Quantifying velocity structure in star forming regions

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1. Introduction

Star forming regions are an important part of our understanding of the Universe. Their formation and evolution has important implications for our grasp of planet formation, star formation, and stellar evolution. In an effort to understand these regions, several methods have been developed for quantifying aspects of their spatial structure[1] [2] . Such methods of quantifying spatial structure have proved valuable and are well used, but there are not corresponding widely used methods for quantifying kinematic structure. In the absence of such methods, several approaches have been used but they generally depends on subjective, "by-eye" interpretations. We present a new method for quantitatively analysing velocity structure.

2. The method

- For every possible pair of stars calculate the distance between them, Δr, and their velocity difference, Δv.
- Bin the pairs by Δr, and within each Δr bin calculate the average Δv
- Plot average Δv as a function of Δr.

3. Defining velocity difference, Δv

Two definitions of Δv are used to highlight different aspects of kinematic structure. The first definition is referred to as the magnitude definition, Δv_M, and it is the magnitude of the difference between the two velocity vectors. This definition is a useful raw measure of the disparity between stellar velocities. Alternatively Δv is defined as the time differential of Δr. This measures how the distance between two stars is changing, i.e. how fast they are moving towards/away from each other. This is the directional definition, Δv_D, and it is useful for studying if regions are expanding or contracting.

4. Applying the method

Fig. 1 shows a simulated region with a high degree of spatial and velocity substructure. This data is very difficult to interpret by eye, and any conclusions drawn from such a visual analysis would be inherently subjective, risking the introduction of bias. Further the results of such a subjective analysis would make it difficult/impossible to quantitatively compare the structures of different regions or to compare simulations to observations. Instead the method presented in this poster is applied to the region and the results are shown in Fig. 2. The results using the magnitude definition of velocity difference, Δv_M (see section 3), are shown in blue and the results using the directional definition, Δv_D are shown in orange.

The results using Δv_M show that the magnitude of the difference between stellar velocity vectors increases the further apart stars are up until Δr scales of around 0.9 pc. At larger spearations it seems to plateau indicating beyond this scale stars have roughly uniform velocity differences regadless of their separation. The results using Δv_D show a peak at Δr = 0.5 pc and a trough at Δr = 1 pc. This means that stars that are ~ 0.5 pc from each other tend to move away from each other on average, and stars around 1 pc apart tend to move towards each other. This highlighs that a simple question "Is the region expanding or contracting?" may not have a simple answer as exapansion and contraction are *both* occuring, just on different scales. There in insufficient space in this format for a full analysis of the physical interpretation of the results in Fig. 2. Nevertheless this illustrates how the method can be used to transform messy, multidimensionsal data into a clean, quantative output that is much easier to interpret.

Fig. 3 deomstrates how colour-coding can aid this interpretation. In it stars are colour coded according to how heavily they contribute to Δr bins from 0.3—0.6 pc, i.e. the range where Δv_D peaks. It makes it clear that two substructures, which have been circled, contribute most heavily and as such play an important roll in the region's kinematic structure.

