Stellar Endpoints

A presentation by Katie Reyes

White Dwarf Stars

Medium.com

The Basics

- Hot dense core of low mass star ($< 10\ M_{\odot}$) at end of its life
- Left over after planetary nebula dissipates
- Typical radius: earth
- Typical mass: sun
- No more fusion → gravitational pressure balanced by electron degeneracy pressure
- Therefore, maximum mass $1.4\ M_{\odot}$
- Made mostly of carbon and oxygen
- Atmosphere mostly hydrogen
- Most common end to lifetime of a star

Classification

Letters:

- First letter: type of star
  - For white dwarfs, “D” = degenerate star
- Second letter: primary spectroscopic characteristic
  - E.g. “Q” = carbon most abundant element in atmosphere
- Third letter and on: secondary composition for trace elements
  - E.g. “A” = Trace amounts of hydrogen in atmosphere
- All together: DQA

Spectral Type Symbols and Characteristics
DA – Only Balmer lines; no He I or metals present
DB – He I lines; no H or metals present
DC – Continuous spectrum, no lines deeper than 5% in any part of the electromagnetic spectrum
DO – He II strong; He I or H present
DZ – Metal lines only; no H or He lines
DQ – Carbon features, either atomic or molecular in any part of the electromagnetic spectrum
Additional Symbols
P – Magnetic white dwarfs with detectable polarization
H – Magnetic white dwarfs without detectable polarization
X – Peculiar or unclassifiable spectrum
E – Emission lines are present
? – Uncertain assigned classification; a colon (:) may also be used
V – Optional symbol to denote variability
d – Circumstellar dust
C I, C II, O I, O II – added within parentheses to hot DQ star types to indicate presence of these atomic species

Classification

Numbers:

- Immediate follow letters
- First number: surface temperature classification
  - Based on color temperature of modeled atmosphere
  - Integer or half-integer equal to 50400 K/T_{eff} up to 13
  - E.g. “4” : 50,400 K/13,000 K = 3.9
  - E.g. “1.5” : 50,400 K/33,000 K = 1.5
  - Temperatures > 50,400 K: use decimal to the tenths place
  - E.g. “.8” : 50,400 K/63,000 K = 0.8
- Second number: gravity classification
  - Log(g) from 7 to 9, rounded to tenths place
  - After underscore

Classification

Example: DQAB1.5_8.7

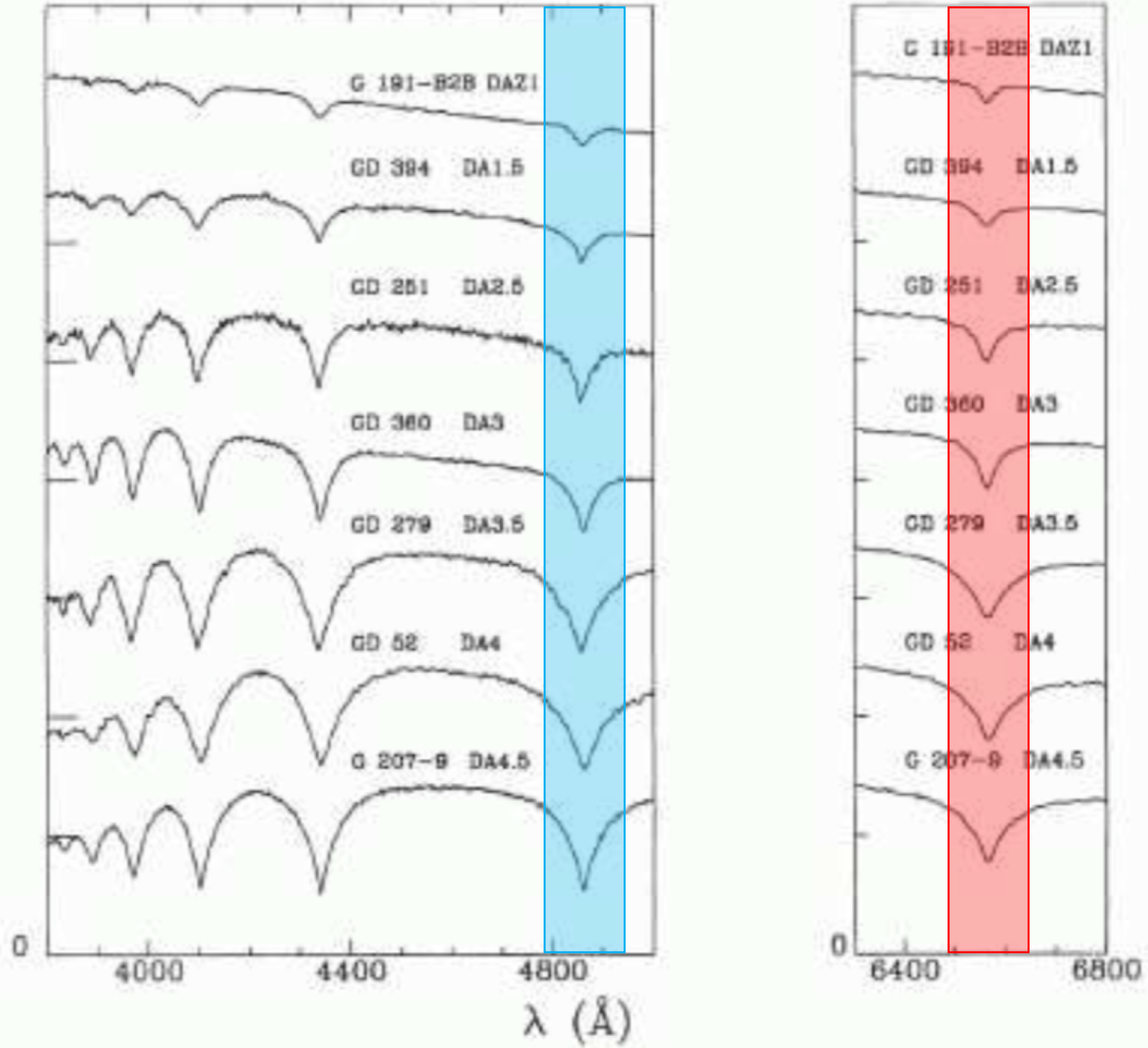
- white dwarf with atmosphere composed of mainly carbon with trace amounts of hydrogen (A) and helium (B), surface temperature ~33,600 K, log(g) = 8.7

One additional letter

- add “d” to end to indicate a dusty circumstellar disk
- Reddening

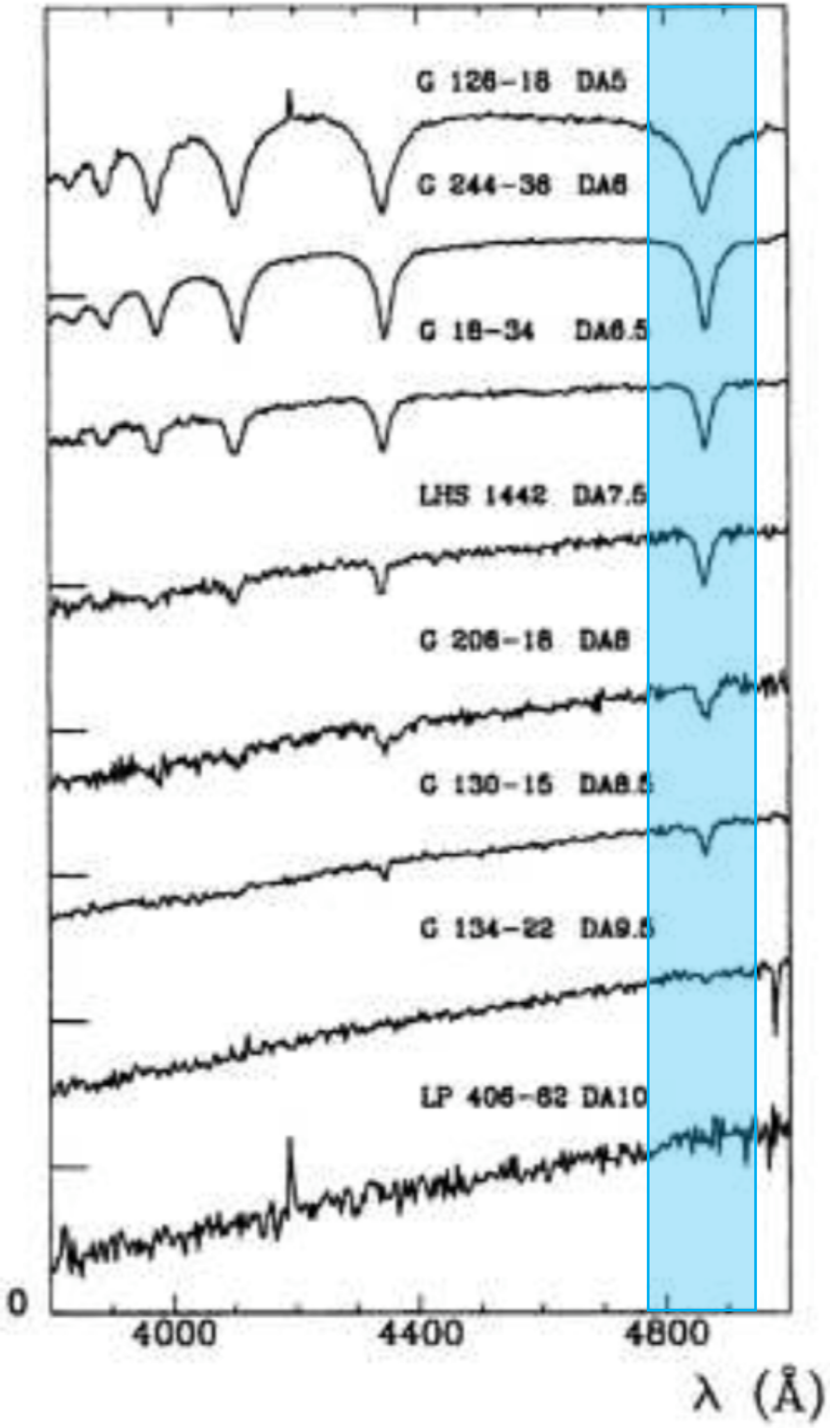
Letter in front of star spectrum similar to WD:

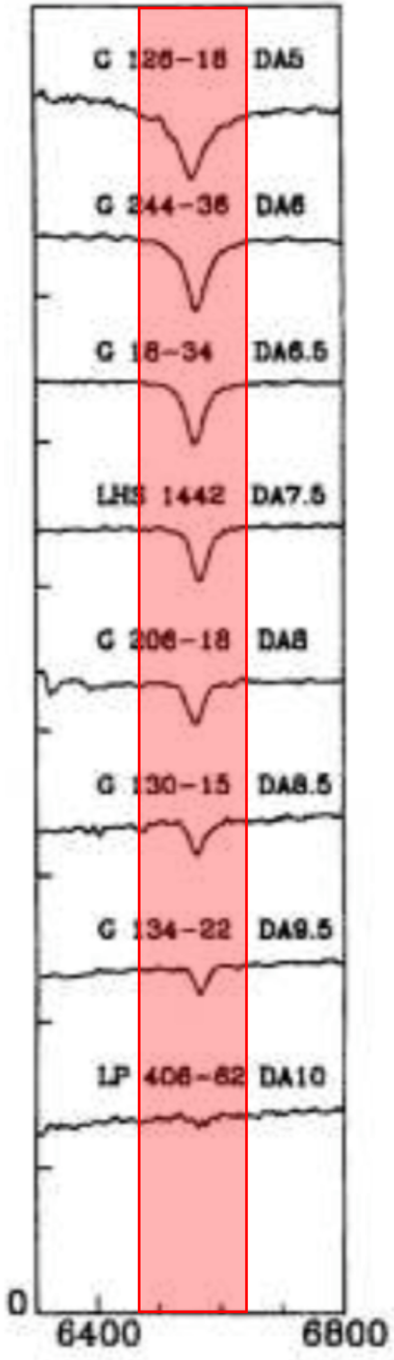
- Lower-case
- Describes width of lines in spectra
- “d” = diffuse: broadened due to gravity
- “n” = narrow: narrow line
- “s” = sharp: sharpened line due to low gravity



