XIII JORNADAS DE INTRODUCCIÓN A LA INVESTIGACIÓN

FACULTAD DE CIENCIAS FÍSICAS - 30 de abril al 7 de mayo 2025

Astrofísica estelar y exoplanetas
(Grupo UCM: Sistemas Estelares, Espectrometría y Fotometría)

SESIONES INFORMATIVAS Y DE PUERTAS ABIERTAS

Departamento de Física de la Tierra y Astrofísica (FTA)

- Astrofísica estelar y exoplanetas

* ***"De las estrellas frías a los exoplanetas"***
David Montes (Prof. del Dpto., IP proyecto, Director grupo UCM)

* ***"La metalicidad de las estrellas M más allá de la espectroscopía de alta resolución"***
Christian Duque Arribas (Doctorando del Dpto.)

* "***Caracterización de las estrellas M hacia el disco galáctico***"
Miriam Cortés Contreras (Prof. del Dpto.)

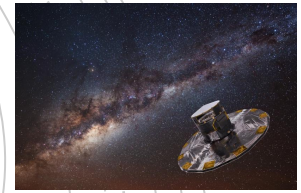
* "***Detección de sistemas exoplanetarios alrededor de enanas M: mitigando el ruido estelar***"
Javier Banegas (Doctorando del Dpto.)

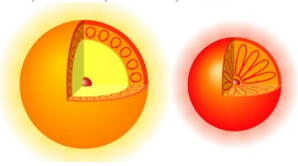
Lugar: Seminario 215, Dpto. FTA, planta 4ª
Fecha y hora: 7 mayo 2025 a las 15:30

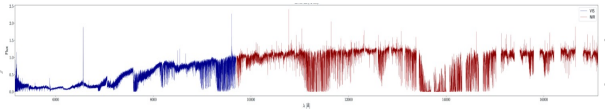
De las estrellas frías a los exoplanetas:

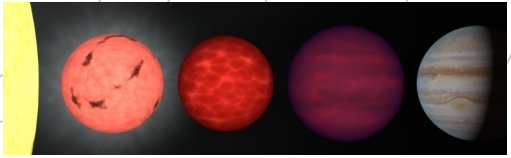
David Montes (FTA)

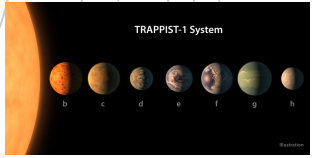
SEEF (Sistemas Estelares, Espectroscopía y Fotometría)







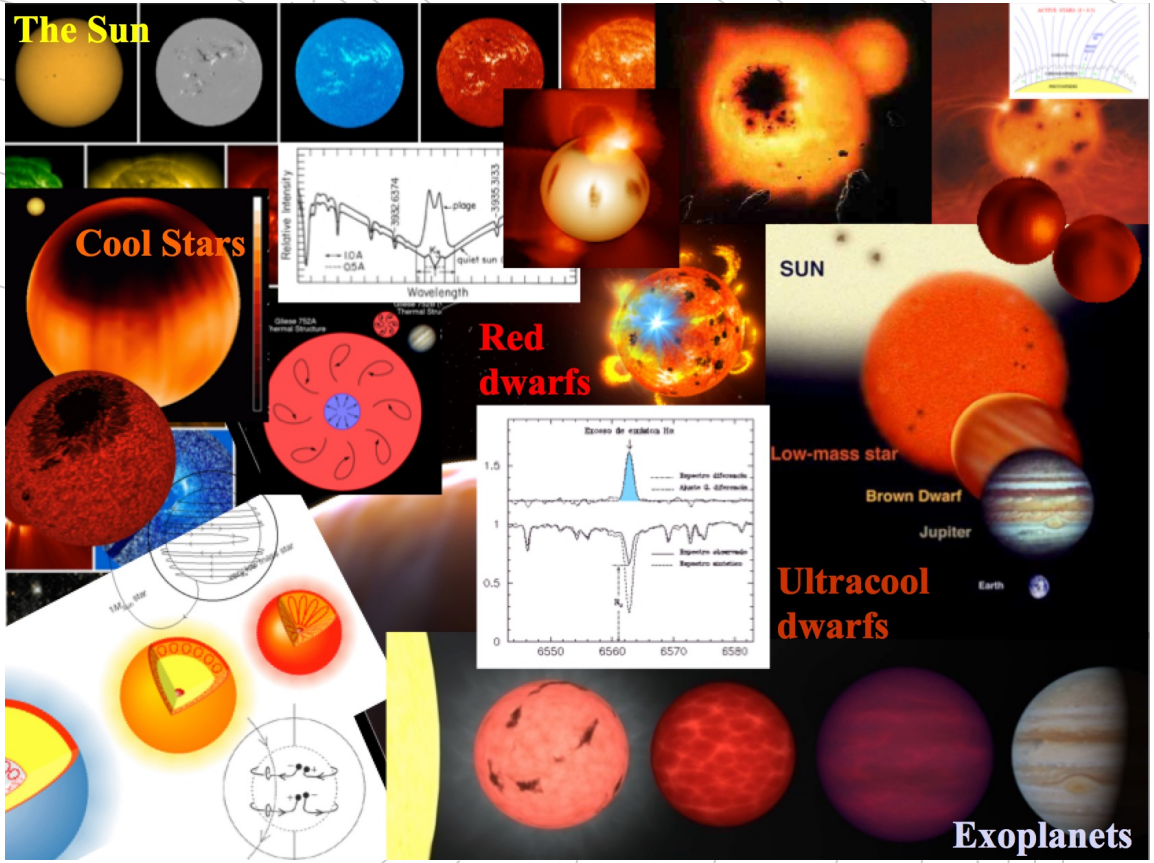




IPARCOS

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

Astrofísica estelar y exoplanetas



IPARCOS

SEEF
(Stellar Systems, Spectroscopy and Photometry)

Astrofísica estelar y exoplanetas

- **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/

- **IPARCOS**-UCM (Instituto de Física de Partículas y del Cosmos de la UCM)

  https://www.ucm.es/iparcos/

- Grupo de investigación (**SEEF**)

  https://webs.ucm.es/info/Astrof/invest/actividad/actividad.html

FACULTAD DE CIENCIAS FÍSICAS

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Astrofísica y física de altas energías

IPARCOS

SEEF
(Stellar Systems, Spectroscopy and Photometry)

Astrofísica estelar y exoplanetas

David Montes

https://fisicas.ucm.es/grupos/grupo/66

Grupos de Investigación

910491 SISTEMAS ESTELARES. ESPECTROSCOPIA Y FOTOMETRÍA

BUENO (87.00).

Centro:	F. CIENCIAS FISICAS www
Ámbito - Área AEI:	ÁREA DE EXPERIMENTALES - FÍSICA Y CIENCIAS DEL ESPACIO
Valoración :	BUENO (87.00)
Acrónimo - E_Mail:	- dmontes@ucm.es
Director/es:	MONTES GUTIERREZ, DAVID
Miembros:	CABALLERO HERNANDEZ, JOSE ANTONIO; CASTRO RUBIO, ELISA DE ; CORTES CONTRERAS, MIRIAM ; DUQUE ARRIBAS, CHRISTIAN ; FERNANDEZ FIGUEROA, MARIA JOSE; GOMEZ MARFIL, EMILIO ; GONZALEZ ALVAREZ, ESTER ; GORGAS GARCIA, FRANCISCO JAVIER ; ROCA FABREGA, SANTI ; TABERNERO GUZMAN, HUGO MARTIN
Líneas de investigación:	Actividad cromosférica estelar, estrellas de los últimos tipos espectrales; Grupos cinemáticos y cúmulos estelares jóvenes.; Regiónes de transición y Coronas estelares, emisiones ultravioleta y rayos X; Caracterización espectroscópica de estrellas frías con posibles planetas o componetes subestelares; Espectrosopia de alta resolución, parámetros estelares
Palabras clave:	Actividad magnetica; cinematica; abundancias; fulguraciones; Cromosferas; Estrellas frías; Espectroscopia; Actividad estelar; Exoplanetas
Acceso a su web:	Acceder

IPARCOS

910491 **SISTEMAS ESTELARES. ESPECTROSCOPIA Y FOTOMETRÍA**
ÁREA DE EXPERIMENTALES. FÍSICA Y CIENCIAS DEL ESPACIO. BUENO (87.00).

Portal de Producción Científica — UNIVERSIDAD COMPLUTENSE MADRID — IDENTIFÍCATE

GRUPOS | INVESTIGADORES/AS | RESULTADOS

Sistemas estelares. Espectroscopia y fotometría

DETALLE | LÍNEAS DE INVESTIGACIÓN | PROYECTOS | PUBLICACIONES | COLABORAC

SEEF
(Stellar Systems, Spectroscopy and Photometry)



Constituido el 22 de diciembre de 2004

Responsable: DAVID MONTES GUTIÉRREZ

Facultad: Ciencias Físicas

Departamento: Física de la Tierra y Astrofísica

Centro/Instituto: Instituto de Física de Partículas y del Cosmos (IPARCOS)

Correo electrónico: dmontes@ucm.es

Página web: http://www.ucm.es/info/astrof/invest/actividad/actividad.html

Astrofísica estelar y exoplanetas

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

Astrofísica estelar y exoplanetas

- **Prof.**
  - Prof. David Montes (PTU)
  - Profa. Miriam Cortés Contreras (PAD)
  - Prof. F. Javier Gorgas (CU)
  - Profa. Elisa De Castro
  - Profa. Mª José Fernández-Figueroa
  - Prof. Manuel Cornide,
- **PostDocts:**
  - Dr. Hugo M. Tabernero
  - Dra. Ester González Álvarez
  - Dra. Marta L. Gutiérrez Albarran
  - Dr. Emilio Gómez Marfil
  - Dr. Enrique Díez Alonso (Univ. Oviedo)
  - Dr. F. Javier Alonso Floriano (Leiden Univ.)
  - Dr. Shinjirou Kouzuma (Chukyo Univ. Japan)
  - Dr. Javier López-Santiago
  - Dra. Mª.Cruz Gálvez

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

Astrofísica estelar y exoplanetas

PhD students:

- Fernando Labarga Ávalos
- Christian Duque Arribas
- Julián A. Rodríguez Baquerizo
- Javier Banegas Paredes
- Francisco Javier González Payo
- Dr. Miguel Ángel López García
- Dr. Victor Pereira Blanco
- Dra. Inés Crespo-Chacón
- Dra. Magdalena Hernán Obispo
- Dra. Raquel M. Martínez Arnáiz

Other col.:

- José Antonio Caballero (CAB)
- Enrique Solano (CAB)
- Alexis Klutsch (IfA&A, *Tübingen, Germany*)
- Jonay Isaí González Hernández (IAC)
- Dr. Antonio Frasca (Catania),

Funding:

NATIONAL RESEARCH PROJECTS & EU

- Subproject title: "**Characterization of late-type dwarfs: exoplanet hosts and young stars**".
- Coordinated project title: "**Evolución y caracterización de sistemas planetarios**".

Funding body and reference: Ministerio de Ciencia e Innovación (Ministry of Science and Innovation); **PID2022-137241NB-C44**, «Proyectos de generación de conocimiento» («Projects for the generation of knowledge"»).
Participant entities: UCM, CAB, IAA, IAC;
Duration, from: 2023 to: 2026.
IP: **David Montes**

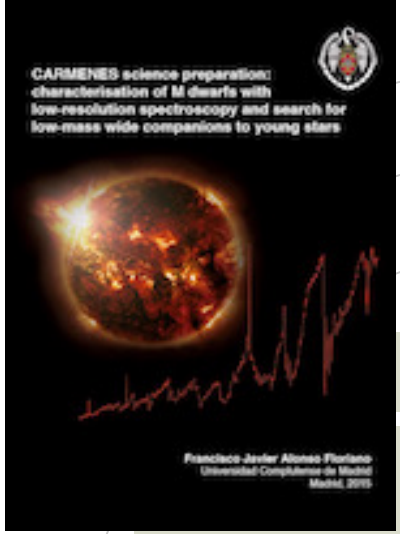
- Project: "**Tecnologías avanzadas para la exploración del Universo y sus componentes**",

Plan complementario en el área de astrofísica y física de altas energías en el marco del componente 17, inversión 01 del Plan de Recuperación, Transformación y Resiliencia (**PRTR**) financiado por la Unión Europea – Next Generation-EU por importe de 1.621.500 €.
PR47/21 TAU-CM PRTR-CM (CM) and (PRTR),
IP: **Ignazio Scimemi**, IPARCOS institute.
Participant entities: Universidad Autonoma de Madrid (centros CIAFF-UAM, IFT-UAM);
Universidad Complutense (centro IPARCOS); CSIC (Centro de Astrobiologia CAB);
CIEMAT (Fisica de Particulas, CIEMAT-FP).
Duration, from: 31 dec 2020 to: 30 mar 2025

- Project: "**Censo de la Vecindad Solar en dirección al Centro Galáctico**" CeVeSo-GC

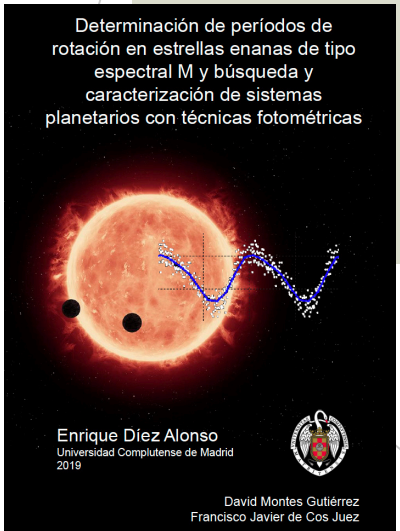
Ayudas para la realización de proyectos liderados por **doctores emergentes**, dentro del Convenio entre la **Comunidad de Madrid** y la **UCM** para el fomento de la investigación y la transferencia de tecnología (2023-2026). Convocatoria 2024.
Duration, from: 2025 - 2026
IP: **Miriam Cortés Contreras**

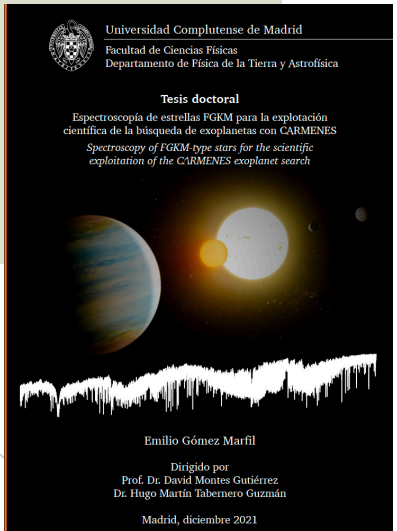
Últimas tesis doctorales defendidas

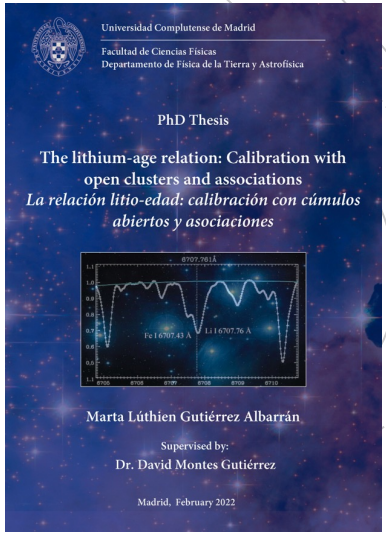






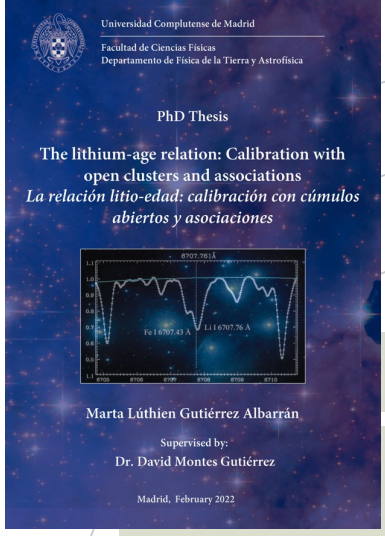




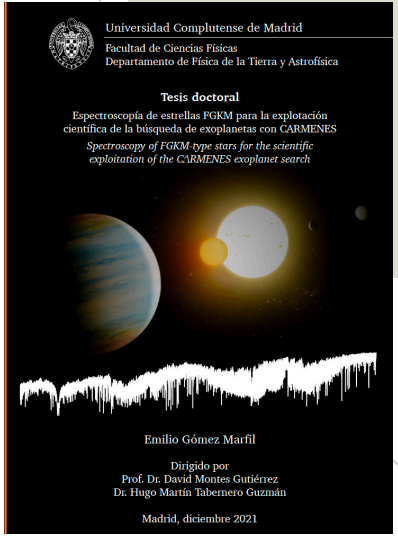


https://webs.ucm.es/info/Astrof/users/dmg/tesis_dirigidas_dmg.html

Recent PhD Thesis defended



- Titulo: "**La relación Litio-Edad: calibración con cúmulos abiertos y aociacion**
  Autor: Marta Lúthien Gutiérrez Albarran
  Director: David Montes
  Universidad Complutense de Madrid. Año de inicio: 2014-2015, TP
(Fecha de lectura: 10 mayo 2022) - Enlade a la Tesis - 2022PhDT.....6G



- Titulo: "**Espectroscopia de estrellas FGKM para la explotación científica de la búsqueda de exoplanetas con CARMENES**"
  Autor: Emilio Gómez Marfil
  Director: David Montes y Hugo Taberbernero
  Centro: Universidad Complutense de Madrid. Año de inicio: 2016-2017
(Fecha de lectura: 4 febrero 2022) - Enlade a la Tesis - 2022PhDT.....16M

PhD Thesis in progress

- Titulo: “**Detección de sistemas exoplanetarios alrededor de enanas M: mitigando el ruido estelar**”
  Autor: Javier Banegas Paredes
  Director: David Montes y Esther González-Álvarez
  Año de inicio: 2024-2025

- Titulo: “**Composición química detallada y cinemática de estrellas FGKM de la vecindad solar**”
  Autor: Julián A. Rodríguez Baquerizo
  Director: David Montes y Hugo Taberbernero
  Año de inicio: 2021-2022. To be defended: 2026

- Titulo: “**La metalicidad de las estrellas M: calibraciones fotométricas y espectroscópicas**”
  Autor: Christian Duque Arribas
  Director: David Montes y Hugo Taberbernero
  Año de inicio: 2020-2021. To be defended: 2025

- Titulo: “**La actividad cromosféria de las estrellas M de CARMENES**”
  Autor: Fernando Labarga Ávalos
  Director: David Montes
  Año de inicio: 2016-2017, TP. To be defended: 2025

- Titulo: “**Multiplicidad de sistemas estelares en la vecindad solar, binarias de alta separación y estrellas con planetas**”
  Autor: Francisco Javier González Payo
  Director: José A. Caballero Hernández y Miriam Cortés Contreras
  Año de inicio: 2019-2020, TP. To be defended: Junio 2025



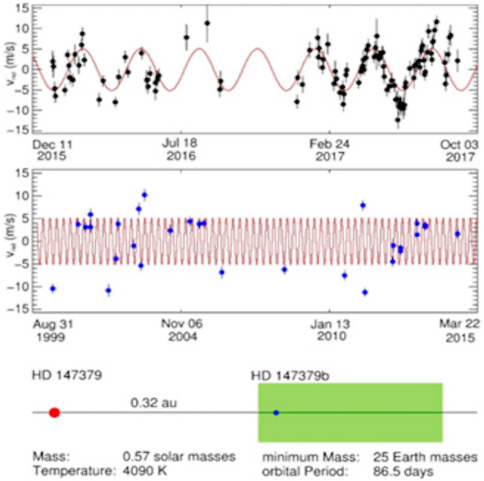
Grupo de Astrofísica Estelar y Exoplanetas

Areas of research:

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

EXOPLANETAS

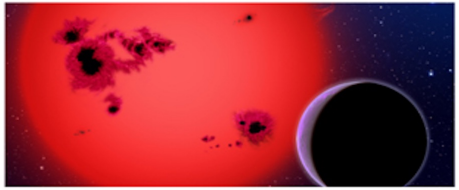
CARMENES es un espectrógrafo de alta resolución en el óptico e infrarrojo cercano para el telescopio de 3.5m del observatorio de Calar Alto.



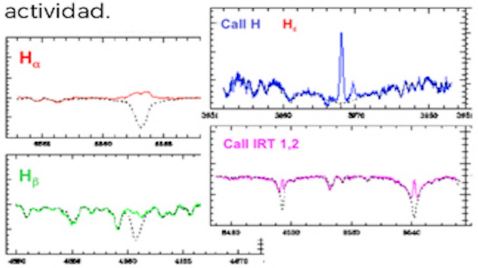
Está optimizado para la búsqueda de planetas alrededor de estrellas muy poco masivas (tipo espectral M). Es capaz de obtener velocidades radiales con una precisión de 1 m/s.

ACTIVIDAD ESTELAR

Fenómenos asociados a la actividad magnética en estrellas frías (tipos FGKM).



Espectroscopía de alta resolución para determinar sus principales parámetros atmosféricos, abundancias químicas y actividad.



La misión Gaia proporciona astrometría que permite estudiar la cinemática.

Exploraciones como GES (Gaia ESO survey) complementan desde Tierra estas observaciones.

