Slide 0 - Instructions:

- To move slides, use the arrow keys or swipe on your mobile device
- To go to full screen, press "f"
- To print as PDF, go to this URL: ?print-pdf, then print (warning: may be slow and not work on all browsers).
- To see an overview, press `esc`

Dynamical, accretion, and photoevaporative truncation of disks living in dense clusters

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University of Florida, Gainesville

with Justin Otter, John Bally, Nick Ballering, Ciriaco Goddi, Dick Plambeck, Melvyn Wright, and Josh Eisner

Slides available at https://keflavich.github.io/talks/EPOS_2022.html

Opening Summary

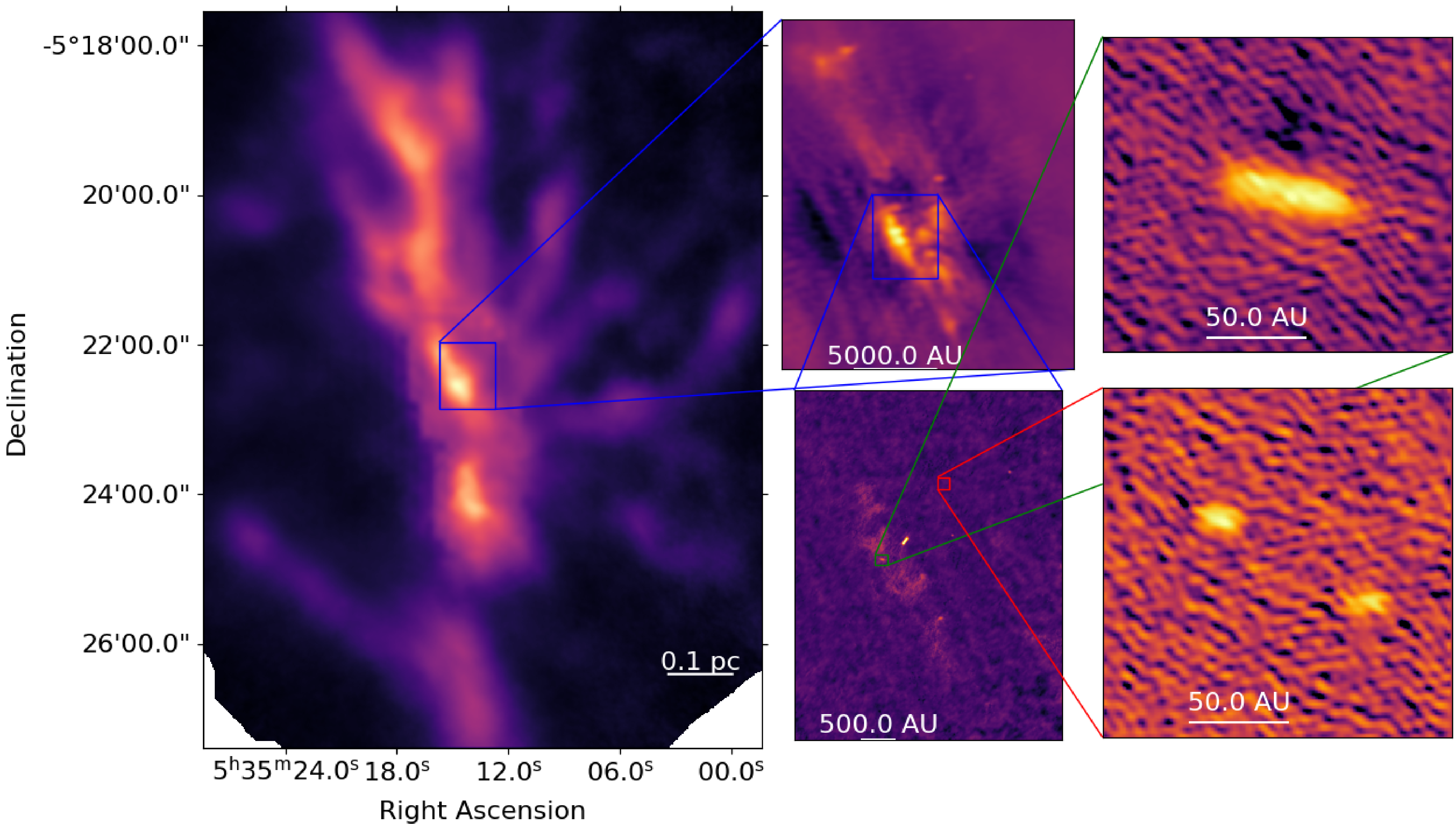
1. Most of the star systems in the OMC1 cluster are disk-bearing
2. Disks in OMC1 and the ONC are both *more massive* and *smaller* than in smaller SFRs
3. Photoevaporative feedback may affect ONC stars, but OMC must be either dynamically or accretion truncated

Otter+ 2021

Star formation in bound clusters is different

(at least for disks)

The Orion Hot Core



Schuller+ 2021 ARTEMIS data

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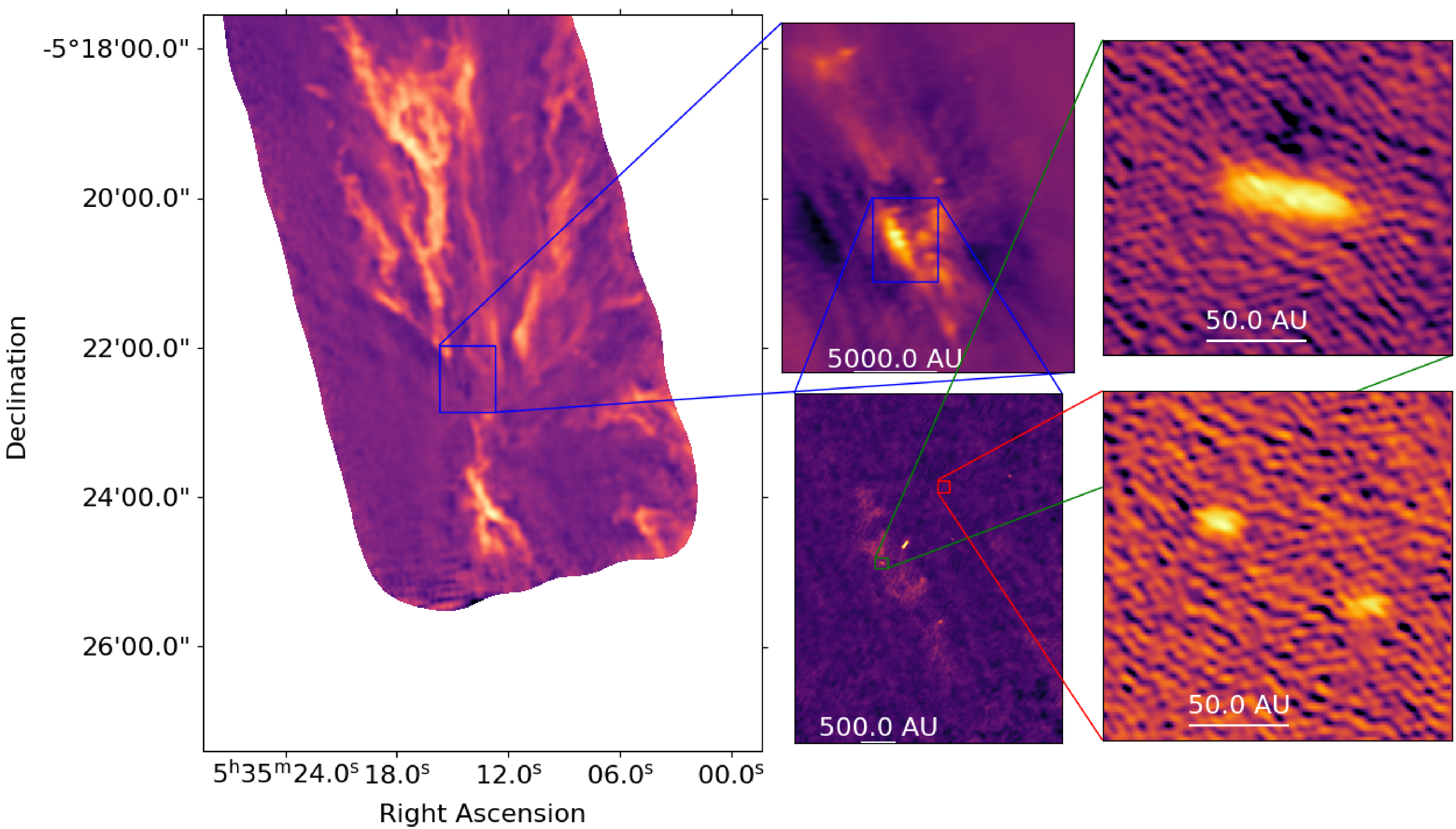
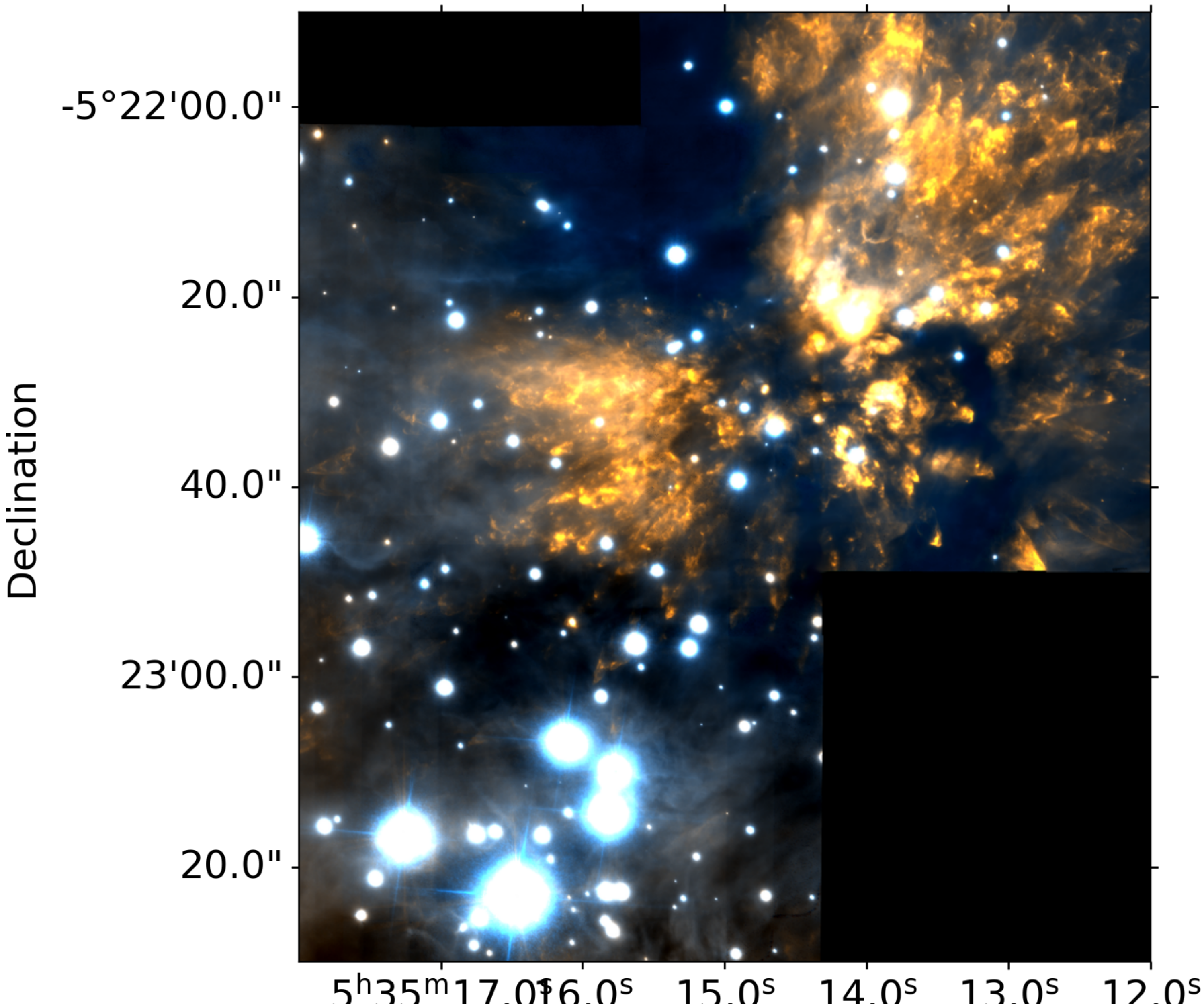
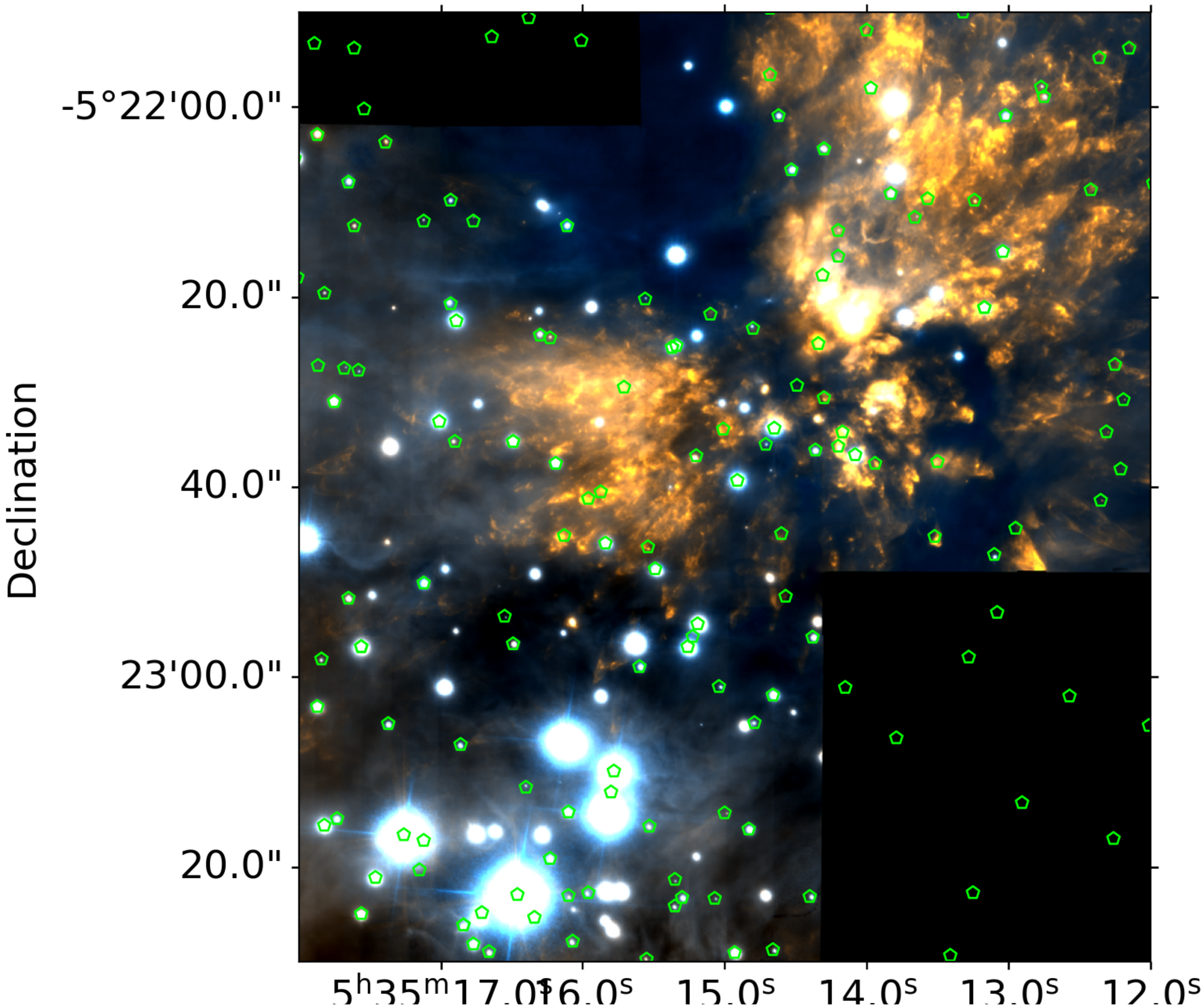


Hacar+ 2018 N_2H+

ONC+OMC: Gemini image



ONC+OMC: IR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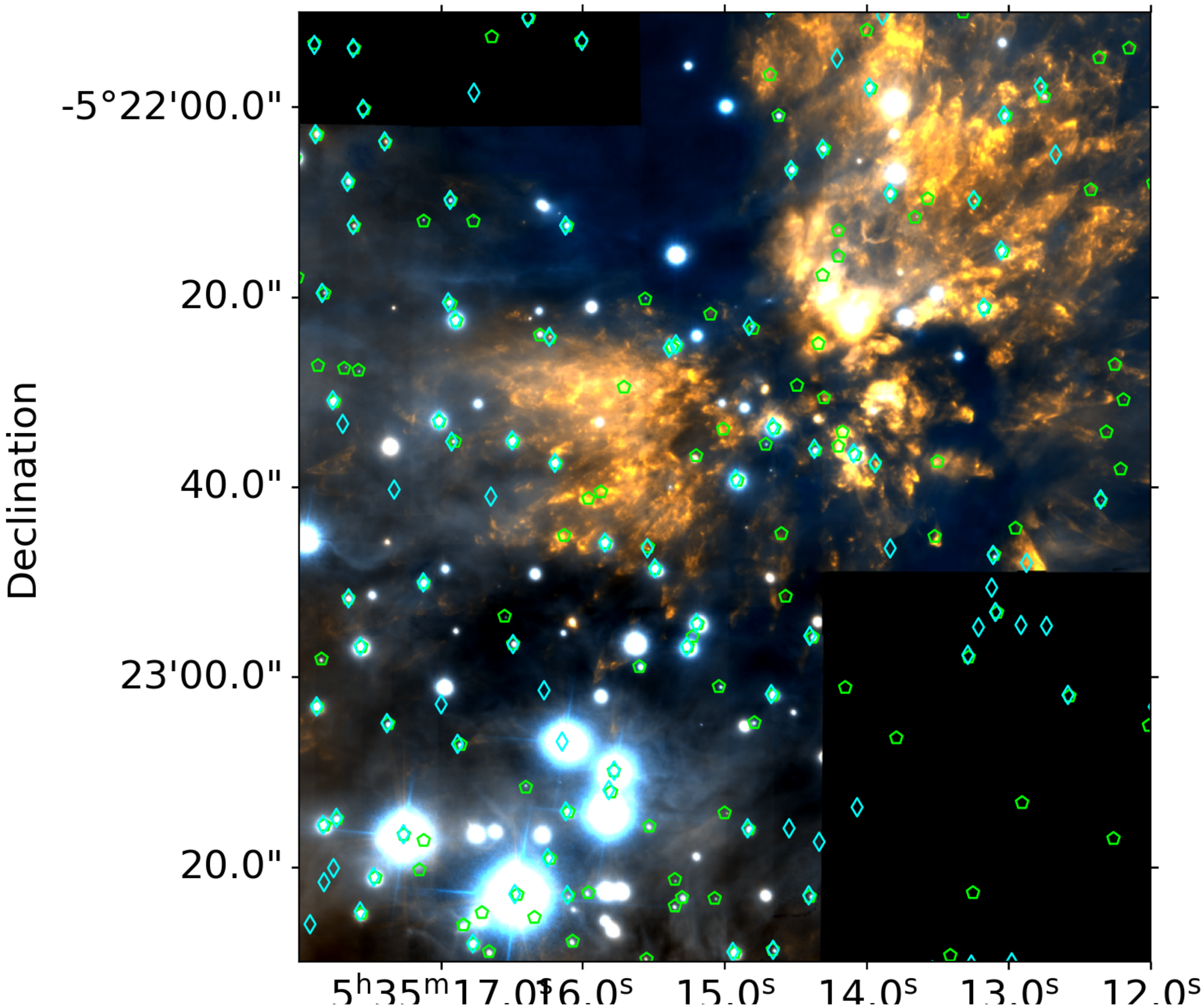
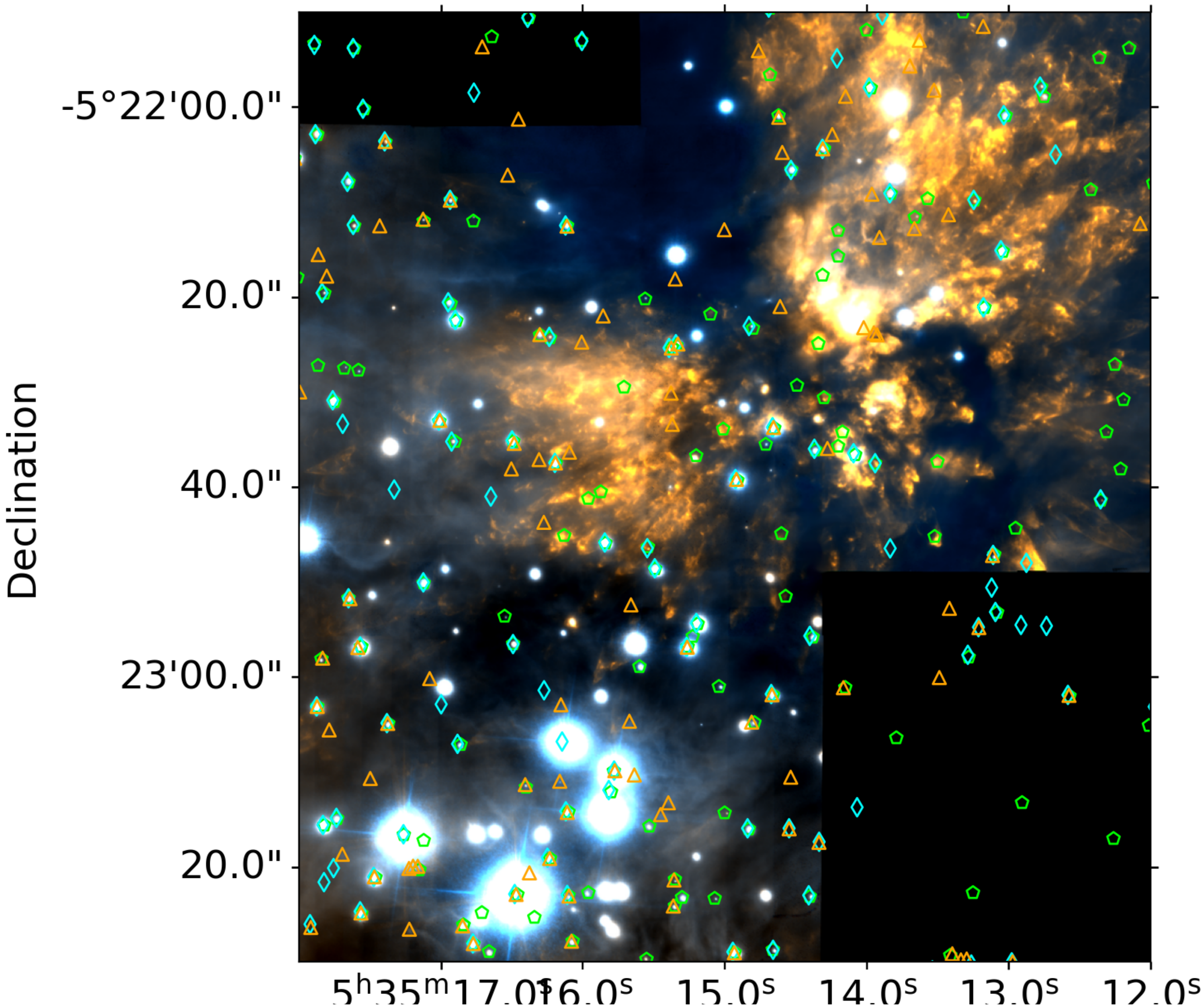
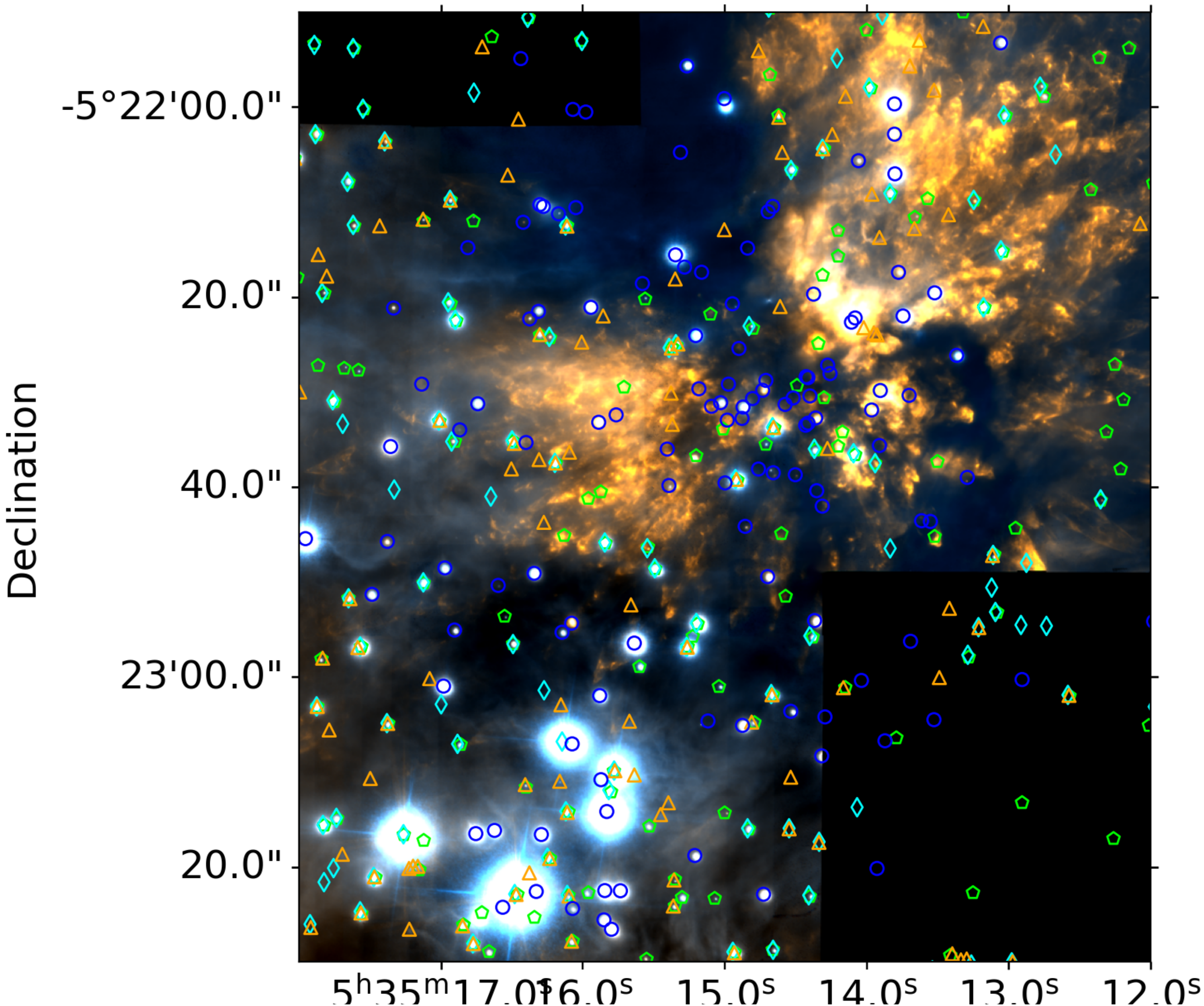
ONC+OMC: IR + X-ray



ONC+OMC: IR + X-ray + radio



ONC+OMC: IR + X-ray + radio + mm



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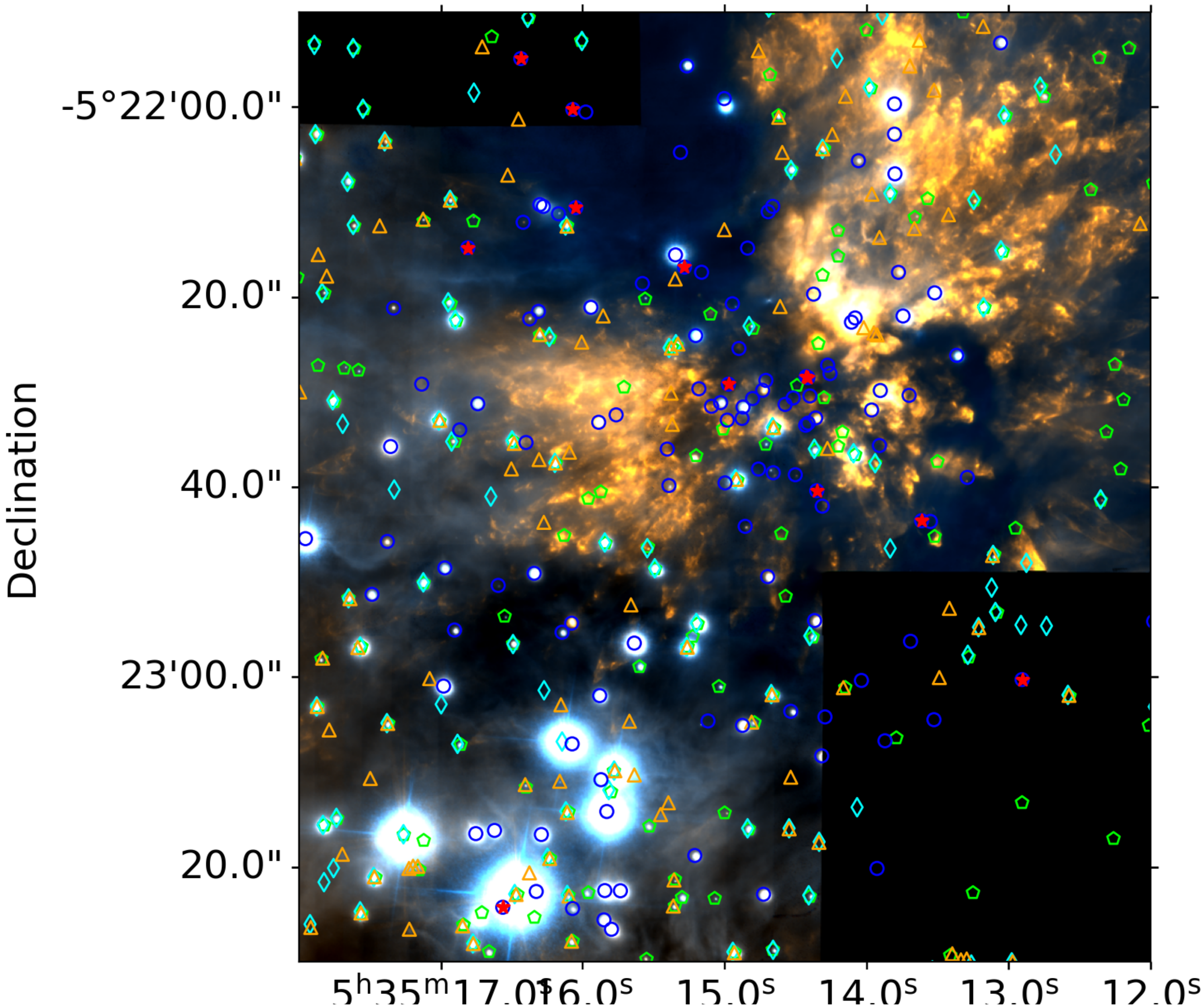

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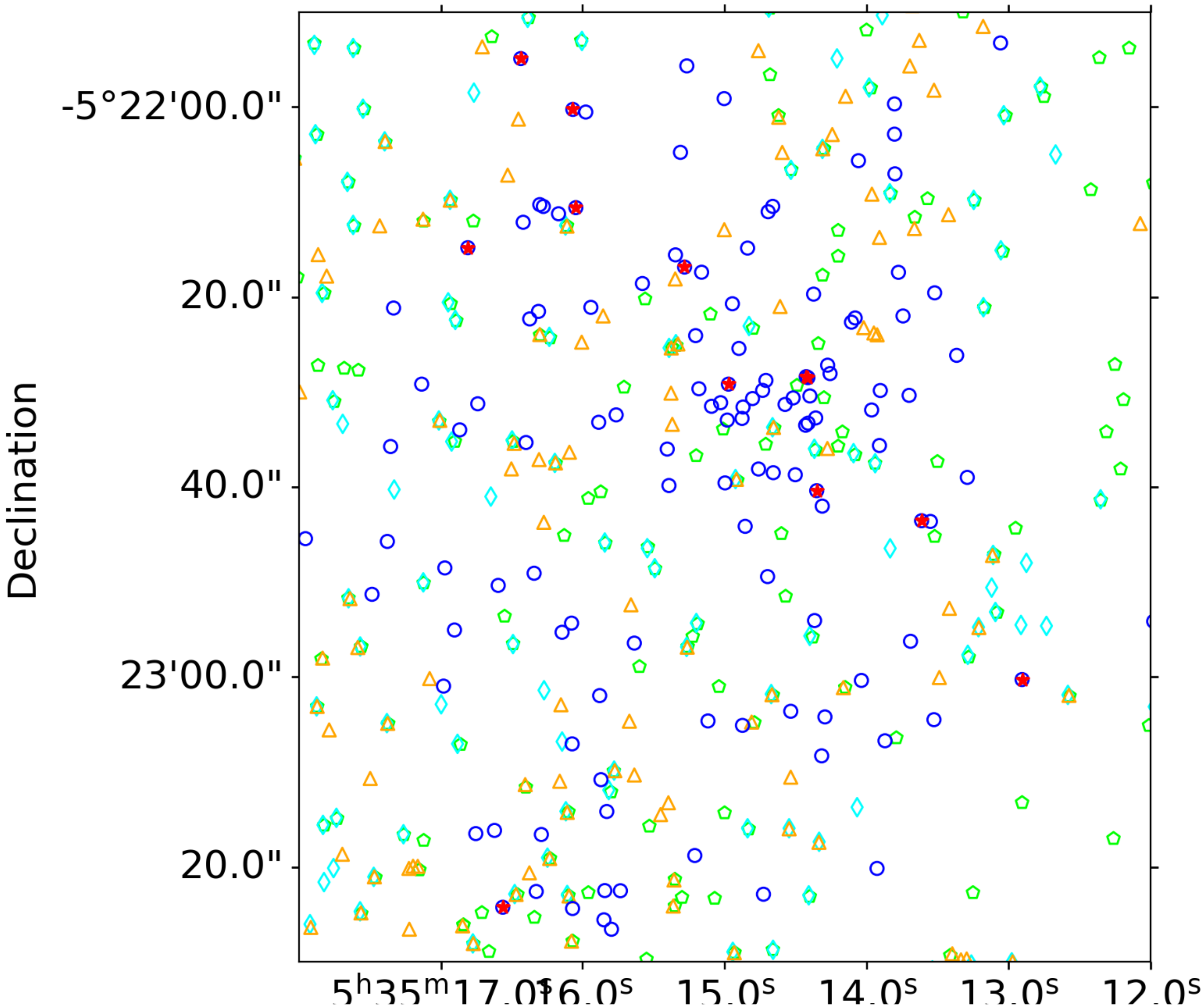

