



Dendrogram analysis of Large-Area CARMA Images in Perseus: the Dense Gas in NGC 1333, Barnard 1, and L1451

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Dendrogram analysis of Large-Area CARMA Images in Perseus

Big Picture Question

- What causes such diversity in the amount of star formation between molecular clouds and even within individual molecular clouds?

Dendrogram analysis of Large-Area CARMA Images in Perseus

Perseus
Molecular
Cloud

- 235 pc away (Hirota et al. 2008)
- Several clusters of dust and stars within few parsecs show a wide range of activity.

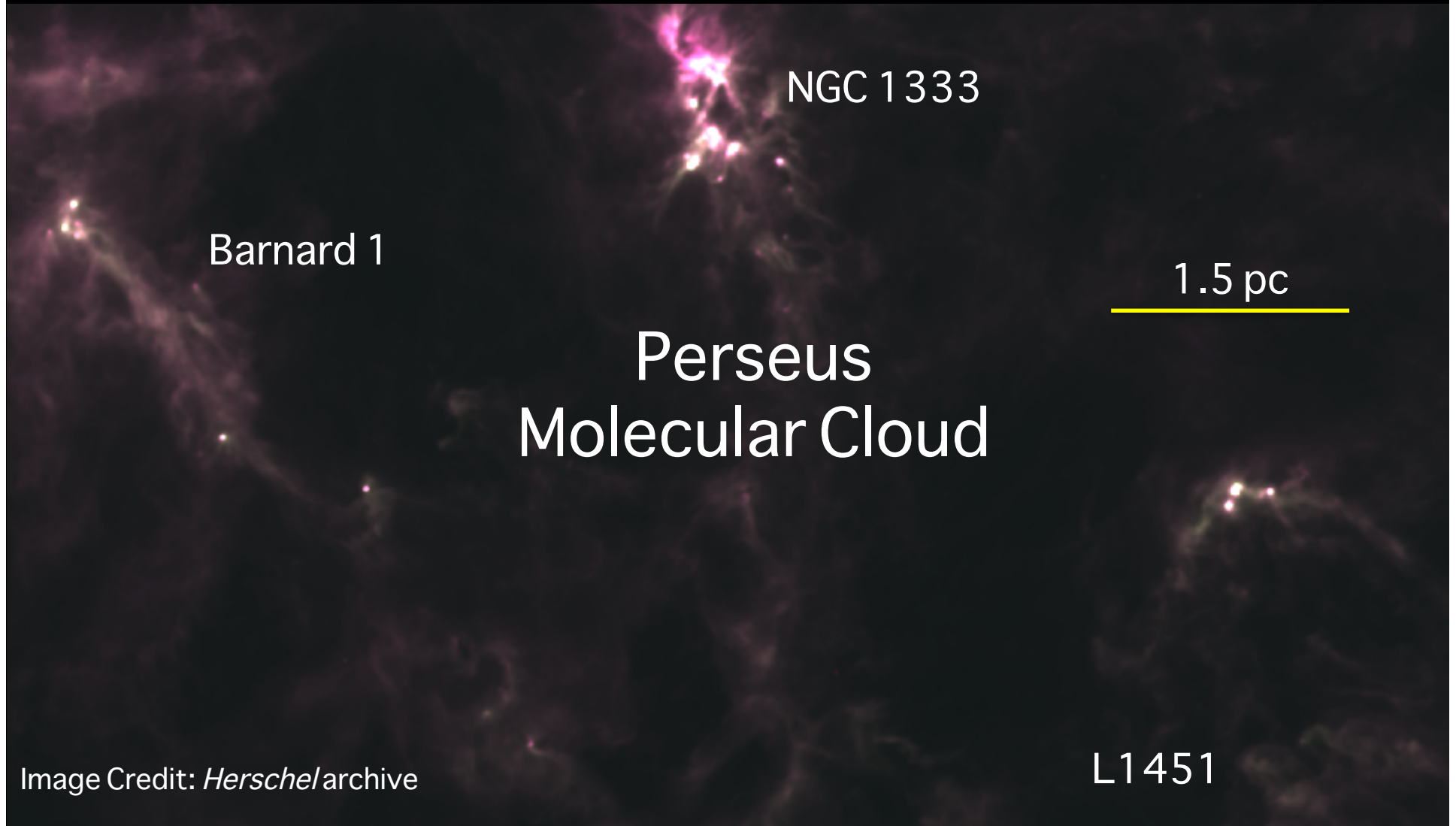


Image Credit: *Herschel* archive

L1451

Dendrogram analysis of Large-Area CARMA Images in Perseus

Observational Experiment

- ① Observe the dense gas in diverse clusters : CLASSy
- ② Create *non-binary* dendrogram representation of dense gas.
- ③ Compare dendrogram structure with star formation diversity.