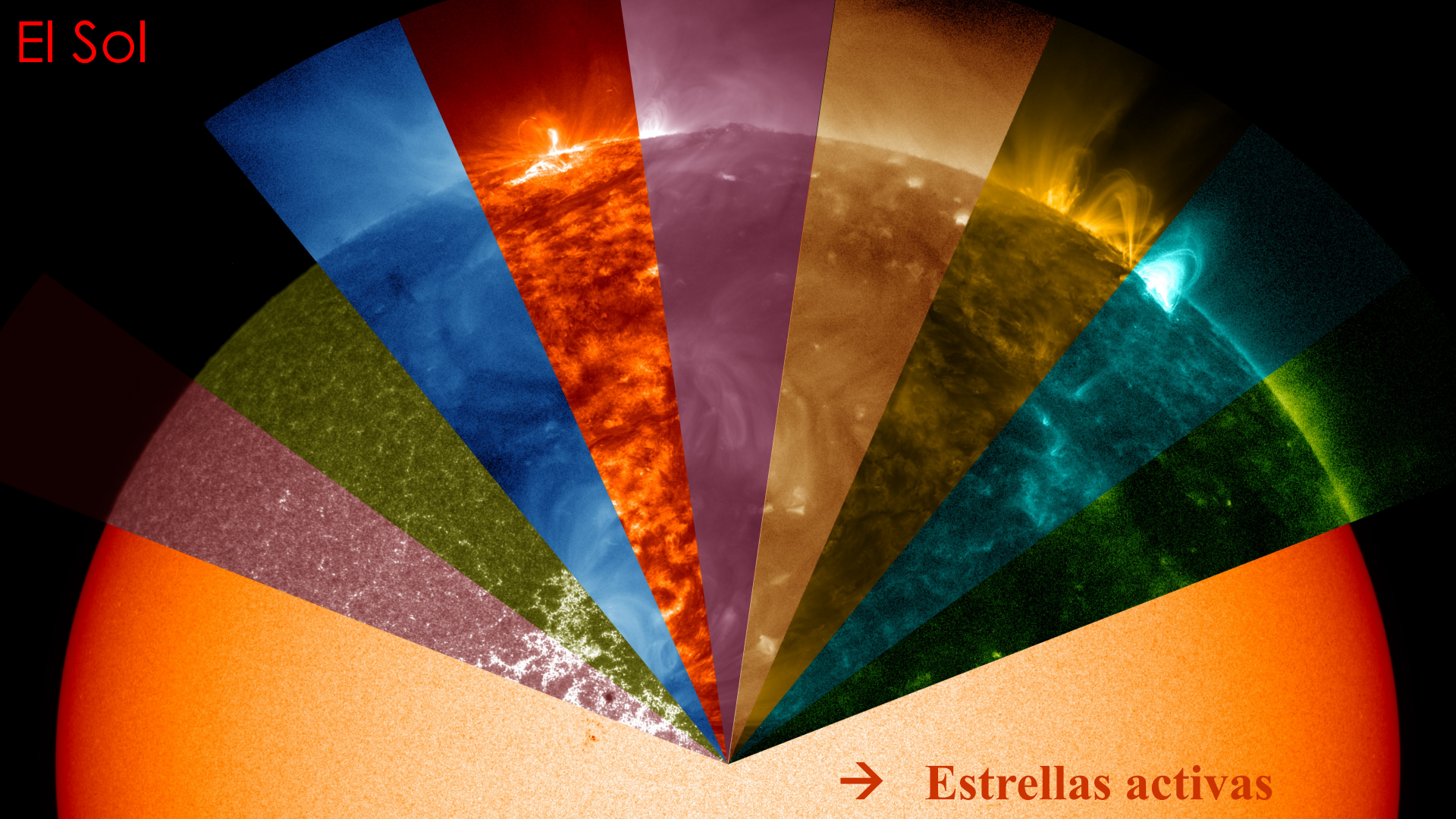
IPARCOS

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

Areas of research:

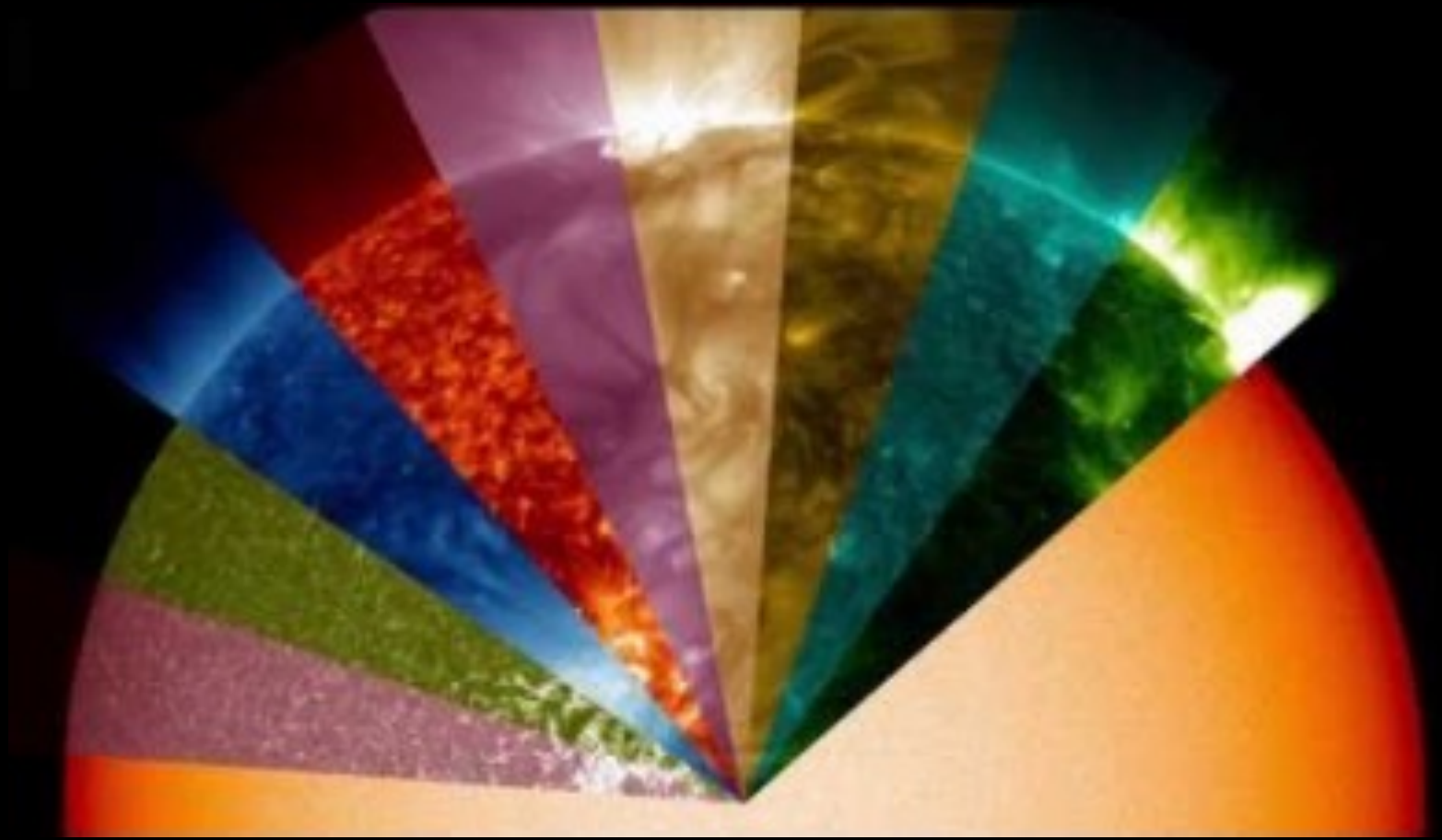
- Cool Stars (FGK)
- Stellar parameters ($T_{\rm eff}$, log$g$), [Fe/H])
- Abundances ([X/H], [X/Fe])
- Stellar activity (starspots, chromosphere, transition region, corona, flares, prominences, etc…)
- Rotation, age, kinematics
- Open clusters
- Stellar kinematic groups
- Nearby stars
- Red dwarfs stars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

El Sol



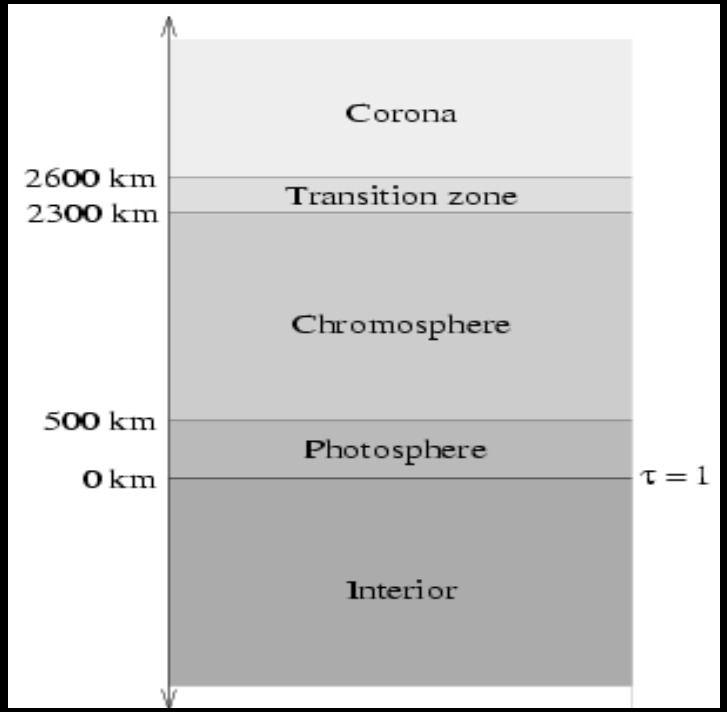
→ **Estrellas activas**

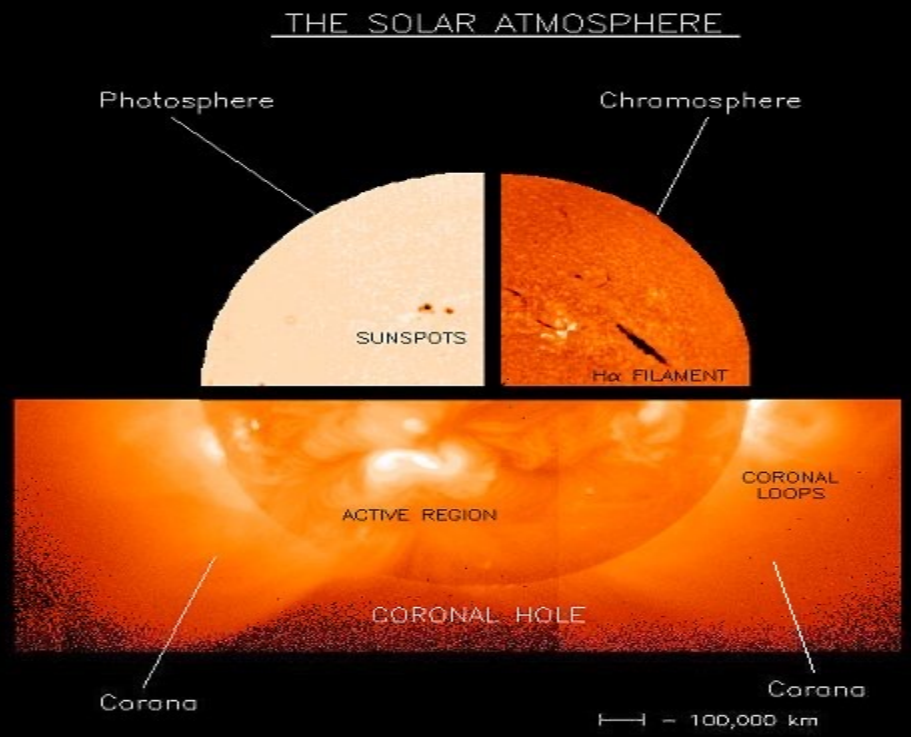
Jewel Box Sun

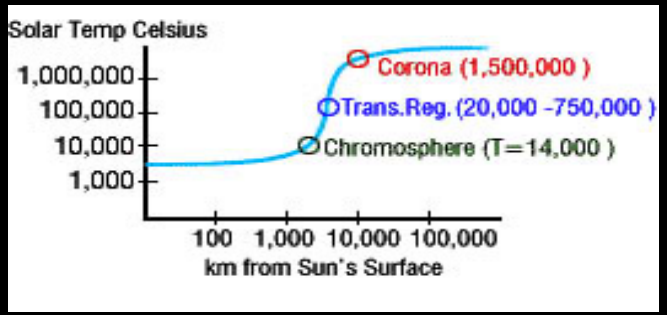


NASA movie of the sun based on data from NASA's Solar Dynamics Observatory, or SDO, shows the wide range of wavelengths - invisible to the naked eye - that the telescope can view. SDO converts the wavelengths into an image humans can see, and the light is colorized into a rainbow of colors.

Atmósfera del Sol:
Cromosfera,
Región de Transición
y Corona.







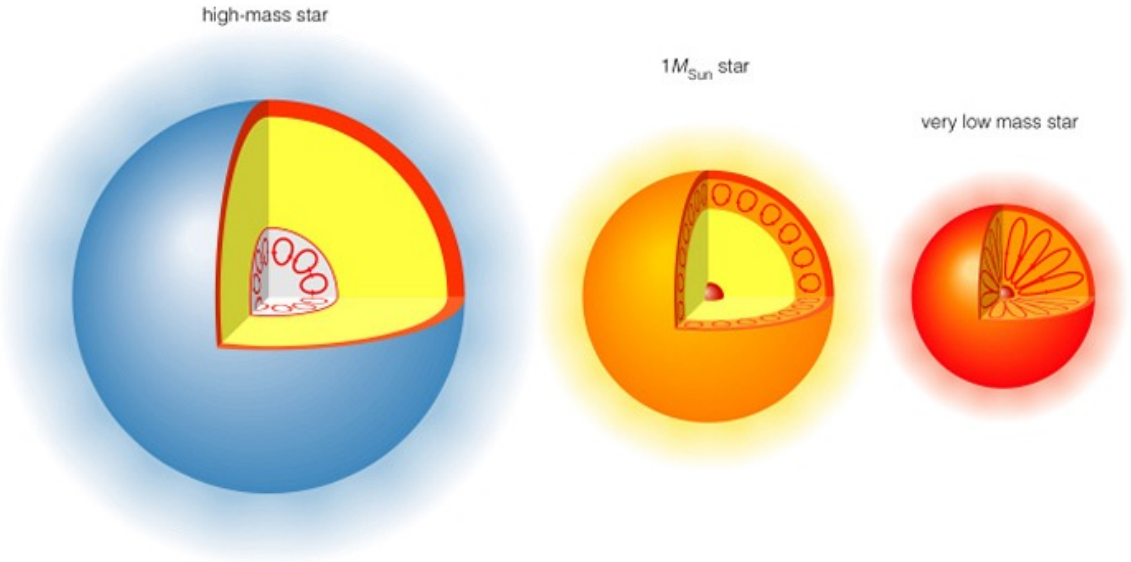
¿Que son las estrellas frías?



→ **Estrellas Frías**

Estrellas Frías (tipos F, G, K, M, L, T).

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

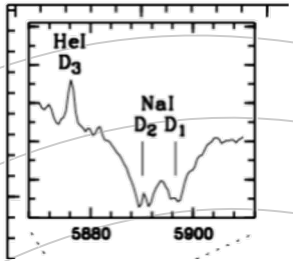


Estrella Caliente

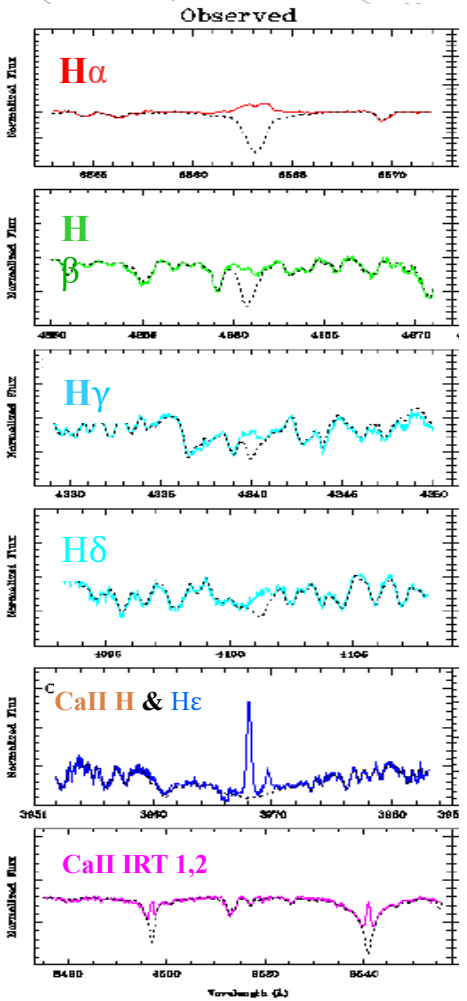
Estrellas Frías FGK
El Sol
Zona convectiva

Estrellas M completamente convectiva
> M3.5

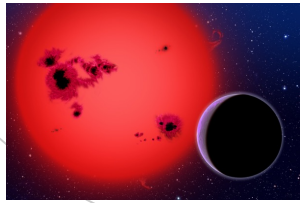
IPARCOS

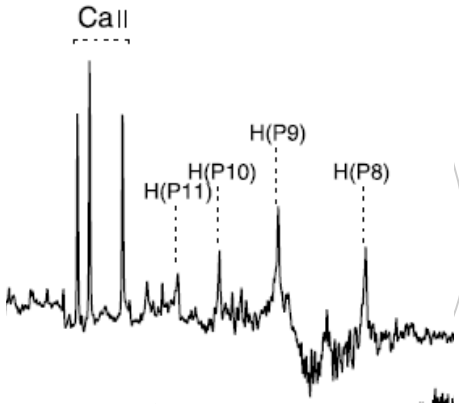


- **Chromospheric activity indicators:**
  - Ca II H&K
  - Serie de Balmer:
    Hα, Hβ, Hγ, Hδ, Hε, …
  - Mg Ib
  - Na I D_1, D_2
  - He I D_3
  - Ca II IRT
  - He I 10830



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

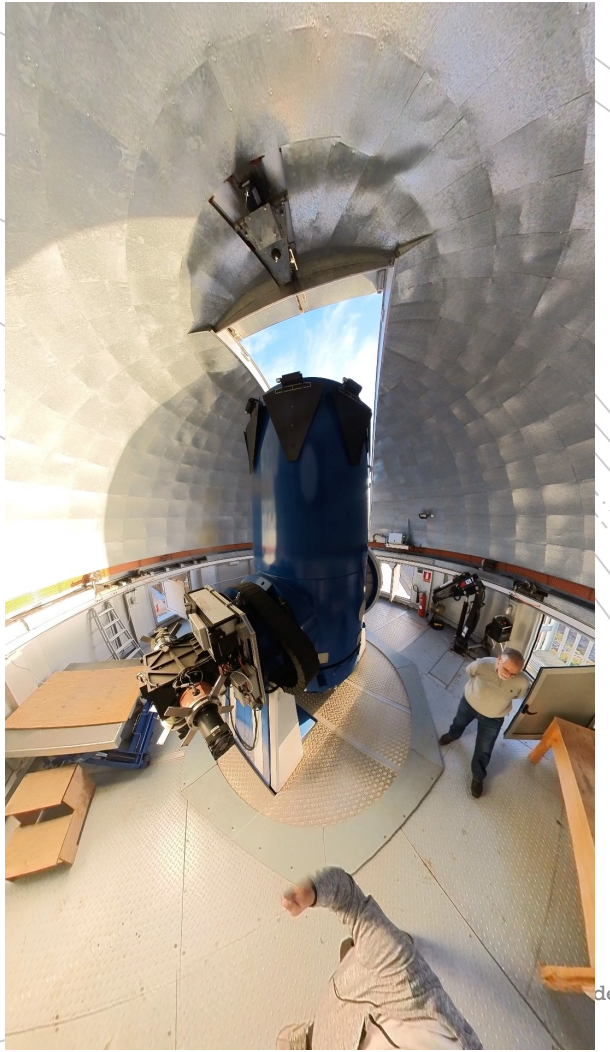




David Montes

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Cool Stars,
Stellar Parameters,
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Exoplanetas
group:



International collaborations

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

- Ground based optical and infrared telescopes





- Space missions







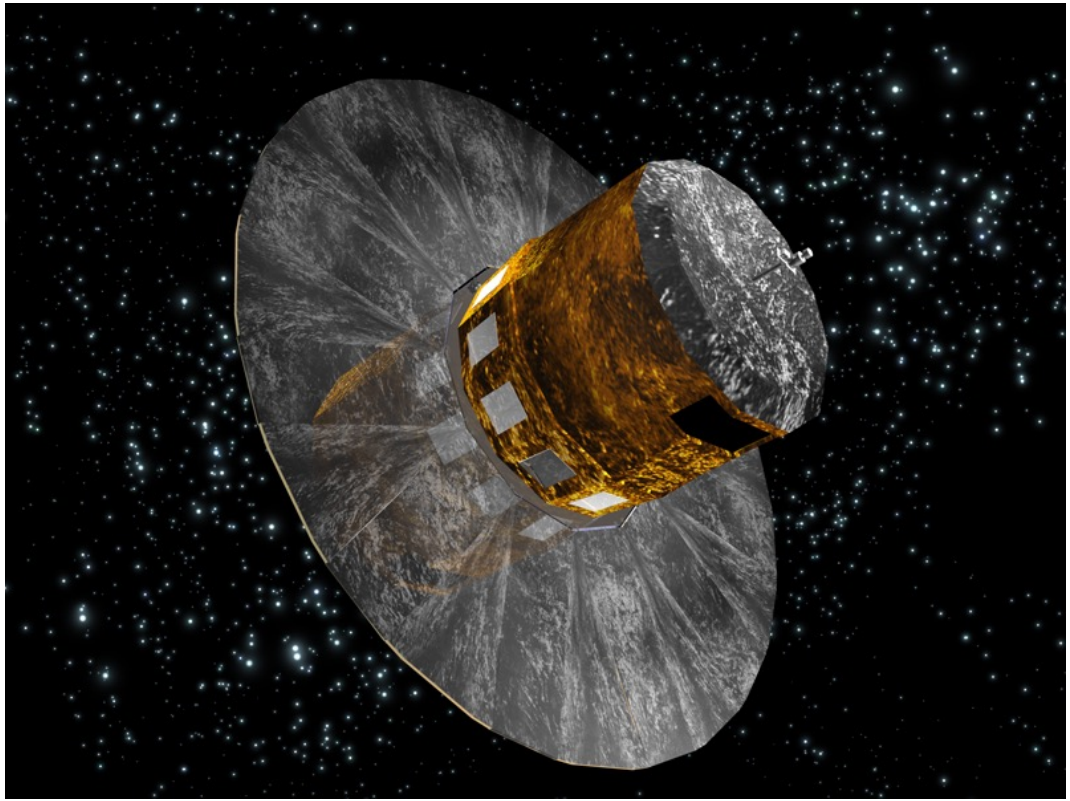
Paralaje trigonométrico (π)
Movimiento propio (μ)

Satélite Gaia
(2013-)

Precisión: microarcsecond

$$\Delta\pi = 0.000001\ ''$$

La estrella más cercana tiene una paralaje de solo 0,77 segundos de arco. Una estrella en el centro de la Galaxia tiene una paralaje de 0,0001 segundos de arco. Para medir ángulos tan pequeños hace falta un instrumento como Gaia.



http://www.esa.int/Our_Activities/Space_Science/Gaia

WHAT IS GAIA?