Type DA: Hot

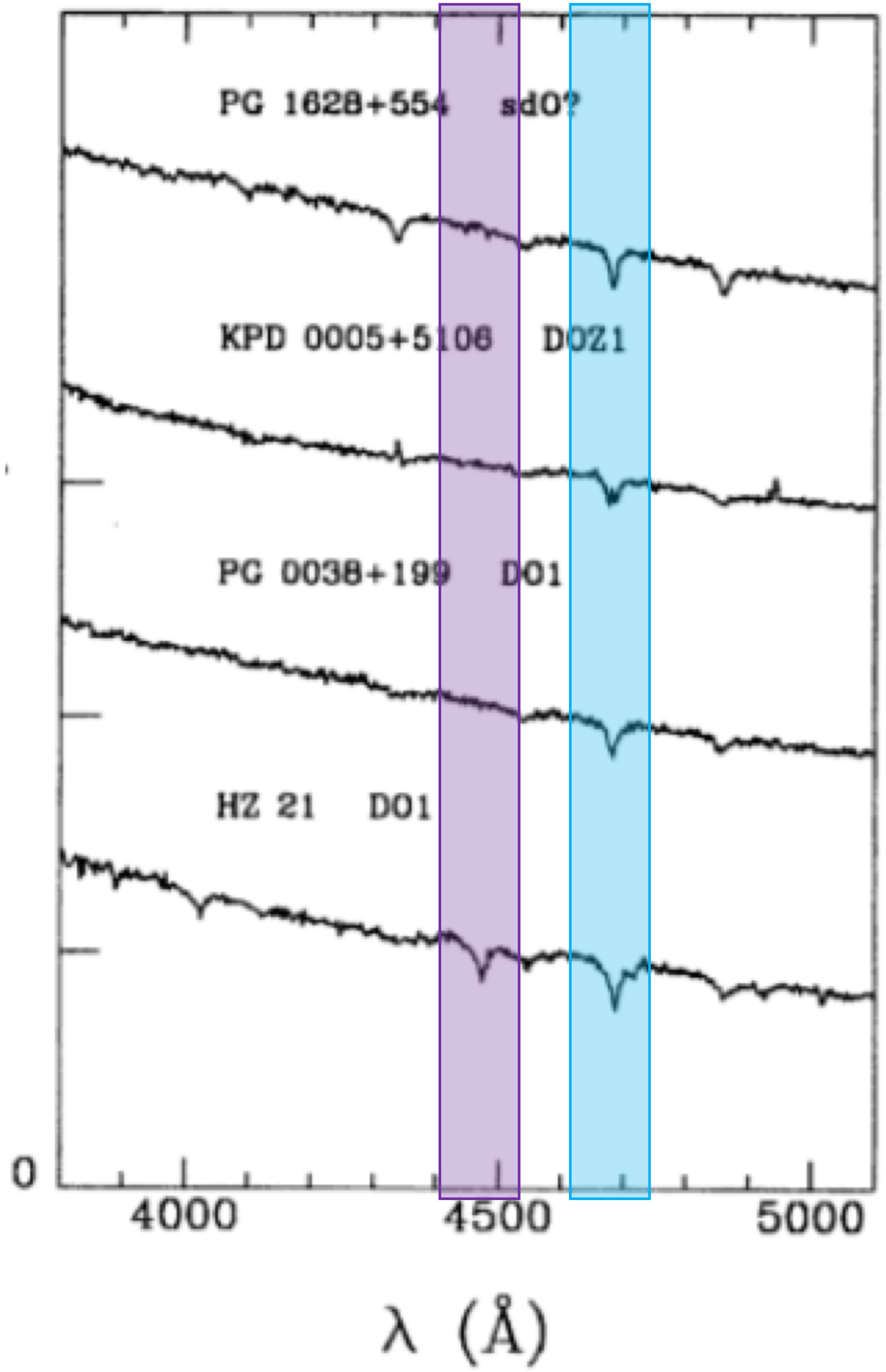
- Only Balmer lines present, no He I or metals
- Very broad hydrogen lines → very high gravity
- Top to bottom: hotter to cooler stars
- Deeper and sharper
- Can see classification next to line
- Hα **λ**6565: red
- Hβ **λ**4681: blue





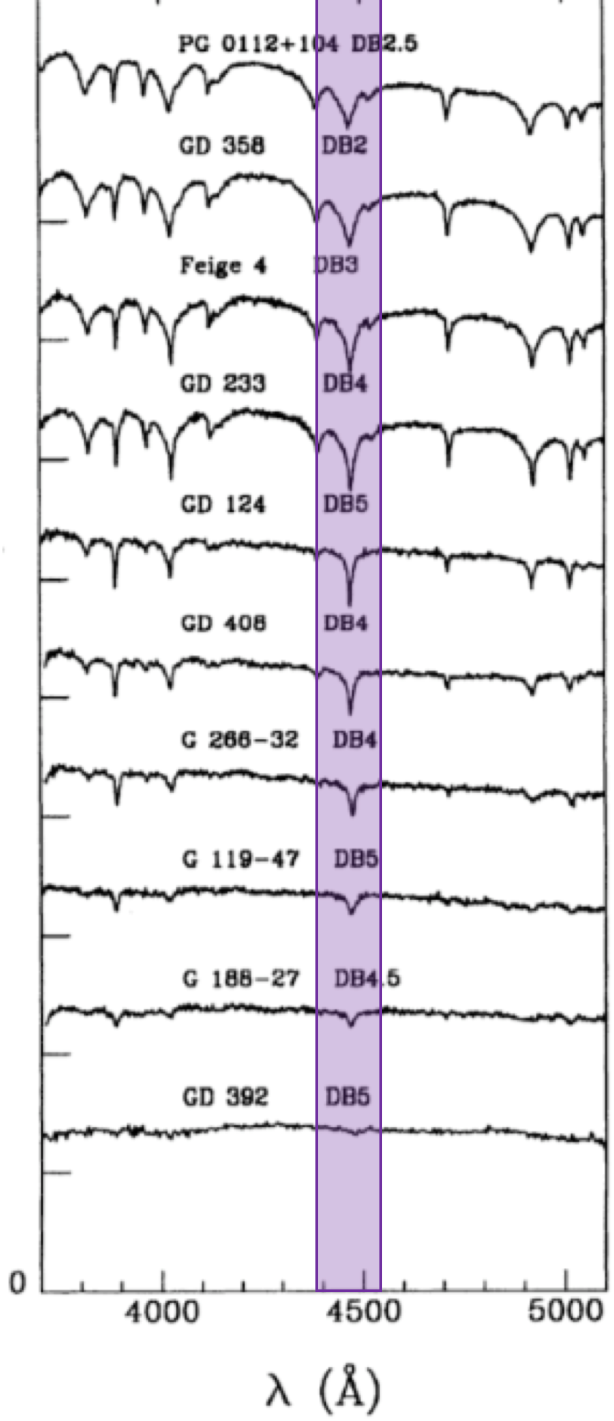
Type DA: Cool

- broad hydrogen lines → high gravity
- Cooler white dwarfs
- Top to bottom: hotter to cooler stars
- Balmer lines become sharper and weaker for cooler stars
- Almost dissapear
- **Hα λ**6565: red
- **Hβ λ**4681: blue



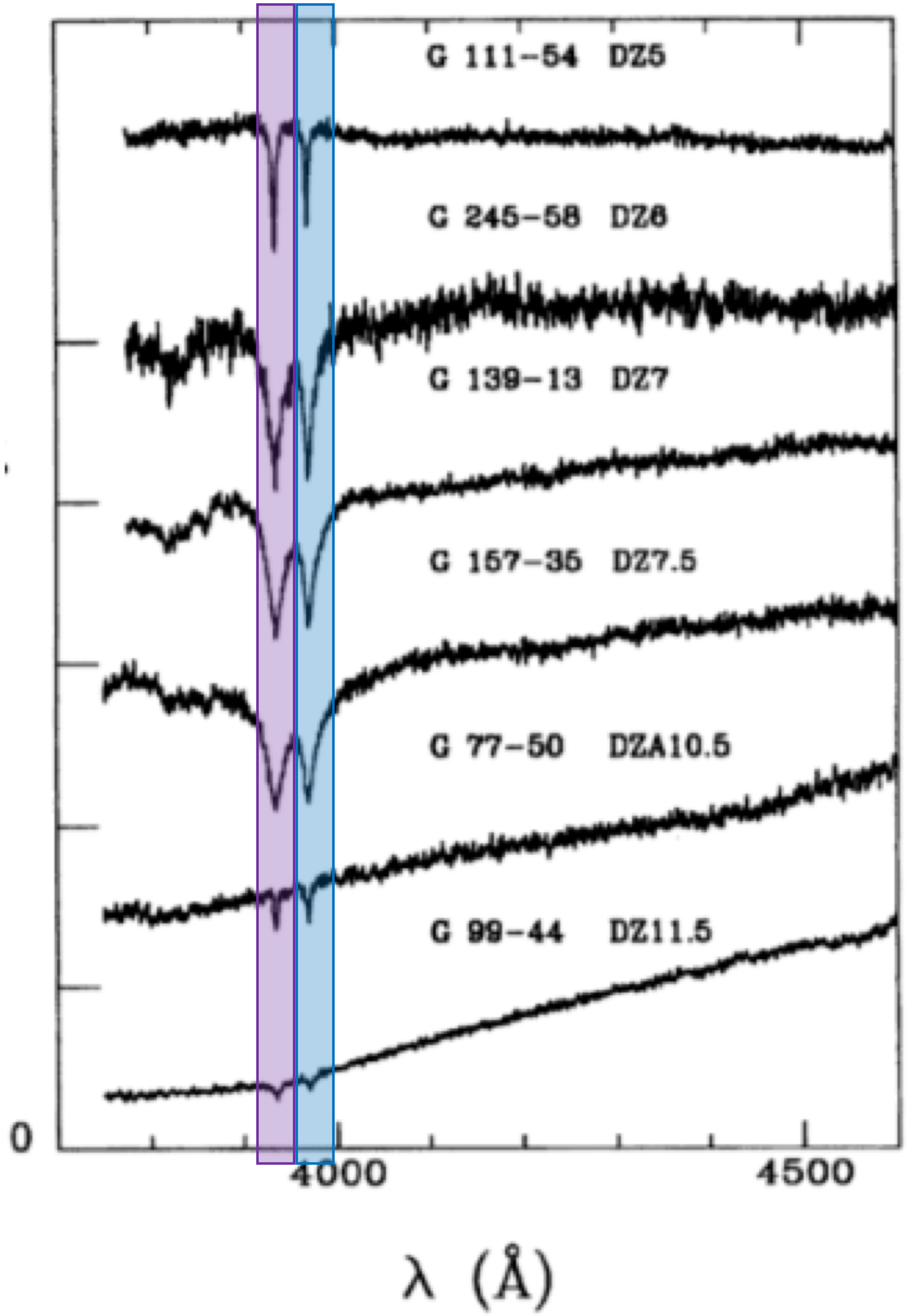
Type DO

- Strong He II lines, sometimes He I and H lines seen
- Bottom three spectra top to bottom: hotter to cooler stars
- Top star: narrower lines indicate lower gravity, so classified as sdO (sub dwarf O star, not a WD)
- He II λ4686: blue
- He I λ4471: purple



