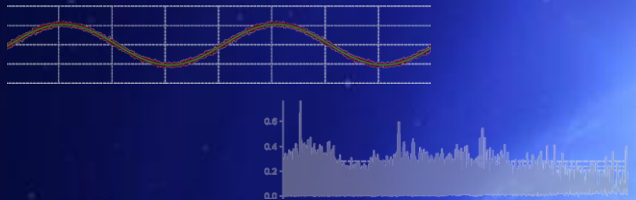
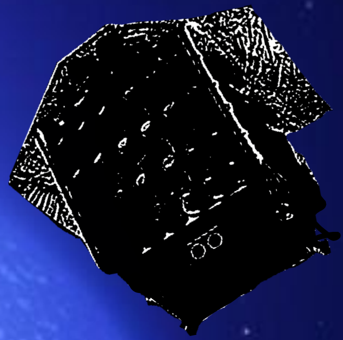
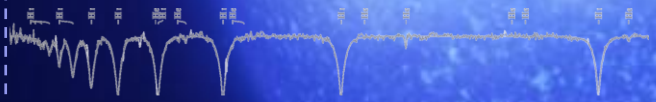
Hot subluminous stars in the Plato era

by Anna Gebhardt







The stellar group ‘in Bamberg’:

Ulrich Heber, Sebastian Weich, Lennard Kufleitner, Matti Dorsch, Aakash Bhat, and me

(ESO/L. Calçada, INAF-Padua/S. Zaggia)

July 20th, 2026

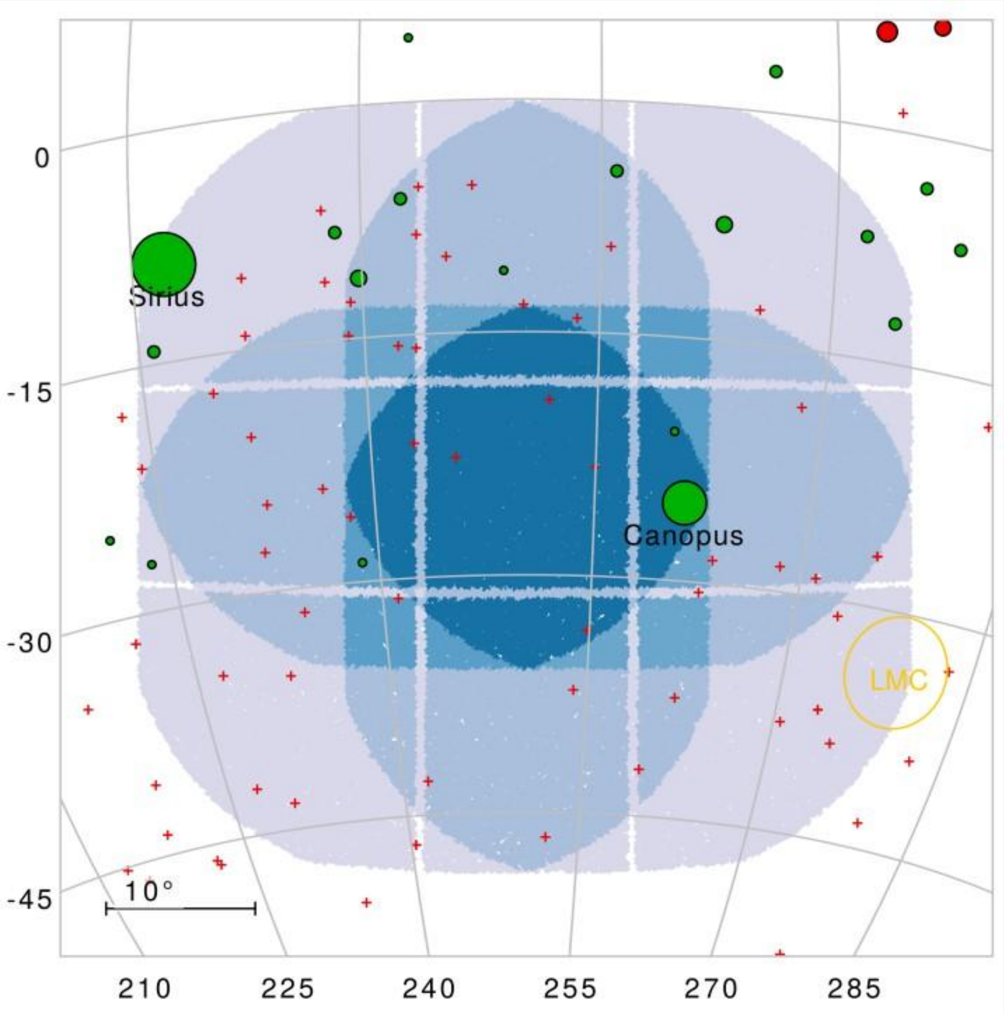
Dr. Karl Remeis-Observatory Bamberg

The *PLATO* mission - Complementary Science and Guest Observers

PLAnetary **T**ransits and **O**scillations of stars in LOPS2

- Launch planned by 01.01.2027
- topics not covered by the core program
- 8% of the total mission telemetry budget (~35 Gbit/day)
- Information about hot subdwarf population needed

(Credit: OHB System AG)



(Nascimbeni et al., 2021)

- High-precision, long-baseline photometry (up to 2 years)
- Sensitive to low-amplitude variability

↔ TESS

Science cases

The hot subdwarfs in the *PLATO* field proposal

Asteroseismology

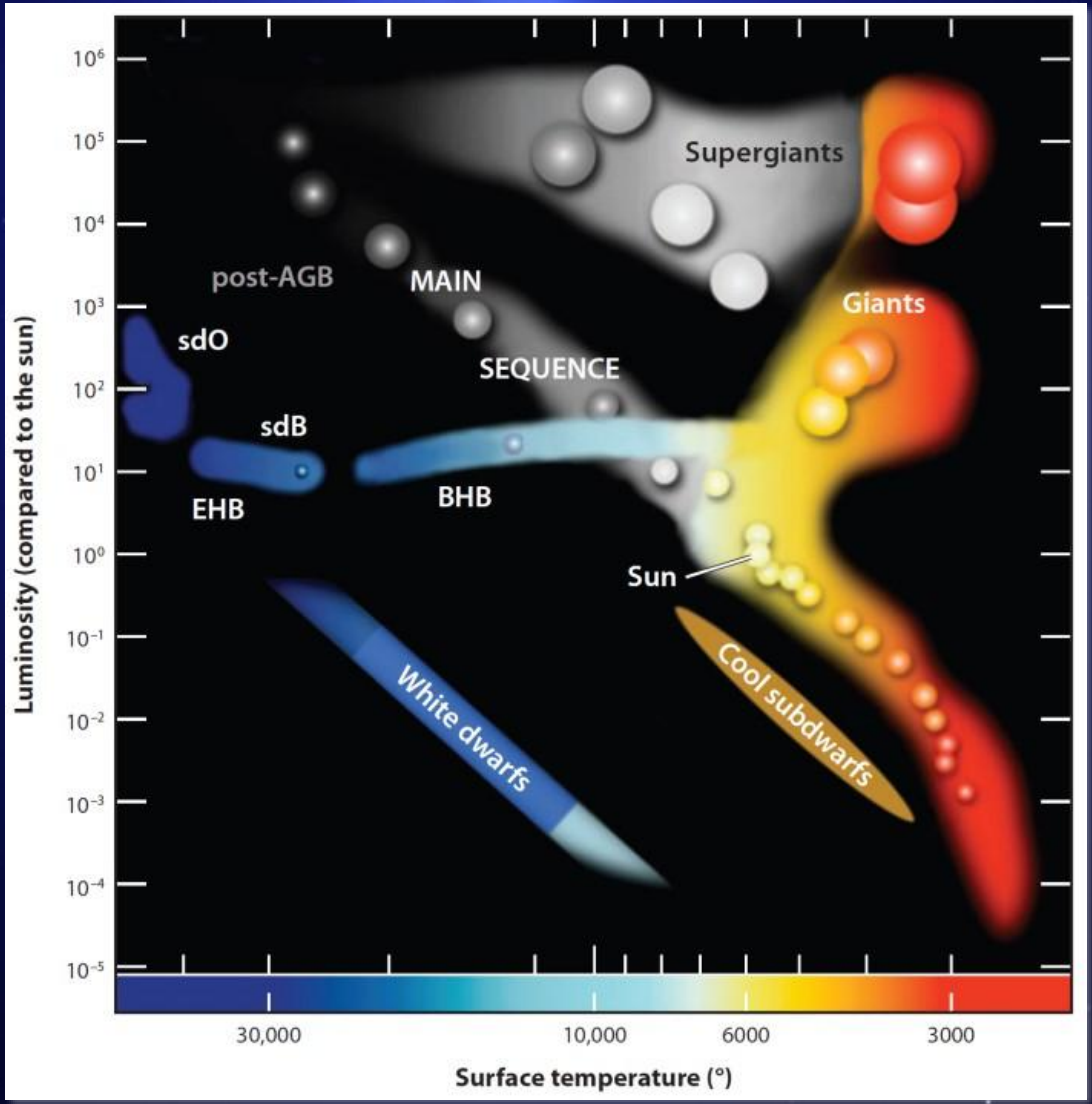
- Internal structure and core composition
- Residual nuclear burning
- Mass-radius constraints

Variability & Binaries

- Eclipses
- Reflection effects
- Ellipsoidal modulation
- Companion-induced variability

(ESO/L. Calçada, INAF-Padua/S. Zaggia)

Stellar evolution

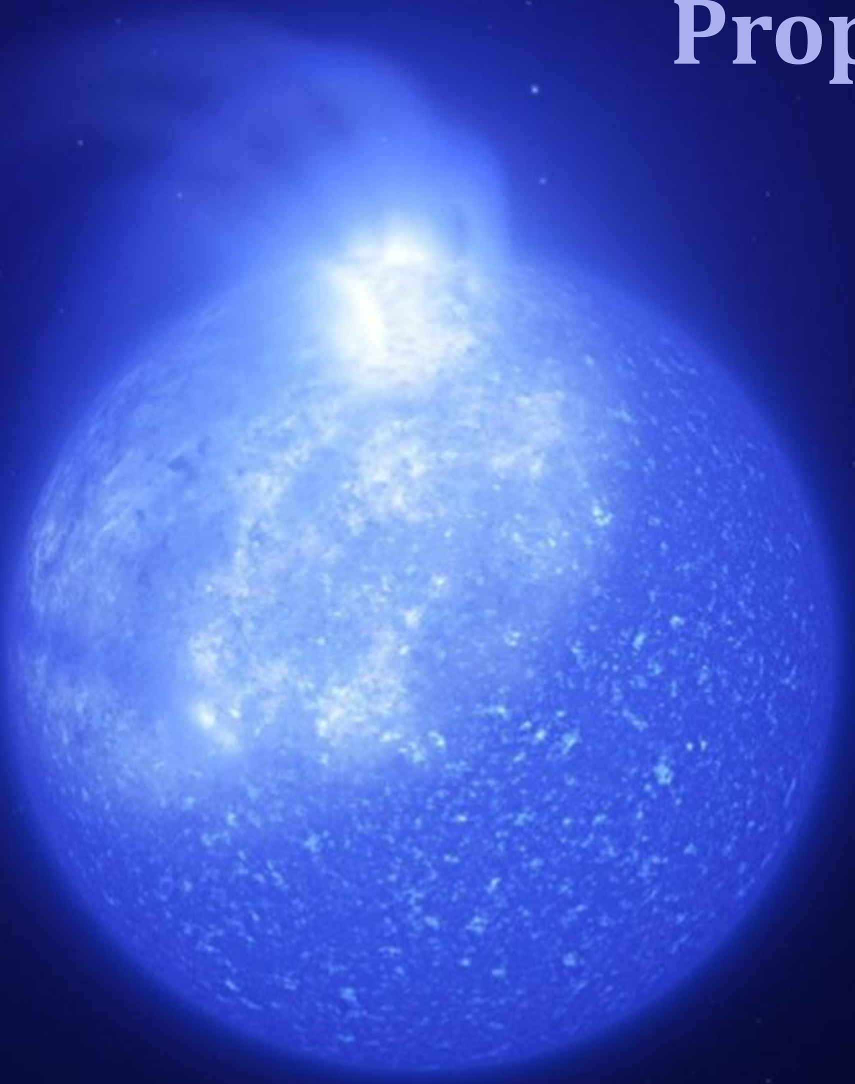


(Heber, 2009)

(ESO/L. Calçada, INAF-Padua/S. Zaggia)

Properties

sdB/O



$0.1 \sim 0.3\ R_\odot$

$10 \sim 100\ L_\odot$

$0.5\ M_\odot$

log(🍎) $4.5 \sim 6.5$ cm s^{-2}

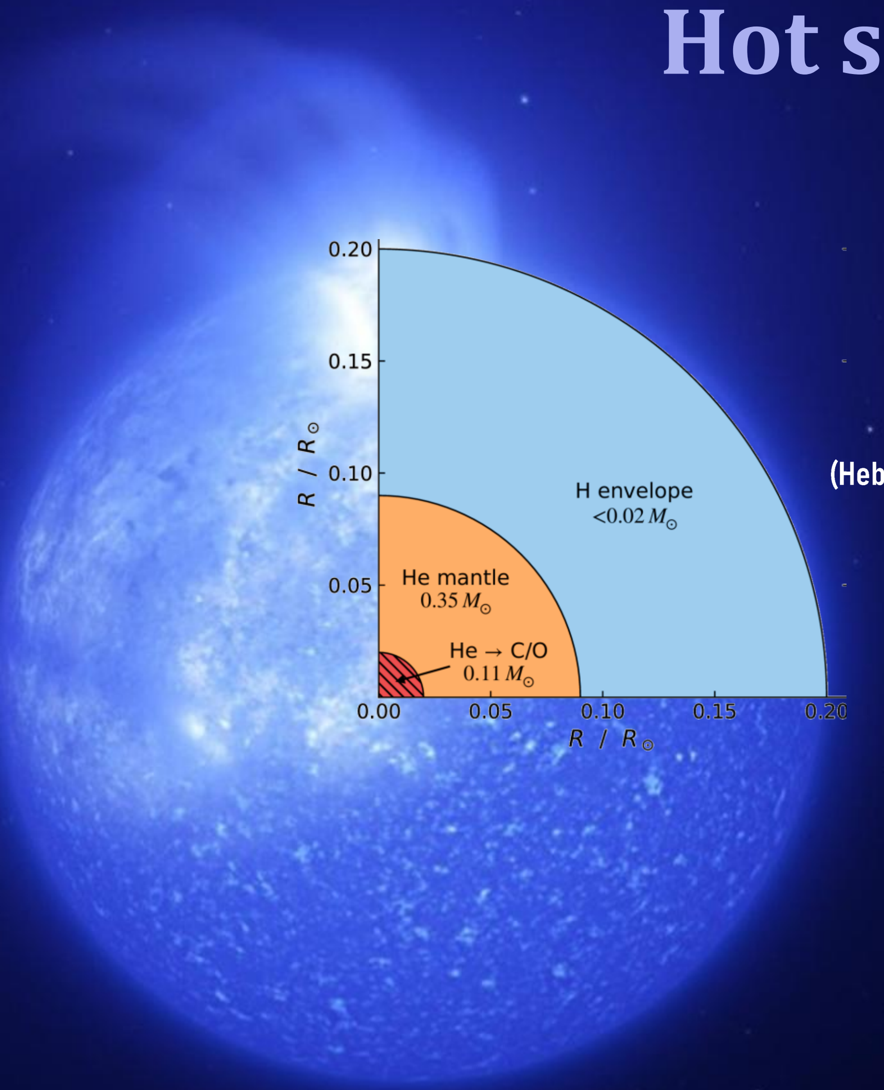
log(🍎$_\odot$) ~ 4.44 cm s^{-2}

$20.000 \sim 100.000$ K

(ESO/L. Calçada, INAF-Padua/S. Zaggia)

Hot subdwarf stars

sdB/O



(ESO/L. Calçada, INAF-Padua/S. Zaggia)

(Heber, 2024)

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log(🍎) $4.5 \sim 6.5$ cm s^{-2}

log(🍎$_\odot$) ~ 4.44 cm s^{-2}

$20.000 \sim 100.000$ K

Hot subdwarfs can **not** be explained by normal single stellar evolution.

Binary interaction

Stable mass transfer:
Roche lobe overflow (RLOF)

- Undergoing channel depends on the initial mass ratio
- Many hot subdwarfs are not in binaries

RLOF channel

(mass ratio < 1.2 - 1.5)

(Podsiadlowski et al., 2008)

Binary interaction

Stable mass transfer:
Roche lobe overflow (RLOF)

Unstable mass transfer:
Common envelope evolution (CEE)

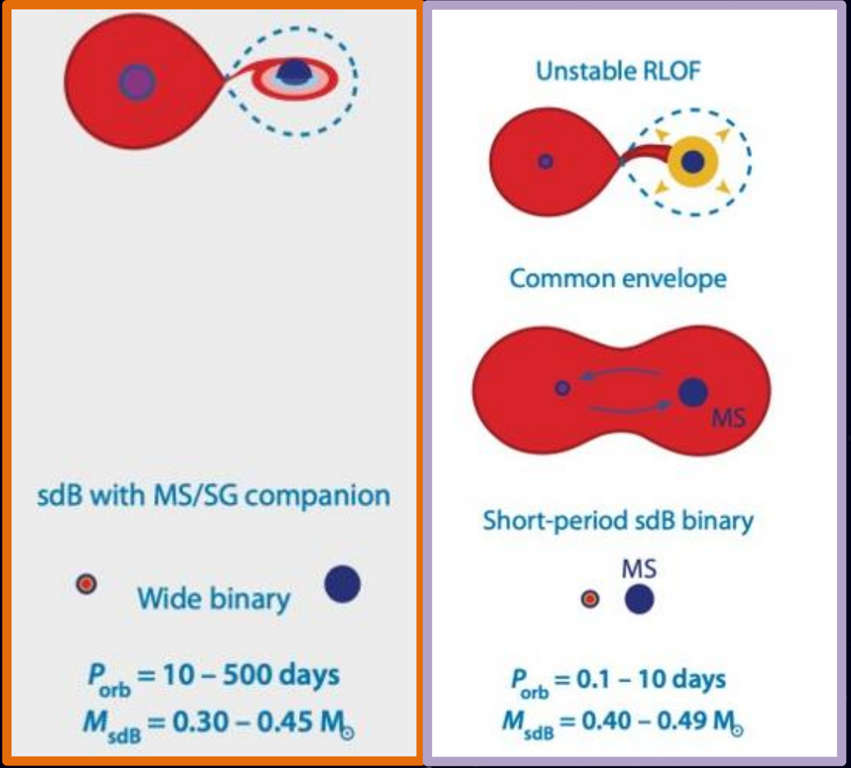
- Undergoing channel depends on the initial mass ratio
- Many hot subdwarfs are not in binaries

RLOF channel

(mass ratio < 1.2 - 1.5)

CE channel

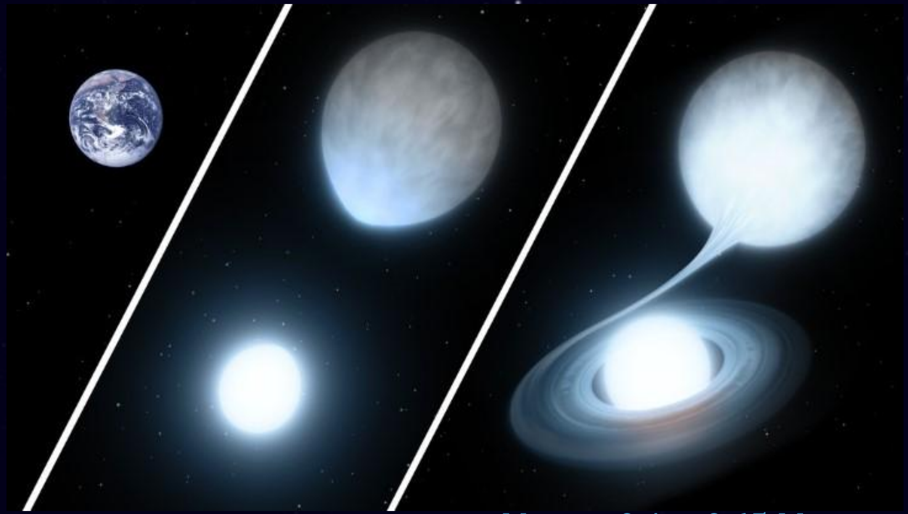
(mass ratio > 1.2 - 1.5)



(Podsiadlowski et al., 2008)

He-White dwarf mergers

(Credit: Caltech, 2019)



$M_{\mathrm{sdB}} = 0.4 - 0.65\ \mathrm{M}_\odot$

- Can explain single hot subdwarfs
  - The donor star gets tidally disrupted and accreted
    - Usually He-WD + He-WD

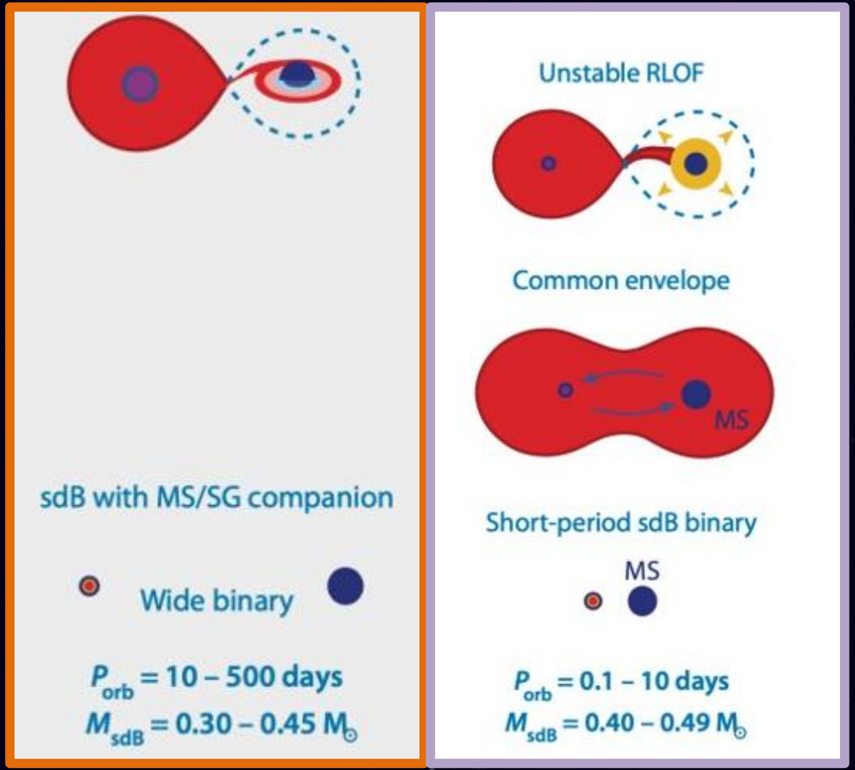
SINGLE STARS

RLOF channel

(mass ratio < 1.2 - 1.5)

