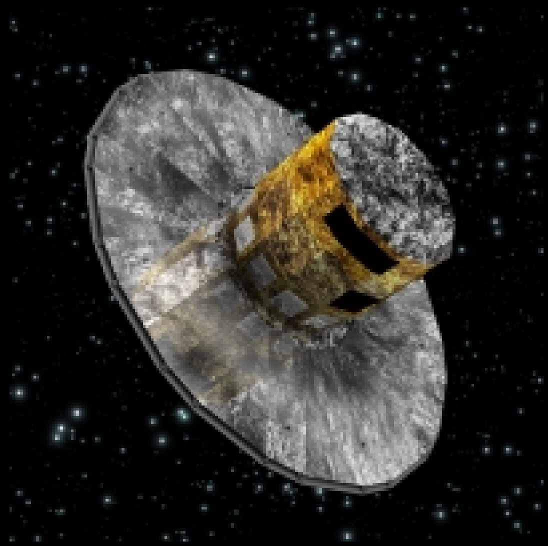
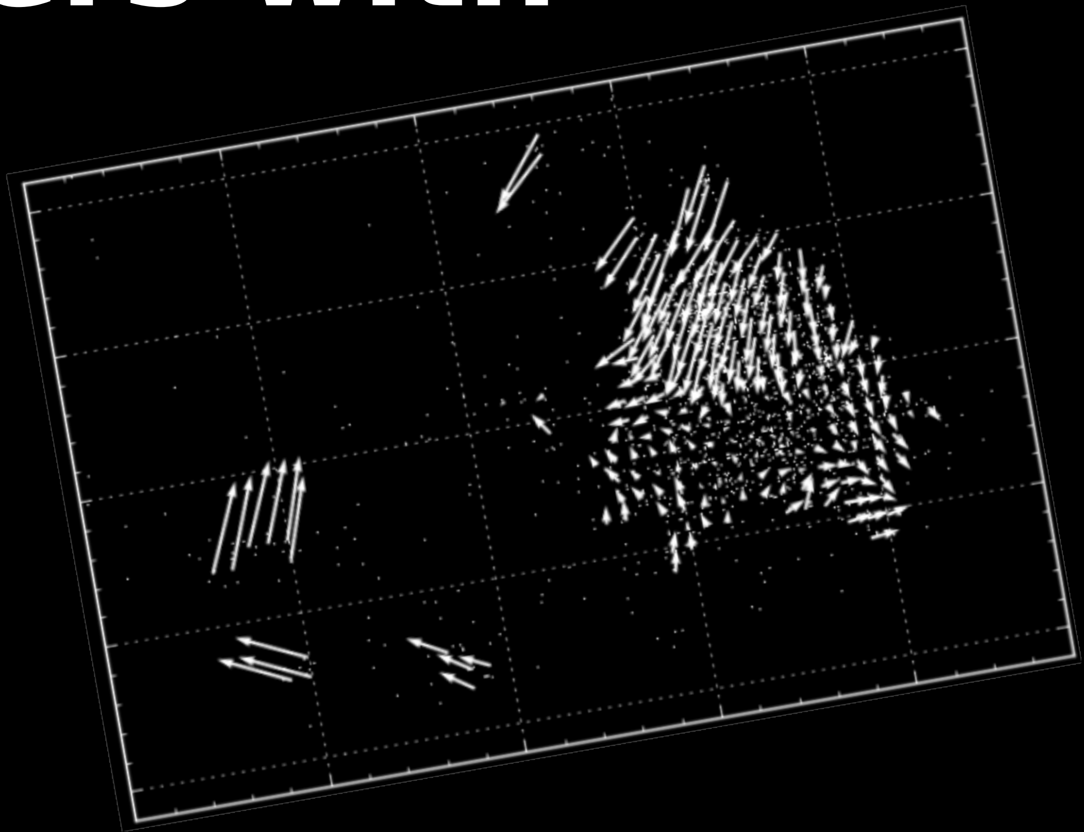
Revealing kinematic substructure in young stellar clusters with Gaia DR2





Tristan Cantat-Gaudin

StarFormMapper Workshop

Université de Grenoble 30/08/2018

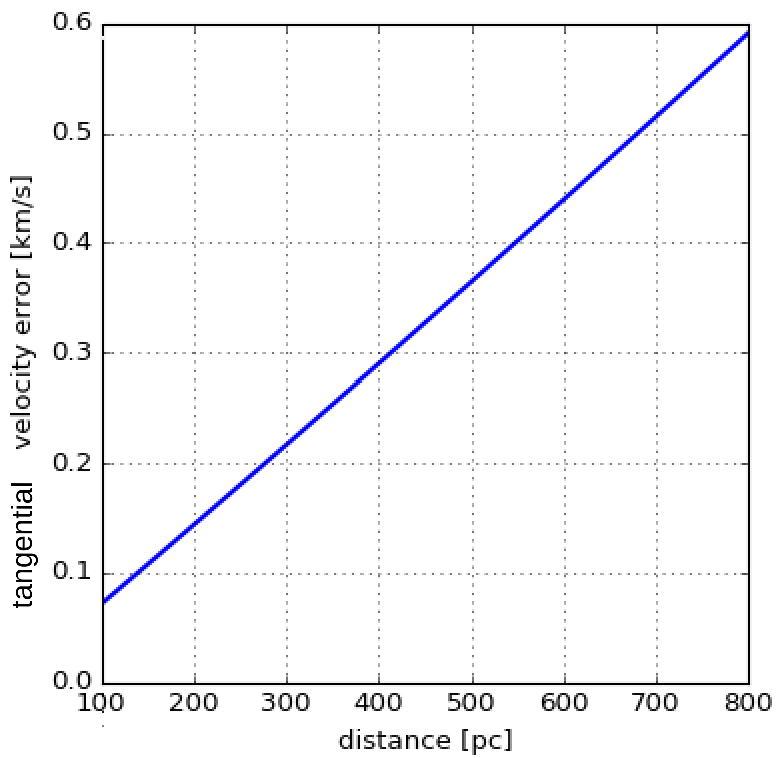
ICCUB

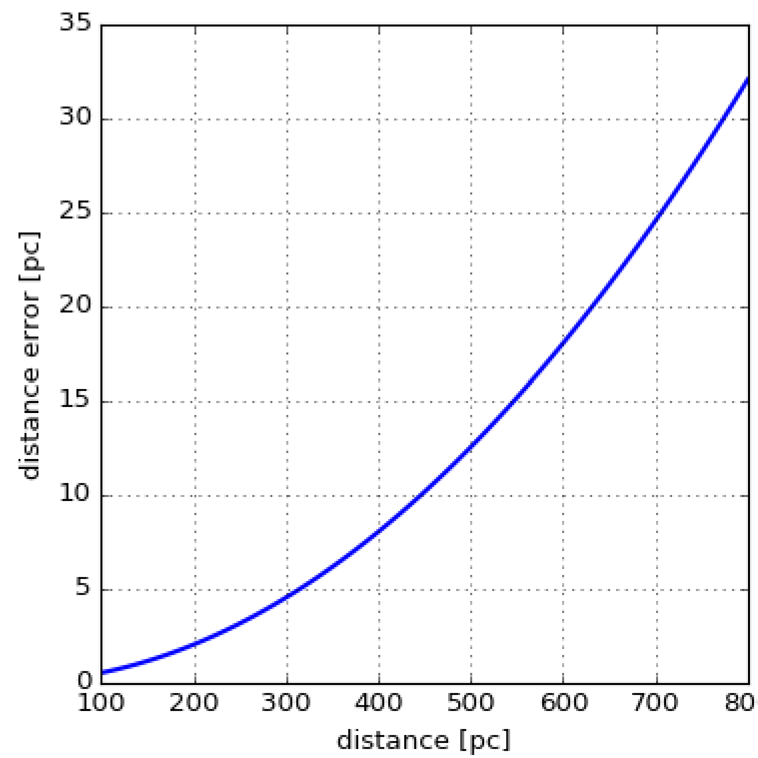
Universitat de Barcelona

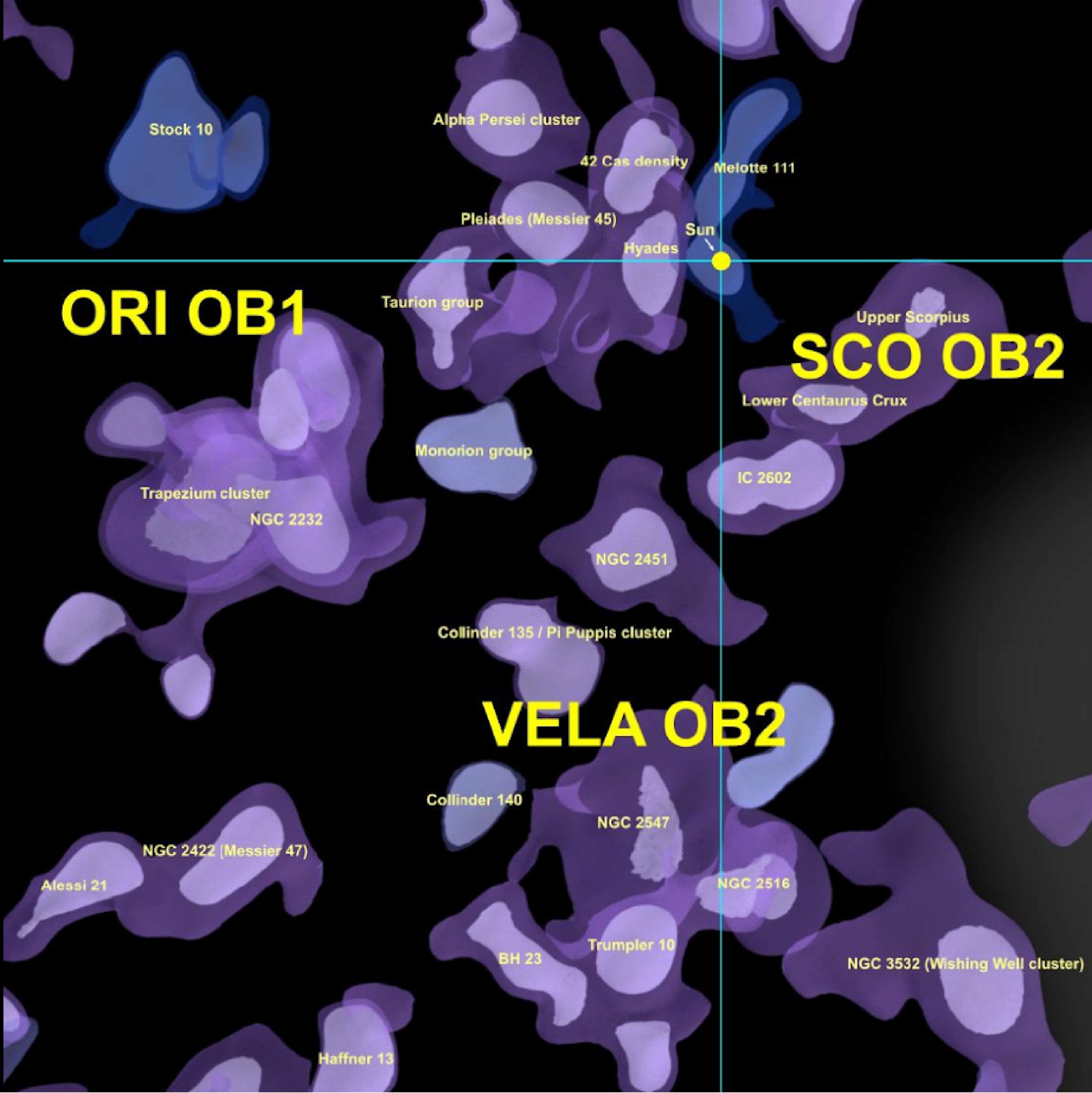
Gaia capabilities in physical units

For stars brighter than G~18, typical proper motion uncertainties are under 0.1 mas/yr and parallax uncertainties under 0.05 mas.

At a distance of 500 pc this is ~0.4 km/s and under 15 pc.





