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THE GALACTIC DISTRIBUTION OF WOLF-RAYET STARS

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The results of the investigation of the Galaxy distribution of Wolf-Rayet stars have been presented. This investigation is important for the understanding of the evolutionary properties WR stars. It is known that in the formation of these stars, the main factor is the mass loss rate. Massive O star by losing a significant amount of mass transforms into WR star. On the other hand, the mass loss rate depends on metallicity. It is known that metallicity in our Galaxy decreases from the center to the outer parts. Therefore, by investigating the galaxy distribution of WR stars we could clarify the role of metallicity in the formation of these stars. WR stars separate into WN, WC, and WO subtypes. We could also clarify the evolutionary relations between different subtypes. By using the correct values of distances we plotted the galactic distribution of WR stars. Although the Galactic distribution of these stars has also been carried out before, it is important to perform new research. Because every year new stars are discovered and the distances to these stars are already determined correctly than used in earlier researches.

Keywords: Wolf-Rayet stars – Milky Way Galaxy – metallicity – O type stars

1. INTRODUCTION

In this paper, we investigate the galactic distribution of Population I Wolf-Rayet (WR) type stars. Though Population I WR type stars were discovered more than two hundred years ago, many features of these stars are still difficult to explain [1]. These stars are massive young stars at the final stages of their evolution and located in OB associations and galaxy clusters. There are also Population II WR stars, which have spectra with the spectrum like Population I WR stars [2].

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These are less massive and luminous central stars of planetary nebulae [2]. The observational properties of Population I WR stars are comprehensively discussed in [1, 3–6].

Population I WR stars is located in the spiral arms of our Galaxy. It is known that the massive star should lose a significant amount of mass to become WR star. On the other hand, the mass loss rate depends on metallicity [7] and the metallicity in our Galaxy decreases from the center to the outer parts [8]. For the understanding role of metallicity in the formation of WR phenomena it is reasonable investigation of the galactic distribution of WR stars.

In [9–11] empirically determined the relation between the mass loss rate of early-type massive stars as a result of radiation pressure on spectral lines. The empirical dependence of the mass loss in stellar winds on the metal content of their atmospheres is studied. Assuming a power-law dependence of mass loss on metal content, authors of [9, 10] found the following mass loss vs. metallicity relation: $\dot{M} \propto Z^{0.83\pm0.16}$

The distribution of the WR stars in our Galaxy for the first time was performed in [12]. At that time were known only 123 galactic WR stars and distances were not known. Because in [12] the galactic distribution was studied by using only galactic coordinates. The main result of this investigation was revealing the absence of WR stars between $137° - 222°$ [12] galactic longitudes. In [13] by using the calculated distances for individual stars the first time plotted the spatial distribution of WR stars in our Galaxy. In subsequent years, this problem was studied in [14–16]. Discovering the new WR stars [17, 18] and more correctly determining of heliocentric distances of these stars makes it reasonable to perform the new investigation of galactic distribution of these stars.

2. DETERMINATION OF GALACTOCENTRIC DISTANCES

For the determination of galactocentric distance i.e. distances from the center of the Galaxy of WR stars, we used the heliocentric distances i.e. distances of stars from the Sun. Heliocentric distances can be easily converted to galactocentric distances by subtracting the heliocentric space vector of the Galactic center, R_0, from the heliocentric space vector of the object under study R. The distance of the star from the Galactic center (R) is determined by using the following formula [23]:

$$R = \sqrt{[d\cos(b)\cos(l) - R_0]^2 + d^2\cos^2(b)\sin^2(l) + d^2\sin^2(b)} \qquad (1)$$

where R_0 is the distance of the Sun from the Galactic center, 1 , b, and d the Galactic longitude, Galactic latitude, and heliocentric distance respectively of the star. The value of the distance of the Sun from the Galactic center (R_0) is adopted as 8.23 kpc [19]. Note that for the stars located inside or outside of the Solar circle in Galaxy, we could calculate galactocentric coordinates by using this formula.

3. THE RADIAL DISTRIBUTION OF WR STARS

By using heliocentric distances, we plotted the radial (l, d) distribution of WR stars (Fig.1). It is known that WR type stars separate into three subtypes, WN, WC, and WO. We plotted the histogram of radial distribution of Galactic WR stars in three regions: 0-5 kpc, 5-10 kpc, and 10-15 kpc from the Galactic center (Fig.2).

Fig.1 shows the distribution of stars along the spiral arms of our galaxy. For the revealing distribution of WR stars along the spiral arms the picture of our galaxy taken from [24] superimposed with the Fig.1. It is known that since the 1950s, astronomers have known that our galaxy has a spiral structure [20]. The main parts of our galaxy are a nucleus (massive black hole), a central bulge, a disk, spiral arms, a spherical component, and a halo. Gaia mission of the European Space Agency has been mapping our galaxy since 2014, by using the results of measurements of the precise positions and distances from Earth of approximately two billion stars [21]. Due to Gaia satellite star mapping the spiral structure of our galaxy is revealed more distinctively. It is known that the spiral arms emanate from the galactic center and wind through the galactic disc. The spiral arms are actively star formation regions, where located young stars, interstellar dust, and gas. Stars are born from clouds of molecular gas and shine for billions of years in spiral arms. The exact number of arms, and their shapes, are difficult to determine because we are located within our Galaxy. Interstellar dust and gas are primary matters for the formation of new stars.

