THE ASTROPHYSICAL JOURNAL, 467:265–271, 1996 August 10

ON THE EVOLUTION OF THE STELLAR MASS SPECTRUM: POSSIBLE EVIDENCE FOR STELLAR EVAPORATION

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Received 1995 October 30; accepted 1996 February 27

ABSTRACT

The authors continue the analysis of the results of their previous paper in which a pure coagulation model was applied to star clusters in general. By combining in a certain way the free parameters of the model, it is possible to evaluate the ratio of the total mass of the cluster as it is today to what it was at its formation, according to the model. A correlation is found between this ratio and the age of the cluster. The analysis of this correlation also gives order-of-magnitude estimates of different processes such as accretion rate, evaporation rate, and timescale of disruption by evaporation (or mean life expectancy). These estimates are found to be in agreement with other published results. It is also found that the mass-loss rate of the cluster is proportional to the amount of coagulation that occurred. All in all, it is shown that the coagulation model, although simplistic, merits more attention.

Subject headings: celestial mechanics, stellar dynamics — globular clusters: general — open clusters and associations: general — stars: luminosity function, mass function — stars: statistics

1. INTRODUCTION

The formation and internal dynamics of stellar clusters is an old but still very fascinating subject. One of the main reasons for this ongoing fascination is the fact that each cluster represents a laboratory for testing various theories of star formation and stellar dynamics. By assuming that each member of the cluster was created at about the same time and that each of these has roughly the same initial composition, one can thus test if a theory can explain the resulting variety of masses and compositions. In fact, the most striking feature to explain is the mass spectrum and its variations, not only from cluster to cluster but inside the cluster itself. Some recent reviews regarding initial mass function (IMF) problems are those of Scalo (1986), Larson (1987), and Zinnecker (1987).

In a previous paper (Allen & Bastien 1995, hereafter Paper I), we compared the predictions of a time-dependent solution to the coagulation equation found by Lejeune & Bastien (1986) with observed mass spectra of different types of stellar clusters. It was found that the coagulation model is very good at reproducing a wide range of mass spectra with only two adjustable parameters called coagulation indicators. It was found also that a certain combination of these parameters can give us the ratio of the present total mass contained in stars to the value it had at the formation of the cluster. This ratio can be useful in showing the relative importance of accretion and evaporation. It can be used also to calculate timescales for these processes.

The aim of this paper, therefore, is to find out more about the information that can be deduced on these physical mechanisms from the two parameters found for each stellar cluster. How this can be done is explained in § 2; the results are presented and discussed in § 3.1 for coagulation indicators and in §§ 3.2, 3.3, and 3.4 for the evolution of the total number of fragments, the mean mass of the fragments, and the total mass of the cluster, respectively. Section 3.4 also includes evaluation of the mean accretion rate and mean evaporation rate for the clusters. Finally, we conclude in § 4.

2. THEORY

First we enumerate some definitions of terms used in this paper in order to rule out any misunderstandings. Throughout this work, we will use the term "cluster" in a general way by letting it include open clusters, globular clusters, OB associations, or galaxies. Whenever confusion may arise, we will use the correct terminology for the type of cluster. In the same vein, we will use the term "fragment" to freely designate stars, protostars, or clumps in molecular clouds. We are fully aware that the terms encompassed by our terminology are physically different, and no attempt is made to treat them as a physical ensemble. The aim of our terminology is only to simplify the text. One last term used in this paper that needed clarifying is "total fragment mass" symbolized by M_t or M_0, which means the total mass of the cluster in terms of fragments, neglecting the leftover gas or dust, as observed today and as it was at the formation of the cluster, respectively, according to the model.

We outlined in Paper I the theory behind the two coagulation indicators. We will state briefly their meaning, since the details can be found in Paper I. The Lejeune & Bastien (1986) time-dependent solution to the coagulation equation included two free parameters, C and m_0, that are simply the ratio of the total number of fragments in the cluster as observed today to the value predicted by the model at the formation of the cluster, and the initial mean mass of the fragments as predicted by the model, respectively. The time-dependent solution with these two free parameters was fitted to observed mass spectra of star clusters to investigate the importance of coagulation. The parameters can be used to evaluate the amount of coagulation that occurred in the cluster by knowing that the total number of fragments should decrease with time if coagulation is occurring (and therefore, the ratio N/N_0 (i.e., C) should decrease accordingly), and that the mean mass of the fragments should obviously increase with time with coagulation; thus, the ratio $\bar{m}/m_0$ (where $\bar{m}$ is the present-day mean mass of the fragments) should increase with coagulation also. A combination of these parameters can be used also to evaluate the amount of mass loss by the cluster. Indeed, the coagulation indicators are linked by

$$\frac{\bar{m}}{m_0} = \frac{(M_{\rm tot}/N)_{t'={\rm today}}}{(M_{\rm tot}/N)_{t'=0}} = \frac{M_t}{M_0}\frac{N_0}{N} = \frac{M_t}{M_0}\frac{1}{C}, \quad (1)$$

and we see that, if no mass loss or mass gain occurred (i.e., if $M_t/M_0 = 1$), we obtain

$$\frac{\bar{m}}{m_0} = \frac{1}{C}. \quad (2)$$

We will see in the next section that this is not exactly the case.

