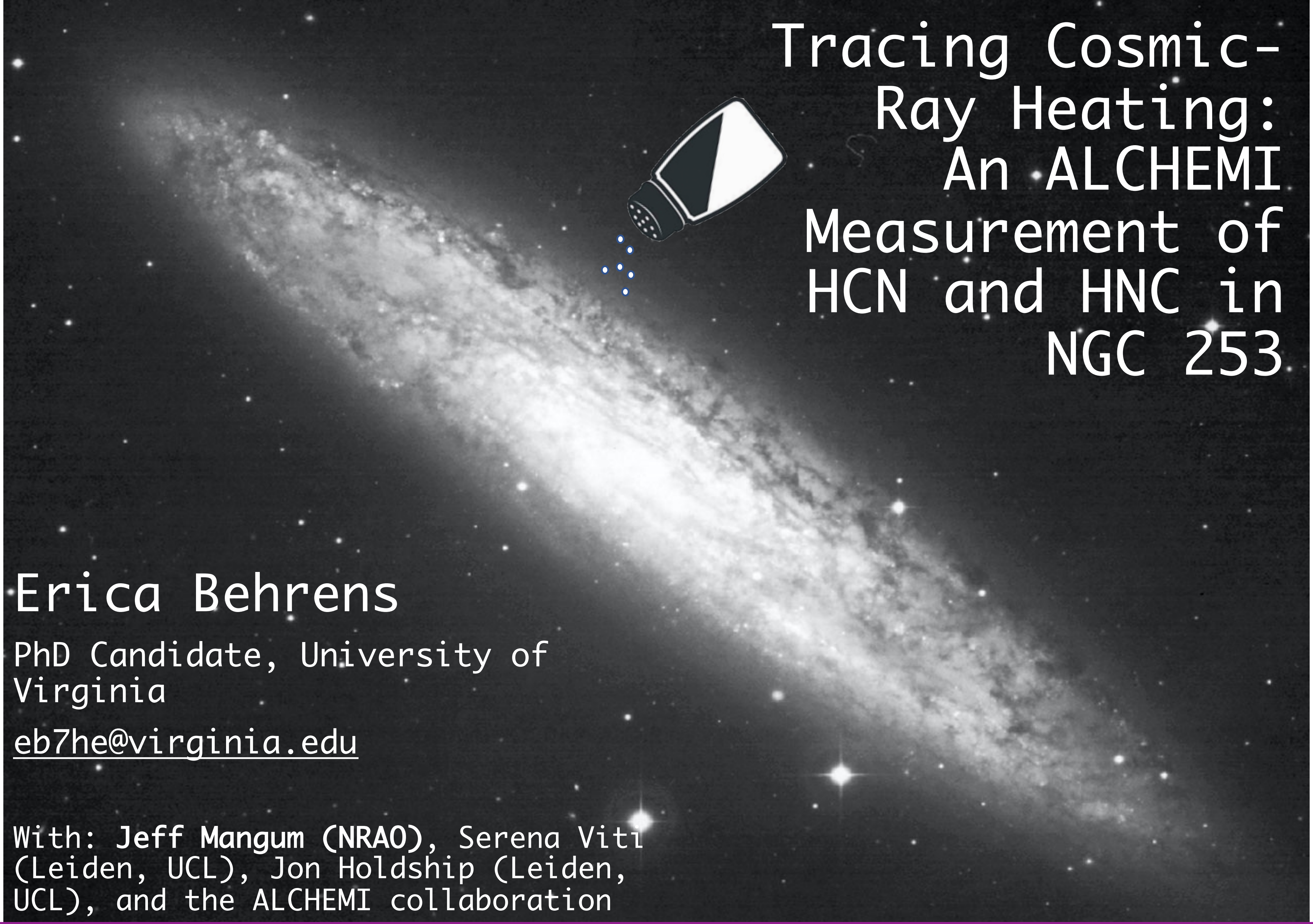

Tracing Cosmic-Ray Heating: An ALCHEMI Measurement of HCN and HNC in NGC 253

Erica Behrens

PhD Candidate, University of Virginia

eb7he@virginia.edu

With: **Jeff Mangum (NRAO)**, Serena Viti (Leiden, UCL), Jon Holdship (Leiden, UCL), and the ALCHEMI collaboration

Tracing Interstellar Heating: An ALCHEMI Measurement of the HCN Isomers in NGC 253

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Christian Henkel[14,16] Ko-Yun Huang[3] P. K. Humire[14] David S. Meier[17,18]
And Víctor M. Rivilla[15]

et al.

(ALMA Comprehensive High-resolution Extragalactic Molecular Inventory (ALCHEMI) collaboration)

ABSTRACT

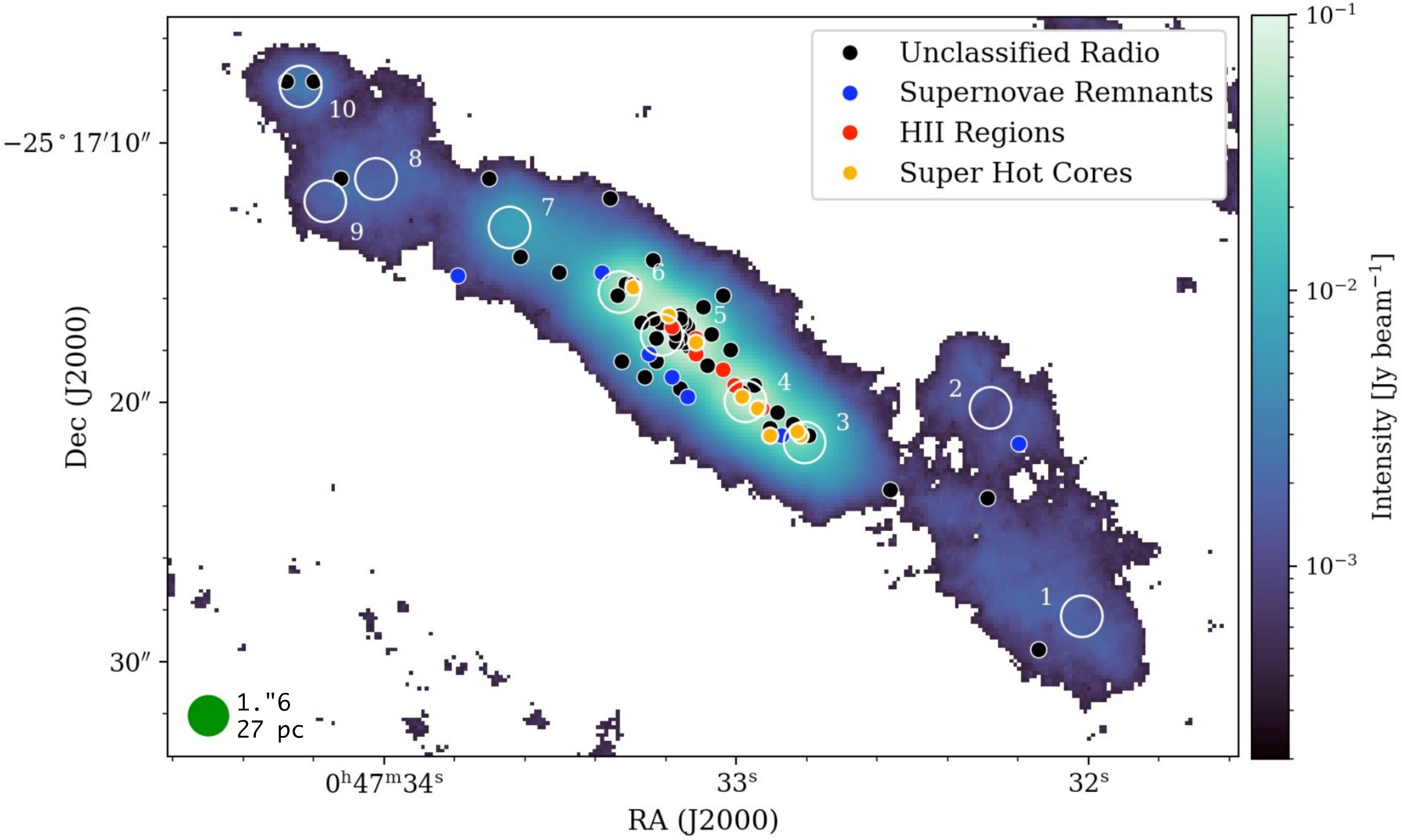
We analyze HCN and HNC emission in the nearby starburst galaxy NGC 253 to investigate its effectiveness in tracing heating processes associated with star formation. This study uses multiple HCN and HNC rotational transitions observed using ALMA via the ALCHEMI Large Program. To understand the conditions and associated heating mechanisms within NGC 253's dense gas, we employ Bayesian nested sampling techniques applied to chemical and radiative transfer models which are constrained using our HCN and HNC measurements. We find that the volume density n_{H_2} and cosmic ray ionization rate (CRIR) ζ are enhanced by about an order of magnitude in the galaxy's central regions as compared to those further from the nucleus. In NGC 253's central GMCs, where observed HCN/HNC abundance ratios are lowest, $n \sim 10^{5.5}$ cm^{-3} and $\zeta \sim 10^{-12}$ s^{-1} (greater than 10^4 times the average Galactic rate). We find a positive correlation in the association of both density and CRIR with the number of star formation-related heating sources (supernova remnants, HII regions, and super hot cores) located in each GMC, as well as a correlation between CRIRs and supernova rates. Additionally, we see an anticorrelation between the HCN/HNC ratio and CRIR, indicating that this ratio will be lower in regions where ζ is higher. Though previous studies suggested HCN and HNC may reveal strong mechanical heating processes in NGC 253's CMZ, we find cosmic ray heating dominates the heating budget, and mechanical heating does not play a significant role in the HCN and HNC chemistry.

