Spatial Statistics for Star-Forming Regions

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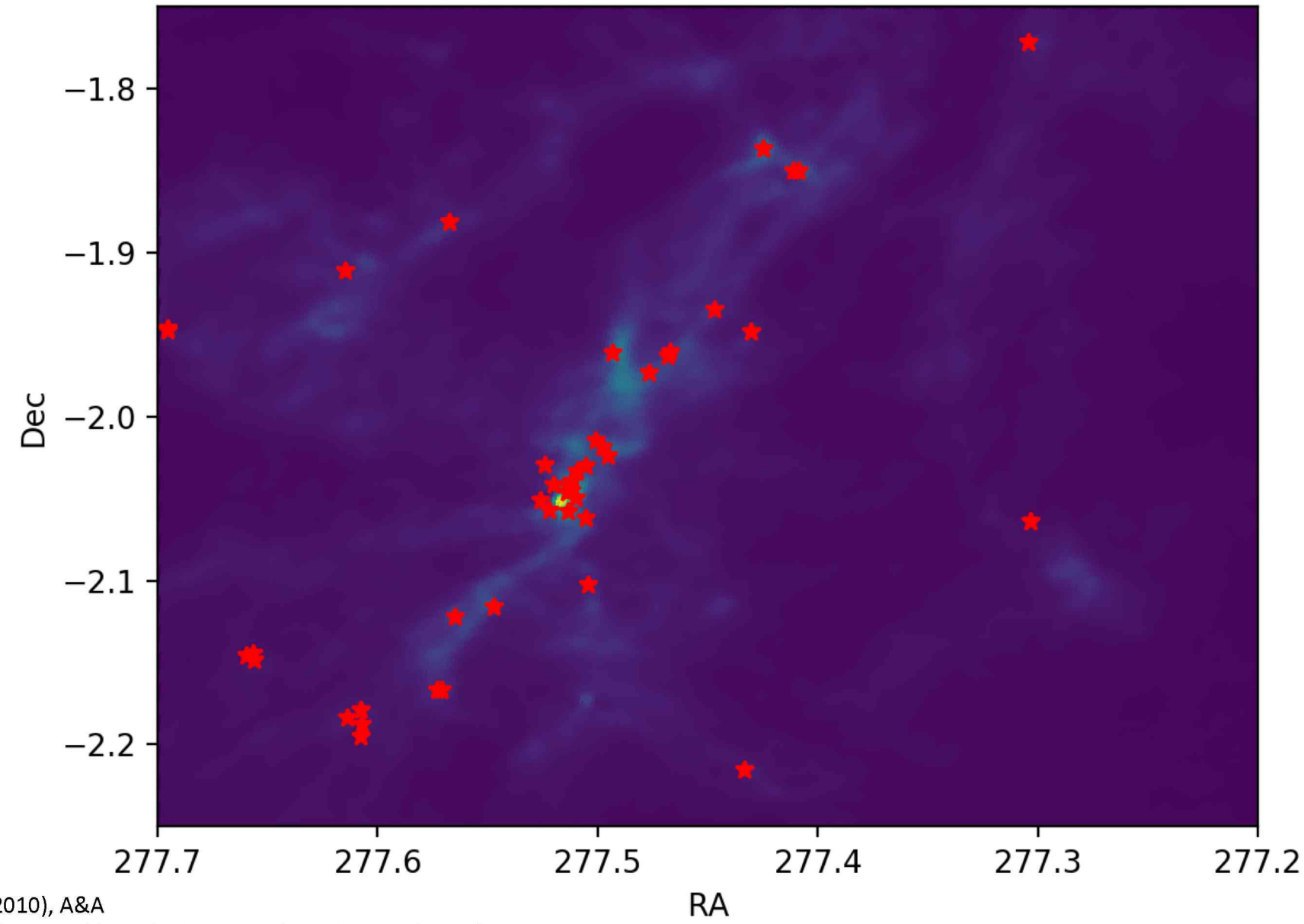
Outline

- Star formation – YSO distribution
- Introduce spatial statistics
- Introduce a plausible first-order model
- Test the model against the data



Herschel data: André et al (2010), A&A
Class 0/I YSO locations: Dunham et al (2015), The Astrophysical Journal Supplementary Series
Serpens south: Gutermuth (2008), The Astrophysical Journal Letters

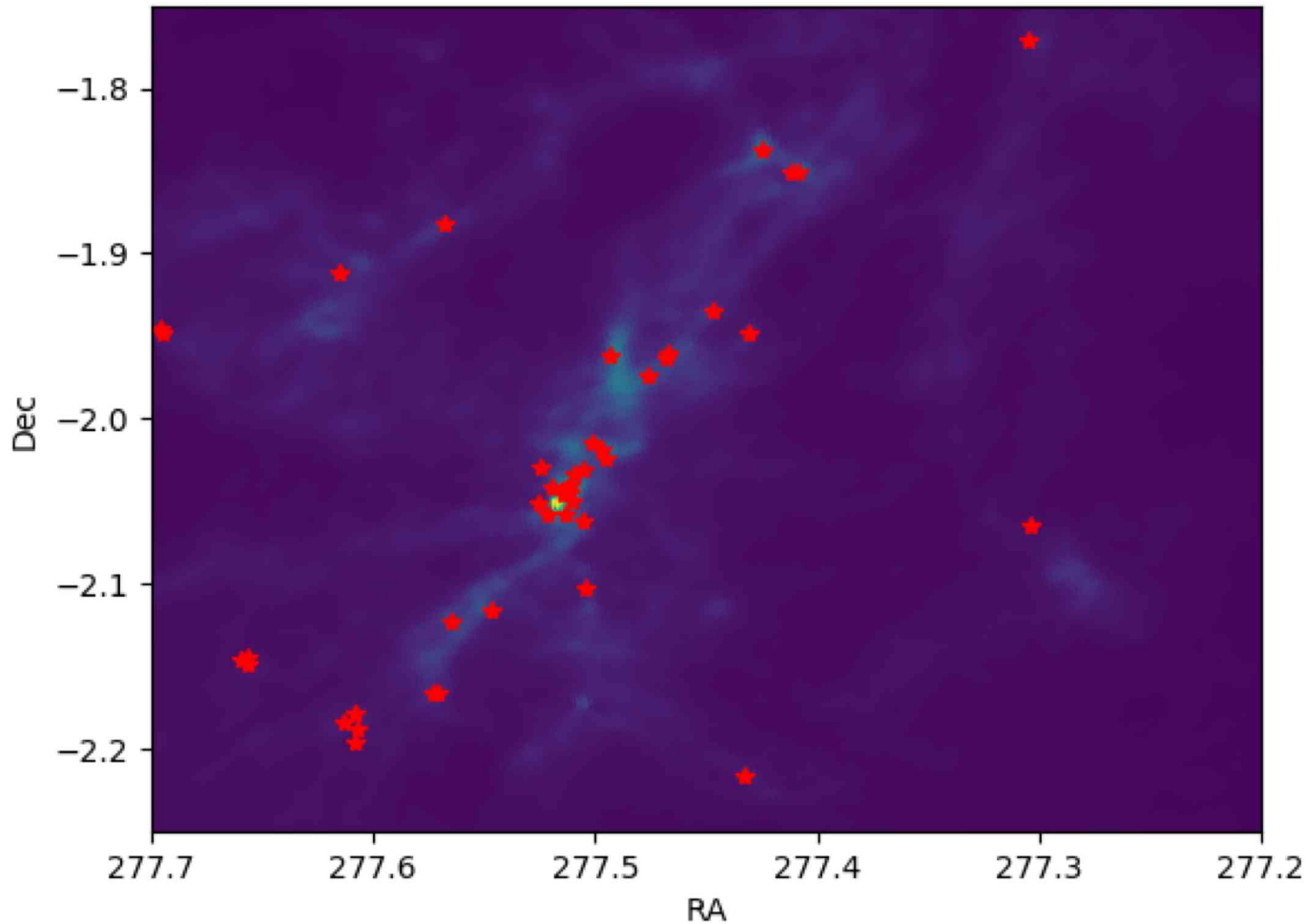
Spatial Statistics

- Spatial point process

Stochastic mechanism that generates a countable set of events in a plane.

- Spatial point pattern

Realisation of a spatial point process.

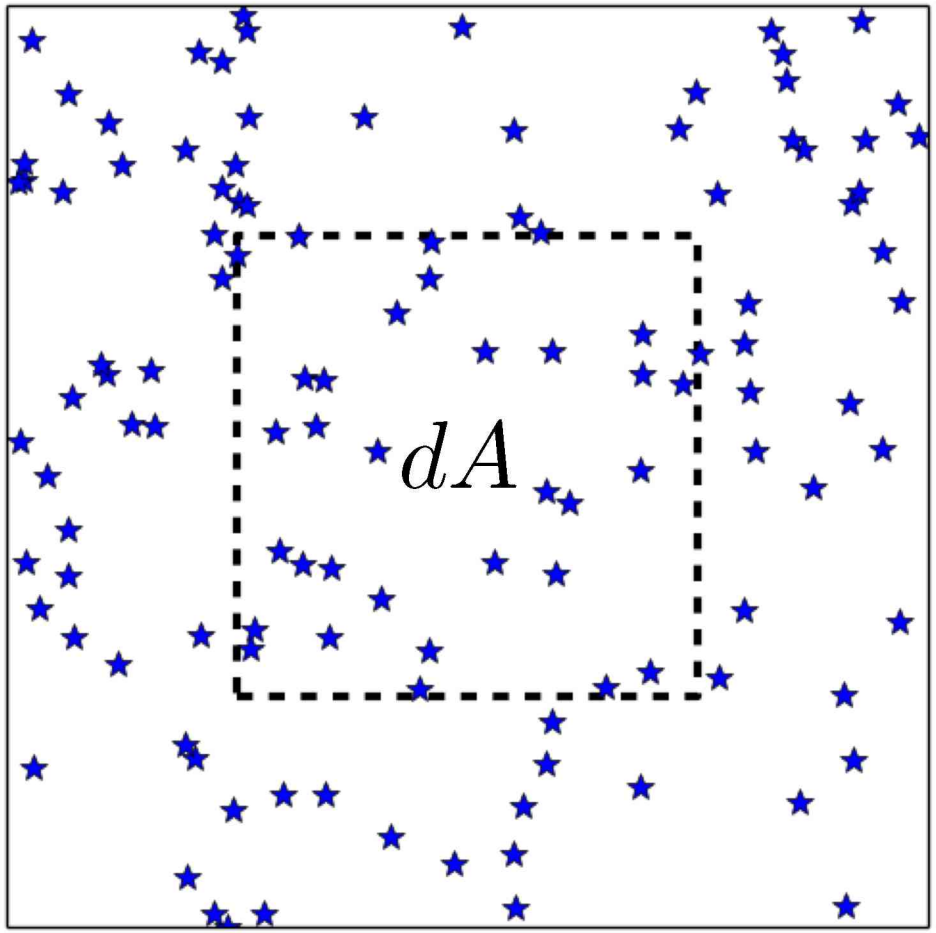


First-Order effects

- First-order effects are effects due to the environment.
- Probability is a function of position.
- You're more likely to find astrophysicists where there is coffee.

