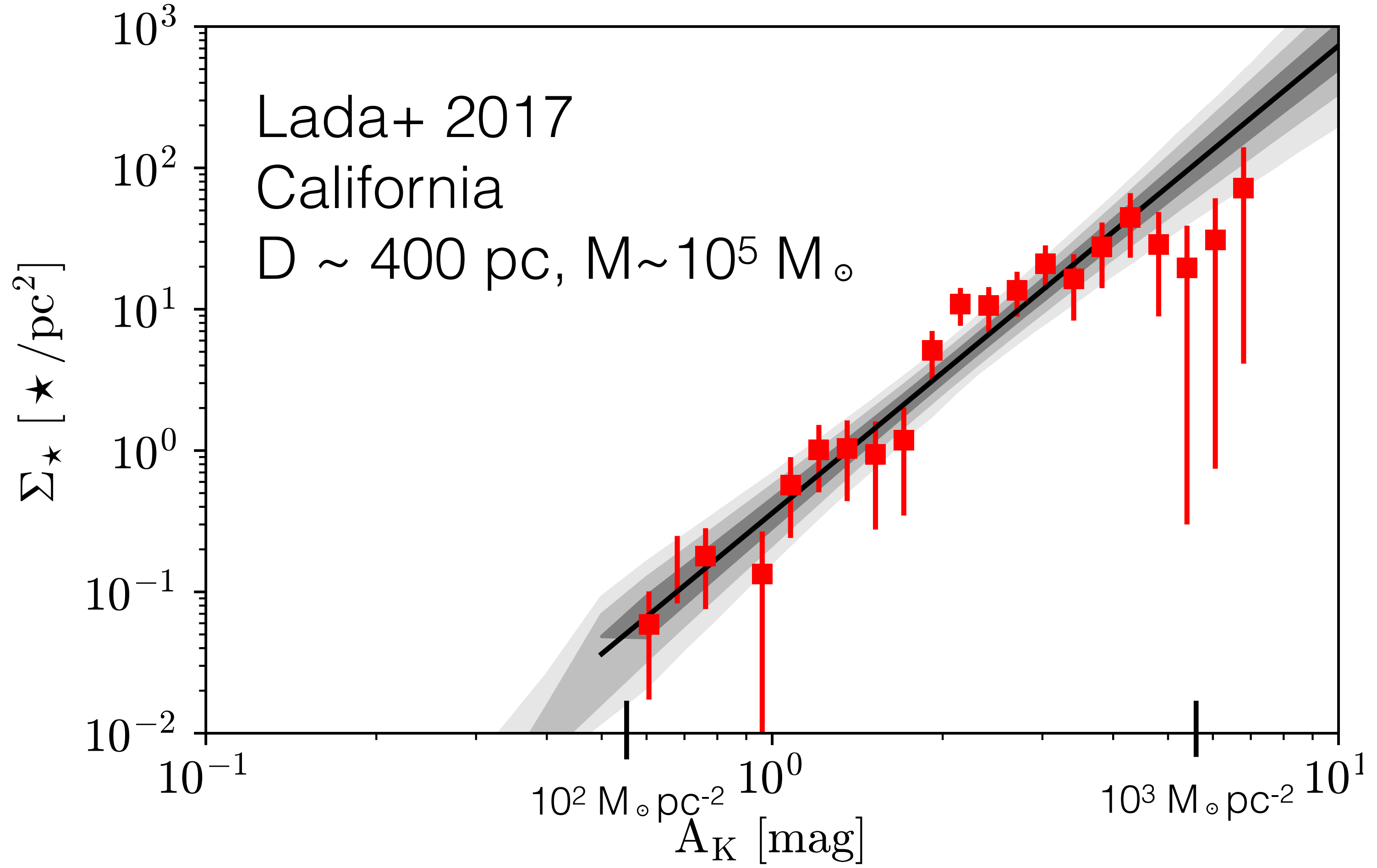
Local Cloud Comparison

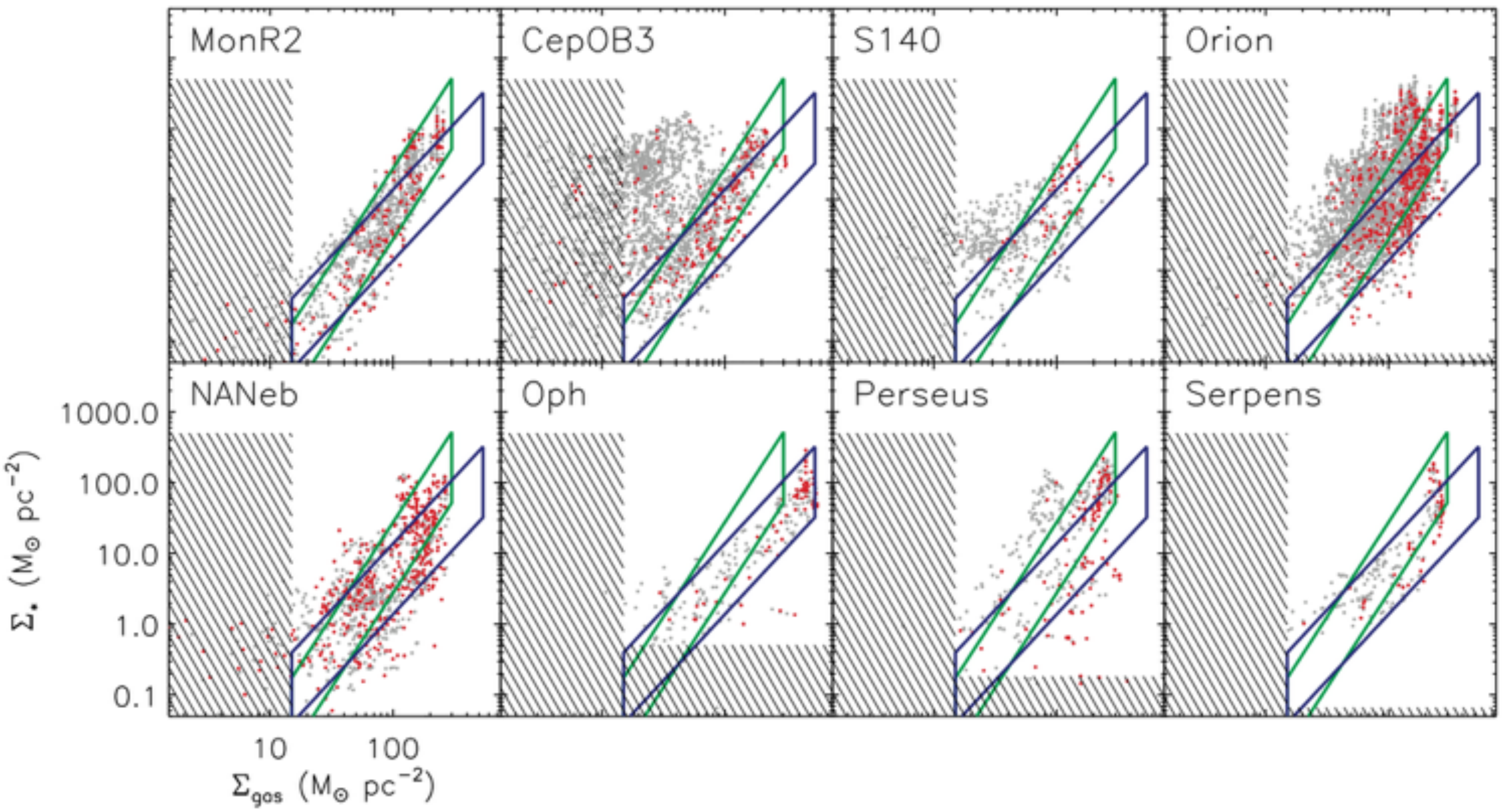




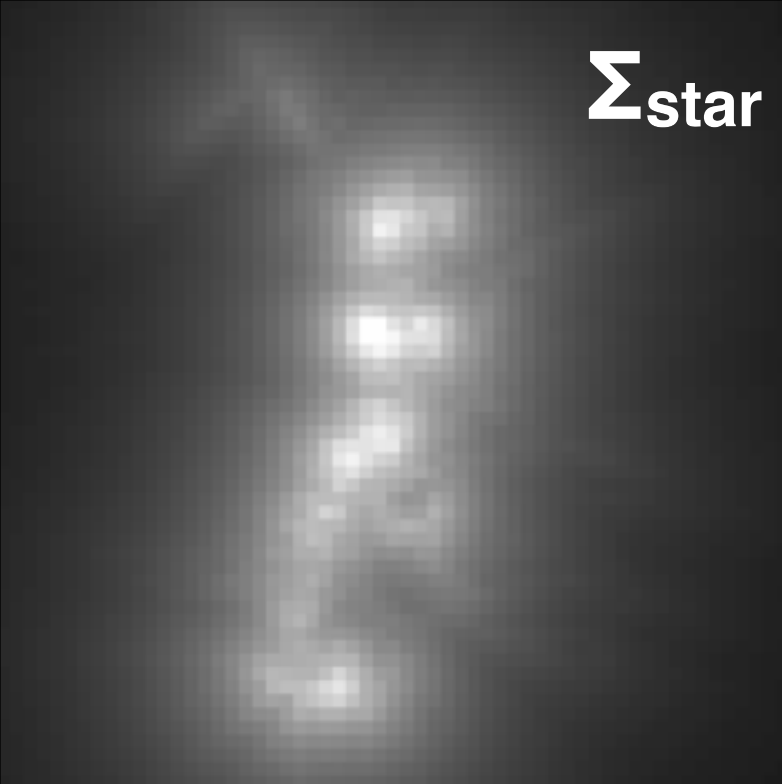
Local SF Laws within clouds:

