DETERMINACIÓN DE PARÁMETROS ESTELARES MEDIANTE ESPECTROSCOPÍA DE ALTA RESOLUCIÓN CON EL INSTRUMENTO

carmenes

VIII Jornadas de Introducción a la Investigación

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VNIVERSITAS COMPLVTENSIS MATRITENSIS

GOBIERNO DE ESPAÑA

MINISTERIO DE EDUCACIÓN, CULTURA Y DEPORTE

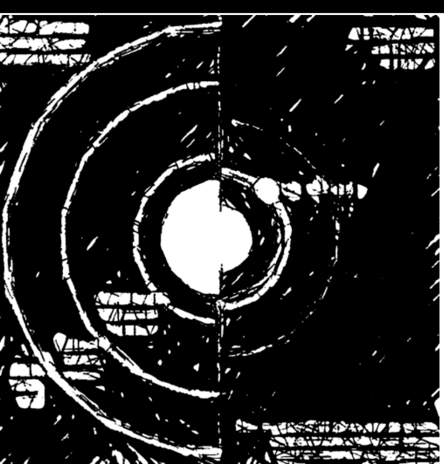
Outline

Calar Alto high-Resolution search for M dwarfs with Exoearths with Near-infrared and optical Échelle Spectrographs

CARMENES is also:

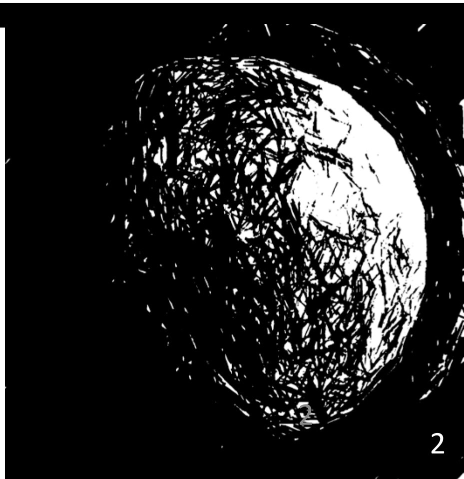
- A consortium of 11 institutions (5 German + 5 Spanish + Calar Alto Observatory).
- A project that aims at the detection of low-mass planets in their habitable zones by means of a survey of ~300 late-type (M) main-sequence stars.

Its science survey of Guaranteed Time Observations (GTO) started on **1th January 2016** and will last for at least five years.



We are also reaping the rewards of CARMENES observations. Some highlights:

- Ribas et al. 2018, Nature, 563, pp. 365-368
- Kaminski et al. 2018, A&A, 618, A115
- Reiners et al. 2018, A&A, 609, L5

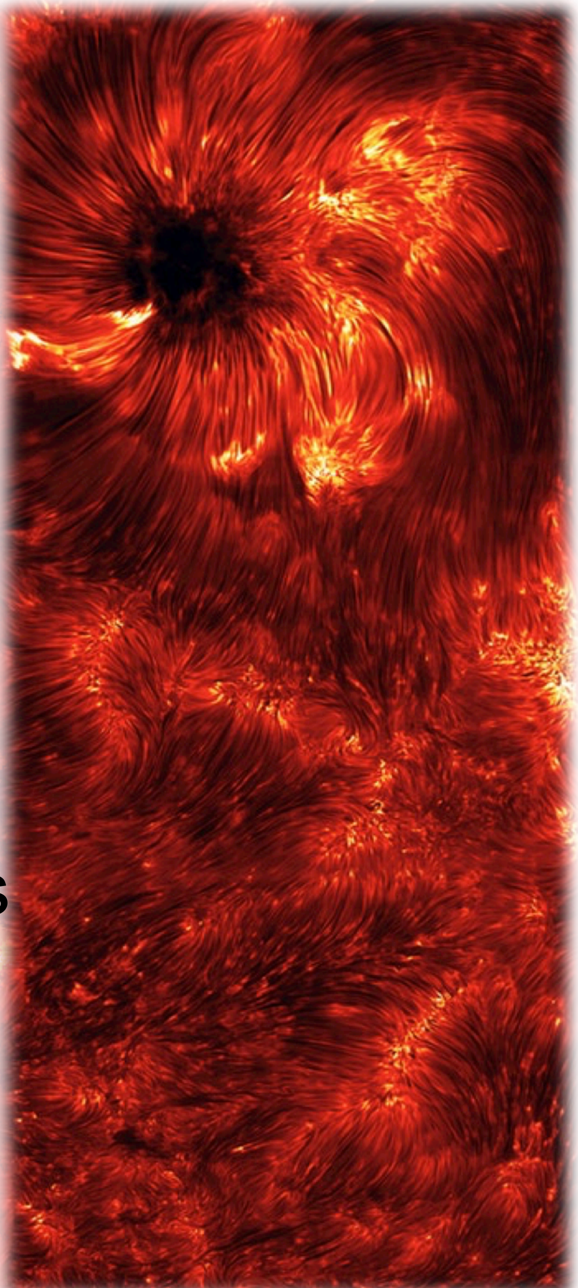


Aims & Methods

Aim: Our goal is to determine the **stellar atmospheric parameters** (T_{eff}, log g, and [M/H]) of **M-type dwarfs** observed with CARMENES under its **GTO programme** by means of the **spectral synthesis technique**.

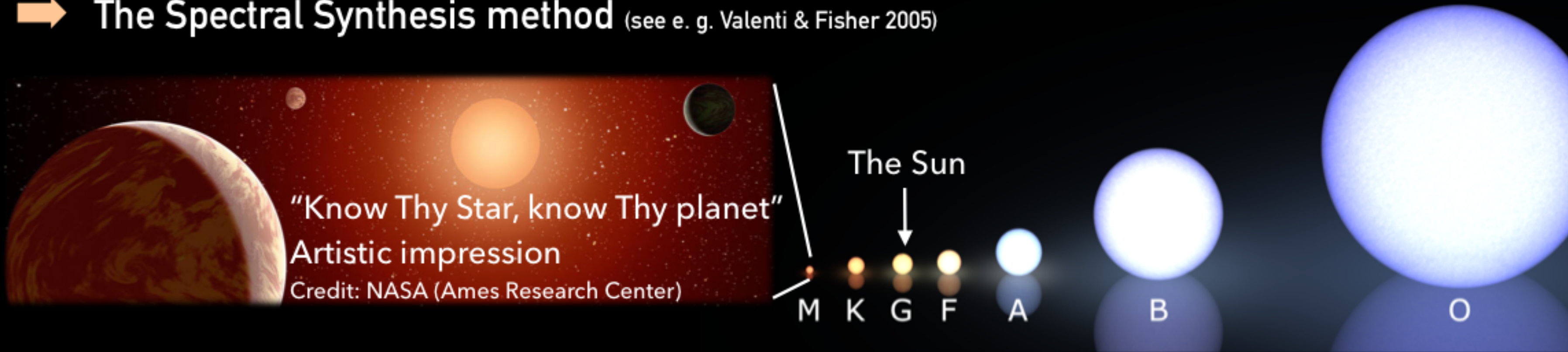
Why? Three main reasons:

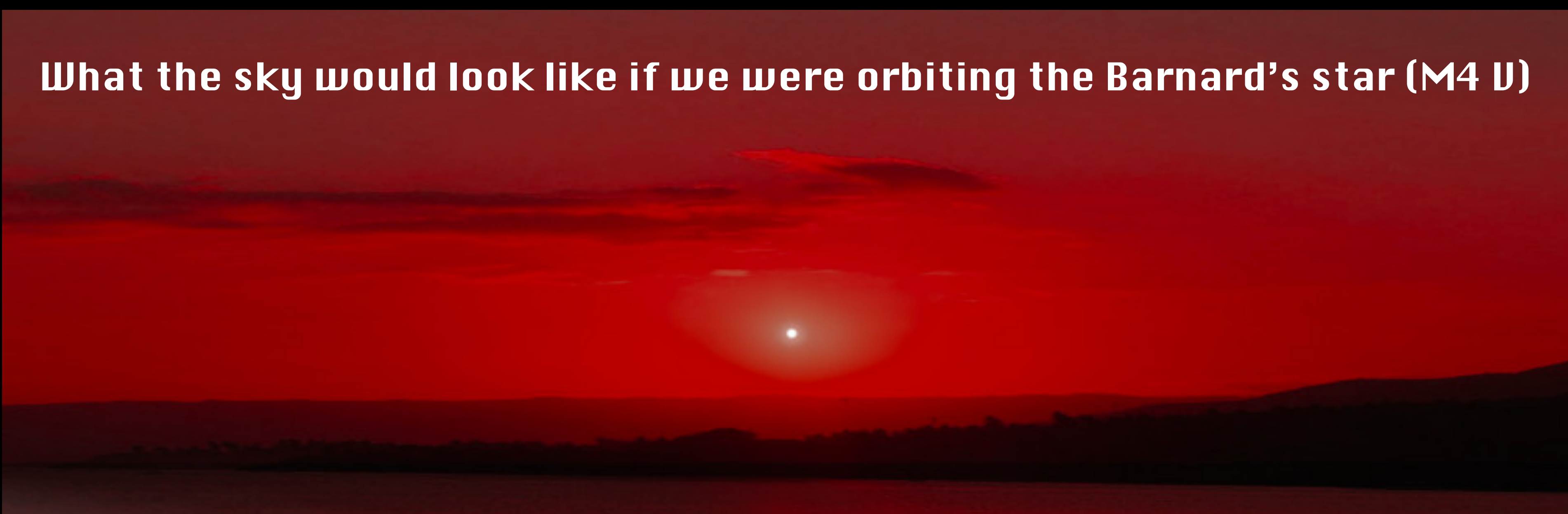
- Habitable zones
- Statistics on exoplanetary systems
- Influence on other parameter determinations (stellar mass, radius, age)



