

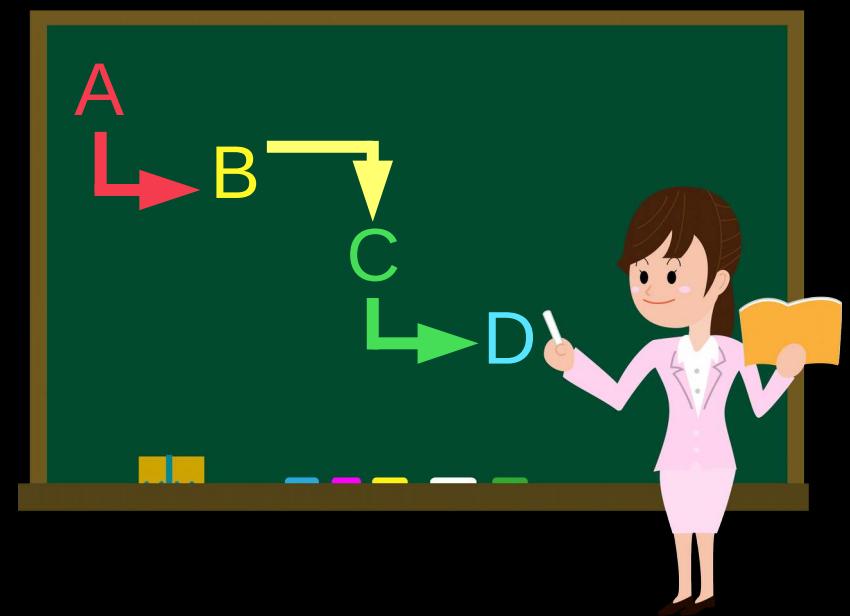
Dancing Clusters: Quantitatively Tracing Spatial Evolution and the Morphological Features of YMCs

Anne Buckner (University of Leeds)
& the SFM Collaboration



Talk Outline

- ◆ Stellar substructure & association
- ◆ INDICATE
- ◆ NGC 3372
- ◆ Westerlund 1



Stellar Substructure & Association

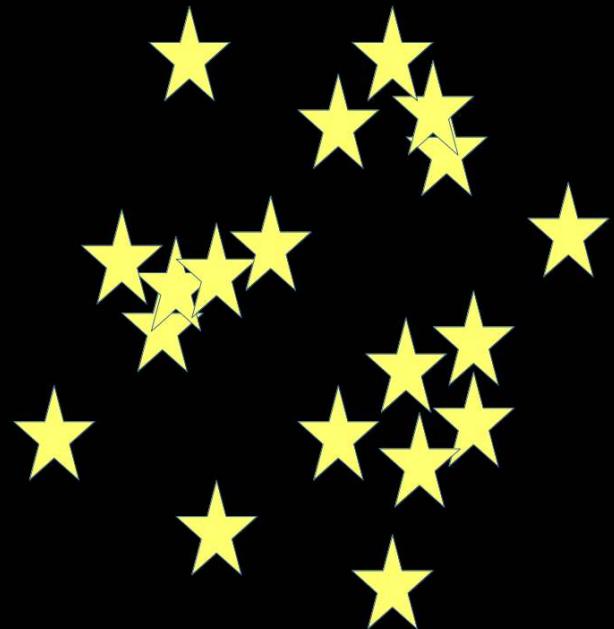
- Discriminate between different modes of Massive SF
- Observational challenges:
 - Incomplete catalogues (particularly low mass)
 - Lack 6-parameter astrometric solution

Stellar “Substructure”



Stellar “Substructure”

- Discrete star groupings



Stellar “Substructure”

- Discrete star groupings



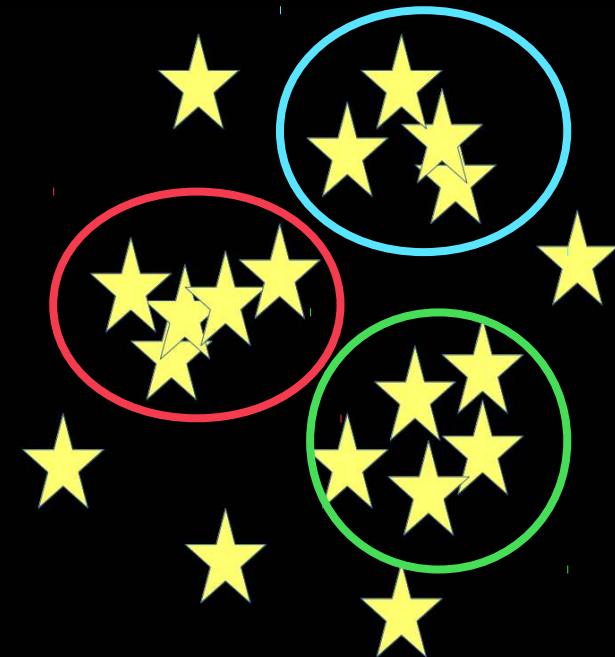
Stellar “Substructure”

- Discrete star groupings
- Find using clustering algorithms
(k-means, DBSCAN, OPTICS etc.)



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**Q. Where are - and what stars
are in- clusters?**

Stellar “Association”

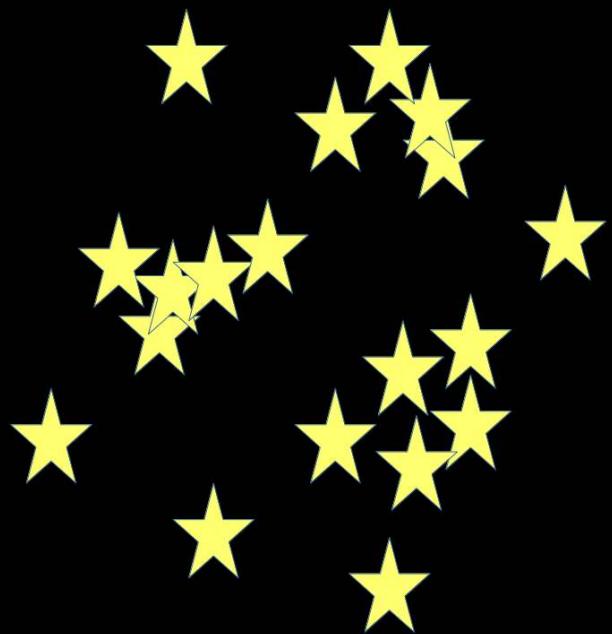
- Point processes
 - intensity
 - correlation
 - spatial distribution

Stellar “Association”

- Point processes
 - intensity
 - correlation
 - spatial distribution

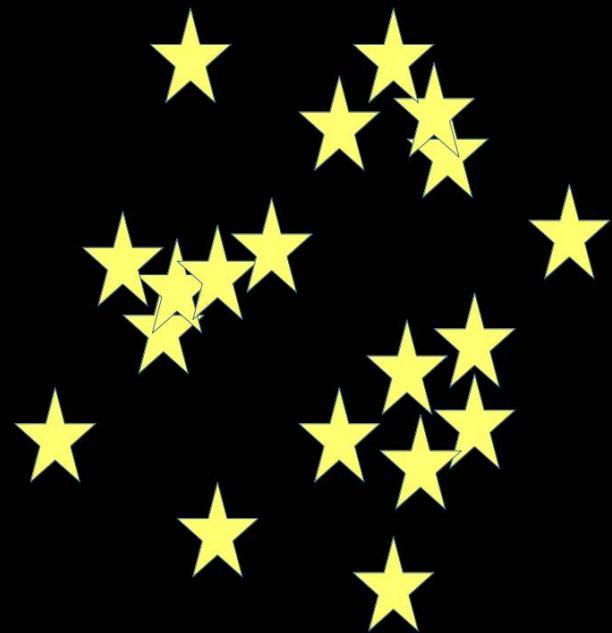
Q. How “clustered” are stars?

Stellar “Association”



Stellar “Association”

- Global measures



Stellar “Association”

- Global measures



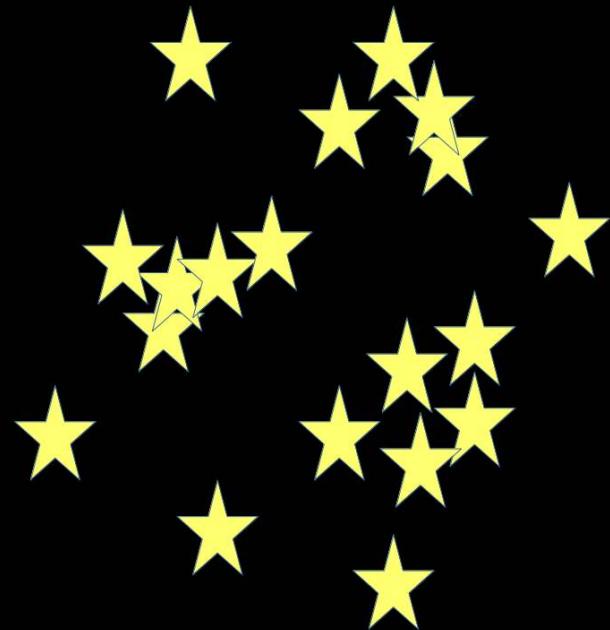
Stellar “Association”

- Global measures
 - 2-point correlation function
 - Hopkins Statistic



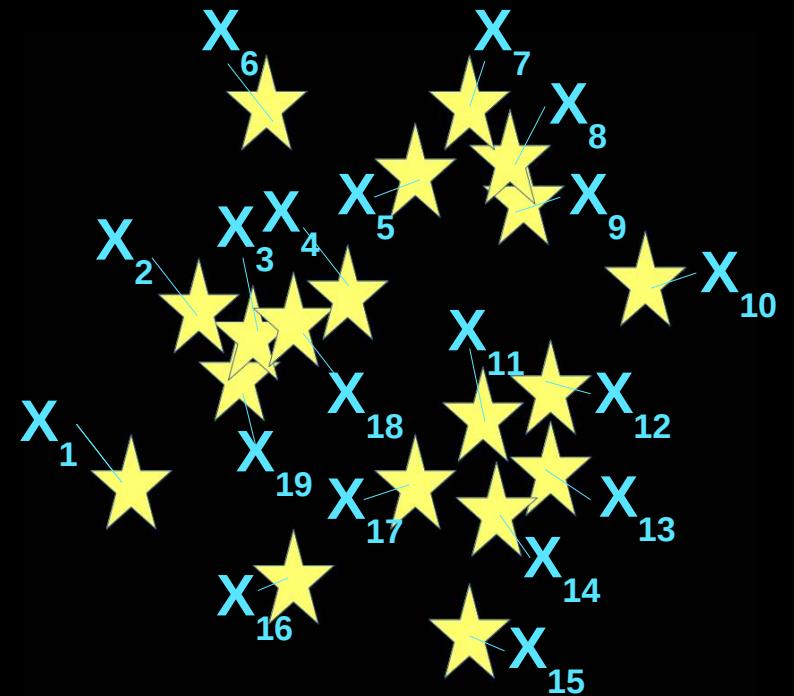
Stellar “Association”

- Global measures
 - 2-point correlation function
 - Hopkins Statistic
- Local measures



Stellar “Association”

