Emerging Variety of Binary Systems among Objects with Gas-and-Dust Envelopes

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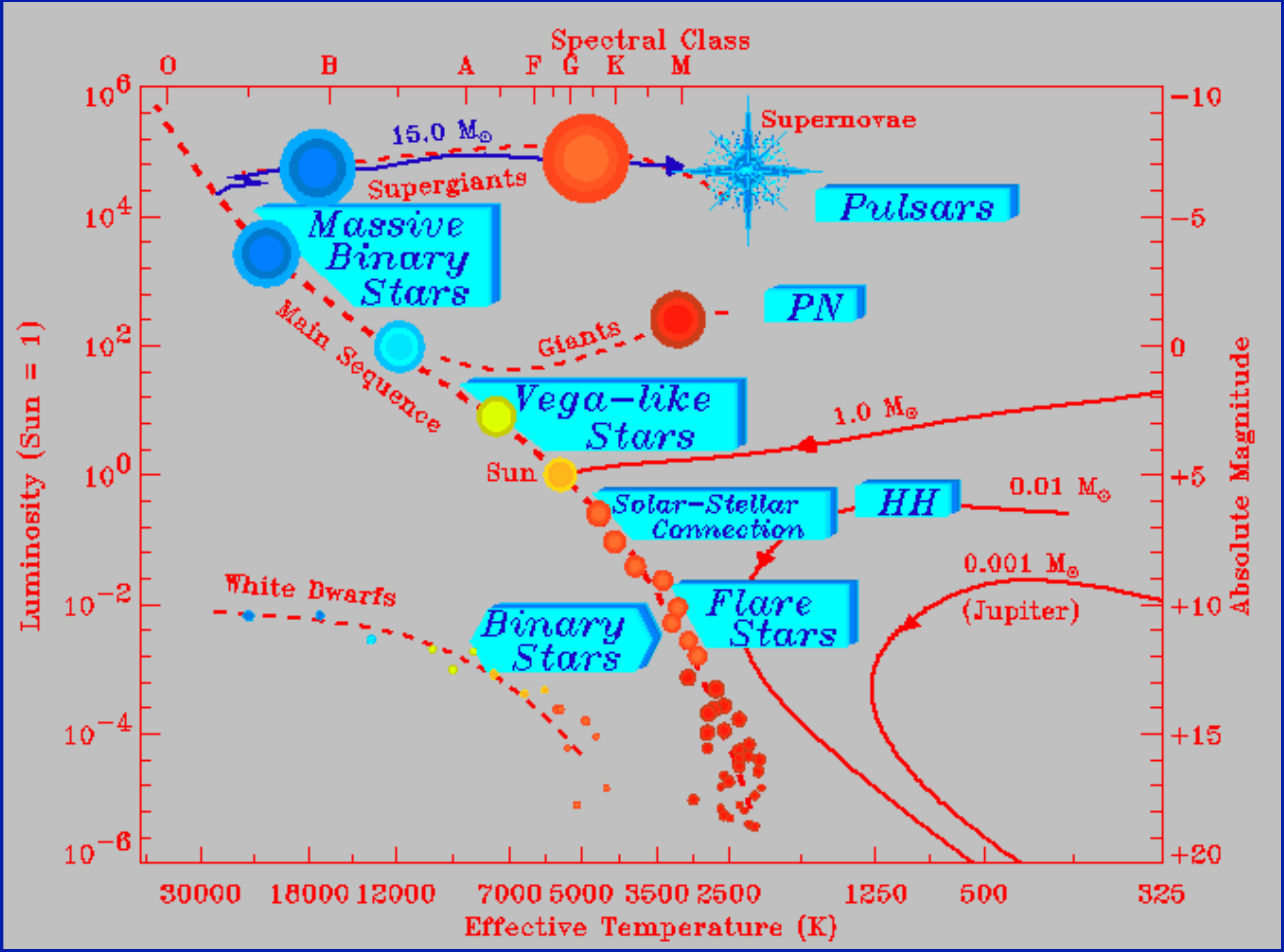
Outline

- World of Stars and Evolution of Our Understanding of It
- Binary Stars and What We Observe from Them
- The B[e] Phenomenon and FS CMa Type Objects
- Known and Suspected FS CMa Type Binaries

Hertzsprung-Russell Diagram



Stellar Fundamental Parameters

Hertzsprung-Russell diagram

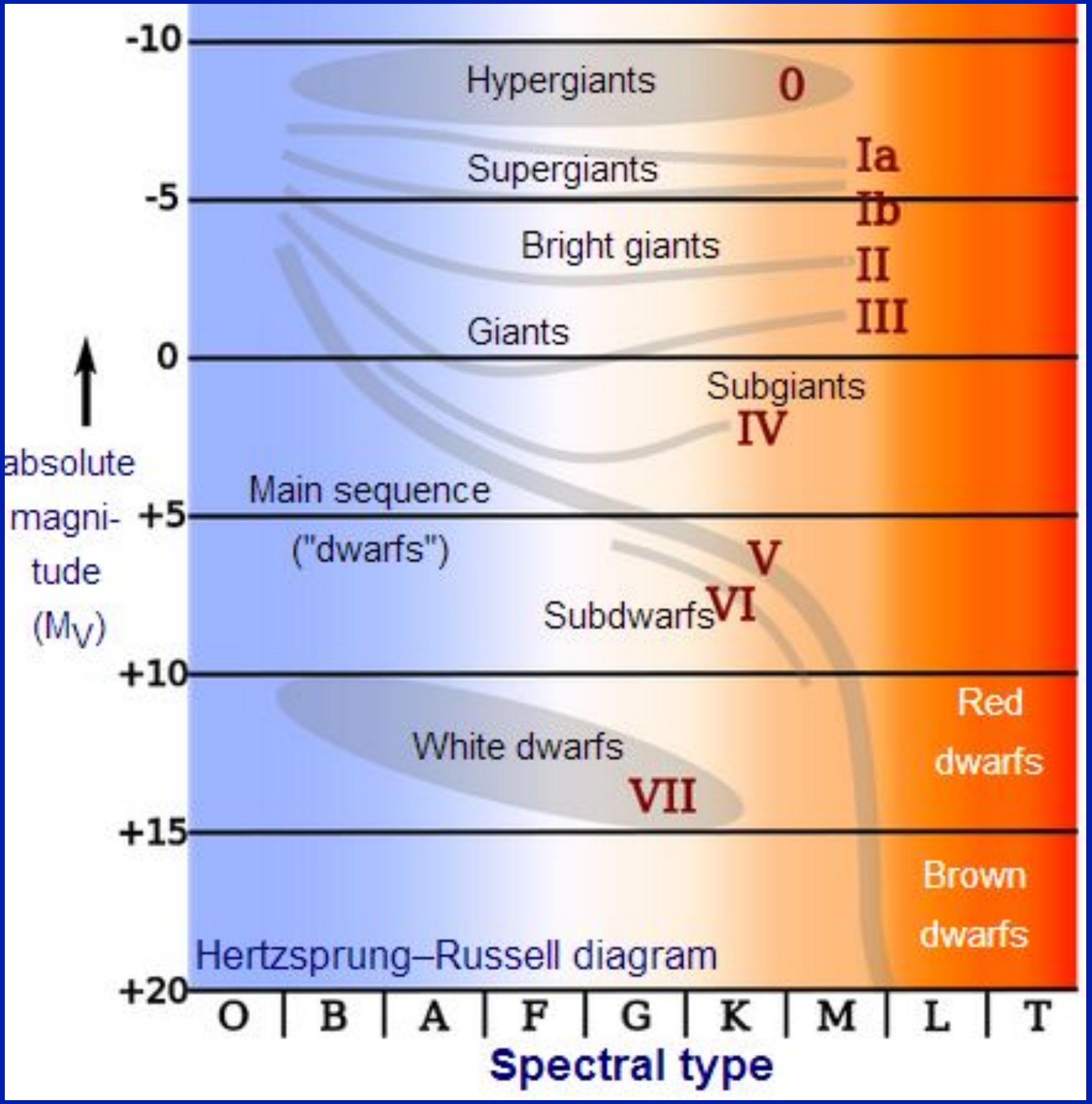
$$L = 4\pi R^2 \sigma T_{eff}^4$$

$$2.5 \log (L/L_{\odot}) = M_{bol\odot} - M_{bol}$$

$$M_{bol} = M_V + BC$$

$$BC = f(T_{eff})$$

$$M_V = V + 5 - 5\log D$$



Stellar Groups

Be stars - phenomenon/evolutionary stage – 1866

T Tau stars – pre-main-sequence low-mass stars – 1945

Herbig Ae/Be – pre-main-sequence intermediate-mass – 1960

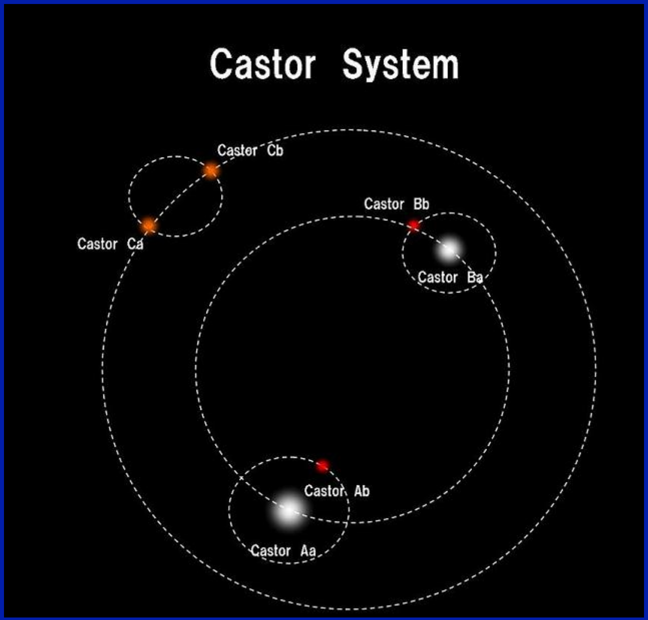
Luminous Blue Variables – evolutionary stage of very massive stars – 1970's

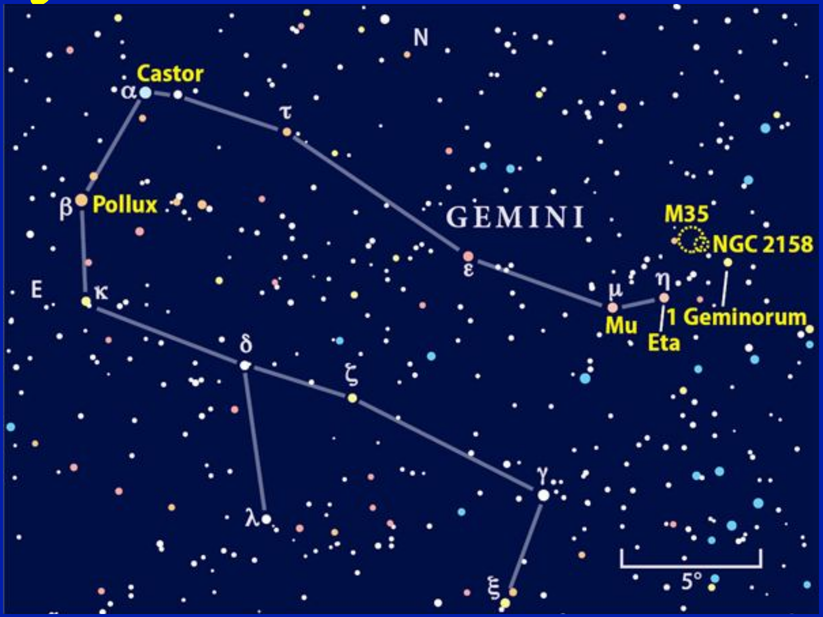
Vega-type – main-sequence stars with debris protostellar envelopes – 1984

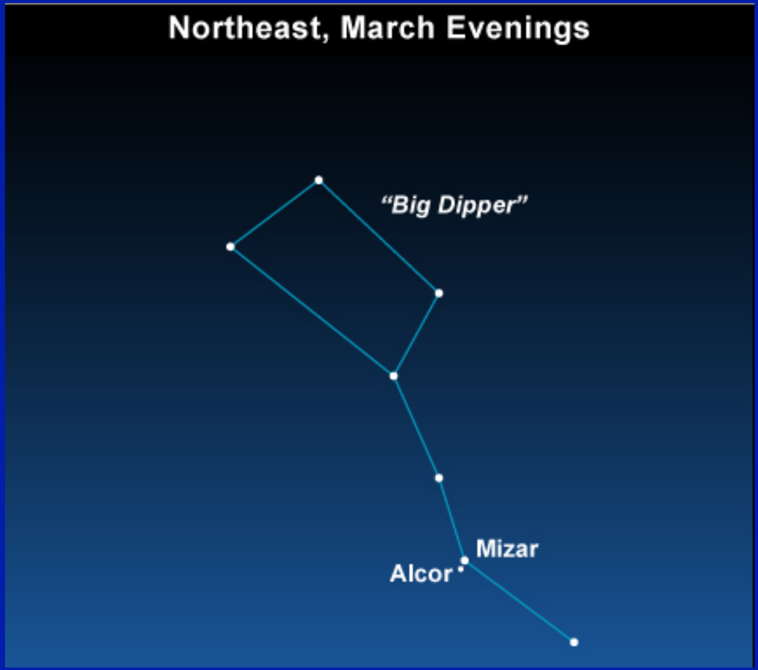
Proto-Planetary Nebulae – transition objects/late evolutionary stage of low-mass stars – 1988

