# Echelle spectrograph for Rozhen NAO

Haralambi Markov
Institute of Astronomy and NAO, Bulgarian Academy of Sciencies, BG-1784 Sofia
hmarkov@astro.bas.bg
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**Abstract.** The current practice of high-dispersion spectral observations in the Rozhen National Astronomical Observatory is presented. The advantages of the echelle spectrograph as alternative for increasing of the efficiency of such observations are revealed. The basic components of an eshelle spectrograph are discussed and one variant, suitable for the Rozhen NAO, is described in principle. A brief survey of the current experience in the processing of eshelle spectrogrems in the NAO is given.
**Key words:** spectroscopy; echelle spectrograph

## Ешеле спектрограф за НАО - Рожен

Хараламби Марков

Представена е текущата практика на високодисперсни спектрални наблюдения в Националната Астрономическа Обсерватория Рожен. Изявени са преимуществата на ешелния спектрограф като алтернатива за повишаване на ефективността на тези наблюдения. Обсъдени са основните компоненти на ешелния спектрограф и е представен по принцип един вариант, подходящ за НАО-Рожен. Даден е кратък преглед на текущия опит в обработката и анализа на ешелни спектри в НАО.

## 1 Current problems with high dispersion spectroscopy in the Rozhen NAO

The Rozhen NAO is equipped with an Coudé spectrograph designed especially for the NAO 2-m telescope. Thanks to this instrument Bulgarian astronomers more than 30 years conduct scientific investigations based on high dispersion spectroscopy(up to R $\approx$ 30000). The Rozhen Coudé spectrograph camera, achieving best spectral resolution, is designed to register a spectral range of about 130 nm with a single exposure. The focal plane is curved and the spectrum is spread out physically on $\sim$ 300 mm. Originally the camera is designed to register the spectrum on a narrow-stripped photographic plates.

The implementation of the CCD photon detector with its high quantum efficiency improved the limit magnitude and the S/N ratio of the single spectrum, but the small physical dimension of the CCD chip (the most widespread are 25-30 mm wide) lowered dramatically the efficiency of the spectral observations as a whole. This happened for two main reasons: a)to cover wide spectral region we have to obtain many spectra taken at consecutive grating angles and b)for every angle we have to obtain separate so called 'calibration images' (flat field and comparison spectra). These are time consuming procedures and the scientific tasks we can effectively cover with our Coudé spectrograph was highly reduced, e.g. it is not possible to monitor spectral features behavior in different spectral regions at the same time. The things went even worse if one have to observe latge sample of stars.

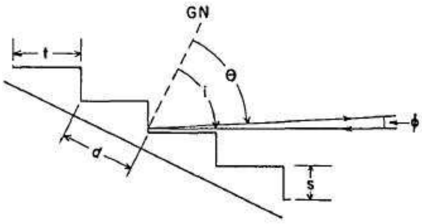


**Fig. 1.** Echelle grating surface.

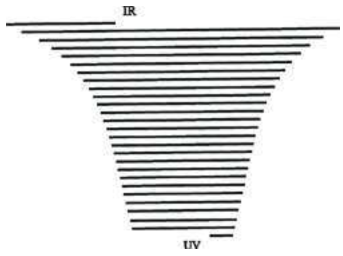


**Fig. 2.** Echellegram.

## 2 The solution

Above listed problems are solved in general by spectrographs based on echelle grating – a plane grating which surface is blazed with a well shaped(large spaced) grooves to be more efficient throughout a very wide range of wavelengths(fig. 1). These spectrographs use the grating at high angles of incidence and diffraction or essentially at very high orders to take advantage of the consequent high resolution and dispersion. This results in multiple overlapping high orders.

Since this overlap is not directly useful, a second, perpendicularly mounted, dispersive element (grating or prism) is inserted as an "order separator" or "cross disperser" into the beam path of the spectrograph. As well echellegram is a two dimensional image (fig. 2) assembled from multiple linear segments(orders) covering with a single exposure wide spectral range with high spectral resolution. This spectrum is well suited to be registered with a CCD detector. The modern echelle spectrographs strongly improve the efficiency of high resolution spectroscopy achieving a dispersion up to an order better than the classical Coudé spectrographs. Their compact dimensions allow the working environment - temperature, humidity and mechanical stability to be controlled with a higher precision and for a long period of time.

