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Tracing of the chemical evolution of the massive elliptical galaxy NGC 3377 using a merger scenario

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Abstract

Mergers are thought to play a significant role in the formation of galaxies in clusters. The chemical evolution of the halo of the massive elliptical galaxy NGC 3377, a member of the Leo cluster, is considered in the framework of such a merger scenario. An open chemical evolution model is set up to calculate the metallicity distributions of pre-merging fragments. The model assumes that pristine gas was accreted onto the fragments during their whole evolution before their merger. The metallicity distribution resulting from the overlay of a variable number of fragments is then compared to observational data for NGC 3377. It was found that the observed metallicity distribution function of this elliptical galaxy is reproduced by merging at least five fragments from two different groups, namely low-and high-metallicity fragments.

Keywords: Chemical evolution; Merger scenario; Metallicity distribution function; Haloes of massive elliptical galaxies; NGC 3377

1. Introduction

The hierarchical clustering theory considers the formation of massive galaxies by merger of smaller ones. Galactic mergers play a central role in the formation of early-type galaxies, especially of massive ones (Kauffmann, 1996). Studies of the outskirts of these galaxies at low red shifts are powerful probes of the hierarchical mass assembly of galaxies.

Usually, the mergers are considered to be divided into two groups by their masses – the major mergers, with mass ratios from 1:1 till 1:4, and the minor mergers, with mass ratios of 1:4 and below. Traditionally, the major mergers are considered as the main cause of the transformation of disk systems to elliptical ones (Cox et al., 2006). At the same time, the minor mergers are believed to merely build galactic disks (Read et al., 2008). Dry, collisionless mergers and stellar accretion events are considered to be main candidates for the strong mass and size evolution of stellar spheroids at $z < 2$ (Hopkins et al., 2009). Early-types galaxies can increase their sizes by minor dry merges, which add stars to the outskirts of massive galaxies (Oser et al., 2012). Particularly, Trujillo (2011) have exploited the local mass–size relation of elliptical galaxies and found that there is one possible way of the formation of elliptical galaxies on $z \sim 1$, such as the minor dry mergers (Trujillo, 2011). Genel et al. (2010) demonstrate that the fraction of observed massive early-type mergers is not sufficient to explain the number of massive ellipticals. van Dokkum (2005) concludes that the majority of today's most luminous field elliptical galaxies were assembled at low red shifts through mergers of gas-poor, bulge-dominated systems.

It is generally believed that most of the red bulged-dominated galaxies can be formed by major dry wet mergers and minor mergers, but the structure of remnants is expected to be very different (Cox et al., 2006; Bournaud

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et al., 2005). A study of the sample of red-sequence galaxies, defined by van Dokkum (2005) as the results of dry mergers, shows that merger remnants with the young stellar population cannot be completely dry. For them, the authors favoured the major mergers because the metallicity value of the young components appeared to be very large (Sanchez-Blazquez et al., 2009). In fact, the metallicity distribution functions have the same shape in the case of the major merger as well as in the case of the hierarchical merging (Beasley et al., 2009). Whereas Oogi and Habe (2012) argued that a size growth by dry minor mergers can be common for high-z massive early-type galaxies, Cimatti et al. (2012) came to the conclusion that a size growth by a minor merger is sufficient from $z \sim 1$ to the present. However, Nipoti et al. (2012) believed that neither the minor nor the major merger can be the main mechanism to explain the fast size growth at higher red shifts.

Now the observational data affirm that a merger process plays a significant role in galaxy formation (see van Dokkum (2005) and references therein). At the same time, there is some evidence for the traditional arguments against the central role of mergers in the early-type galaxy formation, for example, in the correlation between abundance ratios and host galaxy properties (Pipino and Matteucci, 2008).

