AG Draconis

A high density plasma laboratory

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CCLRC Rutherford Appleton Laboratory

Overview

- CHIANTI database
- Symbiotic Stars
- AG Draconis
- FUSE
- FUSE observations of AG Dra
- HST/STIS observations of AG Dra
- Implications for nebular structure

The CHIANTI database

- Database for astrophysical emission line spectroscopy
  - Elements up to Zn; no Li, Be, B, etc.
  - Densities up to ~10^{16} cm^{-3}
  - Ions and neutrals, no molecules
- Atomic data for processes within ion
  - Electron/proton excitation
  - Radiative decay, photon excitation
- Regularly updated
- *Freely available*

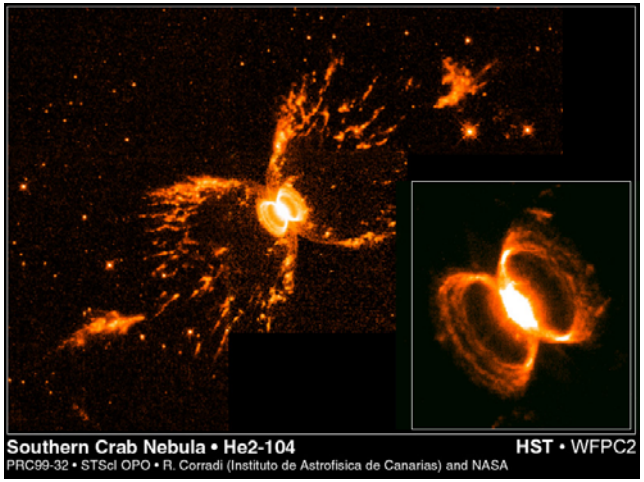
- www.chianti.rl.ac.uk

The CHIANTI database

- Part of the XSTAR, APED and ADAS atomic codes
- Over 300 citations to CHIANTI papers
- CHIANTI part of SOHO, TRACE and RHESSI data analysis software
- Applications:
  - the Sun and cool stars
  - Jupiter-Io plasma torus
  - supernova remnants
  - galaxy clusters

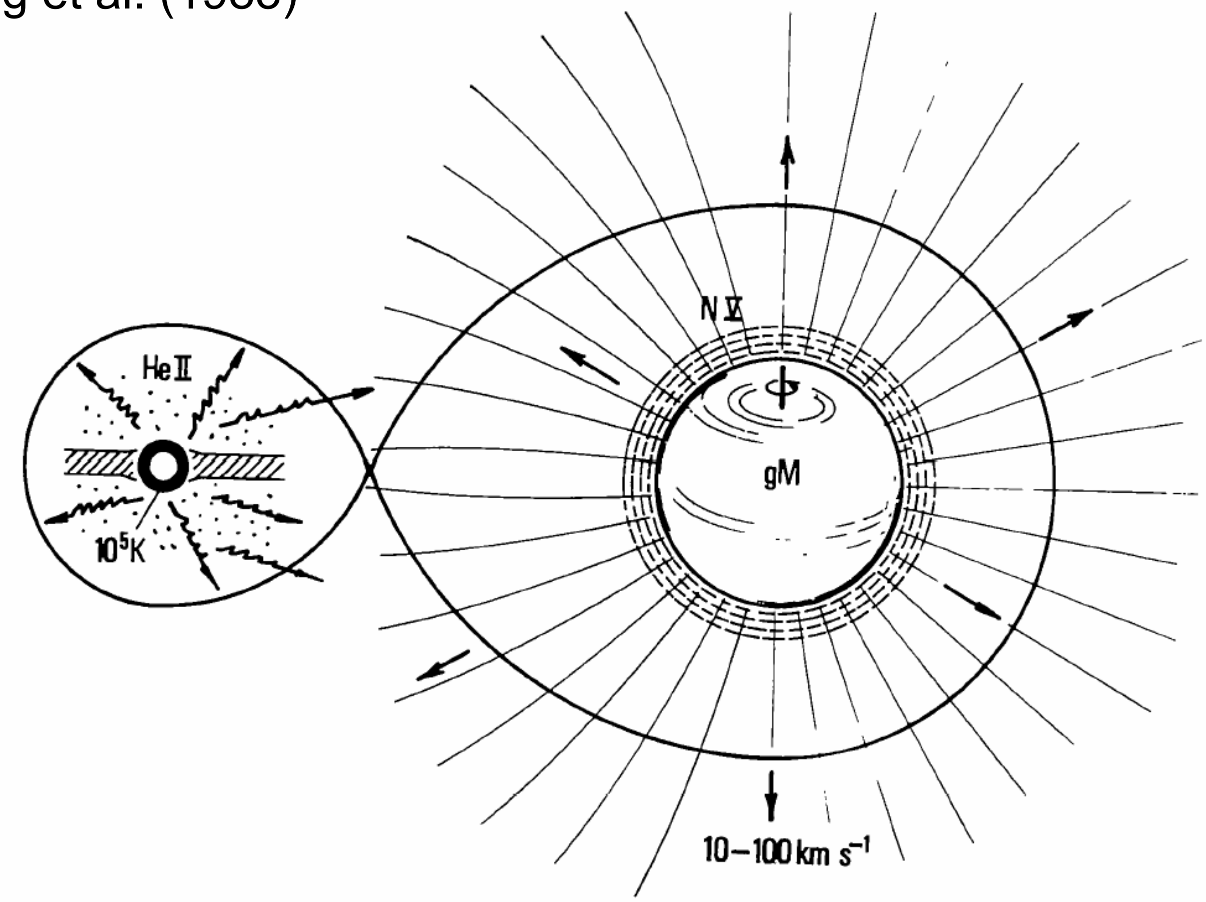
Symbiotic Stars

- Interacting binary systems: red giant + hot compact star (white dwarf)
- Long period (1-100 yrs)
- Strong nebular emission
- Undergo outbursts
  - Thermonuclear runaways
  - White dwarf accretes material from giant's wind
- Examples:
  - Z And, AG Peg, RR Tel, CH Cyg, R Aqr



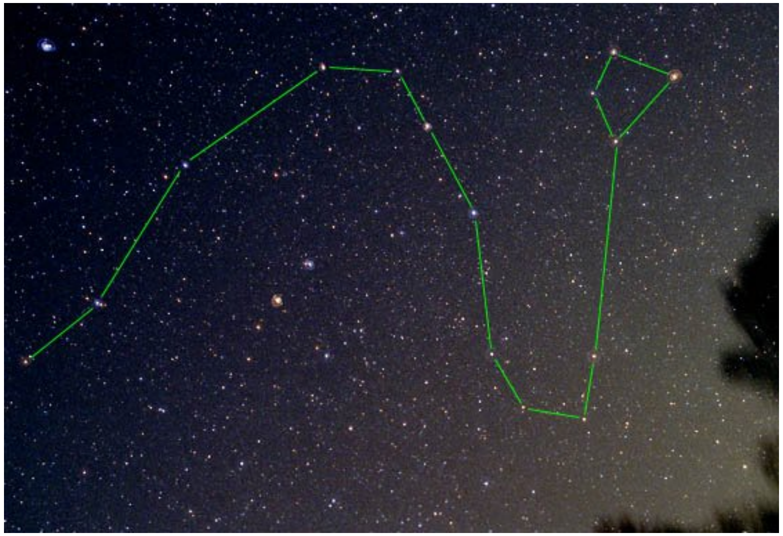
Symbiotic cartoon

Friedjung et al. (1983)

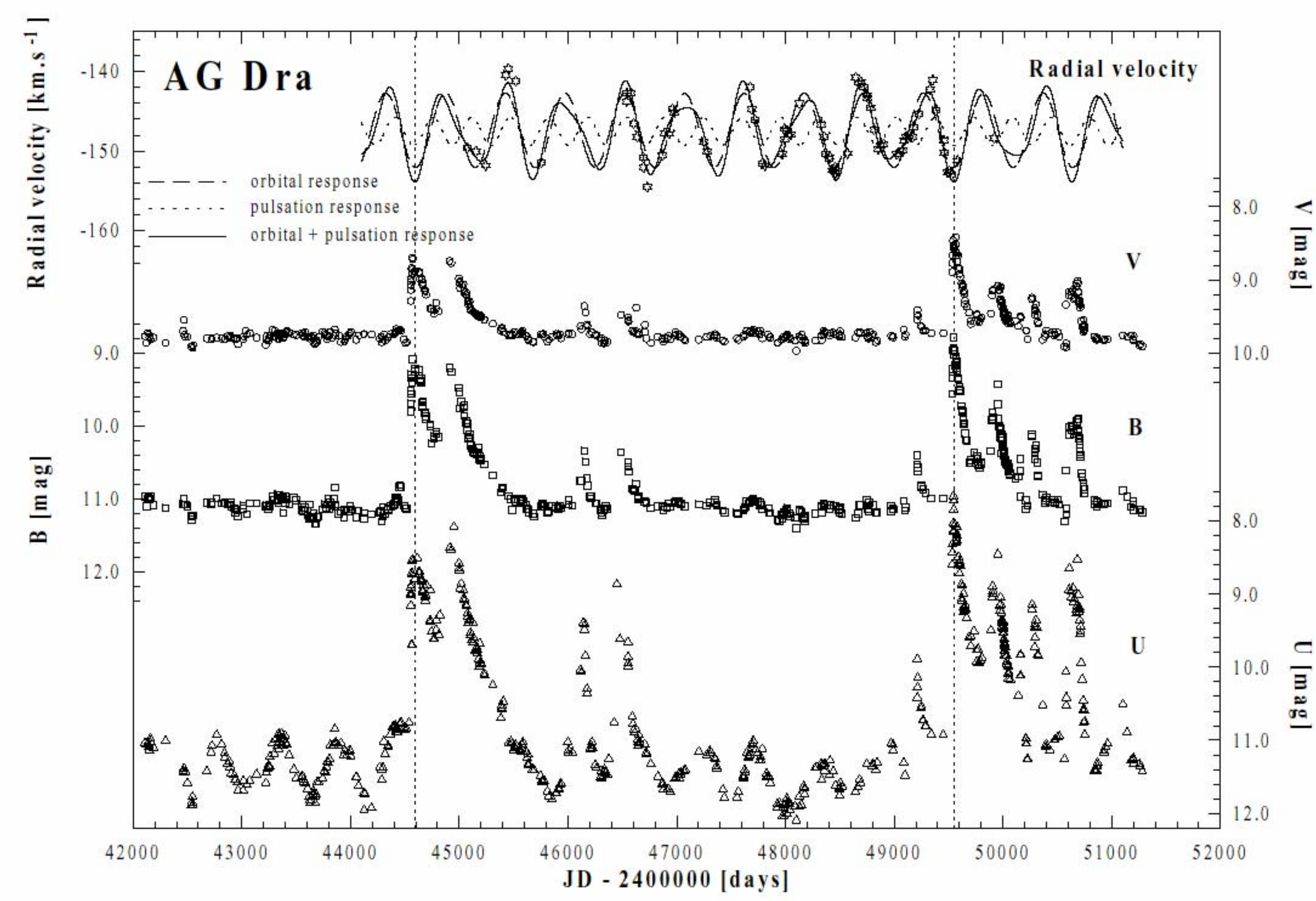


AG Draconis

- K0-4 giant + white dwarf
  - components not resolved
  - non-eclipsing binary
- 550 day period
- Separation ≈1.5-3.0 AU
- 2500 pc distant (uncertain)
- High declination (b=41°)
- V=9.82
- Outbursts on ≈15 year timescale (last in 1994)



AG Dra light curve



Galis et al. (1999)