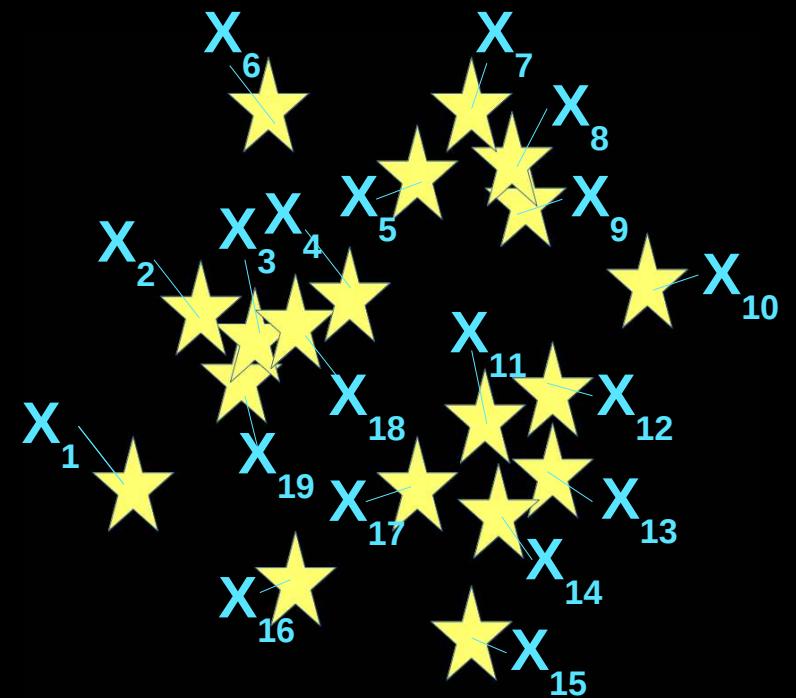
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Stellar “Association”

- Global measures
 - 2-point correlation function
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INDICATE

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- Local measure of degree of stellar association
- Any parameter space
- 2+D

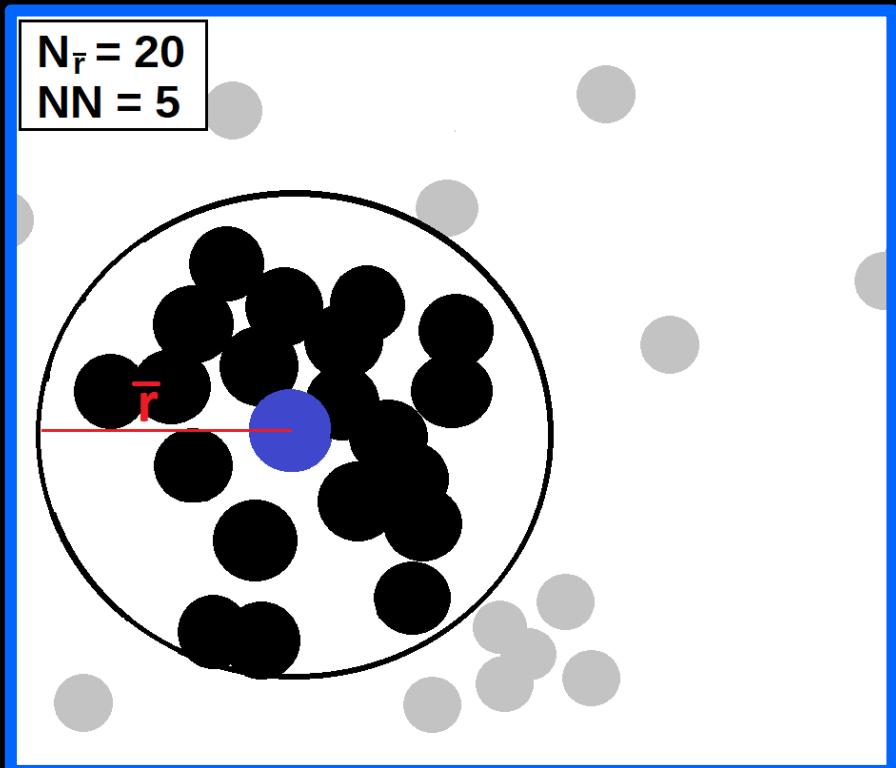
INDICATE

- Local measure of degree of stellar association
- Any parameter space
- 2+D
- Assigns a clustering index to each star
- Comparison of number of nearest neighbours with an evenly spaced control field

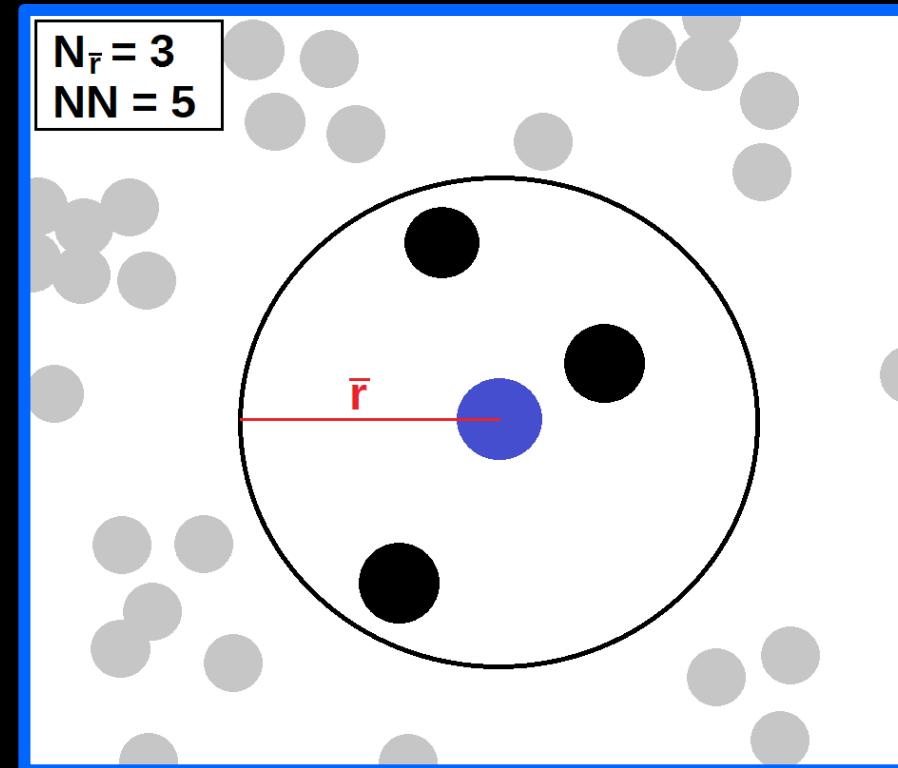
INDICATE

- Local measure of degree of stellar association
- Any parameter space
- 2+D
- Assigns a clustering index to each star
- Comparison of number of nearest neighbours with an evenly spaced control field
- Meaningful index values → calibrated against random distributions