First-Order Intensity

$$\lambda(x,y) = \lim_{dA \to 0} \left\{ \frac{E[N(dA)]}{dA} \right\}$$



- For a stationary process λ(x,y) = λ,
- the mean number of events per unit area.

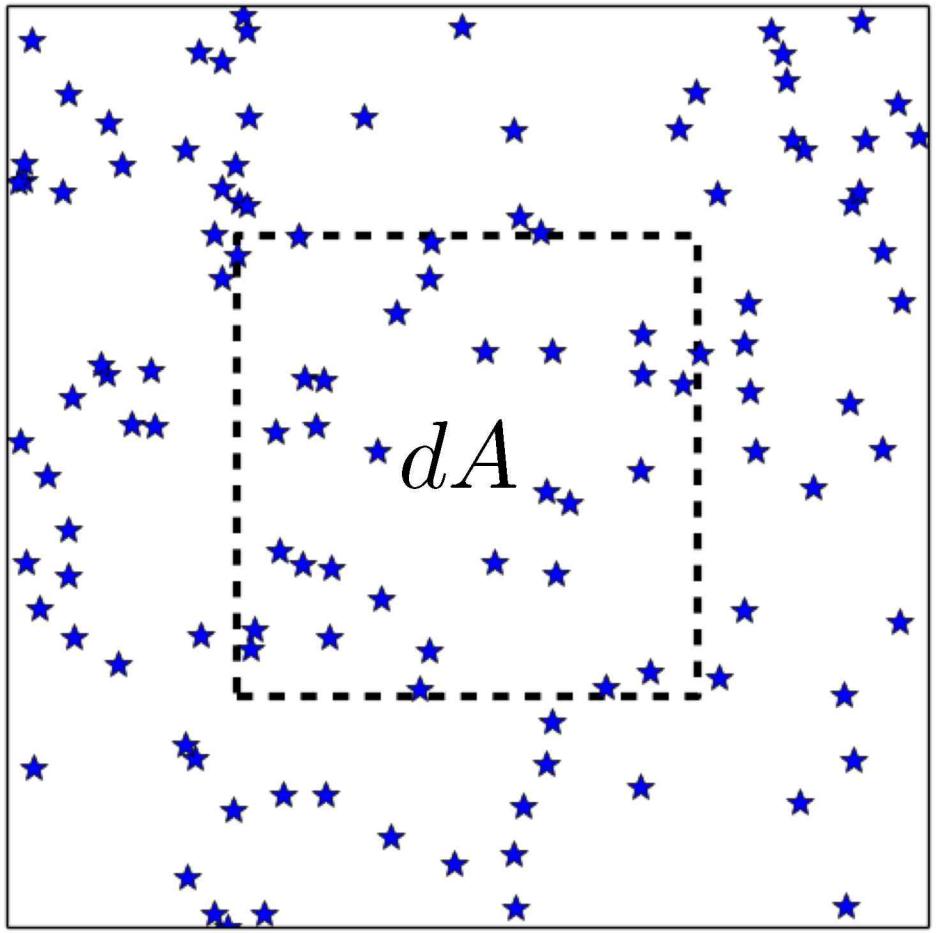
Diggle, J. (2013) Statistical Analysis of Spatial and Spatio-Temporal Point Patterns, Third Edition

First-Order Intensity

The number of YSOs follows Poisson distribution with mean

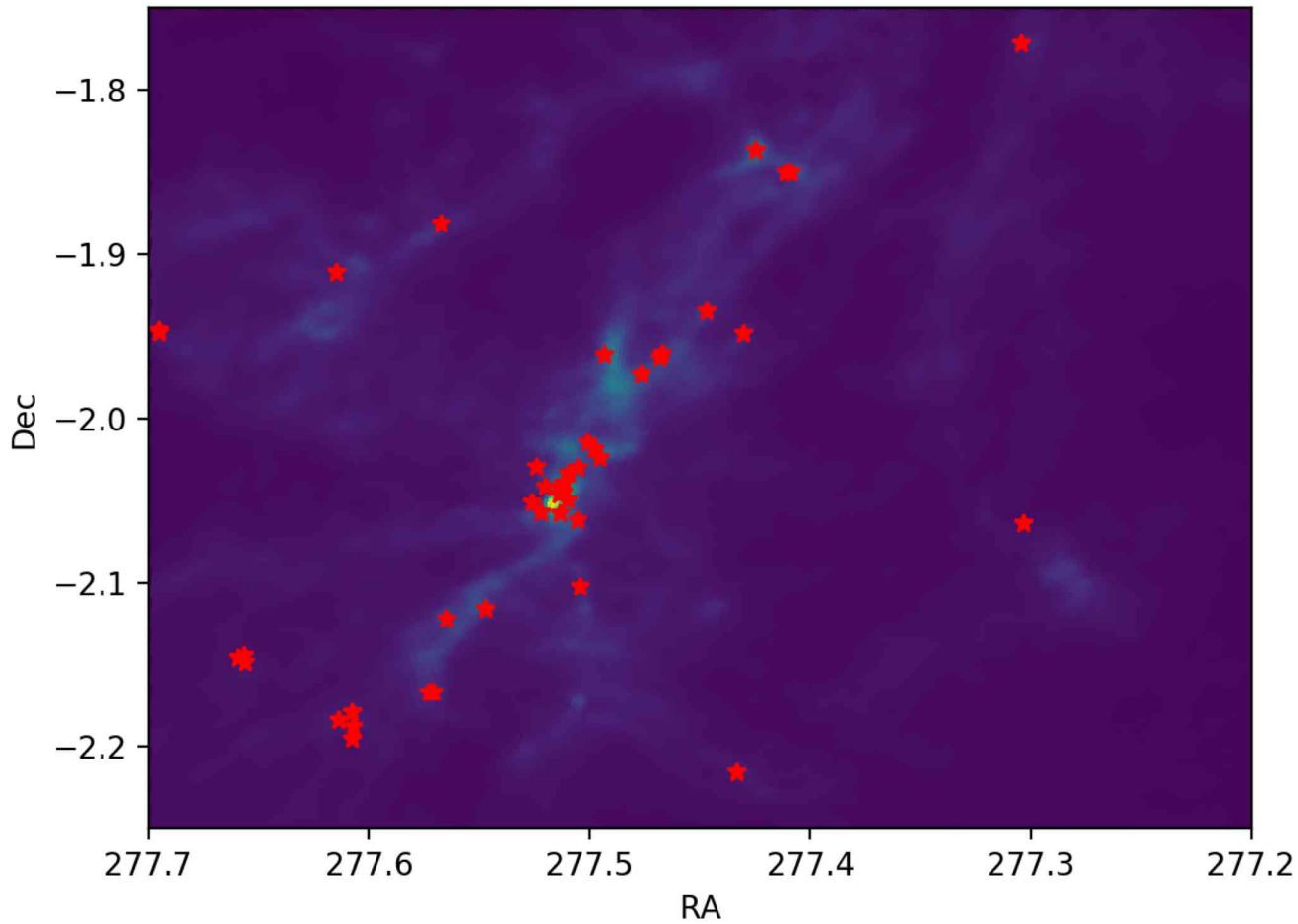
$$\int_A \lambda(x,y)dxdy$$

Processes with λ(x,y) are known as inhomogenous Poisson processes.

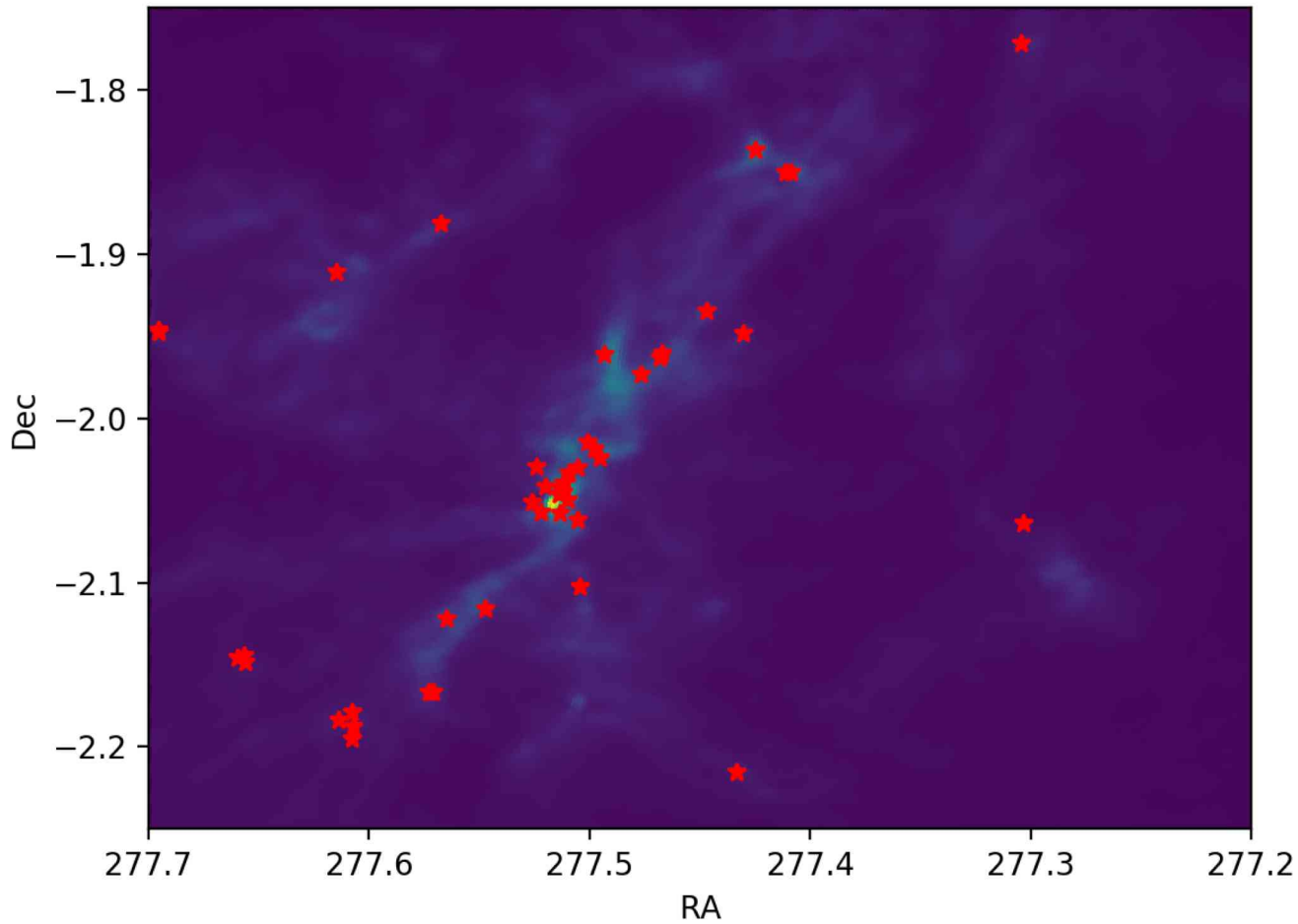


Diggle, J. (2013) Statistical Analysis of Spatial and Spatio-Temporal Point Patterns, Third Edition

Can we find the $\lambda(x, y)$ of a star forming region?