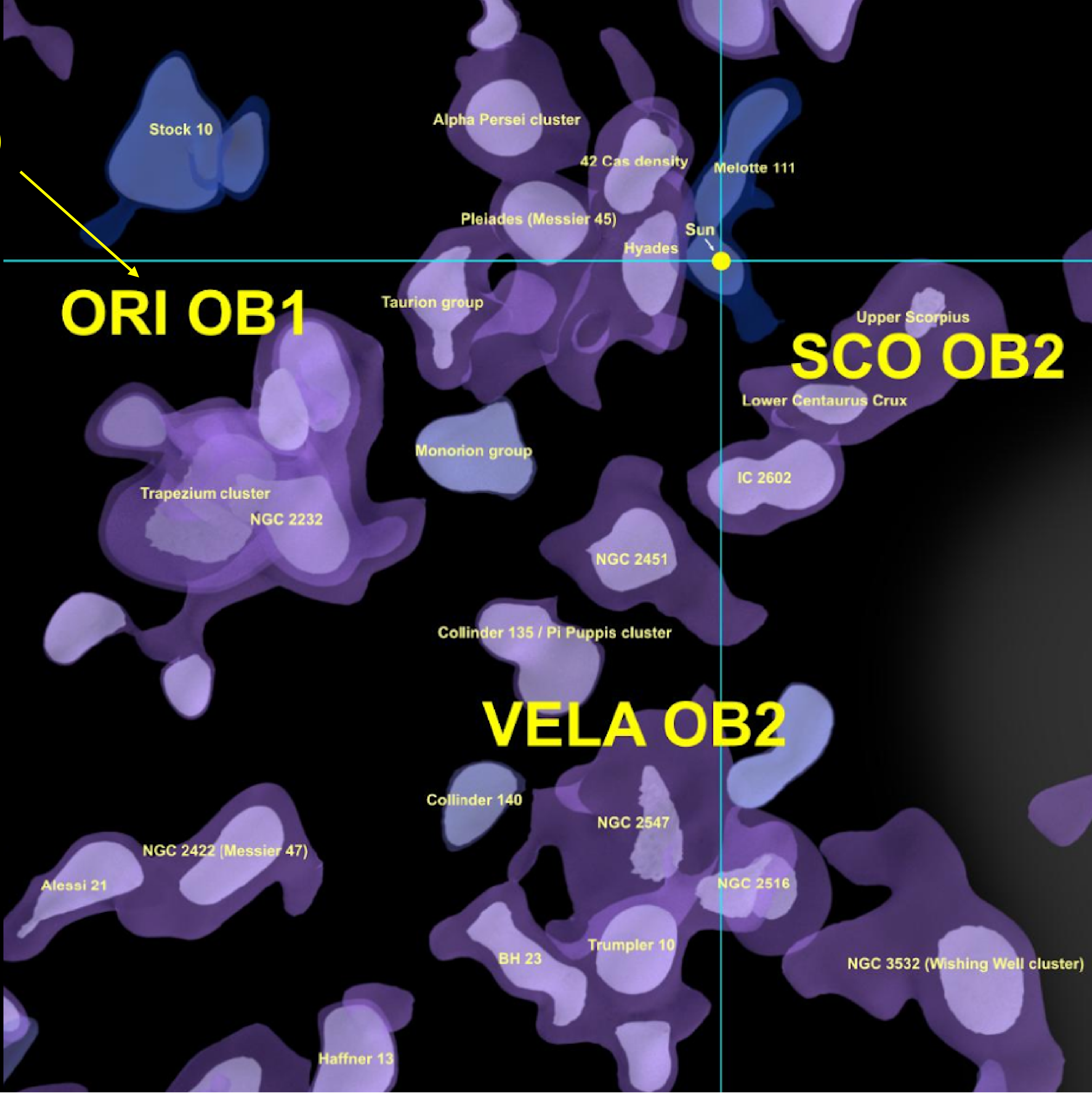


Galaxy Map / K. Jardine

Orion

Kounkel et al. (2018)
ApJ 156 84

Grosschedl et al. (2018)
arXiv:1808.05952



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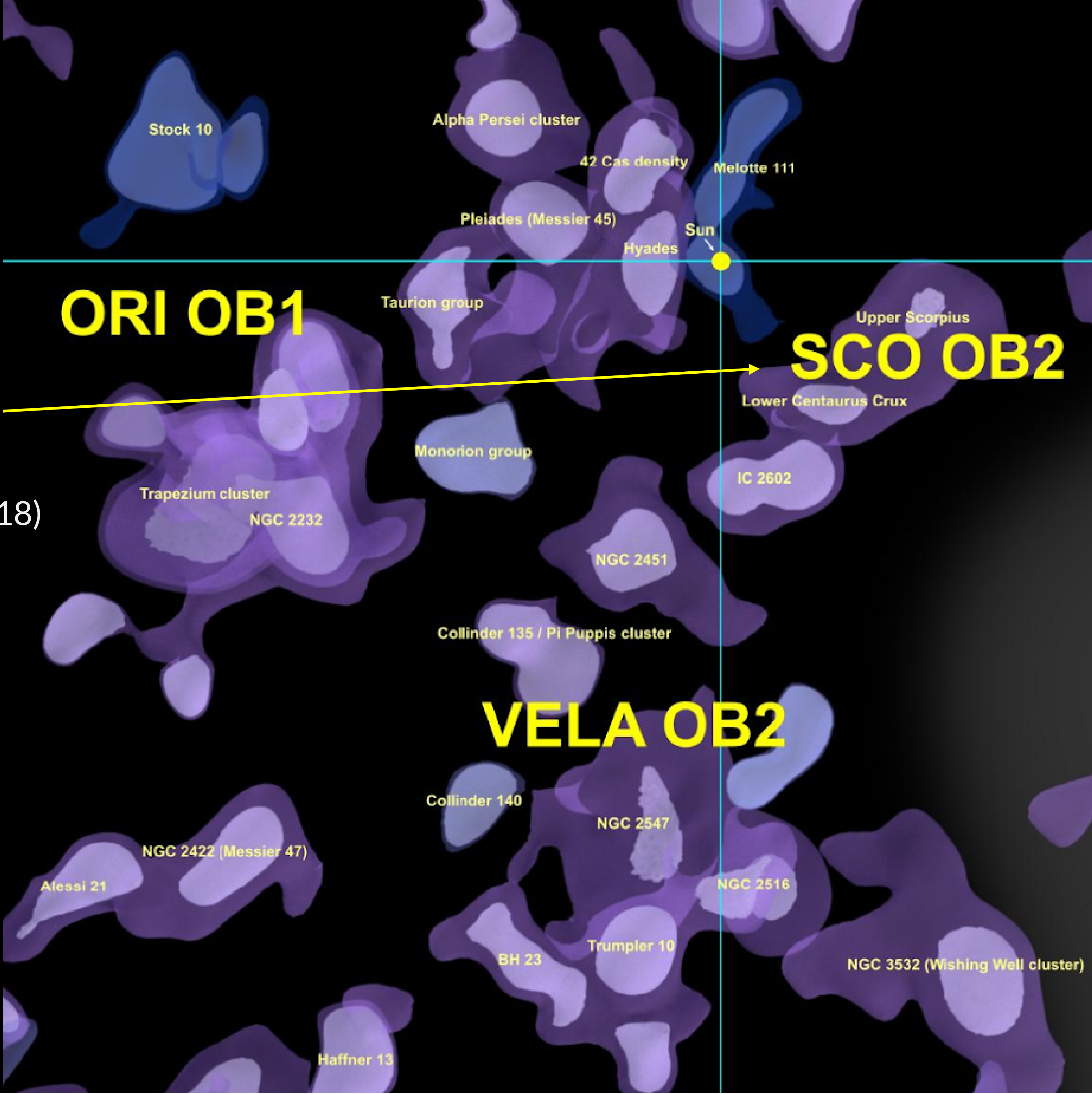

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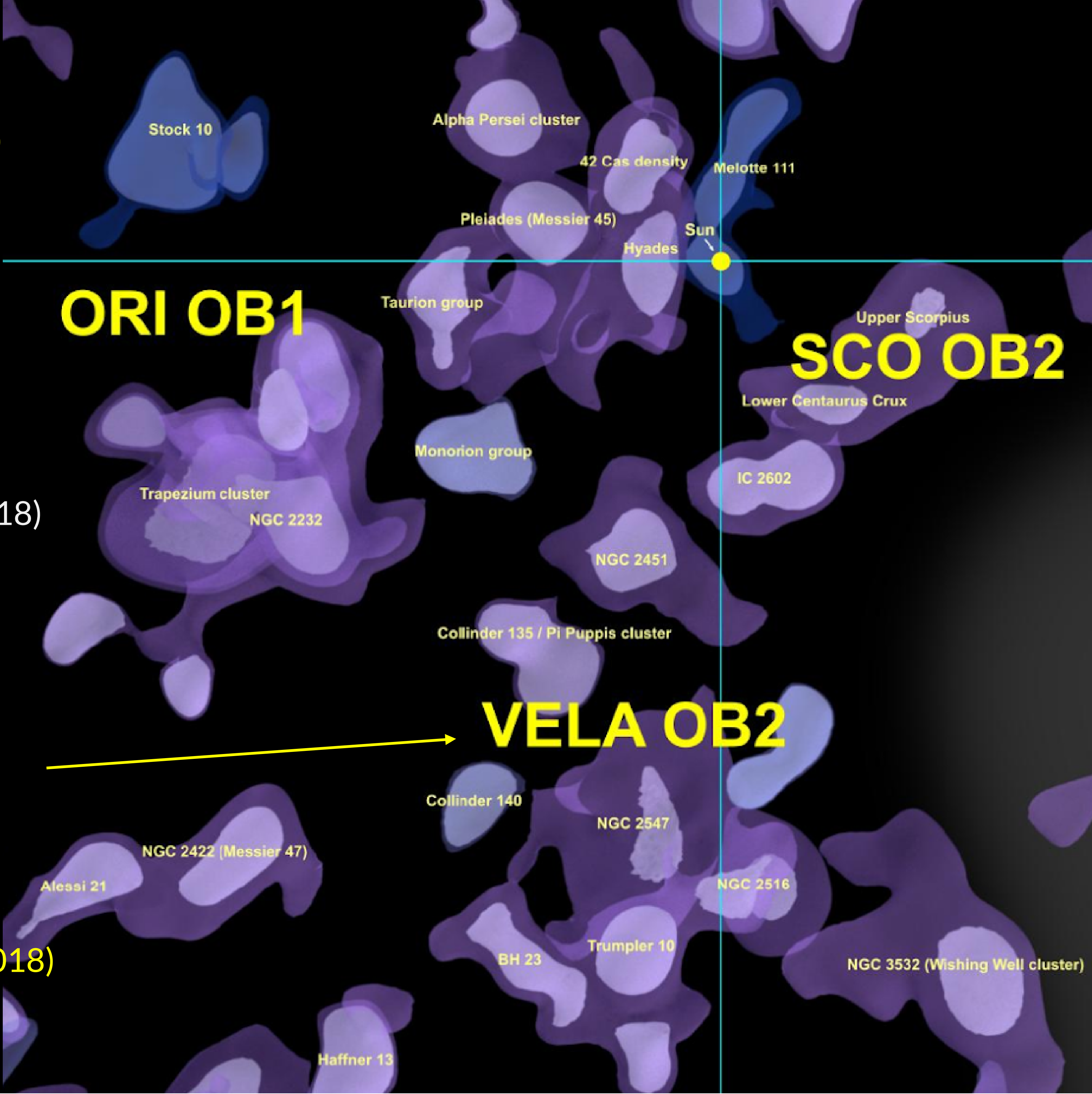
Vela OB2
Franciosini et al. (2018)
arXiv:1807.03621
Beccari et al. (2018)
arXiv:1807.07073
Armstrong et al. (2018)
MNRAS 480 121
Cantat-Gaudin et al. (2018)
arXiv:1808.00573



Galaxy Map / K. Jardine

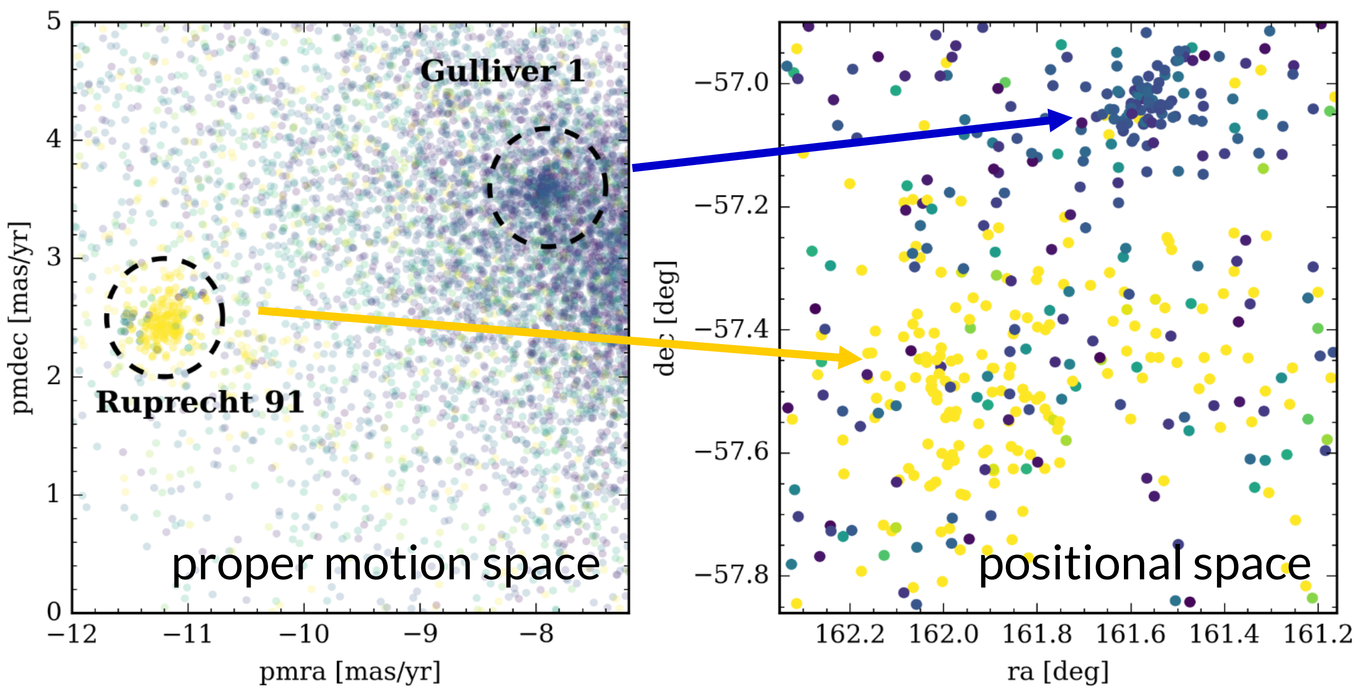
Outline

1) Finding coherent structures in multi-dimensional spaces

2) Structure in the Vela OB2 complex

1. Finding coherent structures in multi-dimensional spaces

Key idea: stars with **similar proper motions and parallaxes** should appear clearly non-randomly distributed on the sky. For well-behaved, relaxed, older clusters, all stars basically exhibit the same proper motion.

