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Spectral Variations of DY Cen

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Abstract. Two high resolution spectra of the hot RCrB star DY Cen in the red region are compared. The photospheric absorption lines show a radial velocity variation of 12 km s^{-1} between 1989 July and 1992 May. Emission components to some CII lines present in 1989 are almost entirely absent in 1992. Nebular forbidden lines of [OI], [NII] and [SII] appear unchanged from 1989 to 1992.

Key words: Hot RCrB stars—radial velocity—photospheric and nebular lines.

1. Introduction

As a peculiar star, DY Cen is triply distinguished. Firstly, it is one of the select number of R Coronae Borealis stars in the Galaxy. These are hydrogen-deficient supergiants which at unpredictable times fade rapidly and severely as a cloud of carbon dust covers their photospheres. Secondly, DY Cen is one of just three hot RCrBs. Most RCrBs are classified as F-type with effective temperatures around 7000 K but DY Cen, an early B-type supergiant, has an effective temperature of 20,000 K (Jeffery & Heber 1993). (MV Sgr and V348 Sgr are the other two hot RCrBs). Thirdly, unlike most RCrBs, DY Cen's atmosphere has a substantial amount of hydrogen (Rao 1986; Pollacco 1989): Jeffery & Heber's (1993) analysis of Balmer and HeI lines gave a number density ratio H/He = 0·1.

Identification of DY Cen as an RCrB star was made by Hoffleit (1930) who noted that the star had shown 4 RCrB-like declines. No additional reports of declines have appeared but the star may have gradually faded over the last 40 years (Bateson 1978). An infrared excess (Kilkenny & Whittet 1984; Walker 1986) signals the expected presence of circumstellar material. The hot RCrBs V348 Sgr and MV Sgr are associated with emission line nebulae. Earlier, we showed that nebular lines are present in the red spectra of DY Cen (Rao, Giridhar & Lambert 1993). In short, DY Cen bears the photometric and spectroscopic hallmarks of an RCrB and, in particular, of a hot RCrB.

In this paper, we describe in some detail the spectrum of DY Cen in the red spectral region. We present a spectral atlas. We combine our previous spectrum from 1989 with a new spectrum obtained in 1992 to comment on the spectral variations of DY Cen. This atlas complements that provided by Leuenhagen, Heber & Jeffery (1994) for DY Cen from 4000 Å–4990 Å. These authors use DY Cen as a comparison star for that other hot RCrB V348 Sgr and also present a red spectrum (5790 Å–6800 Å) of the latter.

2. Observations

Two spectra are compared. Both were obtained with the Cassegrain echelle spectrometer of the 4 m telescope at the Cerro Tololo Inter-American Observatory. A spectrum with the air-Schmidt camera and a GEC CCD was obtained on 16th July 1989 covering the spectral range 5475 Å–6830 Å at a resolution of about 25,000—this spectrum was used by Rao *et al.* (1993). The second spectrum obtained on 20th May 1992 with the long camera and a Tektronix 1024 × 1024 pixel CCD covered the range 5480 Å–7080 Å at a resolution of approximately 40,000. In both cases a Th-Ar hollow cathode lamp was observed immediately following the exposure on DY Cen. The 1989 spectrum was reduced at the Vainu Bappu Observatory, Kavalur using the RESPECT software (Prabhu, Anupama & Giridhar 1987). The 1992 spectrum was reduced using the IRAF echelle software package on the Sparc10 at Bangalore.

The spectra are presented in Figs. 1–21 where a single echelle order is given in each figure. The 1989 spectrum is plotted on the top and the 1992 spectrum at the bottom. Obvious lines are identified and key characteristics are summarized in Table 1. The wavelength scale is such that the photospheric lines are corrected for the radial velocity.

3. Spectrum variations

3.1 *The photospheric lines*

Absorption lines such as the high excitation lines of CII, NII, OII, NeI, AlIII, and SiIII are presumably formed in the photosphere. With the exception of the CII lines, the equivalent widths of the photospheric lines are little changed between 1989 and 1992. (The CII lines may be filled in by emission to a greater extent in 1992.) There is a change in the photospheric radial velocity—see Table 2: the mean velocity of 41 km s^{-1} in 1989 from a collection of CII, NII, and NeI lines had fallen to near 29 km s^{-1} in 1992 as measured from CII, NII, OII, NeI, and AlIII lines.

This clear detection of a variable radial velocity is consistent with the few previously available determinations. Herbig (1990, private communication) reported a velocity of 29 km s^{-1} for 1982 April. Pollacco & Hill (1991) measured $15{\cdot}1 \pm 2{\cdot}5$ km s^{-1} for 1988 March. Quite obviously, many additional determinations are needed to determine if the radial velocity variations are periodic and to attribute them to a physical mechanism such as membership in a spectroscopic binary or photospheric pulsations.

3.2 *The nebular lines*

Nebular forbidden lines of [OI], [NII], and [SII] were identified by Rao *et al.* (1993). The 6583 Å [NII] and the 6716 Å and 6730 Å [SII] lines are blended with photospheric absorption lines. In particular, the red wings of the [SII] lines are badly mutilated in the 1992 spectrum. The equivalent widths of these forbidden lines (Table 3) appear little changed between 1989 and 1992. On the assumption that the continuum flux was little changed, the emission lines have kept a more or less constant flux.

The radial velocity (Table 3) of the nebular lines was unchanged too between 1989 and 1992: the mean velocity is 23 km s^{-1} to within an uncertainty of about 2 km s^{-1}.

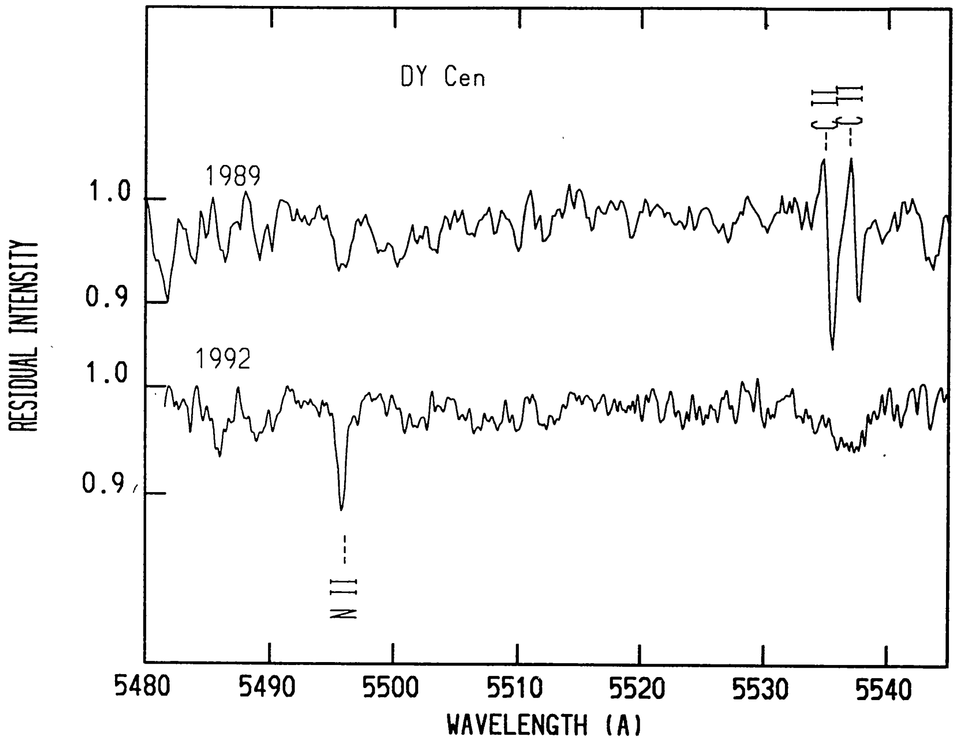

Figure 1. Spectra of DY Cen in 1989 and 1992 for the region 5480–5545 Å. Note the CII lines with the inverse P-Cygni profiles in the 1989 spectrum.

