Acknowledgements

I am most grateful to the observers mentioned in the footnotes to Table I for their coöperation in the observational coverage of the periastron passage of HD 192644 in 1997/8.

References

(1) T. Oja, *A&AS*, **71**, 561, 1987.
(2) *The Hipparcos and Tycho Catalogues* (ESA SP-1200) (ESA, Noordwijk), 1997, **9**, 2006.
(3) A. J. Cannon & E. C. Pickering, *HA*, **98**, 167 & 255, 1923.
(4) E. H. Olsen, *A&AS*, **39**, 205, 1980.
(5) N. Ginestet *et al.*, *A&AS*, **123**, 135, 1997.
(6) W. P. Bidelman, in R. F. Garrison (ed.) *The MK Process and Stellar Classification* (David Dunlap Obs., Toronto), 1984, p. 45.
(7) R. & R. Griffin, *JA&A*, **9**, 193, 1988.
(8) R. E. M. Griffin & R. F. Griffin, *MNRAS*, **312**, 225, 2000.
(9) C. W. Allen, *Astrophysical Quantities* (Athlone, London), 1973, p. 263.
(10) R. E. M. Griffin *et al.*, *A&A*, **254**, 289, 1992.

EMISSION-LINE SPECTRA OF XX OPHIUCHI IN 1996 AND 1997

By Aruna Goswami & N. Kameswara Rao
Indian Institute of Astrophysics, Bangalore 560034, India

and David L. Lambert
Department of Astronomy, University of Texas at Austin, TX 78712, USA

The star XX Ophiuchi has been known to exhibit peculiar spectral variability since the work of Merrill in 1924. A high-resolution spectroscopic study of XX Oph in 1996 July and 1997 June shows distinctly different line profiles in several spectral regions, the most pronounced being in the sodium *D* and Hα lines. The 1997 spectra exhibit *D* lines in emission with highly blue-shifted absorption components while in the 1996 spectra the absorption components are weak or absent. The Hα profile in 1997 is in emission with a flat top and broad wings while the 1996 spectrum has a sharp emission core and broad wings with several dips. Significant differences in profiles and velocities are also found in some other spectral regions, such as the oxygen triplet at 7774Å and Ca II *H* & *K*. Both sets of spectra exhibit emission lines, mostly due to ionized iron. We have estimated the displacement velocities of the strong emission-line profiles and their absorption components wherever possible. We have traced the available spectroscopic history of XX Oph and examined possible physical scenarios that might account for its peculiar variability. However, to understand the nature of this unusual object, high-dispersion spectra, particularly during episodes showing strong absorption components, are essential.

Introduction

The star XX Oph (MWC 269, HD 161114) has long been known to exhibit complex spectroscopic and photometric variations. No close match to its spectrum is known. Only three stars, BD +11° 4673, HD 190073, and MWC 560, have spectra resembling in part that of XX Oph, which makes it a particularly interesting object to study.

XX Oph has been known as an emission-line star since the discovery of Hα and many other hydrogen lines markedly in emission[1]. While spectra taken during 1921–1923 revealed numerous emission lines of ionized iron — the reason behind the star being dubbed an 'iron star' — the spectra in 1925 were found to be dominated largely by blue-shifted absorption lines[2]. Moreover, the 1925 spectra were characterized by lines of ionized titanium, stronger and more numerous than those of iron[3,4]. In later years the spectra were again found to be dominated by emission lines of iron. The star has also reportedly undergone periods where P-Cygni profiles or only absorption lines were present[5].

The discovery of XX Oph as a variable star dates back to 1924 when it was thought[6] to be of the R CrB type. However, extensive photographic observations of XX Oph and detailed studies of its light variation showed the photographic magnitudes to be fairly constant[6,7]. Photometric observations of XX Oph in the *UBV*, *VRI*, and *JHKLM* pass-bands made between 1981 April and 1984 April demonstrated no major variability[9], ranging only from $8^{m}\cdot87$ to $9^{m}\cdot09$. Using a combination of broad and narrow-band photometry, Lockwood *et al.*[10] found that the continuum shape from 0·36 to 10·2 μm is consistent with the contributions from a binary system of which the components are of spectral types B0III and M6III. The relative luminosities of the two components were found to be $\Delta M_v \sim 4^{m}\cdot3$. From the measured strengths of CO and H_2O molecular bands they further determined the luminosity type of the cool companion to be somewhere between M6I and M6III.

