The impact of stellar helium content and recent stellar measurement effort

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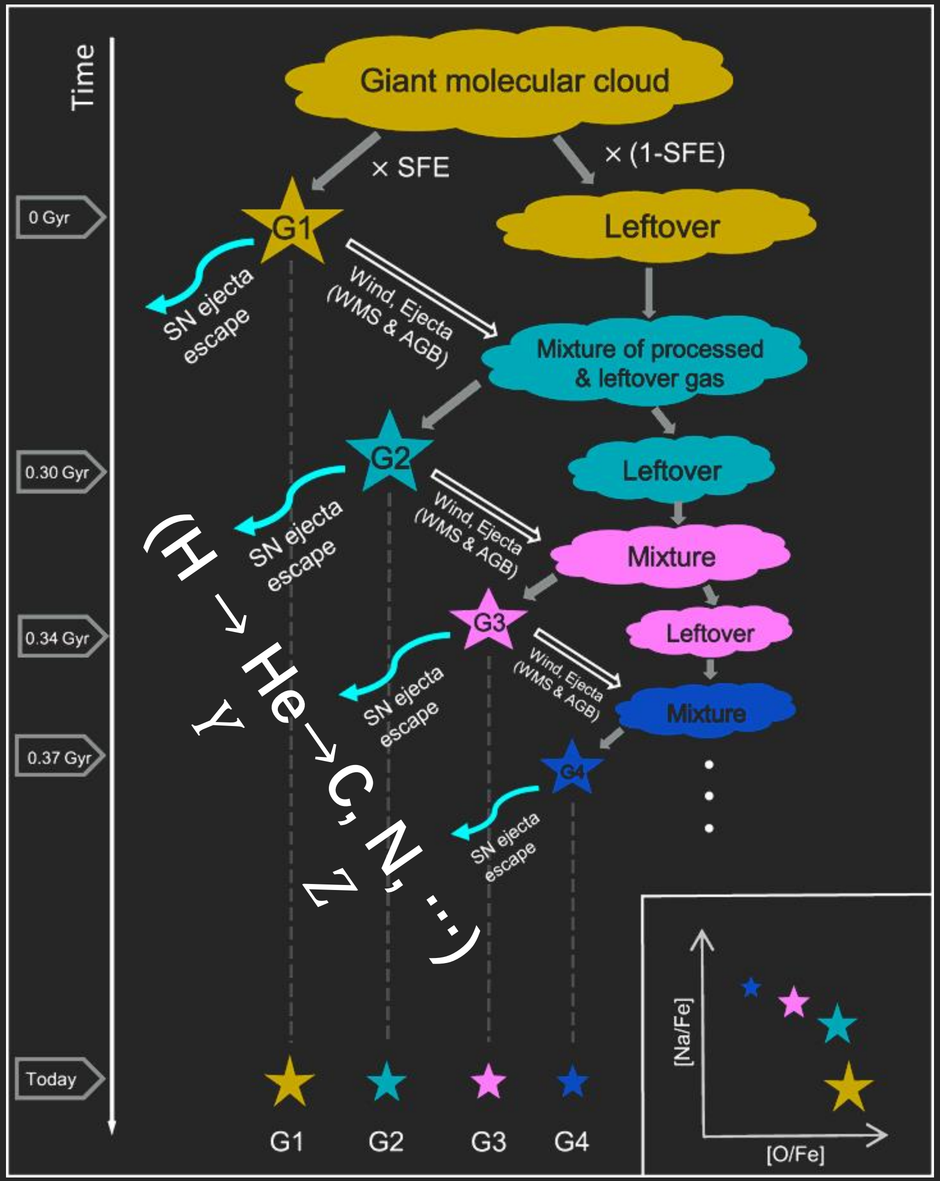
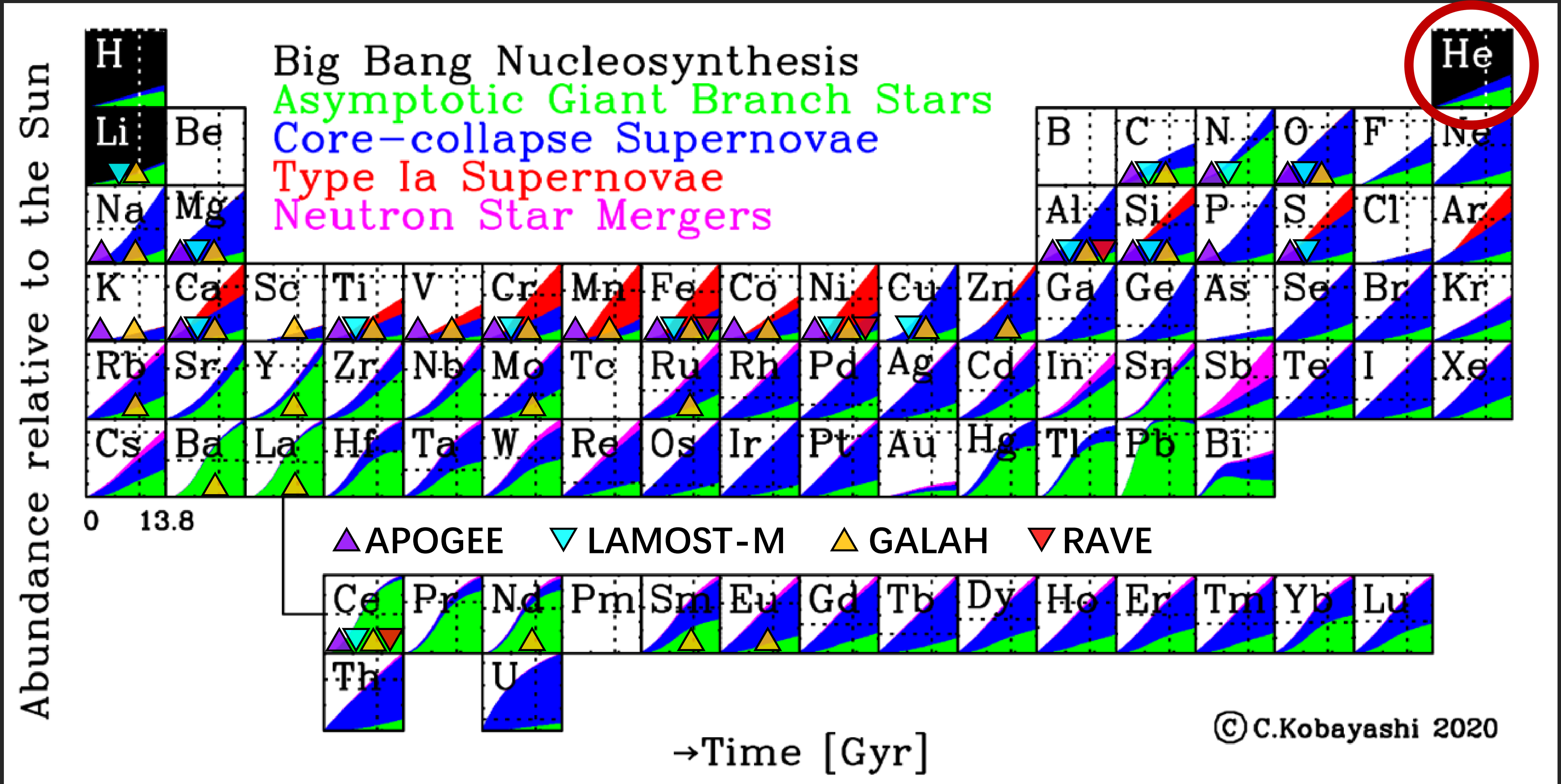
Stellar nucleosynthesis

- Start point: H, He, Li
- 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.



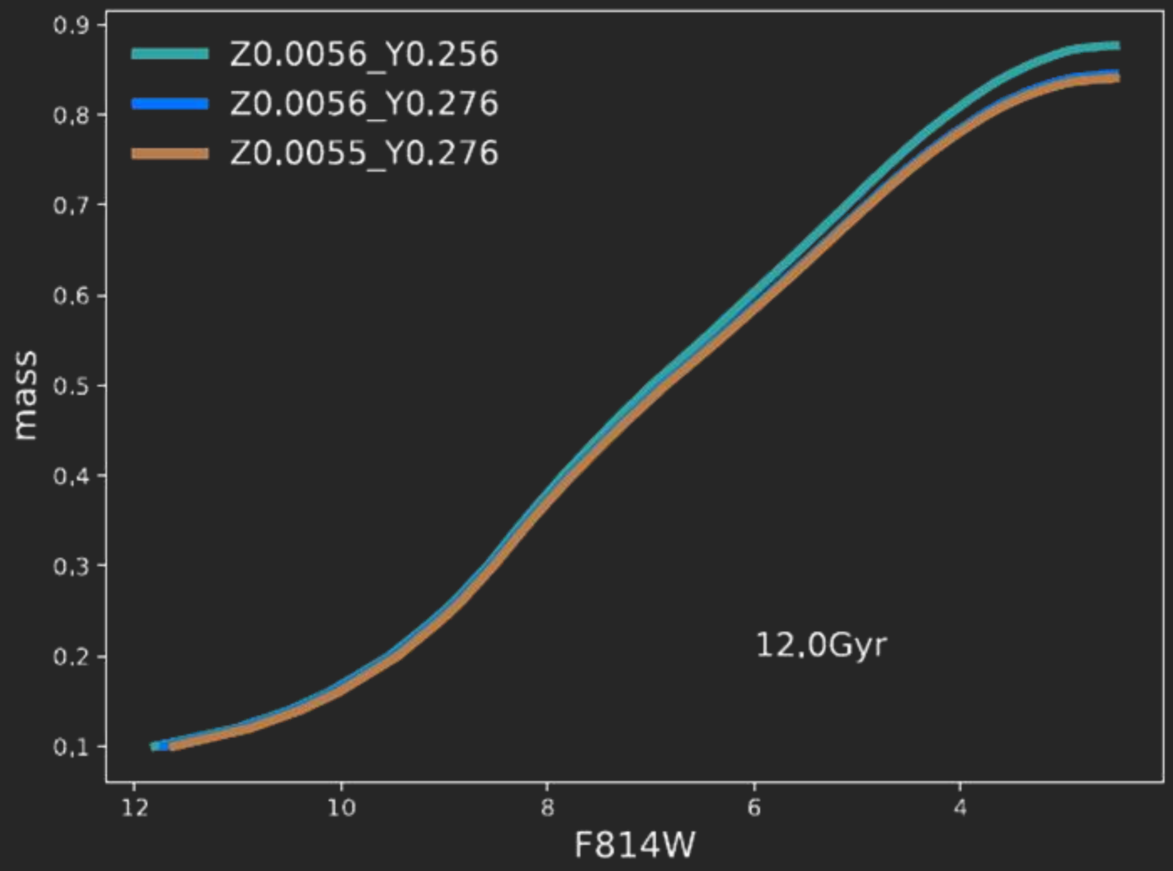
Kim&Lee (2018)

The elements being modelled / measured



Why helium?

- He-rich stars will be hotter, brighter, and evolve faster.
  - Mass-luminosity relation changes. → wrong IMF.
  - Chemical evolution in he-rich galaxy is faster.



Fu (PhD thesis, 2017)

Why helium?

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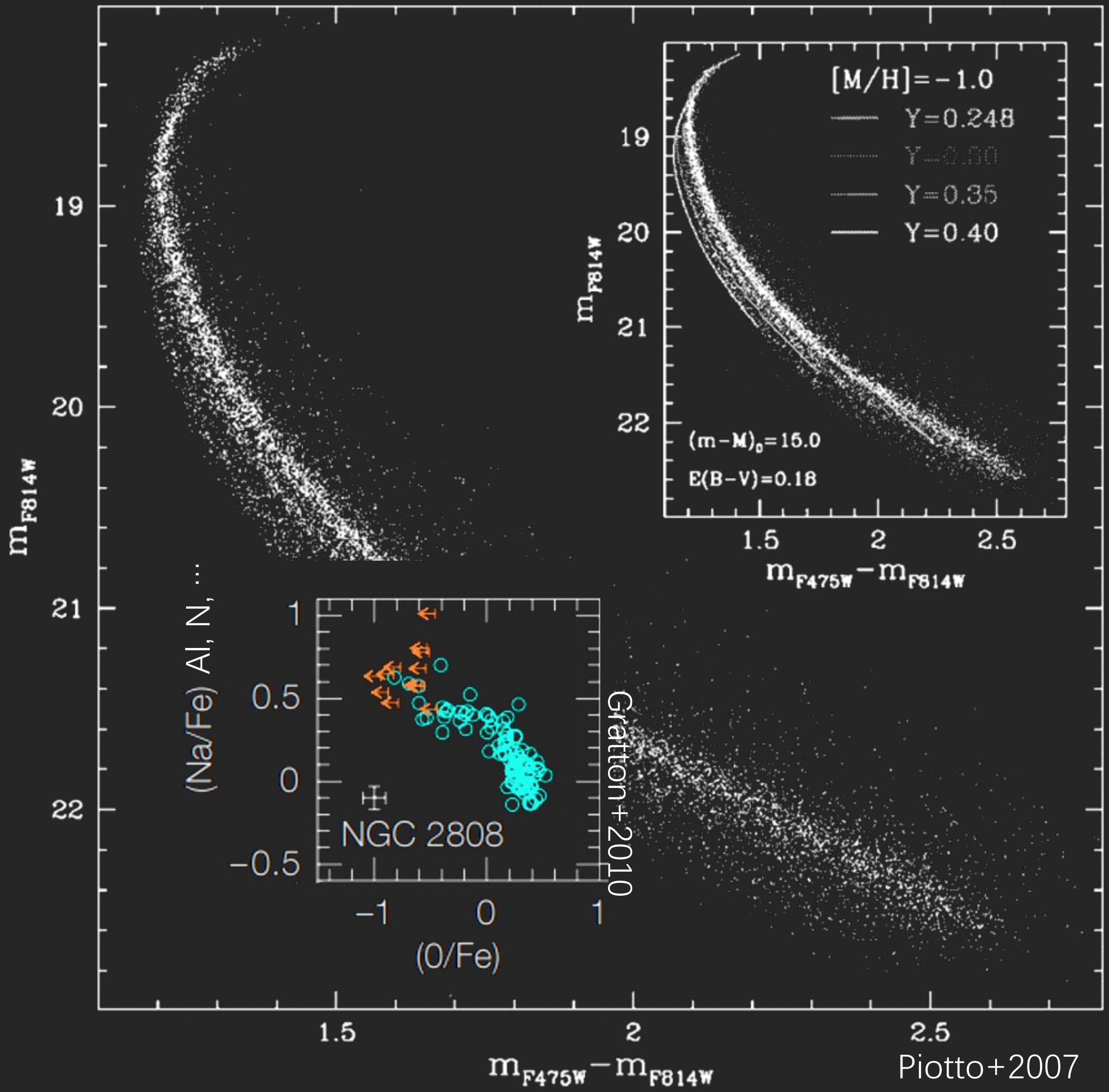
- Helium enrichment is indicated by multiple stellar populations in globular clusters.



Piotto+2007

Why helium?

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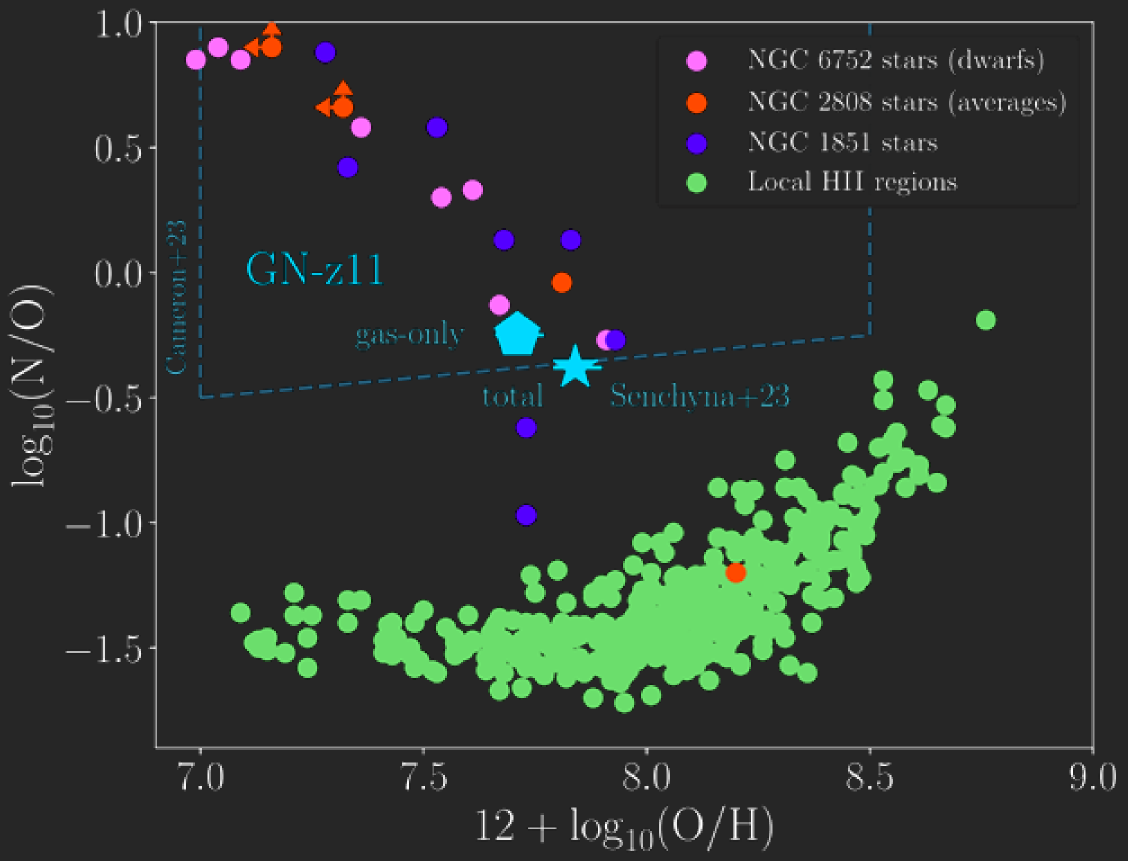
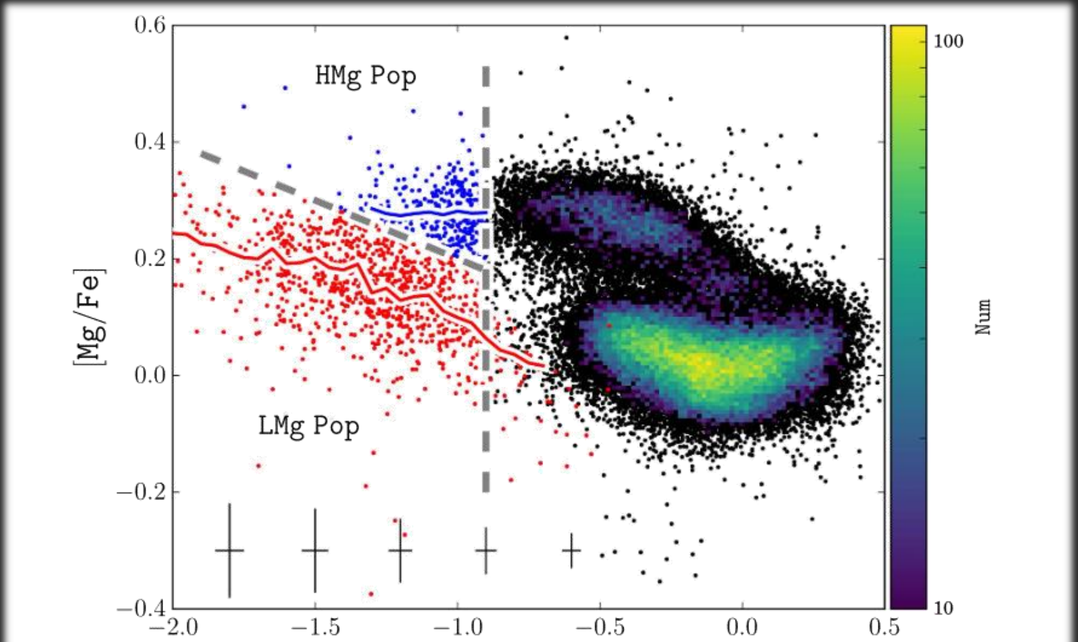
  - Chemical evolution in he-rich galaxy is faster.
- Helium enrichment is indicated by multiple stellar populations in globular clusters.
- Also in high-z galaxy!

