F-type Stars:
A Link Between Worlds

(Chapter 6 – Gray & Corbally)

Rachael Merritt

ASTR 8000

14 February 2019

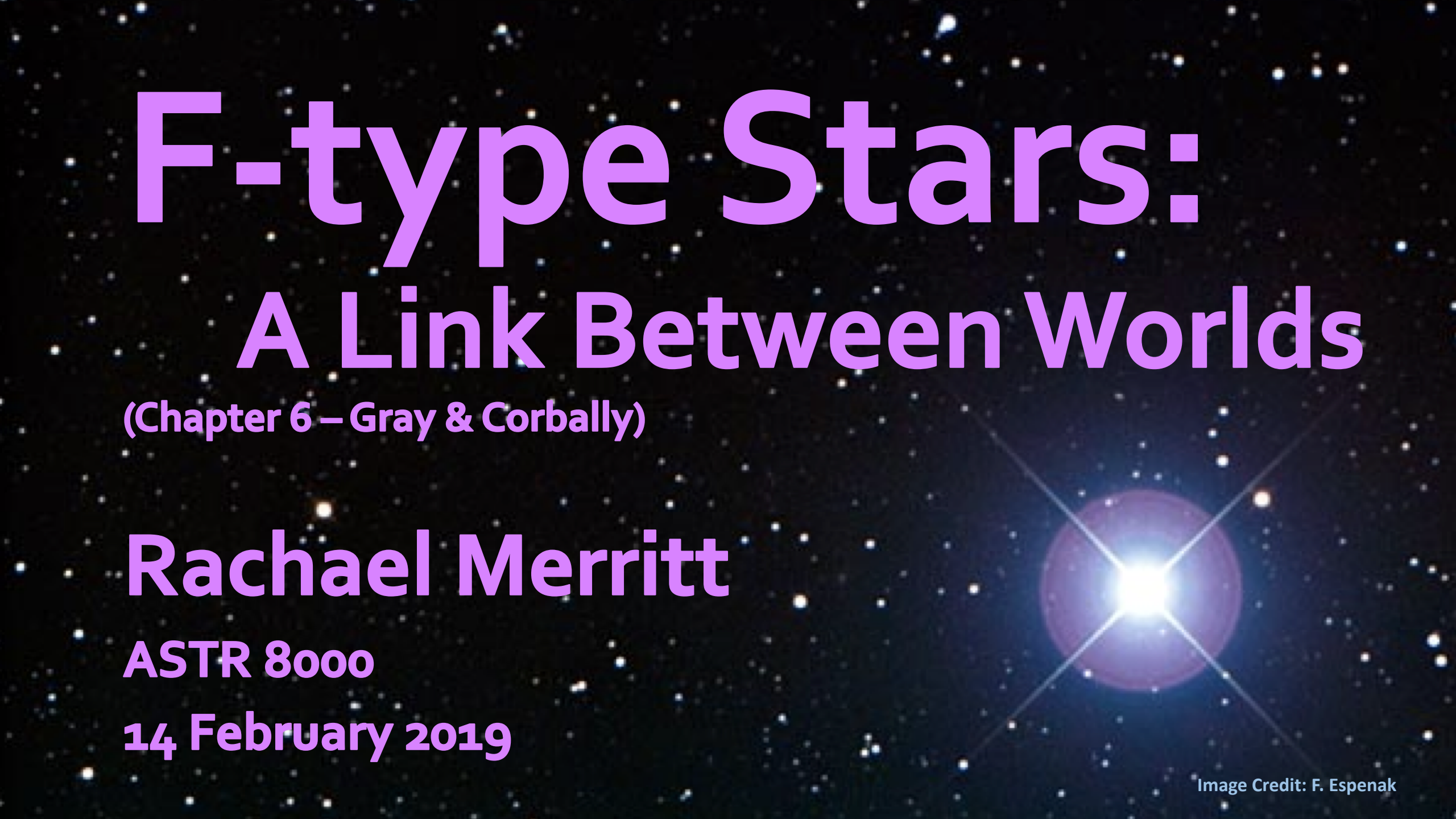
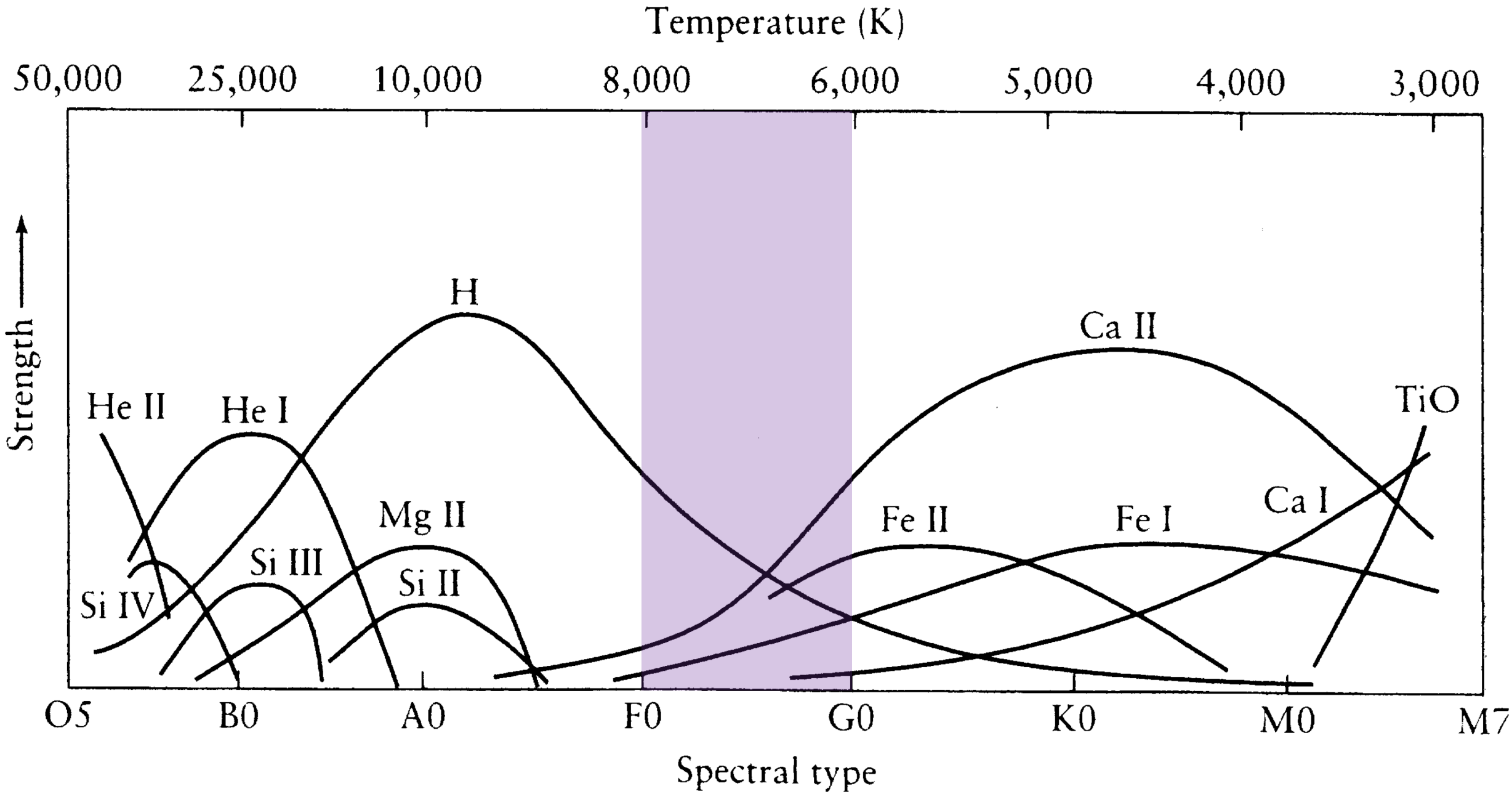


Image Credit: F. Espenak


Temperature (K)
50,000
25,000
10,000
8,000
6,000
5,000
4,000
3,000
Strength
H
Ca II
He II
He I
TiO
Mg II
Fe II
Fe I
Ca I
Si III
Si II
Si IV
O5
B0
A0
F0
G0
K0
M0
M7
Spectral type

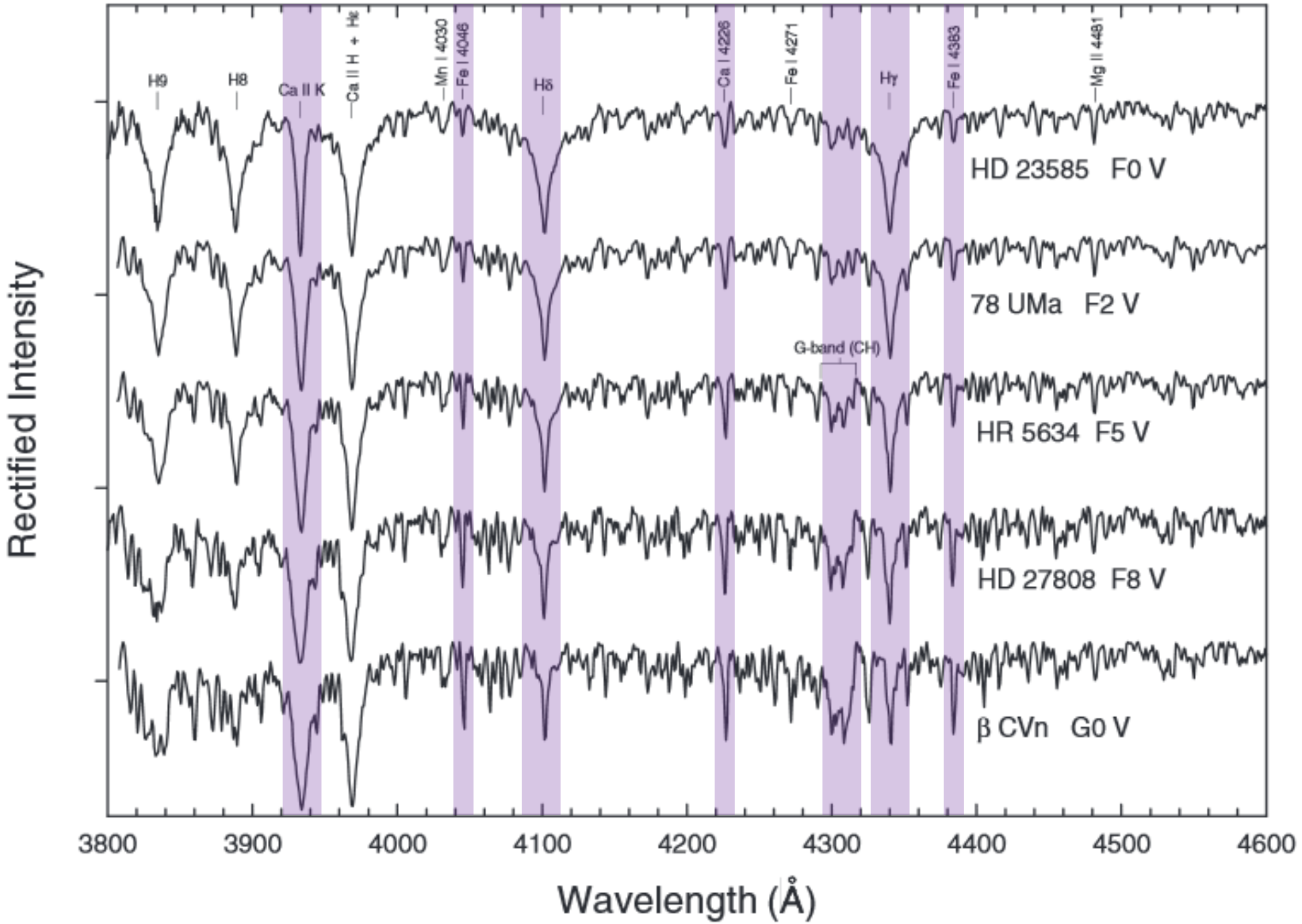
M-stars are red,
O-stars are blue,
F-stars are stars that can't decide what to do!

Linking Worlds

- ★ Transition from radiative atmosphere to convective atmosphere
  - ★ Chemical peculiarities
  - ★ Magnetic fields
  - ★ Rotational velocities
- ★ Appearance of molecular bands
- ★ Population II MS stars

Temperature Criteria

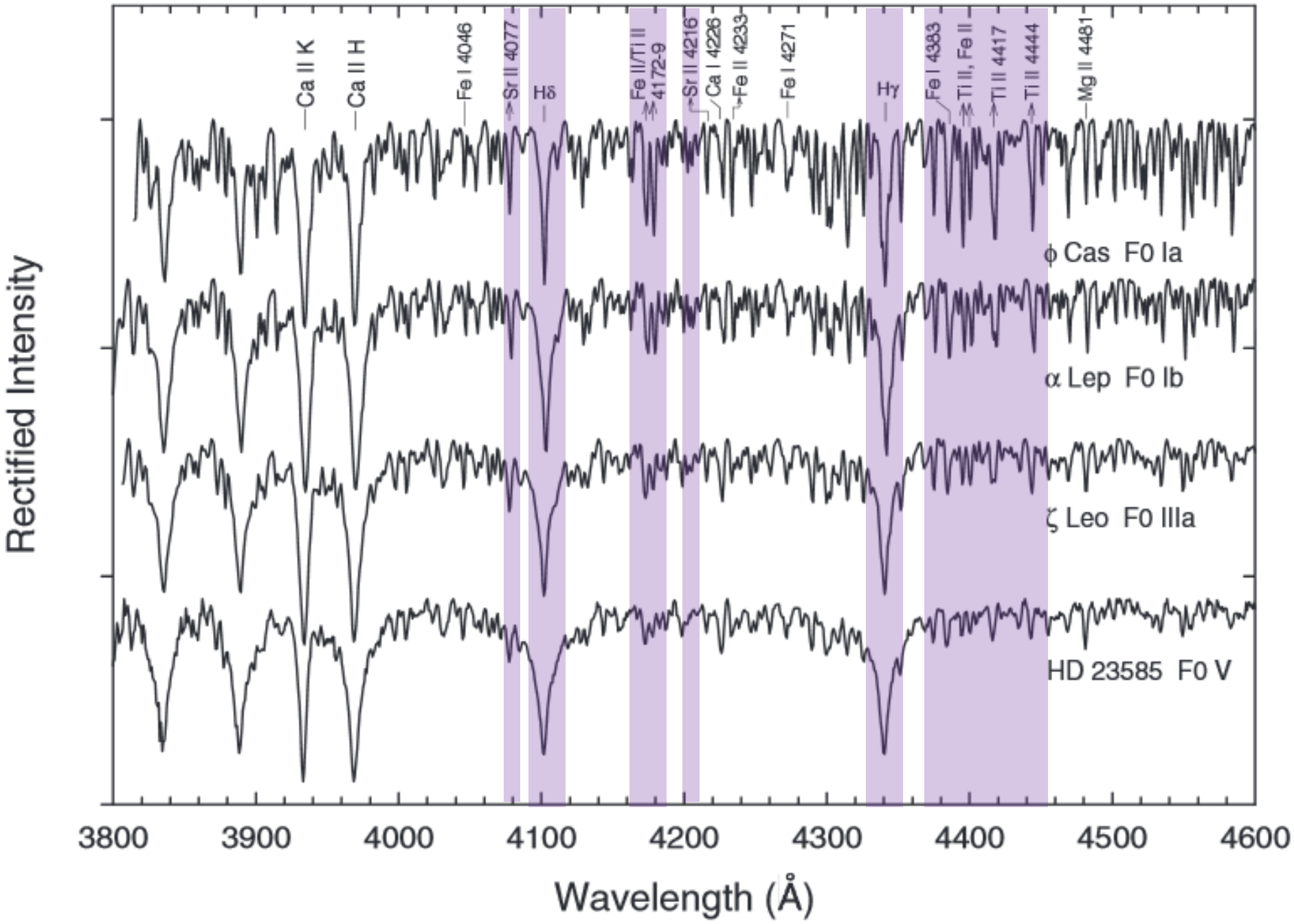
- ★ Hydrogen
  - ★ Least effected by metallicity
- ★ Metal lines
  - ★ Ca II-K (plateaus >F3)
  - ★ Fe I λ4046/4383, Ca I λ4226 (all F-types)
  - ★ G-band (>F3)
- ★ Beware of abundances!!
  - ★ Oddballs do occur (e.g. ρPups, Barium dwarfs)


