Boletim da Sociedade Astronômica Brasileira, **30**, no. 1, 154-155

Fractal parameter algorithm for young star clusters

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Abstract. In previous works, we measured the fractal parameter Q for a set of clusters and the results were correlated with others clusters properties showing that almost half of these groups shows a relation between its parental cloud fractal dimension. In this study, it was analyzed a sample of young star clusters with the purpose of investigating inherent cluster properties and the stellar components dynamical evolution. Above all, the Q parameter measured for the clusters and its correlations with King's profile. These properties can take us to conclusions about the initial formation conditions of the clusters (hot or cold collapse), initial evolution (bonded or not) and its expected galactic dynamical evolution(crossing time). These studies can also provide information about the galaxy influence history on clusters and how they were affected by the passage through the structures. To analyze and study the data, it was necessary the development of numerical routines, done in C++, that organized and plotted the processed data.

Resumo. Em trabalhos anteriores, medimos o parâmetro fractal Q para um conjunto de clusters e os resultados foram correlacionados com outras propriedades dos clusters e mostram que quase metade desses grupos apresenta uma relação com a dimensão fractal de sua nuvem parental. Neste projeto foi feita a análise de uma amostra de aglomerados de estrelas jovens com o intuito de investigar as propriedades inerentes ao agrupamento e evolução dinâmica das componentes estelares. Em especial, o parâmetro Q medido para os clusters, e suas correlações com o perfil de King. Estas propriedades podem levar a conclusões sobre as condições iniciais de formação de clusters (colapso frio ou colapso quente), evolução inicial (ligada ou não) e sua evolução dinâmica galáctica esperada (tempo de cruzamento). Esses estudos também poderão nos dar informações sobre a história da influência da Galáxia sobre os clusters e como estes foram afetados por sua passagem pelas suas estruturas. Para o estudo e análise dos dados foi necessário o desenvolvimento de uma série de rotinas numéricas, realizado em C++, que organizaram e plotaram os dados tratados.

Keywords. Chaos – ISM: clouds – Methods: data analysis – Stars: pre-main sequence

1. Introduction

During the study of the characteristics of star formation clusters it is observed a wide scale of values and qualities (Lada & Lada 2003). Young star clusters can be found both in a large young star aggregate and in compacts concentrations of protostars embedded star formation regions. Considering ongoing models and star formation processes (Elmegreen 2011), it is evident the necessity of an investigation about the natural connection between these several scales of groups and agglomerates. Very likely, all these star formation processes might be related, despite the differences in scale.

In previous works (Gregorio-Hetem et al 2015, Fernandes et al. 2012), an analysis of a huge young star cluster sample was done in order to investigate intrinsic properties of the grouping and dynamical evolution of stellar components. In these studies, a special attention was given to the statistical parameter (Cartwright & Whitworth 2004), measured for the clusters, and its possible correlations with the fractal dimension estimated for the projected clouds (Hetem & Lépine 1993). These works demonstrate that more than 50% of the samples show substructures (or subgroups) that, once analyzed under a statistc and geometric view, exhibit a tendency to reproduce artificial simulations of stellar distributions (Lomax, Whitworth & Cartwright 2011).

The fractal geometry (or chaotic – not just random) of distributions of size and mass in interstellar gas relations have been evaluated for many studies (Hetem & Lépine 1993; Elmegreen & Falgarone 1996) and have been determinated by surveys of cloud imaging from literature.

2. Methodology

The parameter Q , which carries information about the cluster fractal structure, is a dimensionless quantity given by equation 1,

$$Q = \frac{\bar{m}}{\bar{s}} \tag{1}$$

where $\bar{m}$ and $\bar{s}$, normalized mean edge length and mean separation of points respectively, are statistical parameters that depend on the geometric distribution of data points (Cartwright & Whitworth 2004), as shown by equations 2 and 3.

$$\bar{m} = \frac{1}{(A_N N)^{1/2}} \sum_{i=1}^{N-i} m_i \tag{2}$$

A_N is the area of the smallest circle that contains all points (Megiddo 1983) and m_i is the length of edges in the minimum spanning tree (Gower & Ross 1969).

$$\bar{s} = \frac{1}{N(N-1)R_N} \sum_{i=1}^{N-i} \sum_{j=1+i}^{N} |\boldsymbol{r_i} - \boldsymbol{r_j}| \tag{3}$$

R_N is the radius of the smallest circle that contains all points and $\boldsymbol{r_i}$ and $\boldsymbol{r_j}$ are vector position of points.

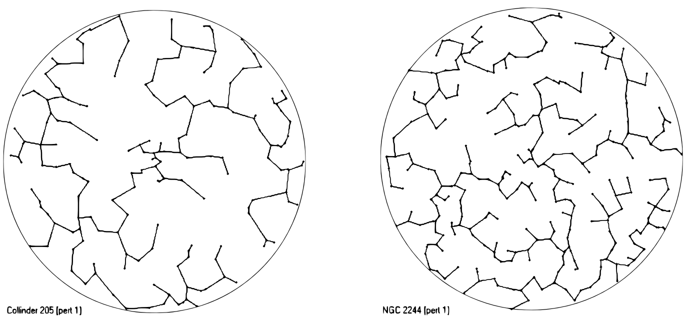
3. Results

The parameters Q, $\bar{m}$ and $\bar{s}$ obtained through our numerical routines for the clusters are presented in table 1.