European mission

Structure

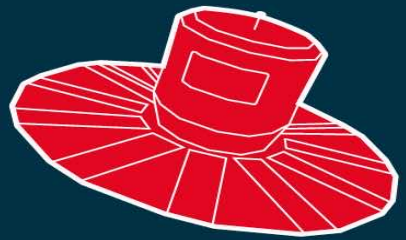
Origin

Evolution

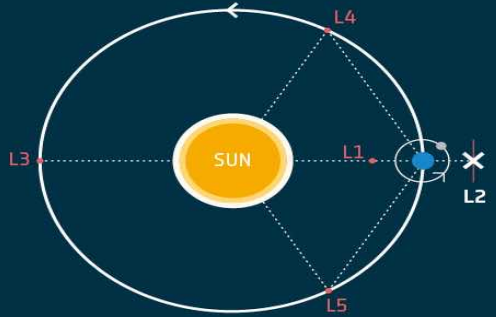
Most accurate
3D map of our galaxy

Almost
2 billion objects

Position,
velocity,
brightness,
temperature,
composition,
type



2 optical telescopes
3 instruments
1 billion pixel camera



In orbit around
Lagrange point 2

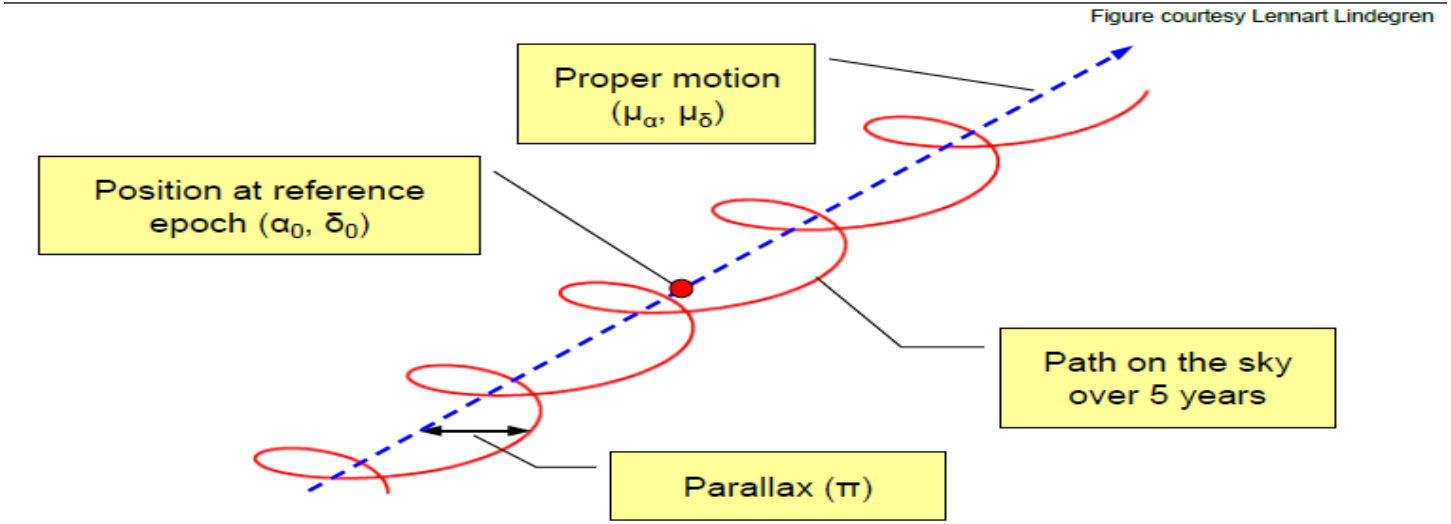
Inside our galaxy:

Stars, binary stars, exoplanets,
interstellar medium, Solar System objects

Outside our galaxy:

Quasars and other galaxies

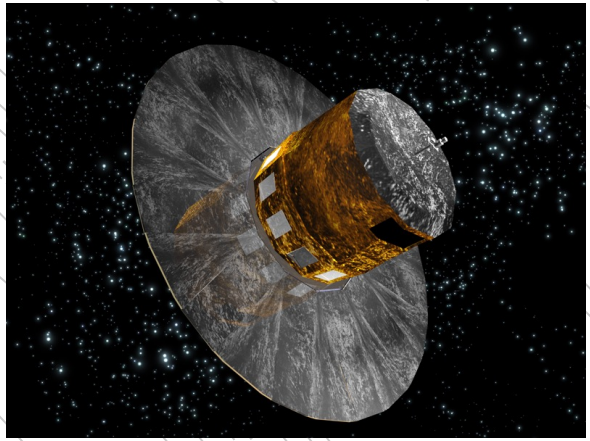
Paralaje (π) + Movimiento propio (μ):



Monitor this path for 10^9 stars during 5 years and fit, for each star, a five-parameter model to retrieve reference position, proper motion, and parallax (for a given instrument calibration and attitude)

IPARCOS

Gaia astrometric mission ESA



The SEEF group is involved in the scientific exploitation of the Gaia data and participate in the Spanish network of excellence REG (Red Española para la explotación científica de Gaia).

Gaia- **DR1.** (09 – 2016)
Gaia- **DR2** (04 – 2018)
Gaia- **EDR3** (12 - 2020)
Gaia- **DR3** (6 – 2022)

GAIA EARLY DATA RELEASE 3

esa

1 811 709 771
stellar positions

1 806 254 432
brightness
in white light

1 542 033 472
brightness
in blue light

1 540 770 489
colour

1 554 997 939
brightness
in red light

1 467 744 818
parallax and
proper motions

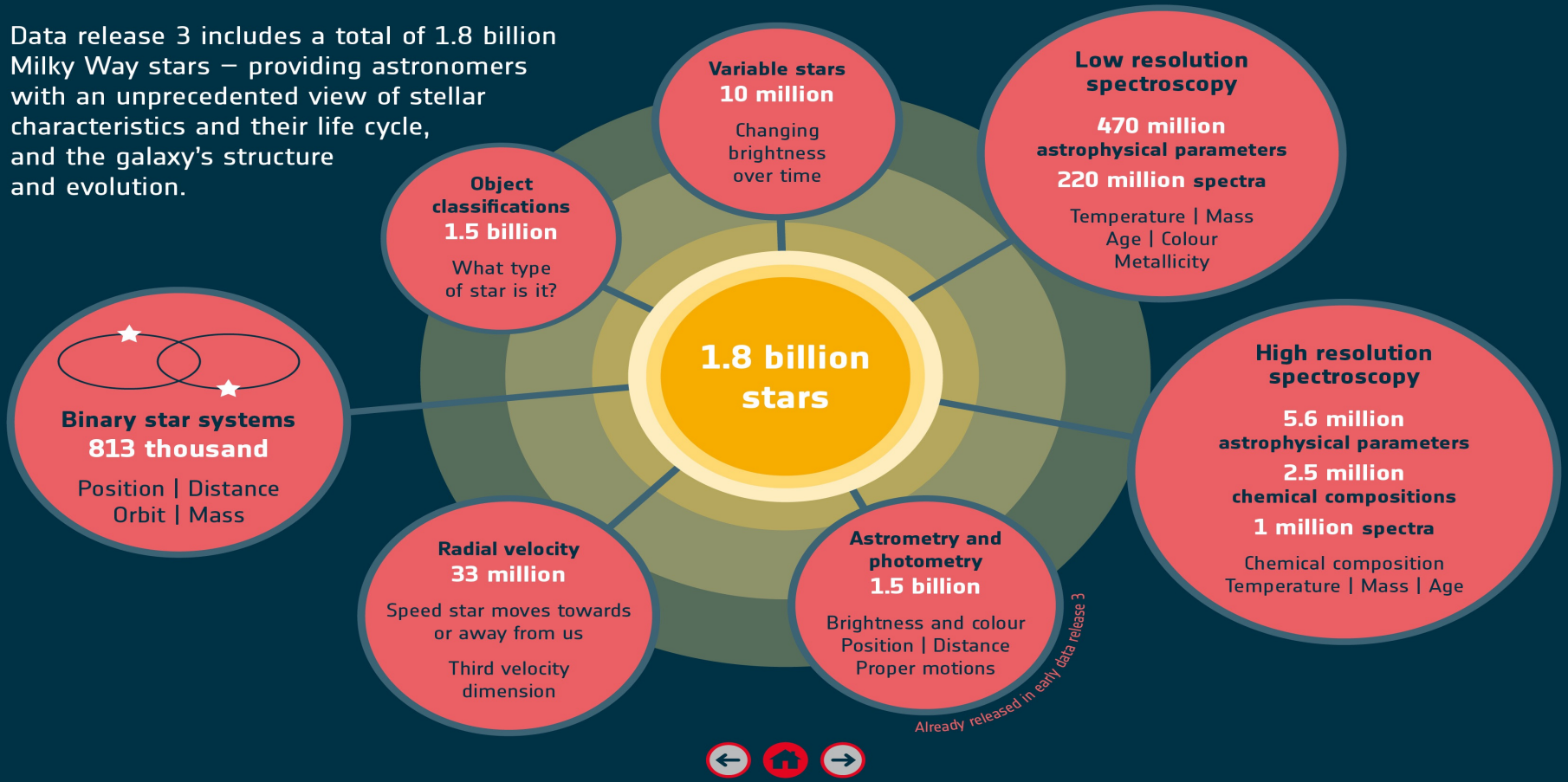
1 614 173
extragalactic
sources

#SpaceCare #ExploreFarther



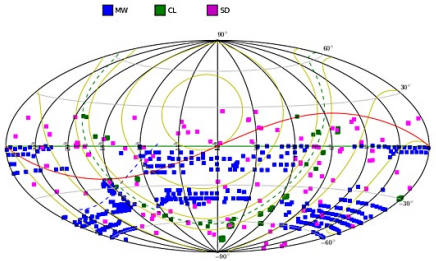
MILKY WAY STARS

Data release 3 includes a total of 1.8 billion Milky Way stars – providing astronomers with an unprecedented view of stellar characteristics and their life cycle, and the galaxy's structure and evolution.

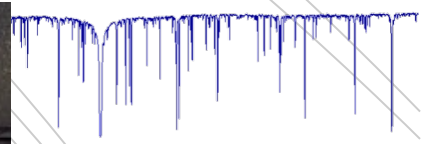


IPARCOS









GES (Gaia-ESO spectroscopic Survey)

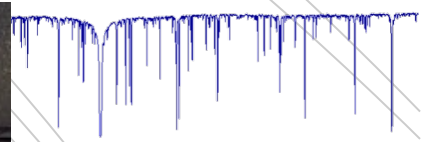
Public spectroscopic survey, targeting ≥ 10^5 stars, systematically covering all major components of the MilkyWay, from halo to star forming regions.

The SEEF group participate in the **WG 11** (UVES **FGK stars**) and **WG 12** (**pre-main sequence stars**) and has developed (Tabernero 2014, PhD. Thesis UCM) automatic tools to derive stellar atmospheric parameters: effective temperature ($T_{\rm eff}$), surface gravity (log$g$), metallicity ([Fe/H]), and the microturbulent velocity (ξ) as well as abundances (i.e., [X/H], [X/Fe]) for 20 different chemical elements (Na, Mg, Al, Si, Ca, Ti, V, Cr, Mn, Co, Fe, Ni, Cu, Zn, Y, Zr, Ba, Ce, and Nd) of FGK stars using the equivalent width (*EW*) method.

IPARCOS

GES (Gaia-ESO spectroscopic Survey)





The automatics codes ***StePar*** and ***SteAbu*** developed have been tested with well known stars (benchmarks stars) providing very accuracy results and used to apply the "*Chemical Tagging*" technique to test the common origin of two young stellar kinematic groups (Tabernero et al. 2012A&A...547A..13T; 2017A&A...597A..33T).

Recent Publications:

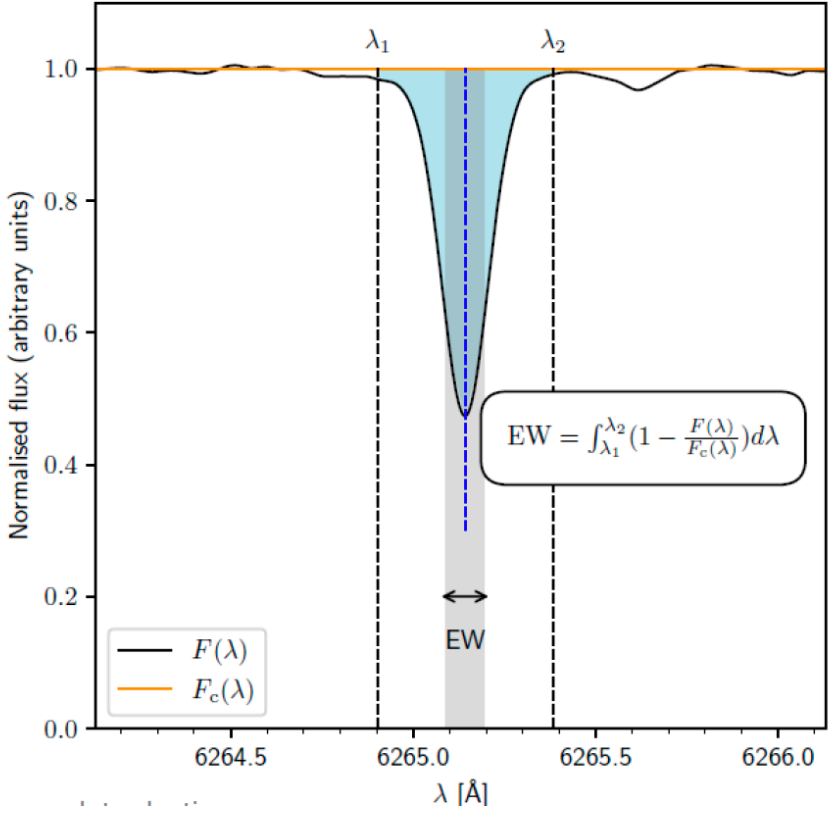
- "*The Gaia-ESO Survey: The analysis of high-resolution UVES spectra of FGK-type stars*", Smiljanic et al. 2014A&A...570A.122S

- "*Gaia-ESO Survey: Analysis of pre-main sequence stellar spectra*", Lanzafame et al., 2015A&A...576A..80L

The equivalent width (EW) method

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

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



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

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.

The STEPAR code

★ Automated implementation of the EW method
★ Written in Python 3
★ Publicly available at GitHub:
https://github.com/hmtabernero/StePar

Grid of MARCS models (Gustafsson et al. 2008)

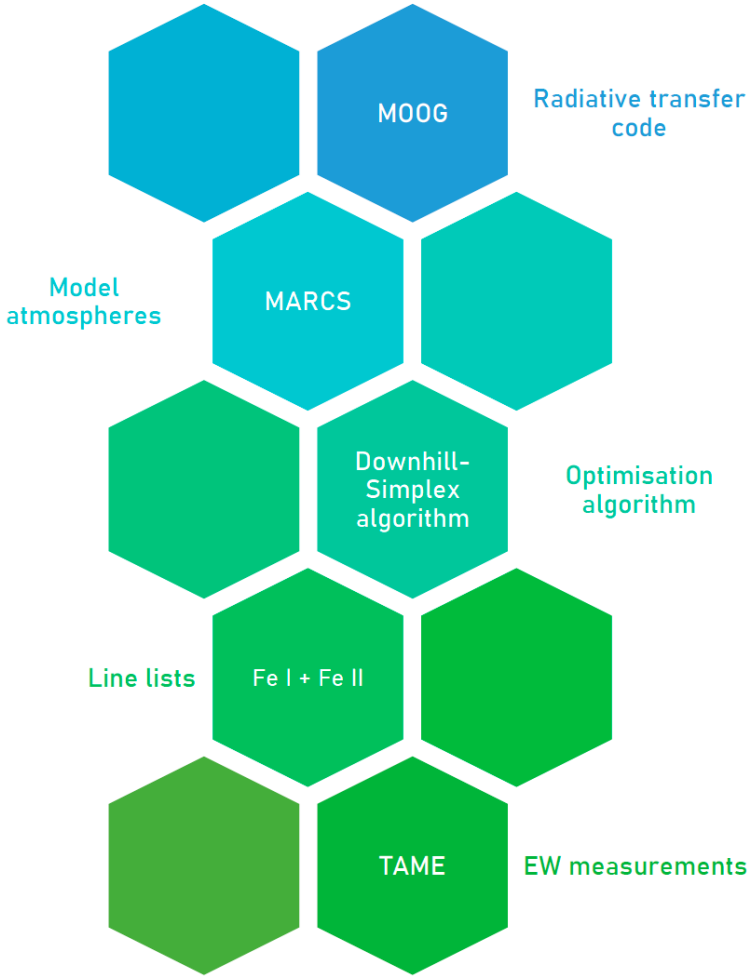
MOOG (Sneden, 1973)

EW measurements: TAME (Kang & Lee 2012)

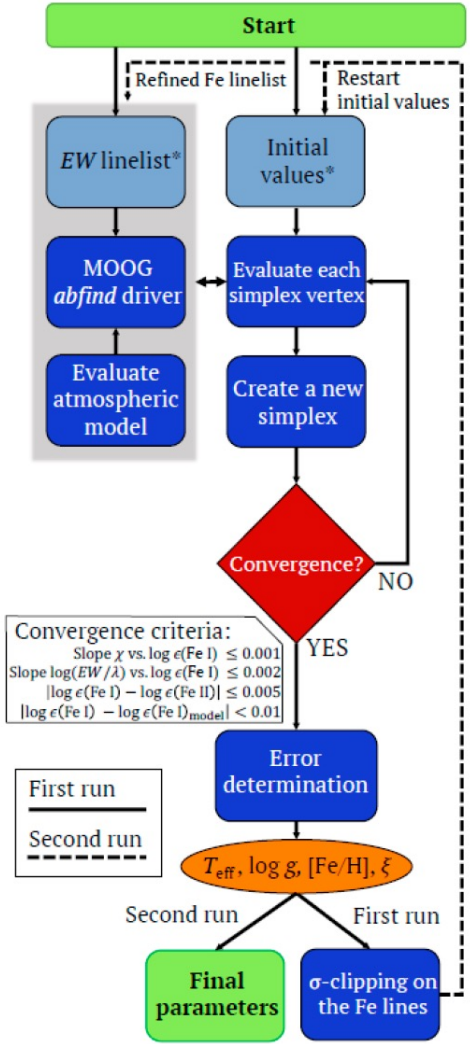
- smoother = 4
- space = 3
- lineresol = 0.1
- miniline = 2

EW filter: $10\ \text{mÅ} < \text{EW} < 120\ \text{mÅ}$

Output: T_{eff}, $\log g$, [Fe/H], ξ



STEPAR ingredients (Tabernero et al. 2019) 2019A&A...628A.131T

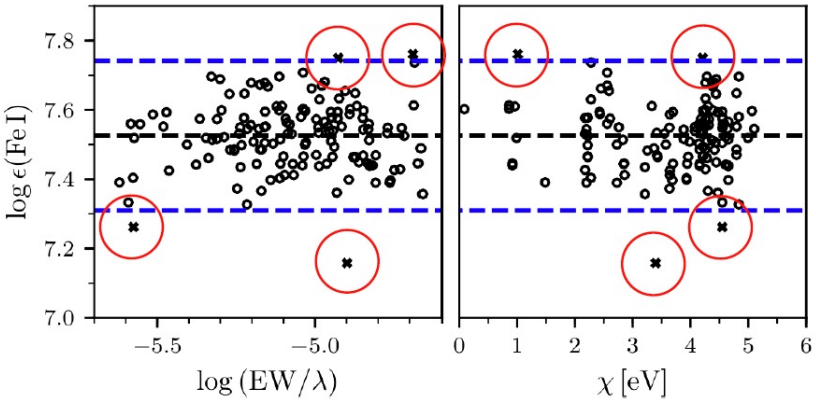


★ StePar workflow (Tabernero et al. 2019) 2019A&A...628A.131T
Two simplex runs (σ clipping)

★ Convergence criteria:
Slope χ vs. log ϵ(Fe I) ≤ 0.001
Slope log(EW/λ) vs. log ϵ(Fe I) ≤ 0.002
| log ϵ(Fe I) – log ϵ(Fe II) | ≤ 0.005
| log ϵ(Fe I) - log ϵ(Fe I)$_{model}$| < 0.01

★ Uncertainties: $\Delta\xi \Rightarrow \Delta T_{\rm eff} \Rightarrow \Delta \log g \Rightarrow \Delta$[Fe/H]

NARVAL spectrum of the Sun (Blanco-Cuaresma et al. 2014)



IPARCOS

GES
(Gaia-ESO spectroscopic Survey)

- **The Gaia-ESO Survey: Homogenisation of stellar parameters and elemental abundances**
Hourihane, A.; François, P.; Worley, C. C. and 59 more
2023A&A...676A.129H 2023/08

- **The Gaia-ESO Public Spectroscopic Survey: Implementation, data products, open cluster survey, science, and legacy**
Randich, S.; Gilmore, G.; Magrini, L. and 162 more
2022A&A...666A.121R 2022/10

- **The Gaia-ESO Public Spectroscopic Survey: Motivation, implementation, GIRAFFE data processing, analysis, and final data products**
Gilmore, G.; Randich, S.; Worley, C. C. and 165 more
2022A&A...666A.120G 2022/10

- **The Gaia-ESO survey: Age-chemical-clock relations spatially resolved in the Galactic disc**
Viscasillas Vázquez, C.; Magrini, L.; Casali, G. and 33 more
2022A&A...660A.135V 2022/04

- **Gaia-ESO Survey: Role of magnetic activity and starspots on pre-main-sequence lithium evolution**
Franciosini, E.; Tognelli, E.; Degl'Innocenti, S. and 24 more
2022A&A...659A..85F 2022/03

- **The Gaia-ESO Survey: Membership probabilities for stars in 63 open and 7 globular clusters from 3D kinematics**
Jackson, R. J.; Jeffries, R. D.; Wright, N. J. and 26 more

The *Gaia*-ESO Survey: Calibrating the lithium-age relation with open clusters and associations

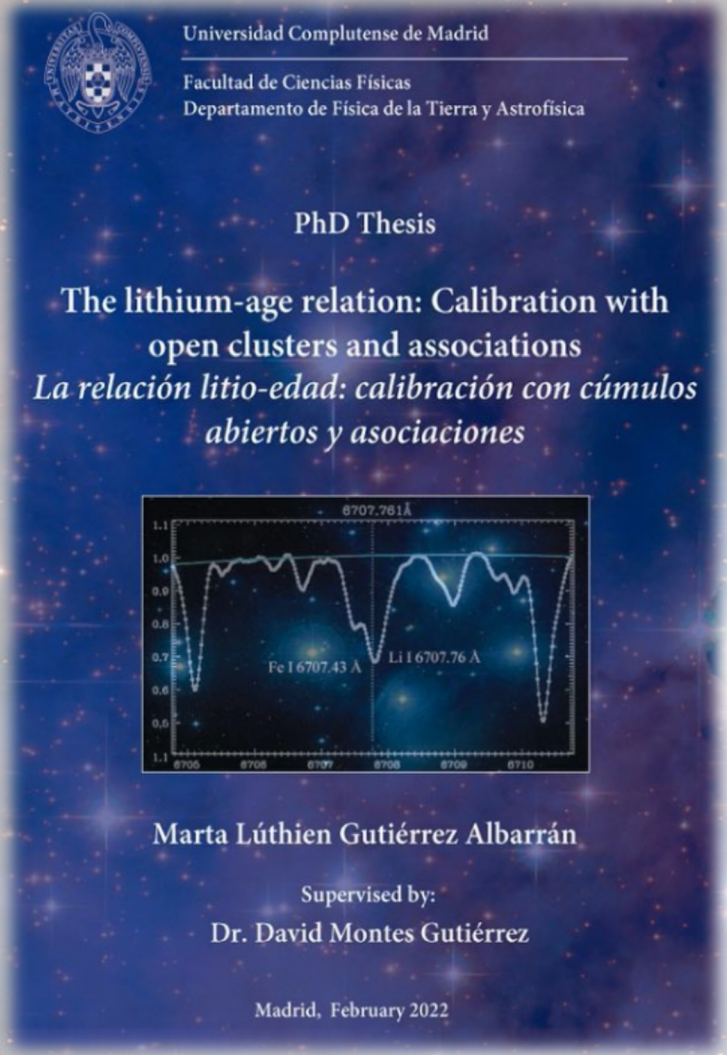
M.L. Gutiérrez Albarrán[1], D. Montes[1], M. Gómez Garrido[1,2], H. M. Tabernero[1,3], J.I. González Hernández[4,5], E. Marfil[1], and GES collaborators.