Rectified Intensity
Wavelength (Å)
3800
3900
4000
4100
4200
4300
4400
4500
4600
Hθ
H8
Ca II K
Ca II H + Hε
Mn I 4030
Fe I 4046
Hδ
Ca I 4226
Fe I 4271
Hγ
Fe I 4383
Mg II 4481
G-band (CH)
HD 23585 F0 V
78 UMa F2 V
HR 5634 F5 V
HD 27808 F8 V
β CVn G0 V

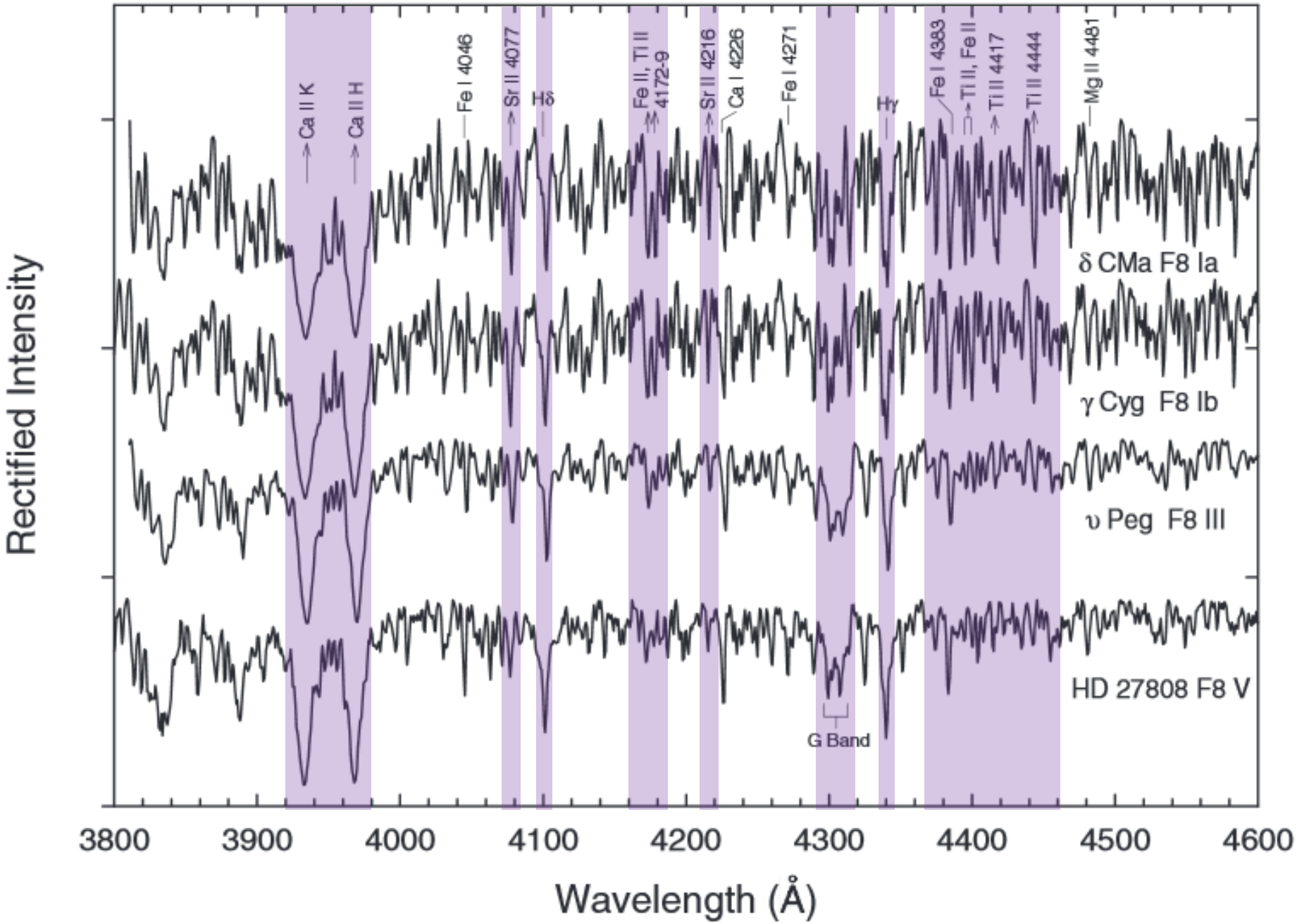
Luminosity Criteria

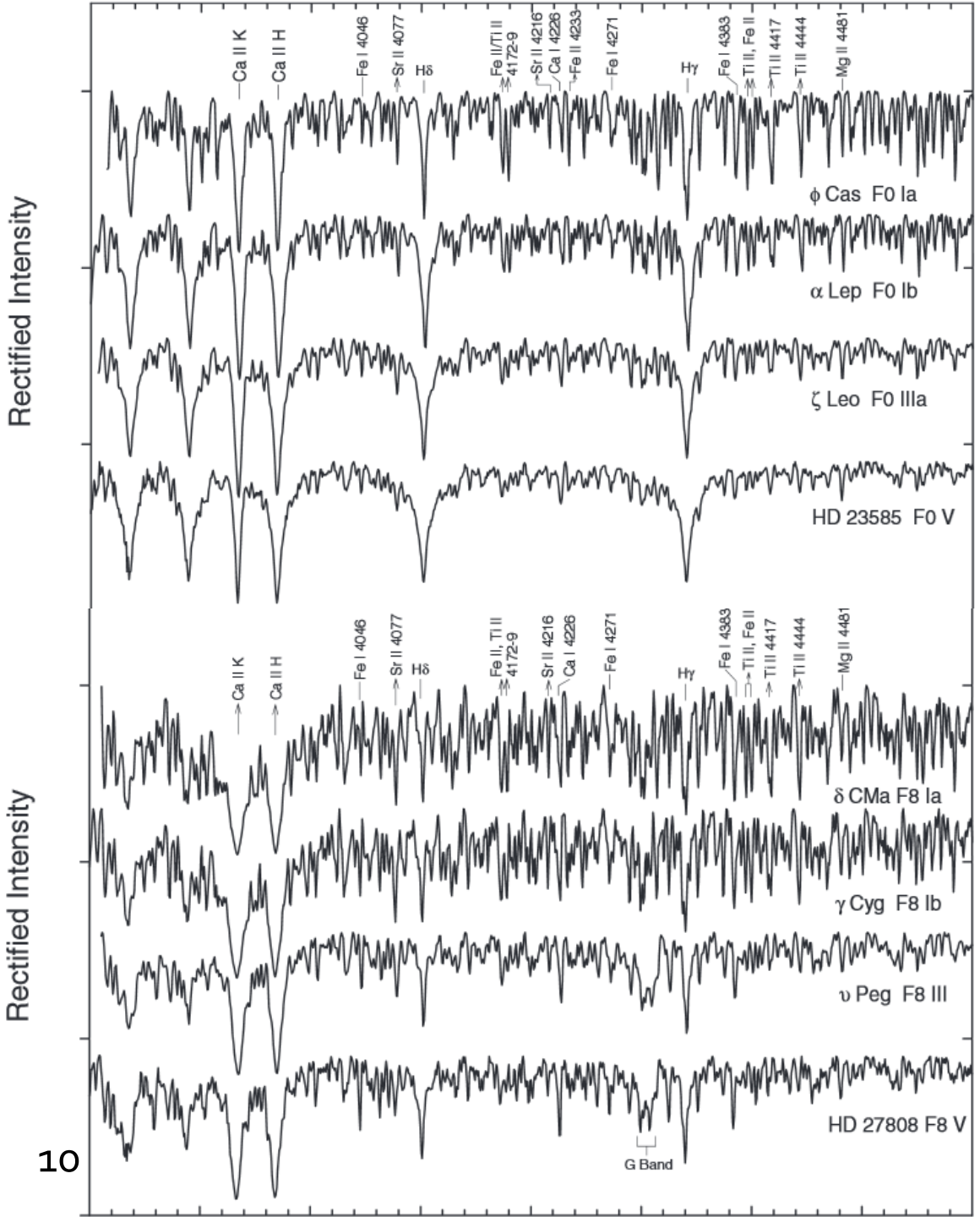
- ★ Ionized Fe and Ti (<F6)
  - ★ Ti II/Fe II forest ~λ4500
- ★ Sr II (λ4077,4216)
  - ★ Becomes useful for F6 and later
- ★ Ca II K & H
  - ★ Mildly useful >F8
- ★ Hydrogen and G-band

F0


Ca II K
Ca II H
Fe I 4046
Sr II 4077
Hδ
Fe II/Ti II 4172-9
Sr II 4216
Ca I 4226
Fe II 4233
Fe I 4271
Hγ
Fe I 4383
Ti II, Fe II
Ti II 4417
Ti II 4444
Mg II 4481
ϕ Cas F0 Ia
α Lep F0 Ib
ζ Leo F0 IIIa
HD 23585 F0 V
Rectified Intensity
3800
3900
4000
4100
4200
4300
4400
4500
4600
Wavelength (Å)

F8


Ca II K
Ca II H
Fe I 4046
Sr II 4077
Hδ
Fe II, Ti II 4172-9
Sr II 4216
Ca I 4226
Fe I 4271
Hγ
Fe I 4383
Ti II, Fe II
Ti II 4417
Ti II 4444
Mg II 4481
δ CMa F8 Ia
γ Cyg F8 Ib
υ Peg F8 III
HD 27808 F8 V
G Band
Rectified Intensity
3800
3900
4000
4100
4200
4300
4400
4500
4600
Wavelength (Å)



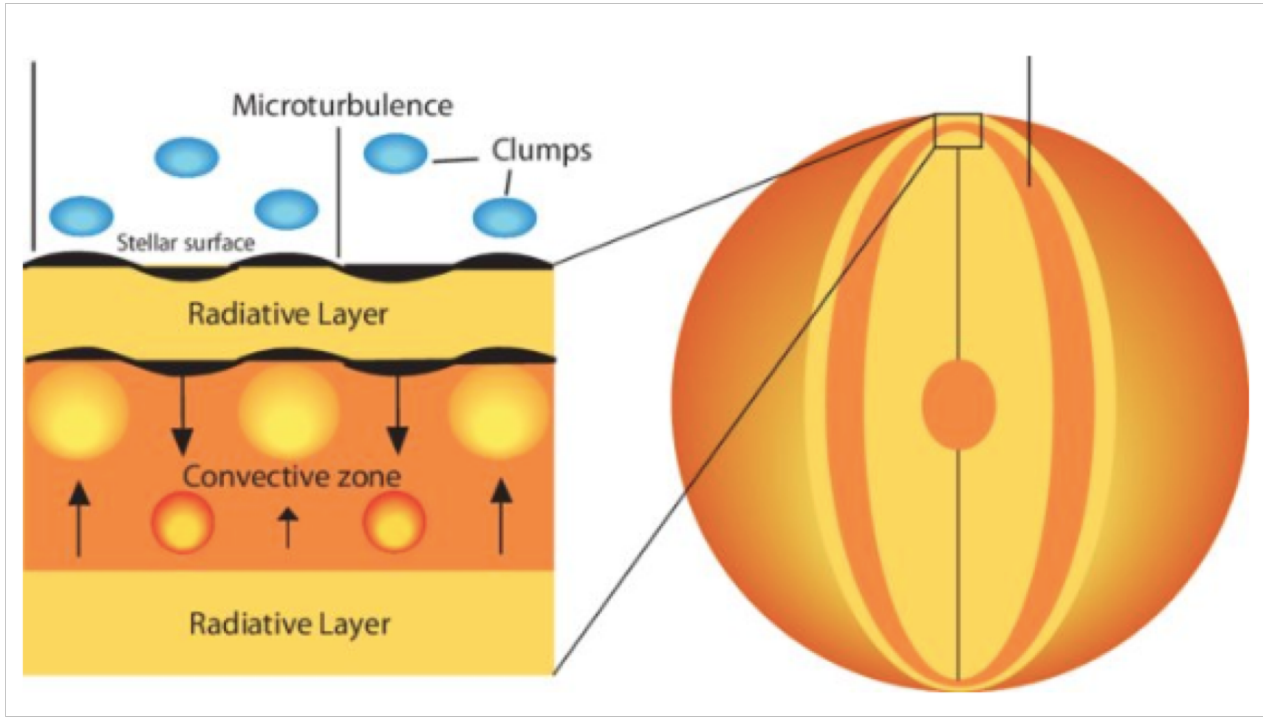
- ★ **Ionized Fe and Ti (<F6)**
  - ★ **Ti II/Fe II forest ~λ4500 (F0-F2)**
- ★ **Sr II (λ4077,4216)**
  - ★ **Useful for F6 and later**
- ★ **Ca II K & H**
  - ★ **Mildly useful >F8**
- ★ **Hydrogen and G-band**

Physics of Luminosity Criteria

- ★ **Metastable levels of Ti II & Fe II**
  - ★ Transitions to lower levels are forbidden
  - ★ Can only get to ground state through collision
  - ★ Okay for dwarfs and giants, problem for supergiants
- ★ **Sr II lines are resonance lines**
  - ★ Care about how electron density influences ionization equilibrium

Physics of Luminosity Criteria

- ★ Microturbulent velocity
  - ★ Turbulent cell size smaller than free mean path
  - ★ Leads to broader, stronger lines
  - ★ Keep this in mind for spectroscopic parallax!