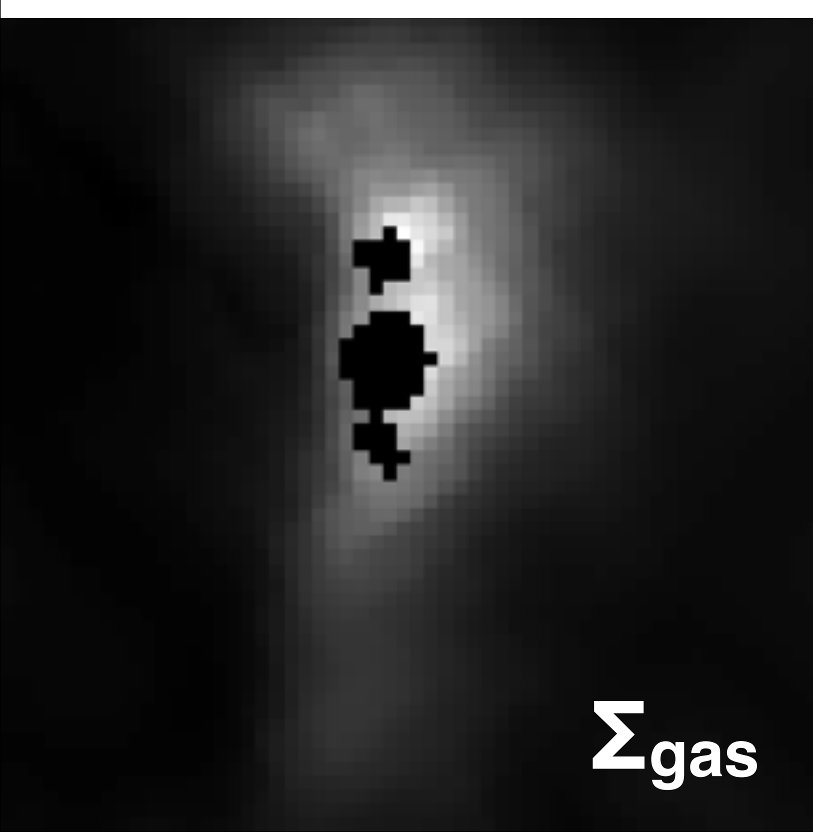
Protostellar vs Gas Surface Density

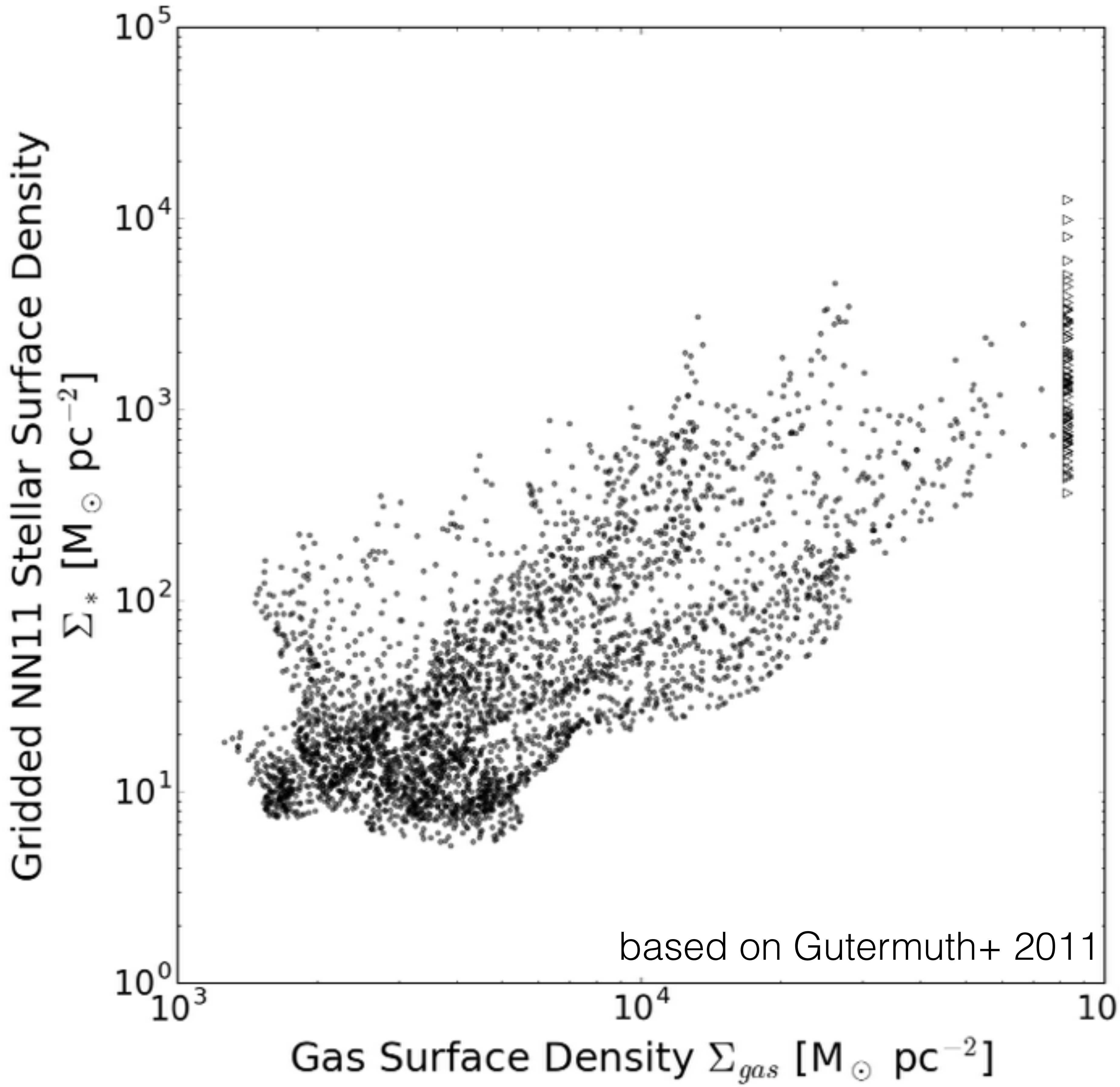




