N-body Model of Open Cluster Remnant NGC 1901

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ABSTRACT

Milky Way galaxy hosts more than 2000 open clusters. Some of them are evolved clusters that dissolved by Galactic tidal field, leave behind only few members and known as Open Cluster Remnants (OCR). They have very low surface density but high binary fraction. One of well-studied OCRs is NGC 1901 ($\alpha = 5^h18^m15^s$ and $\delta = -68°26'12"$; l = 279.022° and $b = -33.603°$). This middle aged (approximately 400 to 850 Myr) cluster is 400 pc away from sun at the same direction of Large Magellanic Cloud. Based on astrometric, photometric, and spectroscopic observation, there are 13 cluster members confirmed with binary fraction of 62%, mostly A-F stars. According to several data and parameters derived from the observation of NGC 1901, the authors performed some N-body models using various initial mass function (IMF), density parameter, number of member, and primordial binary fraction. Evolution of these model were simulated under Galactic tidal field until completely dissolved. Model B84-600 with 600 members (single and binary), Kroupa IMF, density parameter W0 = 4, along with 40% primordial binary fraction gives fairly good result. At cluster age $t \sim 800$ Myr, this model leaves only 7% of its initial members with 50% binary fraction. Cluster's structure which is parameterized by core radius (r_c) 1.9 pc and tidal radius (r_t) 5.6 pc rather close to observational study, r_t = 6.2 pc. However, with density parameter $\log(r_t/r_c) = 0.45$, this model is more loose compared to another observational analysis which yields $\log(r_t/r_c) = 0.64$.

Keywords: Open Cluster Remnants – Simulation

1 INTRODUCTION

Milky Way galaxy composed by some elementary components, one of them are open clusters orbiting galactic center in the disc. Each cluster contain hundreds to thousands stars which born and evolve together. Along with member stars' evolution, open cluster experiences a dynamical evolution under influence of Galactic tidal field. If the internal bonding of the cluster is stronger than the external field, it has greater probability to survive. The other way, smaller cluster with few member will dissolve and come to an end which is known as open cluster remnant (OCR). This kind of object is characterized by low surface density and high binary fraction.

Bica et al. (2004) predicted that there are about 500 OCR in Galactic disc, but difficult to find since they are almost mingle with another field stars. One of well-known OCR which have been discussed by several authors is NGC 1901, an observational template of open cluster remnant (Carraro et al., 2007).

Standing on SOS (Simulation-Observation-Simulation) scheme, author make direct N-body model using Starlab 4.4.4 (Portegies-Zwart et al., 2001) since star cluster evolution, especially open cluster with few members, not only dynamical matter but also include stellar evolution of its every member. The model will be created based on observational data from literatures.

Model-cluster's population characterized by its initial mass function (IMF) and present day mass function (PDMF) would be the main consideration of this study recalling that OCRs tend to have fewer low-mass stars (de la Fuente Marcos, 1998). Another considered parameter are binary fraction and cluster's structure.

2 OPEN CLUSTER REMNANTS

There are about 2140 visible open clusters in Milky Way (Dias et al., 2002, recent update in November 2010). Open cluster contains hundreds to thousands members which are born and evolve together. Internal dynamic of open cluster, combined to external perturbation tend to break up cluster's gravitational bound, dissolve in relatively short time leaving OCR. Open cluster with more members has higher probability to survive and longer life time.

According to theoretical analysis and observational data, there are some features belong to a group of stars that categorized as OCR:

- **Low surface density.** As dissolved star cluster, OCRs are hardly distinguished among field stars since they have low stellar density, a bit higher than their vicinity. Around Solar neighborhood, the value approximately is 0.044 M⊙/pc^3. But, to survive in Galactic tidal field, it must be more than 0.08 M⊙/pc^3. Intermediate clusters with 200-500 members contain 10-20% members during the OCR stage, whereas bigger clusters with 750-1000 stars will consist only 7% of their initial members (de la Fuente Marcos, 1998).

- **Lack of low-mass stars.** Open clusters may experience mass-loss through evaporation during their dynamical evolution which tends to eject low-mass stars. The consequence of this process is that OCRs will have smaller number of low-mass stars than expected.
- **High binary fraction.** Binaries, especially strong primordial binaries can be regarded as bound system with greater mass that harder to be expelled from the cluster. Finally, OCR with fewer members contain binaries with higher fraction. From simulation, de la Fuente Marcos (1998) acquired that N-body model with 30% primordial binaries will have 80% binary fraction at the last stage of its evolution.
- **Indicating physical group characteristics.** Member stars of OCR are localized in limited space in Galaxy, have their common velocity, age, and chemical composition such that give clear feature in kinematics and H-R diagram.