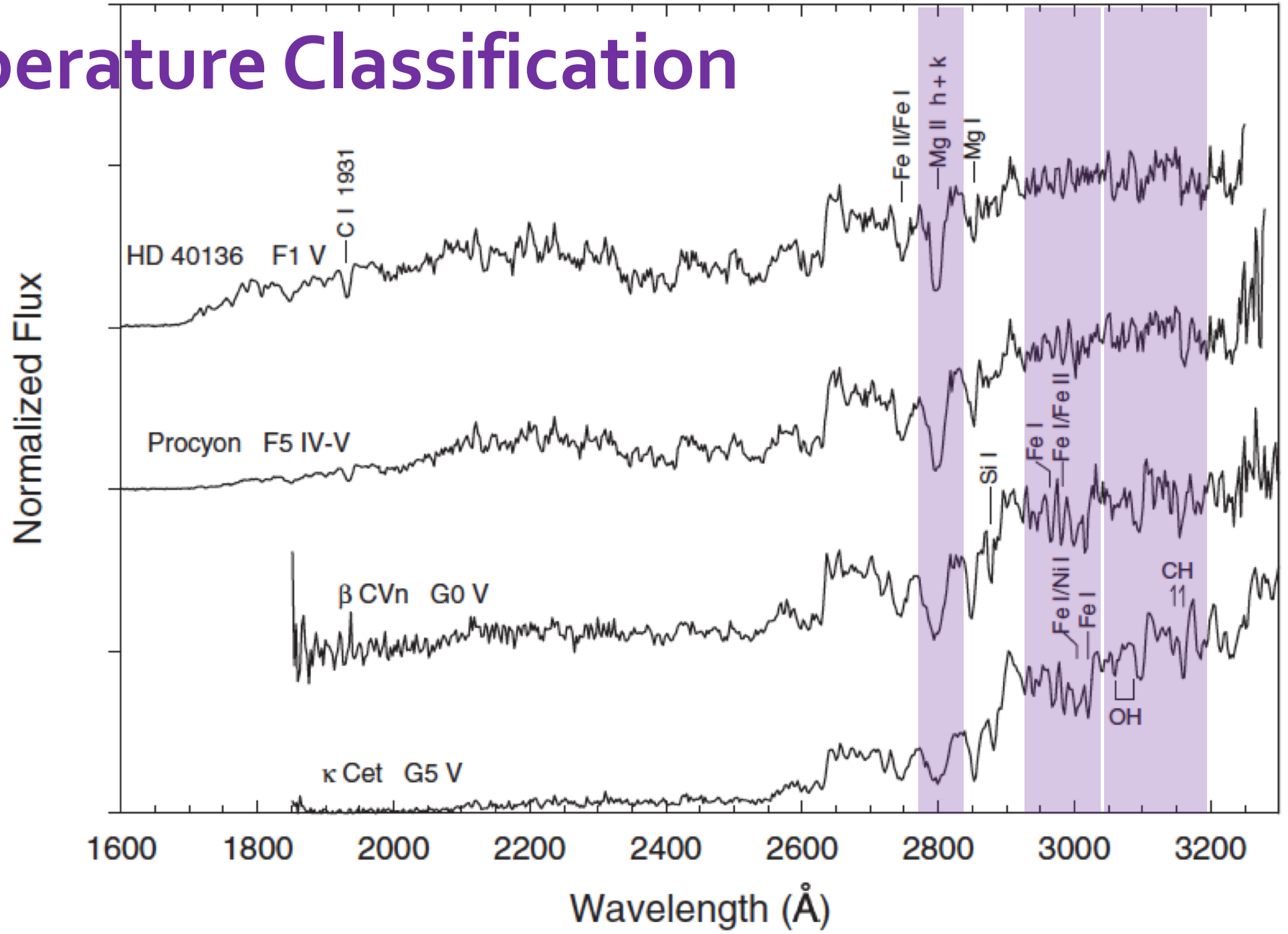
Cantiello et al. 2009, *A&A*, 499, 1

F-types in the UV

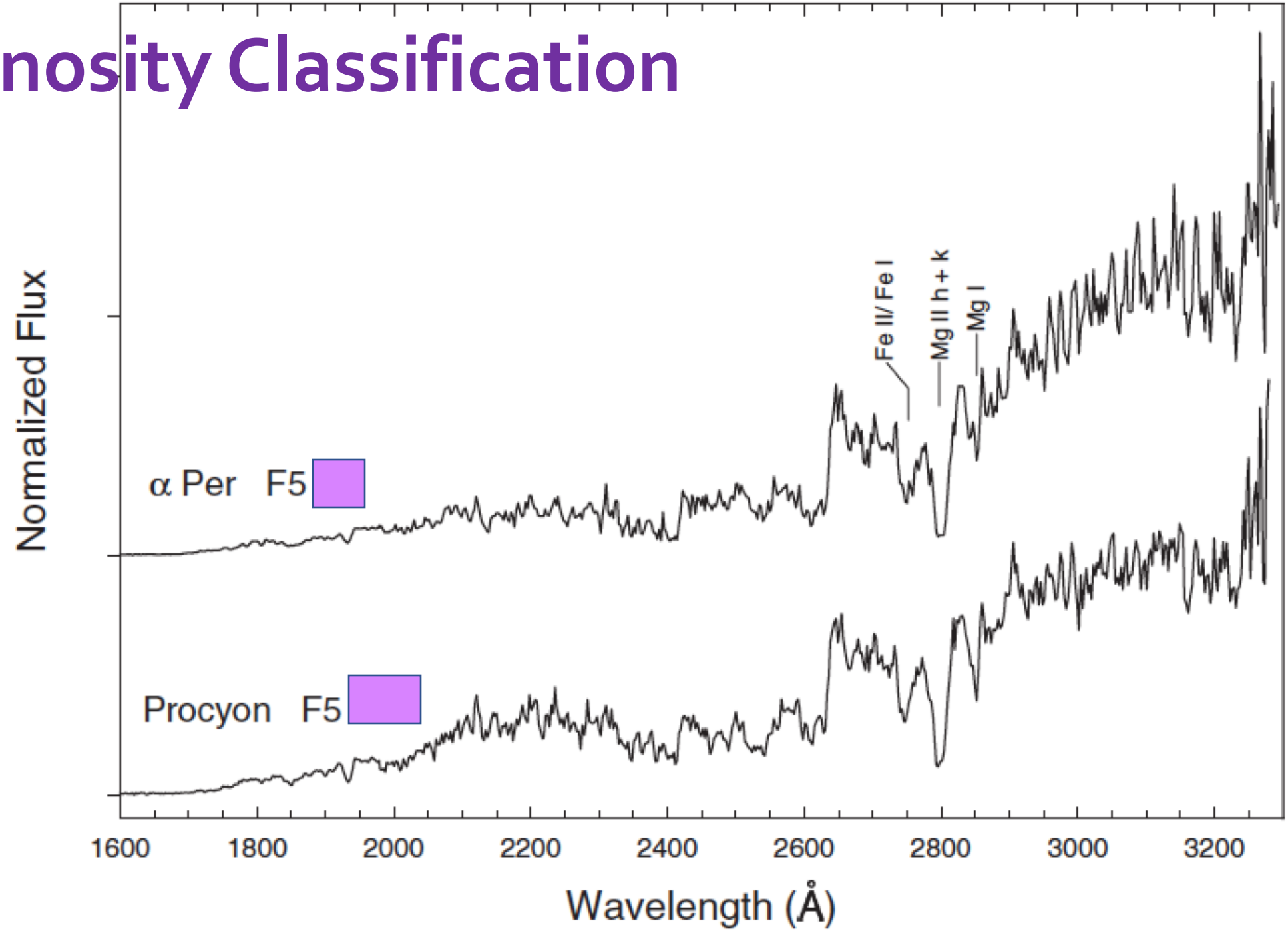
Not done.

- ★ But if it were…
  - ★ SED strongly dependent on metallicity
  - ★ Mg II h & k lines good indicator of spectral morphology across all F-types
  - ★ Fe I, Fe II, Ni I show up in late types (~ λ2990)
  - ★ Made it into G-types once CH and OH features appear (λ3066/3092, λ3145/3160)

