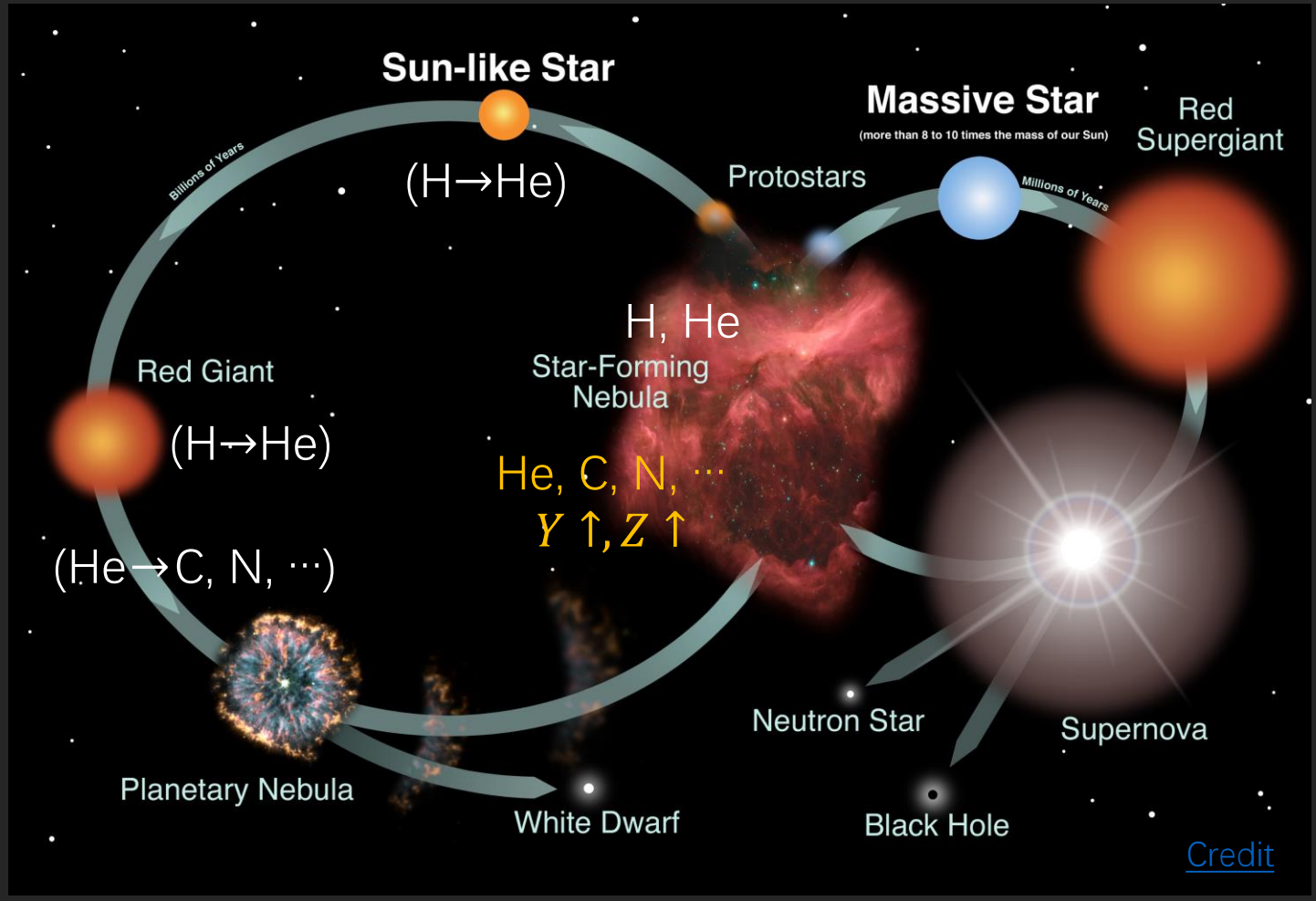
Toward the helium abundance: The behavior of the helium 10830Å in the open cluster Stock 2 and field stars

Mingjie Jian (简明杰) @ Department of Astronomy, Stockholm University

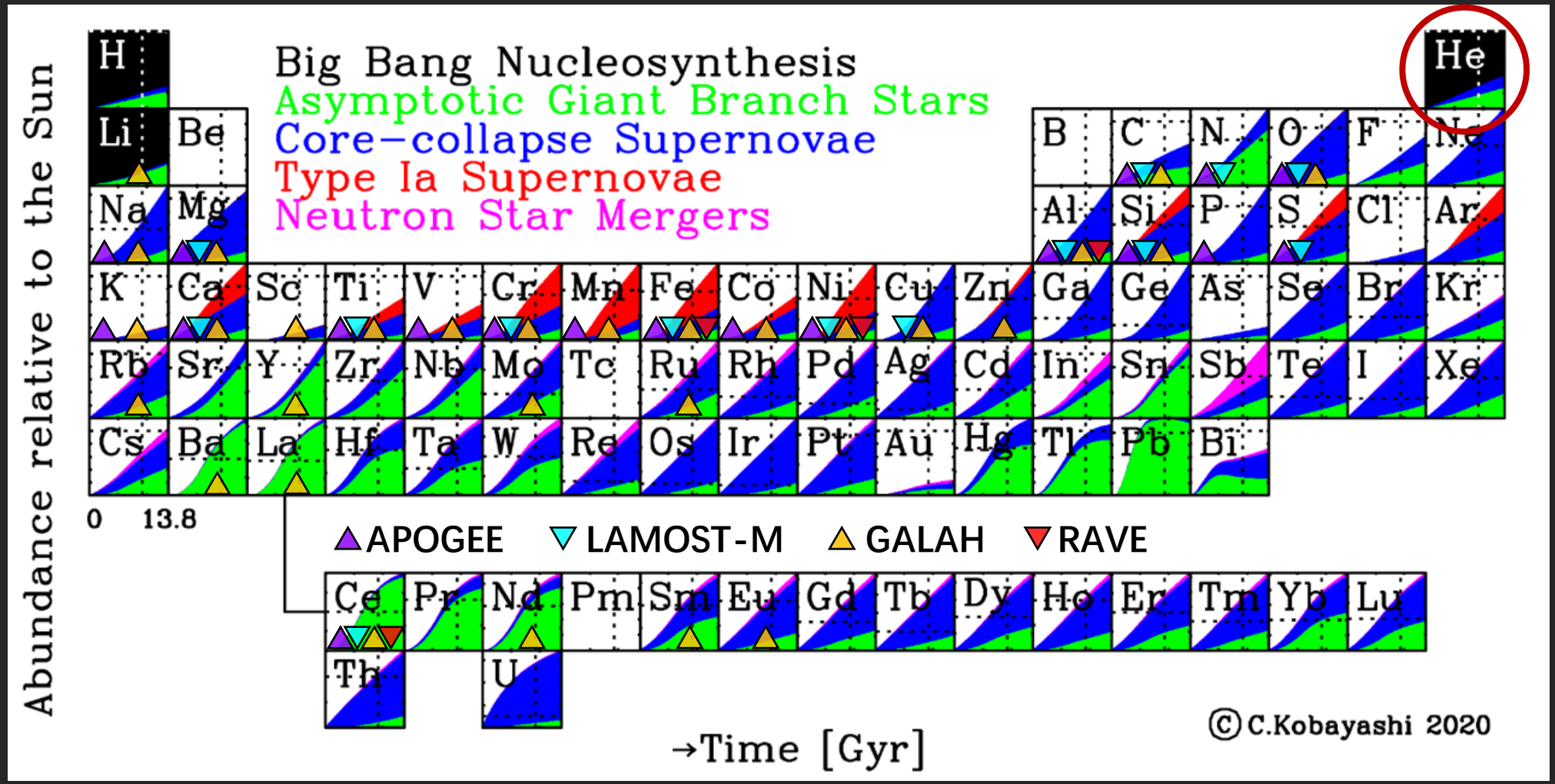
Xiaoting Fu (符晓婷), Noriyuki Matsunaga (松永典之), Valentina D'Orazi, Angela Bragaglia, Daisuke Taniguchi (谷口大輔), Min Fang (房敏), Nicoletta Sanna, Sara Lucatello, Antonio Frasca, Javier Alonso-Santiago, Giovanni Catanzaro, Ernesto Oliva, and the WINERED team

Stellar nucleosynthesis

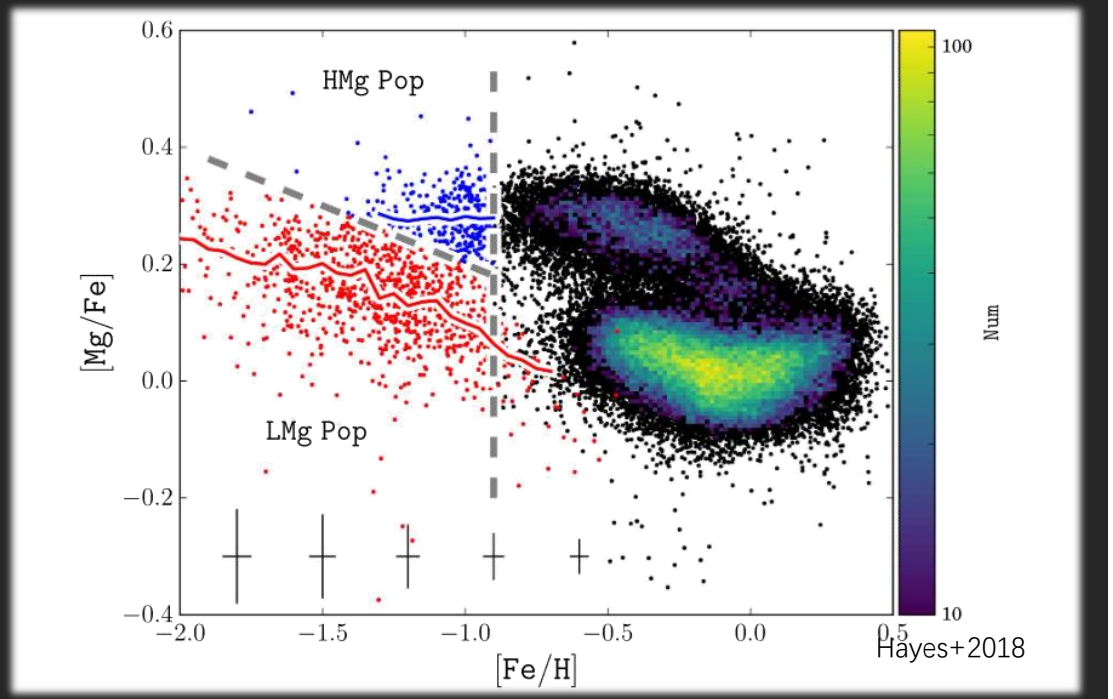
- Helium and heavier elements are enriched in the “material cycle”.
- The next generation stars are born with enriched chemical compositions:
  - Y, Z: mass ratio of helium and heavier elements of a star.

