The STELLA échelle spectrograph, five years of robotic high-resolution spectroscopy

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Abstract. The STELLA robotic observatory is made up of two 1.2m telescopes. One is feeding an échelle spectrograph with a spectral resolution of 55,000 since 2006, the other is equipped with an imaging instrument with a field of view of 22′. Data are collected during every clear night, calibration data are also taken during bad weather periods to assure the functionality of the system. All CCD frames are stored locally and immediately queued for transfer to the AIP. All environmental data together with meta-data about the scientific observations are stored in a SQL database, which is replicated to our data center in Potsdam. Data reduction is started after each observing night, results of the post-reduction analysis, like radial velocity and stellar parameters, along with the reduced spectra are inserted into the database. This database, with information spanning from how often a target is picked, when it has been successfully acquired, how big were the guiding errors, all the way to radial velocities measurements is an essential tool for both data analysis and quality control.

Keywords: STELLA – control system – robotic

1. The STELLA observatory

STELLA is located at Teide observatory, located on the Tenerife island at an altitude of about 2400 m, and started routine operation in June 2006. It consists of a single rectangular building (Fig. 1) which houses the two telescopes (Fig. 2). The building is equipped with a roll-off roof, that can be opened and closed independently of the telescope position. The power of the roof drives is backed by a UPS, and a watchdog

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†Based on data obtained with the STELLA robotic telescope in Tenerife, an AIP facility jointly operated by AIP and IAC.

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Figure 1. The STELLA building at dusk. The telescope to the left is STELLA-2 with the tubular acquisition and guiding unit at the top. The imaging STELLA-1 at the right has a large secondary mirror to obtain a field-of-view of 24″.

Figure 2. The STELLA telescopes. Left: The STELLA-1 telescope is optimized for wide-field imaging, the field of view is about 24″. Wide Field STELLA Imaging Photometer (WiFSIP) with its 24-position filter-wheel is visible on the right side of the telescope. Right: The STELLA-2 telescope, with the tubular acquisition and guiding unit and the prime-focus corrector. For coarse acquisition, a 150 mm refractive telescope is used on both telescopes.

makes sure the roof is closed if the control system fails. The first telescope, STELLA-1, was installed first and was used to feed light to the STELLA échelle spectrograph (SES) until 2010. Later that year, it was equipped with a wide field imaging instrument (WiFSIP). From then on, the second telescope, STELLA-2, was used to feed light to the SES. For this purpose, a prime-focus corrector with a simple acquisition and guiding unit was installed. Both telescopes have an aperture of 1.2 m and a f-ratio of about 8. The SES is located in a thermally controlled room, mounted on an optical bench which is again thermally insulated. It records the visible spectrum from 380 to 870 nm in one image at a resolving power of 55,000.
Figure 3. Shift of calibration lines with time and barometric pressure. The inset shows the residual scatter not caused by barometric pressure which is probably dominated by thermal effects.

2. SES Operations & Control system

STELLA is a robotic observatory. There is no remote control, no user interaction is necessary or even possible in routine operation. Building and environment control are a physically and logically separate subsystems, observations just depend on the roof to be open. Each telescope’s Master Mind chooses the optimum target at any time from its pool of proposed observations (dispatch scheduling). User defined merit functions are used to weigh the observing parameters. Details about the STELLA Control System (SES) can be found Granzer et al. (2011).

The raw data of the SES are recorded locally on disk and are then compressed using a loss-less algorithm. Then its meta-data are recorded into a SQL database, which is replicated to the AIP in Potsdam, and the raw data are queued for transfer. The data transfer usually happens within a few minutes, and at the end of each observing night the SES pipeline reduces the night’s data and puts the results of the data reduction into the database.

Data reduction relies on the IRAF-based STELLA data-reduction pipeline (Ritter & Washuettl 2004; Weber et al. 2008). The images were corrected for bad pixels and cosmic-ray impacts, Bias levels were removed by the subtraction of the mean of the master bias frame. The target spectra were flattened by dividing by a nightly master flat which has been normalized to unity. The nightly master flat itself is constructed from 50 to 100 individual flats observed during dusk, dawn, and around midnight. After removal of the scattered light, the one-dimensional spectra were extracted using the standard IRAF optimal extraction routine (Horne 1986). Wavelength calibration
is done using consecutively recorded Th-Ar spectra. Then we determine the radial velocity of each observation, estimate $v \sin i$, and run PARSES (Allende Prieto 2004) to obtain the basic stellar parameters ($T_{\text{eff}}$, $\log g$, [Fe/H]). Finally, the extracted spectral orders were continuum normalized by dividing with a flux-normalized synthetic spectrum of the derived spectral classification.

