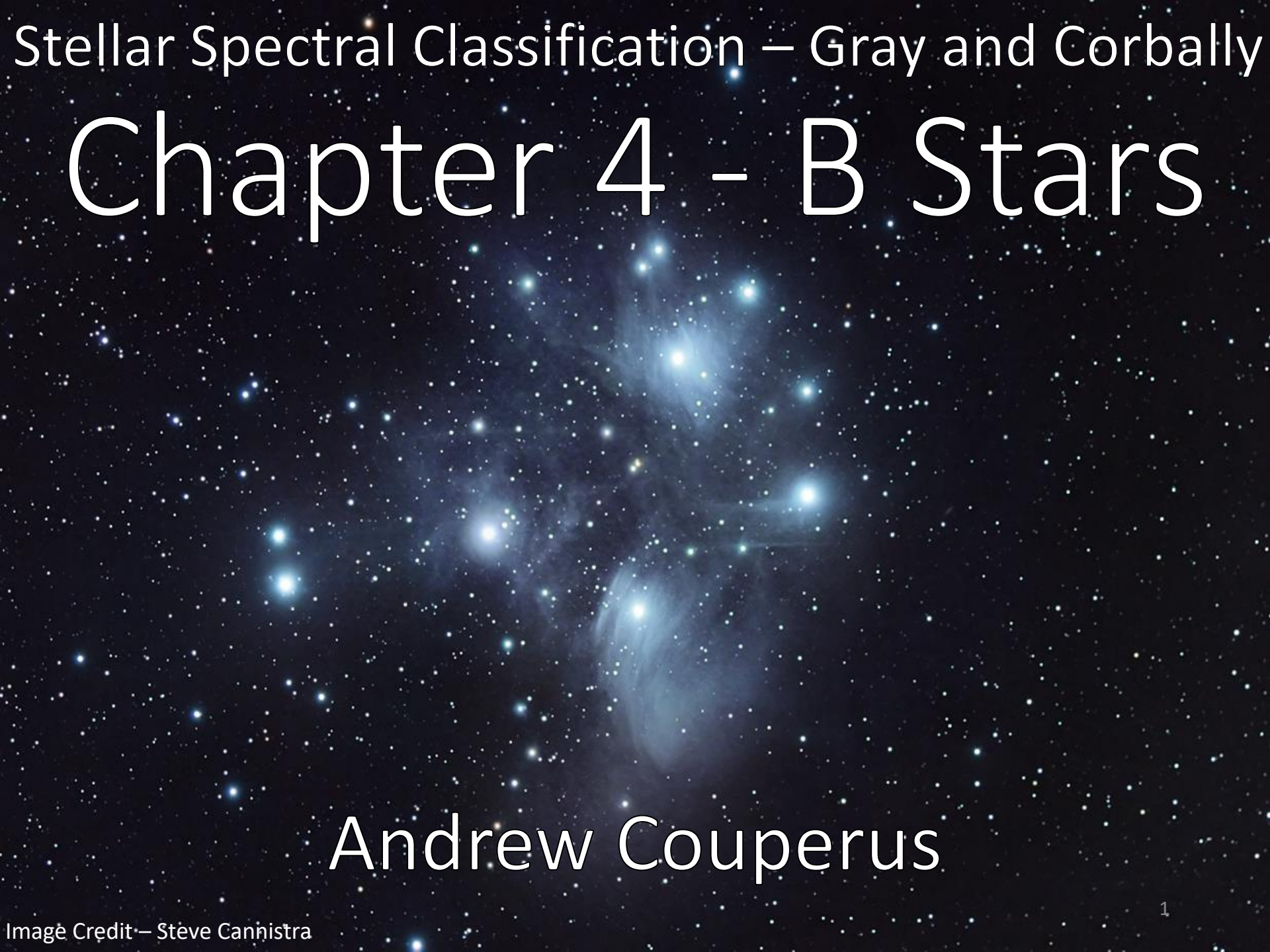
Stellar Spectral Classification – Gray and Corbally