Further information

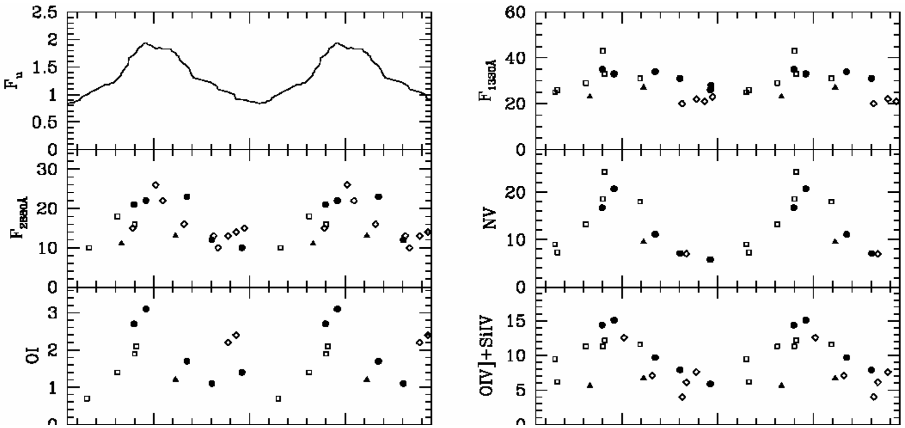
- $L_X=10^{32}$ erg s^{-1}
  - Supersoft X-ray source
- Halo giant, [Fe/H]=-1.3
  - leads to high mass loss from giant (Smith et al. 1996)
  - cause of symbiotic phenomena?
- Radial velocity -147.5 km s^{-1}
- Giant enriched in s-process elements (Ba, Sr)
  - from evolution of white dwarf

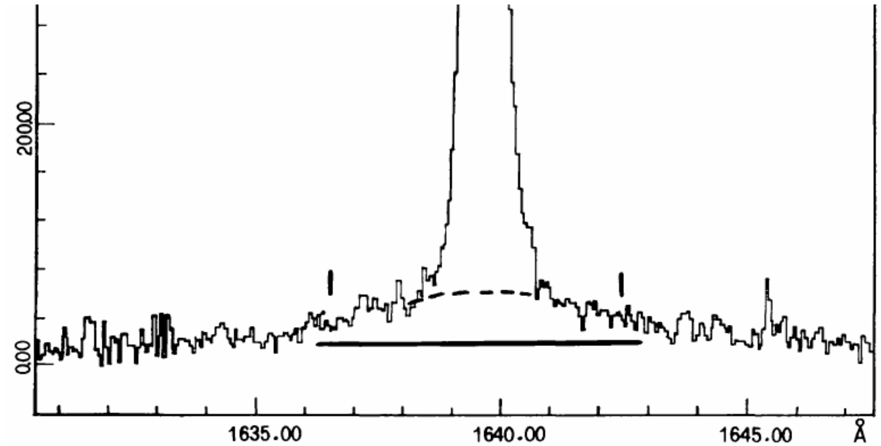
White Dwarf

- T_{eff}=100,000 K from UV continuum (Mikolajewska et al. 1995)
- T_{eff}=170,000 K from X-rays (Greiner et al. 1997)
- White dwarf radius: ≈0.1 $R_{\odot}$

IUE results

- Strong resonance lines (N V, C IV, Si IV, He II)
- Emission lines and continuum modulated on orbital timescale
- O IV density: 10^{10} cm^{-3}
- Nebula temperature: 15-30,000 K
- Broad wings on He II λ1640 profile





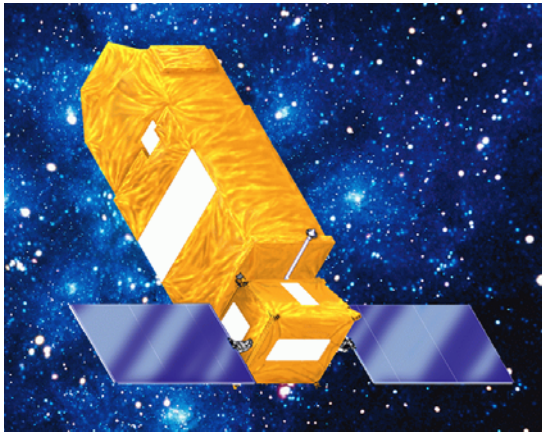
Nebula vs. Sun comparison

- Electron density (10^{10} cm^{-3}) similar to that of Sun's transition region
- Nebula temperature is roughly uniform; no increase with ionization stage
  - 15-30,000 K
  - High ionization species formed by photoionization

New space data

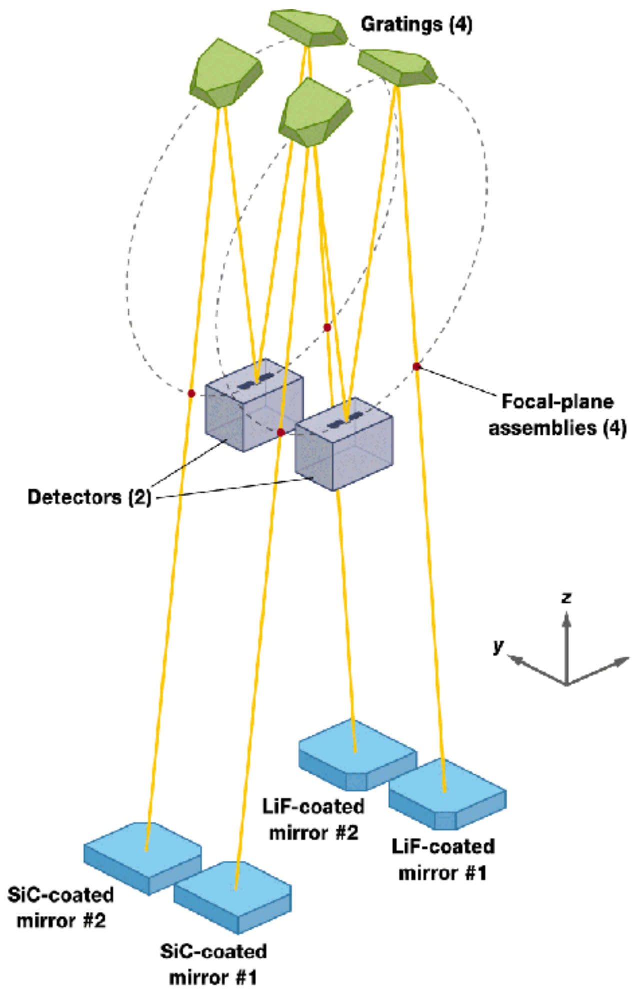
- FUSE
  - 2000 March
  - 2001 April
- HST/STIS
  - 2003 April

- 3 more observations with FUSE to follow (2004/2005)



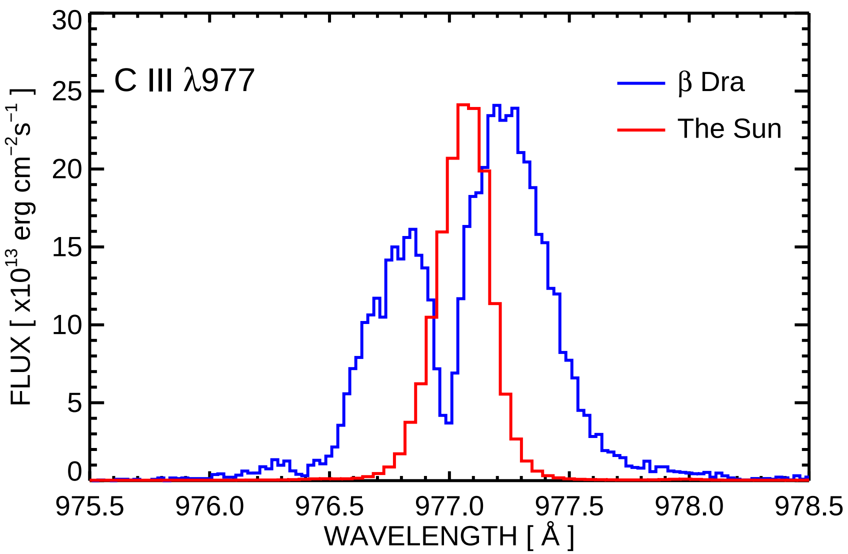
FUSE

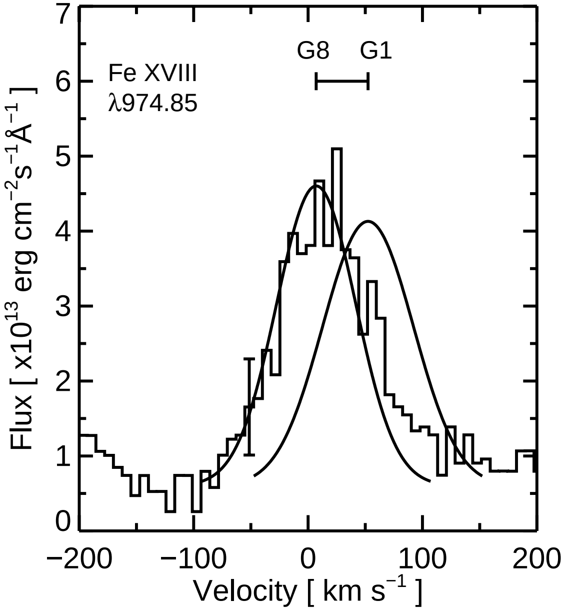
- Far Ultraviolet Spectroscopic Explorer
- PI: Warren Moos (JHU)
- Launched in 1999
- 905-1187 Å
- $\Delta\lambda/\lambda$=15-20,000
- Primary goal to measure D/H ratio