We plot in Figure 1 the qualitative influences of four processes involved in different ways and times in the formation of a star cluster on the different parameters discussed above, i.e., N/N_0, $\bar{m}/m_0$, and M_t/M_0. The four lines show, respectively, the influence of coagulation, accretion, fragmentation, and stellar evaporation. Each little graph shows the qualitative evolution of the parameter (N/N_0 in the first column, $\bar{m}/m$ in the second column, and M_t/M_0 in the third column) *if there was only one process occurring at a time.*

All these processes will have diverse evolutions and importances that will depend on the model chosen; the graphs in Figure 1 are oversimplifications of reality. It is obvious that fragmentation, much less accretion and coagulation, cannot be constant over time; these processes change their environment and hence the availability of "material" that feeds them in the first place. Moreover, some of these processes must occurr concurrently for some time and influence each other. The outcome of this mingling is too difficult analytically to predict accurately and depends on too many free parameters to let us be able to discriminate between different models just by using the observational data we used in this paper. We feel, however, that a simple comparison involving only one process (in this case coagulation) can still be useful, if only to give us an indication of the relative importance of the other processes involved in the making of a typical star cluster.

By comparing the results we obtain with the theoretical graphs of Figure 1, it should be possible to discriminate between processes; at least it should help us in knowing which one is more important in the making of the stellar mass spectrum of a cluster. The results of this comparison are found in the next section.

3. DISCUSSION

3.1. *Coagulation Indicators*

Figure 2 shows the relationship between the two coagulation indicators discussed in § 2. We have included the four

