BACHES – A Compact Light-Weight Echelle Spectrograph for Amateur Astronomy

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BACHES is a low-cost, light-weight echelle spectrograph suitable for observations of bright stars coupled with small telescopes up to 35 cm (14″) in diameter. The resolving power reaches 19 000 in a continuous spectral range between 390 and 750 nm. The throughput of the instrument including the telescope and detector is 11 % peak at 500 nm. With this efficiency spectra of stars of visual magnitude 5 can be obtained in 15 min exposure with a S/N of 50. One of the goals of the instrument is to monitor the spectral variability of Balmer emission lines in Be stars.

The availability of key components such as diffraction gratings and high-sensitivity CCD cameras at affordable prices now allows the construction of inexpensive but fairly high-performance spectrographs. A large number of amateur astronomers routinely take spectra of planets, stars, comets and bright extended objects. Thus some years ago we started building low-resolution spectrographs for small telescopes. These models were rather heavy and cumbersome and therefore had to use optical fibres to link to the telescope. FIASCO (FIbre Amateur Spectrograph Casually Organised) was our first prototype. Using a 200 µm fibre linked to a 25-cm telescope, a Peltier-cooled CCD camera and a 600 l/mm grating, we obtained spectra with a resolving power of 600. However, even with this spectrograph we were able to detect the sodium lines in comets Hyakutake and Hale-Bopp in 1996 and 1997 respectively (Avila 1999). Nowadays, the amateur spectroscopy community is moving towards higher resolving power in order to include more ambitious scientific goals, such as surveys of the spectral variability of Balmer emission lines in Be stars and even detection of exoplanets (Kaye 2006).

Following this evolution, we therefore designed an echelle spectrograph light enough to be attached directly to small telescopes. The weight should not exceed 2 kg (without the CCD camera) and the size should be reasonably commensurate with that of typical amateur telescopes. Thanks to the availability of low-cost echelle gratings and light-weight (but still relatively bulky) CCD cameras, we could achieve these objectives. The development of the instrument was a collaboration between a group from ESO and the mechanical workshop for apprentices of the Max-Planck-Institut für extraterrestrische Physik in Garching.

The first light of BACHES took place in September 2006 with observations of bright stars like Albireo and Deneb with a 35-cm Celestron telescope. In March 2007 we initiated observations of Be stars (primarily ζ Tau).

The instrument

BACHES ('pothole' in Spanish) stands for BAsic eCHElle Spectrograph. Figure 1 shows the instrument attached to a 25-cm telescope. A 25 × 100 µm slit engraved in a reflective nickel plate is used to check the position of the star in front of the slit. A Phillips ToUcam webcam monitors the image of the star on the slit plate. A doublet collimates the telescope beam to a 79 l/mm, 63° echelle grating. Then the diffracted beam reaches a diffraction grating acting as cross-disperser. Finally an objective is used to project the spectrum on the CCD. The camera is an SBIG ST-1603ME with an array of 1530 × 1020 pixels of 9 µm. The spectrum is composed of 29 complete orders covering a range between 390 and 750 nm. The instrument has been designed to match F/10 apertures and the slit width projects on to 2.4 pixels. Figure 2 shows the spectrum of a thorium lamp. The measured resolving power ($\lambda/\Delta\lambda$) is between 18 000 and 19 000 over the entire spectral range.

The data reduction is carried out with an adapted version of the ECHELLE package in MIDAS. The process performs the following steps: bias level and dark current subtraction; removal of hot pixels; wavelength calibration with a thorium-argon lamp; extraction of the 1D spectrum; rebinning to wavelength units. MIDAS scripts are used to automate the identification of the thorium-argon lines for

Figure 1: BACHES attached to a Celestron CGE 11″ telescope with a Losmandy Equatorial G-11 mount.