According to the modern view, there are four main spiral arms (the Norma and Cygnus, Sagittarius, Scutum-Crux, and Perseus) and the number of fragments of arms. Our Sun lies near a small, partial arm called the Orion Arm, or Orion Spur, located between the Sagittarius and Perseus arms. The Sun is located at a distance of 8.23 kpc from the center of the Galaxy [19].

The stars of our galaxy divided into two populations: Population I and Population II. Population I stars are found only in the disk and move in nearly circular orbits around the galactic center. Examples are bright supergiant stars, main-sequence stars of high luminosity (spectral classes *O* and B), which are concentrated in the spiral arms, and members of young open star clusters. Interstellar matter and molecular clouds are found in the same places as Population I stars.

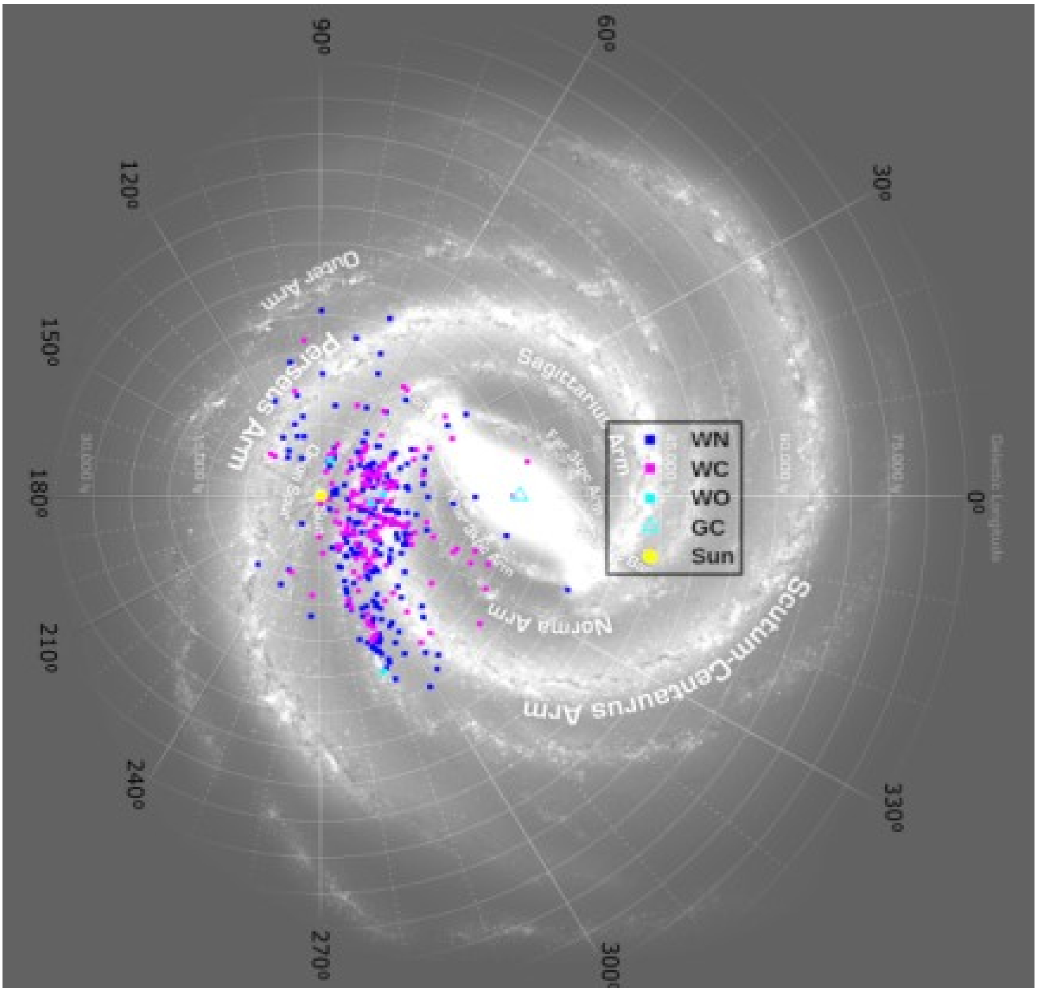

Fig. 1. The radial (l, d) Galactic distribution of WR stars. The distance of Sun from the Galaxy center adopted as 8.23 kpc. There are 76 WR stars at the Galactic Center.