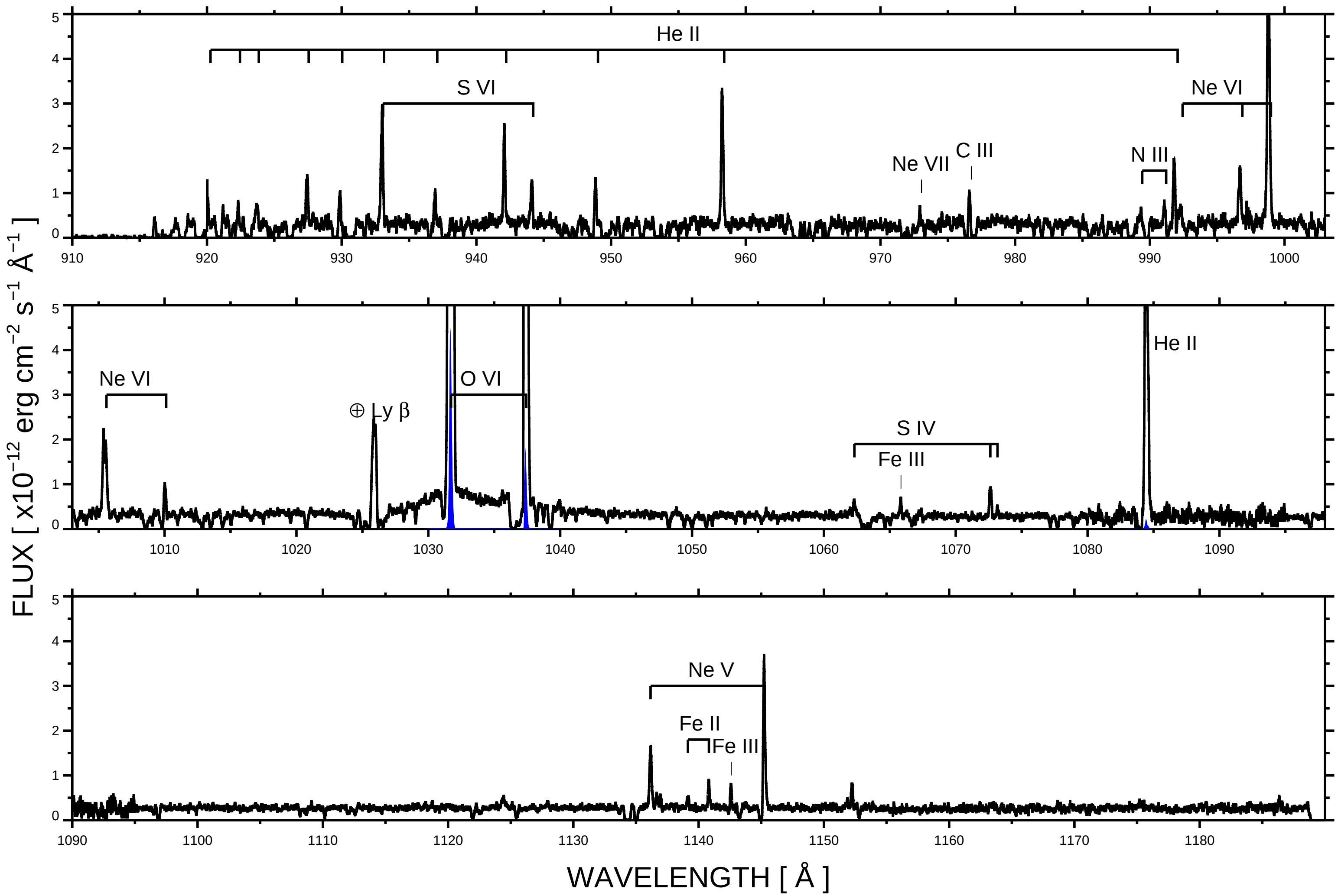
FUSE spectroscopy

- Access to higher ionization species than HST, IUE
- Resonance lines: C III λ977, O VI λλ1032, 1038
- Intercombination lines: Ne V λ1145, Ne VI λ999
- H I Lyman series; He II Balmer series



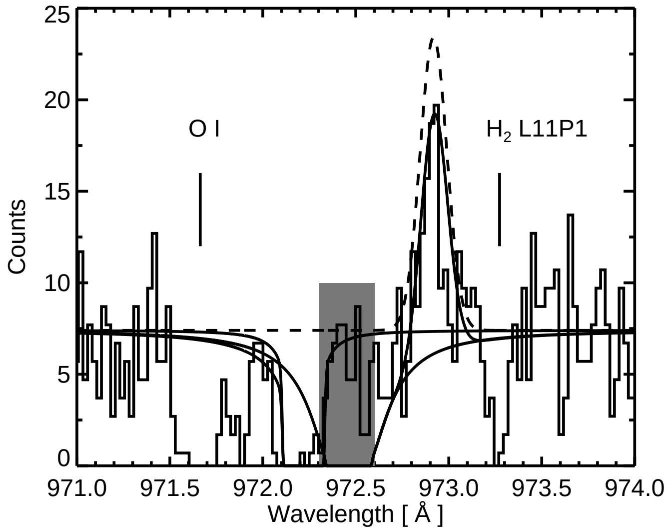


FUSE AG Dra spectrum



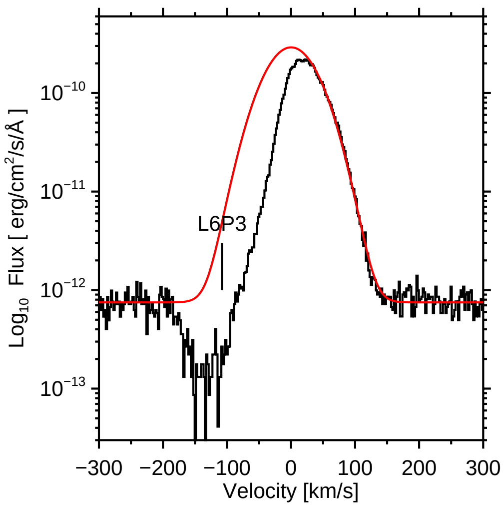
Ne VII recombination line

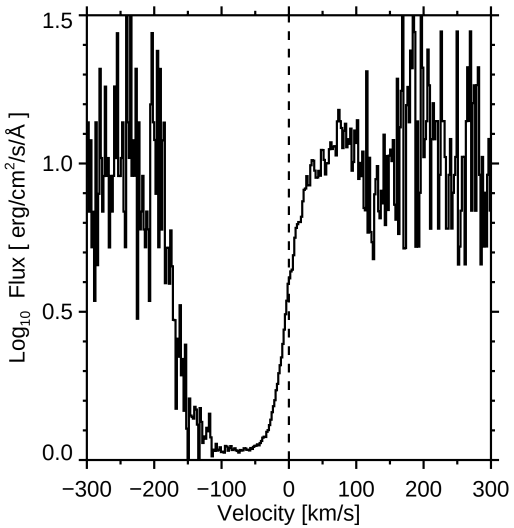
- Weak line close to H Lyman-γ absorption
- Corrected wavelength: 973.35Å
- Matches Ne VII 2s2p $^1P_1$ – $2p^2$ $^1D_2$ transition (973.35Å)
- In nebular plasmas, transition formed through recombination
  - e.g., O V λ1371 line
- *Implies existence of Ne VIII in nebula* [IP=207.3 eV]



O VI resonance lines

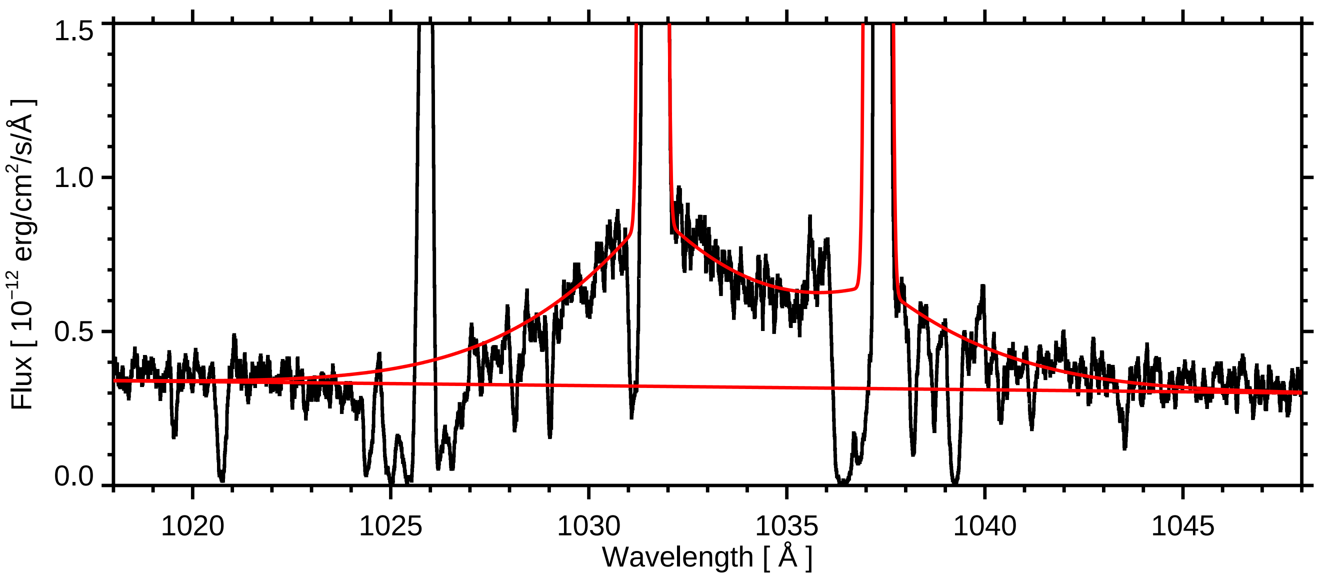
- λ1032/λ1038 ratio ≈ 2:1
- λ1038 affected by interstellar absorption (H_2 & C II)
- Broad wings (FWHM ≈6Å)
- Profiles asymmetric, red-shifted & P Cygni absorption





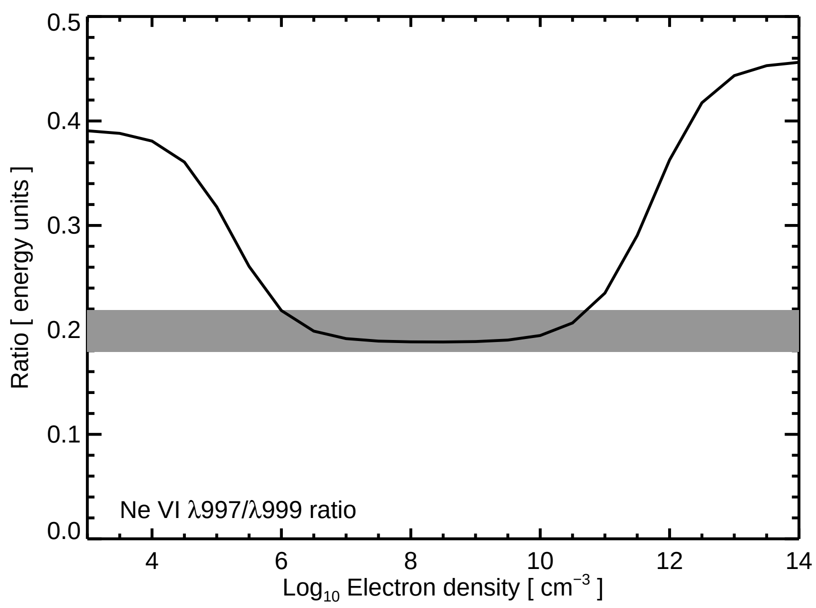
O VI Broad Wings

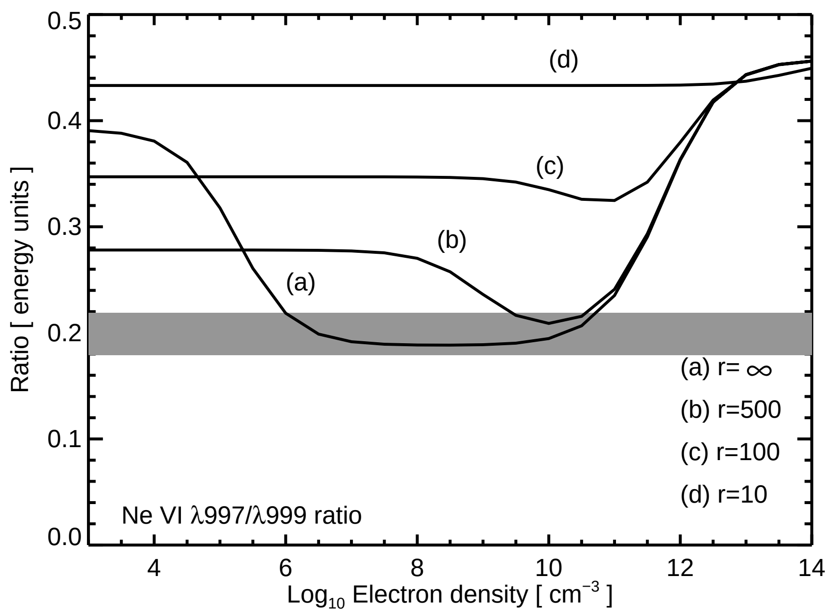
- Due to electron scattering (Schmid et al. 1999)
- $\tau \approx \sigma_T N_e r$ (r=sphere radius)
- flux $\propto N_e r^3$
- $r=11\ R_\odot$, $N_e=10^{11}\ \mathrm{cm}^{-3}$



