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Monitoring mass motions of Betelgeuse's photosphere using robotic telescopes

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Abstract. We started monitoring Betelgeuse using STELLA/SES, the STELLA échelle spectrograph fed by a robotic 1.2 m telescope on Tenerife, and the automatic photometric telescope (APT) T7 in Arizona in fall 2008. In this first observing season, we have collected 67 high resolution spectra from 390 to 900 nm at a resolution of 50,000 and a S/N between 100 and 300, and a comparable number of photometric observations in the Hα filter. In this presentation, we report on the initial findings based on this first data set: Radial velocities, effective temperature (along with surface gravity and metallicity) are automatically computed by the STELLA/SES data reduction & analysis pipeline. We compare these global measurements and the photometric brightness with velocities and temperature indicators derived from individual spectral lines, to bring these values in line with recently published observations. Furthermore we compute synthetic line profiles from state-of-the-art 3D stellar convection models, and compare the line-profiles, their shapes and positions to our observations. The final aim of the observing program is to find out if the spectral line variations can be explained using these non-magnetic convection models.

Key words. Stars: atmospheres – Stars: observations

1. Introduction

Betelgeuse (α Ori) is a red supergiant star with spectral type M2Iab. Its brightness varies on timescales of years, as well as the shape of its spectral lines. See Gray (2008) for an overview of the stars properties and a recent discussion of the spectral-line variations.

2. Observations

The spectroscopic data were obtained with the STELLA/SES robotic telescope and spectrograph on Tenerife (Weber et al. 2008). The 1.2-m STELLA-I telescope (Fig. 1) is operated

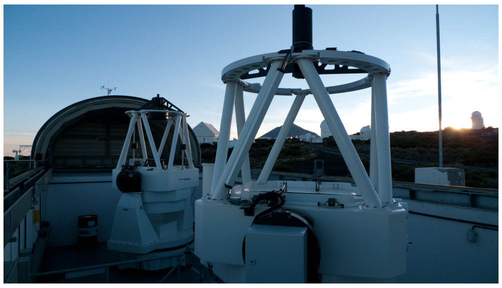

Fig. 1. The two STELLA telescopes on Tenerife: To the left the STELLA-I telescope, which feeds the spectrograph now, but will host an imaging instrument from 2010 on. To the right the STELLA-II telescope, which will feed the spectrograph from 2010 on.

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in fully robotic model, picking the best target based on a complex set of rules which are provided with each observing proposal. The telescope feeds the light through a 50 μm optical fiber to the bench mounted STELLA échelle spectrograph (SES), which is located in a climatically controlled room. The SES records the optical spectrum from 390 nm to 900 nm, with some small gaps above 700 nm, at a spectral resolution of 50,000. The observed spectra are automatically transfered to the STELLA-datacenter at the AIP, where they are reduced and post-processed. Post-processing includes radial-velocity measurements and the determination of $T_{\rm eff}$, metallicity and surface gravity. Unfortunately, since the lower temperature of our model-grid is 4500 K, only the radial velocity measurements could be used in the case of Betelgeuse.

The photometric data were obtained with the Amadeus 0.75-m automatic photoelectric telescope (APT), part of the University of Vienna twin APT at Washington Camp (Strassmeier et al. 1997). Fairborn observatory is located in Southern Arizona close to the Mexican border town Nogales. It hosts a total of fourteen telescopes, all of them operated robotically. The telescope is equipped with Johnson/Cousins (Bessell 1979) $V(RI)_C$ filters and a Hα-narrow filter. The measurements are carried out differentially in respect to a comparison and a check star. The order of observations is as follows: N-CK-S-C-V-C-V-C-V-C-S-CK, where N is a bright navigation star, CK the check star, S the sky background, C the comparison star, and V the main target (variable star). Since Betelgeuse is too bright to be observed in the broad Johnson/Cousins filters, we use the Hα-narrow filter to track its brightness variations. Since no standard stars are usually observed in this filter, only the Hα brightness relative to the comparison star is recorded.

In Fig. 2, we show the variation of the brightness of Betelgeuse together with the radial velocity variations, the V I 6251 to Fe I 6252 line ratio as temperature indicator, and the width of the Fe I 6430 line. As expected, the brightness follows the temperature indicators well. The radial velocity in general follows the same trend, but seems to be a bit out of phase: while the brightness was still dropping at the beginning of our observations, the radial velocity was already rising.

