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CHEMICAL EVOLUTION OF THE GALACTIC DISK VIA SIMULATIONS OF THE OPEN CLUSTER SYSTEM

T. E. Tecce,[1] L. J. Pellizza,[2] and A. E. Piatti[1]

RESUMEN

En este trabajo presentamos simulaciones numéricas del sistema de cúmulos abiertos de la Vía Láctea, con el objetivo de poner cotas a la evolución de la tasa de formación estelar y de la metalicidad del disco galáctico. Encontramos que las propiedades del sistema de cúmulos abiertos pueden ser descriptas suponiendo una tasa de formación estelar prácticamente constante, un gradiente radial de metalicidad primordial que se mantiene constante en el tiempo, y la inexistencia de una relación edad-metalicidad.

ABSTRACT

We present numerical simulations of the system of open clusters of the Milky Way, whose aim is to provide constraints on the evolution of the star formation rate and the metallicity of the galactic disk. We find that the properties of the open cluster system are well described assuming an almost constant SFR for the disk, a primordial radial metallicity gradient which remains the same at all times, and the inexistence of an age-metallicity relationship.

Key Words: **GALAXY: DISK — GALAXY: EVOLUTION — METHODS: NUMERICAL — OPEN CLUSTERS AND ASSOCIATIONS: GENERAL**

1. INTRODUCTION

In recent years, a long debate has been maintained about the constancy of the star formation rate (SFR) of the galactic disk (Twarog 1980; Scalo 1987; Soderblom et al. 1991; Rocha-Pinto et al. 2000; Lamers et al. 2005), its chemical homogeneity (Chiappini et al. 2001; Piatti et al. 1995; Chen et al. 2003) and the existence of an age-metallicity relationship (AMR) for disk stars (Rocha-Pinto et al. 2000; Feltzing et al. 2001). Assuming that open cluster (OC) formation follows the general star formation trend, one approach to studying these issues is to use the properties of the OC system of the Milky Way to trace the evolution of the SFR and chemical composition of the disk, and the presence of metallicity gradients in it. In this work we simulate the OC system of the galactic disk, assuming different models for the SFR, AMR and metallicity gradients, and compare the resulting properties with those of the real OC system. We explore the consequences of our assumptions on these properties and decide whether they can explain the observations.

[1]Instituto de Astronomía y Física del Espacio (CONICET-UBA), C.C. 67 Suc. 28 (1428) Ciudad Universitaria, Buenos Aires, Argentina (tomas, andres@iafe.uba.ar).

[2]AIM - Astrophysique Interactions Multi-échelles (UMR 7158 CEA/CNRS/Université Paris 7), CEA Saclay, DSM/DAPNIA/Service d'Astrophysique, Bât. 709, L'Orme des Merisiers, 91191 Gif-sur-Yvette, France (lpellizz@cea.fr).

2. THE SIMULATED OC SYSTEM

In our simulations we generate a set of OCs by a combination of Monte Carlo algorithms, which provide cluster formation times (hence present ages), positions, masses and metallicities. At the heart of the simulations there are two assumptions: (a) the SFR of the disk as a function of time, and (b) the metallicity of the gas as a function of position and time (this last hypothesis includes both possible AMR and metallicity gradients). The SFR density $\rho_{\rm SFR}$ is proportional to the SFR and assumed to follow Schmidt's law,

$$\rho_{\rm SFR}(\vec{x},t) \propto {\rm SFR}(t)\rho_{\rm g}^{1.5}(\vec{x}), \qquad (1)$$

where $\rho_{\rm g}$ is the density of gas in the disk, taken from the standard model of Dehnen & Binney (1998). OC formation times and positions are drawn from the SFR density. Metallicities of the OCs are drawn from the assumed metallicity of the gas as a function of their position and time, and their masses from a standard initial mass function (Lamers et al. 2005). Finally, we compute a mean destruction time for OCs as a function of their mass and individual lifetimes are assigned via a Monte Carlo simulation, all this based on the model of Lamers et al. (2005). This is the main difference with our previous model (Tecce et al. 2006), in which the mean lifetimes from the model of Lamers et al. (2005) were taken directly as OC lifetimes. For every OC that survives to the present we compute its dynamical evolution, using the model for the galactic potential by Dehnen & Binney (1998). In this way we obtain the simulated present OC system of the entire Milky Way.

3. COMPARISON WITH OBSERVATIONS

Our first simulation assumes constant SFR and metallicity distributions. We generated $\sim 10^7$ clusters from 10 Gyr in the past onwards, and we have compared the resulting system with the catalogue of Kharchenko et al. (2005). For this comparison we select from our simulated sample those clusters which are at a distance of up to 600 pc from the Sun, because the catalogue of Kharchenko et al. (2005) is complete only to this distance. From this test we have determined that a constant SFR gives a good representation of the OC data, except for two age periods (between 0.6–0.2 Gyr and 0.16–0.06 Gyr in the past) in which the Kharchenko et al. (2005) data cannot be fit within observational errors, thus implying a change in the SFR. The total SFR suggested by our simulations, $(0.9\pm0.1)\ M_{\odot}\ \mathrm{yr}^{-1}$, is consistent with the values for normal spiral galaxies (Kennicutt 1998).

In the following simulations we used the SFR obtained from the previous one and assumed first no AMR (i.e. a random metallicity distribution in the interval [-0.7,0.3], simulation 2), then the simple linear AMR proposed by Rocha-Pinto et al. (2000) ($[Fe/H](t) = 0.2 - 0.09\mathrm{Gyr}^{-1}t$, simulation 3), and finally no AMR but a radial gradient, taken to be that observed in the OC system at the present time ($[Fe/H](R) = 0.75 - 0.09\mathrm{kpc}^{-1}R$, simulation 4). In all three cases we selected from our simulated system all OCs with $5\ \mathrm{kpc} < R < 14\ \mathrm{kpc}$, a sample comparable to the catalog of Chen et al. (2003). Simulation 2 disagrees completely with the observed data, as it predicts a flat metallicity distribution which is not observed. Simulation 3 reproduces fairly well the observed metallicity distribution, but fails to produce a radial metallicity gradient like the one observed. Finally, simulation 4 agrees well both with the observed metallicity distribution and the radial gradient.

4. CONCLUSIONS

We presented a set of simulations of the OC system of the Milky Way, devised to investigate the evolution of the SFR and metallicity of the disk and the existence of metallicity gradients. From these simulations we conclude that OC data are successfully represented by a model given by an almost constant disk SFR of $(0.9 \pm 0.1)\ M_{\odot}\ \mathrm{yr}^{-1}$ (except for two small changes at recent epochs), no AMR, and a radial metallicity gradient which remains constant at its primordial value of -0.09 dex kpc^{-1} (equal to the one determined by observations).

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