A Phenomenological Model for the Evolution of Proto-Galaxies

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ABSTRACT

The contraction model of Field and Colgate for proto-galaxies, first proposed to describe the observed properties of quasars, is generalized and used to investigate the evolution of galaxies. The LEDA data base for elliptical, spiral, compact and diffuse galaxies is employed and it is shown that the above model is consistent with observational evidences regarding their dynamical evolution, star formation rate and different morphologies.

Key words: galaxies: formation – galaxies: luminosity function – quasars: general –galaxies: phenomenology.

1 INTRODUCTION

It is generally thought that the galaxies are formed by cooling and condensation from the intergalactic gas clouds of sufficiently high densities [1,2,3,4]. The recent great advances in observational technologies made the proto-galaxies (PGs) one of the most exciting and lively fields of extragalactic astronomy. Rees and Ostriker [5] argued that the collapse of a virialised gas for which the cooling time is shorter than dynamical time will lead to the formation of a galaxy. White and Rees [6] solved the problem of cooling catastrophe hierarchical model of Rees and Ostriker, by introducing the idea of feedback resulting from energy release from supernovae associated with the early generation of stars and reheating the gas before having a chance to condense. On the other hand, the initial total mass [7], the initial angular momentum [8] and the initial density distribution [9] play a significant role in evolution history of the galaxies. Here, we consider the Field and Colgate (FC) model [10] and generalized it to include the effect of initial mass and initial size as well as initial angular velocity. To do this, and to have a conserved dynamical quantity during the collapse of the cloud, we introduce the specific angular momentum (SAM) as parameter which governs the evolution. Furthermore, it is known that the star formation history of the galaxies depends on their rotations [11]. Therefore, one expects that the observed luminosities of the galaxies would be affected by star formation rate (SFR), which itself may depend on SAM. From this point of view, SFR may be included in the FC model. The generalized version of the FC model (in the form mentioned above), called GFC model, is used to explain the observed properties of galaxies such as, their morphologies, luminosities, compactness, evolution and SFR. The LEDA

database of 100,000 galaxies [12] is used as our source data. It is shown that the SAM of PGs has a significant effect on their evolution. In addition, the different values of SAM for different morphologies, together with their SFR may be employed to present a conjecture about their origin.

In section 2 the FC model is reviewed and is generalized to introduce the GFC model. In section 3 the GFC model is examined versus the observational data. It is shown that this model is capable of explaining various aspects of galaxies. Section 4 is devoted to the concluding remarks.

2 GFC MODEL

The FC model was first introduced to describe the observational properties of quasars. This model assumes that for proto-galaxies of the same mass and size, the average mass of their constituent stars, their total energy output and their final size at the end of galaxy formation depend on their initial angular velocities. According to this model, the proto-galaxies with lower angular velocities would be eventually converted to more compact and luminous objects such as quasars and compact galaxies. This proposition may be tested by using the observational data obtained in galaxy surveys. However, before doing this, a few points must be taken into account. In contrast to the assumptions of FC model, the angular velocity is not a conserved quantity during the contraction processes. Therefore, the observed angular velocities do not indicate any relevance to their initial values which the proto-galaxy starts the contraction with. Thus another parameter must be replaced by angular velocity which keeps a constant value during the contraction. Another point is that the typical mass and size assumed for

all proto-galaxies in FC model do not make any sense. In the other words, one actually expects some kind of distribution for these quantities rather than a fixed value. Thus upon these considerations, we propose the angular momentum (i.e. angular momentum per unit mass) instead of angular velocity and call the revised version of FC model as generalized FC or GFC model. However, the specific angular momentum (hereafter SAM) is assumed to be constant during the contraction process. This assumption does not essentially change the dynamical grounds of the FC model and revise it only to obtain a better fit to observations. In fact, FC model will emerge as a special case from GFC model. In the framework of GFC model, a given SAM may correspond to different values for masses and sizes of proto-galaxies. Now the lower (higher) values of SAM will eventually lead to more compact (diffuse) and luminous (faint) galaxies. These will be confirmed observationally in the next sections. As mentioned before, the FC model is proposed to describe the observational properties of quasars. However, because of the lack of required data for these objects, one may use the already available data for galaxies. If the model is shown to work well for galaxies, one might try to extend it for quasars, too. On the other hand, compact objects will possess much more massive stars. Therefore, one should argue that by rapid energy consumption they must evolve faster than those having low mass stars. This processes if done for quasars which by GFC model are extreme case of galaxies with less SAM, will eventually make them to disappear as a result of the collapse followed by consuming their energy sources. Thus, GFC model predicts an evolutionary "decay mechanism" for quasars in the course of time. We will show that this process may be equally applied for compact galaxies and those with lower SAM, which, in turn, have young blue stars and less interstellar gas.

