Stellar atmospheric parameters of FGKM-type stars from high-resolution optical and near-infrared CARMENES spectra

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The CARMENES instrument

- High-resolution, optical and near-infrared echelle spectrographs @ 3.5 m telescope at the Calar Alto observatory, Almería, Spain.

VIS channel	NIR channel
$\Delta\lambda$ = 520 – 960 nm	$\Delta\lambda$ = 960 – 1710 nm
R = 94 600	R = 80 400

- Radial velocity (RV) survey of ~300 M dwarfs to detect Earth-mass planets (Guaranteed Time Observations programme).

[Quirrenbach et al. 2018, SPIE]

The CARMENES stellar library

- 140 CARMENES spectra of bright dwarfs, giants, and supergiants with spectral types from O4 and M6 (+ Sun).

[Caballero et al. in preparation]

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Stellar atmospheric parameters of FGK-type stars from high-resolution optical and near-infrared CARMENES spectra

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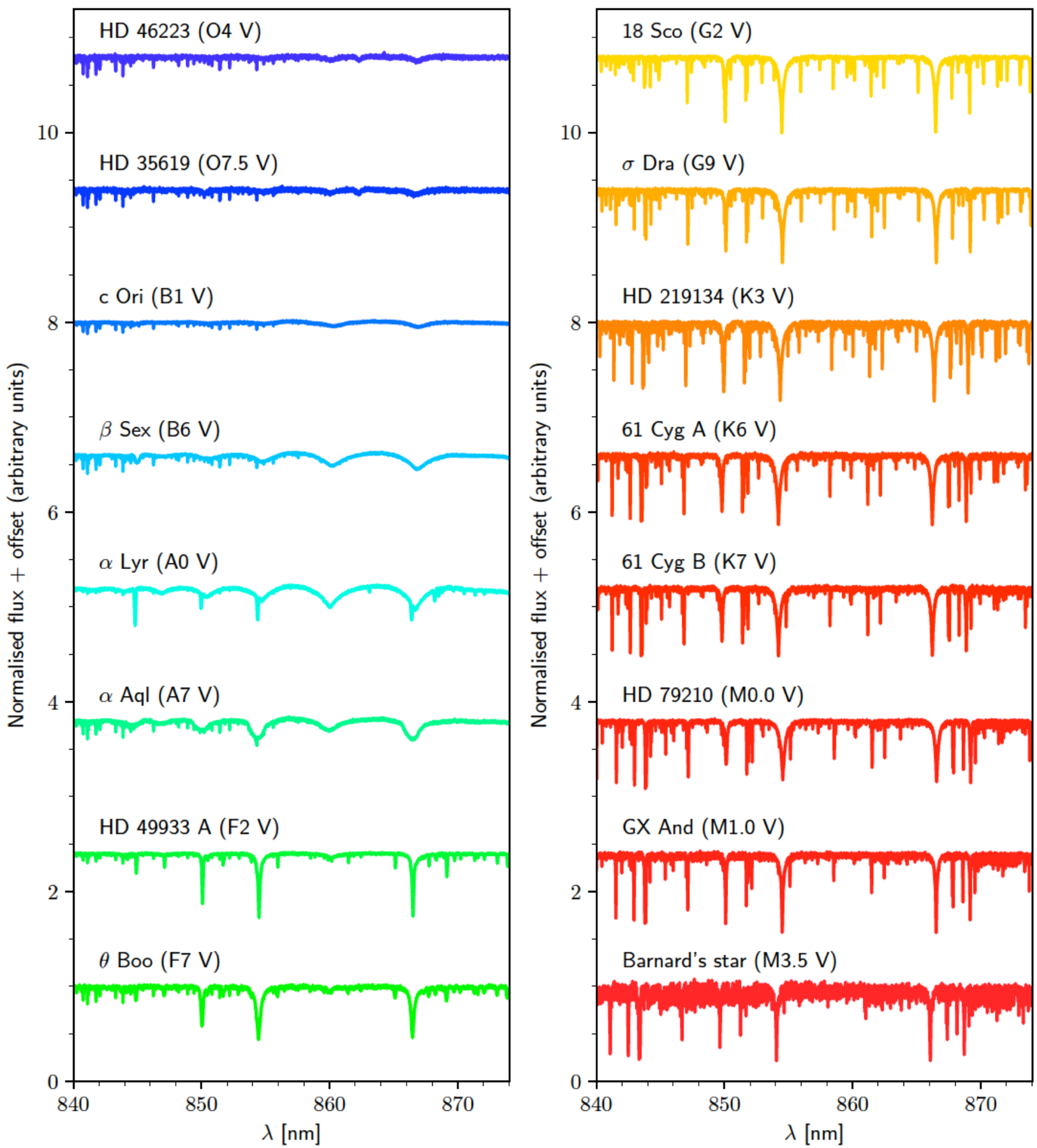
- Stellar atmospheric parameters of the 65 FGK-type stars found in the library have already been derived in Marfil et al., 2020, MNRAS, 492, 4 using the EW method (StePar code, Tabernero et al., 2019, A&A, 628, A131).


