



UCM



FACULTAD DE CIENCIAS FÍSICAS



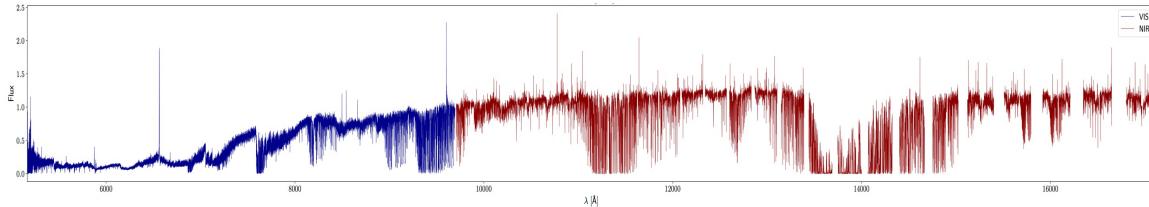
IPARCOS

# CARMENES in Madrid: Stars (with exoplanets)



David Montes ([dmontes@ucm.es](mailto:dmontes@ucm.es)),  
and the CARMENES consortium

Departamento de Física de la Tierra y Astrofísica (FTA) e IPARCOS-UCM, Facultad de Ciencias Físicas,  
Universidad Complutense de Madrid, UCM, E-28040, Madrid, Spain



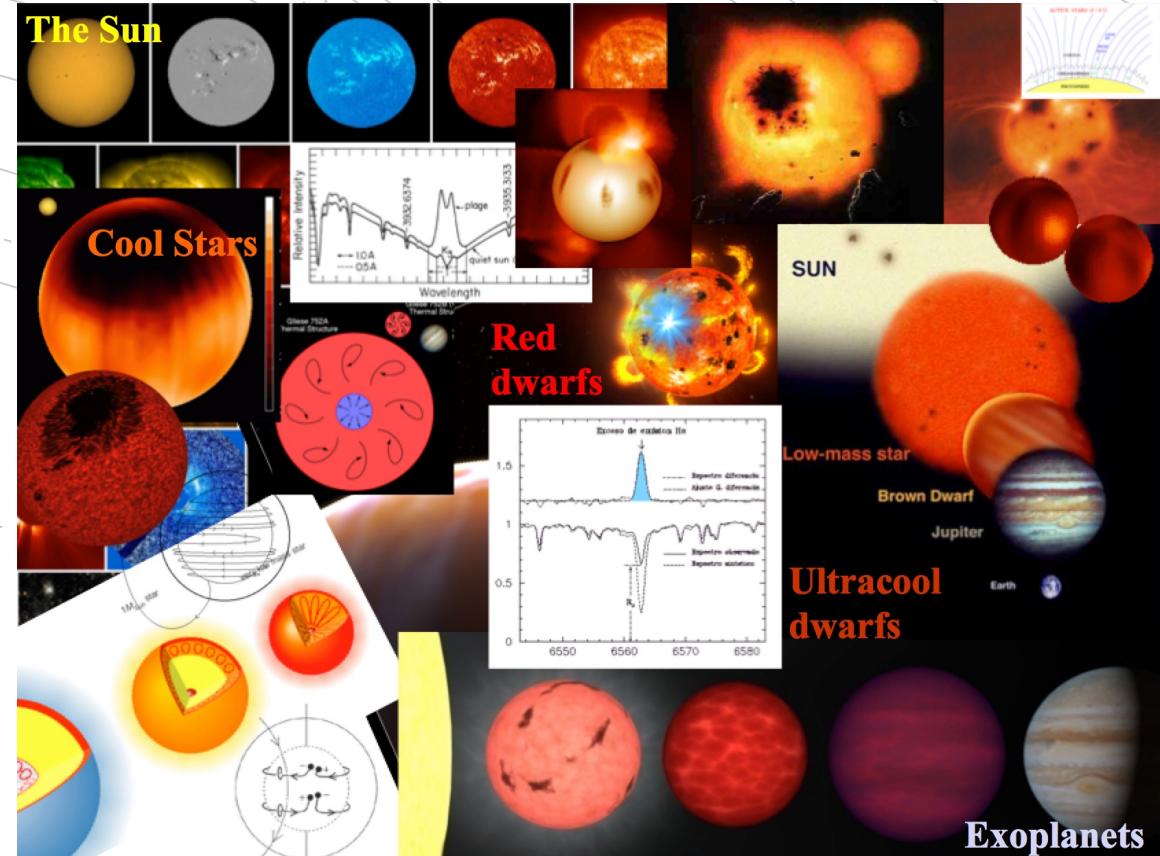


IPARCOS



UCM

Cool Stars,  
Stellar Parameters,  
Stellar Activity,  
Exoplanetas  
group:





UCM

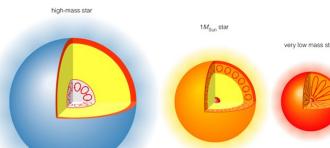
## SEEF (Stellar Systems, Spectroscopy and Photometry)

- **UCM (Univ Complutense de Madrid)**  
<https://www.ucm.es>
- **Facultad. C.C. Físicas**  
<https://fisicas.ucm.es>
- **Dpto. de Física de la Tierra y Astrofísica**  
[https://www.ucm.es/fisica\\_de\\_la\\_tierra\\_y\\_astrofisica/](https://www.ucm.es/fisica_de_la_tierra_y_astrofisica/)
- **IPARCOS-UCM (Instituto de Física de Partículas y del Cosmos de la UCM)**  
Institute of Particle and Cosmos Physics  
<https://www.ucm.es/iparcos/>
- **Grupo de investigación (SEEF)**  
<https://webs.ucm.es/info/Astrof/invest/actividad/actividad.html>



UCM

Cool Stars,  
Stellar Parameters,  
Stellar Activity,  
Exoplanetas  
group:



David Montes

## ■ Areas of research:

- Cool Stars (**F G K M**)
- Stellar parameters ( $T_{\text{eff}}$ ,  $\log g$ ), [Fe/H])
- Abundances ([X/H], [X/Fe])
- Stellar activity (starspots, chromosphere, transition region, corona, flares, prominences, etc...)
- Rotation, age, kinematics
- Open clusters
- Stellar kinematic groups
- Nearby stars
- Red dwarfs stars (**M**)
- Exoplanets (detection and characterization)



# CARMENES

# carmenes

**C**alar  
**A**lto high-  
**R**esolution search for  
**M**dwarfs with  
**E**xoeartns with  
**N**ear-infrared and visible  
**E**chelle  
**S**pectrographs

**MPIA** (Heidelberg) • **IAA** (Granada) • **LSW** (Heidelberg) • **ICE** (Barcelona) • **IAG** (Göttingen) • **IAC** (Tenerife) • **TLS** (Tautenburg) • **UCM** (Madrid) • **HS** (Hamburg) • **CAB** (Madrid) • **CAHA** (50% MPG + 50% CSIC)



Unión Europea  
Fondo Europeo  
de Desarrollo Regional  
"Una manera de hacer Europa"



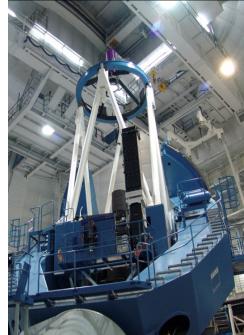
MAX-PLANCK-GESELLSCHAFT



CSIC



Calar Alto



David Montes

<http://carmenes.caha.es/>



Calar Alto

# CARMENES input catalogue



- CARMENES **input catalogue** of  
~**2200** nearby bright **M dwarfs** ( $\delta > -23$  deg)
- ~**300 GTO** (**G**uaranteed **T**ime **O**bservations) **targets**
- **CARMENCITA:**  
**CARMENES** **C**ool dwarf **I**nformation and **d**a**T**a **A**rchive
- **Science preparation** (Low-res & High-res spectra)
  - “**CARMENES: data flow**”  
(Caballero et al. [2016SPIE.9910E..0EC](#))





CARMENES  
science  
preparation

# **CARMENES** **input catalogue** **of M dwarfs.**

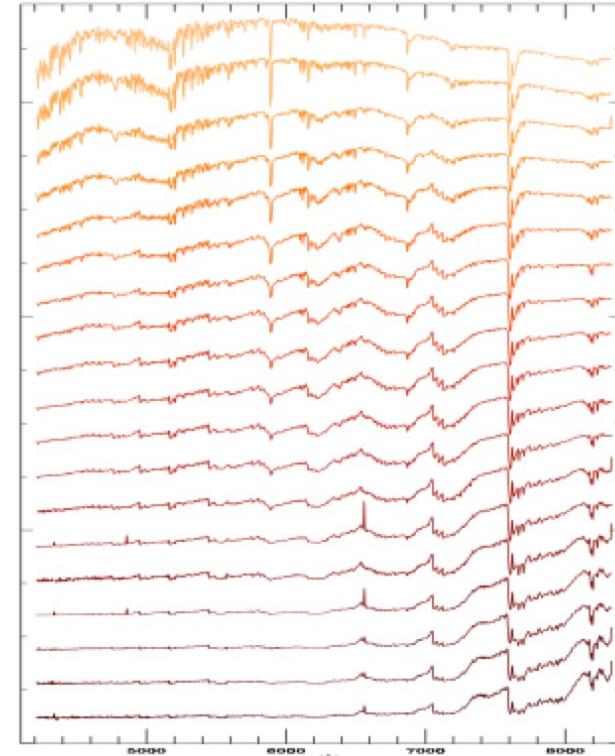


## CARMENES science preparation

**CARMENES input catalogue of M dwarfs.**

David Montes

- I. Low-resolution spectroscopy with CAFOS  
(Alonso-Floriano, et al., [2015A&A...577A.128A](#))



Spectral types for all 753 stars, of which 305 are new and 448 are revised.