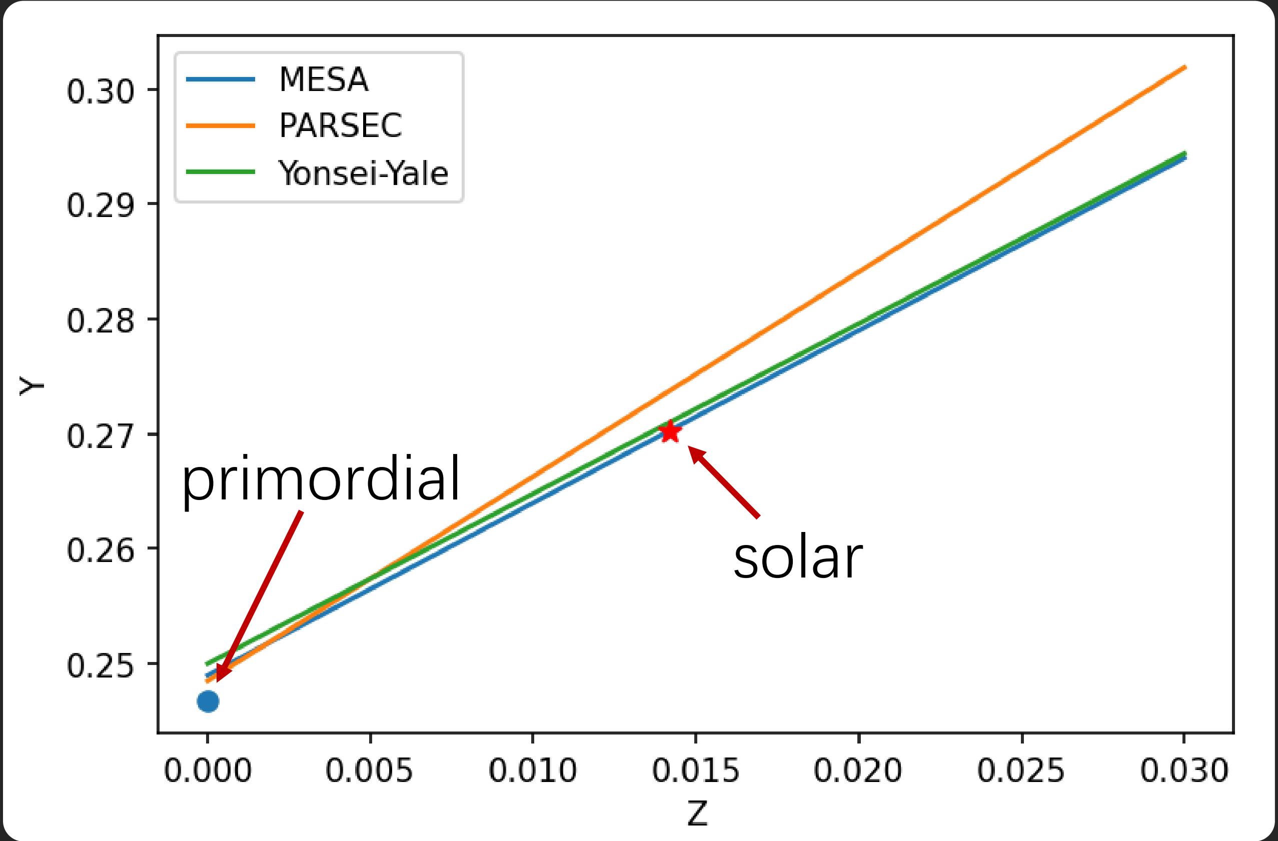


Senchyna+2024

What do we know
about stellar Y?

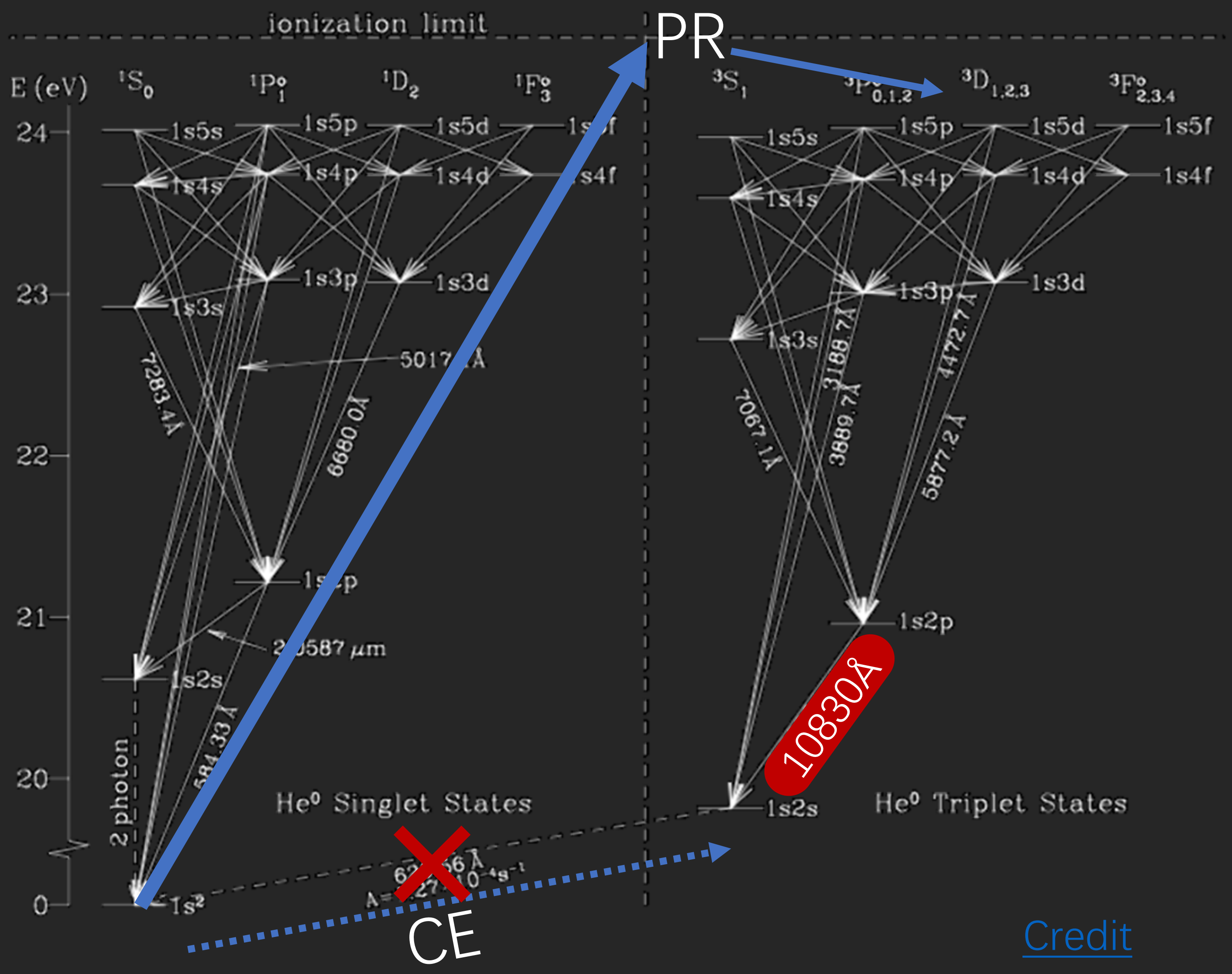


Hayes+2018



Where,
are the helium lines?

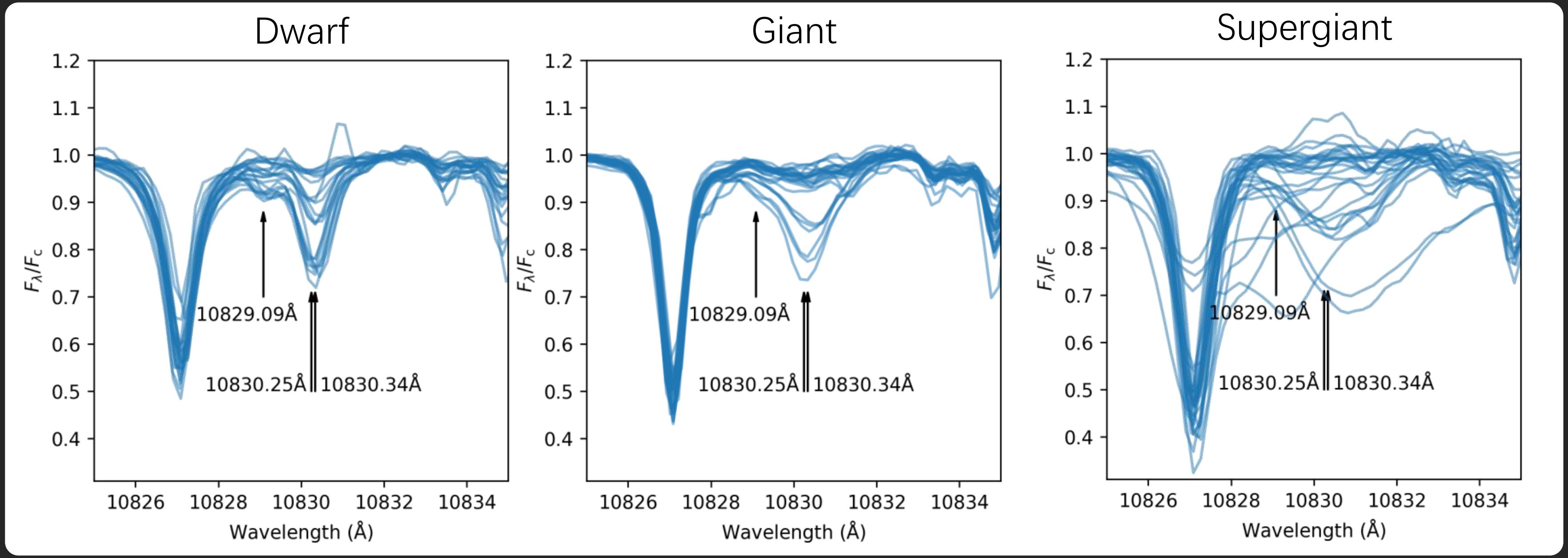
- Resonance lines:
  - In UV wavelength
  - Weak in FGK type stars
- He 10830
  - Formation mechanisms:
    - Photoionization Recombination.
    - Collisional Excitation.



[Credit](#)

Target line: The He 10830

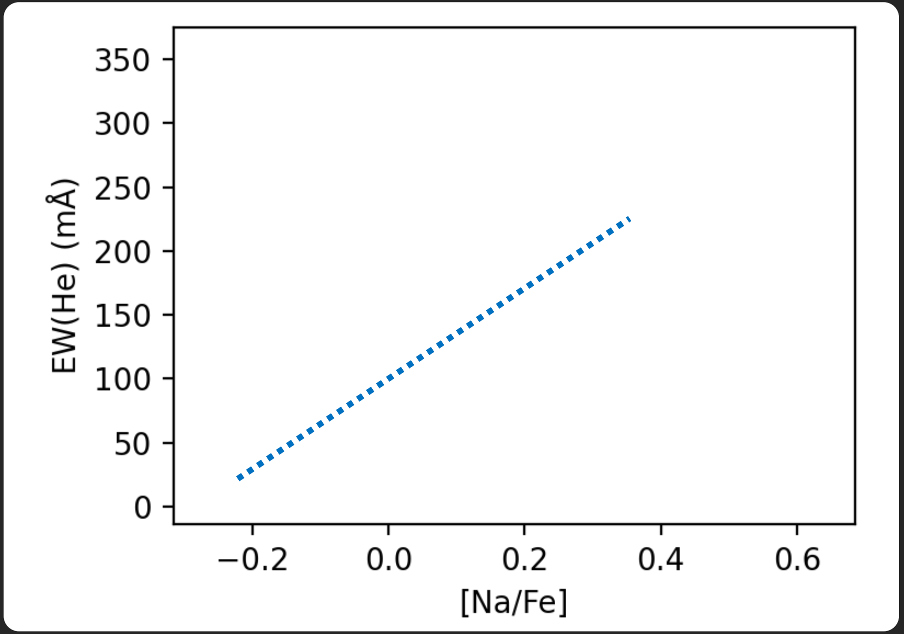
- He 10830 is a helium absorption feature which appears in most of the late-type stars' spectra.
- Near infrared: suffers less extinction.



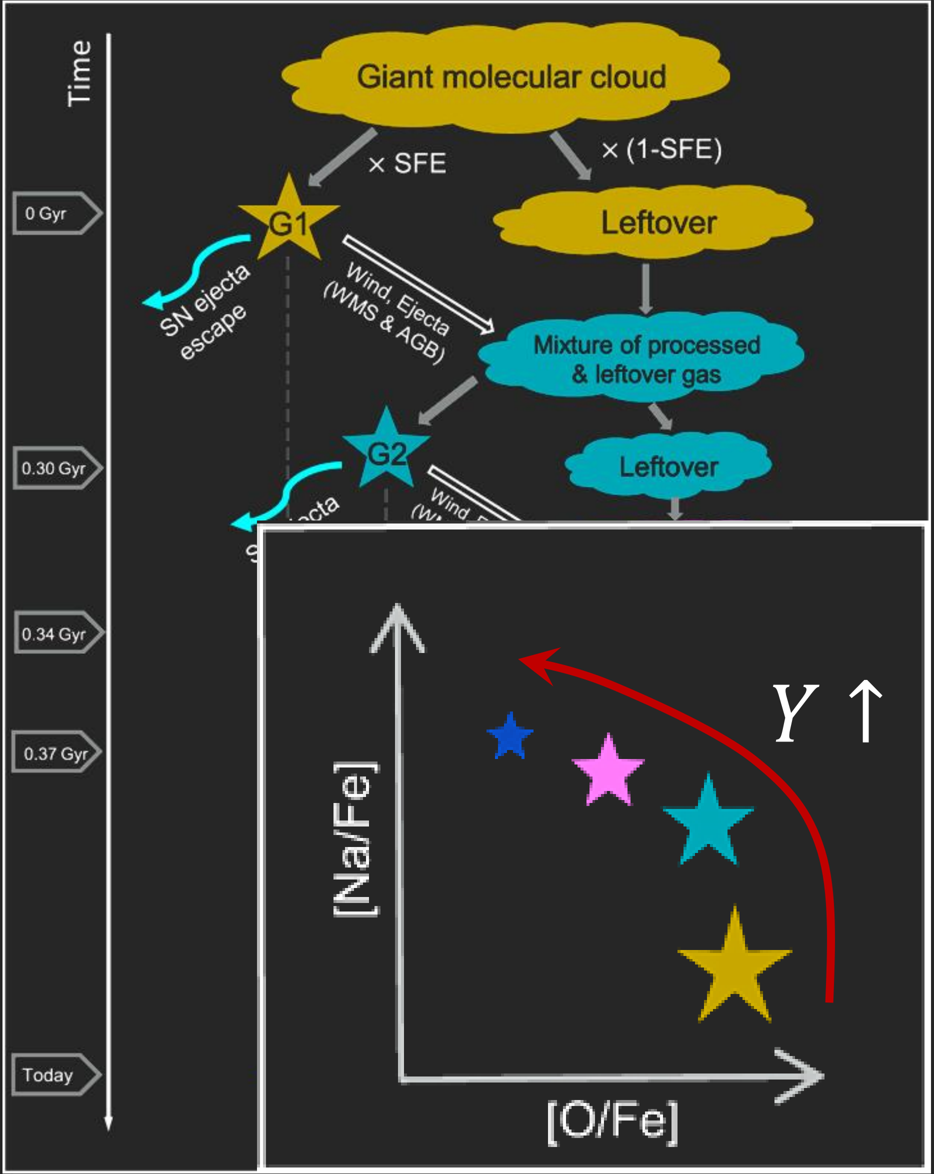
→ Y?

He 10830 and Y
in globular cluster (GC) members

- *"If spectra could be obtained in a globular cluster, providing a larger sample of similar stars, the relative abundance of helium might be assessed."* -- Dupree+ (2009)



- The evidence of He 10830 equivalent width (EW) difference is not obvious.

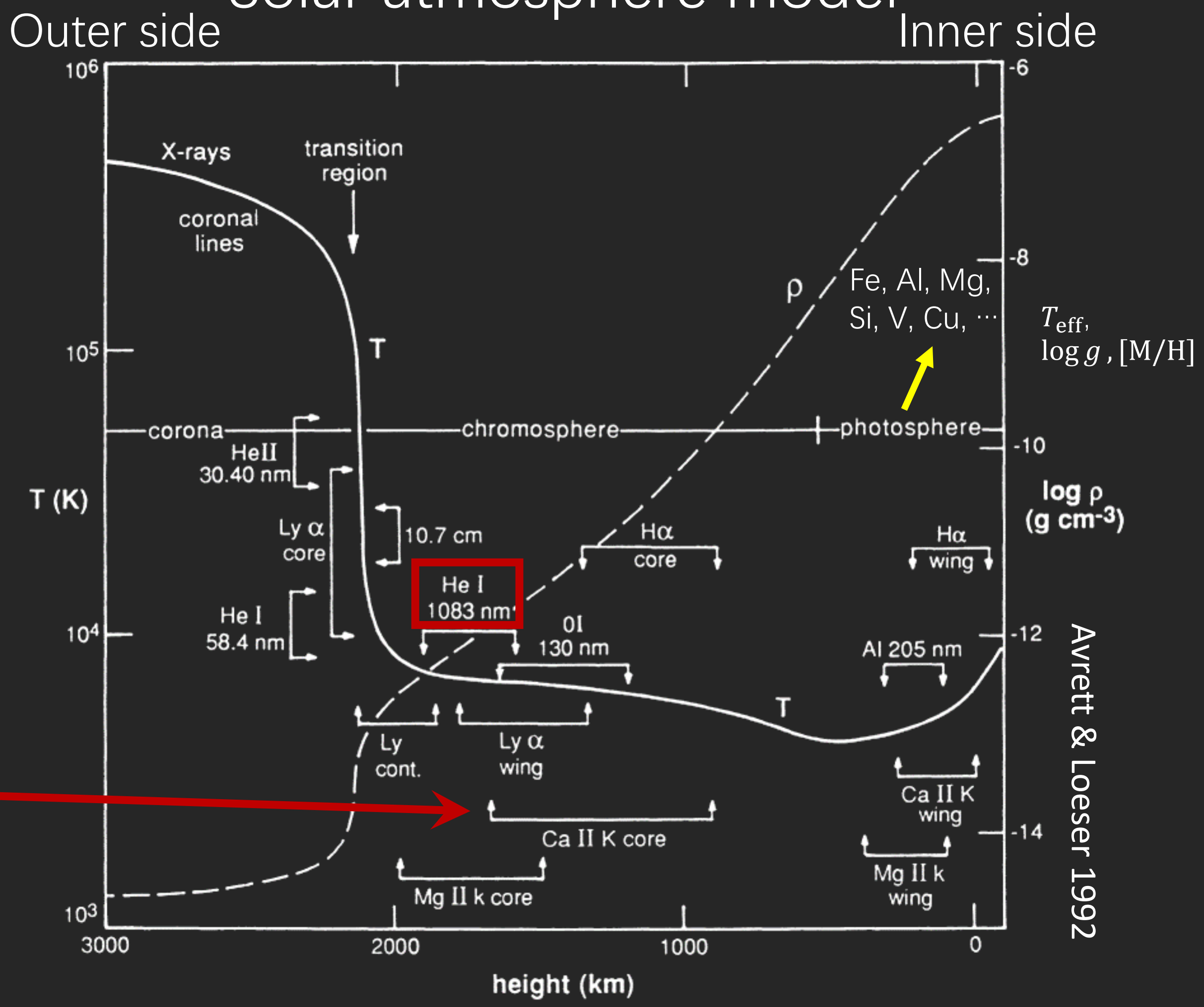


Kim&Lee (2018)

Can He 10830 be used to measure Y?

