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Detection of a White Dwarf in a Visual Binary System

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[1] Guest Observer at the IUE Observatory.

Abstract

The F6 giant HD 160365 was detected to have a white dwarf companion about 8 arcsec south of the star. The UV energy distribution observed with IUE shows that the white dwarf has an effective temperature of 23,000 $\pm$ 2,000 K. If log g = 8 the Lyα profile indicates an effective temperature around 24,500 K. Using the theoretical models by Wesemael *et al.* one finds a visual magnitude of $m_v \sim 16.5$. For $T_{eff} = 24{,}500$ K one expects for a white dwarf a luminosity of $\log L/L_\odot \sim -1.3$ and $M_V \sim 10.67$. This gives a distance modulus for the system of $m_v - M_V = 5.83$ and an absolute magnitude $M_v = 0.3$ for the giant.

I. Observations

When observing the F6III giant HD 160365 with IUE it was discovered that the star has a hot companion roughly 8" south of the giant. A slight apparent wavelength shift of Lyα may show that the companion is also displaced by a few arcsec in the east-west direction. The spectra of the two stars are reasonably well separated.

In Figure 1 we show the energy distribution for the combined spectrum. The visibility of flux shortward of Lyα shows that the companion is a B star.

In Figure 2 we show the cross-section through the spectra perpendicular to the direction of dispersion for a 100 Å wavelength band 1400 Å $< \lambda <$ 1500 Å. The abscissa gives the "line" number showing the position along the long axis of the entrance aperture to the IUE spectrograph. The ordinate gives again the flux numbers which can be transformed into actual fluxes by means of the sensitivity curve. The main peak shows the flux of the companion, the smaller peak the one for the giant. The two spectra are separated by 8 "lines" corresponding to about 8 arcsec. The point spread functions slightly overlap at "line" 53. It is obvious, however, that at these wavelengths the influence of the giant spectrum on the companion spectrum is minimal if we use the lines no 44 to 53 for the extraction of the companion spectrum. For $\lambda >$ 1500 Å the contribution of the giant relative to the companion increases. We may expect corrections of up to 10% $\pm$ 5% for the longest wavelengths shown.

In Figure 3 we show the spectral energy distribution derived from summing up the fluxes for "lines" 44 to 53. The fluxes over the whole wavelength band may be somewhat too low because the image of the companion was close to the edge of the entrance aperture and some light may have been lost. A wavelength shift observed for the stellar Lyα may indicate that also in the east-west direction the companion was not centered in the entrance aperture. This could also cause loss of some light. We do, however, not think that a major fraction of the light was lost. The maximum of the point spread function was certainly within the entrance aperture, because the spectrum is well defined. A light loss of up to about 30% can probably not be excluded.

II. The Continuous Energy Distribution

In Figure 2 we have drawn two straight lines representing the theoretical energy distributions for hydrogen white dwarfs with log g = 8 and with T_{eff} = 22,500 K and 25,000 K, according to Wesemael *et al.* 1980. Within the limits of error of our observations both values are possible.

As plotted the observed flux at 1526 Å is 3.25 10^{-16} erg cm^{-2} sec^{-1} A^{-1}. According to Wesemael *et al.* we then expect a visual flux at 5500 Å of $f_v = 8.4 \cdot 10^{-16}$ erg cm^{-2} sec^{-1} A^{-1} if T_{eff} = 25,000 K. According to Code, Holm and Bottemiller (1980) we have f_v = $3.6 \cdot 10^{-9}$ erg cm^{-2} sec^{-1} A^{-1} for $m_v = 0$. We then derive an apparent visual magnitude of $m_v = 16.6$ for 25,000K. For T_{eff} = 22500 K we find $m_v = 16.3$. If 30% of the light was lost at the edge of the entrance aperture the m_v has to be changed by $\Delta m_v = -0.28$.

According to Weidemann 1975 we expect for a white dwarf with T_{eff} = 24,500 K a luminosity of $\log L/L_\odot = -1.3$ leading to $M_{bol} = 8.00$ and $M_V \sim 10.67$. We have adopted the bolometric correction given by Wesemael *et al.* With $m_v \leq 16.5$ for the white dwarf this gives a distance modulus of $m_v - M_v \leq 5.83$. If the stars are at the same distance we find for the F6 III star with $m_v = 6.12$ that $M_v \leq 0.29$ and d ~ 146 pc.

The angular separation of the stars of about 8" then implies a distance of 1172 au for the companions if they belong together. Since the radial velocity for the giant is known this pair offers another possibility to determine the relativistic red shift for the white dwarf and thereby determine its mass directly.

