Stellar classification by means of CCD spectrography

by M.M.M. Santangelo [1,2]

&

M. Pasquini [1,2]

[1] I.R.F. Istituto Ricerche Fotometriche (LU), Italy

[2] O.A.C. Osservatorio Astronomico di Capannori (LU)

Instruments and technical specifications

- **Hardware:**
  Meade Schmidt-Cassegrain 30cm telescope f/10 from OAC.

  Sbig ST-9XE CCD camera with 512x512 (20μm) pixels from OAC

  Sbig DSS-7 spectrograph with a 300 lines/mm diffraction grating, and 50μm wide long-slit from OAC .
  Dispersion: 1.2 nm/pixel

- **Software:**
  CCDOps (version 5.47)
  DSS7 (version 1.0)
  AIP4 for windows (version 2.1.10)

Modified two-parametric MK classification

- **Spectral classes**:
  O B A F G K M L T
  Oh Be A Fine Girl Kiss Me (Lovely Tenderly)

- **Subclasses** (not all of them need to be present in each class):
  0,1,2,3,4,5,6,7,8,9

- **Luminosity classes:**
  (0 hyphergiants)
  I supergiants
  II bright giants
  III giants
  IV sub-giants
  V dwarfs
  (VI subdwarfs)
  (VII white dwarfs)

Important points to be known

- Continuum
- Spectral features:
  lines
  bands
- Emission lines
- Absorption lines
- Wavelength calibration
- Flux calibration
- Equivalent width of spectral lines

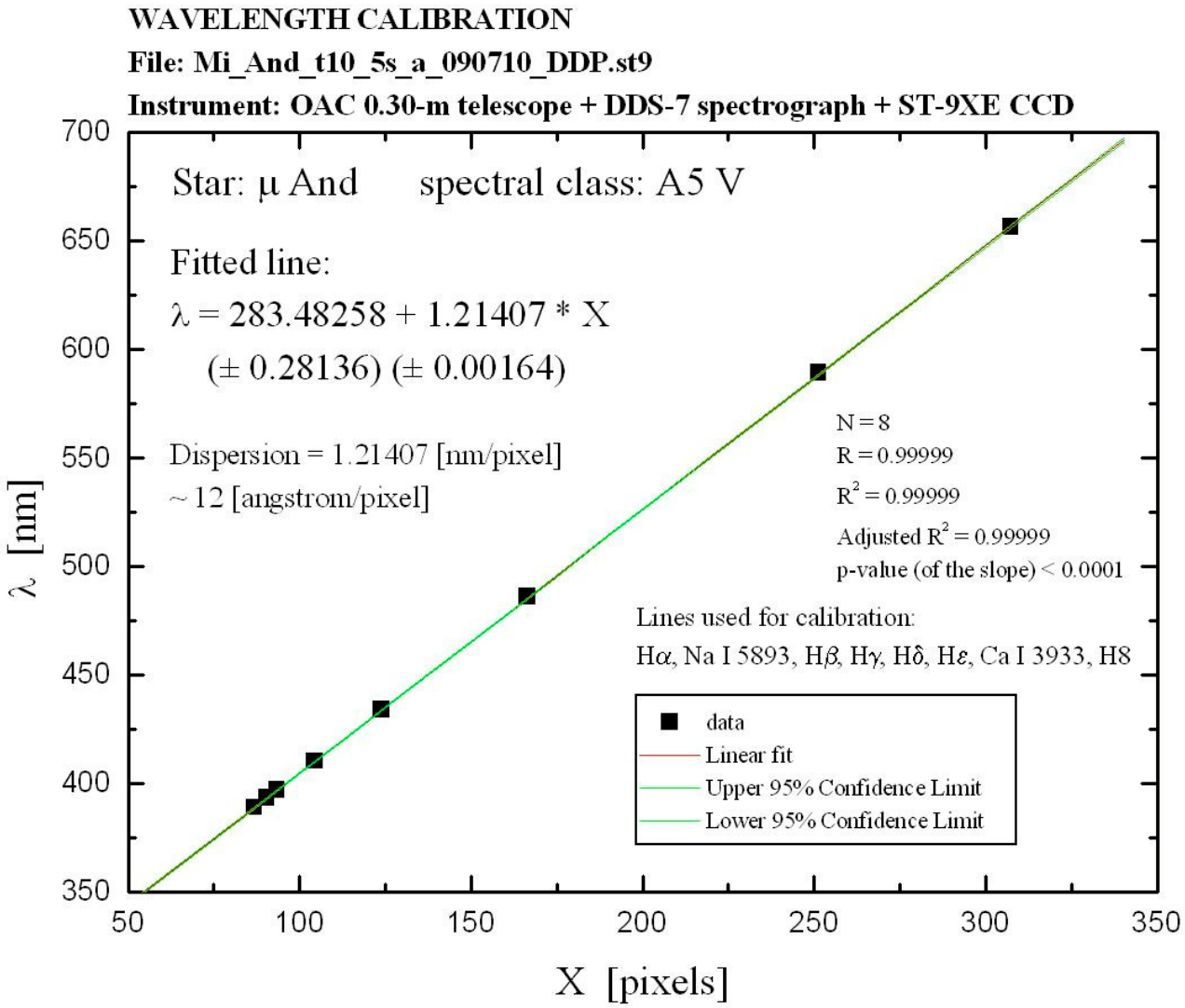
Important steps of the pre-processing

- 1) Removing bias+dark and night sky
- 2) Flat field
- 3) (electronic) Widening
- 4) Wavelength calibration
- 5) Flux calibration

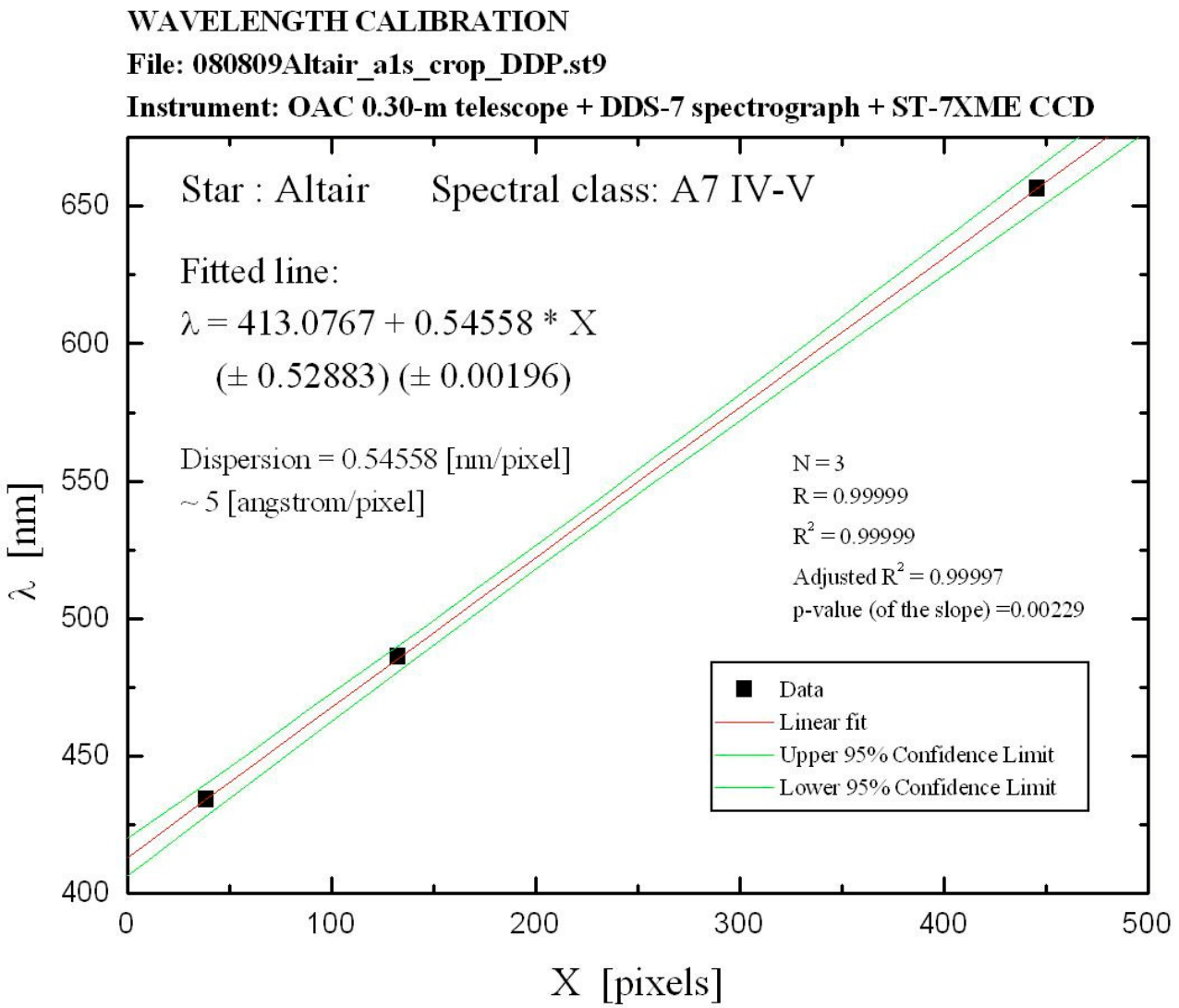
Note:

If you are not doing spectrophotometry, and if you don't need to measure equivalent widths (but simply you want to classify spectra by comparing them with those of standards obtained in the same night), then you can even omit the points 2 and 5.

Wavelength calibration



Wavelength calibration



Ways for classifying stellar spectra

- Classification by means of **visual comparison** with standard stars

- Classification by means of computing **numerical indexes** (for example: ratios between equivalent widths of lines)

- Classification by means of **numerical taxonomy** based on algorithms (least chi-square, Artificial Neural Networks)

- Classification by mean of comparisons between **synthetic models** of spectra made by computers and real spectra taken at the telescope

OAC's library of CCD stellar spectra

- OAC's library of stellar spectra (OAC – LSS) is a library of low resolution long-slit CCD stellar spectra between 350 and 950 nm. The stars of OAC-LSS (especially those reproduced in this digital atlas) are taken mainly from Garcia's (1989) or Keenan's lists of MK spectral standards.

- To the date of Dec 23th 2011, OAC's library of stellar spectra contains 241 CCD stellar spectra.
  Here are reproduced 152 of these 241 CCD stellar spectra.

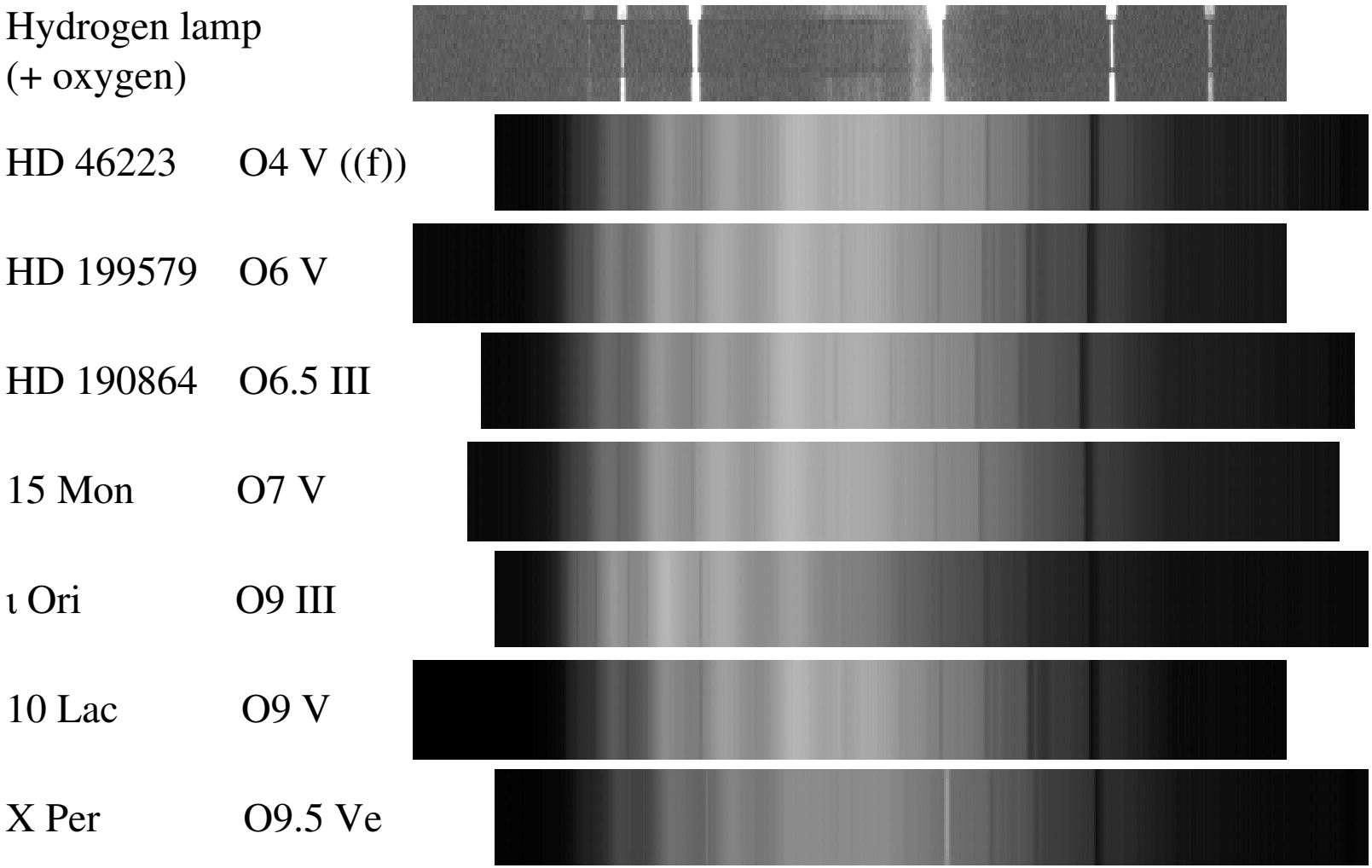
- All CCD frames in OAC-LSS were taken by the director of OAC, M.M.M. Santangelo, with the instruments of OAC, often with the collaboration of M. Pasquini.

- In each page of this library is reproduced a spectrum of the Hydrogen lamp (the first 2 brighter lines are Hα and Hβ).

