Young star forming region in clusters and associations

Tracking fossil imprints in spatial star distribution: a multiscale analysis of YSOs

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Outline

1. (2D) Spatial distribution of stars in Taurus

- *Multiples & Ultra-wide pairs* *(Joncour et al 2017)*

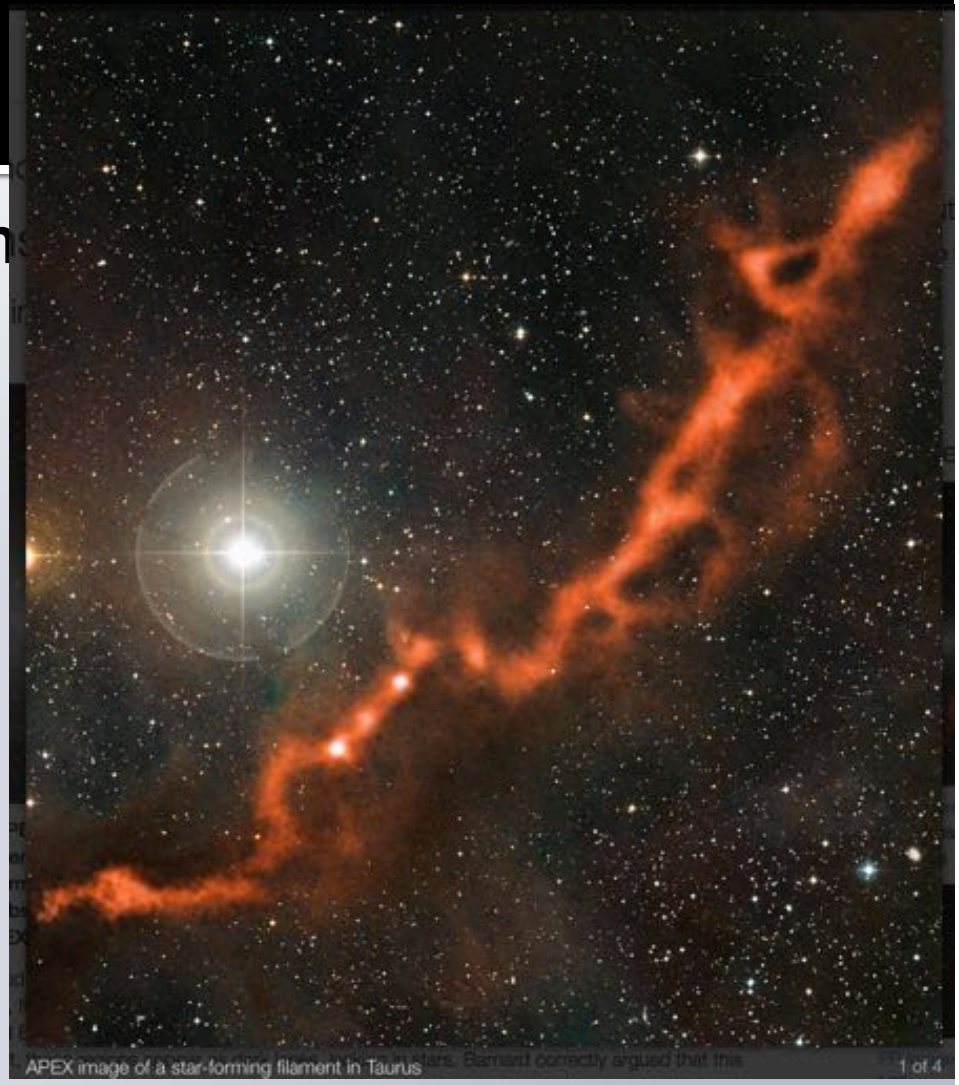
- NESTs (baby-clusters) (Joncour et al, almost sub…)

-Multiscale structures

- (Joncour et al, in prep)

2.First raw results on extended Serpens main

(if enough time)

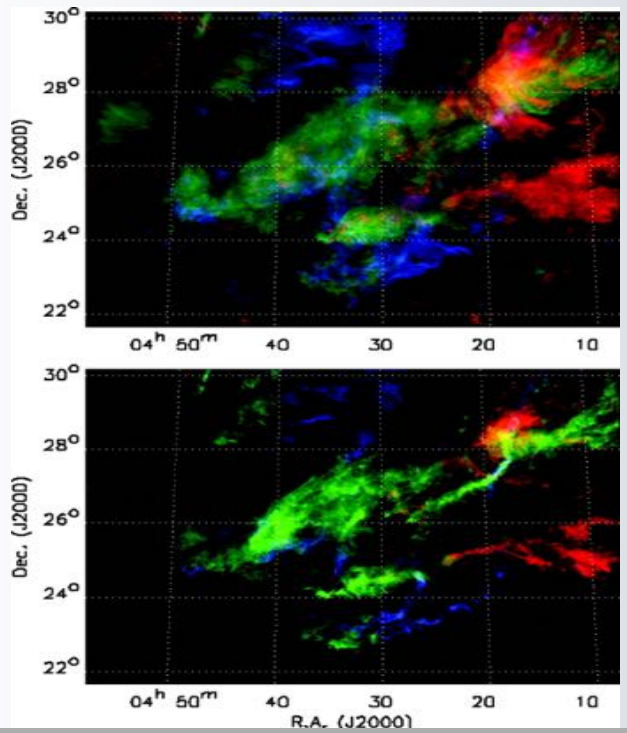


Credit: ESO/APEX (MPIfR/ESO/OSO)/A. Hacar et al./ Digitized Sky Survey 2. Acknowledgment: Davide De Martin.

Why Taurus? Taurus a nearby quiescent low-mass star forming region, the most studied ever

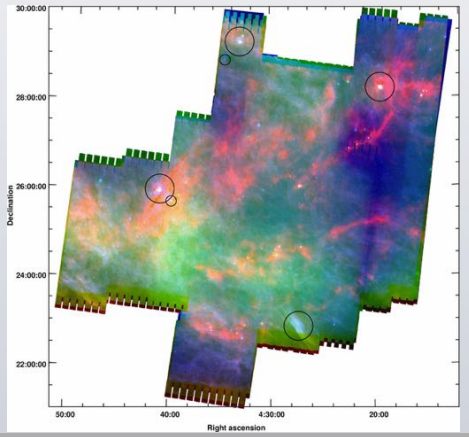
Distance: 140 pc Diameter: 25pc Depth: 20 pc *(Torres 2007, 2009)*

- Low turbulent gas dispersion (0.2 to 2 km/s)
- low stellar density (1 pc^{-2})
- While giant molecular cloud (2.4 10^4 Msun) large extension - 350 YSOs



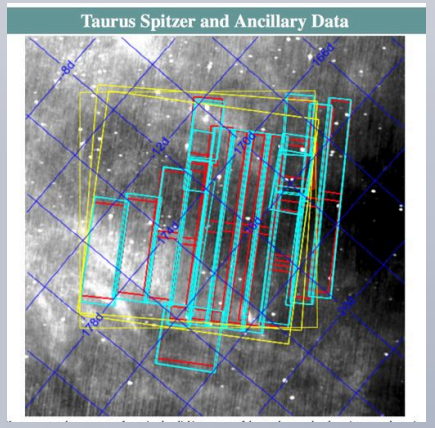
FCRAO Radio image in ^{12}CO (Top) and ^{13}CO (Bottom) of Taurus, Goldsmith et *al* 2008

