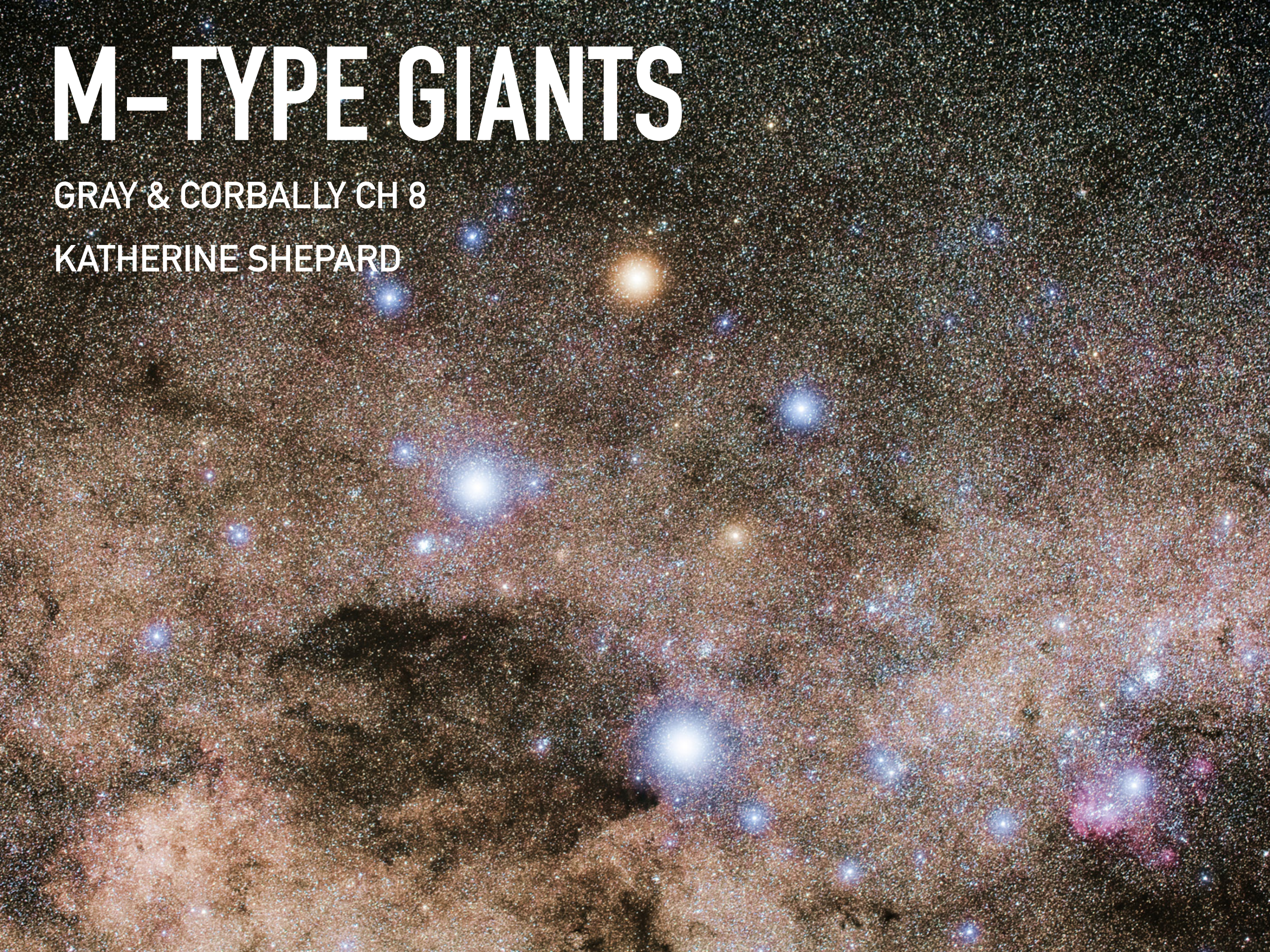


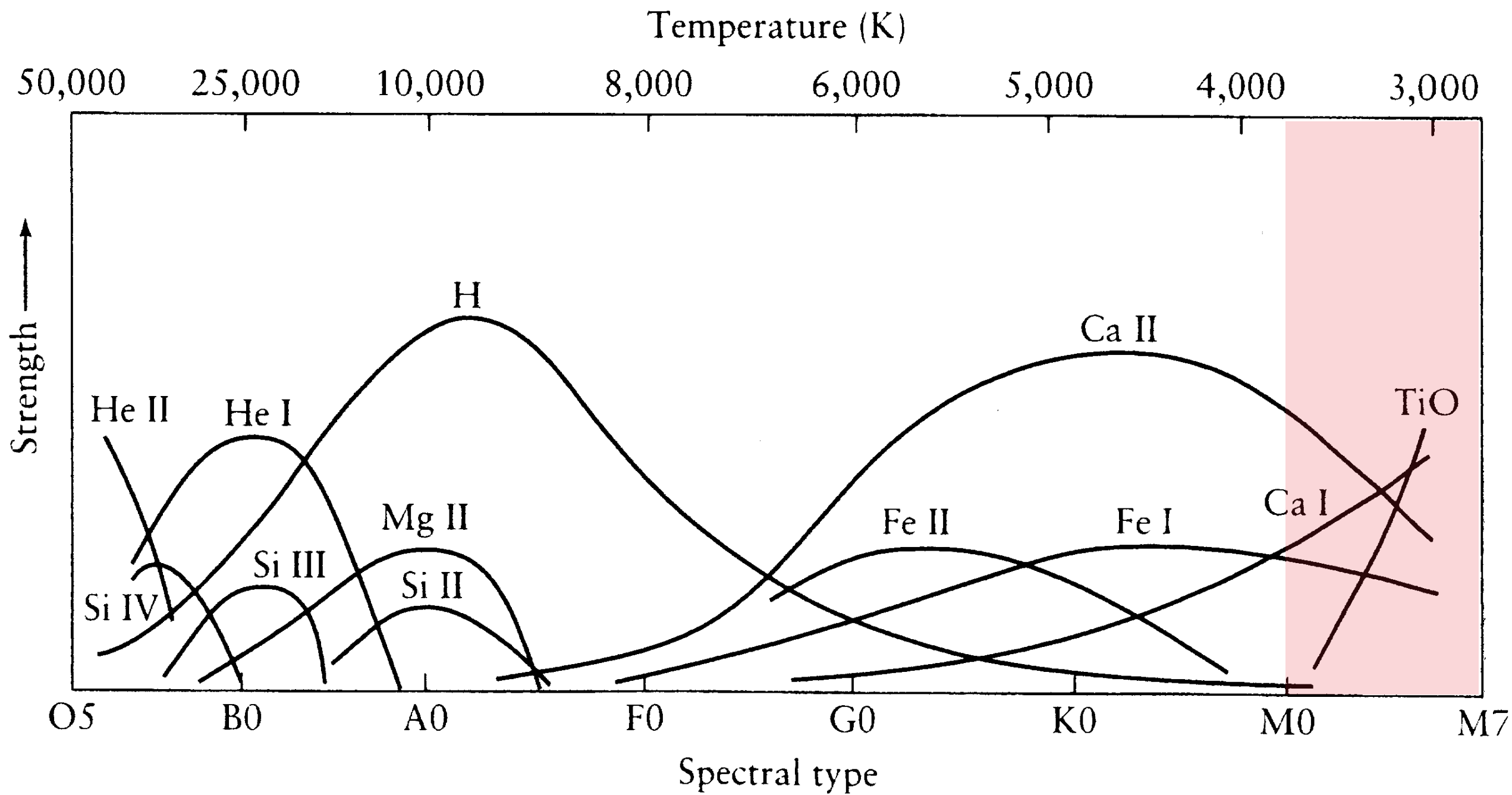
M-TYPE GIANTS

GRAY & CORBALLY CH 8

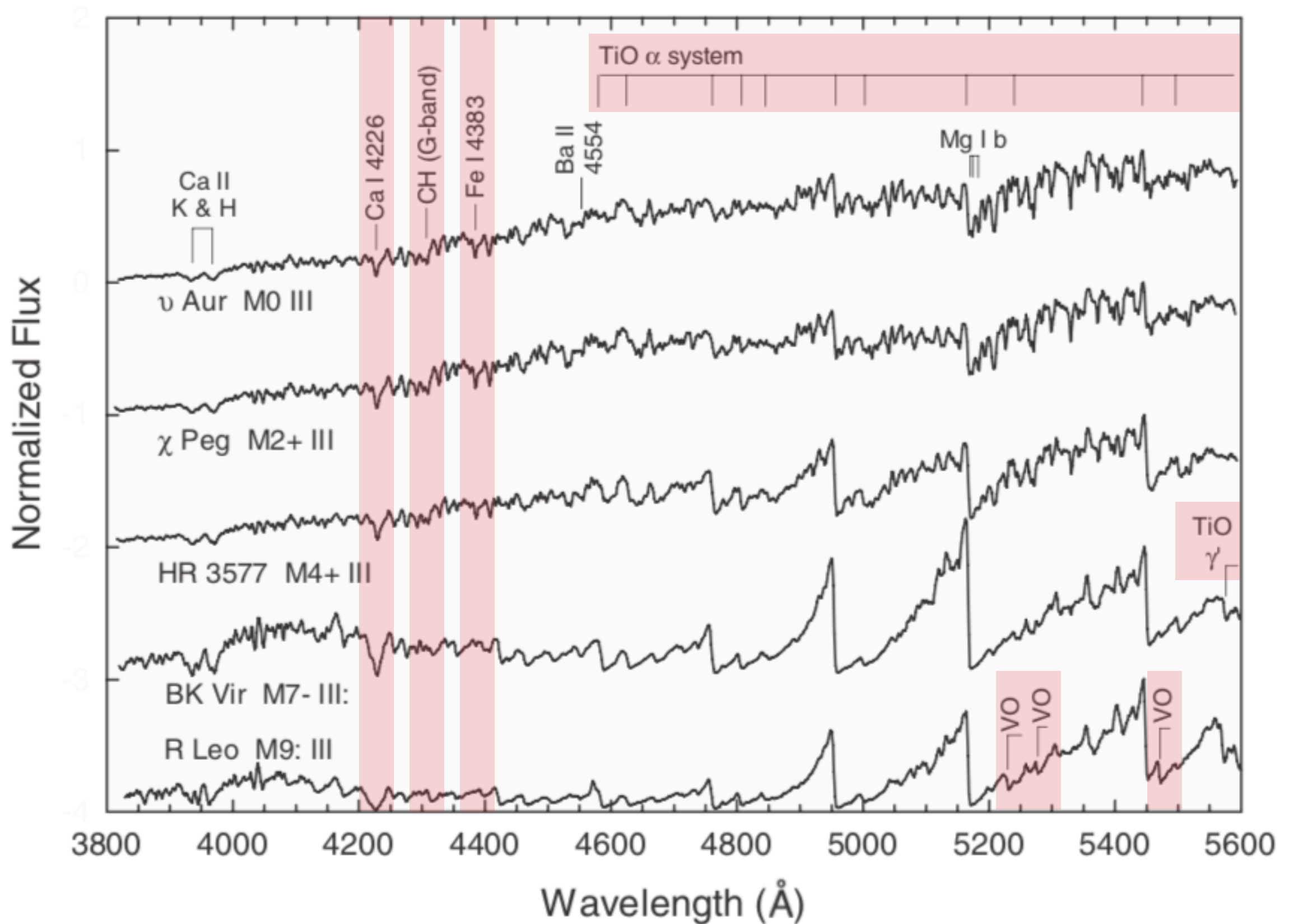
KATHERINE SHEPARD



LINE STRENGTH VS. TEMPERATURE



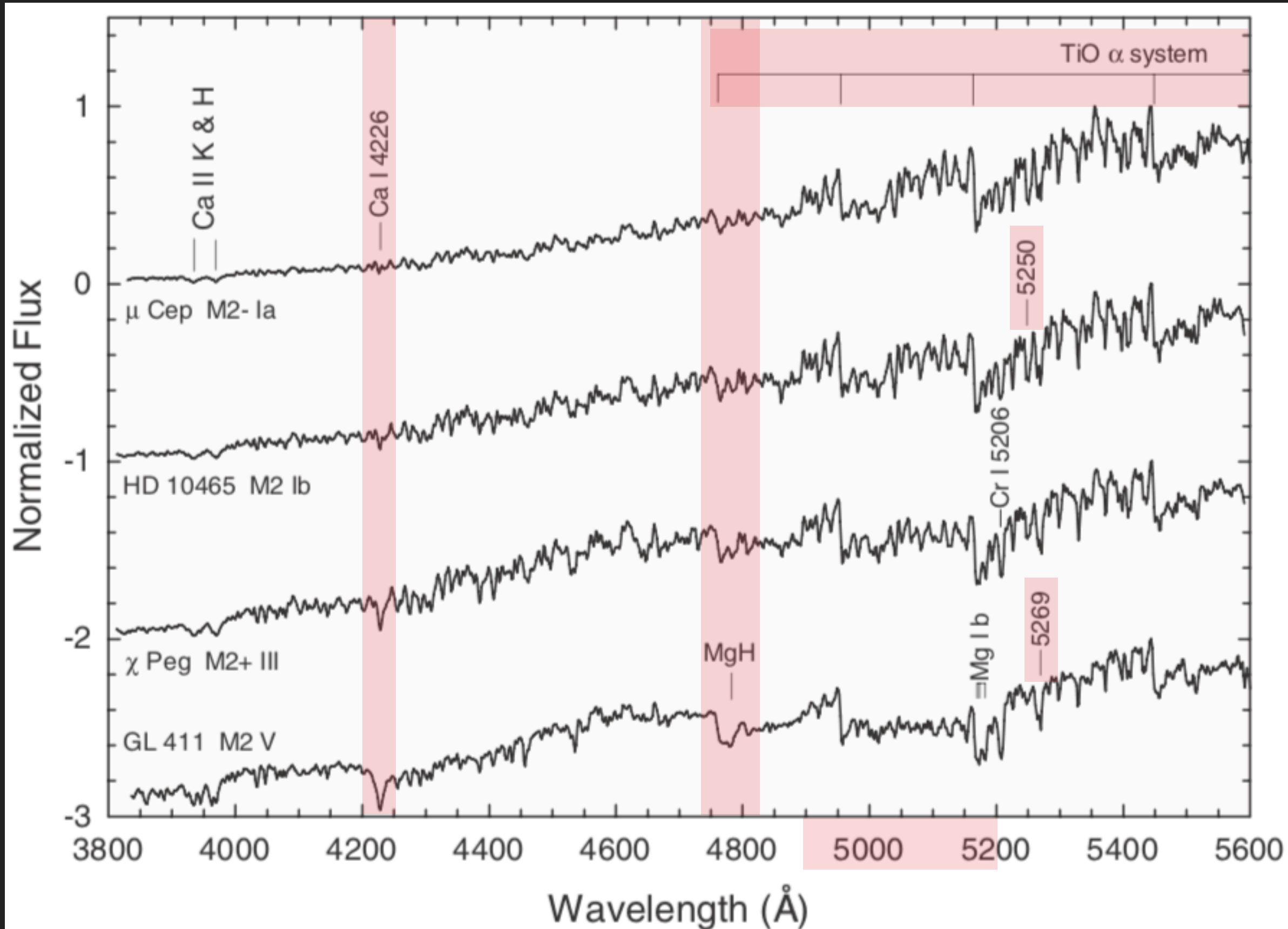
TEMPERATURE CRITERIA



LUMINOSITY CRITERIA

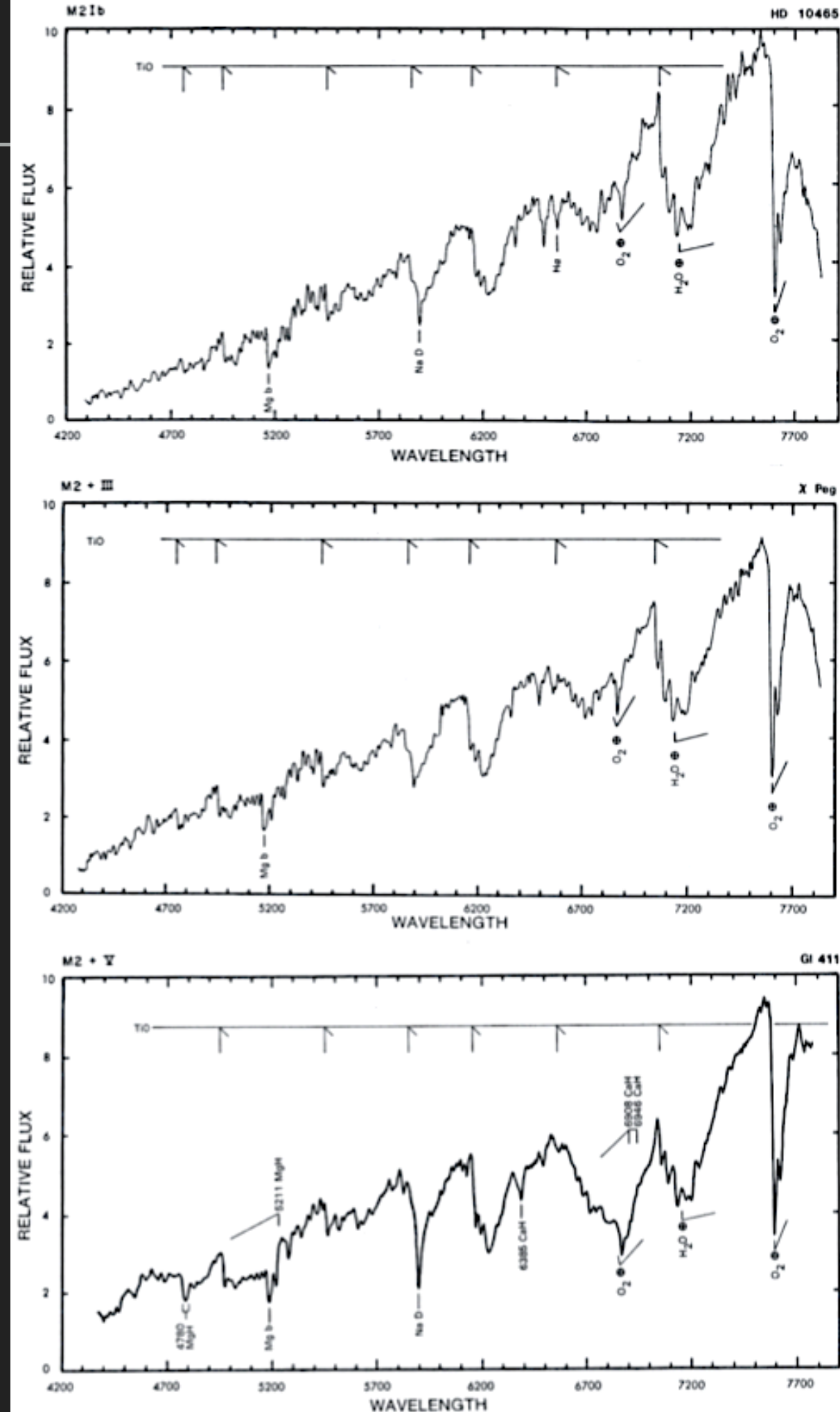
- ▶ Absorption Ca 4226
- ▶ MgH/TiO 4770
 - ▶ MgH dominates in dwarfs
- ▶ 5250/5269
 - ▶ 5250 - intersystem Fe I triplet - direct relationship with luminosity