B[e] stars – phenomenon in a wide variety of objects – 1976

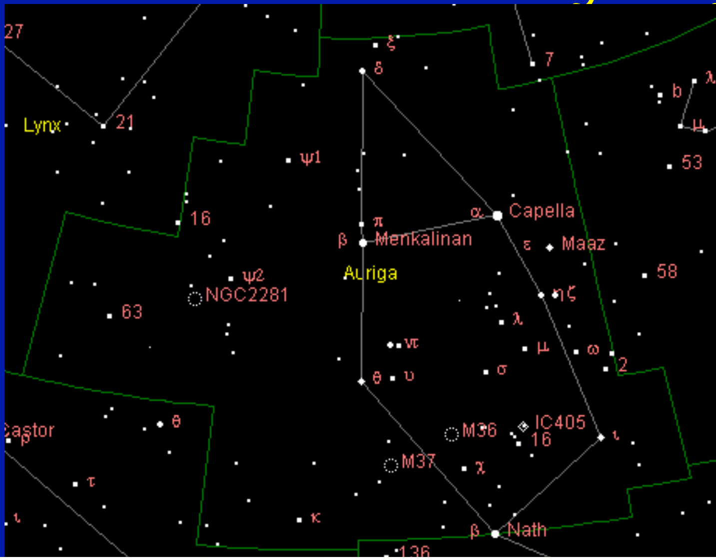
Binary Systems

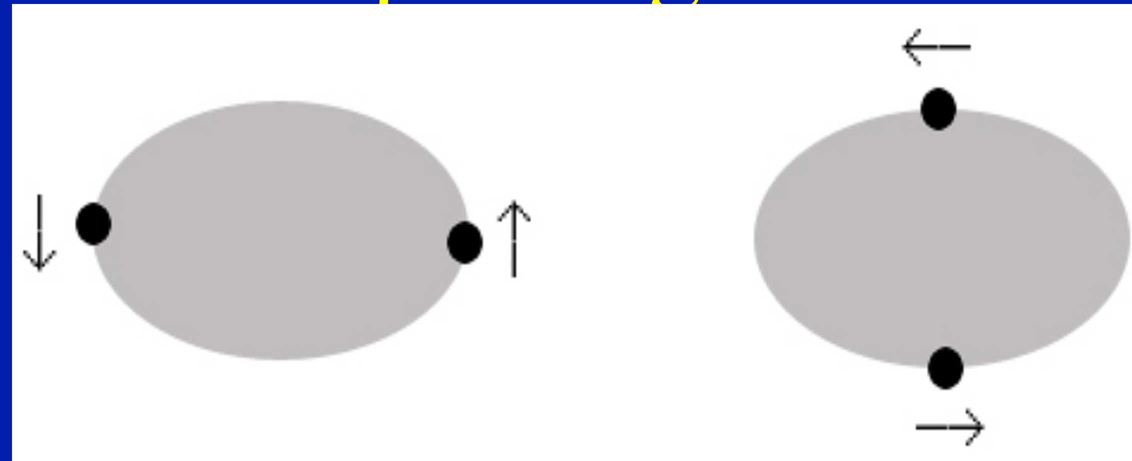


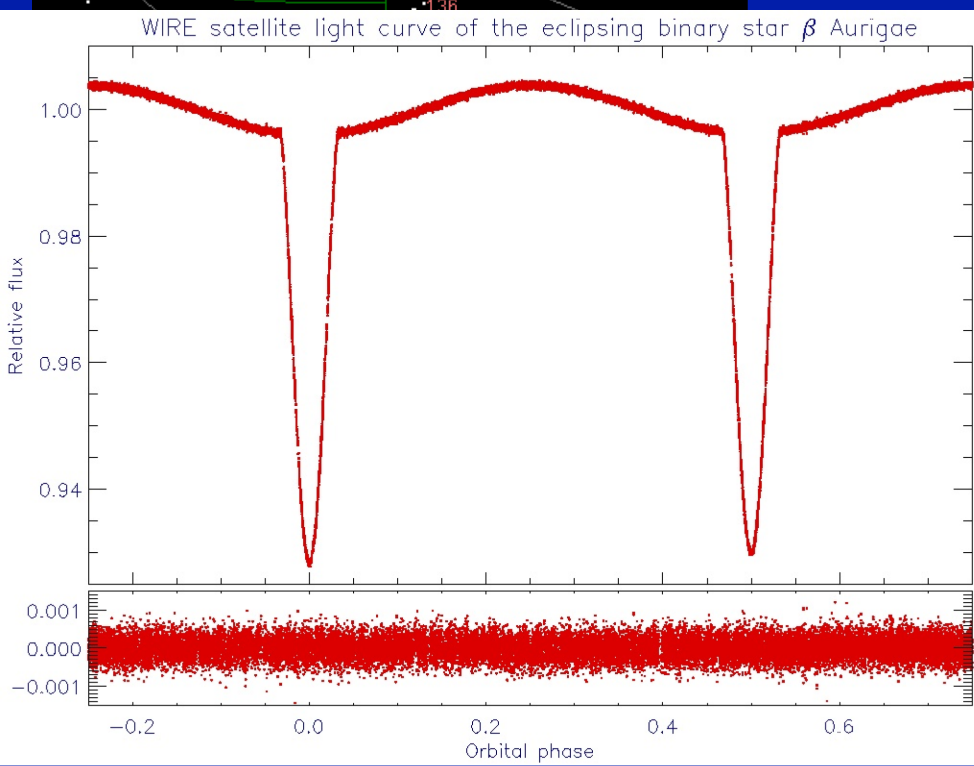




Binary Systems – β Aurigae







<u>β Aurigae orbital parameters</u>

Orb. period – 3.96 days

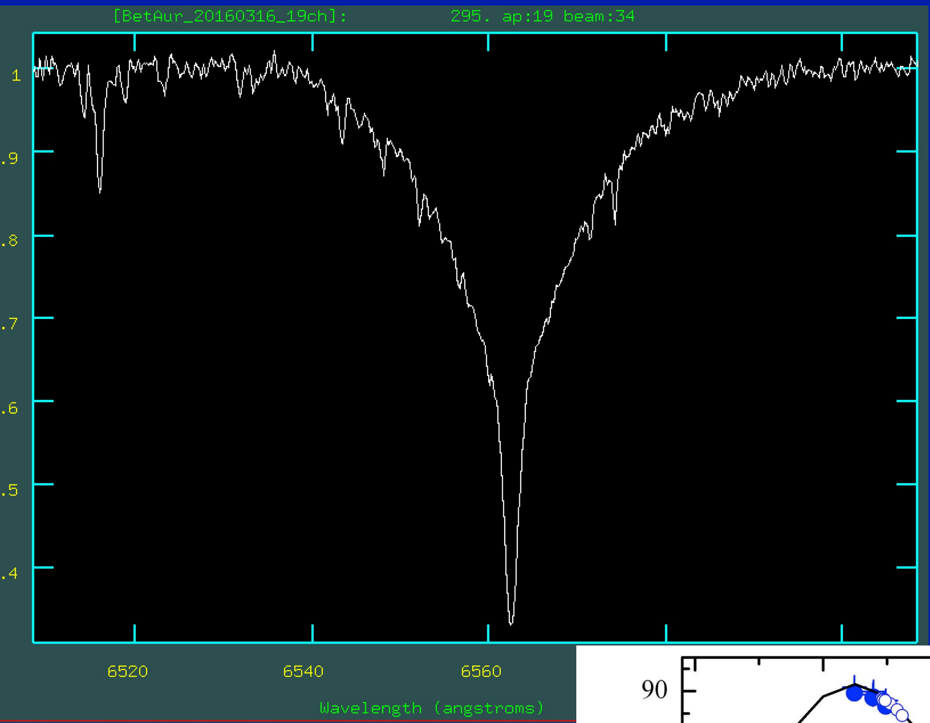
$e = 0.0$

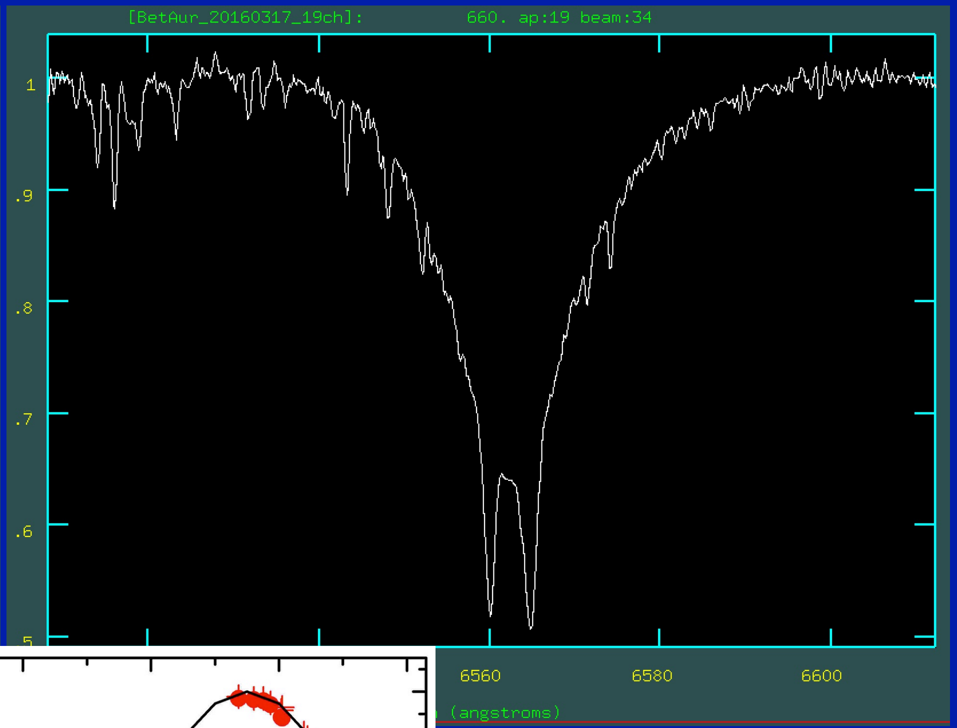
$M_1 = 2.39 \pm 0.01\ M_\odot$

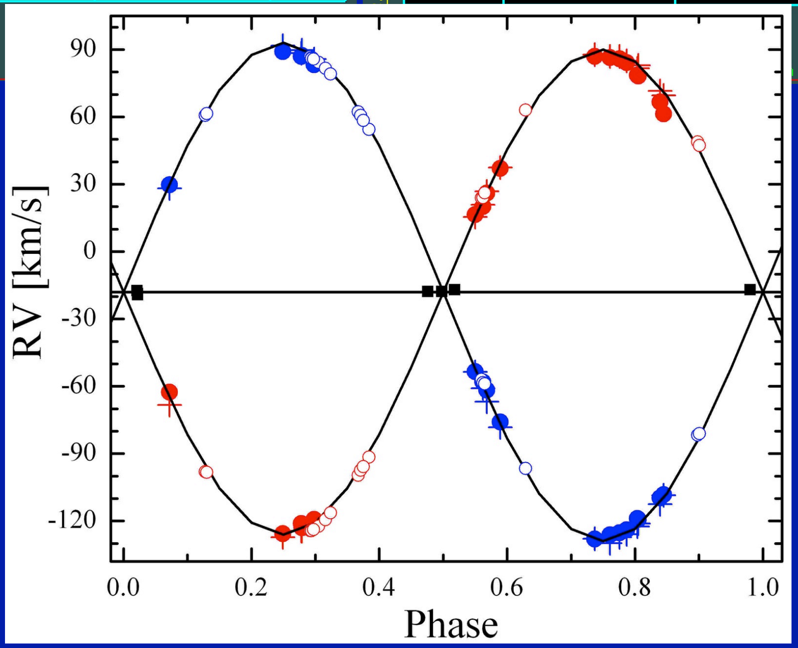
$M_2 = 2.32 \pm 0.01\ M_\odot$

$a = 0.08$ A.U.