In spectroscopy, two of the most widely-used spectroscopic methods to determine stellar atmospheric parameters are:

- The Equivalent Width (EW) method (see e. g. Sousa et al. 2008)
- The Spectral Synthesis method (see e. g. Valenti & Fisher 2005)

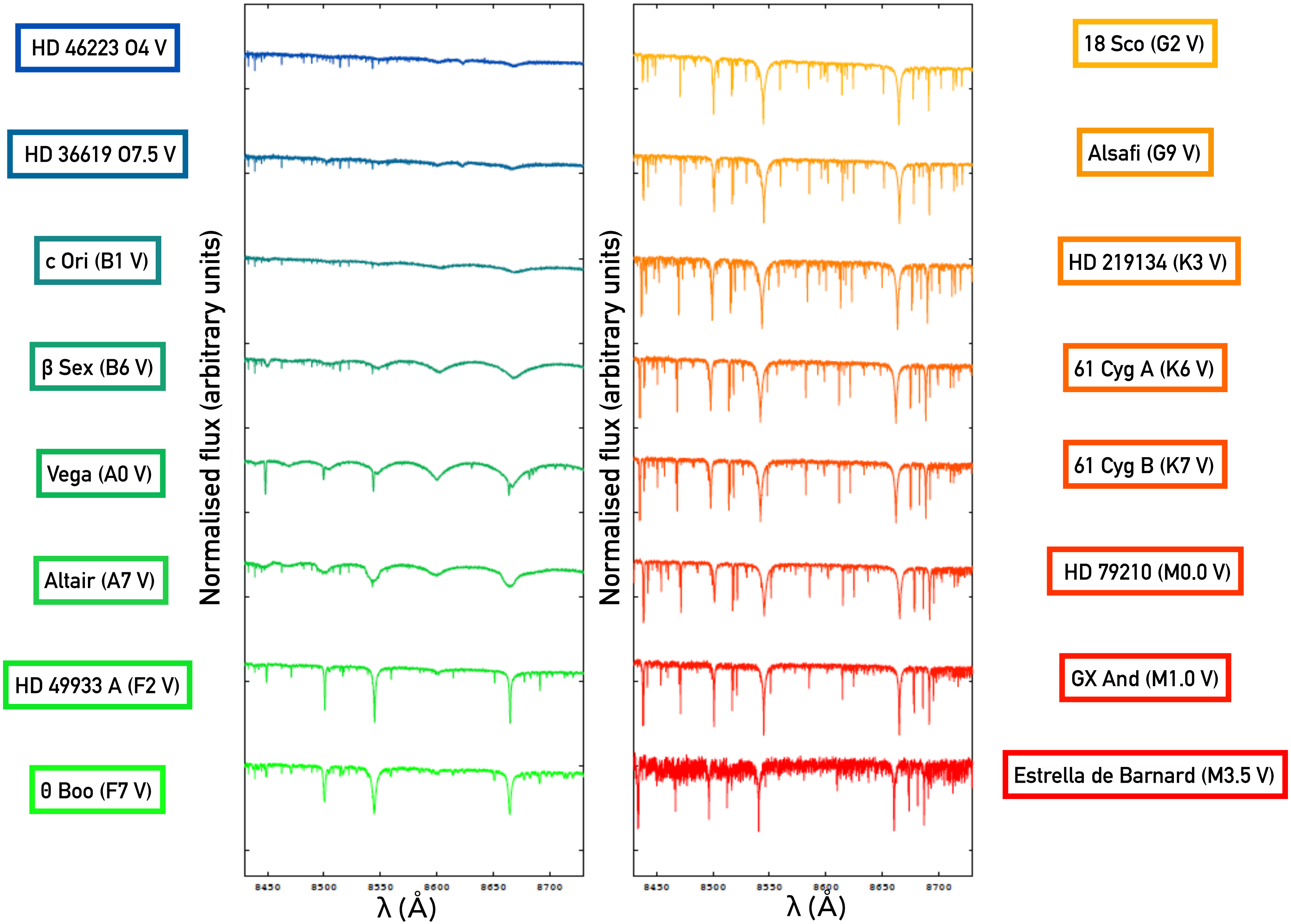




- The CARMENES spectral library
- the EW method

The CARMENES stellar library

Infrared calcium II triplet
(λ = 8498 Å, 8542 Å, 8662 Å)



The Equivalent Width (EW) method

This method relies on the measurements of the equivalent widths of a given selection of spectral lines and derives the stellar parameters of the star under the assumption of local thermodynamic equilibrium (LTE) (Andreasen et al., 2016, A&A 585, A143).

To apply this method, we use two different pieces of software:

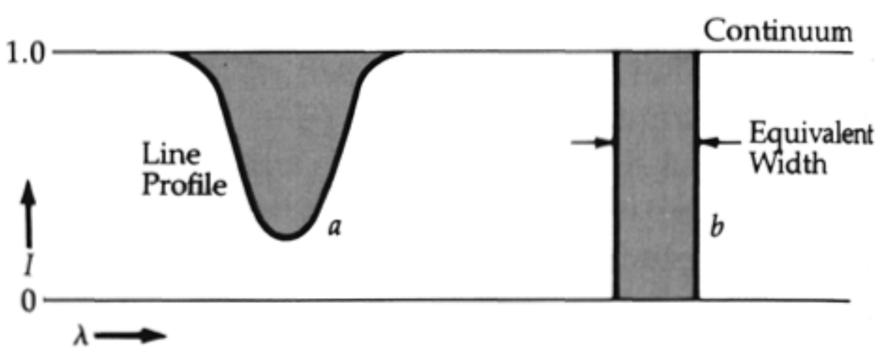
➡ TAME (Kang et al., 2012, MNRAS 425, 3162-3171)

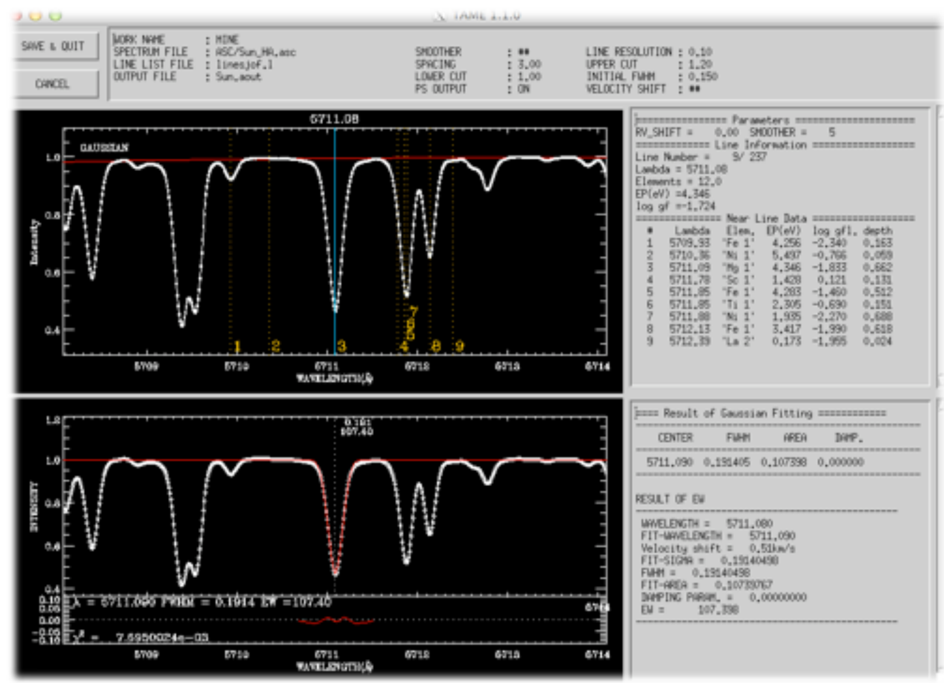
➡ StePar (Tabernero et al., 2012, A&A, 547, A13).

TAME is used for measuring the EW of the lines under analysis on each of our spectra.