Can we find the $\lambda(N_{H_2})$ of a star forming region?

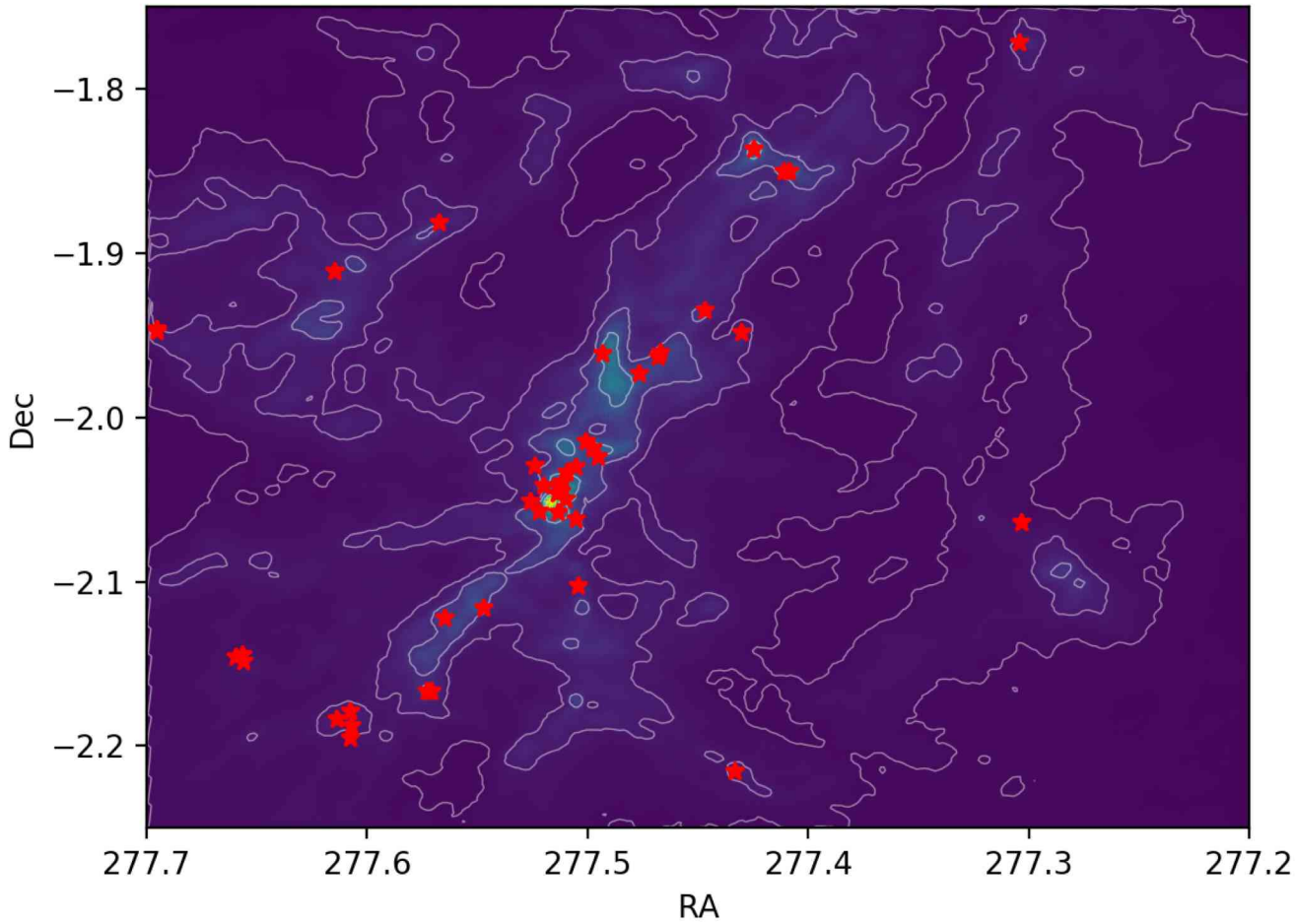


Estimating First-Order Intensity

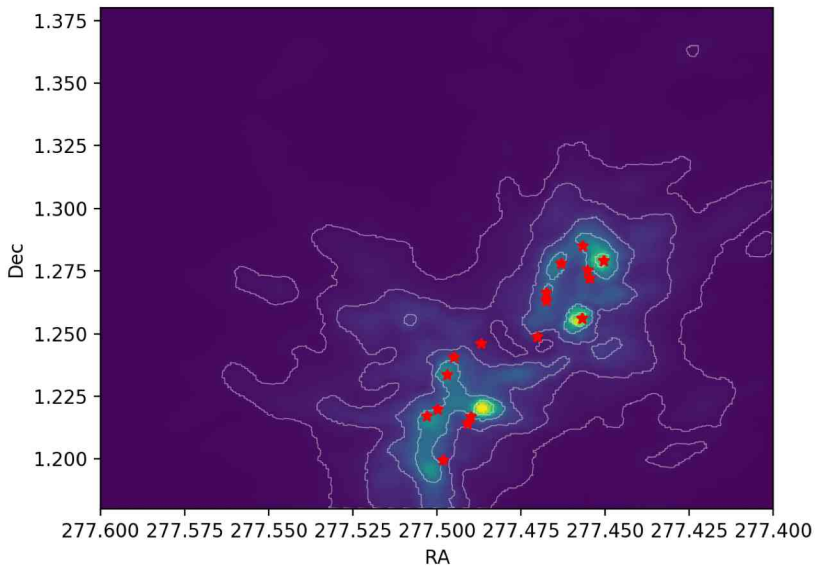
$$\hat{\lambda}(\mathrm{N_{H_2}}) = \frac{N_{\mathrm{YSOs}}(\mathrm{N_{H_2}})}{\mathrm{Area}(\mathrm{N_{H_2}})}$$

Estimate densities of YSOs within column density bins,

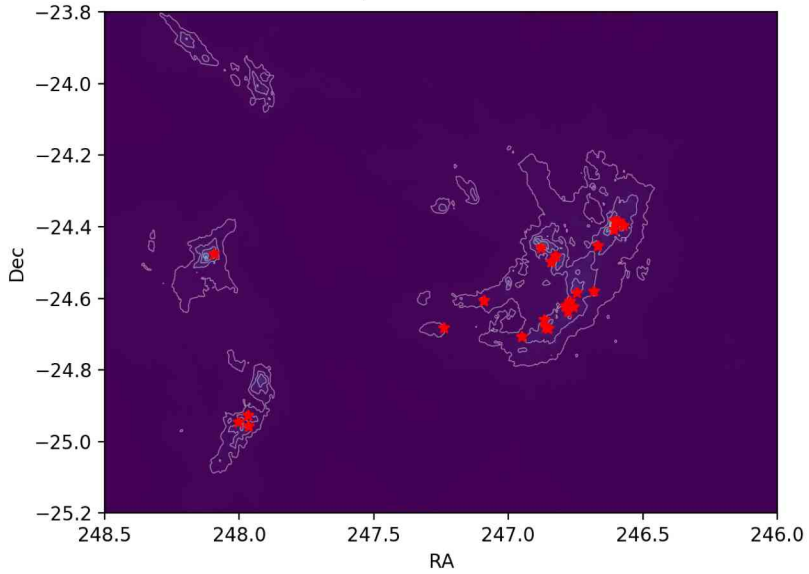
(Hatchell et al., 2005)