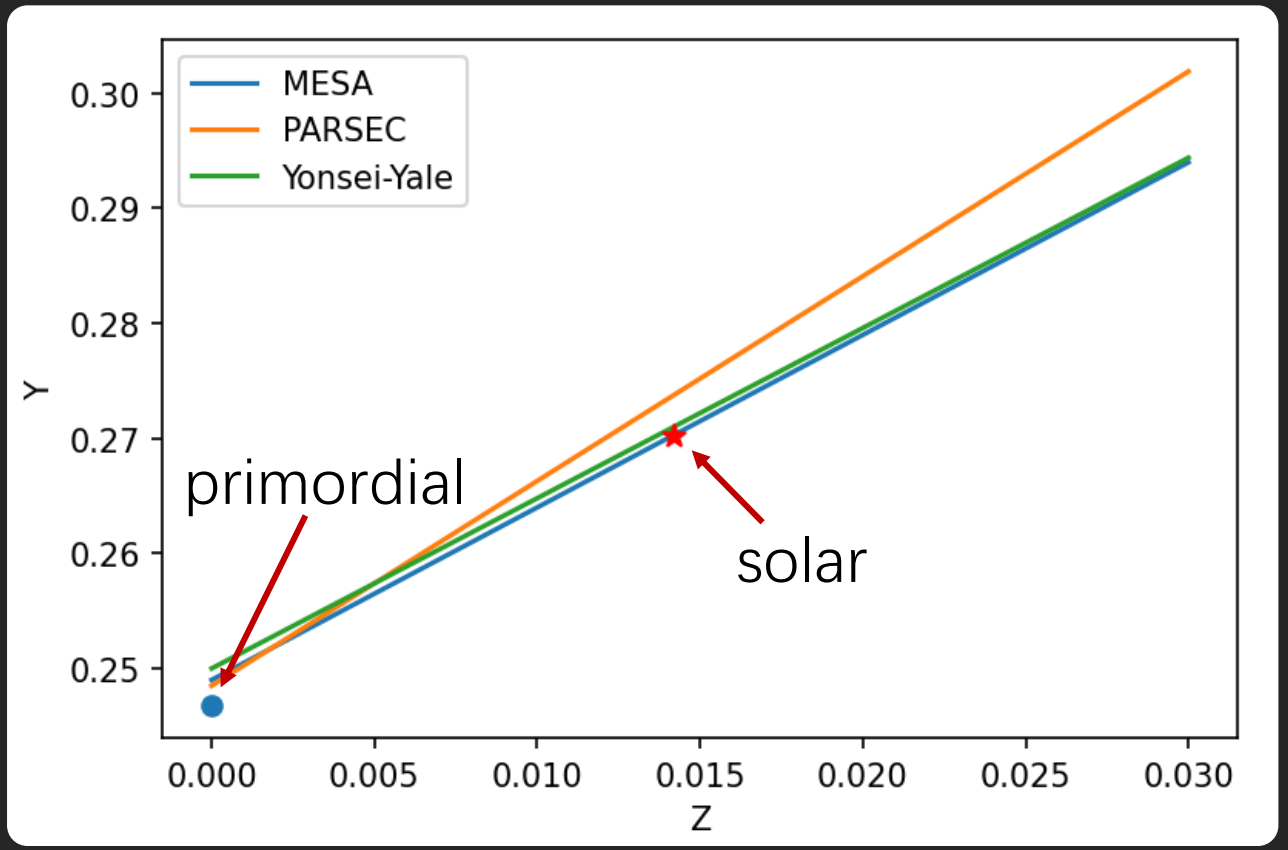


The elements being measured



Mg – Fe vs Y – Z diagram



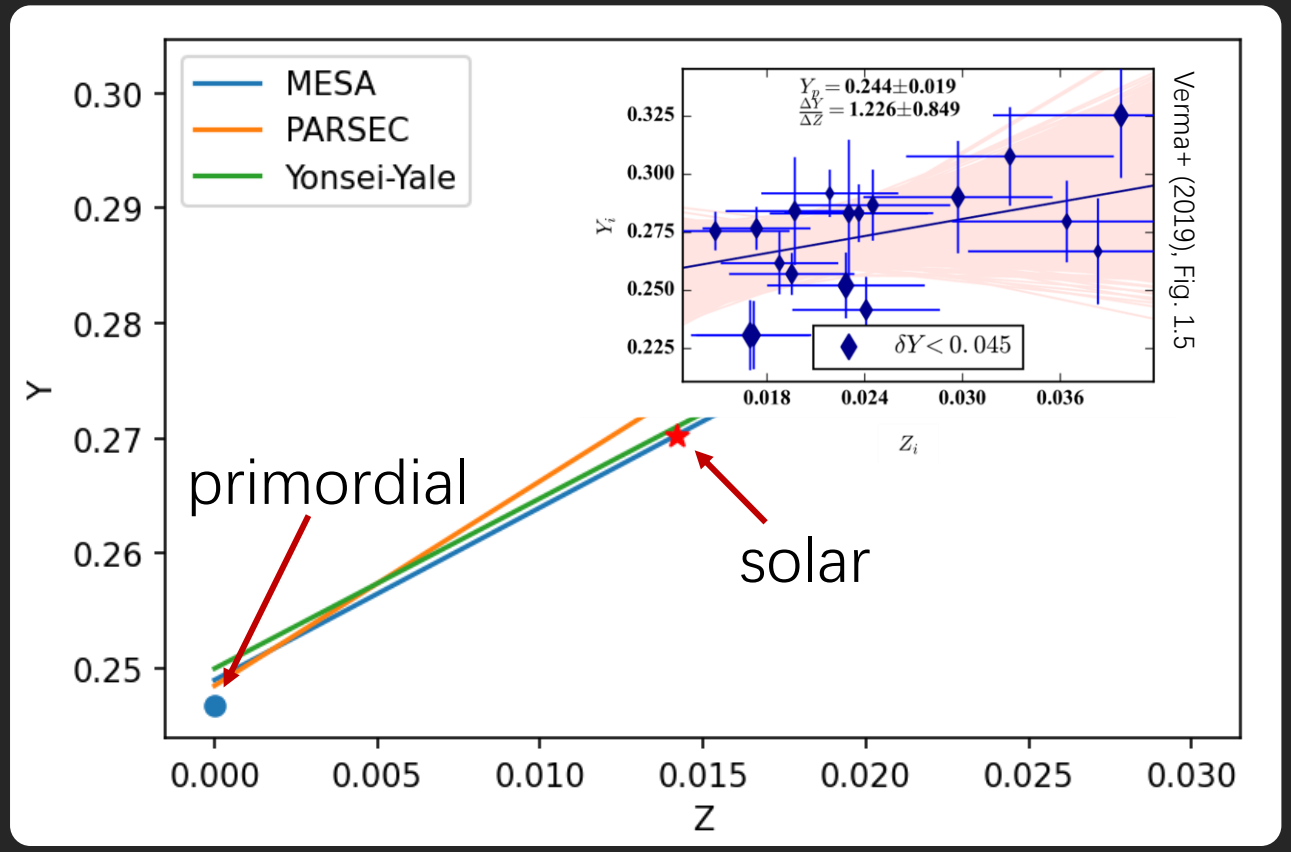


Universal helium enrichment law?

No!

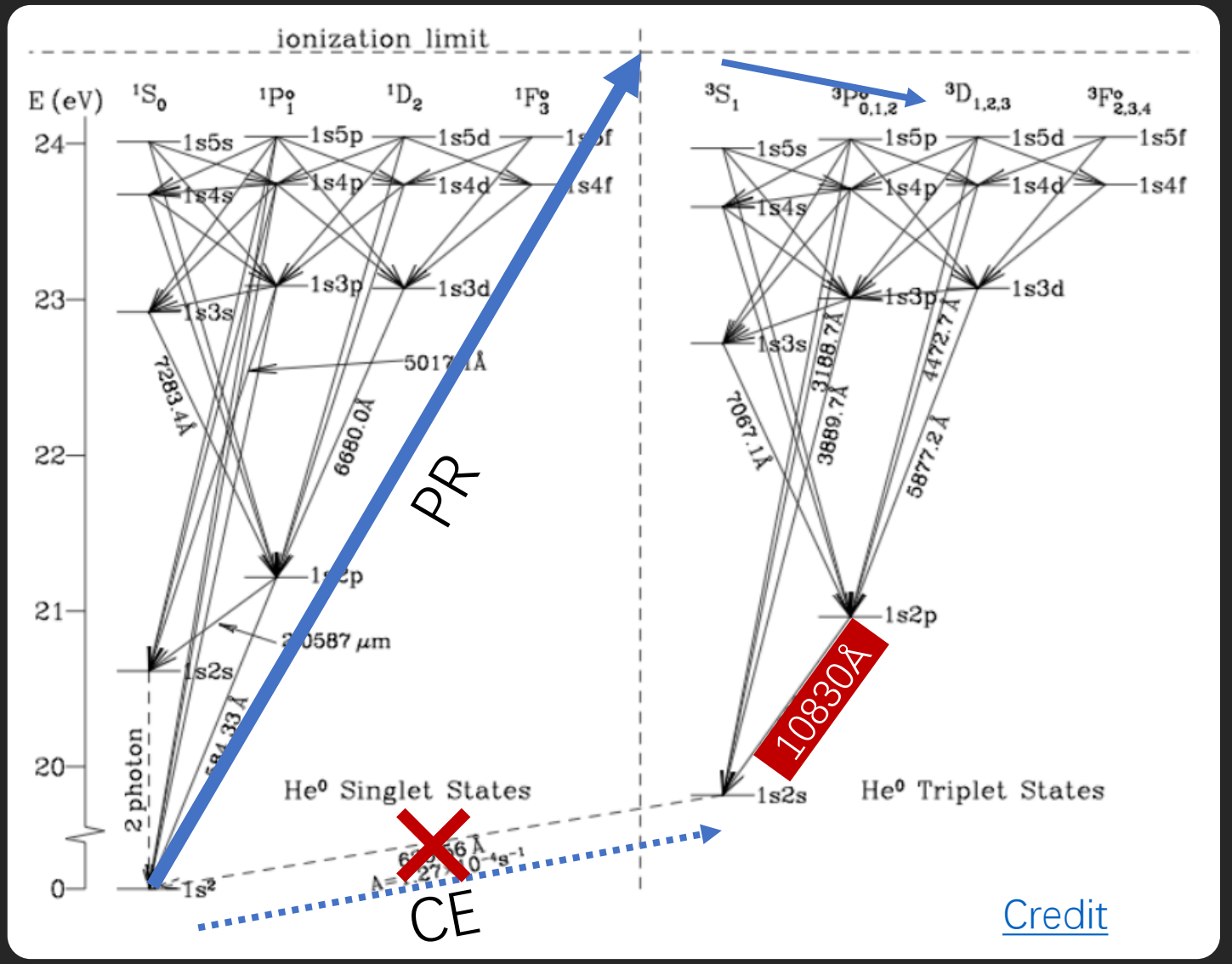
- Linear relation fitted by primordial and solar Y, Z.

