Analysis of UV spectra of white dwarfs in binary systems

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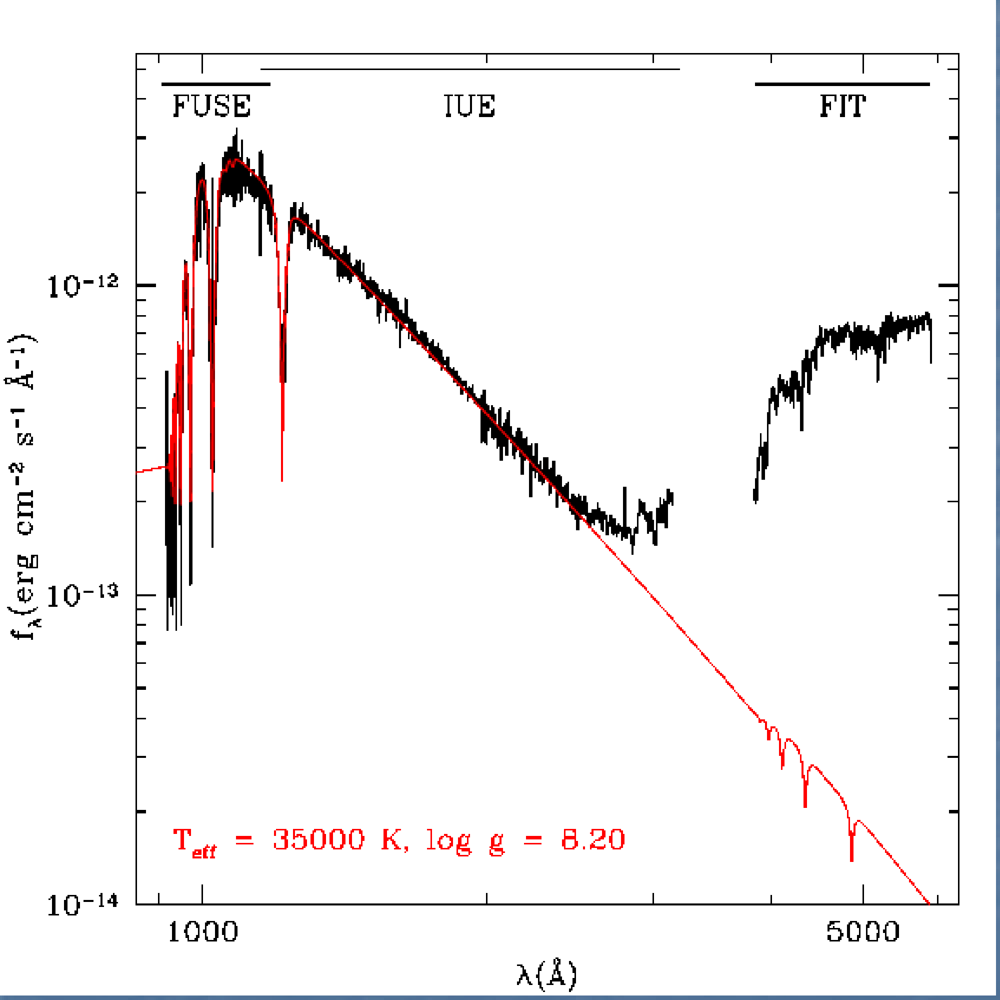
Overview

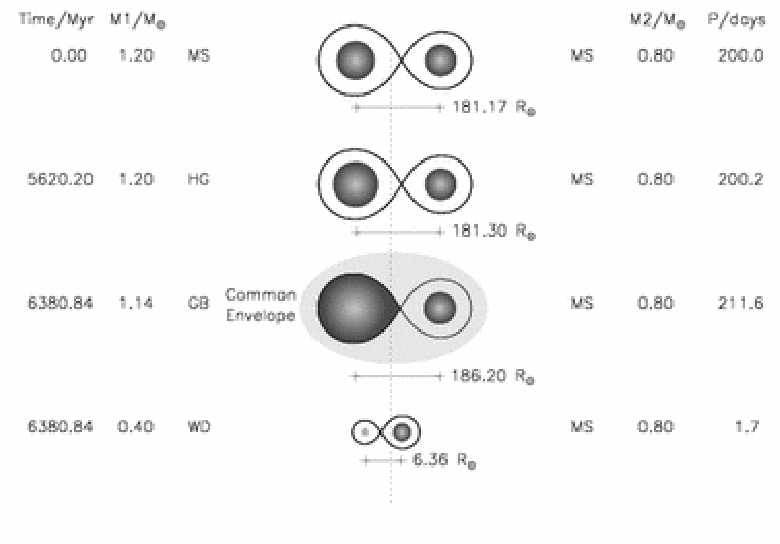
- Post common envelope binaries.
- FUSE – Far Ultraviolet Spectroscopic Explorer.
- Atmospheric parameters of the white dwarfs.
- Binary parameters – measuring the white dwarf velocities.
- Abundance measurements of heavy elements.
- Further work – analysis of more FUSE spectra of white dwarfs.

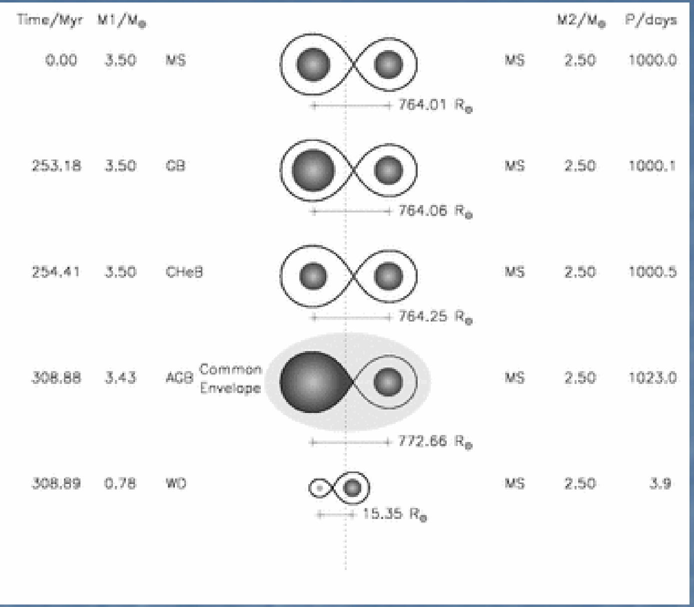
V471 Tauri



- V471 Tau is the first post-CE binary to be discovered (Nelson & Young 1970).
- Eclipsing K2V + DA binary (V = 9.5)
- P_{orb} = 0.521 days
- White dwarf (Werner & Rauch 1997):
  - T_{eff} = 35125 ± 1275 K
  - log g = 8.21± 0.23
  - M = 0.76 ± 0.02 $M_?$

Post Common Envelope Binaries

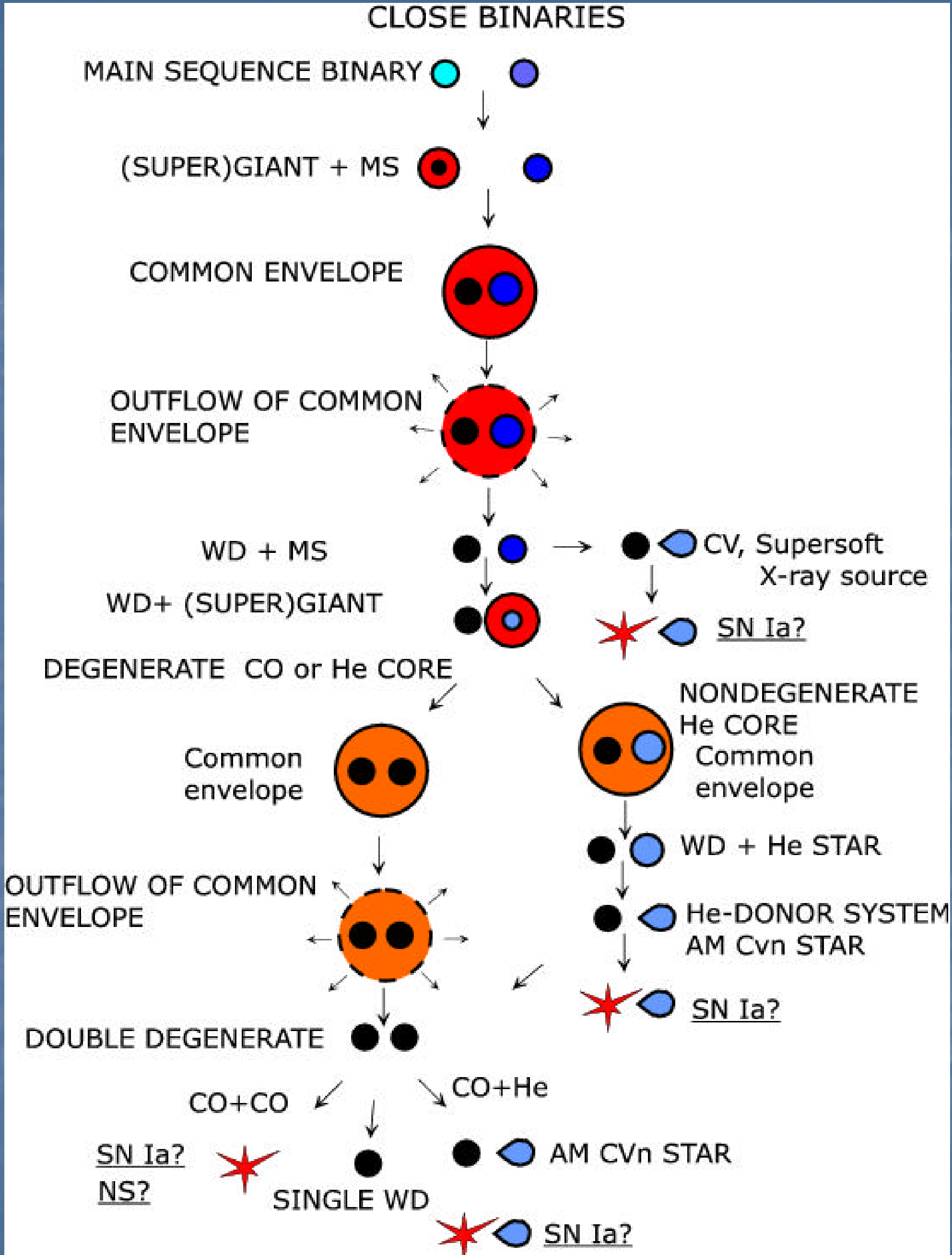




Willems & Kolb (2004)