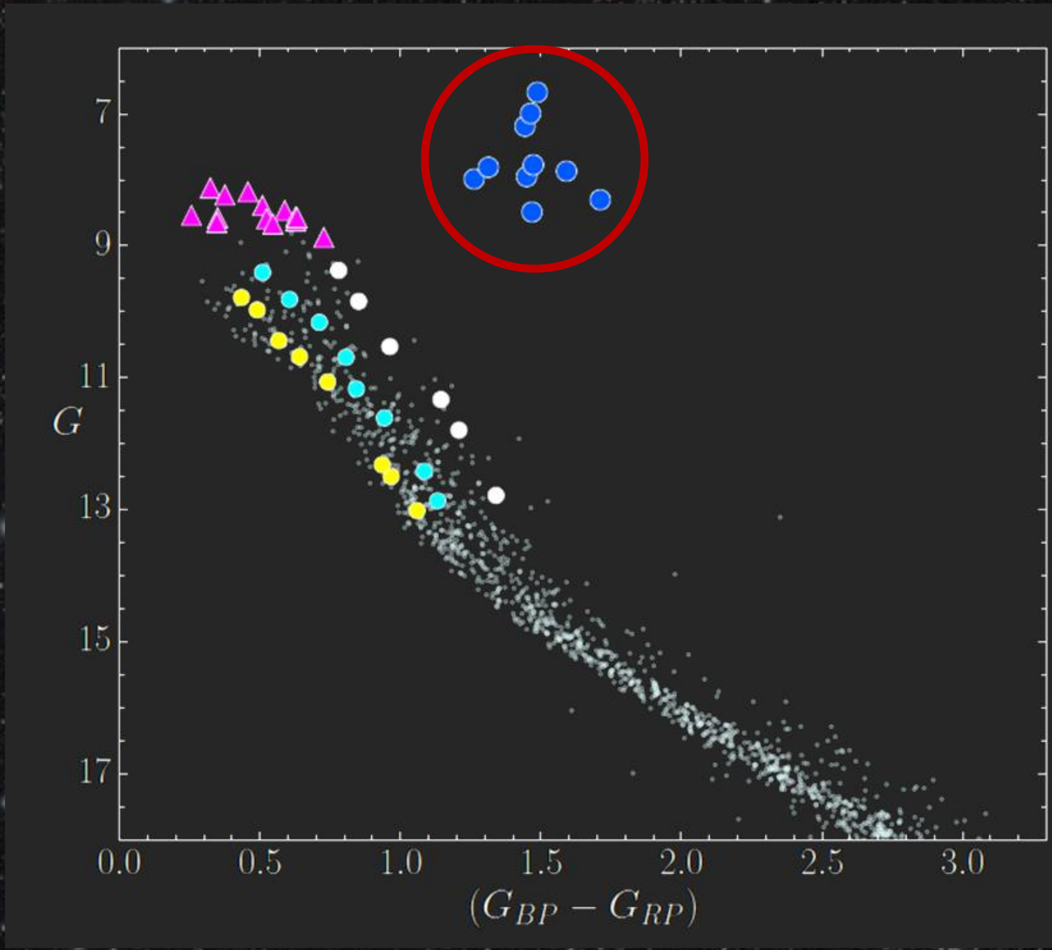
- Previous: stars with varied Y
  - Derive correlation between $EW_{\mathrm{He10830}} \leftrightarrow (Y, \text{chromosphere}, T_{\mathrm{eff}}, \log g, [\mathrm{M/H}])$
  - Relation will be messy.
- Stars with same Y, T_{eff}, $\log g$, $[\mathrm{M/H}]$
  - Derive correlation between $EW_{\mathrm{He10830}} \leftrightarrow$ (chromosphere; Ca II HK)
  - → Clear conclusion.

Solar atmosphere model



~~Globular~~ Open cluster: Stock 2

- Single stellar population:
  - same age, similar chemical composition ($\pm\sim0.1$)
- Age: 450Myr (young!)
- [Fe/H] = -0.07
- Red clump (RC) stars
  - Similar $T_{\rm eff}$ and $\log g$.



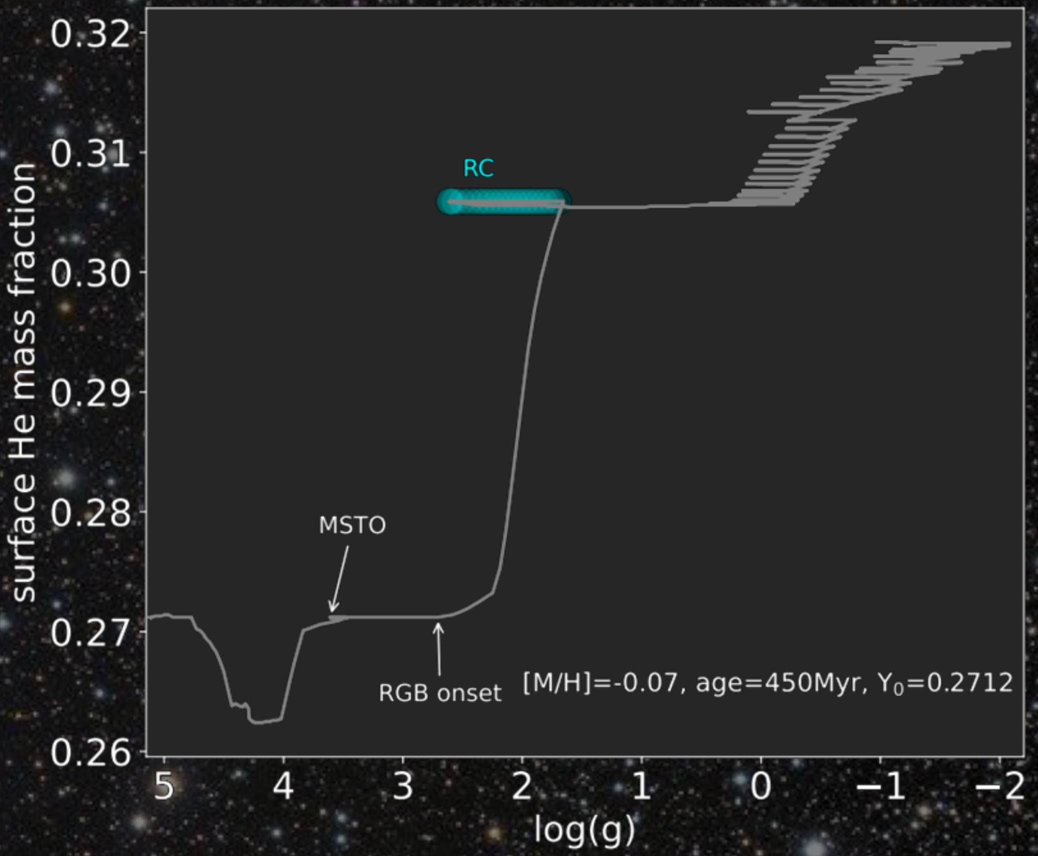
Alonso-Santiago+2021

Credit

Red clump stars in Stock 2

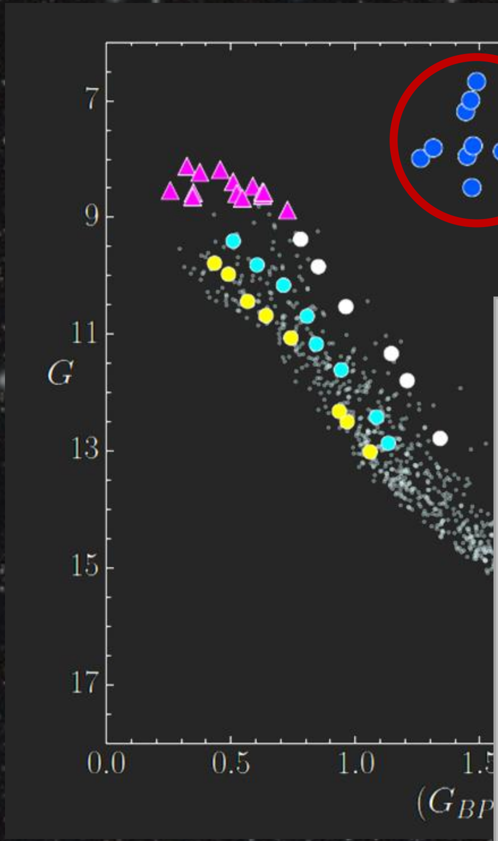
- The Y in dwarfs:
  - Varies (diffusion, first dredge-up)
- The Y in RCs:
  - The Y are similar
  - Their Ys are expected to be larger than those in main-sequence phase.

Y Isochrone (PARSEC)



Observation

- Stellar Population Astrophysics
  - Large Programme, 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.



- @Telescopio Nazionale Galileo
- Wavelength
  - 3870-6910Å + 9530-24230Å
- Resolution
  - 115,000 + 50,000
- Target
  - Open cluster Stock-2
  - 9 red clumps

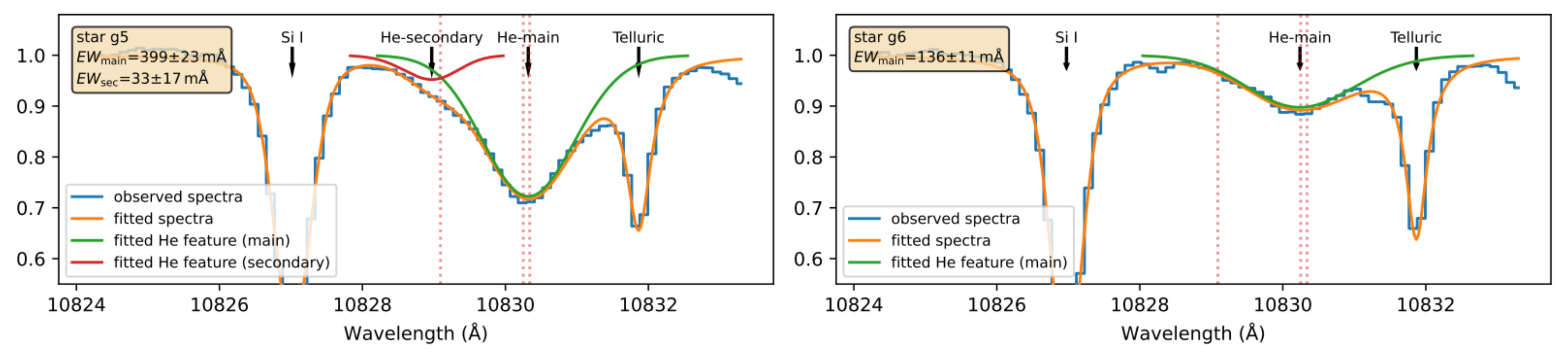
Measurement of He 10830

He 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 center
- γ:asymmetry

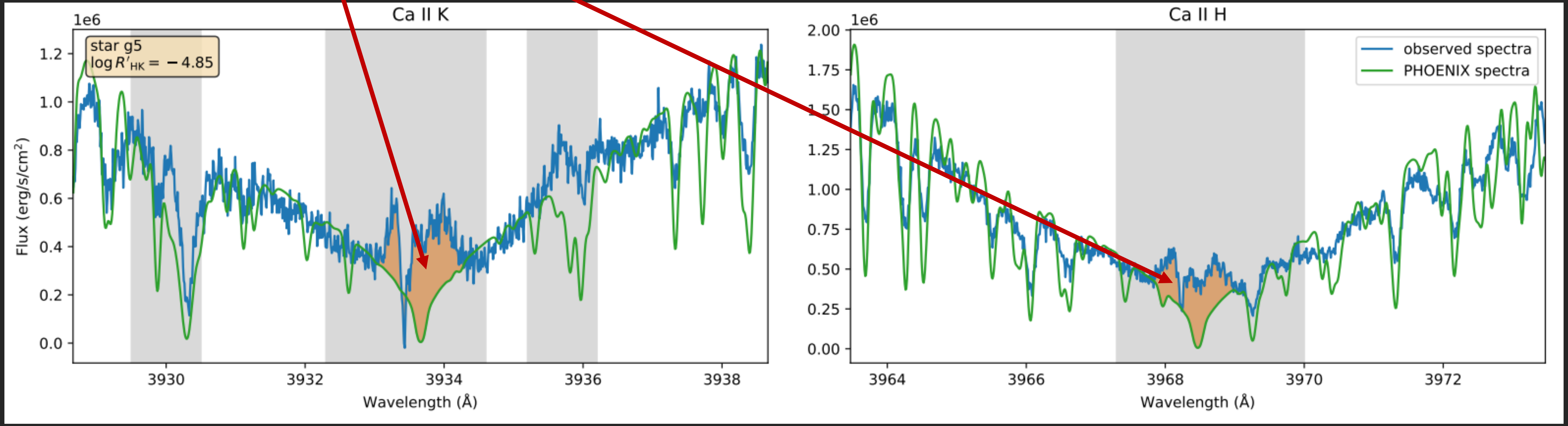
- EW: equivalent width
- $\lambda_{\mathbf{peak}}$: peak wavelength
- B/R: blue-to-red ratio



Measurement of Ca II HK lines

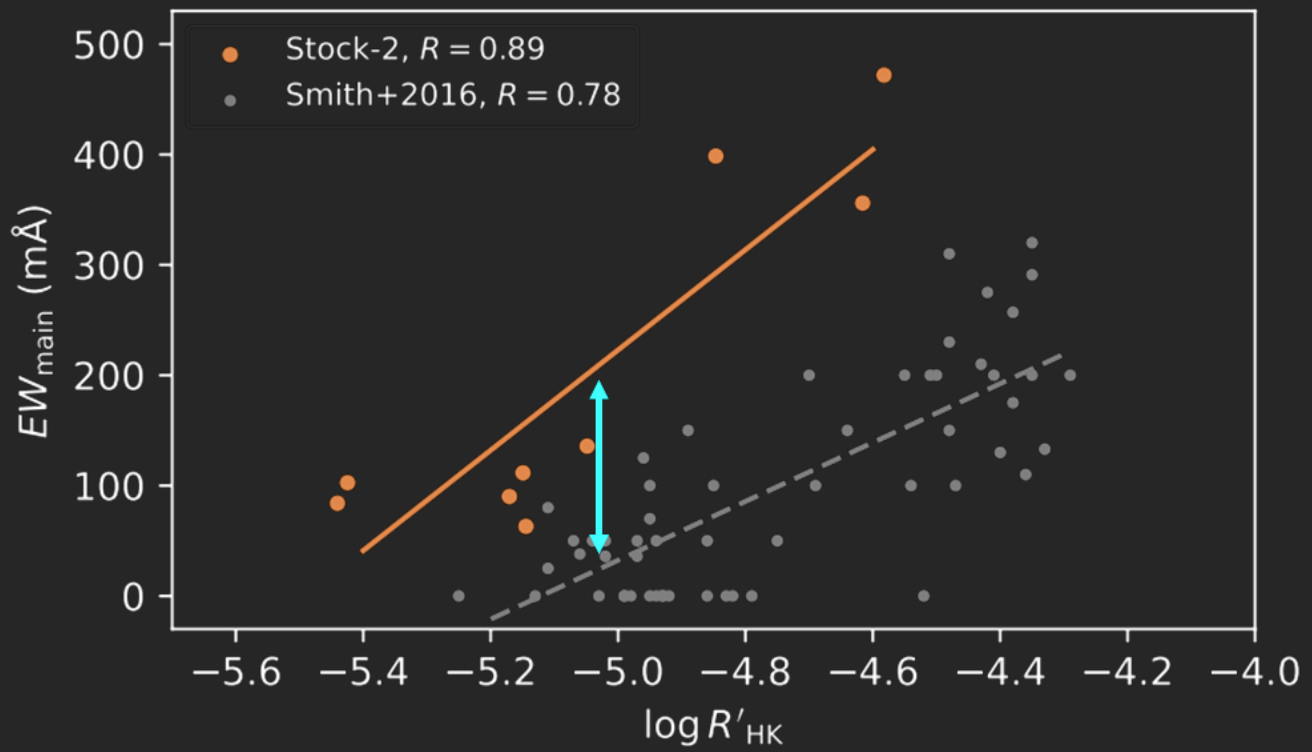
For constraining the chromospheric structure

- 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(He10830) relation

- Linear relation
  - For Stock 2 RCs and field dwarfs
  - Need to include chromosphere structure.
- The EWs of RCs are larger than dwarfs ([Fe/H]~0).
  - Stock 2 age: 450Myr (young!)
- $Y_{\mathrm{RC}} > Y_{\mathrm{dwarf}}$



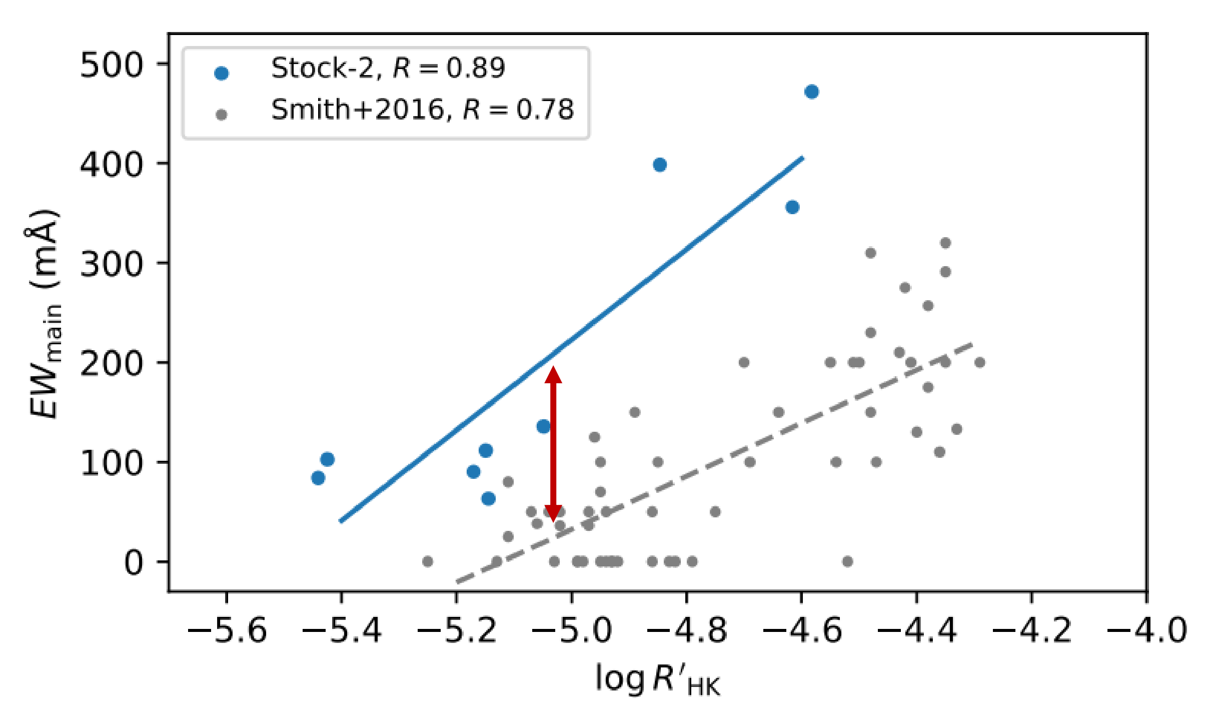
He10830 can be used to trace Y together with Ca II HK lines for RC stars.

Summary

- Helium is an important yet unexplored element in the material evolution.
- He 10830 line have the potential to be used as helium abundance tracer.
- 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
- We found the first positive support for its abundance tracer usage.
- SPA project: 1 cluster done, 20+ cluster to go!

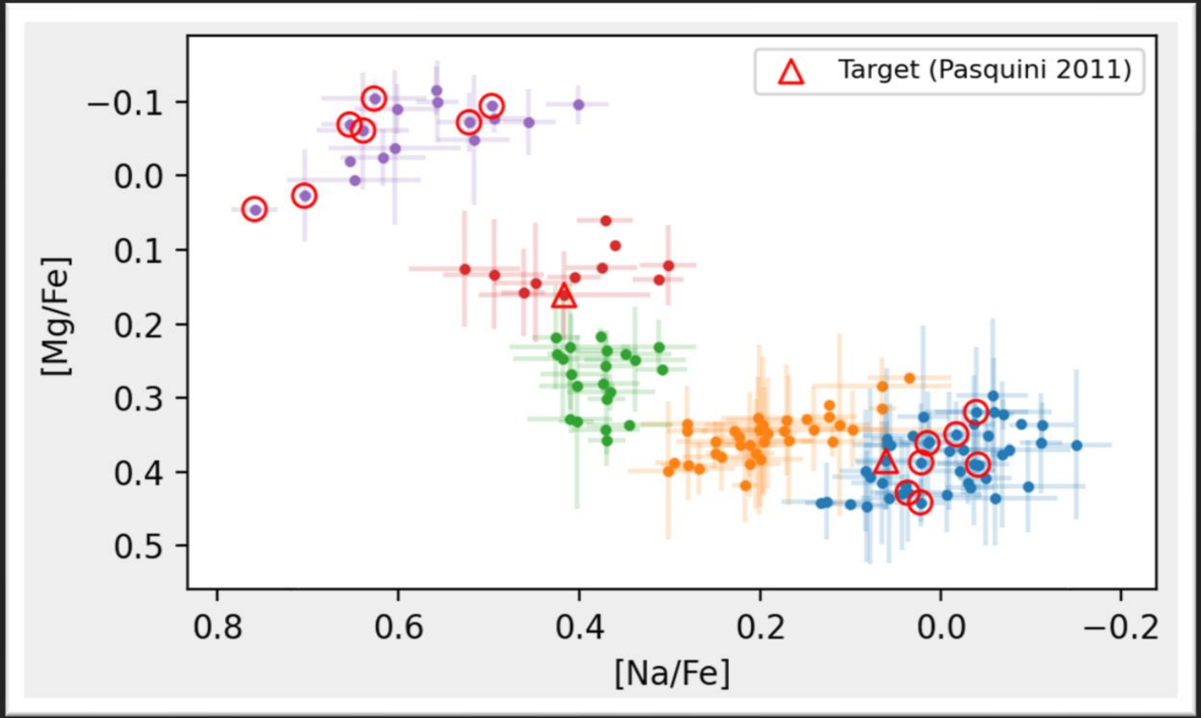
How to extend: 1. More stars

- More stars in blue:
  - SPA spectra for giants in other OCs.