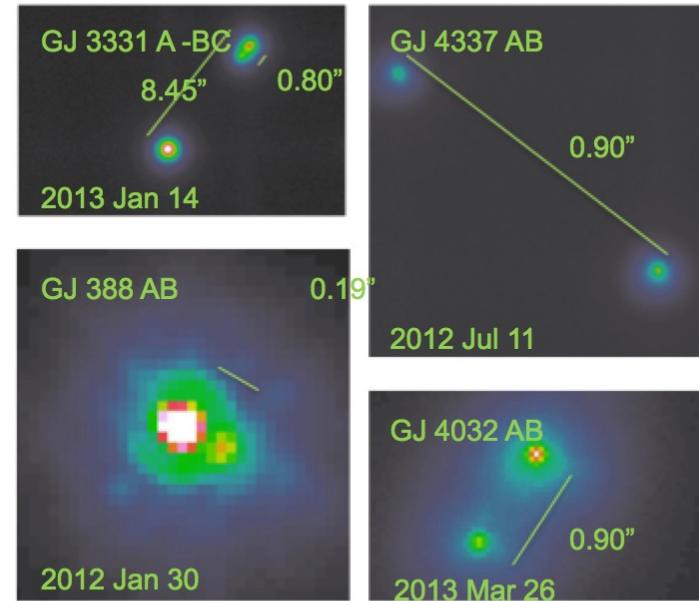


## CARMENES science preparation

**CARMENES input catalogue of M dwarfs.**

David Montes

### - II. High-resolution imaging with FastCam (Cortés-Contreras, et al., [2017A&A...597A..47C](#))



From the 490 observed stars, we detected 80 companions in 76 systems, of which 30 are new discoveries. Another six companion candidates require additional astrometry to confirm physical binding. The multiplicity fraction in our observed sample is  $16.7 \pm 2.0\%$ .

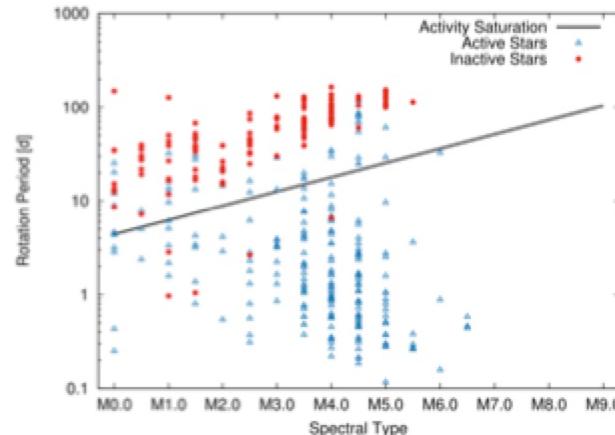
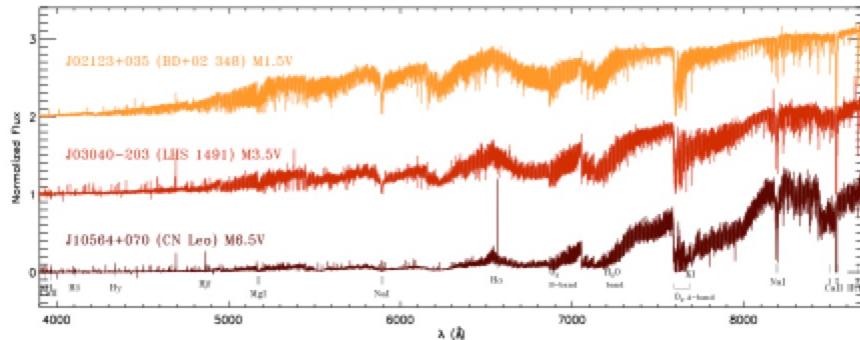


# CARMENES science preparation

**CARMENES input catalogue of M dwarfs.**

David Montes

- III. Rotation and activity from high-resolution spectroscopic observations  
(Jeffers, et al., [2018A&A...614A..76J](#))



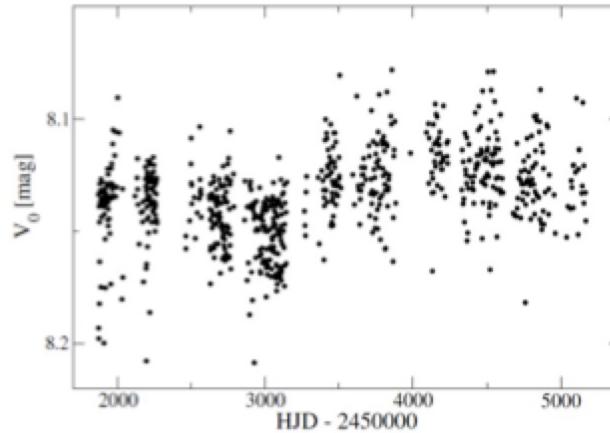


## CARMENES science preparation

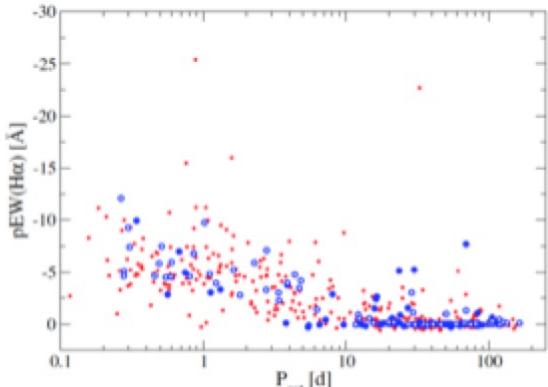
**CARMENES input catalogue of M dwarfs.**

David Montes

- IV. New rotation periods from photometric time series  
(Díez Alonso, et al. 2018, A&A, arXiv:1810.03338)



Rotational periods  
from long-term  
photometric  
monitoring surveys  
(MEarth, ASAS,  
SuperWASP, NSVS,  
Catalina, ASASSN,  
K2, and HATNet).

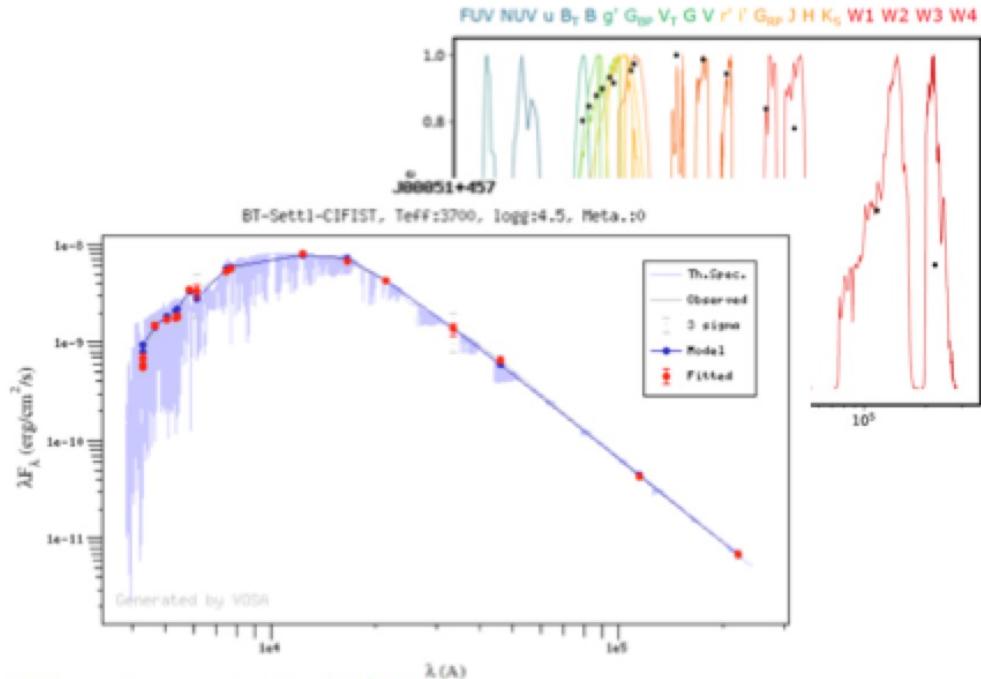




## CARMENES science preparation

**CARMENES input catalogue of M dwarfs.**

### Spectral energy distributions and luminosities of M dwarfs



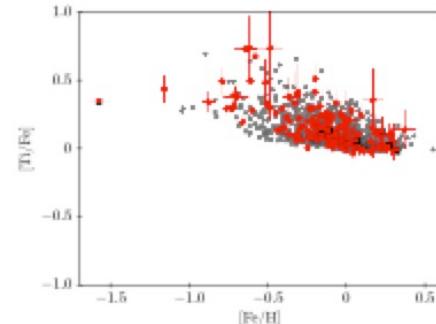
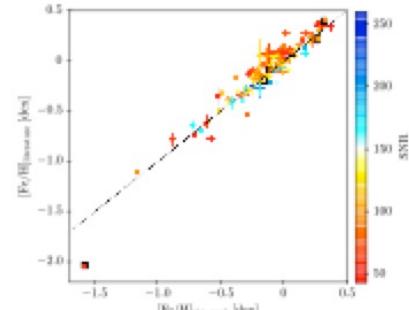
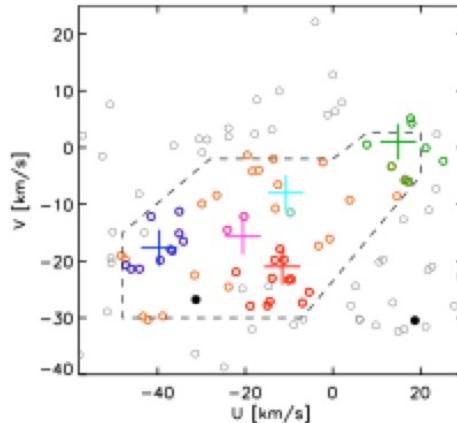
Cifuentes et al. [2020A&A...642A.115C](#)



## CARMENES science preparation

**CARMENES input catalogue of M dwarfs.**

### Calibrating the metallicity of M-dwarfs with wide visual binaries (FGK+M)



(Montes et. al., [2018MNRAS.479.1332M](#)).