INDICATE



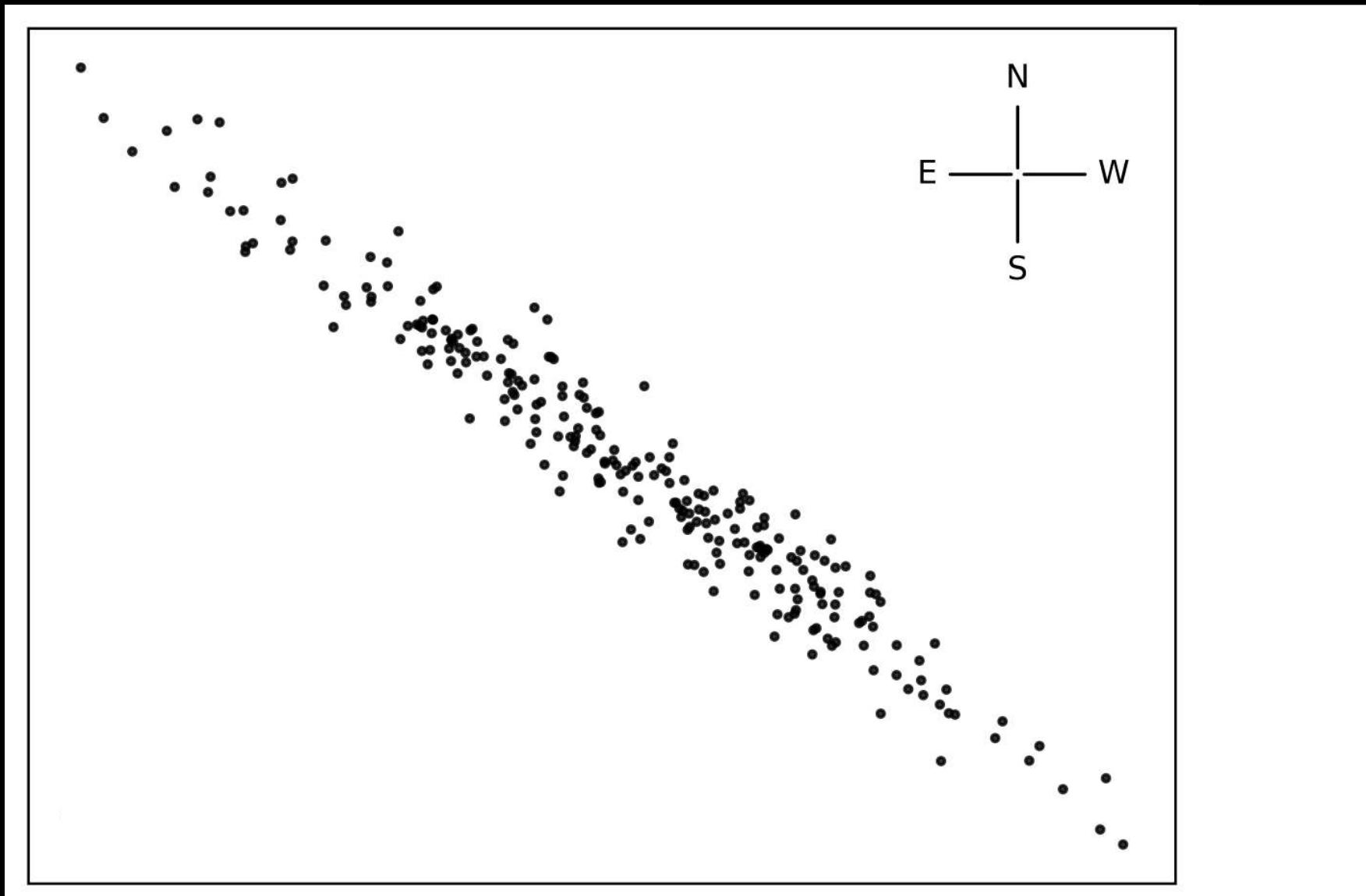
$$I = 20/5 = 4$$



$$I = 3/5 = 0.6$$

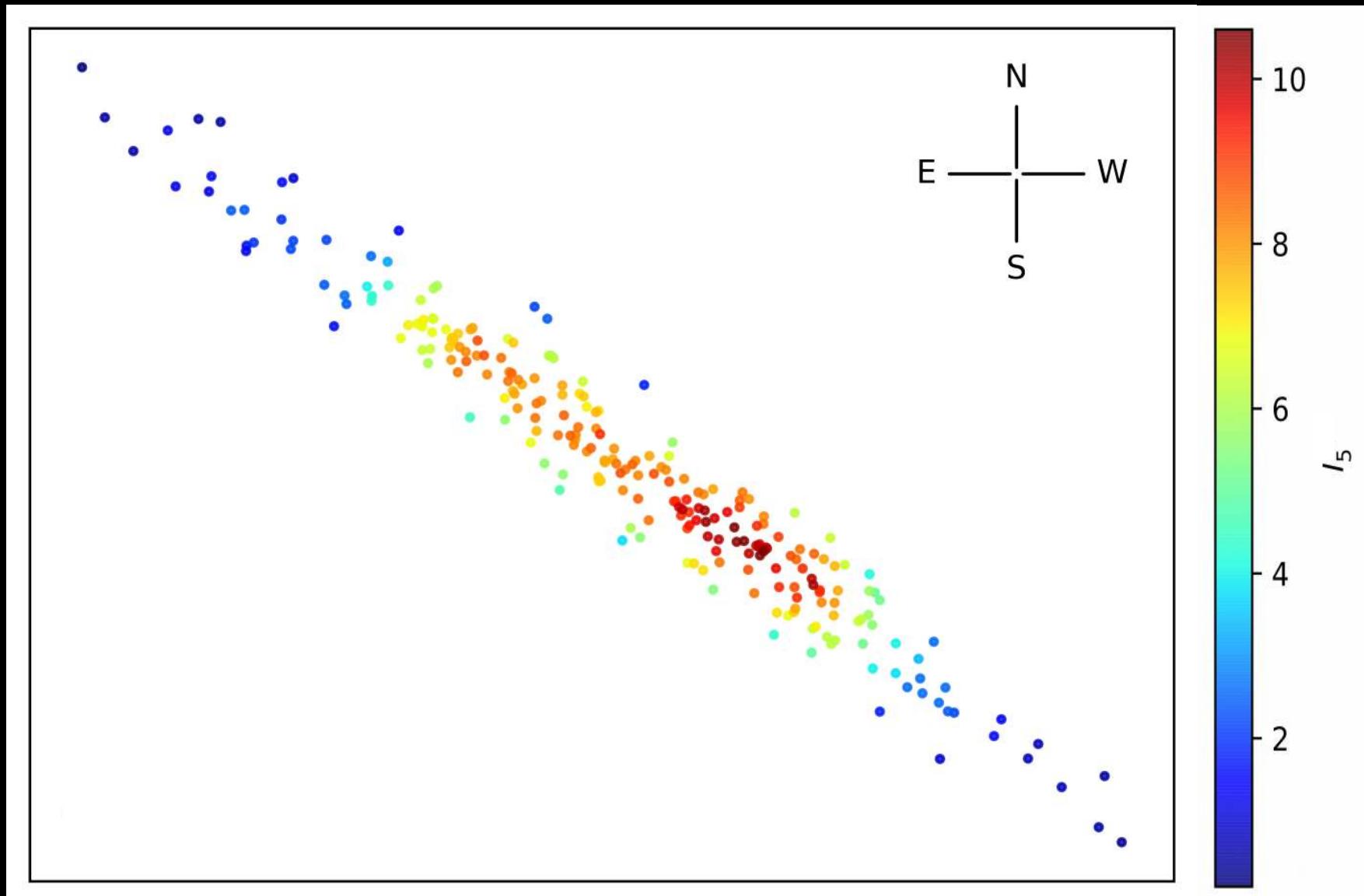
INDICATE

Example



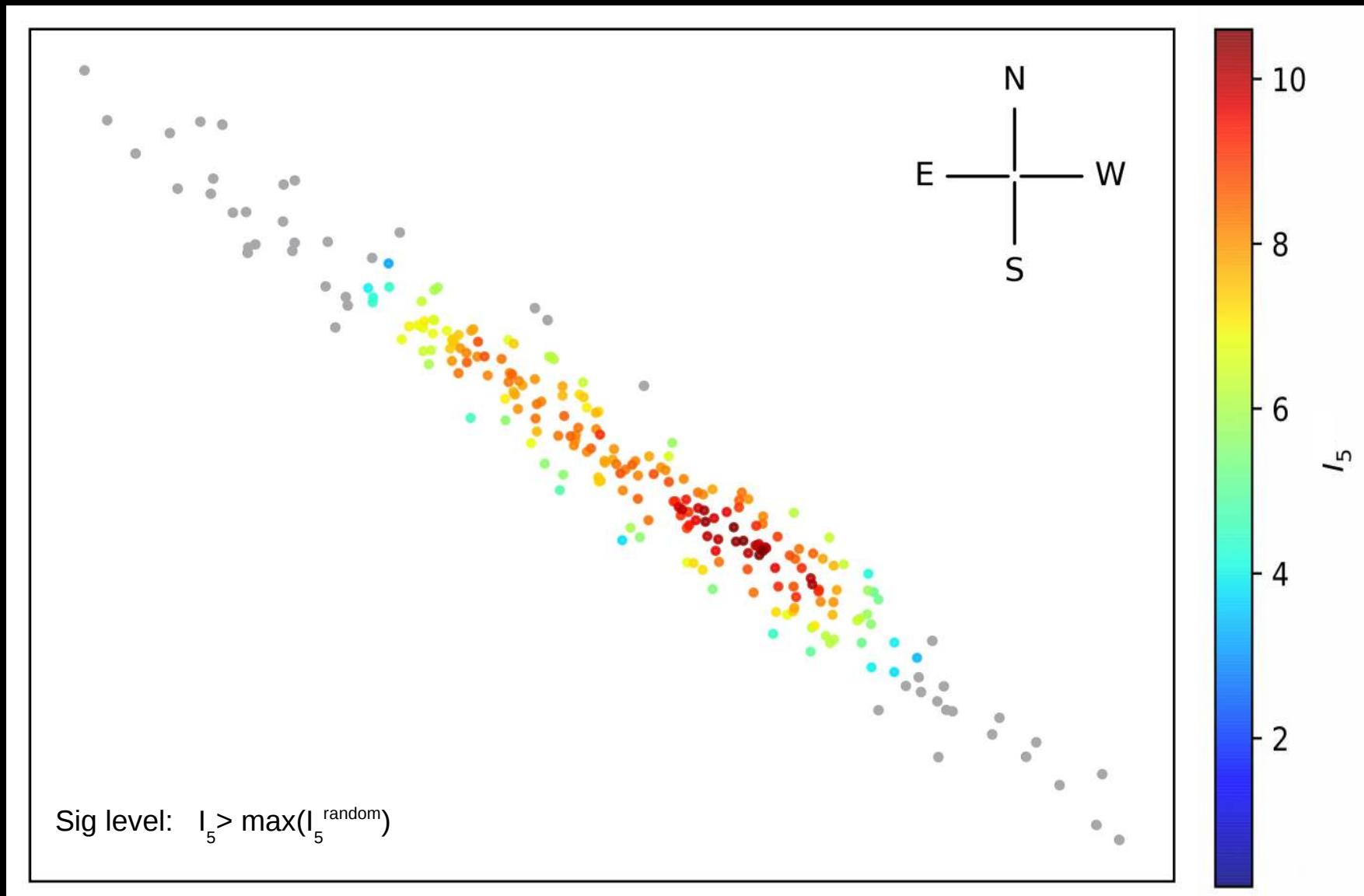
INDICATE

Example



INDICATE

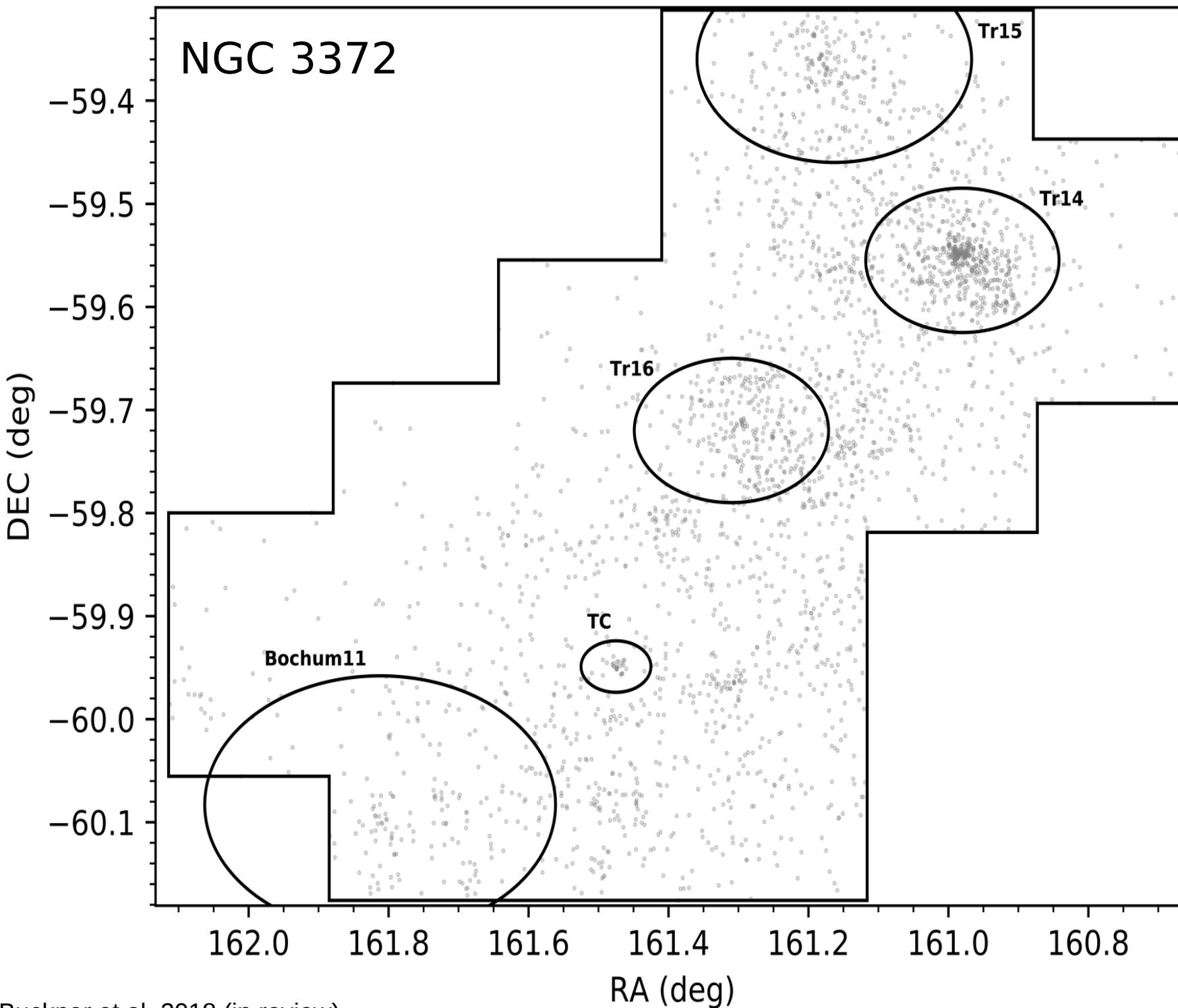
Example

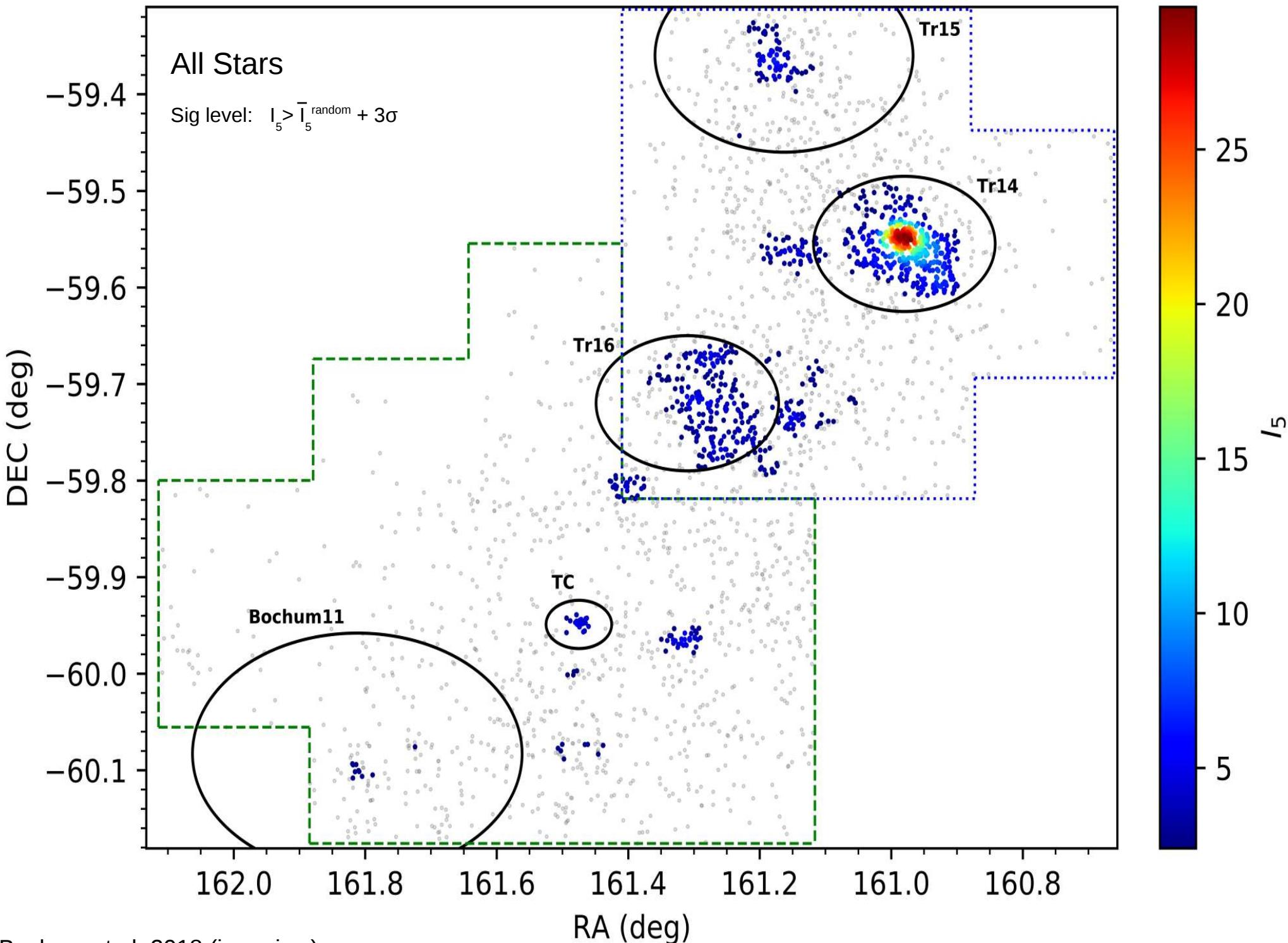


Lets apply to some