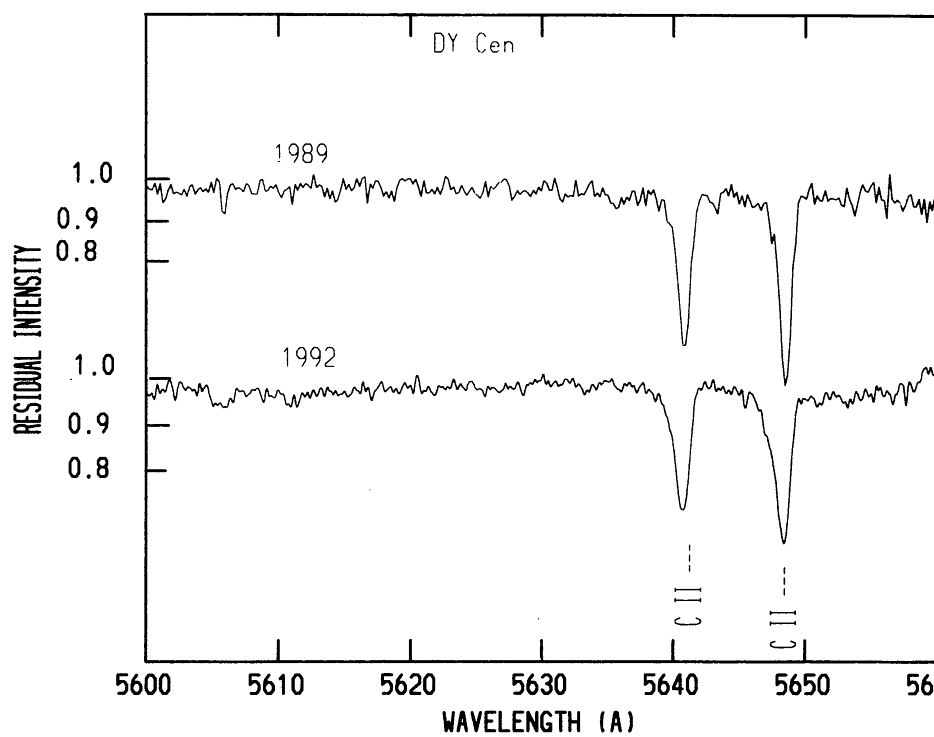

Figure 2. Spectra of DY Cen in 1989 and 1992 for the region 5600–5660 Å. Note the two strong CII lines which are markedly asymmetric in the 1992 spectrum.

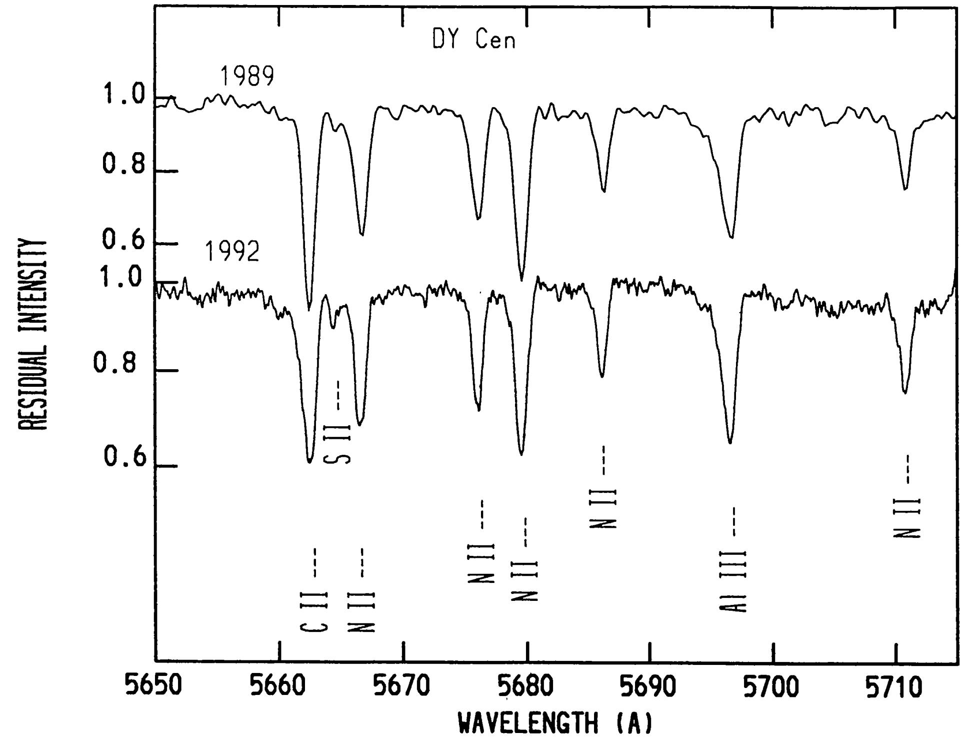

Figure 3. Spectra of DY Cen in 1989 and 1992 for the region 5650–5710 Å. Note the strong CII, NII, and AlIII lines which are little changed between 1989 and 1992.

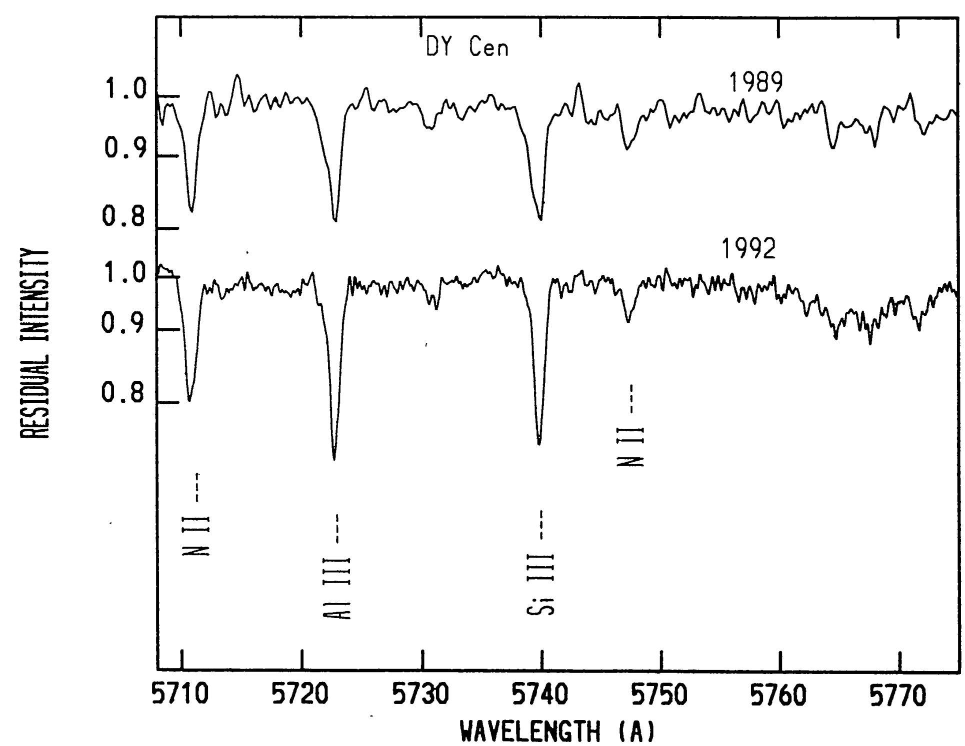

Figure 4. Spectra of DY Cen in 1989 and 1992 for the region 5710–5775 Å. Note the strong NII, AlIII, and SiIII lines which are little changed between 1989 and 1992.

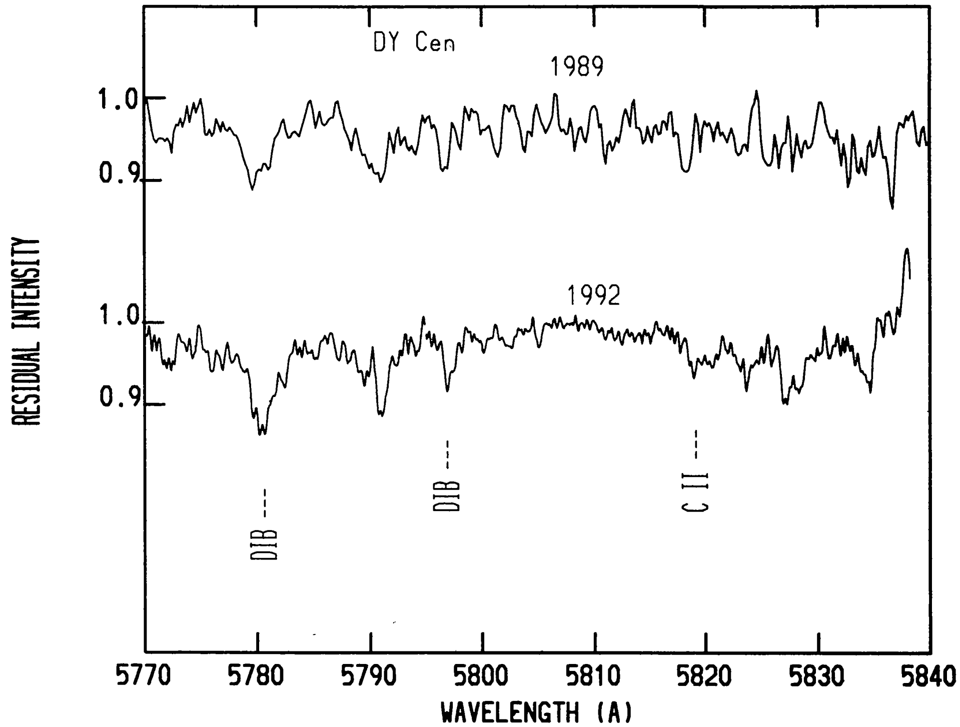

Figure 5. Spectra of DY Cen in 1989 and 1992 for the region 5770–5840 Å. Note the two diffuse interstellar bands (DIB).