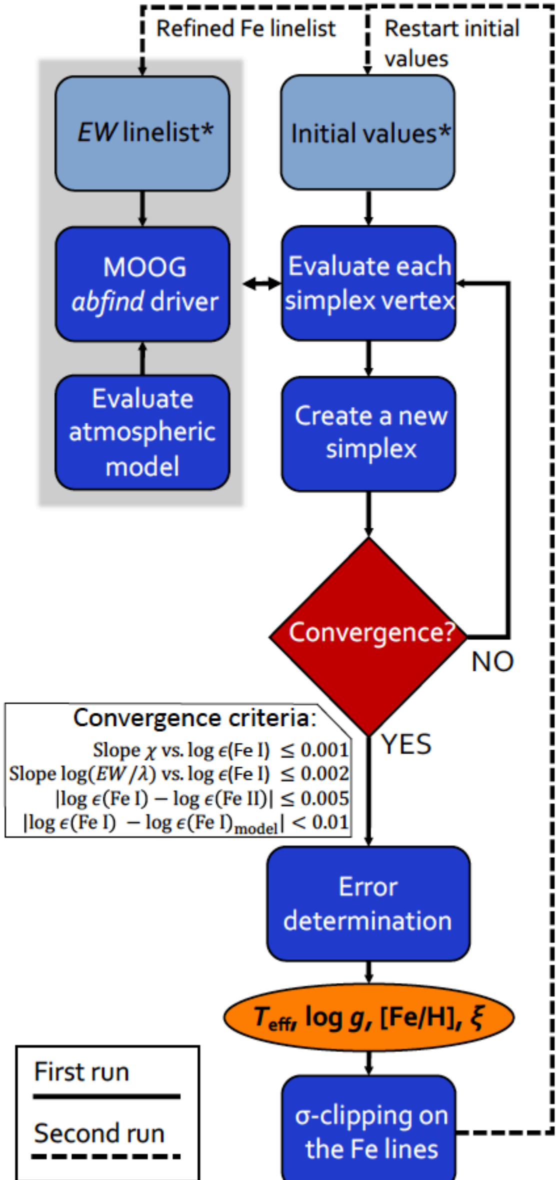
Formal definition of the Equivalent Width:

$$\boxed{W_\lambda = \int \left(1 - \frac{F_\lambda}{F_0} \right) d\lambda}$$





StePar (Tabernero, H. M., Marfil, E. Montes, D. et al., A&A, submitted)



StePar: an automatic code to infer stellar atmospheric parameters

H. M. Tabernero[1], E. Marfil[2], D. Montes[2], and J. I. González Hernández[3,4]

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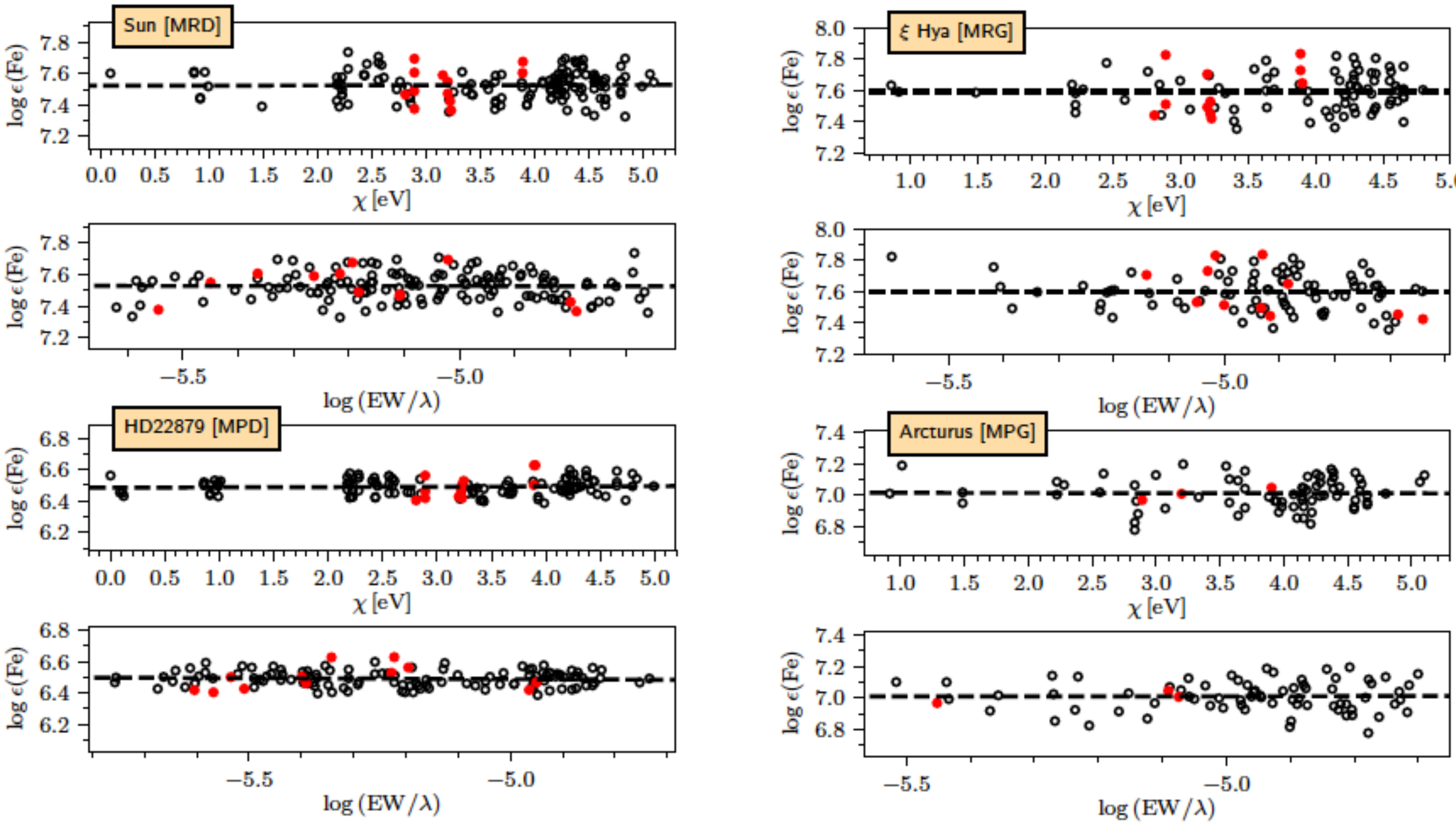
Received 1 March, 2019; accepted month day, 2019

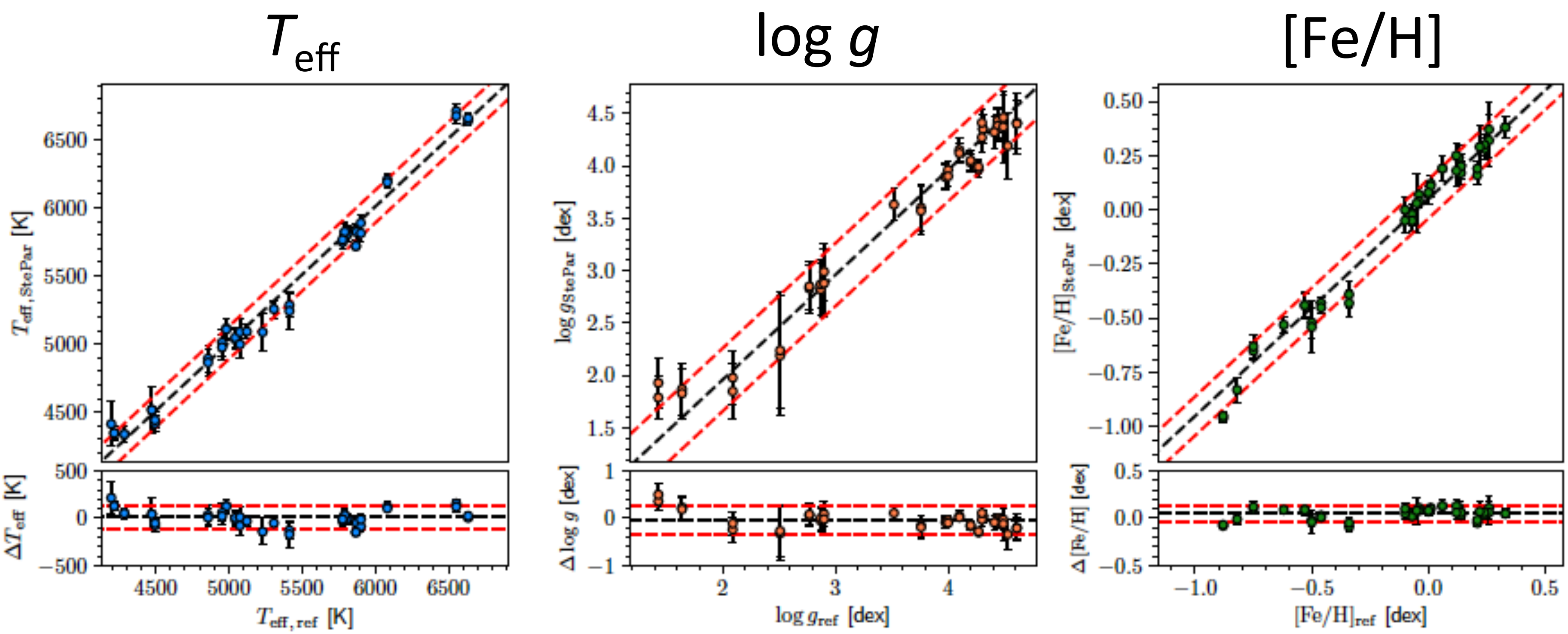
Gaia ESO Survey: UCM node
Tabernero et al., A&A, 2012, 2014
Montes, D. et al. MNRAS, 2018
Marfil, E. et al., A&A, in prep.