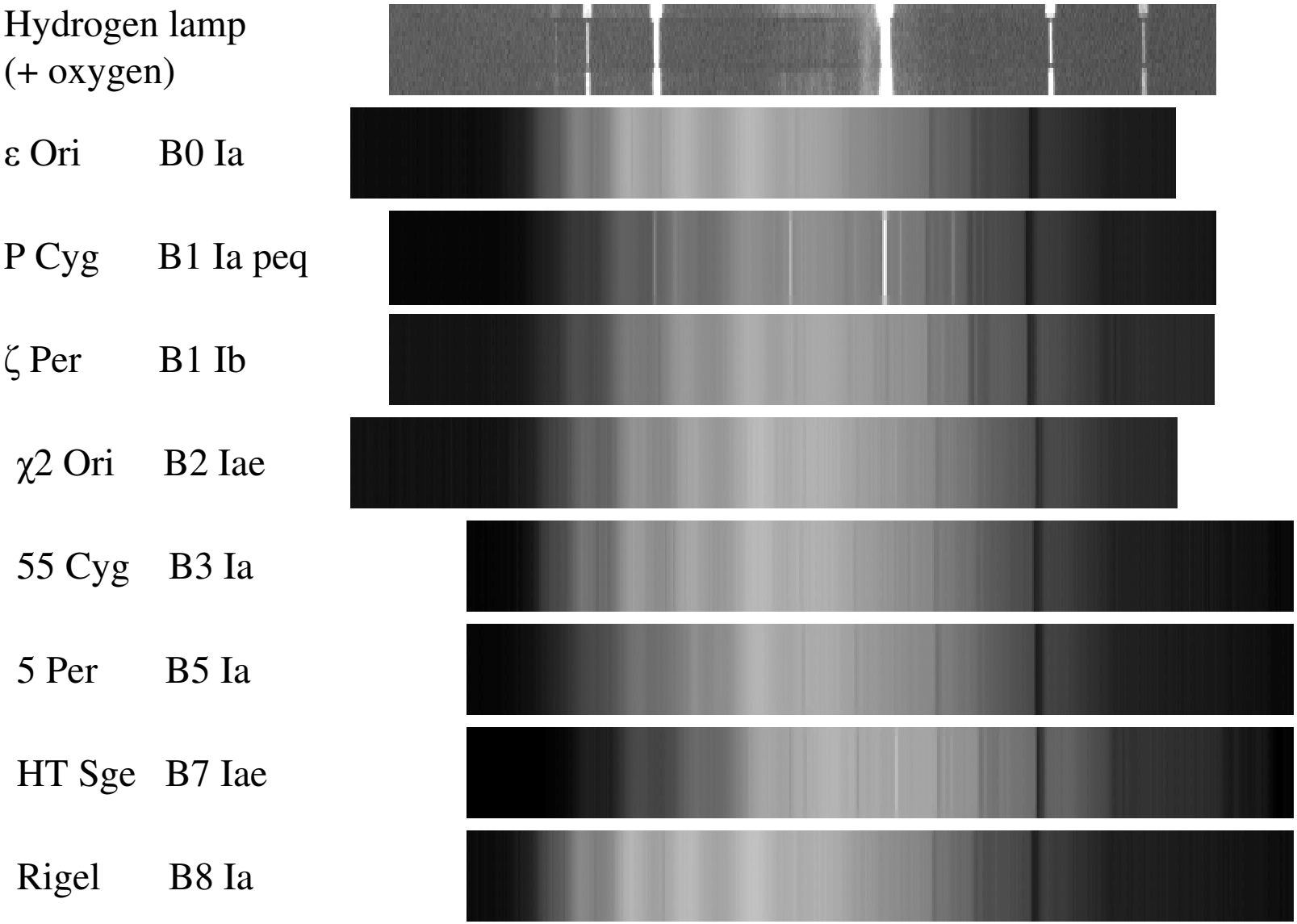
Distribution of CCD stellar spectra in OAC's library

O	7
B	47
A	36
F	33
G	36
K	35
M	33
S	7
C	7
Total	241

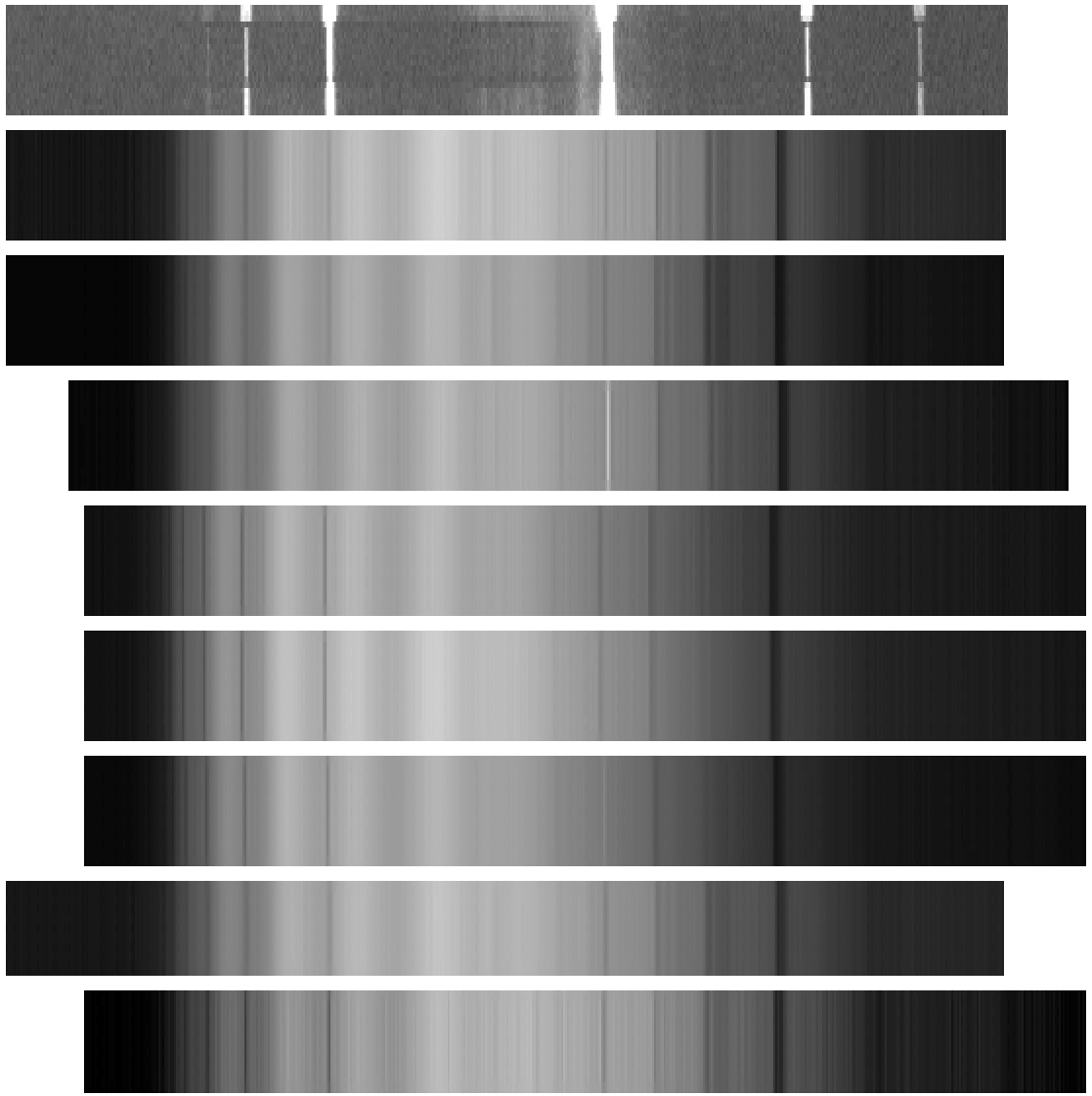
O stars (all luminosity classes)



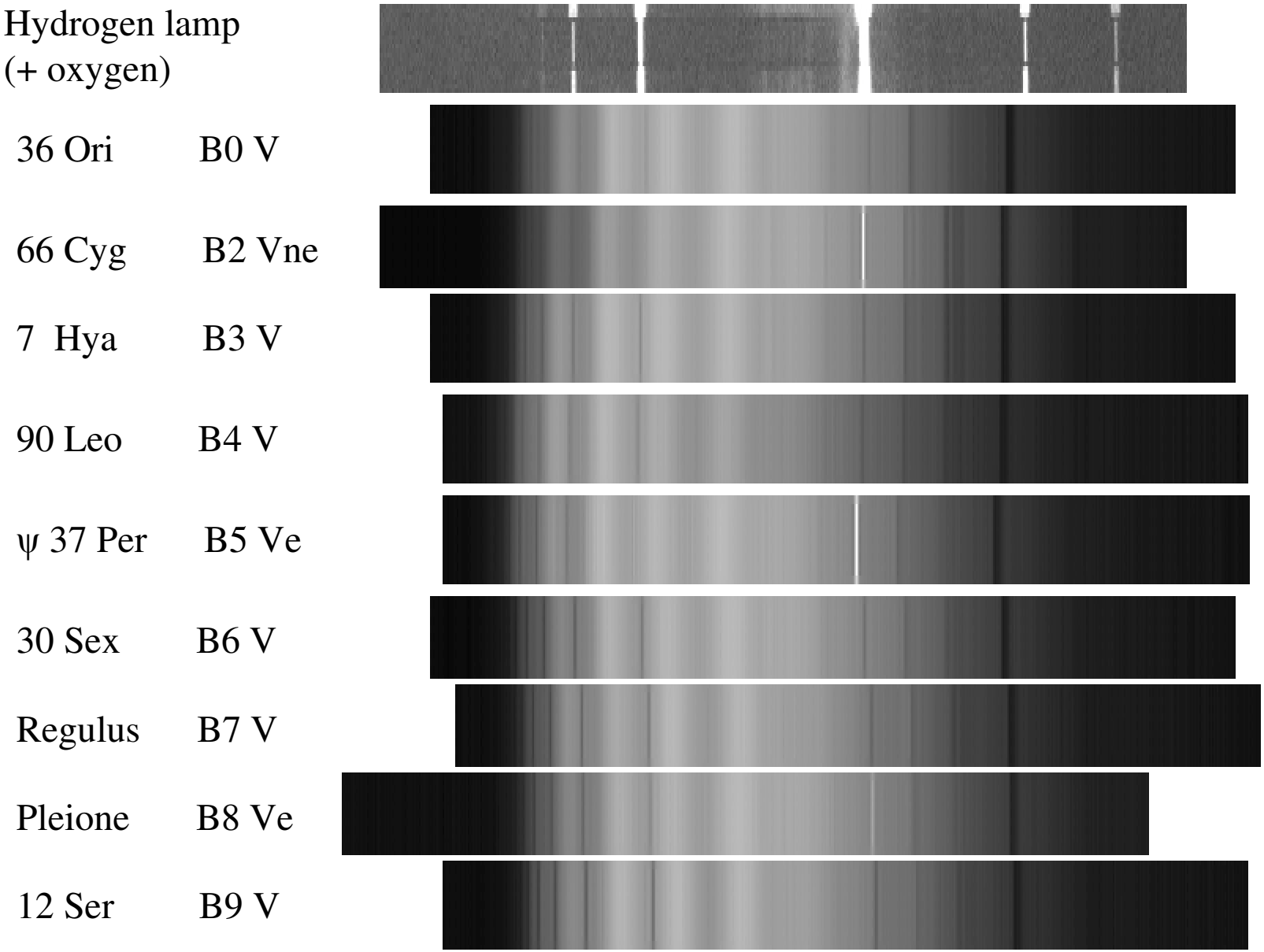
B supergiants



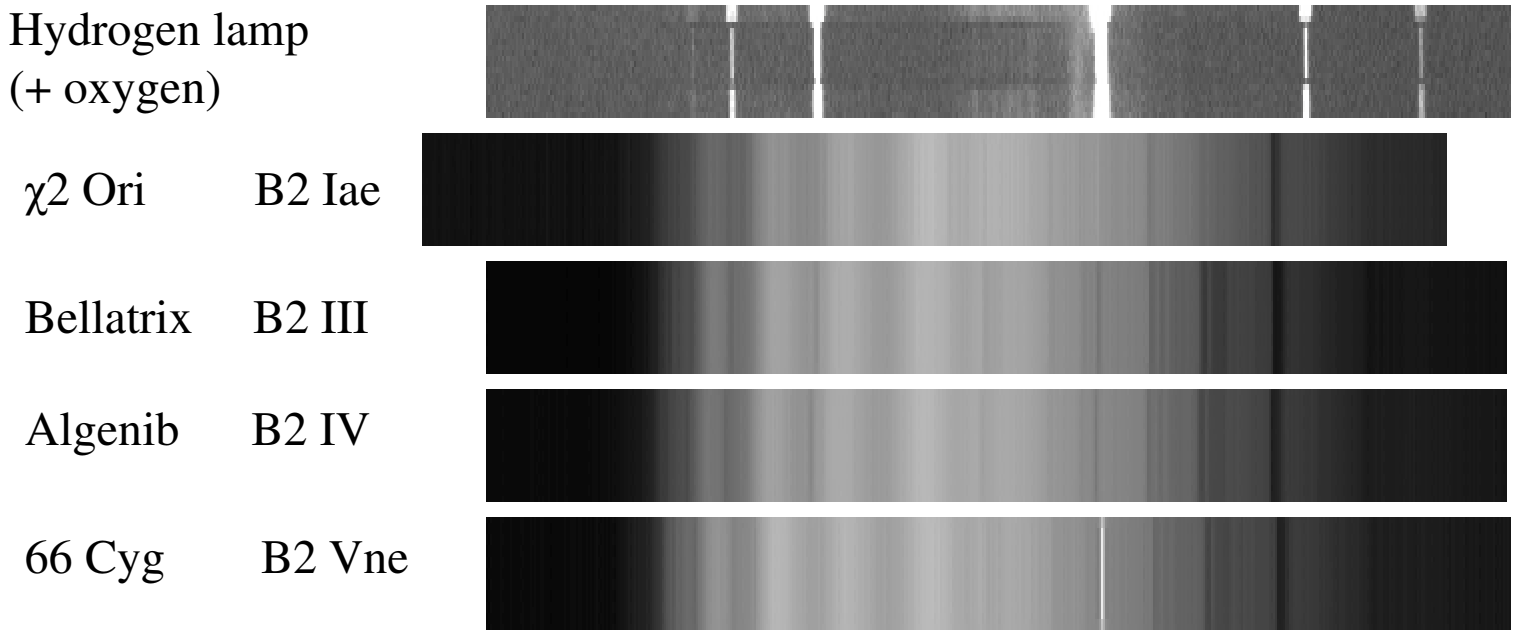
B giants


Hydrogen lamp
(+ oxygen)
o Per B1 III
Bellatrix B2 III
ω Ori B3 IIIe
τ Ori B5 III
Electra B6 III
Alcyone B7 IIIe
τ And B8 III
14 Lyr B9 III

B dwarfs

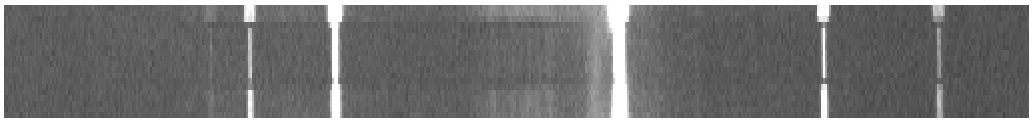

Hydrogen lamp
(+ oxygen)
36 Ori B0 V
66 Cyg B2 Vne
7 Hya B3 V
90 Leo B4 V
ψ 37 Per B5 Ve
30 Sex B6 V
Regulus B7 V
Pleione B8 Ve
12 Ser B9 V