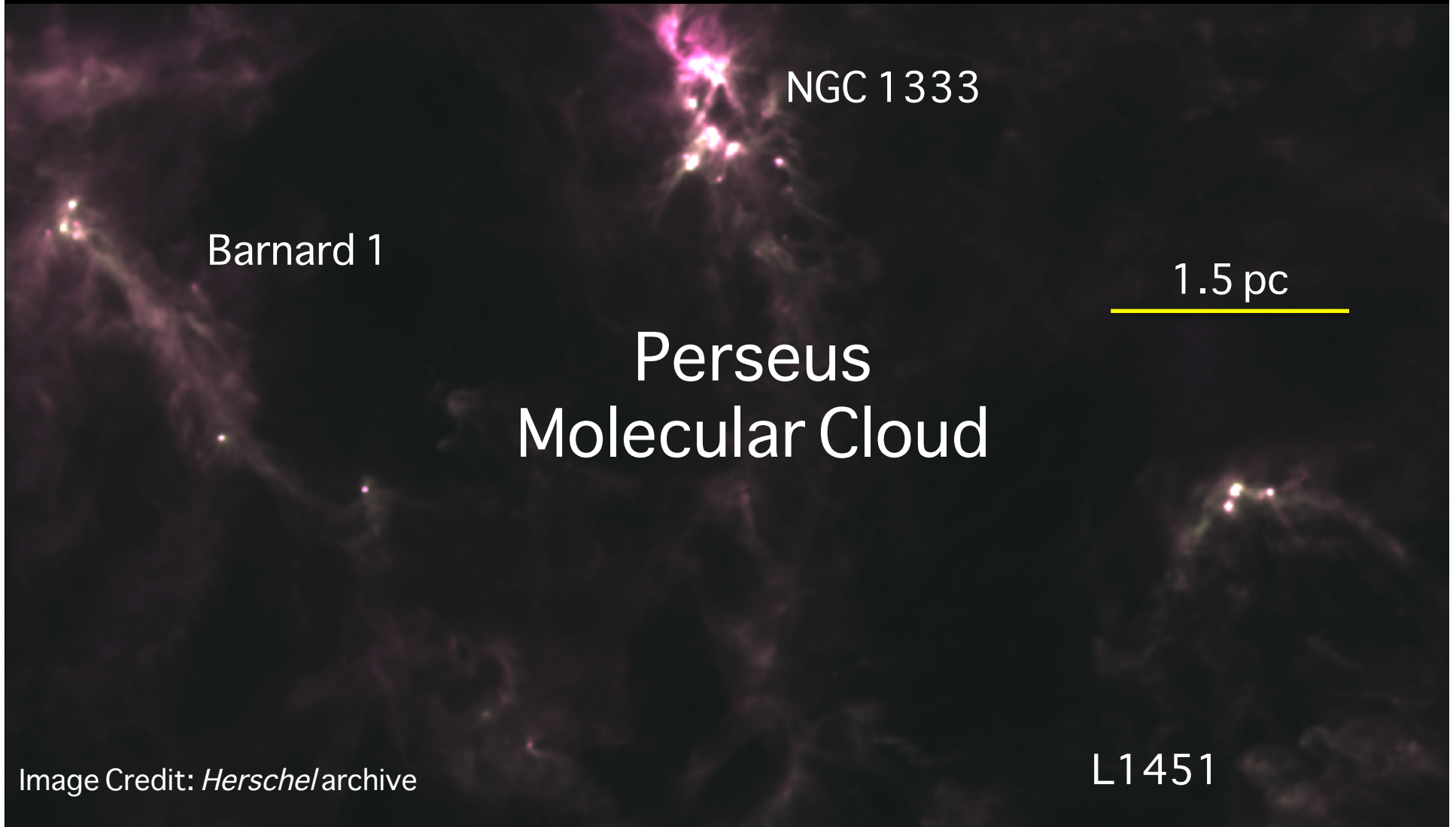
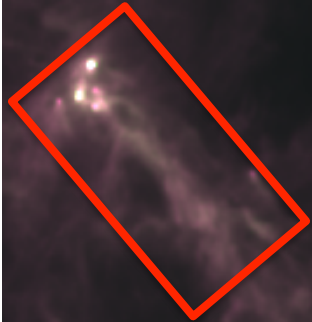


Image Credit: *Herschel* archive

L1451

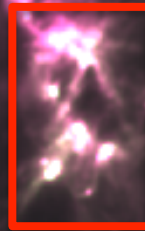
① Observe the dense gas in diverse clusters : CLASSy

Composite *Herschel*
250, 350, 500 μm view



Barnard 1
Moderate-Activity
 ~ 150 sq. arcmin.

~ 3.5 pc



NGC 1333
High-Activity
 ~ 100 sq. arcmin.

CARMA Key
Project
mapping areas

~ 5.5 pc

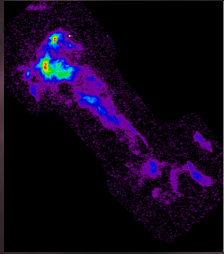


L1451
Low-Activity
 ~ 150 sq. arcmin

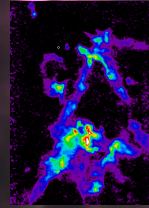
- Three levels of star formation activity
- Sensitivity to wide range of spatial scales
(~ 1600 AU up to ~ 1 pc)
- N_2H^+ , HCN, HCO^+ J=1-0