Ne VI intercombination lines

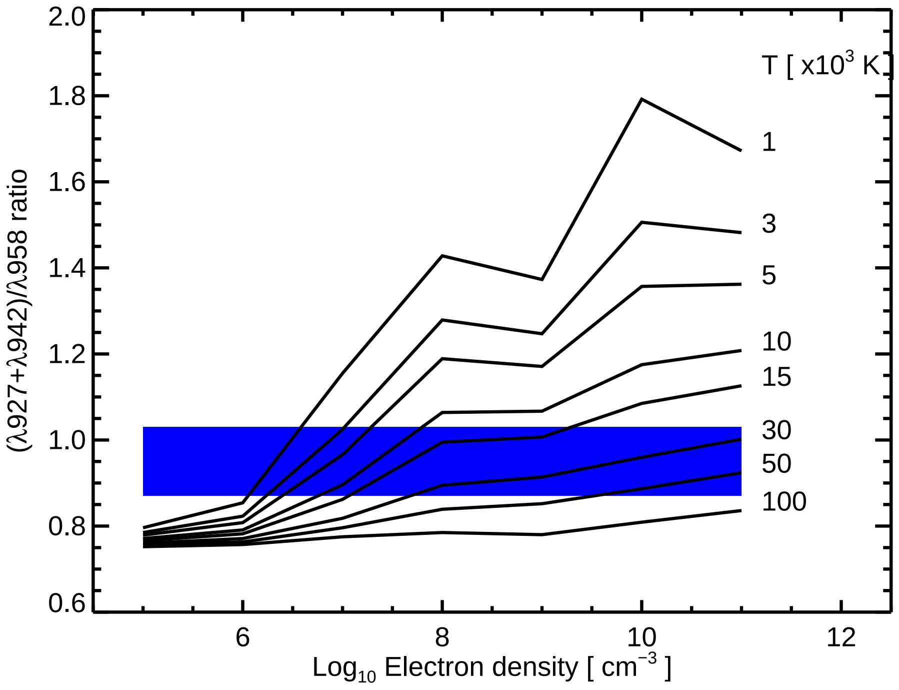
- $2s^2 2p\ ^2P - 2s2p^2\ ^4P$ transitions at 992-1010 Å
  - analogous to O IV lines @ 1400Å
- λ997/λ999 ratio sensitive to density





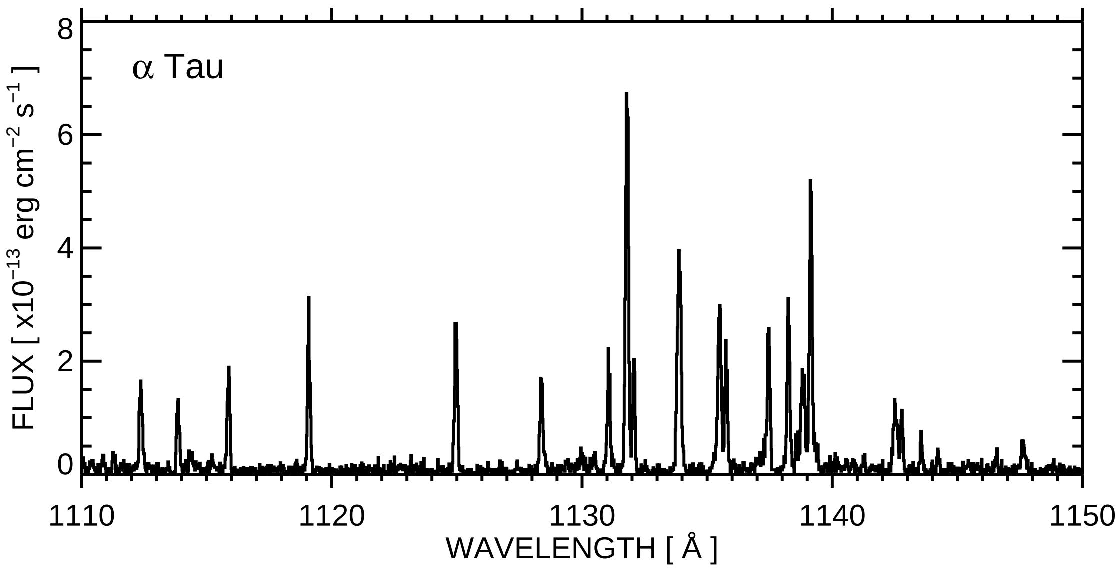
He II Balmer series

- Lines identified up to n=20
- Strengths sensitive to density, temperature and extinction
- Atomic data from Storey & Hummer (1995)



Fe II & Fe III lines

- Several weak, unidentified lines in FUSE spectrum
- Could be fluoresced Fe II and Fe III lines?
- Harper et al. (2001) identified Fe II lines in giants and supergiants fluoresced by hydrogen Ly-α



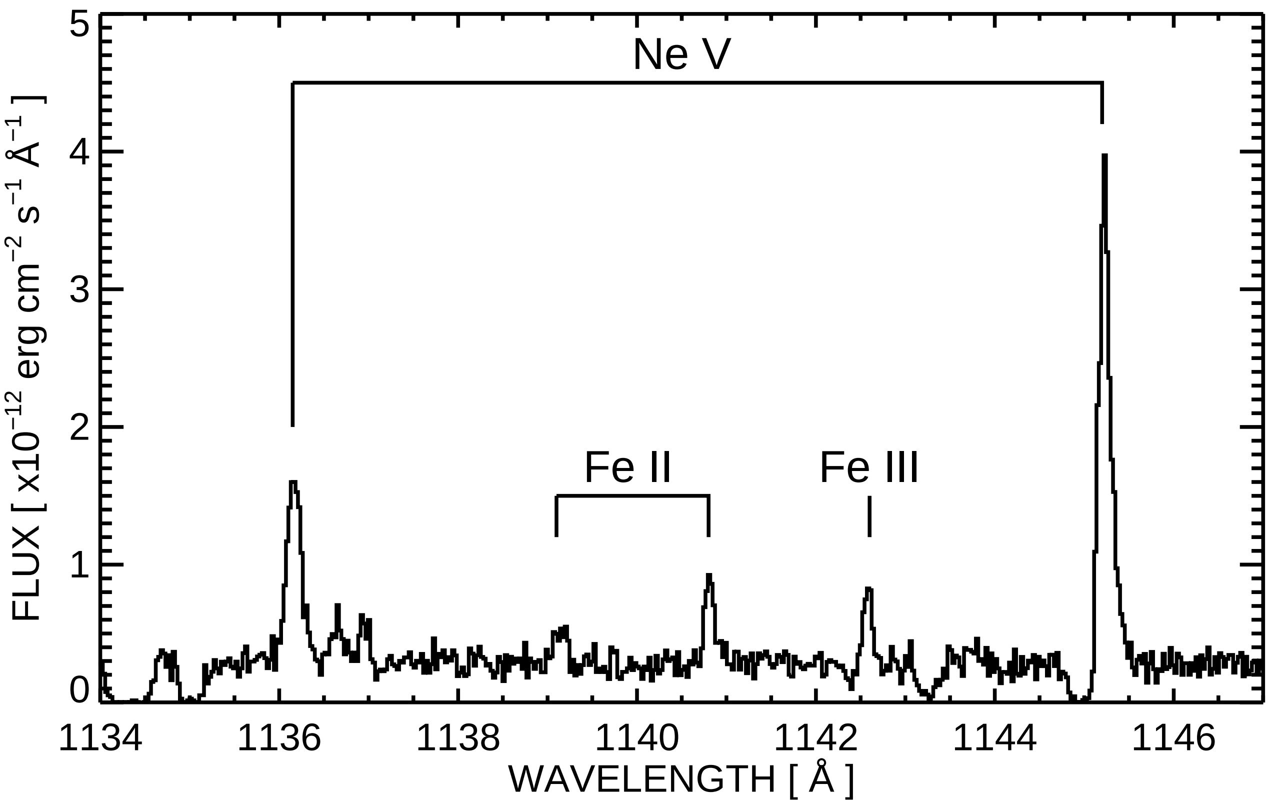
Predicted Fe II lines

Pumping line	Pumped Fe II line	Fluoresced line	Predicted flux	
O VI 1032	1032.041	978.697	6.8	✗
		981.468	5.5	✗
		1114.355	1.8	✗
		1126.677	2.8	✗
		1139.494	1.3	✓
		1141.172	10.0	✓
		1142.370	2.8	✗

Predicted Fe III lines

Pumping line	Pumped Fe III line	Fluoresced line	Predicted flux	
O VI λ1032	1032.119	1066.195	1.5	✓
		1070.557	9.1	?
		1142.956	10.0	✓
O VI λ1038	1037.459	1035.769	1.4	✗
		1071.747	0.6	✗
		1142.461	0.7	✗

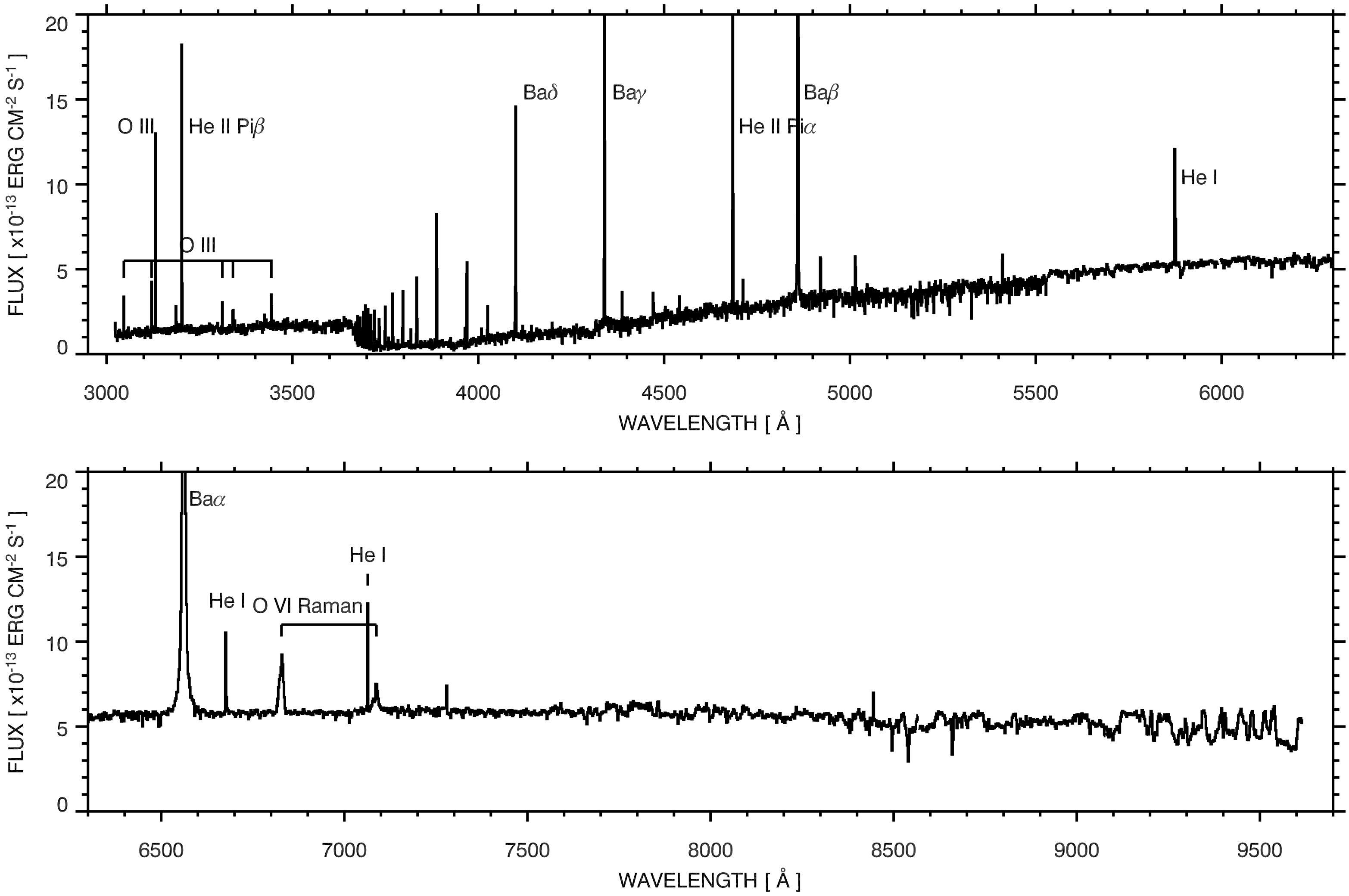
AG Dra Fe II, III lines



HST/STIS observation

- 2003 April
- Complete spectra from 1140 to 9617Å
  - CCD spectra, 3025-9600 Å, $\Delta\lambda/\lambda$=5-10,000
  - MAMA spectra, 1140-3110 Å, $\Delta\lambda/\lambda$=30-45,000