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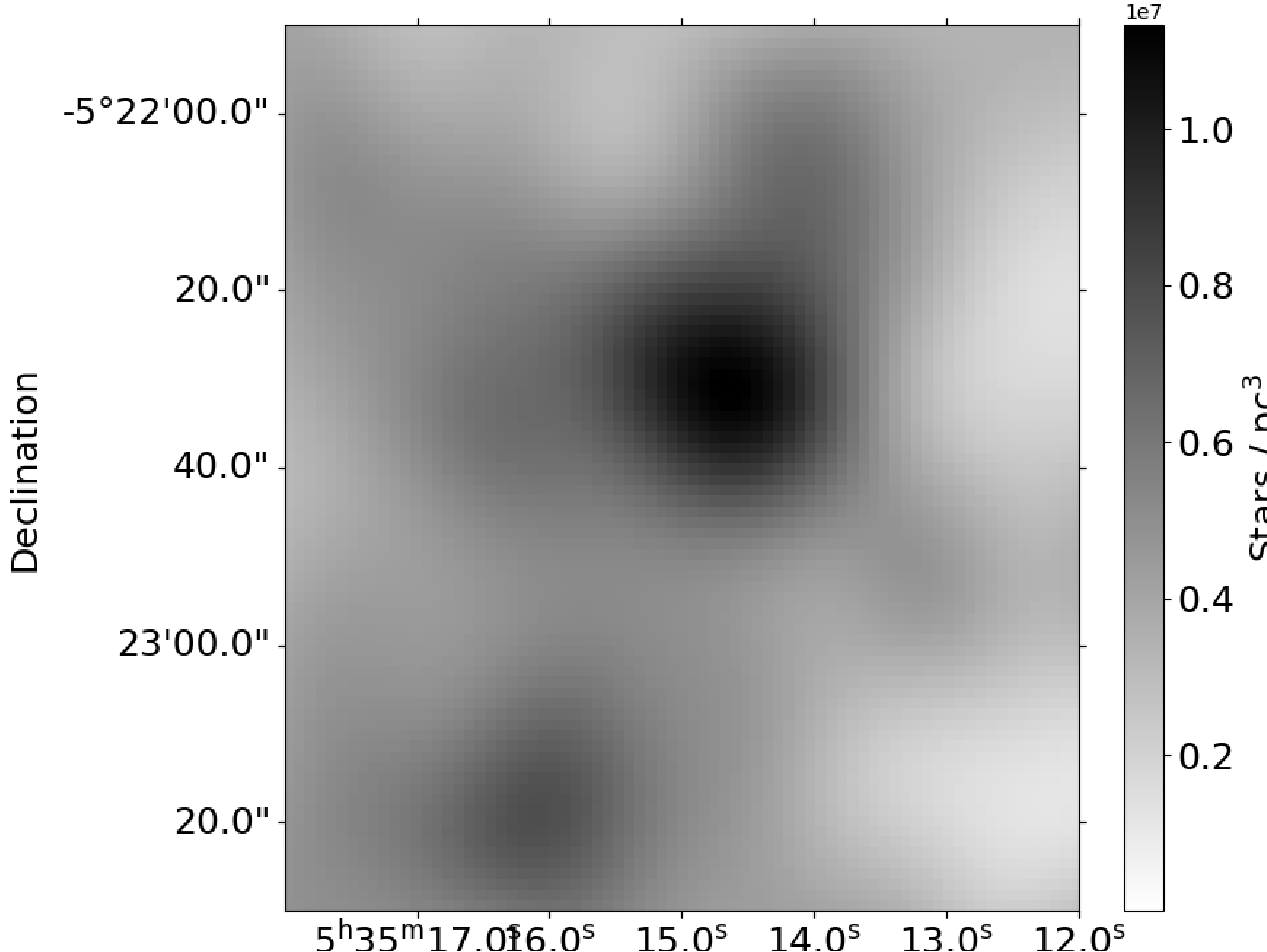

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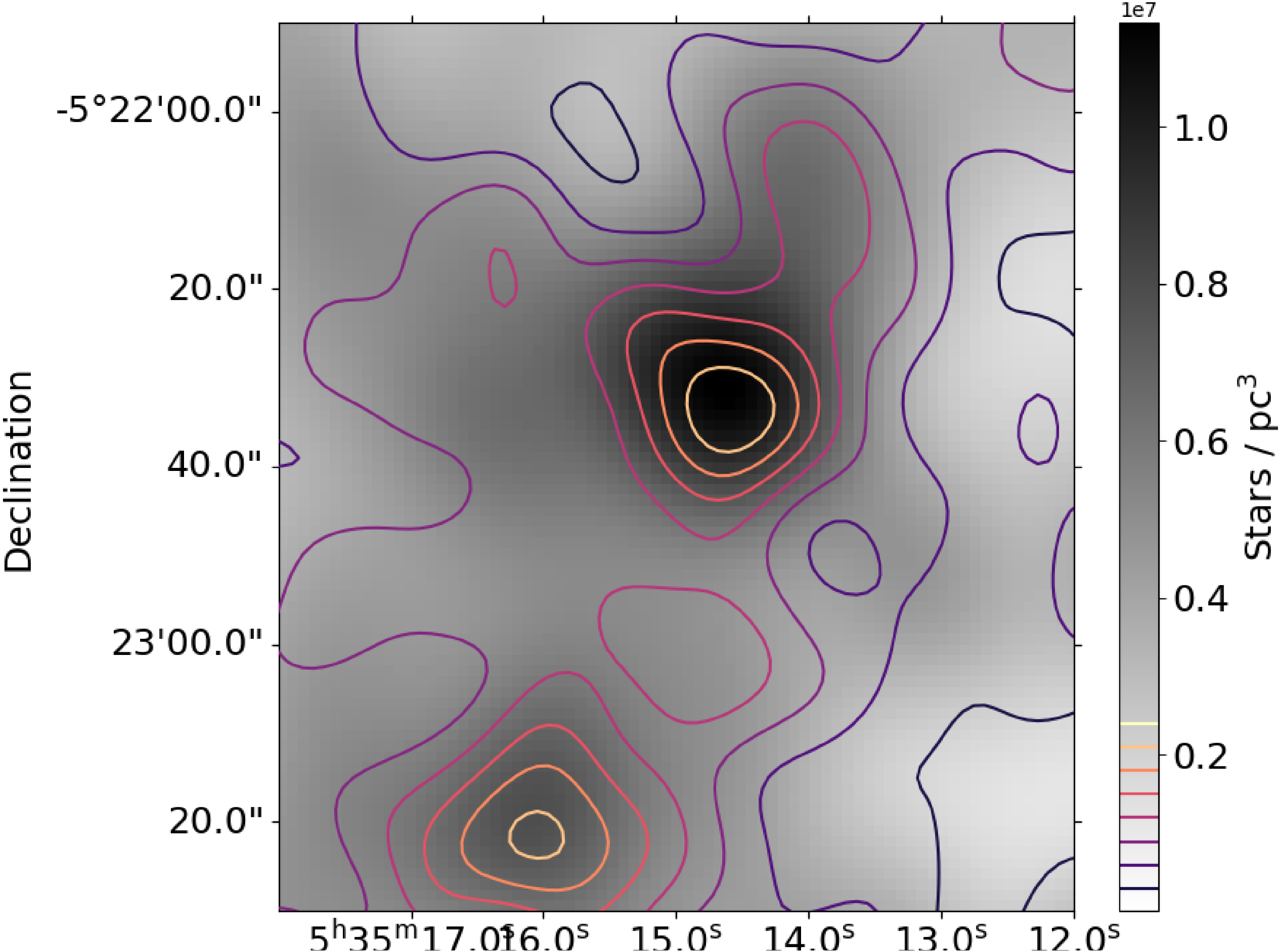

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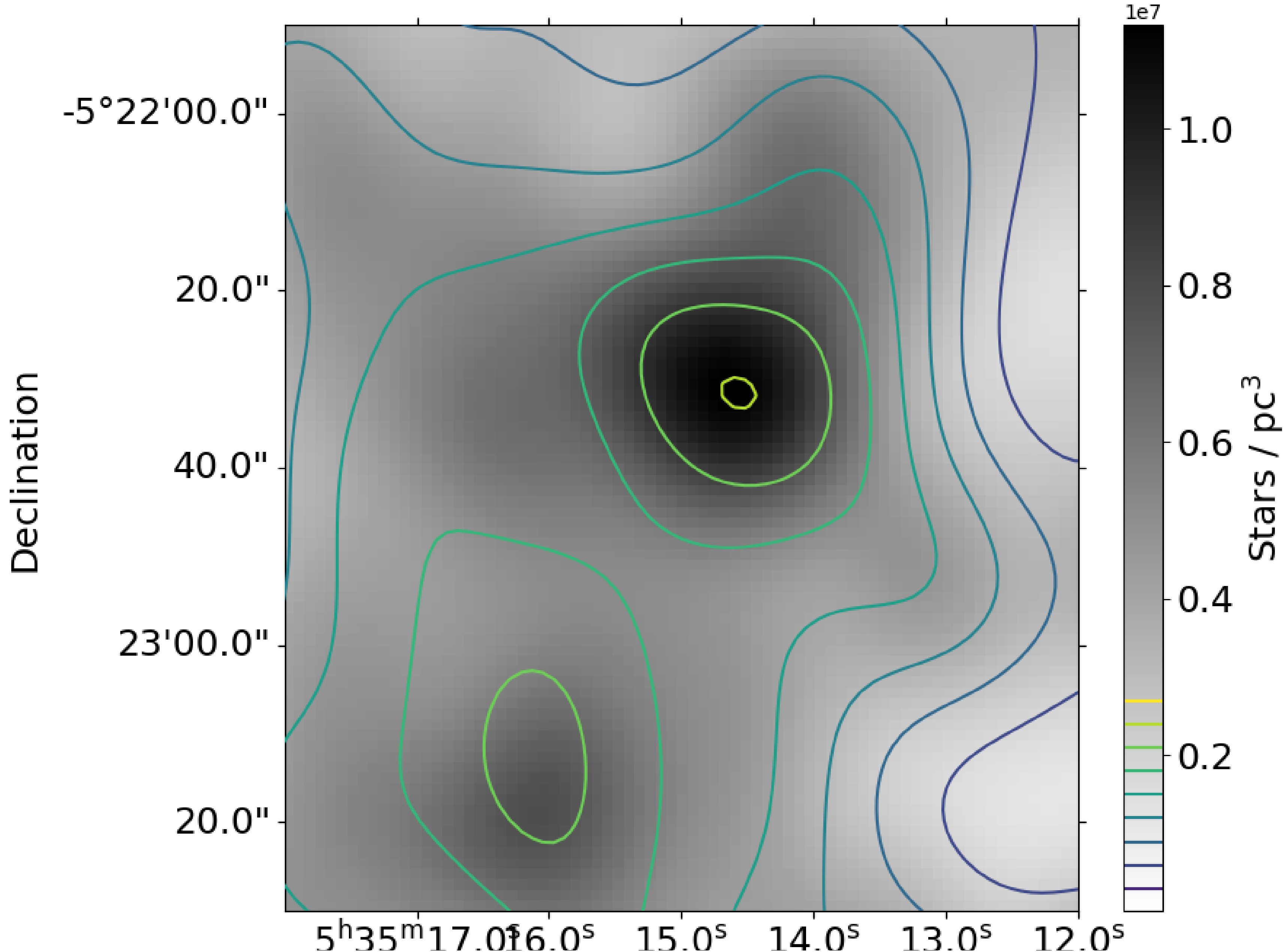

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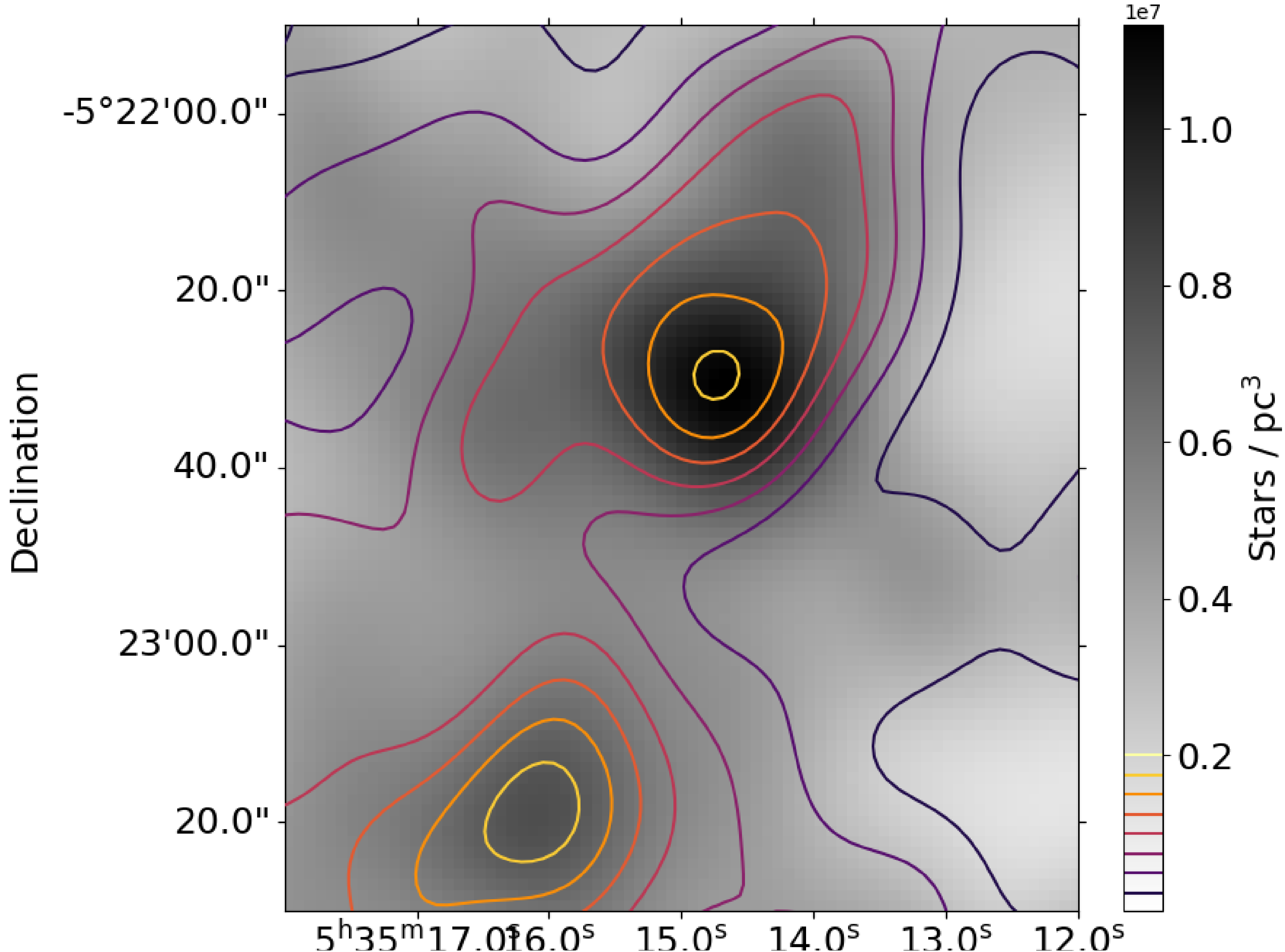

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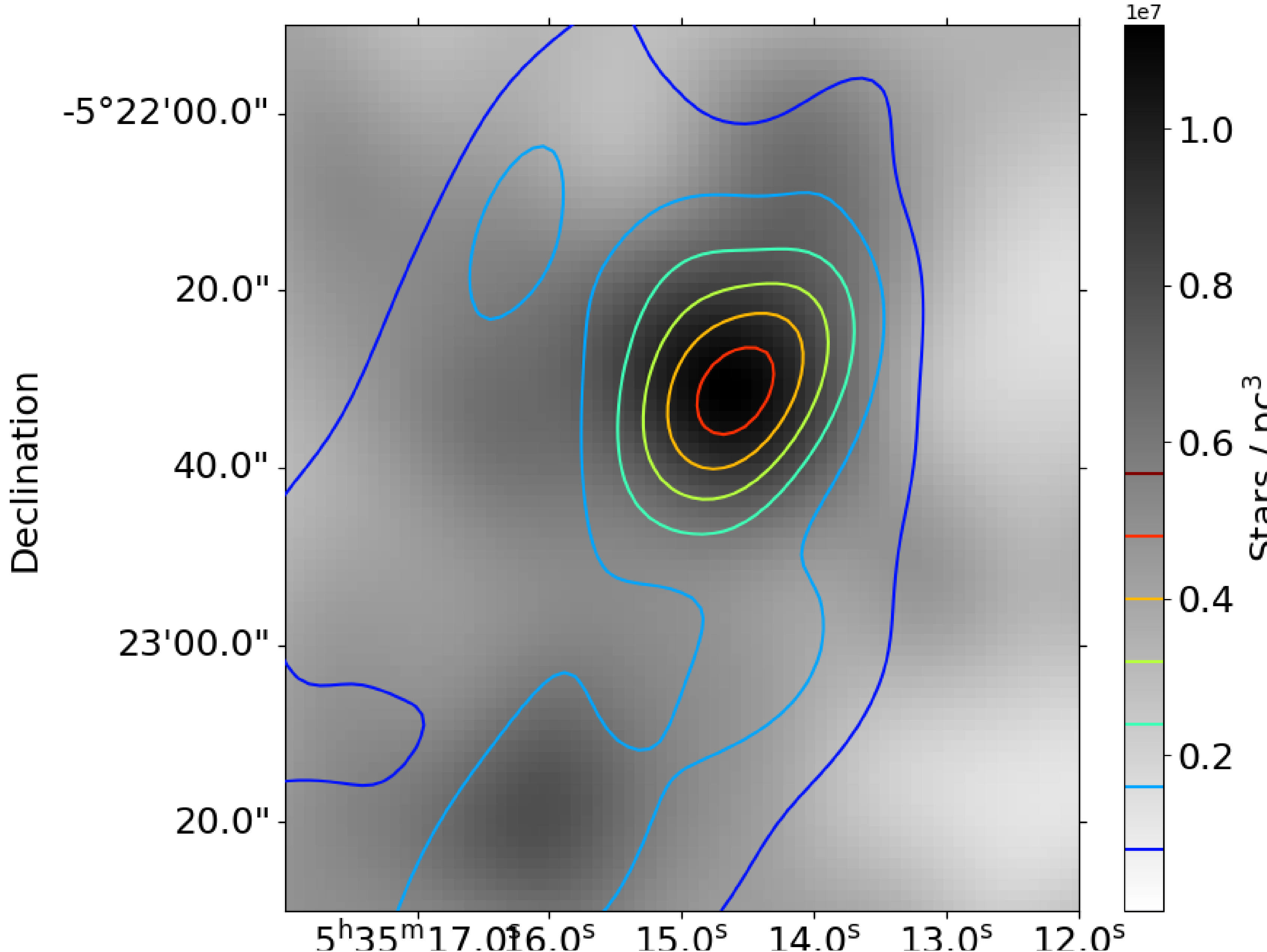
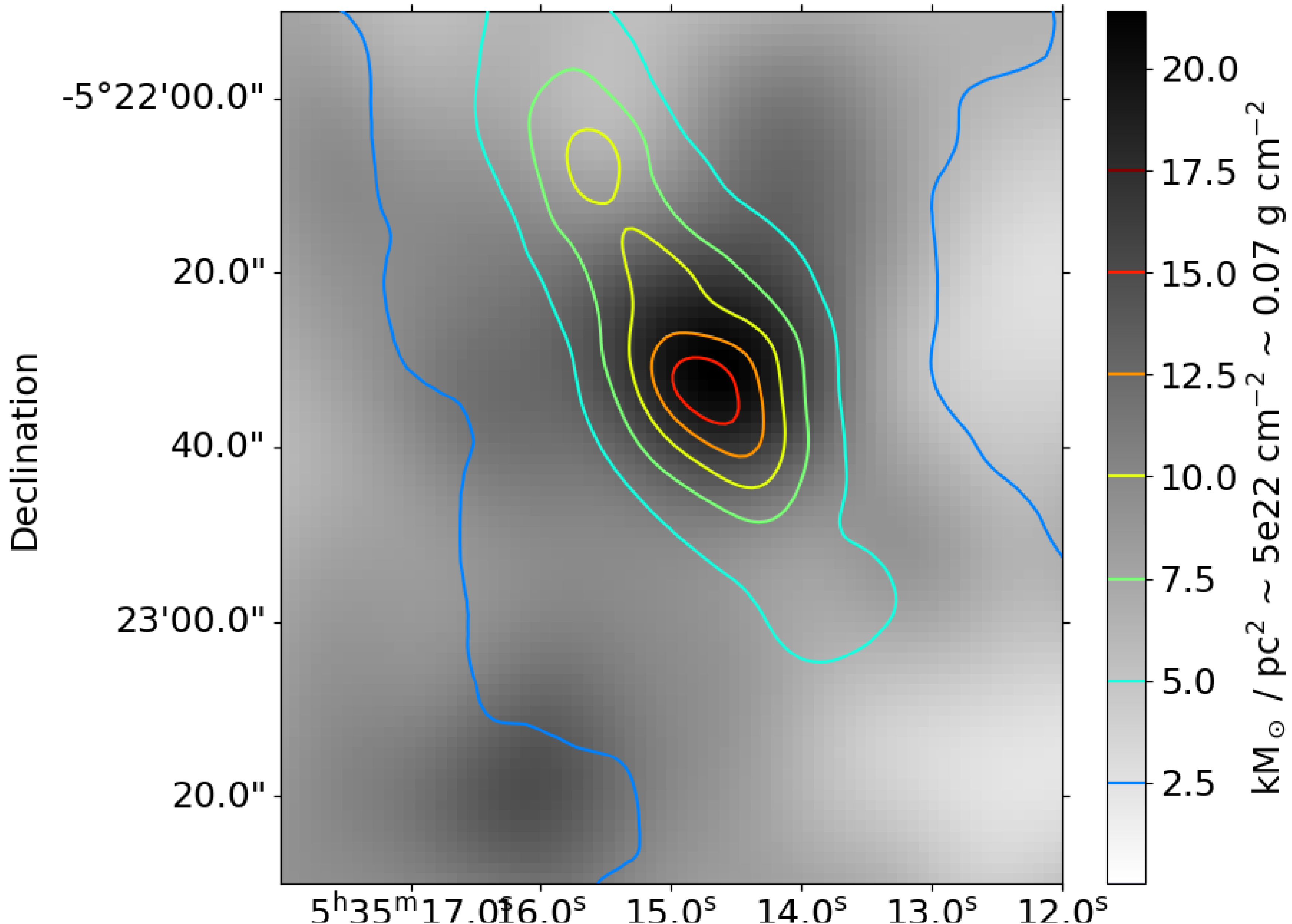


Gas vs Stars



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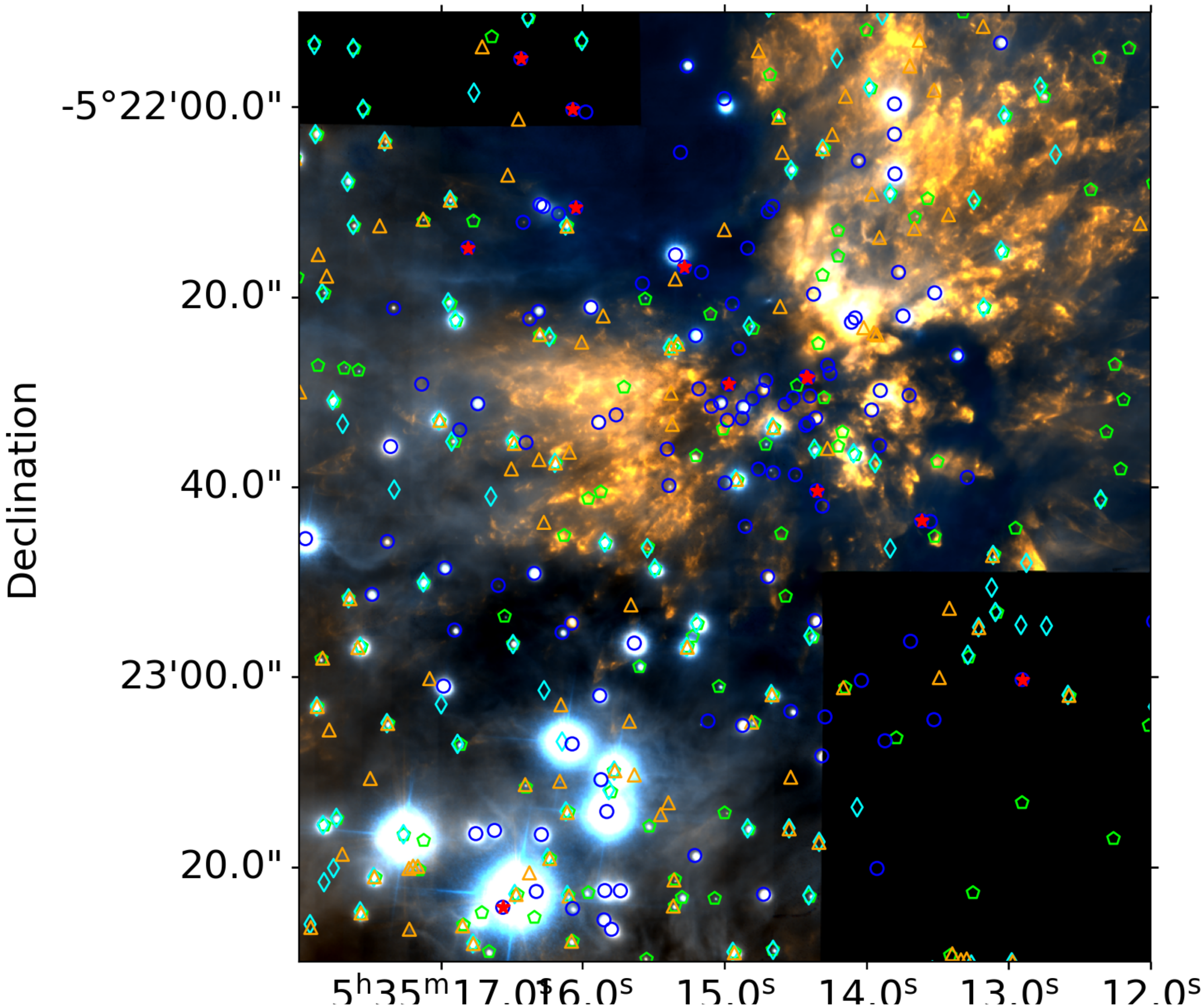
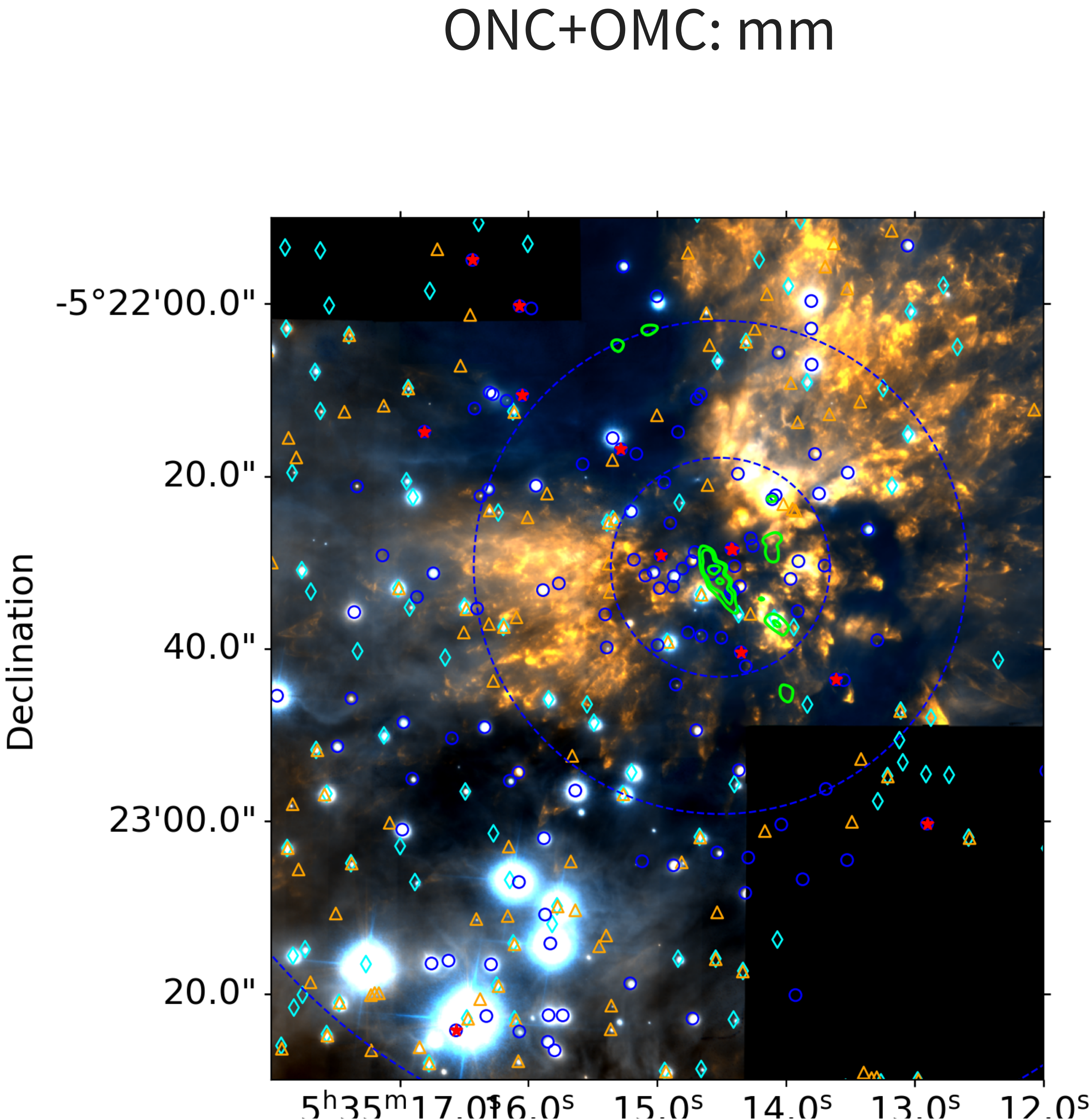
2.5
kM⊙ / pc² ~ 5e22 cm⁻² ~ 0.07 g cm⁻²

