Stellar atmospheric parameters of FGK-type stars (EW method) and M-type stars (spectral synthesis) from high-resolution optical and near-infrared CARMENES spectra

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Abstract We aim to review the equivalent width (EW) method and the spectral synthesis technique to derive stellar atmospheric parameters of FGKM-type stars in light of the optical and near-infrared spectra obtained with CARMENES, the high-resolution, double-channel spectrograph installed at the 3.5 m telescope at the Calar Alto Observatory (Almería, Spain). On the one hand, we show the results for 65 FGK-type stars observed with CARMENES and analysed with the StePar code, a Python implementation of the EW method, placing special emphasis on the impact of the near-infrared wavelength region on the parameter computations. On the other hand, we also highlight the stellar atmospheric parameters obtained for the target M dwarfs in the CARMENES Guaranteed Time Observations (GTO) programme by means of the spectral synthesis technique as implemented in the StEParSyn code.

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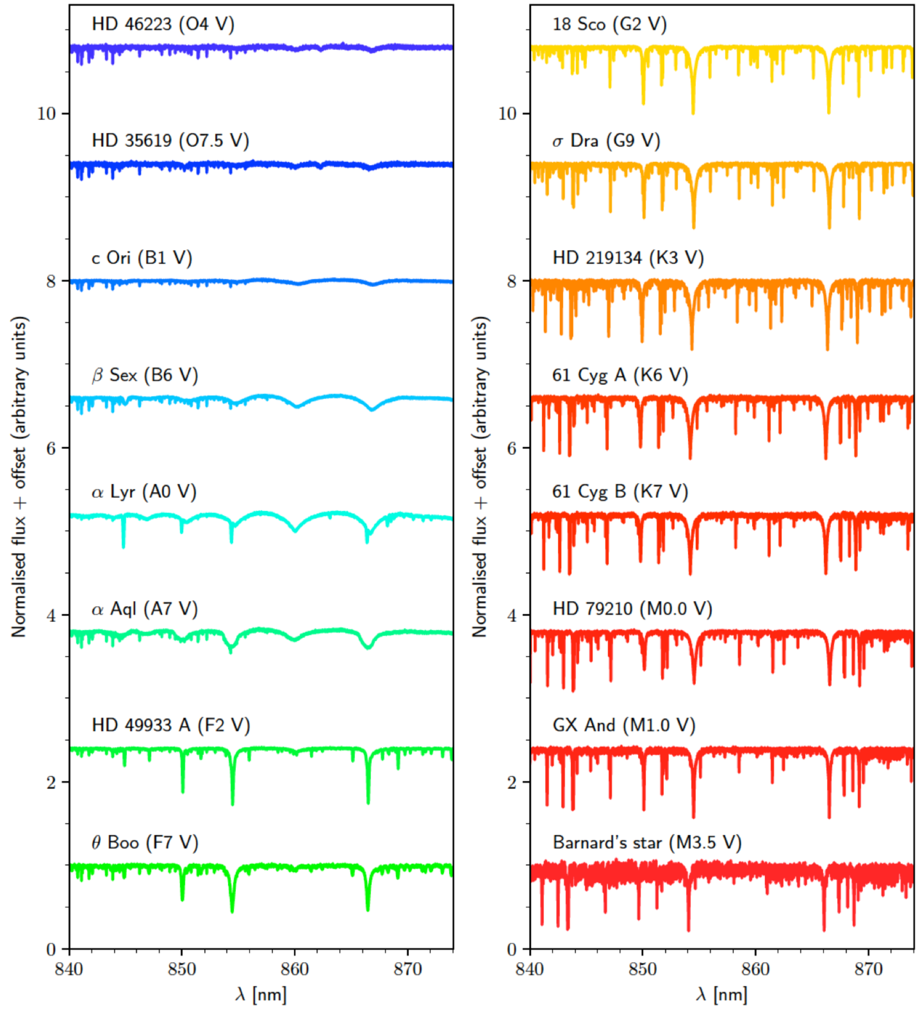


CARMENES spectra of representative stars around the infrared Ca II triplet.