① Observe the dense gas in diverse clusters : CLASSy

Composite *Herschel*
250, 350, 500 μm view



$\sim 3.5 \text{ pc}$



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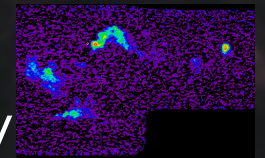
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Barnard 1
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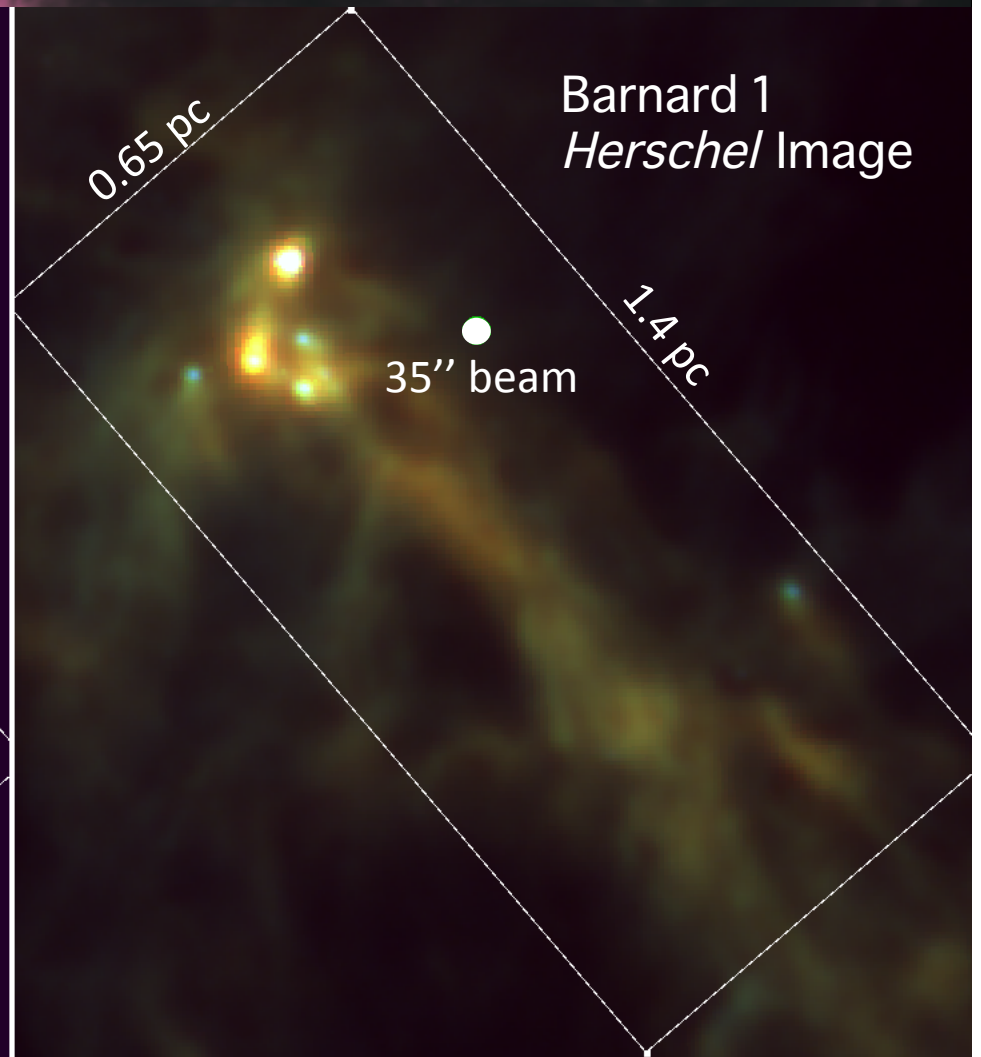
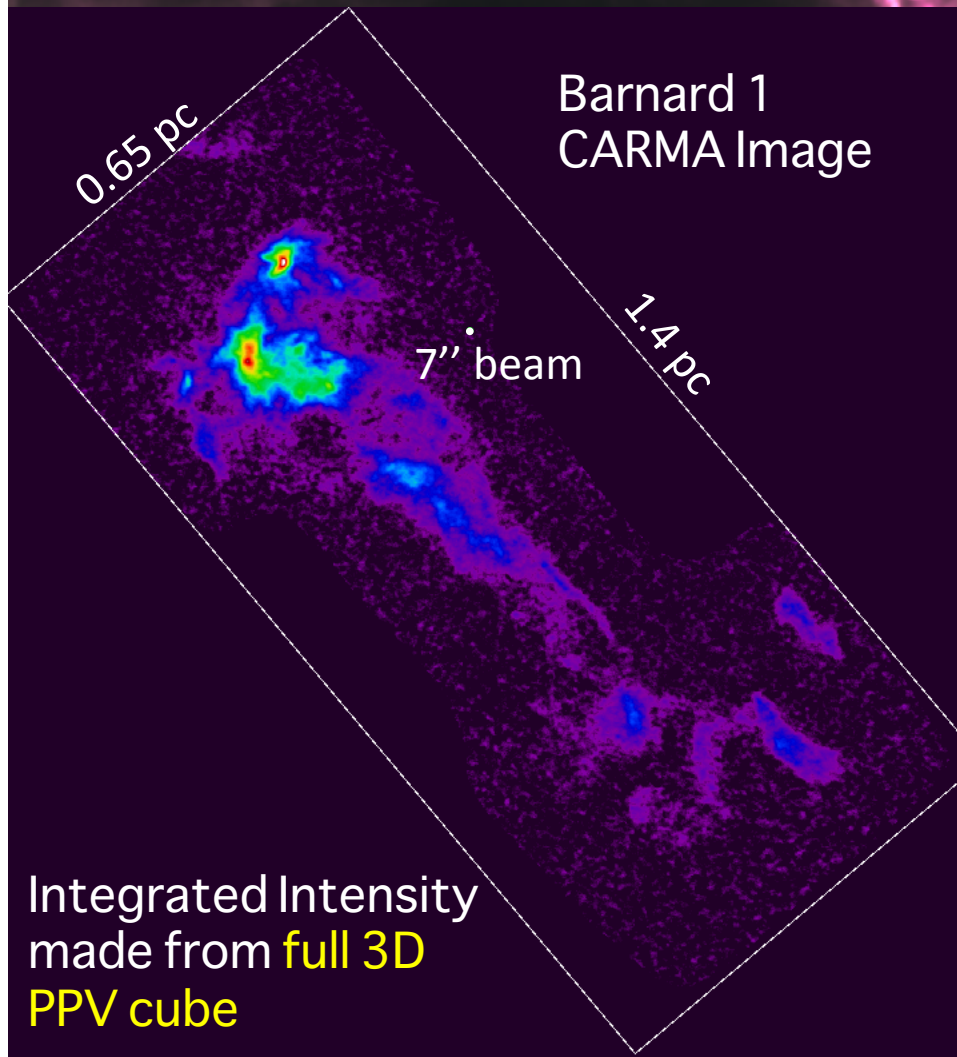
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- Sensitivity to wide range of spatial scales
($\sim 1600 \text{ AU}$ up to $\sim 1 \text{ pc}$)
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L1451
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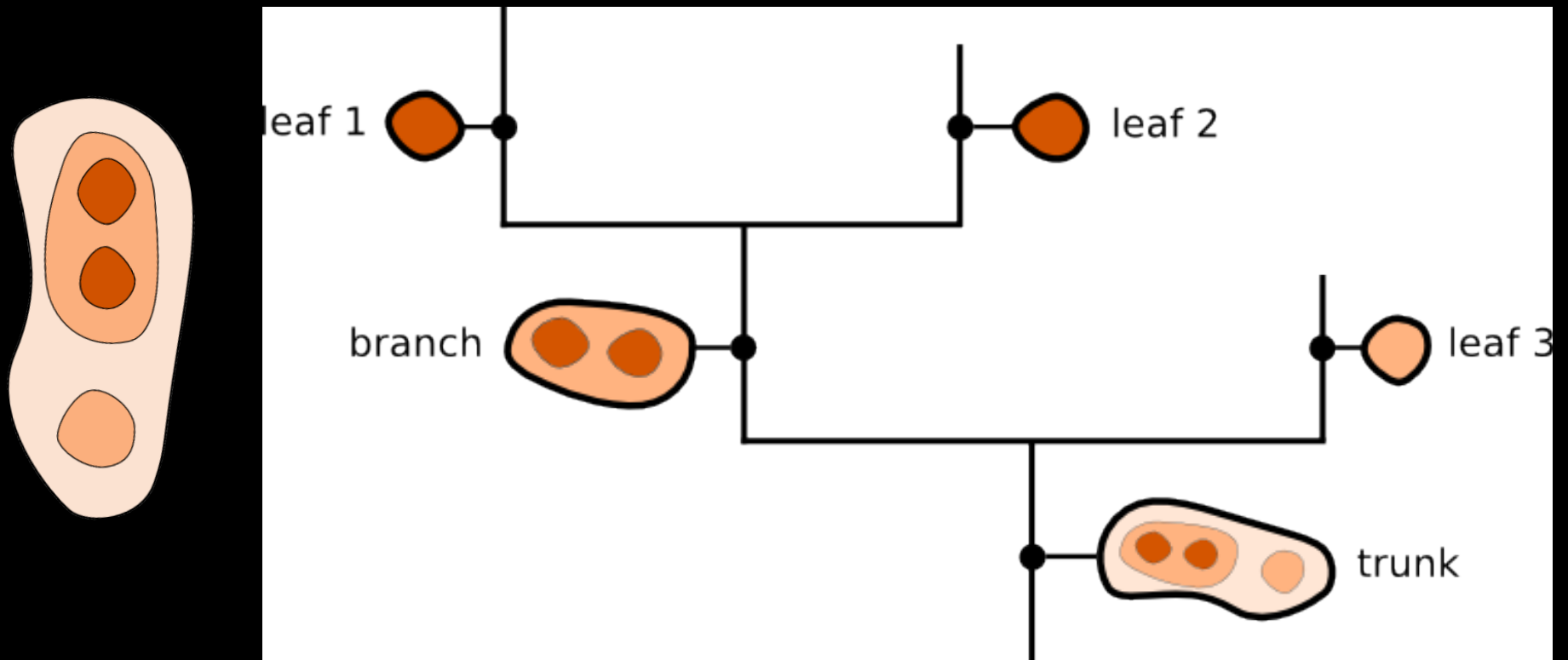


