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Plan de Recuperación, Transformación y Resiliencia

GENERALITAT VALENCIANA
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GVANEXT
Fondos Next Generation en la Comunitat Valenciana

ASFAE
ASTROFÍSICA Y FÍSICA DE ALTAS ENERGÍAS

# Herramientas de análisis automático para espectros estelares

**Ignacio Negueruela**

Universidad de Alicante

Marzo 2024, Alicante

# Outline

- The astrophysical context
- The WEAVE project
- The Astro+ database
- Where are we now and where are we going

The ASFAE's research projects acknowledge the financial support from the MCIU with funding from the European Union NextGenerationEU and Generalitat Valenciana.

# Definition of massive star

- Stars initiating Carbon burning (≥ 8 $M_\odot$).
- Stars ending up their lives in supernova explosions (≥ $8.5^{+1}_{-1.5}$ $M_\odot$ – **Smart+ 2009, MNRAS 395, 1409 –** but closer to 10 $M_\odot$ from theory – e.g. **Jones+ 2013, ApJ 772, 150**).
- Stars with self-initiating radiation-driven winds .

  - **OB stars (O2-B2 V, O2-B9 I-III –** Reed 2009, AJ 125, 2531**)**
  - **Later type supergiants: the most luminous AFGK SGs, M-type SGs**

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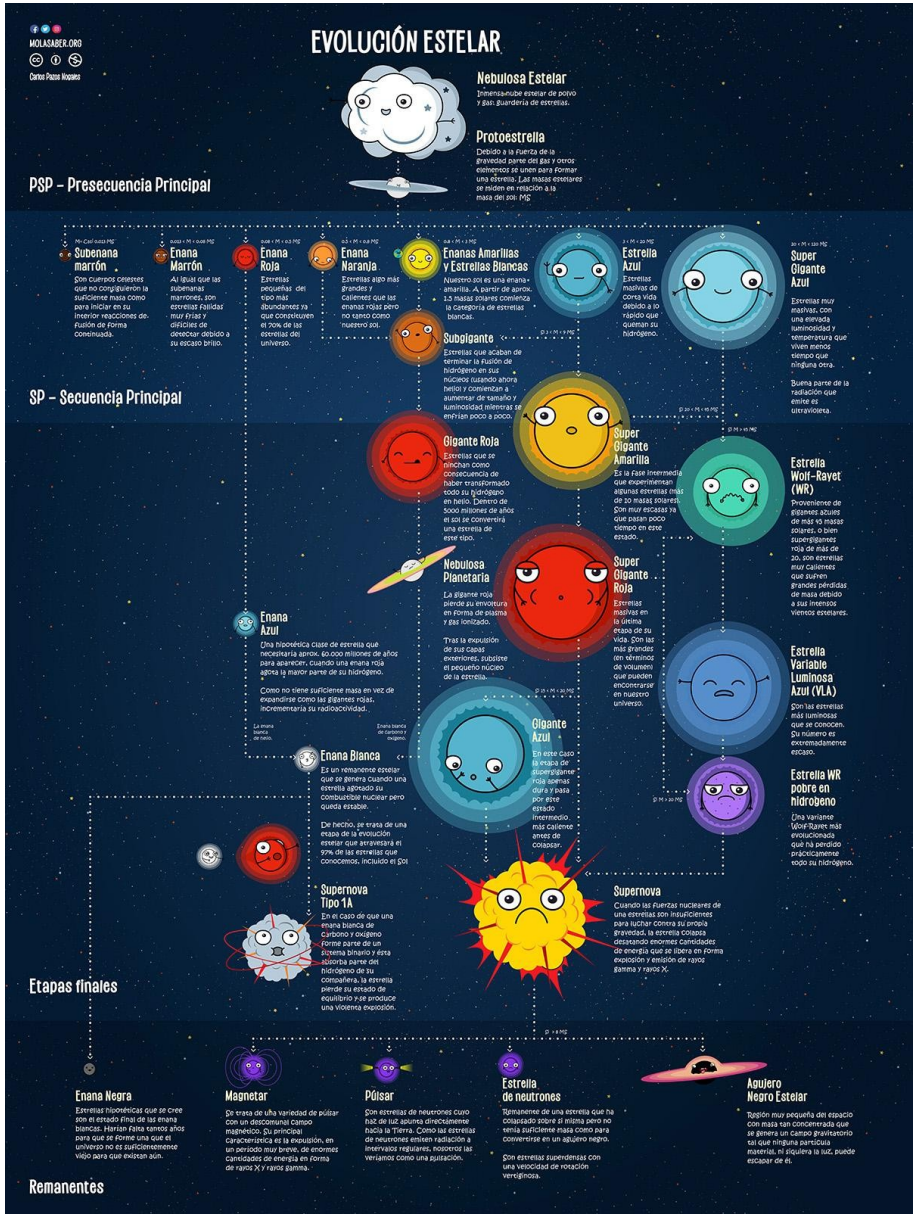


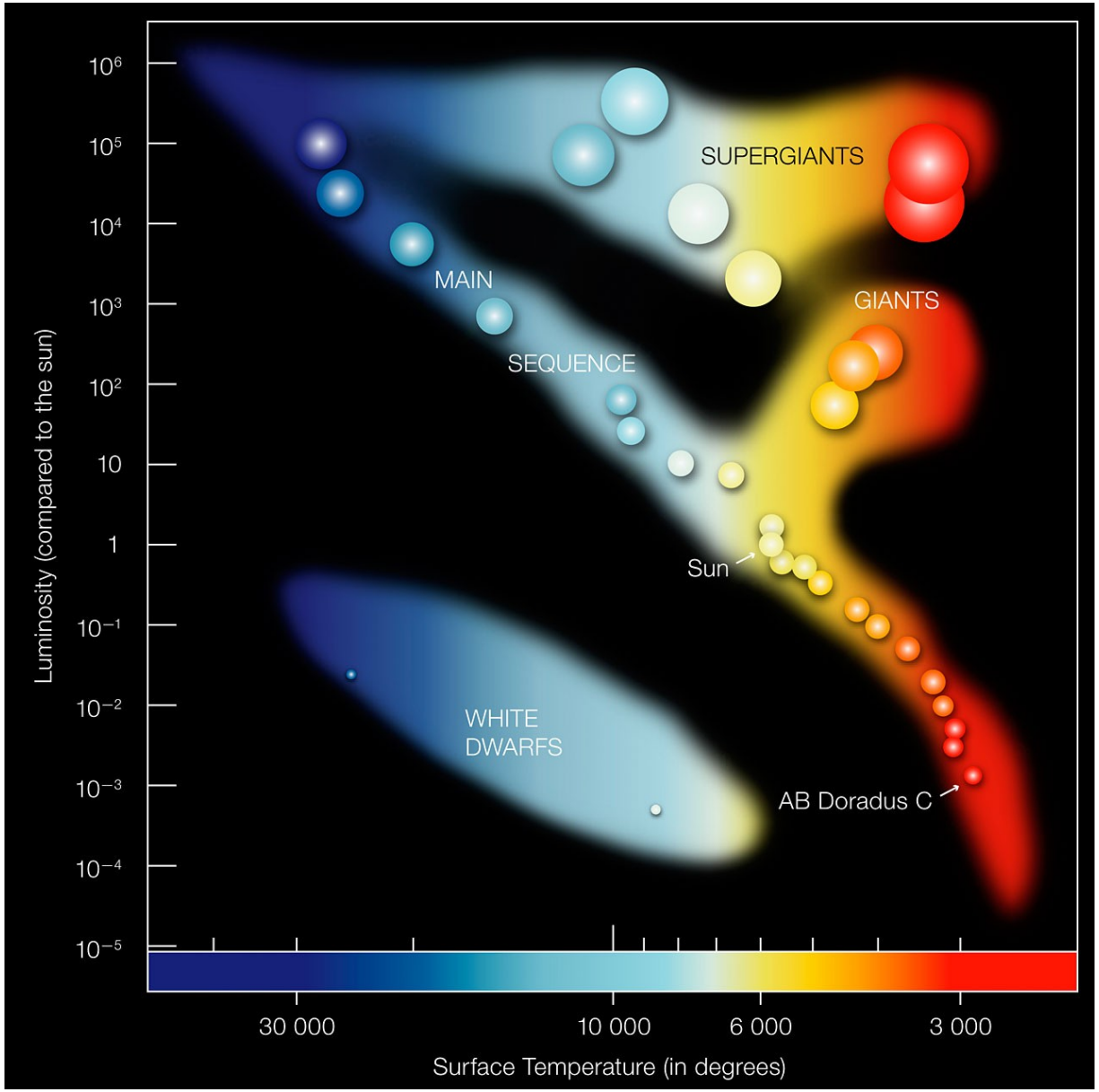


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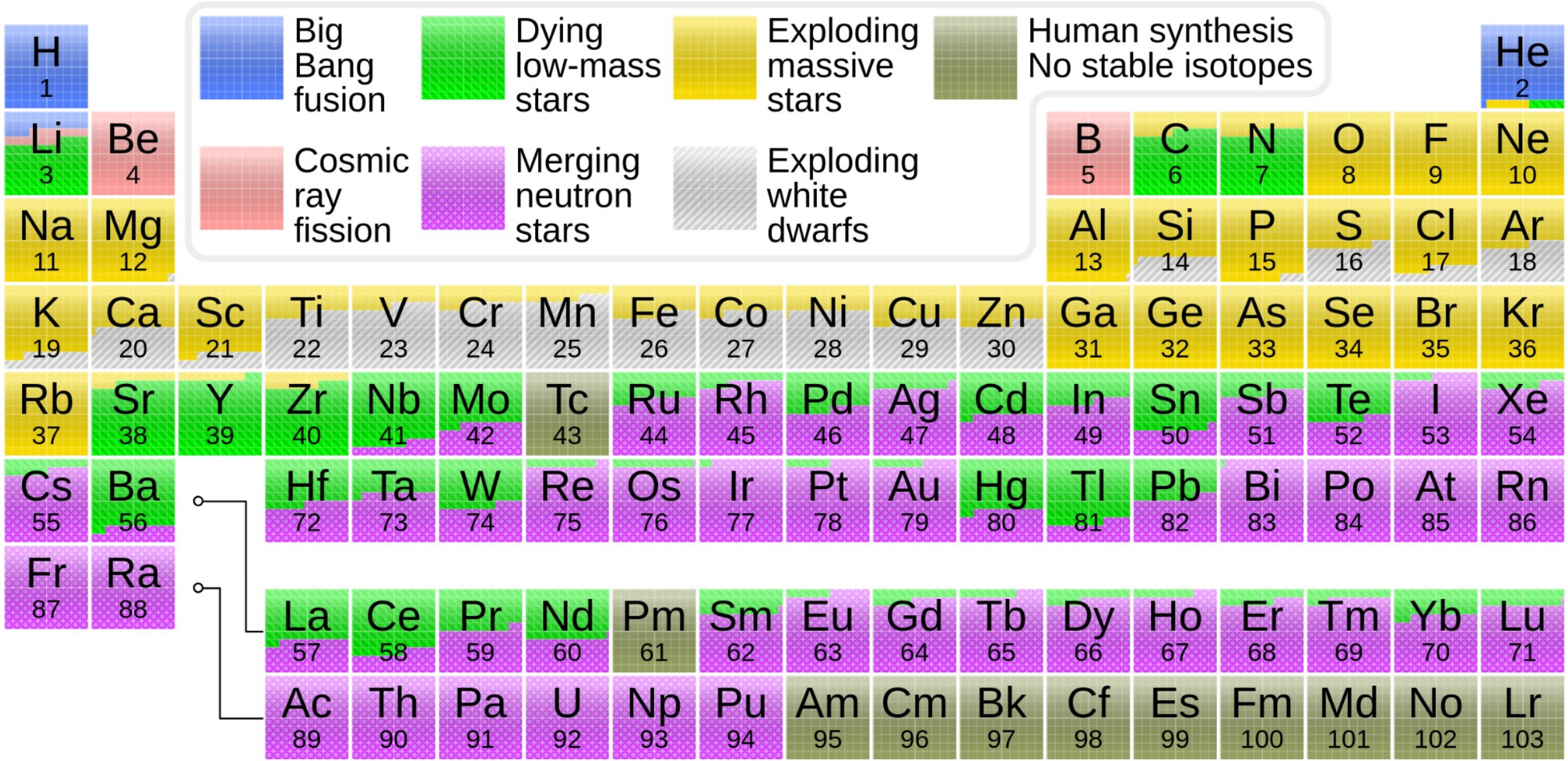


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# Effects of massive stars on their environment

High-mass stars impact on the environment, via **stellar winds**, **UV radiation**, and, eventually, **supernova explosions**. Main effects are:

- **Ionisation** of neutral atoms (creation of H II regions) – in cosmology, reionisation
- Generation of shock waves within molecular clouds ⇒ **dispersion**, end of star formation.
- Destruction of accretion disks around lower-mass (proto-)stars

On the long term, they are the **progenitors of compact objects** ⇒ generation of **high-energy sources**, gravitational wave event progenitors.

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# Effect on star formation

**Cloud destruction.**

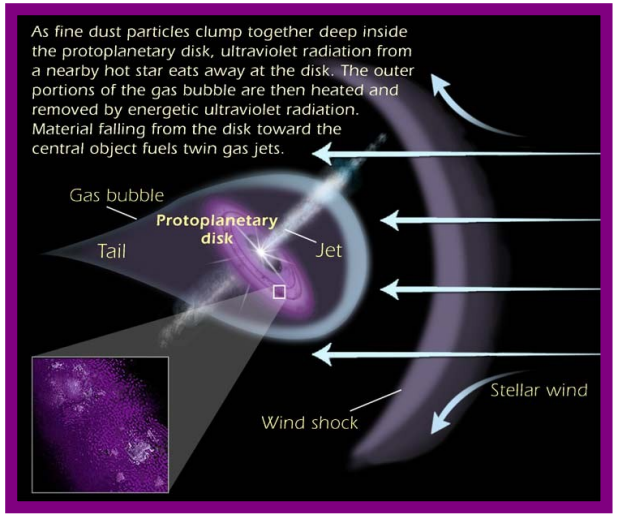
**Radiation pressure sweeping away material.**

⇦

**High-mass stars**

⇨

**Triggering of new generations.**




LL Orionis, HST images

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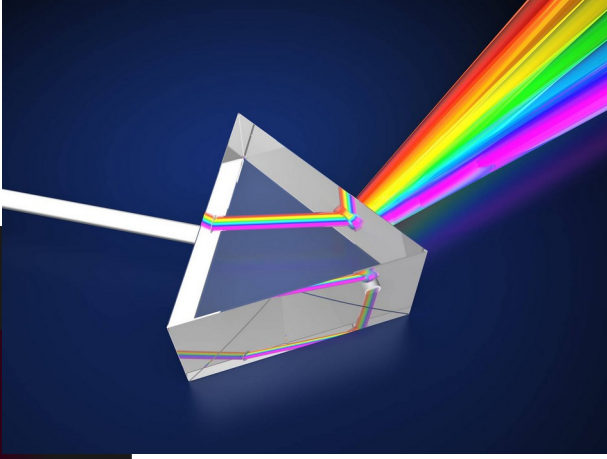
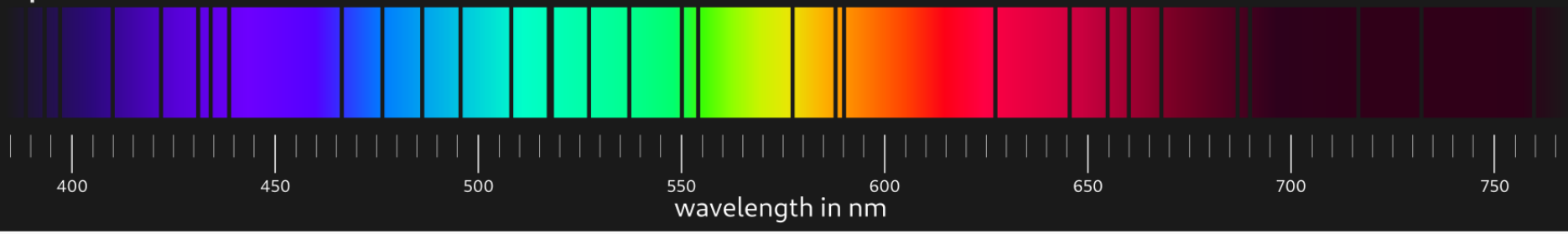


