Mass Loss from Stars and the Evolution of Stellar Clusters
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Star Clusters in the Solar Neighborhood: a Solution to Oort's Problem

Henny J. G. L. M. Lamers and Mark Gieles

Astronomical Institute, Utrecht University, Princetonplein 5, 3584-CC Utrecht, The Netherlands

Abstract. In 1958 Jan Oort remarked that the lack of old clusters in the solar neighborhood (SN) implies that clusters are destroyed on a timescale of less than a Gyr. This is much shorter than the predicted dissolution time of clusters due to stellar evolution and two-body relaxation in the tidal field of the Galaxy. So, other (external) effects must play a dominant role in the destruction of star clusters in the solar neighborhood. We recalculated the survival time of initially bound star clusters in the solar neighborhood taking into account: (1) stellar evolution, (2) tidal stripping, (3) perturbations by spiral arms and (4) encounters with giant molecular clouds (GMCs). We find that encounters with GMCs are the most damaging to clusters. The resulting predicted dissolution time of these combined effects, $t_{\rm dis} = 1.7(M_i/10^4\,M_\odot)^{0.67}$ Gyr for clusters in the mass range of $10^2 < M_i < 10^5\,M_\odot$, is very similar to the disruption time of $t_{\rm dis} = 1.3 \pm 0.5(M_i/10^4\,M_\odot)^{0.62}$ Gyr that was derived empirically from a mass limited sample of clusters in the solar neighborhood within 600 pc. The predicted shape of the age distribution of clusters agrees very well with the observed one. The comparison between observations and theory implies a surface star formation rate (SFR) near the sun of 3.5 10^{-10} $M_\odot {\rm yr}^{-1}{\rm pc}^{-2}$ for stars *in bound clusters* with an initial mass in the range of 10^2 to 3 10^4 $M_\odot$. This can be compared to a total SFR of 7 - 10 $\times10^{-10}$ $M_\odot {\rm yr}^{-1}{\rm pc}^{-2}$ derived from embedded clusters or $3 - 7$ 10^{-9} $M_\odot {\rm yr}^{-1}{\rm pc}^{-2}$ derived from field stars. This implies an infant mortality rate of clusters in the solar neighborhood between 50% and 95%, in agreement with the results of a study of embedded clusters.

1. Introduction

Jan Oort pointed out in 1958 that "in general, galactic clusters do not appear to grow much older than 0.5 Gyrs" (Oort 1958). Later, Wielen (1971) derived a mean dissolution time of 0.2 Gyr from the age distribution of open clusters within about 1 kpc from the Sun. Spitzer (1958) suggested that the short lifetime may be due to the fact that low density clusters ($\lesssim 1 M_\odot {\rm pc}^{-3}$) may be destroyed by encounters with passing interstellar clouds.

The destruction of star clusters occurs in two stages (see Bastian & Gieles, these proceedings, for a review.):
(1) At young ages (< 10 or 20 Myr) most of the clusters dissolve because the gas that is left over from the giant molecular cloud (GMC) is removed from the cluster by stellar winds and supernovae. This loss of binding energy causes a large fraction of the embedded clusters to dissolve into the field. This "infant mortality" (Lada & Lada 2003) depends critically on the star formation efficiency and appears to be independent of the initial cluster mass. (Bastian et al. 2005

suggest that this occurs within ~ 10 Myr, whereas Fall et al. 2005 suggest that it occurs over a much longer timescale of $\sim$ Gyr). Theoretical studies, e.g. Kroupa & Boily (2002) and references therein, show that the gas removal phase and the resulting infant mortality last about ~ 10 Myr (see also Lada & Lada 2003).
(2) At later ages clusters can be destroyed by external effects such as the tidal field, and perturbations due to encounters with GMCs, with spiral arms and the Galactic disk. This effect is mass dependent: massive clusters survive longer than low mass clusters.
This paper deals with the second effect, but we also derive the infant mortality rate for clusters in the solar neighborhood (SN).