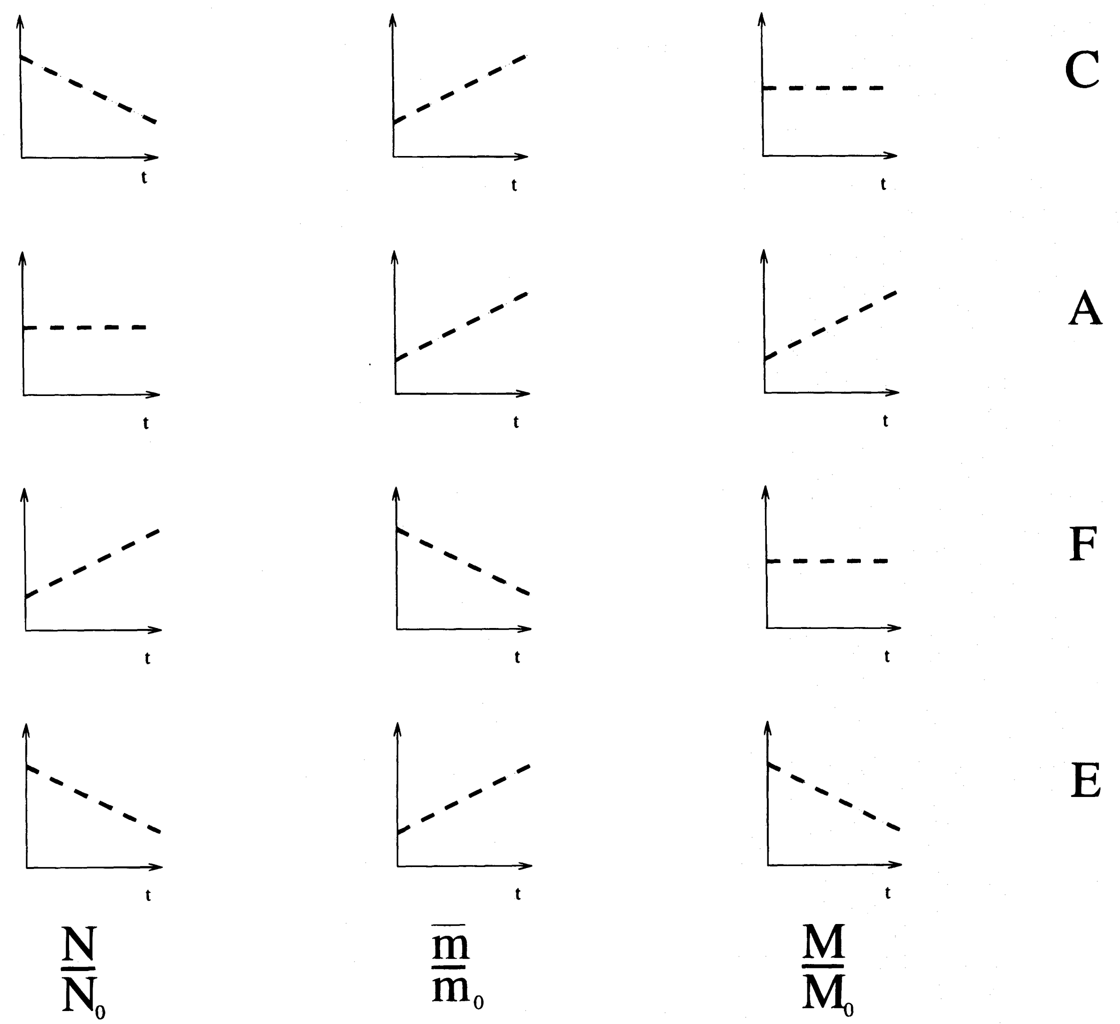

FIG. 1.—Qualitative influence of coagulation (C), accretion (A), fragmentation (F), and evaporation (E) on the ratio of total number of fragments (N/N_0), on the ratio of the mean masses of the fragments ($\bar{m}/m_0$), and on the ratio of the total fragment masses (M/M_0), in the case in which each process occurs *independently* of others.

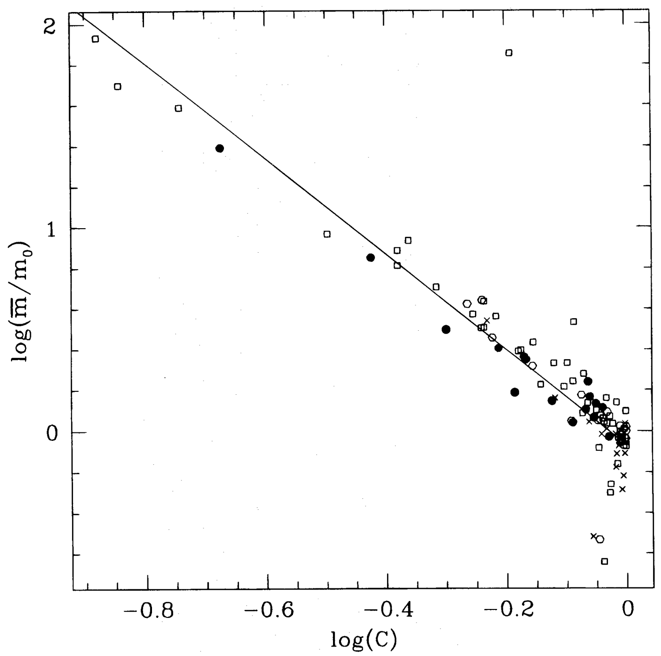

FIG. 2.—Relationship between the coagulation indicators. Open boxes are for open clusters, filled circles are for OB associations, diagonal crosses are for globular clusters, and open hexagons are for galaxies. The straight line is the best-fit regression with every point included. The point at $\log(\bar{m}/m_0) \simeq 1.9$ and $\log(C) \simeq -0.2$ is the young open cluster ρ Oph.

types of clustering studied in Paper I; the open boxes are for open clusters, the filled circles are for the OB associations, the diagonal crosses are for globular clusters, and the open hexagons are for the galaxies. The straight line represents the best fit for all the 101 points and was calculated with standard linear regression methods. Table 1 shows the numerical results of linear regressions for each type of grouping. The first column contains the type of cluster, and the second column contains the number of points used for the regression. The next four columns list the parameters along with their standard deviation according to the regression law

$$\log\left(\frac{\bar{m}}{m_0}\right) = A \log(C) + B . \tag{3}$$

Finally, the seventh column lists the square of the correlation coefficient, the eighth column lists the total χ^2 of the fit, and the last column contains the associated probability that this fit is good.

It is clear from Figure 2 that the coagulation indicators are coherent. We see also that most clusters are located in the lower right-hand corner of the graph, where the amount of coagulation that occurred is relatively small. Moreover, the fact that the regression values found for each type of clustering are very close to each other (within the limits of uncertainty) even though we are dealing with very different environments demonstrates the polyvalence of the coagulation model.

According to the regression results for all types of clusters, we obtain

$$\frac{\bar{m}}{m_0} \sim \frac{1}{C^{2.3}} , \tag{4}$$

which can be thought of as a contradiction of what was expected. Indeed, we saw in the preceding section (eq. [2]) that, providing no evaporation occurred in the cluster, we are supposed to obtain

$$\frac{\bar{m}}{m_0} \sim \frac{1}{C} . \tag{5}$$

It is clear that some change in the total stellar mass has occurred in the cluster, but what is less clear at first glance is why we find empirically

$$\frac{M_t}{M_0} \sim \frac{1}{C^{1.3}} . \tag{6}$$

In other words, we find that the amount of mass contained in stars at a time t is roughly proportional to the amount of coagulation that occurred. This apparent paradox can be resolved if we remember that

$$\frac{M_t}{M_0} = \frac{\text{Total stellar mass observed today}}{\text{Initial total fragment mass predicted by the model}} . \tag{7}$$

Hence, the more coagulation there is, the more stars will be formed that would otherwise have become yet unobservable "brown dwarfs." Thus, the ratio M_t/M_0 will increase with coagulation for a constant time.