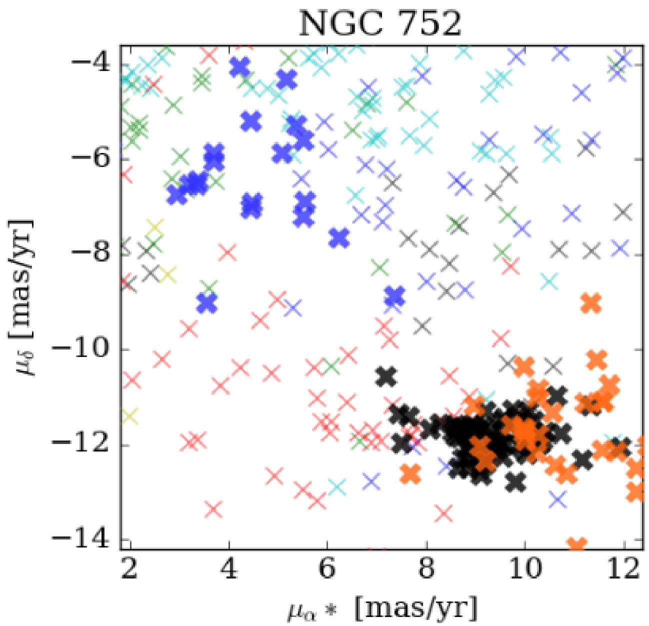


You do not need to define a distance in any space or a certain density to catch stars that are “similar”.

The UPMASK approach

Recipe adapted from Krone-Martins & Moitinho (2014).

Step 1: make groups of 15-30 stars in 3D **proper motion + parallax** space. k-means clustering works well for this.



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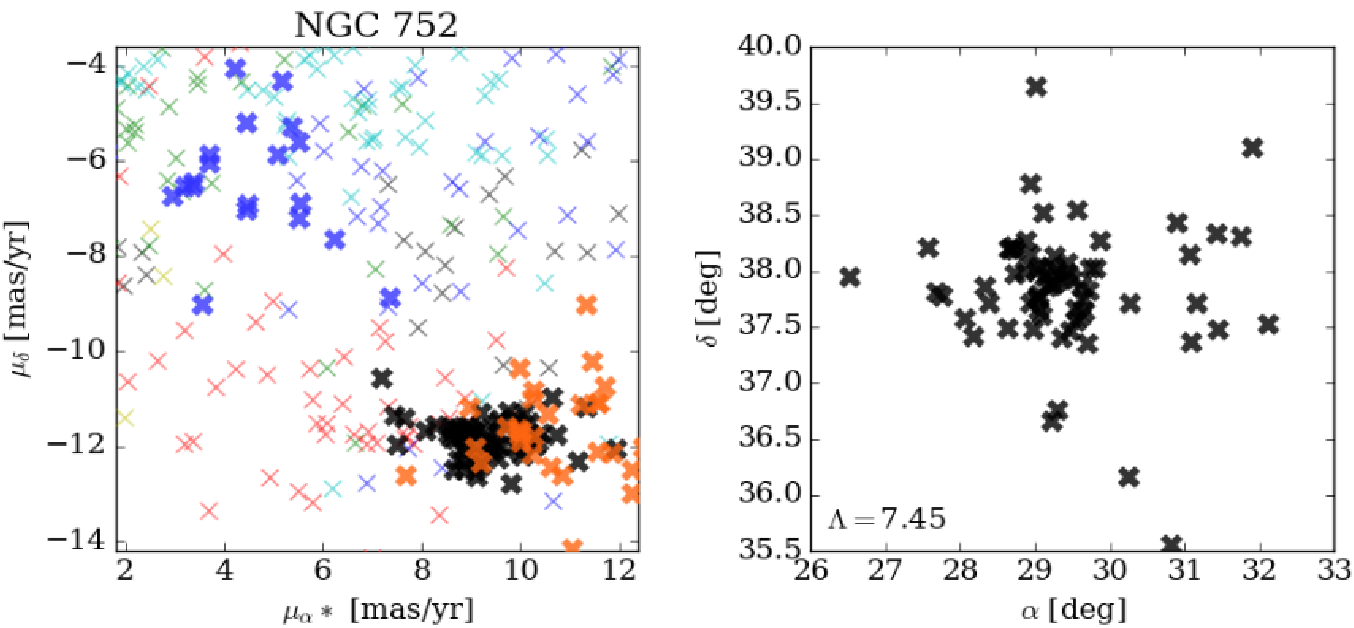

Step 2: look at the spatial **(ra,dec)** distribution of the stars in each group.
Is their spatial distribution more concentrated than a random distribution?

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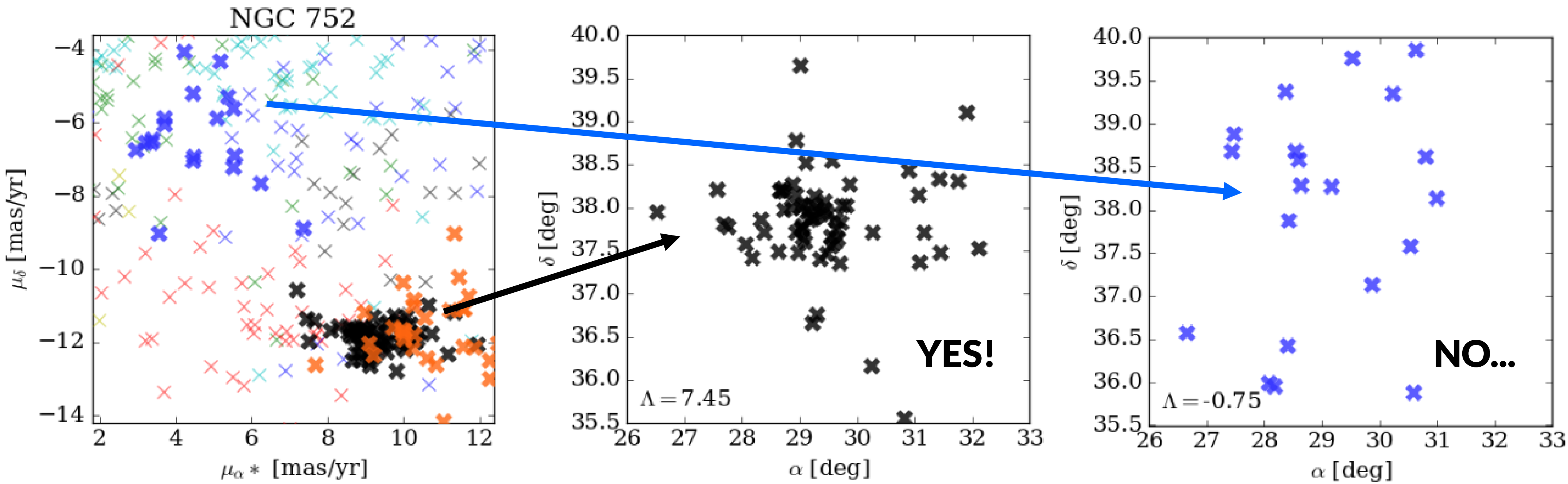


Step 2: look at the spatial **(ra,dec)** distribution of the stars in each group.
Is their spatial distribution more concentrated than a random distribution?

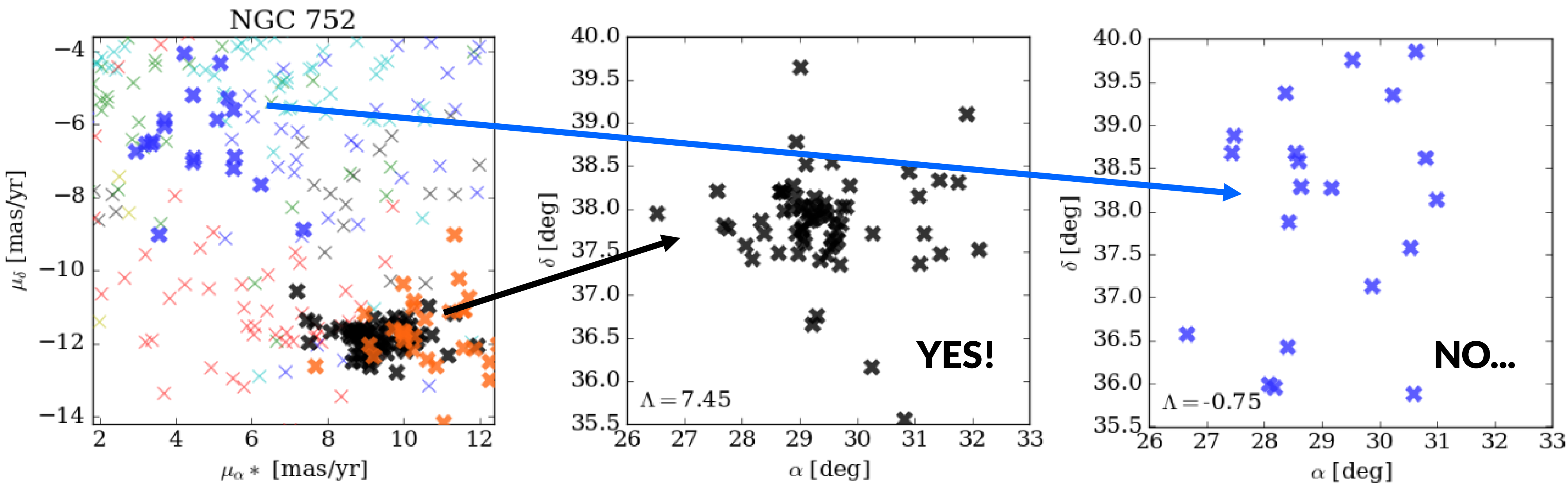
Determine the Minimum Spanning Tree for those stars, and the median branch length L.

YES if: L < Lrandom – 3 x sigmaLrandom

where Lrandom is the expected L for a random distribution
sigmaLrandom is the corresponding standard deviation

The UPMASK approach

This only returns a YES or NO answer for every group.



Now build a new dataset, shuffling the points based on their nominal uncertainties.
Apply the same steps again on this new dataset.

