

The Fractal Structure of the Young Blue Clusters and Associations in Nearby Galaxies

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Abstract. It is known that the location of the stars, from young open clusters to large blue groups, follows fractal and sub-fractal patterns inherited from the original molecular clouds in the star-forming process. In this work, we compared different mock models and real observations. Also, for comparison purposes, we made mock models of non-fractal cusp clusters using different parameters to describe the star density. We also computed the Q parameter. This parameter describes the geometrical structure of object distribution and statistically quantifies the fractal substructures, distinguishing fragmented from smooth distributions. We also compared model realizations and real observations in the same way. We presented the results of measuring the Q parameter with different amounts of objects and levels of contamination by field stars. In this way, we could understand the Q value behavior in poor stellar clusters and the impact of the field stars. We compare and show a new algorithm that produces a circular symmetry instead of the box-shape type commonly used to simulate fractal structures in the astronomical context.

1. Introduction

The Hubble Space Telescope (HST) and other ground-based instrumentation have already obtained observational data of regions of stellar formation for several close galaxies. So, with these data, we could find the groups of the bright blue stars and measure their parameters and physical properties—magnitudes, colors, and spatial distributions of the stars in the cluster. To check the quality of estimating the fractal dimension of a cluster and other parameters, it is useful to model mock clusters with known parameters (e.g., fractal dimension, numbers of stars, foreground contamination, etc.) and remeasure using the known algorithms to test them. In other words, if we can recover the original parameters in the simulated clusters, we are doing a good job when we are dealing with the real ones. So, if the modeling works and the fractal dimension estimation is good, we can use the mock clusters to check where the algorithms work and where they do not. For example, we can verify the minimum quantity of stars needed, how the estimation is affected by the contamination of field stars, etc.

2. Fractal and Non-Fractal Models

We tested three models, two from the literature and one we developed. We built all these models in a 3D space. Then, they were rotated and projected over a 2D dimension to simulate sky-projected observations of a cluster or a large stellar formation structure. The models used were:

- Box fractal model from CW (Cartwright & Whitworth 2004). Most researchers have chosen this model to simulate clusters with fractal and sub-fractal dimensions. It is based on a grid of 3D points selected using random numbers to match a determined fractal dimension. So, the selected points became “parents” of a new generation of points. Each “child” is created in the center of 8 smaller boxes surrounding the parent point. Therefore, each point is tested to a probability of survival related to the fractal dimension that is being modeled. Then, points that do not follow a spherical distribution are removed until the number of points is reached. The input parameters for this model are the fractal dimension and the number of points. This way of modeling has been criticized by Daffern-Powell & Parker (2020) considering that these models create unreal box fractal structures. We found this may be due to the angle between the “child siblings” points being fixed at 70.52 or 109.47 degrees.
- The second type of modeling used is a modified version of the models from Elmegreen (1996). These models were designed to simulate the inter-cloud structure of the turbulent fractal interstellar medium.
- Spherical distribution models. We propose these models to avoid the box fractal structure of CW, giving a more natural sphere shape. These models are similar to CW models, the main difference being that we created the “children” at a distance R (or $-R$) from their “parents” and located over the Cartesian axes of a system centered in each “parent.” In this case, as in the CW fractal model, the maximum number of live children possible will be 6, not 8. More iterations are needed in the spherical model to get the same number of total stars because fewer stars are being formed in each generation. Therefore, for the same number of points, the realizations following our models have deeper substructures than those obtained with the CW fractal model.
- To build a non-fractal model, we followed the recipe given by CW and created star groups as a random distribution of stars that follows a $F \sim r^{-\alpha}$ law. Where r is the radial position of the stars and α is the concentration factor. For example, a large α would make a more centrally concentrated cluster.

3. The Q Parameter, Modeling and Measurements

We investigated the fractal properties of clustering of young structures following the procedure given by Rodríguez et al. (2019). We compute the Q parameter introduced by (Cartwright & Whitworth 2004) to distinguish between a smooth large-scale radial density gradient and multi-scale fractal clustering. The Q parameter is defined as the ratio of two other parameters ($Q = \bar{m}/\bar{s}$) that have a specific meaning: $\bar{m}$, which is the mean edge length in a minimum spanning tree (MST). The MST is the shortest