[1]Departamento de Física de la Tierra y Astrofísica and IPARCOS-UCM, Facultad de Ciencias Físicas, Universidad Complutense de Madrid, E-28040, Madrid, Spain; [2] Observatorio Astronómico Nacional (OAN-IGN), Alcalá de Henares; [3] Instituto de Astrofísica e Ciências do Espaço, Universidade do Porto; [4] Instituto de Astrofísica de Canarias (IAC); [5] Universidad de la Laguna, Tenerife.

Abstract

Li depletion is strongly **age-dependent** but currently available data have shown a complex pattern of Li depletion on the pre- and main-sequence stars that is not yet understood. The lithium abundance observed in late-type stars depends not only of the age and the temperature but also on metallicity, mixing mechanisms, convection structure, rotation and magnetic activity. The large number of stars observed within the Gaia-ESO survey (**GES**) for many open clusters and associations can be used to calibrate the **lithium-age relation** and its dependence with other parameters that can be derived from the UVES and GIRAFFE spectroscopic observations. We performed a thorough analysis of **membership and Li abundance of 20 clusters** observed in **GES (iDR4)**, ranging in age from **young clusters and associations**, to **intermediate-age and old open clusters**, in order to conduct a comparative study. All this allowed us to characterize the properties of the members of these clusters, as well as identify a series of **field contaminant stars, both lithium-rich giants and non-giant outliers**.

Gutiérrez Albarrán, M. L.; Montes, D.; et al. 2020A&A...643A..71G



Facultad de CC. Físicas
Universidad Complutense de Madrid

La relación Li-edad

Marta Lúthien Gutiérrez Albarrán

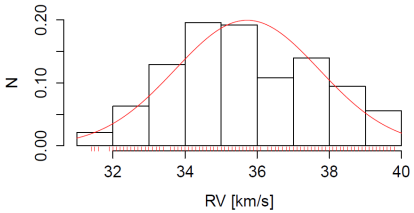
Data: Cluster sample

- *Young (1-50 Myr)*
- *Intermediate-age (50-700 Myr)*
- *Old (>700 Myr)*

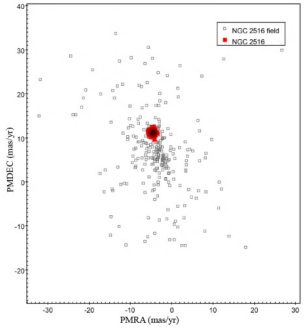
Cluster name	Age (Myr)	E(B-V)[a] (dex)	Distance (kpc)
NGC 6530	1–2	0.44 ± 0.10	1.33
ρ Oph	1–3	0.76 ± 0.13	0.13 ± 0.01
Trumpler 14	1–3	0.61 ± 0.10	2.90
Cha I	2	0.18 ± 0.08	0.16 ± 0.02
NGC 2244	4	0.49 ± 0.09	1.59
NGC 2264	4	0.05 ± 0.05	0.76
λ Ori	6	0.09 ± 0.04	0.41
Col 197	13	0.64 ± 0.07	0.80–0.90
γ Vel	10–20	0.04 ± 0.03	0.35–0.40
NGC 2232	18–32	0.04 ± 0.03	0.32
NGC 2547	20–45	0.06 ± 0.03	0.36 ± 0.02
IC 2391	36 ± 2 [c]	0.03 ± 0.01	0.16 ± 0.01
IC 2602	35 ± 1 [c]	0.04 ± 0.02	0.15 ± 0.01
IC 4665	38 ± 3 [c]	0.15 ± 0.02	0.36 ± 0.01
NGC 2451 B	39 ± 1 [c]	0.10 ± 0.03	0.36
NGC 2451 A	44 ± 2 [c]	0.02 ± 0.02	0.19

Cluster name	Age (Myr)	E(B-V)[a] (dex)	Distance (kpc)
NGC 6405	94	0.14 ± 0.04	0.46
Blanco 1	94 ± 5 [c]	-0.01 ± 0.03	0.23–0.24
NGC 6067	120	0.34 ± 0.04	1.4–1.7
NGC 6649	120	1.43 ± 0.05	1.8 ± 0.1
NGC 2516	125–138	0.11 ± 0.03	0.41
NGC 6709	173 ± 34 [c]	0.27 ± 0.02	1.1
NGC 6259	210	0.63 ± 0.09	1.9
NGC 6705	280	0.40 ± 0.06	1.88
Berkeley 30	300	0.51 ± 0.04	4.7–4.9
NGC 6281	314	0.18 ± 0.02	0.47–0.51
NGC 3532	399 ± 5 [c]	0.05 ± 0.02	0.48–0.49
NGC 4815	560	0.70 ± 0.07	2.40–2.90
NGC 6633	575	0.15 ± 0.04	0.39
NGC 2477	700	0.31	1.4
Trumpler 23	800	0.68 ± 0.04	2.20
Berkeley 81	860 ± 100	0.85 ± 0.04	3.00
NGC 2355	900	0.13 ± 0.03	1.80 ± 0.07
NGC 6802	900	0.79 ± 0.06	1.80
NGC 6005	973 ± 4 [c]	0.49 ± 0.06	2.70
Pismis 18	1200 ± 400	$+0.22 \pm 0.04$	2.20
Melotte 71	1294 ± 89 [c]	0.11	2.2–3.2
Pismis 15	1300	0.56 ± 0.05	2.6–2.9
Trumpler 20	1400	0.37 ± 0.03	3.00
Berkeley 44	1600	0.90 ± 0.07	1.80–3.10
NGC 2243	4000 ± 120	0.04 ± 0.04	4.50
M67	4000–4500	0.059	0.90

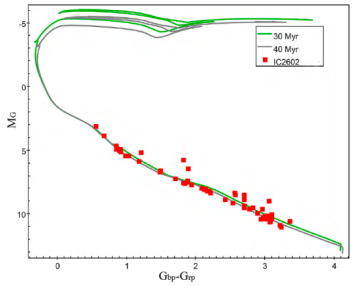
1) Membership analysis to obtain lists of robust cluster candidates



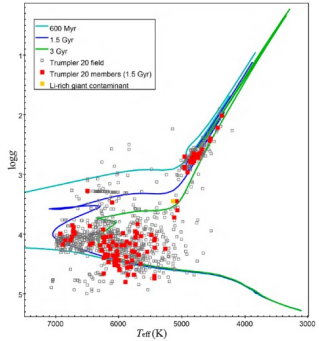
1) Analysis of *RV* distributions

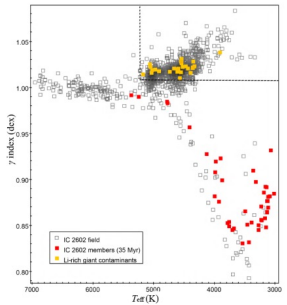


2) *Gaia* astrometry: proper motions and parallax

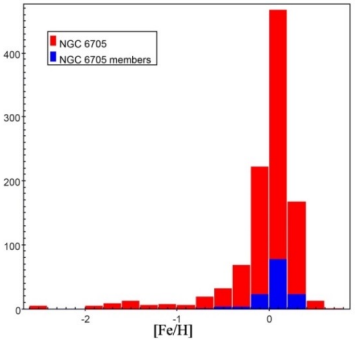


3) *Gaia* photometry (CMDs)

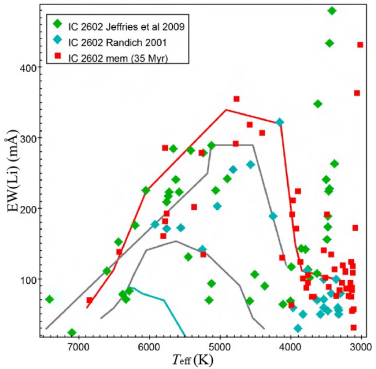




4) Gravity indicators: Kiel diagram and **(γ, $T_{\rm eff}$) plane**



5) [Fe/H] metallicity

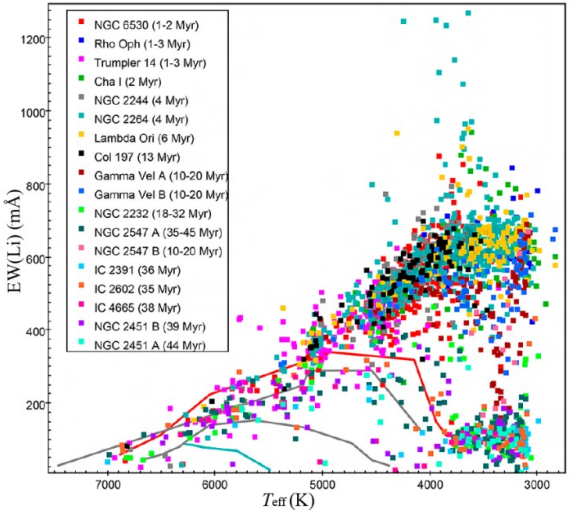


6) Position in *EW*(Li) vs $T_{\rm eff}$ diagram with **empirical envelopes as guide**.

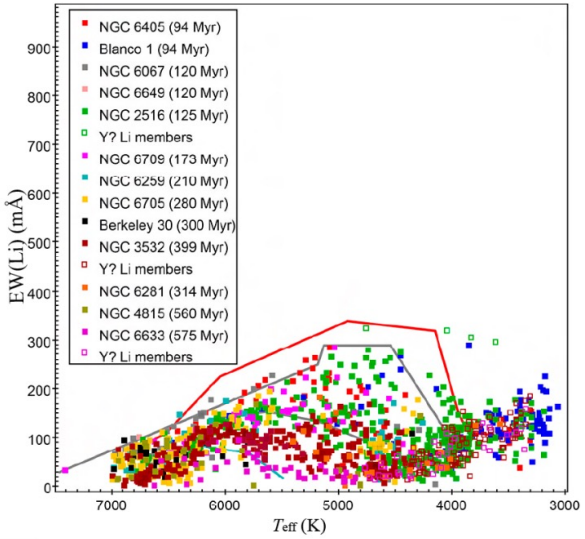
7) *Gaia* DR1, DR2 and EDR3 studies

Final member selections for all target clusters

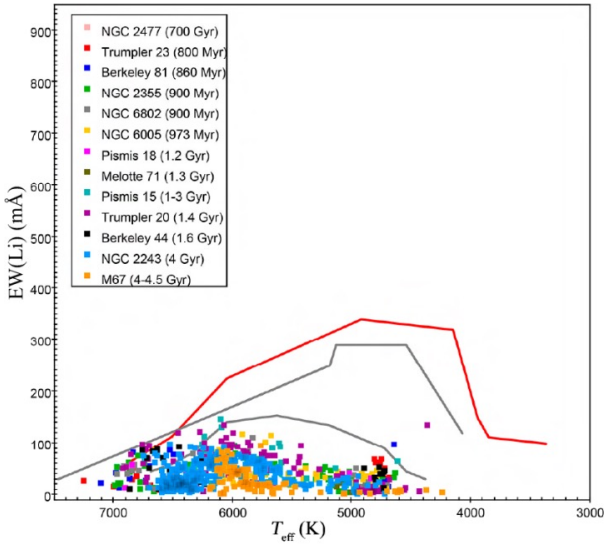
Young clusters (1-50 Myr)



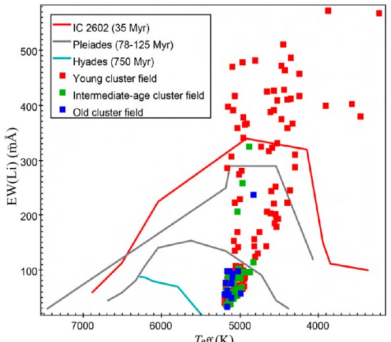
Intermediate–age clusters (50-700 Myr)



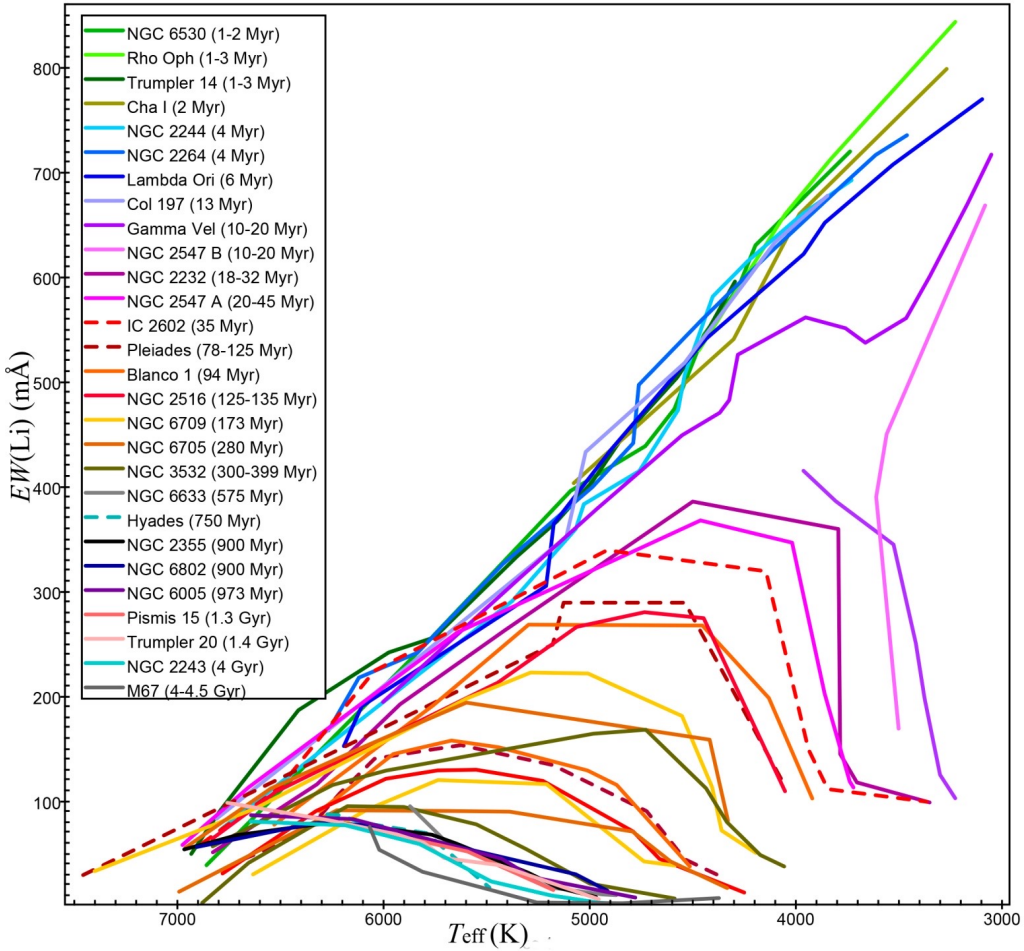
Old clusters (>700 Myr)



❖ Additional result → **Preliminary lists of Li-rich giant contaminants** for **23** target clusters, defined as those giant field outliers with **A(Li) ≥ 1.5**.



The Li-age relation: Final empirical Li envelopes



***EW*(Li) vs T_{eff} diagrams** with the **empirical Li envelopes obtained for 27 out of the 42 clusters in the sample**.

Future work: These empirical Li envelopes can be used to **estimate age ranges** for **GES iDR6 MW field stars**, whose age is still unknown.

Qualitative Li envelopes → automated method to create **quantitative envelopes for more precise age estimates.**

Paper II y III submited

Astronomy & Astrophysics manuscript no. output
October 25, 2023
©ESO 2023

The *Gaia*-ESO Survey: Calibrating the lithium–age relation with open clusters and associations ⋆ ⋆⋆

II. Expanded cluster sample and final membership selection.

M.L. Gutiérrez Albarrán[1], D. Montes[1], H.M. Tabernero[1,2], J.I. González Hernández[3,4], E. Marfil[1,5], A. Frasca[6], A. C. Lanzafame[7,6], A. Klutsch[8,6], E. Franciosini[9], S. Randich[9], R. Smiljanic[10], A. J. Korn[11], G. Gilmore[12], E. J. Alfaro[13], T. Bensby[16], K. Biazzo[17], A. Casey[20], G. Carraro[23], F. Damiani[15], S. Feltzing[16], P. François[22], F. Jiménez Esteban[14], L. Magrini[9], L. Morbidelli[9], L. Prisinzano[15], T. Prusti[21], C. C. Worley[19], S. Zaggia[18] and GES builders

(Affiliations can be found after the references)

Received , 2023; accepted ,

ABSTRACT

Context. The Li abundance observed in pre- and main-sequence late-type stars is strongly age-dependent, but also shows a complex pattern depending on several parameters, such as rotation, chromospheric activity and metallicity. The best way to calibrate these effects with the aim of studying Li as an age indicator for FGK stars is to calibrate coeval groups of stars, such as open clusters and associations.
Aims. We present a considerable target sample of 42 OCs and associations, with an age range of 1 Myr–5 Gyr, observed within the *Gaia*-ESO survey (GES), and using the latest data provided by GES iDR6 and the then newest release of *Gaia* EDR3. As part of this sample, we have updated and improved the membership analysis for all 20 OCs presented in our previous article (Gutiérrez Albarrán et al. 2020).
Methods. We performed detailed membership analyses for all target clusters to identify likely candidates, using all available parameters provided by GES, complemented with detailed bibliographical searches, and based on numerous criteria: From radial velocity (*RV*) distributions, to the astrometry (proper motions and parallaxes) and photometry provided by *Gaia*, to gravity indicators ($\log g$ and the γ index), [Fe/H] metallicity, and Li content in EW(Li) vs $T_{\rm eff}$ diagrams.
Results. We obtained updated lists of cluster members for the whole target sample, as well as a selection of Li-rich giant contaminants, obtained as an additional result of the membership process. Each selection of cluster candidates was thoroughly contrasted with numerous existing membership studies using data from *Gaia* to ensure the most robust results.
Conclusions. These final cluster selections will be used in the third and last paper concluding this work to describe a comparative study that characterizes the observable Li dispersion in each cluster and analyses its dependence with several parameters, thus allowing us to calibrate a Li-age relation and obtain a series of empirical Li envelopes for key ages in our sample.

Key words. Galaxy: open clusters and associations: general – Stars: late-type – Stars: abundances – Techniques: spectroscopic

1. Introduction

Lithium in the form of its main isotope ^{7}Li (henceforth Li) is mainly observable through the spectral resonance lines of neutral Li, forming a doublet at 6707.76 Å and 6707.89 Å (e.g., Pallavicini et al. 1992; Soderblom 2010; Lyubimkov 2016; Randich & Magrini 2021). Li is a very fragile element that is easily destroyed in stellar interiors, burning at temperatures above ~ 2.5–3×10^6 K, corresponding to the temperature at the base of the convective zone of a solar-mass star on the zero-age main sequence (ZAMS) (e.g., Pallavicini et al. 1990; Siess et al. 2000; Magrini et al. 2021). As a result, Li is slowly being depleted and its surface abundance decreases over time in solar-type and lower mass FGK stars. The depletion of Li in these stars is strongly mass (colour) and age dependent: Li depletion increases with decreasing mass at a given age, and the timescales for significant Li depletion typically range from 10–20 Myr in M-type stars, to ~ 100 Myr in K-type stars, and ~ 1 Gyr in G-type stars (e.g., Jeffries et al. 2014; Soderblom et al. 2014; Lyubimkov 2016; Randich & Magrini 2021). For their part, Li-rich giants show an additional contribution of surface Li that can only be accounted for with non-standard mixing mechanisms (e.g., Casey et al. 2016; Lyubimkov 2016; Magrini et al. 2021). As it only survives in the outer layers of a star, Li is a very sensitive indicator of youth in late-type stars, a useful tracer of stellar evolution for PMS (pre-Main Sequence), MS and post-MS star, and is also particularly relevant for the determination of the age of stellar open clusters (OCs) and associations (e.g., Sestito & Randich 2005; Bouvier et al. 2018; Dumont et al. 2021a,b; Randich & Magrini 2021). For a more comprehensive overview on Li as an age indicator and the mechanics of Li depletion, we refer the reader to the introductory chapter of the published thesis and all references therein (Gutiérrez Albarrán 2022).

The present work is the second out of three papers where we have studied Li as an age indicator for pre- and main-sequence

⋆ Based on observations collected with ESO telescopes at the La Silla Paranal Observatory in Chile, for the *Gaia*-ESO Large Public Spectroscopic Survey (188.B-3002, 193.B-0936).
⋆⋆ All tables in Appendix C available in electronic form at the CDS via ...

Astronomy & Astrophysics manuscript no. output
October 25, 2023
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The *Gaia*-ESO Survey: Calibrating the lithium–age relation with open clusters and associations ⋆

III. Calibration and dependence with stellar parameters.

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(Affiliations can be found after the references)

Received , 2023; accepted ,

ABSTRACT

Context. The Li abundance observed in pre- and main-sequence late-type stars is strongly age-dependent, but also shows a complex pattern depending on several parameters, such as rotation, chromospheric activity and metallicity. The best way to calibrate these effects is to calibrate coeval groups of stars, such as open clusters and associations.
Aims. We made use of the lists of candidate members obtained in the companion paper to this work (Gutiérrez Albarrán et al. 2023) for a target sample of 42 open clusters, ranging from 1 Myr to 5 Gyr and observed within the *Gaia*-ESO survey (GES), with the aim of studying Li as an age indicator and deriving an empirical Li-age relation for FGK late-type stars.
Methods. We conducted a comparative study that allowed us to quantify the observable Li dispersion in each cluster, and analyse in detail its dependence with several other stellar parameters derived from GES: rotation, chromospheric activity (Hα), accretion processes, and metallicity. We also compared our analyses with various correlations and findings of earlier publications, from the Li-rotation and Li-activity connections, to the effects of metallicity in the Li depletion of coeval clusters.
Results. The identification of likely candidates for all clusters and the characterization of their properties allowed us to calibrate a Li-age relation and obtain a series of empirical Li envelopes for key ages in our sample. We also constrained the Li depletion boundary for those clusters in the 15–500 Myr age range with the aid of several models.
Conclusions. This work, additionally presented in full as a thesis in Gutiérrez Albarrán (2022), has concluded our aim to analyse the dependence of Li depletion on several GES parameters and calibrate a preliminary empirical Li–age relation. As part of our future work, such a calibration will allow us to estimate age ranges for GES field stars, and identify their potential membership to young associations and stellar kinematic groups of different ages.