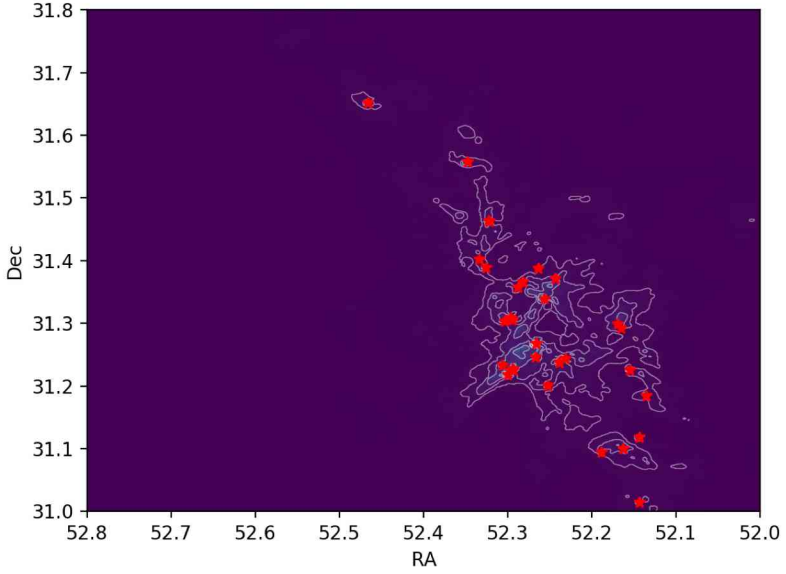
Serpens Main



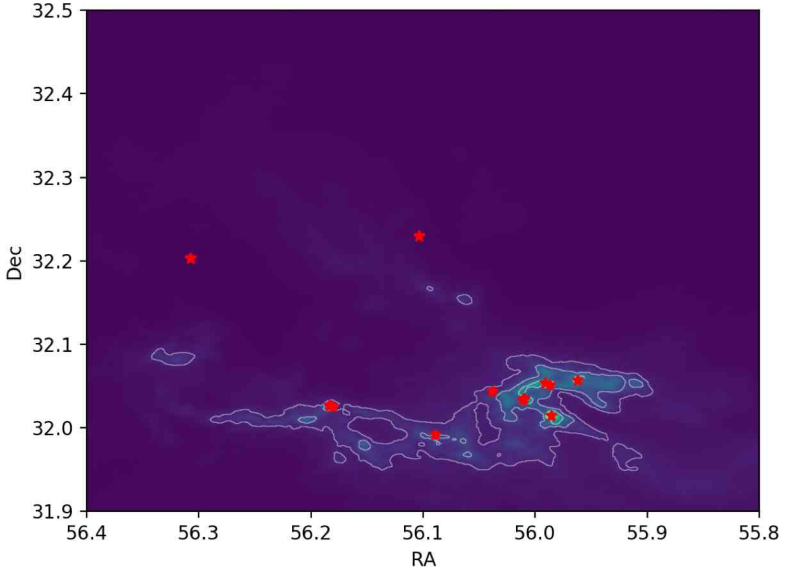
Ophiuchus



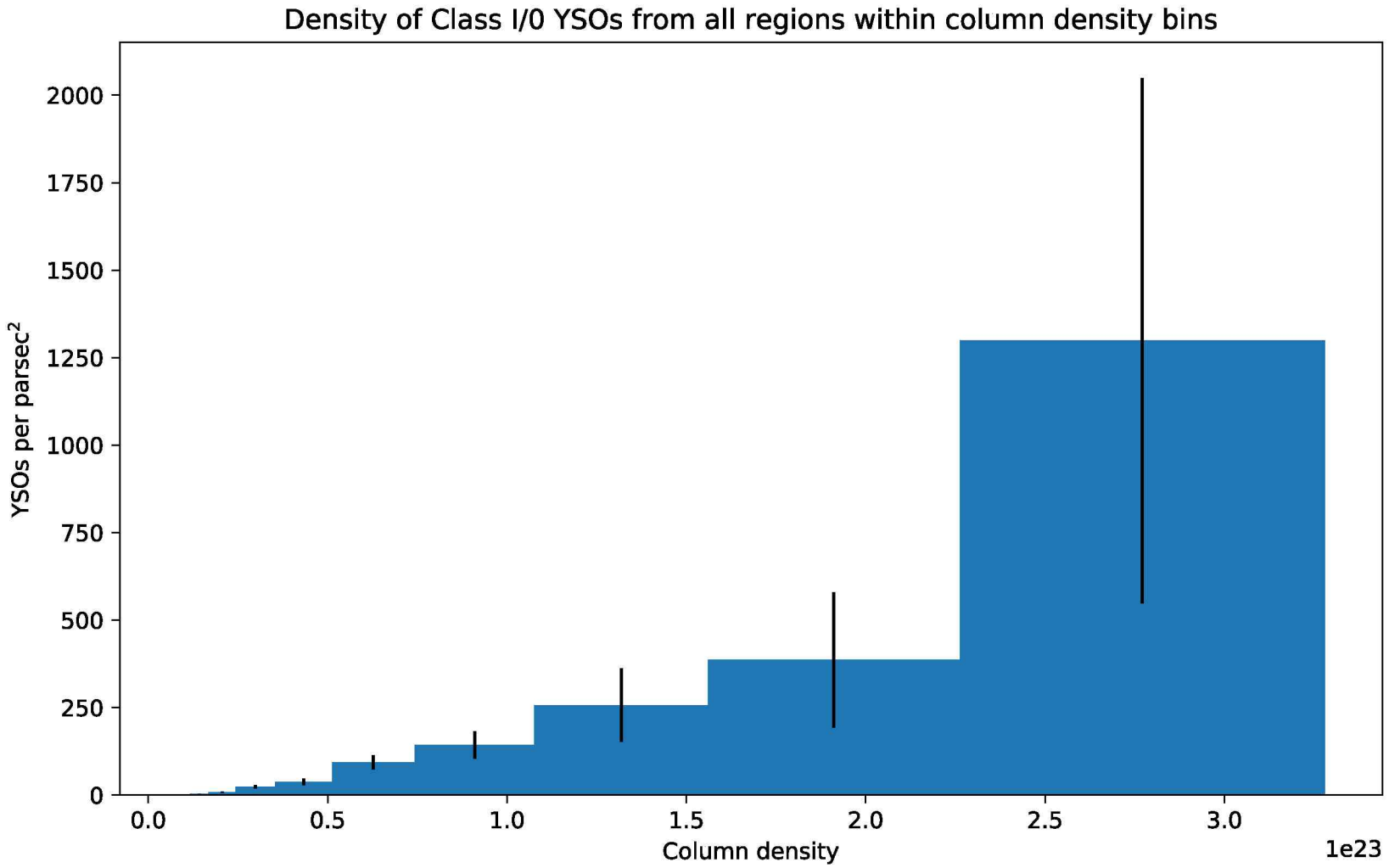
NGC1333



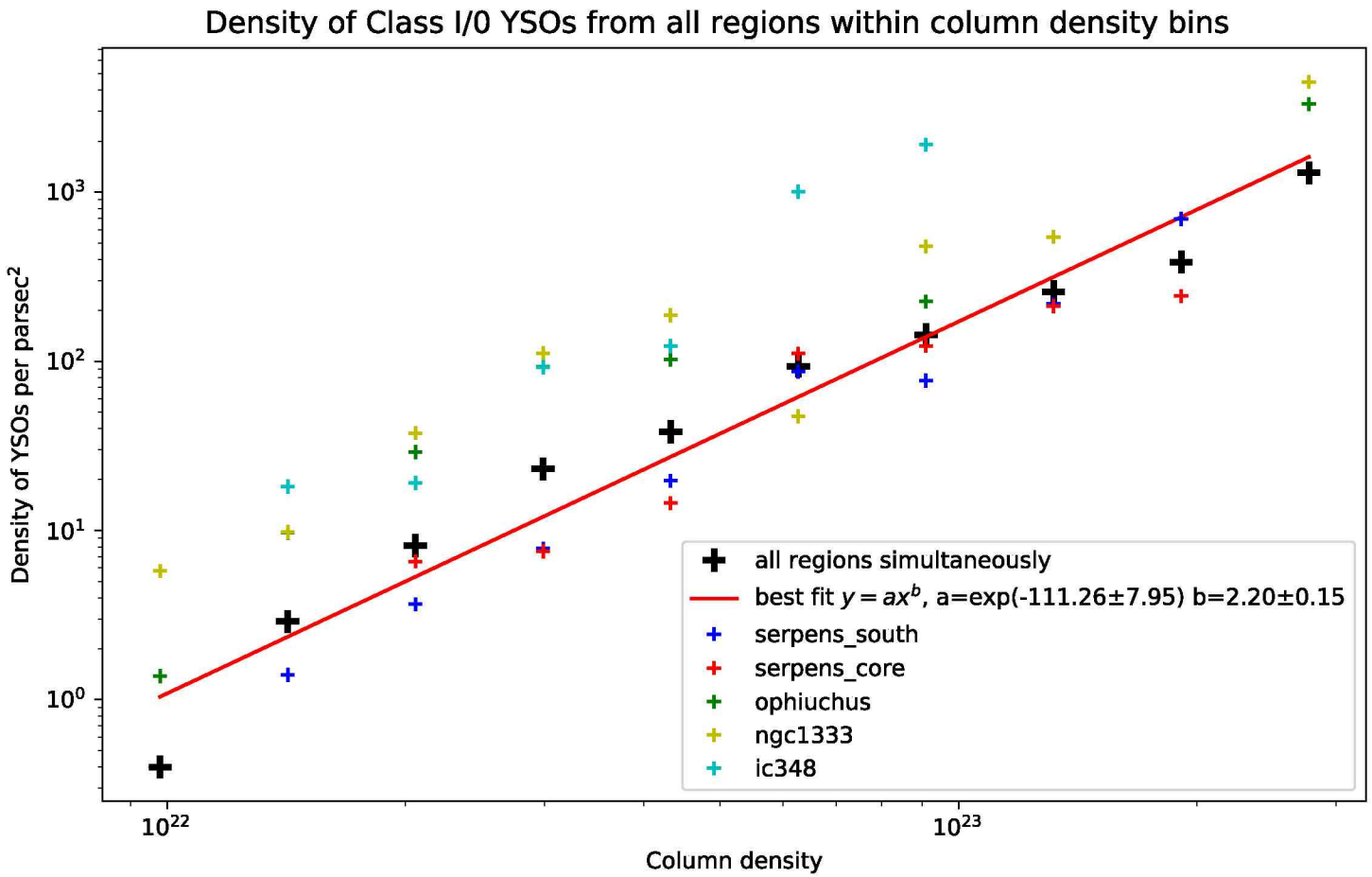
IC348



Estimating the First-Order Intensity



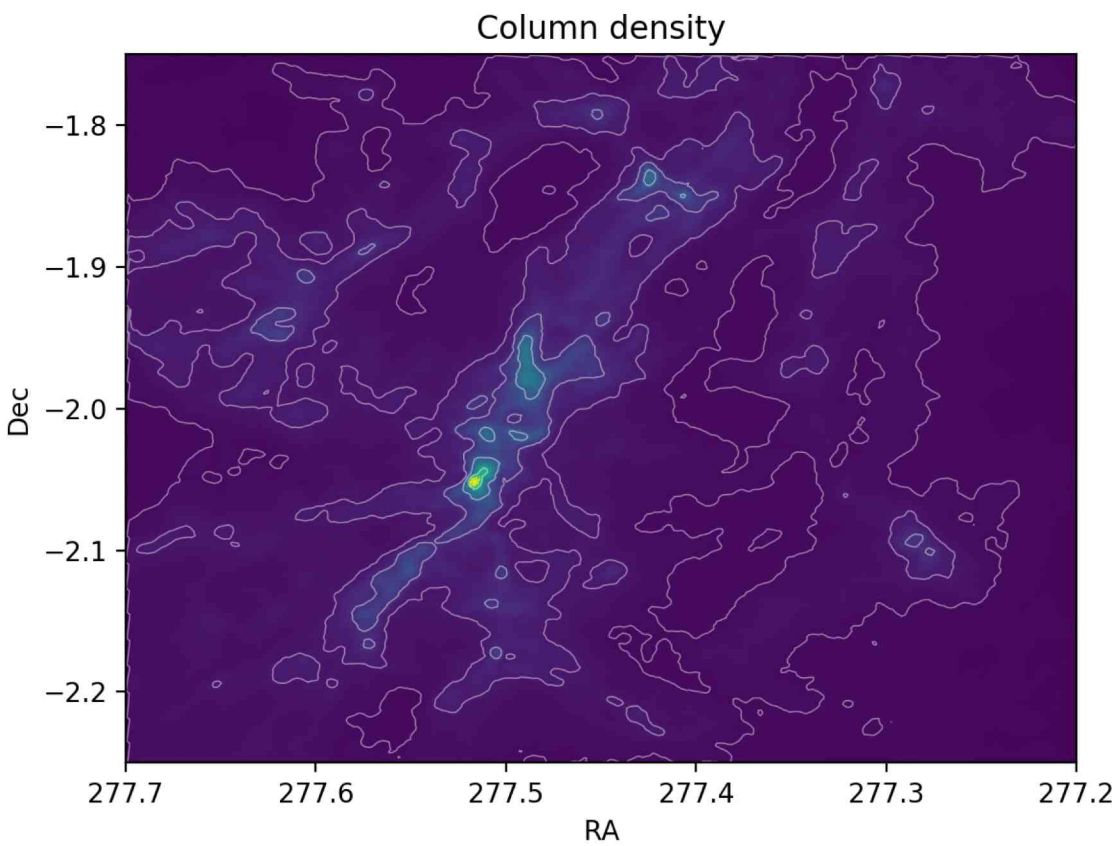
Estimating the First-Order Intensity

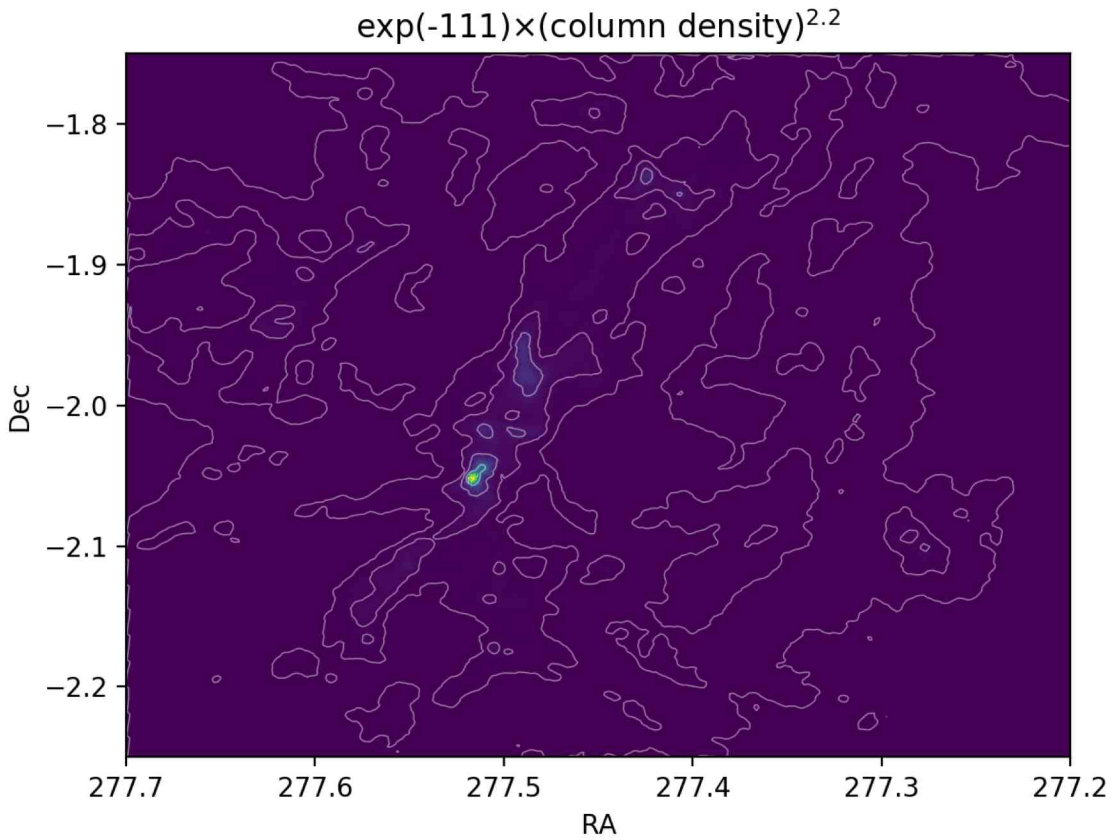


