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MECHANISMS FOR FORMING THE INHOMOGENEOUS STRUCTURE OF PLANETARY NEBULAE

Abstract. The inhomogeneous distribution of gas in planetary nebulae manifests in the form of numerous jets, globules and filaments. Details of the heterogeneous structure are found not only in extended, sufficiently evolved objects, but also in young compact objects which dynamic age does not exceed 1000 years. The problem of the formation of heterogeneity in the early stages of the planetary nebulae evolution is relevant recent years. The interaction of the hot fast wind of the central star with the substance ejected at the stage of the "red" giant under the influence of a slow but powerful wind, is considered as a possible mechanism. In this case, the formation of jets and globules occurs under the shock waves that accompany the stellar wind.

The central sources in some planetary nebulae are binary stellar systems. The processes of mass exchange between stellar components can also lead to the formation of an inhomogeneous shell structure.

In this paper, we consider the results of modern methods for studying planetary nebulae, including observations on space telescopes, which allow to evaluate the reality and effectiveness of the proposed mechanisms for the formation of heterogeneous structures.

Key words: planetary nebulae, mechanisms of forming the inhomogeneous structures.

Introduction The inhomogeneous structure of planetary nebulae is the subject of study by theorists and experimenters. It was assumed that polar jets, large-scale globules and bipolar structures are formed by the interaction of the residual stellar wind of the red giant and the hot wind of the central star. However, the study of a large group of young objects, shows that envelopes with a dynamic age <2000 years already exhibit a complete set of inhomogeneities found in large nebulae [1]. Thus, it turns out that inhomogeneities are formed at even earlier stages of the evolution of planetary nebulae, at a low central star temperature and before the appearance of a fast stellar wind.

Recent years, the search and analysis of inhomogeneities in the structure of young planetary nebulae have become a favorite topic of many researchers [2-8]. An assumption was made about the role of the accretion disk as a source of bipolar emissions [4,5]. Modern observations of planetary nebulae on space telescopes, obtained with high resolution, give new information for the creation of new models describing the formation and evolution of these objects.

In 1983 San Kwok [6] proposed a model of interacting winds to explain the structure of planetary nebulae. According to the model, the hot high-velocity wind of the central star interacts with matter ejected at the "red" giant stage. As a result, the outer boundary of the shell is formed. The details of the inhomogeneity in the distribution of gas in the nebula, namely jets, globules, possibly arise due to shock waves, which in turn are the source of radiation in the X-ray region.

In some cases, the inhomogeneous structure of the nebula is formed due to the mass exchange processes between the components of the binary stellar system in the center of the nebula. By now, nebulae with double central sources are 12-15% of their total number.

Zones of low ionization are found in images of many planetary nebulae. The gas in these zones has the same electronic temperature as the neighboring regions, but a low electron density. Modern methods of observation show that shock ionization "works" in the low-excitation zones, while the main envelope is ionized by ultraviolet quanta of the central source.

The results of modern observations on space telescopes

Photometric and spectral observations in the far infrared and submillimetric spectral ranges were carried out on the Herschel space telescope. Images of 18 planetary nebulae and a spectrogram of all the stars evolving from the Asymptotic branch of the red giants to the stage of planetary nebulae were obtained [10]. The obtained data allow, among other things, to assess the physical state and chemical composition of matter in the vicinity of the studied objects.

Images obtained with high resolution on the Hubble telescope have great importance for the study of the structure of nebulae. Thus, observations of ten compact planetary nebulae, which were carried out on this telescope, allow to discover for the first time numerous fine details of an inhomogeneous structure: arcs, two-dimensional rings, tori and halo [11]. Obtained data lead to the suggestion that such heterogeneous structures are inherent in most planetary nebulae and are formed in the early stages of evolution. Assuming that the cause of the formation of inhomogeneities can be the interaction of the early wind of the red giant and the later wind of the central star, the authors note that there must be several stages of fast stellar wind, different in duration and in direction. Such assumption is useful for explanation of the observed age difference between structural details within a single shell [12, 13].

So-called "hot bubbles" - central cavities filled with hot gas, are observed in many planetary nebulae [14]. They are formed under the action of a fast shock heated stellar wind. The stellar wind pushes out the substance thrown out at the stage of the red giant. Such zones should be "visible" in the X-ray range. Indeed, observations of the NGC 3234 nebula, performed on the XMM-Newton telescope, recorded soft diffuse X-Ray radiation with a temperature of 2.35×10^6 K and a luminosity of $2 \cdot 10^{30}$ erg / sec (for D = 0.55 kpc), which is formed in a hot bubble. An analysis of the chemical composition of plasma - the source of diffuse X-ray in different nebulae indicates that it is actually created by a hot stellar wind, but traces of the residual gas of the cold envelope are still present. Perhaps, these are dense features formed in collimating flows or filaments, formed during additional ejection of gaseous fragments from the central star. Hard X-ray radiation coming from the central star, can be created by coronal emission from the invisible component of a binary star or by a shock wave arising in a fast stellar wind.

A fairly rare event in the evolution of planetary nebulae - a repeated ejection of the envelope, is recorded in two objects. The old, highly evolved nebula A30 became famous after a dense shell of a new generation, practically devoid of hydrogen, was discovered near its central star [15]. Estimates of its dynamic age: 850 ± 200 years are obtained from a change in the angular size, the known velocity of expansion, and distance [16]. The complex structure of this new envelope is clearly visible on the images obtained with the Hubble telescope. Numerous jets indicate the movement of gas fragments from the center to the periphery. The X-ray radiation of an object can be divided into two components: a point source in the central star direction and an extended source corresponding to the position of the new envelope. The interaction of the modern stellar wind with the material of the secondary shell leads to shock heating of the plasma, which becomes the source of diffuse X-ray radiation. The origin of the X-ray radiation from the central star is still unclear.

Low - ionization zones in the form of globules are observed on the images of many planetary nebulae, including those obtained on the Hubble telescope. Studies have shown that the gas in these zones has the same electronic temperature as the neighboring regions, but a low electron density. Modern methods of observation made it possible to establish that the shock ionization mechanism "works" in the low-excitation zones, while the main envelope is ionized by ultraviolet quanta from a central source [17].

An analysis of the latest data obtained for the central stars of planetary nebulae in different spectral ranges, was carried out in [18]. Studies show that about 12-15% of the central stars, (according to some estimates, up to 30%), are binary systems. The orbital periods for these close binary systems are generally less than one day. A correlation between the central source binarity (the position of the orbital plane) and the spatial orientation of the envelope is traced. The interaction between the components of the central stellar system can lead to formation of bipolar shapes, as well as to the appearance of additional structural inhomogeneities.

Conclusions

The problem of the heterogeneous structure of planetary nebulae, even in the early stages of evolution, is very urgent and requires its solution. The corresponding mechanisms responsible for the