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On the kinematic state of the atmosphere within IRAS 07430+1115 system

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Abstract. Having obtained high-resolution optical spectra with the NES spectrograph of the 6-m telescope BTA, we investigated the variability of the spectral features and radial velocity for a cold star which passed the asymptotic branch of giants and is associated with the IRAS 07430+1115 source. The optical spectrum of this post-AGB star with altered chemical composition is purely absorbtional, emissions and other peculiarities are absent in the spectrum. From the measurements of the positions of many metal absorbtions (mainly ions of heavy *s*-process metals) a weak variability of the radial velocity was revealed. The velocity varies with the average value $V_r = 37.0$ km/s and the standard deviation $\Delta V_r \approx 0.8$ km/s, which may be a consequence of low-amplitude pulsations in the atmosphere of a far evolved star. The position of the Hα line core varies within 40.5–43.8 km/s. Based on measurements of the positions of the rotational components of the (0;0), (1;0) and (2;0) Swan bands of the molecule C_2 origin in the circumstellar envelope, the average radial velocity $V_r(\text{Swan}) = 21$ km/s and the expansion velocity typical for post-AGB stars envelope $V_{\text{exp}} \approx 16$ km/s are determinated. Using the intensity of the infrared triplet of oxygen, we estimated the luminosity of the central star of the IRAS 07430 system $\log L/L_\odot \approx 3.1$ which is within the range of values for post-AGB stars.

Keywords: stars: AGB and post-AGB, oscillations (including pulsations), atmospheres

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1 Introduction

Interest in AGB stars and their closest descendants—post-AGB stars is due to their influence on the evolution of the chemical composition of galaxies, since in the depths of these stars, physical conditions arise for the synthesis of heavy metals nuclei, their subsequent dredge-up into the stellar atmosphere and subsequently into the envelope and interstellar medium. As a result of these processes, AGB stars are the main circumstellar suppliers of all elements heavier than iron synthesized through slow neutronization of nuclei (see for details Herwig 2005). The 6-m telescope of the BTA performs detailed spectroscopy of a sample of stars with initial masses in the range of about 2–8 $M_{\odot}$ that passed evolutionary stages with nucleosynthesis, mixing, as well as the episodes with mass loss due to the stellar wind at different rates. Spectral data analysis aims to determine the fundamental parameters and features of the chemical composition of stellar atmospheres of the stars, as well as to search for variability of specific spectral details and patterns of radial velocities. Numerous results obtained by us, during spectroscopy and spectral monitoring, are summarized in the review Klochkova (2019). Our spectroscopy program also includes a pair of related G-supergiants in IR systems IRAS Z02229+6208 (hereinafter named as IRAS Z02229) and IRAS 07430+1115 (IRAS 07430). Reddy et al. (1999) analyzed the data from the echelle high-resolution spectra and published the parameters of this pair of stars and features of the chemical composition of their atmospheres. As a result, the Reddy et al. (1999) came to the conclusion that the metallicity of the stellar atmosphere is reduced: $[\mathrm{Fe/H}]_{\odot} = -0.5$ at large excesses of carbon $[\mathrm{C/Fe}]_{\odot} = +0.8$ and *s*-process heavy metals $[\mathrm{s/Fe}]_{\odot} = +1.4$. Details of the chemical composition indicate that both stars passed the evolutionary stage of AGB and the episode of the third mixing. This study confirmed the related nature of two stars with large IR flux excesses.

Stars with large IR flux excesses are weak in the visible range due to the significant circumstellar extinction. For a long time there was no repeated registration of an optical spectrum of IRAS 07430. Carrying out spectral monitoring is hampered by its weak visible brightness ($V = 12\overset{\mathrm{m}}{.}8$, Hrivnak et al. 2022). In this article, we present the results of the analysis of several optical spectra of IRAS 07430 obtained at the 6-m telescope BTA on arbitrary dates in 2018–2024 to search for possible profile variability of spectral details and temporal behavior of radial velocity patterns in the atmosphere and circumstellar envelope of the star.

2 Observations, results and their discussion

Spectra of IRAS 07430 were obtained with the echelle spectrograph NES (Panchuk et al. 2017), located stationary at the Nasmyth focus of the 6-m telescope. Obser-

Table 1. Results of measurements of heliocentric radial velocity V_r in the IRAS 07430 system, the number of features used are indicated in parenthesis.

Date	V_r, km/s		
	Absorptions	Hα (core)	Swan
19–23.12.1996*	35 ± 1		22 ± 1 (23), 24 ± 1 (12)
06.04.2018	36.6 ± 0.14 (268)	40.5	21.4 ± 0.6 (11)
11.04.2018	36.2 ± 0.12 (380)	41.2	20.2 ± 0.3 (28)
07.12.2019	37.7 ± 0.16 (488)	43.8	20.0 ± 0.2 (28)
27.03.2024	39.2 ± 0.14 (194)	42.3	20.7 ± 0.2 (55)

* — average V_r value for 1996 is based on data from the article Reddy et al. (1999).

vation dates are indicated in Table 1. The recorded spectral range on our spectra is $\Delta\lambda = 470$–778 nm. Identification of details in the spectrum was carried out using the spectral atlas (Klochkova et al. 2007).