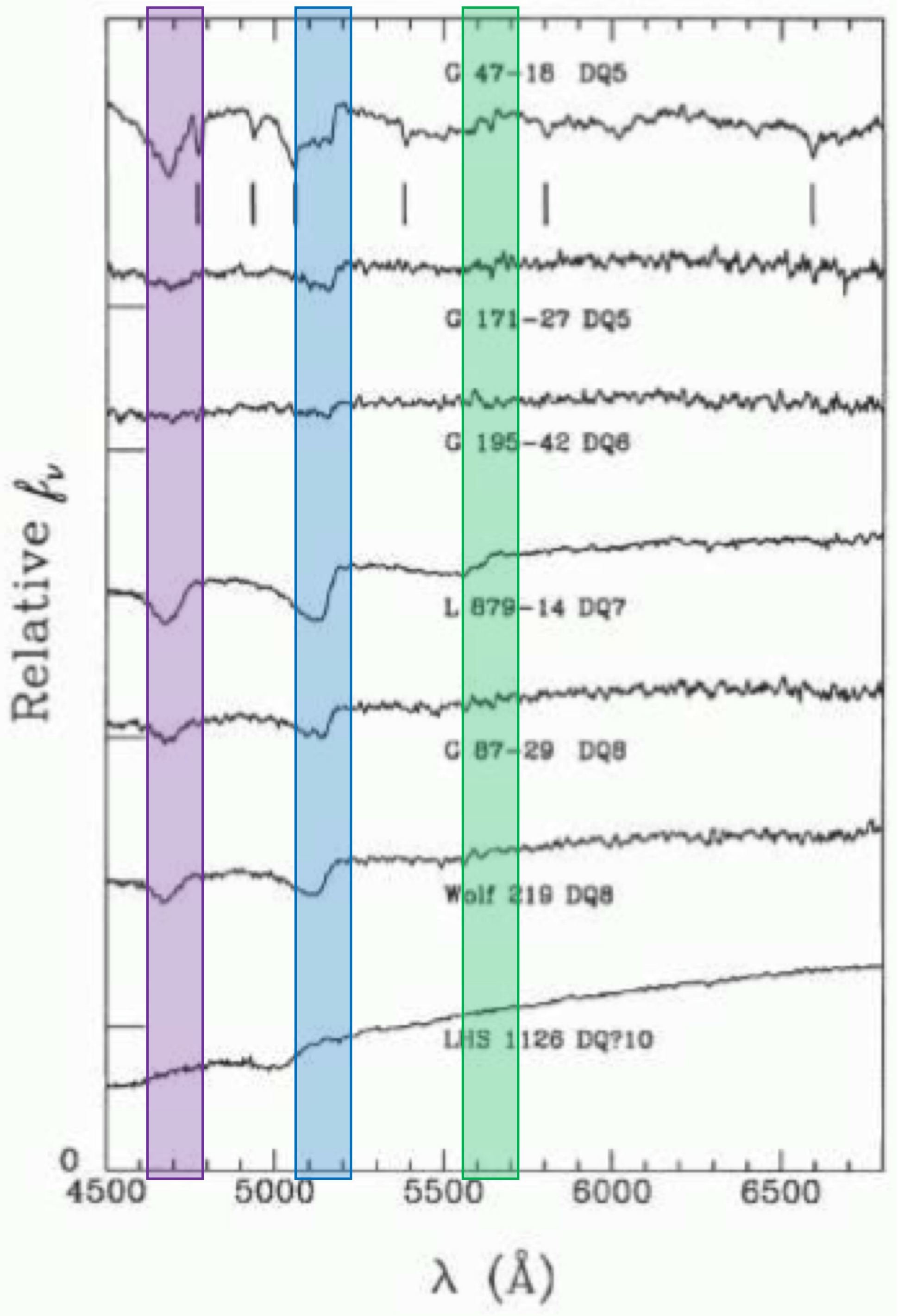
Type DB

- He I lines present, no H lines or metals
- Note: caption indicates H and metal lines common for DB WDs…
- Top to bottom: hotter to cooler stars
- He I line strong for hotter stars; gets weaker and almost disappears for coolest star at bottom
- He I λ4471: purple



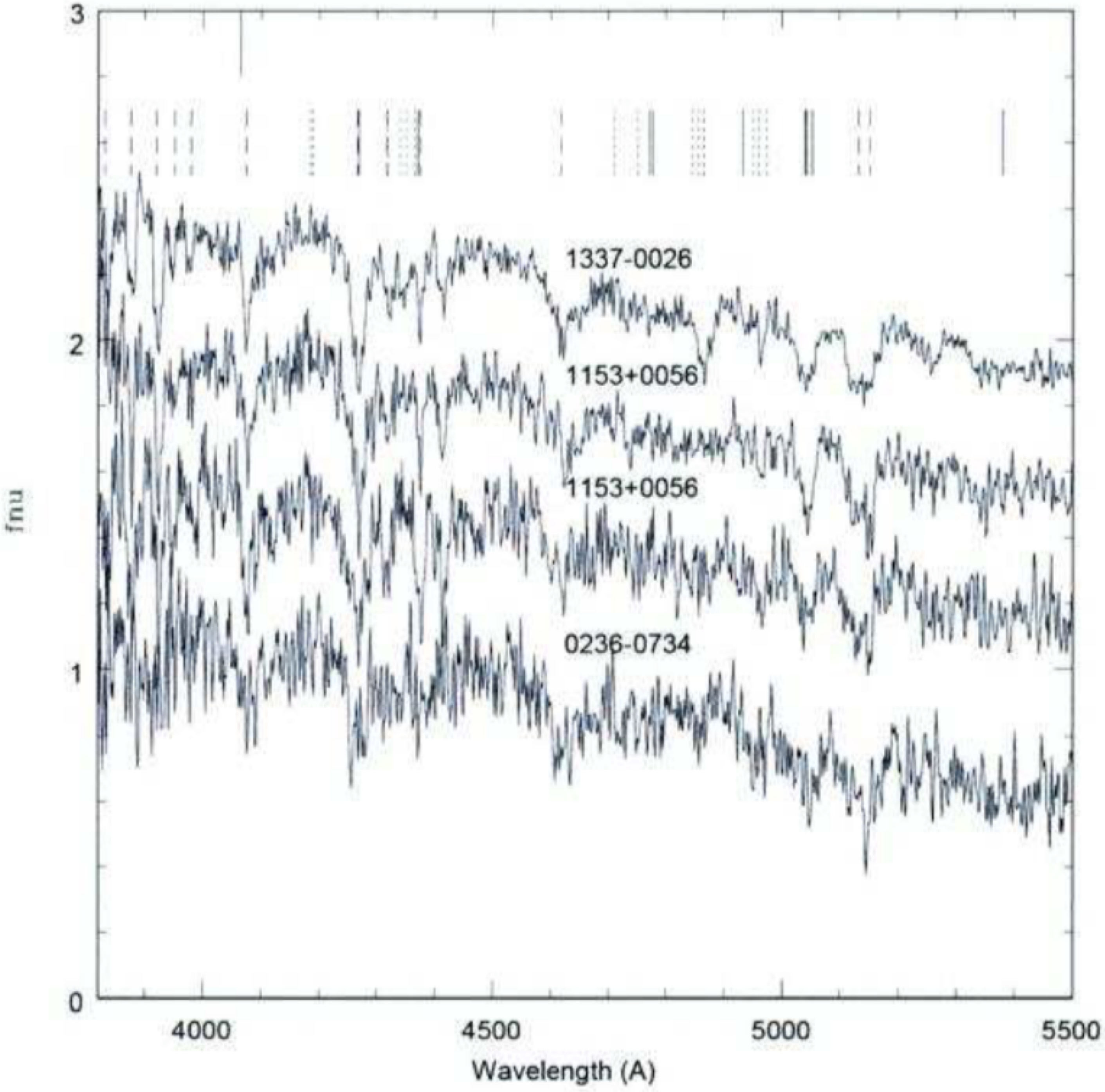
Type DZ

- Only metal lines seen, no H or He present
- Note: caption indicates He rich…
- Generally cooler stars
- Top to bottom: hotter to cooler stars
- Ca II H line λ3969: blue
- Ca II K line λ3934: purple
- Mg I λ3835 & Fe I λ3730



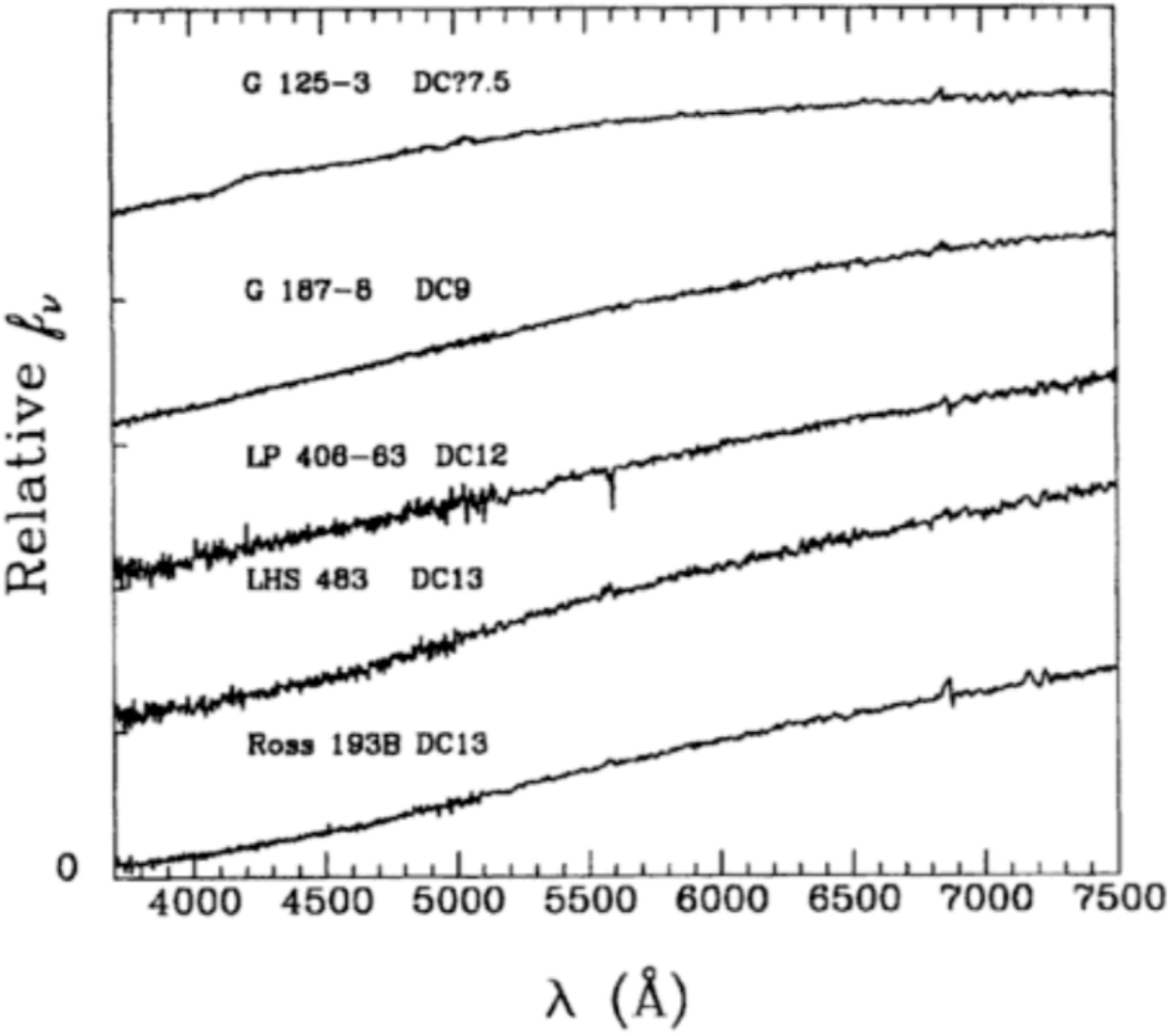
Type DQ

- Carbon lines (atomic and/or molecular)
- Cool, He rich
- Top to bottom: hotter to cooler stars
- Molecular carbon triplet system Swan bands:
    - **λ**4382: not pictured
    - **λ**4737: purple
    - **λ**5165: blue
    - **λ**5635: green
- Top star (marked): C I lines
- Bottom star: very broadened and shifted C_2 bands, very cool



Hot DQ

- New classification
- T > 28,000 K
- Typical DQ T < 12,000 K
- No H or He
- Could be massive DO or DB WDs pull carbon up into atmosphere
- Lines:
  - C I: solid marks
  - C II: dashed marks
  - O II: dotted marks (possible in top spectrum)



Type DC

- Continuous spectra, no lines
- Features are just glitches (incomplete correction O_2 in atmosphere)
- Top to bottom: hotter to cooler stars
- Very cool: bottom star DC13

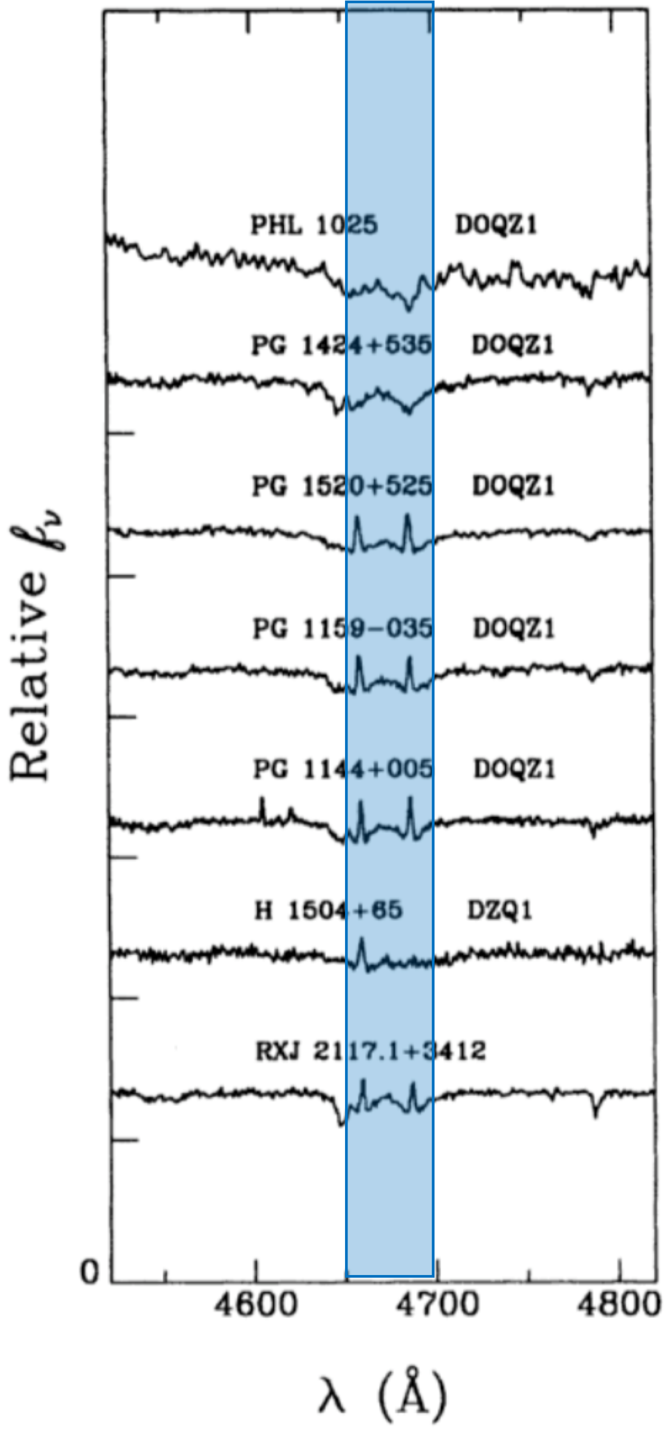
WDs in UV and IR

UV:

- Hottest WDs peak in UV
- Good for determining temperature and abundance ratios
- Metallic lines stronger than in visible: C IV, Mg I λ2852, Mg II λ2796 & λ2803, and Ca II λ1840
- In far-UV, trace carbon in He rich DB WDs could indicate weak winds in atmosphere
- Far-UV lacks reference spectra

IR:

- Can be used to find cooler companions of hot WDs
- Also lacks reference spectra



PG 1159 Stars

- Hot pulsating pre-white dwarfs
- No pure He outer layer yet due to lack of gravitational diffusion
- No H or He I lines
- Strong blend of He II and C IV for λ4650 - λ4690; also strong O line
- Similar to DQ WDs, only hotter
- Three groups (in order of increasing temperature):
  - A group: top two spectra; only absorption
  - E group: middle four spectra; emission features from core
  - lgE group: bottom spectrum; emission features and sharper absorption features (lower gravity)

Novae

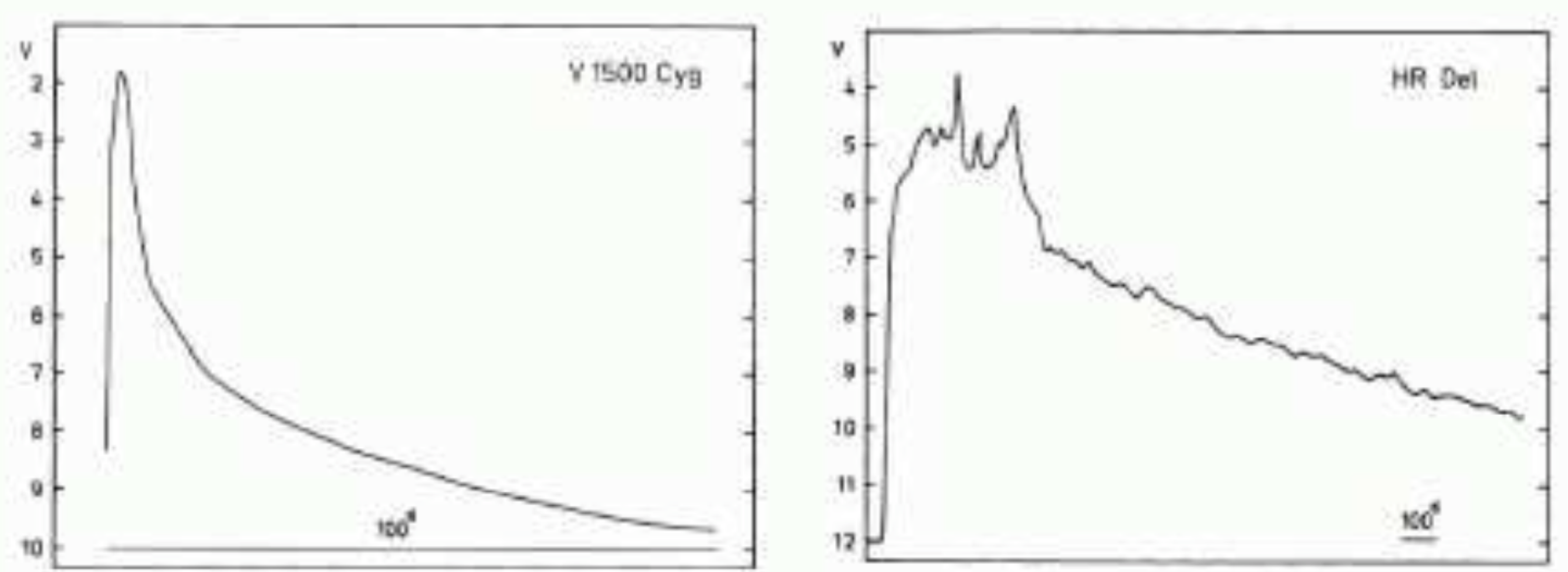
Phys.org

Classical Novae

- Naming: brightening of “new star”
- Most common type of novae
- Eruption causes brightness increase 7-16 magnitudes
- Fades over weeks or months
- Belong to cataclysmic variables
- Close binary stars: usually WD (primary) + main sequence star (secondary)
- WD accretes H rich matter from main sequence star onto its surface
- Creates H rich dense outer layer, heats up
- Reaches critical temperature → runaway thermonuclear reaction → violent ejection of outer layer → luminosity at Eddington limit → expanding shell
- Shell (seen in visible) + winds form characteristic emission lines

Classical Novae

- Can also be characterized by light curves
  - Fast: smooth light curves (left)
  - Slow: irregular light curves (right)



Classical Novae Spectral Classification

- Tololo Nova Spectral Classification System
- Post-outburst spectra
- Difficult to capture spectra of nova at "maximum light"
    - Unpredictable, occurs quickly, must be quick to point telescope
    - Therefore, uncertainty in spectrum at "maximum light"
- Absorption spectra resembles A or F supergiants
- Emission features seen

Tololo Nova Spectral Classification System

Novae spectra belong to one of four phases in range 3400 – 7500 Å

Phase C: coronal phase

- [Fe X] λ6375 emission line stronger than nebular [Fe VII] λ6087 line

Phase P: permitted phase

- Strongest non-Balmer line is a permitted transition (and spectrum not in coronal phase)

Phase A: auroral phase

- Forbidden auroral line has greater flux than strongest non-Balmer permitted line (and spectrum not in coronal phase)

Phase N: nebular phase

- Strongest non-Balmer line is a forbidden nebular line (and spectrum not in coronal phase or auroral phase)

Tololo Nova Spectral Classification System

Phase C: coronal phase

- [Fe X] λ6375

Phase P: permitted phase (2 classes)

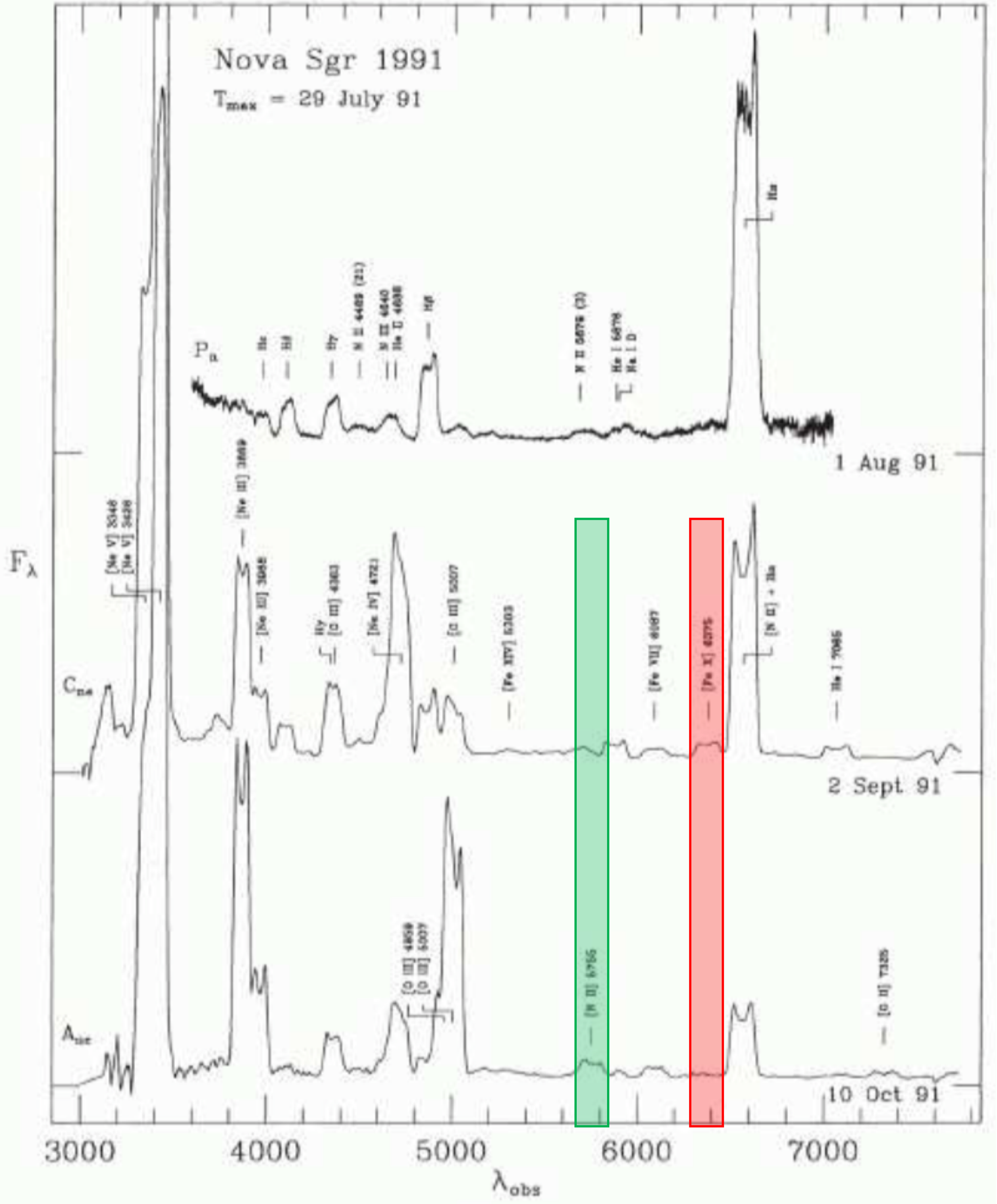
- Fe II novae: evolve slowly spectroscopically, low-ionization transitions
  - Fe II, Na I, O I, Mg I
- He/N novae: evolve quickly, broad emission lines, higher excitation transitions
  - He II λ4686, He I λ5876, N II λ5001 or λ5679, N III λ4640

Phase A: auroral phase

- [N II] λ5755, [O III] λ4363, [O II] λ7319 or λ7330

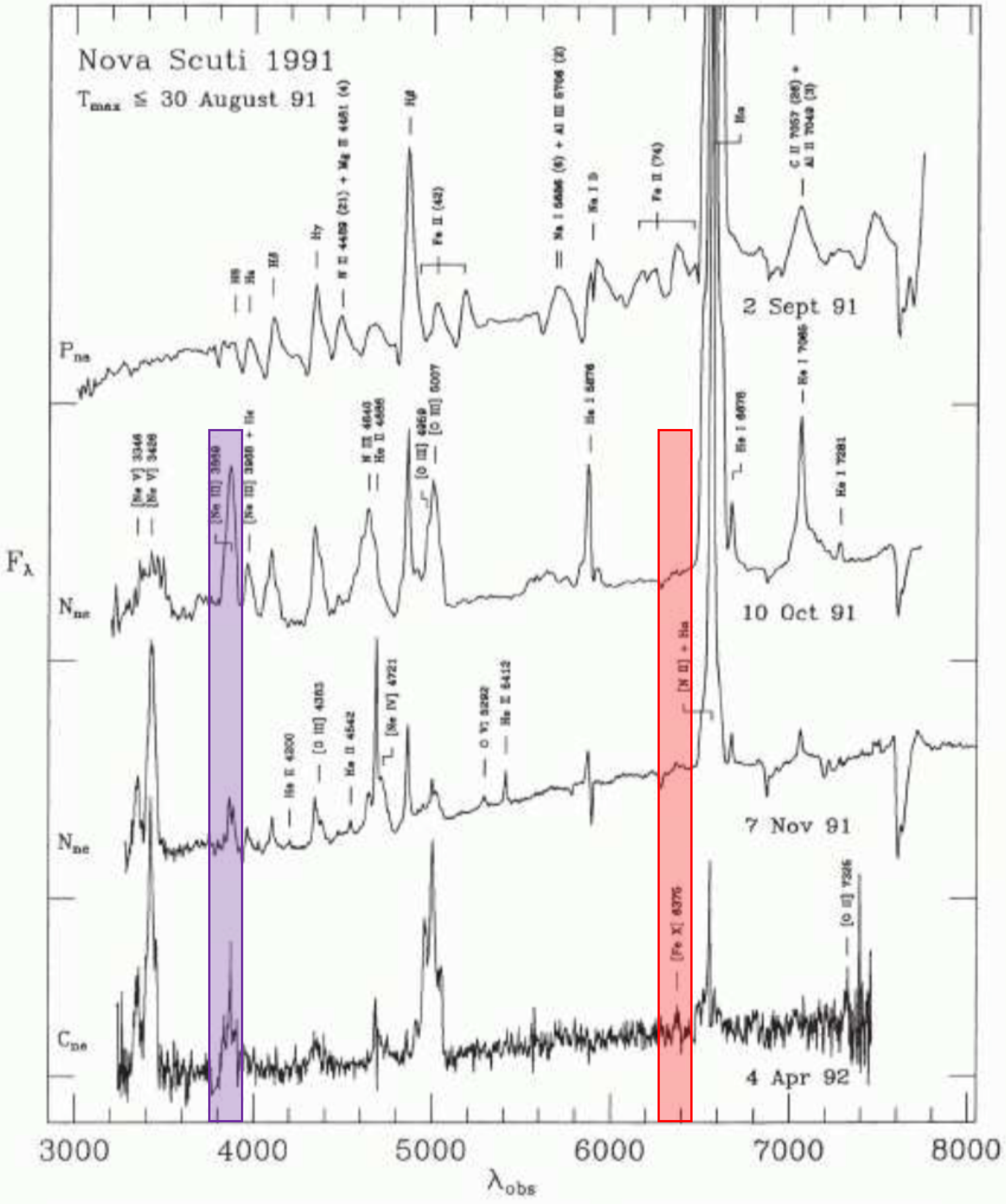
Phase N: nebular phase

- [O III] λ5007, [N II] λ6584, [Ne III] λ3869, [Fe VII] λ6087



Coronal → Auroral Phase

- Fast He/N nova
- Developed coronal spectrum, then quickly faded
- [Fe X] λ6375
- [N II] λ5755



Nebular → Coronal Phase

- Fe IIb nova
- Strong neon forbidden lines
- Emission line width decreases over time
- [Ne III] λ3869
- [Fe X] λ6375

Tololo Nova Subclasses

Subclasses depend on strongest non-Balmer lines

denoted by lowercase subscript

Examples: coronal phase

- he = He I **λ**5876 or **λ**7065
- he^{+} = He II **λ**4686
- n = N III **λ**4640, N II **λ**5679, [N II] **λ**6584
- o = [O III] **λ**5007
- etc.

Phases P, A, and N also have several subclasses

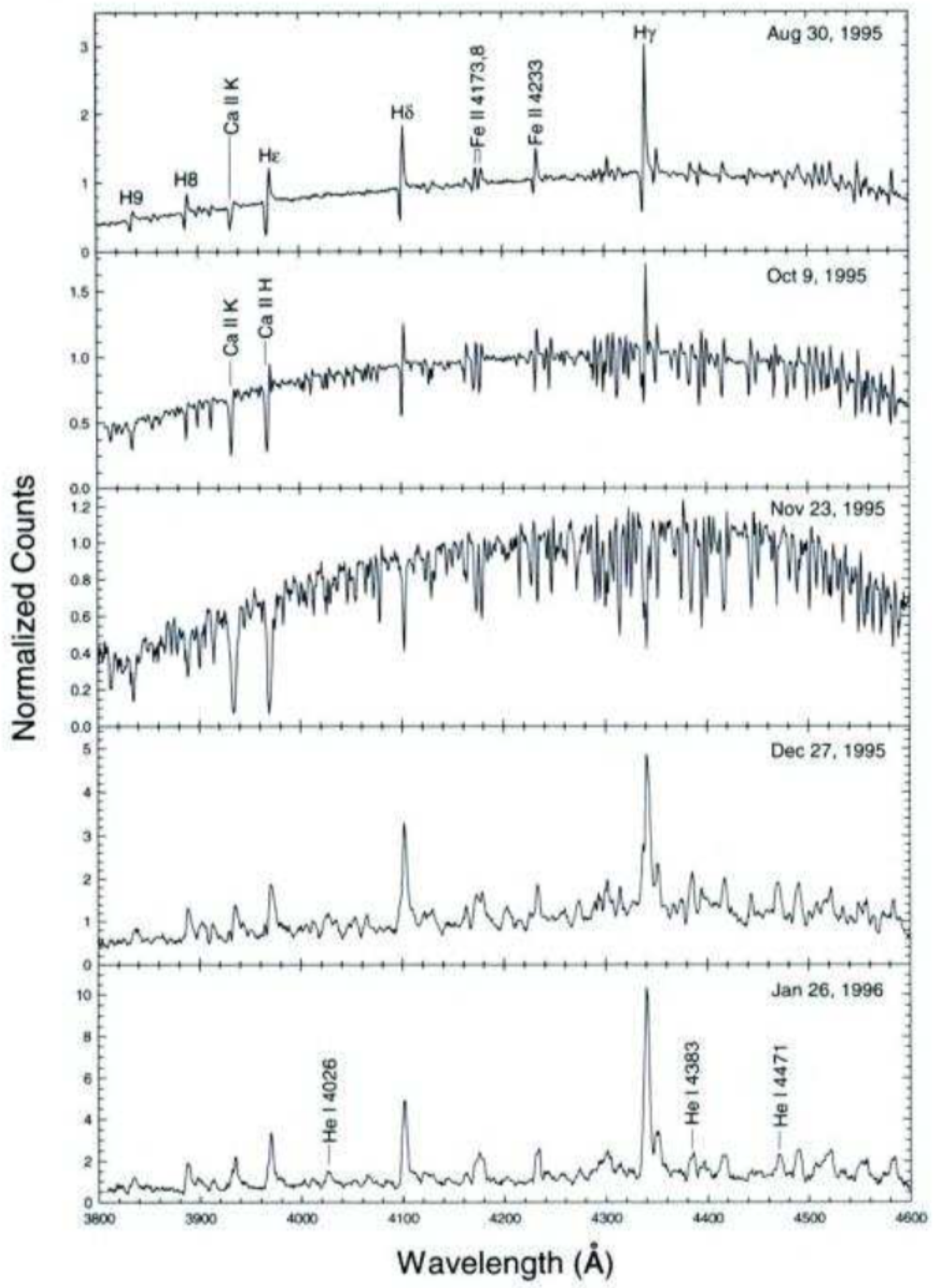
Additional Subclasses

- Lowercase superscript
- Example: o = flux of O I **λ**8446 > flux of H**β**

Tololo Nova Spectral Classification System

- Evolutionary Sequence
- Example: $P_n C_{ne} A_{ne}$
- Permitted phase → coronal phase → auroral phase

- Some novae do not fit into this classification system
- Example: Nova Cas 1995



Nova Cas 1995

- Does not fit in Tololo Nova Classification System
- All mission lines faded
- Spectra resembled A or F supergiant
- Then some emission lines reappeared

Other Cataclysmic Variables

Recurrent novae:

- OBSERVED, classical nova could be a recurrence, but not observed
- Runaway thermonuclear event or large mass transfer event

Dwarf novae:

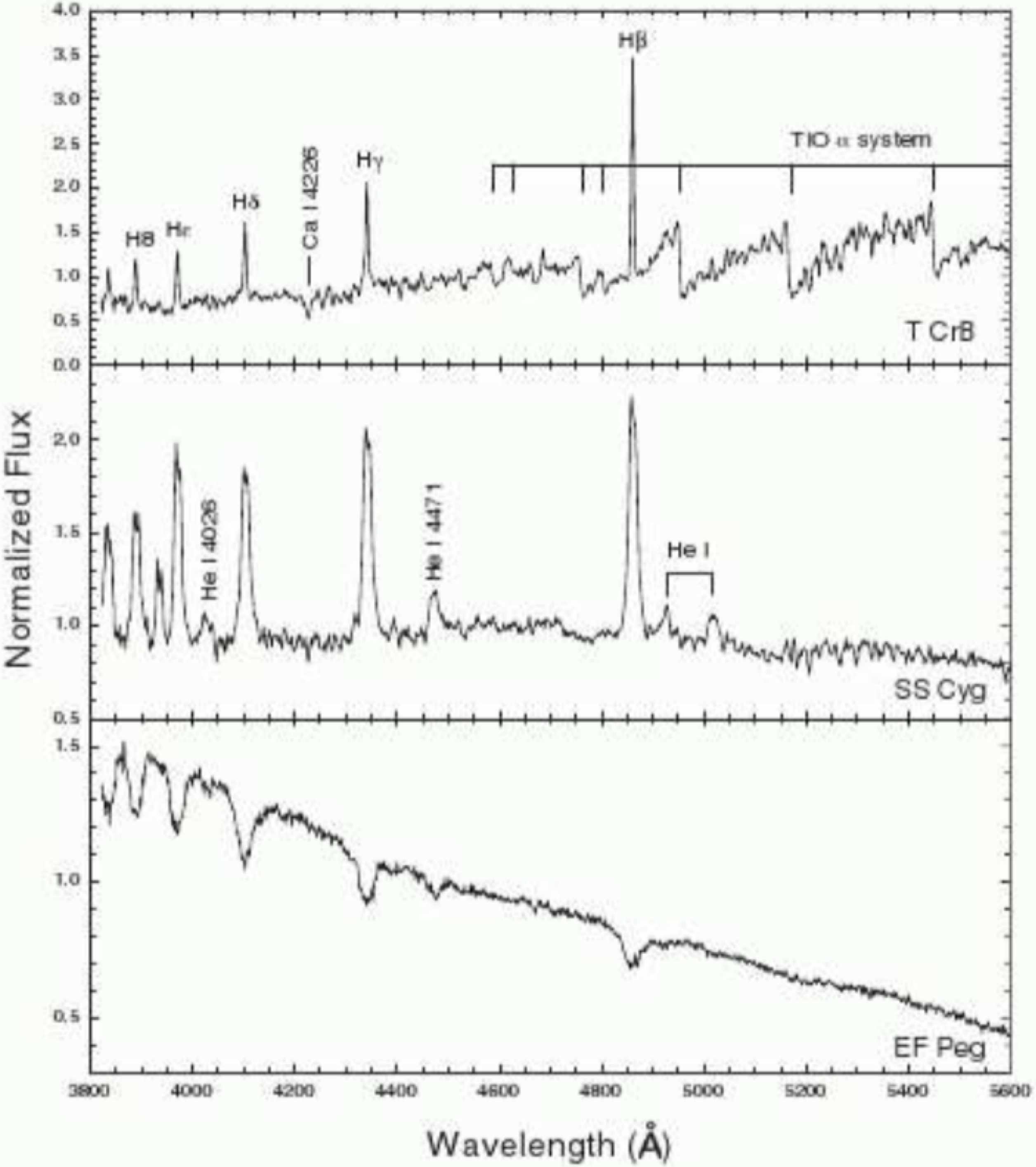
- Periodic brightening of 2-5 magnitudes over weeks to years
- Emission lines during quiescence, absorption lines during outburst
- Outburst from instability in accretion disk

Helium cataclysmic variables:

- Mass transfer of helium rich matter instead of hydrogen rich matter to WD

Polar Variables:

- Strong magnetic fields that funnel accreting mass onto magnetic pole on WD surface



Cataclysmic Variables

Top: recurrent nova

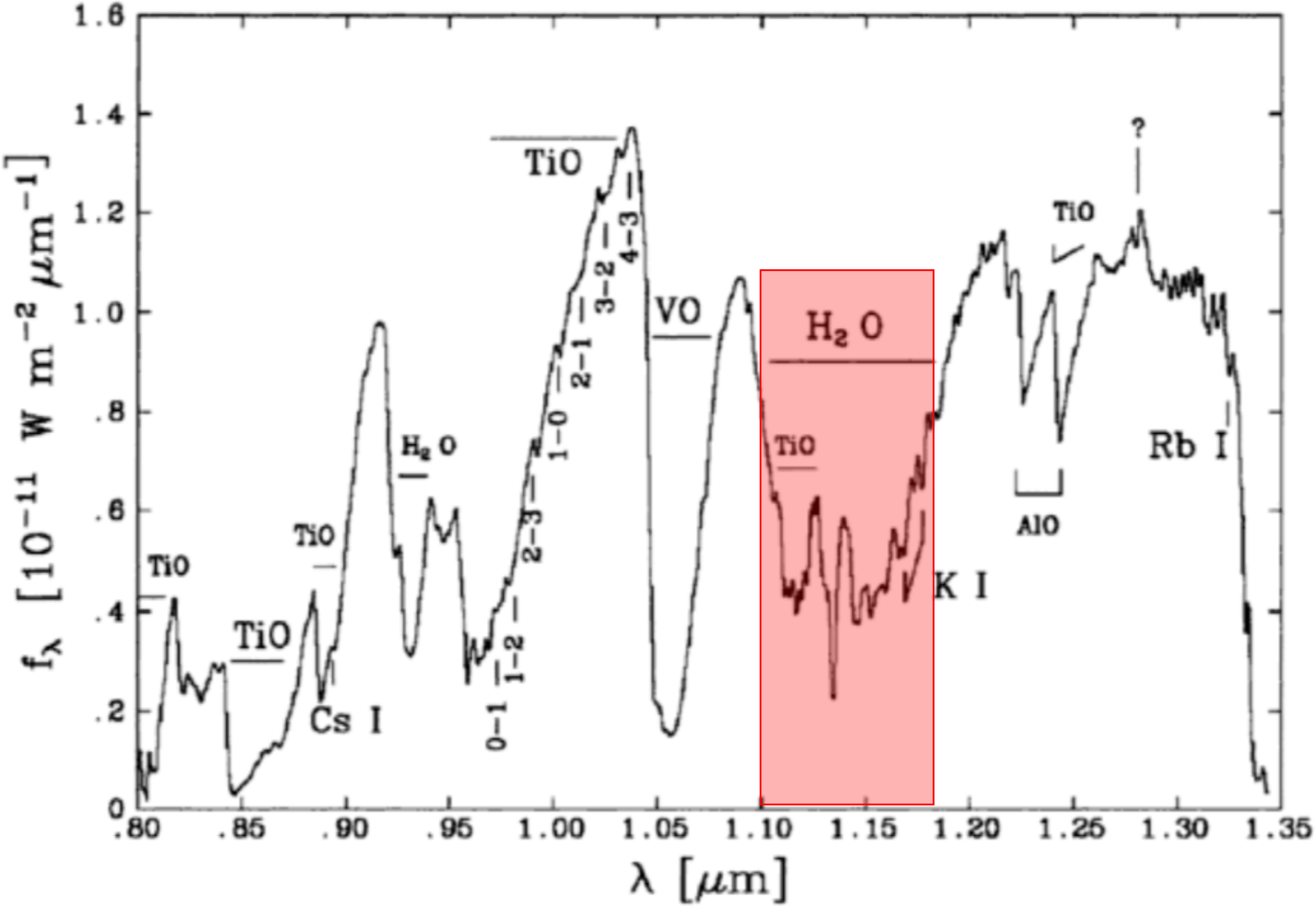
- T CrB ”blaze star”
- At quiescence
- M-giant spectrum + superimposed Balmer emission

Middle: dwarf nova

- SS Cyg, U Gem-type
- At quiescence

Bottom: dwarf nova

- EF Peg, SU Uma-type
- At super outburst (absorption)



V838 Mon

- Neither nova or supernova
- Likely stellar or planetary merger
- Spectrum of cool supergiant
- Near IR spectrum

Supernovae

Theatlantic.com

The Basics

- 1) Massive stars > $8M_\odot$ undergo cataclysmic collapse of iron core
  - Cannot produce energy from fusing iron
  - Endothermic reaction
- 2) Binary system mass transfer where one star is a WD near the Chandrasekhar limit (1.4 $M_\odot$) and made of carbon and oxygen
  - Chandrasekhar limit due to electron degeneracy pressure
  - WD accretes matter from companion → WD reaches Chandrasekhar limit → explosion of carbon and oxygen
- Luminosity can briefly exceed galactic luminosities
- Most energetic event known in universe (aside from some gamma ray bursts)

Classification

Type I: no hydrogen lines

- Broad absorption lined from Si II, Fe II, Ca II, and O I
- Type Ia: strong Si II absorption, notably λ6150
- Type Ib: strong He I, notably λ5876
- Type Ic: weak or no He I (sometimes hard to distinguish between Ib and Ic)

Type II: hydrogen lines present

- Early type II show broad lines
- Type IIb: spectra resembles type Ib
- Type IIn: narrower lines
- Type IIL: light curve has single maximum, then steep linear decline
- Type IIP: light curve shows plateau soon after maximum