- The common envelope (CE) scenario was first developed by Paczynski (1976).
  - In a system containing two MS stars, the more massive will evolve off the MS first and fill its Roche lobe, initiating mass transfer.
  - Mass transfer may be dynamically unstable forming a common envelope.
  - Friction will cause the two stars to lose angular momentum to the envelope.
  - This energy transfer will allow the envelope to be expelled.

Pre-CVs



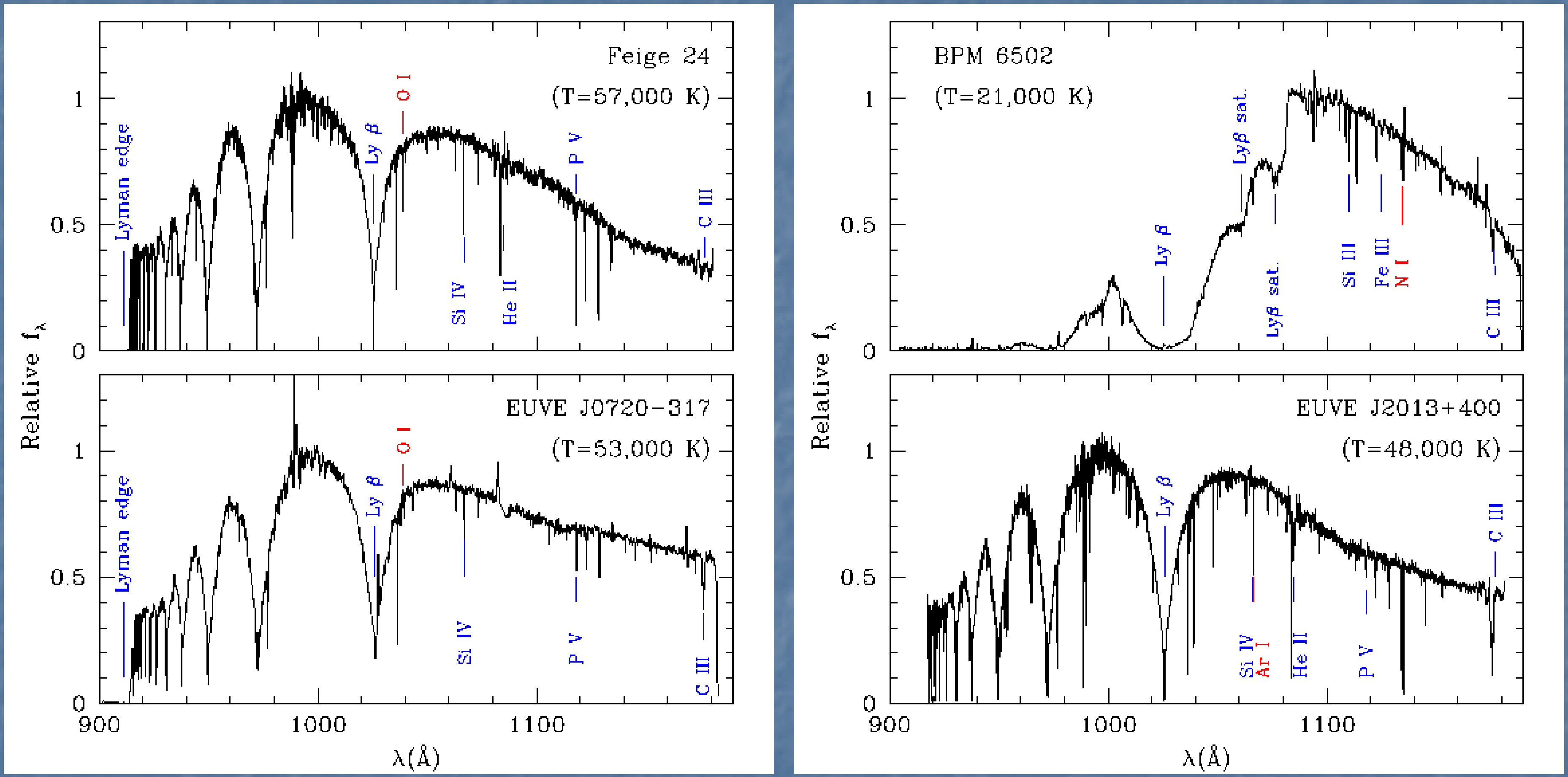
Postnov & Yungelson (2006)

- A post-CE binary can further evolve into a CV.
  - Gravitational radiation
  - Magnetic braking
- Can go through a second CE phase to become a double degenerate system.
- Possible Type Ia supernovae progenitors.

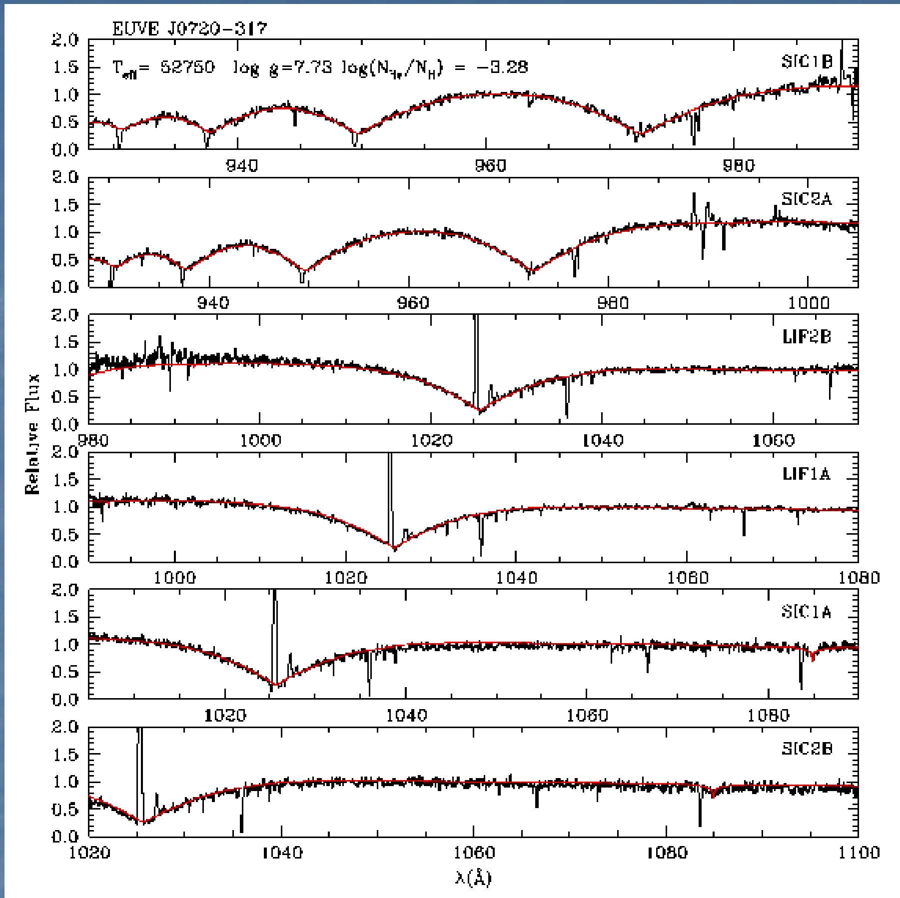
FUSE

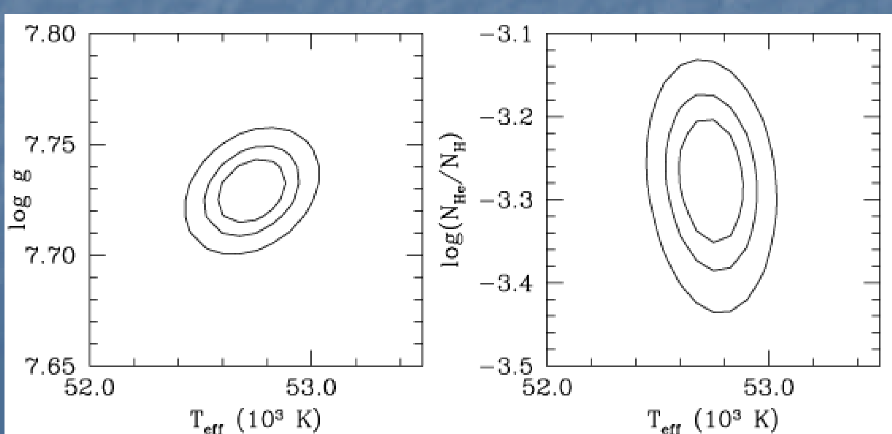
- The Far Ultraviolet Explorer (FUSE) was a NASA observatory capable of obtaining high resolution (R ~ 20000) spectra between 940 and 1190 Å.
- The satellite was launched 24th June 1999.
- FUSE was shut down in October 2007.
- Several white dwarfs have been observed (atmospheric parameters, abundance measurements, ISM).
- Provides an additional window in the study of hot white dwarfs in binary systems.