Luminosity effects at B2



Luminosity effects at B5

Hydrogen lamp
(+ oxygen)

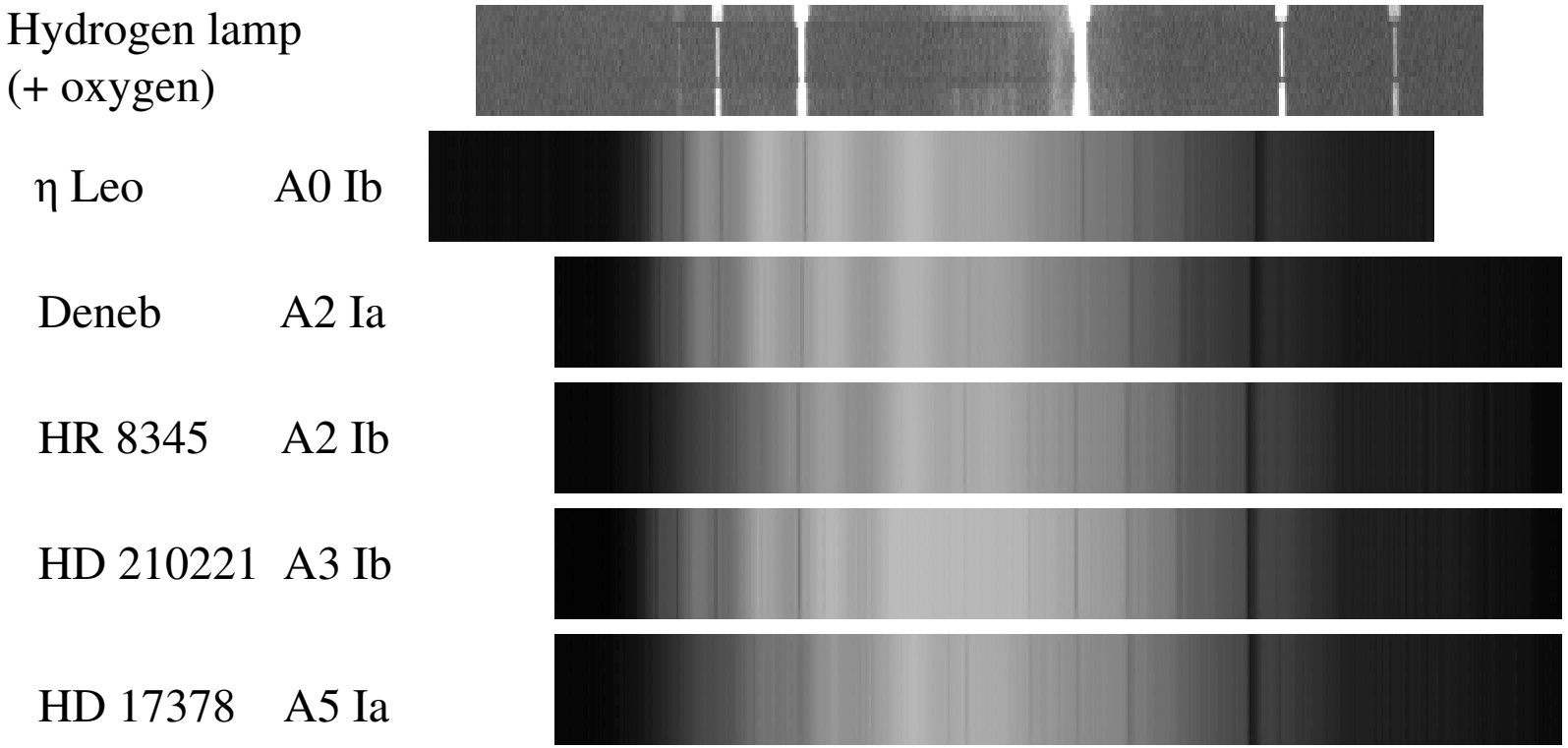


5 Per B5 Ia

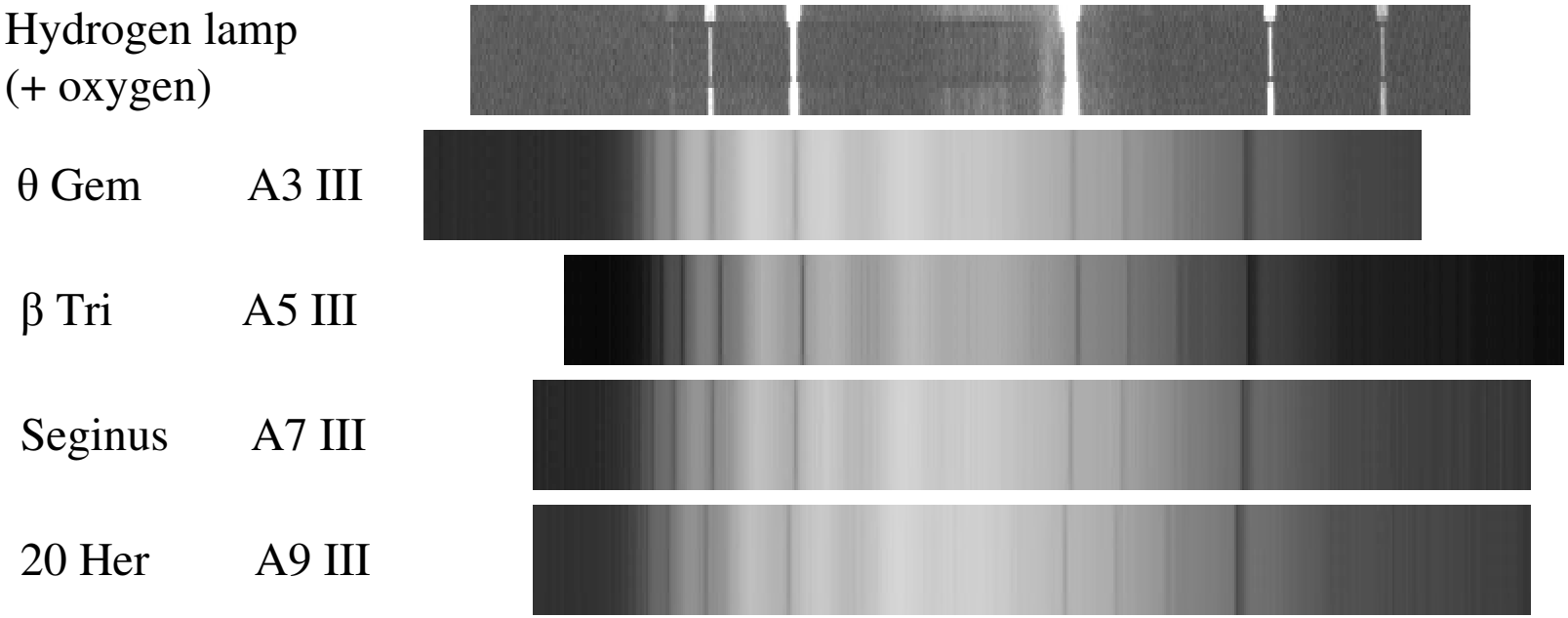
τ 20 Ori B5 III

HD 36936 B5 V

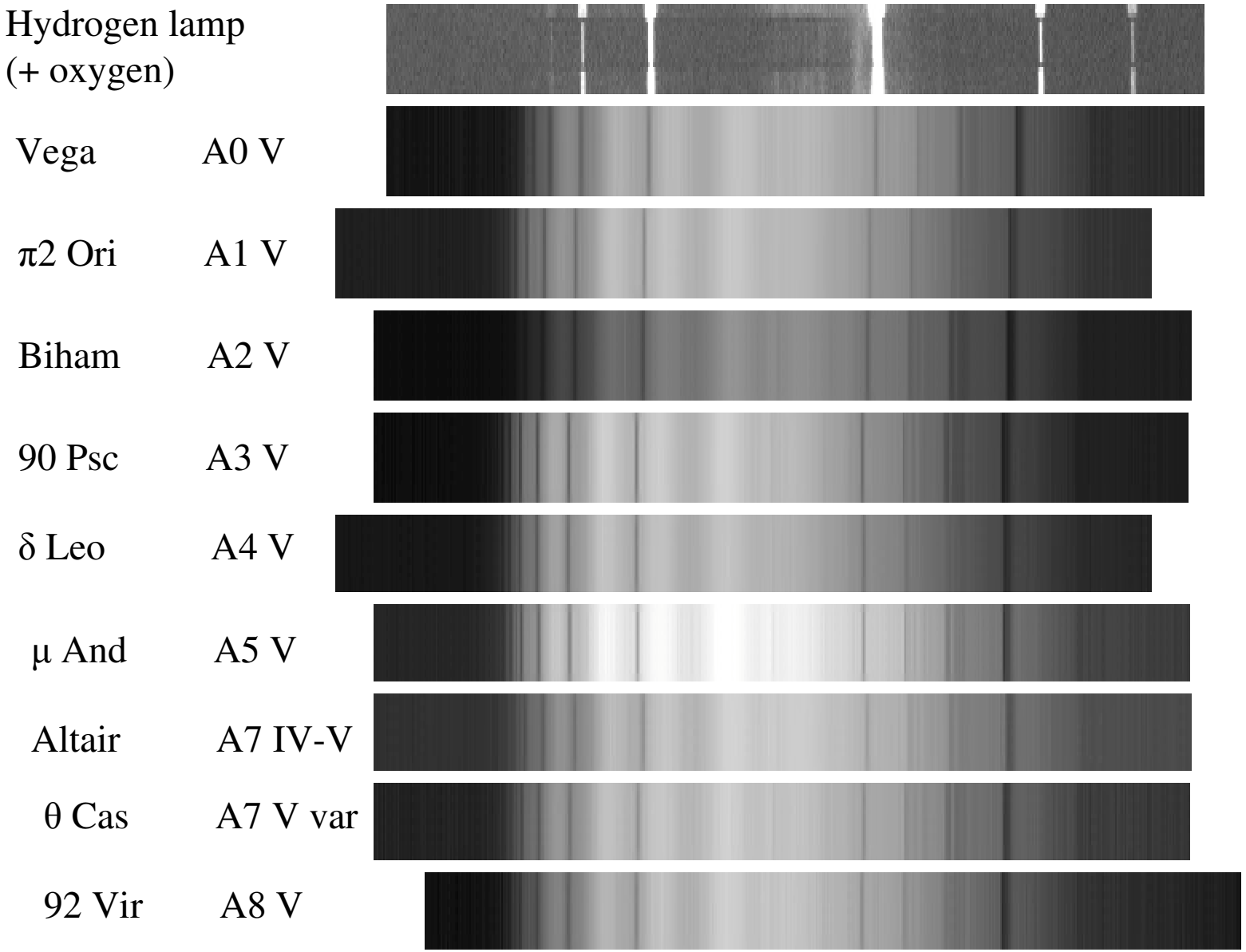
A supergiants



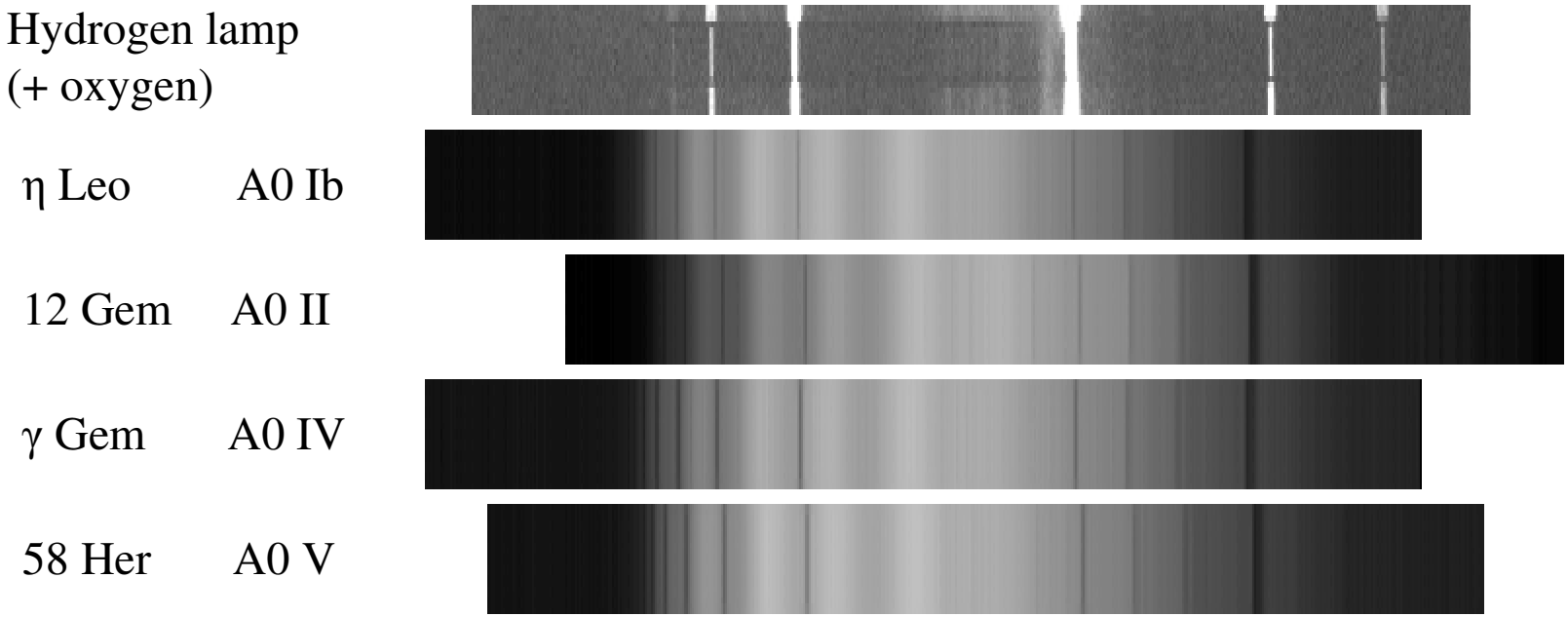
A giants


Hydrogen lamp
(+ oxygen)
θ Gem A3 III
β Tri A5 III
Seginus A7 III
20 Her A9 III

A dwarfs


Hydrogen lamp
(+ oxygen)
Vega A0 V
π2 Ori A1 V
Biham A2 V
90 Psc A3 V
δ Leo A4 V
μ And A5 V
Altair A7 IV-V
θ Cas A7 V var
92 Vir A8 V