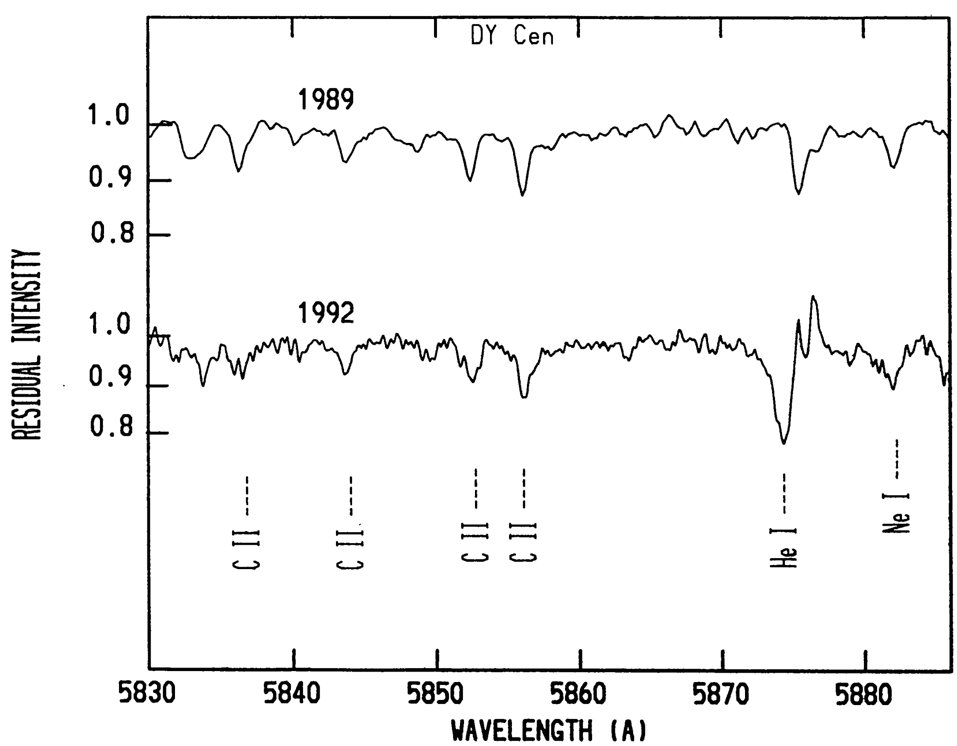

Figure 6. Spectra of DY Cen in 1989 and 1992 for the region 5830–5880 Å. Note the difference in the profile of the HeI triplet line at 5875 Å.

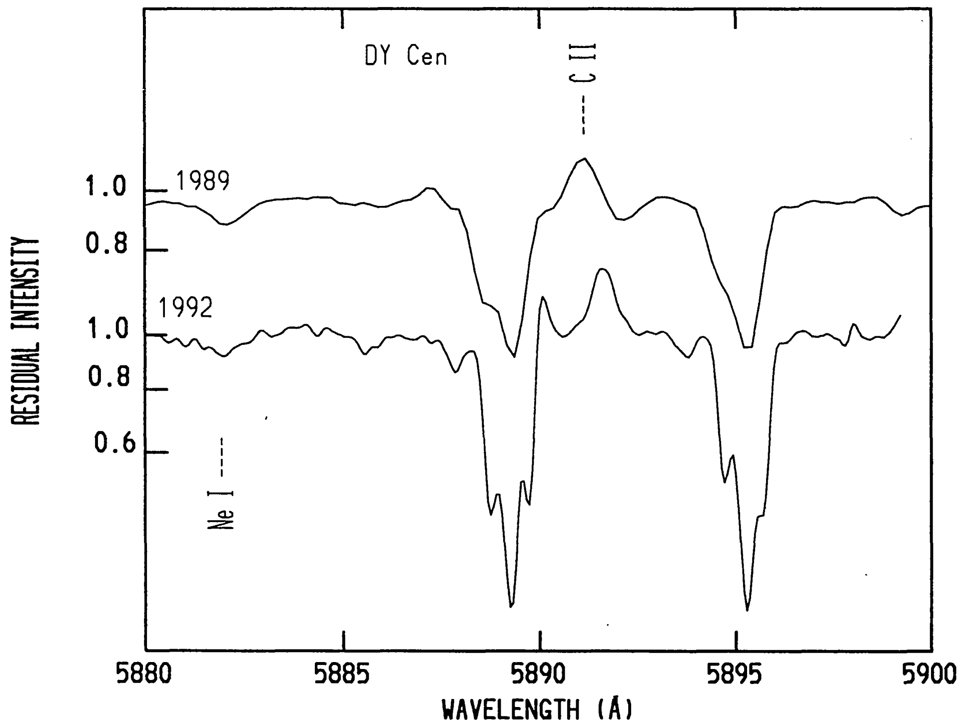

Figure 7. Spectra of DY Cen in 1989 and 1992 for the region 5880–5900 Å. Note the NaD absorption lines which owing to the superior resolution of the 1992 spectrum show multiple components not so easily seen in the 1989 spectrum.

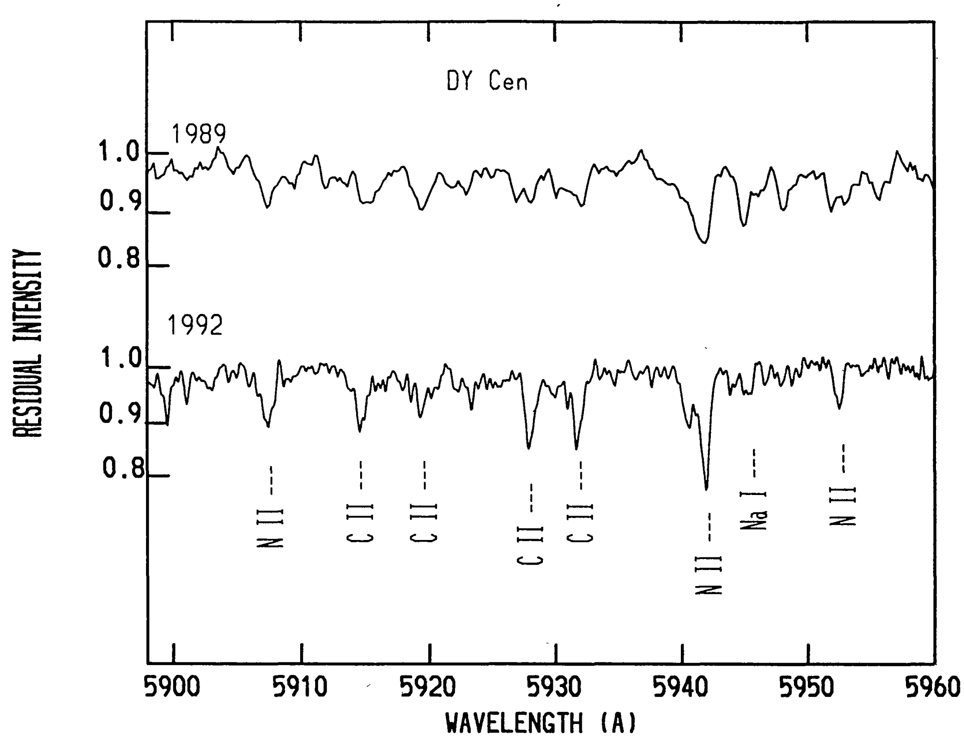

Figure 8. Spectra of DY Cen in 1989 and 1992 for the region 5900–5960 Å. Note the CII and NII lines which are little changed between 1989 and 1992.