III. The Hydrogen Lyα Line

On our spectra we can measure the Lyα line profile and compare it with theoretical line profiles. We assume log g = 8 as is appropriate for most white dwarfs. In Figure 4 we show the observed energy distribution (averaged over 3 measuring points as provided by the IUE observatory) around Lyα and compare it with theoretical line profiles as given by Wesemael *et al.* for T_{eff} = 25,000 and 22,500K. The comparison indicates a T_{eff} of slightly less than 25,000 K. We adopt T_{eff} = 24,500K ± 500 K. (We have to remember that the IUE spectrograph in its low resolution mode provides only a resolution of 6 Å. We may therefore expect some instrumental broadening.) Larger gravities than log g = 8 would require somewhat higher temperatures. The continuum energy distribution does, however, not permit higher temperatures. There is not enough energy shortward of 1200 Å. Somewhat smaller g and smaller T are possible.

IV. Absorption Lines of Heavy Elements

Several weak dips are seen in the companion spectrum for $\lambda < 1500$ Å. The signal to noise ratio is very low so we cannot be sure of the reality of these dips. Nevertheless we list the approximate wavelengths of the dips in Table 1 and also possible identifications. Since the stellar Lyα line appears to be shifted by −4.5 Å supposedly because of the incorrect centering in the entrance aperture, the same shift is expected for other lines. For identification we should therefore add 4.5 Å to the measured wavelength. With this in mind most of the dips occur at wavelength were several CI lines are observed in the lab. A few other dips might perhaps be identified with Silicon lines. From our low signal to noise spectra we can certainly not claim that we have identified CI and CII lines but Table 1 looks suggestive. High resolution spectra need to be taken to confirm or reject this suspicion. The star is, however, too faint to be observed with IUE in the high resolution mode.

Using the Saha equation for a rough estimate we find that about 0.1% of the carbon may still be neutral at this temperature.

V. Summary

From the observed energy distribution of the hot visual companion to the F6 III star

HD 160365 we determine a T_{eff} of $22500 < T_{eff} < 25,000$ K. From the Lyα line profile we determine $T_{eff} = 24{,}500\ ^{+500}_{-2000}$ K.

With the observed flux at 1526 Å namely $f_\lambda = 3.25\ 10^{-14}$ erg cm^{-2} sec^{-1} A^{-1} and the theoretical ratio $\frac{f_\lambda}{f_v} = 38.65$ for $T_{eff} = 25{,}000$ K according to Wesemael *et al.* (1980) we find a visual flux $f_v = 1.08\ 10^{-15}$ erg cm^{-2} sec^{-1} A^{-1}. According to Code, Holm and Bottemiller (1980) this leads to $m_v = 16.6$ for 25,000 K. For 22,500 K an apparent visual magnitude of $m_v = 16.3$ is derived assuming that no reddening correction is required.

If the white dwarf has a mass of 0.6 $M_\odot$ (corresponding to log g = 8) it is expected to have a luminosity of $\log L/L_\odot = -1.3$ and an absolute magnitude of $M_v = 10.67$. This gives a distance modulus of 5.8 if $T_{eff} = 24{,}500$ K as adopted, and a distance d = 144.5 pc = 4.46 10^{20} cm. Using this also for the giant we derive for this star $M_v = 0.3$. This appears to be a reasonable value making it highly probable that the stars do indeed belong together. If we lost about 30% of the light because the image of the white dwarf was close to the edges of the entrance aperture then the real distance modulus would be 5.52.

From the ratio of the observed flux at 1526 Å to the theoretically expected flux we can determine the angular radius for the white dwarf. For $T_{eff} = 25{,}000$K we find $R/d = 1.78 \cdot 10^{-12}$ and for 22,500K a ratio $R/d = 2.2 \cdot 10^{-12}$, from which we interpolate for $T_{eff} = 24{,}500$ that $R/d = 1.86\ 10^{-12}$. Here R is the radius of the star. With the distance of 144.5 pc we then derive $R \approx 8300$ km. If we have lost 30% of the light the actual flux at 1526 A is a factor of 1.3 larger, the visual magnitude is less, the distance becomes smaller but the radius comes out to be the same. According to Hamada and Salpeter (1961) a He white dwarf with 0.6 $M_\odot$ is expected to have $R/R_\odot = 1.19\ 10^{-2}$ leading to R = 8282 km. The agreement with the value derived above is surprisingly good, showing that our derivations are consistent.

