Hot subdwarfs from the Hamburg Quasar Survey

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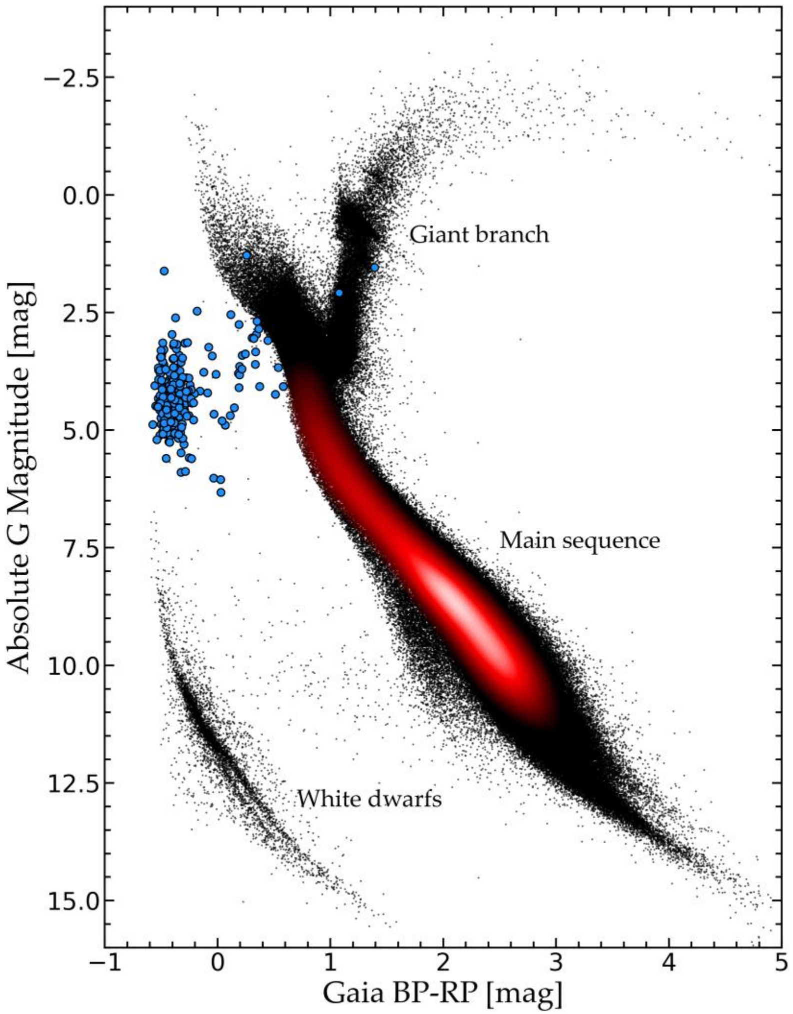
Hot subdwarf stars

- $T \sim 20000\,K \;-\; 100000\,K$
- $\log g \;\sim 4.5 \;-\; 6.5$
- $M \sim 0.5\,M_{\odot}$
- $R \sim 0.1\,R_{\odot} \;-\; 0.3\,R_{\odot}$
- $L \sim 10\,L_{\odot} \;-\; 1000\,L_{\odot}$

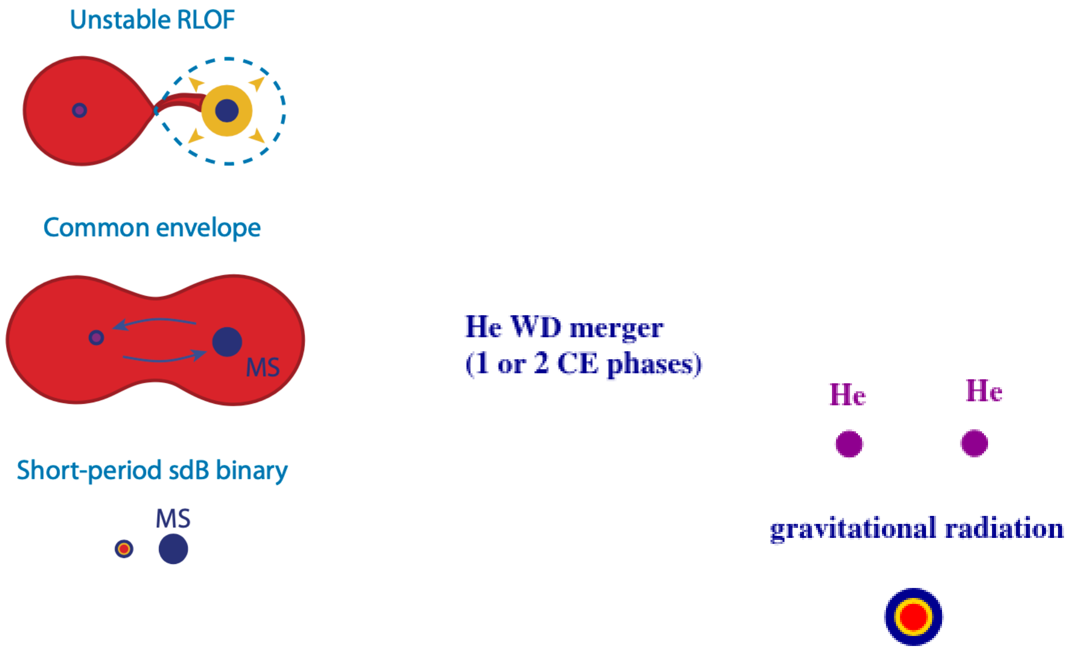
  - **Stripped core of RGB-star**
  - **Formation:**
    - **Requires binary evolution with mass exchange**



Dawson 2024

Formation

- Binary star evolution
  - Common envelope evolution
  - Stable Roche-Lobe overflow (RLOF)
  - White dwarf merger



Podsiadlowski 2008

The Hamburg Quasar Survey (HQS)

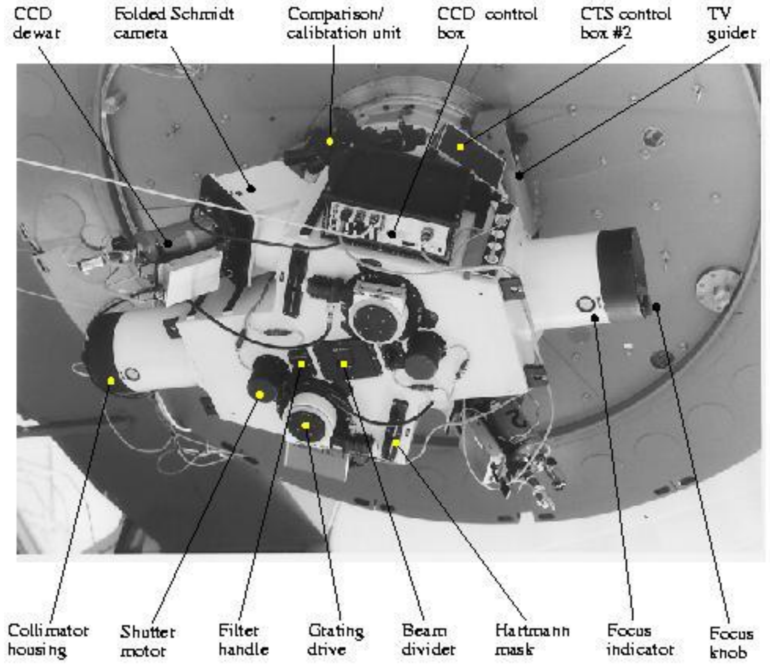
- Hamburg Quasar Survey (HQS)
  - wide-angle objective prism survey in the 1980s/90s
  - 80 cm Schmidt telescope in Calar Alto, Spain
  - Main goal: Quasars
  - HQS spectral resolution 45 Å at H_δ

Follow-up spectroscopy required

Spectral observations

- Spectroscopic follow-up to HQS
  - 1990s: detailed spectra of candidates
  - 3.5m/ 2.2m telescopes in Calar Alto
  - Spectral resolutions ~10x better