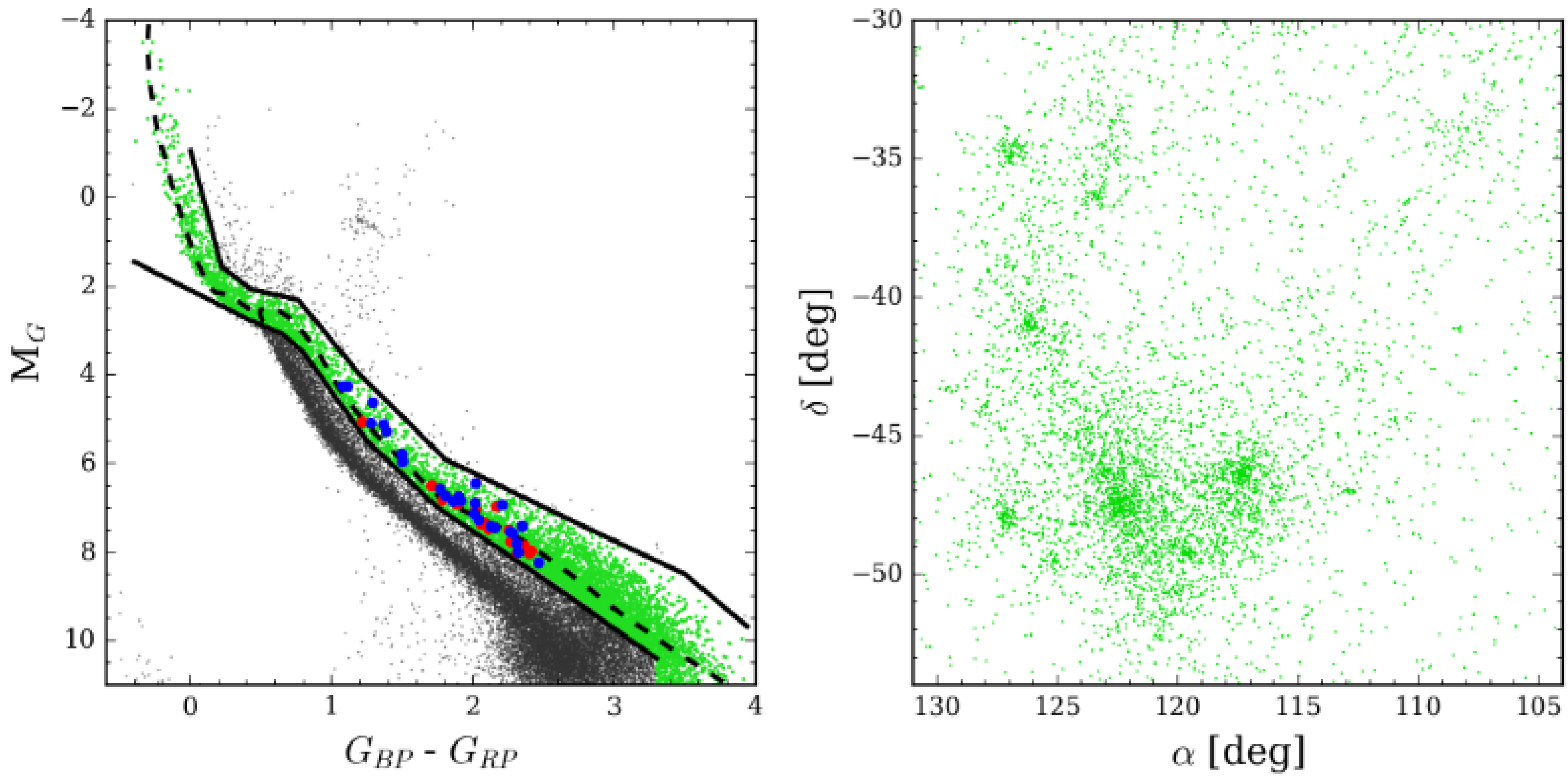
Do this with 100 different realisation (each time adding random errors to the nominal values).
The groups will be slightly different each time.

Some stars might be in a YES group 98 times and others only 5 times.
Which can be interpreted as a **membership probability** of 98% and 5%.

2. Application to the Vela OB2 complex

The Vela OB2 contains ~10 Myr old stars.
Known to be made up of at least two kinematic groups (Jeffries et al. 2013).
Possibly connected to the older cluster NGC 2547, 2° to the south (Sacco et al. 2015).

A photometric selection of 10 Myr old stars already shows a lot of spatial structure:

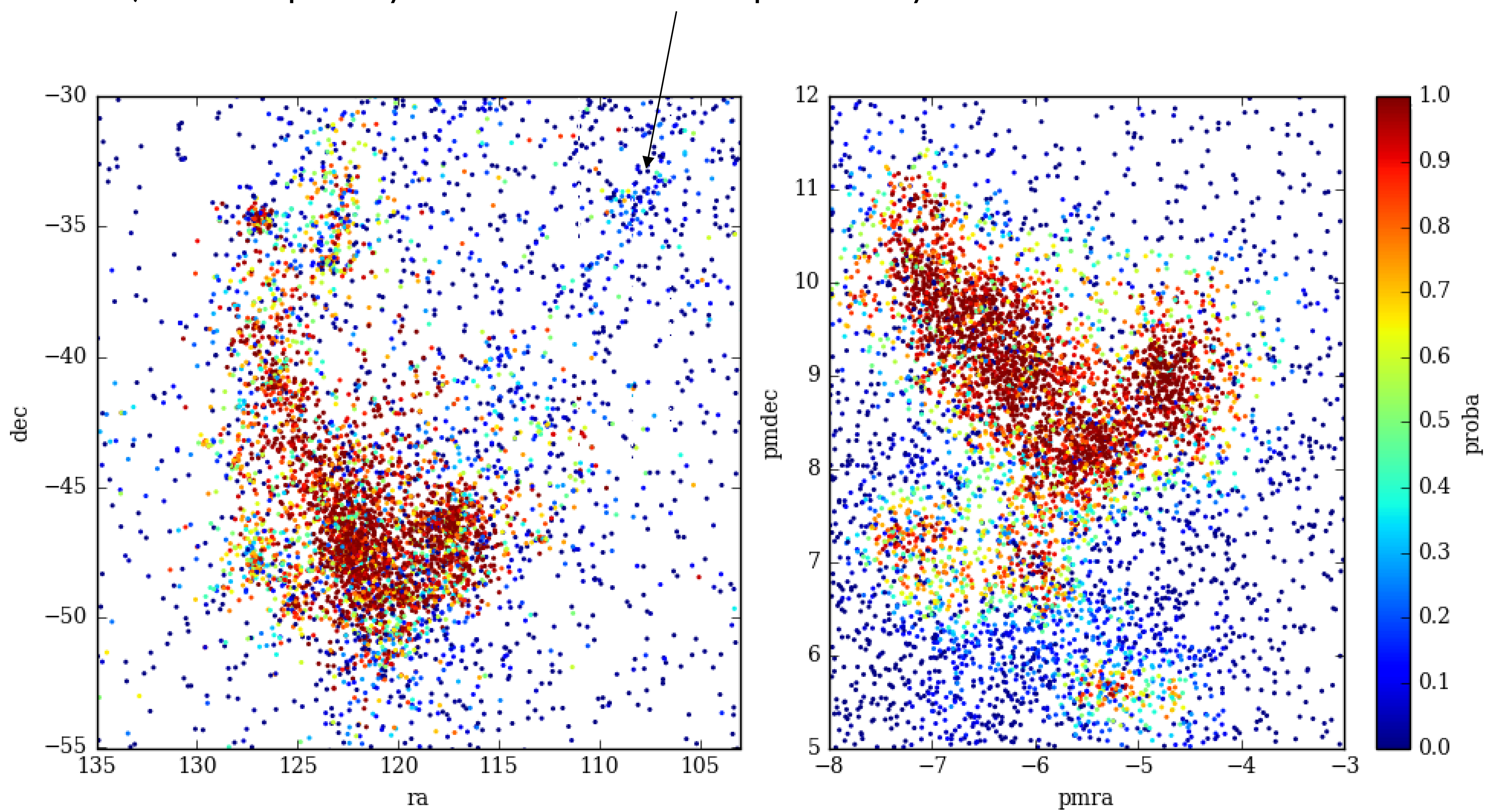


The structure is much more extended than previously thought. Luckily Gaia is all-sky so we can just make larger queries to the archive!

2. Application to the Vela OB2 complex

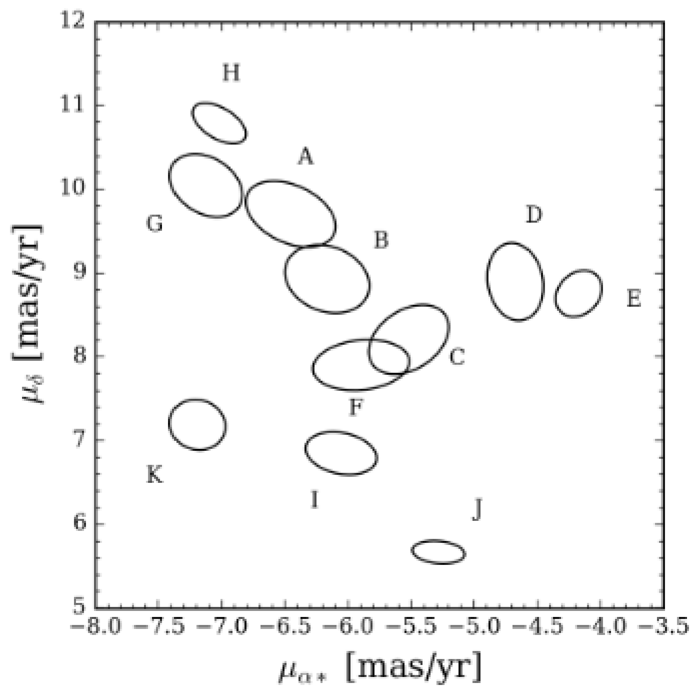
Applying UPMASK reveals a lot of distinct proper motion groups that are also coherent in spatial distribution.

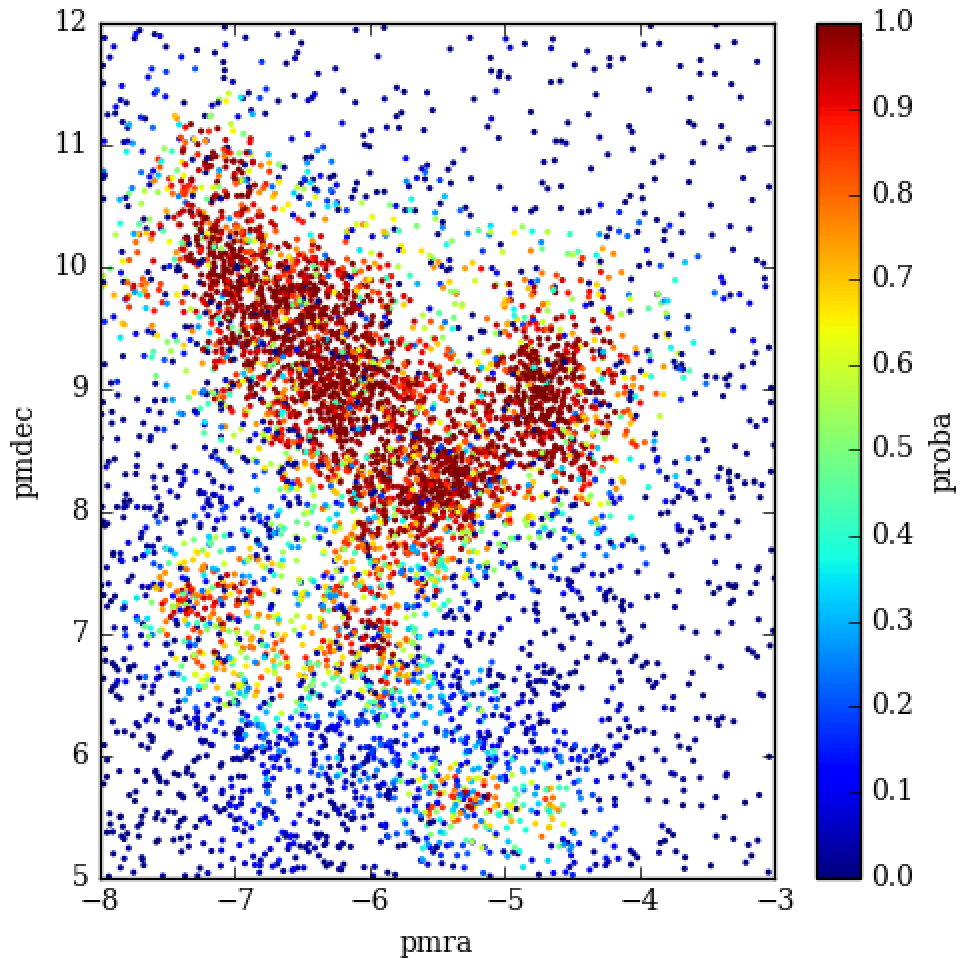
It also flags stars whose astrometric neighbours (stars with similar proper motions and parallaxes) are not spatially concentrated as “low probability”.