Starting with the pioneering work of Spitzer on the dynamics of star clusters, many studies have been devoted to the understanding and prediction of the survival times of open clusters and globular clusters in our galaxy. These theories predict that the dissolution time of clusters depends on their initial mass: massive clusters survive longer than low mass clusters (e.g. Spitzer 1958; Wielen 1985; Chernoff & Weinberg 1990; Gnedin & Ostriker 1997 and references therein). Baumgardt & Makino (2003) (hereafter BM03) showed from N-body simulations that the predicted dissolution time of a cluster in the tidal field of the Galaxy depends on the number of stars, N, in the cluster as $t_{\rm dis} \sim \beta\,(N/\ln \gamma N)^x$, where γN is the Coulomb logarithm and the constants β and x depend on the initial concentration of the cluster. Gieles et al. (2004) showed that this can be written as

$$t_{\rm dis} = t_4 (M_i/10^4 M_\odot)^\gamma \tag{1}$$

with $\gamma = 0.62$, where t_4 is the disruption time of a cluster with an initial mass $M_i = 10^4 M_\odot$. This same power-law dependence was derived empirically from a study of cluster samples in four galaxies by Boutloukos & Lamers (2003)(hereafter BL03). The dynamical models of BM03 result in a $t_4 = 6.9$ Gyr for clusters in the SN. Since the mean mass of the open clusters in the SN is about a 10^3 $M_\odot$, the "mean lifetime" of clusters in the SN, predicted by BM03, would be a few Gyr, i.e. much longer than the empirical value of 0.2 Gyr derived by Wielen (1971).

To solve this discrepancy, we have started a series of studies of different effects that might play a role in limiting cluster lifetimes. These effects are:
(1) mass loss by stellar evolution,
(2) dissolution by two-body relaxation in the tidal field of the Galaxy,
(3) perturbations due to the passage of spiral arms,
(4) perturbations due to encounters with GMCs.
At the same time we rederived empirically the cluster dissolution times of open clusters in the SN, based on the new cluster sample of Kharchenko et al. (2005). We compare the predicted and the observed age distributions in clusters to see which one of the possible destruction mechanisms is the most important one in the SN. This comparison also results in an estimate of the star formation rate and infant mortality rate. (For the full study, see Lamers & Gieles 2006.)

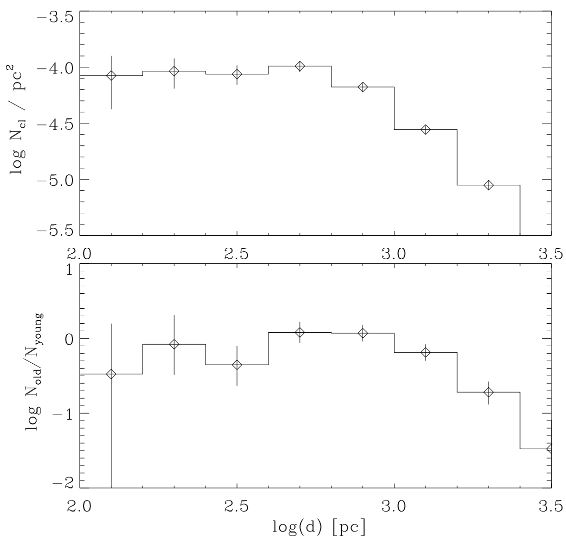

Figure 1. Top: The surface density distribution of open clusters in the Kharchenko et al. (2005) sample, projected onto the Galactic plane. Bottom: The ratio between the number of old (> 0.25 Gyr) and young (< 0.25 Gyr) clusters as a function of distance. Both distributions are flat within their uncertainties up to 600 pc.

2. The observed Age Distribution of Clusters in the Solar Neighborhood

Kharchenko et al. (2005) published a catalog of 520 galactic open clusters in the SN with the values of angular sizes of cluster cores and coronae, heliocentric distances d, $E(B-V)$, mean proper motions, radial velocities and ages. These parameters have been determined by homogeneous methods and algorithms including a careful procedure of cluster member selection. The basis of this study is the ASCC-2.5 - All-Sky Compiled Catalog of about 2.5 million stars down to $V \simeq 14$ (completeness limit at $V \simeq 11.5$), with proper motions and B, V magnitudes based on the $Tycho-2$ data and supplemented with *Hipparcos* data and some ground-based catalogs.

Cluster membership is based on a combined probability which takes into account kinematic (proper motion), photometric and spatial selection criteria. Cluster ages were determined with an isochrone-based procedure which provides a uniform age scale. This resulted in the most homogeneous catalog of open clusters in the SN. Lamers et al. 2005a (L05) have shown that the lower mass limit of the clusters in the Kharchenko et al. sample is about 100 $M_{\odot}$.