Luminosity effects at A0



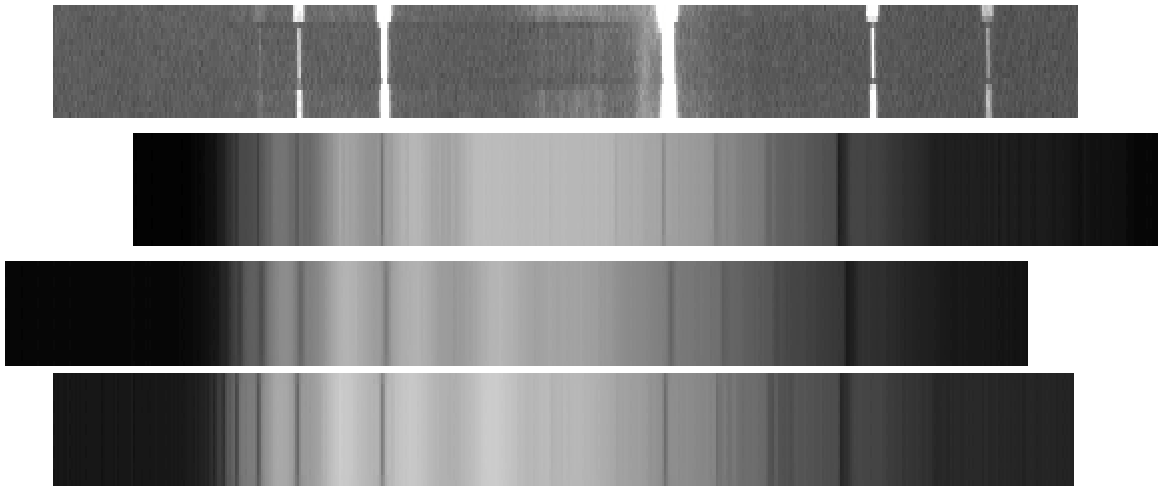
Luminosity effects at A3

Hydrogen lamp
(+ oxygen)

HD 210221 A3 Ib

θ Gem A3 III

90 Psc A3 V



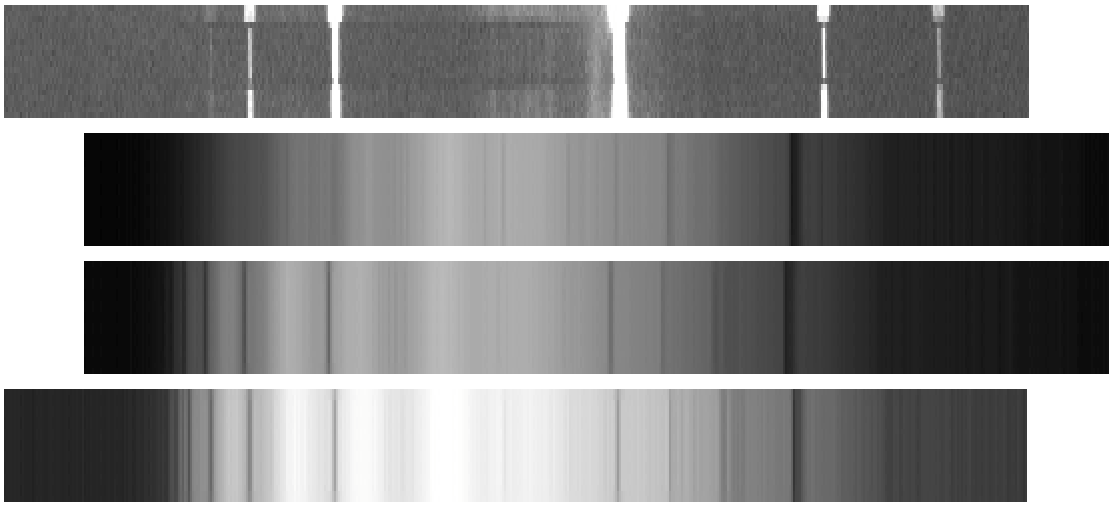
Luminosity effects at A5

Hydrogen lamp
(+ oxygen)

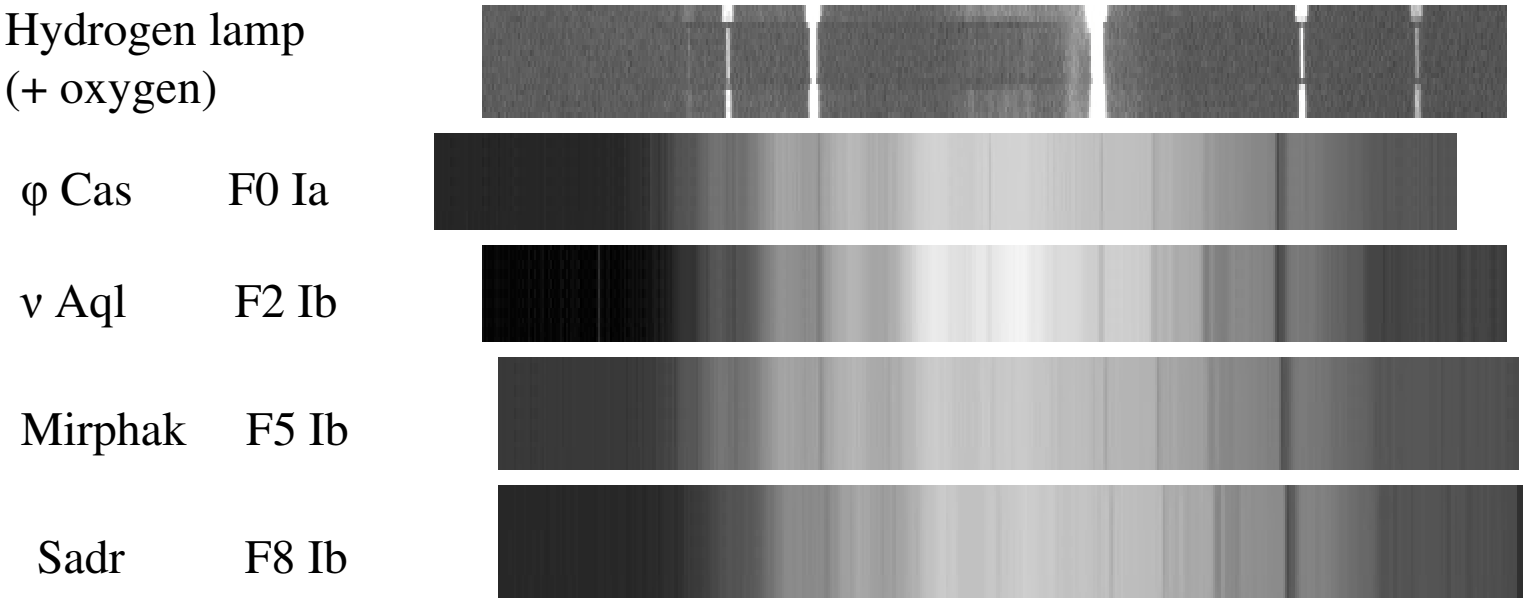
HD 17378 A5 Ia

β Tri A5 III

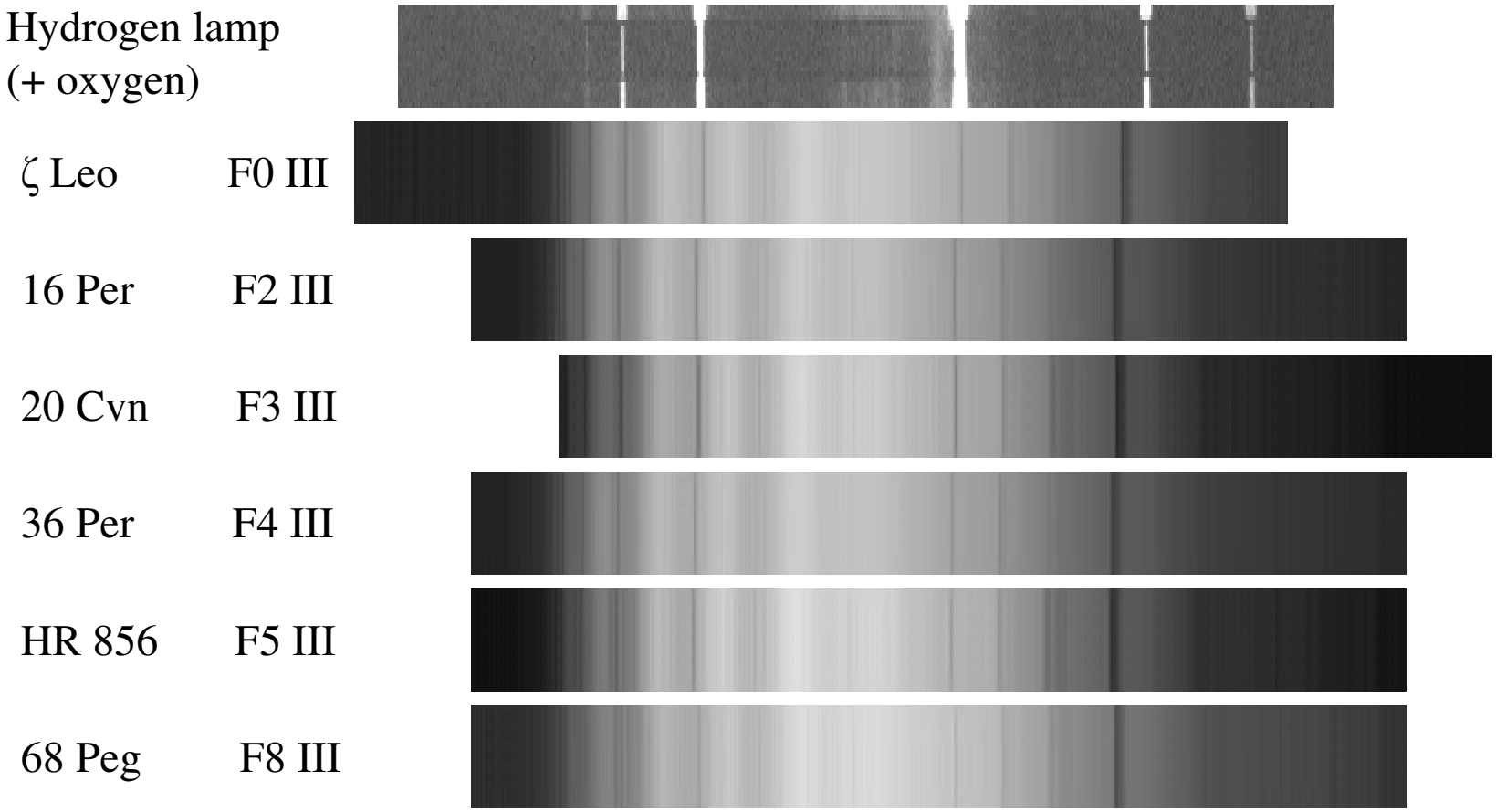
μ 37 And A5 V



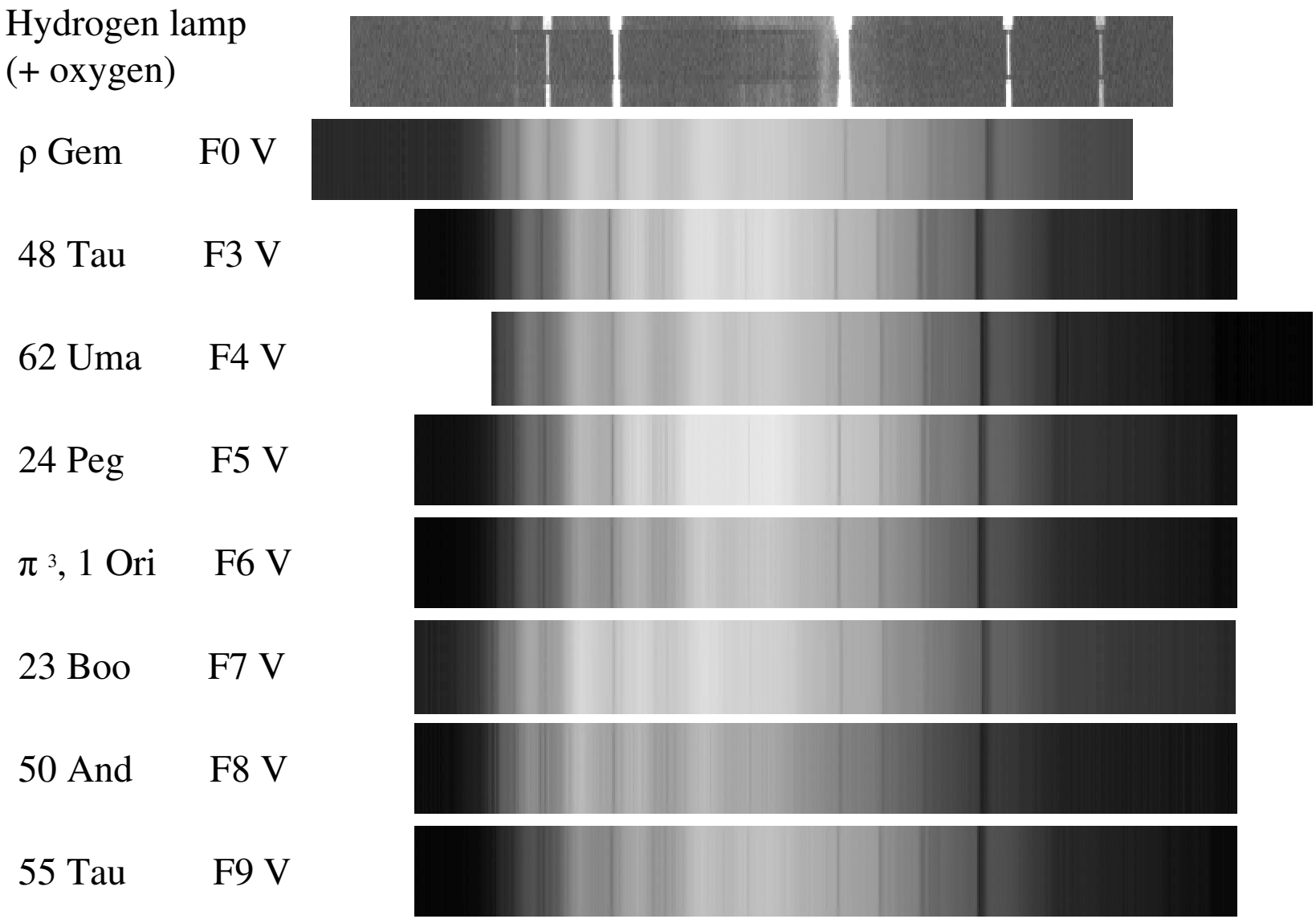
F supergiants



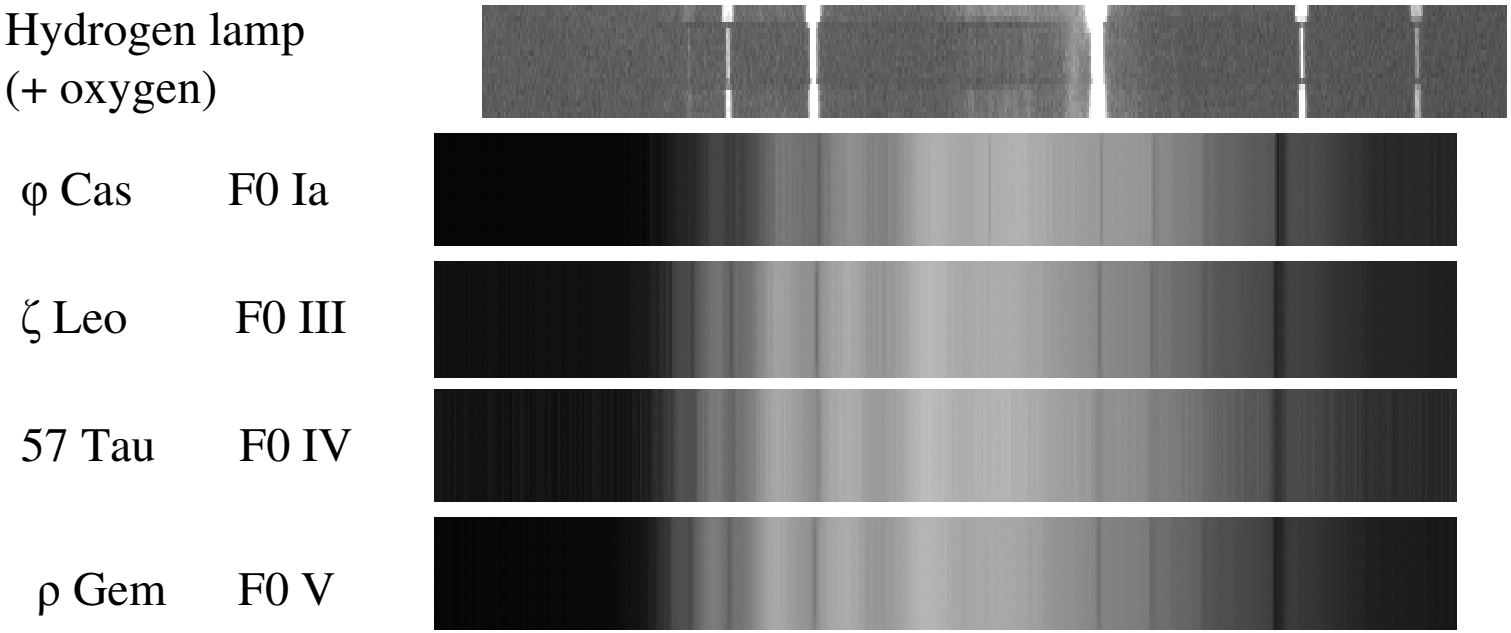
F giants


Hydrogen lamp
(+ oxygen)
ζ Leo F0 III
16 Per F2 III
20 Cvn F3 III
36 Per F4 III
HR 856 F5 III
68 Peg F8 III