The complete spectrum of light visible to a human eye:

Absorbtion spectrum of the element hydrogen:

Spectral lines of the sun:




# Absorbtion spectra of hydrogen and the sun

SILICANN SYSTEMS GMBH

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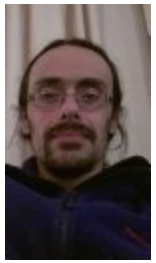
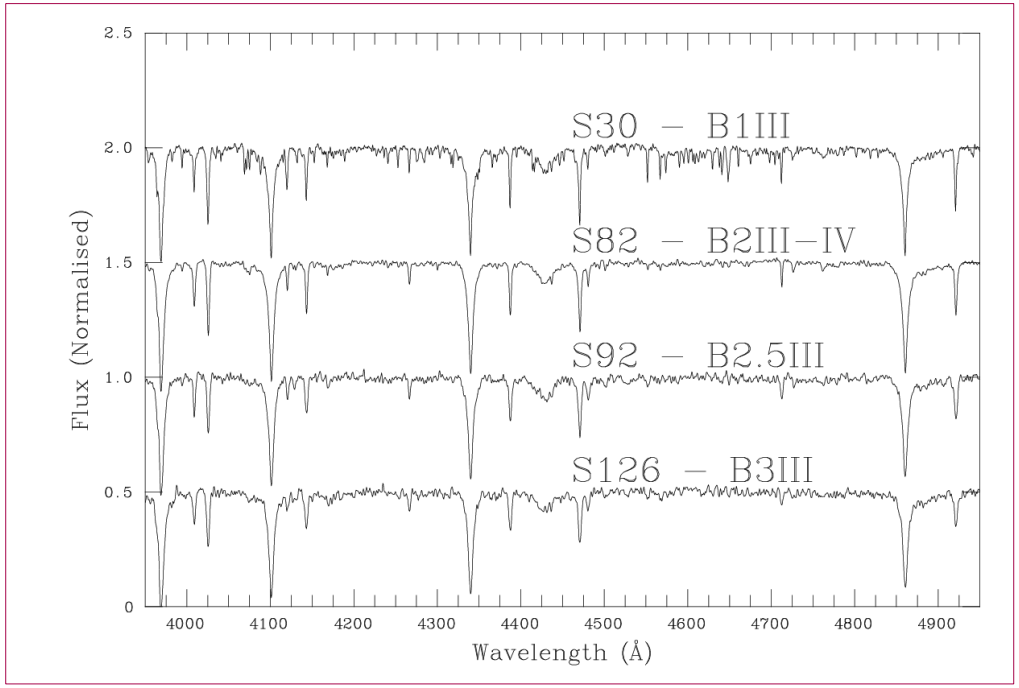
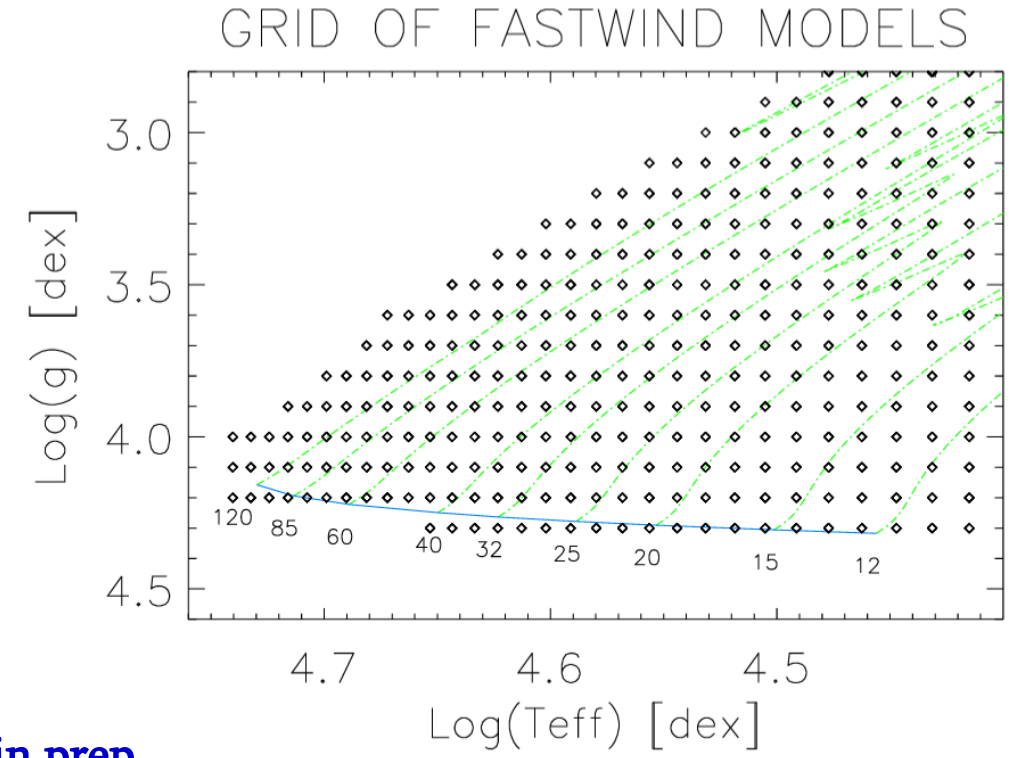
# Stellar parameters for OB stars

Spectral resolution $R \sim 10000$ is desirable, but
$R \sim 5000$ with high S/N will do the job.



**Analysis by N. Castro (AIP, Germany)**




A sample of giants in NGC 663 **Marco+ in prep.**

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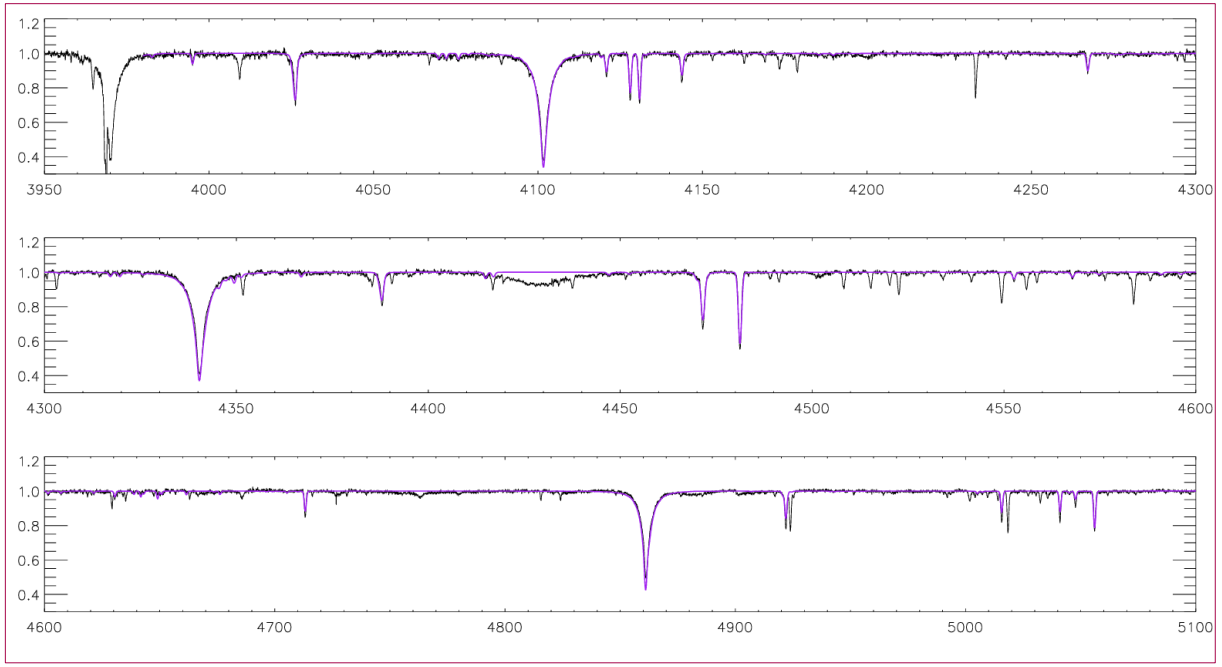
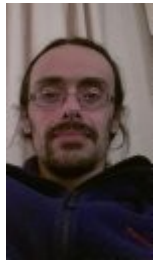
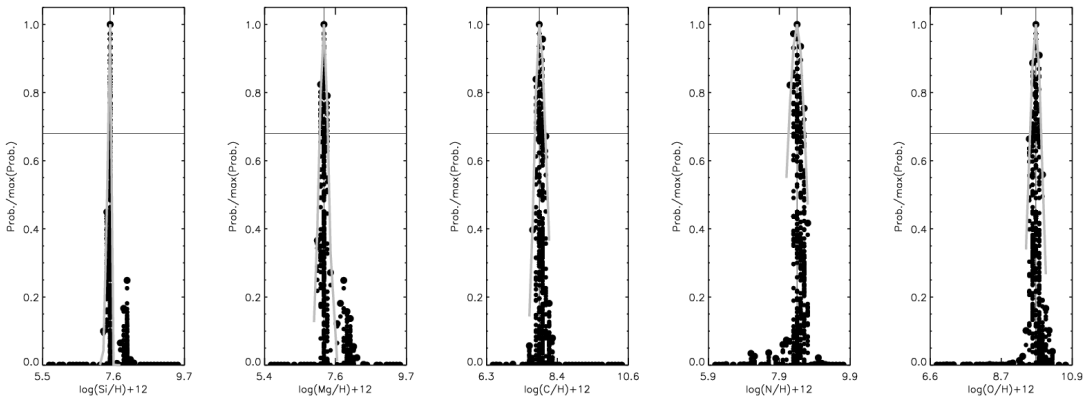
# Abundances for OB stars

Spectral resolution $R > 10000$ is necessary with $> 20000$ highly desirable



Analysis by N. Castro (AIP, Germany)




Automatised abundance determination for a supergiant in NGC 663 **Marco+ submitted.**

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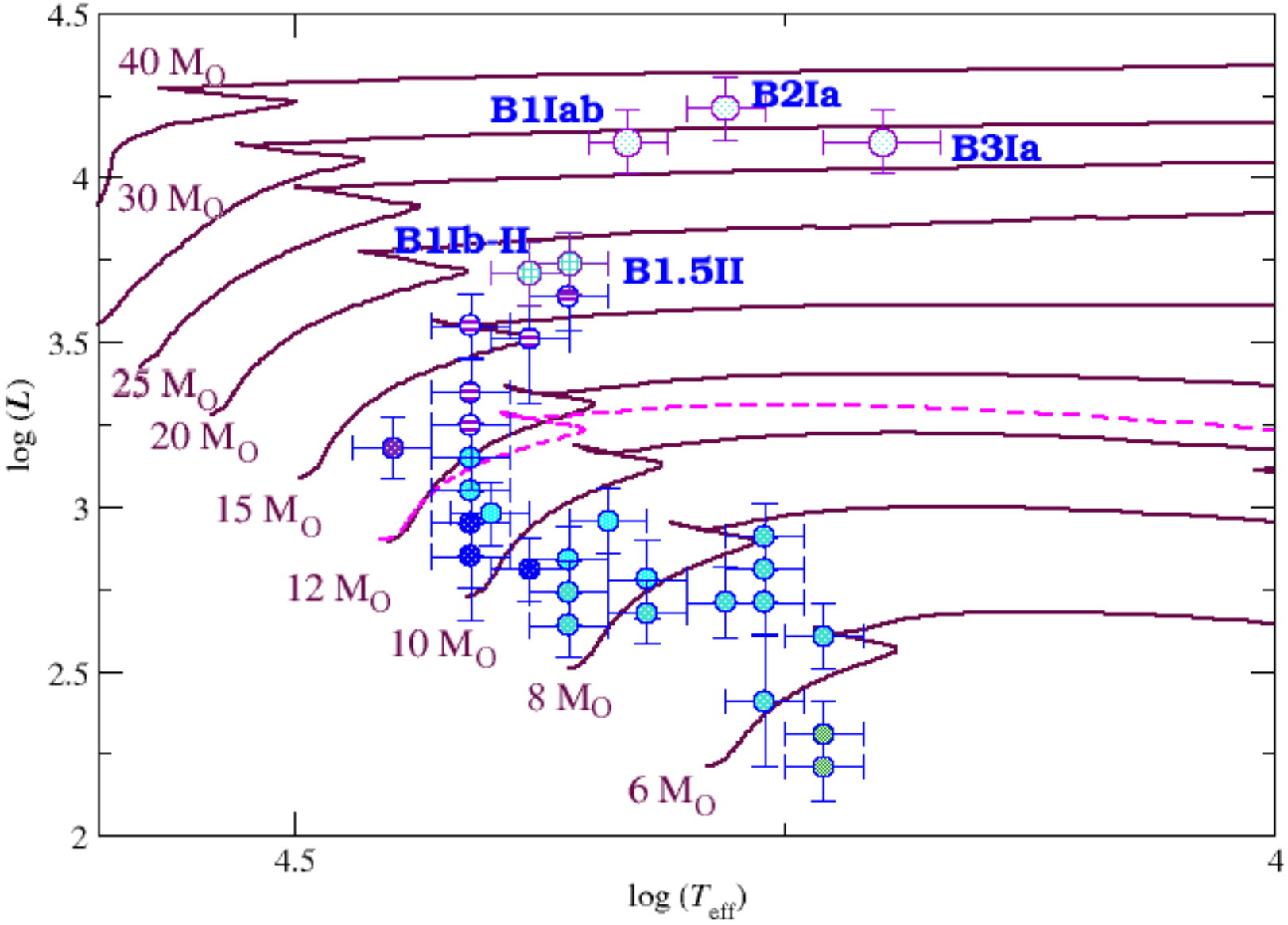