Check out the paper on arxiv!

Behrens et al., accepted to *ApJ*

NGC 253: The Prototypical Starburst

$d \sim 3.5$ Mpc away



GMCs from Leroy et al. (2015)

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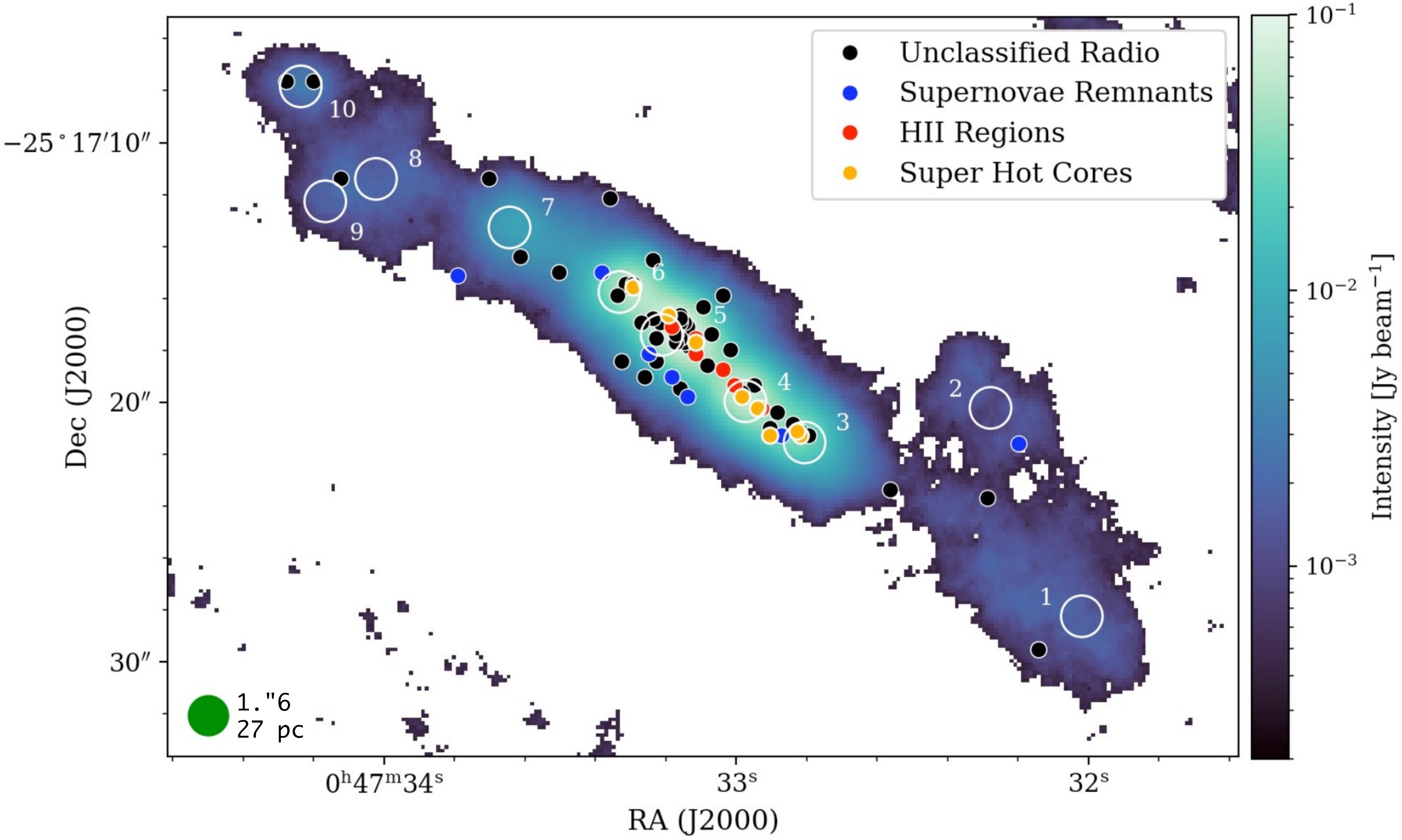
Nuclear starburst: half of total SF occurring in central kpc



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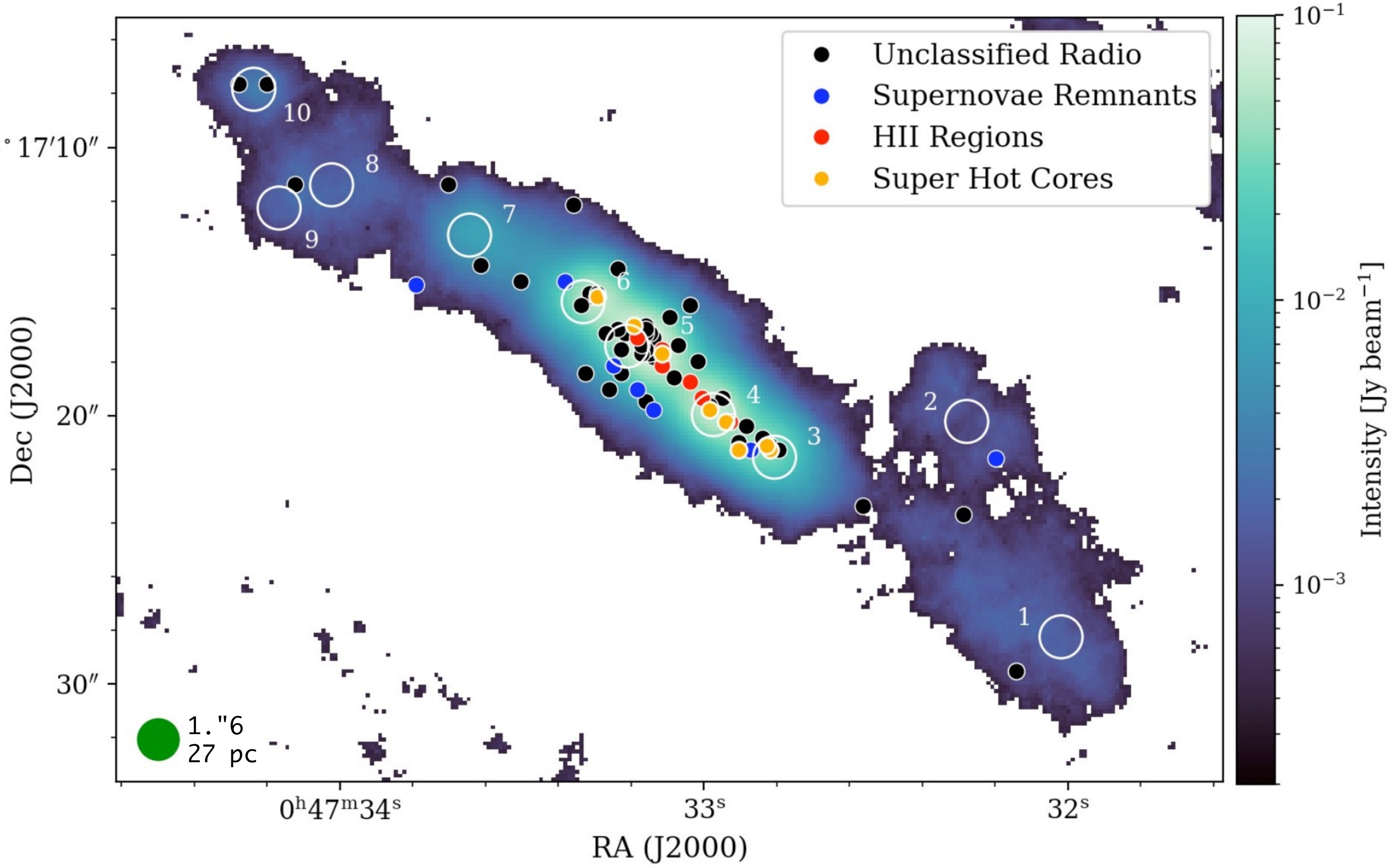