- ▶ Resolution worse than 3.6 \AA
 - ▶ 4900-5200 general morphology
- ▶ Resolution better than 2 \AA
 - ▶ Absorption in
 - ▶ Ca I triplet at 4425, 4435, 4455
 - ▶ Cr I triplet at 4254, 4260, 4290

LUMINOSITY CRITERIA



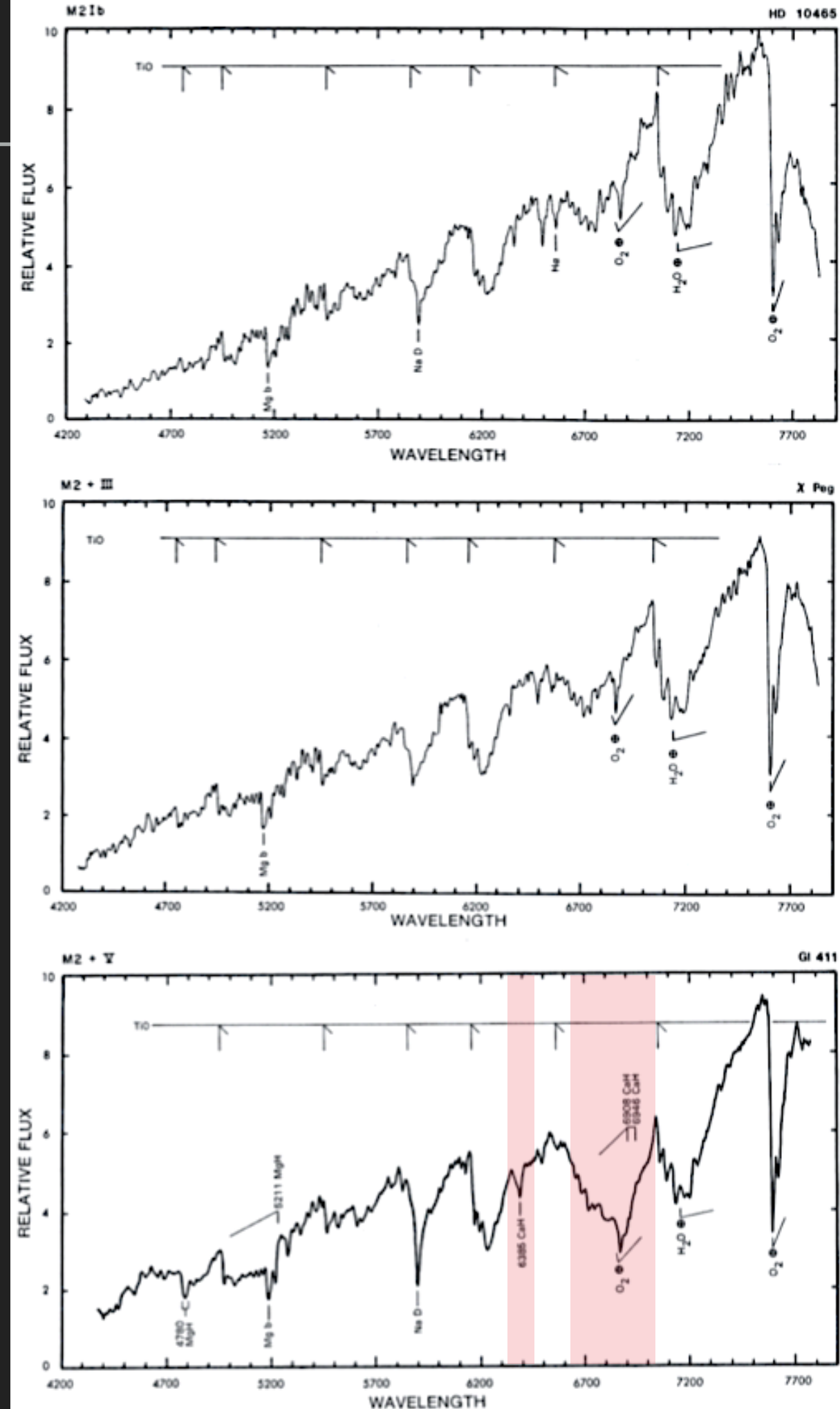
NIR & IR CLASSIFICATION

- ▶ Luminosity
 - ▶ Na(D) doublet enhanced
 - ▶ TiO bands
 - ▶ CaH A-band 6946, 6908
 - ▶ CaH B-band 6385
 - ▶ 6362 CaH decreases & Ti, Fe, Cr blend increases
- ▶ Temperature
 - ▶ TiO bands
 - ▶ KI 7665, 7699 iteratively