Post-CE binaries



- We obtained FUSE spectra of four close binary systems.

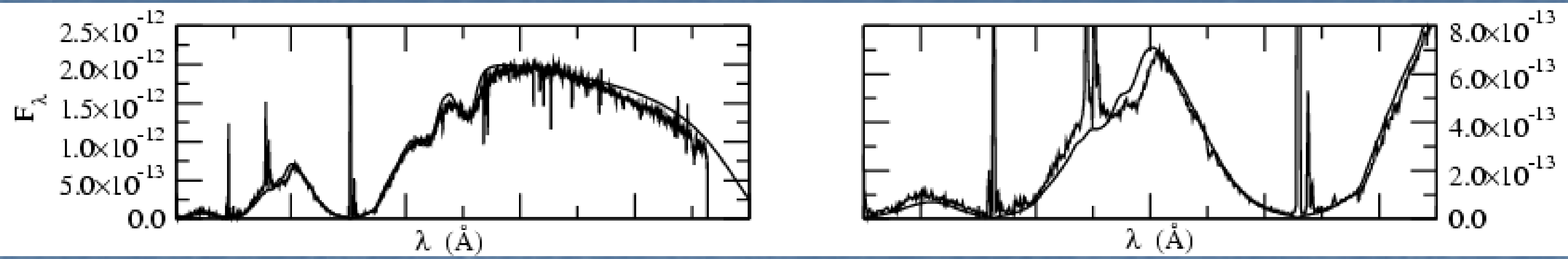




Atmospheric parameters

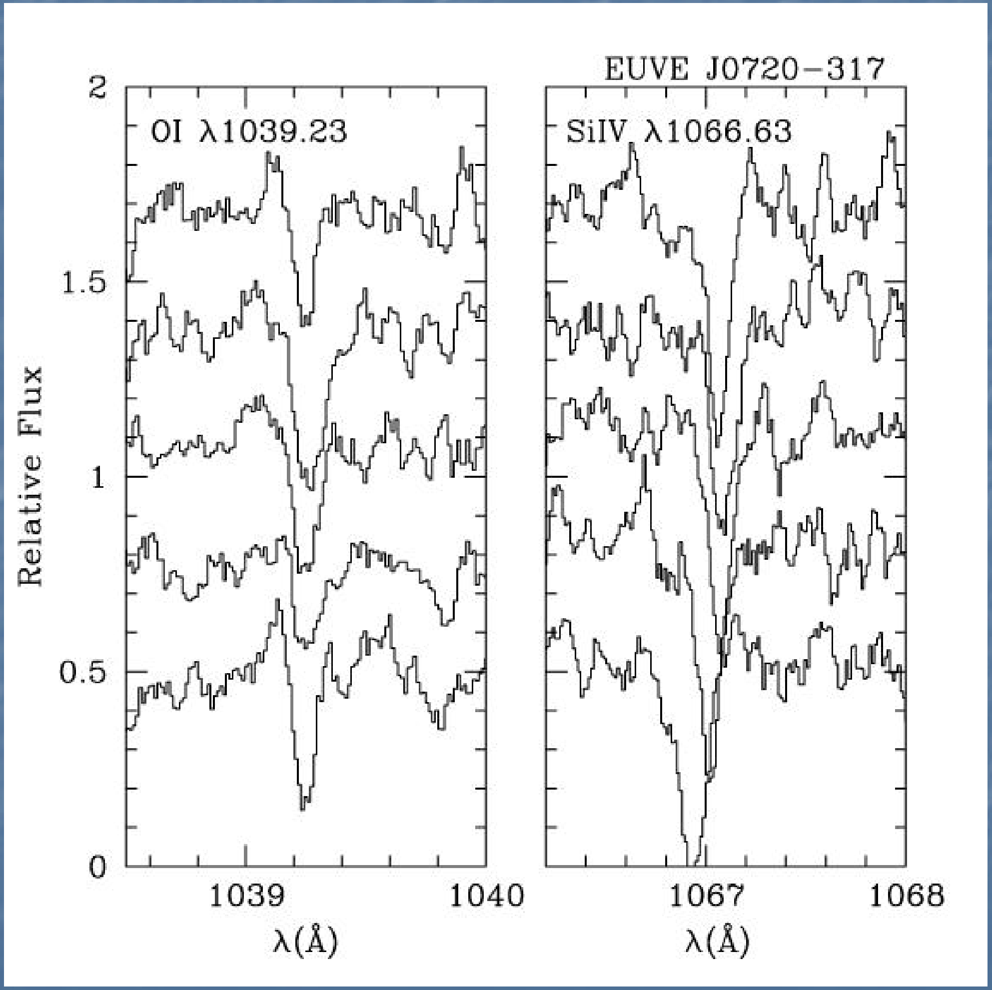
- We computed a grid of LTE models
  - T_{eff} = 30000 – 70000 K (4000 K)
  - log g = 7.0 – 9.5 (0.25 dex)
  - log(N_{He}/N_H) = -4.0 – 0.0 (0.5 dex)
- We fitted 6 channels simultaneously.
- Excluded regions that show interstellar absorption.
- Similarly we fitted the spectrum of EUVE J2013+400
  - T_{eff} = 47800 ± 200 K
  - log g = 8.20 ± 0.03
  - log (N_{He}/N_H) = -2.90 ± 0.08

Atmospheric parameters



- The FUSE spectrum of Feige 24 was analyzed by Vennes et al. (2005).
  - T_{eff} = 64700 ± 3000 K
  - log g = 7.58 ± 0.25
- Hébrard et al. (2003) compared the FUSE spectrum of BPM 6502 to a model spectrum with T_{eff} = 21380 K and log g = 7.86
  - Quasi-molecular satellites (H_2, H_2^+) of Lyα, Lyβ and Lyγ.

Binary Parameters



- We used the FUSE spectra to measure radial velocities of the white dwarf.
- Used the ISM absorption lines (local interstellar cloud) to fix the zero point of the wavelength calibration (Lallement et al. 1995)