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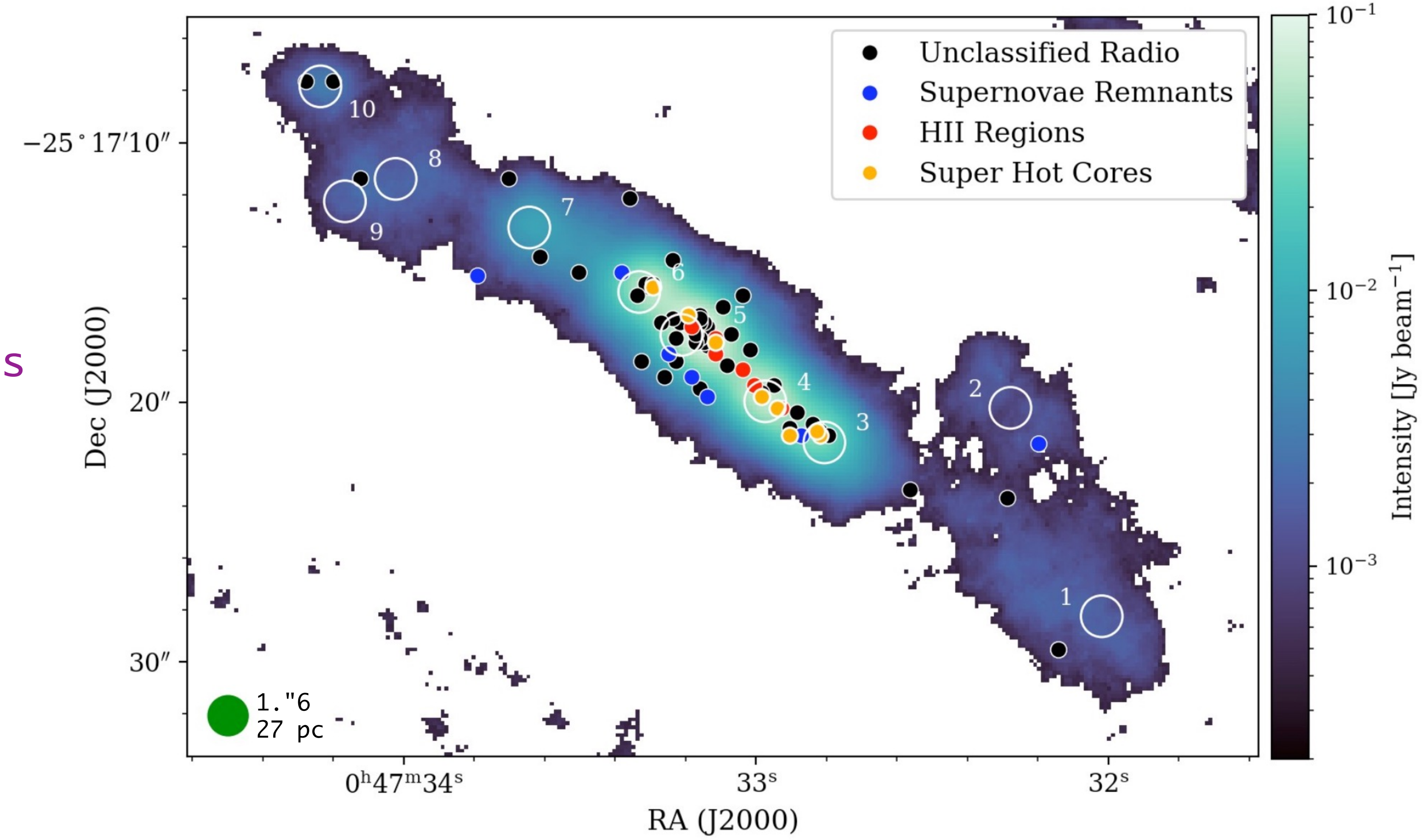
Use ALMA Comprehensive High Resolution Extragalactic Molecular Inventory (ALCHEMI) dataset (Martín et al. 2021)



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Dominant Heating Mechanisms in Starbursts

What processes are causing the kinetic temp to rise—and what is the source of this heating?

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Observations: HCN and HNC 1–0, 2–1, 3–2, and 4–3 rotational transitions

Chemical model: UCLCHEM, a two-phase gas-grain chemical modeling code

Radiative Transfer Model: RADEX (via SpectralRadex)

Sampling the Parameter Space

Table 3. Prior Distributions

	Parameter	Range	Distribution Type
T	Temperature	50–300 K	Uniform
n	Volume Density	10^3–10^7 cm^{-3}	Log-uniform
ζ	Cosmic Ray Ionization Rate	10–10^7 ζ_0 [a]	Log-uniform
N_{H_2}	H_2 Column Density	10^{22}–10^{25} cm^{-2}	Log-uniform

[a] $\zeta_0 = 1.36 \times 10^{-17}\,s^{-1}$

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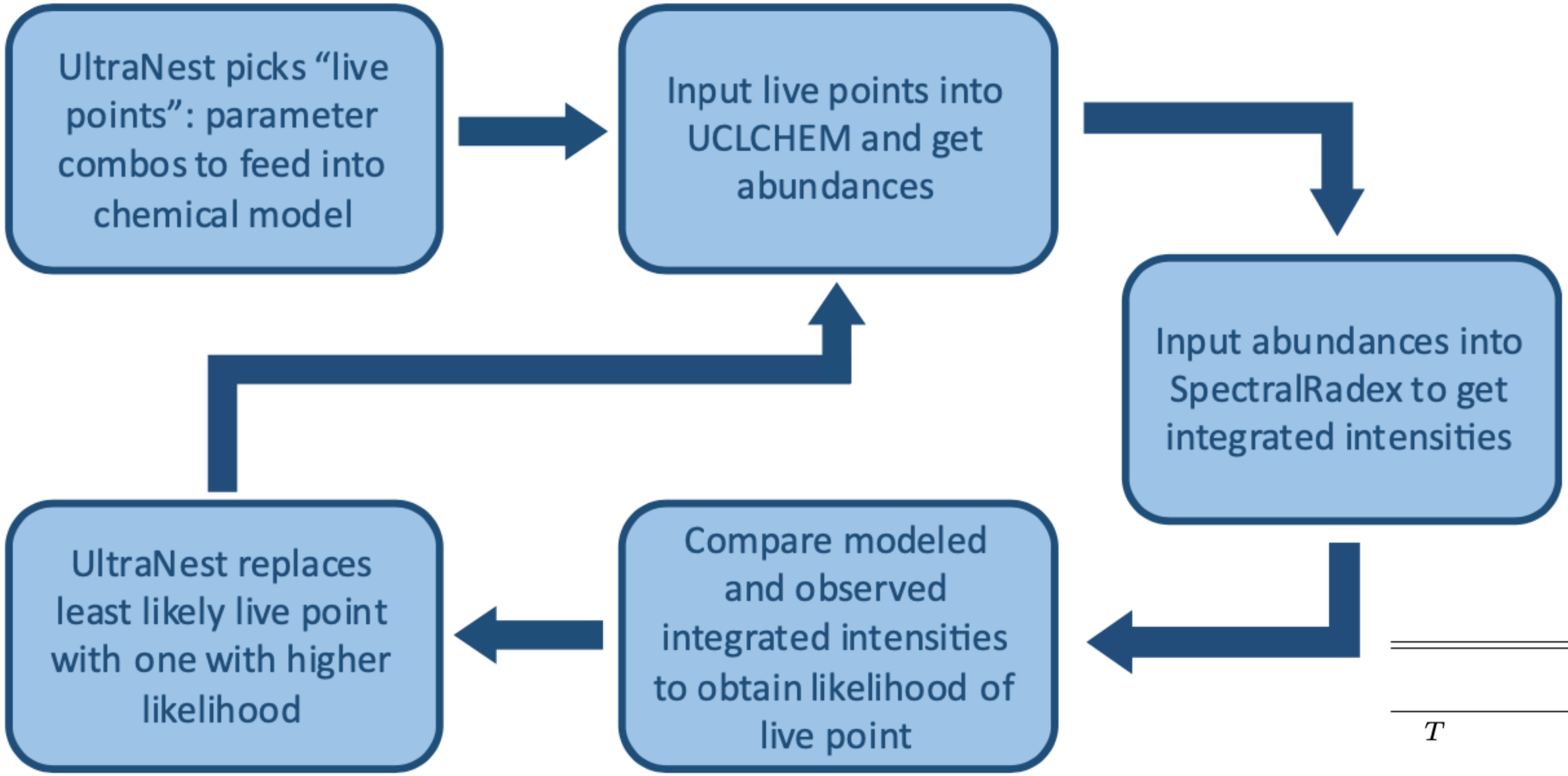
→ ζ: 10^{-16} – 10^{-10} s^{-1}

