Precise relative temperature calibration of solar-type stars using equivalent width ratios of spectral lines

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Abstract

For most known transiting planets, the errors on the planet parameters are dominated by the errors on stellar parameters. Determining precise stellar effective temperature (T_{eff}) is fundamental to characterise exoplanets, and to many other areas in astrophysics.

We present a method to derive precise relative temperature using temperature calibrated equivalent width ratios (r_{EW}). We select and calibrate 189 r_{EW}, and present how they can be used to derive relative temperatures of solar-type stars (T_{eff}=5000-6300K) with uncertainties down to 5K.

Finally, we discuss potential applications of this method to exoplanets.

Method

The **equivalent width** (EW) of spectral lines is a function of temperature, and can be used as a sensor of stellar temperature (T_{eff}). Using **ratios** of equivalent width obviates the dependency of single lines on instrumental or rotational broadening.

Each **calibrated** r_{EW} is used to derive an individual measurement of the stellar temperature ($T_{eff,r}$). Thus, the precision on the **combined temperature** (σ_{final_Teff}) is improved by a factor $\sqrt{N_{ratio}}$.

(N_{ratio} = number of ratios)

$$\sigma_{final\,T_{eff}} = \frac{\sigma_{combined\,T_{eff}}}{\sqrt{N_{ratio}}}$$

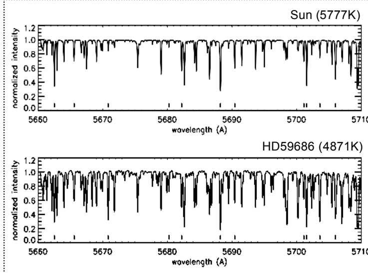

Fig 1: Some spectral lines are highly sensitive to temperature variations (eg: line at 5670.85A). *Top:* solar spectrum. *Bottom:* spectrum of a cooler star. Some spectral lines used are marked with a dash.

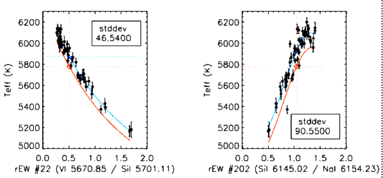

Fig 2: Line ratios have different dependence on temperature. Here are two examples of calibrated equivalent width ratios. *Left:* ratio with smallest dispersion in our sample of ratios, *right:* ratio with largest accepted dispersion. The soild red lines are the final calibration lines (adjusted to the solar temperature).

Calibration

The **spectral lines selected** are weak (EW<200mA), unblended, from neutral chemical elements, and with wavelength between 5200A and 6800A.

The **spectral lines combined into ratios** are close in wavelength ($\Delta\lambda$<70A), with different sensitivity to temperature (Δ(excitation potential)>3eV), and from different chemical elements showing similar behaviour of abundance with metallicity (Gilli et al. 2006).

The **reference temperatures** of calibration stars have been homogeneously derived by Santos et al. (2004, 2005) using stellar atmosphere models. The spectrum used for the calibration stars are UVES and FEROS spectra.

The temperature dependency of each ratio is fitted using a **3rd order polynomial** function. In each ratio, the **zero point** of the T_{eff} scale is adjusted to derive the solar T_{eff} (5777K). The **uncertainty** of each calibrated ratio ($\sigma_{Teff,r}$) is the standard deviation around the fit.

Our **final calibration set** is composed of 189 calibrated ratios with $\sigma_{Teff,r}$<91K.

Deriving stellar T_{eff}

Equations to derive final T_{eff} and associated uncertainty:

$$final\,T_{eff} = \frac{\sum_r \frac{T_{eff,r}}{\sigma^2_{Teff,r}}}{\sum_r \frac{1}{\sigma^2_{Teff,r}}}$$

$$\sigma_{final\,T_{eff}} = \frac{1}{\sqrt{N_{ratio}\sum_r \frac{1}{\sigma^2_{Teff,r}}}}$$

The **sums** are over the ratios with derived $T_{eff,r}$ within +/- 3σ of the median of all derived $T_{eff,r}$.

The calibration set has been **tested** on 5 solar-type stars with CORALIE spectrum. The derived T_{eff} are close to the ones published by Santos et al.

Example (Fig 3):

star	Santos et al	this work
HD106252	5899+/-35	5829+/-5

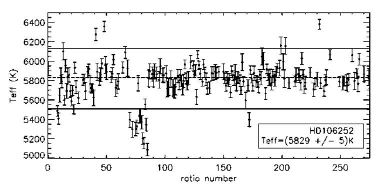

Fig 3: Application of the calibrated ratios to derive T_{eff} with precision down to 5K, for an example test star. Each point is the $T_{eff,r}$ derived by each ratio. The final T_{eff} is the combination of the $T_{eff,r}$ within +/- 3σ (solid lines) of the median of all $T_{eff,r}$.

Limitations & Applications

The absolute temperatures derived with this method suffer from the same **systematic errors** as the temperatures used for the calibration stars and for the sun. The ratios of equivalent width are calibrated in a limited **temperature range** (5000-6300K).

However, the calibrated ratios can be used to derive precise temperatures for planet host stars, and thus **precise stellar radii**, fundamental to derive precise planet radii and to constrain planet evolution models (Fig 4).

$$R_* = \left(\frac{4\pi\sigma}{L_*}\right)^{1/2} T_{eff}^{\ 2} \qquad R_p = \left(\frac{\Delta F}{F}\right)^{1/2} R_*$$

The calibrated ratios can also be used to **differentiate stellar spots from transits** by measuring the temperature variation induced by stellar spots (Fig 5).

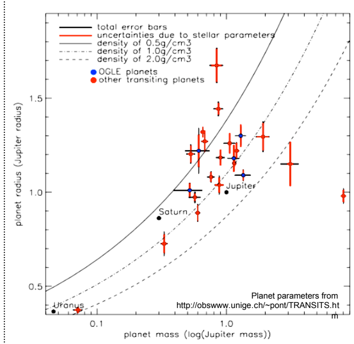

Fig 4: Mass radius diagram of the known transiting planets. The red error bars are the uncertainties on the planet radius and mass due to the uncertainties on the host star radius and mass. Improving the precision on the stellar parameters (of which T_{eff}) will improve the precision on the planet radius and mass.

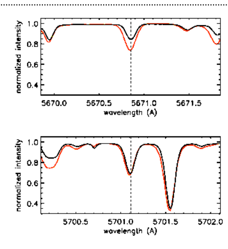

Fig 5: Stellar spots can be identified by monitoring drops in the stellar temperature. These drops modify the strength of the spectral lines and can be measured using the calibrated equivalent width ratios. The black line is the spectrum of the sun (5777K). The red line is a simulated spectrum of a star at 5777K with a spot at 4871K covering 20% of its surface.

Conclusions

We temperature calibrated 189 **ratios of equivalent width**. We showed that they can be used to derive stellar T_{eff} with **precision** down to 5K. The calibrations are **valid for temperature** between 5000 and 6300K. The **systematic errors** in derived T_{eff} come from the temperatures used for the calibration stars. The calibrated ratios can help in the **detection of exoplanets** (by identifying stellar spots mimicking transits), and in **their characterisation** (by reducing uncertainties on planet radius and mass).

Data: This work made use of reduced, continuum subtracted spectra from UVES, FEROS and CORALIE spectrographs, kindly provided by N. Santos and G. Israelian.

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