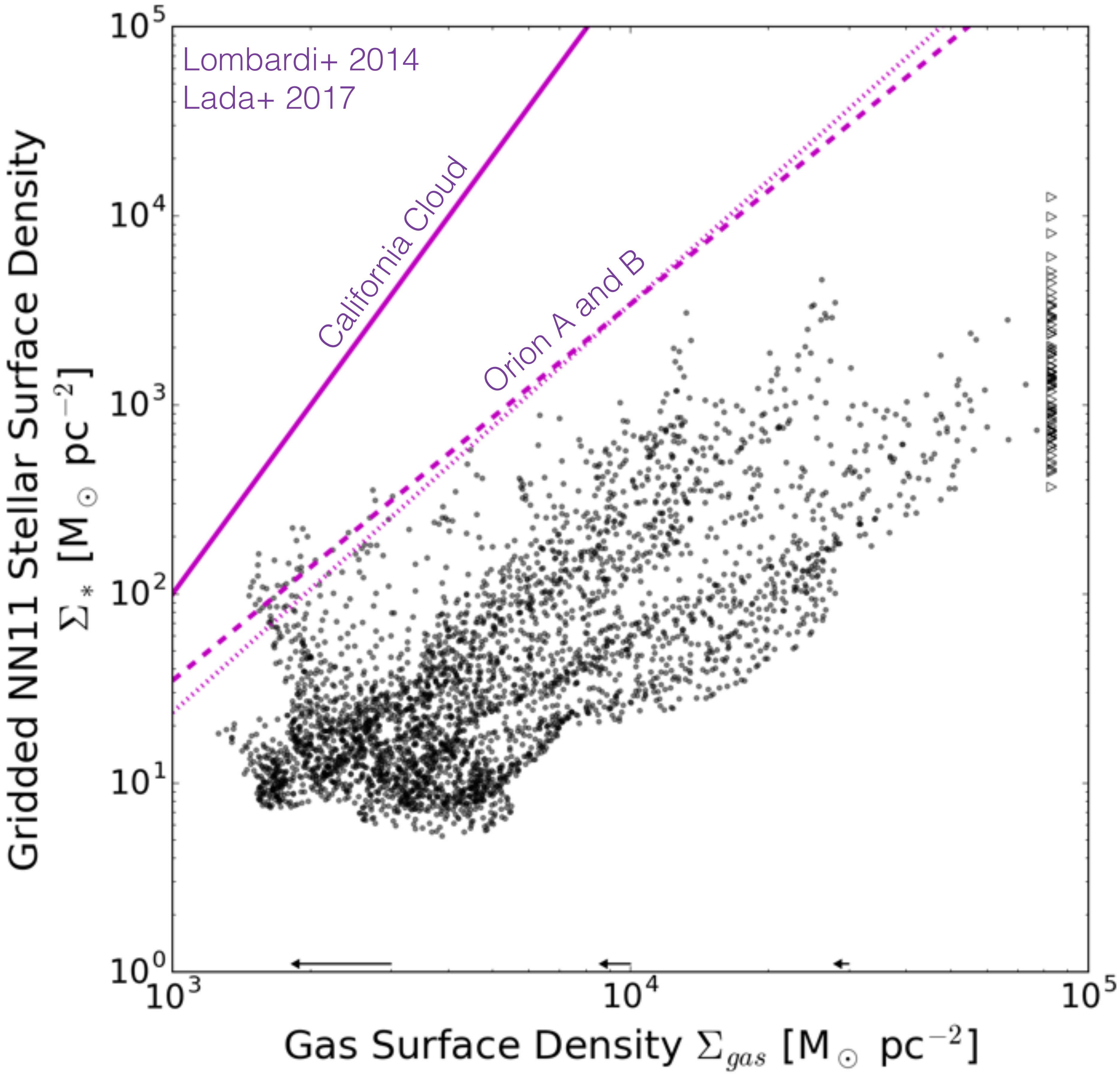
Gutermuth+ 2011
D ~ 150-1500 pc,
M~10^4-10^5 M$_\odot$