The study of variability in the spectra of IRAS 07430 is complicated because of several factors. Firstly, the visible brightness of this star is the limit for high-resolution spectroscopy. But we must reach the signal-to-noise ratio needed, in particular, to identify numerous narrow rotational details of Swan bands (see Fig. 1). Secondly, a high degree of blending caused by the saturation of the spectrum with strong ions absorbtions, the equivalent widths of which are often comparable to or exceed the intensity of Hα. Fragments of the spectrum in Fig. 1 illustrate the fact of the profusion of strong absorbtions. A separate problem is the lack of reliable radiospectroscopy data, which provides the real systemic velocity for stars with envelopes.

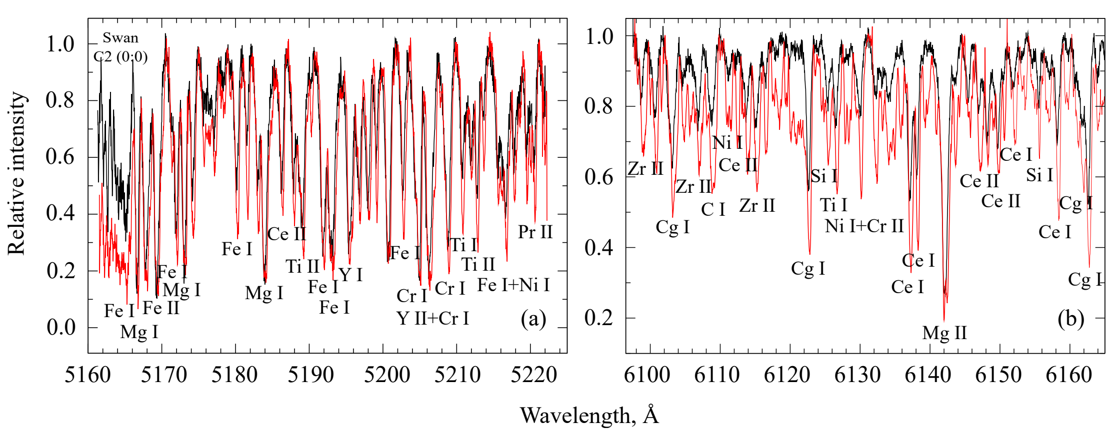

Fig. 1. Fragments of the IRAS 07430 spectrum obtained on 2019.07.12.

The most important milestone in the study of post-AGB stars is the availability of the results from the Gaia mission and the catalog Gaia DR3. Reliable parallaxes of stars provide the determination of distances, luminosity, initial and current masses of stars. The main parameters obtained this way, combined with the detailed chemical composition of atmospheres of evolved stars, provide refinement of the evolution stage and restoration of their history of changes in chemical composition. Modeling based on Gaia DR3 data of parameters for an extensive sample of post-AGB stars was performed by Kamath et al. (2022). In the framework of our work, we are especially interested in the results of this article about the status of the star associated with IR source IRAS 07430, for which extremely low luminosity $L = 20\,L_{\odot}$ is determined by Kamath et al. (2022). At same time, the luminosity of a related star in the system IRAS Z02229 is many times higher: $L = 12\,959\,L_{\odot}$ (Kamath et al. 2022). With a large difference in luminosity estimations, both stars have close equivalent widths of the oxygen triplet O I λ7774, which serves as a reliable criterion for the luminosity value M_V for F–G supergiants. In the spectra of IRAS Z02229 and IRAS 07430 W_{λ}(O I λ7774)= 0.99 Å and 0.91 Å respectively. Using the dependence M_V–W_{λ}(O I) from the paper Kovtyukh et al. (2012), we obtained for IRAS 07430 the absolute value $M_V \approx -3^{\rm m}$ and luminosity $\log L/L_{\odot} \approx 3.1$, which is within the range of values for post-AGB stars.

As follows from the data in the third column of Table 1, the position of the Hα core varies within a small interval 40.5–43.8 km/s. Weak asymmetry of its profile is noticeable on some observation nights. The reason may be a weak wind, due to which the blue wing of this line is changed. However, this fact requires new observations with a high S/N ratio.

For the well-studied post-AGB star HD 56126, there is a difference in V_r, measured from absorbtions of different degrees of excitation, formed at different depths in the atmosphere. However, we did not find a similar dependence in the spectrum of IRAS 07430. The independence of V_r(abs) from line depth indicates the absence of velocity stratification in the atmosphere of IRAS 07430.