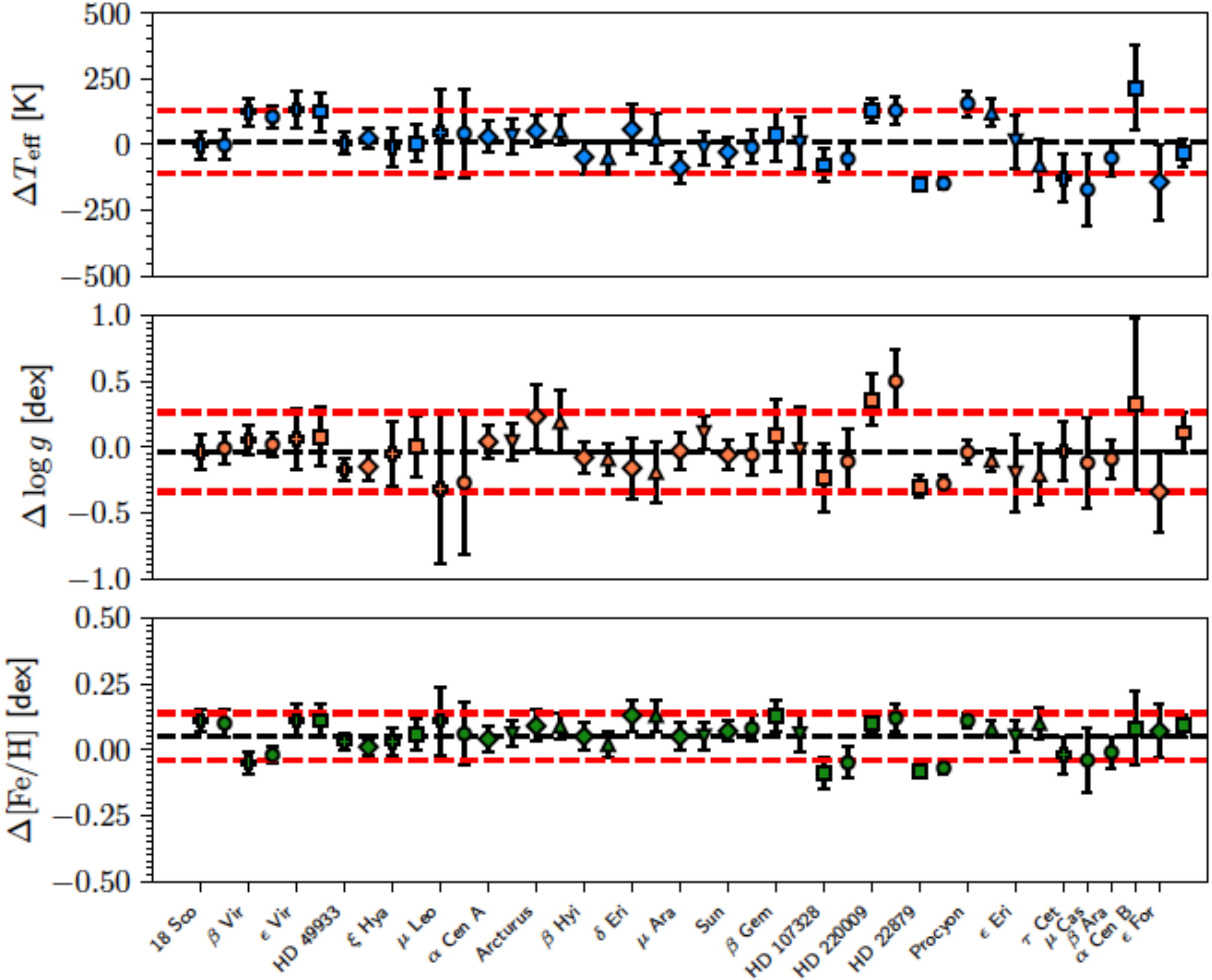
StePar workflow diagram

MOOG standard output (Fe abundance vs. excitation potential and EW)



Testing StePar against Gaia benchmark stars





500
250
0
−250
−500
ΔTeff [K]
1.0
0.5
0.0
−0.5
−1.0
Δ log g [dex]
0.50
0.25
0.00
−0.25
−0.50
Δ[Fe/H] [dex]
18 Sco
β Vir
ϵ Vir
HD 49933
ξ Hya
μ Leo
α Cen A
Arcturus
β Hyi
δ Eri
μ Ara
Sun
β Gem
HD 107328
HD 220009
HD 22879
Procyon
ϵ Eri
τ Cet
μ Cas
β Ara
α Cen B
ϵ For

The CARMENES stellar library

(Caballero et al. A&A, in prep.)

Surface gravity

Giants | 4.00 | Dwarfs | log g

Metallicity

Extremely Metal-Poor | -1.50 | Metal-Poor | -0.30 | Metal-Rich | [Fe/H]

Metal-Rich Dwarfs [MRD]	18 Sco	Metal-Rich Giants [MRG]	ϵ Vir
Metal-Poor Dwarfs [MPD]	μ Cas	Metal-Poor Giants [MPG]	Arcturus

Some of the investigated stars are also Gaia Benchmark Stars (Jofré et al. 2014, Heiter et al. 2015), which are meant to serve as reference stars of spectroscopic surveys since their parameters have been determined independently from spectroscopy. This in turn will help us assess and validate our own method.

Selected spectral lines along with their atomic parameters come from VALD3 database (Ryabchikova et al. 2015)

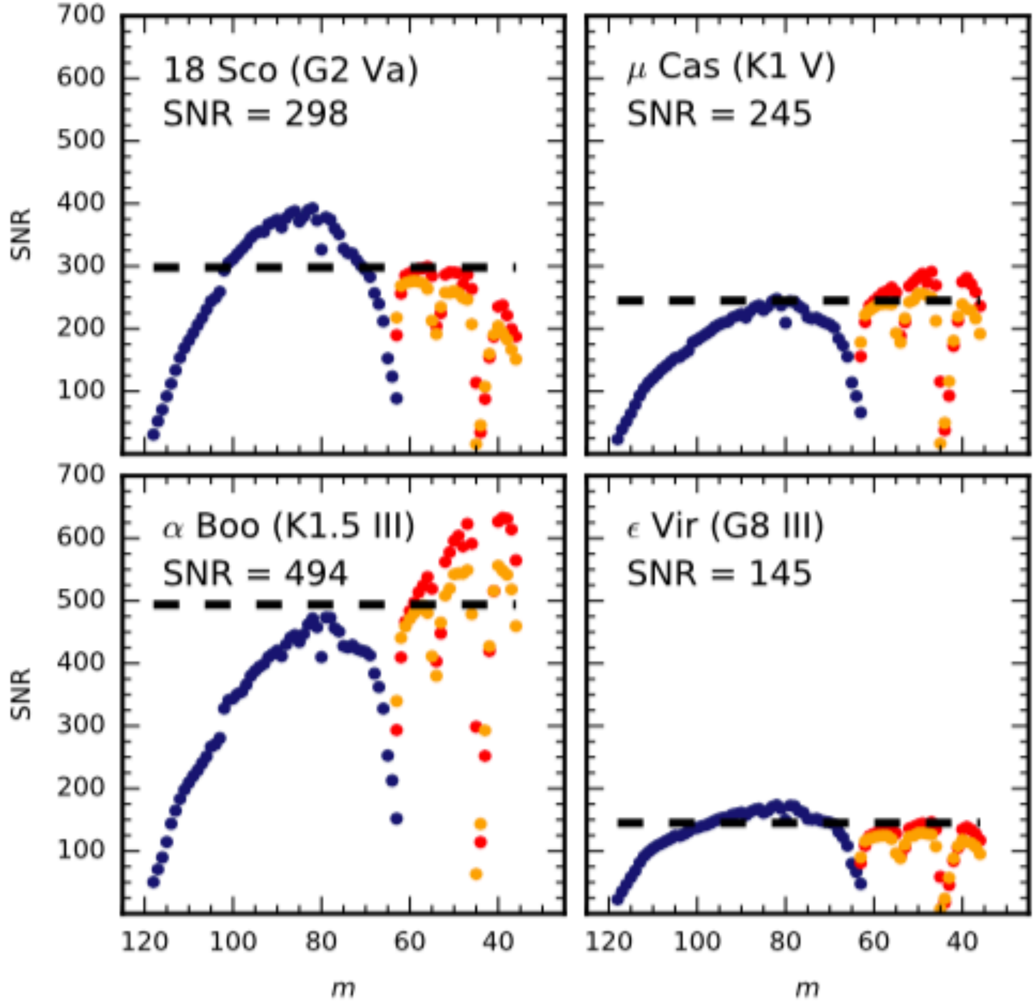


Fig. 2. Signal-to-noise ratio (SNR) of the FITS spectra of the reference stars as a function of the spectral order m. The dashed black lines lie at the global SNR estimation given by iSpec.