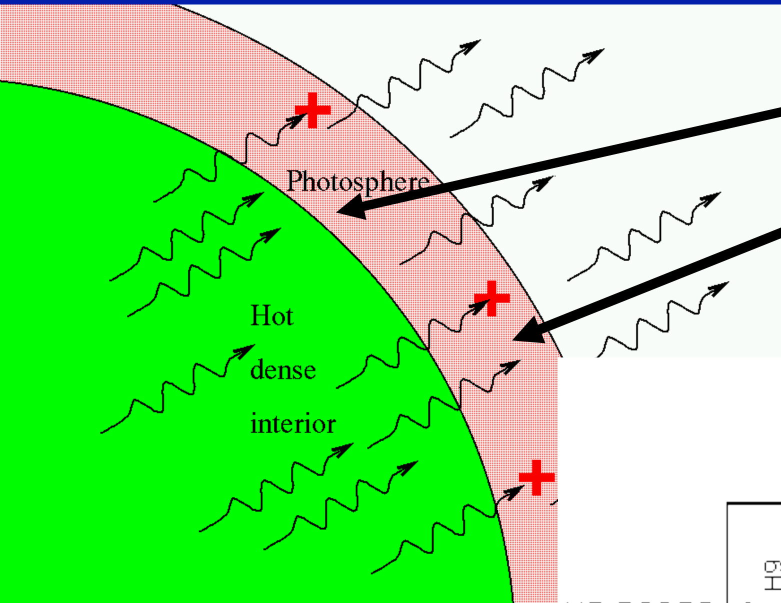
Binary Systems – β Aurigae





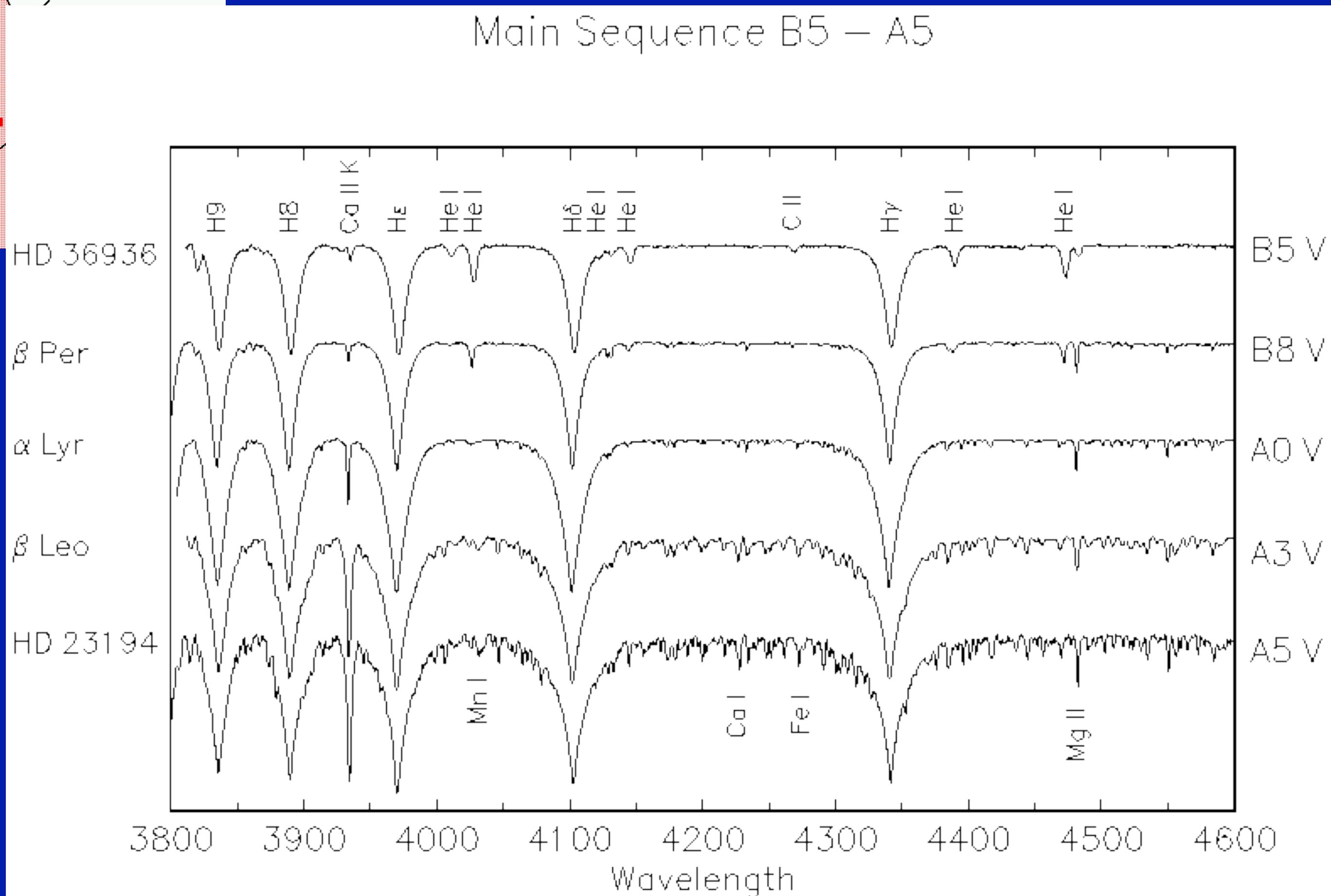


Normal Star Spectra

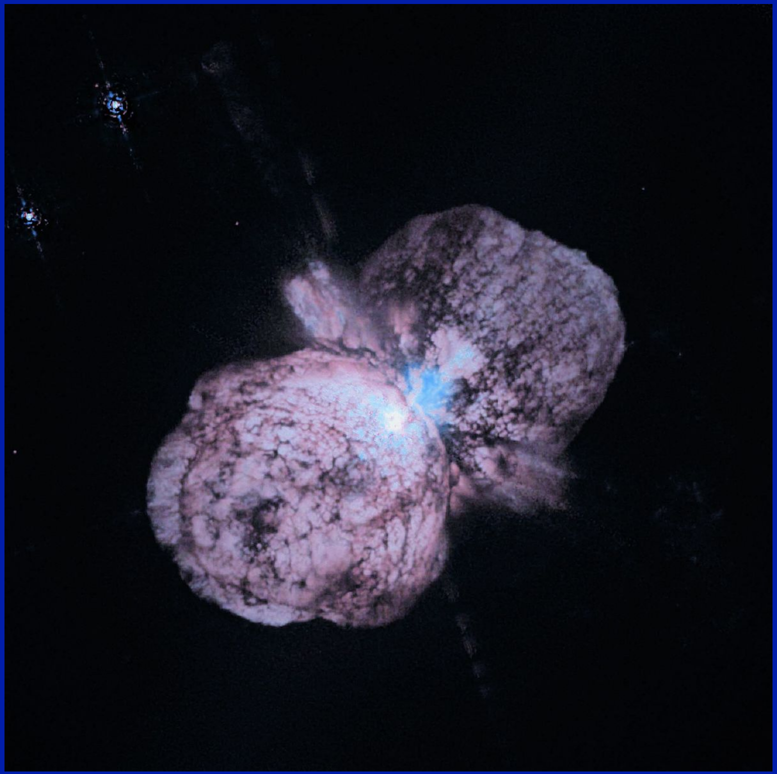


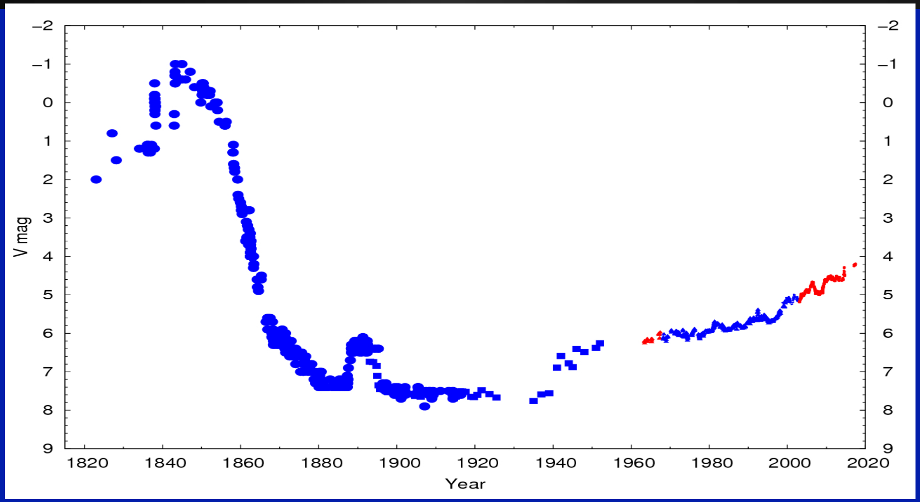
Photosphere – continuum

Atmosphere – absorption lines



Massive Interacting Binaries

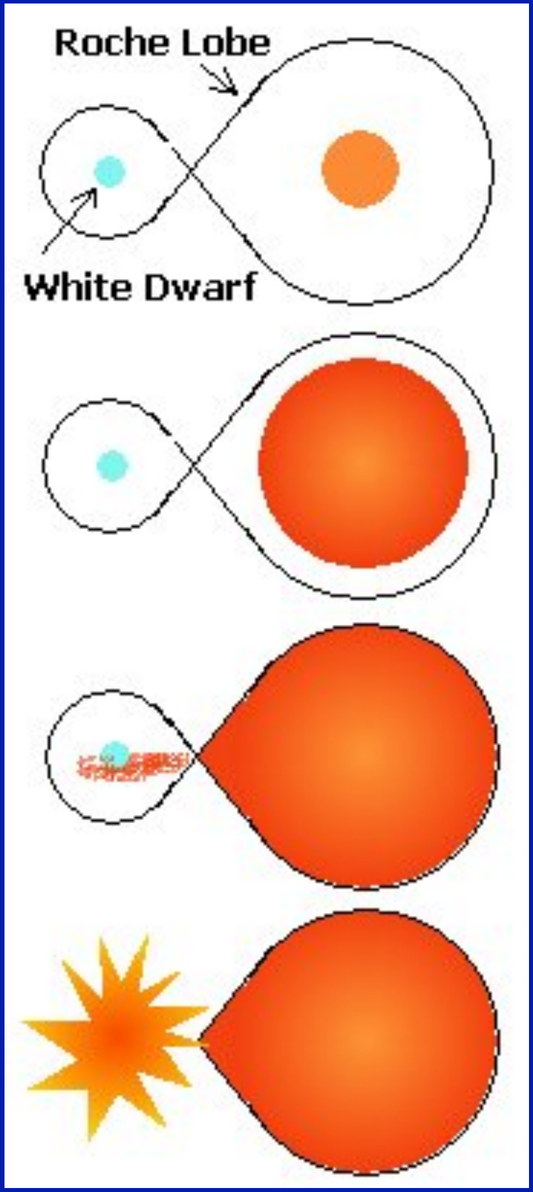


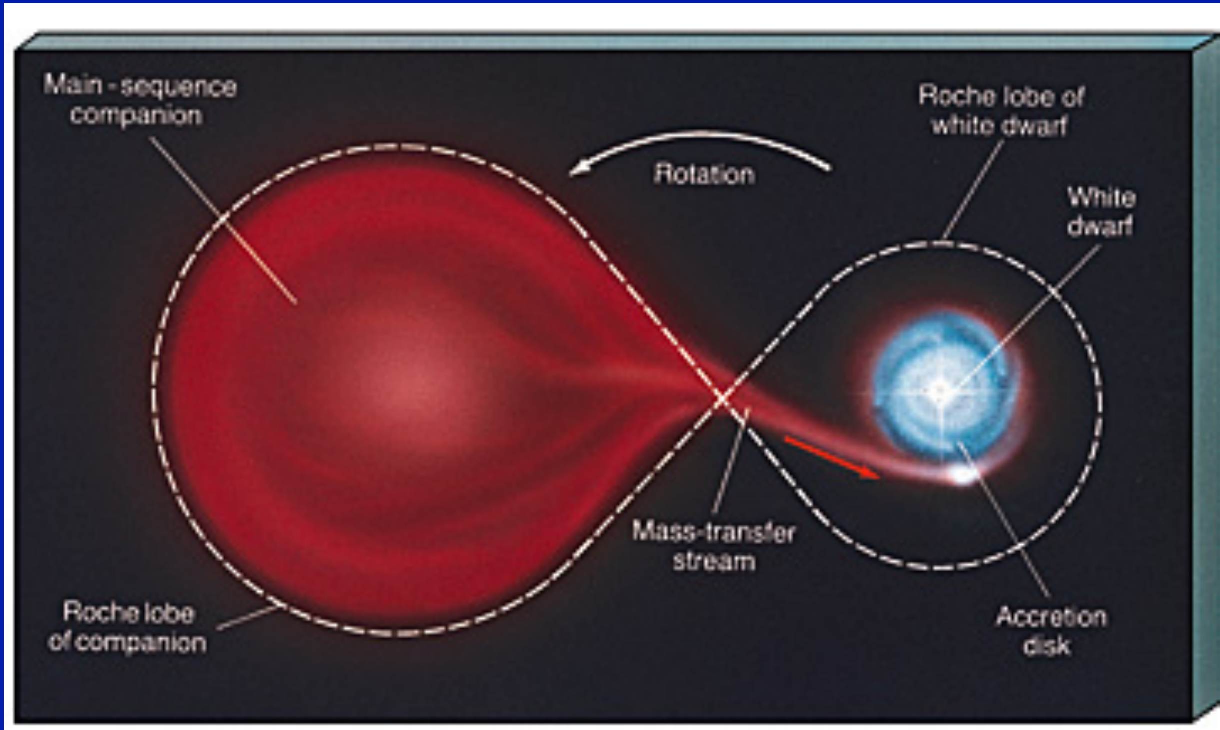


η Carinae – the most massive binary in the Milky Way

120 + 80 $M_{\odot}$, orbital period ~ 5.5 years

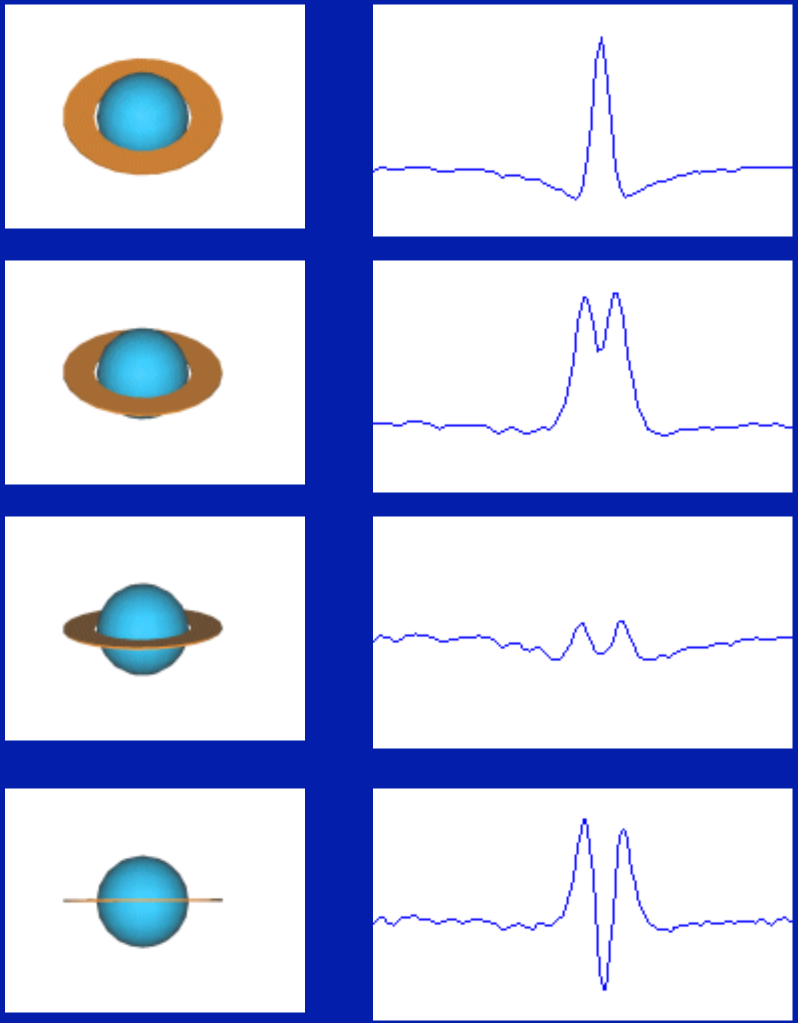
Contact Binaries





Be Stars/The Be Phenomenon

Line emission discovered in 1866

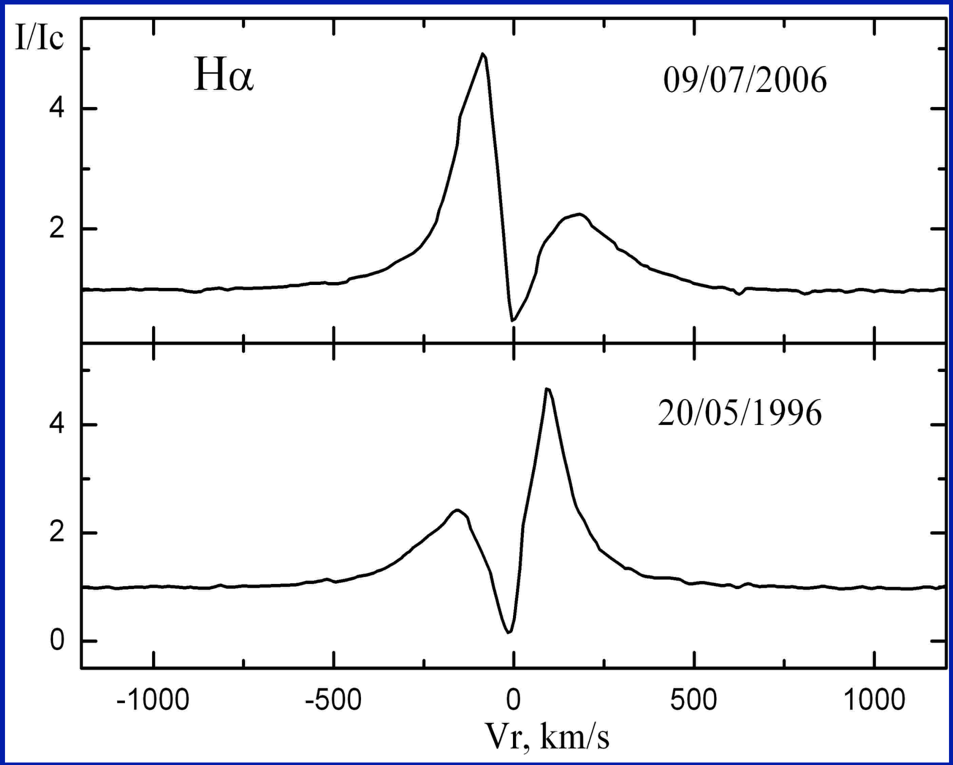


✓Circumstellar gas is distributed in a disk

✓Stars – fast rotators

✓Luminosity – near main sequence

48 Librae



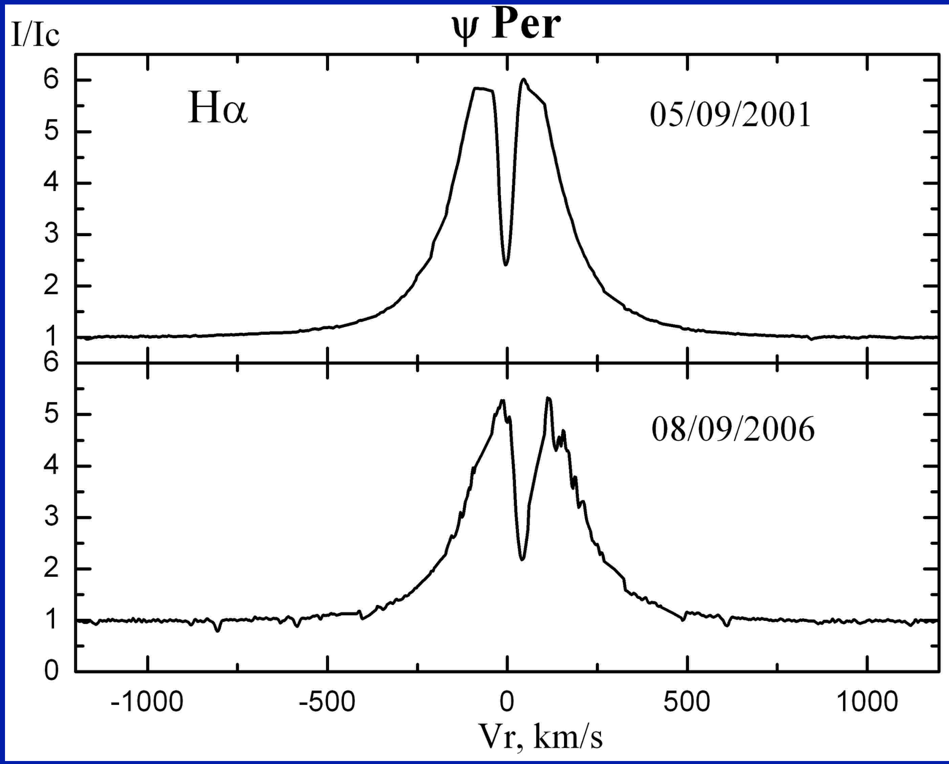
V ~ 4.8-4.95 mag

B4 IIIe

D=157±17 pc

V sin *i* ~ 400 km/s

ψ Persei



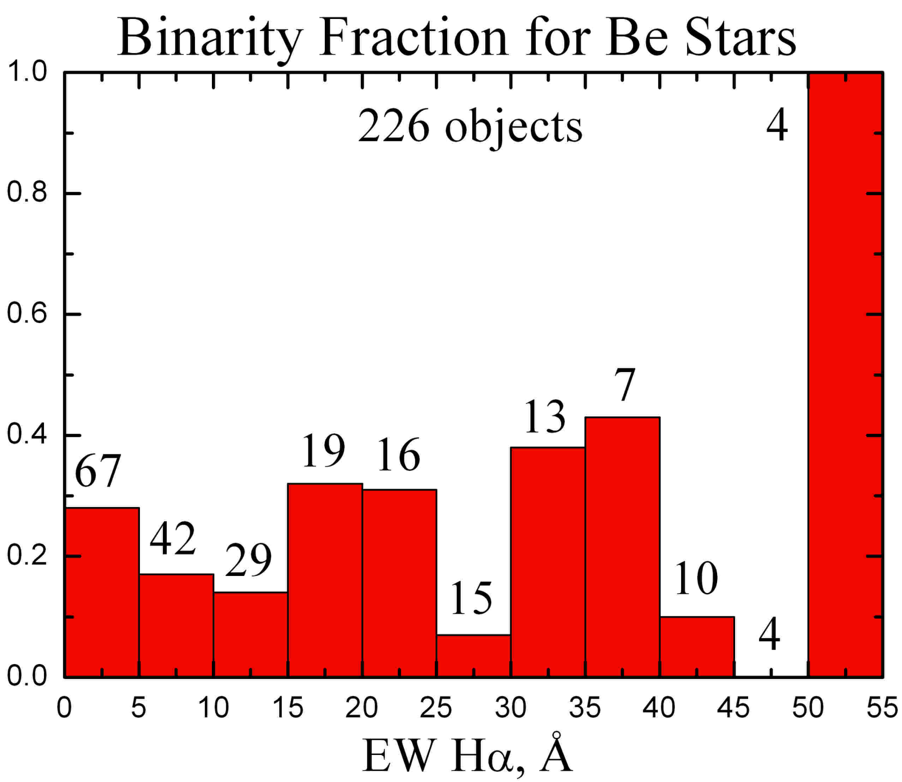
V ~ 4.2 mag

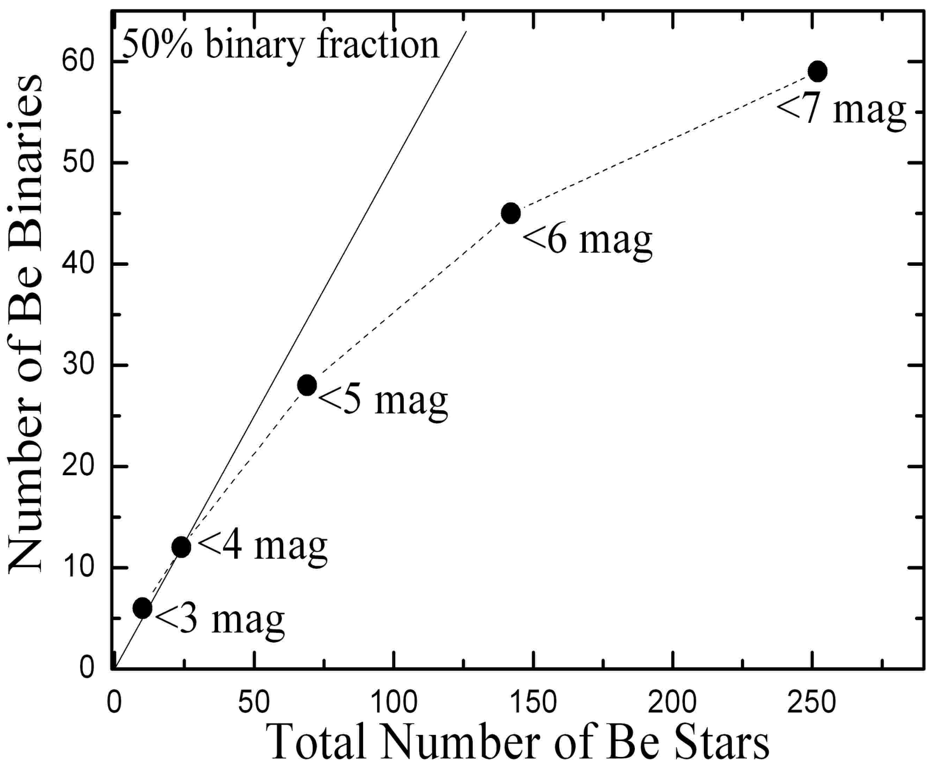
B5 Ve

D=215±30 pc

V sin *i* ~ 212 km/s

Binary Statistics





Be binaries – Be-primary + non-degenerate secondary

Miroshnichenko (2011, IAU Symp.272, 304)

- Weak-lined objects can be single or close binaries
- Strong-lined objects can be wider binaries

Binary Stars

- Most massive stars are binary or multiple
- Over 50% Be stars should be binaries
- Many stars with the B[e] phenomenon are either confirmed or suspected binaries

Binary stars that undergo mass exchange make the evolution of stars and galaxies more complicated and diverse.