3   GFC MODEL VERSUS OBSERVATION

Let us investigate the dependence of SAM for different morphologies and types of galaxies on their SL. The data is extracted from LEDA data base. First, we compare the behavior of SAM versus SL for the ellipticals and spirals as two distinct morphologies. Then the same thing is done for different types of spirals, according to the de Vaucouleurs classification.

3.1   GALAXIES WITHIN THE SAME MORPHOLOGICAL TYPE

According to the GFC model, we expect that the luminosities of galaxies increase as their SAM decrease. Figure 1 shows the behavior of SAM for 56 elliptical galaxies in terms of their luminosity. The result shown in Fig. 1, however, is not consistent with GFC model.

To get the expected result one might use the specific luminosity (luminosity per unit mass), instead of luminosity itself for the galaxies. The results obtained in such a way are shown in Fig. 2.

The best fitted curve to this figure has the form $y = a + b \exp(-\frac{x}{c})$, with $a = 1.05$, $b = 34.41$, $c = 0.4$. Here, y is specific luminosity in units of $(\frac{L_\odot}{M_\odot})$ and x is SAM in units of $(pc^2 yr^{-1})$.
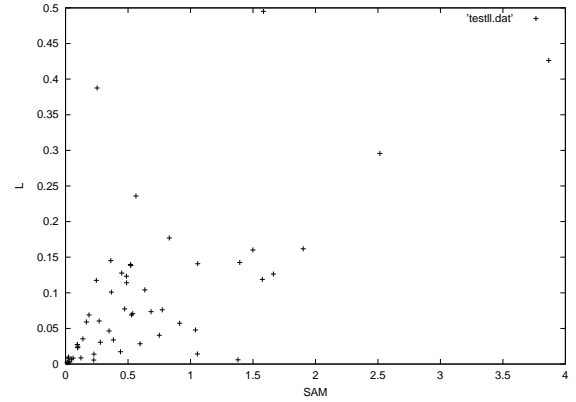

Figure 1. Variation of luminosity (L) of 56 elliptical galaxies (in units of $10^{10} L_\odot$) versus their SAM ($pc^2 yr^{-1}$)
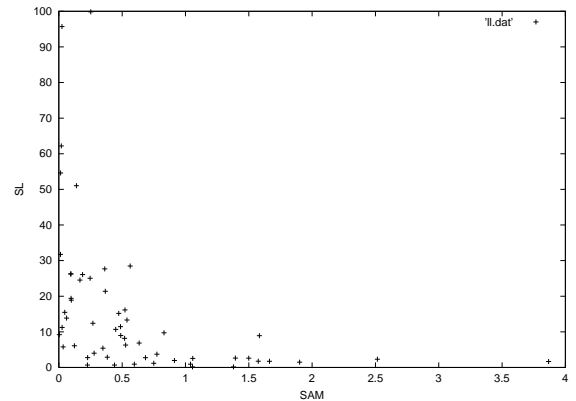
.

Figure 2. Variation of SL ($\frac{L_\odot}{M_\odot}$) versus SAM for elliptical galaxies.