① Observe the dense gas in diverse clusters.



② Create *non-binary* dendrogram representation of dense gas.

Toy Dendrogram Example

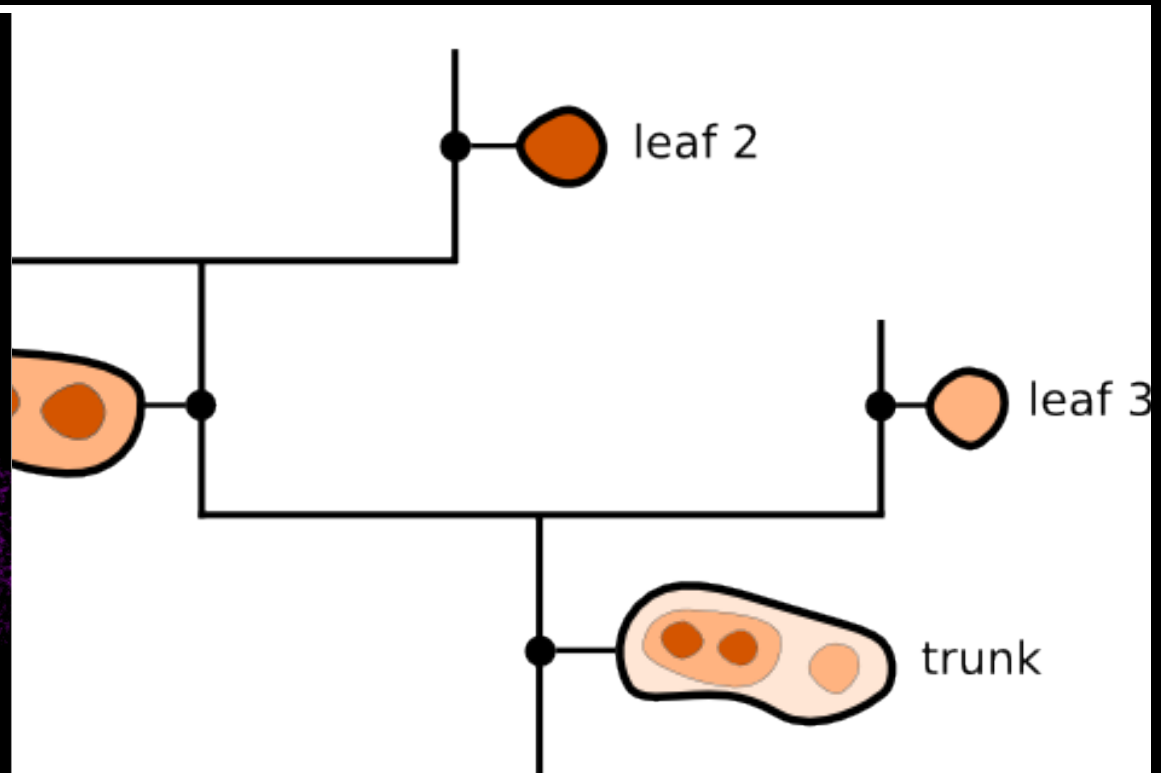
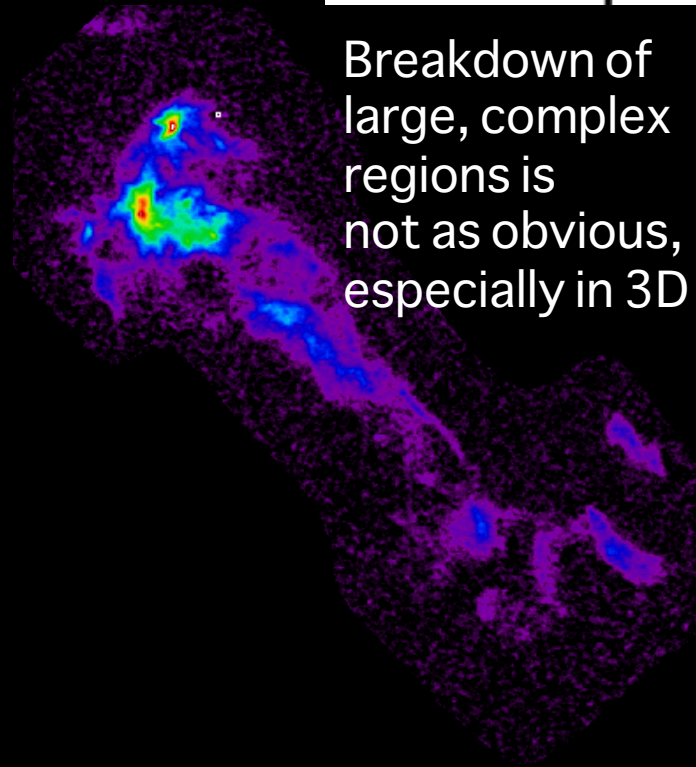


