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The chemical evolution of the halo of the M33 galaxy

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Abstract

The chemical evolution of the halo of the M33 (Triangle) galaxy is considered. We suppose a galactic stellar halo to be formed as separate fragments which then merge. Our results show that the M33 halo metallicity distribution function can be reproduced in the framework of such a merger scenario of the chemical evolution. The halo stellar population of M33 was likely formed from two fragments only. It was found that gas accretion plays a significant role during the evolution of fragments before their merger. The presence of gas accretion during the fragment evolution allows us to obtain a gas mass fraction which is sufficient for the disk formation after the merger of the fragments.

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1. Introduction

The oldest stellar systems retain information about the processes that took place in galaxies at the early epochs of their formation. Studies of the ages and metallicities of these systems allow us to put restrictions on the theoretical description of the processes of galaxy formation. Thus, a halo stellar population is a good environment to test a model of the formation process of a protogalaxy.

To explain the observed correlation between eccentricity and metallicity of Galactic dwarf stars, Eggen et al. (1962) considered the fast collapse of a monolithic protogalactic cloud taking place during 2×10^8 yr. When studying the Galactic globular clusters, Searle and Zinn (1978) find that the globular cluster system can be divided into two subsystems with different kinematic and chemical characteristics. The globular cluster metallicity distribution functions of other galaxies (spirals and giant ellipticals) indicate the presence of two (and even more) globular cluster subsystems (Harris et al., 1992; Geisler et al., 1996; Forbes et al., 1998; Cohen et al., 1998; Barmby et al., 2000; Larsen et al., 2001). It is hard to explain such a division of globular clusters into two subsystems in the framework of the monolithic collapse model. Searle and Zinn (1978) proposed the merger scenario of galactic formation; in the framework of their model the halo stars and halo globular clusters were formed in fragments which merged with the main body during more than 1 Gyr. If a galaxy were formed by a fast monolithic collapse, in which the time of interstellar medium enrichment is shorter than the collapse time, then galactic halo stars and globular clusters should show a correlation between their ages and metallicities. On the other hand, if the halo stellar population were formed in fragments evolving independently from each other, it should not show such a correlation (Searle and Zinn, 1978).

There are a considerable number of observations indicating the significant role of accretion in the formation of a galaxy. Carney et al. (1996) found that Galactic

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high-velocity low-metallicity halo stars can be separated into two populations – the ''high'' and the ''low'' halos. They supposed the origin of the low halo to be connected with the disk formation; it is obvious that the high-halo stars were formed in dwarf satellites galaxies, which were captured by our Galaxy, as shown by their retrograde rotation and the lack of radial metallicity gradients. Several tens of high-velocity low-metallicity halo stars with low α-element abundance ratio, compared with most of halo field stars, are known. All these stars have large apogalactic distances, i.e. they could be formed inside galaxies-satellites whose chemical evolution proceeded independently from our Galaxy's evolution, and which were captured by the Galaxy subsequently (Ivans et al., 2001). The nearest dwarf galaxy Sagittarius is an example of the same capture (Ibata et al., 1994). Another example is the Magellanic Stream which is the result of gas capture from Magellanic Clouds (Putman et al., 1998). In the halo of M31 a large stellar stream was also found with metallicity [Fe/H] > −0.7. It is supposed that this formation is a part of a large stellar stream that connects two dwarf galaxies, NGC 205 and M32 (Ibata et al., 2001).

The stellar population of the ω Centauri globular cluster shows signs of the presence of multiple stellar populations, which points to more than one star formation epoch in this cluster. This allows one to assume ω Centauri to be a part of a more massive system, that merged with our Galaxy earlier (Lee et al., 1999). The observations of the stellar stream in the halo at a distance 4–5 kpc above the Galactic plane show retrograde rotation of the members of the stream; probably, the stream is a dwarf galaxy's remnant captured by our Galaxy earlier (Majewski et al., 1994).