Context

The accurate computation of the **stellar atmospheric parameters of FGKM-type stars from high-resolution spectra**, namely T_{eff}, **log *g***, and **[M/H]**, is fundamental not only to our current understanding of the Milky Way but also to recent planet formation theories.

Two widely-used techniques to derive the former parameters are the **EW method**, best suited for the analysis of FGK-type spectra, and the **spectral synthesis**. We present the application of both techniques to FGKM-type spectra obtained with the CARMENES instrument.

CARMENES high-resolution, optical and near-infrared échelle spectrographs @ 3.5 m telescope at the Calar Alto observatory (Almería, Spain) (Quirrenbach et al. 2018).

VIS channel	NIR channel
Δλ = 520 – 960 nm	Δλ = 960 – 1710 nm
R = 94 600	R = 80 400

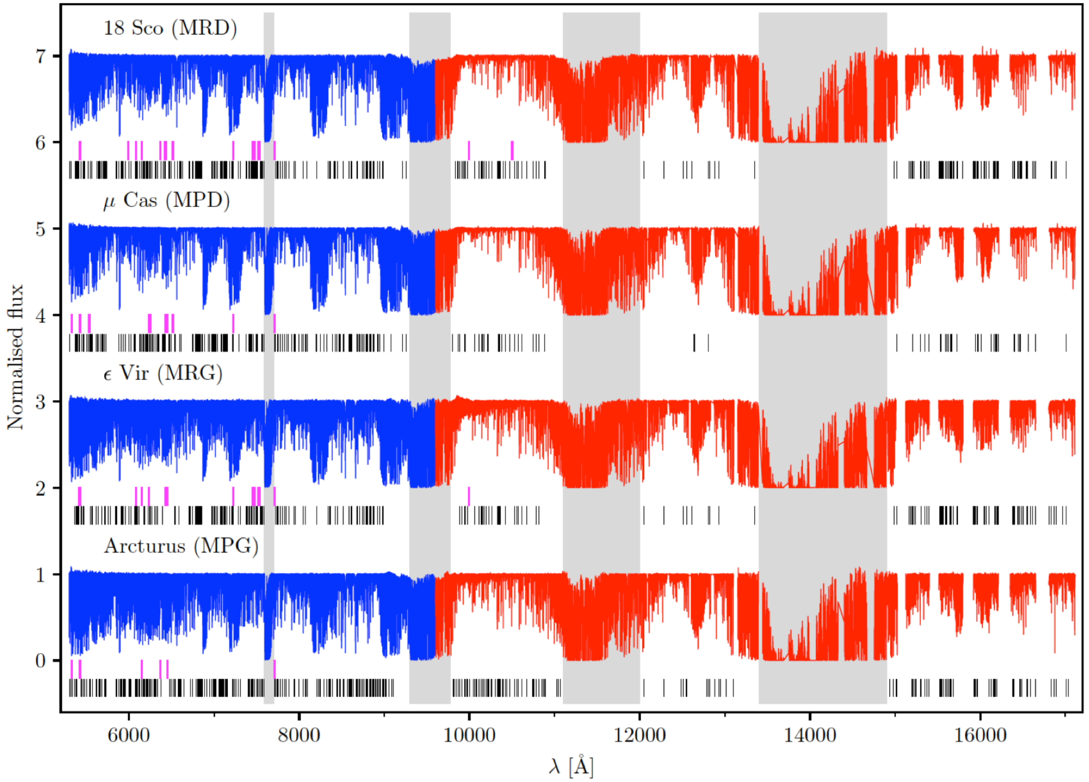
Methodology

EW method for the analysis of FGK-type stars (Marfil et al. 2020)

- ☆ 65 representative FGK-type spectra (including the Sun) taken from the CARMENES stellar library (Caballero et al., in prep.).
- ☆ Ionisation and excitation balance of Fe I and Fe II lines under the assumption of LTE.
- ☆ Use of the STEPAR code (Tabernero et al. 2019) as the implementation of the EW method.
- ☆ Expansion of former Fe I-Fe II line lists into the near-infrared covered with CARMENES (Tabernero et al. 2019, Andreasen et al. 2016).
- ☆ Assessment of the overall impact of the inclusion of the NIR in the parameter computations.