- Globular clusters:
  - Y variation
- Asteroseismology:
  - smaller slope



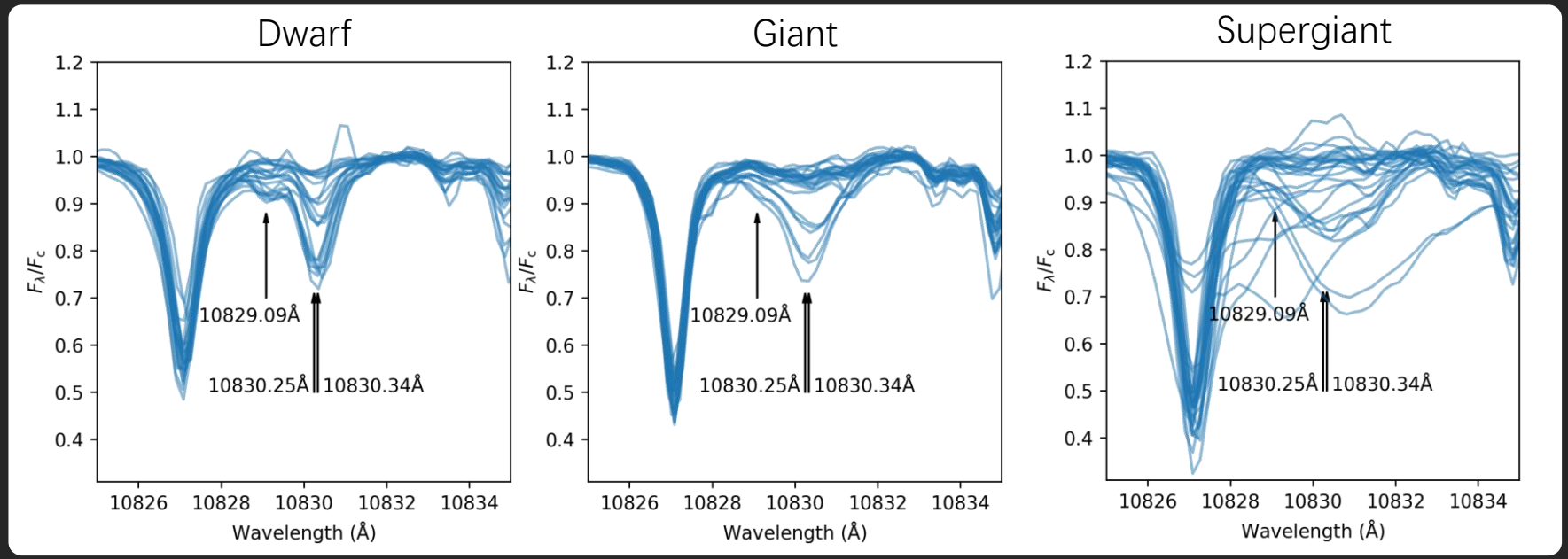
He energy levels

- Resonance lines:
  - In UV wavelength
  - Weak in FGK type stars
- He 10830
  - Present in most late-type stars and formed in the chromosphere.
  - Formation mechanisms:
    - Photoionization Recombination (PR), triggered by high-energy photons from the corona.
    - Collisional Excitation (CE)



Target line: The He 10830

- He 10830 is a helium absorption feature which appears in most of the late-type stars' spectra.
- Near infrared: suffers less extinction.

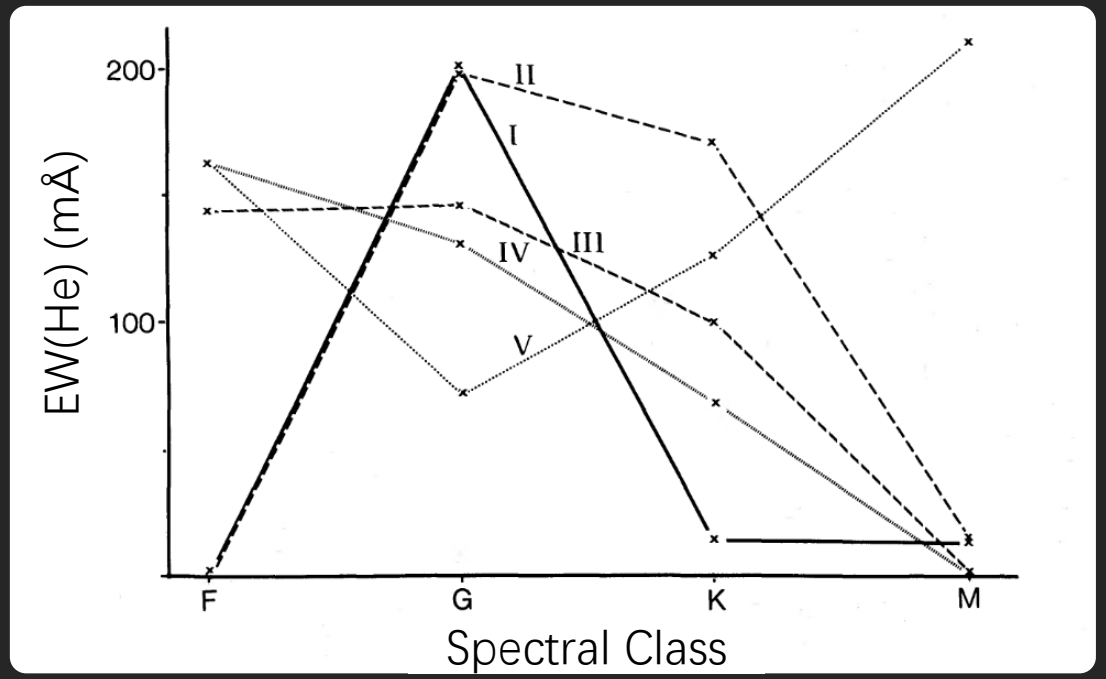


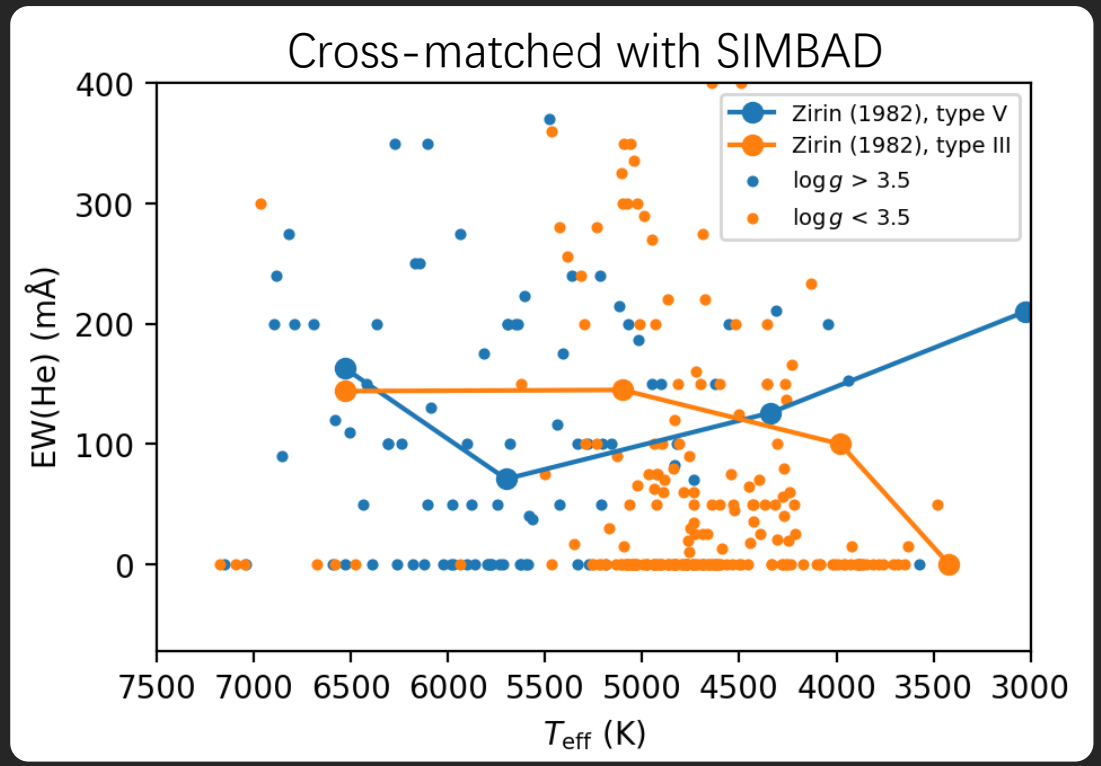
→ *Y*?