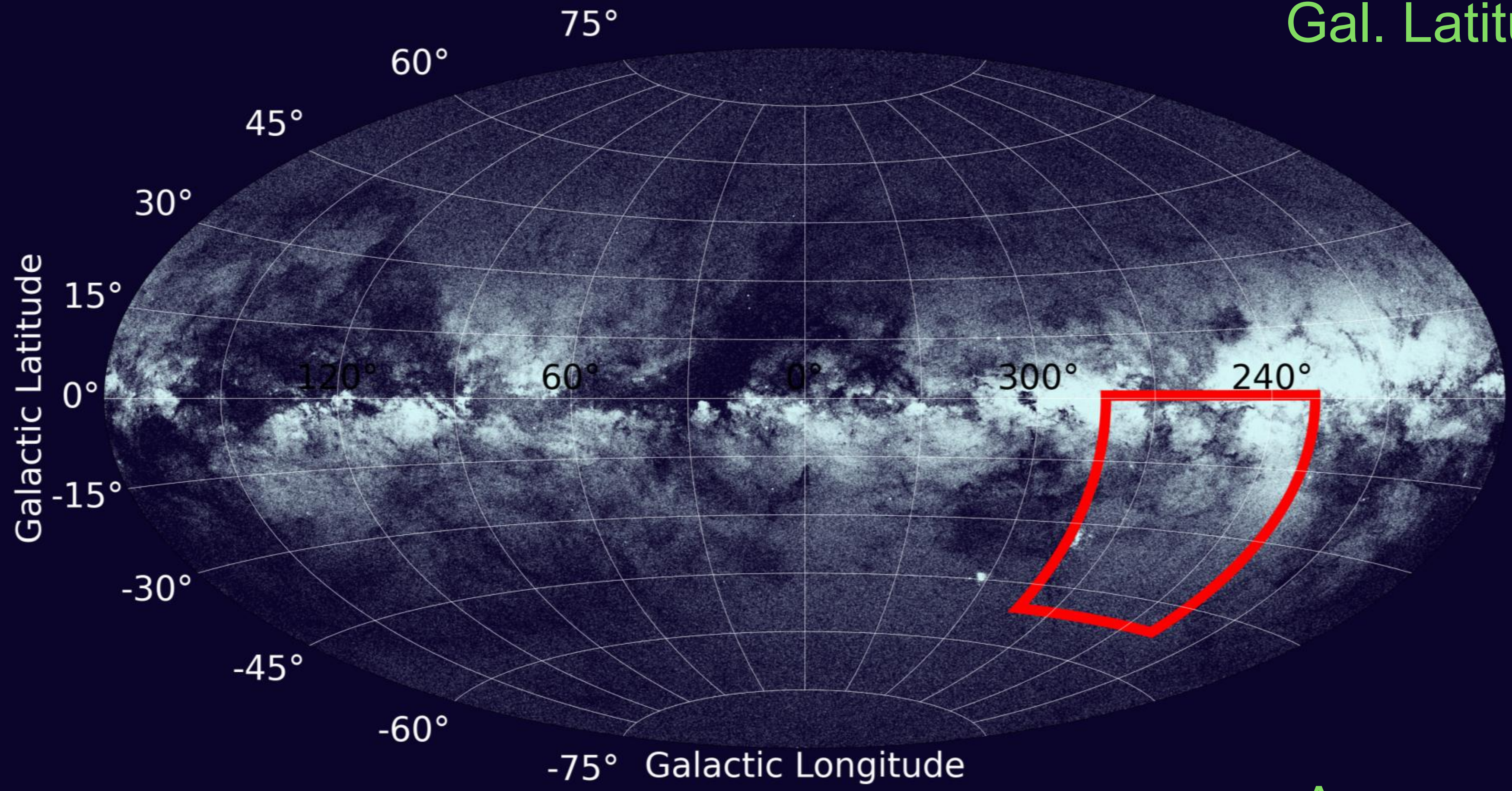
CE channel

(mass ratio > 1.2 - 1.5)



(Podsiadlowski et al., 2008)

BINARIES



Gal. Longitude 230.9° ~ 280.9°

Gal. Latitude - 49.6° ~ 0.4°

Parallax > 0 mas

Parallax error < 20 %

Colour - 0.7 ~ 0.7 mag

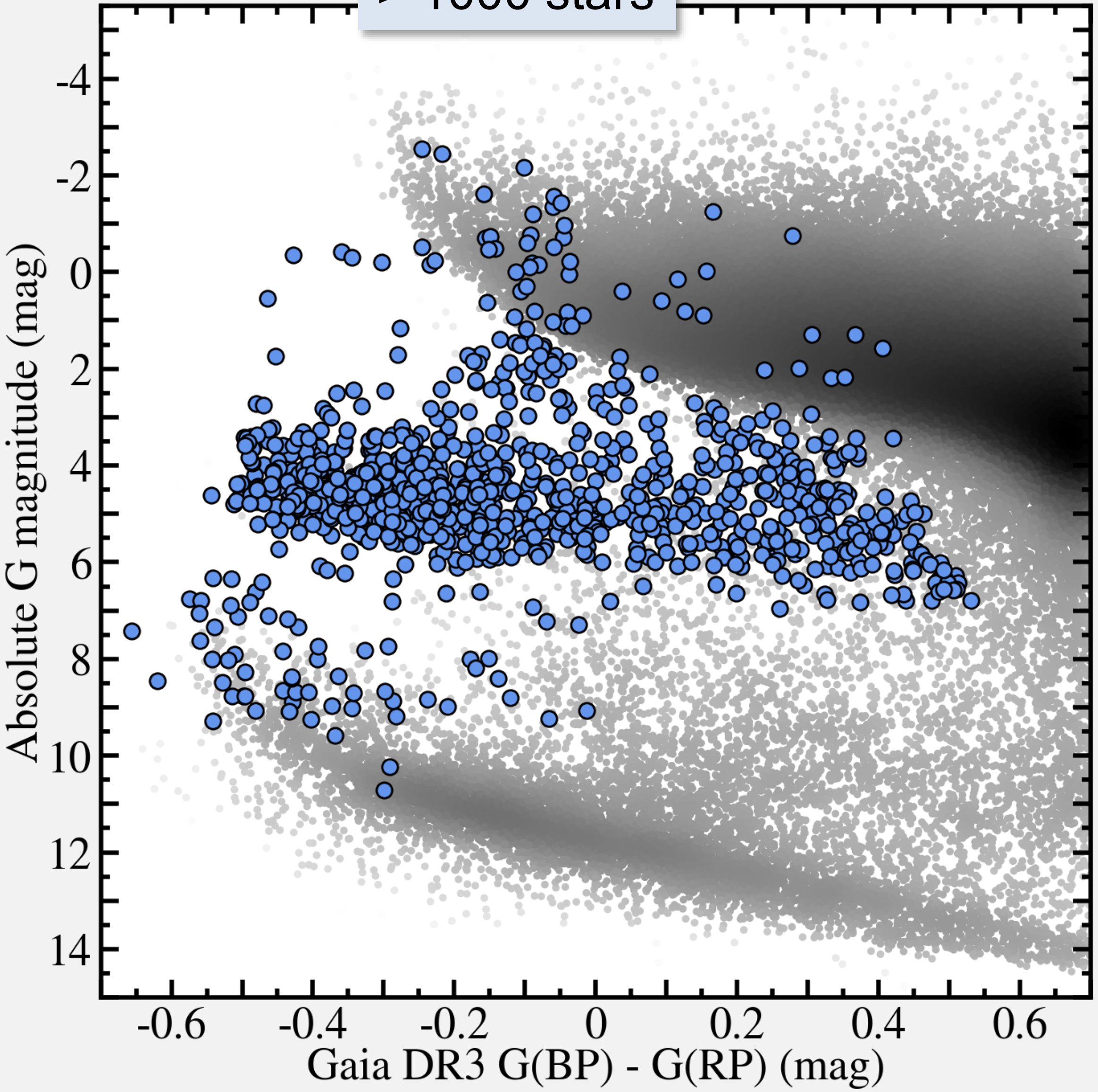
Apparent magnitude < 19.5 mag

Sample selection

Sample:

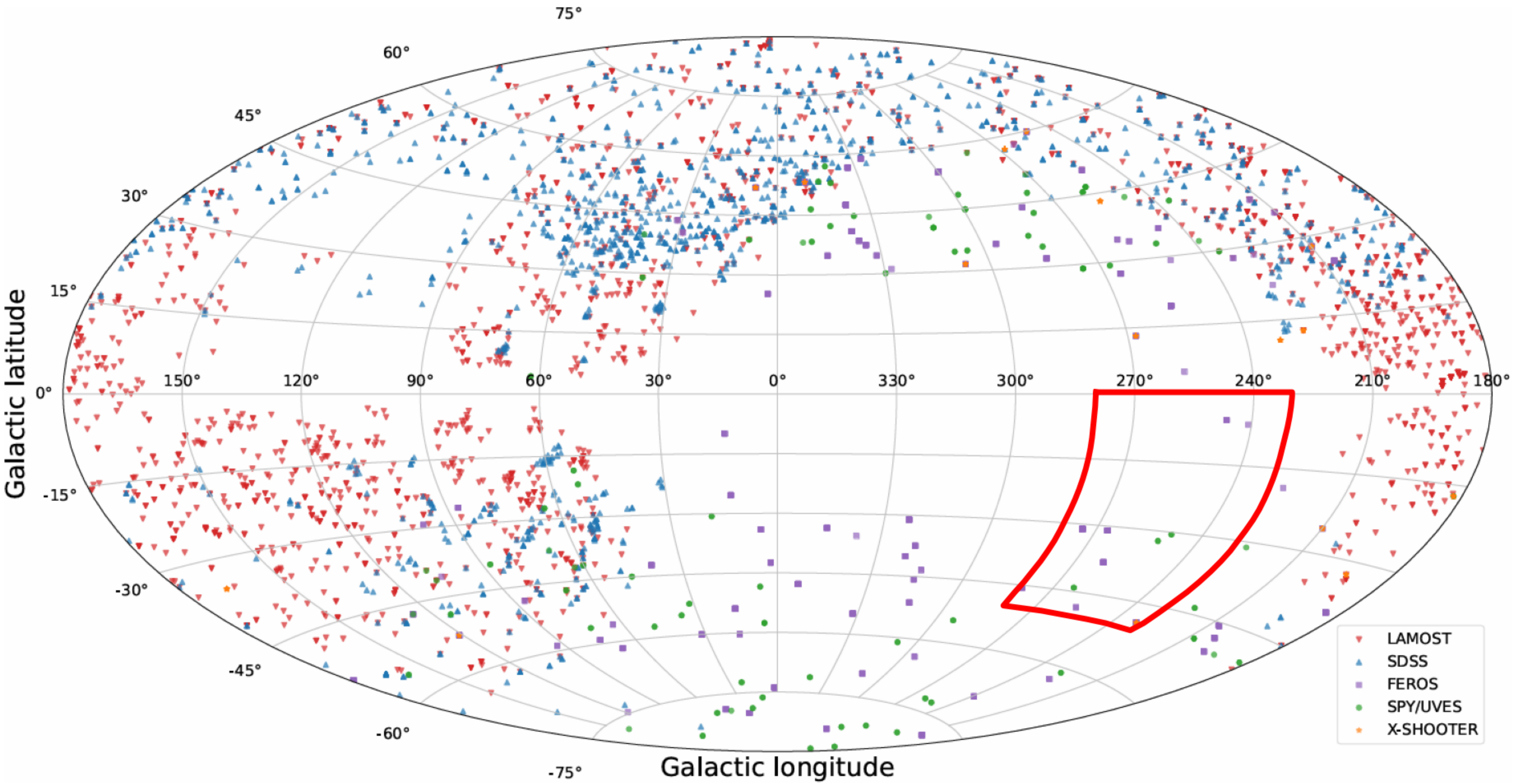
- Known hot subdwarfs
  (Geier, 2020 + Culpan, 2023)
- Candidate hot subdwarfs
  (Geier, 2019 + Culpan, 2023)

> 1000 stars



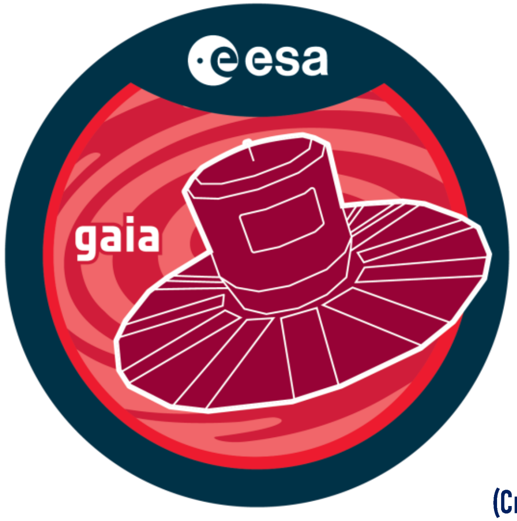
$M_G = m_G + 5 + 5 \cdot \log_{10}(\varpi/1000)$

Coverage of spectroscopic surveys



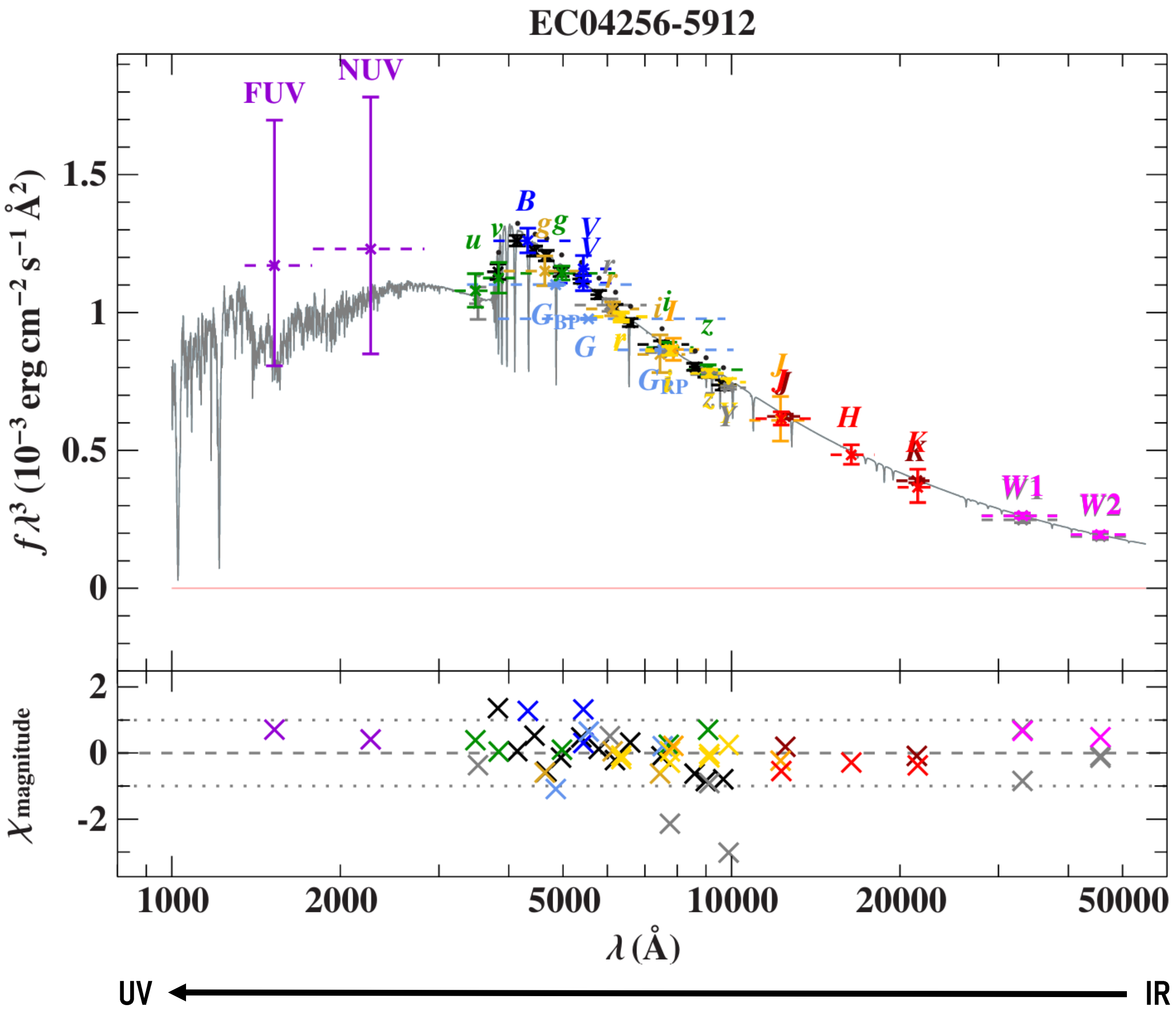
(Weich, 2025)

Gaia DR3 + SED fits: stellar parameters



(Credit: Gaia/ESA)

parallax ϖ



→ Temperature T_{eff}

→ Interstellar reddening $E(\mathrm{B-V})$

→ Angular diameter Θ

Composite binary SED fits

parameters for the companion star:

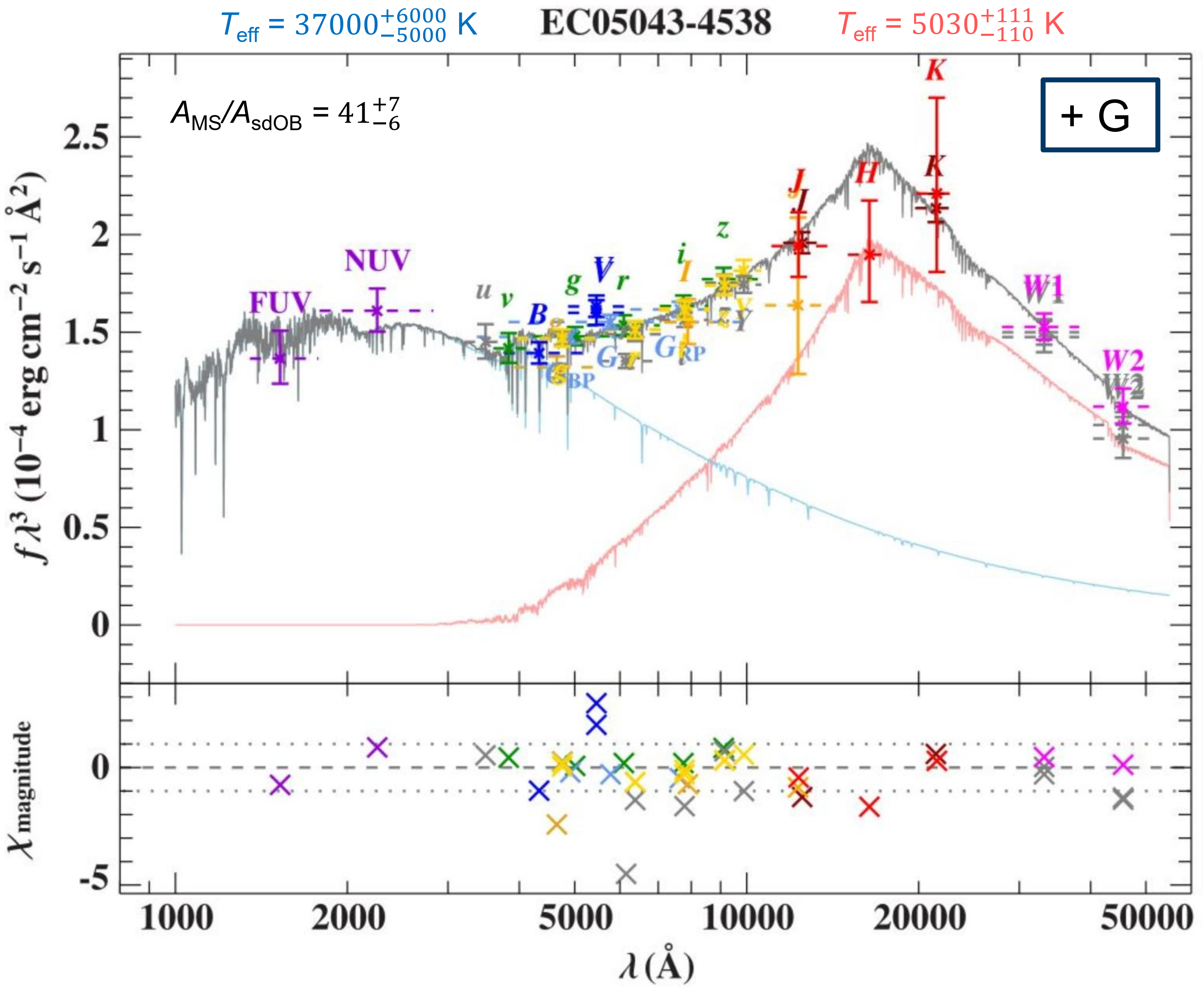
- log g: (4.5 ± 0.1) cgs | • T_{eff}: 2.3 ~ 7 kK

$$A = 4\pi\, R^2$$

$$R_{\mathrm{sdOB}} = 0.113\, R_{\odot}$$

$$R_{\mathrm{MS}} = 0.72\, R_{\odot}$$

$$\frac{A_{\mathrm{MS}}}{A_{\mathrm{sdOB}}} = \left(\frac{R_{\mathrm{MS}}}{R_{\mathrm{sdOB}}}\right)^2 = 41$$