Figure 1 shows the distance distribution of the density of clusters projected onto the Galactic plane, in number per pc^2. Within the statistical uncertainty the surface density is constant up to at least 600 pc. The lower part of the figure shows the ratio between old ($t > 0.25$ Gyr) and young ($t < 0.25$ Gyr) clusters as a function of distance. Up to a distance of about 1 kpc there is no significant change in this ratio within the statistical uncertainty. This is important for our

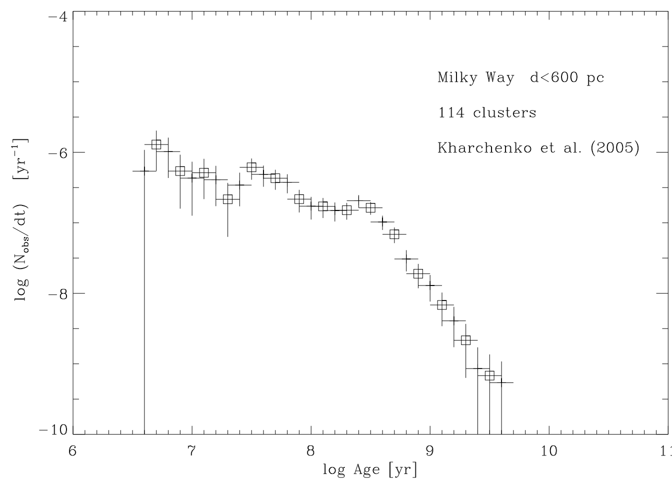

Figure 2. The age histogram in units of number per year, in logarithmic age-bins of 0.2 dex, of 114 open clusters within $d < 600$ pc from Kharchenko et al. (2005). In order to show the effect of binning the data, the distributions are plotted for two sets of bins, shifted by 0.1 dex, with and without squares respectively. The error bars indicate the 1σ statistical uncertainty. The distribution decreases to older ages, with a small bump around $\log(t/\mathrm{yr}) \simeq 8.6$. For $\log(t/\mathrm{yr}) < 7.5$ the distribution is uncertain due to large error bars.

study because it shows that the sample of clusters within 600 pc has no age bias. Figure 2 shows the age distribution in number per year of the 114 clusters within 600 pc in the Kharchenko sample. This distribution decreases with age, apart from a small local maximum around $\log(t/\mathrm{yr}) \simeq 8.6$. The distribution at young ages is sensitive to the choice of the age-bins and shows a significant scatter. The steep slope at $\log(t/\mathrm{yr}) > 8.8$ demonstrates that cluster disruption is important.

3. The evolution of the mass of star clusters

3.1. Mass Loss by Stellar Evolution

The stellar mass loss from clusters has been calculated by various groups. We adopt the *GALEV* models for clusters with a Salpeter type mass function in the range of $0.15 < M/M_{\odot} < 85$ (Anders & Fritze-v. Alvensleben 2003). These models are based on stellar evolution tracks from the Padova group, which include overshooting, mass loss due to stellar winds and supernovae. L05 have shown that the fraction of the initial cluster mass that is lost by stellar evolution, $q_{\mathrm{ev}}(t) = \Delta M/M_i$, can be approximated accurately by

$$\log q_{\mathrm{ev}}(t) = (\log t - a_{\mathrm{ev}})^{b_{\mathrm{ev}}} + c_{\mathrm{ev}} \quad \text{for} \quad t > 12.5 \text{ Myr.} \tag{2}$$

with t in yrs and $a_{\mathrm{ev}} = 7.00$, $b_{\mathrm{ev}} = 0.255$ and $c_{\mathrm{ev}} = -1.805$ for solar metallicity models with a Salpeter mass function.

This function describes the mass loss of the models at $t > 12.5$ Myr with an accuracy of a few percent. The mass loss at younger ages is negligible because stars with $M_* > 30\ M_\odot$ hardly contribute to the mass of the cluster due to the small number of stars. (These stars do play an important role in the infant mortality because they are responsible for the fast removal of the gas from the clusters.) The mass loss from clusters by stellar evolution can then be described as

$$\left(\frac{dM}{dt}\right)_{\rm evol} = -M(t)\frac{dq_{\rm ev}}{dt}. \tag{3}$$

3.2. Mass Loss by the Galactic Tidal Field

BM03 have calculated a grid of N-body simulations of clusters in circular and elliptical orbits in the tidal field of a galaxy for different initial cluster masses, galactocentric distances R, and different cluster density profiles. The stars follow a Kroupa initial mass function without primordial binaries, and stellar evolution is taken into account during the evolution. BM03 and Lamers et al. (2005b) have shown that the predicted dissolution time can be expressed as a function of the initial cluster mass as

$$t_{\rm dis} = t_4\ (M_i/10^4\ M_\odot)^{0.62}, \tag{4}$$

where t_4 is a constant that depends on the tidal field strength of the galaxy in which the cluster moves and on the ellipticity of its orbit. We adopt the value of $t_4 = 6.9 \times 10^9$ yr from BM03 for clusters in circular orbits at $R_0 = 8.5$ kpc. Applying this result of BM03 to clusters in the SN, which are on average of lower mass than considered in their study, results in an overestimation of the dissolution time of low mass clusters by less than a factor 2 or so (see Fig. 5 of BM03). This is because low mass clusters, with total lifetimes less than about a Gyr, contain massive stars during most of their lifetime. These stars are very efficient in ejecting stars by two-body interactions.

