Publ. Astron. Obs. Belgrade No. 92 (2013), 21 - 26 *Contributed paper*

THE STELLA ROBOTIC OBSERVATORY ON TENERIFE

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Abstract. The STELLA project is made up of two 1.2 m robotic telescopes to simultaneously monitor stellar activity using a high-resolution spectrograph on one telescope, and an imaging instrument on the other telescope. The STELLA Échelle spectrograph (SES) along with the building has been in operation successfully since 2006, and is producing spectra covering the visual wavelength range between 390 and 870 nm at a spectral resolution of 55 000. The stability of the spectrograph over the entire two year span, measured by monitoring 15 radial velocity standard stars, is 30 to 150 m/s rms. The Wide-field stellar imager and photometer (WIFSIP) was put into operation in 2010, when the SES-lightfeed was physically moved to the second telescope. We will give an overview of the main scientific topics of the bulk of the observing programs.

1. INTRODUCTION

STELLA (short for STELLar Activity) is a fully autonomous observatory located at Teide observatory on Tenerife, Spain. The Teide observatory is located in the vicinity of Teide peak at Izaña, longitude 16°30′35"W and at latitude 28°18′00"N at an altitude of 2390m above sea level. STELLA consists of two independent, 1.2m telescopes, each of them serving a single instrument to avoid the necessity of instrument change. Both telescope have been manufactured by Halfmann Telescope in Augsburg, Germany and are modern az-alt telescopes with a maximum slewing speed of 10°/s. The observatory housing was finished in spring 2002, well before the telescopes have been delivered. It consists of two roll-off roof-halves, which are driven by standard industry crane motors. The early completion of the building left ample time for testing the reliability of building operation which main focus is a reliable protection of the instruments during bad weather periods. The meteorological observing conditions are measured by two separate weather stations. So far, the building automation has never failed to protect the instruments during harsh weather phases. All of the algorithms developed in the beginning are still in place unchanged, the only addition to the meteorological system has been the addition of a dust meter to allow the detection of low-altitude Sahara dust, a rather common phenomenon on the Canaries known as *Calima*.

The Stella-I telescope, which is an f/8 Cassegrain system with two available Nasmyth ports, has been delivered in the end of 2004. This telescope is optimized for wide field-imaging with an field-of-view of 24 arc minutes, but was originally feeding the STELLA Échelle Spectrograph (SES), an échelle spectrograph with a spectral resolution of 55 000 and a simultaneous wavelength coverage from 390 to 870 nm, which achieved first light on this telescope in September 2005. An acquisition and guiding until was constructed for the fixed Nasmyth port, which held the fiber input to the spectrograph, a focus pyramid and a gray beam-splitter to divert 4% of the light to a small, uncooled KAF-0402 detector system (Strassmeier et al. 2004).

In late 2005, the second telescope, STELLA-II has been delivered. STELLA-II is equipped with only one f/8.4 focus at the top ring, where a refracting corrector

Figure 1: View of the STELLA building just after sunset, the roof is rolled off to the sides of the building. The STELLA-I telescope is located at the right (West) side of the building and is open for sky flat fields, the STELLA-2 telescope is located at the left (East side). Also visible at the right edge is the ASIVA, an infrared cloud monitor, located on it own column about 20m from the main building.

system corrects the light from the spherical primary for a field of approximately one arc minute. The light enters the 50μm fiber in a small unit which also houses an optics wheel with as set of fixed atmospheric dispersion correctors, a small focussing unit and a acquisition camera which is also used for guiding on the residual light reflected from the inclined, reflective pinhole.

The formal opening of the observatory took place in May 2006, and the SES science demonstration program was started soon thereafter. The second instrument, the wide-field imaging photometer WiFSIP (Wide Field Stella Imaging Photometer) was completed in 2009. It underwent testing on our 80cm sister telescope of STELLA-I, RoboTel, located at the AIP campus in Babelsberg. This telescope is now equipped with another WiFSIP copy. WiFSIP features in brief:

- 4k$\times$4k ITL chip with 15μm pixel and support four-amplifiers readout.
- The usable field-of-view is 22 arc-minutes squared.
- Johnson UBV(RI)$_C$, Sloan u'g'r'i'z' filters, and a full Strømgren set uvby including H$_\beta$ wide and narrow.
- H$_\alpha$ photometry with a wide (FWHM=18nm) and a narrow filter (FWHM=3nm).