F dwarfs


Hydrogen lamp
(+ oxygen)
ρ Gem F0 V
48 Tau F3 V
62 Uma F4 V
24 Peg F5 V
π 3, 1 Ori F6 V
23 Boo F7 V
50 And F8 V
55 Tau F9 V

Luminosity effects at F0



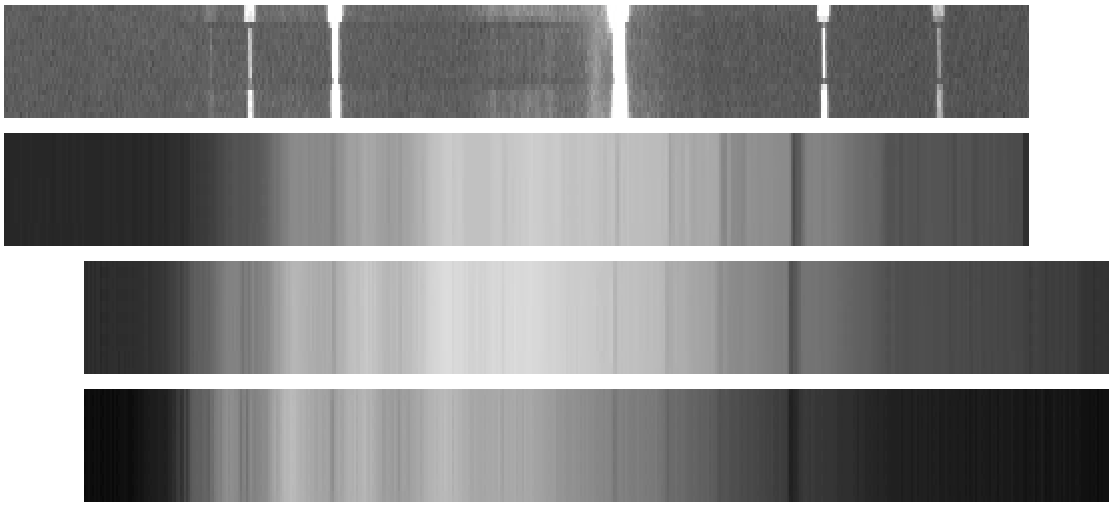
Luminosity effects at F8

Hydrogen lamp
(+ oxygen)