According to Weidemann (1968) a 0.6 $M_\odot$ white dwarf with $T_{eff} = 24{,}500$ K has been a white dwarf since about 3 10^7 years. An F6 III giant with $M_v = 0.3$ probably started out on the main sequence as an early A or late B star with a mass around 2.5 $M_\odot$ and a lifetime of about 10^9 years. The white dwarf is then only slightly ahead in its evolution. The original mass difference must have been very small.

With the present separation of about 1000 au mass transfer by Roche lobe overflow at the time when the white dwarf progenitor was a luminous red giant seems to be excluded even though the two stars were probably much closer at that time. If there was any mass transfer it could have been only by means of a strong stellar wind. It would be interesting to check whether any signs of this can be seen in the surface abundances of the F6 giant whose convection zone is still shallow.

From the strengths of the transition layer emission lines in the F6 III star we estimate an overabundance of carbon relative to nitrogen by a factor of $\Delta\log N/C \sim 0.35 \pm 0.05$, but the N V line is in the Lyα wing of the white dwarf and is therefore hard to measure. The overabundance of carbon relative to silicon is only about 0.1 dex.

If CI lines are indeed seen in the white dwarf spectrum they might be due to some circumstellar material kept in the system due to the giant.

The radial velocity of the F6III star is known and the orbital velocity has to be extremely small. The white dwarf is therefore another candidate to determine the relativistic redshift and check whether it is consistent with a mass of 0.6 $M_\odot$ and the derived radius. Unfortunately the orbital period is too long to be useful for a binary mass determination.

Acknowledgement

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References

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Table 1

Possible dips in the white dwarf spectrum

and possible identifications

λ measured	element	λ lab.
1244	Si II	1246.7 - 1251.2
1255 (broad)	C I	1260.5 - 1261.1
1278	C I	1279.3 - 1280.9
1285	C I	1288.1 - 1288.6
1295	Si III	1296.7 - 1301.1
1311	C I	1311.4 - 1315.9 (Si III 1312.6)
1325	C I	1328.9 - 1329.6
1340	C II	1334.5 - 1335.7 (?)
1412	Si III	1417.2
1465 (broad)	C I	1459.1 - 1470.2
1555	C I	1560.3 - 1561.4