star forming regions

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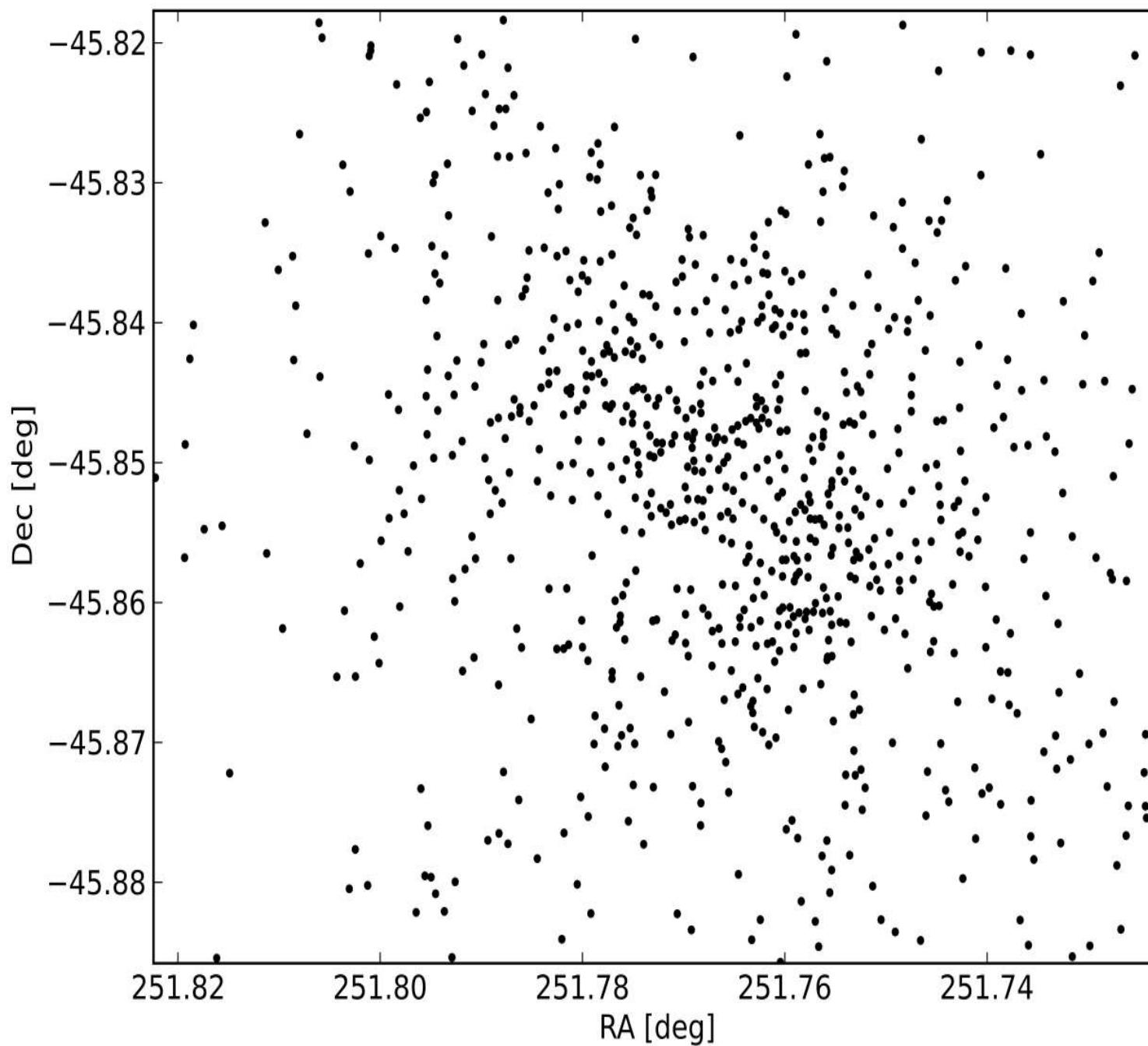


Westerlund 1

Age ~ 5 Myr
 $A_v \sim 10\text{-}12$ mag
 $D \sim 4$ kpc
~2 pc across
 $M \sim 10^5 M_\odot$

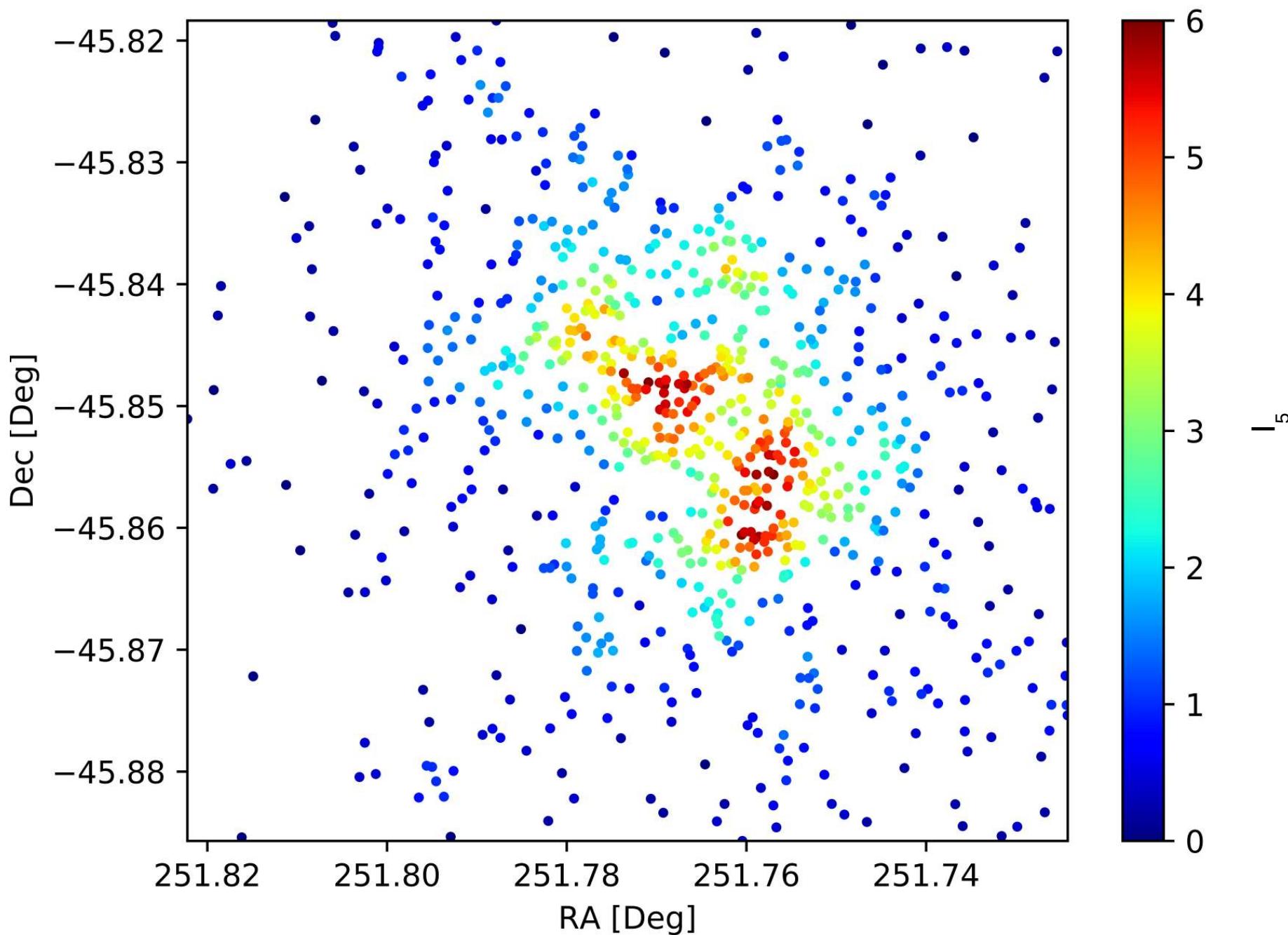
NIR $M_* > 5M_\odot$

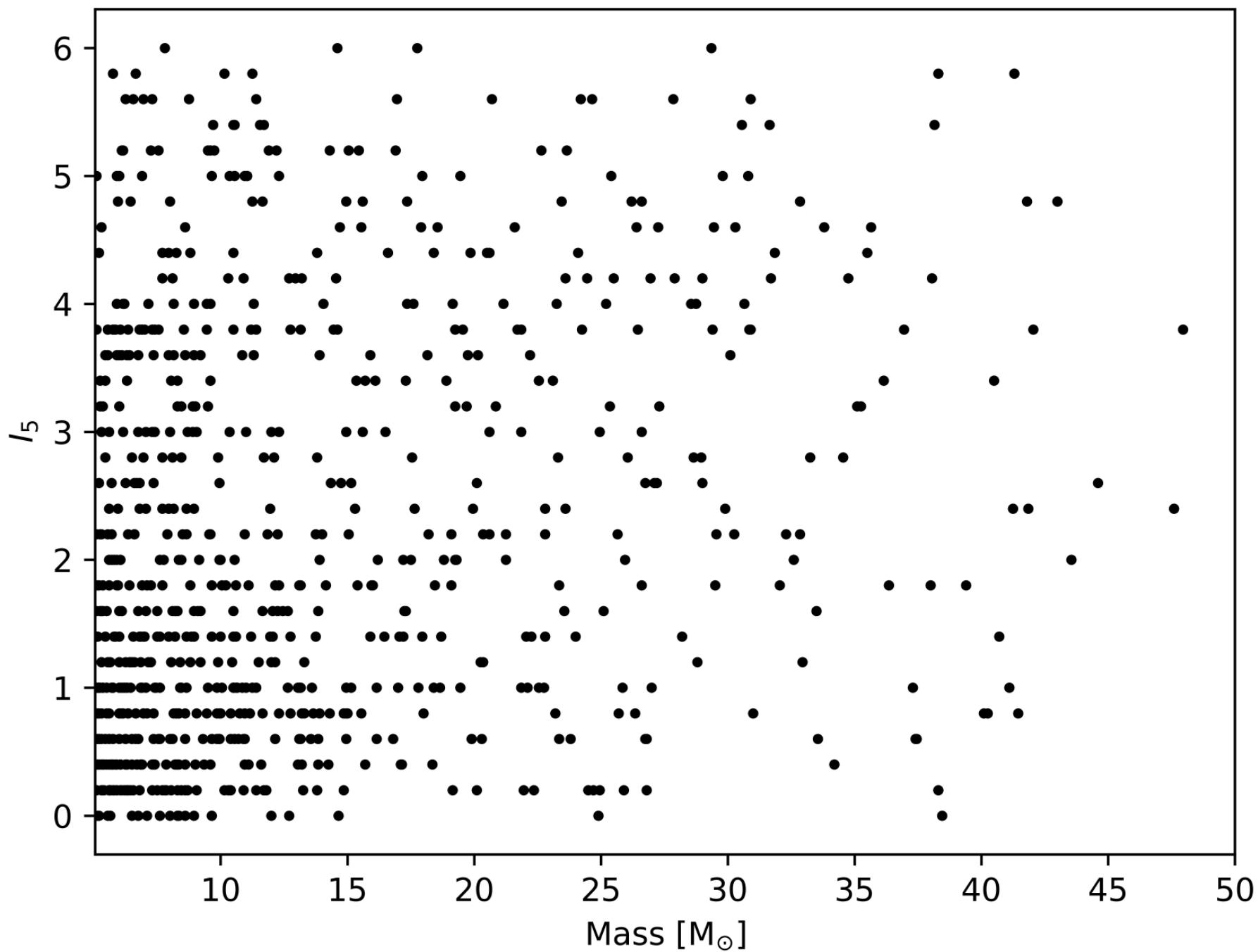
Gennaro et al. (2017)