Sampling the Parameter Space



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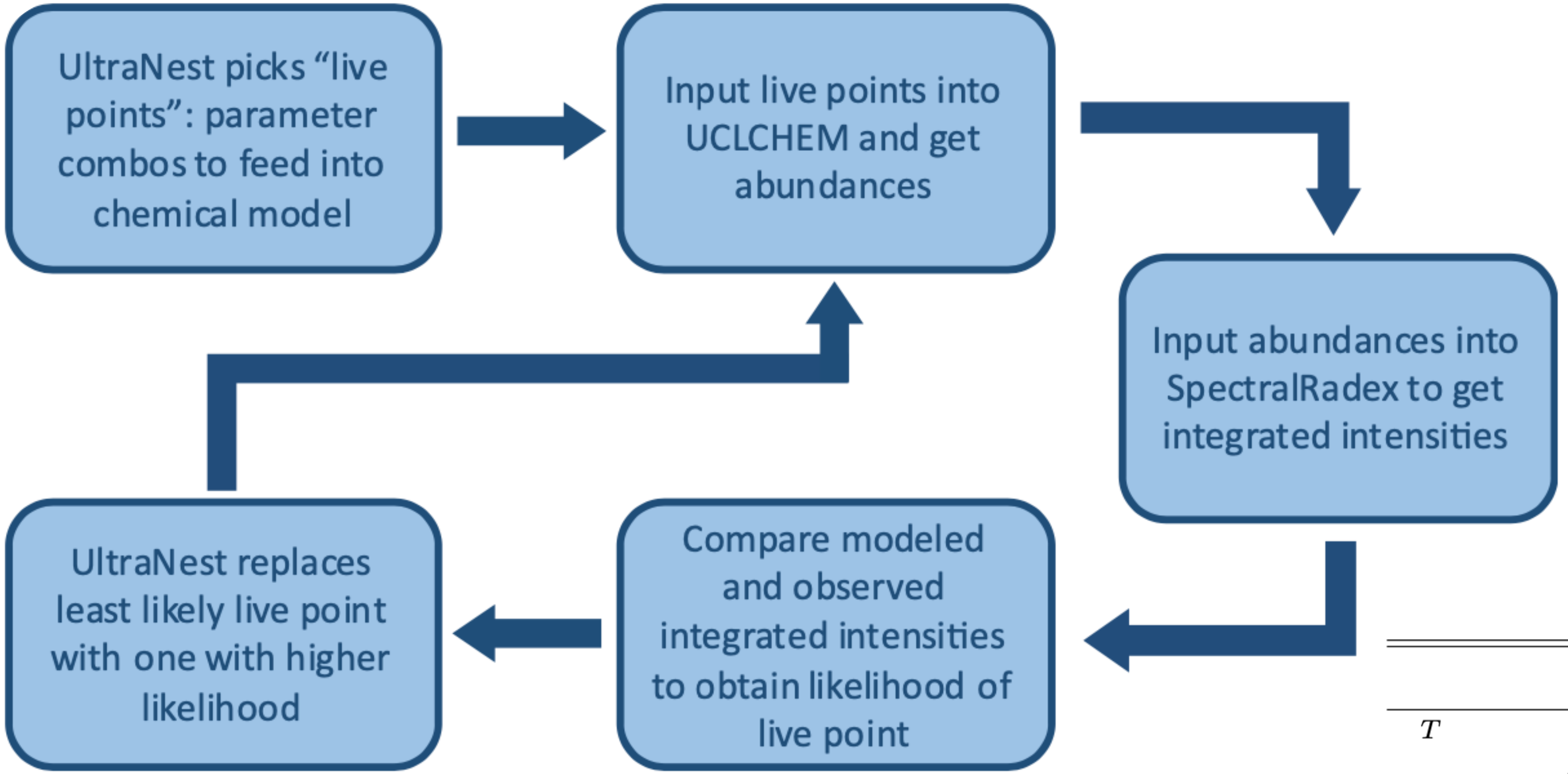

Use Bayesian nested sampling technique via UltraNest package

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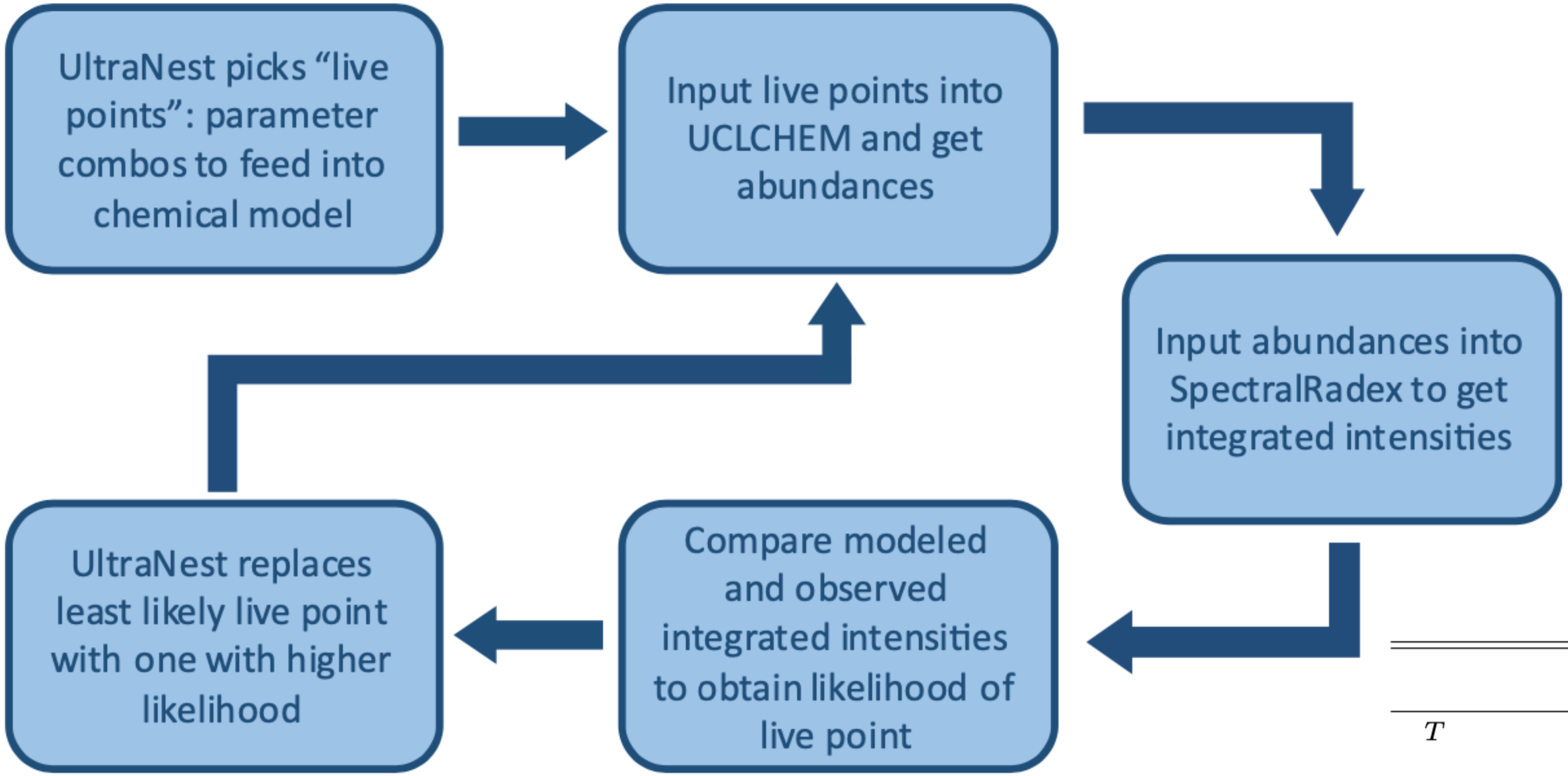

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Compare observations and models to determine most likely parameter combinations