Population II stars show no correlation with the location of the spiral arms. These objects are found throughout the Galaxy. Some are in the disk, but many others move in elliptical orbits because they are at high distances from the galactic disk. Examples are central stars of planetary nebulae and RR Lyr type variable stars. The stars in globular clusters, found almost entirely in the Galaxy's halo, are also classified as population II. These stars are the old metal-poor stars that form mainly the halo of the galaxy.

Population I stars are younger and metal-rich stars. They form the disk of the galaxy. The WR type stars are Population I stars. As seen from Fig.1 these

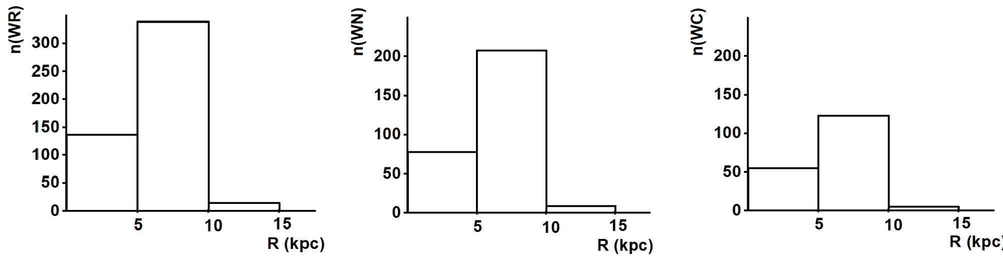

Fig. 2. The histogram of radial distribution of Galactic WR (left), WN(middle) and WC (right) stars.

stars are located mainly in Sagittarius, Scutum-Crux Arm. In this region, there are both WN and WC subtypes. But as seen from Fig.1 WN stars are more in the outer part and WC stars in the inner part of the galaxy. In Perseus Arm also there are a few WR type stars and these stars are mainly WN stars. At the galactic center, there are 76 WR stars (39 WN, 34 WC).

We studied the galactic distribution of WR stars also by plotting the histogram of radial distribution of Galactic WR, WN, and WC stars (Fig.2). As seen from Fig.2 WR, WN, and WC stars are located mainly at distances 5-10 kpc from the galactic center.

4. DISTRIBUTION OF WR STARS PERPENDICULAR TO THE GALACTIC PLANE

Fig. 3 shows the height above the Galactic plane (z) versus the galactic longitude (l), i.e. the (l, z) distribution of WR, WN, and WC stars. According to the results of the theoretical investigation, the WR stars located above ±250 pc from the galactic plane are considered a candidate for the "runaway" stars [5, 6]. Location of these stars at high distances from the galactic plane explained with the kick velocity obtained by the binary system during the supernova explosion. These stars are considered as WR stars with compact components (WR + C). The letter C marks the compact component (neutron star or black hole). However, further studies did not confirm that these stars could be WR + C systems [5, 6]. The high distance above the galactic plane and the high spatial velocity of these stars can be explained by the ejection of these stars from massive star clusters due to the action of collective interactions [22].

As seen from Fig.3 the WR stars are confined mainly to the strip ±250 pc around the galactic plane and some WR stars are located at the distances $z > \pm 250$ pc from the galactic plane. By comparison of the l, z distribution for WC and WN stars we could conclude that more WN stars at the distances

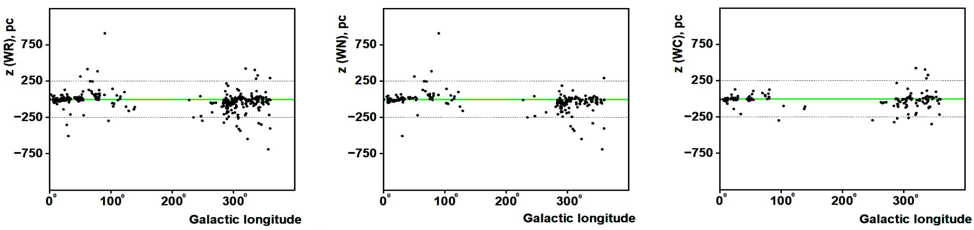

Fig. 3. The height above the Galactic plane (z) as function of the galactic longitude, for WR (left), WN(middle) and WC(right) stars. The stars confined to the strip ± 250 pc separated.

$z > \pm 250$ pc from the galactic plane than WC stars (Fig.3). We also could conclude the absence of WR stars at the galactic longitudes approximately $140° - 230°$ (Fig.3).

5. CONCLUSIONS

The main results of this investigation are:

1. WR stars located mainly in Sagittarius and Scutum-Crux Arms of the Galaxy;
2. In contrast to WN stars, the WC stars dominate the inner part of the Galaxy;
3. In the Perseus arm also there are few WR stars, but they are mainly WN subtype stars;
4. WR stars are mainly located at distances 5-10 kpc from the galactic center;
5. Some WR stars are located at the distances $z > \pm 250$ pc from the galactic plane, and among these stars WN type WR stars are dominant;
6. In the $\sim 140° - 230°$ galactic longitudes, the WR stars have not been found.

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