Exposing Star Formation through the spatial structure of young stellar objects

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We detect the most significant local spatial substructures of young stellar objects (YSOs) in 39 star-forming regions. We compare them to the distribution of massive stars and molecular gas to shed light on the star formation (SF) process.

Catalog of YSO substructures

1. Consistent, robust substructure retrieval

S2D2 (González+21, available for the community here)

- **S2D2** is a clustering tool to search for **NESTs (Nested Elementary STructures)** based on DBSCAN (Ester+96) and nearest neighbour statistics (Joncour+ 17, 18).
- NESTs are very small and compact structures in the YSO distribution, significant above random expectation, that in pristine regions can trace the preferential sites of star formation.

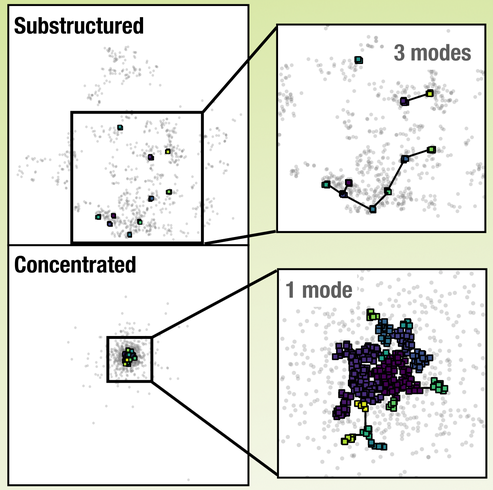


Fig1: Example of NESTs and modes retrieved in substructured and concentrated regions

- **S2D2** was calibrated in synthetic clusters of substructured, homogeneous and concentrated spatial distributions with robust and consistent results.
- The distribution of NESTs traces the large scale structure: **the significant modes of SF.**
- We separate the significant modes of SF by pruning the branches of the Minimum Spanning Tree of the NESTs (inter-NEST distance) that are larger than 25% the size of the region.

- Concentrated regions have only one significant mode of SF, i.e. are **unimodal,** while substructured ones are **multimodal** (Fig. 1).

2. Homogeneous sample

MYStIX (Feigelson+13)
SFiNCs (Getman+17)

- YSO selection:
  - MID-IR
  - X-ray
  - Catalogued OB stars

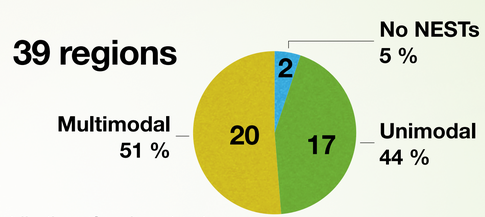


Fig 2: Distribution of region structure

Relation between SF modes and the gas and massive star distributions

- We classify the SF modes, according to whether they can be (Table 1):
  - **Embedded** in their natal cloud, as traced by the highest Herschel 500 micron emission in the region.
  - **Influenced by massive stars** in their surroundings.

Table 1:Summary of types of modes

Herschel data in 33 regions 57 modes		Overlap with gas (0.05% most intense emission)	
		YES: 56.1%	NO: 43.9%
OB Stars	NO: 54.3%	T1 36.8%	T3 17.5%
	YES: 45.7%	T2 19.3%	T4 26.4%

- **T1** modes seem to trace areas of active SF of low mas stars and are the majority type in unimodal regions (Fig. 3).
- In **T4** modes we expect the massive stars to have contributed to the lack of gas, hindering SF. T4 are mainly in multimodal regions (Fig. 4).
- The interplay between YSOs, gas and massive stars in **T2** and **T3** modes needs to be individually assessed.