As a rule echelle spectrographs highly improve the efficiency of middle class telescopes working in places with poor seeing (2-3 arcsec) and not stable meteorological conditions. At present many telescopes of one to two meter class are "upgraded" with an echelle spectrographs. A good examples are: FEROS (1999, 1.5-m, ESO La Sila, Chile), HERMES (2004, 1.2-m Mercator telescope, Observatorio del Roque de Los Muchachos, La Palma), BESO (2006, 1.5-m Hexapod telescope at Observatorio Serro Armasones, Chile), SOPHIE (2006, 1.93-m, L'Observatoire de Haute Provence, France), NARVAL spectropolarimeter (2006, 1.93-m Telescope Bernard Lyot, Pic du Midi, France) and the most recent instrument - CHIRON (2011, 1.5-m SMARTS consortium telescope at CTIO, La Serena, Chile). Here we intentionally omit the four-meter and bigger class telescopes.

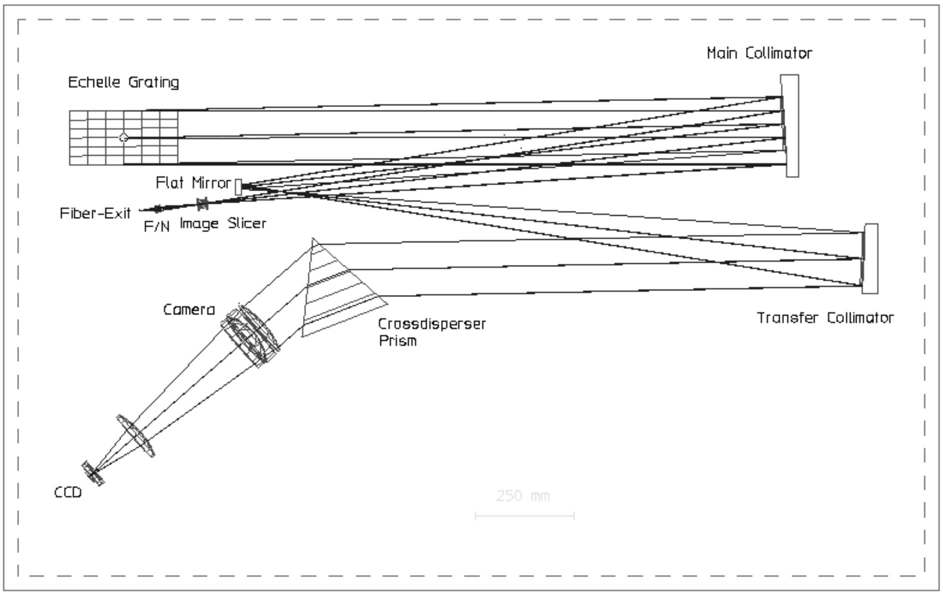


**Fig. 3.** Echelle spectrograph "white pupil", principal scheme.

## 3 Main components of the modern echelle spectrograph

The echelle spectrographs construction is refined continually more than 70 years following the requirements of good quality spectroscopy - high spectral resolution and light efficiency and wider spectral window. Figure 3 shows a principle scheme of a modern echelle spectrograph (Kaufer [1997]). The modern echelle spectrograph is an opto-mechanical complex which apart of the spectrograph itself encompasses supplementary structural components as follows: light feeding, spectrum registration(camera and CCD detector) and calibration tools. Here are the basic structural features of these spectrographs

- *Location.* Modern echelle spectrographs are separated from the telescope and are placed in a special room usually underfloor to the telescope. Additionally the spectrograph is enclosed into thermally stabilized and humidity controlled chamber. Temperature and vibration stabilization of the spectrograph ensures high precision radial velocity measurements. The main optical components of the spectrograph - the echelle grating(fig. 4), the collimators(main and transfer), the flat folding mirror(key 'white pupil' component), the crossdisperser prism - are mounted on a bench. The bench itself is an optical table which guarantees sufficient static and dynamic stiffness for the spectrograph components. It is based on four passive vibration isolators capable to damp floor vibrations generated by building vibrations due to dome rotation or micro earthquakes. No movable parts in the spectrograph optical scheme are recommended. Most recent echelle spectrographs are designed under 'white pupil' configuration (Baranne [1988]). Among the pure optical profits this configuration ensures more compact overall size of the spectrograph. E.g. FERROS bench dimensions are 2500x1500x200 mm. The approximate space requirements for the spectrograph itself accounting for the removable enclosure are 4 m in length, 2.8 m in width and 2 m in height (Kaufer [1997]). These are very common dimensions for other spectrographs also. The specified performances are - base temperature $15 - 17\,^{\circ}$C, temperature stability in the room $\pm 0.5\,^{\circ}$C but under the chamber up to $\pm 0.1\,^{\circ}$C, humidity control <60 %