EW(He) – spectral type trend

Observations before 1990s

- Zirin (1982)





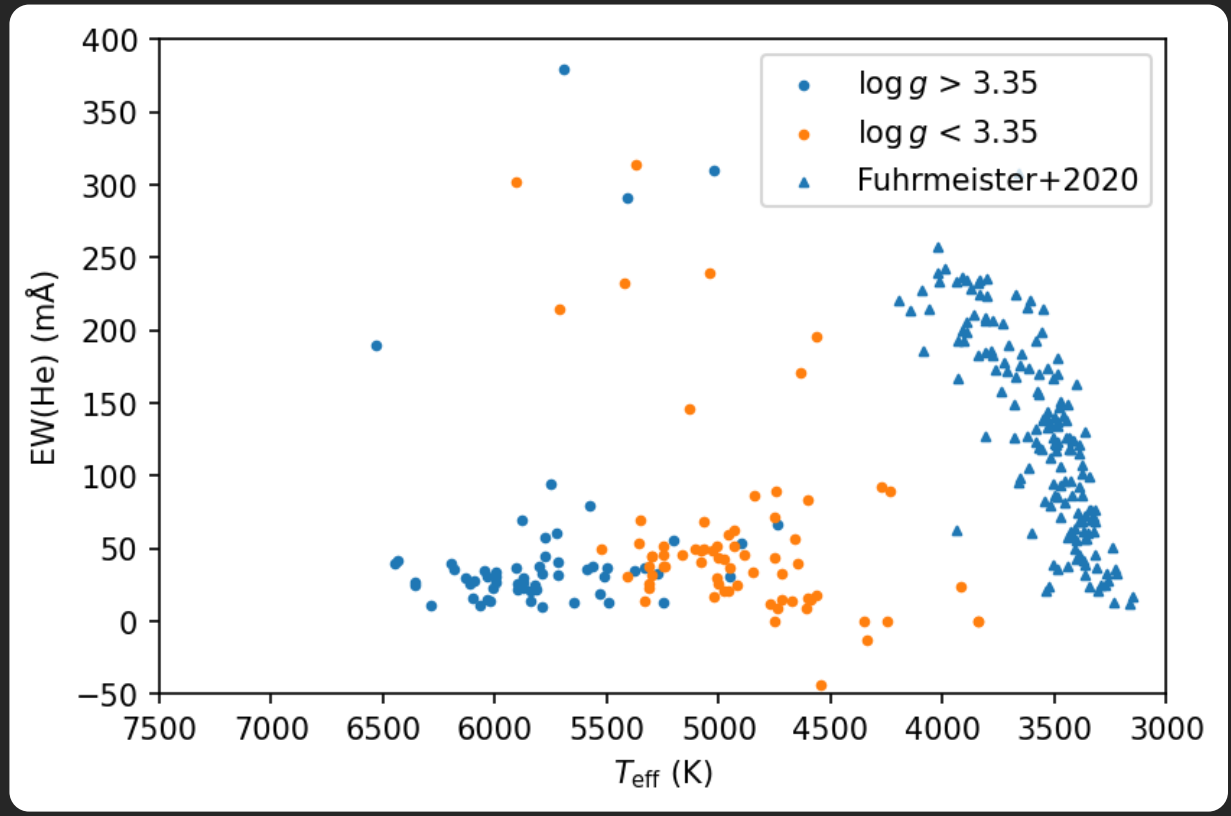
- Only rough trends were derived.

EW(He) – T_{eff} trend

Observations after 1990s

- Most of the stars are metal-poor except for those from Fuhrmeister+(2020).
- No clear trend is found except for the M-dwarfs.

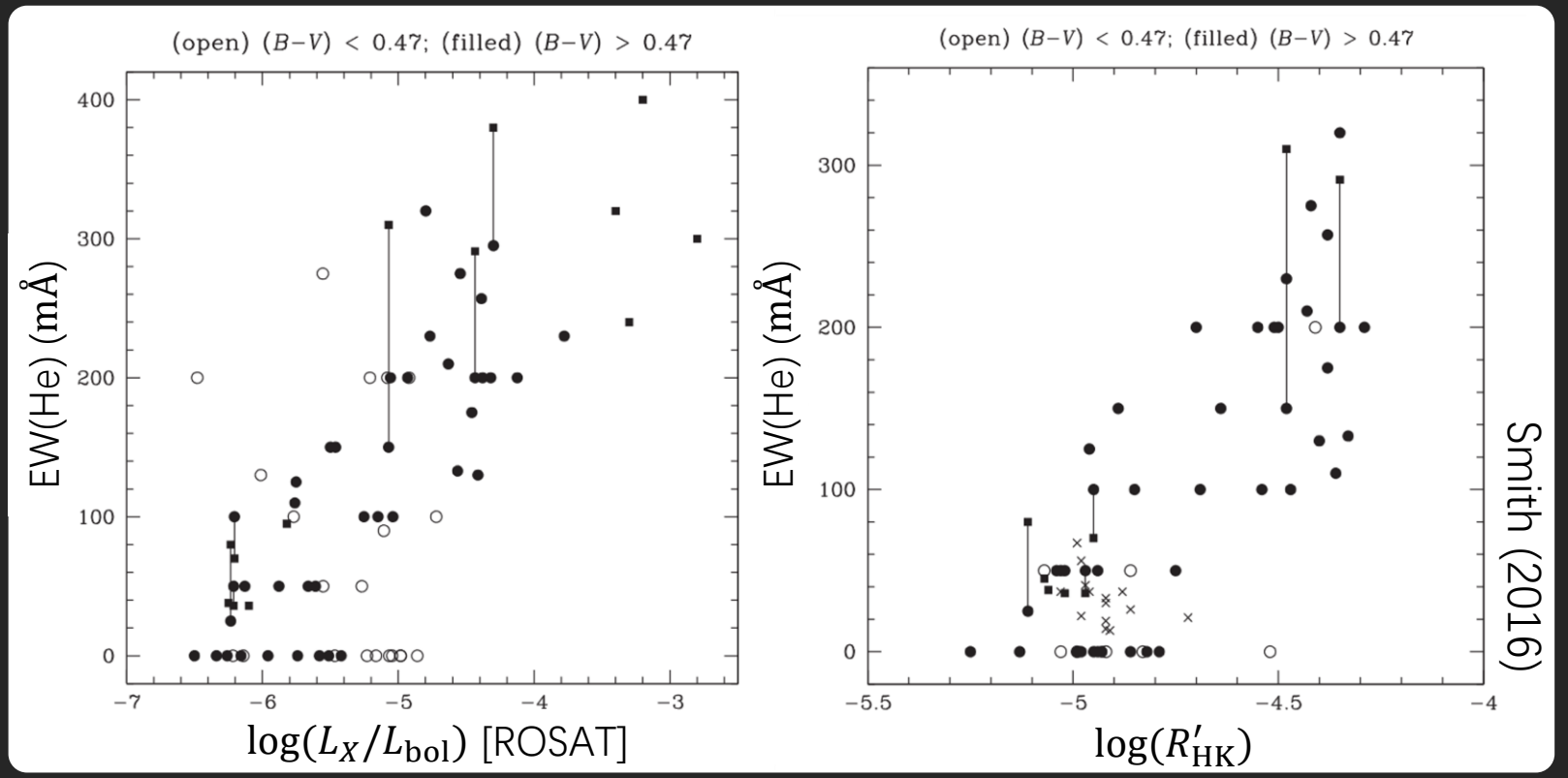
- A new sample of stars with similar surface helium abundance is necessary.



Connection with formation mechanisms

- Previous works suggest EW(He) are correlated with both $\log R'_{\rm HK}$ and $\log L_{\rm X}/L_{\rm bol}$.

- Can He 10830 be used to measure Y?



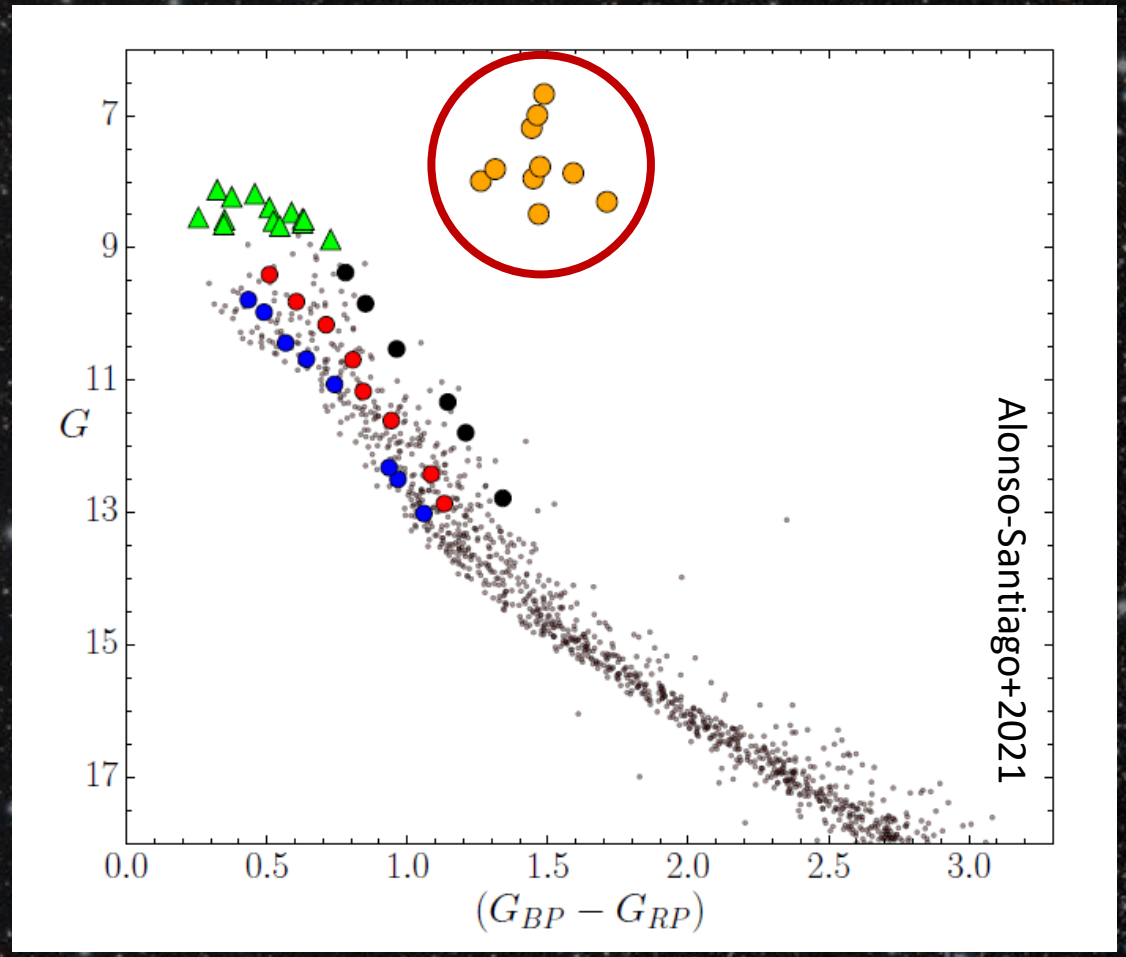
Stars with varied Y

$(Y, \log R'_{\rm HK}, L_{\rm X}, T_{\rm eff}, \log g)$

Stars with same Y, $T_{\rm eff}$, $\log g$, [M/H]

Stock 2: an open cluster

- Single stellar population:
  - same age, similar chemical composition
- Age: 450Myr
- [Fe/H] = -0.07
- MSTO stellar mass: $\approx 2.8 M_{\odot}$
  - (Alonso-Santiago+2021)