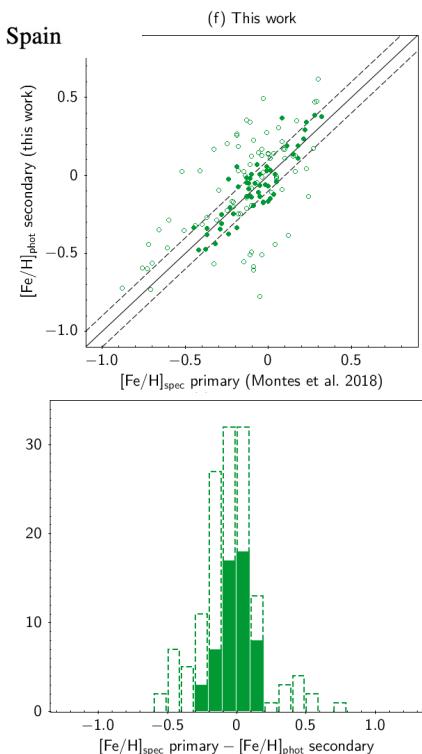
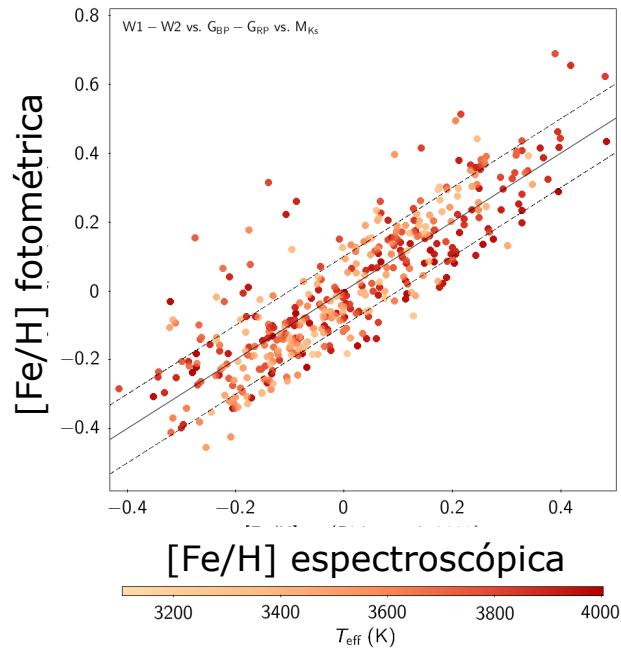
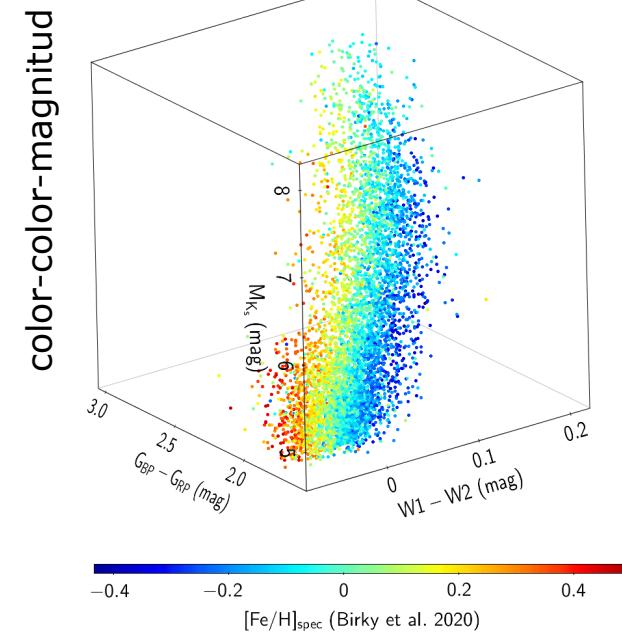
# Photometric calibrations of M dwarf metallicity with Markov chain Monte Carlo and Bayesian inference

C. Duque-Arribas<sup>1</sup>, D. Montes<sup>1</sup>, H. M. Tabernerero<sup>2</sup>, J. A. Caballero<sup>3</sup>, J. Gorgas<sup>1</sup> and E. Marfil<sup>1,2</sup>

<sup>1</sup> Departamento de Física de la Tierra y Astrofísica & IPARCOS-UCM (Instituto de Física de Partículas y del Cosmos de la UCM), Facultad de Ciencias Físicas, Universidad Complutense de Madrid, 28040 Madrid, Spain  
e-mail: chrdue@ucm.es

<sup>2</sup> Centro de Astrobiología (CSIC-INTA), carretera de Ajalvir km 4, 28850 Torrejón de Ardoz, Madrid, Spain

<sup>3</sup> Centro de Astrobiología (CSIC-INTA), ESAC, camino bajo del Castillo s/n, 28691 Villanueva de la Cañada, Madrid, Spain





CARMENES  
science  
exploitation

# The CARMENES search for exoplanets around M dwarfs.

# CARMENES spectra

NIR: 0.96-1.71  $\mu\text{m}$ ,

28 orders

2 2kx2k Hawaii-2RG,

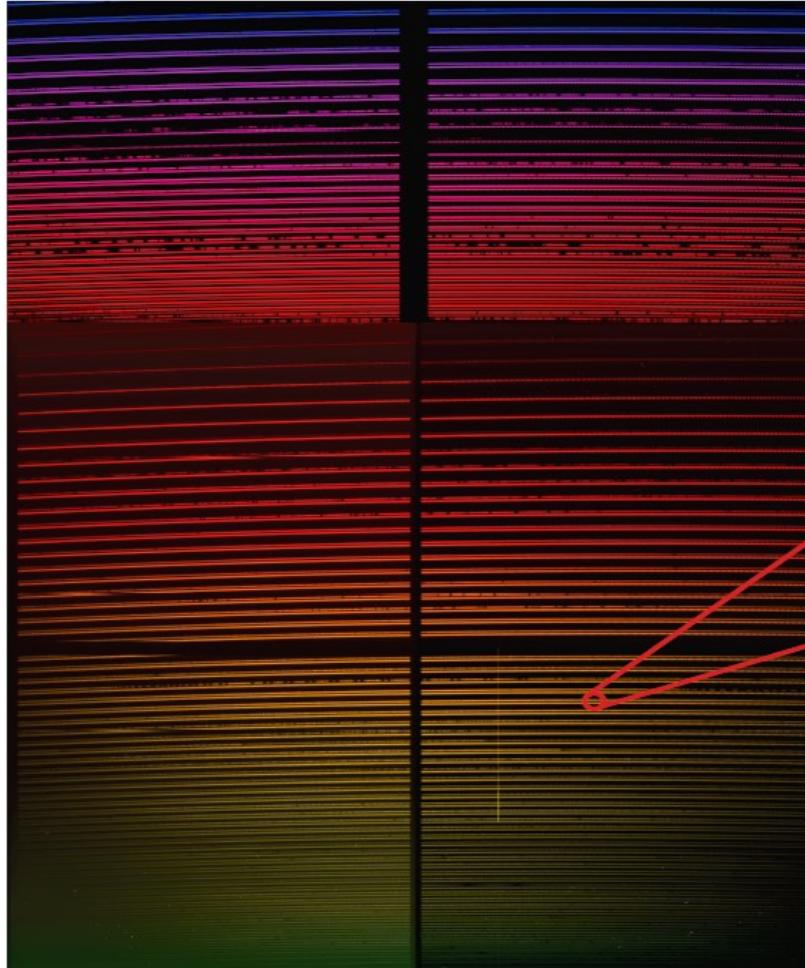
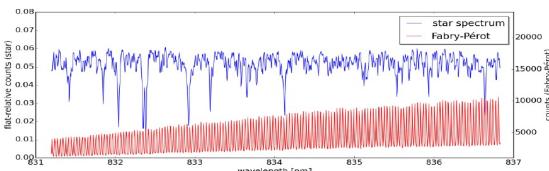
$R = 80\,400$