- *Feeding.* Echelle spectrographs are usually fiber fed. The light attenuation in modern optical cables is negligible for the distances of some dozen meters - the usual separation between the telescope and the spectrograph. There are options two fibers to be used simultaneously. One fiber to record the object spectrum. The second fiber is fed either by the sky background or by a calibration lamp to monitor the instrument stability during the exposure. With an front-end opto-mechanical unit the light of the Cassegrain focus is coupled into the fibers via microlenses. The entrance of the spectrograph, a rectangular slit is fed by round fibers and part of the light is lost as well (fig. 5, right panel). The image slicer is a device ensuring this light to be redirected to the spectrograph. The use of an image slicer (see fig. 5, Steiner [2006]) placed in front of the spectrograph slit is optional but it is highly recommended in order to increase the light efficiency and to ensure higher spectral resolution in poor image seeing conditions.
- *Spectrograph camera and detector.* Camera is a separate key unit for the echelle spectrograph and is ordered and manufactured for every particular case. The housing of the spectrograph camera is delivered by the optics manufacturer and includes the field lens, which acts simultaneously as entrance window of the CCD dewar. The camera and its focusing unit are mounted on a separate stable breadboard next to the spectrograph bench. As a rule its output have to be tightly conjucted with CCD detector parameters. It is recommendable the spectrograph to be equipped with a CCD camera incorporating a monolithic and back-illuminated chip with at least 2048x4096 pixels of 15 $\mu$m size. The CCD shutter will control the exposure duration. A special wheel mounted Hartman diaphragm is foreseen at this place in order the camera focus alignment to be performed regularly. Cooling the CCD camera needs special attention in connection with the temperature control of the room and spectrograph chamber and have to be solved in appropriate manner for the particular CCD camera. Liquid nitrogen cooling does not be a solution for echelle spectrograph. Most reliable cooling can be achieved by mechanical pumps(cryo-coolers) or Peltier junctions(thermoelectric coolers).
- *Calibration unit.* This includes different kind of lamps with stabilized voltage and current supply. This will be used to feed the object and sky fiber entrances with emission line spectra for the wavelength calibration and a continuum-light source for flattening purposes. Here the main functional components are:

  1. *flatfield unit* which purpose is to provide a UV enhanced continuum spectrum usually by using halogen lamps. Usually these are two lamps with different intensity. More intensive one is designed for the blue

range where the detector is less sensitive. In front of this lamp a red blocking filter combination will make this halogen lamp to look 'blue'.
2. a line spectrum for *wavelength calibration* is usually provided by ordinary hollow cathode Thorium-Argon lamp.
3. *iodine cell*(optional). The iodine absorption cell is used to create a fiducial wavelength scale for very precise (m/s) radial velocity measurements. Most iodine features are located between 500 and 620 nm, quite appropriate for radial velocity determinations of late-type stars. The iodine cell is physically located such way that to feed simultaneously the same fiber with the object and to be moved in and out of the optical beam optionally.

All calibration elements will be placed into a front-end unit mounted in the Cassegrain focus of the telescope. Here also have to find place an unit ensuring telescope guiding. It will use the stellar image aureole not falling into the fiber entrance. This light will be coupled with an extra fiber feeding separate(smaller) CCD detector which interface will be connected with the guiding system of the telescope.

*Data Reduction Software* completes the entire process of spectra acquisition. This should be available at the telescope workstation and allow on-line data reduction. This requires efficient coding of all routines working with the large image frames. The package should include - precise order definition and wavelength calibration, background subtraction, flat-field correction, optimal order extraction, re-binning, order merging, correction for the instrument response function, sky subtraction, graphical user interface, cross-correlation facilities, time-series analysis facilities, data-archive facilities.