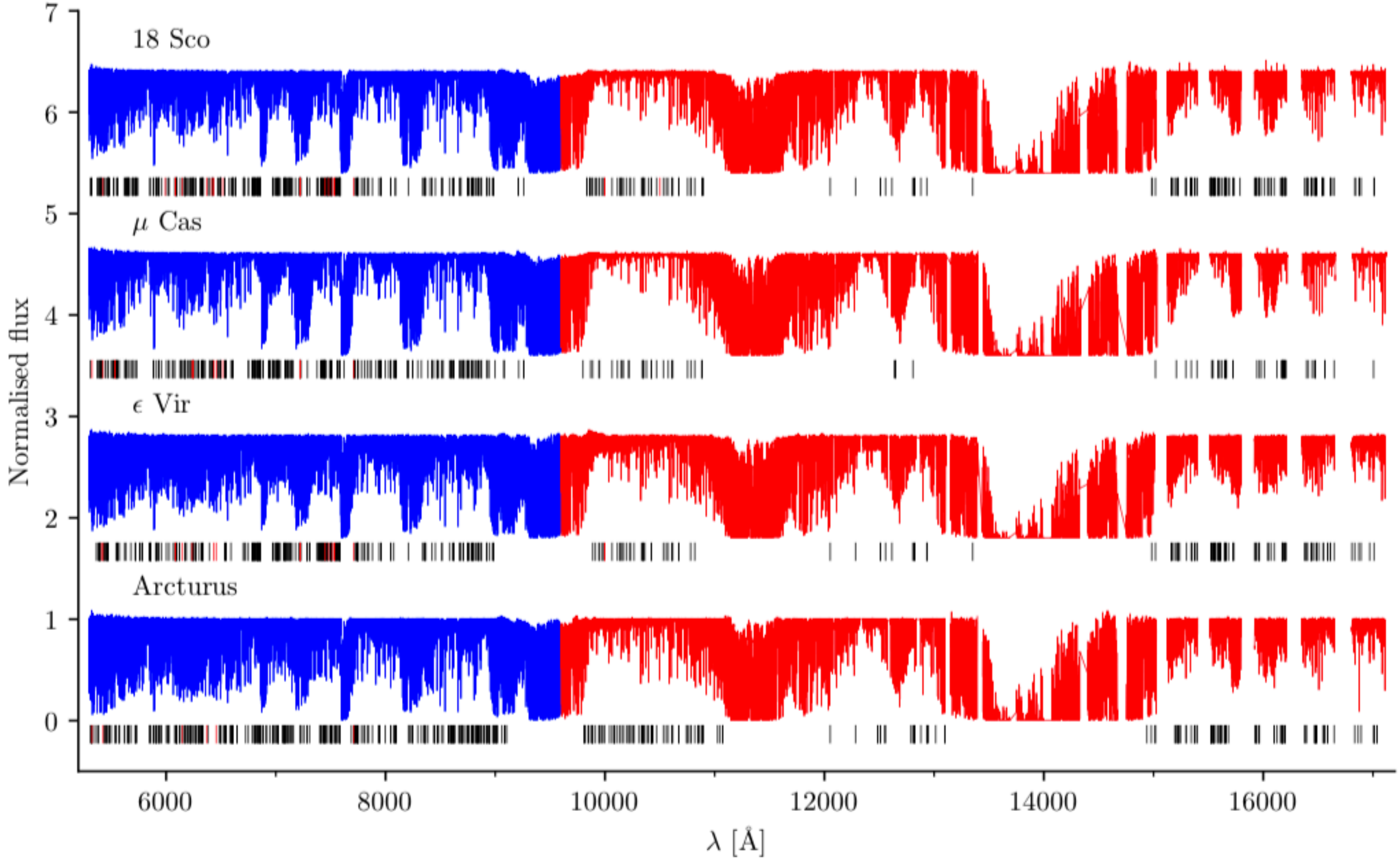
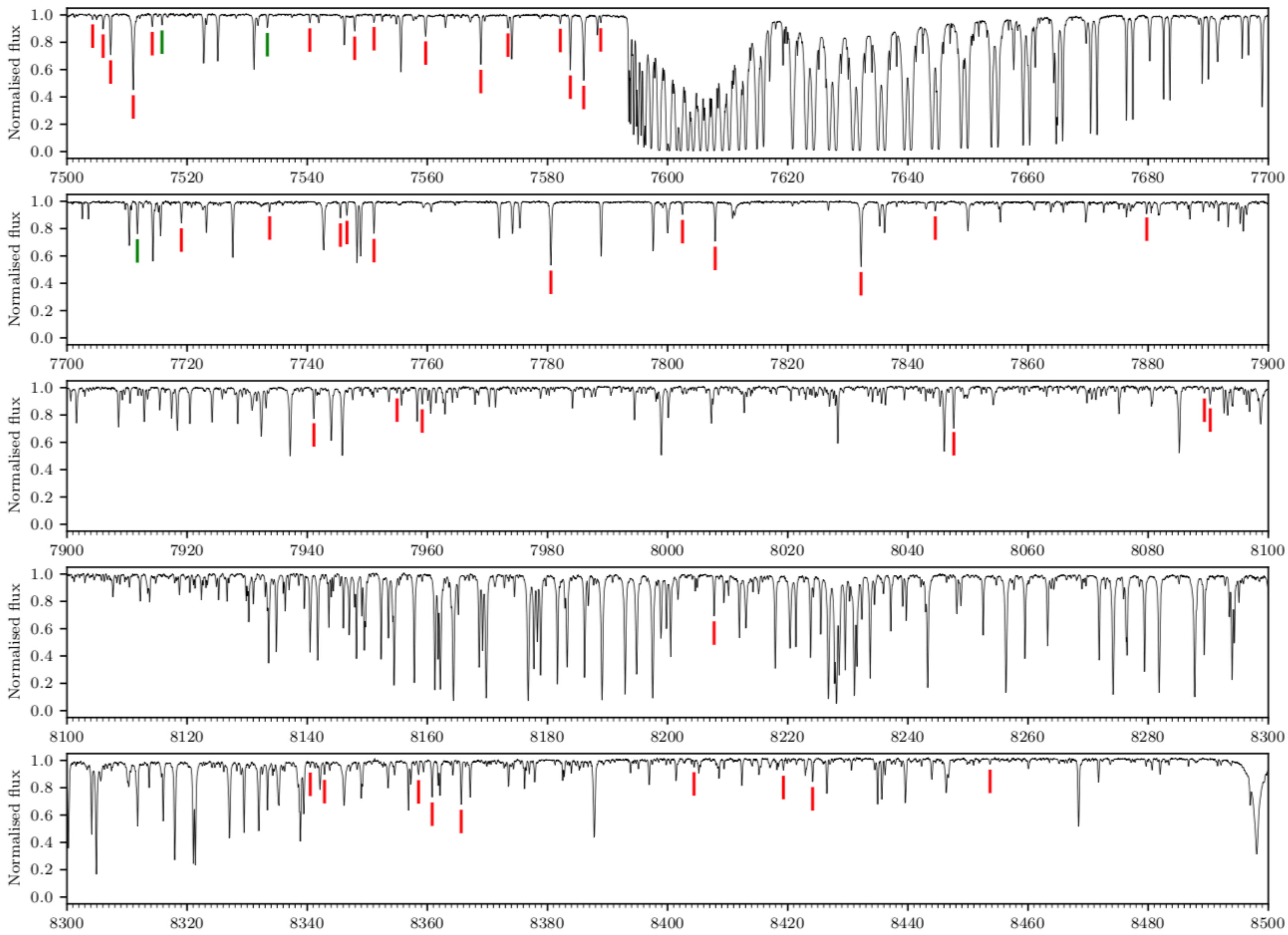


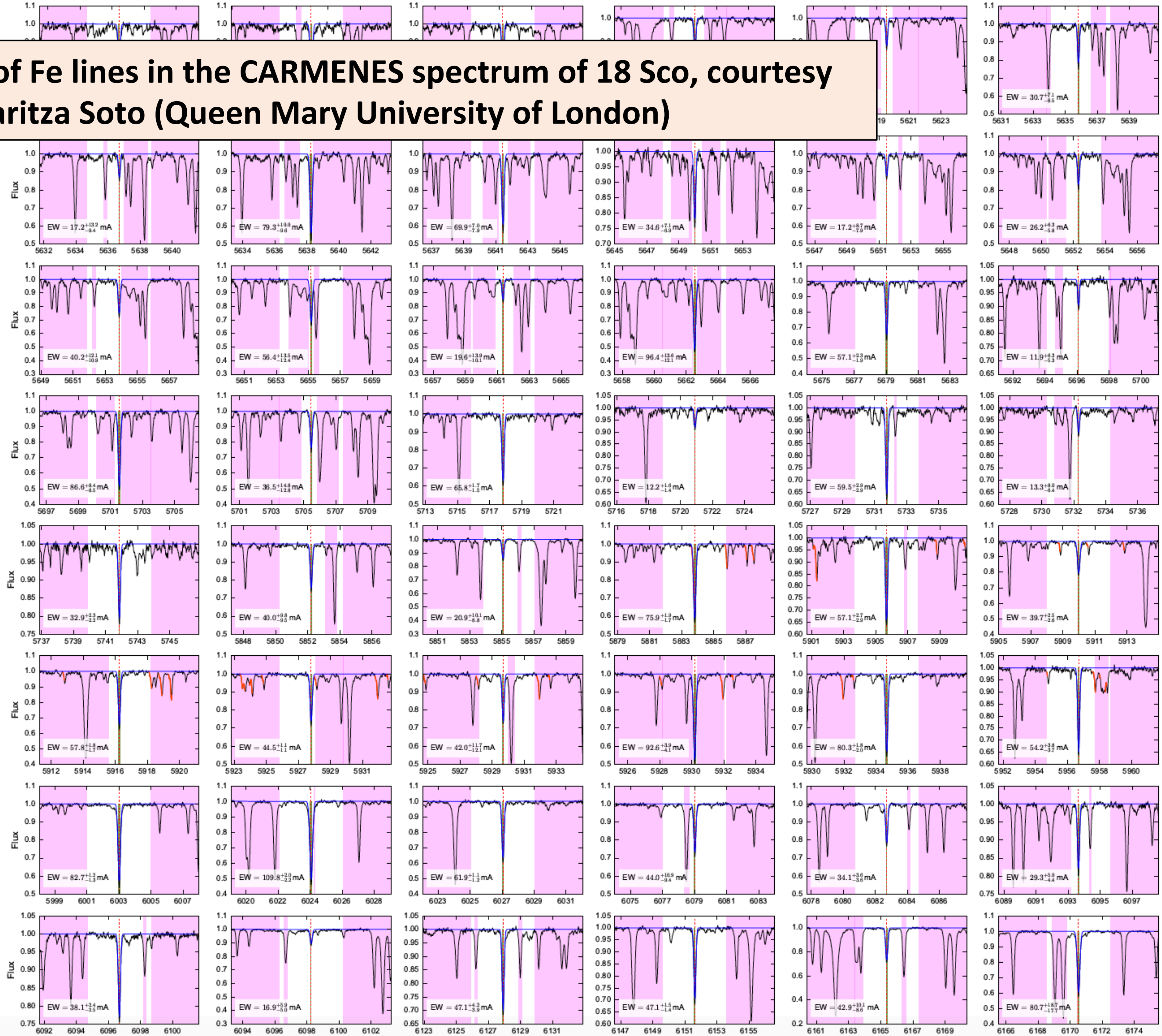
Fig. 4. Distribution of the selected Fe I and Fe II spectral lines in the CARMENES spectra of the reference stars. From top to bottom: 18 Sco, μ Cas, ϵ Vir, and Arcturus.