III

IV

B1 V

B1.5 V

B2 V

B2.5 V

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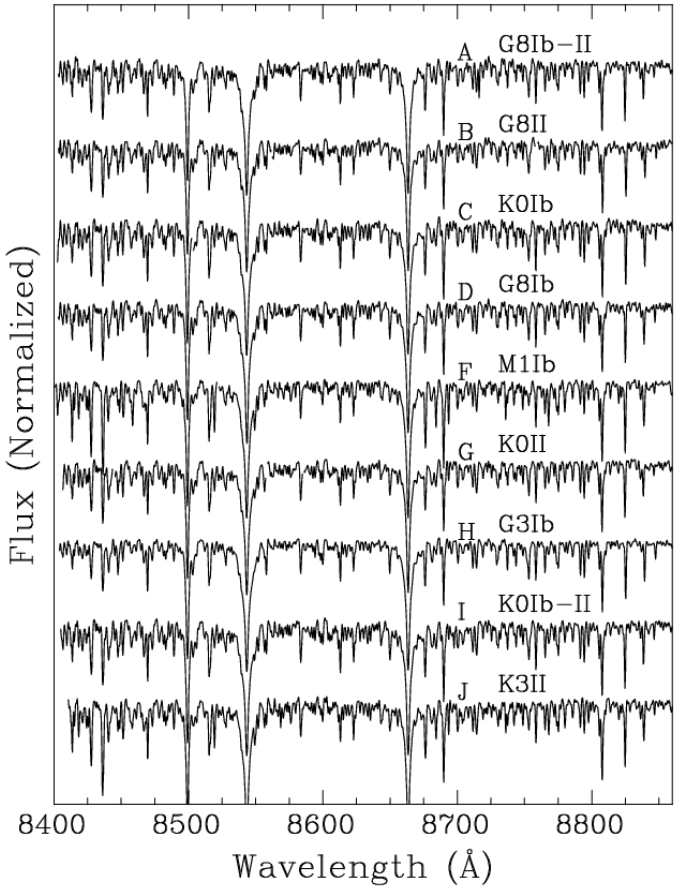
# Stellar parameters for cool supergiants

Spectral resolution $R \sim 10000$ is wanted, although a bit less may do

| Star | Other name | *Gaia* DR2 | Spectral type | $T_{\rm eff}$ (K) | log $g$ | [M/H] (dex) | $v_{\rm hel}$ (km s$^{-1}$) | RV (*Gaia*) (km s$^{-1}$) |
|---|---|---|---|---|---|---|---|---|
| A | TYC 5121−543-1 | 4256511915482900608 | G8 Ib–II | 4693 ± 46 | 1.1 ± 0.11 | −0.05 ± 0.06 | 40.6 ± 0.2 | – |
| B | GSC 05121−00622 | 4256512843232515840 | G8 II | 4620 ± 51 | 1.42 ± 0.12 | +0.01 ± 0.07 | 42.4 ± 0.2 | 40.1 ± 0.4 |
| C | TYC 5121−819-1 | 4253508943153458048 | K0 Ib | 4639 ± 40 | 0.88 ± 0.11 | +0.02 ± 0.06 | 39.8 ± 0.2 | – |
| D | TYC 5121−218-1 | 4253508702635208832 | G8 Ib | 4640 ± 48 | 1.02 ± 0.11 | −0.07 ± 0.06 | 41.1 ± 0.2 | 40.8 ± 0.5 |
| E | CM Sct | 4253603501158148736 | –[a] | 5431 ± 36 | 1.03 ± 0.09 | −0.15 ± 0.04 | 47.4 ± 0.3 | – |
| F | TYC 5121−758-1 | 4253603501158148736 | M1 Ib | 3840 ± 20 | 0.33 ± 0.09 | −0.10 ± 0.05 | 41.6 ± 0.2 | – |
| G | | 4256511468842481408 | K0 II | 4725 ± 44 | 1.33 ± 0.09 | +0.12 ± 0.05 | 41.5 ± 0.2 | 41.6 ± 0.4 |
| H | TYC 5121−684-1 | 4253603501158148736 | G3 Ib | 5105 ± 27 | 0.72 ± 0.08 | −0.07 ± 0.04 | 41.1 ± 0.2 | 41.8 ± 0.2 |
| I | TYC 5125−1531-1 | 4253499219346450432 | K0 Ib-II | 4755 ± 22 | 0.91 ± 0.06 | +0.08 ± 0.03 | 43.5 ± 0.6 | 42.1 ± 0.3 |
| J | | 4253597556923196672 | K3 II | 4137 ± 40 | 0.65 ± 0.1 | −0.06 ± 0.06 | 43.4 ± 0.2 | – |




A sample of low-luminosity supergiants in Valparaiso 1 **Negueruela+21, MNRAS 505, 1618**

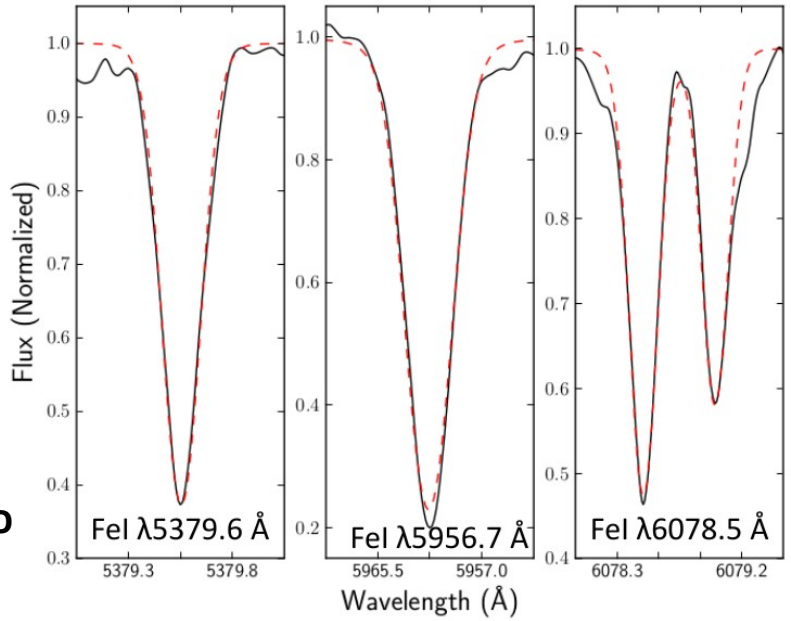
**Analysis by H. Tabernero (UCM) with** `StePar Syn`

The ASFAE's research projects acknowledge the financial support from the MCIU with funding from the European Union NextGenerationEU and Generalitat Valenciana.

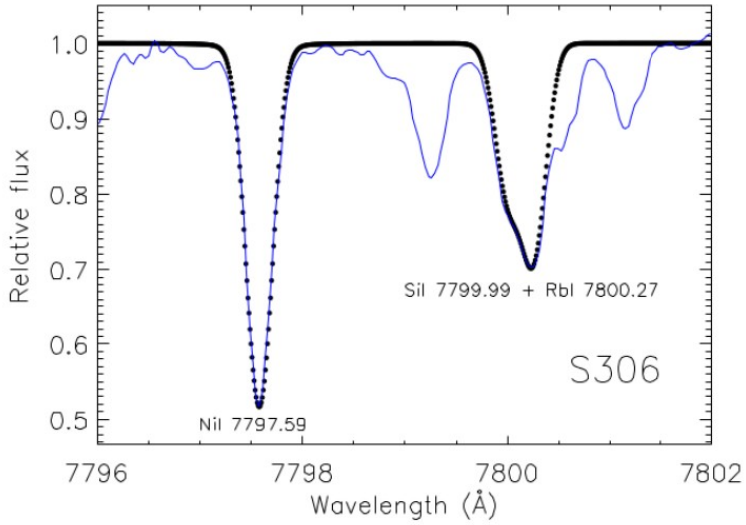
# Abundances for cool supergiants

## Spectral resolution $R > 20000$ is mandatory

**Thesis of J. Alonso Santiago (now at INAF-Catania)**




**Line fitting**




Low-luminosity supergiants in NGC 6067

Alonso Santiago+17, MNRAS 469, 1330

**Line synthesis**

**Analysis with** `SteParSyn`

The ASFAE's research projects acknowledge the financial support from the MCIU with funding from the European Union NextGenerationEU and Generalitat Valenciana.

# The WEAVE project

- Next generation instrument for the 4.2 m WHT in La Palma
- Led by ING (Spain, UK; The Netherlands) with substantial backing from other European countries
- > 150 researchers involved in design and science teams

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- Multi-mode spectrograph with:
  - Multi-object
  - Large integral field
  - Several mini-IFU
- Two resolutions offered
- Operation mostly in survey mode, with several survey strands covering stellar astrophysics, galaxy evolution and cosmology
- Expected to be a major player, but already delayed by 6 years.
- LIFU is in operation with some survey observations done since summer
- MOS in comissioning

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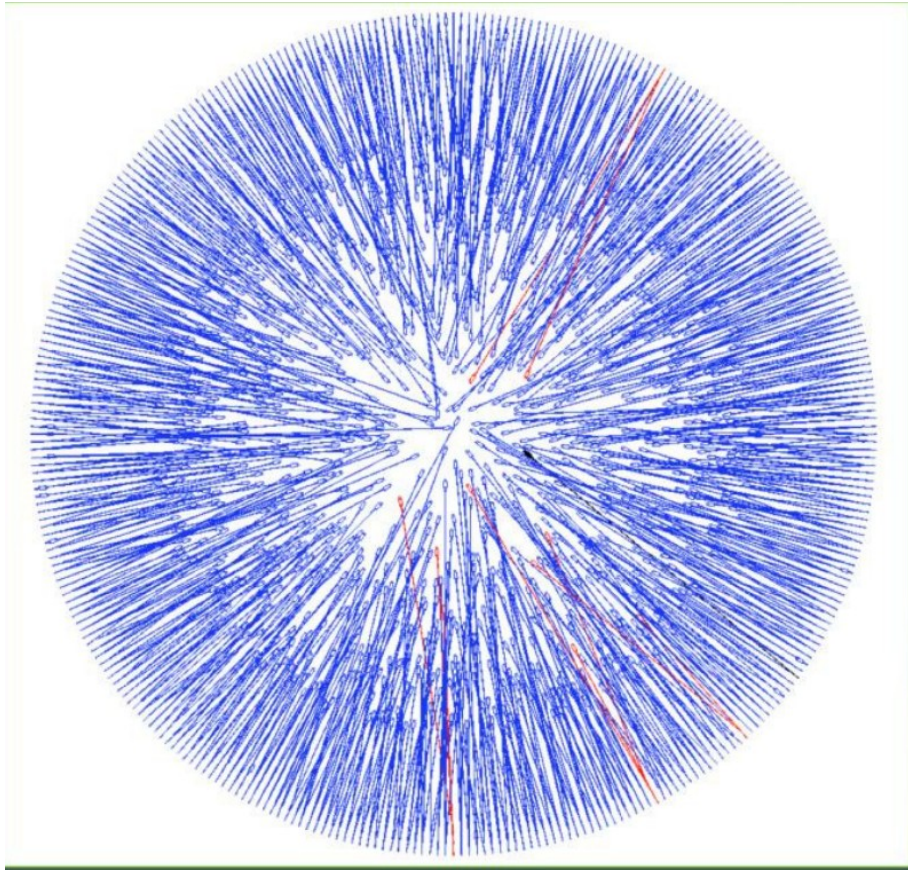
# More than 900 fibers can be allocated by the two robot positioners



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# Main surveys at R ~ 5000

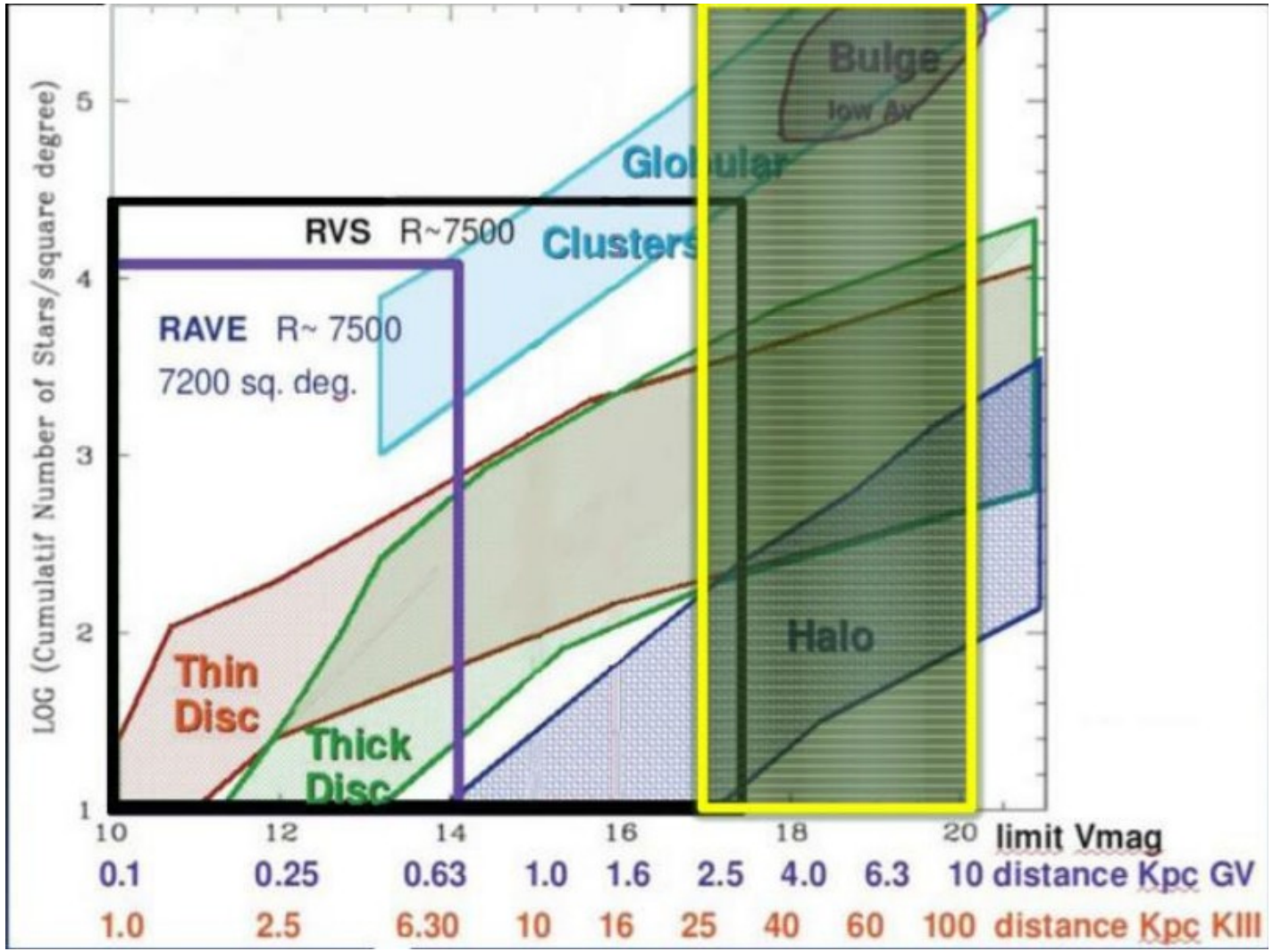


Image by Vanessa Hill (OCA)

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# High-resolution mode at R ~ 20000

