# Low-dispersion spectroscopy of late stars with the focal reducer FoReRo2 at the 2-m telescope of the Rozhen NAO

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**Abstract.** The paper presents analysis of FoReRo2 spectra of 17 G, K and M spectral standards and 2 variable stars that cover the range 5000-7000 A with resolution 5.224 A/pix. The FoReRo2 spectra of the spectral standards allow to derive criteria for spectral classification of late stars for the observed spectral range. The presented low-dispersion spectra of the famous stars MWC 560 and HBC 722 illustrate the possibilities and advantages of the time-saving FoReRo2 spectroscopy. It opened the possibility to obtain the first spectrum of brown dwarf, TVLM 513-46546, at Rozhen. Due to these good and hopeful results we suggest the FoReRo regime of the 2-m telescope to be used as a reserve mode for different tasks.
**Key words:** late stars, low-dispersion spectroscopy

### Нискодисперсна спектроскопия на късни звезди с фокалния редуктор FoReRo2 към 2-м телескоп в НАО-Рожен

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Представени саFoReRo2 спектри на 17 G, K и M спектрални стандарти и 2 променливи звезди, покриващи интервала 5000-7000 A с разделителна способност 5.224 A/pix. Спектрите на спектралните стандарти позволиха формулиране на критерии за класификация по температура на късни звезди за наблюдавания диапазон. Получените FoReRo спектри на 2-те известни променливи звезди, MWC 560 и HBC 722, илюстрират възможностите и предимствата на нискодисперсната, времеспестяваща FoReRo2 спектроскопия. Тя ни позволи да получим първия спектър на кафяво джудже, TVLM 513-46546, в НАО-Рожен. Въз основа на получените добри и обнадеждаващи резултати предлагаме FoReRo режимът на 2 м телескоп да се използва по-широко като резервен за различни задачи.

## Introduction

Considerable part of the interesting astronomical objects is not accessible for spectroscopic observations due to their weakness. This refers to the largest degree to the late stars and as result they are understudied although they present the most numerous objects in our Galaxy. For instance, only few dozens of the late dwarfs have global parameters obtained by observations. That is why the empirical relations mass-luminosity and mass-radius are not well-determined for the late stars.

The low-resolution spectroscopy gives some possibility to overcome this problem. It allows to extract information about the emission of the weak stars into spectral lines as well as about their energy distribution in different spectral ranges.

In order to expand the possibility for a spectral study of weak stars (for which Coude spectra are impossible) we undertook testing of low-dispersion spectroscopy with the focal reducer FoReRo2 attached to the 2-m telescope of the Rozhen National Astronomical Observatory.

This paper presents the first results of the FoReRo2 spectroscopy of late stars and illustrates its advantages.

## 1 Equipment and observations

The parameters and optical scheme of the focal reducer FoReRo2 can be found at the site of the Rozhen National Astronomical Observatory:

http://www.astro.bas.bg/forero/info.

The equipment for FoReRo spectroscopy included also the CCD camera 'Versarray' (512 x 512 pixels, 24 x 24 $\mu$m) and grism (300 lines/mm). This equipment gives spectral resolution 5.223 A/pix in the range 5000-7000 A.

We used only the red channel of FoReRo-2 because the goal was to study late stars.

Our observations were made on February 7 2011 and March 11-13 2011. The exposures were 5 min. 2-4 spectra were taken for each object (depending on the brightness) which further were stacked.

The reduction of the spectra was performed using IRAF packages by bias subtraction, flat fielding, cosmic ray and nebular lines removal, one-dimensional spectrum extraction. The spectra were normalized to the local continuum. The night sky lines as well as Rb source of emission spectrum were used for wavelength calibration (Fig. 1). The most intensive night lines at Rozhen sky were OI 6300.3, OI 5577.3, OI 6364 and NaI 5890+5896 that were identified using the atlas of the spectral lines (Osterbrock & Martel 1992).

## 2 Analysis of the results

Table 1 presents the list of the observed stars while their FoReRo spectra are shown in Figs. 2-6. The first 17 stars in Table 1 are spectral standards (stars with known spectral type and luminosity class) while the last 2 stars are interesting (famous) variables.

The decreasing of the continuum of all spectra at the short wavelength end is due to the weak sensitivity of the CCD in the observed range.