CARMENES spectrum of 18 Sco

VIS channel @ 7500-8500 Å



EWs of Fe lines in the CARMENES spectrum of 18 Sco, courtesy of Maritza Soto (Queen Mary University of London)



Stellar parameters of GTO M dwarfs

Aim: To spectroscopically derive the atmospheric stellar parameters of CARMENES GTO M dwarfs: T_{eff}, log g, [M/H]

Method: Line-based approach. **Three steps:**

STEPARSYN Tabernero et al. 2018

1. Careful **selection of relevant Fe and Ti lines** found in CARMENES spectra
2. **Grid of synthetic spectra** on narrow spectral regions around the selected lines
3. ***MCMC* algorithm** for the ***probability distribution functions*** of the target parameters based on the comparison between the real spectra and the grid.

WP3070: Stellar parameters

Division of the parameter space*: T_{eff}

"Hot" M dwarfs: GX And (M1.0 V)

"Lukewarm" M dwarfs: Luyten's star (M3.5 V)

"Cold" M dwarfs: Teegarden's star (M7.0 V)

* Reference stars: Reiners et al. (2018) spectral atlas.

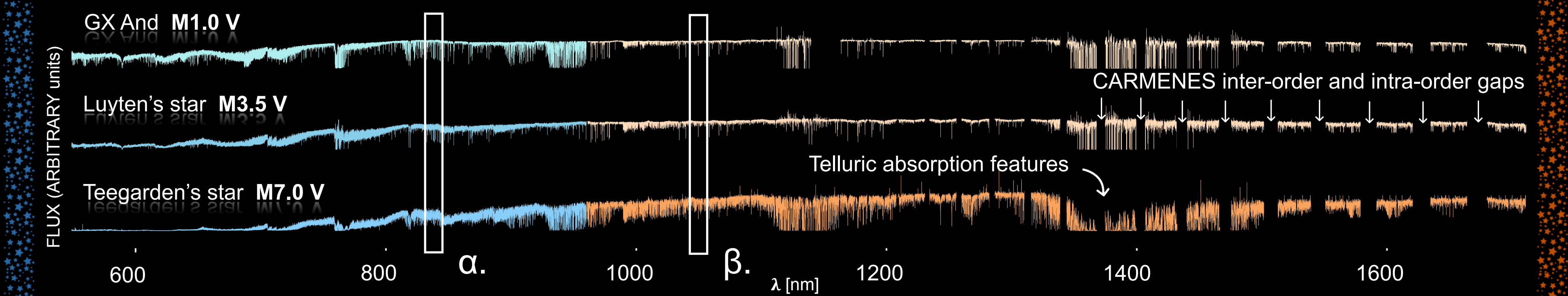
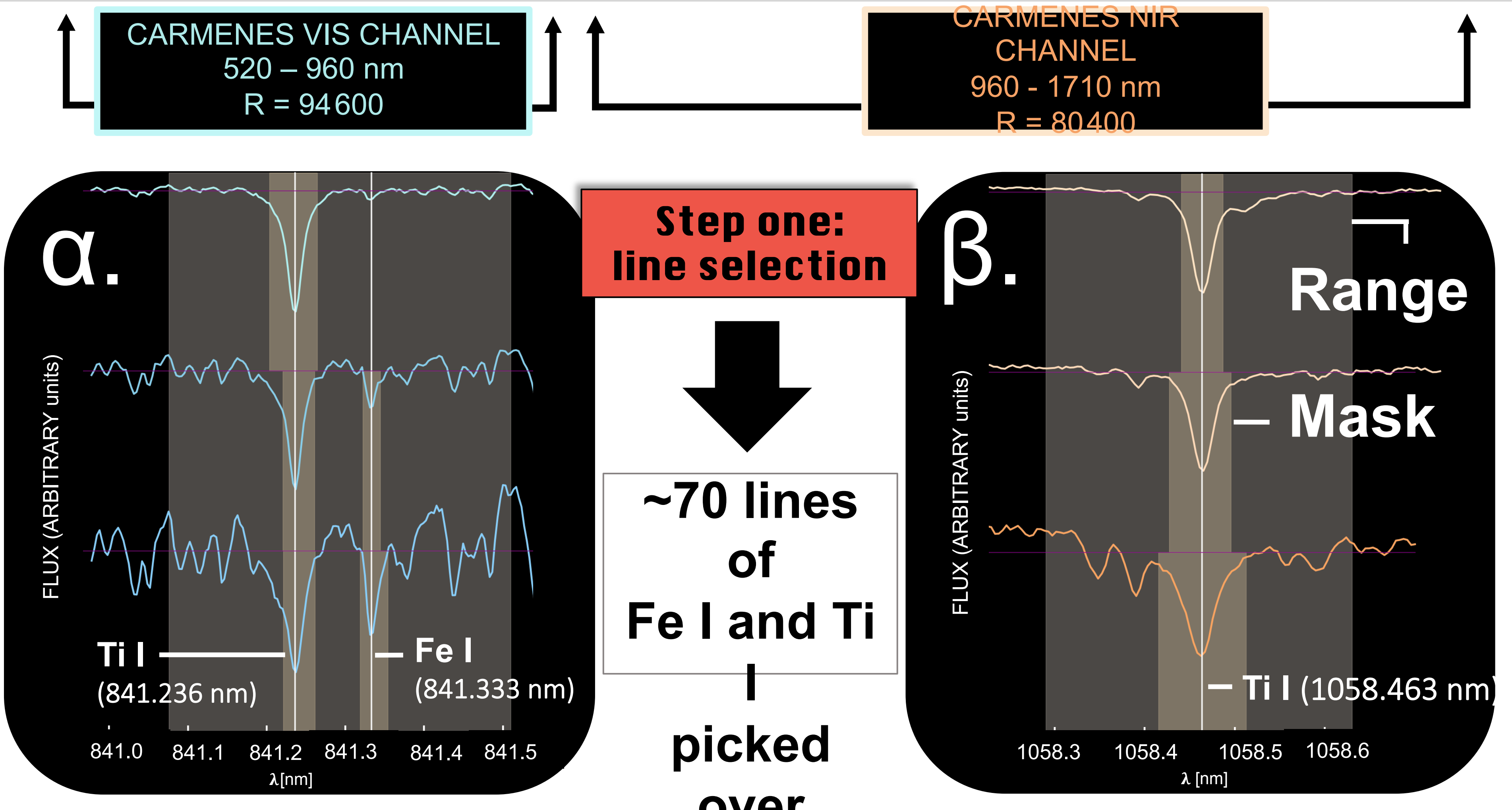


Figure 1. From top to bottom, individual CARMENES spectra of our three reference stars GX And (M1.0 V), Luyten's star (M3.5 V) and Teegarden's star (M7.0 V), respectively.