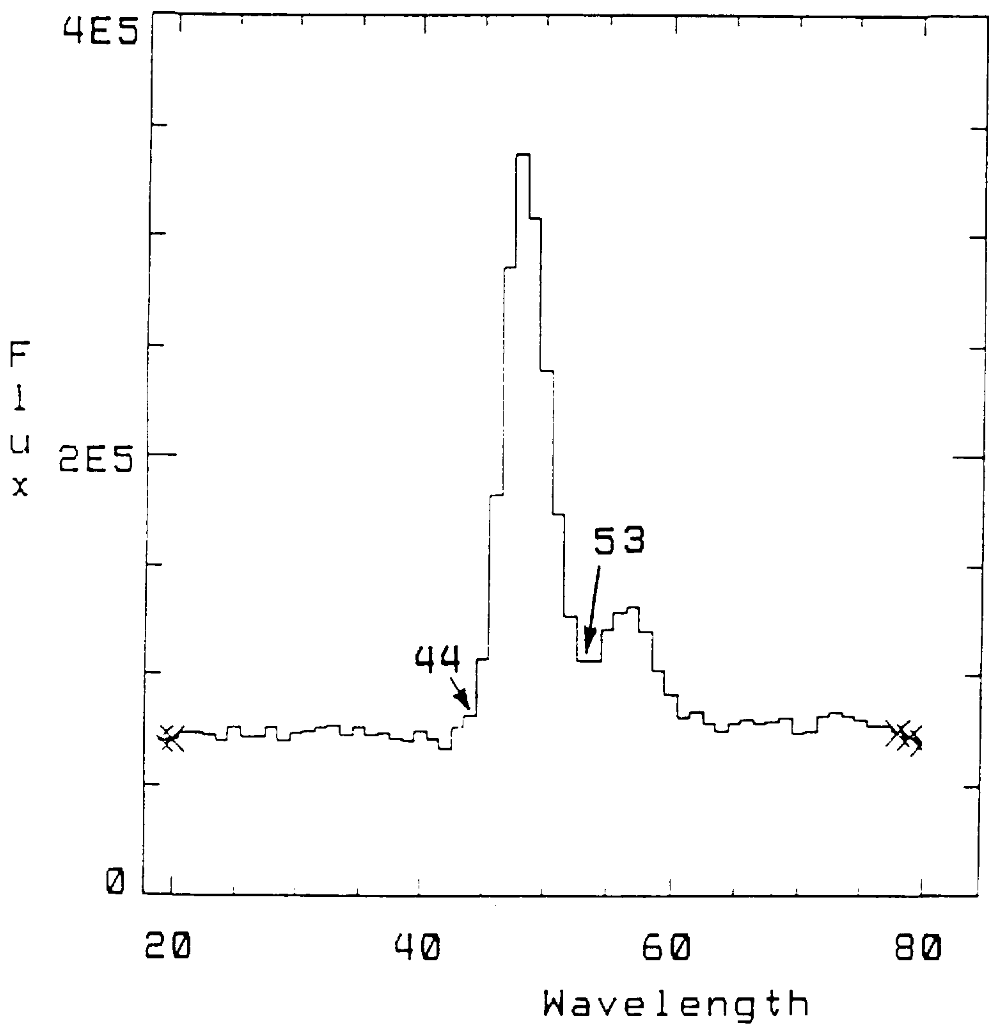
Figure Captions

Figure 1. The energy distribution for the combined spectrum of the F6 giant and the white dwarf companion is shown as a function af wavelength.

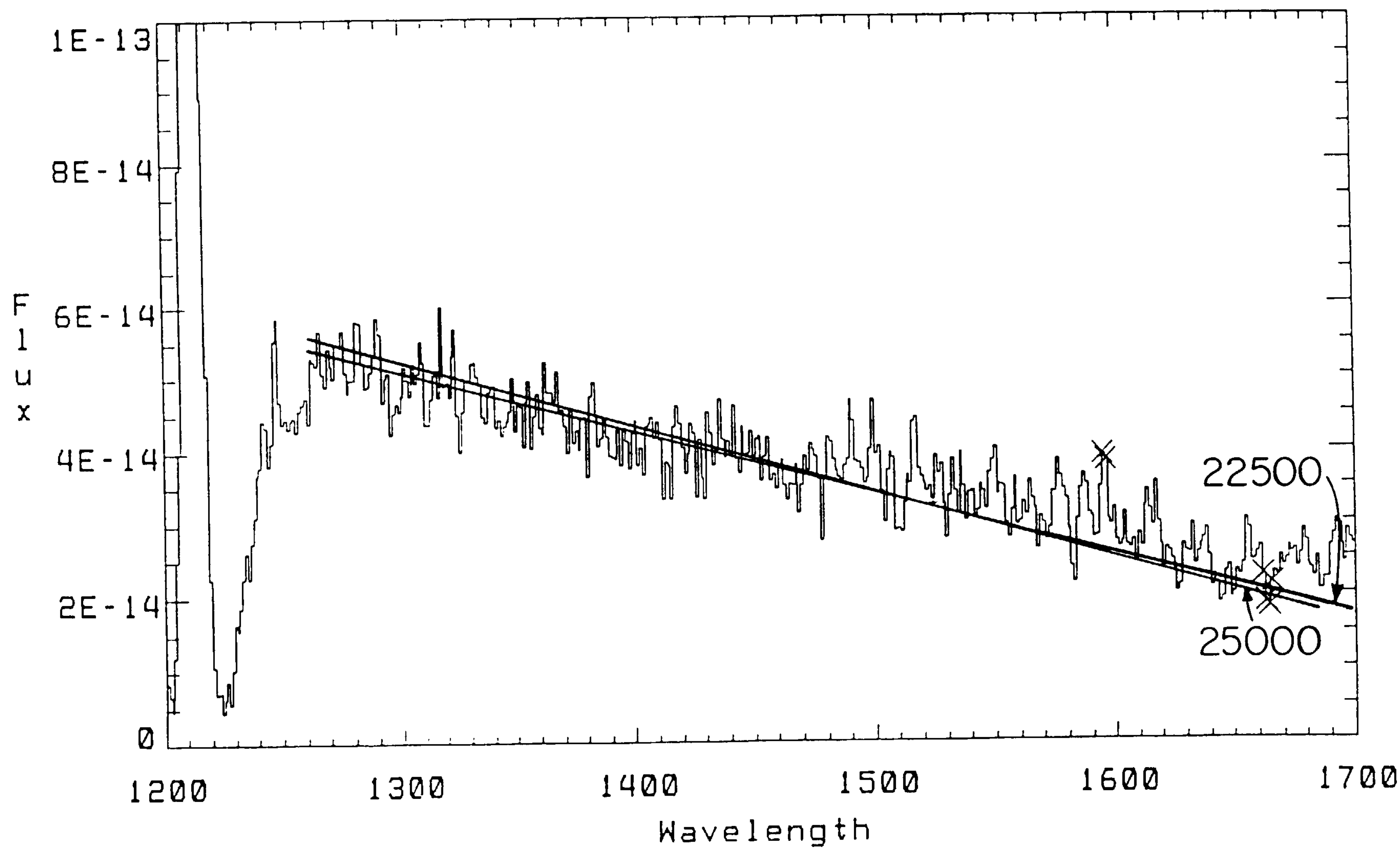
Figure 2. For the wavelength band 1400 Å $< \lambda <$ 1500 Å we show a cross section through the spectrum perpendicular to the direction of dispersion, *i.e.*, parallel to the long axis of the entrance aperture. The spectra of the two stars are well separated. The main maximum is due to the companion, the smaller maximum to the F6 III star. Only at position 53 do the two spectra overlap.