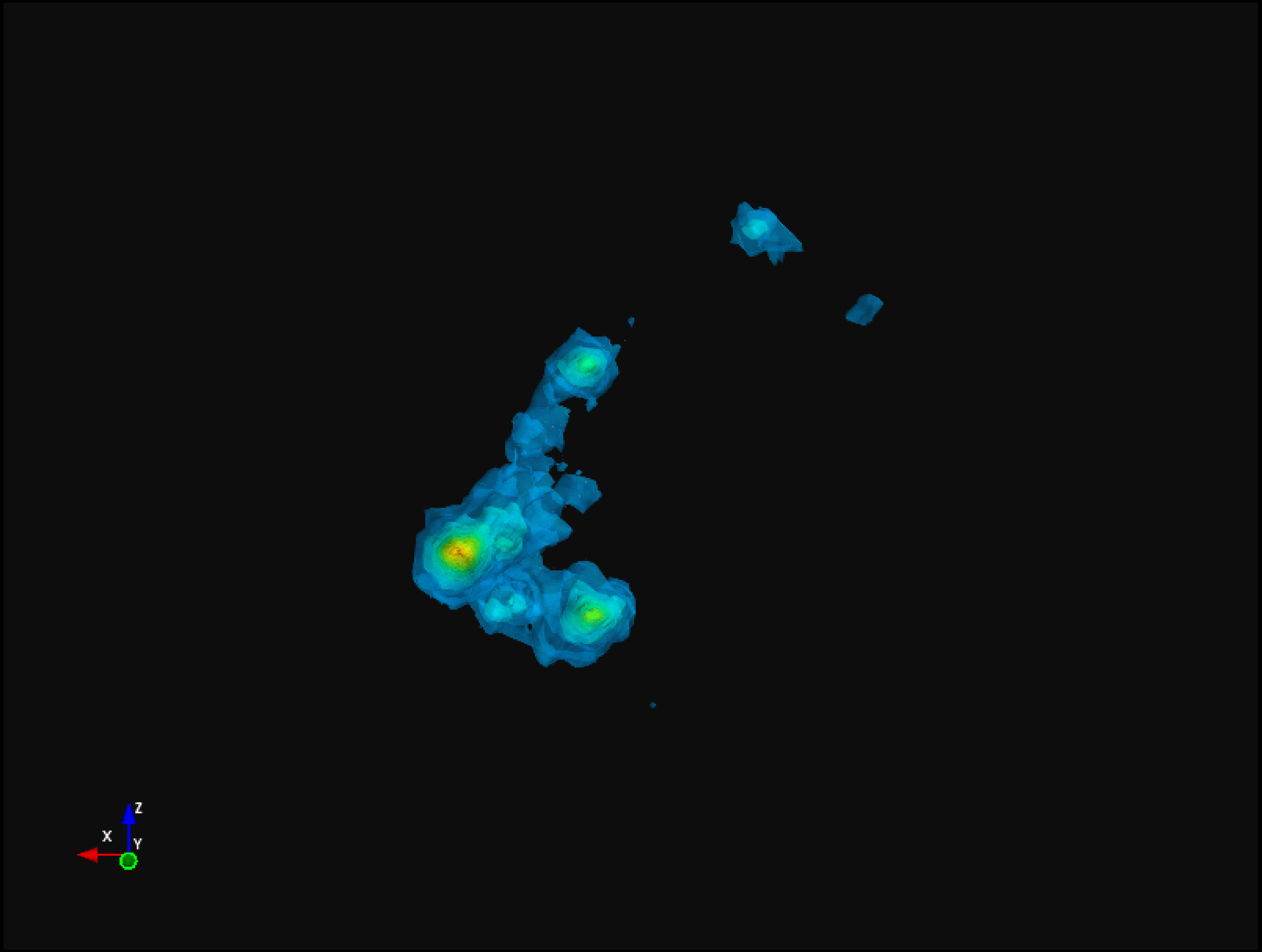
2. Application to the Vela OB2 complex

Those components can be disentangled through Gaussian Mixture Modelling...

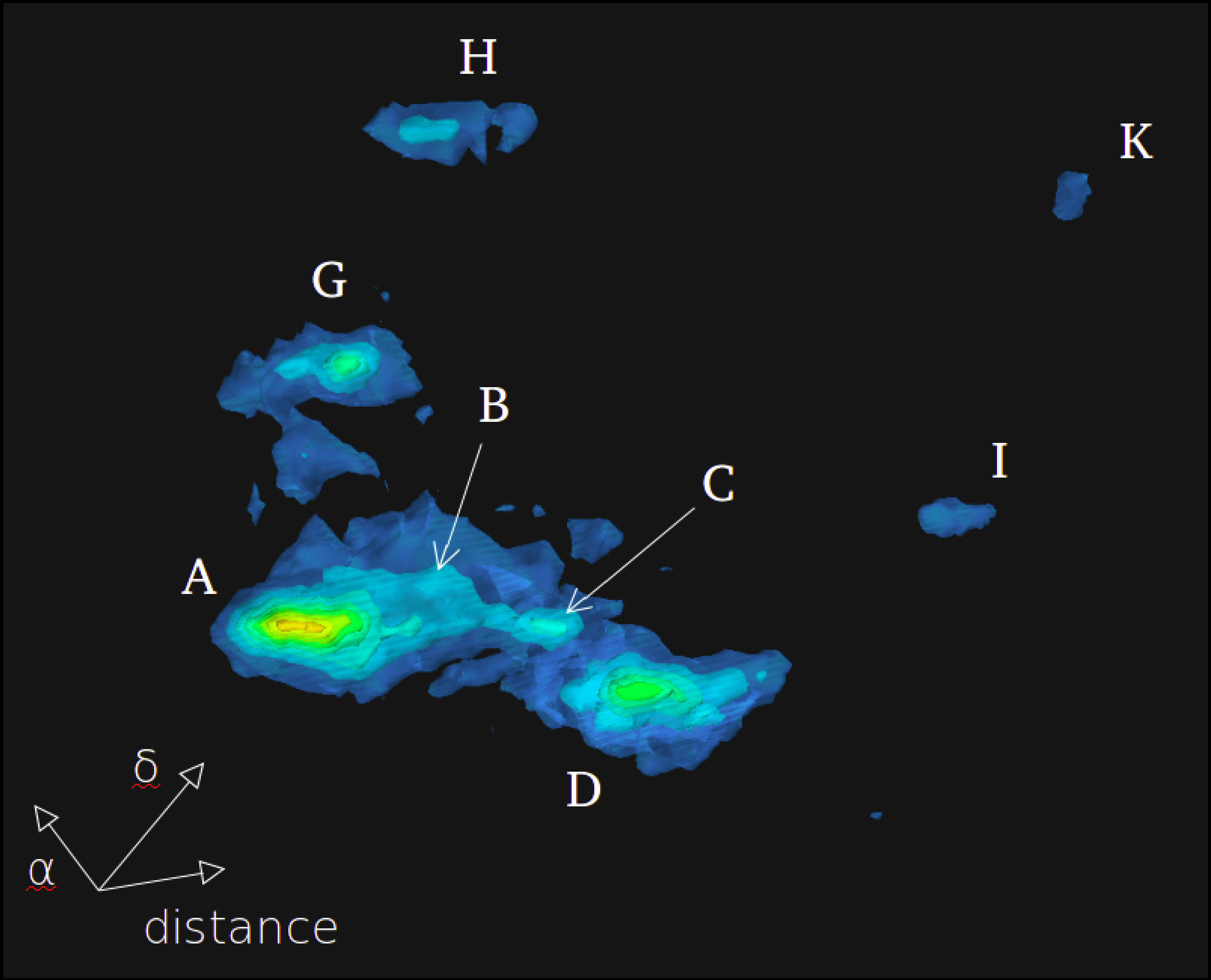




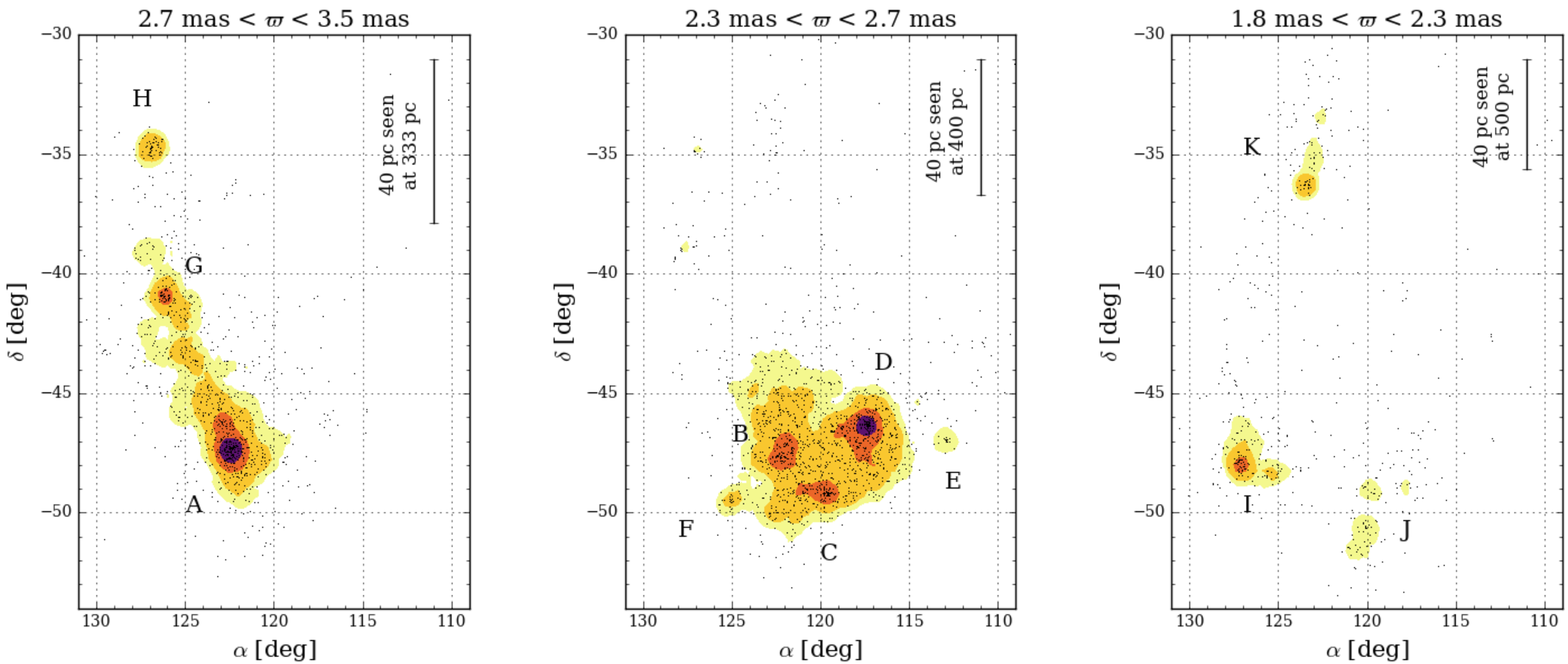
We can convert Gaia parallaxes to distances and look at the 3D distribution of those young stars!



Z pointing up to north Galactic pole. Y pointing towards the observer.

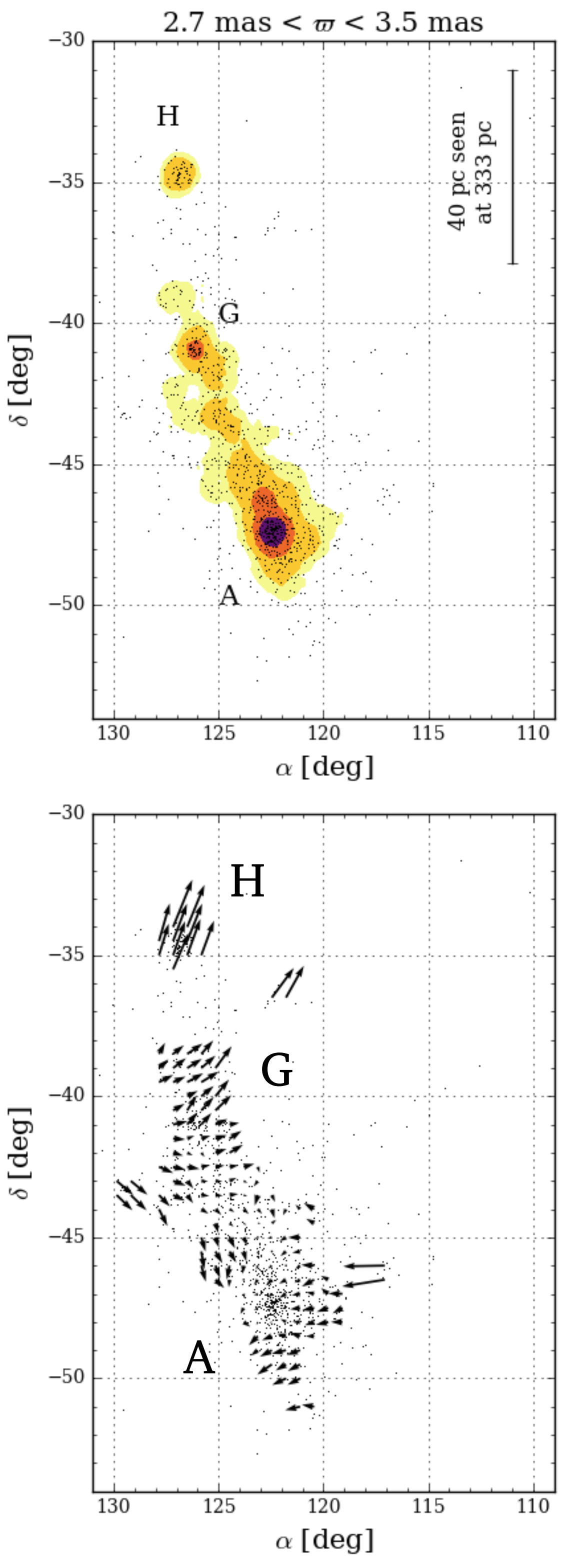


Clear ring-like shape, 130 pc to 180 pc across.