Key words. Galaxy: open clusters and associations: general – Stars: late-type – Stars: abundances – Techniques: spectroscopic – Stars: rotation – Stars: activity

1. Introduction

While standard models of stellar evolution, with convection as the only mixing mechanism, predict that stellar Li abundances should only be a function of effective temperature, mass and age (e.g., Soderblom et al. 1990; Soderblom 2010; Dumont et al. 2021b; Randich & Magrini 2021), the Li abundances observed in various studies for solar and late-type stars in open clusters (OCs) of different ages have shown a significant spread in Li abundance at a given colour (or mass) which could not be attributed to observational errors (e.g., Soderblom et al. 1993; Jeffries et al. 2014; Barrado et al. 2016; Bouvier et al. 2018). Observations have shown a complex pattern of Li depletion for PMS (pre-Main Sequence) and MS (Main Sequence) stars that is not a simple function of mass and stellar age only, but also depends on a series of other factors and parameters, such as rotation, activity, metallicity, accretion, magnetic activity, and convection structure (e.g., Randich et al. 2002; Pallavicini et al. 2005; Bouvier 2008; Soderblom et al. 2014; Barrado et al. 2016; Castro et al. 2016; Lyubimkov 2016; Randich & Magrini 2021). This indicates the presence of a variety of additional non-standard mixing processes (in addition to convection) that would account for the observed enhanced Li spread in FGK stars, such as rotational mixing, convective overshooting, mass loss through stellar winds, internal gravitational waves, tachocline mixing, or penetrative convection (e.g., Soderblom et al. 1990; Pallavicini et al. 1997; Jeffries 2014; Bouvier et al. 2018; Dumont et al. 2021b; Randich & Magrini 2021; Romano et al. 2021).

Even though a large amount of theoretical and observational work has been dedicated to the understanding of Li and its evolution, the complex pattern of Li depletion in PMS and MS stars is not yet well understood, preventing a more precise and quantitative use of Li as an age tracer (e.g., Sestito & Randich 2005; Randich & Magrini 2021). The most precise way to characterize the dependence of Li on these stellar parameters and derive a reliable Li-age relation is to conduct a comprehensive study of stellar groups with similar ages, such as OCs, associations, and

⋆ Based on observations collected with ESO telescopes at the La Silla Paranal Observatory in Chile, for the *Gaia*-ESO Large Public Spectroscopic Survey (188.B-3002, 193.B-0936).

Exoplanets: planets in other stars



The 5Ws: who, what, where, when and why of exoplanets



https://www.esa.int/ESA_Multimedia/Videos/2025/05/Exoplanets_explained_by_Nobel_Prize_winner_part_1_The_5_Ws

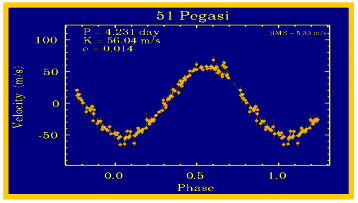
The 5Ws: who, what, where, when and why of exoplanets

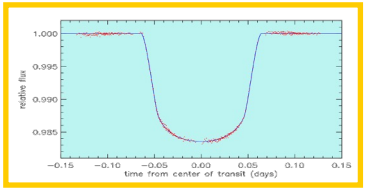


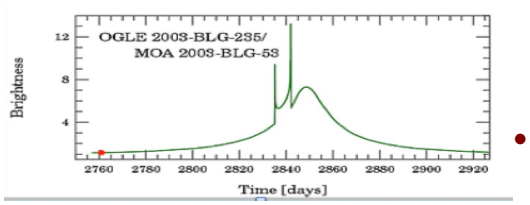
https://www.esa.int/ESA_Multimedia/Videos/2025/05/Exoplanets_explained_by_Nobel_Prize_winner_part_1_The_5_Ws

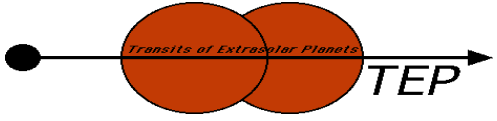
Métodos de detección

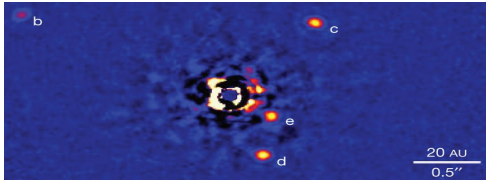
- Velocidad radial (efecto Doppler).
- Tránsitos fotométricos.
- Microlentes gravitatorias.
- Timing (eclipses, pulsaciones).
- Imagen directa.
- Astrometría.









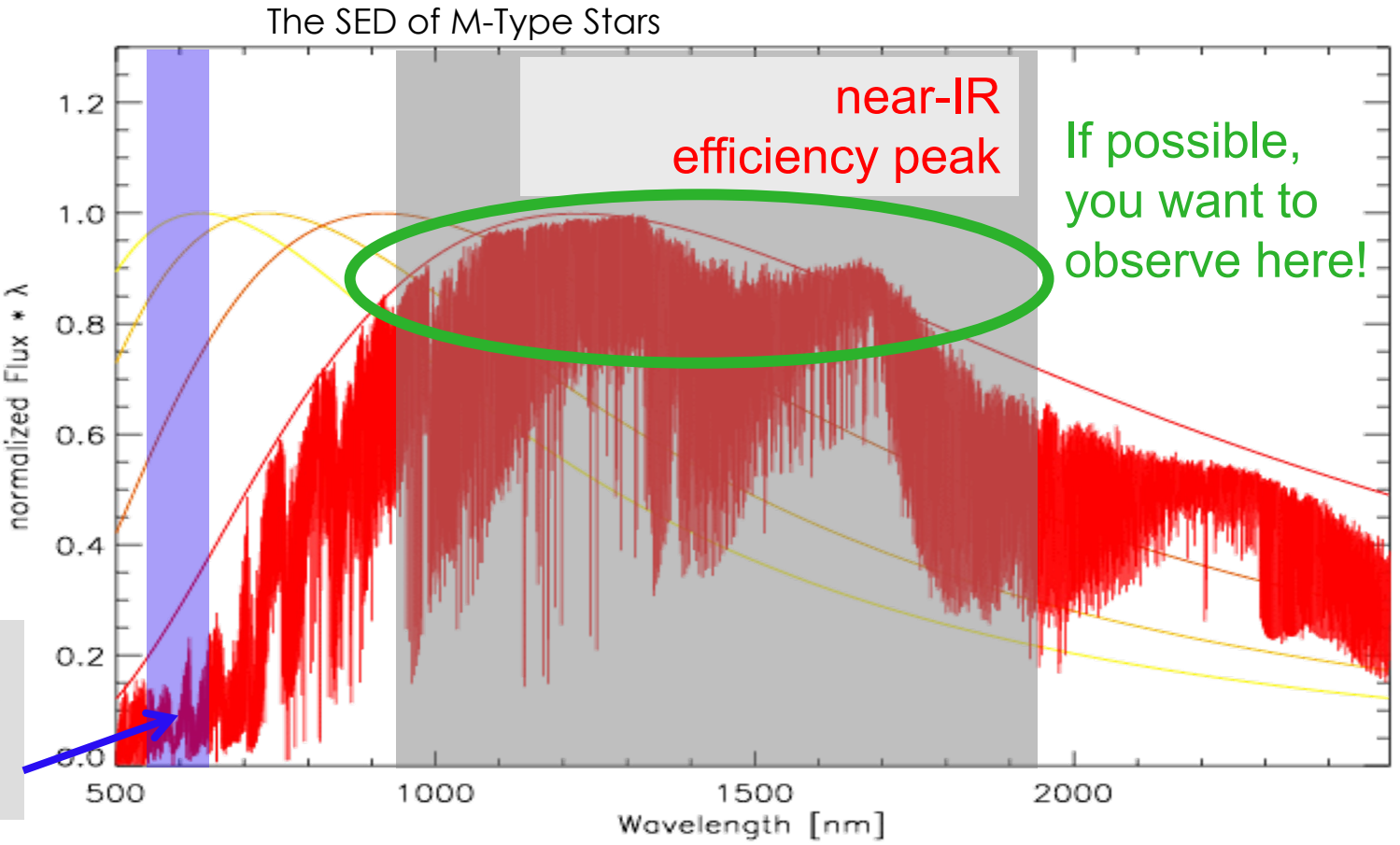


- WATCHING FOR WOBBLE
  Radial Velocity
- SEARCHING FOR SHADOWS
  Transits
- LIGHT IN A GRAVITY LENS
  Gravitational Microlensing
- Timing
  (eclipses, pulsation)
- TAKING PICTURES
  Direct Imaging
- MINISCULE MOVEMENTS
  Astrometry

(the redder, the better)

HARPS Δλ = 533-691 nm

But M dwarfs are faint (and active) in the optical!

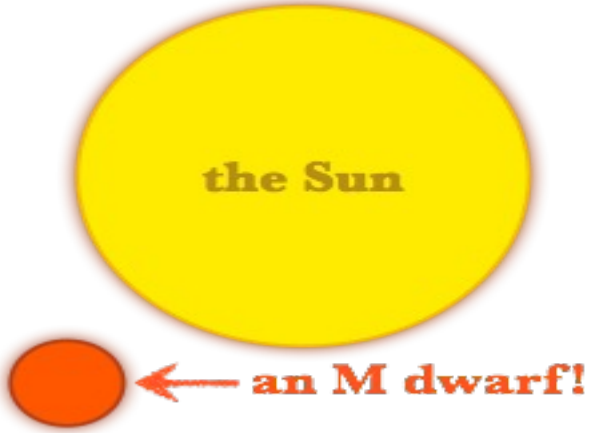


"classical" *visible light* RV instruments

Why M stars?

- **Bigger Doppler signal**

→ the **lower masses** of the stars means the gravitational tug of an Earth-mass planet will result in a **larger stellar motion**, resulting in a **bigger Doppler signal** than observed for Sunlike stars.



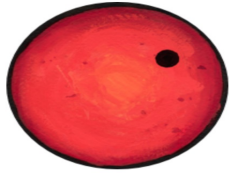
- **HZ is much closer**

→ are also **cooler**, the HZ is much **closer** to the star. The **shorter orbital radii** results in **shorter orbital periods**, allowing us to discover them using less telescope time.

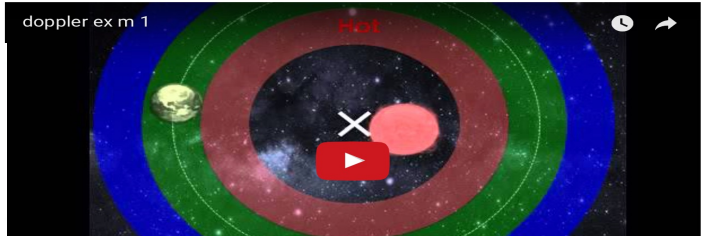


- **Large fracction block**

→ increases the probability the planets will **transit** → opportunity to characterize their atmospheres, and percentage of light blocked by a transiting planet is larger.



And here is the motion induced by the same planet around an M dwarf:



http://hpf.psu.edu/the-purpose-of-hpf/

carmenes

El cazador de exoplanetas de Calar Alto

CARMENES. ¿Qué?: un nuevo espectrógrafo óptico-infrarrojo. ¿Dónde?: en Calar Alto, Almería. ¿Cuándo?: su primera luz en 2015. ¿Cómo?: con el método de velocidad radial. ¿Para qué?: para descubrir planetas como el nuestro alrededor de las estrellas más cercanas al Sol.

MAX-PLANCK-GESELLSCHAFT CSIC ICE INSTITUT FÜR ASTROPHYSIK GÖTTINGEN TLS DFG DLR Unión Europea Fondo Europeo de Desarrollo Regional "Una manera de hacer Europa" Calar Alto

IPARCOS

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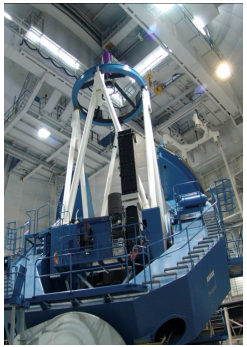
CARMENES

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Calar
Alto high-
Resolution search for
M dwarfs with
Exoearths with
Near-infrared and visible
Echelle
Spectrographs

Calar Alto

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

DFG

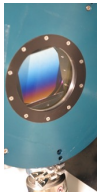
http://carmenes.caha.es/

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CARMENES

<u>At UCM</u>: CCD detector characterization (Art. 83 with Fractal SLNE) @ LICA

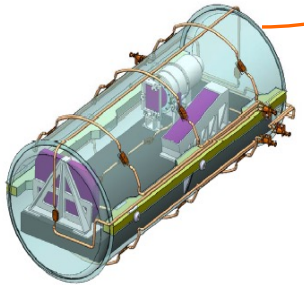


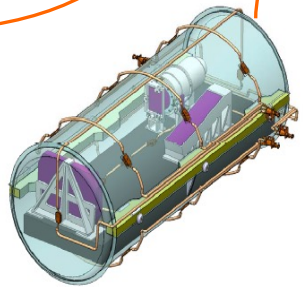
David Montes

CARMENES, the instrument

carmenes

Two fibre-fed stabilised échelle spectrographs (R=82,000) inside the coudé room of the 3.5 m CA telescope (NIR and VIS)







IPARCOS

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CARMENES

CARMENES radial velocity instrument

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→ Search for **Earth-like habitable planets** around low-mass stars (**M-stars**)

– Number and formation mechanisms

– Properties and habitability

• Survey of **300 M dwarf** stars simultaneously in visible light and near-infrared

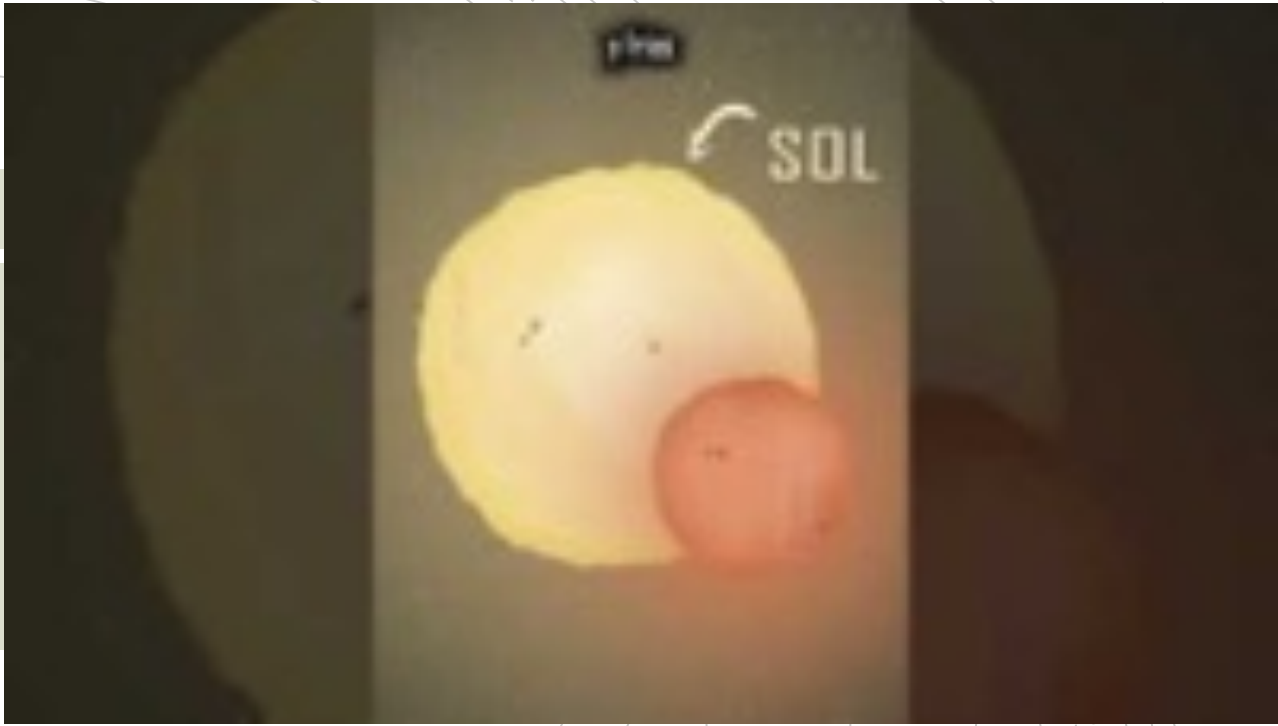
• GermanSpanish instrument for 3.5-m Calar Alto

• 600 - 750 "useful" nights guaranteed

• Survey on-going **since Jan 1, 2016**

- "***CARMENES instrument overview***"
  (Quirrenbach et al. 2014SPIE.9147E..1FQ)
- "***CARMENES: an overview six months after first light***"
  (Quirrenbach et al. 2016SPIE.9908E..12Q)
- "***CARMENES: high-resolution spectra and precise radial velocities in the red and infrared***"
  (Quirrenbach et al. 2018SPIE10702E..0WQ)
- "***The CARMENES M-dwarf planet survey***"
  (Quirrenbach et al. 2020SPIE11447E..3CQ)

CARMENES



CARMENES, el arma secreta para buscar exoplanetas - Buscando exoplanetas / Andalucía en el Espacio - Buscando exoplanetas: PARTE 3!

David Montes

CARMENES input catalogue

→ CARMENES **input catalogue** of
~2200 nearby bright **M dwarfs** (δ > −23 deg)

→ **~300 GTO (G**uaranteed **T**ime **O**bservations**) targets**

→ **CARMENCITA**:
CARMENES **C**ool dwarf **I**nformation and da**T**a **A**rchive

→ **Science preparation** (Low-res & High-res spectra)
- "***CARMENES: data flow***"
(Caballero et al. 2016SPIE.9910E..0EC)

CARMENES input catalogue of M dwarfs.

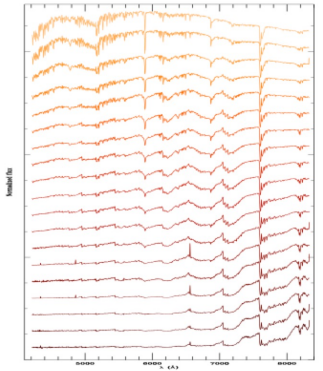
IPARCOS

carmenes

CARMENES science preparation

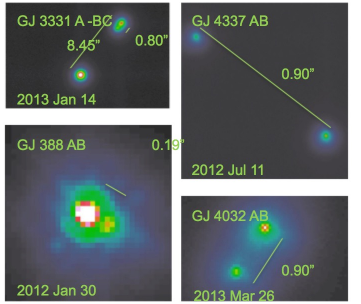
David Montes

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



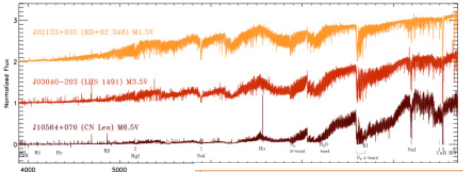
Spectral types for all 753 stars, of which 305 are new and 448 are revised.

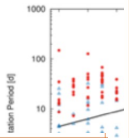
- II. High-resolution imaging with FastCam
(Cortés-Contreras, et al., 2017A&A...597A..47C)



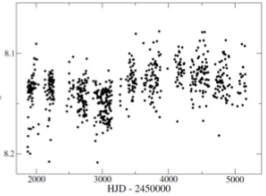
From the 490 observed stars, we detected 80 companions in 76 systems, of which 30 are new discoveries. Another six companion candidates require additional astrometry to confirm physical binding. The multiplicity fraction in our observed sample is 16.7 ± 2.0%.

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

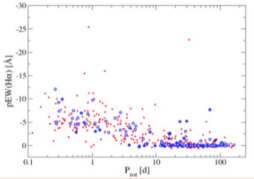




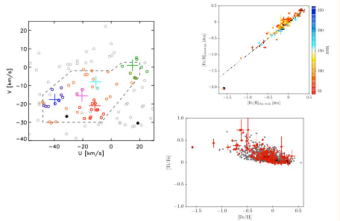
- IV. New rotation periods from photometric time series
(Díez Alonso, et al. 2018, A&A, arXiv:1810.03338)



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

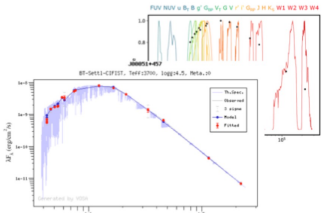


Calibrating the metallicity of M-dwarfs with wide visual binaries (FGK+M)



(Montes et. al., 2018MNRAS.479.1332M).

Spectral energy distributions and luminosities of M dwarfs



Cifuentes et al., 2019, in prep.



Carmencita:
Know thy star, know thy planet

J. A. Caballero, C. Cifuentes, M. Cortés-Contreras, D. Montes, P. J. Amado, V. J. S. Béjar, E. Díez Alonso, J. C. Morales, S. V. Jeffers, V. Perdelwitz, A. Quirrenbach, A. Reiners, D. Revilla, I. Ribas, P. Schöfer, Y. Shan, W. Seifert, L. Tal-Or and the CARMENES team[1,2,3,4,5,6,7,8,9,10,11]

[1] Max-Plack-Institut für Astronomie · [2] Instituto de Astrofísica de Andalucía · [3]Landessternwarte Königstuhl · [4]Institut de Ciències de l'Espai · [5] Institut für Astrophysik und Geophysik · [6] Universidad Complutense de Madrid · [7] Thüringer Ladessternwarte Tautenburg · [8] Instituto de Astrofísica de Canarias · [9] Hamburger Sternwarte · [10]Centro de Astrobiología · [11] Centro Astronómico Hispano en Andalucía

CARMENES science preparation

2025hsa..conf...22C

David Montes

One saved observatory, more than 70 new exoplanets, 120 PhD/MSc/BSc theses, over 140 refereed publications, and thousands of citations since the start of operations in January 2016 are a proof of the success of the CARMENES project at the 3.5 m Calar Alto telescope. There are multiple explanations for that success, from the hardworking dedication of many individuals in both Germany and Spain (engineers, students, postdocs, seniors), through a number a good technical decisions (optics, mechanics, electronics, software), to something more subjective such as the team spirit and friendliness. One of those success explanations is also the CARMENES input catalogue, dubbed **Carmencita**. Led from Spain, **Carmencita** is more than a simple catalogue, as it has included plenty of data taken from the literature and collected by ourselves on the brightest, closest M dwarfs observable from Almería. Many of the eventually targeted M dwarfs are now known to host planets with the greatest Earth Similiarity Indices or that are the most suitable ones for spectroscopic studies with the *James Webb* Space Telescope. Below we summarise the effort by uncountable researchers and students that helped creating **Carmencita**: astrometry, photometry, spectroscopy, activity, kinematics, multiplicity, stellar parameters and everything that one can think of an exoplanet host star... Because one needs to know the star to know its planet!