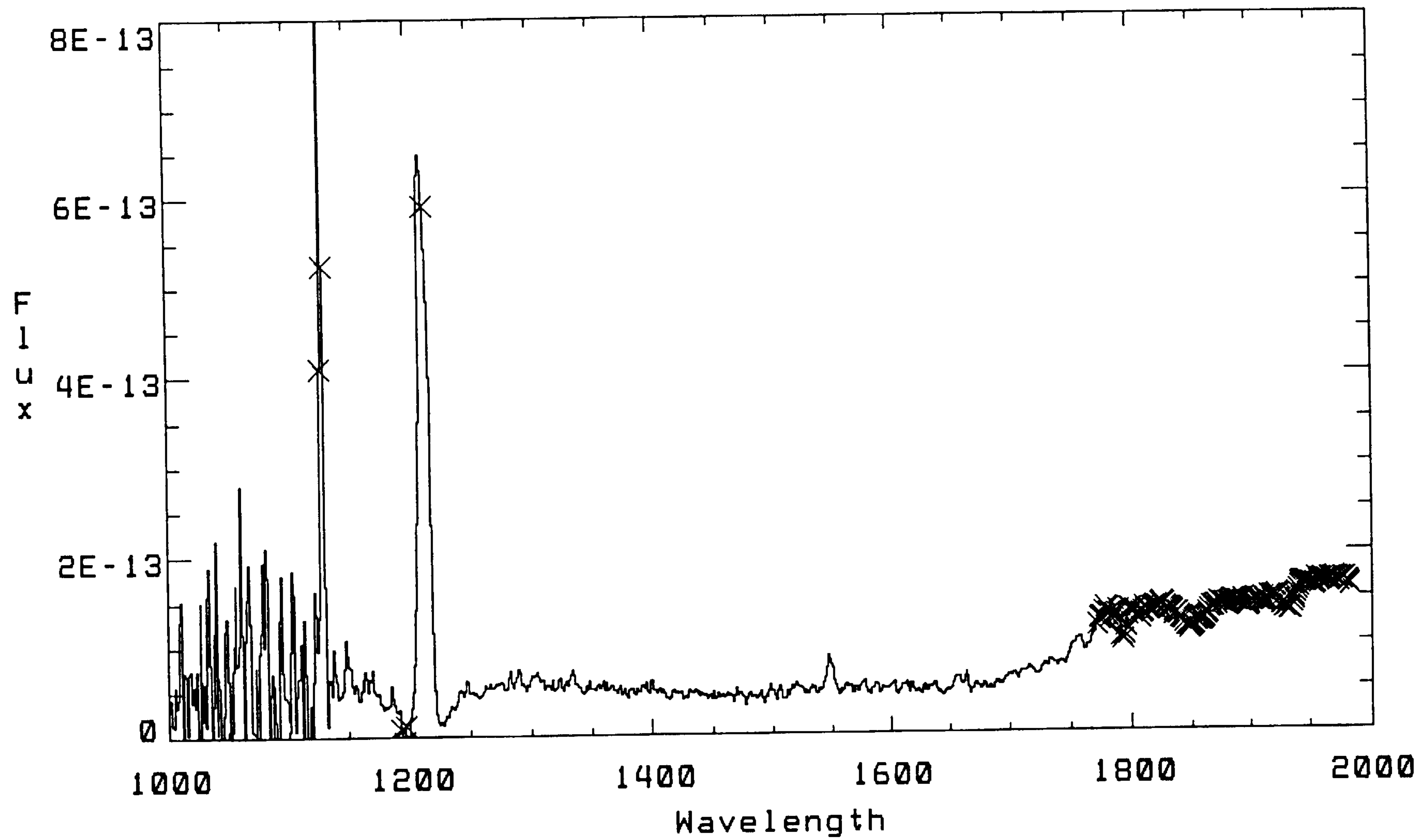
Figure 3. We show the spectral energy distribution of the white dwarf, obtained by summing the "lines" 44 to 53. For $\lambda >$1500 Å some contamination from the cool star is seen.