Chapter 4 - B Stars

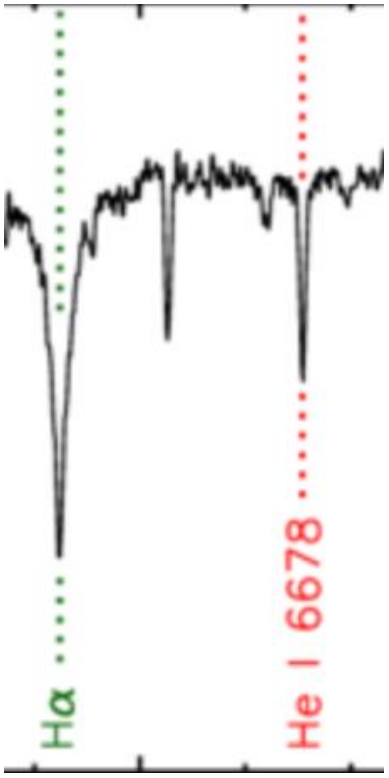


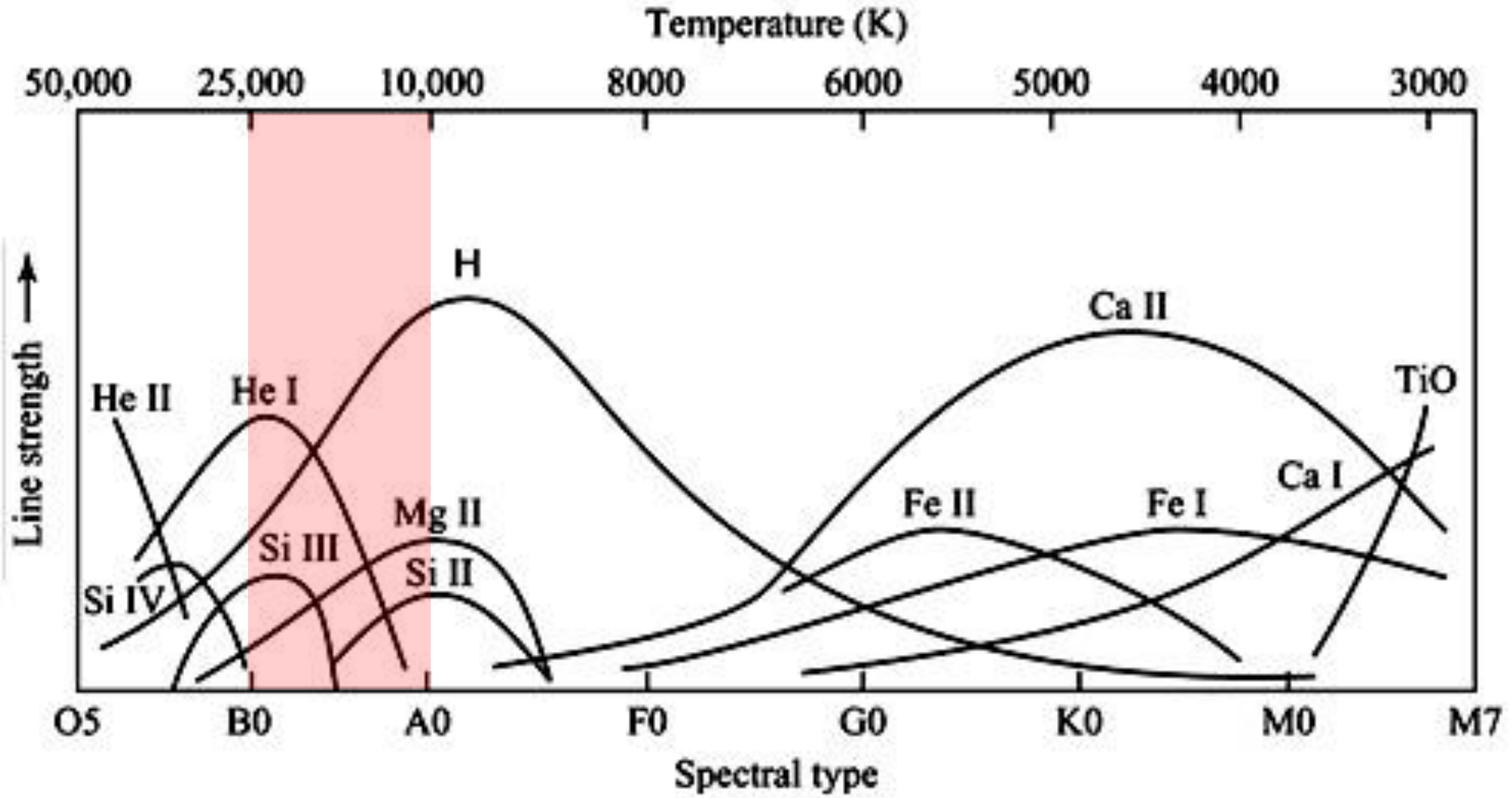
Andrew Couperus

Image Credit – Steve Cannistra

Classification - Temperature

- He I lines (B2 max)
- Strengthening H Balmer lines

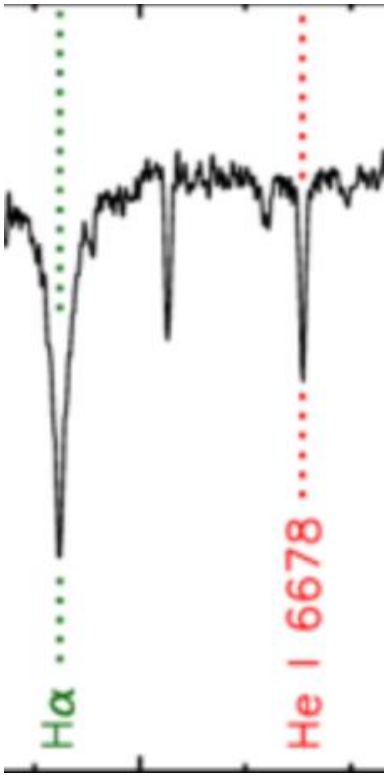


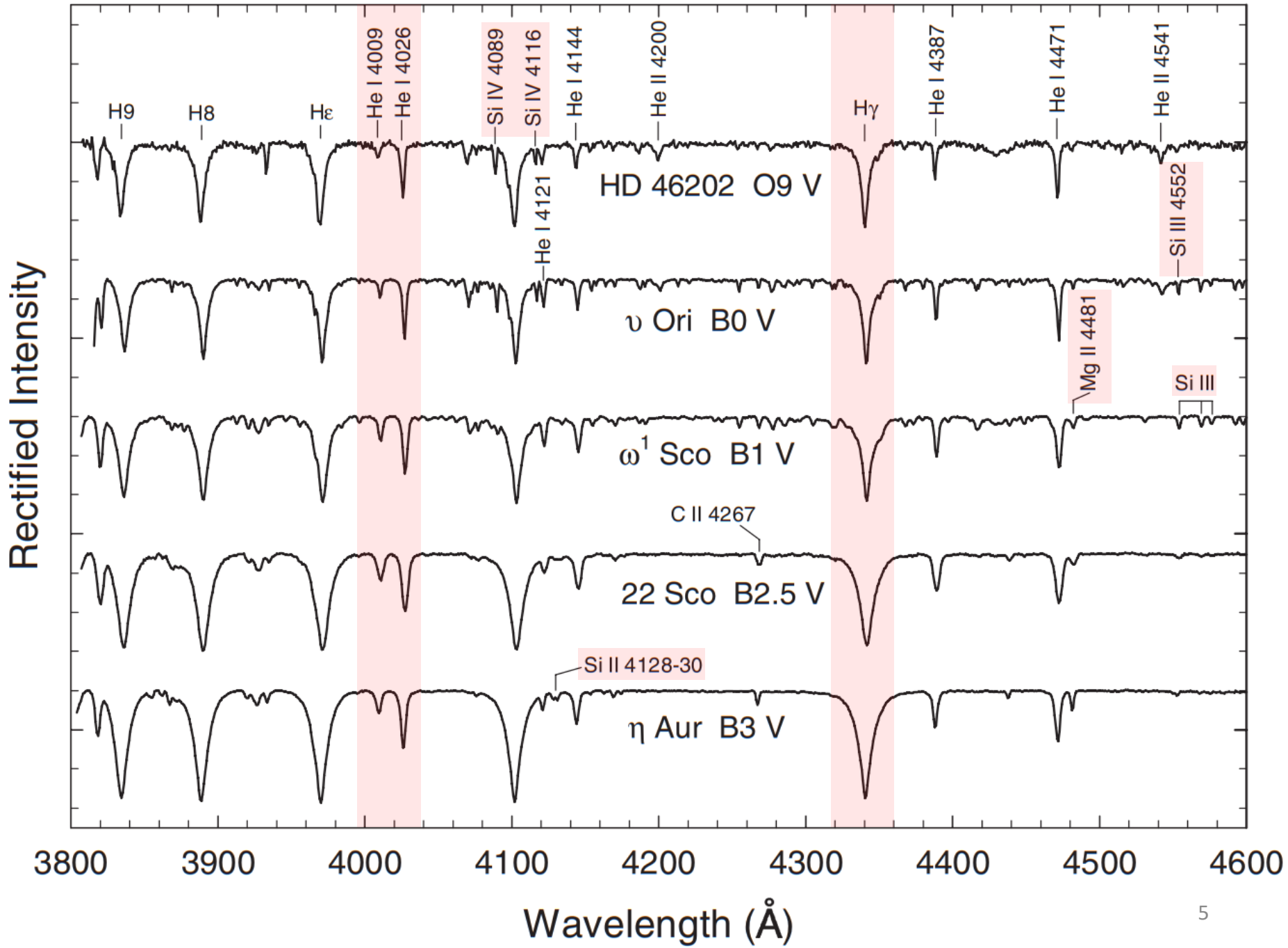


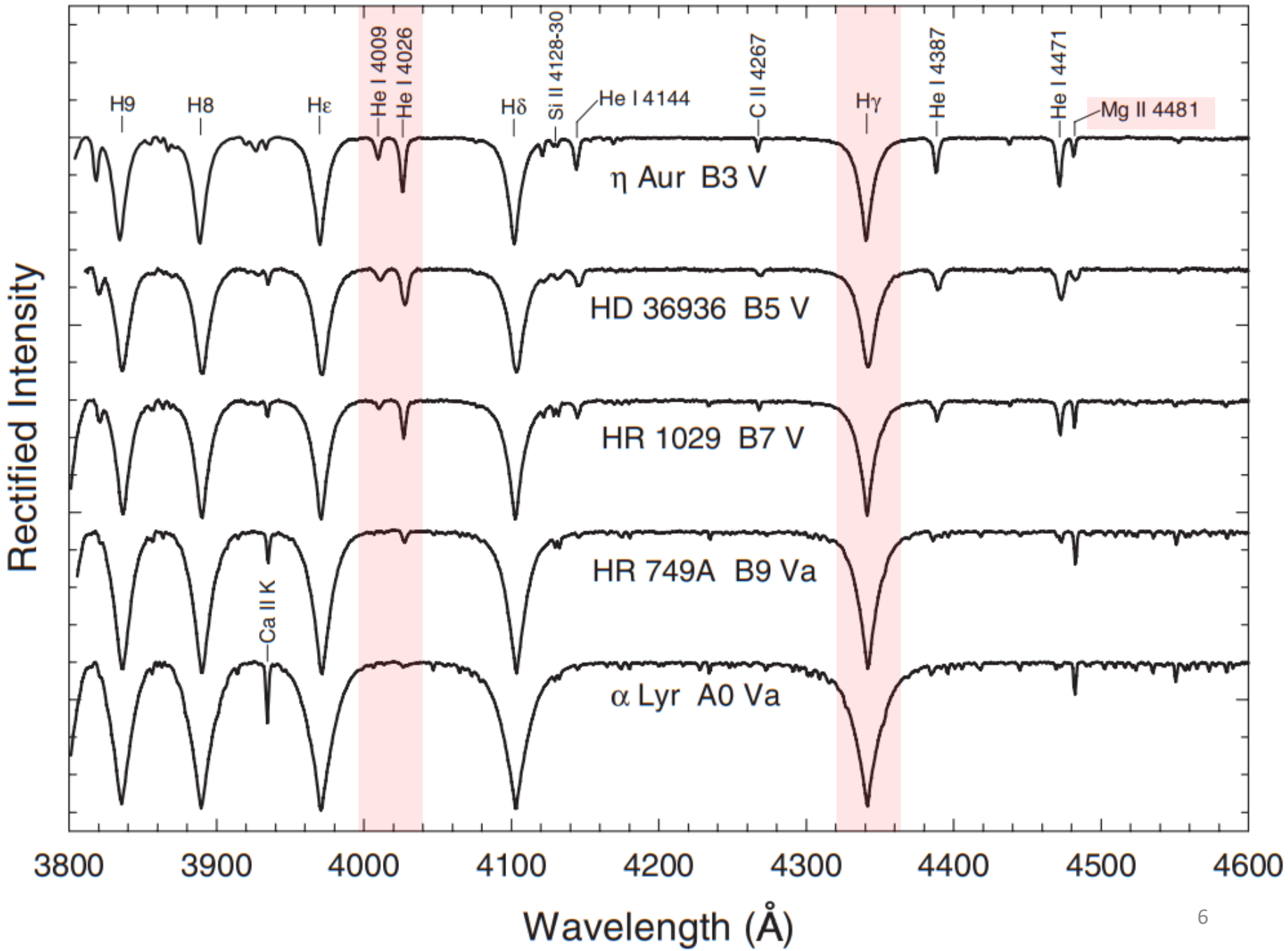
25,000K <-> 10,000K

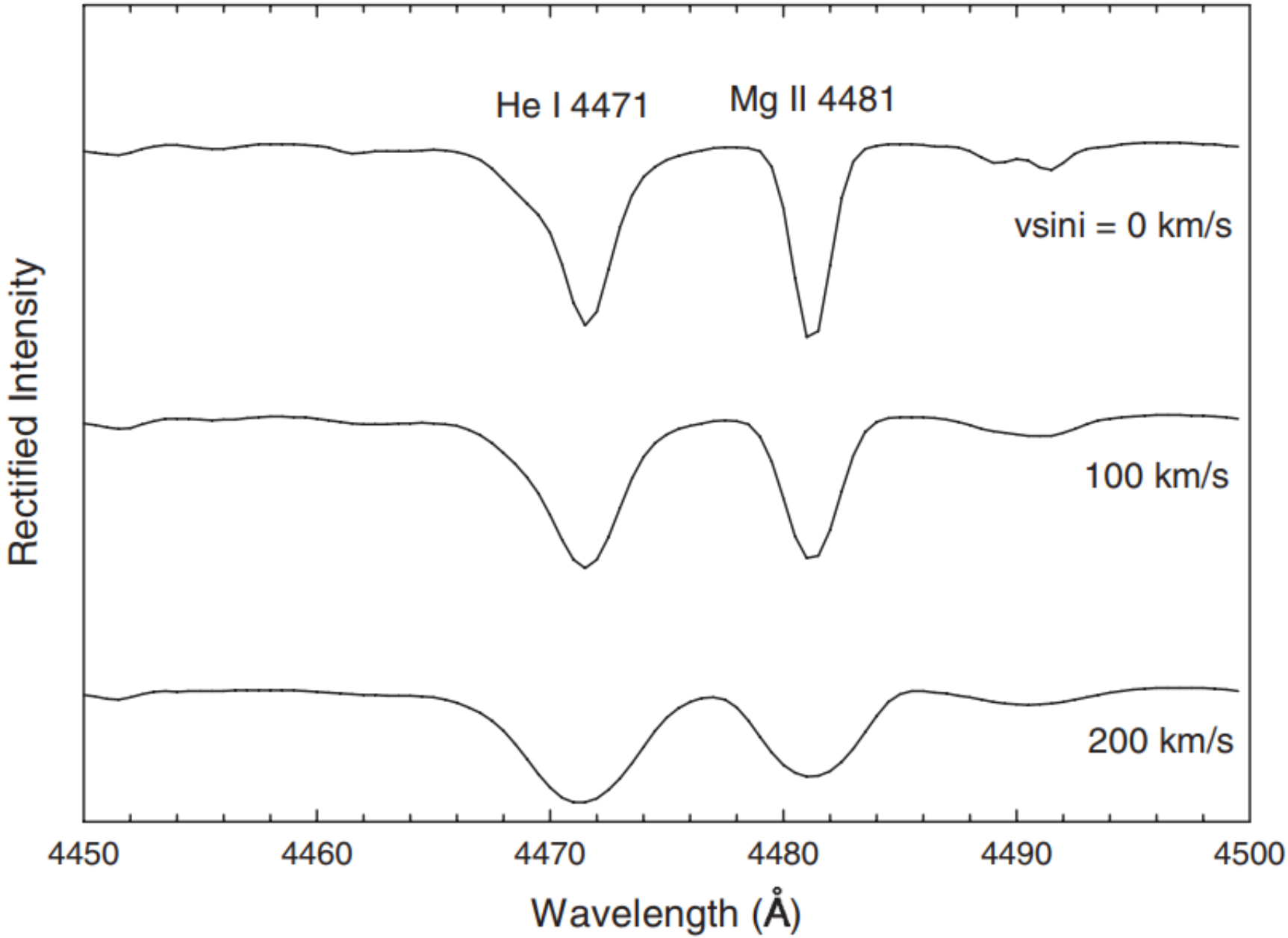
Classification - Temperature

- He I lines (B2 max)
- Strengthening H Balmer lines
- He anomalies
- Si II + Si III + Si IV
  - B0-B3 Temp diagnostic
- Mg II + He I
  - >B3 Temp diagnostic
- Broadening mechanisms
  - Classification degeneracy




H9
H8
Hε
He I 4009
He I 4026
Si IV 4089
Si IV 4116
He I 4121
He I 4144
He II 4200
Hγ
He I 4387
He I 4471
He II 4541
Si III 4552
HD 46202 O9 V
υ Ori B0 V
Mg II 4481
Si III
ω¹ Sco B1 V
C II 4267
22 Sco B2.5 V
Si II 4128-30
η Aur B3 V
Rectified Intensity
3800
3900
4000
4100
4200
4300
4400
4500
4600
Wavelength (Å)


H9
H8
Hε
He I 4009
He I 4026
Hδ
Si II 4128-30
He I 4144
C II 4267
Hγ
He I 4387
He I 4471
Mg II 4481
η Aur B3 V
HD 36936 B5 V
HR 1029 B7 V
HR 749A B9 Va
Ca II K
α Lyr A0 Va
Rectified Intensity
3800
3900
4000
4100
4200
4300
4400
4500
4600
Wavelength (Å)


He I 4471
Mg II 4481
vsini = 0 km/s
100 km/s
200 km/s
Rectified Intensity
4450
4460
4470
4480
4490
4500
Wavelength (Å)