The mass loss due to the Galactic tidal field can then be written as

$$\left(\frac{dM}{dt}\right)_{\rm tidal} = \frac{-M(t)}{t_{\rm dis}} = \frac{-(M/10^4 M_\odot)^{0.38}}{t_4/10^4}\ M_\odot {\rm yr}^{-1}. \tag{5}$$

3.3. Mass Loss by Spiral Arm Perturbations

When clusters cross a spiral arm, the enhancement of the ambient density gives rise to time dependent tidal forces that can accelerate stars out of the cluster. These external perturbations are most destructive for clusters with low density and for passages with low relative velocity, $V_{\rm drift}$. The solar neighborhood is close to the corotation radius of the spiral arms, where the effect is largest. Although the time between spiral arm passages at that location is long, $\propto V_{\rm drift}^{-1}$, the mass loss per passage is high, i.e. $\propto V_{\rm drift}^{-2}$ (Gieles et al. 2006a, hereafter GAPZ06).

GAPZ06 calculated the dissolution time of clusters in the SN due to perturbations by spiral arms by means of N-body simulations. For the density of the clusters, they adopted the observed mean mass-radius relation of clusters as observed in nearby spiral galaxies by Larsen (2004): $r_{\rm h} = 3.75\ (M/10^4 M_\odot)^\lambda$ with $\lambda = 0.10 \pm 0.03$, where $r_{\rm h}$ is the half mass radius. Here we have converted the cluster radius $r_{\rm eff}$ given by Larsen into the halfmass radius $r_{\rm h}$ using $r_{\rm eff} = 0.75 r_{\rm h}$ (Spitzer 1987). For a density contrast of the gas component of the spiral arms based on observations, and a mean drift velocity of $V_{\rm drift} = 12.5$ (Dias & Lépine 2005), GAPZ06 found a mean dissolution time of

$$t_{\rm spir} = 20 \left(\frac{M}{10^4\,M_\odot}\right)\left(\frac{3.75\,{\rm pc}}{r_{\rm h}}\right)^3 = 20\,\left(M/10^4\,M_\odot\right)^{1-3\lambda}\ {\rm Gyr}. \qquad (6)$$

Notice that for $\lambda = 0.1$ the disruption time due to shocking by spiral arms has almost the same mass dependence, i.e. $\propto M^{0.7}$, as that due to the tidal field (BM03) and as found empirically (BL03), viz. $M^{0.62}$.

The mass loss of clusters due to spiral arm shocks is

$$\left(\frac{dM}{dt}\right)_{\rm spir} = \frac{-M(t)}{t_{\rm spir}} = -0.5\left(\frac{M(t)}{10^4\,M_\odot}\right)^{0.3}\ M_\odot\,{\rm Myr}^{-1}. \qquad (7)$$

3.4. Mass Loss by Giant Molecular Cloud Encounters

Spitzer (1958) suspected already that encounters with GMCs play an important role in the destruction of clusters in the SN. Similar to the case of spiral arm perturbations, the disruptive effect of the encounters depends on the density of the star cluster and on the relative velocity between the cluster and the cloud. However in the case of an encounter with a GMC, the mass loss also depends on the mass of the GMC and on the distance of the passage at the moment of closest approach. This implies of course that the dissolution of clusters due to encounters with GMCs can only be described in a statistical way, when all effects are properly averaged over the encounter probabilities.

Gieles et al. (2006b, GPZB06) studied the encounters between GMCs and clusters with N-body simulations. They showed that the relative mass loss due to a shock, i.e. $\Delta M/M$, is only about 20 % of the relative energy gain $\Delta E/E$. This is because a large fraction (~ 80 %) of the energy gained in an encounter goes into ejecting stars with a velocity exceeding the escape velocity. This implies that the disruption time should *not* be defined as the timescale for injecting the same energy as the cluster binding energy (e.g. Ostriker et al. 1972), but as the time scale to bring the cluster mass to zero.

