AGB Stars as an Indicator of Long-Past Bursts of Star Formation in Galaxies

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Abstract. It is possible to determine the age of long-past bursts of star formation in galaxies by studying the luminosity function of AGB stars. In spiral and irregular galaxies, the age of AGB stars ranges from 100 million to several billion years. The older the AGB stars are, the lower is their luminosity. Theoretical isochrones of stars can be used to obtain the relationship between the luminosity of AGB stars and their age. During a burst of star formation, many stars of the same age appear in galaxies, and this excess is initially observed as a region of young supergiants, and hundreds of millions of years later, when the region of past star formation is not visible, an excess of AGB stars with an age corresponding to the age of the burst of star formation will be observed in the Hertzsprung–Russell diagram.

Keywords: stars: AGB and post-AGB; galaxies: star formation

DOI:10.26119/978-5-6045062-0-2_2020_280

1 Spatial Distribution of Young and Old Stars in Galaxies

Star formation processes of varying intensity take place in all spiral and irregular galaxies. In some galaxies they can be detected by the weak concentration of blue stars, while in other galaxies the star formation process covers a significant part of the galaxy. Violent star formation is often observed in the interacting galaxies, where the regions of blue supergiants stand out brightly.

However, such a spectacular representation of the star formation process applies only to stars of a relatively young age — no more than several tens of millions of years. And how do such star-forming regions look like hundreds of millions of years later? Fig. 1 demonstrates a Hertzsprung–Russell diagram

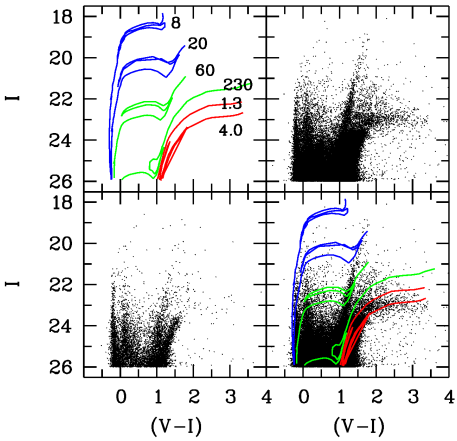


Fig. 1.

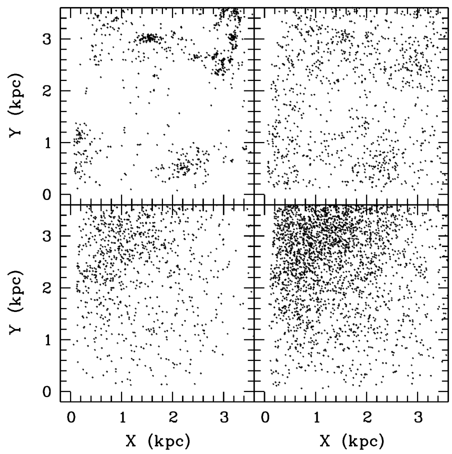


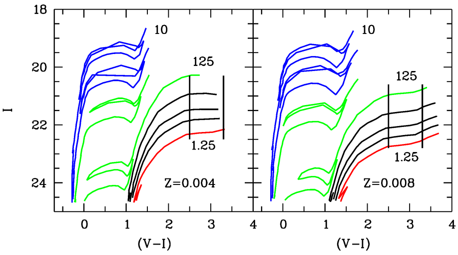
Fig. 2.

that is usually observed in dwarf galaxies, with Bertelli et al. (1994) theoretical isochrones for metallicity $Z = 0.008$. The diagram indicates the age of the isophotes in million years and it can be seen that the massive stars significantly change their position in the Hertzsprung-Russell diagram during their evolution. The agreement between theoretical isochrones and the results of observations is shown in the same diagram (Fig. 1), that shows the results of photometry of the irregular dwarf galaxy Holmberg II, in which the theoretical isochrones are inscribed. Based on these isochrones, one can select stars of different ages on the Hertzsprung-Russell diagram (CM diagram).

Figure 2 demonstrates the location of stars of different ages (less than 10 Myr, from 10 to 100 Myr, from 150 Myr to 1 Gyr, > 1.5 Gyr), which are selected in the CM diagram of Fig. 1. Fig. 2 shows compact regions of very young supergiants, more scattered regions of stars that are tens of million years old, and the absence of any apparent concentration of stars over 100 million years old. Of course, this is to be expected, since stellar complexes are dynamically unstable and the stars are leaving them. That is, if young supergiants are visible in star-forming regions, then older AGB stars have already scattered over considerable distances. Is it possible to get information about the past star formation from them?

