ON THE PROPERTY OF PARENT CLOUDS TO FORM OB ASSOCIATIONS. Hideyuki Kamaya, *Department of Astronomy, Kyoto University, Kyoto 606-8502, Japan (kamaya@kusastro.kyoto-u.ac.jp).*

abstract

The evolution of a star cluster is crucial for understanding the evolution of the interstellar medium and galactic structure. Thus, we should investigate the relation between the initial and final evolution stages of the cluster. In this poster, we try to present an observational strategy to find this relation while theoretically constraining the dissolution velocity of the young clusters. Once the virial equilibrium for the parent cloud of the cluster is assumed, we determine the velocity dispersion of the dissolution of the cluster. Hypothesizing the star formation efficiency (SFE) to be 0.1, we find that the typical dissolution velocity is $\sim$1 km s^{-1}. Once we adopt this result and the galactic dust-gas mass ratio, the expected infrared flux can be estimated for the individual parent clouds. If we recognize such an infrared luminous cloud without star formation through observation, it is considered to be the parent cloud for the OB association. The necessary angular resolution for their spatial resolution is $\sim$0.1 arcsec that coincidently corresponds to the Jeans length, when the external galaxies are located at $\sim$ 10 Mpc. The search for these infrared clouds becomes a subject for future study.

1 Introduction

The origin and evolution of clusters belong to a classical set of problems. Recently, it has been recognized that understanding these problems is very important to know how disks of spiral galaxies form and evolve [1], [2], [3], and so on because star complexes and associations are fundamental and elementary cells of star formation [4].

In particular, we do not understand the relation between the initial and final evolutionary stages of the cluster. In order to find this, the mass loss process from the parent cloud should be investigated precisely. In other words, the star formation efficiency (SFE) must be considered. Previously, an SFE of ~ 0.5 was regarded to be a critical value, judging whether the star cluster was bound. According to Boily & Kroupa [5] and [6], even if the mass loss is significant and SFE is smaller than 0.5, the star clusters can be bound by self-gravity. They insist that for dissolving clusters, the SFE is smaller than $\sim$ 0.1. Hence, in this poster, focusing on the case of SFE$\sim$ 0.1, we investigate the evolution of the parent clouds to form star clusters.

2 Results

In the previous paper [7], a theory for investigating some elemental connections between the formation and evolution of clusters was described. However, the dissipation of energy during cluster formation and the observational implication of the parent cloud were not considered precisely. This poster examines the effect of energy dissipation and presents some observational properties of the parent cloud of the clusters. The proposed observational strategy will relate the initial and final conditions of cluster evolution.

We briefly summarize the assumptions adopted in the previous paper [7] : (1) During the formation epoch of the cluster, the parent cloud is a uniform sphere in virial equilibrium under the external pressure of ISM. (2) The gas content of the parent cloud is removed rapidly. (3) In order to simplify the discussion, we exclude the effects of angular momentum and figure rotation of the parent cloud. (4) The energy for the stellar component is conserved to estimate the dissolution velocity.

As a result, we have

$$< v_1^2 >=$$

$$\frac{GM_0}{2R_0}\left(1-\Gamma_{CFE}-2\Gamma_{SFE}\right)+\frac{3p_0V_0}{M_0}\left(1-\Gamma_{CFE}\right). \quad (1)$$

Here, $< v_1^2 >$ is square of velocity dispersion of a star cluster, G is gravitational constant, M_0 is mass of the parent cloud, R_0 is size of the parent cloud, Γ_{CFE} is the dense core formation efficiency inside the parent cloud, Γ_{SFE} is the starformation efficiency, p_0 is the external pressure around the parent cloud, and V_0 is the volume of the parent cloud. Thus, we can describe $\sqrt{< v_1^2 >}$ by means of Γ_{SFE}, Γ_{CFE} and a_0 once the size of the parent cloud is estimated to be the Jeans length:

$$\sqrt{< v_1^2 >} =$$

$$\left[\frac{\pi^2}{6}\left(1-\Gamma_{CFE}-2\Gamma_{SFE}\right)+3\left(1-\Gamma_{CFE}\right)\right]^{0.5} a_0. \quad (2)$$

If we take $\Gamma_{SFE} = 0.1$ and $\epsilon_{SFE} = 0.5$, $\sqrt{< v_1^2 >} \sim 1.84a_0$. When a_0 is 0.8 km s^{-1} which is a typical sound velocity of the cold neutral ISM, $\sqrt{< v_1^2 >} \sim 1.5$ km s^{-1}; this is almost the expected dissolution velocity through observation as described below.