3. Models

We used star-in-a-box models from Freytag et al. (2002) to test if the line-profile variations on Betelgeuse are indeed caused by giant convection cells as the hydrodynamic models suggest. To test the influence of the choice of model we used two different ones, namely st35gm03n07 with 12 $M_\odot$ resulting in a surface gravity of −0.34, and st35gm04n29 with 5 $M_\odot$ resulting in a surface gravity of −0.47. We calculated 6 spectral lines, Fe I 6430, Fe II 6432, V I 6251 Fe I 6252, Ti I 6261, and Ti I 6273, for about 20 snapshots for each of these models using the spectral-line-calculation part of our Zeeman Doppler Imaging code (Carroll et al. 2008). At first we planned on using the Fe I 6430 to Fe II 6432 ratio (Strassmeier & Schordan 2000) to trace the temperature variations, since it seems well suited for extrapolation to lower temperatures. Unfortunately, despite a considerable line strength in the spectral lines from the models, the Fe II 6432 line was not present in the observations (see Fig. 4). This could be an indicator for a mismatch in temperature between observations and model. As a temperature-indicator we used the ratio of V I 6251 to Fe I 6252 instead (Gray & Brown 2001).

The results of the model calculations are shown in Fig. 3. The two different models show surprising different values for the four indicators shown. Therefore we could not plot all of the values to the same scale as in Fig. 2. The brightness is shifted by an arbitrary amount to reach the same relative numbers, as were the radial velocities.

4. Discussion & outlook

Comparing Fig. 2 with Fig. 3 shows some overall similarities between model and observations. But the magnitude of the variations of the four indicators is best matched by the

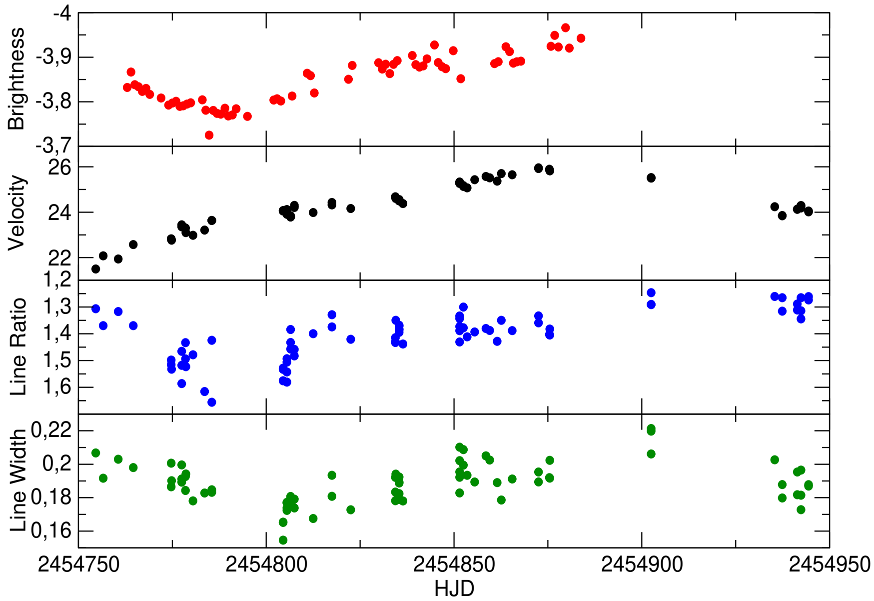

Fig. 2. Results of first observing season, from top to bottom: The brightness variation in the Hα-filter relative to a comparison star, the radial velocity variation relative to an artificial template spectrum of similar spectral type, the V I 6251 to Fe I 6252 line-depth ratio, and the Fe I 6430 line width.