VIS: 0.52-0.96  $\mu\text{m}$ ,

61 orders

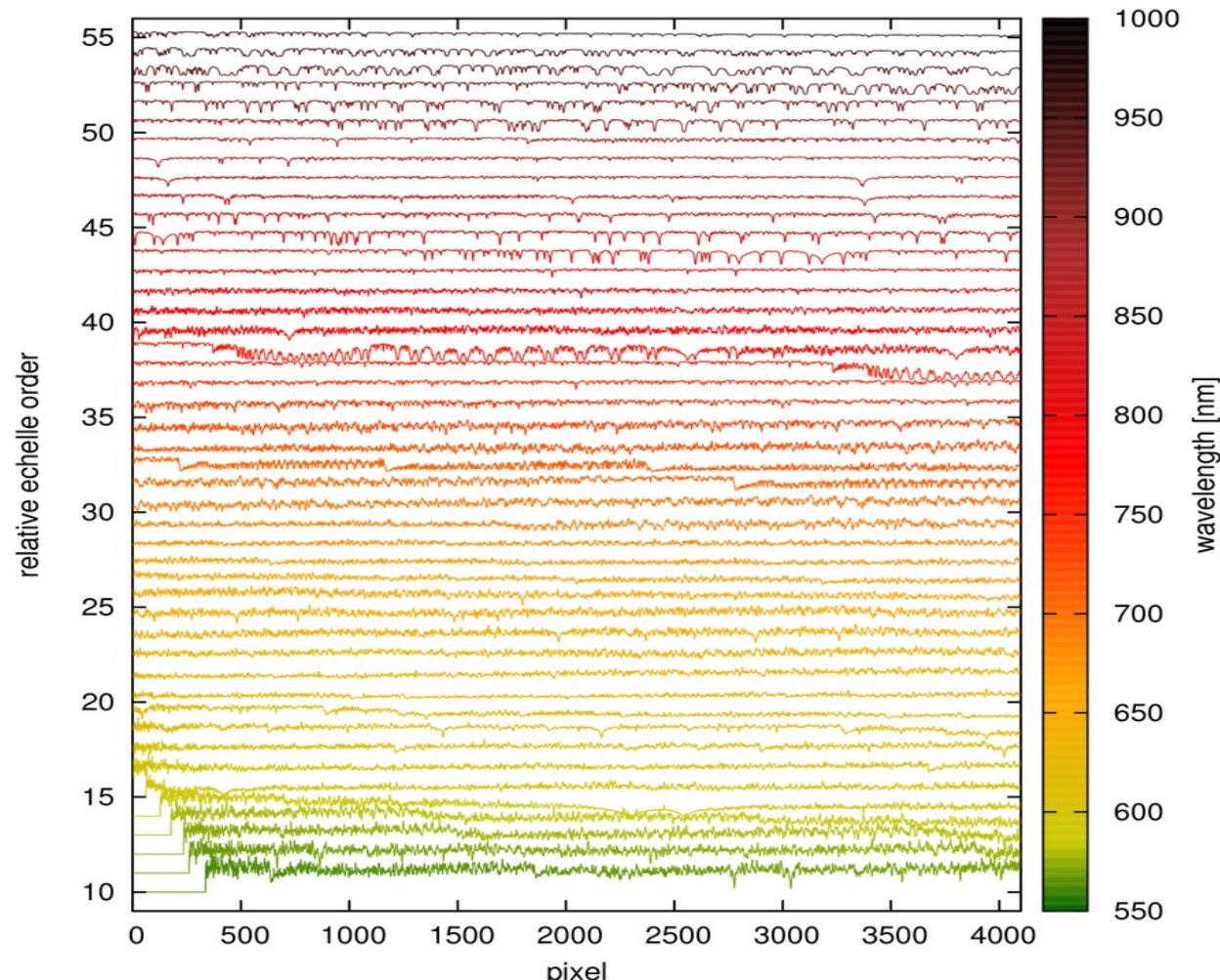
4kx4k e2v CCD231-84,

$R = 96\,500$



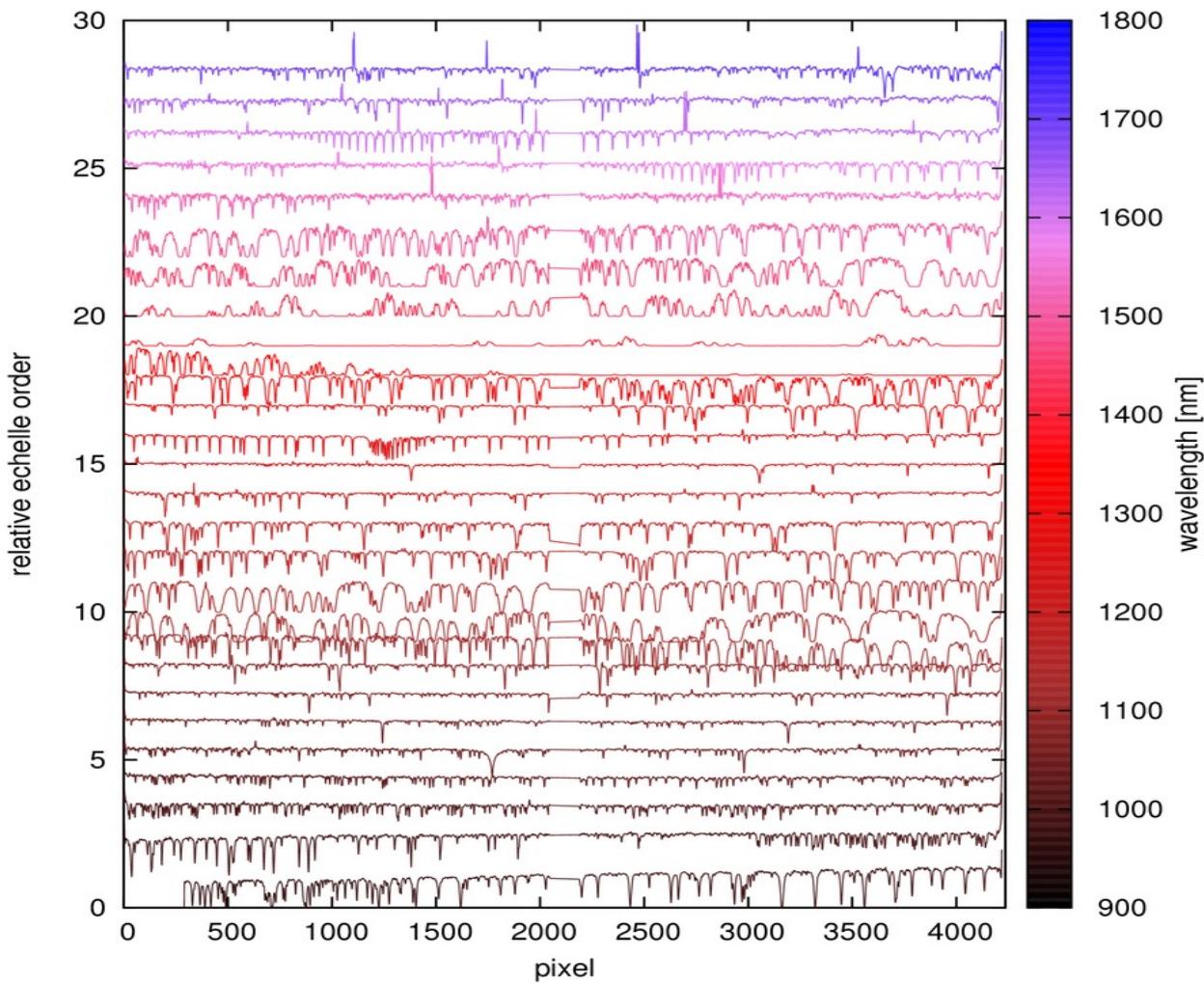
# CARMENES spectra

VIS: 0.52-0.96  $\mu\text{m}$ ,  
61 orders  
4kx4k e2v CCD231-84,  
 $R = 96\,500$



# CARMENES spectra

NIR: 0.96-1.71  $\mu\text{m}$ ,  
28 orders  
2 2kx2k Hawaii-2RG,  
 $R = 80\,400$



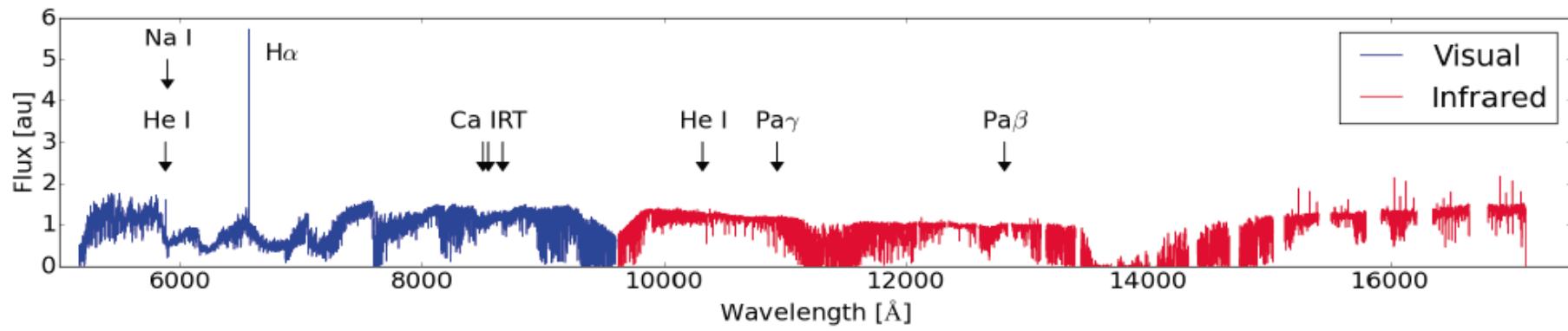
# CARMENES spectra



## VIS + NIR Observations:

**VIS:** 0.52-0.96  $\mu\text{m}$ , 4kx4k e2v CCD231-84,  $R = 96\,500$

**NIR:** 0.96-1.71  $\mu\text{m}$ , 2 2kx2k Hawaii-2RG,  $R = 80\,400$



(YZ CMi, M4.5Ve)  
Poster #191, Czesla et al.

# CARMENES spectra

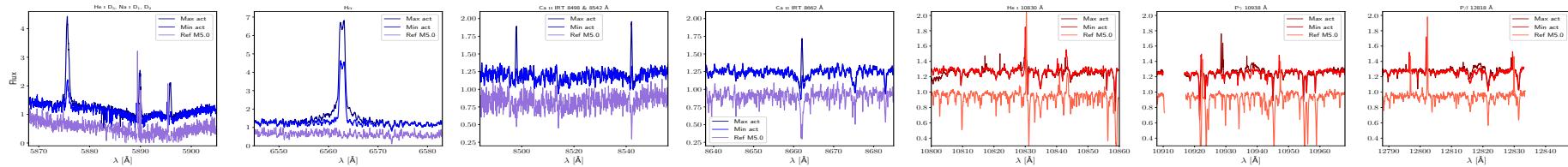
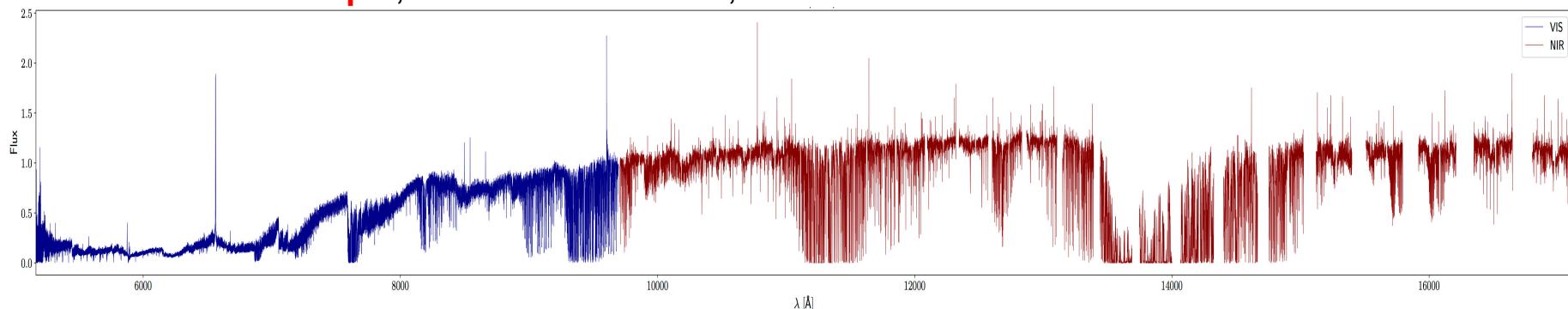


## VIS + NIR Observations:

**VIS:** 0.52-0.96  $\mu\text{m}$ , 4kx4k e2v CCD231-84,  $R = 96\,500$

**NIR:** 0.96-1.71  $\mu\text{m}$ , 2 2kx2k Hawaii-2RG,  $R = 80\,400$

**Estrella M5.5V**





# CARMENES science exploitation

The **CARMENES** search for exoplanets  
around M dwarfs.