CARMENES input catalogue of M dwarfs
I. Low-resolution spectroscopy with CAFOS*

Alonso-Floriano et al. 2015
A&A 577, A128
I. Low-resolution spectroscopy with CAFOS


CARMENES input catalogue of M dwarfs
II. High-resolution imaging with FastCam*

Cortés-Contreras et al. 2017
A&A 597, A47
II. High-resolution imaging with FastCam


CARMENES input catalogue of M dwarfs
III. Rotation and activity from high-resolution spectroscopic observations*,**,***

Jeffers et al. 2018
A&A 614, A76
III. Rotation and activity from high-resolution spectroscopic observations

carmenes


CARMENES input catalogue of M dwarfs
IV. New rotation periods from photometric time series*

Diez Alonso et al. 2019
A&A 621, A126
IV. New rotation periods from photometric time series


CARMENES input catalogue of M dwarfs
V. Luminosities, colours, and spectral energy distributions*

Cifuentes et al. 2020
A&A 642, A115
V. Luminosities, colours, and spectral energy distributions


CARMENES input catalogue of M dwarfs
VI. A time-resolved Ca II H&K catalog from archival data*

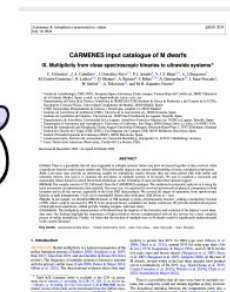
Perdelwitz et al. 2021
A&A 652, A1116
VI. A time-resolved Ca II H&K catalog from archival data


CARMENES input catalog of M dwarfs
VII. New rotation periods for the survey stars and their correlations with stellar activity*

Shan et al. 2024
A&A 684, A9
VII. New rotation periods for the survey stars and their correlations with activity


CARMENES input catalogue of M dwarfs
VIII. Kinematics in the solar neighbourhood

Cortés-Contreras et al.
A&A to be submitted
VIII. Kinematics in the solar neighbourhood


CARMENES input catalogue of M dwarfs
IX. Multiplicity from close spectroscopic binaries to ultrawide systems*

Cifuentes et al.
A&A to be submitted
IX. Multiplicity from close spectroscopic binaries to ultrawide systems

IPARCOS

carmenes

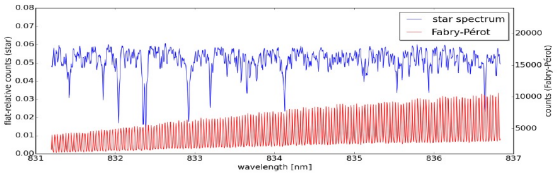
CARMENES science exploitation

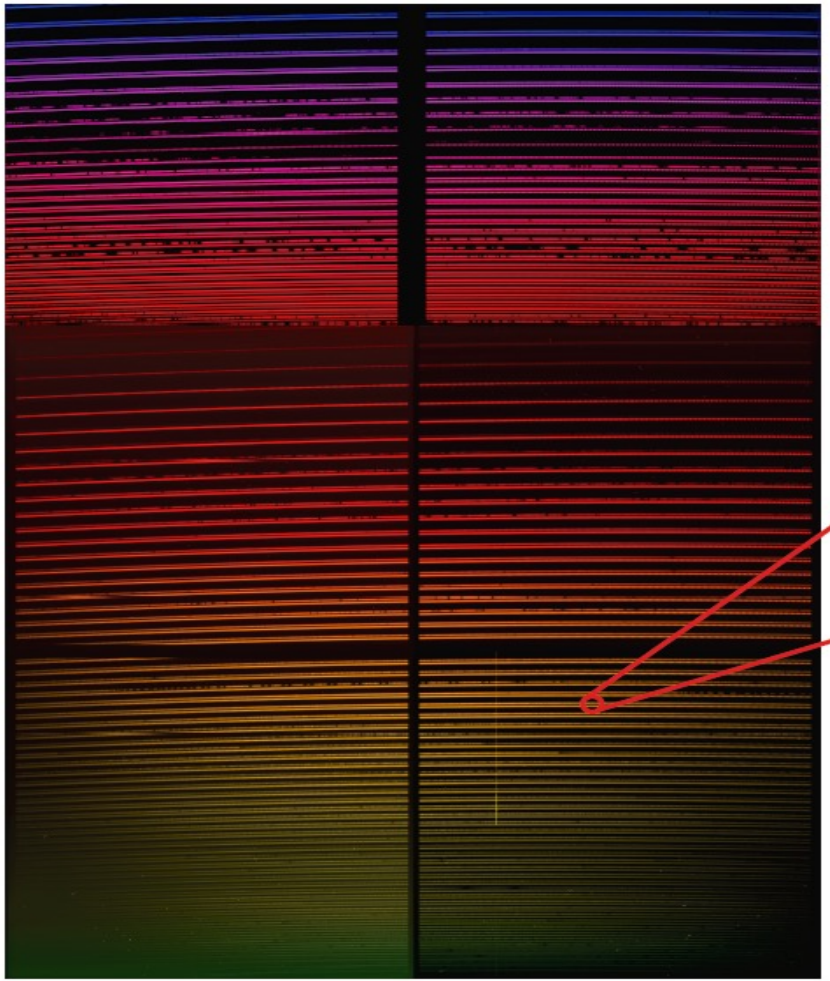
The CARMENES search for exoplanets around M dwarfs.

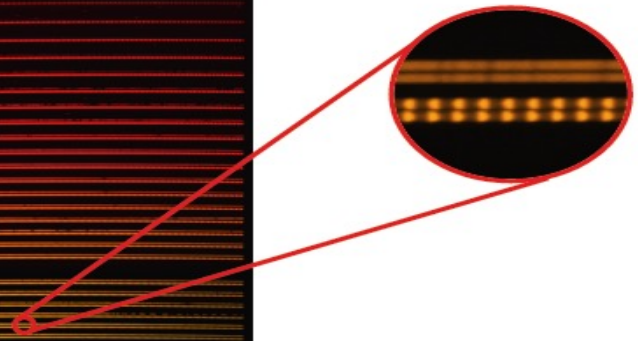
CARMENES spectra

NIR: 0.96-1.71 µm,
28 orders
2 2kx2k Hawaii-2RG,
R = 80 400

VIS: 0.52-0.96 µm,
61 orders
4kx4k e2v CCD231-84,
R = 96 500



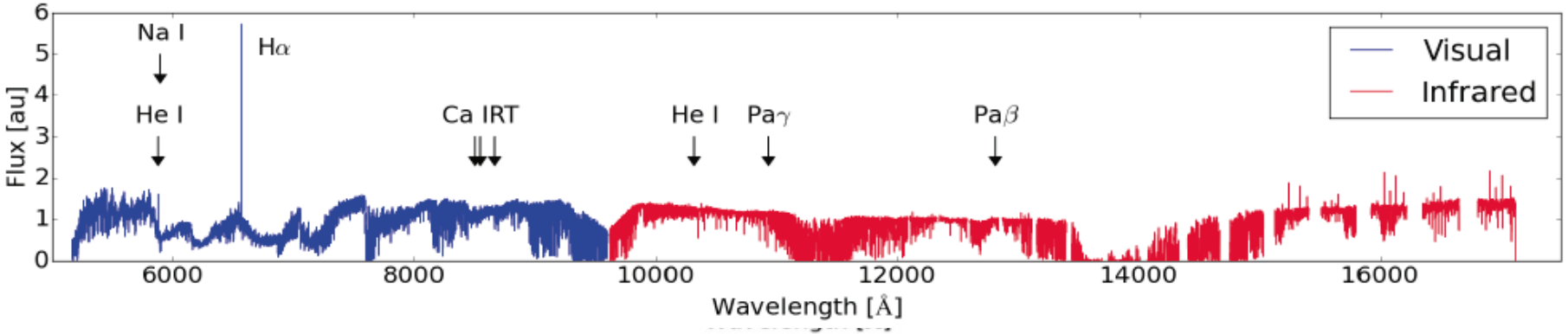




CARMENES spectra

VIS + NIR Observations:

VIS: 0.52-0.96 μm, 4kx4k e2v CCD231-84, *R* = 96 500
NIR: 0.96-1.71 μm, 2 2kx2k Hawaii-2RG, *R* = 80 400



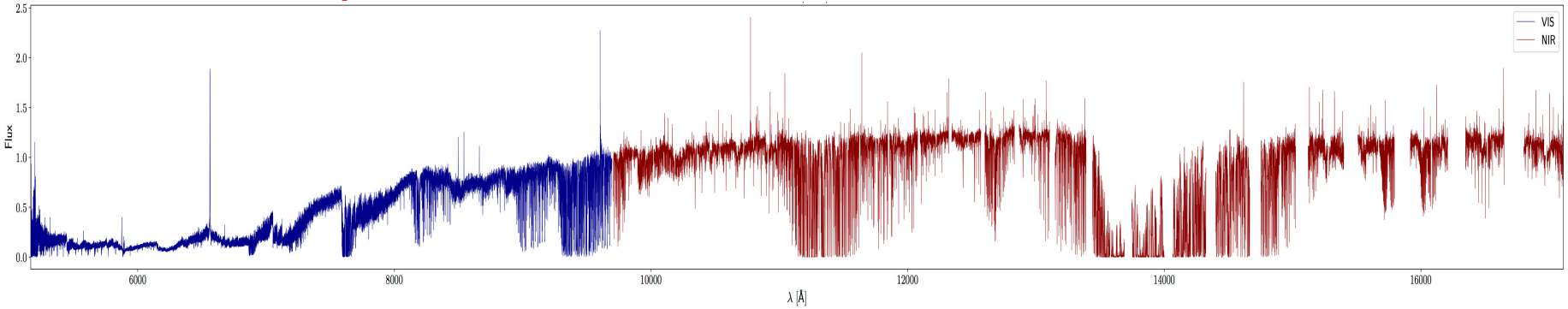
(YZ CMi, M4.5Ve)
Poster #191, Czesla et al.

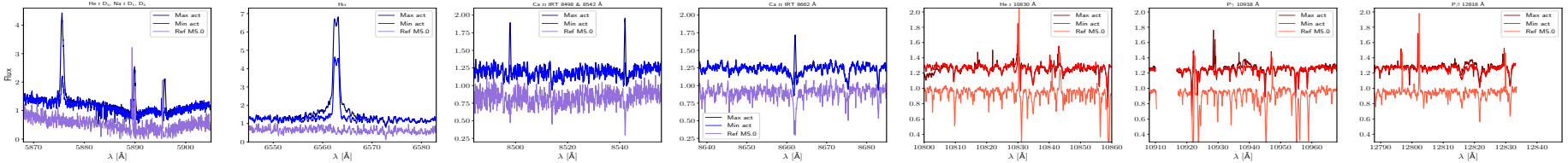
CARMENES spectra

VIS + NIR Observations:

VIS: 0.52-0.96 μm, 4kx4k e2v CCD231-84, *R* = 96 500
NIR: 0.96-1.71 μm, 2 2kx2k Hawaii-2RG, *R* = 80 400

Estrella M5.5V





Template spectra: high-quality and telluric-free spectrum per target

A&A, 680, A73 (2023)
https://doi.org/10.1051/0004-6361/202346524
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Astronomy & Astrophysics

The CARMENES search for exoplanets around M dwarfs

Telluric absorption corrected high S/N optical and near-infrared template spectra of 382 M dwarf stars★

E. Nagel[1,2,3], S. Czesla[3,1], A. Kaminski[4], M. Zechmeister[2], L. Tal-Or[5,2], J. H. M. M. Schmitt[1], A. Reiners[2], A. Quirrenbach[4], A. García López[6,7], J. A. Caballero[6], I. Ribas[8,9], P. J. Amado[10], V. J. S. Béjar[11,12], M. Cortés-Contreras[13], S. Dreizler[2], A. P. Hatzes[3], Th. Henning[14], S. V. Jeffers[15], M. Kürster[14], M. Lafarga[16], M. López-Puertas[10], D. Montes[13], J. C. Morales[8,9], S. Pedraz[17], and A. Schweitzer[1]

Table C.1: CARMENES M dwarf sample of telluric absorption corrected high S/N template spectra[(a)].

#	Karmn	Name	GJ	α	δ	Spectral type	J [mag]	# VIS obs	S/N	# NIR obs	S/N
1	J00051+457	BD+44 4548	2	00 05 10.89	+45 47 11.6	M1.0	6.70	53	833	44	756
2	J00067-075	GJ 1002	1002	00 06 43.20	-07 32 17.0	M5.5	8.32	91	641	80	948
3	J00162+198E	LP 404-062	1006B	00 16 16.15	+19 51 50.5	M4.0	8.89	19	295	17	333
4	J00183+440	GX And	15A	00 18 22.88	+44 01 22.6	M1.0	4.85	222	2040	196	2230
5	J00184+440	GQ And	15B	00 18 25.82	+44 01 38.1	M3.5	6.79	195	1539	179	1972
6	J00286-066	GJ 1012	1012	00 28 39.46	-06 39 49.2	M4.0	8.04	50	714	43	803
7	J00389+306	Wolf 1056	26	00 38 59.04	+30 36 58.4	M2.5	7.45	61	911	55	944

→ template division telluric modeling (TDTM) technique
→ based on the Earth's barycentric motion throughout the year,
→ disentangling telluric and stellar spectral components.

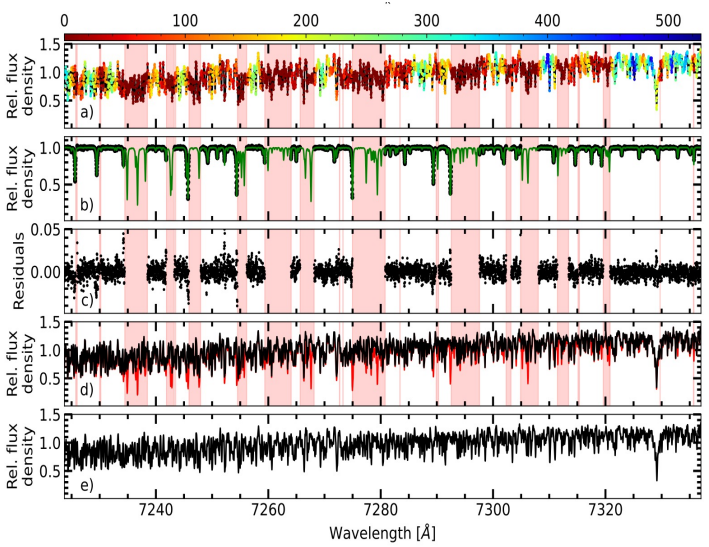
Very high S/N

GTO CARMENES

CARMENES data archive

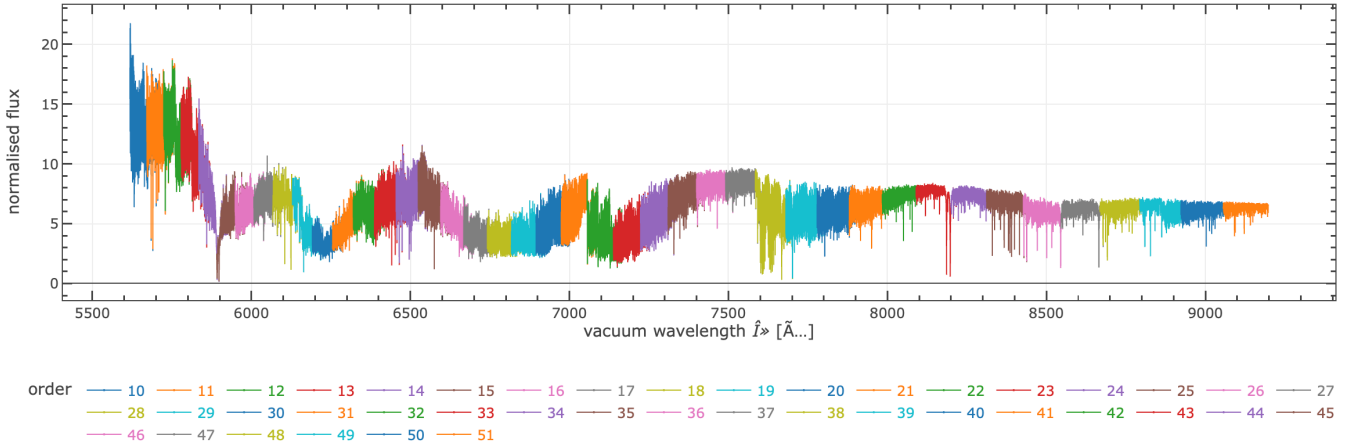
The CARMENES search for exoplanets around M dwarfs. Telluric absorption corrected high S/N optical and near-infrared template spectra of 382 M dwarf stars
(Nagel, Czesla, Kaminski et al. 2023 A&A, in press)

http://carmenes.cab.inta-csic.es/gto/jsp/tellurics_tac.jsp

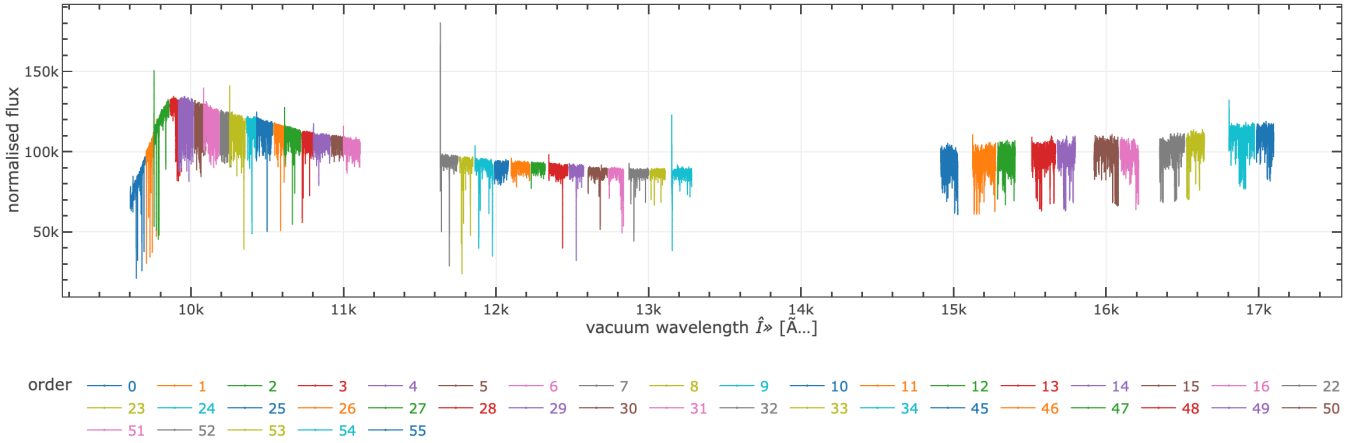


Template spectra: high-quality and telluric-free spectrum per target

Luyten'sStar
(J07274+052)
M3.5 V
VIS



Luyten'sStar
(J07274+052)
M3.5 V
NIR



Fits files and plots available at: http://carmenes.cab.inta-csic.es/gto/jsp/tellurics_tac.jsp

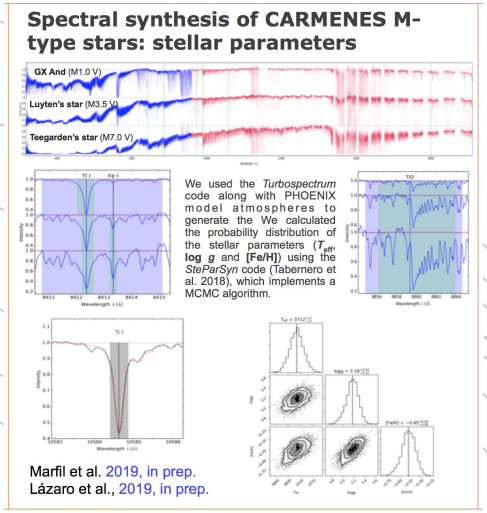
IPARCOS

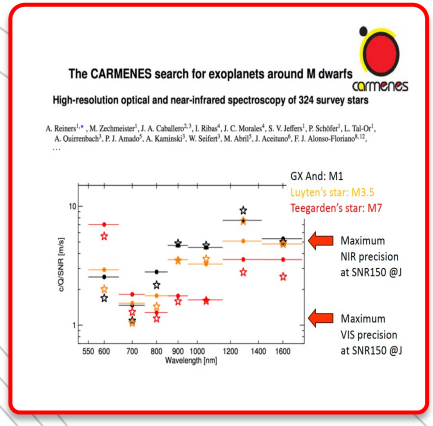
carmenes

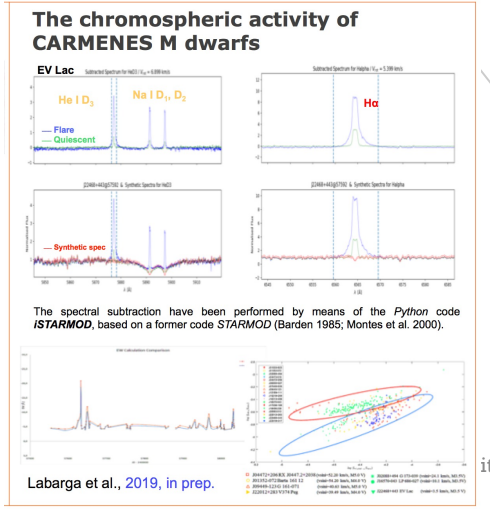
CARMENES science exploitation

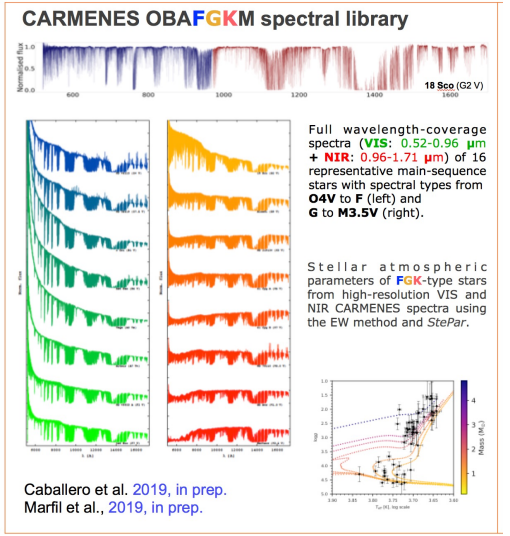
The CARMENES search for exoplanets around M dwarfs.

David Montes









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 $T_{\rm eff}$, log$g$, [Fe/H] and $V_{\rm broad}$ 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%.