ONC+OMC: IR + X-ray + radio + mm





ONC+OMC: mm
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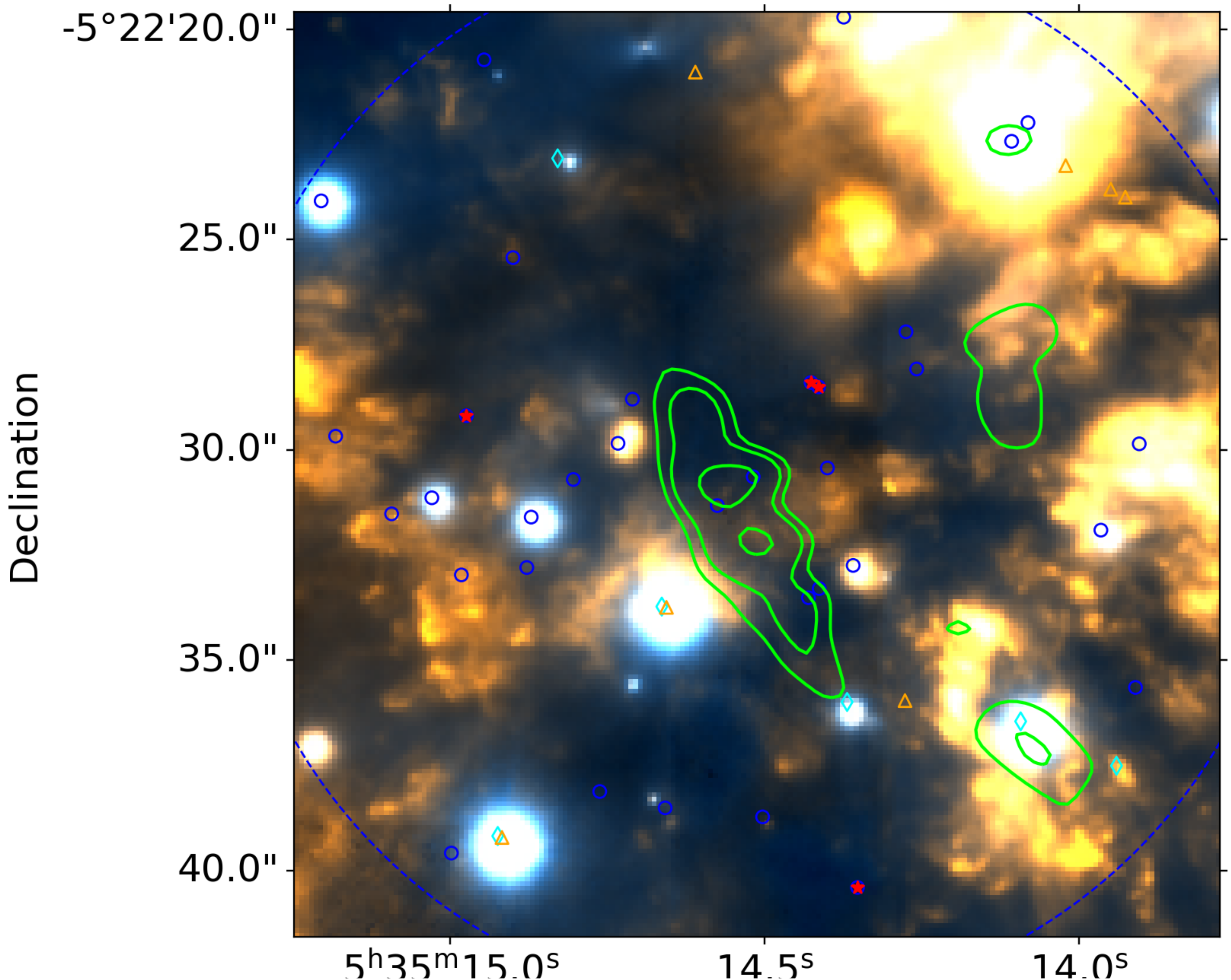
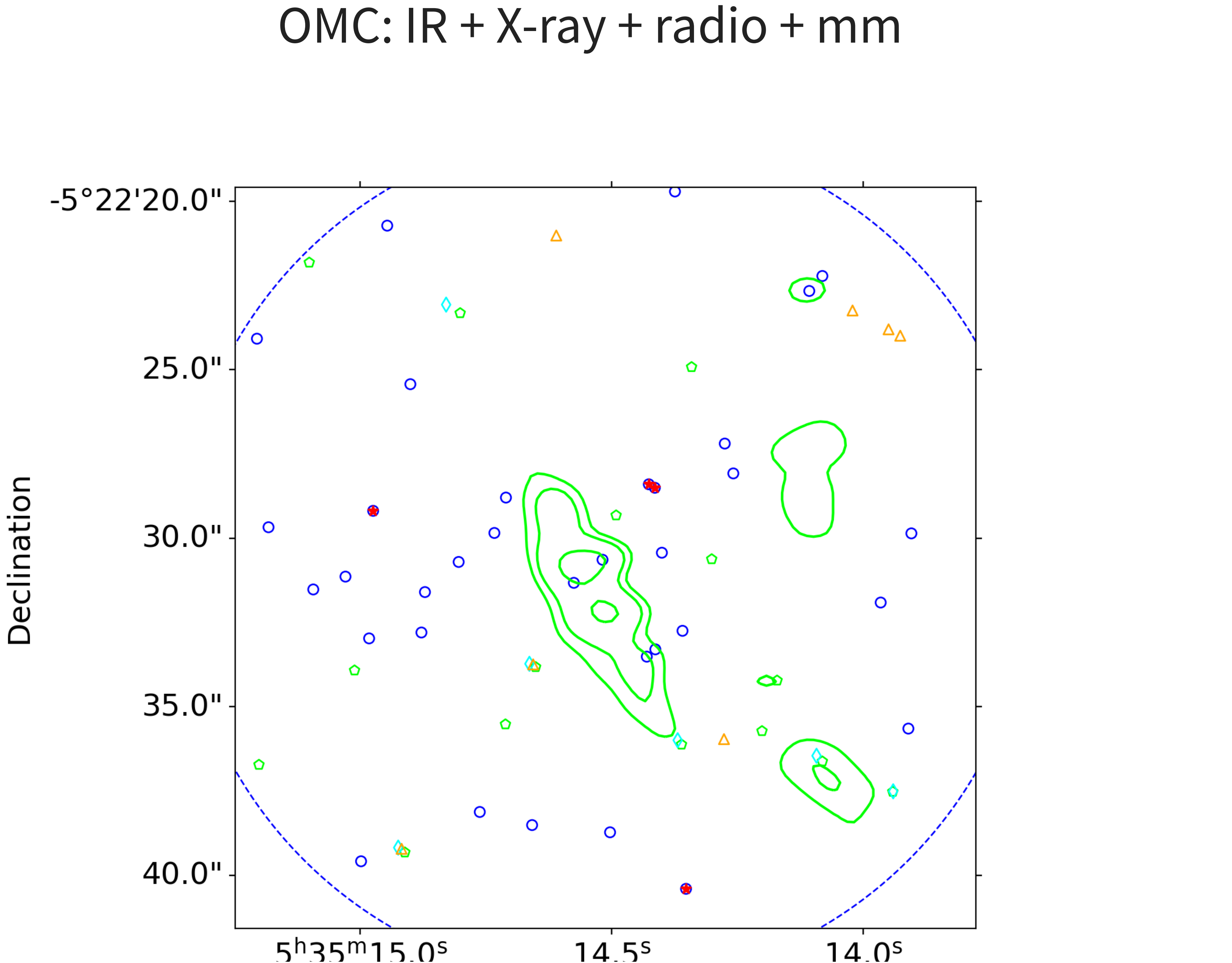
OMC: mm




OMC: IR + X-ray + radio + mm
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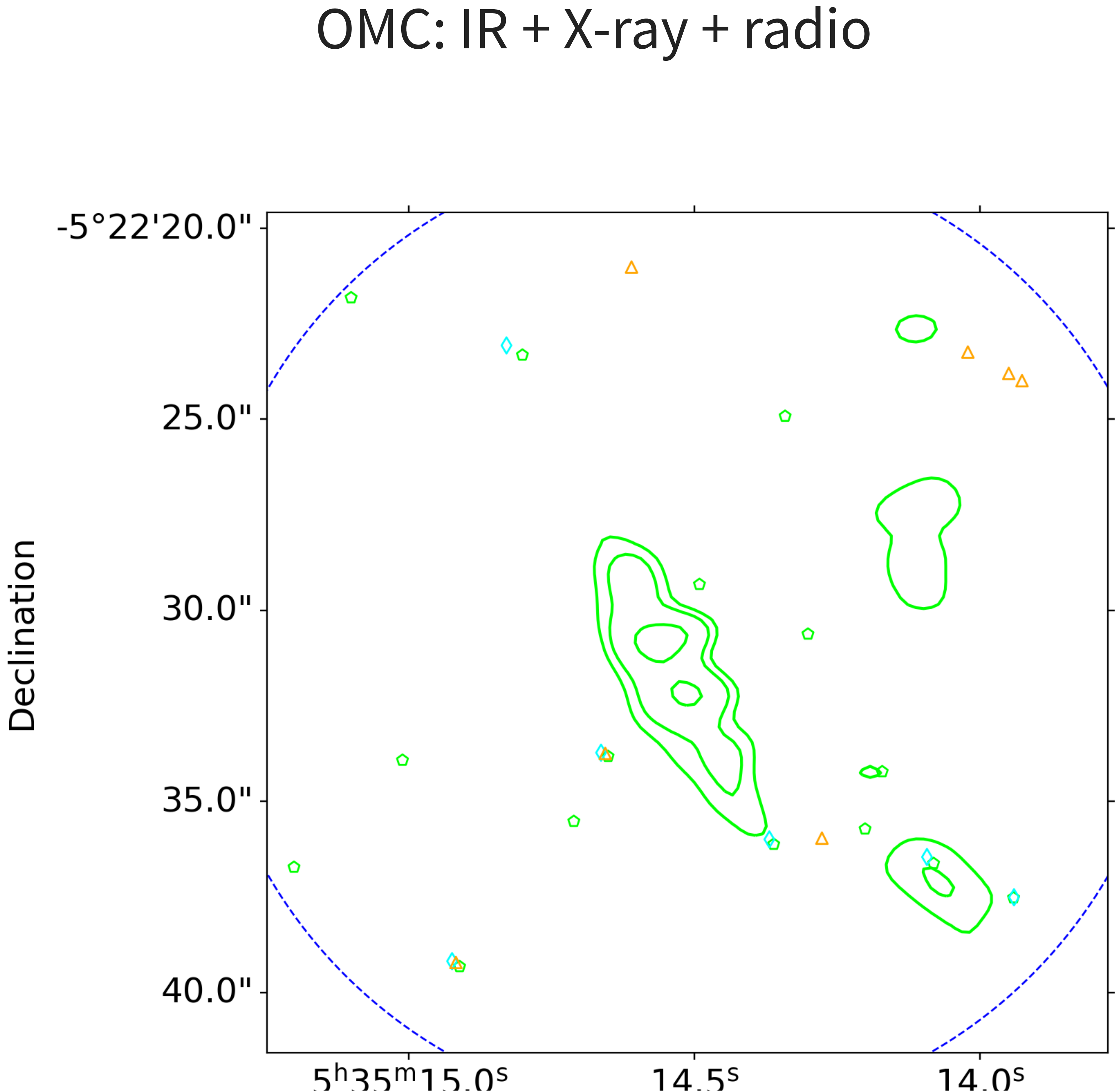
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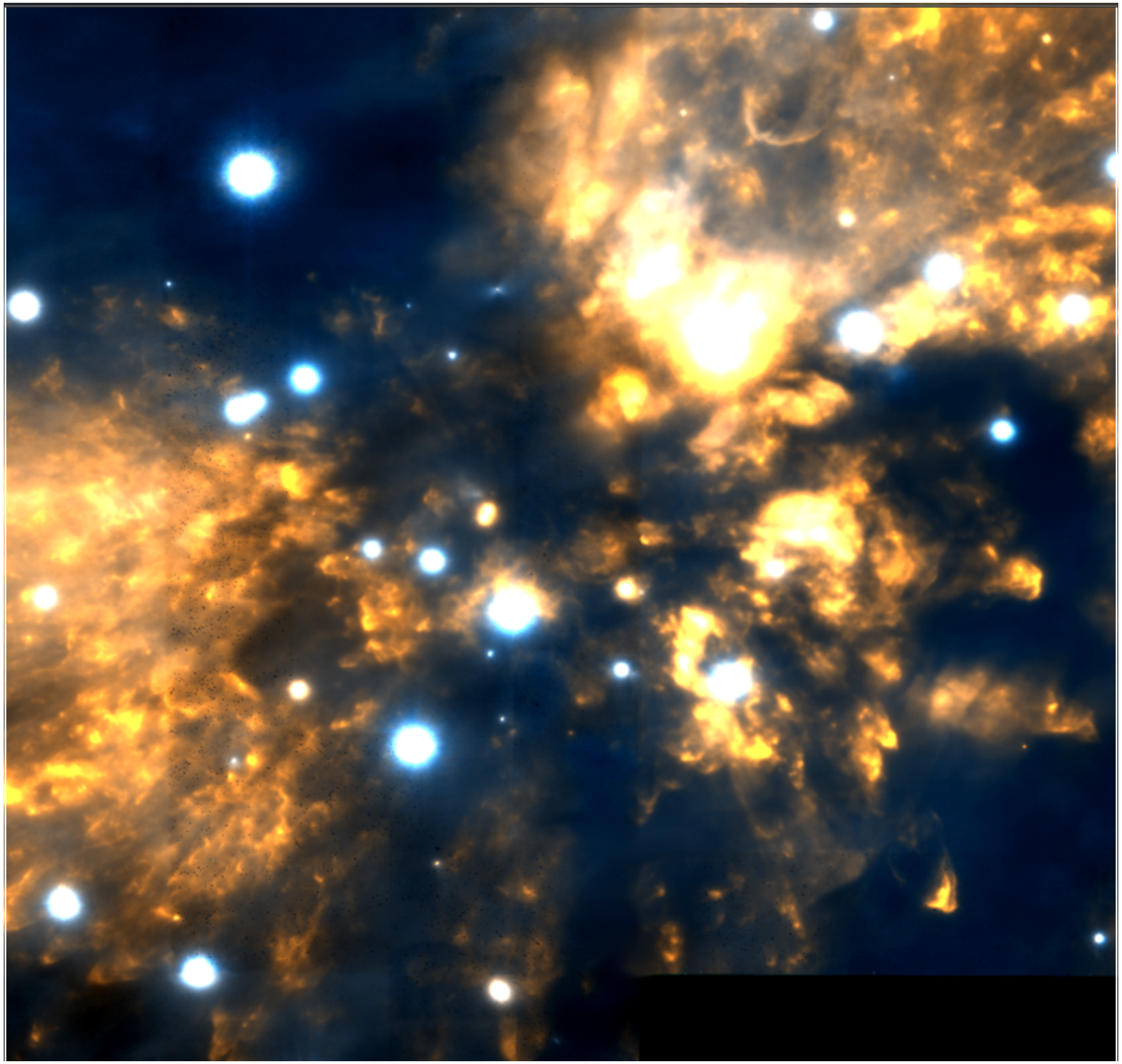
The OMC Cluster is dense & full of disks



FOV: 0.07 pc (16000 AU)
72 YSOs
one "hot core"

N^*_{OMC}(Otter+ 2021) = 1.6 x 10^5 pc^{-3}
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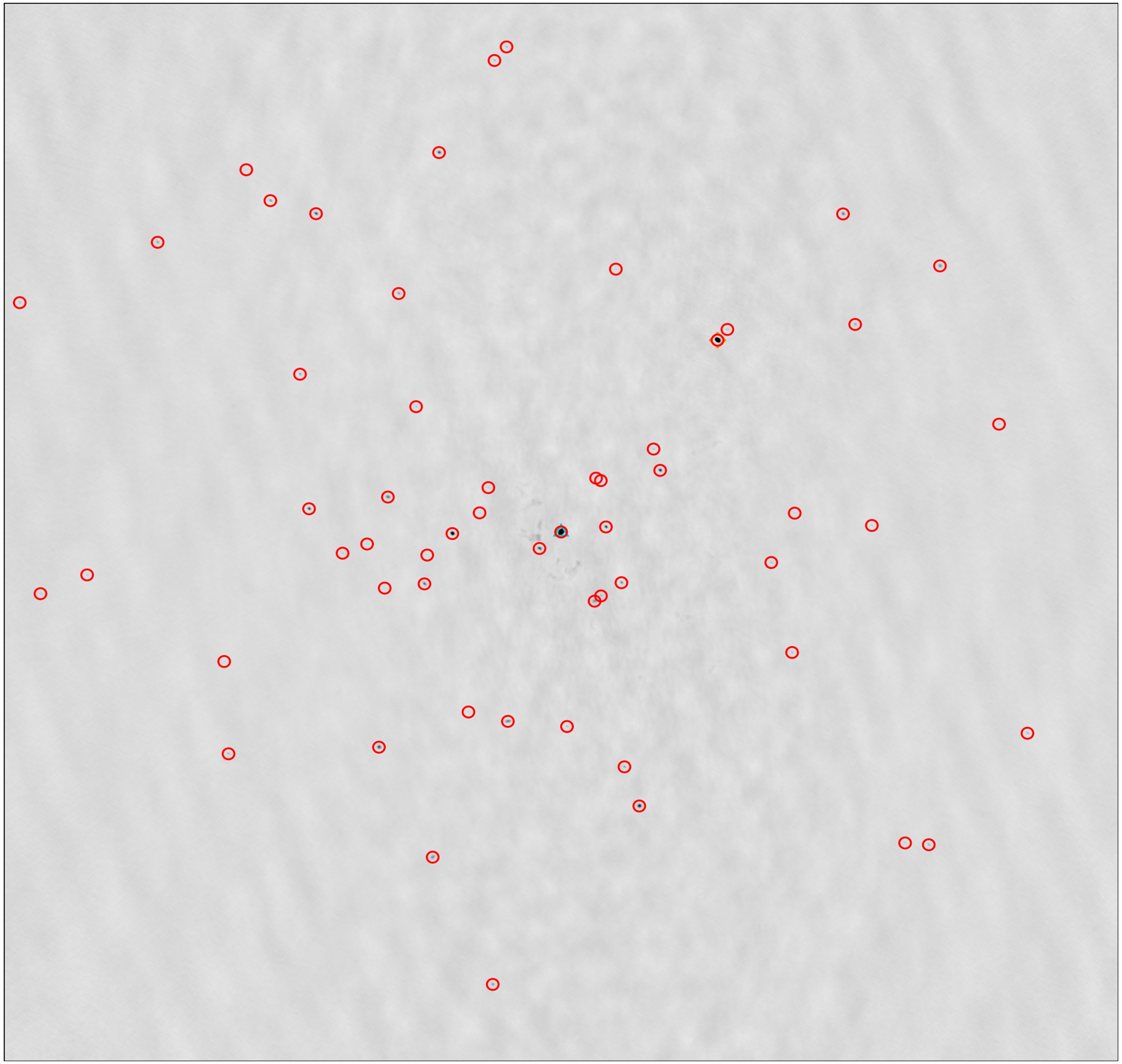

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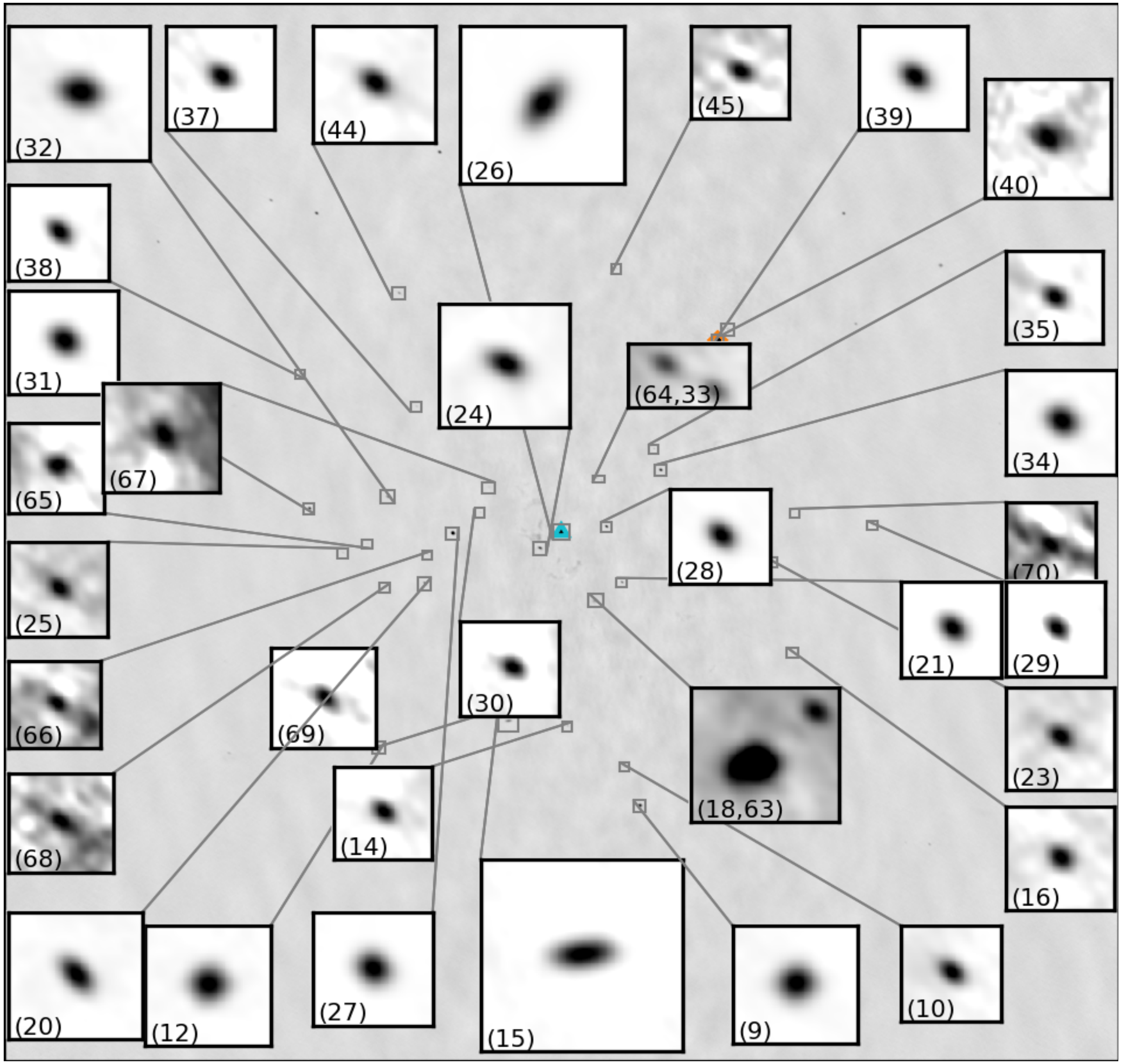

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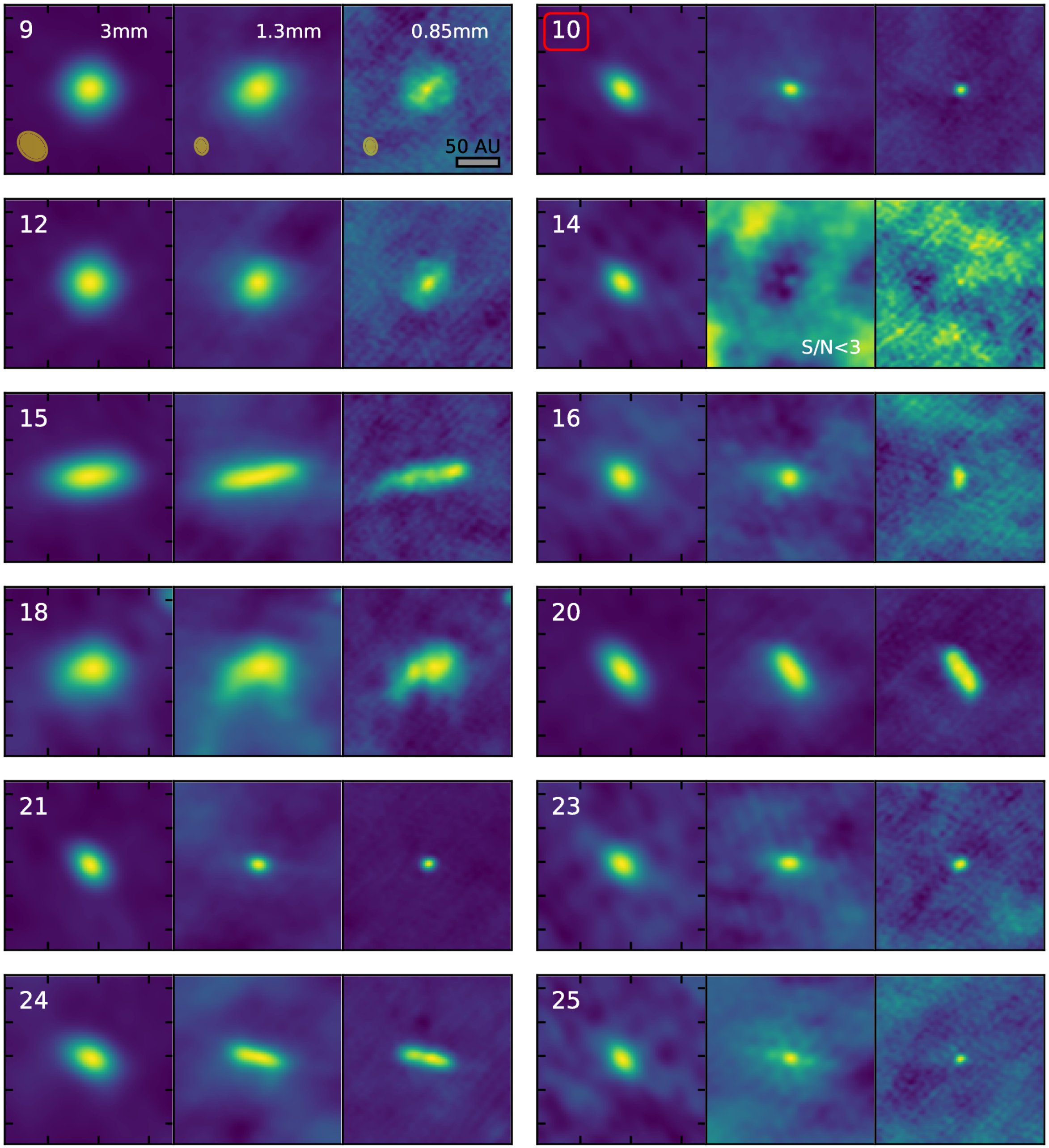
The disks are (mostly) resolved



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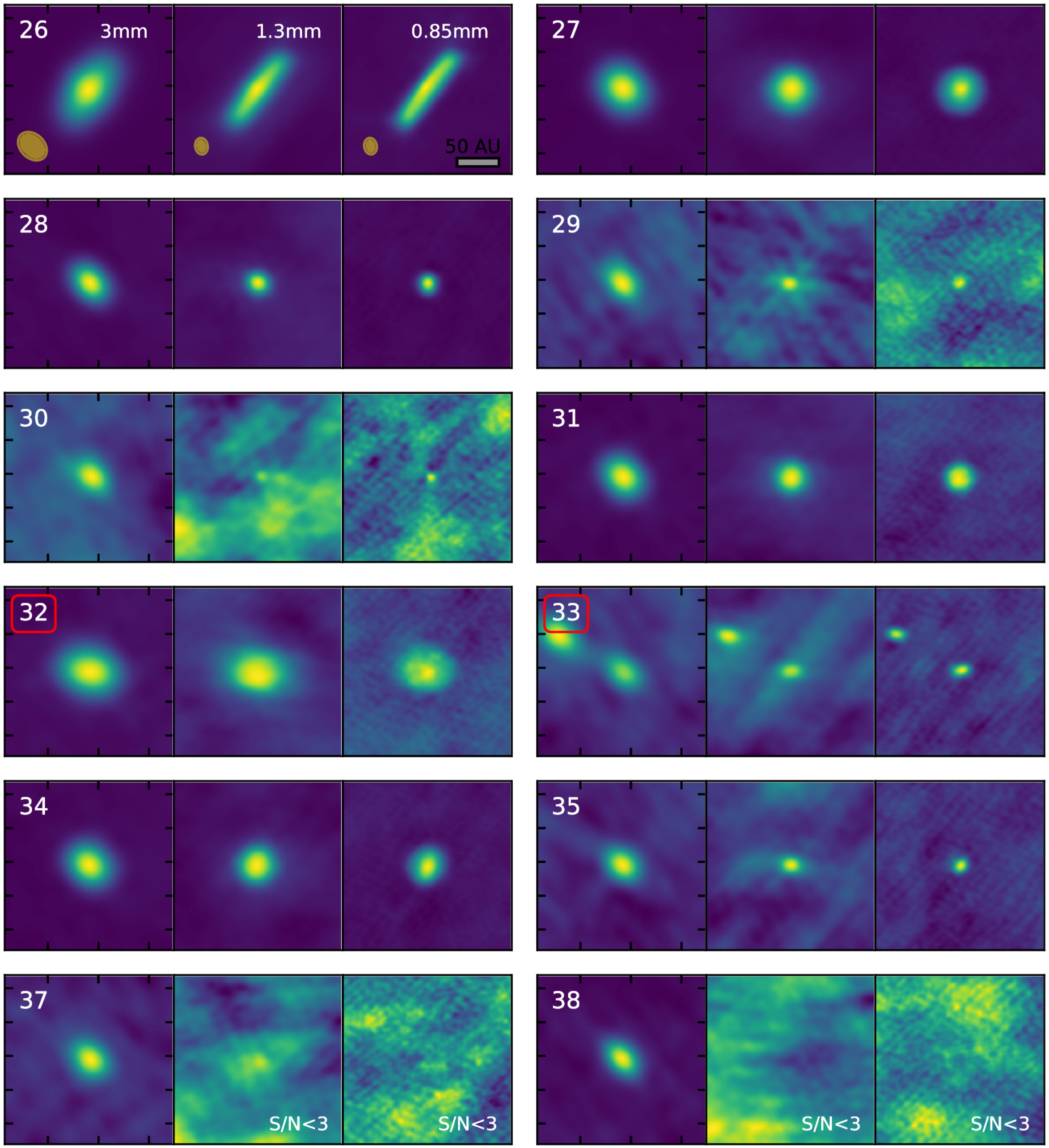

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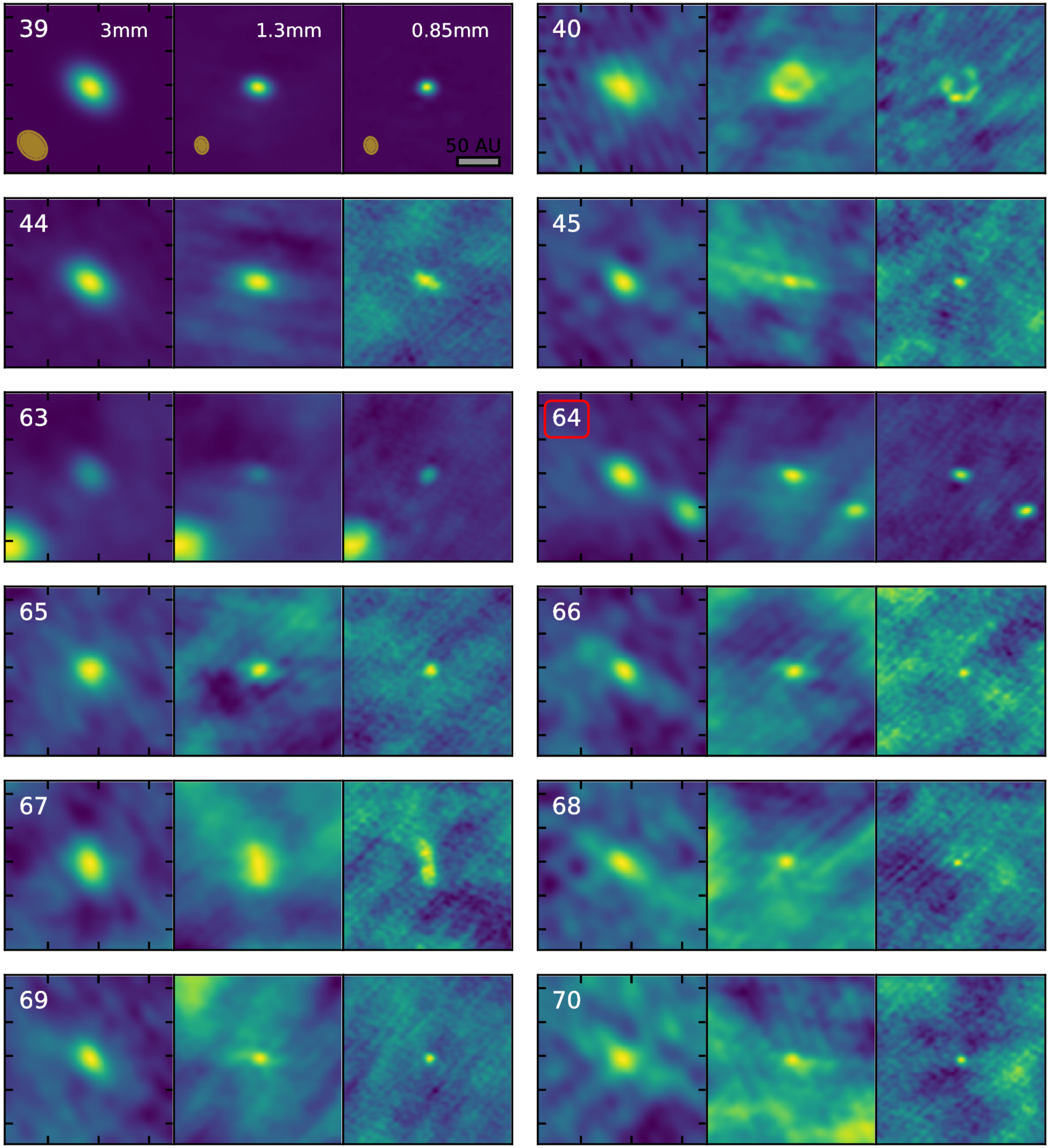
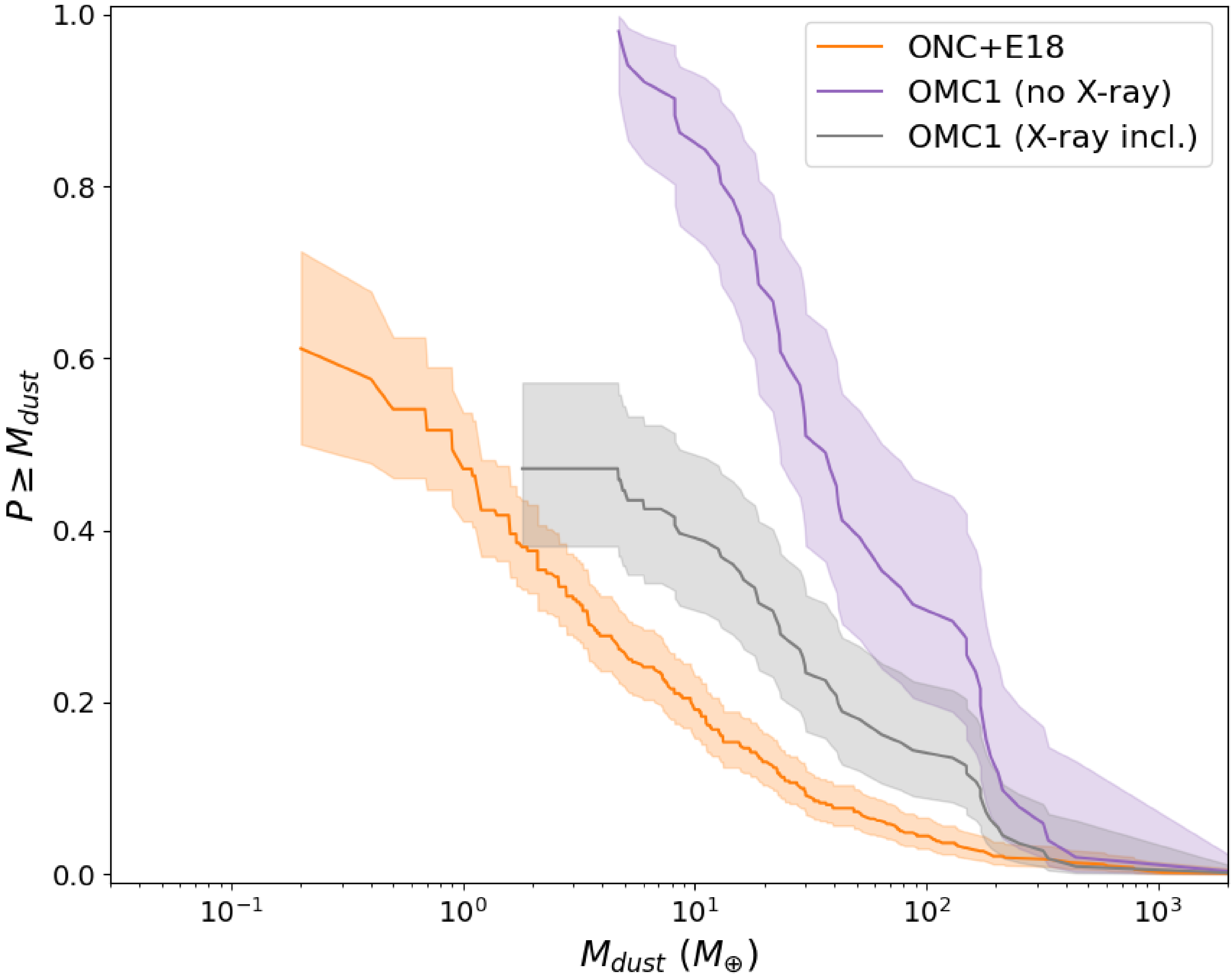
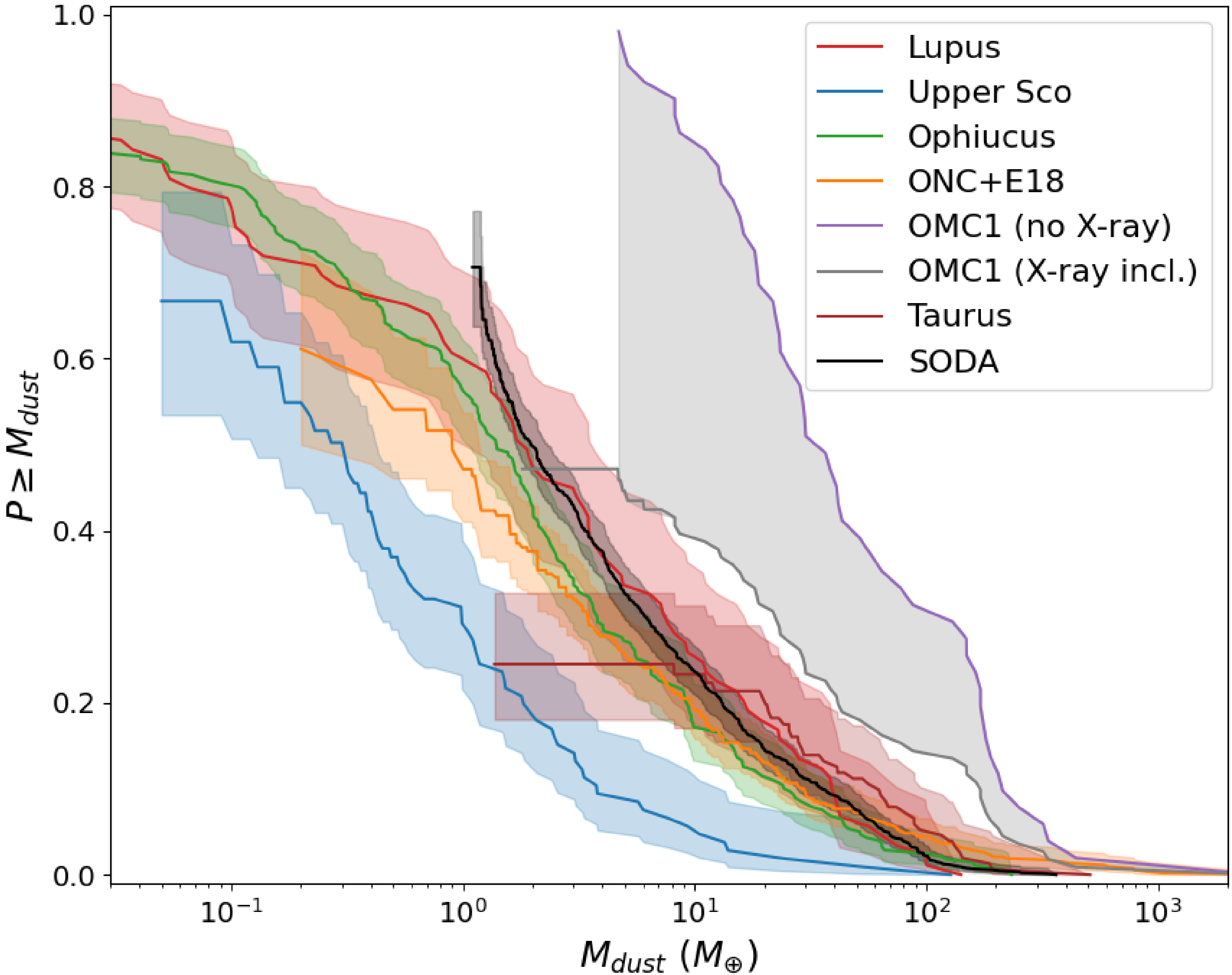