Problems finding binaries:

- large brightness difference between the components
- effects of the variable circumstellar medium

The B[e] Phenomenon

Discovery – Allen & Swings(1976, A&A, 47, 293)

- 65 B-type stars (out of 700) with forbidden line emission ([Fe II], [O I], [O III]) and IR excess at λ=2 μm
- Five groups of B[e] stars: **supergiant B[e], pre-main-sequence B[e], compact Planetary Nebulae B[e], symbiotic B[e], and unclassified B[e]**
- Key features: large envelopes/disks + circumstellar dust
- 32 unclassified B[e] – no absorption lines observed → no distance OR similar to classified B[e] objects

Most of these became FS CMa objects + ~50 newly found

B[e] Objects on HRD

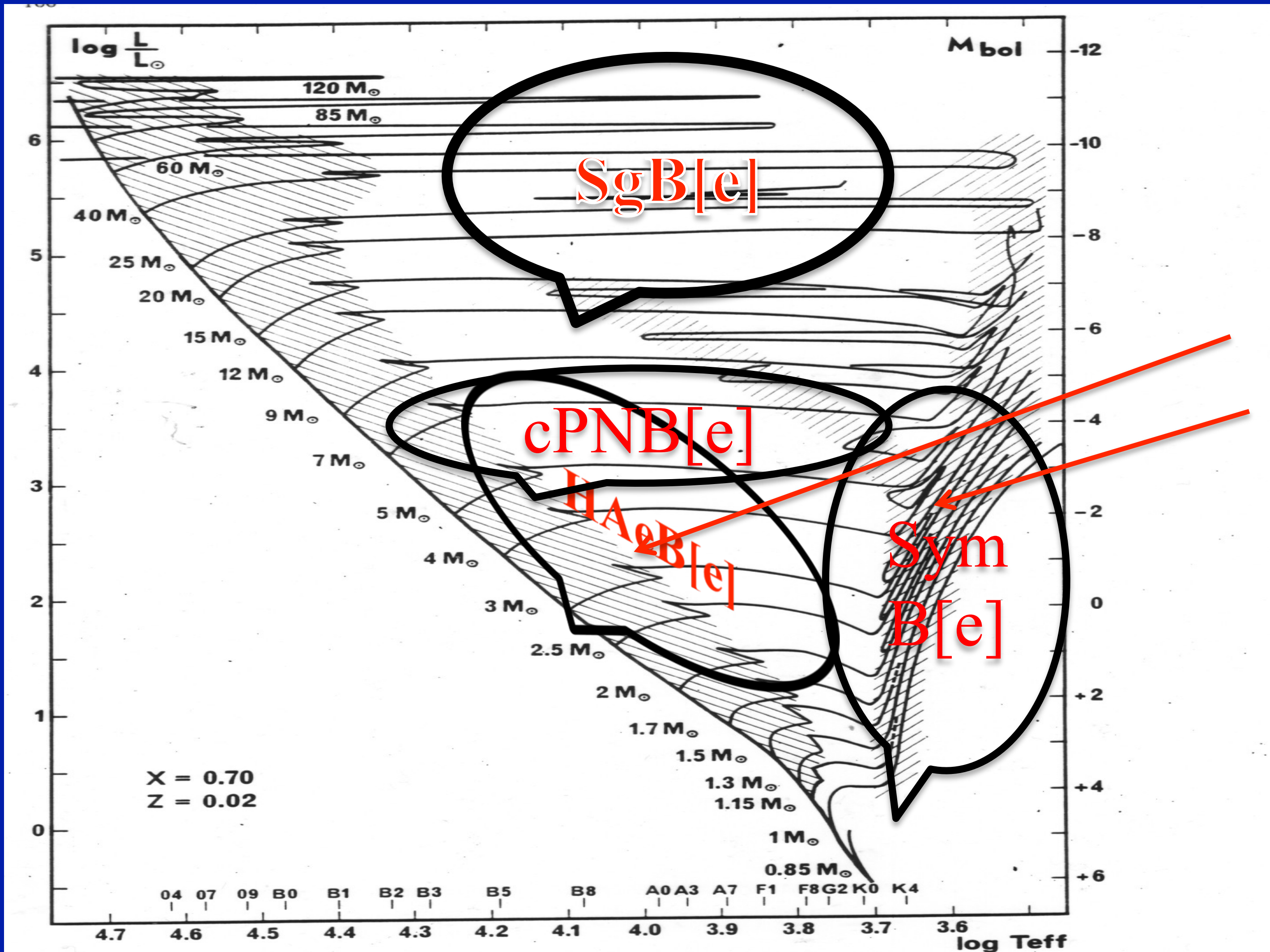


Fig. 15. Theoretical HR diagram for the ensemble of the calculated models with an overshooting parameter $\alpha_{over} = d_{over}/H_p = 0.25$ for initial masses $M > 1.15 M_\odot$. The slow phases of nuclear burning are indicated by hatched areas

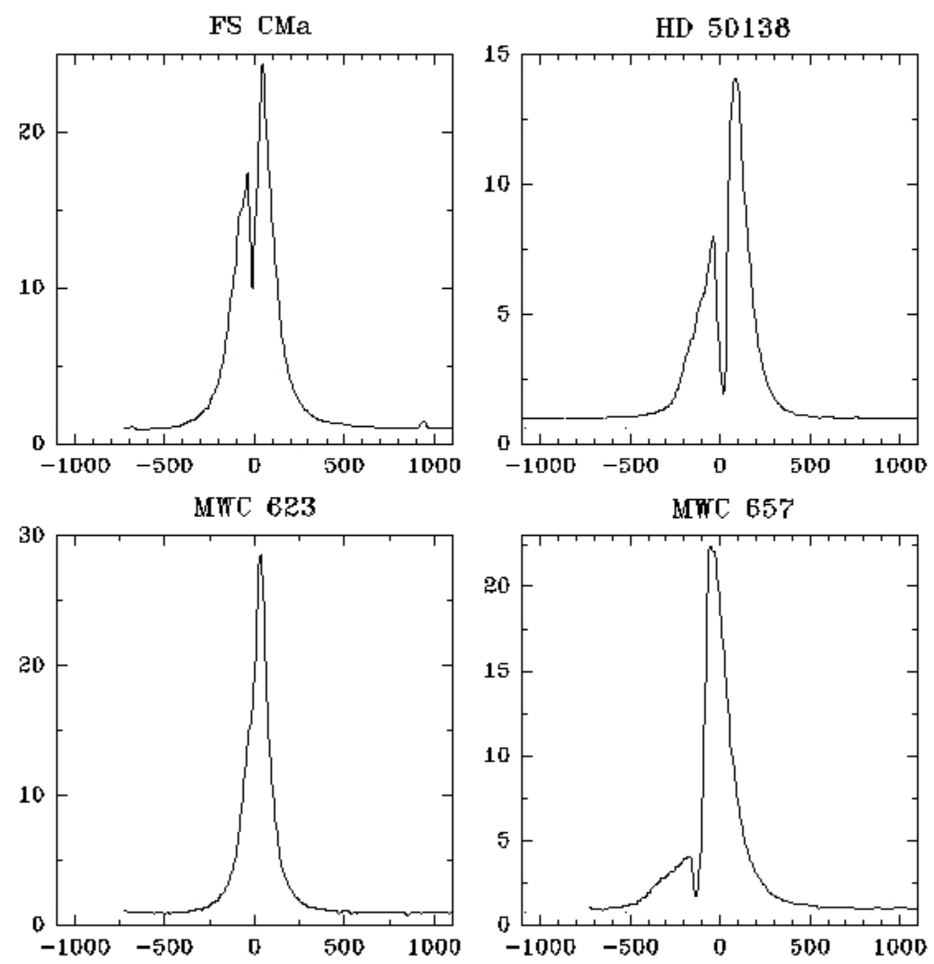
<u>FS CMa</u>

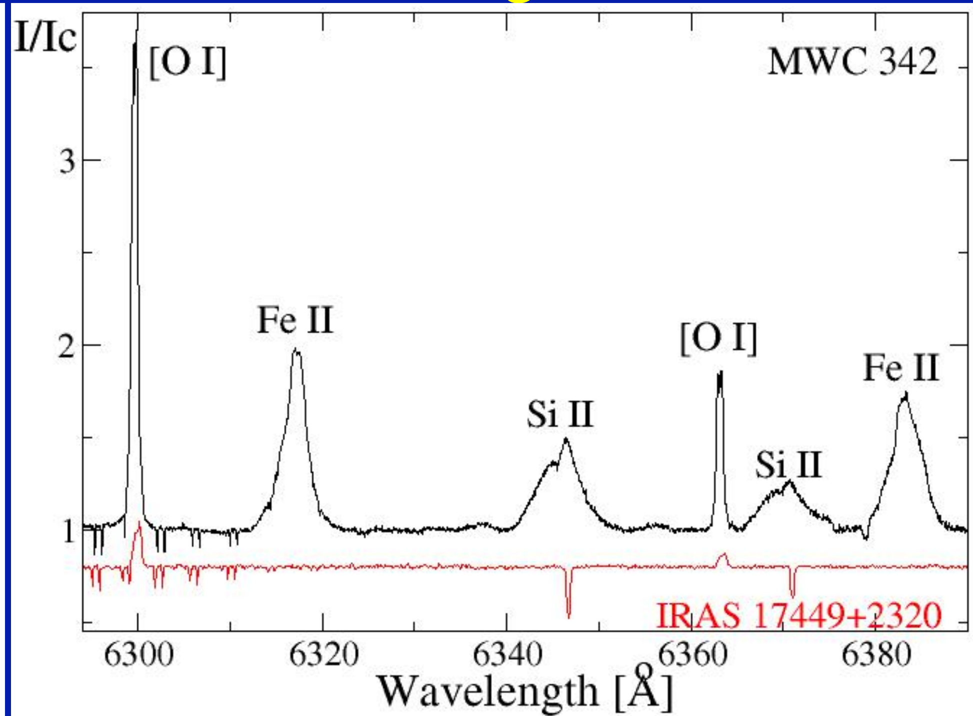
Hot

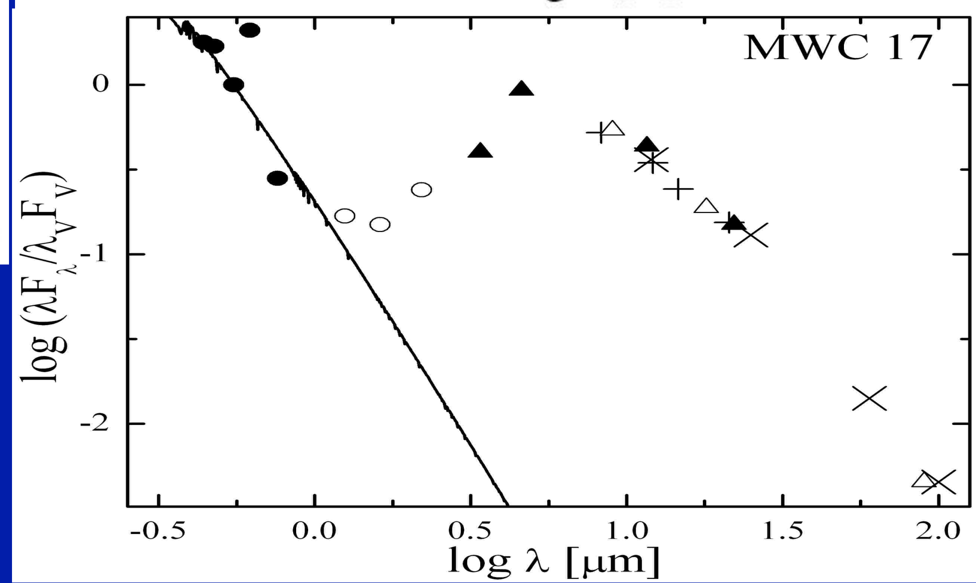
Cool

comps.

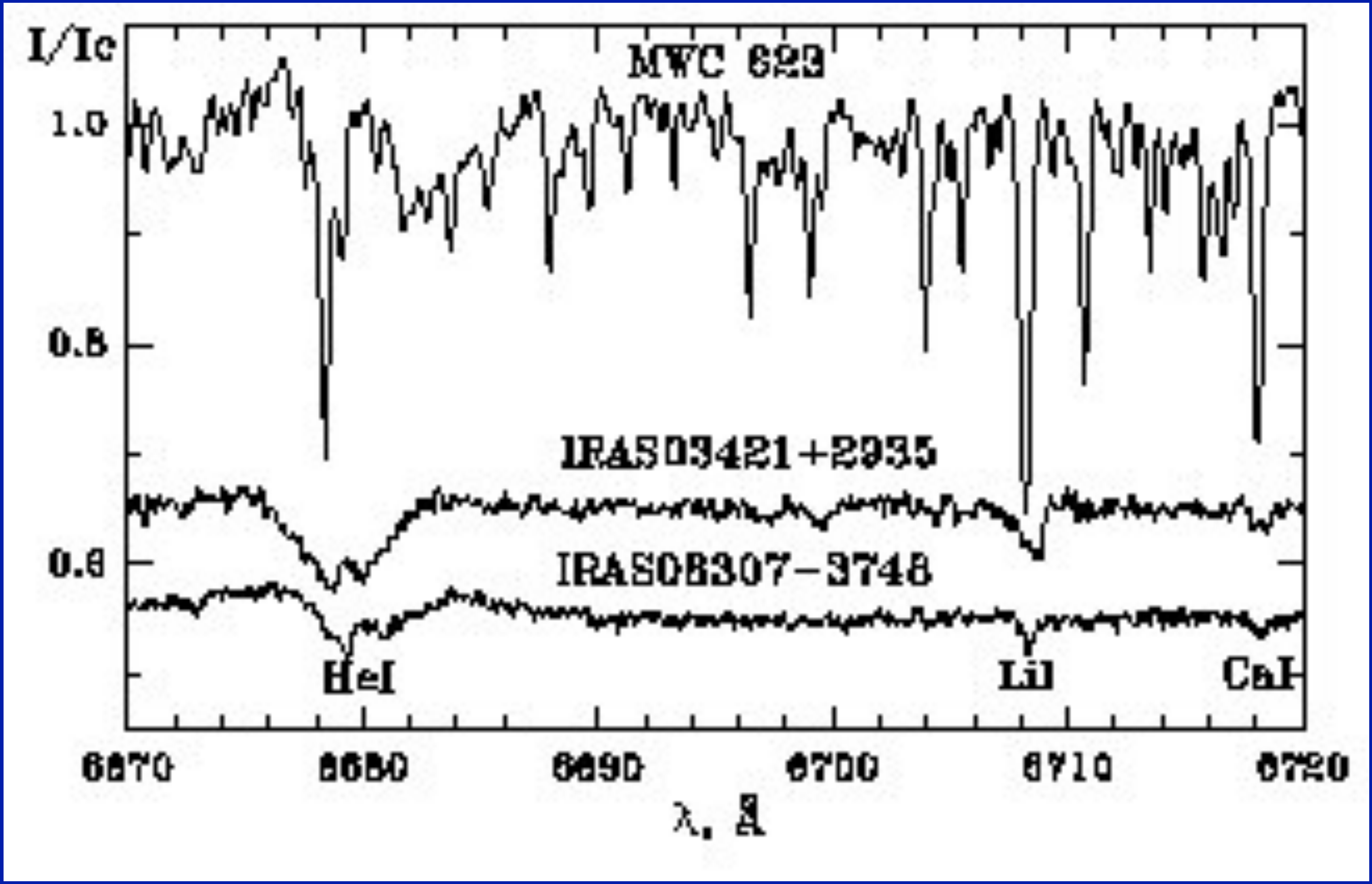
Properties of FS CMa objects







Binarity Signatures: Li 6708



Known FS CMa type Binaries

Double-lined:

- MWC 623
- CI Cam (P=19.4^d)
- MWC 728 (P=27.5^d)
- FX Vel
- AS 174
- IRAS00470+6429
- IRAS07080+0605
- V669 Cep
- IRAS07377-2523

Single-lined:

Spectro-astrometry:

- FS CMa (V ~ 7.5 mag)
- HD 50138 (V ~ 6.6 mag)
- HD 85567 (V ~ 8.6 mag)

Orbital motion detected:

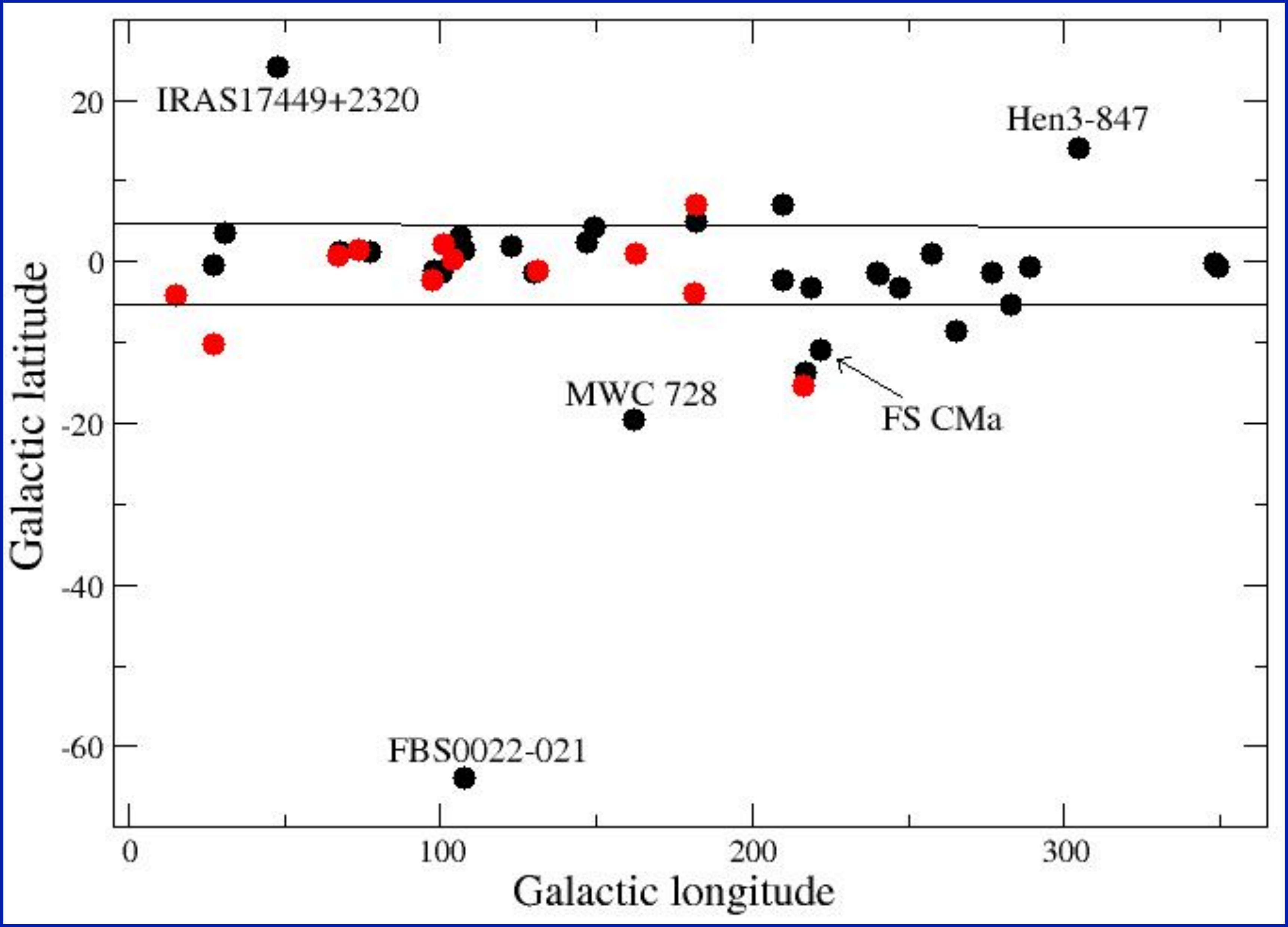
GG Car (V~8.7, P=31.03^d) – sgB[e]?