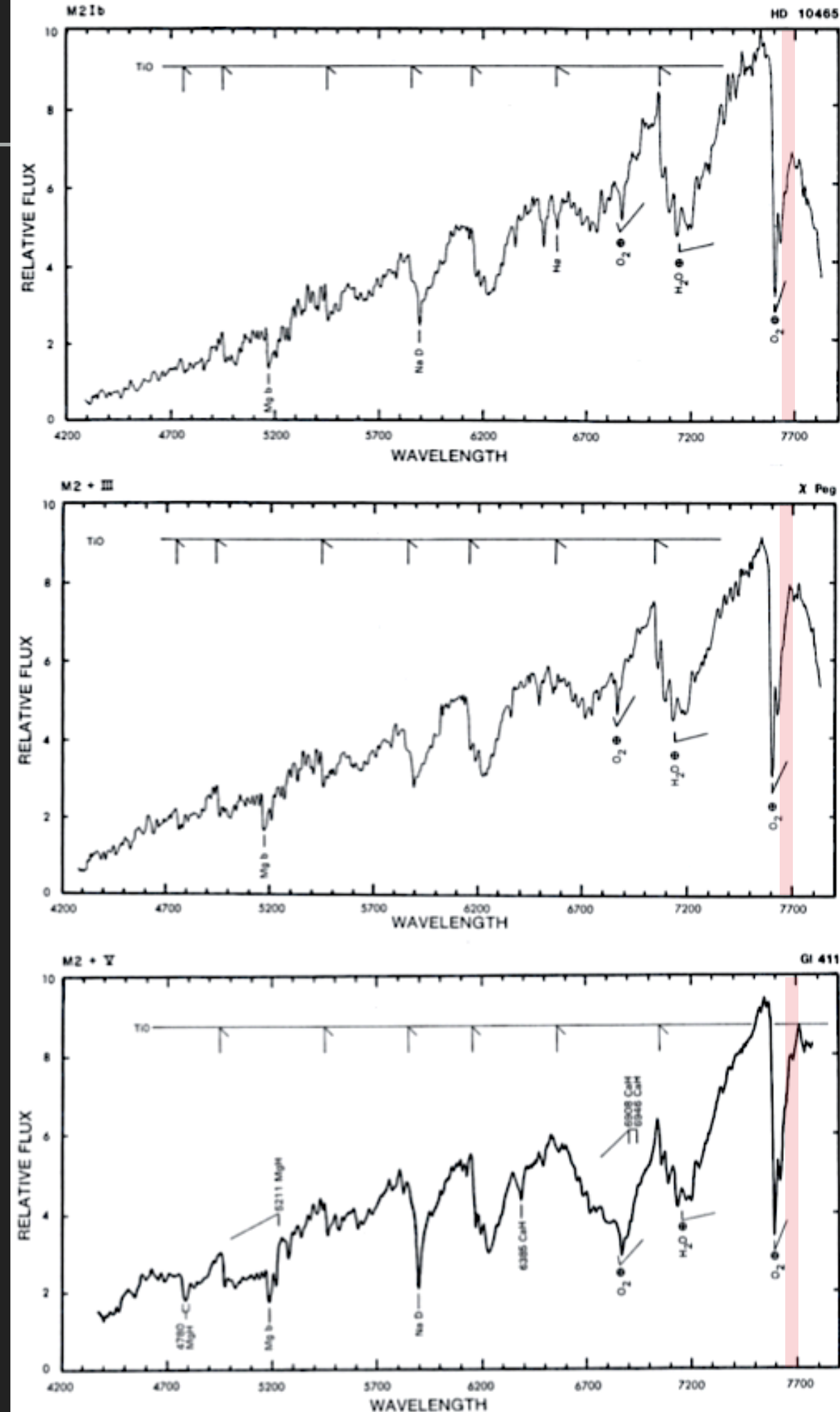
NIR & IR CLASSIFICATION

- ▶ Luminosity
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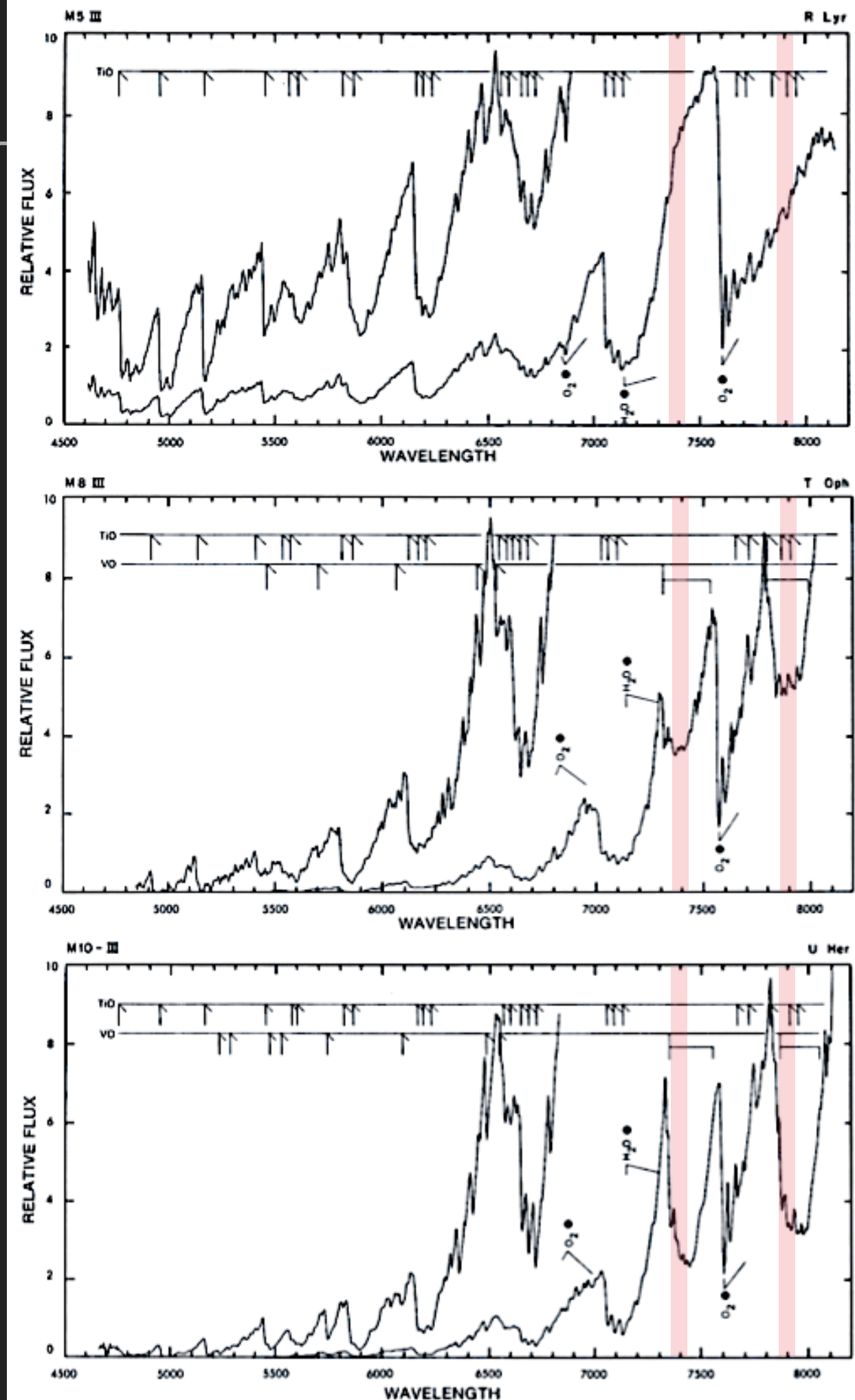
NIR & IR CLASSIFICATION

- ▶ Luminosity
 - ▶ Na(D) doublet enhanced
 - ▶ TiO bands
 - ▶ CaH A-band 6946, 6908
 - ▶ CaH B-band 6385
 - ▶ 6362 CaH decreases & Ti, Fe, Cr blend increases
- ▶ Temperature
 - ▶ TiO bands
 - ▶ **K I 7665, 7699 iteratively**



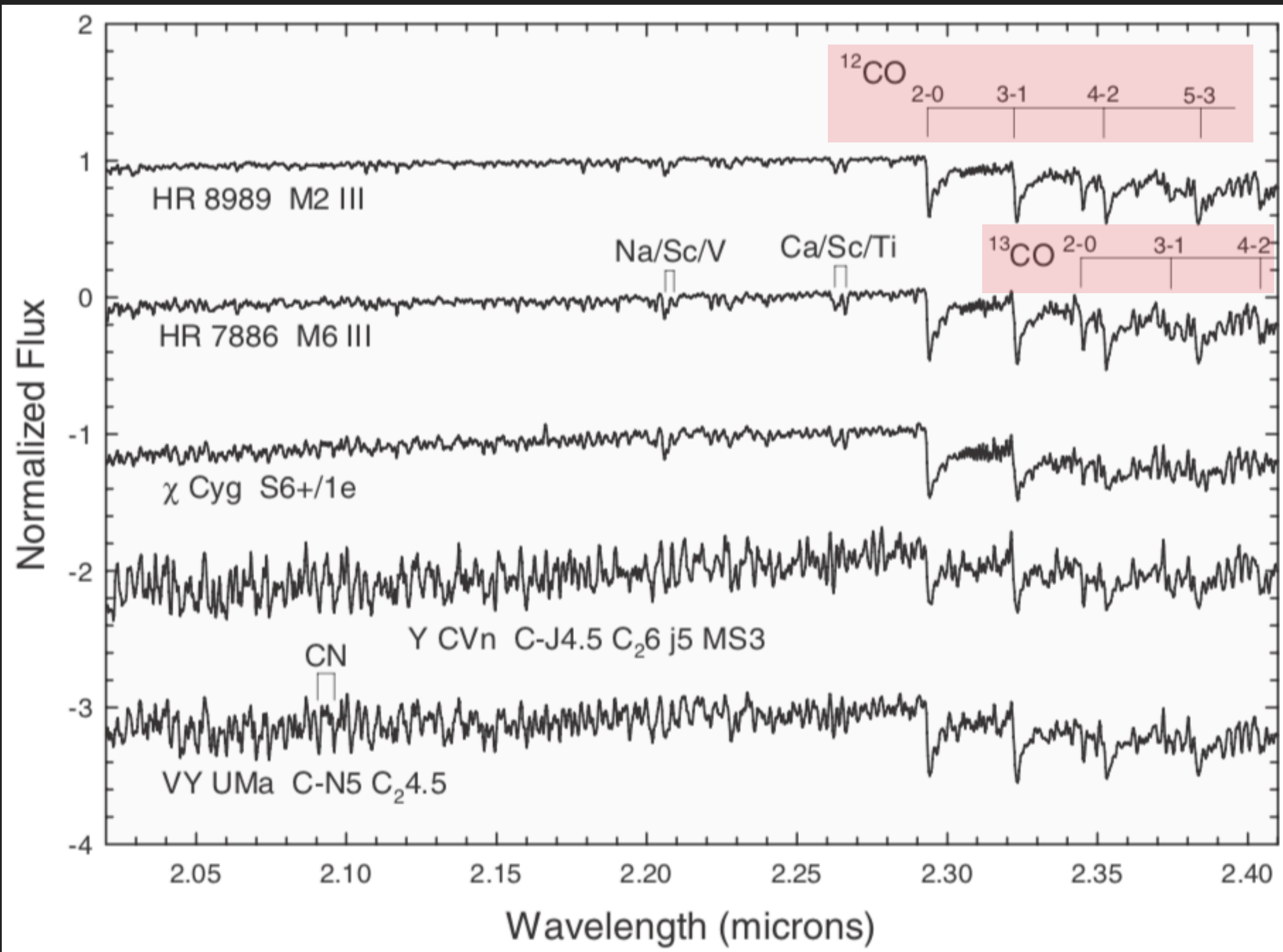
NIR & IR CLASSIFICATION

- ▶ Luminosity
 - ▶ Na(D) doublet enhanced
 - ▶ TiO bands
 - ▶ CaH A-band 6946, 6908
 - ▶ CaH B-band 6385
 - ▶ 6362 CaH decreases & Ti, Fe, Cr blend increases
- ▶ Temperature
 - ▶ TiO bands
 - ▶ K I 7665, 7699 iteratively
 - ▶ **M7+, VO 7400, 7900**