Temperature Classification

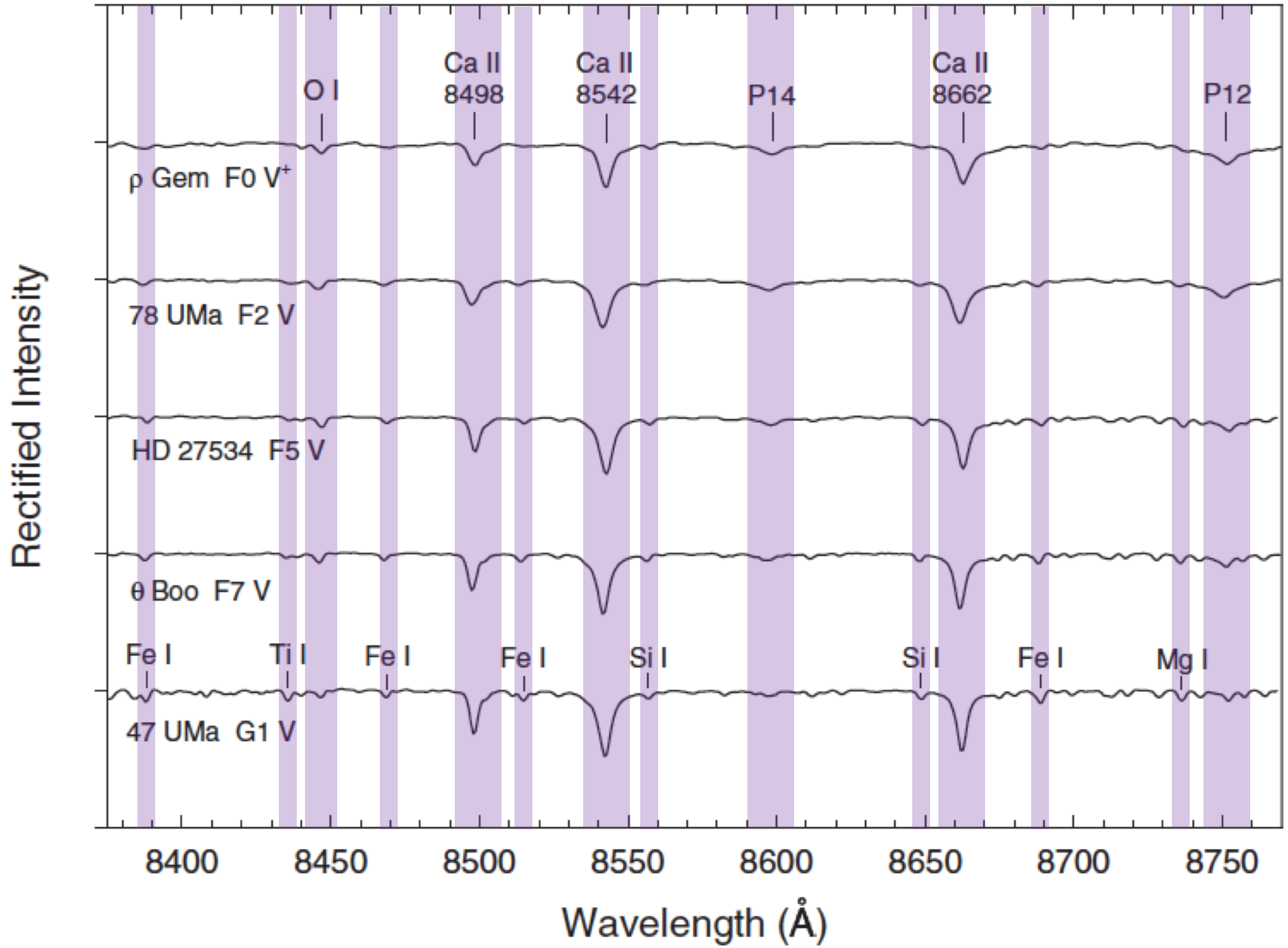


Luminosity Classification



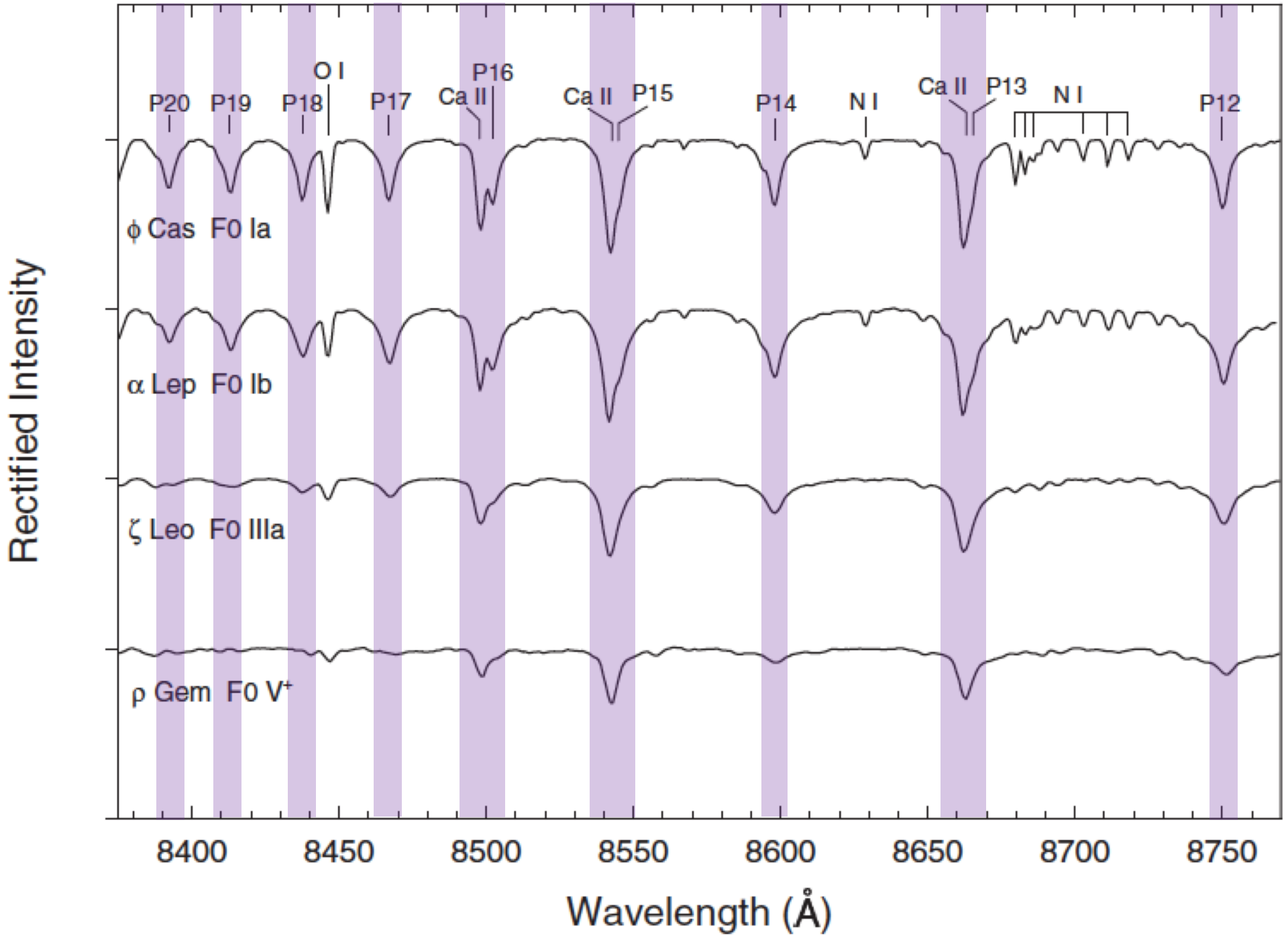
F-types in the IR (Hα to 1μm)

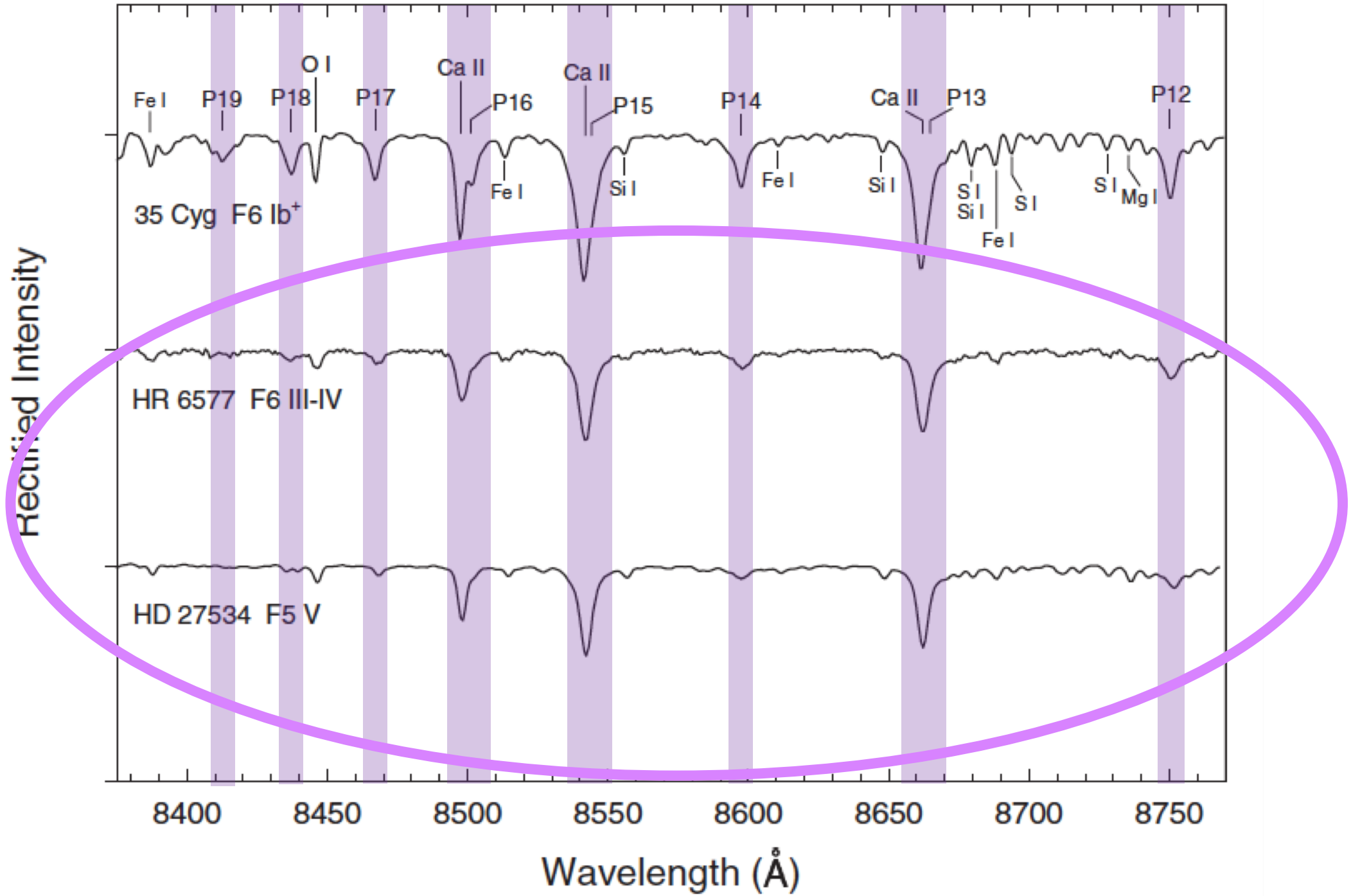
- ★ λ8375-8770 basically telluric free!
- ★ Temperature Criteria
  - ★ Paschen-series lines
    - ★ Decrease in strength to later types
  - ★ Ca II (λ8498-8662) triplet
    - ★ Increases in strength to later types
  - ★ Metallic lines (Fe, Si, Mg)
    - ★ Become prominent in late F-type into G-type


O I
Ca II 8498
Ca II 8542
P14
Ca II 8662
P12
ρ Gem F0 V+
78 UMa F2 V
HD 27534 F5 V
θ Boo F7 V
47 UMa G1 V
Fe I
Ti I
Fe I
Fe I
Si I
Si I
Fe I
Mg I
Rectified Intensity
8400
8450
8500
8550
8600
8650
8700
8750
Wavelength (Å)

F-types in the IR (Hα to 1μm)

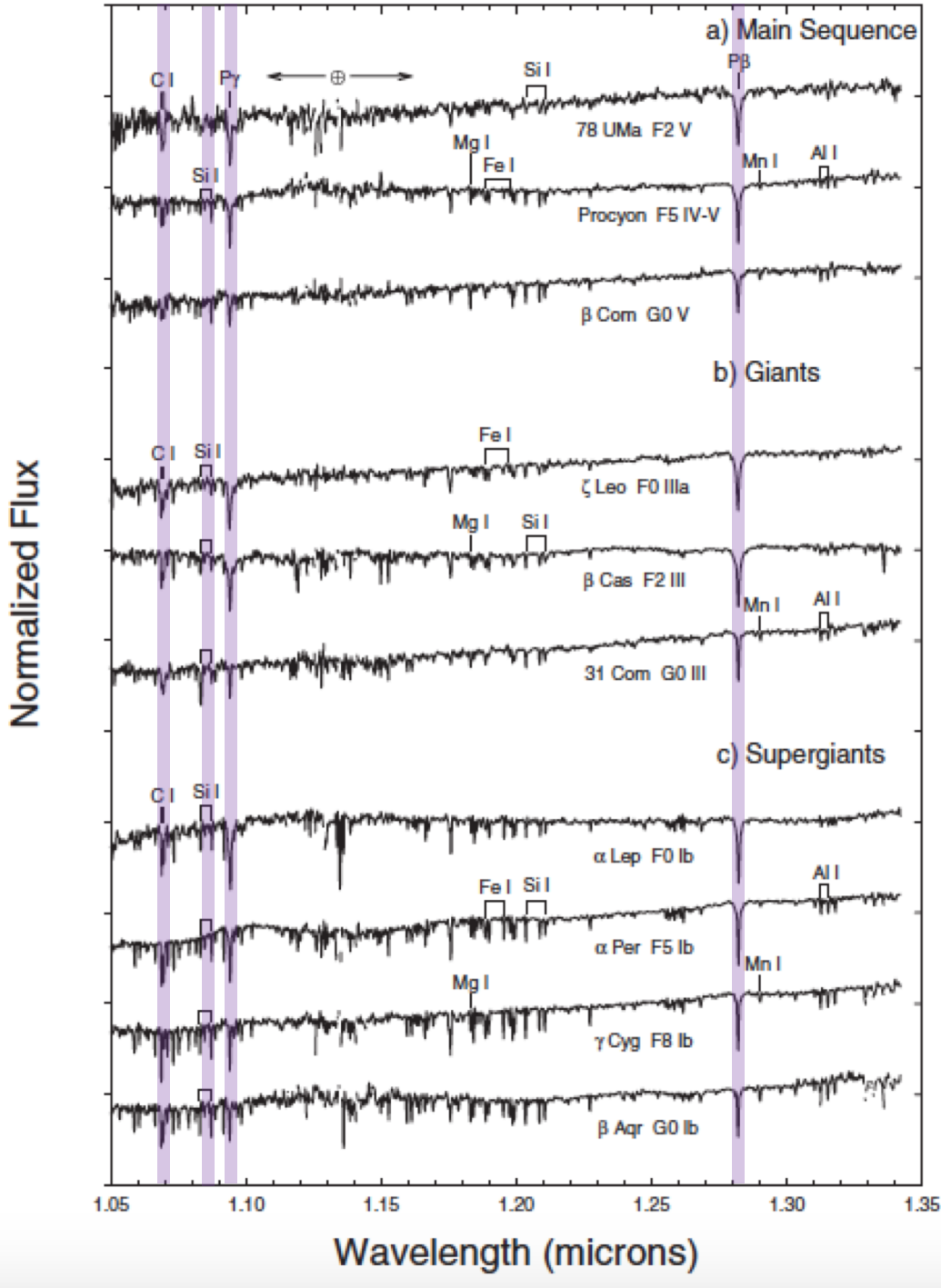
- ★ Luminosity Criteria
  - ★ Paschen-series lines
    - ★ Good indicator, but loss of sensitivity in late types
  - ★ Ca II (λ8498-8662) triplet
    - ★ Overlap with higher Paschen lines
    - ★ Hard to distinguish between dwarfs and giants
  - ★ Classification "dead zone"
    - ★ Lack of both temperature and luminosity sensitivity F5-G0 → Dwarf? Giant??


P20
P19
P18
O I
P17
Ca II
P16
Ca II
P15
P14
N I
Ca II
P13
N I
P12
φ Cas F0 Ia
α Lep F0 Ib
ζ Leo F0 IIIa
ρ Gem F0 V+
Rectified Intensity
8400
8450
8500
8550
8600
8650
8700
8750
Wavelength (Å)


Fe I
P19
P18
O I
P17
Ca II
P16
Fe I
Ca II
P15
Si I
P14
Fe I
Si I
Ca II
P13
S I
Si I
Fe I
S I
S I
Mg I
P12
35 Cyg F6 Ib+
HR 6577 F6 III-IV
HD 27534 F5 V
Rectified Intensity
8400
8450
8500
8550
8600
8650
8700
8750
Wavelength (Å)

