THE MODELLING OF THE MASS–METALLICITY RELATION FOR THE LOCAL GROUP DWARF GALAXIES

M.V. Ryabova[1], Yu.A. Shchekinov[1,2]

[1] Southern Federal University, Rostov-on-Don, Russia, *rgyaf@yandex.ru*
[2] Special Astrophysical Observatory, Nizhnyi Arkhyz, Russia, *yus@phys.rsu.ru*

ABSTRACT. We present results of modelling of the mass-metallicity relation for the Local Group dwarf spheroidal (dSph) galaxies. In this work, we use a single-zone chemo-dynamical model. Our model is based on the scheme suggested by C. Firmani and A. Tutukov (1992). The behaviour of the dark-to-visible mass ratio has been taken from M.-M. Mac Low & A. Ferrara (1998). We have considered two classes of models: open and closed. The obtained mass-metallicity relation for the open model shows that the galaxies can be divided into two distinct classes: low-mass ($M_{tot} < 10^8 M_\odot$) and high-mass ($M_{tot} > 10^8 M_\odot$) groups which agrees with observation data.

Key words: Dwarf galaxy, local group, mass–metallicity relation.

1. Introduction

One of the fundamental problems, connected with chemical evolution of stellar systems including globular clusters and galaxies, is the problem of dependence of stellar system average metallicity on its mass. The solution of this problem is not trivial because the mass-metallicity relation can be determined by many factors, in particular, by exchange of material with an environment. It seems that the more massive self-enriched systems should have more metals. For low-mass systems the situation can change, because only those systems where the total energy from SNe is smaller than their binding gravitational energy can survive, otherwise they are destroyed and cannot be observed as separate stellar units.

To investigate this problem we carried out the modelling of the mass-metallicity relation for low-mass stellar systems – dwarf galaxies.

2. The model

We have applied a standard set of the integro-differential equations describing an exchange of mass between the stellar and gas components, the elemental abundances, and also the dynamic equation connecting the supernovae (SNe) explosion energy and dynamic characteristics of the system (Firmani & Tutukov 1992).

It is known that dwarf galaxies contain dark matter determining the gravitational potential of the system. In our calculations we used the empirical dark-to-visible mass ratio $M_h/M_g = 34.7 \cdot (M_g/10^7 M_\odot)^{-0.29}$, where M_h is the total halo mass, M_g is the baryon mass (Mac Low & Ferrara 1999).

3. Mass–metallicity relation

Two classes of models have been considered: the open and closed. In open model the fraction of mass which can be ejected from galaxy as a function of the total number of SNe is given by

$$\delta = \begin{cases} 1, & N_t < 100 \\ 1.76 - 0.165 \ln(N_t), & N_t > 100 \end{cases}$$

The ejection is inhibited for galaxy's mass above certain value $10^9 M_\odot$ (Ferrara et al. 2000).

Two important issues have to be mentioned: first, the increase of the total galactic mass increases its gravitation potential. Second, while the galactic mass increases star formation becomes less coherent through the galactic area and the energy from SNe dissipates in the surrounding interstellar gas.

The results of calculations for closed and open models are shown on Fig. 1. For closed models, we have obtained an obvious result: the metallicity reaches constant value when the galactic mass increases. For open models a nonmonotonous dependence in the range of mass from $5 \cdot 10^6$ to 10^9 is observed. The obtained mass-metallicity dependence allows to distinguish the whole range of masses on to two intervals with a completely different behaviour: $M_{tot} < 10^8 M_\odot$ and $M_{tot} > 10^8 M_\odot$.

In the work by Tamura et al. (2001) the massmetallicity relation among the Local Group dSph galaxies has been examined. It was noticed that dSph galaxies

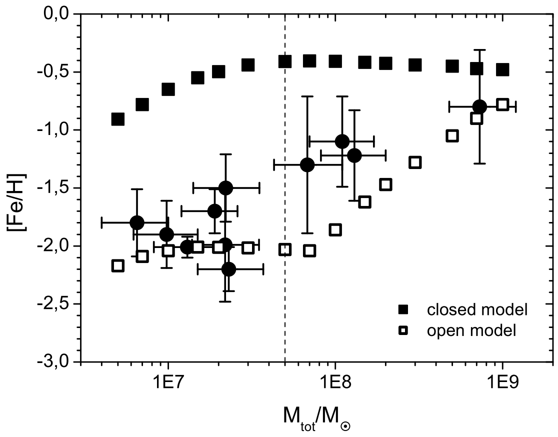

Figure 1: The mass-metallicity relation for closed and open models. Circles are the observed mass-metallicity relation for the Local Group dSph galaxies (Tamura et al. 2001).

can be divided by mass on to two groups: low mass and high mass galaxies (vertical dash line on Fig. 1 indicates the boundary between the groups).

It is easy to see that the modelled mass-metallicity relation for the open model is in a quite good agreement with the observed dependence.

The numerical calculation within the frameworks of a single-zone scheme depends on several free parameters. One of such a parameter is the dissipation time estimated phenomenologically. The dependence of the mass-metallicity relation on dissipation time has been investigated. The results of calculations for the open model are shown on Fig. 2. As can be seen that the mass-metallicity relation for small dissipation time greatly differs from all other obtained dependencies (especially by its anticorrelation for low masses $M_{tot} < 10^8 M_\odot$). In the range $M_{tot} > 10^8 M_\odot$, the metallicity grows with the galactic mass independently of dissipation time. Such a behaviour is observed in dSph galaxies, which still remains unexplained. Our simulations allow to conclude that it is determined by the mass exchange with an environment and by the corresponding metal losses. The decrease of metallicity with mass in the range of low masses can be explained by that the gravitational potential in this case is small in comparison with SNe explosion energy. The subsequent increase of galactic mass leads, on the one hand, to increase of the gravitational binding energy, and on the other hand, to desynchronization of SNe explosions followed by considerable energy loss in the interstellar gas.

We also have investigated the dependence of the mass–metallicity relation on the age of system. It was found that in the low mass range the metallicity decreases when the age decrease. In the high mass range the metallicity values are independent of the age.

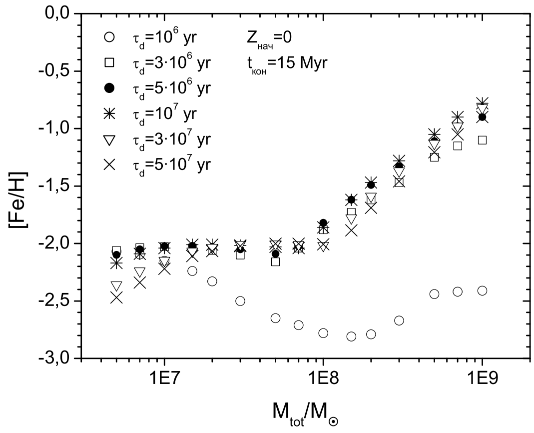

Figure 2: The mass-metallicity relation for open models with variations of dissipation time.

3. Summary

The obtained results allow to draw the following conclusions:

- The gravitational potential (dark matter) essentially influences on the mass-metallicity relation.
- The observed nonmonotonous behaviour of mass-metallicity relation for low-mass dwarf galaxies represents a transition from the systems with weak gravitational potential to the systems with high potential.
- The observed mass-metallicity relation in the low mass end can be described by the dissipation time 10^7 yr, while in the high mass range by the dissipation time $> 10^7$ yr.
- In high mass galaxies $M_{tot} > 10^8 M_\odot$ enrichment takes place on a short timescale.

Acknowledgements. This work was supported by the Federal Education Agency (project code RNP 2.1.1.3483).

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