- Very few high-mass stars -> Few high-flux ionising winds



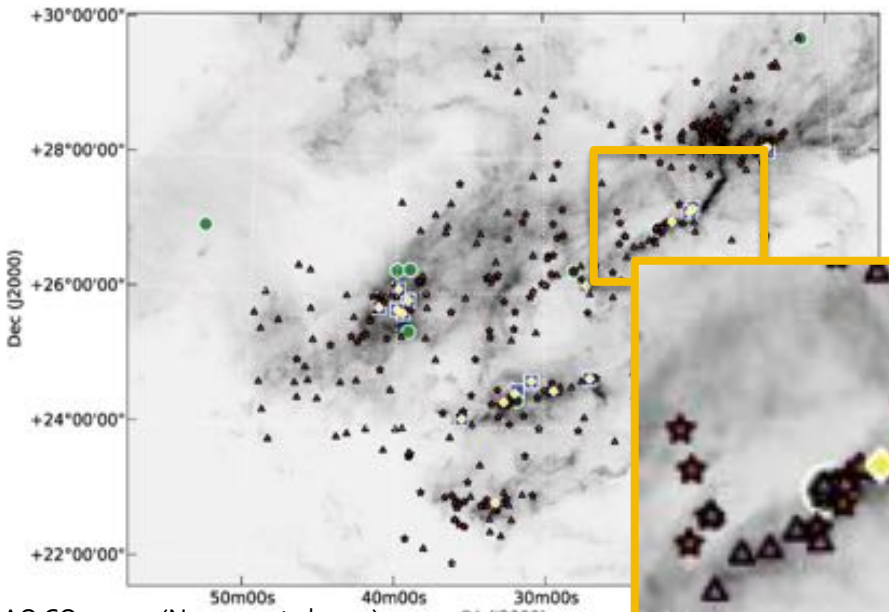
Spitzer mosaic of IRAC and MIPS images of Taurus, Mooley et *al* 2013

- Complete census (350 members) down to very low-mass stars (down to 0.02 Msun)

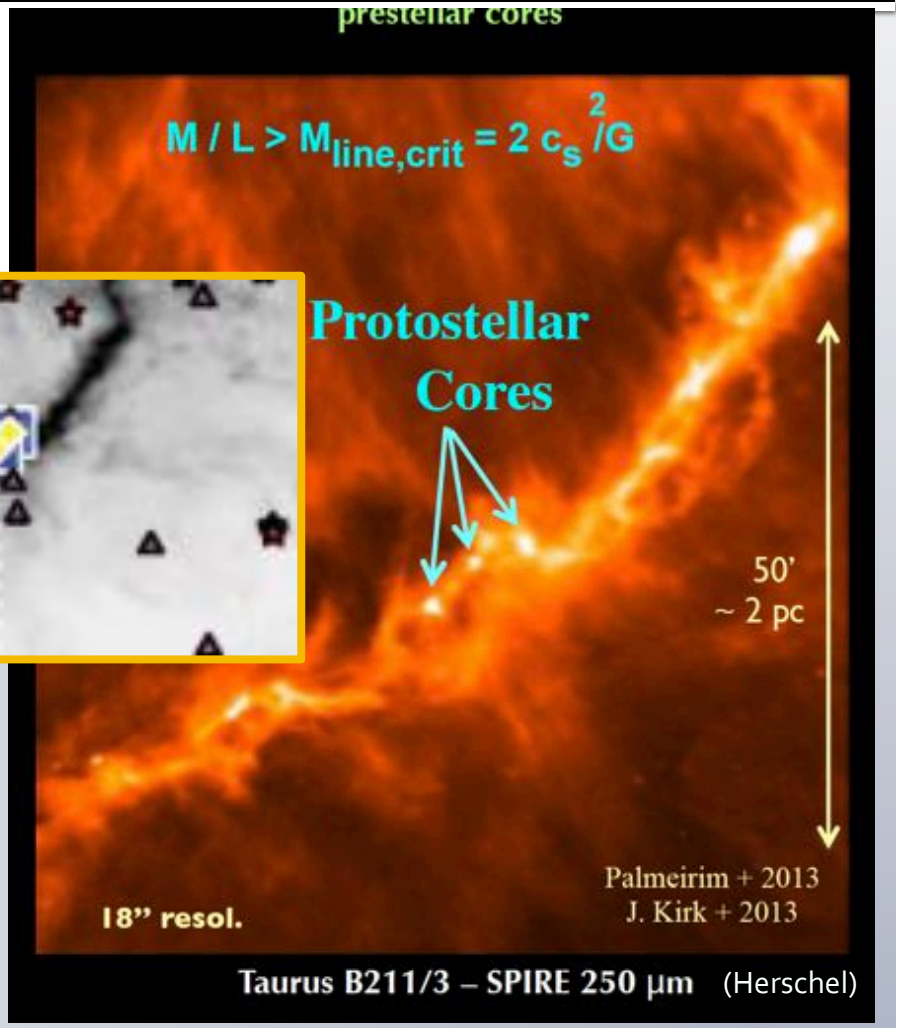


Spitzer Map of the Taurus Molecular Clouds

Why focusing on spatial distribution of young stars ?



FCRAO CO survey (Narayan et al 2012)



(Herschel)

Young stars trace the gas distribution from which they formed

-> **pristine imprints:** Powerful diagnostic to assess star cluster formation (Hartmann 2002)

Spatial clustering
Local substructures detection

Clustering algorithms

Study of unsupervised clustering algorithms, amongst the "jungle"

- Hierarchical techniques :
  - built-in hierarchy
  - single link technique although the most simple and reliable, suffers from chaining effect, noisy effects, complete clustering…
- Partition techniques (Kmeans) : fixed number of clusters, convex structure detection biased (voronoi based method),…

  Probability Model-Based Clustering (components mixture & EM)

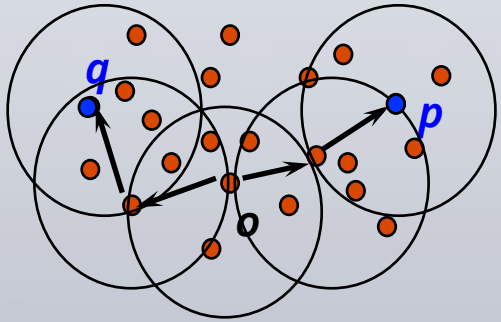
- **Density based techniques**

⇒ Dbscan algorithm appears to be the best choice for a spatial clustering for low-D data, it handles noise/outliers, partial clustering, arbitrary shape detection

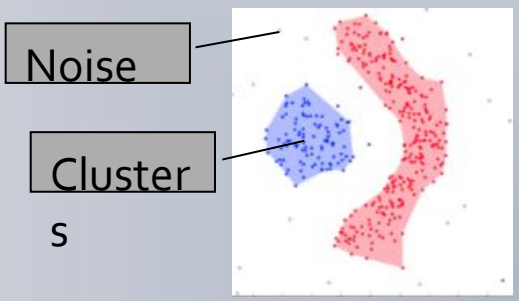
Key idea of dbscan

- Two parameters to define the neighborhood: radius ε and number of stars $>N_{min}$ around a star

- Key idea **:** two stars *p* and *q* belong to the same "cluster", based on the connectivity of the points having a similar neighbourhood density (Ester et al.,1996).



- **Noise /outliers** : set of stars that does not belong to any "groups" of the dataset

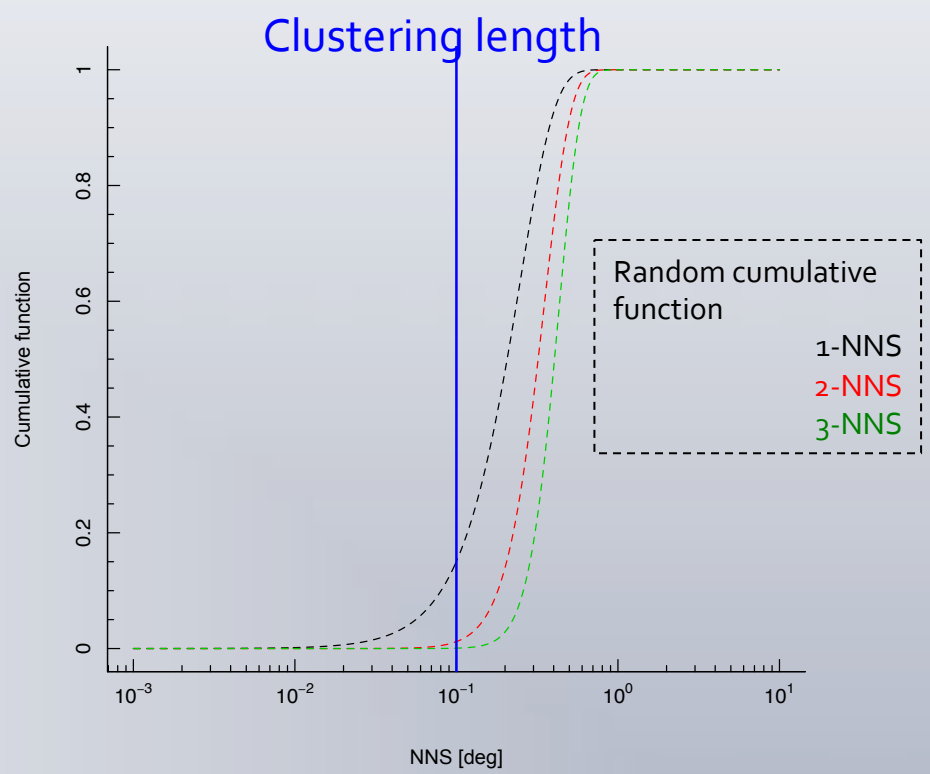


Detection at the 99.4% confidence level: constraints parameters ε and N_{min}

- One point correlation function to constraint Neighborhood **radius $\varepsilon = r_C$ =0.1 deg** (clustering length) based on **the one point correlation function**