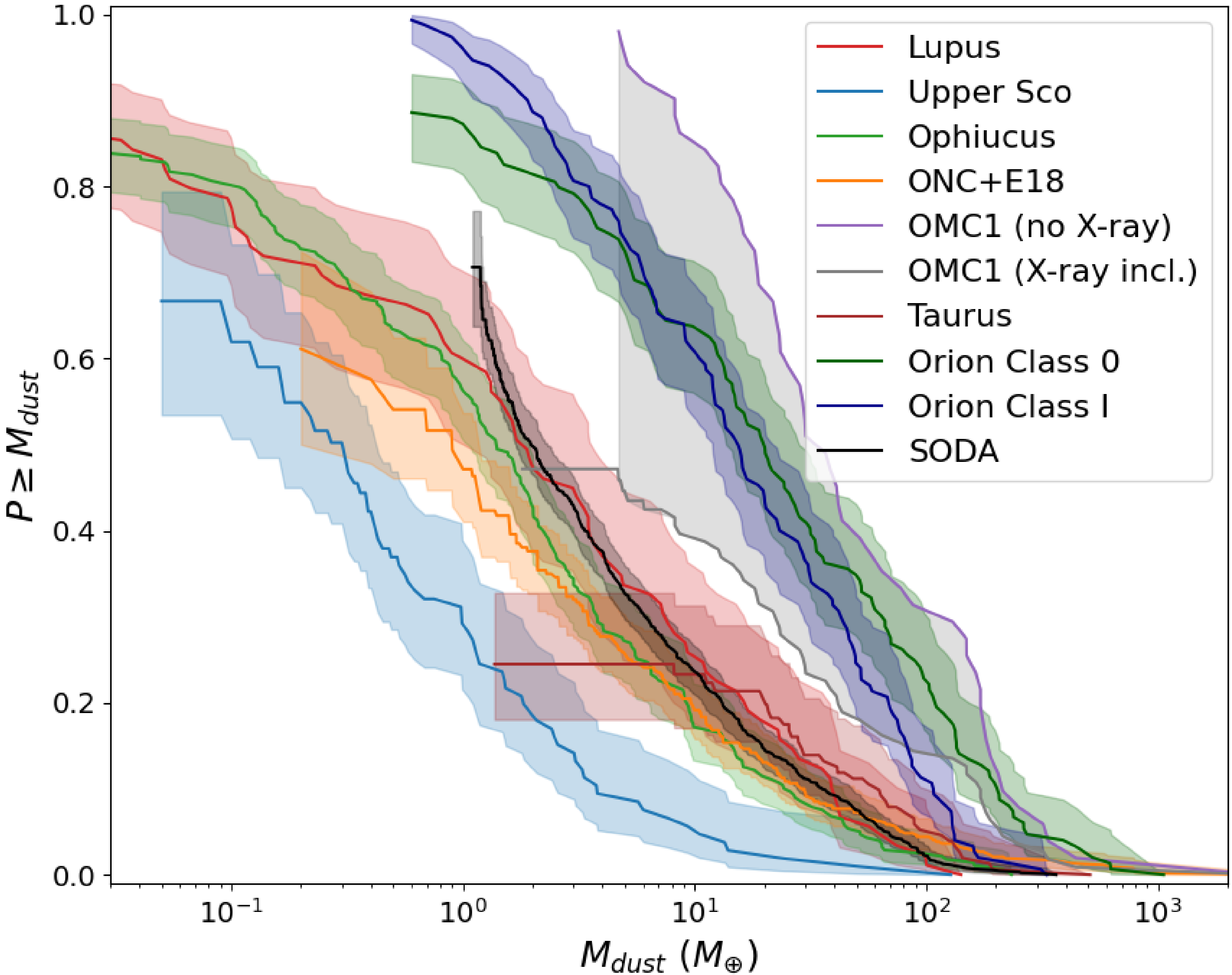
OMC DISKS ARE MASSIVE



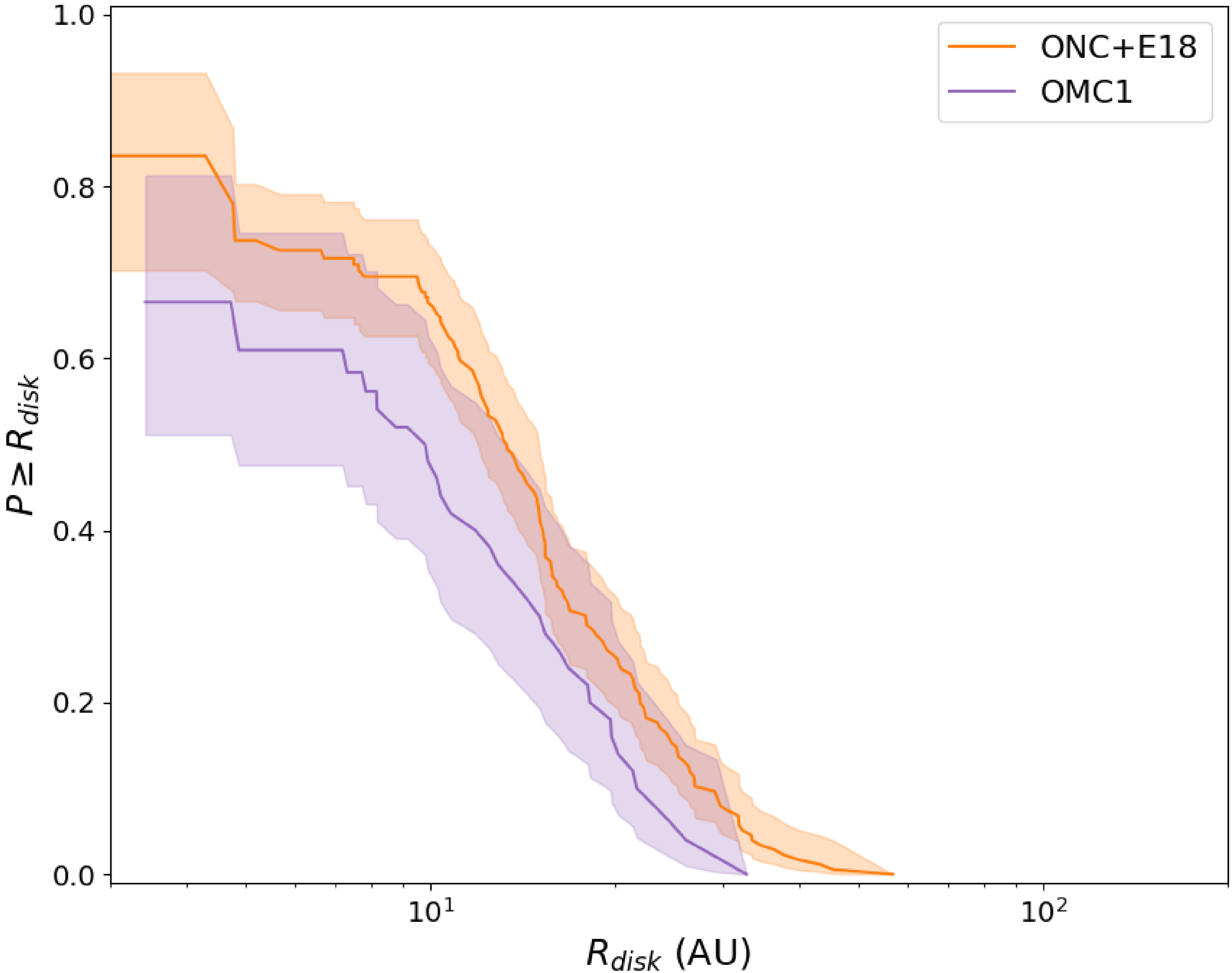
OMC DISKS ARE MORE MASSIVE



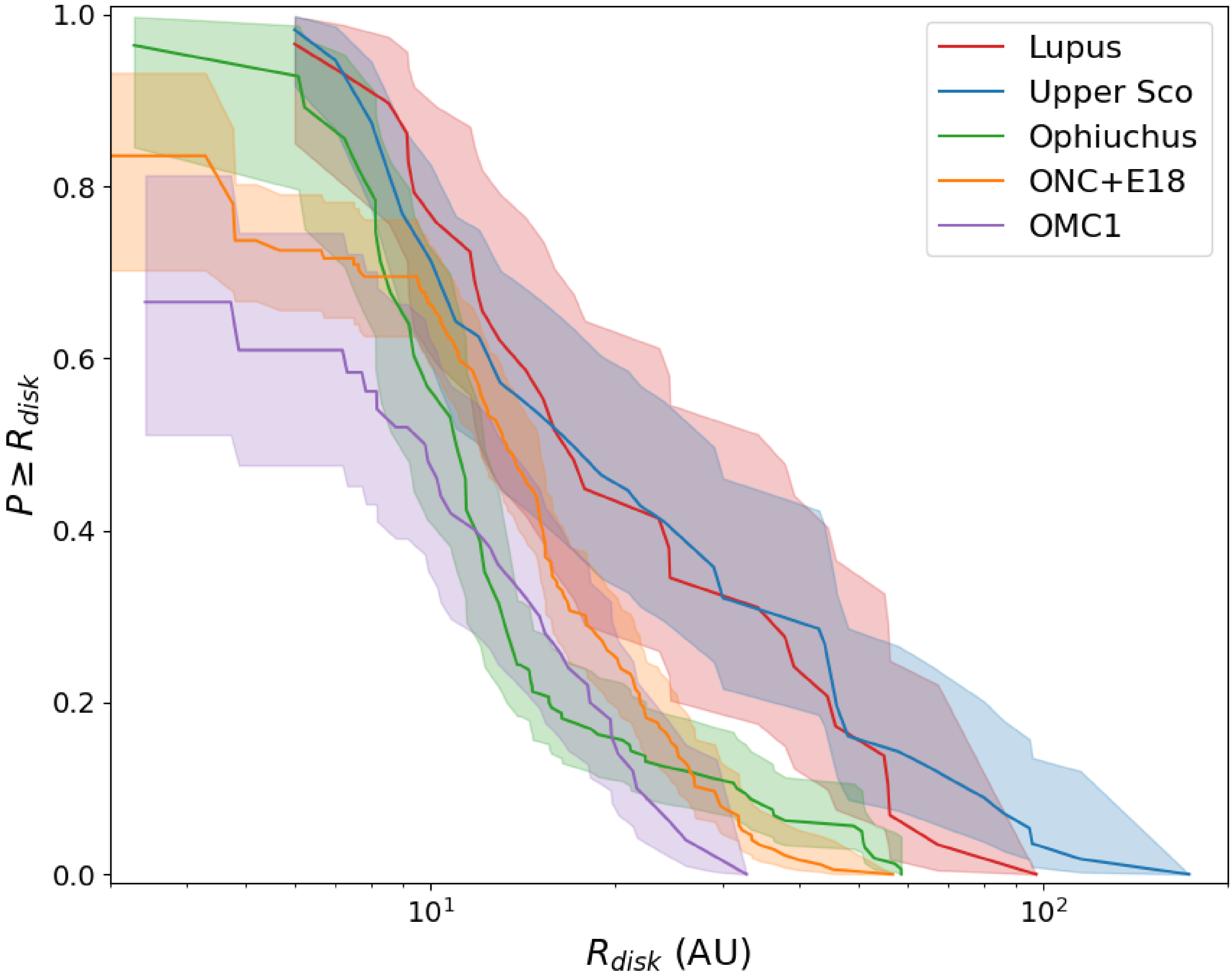
OMC disks are more massive (Like class 0 & I)



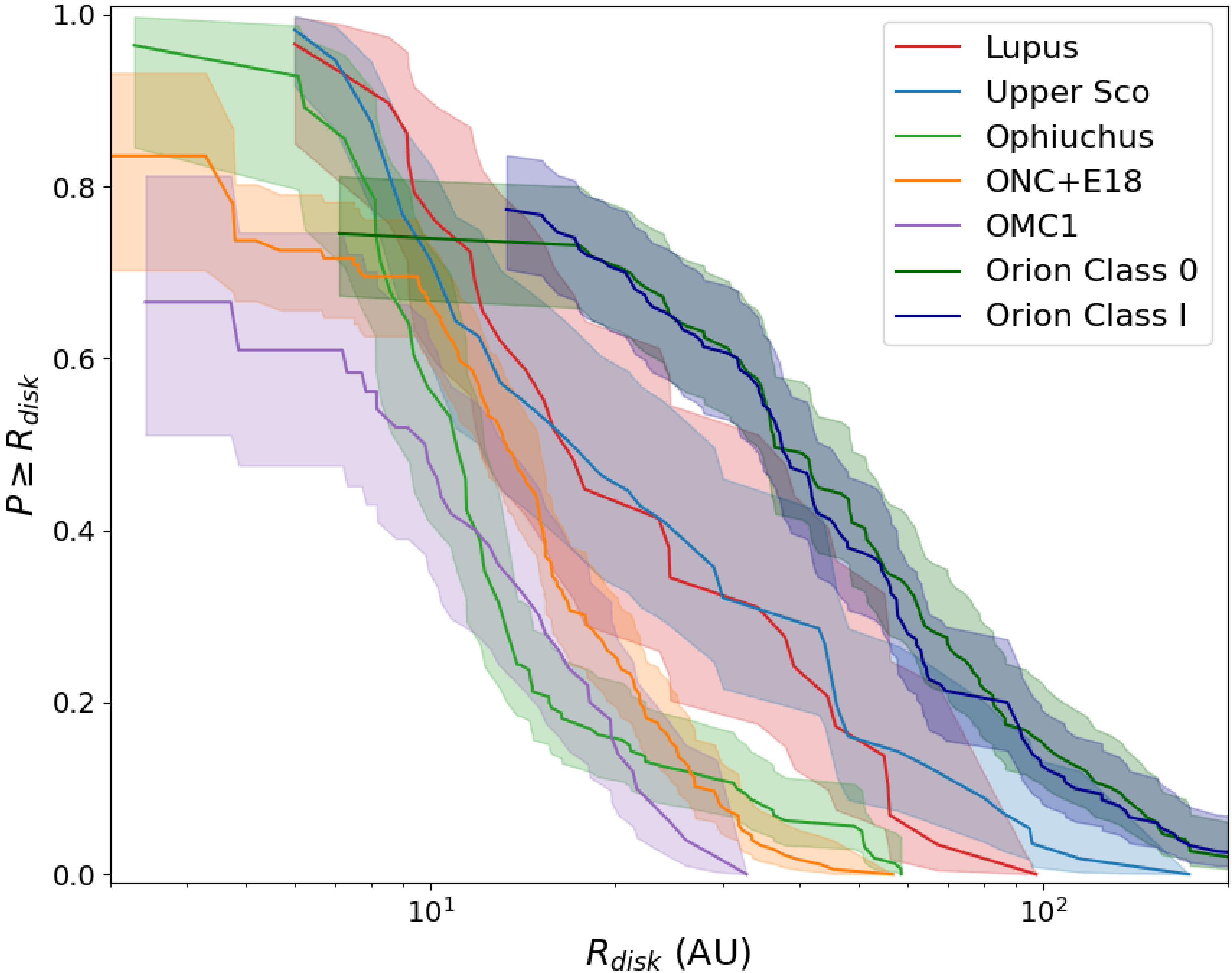
ONC AND OMC DISKS ARE SMALL



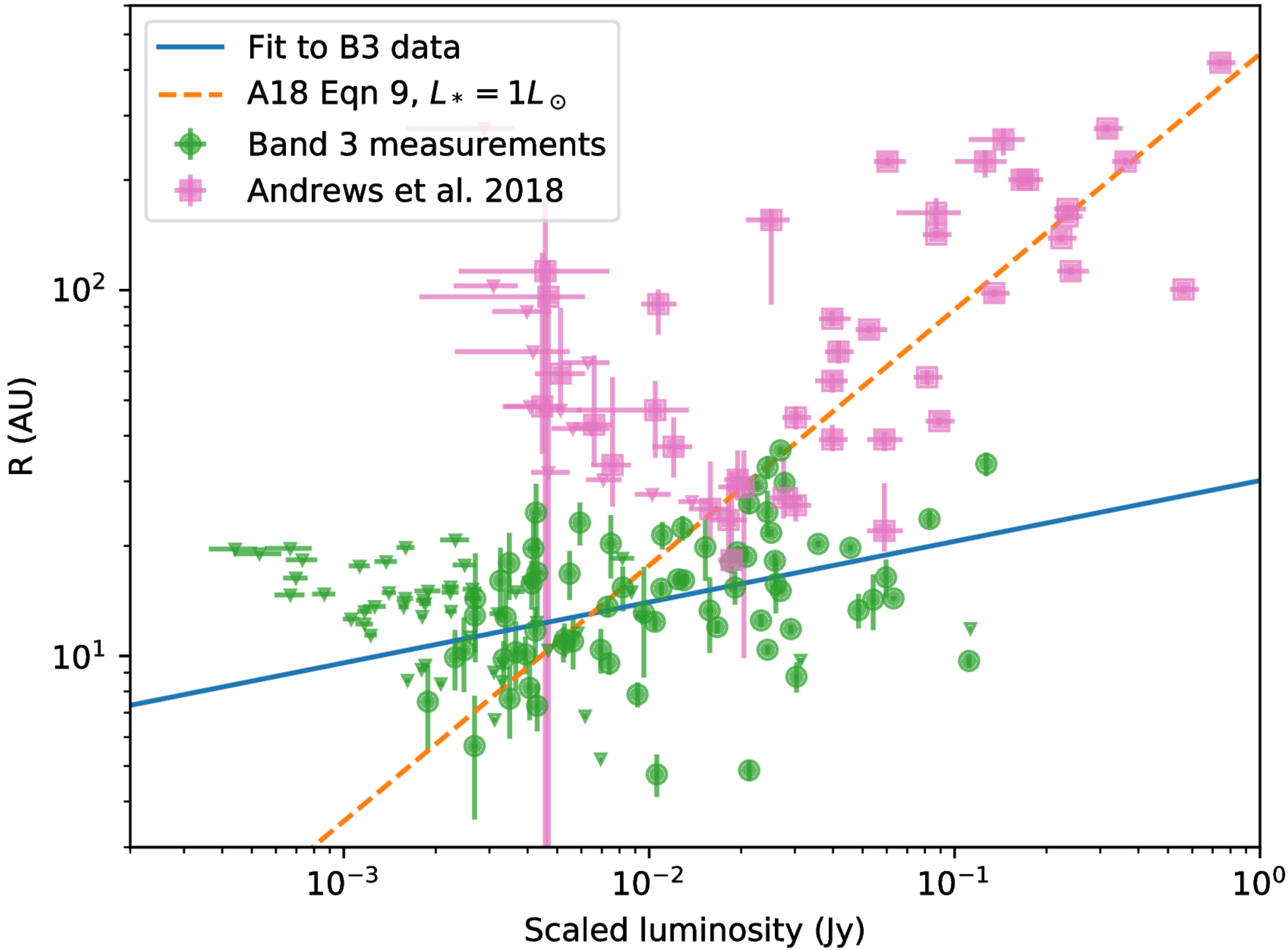
ONC AND OMC DISKS ARE SMALLER



ONC AND OMC DISKS ARE SMALLER THAN CLASS 0 & I



Scaling relations don't line up

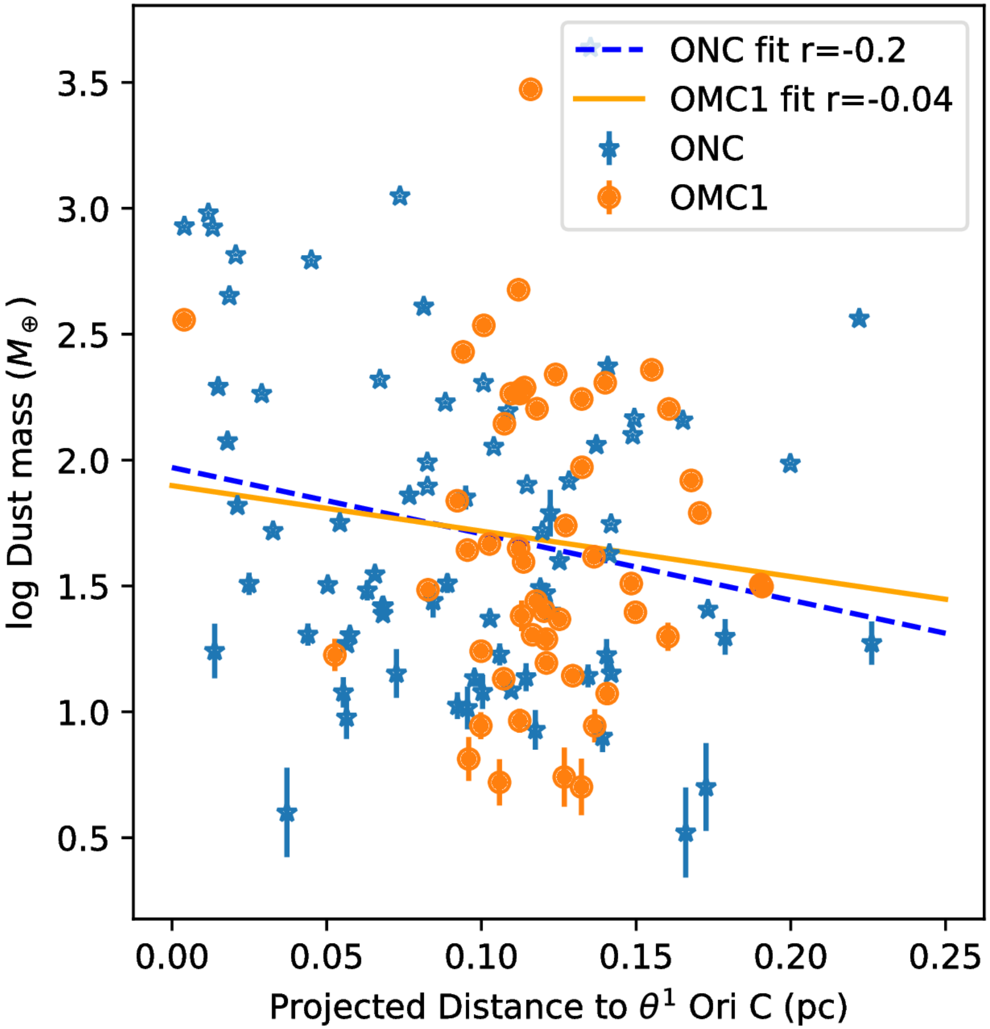


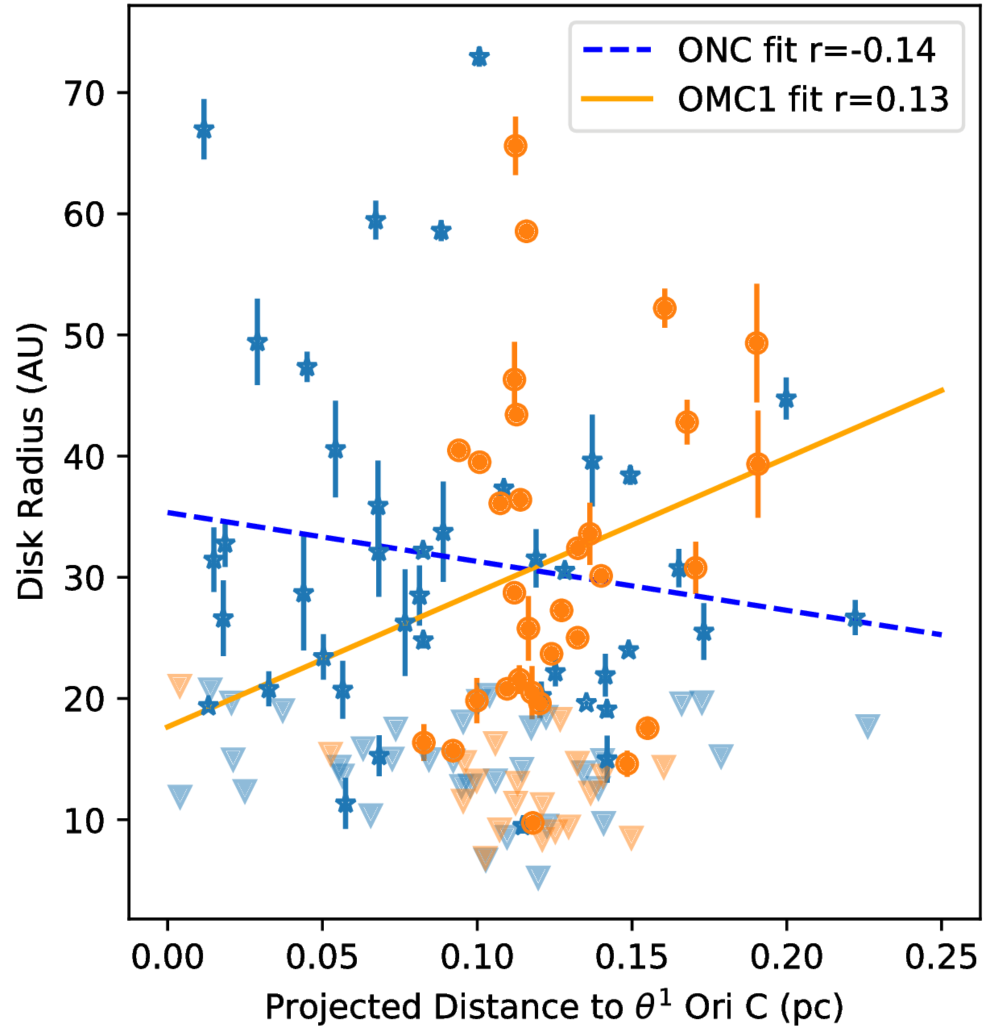
What shrinks disks in clusters?

- Photoevaporation (e.g., the proplyds; McCullough+ 1995, Bally+ 1998) (see also Haworth et al. 2018; Parker et al. 2021)
- Dynamical interactions (e.g., Vincke & Pfalzner 2016)
- Face-on accretion (e.g., Wijnen+ 2017)

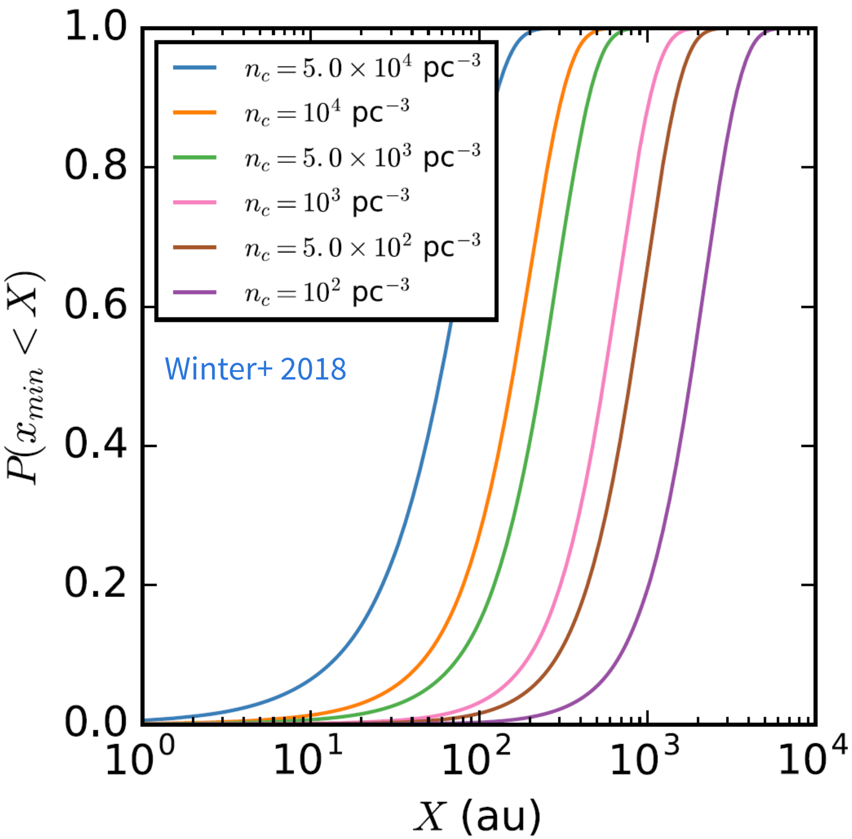
Truncation is not solely due to photoevaporation

OMC sources are shielded, so they don't get photoevaporated.