The obtained FoReRo spectra allow us to formulate criteria for spectral classification of late stars by their spectra in the observed spectral range 5000-70000 A as well as to derive the first results from this type of observations:

(1) The spectrum of the standard A0V star in the range 500-700 $nm$ is poor of spectral features excluding the deep $H\alpha$ line.

(2) The number of absorption lines as well as their depths increase through the G spectral type (Fig. 2). The depth of the absorption $H\alpha$ line is up to 2.5 times smaller than that of the A0V spectrum The depth of NaI 5890 A increases around 5 times through the G spectral type (Fig. 2). The depth of the weak line 6500 A increases to the late G subclasses. Hence, the depths of

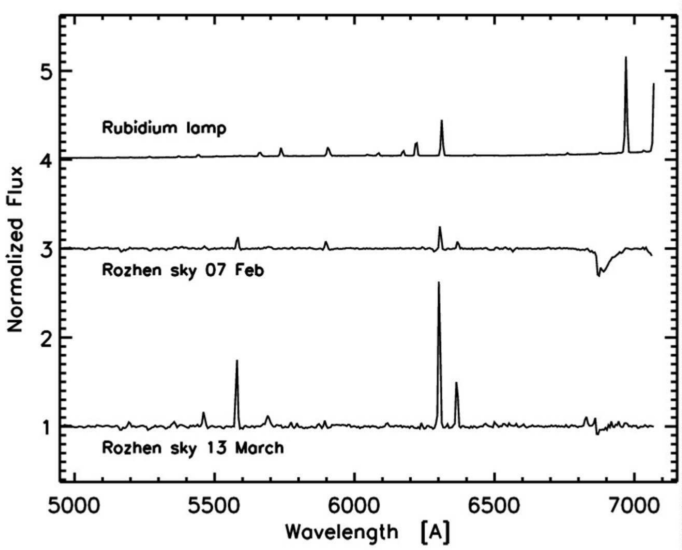


**Fig. 1.** FoReRo spectra of the night sky and of Rb source used for wavelength calibration

the lines $H\alpha$, NaI 5890 A and 6500 A may serve as quantitative criteria for temperature into the spectral type G.

(3) The strongest spectral feature for the K stars in the range 5000-7000 A is the line NaI 5890 A and its depth continues to increase to the late K subclasses. The depth of the line 6500 A also continues to increase whereas the $H\alpha$ line decreases (Fig. 3). As a result the line 6500 A becomes stronger than $H\alpha$ in the K7V spectrum. The new feature is the line 6195 A that appears in the K0V spectrum and becomes stronger to the K7V spectral type. Hence the ratios of the depths of the lines NaI 5890 A, $H\alpha$, 6500 A and 6195 A may serve as criteria for temperature classification of the K stars.

It should be pointed out that according to Kirkpatrick et al. (1991) the strongest features in the observed spectral range for the K dwarfs should be the CaH molecular bands (6346; 6382, 6389; 6750, 6903, 6908, 6921, 6946, 7050) while the low-resolution FoReRo spectroscopy led to different criteria.

(4) The FoReRo spectra of the M stars dramatically change through the subtypes. The spectra of the early M0-0.5V stars look like those of the K stars with additional two absorption bands centered at 6250 A and 6800 A (Fig. 4). A new absorption band centered at 5950 A appears in the intermediate M spectra and as a result the line NaI 5890 A is not so distinct yet but the most impressive features is the absorption band 6200-6400 A. Another feature of the late M stars spectra in the observed range is the very broad "emission" region around the $H\alpha$ line.

It is difficult to determine the position of the continuum itself in the range 5000-7000 A due to the absorption bands that become quite strong and wide