We can also think of this fact as an observational bias. Just imagine a primordial pool of fragments with an undetermined mass spectrum (the form and mechanism of formation of the IMF is unimportant for the purpose of this discussion). Some of these fragments are too small to become protostars, and most will remain so, assuming accretion is a rapidly decreasing function of time. Without coagulation, the observable number of fragments today will roughly be that of the fragments that already had a sufficient mass to become stars. If you put coagulation into the picture, you take less massive fragments to make more massive ones and hence raise the number of fragments that will have a sufficient mass to become stars and be observable later. Moreover, the value of M_t comes from photo-

TABLE 1

LINEAR REGRESSION RESULTS

Type	Number	A	σ_A	B	σ_B	R^2	χ^2	Probability
Open clusters	56	−2.281	0.162	−0.017	0.039	−0.886	3.210	1.000
OB associations	16	−2.032	0.121	−0.030	0.029	−0.976	0.092	1.000
Globular clusters	16	−3.147	1.211	−0.232	0.085	−0.571	1.093	1.000
Galaxies	13	−2.643	0.560	−0.096	0.073	−0.818	0.386	1.000
All	101	−2.342	0.132	−0.068	0.028	−0.872	5.260	1.000

metric results as opposed to dynamical considerations. Indeed, M_t is calculated from the *observed* stars and neglects the population of brown dwarfs that most certainly are there, though they are as yet unobservable.

Another way to explain the dependency of M_t/M_0 on the value of C is by including the accretion process. It is well known that the rate of accretion of a star is proportional to the square of its mass (see, for example, Katz 1987, pp. 188–194). Thus, the more coagulation there is, the more massive stars will be created and the higher the corresponding accretion rate. What this means is that the ratio M_t/M_0 can be higher than one for a single star as well as for the whole cluster. If we assume that

$$\frac{M_t}{M_0} \sim A , \quad (8)$$

where A is the accretion rate integrated over all the stars in the cluster, and also that

$$A \sim M^2 \sim \text{coagulation} \sim 1/C , \quad (9)$$

we obtain

$$\frac{M_t}{M_0} \sim \frac{1}{C} , \quad (10)$$

which is similar to what we found empirically. Still, we must remember that the preceding considerations are purely qualitative and that the dependency can be different.

3.2. *Time Evolution of C*

We saw in Figure 1 that C and time will show a positive correlation if fragmentation is at work, a null correlation if there is only accretion, and a negative correlation if coagulation and/or evaporation is present. Figure 3 is a plot of log (C) versus log (age) for 44 open clusters (*open boxes*) and two OB associations (*filled circles*). The data for the ages of open clusters and OB associations were taken from Lynga (1987). The data for globular clusters and galaxies were not used for the following calculation, since we did not have good age estimates for these types of clusters. The straight line is the best-fit law according to a linear regression applied to all the points. The equation results from this regression is

$$\log (C) = (0.111 \pm 0.027) \log (\text{age}) - (0.999 \pm 0.204) , \quad (11)$$

with a reduced correlation coefficient $r^2 = 0.268$. One can see that there is probably no correlation between these two quantities, or only a weak one.

If one is to assume that there is one and that it follows the regression law, then the implied positive correlation would suggest that fragmentation is responsible (according to Fig. 1). But this is unreasonable, since the youngest clusters of Figure 3 are already too old for their fragments to be experiencing any fragmentation in the sense of star formation. On the other hand, if one is to assume that there is no correlation between log (C) and log (age), then one should believe that accretion is responsible for this fact (see Fig. 1). It is also possible that the four processes described in Figure 1 are all (or partly) acting on the mass spectrum and that one cannot discriminate between them. Remember that the graphs in Figure 1 are for processes occurring *one at a time*.