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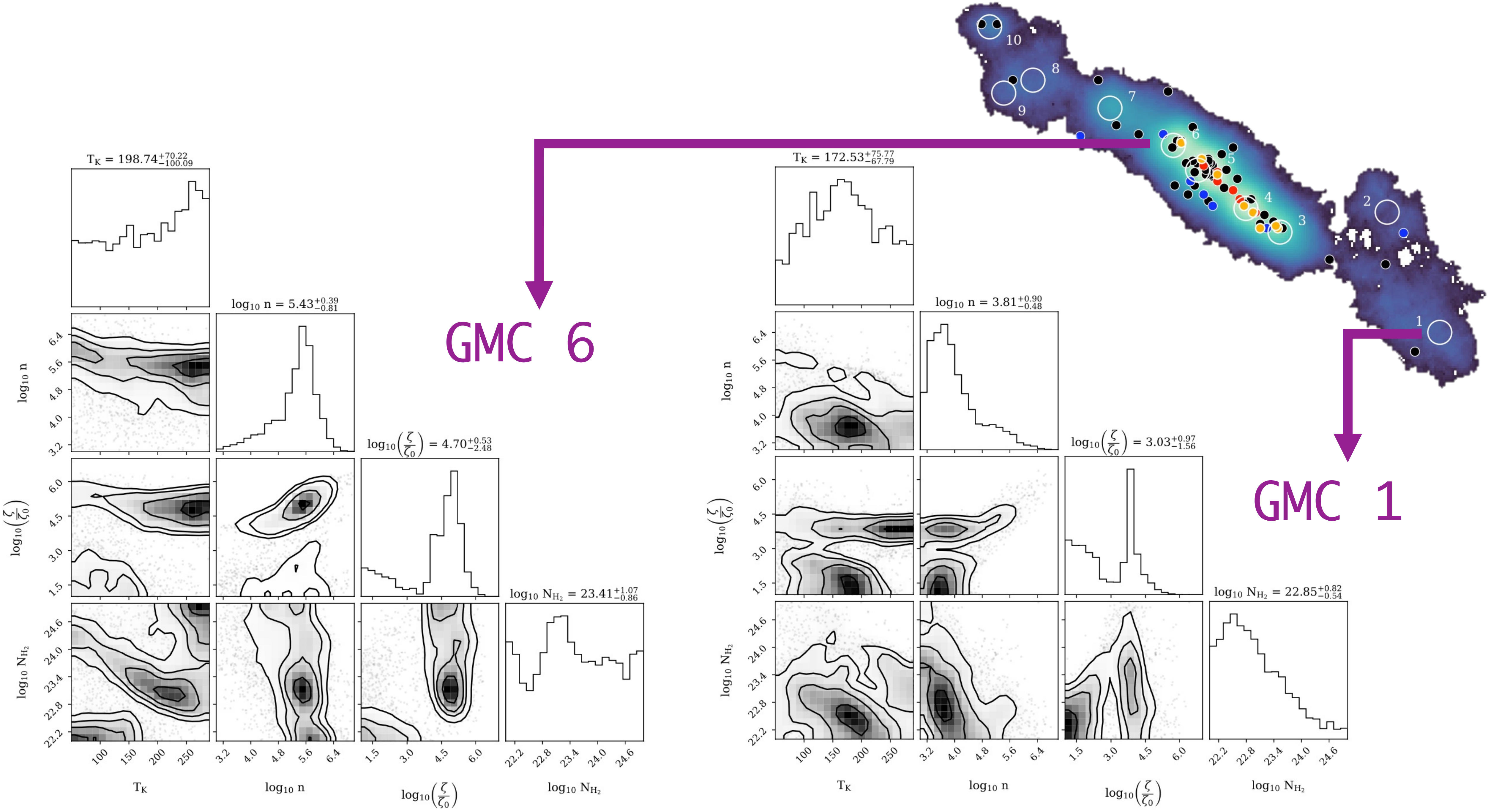
GMC 6
GMC 1
$T_K = 198.74^{+70.22}_{-100.09}$
$\log_{10} n = 5.43^{+0.39}_{-0.81}$
$\log_{10}\left(\frac{\zeta}{\zeta_0}\right) = 4.70^{+0.53}_{-2.48}$
$\log_{10} N_{H_2} = 23.41^{+1.07}_{-0.86}$
$T_K = 172.53^{+75.77}_{-67.79}$
$\log_{10} n = 3.81^{+0.90}_{-0.48}$