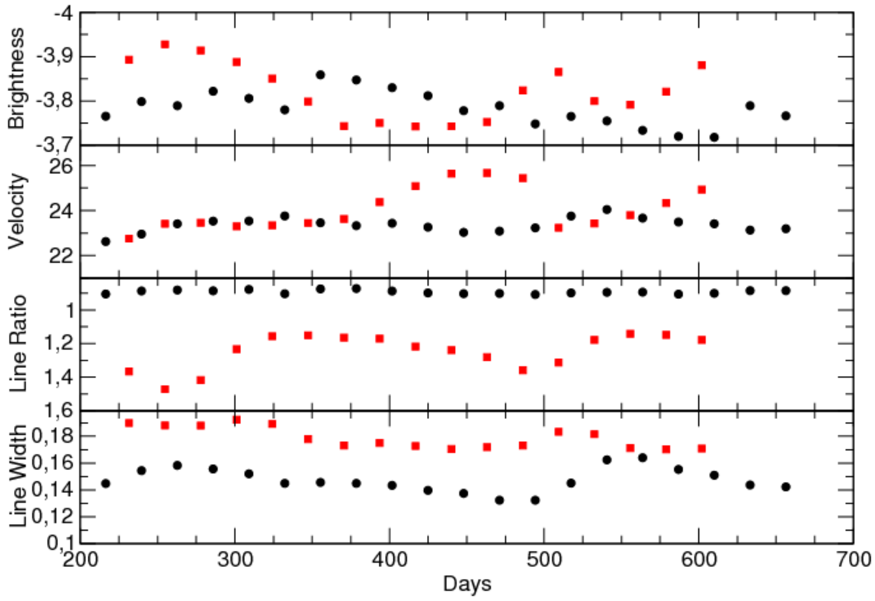

Fig. 3. Results as in Fig. 2, but derived from a series of snapshots from the two models st35gm03n07 (circles) and st35gm04n29 (squares): The brightness corresponds to the continuum brightness at 6251 Å, the velocity to the shift of the spectral line-cores, the line ratio is again the V I 6251 to Fe I 6252 line-depth ratio, and the line width from the Fe I 6430 line.

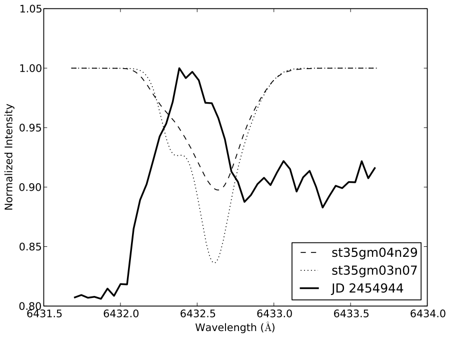

Fig. 4. Comparison of one Fe II 6432 observation with the models. The only trace of the line is a small asymmetry in the blue wing of the neighboring line. The line profile of st35gm04n29 is significantly weaker.

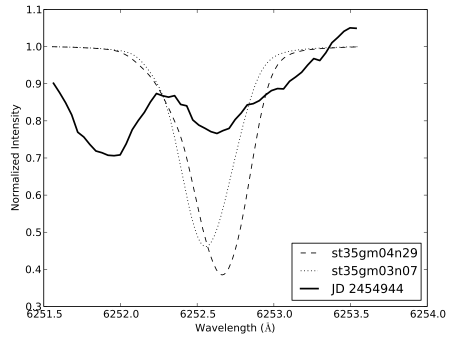

Fig. 5. Comparison of one Fe I 6252 observation with the models. This line is much too strong in these models.

st35gm04n29 model. Especially the temperature indicators (bottom two panels) are very different. Another indication for an increasing temperature mismatch in the st35gm03n07 model (in comparison with st35gm04n29) is shown in Fig. 4. If one looks only at st35gm04n29 model in Fig. 3, one can also see a phase gap between the brightness and the radial velocity increase approximately at the center of the data set.

This comparison of a few observables looks promising, but looking at the match of observed versus calculated line profiles is a different matter. The Fe II 6432 is barely visible in the observed spectra, but the model calculations show a moderate line strength (Fig. 4). The Fe I 6252 (Fig. 5) to the contrary, shows much stronger spectral lines from the models than from the observations. The fact that the st35gm03n07 fits better (or less bad) is an indicator, that molecular contributions to the continuum opacities (which are neglected in our line-profile calculations) are at least partly the reason for this discrepancy.

As a next step, we plan on using SPECTRUM[2] (Gray & Corbally 1994) for the calculation of the spectral line contributions for the individual lines-of-sight. This will allow for broader spectral regions comparable to our échelle-orders and also automatically includes correct treatment of molecular continuum opacities. Additionally, we plan to increase the base of models to compare our observations with. And last but not the least we will continue to monitor the mid- and long-term variability of Betelgeuse with our robotic telescopes.

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