Photo: C. Guirao, ESO

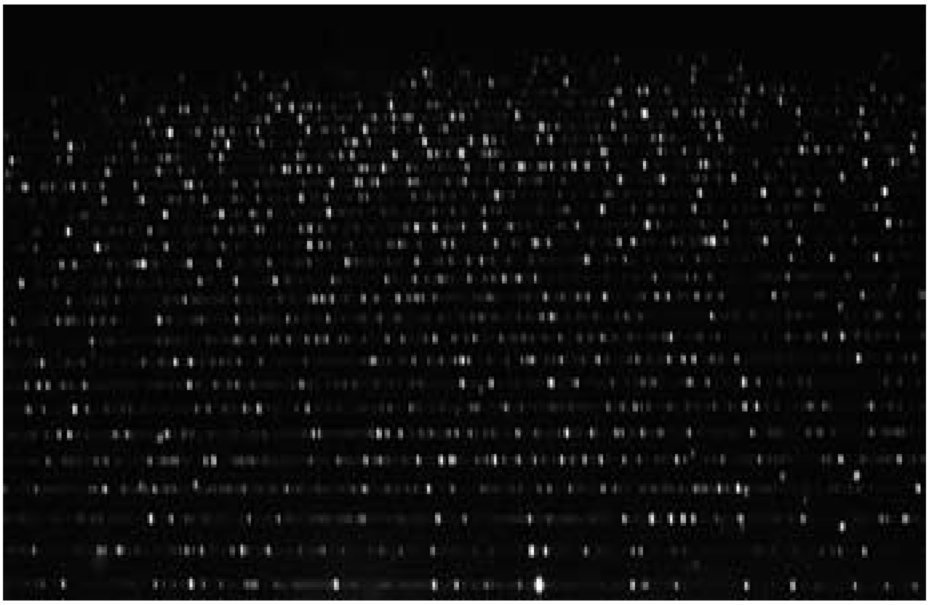

Figure 2: Spectrum of a thorium-argon calibration lamp with a 5 s exposure. 1500 lines are detected and 80 % are typically identified (calibrated) with the MIDAS/ECHELLE calibration procedure.

wavelength calibration and for executing a kind of pipeline. The data reduction package and a demonstration can be found at *www.eso.org/projects/caos/spectrograph/baches.html*. Since MIDAS can run under Windows through the Linux emulator Cygwin/CygwinX, a single computer can be used for both acquisition and reduction of the spectra.

The measured peak throughput of BACHES is 27 % at 504 nm. The quantum efficiency (QE) of the CCD at this wavelength is 52 % according to the data sheet. Assuming a throughput of 81 % for the telescope (corrector plate and 2 Al mirrors), the total throughput from the atmosphere to the detector is 11 %. For comparison the peak efficiency for the red arm of UVES under the same conditions is around 17 %. But for an instrument thousands of times cheaper than UVES, the efficiency is not bad, especially since most of the difference is due to the difference in both the QE of the CCDs used and the echelle grating. On the sky, with our equipment, we can observe stars down to $m_v = 5$ with an exposure time of 900 s and a measured signal-to-noise ratio of around 50 per pixel.

The main problem encountered with this prototype was the relatively poor mechanical stability. In the worst conditions (telescope very low and rotation of the spectrograph through 180 degrees) we observed a shift of the spectrum on the CCD by up to 3 pixels (27 μm). However, the main sources of instability have been identified and will be improved in the next model.

A first step towards scientific application: Variability of Hα and Hβ emission lines in the Be star ζ Tauri

About 10 % of all B-type stars exhibit Balmer (and other) emission lines, which arise from a disc-like circumstellar envelope, composed of material lost by the central B star. How such discs are formed is at most partly understood. But all Be stars are rotating at 90 % or more of their break-up velocity, which must be an important factor. The interplay between ejection mechanisms and dissipative processes in the disc (involving also stellar radiation pressure) often leads to the cyclic build-up and dispersal of the disc, which manifests itself in the appearance and disappearance of the Balmer emission. The spectroscopic monitoring of this variability can reveal important details about the ejection geometry, the circularisation of the ejecta, the geometry and dynamics of the disc, etc., provided the S/N and spectral resolution are sufficient. The nominal performance of BACHES should fully satisfy these requirements. Moreover, there are enough bright Be stars so that at almost any time and location one or more of them are within reach of BACHES. Therefore, the good match between BACHES and Be stars is bidirectional.

In order to verify the suitability of BACHES for such studies, we initiated a series of observations of ζ Tau (HD 37202) with our telescopes. Figure 3 shows the variability of the Hα and Hβ emission lines between 12 March and 25 April 2007. The first spectrum was taken in Garching with our AGAPE telescope, a 35-cm Celestron. At the time of these observations ζ Tau was quite low in the West at an Hour Angle of about 4 hr and the air mass correspondingly high. The spectrum shown is the average of three exposures of five minutes each. The second observation took place on 31 March 2007 in Paranal. Finally, the last two spectra were made in Garching with the AGAPE 35-cm telescope. This time we increased the number of exposures to five (300 s each). As revealed by the extracted spectra, the signal-to-noise ratio is not considerably improved, but 3 × 300 s exposures is enough for an accurate analysis of the hydrogen Balmer lines.