Optical spectra



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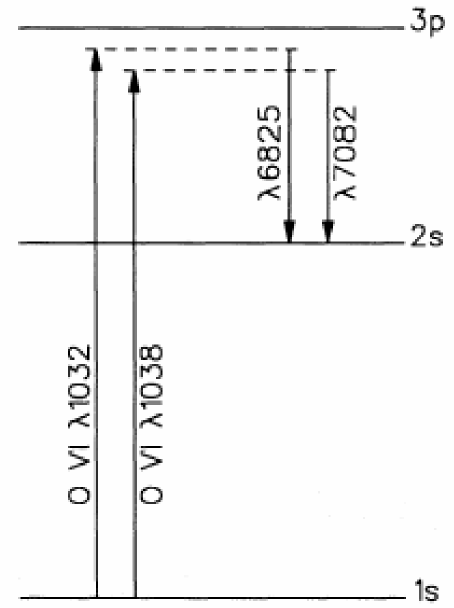
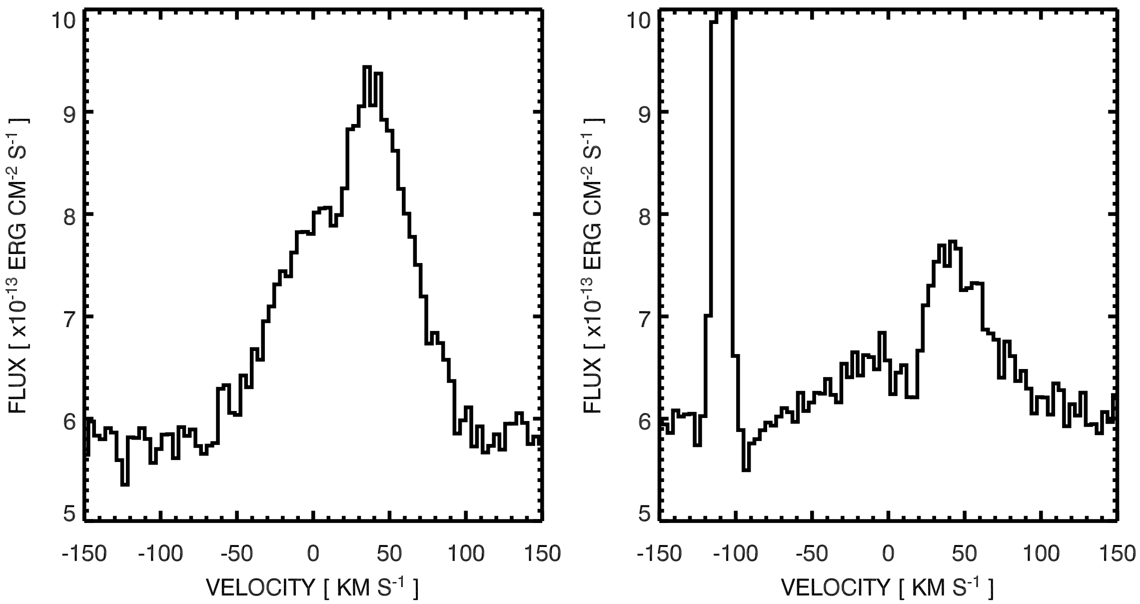
O VI Raman Lines

- Common feature of symbiotic spectra
- O VI λλ1032,1038 photons Raman-scattered off hydrogen
- FWHM ≈ 15 Å
- First identified by Schmid (1989)

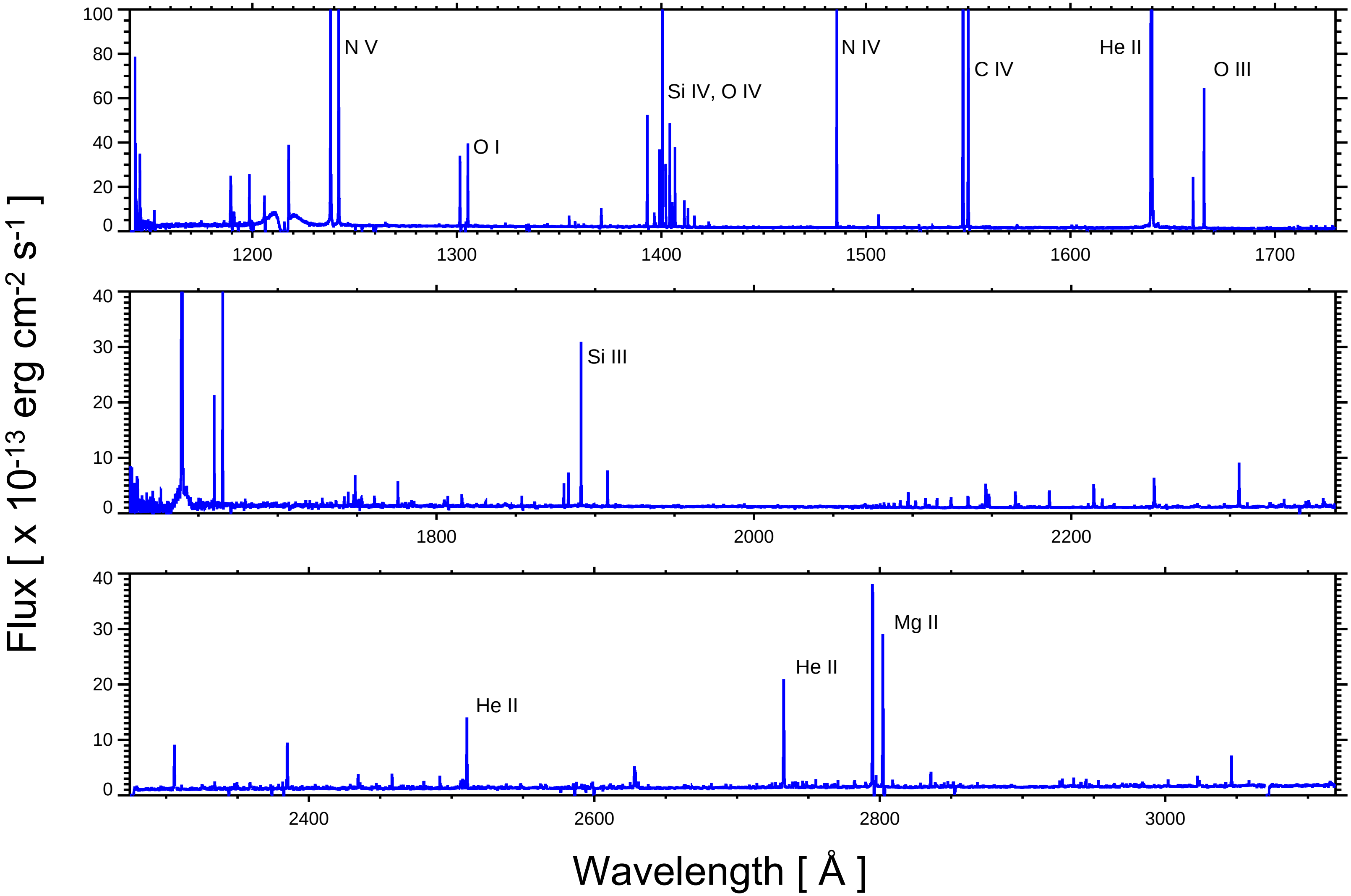


O VI Raman lines

- Ratio of O VI λ1032 to Raman-scattered λ6825 photons is 2:1
  - highest ratio of all symbiotic stars
- Lines are asymmetric