Ginsburg et al 2018: tinyurl.com/SgrB2ALMA-2



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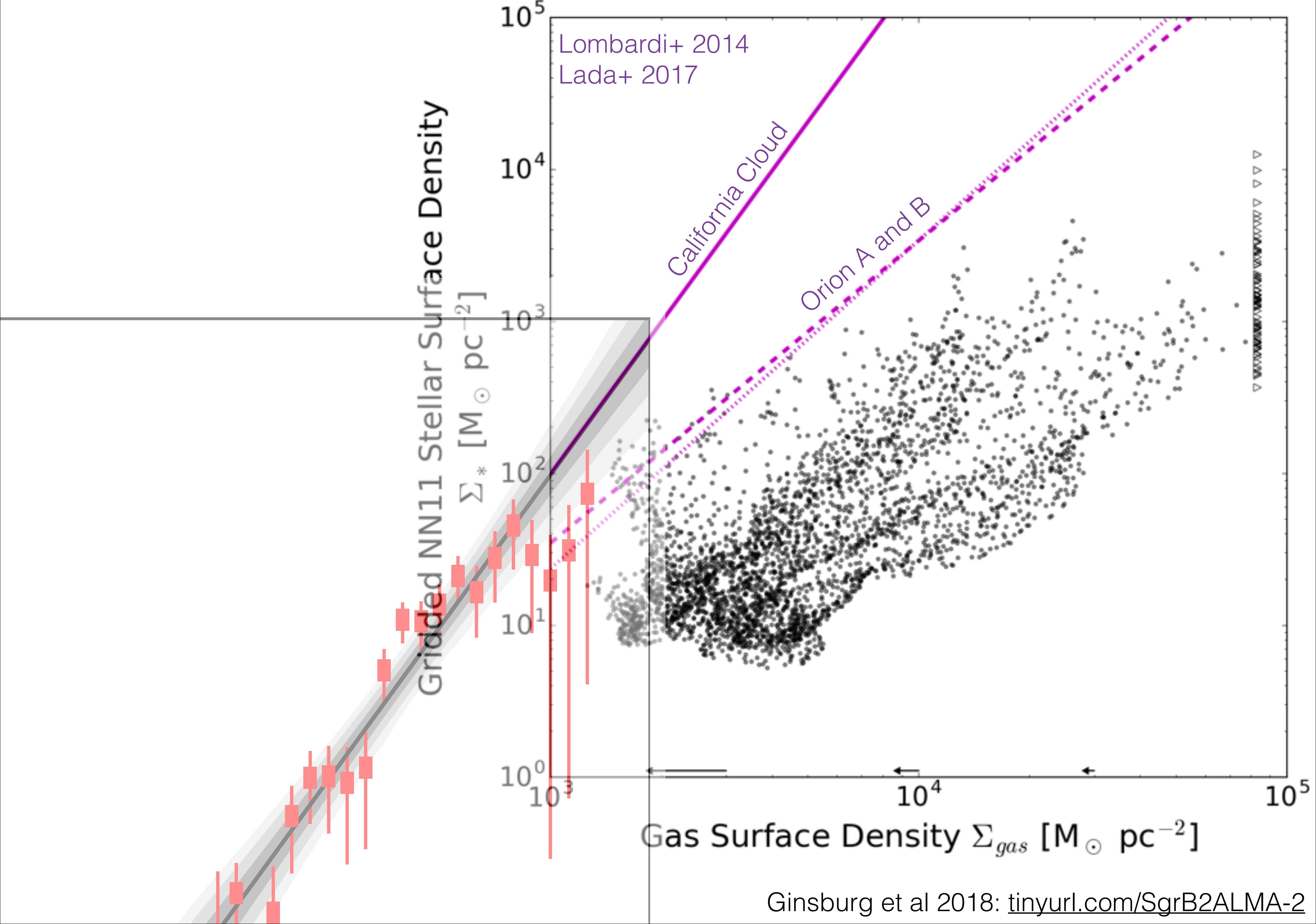

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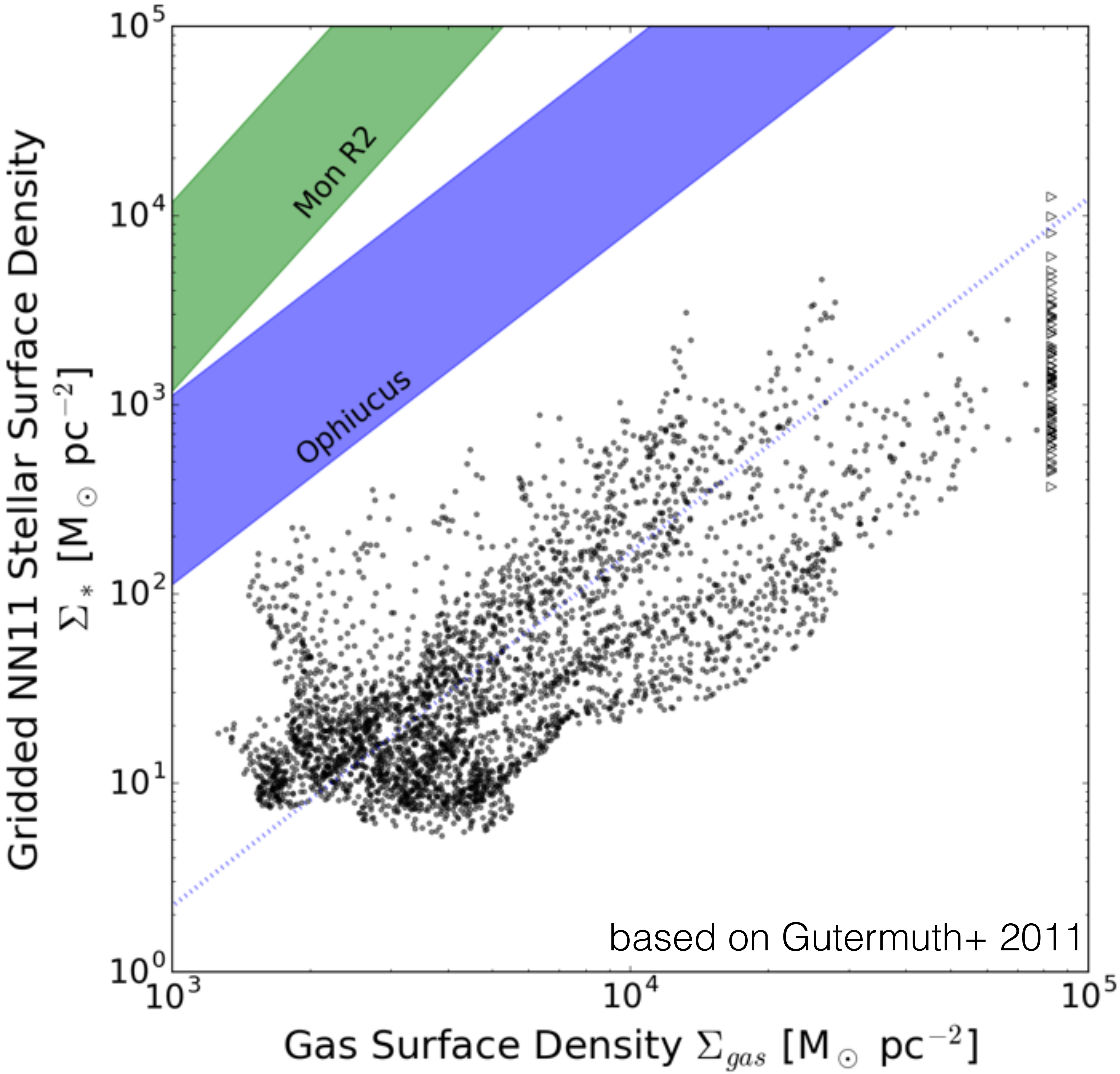
Sgr B2 does not fit on Σ_{gas}-Σ_{star} relations extrapolated from local clouds