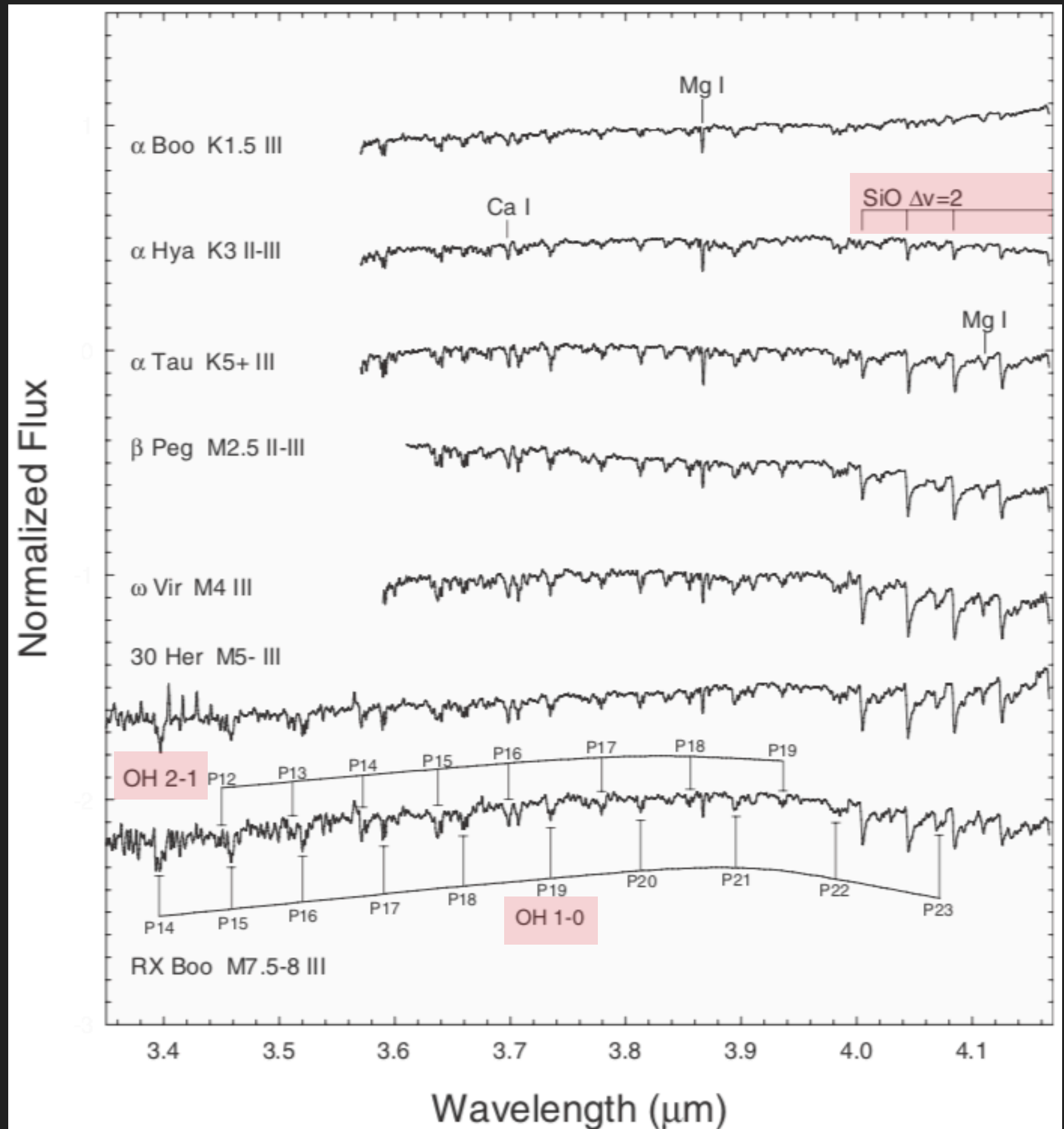
NIR & IR CLASSIFICATION

► K band - CO bands



NIR & IR CLASSIFICATION

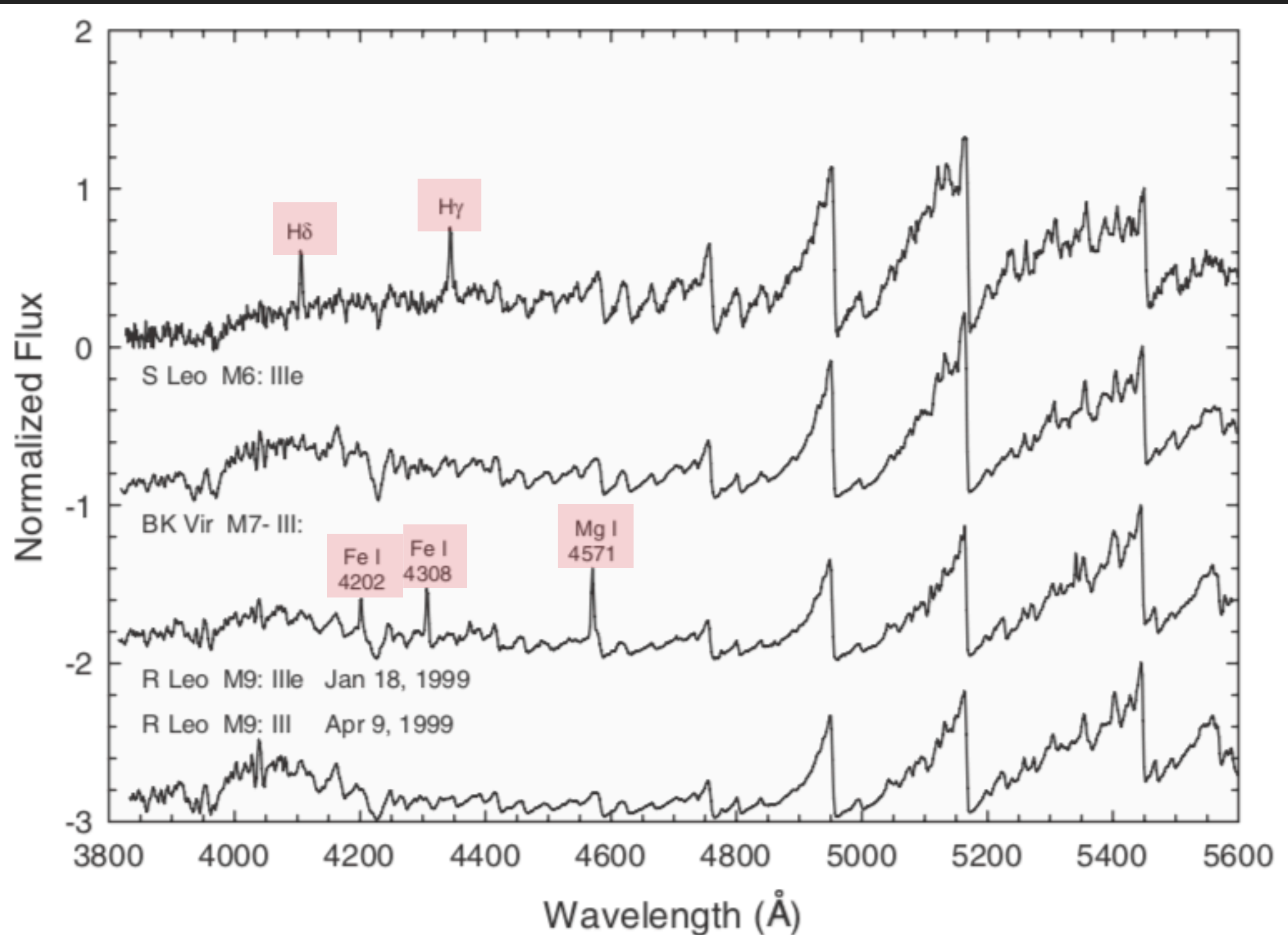
- ▶ L band - SiO
- ▶ P-branch - OH



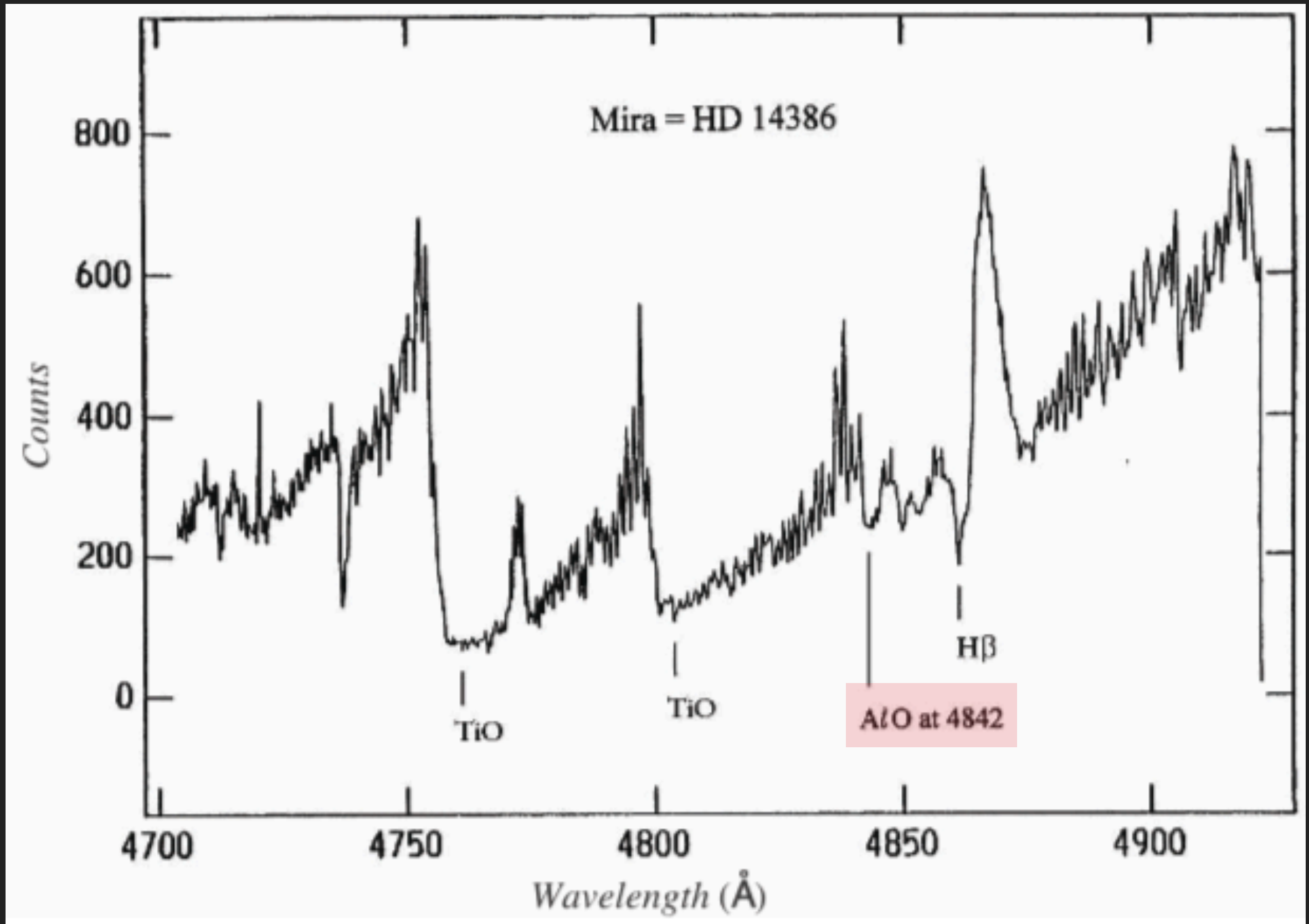
MIRA VARIABLES

- ▶ Similar to M giants
 - ▶ Decreasing temperature
 - ▶ TiO absorption
 - ▶ Atomic lines - Ca I 4226
- ▶ Distinguished by
 - ▶ H & Fe II (high excitation)
 - ▶ Vary with luminosity - strongest at & after maximum, weakest after minimum
 - ▶ Quantity of fluorescence lines