The exponential behavior shows the decreasing luminosity with increasing SAM, in agreement with the GFC hypothesis. The same quantities are obtained for different morphologies of de Vaucouleurs class of spiral galaxies and the results are plotted in Figs. 3 to 6. Again, the results support the GFC model. Of course, the functional form of SAM are not the same for all morphologies. The best fitted curve for 226 galaxies of Sa type (Fig.3) is, $y = a + b \exp(-x)$ where $a = 3.43$, $b = 46.04$, $c = 0.76$ and for 717 galaxies of Sb type (Fig.4) is, $y = a + b \exp(-\frac{x}{c})$ where, $a = 4.88$, $b = 113.75$, $c = 0.59$ and for 1543 galaxies of Sc type (Fig.5) is, $y = a + b \exp(-\frac{x}{c})$ where, $a = 4.89$, $b = 24.31$, $c = 1.61$. For all of the above Figures, there are an exponential best fitted curve showing a behavior similar to the one for Sa type. For 389 Sd type galaxies (Fig.6) the best fitted curve is in the form, $y = a + \frac{b}{(x^{\frac{1}{2}})}$ where, $a = 5.38$, $b = 6.79$ and for 285 Sm type galaxies, $y = a + \frac{b}{x}$ where $a = 12.54$, $b = 2.3$. These figures show a negative power form for variation of
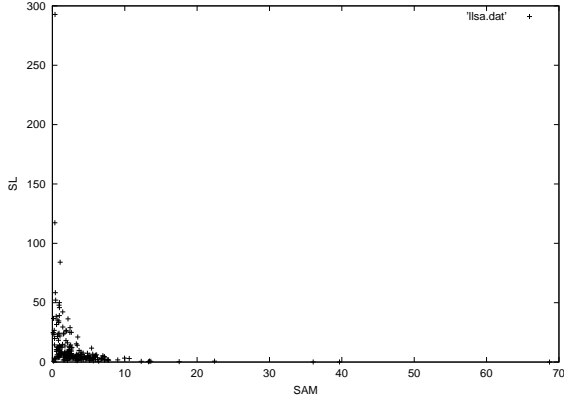
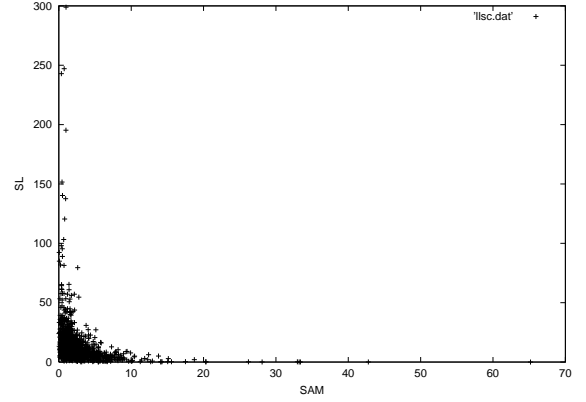**Figure 3.** The same as fig. 2 for 226 Sa type galaxies.

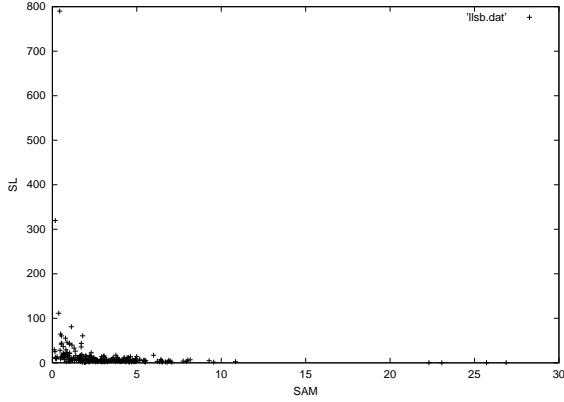**Figure 5.** The same as fig. 2 for 1534 Sc type galaxies.

Figure 4. The same as fig. 2 for 717 Sb type galaxies.
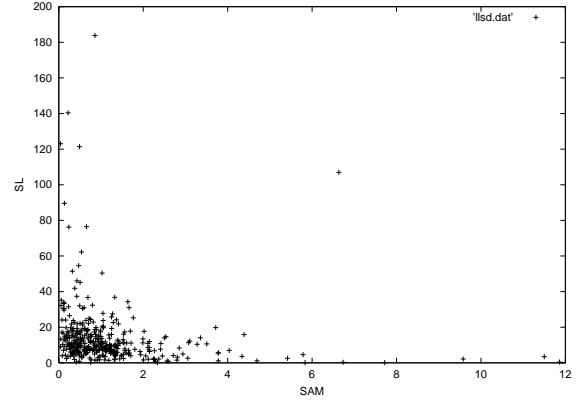

Figure 6. The same as fig. 2 for 389 Sd type galaxies.

SAM and SL.