NIR $M_* > 5M_\odot$

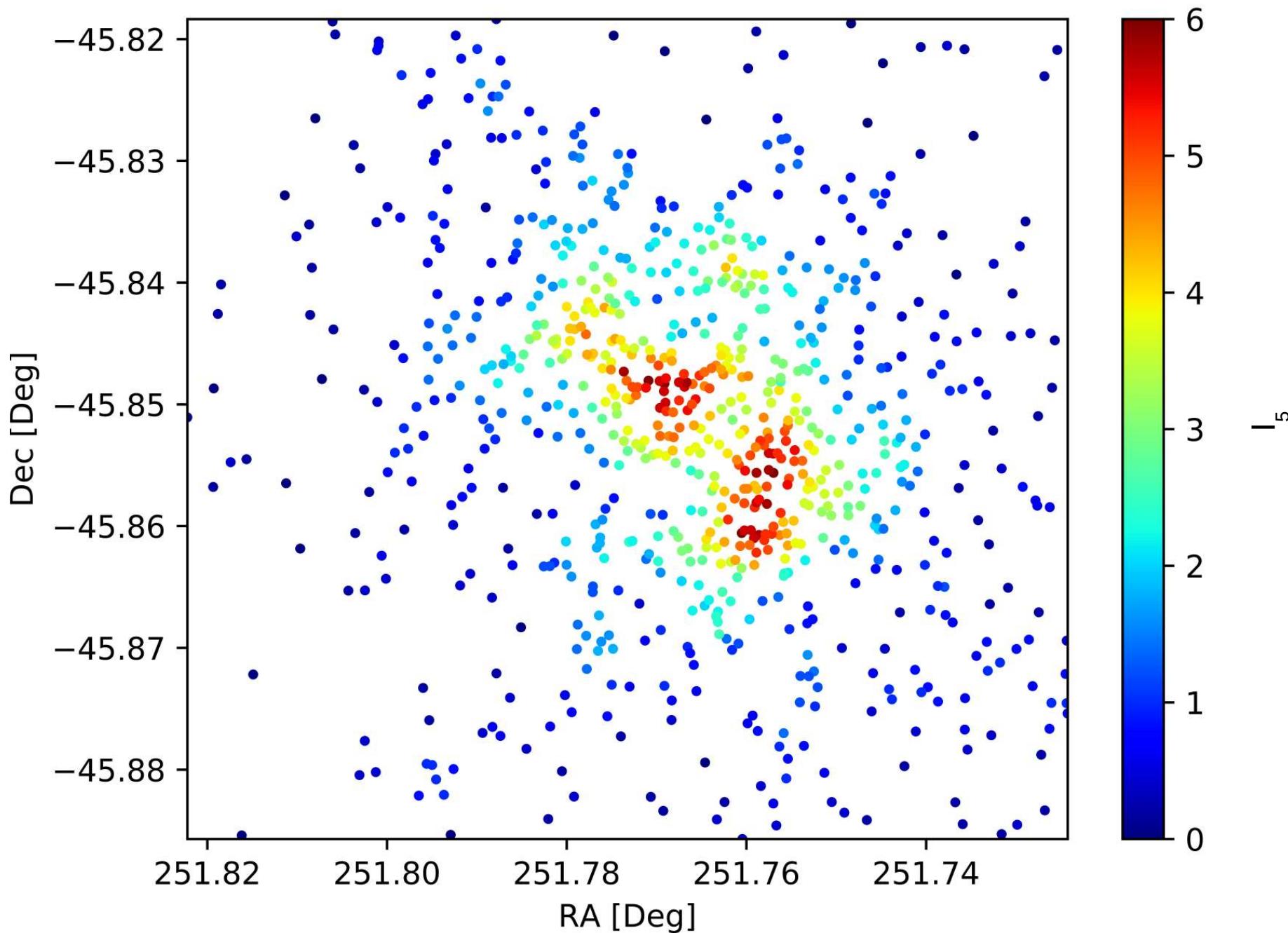
Buckner et al. (2018, in prep)