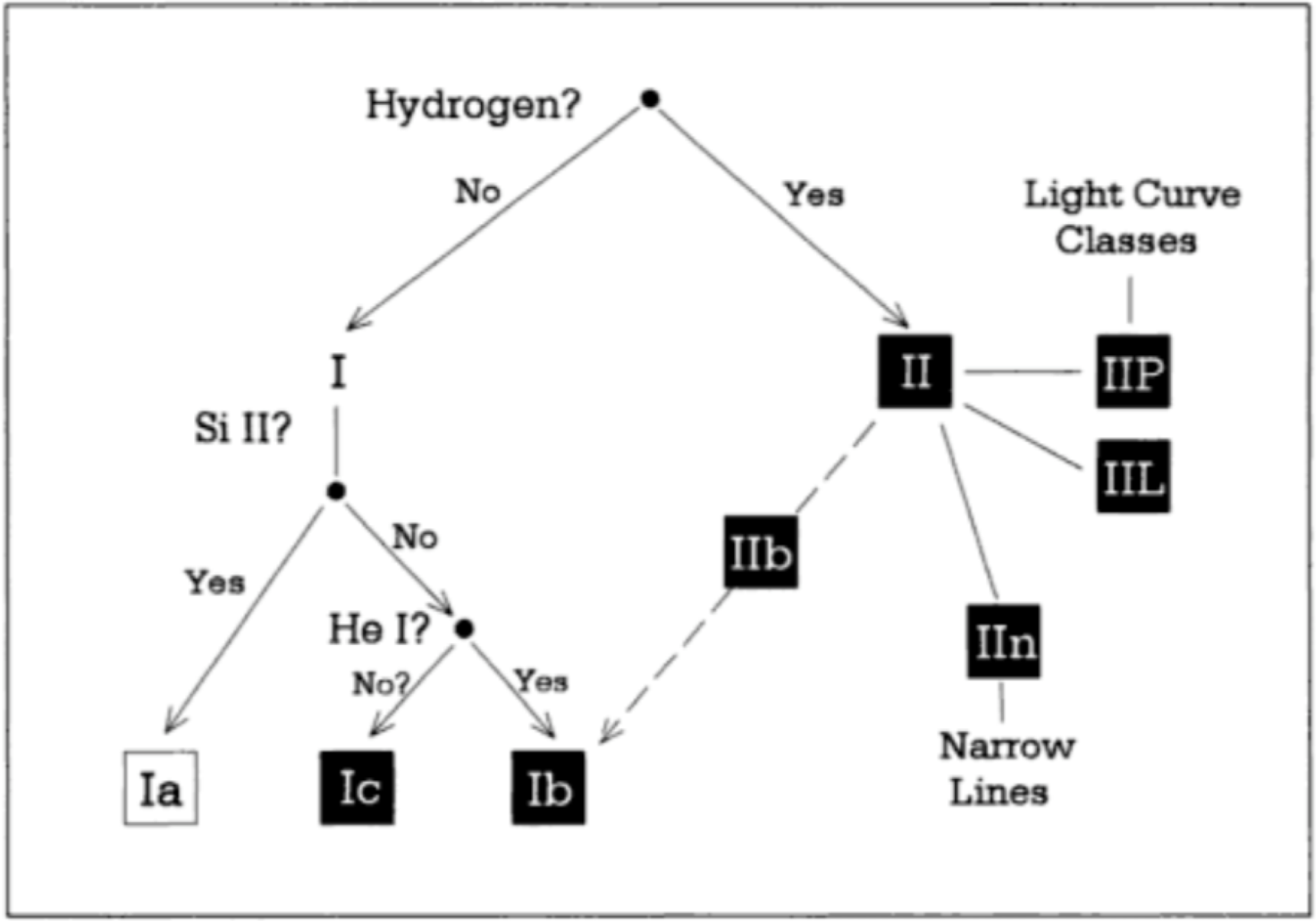
Classification

Type I:

- Type Ia:
  - Binary system mass transfer
  - occur in all galaxy types
- Type Ib & Ic:
  - Core collapse of massive stars: Wolf-Rayet or Luminous Blue Variables
  - do not occur in elliptical galaxies, almost always occur in spiral arms

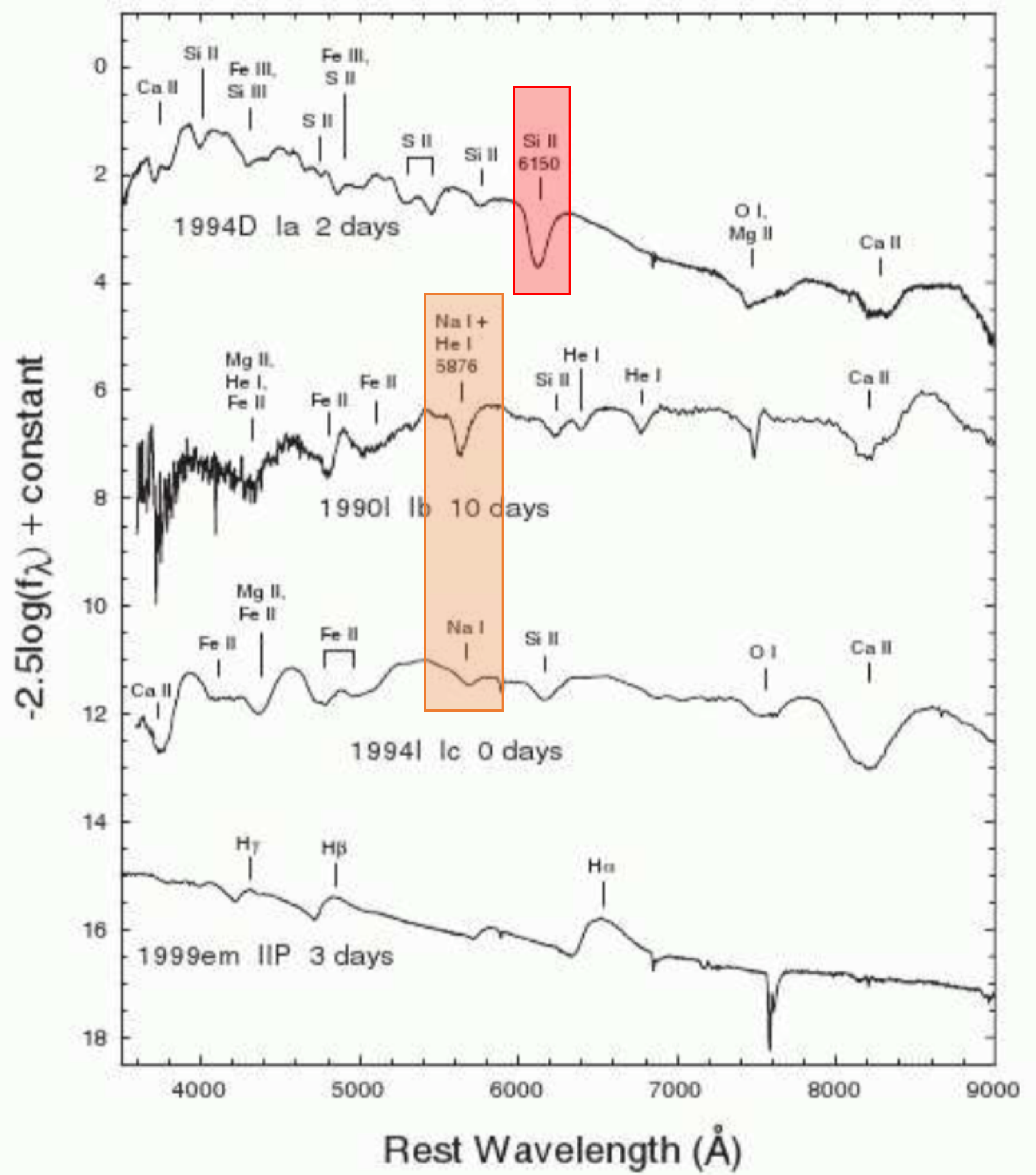
Type II:

- Core collapse of massive red supergiants
- Always occur in spiral or irregular galaxies
- Almost always occur in spiral arms and/or in H II regions



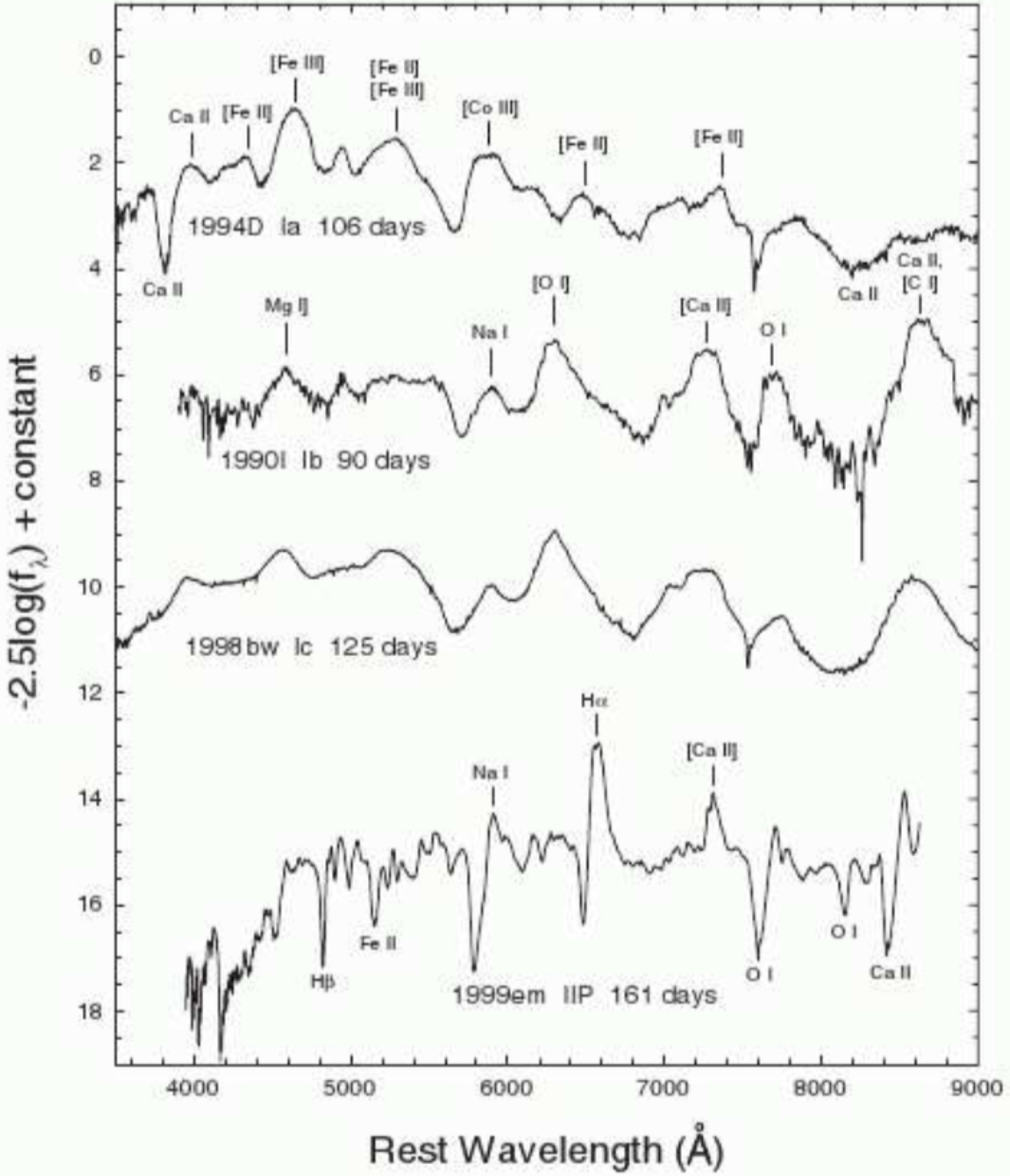
Hydrogen?
No
Yes
Light Curve
Classes
I
Si II?
II
IIP
IIL
No
Yes
IIb
He I?
IIn
No?
Yes
Ia
Ic
Ib
Narrow
Lines