$$\hat{\lambda}(\mathrm{N_{H_2}}) \propto \mathrm{N_{H_2}}^{2.2\pm0.15}$$

$$\bar{N} = \int_A \lambda(x,y)dxdy$$

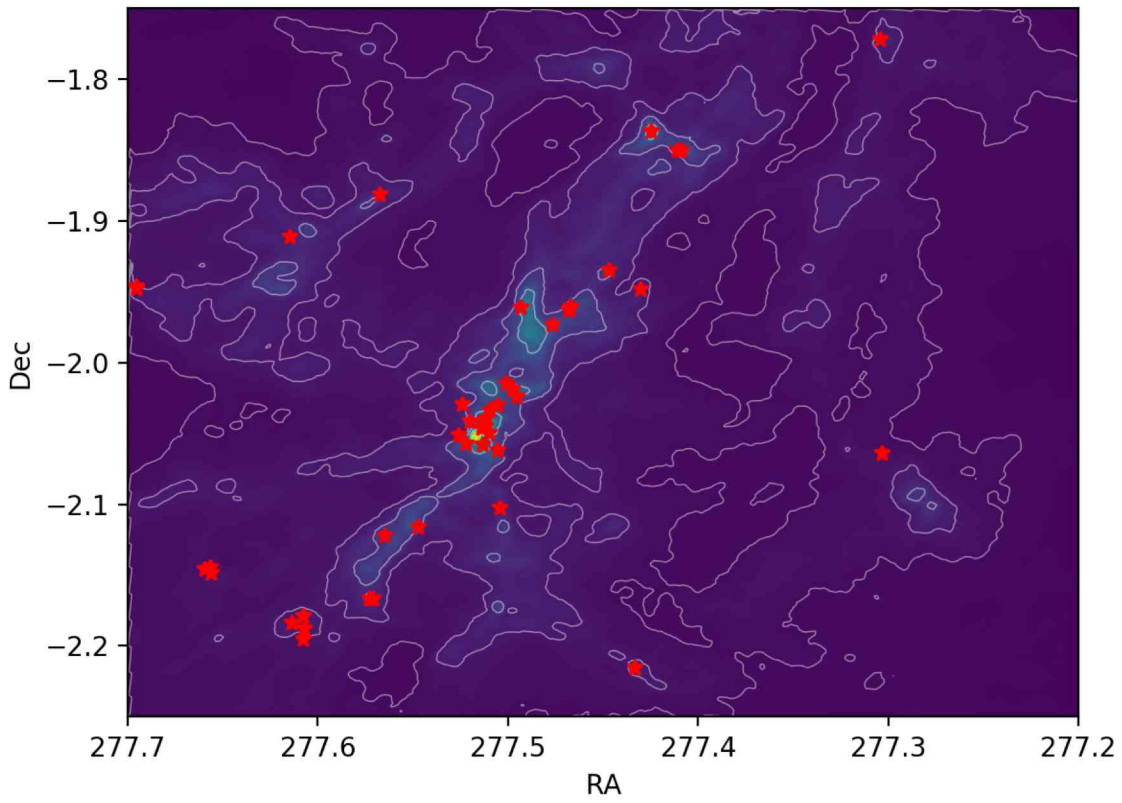
Probability Map



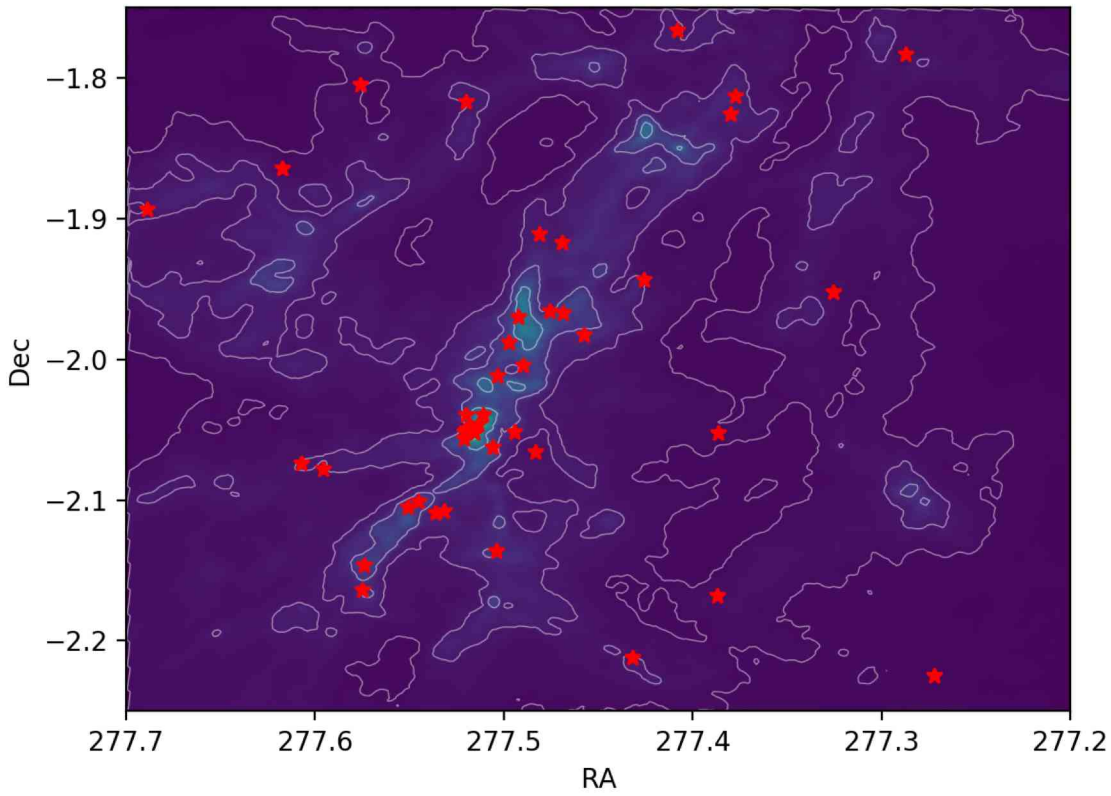


Serpens South

Class 0/I YSOs

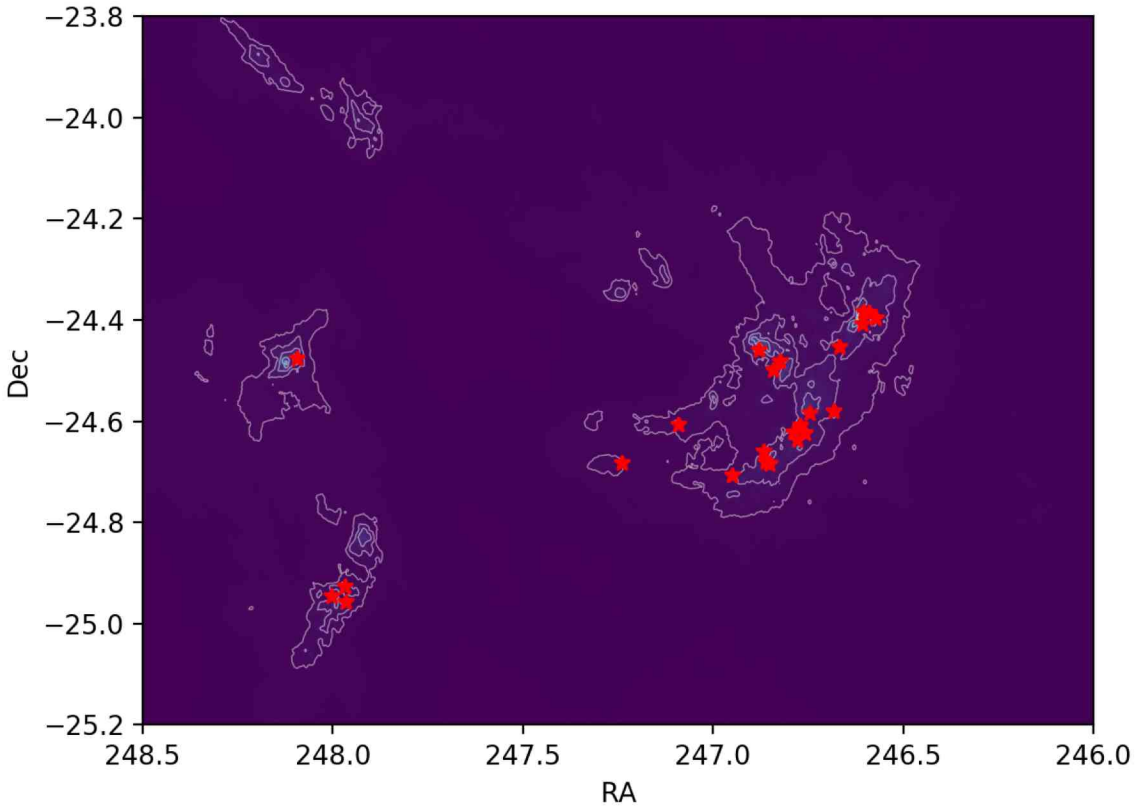


Simulated YSO positions

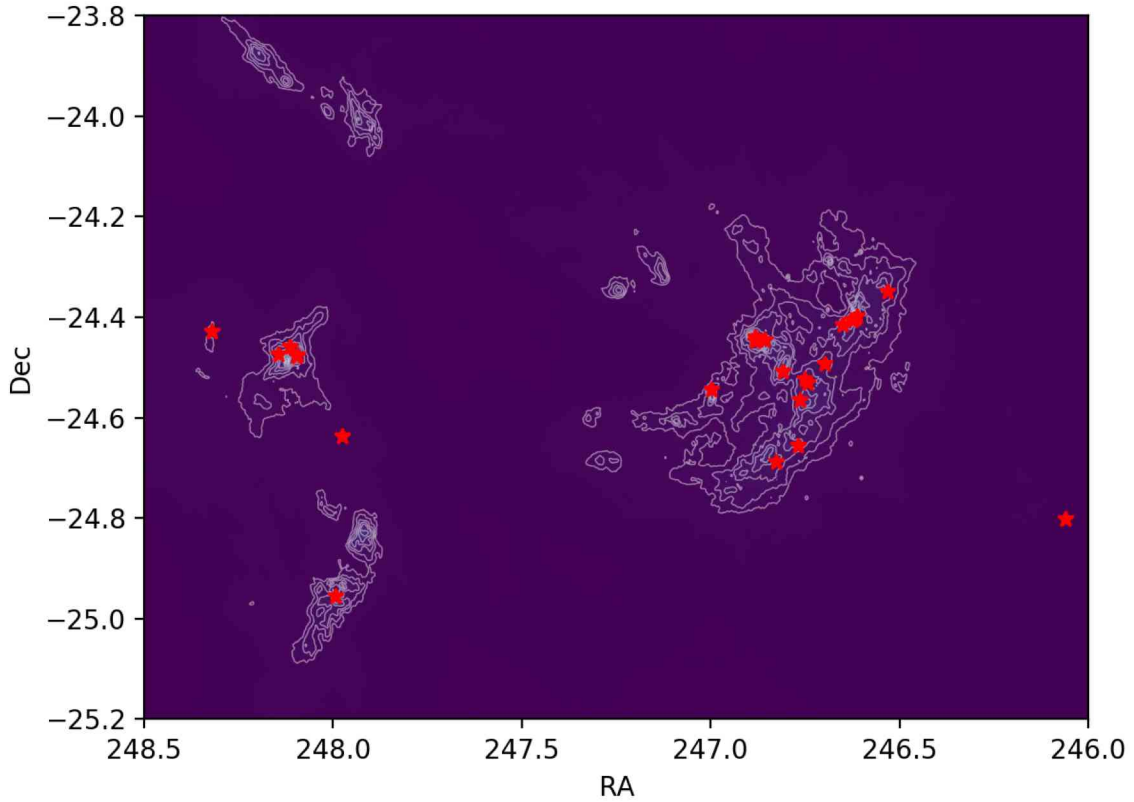


Ophiuchus

Class 0/I YSOs



Simulated YSO positions



O-ring Statistic

