Secrets in the Shadow: High precision stellar abundances of fast-rotating exoplanet host stars

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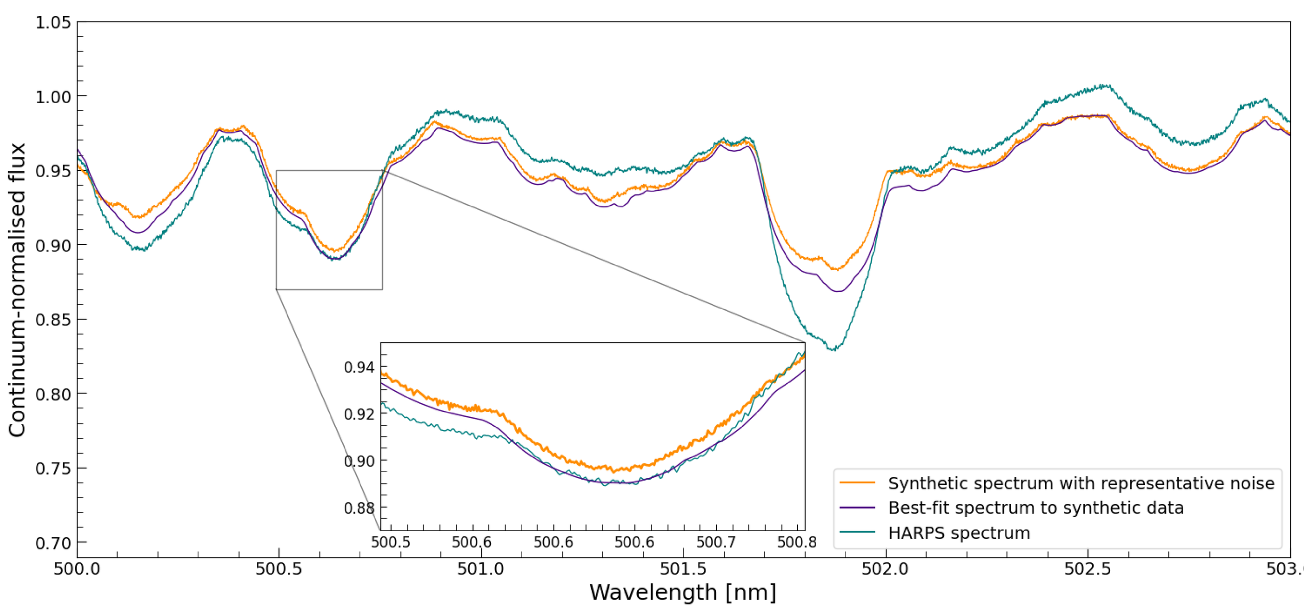
Overview

The spectra of fast-rotating A-type stars have strongly broadened absorption lines. This effect causes blending of the absorption lines, hindering the measurement of the abundances of the elements that are in the stellar photosphere.

We develop a novel method that isolates the stellar spectra behind the planet during a spectral time-series, and reconstructs the disc-integrated non-broadened spectrum of the host star. We have systematically tested this method with model-generated spectra of the transit of WASP-189 b across its fast-rotating A-type host star, assessing the effects of limb darkening, choice of absorption lines, signal-to-noise regime; and demonstrating the sensitivity to photospheric parameters ($T_{\rm eff}$, $\log g$) and elemental abundances. We apply the method to observations with the HARPS high-resolution spectrograph.