Due to its isolated location, the spectrograph is very stable over the years. Fig. 3 illustrates the scatter of our calibration images, which is dominated by atmospheric pressure fluctuations. After correcting for atmospheric pressure changes, the remaining scatter is dominated by temperature fluctuations on the optical bench. This temperature varies about 0.1°C over short timescales due to limited sensor resolution, and with 0.5°C year around due to the changing temperature gradient in the spectrograph room. During times of misalignment of the fiber, there was also a shift in the radial velocities due to spectrograph illumination effects. Fig. 4 shows all observed observations of radial velocity standard stars. More details about the radial velocity measurements and the zero-point of the STELLA radial velocity system can be found in Strassmeier et al. (2010).

### 3. Five years of robotic spectroscopy

Robotic operation of the STELLA observatory with the SES started in June 2006. Since then, the instrument takes data during each clear night. A few technical down-times, approximately one per year, occurred. Some of them were caused by severe weather, which caused prolonged power outages which resulted in some equipment not coming back on-line. Two telescope defects needed to be repaired by an AIP service team.

During the past five years, the overall open shutter time was a bit above 60%, e.g. the time loss due to bad weather, technical failures and calibration amounted to less...
Figure 5. Left: Total open shutter time per night (black bars) compared with the available dark time for each night (red line). Right: At the right, the number of images obtained each night is shown.

Figure 6. Left: The efficiency of the SES, plotted is one average value for each observing night. Right: The obtained average signal-to-noise ratio for various brightness bins. Note the shown are average values, which also incorporate data taken during low-efficiency periods.

During the first months of operation we experienced a lower than expected efficiency of the system. We expected about 3%, but the actual efficiency was usually below 0.5%. A thorough analysis of the light path at the observatory in fall of 2006 unveiled a misalignment of the optical fiber input at the telescope. We fixed that issue, but it re-surfaced after a change in the fiber-adjustment mechanics early 2007 (corresponding to the two shaded areas in Fig. 6). Later efficiency drops were caused by Sahara dust accumulation on the mirrors of the telescope. This dust issue was solved by installing a dust meter which keeps the roof closed during periods of dust. During the transition phase from STELLA-1 to STELLA-2 in 2010, the aperture of the new pinhole mirror in the prime-focus unit was almost completely blocked. Exchanging
this pinhole finally resulted in the previous efficiency region. A future upgrade of the spectrograph should significantly increase the efficiency of the system.

Currently, the limiting magnitude to get a signal-to-noise ratio of more than 100 in less than one hour integration time is roughly 8\text{m}, the practical limit for spectroscopic observations is usually 10\text{m}, but observations have been obtained for stars fainter than 12\text{m} (Fig. 6, right).

4. Future plans

At the end of 2011, an upgrade of the SES is planned. The main goal of the upgrade is to boost the peak efficiency around the $R$-pass-band to increase the limiting magnitude of the system. At the same time, the efficiency of the system towards the blue end should be greatly improved. This is currently limited by the glass of the cross-dispersing prism, the corrector plate of the optical camera, and the lack of an atmospheric dispersion corrector. All three of these issues will be solved. Due to the deployment of a larger CCD detector, we will also eliminate the order gaps in the red part of the spectrum, and create the possibility of simultaneous wavelength calibration by increasing the cross dispersion. The upgrade will consist of a new refractive camera optics that replaces current Schmidt camera for higher throughput, better scattered light performance, and better UV sensitivity, a new CCD camera with four times larger area (4kx4k with 15$\mu$m pixel size instead of 2kx2k with 13.5$\mu$m pixels ), new cross disperser prisms made out of UV-transparent glass to allow for simultaneous calibration and image slicer, silver coating of the spectrograph collimator for higher throughput, and ADC prisms for 4 different altitude ranges. On the software side, we will upgrade the PARSES package to use the complete wavelength range to derive more accurate stellar parameters.

References

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