HD 46223 (O4 V)
HD 35619 (O7.5 V)
c Ori (B1 V)
β Sex (B6 V)
α Lyr (A0 V)
α Aql (A7 V)
HD 49933 A (F2 V)
θ Boo (F7 V)
18 Sco (G2 V)
σ Dra (G9 V)
HD 219134 (K3 V)
61 Cyg A (K6 V)
61 Cyg B (K7 V)
HD 79210 (M0.0 V)
GX And (M1.0 V)
Barnard's star (M3.5 V)
Normalised flux + offset (arbitrary units)
λ [nm]
0
2
4
6
8
10
840
850
860
870

FGK-type stars in the CARMENES stellar library [Marfil et al. 2020]

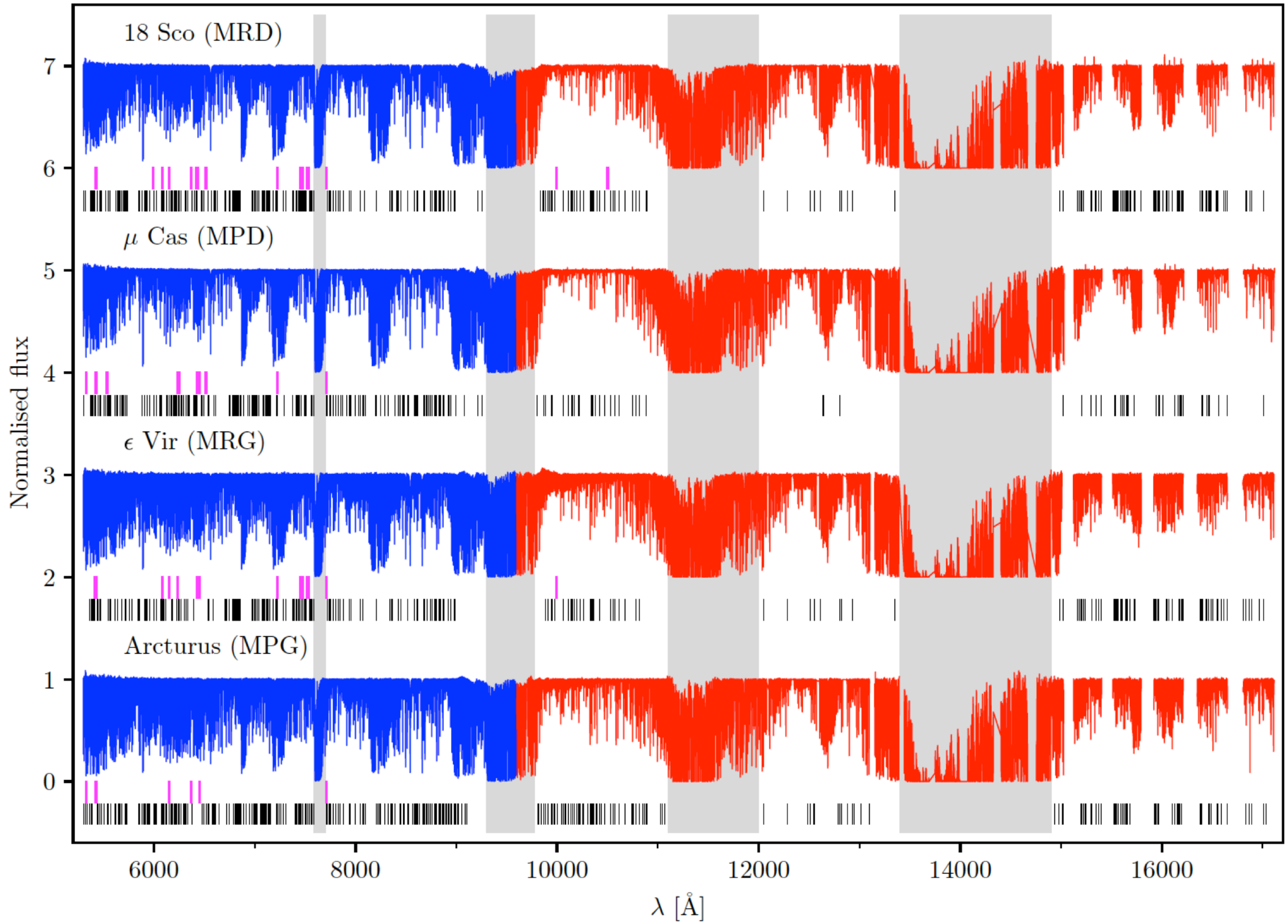


Figure 4. Distribution of the selected Fe I and Fe II absorption lines in the reference spectra. The Fe I and Fe II lines are shown as black and pink vertical lines, respectively, below the spectra. The VIS and NIR channels of the CARMENES instrument are shown in blue and red, respectively. The grey shaded areas show the regions severely affected by telluric absorption.

FGK-type stars in the CARMENES stellar library [Marfil et al. 2020]

Table 1. Number of Fe I and Fe II lines reported in this work, Sousa et al. (2008, Sou08), Andreasen et al. (2016, And16), and Tabernero et al. (2019, Tab19), from 5300 to 17100 Å.

Reference	Line list/region	#lines Fe I	#lines Fe II
This work	MRD	386	16
This work	MPD	295	9
This work	MRG	306	13
This work	MPG	379	4
This work	CARMENES VIS channel	437	21
This work	CARMENES NIR channel	216	2
This work	Globally	653	23
Tab19	MRD	112	8
Tab19	MPD	82	8
Tab19	MRG	72	7
Tab19	MPG	95	5
Tab19	Globally	175	14
Sou08	–	172	19
And16	–	272	12

Total number of selected Fe I and Fe II lines

Stellar atmospheric parameters (STEPAR)

