Very Massive Stars and Intermediate Mass Black Holes

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Abstract. According to the archival data on two large telescopes VLT and SALT in the southern galaxy NGC 5408, we have discovered two very bright sources with unusual observational manifestations. The first object is a candidate for intermediate mass black holes (IMBHs). Its bolometric luminosity is approximately $\sim 2 \times 10^{41}$ erg s^{-1}, the X-ray luminosity in the bright state of the object reaches $\sim 6 \times 10^{37}$ erg s^{-1}. We have estimated the IMBH mass to be about 200-400 solar masses. The second object is not visible in the X-ray range, and its observational characteristics are in good agreement with the concept of very massive stars (VMS). Its bolometric luminosity is about 100 millions that of the sun. Two more VMS candidates in the galaxies NGC 1068, M 74 and NGC 2403 have been discovered as a result of the observational program carried out at the BTA telescope.

Keywords: X-rays: general, stars: massive; stars: black holes

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One of the fundamental problems of modern astrophysics is the question of whether there is an upper limit on the mass of a star. The answer to this question can only be obtained from observations of massive and very massive stars, which we are going to do in our project. Ultraluminous X-ray sources (Fabrika et al. 2015), young star clusters, LBV objects, massive stars and intermediate mass black holes.

Modern models of stellar evolution suggest that stars up to 1000 solar masses may exist. The star is located in the galaxy LMC R136a1 ≈ 180 M$_{\odot}$ (Crowther et al. 2010). Stars with masses of more than 180 solar masses have not yet been discovered. Understanding the nature of objects such as very massive stars and bright blue variables, in particular the determination of their fundamental parameters, will provide an opportunity to test the existing evolutionary theories. In our project, we set the task of discovering and researching such stars.

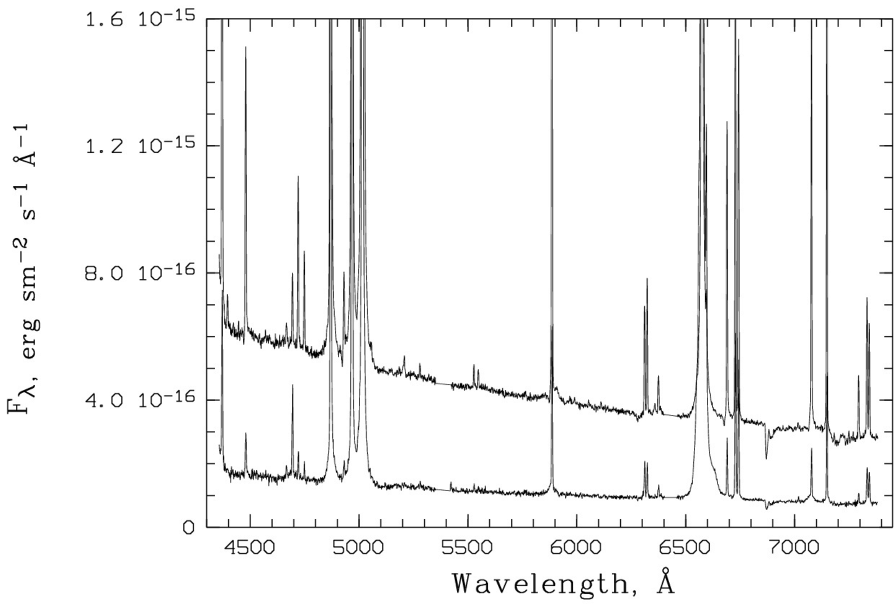

Fig. 1. In the southern galaxy NGC 5408 there are 2 objects: in the upper image VMS, on the lower IMBH. Very bright narrow as well as wide lines He II $\lambda4685$ (broad line), Hβ $\lambda4861$, Hα $\lambda6563$, He I ($\lambda4471, 5876, 6678, 7065$) are visible. Narrow lines [Fe III] $\lambda4658$, [O III] ($\lambda4958, 5006$), [Ar IV] $\lambda4740$, [N I] $\lambda5199$, [N II] $\lambda5754$, [Cl III] ($\lambda5517, 5537$), [O I] ($\lambda6300, 6363$), [S III] $\lambda6312$, [S II] ($\lambda6716, 6730$), [Ar III] $\lambda7751$ and [O II] ($\lambda7719, 7730$) are also formed in the spectrum.

With a decrease in metallicity from three to ten times, there will be a carbon-oxygen core with the appearance of pair instability (PISN), while the Supernova is completely destroyed without a trace. With this metallicity, the destruction of PISN will be from 160 to 260 solar masses. At a lower metallicity, pair pulsating instabilities (PPISN) will already form; these stars form with masses of 60 to 110 solar masses. With huge pulsations, they can dramatically decrease their masses. In the case of more than 150 solar masses, even with pulsations, the same destruction of PISN occurs with a complete scattering of matter (Spera &

Mapelli 2017). For masses over 260 solar masses with metallicities less than 0.1 z, an intermediate-mass black hole (IMBH) is formed through direct collapse.

The spectra obtained with two large telescopes at the SALT and VLT observatories are presented (Fig. 1). Young massive stars, as a rule, are hidden by noticeable dust absorption, in particular, in the object we discovered in the southern galaxy NGC 5408: we observe VMS, as well as IMBH in the supercritical accretion regime.