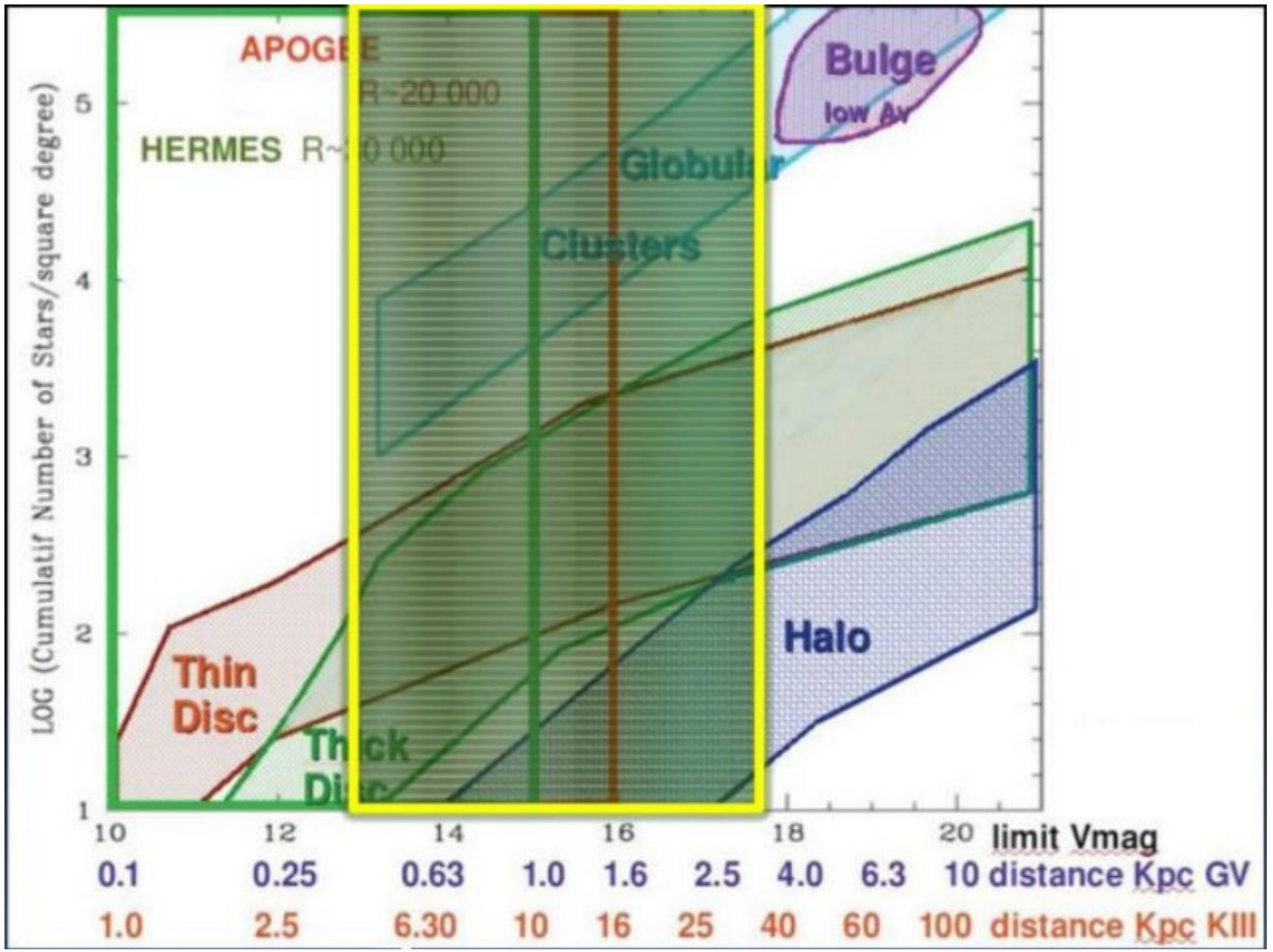


Image by Vanessa Hill (OCA)

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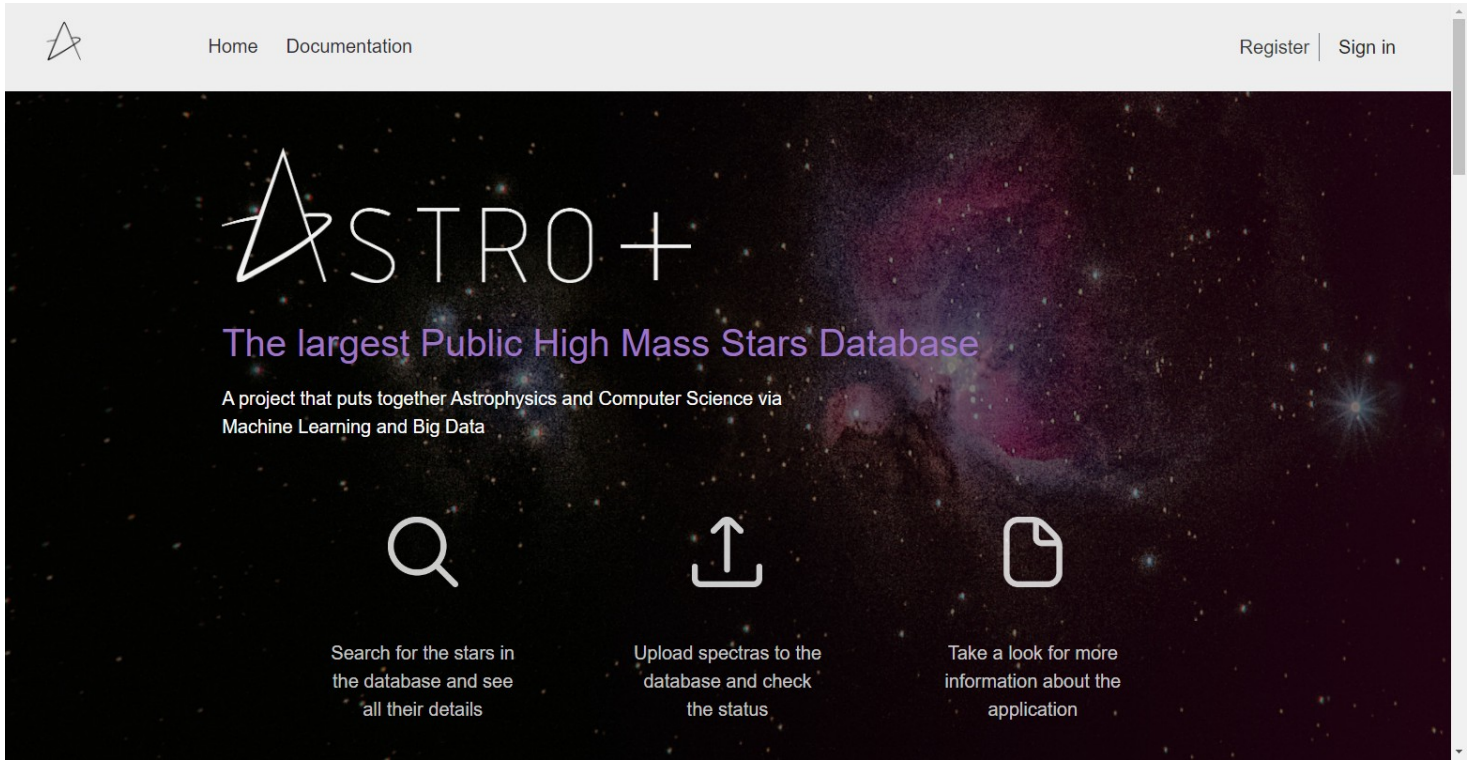
# The Astro+ database (web/server)

P.I. Amparo Marco

**PROMETEO/2019/041**

https://astroplus.ua.es




- **Gather spectra**
- **Unify**
- **Standardize**
- **Analysis tools**

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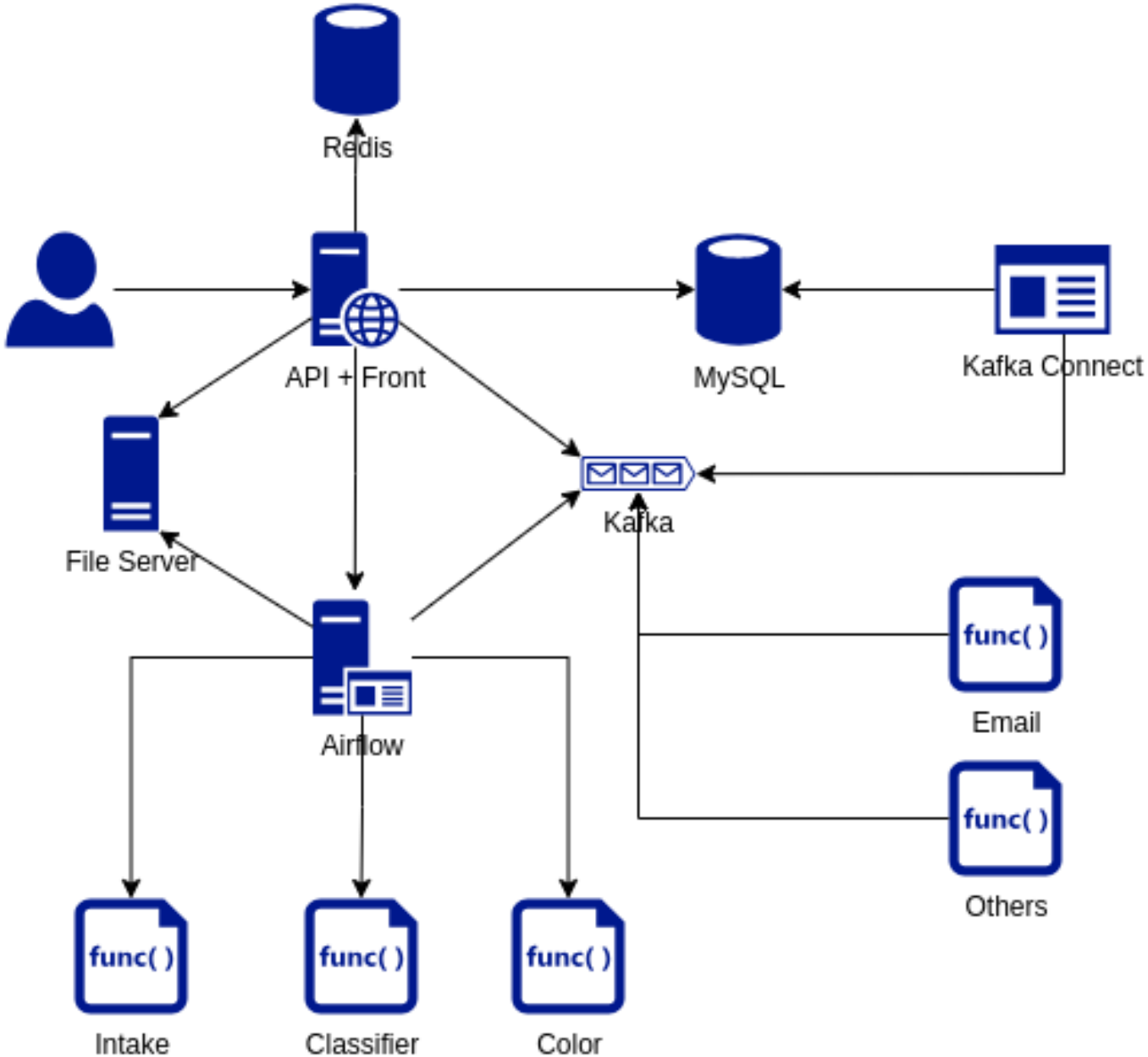


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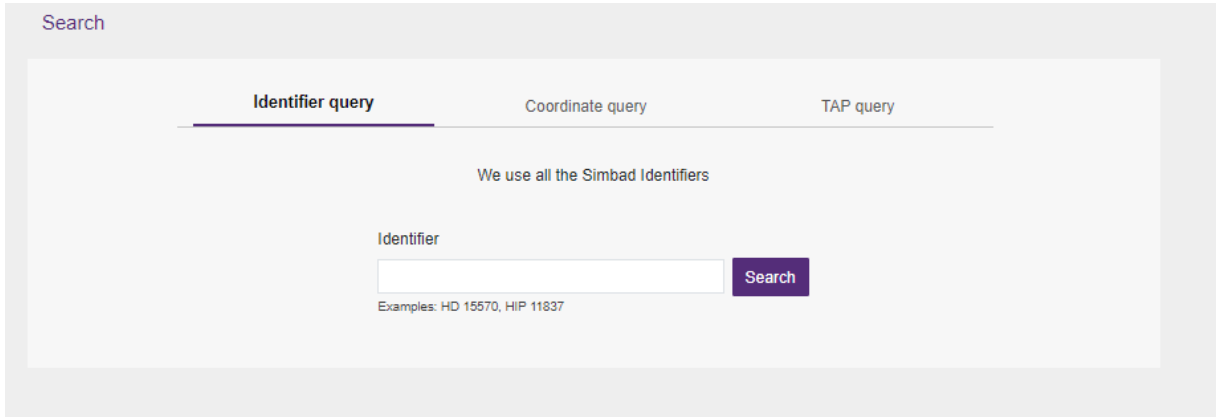
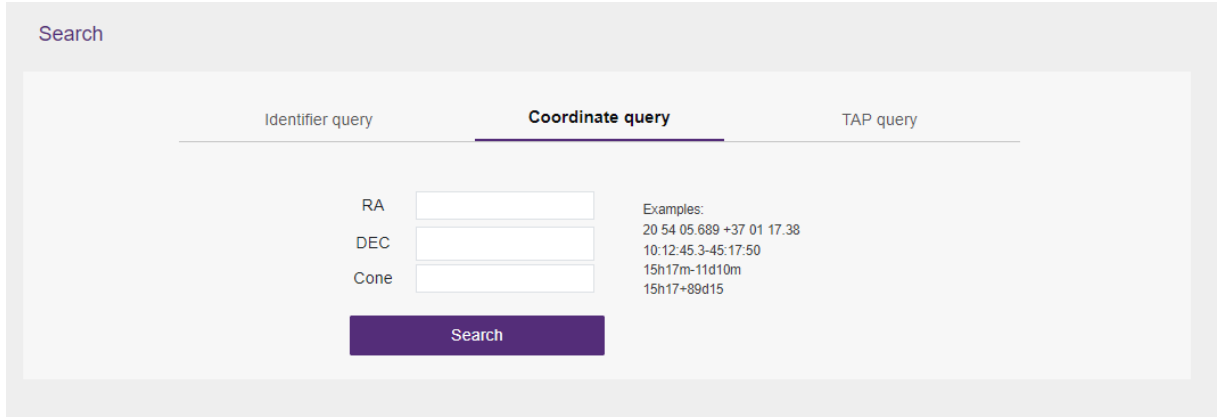
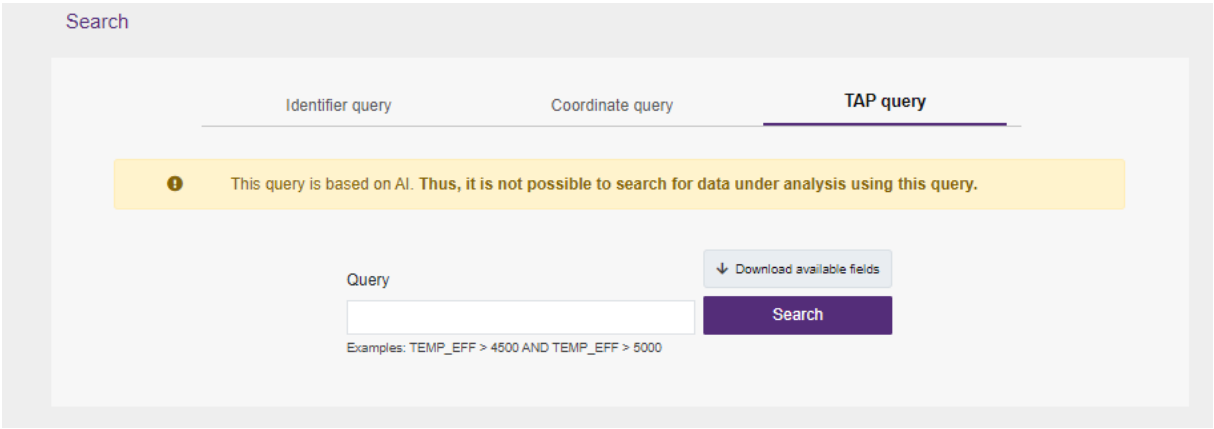
# Search for a spectrum