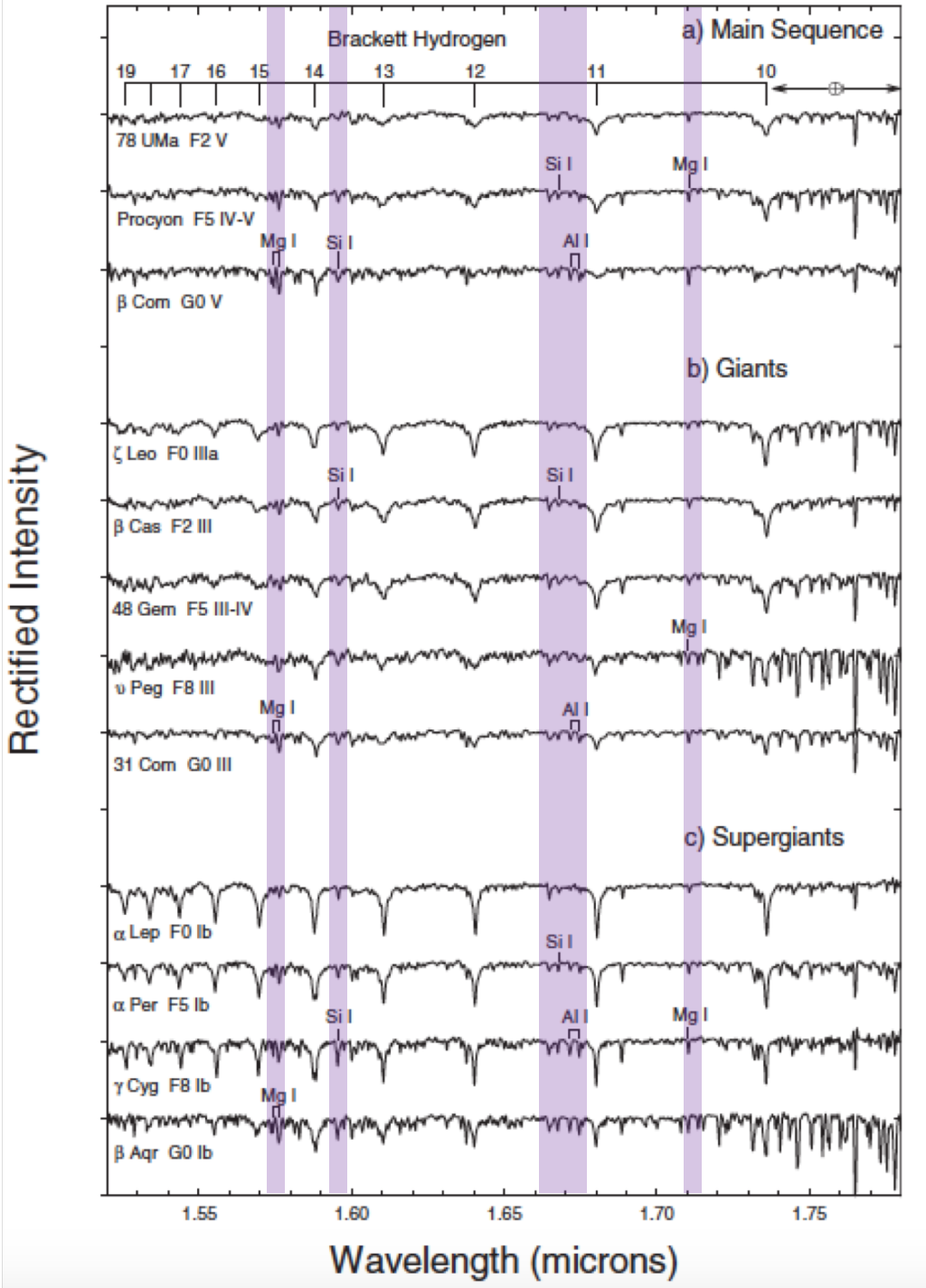
F-types in the IR

- ★ J-band (1.05–1.34μm)
  - ★ Paschen β & γ
  - ★ Ca I & Si I
  - ★ Metal lines



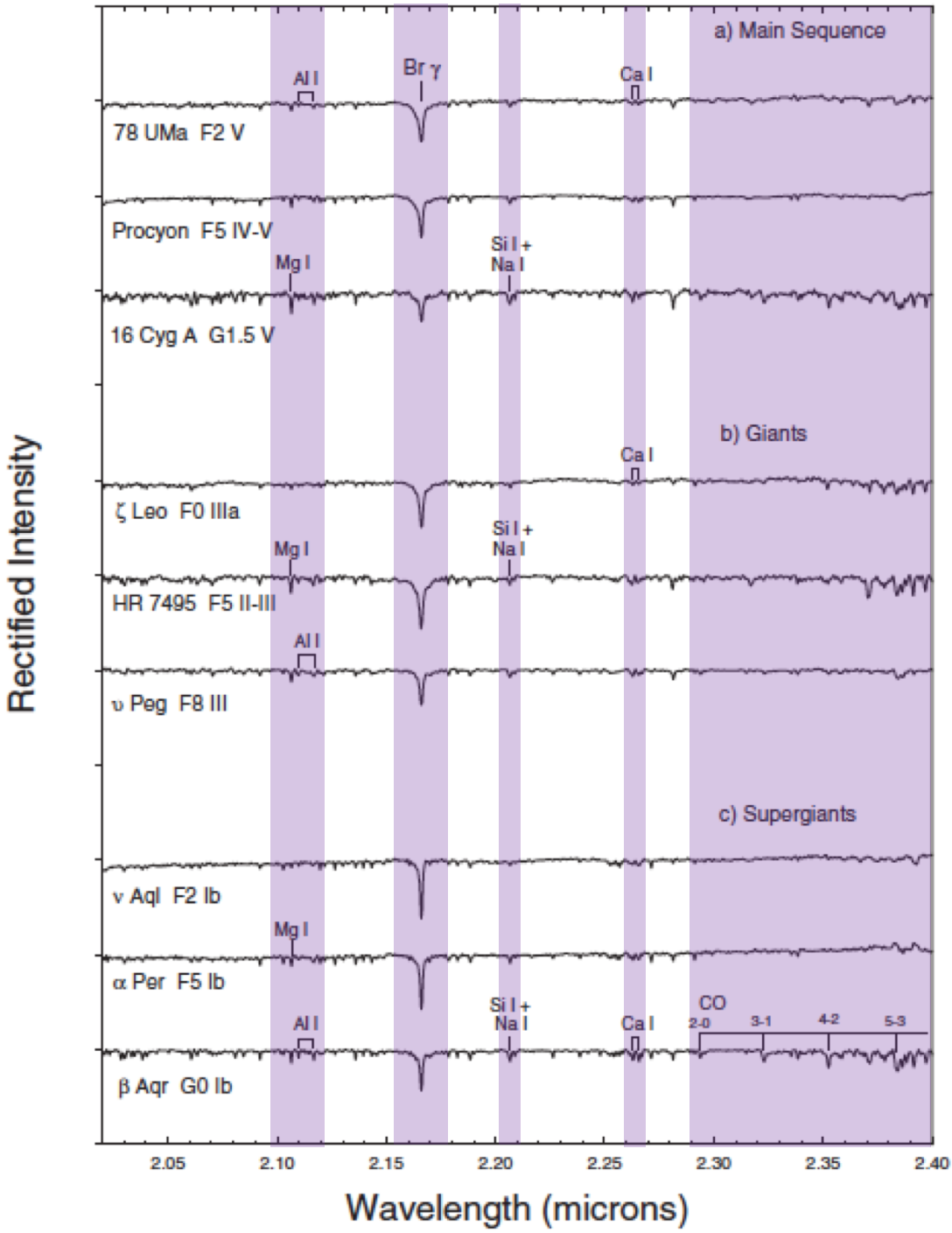
F-types in the IR

- ★ H-band (1.55–1.75μm)
  - ★ Brackett-line series
  - ★ Neutral Metals
    - ★ Si I, Al I, Mg I



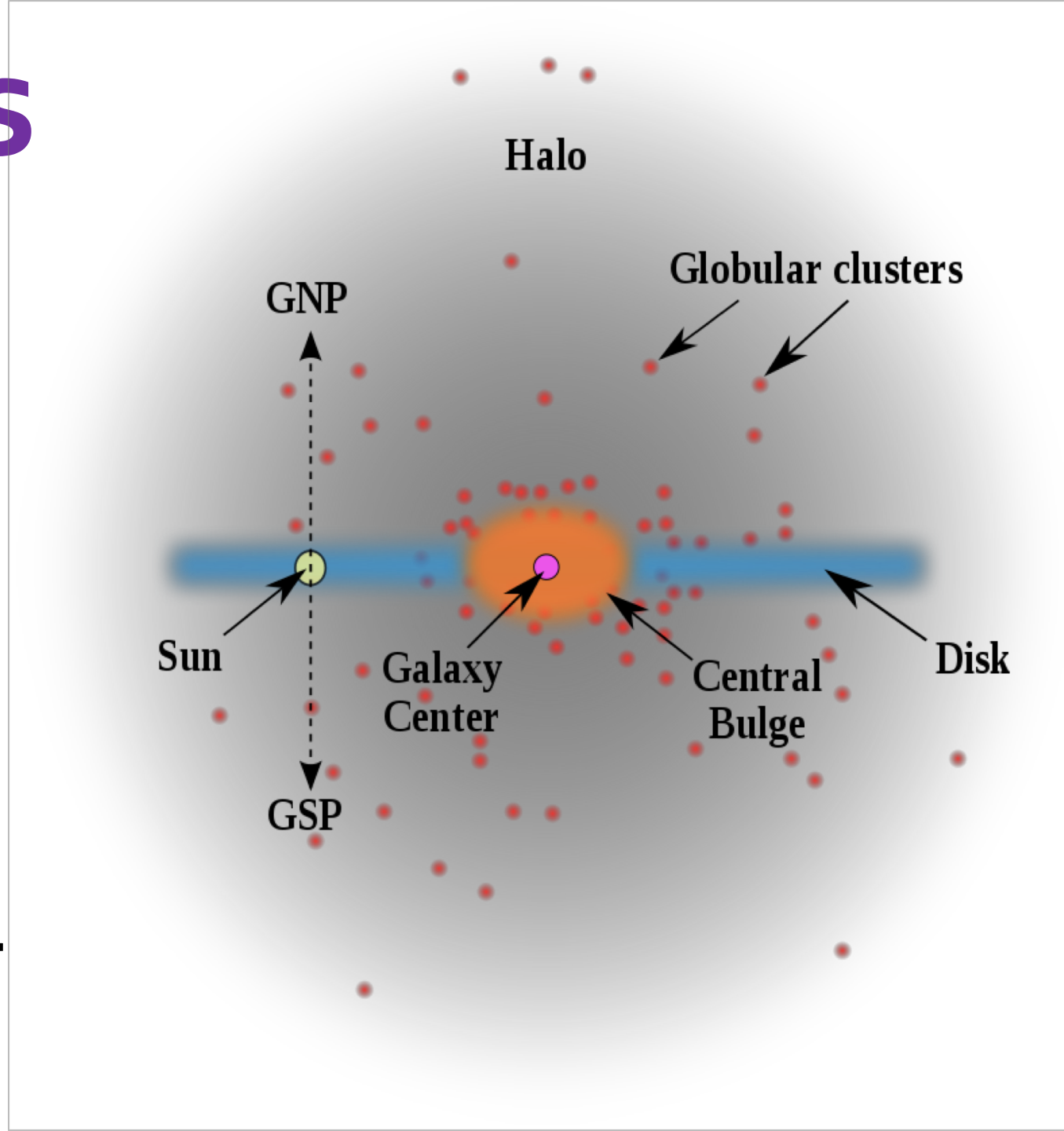
F-types in the IR

- ★ K-band (2.0–2.4μm)
  - ★ Brackett γ
  - ★ Weak neutral metals
  - ★ CO bands



Pop II F-types

- ★ Baade - 1944
  - ★ Population I
    - ★ Disk stars
    - ★ Young, metal rich
    - ★ Lower velocities
  - ★ Population II
    - ★ Halo stars
    - ★ Older, metal poor
    - ★ Higher velocities

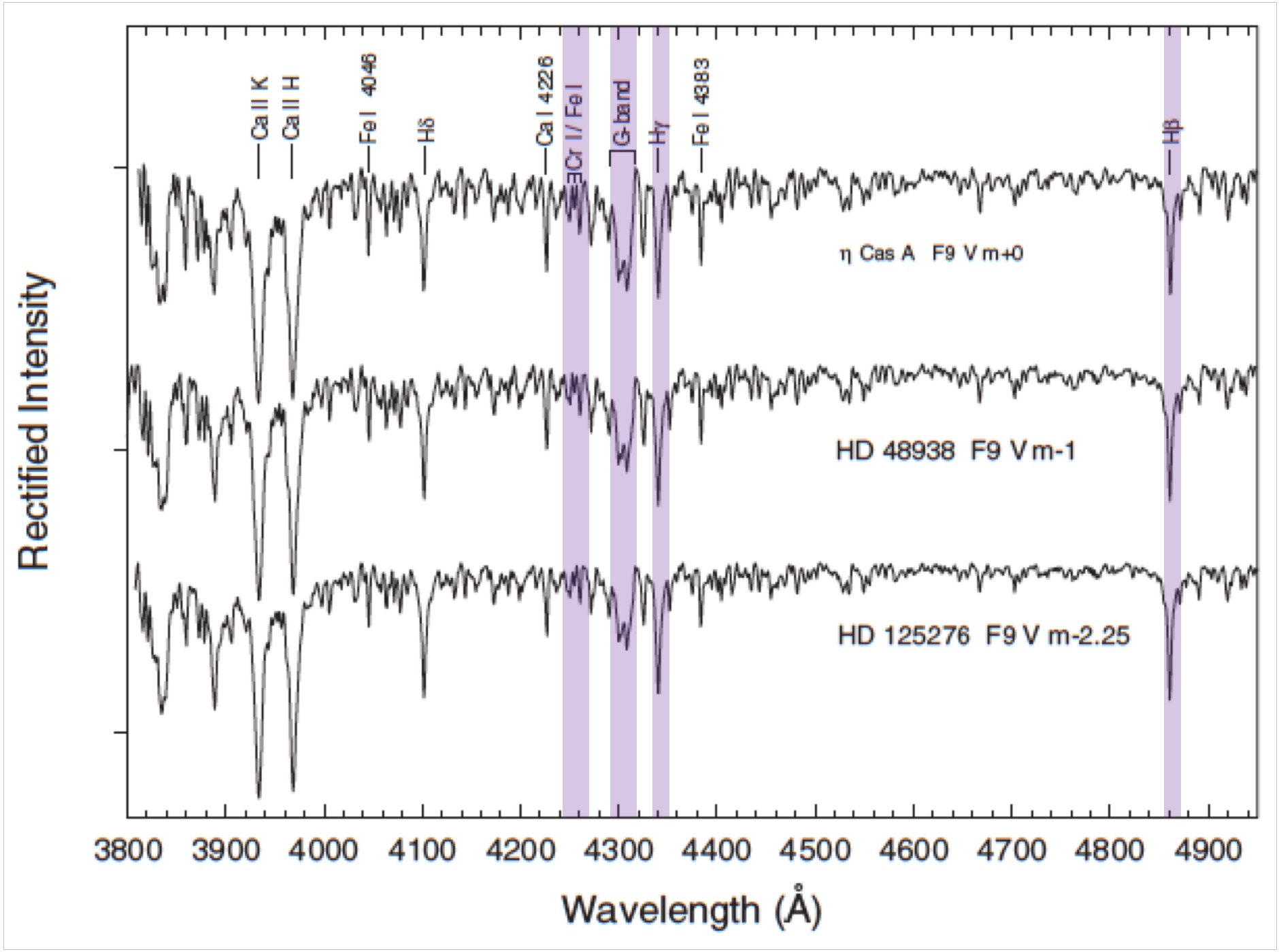


Intermediate Pop II F-types

- ★ Nancy Roman – 1950+
  - ★ Strömgren – 1964, Bond – 1970, Houk – 1975+ , Olsen 1983+, Abt 1986
- ★ Corbally – 1987
  - ★ Fe= –0.13Δ – 0.26
  - ★ Cr I (λ4254, 4275, 4290) triplet resonance with Fe I (λ4250, 4260, 4326) triplet
- ★ Problem: Who is doing the ionizing?