Figure 4. The observed Lyα line profile is shown and compared with theoretical profiles for log g = 8 and T_{eff} = 22,500 K as well as T_{eff} = 25,000K, according to Wesemael *et al.* (1980). The T_{eff} of the star appears to be slightly cooler than 25,000 K.

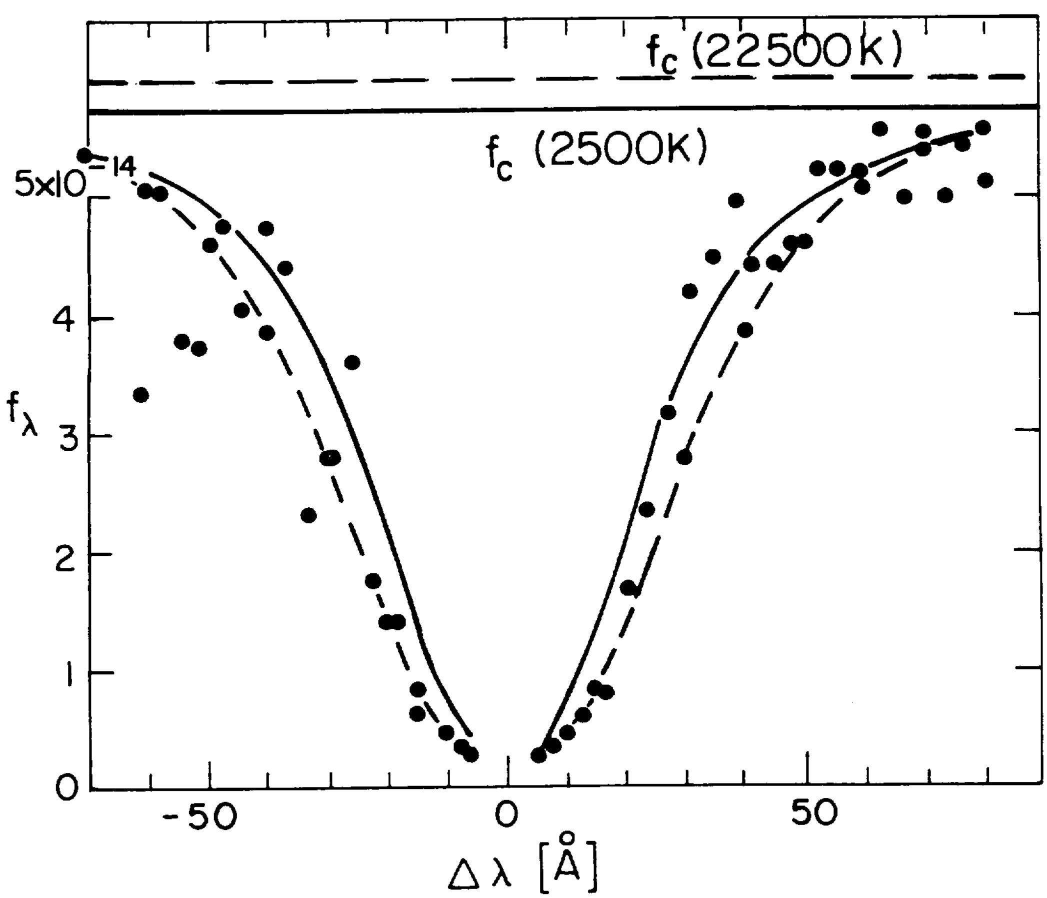


4E5
2E5
0
Flux
44
53
20
40
60
80
Wavelength


1E-13
8E-14
6E-14
4E-14
2E-14
0
Flux
1200
1300
1400
1500
1600
1700
Wavelength
22500
25000



Böhm-Vitense Fig. 1



f_c (22500K)
f_c (2500K)
5x10^-14
4
3
2
1
0
f_λ
-50
0
50
Δλ [Å]