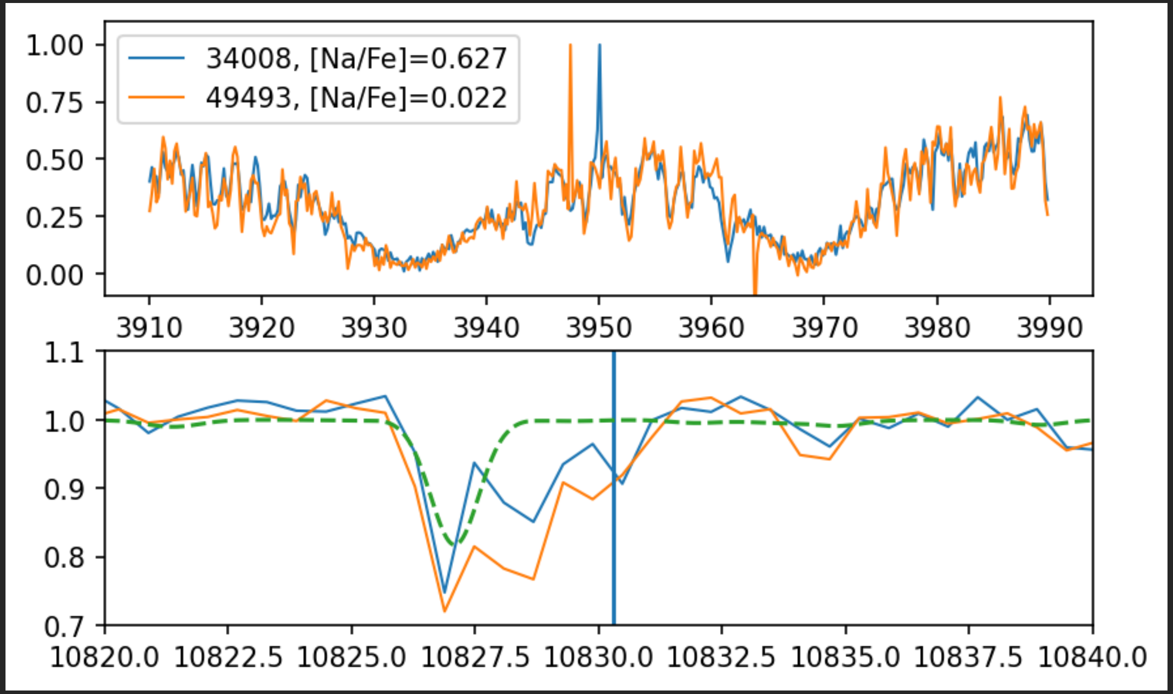
How to extend: 2. Globular cluster?

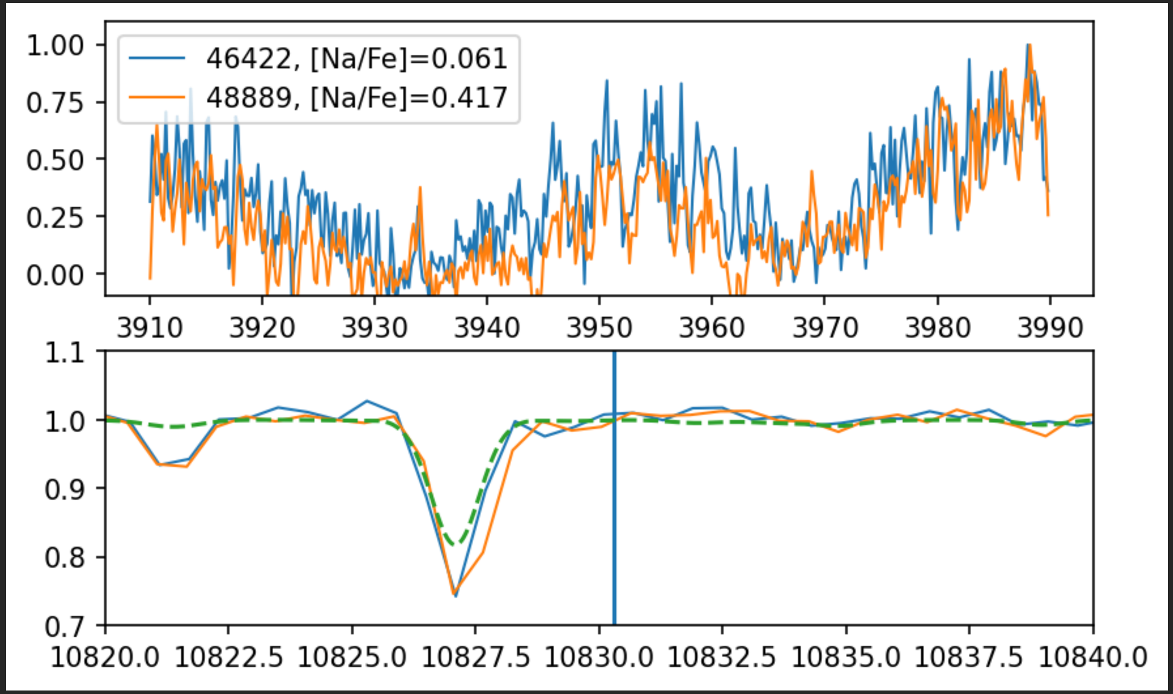
- P110: 110.2446 (PI: Jian)
- X-Shooter for NGC2808 stars

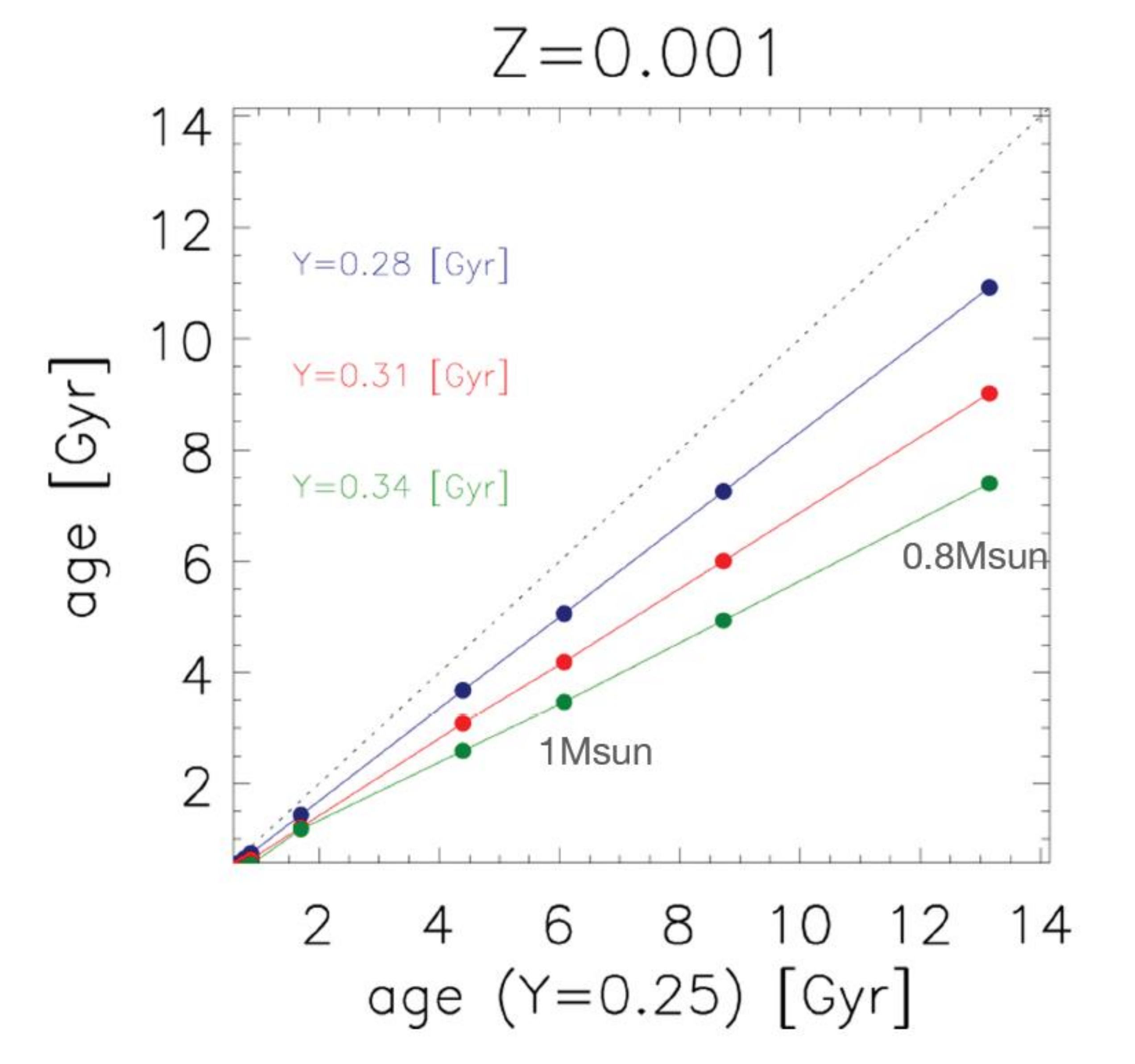


How to extend: 2. Globular cluster?

- The







Fu (PhD thesis, 2017)

Previous observations

Can previous observations tell us about the information of PR/CE mechanism?

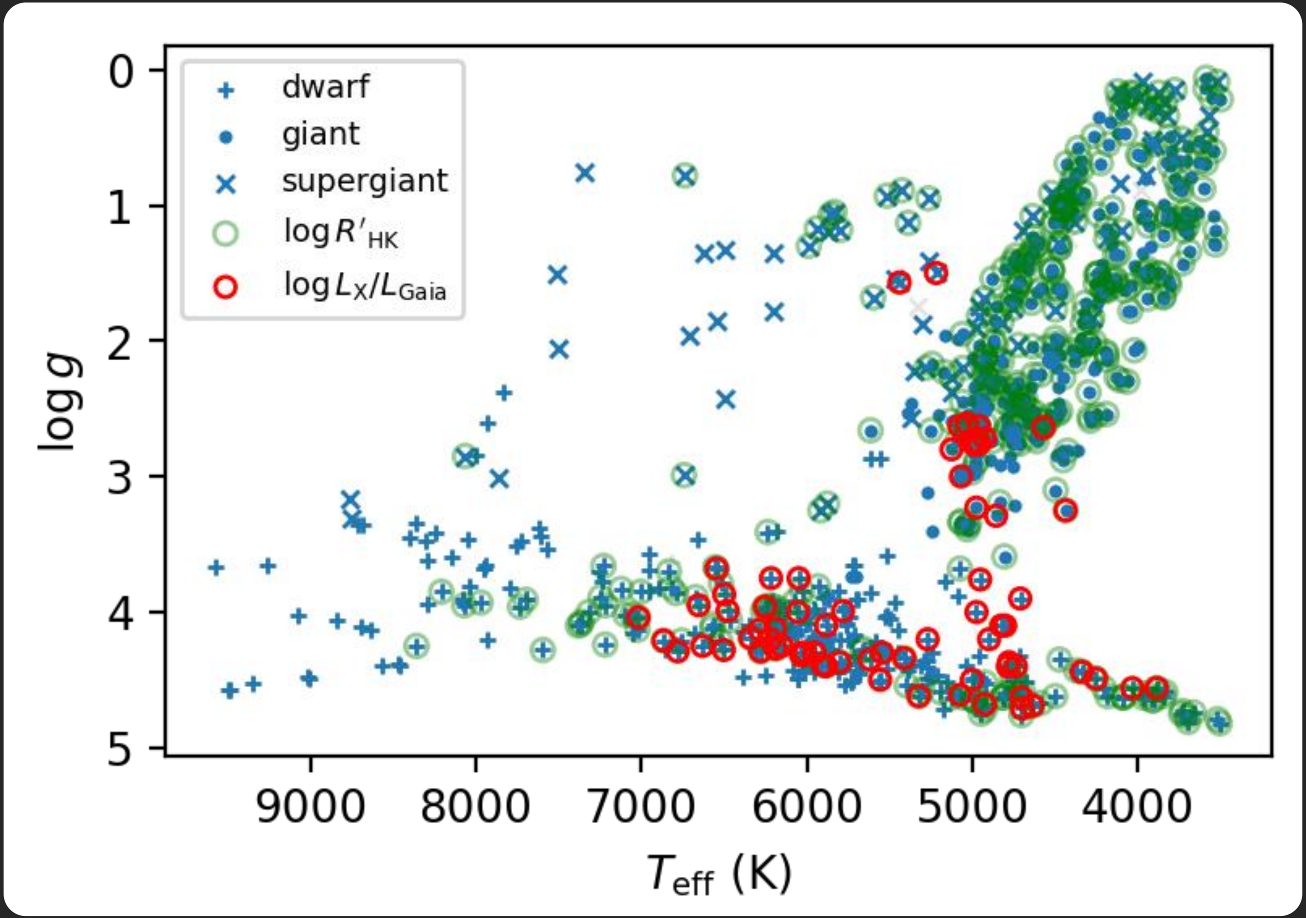
(Chapter 2 in the thesis)

Targets and measurements

What new targets are available? (Chapters 3-5 in the thesis)

EW(He), $\log R'_{\mathrm{HK}}$ and L_{X} measurement

- $N_{\mathrm{all}} = 749$
- EW(He): 719
- $\log R'_{\mathrm{HK}}$: 392
- $\log L_{\mathrm{X}}/L_{\mathrm{Gaia}}$: 72
    - XMM-Newton
    - ROSAT
- A large sample of EW(He) measurement is derived.

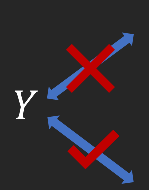


Discussion

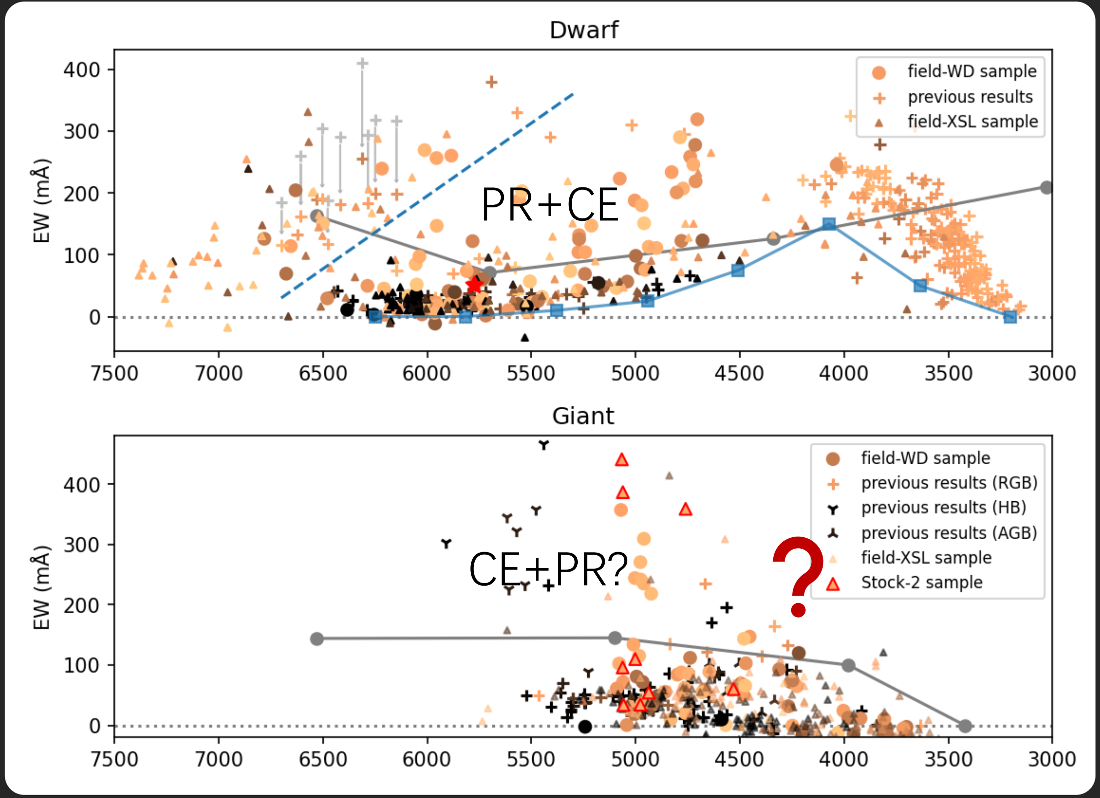
Can He 10830 be used to determine Y, and if so, which star should be the target? (Chapter 8 in the thesis)

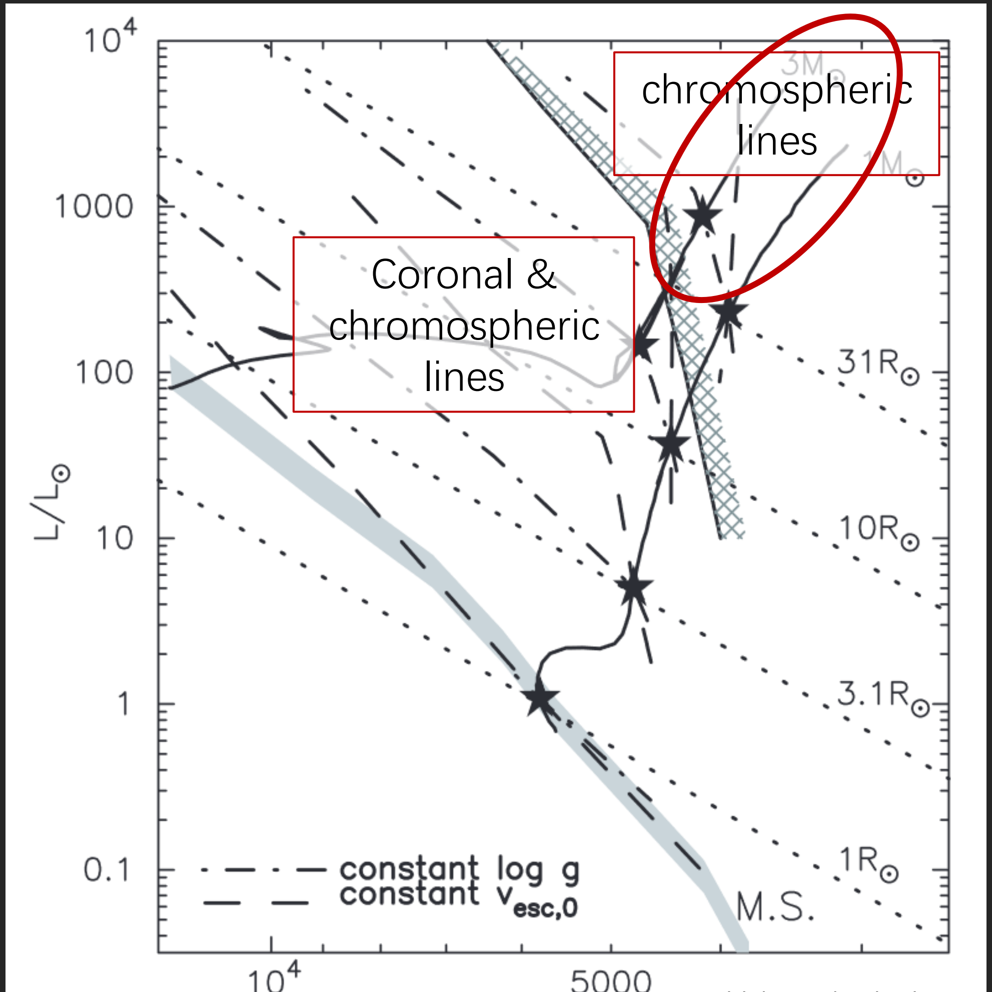
EW(He)-[Fe/H] relation

in cool giants



- Giants rightward of the dividing line would be CE dominated.