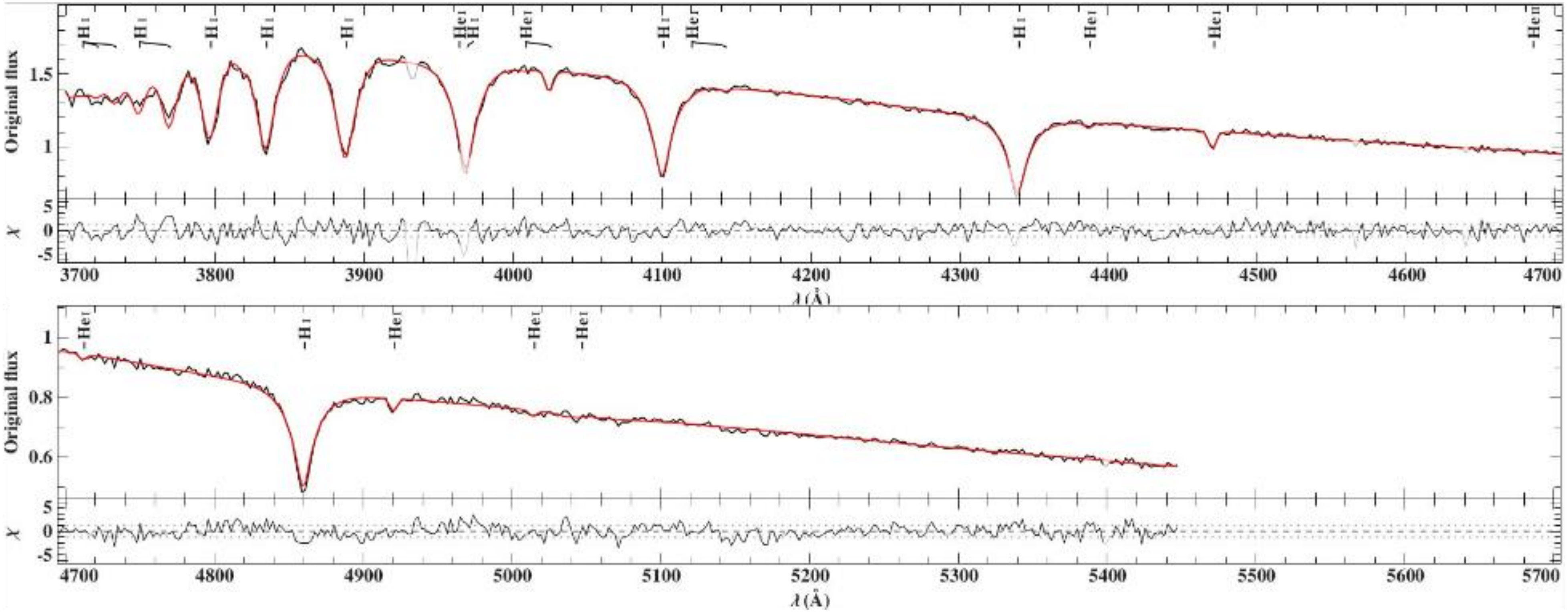
➢ sdB sample studied by Edelmann et al. (2003)
➢ sdO sample: left-over from the original project



TWIN spectrograph

Spectral observations

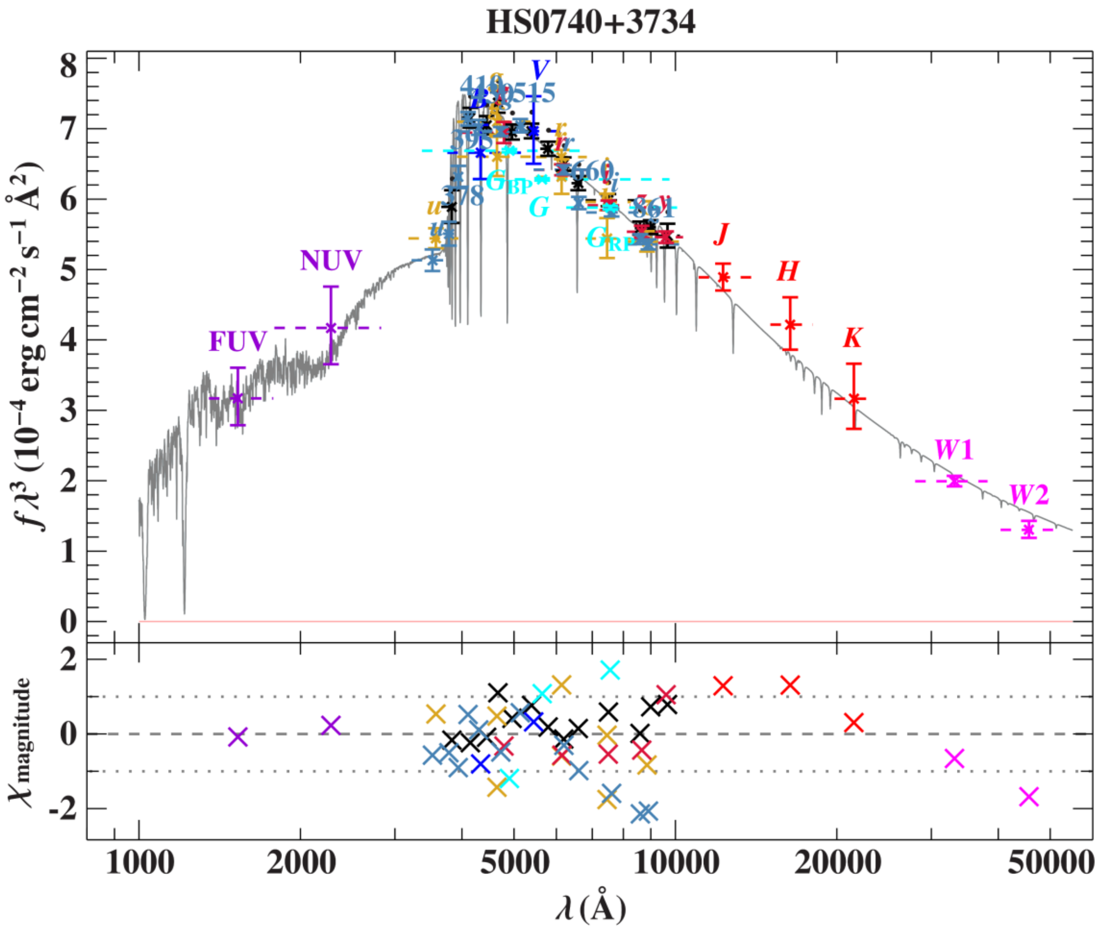
- Spectroscopic Analysis
  - T_{eff}, $\log g$ and He/H, $\mathrm{v_{rad}}$, $\mathrm{v_{rot}} \sin i$



HS0740+3734: Blue channel

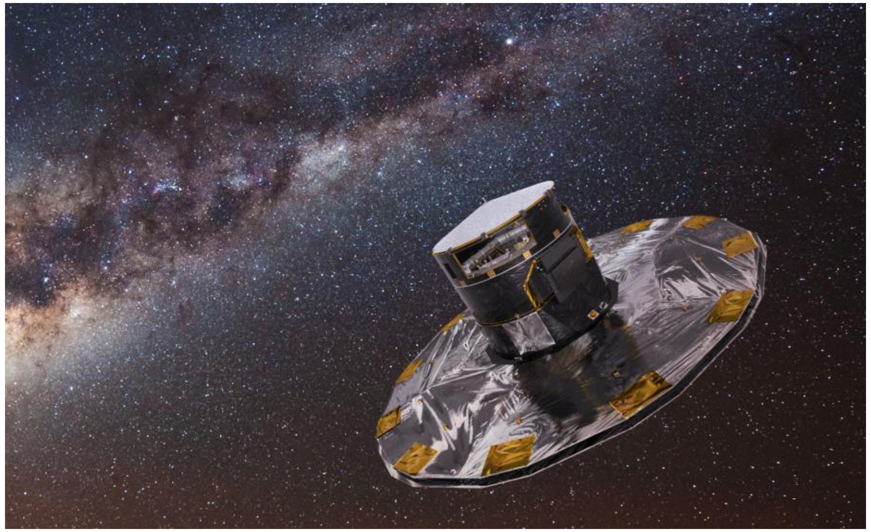
Spectral energy distribution

- Photometric analysis
  - Spectral Energy Distribution (SED)
  - Input T_{eff}, $\log g$ and He/H from spectra
  - Fit for:
    - Angular diameter θ
    - Colour Excess $E(B-V)$