Infrared photometric studies of XX Oph assigned a colour temperature of 2420 K to the IR excess[11]. This excess, which resembles the continuum of an M-type star, could be due to free-free emission but could not be explained by thermal re-radiation of circumstellar dust[12,13]. Kleinmann & Kuhi[12] assigned a temperature of 16500 K to the hot component in XX Oph and estimated a mass-loss rate of ~ 5–$25 \times 10^{-6} M_{\odot}\mathrm{yr}^{-1}$. De Winter & Thé[14] fitted a black-body of 2900 K to the IR excess of XX Oph, indicating a spectral type of M4–M8. A circumstellar dust shell consisting of graphite and silicate particles cannot account for such high temperature. This in turn also lends support to the idea that the Be star in XX Oph has a cool M-type companion. Humphreys & Gallagher[15] too confirmed a spectral type of M5–M6 for the cool companion from near-infrared spectrograms where they found that the strengths of TiO bands with band-heads at 8859Å and 8937Å compare best with an M5 or M6 star.

The spectral classification of XX Oph is, however, yet to be established with certainty. Andrillat and Swings[16] observed P-Cygni profiles of the Pa_6 and He I 10830Å lines in a red spectrum of XX Oph, and classified it as P-Cygni type. Lee[17], following the definition of 'Infrared Stars' by Geisel[11], classified XX Oph as an 'Infrared Star'. The star is classified in *The General Catalogue of Variable Stars*[18] as a 'symbiotic object', featuring deep fadings of long duration, of spectral type Bpec + M5. The symbiotic-star classification includes slow novae, recurrent novae, proto-planetary nebulae, and also mass-transferring binary stars. MWC 560, whose spectra show typical nebular emission lines combined with the spectrum of a cool star, is also classified as symbiotic star. On a time scale of years, its luminosity shows variations of several magnitudes. Some recent studies, however, suggest that symbiotic stars are a heterogeneous collection of objects in a variety of presumably short-lived evolutionary stages. A number of catalogues of symbiotic stars, however, do not include XX Oph as a member[19, 20]. Michalitsianos *et al.*[21] have suggested that XX Oph, along with the peculiar emission line star MWC 560, may perhaps be in a critical stage of interacting-binary evolution, which could eventually lead to the formation of symbiotic stars and symbiotic novae.

Given such peculiar spectral variability, it is important to study this star at different epochs. In particular, to understand the presence and the cause of irregular and high-velocity motions of parts of the atmosphere which cause its peculiarity, it is necessary to study the velocity displacements of the various emission and absorption profiles of the star's spectrum as a function of time. While strong emission lines are believed to be formed in a large quiescent part of the atmosphere, the absorption lines are likely to be produced by gas rapidly moving away from the star's immediate environment. Thus the analysis of the various properties of numerous emission and absorption lines is likely to give us a more comprehensive idea of the structure and density of the envelope and reasons for its peculiar behaviour.

Observations and data reductions

The 1996 spectra of XX Oph were obtained on 1996 July 25 (3 frames each of exposure time 60 minutes) and on 1996 July 26 (2 frames each of exposure time 60 minutes) using *2dcoudé*, a cross-dispersed echelle spectrograph at the coudé focus of the McDonald Observatory's 107-inch (*Harlan Smith*) telescope[22]. The wavelength coverage is from 3880–10100Å and the spectral resolving power is about 60000.

The second-epoch spectra of XX Oph were also obtained using the 107-inch telescope on 1997 June 21. The *2dcoudé* spectrograph provided a wavelength coverage of 3960-10500Å from two exposures, each of 60 minutes duration.

The exposures from the same night were combined to increase the signal-to-noise ratio; a Th+Ar hollow-cathode-lamp exposure was used for wavelength calibration. The CCD data were reduced using the IRAF software package. The radial velocities of the well-defined narrow lines are measurable to an accuracy of about 1 km s^{-1}.