AS 386 (V~10.9, P=131.3^d)

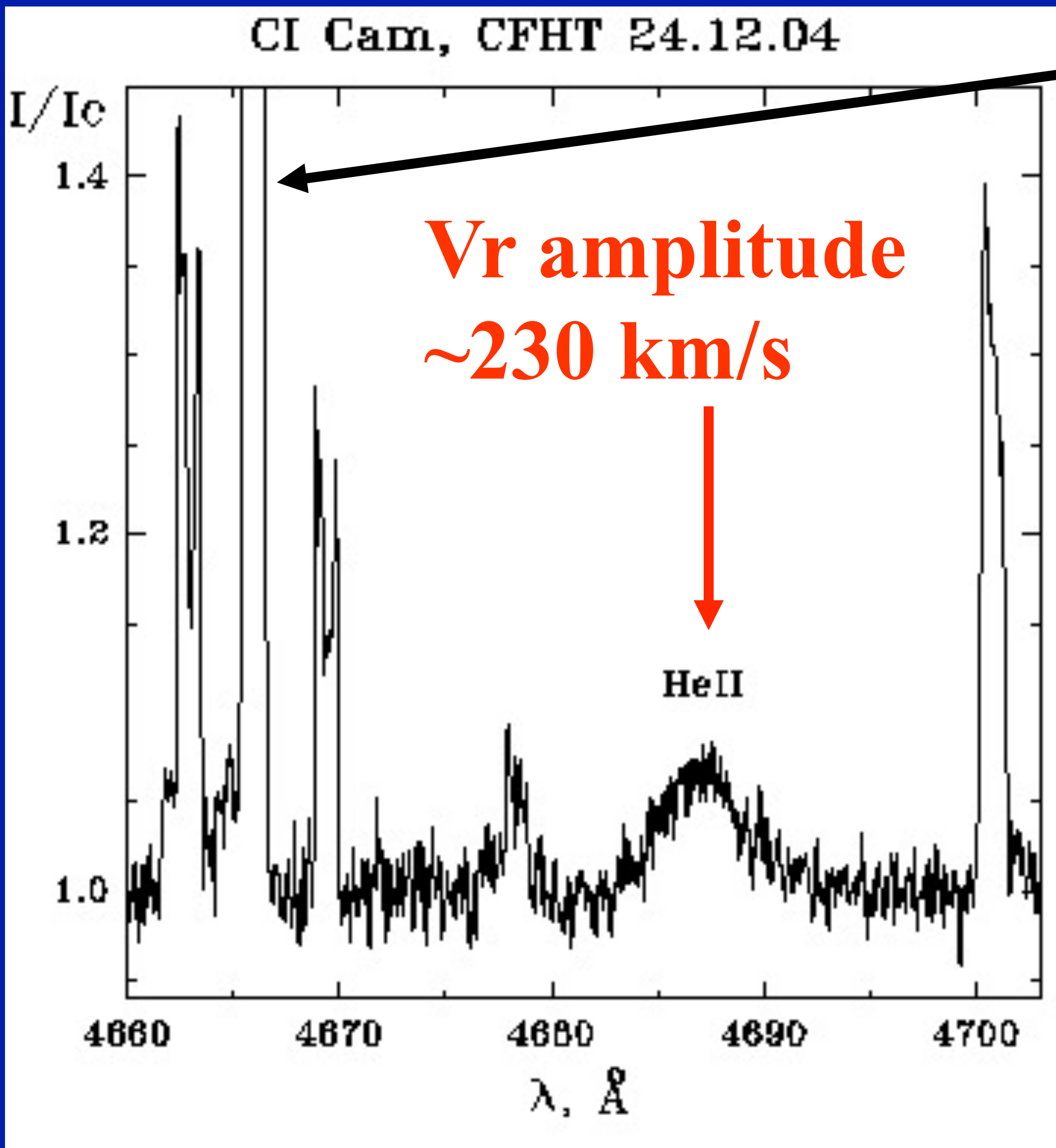
No lines of the secondary component have been detected

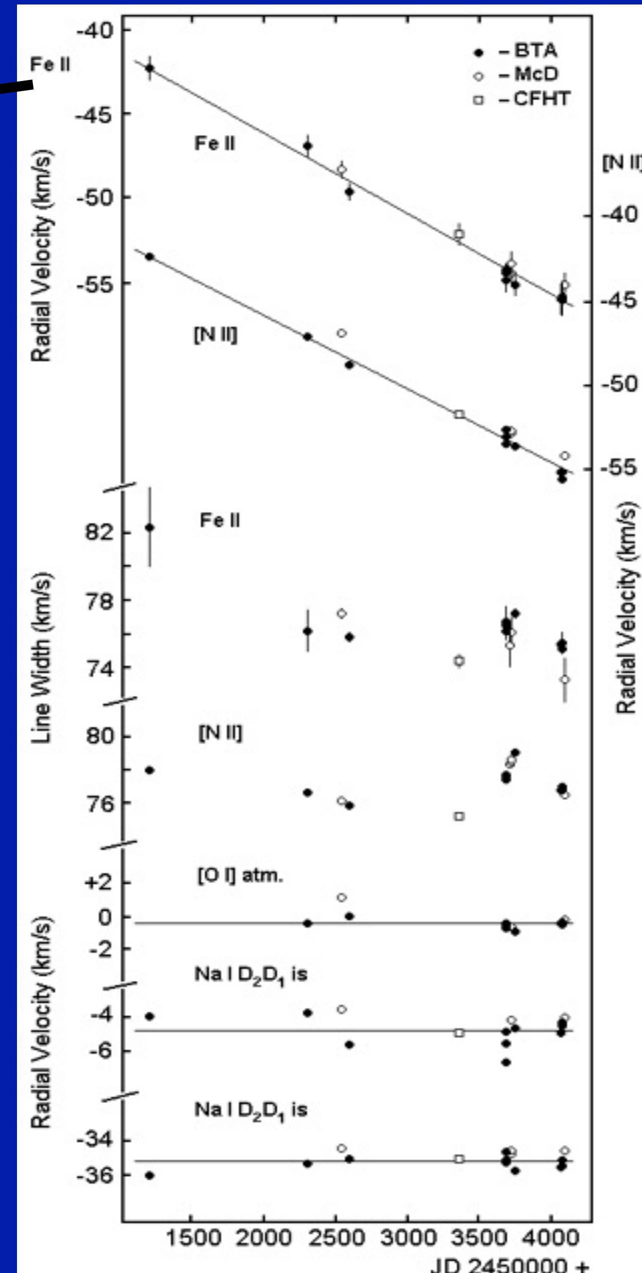
FS CMa Type Binary Model

Galactic Distribution

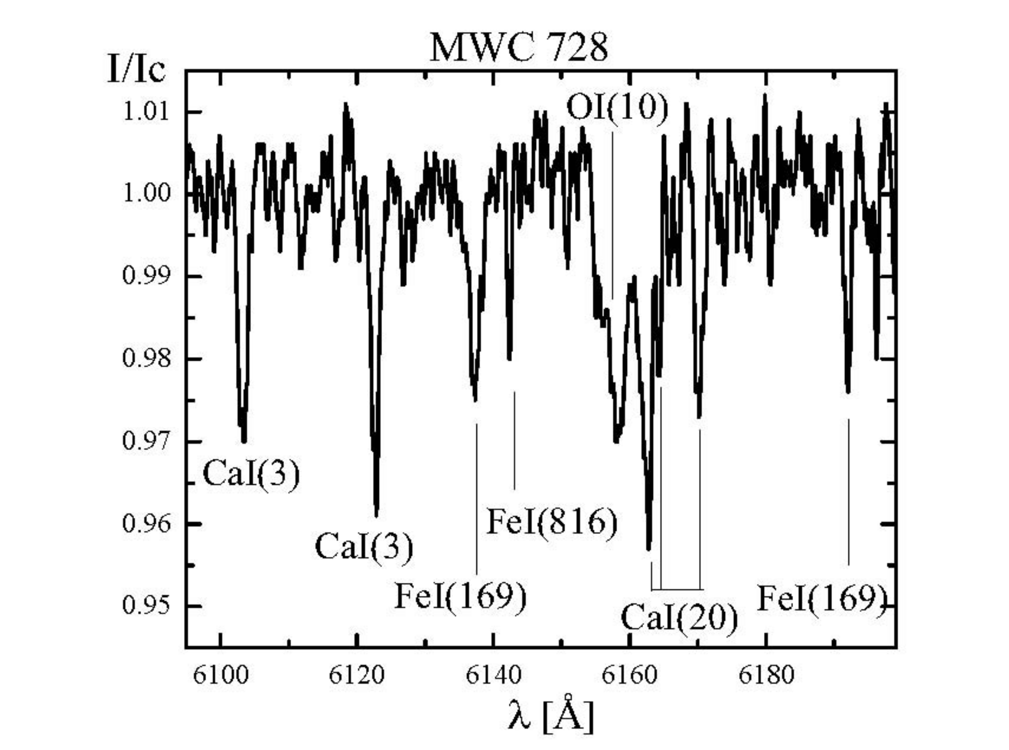


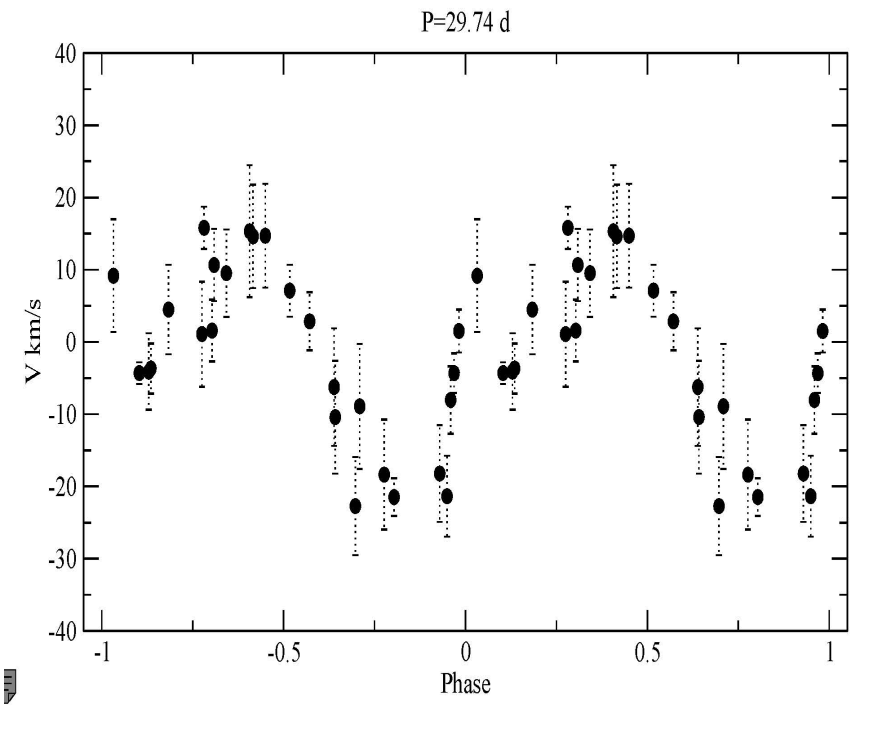
CI Cam


CI Cam, CFHT 24.12.04
I/Ic
1.4
1.2
1.0
Vr amplitude
~230 km/s
HeII
4660
4670
4680
4690
4700
λ, Å


– BTA
– McD
– CFHT
Fe II
Fe II
[N II]
[N II]
Radial Velocity (km/s)
-40
-45
-50
-55
Fe II
Line Width (km/s)
82
78
74
[N II]
80
76
[O I] atm.
+2
0
-2
Na I D_2D_1 is
-4
-6
Na I D_2D_1 is
-34
-36
1500 2000 2500 3000 3500 4000
JD 2450000 +

MWC 728



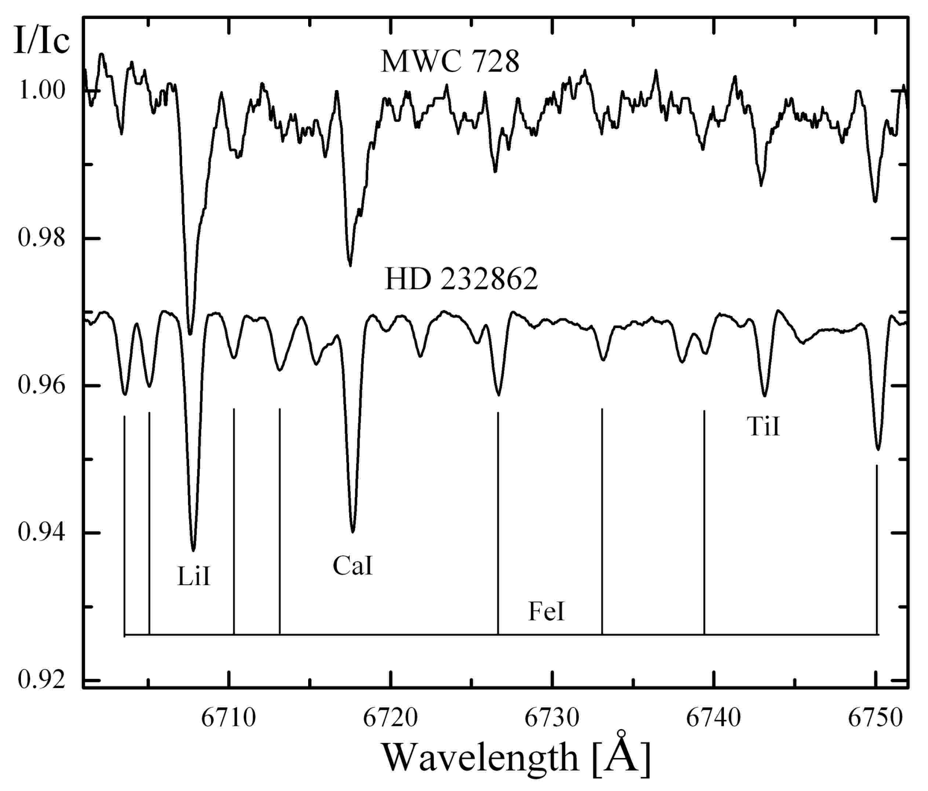


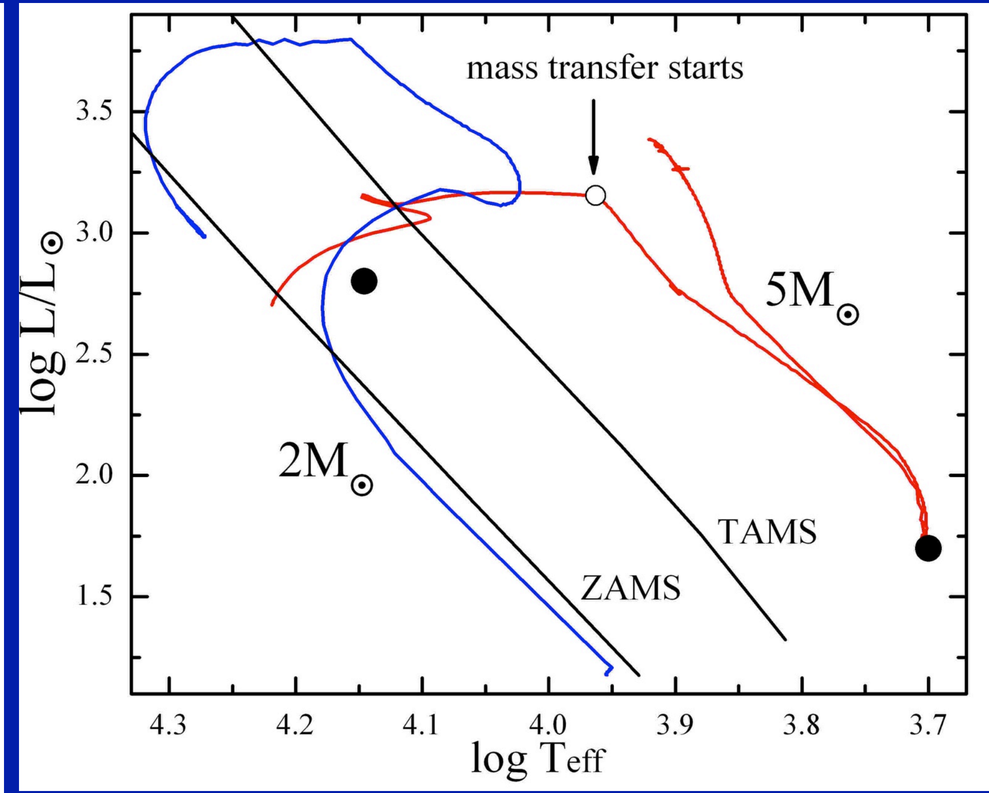
Radial velocities derived by cross-correlation for 25 spectra