Sample selection – error and magnitude cuts

- On the example of non-composites in the HRD (composites and companions analogous)

$$\Delta \log\left(\left(\frac{L}{L_\odot}\right)_{\max}\right) \leq |0.25|$$

$$\Delta \log\left(T_{\mathrm{eff,\,max}}\right) \leq |0.05|\ [\mathrm{K}]$$

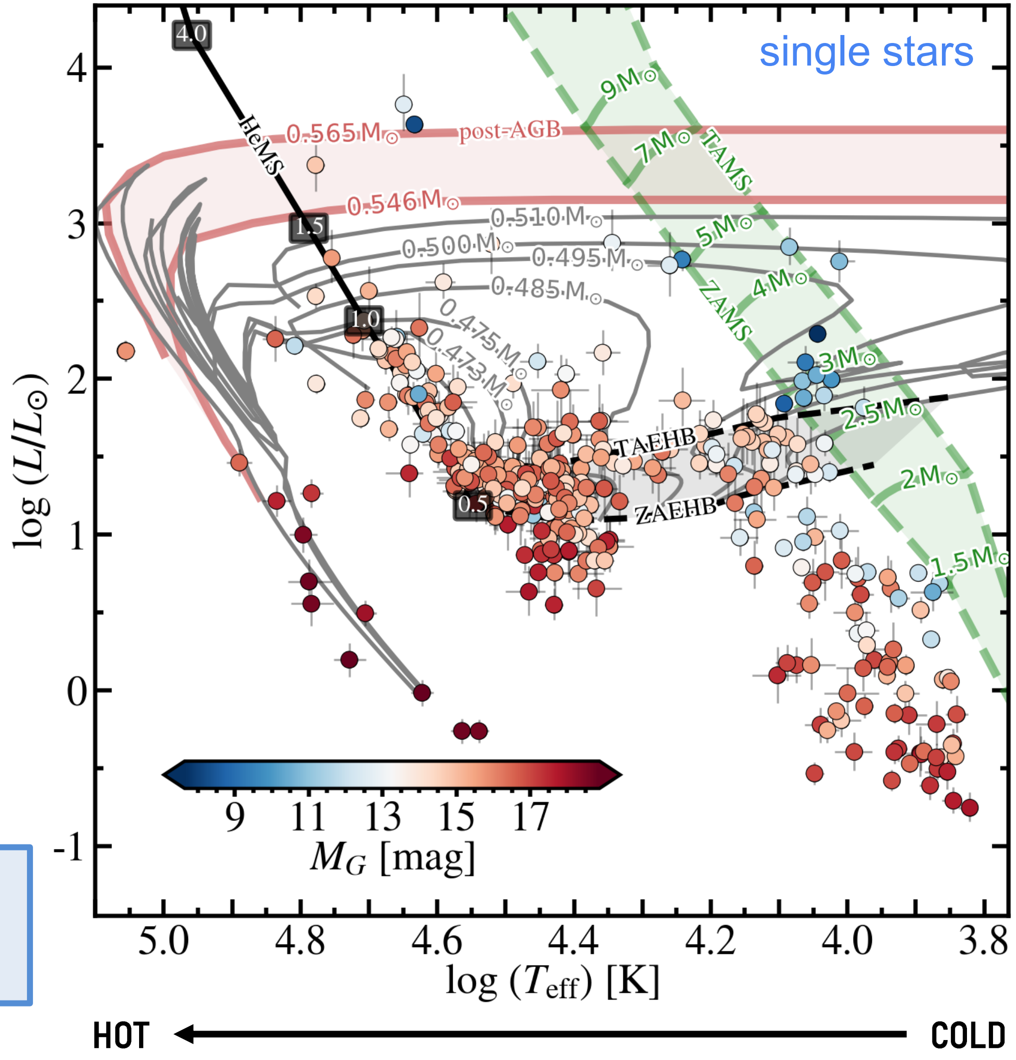
$$\Delta \log\left(\left(\frac{R}{R_\odot}\right)_{\max}\right) \leq |0.1|$$

$$L \propto \left(\frac{\Theta}{2\varpi}\right)^2 T_{\mathrm{eff}}^4$$

$$R = \frac{\Theta}{2\varpi}$$

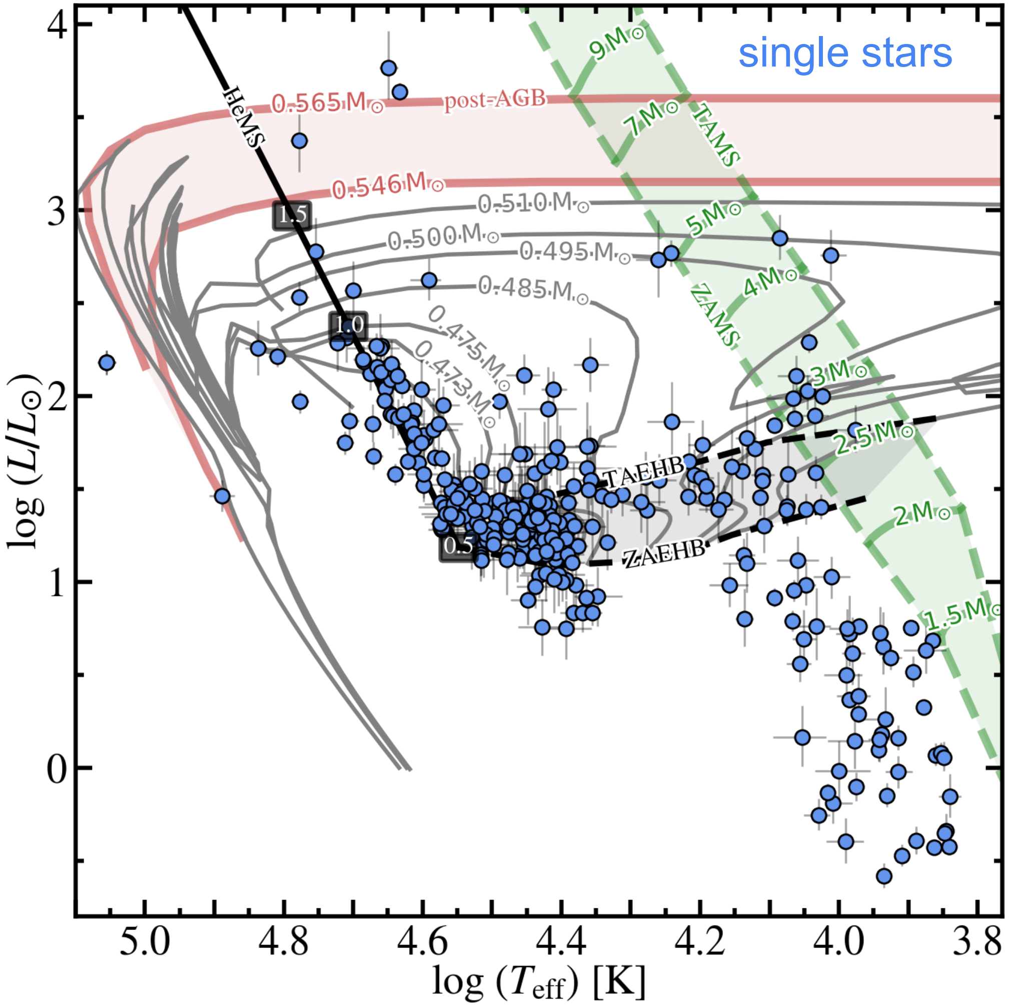
From 1050 → 352 objects

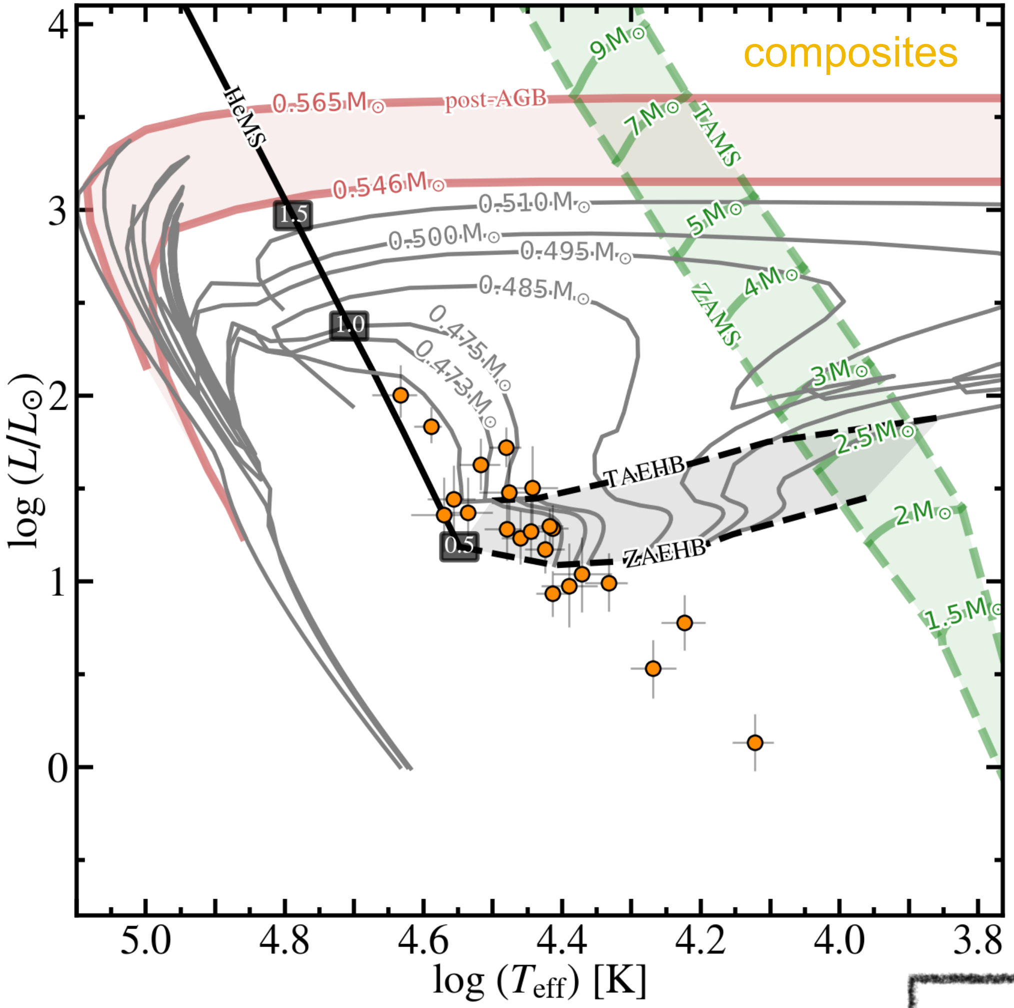
≤ 17 mag for the *PLATO* mission



Fundamental stellar parameters - Luminosity

- The primary star





HOT ← COLD

$$L \propto \left(\frac{\Theta}{2\varpi}\right)^2 T_{\mathrm{eff}}^4$$

(Tracks: Dorman et al., 1993; Schaller et al., 1992; Miller Bertolami, 2016; Paczyński, 1971)

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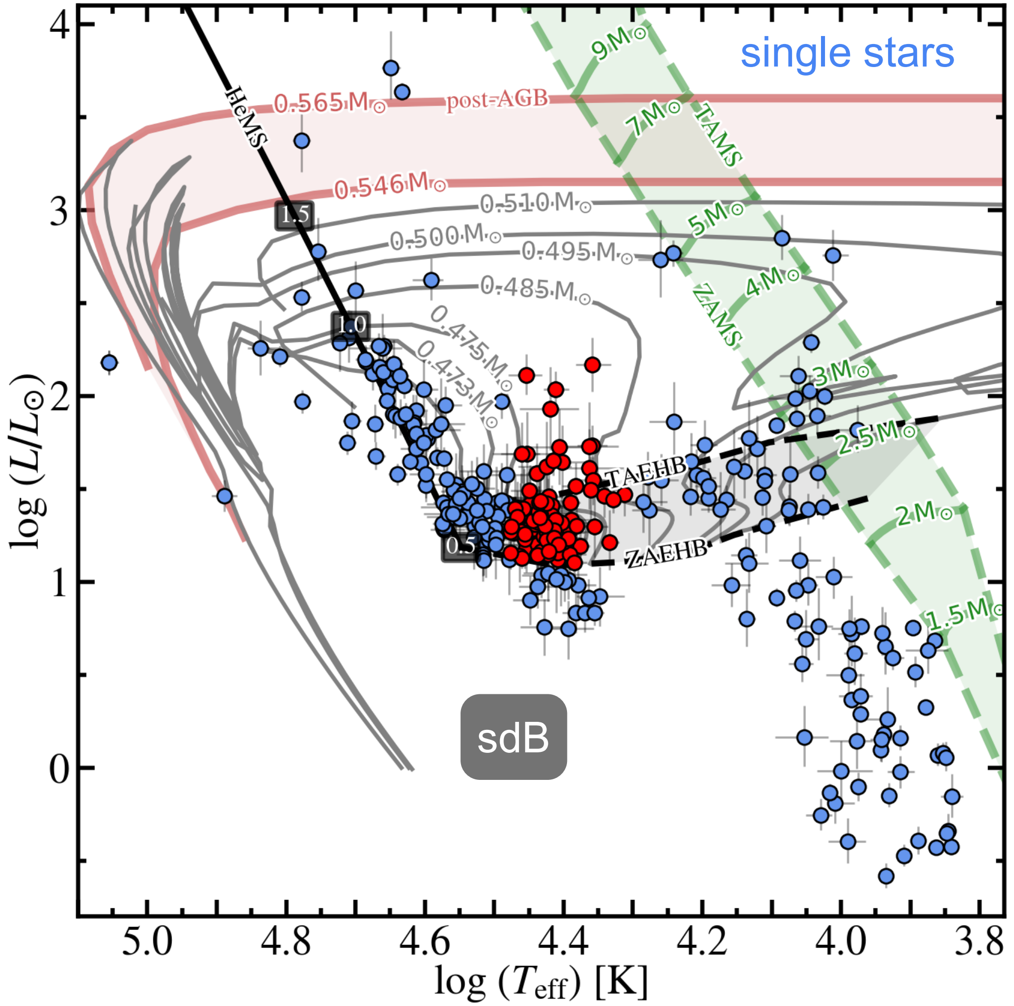

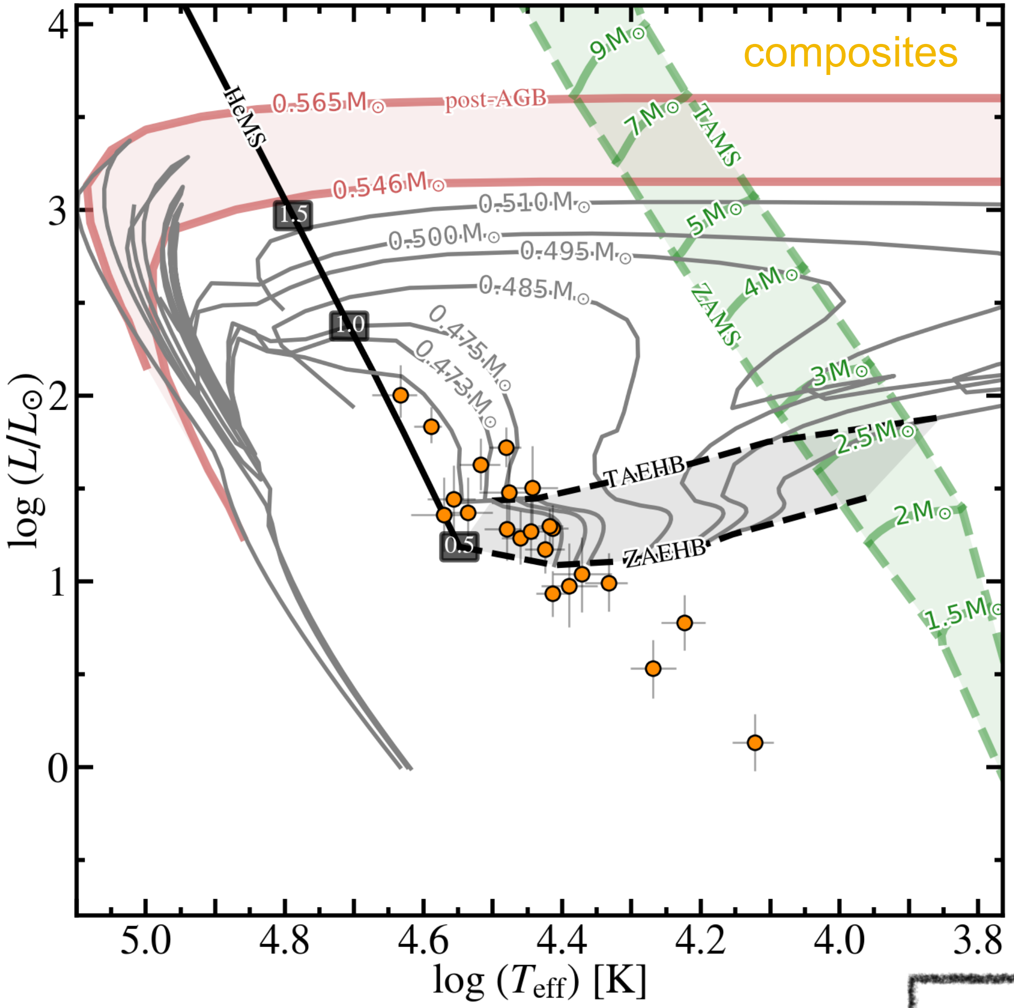

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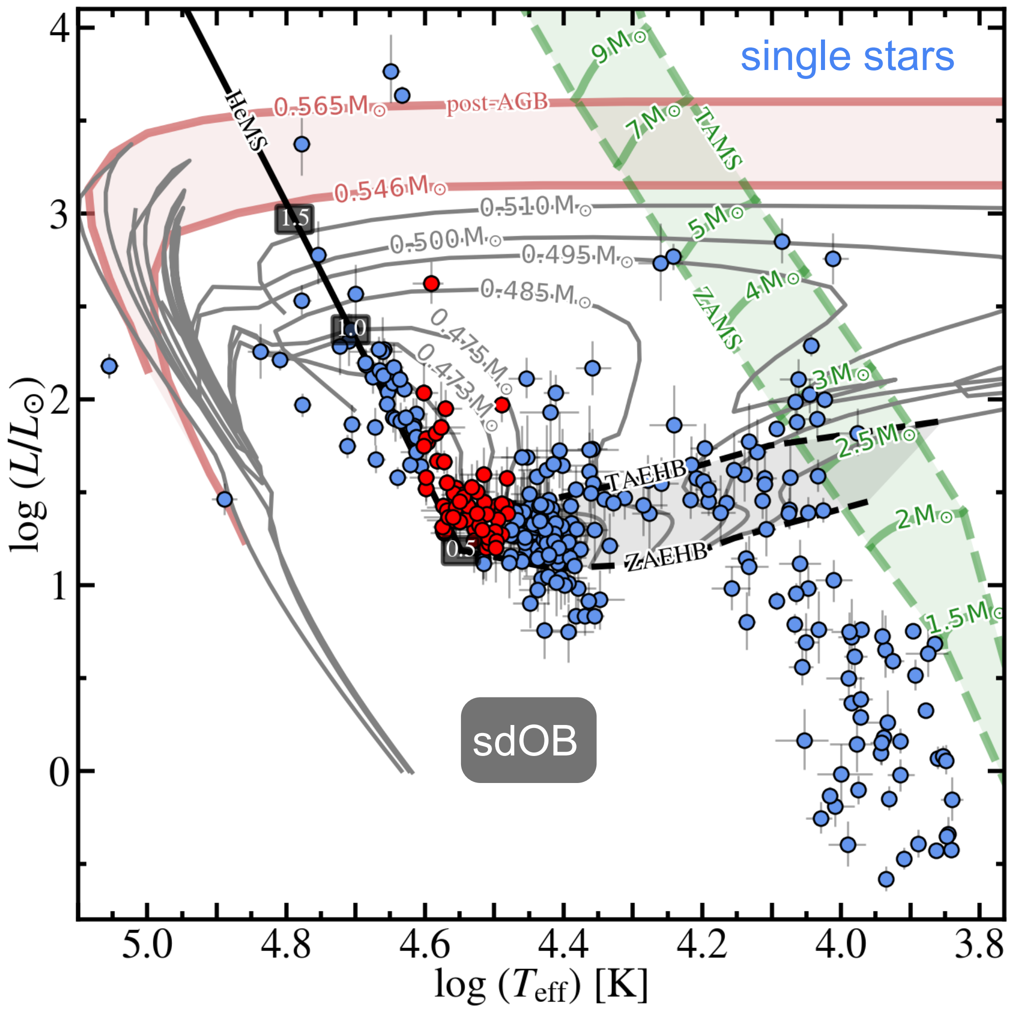

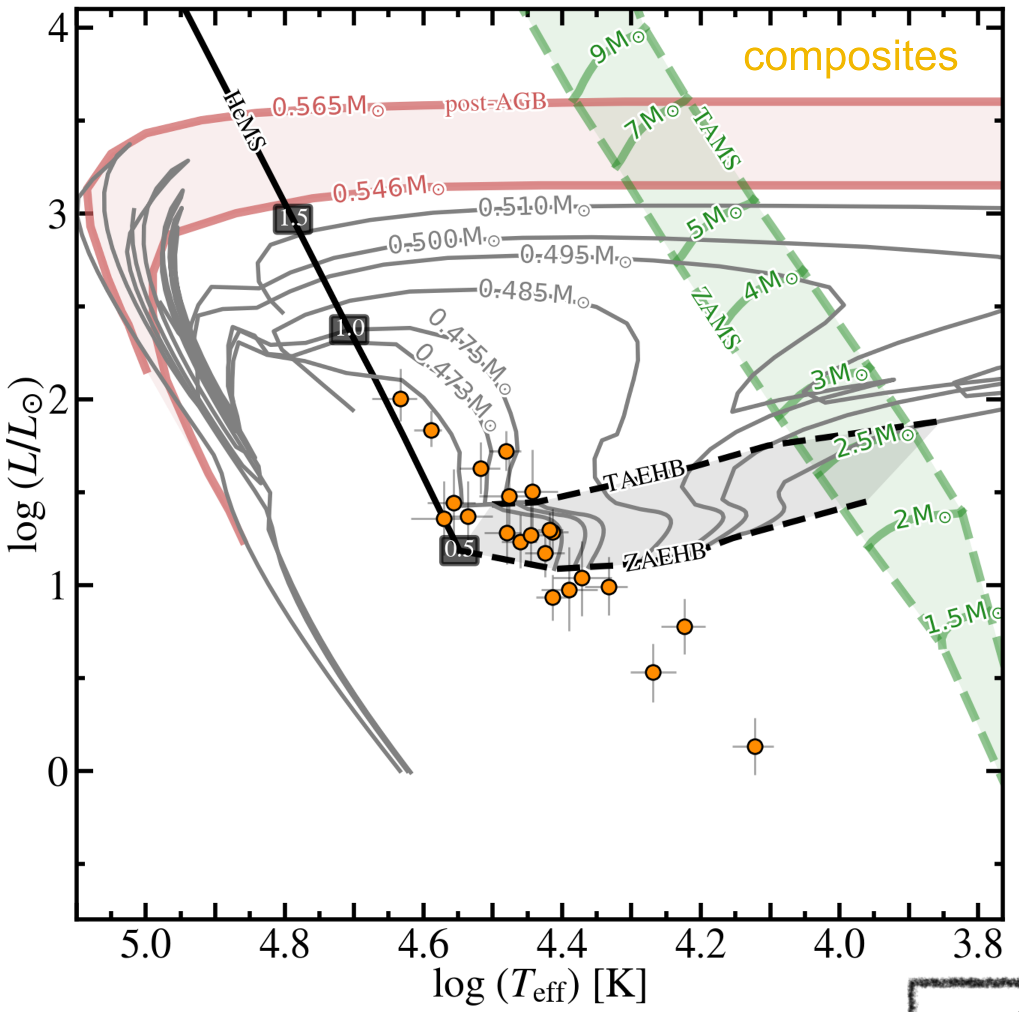

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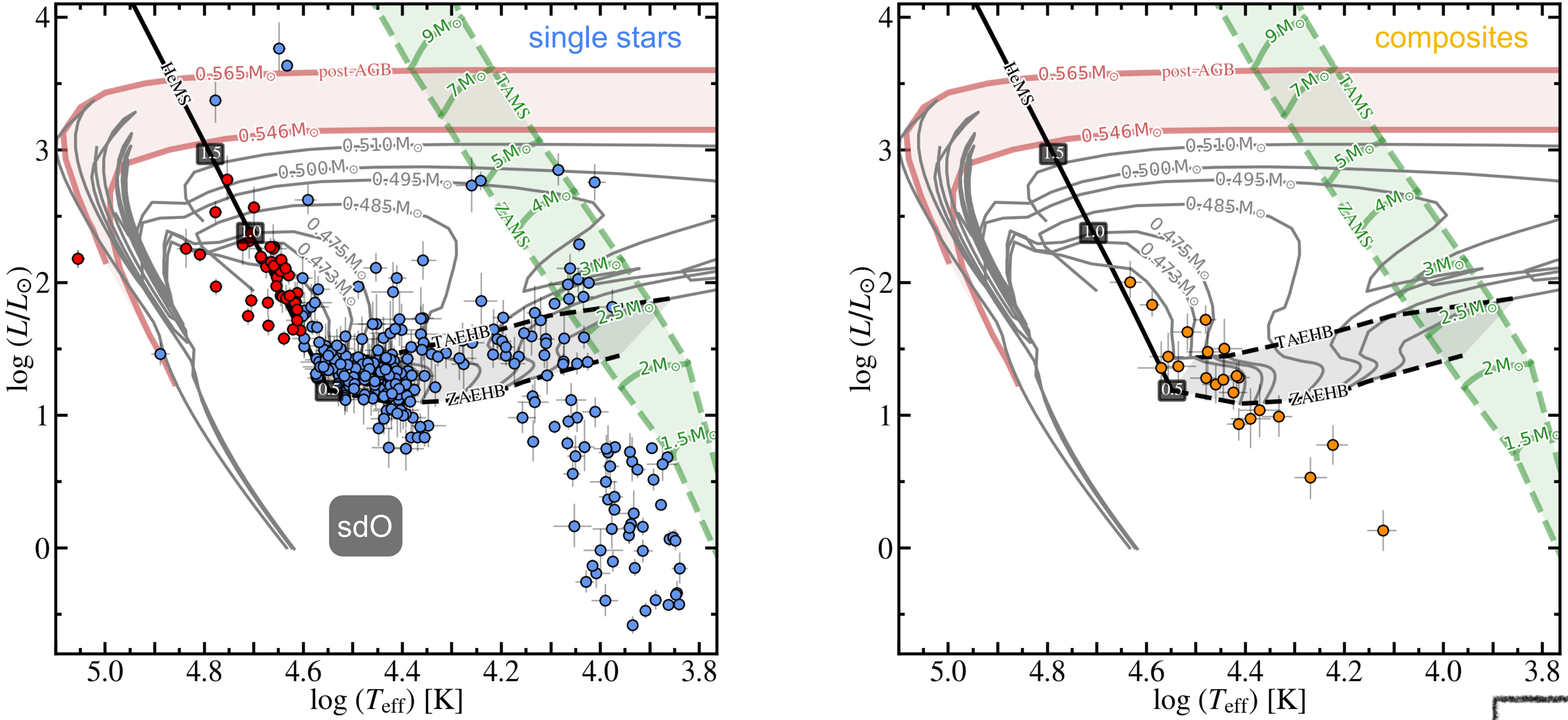