- N_{min} set by the requirement of a high confidence level structure detection (>99.7%) *wrt* random cumulative function of nearest neighbors

- Stellar spatial structures with local density more than a factor 5 higher than the mean density in Taurus:
  - **> 130 stars/deg²**



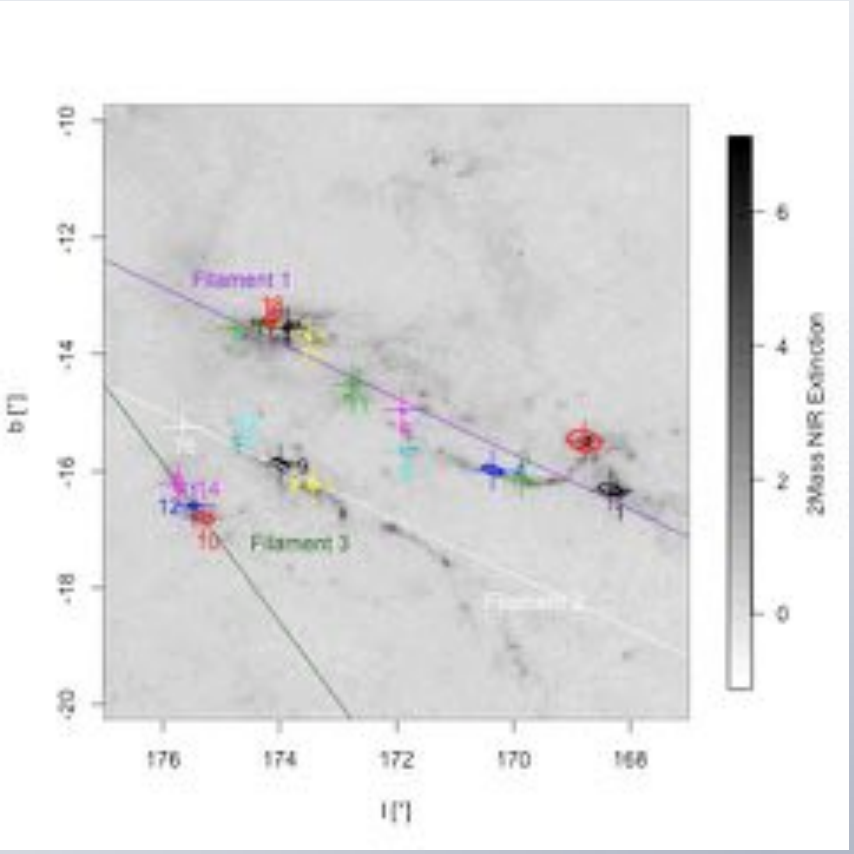
$$\mathcal{W}_1(r) = 1 - exp(-\pi\rho r^2)$$

$$\mathcal{W}_2(r) = 1 - (\pi\rho r^2 + 1)\, exp(-\pi\rho r^2)$$

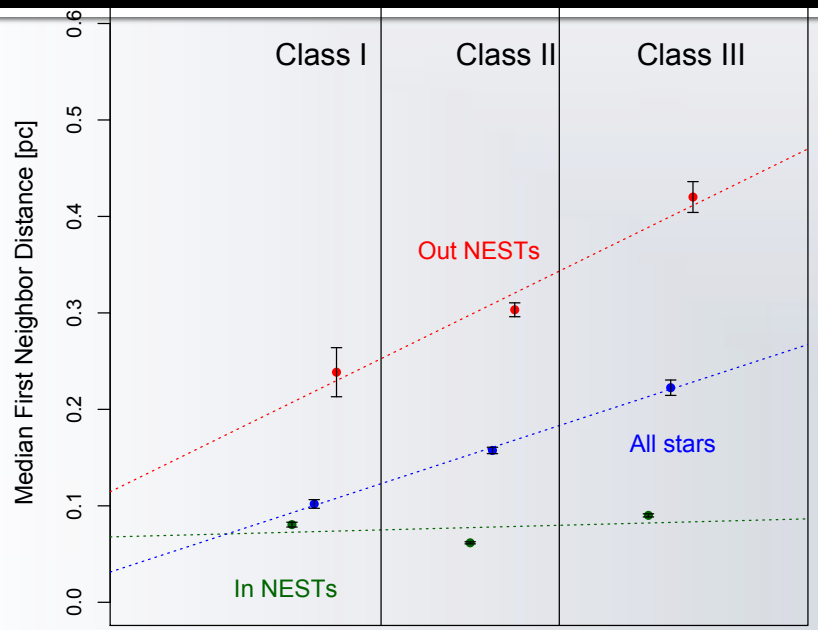
$$\mathcal{W}_3(r) = 1/2\left[exp(-\pi r^2)\left(-\pi\rho r^2(\pi\rho r^2 + 2) - 2\right) + 2\right]$$

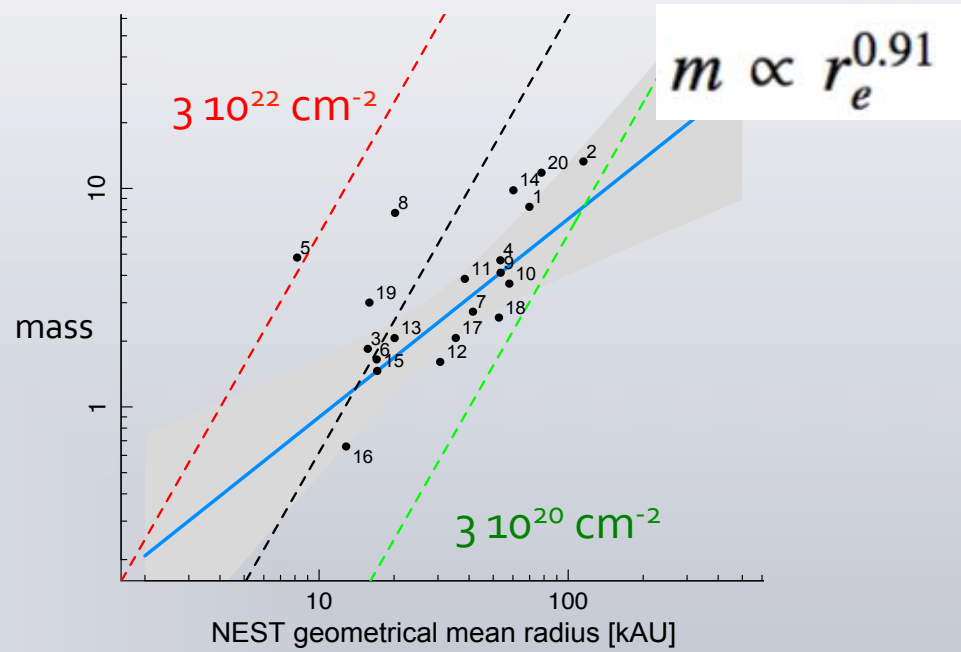
Detection and properties of 20 mini-clusters (NESTs)

- **20 very elongated « mini-clusters », the NESTs** (Nested Elementary Structures) along the filamentary gas structure
- contain 45% of the whole star population
- Members: 4 to 23 stars
- Size from 5 kAU to 80 kAU median (25 kAU), ie UWPs
- Mass from 0.66 Msun to 13.3 Msun (3.34 Msun median)
- Stellar density from 3 10^2 deg^{-2} to 1.5 10^4 deg^{-2} (median ≈10^3 deg^{-2} , ie 168 pc^{-2}