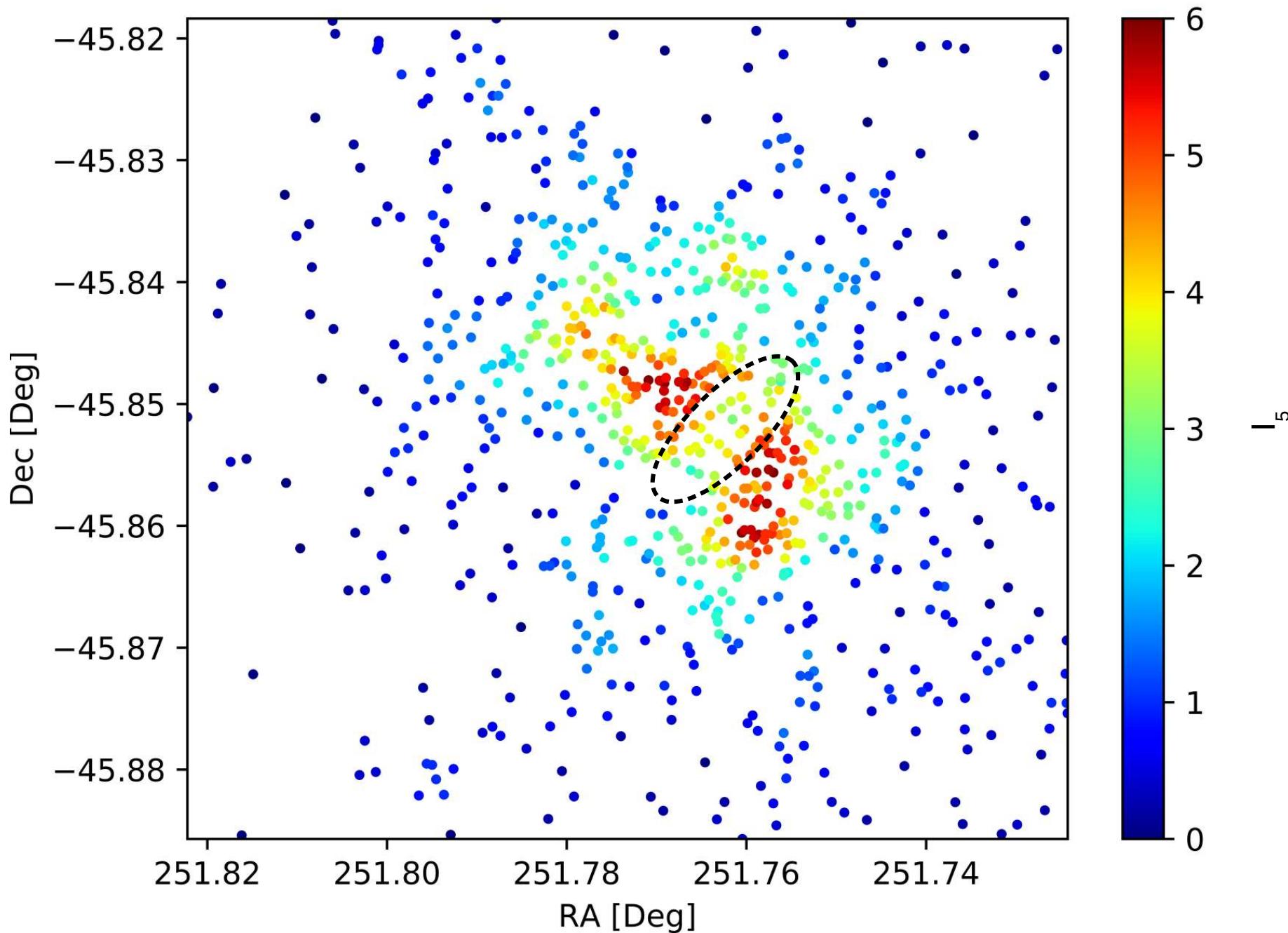
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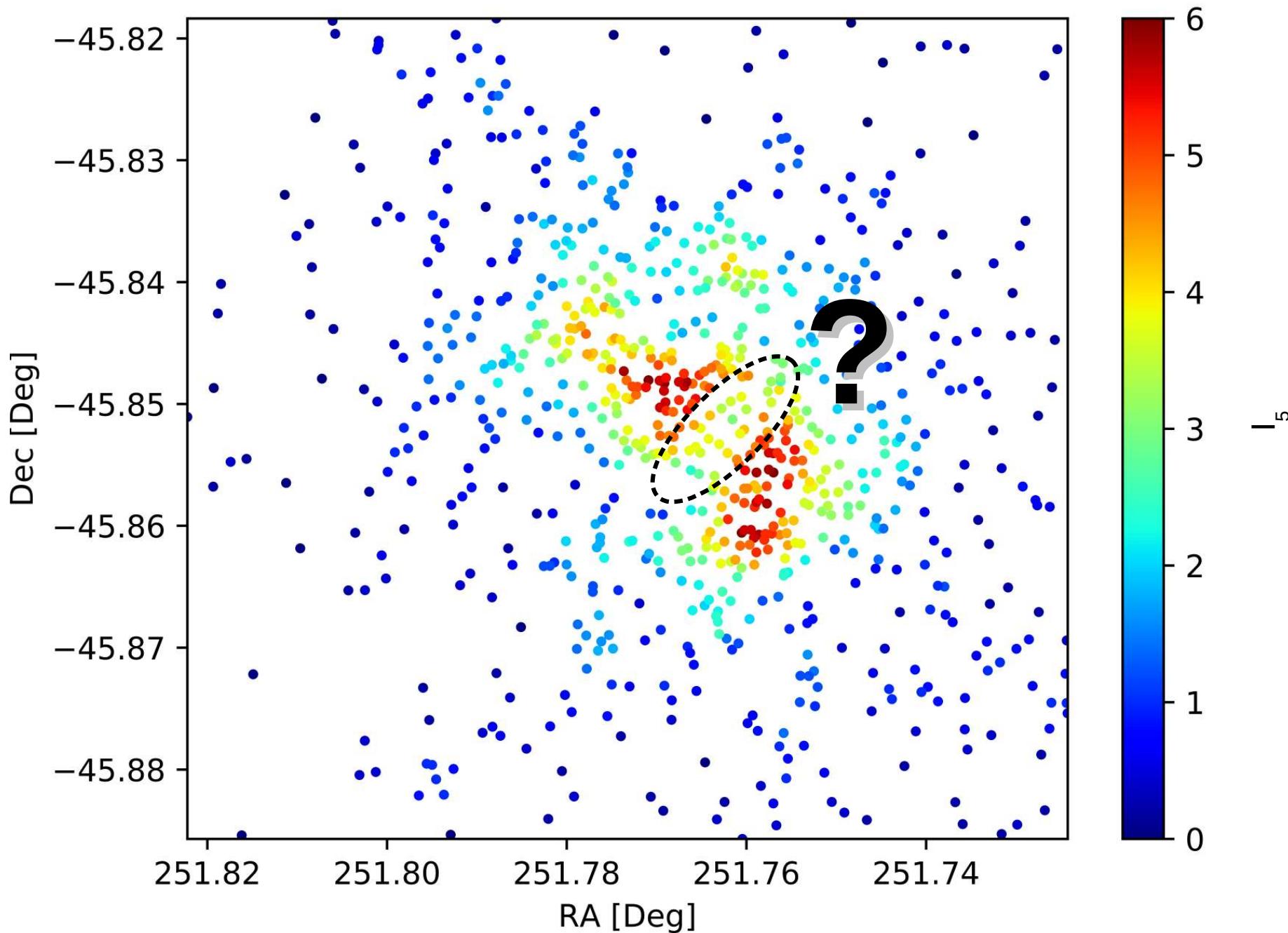
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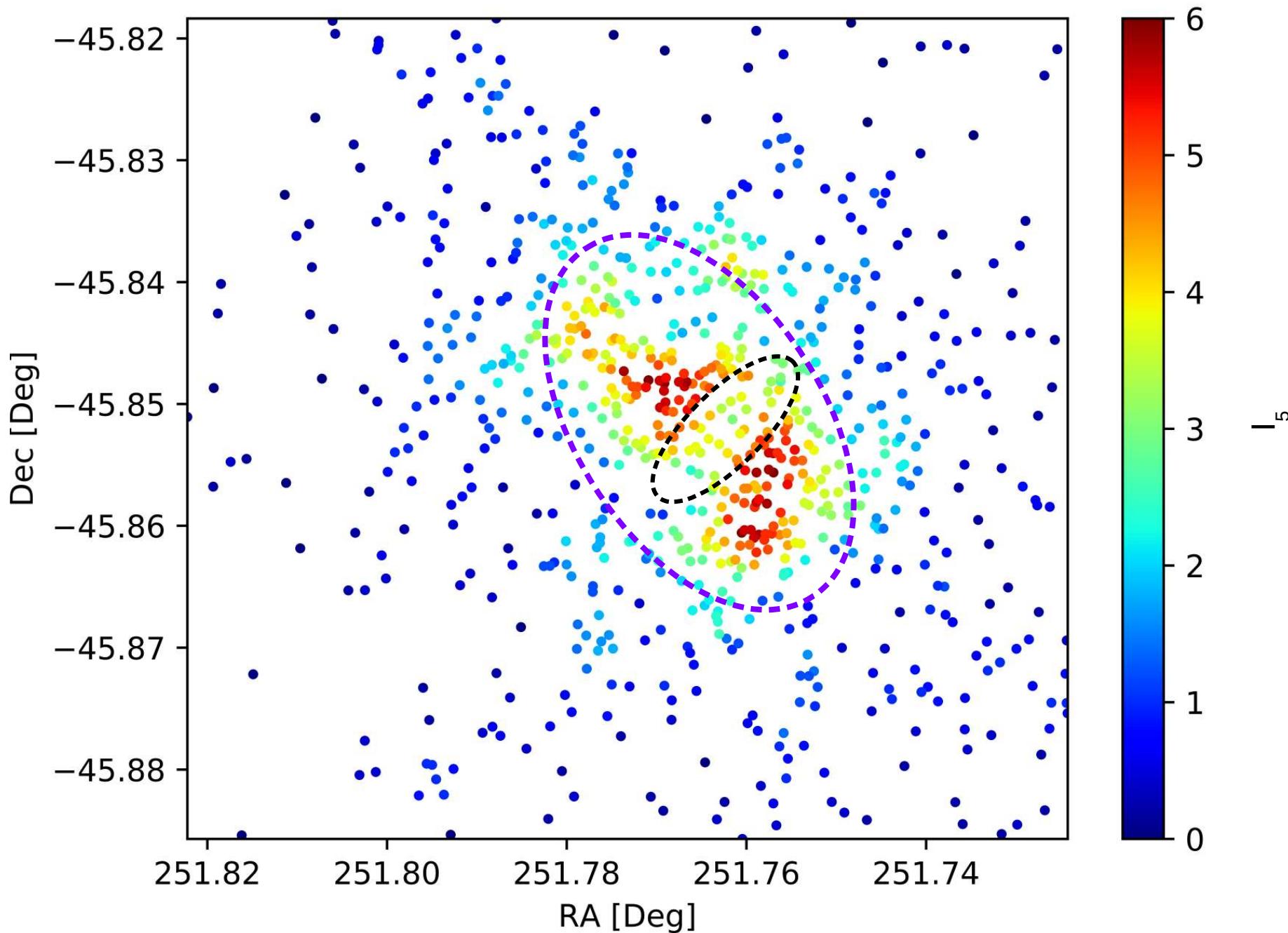
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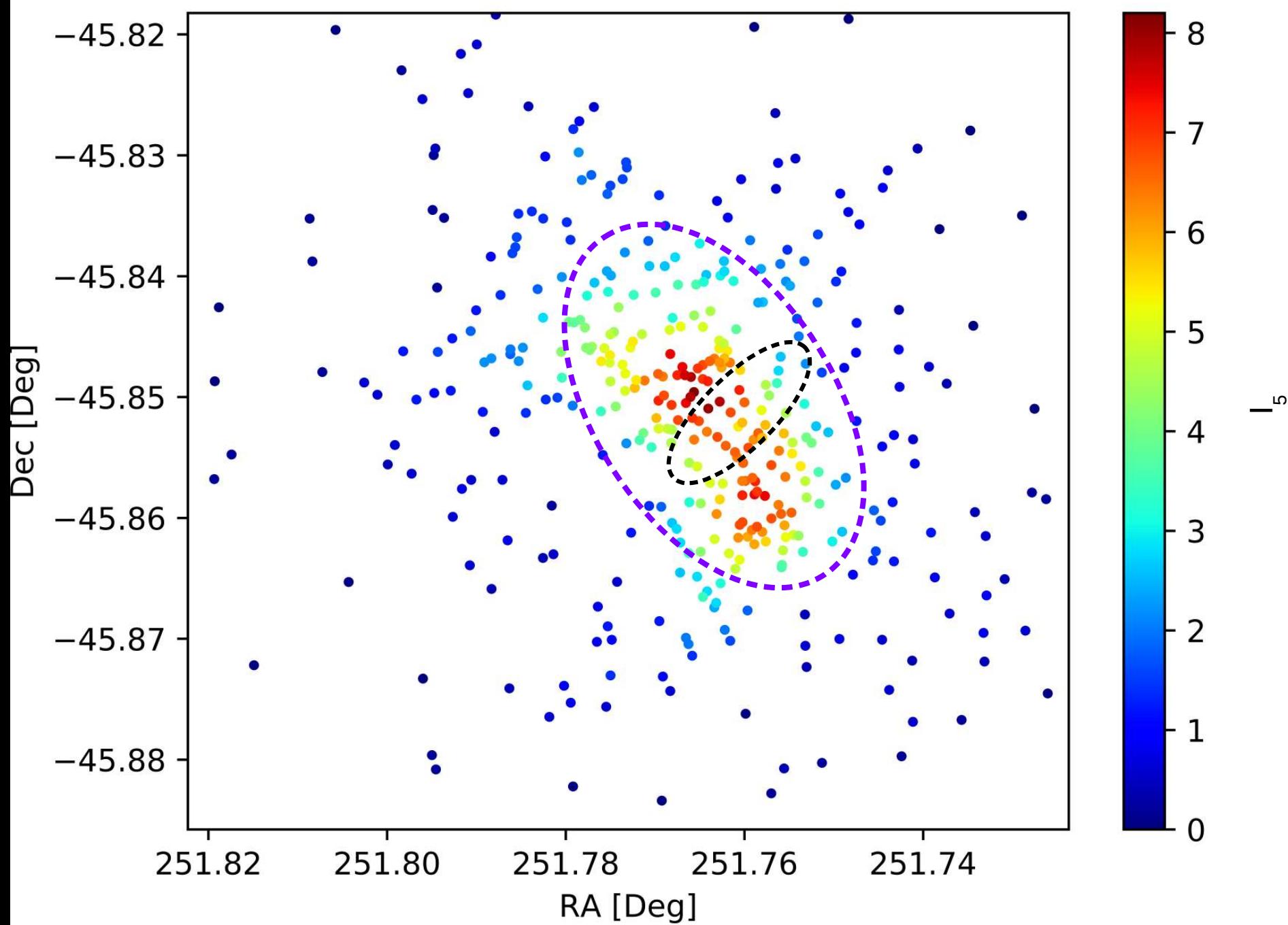
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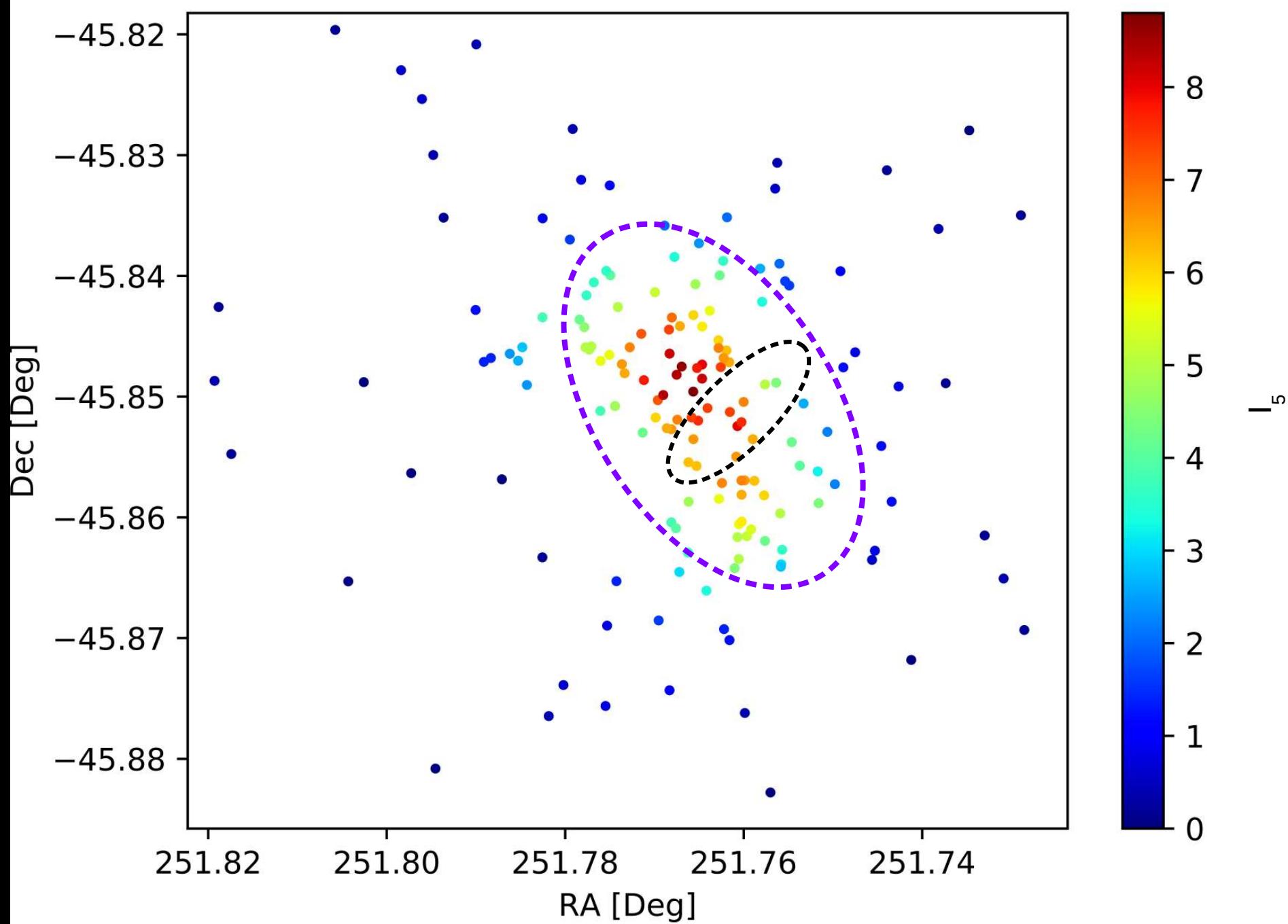
NIR $M_* > 10M_\odot$