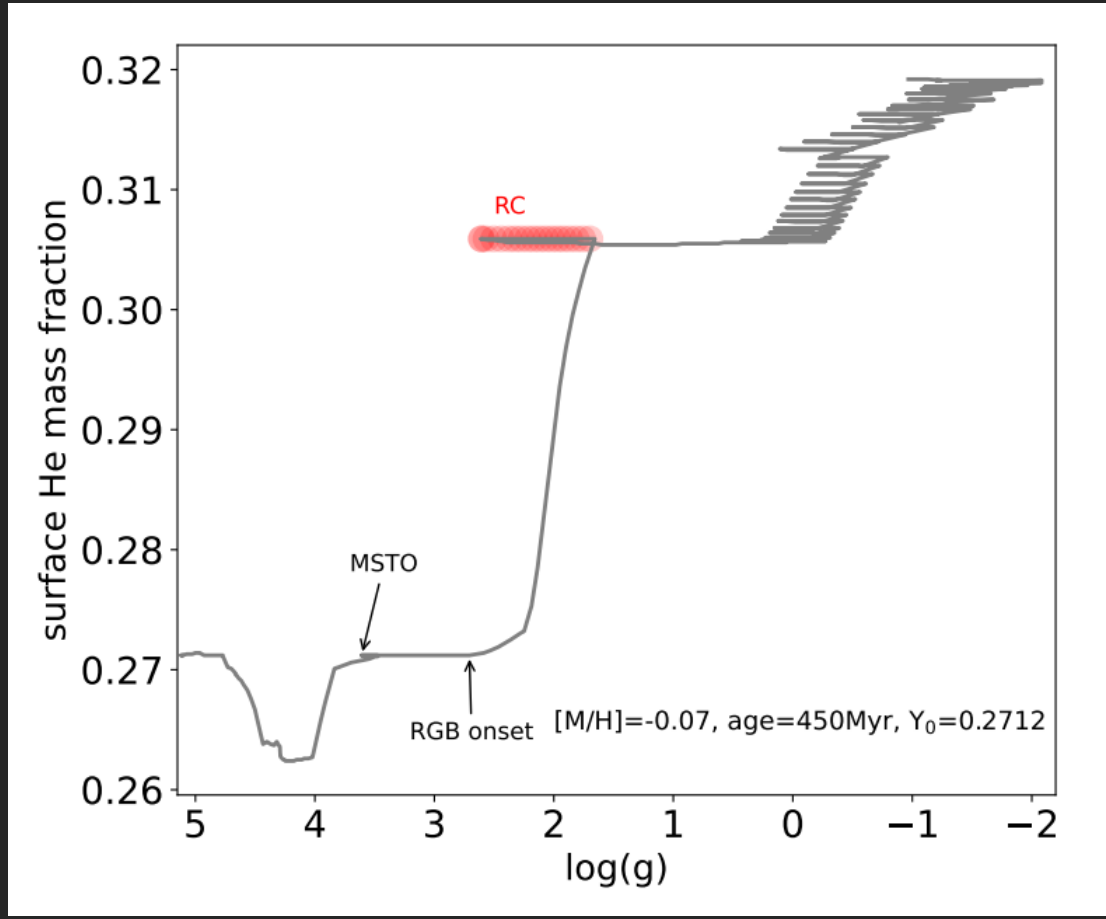


Credit

Red clump stars in Stock 2

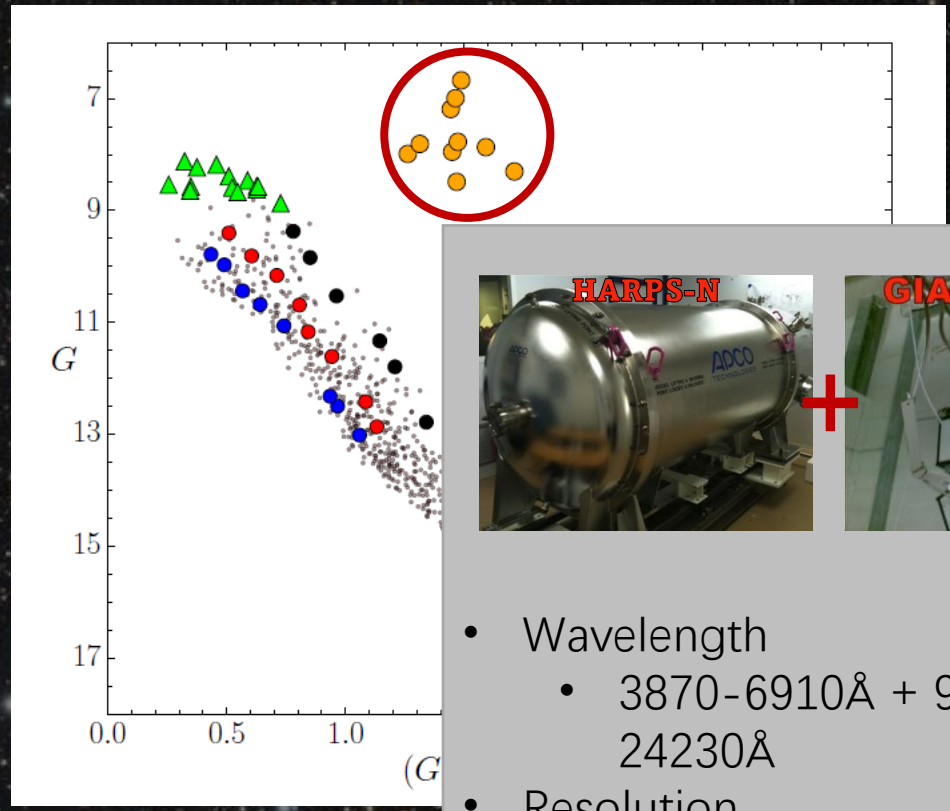
- The Y in dwarfs:
  - Diffusion
  - First dredge-up
- The Y in RCs:
  - The Ys are similar
  - Their Ys are expected to be larger than those in main-sequence phase.

Isochrone



Observation

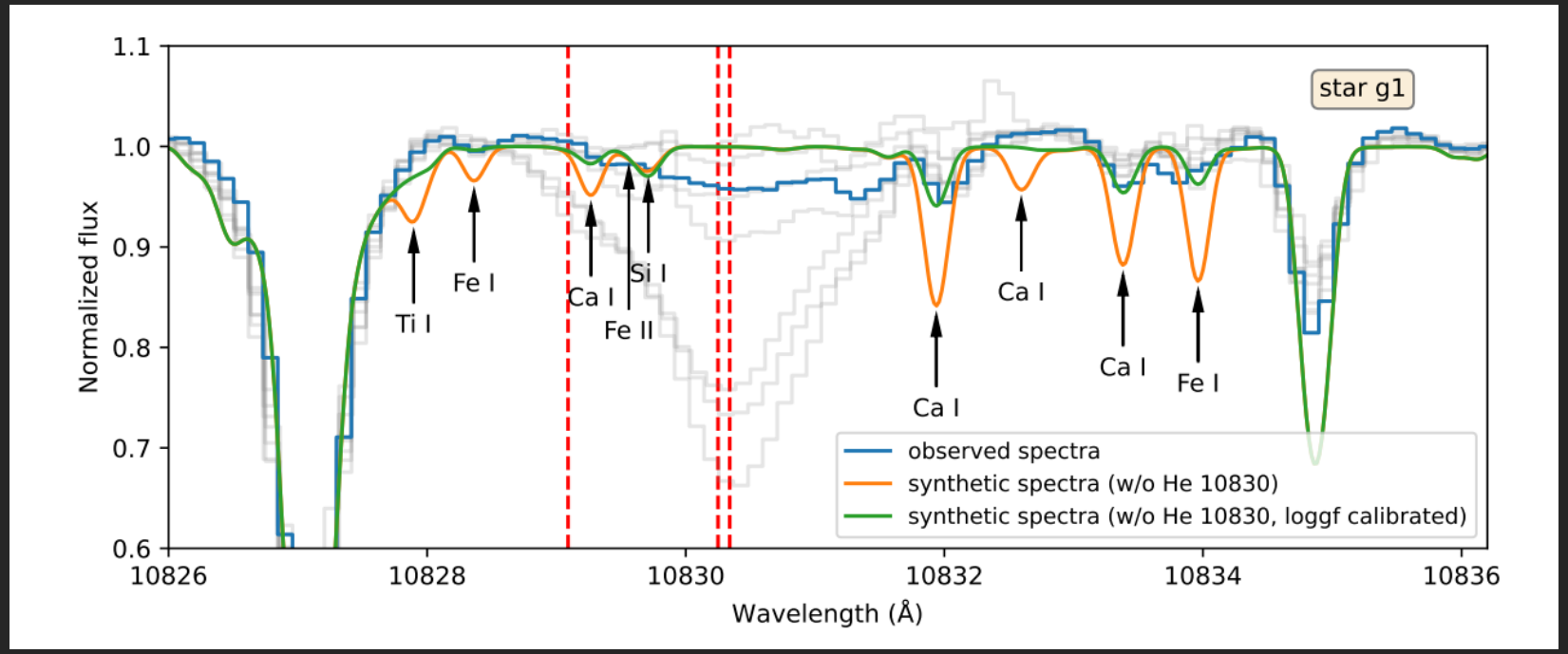
- Stellar population astrophysics
  - PI: L. Origlia
- High spectral resolution:
  - Probe detailed line shape
- Optical and NIR spectra in the same time
  - He 10830 + Ca II HK
  - Avoid temporal variation of He 10830 or Ca II HK lines.



- Wavelength
  - 3870-6910Å + 9530-24230Å
- Resolution
  - 115,000 + 50,000
- Target
  - Open cluster Stock-2
  - 9 giants

Measurement of He 10830
1. blending

- Several weak atomic lines present around He 10830.
- The synthetic spectra are stronger than observed spectra.
- $\log gf$ values requires correction.

