Testing of the new filter system of the 60-cm telescope as a beginning of Rozhen's Hα Stellar Survey (RHaSS)

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Abstract. We proposed modification of the approach for searching for rare objects of different types with positive (or negative) Hα excess based on observations with filters $RedC$, HaN, r', and i'. The paper presents the measured transmission curves of the new broad-band and narrow-band filters of the 60-cm telescope at NAO Rozhen that can be used for this aim. The efficiency of the proposed method for searching for Hα emission candidates based on their position on the diagram $(RedC-HaN)/(r'-i')$ was confirmed by our follow-up spectral observations of the suspected emission candidates from the photometry. The successful tests allow us to announce the beginning of work on creation of Rozhen's Hα Stellar Survey (RHaSS) covering mainly the magnitude range 11-13 mag.
Key words: emission objects, photometry, spectroscopy, photometric system

Introduction

The Hα emission is prominent in the spectra of pre- and post-main-sequence stars, i.e. objects in relatively short-lived phases of their evolution. The scarcity of these targets leads to poor understanding of the crucial evolutionary stages connected with the growth of planetary systems, as well as with the providing of the galactic environment by chemically-enriched matter.

It is assumed that the old photographic Hα surveys are complete in respect to emission stars brighter than 11 mag. On the other hand, the modern INT Photometric Hα Survey (IPHAS) of the Northern Galactic plane covers the magnitude range $13 < r' < 20$, i.e. the stars fainter than 13 mag (Drew et al. 2005). The IPHAS is based on the observations in three filters: Hα filter (Ha) with $\lambda_c = 6568$Å and FWHM= 95Å, as well as two broad-band Sloan filters, r' and i'. The Hα emission candidates are determined by their anomalous locations on the two-color diagram $(r' - Ha)/(r' - i')$ (Robertson & Jordan 1989). Above 5 thousands Hα emission candidates were found as a result of the IPHAS investigations (Witham et al. 2008) and several hundreds of them were confirmed by follow-up spectral observations.

We decided to modify the method of the IPHAS by using the diagram $(RedC - HaN)/(r' - i')$ for searching for Hα emission candidates. The expectation was the narrow-band $RedC$ (Red Continuum) filter to be more effective for this aim than the r' filter.

In order to check this supposition for photometric searching for emission candidates on one hand, as well as to cover the missing magnitude range 11-13 mag of the known Hα surveys on the other hand, we initiated the 60-cm telescope of Rozhen National Astronomical Observatory to be equipped by a new filter system consisting of 3 narrow-band filters and 4 broad-band filters appropriate for Hα survey. This paper presents the results from the measurement of the transmission curves of the new filters, as well as the first observational tests. The obtained results motivated us to begin work on creation of Rozhen's Hα Stellar Survey (RHaSS).

1 The transmission curves of the new filters

Each photometric stellar survey requires detailed knowledge of the used filters. That is why we measured the transmission curves of the new filters to verify if they coincide with those published on the web-site of the manufacturer *Astrodon*. This is especially necessary for the narrow-band filters that have unique characteristics.

The first attempt for a measurement of the filters was made with the Coude spectrograph of 2-m telescope at Rozhen. The Coude spectrum covers only 200Å that is considerably smaller than the width of the Sloan filters. That is why every broad-band filter was exposed several times. But it turned out difficulty (even impossibly) to put together the separate parts of the obtained spectra. Another problem of this measurement was caused by the fact that the new filters were placed after the flat-field lamp and before the slit where the light beam was not parallel.

The next attempt to measure the filter transmissions was carried out in the Laboratory for optical properties of crystals at Shumen University. The equipment included monochromator, calibrated light source and semiconductor detector of light. The wavelength resolution of these measurements was 5-10 nm for the broad-band filters and 2.5 nm for the narrow-band filters (Fig. 1), that was not enough for our purpose.