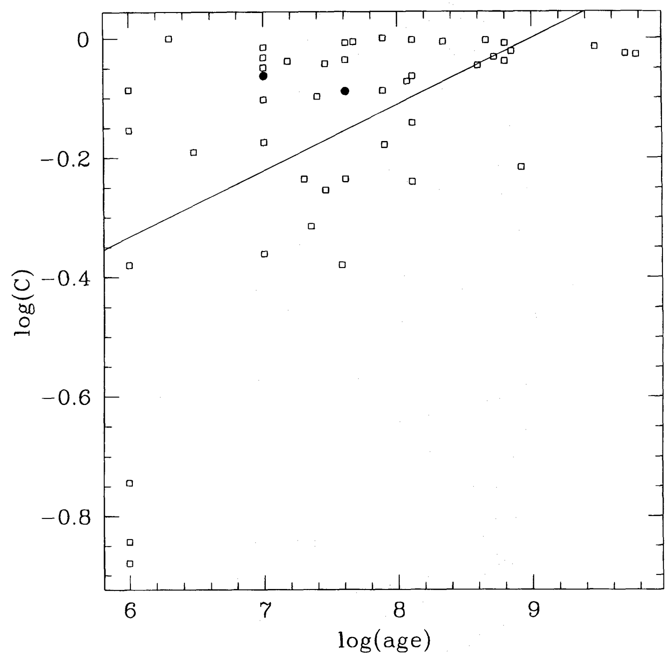

FIG. 3.—Plot of log (C) vs. log (age). The squares are for open clusters, and the filled circles are for OB associations. The straight line is the result of a linear regression on all the points. One can see that the correlation between the two variables is rather low, as attested by the value of the reduced Pearson r-coefficient of 0.518. The three points at the lower left-hand corner are, in decreasing value of log (C), NGC 6334g3, NGC 6334f5, and NGC 6334g2 (the references for these clusters can be found in Paper I).

We conclude by saying that, unfortunately, this plot cannot tell us with certainty what is happening in the dynamics of the star cluster, in the sense of which process is more important and how it evolves.

3.3. *Time Evolution of $\bar{m}/m_0$*

We show in Figure 4 the relationship between the logarithm of the ratio of the mean mass of the stars as it is today to what it was at the formation of the cluster, according to the model [log ($\bar{m}/m_0$)] and the logarithm of the age of the cluster [log (age)]. The symbols are the same as in Figure 3, and the straight line is the result of a linear regression which gives

$$\log \left(\frac{\bar{m}}{m_0}\right) = (-0.367 \pm 0.061) \log (\text{age}) + (3.133 \pm 0.468) , \quad (12)$$

with a reduced correlation coefficient $r^2 = -0.439$. All the points were used for the linear regression. The negative correlation would imply again that fragmentation is in action according to Figure 1. As for Figure 3, this result seems unreasonable because of the age of the clusters. Moreover, it is not impossible to obtain a null correlation if one is to forget the four points near the top left of the graph. So most probably Figure 4 shows no clear correlation between the mass ratios and the age of the cluster.

3.4. *Time Evolution of M_t/M_0*

We show in Figure 5 the relationship between M_t/M_0 and the age of the cluster. The symbols are the same as

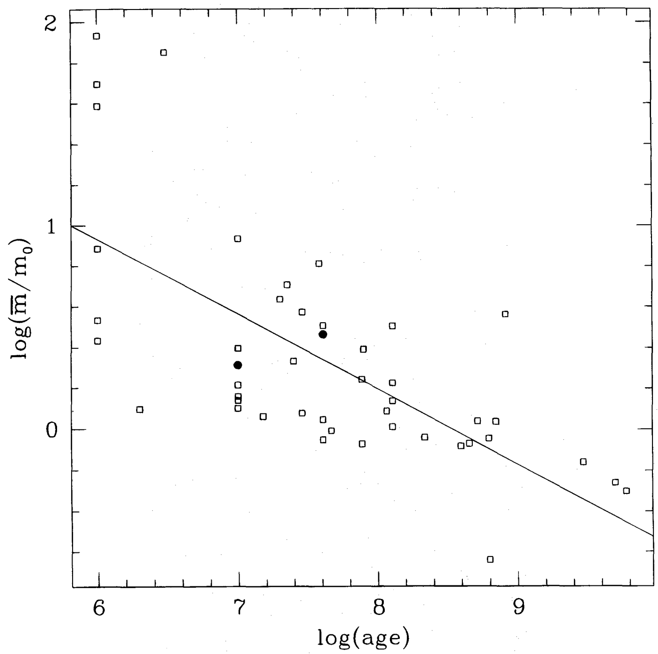

FIG. 4.—Same as Fig. 3 but with $\bar{m}/m_0$. A negative correlation is more plausible in this case, as evidenced by the reduced Pearson r-coefficient ($r = 0.663$). The straight line is the result of a linear regression on all the points. The four points at the upper left-hand corner are, for log (age) = 6 and in increasing value of log ($\bar{m}/m_0$). NGC 6334g3, NGC 6334f5, and NGC 6334g2; the other point at log (age) = 6.48 and log ($\bar{m}/m_0$) = 1.85 is ρ Oph.

those in Figure 1; the straight line is the best fit from a linear regression.