AT HIGH STELLAR DENSITIES, CLOSE ENCOUNTERS ARE FREQUENT



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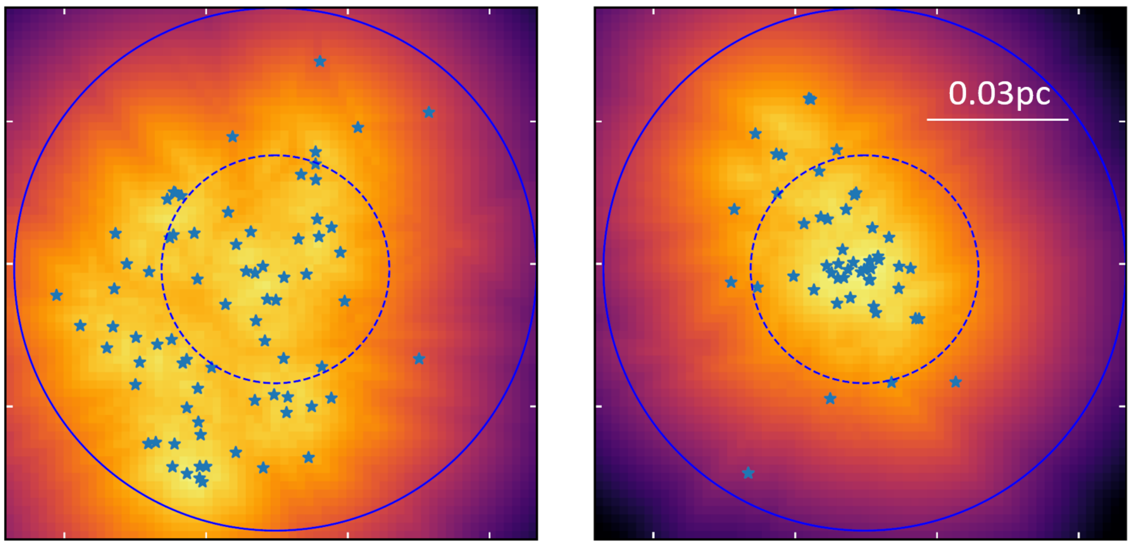
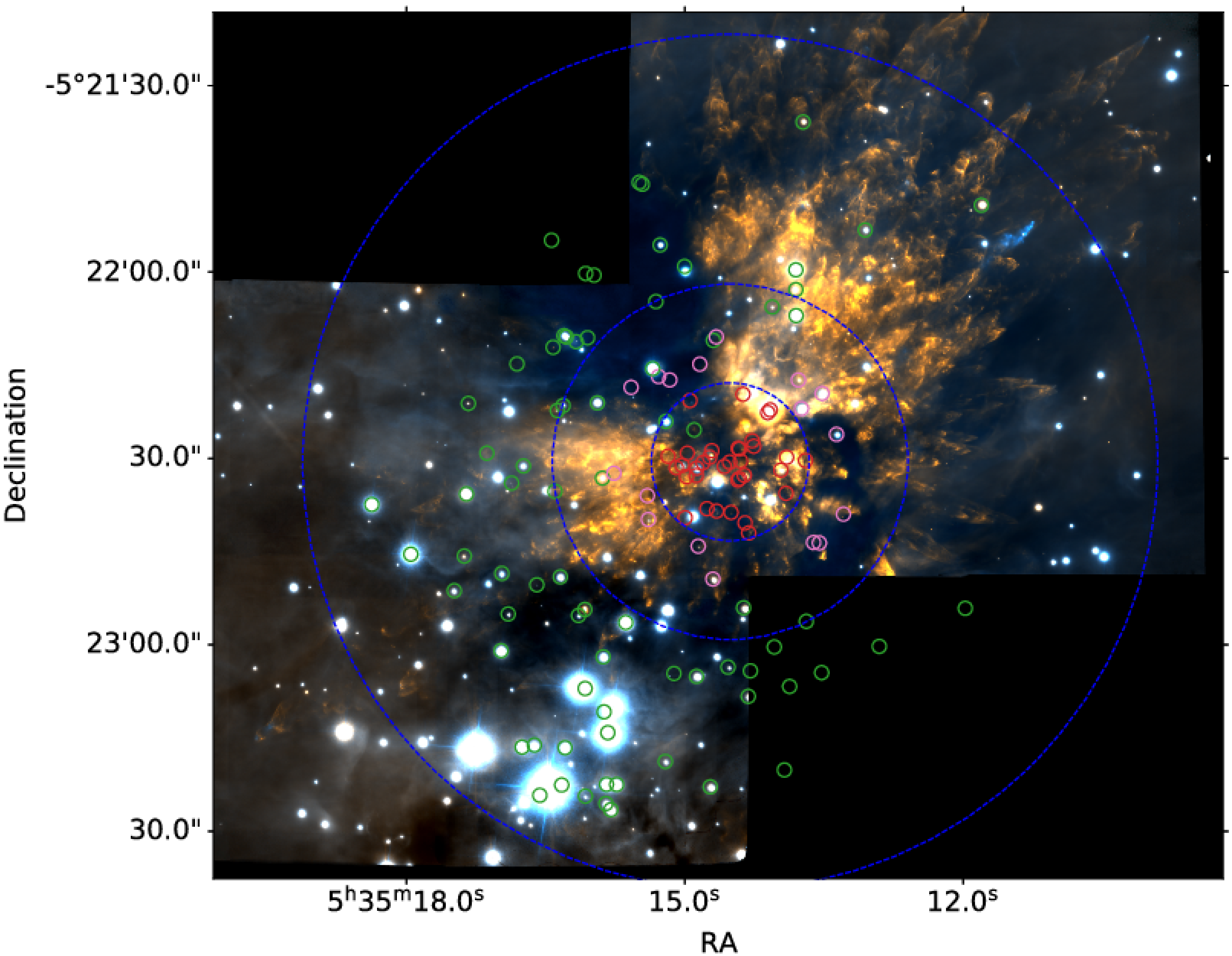
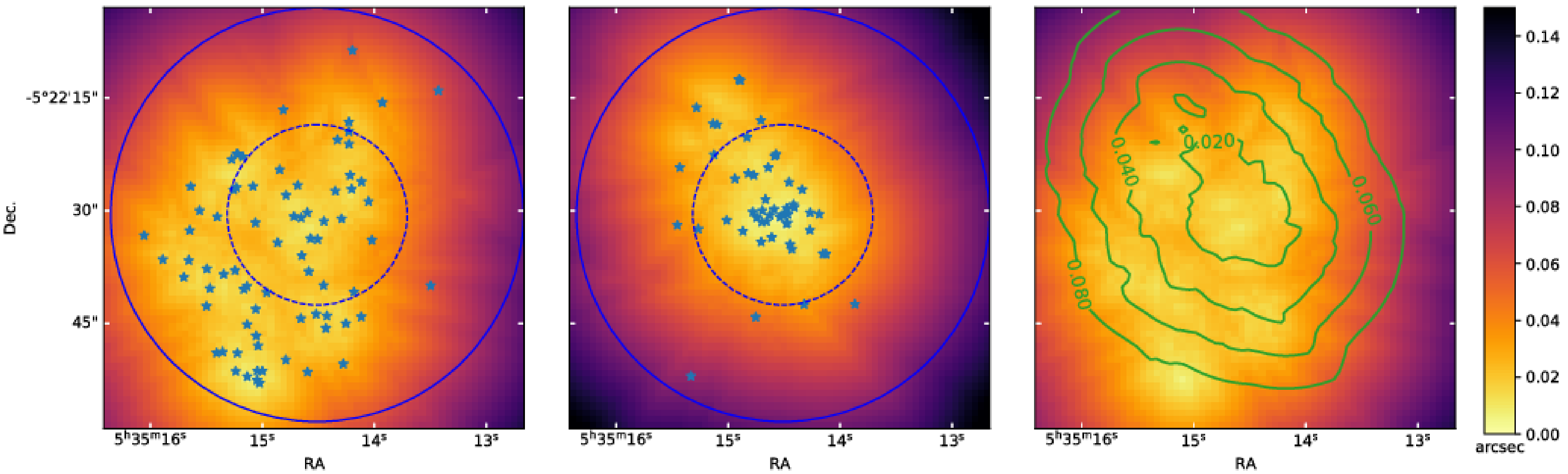


Otter+ 2021: arXiv 2109.14592

How dense are cluster-forming regions?



OMC1 IS DENSER THAN THE ONC



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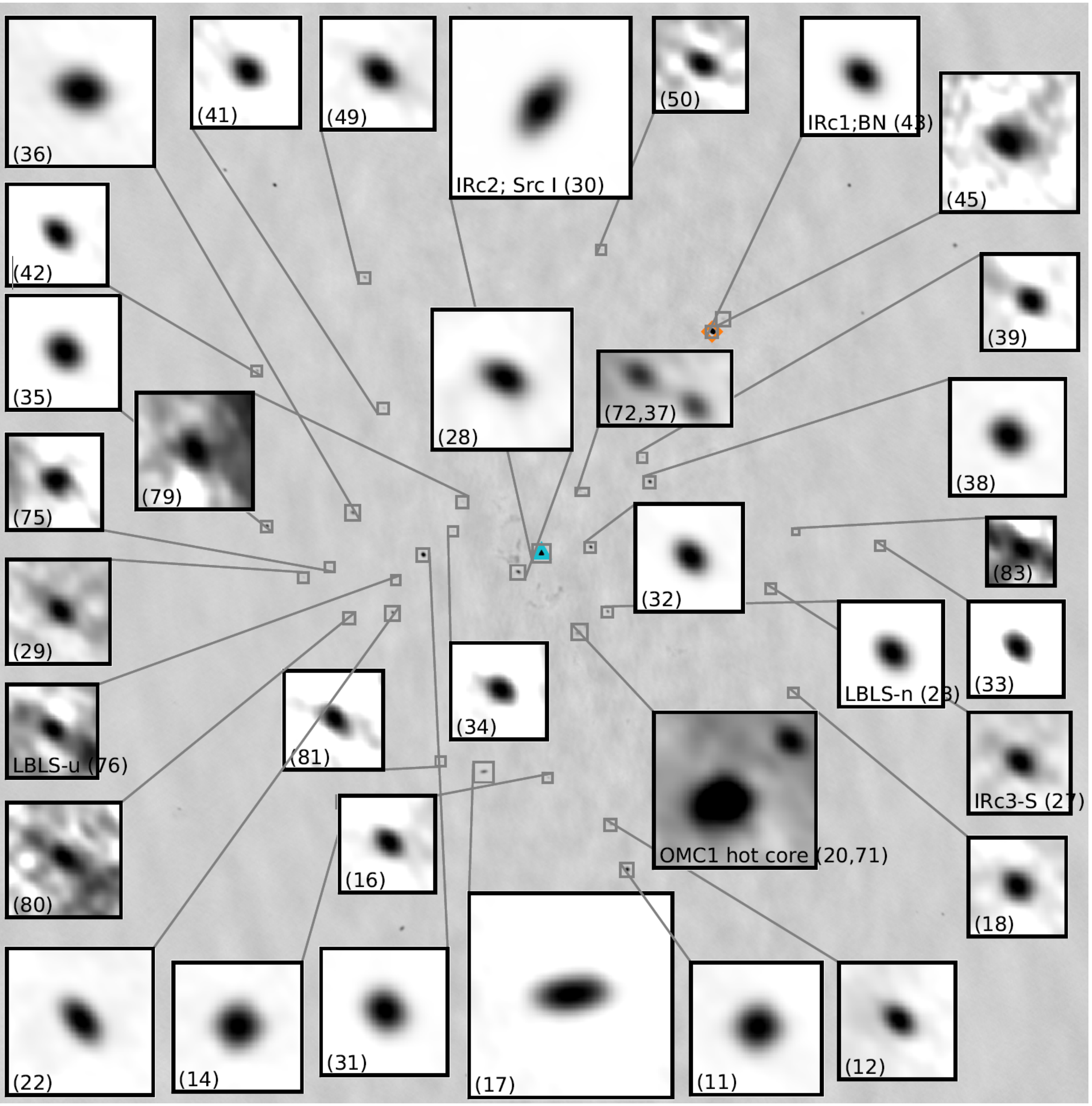
Many new disks in the OMC



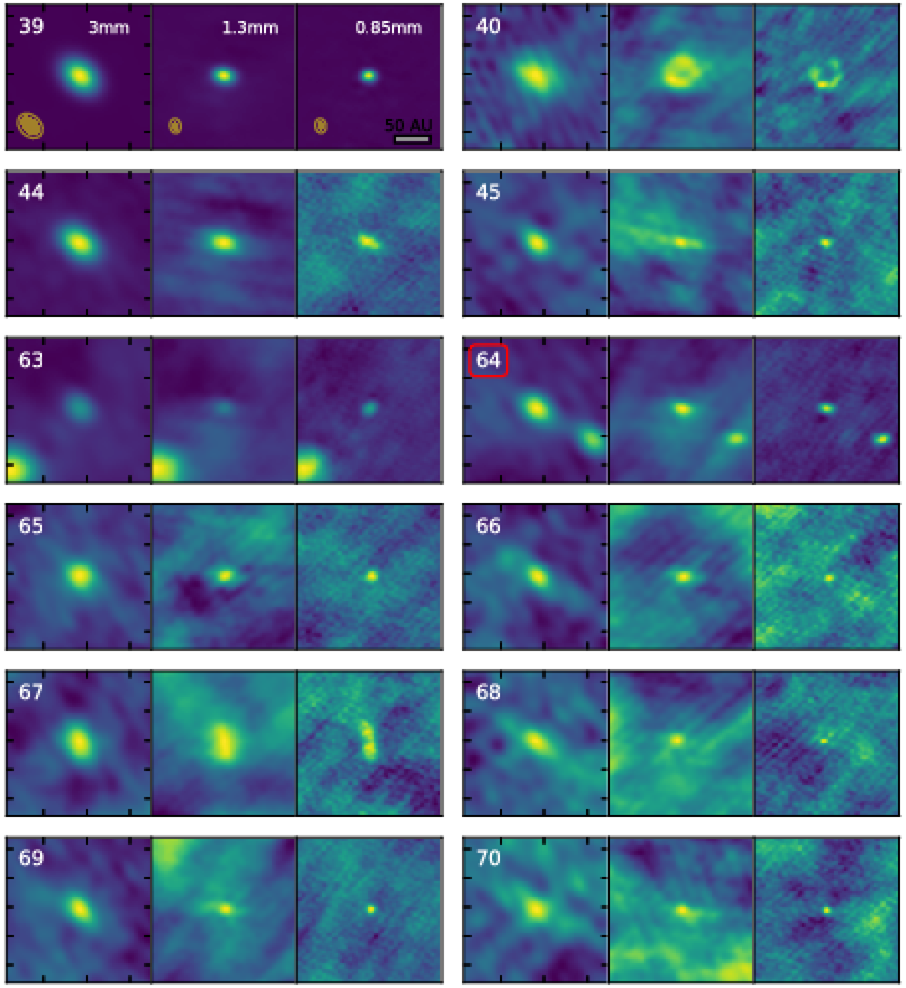
Otter+, resubmitted

FOV: 0.07 pc (16000 AU)

72 YSOs

One "hot core"

Disk Gallery



But are they frequent and close enough?

Interactions on a scale $r = \sigma^{1/2}$ happen on a timescale

$$t \sim (n\sigma v_{disp})^{-1}$$

BUT ARE THEY FREQUENT AND CLOSE ENOUGH?

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$$n \sim 10^{5-6}\text{stars pc}^{-3}, v_{disp} \sim 3\text{km s}^{-1}$$

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For interactions to push to ~ 30 AU (the largest disk),

$$r = \sigma^{1/2} \sim 30\mathrm{AU}\left(\frac{t}{15\mathrm{Myr}}\right)^{-1/2}\left(\frac{n}{10^{6}\mathrm{pc}^{-3}}\right)^{-1/2}\left(\frac{v_{disp}}{3\mathrm{km\ s}^{-1}}\right)^{-1}$$

$15\mathrm{Myr}$ is ~100x too long.

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15Myr is ~100x too long.

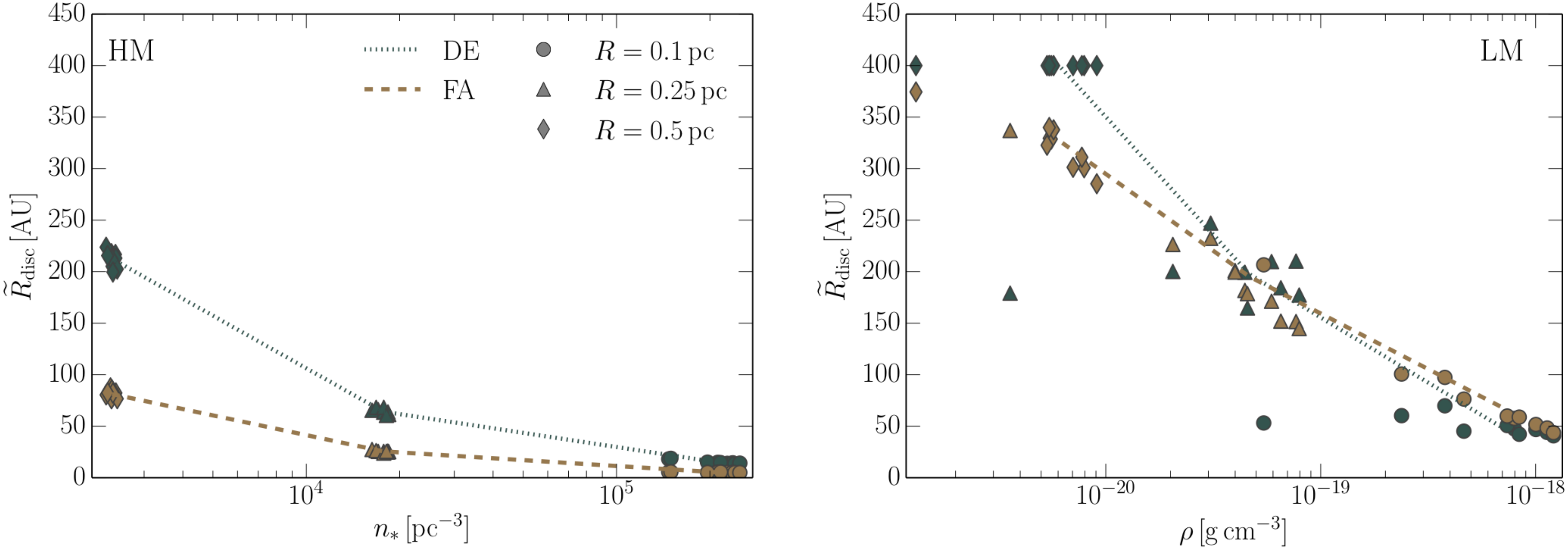
Can squeeze this by a bit b/c disk is smaller than r; Breslau+ 2014:

$$R_{disc} \sim 0.28 r_{peri}\left(\frac{M_1}{M_2}\right)^{0.32}$$

A different calculation of the same (bonus slide):

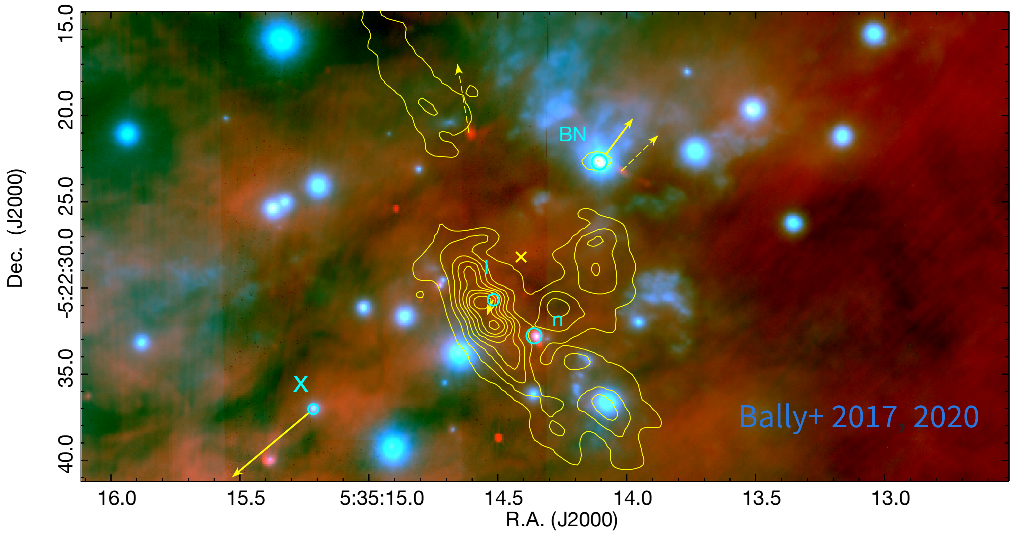
$$r = \sigma^{1/2} \sim 370\mathrm{AU}\left(\frac{t}{0.1\mathrm{Myr}}\right)^{-1/2}\left(\frac{n}{10^6\,\mathrm{pc}^{-3}}\right)^{-1/2}\left(\frac{v_{disp}}{3\mathrm{km\ s}^{-1}}\right)$$

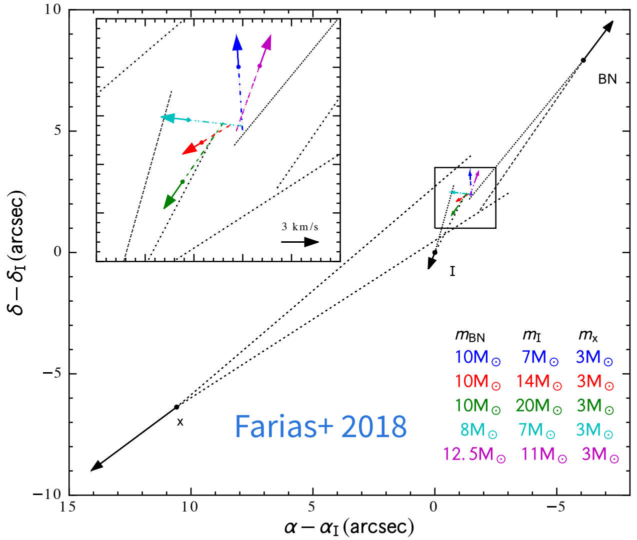
Face-on accretion & ram pressure



Wijnen+2016 and 2017a, b model: face-on accretion brings in low-j material, ram pressure strips loosely-bound material.
Bottom-right: not quite as dense as OMC, still too-big disks, but not a bad match.

Dynamical ends to accretion





The BN/I/x interaction is the poster case of accretion ended by dynamical interaction.

Summary and Prospectives

- Disks are smaller and more massive in the OMC
  - and generally in more gas-rich regions?
- Stellar dynamics are important to disk structure, but gas-disk interactions may be more important
- Dynamics in protocluster regions matter
  - This cycle marks a good time to start measuring proper motions with ALMA!
  - Multiplicity and offset hot cores are a sign of dynamical interactions (also good to examine with ALMA long baselines)
- We need JWST to measure the IR from protostars even in Orion

Other speculations

Do the disks start small and grow later?

Viscous spreading could result in older disks being larger

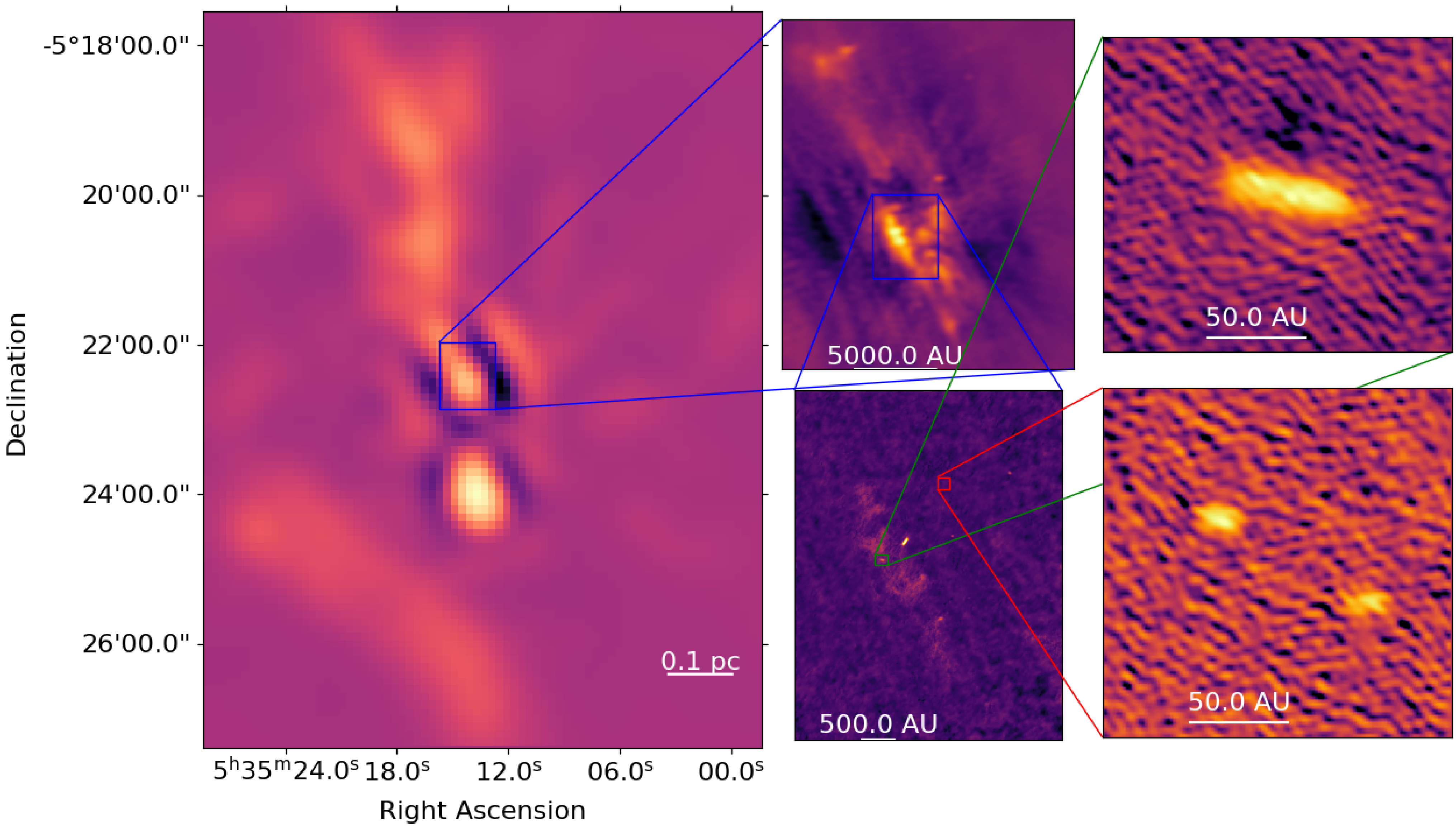
It is possible that only the dust disks are smaller, but the gas disks are still big.

However, all disk radii (Orion & elsewhere) are computed based on dust mass, and there's (presently) no reason to think different environments would preferentially push the dust in.

Maybe the disks are intrinsically smaller in Orion (Caselli, Kuiper)

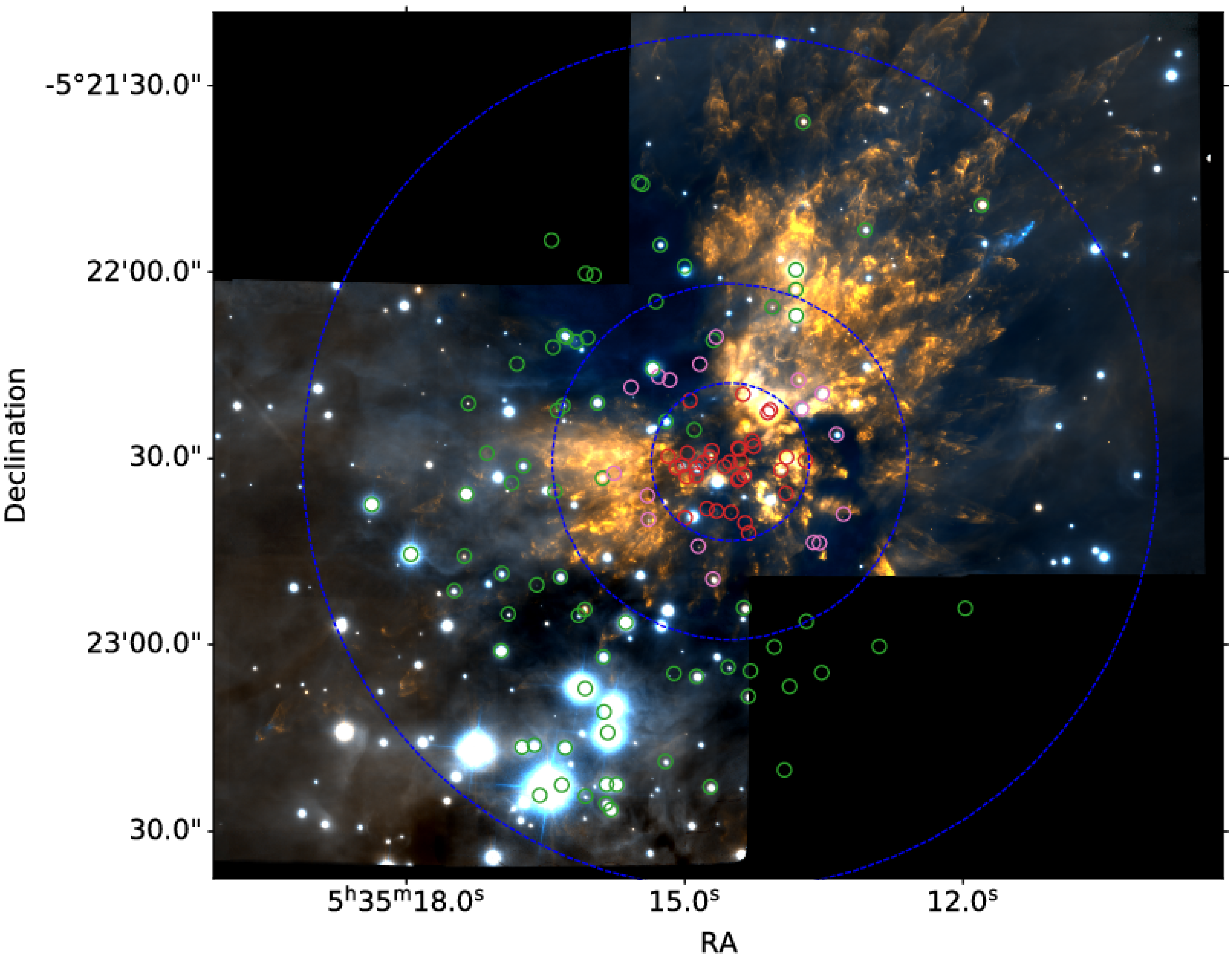
If they're just young, still accreting, maybe they have not grown larger yet (inconsistent w/Tobin results)

The canonical hot core isn't



(e.g., Zapata+ 2011)

Disk-bearing stars on Gemini



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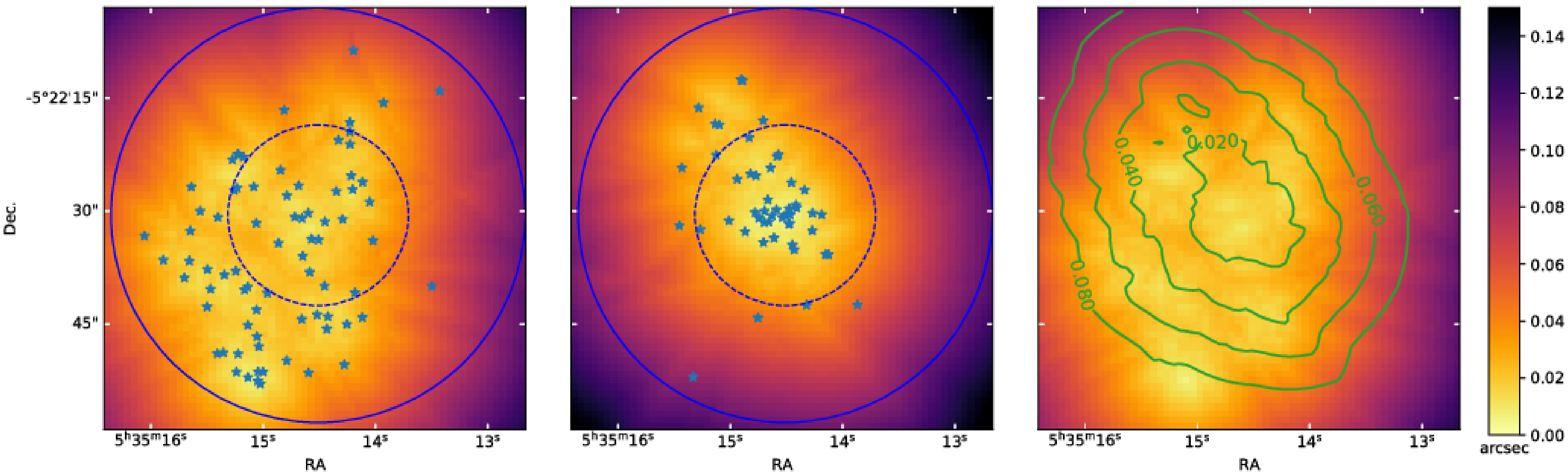