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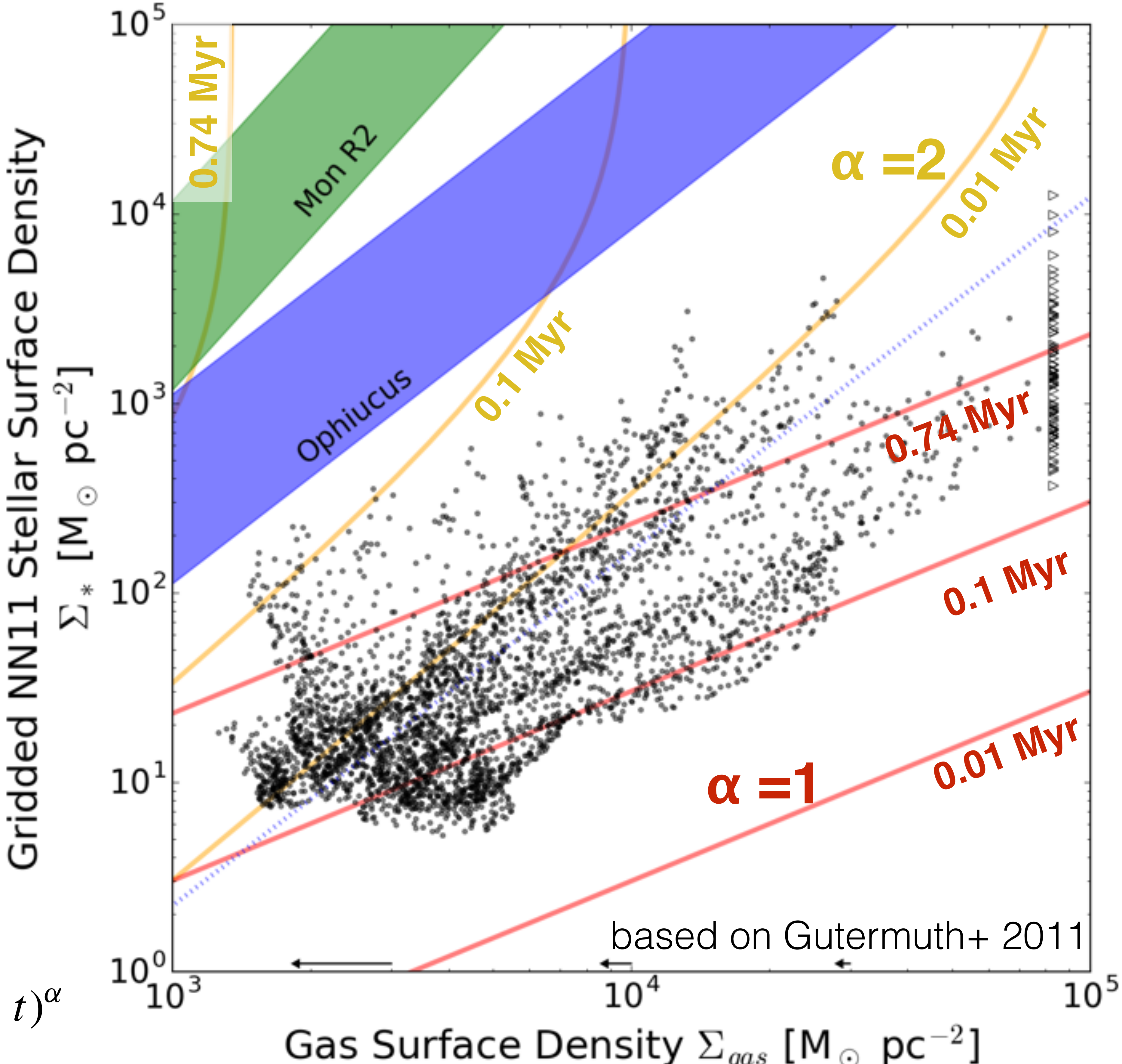
Sgr B2 does not fit on Σ_{gas}-Σ_{star} relations extrapolated from local clouds

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 2018: tinyurl.com/SgrB2ALMA-2

Why is Sgr B2 different?

- Higher Multiplicity
- YSOs actually more massive
- Incomplete
- Multiple clouds along LOS
- Non-uniform IMF (primordial mass segregation)
- Lower local SFE
- **Higher density threshold**

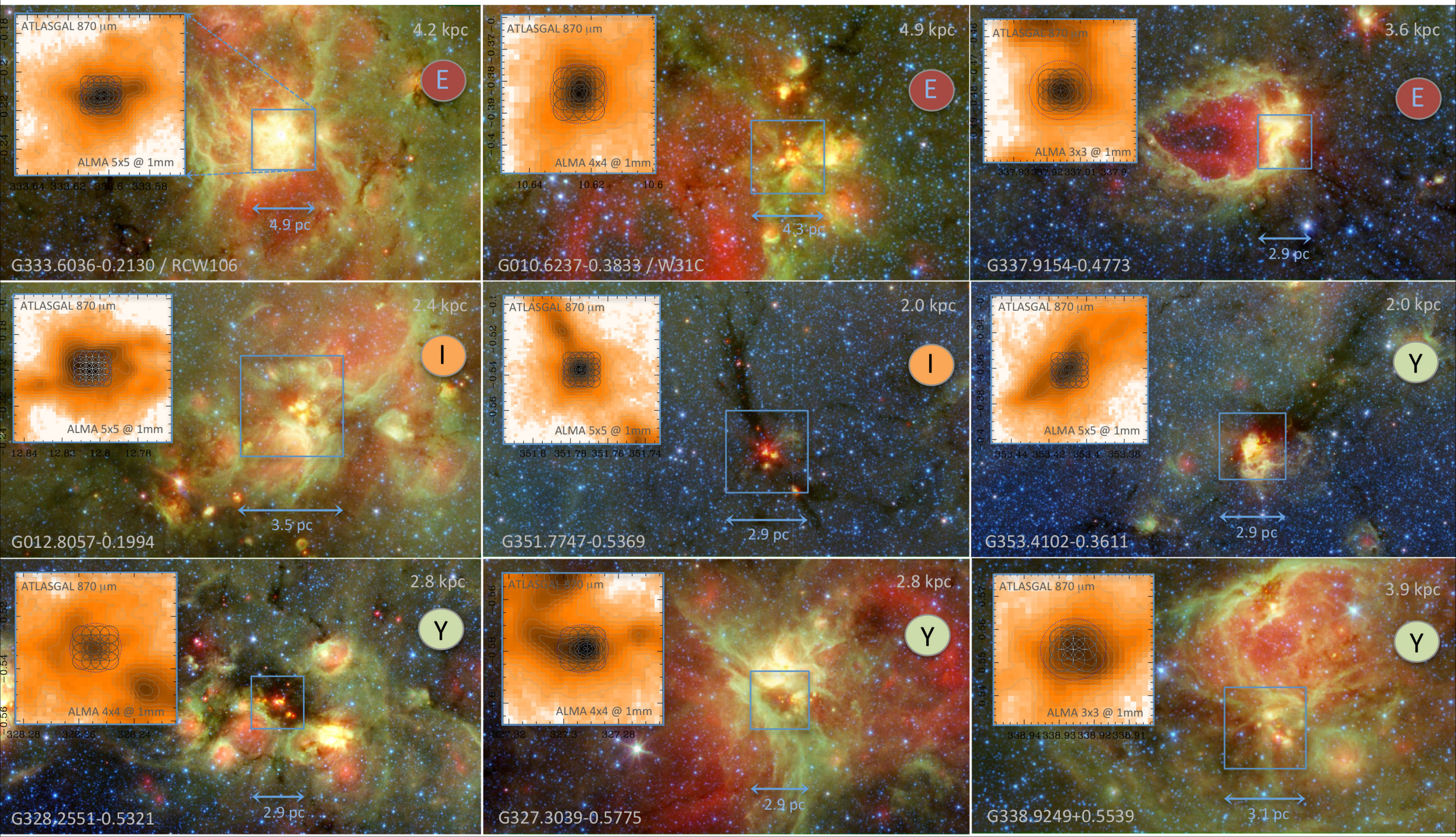
SF in the CMZ is lower than predicted and allows us to test SF relations.