Description of the spectra: the emission lines

The spectra from 1996 & 1997 are both rich in singly-ionized lines, particularly of iron; several Ti II lines are quite prominent, with ionized Si, Sc, Cr, S, Mn, Ca, and neutral O, Na, Fe, Ti, Ni, and Mg also present. The forbidden lines of [O I] at 6300Å, 6364Å, and 5577Å are present in emission. Several other forbidden lines, for example, [Fe II] and [S II] at 4068Å, can be seen in the spectra. These are members of the group of forbidden lines found in emission in B[e] stars and listed by Jaschek and Jaschek[23].

Hydrogen lines: The 1996 Hα profile is characterized by broad wings and narrow emission cores, somewhat similar to those in certain symbiotic stars, such as Z And. The velocity of the central emission peak of Hα is measured to be −20 km s^{-1} on 1996 July 25. The 1997 June spectrum shows Hα also in emission but with a flat top, the centre at a velocity of −6 km s^{-1} (Fig. 1). The base widths are estimated to be, respectively, 11Å and 15Å in the 1996 and 1997 spectra, which are quite small compared to a base width of 50Å estimated by Merrill for the Hα line on his 1950 spectrum. In Table I we have compared the velocities of certain emission lines and their absorption components with the values from Merrill[5].

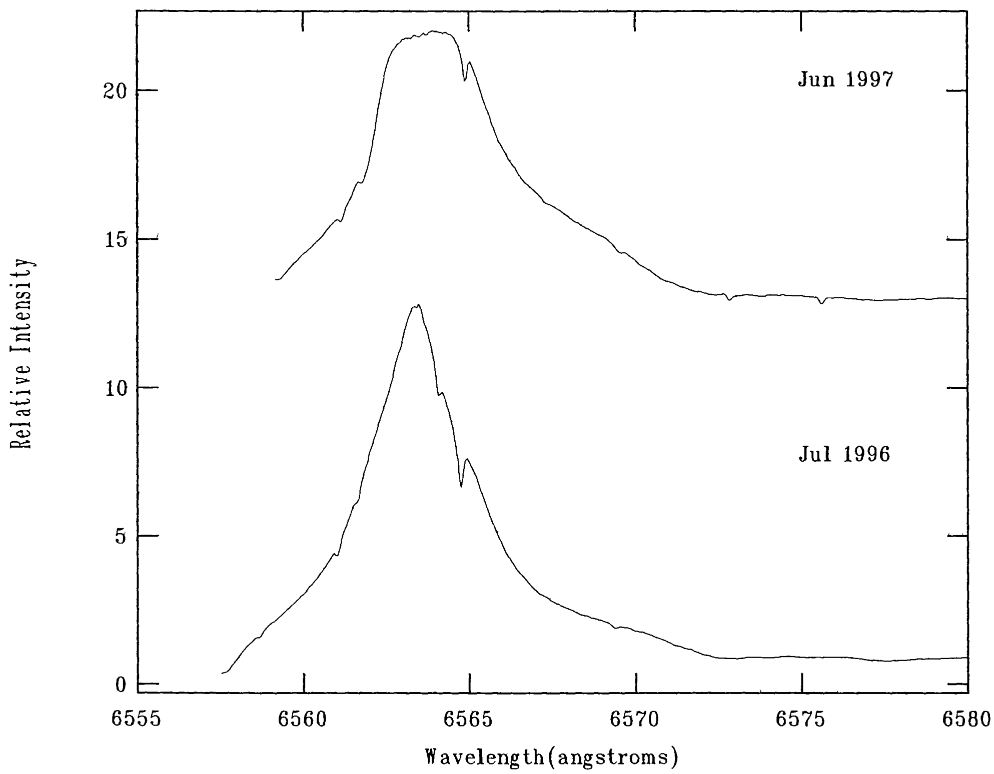

FIG. 1

A comparison of the Hα profile in the 1996 and 1997 spectra of XX Oph.

Merrill's 1959 spectrum of XX Oph is also characterized by strong, wide, and somewhat asymmetrical hydrogen emission lines with strong absorption components having large negative displacements, of ~ −393 km s^{-1} in 1959 and ~ −356 km s^{-1} in 1960, from their corresponding emission components. This difference of 37 km s^{-1} was believed to be real rather than due to measurement errors. Comparable outward velocities were reportedly observed in 1926, 1945, 1949, and 1950 on low-dispersion spectrograms. The absorption features reported by Merrill were transient and appeared in spectra taken in 1926, 1945, 1959, and 1960, although they were not P-Cygni shaped, as at other times.