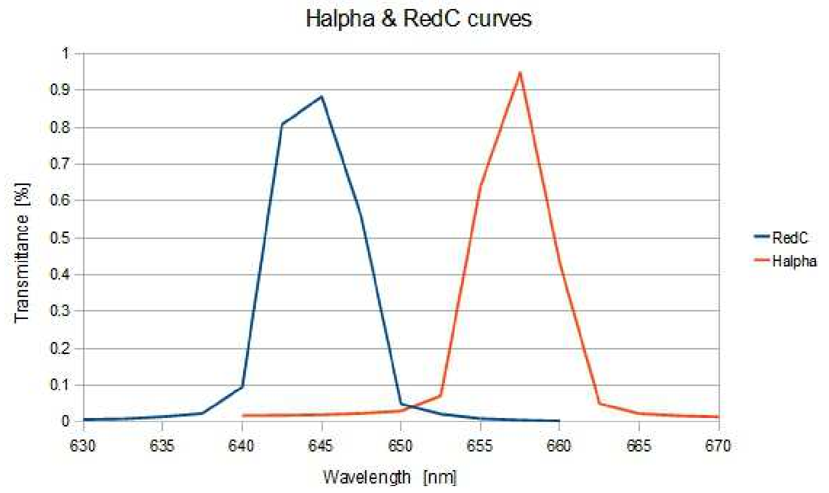

Fig. 1. Low-resolution transmission curves of two of our new filters

To reach the higher precision of the measurement of the transmission curves of the new filters we used the spectrograph of the 60-cm telescope

(Popov & Dimitrov, 2012). It works with two gratings. The narrow-band filters were measured by the grating 1200 lines/mm with resolution 0.5 Å/pixel while the broad-band filters were measured with the grating 300 lines/mm with resolution 2 Å/pixel.

We used a He-Ar-Ne lamp for getting a comparison spectrum and an incandescent lamp for generation of flat field.

All new filters were placed on a holder after the collimator and before the grating where the light beam was parallel. The holder had aperture 30 mm, i.e. smaller size than the aperture of the collimator to avoid vignetting.

The procedure of measurement included four steps:

(a) dark current exposures;
(b) spectra for flux calibration by unfiltered exposures;
(c) exposures with a filter;
(d) spectra for wavelength calibration by a He-Ar-Ne lamp.

Three measurements were made for each filter and the results were averaged.

The reduction procedure was as usual: subtraction of the Master dark current from the Master flux calibration and filter spectra; division of the last reduced spectra in order to eliminate the effect of the light distribution of the flat-field lamp and the different sensitivity of the CCD (Fig. 2) and obtaining of normalized transmission curves; wavelength calibration.

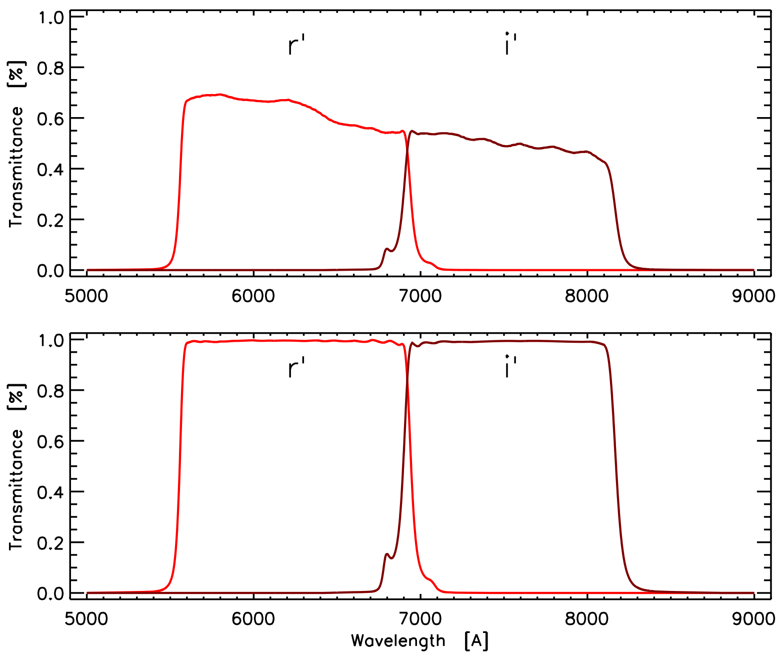

Fig. 2. The reduced (top) and normalized (bottom) transmission curves of our Sloan filters r' and i'

Table 1 summarizes the main parameters of the narrow-band filters Red Continuum (*RedC*), broad Hα (*HaB*) and narrow Hα (*HaN*): wavelength of the maximum transmission λ_{max}; wavelength of the middle of the transmission curve λ_{mid}; full width at middle height (FWHM) of the transmission curve.