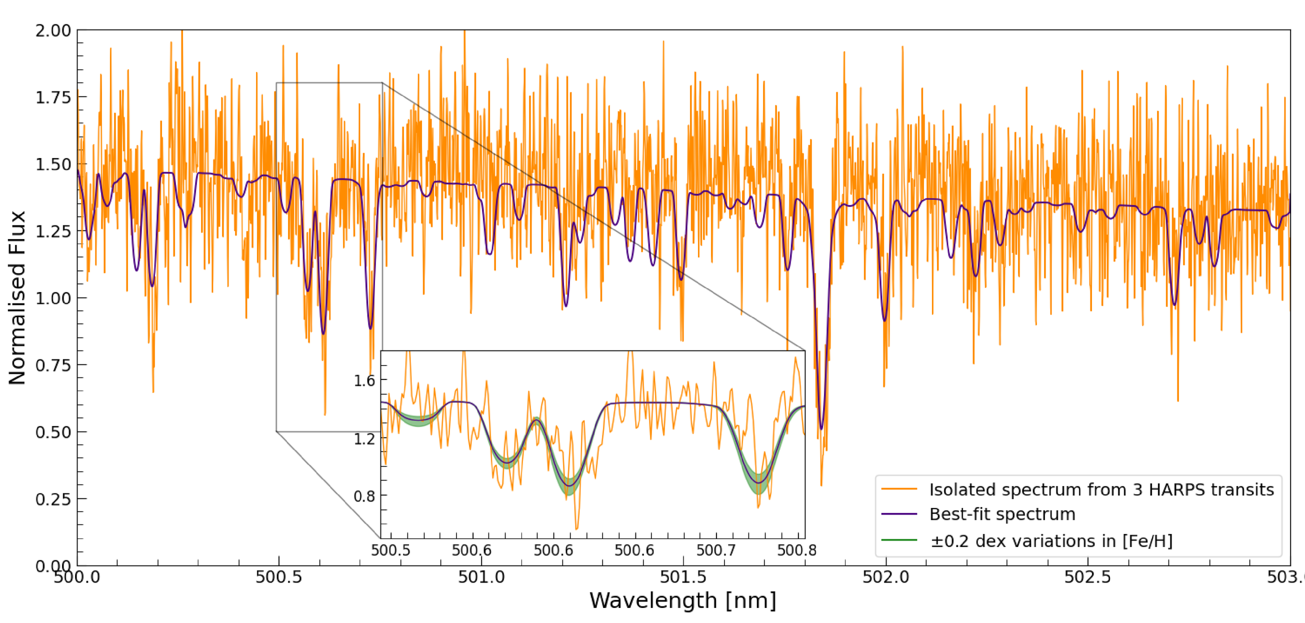
Look for our paper recently submitted to A&A!