3 Discussions

OB associations expand due to their unbound nature. The expansion can be detected if and only if the correct mean streaming motion of the association with respect to the Sun is subtracted from the proper observed motion and radial velocities. This was a very difficult task to accomplish even after utilizing the data of *HIPPARCOS*. Fortunately, de Bruijne [8] succeeded in finding the internal velocity dispersion of nearby OB associations with the assumption of isotropy and compactness. According to this study, the internal velocity dispersion of $\sqrt{< v_{obs}^2 >}$ is approximately $1.0 - 1.5$ km s^{-1}. It should be noted that our theoretical model can predict a similar velocity dispersion of $\sqrt{< v_1^2 >} \simeq 1.5$ km s^{-1} if $\Gamma_{SFE} = 0.1$

and $\Gamma_{SFE} = 0.5\Gamma_{CFE}$. We would like to comment on some detailed studies of velocity dispersion in open clusters (i.e., bound cluster). Indeed, we expect their $\sqrt{< v_{obs}^2 >}$ value to be smaller than our estimate of 1.5 km s^{-1} due to their self-gravity. In fact, McNamara & Sekiguchi [9] reported a value of $\sim$ 1.0 km s^{-1} for M35. Girard et al. [10] maintain the velocity dispersion of M67 to be ~ 0.8 km s^{-1}.

The dissolution process is examined numerically by Brown, Dekker, & de Zeeuw [11]. The internal velocity dispersion of their initial conditions is a few km s^{-1}. According to their results, the discrepancy between the kinematic and nuclear ages of OB associations is attributed to the underestimation of the kinematic age. This occurred because of the overestimation of internal velocity dispersion. Thus, the dissipation of kinetic energy of the parent cloud during the formation of OB associations is discussed in this poster. The importance of external pressure is also suggested numerically by Elmegreen, Kimura, & Tosa [12]. According to their numerical work, the internal velocity dispersion for forming the OB association is determined by the external pressure in a manner similar to eq. (1).

Rewriting eq.(2), we have

$$\Gamma_{SFE} = \frac{4.645 a_0^2 - < v_1^2 >}{\left[\frac{4.645}{\epsilon_{SFE}} + 3.289\right] a_0^2}. \qquad (3)$$

By using eq. (3), we discuss the characteristic case of $\Gamma_{SFE} \sim 0.1$. According to Boily & Kroupa [5] and [6], $\Gamma_{SFE} \sim 0.1$ is the critical value for the bound nature of the cluster. Recently, Clark et al. [13] have also discussed the unbound nature of the OB association. According to their numerical results, $\Gamma_{SFE} \sim 0.1$ denotes the criticality limit of whether or not the association is bound. If these are correct, the cluster formed from the parent cloud with $\Gamma_{SFE} \sim 0.1$ can dissolve when the velocity dispersion of $\sqrt{< v_1^2 >} \sim 1.5$ km s^{-1} when a_0 is approximately 0.8 km s^{-1} andϵ_{SFE} is approximately 2. Indeed, the observational dissolution velocity of the unbound cluster is approximately 1.5 km s^{-1}. Thus, our theoretical consideration, which is formulated under the assumption of the unbound nature described in eq.(3), partially supports their prediction that the star formation efficiency of the parent cloud for a typical dissolving cluster is smaller than ~ 0.1.

It is reasonable to observe the pole-on spiral galaxies in order to search for parent clouds. For a tentative case, we consider the distance of 10 Mpc for the galaxies. When the dust temperature T_d is $\sim$ 10 K due to heating by the collisions of gas particles in the cold phase of ISM, we find that observational far-infrared flux is of the order of sub-Jy $\sim$ mJy for a single parent cloud. This is sufficiently bright for the parent cloud to be detected by the next generation infrared telescopes. However, the necessary angular resolution is approximately 0.1 arcsec that corresponds to the typical Jeans radius of the cold phase of ISM. We estimate it to be 7.6 pc. Thus, surveying the infrared luminous pre-cluster cloud with high angular resolution is of great interest to the next generation project. This observational class will be recognized as bright Maddalena clouds [14] in the band of far-infrared since the Maddalena cloud is known not to indicate any active star-formation.

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