UV Spectrum



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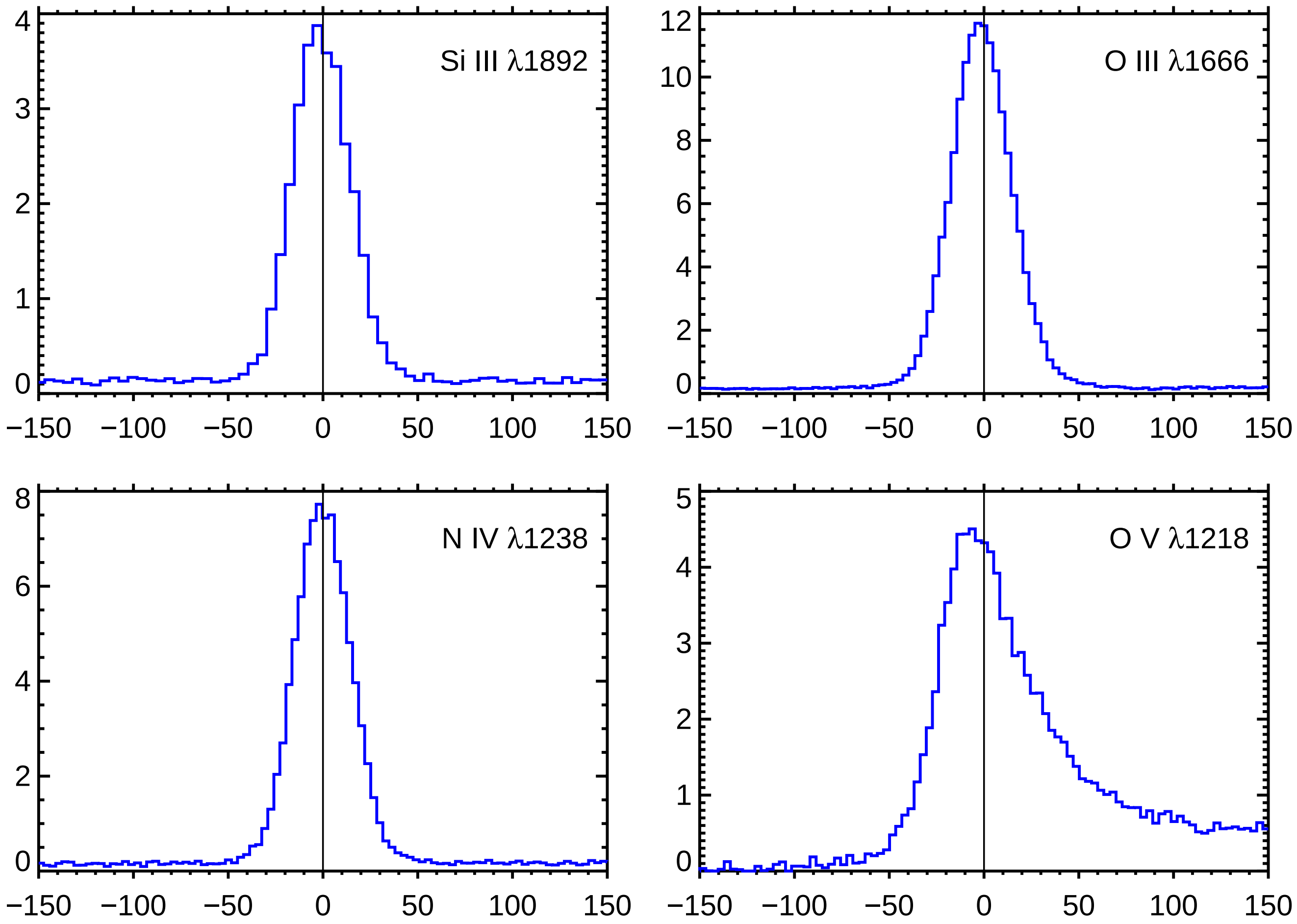
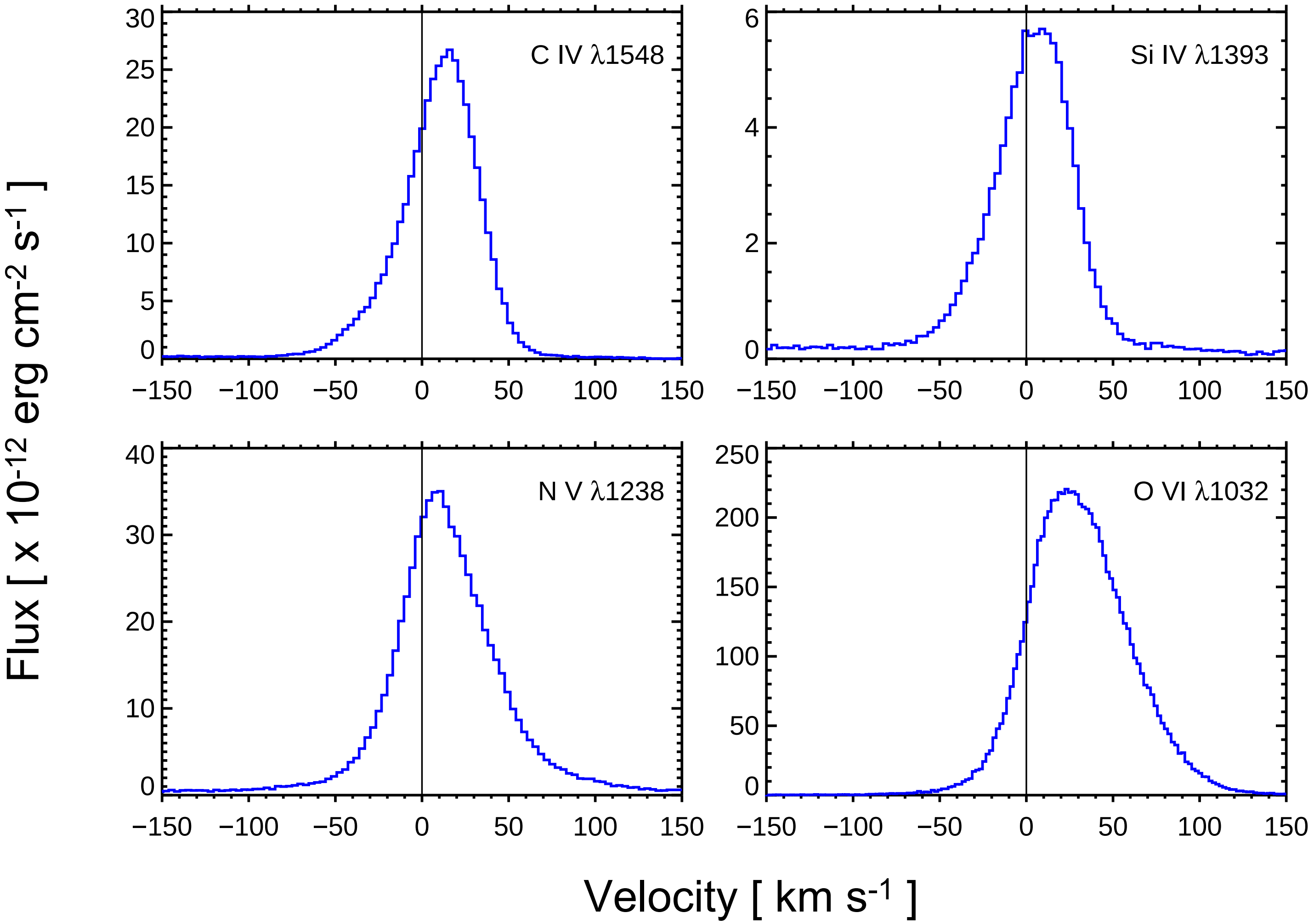
Intercombination lines

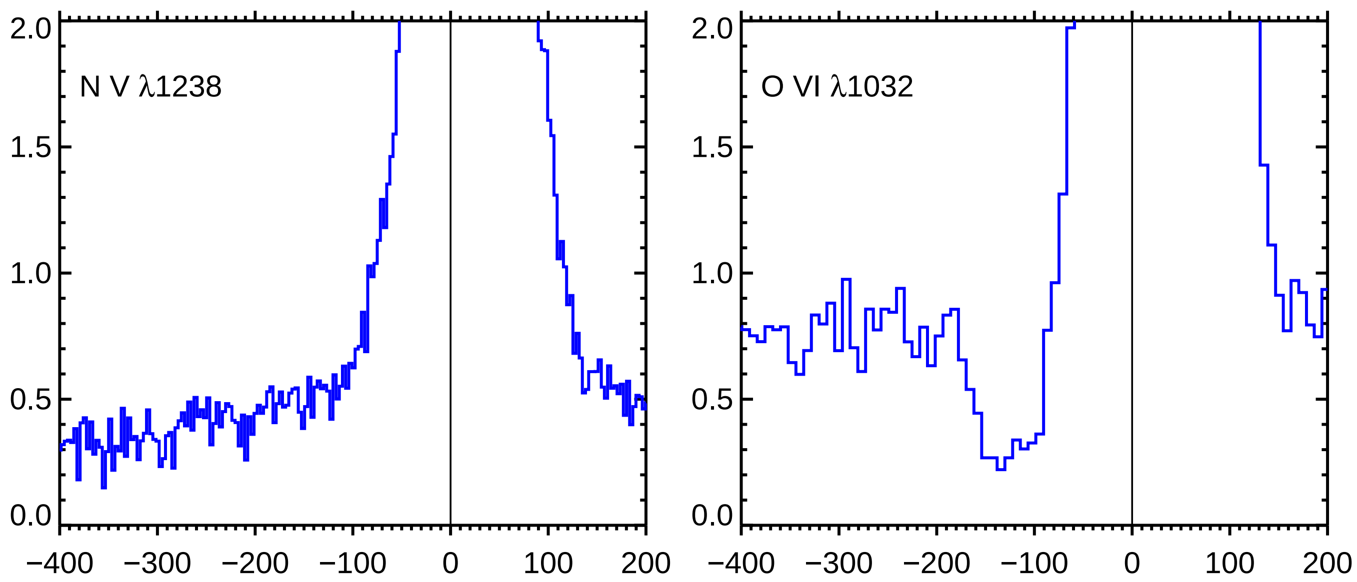


Resonance lines

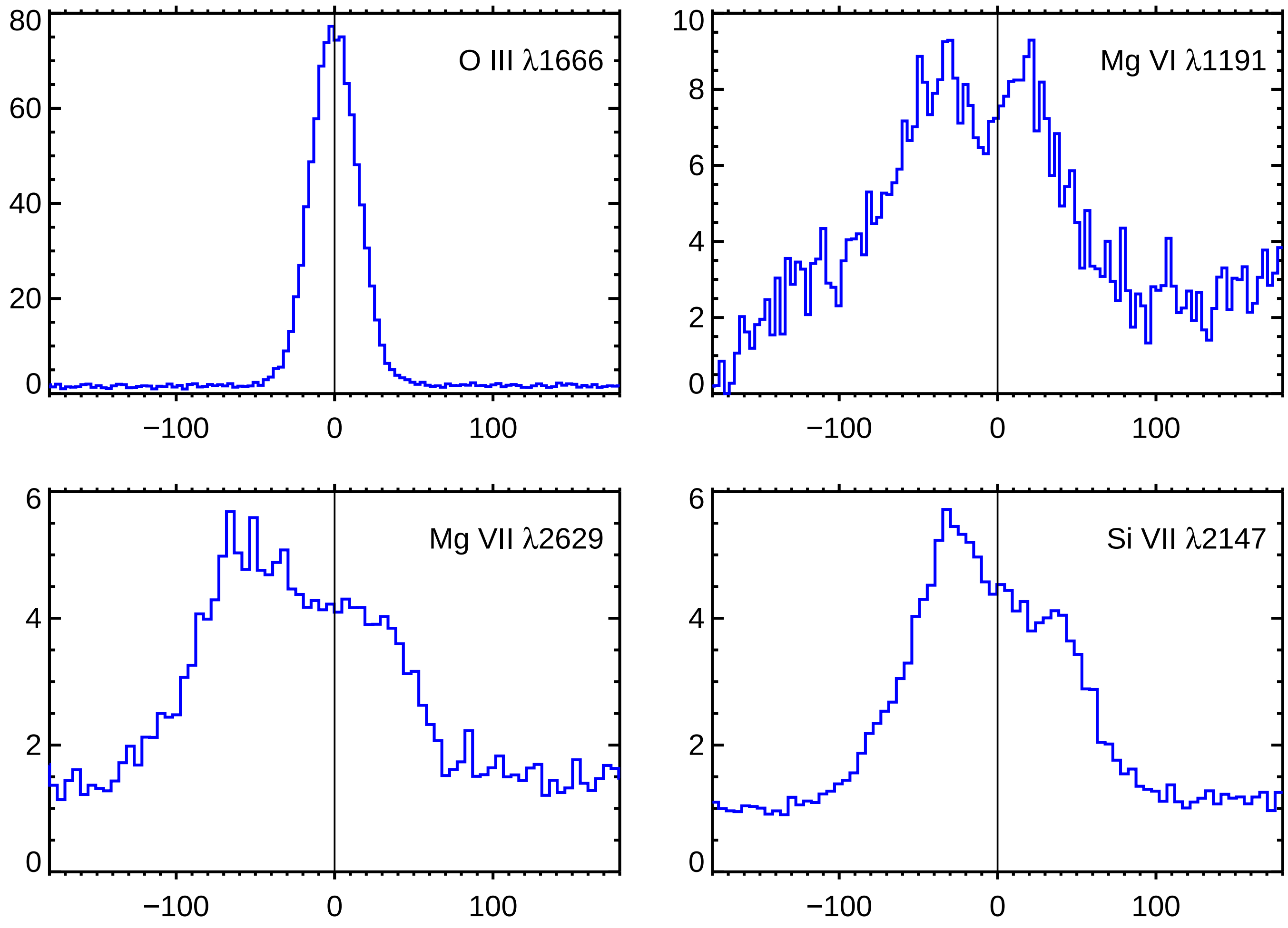


P Cygni profiles?