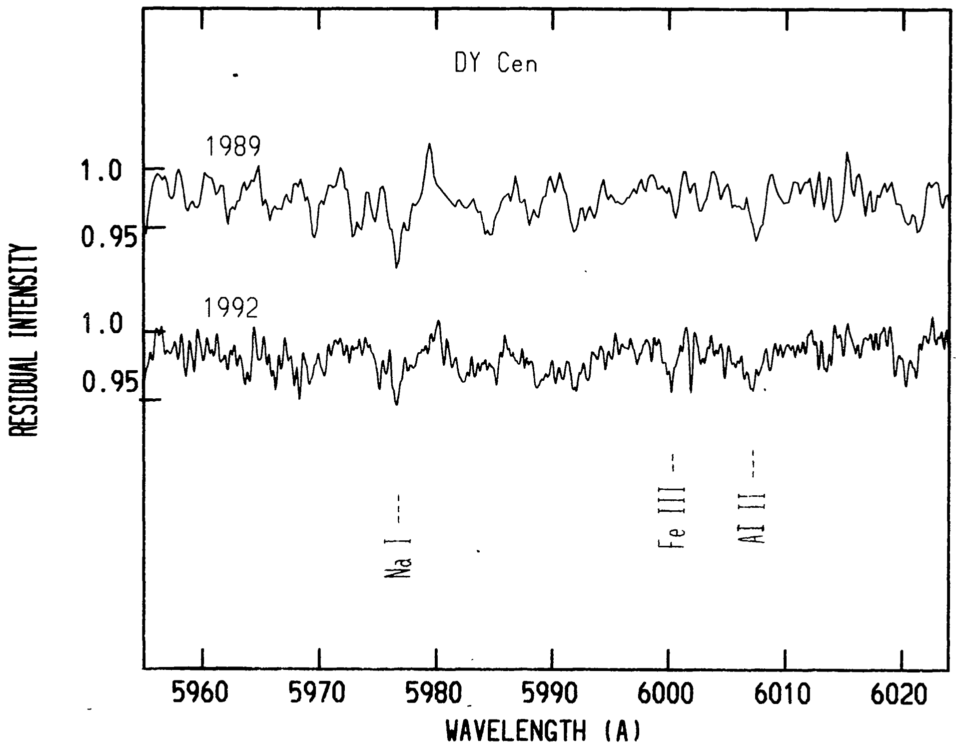

Figure 9. Spectra of DY Cen in 1989 and 1992 for the region 5960–6025 Å.

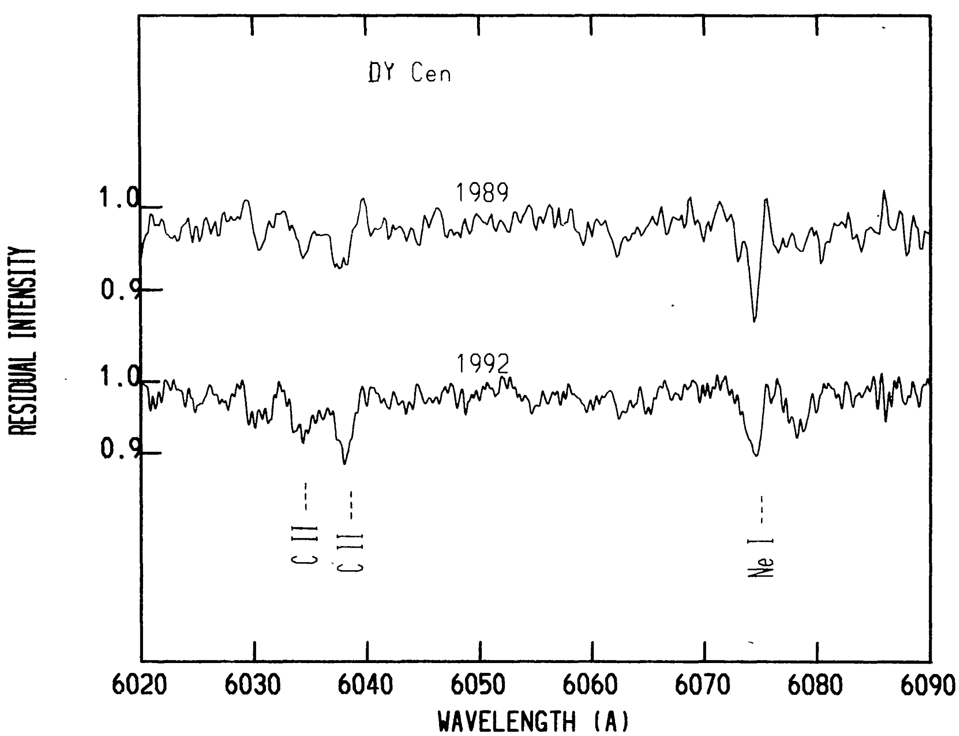

Figure 10. Spectra of DY Cen in 1989 and 1992 for the region 6020–6090 Å. Note the weak CII, and NeI lines which are little changed between 1989 and 1992.

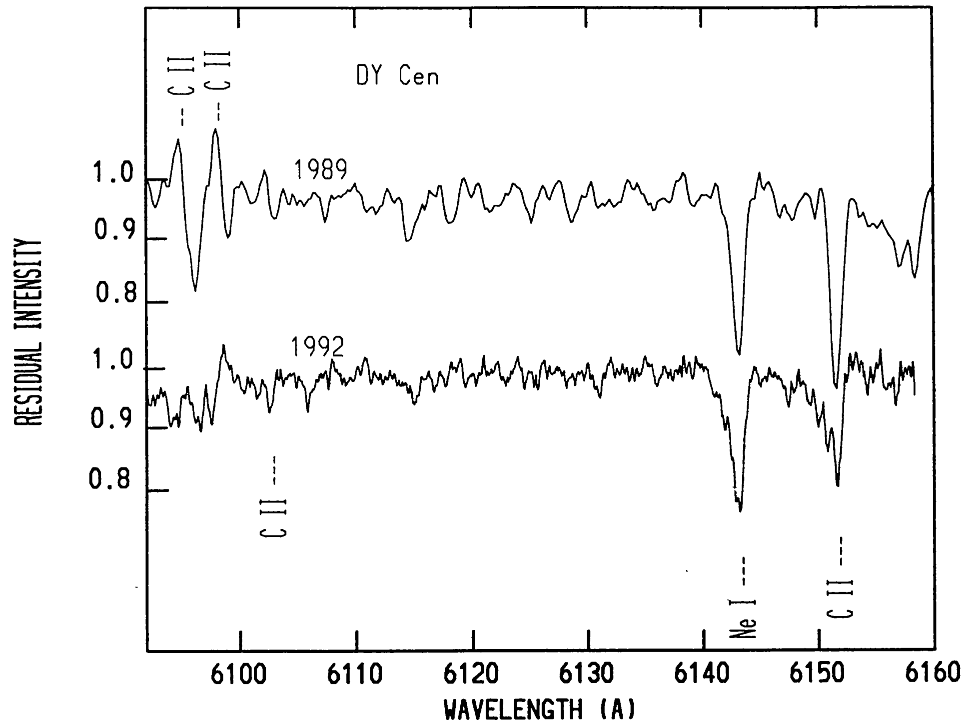

Figure 11. Spectra of DY Cen in 1989 and 1992 for the region 6090–6160 Å. Note the CII lines with inverse P-Cygni profiles in the 1989 spectrum.

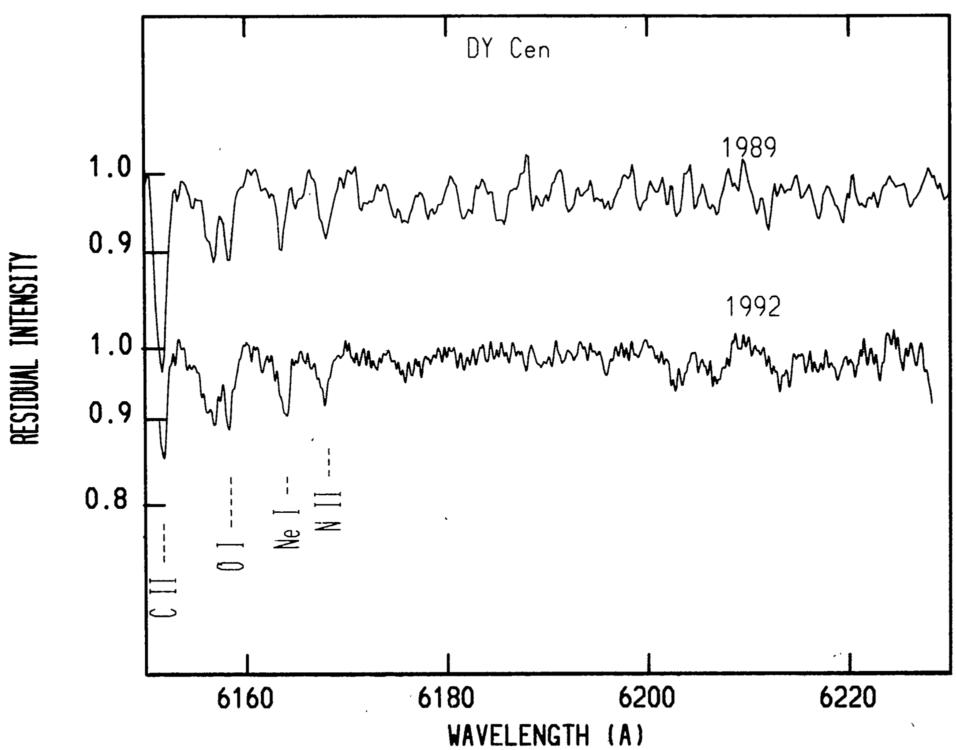

Figure 12. Spectra of DY Cen in 1989 and 1992 for the region 6150–6230 Å.