**Table 1.** List of the observed stars

| Name | $\alpha$ | $\delta$ | mag | Sp |
|---|---|---|---|---|
| HD 109055 | 12 31 41.28 | 22 07 24.4 | 8.8 | A0V |
| HD 87776 | 10 07 39.34 | 15 09 27.0 | 7.1 | G0 V |
| G54-17 | 10 11 48.07 | 23 45 18.7 | 8.4 | G2 V |
| HD 88008 | 10 09 20.12 | 24 32 39.0 | 8.5 | G5 V |
| SAO 61924 | 10 12 01.07 | 29 46 55.1 | 9.8 | G8 V |
| HD 86590 | 10 00 01.71 | 24 33 09.9 | 8.5 | K0 V |
| PPM 100279 | 10 20 34.79 | 29 34 18.0 | 8.8 | K2 V |
| HD 89376 | 10 19 10.64 | 20 33 48.2 | 9.1 | K5 V |
| LTT 13492 | 12 25 34.99 | 21 49 56.3 | 10.1 | K7 V |
| HD 260655 (LHS1858) | 06 37 10.79 | 17 33 53.3 | 9.6 | M0 V |
| SAO 63817 | 13 54 01.93 | 38 44 53.1 | 9.1 | M0 |
| 34 UMa | 10 22 19.74 | 41 29 58.3 | 3.1 | M0 III |
| HD 232979 | 04 37 40.93 | 52 53 37.0 | 8.6 | M0.5 V |
| BD+05 1668 (LHS33) | 07 27 24.50 | 05 13 32.8 | 9.9 | M3.5 V |
| AD Leo | 10 19 36.28 | 19 52 12.1 | 9.4 | M4.5 V |
| EK Boo | 14 46 05.95 | 15 07 54.4 | 5.9 | M5 III |
| TVLM 513-46546 | 15 01 08.19 | 22 50 02.0 | 15.1 | M9.0 V |
| MWC560 | 07 25 51.29 | -07 44 08.1 | 9.1 | M6III |
| HBC722 | 20 58 17.03 | 43 53 43.4 | 18.9 | K8 |

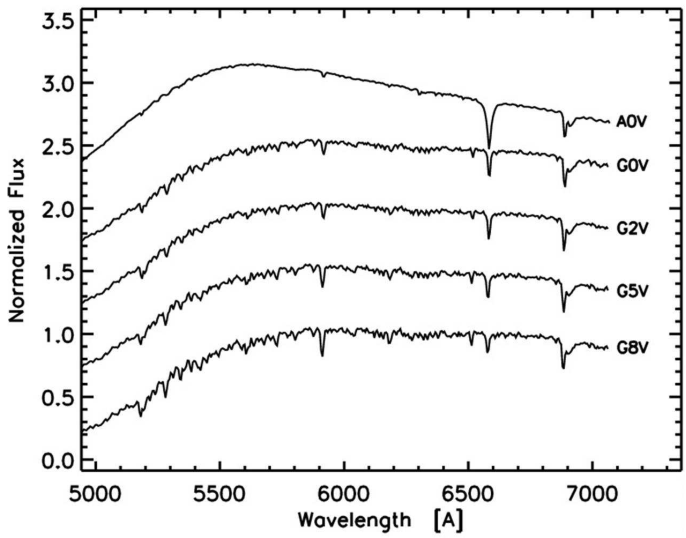


**Fig. 2.** FoReRo spectra of standards of spectral types A0 and G

for the late M subtypes. Moreover, after M3.5 subtype the emission after 6900 A (long-wavelength end of the observed range) steeply increases. This