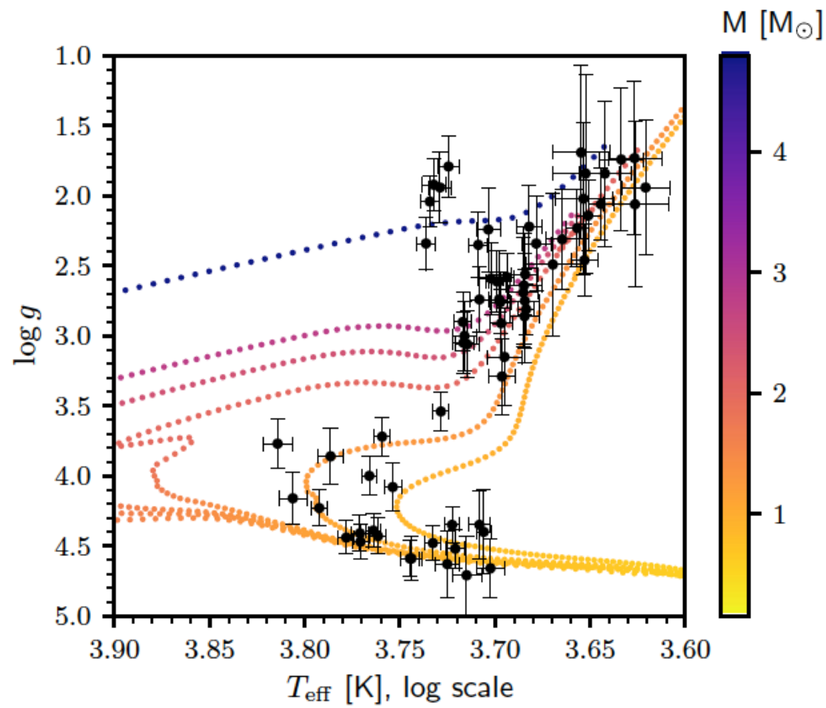


Figure 7. Kiel diagram (log g versus log $T_{\rm eff}$) of the sample along with the YaPSI isochrones at 0.1, 0.4, 0.6, 1, 4, and 13 Ga (for $Z = 0.016$, see Spada et al. 2017).

FGK-type stars in the CARMENES stellar library [Marfil et al. 2020]

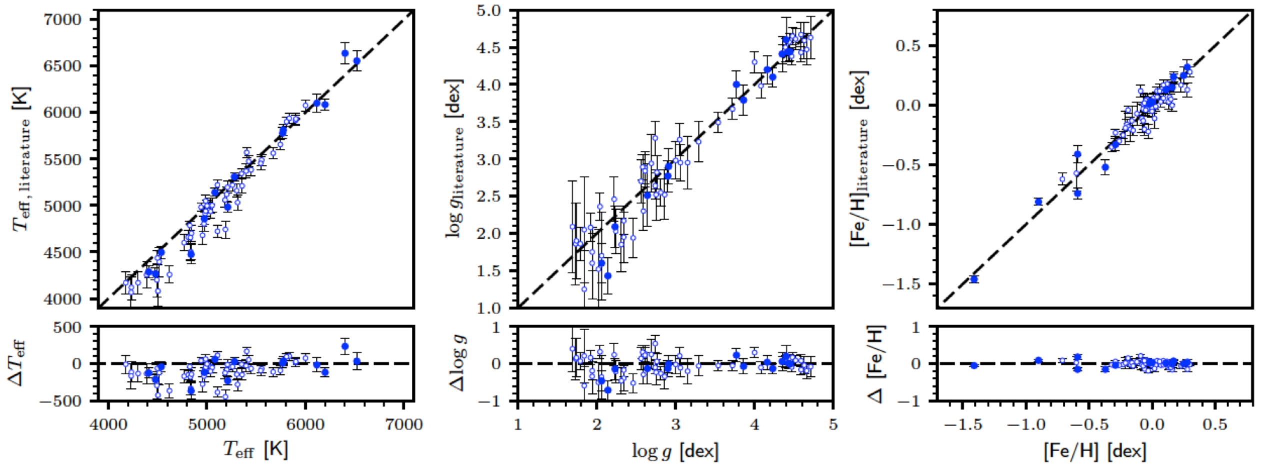


Figure 11. Comparison between the stellar atmospheric parameters obtained with STEPAR including the VIS and NIR channels of CARMENES and the literature values. The blue filled circles are the *Gaia* benchmark stars in our sample. The remaining stars in the sample are shown with the blue open circles. The dashed black lines indicate the one-to-one relationship. From left to right: T_{eff}, $\log g$, and [Fe/H].