David Montes

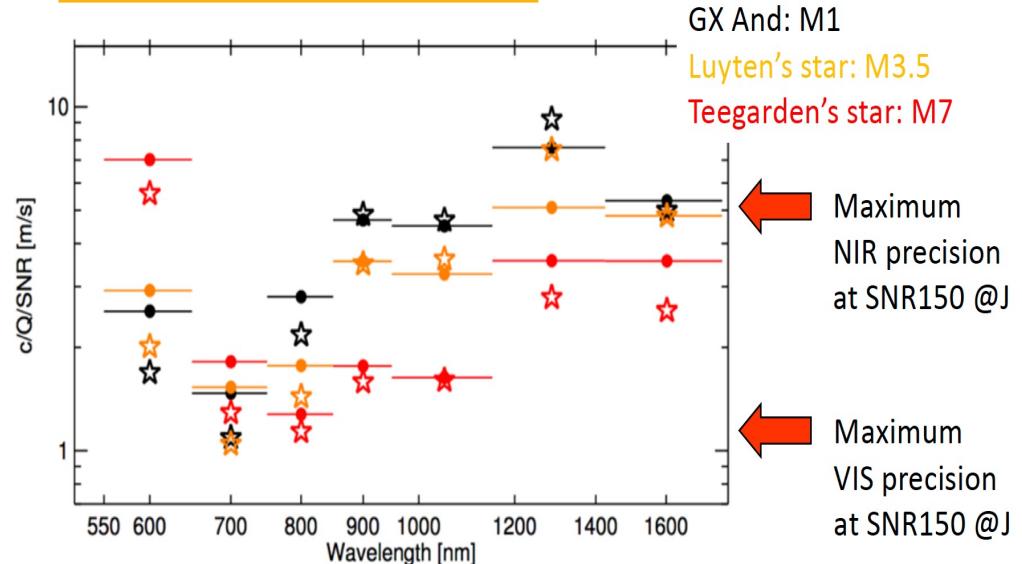
## The CARMENES search for exoplanets around M dwarfs

High-resolution optical and near-infrared spectroscopy of 324 survey stars

A. Reiners<sup>1,\*</sup>, M. Zechmeister<sup>1</sup>, J. A. Caballero<sup>2,3</sup>, I. Ribas<sup>4</sup>, J. C. Morales<sup>4</sup>, S. V. Jeffers<sup>1</sup>, P. Schöfer<sup>1</sup>, L. Tal-Or<sup>1</sup>, A. Quirrenbach<sup>3</sup>, P. J. Amado<sup>5</sup>, A. Kaminski<sup>3</sup>, W. Seifert<sup>3</sup>, M. Abril<sup>5</sup>, J. Aceituno<sup>6</sup>, F. J. Alonso-Floriano<sup>8,12</sup>,

...

2018A&A...612A..49R





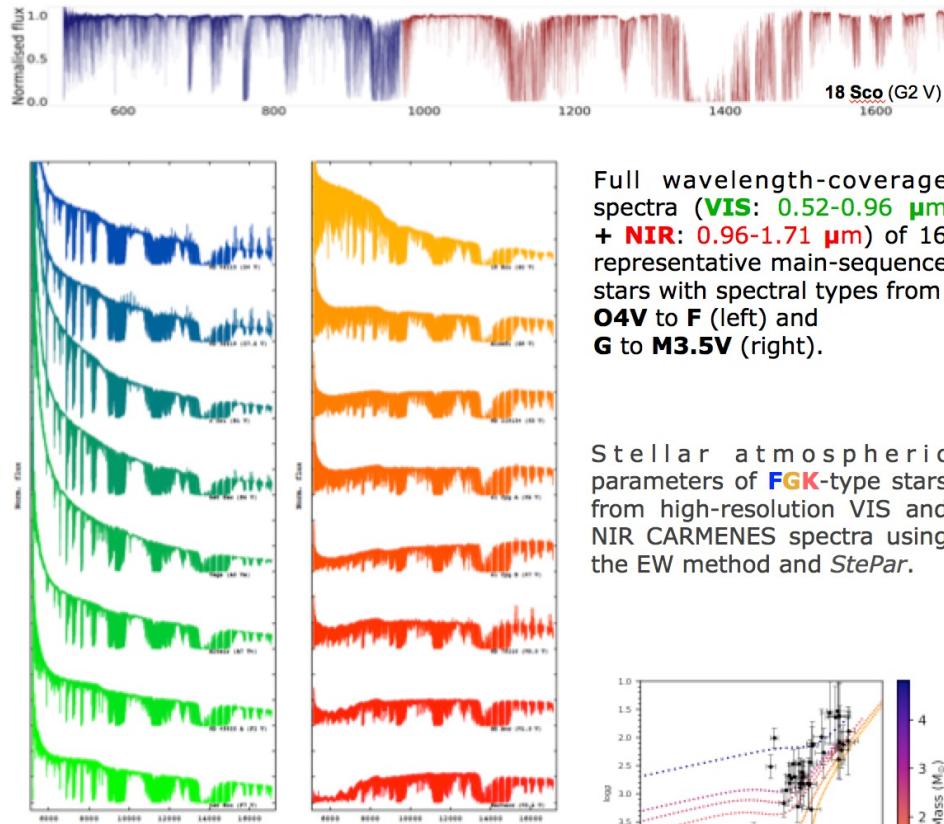
carmenes

# CARMENES science exploitation

The CARMENES search for exoplanets  
around M dwarfs.

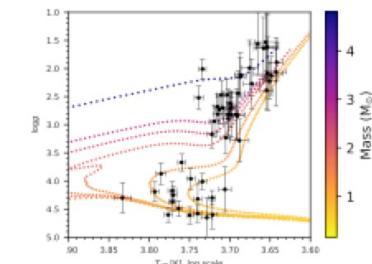
David Montes

## CARMENES OBAFGKM spectral library



Caballero et al. 2019, in prep.

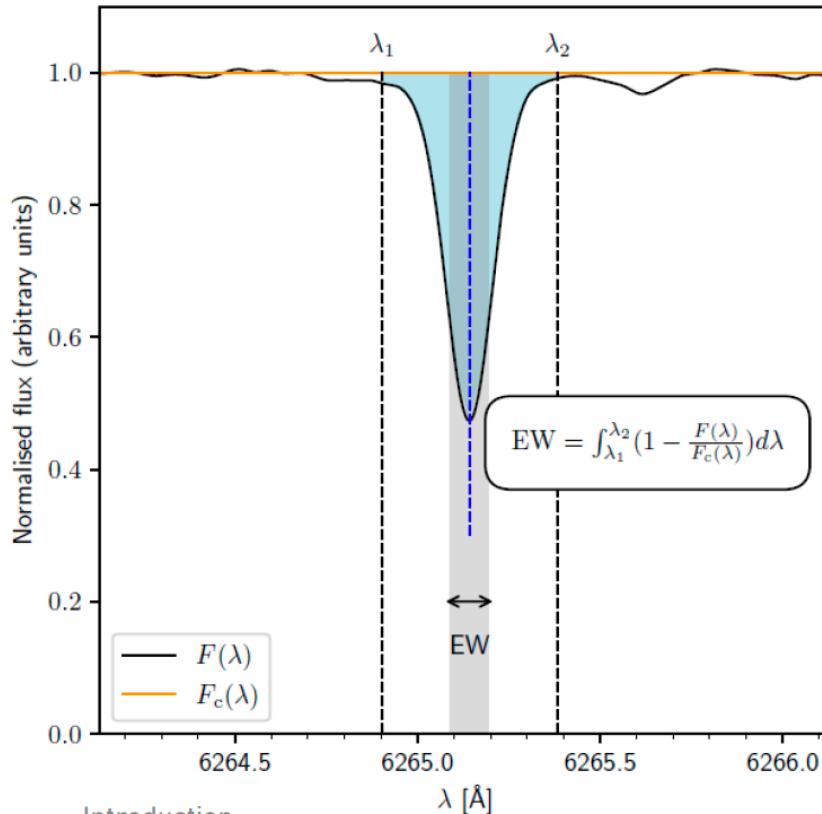
Marfil et al. 2020MNRAS.492.5470M



# The equivalent width (EW) method

Definition of the equivalent width (EW) of a spectral line:

$$EW = \int_{\lambda_2}^{\lambda_1} \left( 1 - \frac{F(\lambda)}{F_c(\lambda)} \right) d\lambda$$

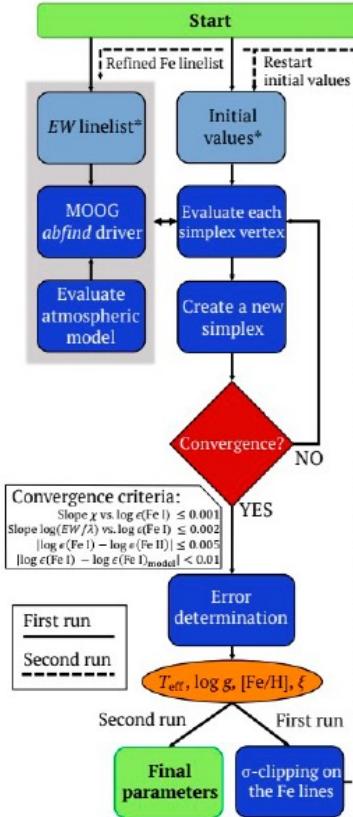


$F(\lambda)$ : flux measured at wavelength  $\lambda$  in the line  
 $F_c(\lambda)$ : interpolated continuum flux at wavelength  $\lambda$

EWs are usually automatically measured

- ★ TAME ([Kang & Lee 2012](#))
- ★ DAOSPEC ([Stetson & Pancino 2008](#))
- ★ ARES ([Sousa et al. 2015](#))
- ★ EWcomputation ([Soto et al. 2021](#))

Curves of growth relate EWs to the column density of the chemical species that causes the line via the Saha and Boltzmann equations.