Sgr B2 is vigorously forming stars, and not just in the main protoclusters

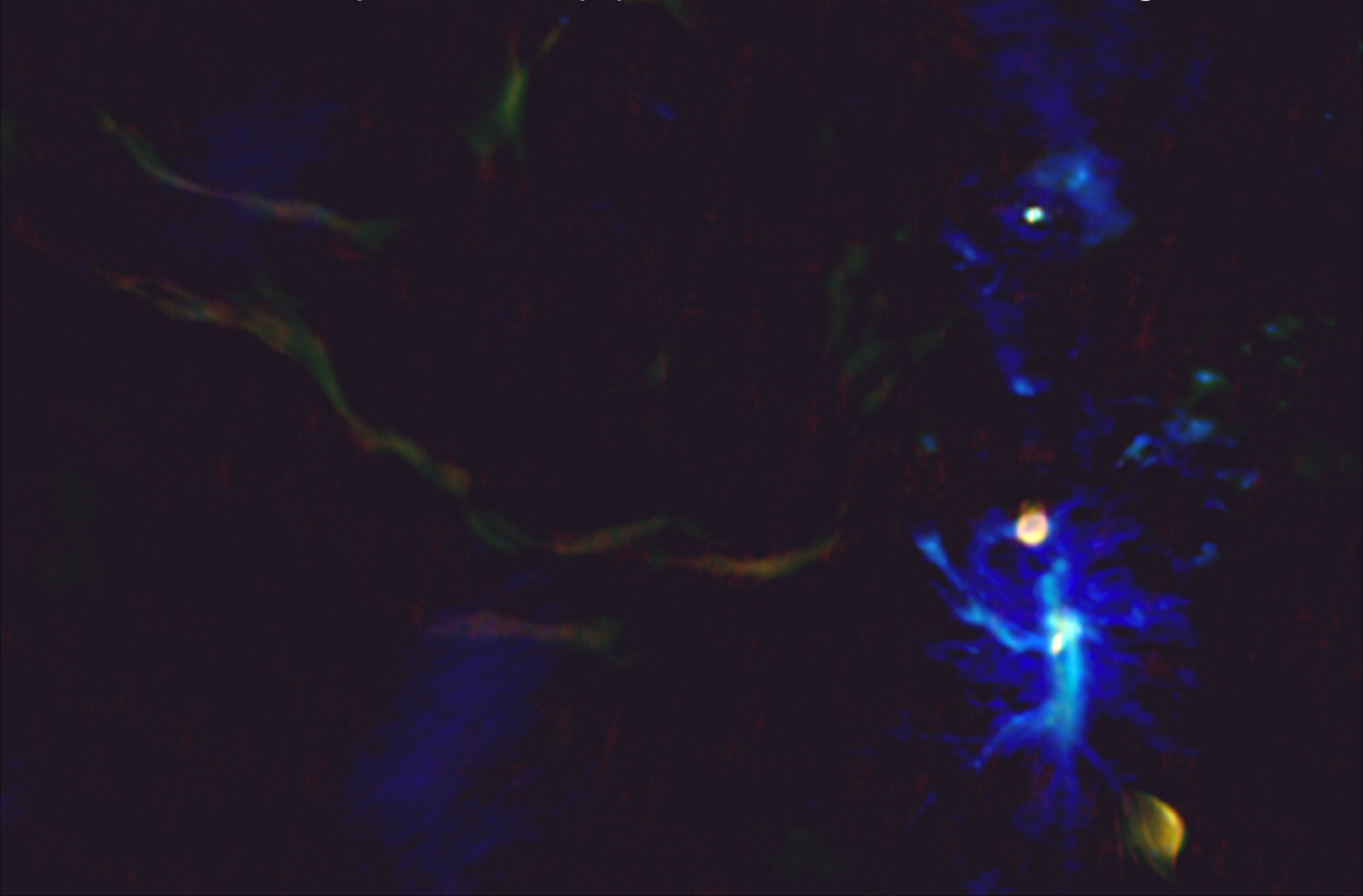
Surface-density star formation relations can’t fit both Sgr B2 and local clouds.

The critical density for SF is higher in CMZ clouds

ALMA-IMF (PI Motte, Ginsburg, Sanhueza, Louvet)
will repeat this experiment on about a dozen high-mass star (cluster?) forming regions



Several ALMA programs to dig in to Sgr B2 at higher resolution & sensitivity to directly probe the lower-mass regime