VIS channel

+

NIR channel

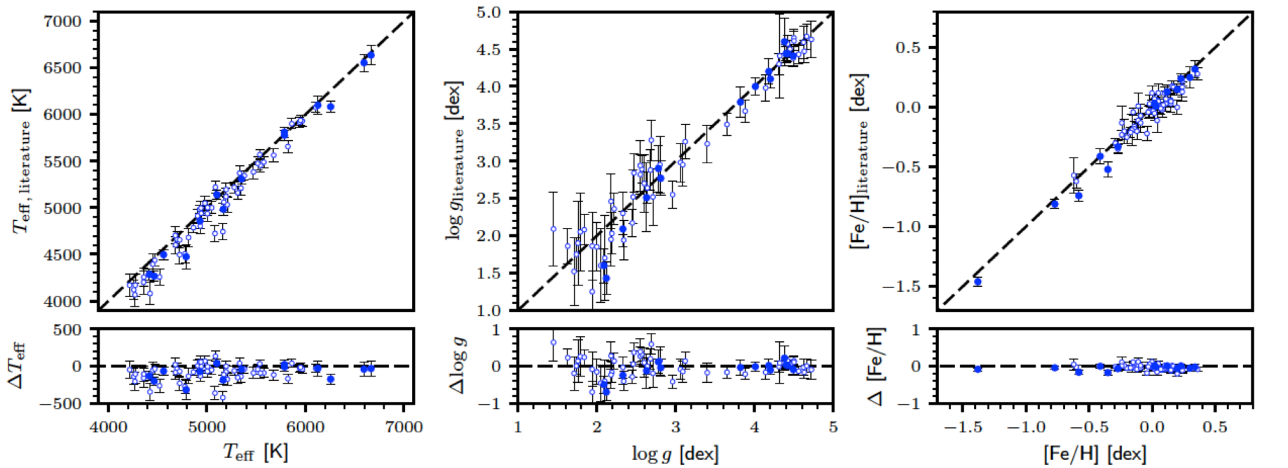


Figure 12. Same as Fig. 11 but restricting the analysis to the Fe I and Fe II lines found in the optical wavelength region covered by the VIS channel of CARMENES.

VIS channel

Gaia Benchmark Stars

- Fundamental parameters obtained independently from spectroscopy, e.g.

  $T_{\rm eff}$ from $L = 4\pi R^2 \sigma T_{\rm eff}^{\ 4}$ (Stefan-Boltzmann law)

  log g from $g = GM/R^2$ (from Newton's law of universal gravitation)

- However, key information is needed to apply these formulae, such as:

  distance

  bolometric flux

  interferometric radius

- Assess any spectroscopic method aimed at the automated analysis of cool stars

[Jofré et al. 2014, 2018; Heiter et al. 2015]

Spectral synthesis in M dwarfs with SteParSyn

Overview

- **The CARMENES RV survey** treasures a wealth of data, i.e. several thousands of high-resolution, high S/N, optical and near-infrared M-dwarf spectra.
- This leads not only to the discovery, orbital and atmospheric characterisation of exoplanets but also to statistically significant conclusions about the nature of M dwarfs (e.g. activity, stellar atmospheric parameters, kinematics).

[Reiners et al. 2018]

- The characterisation of M dwarfs as host stars is a key ingredient in planet formation theories (e.g. impact of stellar metallicity and activity on exoplanets).

Spectral synthesis in M dwarfs with STEPARSYN

Overview

- Passegger et al. (2018): $T_{\rm eff}$**, log *g*, and [Fe/H]** for 300 M dwarfs in the optical (235 observed with CARMENES) fitting PHOENIX-ACES synthetic spectra.
- Passegger et al. (2019): $T_{\rm eff}$**, log *g*, and [Fe/H]** for 282 CARMENES GTO M dwarfs from optical, near-infrared, and optical + near-infrared (PHOENIX-SESAM)
- Schweitzer et al. (2019): **Masses and radii** of 293 CARMENES GTO M dwarfs

$T_{\rm eff}$ following Passegger et al. (2018)