For the first object VMS, the bolometric luminosity is approximately 100 million solar luminosities. Not observed in the X-ray range, this is consistent with the concept of very massive stars. The bolometric luminosity of the lower object is about $\sim 2 \times 10^{41}$ erg s^{-1}. In the X-ray range, the luminosity reaches $\approx 6 \times 10^{37}$ erg s^{-1} and decreases several times in a few days. We find an estimate of the IMBH mass of about 200-400 solar masses.

The main criterion was selection based on HST images in the Hα line and in the wide filter. The candidate must be point like in wide filters and Hα line. Formal machine selection was not allowed, since we are talking about no more than about a hundred galaxies. The selected objects are located in star-forming galaxies and represent stellar sources in the HST images, brighter than V = 22 ($M_V \lesssim -8$ in galaxies D<10 Mpc), they are also bright Hα sources. All of our candidates have very bright emission lines.

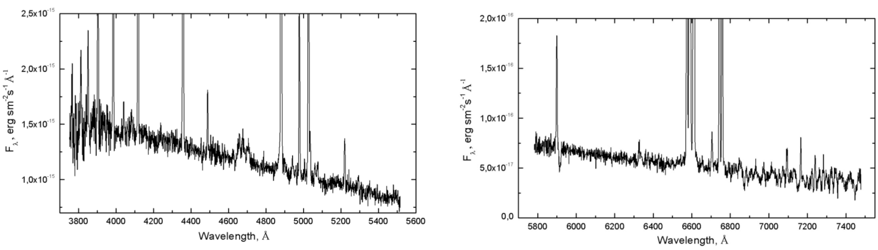

Fig. 2. The BTA telescope in galaxy NGC 1068 may have discovered a VMS object in a young cluster. There are broad lines He II, Bowen blends: N III (λ4634, 4640, 4641), C III (λ4647, 4650, 4651) and H8-Hα, He I.

Three objects were discovered with the BTA telescope. The first object is located in the galaxy NGC 1068 (Fig. 2) in the young cluster VMS, there are quite powerful emission lines with broad components He II, on the left side of the blend N III/C III. On the left wing, broad lines Hβ and Hα are formed, lines He I are also observed, in the region He I $\lambda 5876$, two absorption lines Na I $\lambda 5889, 5895$.

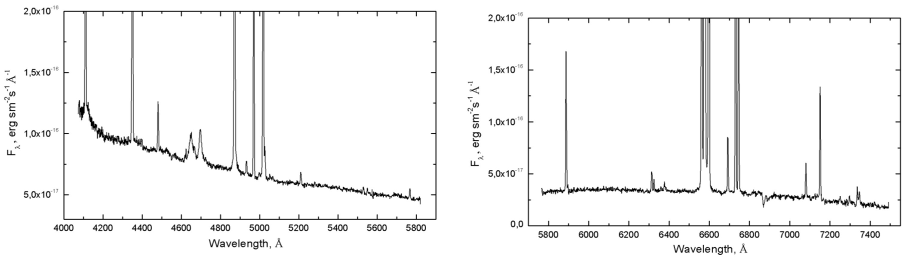

Fig. 3. The BTA telescope in the M 74 galaxy has found a VMS star with a very powerful He II line, and a number of N III/C III (Bowen blends). Also, powerful radiation Hγ, Hβ, Hα, He I is formed.

In another galaxy M 74/NGC 628, VMS was found with powerful emission lines Hγ, Hβ, Hα, He II, N III/C III, as well as the lines He I. There are narrow and very bright lines [O III] ($\lambda 4958, 5006$), [N II] ($\lambda 6548, 6583$), [S II] ($\lambda 6716, 6730$).

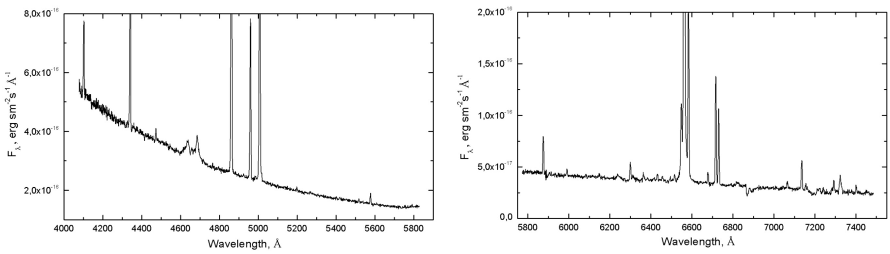

Fig. 4. In the galaxy NGC 2403 with a distance of about 3.4 Mpc, a young cluster with an age of less than 3 million years is forming, as well as, possibly, a very massive star VMS.

In the next galaxy NGC 2403, an object was discovered in a young WR cluster, possibly a very massive VMS star. Lines He II, N III/C III, broad lines Hγ, Hβ, Hα, He I are formed in a massive star; as well as narrow lines. There are very bright narrow lines [O III], [N II], [S II]. The star's temperature is approximately $T \sim 30 - 40\,\mathrm{kK}$.

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