The disruption time of clusters by encounters with GMCs does not depend on the mass of the individual clouds, but only on the *mean density of molecular gas* in the SN. This is because the energy gained by the cluster per individual encounter is proportional to the cloud mass $M_{\rm cloud}$, but the number of encounters per unit time depends on the number density of the clouds. The number density times the mass of the clouds is the mean density of the molecular gas. In other words: 1000 clouds of $10^4\ M_\odot$ have statistically the same disruptive effect as 10 clouds of $10^6\ M_\odot$ if we ignore the tidal field (but see §3.5).

GPZB06 derived an expression for the energy gain and the resulting mass loss for the full range of encounter distances, from head-on to distant encounters. They adopted a mean midplane density of molecular gas in GMCs near the sun of $\rho_{\rm n} = 0.03 M_\odot {\rm pc}^{-3}$, a surface density of individual GMCs of $\Sigma_{\rm n} = 170 M_\odot\ {\rm pc}^{-2}$ (Solomon et al. 1987) and a mean velocity dispersion of clusters and GMCs of $\sigma_v \simeq 10\ {\rm km\,s^{-1}}$.

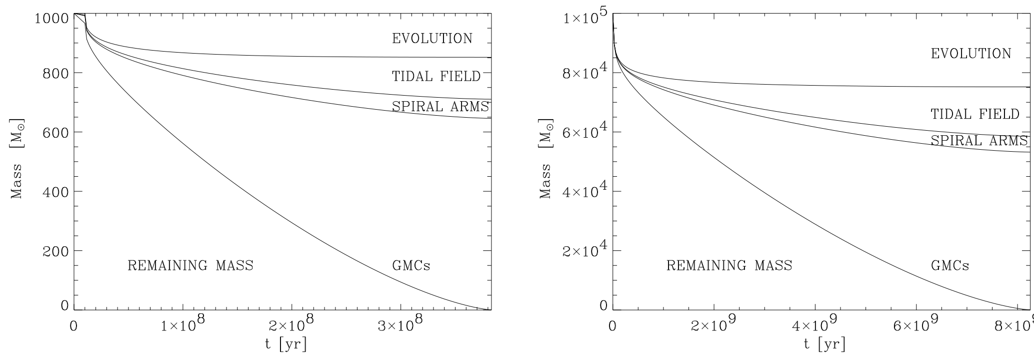

Figure 3. The mass evolution of a cluster with an initial mass of 10^3 (left) and 10^5 $M_\odot$ (right) in the solar neighborhood. The mass loss due to the four separate effects is indicated. Encounters with GMCs are the dominant dissolution effect in the solar neighborhood. A cluster of $M_i = 10^3$ $M_\odot$ dissolves in 0.35 Gyrs and a cluster of 10^5 $M_\odot$ in 8.2 Gyrs.

With these data they derived a mean dissolution time ($t_{\rm GMC}$) for clusters by GMC encounters in the SN, taking into account the relative velocity distribution, the distribution of impact parameters and gravitational focusing. Adopting the mean mass radius relation of clusters (Larsen 2004) (see §3.3) they found

$$t_{\rm GMC} = 2.0 \left(\frac{M}{10^4\,M_\odot}\right)\left(\frac{3.75\ {\rm pc}}{r_{\rm h}}\right)^3 = 2.0\,\left(M/10^4\,M_\odot\right)^{0.7}\ {\rm Gyr}, \qquad (8)$$

The statistical mass loss rate of a cluster due to encounters with GMCs is

$$\left(\frac{dM}{dt}\right)_{\rm GMC} = \frac{-M(t)}{t_{\rm GMC}} = -5.0\,\left(\frac{M(t)}{10^4\,M_\odot}\right)^{0.3} M_\odot\,{\rm Myr}^{-1}. \qquad (9)$$

Notice that the mass dependence is the same as for dissolution by spiral arm shocking, but that the effect is ten times stronger.

3.5. The predicted Mass Evolution of Clusters in the Solar Neighborhood

The mass loss from clusters, due to the combined effects of stellar evolution, tidal stripping, spiral arm shocks and encounters with GMCs, is

$$\frac{dM}{dt} = \left(\frac{dM}{dt}\right)_{\rm evol} + \left(\frac{dM}{dt}\right)_{\rm tidal} + \left(\frac{dM}{dt}\right)_{\rm spir} + \left(\frac{dM}{dt}\right)_{\rm GMC}. \qquad (10)$$

In writing this expression we assumed that the four effects act independently of one another. This may not be the case. For instance, a cluster that has encountered a GMC has an increased radius and is thus more susceptible to tidal stripping than a cluster that did not have a recent encounter. However, we expect this effect to be small, except for the lowest mass clusters.