Broadened spectrum



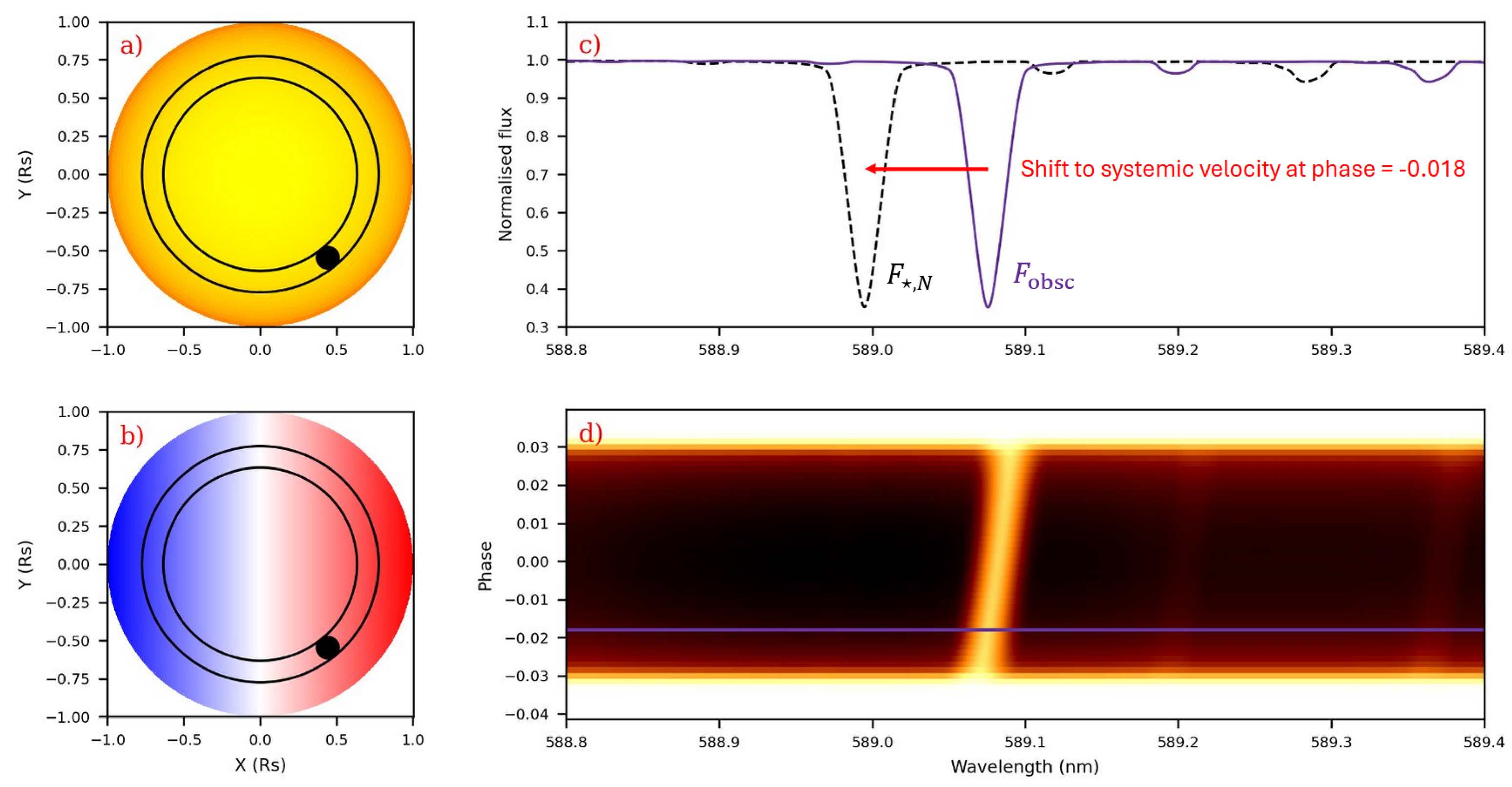
Example segment of the mean out-of-transit stellar spectrum of WASP-189 from 3 nights of simulated HARPS observations (orange) with its best-fit spectrum (purple). The real HARPS spectrum (green) has been included to show how the synthetically generated spectrum compares, illustrating the difficulties of fitting a spectrum with extreme broadening.