If we consider the Galactic chemical evolution in the framework of the Simple Model of chemical evolution, a contradiction with observation data appears. The model predicts more low-metallicity disk stars in comparison with the observations (G-dwarf problem, Pagel, 1997); probably the same problem exists for other galaxies (Henry and Worthey, 1999). Note the G-dwarf problem should be solved taking into account the interaction with the intergalactic medium. An example of such an interaction is the fragment's capture by galaxies.

Schmidt (1959) considered the chemical evolution model of a monolithic protogalactic cloud, i.e. a galaxy formed in the process of monolithic collapse. An alternative scenario of galactic formation is the hierarchic clustering scenario, i.e. the formation of galaxies by merger of smaller systems. In particular, it has been suggested that an elliptical galaxy could be formed as a result of a merger of two massive disk galaxies (Bekki et al., 2003).

Pilyugin (1996) considered a model of chemical evolution of the solar neighbourhood assuming that the formation of the protogalaxy occurred by merger of individual fragments. We use his method to consider the M33 halo chemical evolution within the merger scenario.

In the present work it is supposed that the halo stellar population is composed of a mixture of stars that were formed in fragments originally evolving independently from the main protogalactic cloud and/or from each other. Hence, there should be a set of fragments whose total stellar populations reproduce the observed stellar halo metallicity distribution. The aim of this work is to reproduce the observed metallicity distribution of the halo field stars of M33 and to investigate the chemical evolution of fragments before their merger.

This paper is organized as follows. In Section 2 we describe the chemical evolution of a single fragment before a merger and the merger scenario. In Section 3 we show and discuss the resulting metallicity distribution function obtained in the framework of the model described in Section 2 and discuss the evolution of Local Group spiral galaxies. Finally, in Section 4 we summarize the main conclusions.

2. The model

The chemical evolution describes the change of galactic gas mass, chemical elements, stars and stellar remnants (white dwarfs, neutron stars and black holes) during a galactic evolution. The star formation history is described by a sequence of bursts in the framework of the numerical chemical evolution model; during each burst a population of stars, ejecting the synthesized heavy elements into the interstellar medium, is formed.

2.1. The chemical evolution of a single fragment

The star formation process in a fragment before its merger is considered as a set of bursts with a population of stars formed during each burst.

According to Pilyugin (1994), the mass of gas, m_g, the mass of element i, m_i, and the mass converted into stars and stellar remnants (white dwarfs, neutron stars and black holes), m_s, at the beginning of a star formation burst, t_{b_j} are given by

$$m_g(t_{b_j}) = m_g(t_{b_{j-1}}) - m_{b_{j-1}} + M_{acc} + \sum_{k=1}^{j-1} m_{b_k}[Q_m(\tau_{j,k}) - Q_m(\tau_{j-1,k})] \quad (1)$$

$$m_i(t_{b_j}) = m_i(t_{b_{j-1}}) - m_{b_{j-1}} z_i(t_{b_{j-1}}) + \sum_{k=1}^{j-1} m_{b_k}[Q_m(\tau_{j,k}) - Q_m(\tau_{j-1,k})] z_i(t_{b_k}) + \sum_{k=1}^{j-1} m_{b_k}[Q_i(\tau_{j,k}) - Q_i(\tau_{j-1,k})] \quad (2)$$

$$m_s(t_{b_j}) = m_s(t_{b_{j-1}}) + m_{b_{j-1}} - \sum_{k=1}^{j-1} m_{b_k}[Q_m(\tau_{j,k}) - Q_m(\tau_{j-1,k})] \quad (3)$$

where $\tau_{j,k} = t_{b_j} - t_{b_k}$, $\tau_{j-1,k} = t_{b_{j-1}} - t_{b_k}$, where m_{b_j} is the mass of the star formation burst j, $z_i(t_{b_j})$ is the abundance of element i at the moment t_{b_j}, $\tau_{j,k}$ is the age of burst k at t_{b_j}.