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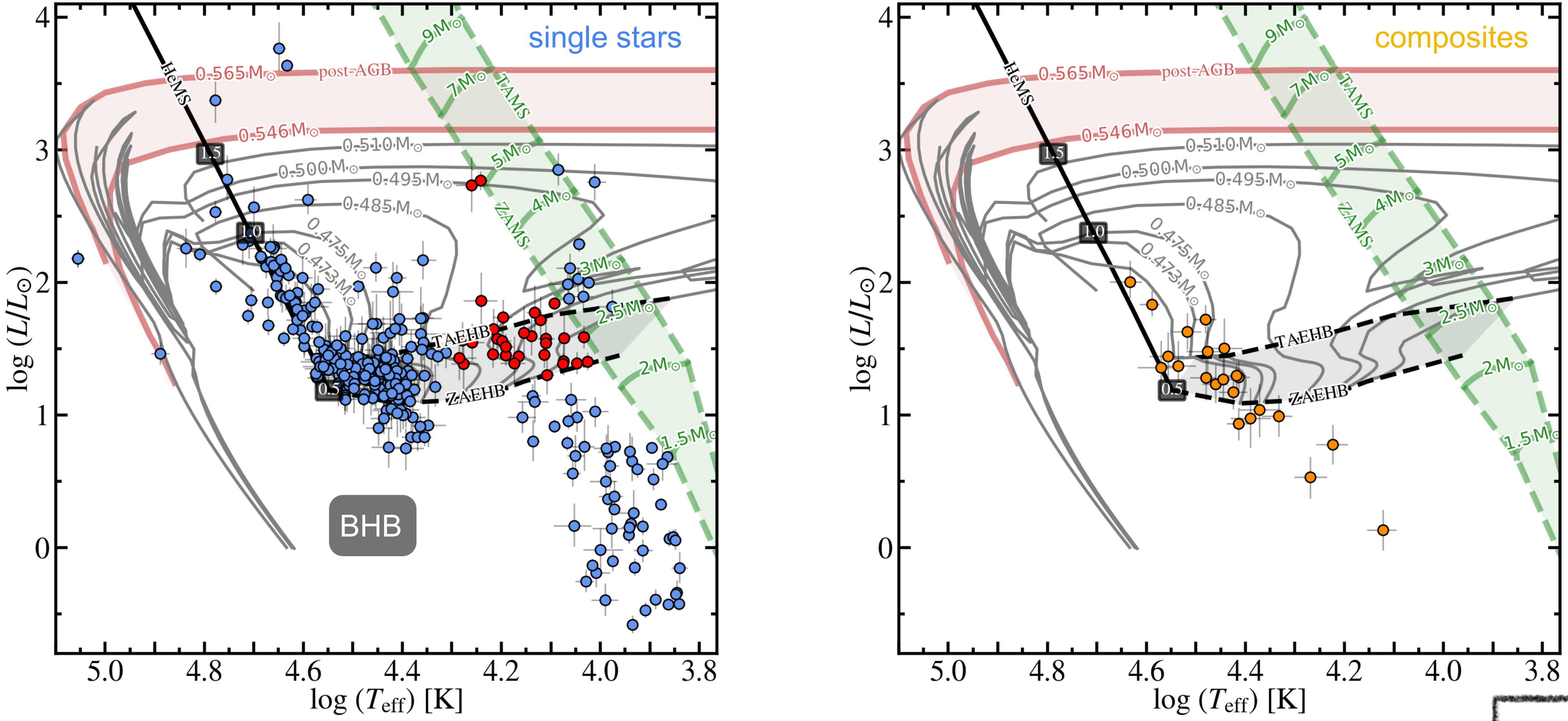

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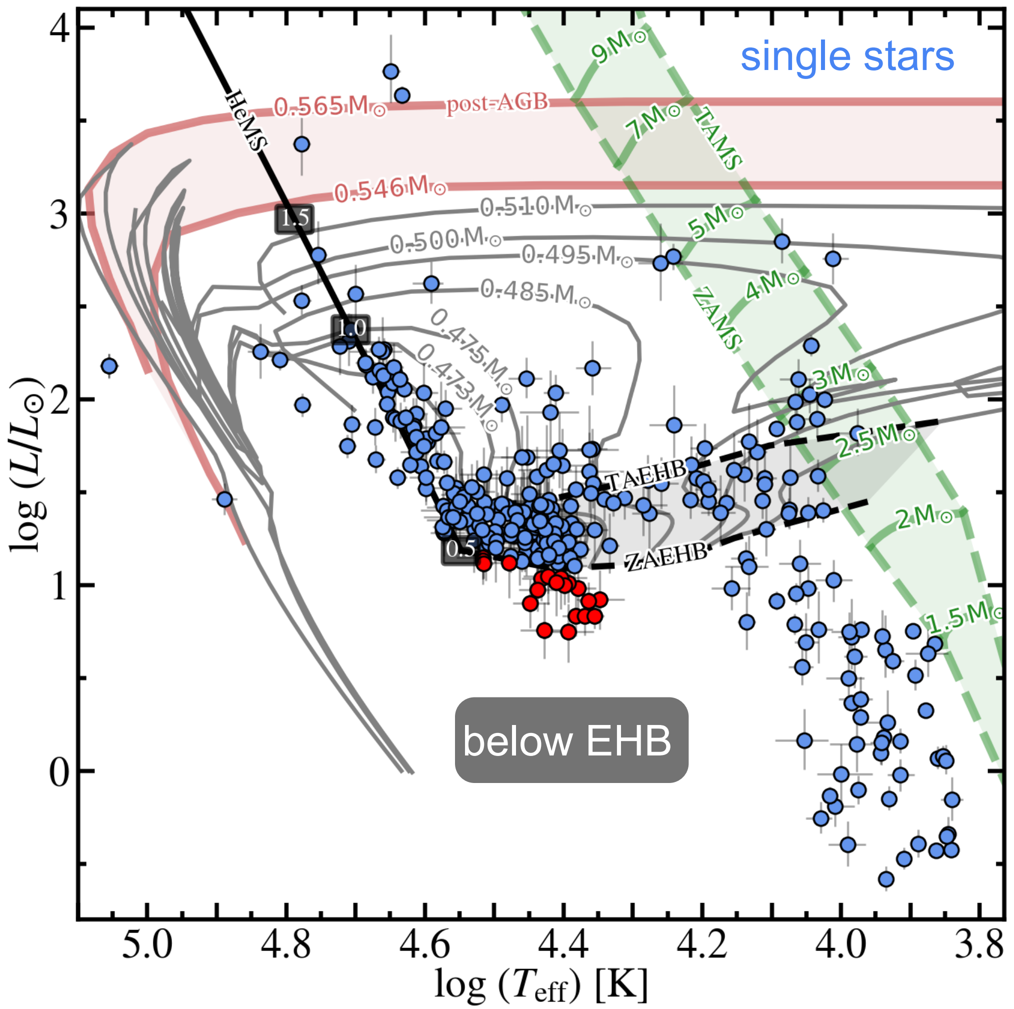

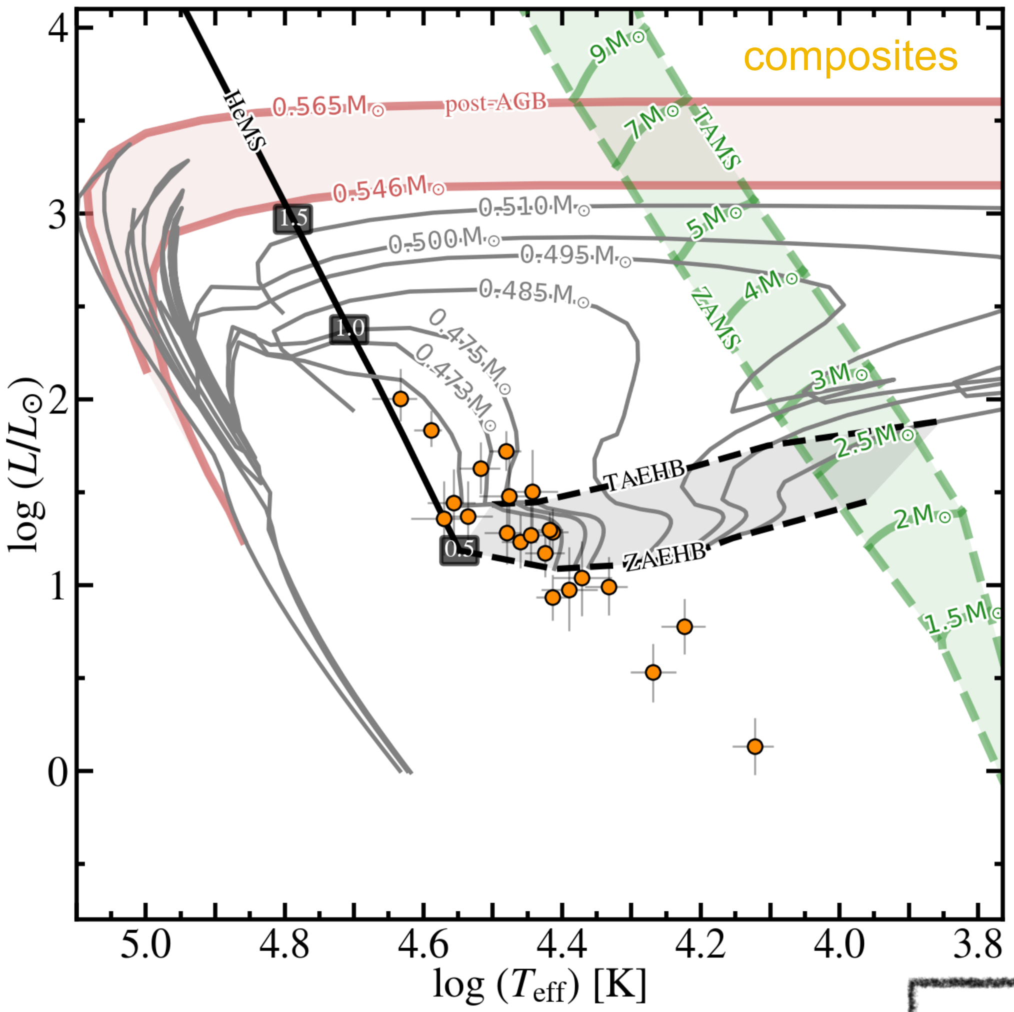

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Fundamental stellar parameters - Luminosity

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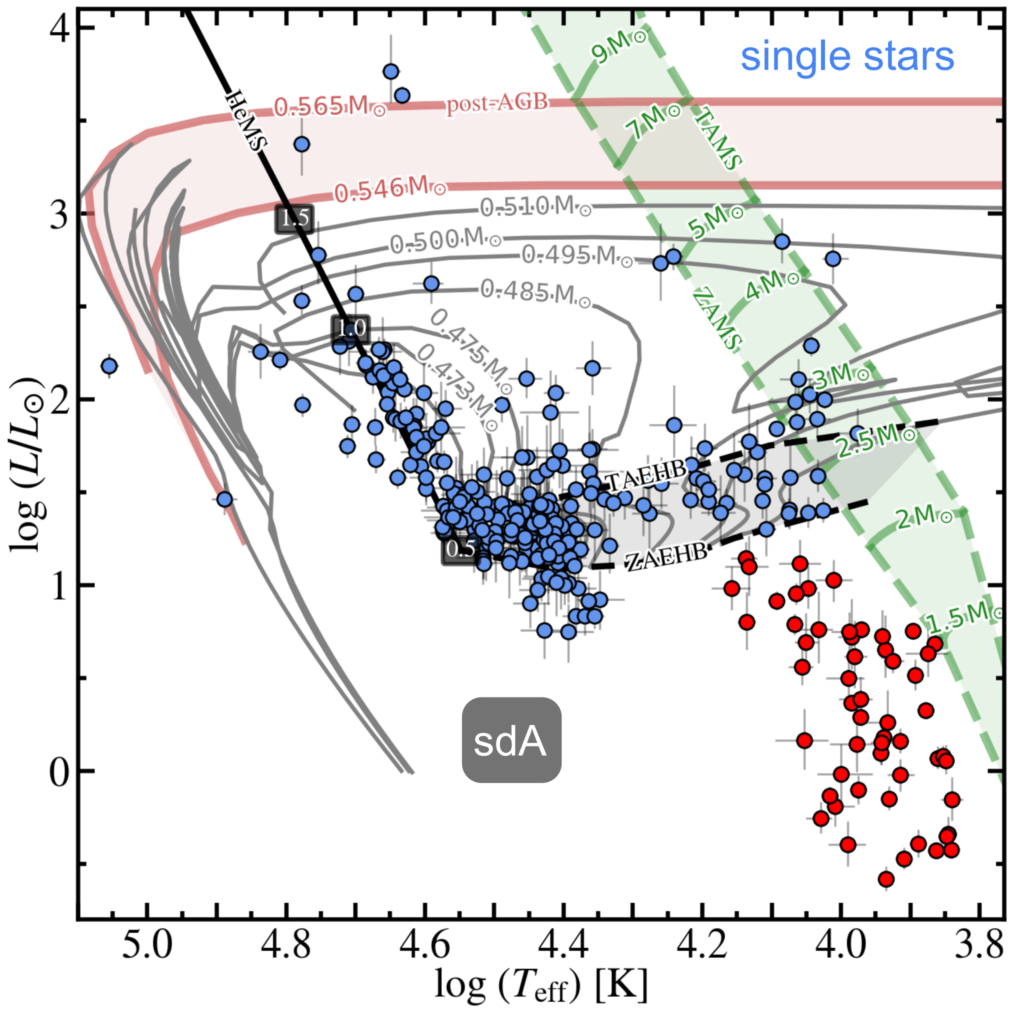

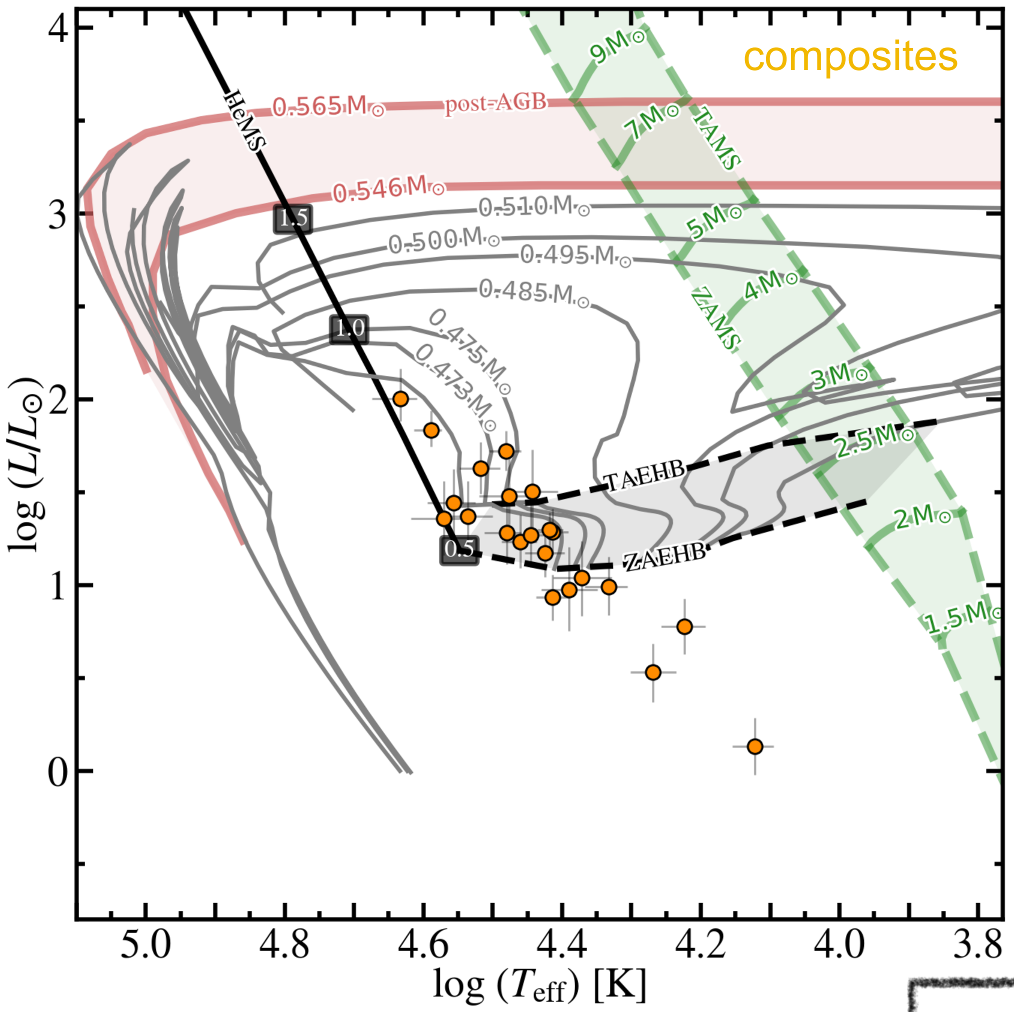

HOT ← **COLD**

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Fundamental stellar parameters - Luminosity

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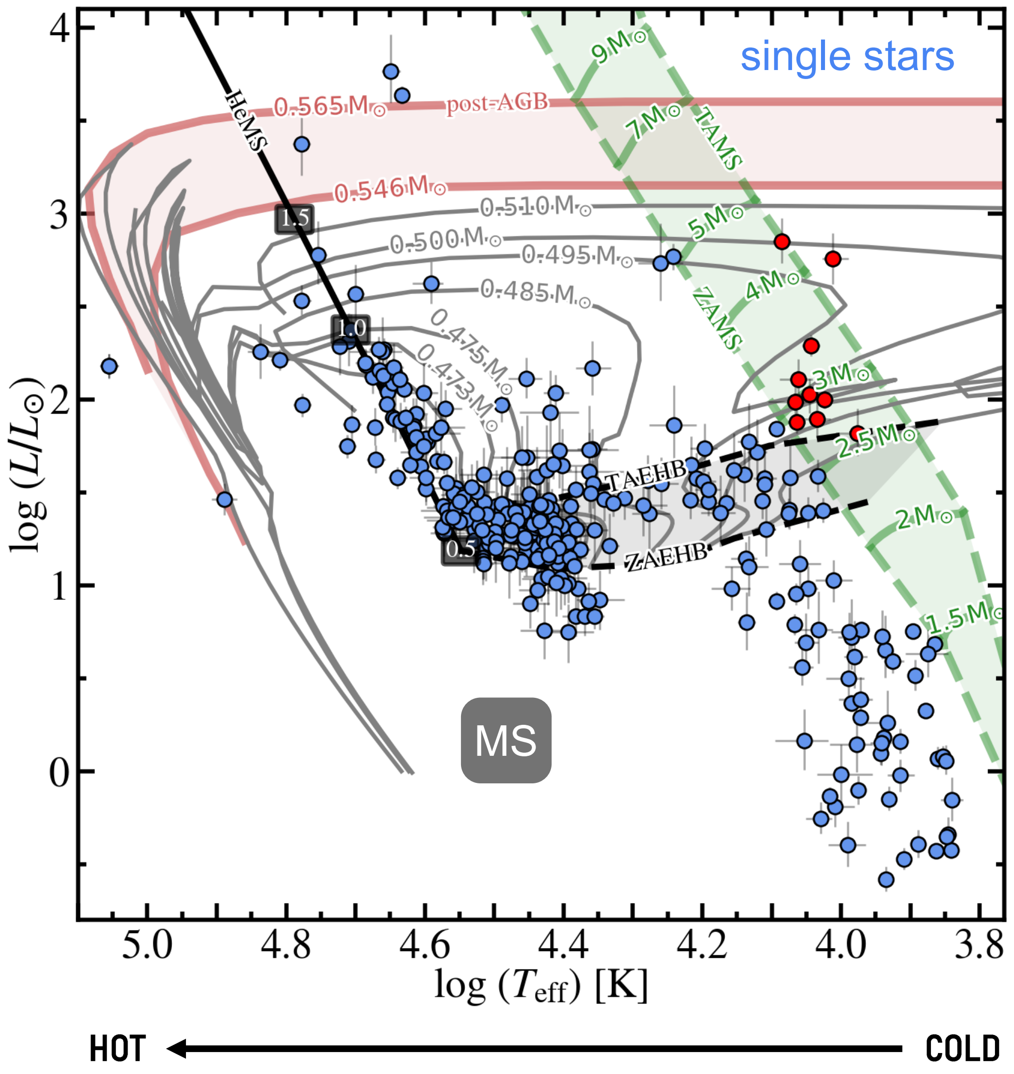