3.2 ELLIPTICALS VERSUS SPIRALS

Spiral galaxies rotate faster than elliptical galaxies[14]. According to GFC model their luminosity is expected to be less. However, this is not supported by low redshift galaxy observations. The discrepancy seems to be removed as follows. In general, most of the observations are limited to the near distances or low redshifts. However, the high redshift observations show that the evolution procedure is not the same for spirals and ellipticals. In other words, they are in different phases of star formation. Ellipticals have stopped their star formation processes because of fast SFR in the past, while spirals are still active and therefore, have some young blue stars producing the observed excess luminosity. Therefore, the final elliptical or luminous spirals not only violate the GFC model, but rather confirm it. That is, ellipticals were started from slowly rotating proto-galaxies compared with those of spirals. Therefore the condensation rate for ellipticals were higher than spirals leading to higher SFR in

a certain phase of evolution for ellipticals. As a result, ellipticals evolved faster than spirals and now contain old stars, showing in some sense, the decay mechanism for galaxies. The same mechanism works for quasars with higher decay rates and it will be investigated elsewhere[15].

3.3 DE VAUCOULEURS TYPES OF SPIRALS

We now look for a relation between SAM and luminosity for different de Vaucouleurs types of spiral galaxies. In Figs. 7 to 13 we illustrate the absolute magnitude or luminosity distribution of spiral galaxies of different de Vaucouleurs type. We may fit Gaussian distributions to these figures and calculate the most probable absolute magnitude, M_{mp}, for which the number of galaxies is maximum, for each group belonging to a specific morphology. Results for M_{mp} as well as the average value of SAM for each type are given in the table. It is seen that SAM increases from Sbc to Sd. However, it fluctuates from Sa to Sbc, whereas the M_{mp} decreases from Sb to Sd and fluctuates from Sa to Sb. If one resorts the table, say by increasing order of SAM, one can find that the L_{mp} increases with decreasing average SAM.
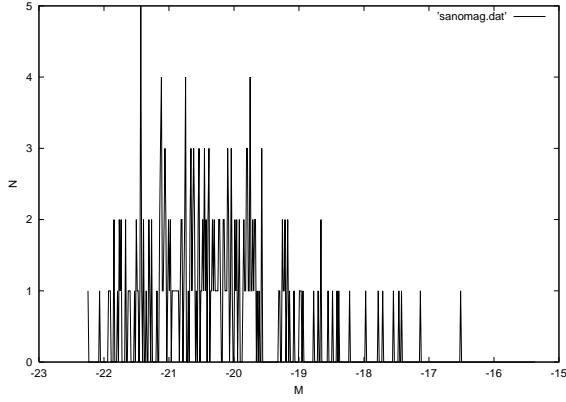
Figure 7. Distribution of the Sa type galaxies in terms of their absolute magnitude.

Figure 8. The same as fig. 7 for about 248 Sab galaxies.

On the other hand, the average mass, $\overline{m}$, corresponding to each type given in the 4th column of the table increases in the same manner as M_{mp} from Sbc to Sd and fluctuates from Sa to Sbc. This phenomenological investigation results shows the role of mass on affecting the M_{mp}. While the ratio of $\frac{L_{mp}}{\overline{m}}$,shown in 5th column of the table, increases from Sbc to Sd and fluctuates from Sa to Sbc. This apparently contradicts with GFC model. However, similar to what we did in section 3.2 for comparison of ellipticals and spirals, one can argue as follows: It is known that the late type spirals are those with greatest amount of dust and gas and highest SFR. This gives the lowest "mass-luminosity" ratio for these type of galaxies which in turn leads to the observed behavior. Thus one may conclude that the SFR plays a significant role in evolution and distribution of galaxies. In the other words, according to the GFC model we expect that for those morphologies of spiral galaxies with less SAM, undergo more rapid "decay mechanism" compared with those having higher SAM. This leads to lower present SFR giving lower SL. Therefore, observed properties not only do not contradict with the GFC model, but also support it.
Also the effect of SAM on SFR discussed above is in agreement with that of Samland and Hensler [12] obtained by a chemo-dynamical approach.