L obtained from integrated broadband photometry + *Gaia* DR2 parallaxes

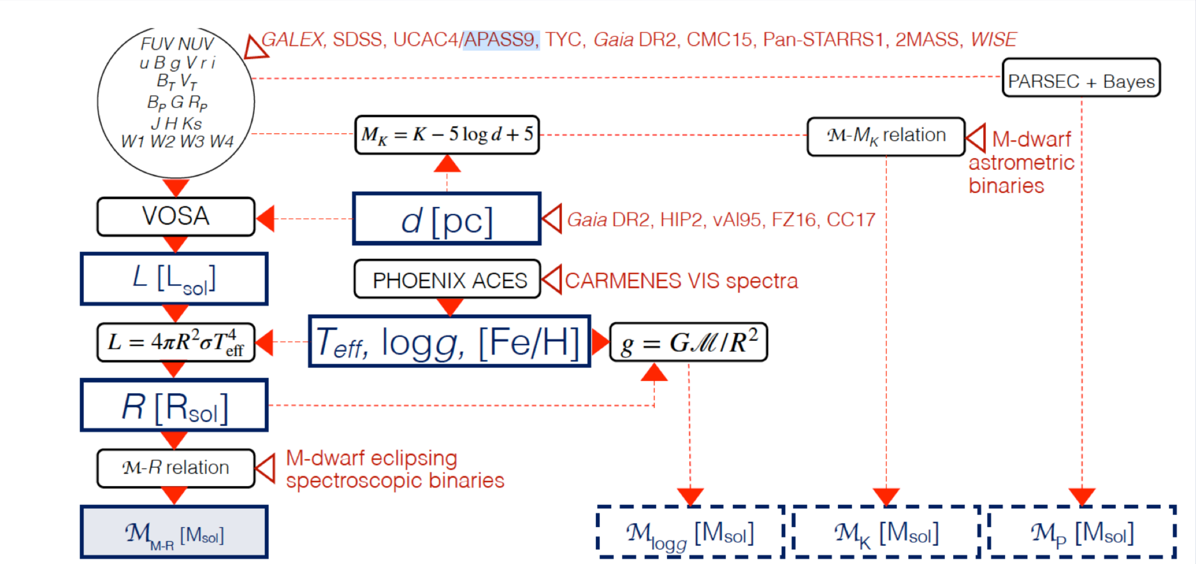
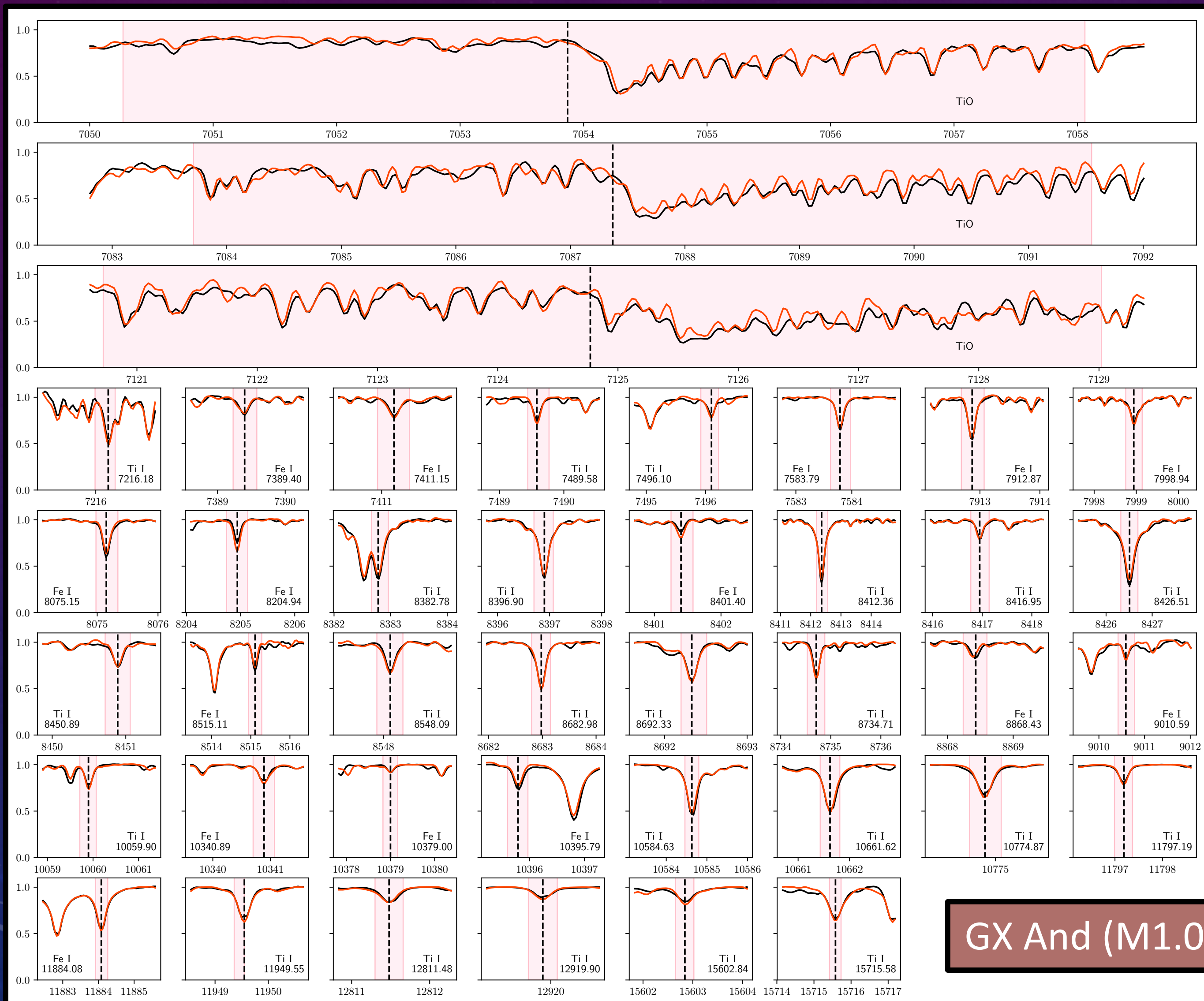