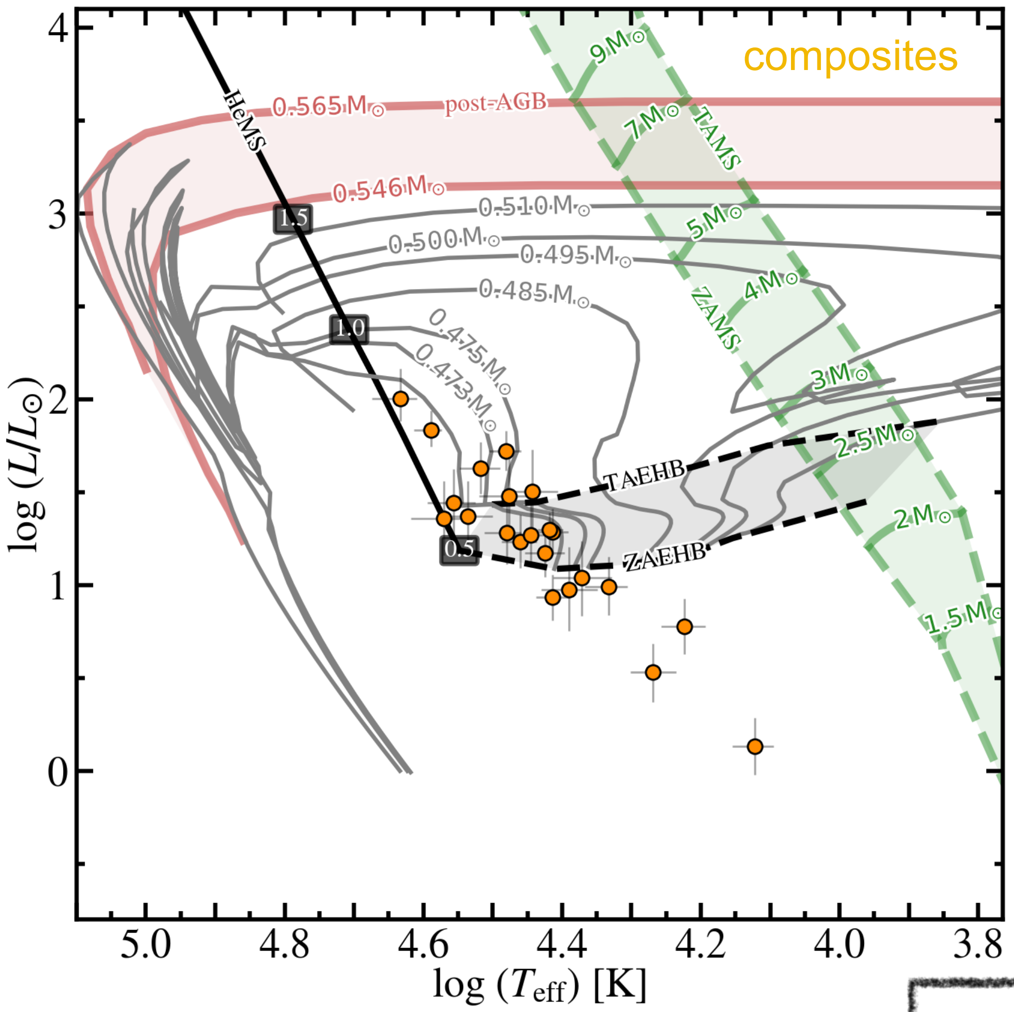

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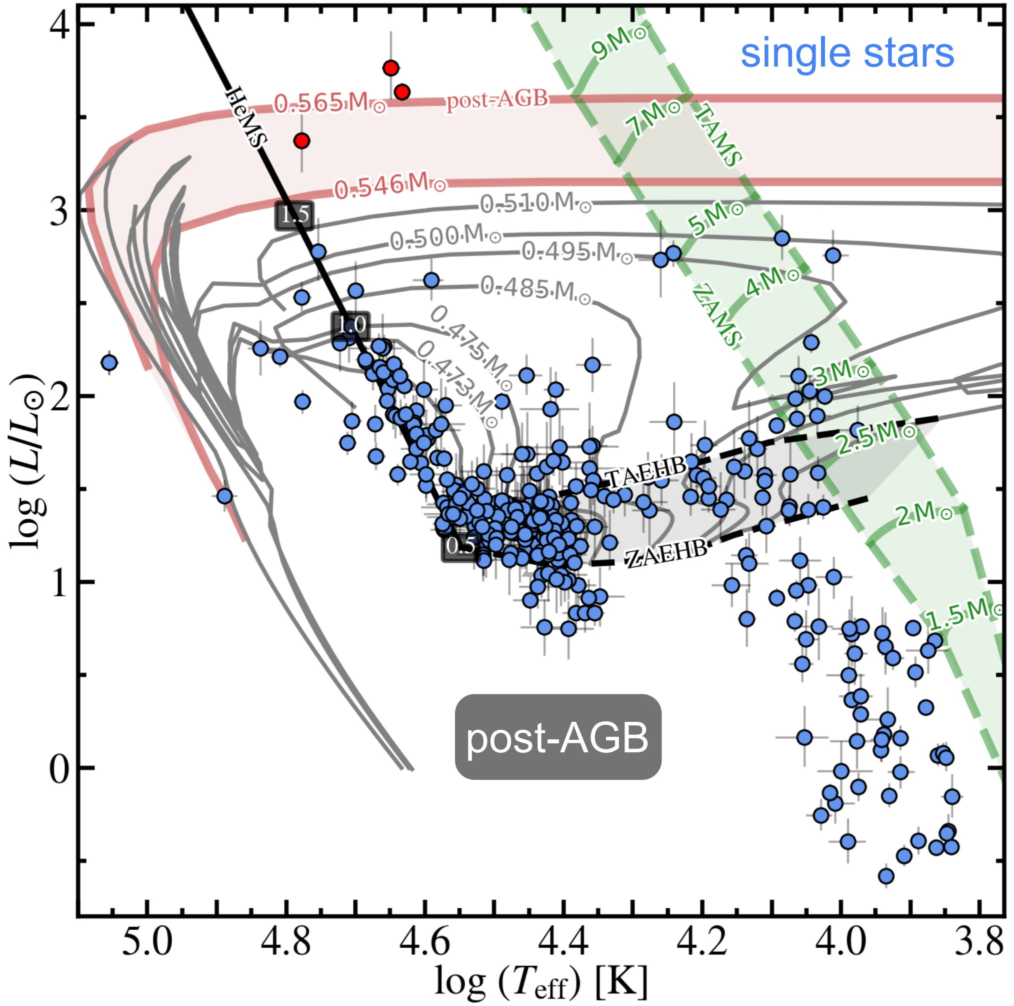

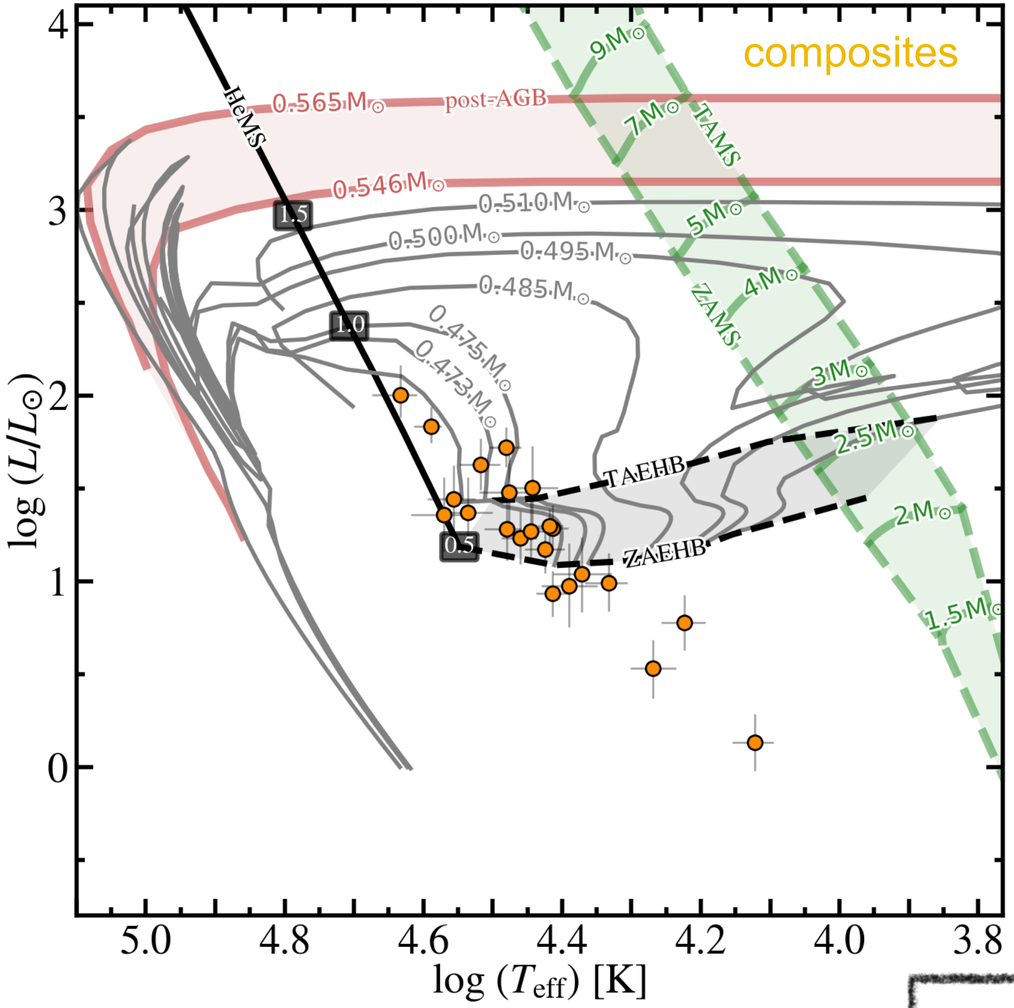

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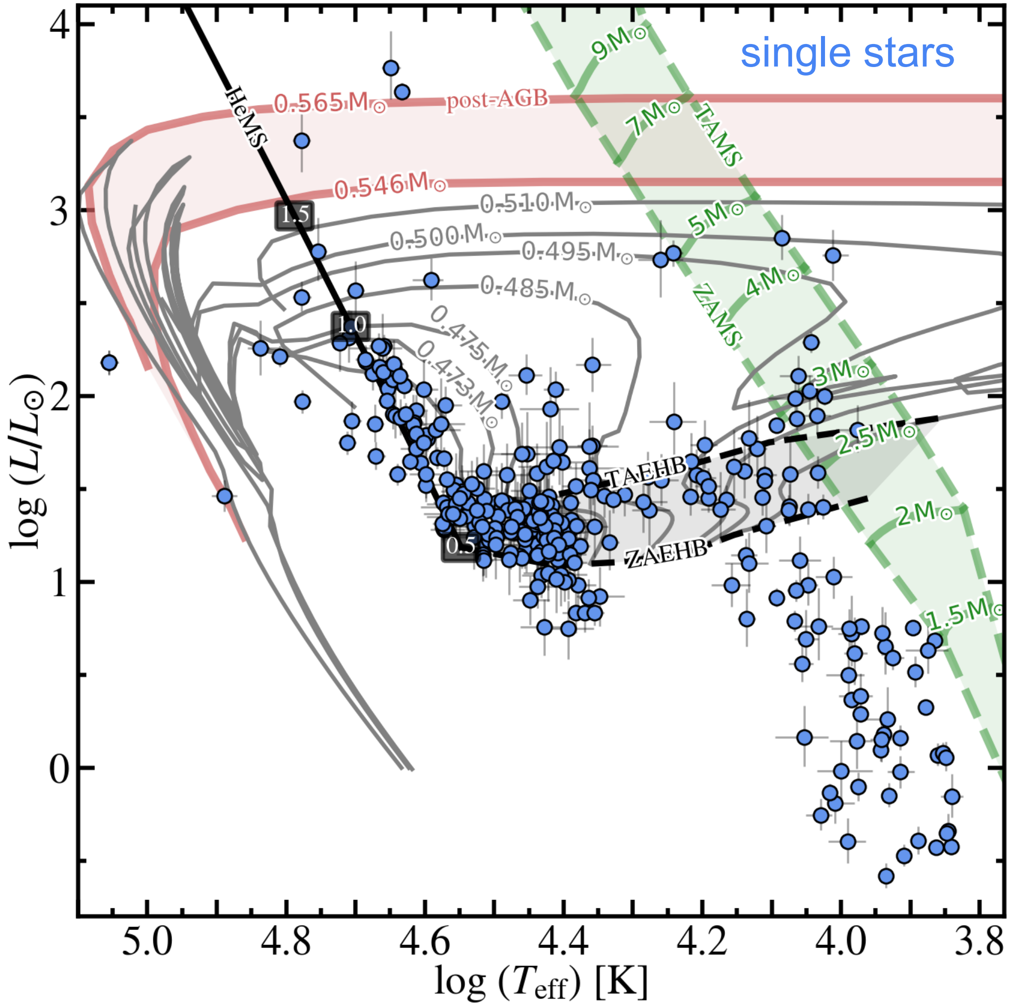
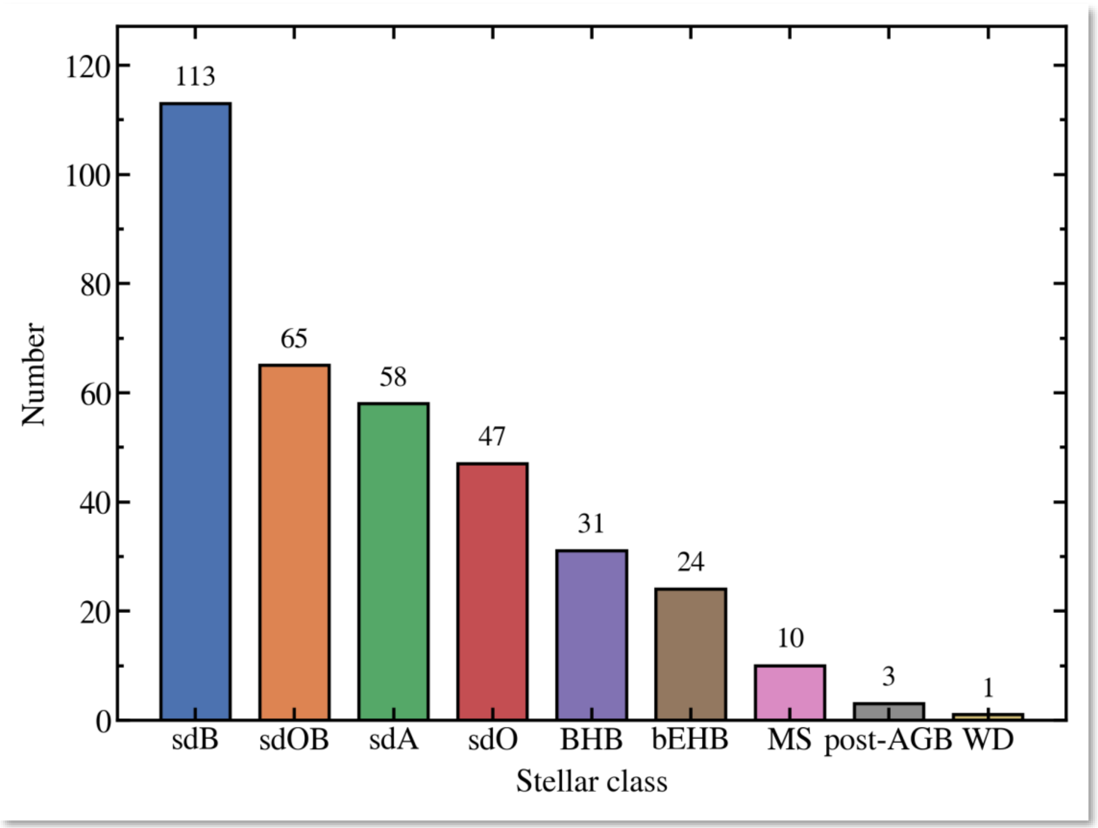
Wrap-up: The targets in the HRD

- Total of 352 objects (SED-confirmed hot subdwarfs ~240, ~8% composite spectrum)

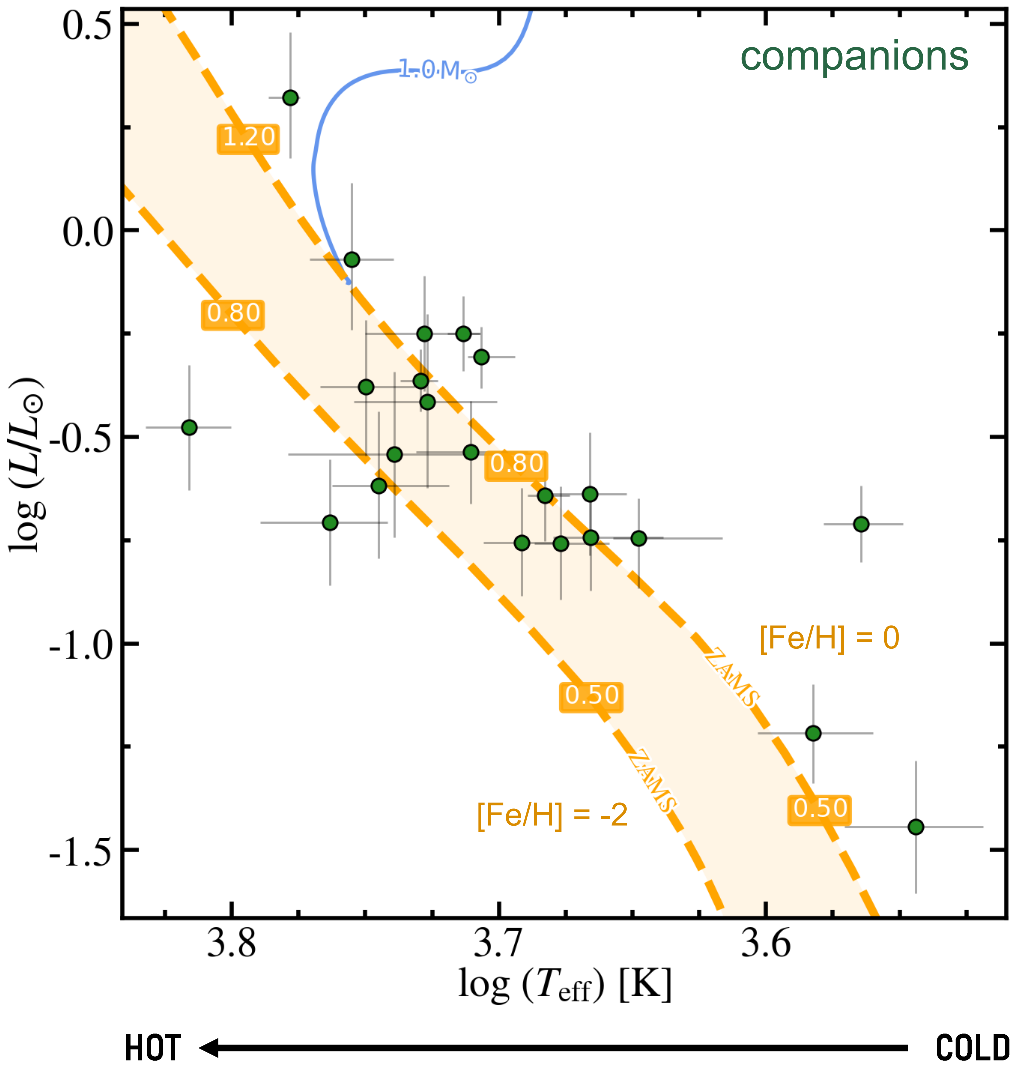




(Tracks: Dorman et al., 1993; Schaller et al., 1992; Miller Bertolami, 2016; Paczyński, 1971)

Fundamental stellar parameters - Luminosity

- The main-sequence companion



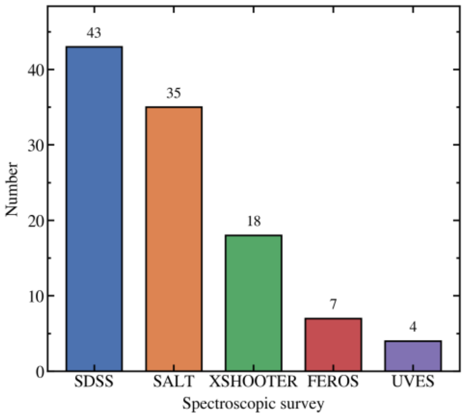
(Tracks: Dotter, 2016)

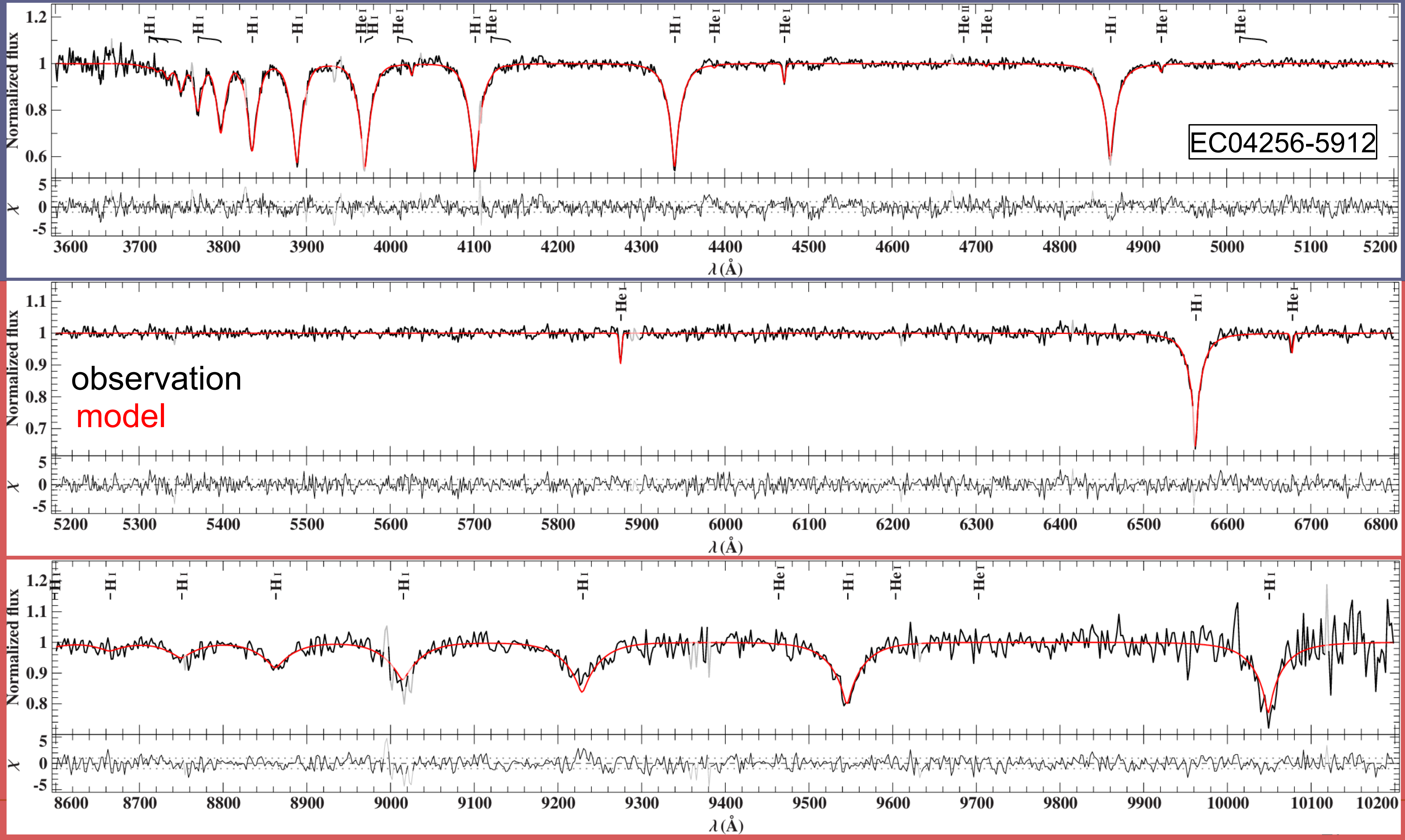
→ mainly normal (F/G/K-type) main sequence stars

Spectral fitting: optical and NIR

(Credit: Sloan Digital Sky Survey, 2022)