Supernova spectra



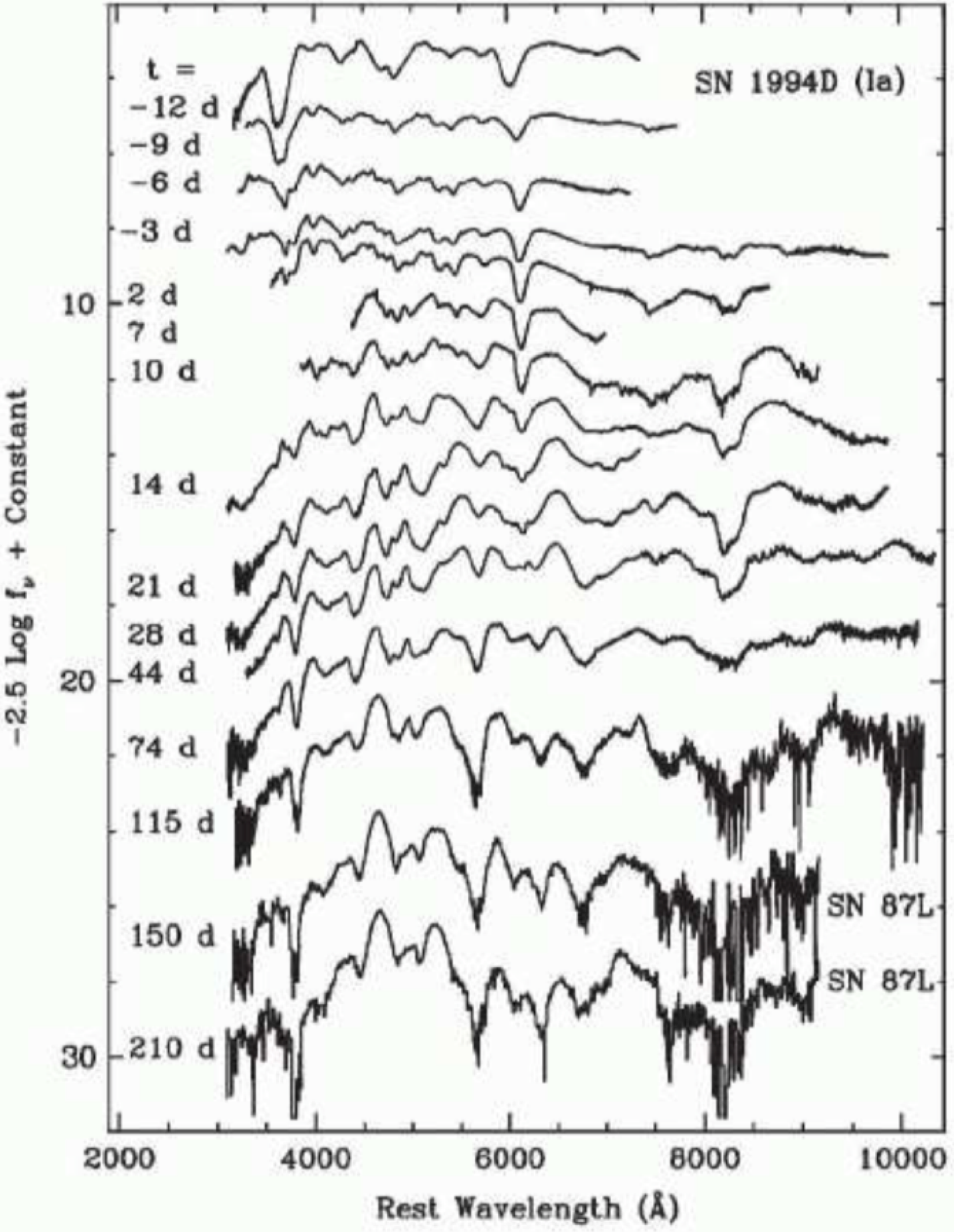
- Shortly after max light
- P-cygni profiles evident
- Broadened lines from large ejection velocity (> 10,000 km/s)
- Top: Type Ia
  - Si II λ6150: red
- Top-Middle: Type Ib
  - He I λ5876: orange
- Bottom-Middle: Type Ic
  - No He I
- Bottom: Type IIP (“plateau”)

Supernova spectra

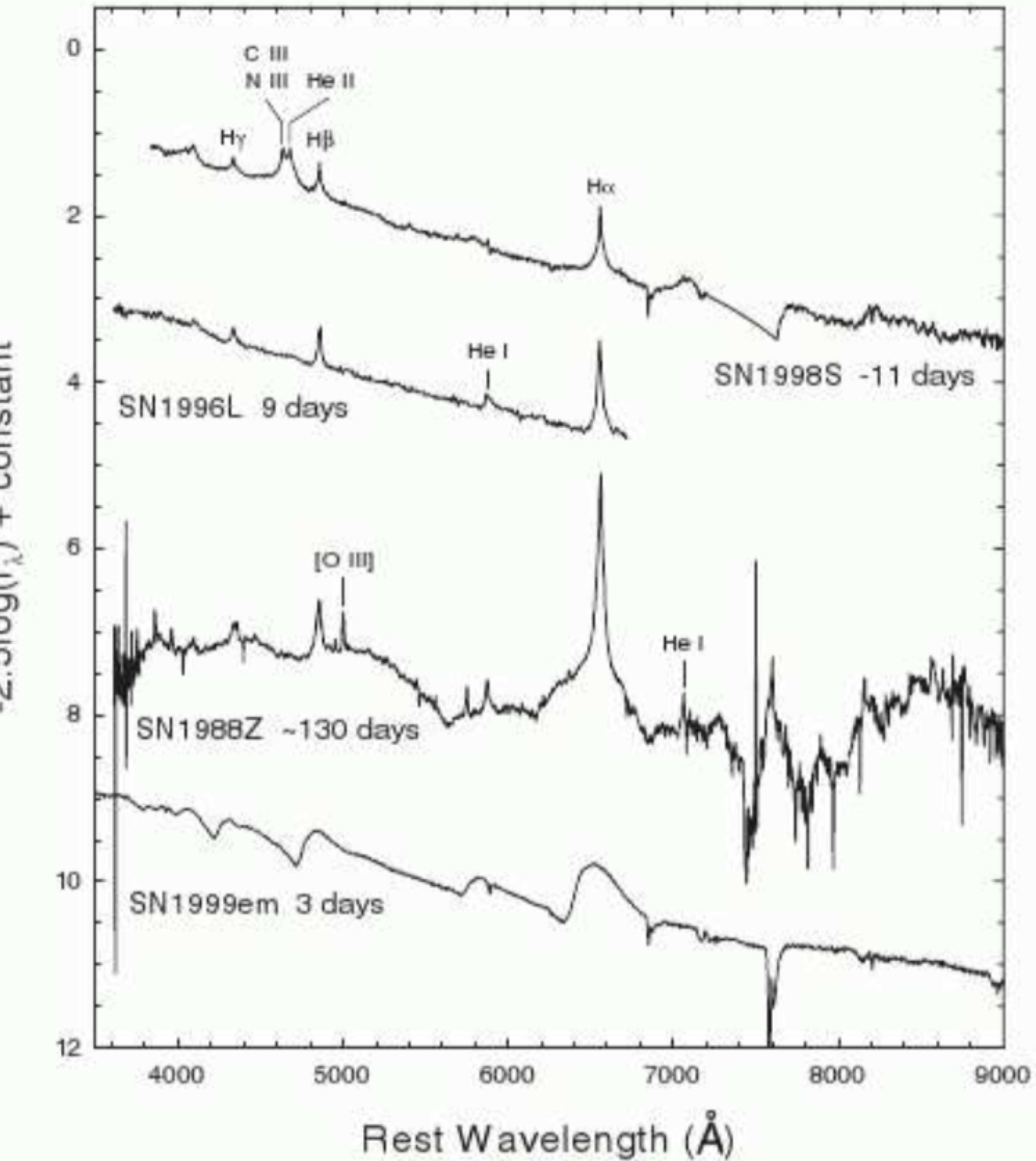


- 3 months after max light
- P-cygni absorption
- Top: Type Ia
  - Fe and Co emission
- Top-Middle: Type Ib
  - C I, O I, Mg I, Na I, Ca II emission
- Bottom-Middle: Type Ic
  - Same as Ib
- Bottom: Type IIP (“plateau”)

Supernova spectra

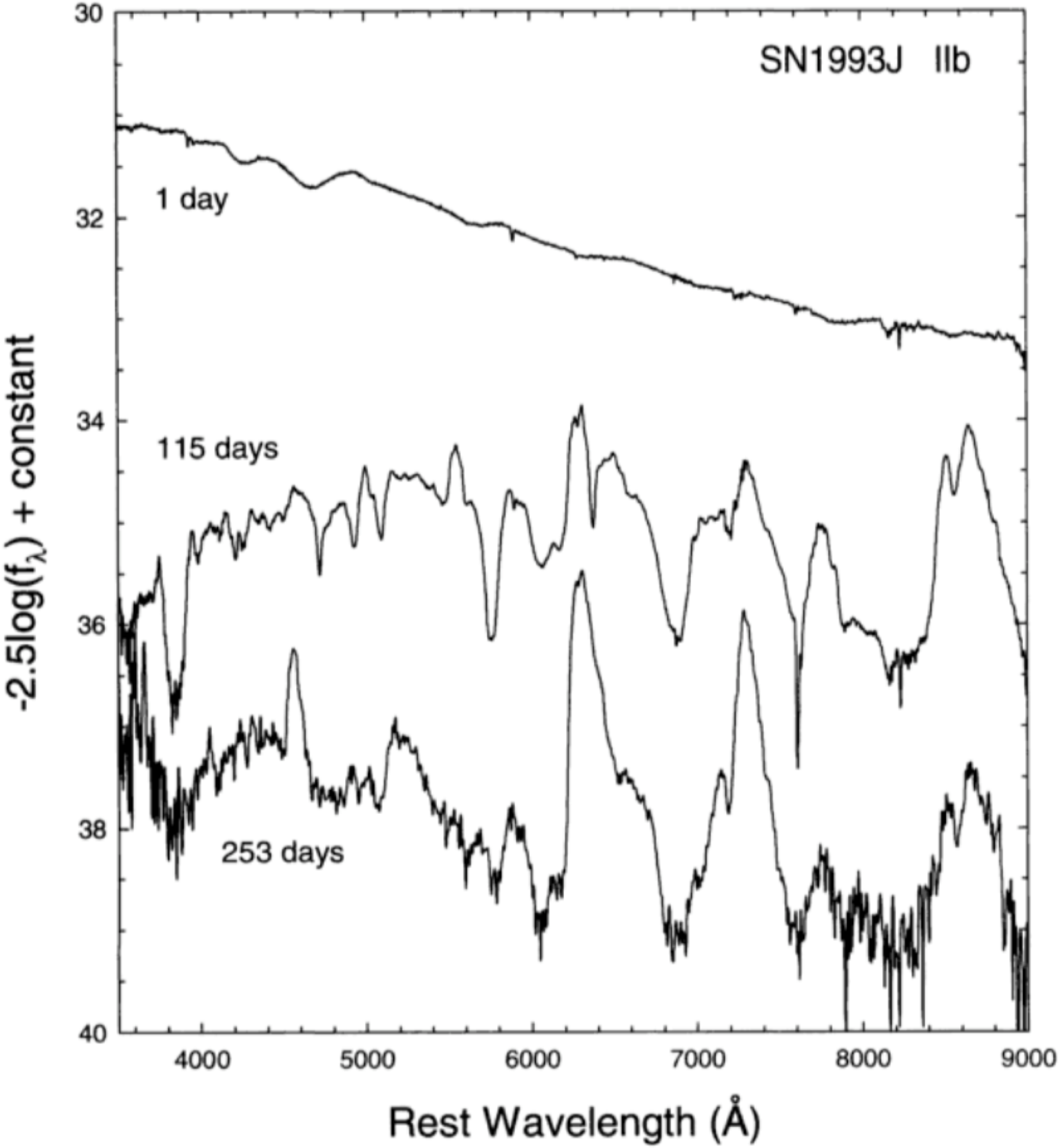


- Spectra can also be used to estimate epoch
- Elapsed time since max light
- Time series



Supernova spectra

- Early Type II usually characterized by broad lines
- Some early Type II demonstrate narrow lines
- Type IIn



Supernova spectra

- Type IIb
- Look like Type Ib

Questions?