The spectral variability that can be seen in Figure 3 is rather complex. It is different from the variability seen in most other Be stars in that the Hα emission has a triple-peaked profile. ζ Tau is a single-lined spectroscopic binary with an orbital period of 132.97 days, and it is thought that the rich structure of the emission profiles is due to this circumstance. One of the objectives of monitoring ζ Tau in the forthcoming observing season is to search for a relation between the spectral variability and the orbital phase.

These few reconnaissance spectra are already sufficient to demonstrate convincingly that, with bright enough targets and/or large enough (but still small) telescopes, BACHES can satisfy the needs even of relatively demanding scientific research projects.

In summary, BACHES is a light-weight, low-cost, medium-resolution echelle spectrograph suitable for science-driven observations of bright stars and especially for the monitoring of time-dependent phenomena. A spectral resolving power of 18 000 is fully adequate for many scientific purposes. Its simplicity and low manufacturing cost make BACHES affordable for student training courses at universities and for advanced amateur observatories alike. We will continue to quantitatively characterise the properties of BACHES, e.g. the stability of the wavelength calibration, the homogeneity and stability of the point-spread function, the correctability of spectra for the echelle ripple function, etc.

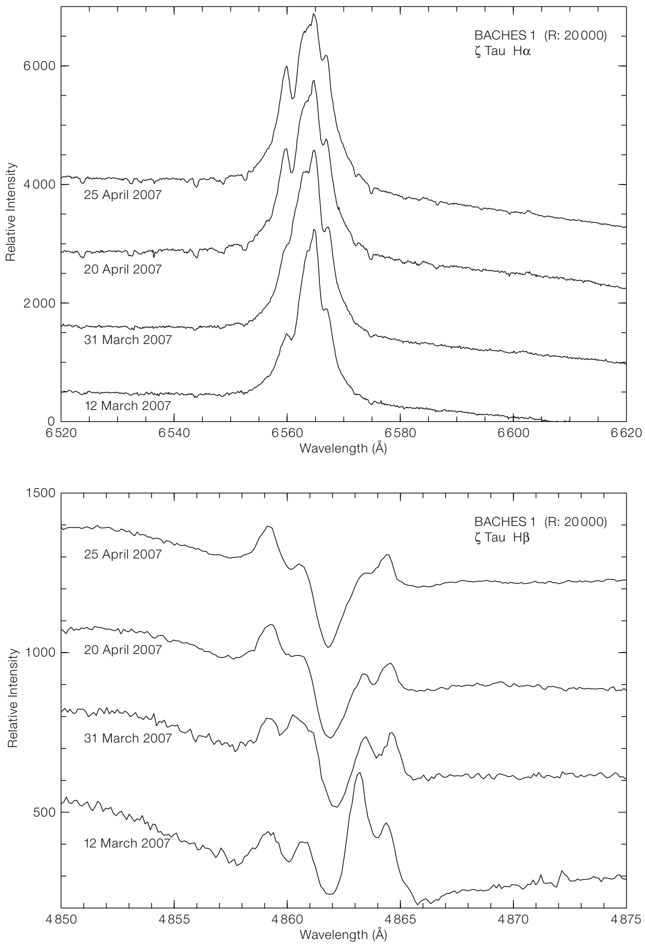

Figure 3: Evolution of Hα and Hβ lines in ζ Tau over 44 days.

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References

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Kaye T. et al. 2006, J. Br. Astron. Assoc. 116, 2
Pollmann E. 2007, IAU Inf. Bull. Var. Stars, 5778
For a list of spectroscopy amateur web sites see for example: *http://www.astroman.fsnet.co.uk/players.htm*

Report on the ESO Workshop on

Obscured AGN across Cosmic Time

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While the radio-loud, obscured quasars (the radio galaxies) have been known and studied for decades, new and sensitive X-ray and mid-infrared surveys are now beginning to reveal large numbers of their radio-quiet counterparts beyond the local Universe. Consequently, we are approaching the compilation of a relatively complete census of AGN of all types covering a large fraction of cosmic time. This is revealing a remarkably intimate connection between the supermassive black hole and its host galaxy. The workshop reported here was designed to explore the results of these rapid observational developments and the nature of the relationships between the stellar and AGN components.

Introduction

Research areas in astronomy occasionally experience a period of rapid growth due either to the development of some new observational capability or to the si-