WiFSIP was delivered to Tenerife in 2010, where it was mounted on STELLA-I. At the same time, the spectrograph input fiber was moved over to STELLA-II achieving 'second first light' in May 2010. Since then, both telescopes are operating, but a few necessary updates are still ongoing: the spectrograph gets a more efficient optical camera, a larger CCD detector system and a modified fiber feed, while the CCD

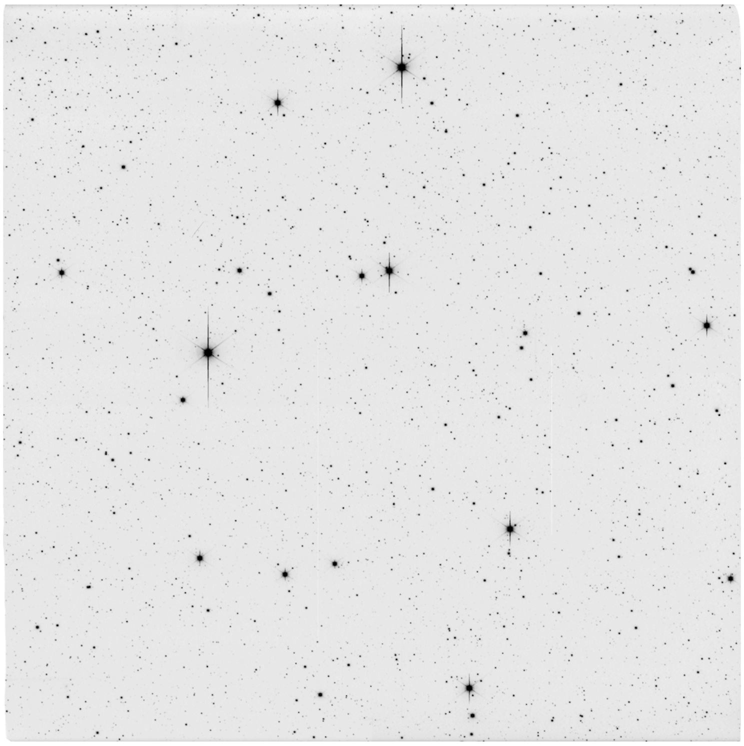

Figure 2: Example SOCS data: a single image of NGC 7092, exposure time 40 s in Sloan r'. We use this passband to derive rotational periods.

detector system of WiFSIP will be replaced with a similar device with better cosmetics and therefore better flat-field accuracy.

2. STELLA/WiFSIP

Due to tight space restrictions, STELLA-I could not be equipped with an off-axis guiding system, which was originally anticipated to fit to the side of the main WiFSIP camera. Instead, a piggy-back mounted auxiliary telescope is used for acquisition and guiding. This auxiliary telescope is a 15cm refracting telescope equipped with a KAF-3200 detector. Differential bending between main and auxiliary telescopes amounts to 136 arc seconds in elevation between horizontal and vertical pointing. A differential pointing model to compensate for this differential bending was derived with an original RMS of 2 arc seconds. Disappointingly, it degraded after half a year to currently roughly 45 arc seconds RMS. This is acceptable for short exposure times up to 25 minutes, depending on pointing direction, but rules out very long exposures.

The current calibration scheme relies on sky-flats, but the installation of an illumination panel inside the dome is being investigated. A smaller version, consisting mainly of an illumination foil, is being tested at the RoboTel telescope in Potsdam. During each twilight, three filters can be measured at ten exposures each. With a total of 18 filters, this allows for repeated observations of flat field with an average cycle

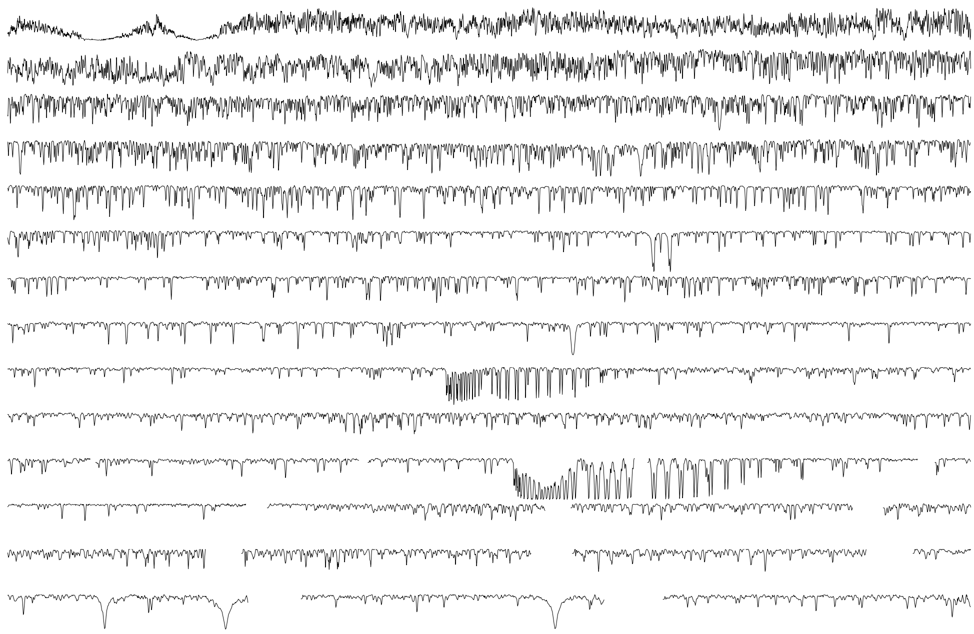

Figure 3: Example SES data: a full spectrum of HD 1. The wavelength coverage is from 390 to 870 nm, the gaps towards the red end of the spectrum are due to the comparably small format CCD detector in use until 2012.

period of three days. Prior to the twilight flat, a number of bias and dark frames are obtained. Regular science frames start at an sun height of $-14°$, but non-standard observations (time critical or targets of opportunity) may commence at any time the sun is at least $6°$ below the horizon. Since first light more than 188000 science frames have been obtained as of Februar 28, 2013.

The first science program, a monitoring program on open stellar clusters is not affected by guiding errors due to the rather short exposure times. Figure 2 shows a full-frame exposure of one of the target clusters, NGC 7092. The image was taken in Sloan r' at an exposure time of 40sec. More than 7000 sources have been detected in this frame, at an average FWHM of 1.3 arc seconds.

2. 1. WIFSIP CORE SCIENCE

The main advantage of the STELLA robotic telescopes is the time domain, since tasks can be defined in a very general way without the need to squeeze the observations in a short time-window. It is was therefore a logical step to combine Stellar Activity and Time series in the core science program of STELLA/WiFSIP, which is the STELLA open cluster survey (SOCS). The main goals of this programs are:

- Rotational Periods of open cluster stars.
- Age sequence of clusters delivers $\Delta P/\Delta t$.

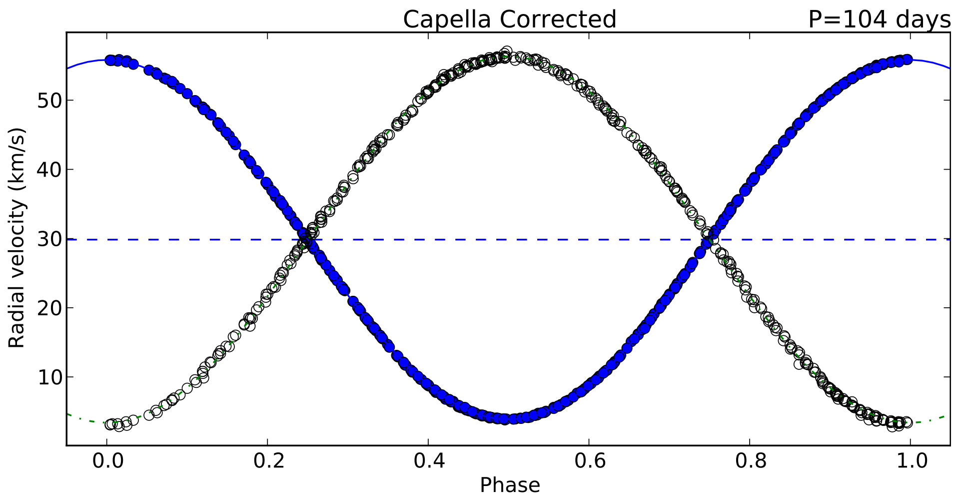

Figure 4: Example SES radial velocity data: we observed Capella for several years to improve the orbital parameters, namely the mass-ratio of the two components.

To achieve this, a cluster age-sequence is observed in a single filter many times to derive the stellar rotation periods, and is observed once in Strømgren filters to derive physical parameters of the cluster member stars. Besides this core-science program, general proposals like planetary transits and gamma-ray burst follow-ups are observed.

3. STELLA/SES

SES is a bench-mounted, white-pupil spectrograph with a fixed wavelength range of 390-870 nm obtained during a single exposure (Weber et al. 2008). Figure 3 shows a spectrum of HD 1, an object observed during the science-verification phase Strassmeier et al. 2010). SES is fed with a 50μm fiber, allowing for a resolution of R=$\Delta\lambda/\lambda = 55000$. For stability, it is located in a temperature controlled environment in a separate room below the telescope bay. Heat foils on the walls and below the spectrograph cover allow us to keep the temperature on the optical table at an average of 19.6°C, with an RMS of 0.68°C, which is a little bit higher than the anticipated 0.5°C, but still allows radial-velocity determination with a long-term error down to ≈50m/s (see Weber & Strassmeier 2011).

The calibration sequence on the spectroscopic instrument starts with a single Thorium-Argon spectrum, followed by a block of 20 bias exposures. Then, another Thorium-Argon spectrum follows. Flat-field is then calibrated by obtaining 60 single exposures. Finally, just before the roof opens, another Thorium-Argon spectrum is obtained. Calibrations are done with dedicated halogen or Thorium-Argon lamps. In total four lamps are present to allow on-the-fly replacement if one burns out. The proper calibration lamp is selected with a linear stage in a light-tight calibration box residing in the main electronics room of the observatory. Its light is fed with a 200μm calibration fiber up to the science fiber entrance at the telescope's AG-unit.

Acquiring on the target star is a two-staged process. A piggy-back telescope identically to the one on STELLA-I is used to raw-acquire the target star. Within the fiber unit of STELLA-II, a small industrial firewire (Unibrain-520b) fiber-viewing camera is used. This camera features a 640×480 pixel progressive scan CCD at a pixel size of 7.4 μm. It has a tunable exposure time from 1 μsec. up to 65 sec., which allows acquiring and guiding of stars from 0^{m} down to 14^{m}. After the coarse acquire with the auxiliary telescope has completed, the fiber viewing camera takes over. Its field-of-view spans roughly 2×1.5 arc minutes, enough to accommodate differential bending effects between the main and the auxiliary telescope. Guiding is done on the light spilled over at the fiber entrance using a simple center-of-gravity method. Since first light, we obtained more than 37000 science spectra.

3. 1. SES CORE SCIENCE

The core-science of SES is time-series Doppler Imaging. This is the science application the observatory and its scheduling system was designed for. Our interest is to monitor changes of stellar activity on stars comparable to the global solar sunspot cycles (which lasts about 11 years) or the decay rates of starspots.

Since this core-science program is very demanding for the scheduler due to the phase-coverage needed for Doppler imaging, only a moderate share of the available time is used by this program. During the remaining time, a wide range of programs are carried out. We observed a number of active stars to obtain updated or new orbital parameters in case they were binaries (Strassmeier et al. 2012), for example. Further examples are revised orbital parameters of Capella (Fig. 4, Weber & Strassmeier 2011), and high-resolution spectra contemporary to FORS-observations of FK Com (Korhonen 2009).

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