1. Age estimate for the distributed population in DS

Gas $\sigma_v \sim 10$ km/s

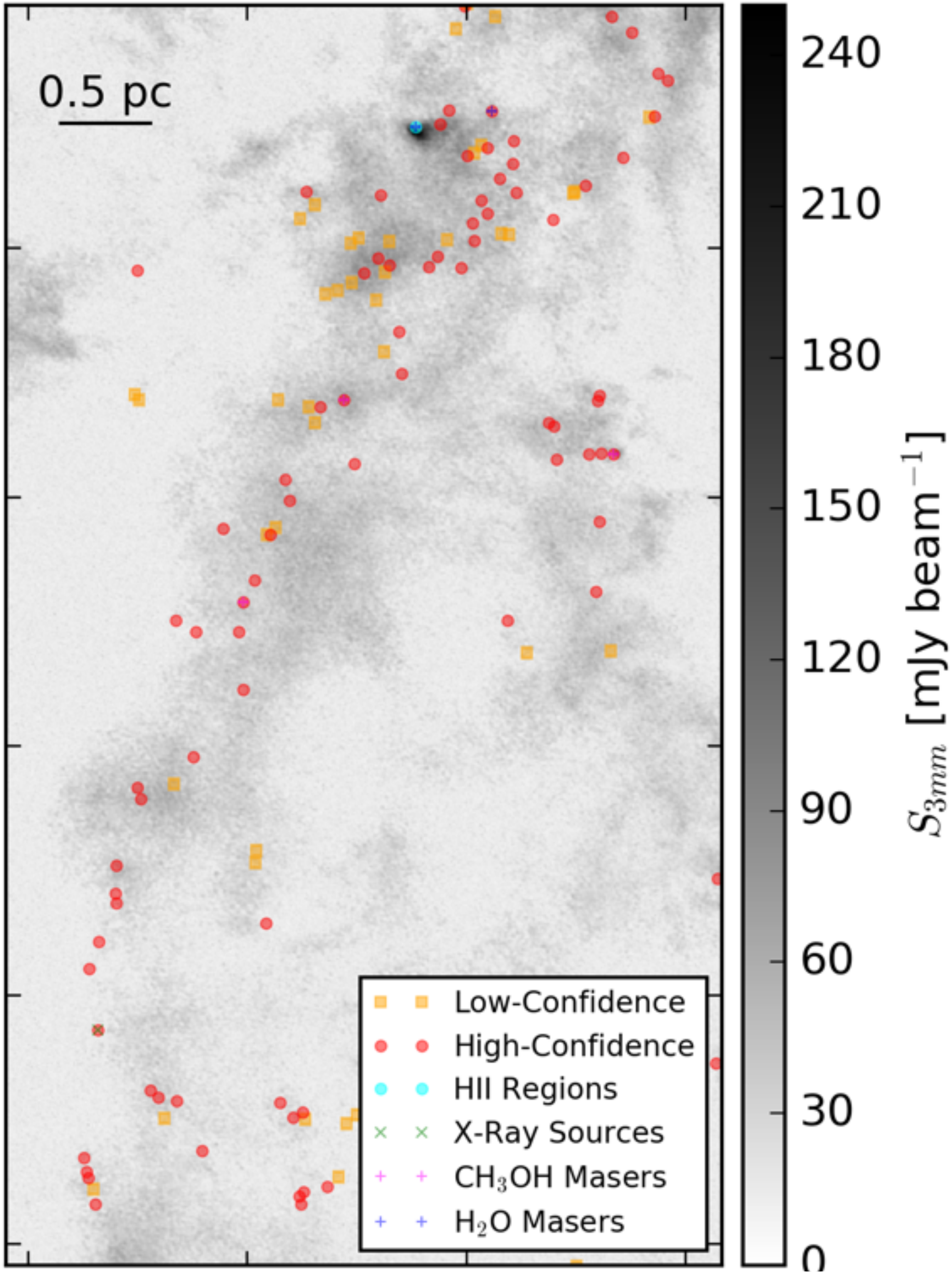
"Ridge" width r~0.5 pc

Most sources within 0.5 pc of the ridge

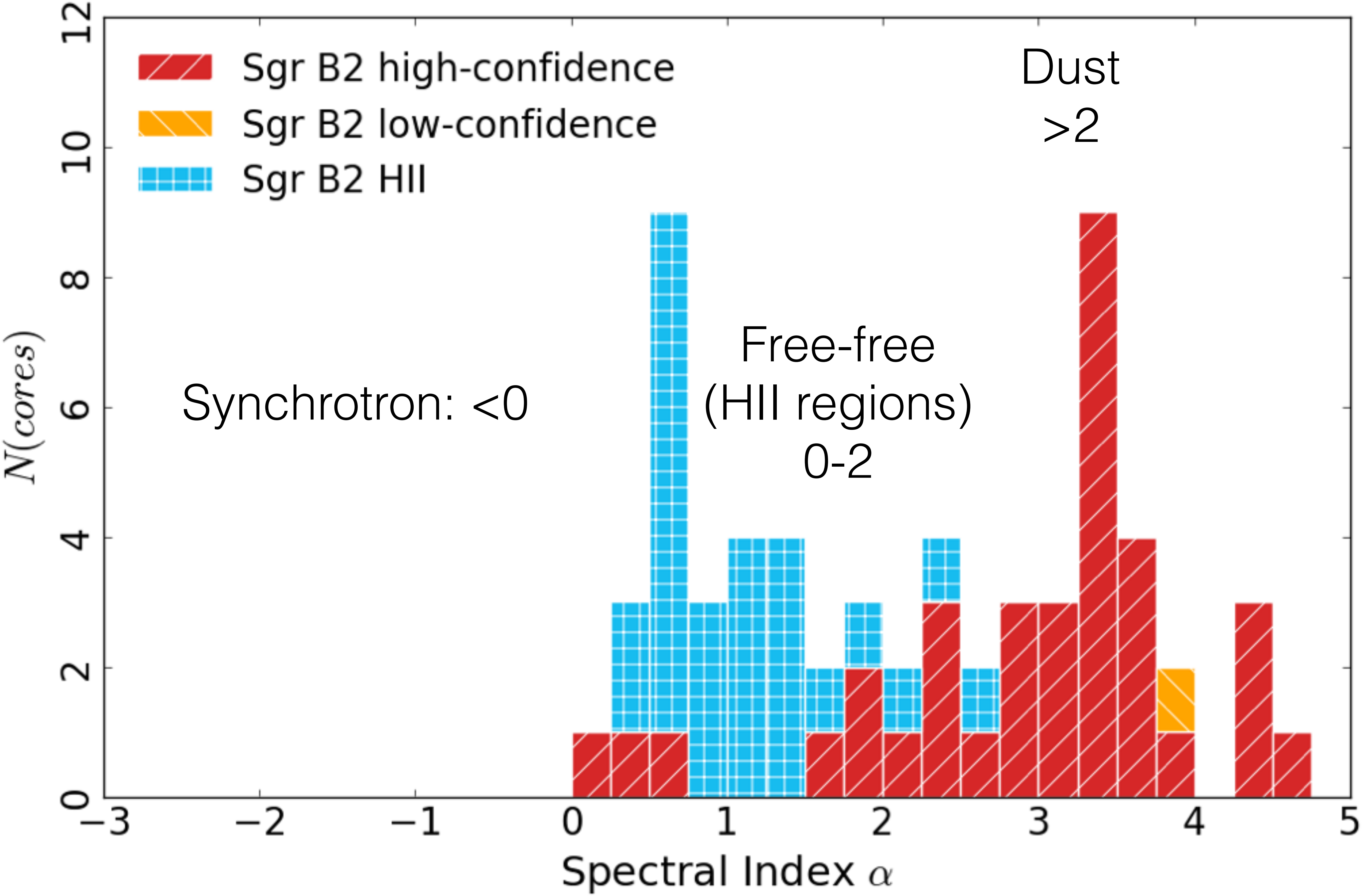
Diffusion (dispersion) timescale

$t = r / \sigma_v = 5\times10^4$ yr

(sims suggest $t = 5 (r/\sigma_v) = 2.5\times10^5$ yr
Offner+2009)