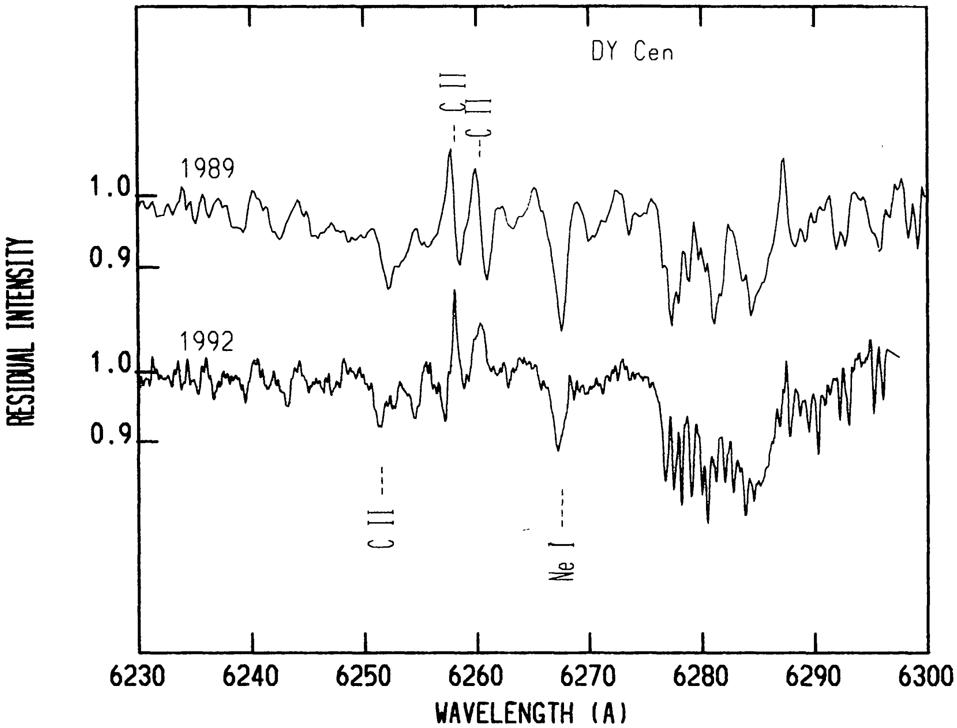

Figure 13. Spectra of DY Cen in 1989 and 1992 for the region 6230–6300 Å. Note the CII lines with inverse P-Cygni profiles in the 1989 spectrum. Absorption band near 6280 Å is due to telluric O_2.

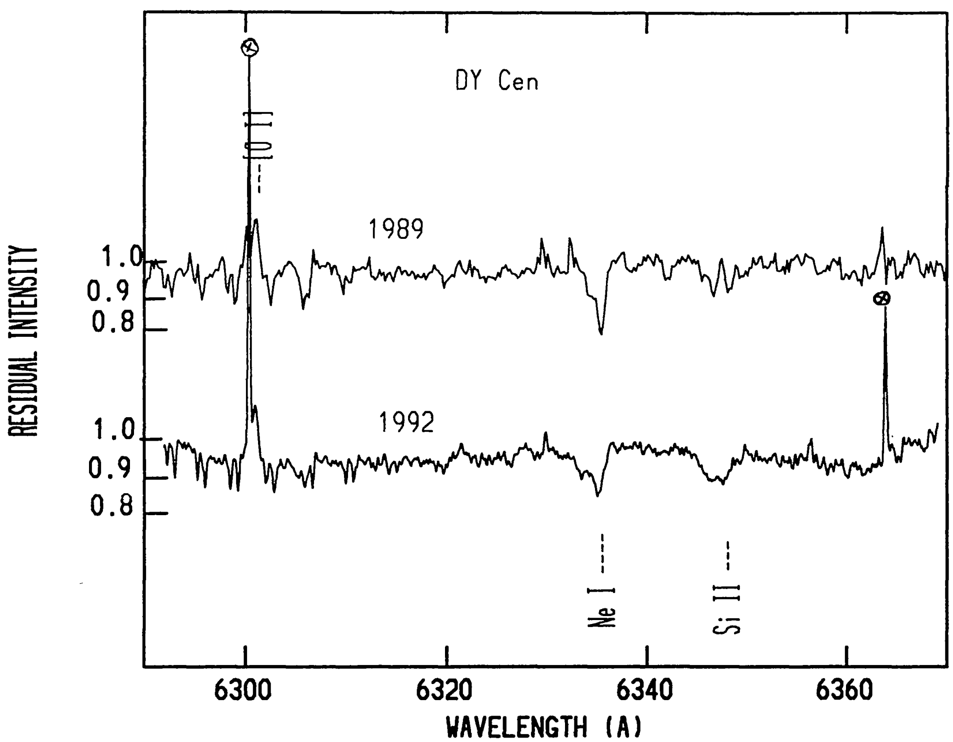

Figure 14. Spectra of DY Cen in 1989 and 1992 for the region 6295–6370 Å. Strong terrestrial emission from [OI] is present at 6300 and 6363 Å. Stellar [OI] emission is present to the red of the terrestrial emission.

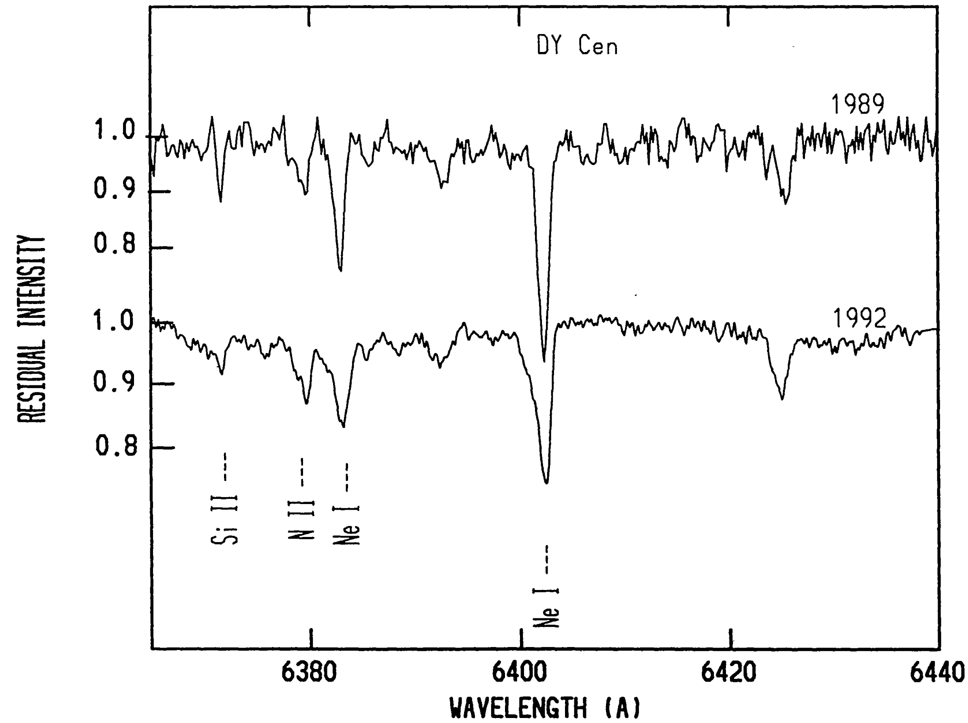

Figure 15. Spectra of DY Cen in 1989 and 1992 for the region 6370–6440 Å. Note the strong NeI line which is markedly asymmetric in the 1992 spectrum which is of superior resolution to the 1989 spectrum.

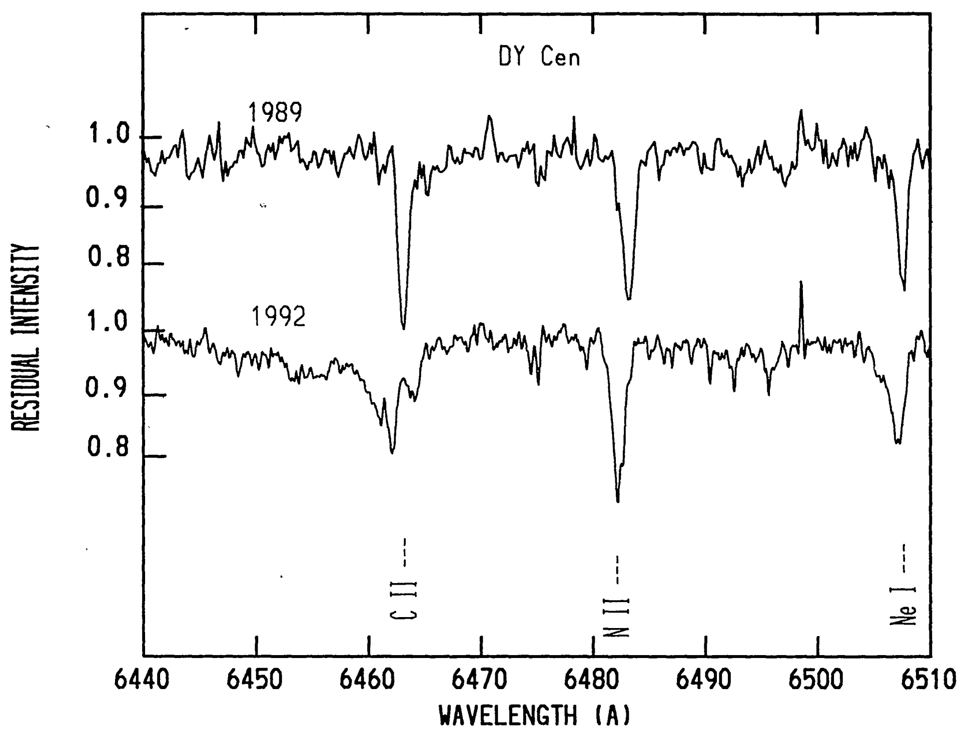

Figure 16. Spectra of DY Cen in 1989 and 1992 for the region 6440–6510 Å. Note the strong lines of CII, NII and NeI.

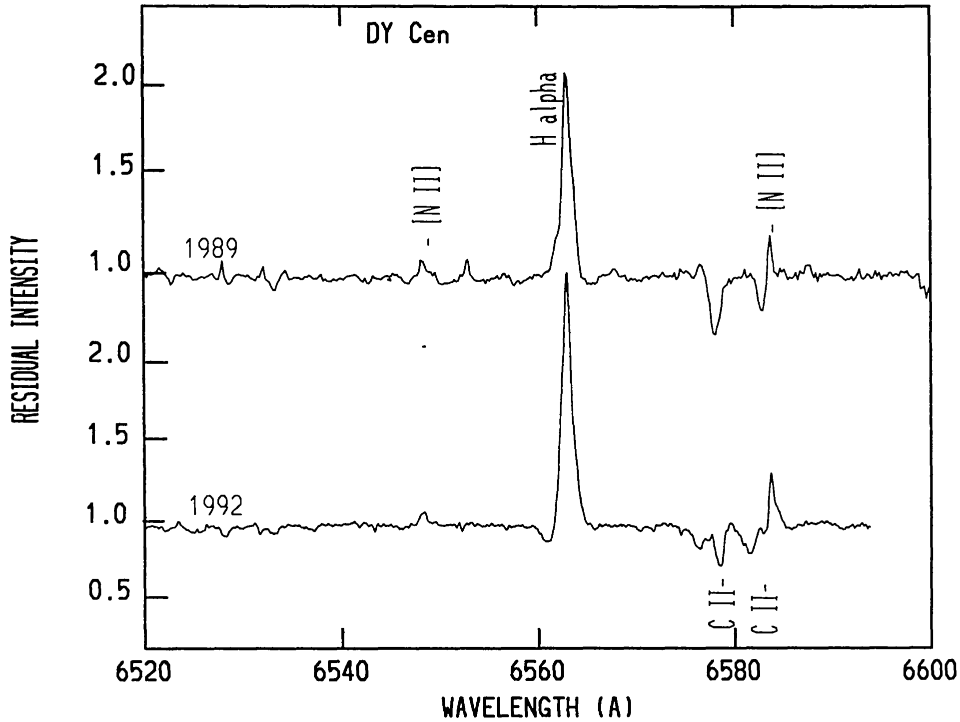

Figure 17. Spectra of DY Cen in 1989 and 1992 for the region 6510–6600 Å. Note the strong emission in H alpha and the weak emission in the [NII] lines.

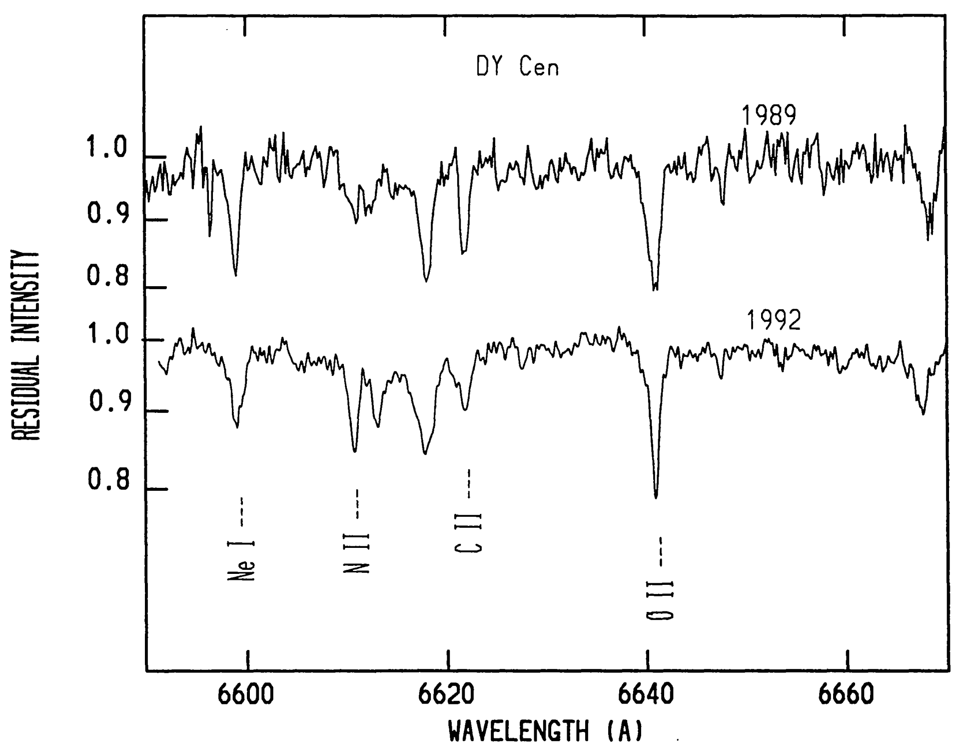

Figure 18. Spectra of DY Cen in 1989 and 1992 for the region 6595–6665 Å. Note the lines of CII, NII, OII, and NeI.

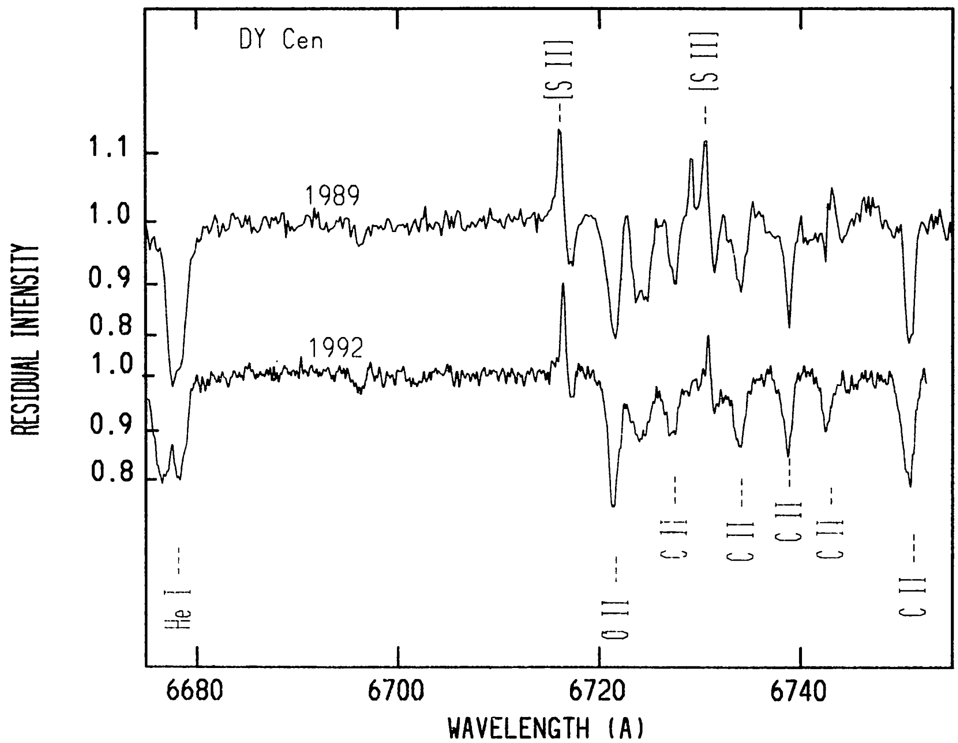

Figure 19. Spectra of DY Cen in 1989 and 1992 for the region 6675–6760 Å. Note the profile variations of the HeI line at 6678 Å the [SII] emission lines, and the strong CII and OII lines.