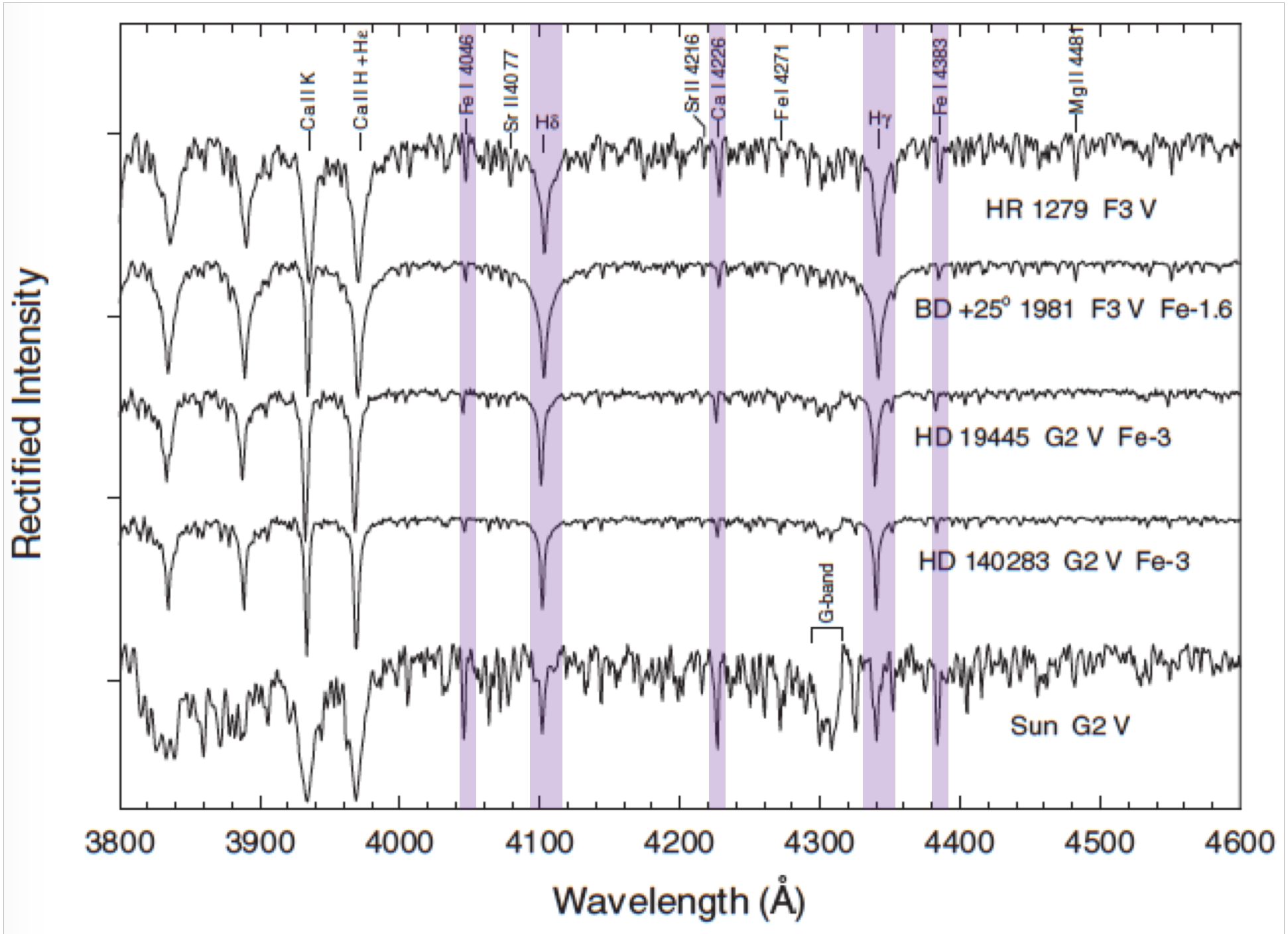
Intermediate Pop II F-types

- ★ Gray 1989
  - ★ Small collection of metal-weak standards
  - ★ Cr I/ Fe I and G-band
  - ★ m ± # (similar to Strömgren system)
  - ★ Need more metal weak standards
- ★ Metal weak >F5 (usually)
- ★ Field Blue Stragglers (FBS)

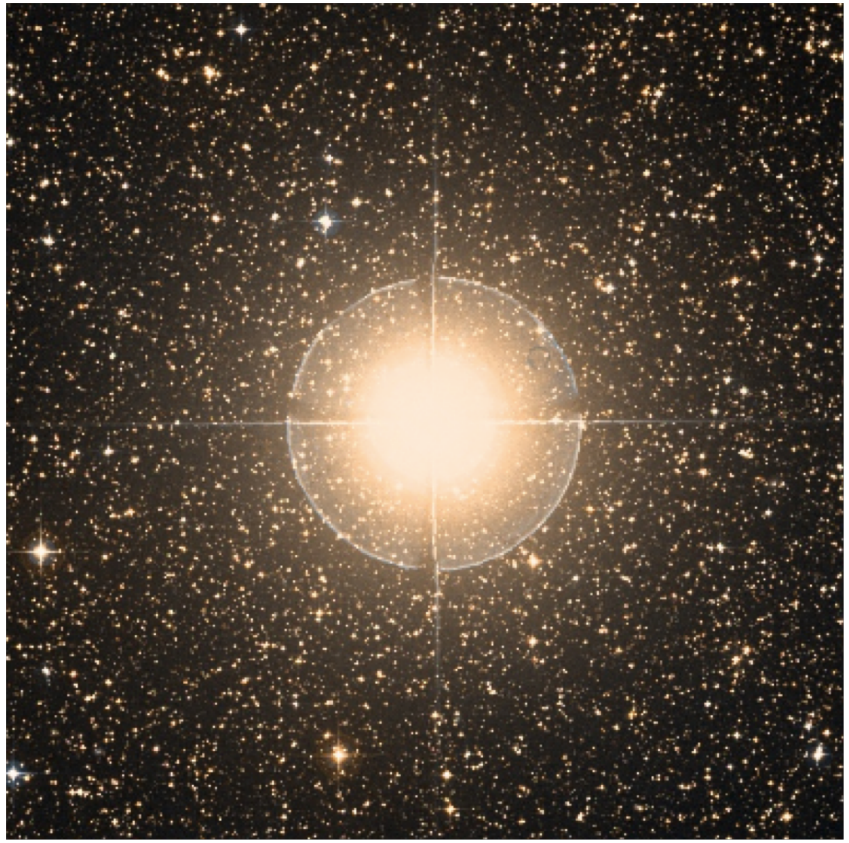

Rectified Intensity
Ca II K
Ca II H
Fe I 4046
Hδ
Ca I 4226
Cr I/ Fe I
G-band
Hγ
Fe I 4383
Hβ
η Cas A F9 V m+0
HD 48938 F9 V m-1
HD 125276 F9 V m-2.25
3800
3900
4000
4100
4200
4300
4400
4500
4600
4700
4800
4900
Wavelength (Å)

F-type Halo Dwarfs

- ★ Adams & Joy – 1922
  - ★ "Intermediate white dwarfs"
  - ★ Between MS and WD sequence
- ★ Roman – 1954
  - ★ No. MS or "turn-off stars" – NOT SUBDWARFS!
  - ★ Very metal-weak, large UV excess
  - ★ Correcting for line blanketing and reddening brings the to proper spot on MS


Rectified Intensity
Ca II K
Ca II H +Hε
Fe I 4046
Sr II 4077
Hδ
Sr II 4216
Ca I 4226
Fe I 4271
Hγ
Fe I 4383
Mg II 4481
HR 1279 F3 V
BD +25° 1981 F3 V Fe-1.6
HD 19445 G2 V Fe-3
HD 140283 G2 V Fe-3
G-band
Sun G2 V
3800
3900
4000
4100
4200
4300
4400
4500
4600
Wavelength (Å)

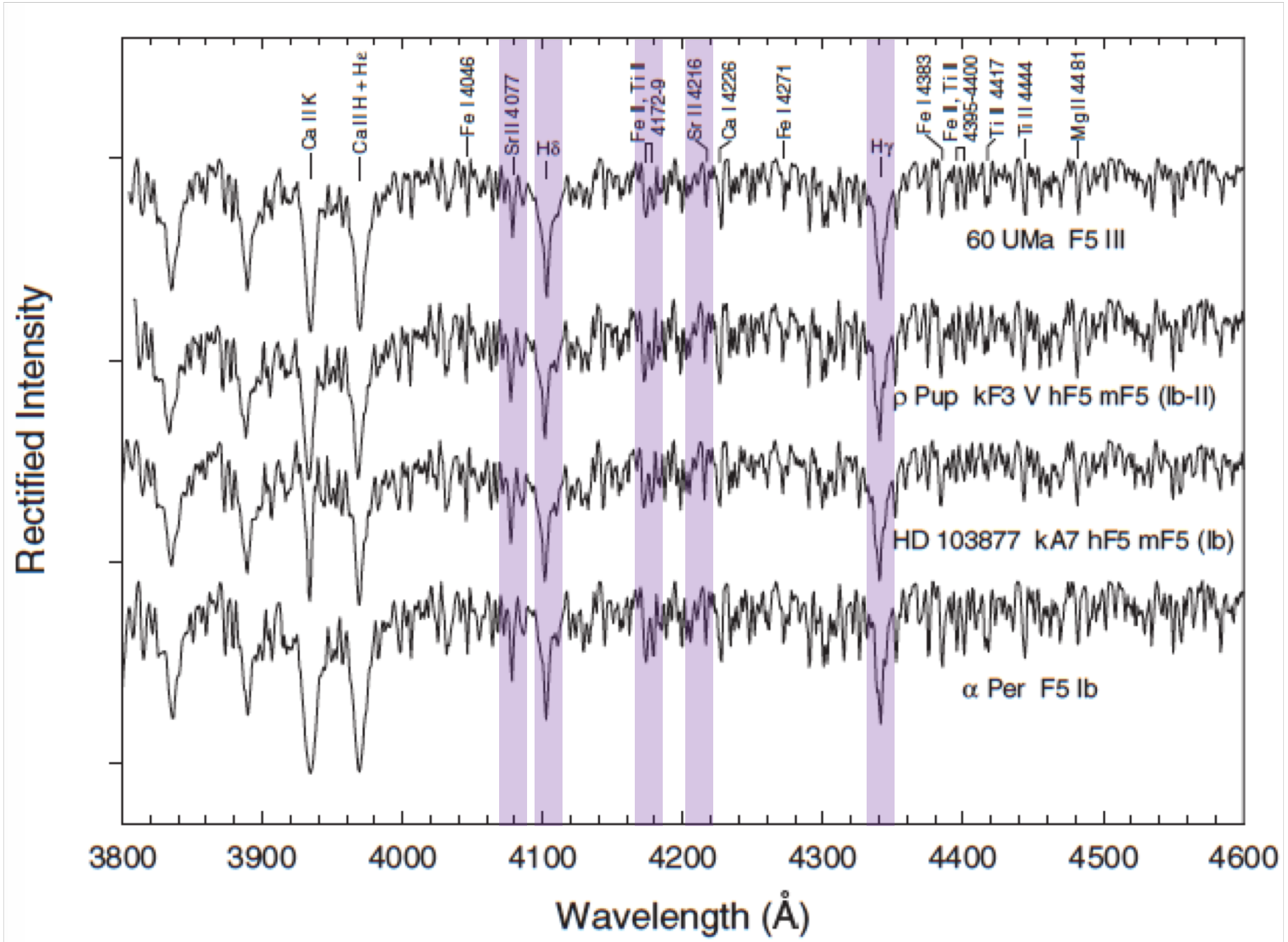
Oddball F-types



- ρ Puppis stars
  - Late type Am stars
  - H lines ~ F5
  - Luminosity types - II–III to Ib
    - Fe II/Ti II (λ4172–9) and Sr II (λ4077/4216)

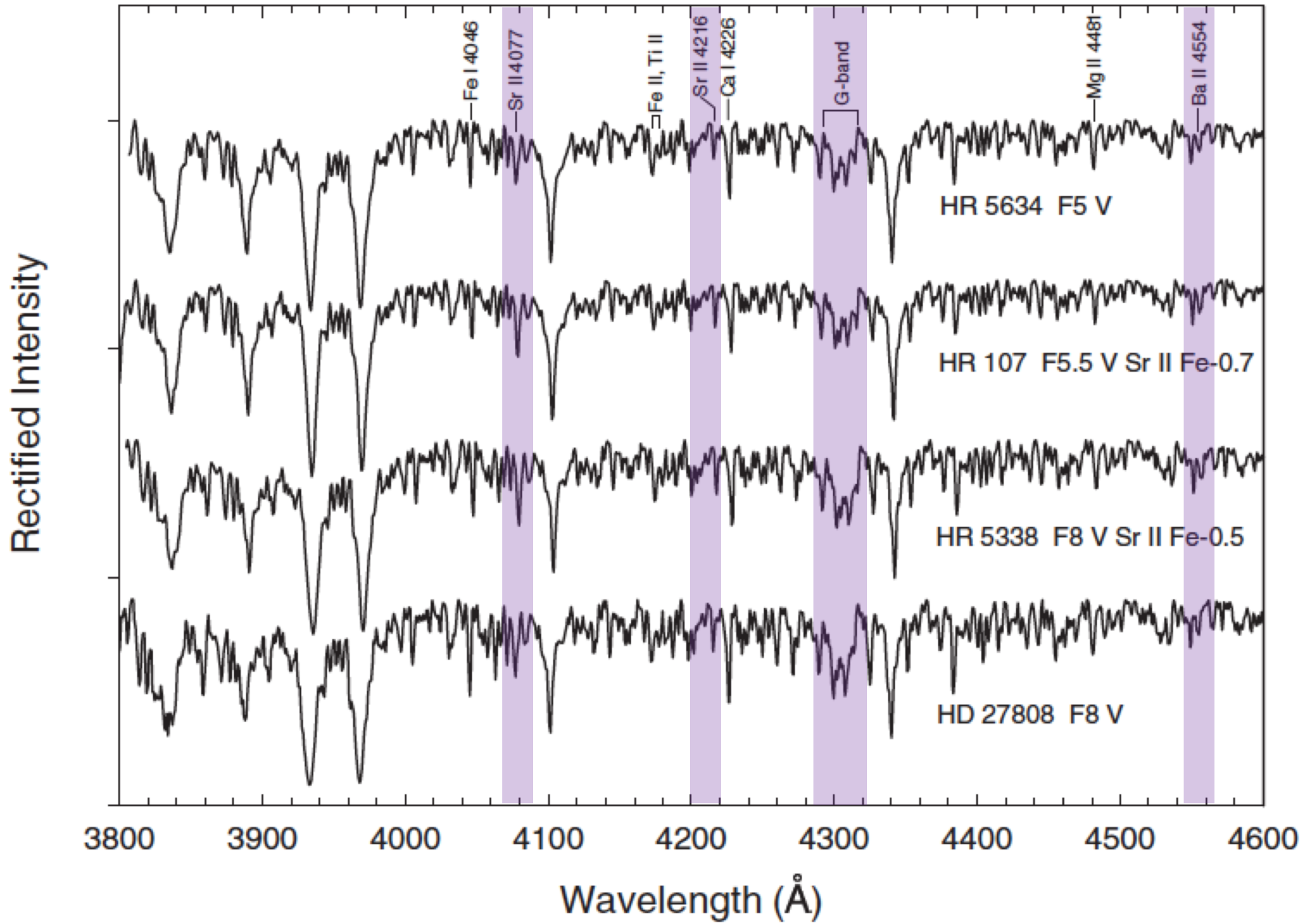
Oddball F-types

- ρ Puppis stars
  - δ Scuti pulsator
  - Settled He in Am atmosphere means no He convection zone
  - δ Scuties need He ionization in He convection zone to pulsate
  - ρ Pups were Am stars during time on MS and have now evolved