Table 1. Parameters of the narrow-band filters

filter	λ_{max} [A]	λ_{mid} [A]	FWHM [A]
RedC	6450.64	6443.62	49.59
HaB	6573.28	6571.46	50.44
HaN	6563.81	6567.83	31.63

The comparison of the measured transmission curves of the narrow-band filters (Fig. 3) with those of the producer on the *Astrodon* Web site led to the following conclusions:

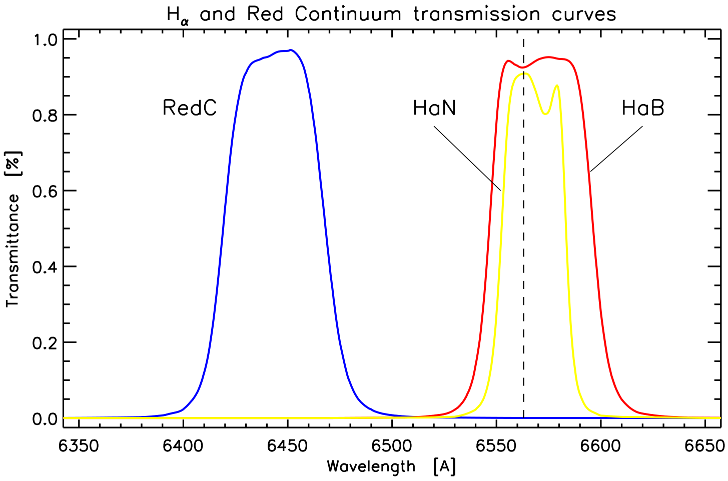

Fig. 3. The measured transmission curves of our narrow-band filters

(a) The plateau of the measured curve of the *RedC* filter is not so flat as that of the published transmission curve;
(b) The measured transmission curve of the *HaB* filter is shifted by 1 nm from the true Hα line toward the red and this shift is bigger than that of the published transmission curve;
(c) There is a dip just at the Hα line on the measured curve of the *HaB* filter while such a feature lacks on the published transmission;
(d) The measured transmission curve of the *HaN* filter is shifted by around 1 nm from the true Hα line toward the red and this shift is bigger than that of the published transmission curve;
(e) The maximum transmission of our *HaN* filter is just at the Hα line while that of the published transmission curve is shifted to the red;

(f) There is a dip at the red end of the plateau of the measured transmission curve of our HaN filter. There is a similar dip but at the blue end of the plateau of the published transmission curve;
(g) The maximum transmission of our HaN filter is just at the Hα line while that of the producer is shifted to the red;
(h) The transmission of our HaB filter at the plateau is bigger than that of our HaN filter.

It should be pointed out that the warranty of the producer the transmission of the narrow-band filters to be over 90 % is fulfilled for our three filters.

The results of the measured transmissions of the broad-band Sloan filters g'(401-550 nm), r'(555-695 nm), i'(690-820 nm), and z'($>$ 820 nm) with average width around 150 nm led to the following conclusions (Fig. 4):

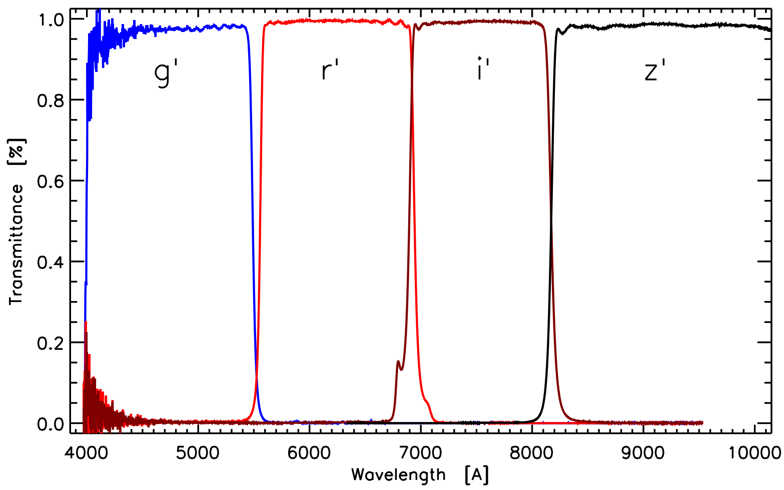

Fig. 4. The measured transmission curves of our Sloan filters g', r', i', and z'.

(a) The transmissions of our four Sloan filters at the maxima are above 98%, i.e. the warranty of the producer they to be over 95 % is fulfilled;
(b) The measured transmission curves (Fig. 4) of our filters are with almost rectangular shape as those of the producer;
(c) The plateaus of the measured transmission curves are slightly notched (Fig. 4);
(d) The scatter of the blue part of the transmission curve of our filter g' (Fig. 4) is not real but due to the weak emission of our flat-field lamp in this wavelength range;
(e) The scatter of the red part of the transmission curve of our filter z' (Fig. 4) is not real but due to the weak quantum efficiency of our CCD camera in this wavelength range.