3.4   COMPACTNESS AND GFC MODEL

We finally use GFC model to study the observational properties of compact (C) and diffuse (D) galaxies given by LEDA data base. Figs. 14 and 15 show the distribution of absolute magnitude for 450 C-type and 230 D-type galaxies, respectively. It is seen that the most probable magnitudes are $\sim$-20.82 and -19.76 for C- and D-type galaxies, respectively. Therefore, the compact galaxies are on the average about one magnitude more luminous than diffuse galaxies, suggesting another observational evidence satisfied by GFC model.
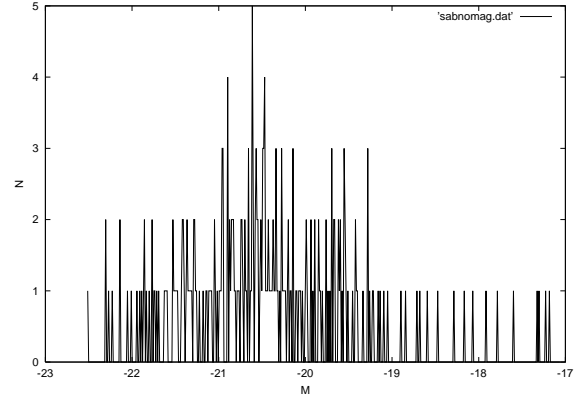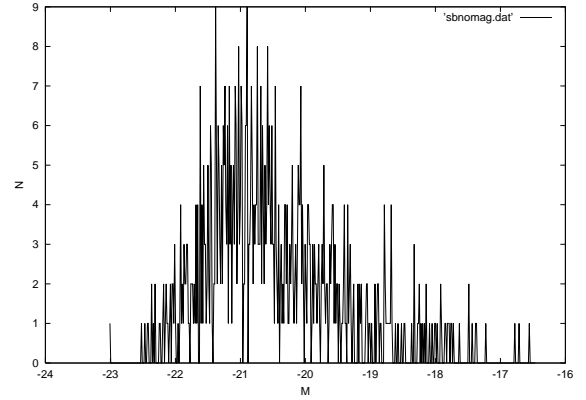

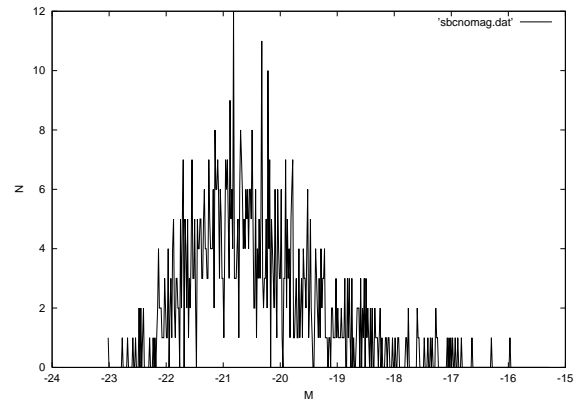**Figure 9.** The same as fig. 7 for about 717 the Sb type galaxies.

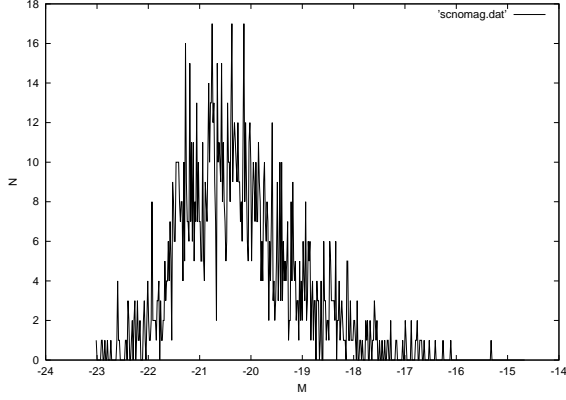**Figure 10.** The same as fig. 7 for about 824 Sbc type galaxies.

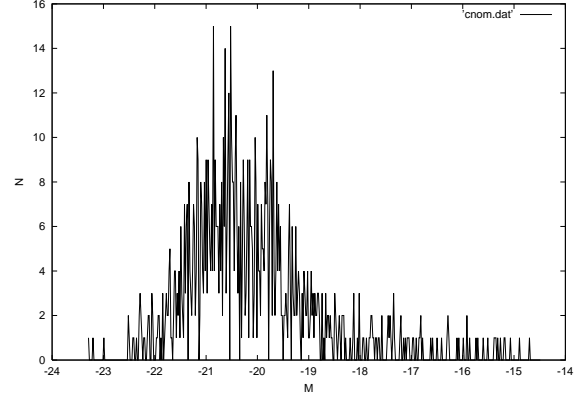**Figure 11.** The same as fig. 7 for about 1534 Sc type galaxies.

