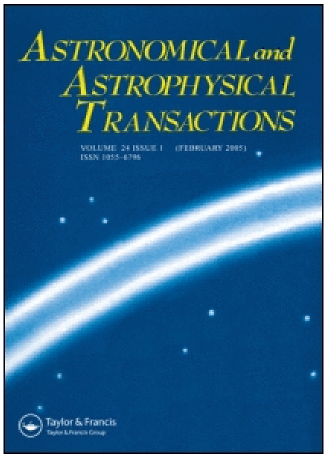

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Globular clusters and dwarf spheroidal galaxies of the outer galactic halo: On the putative scenario of their formation

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GLOBULAR CLUSTERS AND DWARF SPHEROIDAL GALAXIES OF THE OUTER GALACTIC HALO: ON THE PUTATIVE SCENARIO OF THEIR FORMATION

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According to observational data, some of the Galactic globular clusters (GCs) belonging to the outer halo form a separate subsystem of globulars: they are mainly on retrograde orbits, show younger ages than other GCs of the outer halo, etc. Moreover, there is evidence suggestive of a common, accretive origin of at least some of both these GCs and the dwarf spheroidal galaxies, satellites of the Milky Way. I discuss a scenario which, if real, would explain the origin and several peculiar characteristics of the objects under consideration. It is based on two fairly realistic assumptions: (i) the first burst of star formation in which a bulk of the population II formed in the Galaxy and M31, led to a considerable mass loss, up to half mass of each protogalaxy; (ii) the Milky Way together with M31 have formed a binary galactic system since the earliest epoch. Hence I suggest that just after (or during) the formation of their spheroids the Galaxy and M31 mutually exchanged gas by its transfer, in particular, through respective Lagrangian points in approximately the same manner as in interacting binary star systems. So, some objects of the outer Galactic halo may have formed from gas produced in such a process.

KEY WORDS Outer Galactic halo, young globular clusters, dwarf spheroidal galaxies, scenario of origin

1 INTRODUCTION

In my report I address one of the fundamental problems related to the formation of the Milky Way – that of the origin of objects in the outer Galactic halo. Taking into account the variety of observational evidence concerning (1) the second parameter GCs in the outer Galactic halo, as well as (2) the dwarf spheroidal (dSph) galaxies orbiting the Milky Way (and M31), I suggest a possible process which may have occurred within the system Galaxy–M31 in the early epoch. It may have contributed to the formation of the above two kinds of objects. Note, however, that I emphasize the former of them. Here I present my preliminary qualitative considerations with some simple evaluations.

2 BASIC CHARACTERISTICS

It is now well recognized (see, for instance, Lee, 1993; Zinn, 1993; van den Bergh, 1993; Lee et al., 1994, among others, and references therein) that GCs in the outer halo are divided into two subpopulations, 'old' and 'young'. The origin of the latter globulars is quite enigmatic and is not yet quite clear. The reason is that in comparison with old GCs, young ones have a number of peculiar properties and characteristics, of which the basic ones are as follows.

1. Their age differs from that of the old GCs by a few Gyr, typically 1 to 4 Gyr. One supposes age to be responsible for or the main contributor to the second parameter phenomenon exhibited by the predominant red horizontal branch (RHB) morphology of the color-magnitude diagrams (CMDs) of the young GCs.

2. These clusters exhibit peculiar kinematic characteristics. They have, on average, retrograde rotation, whereas old GCs show direct motion with lower dispersion. According to Da Costa (1994) the mean velocities of rotation are $V_{rot} = -45 \pm 81$ km/s and $V_{rot} = 58 \pm 24$ km/s, respectively.

3. As has been noted by Rodgers and Paltoglou (1984) and confirmed by van den Bergh (1993), the metallicities of the clusters under consideration fall in quite a narrow range, within Δ[Fe/H] = 0.4 dex.

4. Three-dimensional distribution of at least part of the GCs with RHB morphology is such that they appear to populate the so-called 'Fornax–Leo–Sculptor stream' consisting of five dSph galaxies orbiting the Milky Way (Majewski, 1994). Moreover, the plane formed by all these objects is nearly orthogonal to the Galactic plane. As for the dSph galaxies themselves (and Magellanic Clouds), satellites to the Milky Way, they are supposed to orbit it either in the same plane (Kunkel and Demers, 1976) or in two different ones (Lynden-Bell, 1982).