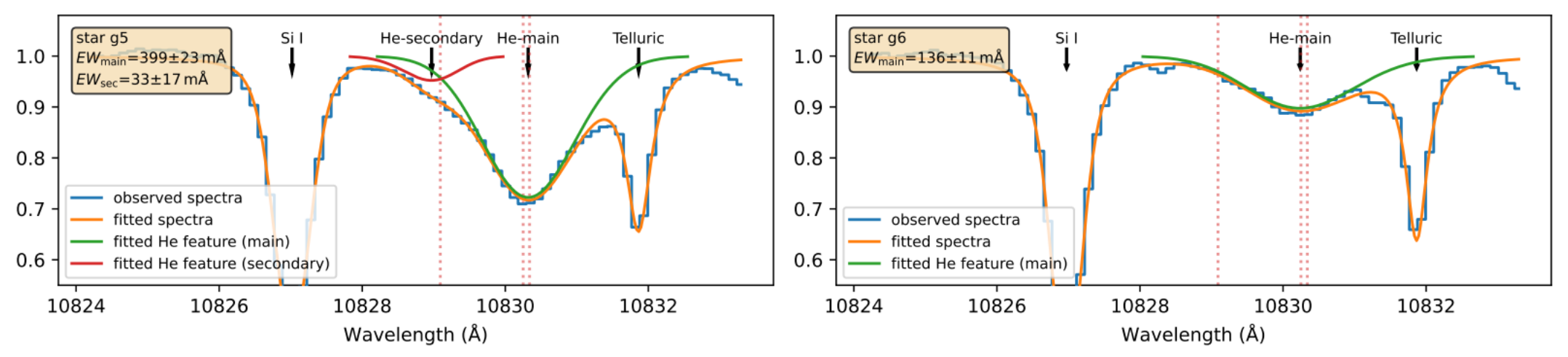


Measurement of He 10830
2. line fitting

- Si I and telluric: Voigt profile
- He features: skew Gaussian profile
  - $\frac{A}{\sigma\sqrt{2\pi}}\left\{1+\mathrm{erf}\left[\frac{\gamma(x-\mu)}{\sigma\sqrt{2\pi}}\right]\right\}\exp\left[-\frac{(x-\mu)^2}{2\sigma^2}\right]$

- A: amplitude
- μ: feature centre
- γ:asymmetry

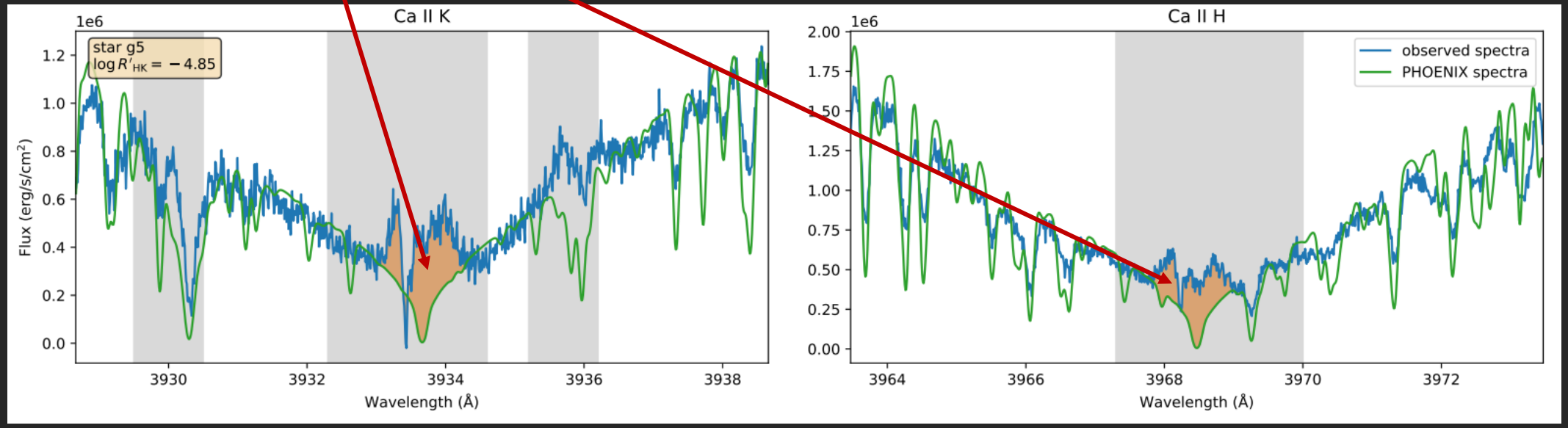
- EW: equivalent width
- λ_{peak}: peak wavelength
- B/R: blue-to-red ratio



Measurement of Ca II HK lines

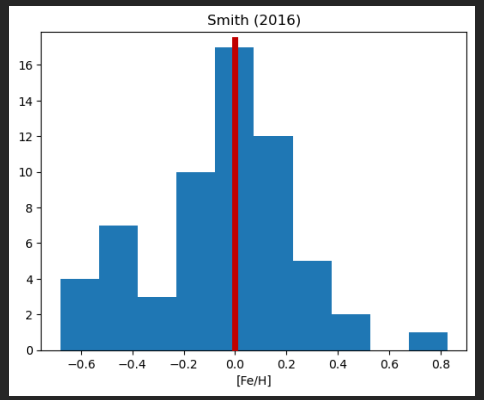
For constraining the chromospheric structure

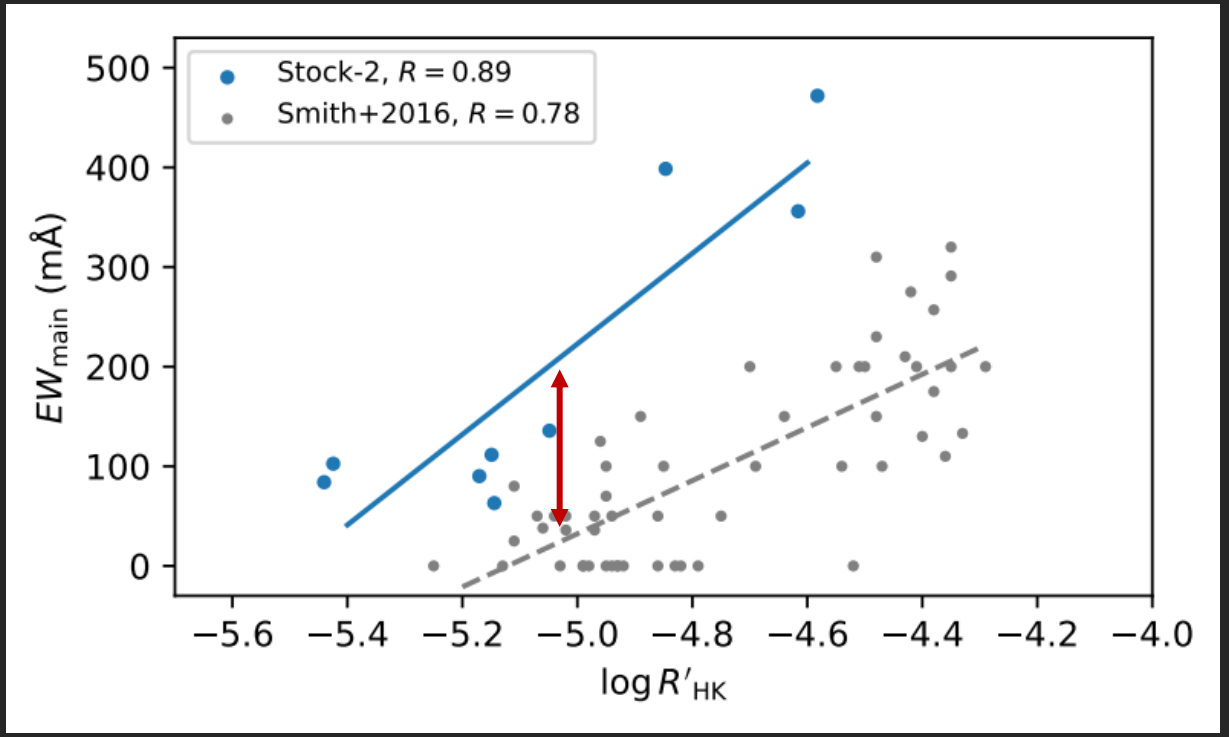
- Measuring the core-emission of the Ca II lines.
- $\log R'_{\mathrm{HK}} = (F'_{\mathrm{K}} + F'_{\mathrm{H}})/\sigma T_{\mathrm{eff}}^4$



$\log R'_{\mathrm{HK}}$ – EW relation

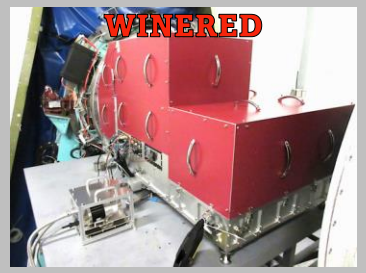
- Linear relation between He 10830 EW and $\log R'_{\mathrm{HK}}$
  - For Stock 2 RCs and field dwarfs
- The EWs of RCs are larger than dwarfs ([Fe/H]~0).
- $Y_{\mathrm{RC}} > Y_{\mathrm{dwarf}}$
- $Y \uparrow \Rightarrow EW \uparrow$





He 10830 in field stars:
Targets and observations

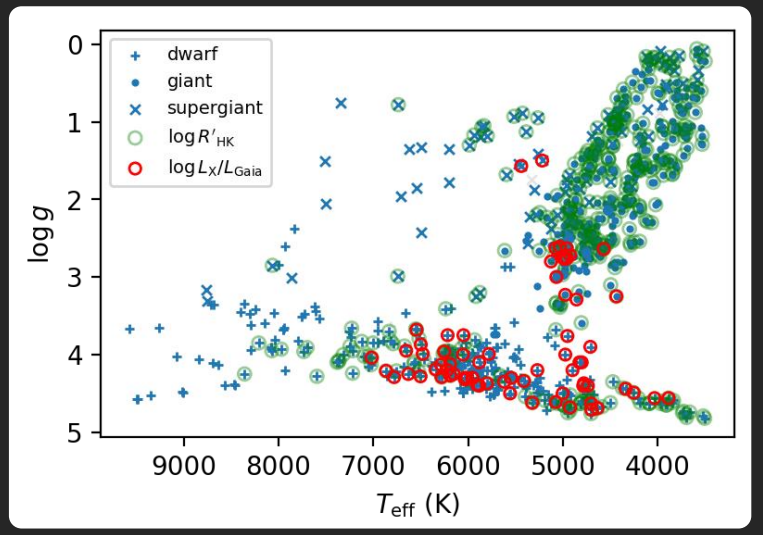
Field-WD



- Wavelength
  - 9100-13500Å
- Resolution
  - 28,000
- Target
  - AFGK type stars
  - 93 dwarfs, 70 giants, 29 supergiants
  - [Fe/H]: -1~0