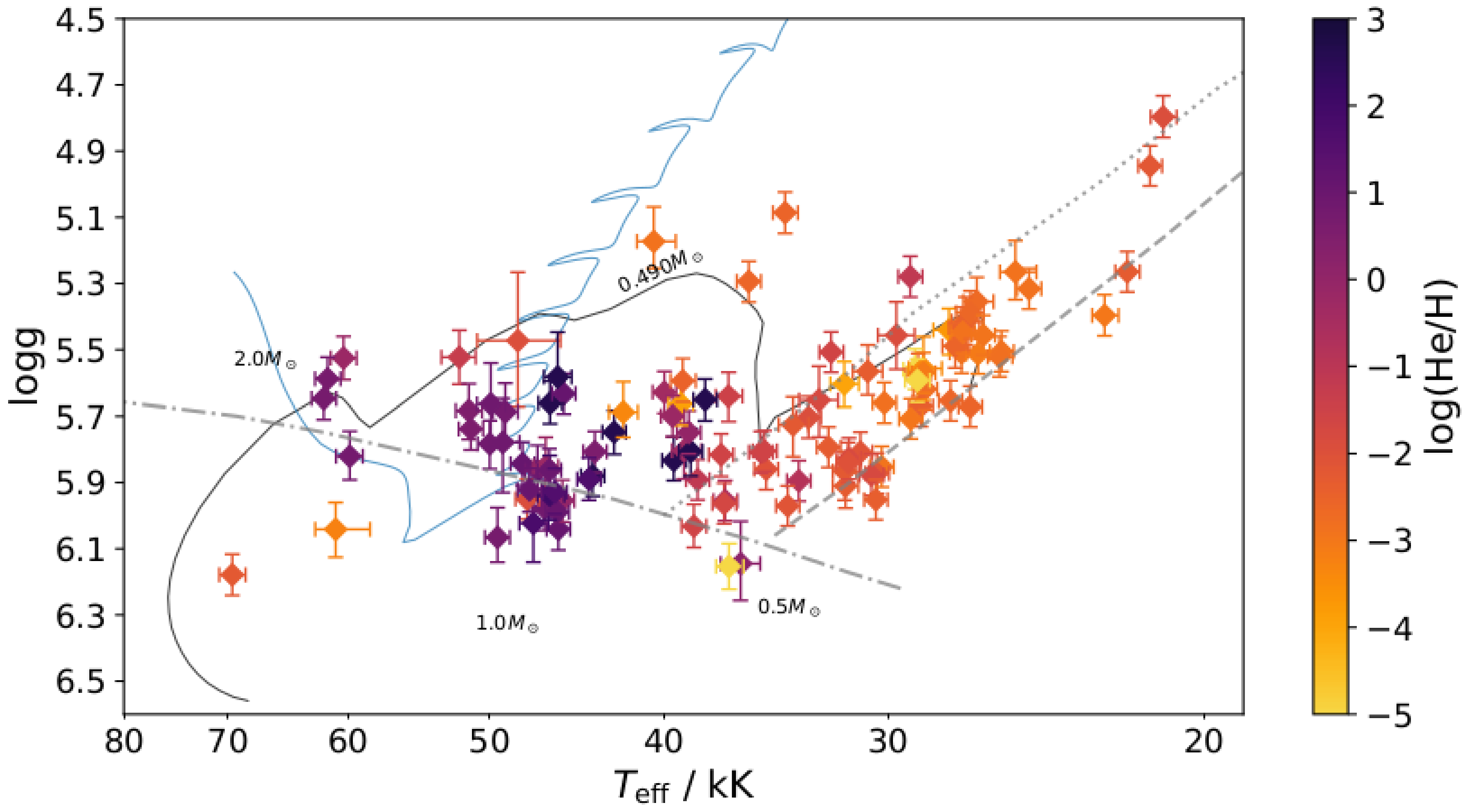
Parallaxes and stellar parameters: R, L, and M

- Gaia and parallaxes
  - Parallax → Distance
  - Gaia mission (ESA)
  - DR3 (Jun. 13, 2022) parallax for 1.5 billion sources
- Stellar Parameters
  - Combine:
    - atmospheric parameters T_{eff} ,$\log g$
    - angular diameter θ
    - parallax ϖ
  - Radius $R = \frac{\theta}{2\varpi}$ Luminosity $L = 4\pi\sigma R^2 T_{\mathrm{eff}}{}^4$ Mass $M = g\,\frac{R^2}{G}$