- ID
- Coordinates
- SQL Query

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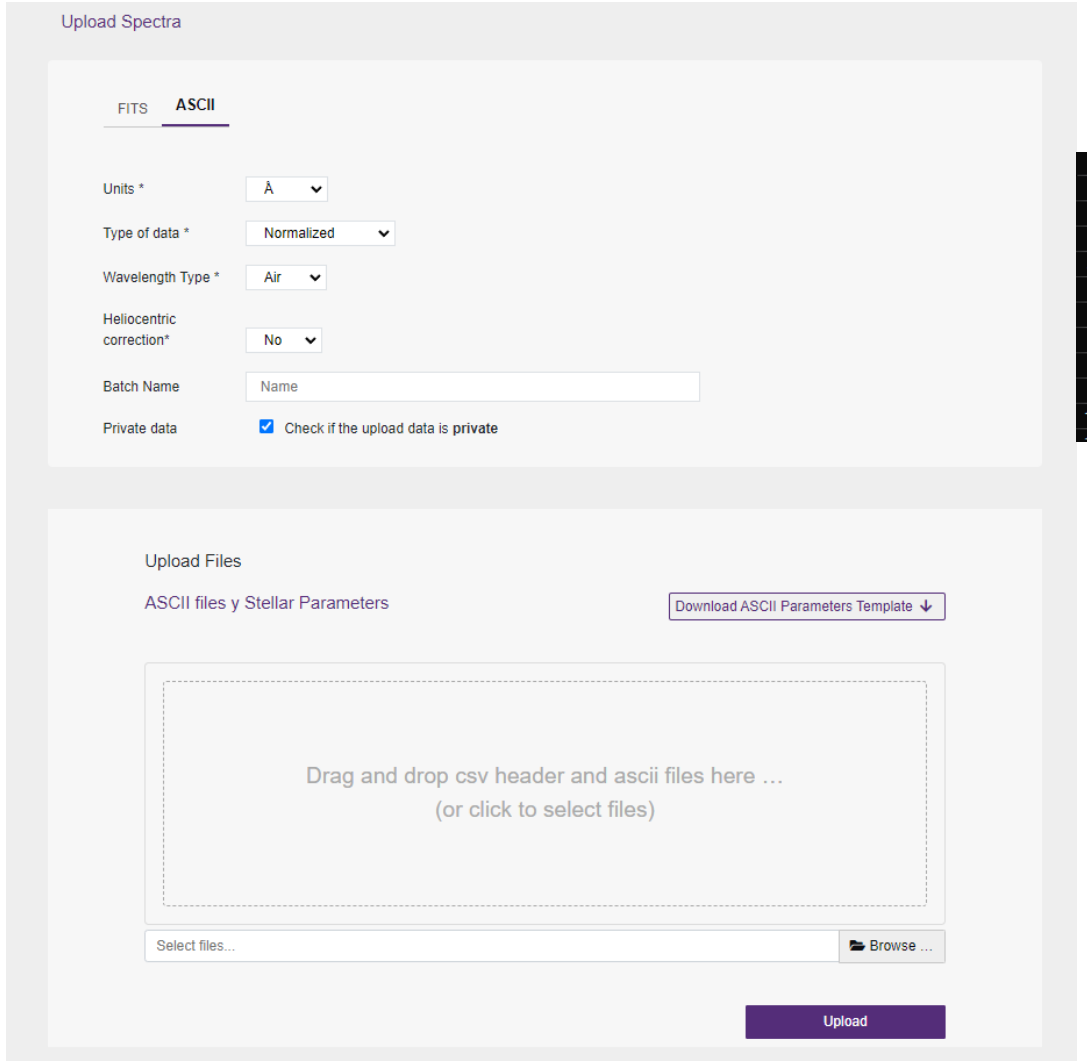
# Upload new data




| | A | B | C | D | E | F | G | H |
|---|---|---|---|---|---|---|---|---|
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| 3 | Star2.dat | HD25420 | 9/7/23 0:00 | 22.3426324 | -11.75634 | WHT | WEAVE | 100 |
| 4 | Star3.dat | HD35270 | 9/7/23 0:00 | -21.6573676 | -7.756335 | WHT | WEAVE | 100 |
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FITS

**ASCII**

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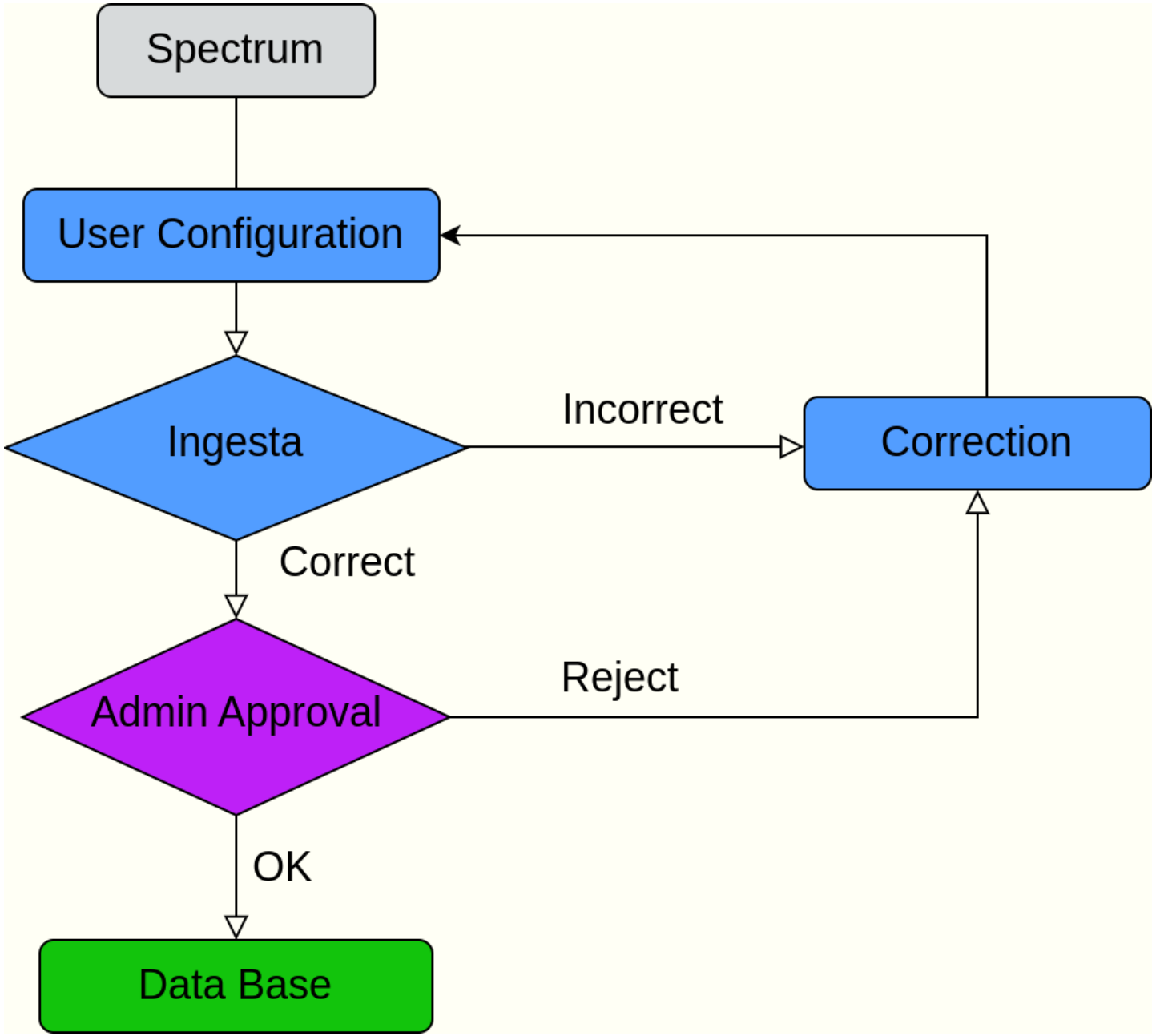


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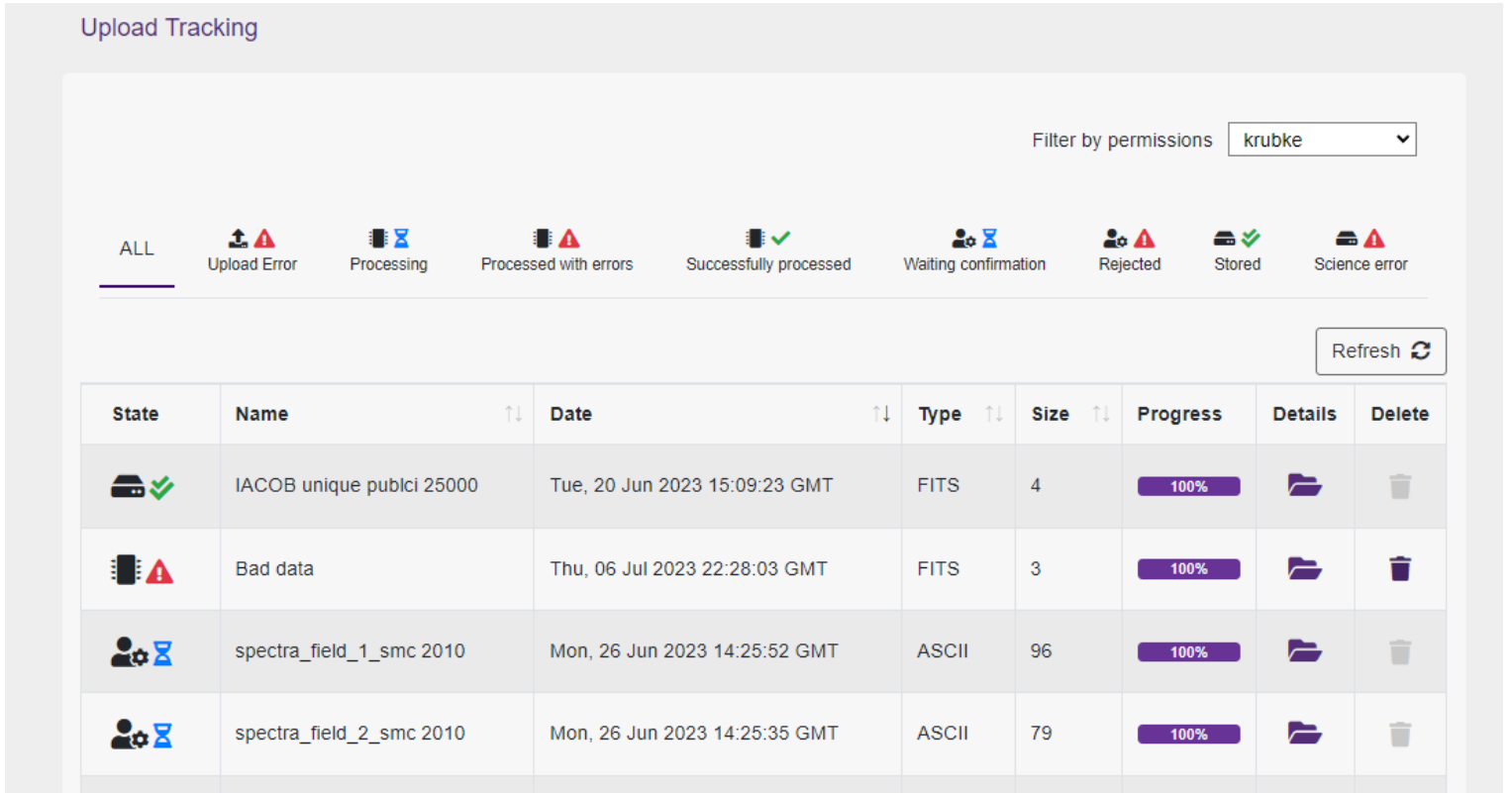
# Upload new data

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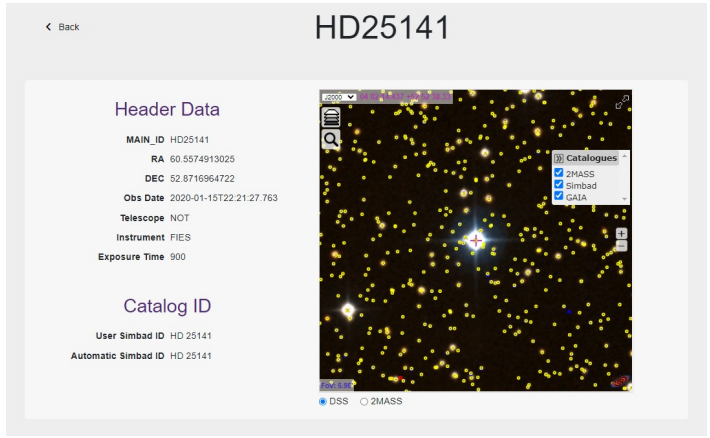
# Assign identification and catalogue data