CLASSIFICATION OF MIRA VARIABLES



CLASSIFICATION OF MIRA VARIABLES



IRREGULARS & SEMIREGULARS

- ▶ Less regular
- ▶ Less extreme
- ▶ Exhibit milder & fewer Mira characteristics

CARBON STARS

- ▶ Classical stars
 - ▶ Temperature & Luminosity = late-G, K, M giants
 - ▶ Large overabundances of C relative to O
- ▶ Spectra dominated by strong molecular bands
 - ▶ CH, CN, C₂
- ▶ Cooler stars
 - ▶ SiC₂, C₃, etc.
- ▶ G-band

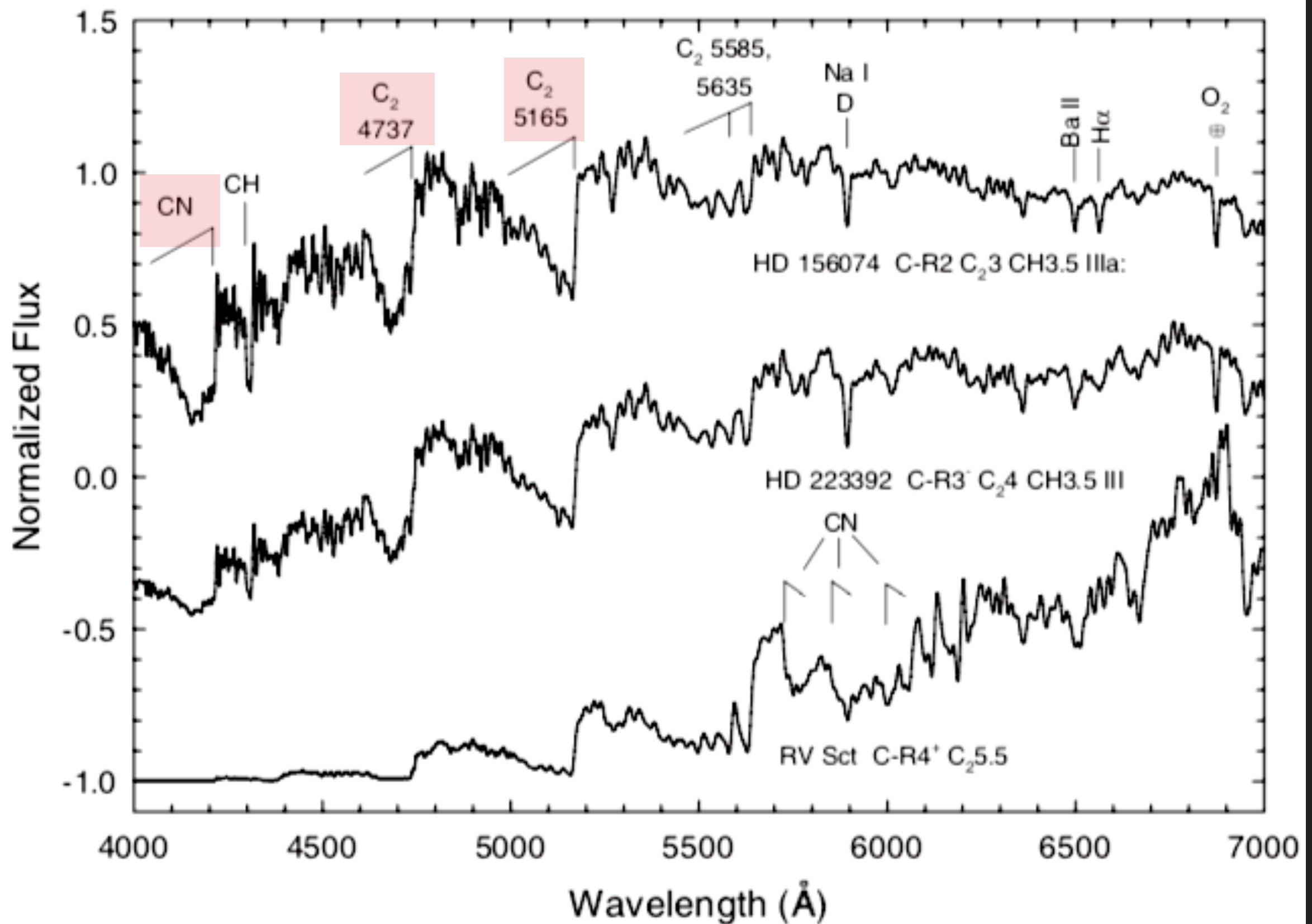
- ▶ Keenan & Morgan 1941
- ▶ Superseded by Keenan 1993
- ▶ Attempt to find ordering of Carbon stars consistent with T_{eff}
- ▶ Assigned a carbon sequence type classification
 - ▶ C0-C7
 - ▶ Range G, K, M stars
- ▶ Strength parameter for Swan bands
 - ▶ 1-5
- ▶ Luminosity not assigned

CARBON STARS: KEENAN CLASSIFICATION

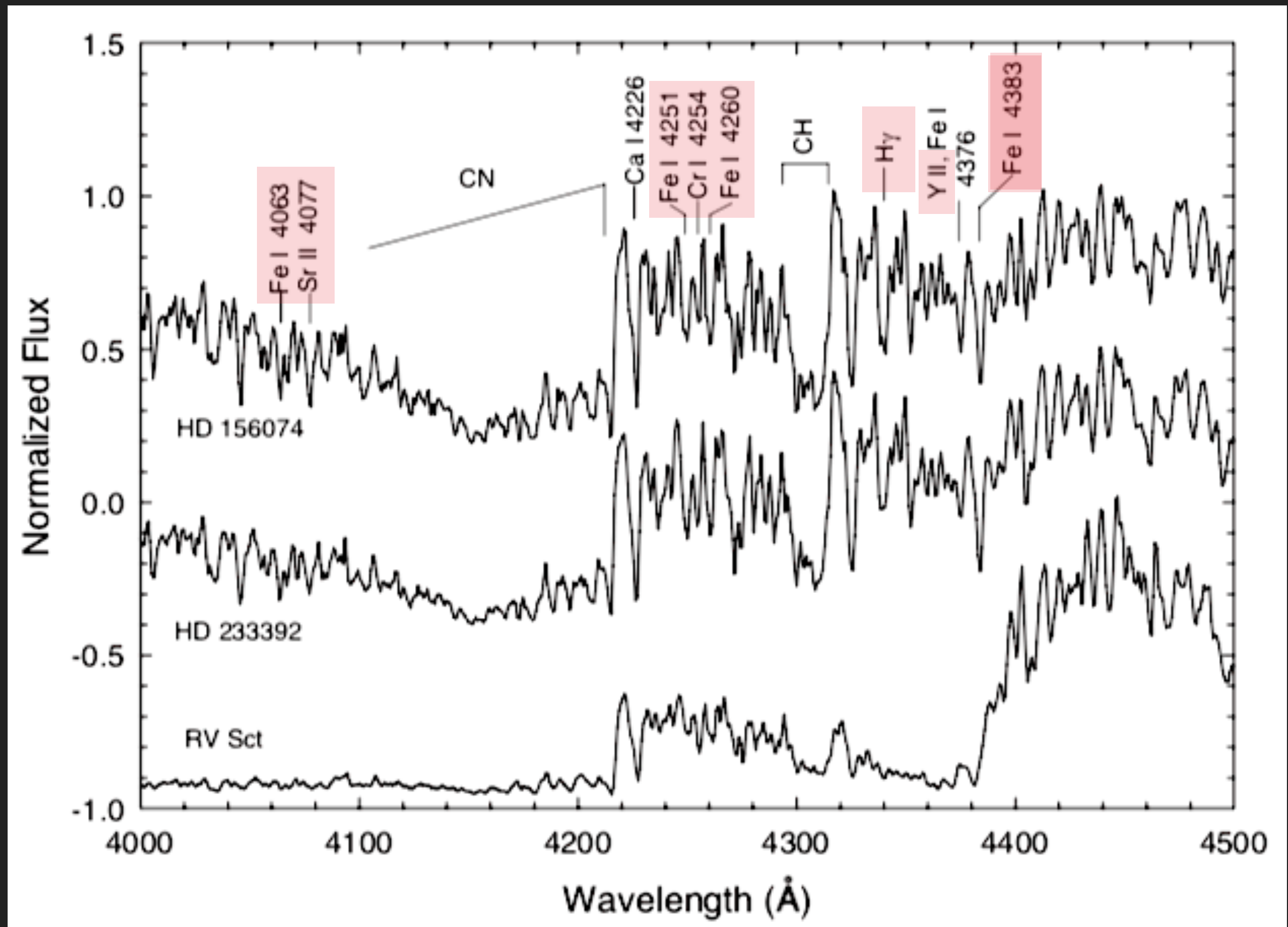
- ▶ C-R stars: corresponds with Harvard R stars
- ▶ C-N stars: corresponds with Harvard N stars
- ▶ C-Hd stars: H deficient
- ▶ C-J stars
- ▶ C-H stars
- ▶ Indexes:
 - ▶ C2: strength of Swan bands, 1-5
 - ▶ CH: $3.5 < \text{C-H star}$
 - ▶ J: ratio of $^{12}\text{C}/^{13}\text{C}$, 1-5, $1=R_{\odot}$
 - ▶ MS: Merrill-Sanford band of SiC_2 present

Equivalent types for oxygen stars	R Sequence	N sequence	CH sequence
G4 – G6	C-R0		C-H0
G7 – G8	C-R1	C-N1	C-H1
G9 – K0	C-R2	C-N2	C-H2
K1 – K2	C-R3	C-N3	C-H3
K3 – K4	C-R4	C-N4	C-H4
K5 – M0	C-R5	C-N5	C-H5
M1 – M2	C-R6	C-N6	C-H6
M3 – M4		C-N7	
M5 – M6		C-N8	
M7 – M8		C-N9	

CARBON STARS: KEENAN CLASSIFICATION: C-R STARS



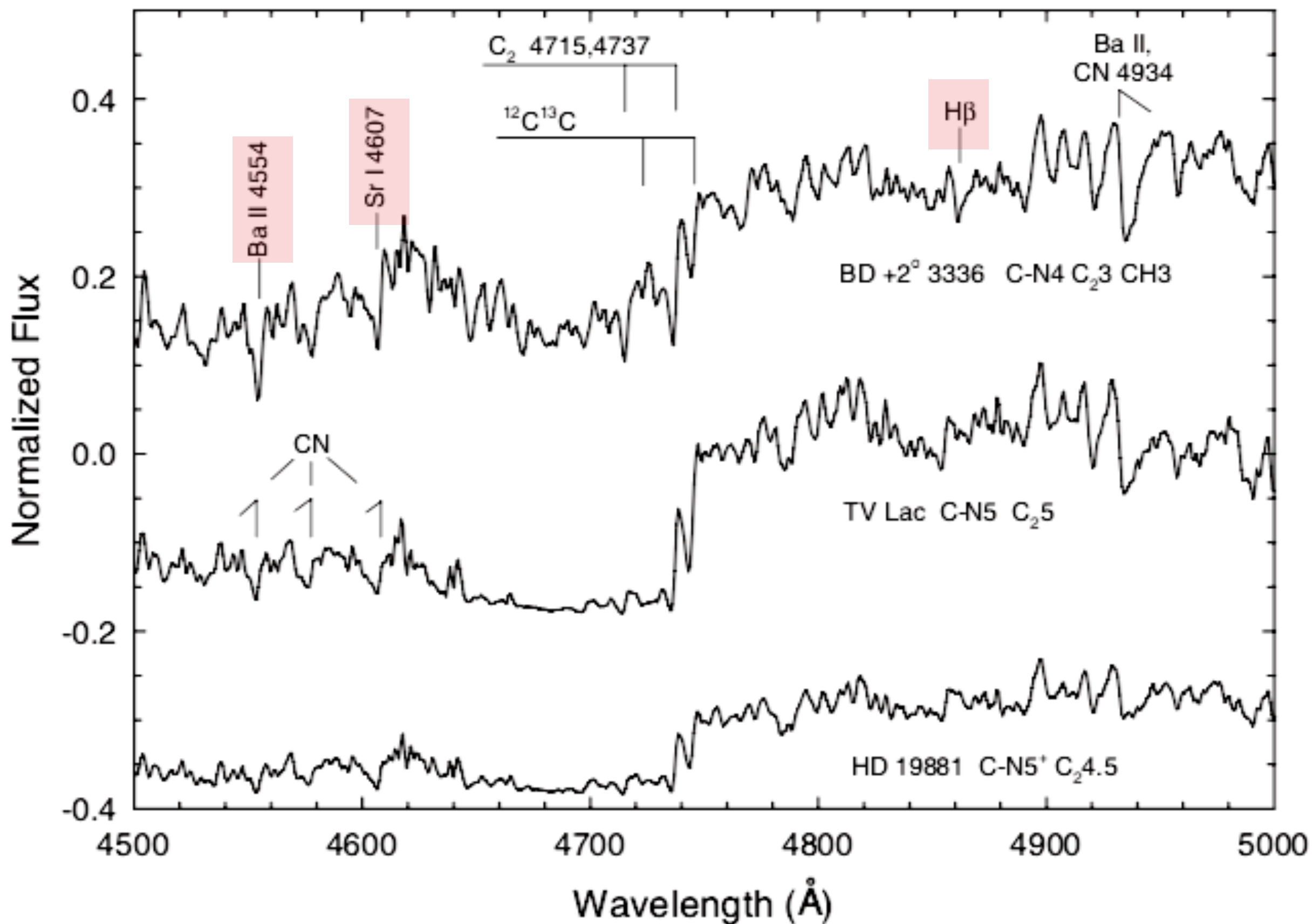
CARBON STARS: KEENAN CLASSIFICATION: C-R STARS