## StePar: an automatic code to infer stellar atmospheric parameters

H. M. Tabernero<sup>1,2</sup>, E. Marfil<sup>3</sup>, D. Montes<sup>3</sup>, and J. I. González Hernández<sup>4,5</sup>

EW method based on four different Fe I-II line lists:

[Tabernero et al. 2019](#)

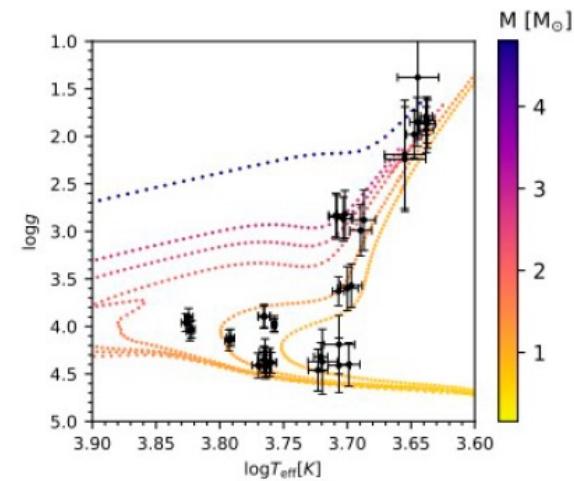
Automated determination of Teff, log(g), [Fe/H], and  $\xi$

MARCS models ([Gustafsson et al. 2008](#))

MOOG code 2017 version ([Sneden 1973](#))

Nelder-mead optimization ([Press et al. 2002](#))

StePar is available in github:  
<https://github.com/hmtabernero/StePar>





IPARCOS

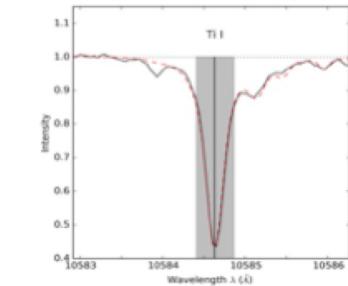
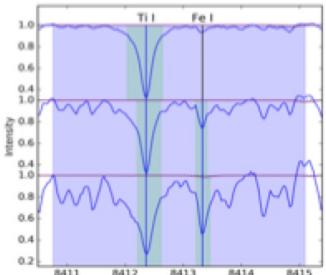
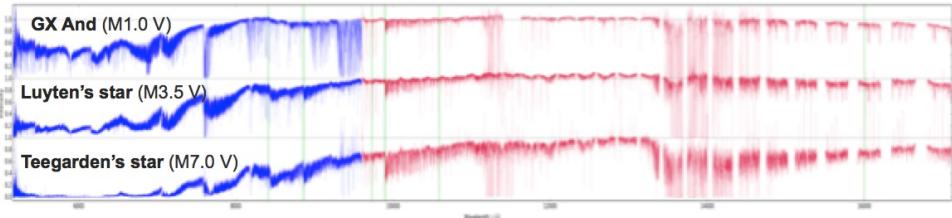
# CARMENES science exploitation

The CARMENES search for exoplanets  
around M dwarfs.

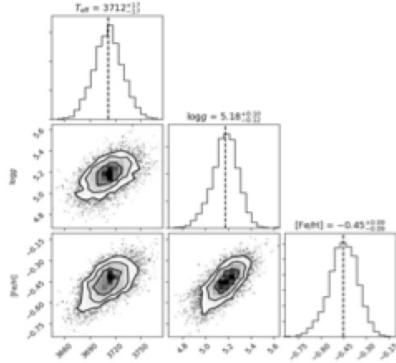
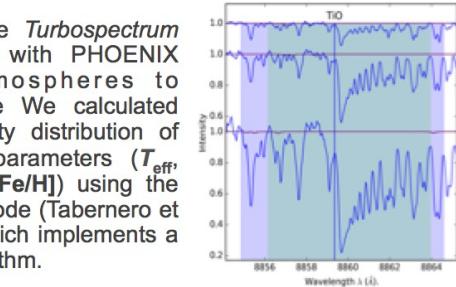
David Montes

## Spectral synthesis of CARMENES M-type stars: stellar parameters

25



We used the *Turbospectrum* code along with PHOENIX model atmospheres to generate the We calculated the probability distribution of the stellar parameters ( $T_{\text{eff}}$ ,  $\log g$  and  $[\text{Fe}/\text{H}]$ ) using the *SteParSyn* code (Tabernero et al. 2018), which implements a MCMC algorithm.



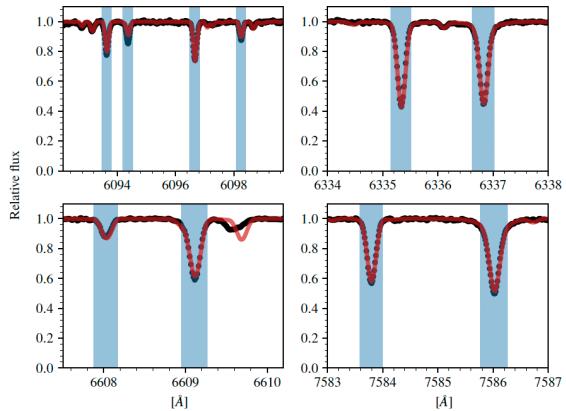
Marfil et al. 2021 in prep

# SteParSyn: a Bayesian code to infer stellar atmospheric parameters using spectral synthesis

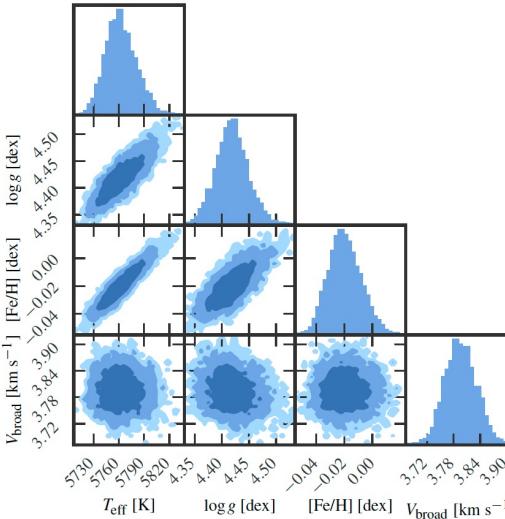
H.M. Tabernero, E. Marfil, D. Montes, and J.I. González Hernández

[2022A&A...657A..66T](#)

- an automatic code written in Python 3.X designed to infer the stellar atmospheric parameters  $T_{\text{eff}}$ ,  $\log g$ ,  $[\text{Fe}/\text{H}]$  and  $V_{\text{broad}}$  of FGKM-type stars following the spectral synthesis method.
- it relies on the MCMC sampler *emcee* in conjunction with an spectral emulator that can interpolate spectra down to a precision < 1%.



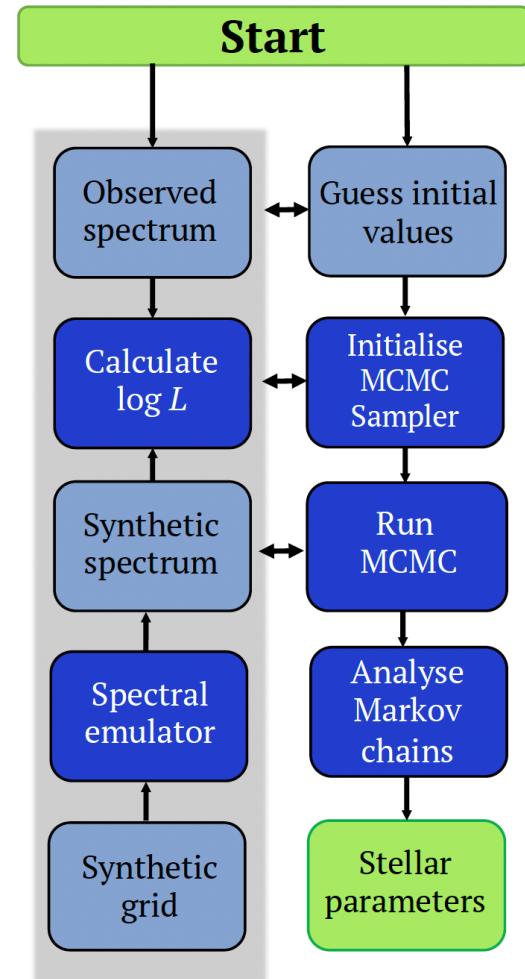
**Fig. 5.** Four representative wavelength regions in the spectrum of 18 Sco. The shaded blue areas represent the line masks, whereas the observations are given the black line while the best fitting synthetic spectrum is represented by a red line.



The code will be available for download at



<https://github.com/hmtabernero/SteParSyn>



# The CARMENES search for exoplanets around M dwarfs.

## Stellar atmospheric parameters of target stars with *SteParSyn*

Marfil, Emilio; Tabernero, Hugo M.; Montes, David; et al.