ESA 2013

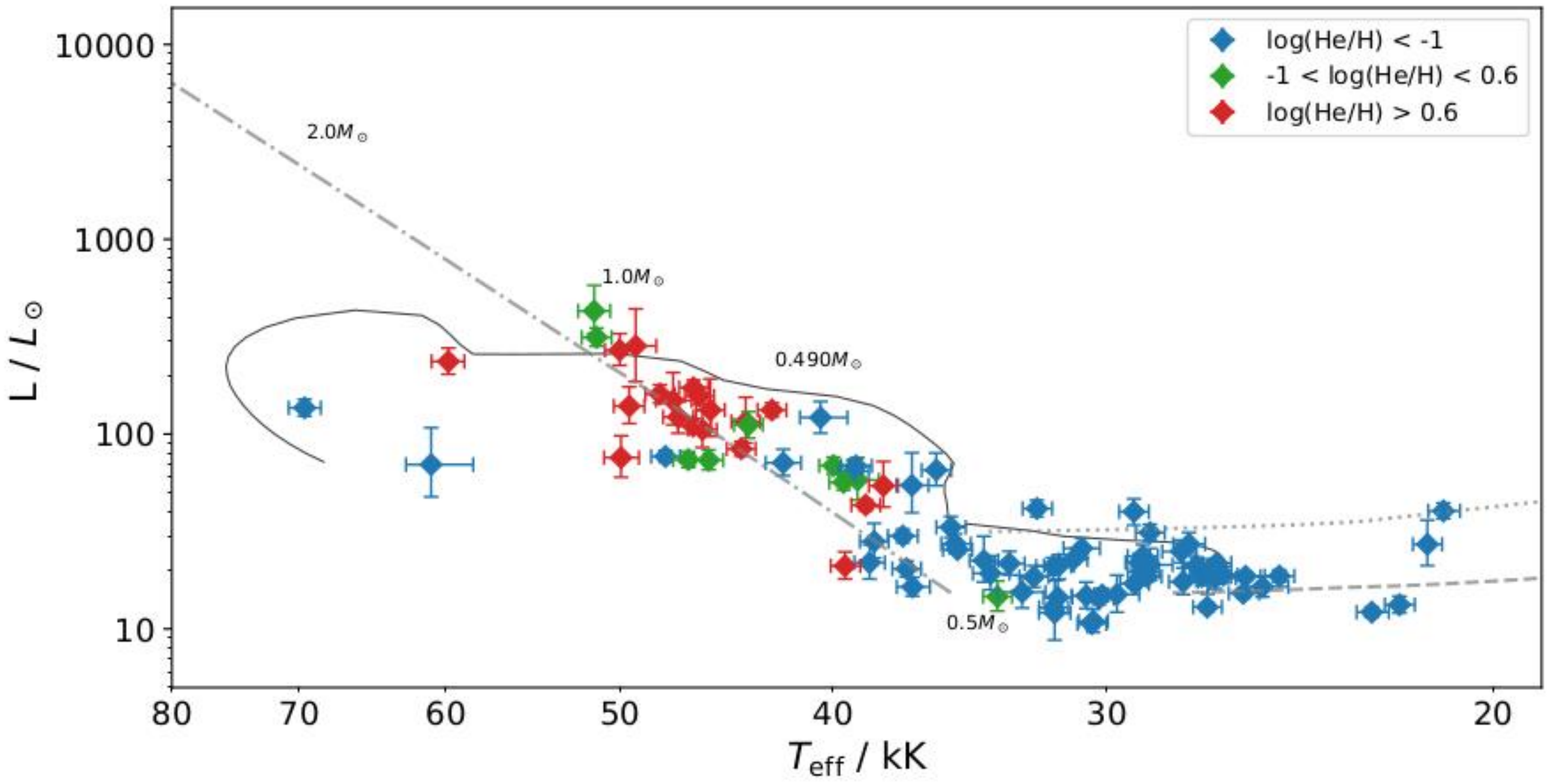
HQS sdB and sdO combined: Kiel diagram



Evolutionary tracks. Post-EHB (black), 0.35+0.35 $M_\odot$ He-WD merger track (blue)

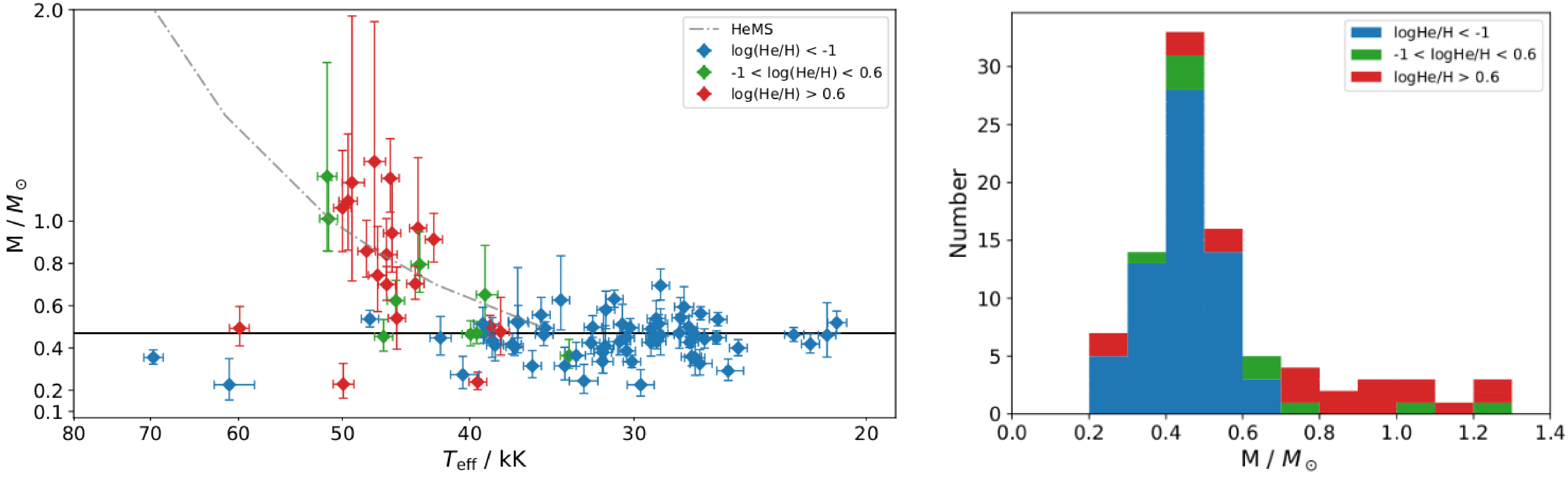
HQS sdB and sdO combined: HRD

Subsample
(70% of the full sample)
with good parallaxes
(<20% uncertainty)



He-rich subdwarfs close to He-main sequence, masses between 0.5 and 1.0 $M_\odot$

HQS sdB and sdO combined: Masses



median mass: **He-poor stars**: M=0.45 $M_\odot$; eHe stars M=0.75 $M_\odot$

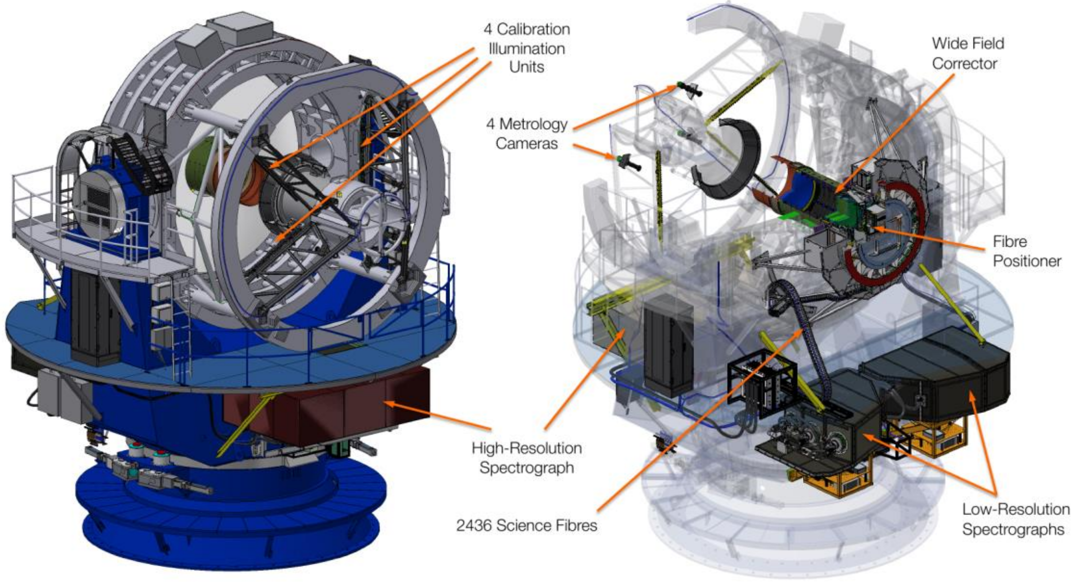
individual uncertainties: ~10-20%

Outlook

- **The future is bright !**
  - Gaia improvement DR4
  - better stellar parameters for more stars

    in particular He-rich sdO (more distant)
  - Spectroscopic survey 4MOST

    → Large samples



4MOST

Summary

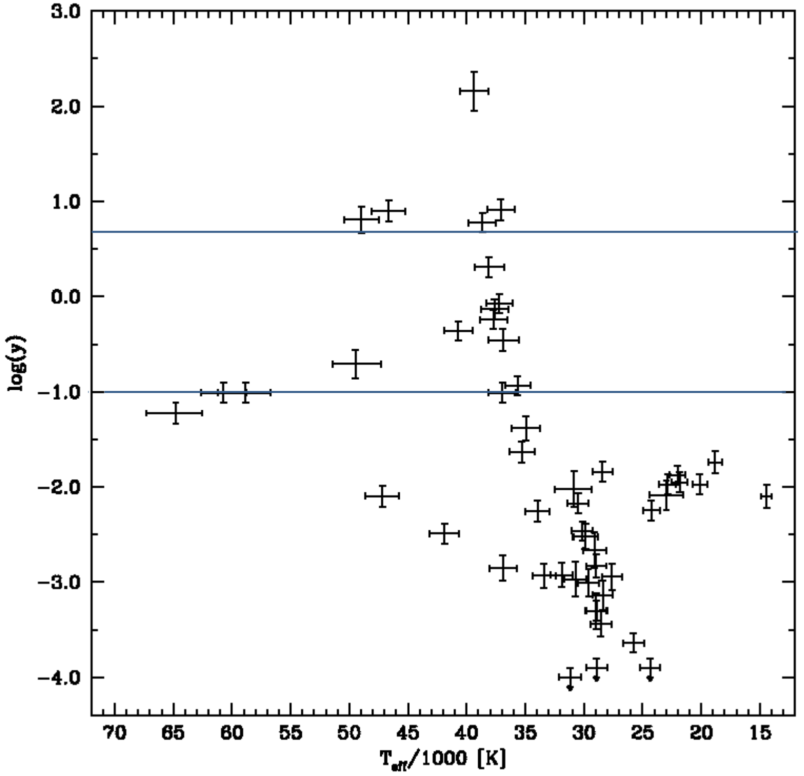
- New **homogenous** grid of stellar atmospheres and synthetic H, He spectra
- Subdwarfs from the HQS form a **homogenous** set of optical spectra: **20 years later**
- SED + parallax: R, L, and M from T_{eff}, $\log g$
- Masses: hydrogen-rich: 0.45 $\mathrm{M}_{\odot}$, eHe: 0.75 $\mathrm{M}_{\odot}$
- HRD: helium poor subdwarfs consistent with EHB evolution,