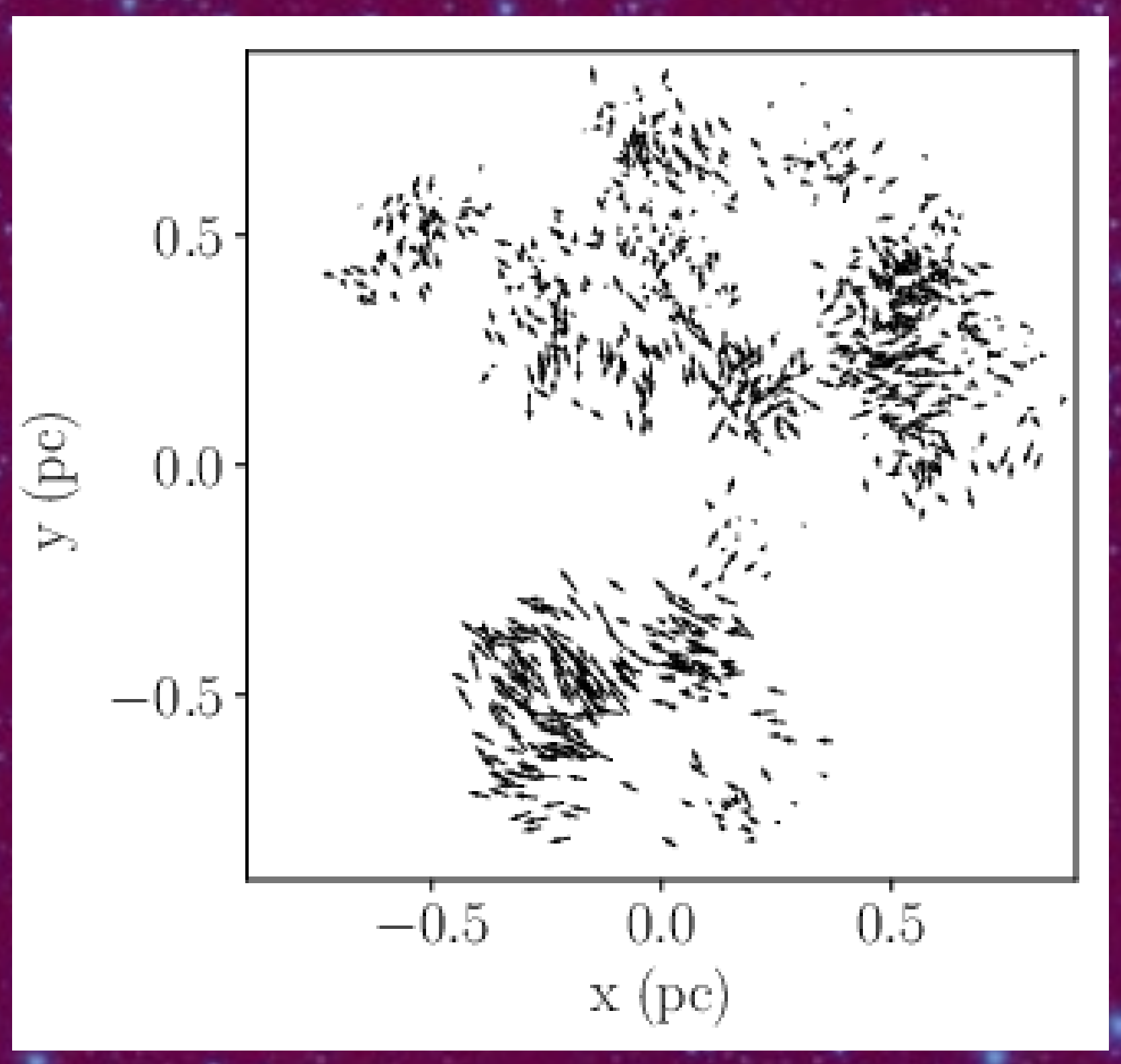

Figure 1:A region with spatial and velocity substructure.