Luminosity Classes

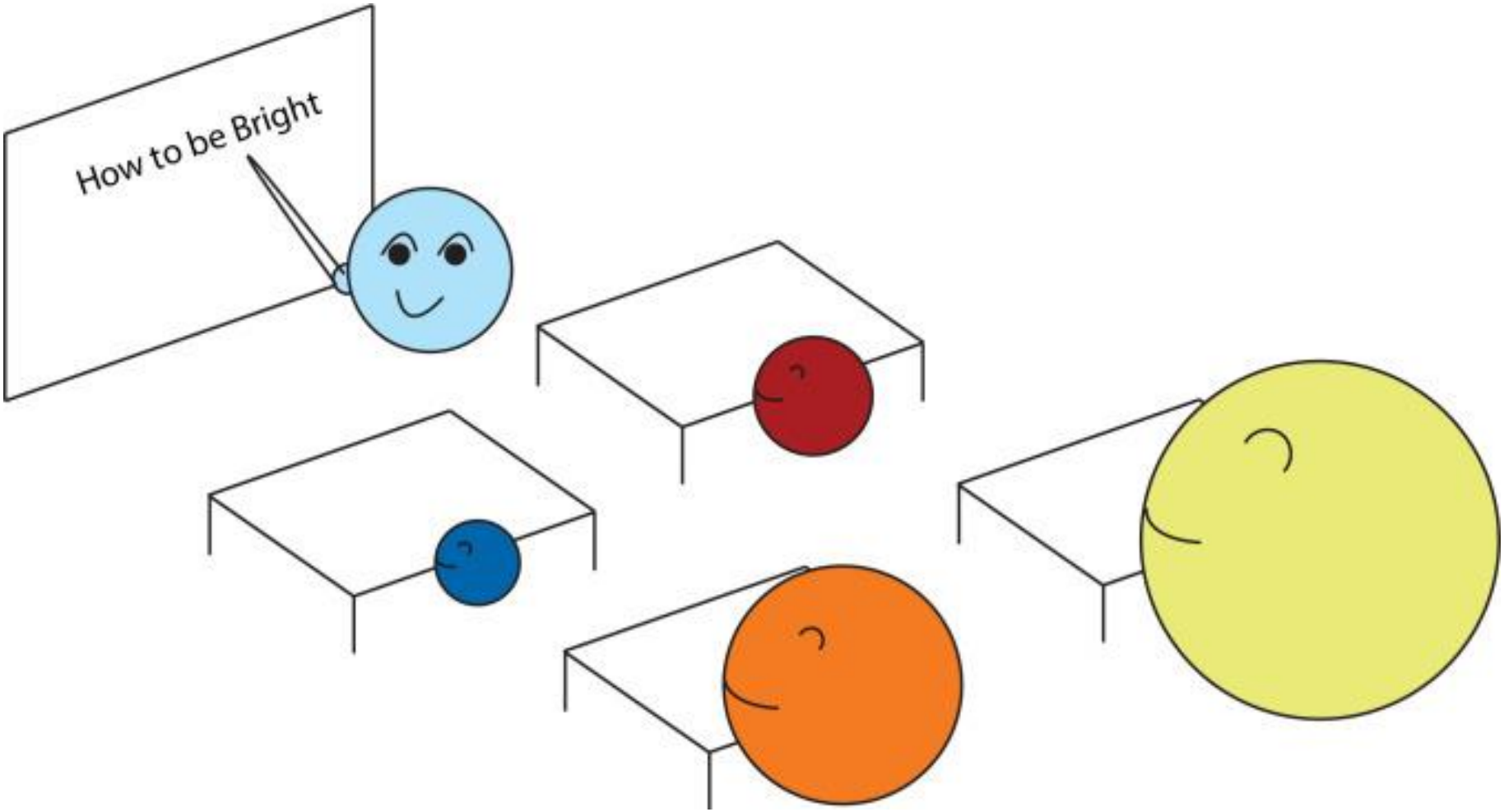


Image Credit – Emma Garrett

Classification – Luminosity

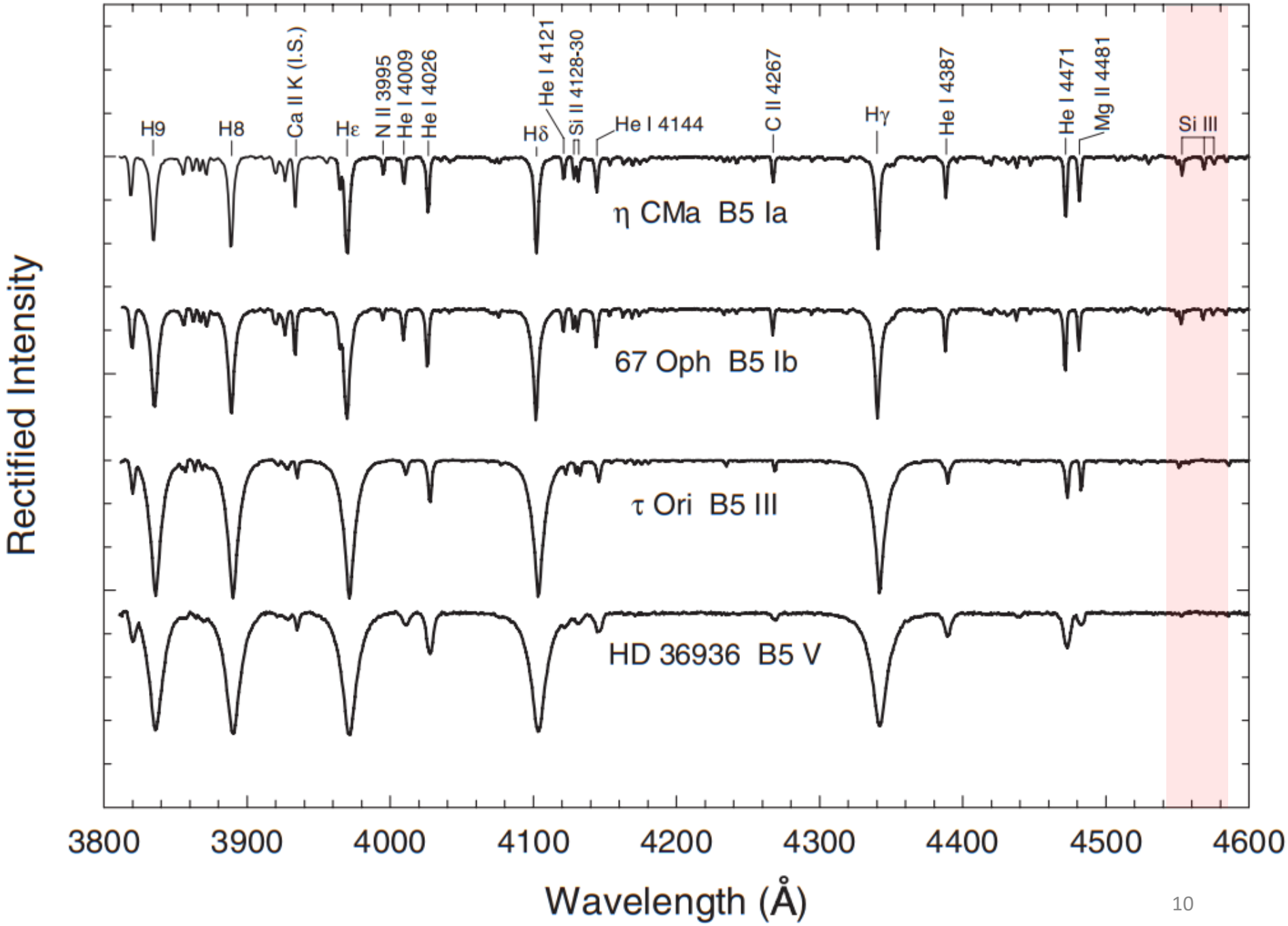
- O II to He I or H
  - CNO anomalies
- Si IV + Si III to He I
  - Early B type <B3
  - Si III for B4/B5
- Balmer lines for late B
- Iterative for T and L class
  - Informs He anomalies

He I 4026 / O II 4070

He I 4387 / O II 4416

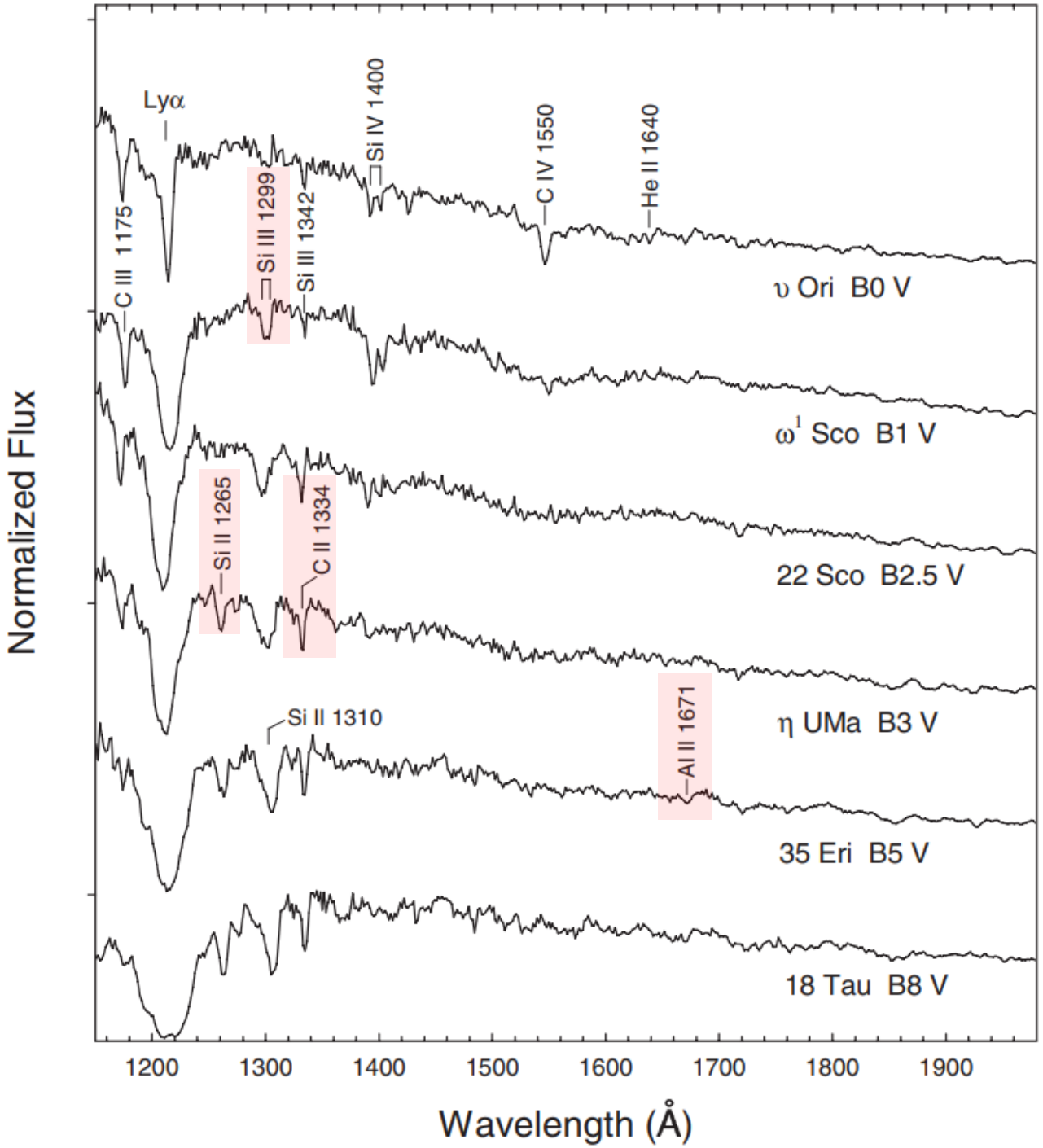
Hγ / O II 4348

I	Supergiants
II	Bright giants
III	Giants
IV	Subgiants
V	Main sequence


H9
H8
Ca II K (I.S.)
Hε
N II 3995
He I 4009
He I 4026
Hδ
He I 4121
Si II 4128-30
He I 4144
C II 4267
Hγ
He I 4387
He I 4471
Mg II 4481
Si III
η CMa B5 Ia
67 Oph B5 Ib
τ Ori B5 III
HD 36936 B5 V
Rectified Intensity
3800
3900
4000
4100
4200
4300
4400
4500
4600
Wavelength (Å)

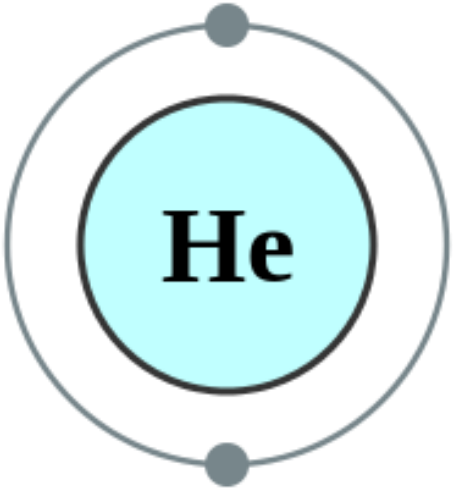
Classification - Ultraviolet

- SED peak in UV
- **Temperature**
  - Si II 1264 / Si III 1299
  - C II 1334 / C III 1175
  - Al II 1671 / Al III 1863
- **Luminosity**
  - Al III 1855, 1863
  - Al II 1671
  - Alternatively Fe III 1891 – 1988
- Wind lines – ‘w’