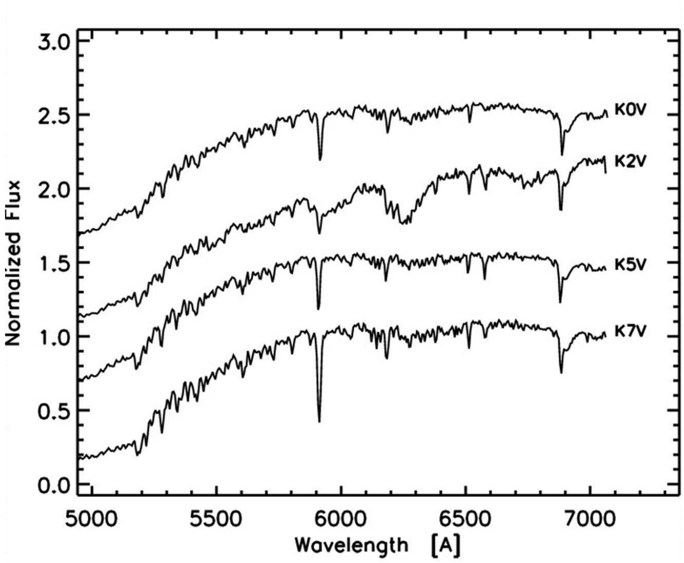


**Fig. 3.** FoReRo spectra of standards of spectral type K

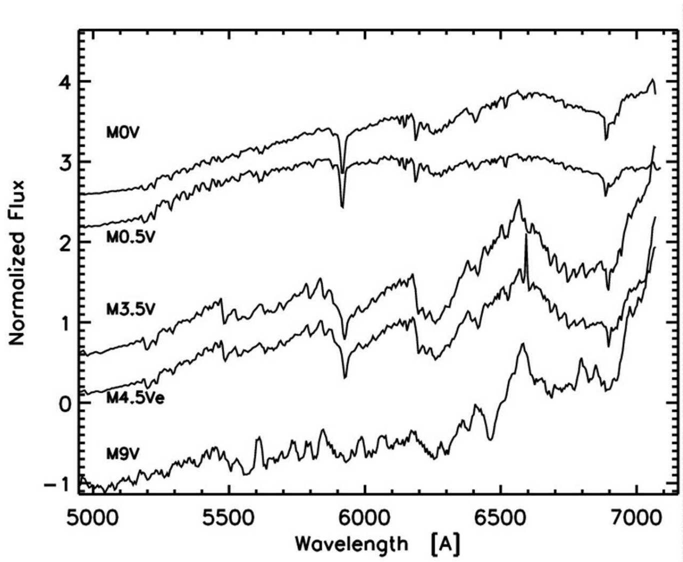


**Fig. 4.** FoReRo spectra of standards of spectral type M

may be the reason the region around the $H\alpha$ line to seem as a wide emission band for the late M subtypes.

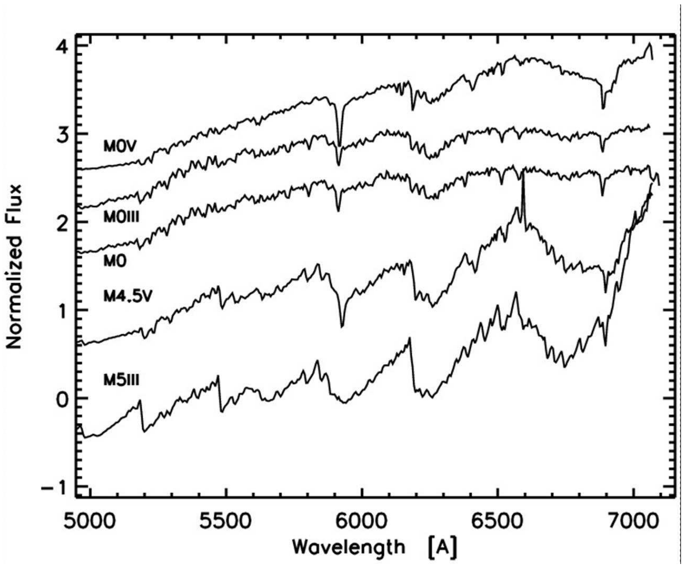


**Fig. 5.** FoReRo spectra of dwarf and giants of spectral type M

Hence the intensities of the absorption bands centered around 6250 A, 6800 A, 5950 A as well as the enhanced emission around the $H\alpha$ line and after 6900 A may serve as criteria for temperature of the M stars.

According to Kirkpatrick et al. (1991) the strongest features of the M dwarfs in the observed range should be the absorption bands of TiO (6322, 6358, 6448, 6512; 6569, 6596, 6629, 6649; 6651, 6680, 6713, 6746, 6814, 6852 A) but they merge in the FoReRo2 spectra.

(5) Some features of the FoReRo spectrum of the star PPM 100279 classified as K2V (Fig. 3) do not correspond to the common trends: there are 2 wide absorption bands 5900-6150 A and 6180-6350 A and the spectrum resembles that of early M star (see Fig. 4). The reasons may be the wrong spectral classification, some peculiarity of the stellar atmosphere or presence of third component (composite spectrum).

(6) We established several differences between the spectra of the M dwarfs and M giants.

The main differences for the early M subtypes are: the line NaI 5890 A is around 2 times deeper for the dwarfs than for the giants (Fig. 5); the line 6500 A is stronger for the giants than for the dwarfs; the range 6300-6800 A of enhanced emission is not so apparent for the giants as for the dwarfs.