Buckner et al. (2018, in prep)



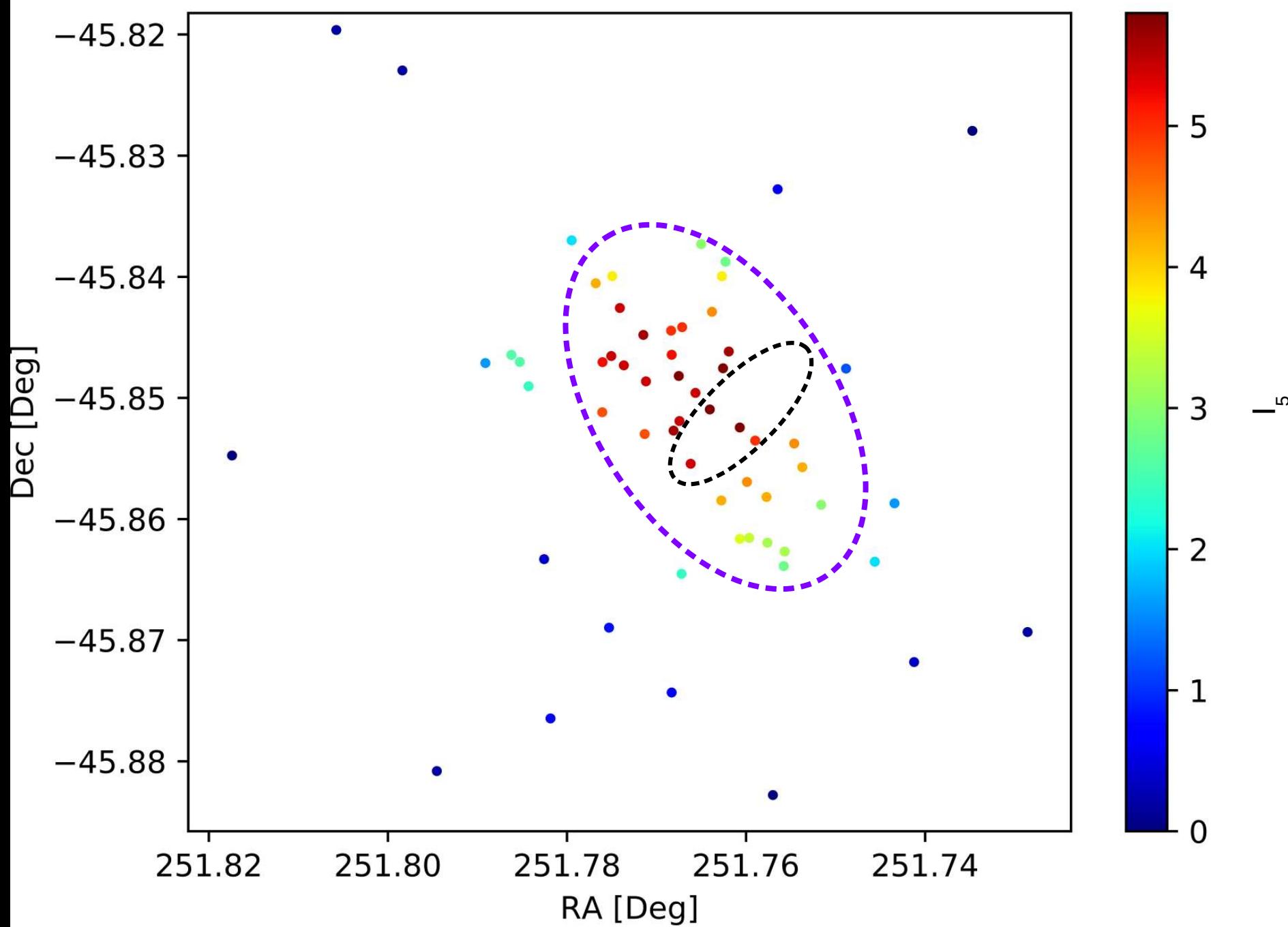
NIR $M_* > 20M_\odot$

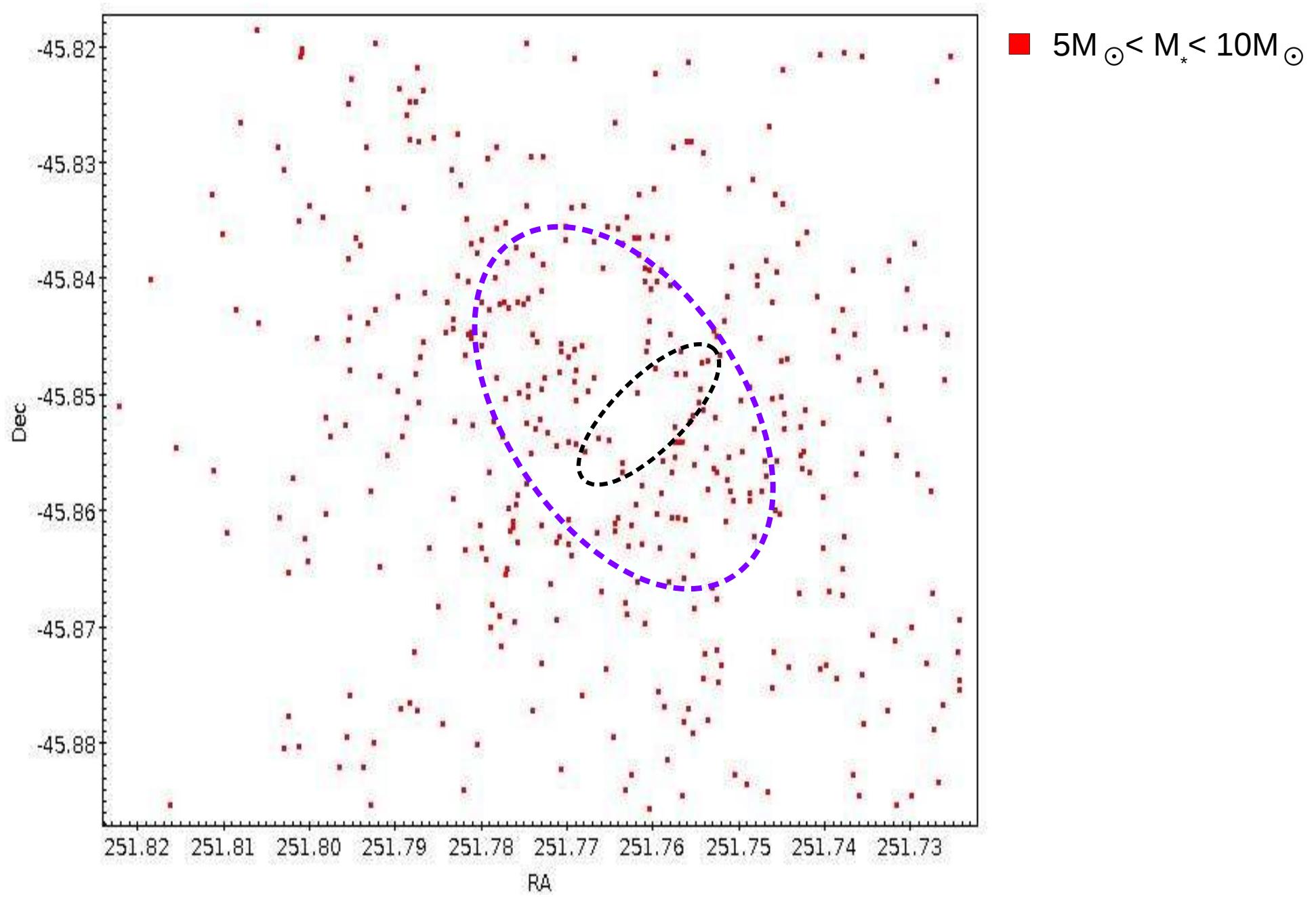
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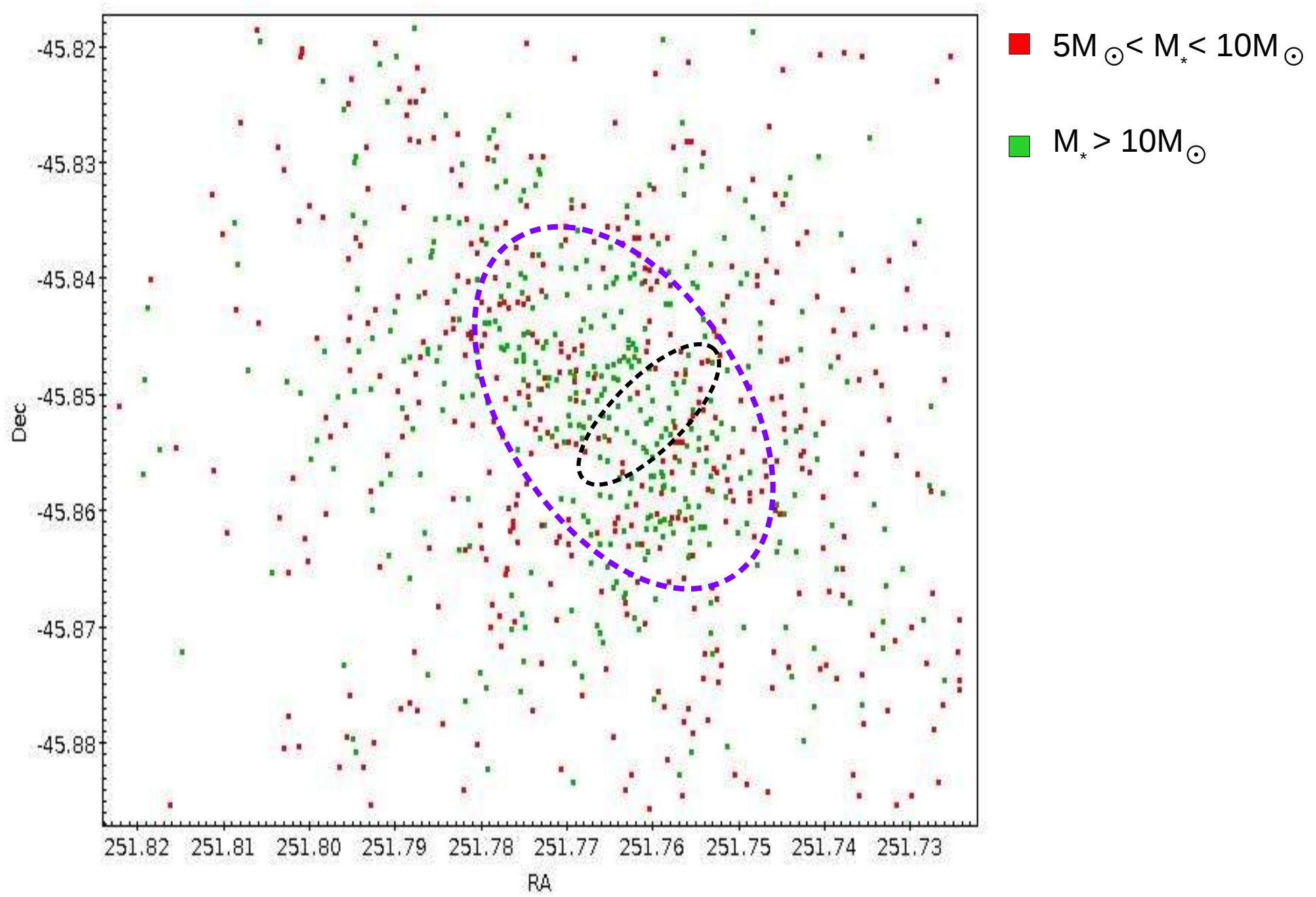