Lyα
Si IV 1400
C IV 1550
He II 1640
C III 1175
Si III 1299
Si III 1342
υ Ori B0 V
ω¹ Sco B1 V
Si II 1265
C II 1334
22 Sco B2.5 V
η UMa B3 V
Si II 1310
Al II 1671
35 Eri B5 V
18 Tau B8 V
Normalized Flux
1200
1300
1400
1500
1600
1700
1800
1900
Wavelength (Å)

Chemical Peculiarities

- Helium strong B stars - Early <B3
  - Near universal strong $\vec{B}$ fields
- Helium weak B stars - Later >B3
  - Weaker $\vec{B}$ fields
  - Color spectrum discrepancy
  - Si / SrTi / PGa subtypes
- He strong variable B stars
  - Magnetic fields?
  - Oblique rotator model



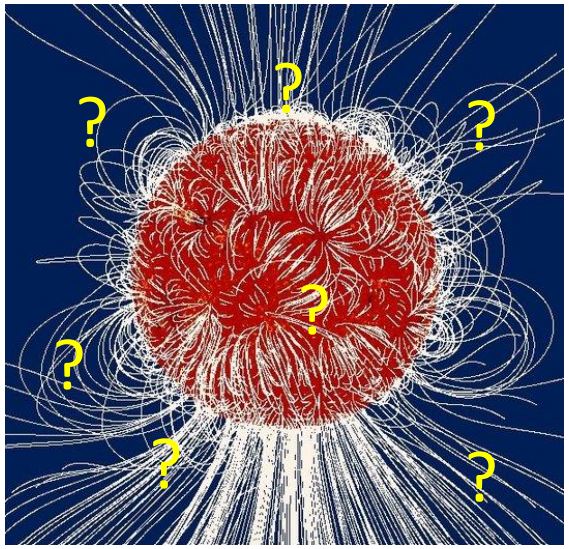
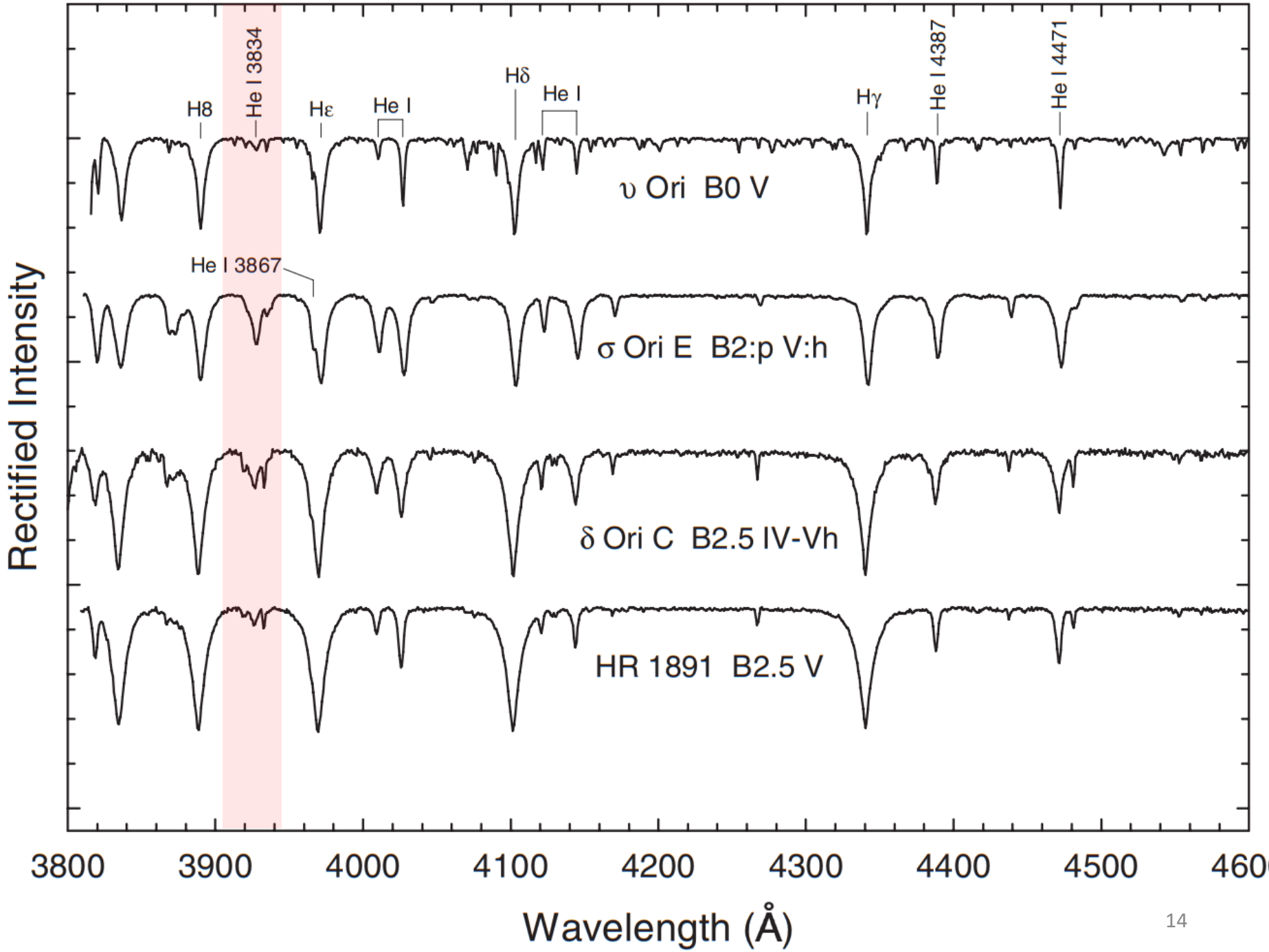
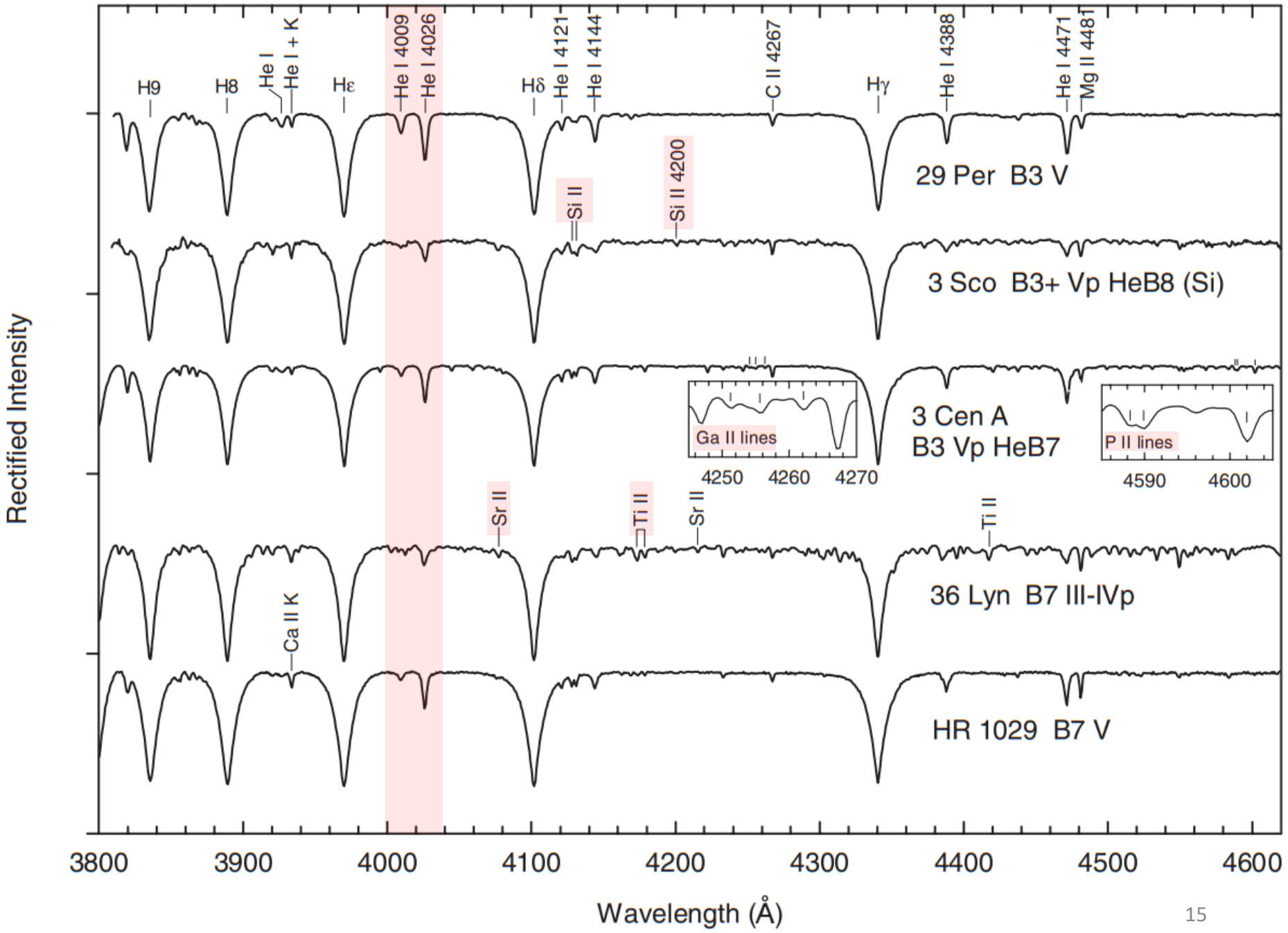


Image Credit – International Planck Research School for Solar System Science

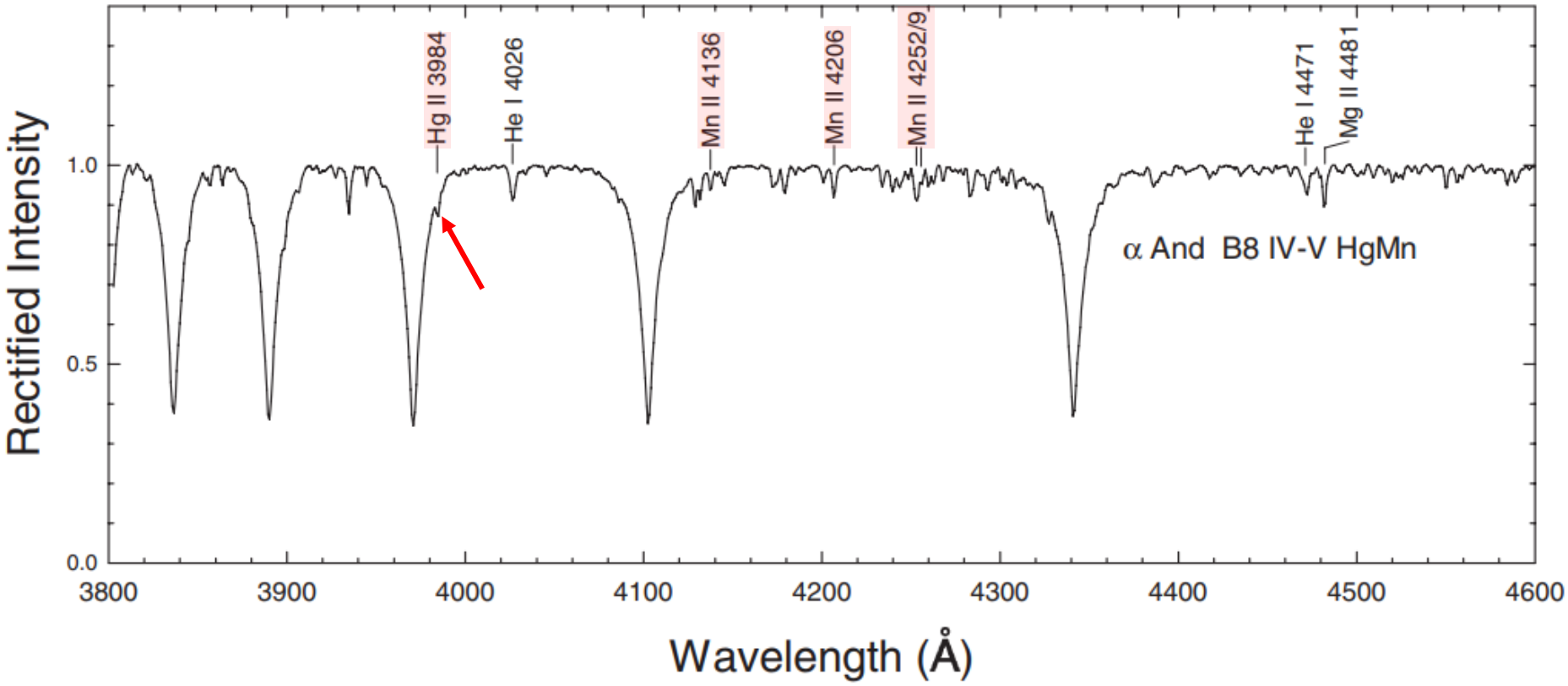

H8
He I 3834
Hε
He I
Hδ
He I
Hγ
He I 4387
He I 4471
υ Ori B0 V
He I 3867
σ Ori E B2:p V:h
δ Ori C B2.5 IV-Vh
HR 1891 B2.5 V
Rectified Intensity
3800
3900
4000
4100
4200
4300
4400
4500
4600
Wavelength (Å)