Youth of the NESTs





No sign of dynamical evolution sign as seen the 1-NNS median as a function of the class

No sign dynamical evolution sign as seen by the NEST mass-radius relation

72% of class I are in the NESTs -> they may be pristine imprints of star formation

One step further

- This detection of overdense stellar region gives information on one scale
- It does not give what's going on at longer length scale
- Need an algorithm to build multiscale analysis
- We choose to implement a Recursive dbscan

Multiscale analysis

Hierarchy: ML-dbscan

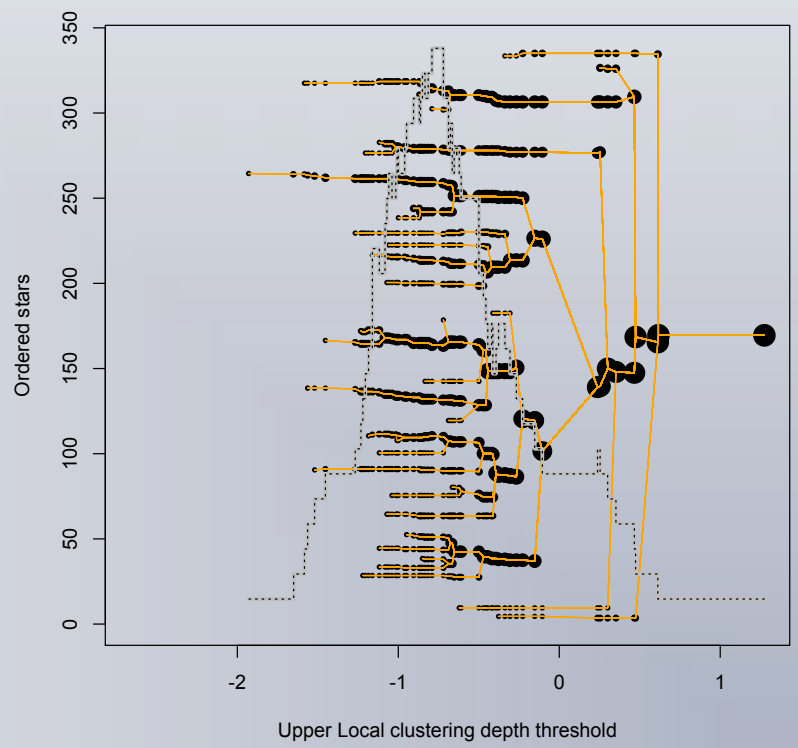
=> **ML-Dbscan : recursive call on *ε–dbscan*** : [Lmax, lmin], δε

- Varying length-scale range allows to build a full multi-level framework

- Step 1 : At each level ε detection of connecred components
- Step 2 : Clustergraph conception: how the components are connected from a level to the next
- Step 3 : hierarchy depth index (Strahler modes) and multiscale spectrum

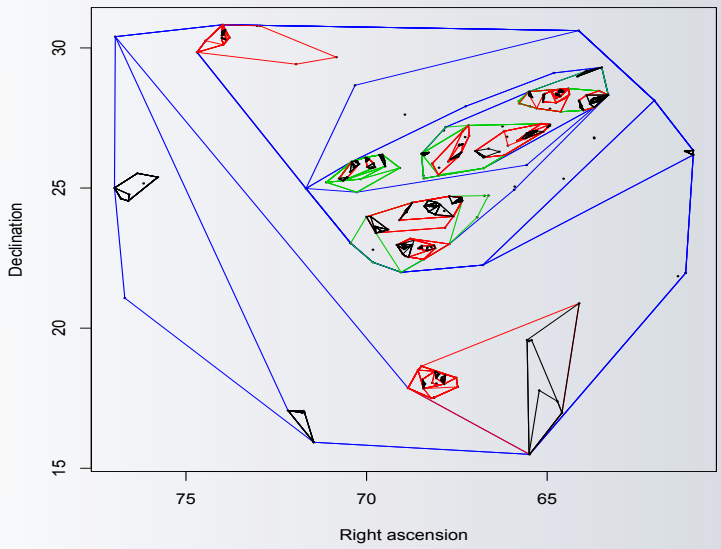
ClusterTree conception multiscale spectrum

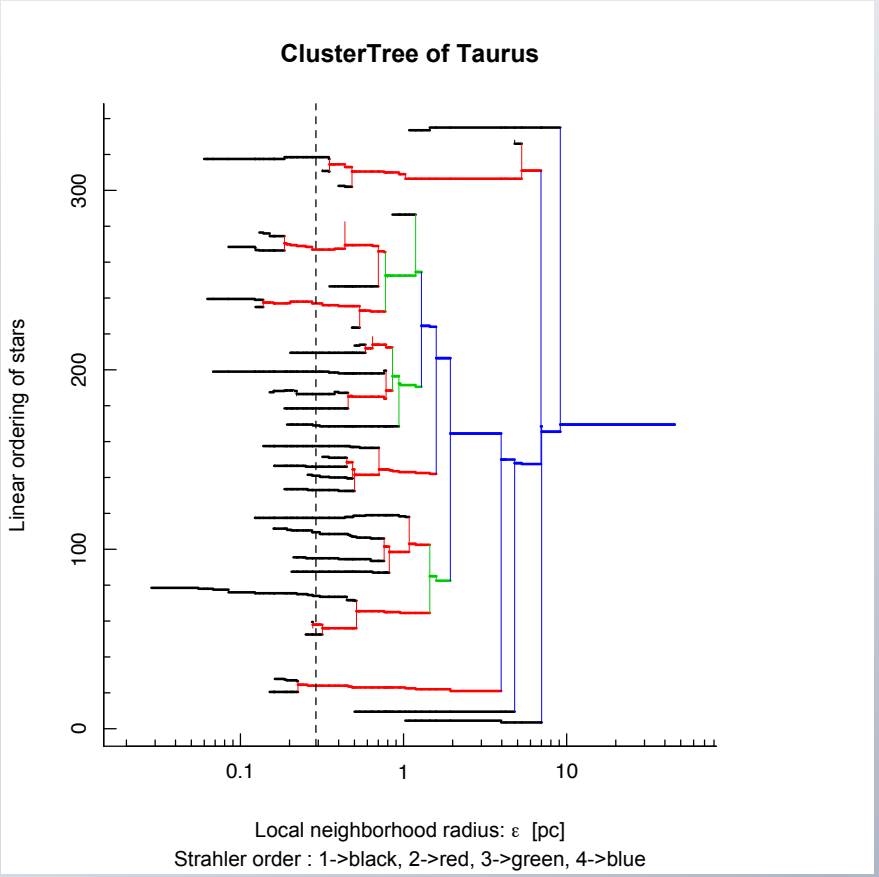
- ClusterTree construction (2D-Layout)
  - X-axe ε local length scale level
  - Y-axe : linear ordering of stars as obtained from hierarchical single linkage
  - Nodes : density-connected components from ML analysis, ie set of stars within the component)
- Node X-coordinate: ε level (step of iteration or value) at which the density component is obtained
- Node Y-coordinate: barycenter of the component based on the topological ordering of the stars within the component
- Edges/links : describe from one level ε to another the stars that are in common in



ClusterTree of Taurus YSOs convex hull structures

Strahler order : quantify the complexity of a hierarchy based on the successive levels of merging substructures