[2021A&A...656A.162M](#)

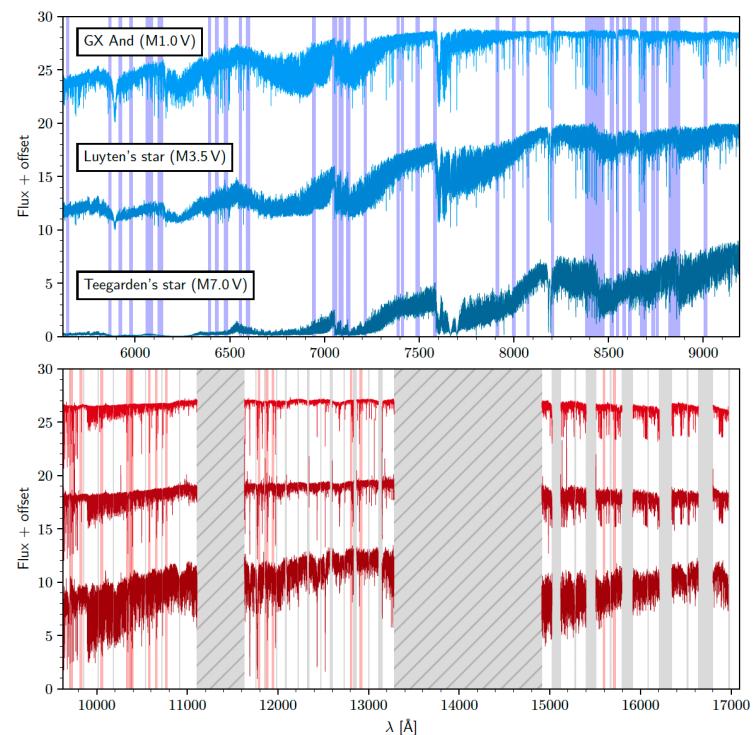
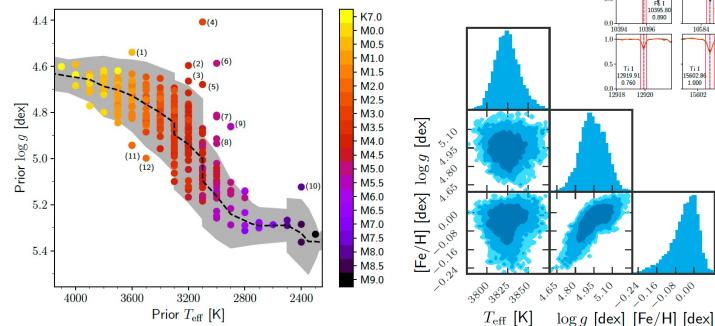


-  $T_{\text{eff}}$ ,  $\log g$ , [Fe/H] of 343 M dwarfs observed with CARMENES

- Using *SteParSyn* (Tabernero et al.  
[2022A&A...657A..66T](#))

- BT-Settl model atmospheres.

- Excellent agreement in  $T_{\text{eff}}$  for M dwarfs with interferometric angular diameter, as well as in the [Fe/H] between the components in the wide physical FGK+M and M+M systems.

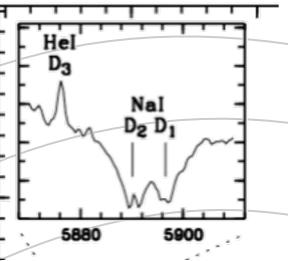
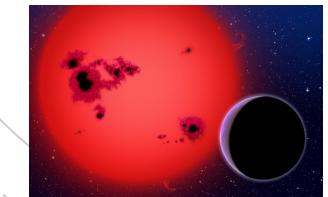


→ 75 magnetically insensitive Fe I and Ti I lines plus the TiO  $\gamma$  and  $\epsilon$  bands.



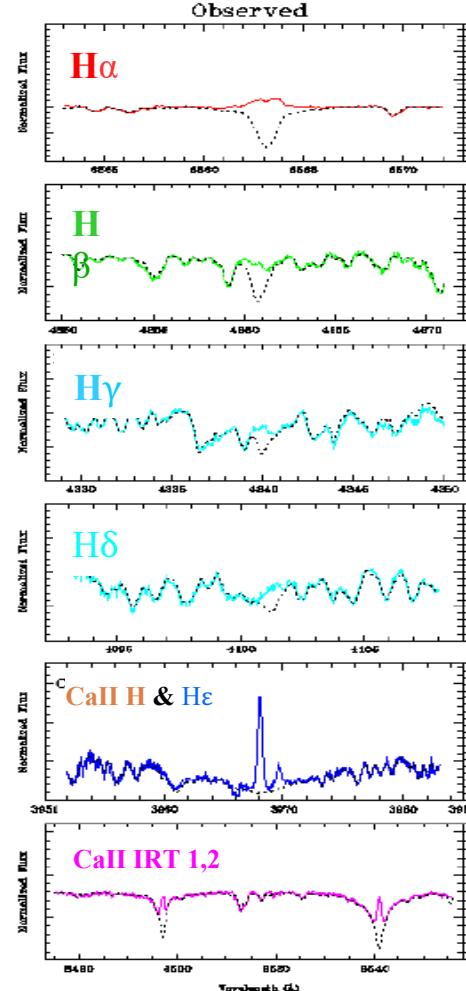
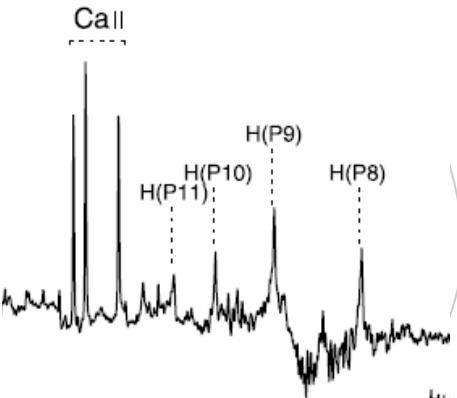
# CARMENES science exploitation

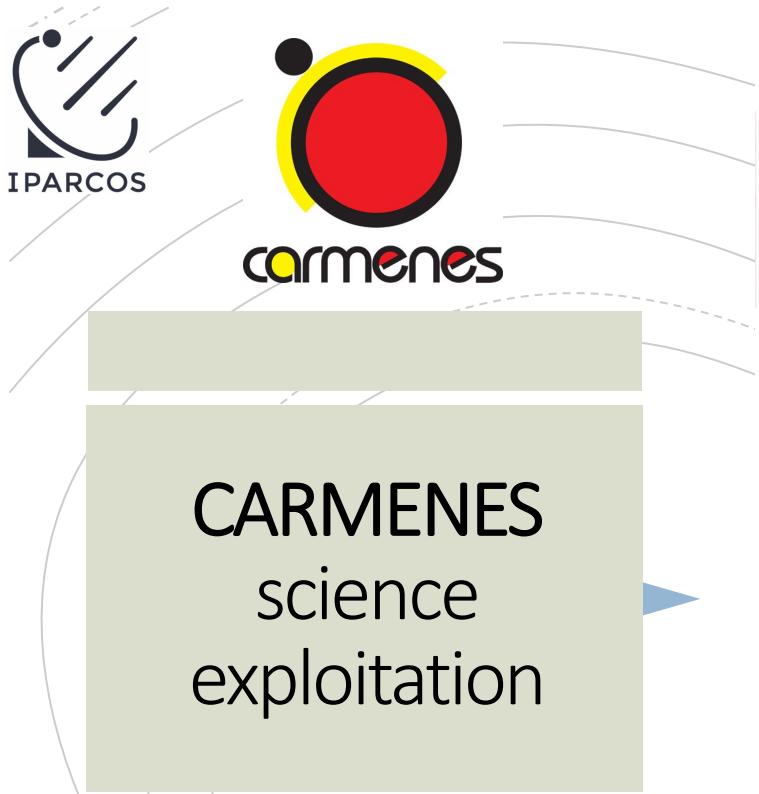
David Montes



## • Chromospheric activity indicators:

- Ca II H&K
- Serie de Balmer:  
 $H\alpha$ ,  $H\beta$ ,  $H\gamma$ ,  $H\delta$ ,  $H\epsilon$ , ...
- Mg Ib
- Na I D<sub>1</sub>, D<sub>2</sub>
- He I D<sub>3</sub>
- Ca II IRT
- He I 10830

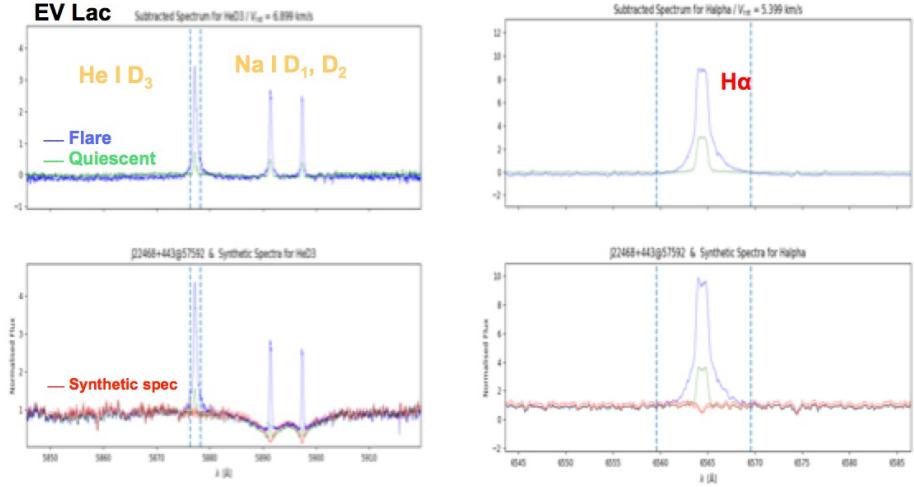




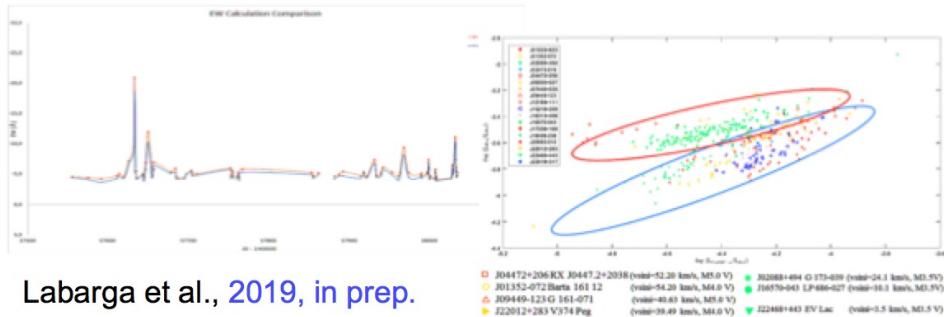
**The CARMENES search for exoplanets around M dwarfs.**

David Montes

## The chromospheric activity of CARMENES M dwarfs



The spectral subtraction have been performed by means of the *Python* code *iSTARMOD*, based on a former code *STARMOD* (Barden 1985; Montes et al. 2000).