In both the 1996 and 1997 spectra, Hβ, Hγ, and Hδ were observed in emission. The absorption component of Hβ was at a velocity of ∼ -334 km s^{-1} in 1996 with a sharp emission peak at velocity of ∼ -19 km s^{-1}. In the 1997 spectrum, the Hβ absorption feature has a broad structure (Fig. 2) and the emission profile has a central dip at a velocity of ∼ -25 km s^{-1}. The base width of the Hβ emission lines extends up to ∼ 6Å and ∼ 4Å, respectively, in 1996 and 1997, compared with a base width of 16.6Å found by Merrill in his 1949 spectra. The absorption component of Hα is out of our spectral range, falling between two orders. The Hγ central emission has a velocity of ∼ -21 km s^{-1}; its absorption component is displaced by ∼ -332 km s^{-1} in 1996. In 1997, the emission line was at a velocity of ∼ -23 km s^{-1} while the absorption component was displaced by ∼ -147 km s^{-1}.

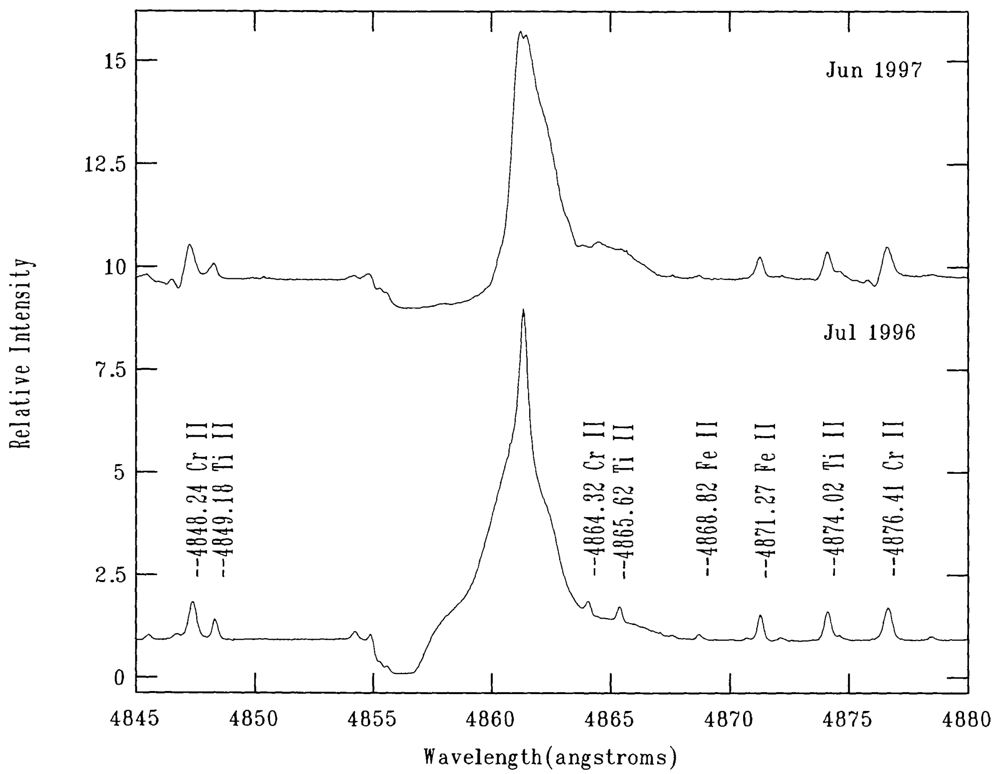

FIG. 2

A comparison of the Hβ profile and some adjacent metallic lines in the 1996 and 1997 spectra of XX Oph.

Fig. 2 displays the profile of Hβ and some adjacent metallic lines. Regarding the R CrB nature of XX Oph[6], the spectra do not indicate any under-abundance of hydrogen and thus it is unlikely that XX Oph belongs to the R CrB-type stars.