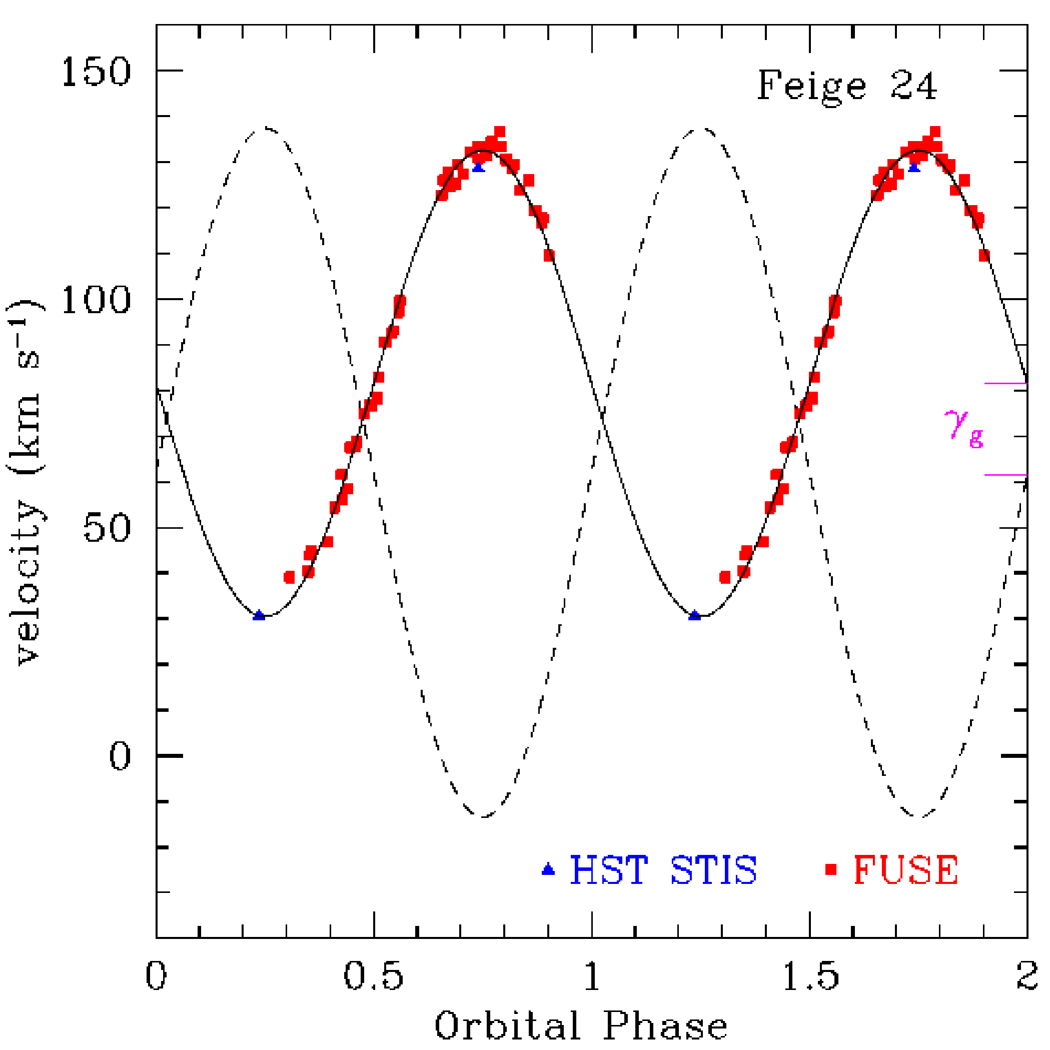
Binary Parameters

- We phased the white dwarf velocities using published ephemerides (based on optical data).
  - The strength of the Hα emission line has been observed to vary in all four systems.
  - Can be explained by the changing viewing angle of the irradiated red dwarf hemisphere.
  - We correct K_{dMe} for this irradiation effect (Vennes et al. 1999).
- We measured the velocity semi-amplitude K_{WD} and mean velocity γ_{WD}.
- We calculate the gravitational redshift of the white dwarf ($v_g = \gamma_{WD} - \gamma_{sys}$).
- We calculated the mass ratios of the binary systems ($q = K_{WD}/K_{RD} = M_{RD}/M_{WD}$).

Feige 24

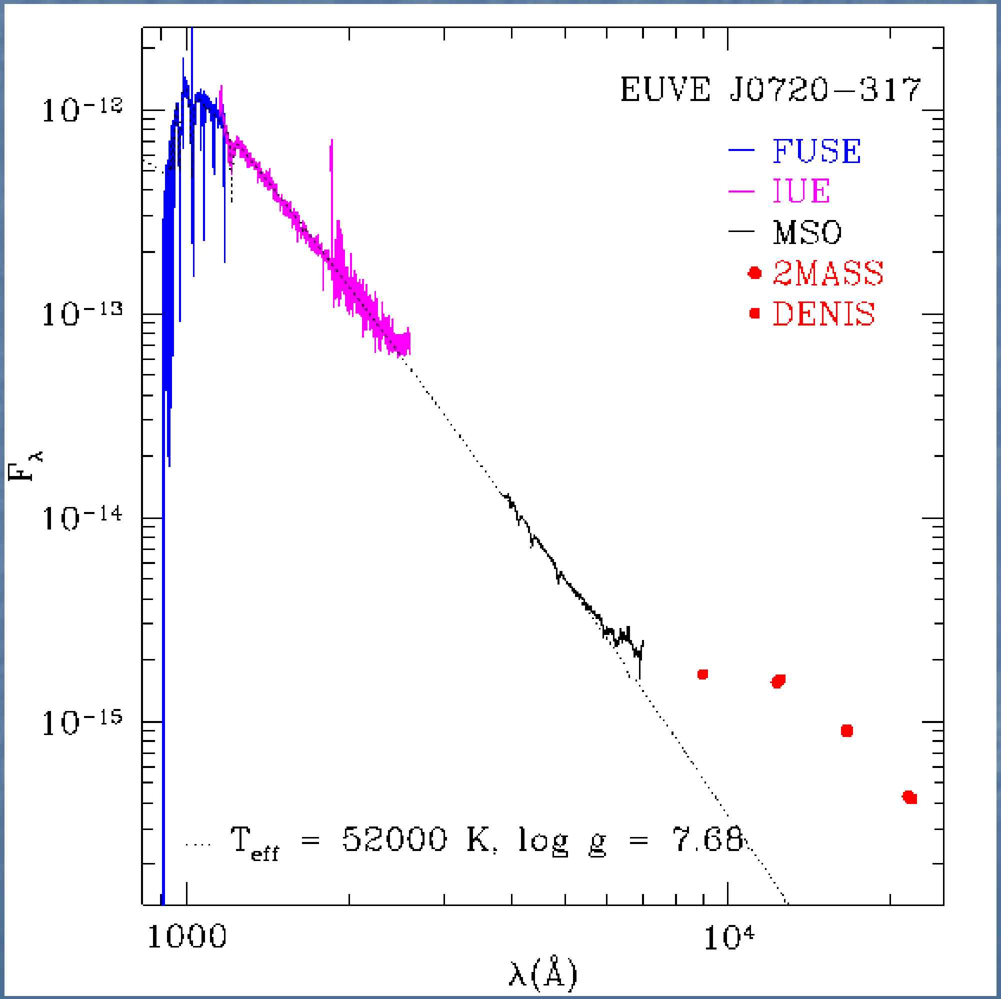
- V = 12.4
- Is a well studied binary.
- Feige (1958) identified this object to have UV excess.
- Eggen & Greenstein (1965) classified it as DAwk, with weak emission lines, suggesting it could be an old nova.
- Holm (1976) and Margon et al. (1976) showed Feige 24 to be very hot (~70 000 K).
- Liebert & Margon (1977) estimated the spectral type of the secondary to be M1-2V.
- Thorstensen et al. (1978) were the first to obtain orbital parameters.
  - Found that the strength of the Hα emission was correlated to the phase.
  - Emission lines originate from the reprocessing of EUV radiation.
- Parallax measurements place the system at d = 68 pc (Benedict et al. 2000).
- Extensive abundance analyses have been conducted (e.g., Vennes et al. 2000).
- Orbital period of 4.23160 ± 0.00002 days (Vennes & Thorstensen 1994).

Feige 24



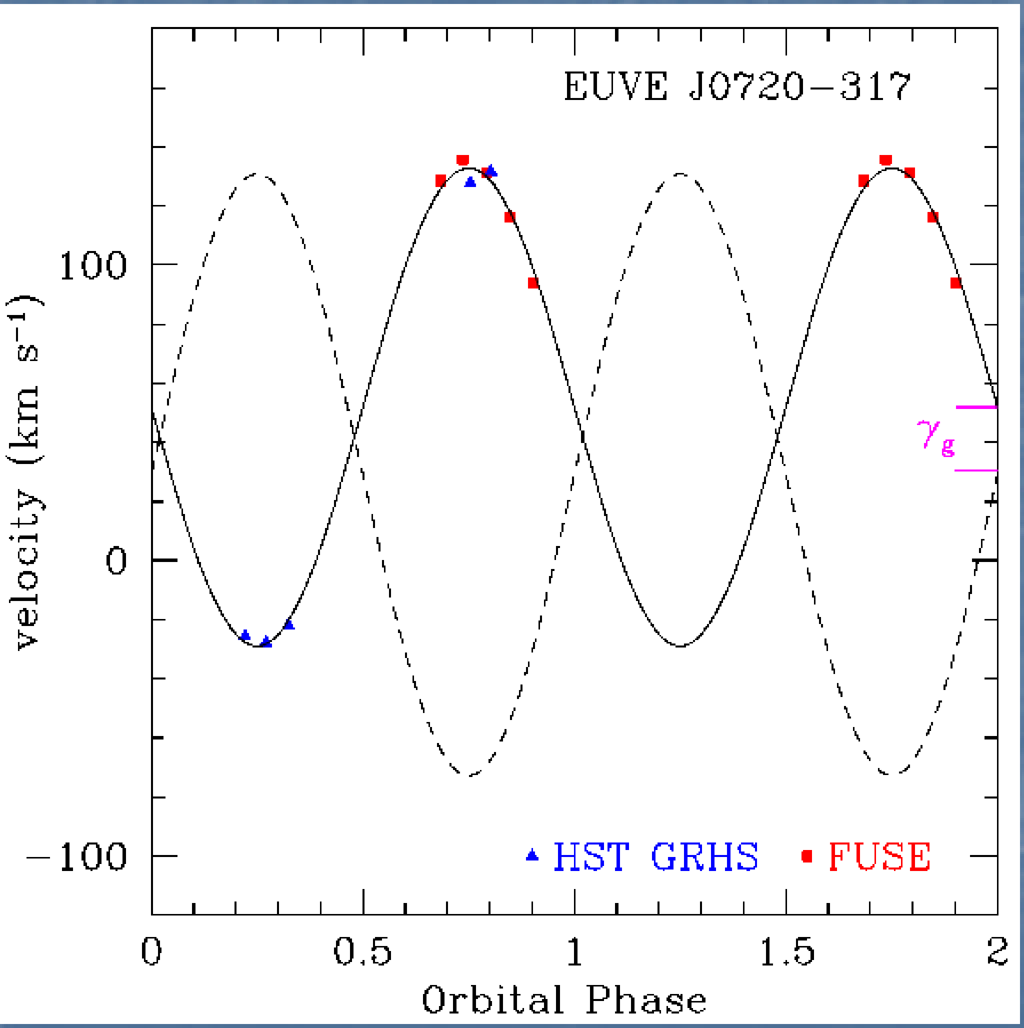
- P = 4.23160 ± 0.00002 d
- K_{RD} = 75.5 ± 2.1 km s^{-1} (Vennes & Thorstensen 1994)
- K_{WD} = 51.0 ± 0.5 km s^{-1}
- q = 0.68 ± 0.02
- v_g = 20.1 ± 1.9 km s^{-1}
  - M_{WD} = 0.57 ± 0.03 $M_?$
  - M_{WD} = 0.58 ± 0.05 $M_?$ (T_{eff} = 57 000 ± 2000 K, parallax)
- M_{RD} = 0.39 ± 0.02 $M_?$
  - R = 0.43 ± 0.02 $R_?$
  - M2

EUVE J0720-317



- V = 14.8
- Was discovered as part of the EUVE/ROSAT surveys.
- Identified as a post-CE system by Vennes & Thorstensen (1994).
- DAO + dM0-2
- Orbital period of 1.262396 ± 0.000008 d (Kawka et al. 2002).
- Vennes et al. (1999) used HST spectra to trace the orbit of the white dwarf.