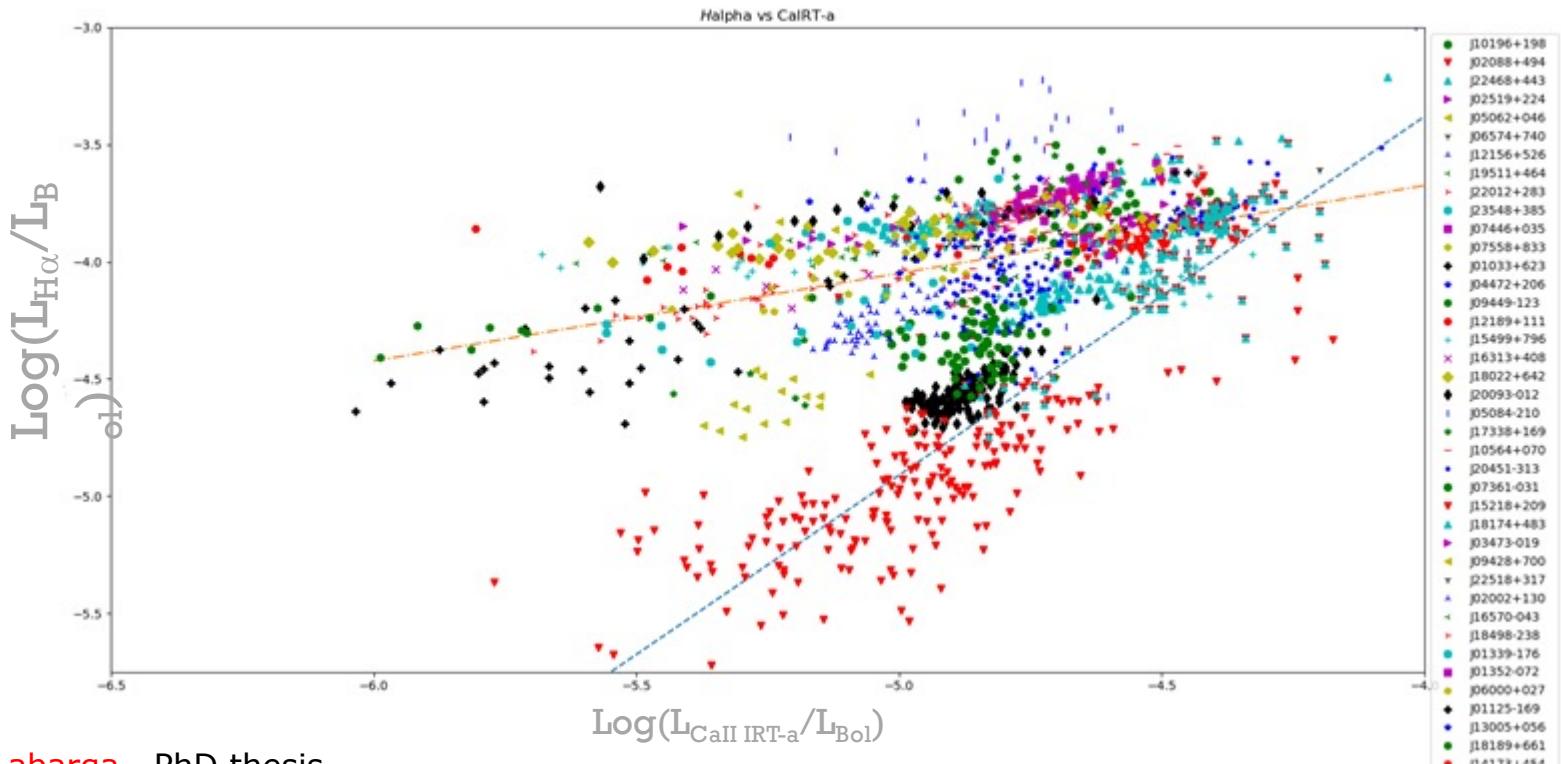




# Analysis of chromospheric flux-flux relationships in CARMENES sample



End up in the flux-flux relationship from the whole subsample  
An adding the [Martínez-Arnaiz et al, \(2011\)](#) values, with the resulting fits

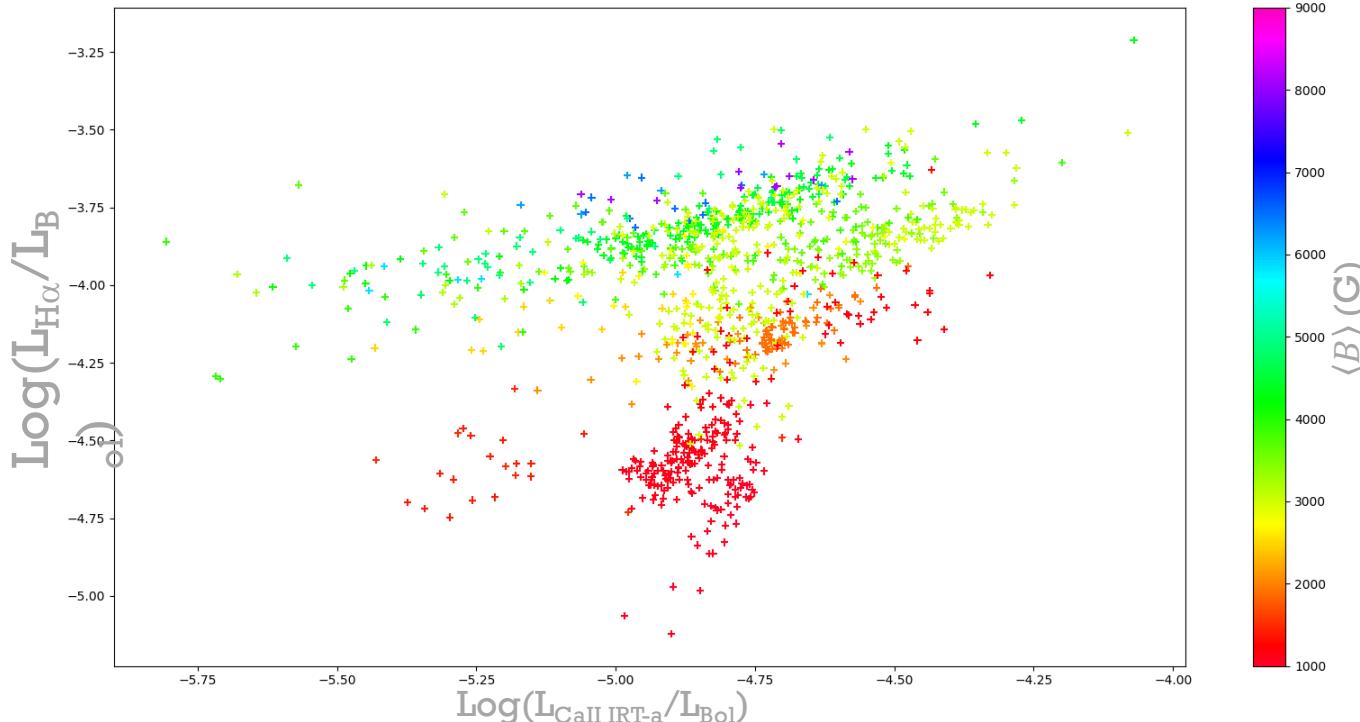




# Analysis of chromospheric flux-flux relationships in CARMENES sample



Trying to elucidate this incorporating the Magnetic Fields for the stars of the CARMENES sample – [Reiners et al. \(2022\)](#)



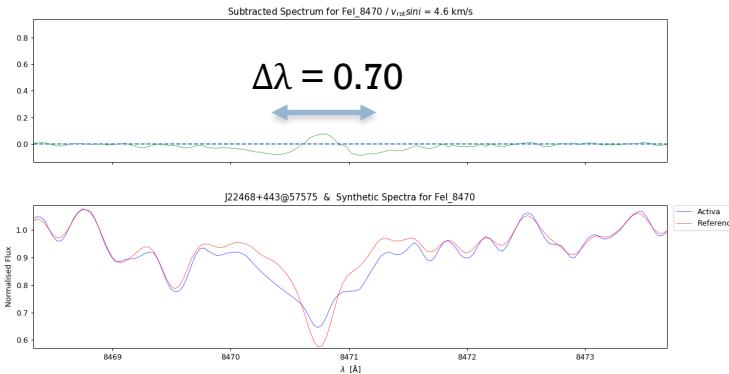
# Chromospheric activity-sensitive + magnetically-sensitive spectral lines

Álvaro López-Gallifa, David Montes (UCM)

New activity-sensitive spectral lines  
(at a flare maximum)

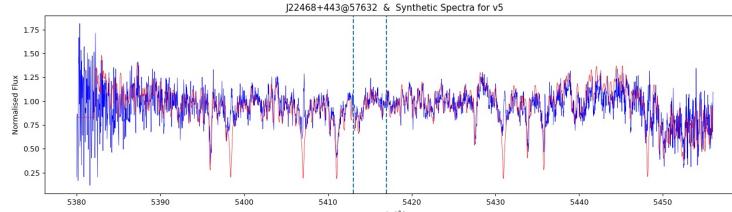
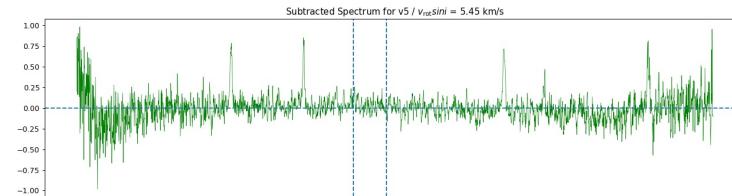


Fe I 8470,72 Å  
*g: effective Landé – factor = 2,50*



J22468+443 EV Lac M3.5 V Template spectrum

FeI 5397,131 Å  
FeI 5405,774 Å  
FeI 5429,706 Å  
FeI 5434,523 Å  
FeI 5446,916 Å



J22468+443 EV Lac M3.5 V Flare maximum



Identification of  
magnetically sensitive lines  
(Zeeman broadening)

**<http://carmenes.caha.es/>**



carmenes