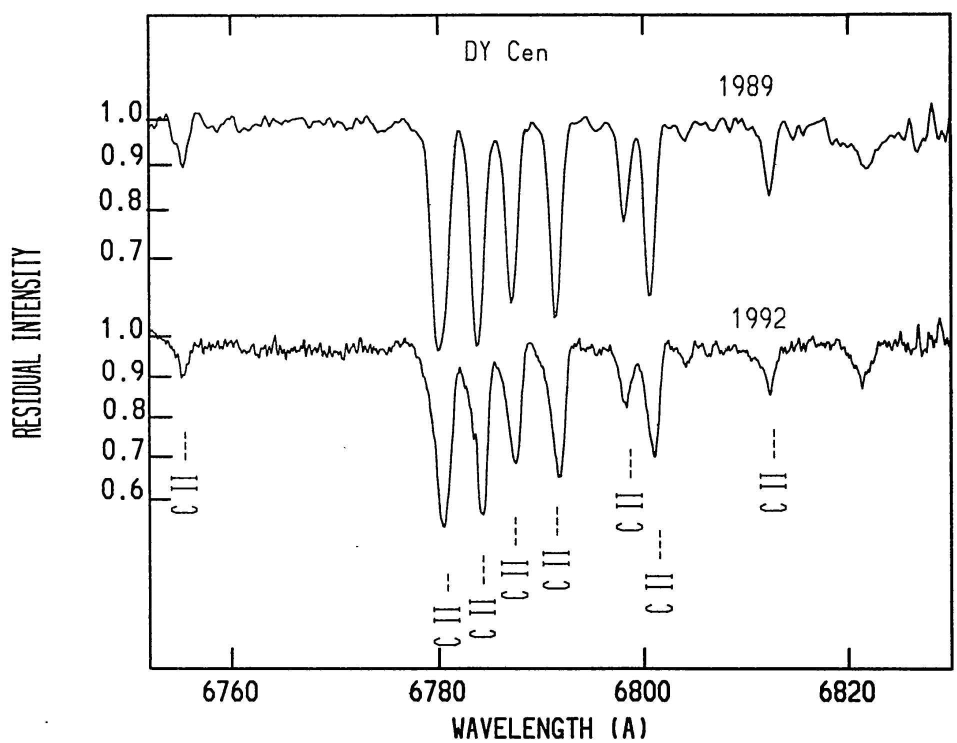

Figure 20. Spectra of DY Cen in 1989 and 1992 for the region 6750–6830 Å. Note the strong lines of CII which are systematically stronger in the 1989 spectrum.

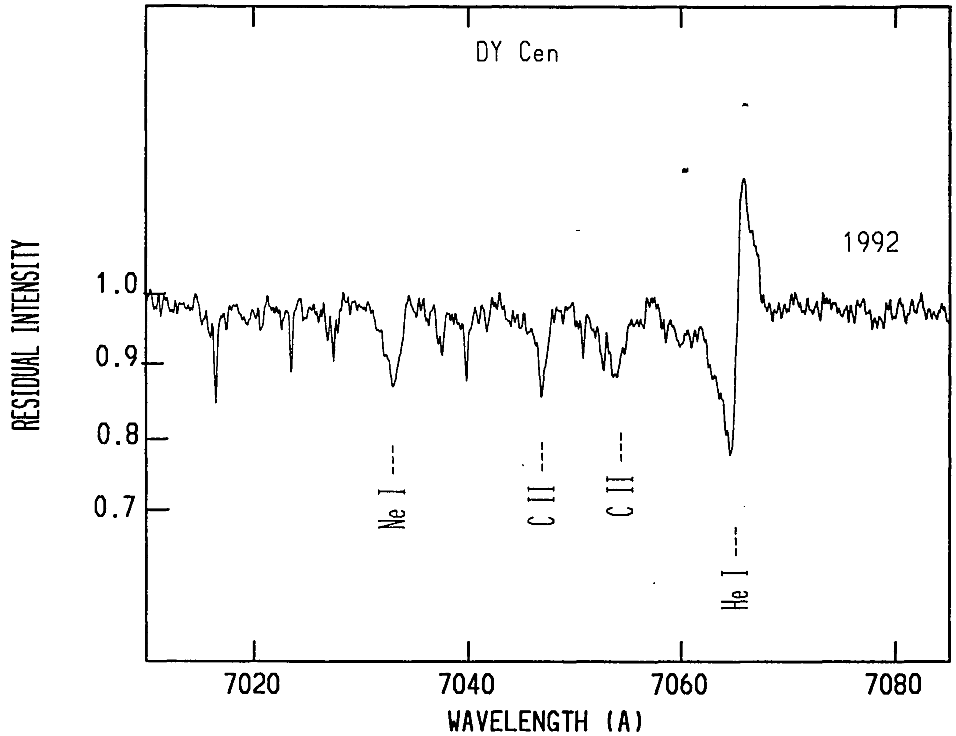

Figure 21. Spectrum of DY Cen in 1992 for the region 7015–7085 Å. Note the HeI line at 7065 Å with a P-Cygni profile.

As noted by Rao *et al.* (1993), the fragmentary data on the photospheric radial velocity suggest that the mean velocity of the nebular lines is close to the star's velocity and that, therefore, the nebular may be arranged symmetrically about the star.

The Balmer line Hα is strongly in emission on both spectra. Quite possibly, much of this emission is from the nebula. The emission core has the same velocity as the forbidden lines. The equivalent width of the Hα emission is about 20% higher in 1992 when a P-Cygni-like absorption also appeared with a velocity of $-69\,\mathrm{km\,s^{-1}}$ for the absorption core.

3.3 *Permitted emission lines*

Emission lines, generally part of an inverse P-Cygni profile, of several CII lines were a marked feature of the 1989 spectrum. These emission lines are almost completely absent from the 1992 spectrum. Table 4 summarizes the absorption and emission equivalent widths and velocities of the 1989 CII lines with prominent inverse P-Cygni profiles. Emission in CII RMT 3 is of similar strength in 1992 and 1989 but the other emission is undetectable in 1992.

The HeI lines at 5875 Å, 6678 Å, and 7065 Å (1992 only) are in our bandpass. These lines show remarkable changes which are summarized in Table 5. The 5875 Å line in 1989 appeared in absorption with possibly two components with the stronger component at the photospheric velocity ($40\,\mathrm{km\,s^{-1}}$) and the weaker component at $8\,\mathrm{km\,s^{-1}}$. In 1992 this line shows a P-Cygni profile with absorption at $-54\,\mathrm{km\,s^{-1}}$ and apparently two emission components: a sharp one at $-2\,\mathrm{km\,s^{-1}}$ and a broader one at $55\,\mathrm{km\,s^{-1}}$.

Table 1. A list of lines observed in DY Cen spectrum.

Wavelength (Å)	Species	RMT	W_λ(mÅ) 1989	W_λ(mÅ) 1992	Comments
5495·65	NII	29	102	150	
5509·67	SII	6	18:	43	
5530·24	NII	63	15	10	
5535·36	NII	63	...	...	If present, masked by CII.
5535·35	CII	10	95,17e	...	Emission in 1989 see the text.
5537·61	CII	10	55,16e	...	Emission in 1989 see the text.
5543·47	NII	63	...	65	
5564·94	SII	6	17:	50	
5640·55	CII	15	364	400	
5648·07	CII	15	384	460	
5662·47	CII	15	440	492	
5664·73	SII	11	50	29	
5666·64	NII	3	312	320	
5676·02	NII	3	280	300	
5679·56	NII	3	415	470	
5686·21	NII	3	200	190	
5696·47	AlIII		410	400	
5710·77	NII	3	220	190	
5722·65	AlIII		280	265	
5730·65	NII	3	20	24	
5739·76	SiIII	4	276	270	
5747·29	NII	9	80	90	
5767·44	NII	9	...	...	Line present but blended.
5818·30	CII	22	37	74	
5823·10	CII	22	36	81	
5827·90	CII	22	74	...	
5835·08	CII	22	...	...	Blended with 5836·35 Å.
5836·35	CII	22	86	97	
5843·61	CII	22	60	100	
5852·49	NeI	6	90	110	
5856·01	CII	22	117	170	
5875·60	HeI	11	110,63	226,12e,48e	See text.
5881·89	NeI	1	62	100	
5889·27	CII	5	...	...	Lost in NaD.
5889·77	CII	5	...	30e	
5891·59	CII	5	77,105e	123e	P-Cygni profile in 1989.
5907·21	CII	44	113	84	
5914·64	CII	44	...	...	
5919·45	CII	44	...	...	
5927·81	NII	28	105	85	Stronger in 1992.
5931·78	NII	28	110	86	Stronger in 1992.
5941·65	NII	28	184	164	Stronger in 1992.
5944·83	NeI	1	...	108	
5952·39	NII	28	52	88	
5957·61	SiII	4	...	...	
5960·90	NII	28	...	...	Absent.
6006·42	AlII	93	90	81	
6030·00	NeI	3	...	...	
6034·42	CII	59	...	...	
6037·96	CII	59	...	...	