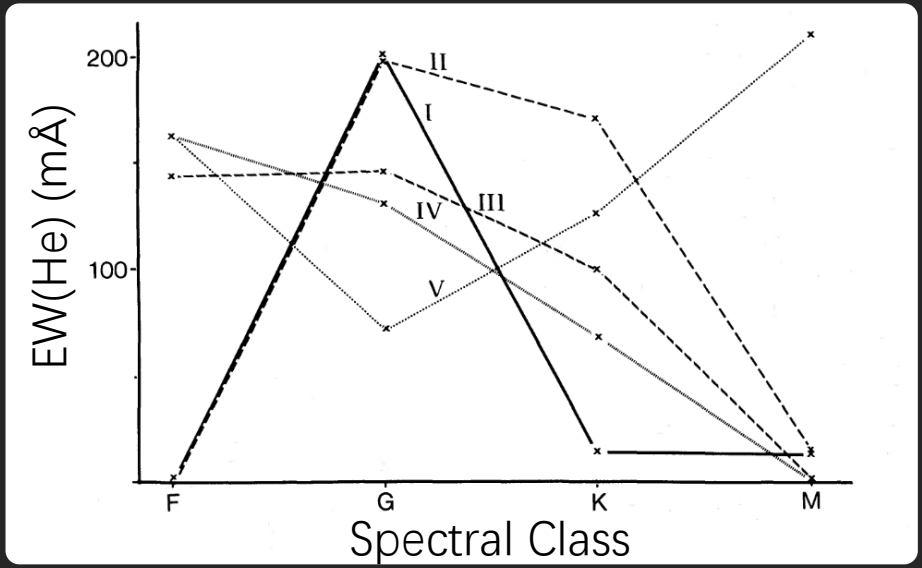
Field-XSL

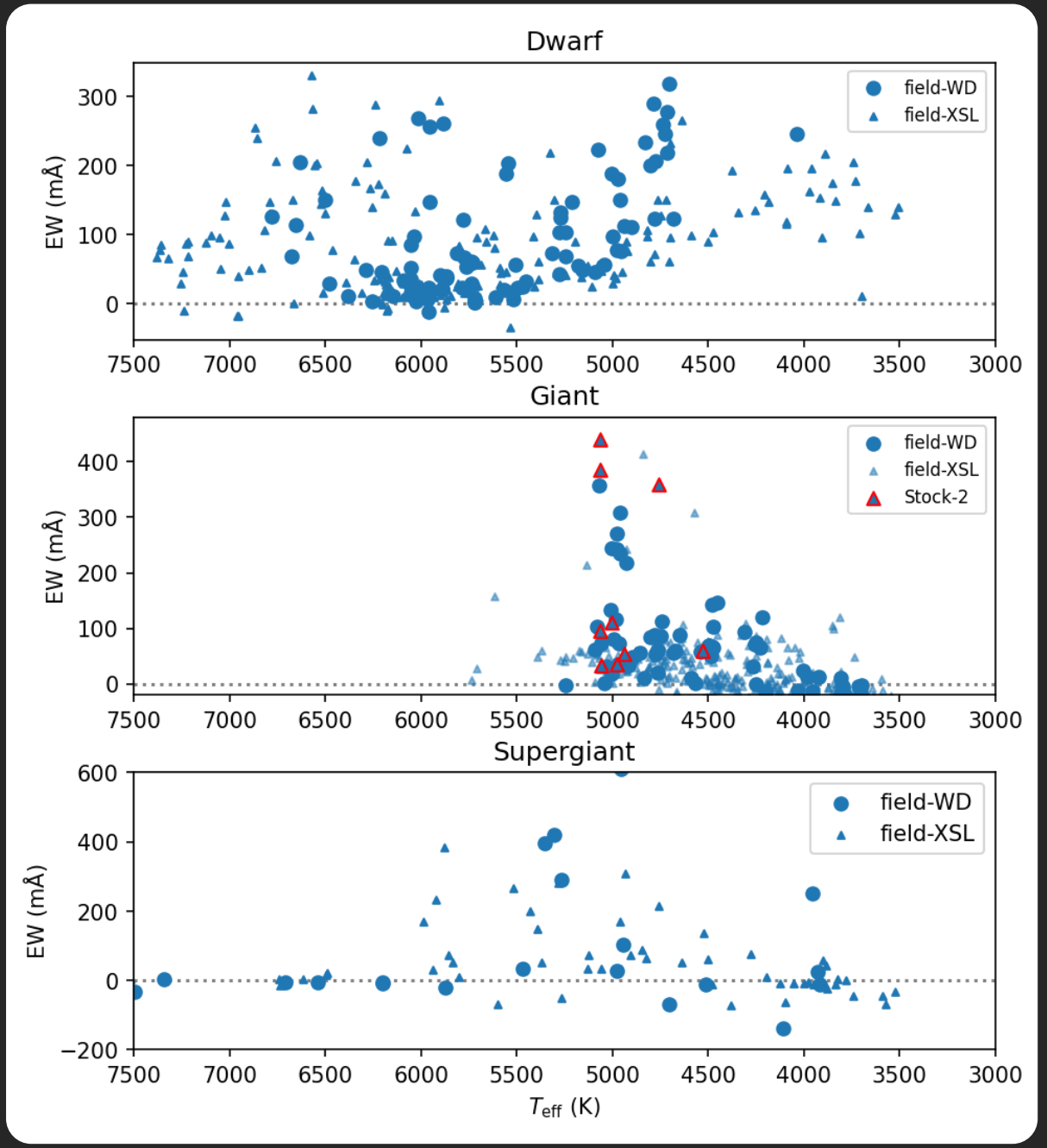
- Wavelength
  - 3000-24800Å
- Resolution
  - 10,000
- Target (X-shooter Spectral Library)
  - AFGK type stars
  - 225 dwarfs, 265 giants, 58 supergiants
  - [Fe/H]: -2~0



EW(He) – T_{eff} trend
of new targets

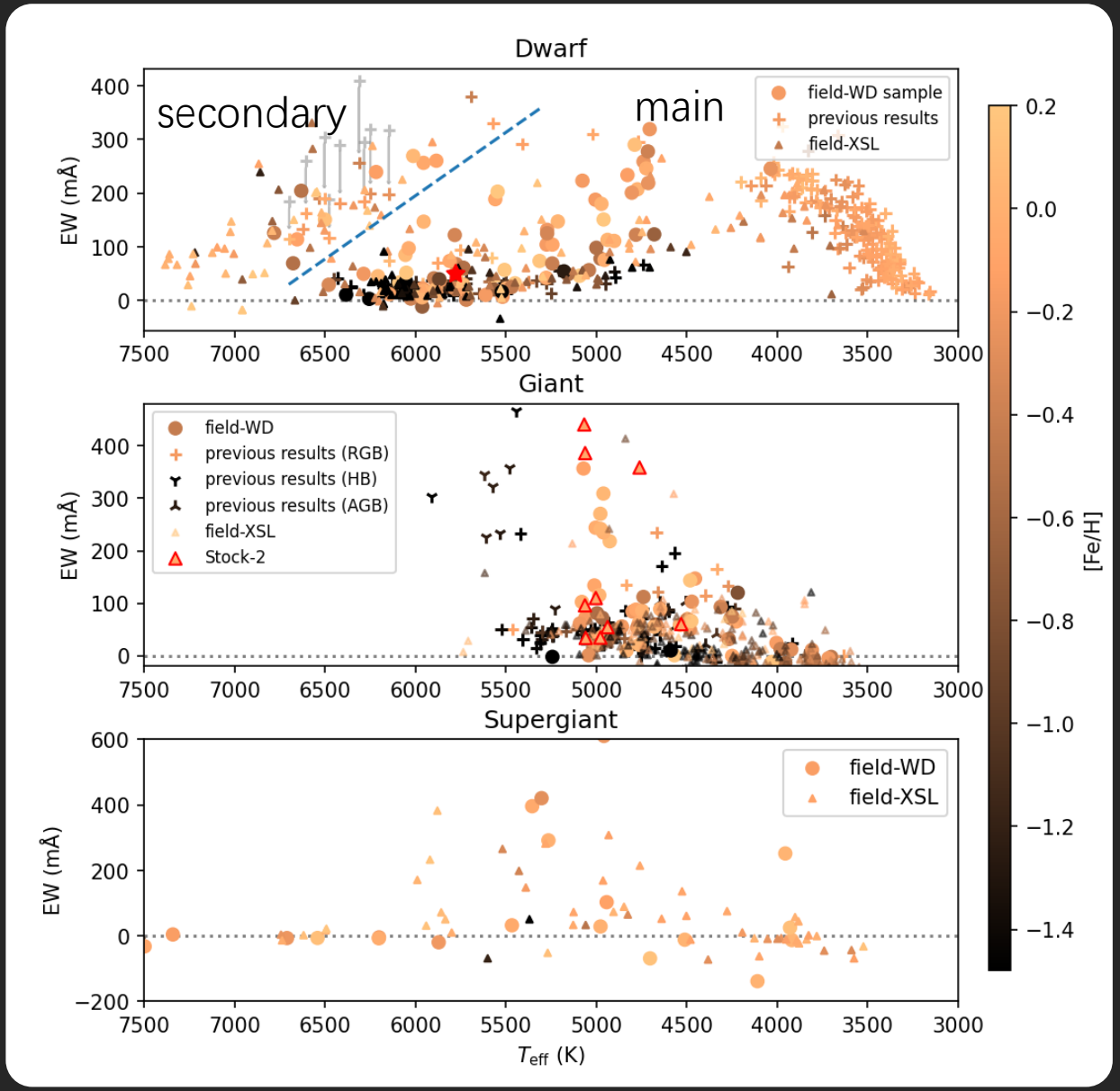
- More detailed trends compared with Zirin (1982)