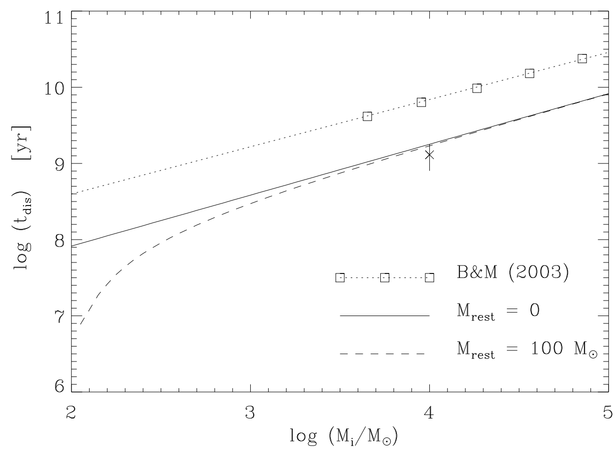

Figure 4. The predicted dissolution times of clusters in the solar neighborhood due to the combined effects of stellar evolution, tidal field, spiral arm shocks and encounters with GMCs, as a function of the initial mass. Full line: total dissolution time. Dashed line: time when the remaining mass is 100 $M_{\odot}$. Squares and dotted line: dissolution time due to stellar evolution and the Galactic tidal field only, predicted by BM03. Cross with error bar: the value of t_4 empirically derived by L05.

We have solved Eq. 10 numerically for clusters of different masses. The results are shown in Fig. 3 for clusters with an initial mass of 10^3 and 10^5 $M_{\odot}$. Notice that encounters with GMCs are the dominant dissolution effect in the solar neighborhood, contributing as much as the three other effects combined. Using the calculated mass decrease of clusters of different initial mass we can predict the age of the cluster when it has a remaining mass of 100 $M_{\odot}$, i.e. the detection limit for clusters in the SN in the Kharchenko sample (see L05). Figure 4 shows the ages of clusters when their remaining mass is 0 and 100 $M_{\odot}$ as a function of the initial mass. The almost linear part can be described by

$$t_{\rm dis} = 1.7(M_i/10^4\ M_{\odot})^{0.67}\ {\rm Gyr} \qquad \text{for} \quad 3.5 \simeq \log M_i/M_{\odot} \simeq 5 \tag{11}$$

The steep decrease at low mass is because clusters with $M_i < 10^3$ $M_{\odot}$ quickly reach the detection limit of 100 $M_{\odot}$. The figure also shows the dissolution times by the Galactic tidal field, predicted by BM03 for clusters with an initial concentration factor $W_0 = 5$ in a circular orbit at $R_0 = 8.5$ kpc and the empirical value of t_4 from L05. Our predicted timescales are about a factor 5 smaller than those due the tidal field only (BM03) but agree with the empirical value (L05).

4. Comparison with observed Age Distribution of Clusters in the Solar Neighborhood

Given the initial mass distribution of the clusters, their formation rate, CFR(t), and the time it takes for a dissolving cluster to fade below the detection limit, we

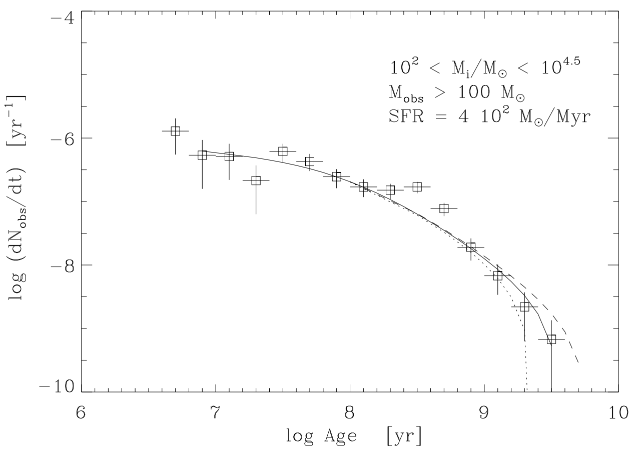

Figure 5. The observed age distribution of an unbiased sample of clusters with $M > 100\,M_\odot$ in the solar neighborhood within 600 pc (Karchenko et al. 2005; L05) in units of nr yr^{-1} is given by squares with the Poisson error bars. The full line shows the predicted distribution for a cluster sample with a maximum mass of $M_{\rm max} = 3\ 10^4\ M_\odot$ and a SFR of 4 $10^2\,M_\odot\,{\rm Myr}^{-1}$ within 600 pc from the Sun. The dotted and dashed lines are for $M_{\rm max} = 1.5\ 10^4\ M_\odot$ and $M_{\rm max} = 6\ 10^4\ M_\odot$ respectively. The bump around 0.4 Gyr suggests an increased SFR at that time.

can predict the distribution of observable clusters as function of age or mass[1]. Here we are interested in a sample of clusters with $M > 10^2\ M_\odot$.