2 Luminosity Function and Age of AGB Stars

If a star formation burst has occurred in the galaxy, then an increased number of young supergiants will be observed in this region initially, but after hundreds of millions of years we will not see the concentration of bright stars in this region. However, on the CM diagram of stars in this region, scattered stars of hundreds



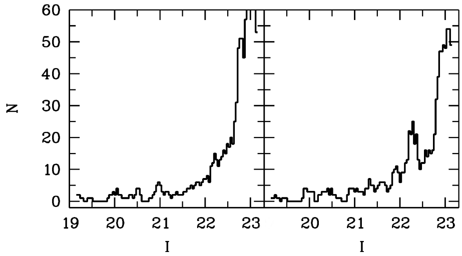
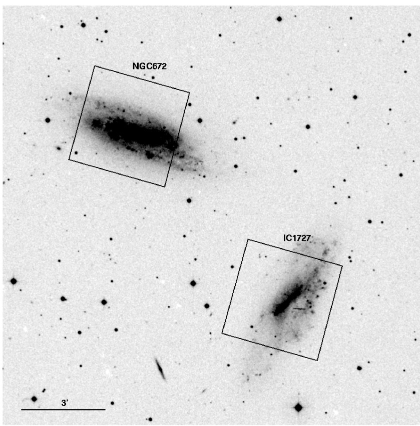


Fig. 3. **Fig. 4.**

of million years old can be determined by their maximum concentration at a certain isochron, which corresponds to the age of the burst of star formation. The maximum will eventually move towards older stars. At the same time, due to the increasingly close location of the isochrones on CM diagram, the contrast of this maximum will decrease and at an age of the order of a billion years it will become hardly noticeable.



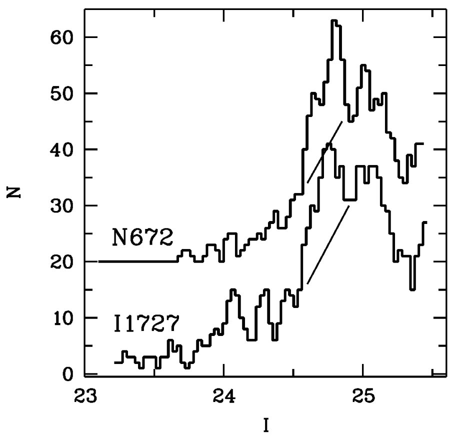


Fig. 5. **Fig. 6.**

Let us consider in further detail Fig. 3, exhibiting Bertelli et al. (1994) theoretical isochrones with the metallicity of stars of $Z = 0.004$ and $Z = 0.008$ and ages from 125 million to 1.25 billion years. If we restrict ourselves to stars in the range of color index $(V - I)$ from 2.5 to 3.3, then we can see that isochrones of this age run parallel to the axis $(V - I)$. This means that the luminosity function for these AGB stars will in fact be a function of age. The fainter the stars, the older they are. Using theoretical isochrones, it is possible to calibrate the resulting luminosity function by the age of the stars. However, as can be seen in Fig. 3, the position of isochrones in the CM diagram depends on their metallicity; therefore, to calibrate the AGB stars by age, we must know their metallicity.

If there are enough AGB stars, then their metallicity is determined by fitting theoretical isochrones into the CM diagram. Otherwise, the metallicity measurements of young red supergiants and old red giants can be used. The metallicity of AGB stars will be between these extremes.

For the Ho II galaxy, Fig. 4 shows the luminosity functions of AGB stars in two regions, one of which is located near the center, and the other at the periphery. The luminosity function of stars in the center has a fairly smooth distribution, while the luminosity function of stars in the periphery shows a peak that corresponds to the age of 650 Myr. Hence, this region contains AGB stars from a long-past burst of star formation.

3 AGB Stars of Interacting Galaxies

Interesting results are obtained for interacting galaxies, since the interaction initiates star formation processes. Fig. 5 shows a snapshot of two interacting galaxies: NGC 672 and IC 1727, and Fig. 6 shows the luminosity functions of AGB stars of these galaxies. Each luminosity function has a local maximum corresponding to a simultaneous burst of star formation in two galaxies in the interval from 450 to 700 million years ago. It is possible that at this time the galaxies were close to each other, which caused an increase in star formation in both galaxies (Tikhonov et al. 2014).

In large spiral galaxies, due to the continuous process of star formation in small regions, it is rather difficult to identify the past burst of star formation. Nevertheless, the selection of AGB stars near the central regions of the galaxy NGC 1672 interacting with NGC 1688 showed an excess of 260 million years old stars (Tikhonov & Galazutdinova 2020).

Acknowledgements. The study was financially supported by the Russian Foundation for Basic Research and the National Science Foundation of Bulgaria as a part of the scientific project N 19–52–18007 and Grant KP–06–Russia–9/2019.

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