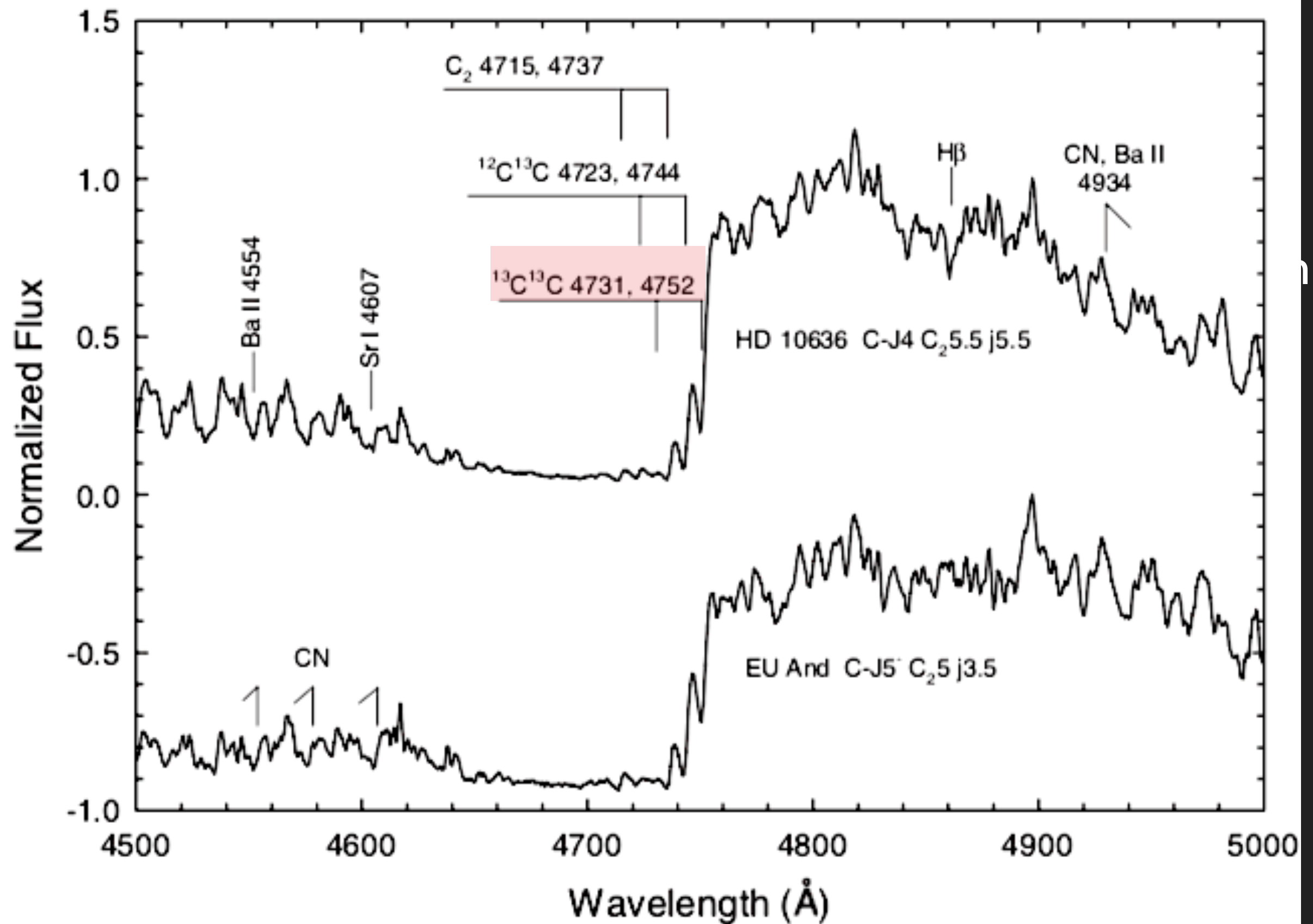
C-N CARBON STARS

- ▶ Majority in narrow temperature range
- ▶ Difference from C-R stars:
 - ▶ Extreme redness
 - ▶ Strong absorption in blue
 - ▶ Generally little/no flux shortward of 4400 Å
 - ▶ C₂ isotopic bands weaker
 - ▶ S-process elements more enhanced

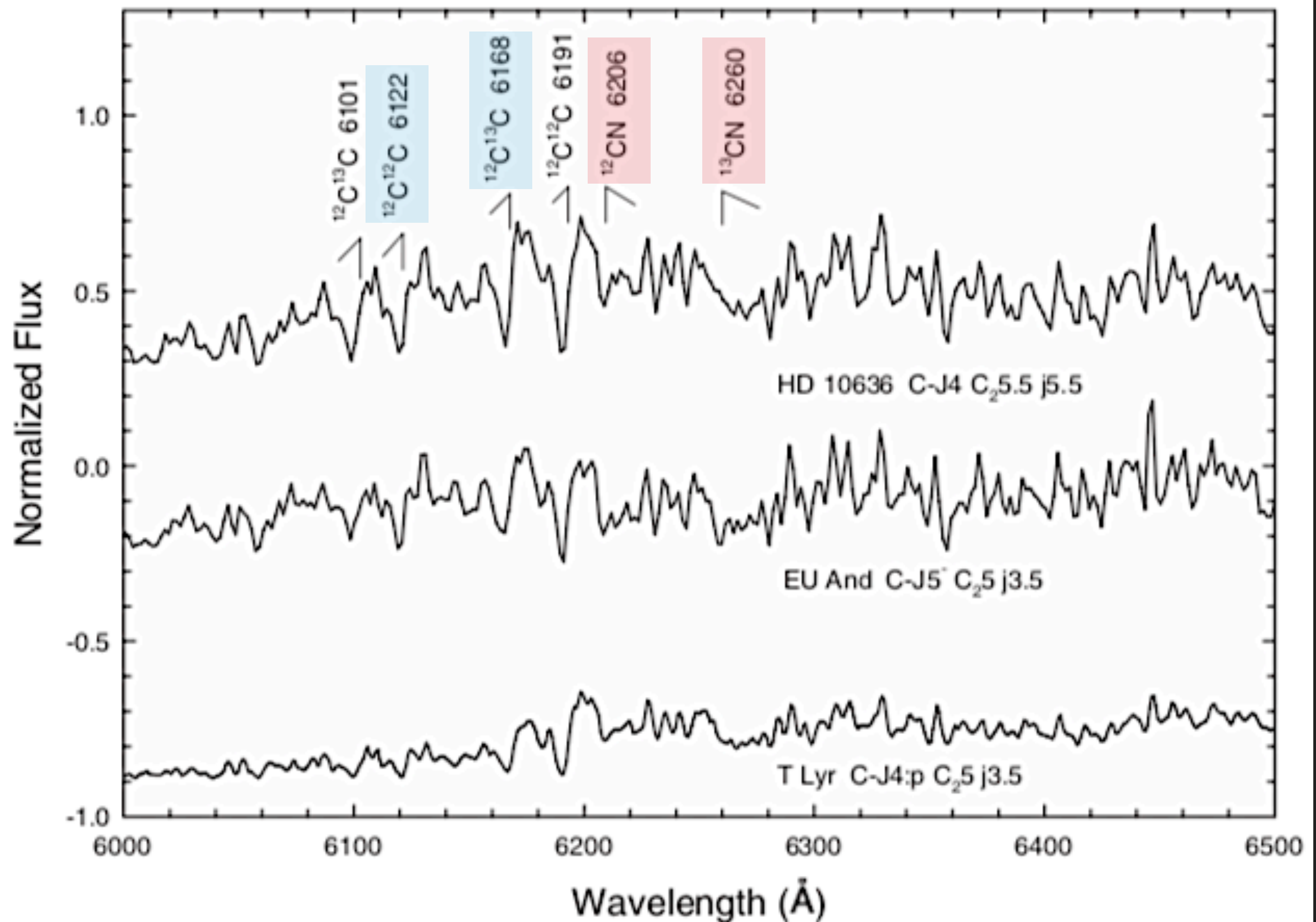
CARBON STARS: KEENAN CLASSIFICATION: C-N STARS



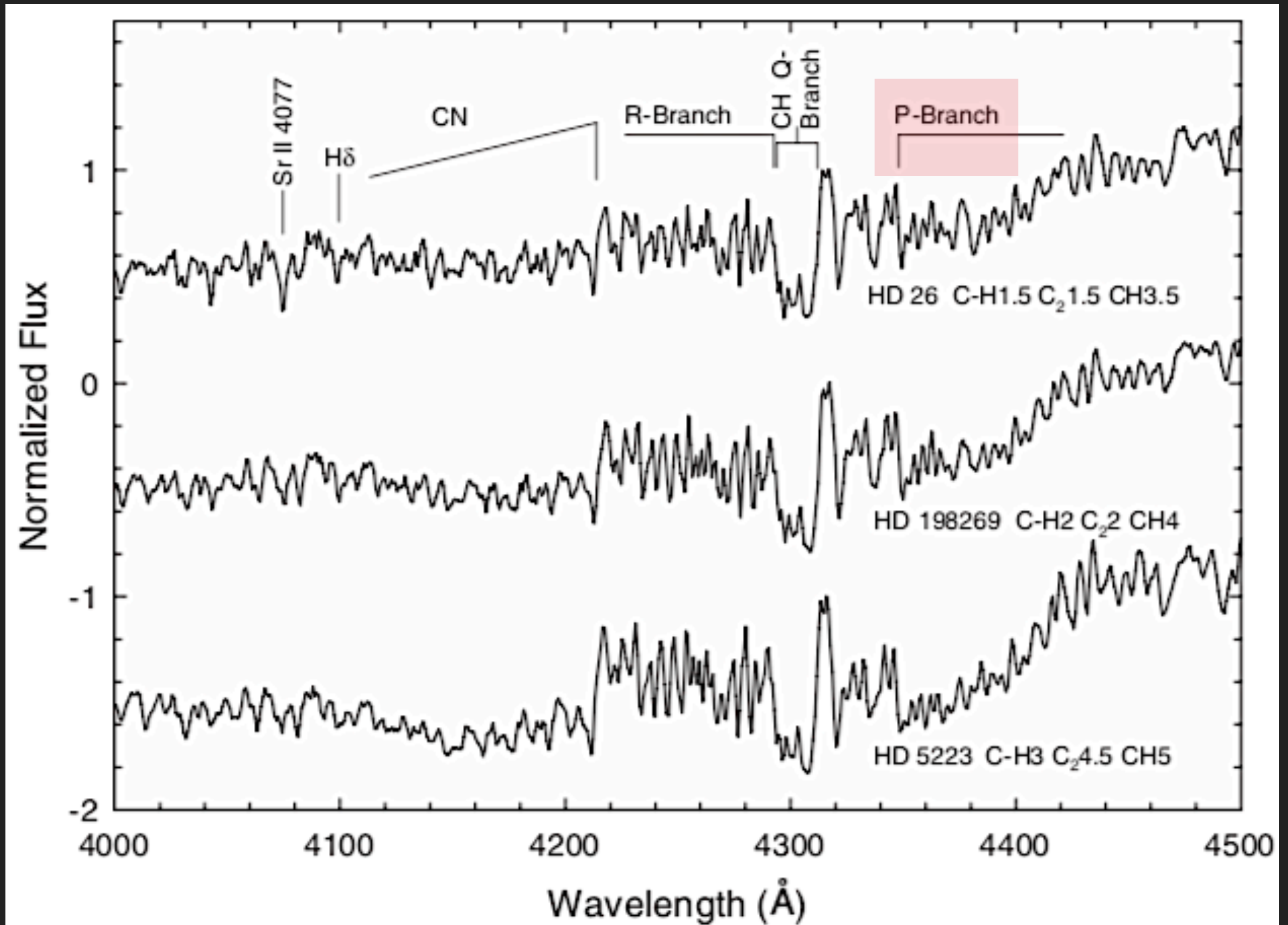
CARBON STARS: KEENAN CLASSIFICATION: C-J STARS