Rectified Intensity
H9
H8
He I
He I + K
Hε
He I 4009
He I 4026
Hδ
He I 4121
He I 4144
C II 4267
Hγ
He I 4388
He I 4471
Mg II 4481
29 Per B3 V
Si II
Si II 4200
3 Sco B3+ Vp HeB8 (Si)
Ga II lines
4250
4260
4270
3 Cen A
B3 Vp HeB7
P II lines
4590
4600
Sr II
Ti II
Sr II
Ti II
Ca II K
36 Lyn B7 III-IVp
HR 1029 B7 V
3800
3900
4000
4100
4200
4300
4400
4500
4600
Wavelength (Å)

Mercury-Manganese B Stars

- Hg II and Mn II enhanced
  - No Hg? Mn B stars!
- B7 – B9 : Luminosity class V to III
- Odd metal abundances - X Lup
  - Strontium / Rare Earth / Pt / Au / Hg
- Isotopic anomalies – Hg and Pt
- Continuation of Am?
  - Weak magnetic fields***
  - Variability – magnetic fields?

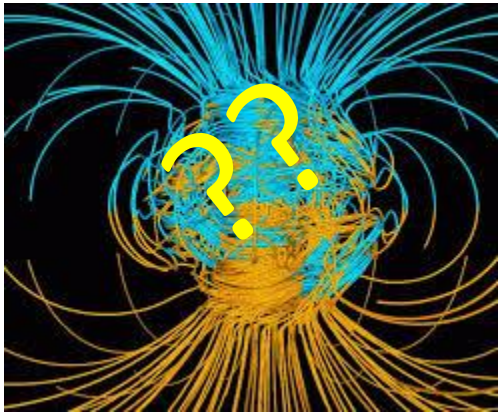
Mercury-Manganese B Stars

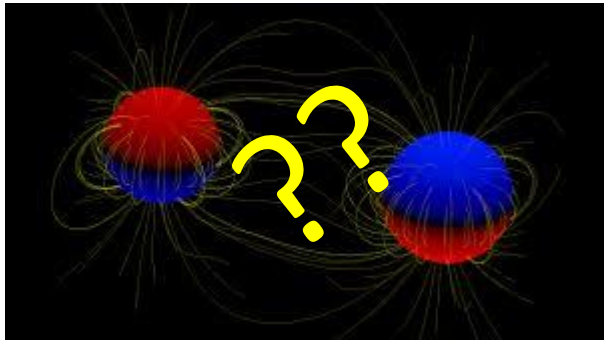


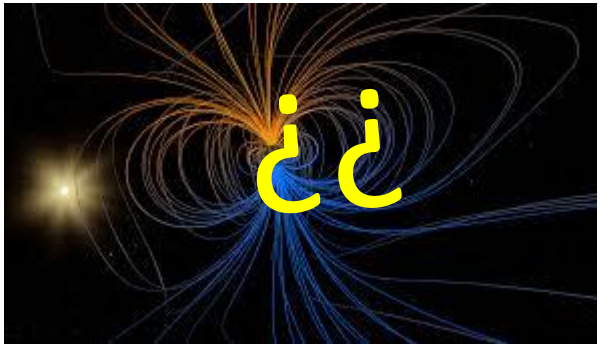
Chemical Peculiarities

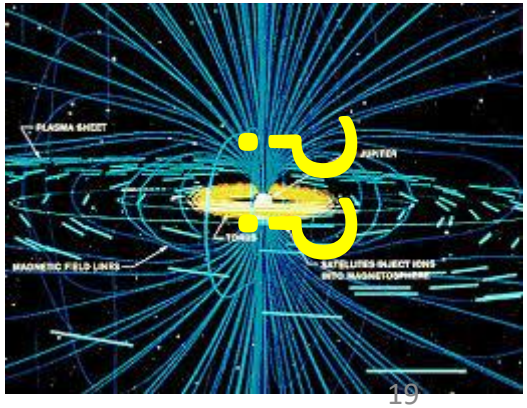
- Magnetic Chemically Peculiar (mCP)
  - He strong -> Si + SrTi -> Ap
- Ap magnetic stars (Chapter 5)
  - B star T without He I
- Nonmagnetic Chemically Peculiar (nmCP)
  - PGa -> HgMn -> hot Am -> Am -> ρ Puppis
- Magnetic ambiguity?
  - Magnetically simple or complex

WHAT'S GOING ON!?!?!





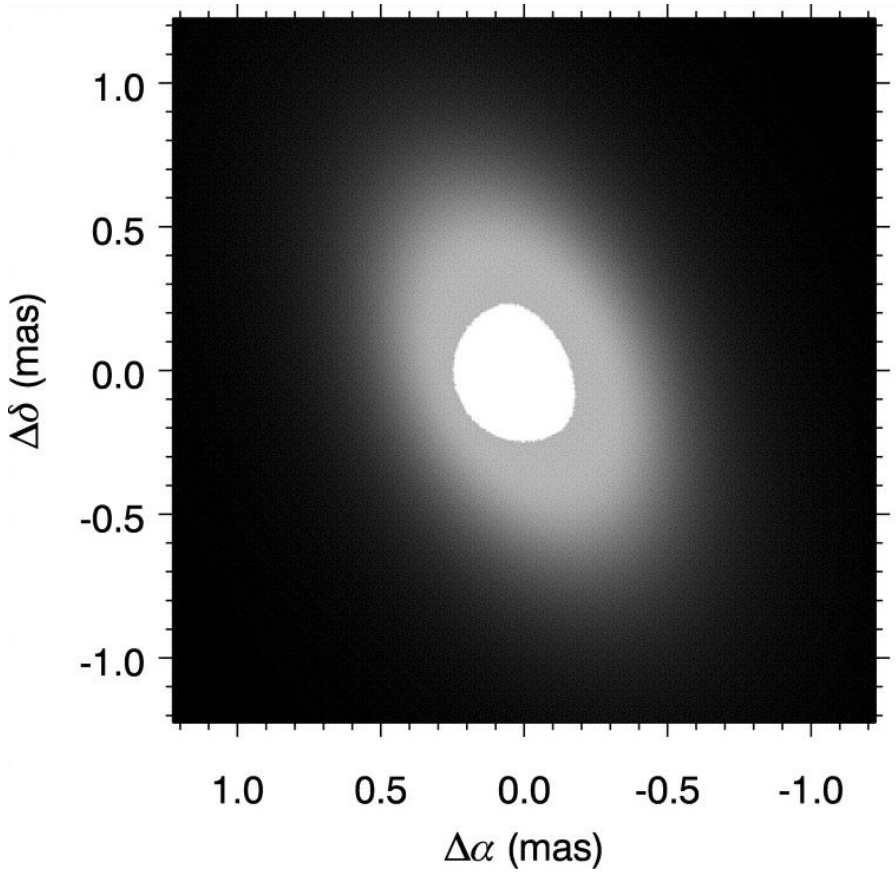




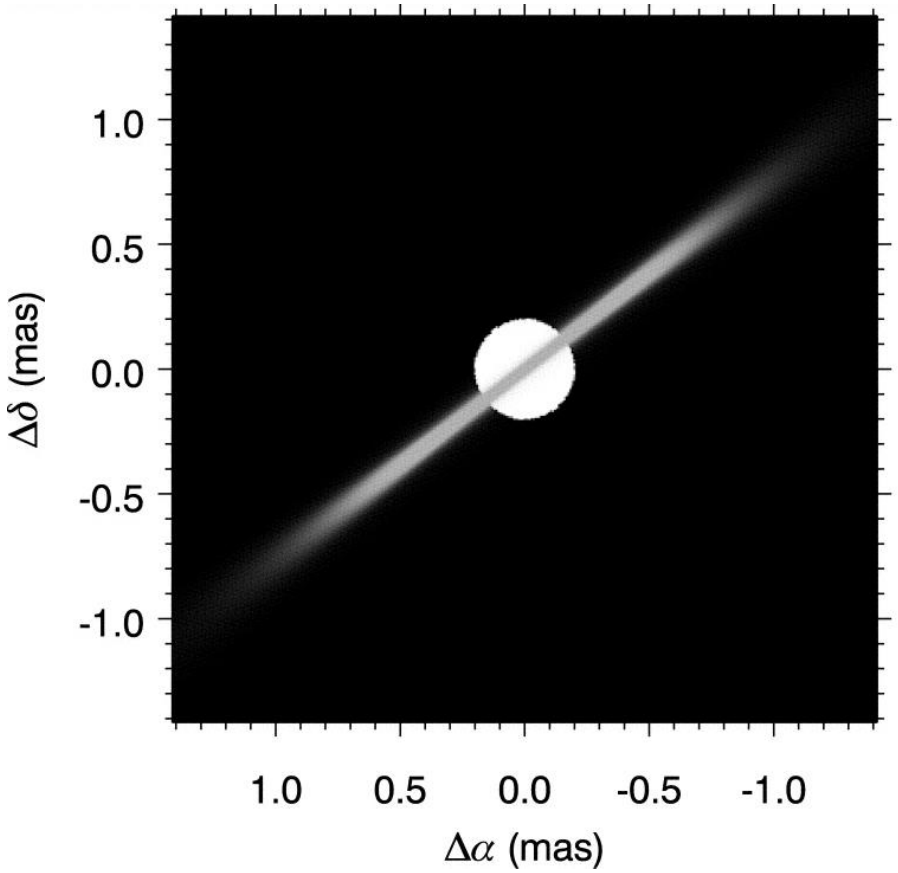
Be Stars

- Show emission!
  - H Balmer, metals like Fe II
  - Not B supergiants, B[e], or Herbig Ae/Be stars
  - Variable
- Hot equatorial gas disk
  - Formation – pulsation / wind / magnetic fields
  - Structure? CHARA!
- All are rapid rotators
- Not rotational break-up (Struve 1931)