Rectified Intensity
Wavelength (Å)
3800
3900
4000
4100
4200
4300
4400
4500
4600
Ca II K
Ca II H + Hε
Fe I 4046
Sr II 4077
Hδ
Fe I, Ti II 4172-9
Sr II 4216
Ca I 4226
Fe I 4271
Hγ
Fe I 4383
Fe I, Ti II 4395-4400
Ti II 4417
Ti II 4444
Mg II 4481
60 UMa F5 III
ρ Pup kF3 V hF5 mF5 (Ib-II)
HD 103877 kA7 hF5 mF5 (Ib)
α Per F5 Ib

Abundance Oddballs

- ★ λ4077 (Sr II) Strong Stars
  - ★ Not Ap St stars – temperature classification between F5 and early G-types
  - ★ ρ Pups! (late Am types)
  - ★ Overabundance of s-process elements
    - ★ Barium Dwarfs
  - ★ Typically metal weak, can have G-band peculiarities

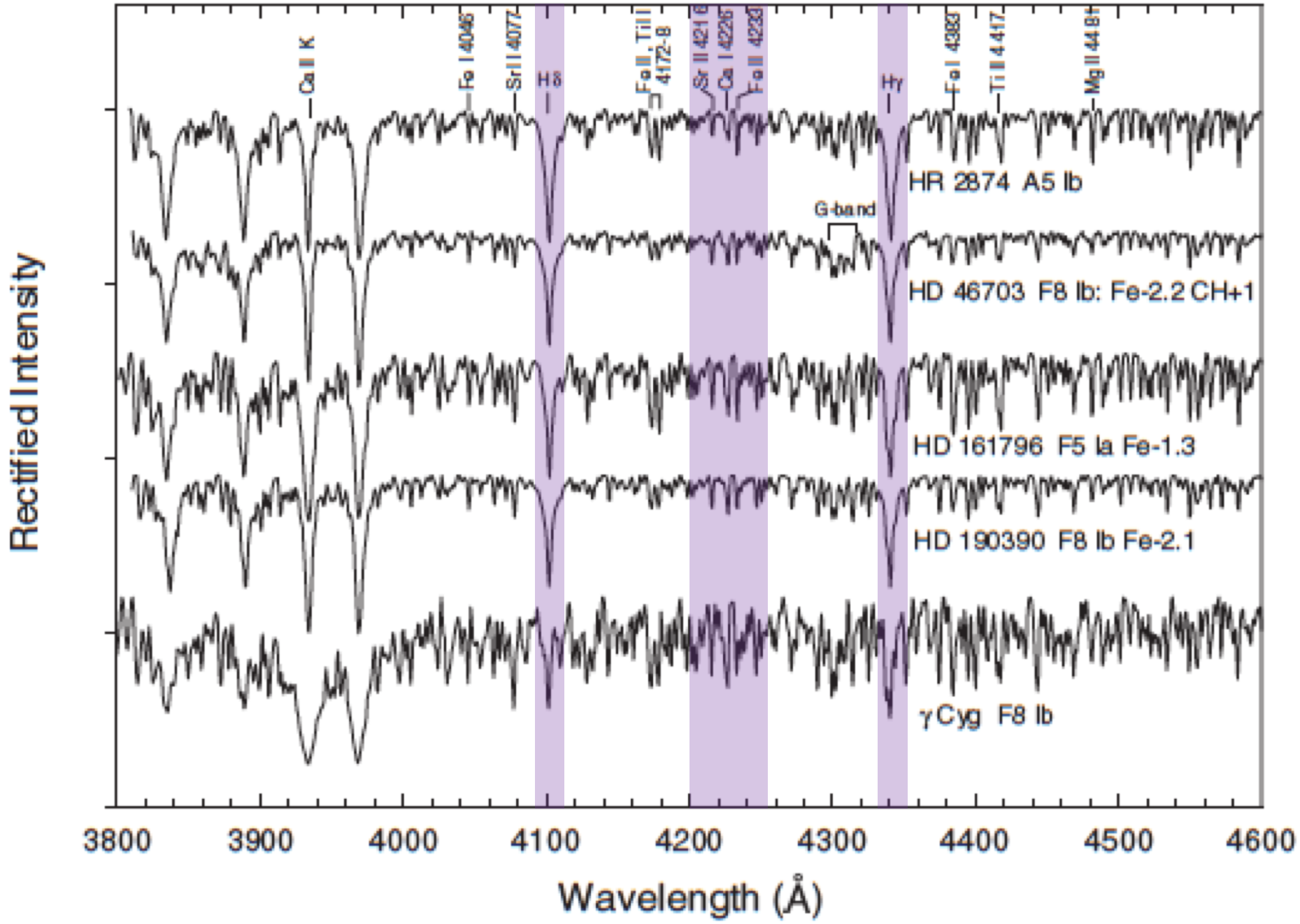

Fe I 4046
Sr II 4077
Fe II, Ti II
Sr II 4216
Ca I 4226
G-band
Mg II 4481
Ba II 4554
HR 5634 F5 V
HR 107 F5.5 V Sr II Fe-0.7
HR 5338 F8 V Sr II Fe-0.5
HD 27808 F8 V
Rectified Intensity
3800
3900
4000
4100
4200
4300
4400
4500
4600
Wavelength (Å)

Oddball F-types

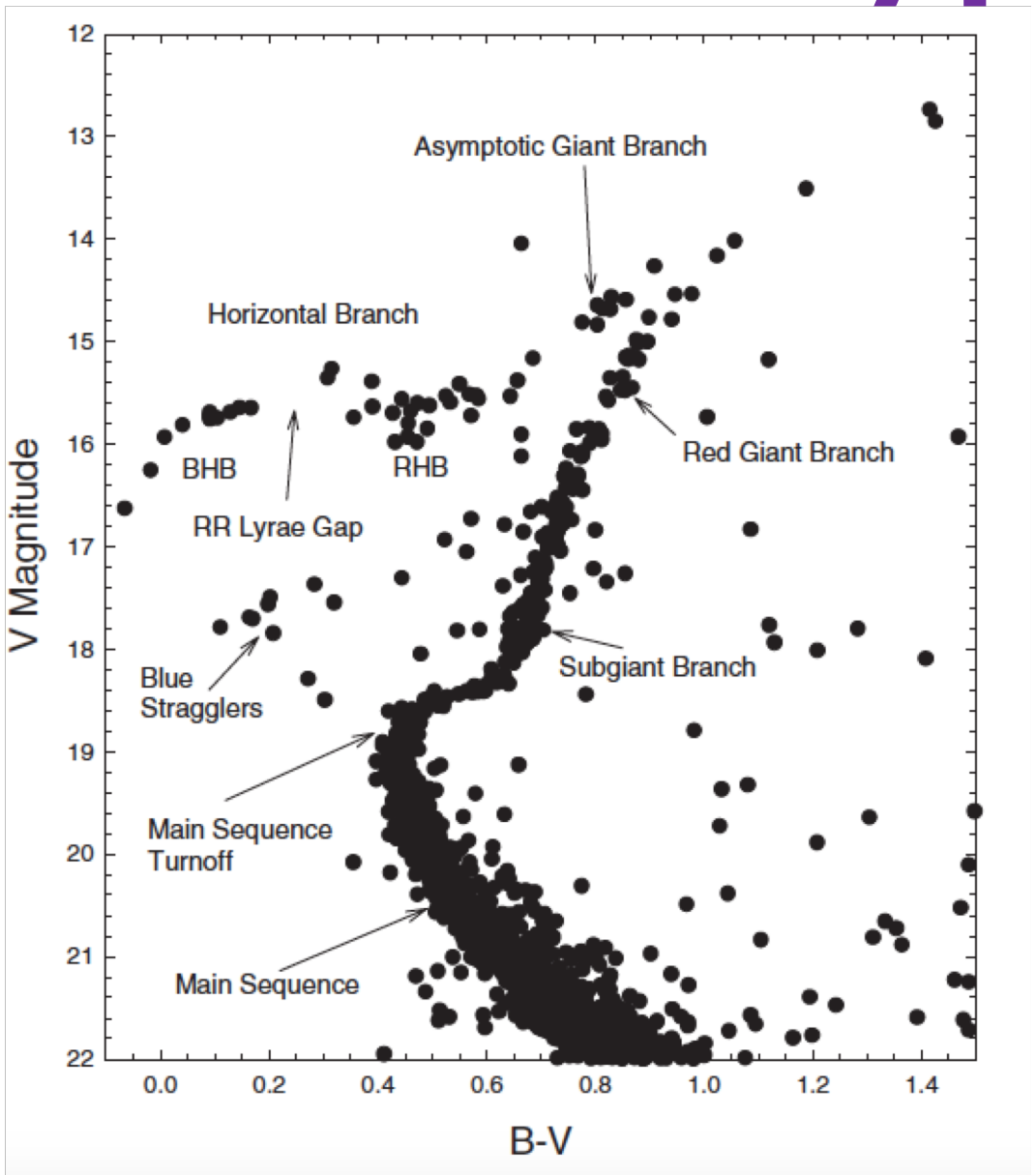
- ★ High Latitude F-type Supergiants
  - ★ Majority of SG are Pop I and in thin disk
  - ★ Oddballs living at high latitudes:
    - ★ High velocities
    - ★ Low metallicities
    - ★ Photometrically and spectroscopically variable

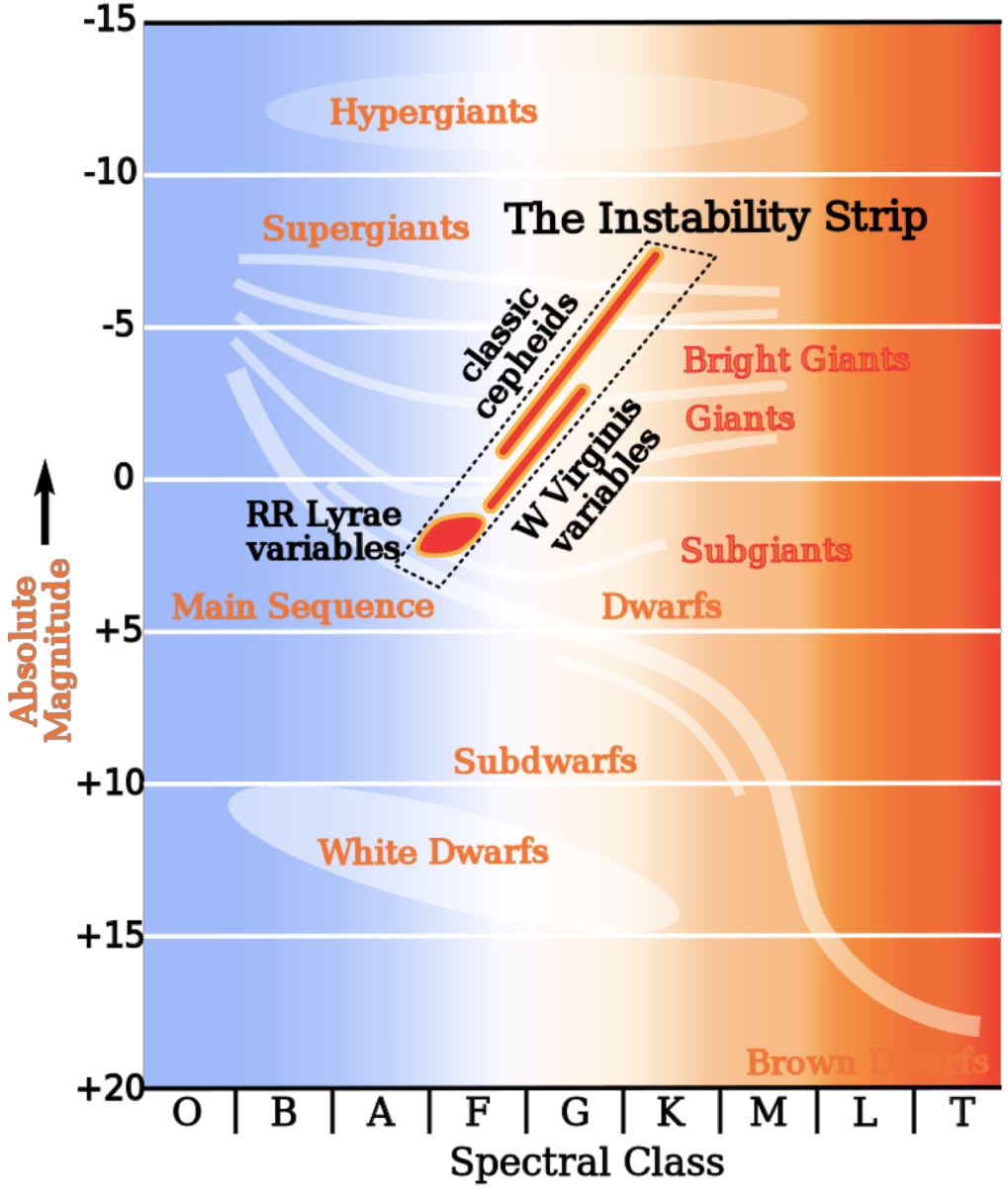
Oddball F-types

- ★ High Latitude F-type Supergiants
  - ★ How did they get there?
    - ★ Ejected (e.g. binary interaction)?
    - ★ Born that way?
    - ★ IMPOSTERS!!
      - ★ Low-mass, post-AGB Pop II stars