The comparison of the transmission curves of our Sloan filters with those of the standard Bessell $BVRI$ filters (provided by Finger Lakes Instrumentation) exhibited their two important advantages (Fig. 5).

1. The transmission curves of the Sloan filters have practically rectangular shape while those of the Bessell filters do not fulfil this important requirement for the photometric observations.
2. The Sloan filters have transmissions above 98 % that is considerable bigger than the transmissions of the Bessell filters (70 % for B, 90 % for V, 81 % for R, and 92 % for I filter).

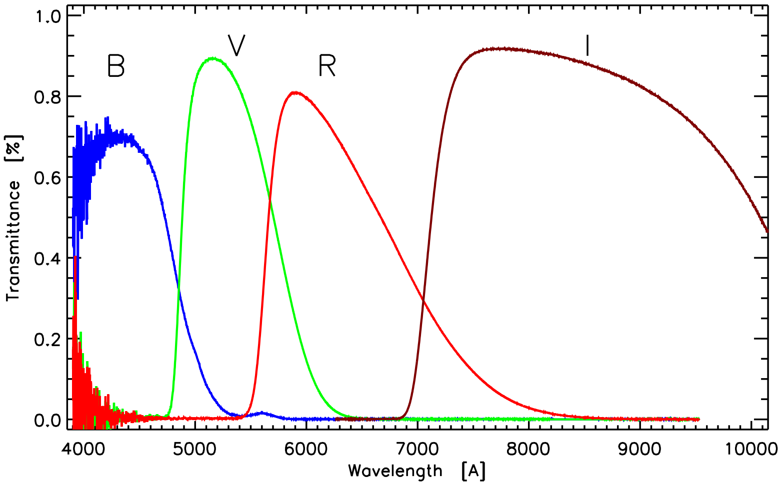

Fig. 5. The measured transmission curves of the standard Bessell $BVRI$ filters

2 Rozhen's Hα Stellar Survey (RHaSS): first results

The test observations of the new filter system for the goals of the planned Rozhen's Hα Stellar Survey were carried out with the 60-cm telescope with focal reducer (field of view 26×26 arcmin) equipped by steeper motor for positioning and guiding (Popov & Dimitrov, 2011).

We observed nearly 100 fields centered around the galactic equator (galactic latitude range $[-10, +10]$). Some of them were stellar cluster's areas.

Each observed field contained from 200 to 3000 stars. The two-color diagram $(RedC - HaN)/(r' - i')$ of the observed stars revealed about 300 targets which positions deviated from the synthetic $(RedC - HaN)/(r' - i')$

dependence of the "normal" stars. That is why they were suspected as emission candidates. Our checking revealed that 127 of them are known emission stars. We consider this result as a manifestation of the efficiency and the adequacy of our approach.

Further we examined the newly detected emission candidates for the presence of Hα emission by spectral observations with the 2-m telescope. Until the middle of 2012 we managed to carry out follow-up low-dispersion spectral observations of 56 candidates and to get Coude spectra of 40 targets brighter than 13.5 mag. Many suspected emission candidates still await spectral confirmation.

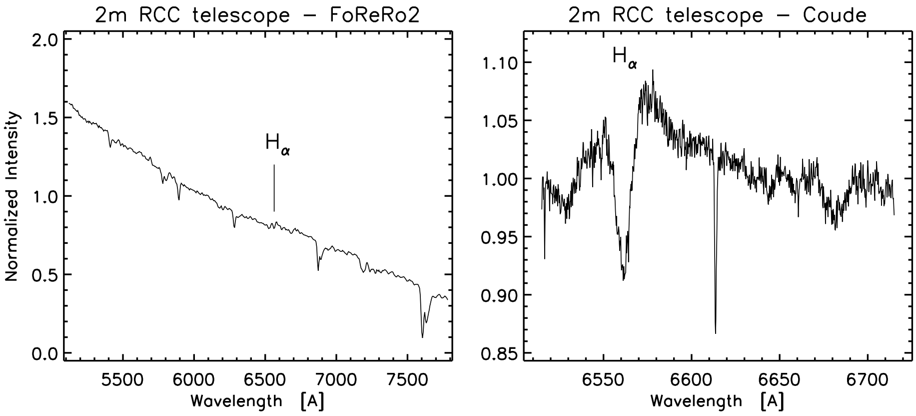

Fig. 6. Low-dispersion spectrum of the new Be star RHaSS J202311+405223 (left) and its Coude spectrum (right)

The spectral observations of the newly detected emission candidates by our photometry led to several conclusions.