- None of the STIS lines show a P Cygni profile



Forbidden lines

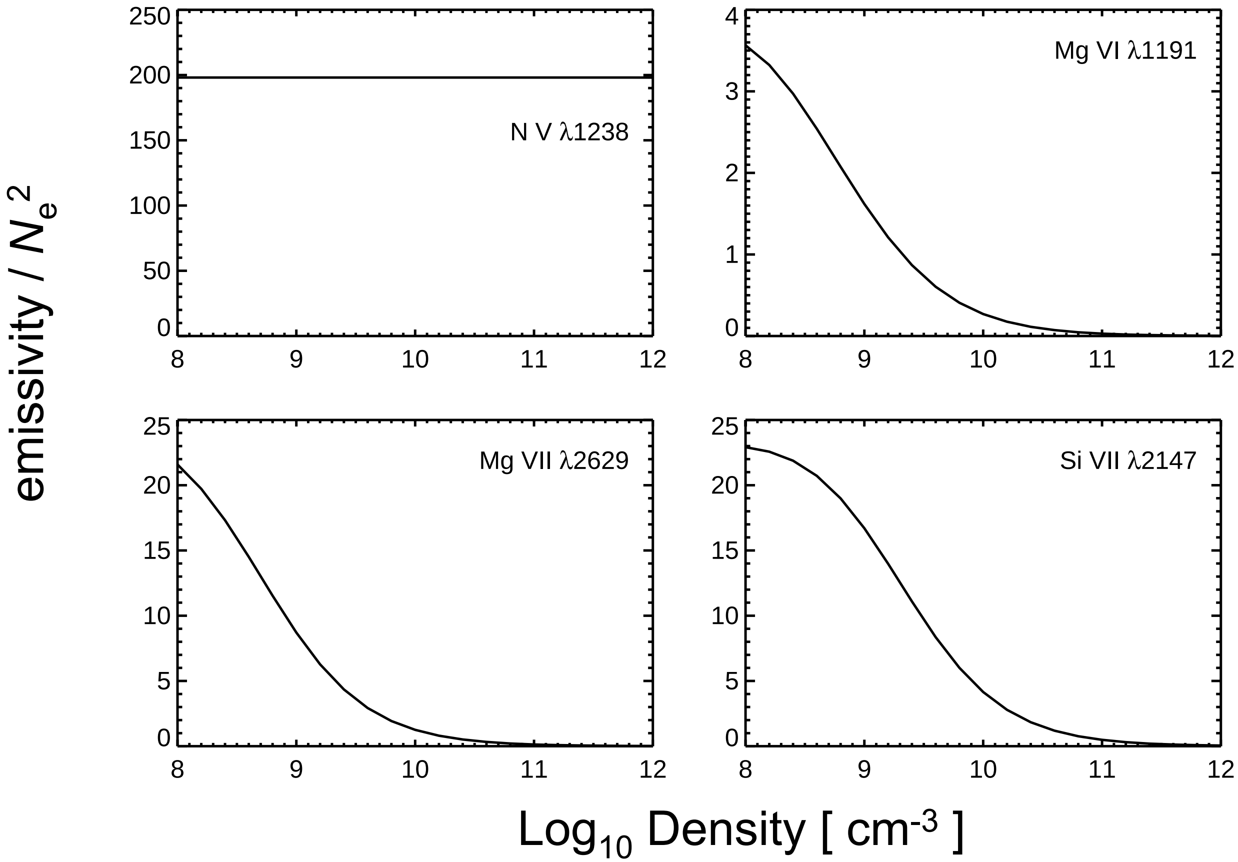


Ionization potentials

Ion	IP [eV]
Si VII	246.5
Mg VII	225.0
Ne VIII	207.3
Mg VI	186.8
Mg V	141.3
O VI	113.9
N V	97.9
C IV	64.5

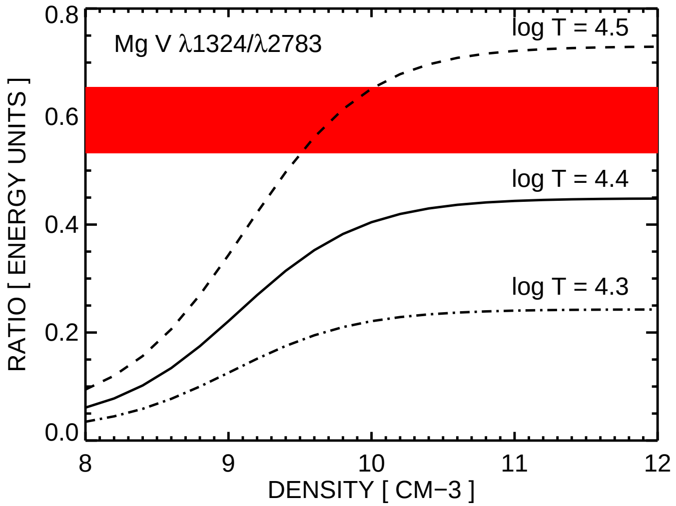
Why see forbidden lines?

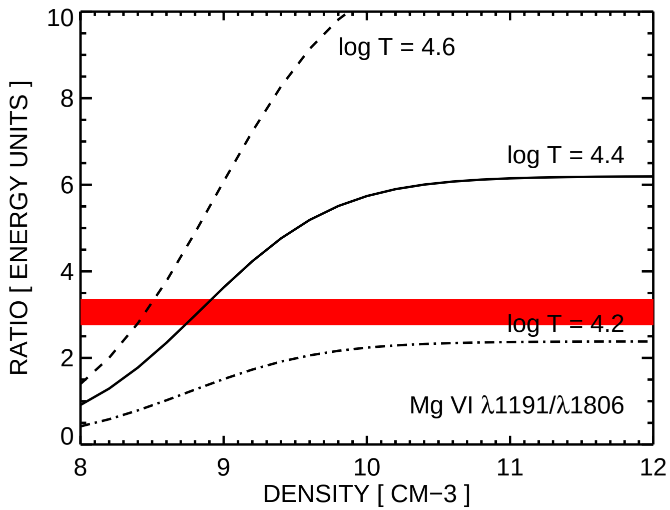
- emissivity $\propto n_j N_e$
  - n_j can be computed with CHIANTI

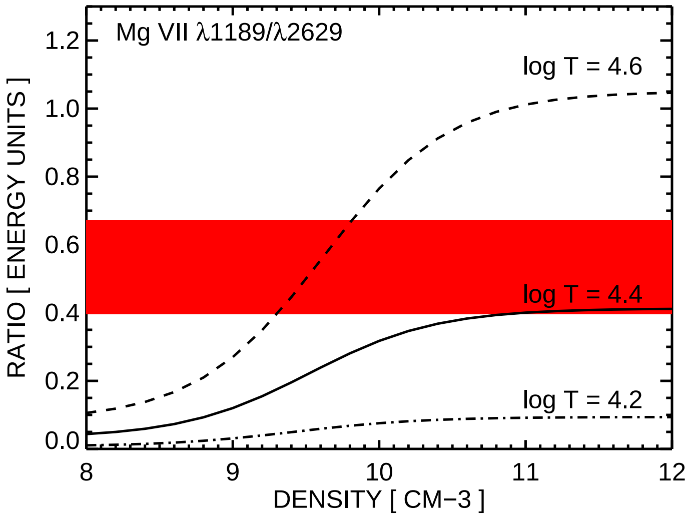


Forbidden line diagnostics

- Lines pairs from Mg V-VII
- Sensitive to *T* and N_e
- E(B-V)=0.05





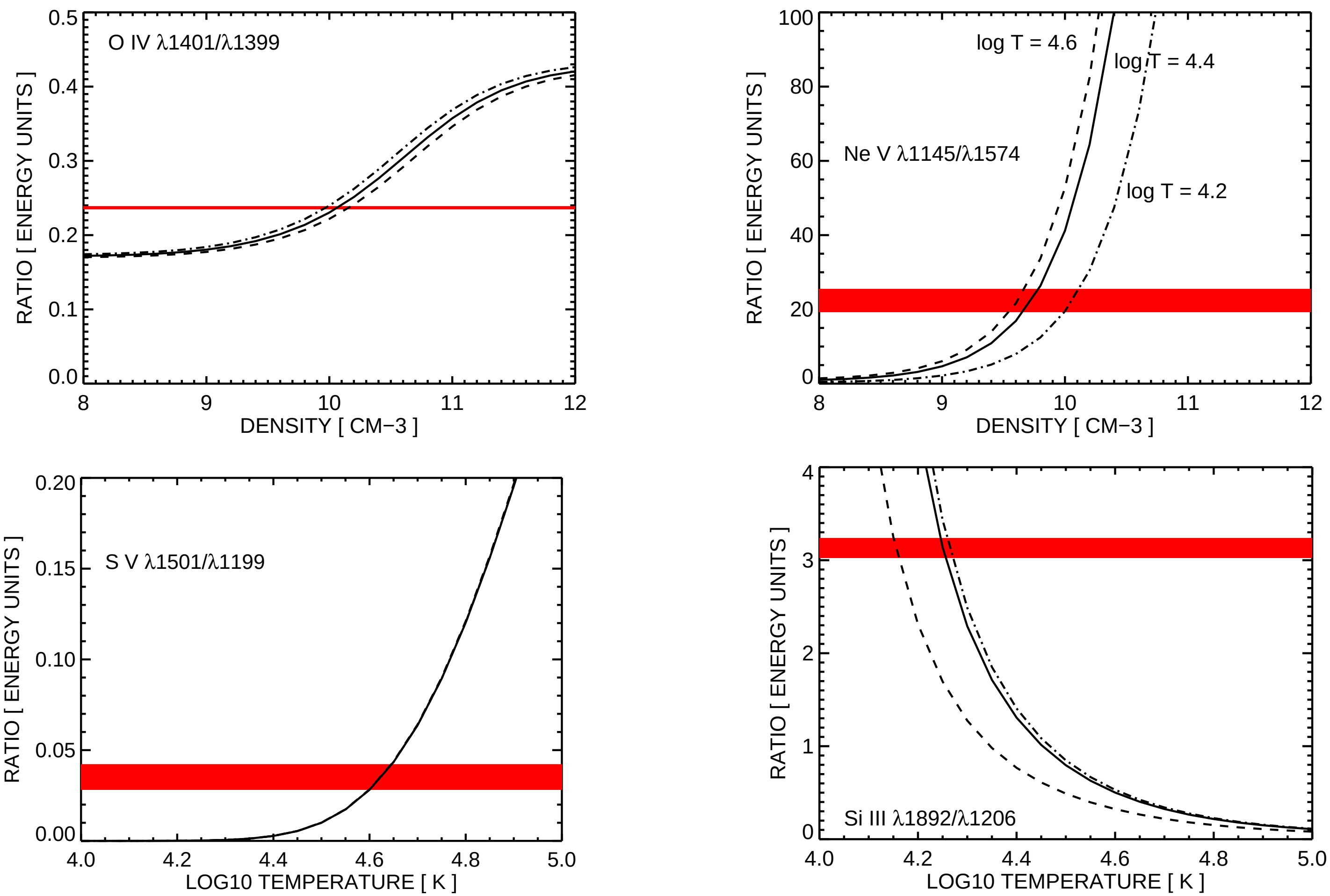


Accretion disk?