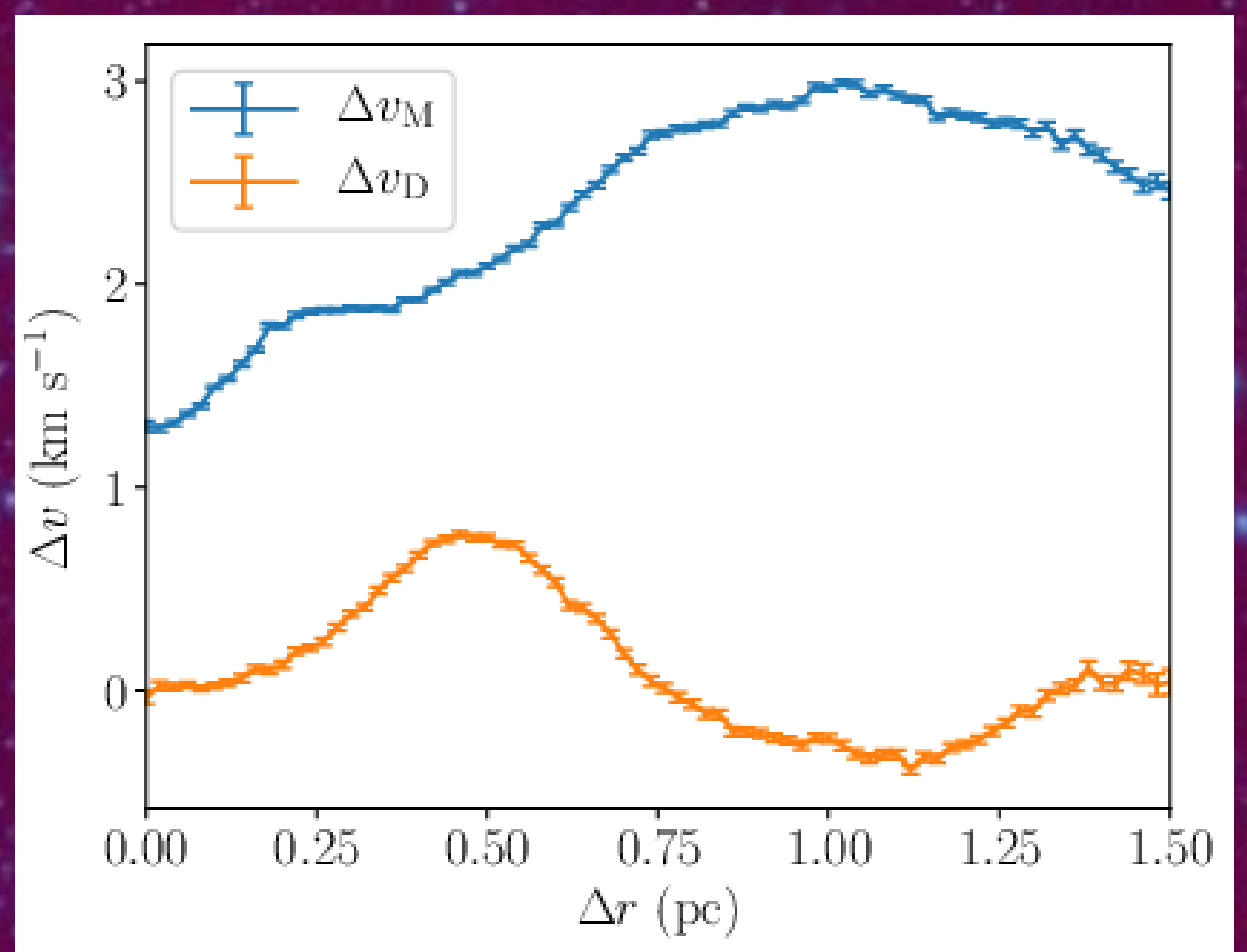

Figure 2:The velocity structure of the region in Fig. 1

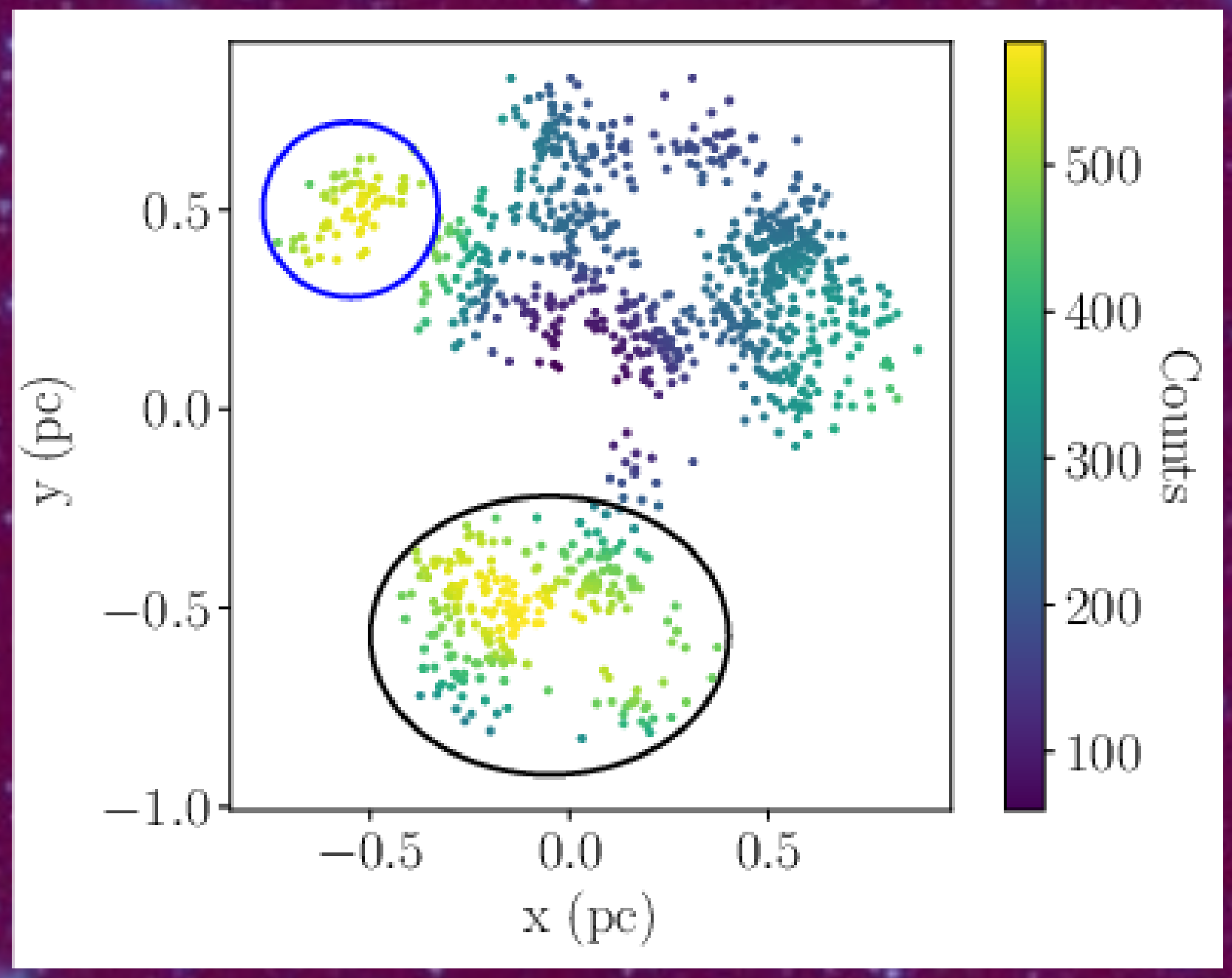

Figure 3:The region in Fig. 1 with stars colour coded according to their counts in Δr bins 0.3—0.6 pc.

5. Conclusions

We present a method of quantifying velocity structure in star forming regions. It is applied to a simulated region with high spatial and kinematic substructure to demonstrate how it can transform complex, messy data into a form that can be more readily and quantitatively analysed.

Background image credit: NASA; References: [1] Allison et. Al., 2009, MNRAS, 395, 1449 ; [2] Maschberger & Clarke, 2011, MNRAS, 416, 541