The merger events left traces in haloes of some massive galaxies as the stellar substructures. Particularly, the merger remnants, such as stellar streams, are observed now in the galactic halo of the Milky Way (Ibata et al., 1994; Majewski et al., 1994) and M31 (Ibata et al., 2001; McConnachie et al., 2009). The stellar metallicity distribution function of the elliptical galaxy NGC 3379 also contains the fine substructure (Harris et al., 2007b). The outer haloes of massive galaxies show metallicity distributions that differ from those of inner haloes. This indicates that outer haloes are not well mixed, and it supports the idea of formation of the haloes of massive galaxies by accretion of their satellites (Cote et al., 1998). Lackner et al. (2012) examined the sample of massive galaxies and found that the fraction of accreted mass ranges from 15% to 40% and increases with a stellar mass. Accreted stars seem to be more metal-poor and older than in situ stars leading to the age and metallicity gradient in massive galaxies, in agreement with observations. Lackner et al. (2012) considered that major mergers does not dominate the formation histories of the massive galaxies because the growth of massive galaxies by merger occured at rates of 2.6% per billion years (Lackner et al., 2012). Tissera et al. (2012) found that the fraction of accreted stars consists of 15% of a disk population and is α-enhanced and older than in situ stars.

Thus, our main question is what the details of the merger-based formation of massive ellipticals are, that is, whether these were major or minor mergers and the properties of objects before mergers. It is natural to suppose that we can find the traces of such processes in haloes of galaxies belonging to galactic clusters rather than in isolated galaxies.

In earlier work, we considered the possibility of a merger formation for the halo of the closest giant elliptical galaxy, NGC 5128. The chemical evolution of the halo of the giant elliptical galaxy NGC 5128 was calculated in the framework of such a merger scenario (Nykytyuk, 2004). We found that the observed metallicity distribution function is reproduced well by the major merger, that is, by merger of two high-mass and high-metallicity fragments only, with the time-dependent accretion of a pristine gas during the evolution of fragments. It is interesting to check if there is a difference in the formation of NGC 5128 and another massive elliptical, NGC 3377. NGC 3377 is an E5 elliptical galaxy in the Leo group. Its stellar metallicity distribution is broad, with peak $log(Z/Z_{Sun}) \sim -0.6$, (Harris et al., 2007a). No significant presence of the young stellar population was found in the stellar halo of NGC 3377 (Harris et al., 2007a), so this galaxy appears to be a good subject to test models of the formation of a galaxy.

Mergers are supposed to dominate in the outskirts of massive galaxies (Lackner et al., 2012) so it would be interesting to investigate the role played by mergers in the halo formation of the massive elliptical NGC 3377. According to Oser et al. (2010), the formation of a massive galaxy can be divided into two phases–the early, rapid in situ formation and later, merger-dominated period. The former is similar to the so-named monolithic collapse. Such a model is also useful for explaining the evolution of compact massive galaxies at $z \sim 2$ (Oser et al., 2012).

Our goal is to test the possibility of the halo formation of NGC 3377 by merger of individual fragments and to study the chemical evolution of fragments before their merger. The paper is structured as follows. Section 2 describes the merger scenario in a galactic chemical evolution. In Section 2, we summarize the main characteristics of the chemical evolution of a single fragment before the merger. In Section 3, the predictions of our model are compared to the observed distribution of stars on the metallicities of NGC 3377 (hereinafter named as the metallicity distribution function) and the result discussed. Finally, in Section 4 some conclusions are drawn.

2. The chemical evolution model of a fragment before merger

The theory of the chemical evolution of galaxies considers a change in the galactic gas mass, chemical elements, and stellar remains during the evolution of a galaxy. The main components of a model of the chemical evolution of a galaxy are the star formation history of a galaxy, the gas inflow/outflow history (in the case of an open model), and the initial stellar yields for a single stellar population.

The numerical chemical evolution model describes the star formation history of a galaxy as a sequence of star formation bursts. A population of stars, ejecting the synthesized heavy elements into the interstellar medium, is 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 stellar remains m_s at the beginning of a star formation burst t_{b_j} are described as follows: