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STELLA Robotic Observatory for Stellar Activity Research

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Abstract

The STELLA Robotic Observatory (abbreviation for STELLar Activity) is a long-term project for observing and monitoring activity tracers on cool stars with two robotic telescopes: STELLA-I equipped with a high resolution echelle spectrograph, a large-format CCD imager and photometer, and STELLA-II also equipped with an optical CCD imager and photometer. After listing the most important technical details we focus on some of the scientific programs planned for routine observations of active stars by STELLA.

Keywords: *Stars: imaging - Stars: activity - Starspots - Instrumentation: spectrographs - Instrumentation: photometers*

1 What makes STELLA robotic?

Automated photoelectric telescopes (APTs) have been widely used in observational astronomy for decades. However, when optimizing the scientific output the automation must not stop at a level, where a single observation is performed by the robotic telescope. The STELLA Robotic Observatory is a long-term project of the Astrophysical Institute Potsdam (AIP) in collaboration with the Instituto de Astrofísica de Canarias (IAC) located at the Teide Observatory in Tenerife, Spain, at 2400 m above sea-level, (in the longitude of 16^h 30^m 35^s west and in the latitude of 28° 18^m 00^s north). Its main scientific objective is the spectroscopic and photometric monitoring of activity tracers on cool stars. STELLA is organized to operate fully automatically, i.e., not only the two telescopes are automatic but also the entire observatory, no human presence is needed for observing - not even in remote control.

STELLA is controlled by the STELLA Control System (SCS). Its duty is the delivery of commands in a correct timing sequence to all other subsystems. SCS is fed by numerous sensors and cameras throughout the building, watching the status of the scientific instruments and their auxiliary equipment, as well as the current environmental conditions, local climate, humidity, cloud positions and other secondary systems like air conditioner.

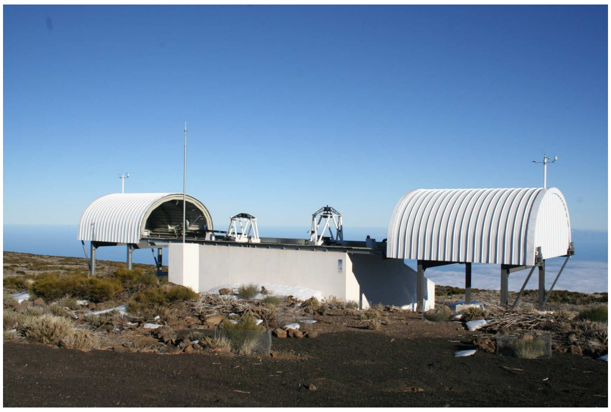

Figure 1: *The view of the STELLA building in Jan 2006. The building itself is automatic, the two roof halves are opened in the evening as ordered by SCS after evaluating the data of the two weather stations.*

2 The telescopes

The STELLA Robotic Observatory consists of two fully automated telescopes. STELLA-I is a 1.2 m diameter f/8 Cassegrain system with a Zeiss Zerodur mirror, an Alt/Az mount, and two Nasmyth foci. The telescope fiberfeeds an echelle spectrograph (SES) and hosts a wide field optical CCD imager and photometer (Wide Field STELLA Imaging Photometer-WIFSIP). The spectrograph has a fixed format to cover the wavelength range 380-860 nm in a single exposure. The 2-pixel resolution is 50,000 with a 50-micron fiber attached to a high-curvature microlens. A pair of 100-micron fibers for resolutions of approximately 25,000 will be available initially. The detector is a 2k×2k back-illuminated thinned CCD with 13.5μm pixels. The STELLA echelle spectrograph (SES) has seen first calibration light from Aldebaran on June 28, 2005.

STELLA-II is also a 1.2 m telescope, f/10, Alt/Az mount, Newton focus, also hosts an optical CCD imager and photometer (WIFSIP-II) and an adaptive optics testbed. WIFSIP-II is based on a large format CCD (22'×22') at a scale of 0.32"/pixel. The detector is a single 4096x4096 back-illuminated thinned CCD with 15μm pixels. Available filters are Strömgren *uvby*, narrow and wide H_α and H_β, Johnson-Bessell $UBVRI$ and the Sloan-filterset.

3 Target selection strategy: dispatch-scheduling

STELLA schedules observing targets according to astronomical conditions, weather and other constraints like the scientific needs of the different science programs. The scheduling schema is the so called dispatch-scheduling, i.e., at any given time all targets are queried for their actual merit and the target with the highest merit is selected.

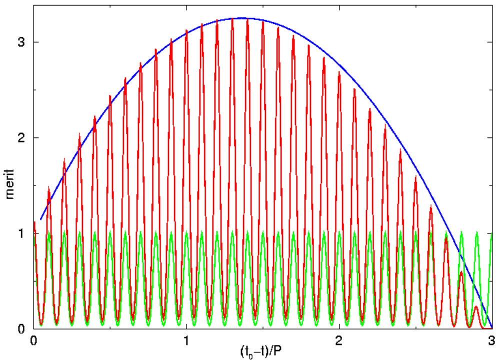

Figure 2: *Target specific merit for Doppler-imaging: taking spectra near peak values of evenly spaced selection windows ensures good phase coverage while the modulator Gaussian keeps observations within a reasonable duration (e.g., in a few rotation periods).*

The merit function $m(t)$ of a certain target is built from two different parts, a slowly varying "time-slot" $s(t)$ and a possibly fast changing "gain" $g(t)$:

$$m(t) = \prod_j s_j(t) \cdot \sum_i g_i(t) \tag{1}$$

Gains are used e.g., to reflect priority of a target, to force observation at culmination (airmass gain) to minimize the telescope slew-time between targets (slew-time gain), to incorporate user fairness (user-gain), to reflect time remaining to observe a given target (window gain), etc. On the other hand, time-slots are used to pick up a target e.g., at regular intervals or only at a certain time, or (not) after/before a certain time, etc. As an example a possible combination of time-slots is shown in Fig. 2.

4 Scientific objectives

In this section we show two examples of studying stellar activity on a shorter and on a longer term. In such studies, in the nearest future, a great help could come from STELLA when performing routine photometric and spectroscopic observations for a large sample of active stars.

4.1 Measuring differential rotation from time-series Doppler images

The surface differential rotation, one key ingredient of dynamo theory, can be measured by tracing spot positions. Doppler imaging technique uses the rotation-induced Doppler-broadening of spectral lines to compute the surface distribution of the temperature. To obtain the surface image of a star, high-resolution spectroscopic observations, evenly distributed over one stellar rotation period, are needed. This turns out to be quite complicated for long period stars. STELLA addresses this problem with a dedicated scheduling routine, which is tailored for Doppler imaging targets. This will make observations for Doppler imaging not only easier, but also more efficient. As a preview of what can be done with STELLA, we present preliminary results of a Doppler imaging study for the giant component of the long period RS CVn star ζ Andromedae.

In our example we use a total of 54 Ca I 6439-Å spectra covering ≈3.8 rotations, collected at NSO between Nov/96-Jan/97. From the spectra we built 36 data subsets with 17 spectra in each in the way, that the first subset consists of the first 17 observations, the next subset is formed from omitting the first spectrum and adding the subsequent one to the end, etc., until the last 17 spectra are included. For each subset Doppler image reconstruction technique is performed using our image reconstruction code `TempMap`$_\epsilon$ originally written by Rice et al. (1989). The result is a time series of altogether 36 Doppler-maps. Then the consecutive but contiguous maps are cross-correlated and the resulting correlation maps are averaged. For the details of this method see Kővári et al. (2004). The resulting ccf map is shown in Fig. 3, where the best fit continuous line represents a weak solar-type differential rotation. The resulting differential rotation parameter $\Delta\Omega/\Omega_{\rm eq}$ of 0.061 ± 0.026 is about one-third of the solar value.

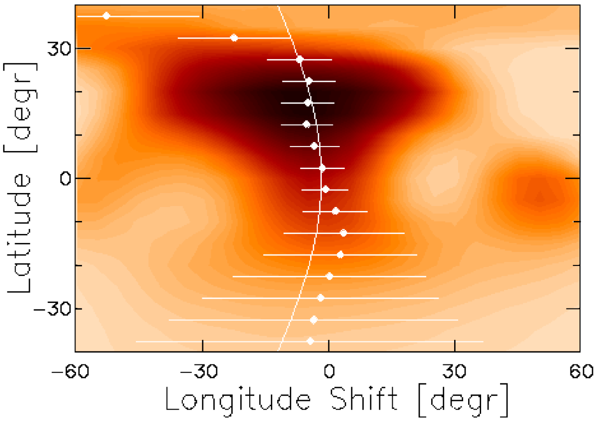

Figure 3: *Average cross-correlation map from the time-series Doppler maps, where the better the correlation, the darker the shade. For each latitude strip the maximum correlation is represented by the Gaussian peaks (dots) and the corresponding FWHMs (bars). The solid line is the best-fit solar-type differential rotation law.*

4.2 Activity cycles from long-term photometric monitoring

Since long-term photometric variations of active stars are known to be governed by changing their overall spot coverage, long-term monitoring can help us in extending our input knowledge for dynamo theory. The relation between activity cycle lenghts and rotational rates can be measured by long-term monitoring of different types of active stars (Oláh et al., 2000; Oláh & Strassmeier, 2002).

An example is given in Fig. 4, showing 23-year long photometric dataset of the single, rapidly rotating solar-like star LQ Hya. Data were collected between 1982-2005 mostly by the Vienna automated photoelectric telescopes, Wolfgang and Amadeus (`www.aip.de/groups/activity/APT/`). The existence of cycles in the stellar brightness in the order of several years is evident, in a good agreement with the cycle period derived from dynamo modelling of this star by Kitchatinov et al. (2000). Photometry, on the other hand, has limited information content: e.g., no butterfly diagram can be constructed from the data in lack of latitude information. On the other hand, simultaneous use of long-term photometry with time-series spectra from the automatic spectroscopic telescope STELLA-I would help in constructing butterfly diagrams for stars, too.

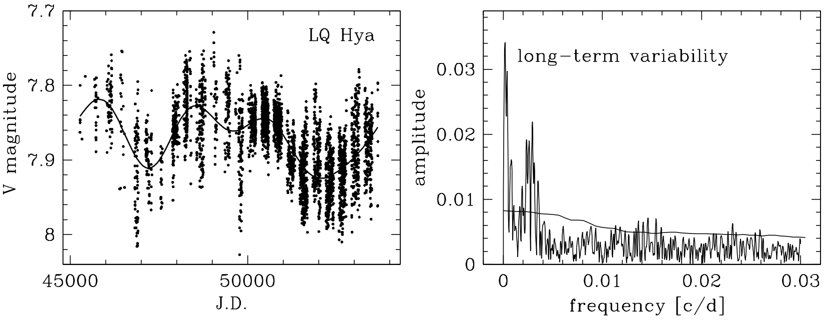

Figure 4: *Long-term monitoring of LQ Hya. Left: 23-year long photometric data fitted with two long-term cycle periods, right: the respective amplitude spectrum.*

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