One can see that there is definitely a link between these two quantities. This correlation cannot be explained by

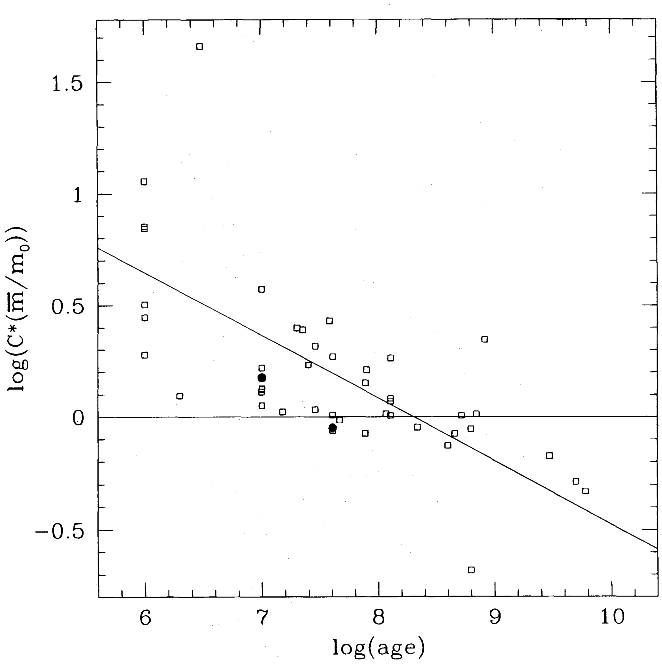

FIG. 5.—Relationship between the ratio of the total fragment mass of the clusters as observed today to what it was at the formation of the cluster as predicted by the coagulation model and the age of the cluster. The symbols are the same as in Fig. 2. The straight line is the best-fit regression law using all the available points. The point at the upper left-hand corner is ρ Oph; the one at (6.0, 1.05) is NGC 6334g2; the one at (8.92, 0.35) is Praesepe, and finally, the one at (8.8, −0.68) is NGC 6633.

coagulation only, since it was shown (Paper I) that it is negligible after times greater than about 10^6 yr for open clusters. The values resulting from the linear regression including all the points give

$$\log\left(\frac{M_t}{M_0}\right) = (-0.256 \pm 0.042) \log(\text{age}) + (2.133 \pm 0.321)\,, \tag{13}$$

with a reduced correlation coefficient $r = 0.669$. The negative correlation is most certainly due to the occurrence of dynamical evaporation of stars, and the spread in values around the best-fit line is probably due to the fact that we are not following *one* cluster through time but rather *many* clusters with *different* initial conditions and thus, clusters that follow different paths in the graph (this comment also applies to the two preceding figures). One thing which remains though is that clusters as a whole are experiencing a loss of mass in terms of stars according to Figure 5. We are more confident that this is the case, since only two processes can affect the total mass ratio according to Figure 1, and they have opposite influences. Moreover, the other process is accretion, and it is probably negligible in the time interval studied.

The magnitude of this mass loss can be estimated from the graph and be consequently confronted with theory. The regression results give us the law

$$\frac{M_t}{M_0} \approx 136^{+148}_{-71}\ \text{age}^{-0.256 \pm 0.042}\,. \tag{14}$$

We can deduce many estimates of the importance of processes from this regression law. For instance, one can evaluate the mean life expectancy of clusters. If one assumes that it is roughly the age at which only $1/e$ of its initial total number of stars remain, i.e., the age at which

$$\frac{M_t}{M_0} \approx \frac{1}{e}\,, \tag{15}$$

then one obtains log $[\tau_e(\text{yr})] \sim 10.0^{+3.5}_{-2.5}$ yr which, although the uncertainty in our value is quite large, is compatible with what one finds for a typical open cluster. Indeed, by knowing that the relation between the evaporation and relaxation times of a cluster is given by

$$t_{\text{evap}} \cong 136 t_{\text{rel}}\,, \tag{16}$$

and by using (Lightman & Shapiro 1978)

$$t_{\text{rel}} \cong 7 \times 10^8\ \text{yr} \left(\frac{N}{10^5}\right)^{1/2} \left(\frac{m}{M_\odot}\right)^{-1/2} \left(\frac{R}{5\ \text{pc}}\right)^{3/2}, \tag{17}$$

with typical values for open cluster of $N = 10^3$, $m = 1\ M_\odot$, and $R \sim 3$ pc, one obtains

$$t_{\text{rel}} \cong 7 \times 10^7\ \text{yr}\,, \tag{18}$$

and thus

$$\log(t_{\text{evap}}) \cong 10.0\,. \tag{19}$$

In another study, Wielen (1971) found that 99.95% of the stars have left the cluster after log (t) = 9.74. Our results are also compatible with this estimate.