Image Credit – Bill Pounds



Gamma Cas

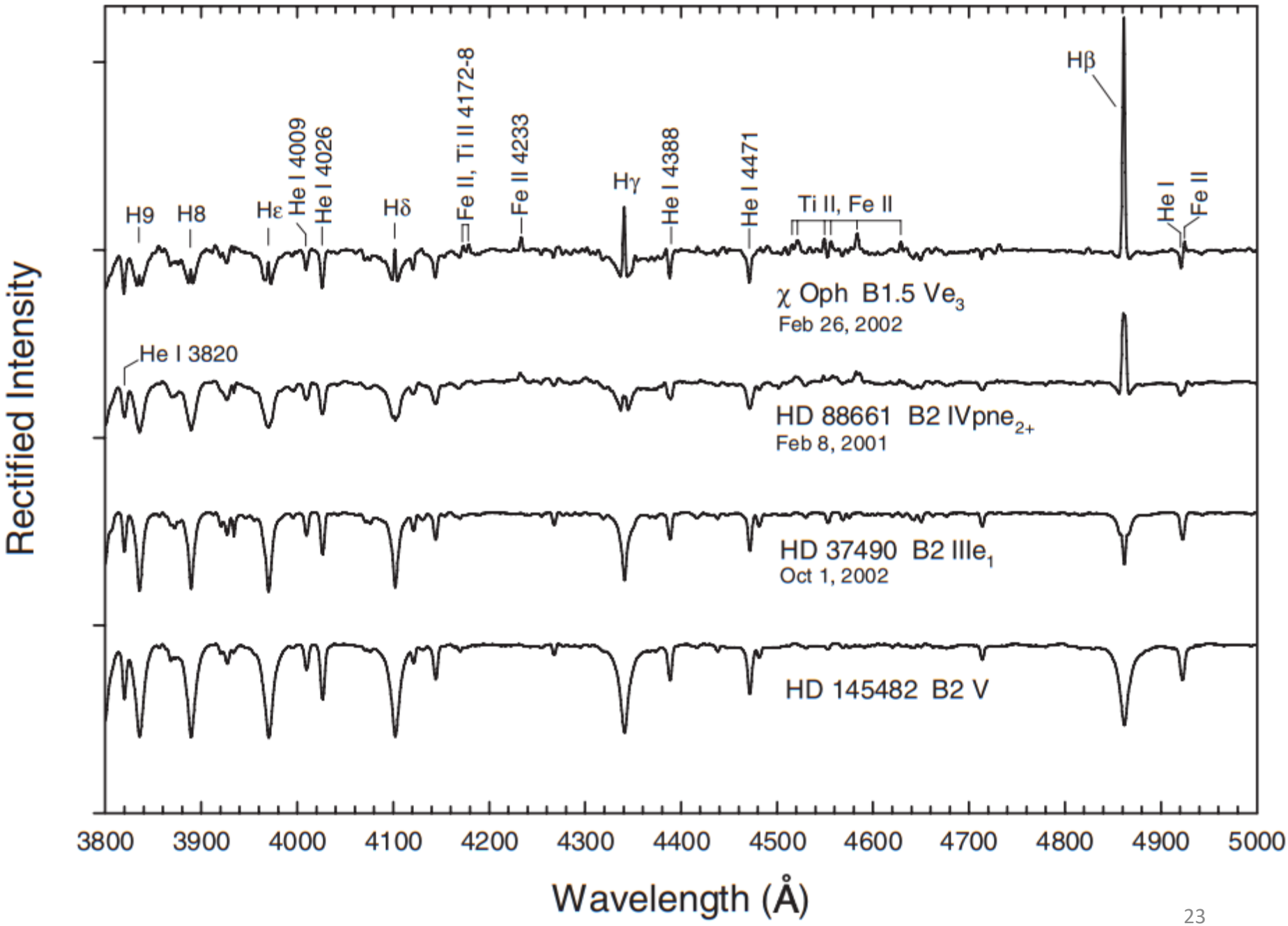


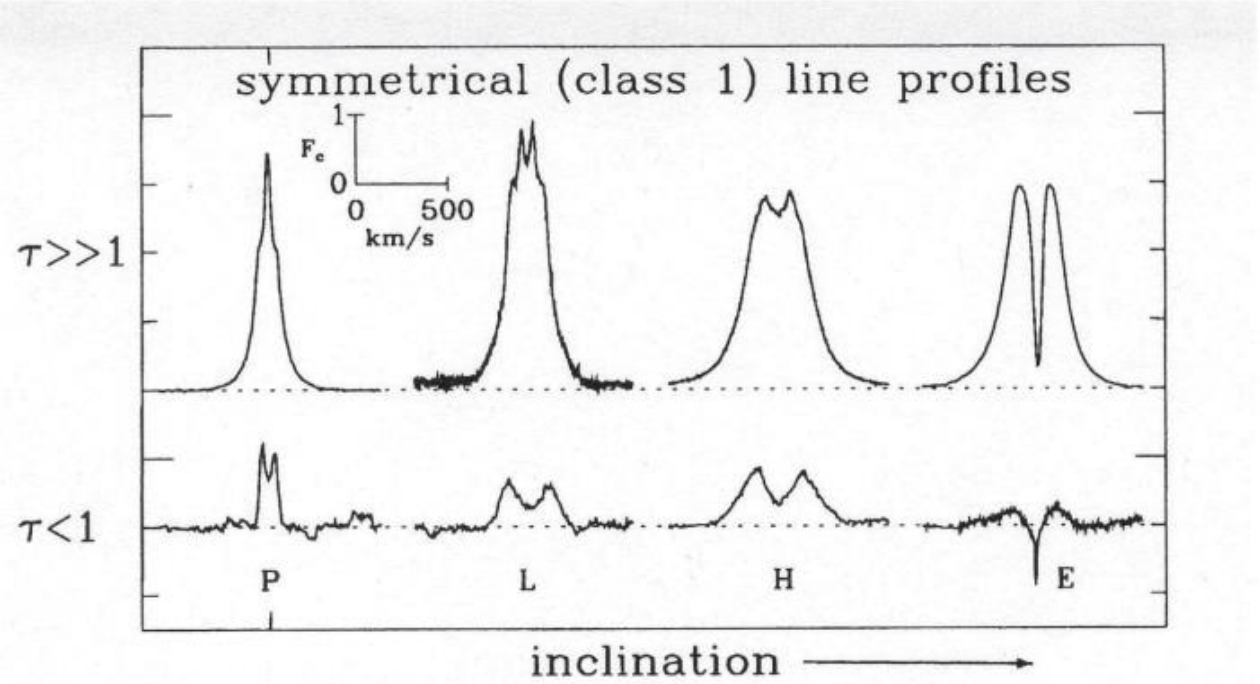
Zeta Tau

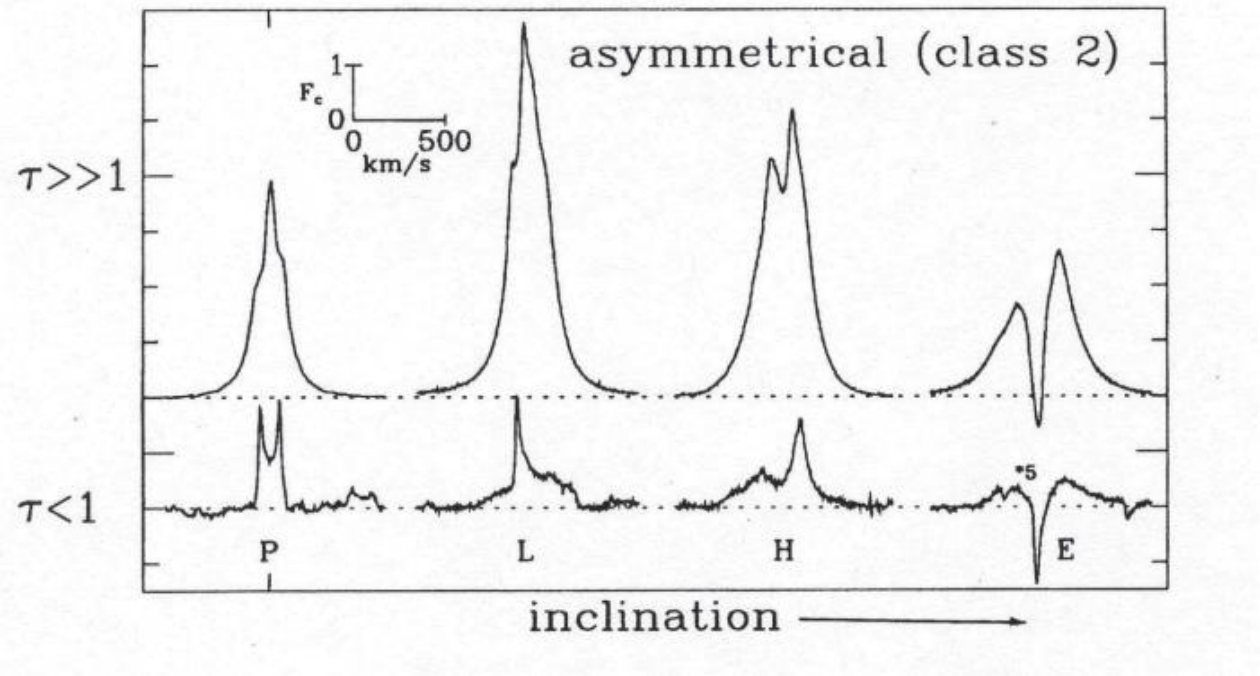
Gies et al. 2007, ApJ, 654, 527

Be Star Classification

- Photospheric star and emission
- Mild Be stars - Balmer wings
  - He I / Mg II 4481 ratio
- Strong Be stars - harder
- Emission classification - Lesh System (1968)
  - MK + emission parameter ‘e’
  - $e_1 \rightarrow e_{1+} \rightarrow e_2 \rightarrow e_{2+} \cdots e_4$
- Jaschek System (1980)
- Line profiles – Hanuschik et al. (1996)

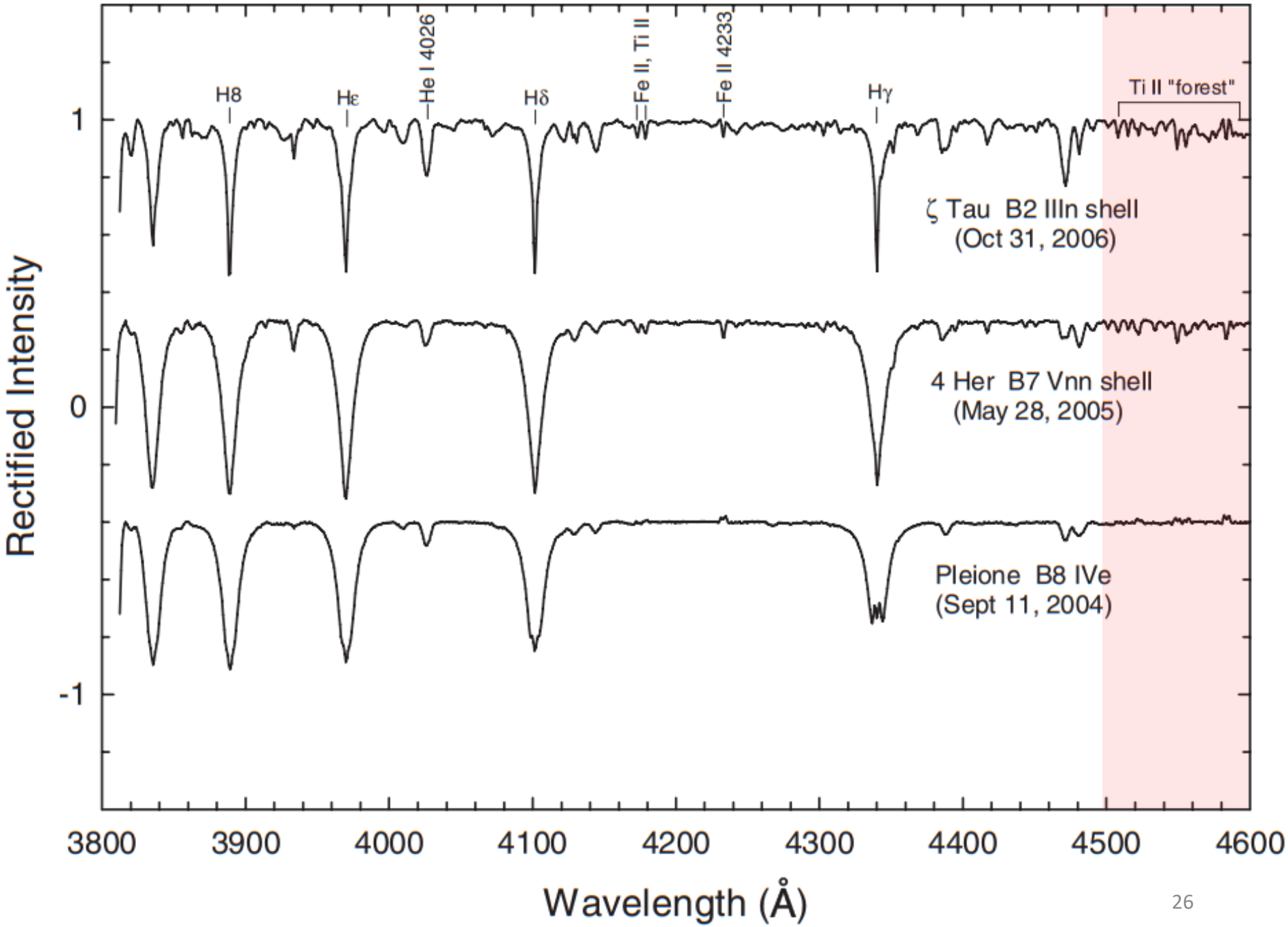

Rectified Intensity
H9
H8
Hε
He I 4009
He I 4026
Hδ
Fe II, Ti II 4172-8
Fe II 4233
Hγ
He I 4388
He I 4471
Ti II, Fe II
Hβ
He I
Fe II
χ Oph B1.5 Ve3
Feb 26, 2002
He I 3820
HD 88661 B2 IVpne2+
Feb 8, 2001
HD 37490 B2 IIIe1
Oct 1, 2002
HD 145482 B2 V
3800
3900
4000
4100
4200
4300
4400
4500
4600
4700
4800
4900
5000
Wavelength (Å)


symmetrical (class 1) line profiles
1
F_c
0
0 500
km/s
τ>>1
τ<1
P
L
H
E
inclination


asymmetrical (class 2)
1
F_c
0
0 500
km/s
τ>>1
τ<1
*5
P
L
H
E
inclination

B Shell Stars and Shell Lines

- Edge on disc - shell lines
  - Pseudo photosphere
- Shell phases - replaces emission
- Deep and narrow H Balmer
- Singly ionized metal absorption
  - Fe II and Ti II
- UV wind lines – normal B
  - Shell phase lines dominate UV


