Modeling the star formation history in the ring galaxy Arp 10 with the help of spectral indices

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ABSTRACT

We use long-slit spectra obtained with the 6-m telescope BTA (Russian Academy of Sciences) to investigate the history of star formation in the peculiar ring galaxy Arp 10. The radial distributions of quasi-Lick spectral indices are calculated from the observed spectra and are compared with the model spectra, the latter are generated using the Starburst99 population synthesis code. Our model includes an outward propagating density wave which triggers star formation in the gas disk, and an old stellar disk. The metallicity of both old and young stellar populations is a function of radius. We show that a mix of the young and old populations is required to explain the radial distribution of the spectral indices. The density wave propagates outward with a moderate speed (of order 40 km/s), and the metallicities of both young and old populations decrease with the radius. The model indices corresponding to the alpha-elements require somewhat higher metallicities as compared to the Fe-peak elements. We acknowledge partial support from grant RFBR 04-02-16518.

1. Introduction

Previous investigations of several ring galaxies have shown that a considerable part of their stellar population was born at the preset epoch as a result of the density wave passing. Hence, most of the stellar population in such objects emerges within a few, or even one event of star formation. Since the wave triggering the star formation propagates inside out, we can see stars with different ages at different locations. Unlike the regular spiral galaxies where stars of different ages are well mixed, the sites of different ages are separated in space in the ring galaxies. This fact makes collisional ring galaxies an excellent laboratory for study the star formation history and general properties of star formation. In this paper we use two long-slit spectra to constrain models of star formation in a collisional ring galaxy Arp 10.

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2. Model components and parameters

2.1. Propagating Star Formation

1. An old stellar exponential disk lies in the background. Its surface brightness and scalelength are parameters of the model which were obtained from our surface photometry data. The bulge is also taken into account.

2. The young stellar population emerges in the exponential gaseous disk after triggering of star formation by outwardly propagating ring density waves. We consider two waves with different speeds which correspond to the external and internal rings in Arp 10.

3. Metallicity of young population in the external ring is tied to the observed values (see Bransford et al. (1998)), but the radial metallicity gradient is variable in our models. Metallicity of stellar population in the center of the old disk and its gradient are the model parameters.

2.2. Synthetic Spectral Indices

The metallicities, surface densities, and ages of the stellar populations are used to find the corresponding spectral indices by interpolation on a grid of indices.

The grid was computed for a variety of metallicities and ages, and is obtained from synthetic spectra produced with the Starburst 99 population synthesis code (Vazquez & Leitherer 2005). We got high-res spectra (resolution 0.3A) from Starburst 99 and convolved them with the instrumental profile of our observed spectra (resolution 5-8 A). Then the spectral indices were defined exactly as in Worthey (1994) and found for all synthetic spectra (thus we got the quasi-Lick indices).

3. Comparison with Observations

Two long-slit spectra for Arp 10 were taken with the 6-m telescope (Special Astrophysical Observatory, Russian Academy of Sciences) and the Scorpio multi-mode spectrograph (Afanasiev & Moiseev 2005). Spectral indices, as defined by Worthey (1994), and their uncertainties were obtained from the long-slit spectra at different radii. SE and NW parts of the long slit spectra were analyzed separately. We incorporate selected indices to get one common chi-square for them. The Powell optimization algorithm was applied to minimize this chi-square value.

4. Results

1. The models which take into account only one kind of stellar population (either young or old) can not explain the radial distributions of spectral indices.
2. Using spectral indices which correspond to the Fe-peak elements, we got pretty similar best-fit values for the model parameters with both our long-slit spectra, see Fig 3 and 4. The mean values of the wave propagation speed in the region of the outer ring is 35 km/s. The inner ring best-fit speed, 30 km/s, is very close to the above value. It corresponds to the ages of the outer and inner rings of 450 and 100 Myr, respectively.

3. The best-fit central metallicity $[\text{Fe/H}]$ for the old population is -0.3 dex and its gradient is -0.09 dex/kpc. The gradient of metallicity of young population is about -0.05 dex/kpc. In comparison to the SE parts of our long-slit spectra, the NW parts give rather similar best-fit model parameters with a smaller value for the outer ring speed.

4. The results shown above reveal two major recent events of propagating star formation in Arp 10 induced by the passing of a satellite-intruder (the satellite was unambiguously identified in Moiseev et al. (2004)).

This research will be continued with a more realistic physical modeling of Arp 10 (enhancing Vorobyov & Bizyaev (2003)) and with more constrains from studies of gas kinematics and abundances analysis.

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Fig. 1.— Image of Arp 10. Positions of the slits are shown in the figure.
Fig. 2.— Long-slit spectra of the nucleus, inner ring, and outer ring in Arp 10.
Fig. 3.— Radial distribution of best-fit synthetic spectral indices (diamonds and solid curve) for spectra #1. Observed indices are shown by filled squares with the error bars.
Fig. 4.— The same as in Fig. 3 for the spectra #2.