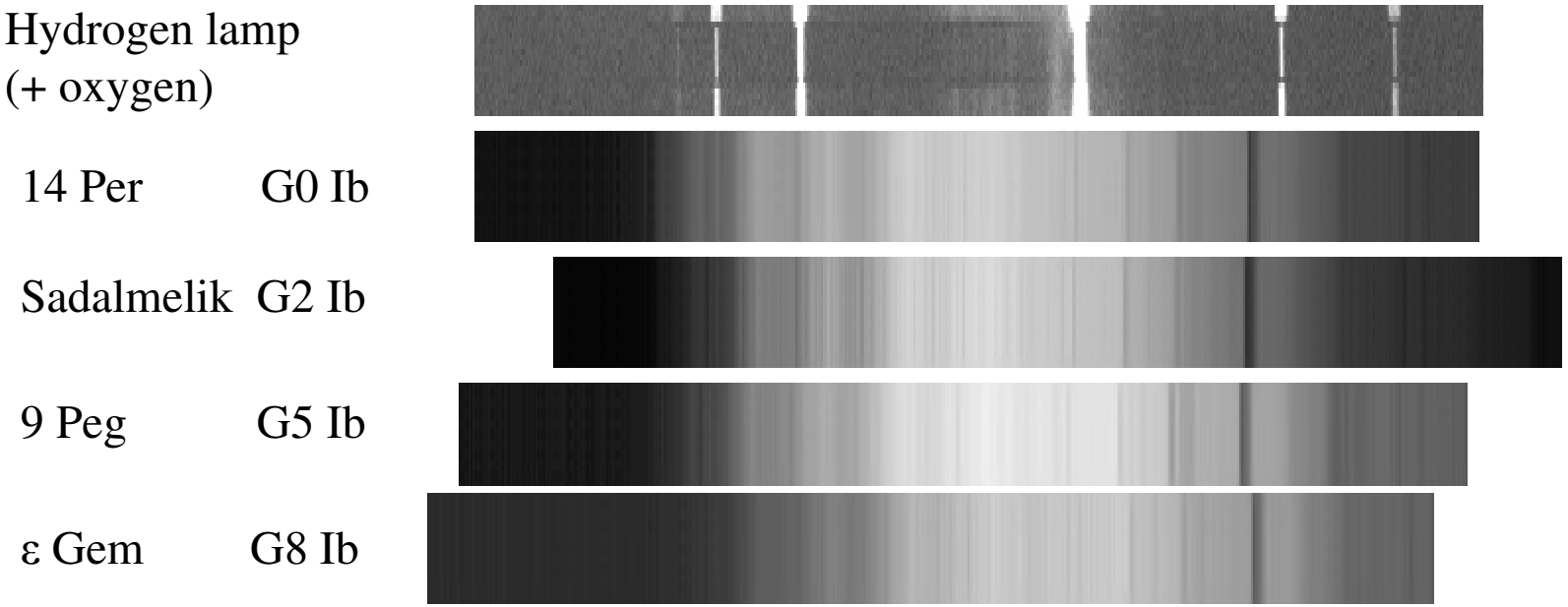
Sadr F8 Ib

68 Peg F8 III

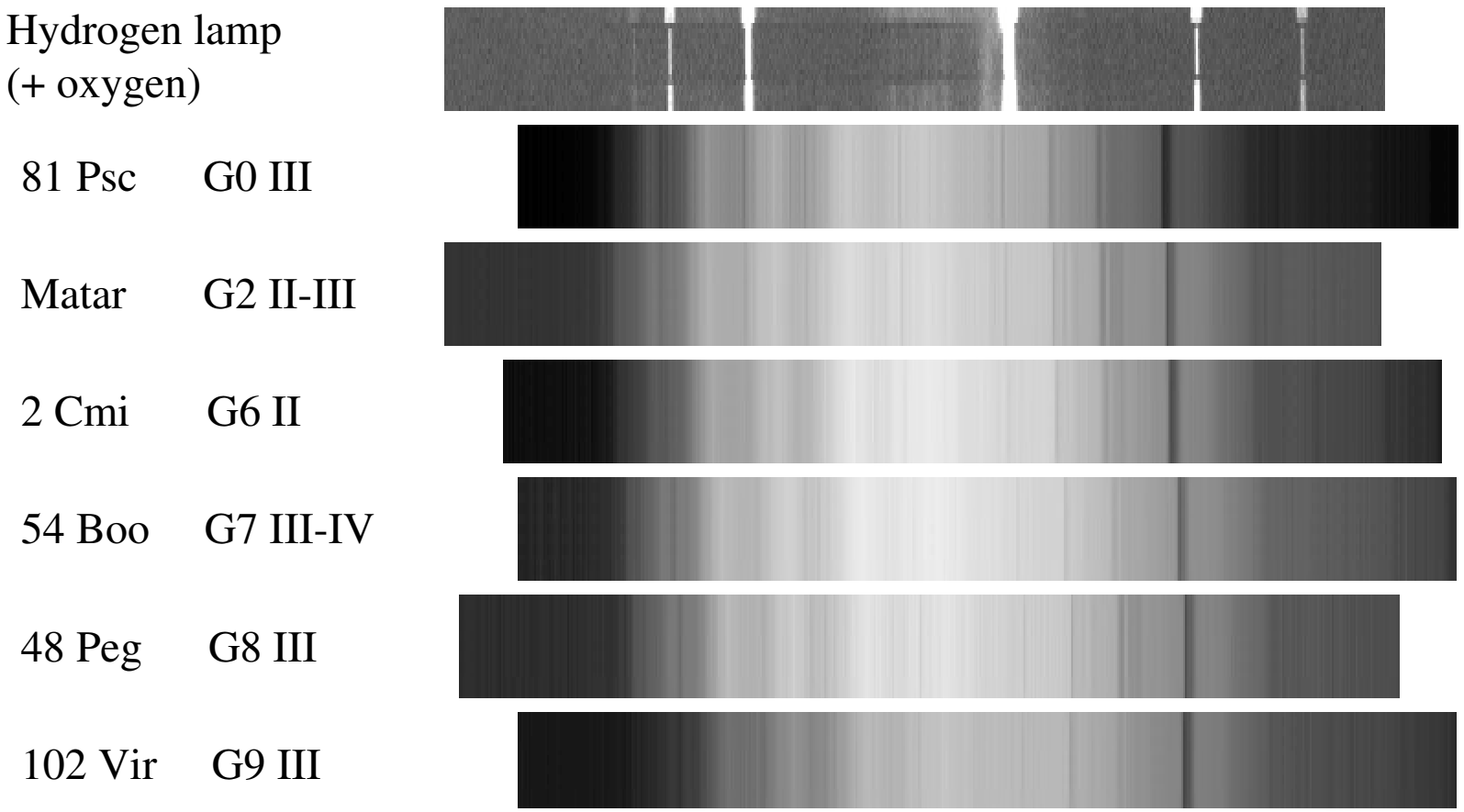
50 And F8 V



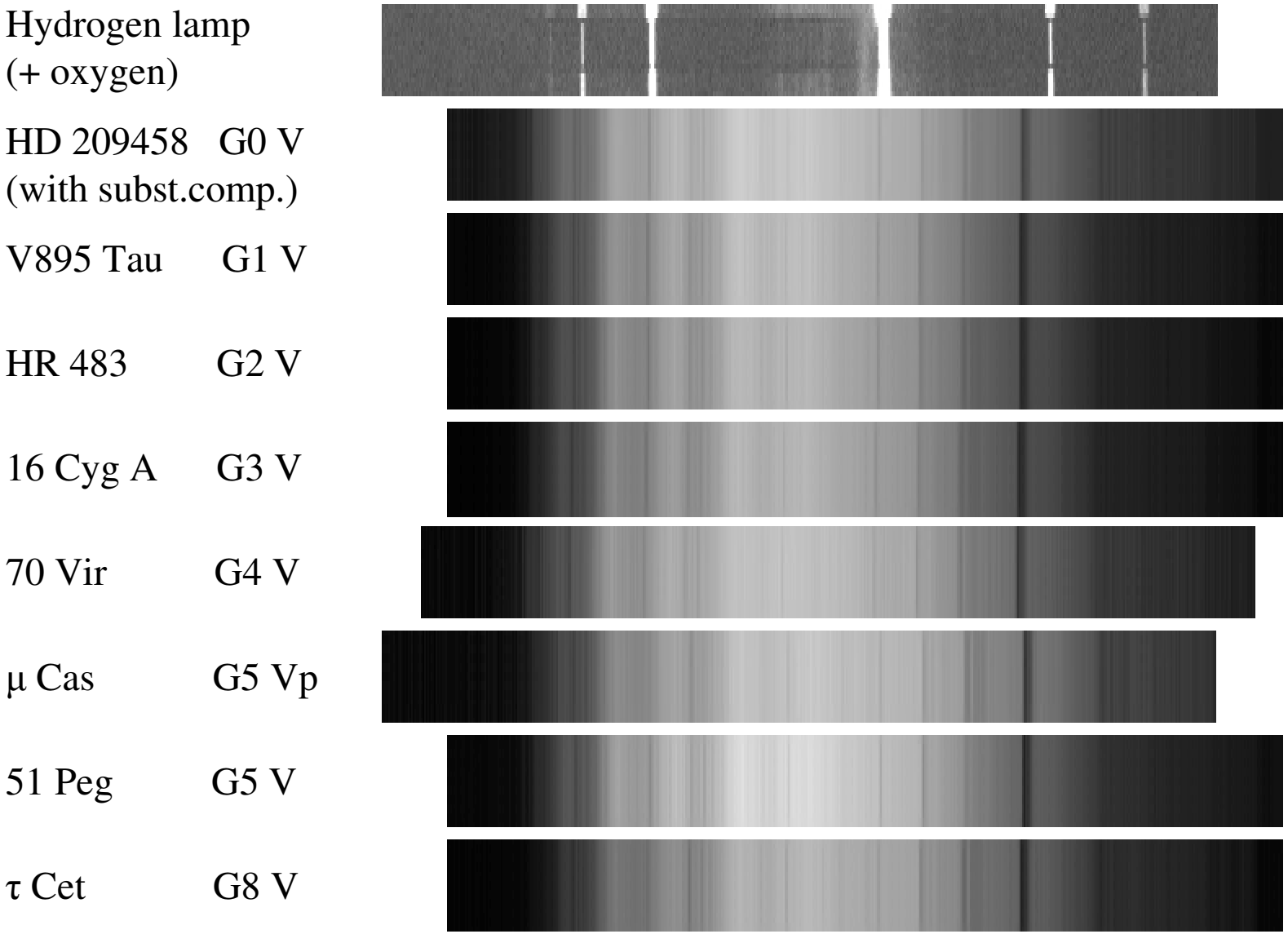
G supergiants



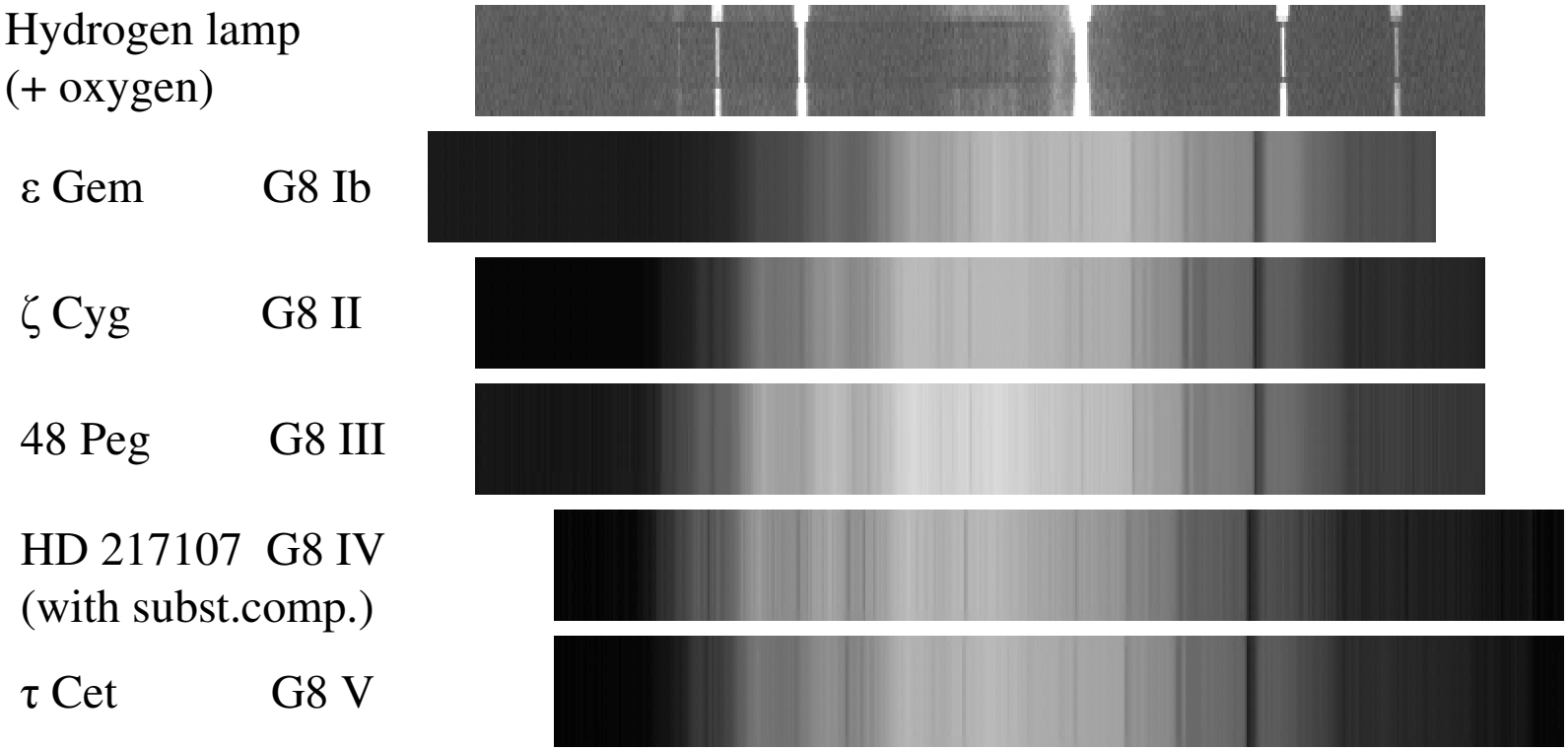
G giants


Hydrogen lamp
(+ oxygen)
81 Psc G0 III
Matar G2 II-III
2 Cmi G6 II
54 Boo G7 III-IV
48 Peg G8 III
102 Vir G9 III

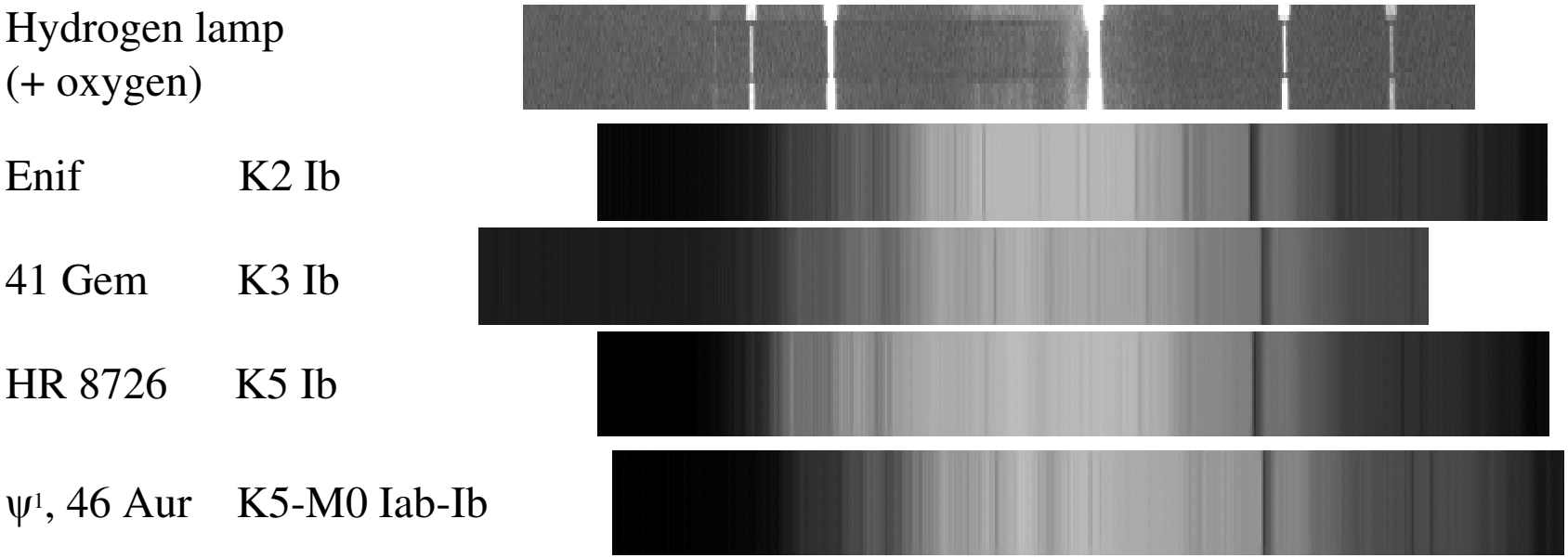
G dwarfs


Hydrogen lamp
(+ oxygen)
HD 209458 G0 V
(with subst.comp.)
V895 Tau G1 V
HR 483 G2 V
16 Cyg A G3 V
70 Vir G4 V
μ Cas G5 Vp
51 Peg G5 V
τ Cet G8 V