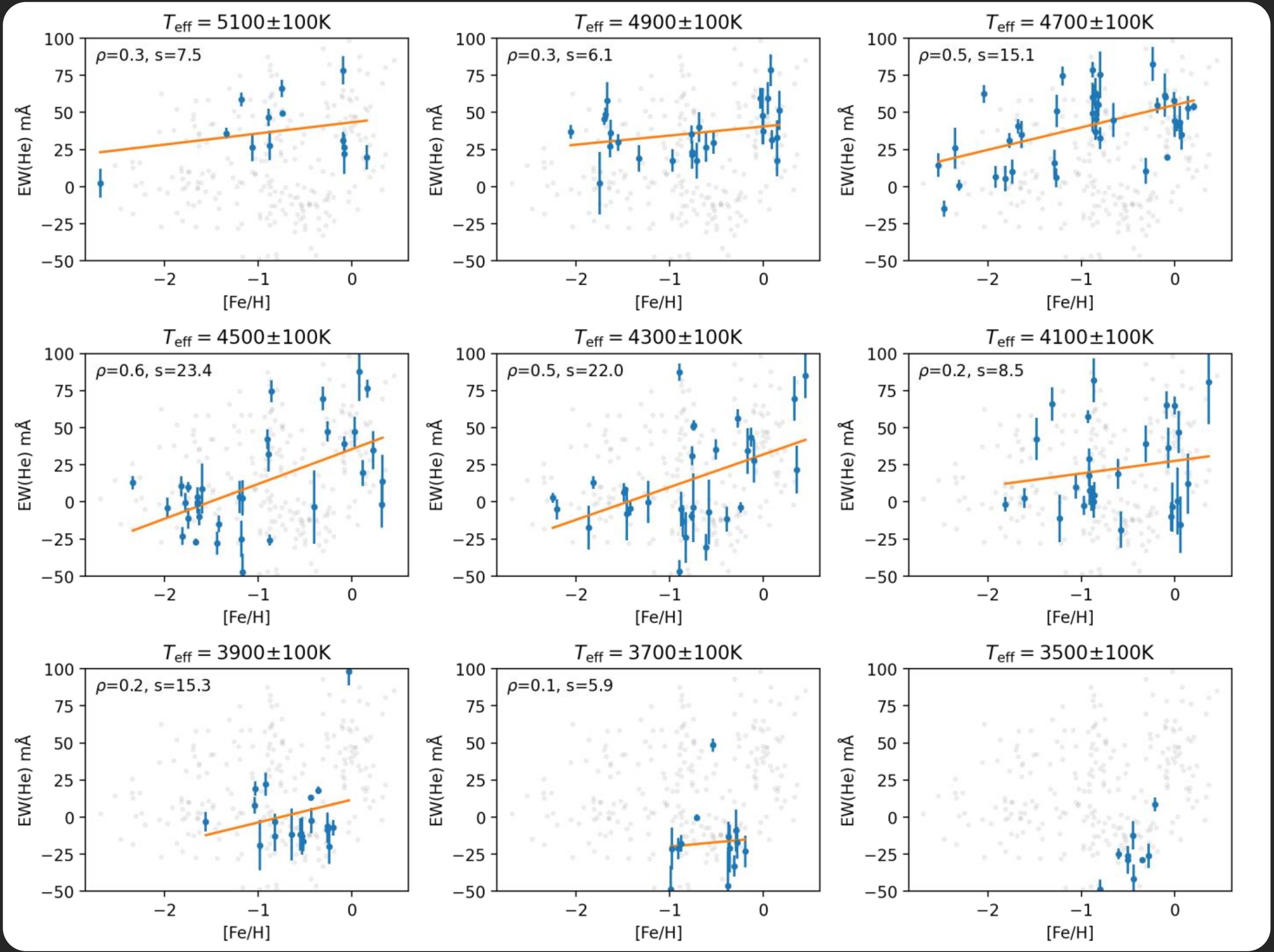
Suzuki (2007), Linsky & Haish (1979)

EW(He) – [Fe/H] relation

for cool giants

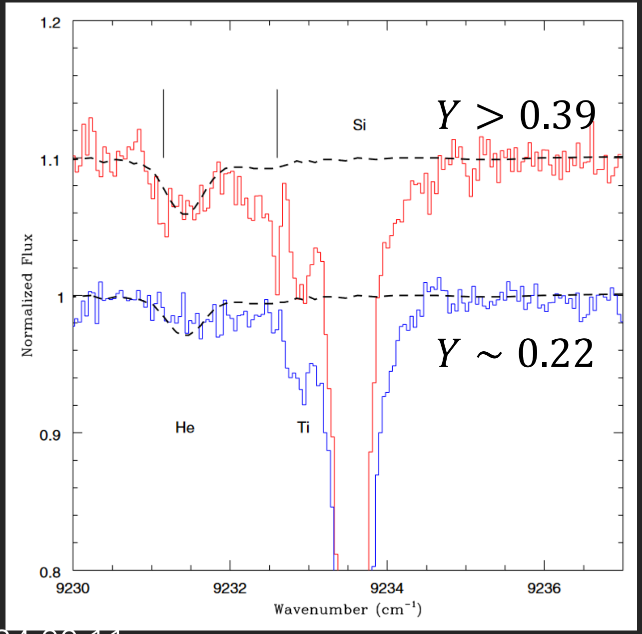
(Fig. 8.3)

- Positive relations between EW(He) and [Fe/H] are found in field-XSL giants with $4300 < T_{\mathrm{eff}} < 4700\mathrm{K}$.
- If they are dominated by CE mechanism, then such relation would be caused by Y variation.



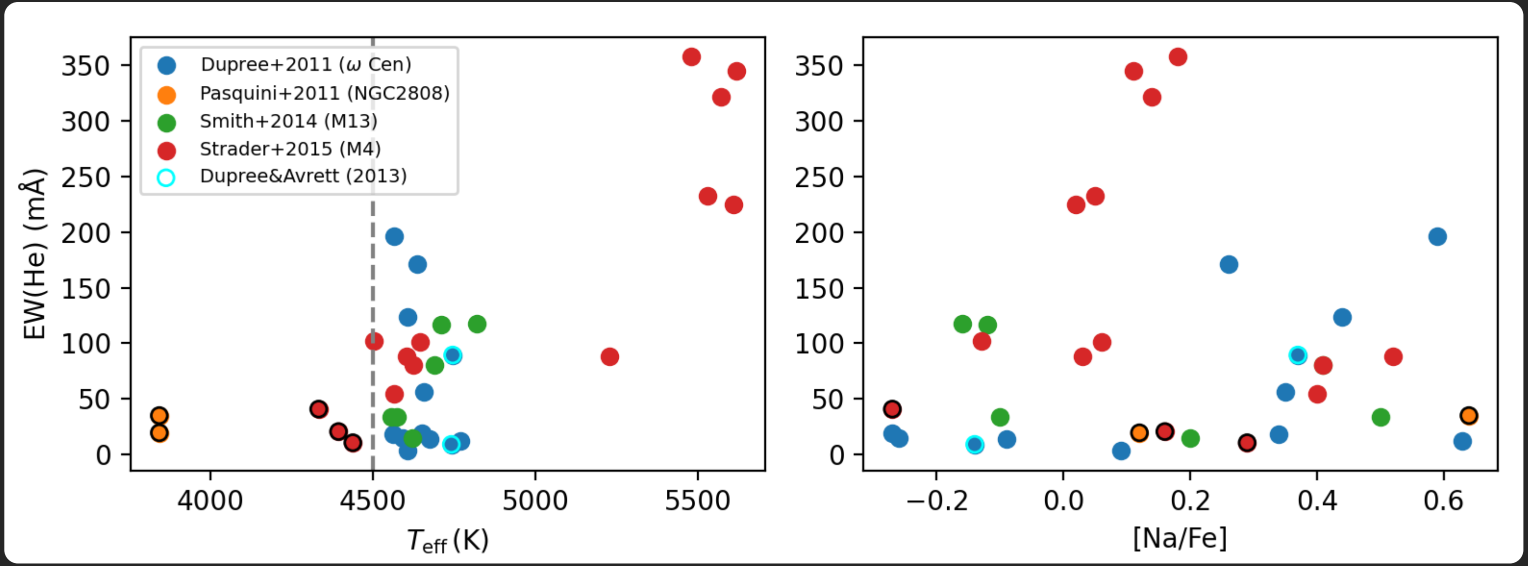
Previous selections of targets in GCs

- Most of the targets are hotter than $4500\mathrm{K}$, which is expected to have some extent of corona.
- Future observation aiming to probe Y difference should focus on the giants with $T_{\mathrm{eff}} < 4500\mathrm{K}$.



Pasquini (2011)

(Fig. 8.1)



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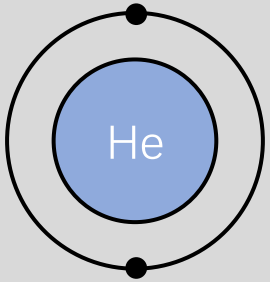
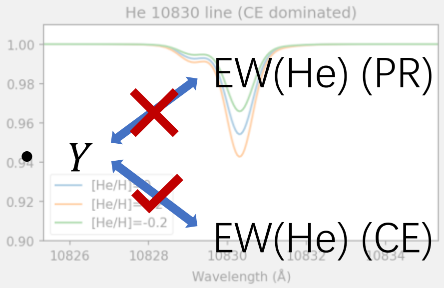
Introduction

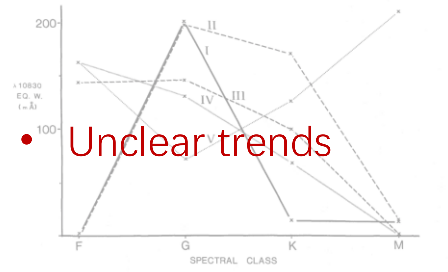


Synthesis



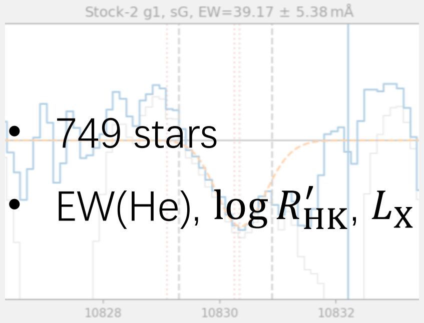
- Y
- EW(He) (PR) ✗
- EW(He) (CE) ✓

Previous observation



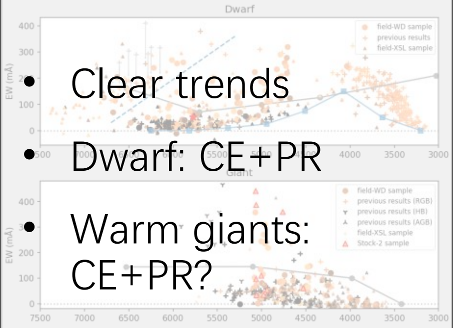
- Unclear trends

Targets and measurements



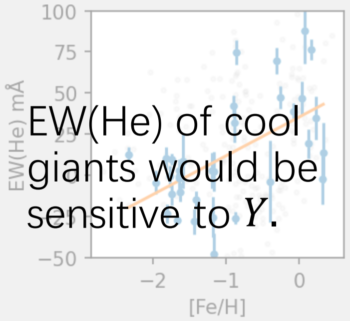
- 749 stars
- EW(He), $\log R'_{\mathrm{HK}}$, L_{X}

Empirical trends



- Clear trends
- Dwarf: CE+PR
- Warm giants: CE+PR?

Discussion



- EW(He) of cool giants would be sensitive to Y.

Conclusion

- What we know about the He 10830:

	Before	After
$\mathrm{EW(He)}$-T_{eff} trend	Rough trends	Detail trends from ~750 stars.
PR/CE mechanism	Exist in dwarfs and giants	Switch between PR/CE for dwarfs and giants
Y sensitivity	---	Only in CE dominated lines
GC target selection	Warm giants (stronger He 10830)	Cool giants (avoid PR mechanism)

Future perspective

- One step closer to the Y from He 10830:
- EW(He) for cool stars are sensitive to Y.

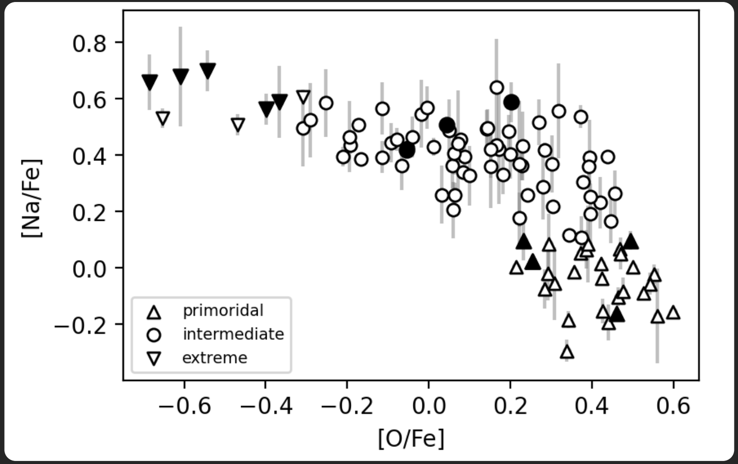
cool giants

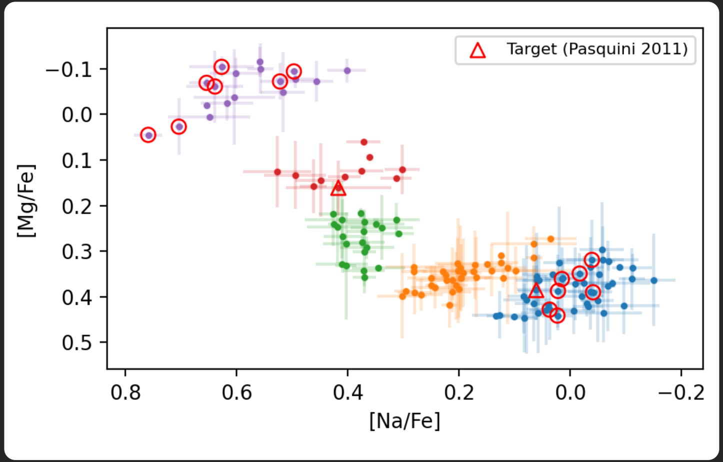
- Reveal the relative Y difference for ~~stars~~ with similar stellar parameters.
  - Globular cluster members.
  - Bulge stars.
- Measure Y using He 10830 and detailed chromospheric modelling.
  - (though the method needs to be established yet)

Planned observations

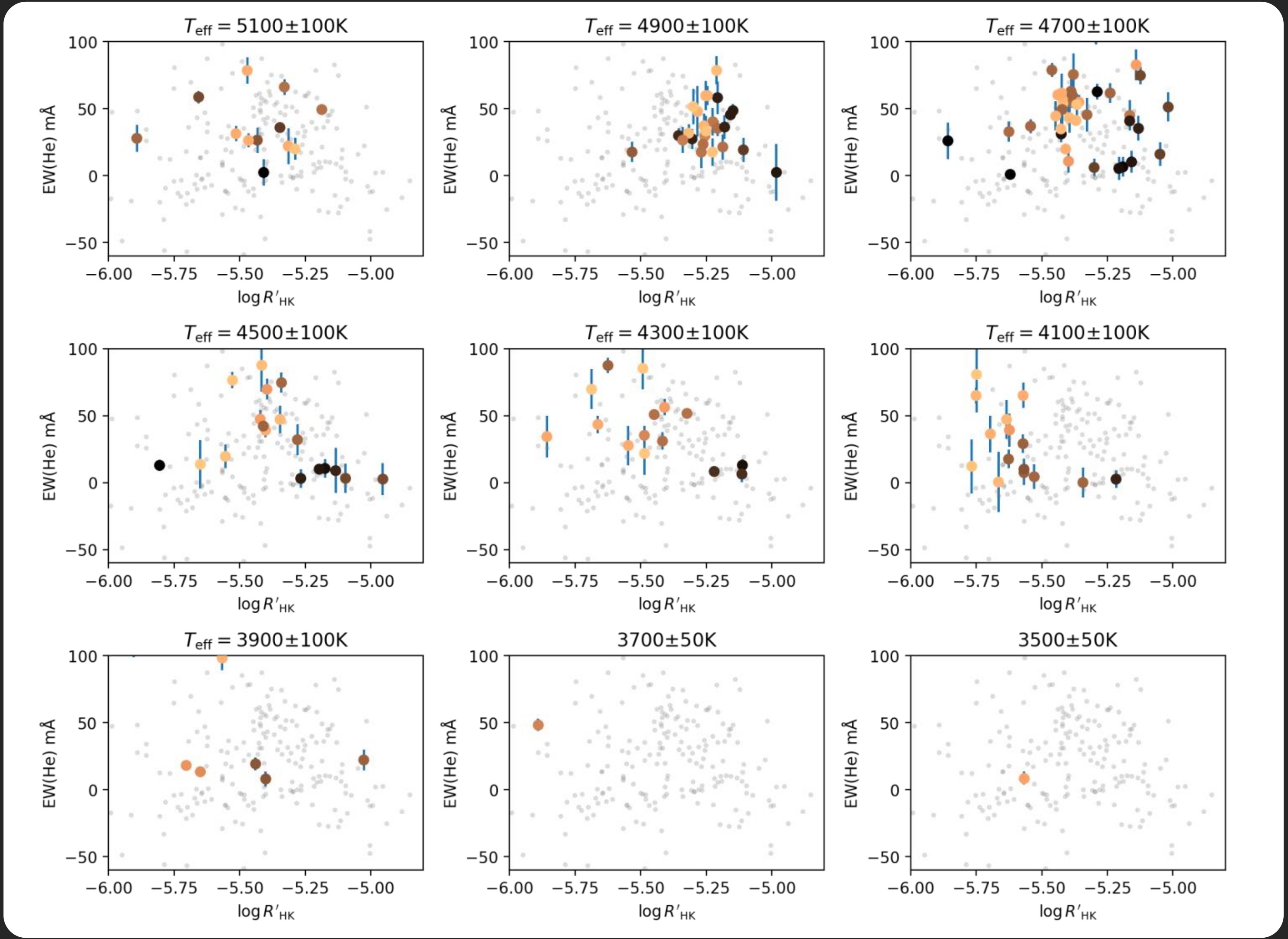
- M5: UT22-2-013 with HPF@McDonald;
- NGC2808: 0110.D-4258(A) with X-Shooter@VLT.
- We expect the EW of He 10830 will be different for the stars in different stellar populations.

M5 $(T_{\mathrm{eff}} < 4500\mathrm{K})$ NGC2808



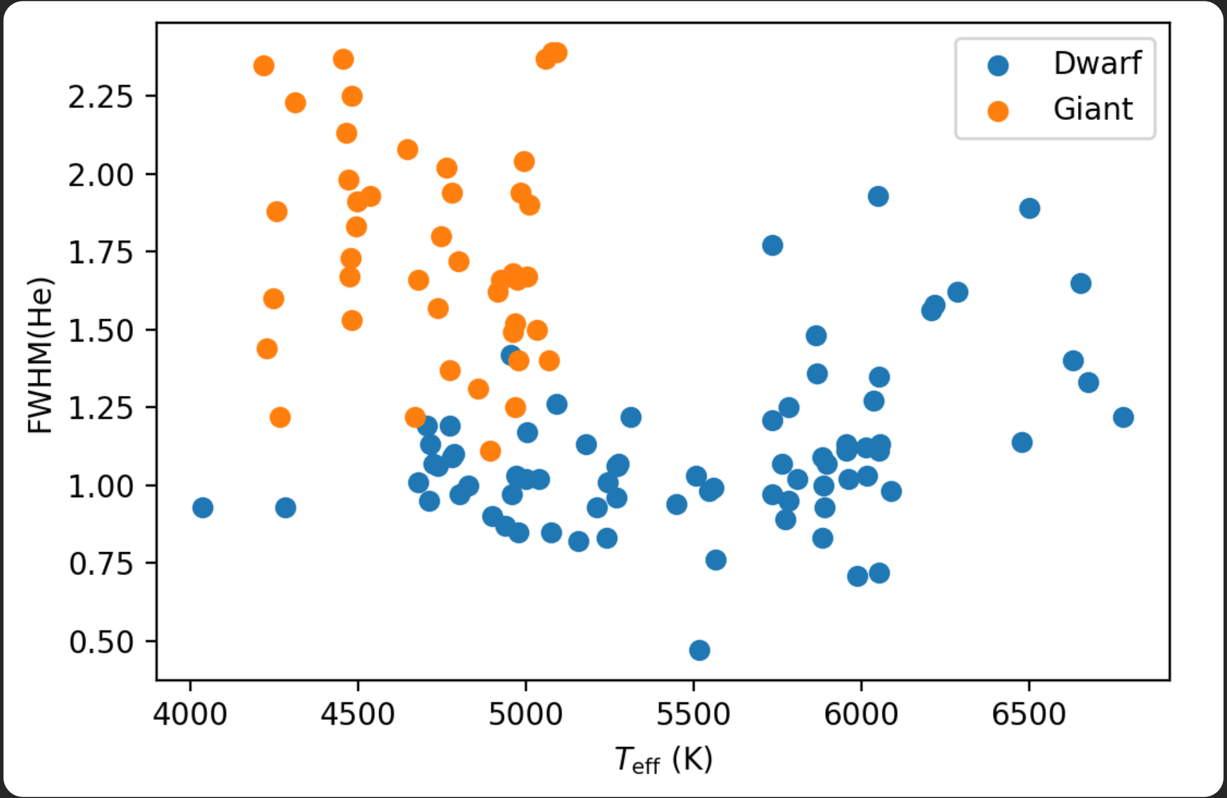


- [Fe/H]: -2~0.2



T_{eff} = 5100±100K
T_{eff} = 4900±100K
T_{eff} = 4700±100K
T_{eff} = 4500±100K
T_{eff} = 4300±100K
T_{eff} = 4100±100K
T_{eff} = 3900±100K
3700±50K
3500±50K
EW(He) mÅ
log R'_{HK}