A dendrogram is a useful quantization of 1D, 2D, or **3D** structures. (Our CARMA images are 3D PPV cubes.)
This dendrogram shows a 2-level hierarchy.

Image Credit: dendrograms.org

② Create *non-binary* dendrogram representation of dense gas.

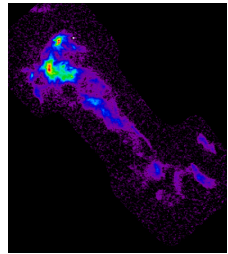
Toy Dendrogram Example



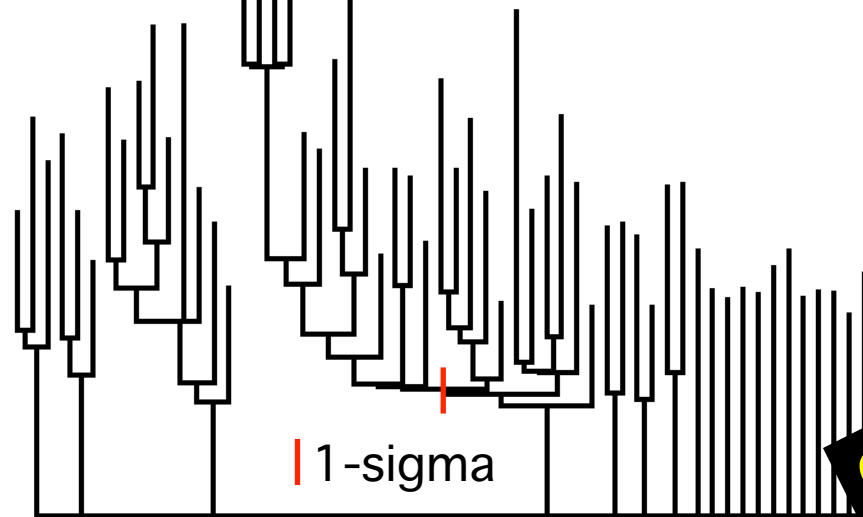
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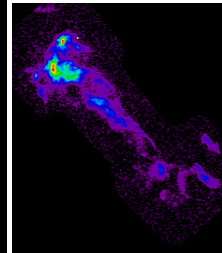
Dendrograms from Real Data



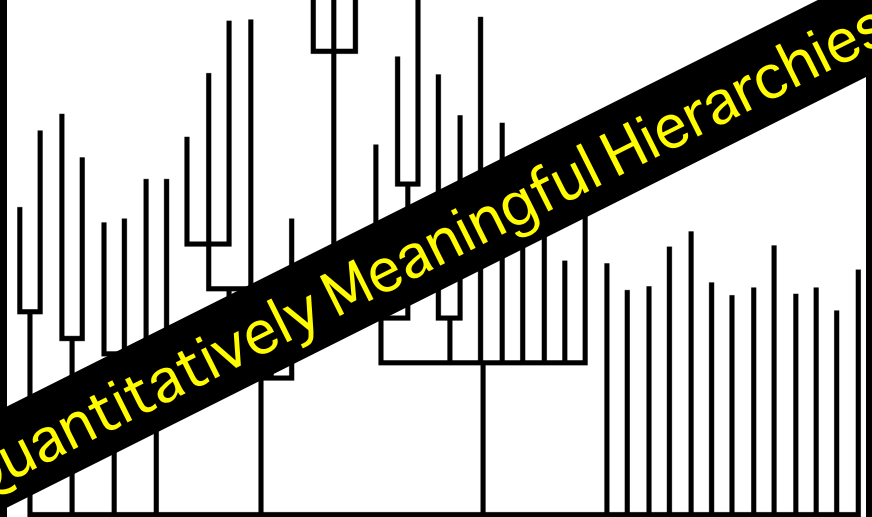
Barnard 1
 N_2H^+ Hierarchy
*produced from
standard
algorithm*