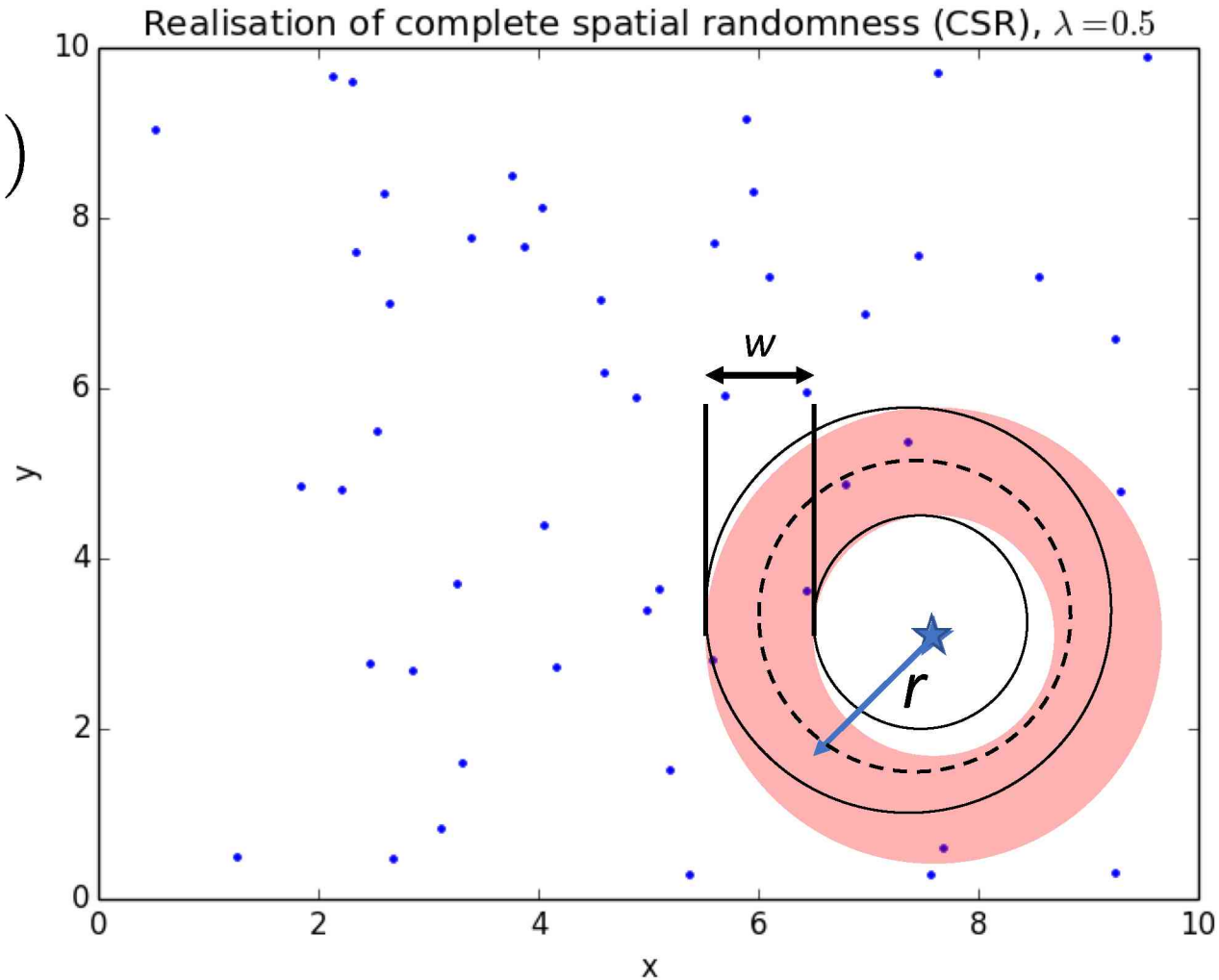
$$\hat{\mathrm{O}}(r) = \frac{A}{n^2} \sum_{\substack{i=1 \\ i \neq j}}^{n} \sum_{\substack{j=1 \\ j \neq 1}}^{n} h_i(r) I_r(i,j)$$

Where:

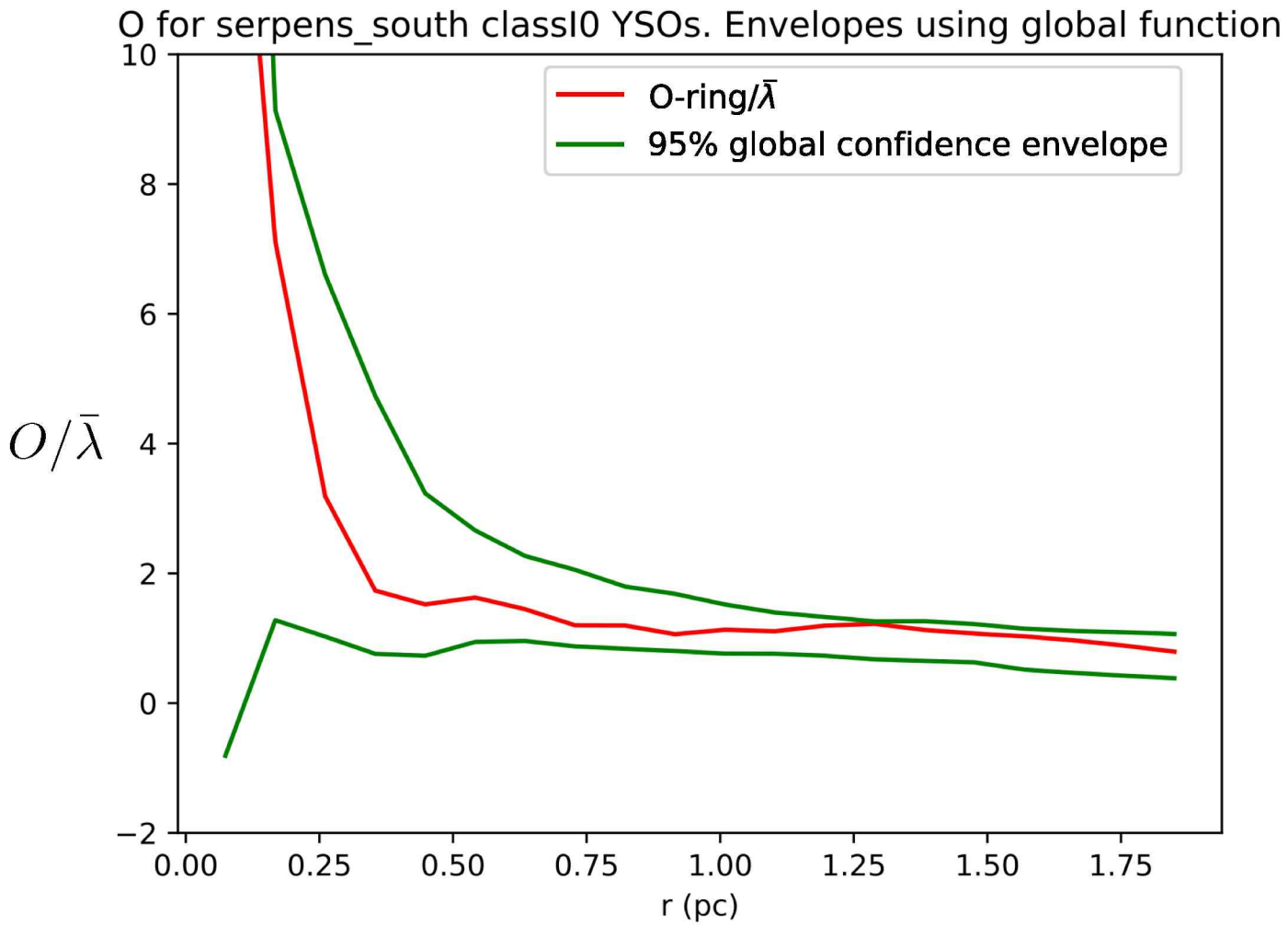
A = area of plot
n = number of points in plot
$h_i(r)$ = edge correction

$$I_r(i,j) = \begin{cases} 1, & \text{if } r - \frac{w}{2} \leq d_{ij} \leq r + \frac{w}{2} \\ 0, & \text{otherwise} \end{cases}$$