## 4 Some conceptual thoughts concerning Rozhen NAO echelle

The concept of the further Rozhen NAO echelle spectrograph looks as follows: bench mounted, fiber fed, two-beam, two or three-slice image slicer, prism crossdispersed, wavelength range $370 - 900nm$ in a single exposure, resolving power $R \approx 50000$, large size (2kx4k) CCD detector, no movable and remotely controlled components besides CCD shutter. The spectrograph could be housed underfloor the 2-m telescope in a separate neighbouring room to the Coudé. This way the length of optical cables are reduced to about 25 meters each.

The expected price of such spectrograph is 600-800 k euros. Financial support for the project could be ensured in two basic manners: a) projects with Ministry of Education and Bulgarian Scientific Found; b) consortium with foreign institutes which have no their own observation facilities but are interested in high dispersion spectroscopy (EU members or non-EU members from the South-East Europe region). At present we need to spend already available trough contract DO 02-85 money, $\sim 150$ k euros, if we want to get additional funds on the next years. For the moment one possible decision is to begin with the acquisition of some of the main components like the the bench, optical cables, the crossdisperser prism, the fold-mirrors, and/or the grating(all together, they will cost $\sim$ 100 k euros) and with preparation of the room.

One realistic view concerning Rozhen NAO echelle spectrograph is that its maintenance will expand over next 3 years (2011-2013) at least. We have to follow three main steps:

- to choose the characteristic of the spectrograph and its final design. On that point there is more or less agreement among the astronomer society in Bulgaria.
- to find the executive team(or institution) which will perform spectrograph assemble and sign the contract. As known the echelle spectrographs are not sold on the market. They are manifactured on demand and the overall maintenance of the spectrograph till its commissioning takes 3-5 years. More than one instruments of this kind have already been manufactured by the University of Heidelberg (Germany), University of Florida (USA), Astrophysical Laboratory in Toulouse (France). The price of the spectrograph depends on the ordered completeness stage. One possible option to reduce the price actually is to offer observing time with 2-m telescope to the organization which will be involved in spectrograph preparation. There is also a choice to invite Dr. Faig Mussaev (Special Astrophysical Observatory, Russia) to assemble the optical part of the spectrograph. Dr. Mussaev has already manufactured a Coudé echelle for Terscol 2-m telescope and Kazan University 1.5-m telescope and a fiber fed echelle for Poznań Spectroscopic Telescope 2 (0.7-m).
- ensuring additional funds required to finalize the project. We are permanently looking for new projects with the NSF and appropriative European founds.

The main scientific goals achievable with an echelle spectrograph are well defined - asteroseismology studies, pulsing stars, search for extrasolar planets, and the study of the mass of binary stars. As we commented above, the absence of such instrument already produces an important hole in the scientific schedule of the Rozhen 2-m telescope, and highly reduces the science productivity of Bulgarian astronomers. The observing facilities of the Rozhen NAO are unique in the South-East Europe and the proposed instrument will strengthen our position not only in the region. It will be a fundamental mid-stone for the successful integration of the Rozhen 2-m telescope among mid-class telescopes in the Europe, to train astronomers in schools relevant to European Astronomy and to perform pilot studies for forthcoming satelit missions.

Meanwhile some preliminary steps have already been done in collecting information, educating young people and gaining some experience in processing and analyzing echellegrams.

- Since 2008 Dr. Konstantinova-Antova and two younger collaborators from the Institute of Astronomy are in close collaboration with Dr. Michel Auriére (Observatoire Midi-Pyrenées, Tarbes, France) on detection and investigation of a magnetic field in the photosphere of late type giants based on echellegrams. She and her Ph.D. student Svetlana Tsvetkova have gained a good experience observing with the spectropolarimeter

NARVAL at the 2-m Bernard Lyot Telescope (Pic du Midi de Bigorre, France).