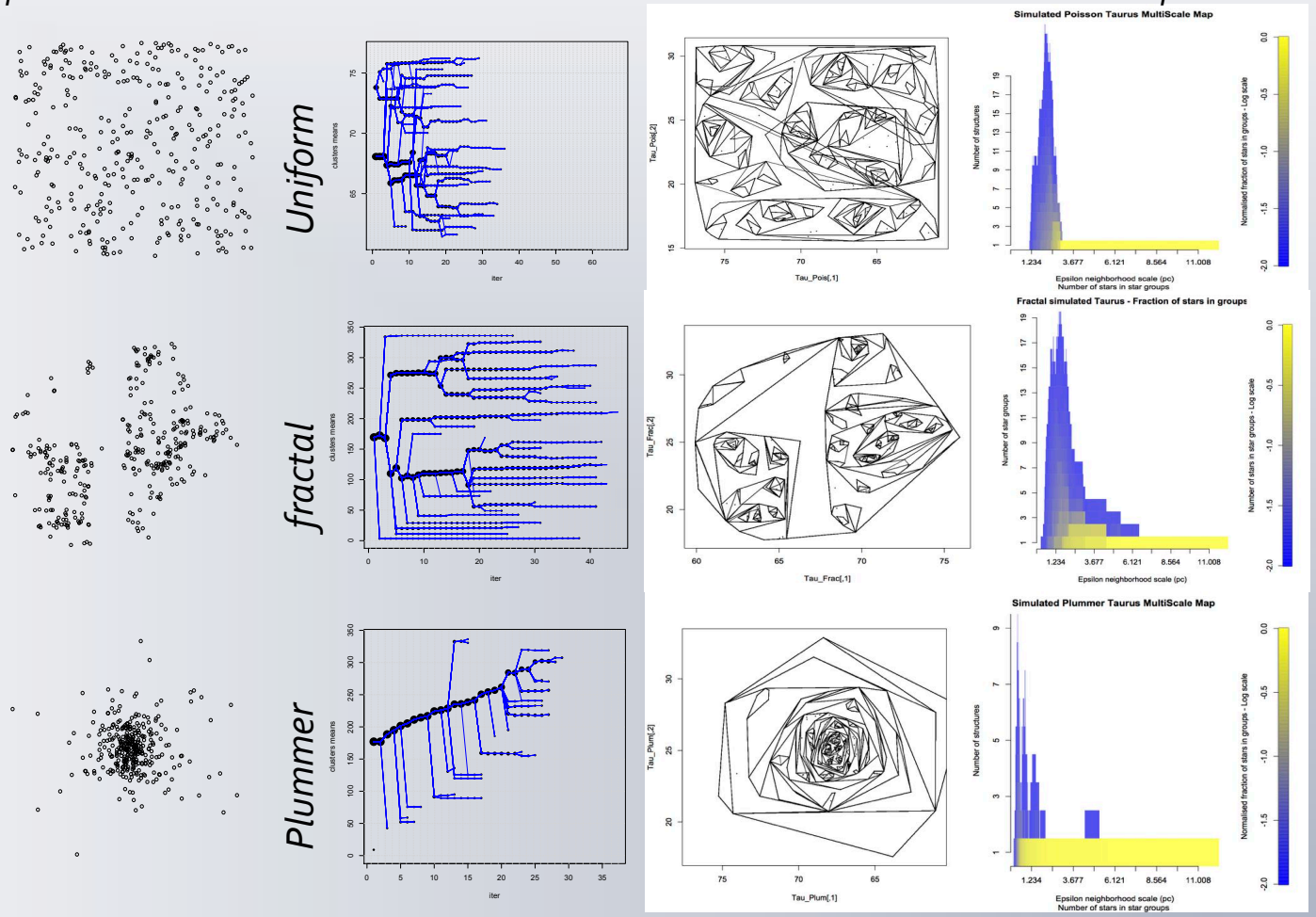
Simulated star clusters

Spatial distribution | *ClusterTree* | *Convex Hull* | *Multiscale spectrum*

[Poisson distribution](#)

[Fractal distribution](#)

[Plummer distribution](#)

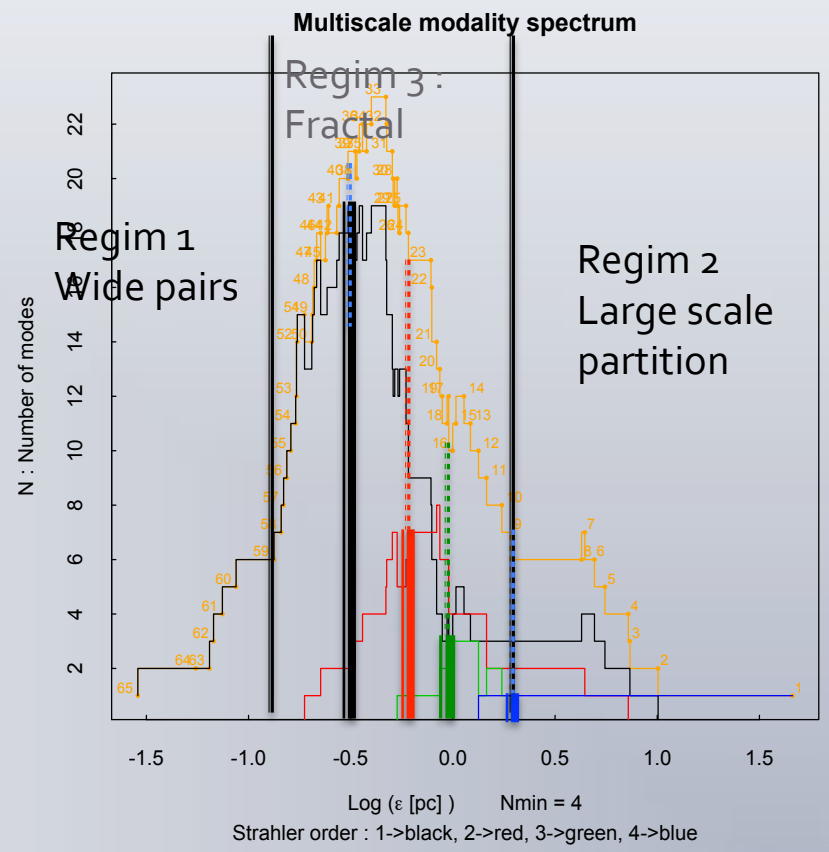


Clusters simulation with "Mcluster" Kuepper et al, 2011

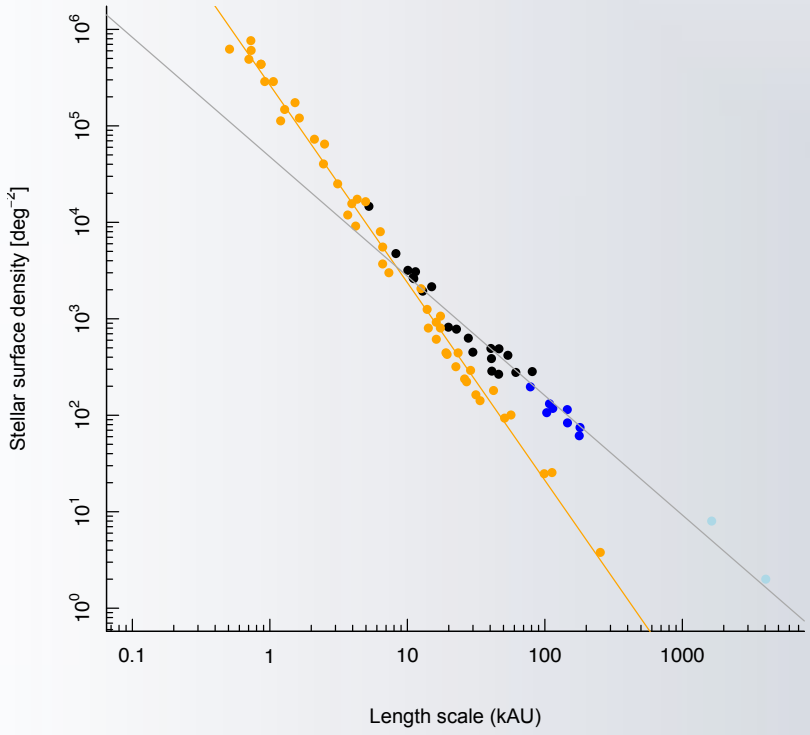
Isabelle Joncour

Multiscale spectrum and Spatial regimes in Taurus

- Identification of global features and patterns at specific local ε−length scale
- 3 distinct regims in modality spectrum
  - Partition at global scale
  - Fractal hierarchy at intermediate scale (substructuration of clusters)
  - Slope Break at shorter length : UWPs regime
- 4 main levels of hierarchy (Strahler number)



Multiscale analysis: from pristine to dynamical evolution imprints?



Surface stellar density from UWPs to the whole Taurus: 2 trends

- UWPs-NESTs: a range of different scale stellar structures retain primordial features even after gas has been accreted or dispersed
- From NESTs to loose groups: dynamical imprints?