  helium-rich on the He - MS with higher masses

Backup: Abundances

Helium abundance: y=He/H

Geier et al. 2024

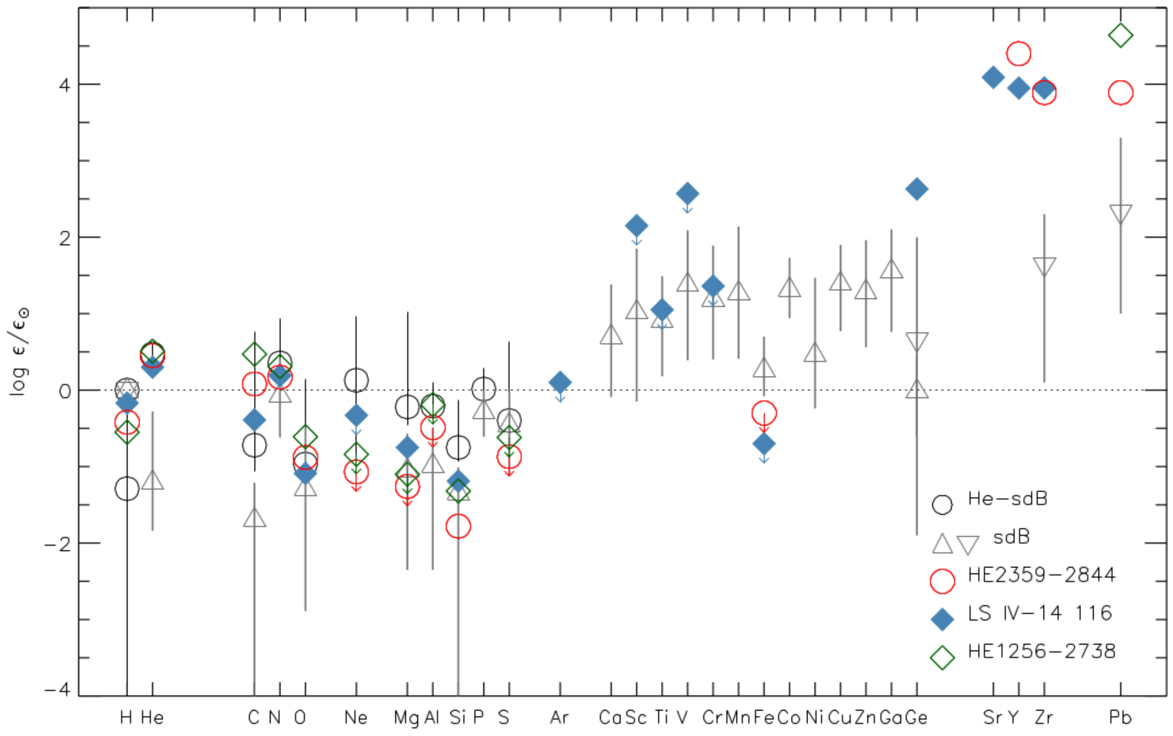


eHe

iHe

He poor

Metal composition



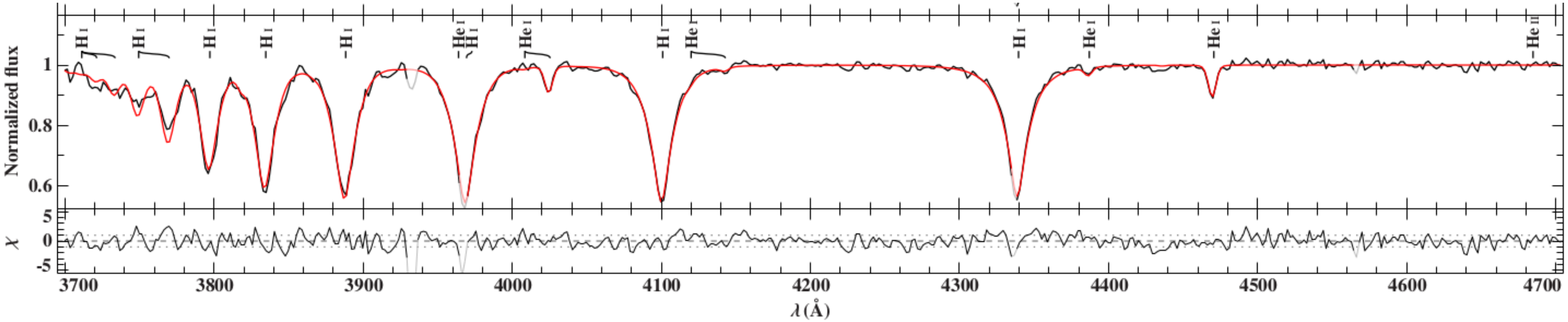
Naslim et al. 2013

Subdwarf Standard composition

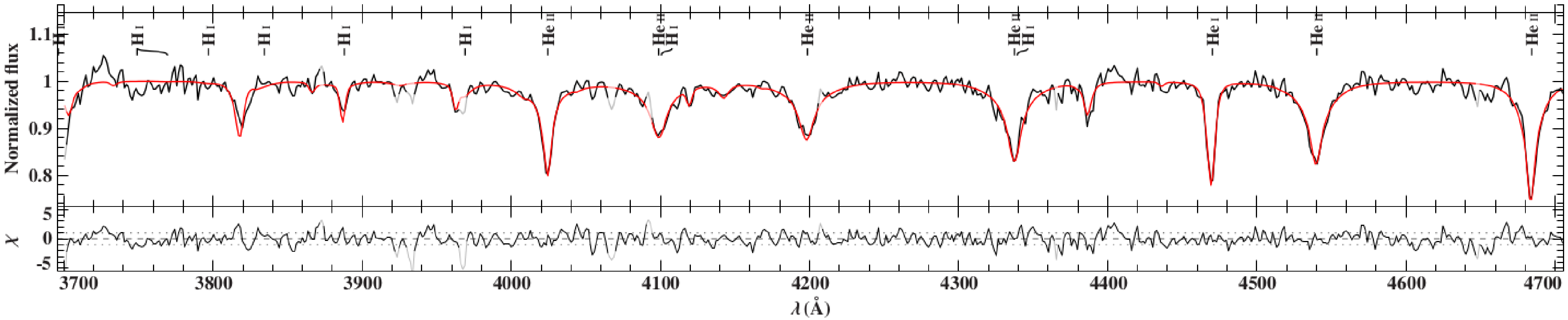
gravitational settling vs. radiative levitation