- Since 2010 Department of Astronomy (Sofia University) and Institute of Astronomy in joint collaboration have a Ph.D student in the International Max Planck Research School for Astronomy and Cosmic Physics at the University of Heidelberg. The aim of his thesis is twofold - Bulgarian student to gain qualification in opto-mechanics and maintenance of echelle spectrographs and to be involved in the exoplanets investigations.
- In the beginning of 2010 the author in collaboration with Dr. Zlatan Tsvetanov (Johns Hopkins University, USA) started a project to explore physical properties of eclipsing binary stars based on STEREO satellite mission photometry. The idea is appropriate stars with variable photometry behavior to be observed spectroscopically with ARC Echelle Spectrograph (Apache Point Observatory, New Mexico, USA) and Rozhen NAO Coudé. More than 10 echelle spectra have already been processed and analyzed by the author. Fig. 6 demonstrates our first result – a composed RV curve of the eclipsing binary system HD103694. The curve is constructed on the base of ARCES(black crosses) and Rozhen Coudé(circles) RV measurements.
- In June 2011, the author, Dr T. Bonev (director of the IA and NAO) and Dr. T. Tenev(an optical engeneer from the Solid State Physics Institute) have realized one week visit in France. They visited Telescope Bernard Lyot (TBL) on top of Pic du Midi de Bigorre, Observatoire Midi-Pyrénées in Tarbes and Laboratoire Astrophysique de Toulouse where they got familiar with the working environment of NARVAL (spectropolarimeter in operation at TBL) and carried out a comprehensive discussions with people involved in construction, maintenance and exploitation of the two spectropolarimeters - ESPaDOnS and NARVAL.

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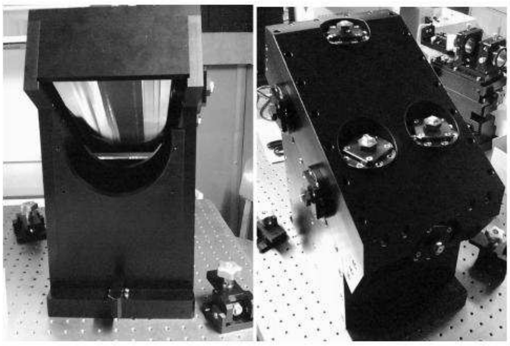

**Fig. 4.** A view of a typical echelle grating in a holder (BESO, Steiner [2006]). The small inclination of the working surface to the incident light is a characteristic feature for these gratings.

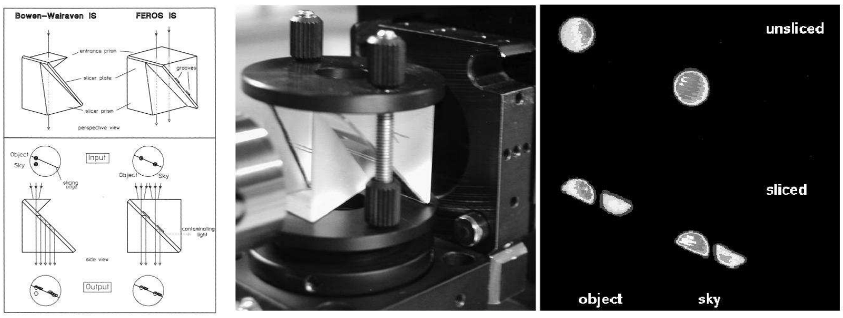


**Fig. 5.** Bowen-Walraven image slicer principle (left) and a sample performance (BESO, Steiner [2006])

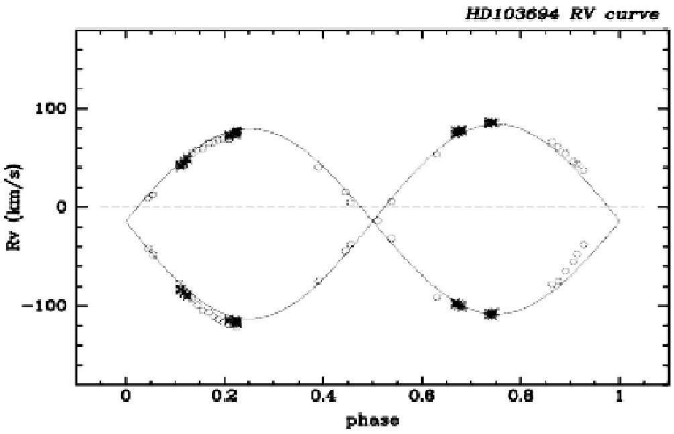


**Fig. 6.** Composite RV curve for the eclipsing binary system HD103694. With black points are marked echelle data but with circles Coudé results.