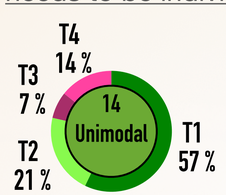


Fig 3: Proportion of types of modes in unimodal regions

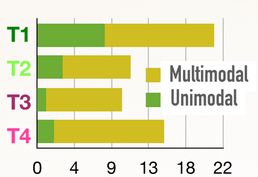
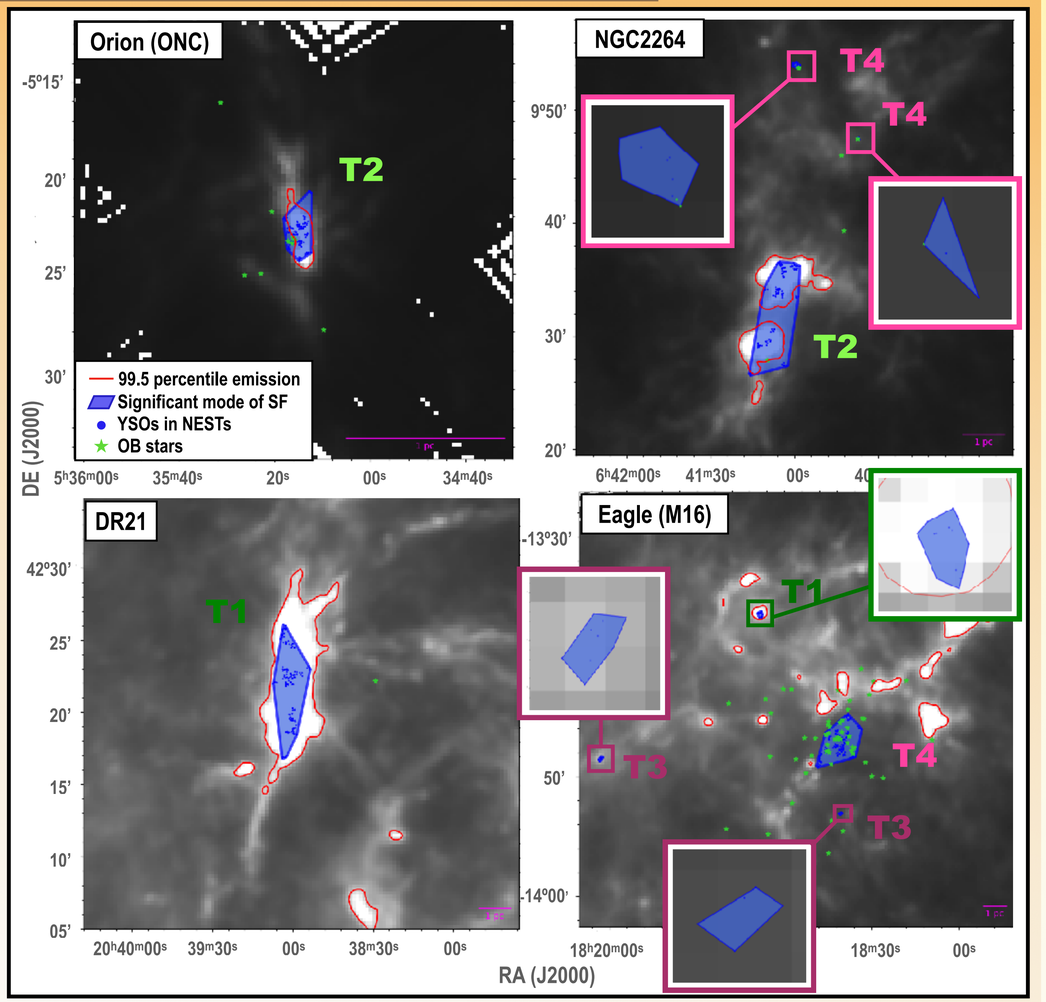


Fig 4: Structure of the containing region by mode



- NESTs trace the significant modes of SF, making a powerful analysis tool to examine the variety that SF can display within a region.
- **We have identified the discrete modes of SF** and shown how they can be related to other variables in their environment (González+ in prep)
- A full, deep understanding of the complexities of SF requires also to study the relationship of modes with kinematical and evolutionary status of YSOs.