In each of our spectra, we measured the radial velocities V_r from the positions of photospheric absorbtions, rotational details of Swan molecular bands, circumstellar details of Na I and K I. Average heliocentric velocity of the central star of the source IRAS 07430 for five dates in Table 1 is equal to V_r(abs) = 37.0 km/s with standard deviation of $\Delta V_r = 0.8$ km/s. For the star in the IRAS Z02229 system the velocity of variability is higher: $\Delta V_r \approx 1.4$ km/s (Klochkova & Panchuk 2022). Based on the measurements of the position of the rotational components of the (0;0), (1;0) and (2;0) Swan bands molecules C_2, we obtained the average values of V_r(Swan) for each date, which are given in the fourth column of Table 1 and close to the results of Reddy

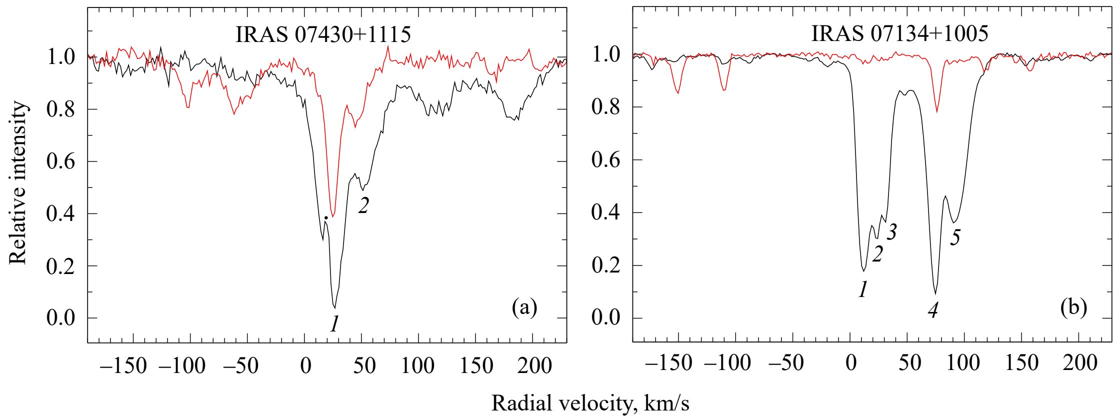

Fig. 2. Profiles of the D-line Na I λ5890 (black line) and K I λ7699 (red line) in the spectrum of IRAS 07430 (a). The dot indicates the position of the telluric emission. On the panel (b) there is the absorbtion profile of Na I λ5890 in the pos-AGB spectrum of the star HD 56126.

et al. (1999). Generally, based on the details formed in the circumstellar envelope, we obtained the average velocity V_r(Swan) = 21 km/s and the envelope expansion velocity $V_{\rm exp} \approx 16$ km/s. This velocity expansion is typical for post-AGB stars. Note, that in the visible wavelength range we did not detect emission components of the Swan bands Reddy et al. (1999) write about. The effect of splitting of strong absorbtions with low excitation potentials (Ba II, La II, Ce II, etc.) was not found for IRAS 07430, detected in the spectrum of IRAS Z02229 by Klochkova & Panchuk (2022).

Let us briefly consider the interstellar features in the spectrum of IRAS 07430. Profile of one of the D-lines of the Na I doublet is presented in the left panel of Fig. 2 together with the line profile K I λ7699. The profiles of both lines contain only two absorbtions: “1”—the envelope component, “2”—the photospheric one. Additional absorbtions, which could be classified as interstellar, are absent. To confirm the conclusion, let us compare the profile of the D2 Na I λ5890 line in the spectra of IRAS 07430 with the profile in the spectrum of a distant ($\pi = 0.3806$ mas) star HD 56126 with close galactic coordinates, presented in the right panel of Fig. 2. The position of the component “4” is consistent with the position of the Swan bands, which indicates its formation in the circumstellar envelope. Component “5” is photospheric: its behavior over time corresponds to the behavior of other photospheric absorbtions (Klochkova et al. 2007). Three shortwave absorbtions “1–3” are interstellar lines.

3 Conclusions

From date to date, the photospheric absorbtion velocity varies around the average value $V_r = 37.0$ km/s with the standard deviation of $\Delta V_r \approx 0.8$ km/s, which may be a manifestation of the low amplitude pulsations in the stellar atmosphere. The position of the Hα core varies within 40.5–43.8 km/s. Based on the position of the significant components of the Swan bands (0;0), (1;0) and (2;0) molecule C_2 formed in the circumstellar envelope, the average radial velocity V_r(Swan) of about 21 km/s and the expansion velocity $V_{\rm exp} \approx 16$ km/s, typical for post-AGB stars, were found.

Expected in the spectra of IRAS 07430 features: radiation stratification velocity in the stellar atmosphere, peculiarity of the Hα profile and splitting of strong absorbtions of heavy metals, which was found in the spectra of IRAS Z02229, are absent.

An unexpected and required of the explanation effect was obtained: with a large difference in luminosity, both stars have almost equal equivalent width of the triplet oxygen O I λ7774: $W_\lambda = 0.99$ Å and 0.91 Å in the spectra of IRAS Z02229 and IRAS 07430 respectively. The discrepancy in estimating of the IRAS 07430 luminosity may be caused by possible parallax uncertainty for AGB supergiants with extensive envelopes (see Andriantsaralaza et al. 2022).

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