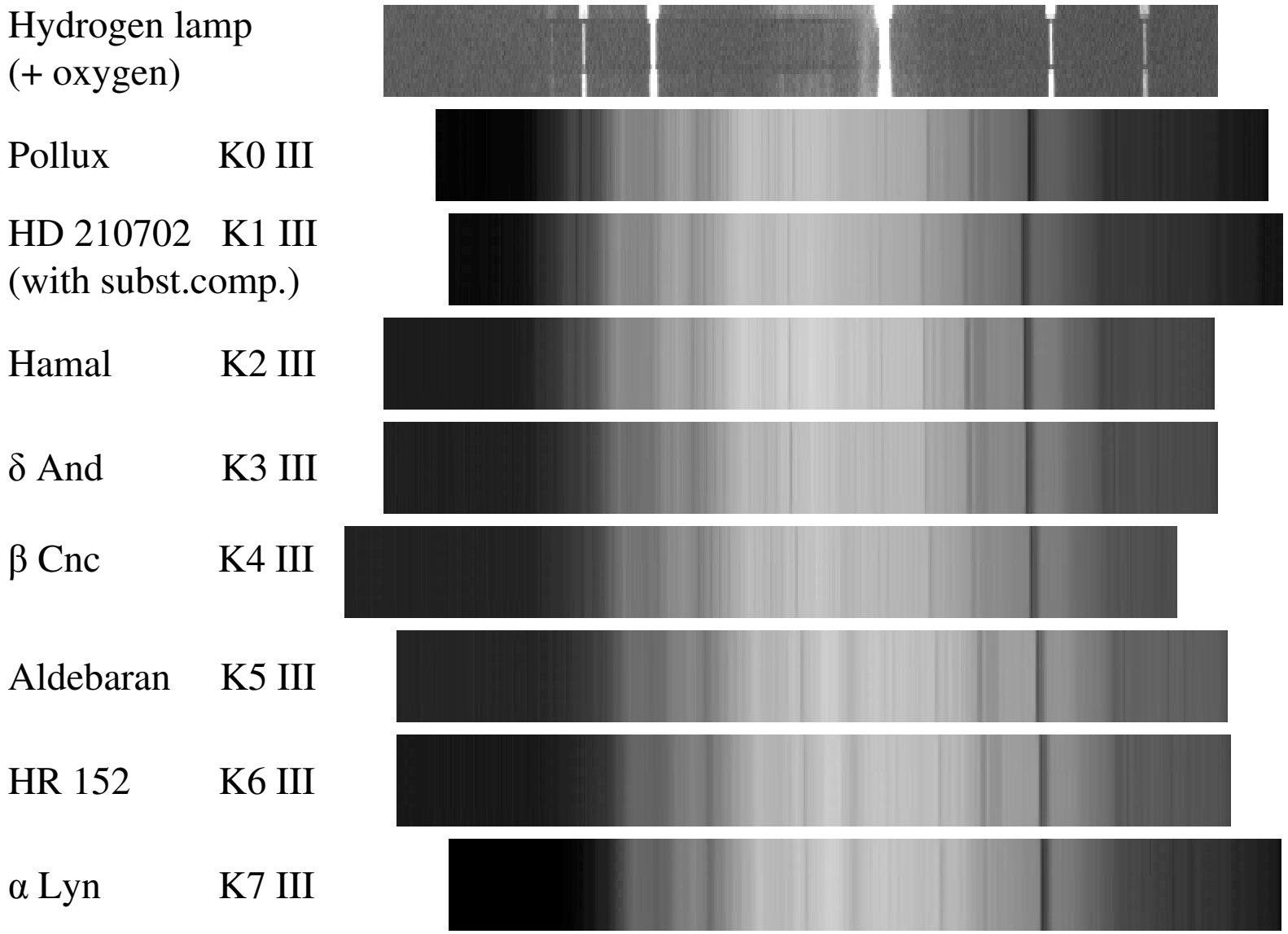
Luminosity effects at G8



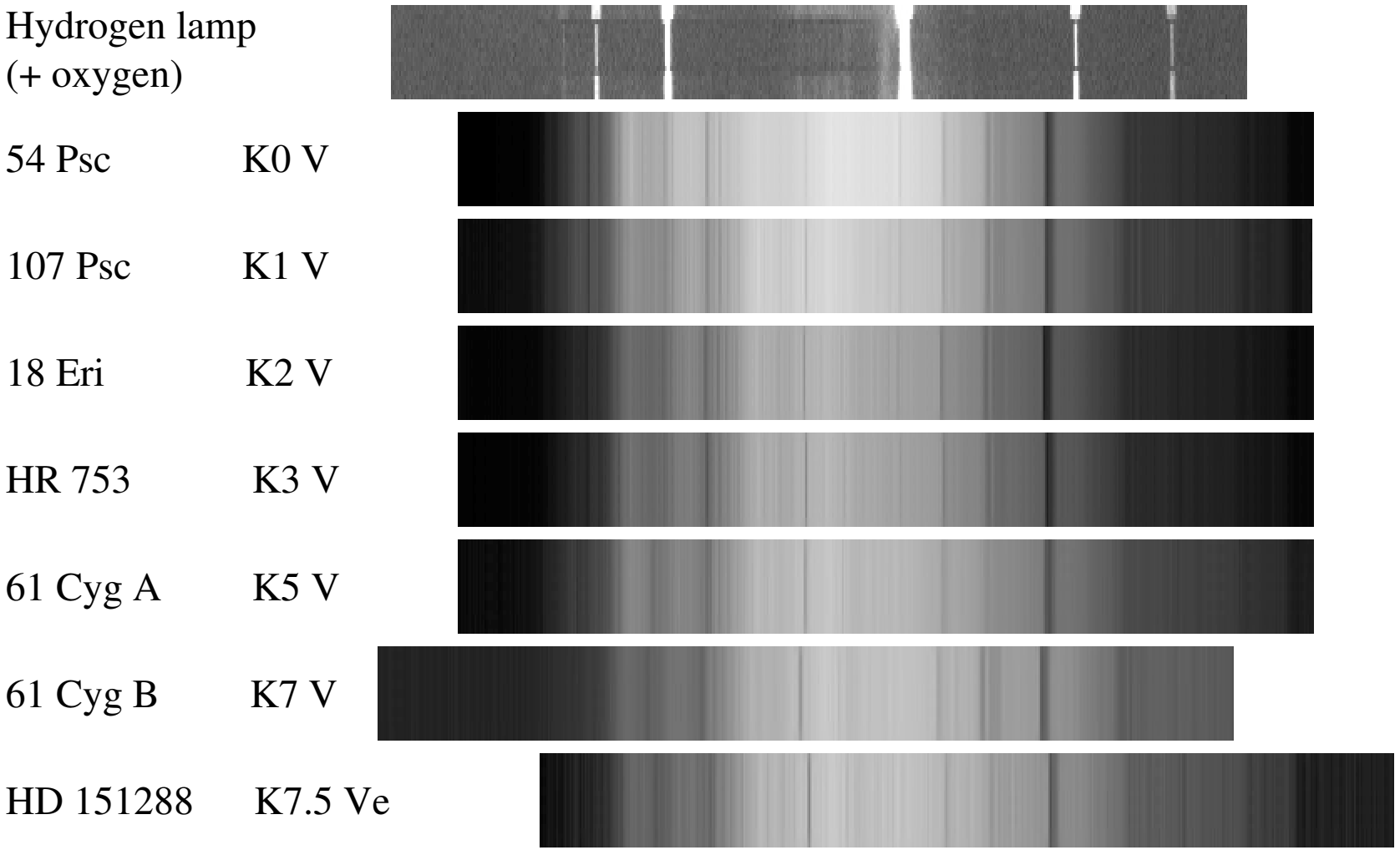
K supergiants



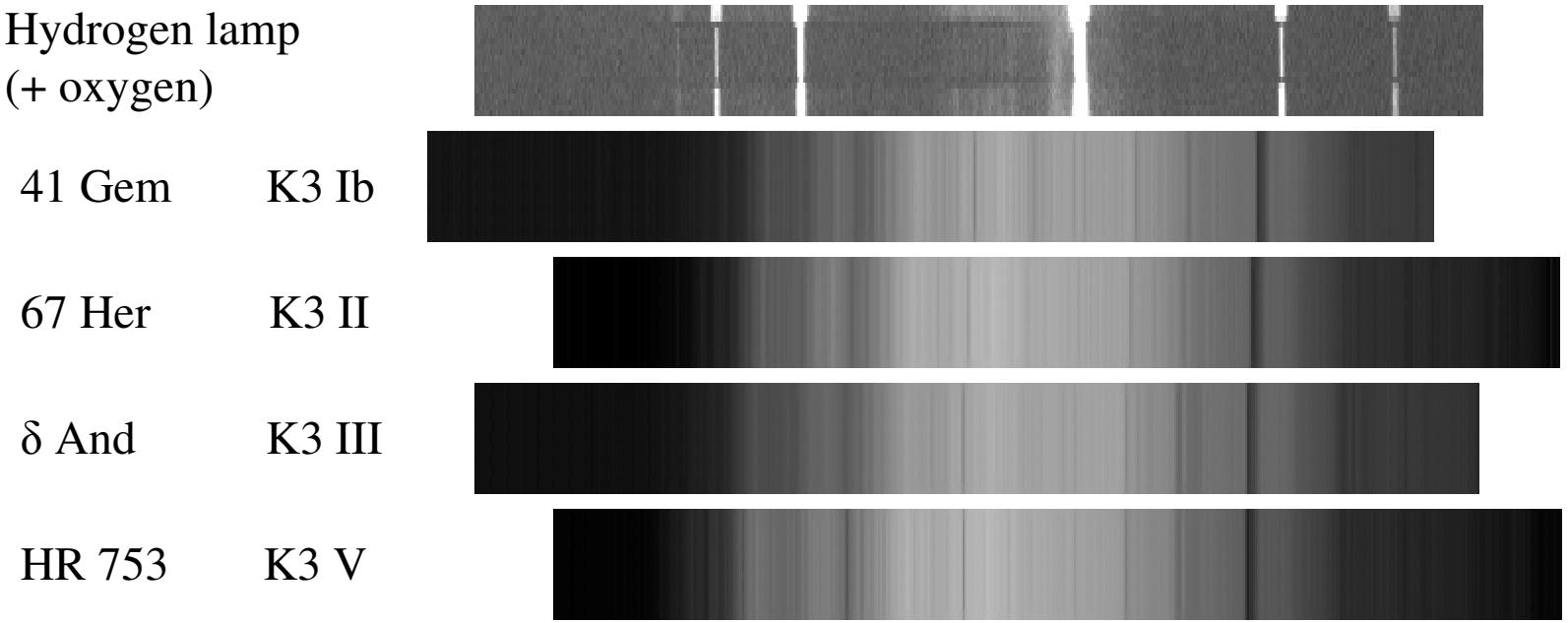
K giants


Hydrogen lamp
(+ oxygen)
Pollux K0 III
HD 210702 K1 III
(with subst.comp.)
Hamal K2 III
δ And K3 III
β Cnc K4 III
Aldebaran K5 III
HR 152 K6 III
α Lyn K7 III

K dwarfs


Hydrogen lamp
(+ oxygen)
54 Psc K0 V
107 Psc K1 V
18 Eri K2 V
HR 753 K3 V
61 Cyg A K5 V
61 Cyg B K7 V
HD 151288 K7.5 Ve

Luminosity effects at K3



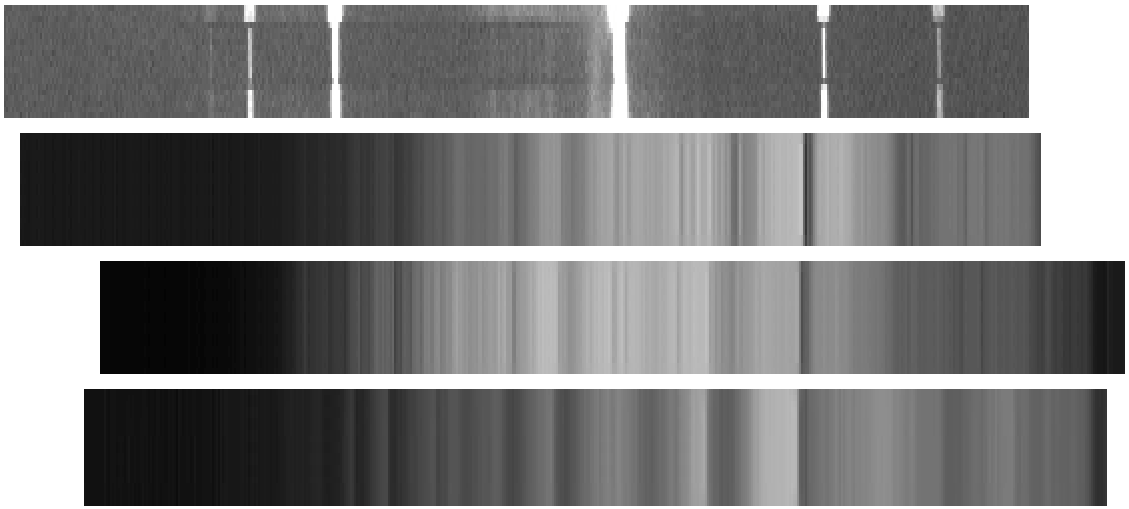
M supergiants

Hydrogen lamp
(+ oxygen)

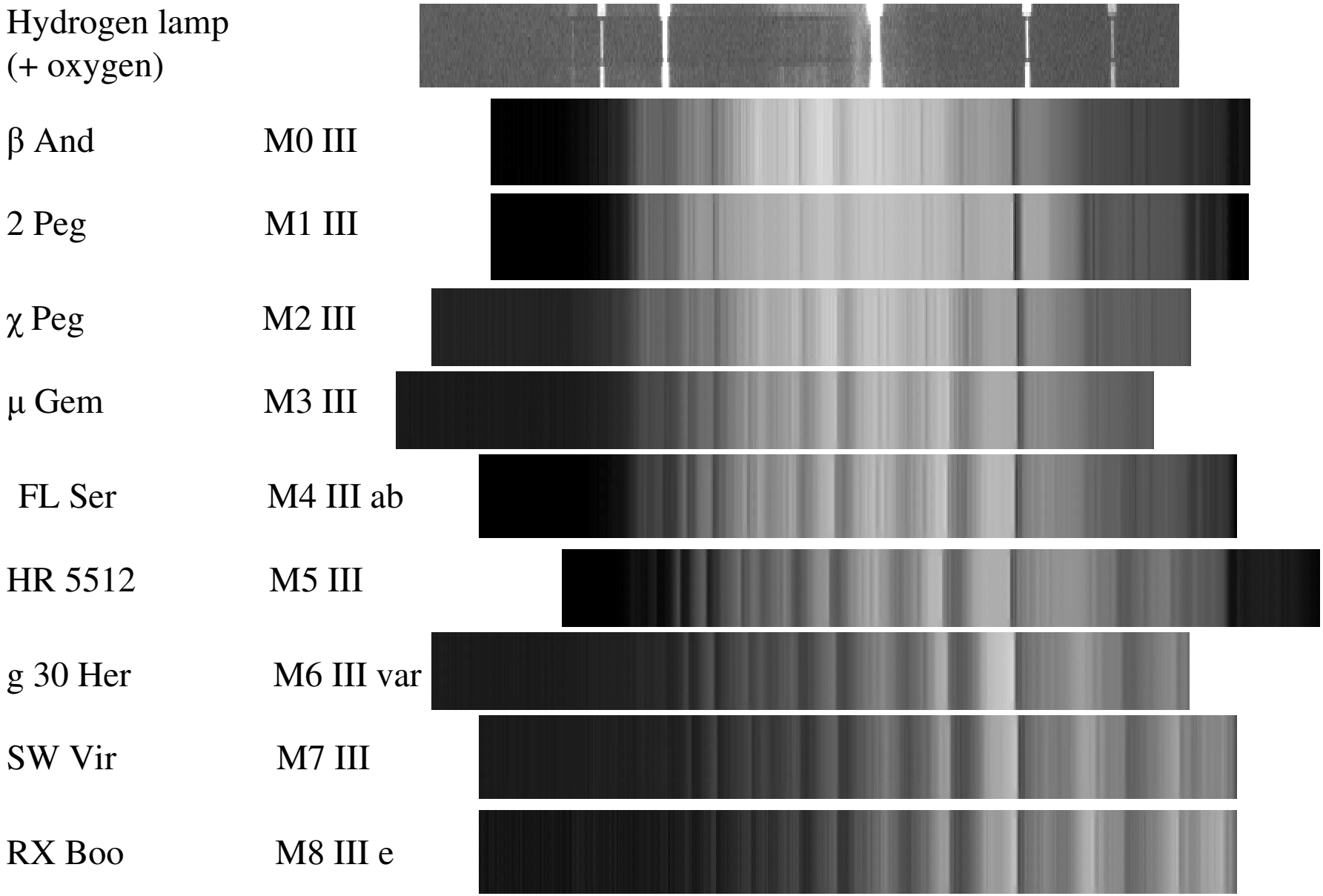
Betelgeuse M1-2 Ia- Ib

HD 10465 M2 Ib

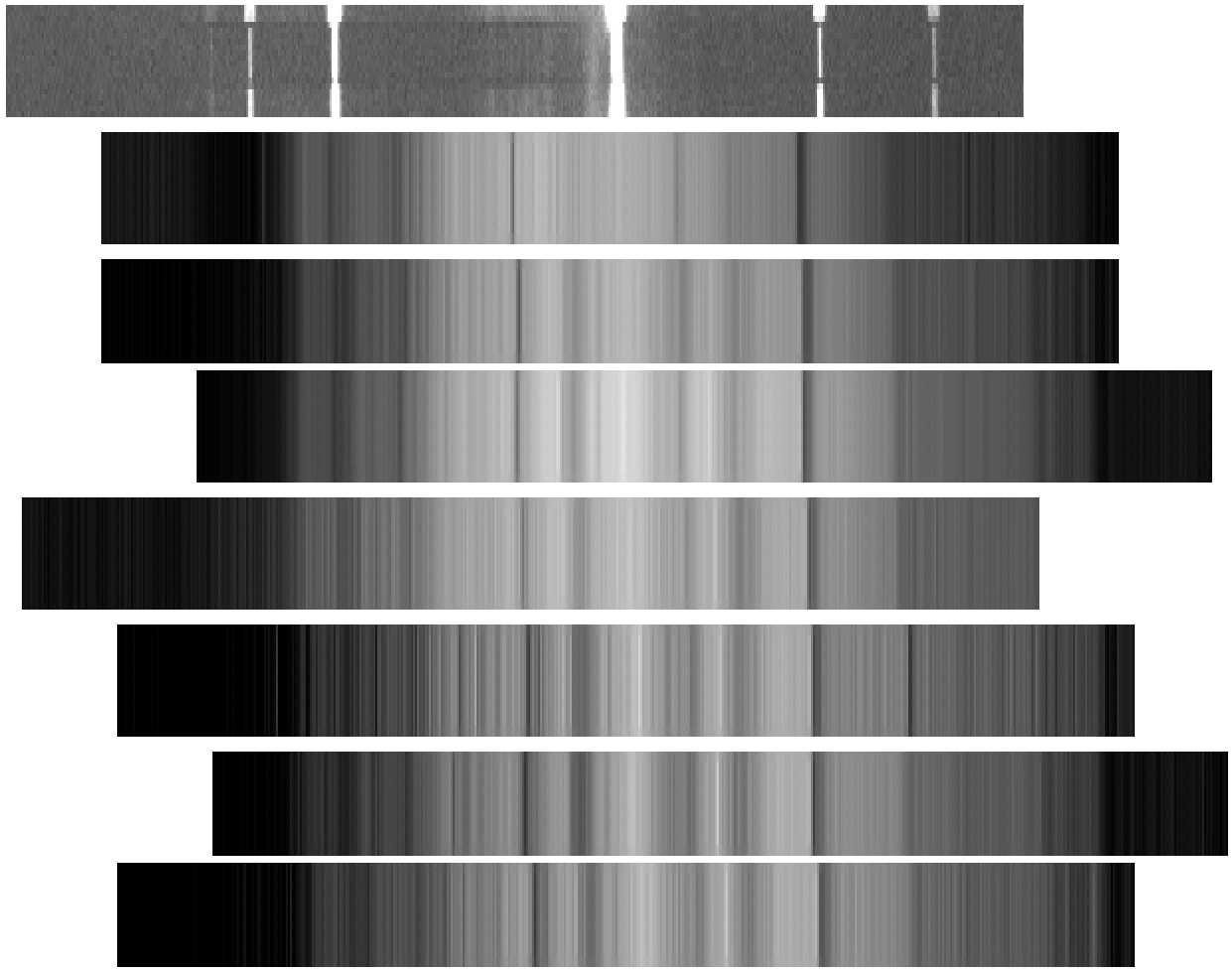
64 Her M5 Ib-II



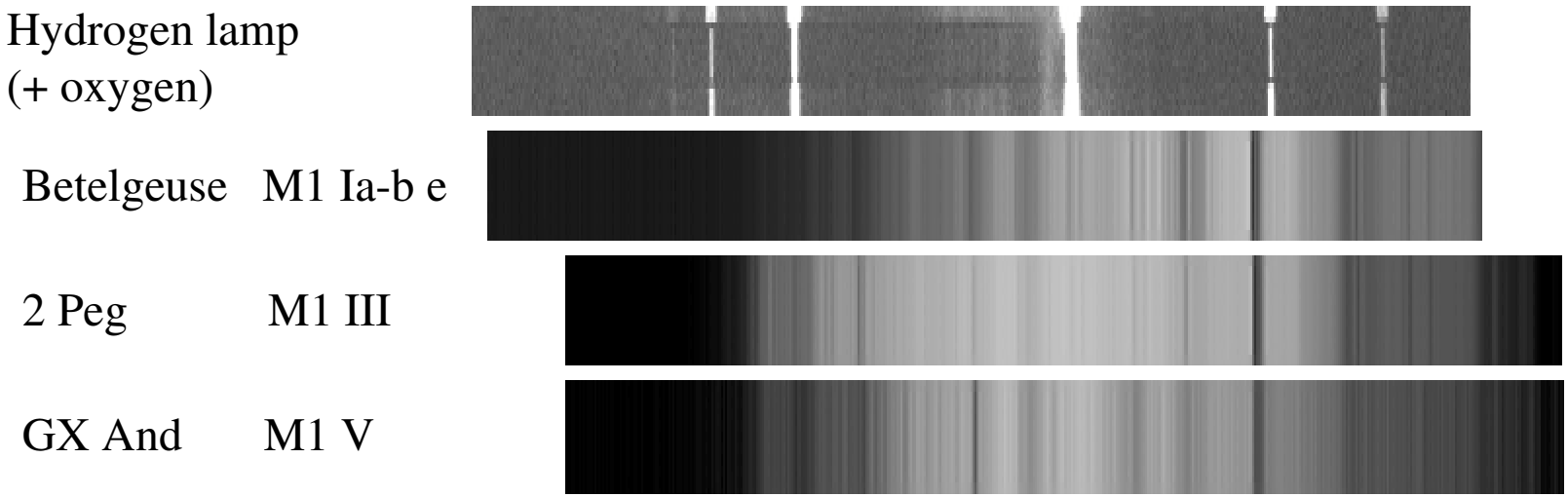
M giants


Hydrogen lamp
(+ oxygen)
β And M0 III
2 Peg M1 III
χ Peg M2 III
μ Gem M3 III
FL Ser M4 III ab
HR 5512 M5 III
g 30 Her M6 III var
SW Vir M7 III
RX Boo M8 III e