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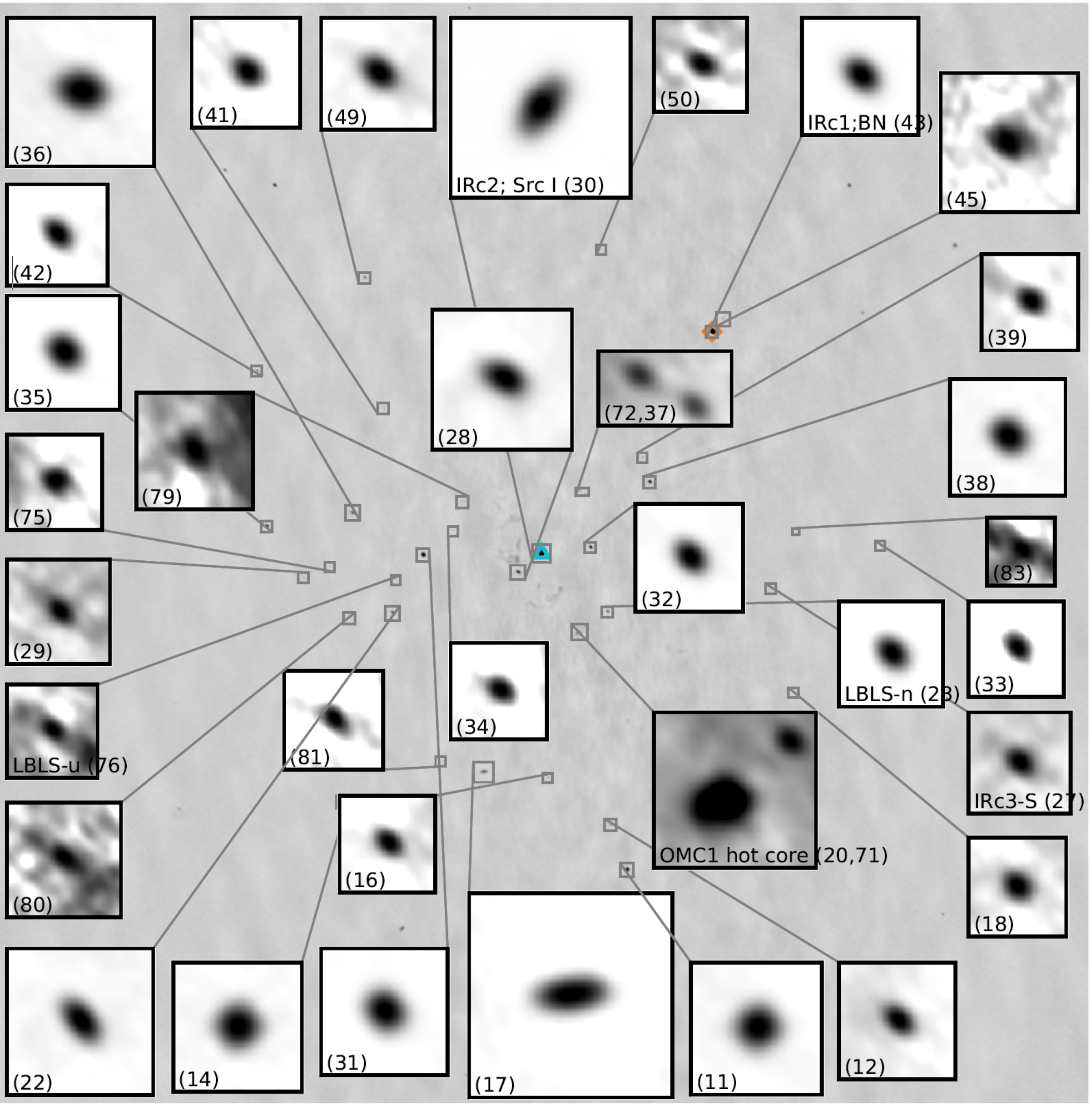
MANY NEW DISKS IN THE OMC



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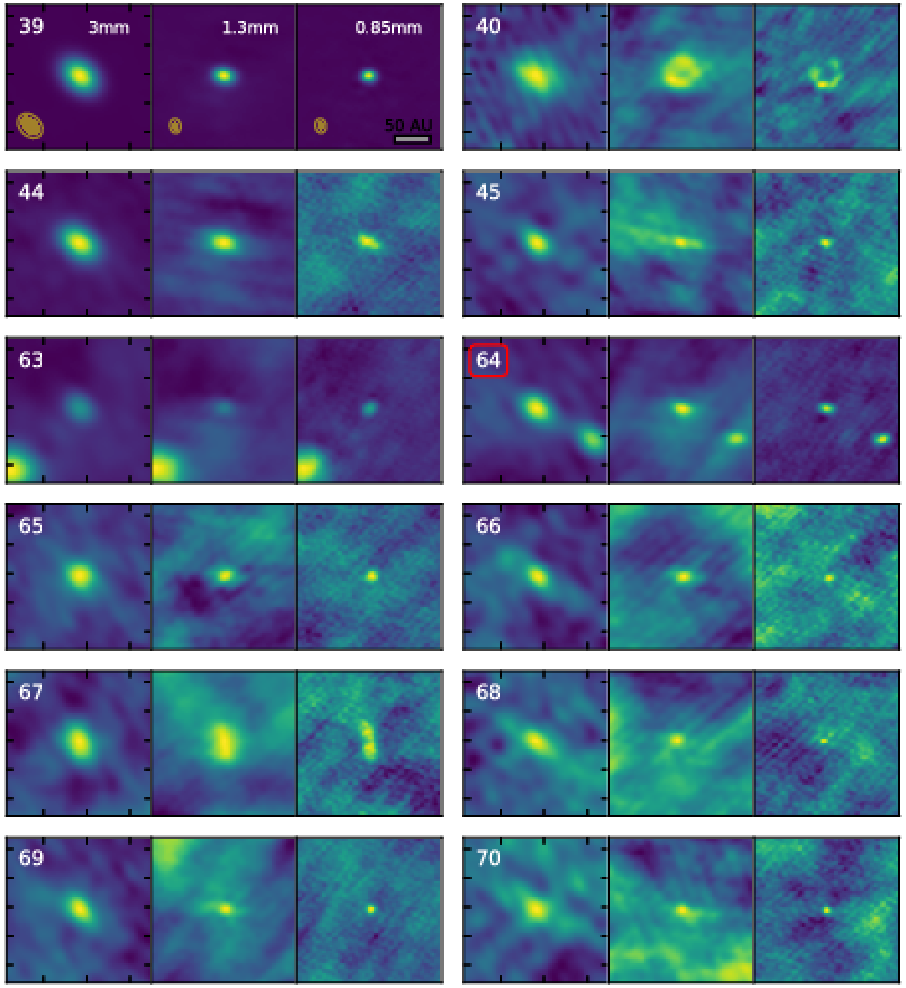
One "hot core"

Disk Gallery



Orion Source I
A disk around a 15 $M_\odot$ YSO

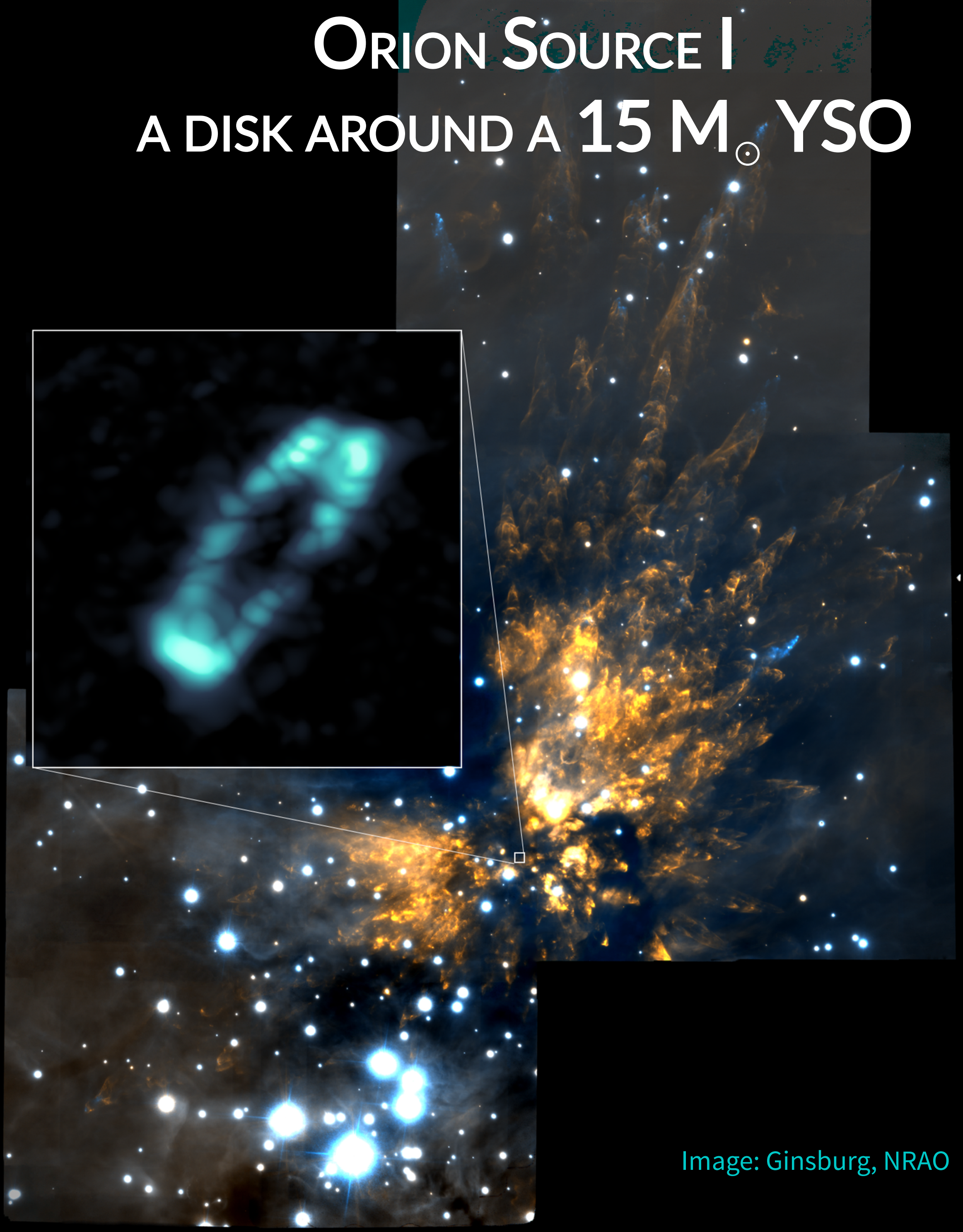
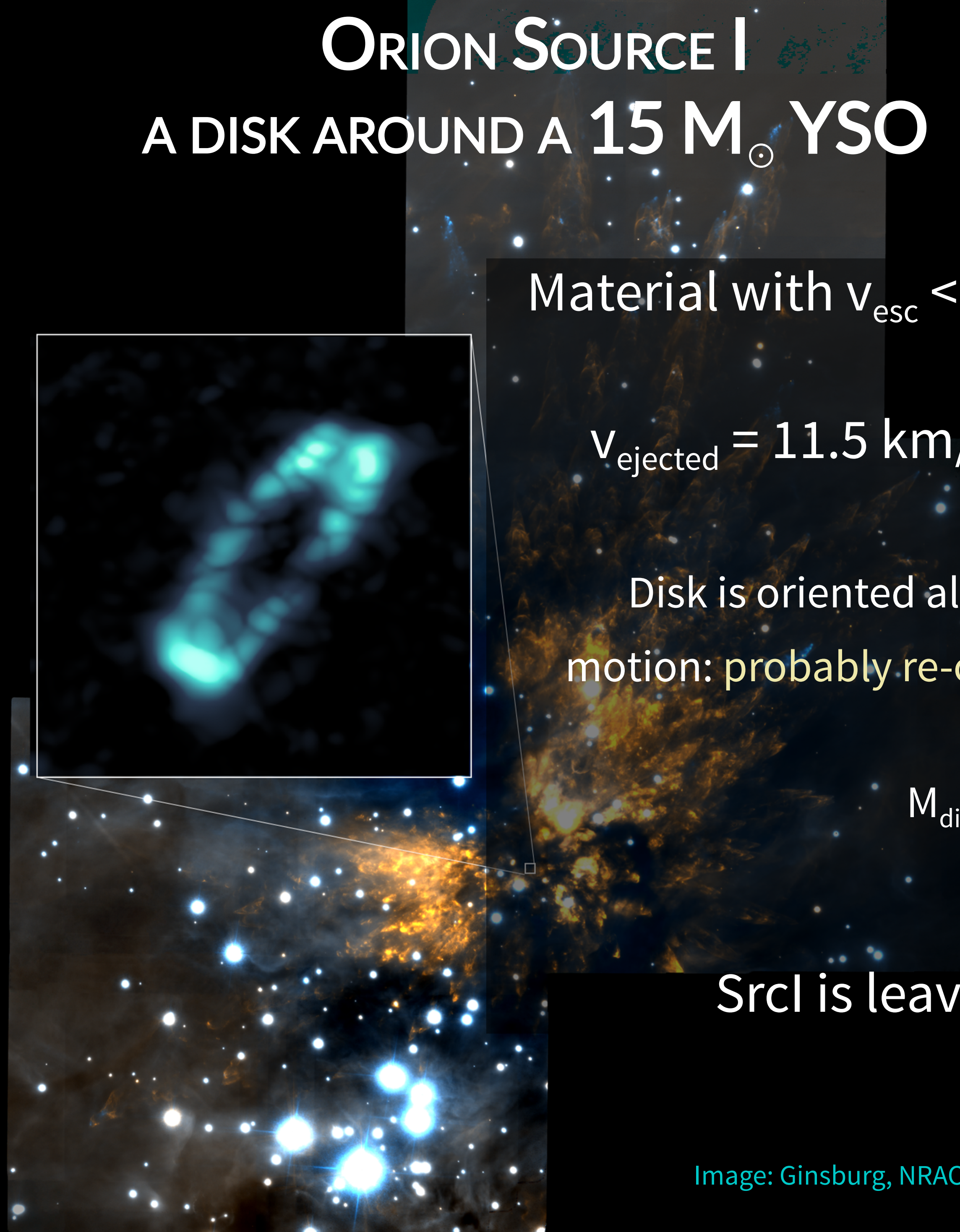


Image: Ginsburg, NRAO

Orion Source I
A disk around a 15 $M_\odot$ YSO



Material with $v_{esc} < v_{ejected}$ was lost.

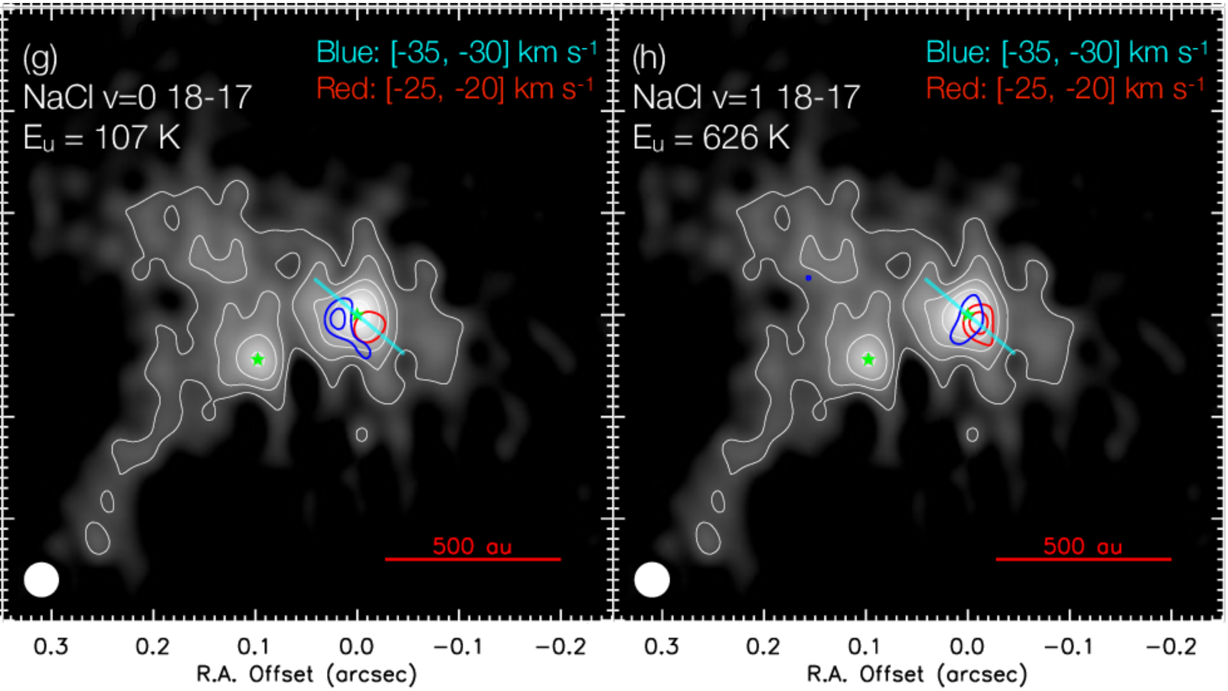
$v_{ejected} = 11.5$ km/s $= v_{esc}(200$ AU$)$

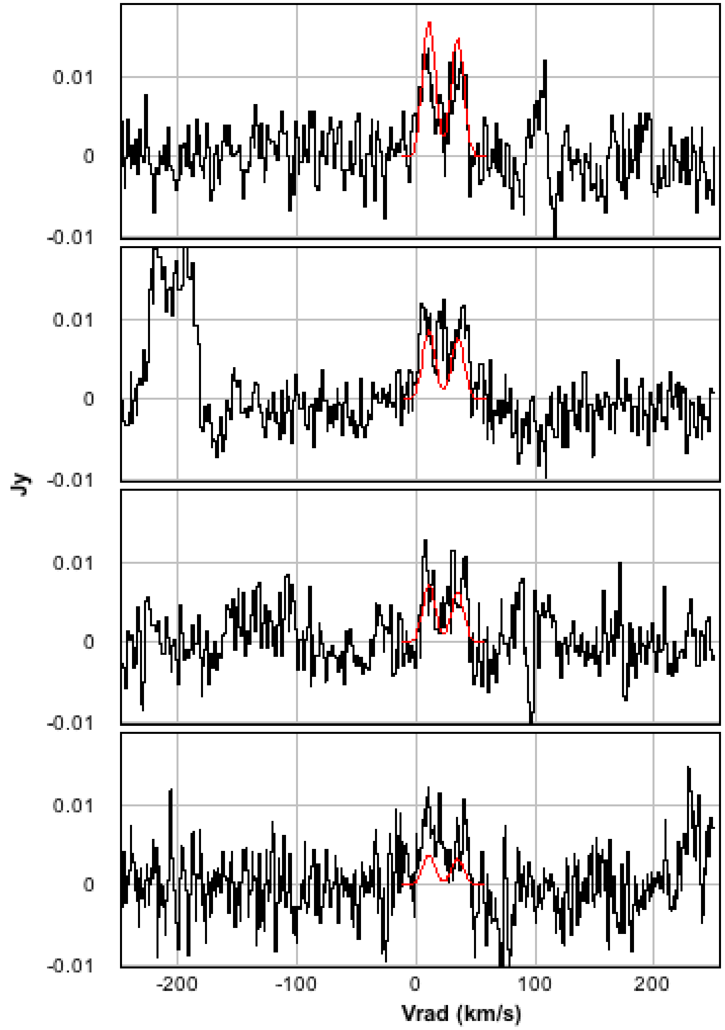
Disk is oriented along the direction of motion: probably re-oriented in ejection

$M_{disk} \sim 0.02 - 2\ M_\odot << M_\star$
(Plambeck+ 2016)

SrcI is leaving the hot core

Image: Ginsburg, NRAO

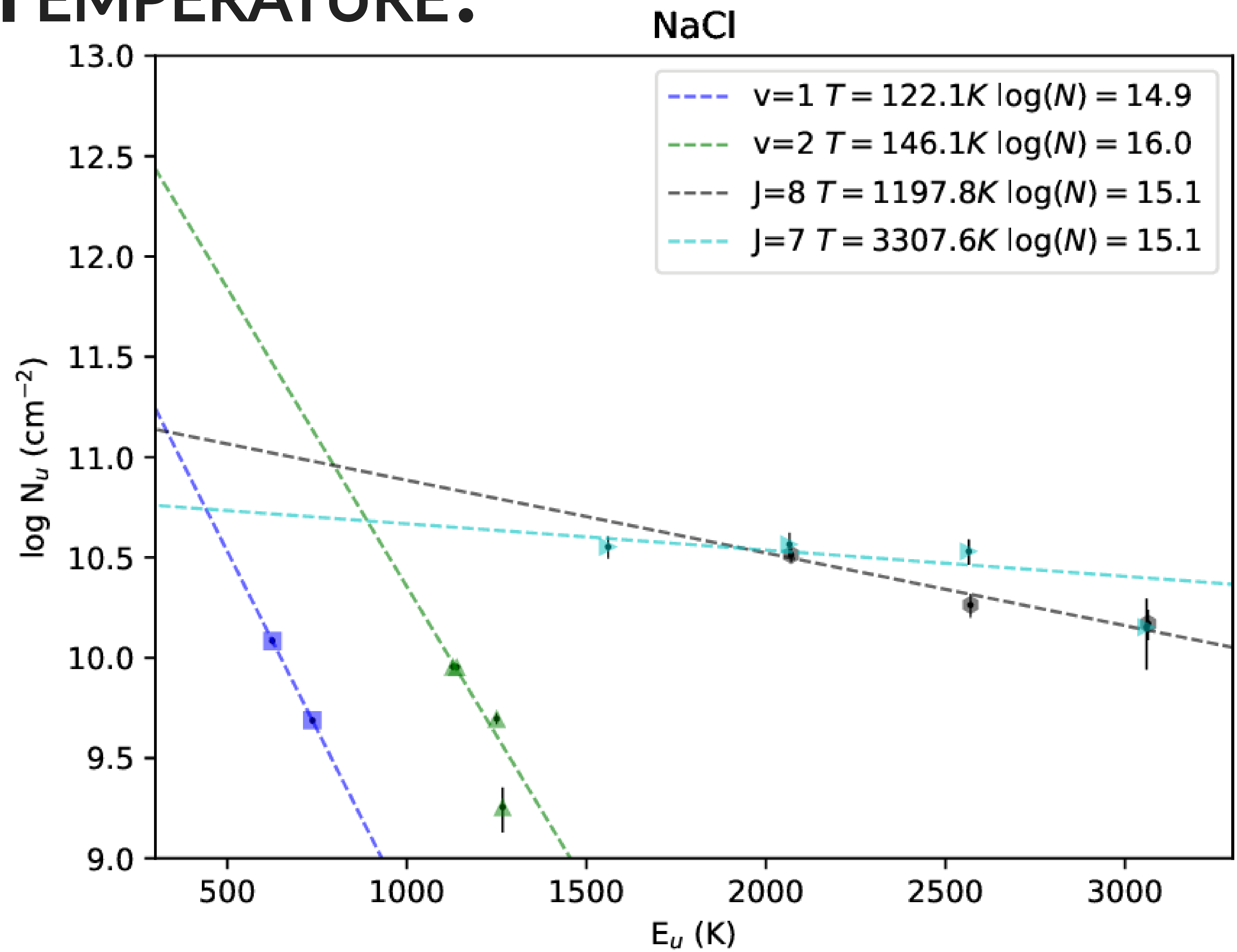




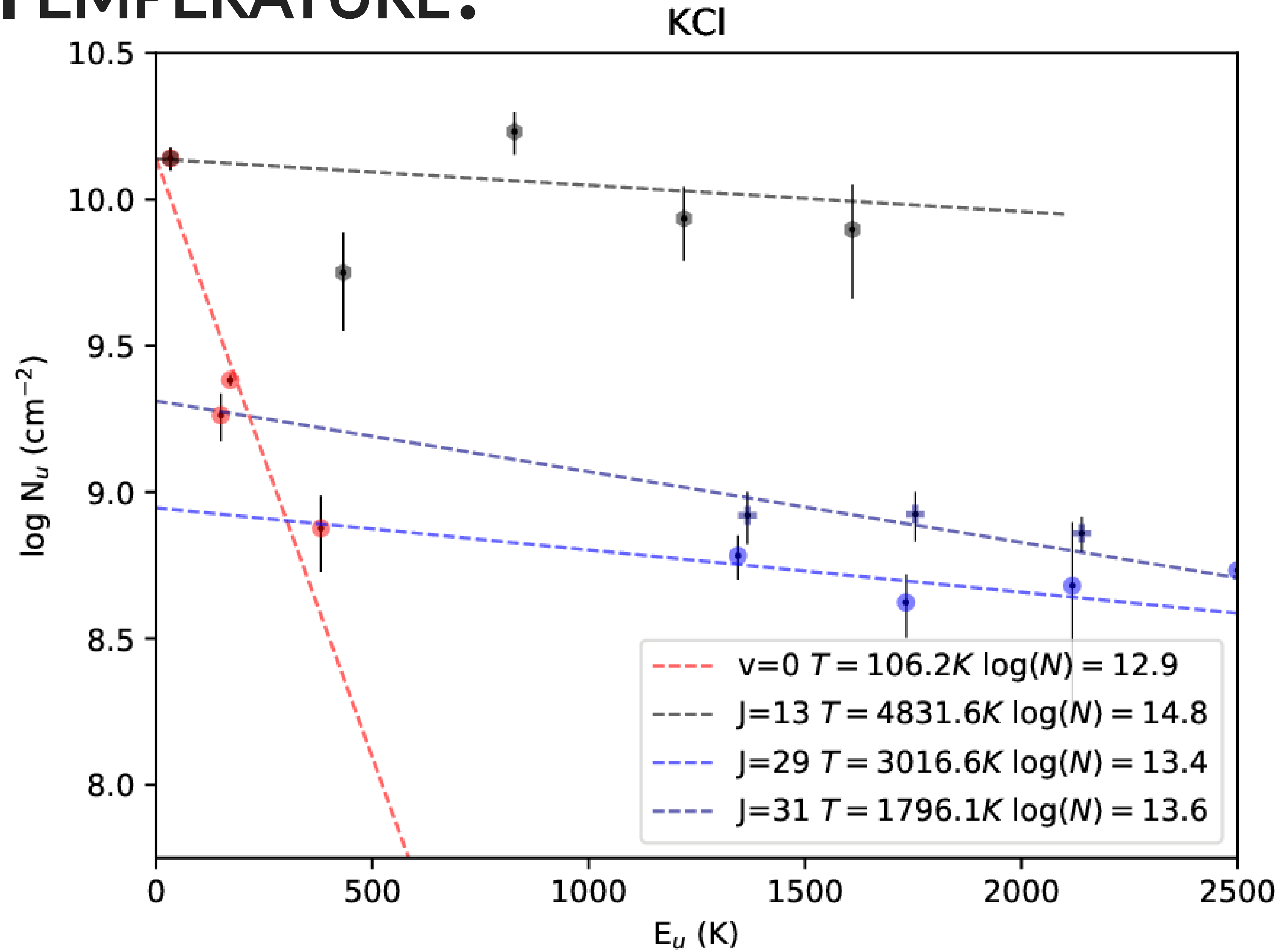
Left: Tanaka+ 2020, pair of NaCl-bearing disks.

Right: G17, Maud+ 2020

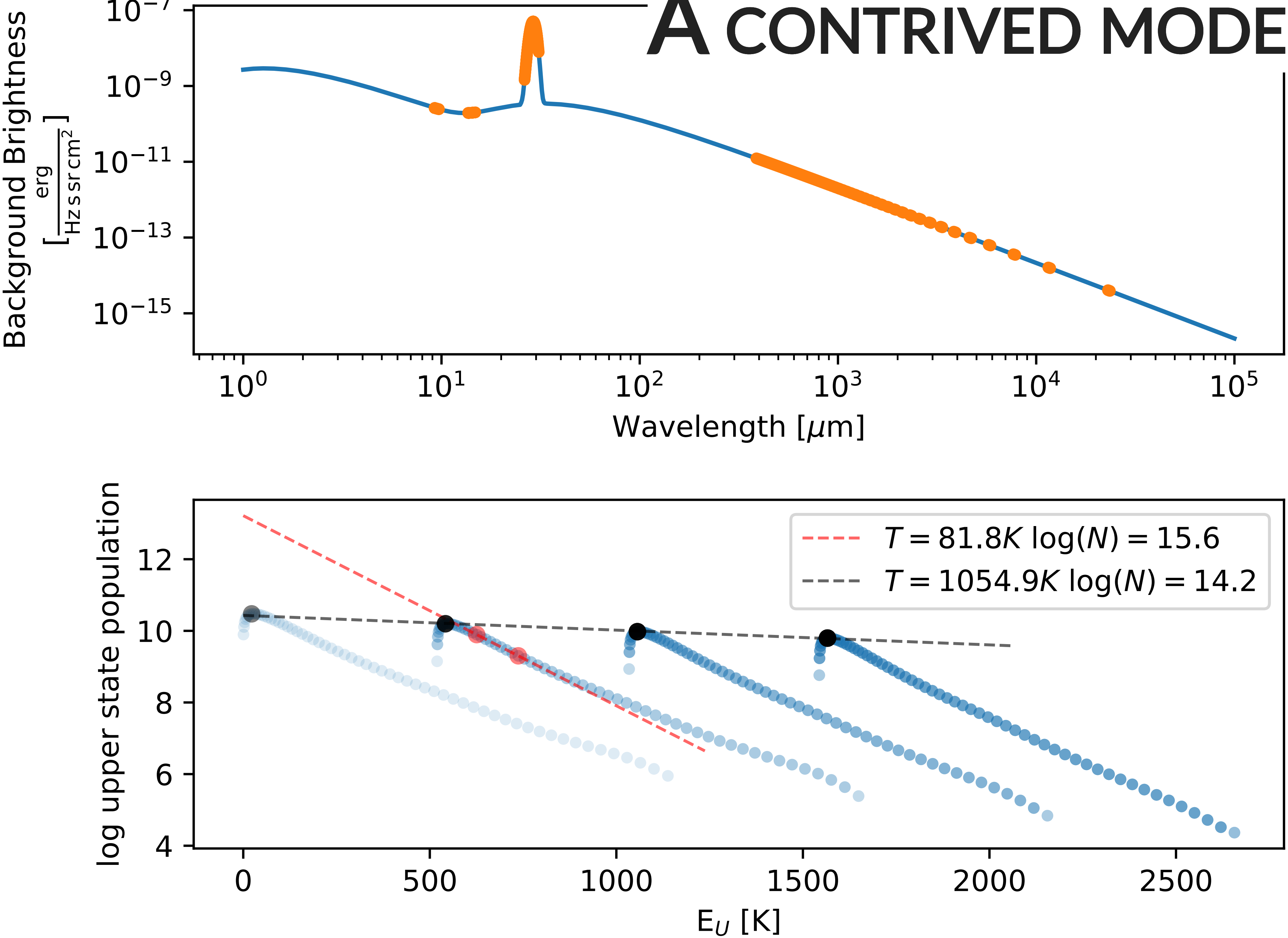
TEMPERATURE?



TEMPERATURE?