NIR $M_* > 30M_\odot$

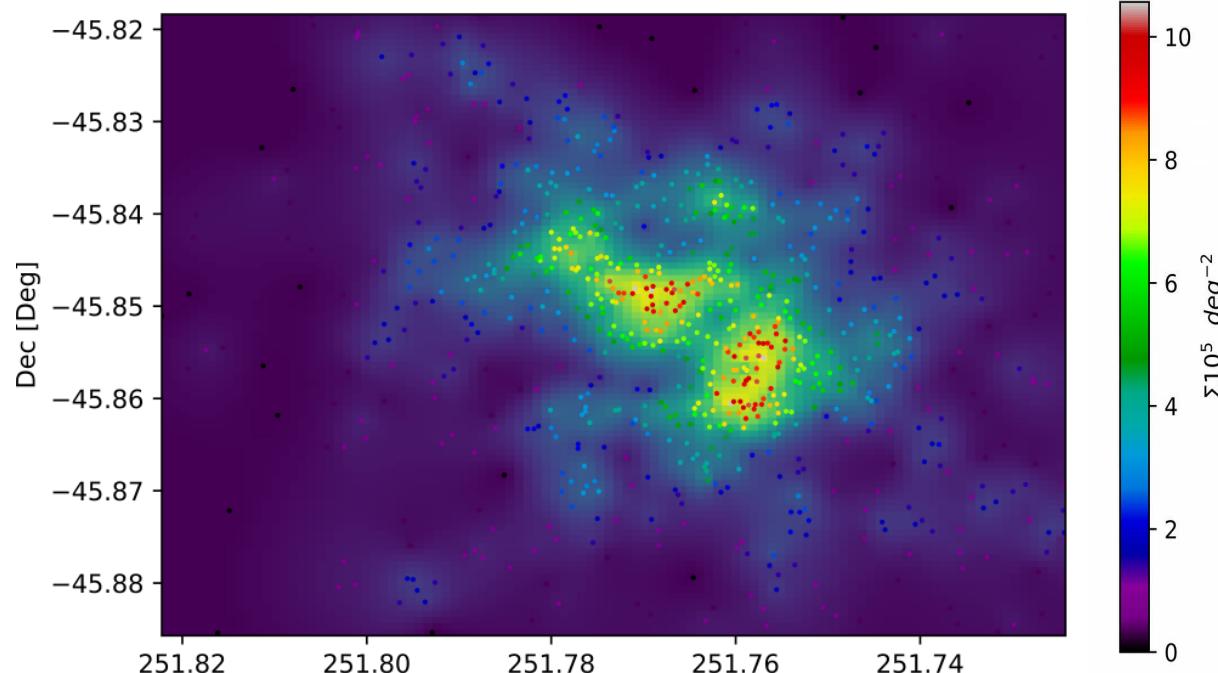
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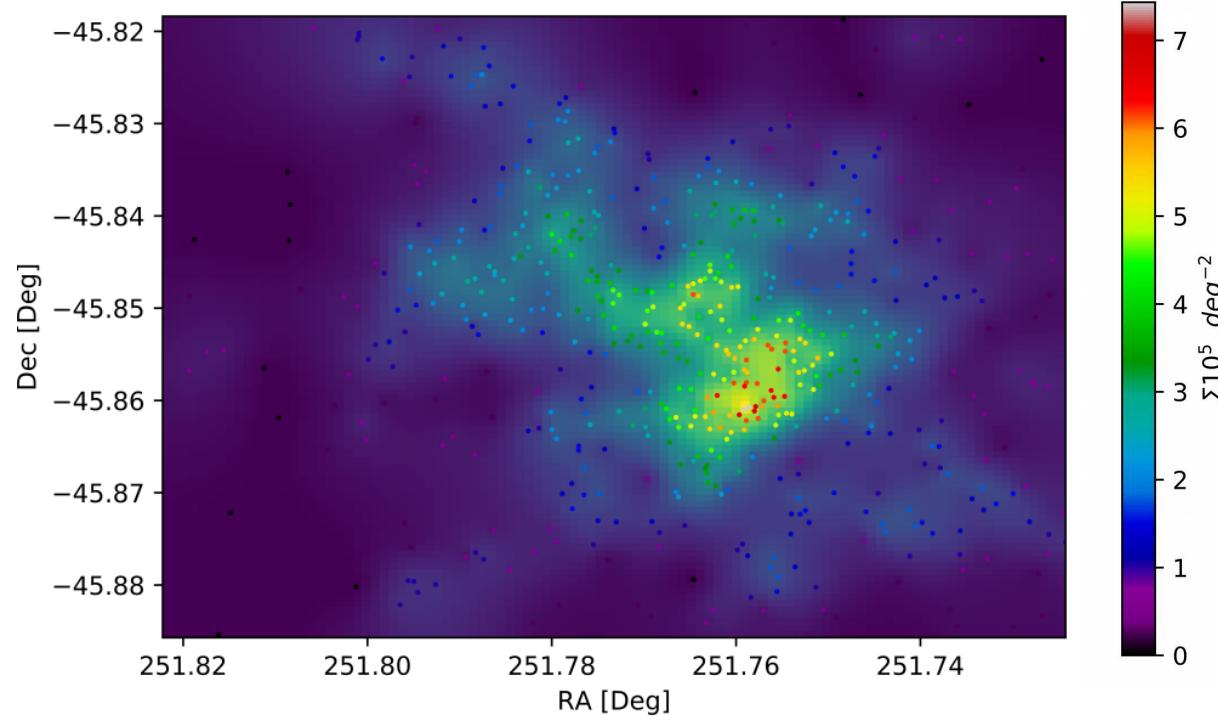


NIR $M_* > 5M_\odot$

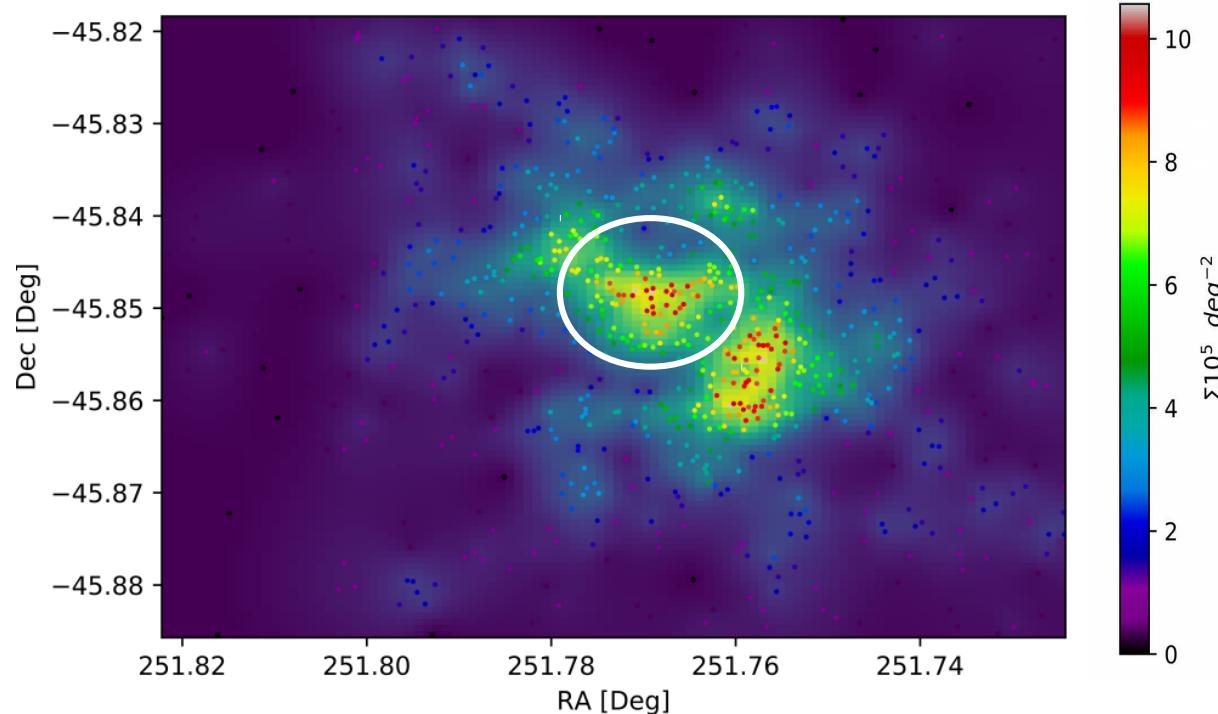


Gaia $M_* > 5M_\odot$

Cleaned matches
with
pm & parallax

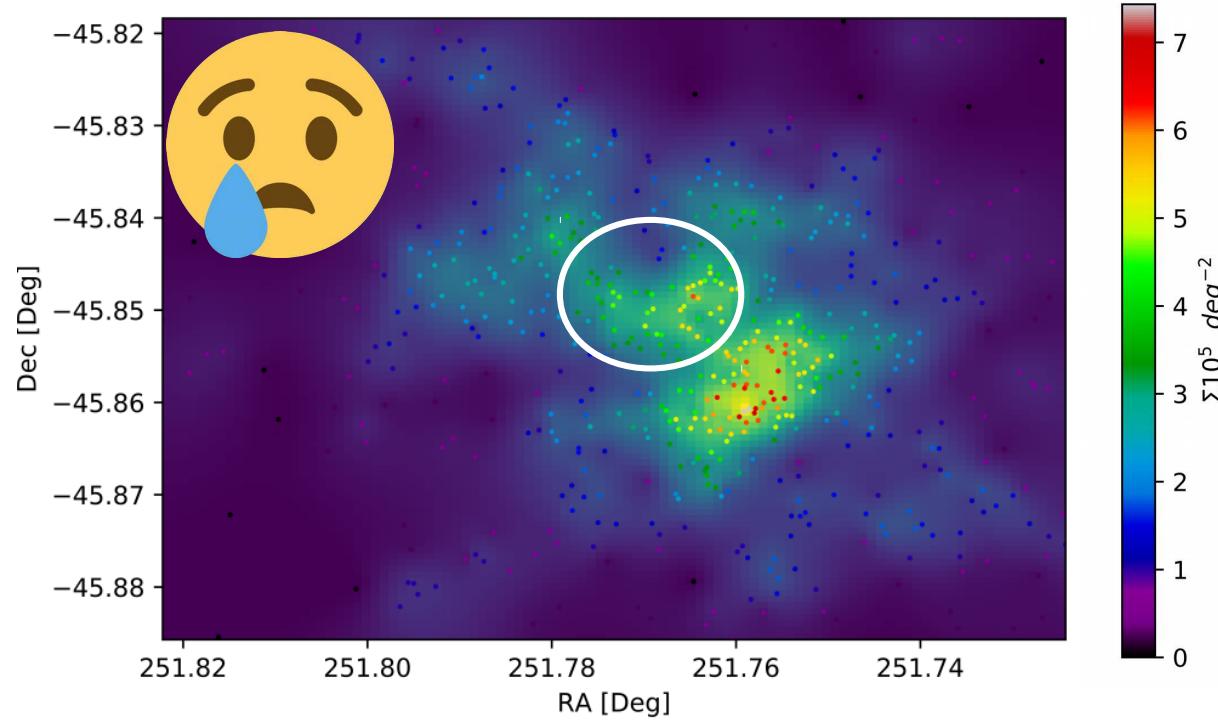


NIR $M_* > 5M_\odot$



Gaia $M_* > 5M_\odot$

Cleaned matches
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Summary

- ◆ INDICATE → powerful local measure of degree of “clustering” of stars
- ◆ 2+D, any parameter space
- ◆ Trace morphological features in SF regions
- ◆ Buckner et al. (2018, A&A, in review)

- ◆ Double core found in Westerlund 1
- ◆ Observational bias or real?
- ◆ Kinematic data required → not available from Gaia DR2