Conclusion

Conclusions

- Tools ready to analyse mutiscale structure of spatial distribution of stars anf perform all kind of statistical analysis

- Analysis of hierarchical structure: from multiples, ultra-wide pairs, NESTs and groups of higher hierarchy in Taurus

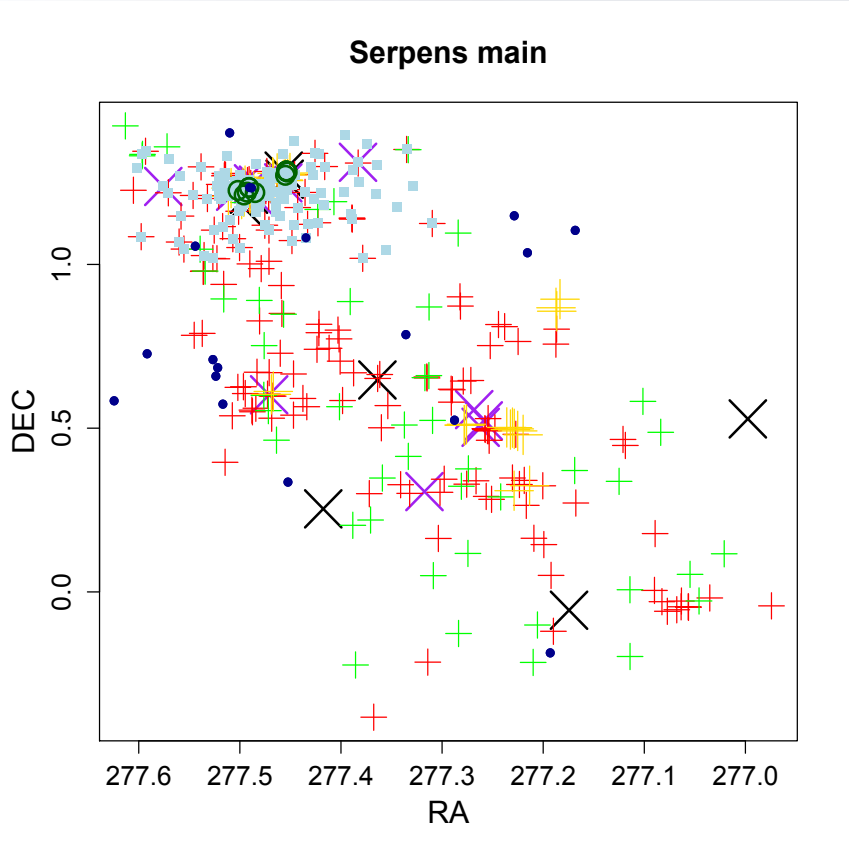
- New constraints for star formation: 72% Youngest objects (class I) are concentrated in NESTs.
- Statistical characteristics of NESTS (geometry, alignment, spacing, members, ...)
- A break in the surface stellar density as a function of characteristic size of the structure suggests pristine imprints to dynamical evolution
- The NESTs are located at the break point betwen UWP and loose groups

7 slides

First brand new (and raw) results on the focus: Serpens main

Collaborators Lee Mundy and Marc Pound

Building a more complete and accurate YSOs catalog in Serpens



YSOs C2d catalog (262)

- Class I[Black x]
- Flat[Purple x]
- II[Red +]
- III[Green +]
- x[Yellow +]

ALMA obs. (11)

- mm sources[Dark green o]

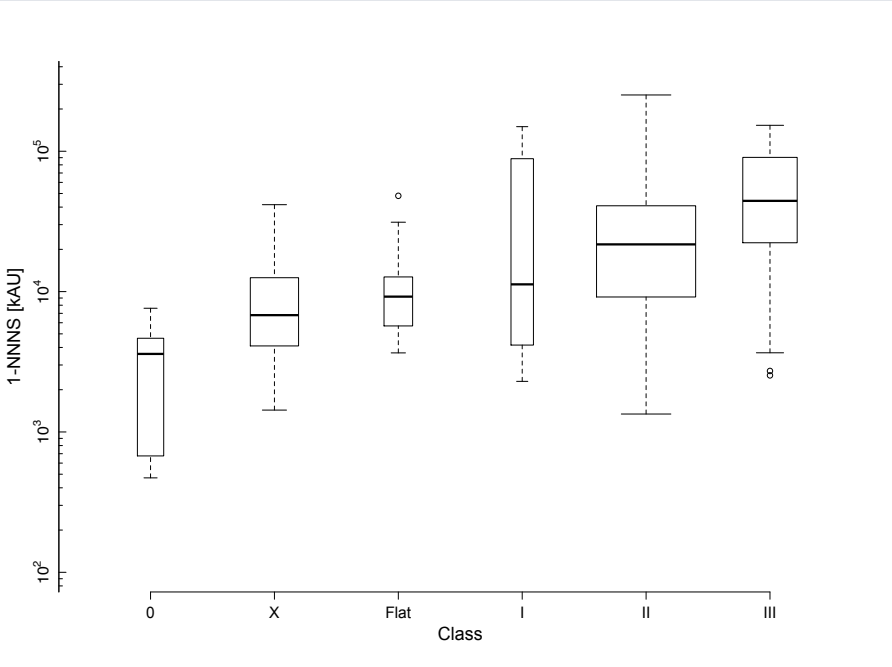
C2d catalog : new YSO candidate (21)

- 70 um [dark blue filled o]

- *light blue 2017 Getman catalog*

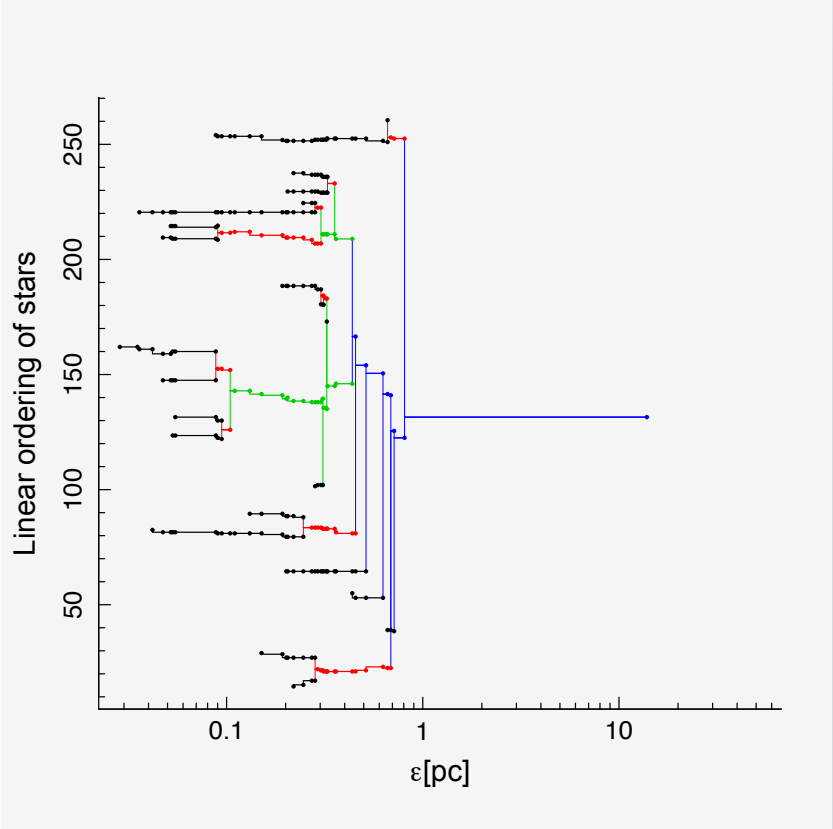
First Neighbor distribution as a function of Class