EUVE J0720-317

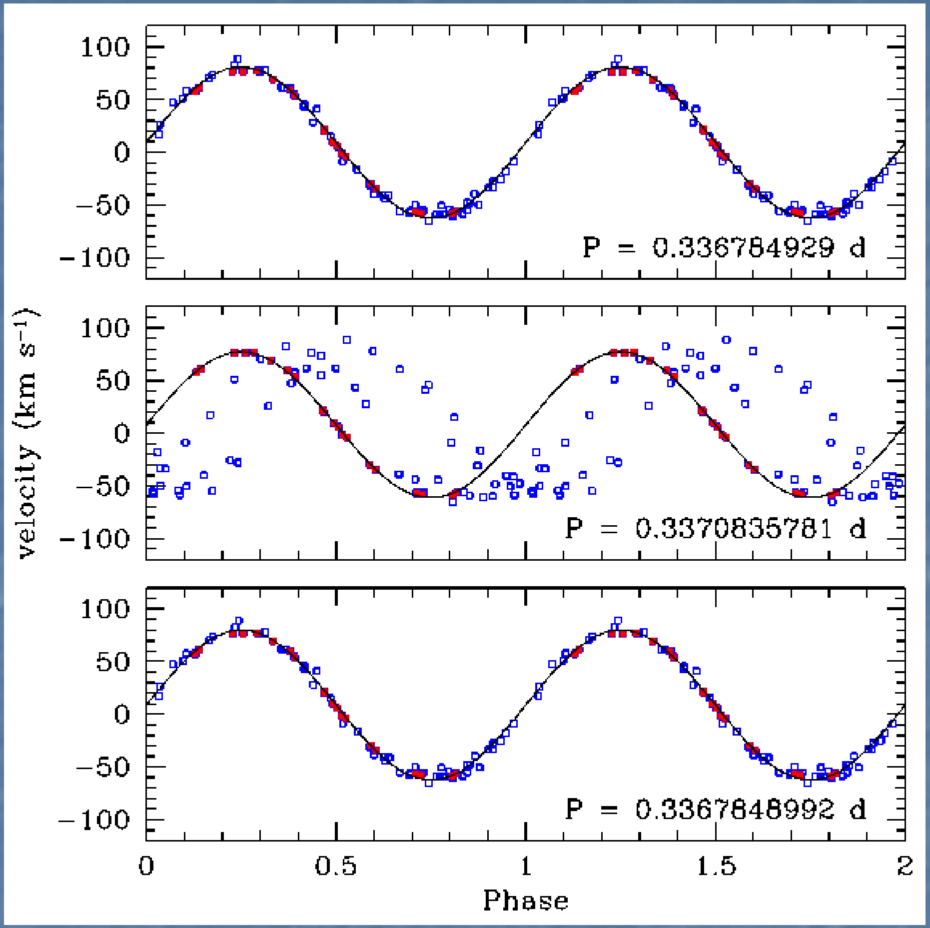


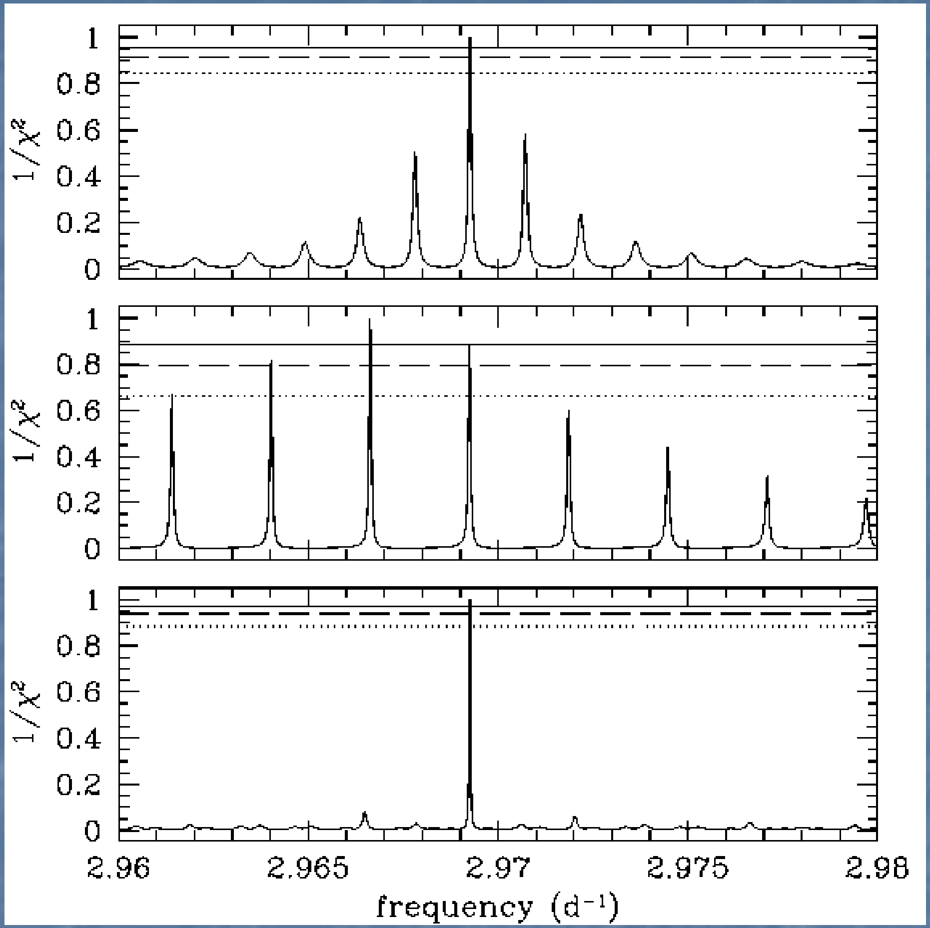
- P = 1.262396 ± 0.000008 d
- K_{RD} = 98.2 ± 1.2 km s^{-1}, $K_{RD,corr}$ = 105.9 ± 3.4 km s^{-1} (Kawka et al.2002)
- K_{WD} = 80.8 ± 1.2 km s^{-1}
- q = 0.76 ± 0.03
- v_g = 21.4 ± 1.9 km s^{-1}
  - M_{WD} = 0.58 ± 0.03 $M_?$
  - M_{WD} = 0.56 ± 0.04 $M_?$ (T_{eff} = 52400 ± 1800 K, log g = 7.68 ± 0.01, Vennes et al. 1997)
- M_{RD} = 0.43 ± 0.03 $M_?$
  - R = 0.47 ± 0.03 $R_?$
  - M2

BPM 6502

- V = 12.8
- A high proper motion star (0.28" yr^{-1}: Luyten 1963).
- Was identified spectroscopically as a white dwarf by Wegner (1973).
- Kawka et al. (2000) identified BPM 6502 as a post-CE and measured an orbital period of 0.33678 d.
- White dwarf effective temperature is 19960 ± 400 K, log g = 7.86 ± 0.09.