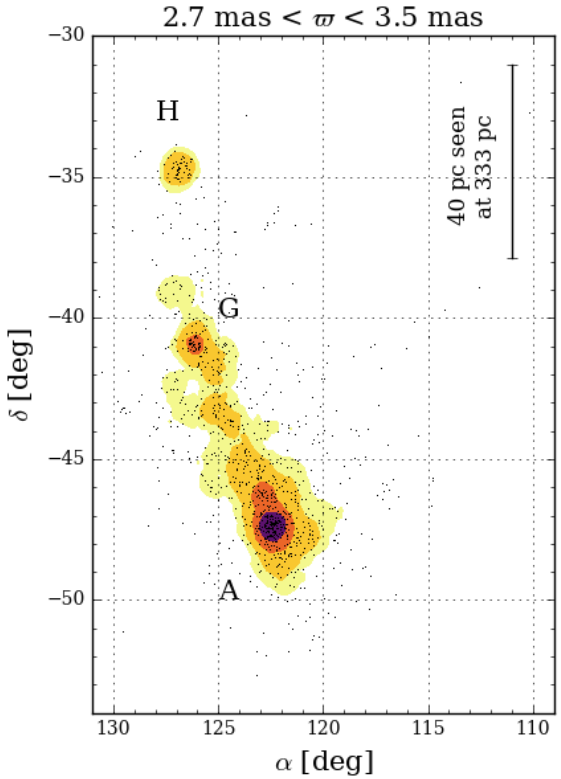
2.7 mas < ϖ < 3.5 mas
2.3 mas < ϖ < 2.7 mas
1.8 mas < ϖ < 2.3 mas
40 pc seen at 333 pc
40 pc seen at 400 pc
40 pc seen at 500 pc
H
G
A
B
C
D
E
F
I
J
K
δ [deg]
α [deg]
−30
−35
−40
−45
−50
130
125
120
115
110

Proper motions reveal signs of expansion

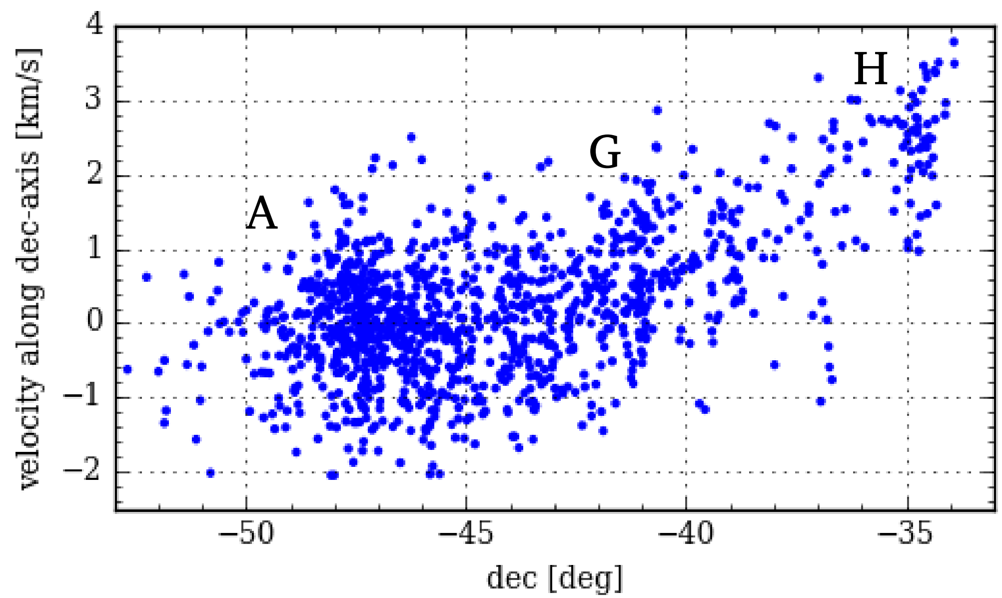


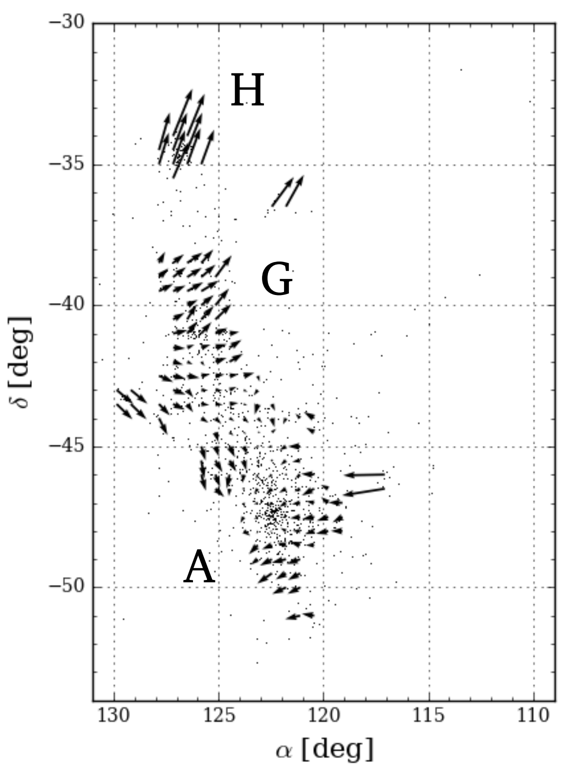
arrows indicate mean tangential
velocity with respect to component A

Proper motions reveal signs of expansion



We observe a velocity gradient in the tangential plane, showing that this A-G-H structure is stretching (expanding).





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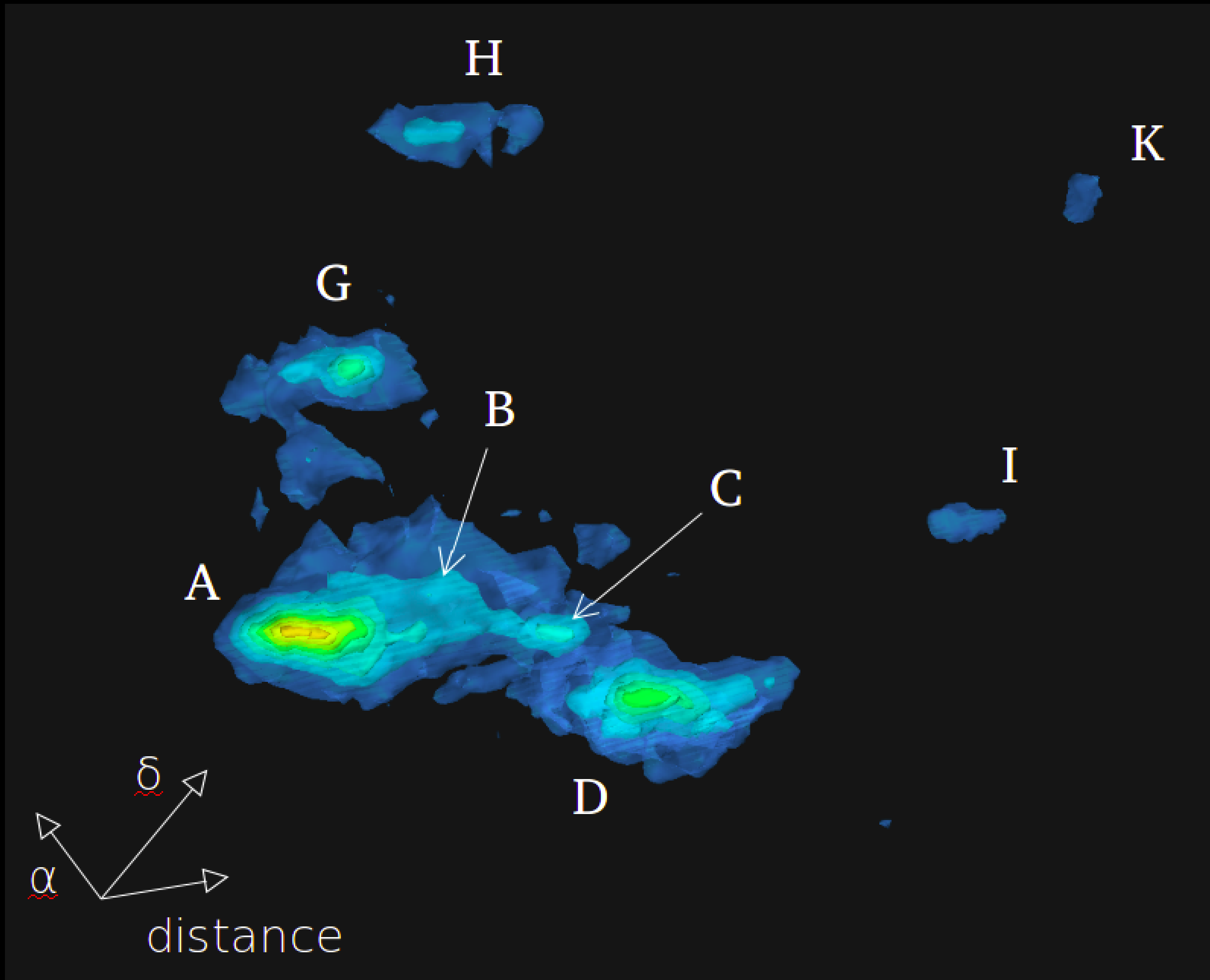
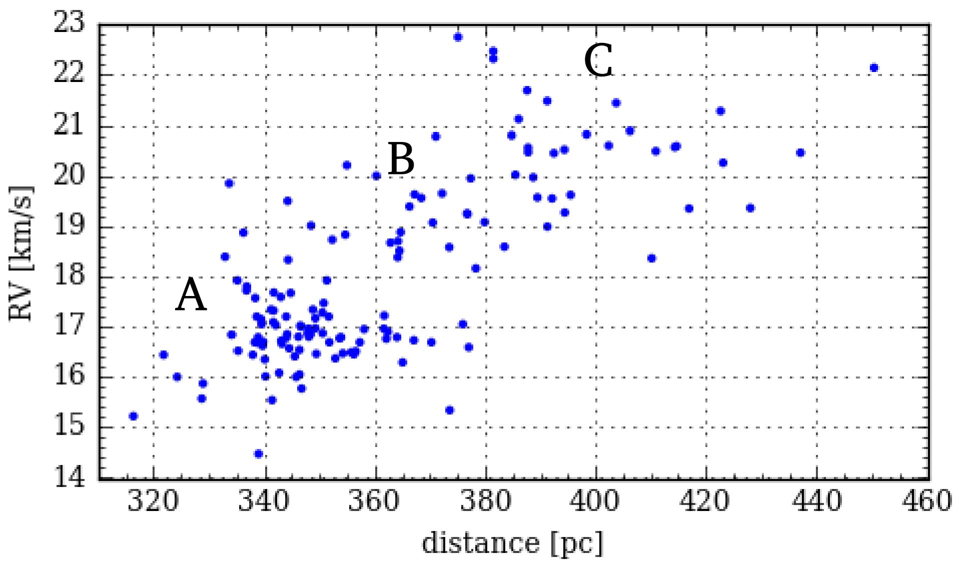
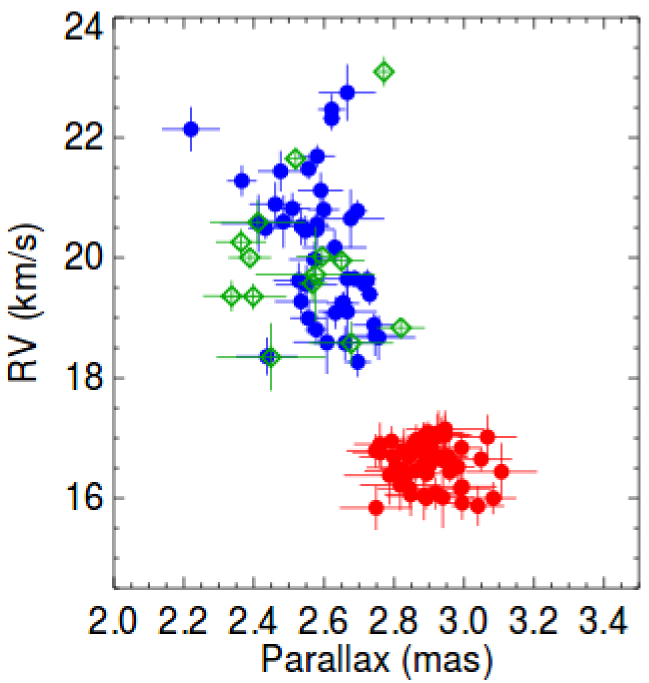