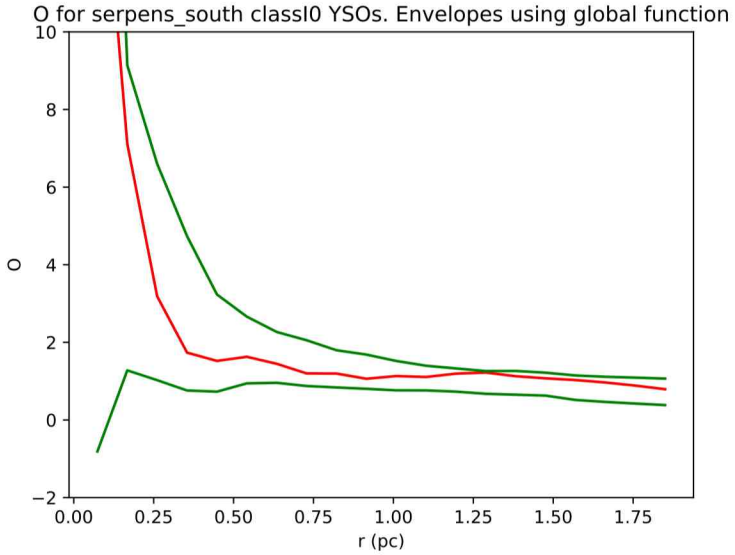
Retter et al (2019), MNRAS

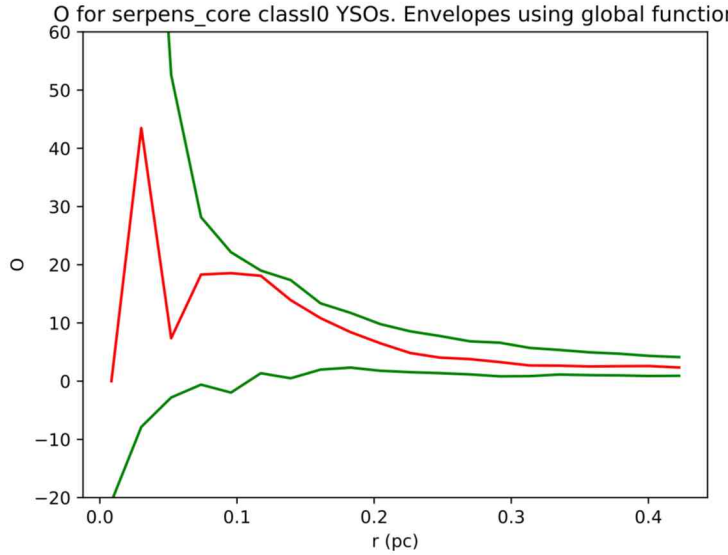


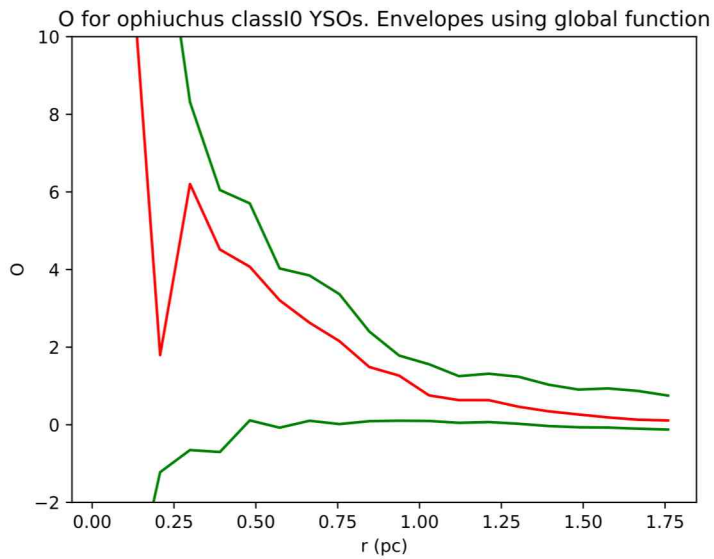
Hypothesis testing

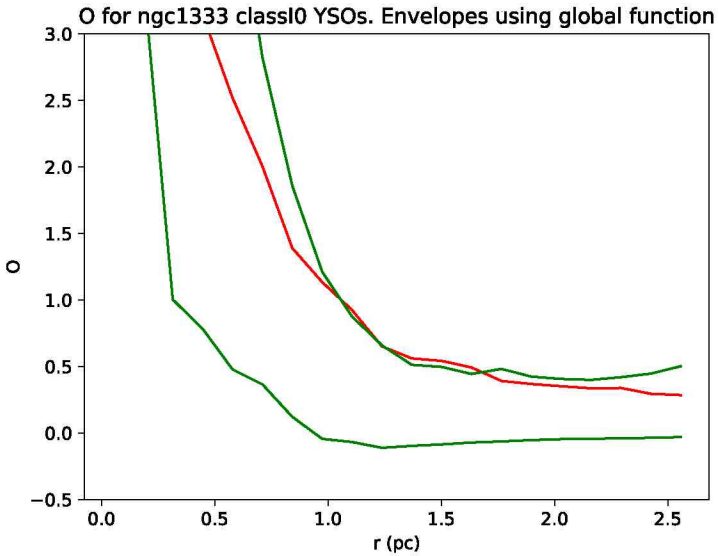


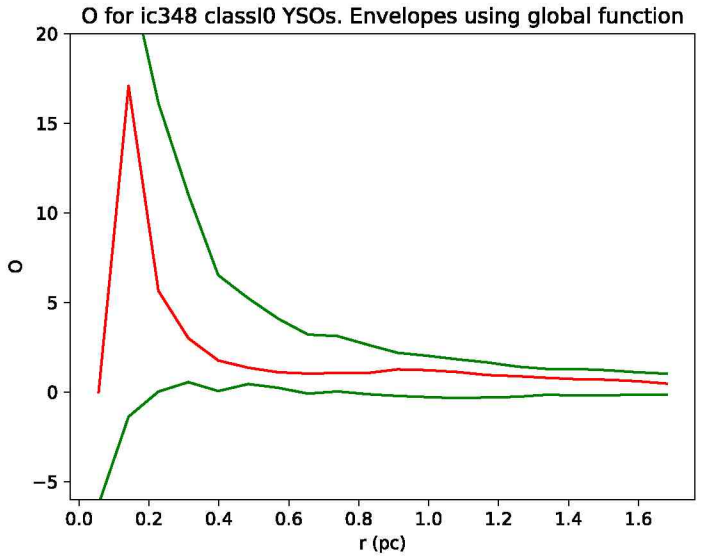
Results


O for serpens_south classI0 YSOs. Envelopes using global function
O
r (pc)


O for serpens_core classI0 YSOs. Envelopes using global function
O
r (pc)

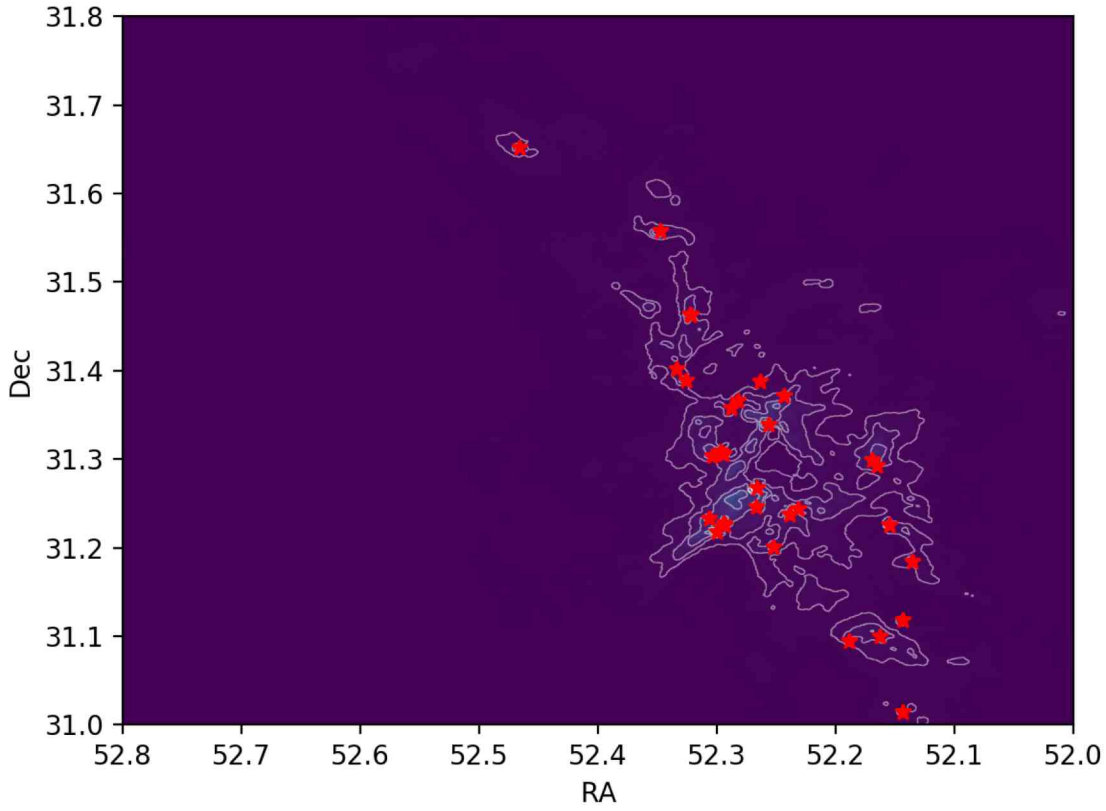

O for ophiuchus classI0 YSOs. Envelopes using global function
O
r (pc)


O for ngc1333 classI0 YSOs. Envelopes using global function
O
r (pc)