2. Spectral Shape

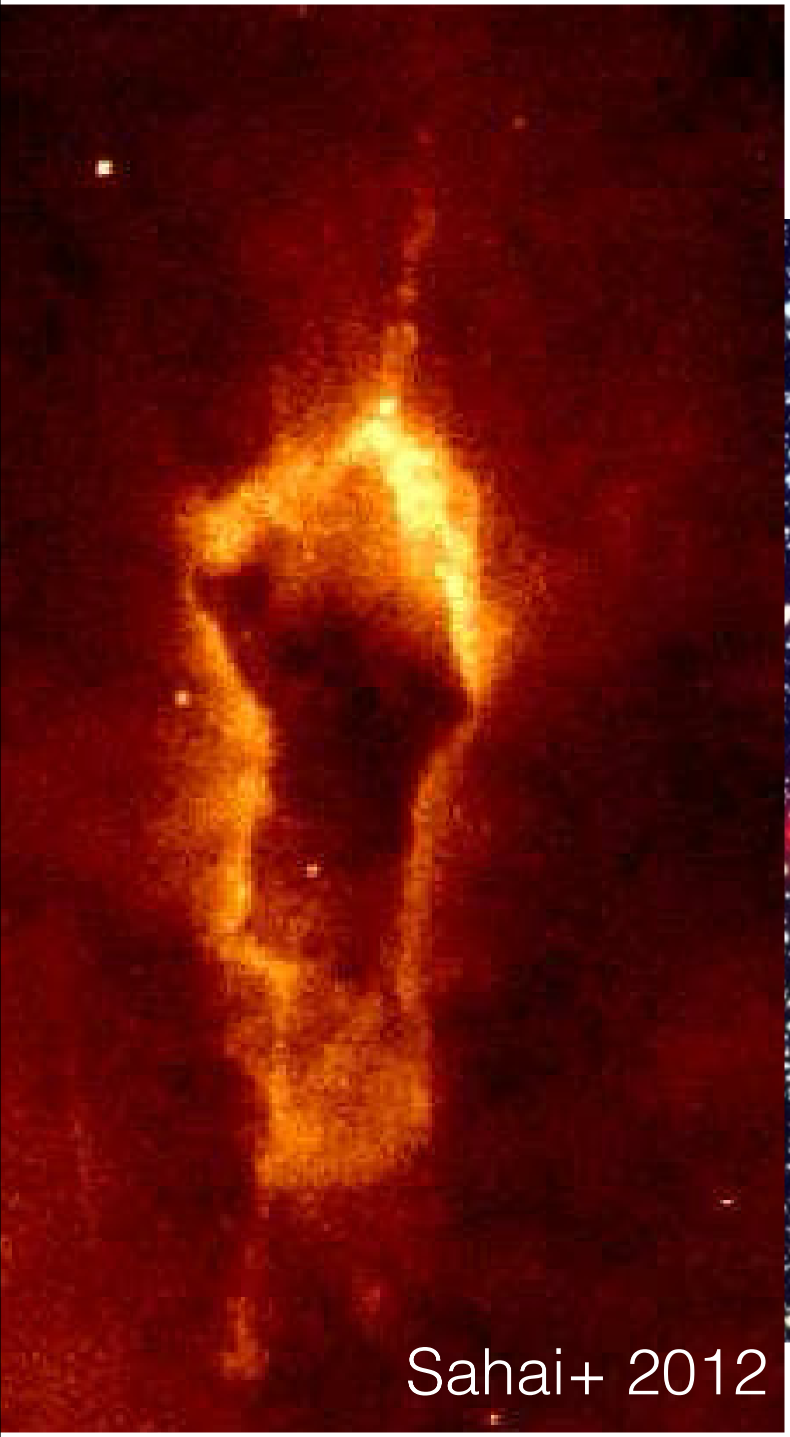


3. Rule out alternatives

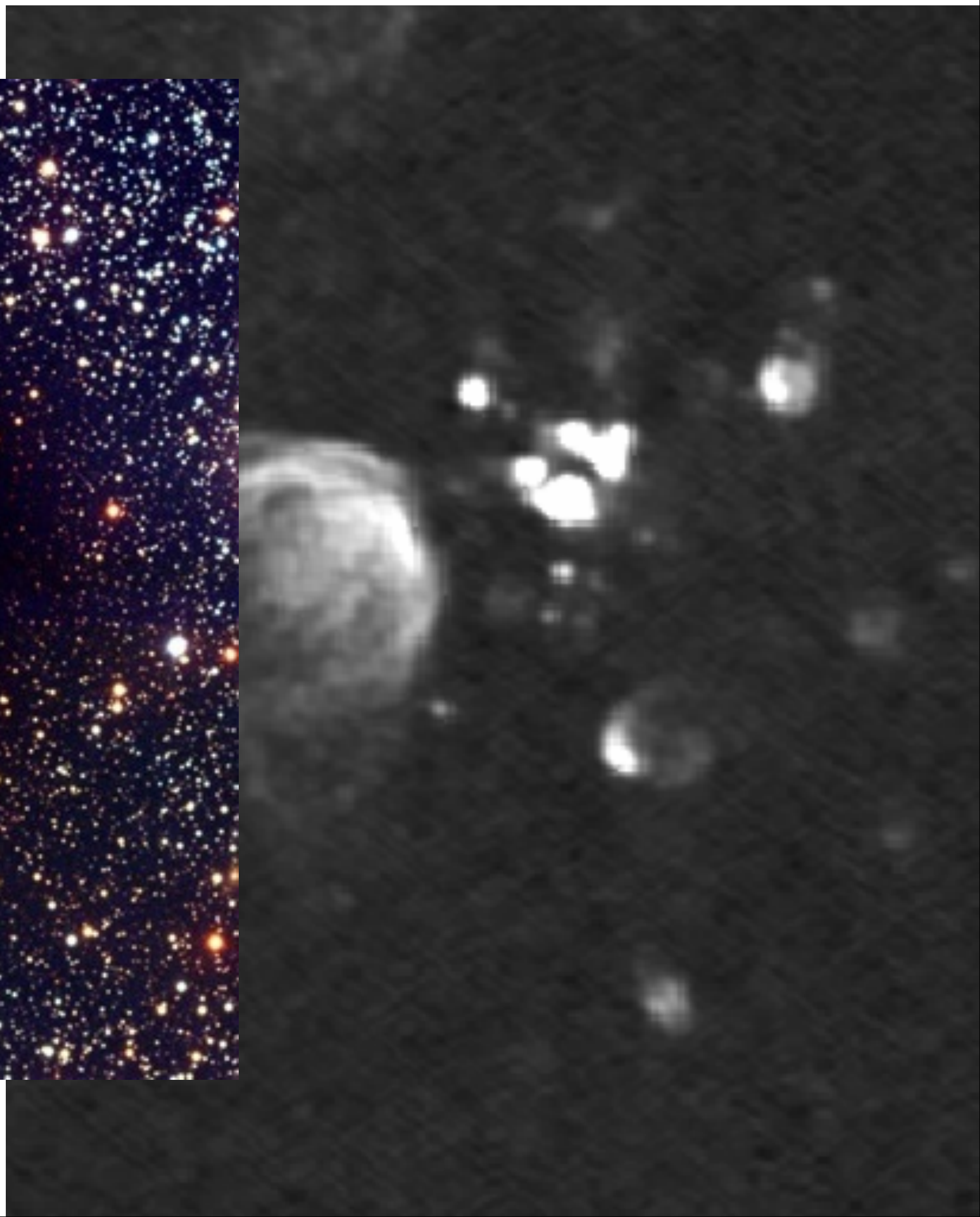
frEGGs:
Too compact, wrong locations

Prestellar Cores:
Too bright, implied mass too large

Compact HII regions:
Can explain some, but not most



Sahai+ 2012



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