$\log_{10}\left(\frac{\zeta}{\zeta_0}\right) = 3.03^{+0.97}_{-1.56}$
$\log_{10} N_{H_2} = 22.85^{+0.82}_{-0.54}$
T_K
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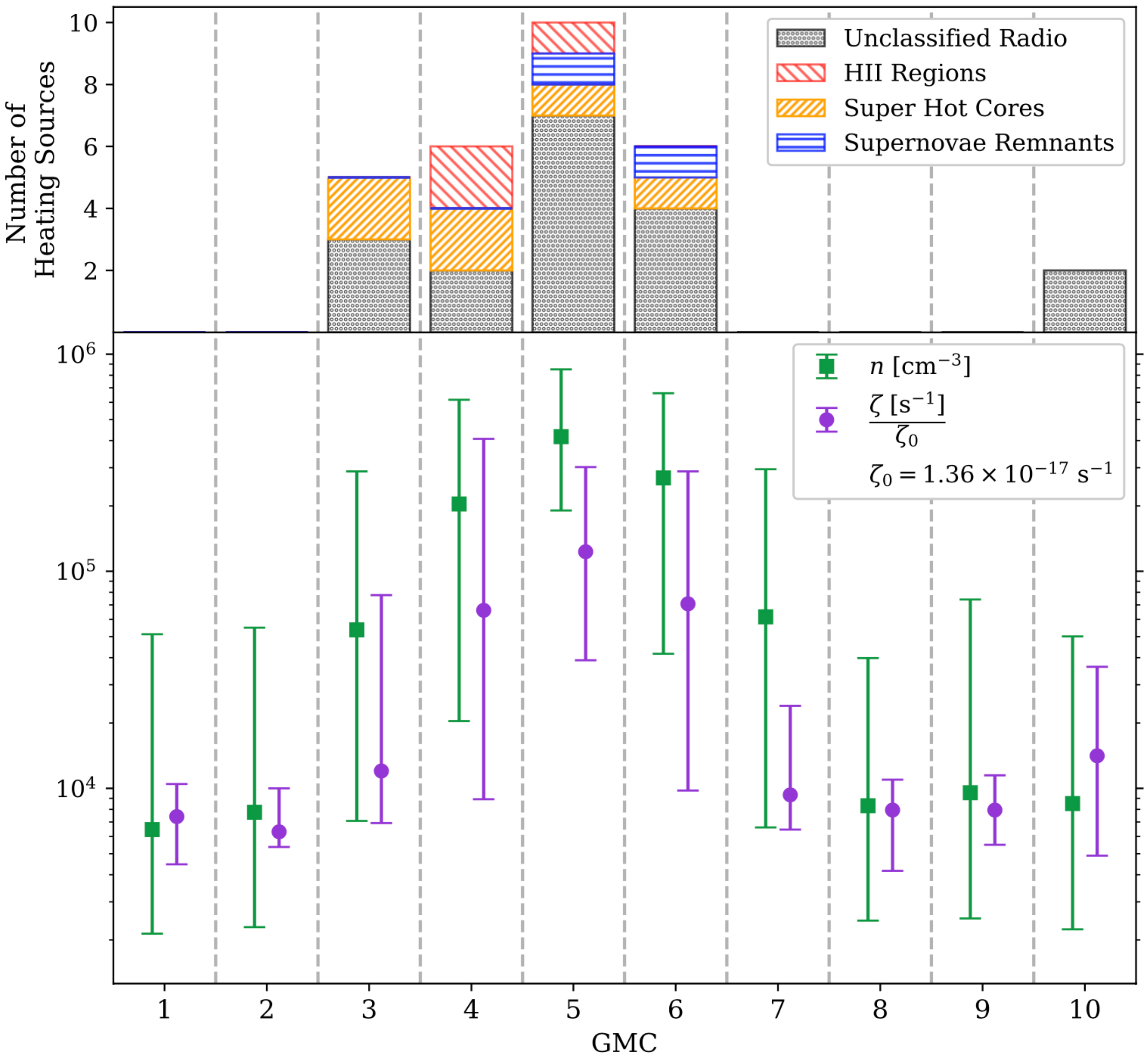
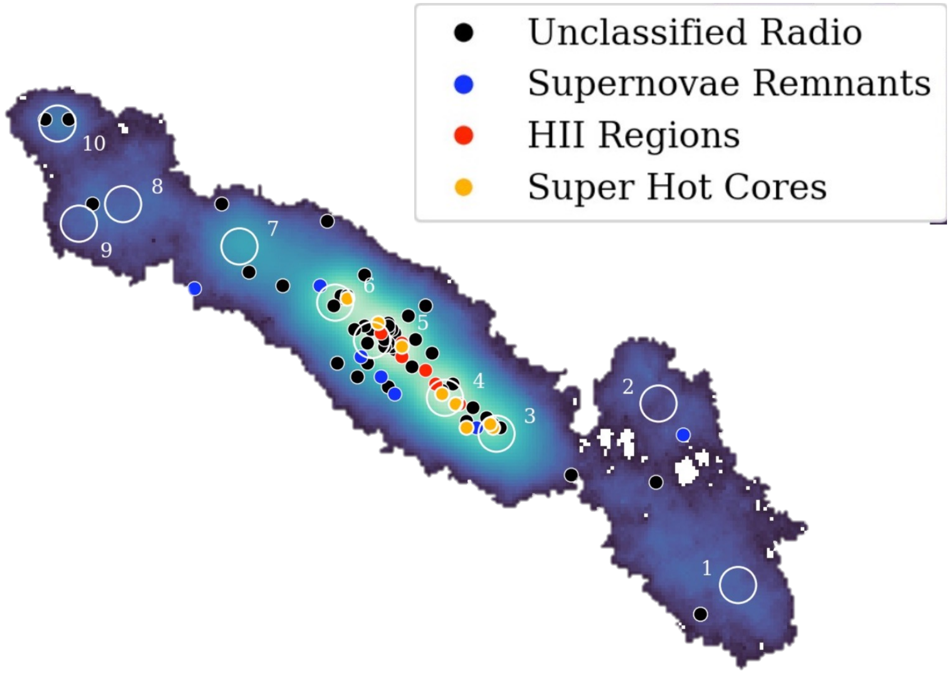
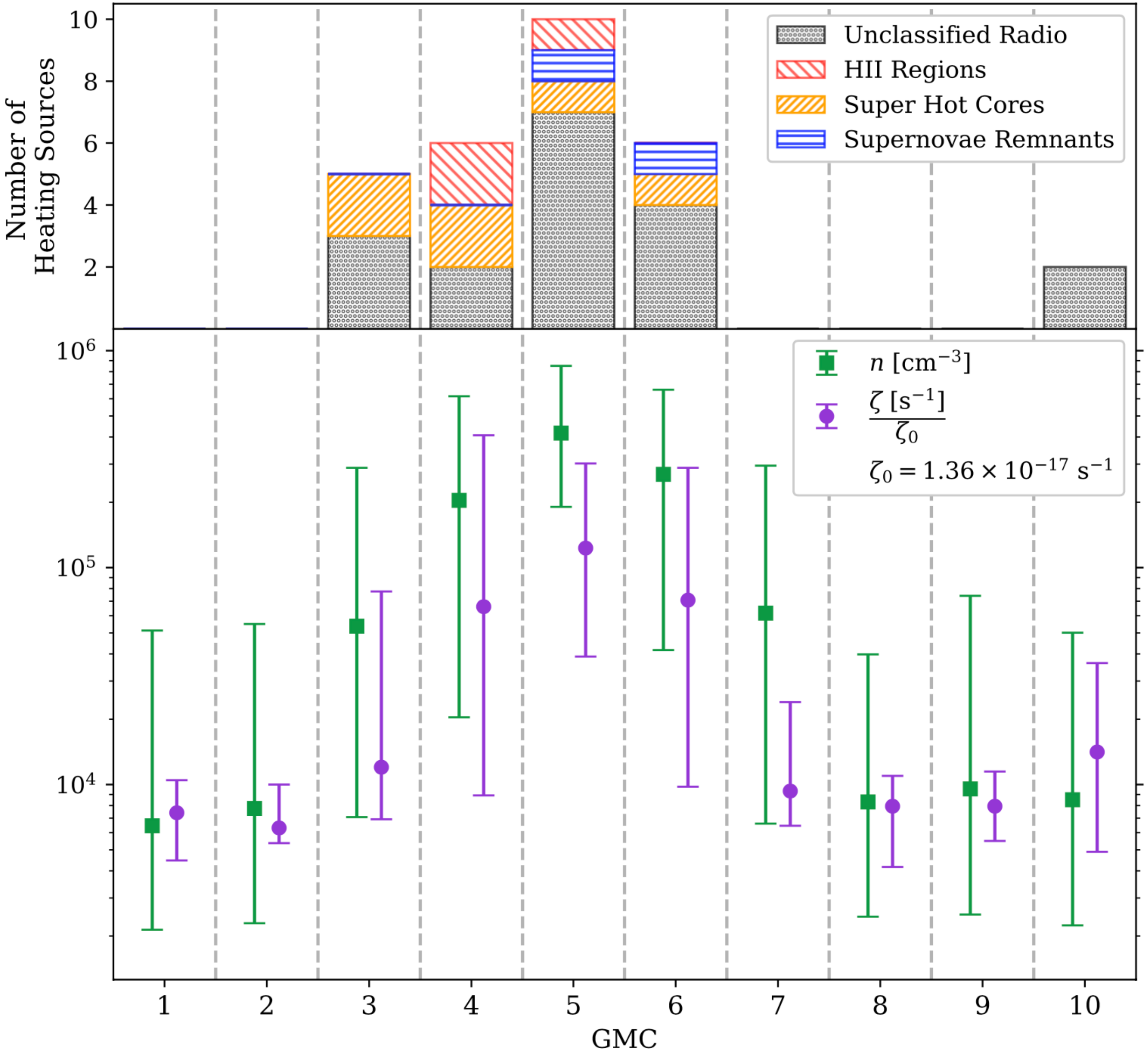
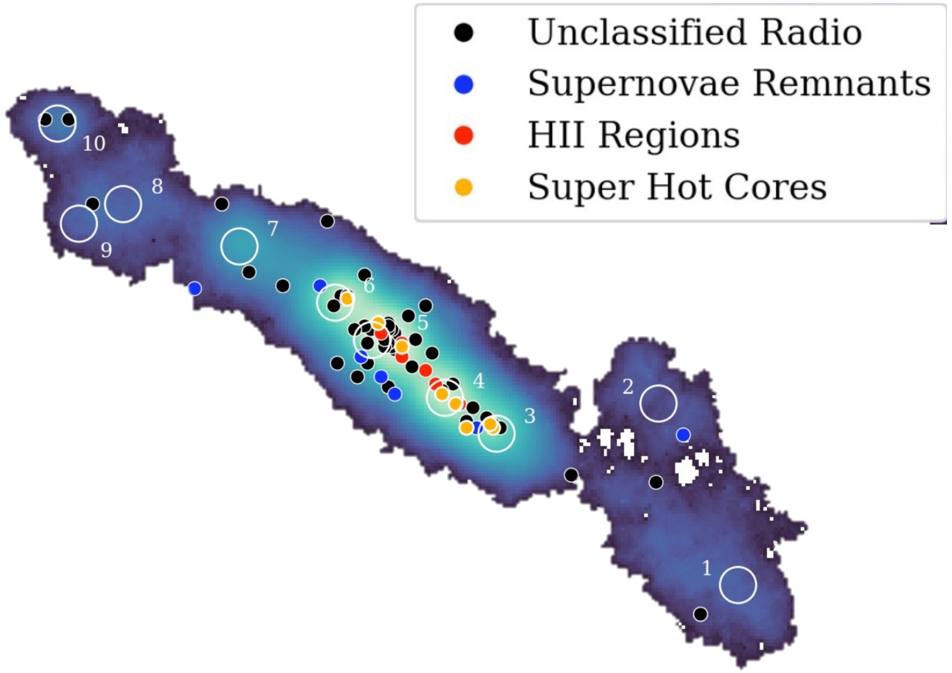
$\log_{10}\left(\frac{\zeta}{\zeta_0}\right)$
$\log_{10} N_{H_2}$
1
2
3
4
5
6
7
8
9
10