For a constant CFR and a power law cluster IMF with a slope of $-\alpha = -2$ (Lada & Lada 2003) the number of clusters with $M > 100\ M_\odot$ as function of age is

$$N_{M>100}(t) = C\ (M_{\rm lim}(t)^{-1} - M_{\rm max}^{-1}), \tag{12}$$

where $M_{\rm lim}(t)$ is the *initial* mass of clusters that reach $M(t) = 100\,M_\odot$ at age t. Clusters of age t with a smaller initial mass have $M < 100\,M_\odot$ by now. $M_{\rm max}$ is the maximum *initial* mass of the clusters that are formed. The constant C is related to the star formation rate (SFR) in bound clusters as SFR $= C\ln(M_{\rm max}/M_{\rm lim})$ for $-\alpha = -2$.

Figure 5 shows a comparison between the observed age distribution of clusters within 600 pc with the predicted distribution for $M_{\rm max} = 3\ 10^4 M_\odot$. This value of $M_{\rm max}$ is adopted because the observed distribution shows a steep drop at log $t \simeq 9.5$ (with only one cluster in the last bin) and Fig. 5 shows that this corresponds to $M_i = 3\ 10^4\,M_\odot$.

The flattening of the predicted distribution at the low age end is due to the fact that clusters with an initial mass in the range of about 100 to 300 $M_\odot$ quickly reach 100 $M_\odot$ (see Fig. 4). The bump in the observed distribution

[1]L05 have derived an expression for the general case of a cluster sample that is set by a *magnitude limit* for any formation history

around $\log(t) \simeq 8.6$ is due to a local starburst (see L05 and Piskunov et al. 2006). There is good agreement in the shapes of the predicted and observed distributions!

The vertical shift that is applied to the predicted curve to match the observed one gives a value of $C = 10^{-4.15}$ in Eq. 12, which corresponds to a SFR of $4\ 10^2\ M_\odot\ \mathrm{Myr}^{-1}$ for bound clusters in the range of $10^2 < M_i/M_\odot < 3\ 10^4$ within 600 pc from the sun and a surface formation rate of $3.5\ 10^{-10}\ M_\odot \mathrm{yr}^{-1}\mathrm{pc}^{-2}$. We can derive the infant mortality rate in the SN by comparing this value with the total starformation rate of at least $7 - 10\ 10^{-10}\ M_\odot \mathrm{yr}^{-1}\mathrm{pc}^{-2}$, derived from embedded clusters with a mass 35 $M_\odot$, by Lada & Lada (2003) or the rate of $3 - 7\ 10^{-9}\ M_\odot \mathrm{yr}^{-1}\mathrm{pc}^{-2}$, derived from the field star population by Miller & Scalo (1979). Our value is a factor 2 to 3 smaller than the lower limit of Lada & Lada and a factor 10 to 20 smaller than the one derived by Miller & Scalo. This implies that at least ∼70 and possibly even 0.95 % of the stars in the SN are born in clusters that dissolve within ∼ 10 Myr.

5. Conclusions and Discussion

Our calculated dissolution times of clusters in the solar neighborhood are about a factor five smaller than predicted by BM03 for clusters in the tidal field of our Galaxy, with only stellar evolution, binaries and two-body relaxation taken into account. This is mainly due to encounters with GMCs. So we can expect that clusters in environments with a high density of GMCs will be destroyed very effectively. This is especially the case in interacting galaxies, such as M51 and the Antennae galaxies. Indeed, Gieles et al. (2005) derived a disruption time t_4 of only 0.2 Gyr for clusters in M51 at a Galactocentric distance of $1 < R < 5$ kpc. This is more than a factor 10 smaller than expected on the basis of the tidal field only. On the other hand, in galaxies with a small GMC density the dissolution time will be set mainly by the tidal field. This is confirmed by the comparison between empirical and predicted dissolution times of several galaxies by Lamers et al. (2005b) (see Fig. 6 of Bastian & Gieles, these proceedings).