FWHM-T_{eff} for field-WD stars



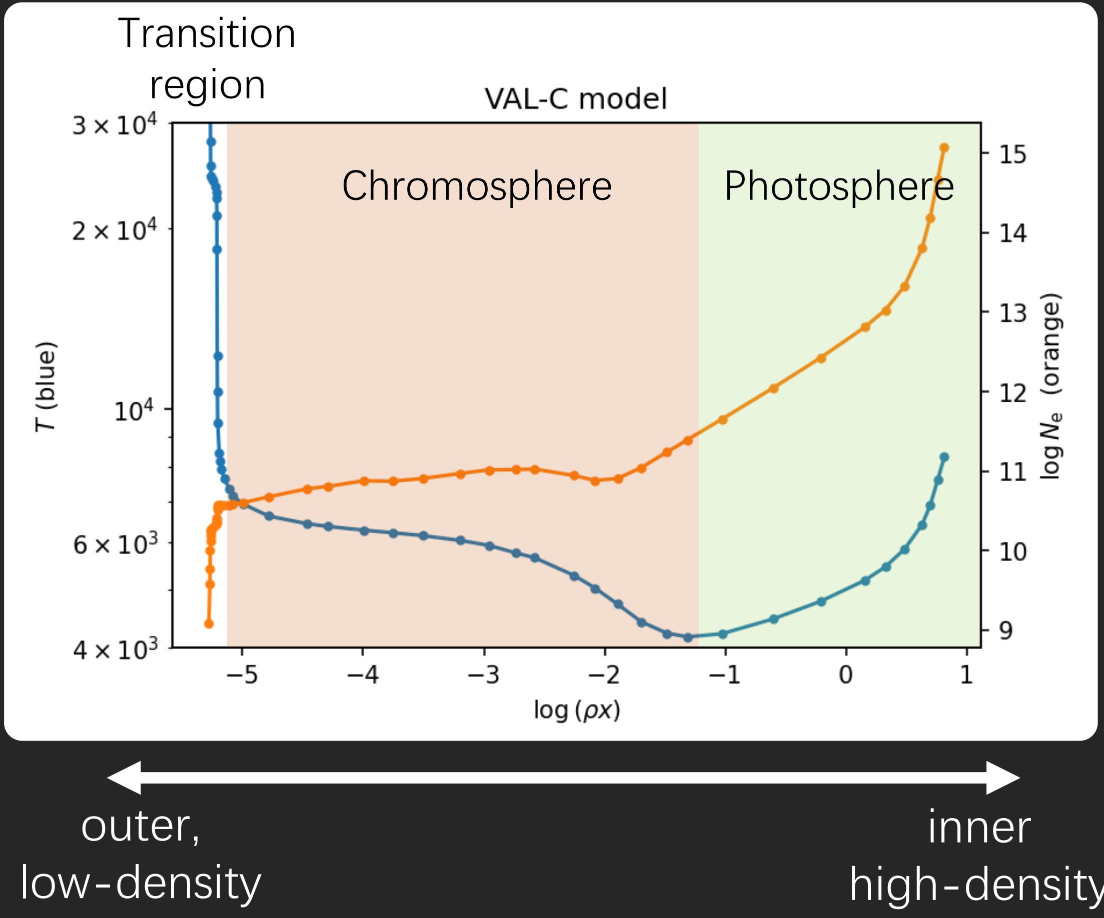
Synthesis of the He 10830

How does Y affect the feature? (Chapter 7 in the thesis)

NLTE radiative transfer calculation

for He 10830

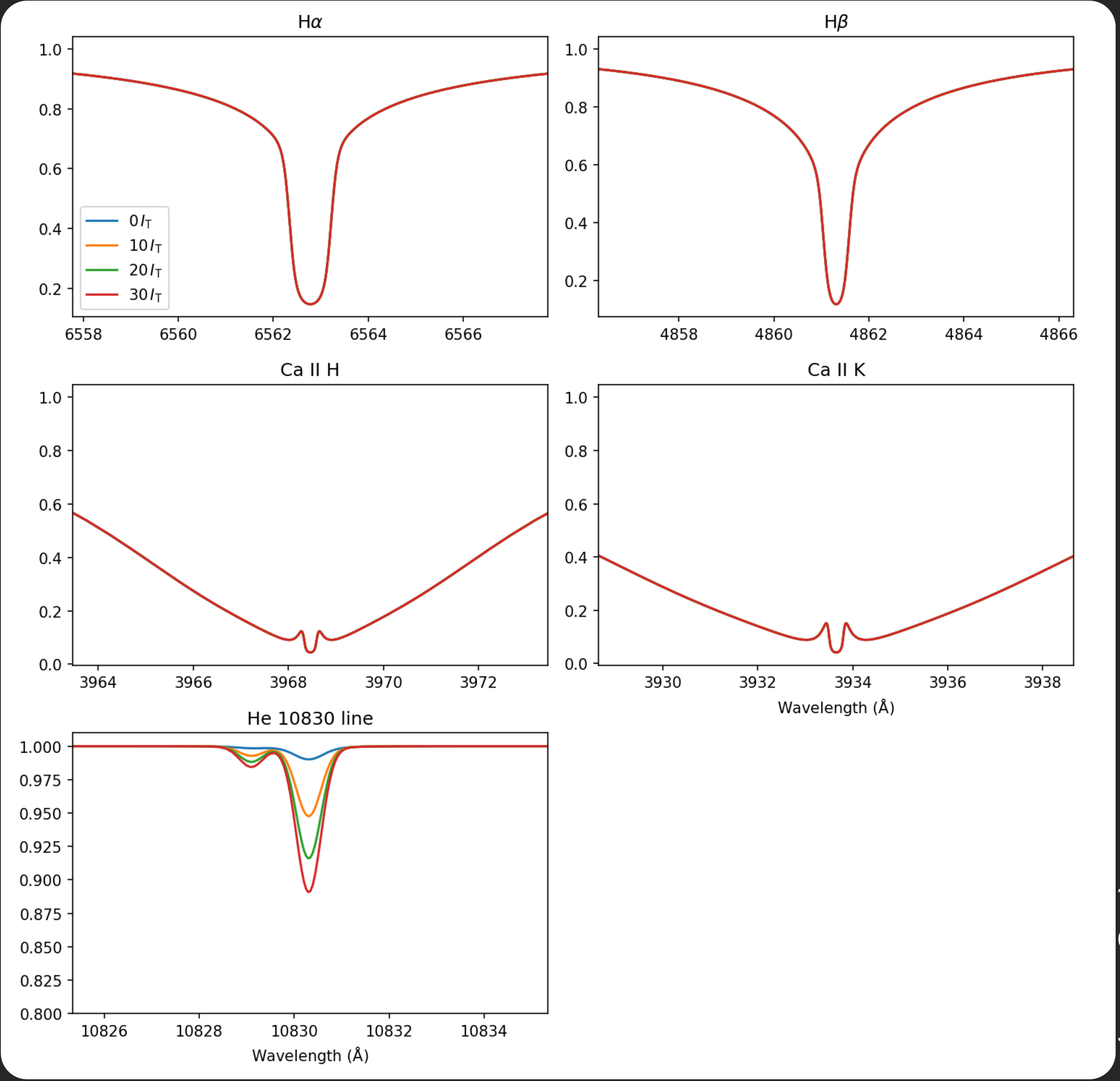
- PR and CE; in chromosphere → NLTE
- Atmosphere model + atom model + external radiation:
  - → $\{n_{\mathrm{H}}\}$, Hα, Hβ lines;
  - → $\{n_{\mathrm{He}}\}$, He 10830;
  - → $\{n_{\mathrm{CaII}}\}$, Ca II H&K lines.
- External radiation: I
  - Tobiska (1991): $I_{\mathrm{T}}(\lambda)$ from 18 to 911Å;
  - Controls the amount of high-energy radiation.



(Fig. 7.1)

PR dominated He 10830

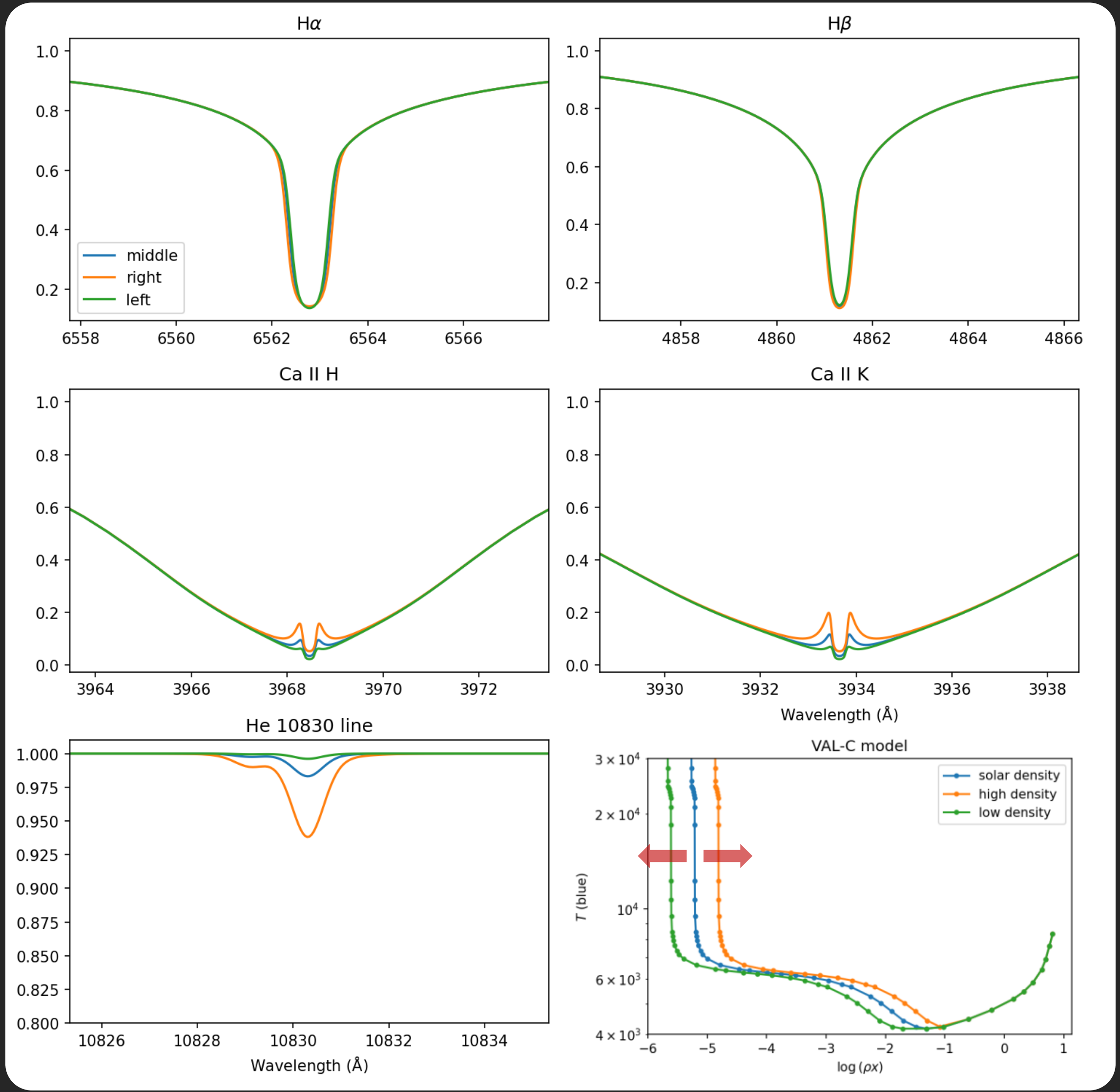
- VAL-C model
- $I = 0, 10, 20, 30\ I_{\mathrm{T}}$
- H and Ca II lines are not affected by external radiation, while He 10830 is sensitive to I.



(Fig. 7.7)

CE dominated He 10830

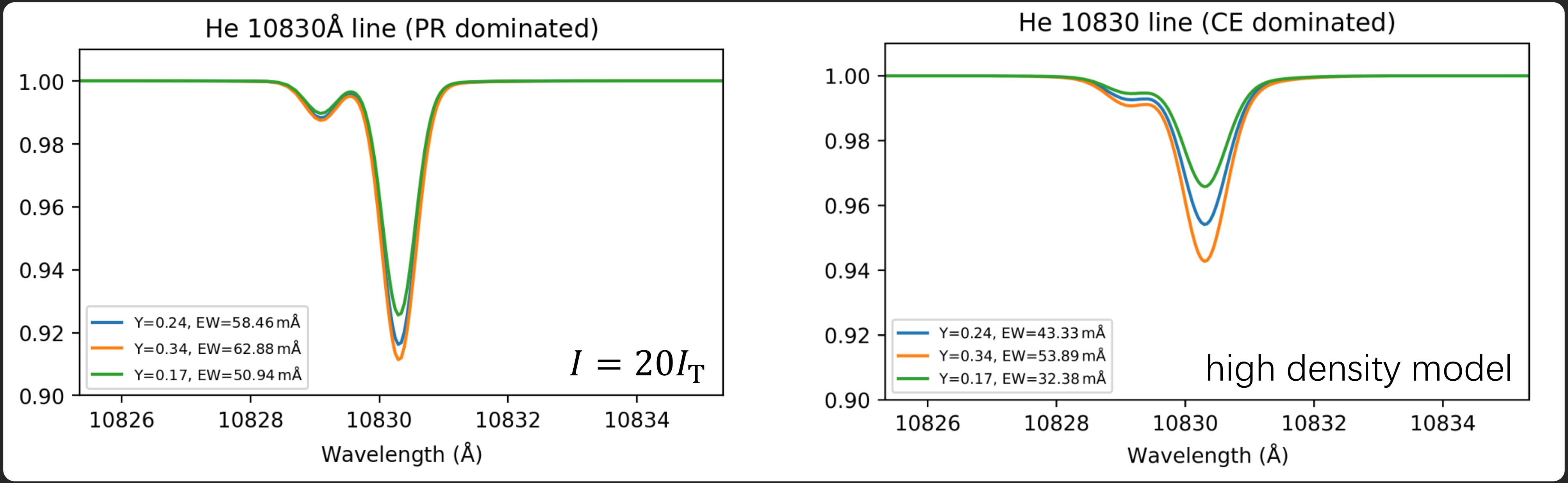
- $I = 0$.
- Varying the position of temperature rise ⇔ changing chromospheric density.
- EW(He) is sensitive to chromospheric density, so does the Ca II line core emission ($\log R'_{\mathrm{HK}}$ increases).



(Fig. 7.11, 7.12)

Sensitivity of the EW to Y

- PR dominated He 10830 only have a small sensitivity to helium abundance.
- CE dominated He 10830 is sensitive to helium abundance.

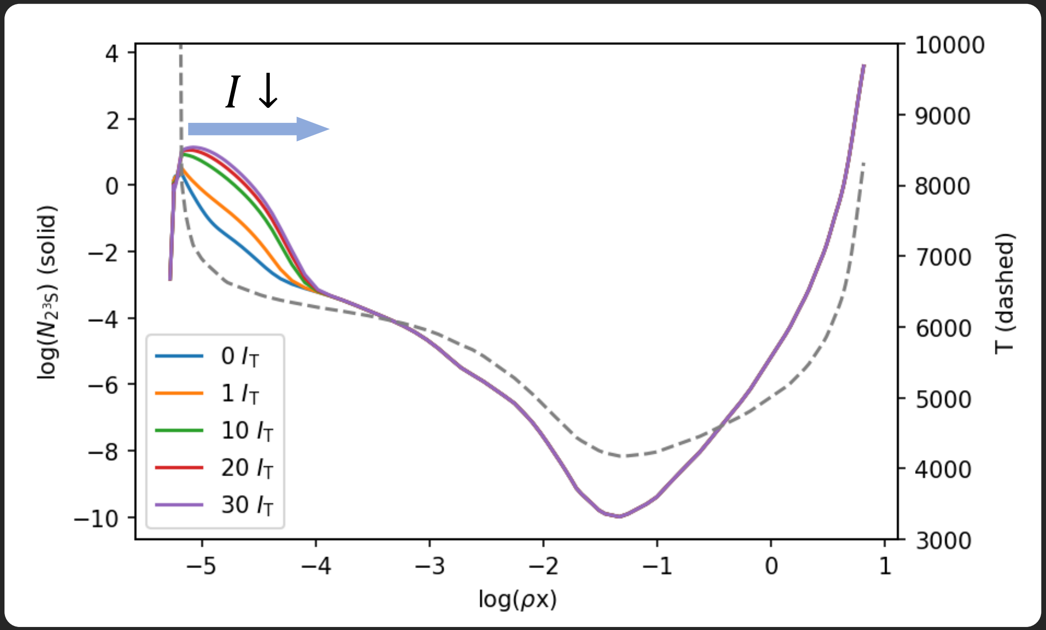


(Fig. 7.14, 7.15)

Explaining the sensitivity
Using the $2^3S(1s2s)$ populations in PR/CE

PR dominant case

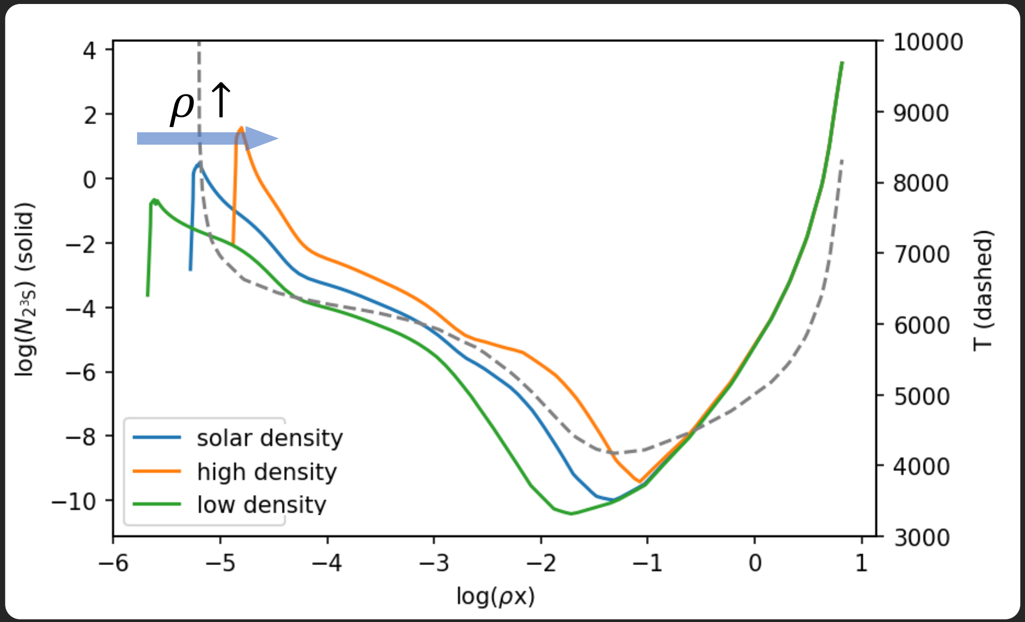
- I absorbed by He I
- $\mathrm{EW(He)} \propto I$



(Fig. 7.10)

CE dominant case

- CE rate $\propto n_\mathrm{e}, n_{1s^2}$
- $\mathrm{EW(He)} \propto Y$



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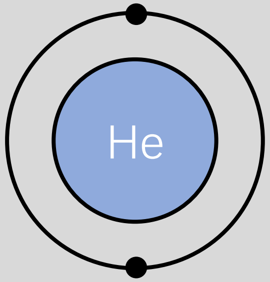
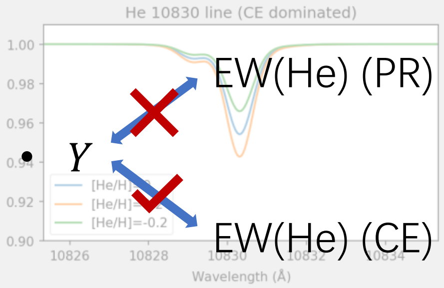
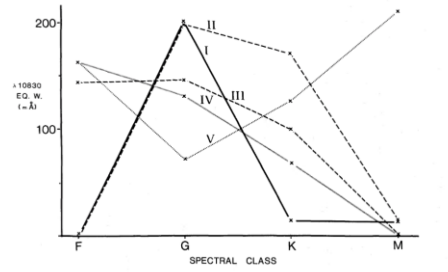
Introduction