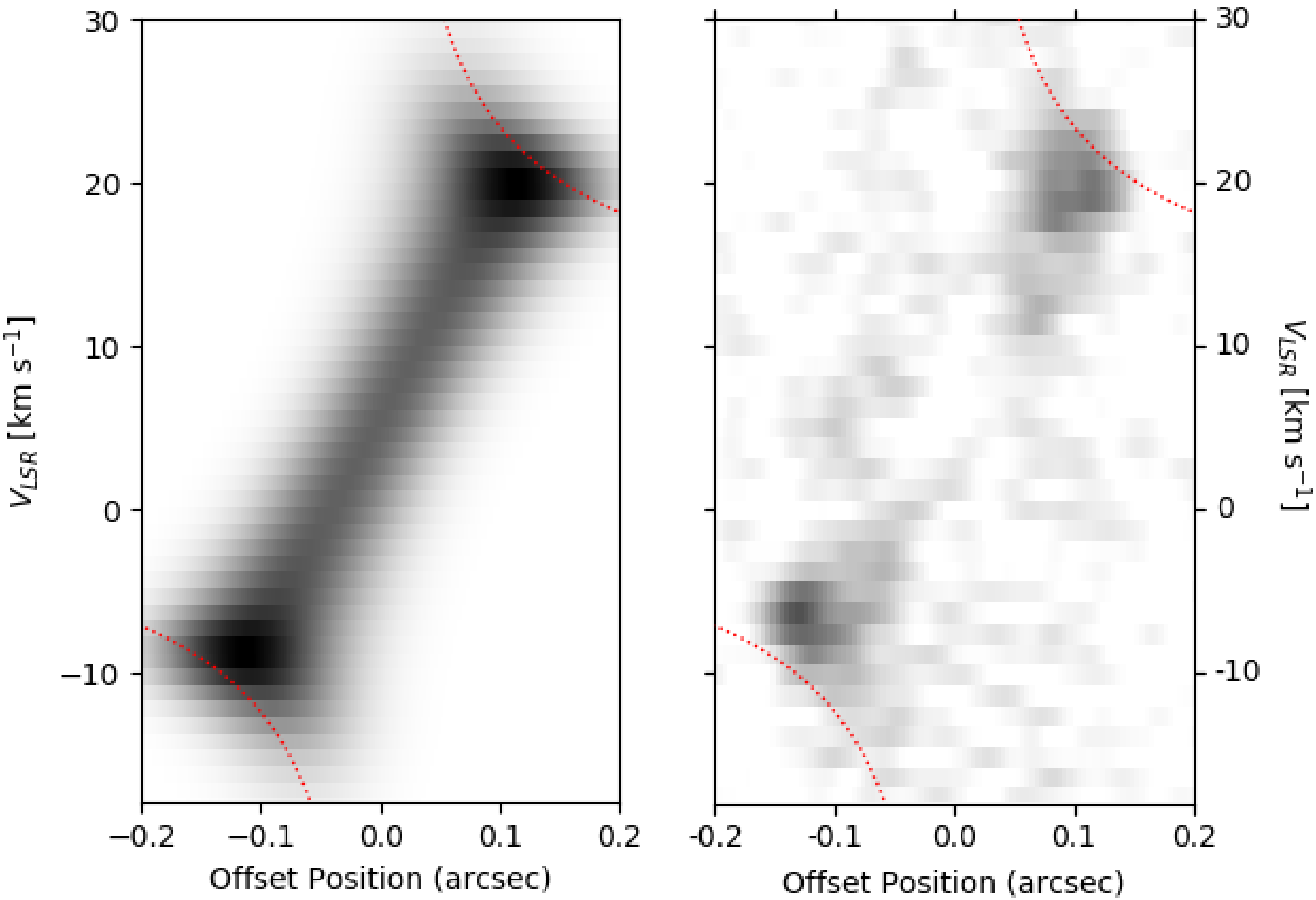


A CONTRIVED MODEL

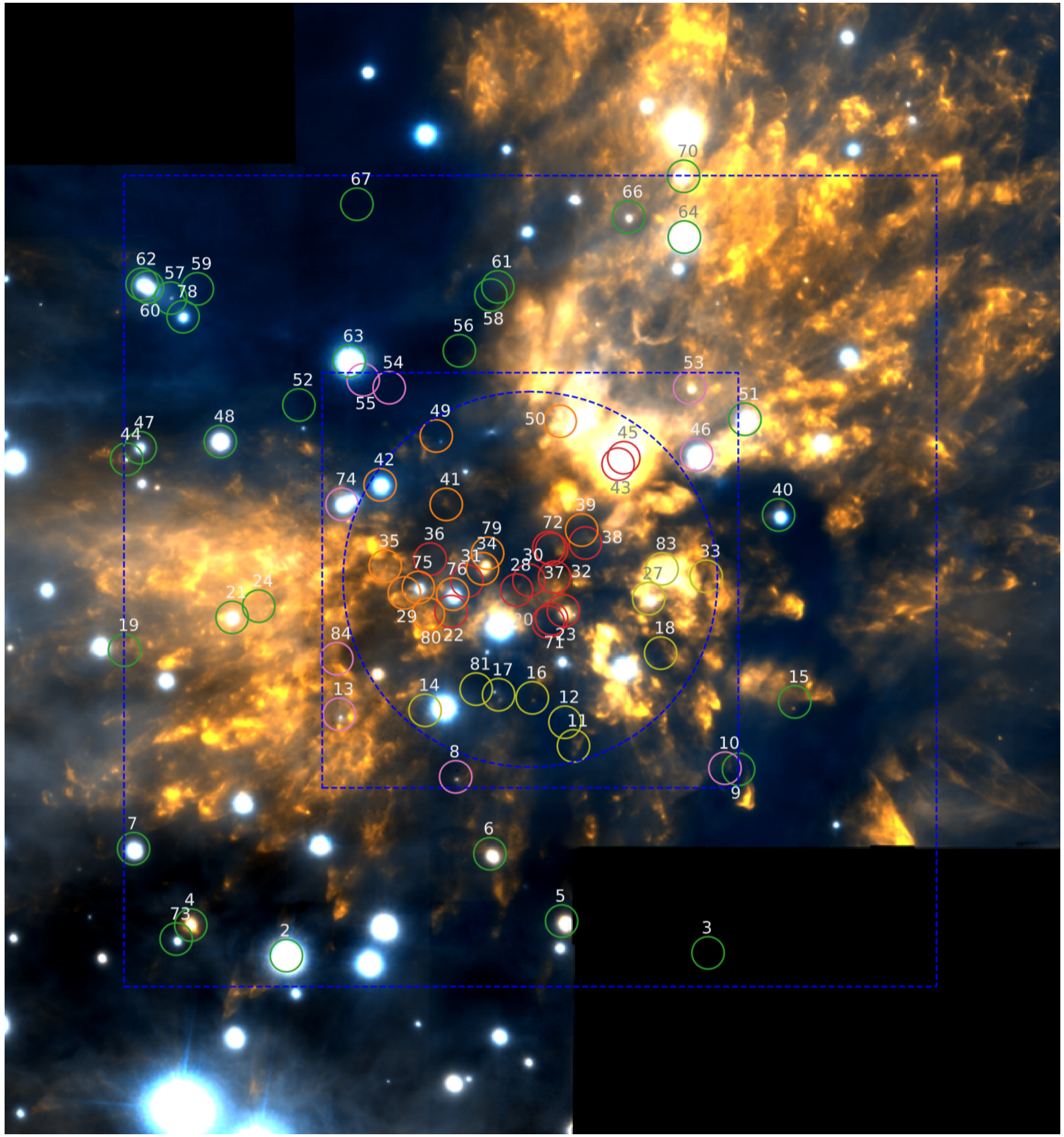


Observing the Keplerian rotation profile of a disk is the most direct way to measure a protostar's mass

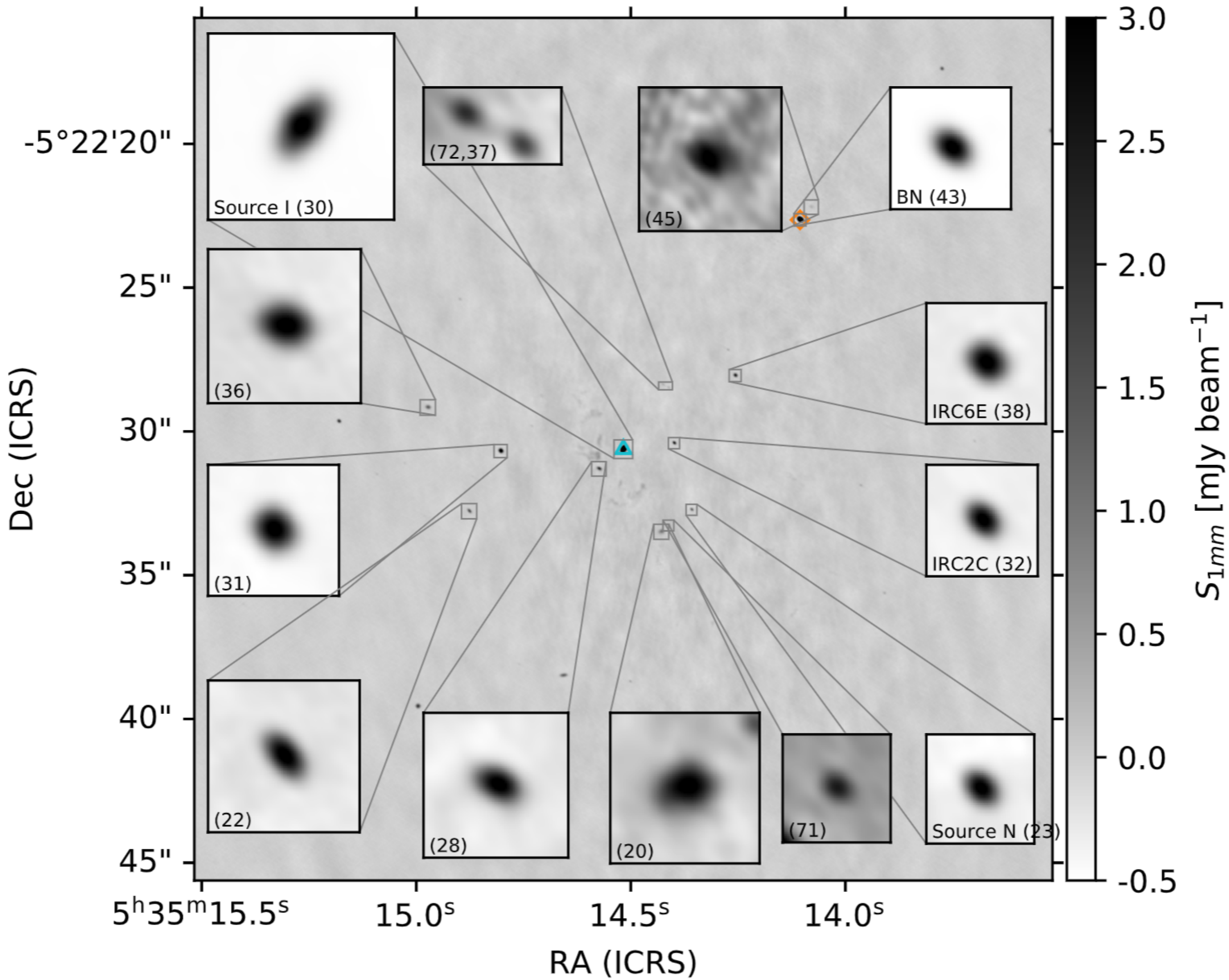
(we can only see the disk, not the star itself)