Table 1. Cluster data and results

Cluster	Q	$\bar{m}$	$\bar{s}$	Nstars
Berkeley 86	0.75218 ± 0.09924	0.68967 ± 0.08855	0.91690 ± 0.02788	86
Collinder 205	0.70082 ± 0.10329	0.66513 ± 0.09685	0.94907 ± 0.02166	177
Hogg 10	0.77455 ± 0.16803	0.69727 ± 0.14714	0.90022 ± 0.04527	88
Hogg 22	0.72174 ± 0.13335	0.69240 ± 0.12497	0.95934 ± 0.03791	98
Lynga 14	0.75372 ± 0.10793	0.70679 ± 0.09763	0.93774 ± 0.03538	67
Markarian 38	0.78586 ± 0.11486	0.69543 ± 0.09748	0.88493 ± 0.03667	58
NGC 2244	0.74330 ± 0.06030	0.67447 ± 0.05430	0.90740 ± 0.00912	296
NGC 2264	0.70326 ± 0.04399	0.65046 ± 0.04040	0.92492 ± 0.00690	293
NGC 2302	0.78474 ± 0.10397	0.65724 ± 0.08428	0.83752 ± 0.02788	70
NGC 2362	0.77863 ± 0.15075	0.64898 ± 0.12352	0.83349 ± 0.02957	132
NGC 2367	0.77900 ± 0.10365	0.64508 ± 0.08277	0.82809 ± 0.02917	61
NGC 2645	0.74542 ± 0.12376	0.65658 ± 0.10673	0.88083 ± 0.02978	104
NGC 2659	0.72893 ± 0.12101	0.68155 ± 0.11198	0.93499 ± 0.02223	220
NGC 3572	0.76514 ± 0.14664	0.69040 ± 0.13023	0.90233 ± 0.03056	151
NGC 3590	0.77843 ± 0.15229	0.75005 ± 0.14199	0.96354 ± 0.04756	81
NGC 5606	0.75310 ± 0.13636	0.66338 ± 0.11742	0.88087 ± 0.03359	99
NGC 6178	0.69149 ± 0.12146	0.69835 ± 0.12004	1.00993 ± 0.03655	104
NGC 6530	0.85984 ± 0.05765	0.64913 ± 0.04188	0.75494 ± 0.01379	63
NGC 6604	0.75843 ± 0.09169	0.68977 ± 0.08123	0.90947 ± 0.02487	90
NGC 6613	0.74977 ± 0.09400	0.68608 ± 0.08454	0.91505 ± 0.02117	135
Ruprecht 79	0.69175 ± 0.13663	0.64583 ± 0.12607	0.93363 ± 0.02806	175
Stock 13	0.74184 ± 0.11059	0.68719 ± 0.09898	0.92634 ± 0.03559	67
Stock 16	0.66747 ± 0.12311	0.64916 ± 0.11804	0.97258 ± 0.03007	141
Trumpler 18	0.75046 ± 0.12243	0.67824 ± 0.10907	0.90376 ± 0.02480	161
Trumpler 28	0.78515 ± 0.11149	0.66102 ± 0.09099	0.84191 ± 0.02935	74

An example of the minimum spanning tree and the smallest circle that contains all points for Colinder205 and NGC2244 is presented in figure 1.



(a) Colinder205 (b) NGC2244

Figure 1. Graphic results for Colinder205 and NGC2244.

3.1. Analysis

The Q parameter, so as $\bar{m}$ and $\bar{s}$, were correlated with with the number of stars, Σ_0 and r_c in many ways.

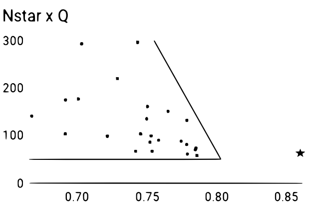


Figure 2. $N \times Q$

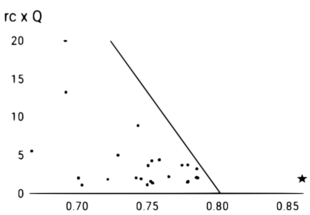


Figure 3. $r_c \times Q$

In graphs of figures 2 and 3 we can see a bottleneck tendency.

All three graphs, figure 2, 3 and 4, show forbidden regions, which boundaries are evidenced by the straight lines, showing a pattern relation between the parameters. However, there is an exception for these patterns, cluster NGC6530, illustrated as the star point. It happened due to a high value of Q, that is a consequence of a low value of $\bar{s}$.

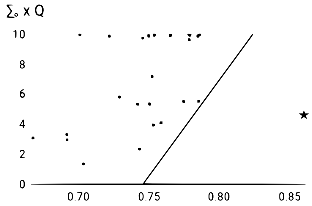


Figure 4. $\Sigma_0 \times Q$

4. Conclusion

By analyzing the obtained data in the present study and the data obtained from "Fitting of King's Model to Young Star Clusters", poster 118, it can be observed that the parameters for the clusters are somehow related, showing behaviours and forbidden regions. The cluster NGC6530 demonstrated a peculiar behaviour in every single relation made, extrapolating all the green lines, due to a low $\bar{s}$. In other words, either our model is not faithful with this cluster for some reason or this cluster have some particular characteristics that were not considered in this study.

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