Although characteristics of OCR has been defined well, observation of OCR isn't simple work. Determining whether any star group is OCR or not is analogous to observing young crescent of the Moon. Contrast parameter is needed to distinguish OCR and field stars.

3 NGC 1901 AS AN OCR

NGC 1901 is group of stars in constellation of Doradus, precisely at α = 5^{h}18^{m}15^s and δ = −68°26′12″ (l = 279.022° and b = −33.603°). Bok & Bok (1960) first consider this group as a loose group with Large Magellanic Cloud as the background. This object was observed in more depth by Sanduleak & Philip (1968), Murray et al. (1969), Pavani et al. (2001), and Carraro et al. (2007). Some physical parameters of NGC 1901 are summarized in Table 1.

Position of NGC 1901 in the Galaxy is not so far from Solar orbit and little bit southward of Galactic disc. Considering Galactocentric distance of the Sun $d_\odot$ = 8.5 kpc, Cartesian coordinate of the OCR is X = 8.55 ± 0.05, Y = 0.30 ± 0.05, and Z = −0.22 ± 0.05 kpc (Carraro et al., 2007), where X is measured from Galactic center toward the Sun, Y perpendicular to X axis in the same direction of Galactic rotation, and Z is perpendicular to Galactic disc.

Table 1. Summary of physical parameters of NGC 1901 gathered from some sources.

distance [pc]	$E_{(B-V)}$	age [Myr]	[Fe/H]	reference
330	0.065	-	-	Sanduleak&Philip (1968)
480	0.06	-	-	Murray et al. (1969)
415	0.06	830	-	WEBDA database
450	0.04	600	-	Pavani et al. (2001)
409	0.02	850	-	Kharchenko et al. (2005)
400	0.04	400	-0.08	Carraro et al. (2007)

As evolved open cluster, NGC 1901 has typical structure. Using fitting of King profile, Piskunov et al. (2007) got that core radius of this cluster is r_c = 0.3 pc while its tidal radius is r_t = 6.2 pc. This result shows that NGC 1901 has a big halo compared to its core. Rather different result comes from study by Carraro et al. (2007). With core and tidal radius of 0.23 and 1.0 pc, this cluster regard as relaxed system with small halo.

Stellar population in NGC 1901 also shows feature of OCR. Carraro et al. (2007) found 13 members which are A-F stars. Lack of late-type star in NGC 1901 proves that this cluster experiences selective evaporation, eject all of its low-mass stars from the cluster region. Besides that, 8 of 13 members are confirmed binary. Thereby, NGC 1901 is truly open cluster remnant with high binary fraction, up to 62%.

Initial member of NGC 1901 can be predicted by fitting of PDMF with IMF (Carraro et al., 2007). Using power-law IMF, predicted cluster member is about 30000 with 10600 M⊙. Using Salpeter IMF (1955), this cluster may had 2750 members with total mass 1100 M⊙, while using two-part (Pflamm-Atenburg & Kroupa, 2006) NGC 1901 initially consists of 820 stars with total mass 328 M⊙.

4 DESCRIPTION OF THE MODEL

Based on physical parameters gained from observational data, 15 model are created (see Table 2) that vary on number of member (N), initial mass function (IMF), density parameter (W_0), and primordial binary fraction (f_b).

Space and velocity distribution of stars inside the cluster is governed by anisotropy King distribution (Heggie & Ramamani, 1995) that influenced by tidal field of Galactic disc at radius 8.5 kpc where the value of Oort constant are A_0 = 14.4 km/s/pc, B_0 = -12.0 km/s/pc, and the adopted local density is ρ = 0.11 M⊙/pc^3. Initially, cluster is in virialized condition with virial radius of 2.5 pc. Mass of stars in the cluster follow Scalo IMF

Tabel 2. Input parameter of NGC 1901 model.

model	f_b	IMF	W_0	N	M	t_{dyn}	t_f	$f_b(t_f)$
A34-600	0,3	Scalo	4	600	443	2,790	1100	-
A34-800	0,3	Scalo	4	800	569	2,461	1000	-
A34-1300	0,3	Scalo	4	1300	975	1,879	1200	-
A36-600	0,3	Scalo	6	600	443	2,790	>2000	-
A36-800	0,3	Scalo	6	800	569	2,461	>1800	-
A36-1300	0,3	Scalo	6	1300	975	1,879	>1400	-
A84-600	0,3	Kroupa	4	600	435	2,814	900	0,40
A84-800	0,3	Kroupa	4	800	573	2,454	1000	0,62
A84-1300	0,3	Kroupa	4	1300	974	1,880	900	0,38
A86-600	0,3	Kroupa	6	600	435	2,814	1700	-
A86-800	0,3	Kroupa	6	800	573	2,454	1700	-
A86-1300	0,3	Kroupa	6	1300	974	1,880	1400	-
B84-600	0,4	Kroupa	4	600	444	2,786	1100	0,55
B84-800	0,4	Kroupa	4	800	576	2,445	1000	0,00
B84-1300	0,4	Kroupa	4	1300	969	1,885	1400	0,45