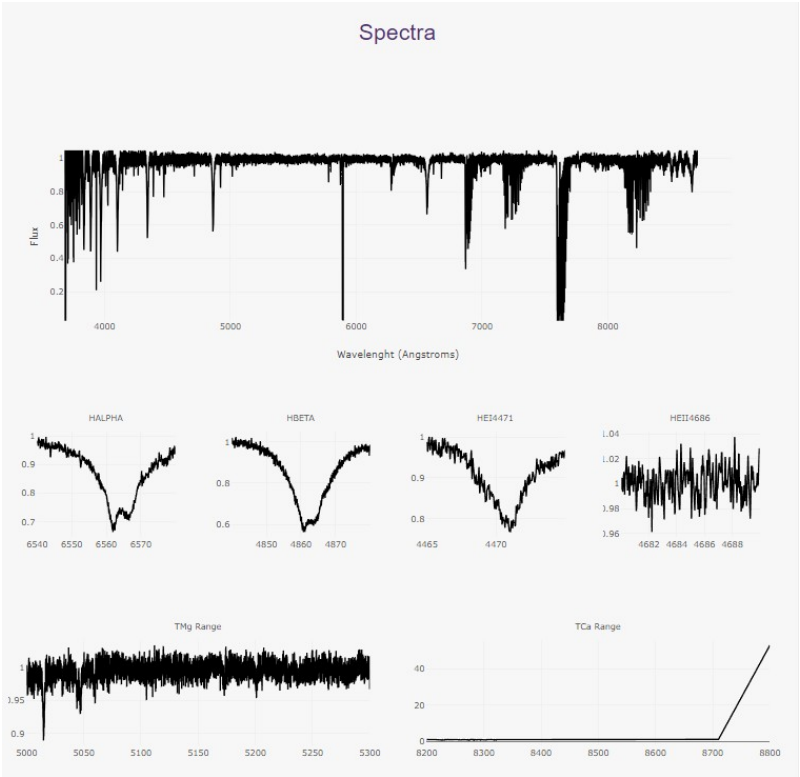
FITS

ASCII

## APIs

- SIMBAD
- 2MASS
- Gaia




| MAIN_ID | RA | RA_PREC | DEC | DEC_PREC | COO_WAVELENGTH | COO_QUAL | COO_ERR_MINA | C |
|---|---|---|---|---|---|---|---|---|
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|---|---|---|---|---|---|
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|---|---|---|---|---|---|---|---|---|---|---|---|---|
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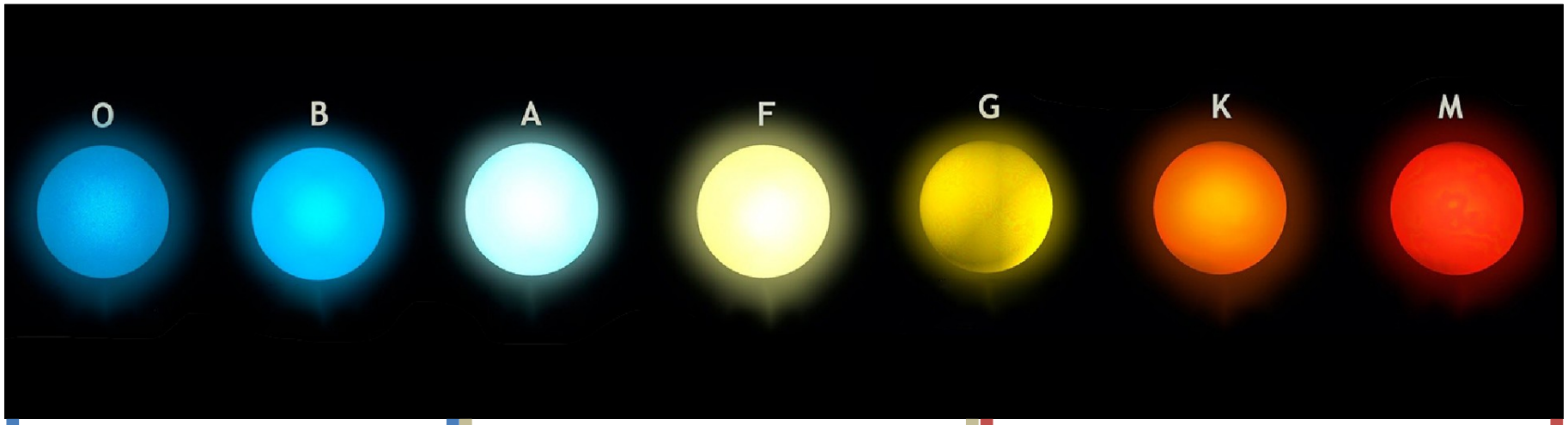
# Analysis




**FASTWIND** | **PHOENIX**

55 000 – 10 000 K | 10 000 – 6 000 K | 6 000 – 3 200 K

**Developer Klaus Rübke**

Astron. Astrophys. 323, 488–512 (1997)

ASTRONOMY AND ASTROPHYSICS

**Atmospheric NLTE-models for the spectroscopic analysis of luminous blue stars with winds**

A.E. Santolaya-Rey[1], J. Puls[2], and A. Herrero[1]

**Atmospheric NLTE-models for the spectroscopic analysis of blue stars with winds**

**II. Line-blanketed models**

J. Puls[1], M. A. Urbaneja[2], R. Venero[3], T. Repolust[1], U. Springmann[4], A. Jokuthy[1], and M. R. Mokiem[5]

A&A 553, A6 (2013)
DOI: 10.1051/0004-6361/201219058
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Astronomy & Astrophysics

**A new extensive library of PHOENIX stellar atmospheres and synthetic spectra**

T.-O. Husser[1], S. Wende-von Berg[1], S. Dreizler[1], D. Homeier[1,2], A. Reiners[1], T. Barman[3], and P. H. Hauschildt[4]

The ASFAE's research projects acknowledge the financial support from the MCIU with funding from the European Union NextGenerationEU and Generalitat Valenciana.

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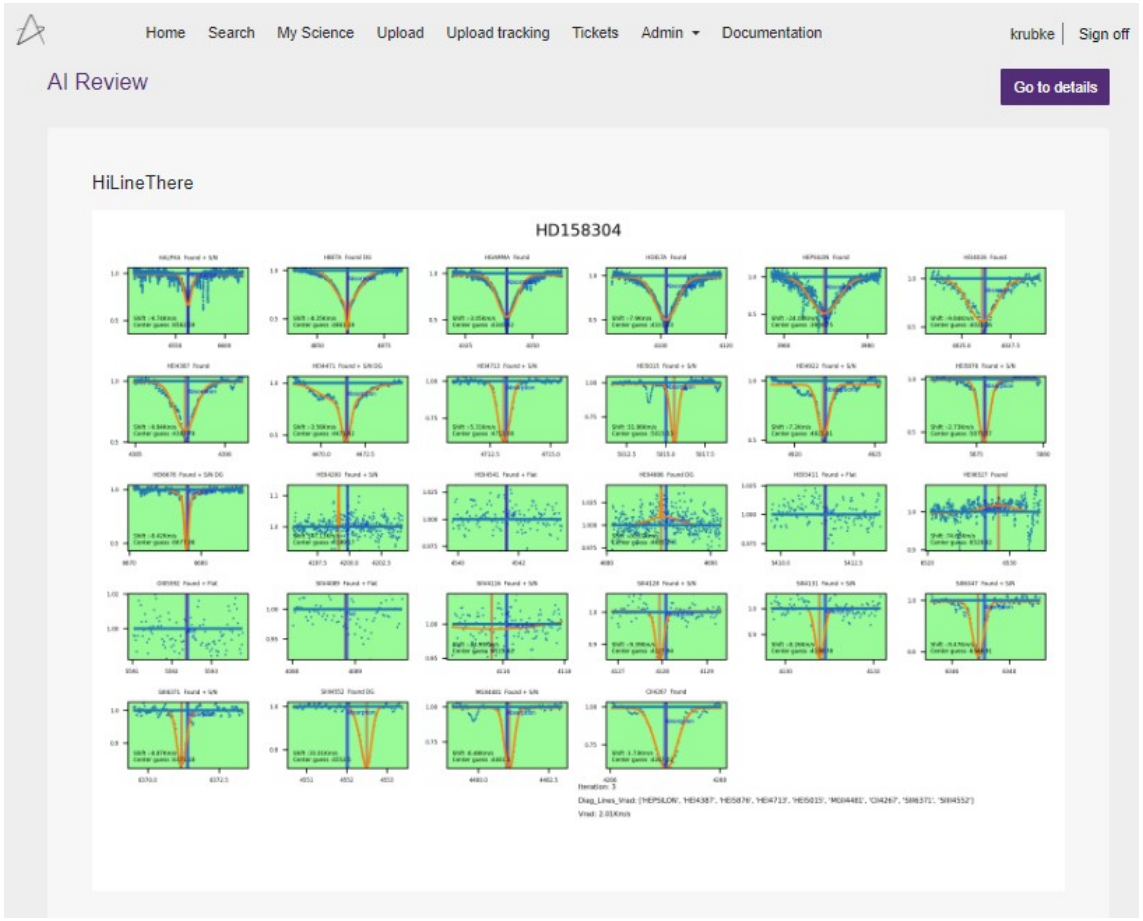
# HILINETHERE




**Developer Klaus Rübke**

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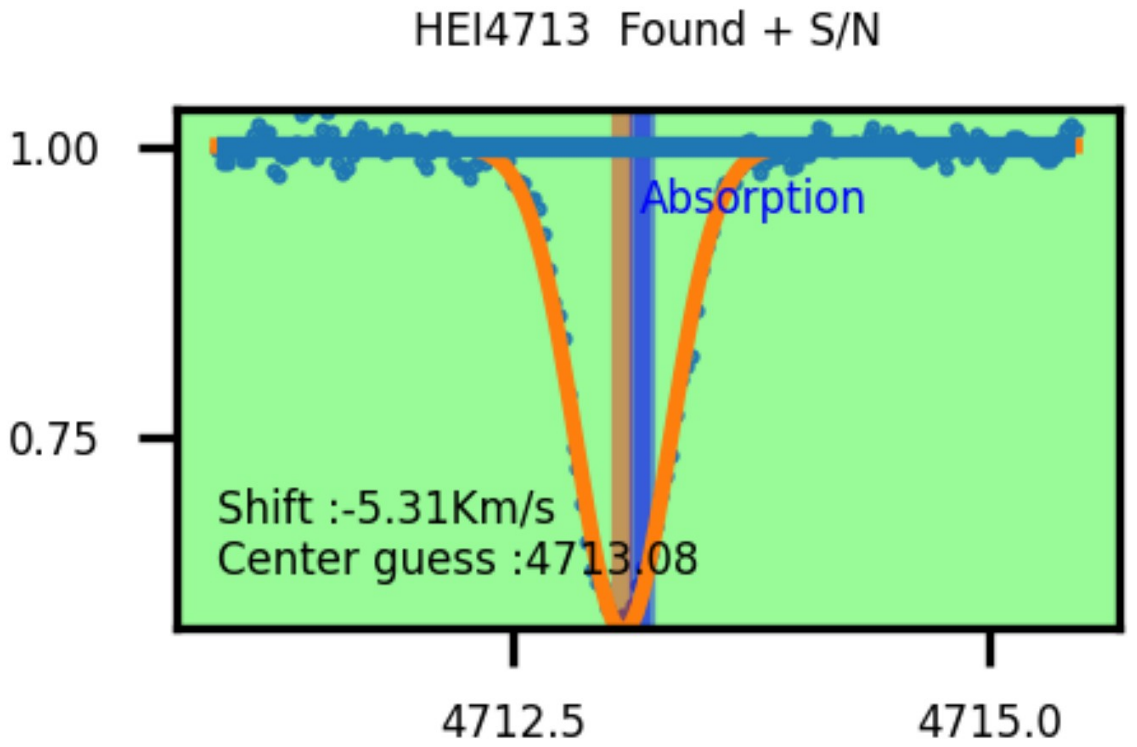


Developer Klaus Rübke

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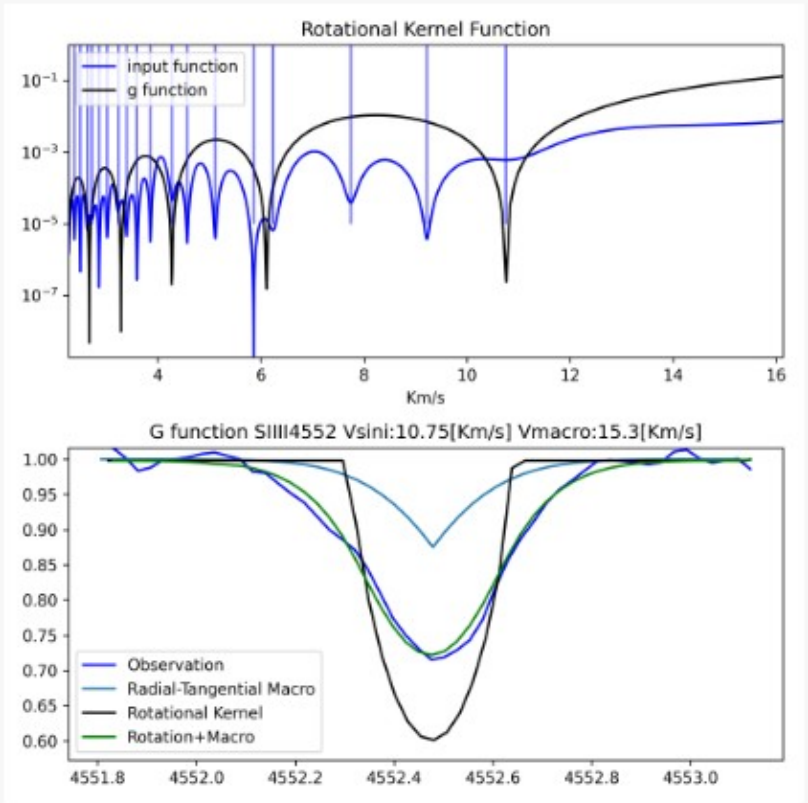
# HILINETHERE

**Table 1.** Diagnostic lines used by Astro+. Lines used for the determination of RV are marked with X, while the lines used to determine $v \sin i$ are numbered according to priority

| Line | Lambda | Vrad | Vsini |
|---|---|---|---|
| HALPHA | 6562.80 | | |
| HBETA | 4861.33 | | |
| HGAMMA | 4340.46 | | |
| HDELTA | 4101.74 | | |
| HEPSILON | 3970.07 | | |
| HEI4026 | 4026.19 | X | |
| HEI4387 | 4387.93 | X | |
| HEI4471 | 4471.47 | X | |
| HEI4713 | 4713.16 | | |
| HEI4922 | 4921.93 | | |
| HEI5876 | 5875.62 | X | |
| HEI6678 | 6678.15 | | |
| HEII4200 | 4199.83 | | |
| HEII4541 | 4541.59 | X | 4 |
| HEII4686 | 4685.71 | | |
| HEII5411 | 5411.52 | X | 3 |
| HEII6527 | 6527 | | |
| OIII5592 | 5592.37 | X | 1 |
| SIII4128 | 4128.07 | | |
| SIII4131 | 4130.89 | | |
| SIII6347 | 6347.11 | | |
| SIII6371 | 6371.37 | | |
| SIIII4552 | 4552 | X | 2 |
| SIIV4089 | 4088.85 | | |
| SIIV4116 | 4116.10 | | |
| MGII4481 | 4481 | X | 5 |
| CII4267 | 4267 | X | 6 |

THE ROTATIONAL SPEEDS OF THE STARS.