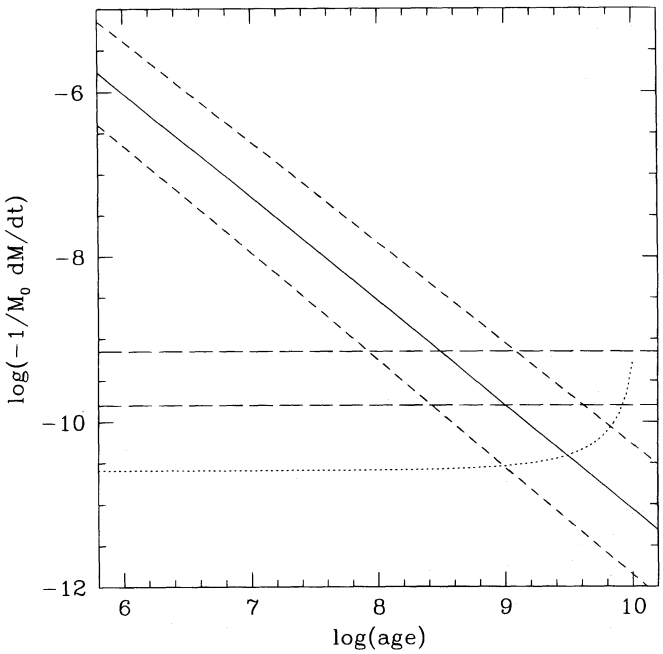

FIG. 6.—Derived relationship between the mass-loss rate and time. The line is obtained from the derivative of eq. (14); short-dashed lines represent the limits of uncertainty (1 σ). The dashed curve is the model of Gurevich & Levin (1950) and King (1958). The long-dashed lines are the limits derived from the simulations of McMillan & Hut (1994). See text for more details.

One can also evaluate the mass-loss rate of the cluster by simply taking the time derivative of equation (14). One obtains

$$\frac{dM}{dt} = -39^{+50}_{-21} M_0 \text{ age}^{-1.26\pm0.04} . \tag{20}$$

We show in Figure 6 the value this equation takes versus the log of the age of the cluster. The straight line is for the middle value, while the broken lines are the limits of uncertainty for 1 σ. We plotted this function only for the range of ages that we had and used for this paper. One can see that the amount of mass loss can be described roughly by

$$\log\left(-\frac{\dot{M}}{M_0}\right) \cong \log(\text{age}) . \tag{21}$$

If one assumes that the typical total mass of a newly formed open cluster is about 10^4 solar masses, then one obtains a value of 10^{-5} $M_\odot$ yr^{-1} for a 10^8 yr old open cluster. This value is somewhat smaller than what we find if we assume a mean mass of 1 $M_\odot$ for the fraction of stars that have speeds greater than twice the escape velocity of the cluster, that fraction being 7.38×10^{-3} in a Maxwellian distribution. A very interesting paper on the evolution of globular clusters by Chernoff & Weinberg (1990) discusses mass-loss rates in detail for different initial conditions. Although their results are for globular clusters, we can compare them to our results by choosing the conditions that are the closest to open cluster characteristics. They use Hénon's Fokker-Planck equation of model relaxation and energy exchange between the stars. Among the free parameters of their model are W_0, the concentration parameter of King models, and α, the spectral index of the IMF. They calculate for various values of these parameters the corresponding time it takes for the cluster to either collapse or disrupt and give the corresponding cluster mass left in units of the initial total mass. If we take these data from their Table 5 to compute very rough average mass-loss rates (they give the detailed evolution of these rates elsewhere in the paper, but we only want to compare their scale to our results), we find that the biggest value is of the order of 10^{-8} $M_\odot$ yr^{-1} for a cluster with $\alpha = 1.5$ and $W_0 = 1$. Now this may seem far from our estimate, but we must remember that this value is for a 9×10^6 yr old cluster and that the uncertainty in equation (20) is quite large. In fact, the lowest value for the rate of mass loss we find for a 9×10^6 yr old cluster with equation (20) is 2×10^{-8} $M_\odot$ yr^{-1}. So equation (20) gives results that are compatible with Chernoff & Weinberg's theoretical results.

Gurevich & Levin (1950) and King (1958) found that

$$\frac{M}{M_0} = \left(1 - \frac{7k_e t}{2t^0_{\rm rh}}\right)^{2/7} , \tag{22}$$

where k_e is a dimensionless constant of the order of ≈ 0.003 and $t^0_{\rm rh}$ is the initial relaxation time. The curve in Figure 6 is the resulting mass-loss rate assuming that $t^0_{\rm rh} = 10^8$ yr. One can see that our results give much larger mass-loss rates than predicted by theory in the range $\log(t) = 6$ to $\log(t) = 9$. On the other hand, the theoretical values are larger in the range $\log(t) > 9.9$. In fact, our results give a mass-loss rate that decreases with time instead of increasing like theory predicts. We do not feel that this is unreasonable, since the cluster should be more dynamically stable with time as it relaxes and the evaporation rate should consequently decrease with time as segregation takes place.