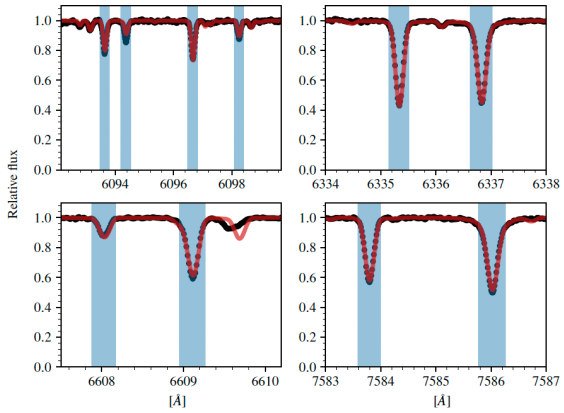
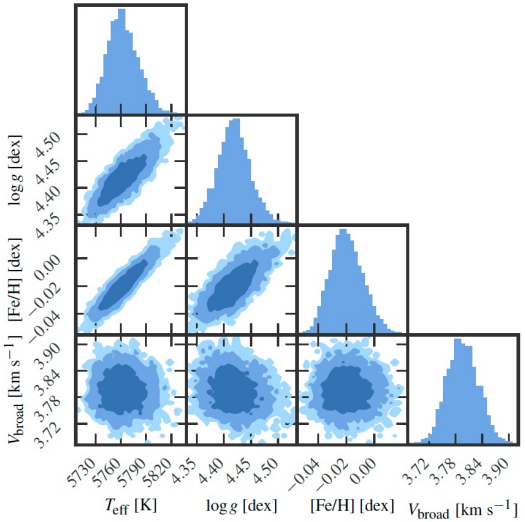
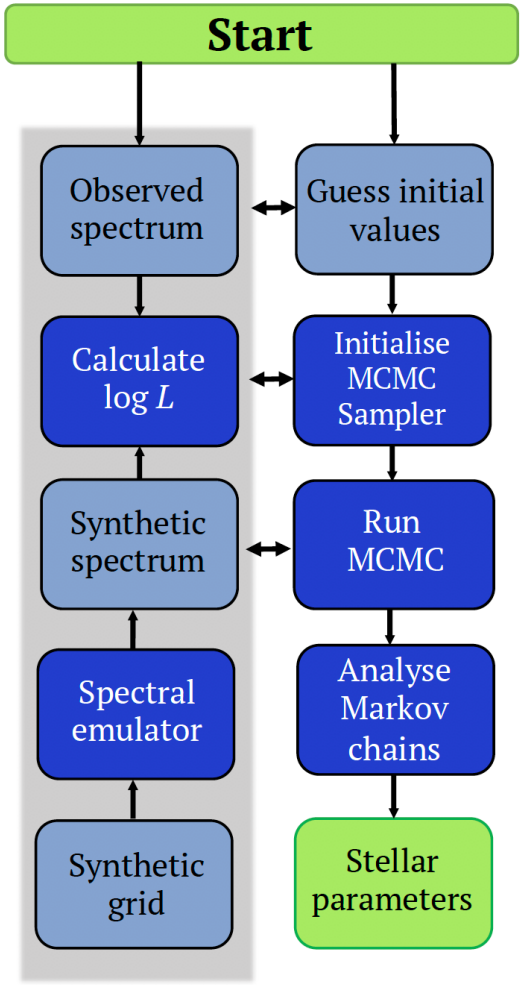


Fig. 5. Four representative wavelength regions in the spectrum of 18 Sco. The shaded blue areas represent the line masks, whereas the observations are given the black line while the best fitting synthetic spectrum is represented by a red line.





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 *StePar*Syn

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

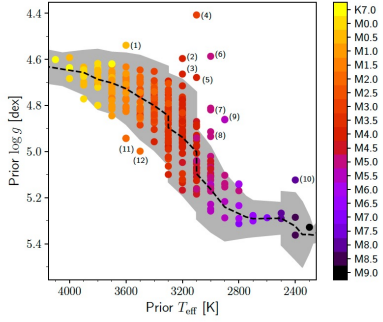
2021A&A...656A.162M

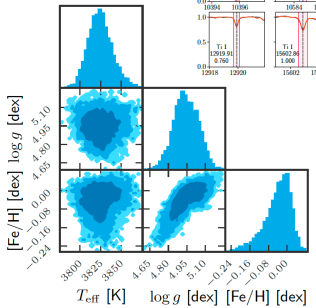
- $T_{\rm eff}$, log*g*, [Fe/H] of 343 M dwarfs observed with CARMENES

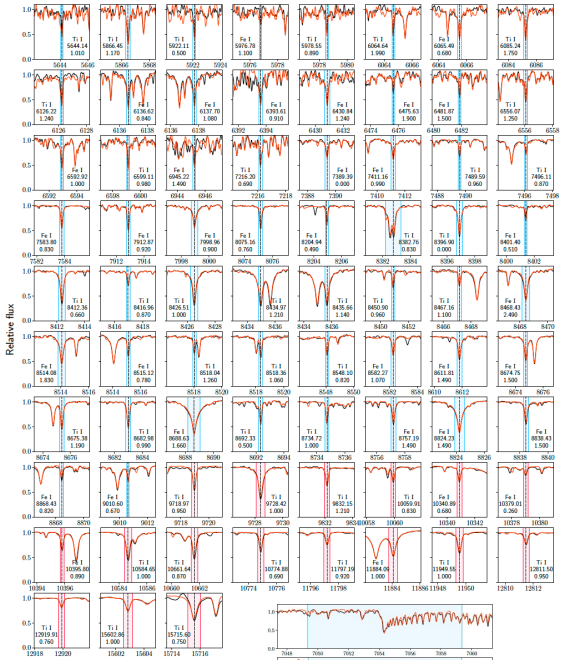
- Using *StePar*Syn (Tabernero et al. 2022A&A...657A..66)

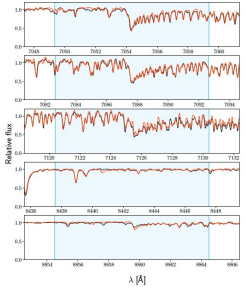
- BT-Settl model atmospheres.

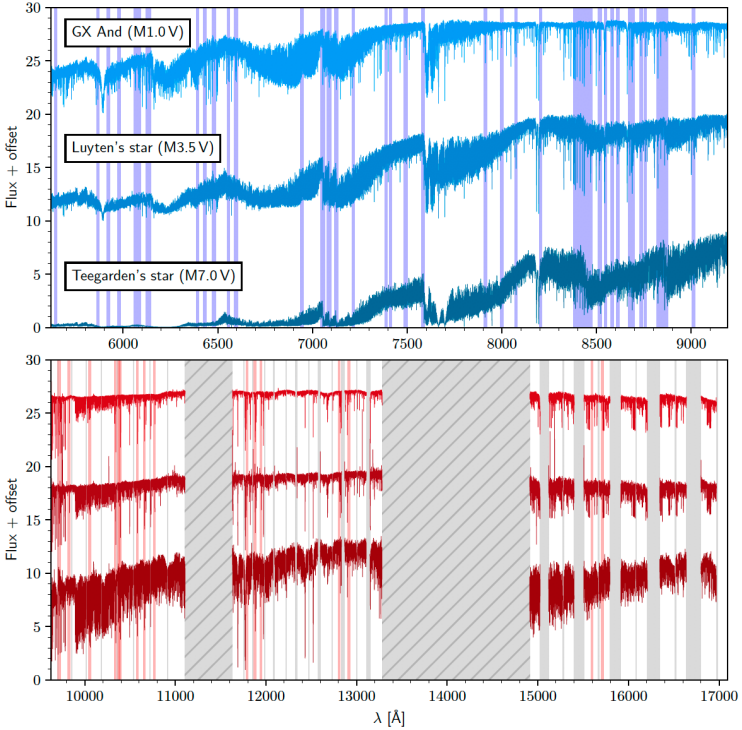
- Excellent agreement in $T_{\rm eff}$ for M dwarfs with interferometric angular diameter, as well as in the [Fe/H] between the components in the wide physical FGK+M and M+M systems.











→ 75 magnetically insensitive Fe I and Ti I lines plus the TiO **γ** and **ε** bands.

Abundances of the M companions

The CARMENES search for exoplanets around M dwarfs

Rubidium abundances in nearby cool stars

C. Abia[1], H. M. Tabernero[2,4], S. A. Korotin[3], D. Montes[4], E. Marfil[4], J. A. Caballero[5], O. Straniero[6], N. Prantzos[7], I. Ribas[8,9], A. Reiners[10], A. Quirrenbach[11], P. J. Amado[12], V. J. S. Béjar[13,14], M. Cortés-Contreras[8], S. Dreizler[9], Th. Henning[15], S. V. Jeffers[10], A. Kaminski[11], M. Kürster[15], M. Lafarga[8,9], Á. López-Gallifa[4], J. C. Morales[8,9], E. Nagel[15], V. M. Passegger[17,18], S. Pedraz[19], C. Rodríguez López[12], A. Schweitzer[17], M. Zechmeister[10]

The CARMENES search for exoplanets around M dwarfs

Not-so-fine hyperfine-split vanadium lines in cool star spectra

Y. Shan[1], A. Reiners[1], D. Fabbian[1,2,3], E. Marfil[4], D. Montes[4], H. M. Tabernero[5], I. Ribas[6,7], J. A. Caballero[5], A. Quirrenbach[8], P. J. Amado[9], J. Aceituno[10,9], V. J. S. Béjar[11,12], M. Cortés-Contreras[5], S. Dreizler[1], A. P. Hatzes[13], Th. Henning[14], S. V. Jeffers[15,1], A. Kaminski[8], M. Kürster[14], M. Lafarga[6,7,16], J. C. Morales[6,7], E. Nagel[17,13], E. Pallé[11], V. M. Passegger[18,17], C. Rodriguez-López[9], A. Schweitzer[17], and M. Zechmeister[1]

The CARMENES search for exoplanets around M dwarfs

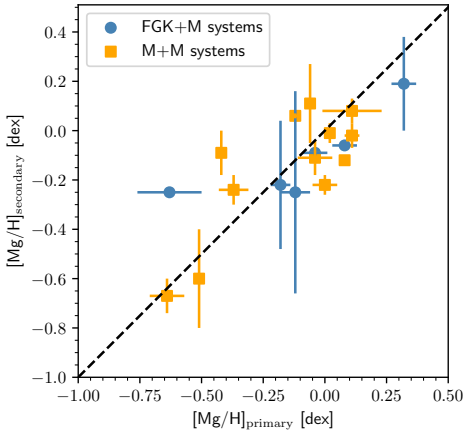
Stellar atmospheric parameters of target stars with StePar Syn

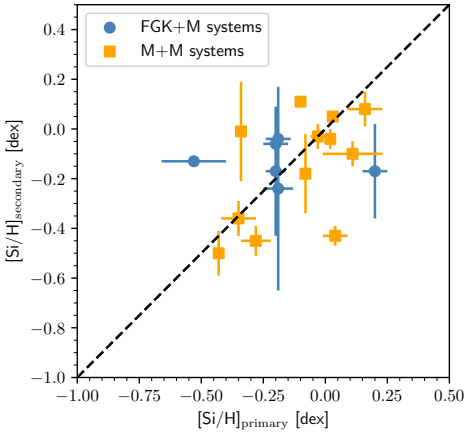
E. Marfil[1,2], H. M. Tabernero[3,4], D. Montes[1], J. A. Caballero[2], F. J. Lázaro[1], J. I. González Hernández[5,6], E. Nagel[7,8], V. M. Passegger[7,9], A. Schweitzer[7], I. Ribas[10,11], A. Reiners[12], A. Quirrenbach[13], P. J. Amado[14], C. Cifuentes[2], M. Cortés-Contreras[2], S. Dreizler[12], C. Duque-Arribas[1], D. Galadí-Enríquez[15], Th. Henning[16], S. V. Jeffers[17,12], A. Kaminski[13], M. Kürster[16], M. Lafarga[10,11,18], Á. López-Gallifa[1], J. C. Morales[10,11], Y. Shan[12], and M. Zechmeister[12]

The CARMENES search for exoplanets around M dwarfs

Magnesium and silicon abundances of K7-M5.5 stars

H. M. Tabernero[1], Y. Shan[2], J. A. Caballero[3], C. Duque-Arribas[1], D. Montes[1], J. I. González Hernández[4,5], M. R. Zapatero Osorio[3], A. Schweitzer[6], Th. Henning[7], M. Cortés-Contreras[1], A. Quirrenbach[8], P. J. Amado[9], A. Reiners[2], I. Ribas[10,11], and CARMENES





IPARCOS

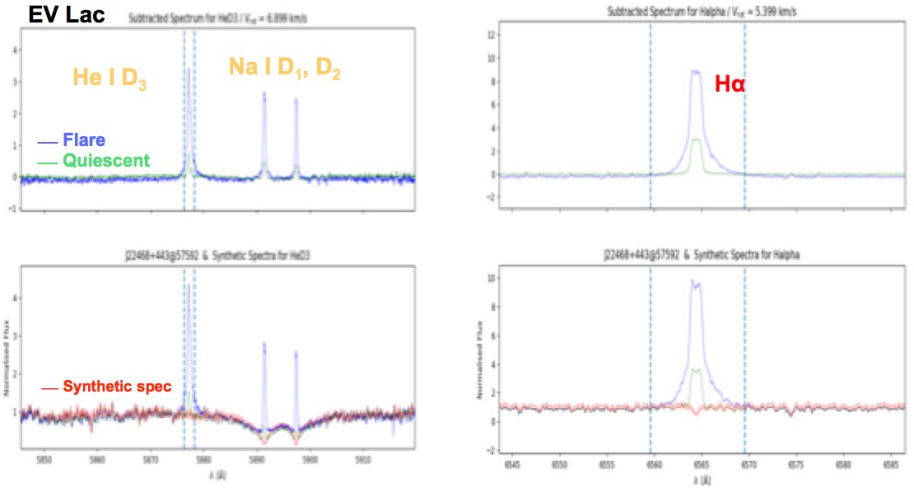
carmenes

CARMENES science exploitation

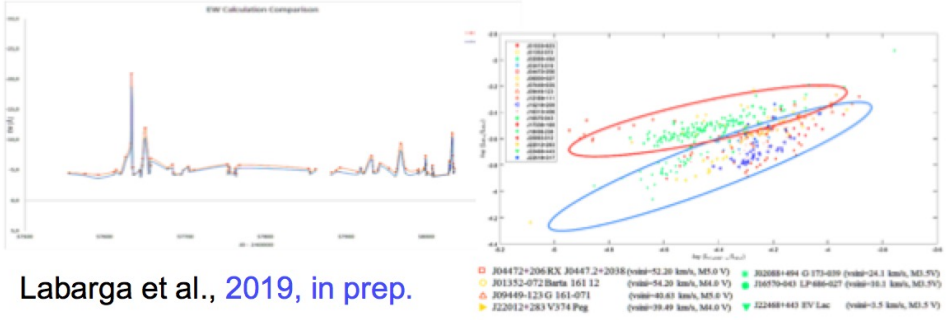
The CARMENES search for exoplanets around M dwarfs.

David Montes

The chromospheric activity of CARMENES M dwarfs



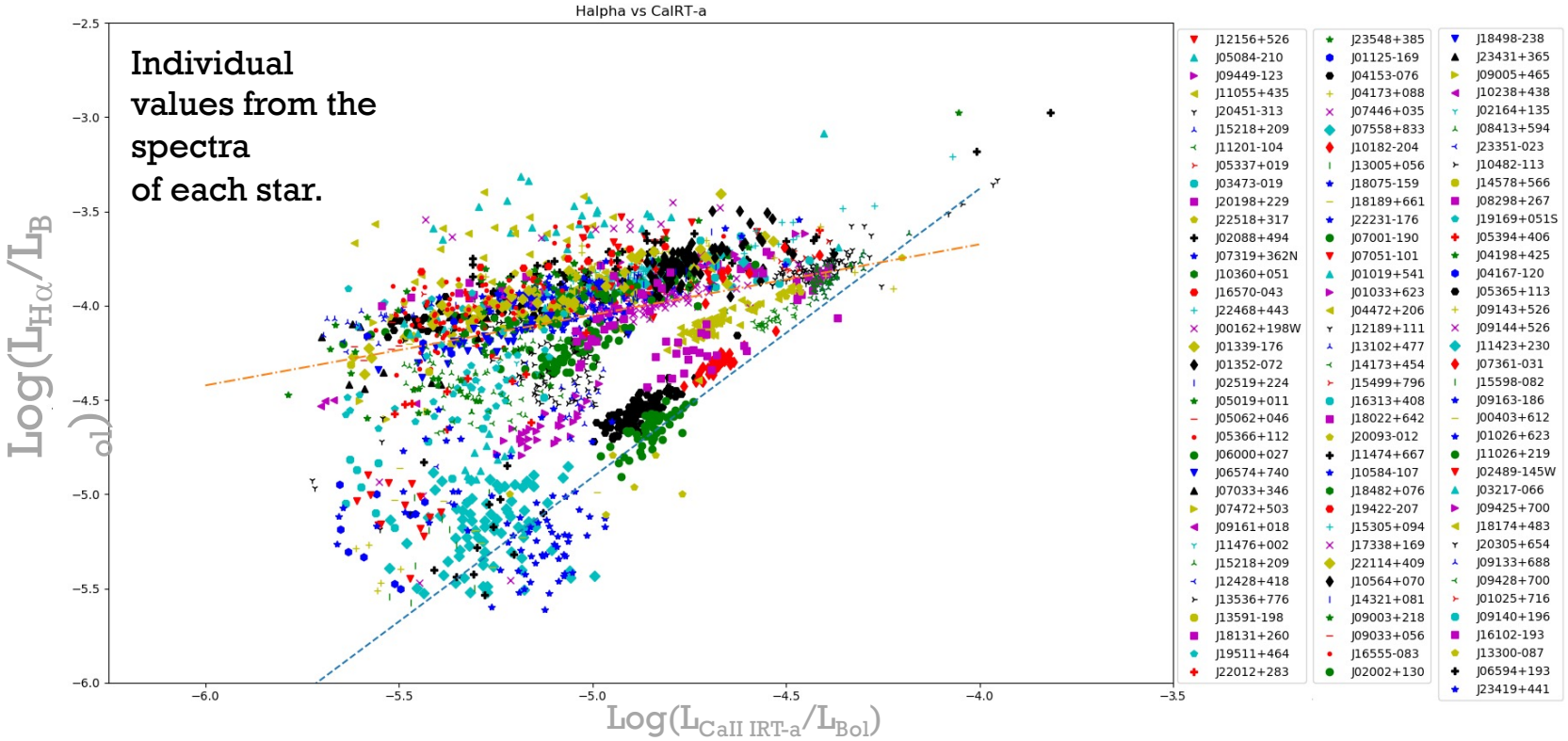
The spectral subtraction have been performed by means of the *Python* code ***iSTARMOD***, based on a former code *STARMOD* (Barden 1985; Montes et al. 2000).



Labarga et al., 2019, in prep.

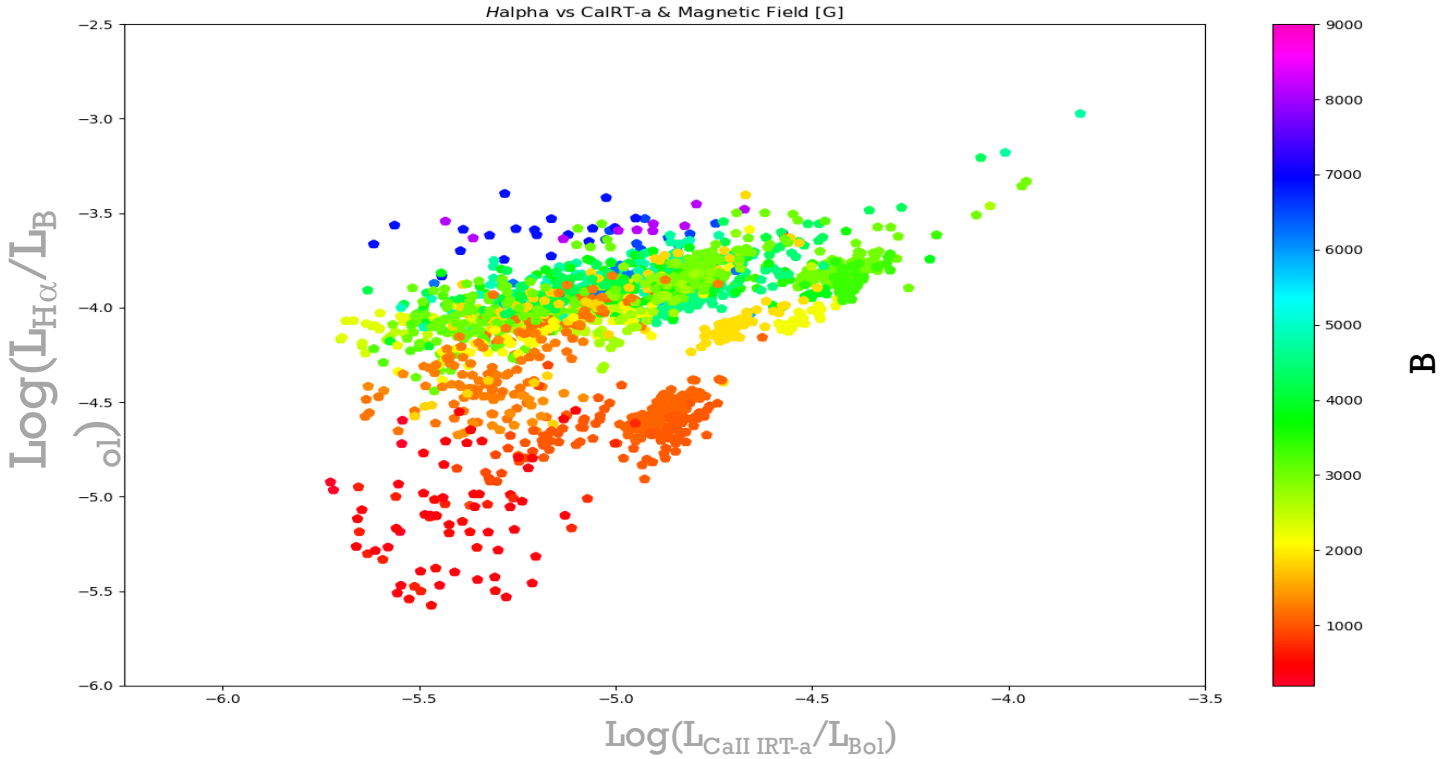
Analysis of chromospheric flux-flux relationships in CARMENES sample

End up in the flux-flux relationship from the whole subsample and adding the Martínez-Arnaiz et al. (2011) fits to power laws



Analysis of chromospheric flux-flux relationships in CARMENES sample

Incorporating the Magnetic Fields for the stars of the CARMENES sample – Reiners et al. (2022)



CARMENES science exploitation

The CARMENES search for exoplanets around M dwarfs.