H
K
G
B
I
C
A
D
δ
α
distance

Radial velocities also reveal signs of expansion

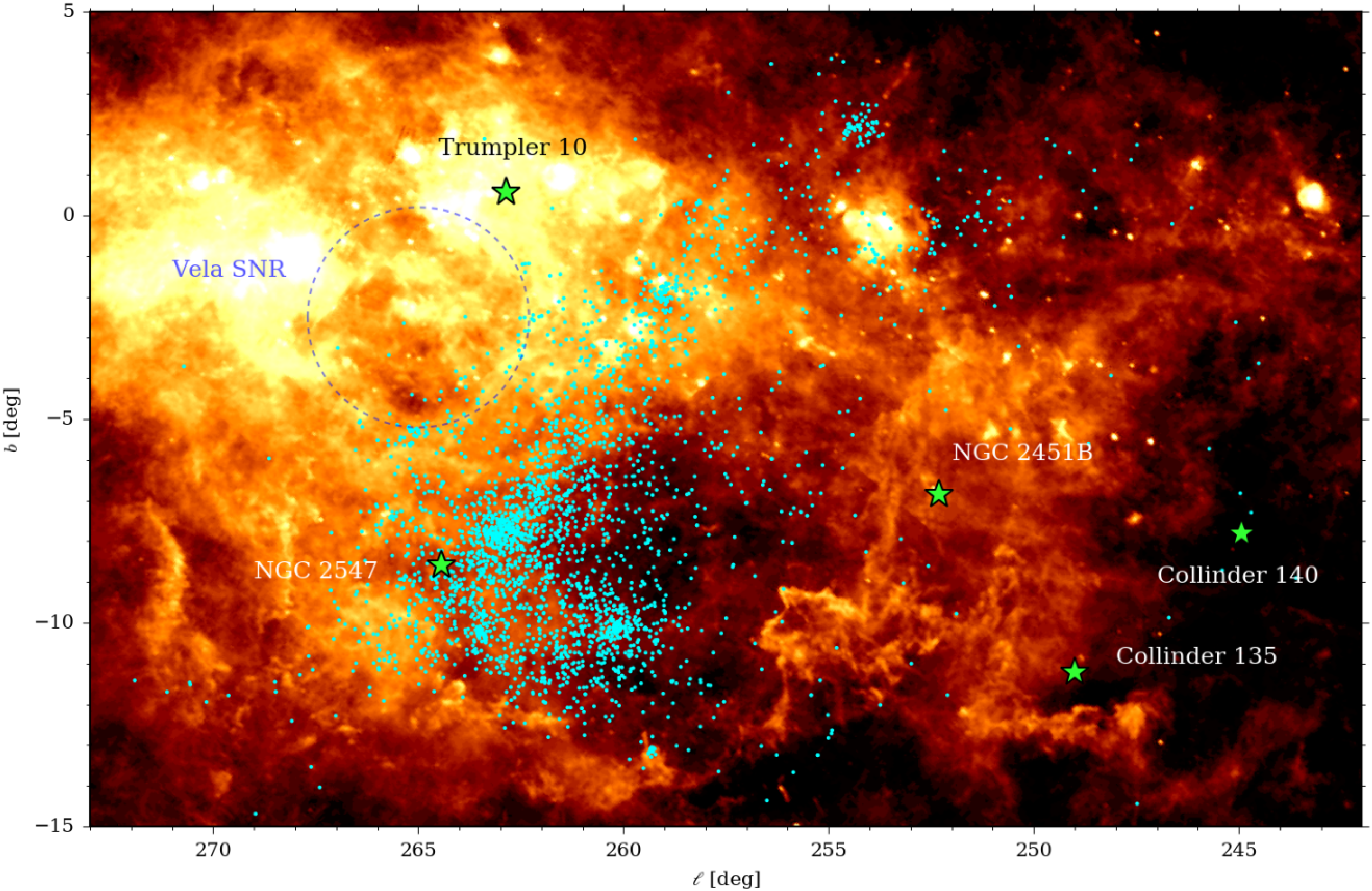
Using radial velocities from the Gaia-ESO Survey we see that the stars along the line of sight going through components A-B-C also exhibit a positive velocity gradient.

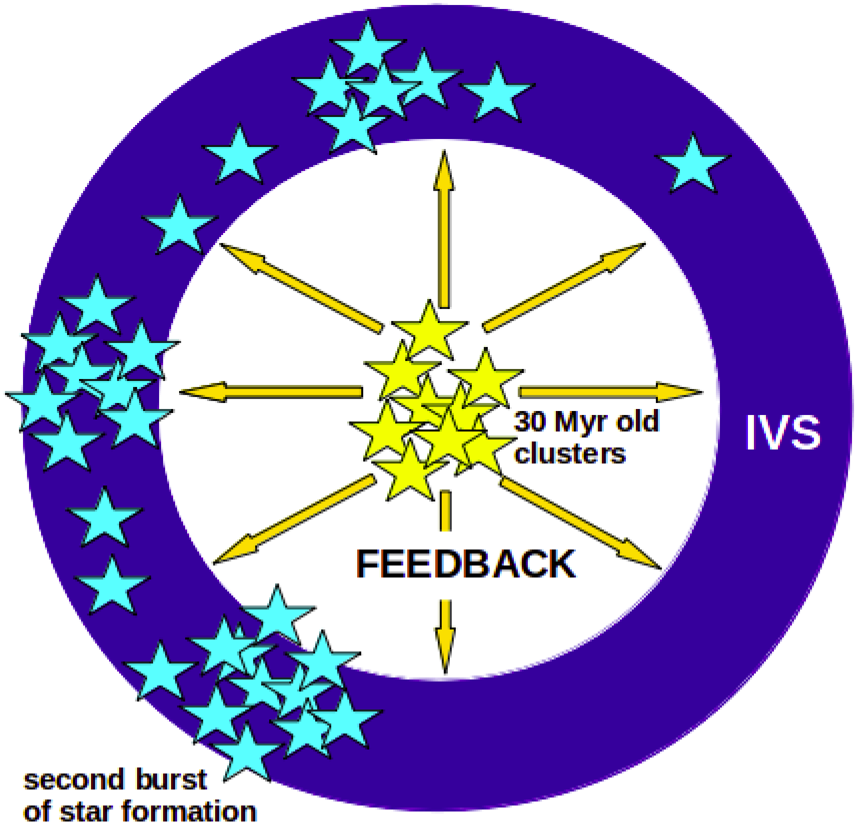


Similar to the findings of Franciosini et al. (2018) except they considered B and C to be one single expanding group.



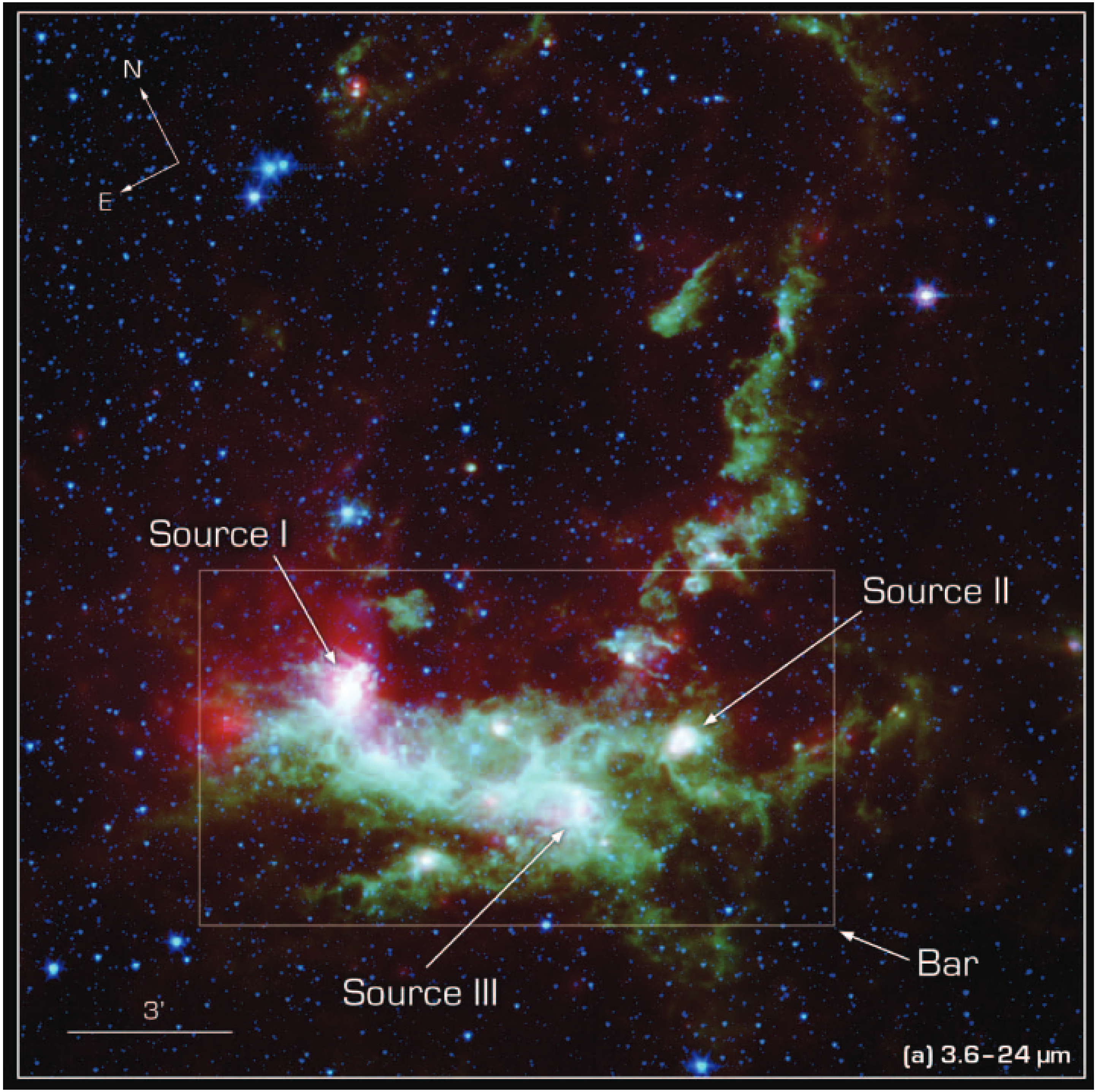
Vela OB2: ~10 Myr stars, mostly located inside the "IRAS Vela Shell".
Nearby: ~30 Myr mainly in 5 clusters but also distributed throughout the region.





Theoretically not too exotic, but first example in the Milky Way?

Star forming region Henize 206 (in the LMC)



Gorjian et al. (2004)

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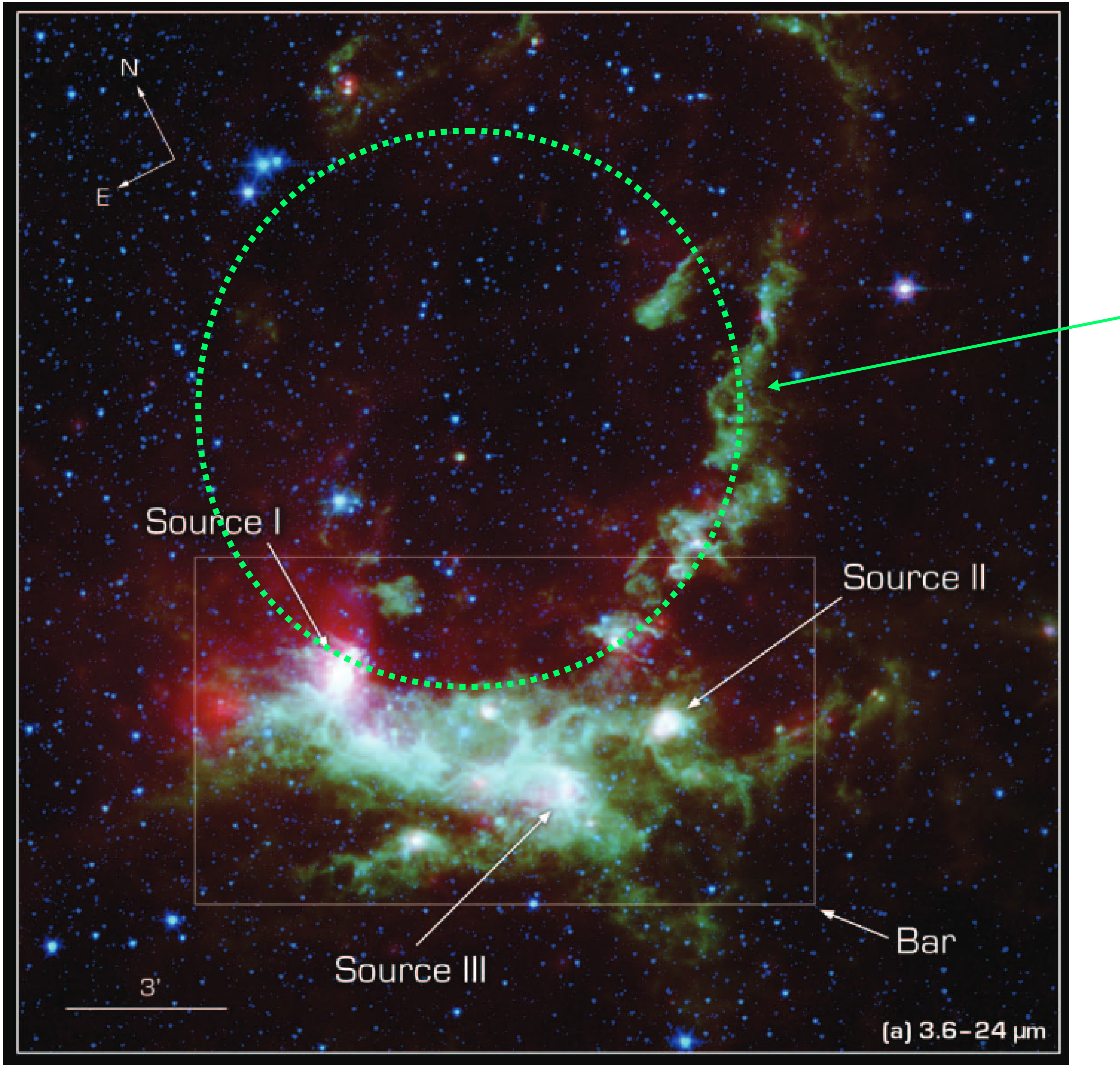