H8
Hε
He I 4026
Hδ
Fe II, Ti II
Fe II 4233
Hγ
Ti II "forest"
ζ Tau B2 IIIn shell
(Oct 31, 2006)
4 Her B7 Vnn shell
(May 28, 2005)
Pleione B8 IVe
(Sept 11, 2004)
Rectified Intensity
1
0
-1
3800
3900
4000
4100
4200
4300
4400
4500
4600
Wavelength (Å)

B[e] Stars

- Forbidden emission lines : [Fe II] and [O I]
- IR excess – hot circumstellar dust
- Few “photospheric” lines – emission dominant!
- Variety of situations! Laymers et al. system (1998)

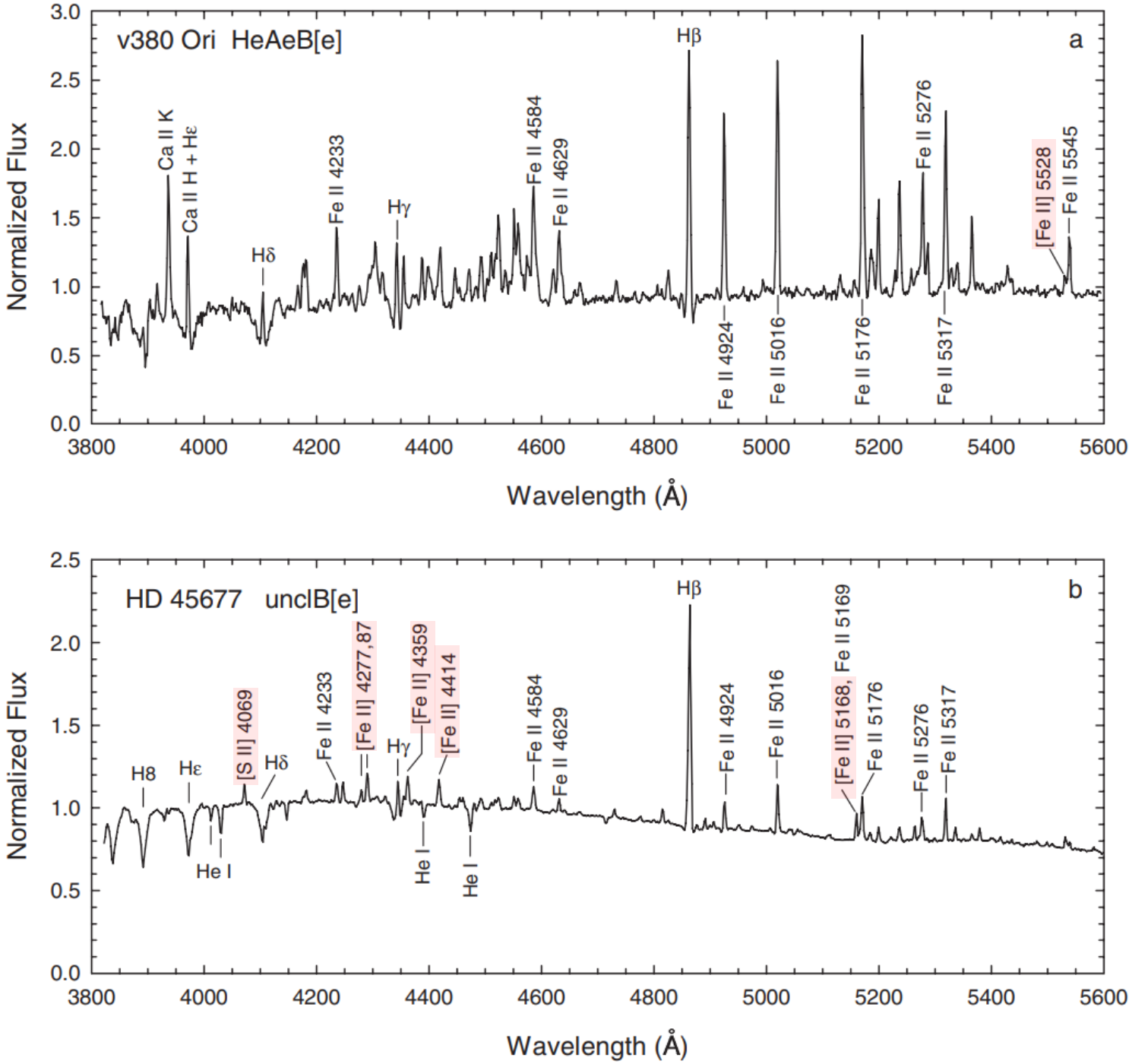
Supergiant - SGB[e] : Pre Main Sequence - HAeB[e]

Symbiotic - SymB[e] : Compact Planetary Nebula - cPNB[e]

Unclassified - unclB[e]

Main Sequence - MSB[e] by Zickgraf (2000)

Non Supergiant Dust-Forming B[e] by Miroshnichenko (2007)


v380 Ori HeAeB[e]
a
Normalized Flux
Wavelength (Å)
Ca II K
Ca II H + Hε
Hδ
Fe II 4233
Hγ
Fe II 4584
Fe II 4629
Hβ
Fe II 4924
Fe II 5016
Fe II 5176
Fe II 5317
Fe II 5276
[Fe II] 5528
Fe II 5545
HD 45677 unclB[e]
b
H8
Hε
[S II] 4069
Hδ
Fe II 4233
[Fe II] 4277,87
Hγ
[Fe II] 4359
[Fe II] 4414
He I
He I
Fe II 4584
Fe II 4629
Hβ
Fe II 4924
Fe II 5016
[Fe II] 5168, Fe II 5169
Fe II 5176
Fe II 5276
Fe II 5317

B Supergiants and LBVs

- Near or above Eddington limit
- Stellar instability -> LBVs
- Mass loss events
- O/B/A type
- Hα P Cygni profile
  - Maybe Hβ – T dependent
- Photometrically and spectroscopically variable
- **See Chapter 11**

LBV - AG Carinae

Image Credit – HST / NASA

OB Hot Subdwarfs

- Extreme Horizontal Branch stars
  - He cores after H mass loss
- Pre-White Dwarf stars
  - Post planetary nebula stars
- sdOB classification
  - T / L class / He class
  - sdB2VI He4
- He class is function of He and Balmer line strengths
  - 0 to 40
  - 0 = No He lines
  - 40 = No H Balmer lines

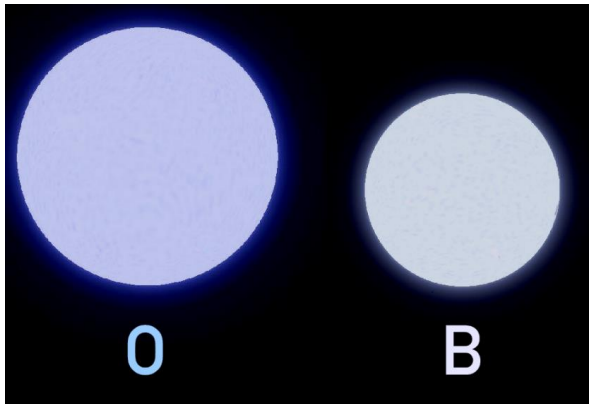
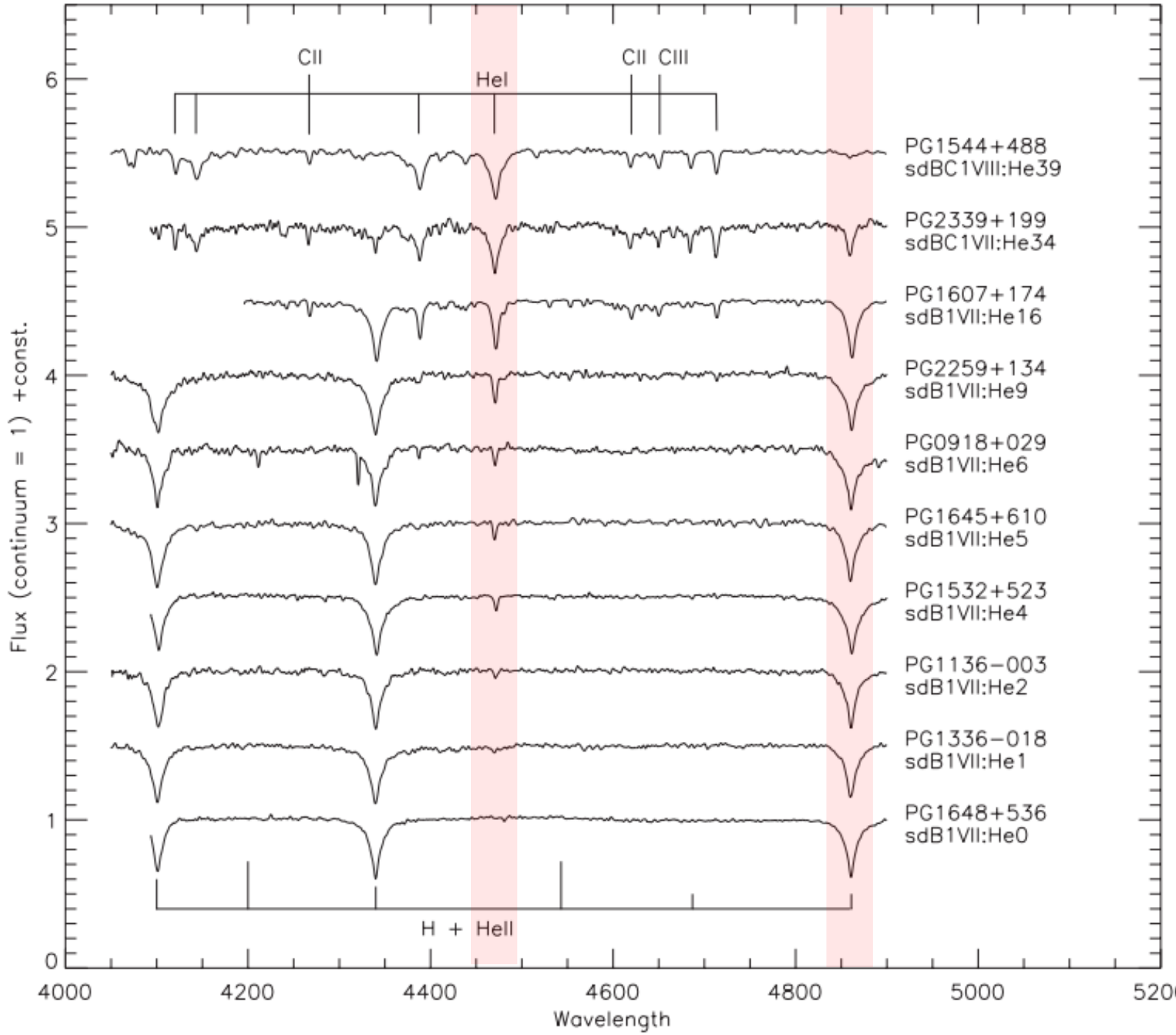