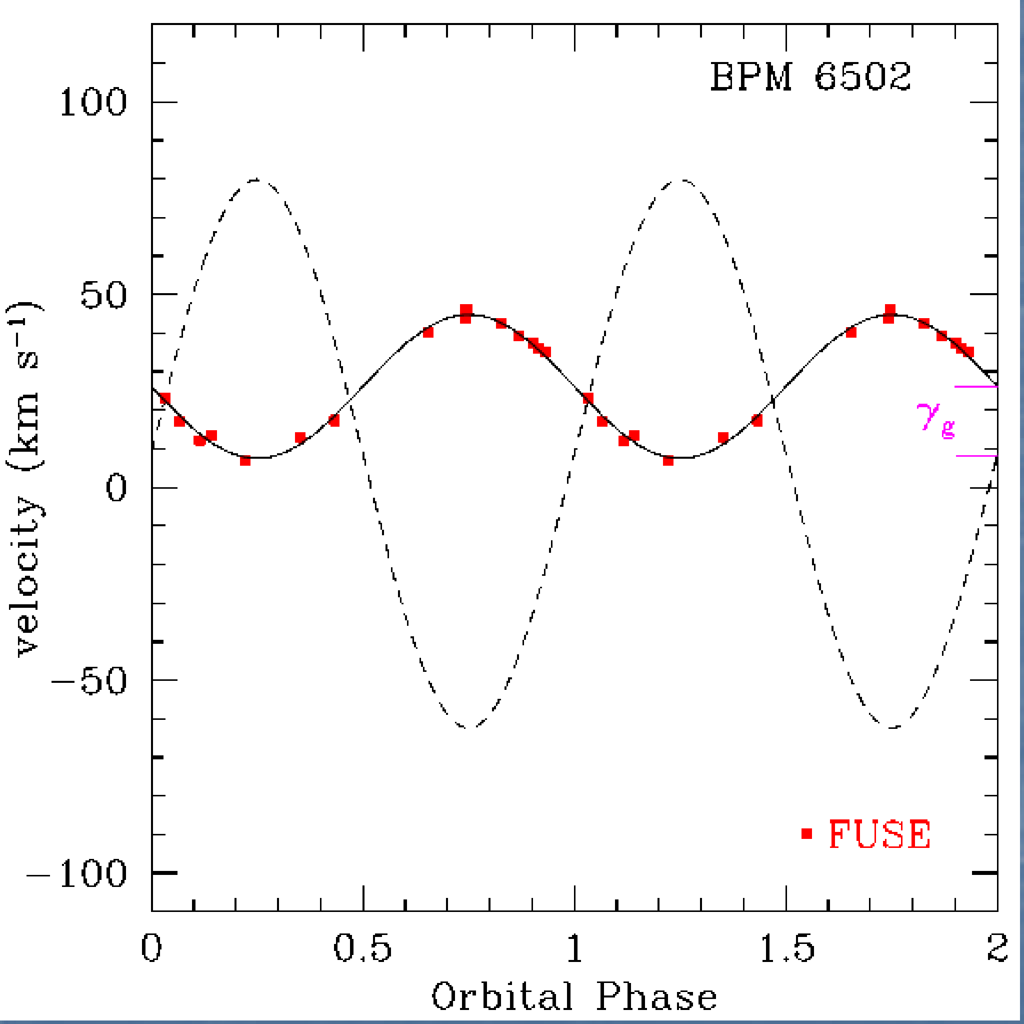
BPM 6502





- Combining the radial velocity measurements from Kawka et al. (2002) and Morales-Rueda et al. (2005).

BPM 6502

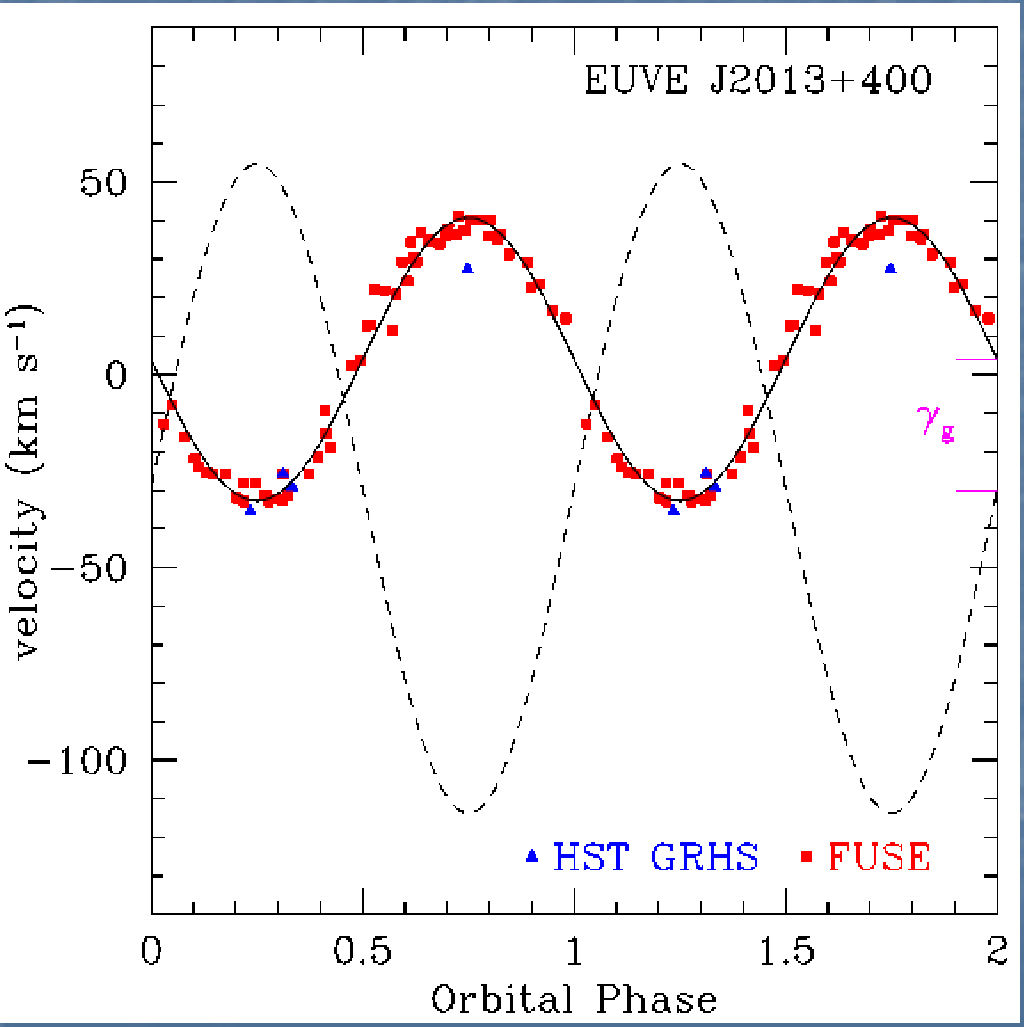


- P = 0.3367849 ± 0.0000006 d
- K_{RD} = 71.1 ± 0.2 km s^{-1}, $K_{RD,corr}$ =75.2 ± 3.1 km s^{-1}
- K_{WD} = 18.6 ± 0.5 km s^{-1}
- q = 0.25 ± 0.01
- v_g = 17.9 ± 0.5 km s^{-1}
  - M_{WD} = 0.46 ± 0.01 $M_?$
  - M_{WD} = 0.55 ± 0.05 $M_?$ (T_{eff} = 19960 ± 400 K, log g = 7.86 ± 0.09, Kawka et al. 2007)
- M_{RD} = 0.14 ± 0.01 $M_?$
  - R = 0.19 ± 0.02 $R_?$
  - M5

EUVE J2013+400

- V = 14.6
- Discovered as part of the EUVE/ROSAT surveys.
- Identified as a post-CE by Thorstensen & Vennes (1994).
- DAO + dM4
- Orbital period of 0.705517 ± 0.000006 d (Vennes et al. 1999).
- Vennes et al. (1999) used HST spectra to trace the orbit of the white dwarf.

EUVE J2013+400



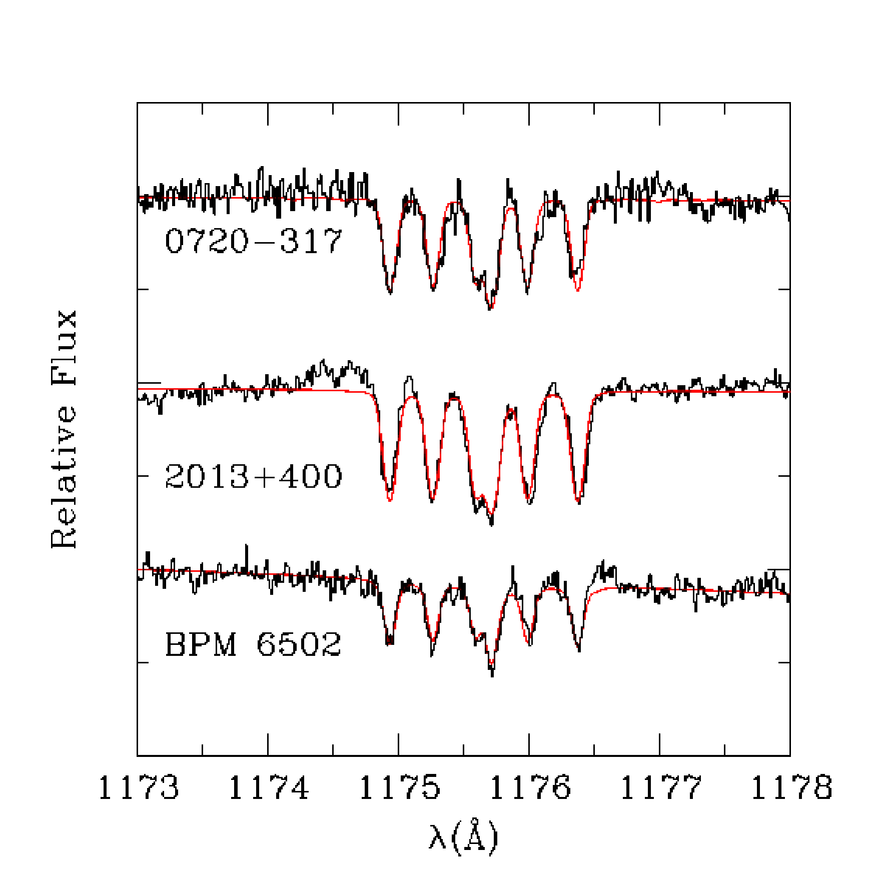
- P = 0.705517 ± 0.000006 d
- K_{RD} = 84.2 ± 0.9 km s^{-1}, $K_{RD,corr}$ = 89.1 ± 2.6 km s^{-1} (Vennes et al. 1999)
- K_{WD} = 36.7 ± 0.7 km s^{-1}
- q = 0.41 ± 0.01
- v_g = 34.0 ± 1.3 km s^{-1}
  - M_{WD} = 0.71 ± 0.02 M?
  - M_{WD} = 0.56 ± 0.03 M? (T_{eff} = 48000 ± 900 K, log g = 7.69 ± 0.09, Vennes et al. 1999)
- M_{RD} = 0.23 ± 0.01 M?
  - R = 0.29 ± 0.01 R?
  - M3