*J. A. Carroll, M.A., Ph.D., and L. J. Ingram, M.A.*

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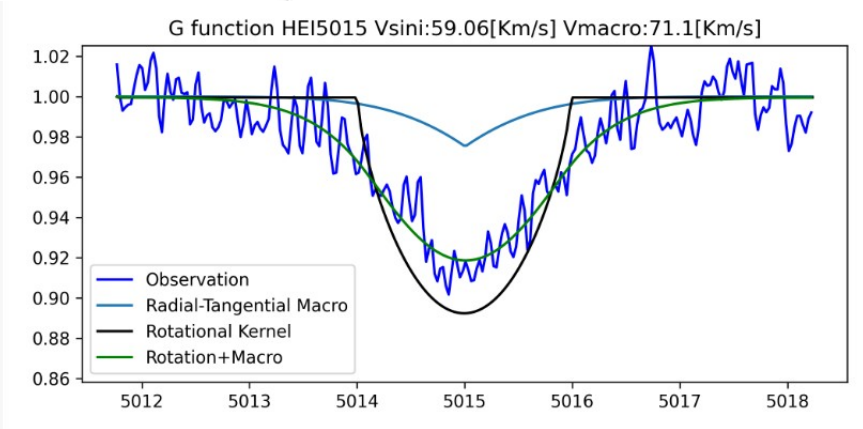
| SIIV4116 | 4116.10 | | |
| MGII4481 | 4481 | X | 5 |
| CII4267 | 4267 | X | 6 |

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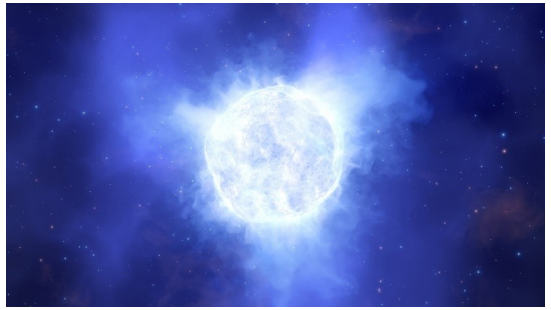
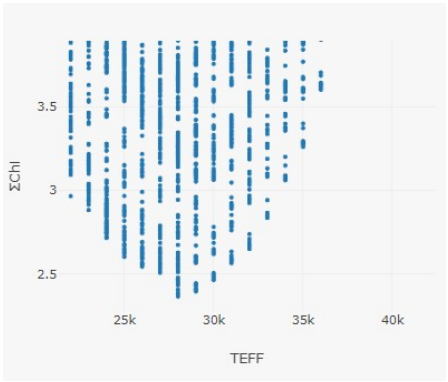
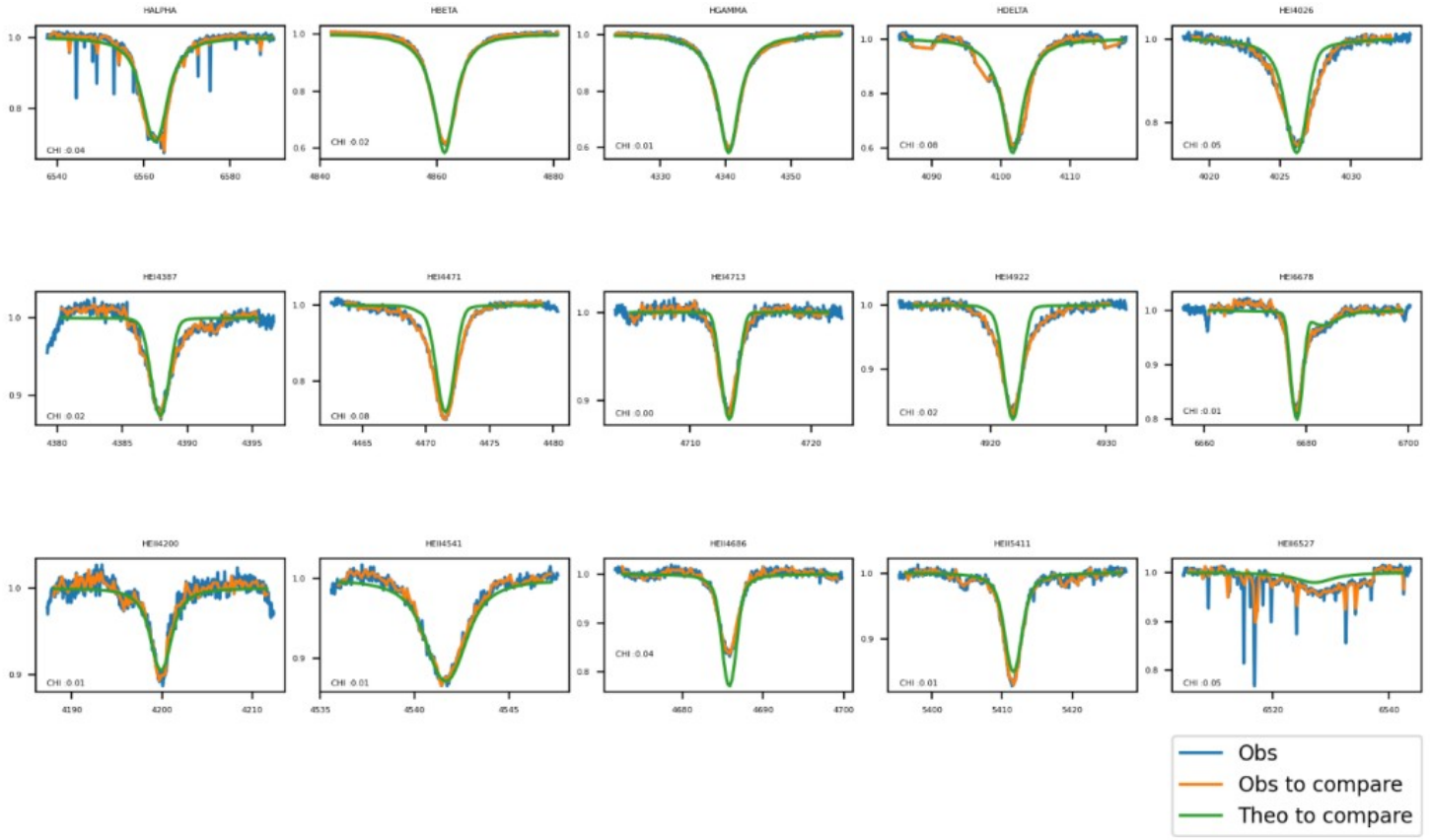
# HICHI

$$\chi^2$$






**Developer Klaus Rübke**

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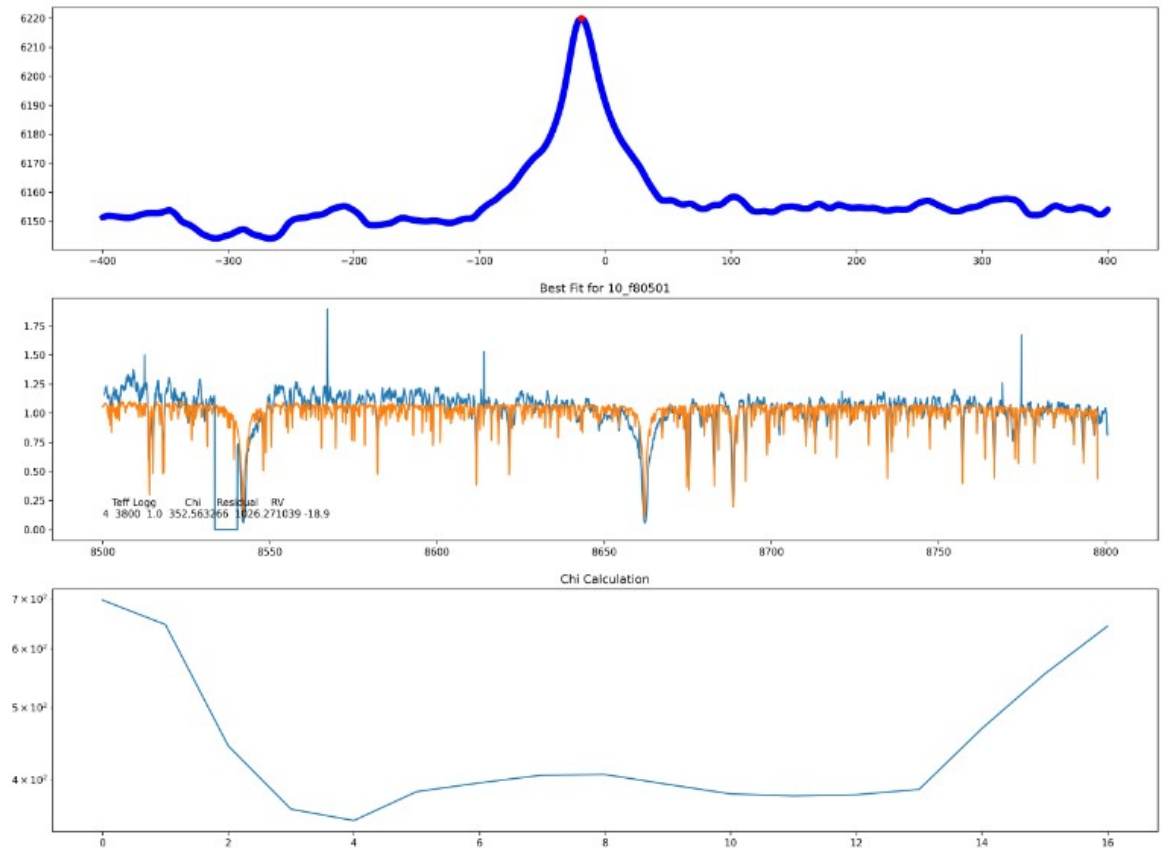
# HIBAND




TO → StePar**Syn**

**Tabernero+ 2022**

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# Quality control

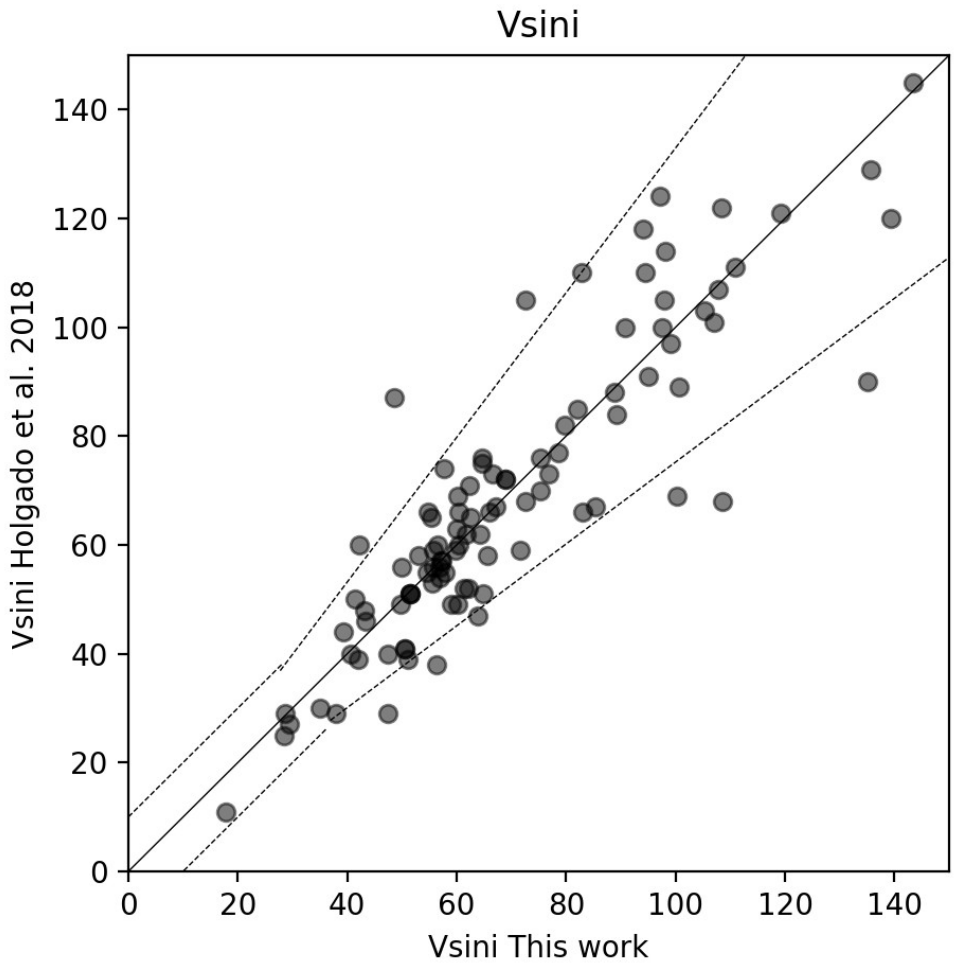
## $v \sin i$ determination

102 Stars

**The IACOB project**

**V. Spectroscopic parameters of the O-type stars in the modern grid of standards for spectral classification**★

G. Holgado[1,2], S. Simón-Díaz[1,2], R. H. Barbá[3], J. Puls[4], A. Herrero[1,2], N. Castro[5], M. Garcia[6], J. Maíz Apellániz[7], I. Negueruela[8], and C. Sabín-Sanjulián[3]

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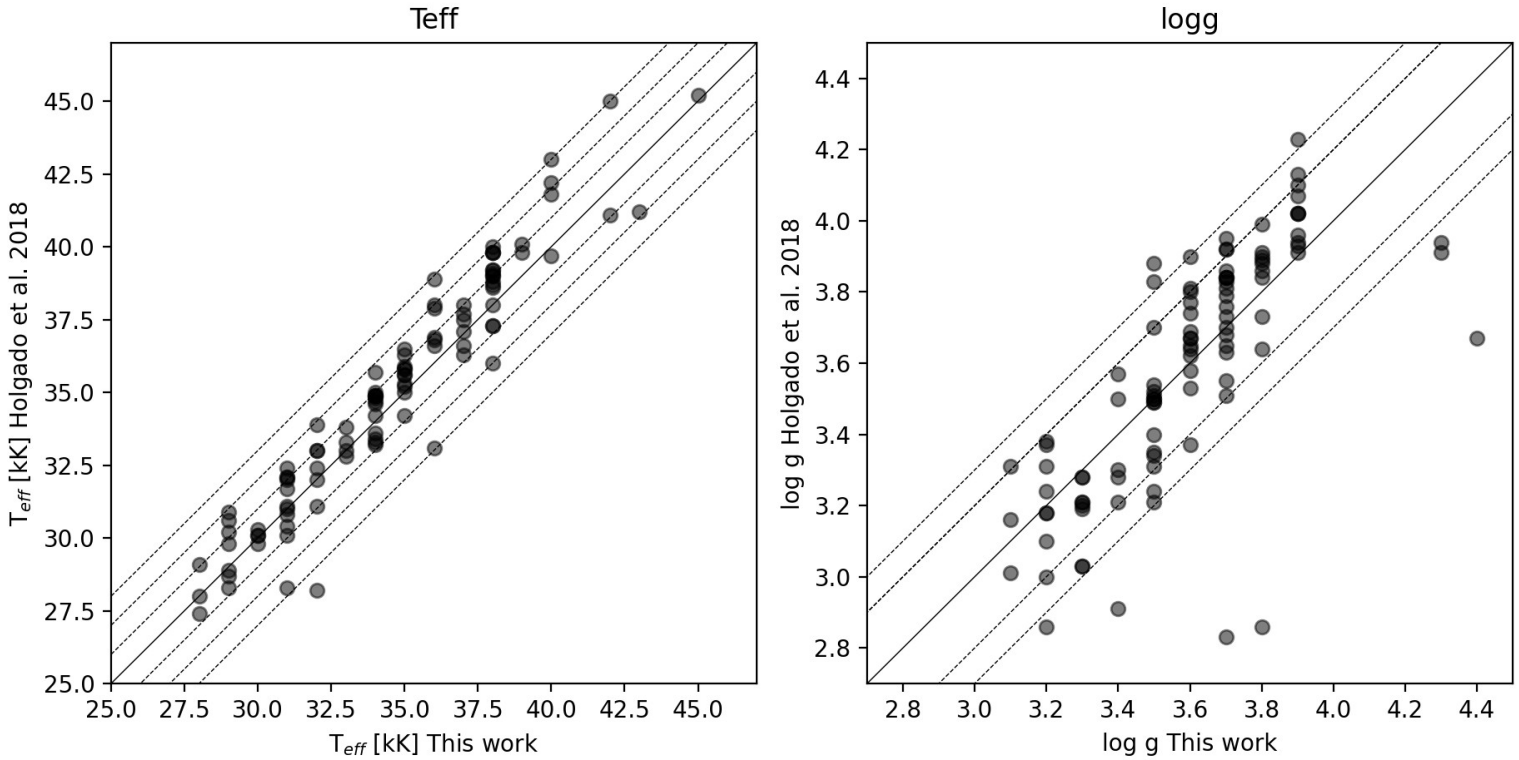
# Quality control