$M_1+M_2 \sim 7\ M_\odot$, the components separation ~ 0.3 AU

The secondary component does not fill its Roche lobe

MWC 728





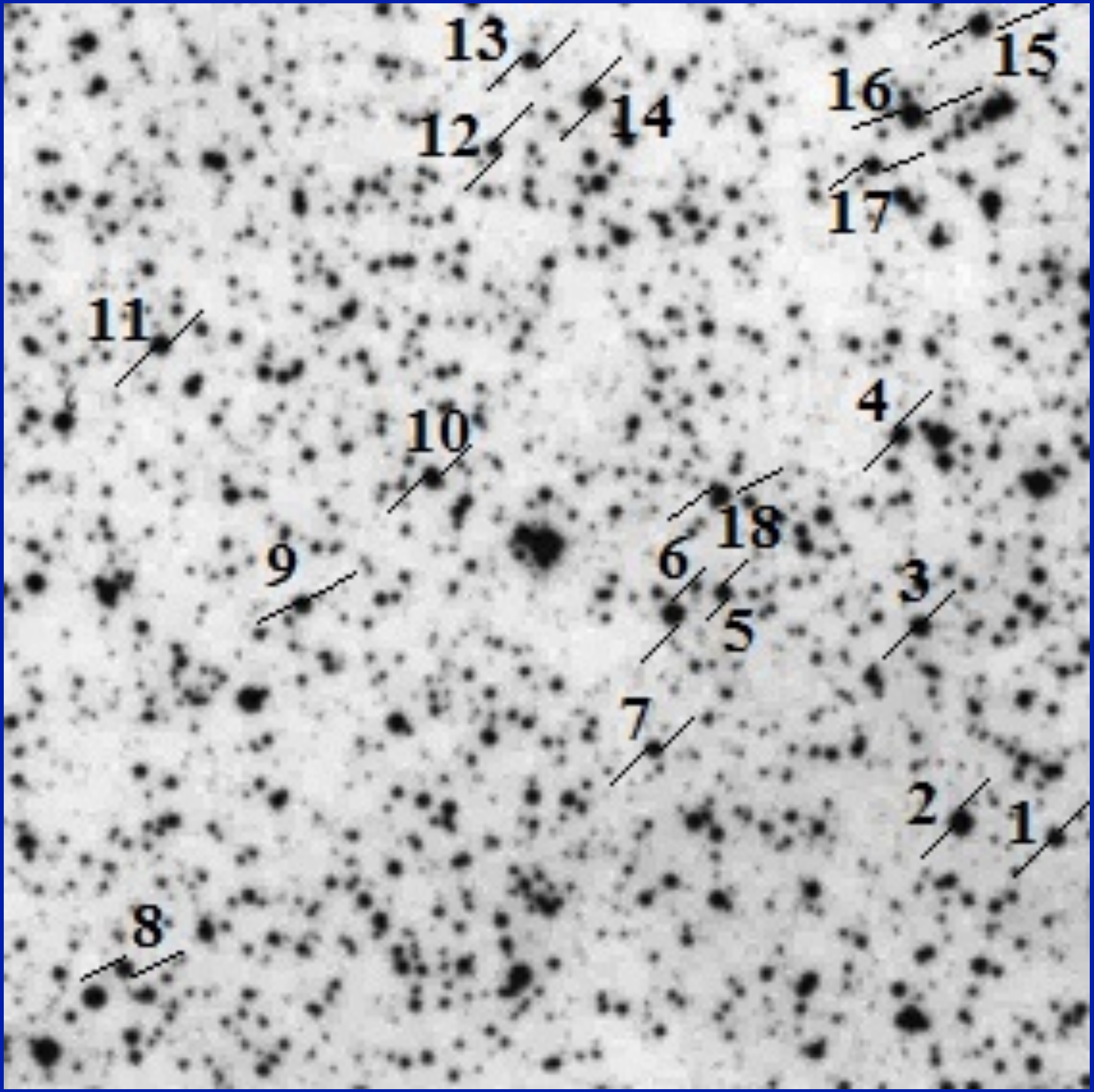
MWC 728 (B5Ve+G8 III) Miroshnichenko+ 2015, ApJ, 809, 129

Comparison star is HD 232862 is a Li-rich G8 giant

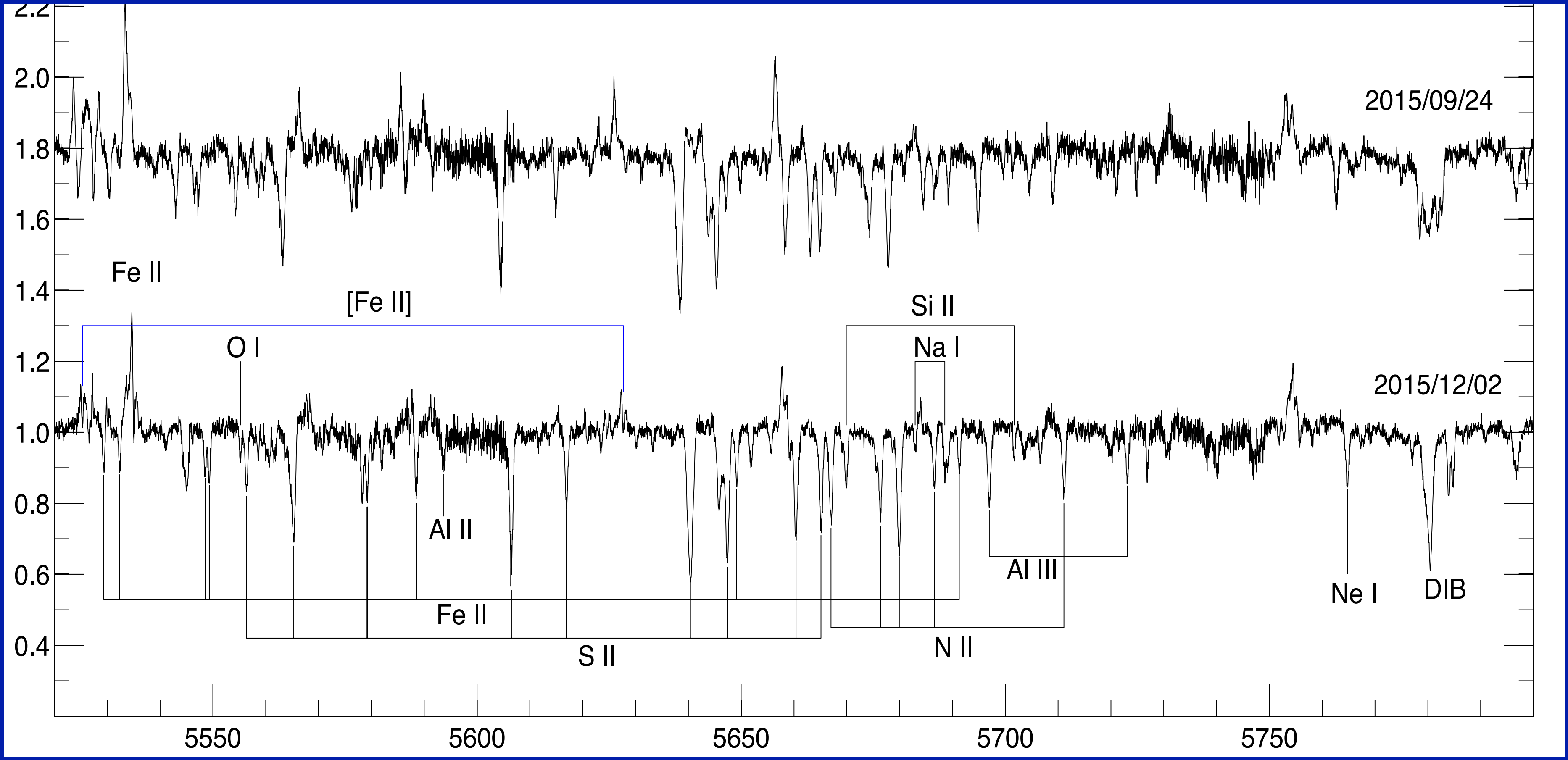
A flat continuum was added to the spectrum of HD 232862 to match the line strengths of MWC 728

AS 386

V = 10.9 mag, located in a crowded field in Cygnus

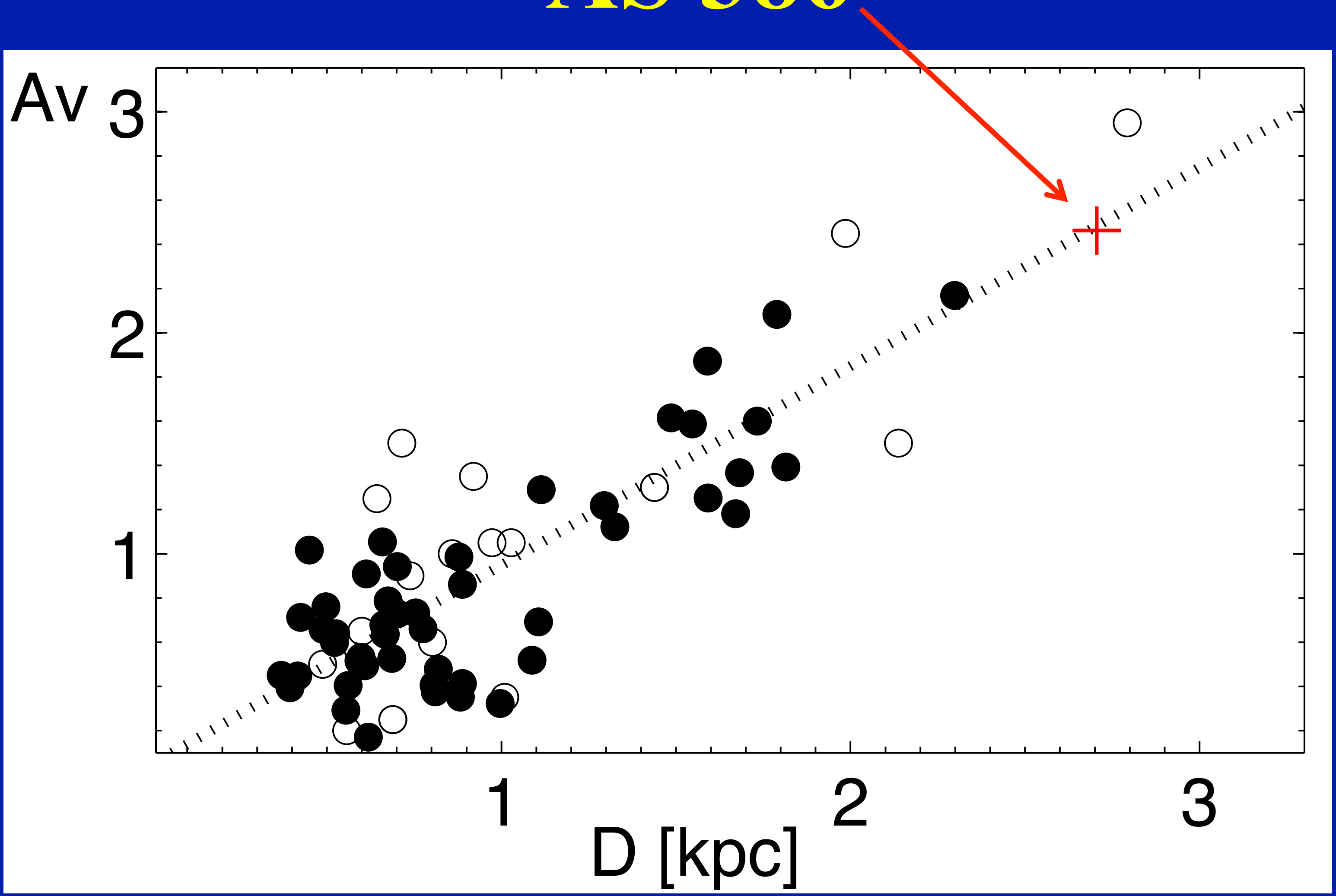


AS 386



The spectrum of a reddened late B-type star with a luminosity of a giant.

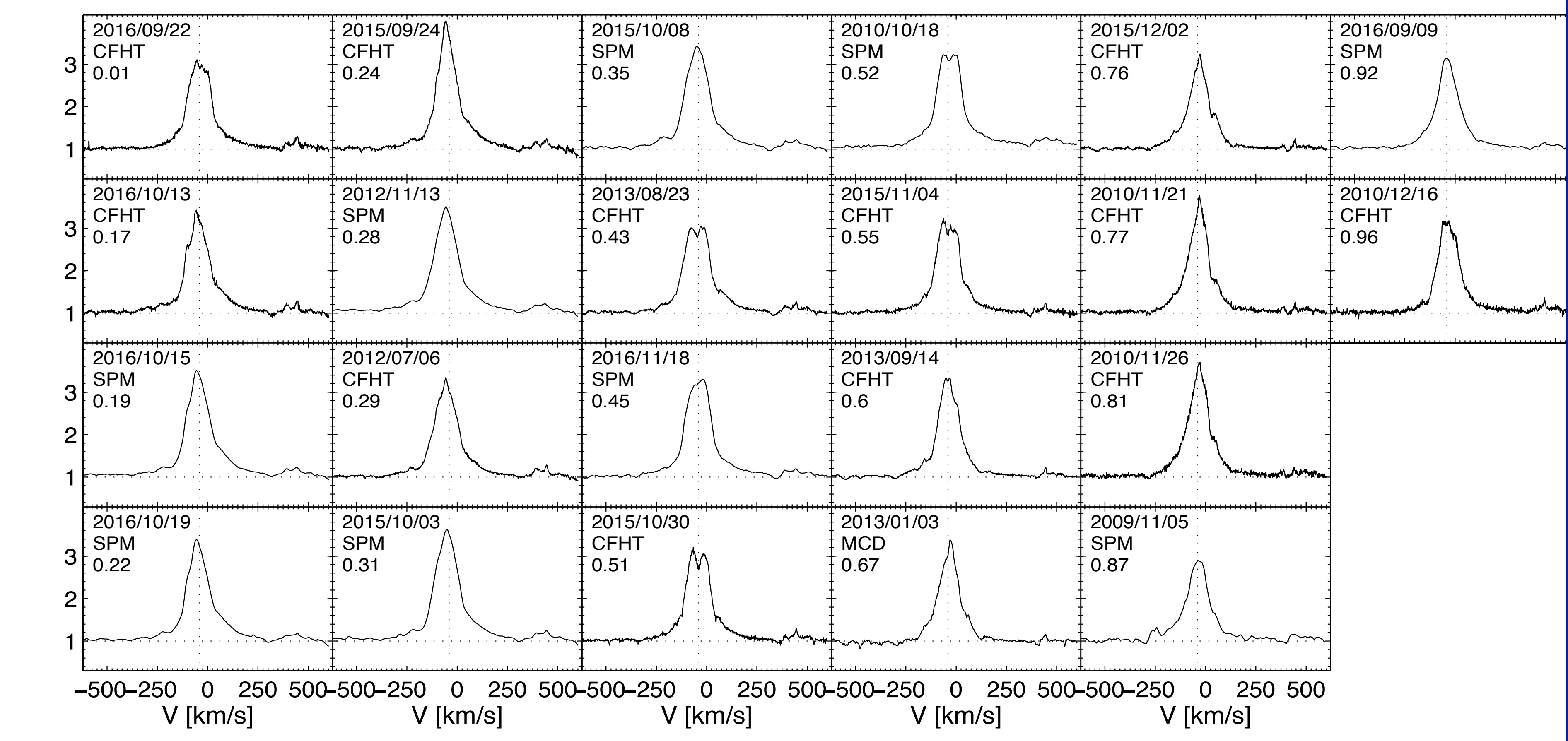
AS 386



Interstellar extinction law based on photometry of stars in the field of AS 386

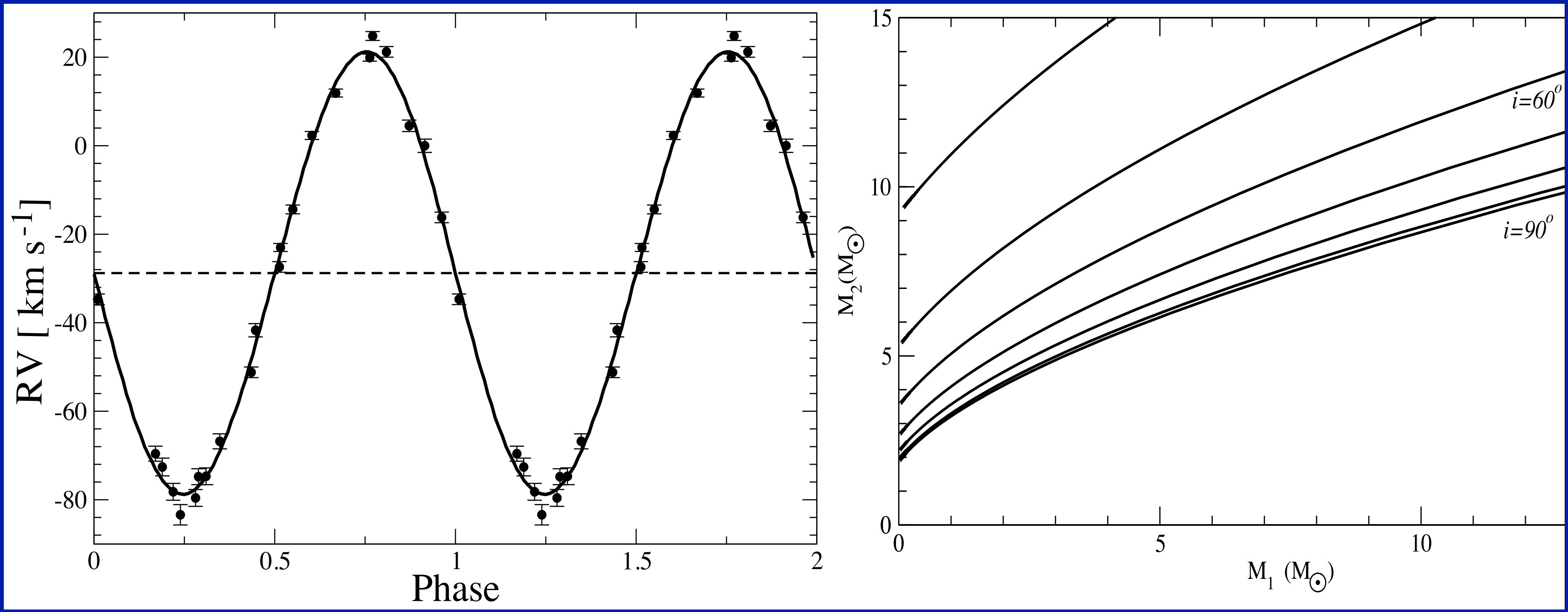
AS 386

25 spectra, 2009-2017 (3.6-m CFHT, 2.7-m McDonald, and 2.1-m OAN SPM), resolution 18000−65000)