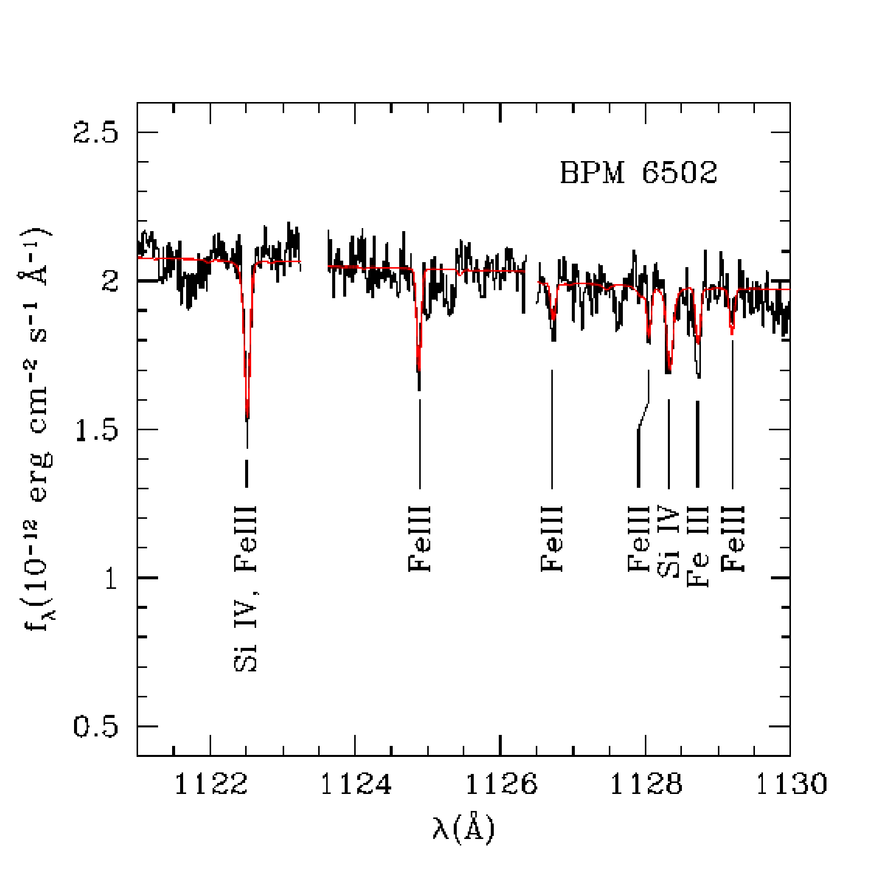
Evolutionary status

Object	Orbital Period	Contact period	t_{sd}	
Feige 24	4.2316 days	0.164 days	2.2×10^{11} yrs	GR, MB
EUVE J0720-317	1.2624 days	0.175 days	3.2×10^{9} yrs	GR, MB
BPM 6502	0.3367 days	0.083 days	3.0×10^{10} yrs	GR
EUVE J2013+400	0.7055 days	0.118 days	1.3×10^{11} yrs	GR

- Magnetic braking is the dominant mechanism for angular momentum loss for binaries with secondary masses larger than ~0.3 $M_?$.
- Magnetic braking is expected to cease when the secondary becomes fully convective.
- Only EUVE J0720-317 will evolve into contact within Hubble time.

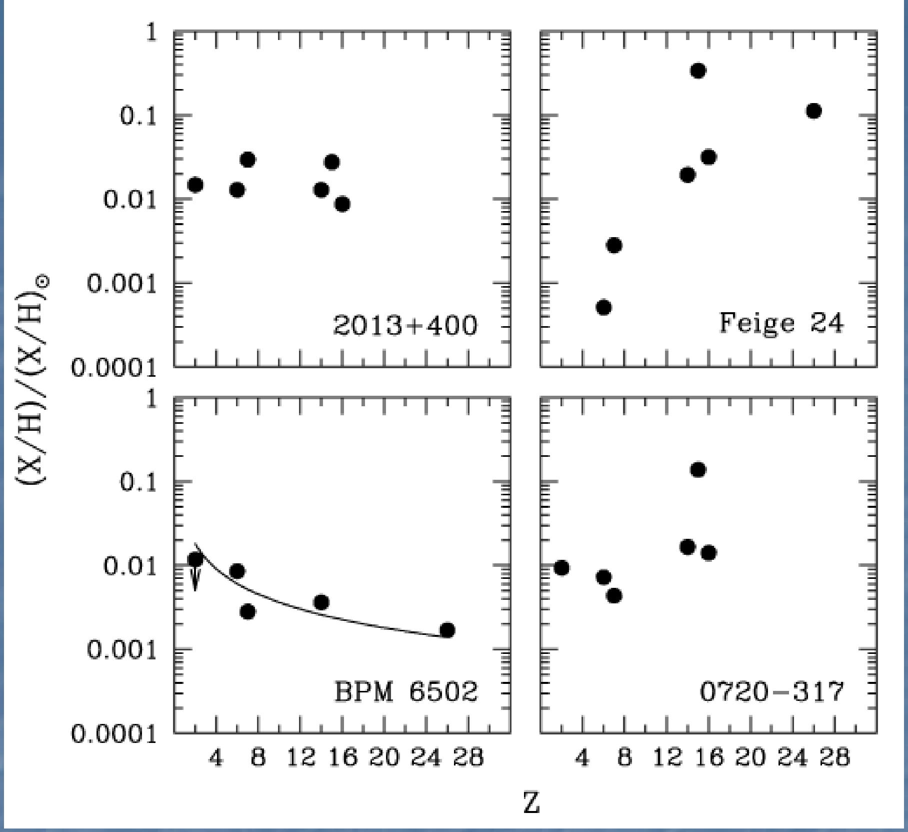
Abundances





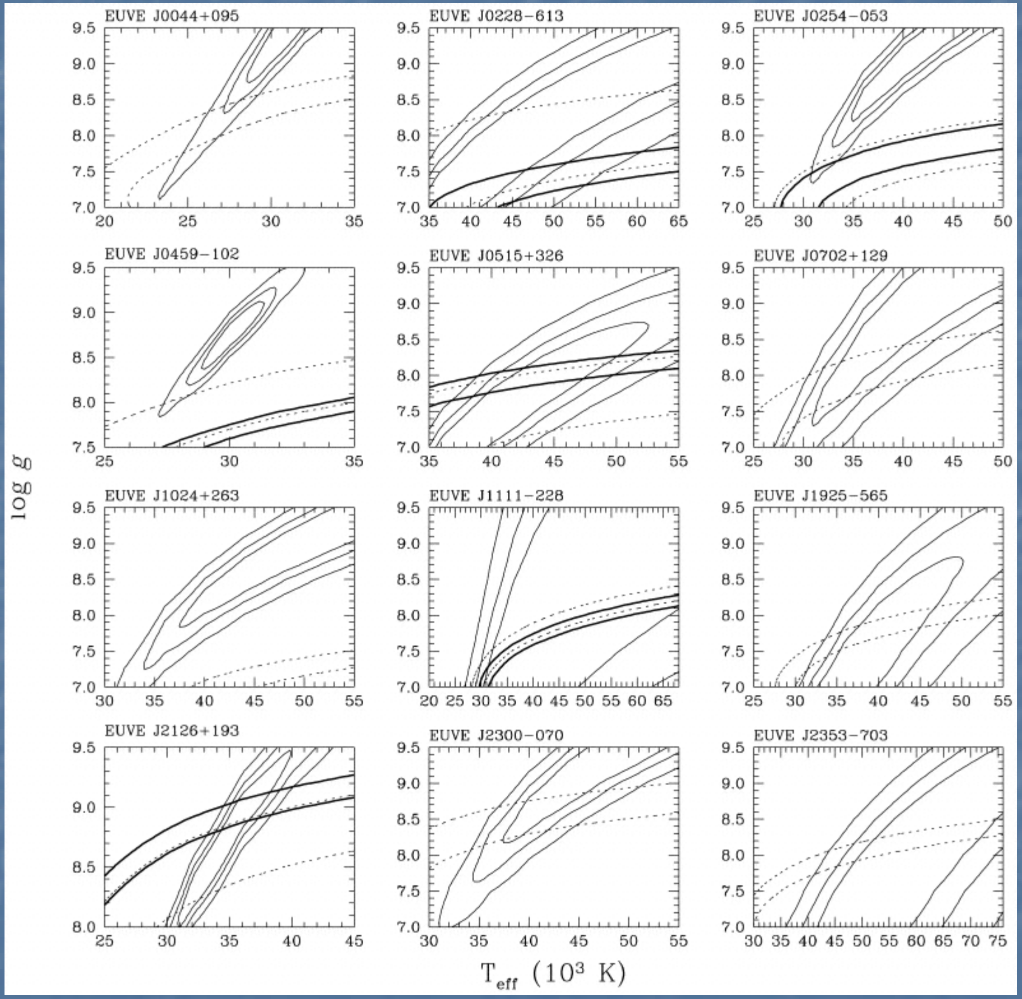
- We calculated a series of NLTE model atmospheres using TLUSTY and SYNSPEC (Hubeny & Lanz 1995).
- Using preliminary abundance estimates, we bracketed the abundance inputs (-0.7,+0.7 dex).