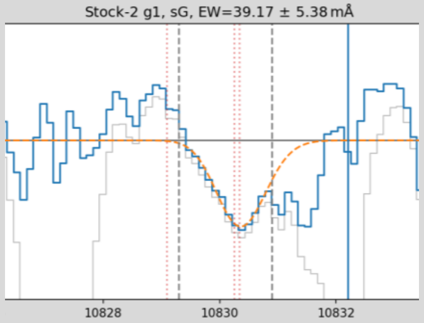
Synthesis



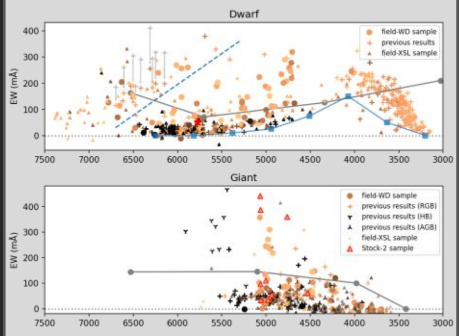
Previous observation



Targets and measurements



Empirical trends



Discussion

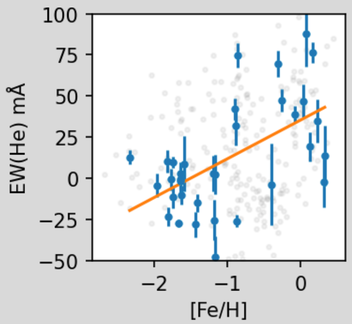
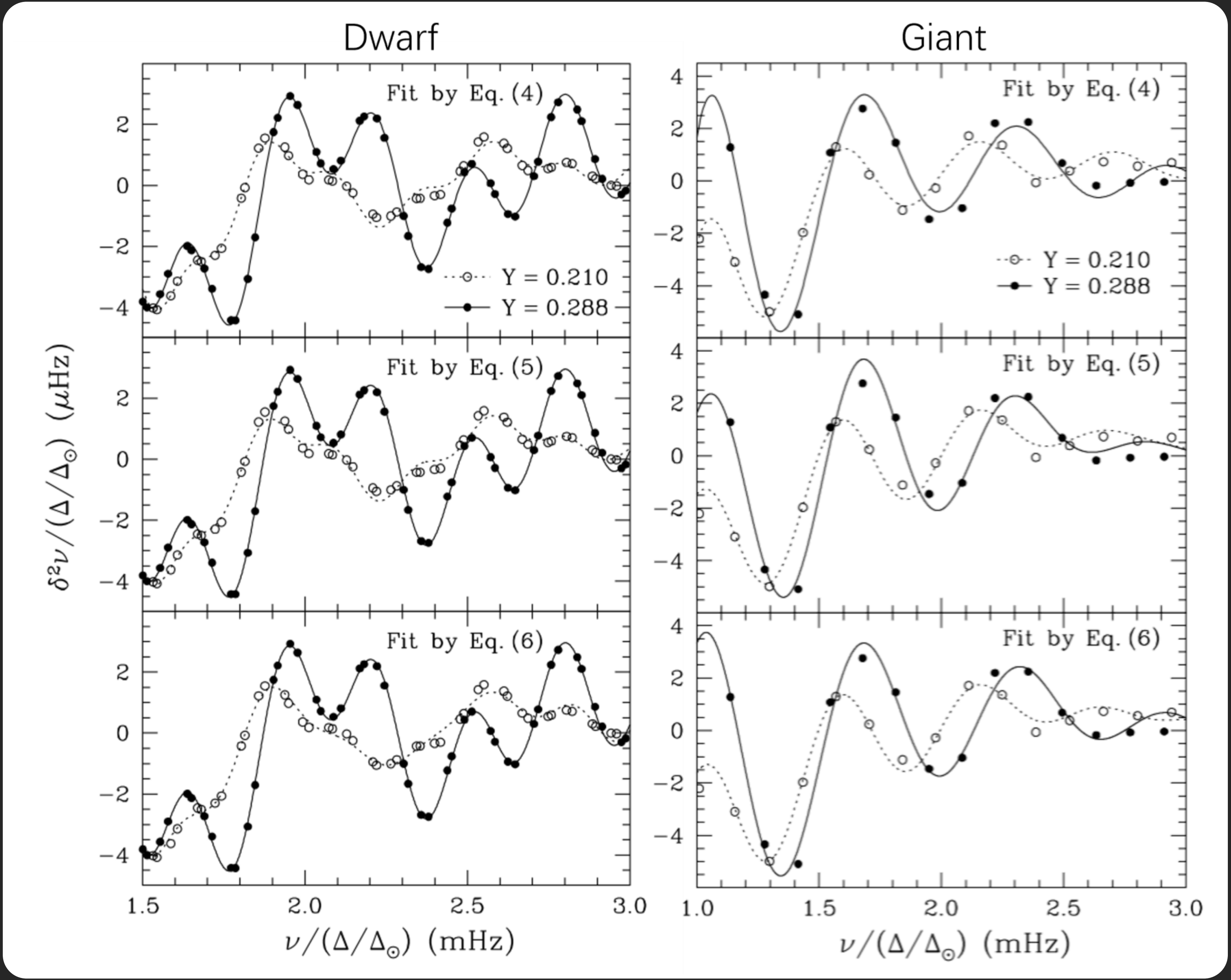


Fig 1.7



Dwarf
Giant
Fit by Eq. (4)
Fit by Eq. (5)
Fit by Eq. (6)
Y = 0.210
Y = 0.288
$\delta^2\nu/(\Delta/\Delta_\odot)$ (μHz)
$\nu/(\Delta/\Delta_\odot)$ (mHz)

Fig 1.8

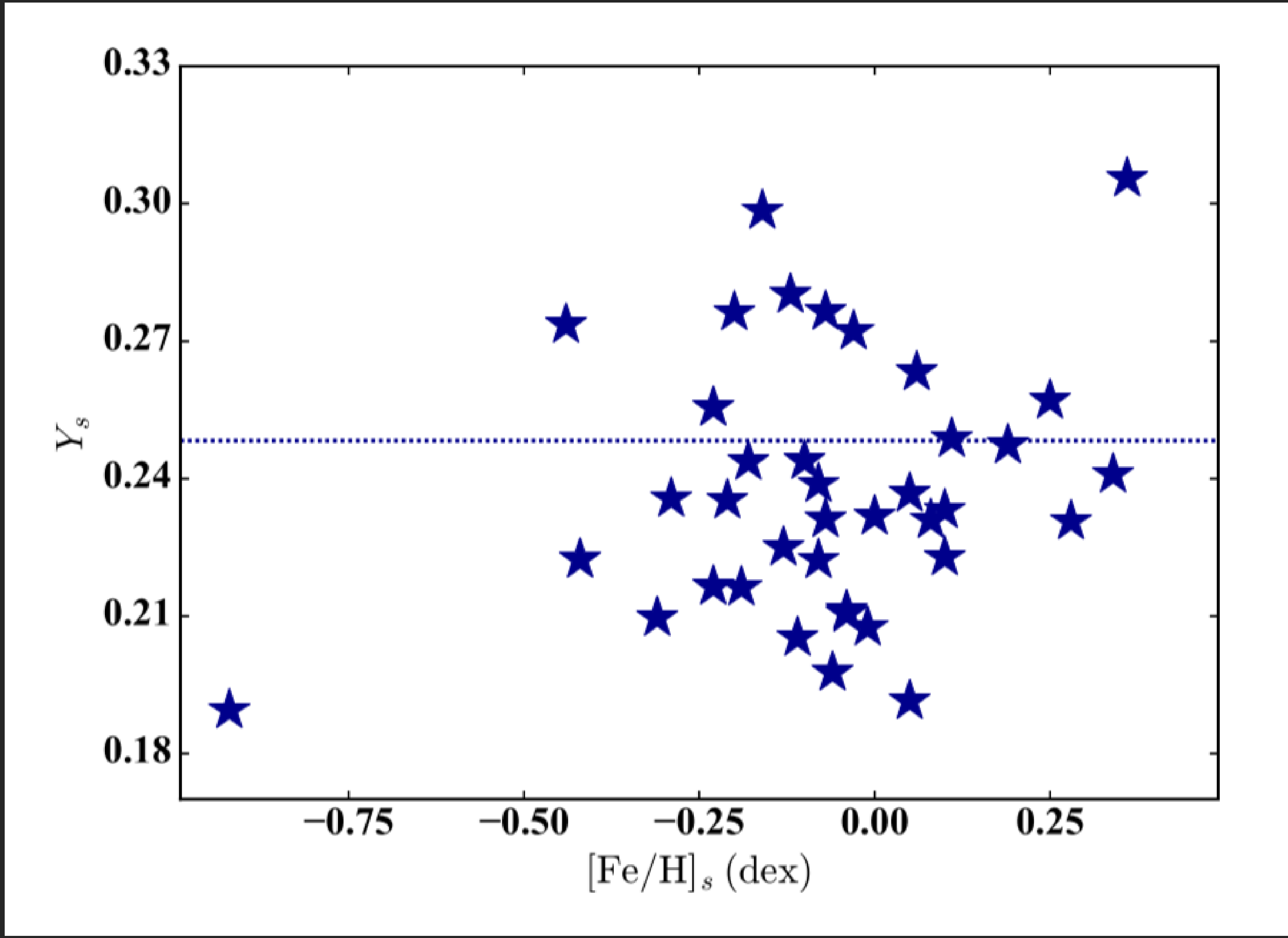
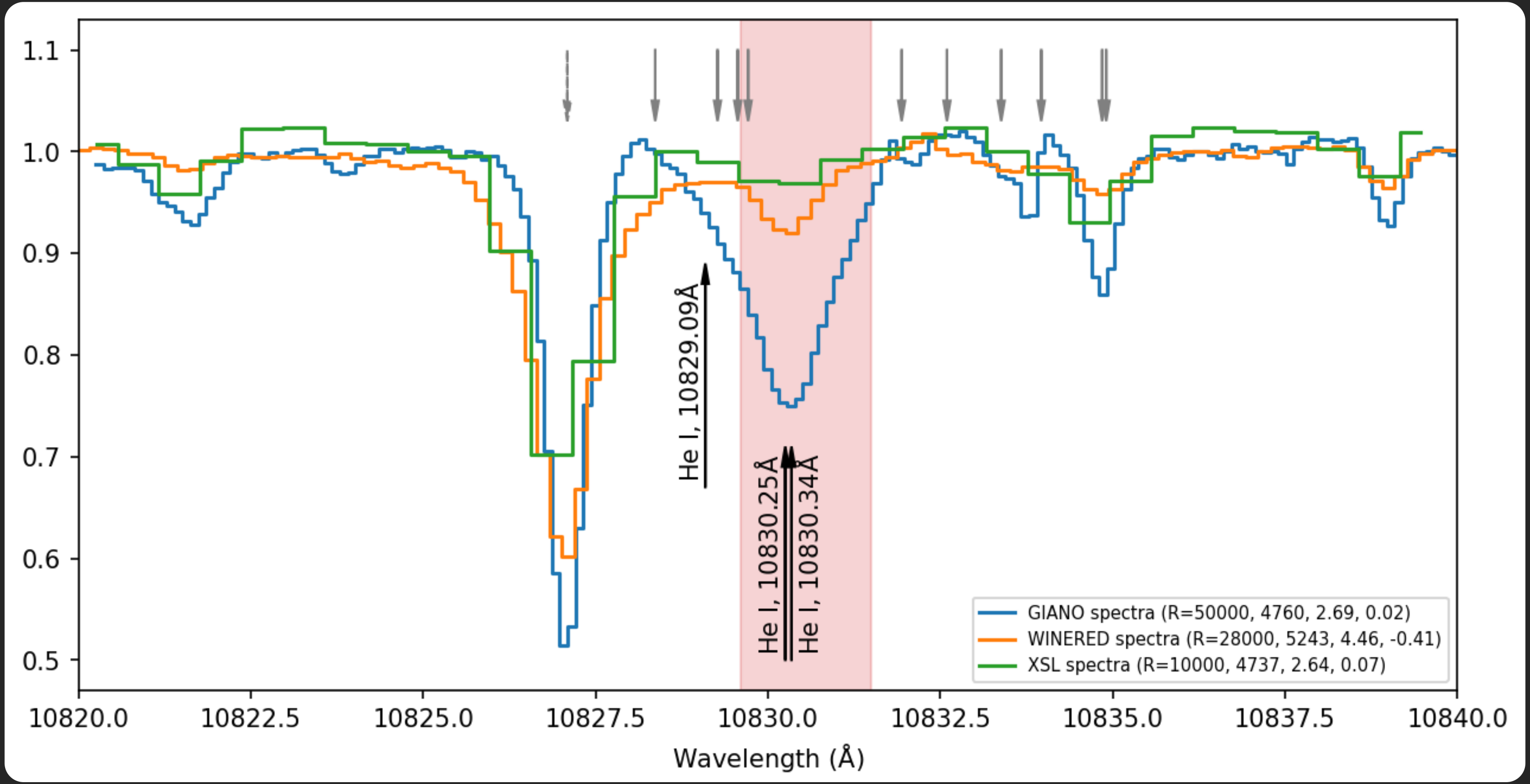
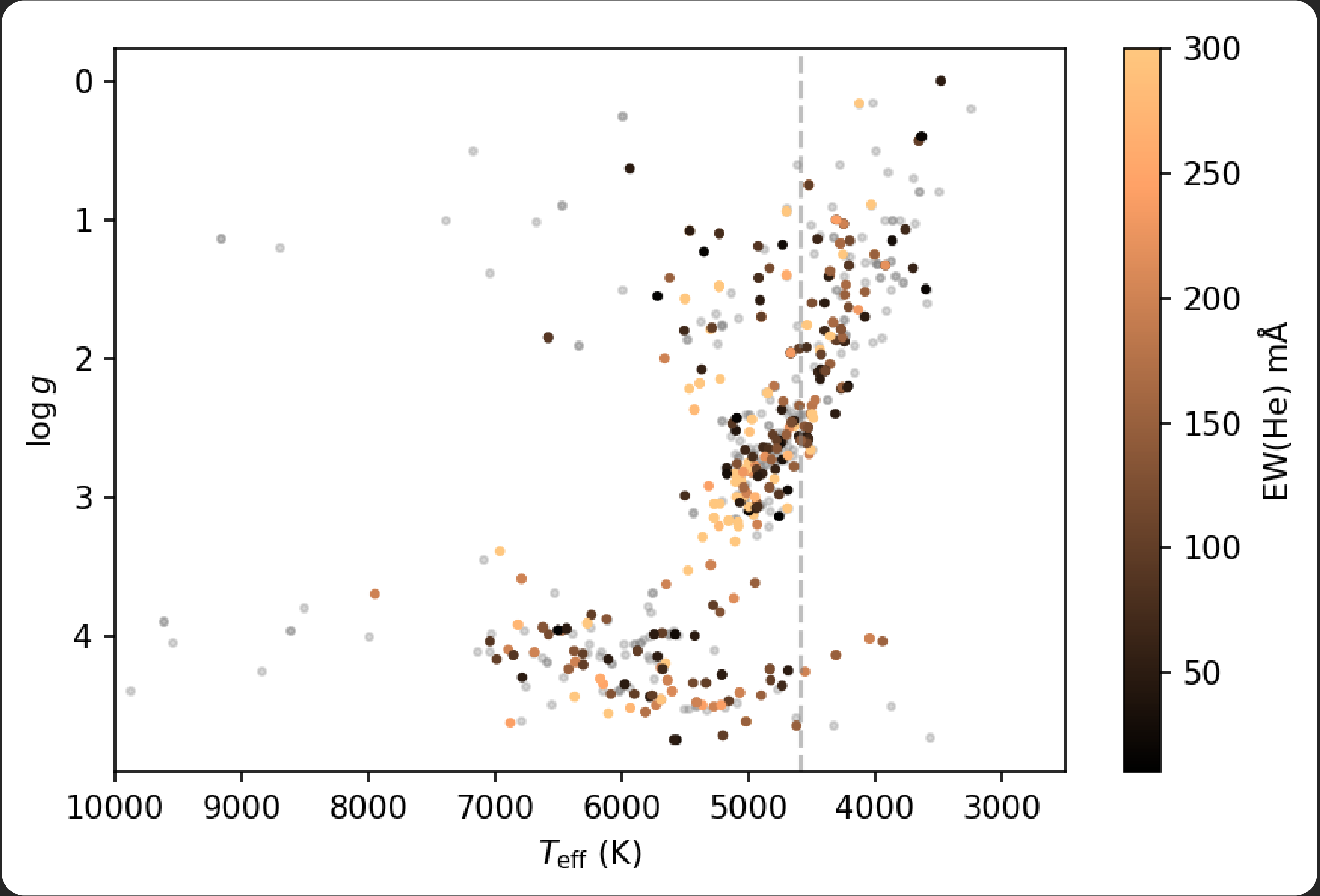


Fig 1.9



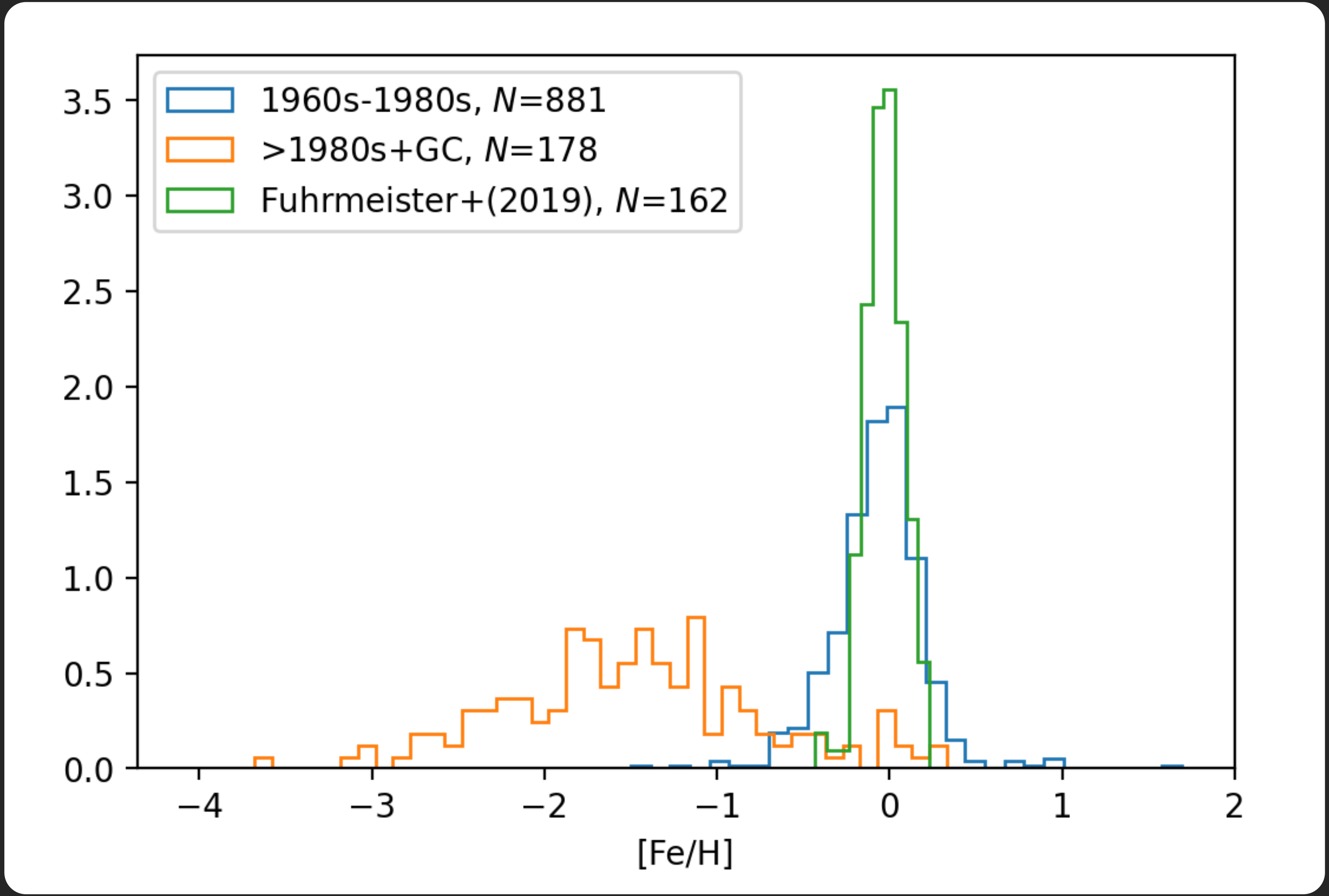
1.1
1.0
0.9
0.8
0.7
0.6
0.5
10820.0
10822.5
10825.0
10827.5
10830.0
10832.5
10835.0
10837.5
10840.0
Wavelength (Å)
He I, 10829.09Å
He I, 10830.25Å
He I, 10830.34Å
GIANO spectra (R=50000, 4760, 2.69, 0.02)
WINERED spectra (R=28000, 5243, 4.46, -0.41)
XSL spectra (R=10000, 4737, 2.64, 0.07)