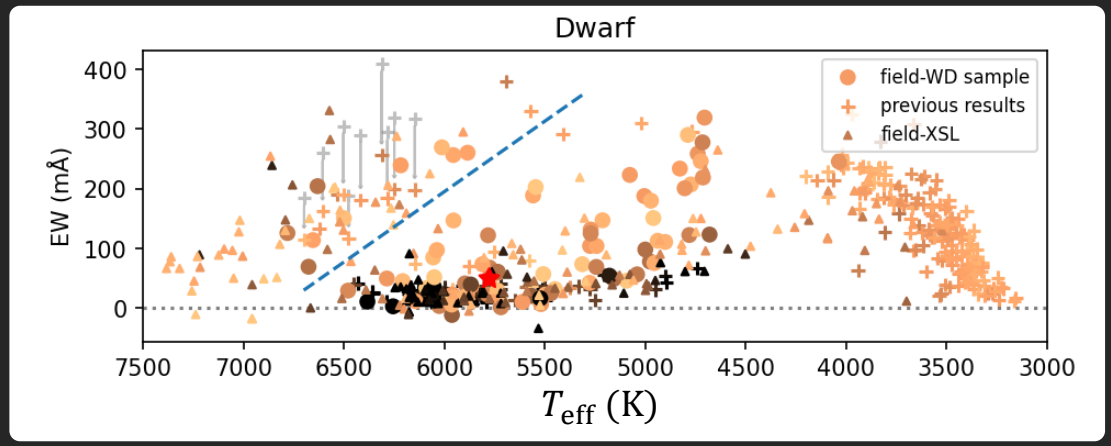
EW(He) - T_{eff} trend

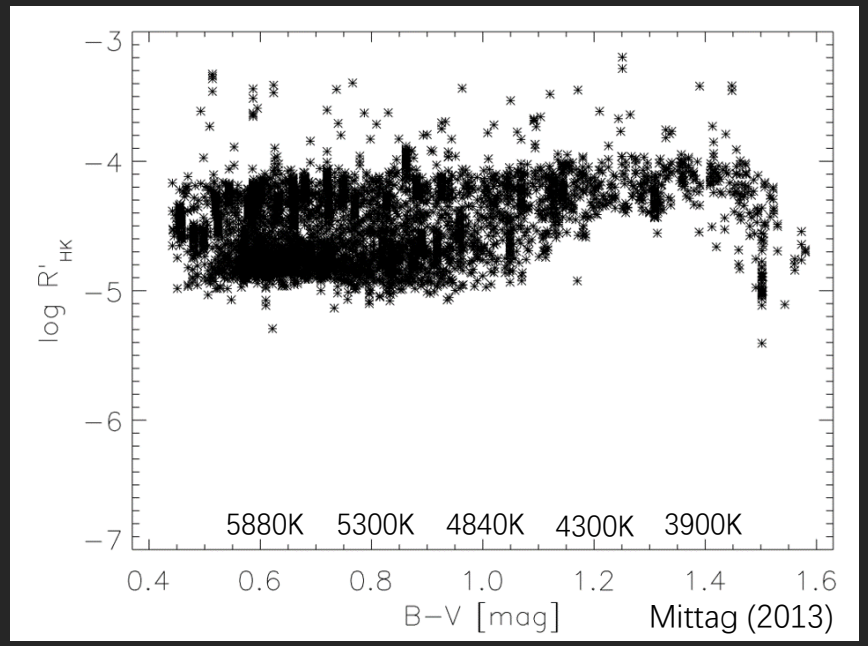
- Dwarf
  - Main and secondary trend;
  - A clear lower boundary in the main trend;
  - Scatter above the lower boundary appears.
- Giant
  - The average EW is smaller than the dwarf's
  - Metal-poor stars tend to have smaller EW.



EW(He) - T_{eff} trend

- The increase of EW(He) is consistent with that in $\log R'_{\mathrm{HK}}$.
- Such behavior implies that the CE formation mechanism appears, in the dwarfs near the lower boundary.

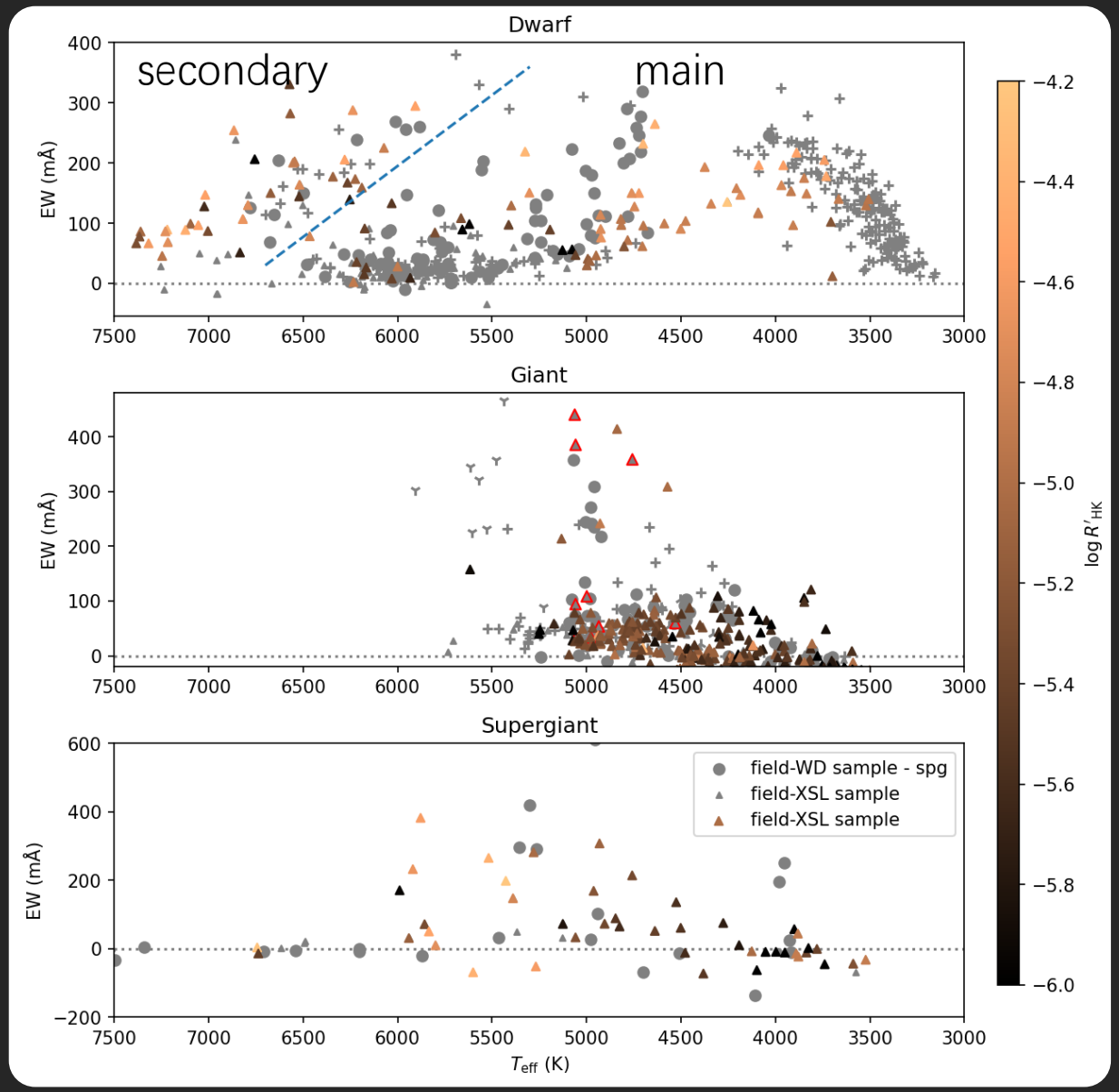




EW(He) - $T_{\rm eff}$ trend with $\log R'_{\rm HK}$

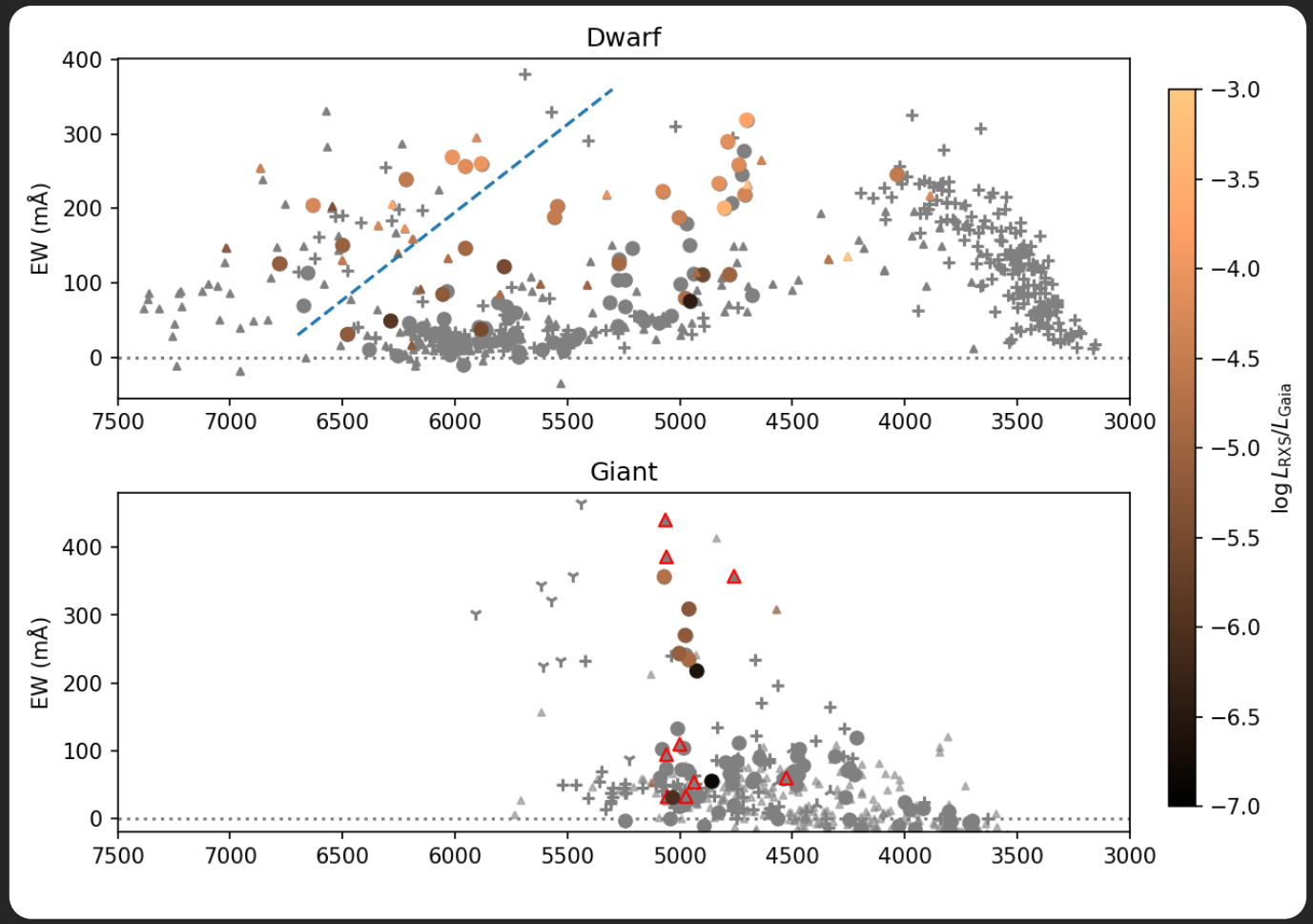
- $\log R'_{\rm HK}$ is larger at $T_{\rm eff}\sim4000$K, and smaller in lower/higher temperatures.
- $\log R'_{\rm HK}$ is also correlated with EW(He) in Stock-2 giants.

(Fig. 6.4)



EW(He) - T_{eff} trend
with L_{X}

- The dwarfs with larger EW(He) also have stronger X-ray radiation.
- The He 10830 for the dwarfs above the lower boundary are dominated by the PR mechanism.
- Such trend is seen but not obvious in the warm giants.



Summary

- The strength and shape of He 10830 and $\log R'_{\mathrm{HK}}$ for the red clump stars in Stock 2 are measured.
  - EW – $\log R'_{\mathrm{HK}}$ linear relation: larger than that for field stars
  - Symmetric line profile: stable chromospheres
- Some empirical trends between He 10830 EW and other parameters present for field stars.
- Observations in He and Ca II line for more cluster would further confirm the possibility of using He 10830 as a helium abundance indicator.