107 non-composite spectra





→ $T_{\rm eff}$

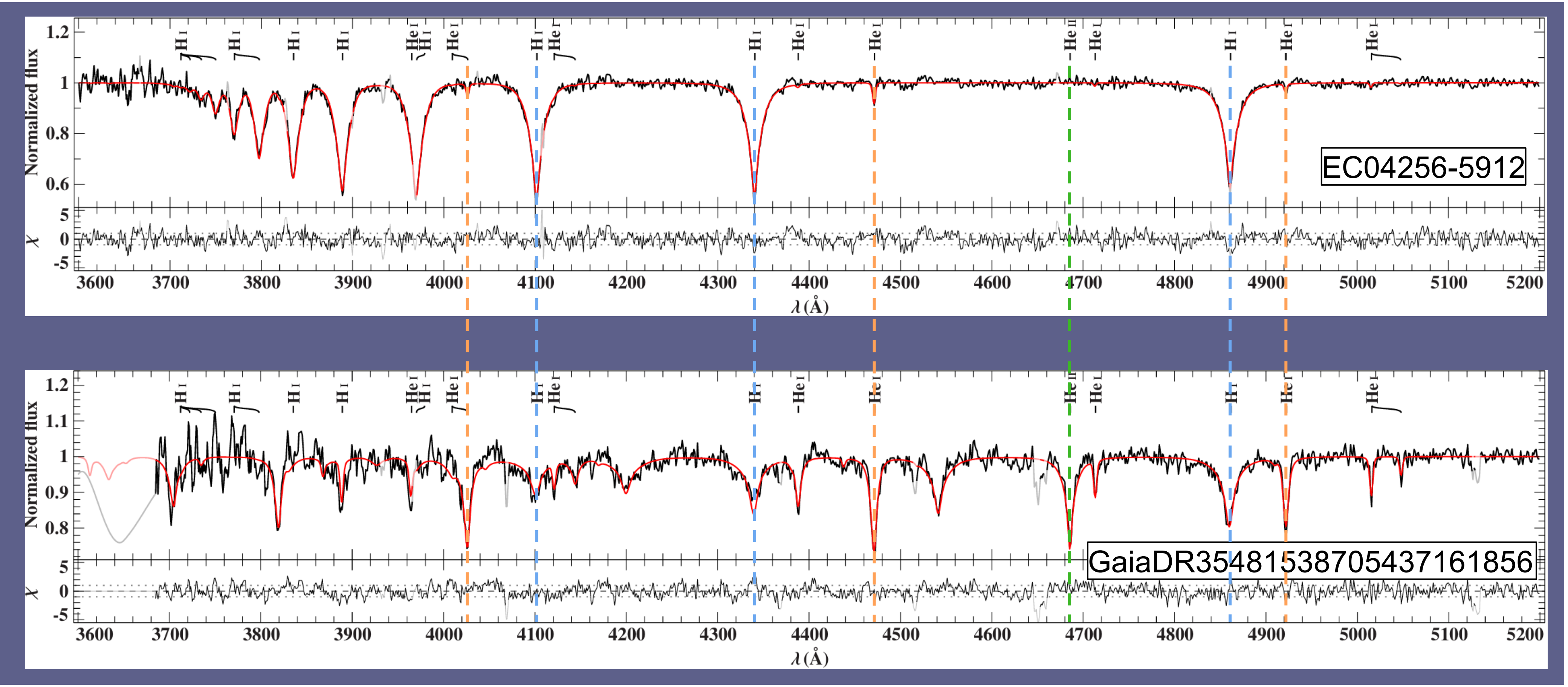
→ $\log g$

→ He/H

→ $v_{\rm rad}$

Spectral fitting: method

(Credit: Sloan Digital Sky Survey, 2022)



sdB

$T_{\mathrm{eff}} = 25960^{+50}_{-40}$ K

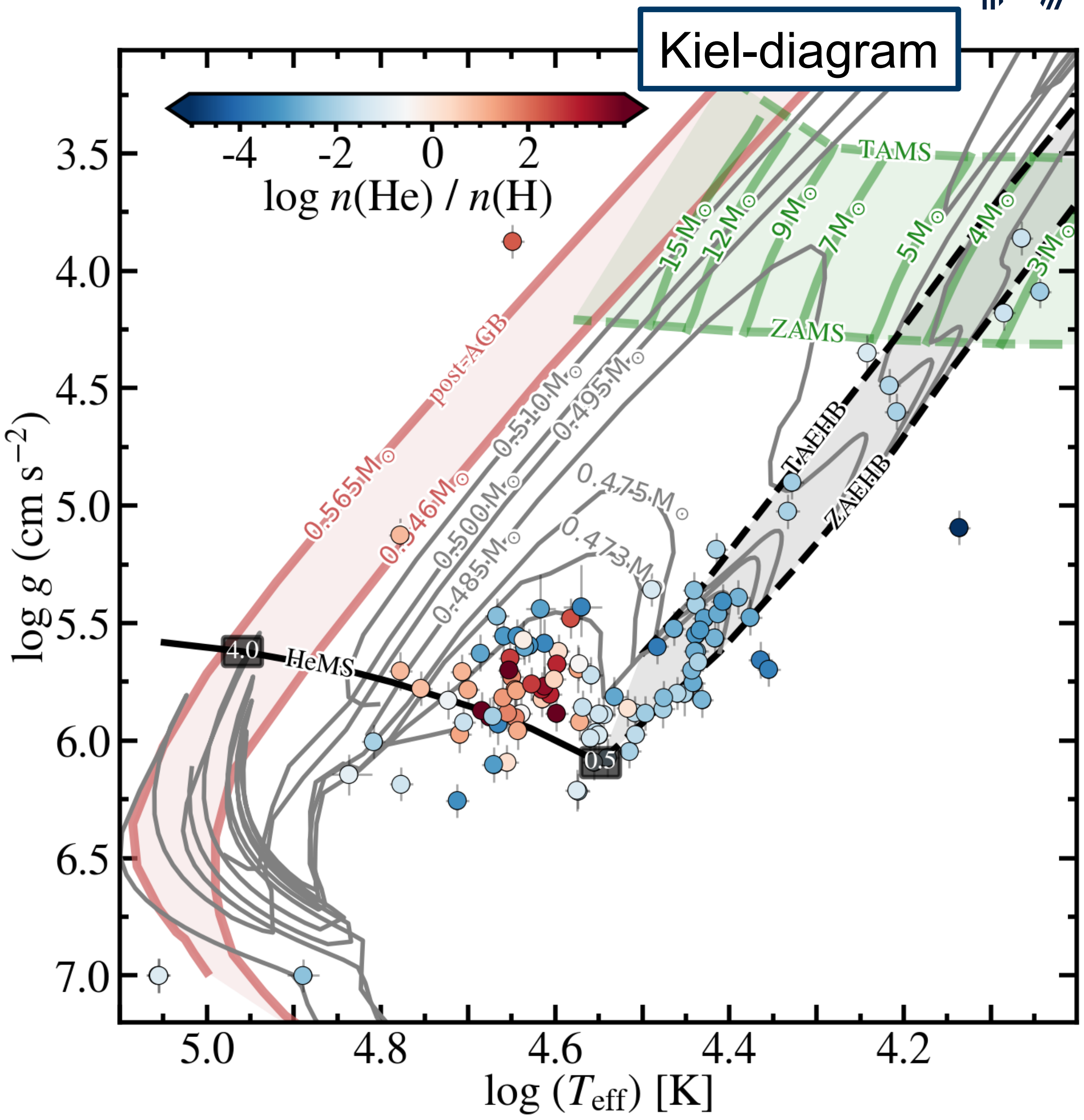
He-sdO

$T_{\mathrm{eff}} = 44030^{+90}_{-60}$ K

→ Re-determine SEDs with T_{eff}, $\log g$, $\mathrm{He/H}$ from spectra

Spectroscopic log *g*

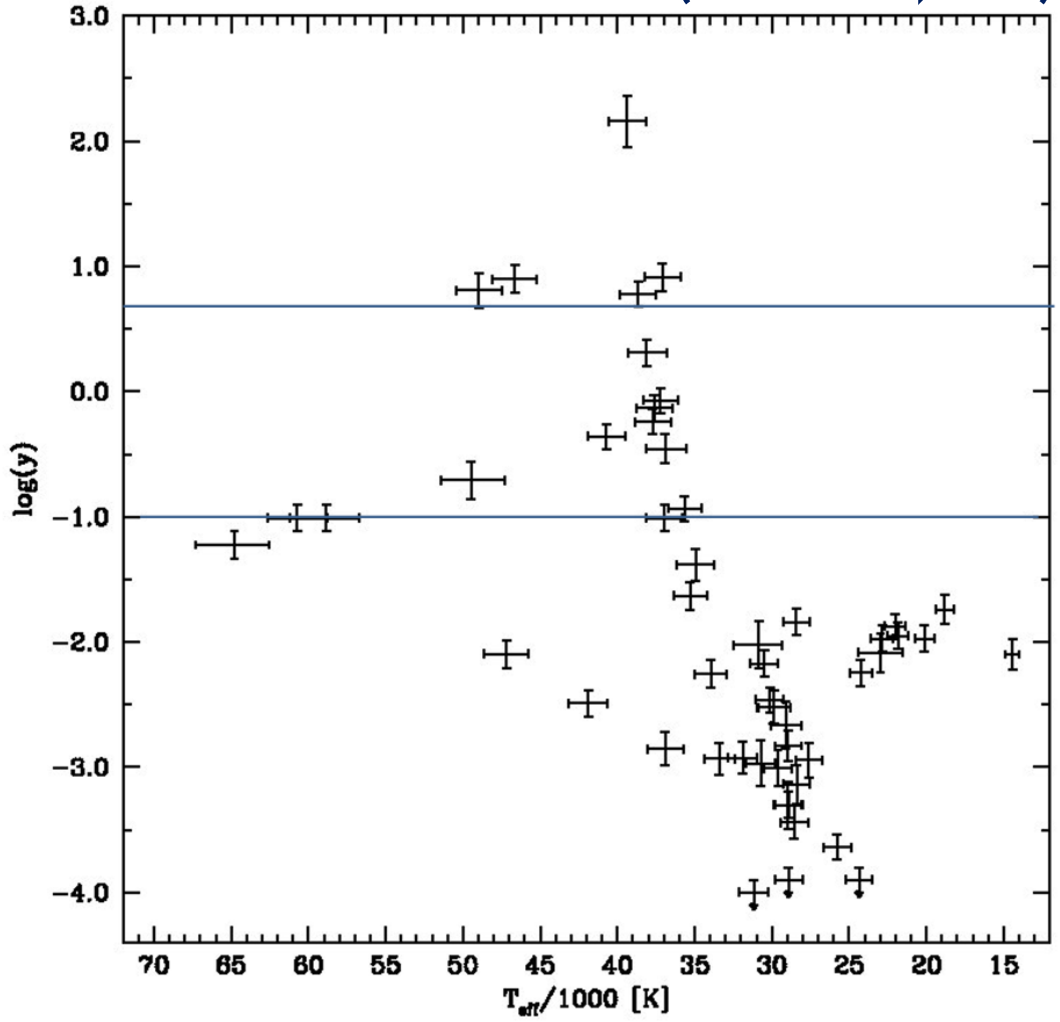
below the EHB evolved from intermediate mass stars

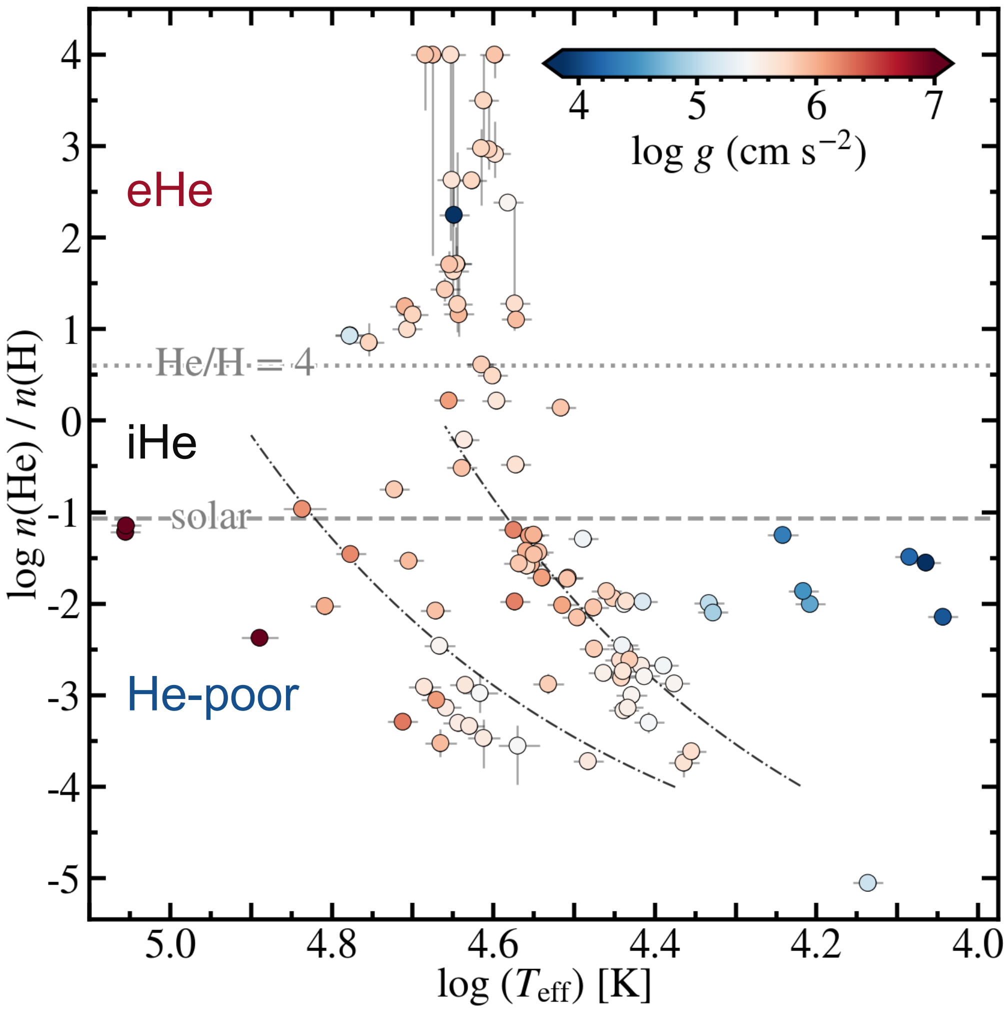


(Tracks: Dorman et al., 1993; Schaller et al., 1992; Miller Bertolami, 2016; Paczyński, 1971)

Spectroscopic helium abundance

(Geier et al., 2024)





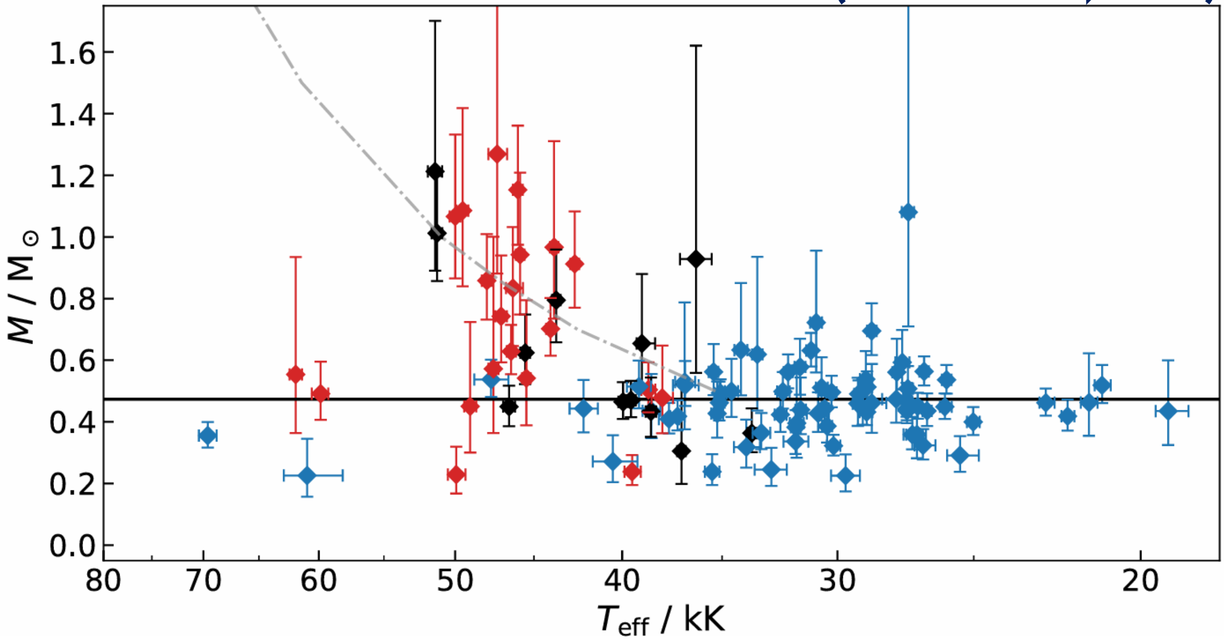
(Tracks: Edelmann et al., 2003; Németh et al., 2012)

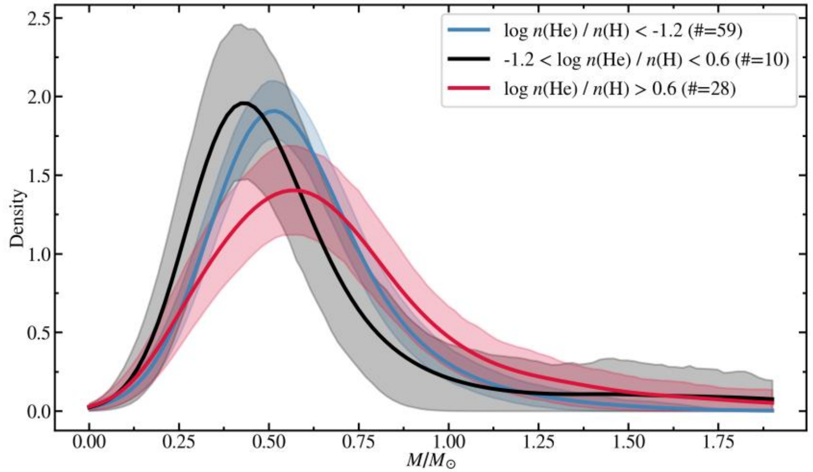
Spectroscopic log g: Mass

$$\boxed{M = \left(\frac{\Theta}{2\varpi}\right)^2 \frac{g}{G}}$$

G the gravitational constant

HQS (Heber et al., 2026)

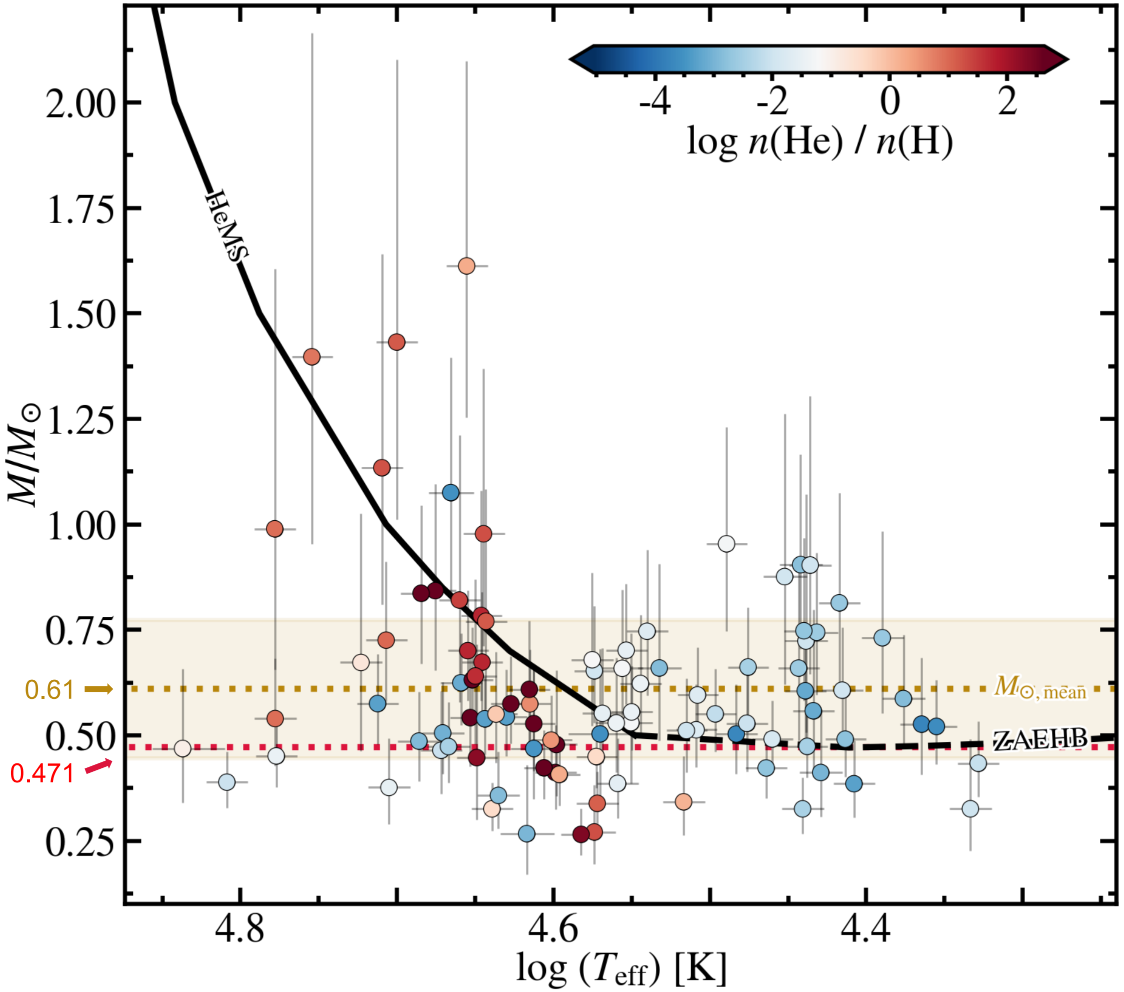




eHe: $M = 0.58\ \mathrm{M}_\odot$

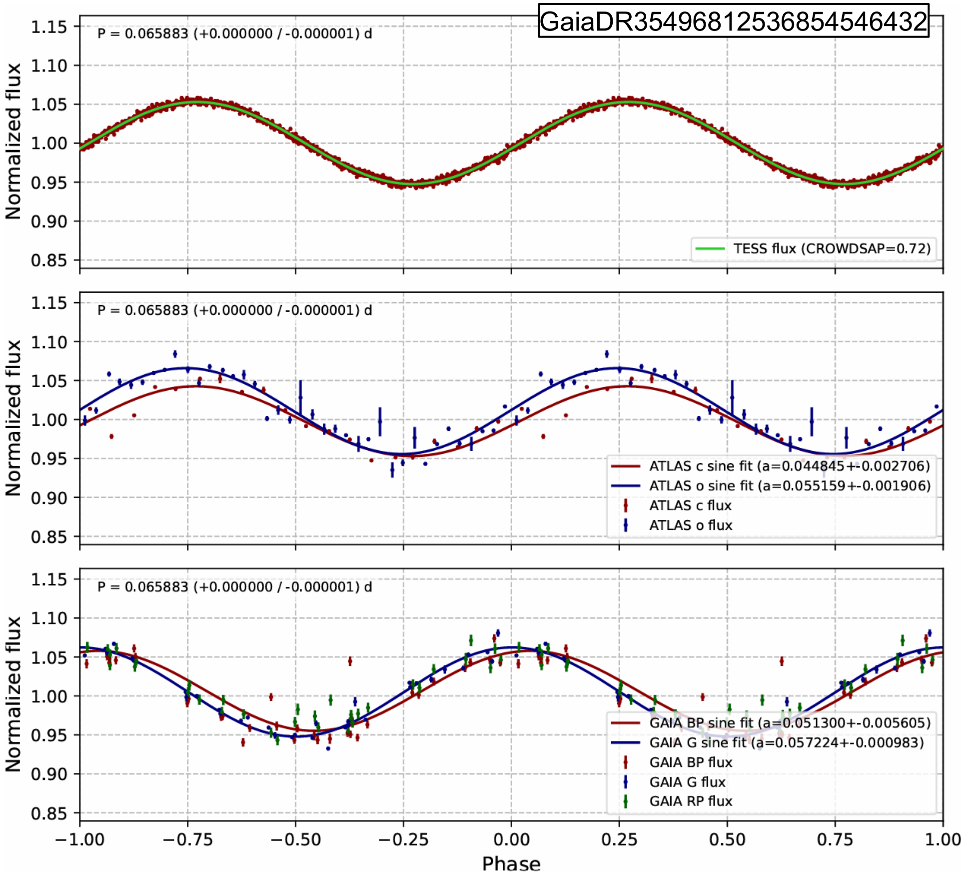
iHe: $M = 0.42\ \mathrm{M}_\odot$

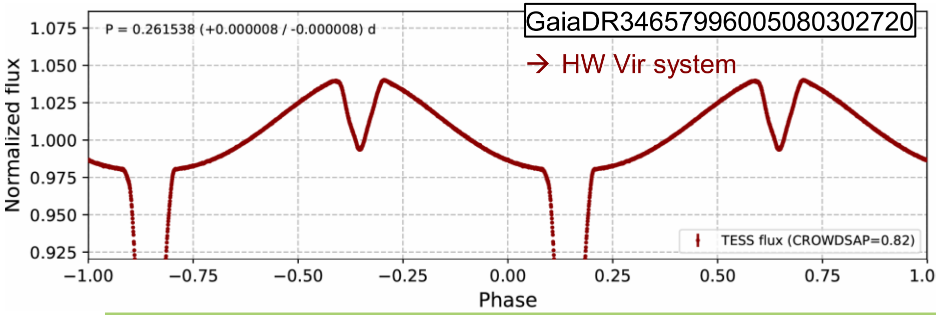
He-poor: $M = 0.52\ \mathrm{M}_\odot$



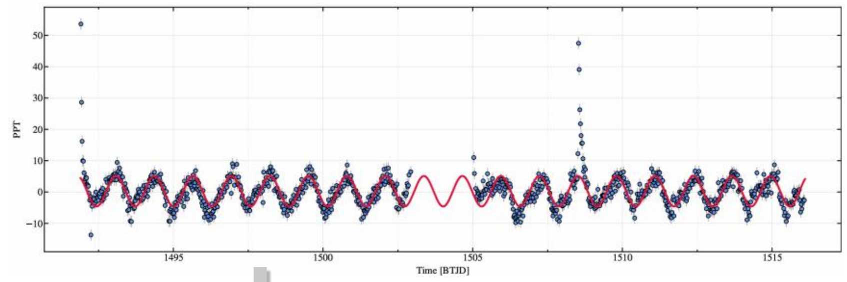
(Tracks: Dorman et al., 1993; Paczyński, 1971)