Step two: spectral synthesis. Key aspects

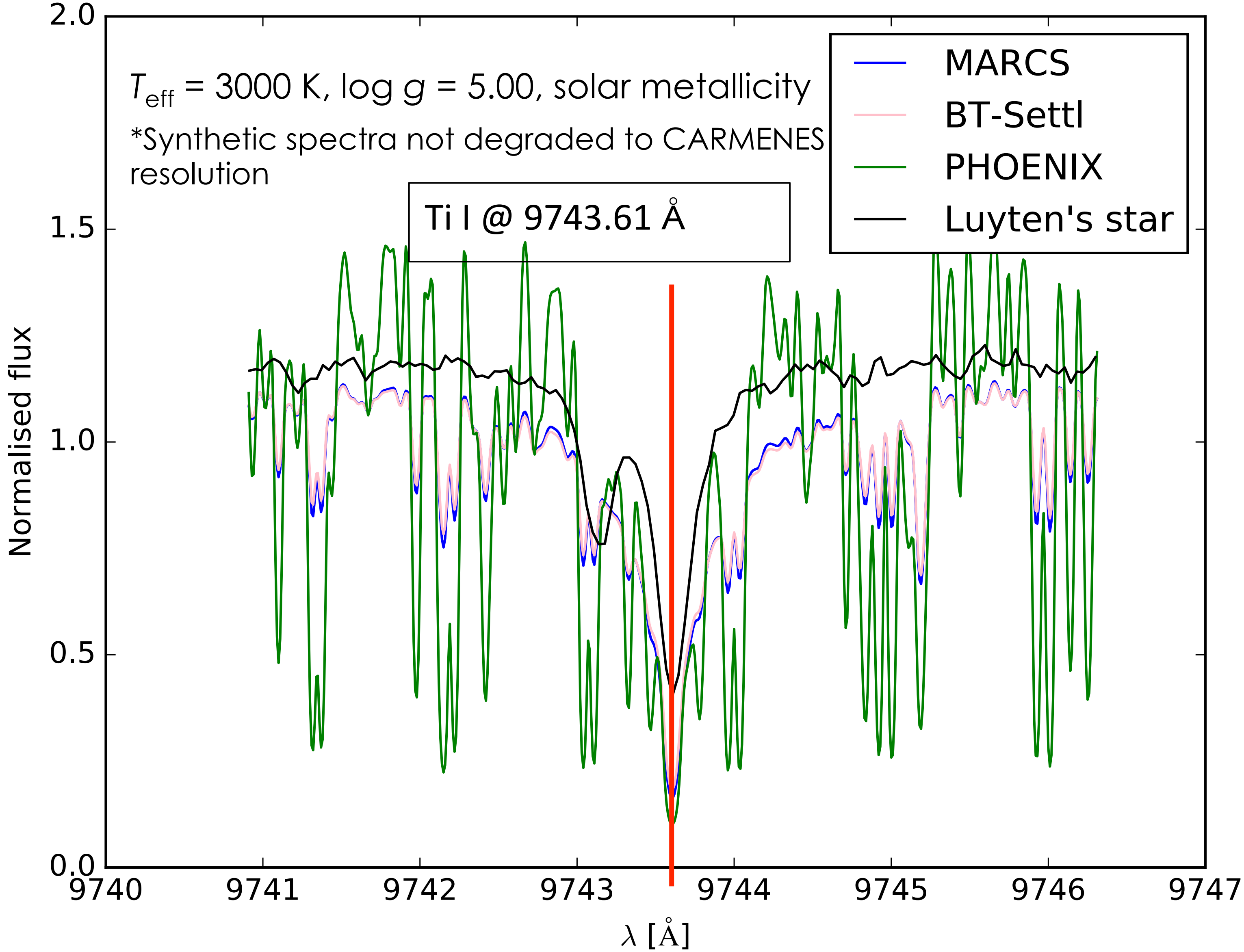
Radiative transfer code: **TurboSpectrum** (Alvarez & Plez 1998, Plez 2012)

We have tried out different model atmospheres:

- MARCS(Gustafsson et al. 2008)
- BT-Settl (Allard et al. 2012, RSPTA 370. 2765A)
- PHOENIX (Husser et al. 2013)

Atomic line data: VALD3 (*extract all* option).
Molecular line data: Mostly from line lists compiled by B. Plez (available at *http://www.pages-perso-bertrand-plez.univ-montp2.fr*) and ExoMol

TiO SiH MgH CaH CrH FeH C_2 ZrO H_2O OH CN CO VO & isotopes



T_{eff} = 3000 K, log g = 5.00, solar metallicity
*Synthetic spectra not degraded to CARMENES resolution
Ti I @ 9743.61 Å
MARCS
BT-Settl
PHOENIX
Luyten's star
Normalised flux
λ [Å]
0.0
0.5
1.0
1.5
2.0
9740
9741
9742
9743
9744
9745
9746
9747

Stellar parameters of GTO M dwarfs

Spectral synthesis: grids

Our grids cover the following parameter space:

Model	Effective temperature	Surface gravity	Metallicity
PHOENIX	2600 K < $T_{\rm eff}$ < 4500 K	4.00 < log g < 6.00	-1.00 < [Fe/H] < 1.00
BT-Settl	2600 K < $T_{\rm eff}$ < 4500 K	4.00 < log g < 5.50 or 6.00*	-1.00 < [Fe/H] < 1.00
MARCS	2500 K < $T_{\rm eff}$ < 3900 K	4.00 < log g < 6.00*	-1.00 < [Fe/H] < 1.00

* Upper limit of log g depends on actual effective temperature of the models.

Any given grid of synthetic spectra is stored in a binary file.

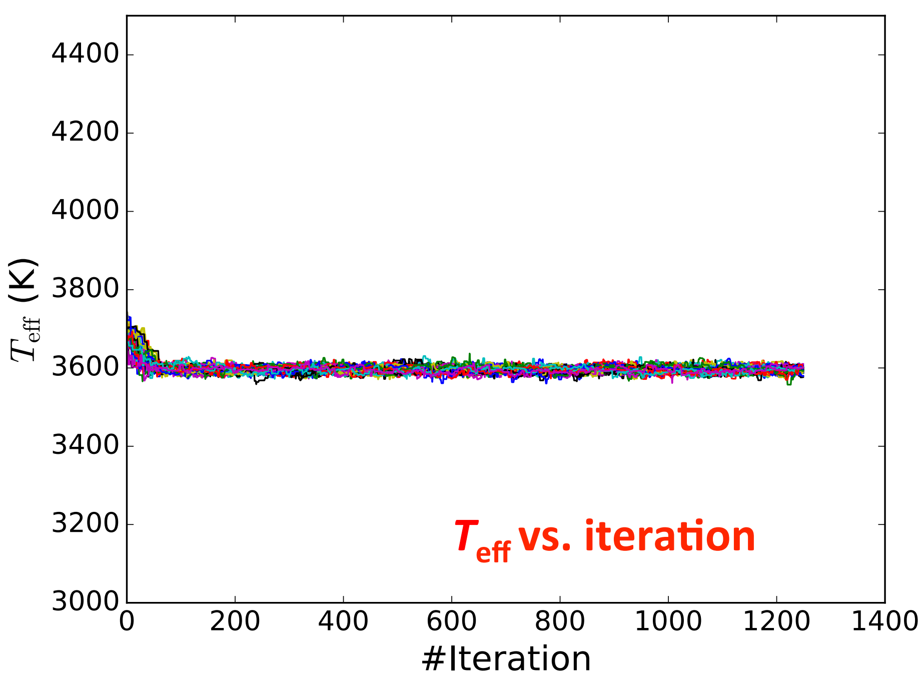
WP3070: Stellar parameters

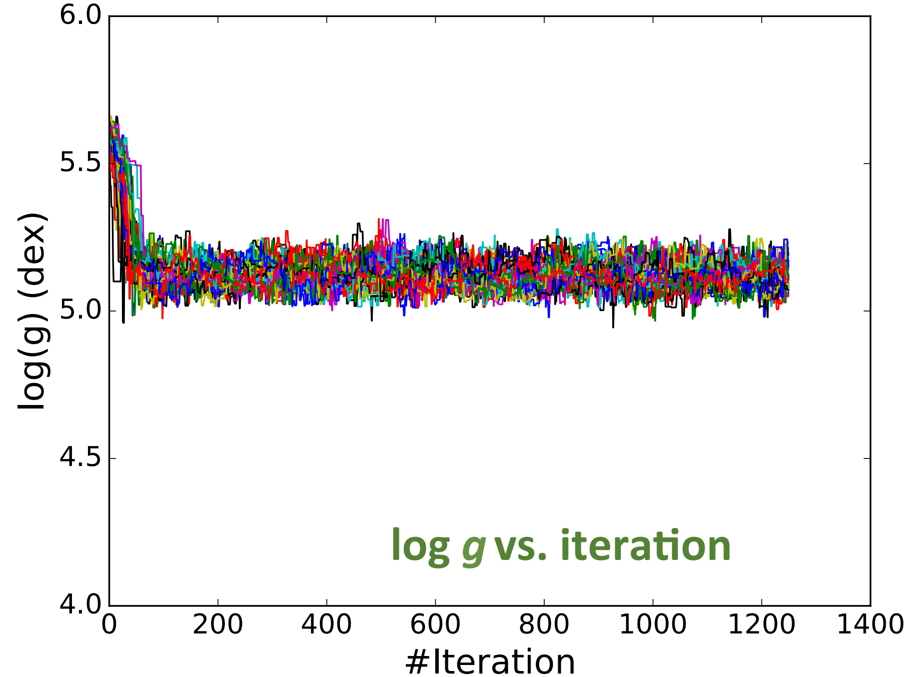
Step 3: MCMC algorithm. STEPARSYN code (Tabernero et al. 2018)

Quick summary:

- PCA emulator on the grid
- Interpolation using Python qhull implementation
- Python packages: scipy.interpolate, emcee (MCMC)
- 1250 chains, 40 walkers, burn in 250