Hα line in the spectrum of AS 386

AS 386



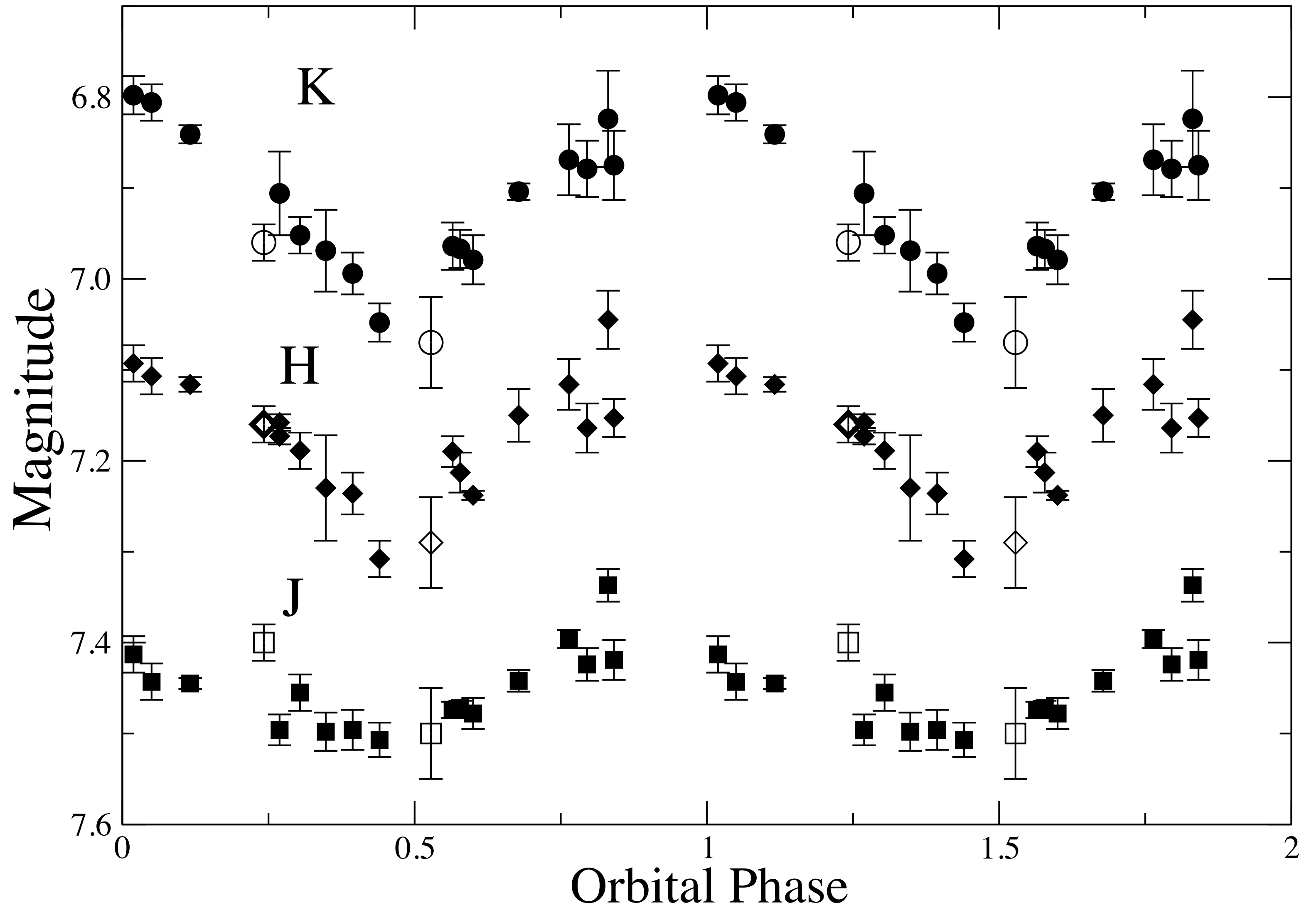
The orbit is circular. Orbital period – 131.29±0.08 days

Radial Velocity Semi-Amplitude – 51±3 km/s

The mass function: $M_2 \sin i / (1+M_2/M_1)^2 = 1.8 \pm 0.3\ M_\odot$

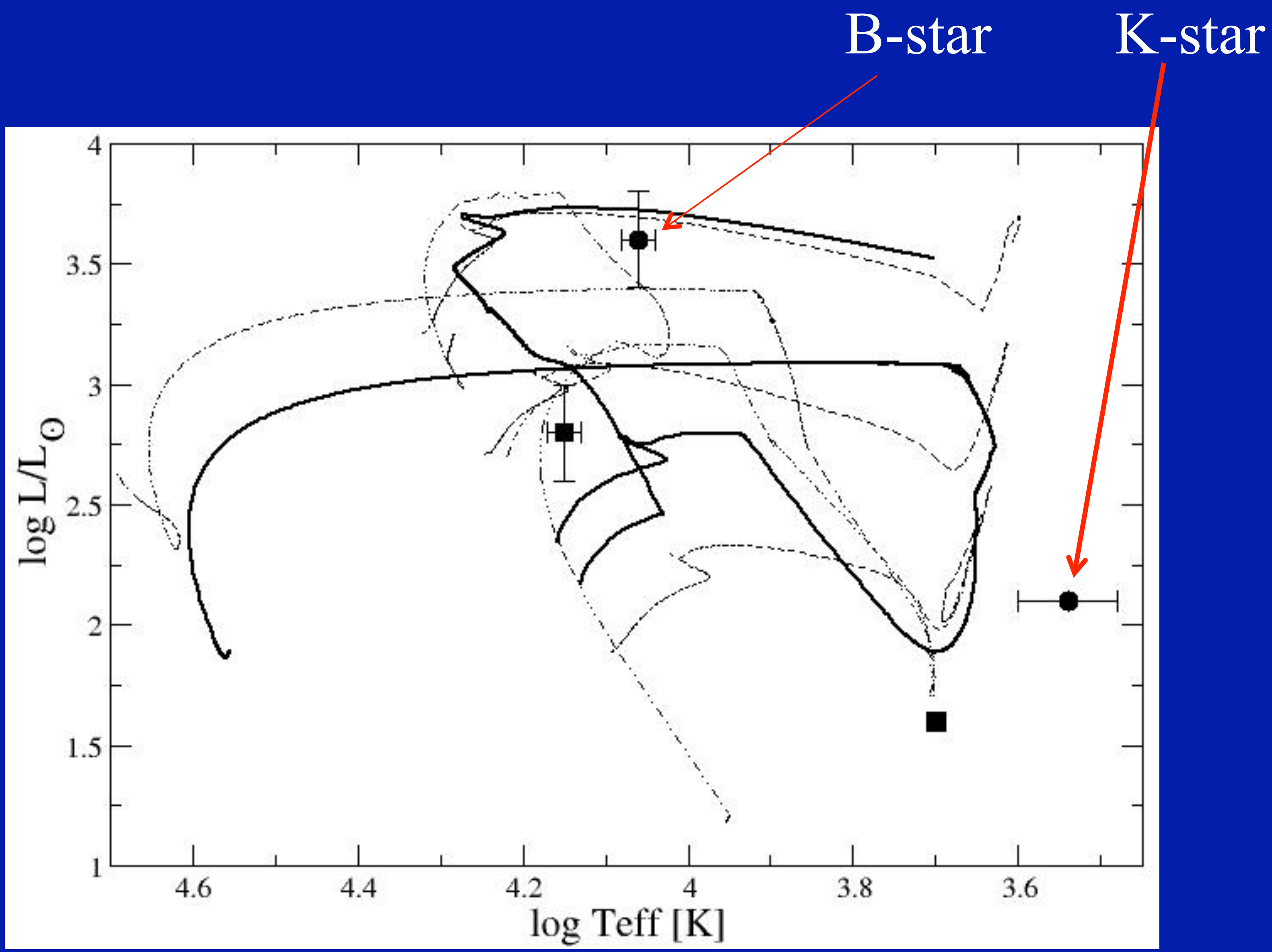
Reasonable masses: $M_1 \sim 5\ M_\odot$, $M_2 \sim 7\ M_\odot$

AS 386 – IR brightness variations



Phase 0.5 – B-star in front of the invisible component

AS 386



AS 386 - Conclusions

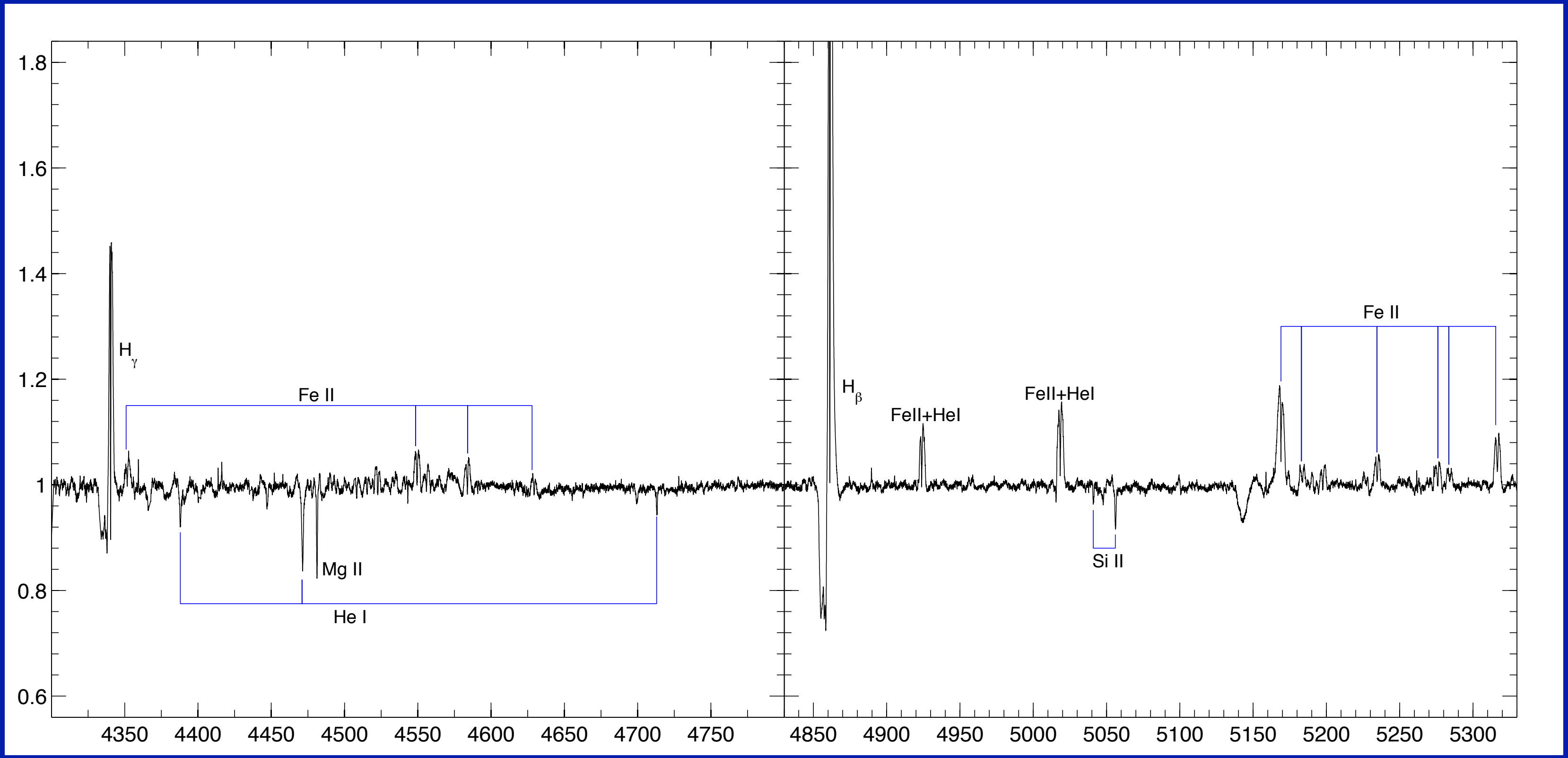
The system consists of a ~5 $M_\odot$ B-type star and a much optically fainter (100 times) cool star with a similar mass.

The visible star spectrum is rich with absorption lines that indicate high abundances of Si, S, N, and Ne.

The near-IR light curve suggests the presence of several components, including a variable contribution of the secondary component.

Overall, the object is probably an evolved binary after an active mass-transfer phase.

HD 85567

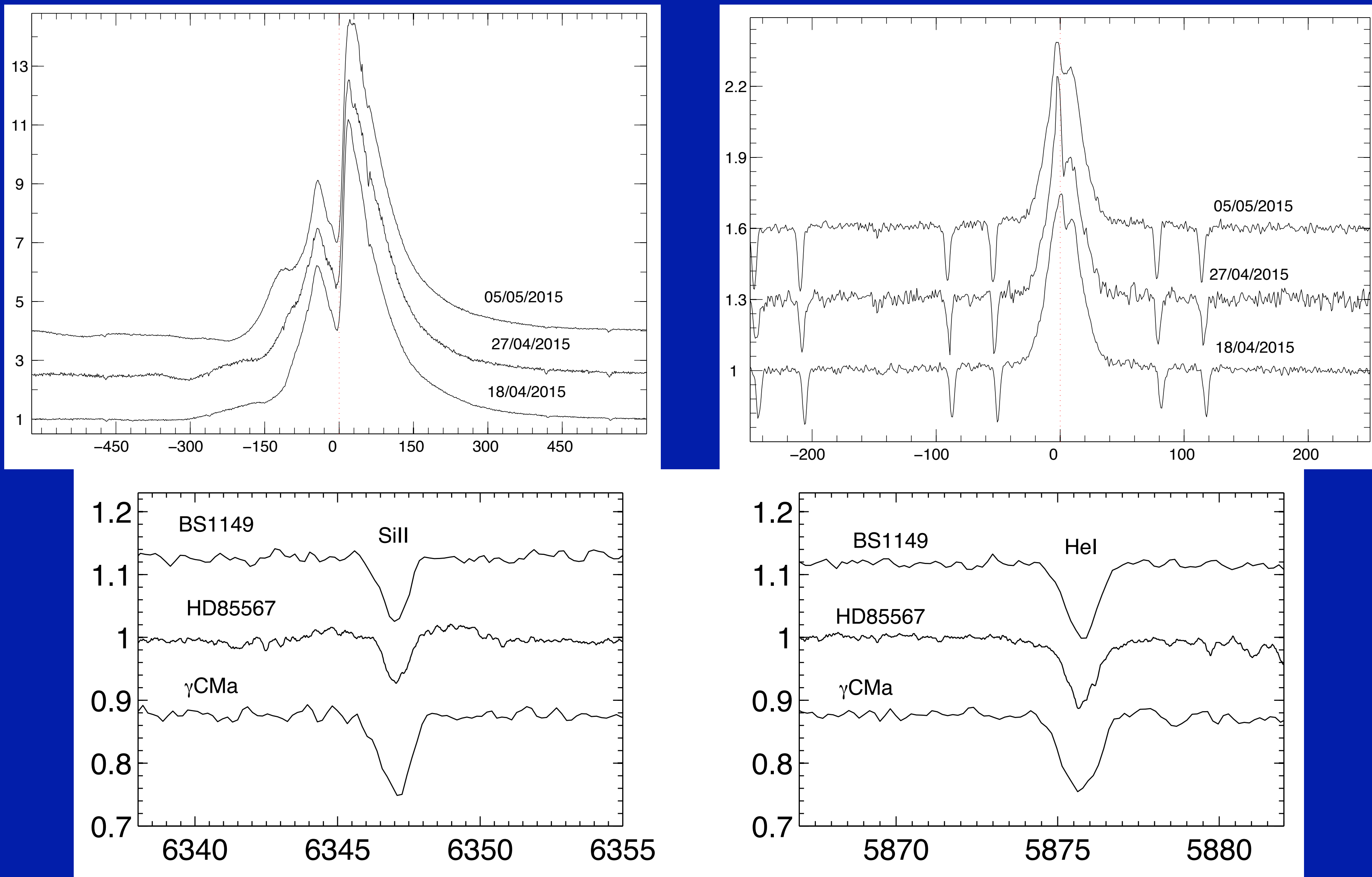


A B5-star with a strong IR excess (Oudmaijer et al. 1992)
FS CMa possible binary (Miroshnichenko et al. 2001) or a HAeB[e] (Wheelwright et al. 2013)

15 spectra - 2012 and 2015, HIRON (R=80000), CTIO

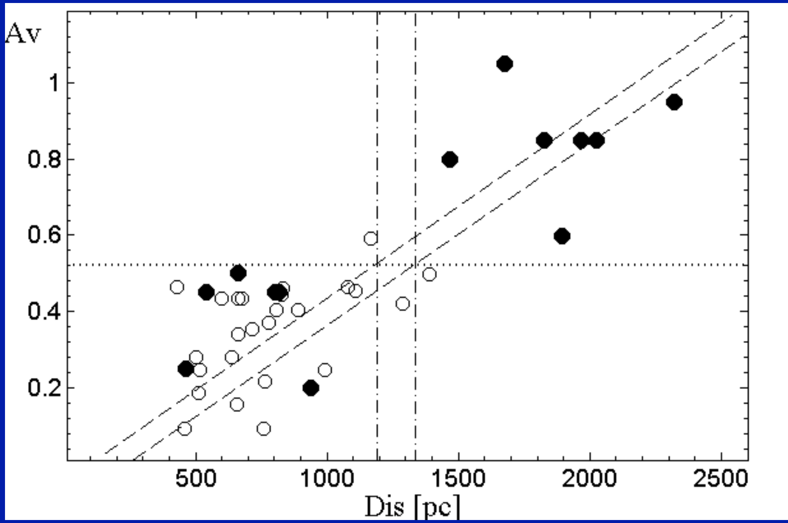
Khokhlov et al. (2017) – evidence against young status

HD 85567

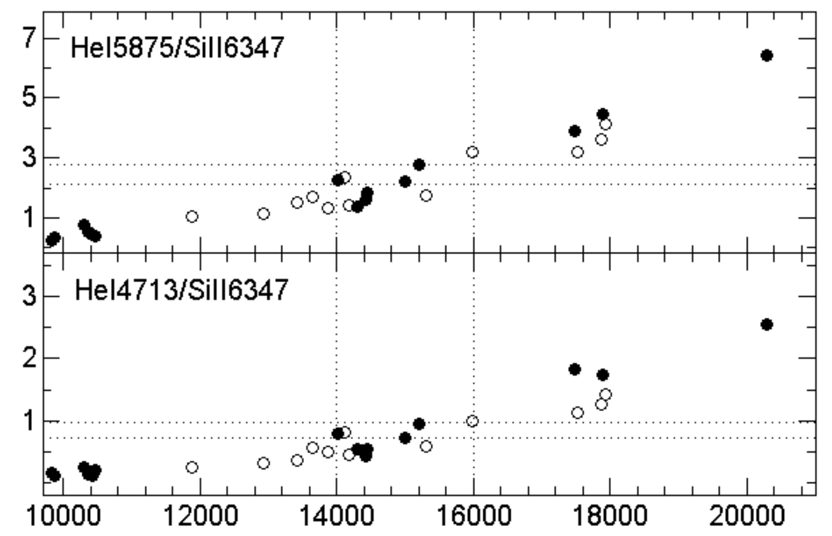


No radial velocity variations of absorption lines was found

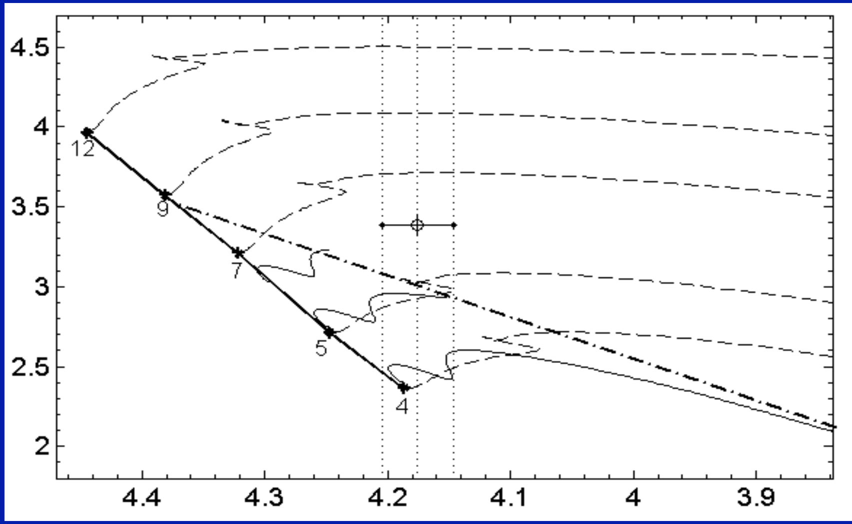
Fundamental parameters of HD 85567



Interstellar extinction in the direction of HD 85567.