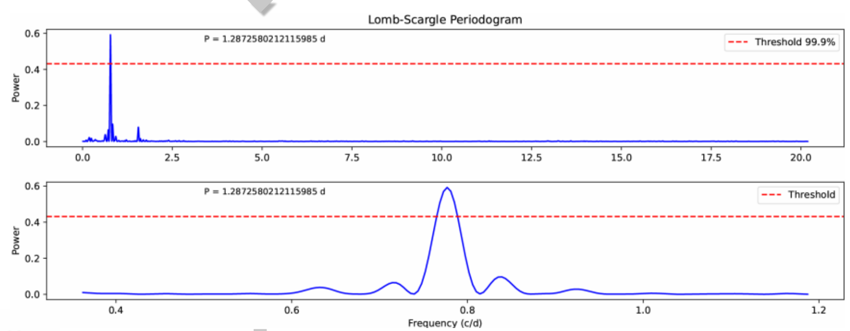
Lightcurves from TESS, ZTF, Gaia, ATLAS

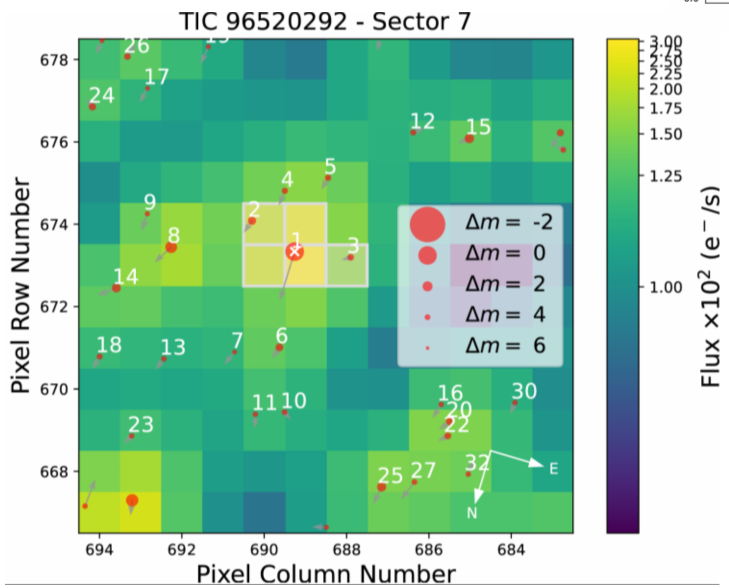


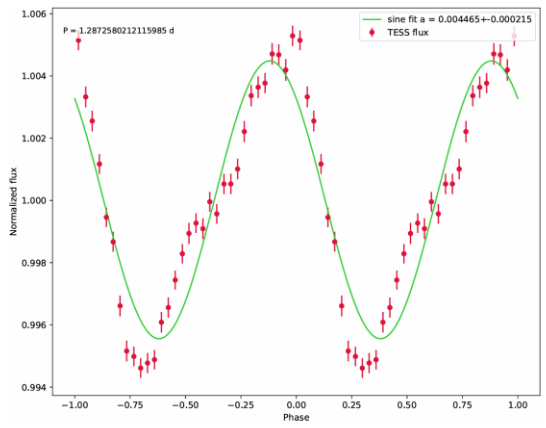


New routine for TESS full-frame lightcurve extraction







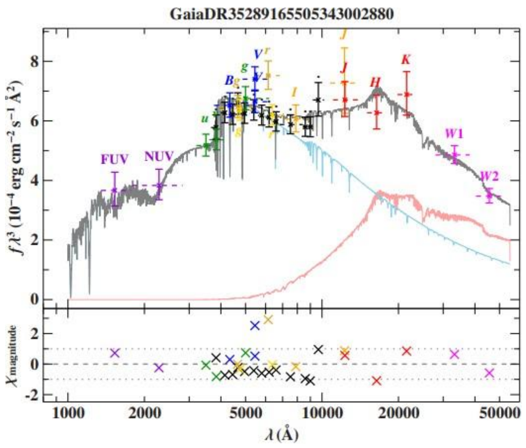


Outlook

→ lightcurve classification

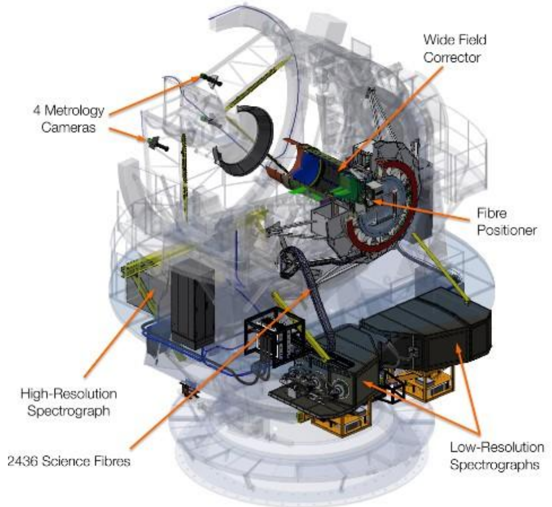
pulsations ♦ eclipses ♦ reflection effect ♦ ellipsoidal variation ♦ doppler beaming ♦ transits

- Application of SED method to many hot subdwarfs



- New data provided by *Gaia* DR4

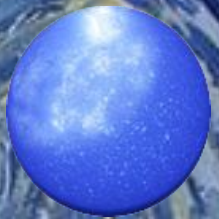
(Credit: Gaia/ESA)



(Credit: 4MOST)

- New large spectroscopic surveys like 4MOST

Thank you for joining!



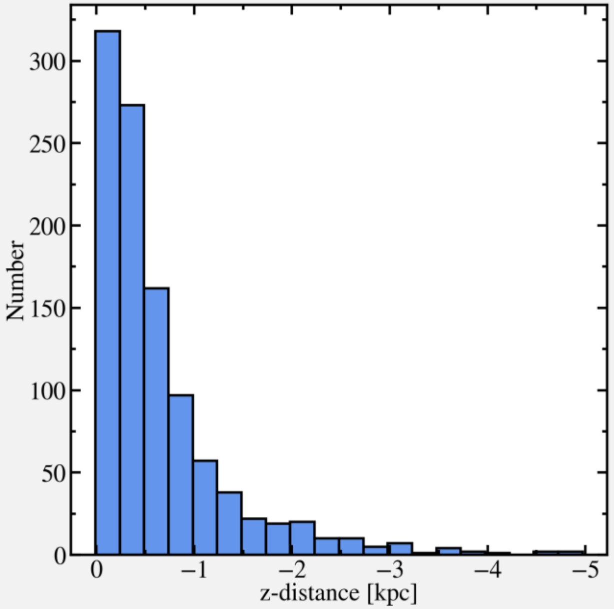
Proposal Contributors:

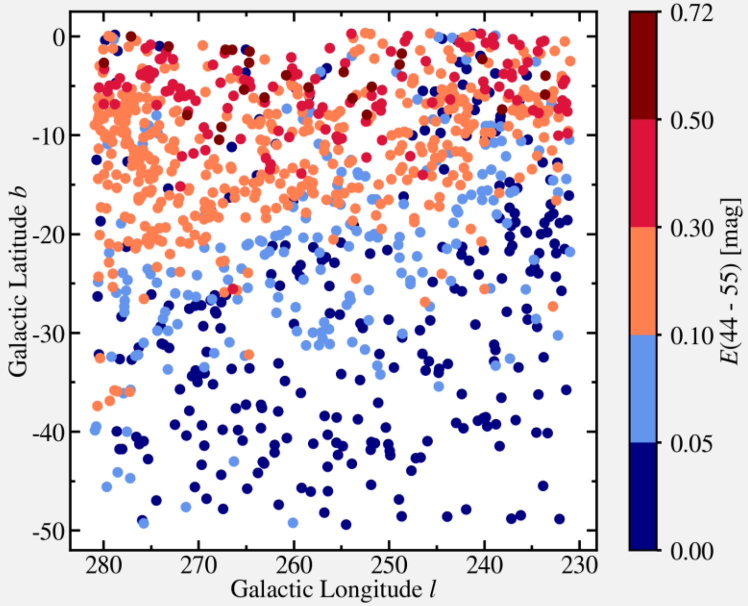
S. Geier, V. Van Grootel, M. Uzundag, V. Schaffenroth, U. Heber, S. Charpinet, S. Randall, N. Jannsen – and me

Sample selection

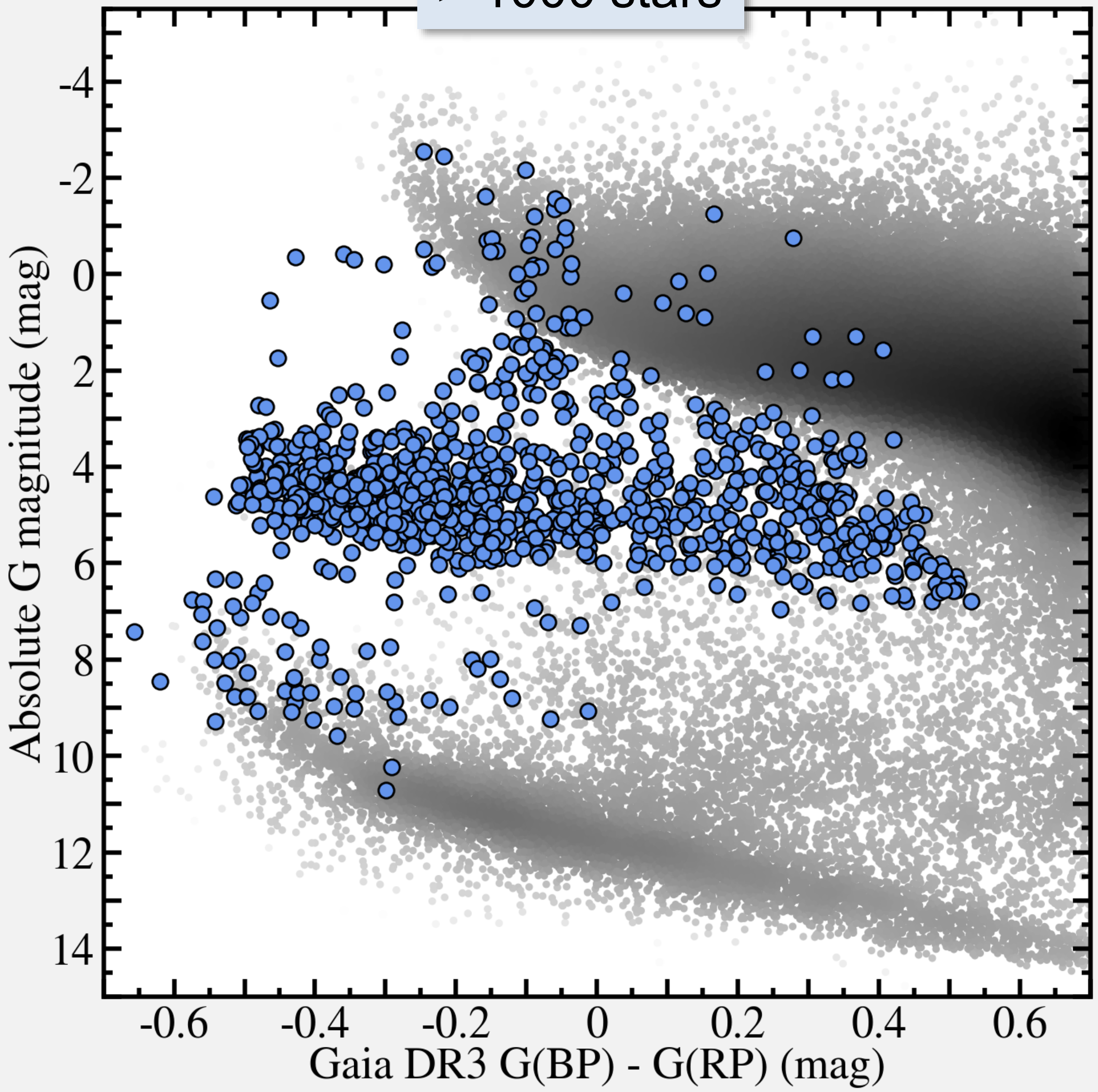
Sample:

- Known hot subdwarfs (Geier, 2020 + Culpan, 2023)
- Candidate hot subdwarfs (Geier, 2019 + Culpan, 2023)



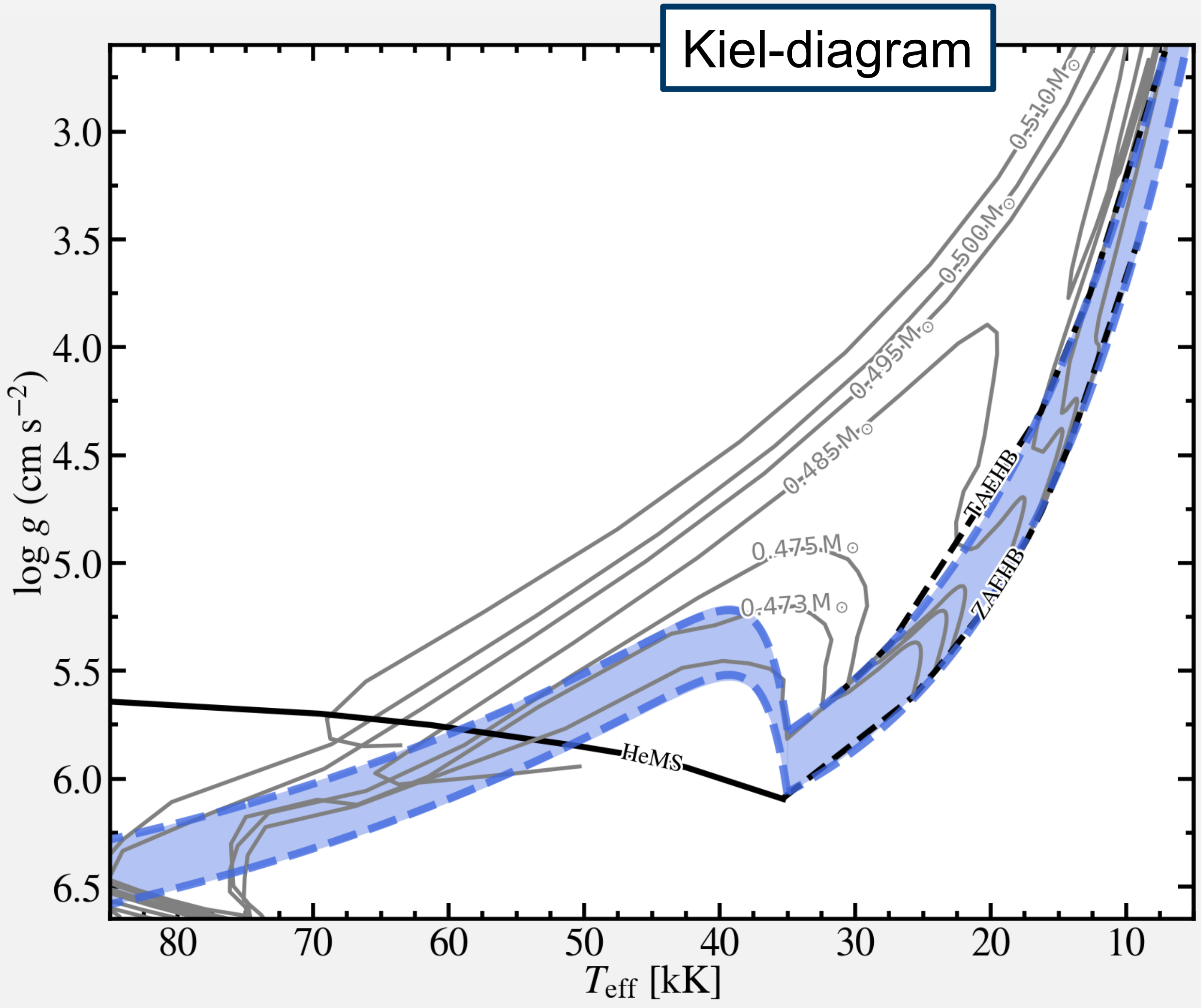


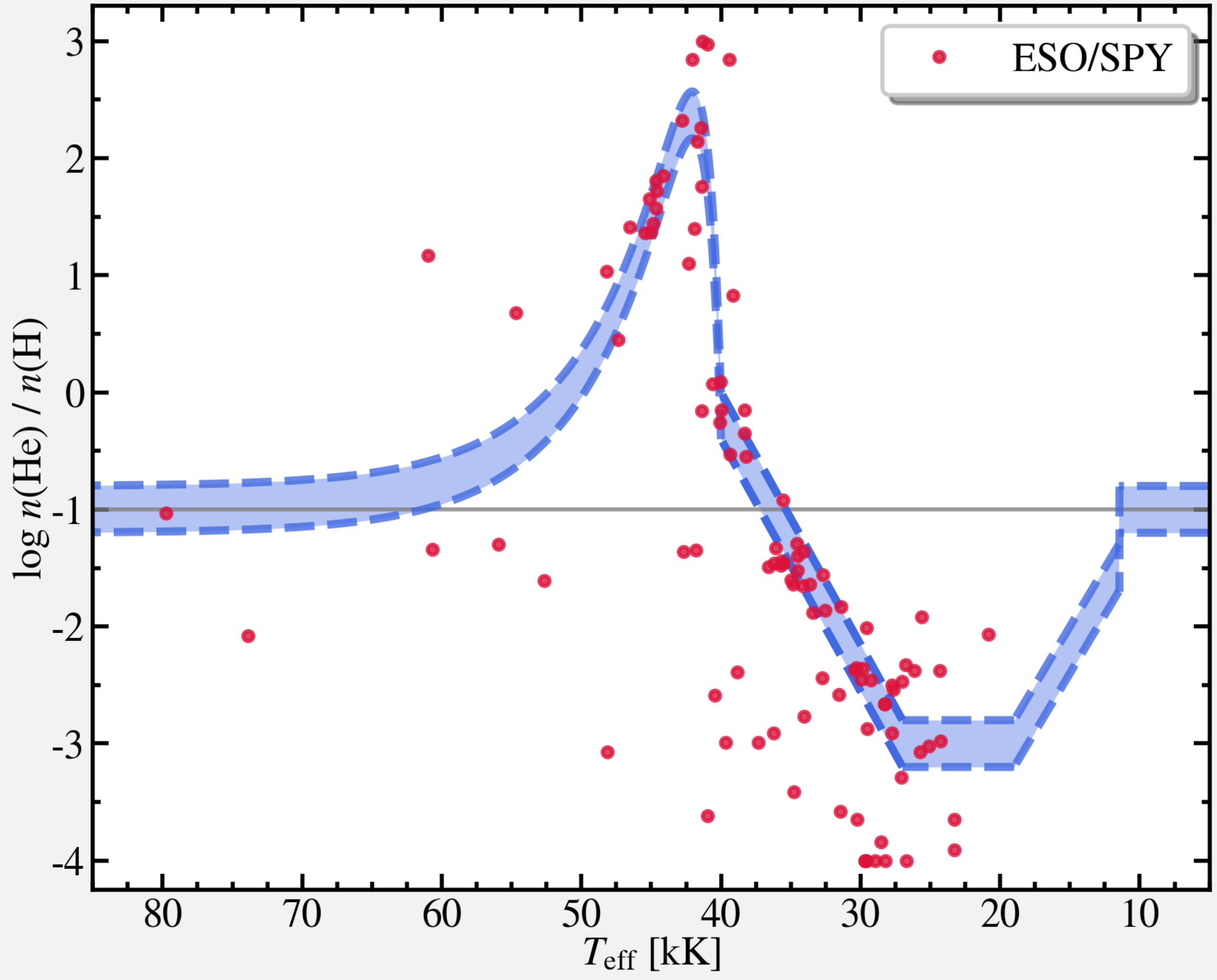
> 1000 stars



$M_G = m_G + 5 + 5 \cdot \log_{10}(\varpi/1000)$

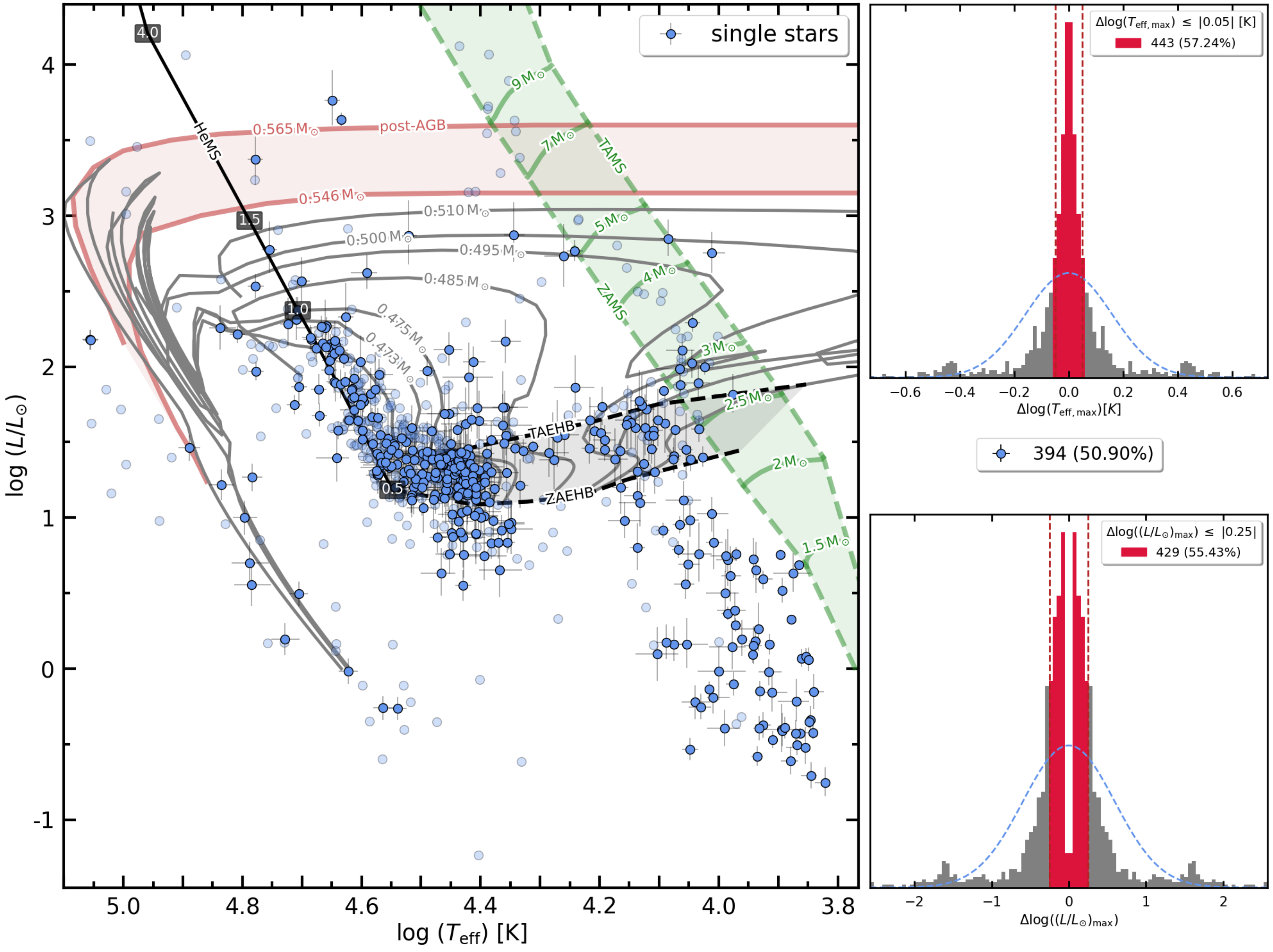
Methodology for stars in the *PLATO* field