Forces binary branching → true hierarchical structure is unknown



Barnard 1
 N_2H^+ Hierarchy
*produced with
new, non-binary
algorithm*

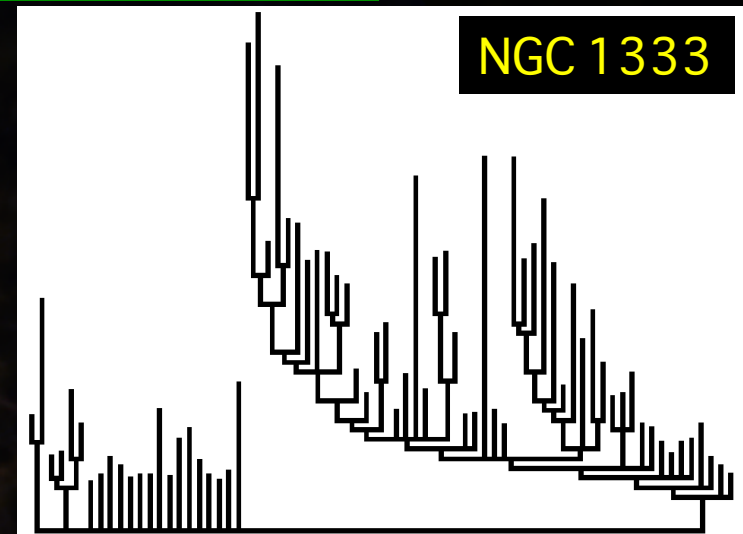
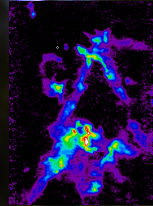
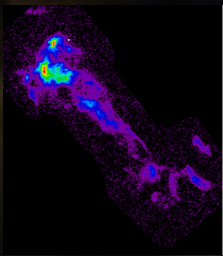


Quantitatively Meaningful Hierarchies

Allows non-binary branching → meaningful hierarchical structure – can use tree statistics (e.g., HS92)

② Create *non-binary* dendrogram representation of dense gas.

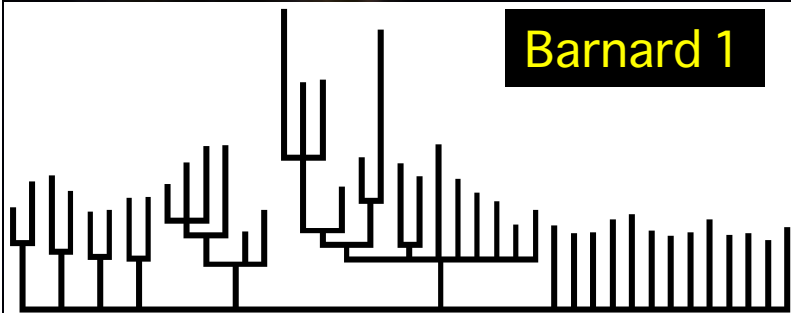
N_2H^+ Non-Binary Dendrograms Across Perseus



NGC 1333

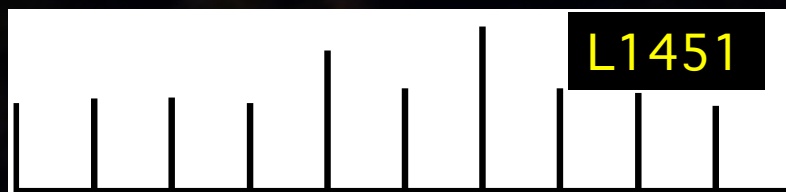
16-Level Hierarchy

Dense gas in NGC 1333 has more hierarchical complexity than in Barnard 1; L1451 dense gas shows no hierarchical structure.



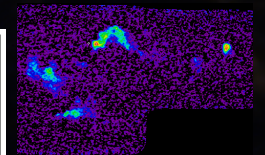
Barnard 1

4-Level Hierarchy



L1451

0-Level Hierarchy



③ Compare dendrogram structure with star formation diversity.

Star Formation Activity Across Perseus

NGC 1333

<i>Spitzer</i> YSOs	70
<i>Herschel</i> 70 micron sources	25
CARMA 3 mm continuum sources	17
SFE _{cloud} (Jørgensen 2008)	14%

Cluster Activity (Stellar Content + Dust):
NGC 1333 > Barnard 1 > L1451

Barnard 1

<i>Spitzer</i> YSOs	12
<i>Herschel</i> 70 micron sources	9
CARMA 3 mm continuum sources	4
SFE _{cloud} (Jørgensen 2008)	5.4%

L1451

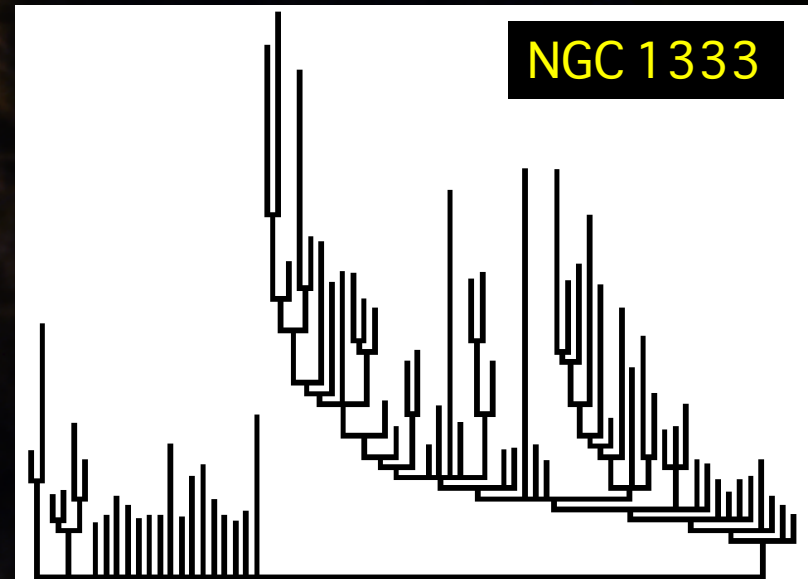
<i>Spitzer</i> YSOs	0
<i>Herschel</i> 70 micron sources	0
CARMA 3 mm continuum sources	1
SFE _{cloud}	0%

③ Compare dendrogram structure with star formation diversity.