Spectral synthesis for the analysis of M dwarfs (Marfil et al. in prep.)

- ☆ Looking for the best match between observed and synthetic spectra.
- ☆ Implemented in the STEPARSYN code (Tabernero et al. 2018 and 2020 in prep.), based on an MCMC algorithm.
- ☆ Synthetic grid based on BT-Settl models (Allard et al. 2012) + Turbospectrum (Plez 2012) + atomic and molecular data gathered from the VALD3 database and other sources.



CARMENES reference spectra for the selection of Fe I and Fe II lines for FGK-type stars (Marfil et al. 2020)

STEPAR code available at: https://github.com/hmtabernero/StePar

Results

Analysis of FGK-type stars (EW method)

☆ Four sets of Fe I and Fe II line lists (653 Fe I and 23 Fe II lines altogether) in the optical and the near-infrared (530-1710 nm) suited for FGK-type stars (metal-rich and metal-poor dwarfs and giants).

☆ Stellar atmospheric parameters of the selected sample (65 FGK-type stars, including the Sun) computed with STEPAR. Some *Gaia* benchmark stars (Jofré et al. 2018) present in the sample helped us test the validity of the results.

☆ Even though our parameter determinations remain in good agreement with the literature values, the increase in the number of Fe I and Fe II lines when the near-infrared region is taken into account reveals a deeper $T_{\rm eff}$ scale that might stem from a higher sensitivity of the near-infrared lines to $T_{\rm eff}$.

Spectral region	Number of selected lines	
	Fe I	Fe II
CARMENES VIS channel	437	21
CARMENES NIR channel	216	2
Both CARMENES channels	653	23

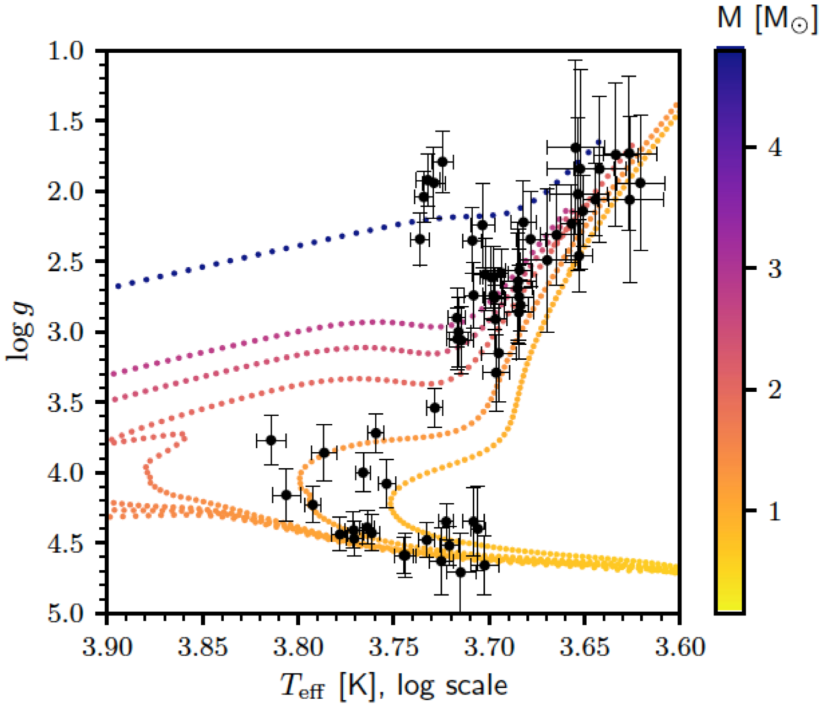


Figure 7. Kiel diagram ($\log g$ versus $\log T_{\rm eff}$) of the sample along with the YaPSI isochrones at 0.1, 0.4, 0.6, 1, 4, and 13 Ga (for $Z = 0.016$, see Spada et al. 2017).