Class	1-NNS median [kAU]
0	3.6
x	6.8
flat	9.2
I	12.3
II	21.7
III	44.3

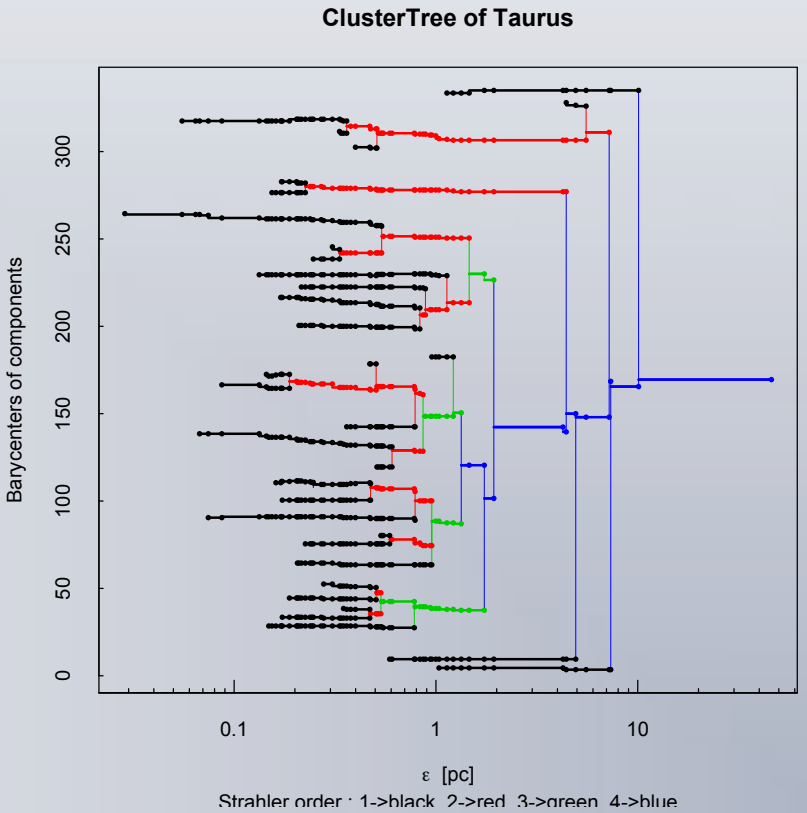


ClusterTree

SERPENS MAIN



TAURUS



Multiscale structures (color Strahler number)

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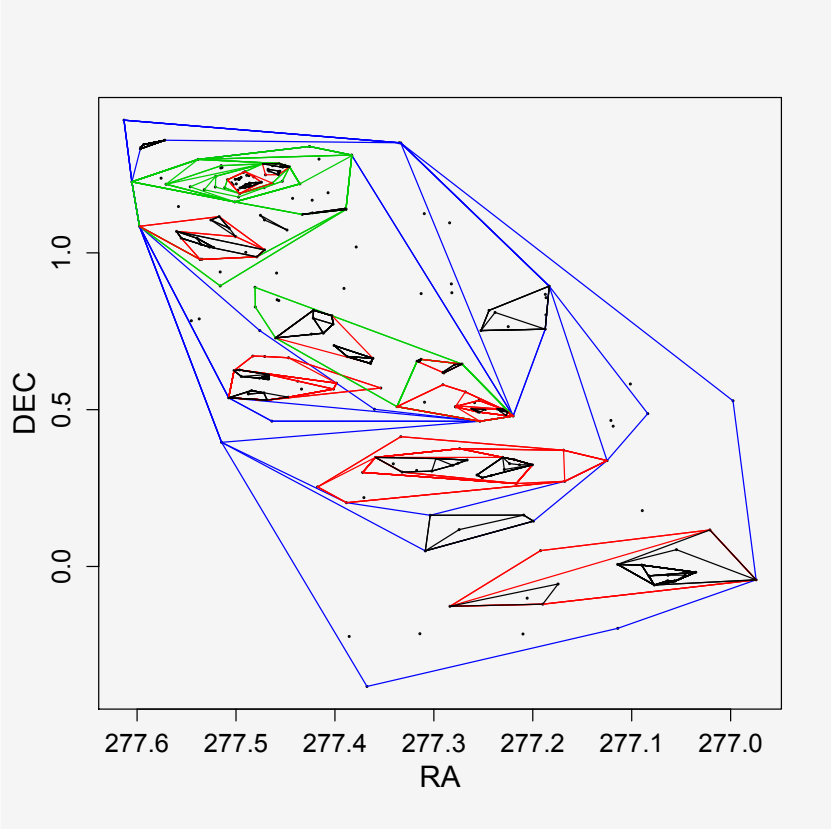

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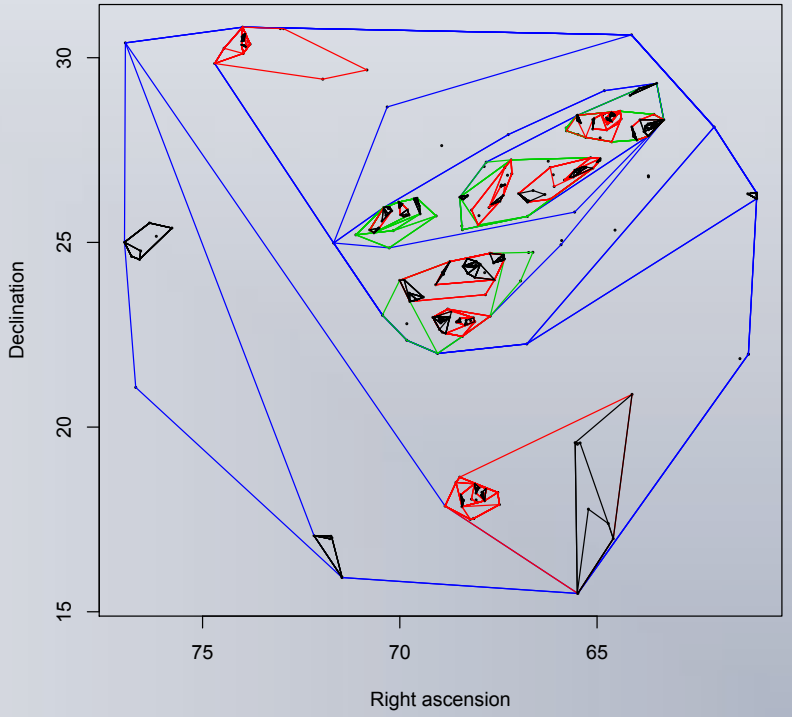

Multiscale and modality spectrum

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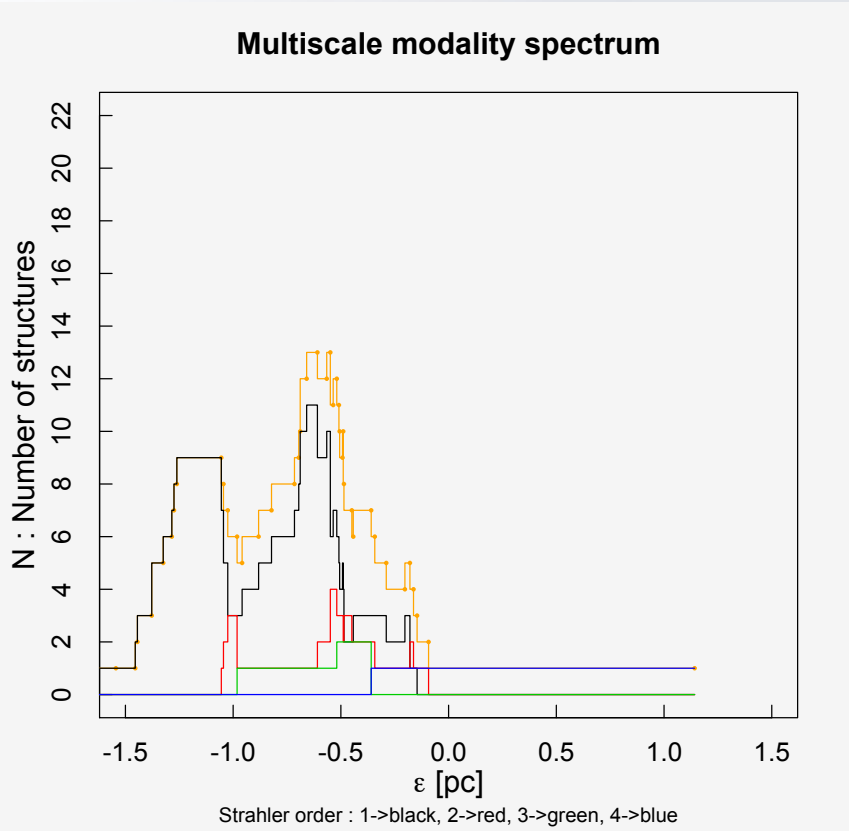