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Note added after submission

In a recent paper Whitmore, Fall & Chandar (astro-ph 0611055) argue that our determination of the disruption time of clusters in the solar neighborhood is influenced by selection effects. They claim that "not including the young embedded clusters from Lada & Lada (2003) can produce an apparent bend in the age distribution, which can be misinterpreted in the BL03 models as evidence for a specific value of the disruption time". This is a curious statement because the embedded clusters are all younger than 3 Myr and the large majority of these clusters will not survive infant mortality (Lada & Lada 2003). Therefore they should not be included in a study of the dissolution of *bound clusters*.

Figure 6 compares our age distribution (open squares with error bars) with the one adopted by Whitmore et al. (filled symbols). They adopted an age distribution which consists of the sample of embedded clusters of Lada & Lada (i.e. with ages $\lesssim 3\,\mathrm{Myr}$) and open clusters (i.e. which have removed their gas) from Battinelli & Capuzzo-Dolceta (1991, MNRAS 249, 76). Lada & Lada (2003) combined these to show the steep drop (1 dex in $\log(\mathrm{d}N/\mathrm{d}t)$ going from the embedded to the unembedded phase (i.e. from $\lesssim 3\,\mathrm{Myr}$ to $\gtrsim 5\,\mathrm{Myr}$), which they refer to as "infant mortality" within 10 Myr.

We see that:
a.) the age distribution of the non-embedded clusters from Lada & Lada (2003) agrees with the one we derived from the Kharchenko et al. (2005) sample in the range $6.75 < \log(t/\mathrm{yr}) < 8.25$.
b.) the one high point at $\log(t/\mathrm{yr}) = 6.25$ is due to embedded clusters, most of which will dissolve by infant mortality (Lada & Lada 2003).

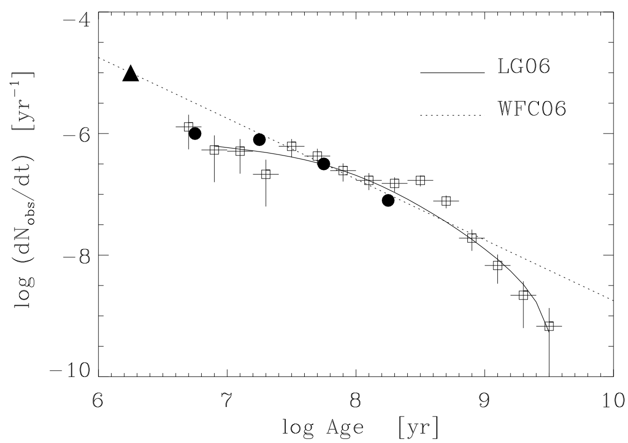

Figure 6. Open squares: the age distribution of clusters in the SN (our sample). Filled symbols: the age distribution adopted by Whitmore et al. (2006). Filled triangle: the embedded clusters of Lada & Lada (2003) at $\log(t/\mathrm{yr}) < 6.5$. Filled circles: the open clusters by Battinelli & Capuzzo-Dolceta (1991). The two distributions agree in the range of overlap. Full line: our fit to the data of non-embedded clusters that was used to derive the dissolution time of clusters that survived infant mortality. Dashed line: Whitmore's linear fit with slope of -1, shifted vertically to match the data at $\log(t/\mathrm{yr}) = 7.75$. This fit does not agree with the flattening of the observed distribution at $\log(t/\mathrm{yr}) < 7.5$ and neglects the decrease at $\log(t/\mathrm{yr}) > 9$.

c.) the straight line adopted by Whitmore et al. is a very poor fit to the observed age distribution as it seriously overpredicts the distribution at $6.7 < \log(t/\mathrm{yr}) < 7.5$ and does not explain the drop in the number of clusters at $\log(t/\mathrm{yr}) > 8.0$. (The peak in the age distribution around $\log(t/\mathrm{yr}) \simeq 8.6$, probably due to an increased star formation episode (L05), is higher than both fits.)

Therefore, we conclude that the statement by Whitmore et al. (2006), that our derived short disruption time is due to the neglect of the embedded clusters, is incorrect. In fact, Fig. 6 shows that the linear fit of slope -1, proposed by Whitmore et al. in support of their model for a mass independent infant mortality over an extended period of time, $\sim$1 Gyr, fits the data of the non-embedded clusters poorly. Our fit of the distribution of non-embedded clusters agrees much better with the observations and results in a dissolution time of bound clusters that agrees very well with the predictions described in this paper.