Monthly Notices of the ROYAL ASTRONOMICAL SOCIETY

MNRAS **492,** 5470–5507 (2020) doi:10.1093/mnras/staa058
Advance Access publication 2020 January 10

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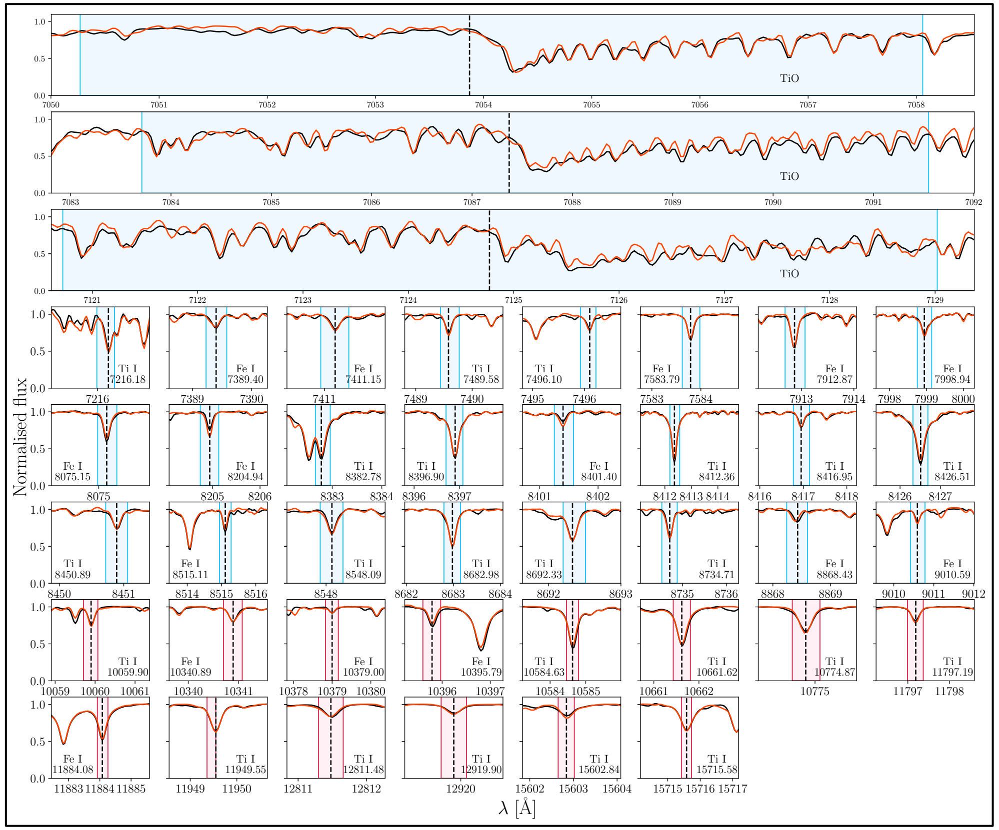
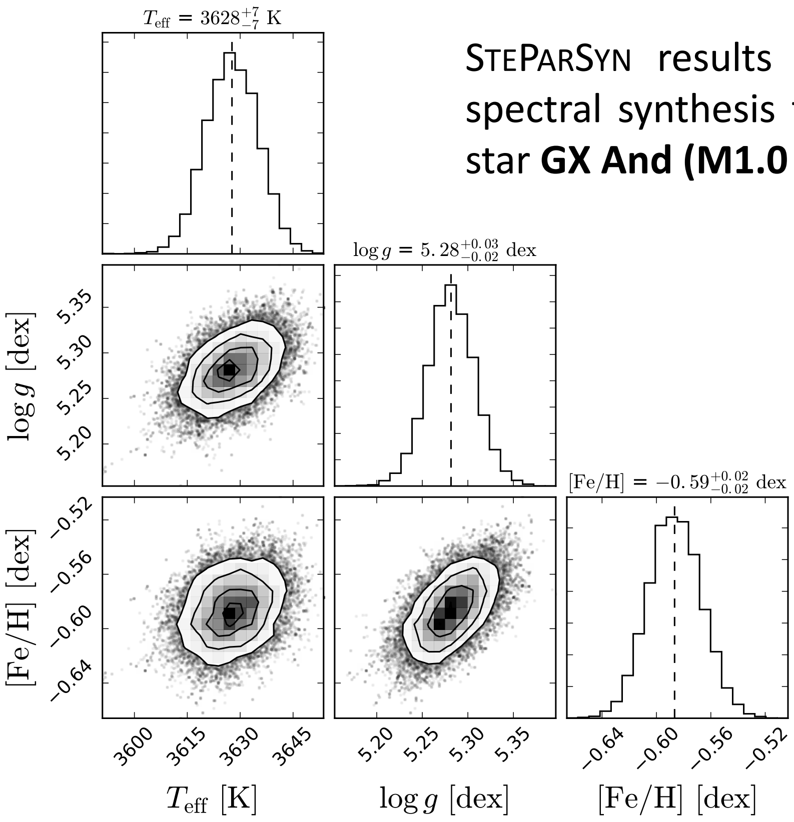
2020MNRAS.492.5470M