David Montes

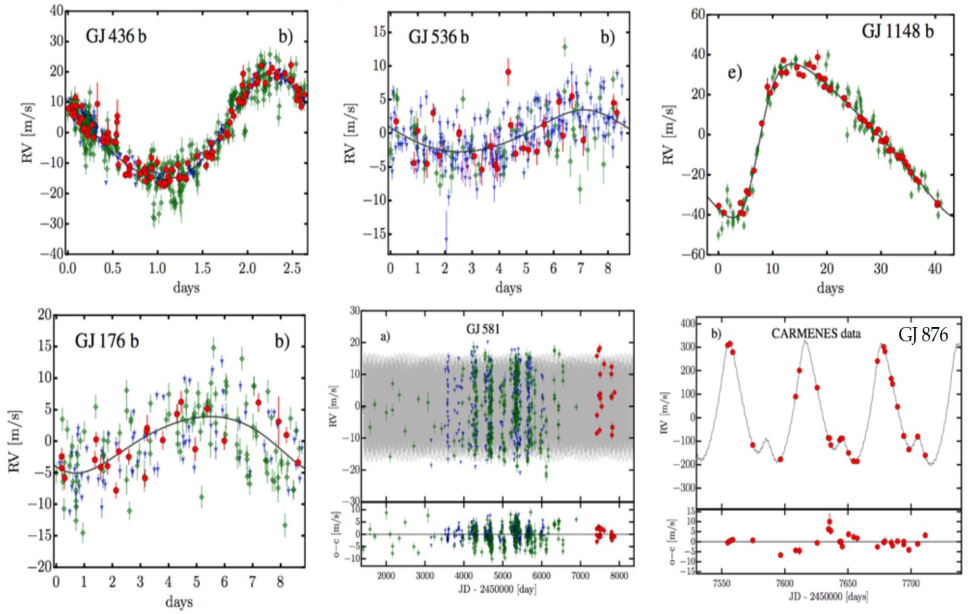
Confirmation of exoplanets

The CARMENES search for exoplanets around M dwarfs

First visual-channel radial-velocity measurements and orbital parameter updates of seven M-dwarf planetary systems*

T. Trifonov[1], M. Kürster[1], M. Zechmeister[2], L. Tal-Or[2], J.A. Caballero[3,5], A. Quirrenbach[5], I. Ribas[7], A

2018A&A...609A.117T



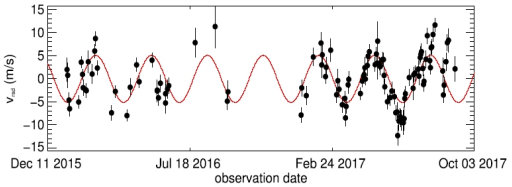
CARMENES science exploitation

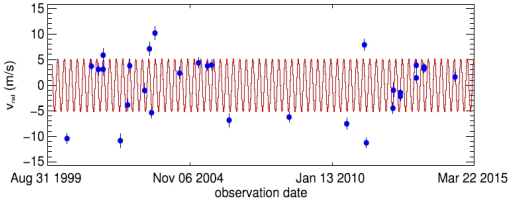
The CARMENES search for exoplanets around M dwarfs.

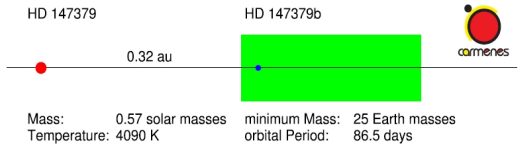
David Montes

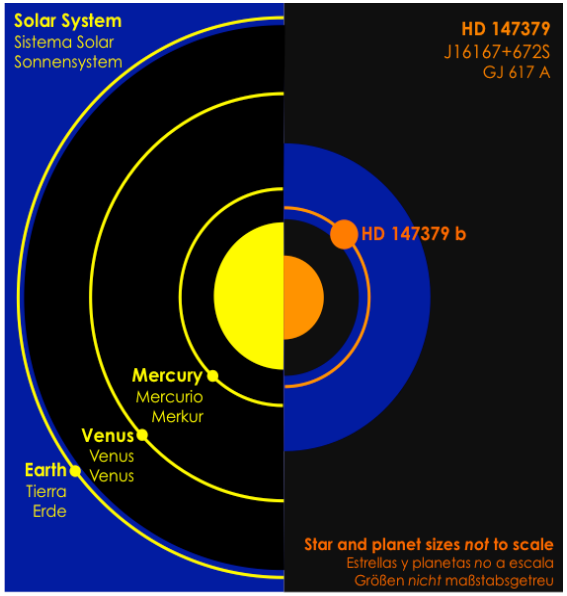
First CARMENES exoplanets

"The CARMENES search for exoplanets around M dwarfs. ***HD147379 b****: A nearby Neptune in an early-M dwarf's temperate zone".*
Reiners, et al. 2018 Astronomy & Astrophysics Letters, A&A 609, L5









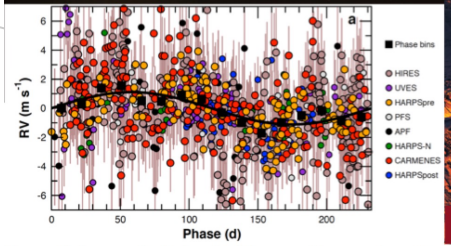
CARMENES science exploitation

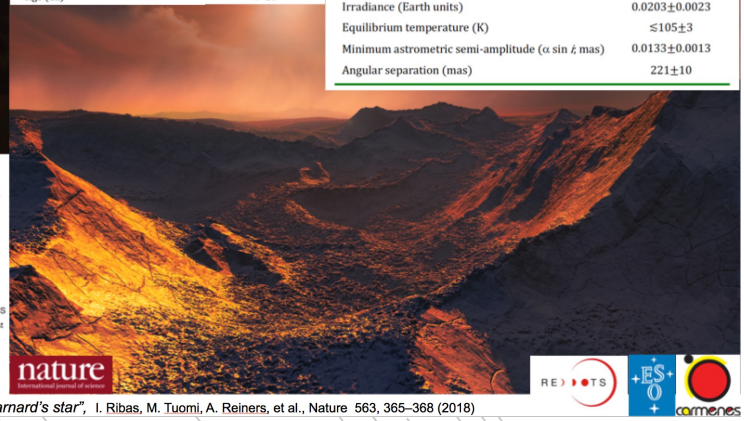
Supertierra fría orbitando la estrella de Barnard



Star parameter	Value
Spectral type	M3.5 V
Mass ($M_\odot$)	0.163±0.022
Radius ($R_\odot$)	0.178±0.011
Luminosity ($L_\odot$)	0.00329±0.00019
Effective temperature (K)	3278±51
Rotation period (d)	140±10
Age (Ga)	7–10

Planet parameter	Value
	Barnard's star b
Orbital period (d)	$232.80^{+0.38}_{-0.41}$
Radial velocity semi-amplitude (m s^{-1})	1.20±0.12
Eccentricity	$0.32^{+0.10}_{-0.15}$
Argument of periastron (deg)	107^{+19}_{-22}
Mean longitude at BJD2455000.0 (deg)	203±7
Minimum mass ($M \sin i$, $M_\oplus$)	3.23±0.44
Orbital semi-major axis (au)	0.404±0.018
Irradiance (Earth units)	0.0203±0.0023
Equilibrium temperature (K)	≤105±3
Minimum astrometric semi-amplitude ($\alpha \sin i$, mas)	0.0133±0.0013
Angular separation (mas)	221±10





"A candidate super-Earth planet orbiting near the snow line of Barnard's star", I. Ribas, M. Tuomi, A. Reiners, et al., Nature 563, 365–368 (2018)

Publication en Nature:

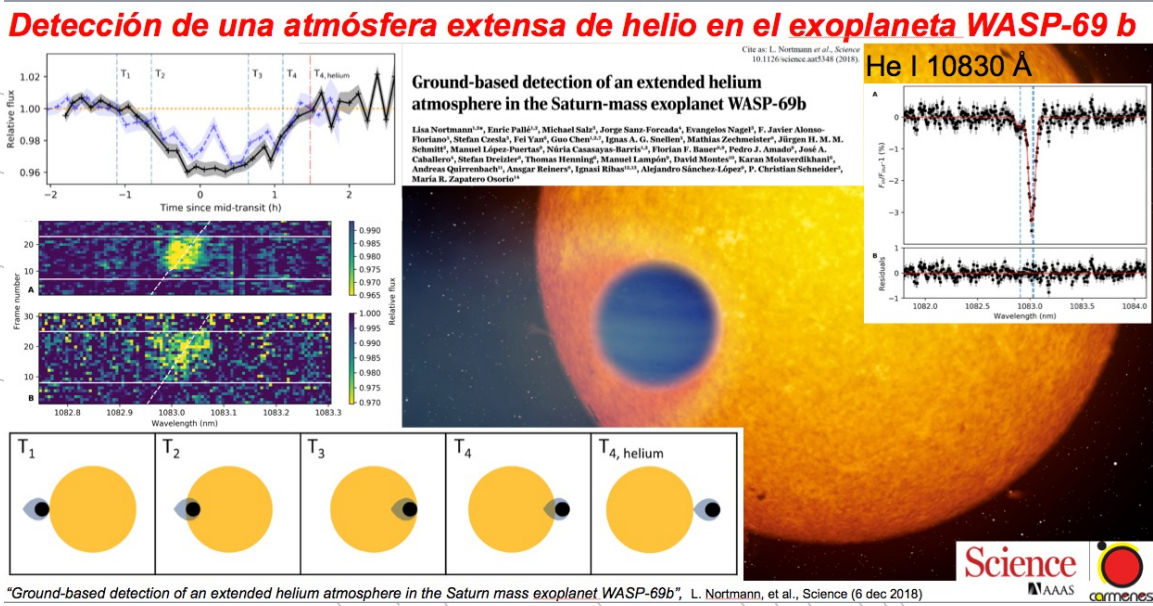
- ***A candidate super-Earth planet orbiting near the snow line of Barnard's star***
I. Ribas, M. Tuomi, A. Reiners, et al.
Nature 15 nov 2018
Nature 563, 365–368 (2018)

The CARMENES search for exoplanets around M dwarfs.

CARMENES science exploitation

CARMENES exoplanet atmospheres characterization

David Montes



Publications:

1: "***Ground-based detection of an extended helium atmosphere in the Saturn mass exoplanet WASP-69 b***",
Nortmann, L., et al. Science 21 Dec 2018: Vol. 362, Issue 6421, pp. 1388-1391

2: "**Detection of He I 10830 Å absorption on HD 189733 b with CARMENES high-resolution transmission spectroscopy**",
Salz, M., et al. A&A 620, A97 (2018)

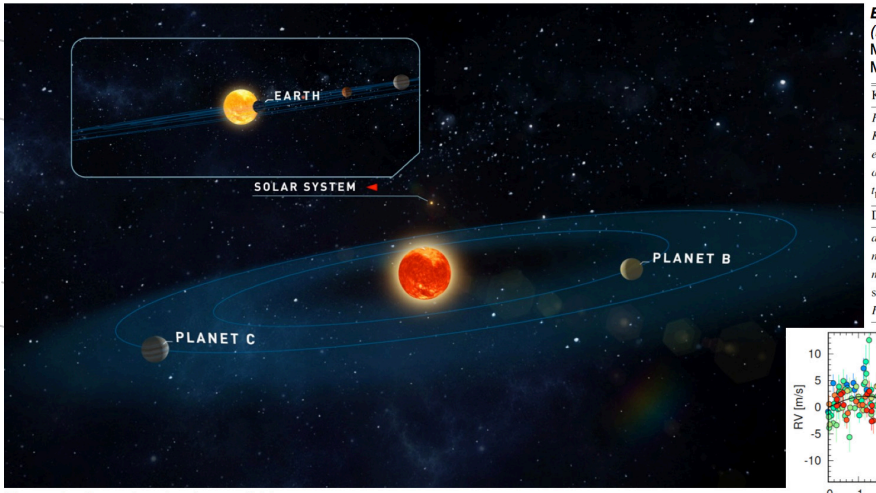
3: "**Multiple water band detections in the CARMENES near-infrared transmission spectrum of HD 189733 b**",
Alonso-Floriano, F. J., et al., 2019A&A...621A..74A

CARMENES science exploitation

The CARMENES search for exoplanets around M dwarfs.

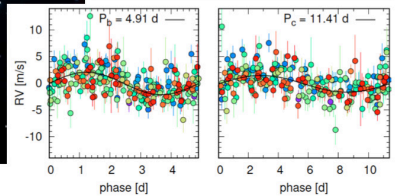
David Montes

Dos planetas templados de masas ≈ a la Tierra en la Estrella de Teegarden



Estrella deTeegarden
(Karmn J02530+168)
M7.0 V, d = 3.831 pc = 12.5 ly
$M = 0.089\ M_\odot$, $R = 0.107\ R_\odot$

Keplerian parameters	Planet b	Planet c
P [d]	$4.9100^{+0.0014}_{-0.0014}$	$11.409^{+0.009}_{-0.009}$
K [m/s]	$2.02^{+0.19}_{-0.20}$	$1.61^{+0.19}_{-0.19}$
e [a]	$0.00^{+0.16}$	$0.00^{+0.16}$
ω [deg]	77^{+52}_{-79}	286^{+101}_{-74}
$t_p - 2\,458\,000$ [d]	$52.3^{+0.7}_{-1.1}$	$53.2^{+3.2}_{-2.3}$
Derived parameters		
a [au]	$0.0252^{+0.0008}_{-0.0009}$	$0.0443^{+0.0014}_{-0.0015}$
$m \sin i\ [M_\oplus]$	$1.05^{+0.13}_{-0.12}$	$1.11^{+0.16}_{-0.15}$
$m\ [M_\oplus]$ [b]	$1.25^{+0.68}_{-0.22}$	$1.33^{+0.71}_{-0.25}$
$\sin i$ [b]	$0.87^{+0.12}_{-0.31}$	
$F\ [S_\oplus]$ [c]	$1.15^{+0.08}_{-0.08}$	$0.37^{+0.03}_{-0.03}$



Teegarden b y c, dos planetas candidatos:
➔ cada uno con una masa mínima de 1.1 $M_\oplus$, orbitando con periodos de 4.91 y 11.4 d sin evidencia de tránsitos.
➔ la cuarta estrella mas cercana con planetas potencialmente habitables, después de Proxima Cen, Tau Ceti, y Luyten's Star.
➔ la estrella más pequeña en la que hasta ahora se ha podido determinar la masa de los planetas directamente.

The CARMENES search for exoplanets around M dwarfs
Two temperate Earth-mass planet candidates around Teegarden's Star,
Zechmeister et al. 2019, A&A, DOI: 10.1051/0004-6361/201935460

Publicación en A&A:

- "***The CARMENES search for exoplanets around M dwarfs. Two temperate Earth-mass planet candidates around Teegarden's Star***", de M. Zechmeister et al., que aparece en la revista Astronomy & Astrophysics el 18 de junio de 2019, 2019A&A...627A..49Z, - DOI https://doi.org/10.1051/0004-6361/201935460

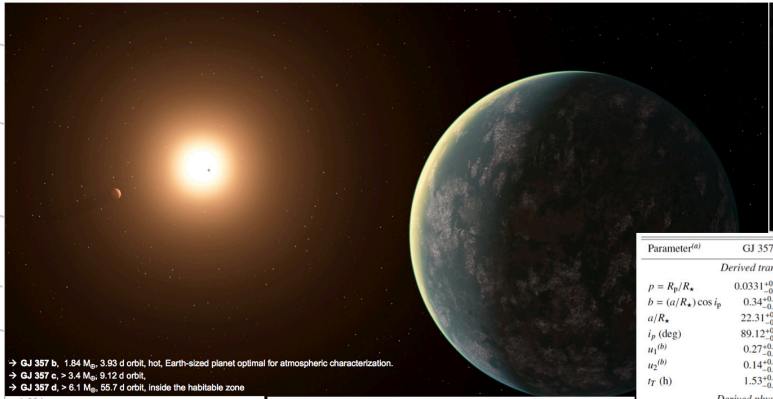
Publicaciones adicionales:
- "***On the Habitability of Teegarden's Star planets***", Amri Wandel, Lev Tal-Or, 2019ApJ...880L..21W

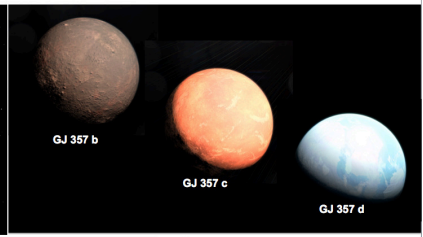
CARMENES science exploitation

The CARMENES search for exoplanets around M dwarfs + TESS.

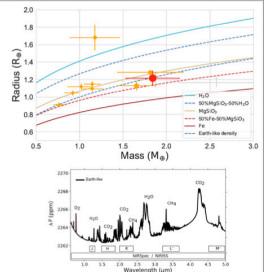
David Montes

Planetary system around the nearby M dwarf GJ 357 – TESS + CARMENES + ...





Parameter[a]	GJ 357 b	GJ 357 c	GJ 357 d
Derived transit parameters			
$p = R_p/R_\star$	$0.0331^{+0.0009}_{-0.0009}$	...	...
$b = (a/R_\star)\cos i_p$	$0.34^{+0.10}_{-0.14}$	...	...
$a/R_\star$	$22.31^{+0.76}_{-0.90}$	...	...
i_p (deg)	$89.12^{+0.37}_{-0.31}$	...	...
u_1[b]	$0.27^{+0.24}_{-0.17}$	...	...
u_2[b]	$0.14^{+0.29}_{-0.24}$	...	...
t_T (h)	$1.53^{+0.12}_{-0.11}$	...	...
Derived physical parameters			
M_p ($M_\oplus$)[c]	$1.84^{+0.31}_{-0.31}$	$> 3.40^{+0.46}_{-0.46}$	$> 6.1^{+1.0}_{-1.0}$
R_p ($R_\oplus$)	$1.217^{+0.084}_{-0.083}$	...	...
ρ_p (g cm^{-3})	$5.6^{+1.7}_{-1.3}$	...	...
g_p (m s^{-2})	$12.1^{+2.9}_{-2.5}$	...	...
a_p (au)	$0.035^{+0.002}_{-0.002}$	$0.061^{+0.004}_{-0.004}$	$0.204^{+0.015}_{-0.015}$
T_{eq} (K)[d]	525^{+11}_{-9}	$401.2^{+10.8}_{-10.7}$	$219.6^{+5.9}_{-5.9}$
S ($S_\oplus$)	$12.6^{+1.1}_{-0.8}$	$4.45^{+0.14}_{-0.14}$	$0.38^{+0.01}_{-0.01}$

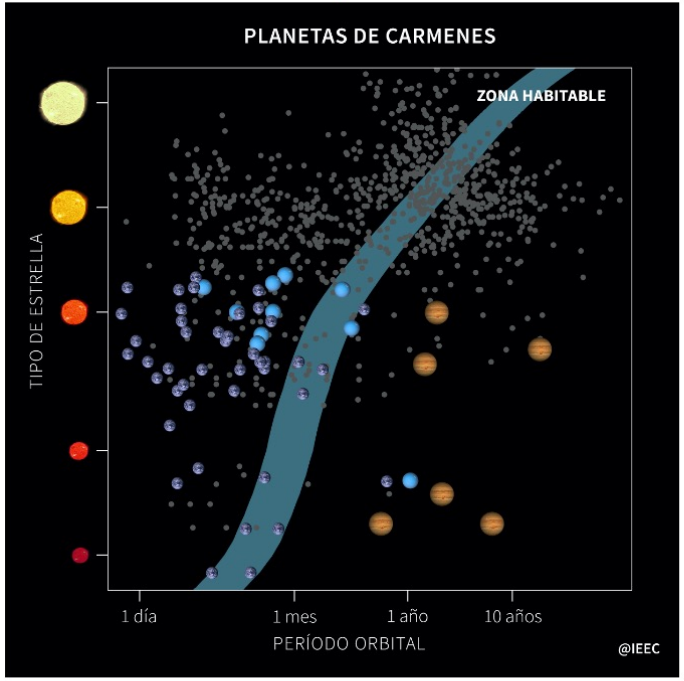


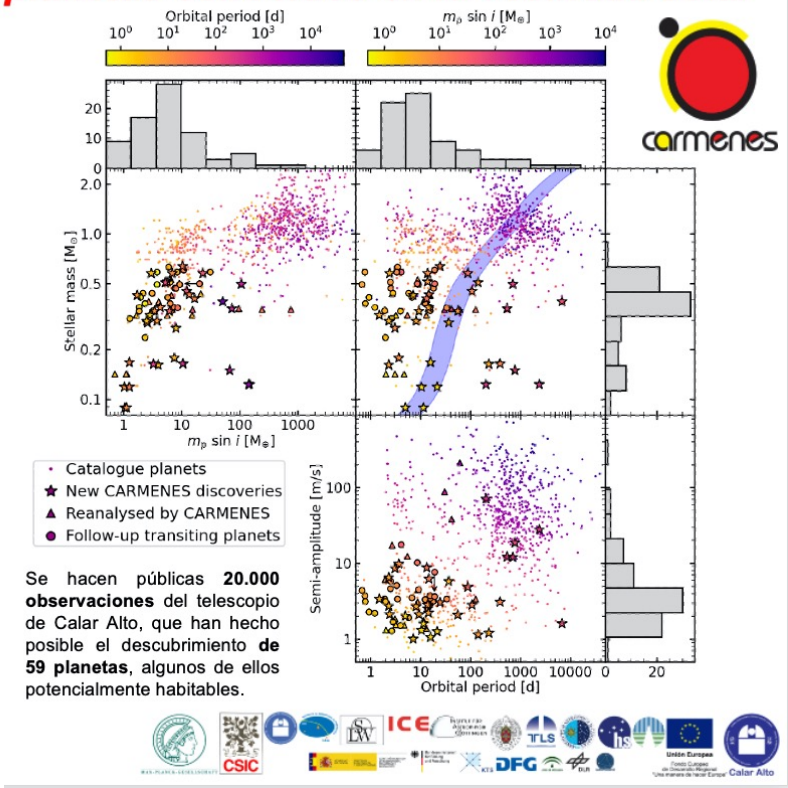
- Planetary system around the nearby M dwarf GJ 357 including a transiting, hot, Earth-sized planet optimal for atmospheric characterization,
Luque, et al. 2019, A&A, DOI: https://doi.org/10.1051/0004-6361/201935801 - TESS Science Conference I - @TessSciCon1 #TESScon

Publicación en A&A:

- **Planetary system around the nearby M dwarf GJ 357 including a transiting, hot, Earth-sized planet optimal for atmospheric characterization,**
R. Luque, E. Pallé, D. Kossakowski, et al., 2019, A&A, 628, A39, 2019A&A...628A..39L, DOI: https://doi.org/10.1051/0004-6361/201935801

CARMENES multiplica el número de planetas conocidos en la vecindad solar





Se hacen públicas **20.000 observaciones** del telescopio de Calar Alto, que han hecho posible el descubrimiento **de 59 planetas**, algunos de ellos potencialmente habitables.

- "*The CARMENES search for exoplanets around M dwarfs. Guaranteed time observations **Data Release 1** (2016-2020)*",

Ribas, et al. 2023, A&A 670, A139

DR1

The new planets cover a broad region of the parameter space (stellar host and orbital period)

Remarkable: CARMENES has discovered the half of RV planets known to orbit star of mass below 0.25 Msun

http://carmenes.caha.es/


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