MCMC chains for GX And

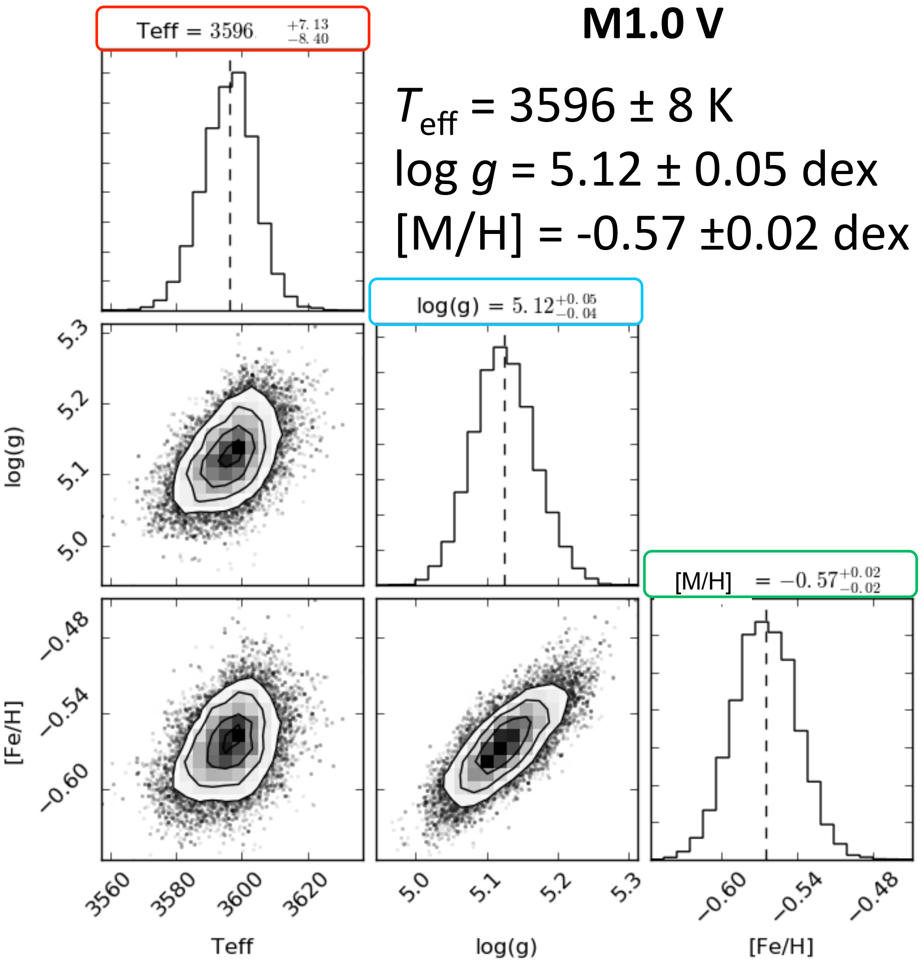




Results: Corner plots and atmospheric stellar parameters.

M1.0 V

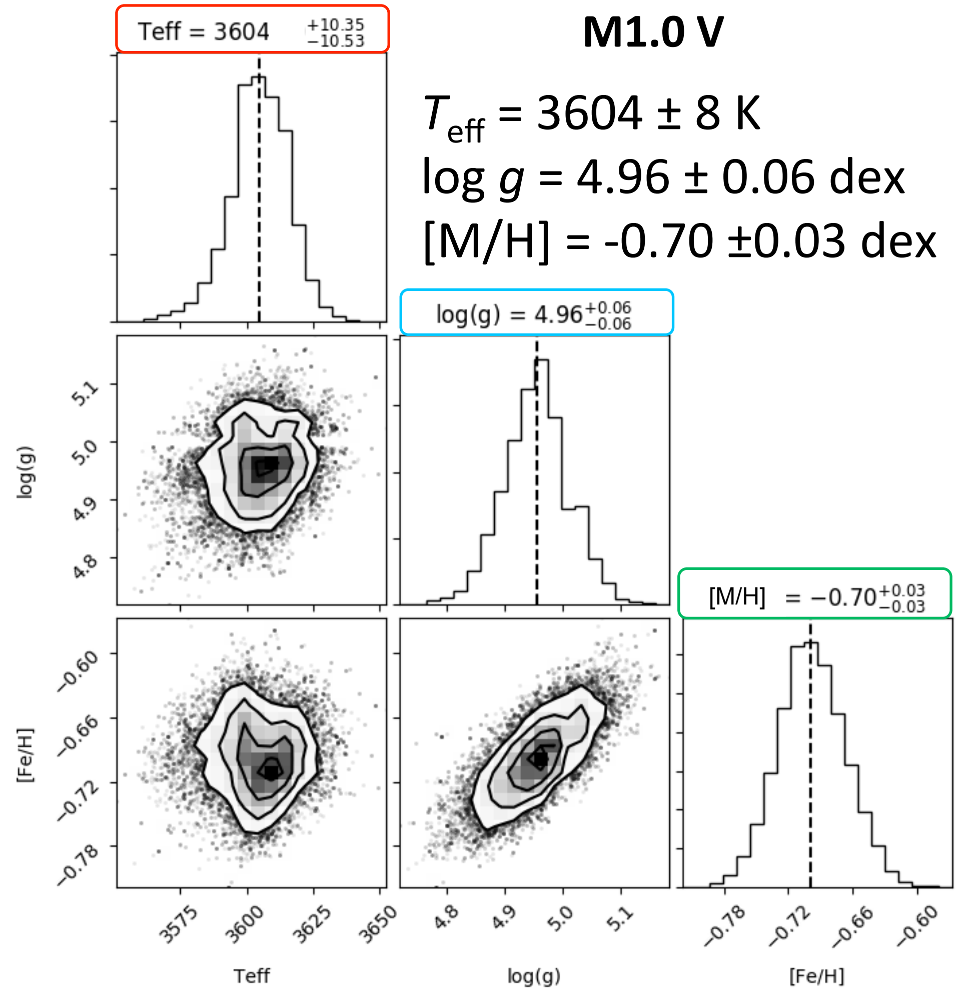
$T_{\rm eff}$ = 3596 ± 8 K
log g = 5.12 ± 0.05 dex
[M/H] = -0.57 ±0.02 dex



GX And (J00183+440)

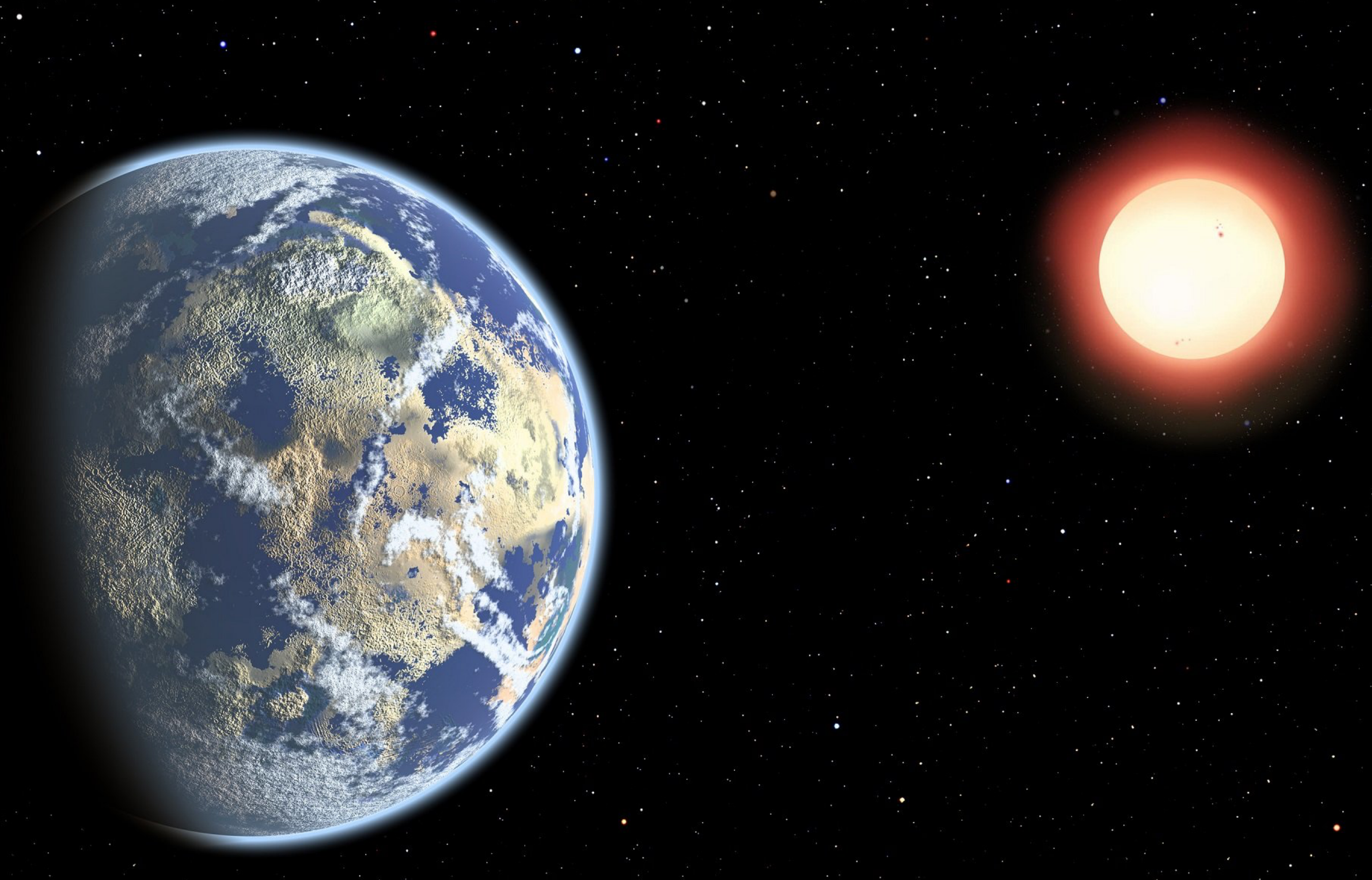
M1.0 V

$T_{\rm eff}$ = 3604 ± 8 K
log g = 4.96 ± 0.06 dex
[M/H] = -0.70 ±0.03 dex



BD+442051A (J11054+435)

Thank you for your attention



Credit: Harvard-Smithsonian Center for Astrophysics