Results Analysis of M dwarfs (spectral synthesis)

- ☆ SteParSyn code (Tabernero et al. 2018 and in prep.) applied to CARMENES template spectra of 346 GTO M dwarfs.
- ☆ Selection of atomic lines (Fe I and Ti I) and molecular bands (TiO) with low magnetic sensitivity (Landé factor g_{eff} < 1) (Passegger et al. 2019) in both CARMENES channels (VIS and NIR), including lines from Tabernero et al. (2018).
- ☆ Narrow ranges around the selected spectral features are synthesised and compared with the template spectra inside predefined spectral masks, following the MCMC algorithm implemented in the SteParSyn code.



Spectral ranges and masks (blue: VIS, red: NIR) for the star GX And. Orange and black lines are the synthetic and template spectra, respectively



SteParSyn results of the spectral synthesis for the star **GX And (M1.0 V)**

Impact and prospects for the future

Impact:

FGK-type stars Assessment of the EW method in the CARMENES VIS+NIR wavelength regions + optimal Fe I-Fe II line lists for FGK-type stars + STEPAR code, publicly available at https://github.com/hmtabernero/StePar.

M dwarfs Analysis of the GTO sample of 346 M dwarfs observed with CARMENES by means of the spectral synthesis technique (Marfil et al. in prep.) through the STEPARSYN code (Tabernero et al. 2018 and in prep.) for all spectral subtypes, activity levels and *v* sin *i* values, in contrast to Passegger et al. (2018, 2019). The STEPARSYN code will soon be available (check out H. Tabernero's SEA 2020 contribution).

Future work:

FGK-type stars

- ☆ Expand optical line lists for chemical abundance analyses in FGK-type stars (Jofré et al. 2015) taken from the CARMENES stellar library into the near-infrared region covered with CARMENES.
- ☆ Use of the spectral synthesis technique through the STEPARSYN code to compute the photospheric parameters of all stars in the CARMENES stellar library that cannot be dealt with the EW method (namely, stars with spectral types earlier than F6 and later than K4 as well as fast rotators, i.e. *v* sin *i* > 15 km/s).

M dwarfs

- ☆ Analyse the impact of activity-sensitive spectral lines, that is, lines affected by chromospheric emission and Zeeman broadening (see Montes et al. SEA 2020 contribution) in the stellar parameter determinations.
- ☆ Derive chemical abundances of different elements in M dwarfs.