CARBON STARS: KEENAN CLASSIFICATION: C-J STARS

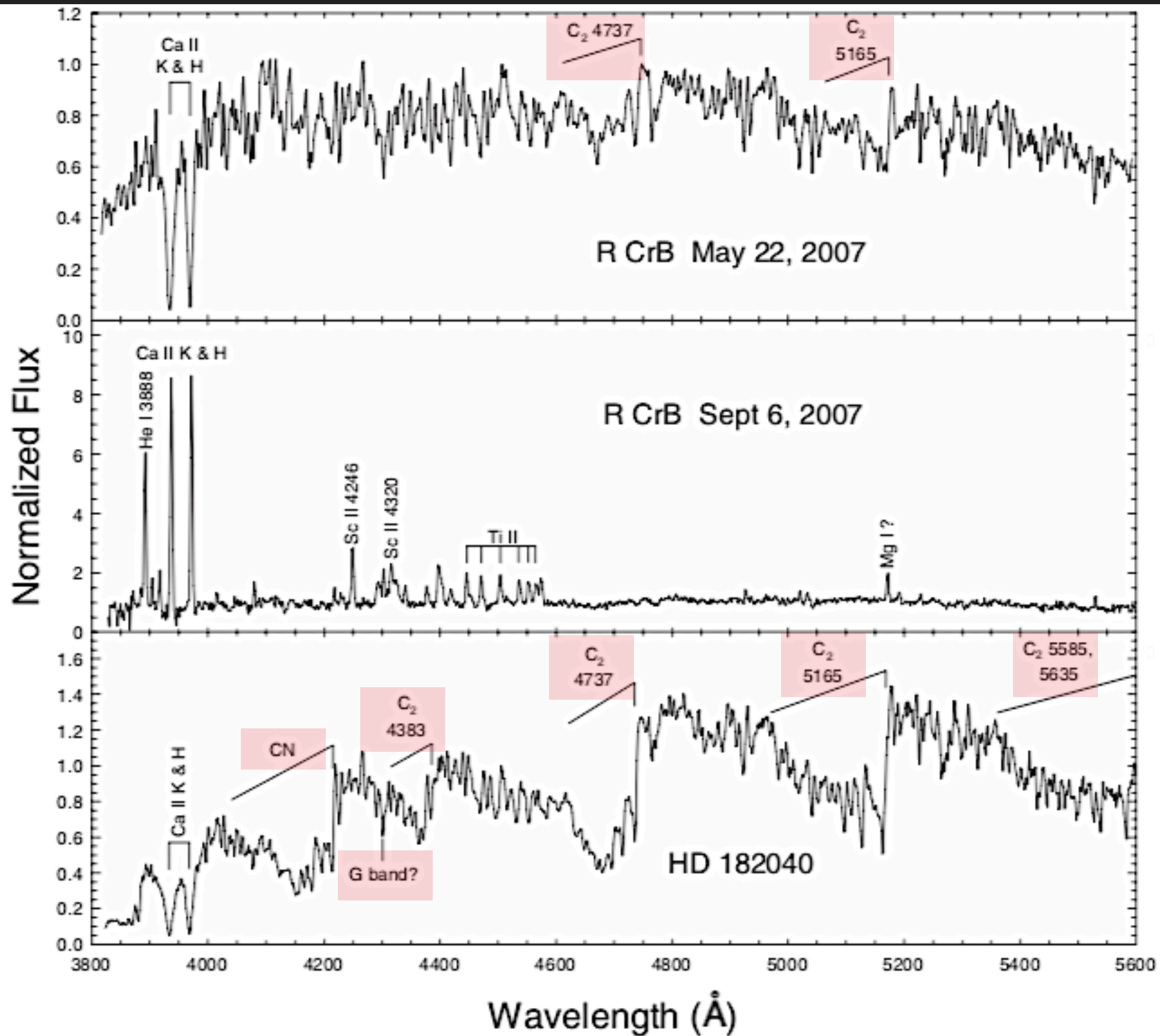


CARBON STARS: KEENAN CLASSIFICATION: C-H STARS



C-HD CARBON STARS

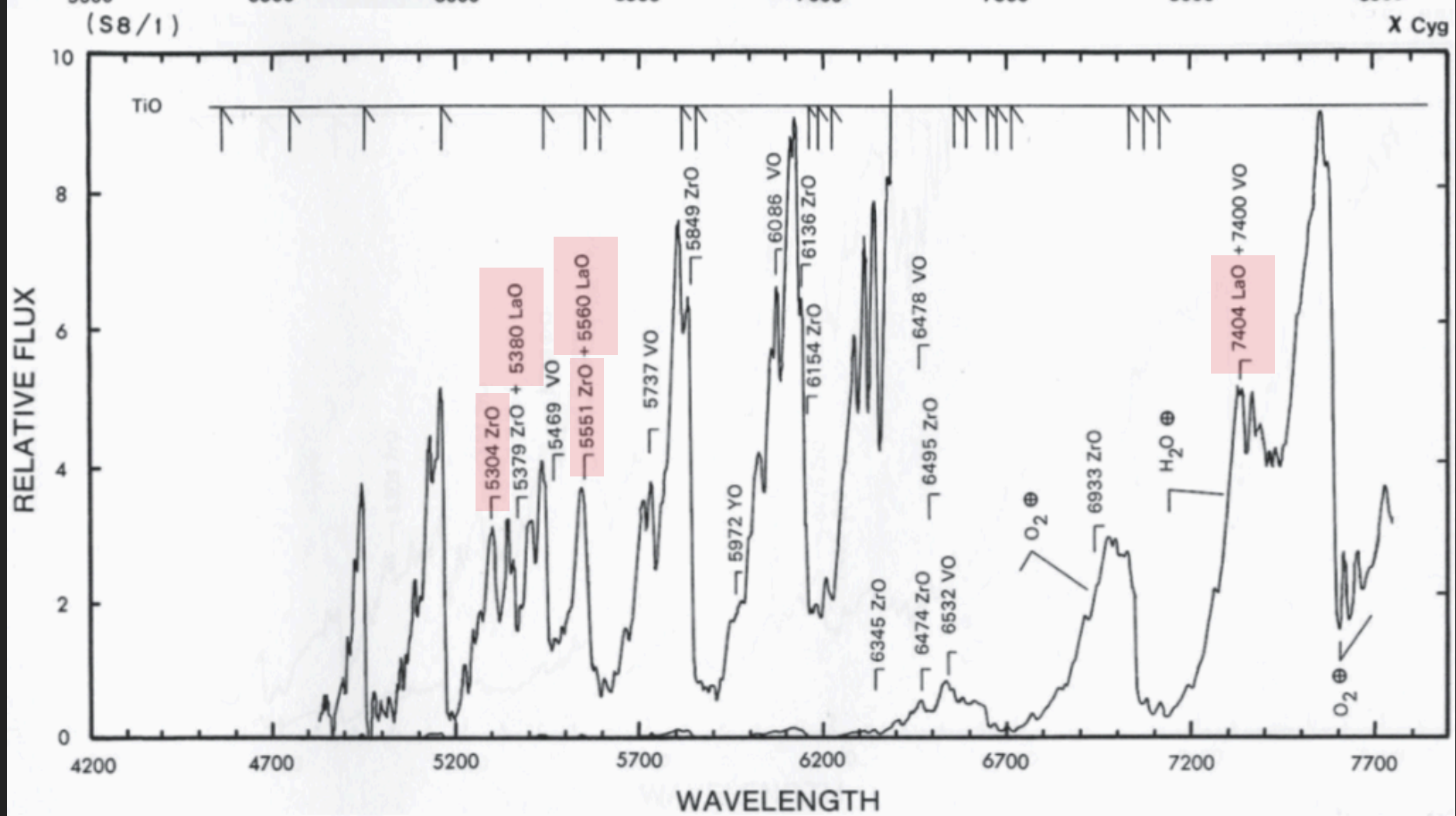
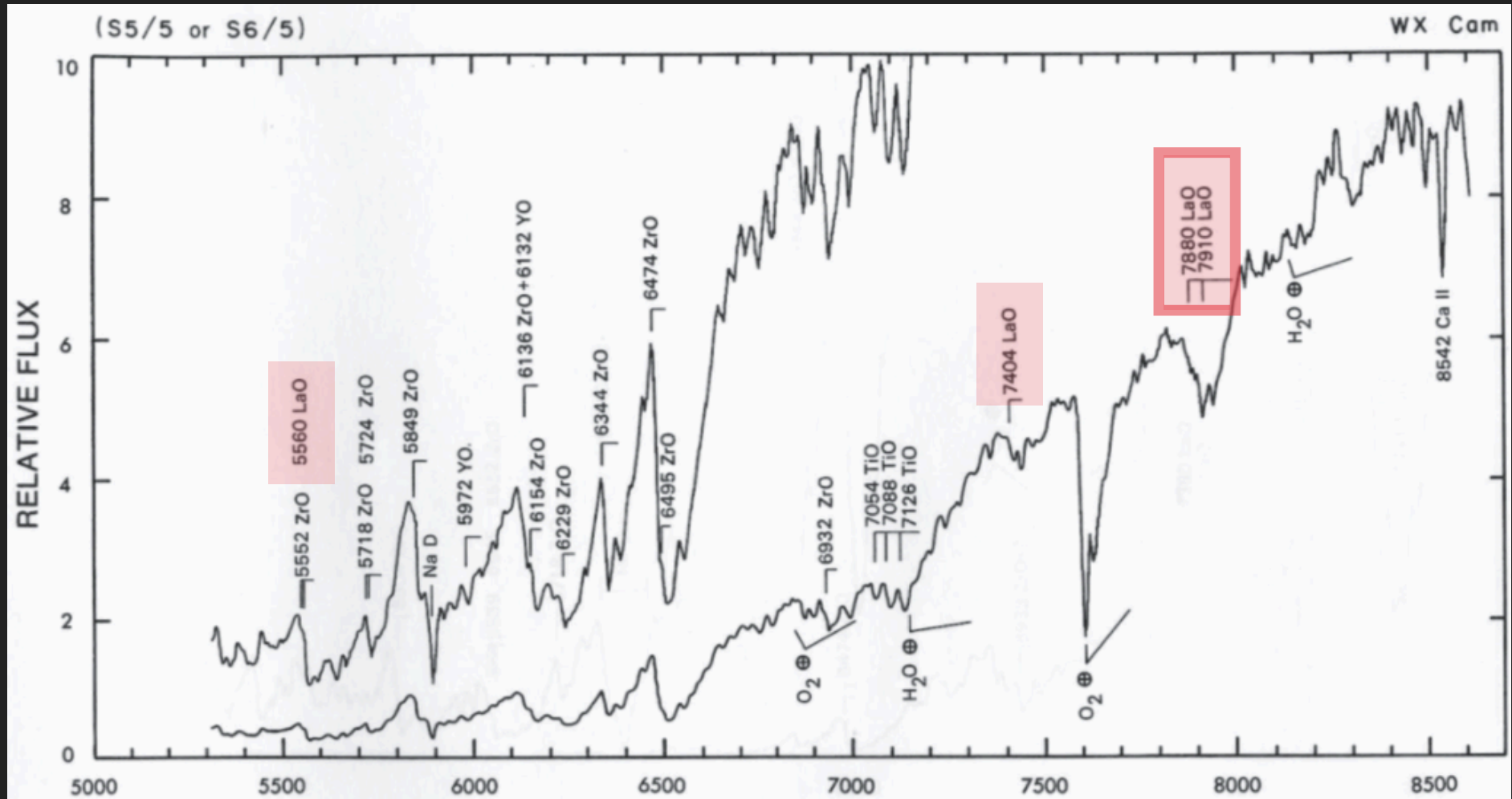
- ▶ R CrB Variables
 - ▶ Most time at maximum light
 - ▶ Fade dramatically at irregular intervals
- ▶ Weakly Variable
 - ▶ Exceptionally rare
 - ▶ Non/Weakly variable
 - ▶ Appear as G-type Ib Supergiants
 - ▶ CN & C₂
 - ▶ Exceptionally weak H lines & G band