Fig. 2. Flowchart of our different roads to masses.

Spectral synthesis in M dwarfs with STEPARSYN

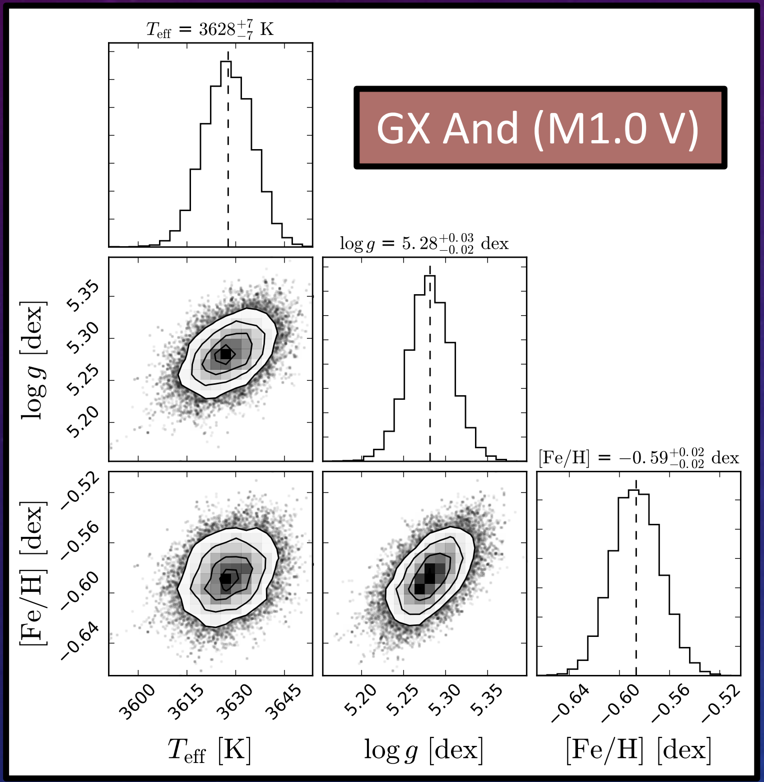


GX And (M1.0 V)

- Molecular bands (TiO)
- Atomic lines (Fe I, Ti I)

Marfil et al. in prep.

Spectral synthesis in M dwarfs with STEPARSYN



Probability distribution functions of the stellar atmospheric parameters ($T_{\rm eff}$, log g, [Fe/H])

However, M dwarfs are not easy!

- Magnetic fields may distort line profiles via e.g. Zeeman broadening
  [Shulyak et al. 2018, Passegger et al. 2019]
- Degeneration log g and [Fe/H] in the parameter space
  [Passegger et al. 2018]
- Telluric contamination (near-infrared)
  [Nagel et al., submitted]

Thank you for your attention!

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