## parameter determination

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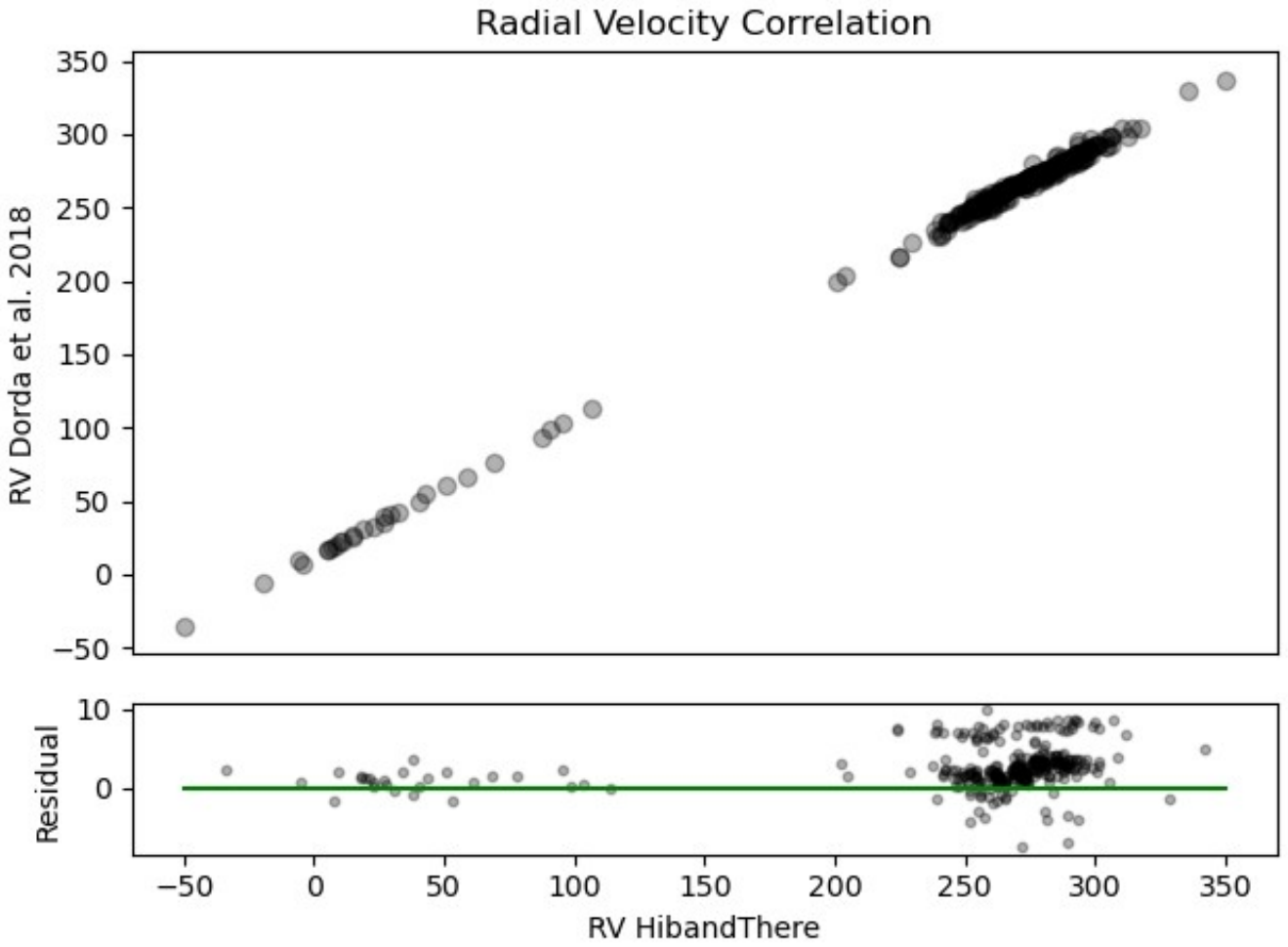
# Quality control




TO → StePar**Syn**

**Tabernero+ 2022**

Dispersion 7 km/s

The ASFAE's research projects acknowledge the financial support from the MCIU with funding from the European Union NextGenerationEU and Generalitat Valenciana.

# Running time

## Fastwind Grid

| Proceso | ANTES | AHORA |
|---|---|---|
| Classificador | 1m50s | 35s |
| HiChi | 1h20m | 20m |
| Stepar | 1h30m | 40-90m |

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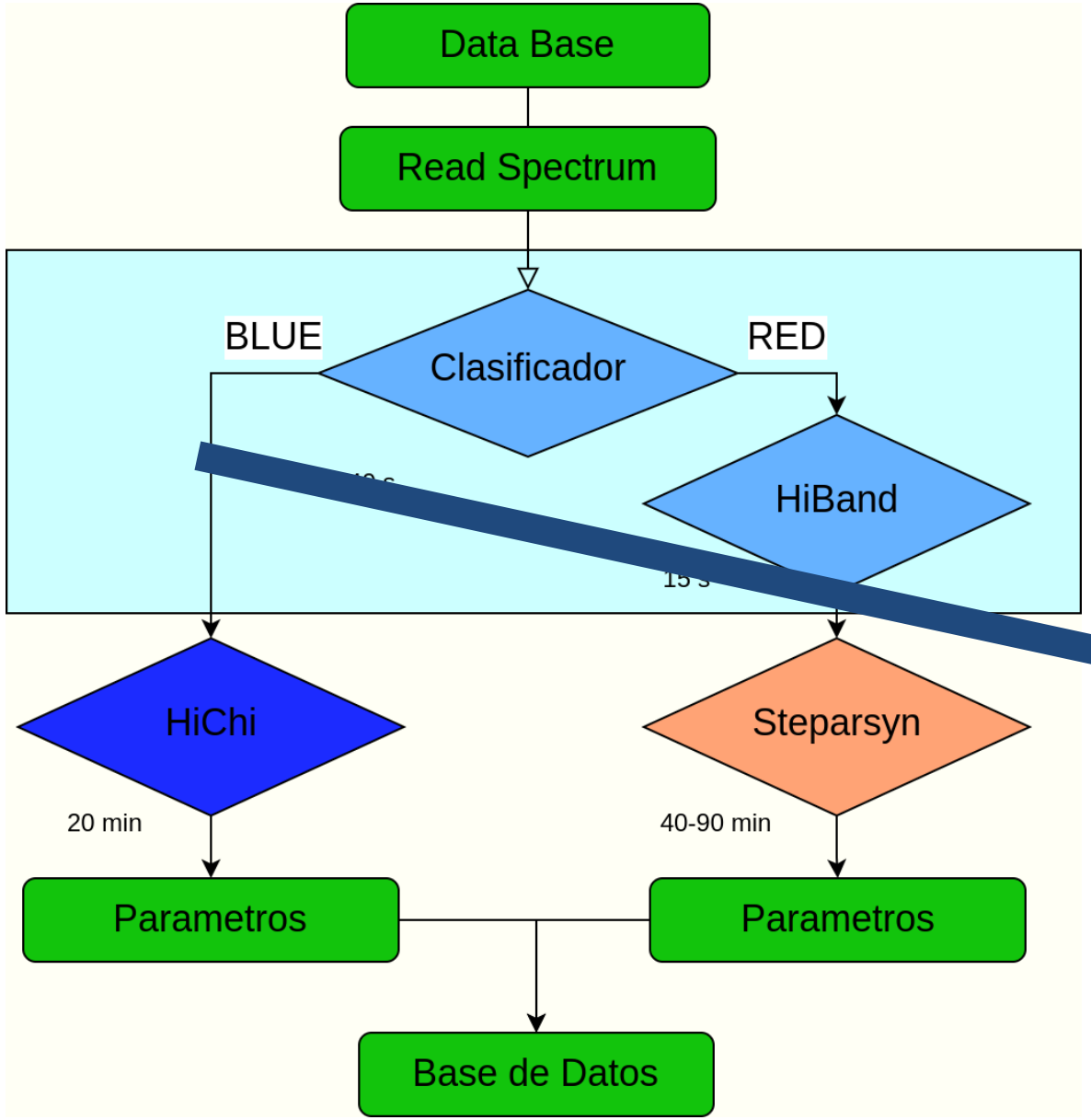


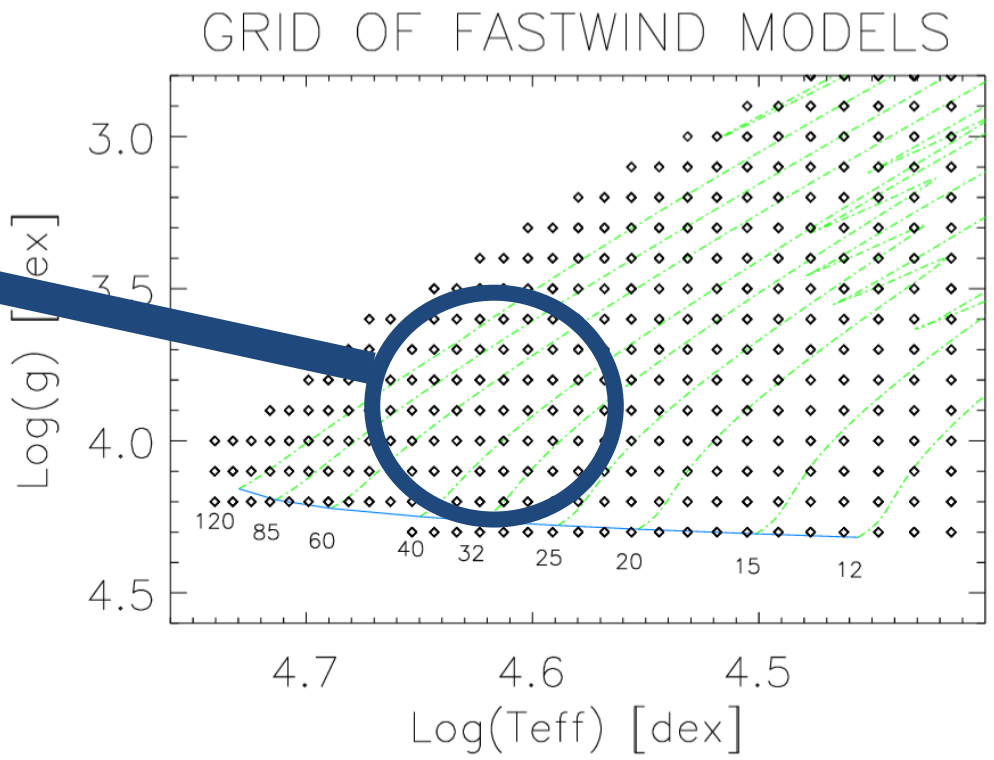


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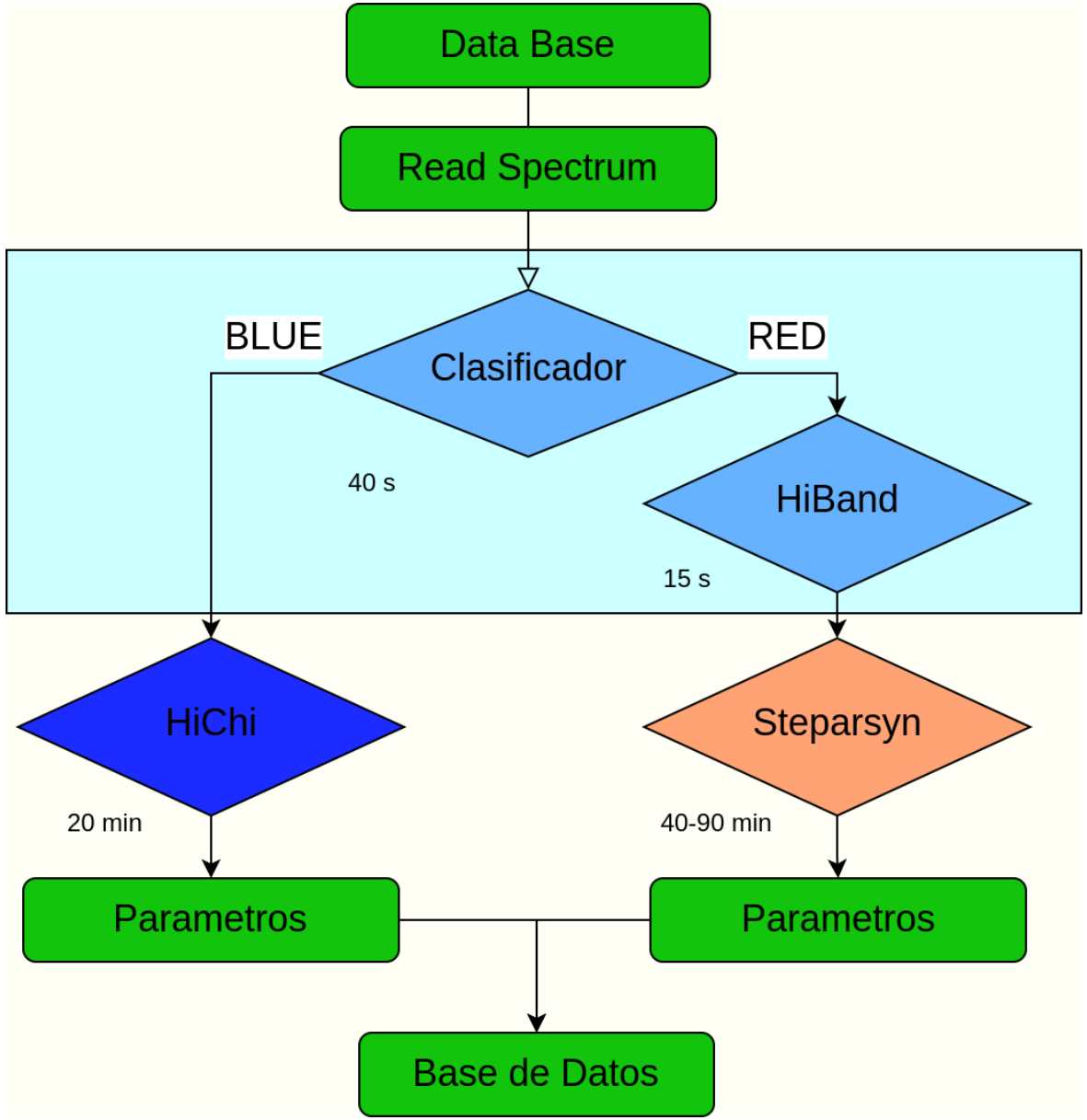


The ASFAE's research projects acknowledge the financial support from the MCIU with funding from the European Union NextGenerationEU and Generalitat Valenciana.


- We are starting to plan a ML tool to determine parameters for the cool stars without having to resort to very time consuming MC simulations.
- Large numbers of spectra with parameter determination needed to train.
- Mid-term goal is a ML tool that will consider ~$10^4$ WEAVE spectra of cool luminous stars and try unsupervised learning.

The ASFAE's research projects acknowledge the financial support from the MCIU with funding from the European Union NextGenerationEU and Generalitat Valenciana.

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ASFAE
ASTROFÍSICA Y FÍSICA DE ALTAS ENERGÍAS

# Herramientas de análisis automático para espectros estelares

**Ignacio Negueruela**

Universidad de Alicante

Marzo 2024, Alicante