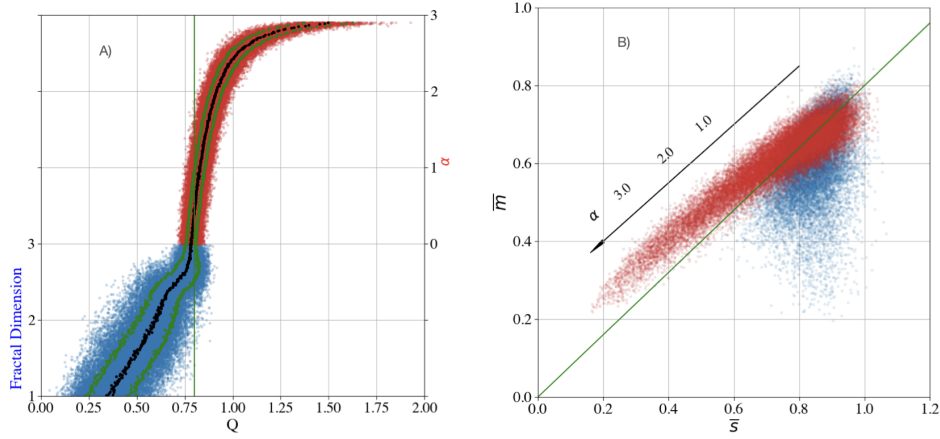


Figure 1. (Left) Panel A combines two different plots; see text. Black points are the average for the same α parameter or the same fractal dimension, while green points are the standard deviations. Black points are the average for the same α parameter or the same fractal dimension, while green points are the standard deviations. (Right) Panel B shows that clusters begin their life having a fractal dimension and evolve to the non-fractal region as a cusp grows inside

possible network connecting all the stars in the cluster, with no closed loops. $\bar{m}$ is also normalized by the cluster area. The other parameter is the $\bar{s}$, the mean separation of the points normalized by the cluster ratio. See Hetem & Gregorio-Hetem (2019) for the procedure for computing the parameters $\bar{m}$ and $\bar{s}$. Values of Q lower than 0.8 are considered diagnostic for fractal structure.

We calculated the Q parameter for the HST Observations and the mock clusters. We found that it detects the original dimension for the simulated clusters in most cases. We reproduced the diagrams of the fractal dimension vs. Q of CW using our new method of creating models. Figure 1 A combines two different plots as CW did but remade with our new way of modeling the fractal structure. The upper one (in red) is the α parameters of the non-fractal clusters models versus the Q parameter. While the bottom one (in blue) is the fractal dimension used versus the Q parameter. Note that at dimension 3 and $\alpha=0$ (no cusp), there is a match between both ways of modeling. This match does not exist in the CW models but is observable in the spherical-shaped ones. In the case of our new way of modeling, we could reproduce any of the properties but with the same advantages over the CW models, like the smooth overlap between fractal models at dimension 3 and non-fractal ones with $\alpha=0$. See (Fig.1) Panel A. In the CW models, this overlap has a visible discontinuity at this overlap point.

4. Analysis

To check the quality of the sphere shape models, we plot $\bar{m}$ vs. $\bar{s}$ for fractal and no fractal clusters. This plot gives an idea of the probable dynamical evolution of the cluster. The cluster is in the fractal region at the beginning of its life. After a time scale comparable to dynamic time, star-to-star interaction creates a central concentration of stars, therefore erasing the fractal structures. So, in the plot, the cluster evolves from

the fractal region to the non-fractal. Figure 1 Panel B left account for this regions in the $\bar{m} - \bar{s}$ diagram.

5. Contamination by foreground stars

One situation that must be considered is the possibility that a few non-member stars from the field stellar population could be wrongly considered members. These stars would eventually modify the path of the MST and then change the value of the Q . Therefore, we evaluated if this problem affects the results of low contamination, for example, from 1% to 20% of alien objects in the sample. To address this contamination, we make mock models for a determined fractal dimension and then contaminate them with a percent of stars randomly and uniformly distributed over the cluster, as would happen with the disk stars in a real galaxy.

Figure 2 shows the result for different star field contamination percentages. This plot shows that a good determination of membership is needed before calculating the Q parameters.

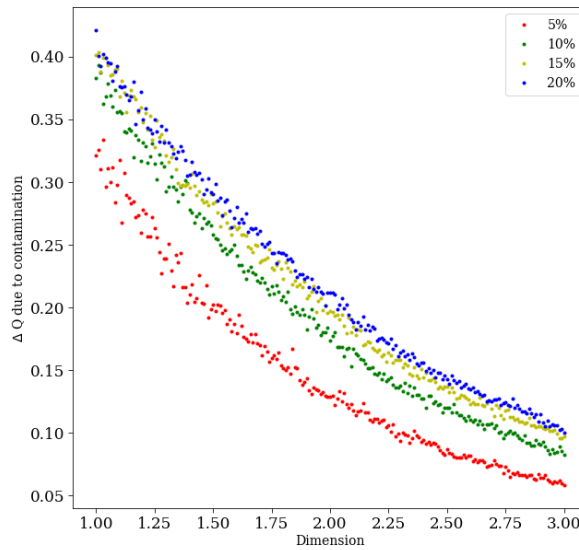


Figure 2. ΔQ is the difference between the Q contaminated and non-contaminated vs. the fractal dimension used to build the models. The colors indicate the percentage of field stars

6. Conclusions

In general, the realizations do a nice job of simulating groups of young stellar populations and their characteristics. The sphere shape models work better than CW models, making for more realistic simulations. The contamination of field stars could be a problem in measuring the Q parameter; a good decontamination method must be applied to the observations before its computation.

References

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