(1) They confirmed the Hα emission of around 30 % of the candidates. Some of the rest candidates probably are emission targets but with transient emission (for instance the Hα emission of the Be stars is not permanent issue). Figure 6 illustrates this supposition by the Be star J202311+405223: its low-dispersion spectra did not show Hα emission in November 2011 while a month later its Hα emission was detected by Coude spectroscopy.
(2) The spectral observations confirmed the Hα emissions of 38 normal Be candidates (Fig. 7, left) and several reddened Be stars (Fig. 7, right).
(3) We discovered one carbon emission star (Fig. 8, left). The suspected several other carbon candidates await spectral confirmation. It should be noted that these objects with $(r' - i') > 2$ are quite rare phenomena.
(4) We discovered three M dwarfs with emission (Fig. 8, right).
(5) Using the photometry by filter z' we found several hundreds candidates of late stars (M giants, carbon stars, brown dwarfs) that await spectral confirmation.

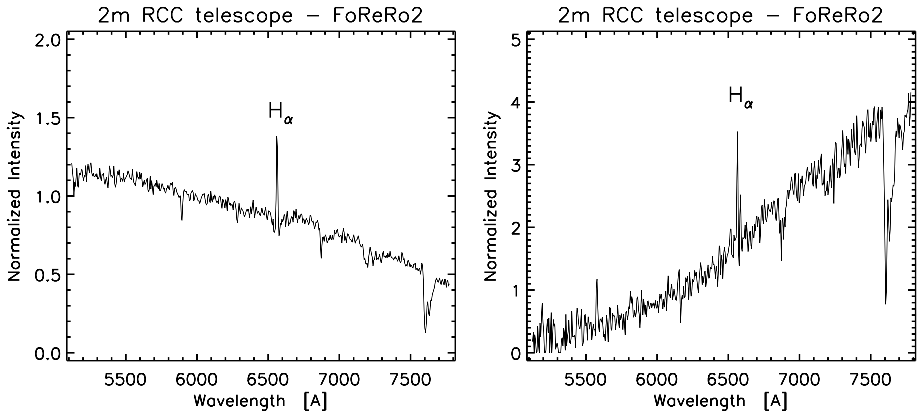

Fig. 7. Confirmed Hα emission of the normal Be star RHaSS J224714+580700 (left) and that of the reddened Be star RHaSS J023321+612643 (right) by our low-dispersion spectroscopy

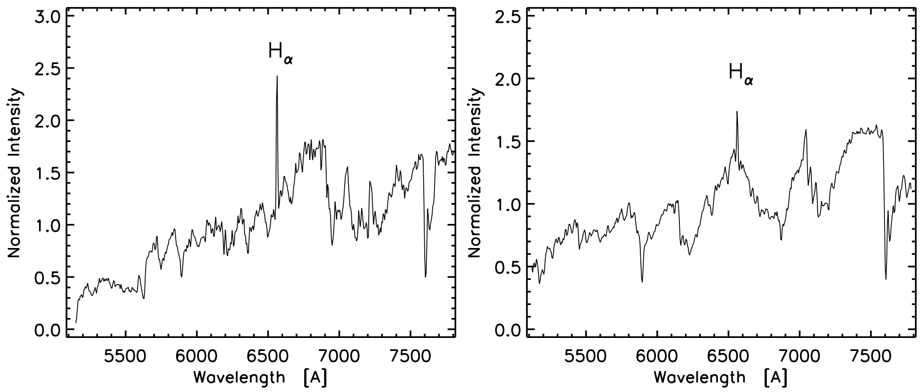

Fig. 8. Confirmed Hα emission of the newly discovered carbon star RHaSS J184108+262032 (left) and that of the Me dwarf RHaSS J195323+292832 (right) by our low-dispersion spectroscopy

(6) We observed several known hydrogen white dwarfs (spectral type DA) in order to make selection criterion for "anti-emission excess" objects by their positions on the diagram $(RedC - HaN)/(r' - i')$.

3 Conclusion

Our test observations for searching for emission stars of different types with the new photometric system of the 60-cm telescope were quite successful. The efficiency of the proposed method for searching for Hα emission candidates based on their position on the diagram $(RedC - HaN)/(r' - i')$ was confirmed by our follow-up spectral observations of the suspected emission candidates from the photometry. Thus, we put the beginning of the Rozhen's Hα Stellar Survey (RHaSS). We plan to realize this work in the next decade.

Moreover, we hope to have a chance further to find interesting Hα emission targets of different types: Be stars, Me stars, cataclysmic stars, symbiotic stars, T Tau stars, etc.

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