The main differences for the intermediate M subtypes are: the line NaI 5890 is absent for the giants while it is present for the dwarfs; the short-wavelength (cut-off) ends of the molecular bands are sharper in the spectra of the giants than those of the dwarfs and as a result the giant' spectra look saw-shaped; the increase of the emission after 6900 A is steeper for giants than for dwarfs; the absorption band around 6400 A is considerably deeper for the dwarfs than for the giants.

It should be pointed out that due to the poor statistics all these criteria might be changed and improved by future observations.

(7) The FoReRo spectrum of the M9V spectral standard differs from the spectra of the early and intermediate M subclasses by the lack of deep absorption bands and by steep increase of the emission after 7000 A. These arguments may be used as criteria for temperature of late M dwarfs, i.e. of early brawn dwarfs. Obviously, the only apparent feature of the M9V spectrum is the enhanced emission around the $H\alpha$ line.

(8) SAO 63817 was the only star from our list of spectral standards (Table 1) which luminosity class was unknown. Its FoReRo2 spectrum looks like that of the M0III star 34 UMa (Fig. 5). That is why we concluded that SAO 63817 is a giant. This result demonstrates the efficiency and usefulness of the FoReRo2 spectroscopy.

(9) In order to illustrate the possibilities and advantages of the low-resolution spectroscopy we chose two wide-known variable stars. Figure 6 shows the variability of the $H\alpha$ lines of the binaries MWC 560 and HBC 722 during 2 consecutive nights. These results cost only 12 min observational time per night. It should be pointed out that HBC 722 with its 19 mag cannot be observed in Coude regime. Thus the FoReRo spectroscopy provides the only possibility to follow-up its spectral behavior during the brightness decrease.

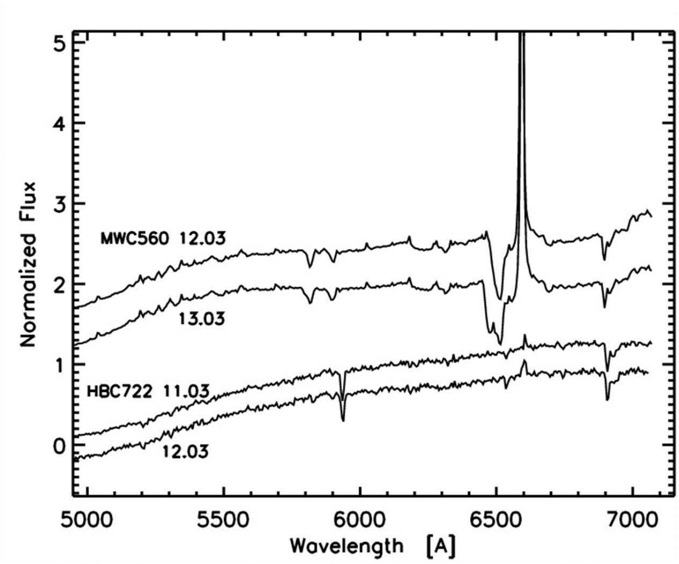


**Fig. 6.** FoReRo spectra of the variable stars MWC 560 and HBC 722

(10) The FoReRo2 spectroscopy is time-saving observational mode. This regime of the 2-m telescope may be used as a reserve one during non-photometric nights and non-satisfactory conditions. The setting of the focal reducer FoReRo2 and the transition to the new regime requires only 5-10 min observational time.

## 3 Conclusion

The main important results from this study allow us to made the following conclusions.

(1) The FoReRo spectroscopy provides the only possibility to study the spectral behavior of flaring stars during the brightness decrease when they are not observable in Coude regime.

(2) The low-resolution spectroscopy allowed us to obtain the first spectrum of brown dwarf, TVLM 513-46546, at Rozhen.

(3) The FoReRo2 spectroscopy gives a chance for fast detection of $H\alpha$ emission (for instance from objects with X-ray emission that are suspected as chromospheric emission sources).

(4) The low-resolution spectroscopy may be used easily to check for existence of third body in binaries with wide spectral lines (by features on the line profiles).

On the base of this study we make 2 suggestions:

(a) A new grism with higher spectral resolution for the red channel of the focal reducer FoReRo2 is necessary. It will provide a possibility for measurement of the radial velocities of weak stars (which Coude spectra at Rozhen are impossible).

(b) The FoReRo regime of the 2-m telescope may be used very successfully as a reserve mode for different tasks.

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