Star Formation Activity Linked to Dense Gas Hierarchy

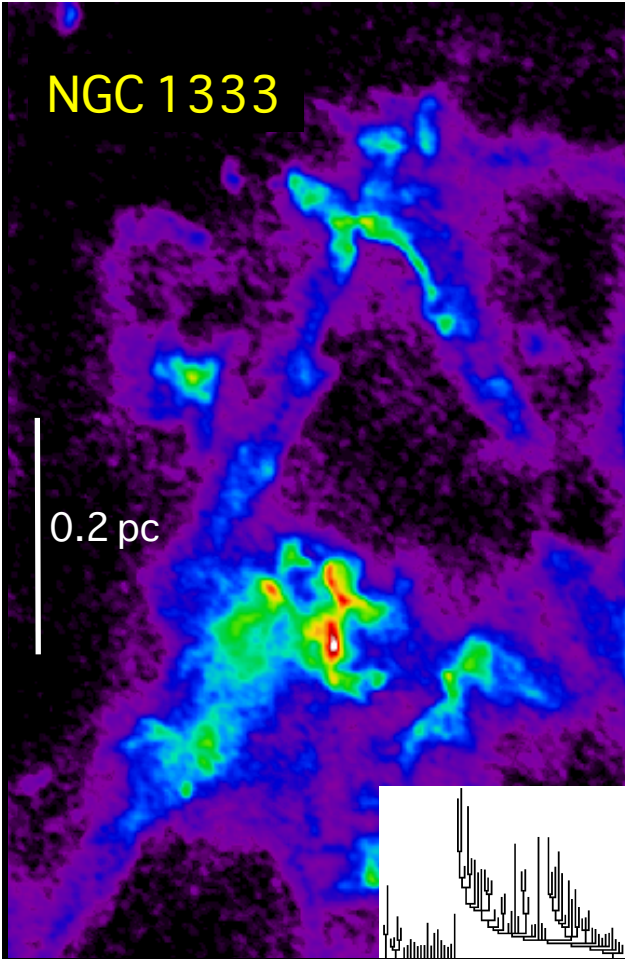
NGC 1333

<i>Spitzer</i> YSOs	70
<i>Herschel</i> 70 micron sources	25
CARMA 3 mm continuum sources	17
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The diversity of star formation correlates with the diversity of dense gas hierarchical complexity on scales from $\sim 0.01 - 1$ pc.

NGC 1333



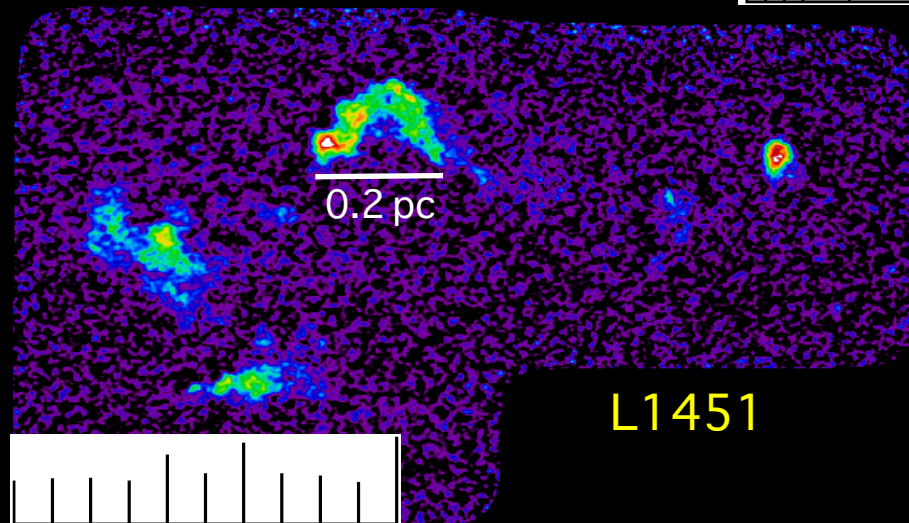
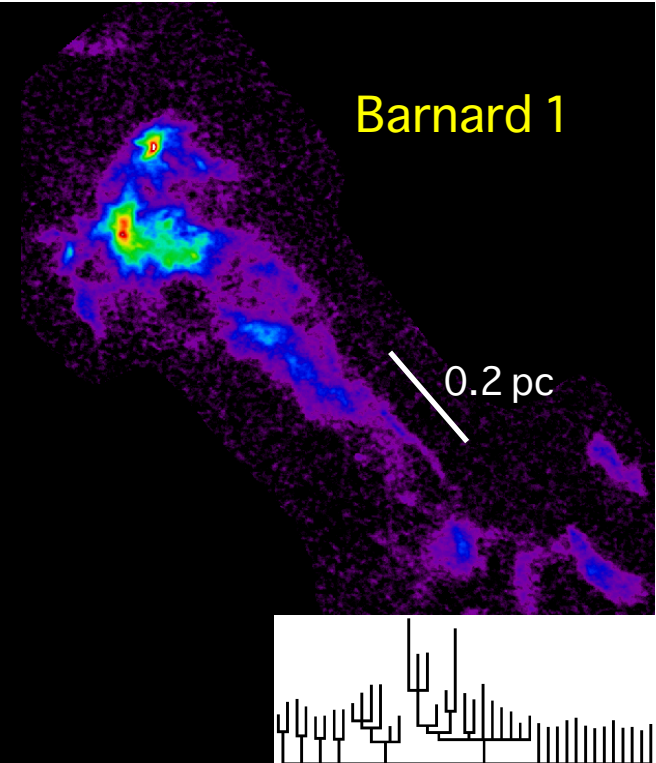
Showing CLASSy
maps of N_2H^+
integrated intensity