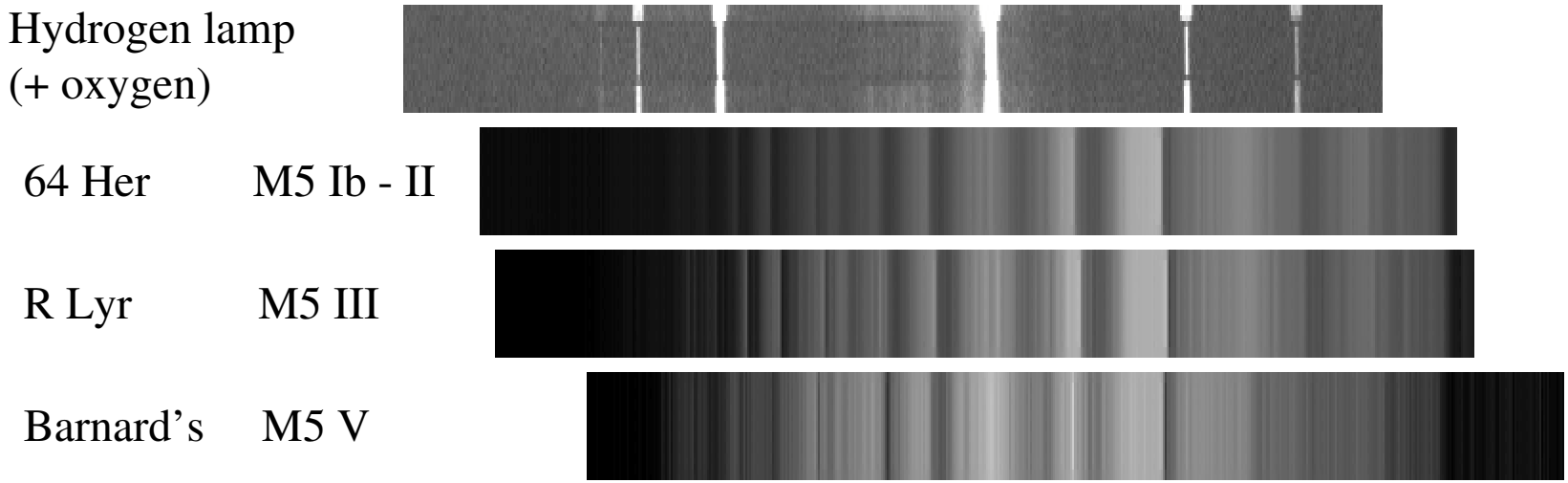
M dwarfs


Hydrogen lamp
(+ oxygen)
HD 19305 M0 V
GX And M1 V e
Gl 411 M2 V
HD 180617 M3 V
EQ Peg M4 Ve
Barnard's M5 V
GQ And M6 V e

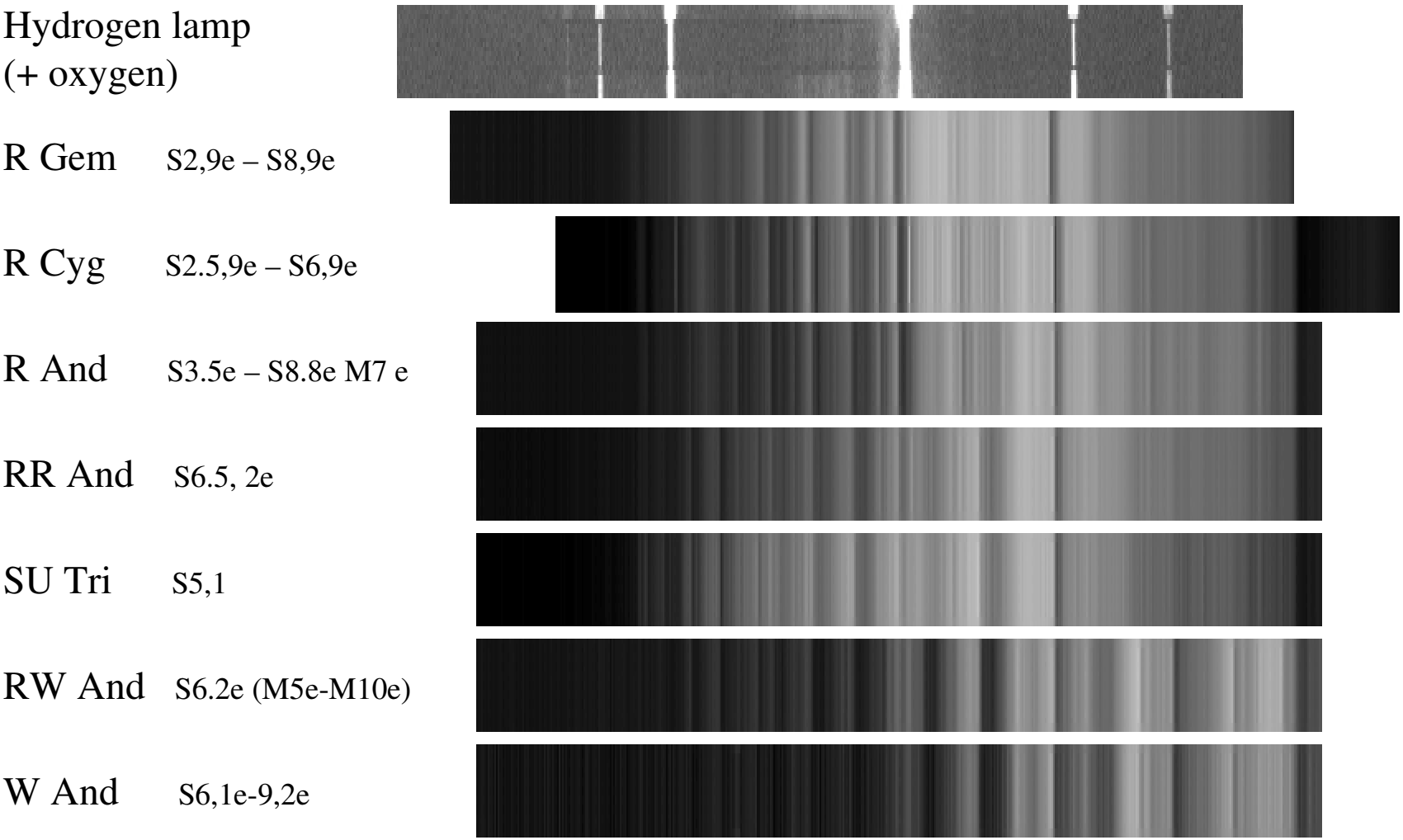
Luminosity effects at M1



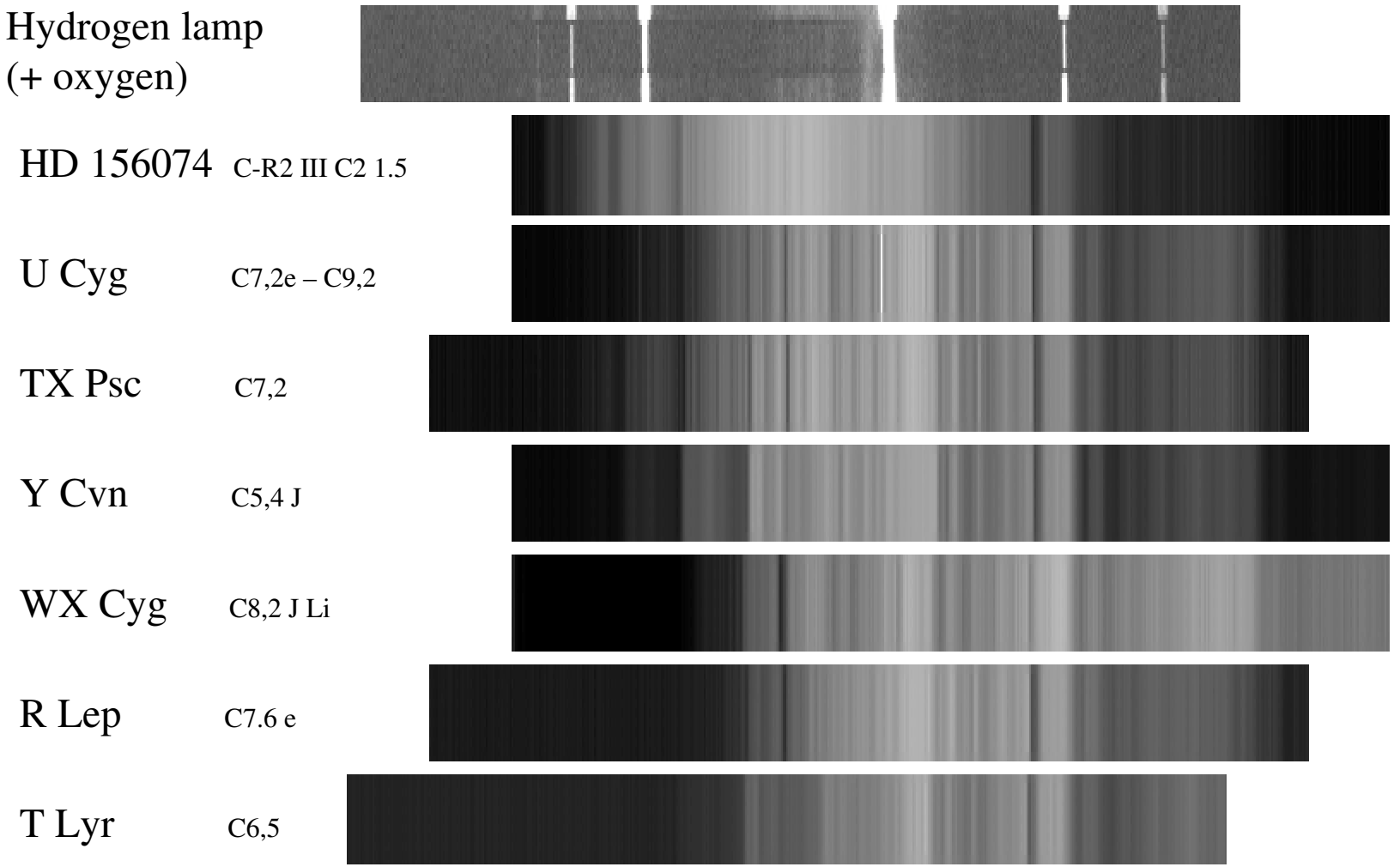
Luminosity effects at M5



S stars


Hydrogen lamp
(+ oxygen)
R Gem S2,9e – S8,9e
R Cyg S2.5,9e – S6,9e
R And S3.5e – S8.8e M7 e
RR And S6.5, 2e
SU Tri S5,1
RW And S6.2e (M5e-M10e)
W And S6,1e-9,2e

C (carbon) stars



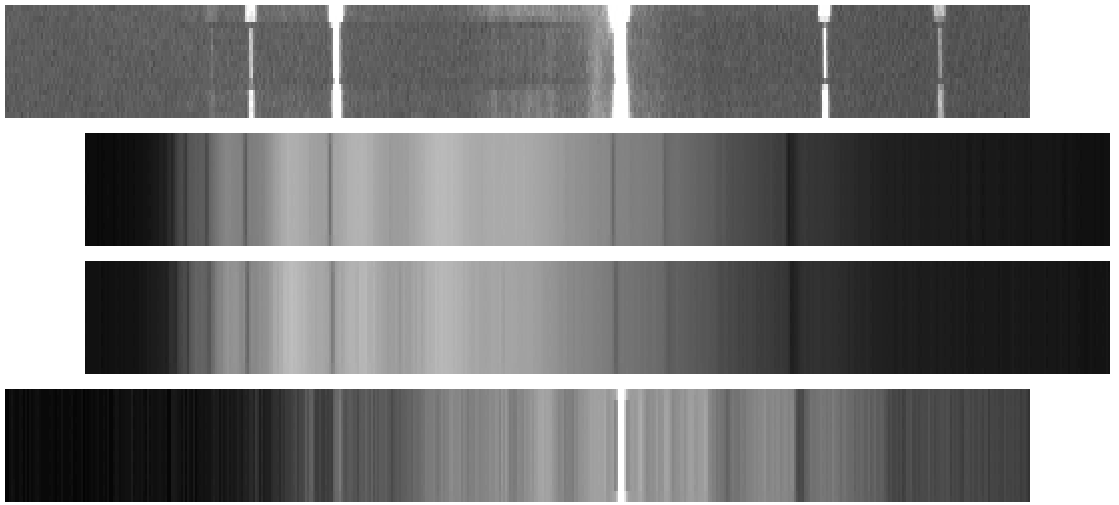
Peculiar stellar spectra

Hydrogen lamp
(+ oxygen)

θ, 37 Aur A0 p Si

63 Tau A1 m

AG Peg WN6 + M3 III



Hill et al.'s M_v – W(Hγ) relationship

- $M_V = -9.09+(1.776-0.0586*s)*W(H\gamma)$

where:
Mv = V band absolute magnitude
s = numeric index (integer) from 0 at B0 to 13 at A3
W(Hγ) = equivalent width of Hγ line

Useful range: from O6 I to A3 I
Source: Hill et al., 1986

Osmer's M_v – W(OI) relationship

- $M_V = -2.62*W(OI_{7774})-2.55$

  where:
  M_V = V band absolute magnitude
  $W(OI_{7774})$ = equivalent width of OI line at 7774 A

  Useful range: from F0 I to F9 I
  Source: Osmer, 1971

Wilson-Bappu effect

- $M_V = -15.8*\log(w)+29.4$

  where:
  M_V = V band absolute magnitude
  $w = (\lambda_r - \lambda_0) - (\lambda_v - \lambda_0)$
  w of K line of Ca II at 3933 A

  Source: Wilson & Bappu, 1957

Conclusions

- At OAC we obtained a library of more than 200 stellar spectra taken with a CCD spectrograph in the wavelenght range from ~ 350 nm to ~ 950 nm
- We proved the usefulness of this library in classifying previously unknown stellar spectra
- IRF staff recently implemented a beta version of a software for automatic spectral classification which is based on an algorithm with Artificial Neural Networks
- Most of this library is disposable on-line in the Internet site of OAC

Final aphorisms

Experience:

- "About experience, it is what remains when we loose all other things".
  From: "Il mulino del Po" (1938-1940) (in italian)
  Riccardo Baccelli (1891-1985)

- "Experience is the name we give to our mistakes"
  Oscar Wilde