Long-slit and Fabry-Perot spectroscopy of collisional ring galaxy Arp 10

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ABSTRACT

We present results of Fabry-Perot and long-slit spectroscopy of the peculiar galaxy Arp 10. The ionized gas velocity field shows evidence for significant radial motions in both outer and inner galactic rings. Long-slit spectroscopy reveals gradients of age and metallicity of stellar population in agreement with the propagating nature of star formation in the galaxy. We present strong evidence that a small “knot” at 5 arcsec from the center of Arp 10 is its dwarf elliptic satellite, the most probable “intruder” responsible for triggering the expanding rings in Arp 10.

1 Introduction

Arp 10 appeared in the Arp Atlas of Peculiar Galaxies [1] as an RN galaxy, i.e. a galaxy containing a ring structure and a bright nucleus. Further high resolution studies of Arp 10 ([2],[3]) have shown that it actually has two rings (the inner and outer one), nucleus, and extended outer arc. There exist a controversy about the origin of such a complicated structure. According to [3], the system of rings and arcs in Arp 10 is formed by a direct face-on collision with one of Arp 10 companions, in which case Arp 10 represents a classical collisional ring galaxy. In the later paper [4] the same authors argue that Arp 10 is formed as a result of merging of a companion with the disk of Arp 10, in which case Arp 10 is a merging system. The nearby companion was rejected as an intruder candidate and a bright unresolved knot at 5 arcsec from the center of the galaxy was proposed as a possible candidate to the real intruder ([4]). The oxygen abundance of one half of the solar was estimated for a few bright knots in the outer ring ([5]).

2 Observations

We conducted the complex spectral study of Arp 10 with the help of scanning Interferometer Fabry-Perot (IFP) as well as a long-slit spectroscopy. Observations were carried out with the multimode focal reducer SCORPIO ([6]) at 6-m telescope (Special Astrophysical Observatory, Russian Academy of Sciences) in September and November 2003. The main goals of this study are to trace and
to model the propagation of induced wave of star formation through the disk of Arp 10, to estimate the age of the rings and to identify the intruder.

The $H\alpha$ emission map is shown in Fig. 1. Two star forming rings and the outer arc are clearly seen, the latter looks like debris of a spiral arm. It implies that pre-collisional Arp 10 was a large spiral galaxy and it had a non-negligible stellar population which formed spiral arms.

The $H\alpha$ velocity field of Arp 10 was obtained via 7320 seconds integration with IFP in 32 spectral channels. It is shown in Fig. 2. We fit a model velocity field taking into account the regular rotation and projection effects. The radial velocities in the central part of Arp 10 are shifted systematically against all other regions in the galaxy. This feature is most probably caused by systematic vertical motions of the ionized gas around the inner ring. Figure 3 shows the velocity residuals map which reveals the presence of an expanding outer ring. The superimposed isophotes in Fig. 3 show the $H\alpha$ emission which seems to coincide with the highest values of residuals. The expansion velocity of the NW part of the outer ring exceeds $100 \text{ km s}^{-1}$ (in the plane), whereas it attain only $30 \text{ km s}^{-1}$ at the SE part. Therefore, the asymmetric shape of the outer ring may be caused by a systematic difference in the ring expansion velocity.
Figure 2: The velocity field of Arp 10 in $H_\alpha$.

Figure 3: Residuals after subtraction of circular motion from Fig.2.
Three long-slit cuts were made through the nucleus of the galaxy and through the knot (see Fig. 1 for the cut positions). The spectral resolutions were 5 and 11 Å/pixel, and the overall total integration time was 13500 sec. The spectra of nucleus, inner and outer rings are shown in Fig. 4. They reveal a bulk of young stellar population in the rings in contrast to the center of Arp 10, where the old population dominates.

We use the long-slit spectra to determine available Lick indices ([7]). It enables us to estimate the age and metallicity of stellar population along the radius of the galaxy. The filled diamonds in Fig. 5 show the measured indices \(\text{Mg}1\), \(\text{Mg}2\), and \(\text{Fe}4531\) at different galactocentric distances. The theoretical indices as predicted by the single burst models (based on [8]) are plotted in Fig. 5 by curves. The solid, dotted, and dashed curves are obtained for a single-population model with \([\text{Fe/H}] = 0, -1,\) and \(-1.7\), respectively. The filled squares in each curve correspond to a 10, 5, 3, 1, 0.9, 0.8, 0.7, 0.6, 0.5 and 0.4 Gyr old stellar population (from left to right). The x-axis spacing of the model curves is an arbitrary linear function of the model age. It is seen that the nucleus of Arp 10 consists of mostly old and abundant stellar population. Given the metallicity in the outer ring is rather high (1/2 of solar according to [5]), one can argue that the stellar population is getting systematically younger toward the edge of the galaxy, and that its age changes smoothly with the radius. It supports the propagating nature of star formation in Arp 10. Since the old population is non-negligible in the inner parts of Arp 10, a more complex modeling is required to estimate the age of young population there.

The spectrum of the bright knot located at 5′′ from the galactic center is shown in Fig. 6. It provides evidence that the knot is not a bright projected star, but a dwarf elliptic galaxy located nearby Arp 10. Its radial velocity is 350 km s\(^{-1}\) higher than that of the main galaxy. The line-of-sight velocity dispersion is of the order of 100 km s\(^{-1}\). It is comparable with 160 km s\(^{-1}\) dispersion inferred for the center of Arp 10. If the dwarf satellite is gravitationally bound, its mass should be roughly 10% of that of Arp 10. Alternatively, and more...
Figure 5: Lick indexes $Mg_1$, $Mg_2$ and $Fe_{4531}$ at different distances from the center of Arp 10 (solid squares). The curves correspond to distribution of the index for the model single-burst populations of the ages 10, 5, 3, 1, 0.9, 0.8, 0.7, 0.6, 0.5 and 0.4 Gyr and metallicities $[Fe/H]=0$ (solid), -1 (dotted) and -1.7 (dashed). The open diamond designates the intruder (see below).

Figure 6: Spectrum of the bright knot, the proposed intruder. Hydrogen absorption lines indicate the presence of significant fraction of A-stars which reveal a few $10^8$ yrs old population.
probably, the satellite has almost been completely destroyed and absorbed. The Balmer absorption lines (H\(\beta\), H\(\gamma\), H\(\delta\)) are well seen in the spectra what reveals the presence of significant population of A-stars. Hence, the satellite experienced an episode of star formation a few hundred million years ago, which corresponds to the expected time passed since the collision.

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