Backup: Spectra

- Optical spectra



sdB-star



sdO-star

Backup: He/H vs T_{eff}

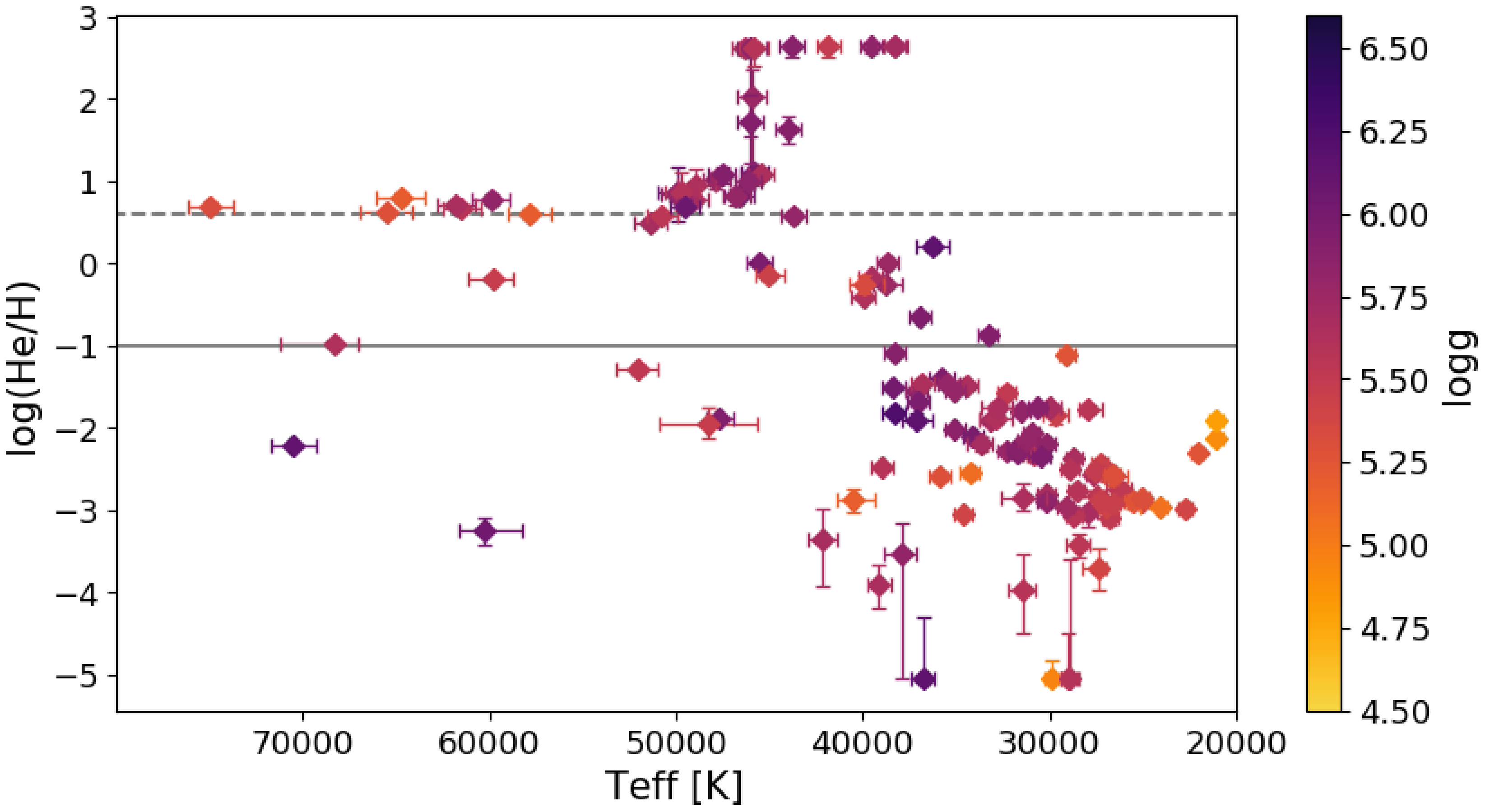
extremely He sdO

He/H = 4 - - - - - - -

intermediate He-sdO

solar ————————

He-poor sdB/O



Backup: Composite sdB stars

- SED fit: E(B-V), T_{eff} (FGK), Surface ratio

+ parallax: R and L of both components

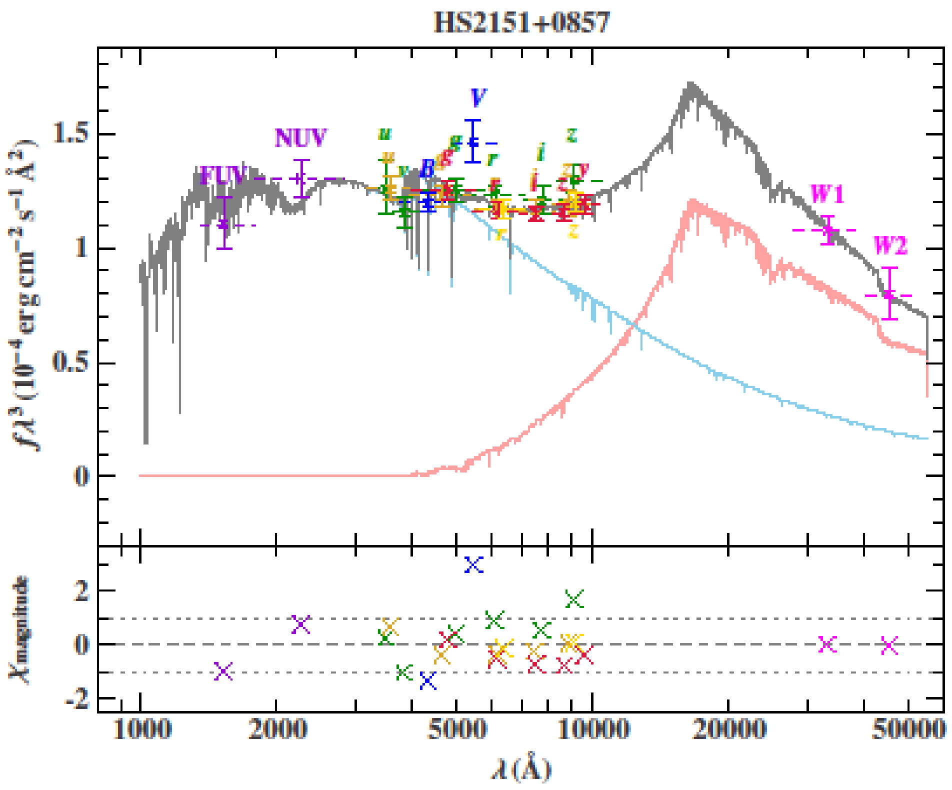
- Edelmann et al. (2003):

  18 sdB composites from

  spectral features:

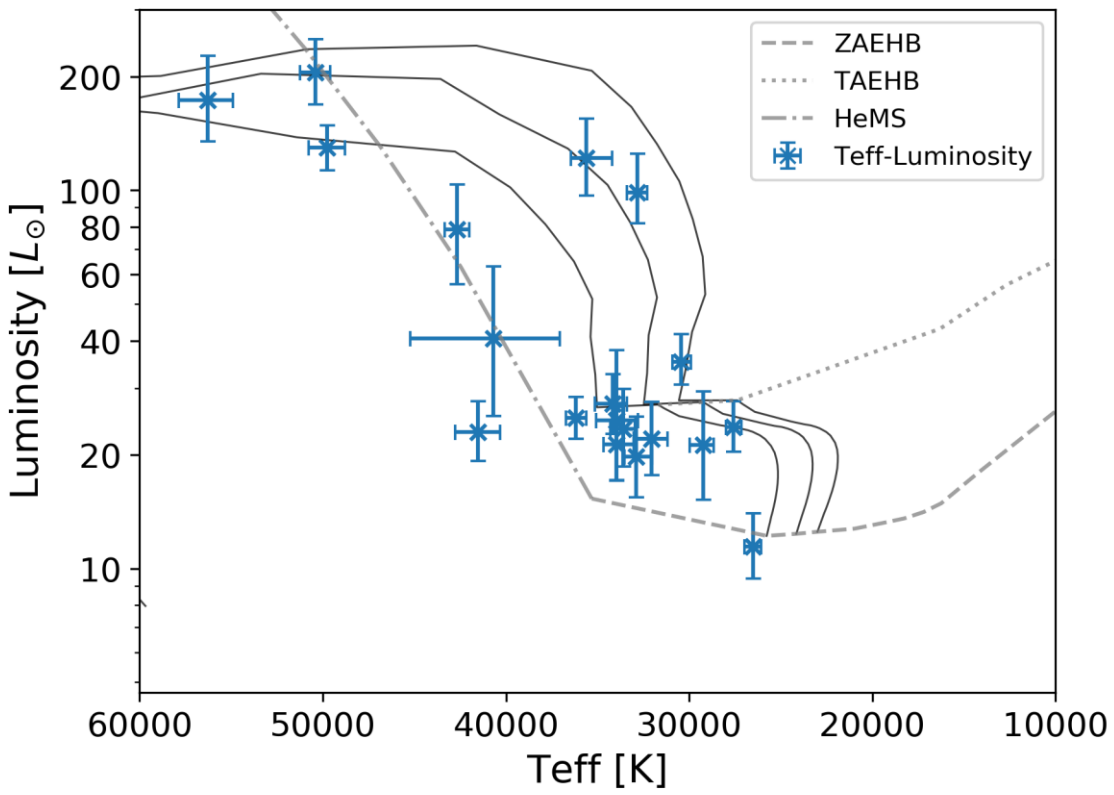
  All confirmed by SED fit (IR excess)

- 3 new composites from SED



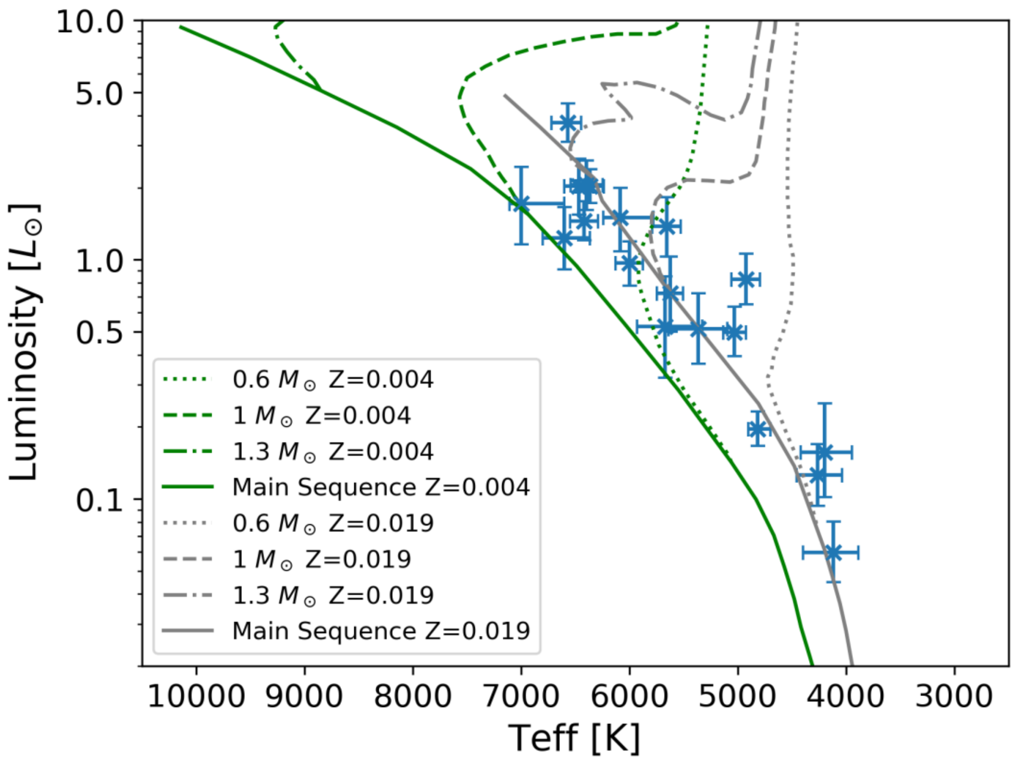
Backup: Composite sdB stars

- Stellar Parameters from single model fits
  - Composites: The subdwarf

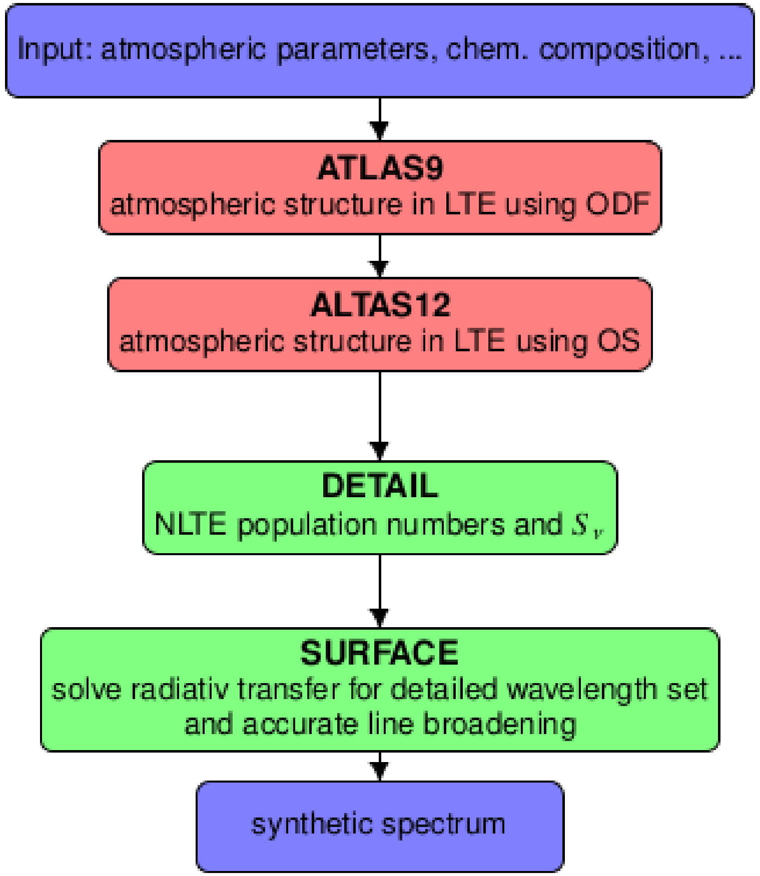


Backup: Composite sdB stars

- Stellar Parameters
  - Composites: The main-sequence companion



Backup: Model atmospheres and synthetic spectra: The ADS approach



- **ATLAS9/12** Temperature-density stratification for preselected metal abundance distribution
- **DETAIL:**NLTE departure coefficients for H and He levels
- **SURFACE:** Spectrum synthesis of H and He lines
- Input physics: One fits all
- homogeneous grid of synthetic spectra and spectral energy distributions for the entire parameter space:

T_{eff} = 15000...115000K, $\log g$ = 4.6...7.0,

log He/H=-5..+3, log Z= -2, -1, 0,+1 * Standard

Backup: The HQS sdB sample – a benchmark for the new model generation

Analysis Edelmann et al. 2003

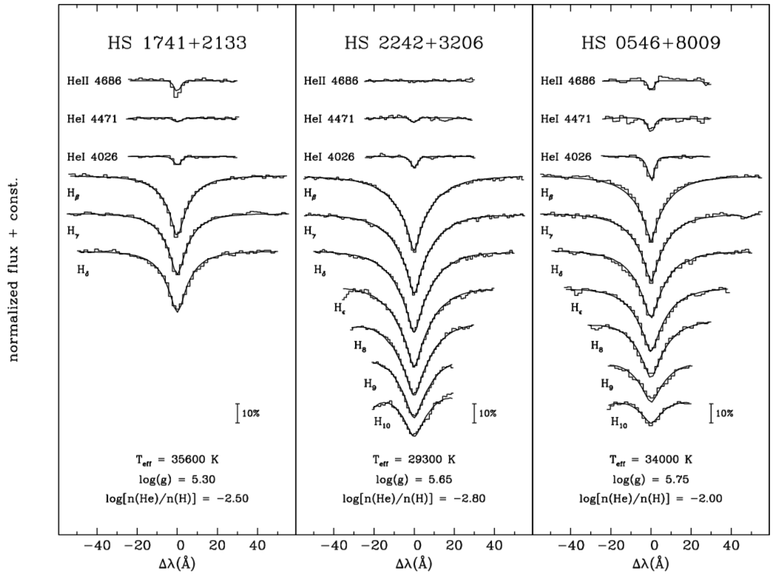
NLTE vs metal line blanketing

$\sim T_{\mathrm{eff}} < 27000\ K$: LTE (metal line blanketing, Heber et al. 2000)

$\sim T_{\mathrm{eff}} > 35000\ K$, NLTE, no metals (Napiwotzki 1997)

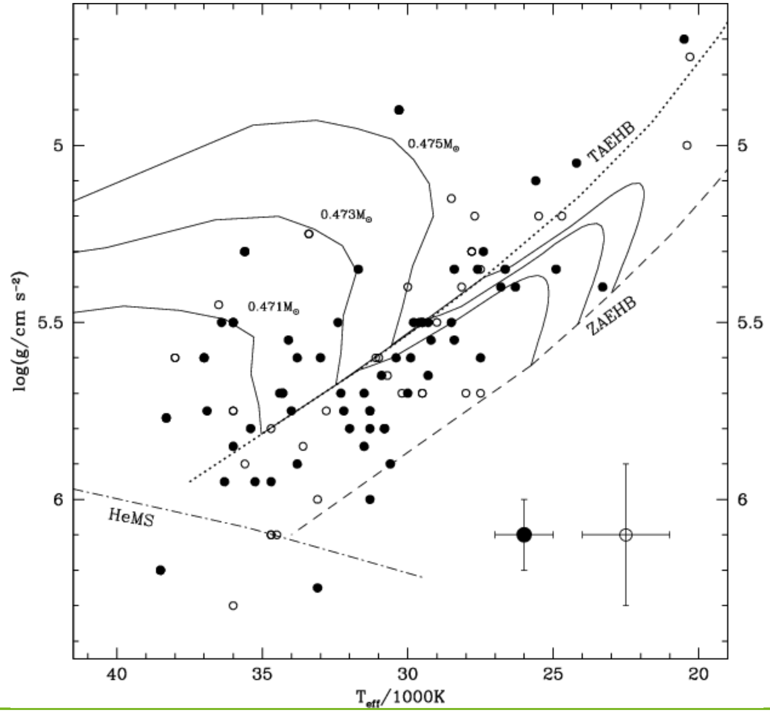
$\sim 27000\ K\ < \ T_{\mathrm{eff}}\ < \ 35000\ K$:

mean of LTE and NLTE

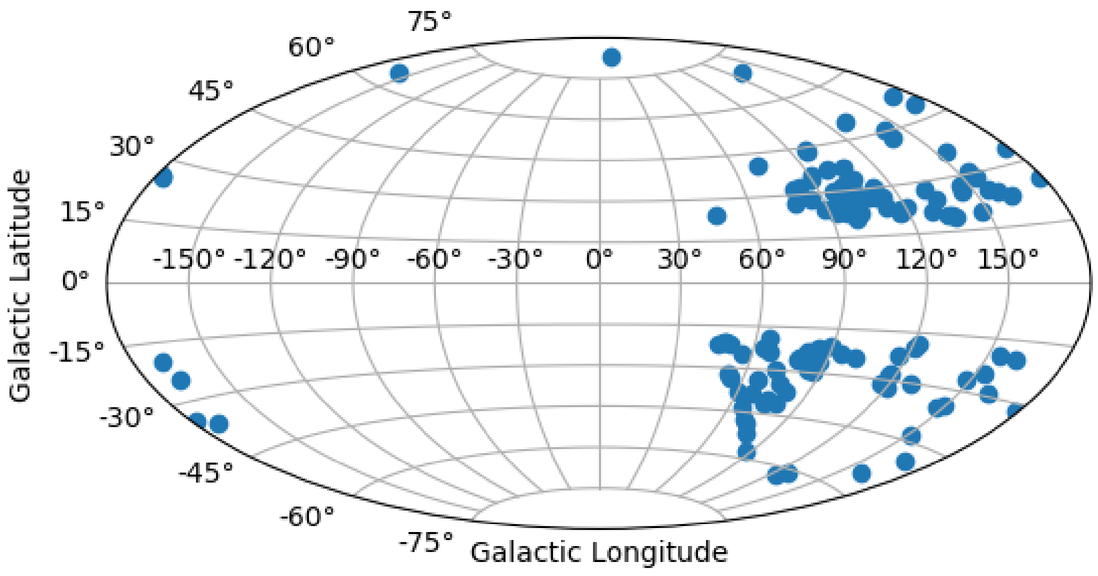


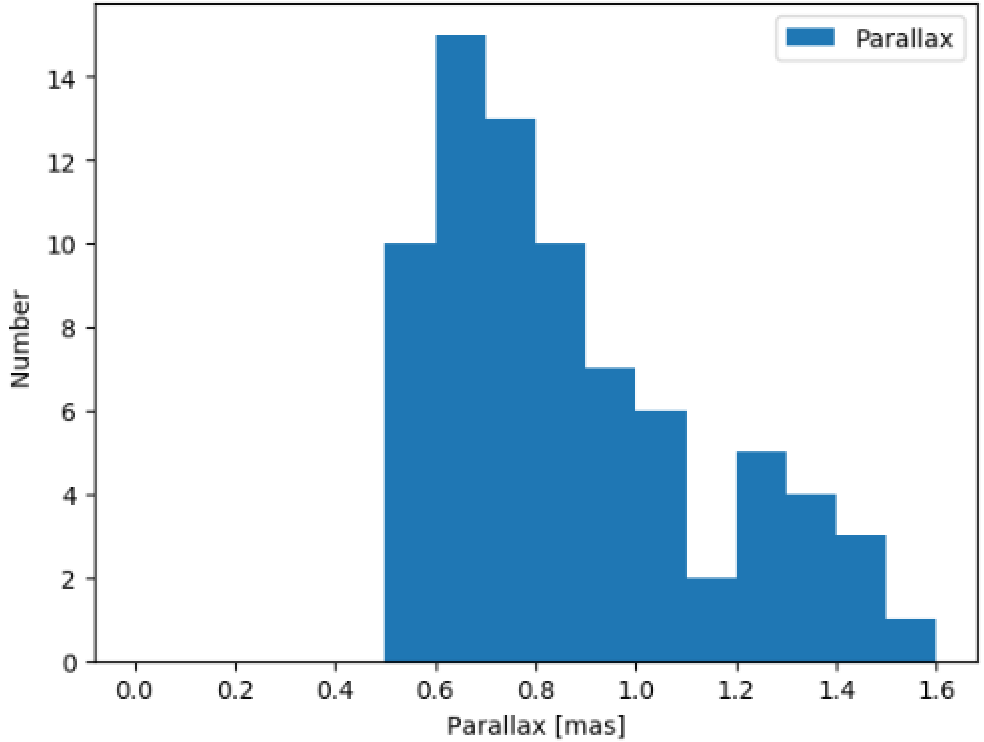
selected H and He lines

Kiel diagram:
non-composite sdB stars



Backup: Hot subdwarf targets





Random sample of hot subdwarfs:

North and South of Galactic plane

at |b| > 15°

distances 600-2000pc:

good parallaxes for many

Backup: Formation