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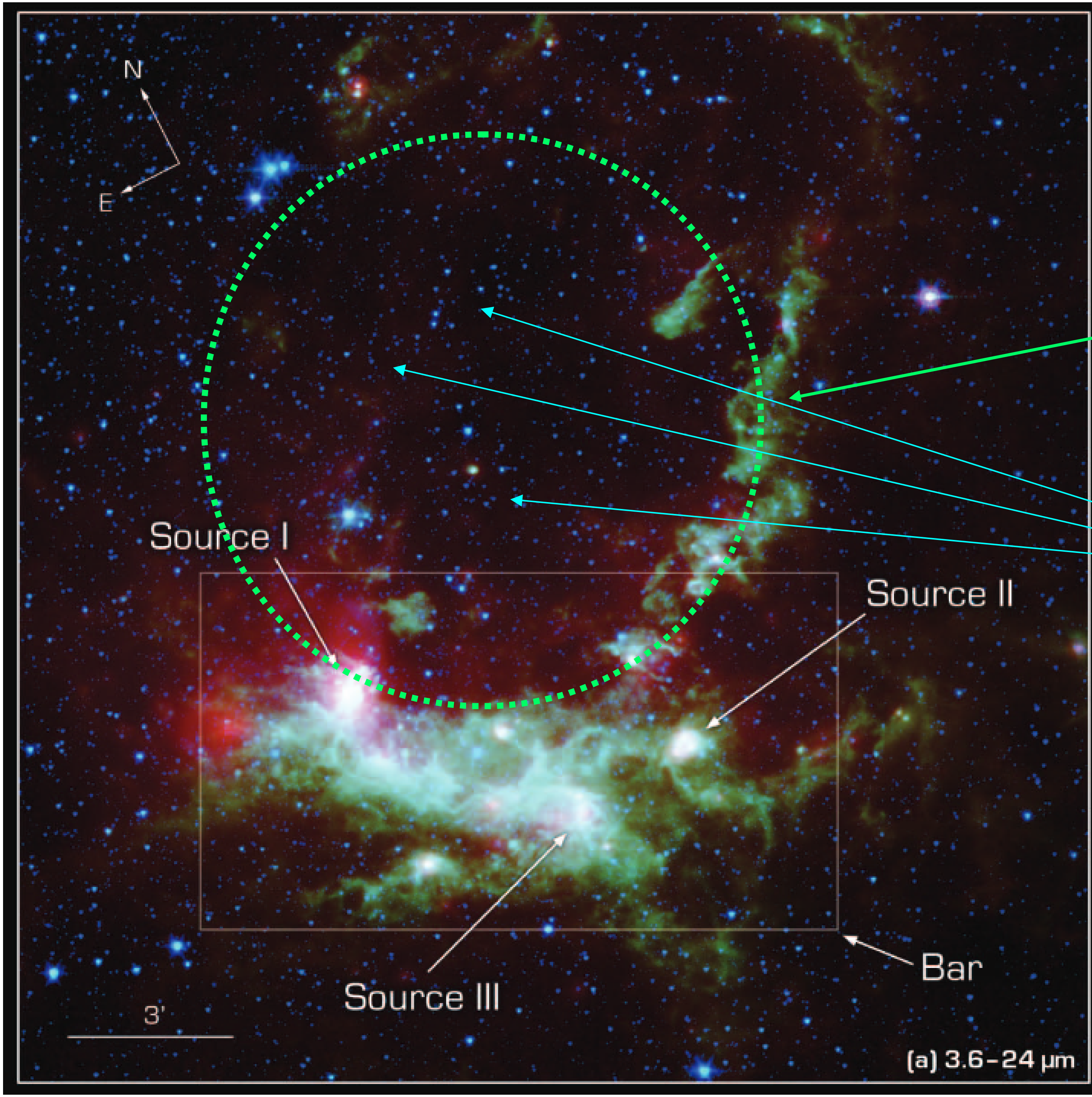

Supernova-driven expanding shell

~ 10 Myr old stars (Bica et al. 1996)

Gorjian et al. (2004)

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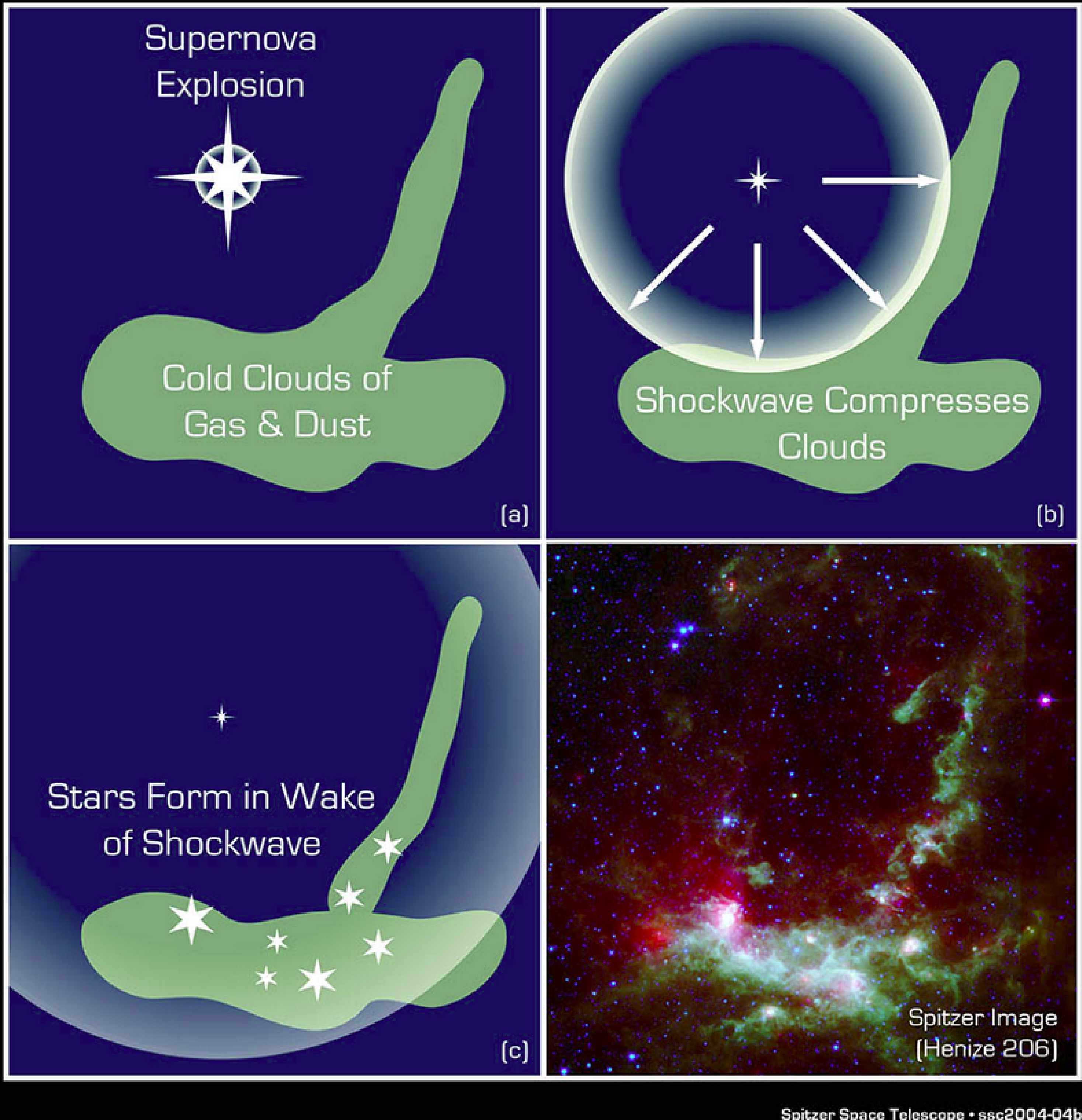

Credit: NASA/JPL-Caltech/R. Hurt (SSC-Caltech)

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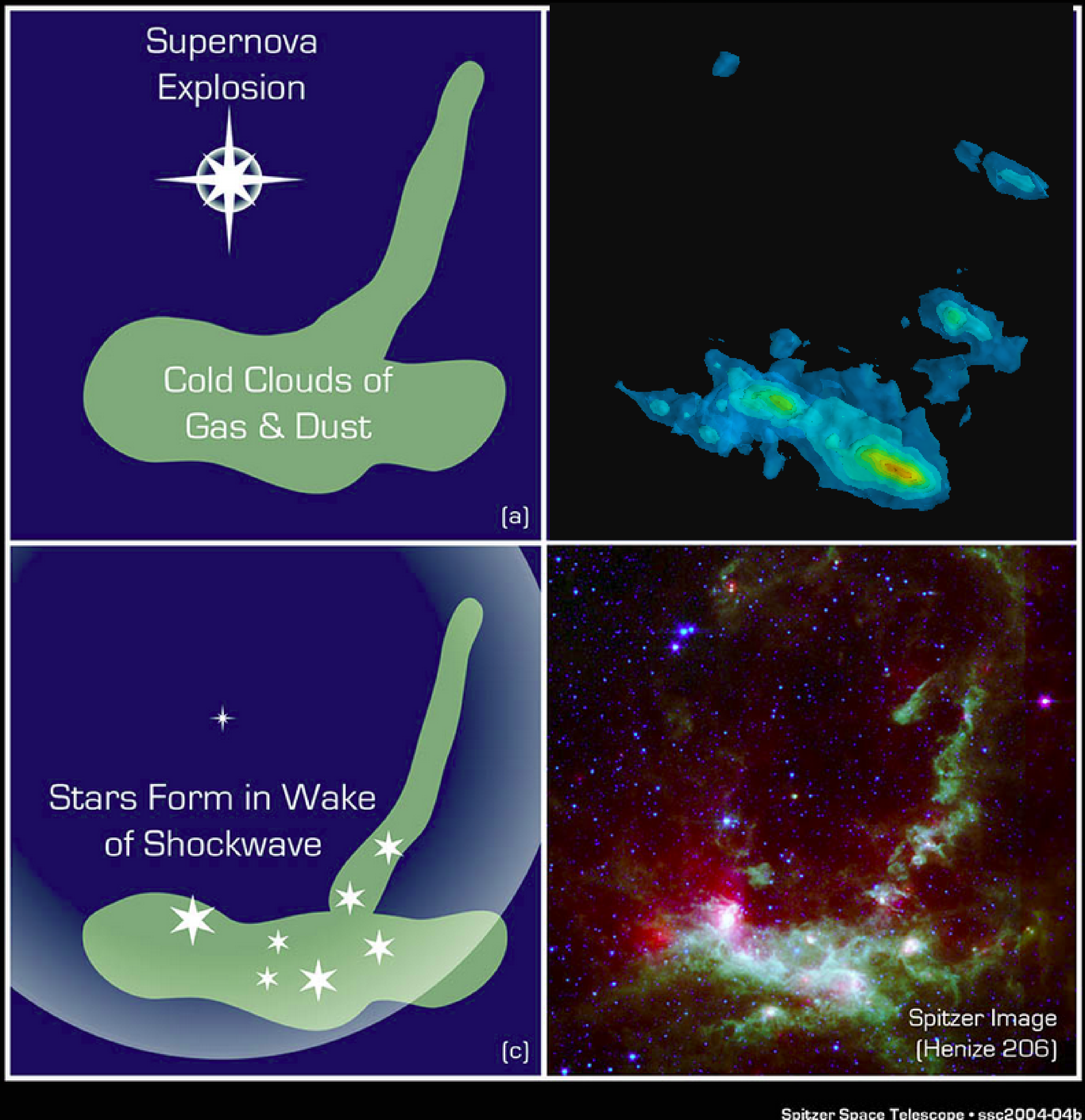

Credit: NASA/JPL-Caltech/R. Hurt (SSC-Caltech)

Summary

- The Gaia DR2 proper motions provide an exquisite velocity precision for objects within a few hundred pc.

- The Gaia DR2 parallaxes allow for a detailed 3D view.

- Unsupervised classification helps us highlighting structures.

- We find that the ~10 Myr stars of the Vela OB2 are distributed across a much larger scale than previously thought.

- They are distributed in an expanding 150 pc ring that might have been initiated by a supernova from an older population.