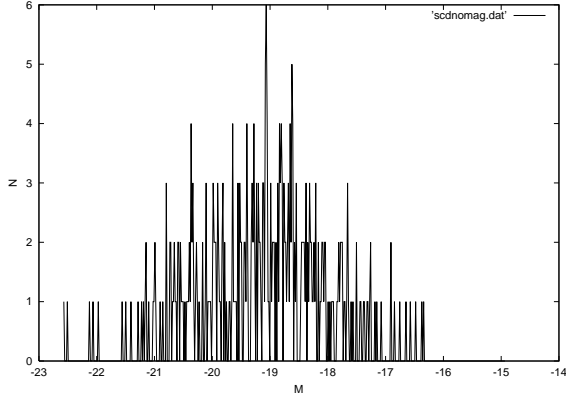**Figure 14.** The same as fig. 7 for about 450 C type galaxies.

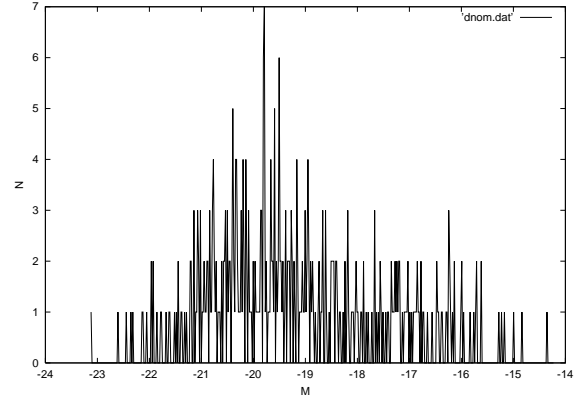**Figure 12.** The same as fig. 7 for about 339 Scd type galaxies.

Figure 15. The same as fig. 7 for about 230 D type galaxies.

4 CONCLUSIONS

We have used the LEDA data base with complete morphological classification to study the phenomenological investigation in the framework of the GFC model. We conclude as follows:

a) Within the same morphological type the expected behavior of SAM in terms of luminosity is not seen. However, this is not surprising because of difference in masses of galaxies. Further, it is shown that when we use SL instead of L for different masses of galaxies, the discrepancy is removed by compensating the role of mass. Therefore, we receive confirmation for GFC model.

b) For different morphologies, SFR of each type has a significant role in the value of the most probable luminosity per unit average mass. This may not be looked as a discrepancy with GFC model, because the SFR history depends on SAM showing a weak form of the "decay mechanism" inherent in the GFC model, for galaxies, too.

c)The distribution of compact galaxies in terms of their absolute magnitude, shows higher average luminosities compared with diffuse galaxies. This is another aspect of the GFC model.
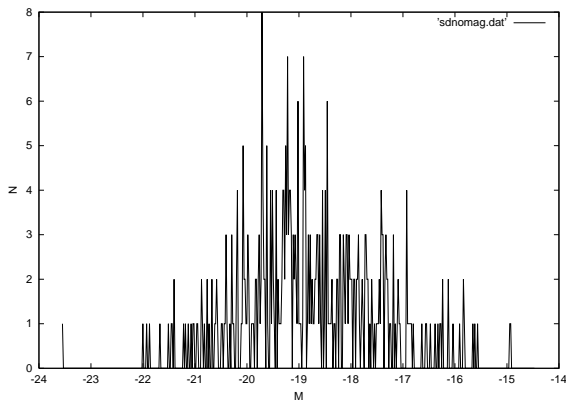

Figure 13. The same as fig. 7 for the Sd type galaxies.

Table 1. In this table, the morphological type, SAM in units of $pc^2 yr^{-1}$, the most probable absolute magnitude (M_{most}), the average mass ($\bar{m}$) in units of $10^{11} m_\odot$ and the most probable luminosity-average mass ratio in units of $\frac{L_\odot}{M_\odot}$ are shown.

$L_{\frac{most}{\bar{m}}}$	$\bar{m}$	M_{most}	$S\bar{A}M$	$morphs$
0.425	0.46	-20.99	0.32	Sab
0.391	0.44	-20.85	0.405	Sbc
0.416	0.41	-20.84	0.428	Sc
0.121	1.22	-20.68	0.448	Sa
0.491	0.37	-20.91	0.468	Sb
0.429	0.12	-19.54	0.494	Scd
0.471	0.08	-19.21	0.504	Sd

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