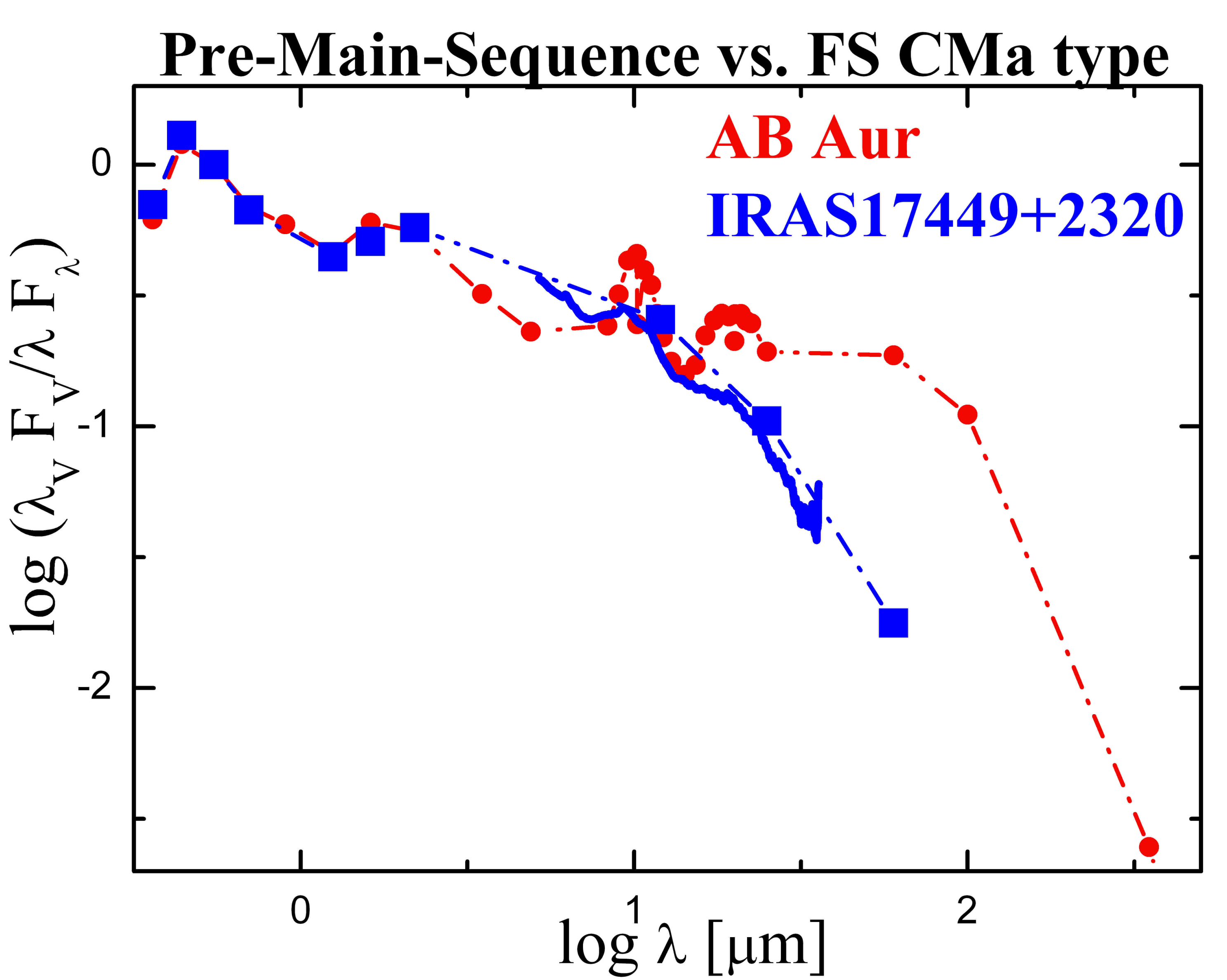


Teff versus EW ratio of He I 4713/Si II 6347
Teff versus EW ratio of He I 5876/ Si II 6347
Circles: data for normal B – type stars
(filled — OHP, open — TCO).

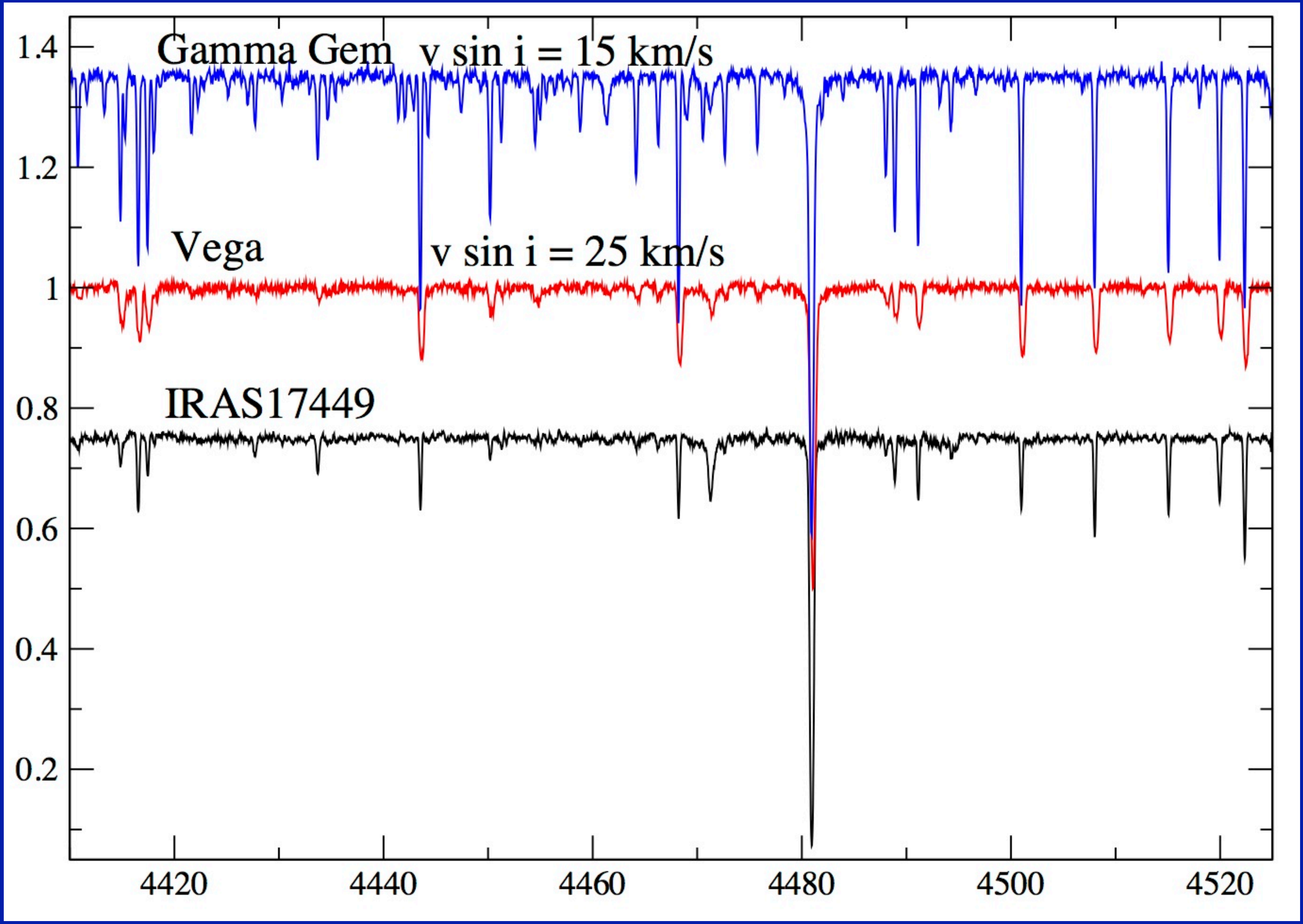


Hertzsprung–Russell diagram with evolutionary tracks of PMS stars from Tognelli et al. (2011) (thin solid lines) and rotating single stars from Ekstrom et al. (2012) (dashed lines).

IRAS 17449+2320



IRAS 17449+2320



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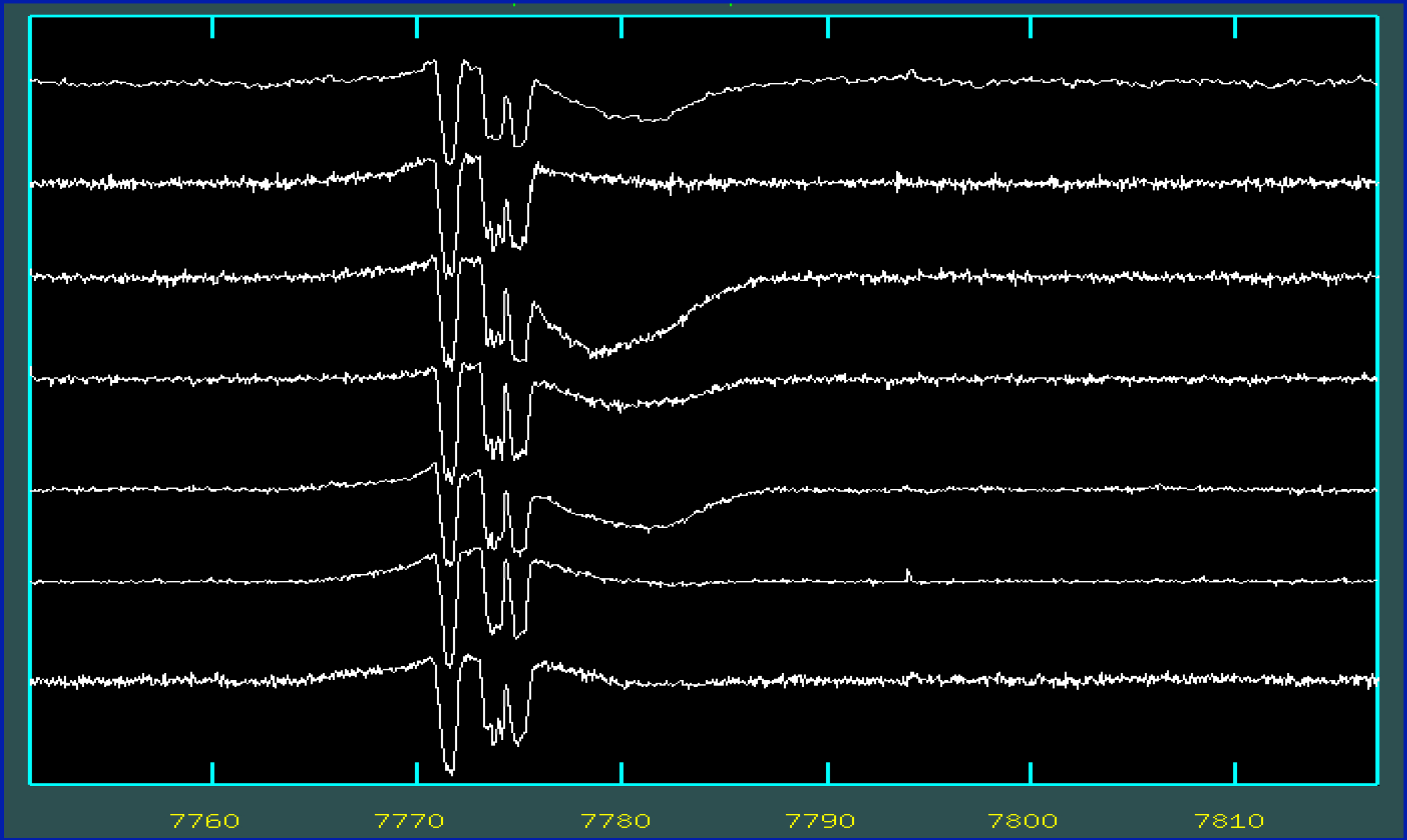
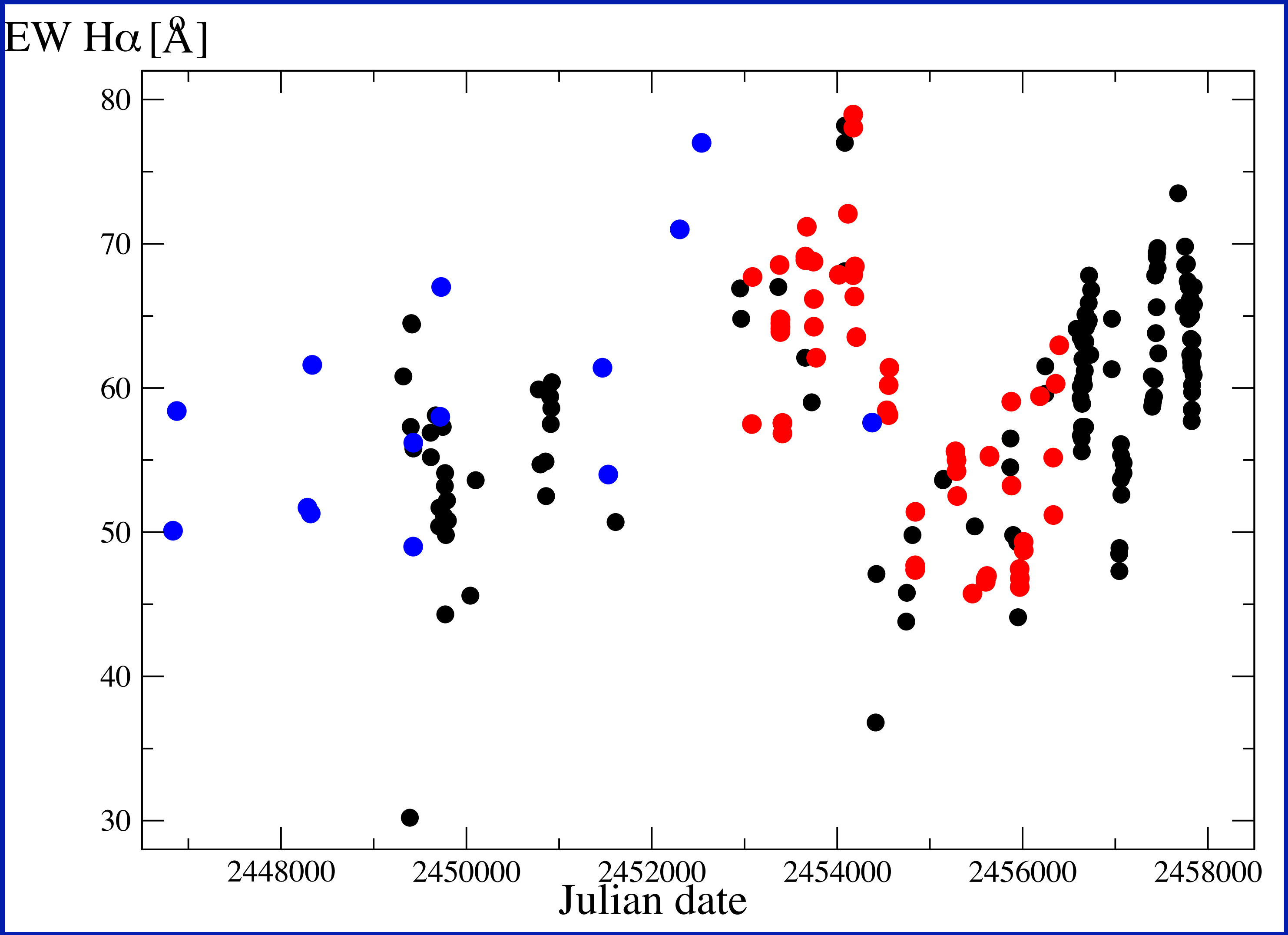


Variations of the oxygen triplet at 7772-7775 Å (2006-2017)

HD 50138 – the brightest FS CMa Object



Possible periodicity on a timescale of 10-15 years

Problems and Questions

- Mass loss mechanisms:
  - Similar to that in Be stars if single?
  - Mass transfer in close binaries?
  - Explosion in mergers?
- Binary fraction:
  - Most known Galactic sgB[e] are binaries
  - SymB[e] are binaries by nature
  - 1/3 FS CMa objects show signs of binarity
- Why are there many Be stars within 1 kpc from the Sun and only a few B[e] objects?
- How to model circumstellar envelopes?

Conclusions

- The main hypothesis on the nature of the FS CMa objects – components interaction in binary systems of intermediate mass (2 – 10 $M_{\odot}$)
- Other possibilities – binary mergers or unusually strong stellar wind from a single star
- Signatures of binarity are diverse and require long-term observations
- The number of confirmed binary systems grows with the amount of collected material