Center GMCs: $\zeta \sim 10^{-12}$ s^{-1}
Outer GMCs: $\zeta \sim 10^{-13}$ s^{-1}
→ agree with Harada+21, Holdship+21,22





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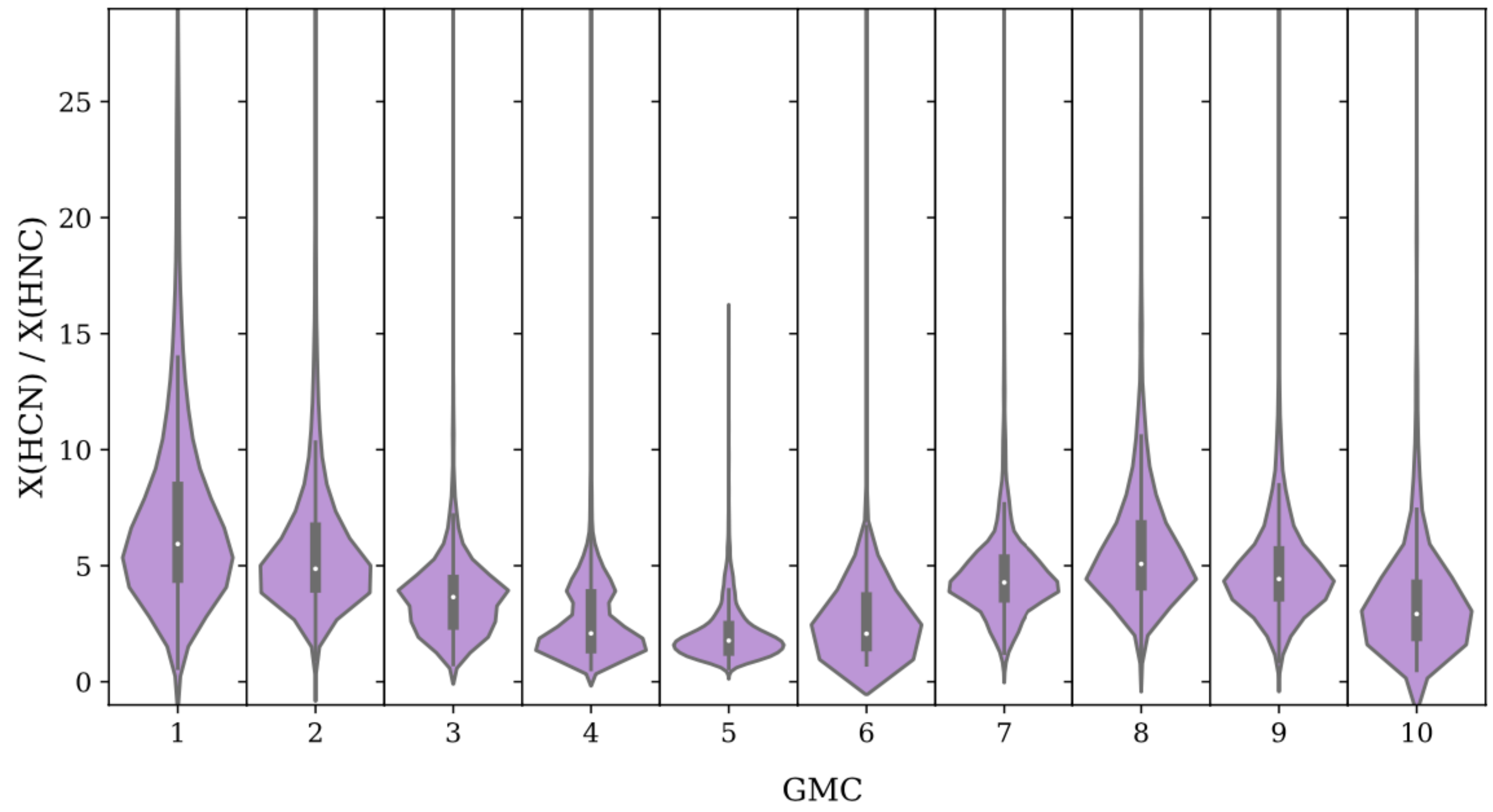
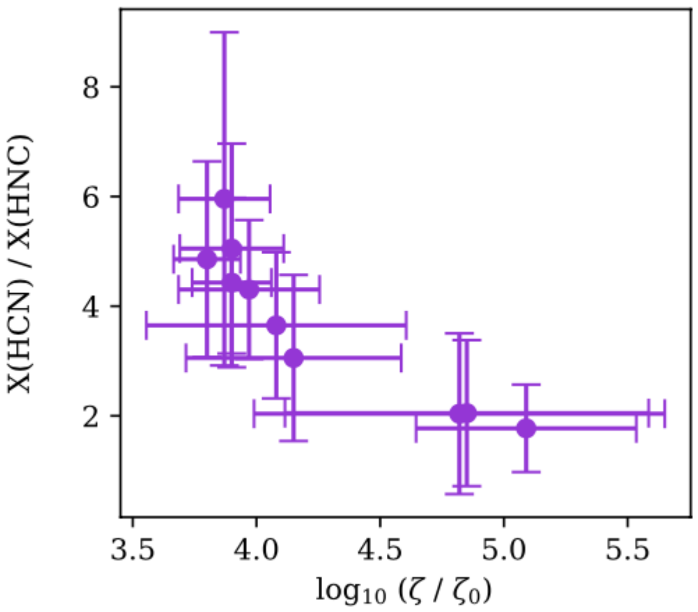
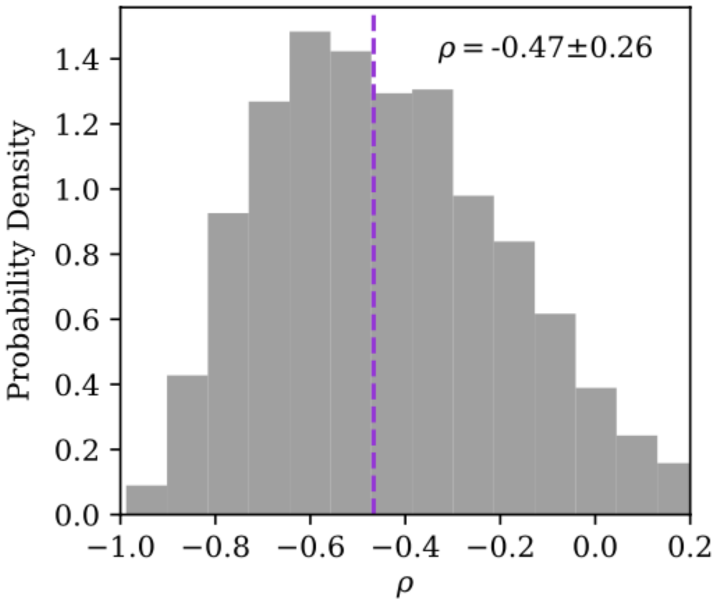
Correlation between CRIR/density and # of heating sources: $\rho \sim 0.67/0.60$



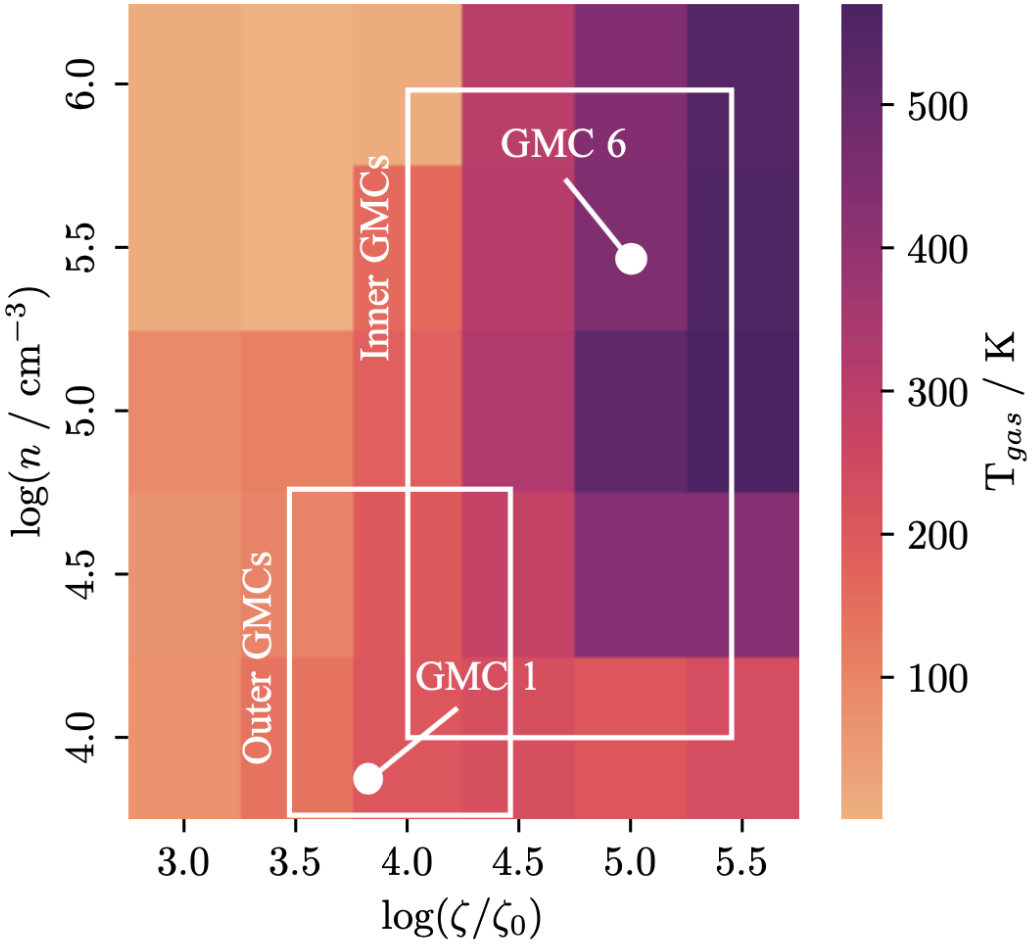




Lower HCN/HNC ratio → higher CRIR

What does this tell us about heating in a starburst environment?