(Continued)

Table 1. (*Continued*)

Wavelength (Å)	Species	RMT	W_λ(mÅ) 1989	W_λ(mÅ) 1992	Comments
6074·34	NeI	3	140	163	
6095·29	CII	24	168,34e	...	
6098·51	CII	24	60,53e	...	
6102·56	CII	24	...	...	
6114·60	NII	36	...	...	Present but blended.
6136·89	NII	36	...	...	Very weak.
6143·06	NeI	1	229	340	
6150·76	NII	36	...	...	In wing of CII 6151 Å.
6151·43	CII	22	220	320	
6156·78	OI	10	89	84	
6158·18	OI	10	82	82	
6163·59	NeI	5	58	103	
6167·76	NII	36,60	95	104	
6170·17	NII	36	...	...	
6173·31	NII	36	...	...	
6226·18	AlII	10	...	58	
6242·41	NII	57	...	...	
6250·74	CII	38·03	140	250	
6256·54	CII	38·03	40	70	
6257·18	CII	10·03	74,30e	41,35e	
6259·59	CII	10·03	110,18e	10e,47e	
6266·49	NeI	5	160	220	
6300·23	OI	1F	87	67	
6318·80	NII	46	...	...	
6334·43	NeI	1	140	230	
6340·57	NII	46	...	...	
6346·87	NII	46	...	...	Blended with SiII line.
6347·09	SiII	2	...	...	Looks double.
6371·36	SiII	2	61	81	
6366·79	NII	2	...	...	
6379·61	NII	2	114	100	
6382·99	NeI	3	269	295	
6402·25	NeI	1	213	460	
6461·95	CII	17·04	230	326	
6482·07	NII	8	350	343	
6506·53	NeI	3	190	230	
6532·88	NeI	5	80	85	
6548·06	NII	1F	47	46	
6562·82	HI	1	1473e	1988e,204	
6578·05	CII	2	490,59e	150,268	
6582·88	CII	2	223	250,40e	Affected by [SII] in 1989.
6583·60	NII	1F	126	159	
6598·95	NeI	6	164	200	
6610·60	NII	31	170	100	
6622·05	CII	17·03	150	140	
6641·03	OII	4	187	240	
6678·15	HeI	46	350,250	380,240	
6696·39	AlII	29	43	63	
6717·00	SII	2F	82	67	
6731·30	SII	2F	83	19	

(*Continued*)

Table 1. (*Continued*)

Wavelength (Å)	Species	RMT	W_λ(mÅ) 1989	W_λ(mÅ) 1992	Comments
6717·04	NeI	6	45	81	
6721·35	OII	4	337	271	
6723·65	CII	16·03	...	...	Blended with 6724 Å
6724·56	CII	21	...	...	Blended with 6723 Å
6727·19	CII	21	205	...	
6731·07	CII	21	...	...	Masked by [SII] emission.
6733·58	CII	21	...	...	Blended with 6734 Å line.
6734·00	CII	21	200	141	
6738·62	CII	21	155	255	
6742·43	CII	21	105	131	
6750·55	CII	21	300	354	
6755·16	CII	21	92	126	
6779·93	CII	14	...	...	Blended with 6780 Å
6780·61	CII	14	890	1200	
6783·90	CII	14	640	852	
6787·22	CII	14	425	648	
6791·47	CII	14	510	608	
6798·11	CII	14	200	270	
6800·68	CII	14	380	500	
6812·29	CII	14	170	220	
7032·41	NeI	1	...	220	
7046·26	CII	26	120	...	
7053·09	CII	26	151	...	
7063·49	CII	26	...	...	Blended with HeI absorption.
7065·20	HeI	10	...	200e	See text.

Table 2. Observed photospheric (absorption line) radial velocities of DY Cen in 1989 July and 1992 May.

	1989 July		1992 May	
Species	Vel. (km s^{-1})	No. lines	Vel. (km s^{-1})	No. lines
CII	42 ± 4	25	33 ± 5	20
NII	42 ± 4	14	25 ± 3	10
OII	...	...	29 ± 5	2
NeI	39 ± 4	20	30 ± 4	14
AlIII	...	...	27 ± 1	2

The triplet line at 7065 Å shows a P-Cygni profile with a very sharp transition from absorption to emission. Peak emission is at a velocity of 16 km s^{-1}. The HeI absorption is apparently blended with the CII line at 7063·70 Å (RMT 26) which is represented by two weaker members of the multiplet. The singlet HeI line at 6678 Å is in absorption on both spectra but the 1992 spectrum shows emission in the absorption core. The 1989 absorption line is broader than other lines of similar depth—compare, for example, the HeI line and the other lines between 6720 Å and 6750 Å. This difference is not simply

Table 3. The nebular lines.

Species	Line (Å)	Radial velocity (km s^{-1}) 1989	Radial velocity (km s^{-1}) 1992	W_λ (mÅ) 1989	W_λ (mÅ) 1992
[NII]	6548·06	26	23	47	46
	6583·60	20	17	126	159
[OI]	6300·23	23	24	87	67
[SII]	6717·00	22	23	82	67
	6731·30	22	22	83	19
Hα	6562·82	24	20	1500	2000

Table 4. CII lines with emission components.

Wavelength (Å)	Absorption W_λ (mÅ) 1989	Absorption W_λ (mÅ) 1992	Absorption Rad. Vel. (km s^{-1}) 1989	Absorption Rad. Vel. (km s^{-1}) 1992	Emission W_λ (mÅ) 1989	Emission W_λ (mÅ) 1992	Emission Rad. Vel. (km s^{-1}) 1989	Emission Rad. Vel. (km s^{-1}) 1992
5535·35	95	···	40	···	17	···	3	···
5537·61	55	···	40	···	16	···	1	···
5891·59	77	···	31	···	105	123	−2	20
6095·29	166	···	67	···	38	···	−6	···
6098·51	60	···	50	···	53	···	−5	···
6257·18	74	41	43	−13	30	35	1	32
6259·59	110	···	43	···	19	28	−9	···
6578·05	490	150[a]	14	−67[a]	59	···	−52	···

[a]The line is double with a second (stronger) component of $W_\lambda = 268$ mÅ at a velocity of 33 km s^{-1}.

Table 5. The HeI lines.

Line (Å)	Year = 1989 Absorption W_λ (mÅ)	Year = 1989 Absorption Rad. Vel. km s^{-1}	1992 Absorption W_λ (mÅ)	1992 Absorption Rad. Vel. km s^{-1}	1992 Emission W_λ (mÅ)	1992 Emission Rad. Vel. km s^{-1}
5875	110	8	226	−54	12	2
	63	40	···	···	48	55
6678	350	4	380	−39	···	···
	250	53	240	40	···	···
7065	···	···	234	−33	240	16

due to thermal broadening at photospheric temperatures. The profile in 1992 is clearly doubled with apparent absorption components at -39 and $+40\,\mathrm{km\,s^{-1}}$. We cannot exclude the possibility that filling of an absorption core by emission has created the appearance of two absorption components. If this is the case, the emission is at a velocity of about $+3\,\mathrm{km\,s^{-1}}$ and the absorption component may be close to the $-54\,\mathrm{km\,s^{-1}}$ seen in the 5875 Å line. The fact that the singlet 6678 Å line shows much less prominent emission than the triplet lines at 5875 Å and 7065 Å is not a surprise as the latter are very likely influenced by the fact that the lowest triplet state is metastable.

4. Concluding remarks

DY Cen shows a variable photospheric spectrum with a clear velocity variation between our two spectra. The velocity difference of about $12\,\mathrm{km\,s^{-1}}$ is due likely to an atmospheric pulsation but an intensive program will be needed to establish this and to identify the principal period and its velocity amplitude. Variability extends to the region, presumably just above the photosphere, providing the emission component seen in some CII lines and seen to vary greatly between 1989 and 1992. This region appears to provide a wind whose outflow is presumed responsible for the blue-shifted absorption seen in the HeI lines as part of their P-Cygni-like profiles. The outflow velocity in 1992 was about $30\,\mathrm{km\,s^{-1}}$. Nebular emission lines vary little in velocity, width and equivalent width between 1989 and 1992. They appear to be centred on the systemic velocity and the width of these lines indicates that the nebular has an expansion velocity of not more than about $23\,\mathrm{km\,s^{-1}}$.

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