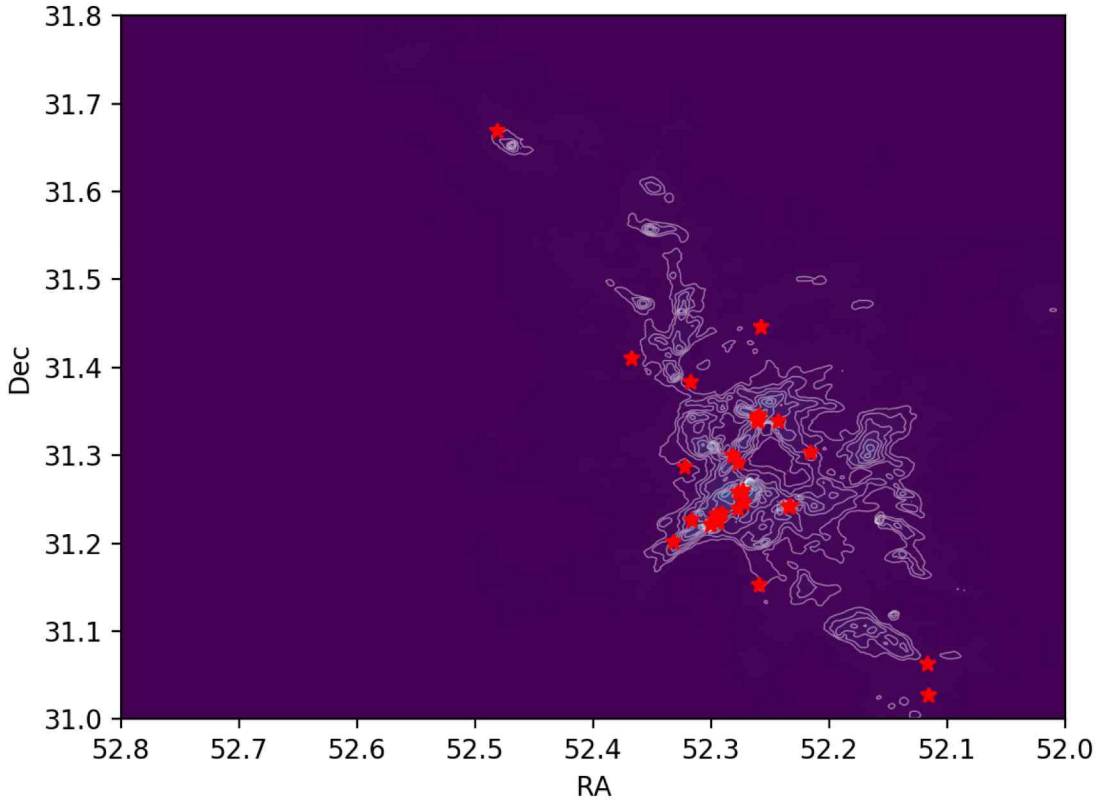

O for ic348 classI0 YSOs. Envelopes using global function
O
r (pc)

NGC1333

Class 0/I YSOs

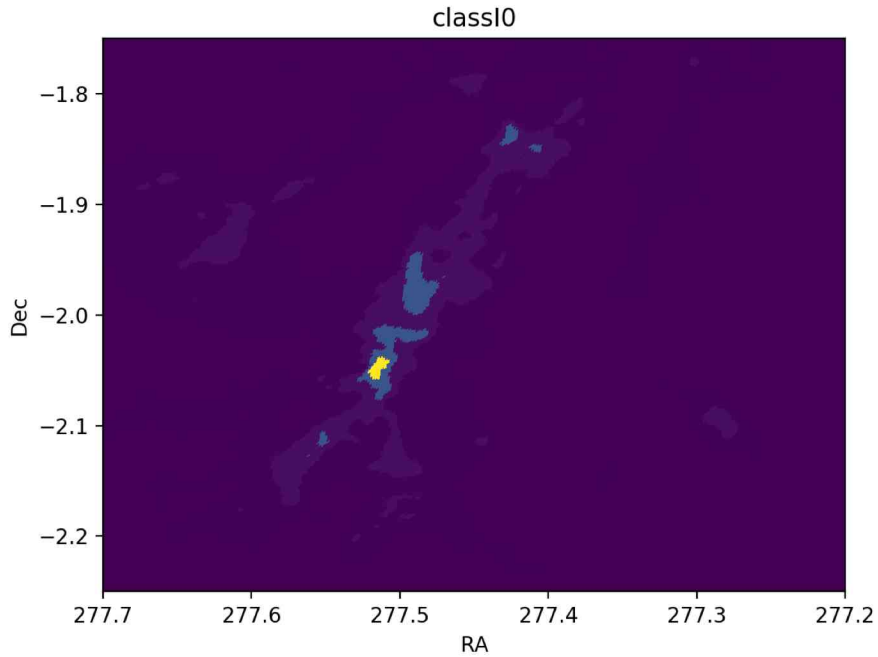


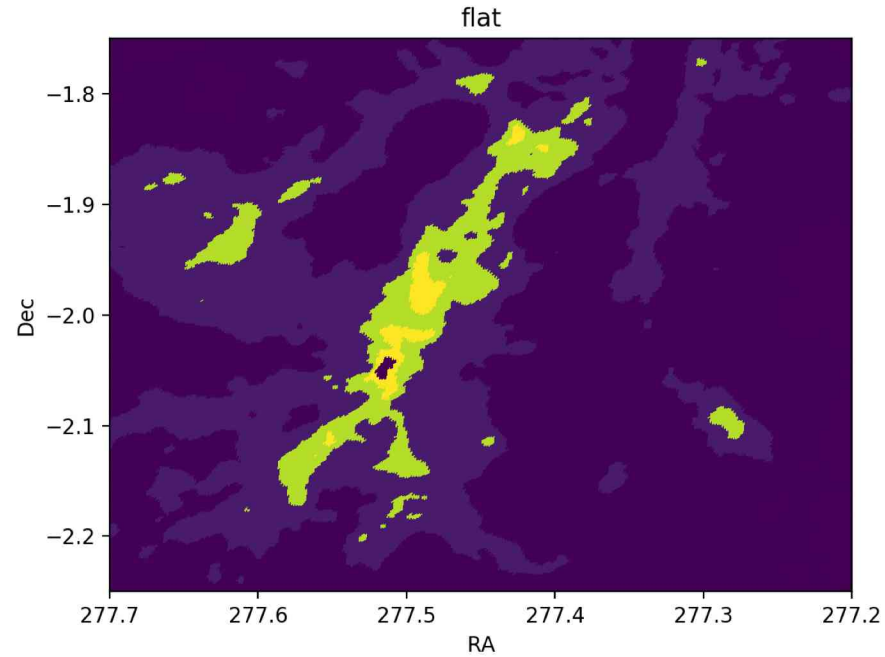
Simulated YSO positions

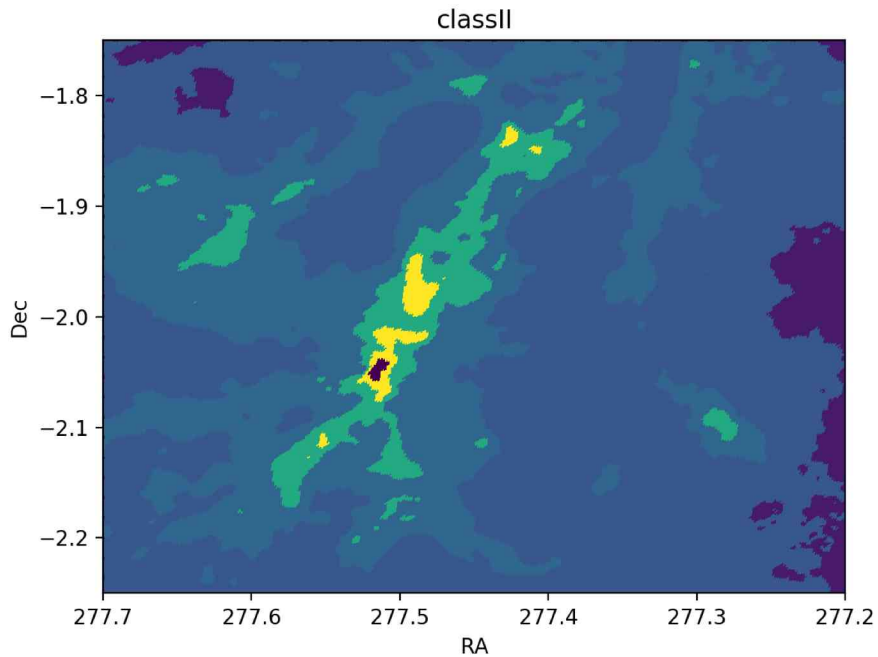


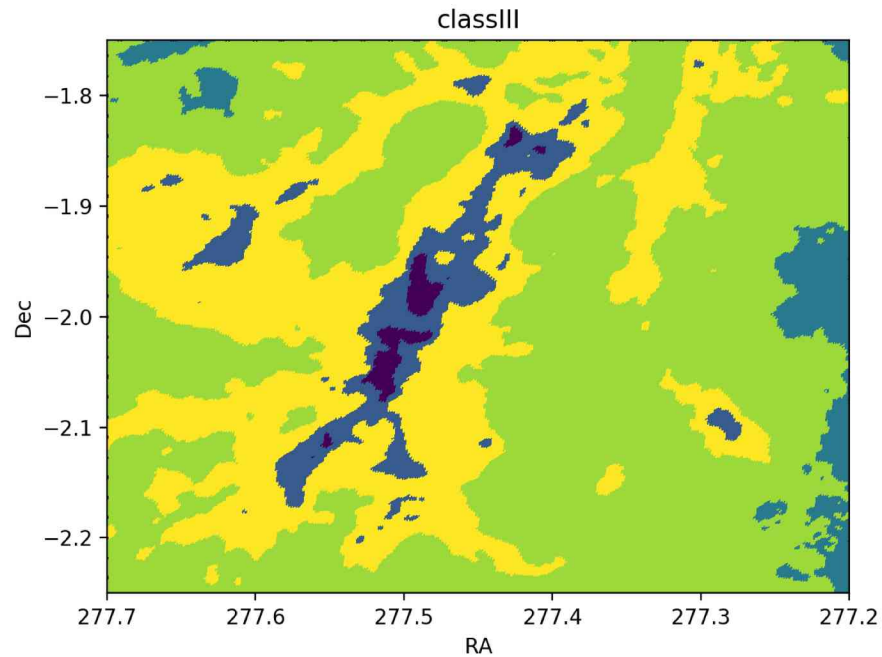
Summary

- We can use spatial statistics to test models of star formation
- The distribution of Class 0/I YSOs is (in some regions) consistent with an inhomogenous Poisson distribution considering only first-order effects.
- The distribution of Class 0/I YSOs is proportional to $N_H^{2.2}$


classI0
−1.8
−1.9
−2.0
−2.1
−2.2
Dec
277.7
277.6
277.5
277.4
277.3
277.2
RA


flat
−1.8
−1.9
−2.0
−2.1
−2.2
Dec
277.7
277.6
277.5
277.4
277.3
277.2
RA


classII
−1.8
−1.9
−2.0
−2.1
−2.2
Dec
277.7
277.6
277.5
277.4
277.3
277.2
RA


classIII
−1.8
−1.9
−2.0
−2.1
−2.2
Dec
277.7
277.6
277.5
277.4
277.3
277.2
RA