Fig 2.4



0
1
2
3
4
log g
10000
9000
8000
7000
6000
5000
4000
3000
T_{eff} (K)
300
250
200
150
100
50
EW(He) mÅ

Fig 2.7



1960s-1980s, N=881
>1980s+GC, N=178
Fuhrmeister+(2019), N=162
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
−4
−3
−2
−1
0
1
2
[Fe/H]

Fig 5.1

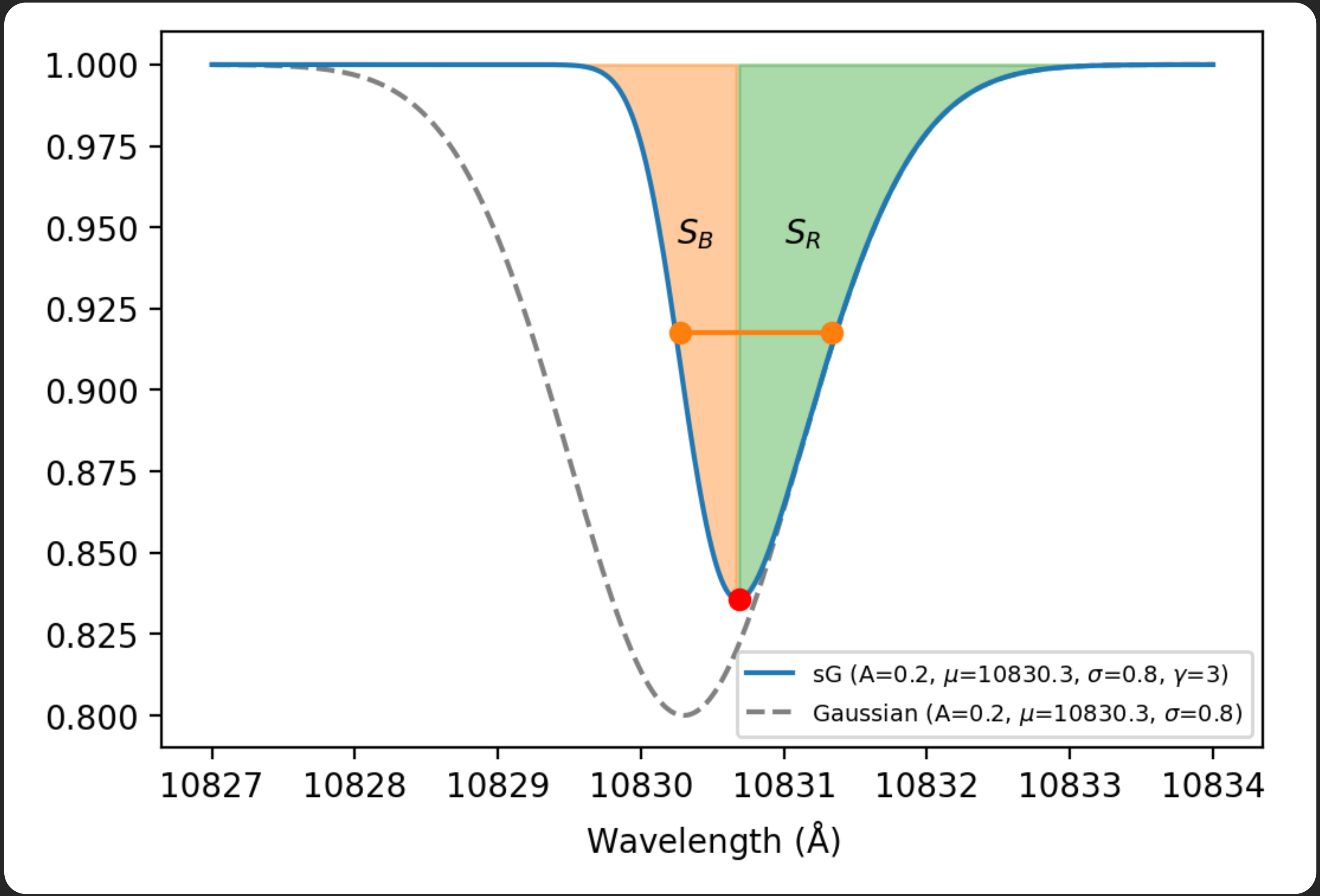
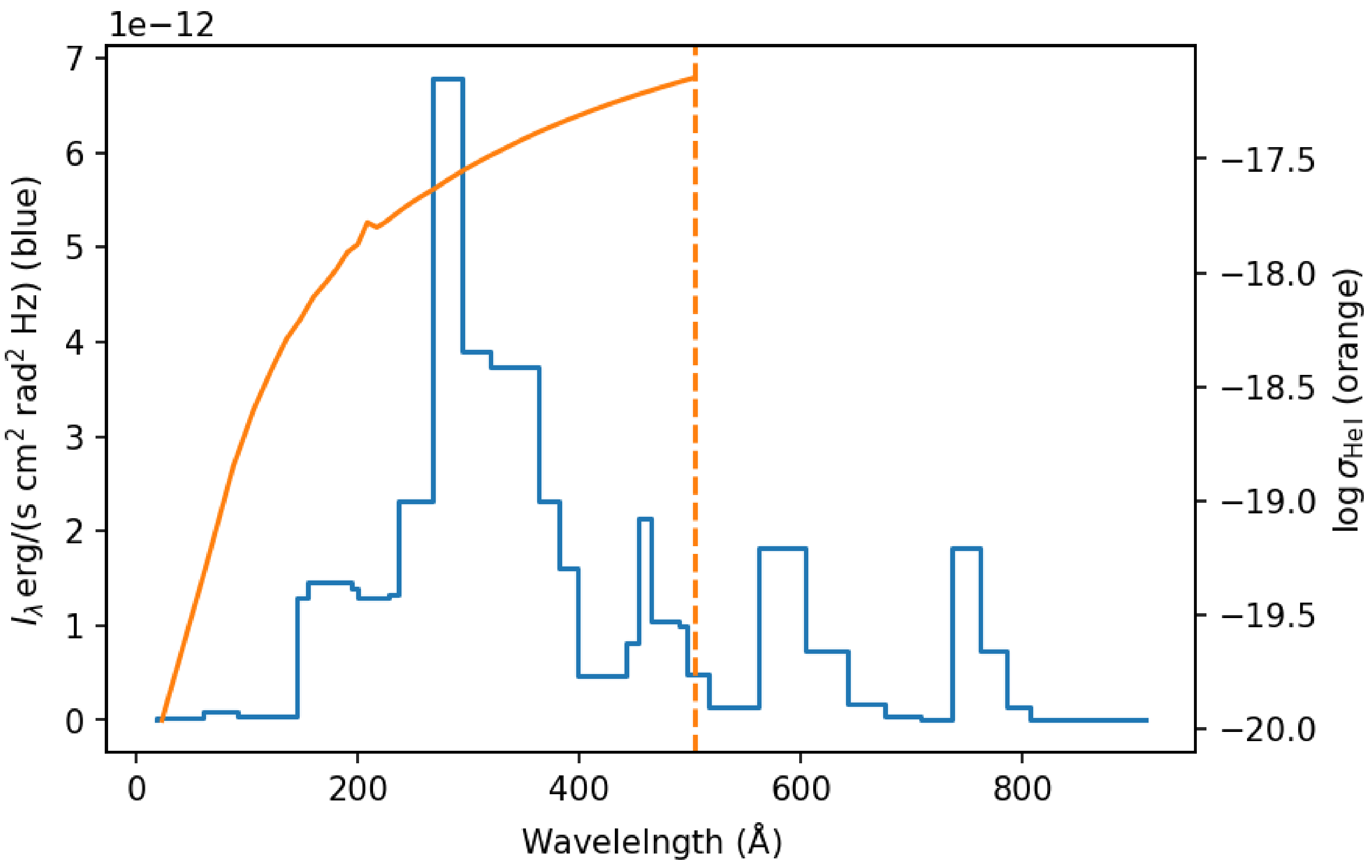
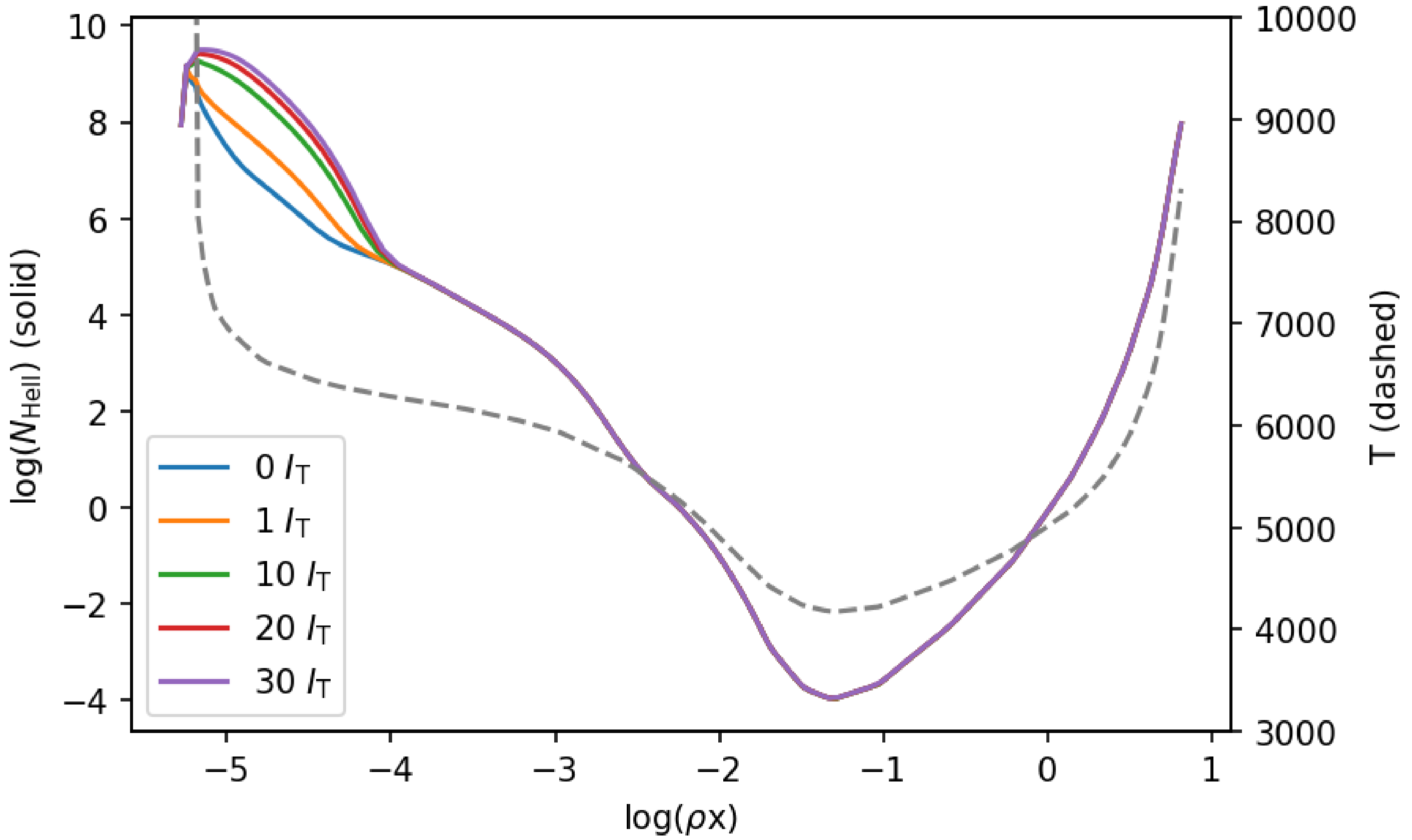

1.000
0.975
0.950
0.925
0.900
0.875
0.850
0.825
0.800
S_B
S_R
sG (A=0.2, μ=10830.3, σ=0.8, γ=3)
Gaussian (A=0.2, μ=10830.3, σ=0.8)
10827
10828
10829
10830
10831
10832
10833
10834
Wavelength (Å)

Fig 7.2



1e−12
7
6
5
4
3
2
1
0
0
200
400
600
800
Wavelelngth (Å)
I_λ erg/(s cm^2 rad^2 Hz) (blue)
−17.5
−18.0
−18.5
−19.0
−19.5
−20.0
log $\sigma_{\rm HeI}$ (orange)

Fig 7.9



10
8
6
4
2
0
−2
−4
log(N_{HeII}) (solid)
10000
9000
8000
7000
6000
5000
4000
3000
T (dashed)
−5
−4
−3
−2
−1
0
1
log(ρx)
0 I_T
1 I_T
10 I_T
20 I_T
30 I_T

Fig 7.13

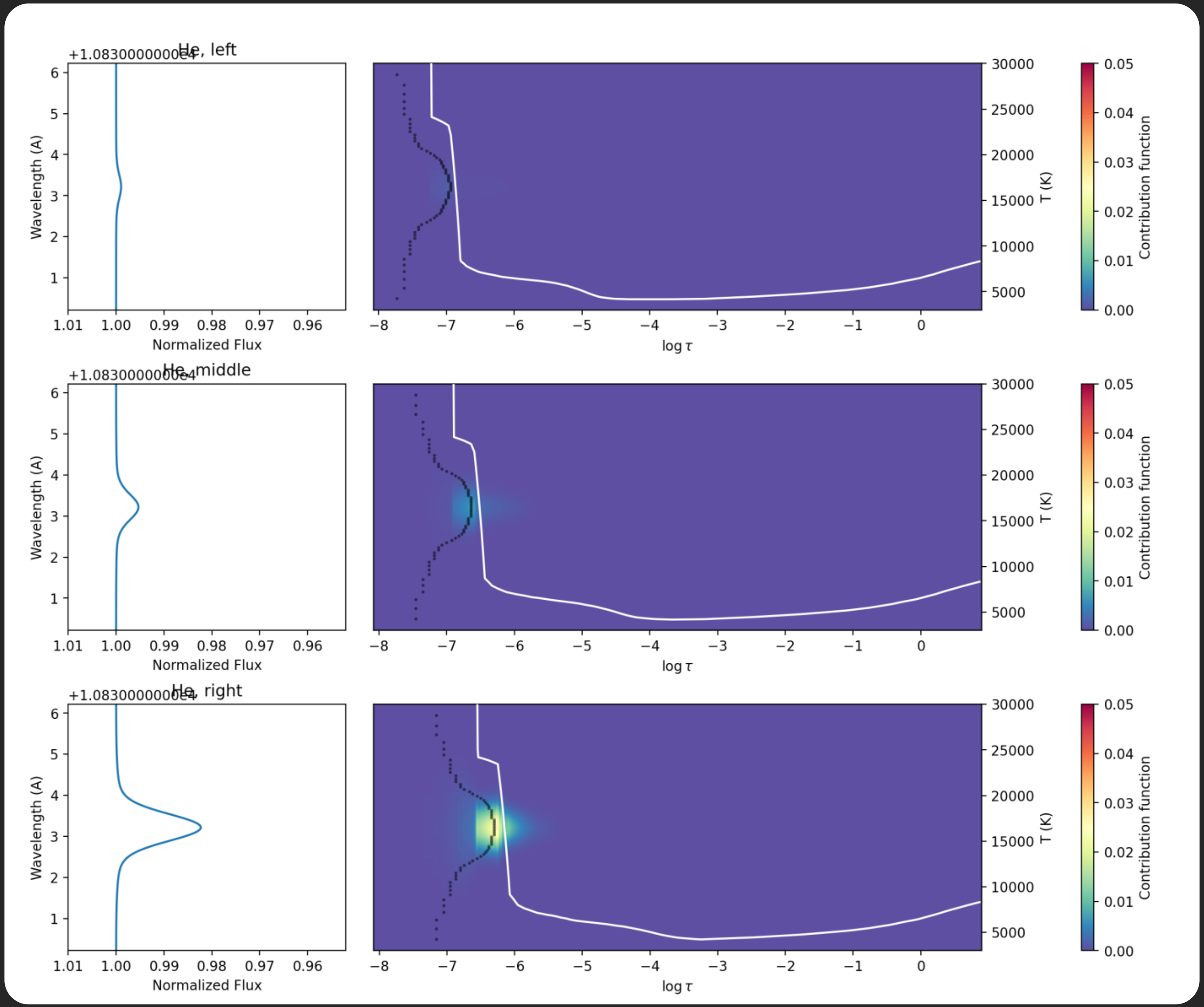
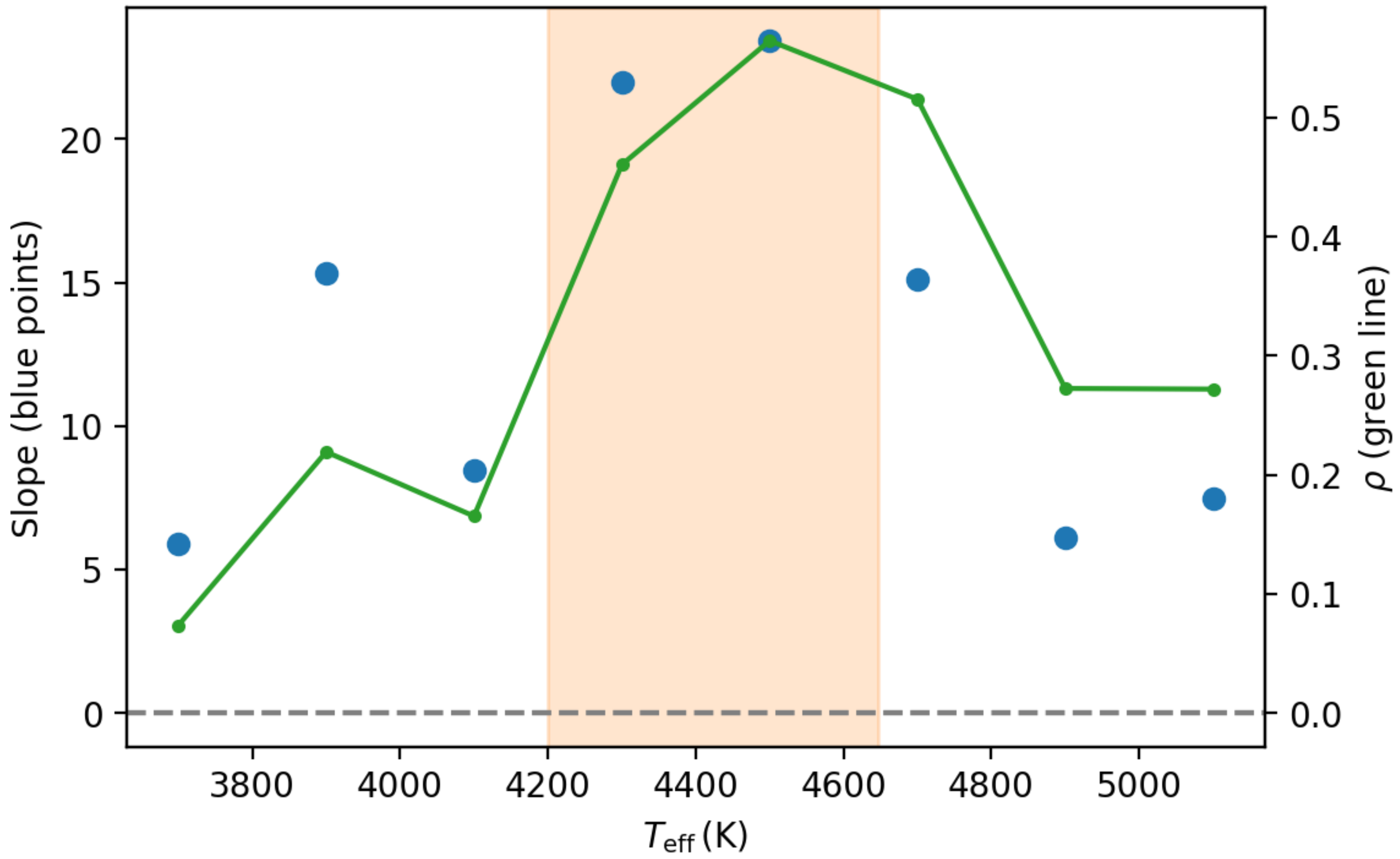

He, left
He, middle
He, right
+1.0830000000e4
Wavelength (A)
Normalized Flux
1.01
1.00
0.99
0.98
0.97
0.96
log τ
T (K)
Contribution function
30000
25000
20000
15000
10000
5000
0.05
0.04
0.03
0.02
0.01
0.00

Fig 8.4



Slope (blue points)
20
15
10
5
0
ρ (green line)
0.5
0.4
0.3
0.2
0.1
0.0
3800
4000
4200
4400
4600
4800
5000
$T_{\rm eff}$ (K)