It is important to point out that in addition to the spatial distribution the outer halo GCs with RHB morphology have other properties in common with the dSph galaxies and their globulars. One important one is that, like the young GCs, CMDs of dSph are strongly affected by the second parameter. To demonstrate this, I present below two typical examples concerning dSph galaxies. In particular, Demers and Irwin (1993) conclude that 'the Leo II diagram is similar to those of outer halo clusters suffering from the second-parameter syndrome', and according to Suntzeff *et al.* (1993) '...Sextans, like Draco, is a 'second parameter' object that may be a few Gyr younger than the typical Galactic globular cluster'.

Note also one interesting relation between the number of dSphs (see, for example, the compiled data of Grebel, 2000) orbiting the Galaxy (N_G) and M31 (N_A). Their ratio, $N_G/N_A \sim 1.5$, is approximately inversely proportional to the ratio of masses of these two spirals.

It is now widely believed that the origin of each kind of stellar system under consideration, the second parameter GCs and dSph galaxies, is more likely due to accretion event(s). Moreover, by comparing the spatial distribution of both these types of objects Majewski (1994) has argued that the dSph galaxies belonging to the 'Fornax–Leo–Sculptor stream', and the young halo clusters with reddest horizontal branch morphology 'may be related through origin to a common Galactic accretion event'.

In this connection I try to answer at least two of the important questions:

– Where did the accreted gaseous material out of which the young GCs (and possibly some dSph galaxies) formed, originate and come from?

– Why has the formation of the outer halo GC system lasted after the formation of the bulk halo objects in rapid collapse?

3 WHY NOT?

At present, the widely accepted working scenario of the origin of the young GCs consists in tidal disruption of a hypothetical, Large Magellanic Cloud-like galaxy or/and of accreted dSph satellites. However, there are a number of difficulties to explain the origin of the majority of these clusters through such a process (e.g., van den Bergh, 1996). I propose another scenario. It is based on the following assumptions:

1. The Milky Way and M31 have formed a binary galactic system since the earliest epoch.

2. As has been argued since the 70s (e.g., Larson, 1974; Bookbinder *et al.*, 1980; Marochnik and Suchkov, 1984; among others), some properties of galaxies (particularly chemical ones) and of hot gas in clusters of galaxies imply a considerable mass loss which may have occurred in the early epoch of formation and evolution of galaxies. It is supposed to be due to gas outflow caused by supernovae–driven wind which accompanies, in particular, the first, powerful star formation event(s). It is believed that such a loss of gas in galaxies, like M31 and Milky Way, may amount to up to half the mass of each protogalaxy ($\Delta M \sim 10^{11} M_\odot$).

Hence it is reasonable to suggest that some portion of the gas expanding out and quitting a parent galaxy (Andromeda) will then be accreted onto its companion (our Galaxy) in roughly the same manner as occurs in a binary star system with gas transfer from one companion to the other. If we accept the present distance between the Galaxy and M31 ($\sim$ 0.7 Mpc), the ratio of their mass ($M_G/M_A \sim 1/1.5$), and also the mean velocity of expanding gas to be of order $\sim$ 400 km/s, then we easily find that the time spent by gas to reach the region of the Lagrangian point between the two galaxies, may be as long as $\sim$ 1 Gyr.

It is important to estimate an upper limit of the mass of gaseous material δM accreted onto the Galaxy if the total amount of gas lost by M31 is $\Delta M (\sim 10^{11} M_\odot)$.

For this purpose I have applied a formula obtained (using some realistic assumptions in the approach of gas accretion in the gravity potential $\varphi \sim 1/R$ of a less massive companion in a binary system) and kindly offered by Postnov (private communication):

$$\delta M \leq \frac{1}{4}\left(\frac{M_G}{M_A}\right)^2 \Delta M \sim \frac{1}{10}\Delta M \sim 10^{10} M_\odot$$

Even if the mass of really accreted gas was an order of magnitude lower than the upper limit estimated and if, in turn, approximately ten percent of this mass was converted into objects ($\sim 10^8 M_\odot$), that would be quite enough to form the majority of the young globulars, a few dSph galaxies, and also some quantity of field stars.

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