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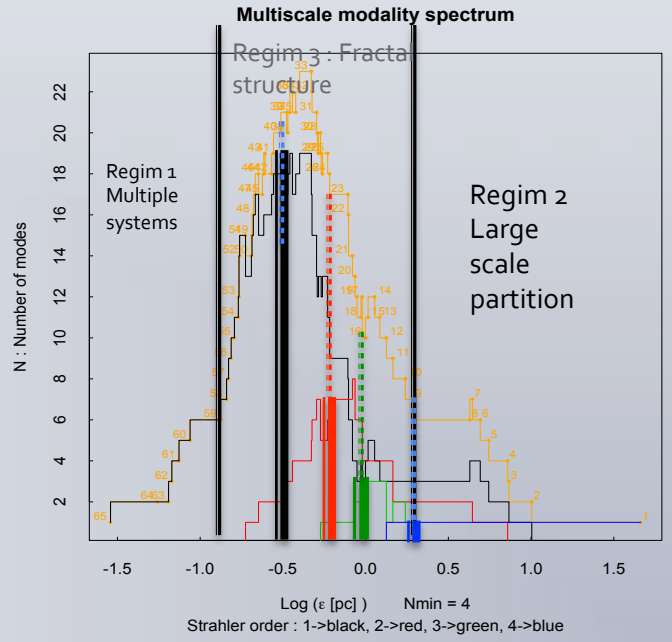
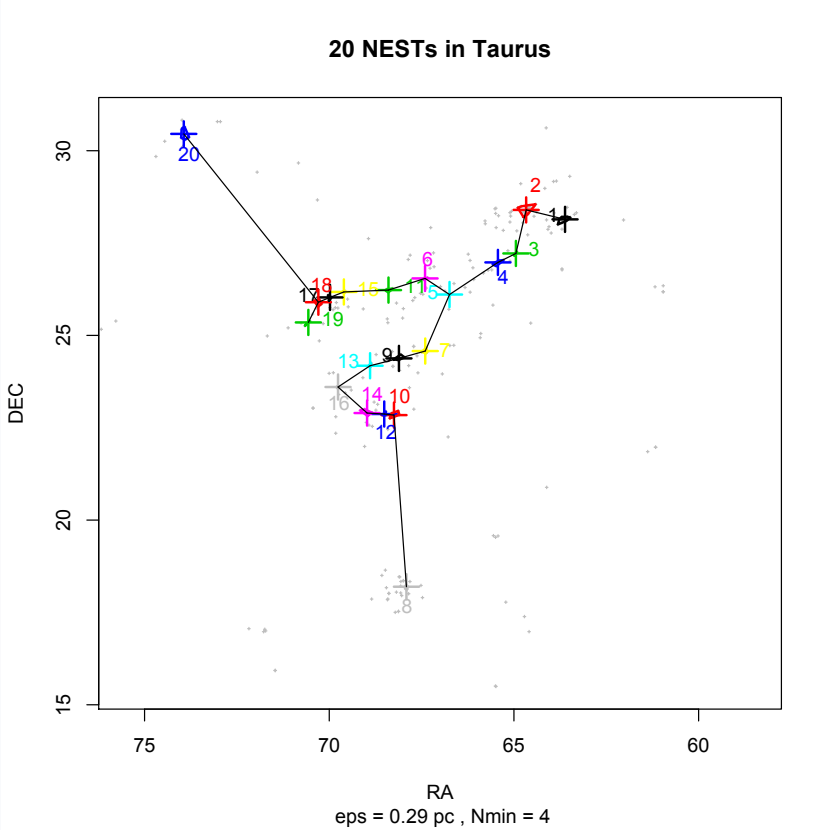


Spatial distribution of NESTs

TAURUS



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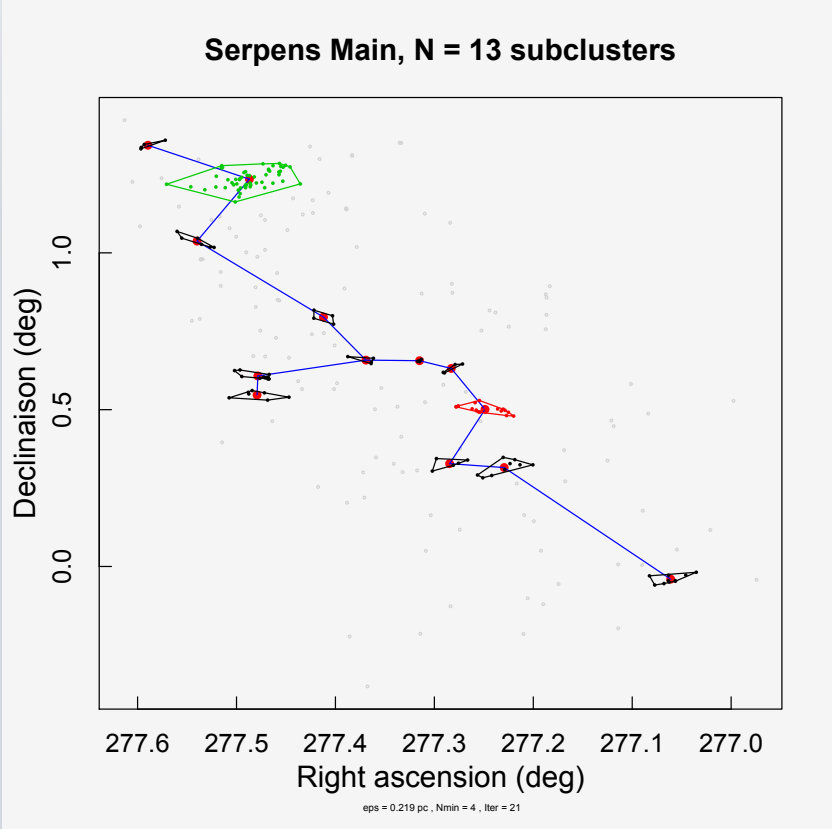
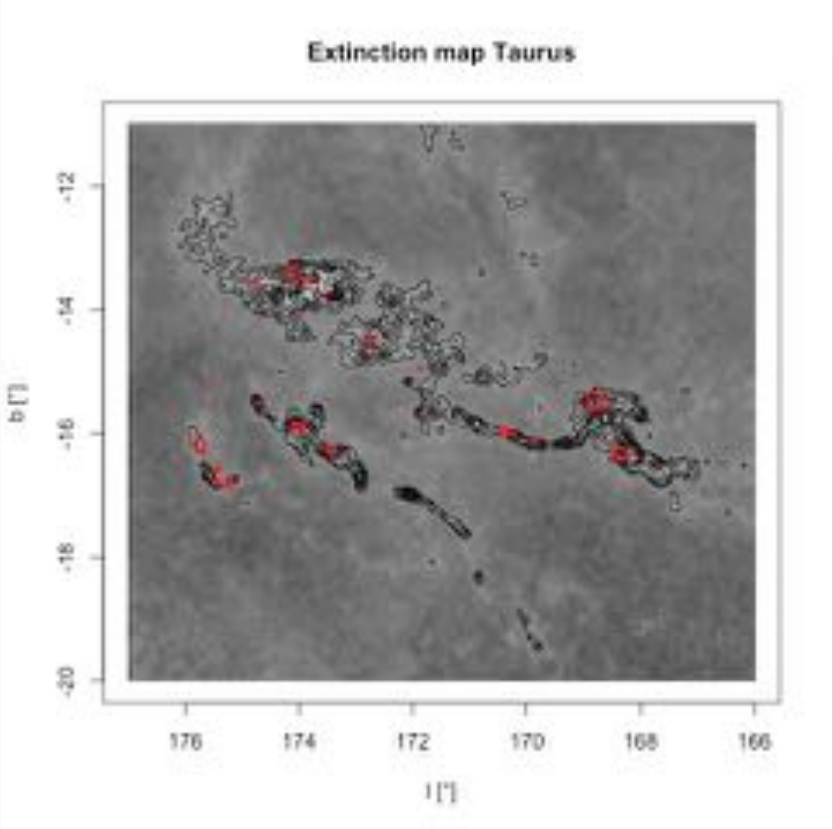


NESTs on NIR extinction map

TAURUS



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