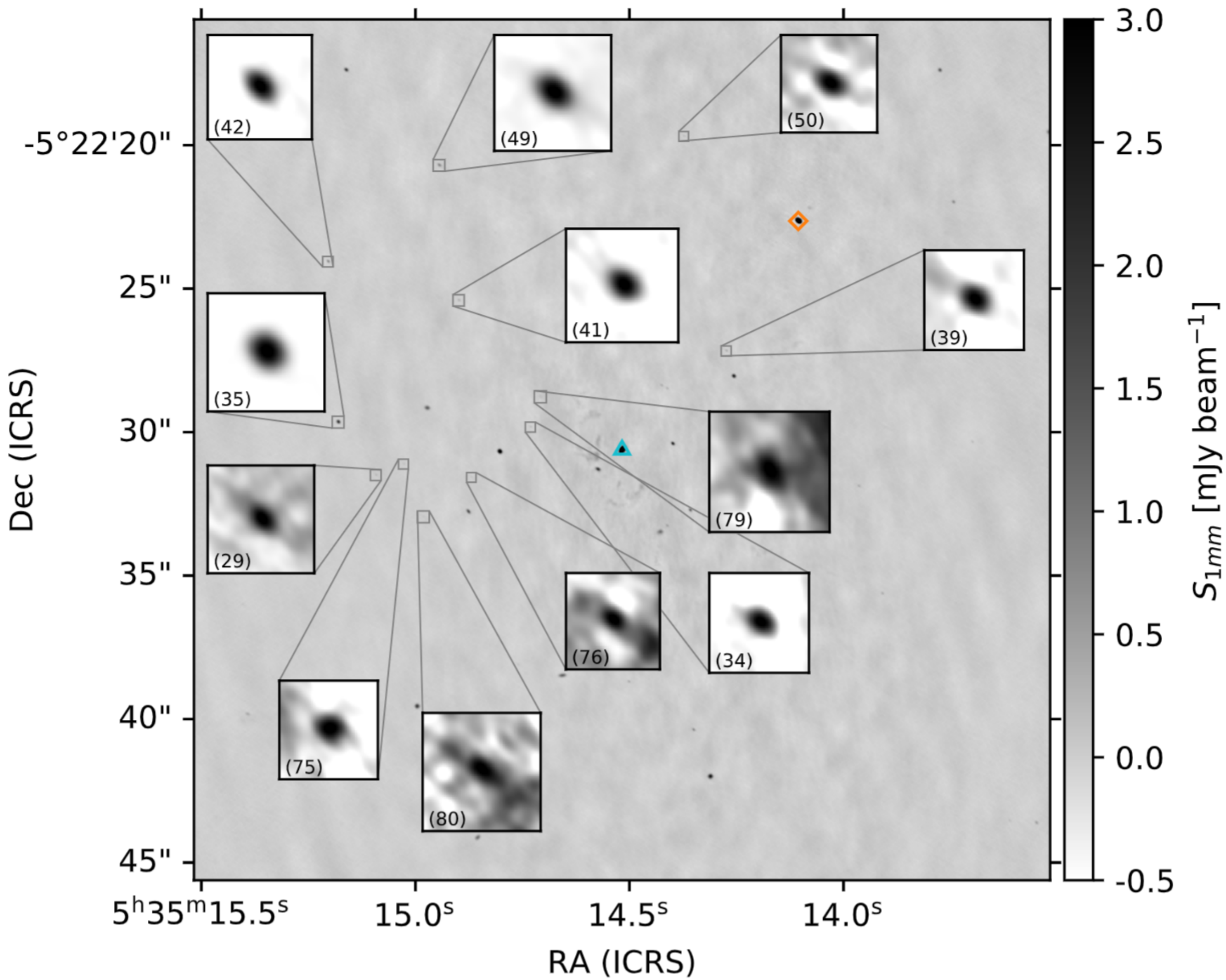
YSO disks in Orion



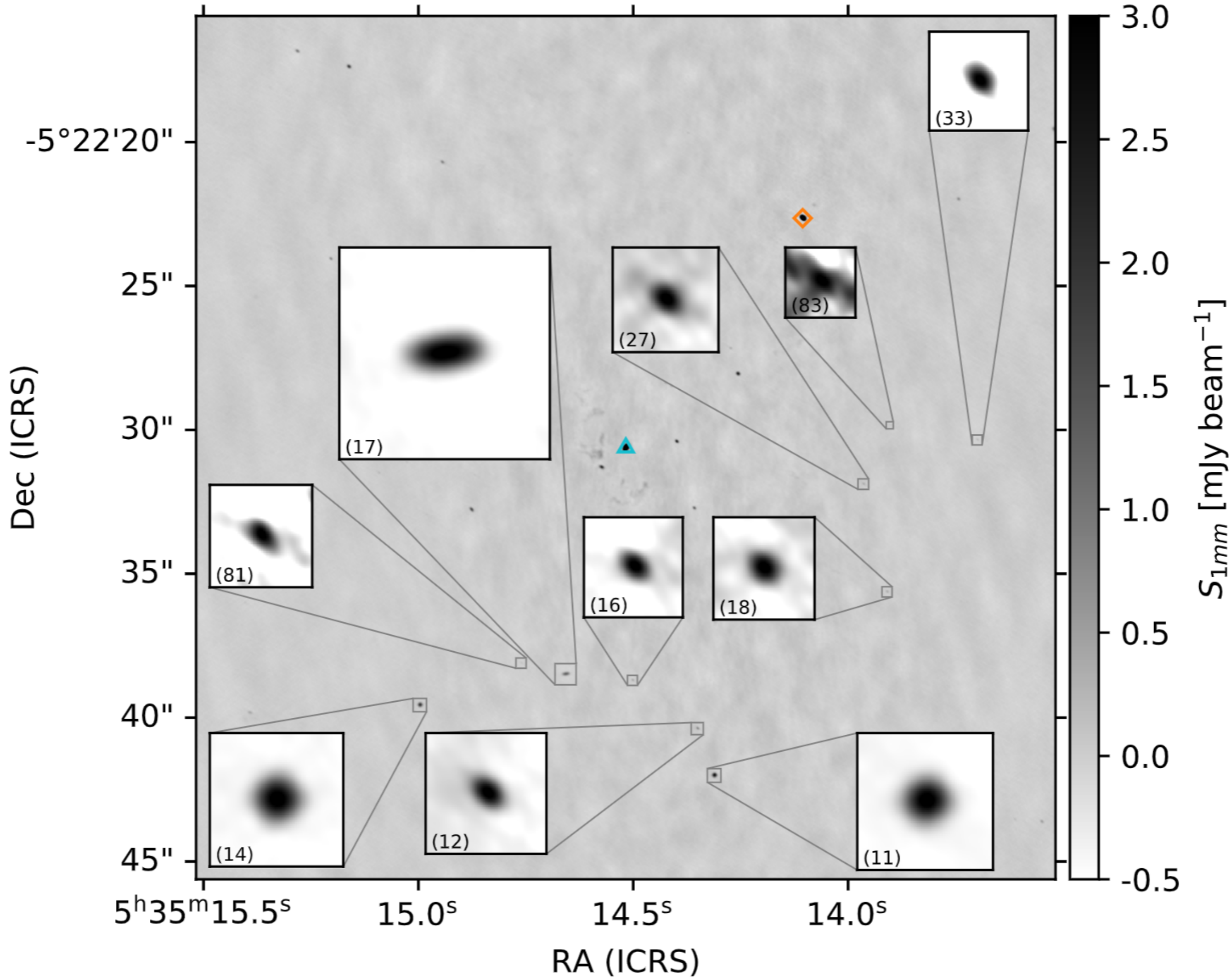
YSO disks in Orion



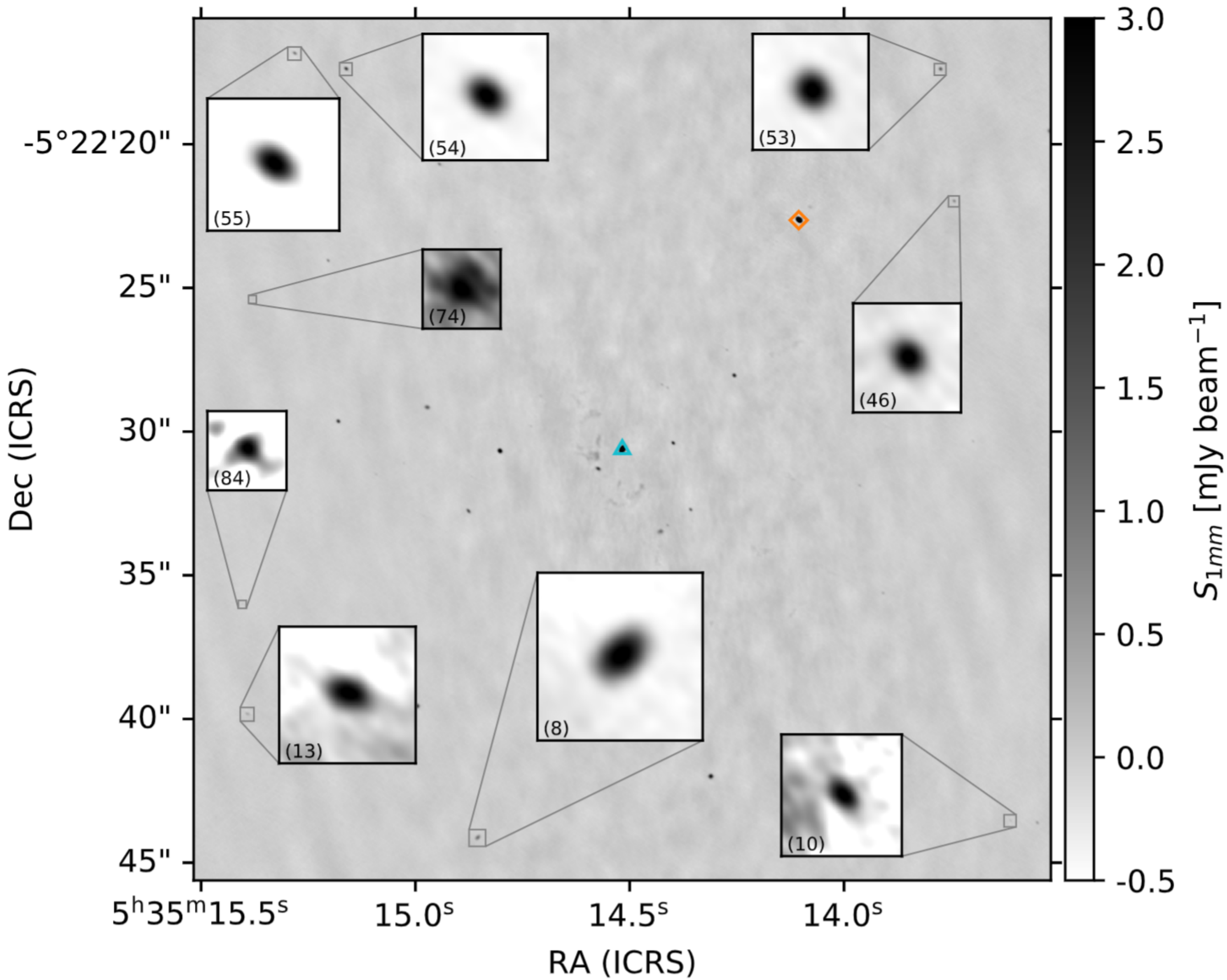
YSO disks in Orion



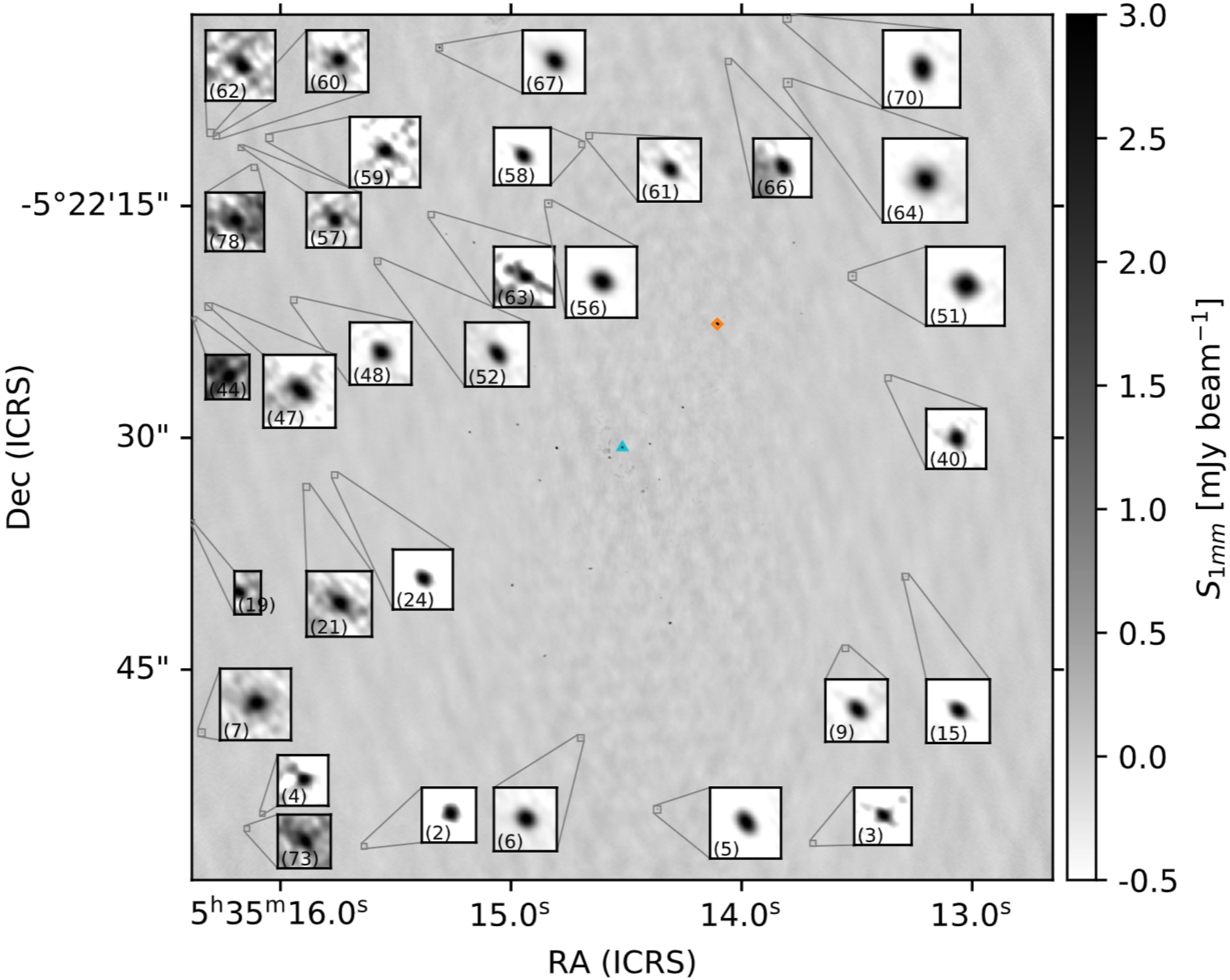
YSO disks in Orion



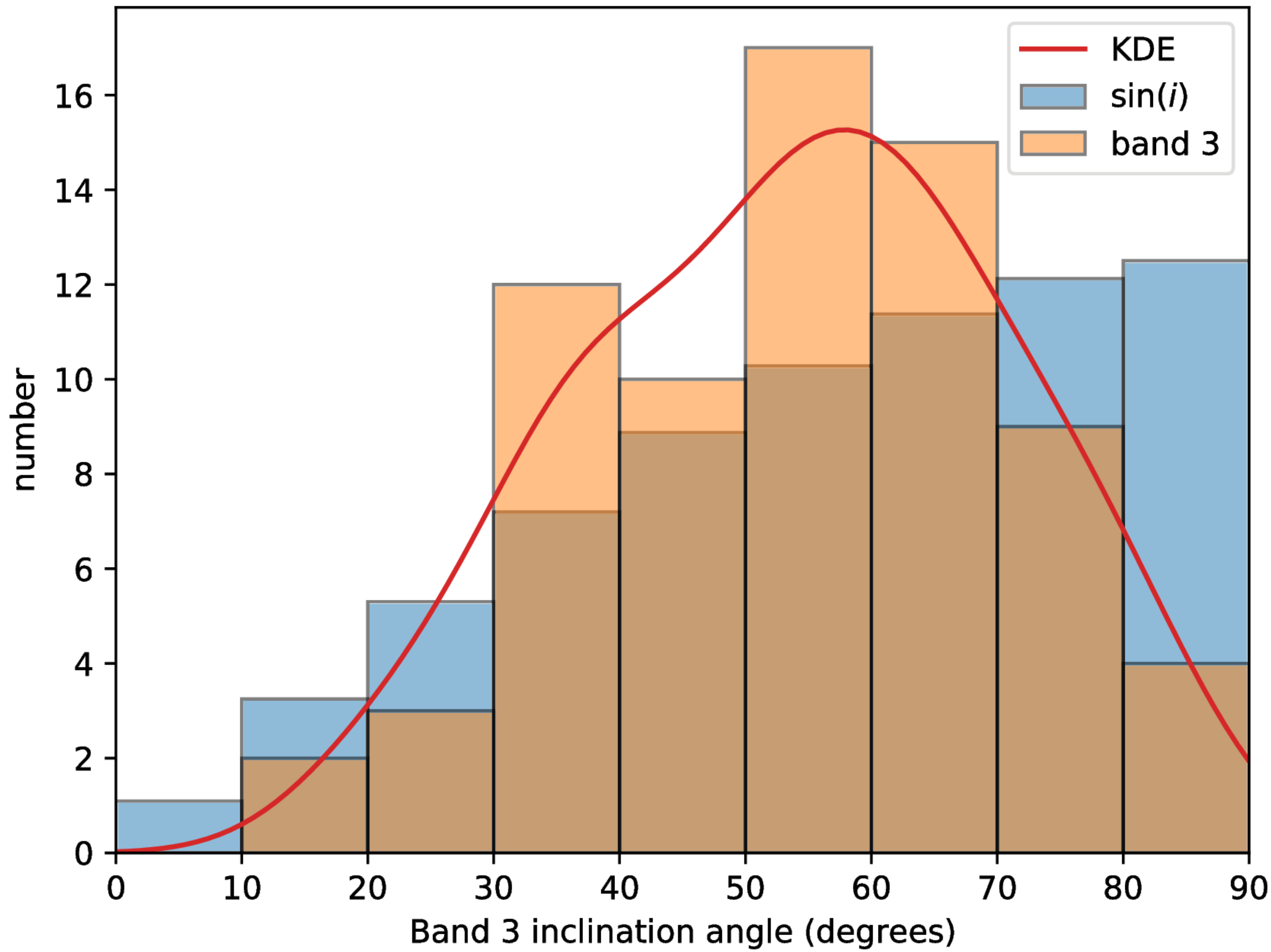
YSO disks in Orion



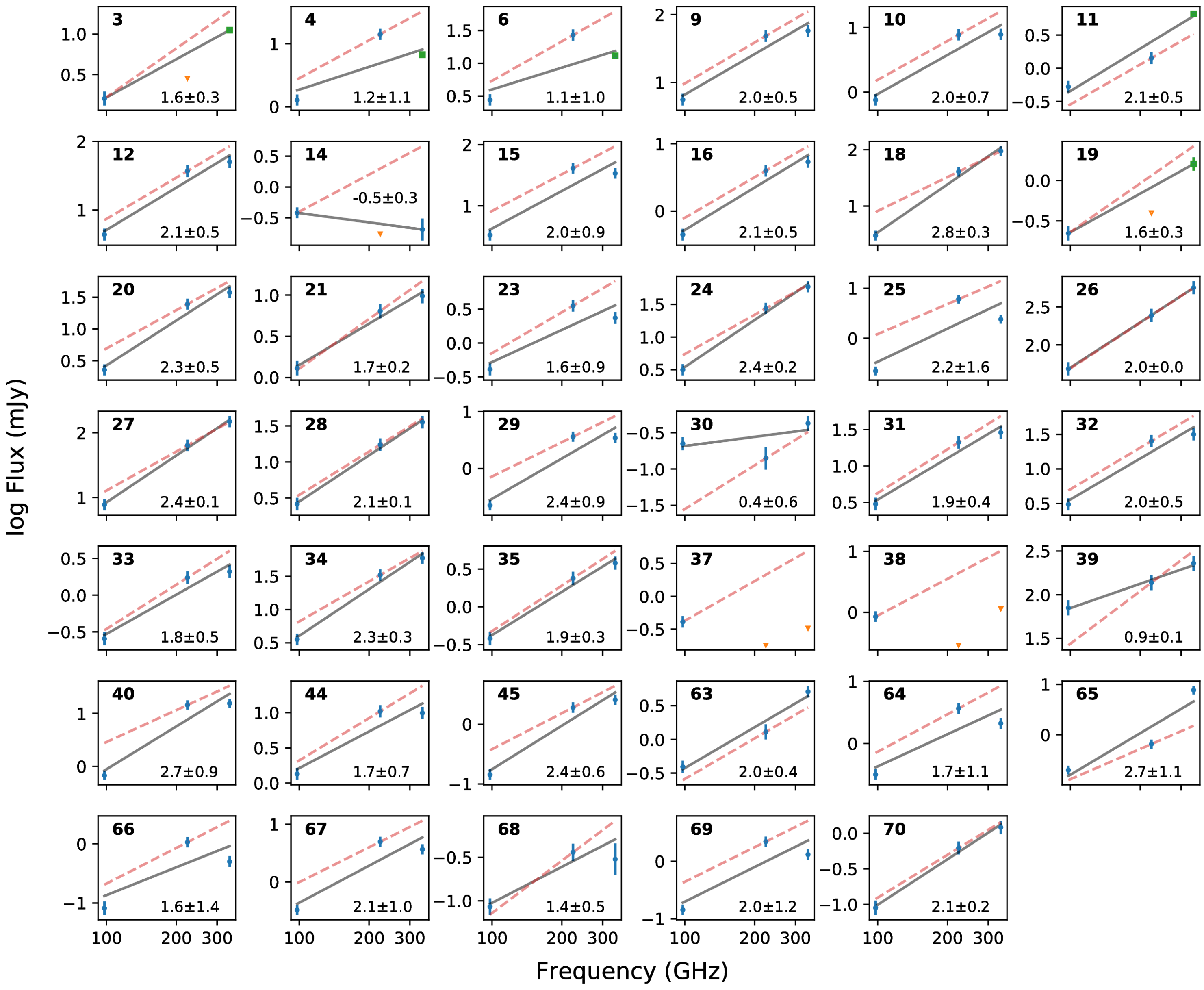
YSO disks in Orion



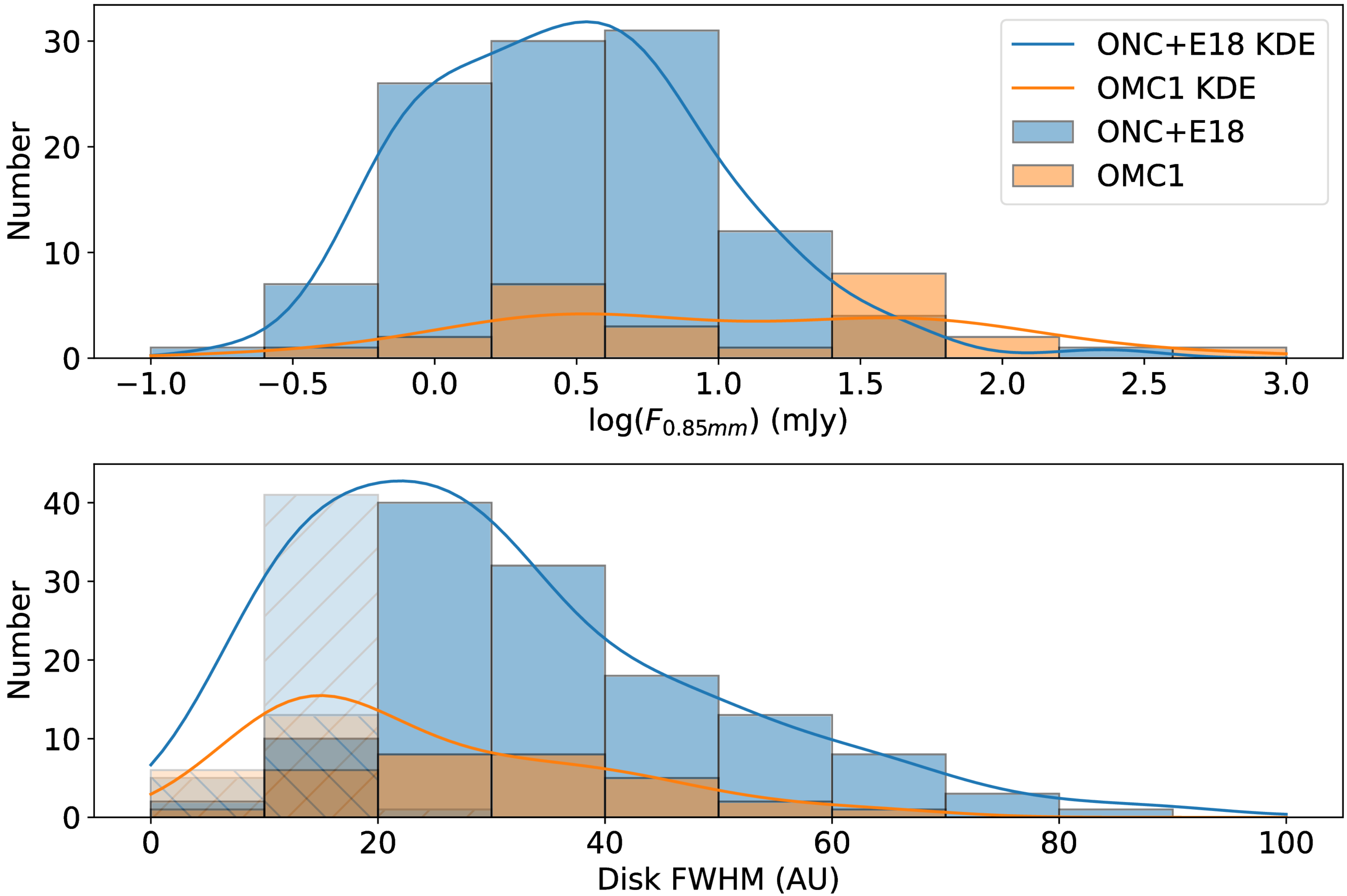
Inclinations are consistent with random



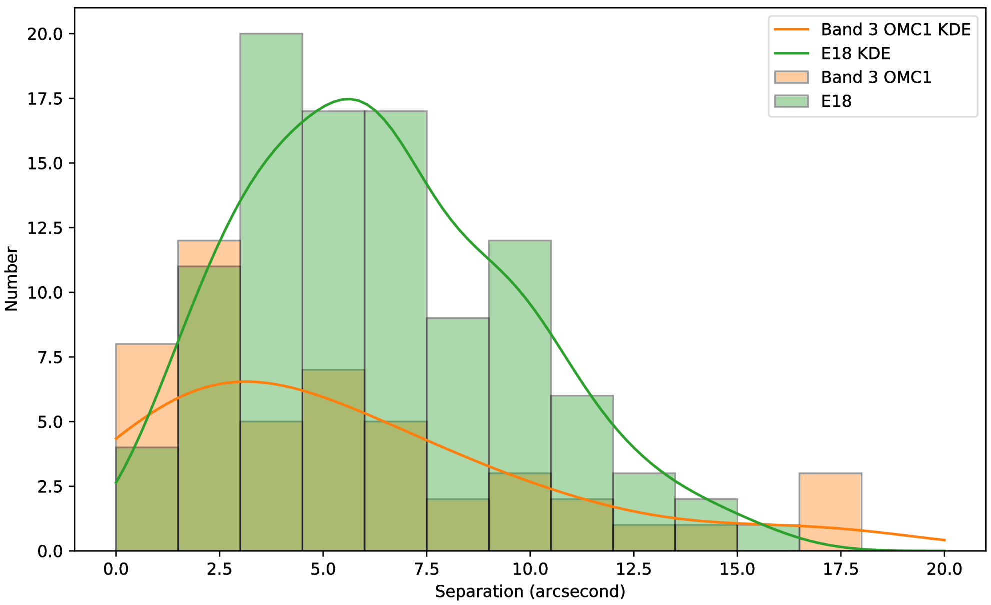
The disks are mostly optically thick



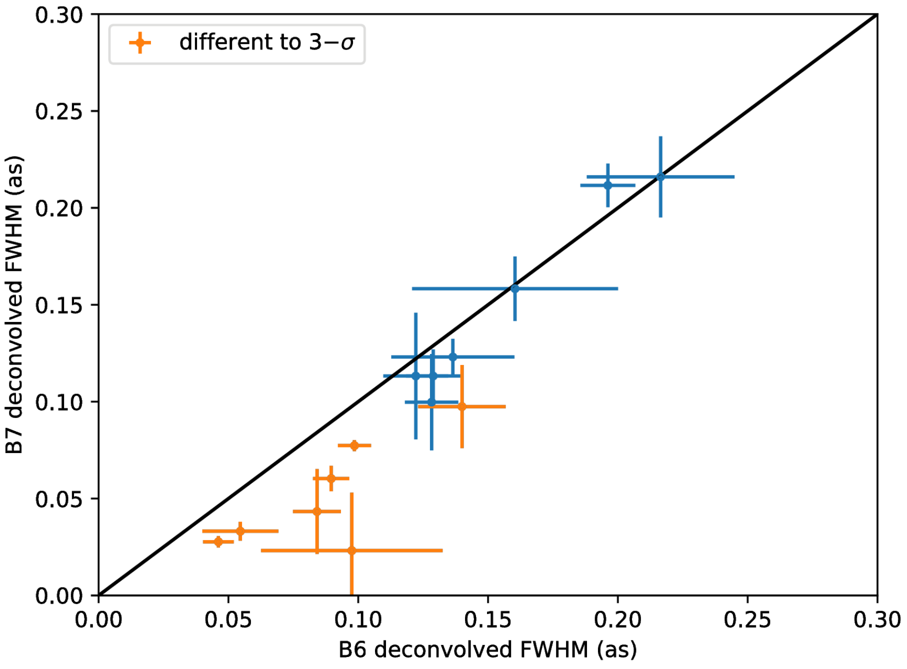
Flux & size histograms



MST SOURCE SEPARATION: ONC VS OMC

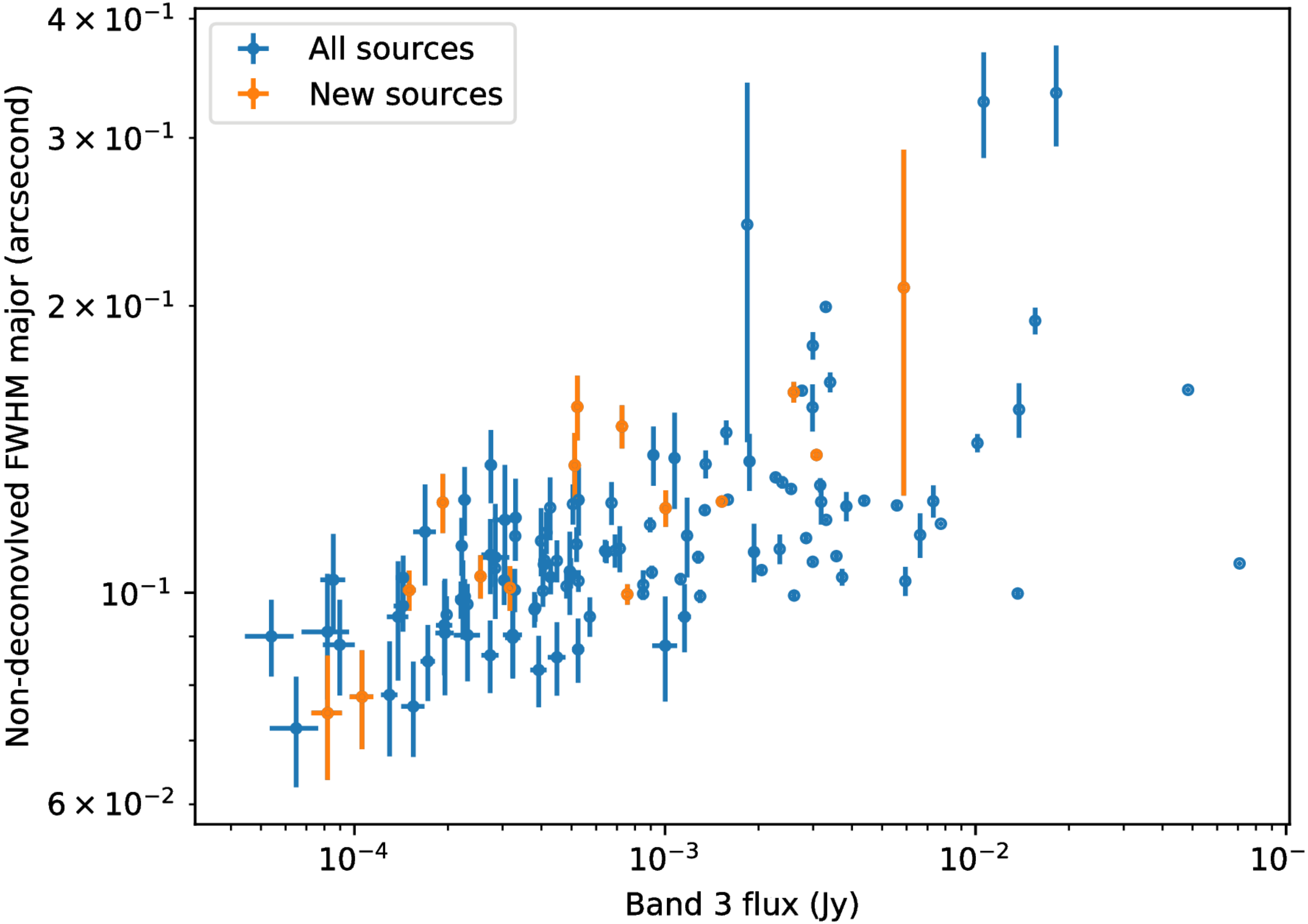


Band-to-band size comparison

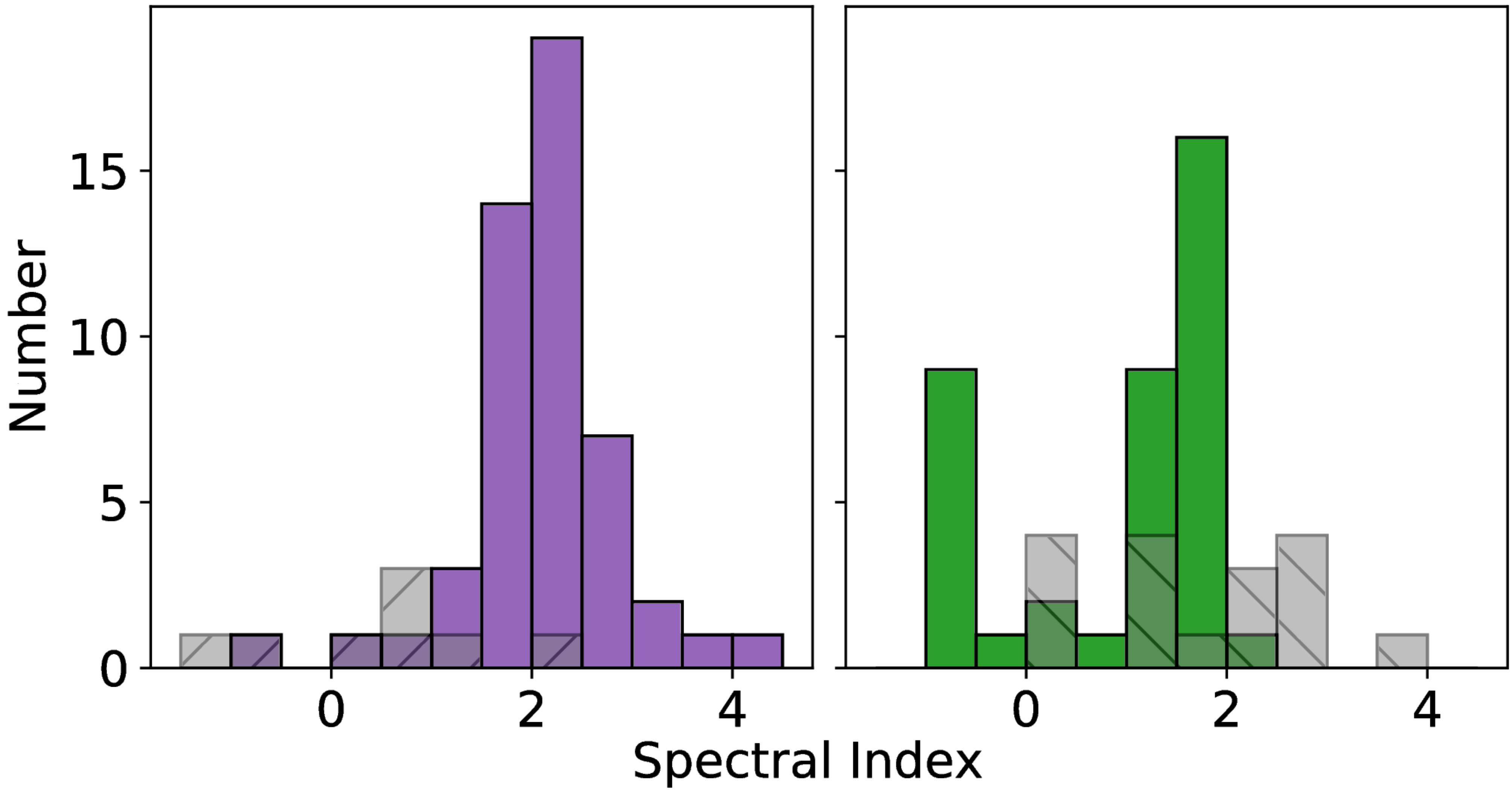


Size vs Flux

The new discoveries aren't all faint

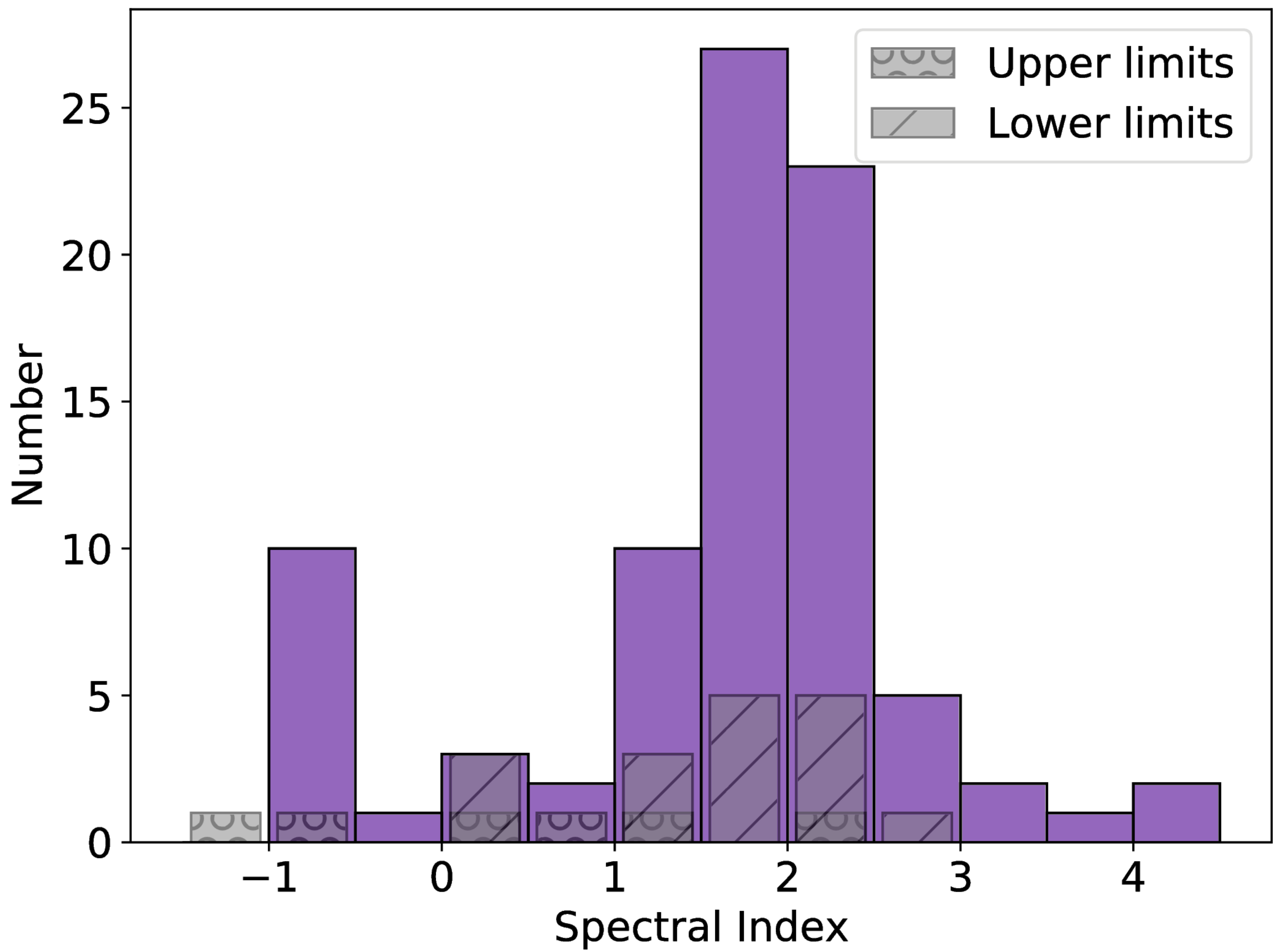


B3-B6 AND B6-B7 SPECTRAL INDICES

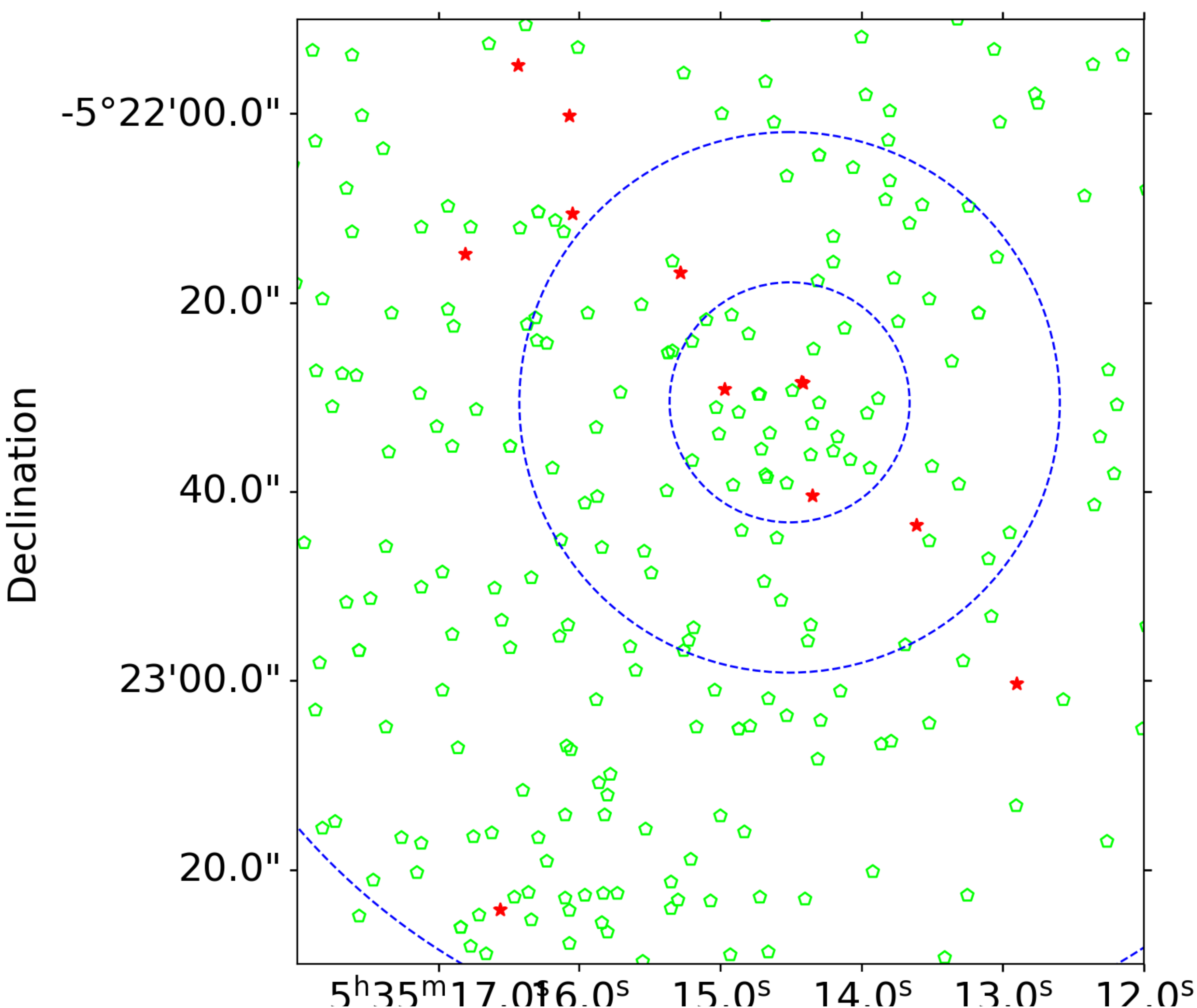


Spectral indices

Grey dashed: upper limits. Grey circles: lower limits

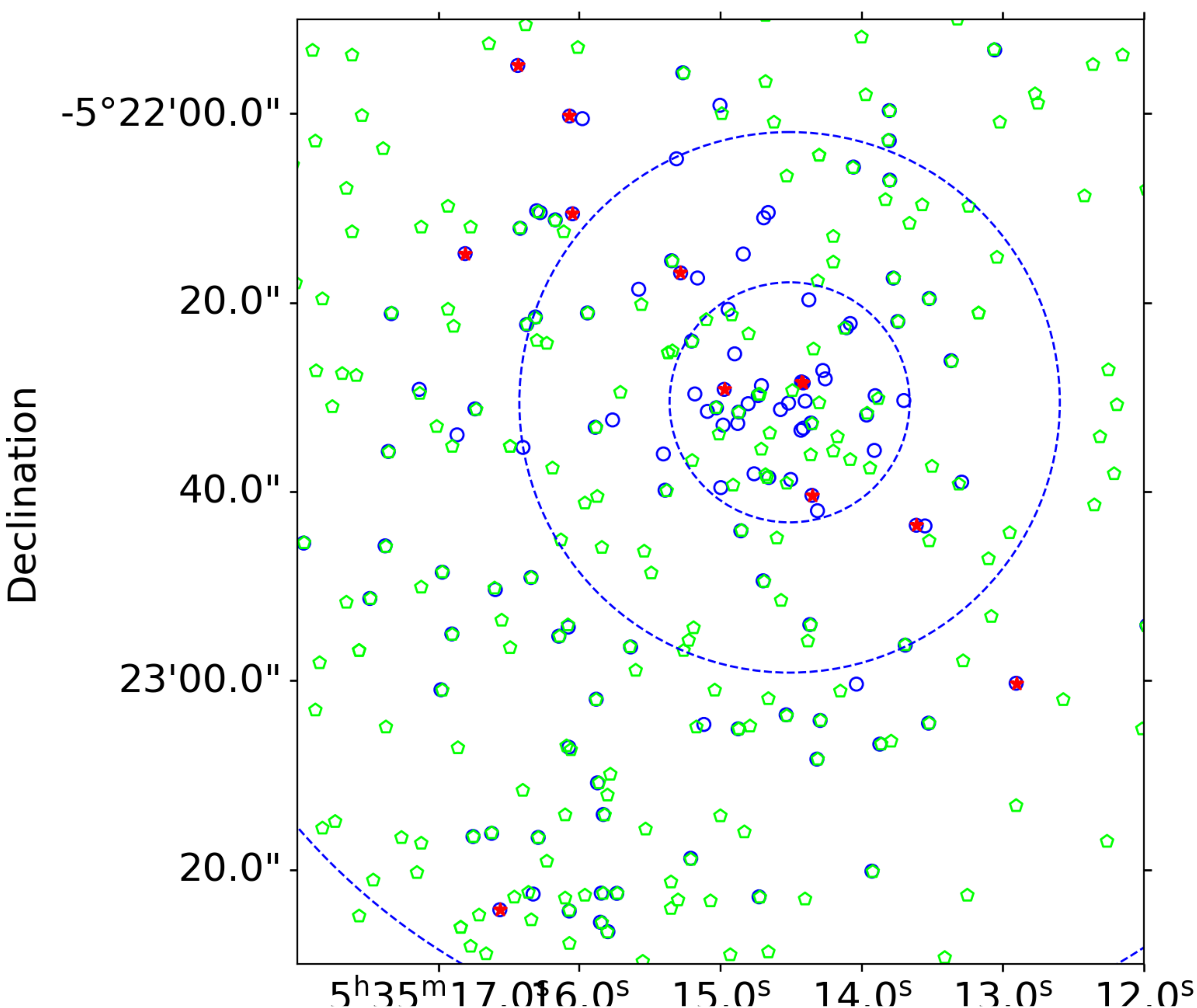


ONC: IR

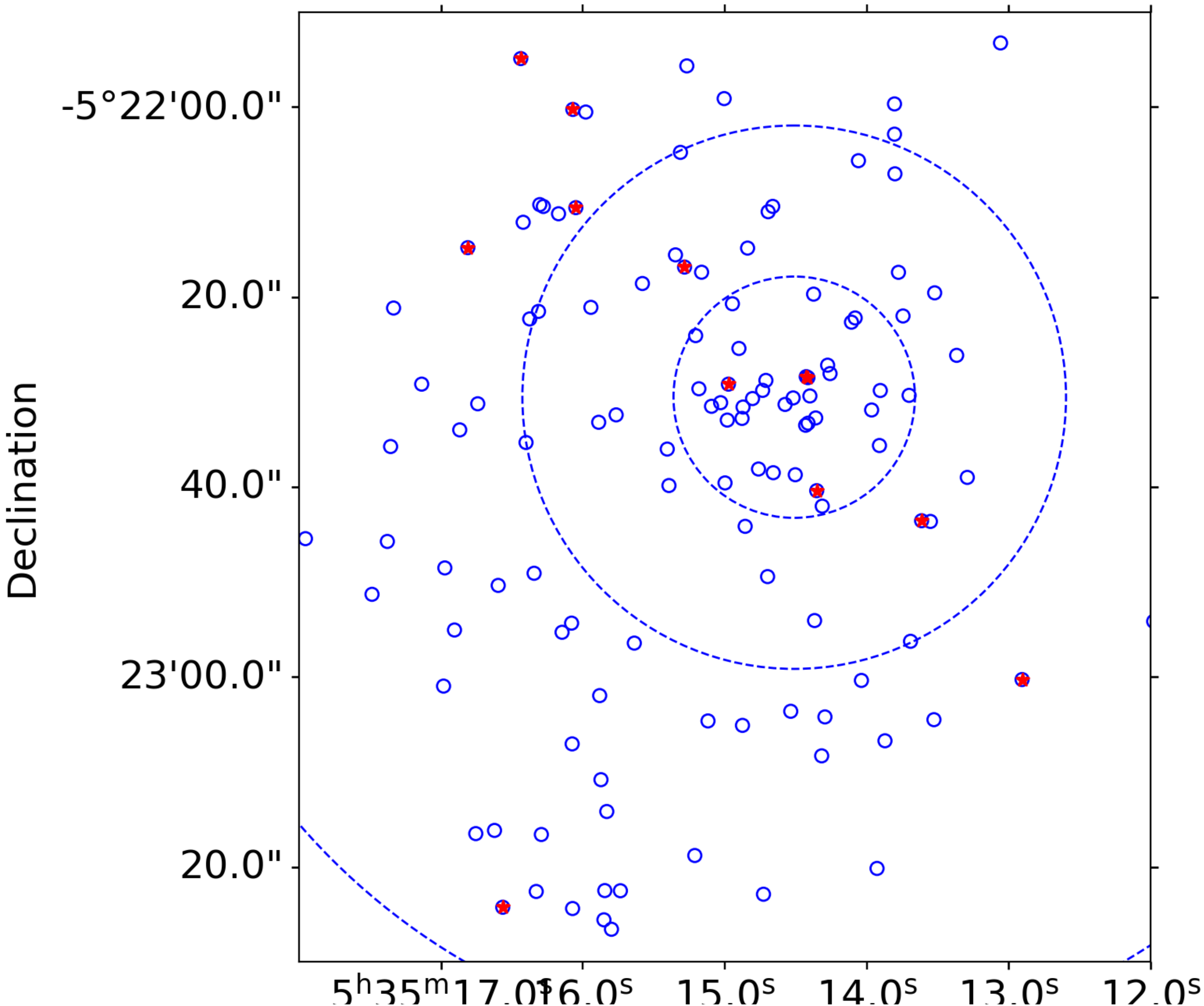


-5°22'00.0"
20.0"
40.0"
23'00.0"
20.0"
Declination
5h35m17.0s
16.0s
15.0s
14.0s
13.0s
12.0s

ONC+OMC: IR+mm


-5°22'00.0"
20.0"
40.0"
23'00.0"
20.0"
Declination
5h35m17.0s
16.0s
15.0s
14.0s
13.0s
12.0s

OMC: mm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20.0"
40.0"
23'00.0"
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Declination
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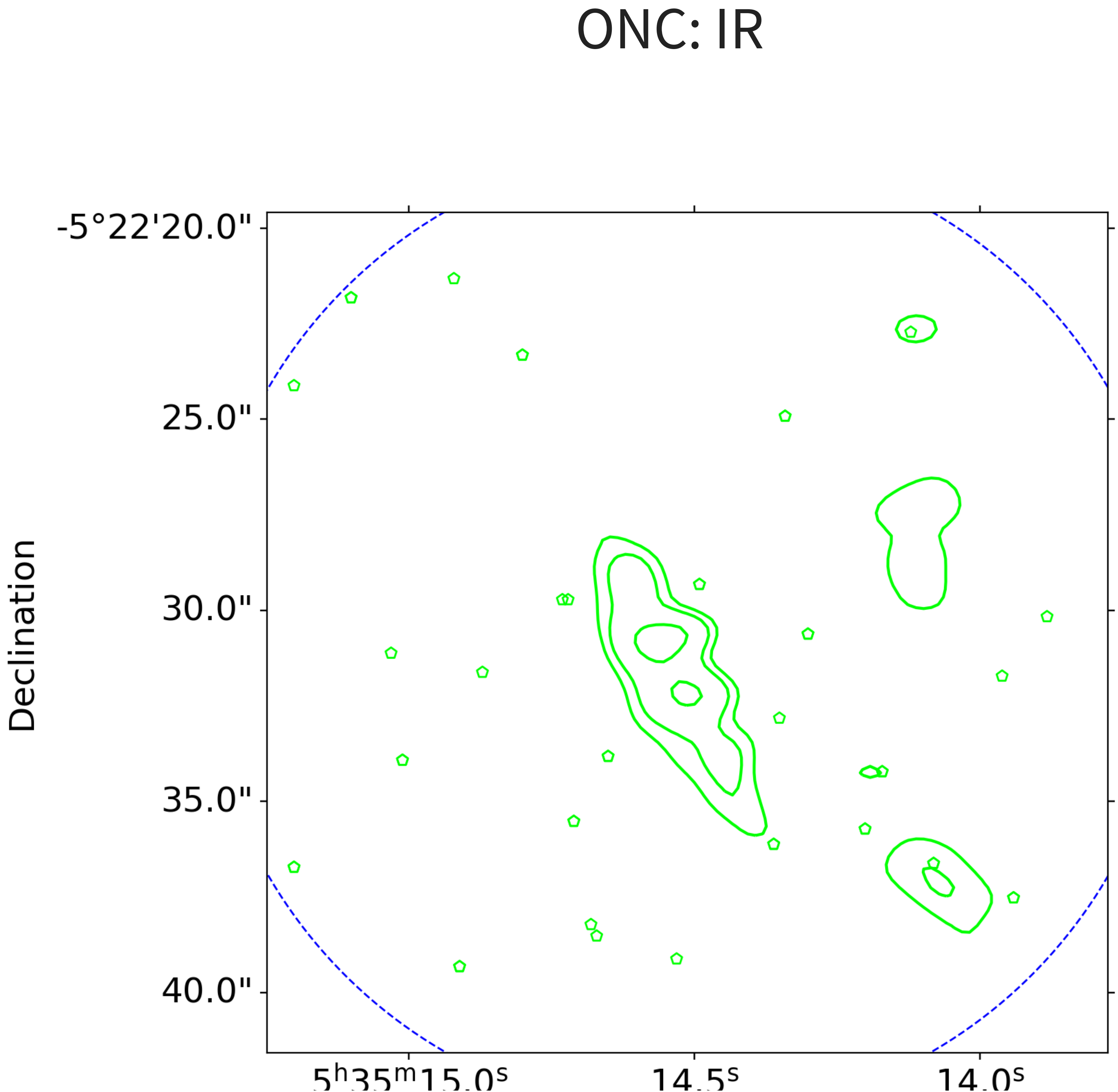
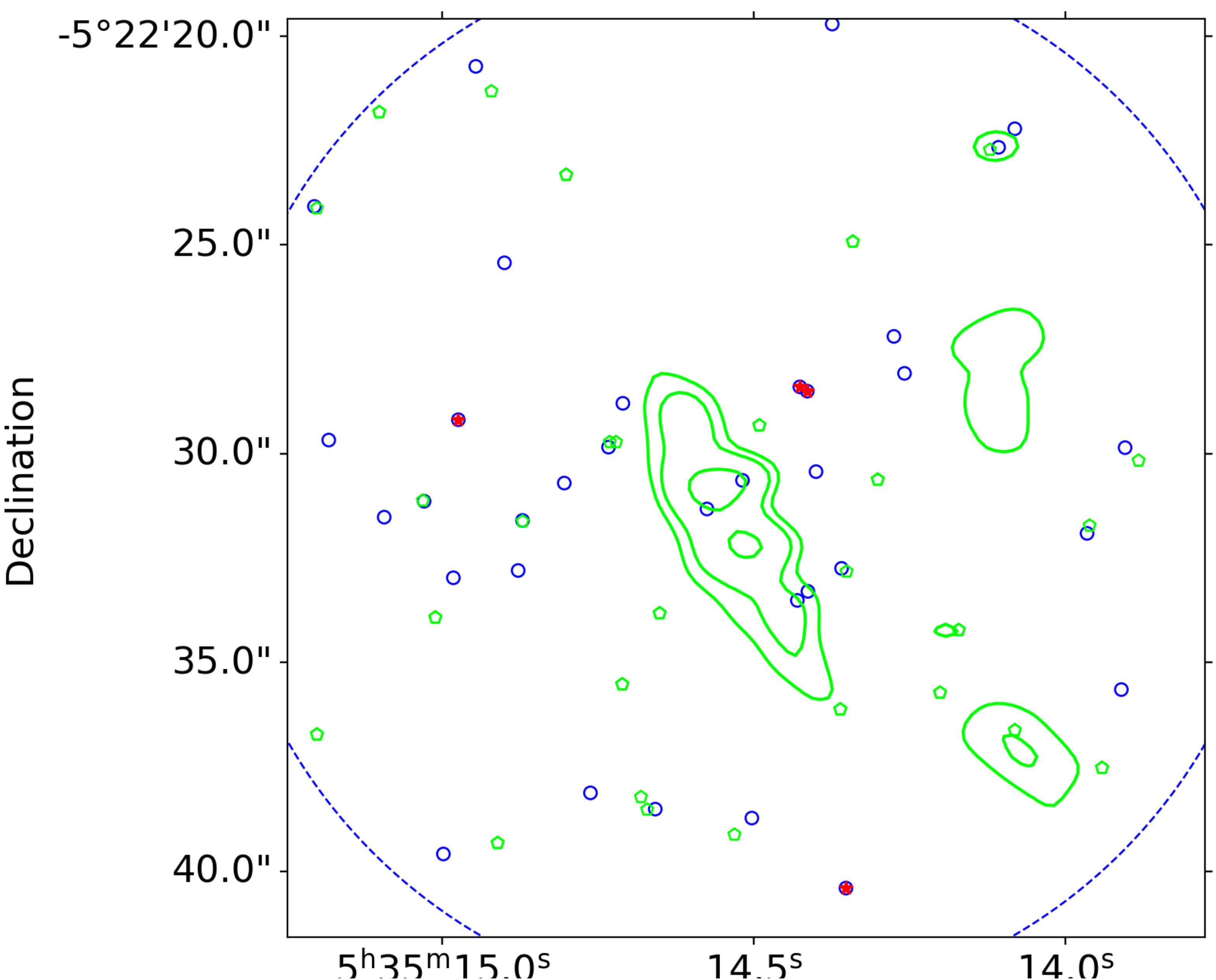
13.0s
12.0s


ONC: IR
Declination
-5°22'20.0"
25.0"
30.0"
35.0"
40.0"
5h35m15.0s
14.5s
14.0s

OMC: IR+mm



OMC: mm