A more recent paper by McMillan & Hut (1994) dealt with N-body simulations of tidally limited star clusters with an initial population of 0%–20% binaries. They presented graphs of the evolution of the total mass over time for different scenarios. We derived mean mass-loss rates from these graphs, and the long-dashed lines in Figure 6 are the

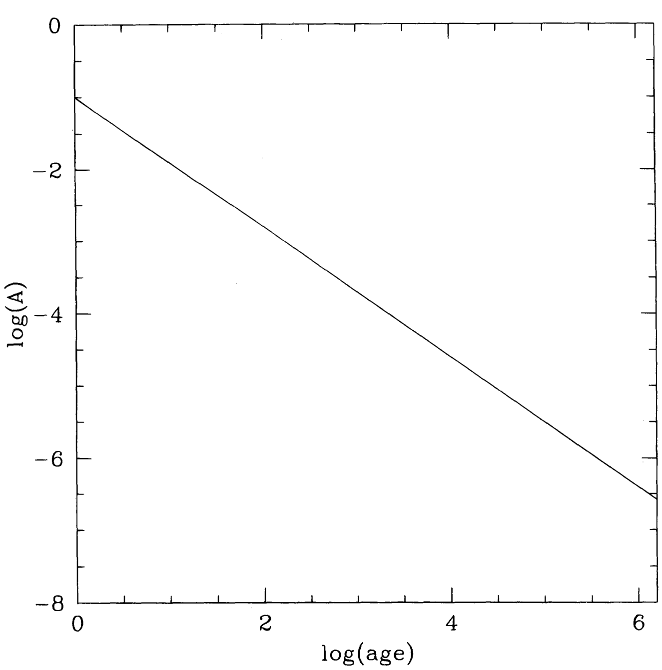

FIG. 7.—Evolution of the accretion rate A over time, as derived from Fig. 6.

limits of the values thus calculated, assuming again that $t_{rh} - 10^8$ yr. One has to remember that these derived values are *means* and in no way represent the exact behavior of the functions, although they can be reasonably approximated by a straight law in the interval of time studied in this paper. One can see that the agreement between our results and the simulations is limited to the time interval $\log(t) \approx 8.0$ to $\log(t) \approx 9.6$. Once again, our results for the mass-loss rate are much larger in the region $\log(t) < 8.0$ than the simulations predict. This value happens to be the typical relaxation time of an open cluster, which leads us to believe, if we are to trust our results, that the period of time between the birth of a cluster and a full relaxation time is ill represented by the above models. This is probably due to the fact that this period in the birth of a cluster is governed more by randomness than by deterministic laws.

One can evaluate also the mean accretion rate A of the cluster fragments by assuming that the ratio M/M_0 reaches it maximum value of about 4.0 at the age of 10^6 yr according to the linear regression results of equation (14). By assuming also that the total mass ratio follows a direct law between log (age) = 0 and log (age) = 6 and that accretion is the only process involved in augmenting the mass of a star, one finds the approximate law for the accretion rate,

$$\frac{\dot{M}}{M_0} \simeq 0.1 \text{ age}^{-0.9} , \qquad (23)$$

which we represent in Figure 7. This law gives a maximum accretion rate value of 10% at the formation of the open cluster, decreasing rapidly with time.

This translates into a maximum accretion rate of 0.1 $M_\odot$ yr^{-1} if one assumes that the mass of a typical open cluster star is 1 $M_\odot$. This value may seem a bit high, but if one calculates the mean value of the accretion rate between log (age) = 0 and log (age) = 6, one obtains 1.1×10^{-5}, which is what is currently believed to be typical (see, for example, Palla & Stahler 1992). Moreover, it already has reached 10^{-4} at the age of 10^3 yr according to Figure 7. One must not forget also that it is undisputedly sure that the accretion rate is much higher at the onset of star formation, e.g., in class O young stellar objects, while it tapers off rapidly to a minimum value quite early in the life of the cluster. Thus, we feel that an accretion rate of 10% at the very birth of the protostar is still reasonable.

4. CONCLUSION

Further analysis of the results of Paper I was made, and we have searched for correlations between the two parameters $C = N/N_0$, $\bar{m}/m_0$, and their product M_t/M_0 with the age of the clusters. We found that the total mass of a cluster decreases with time with an *e*-folding time of about 10^{10} yr, due probably to the dynamical evaporation of stars.

Clearly, the technique should be applied to younger clusters (i.e., clusters with age $\leq 10^6$ yr), which can now be observed with infrared detectors, to find out more about the relative effects of fragmentation, coagulation, accretion, and evaporation.

Finally, the fact that the results of fitting the coagulation model to observations are compatible with other independent estimates does not automatically confer to it the status of validity. Nevertheless, the general agreement with observations shows that it merits more attention.

We would like to acknowledge financial support by the Conseil de Recherche en Sciences Naturelles et en Génie du Canada.

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