(1986) and Kroupa IMF (2001) with lower and upper limit of 0.1 and 100 M⊙. A fraction of stars are chosen as primary component of binary system, while the secondary will be determined randomly with mass range between 0.1 M⊙ to the mass of primary component. Orbital eccentricity of the binaries will have thermal distribution, while their separation are calculated based on system energy (between 1 to 1000 kT). These limit give the widest orbital separation 10^4 AU.

Every model is evolved until the cluster reaches 750 t_{dyn} or completely dissolved leaving only 50 members. Either dynamic or stellar evolution is taken into account here.

5 RESULT AND ANALYSIS

Models with Kroupa IMF experience a little bit faster dissolving process compared to another models that use Scalo IMF. This can be happened because Kroupa IMF gives more massive stars which evolve and suffer heavy mass-loss during the first stage of cluster evolution. Fast dissolution also happen in models with low density parameter W_0 = 4 that reach OCR stage at age less than 1 Gyr. On the other side, number of members doesn't give any significant variation of dissolution rate. This can be the effect of back scattering (Baumgardt, 2001) where a star that moves with escape velocity and almost kicked-out from the cluster can be turned back by another stars' attraction before reaching stripping radius.

One of the model, B84-600 is interesting to be analyzed deeper because this model reach OCR stage at 700 Myr, then at age 800 Myr it consists < 10% initial member with 50% binary fraction. This model also exhibits typical core-halo structure of OCR.

For suppressing any statistical bias, additional 4 simulation is done for B84-600. The result can be seen in Figures 1 and 2.

Similar to another models with IMF Kroupa, this model experiences heavy mass-loss at the early stage of its evolution. Mass-loss rate decreases up to OCR stage where $M_{gugus} \simeq M_{inti}$. It also shows mass function of selectively evaporated cluster (Figure 2).

At age 800 Myr, there is only 7% member left with total mass of 33 M⊙. A half of the survived member are primordial binary with quite strong binding energy. The increase of binary fraction is lower than the result of de la Fuente Marcos (1997) that got f_b = 57% from 33% primordial binary

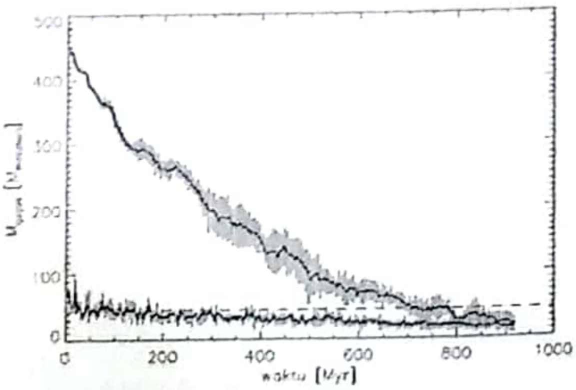

Figure 1. Cluster's total mass (top) and core mass bottom) of model B84-600 as function of time. Thick line represents average mass from 4 simulations accompanied by the deviation.

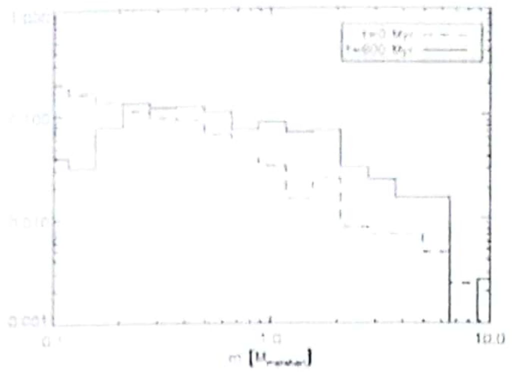

Figure 2. Mass function model B84-600 at age 0 and 800 Myr show the effect of selective evaporation. Averaging calculation is done for 4 simulations.

fraction. But, mass ratio of the binary component are diverse. It is true for intermediate age open cluster remnant.

The structure of the model cluster shows that it is evolved. With core radius r_c = 1.9 pc and tidal radius r_t = 5.6 pc, this model has a low density parameter, e.g. $c = \log(r_t/r_c) = 0.45$. This result is slightly different to observational result from Carraro et al. (2007) who got c = 0.64 yang diperoleh Carraro et al. (2007). Further analysis must be done to bridge structural result from simulation and observation.

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