From PDR modeling: predicted CRIR + density values yield gas temps of 200-400 K



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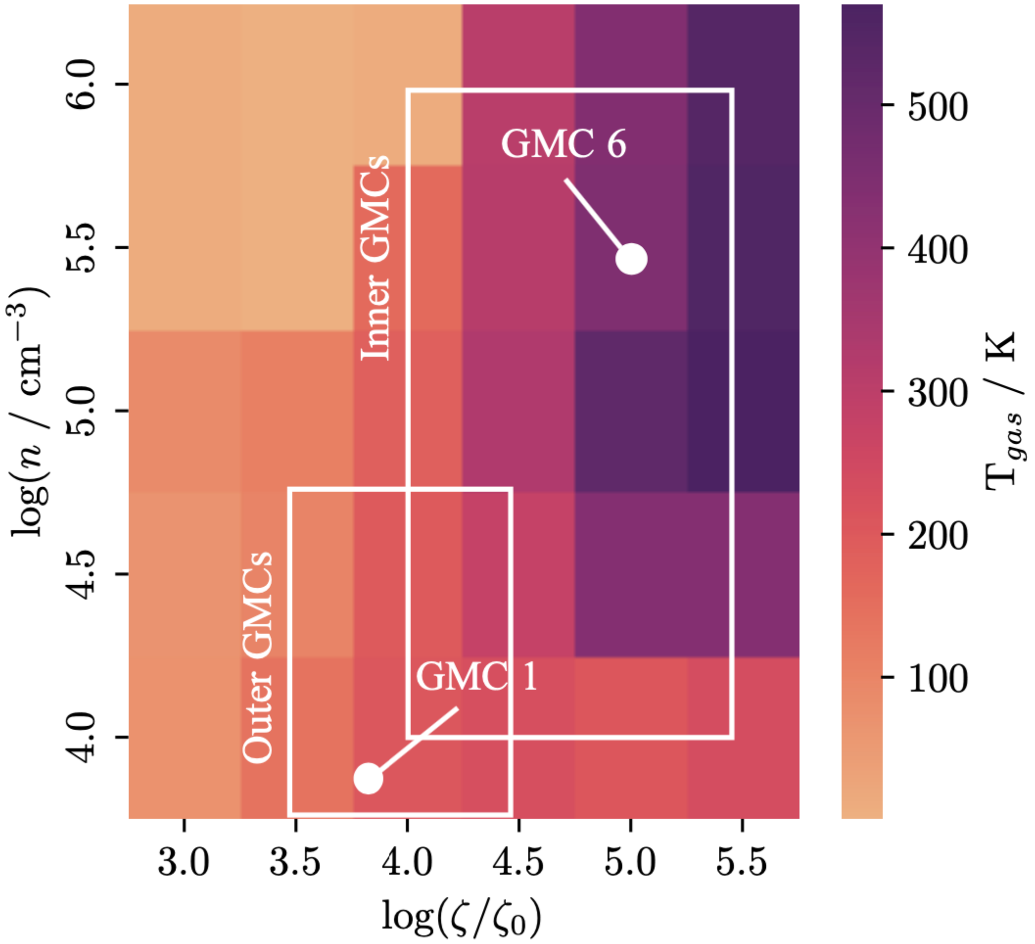

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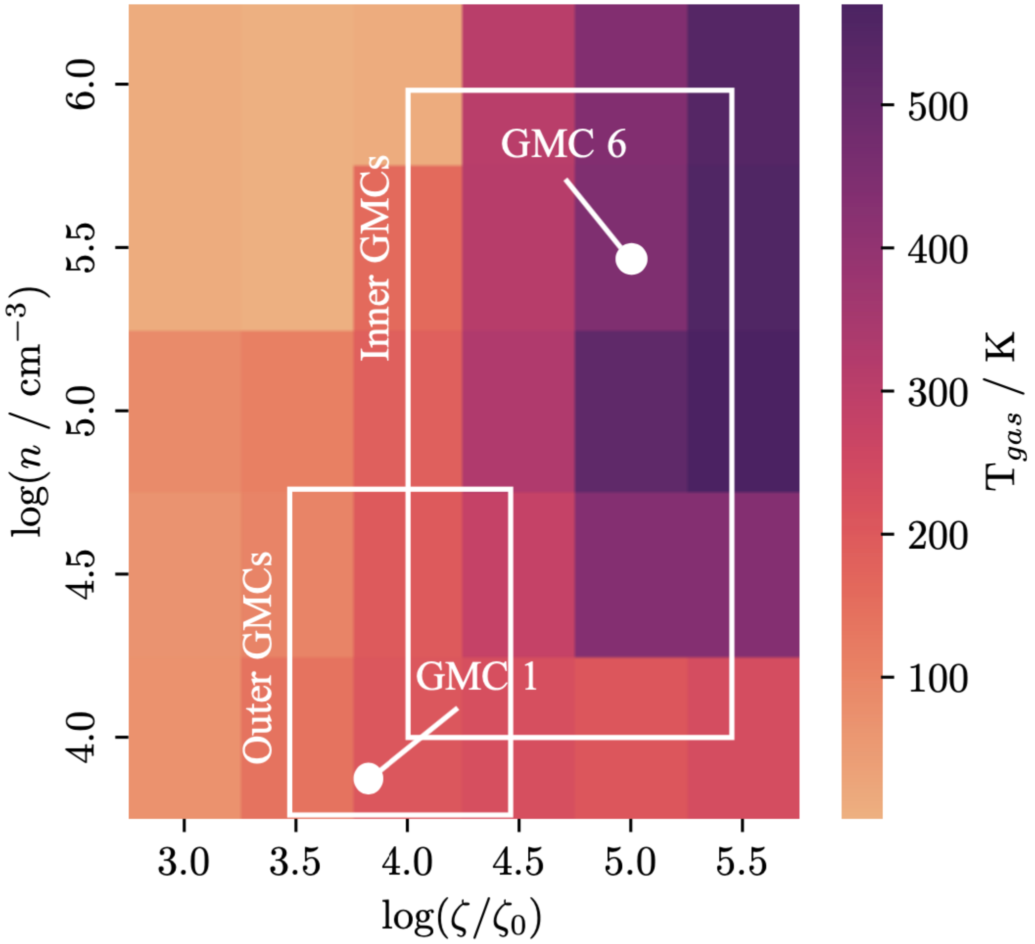

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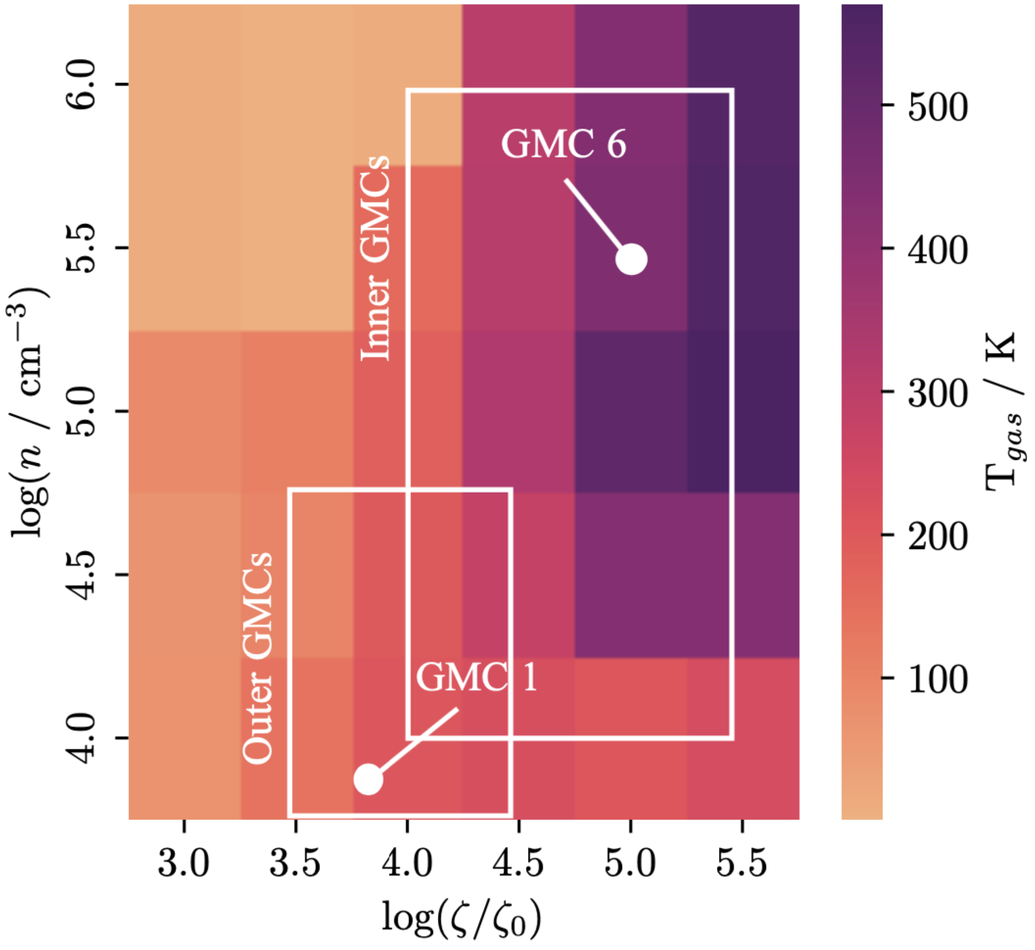
So… what about mechanical heating?



Primary Takeaways

Density and CRIR estimated to be ~10^4–10^5 cm^{-3} and ~10^{-13}–10^{-12} s^{-1} with order-of-magnitude enhancement in central CMZ

See arXiv for details on modeling

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Density and CRIR estimated to be ~10^4–10^5 cm^{-3} and ~10^{-13}–10^{-12} s^{-1} with order-of-magnitude enhancement in central CMZ

Cosmic ray heating alone can explain high kinetic temperatures without requiring additional mechanical heating (though there probably is some…)

See arXiv for details on modeling

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