Abundances



- We measured the abundances of C, N, Si, P, S and Fe.
- O VI was detected however, we were not able to obtain satisfactory fits.
- Feige 24 is similar to the hot star G191-B2B.
- The abundance pattern of BPM 6502, EUVE J0720-317 and EUVE J2013+400 suggest that the heavy elements are accreted from the close late type companion.
- Using the accretion/diffusion model of Fontaine & Michaud (1979) we estimated the possible accretion required to explain the observed abundance pattern.
- This model appears to explain the abundance pattern in BPM 6502 – for which a low rate of 1.1 x 10^{-17} $M_?$ yr^{-1} is required.
- The accretion rates required for EUVE J0720-317 and EUVE J2013+400 are 1.8 x 10^{-19} $M_?$ yr^{-1} and 3.4 x 10^{-19} $M_?$ yr^{-1}, respectively.

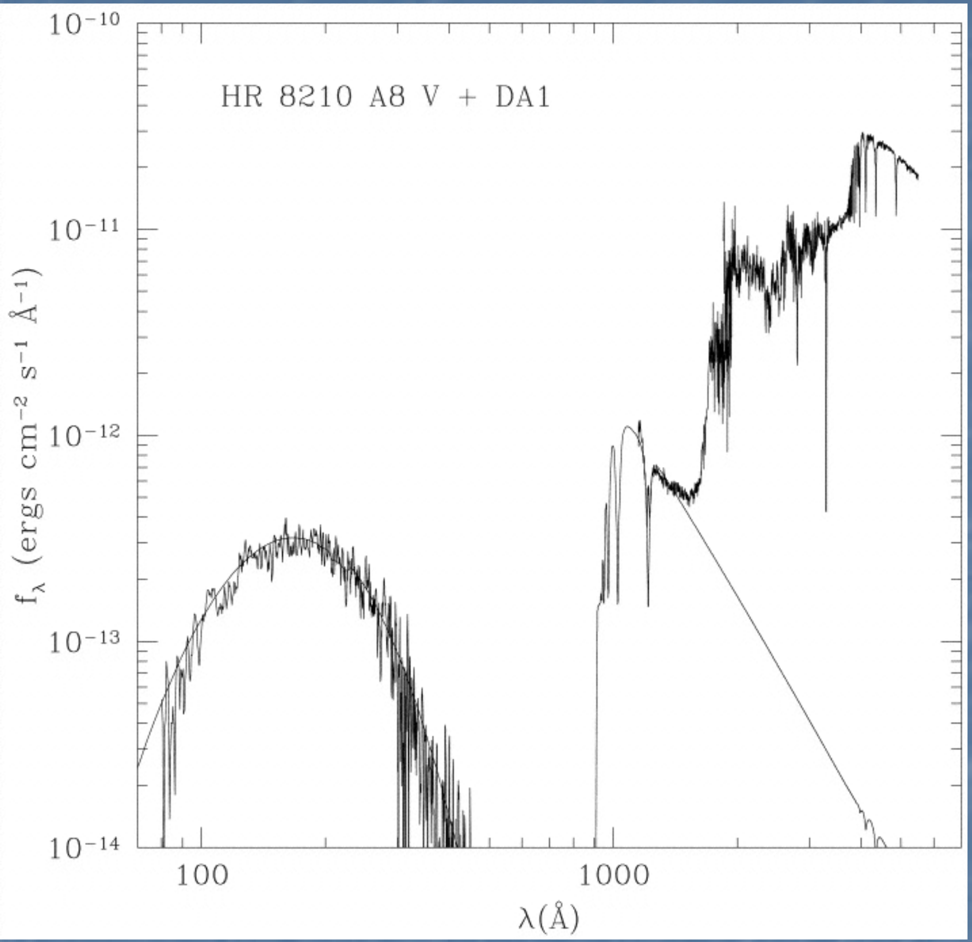
More binaries



Vennes et al. (1998)

- We are extending our study to other white dwarfs in binary systems.
- Primary effort will be to constrain the atmospheric parameters of the white dwarf.
- If possible measure the radial velocities of the white dwarf.

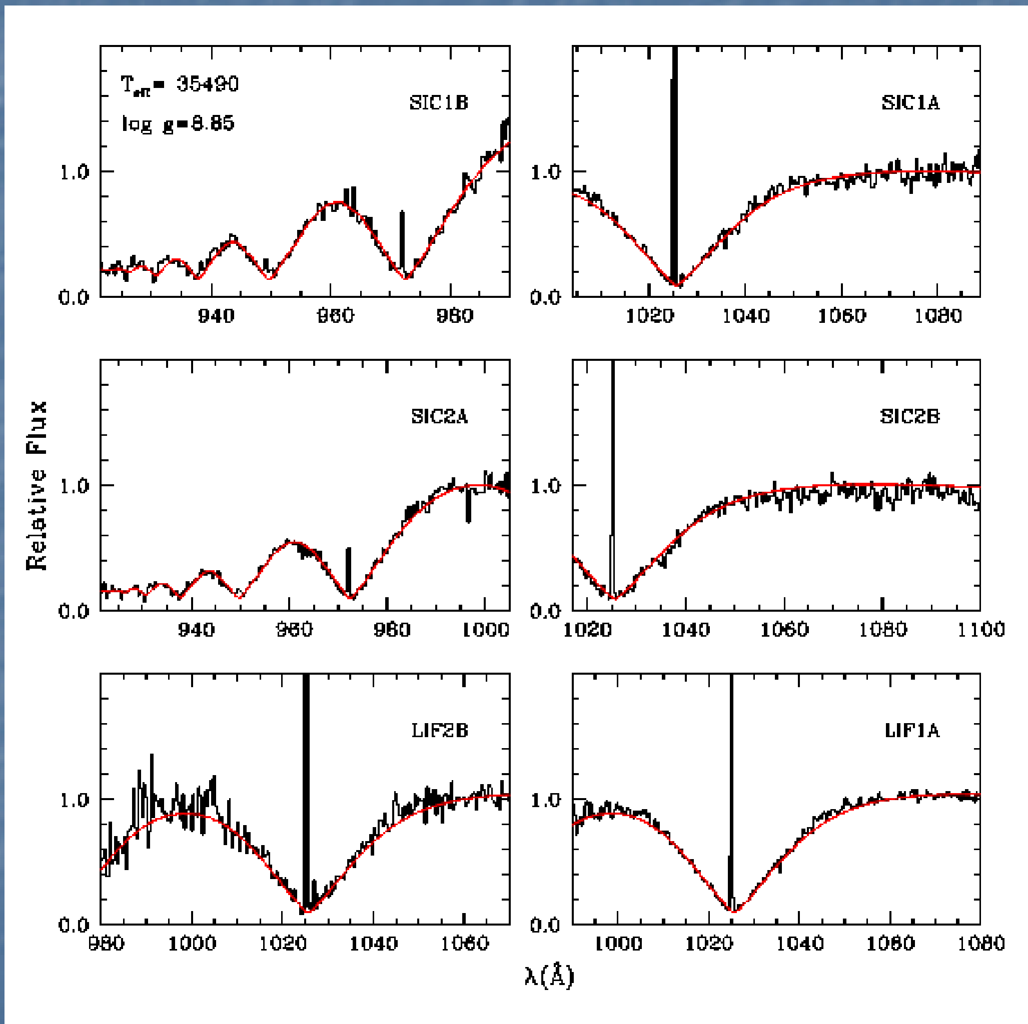
HR 8210 (IK Peg)



- Has been known to be a single lined spectroscopic binary for a number of years (Harper 1927).
- The nature of the companion was not resolved until it was detected by the ROSAT WFC as a strong EUV source (Wonnacott et al., Landsman et al. 1993).
- T_{eff} = 30 000 – 33 000 K was estimated using an IUE spectrum of Lyα.

- Vennes et al. (1998) determined an orbital period of 21.72168 ± 0.00009 days (combining their own data with Harper (1927).

HR 8210



- We confirmed the high mass of the white dwarf by fitting the FUSE spectrum.
- Using mass-radius relations (Benvenuto & Althaus 1999) we obtain M = 1.08 – 1.24 $M_?$.

Summary

- FUSE spectra were fitted with model spectra to determine their atmospheric parameters.
- Measured the radial velocities traced by the orbit of the white dwarf.
- Measured abundances of heavy elements present in the white dwarf atmospheres.
- We are continuing our analyses of FUSE spectra of white dwarfs.