Non-broadened spectrum



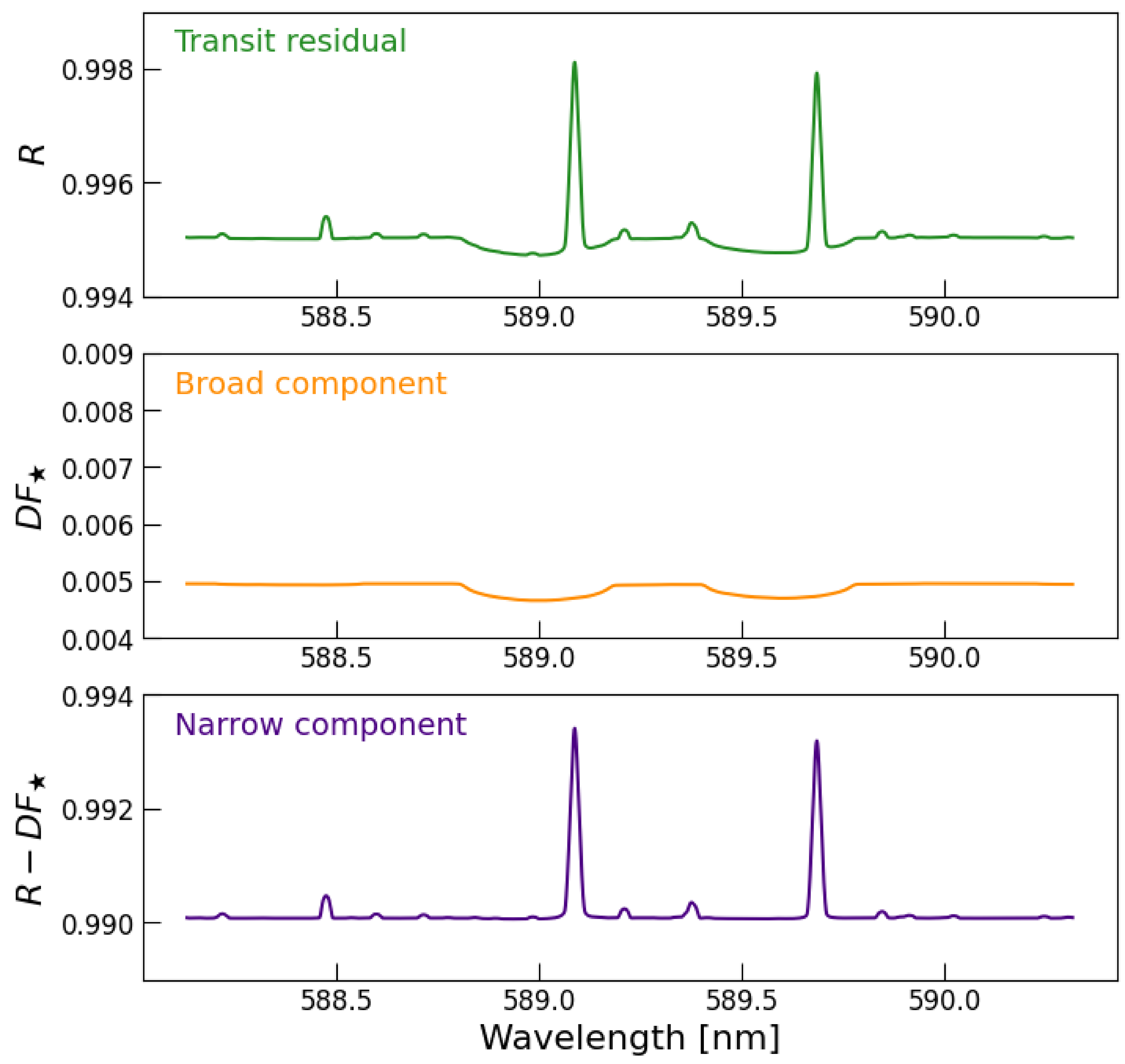
The average isolated spectrum from 3 real HARPS transits (orange) and its corresponding best-fit spectrum (purple) with $T_{\rm eff}$ and $\log g$ fixed to the parameters of Lendl et al. (2020). The shaded green region in the inset indicates ±0.2 variations in metallicity, [Fe/H]

Time series of residual spectra



At various phases as WASP-189 b transits in front of its host star, part of the stellar flux is blocked. Subtracting the out-of-transit stellar observation with the observations as the planet transits generates residual spectra. Figures a) and b) illustrate, respectively, the background flux including limb darkening and the rotational Doppler shift of the spectrum. Figure c) and d) illustrates how the Doppler shift impacts the residual spectra, with c) showing the spectra at phase -0.018, which is the purple line in d).

Residual spectrum



The transit residual, often called the Doppler shadow in exoplanet sciences, contains two components: The rotation broadened stellar spectrum and locally emitted (narrow) stellar spectrum, both scaled by the transit radius.

Abundances of WASP 189

Parameter	Fitted result	Fix to Lendl et al. (2020)
$T_{\rm eff}$ [K]	7900 ± 100	8000
$\log g$	3.4 ± 0.1	3.9
$v \sin i_\star$ [km/s]	9.9 ± 0.1	9.8 ± 0.2
Fitted abundance [dex]		
[Fe/H]	0.5 ± 0.1	0.50 ± 0.09
[Mg/H]	0.7 ± 0.2	0.5 ± 0.2
[Ca/H]	0.5 ± 0.1	0.4 ± 0.1
[Ti/H]	0.54 ± 0.08	0.49 ± 0.09

Fitted results for WASP-189 from 3 stacked transits observed with HARPS. The first column of fitted abundance results assumes fixed $T_{\rm eff}$, $\log g$ and $v \sin i_\star$ from a separate global fit. The second column of fitted abundances assumes fixed $T_{\rm eff}$ and $\log g$ from Lendl et al. (2020).