S-TYPE STARS

- ▶ Late-type giant stars
- ▶ Many LPVs
- ▶ Features = cover same temperatures as M giants
 - ▶ ZrO
 - ▶ TiO
 - ▶ VO
 - ▶ YO
 - ▶ LaO
- ▶ Bridge between Carbon and M stars
- ▶ M → MS → S → SC → C
- ▶ 2 Groups
 - ▶ Intrinsic
 - ▶ Acquire abundance peculiarities due to dredge up
 - ▶ Extrinsic
 - ▶ Acquire abundance peculiarities due to external factor

- ▶ Attempts to
 - ▶ Designate C/O index
 - ▶ Temperature Type
 - ▶ C/O index ≤ 2
 - ▶ C/O index ≤ 4
 - ▶ C/O index > 3
 - ▶ $\text{ZrO} \approx \text{TiO}$
 - ▶ Pure S-type
 - ▶ Red: 6450/6456
- ▶ Estimate Intensity for
 - ▶ ZrO bands
 - ▶ TiO bands
 - ▶ Na I D-lines
 - ▶ YO bands
 - ▶ Li I 6708 line



- ▶ Similarities: N-Carbon Stars & S-type Stars
 - ▶ Red Giants
 - ▶ Semi-regular pulsating variables or Mira variables
 - ▶ Enhanced abundances of C & s-process elements
- ▶ Doesn't explain range of Carbon & S-type stars we see
- ▶ 2 groups of S-type stars can't be distinguished at classification resolution
 - ▶ Intrinsic - Tc-rich, undergoing pulses
 - ▶ Extrinsic - Tc-poor
 - ▶ Essentially all are binaries!
 - ▶ Evolutionary relationship between S-type and Barium stars?

- ▶ High velocity
- ▶ Halo or Thick Disk objects
- ▶ Overabundance of s-process elements
- ▶ Very high binary frequency
- ▶ Mass transfer!

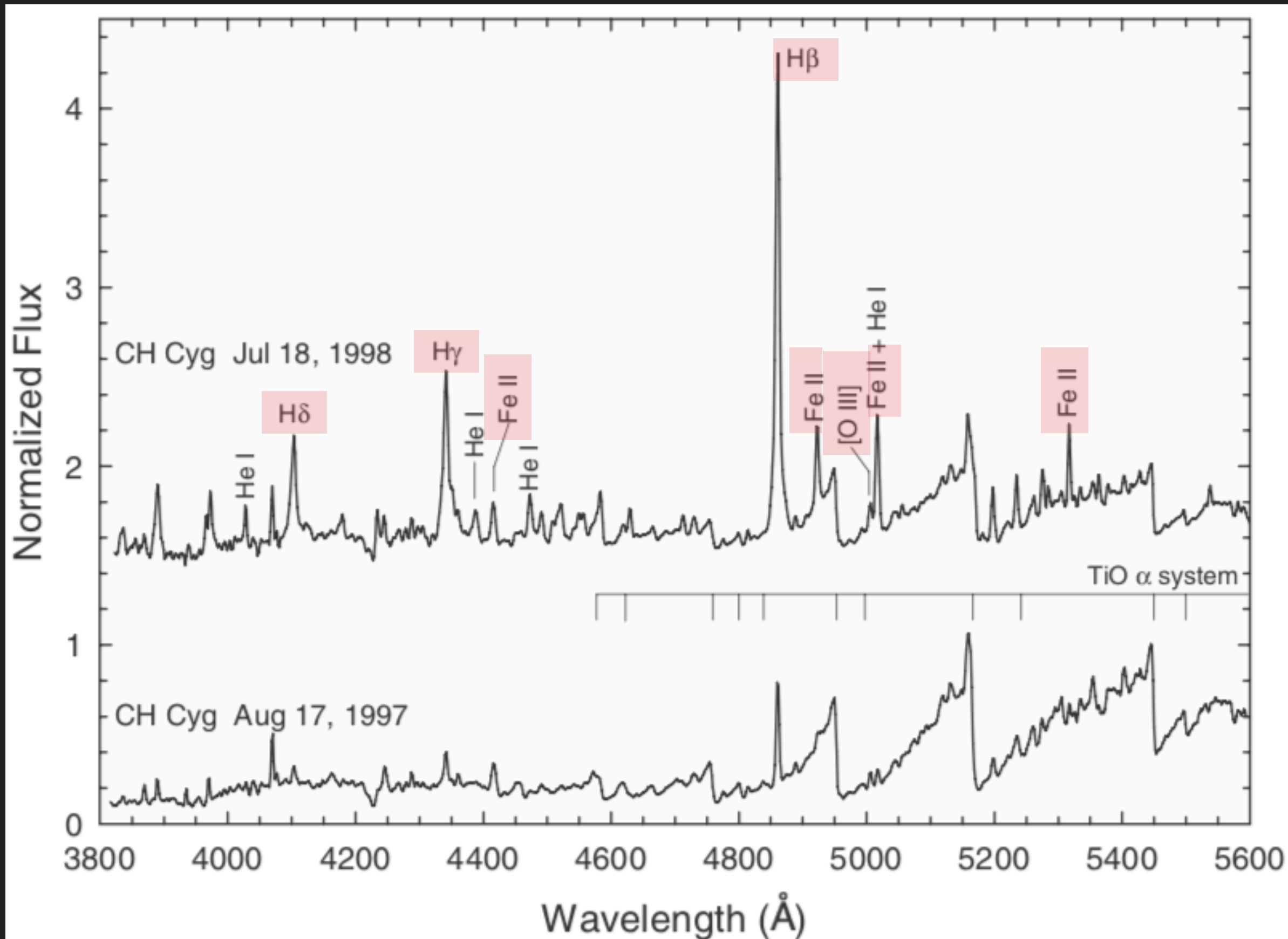
- ▶ Where did the peculiarities come from?
- ▶ Dominy 1984: He Flash
 - ▶ How did it reach the surface?
 - ▶ ???
- ▶ Very low binary frequency
- ▶ RGB instead of AGB

- ▶ Significant fraction have Oxygen rich dust shells
- ▶ Some associated with OH and/or H₂O Masers
 - ▶ ???
- ▶ Large abundance of ¹³C isotope
 - ▶ ???
- ▶ Evolutionary state not yet known

SYMBIOTIC STARS

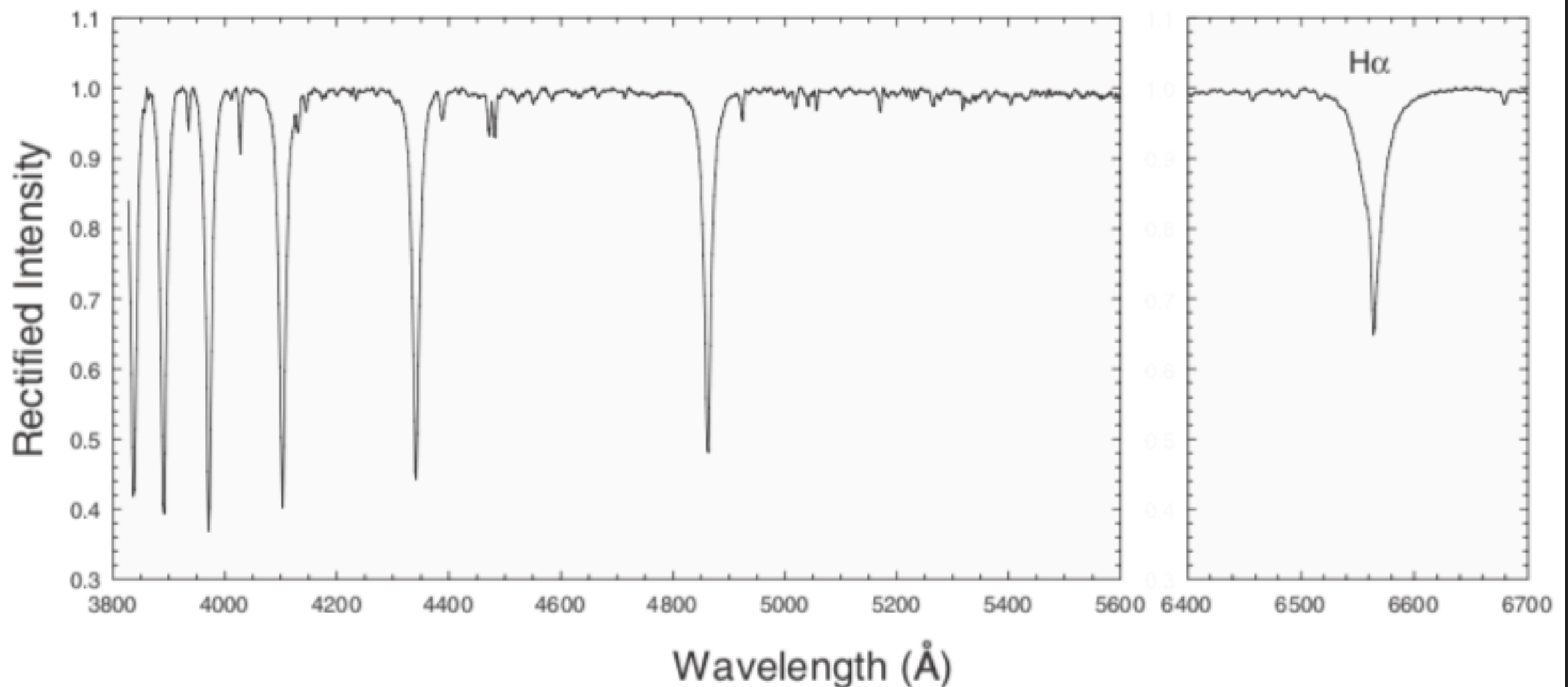
- ▶ Interacting binaries
- ▶ Largest orbital separation
- ▶ UV - signature of hot component
- ▶ Optical - dominated by cool primary
- ▶ 2 Types with 2 Subtypes
- ▶ S-types
 - ▶ Yellow S-types
 - ▶ Red S-types
- ▶ d-types
 - ▶ Yellow dusty SySs
 - ▶ Red dusty SySs
- ▶ Classifying SySs in NIR
 - ▶ Spectral type from TiO & VO bands
- ▶ Luminosity...

SYMBIOTIC & ALGOL STARS



ALGOL STARS

- ▶ Close interacting binaries
- ▶ Composed of
 - ▶ “Classical” mid B - mid F dwarf primary
 - ▶ F - K secondary



QUESTIONS?