$\boldsymbol{T_{\mathrm{eff}}}$ → Literature or *Gaia* DR3

Luminosity – error selection



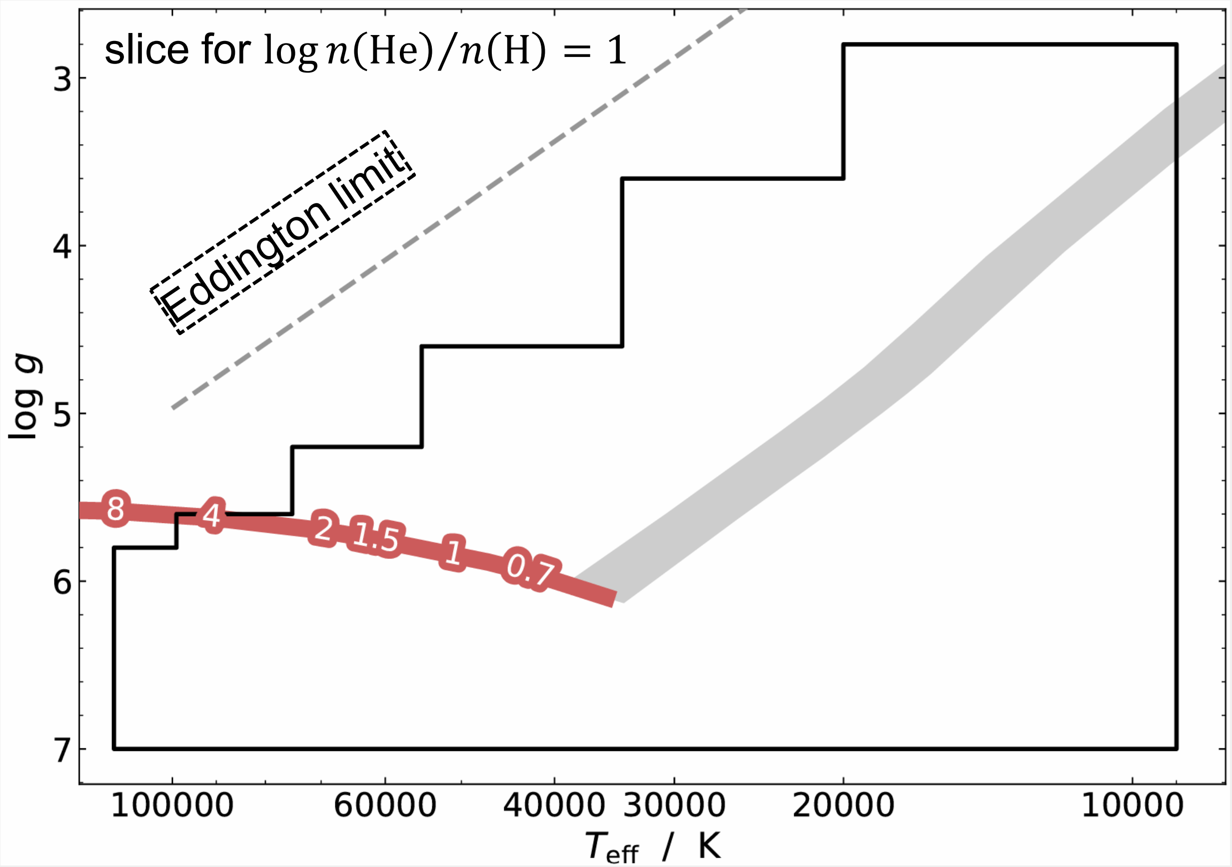
(Tracks: Dorman et al., 1993; Schaller et al., 1992; Miller Bertolami, 2016; Paczyński, 1971)

Spectral fitting: a grid of model spectra

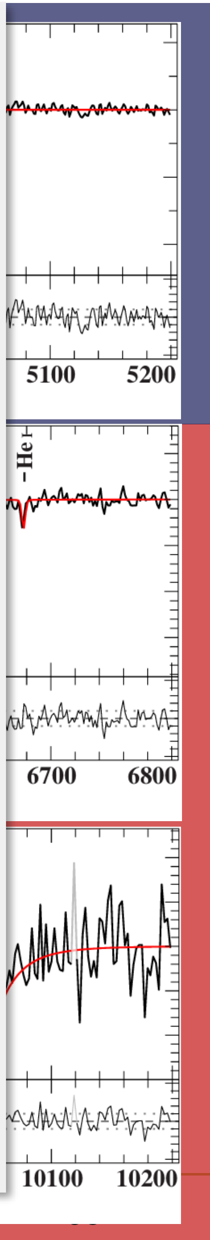
- sdO/B parameter space with > 17000 models
- hybrid LTE and NLTE

  (LTE = Local Thermal Equilibrium)
- metal line blanketing
- global fitting with best x^2

  (developed by A. Irrgang and U. Heber)

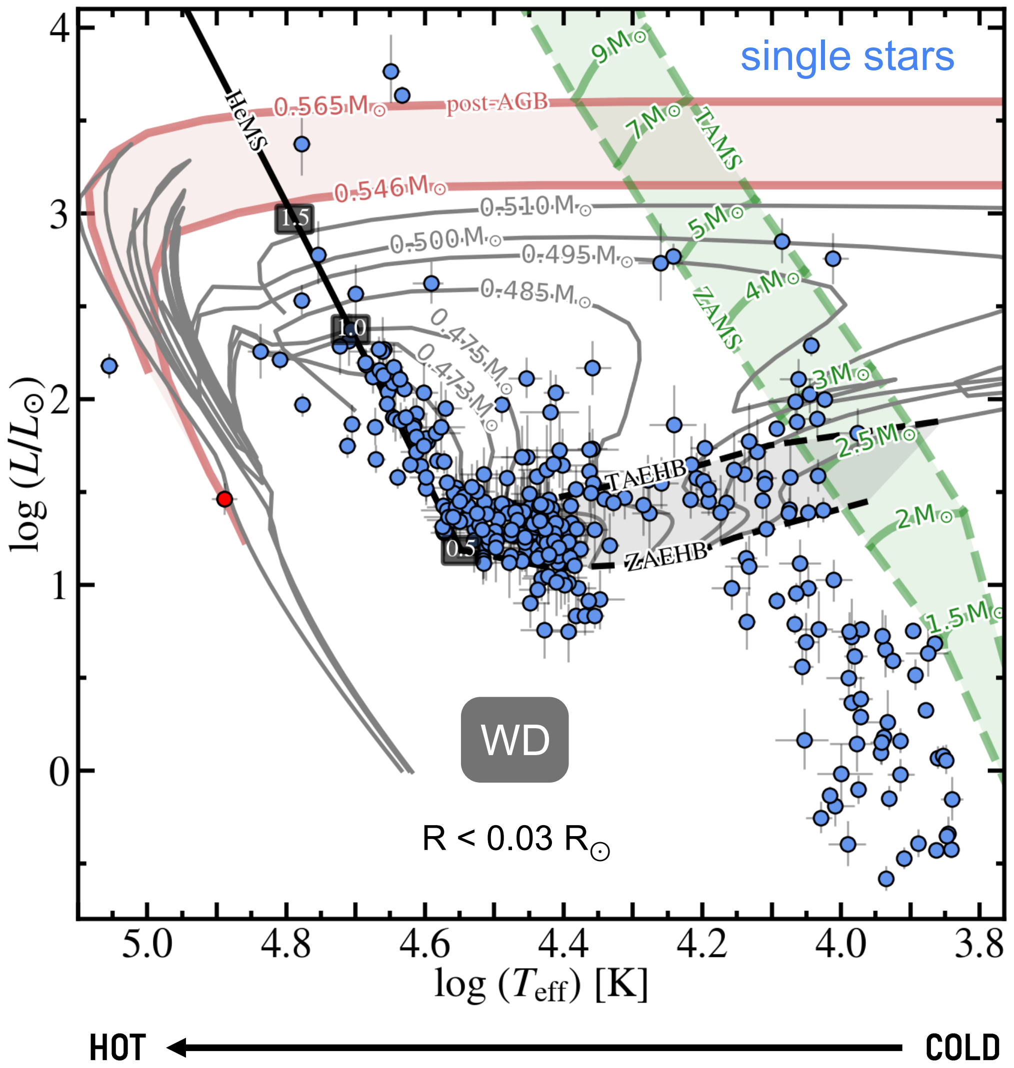


(Heber, 2026)



Fundamental stellar parameters - Luminosity

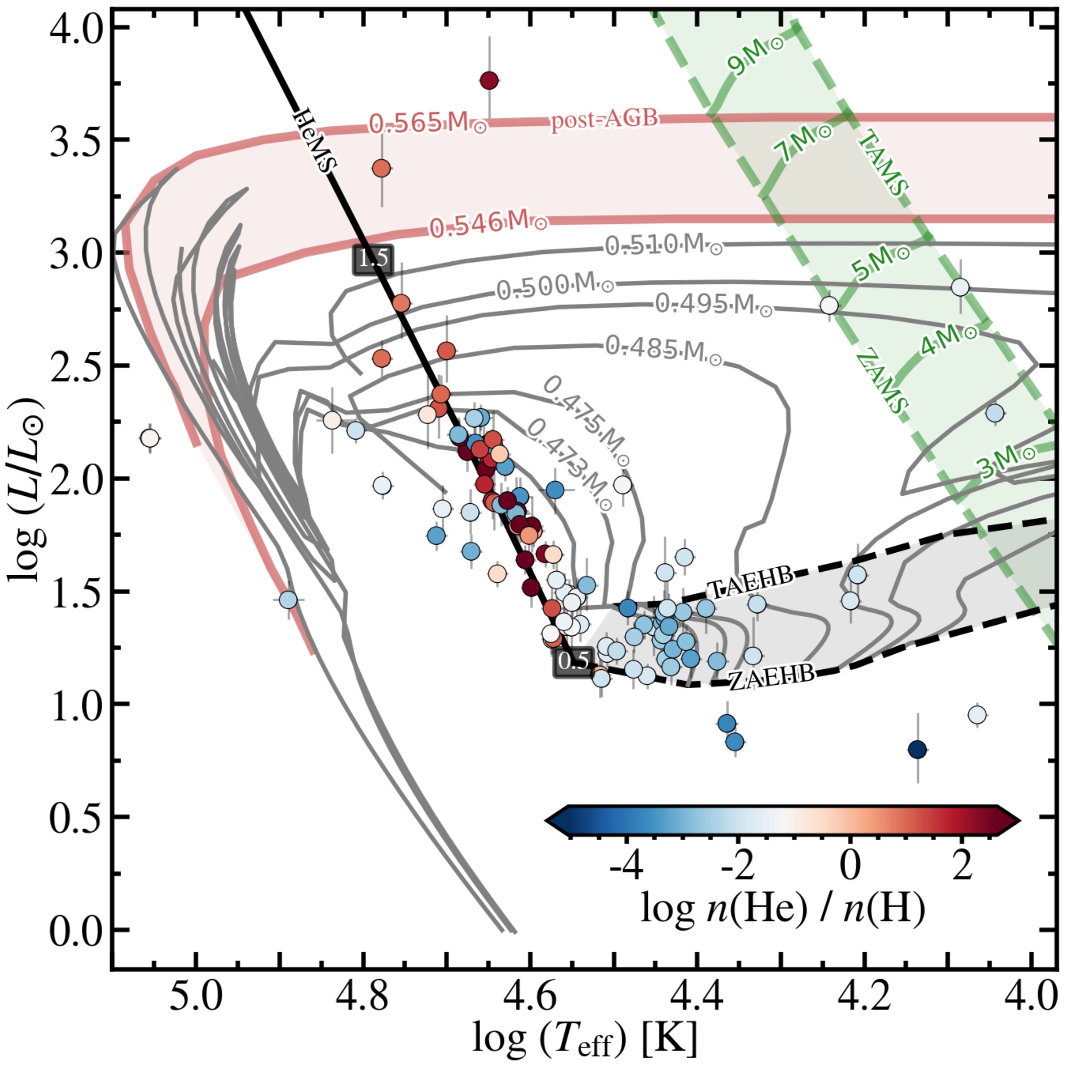
- The primary star



(Tracks: Dorman et al., 1993; Schaller et al., 1992; Miller Bertolami, 2016; Paczyński, 1971)

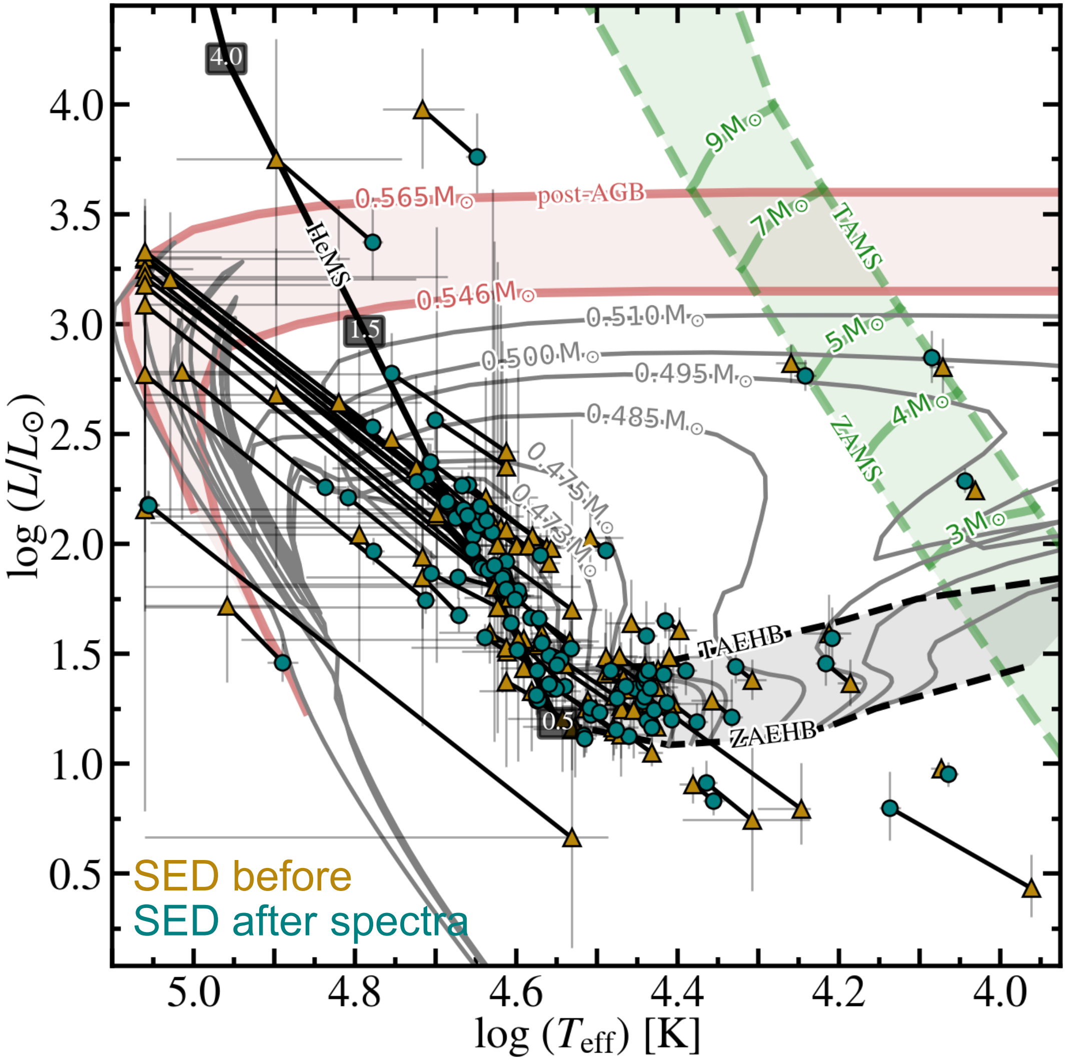
$$L \propto \left(\frac{\Theta}{2\varpi}\right)^2 T_{\mathrm{eff}}^4$$

HRD with spectroscopic parameters

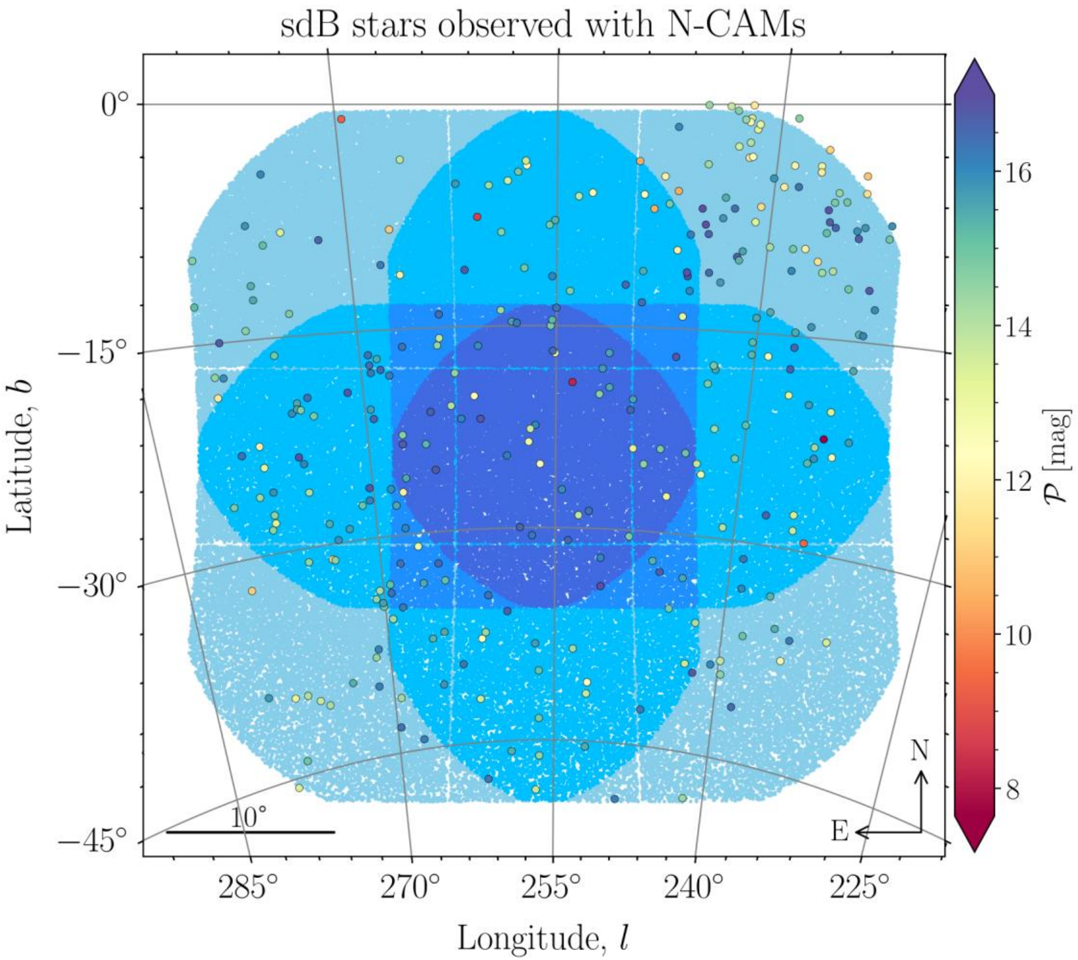


(Tracks: Dorman et al., 1993; Schaller et al., 1992; Miller Bertolami, 2016; Paczyński, 1971)

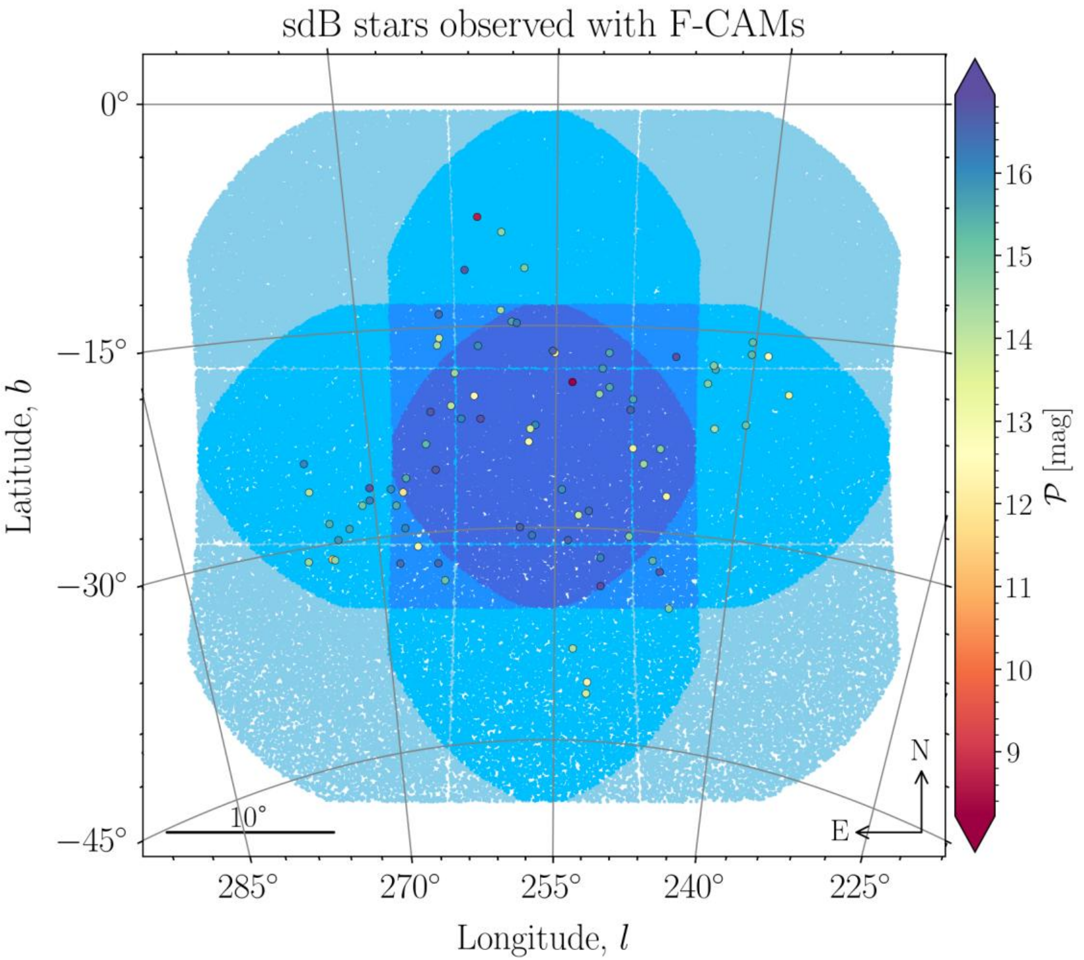
Spectra – a test for the methodology



PLATO-Sim



50 s / 600 s cadence



2.5 s / 25 s cadence

(Credit: N. Jannsen)