- Assume line widths correspond to Keplerian velocity
  - $v_K = \sqrt{(GM/R)}$
- v_K=100 km $s^{-1} \Rightarrow R=9.5\ R_{\odot}$
- Assume sphere of this size gives rise to emission

- $F_{disk}/F_{observed} = 7 \times 10^{-4}$
- cannot reduce observed flux

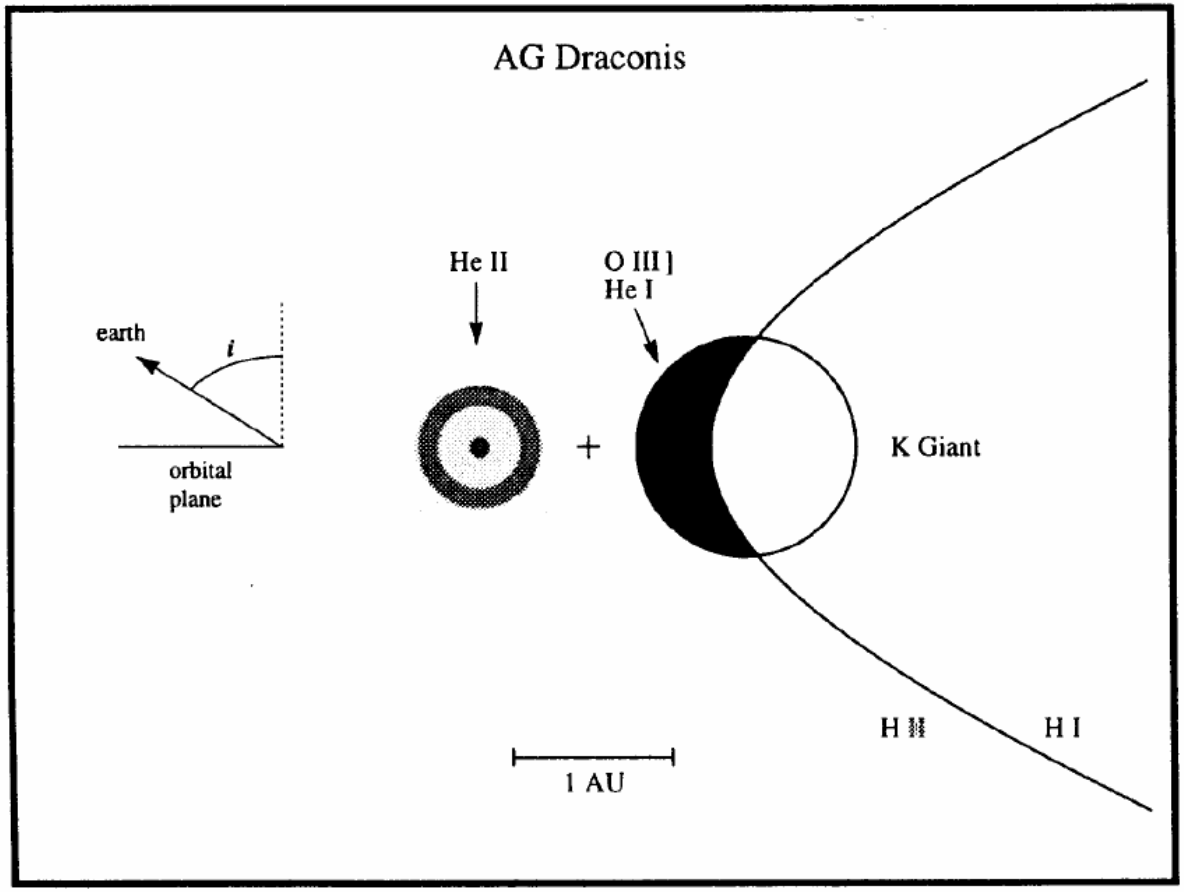
Plasma diagnostics



Fe II lines

Pumping line	Pumped Fe II line	Fluoresced line	Predicted flux	Measured
O VI 1032	1032.041	1141.172	10.0	10.0*
		1776.421	2.5	2.1
		1776.660	14.4	16.8
		1881.201	16.7	14.6
		1884.116	11.3	22.2
O VI 1038	1037.808	1448.393	1.3	0.9
		1663.782	0.7	✗

Nebula structure



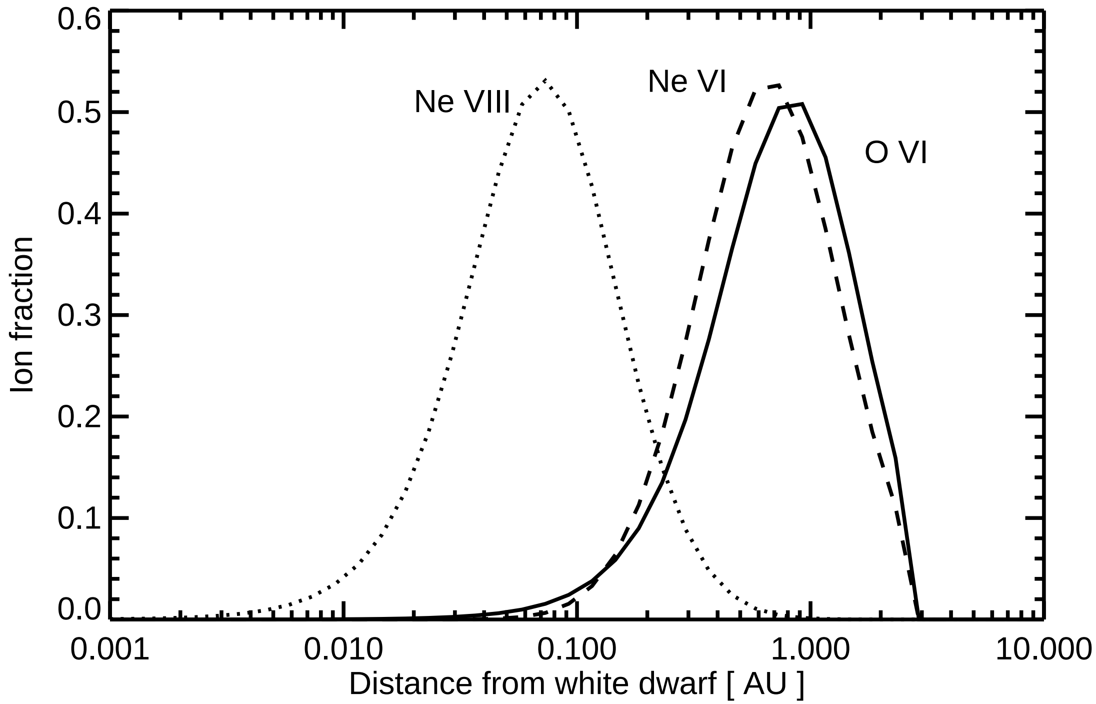
Mikolajewska et al. (1995)

Nebula structure

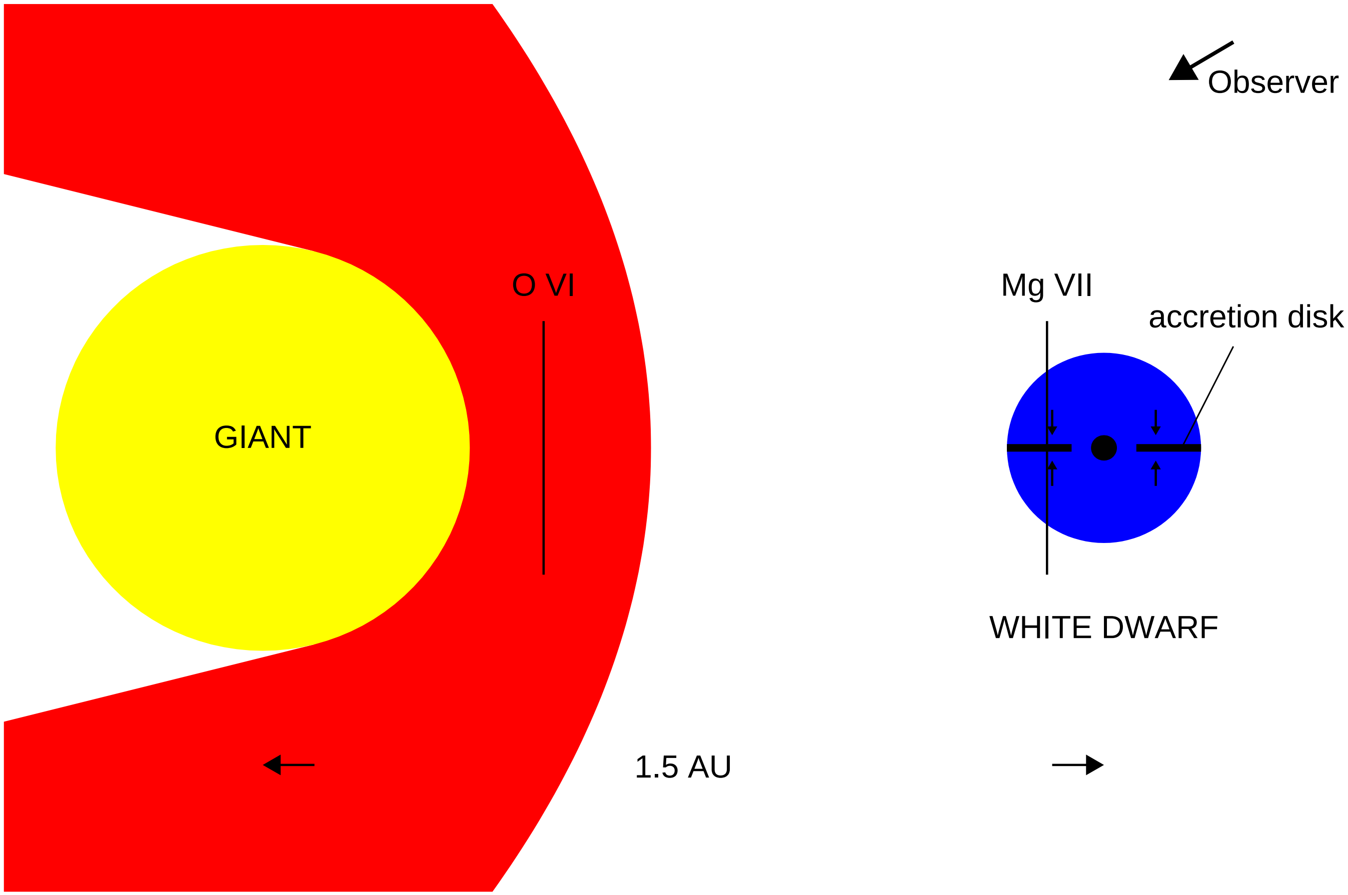
- O VI lines formed close to giant, and reveal acceleration of giant's wind
  - fluoresce Fe II & III lines at giant's surface
  - high degree of Raman scattering
  - Ne VI lines free from photoexcitation
- High ioniz. forbidden lines (Mg VII, Si VII) formed close to white dwarf
  - 170,000K radiation field cannot ionize to this level at large distances

Ionization model

- At what distances are ions when irradiated by a 170,000 K blackbody?
  - assume radius = 0.1 $R_\odot$



New cartoon



Illuminated giant models

- Proga et al. (1996, 1998) have modelled symbiotic star scenario
  - giant atmosphere illuminated by hot white dwarf
  - radiative transfer equations solved
  - WD radiation all absorbed above photosphere
  - 1998 paper adds a giant wind
- Observed spectra reproduced if T_{h}> 100,000 K and L_{h}>630 $L_{\odot}$
- Strong UV emission lines can only be reproduced if giant has a wind, extending to 2-3 R_{giant}

Problems

- Huge emission measure of UV lines
  - leads to volumes ~ 1-2 AU^3
- Why do resonance lines not show greater opacity effects?
- Why do we see high ionization forbidden lines?

Future work

- Apply modern photoionization codes (CLOUDY, XSTAR) to the AG Dra case
- Model the profiles of the resonance lines
- Identify the large number of weak transitions throughout the UV spectrum

- Upcoming FUSE spectra will give much higher S/N spectra, and give coverage at different orbital phases