Image Credit – Wikipedia Commons


CII
HeI
CII CIII
PG1544+488
sdBC1VIII:He39
PG2339+199
sdBC1VII:He34
PG1607+174
sdB1VII:He16
PG2259+134
sdB1VII:He9
PG0918+029
sdB1VII:He6
PG1645+610
sdB1VII:He5
PG1532+523
sdB1VII:He4
PG1136−003
sdB1VII:He2
PG1336−018
sdB1VII:He1
PG1648+536
sdB1VII:He0
H + HeII
Flux (continuum = 1) +const.
Wavelength
0
1
2
3
4
5
6
4000
4200
4400
4600
4800
5000
5200

High Galactic Latitude B Stars

- Faint blue stars at high b
- Mostly WD + sdOB + BHB
  - But not all!
- Handful of “normal” B stars
- Massive population 1 ejected stars
  - Binary (Or More) Interactions (Gies & Bolton 1986)
- Old evolved post-AGB stars
- No evidence for formation within halo

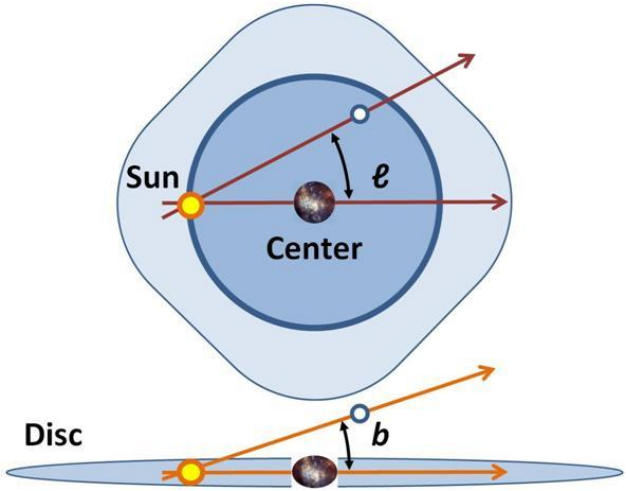
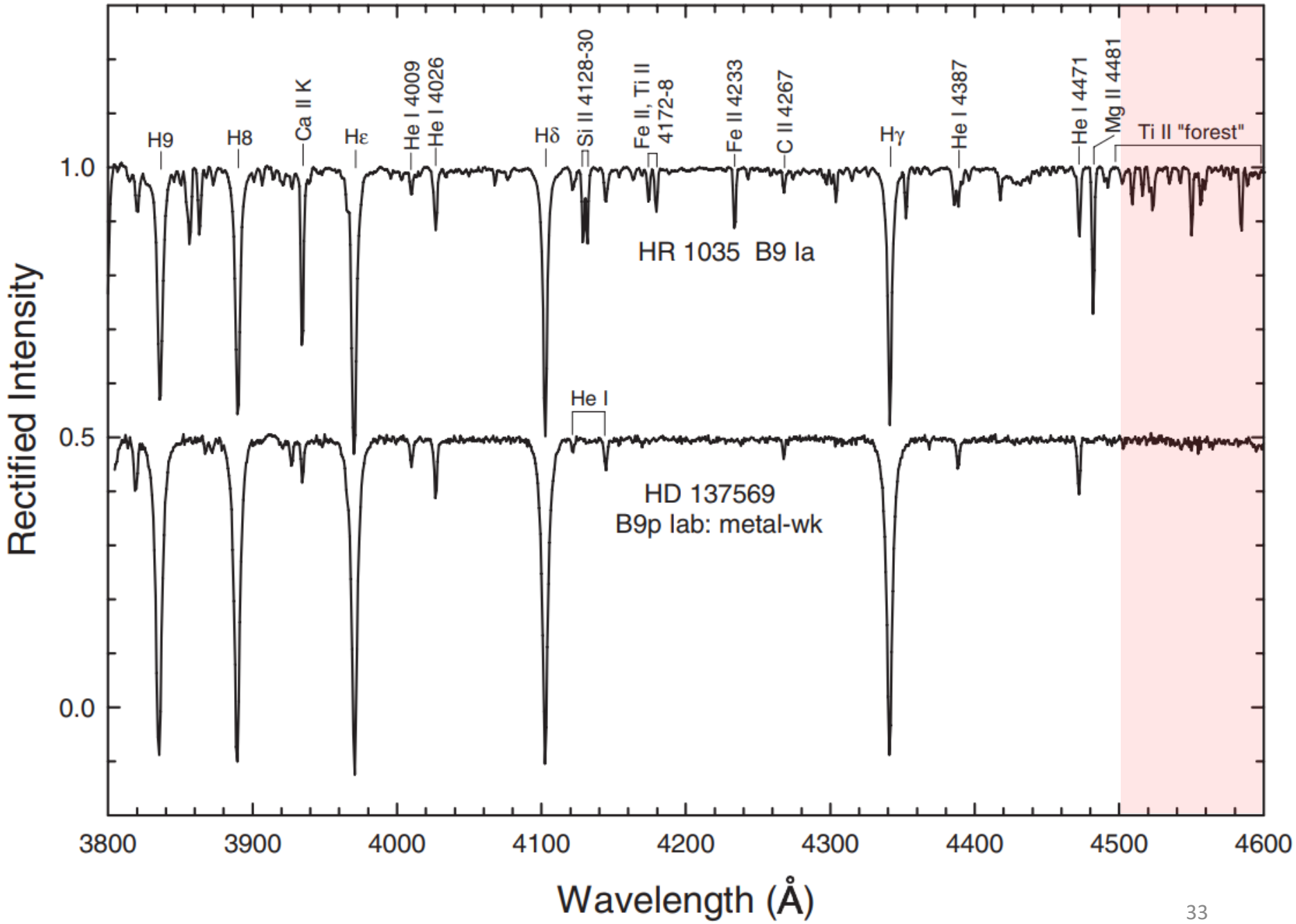


Image Credit – Wikipedia Commons


H9
H8
Ca II K
Hε
He I 4009
He I 4026
Hδ
Si II 4128-30
Fe II, Ti II 4172-8
Fe II 4233
C II 4267
Hγ
He I 4387
He I 4471
Mg II 4481
Ti II "forest"
HR 1035 B9 Ia
He I
HD 137569
B9p lab: metal-wk
Rectified Intensity
1.0
0.5
0.0
3800
3900
4000
4100
4200
4300
4400
4500
4600
Wavelength (Å)

Summary

- Classification of B stars
  - Temperature + luminosity class
- Chemical peculiarities
  - He variability and HgMn stars
- Be stars – emission lines
  - B[e] and shell variants
- B supergiants and LBVs
- OB subdwarfs
- High galactic latitude B stars

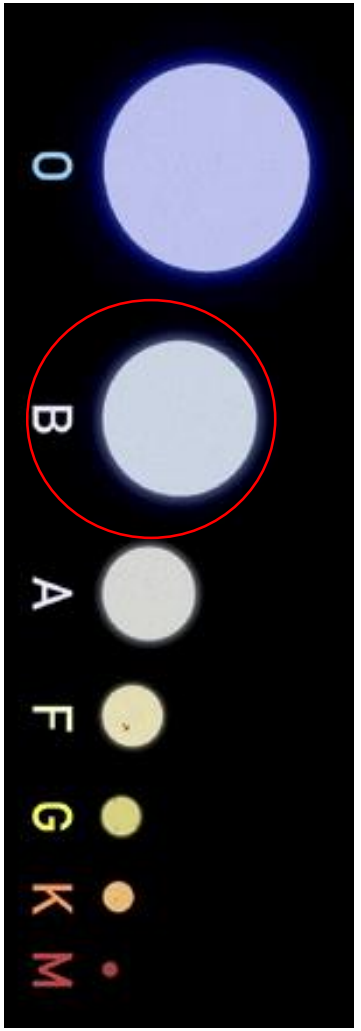
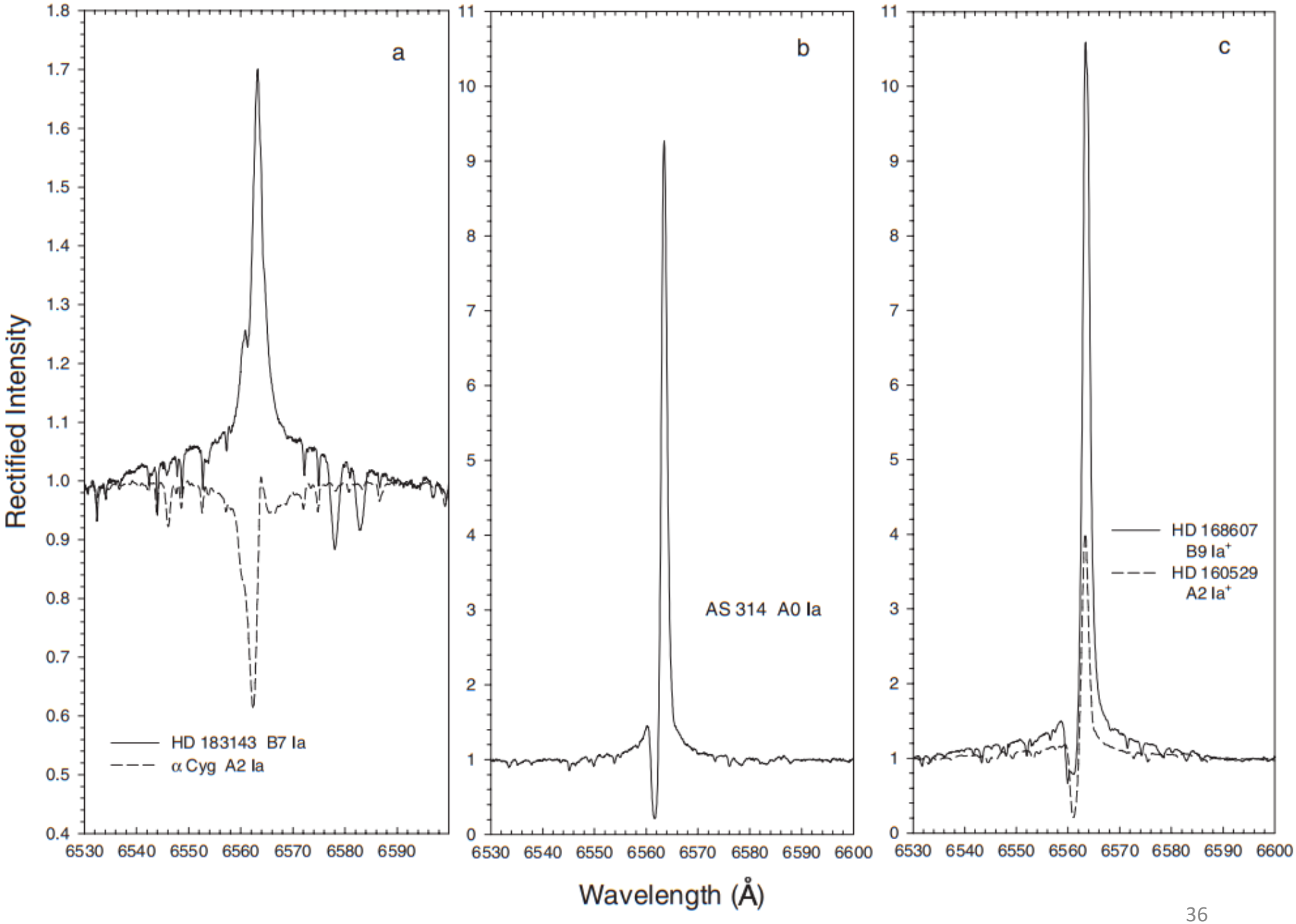


Image Credit – Wikipedia Commons


Questions?


a
b
c
Rectified Intensity
Wavelength (Å)
HD 183143 B7 Ia
α Cyg A2 Ia
AS 314 A0 Ia
HD 168607
B9 Ia+
HD 160529
A2 Ia+