Key Point:
Star formation
activity



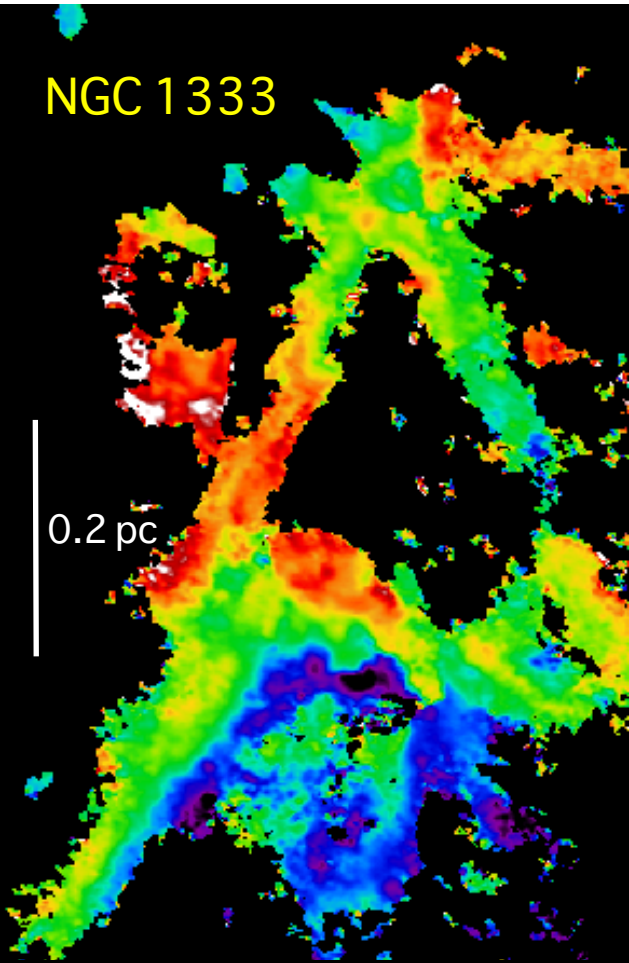
Hierarchical
complexity
of dense gas

Barnard 1

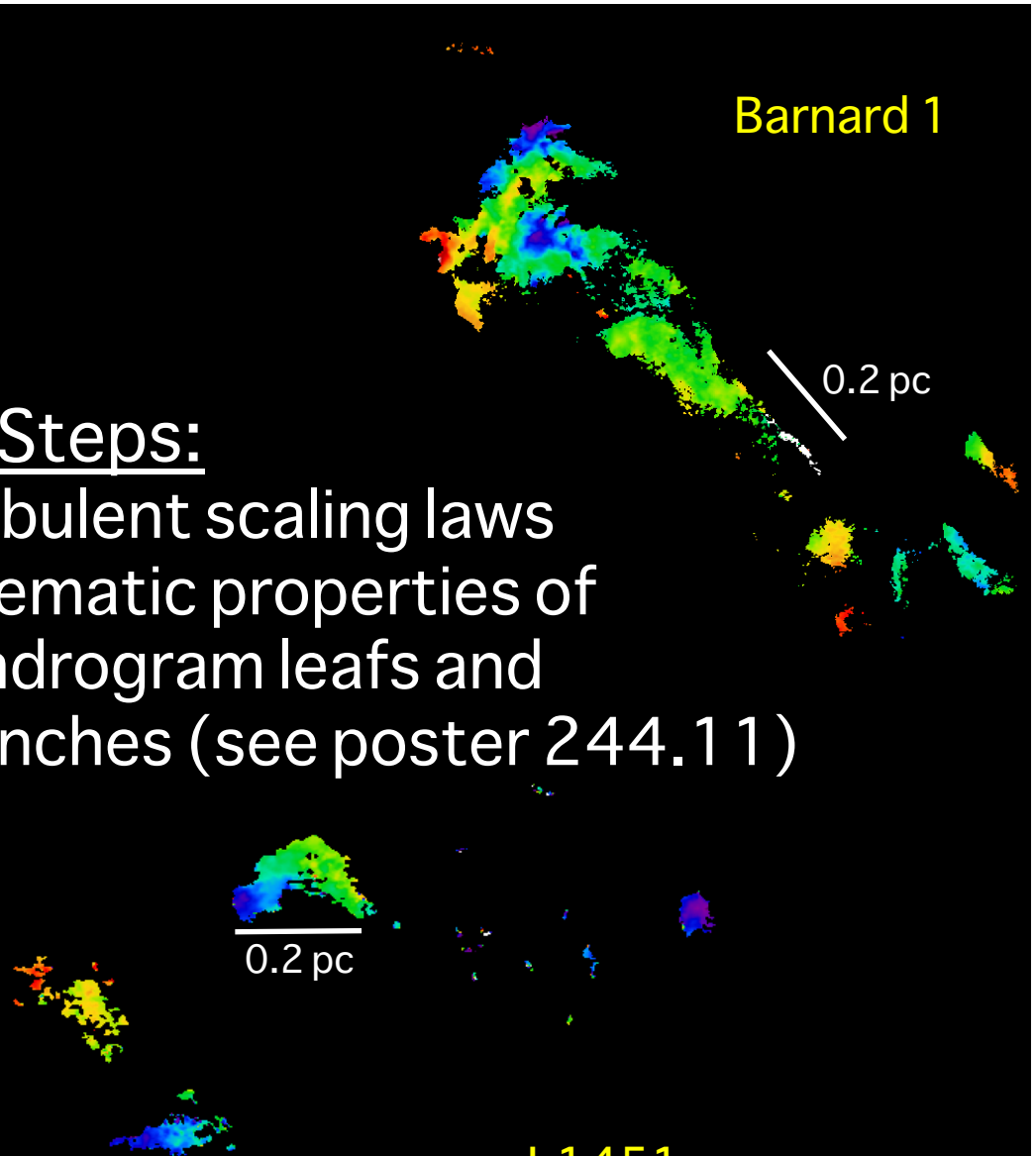


L1451

NGC 1333



Barnard 1



Next Steps:

- Turbulent scaling laws
- Kinematic properties of dendrogram leafs and branches (see poster 244.11)

Showing CLASSy
maps of N_2H^+
centroid velocity

See CLASSy posters in today's star formation session (244.11 and 244.12)