Ca II K
Fe I 4045
Sr II 4077
Hδ
Fe II, Ti II 4172-8
Sr II 4216
Ca I 4226
Fe II 4233
Hγ
Fe I 4383
Ti II 4417
Mg II 4481
G-band
HR 2874 A5 Ib
HD 46703 F8 Ib: Fe-2.2 CH+1
HD 161796 F5 Ia Fe-1.3
HD 190390 F8 Ib Fe-2.1
γ Cyg F8 Ib
Rectified Intensity
3800
3900
4000
4100
4200
4300
4400
4500
4600
Wavelength (Å)

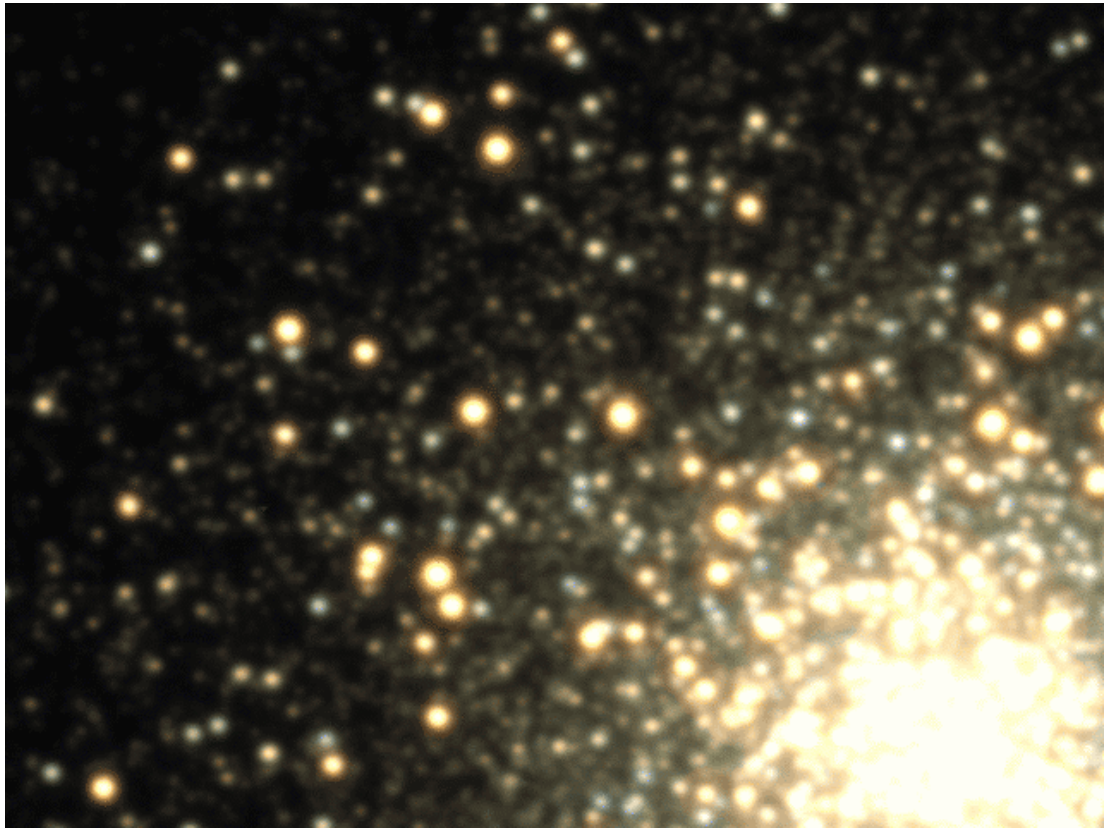
Evolved F-types



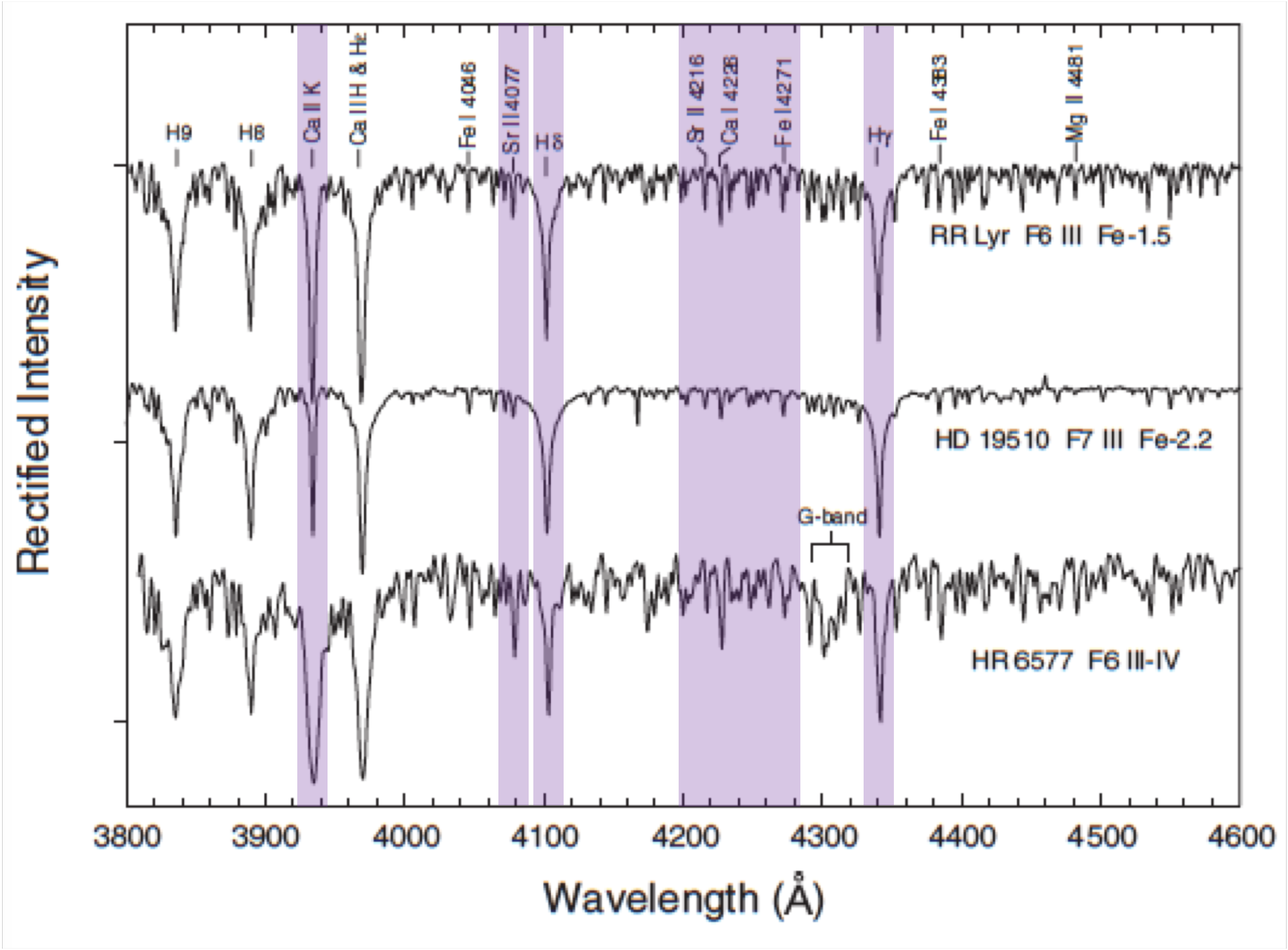


Evolved F-types

- ★ RR Lyrae
  - ★ Variable, no blue-violet peculiarities
  - ★ Metallicity varies
  - ★ ΔS – difference between Hydrogen and Ca II - K

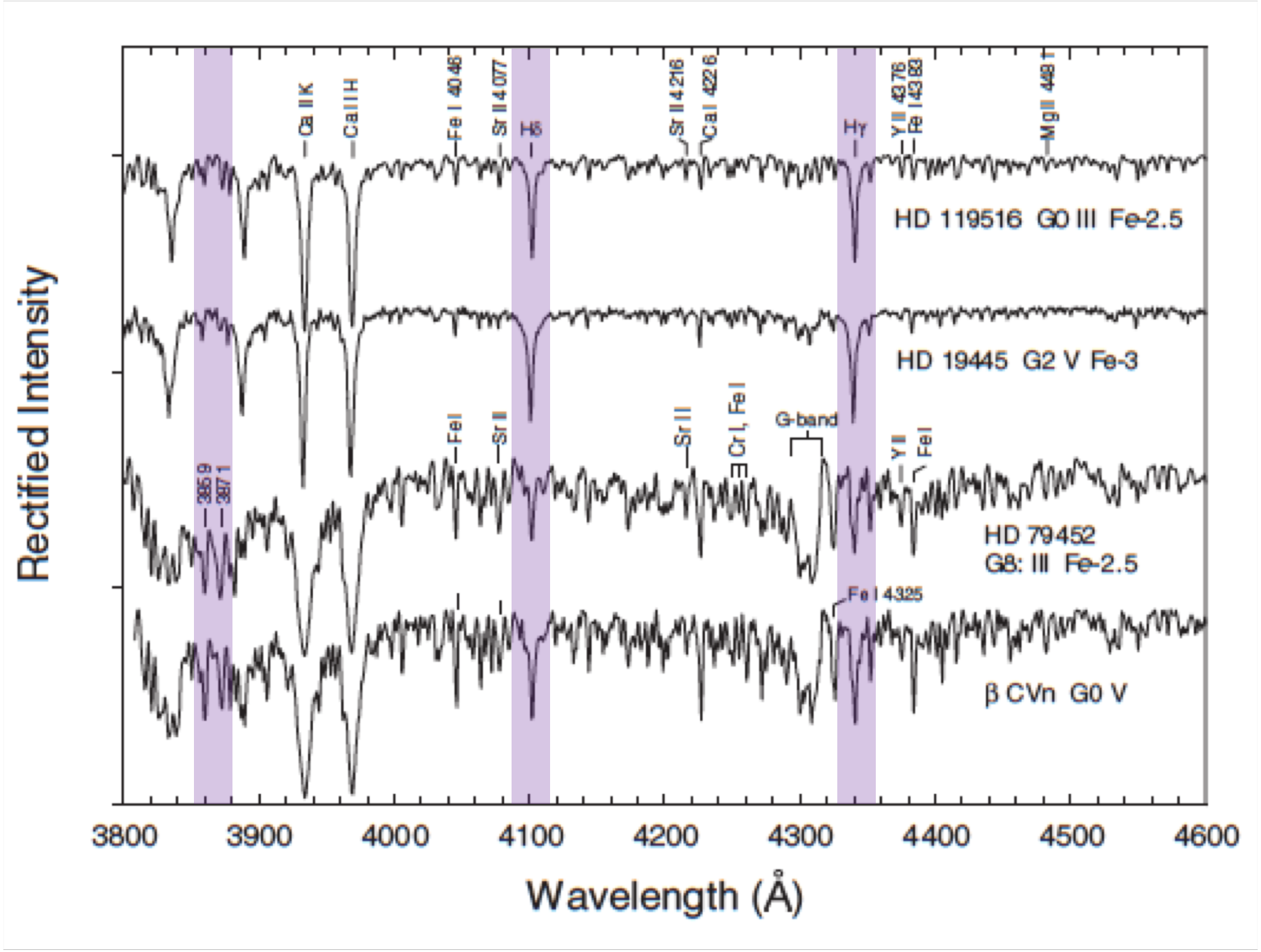


M3 Image credit: J.Hartman (Harvard CfA/K.Stanek (Ohio State)


Rectified Intensity
H9
H8
Ca II K
Ca II H & Hε
Fe I 4046
Sr II 4077
Hδ
Sr II 4216
Ca I 4226
Fe I 4271
Hγ
Fe I 4383
Mg II 4481
RR Lyr F6 III Fe-1.5
HD 19510 F7 III Fe-2.2
G-band
HR 6577 F6 III-IV
3800
3900
4000
4100
4200
4300
4400
4500
4600
Wavelength (Å)

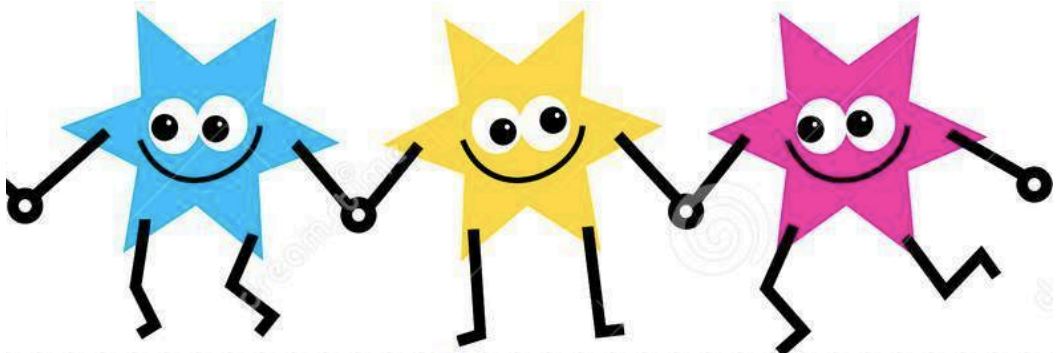
Evolved F-types

- ★ Red Horizontal Branch (RHB) stars
  - ★ Identified through intermediate band photometry
  - ★ Can't agree on classification
  - ★ If you try…
    - ★ Luminosity and metallicity rather than temperature
    - ★ λ3859/λ3871 features


Rectified Intensity
Wavelength (Å)
3800
3900
4000
4100
4200
4300
4400
4500
4600
Ca II K
Ca II H
Fe I 4046
Sr II 4077
Hδ
Sr II 4216
Ca I 4226
Hγ
Y II 4376
Fe I 4383
Mg II 4481
HD 119516 G0 III Fe-2.5
HD 19445 G2 V Fe-3
Fe I
Sr II
Sr II
Cr I, Fe I
G-band
Y II
Fe I
3859
3871
HD 79452
G8: III Fe-2.5
Fe I 4325
β CVn G0 V

Summary

- ★ Transition between atmospheres
- ★ Appearance of Pop II MS stars
- ★ Transitional temperature range
- ★ Transition between wavelengths
- ★ Appearance of molecular lines



Questions?