Helium lines: A number of He I lines — at 3888·646, 3964·724, 4471 (doublet), 4713·143, 4920·35, and 5015·675Å — are observed in absorption. As most of these lines are blended, their velocities cannot be estimated accurately.

The 3888·646Å line is blended with the absorption component of H_8, 3964·724Å with 3968·47Å Ca II, 4920·35Å with the 4923·921Å Fe II line, and 5015·675Å is blended with the Fe II 5018·434Å line. The 4143·76Å line too appears broad and blended.

The blue and violet lines of He I are inconspicuous in Merrill's 1949 spectra but in 1950 4471Å and 4026Å were present as diffuse emission lines.

Oxygen lines: Several permitted O I lines with a relatively low excitation potential are detected in both 1996 and 1997 spectra. These include the 7774Å and 8446Å triplets and a weak 6726·4Å doublet. Fig. 3 compares the oxygen 7774Å triplet in 1996 and 1997.

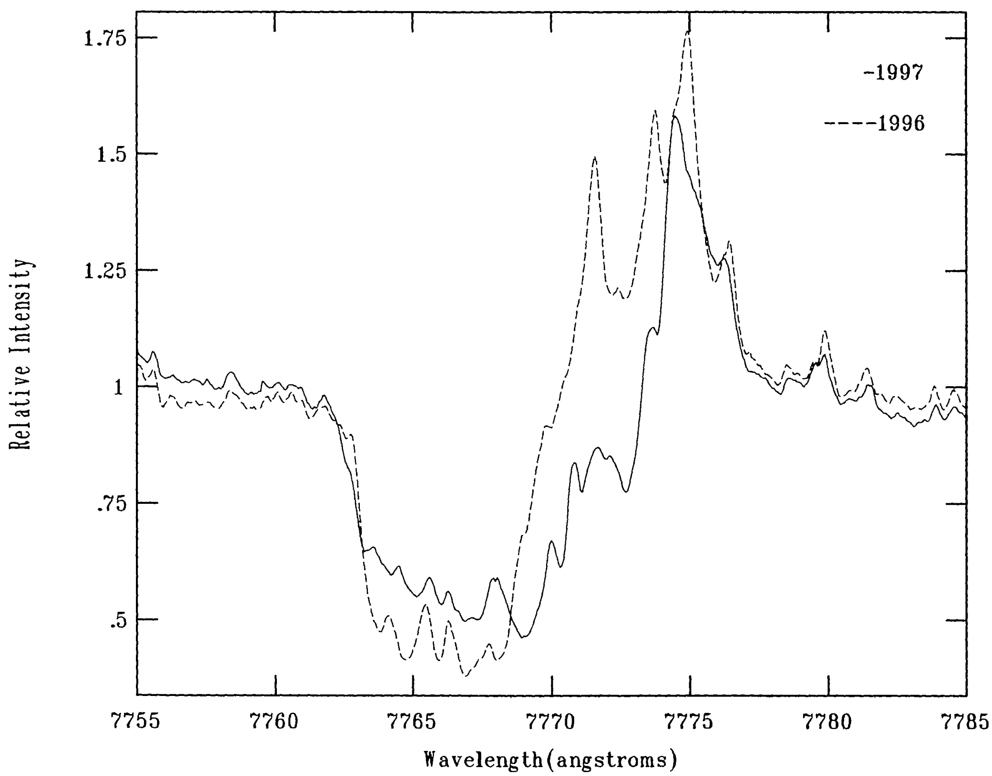

FIG. 3

A comparison of the oxygen-triplet region in the 1996 and 1997 spectra of XX Oph.

Sodium D Lines: In Fig. 4 the dashed curve shows the sodium-line profiles in 1996 while the solid curve shows them in 1997. The large difference between the profiles is clearly visible. In the 1997 spectrum, several blue-shifted components of the *D* lines can be seen; similar absorption components are absent in the 1996 spectrum. This implies that the star was at a very different state of activity, undergoing a rapid change between these observing periods, which was likely to be a mass-loss episode.

The *D* lines were also conspicuous in emission in Merrill's spectra, the bright lines yielding the same velocities as other metallic lines. Their long-ward edges were bordered by strong dark lines, possibly interstellar, while weak diffuse absorptions extended short-ward for about 2Å .

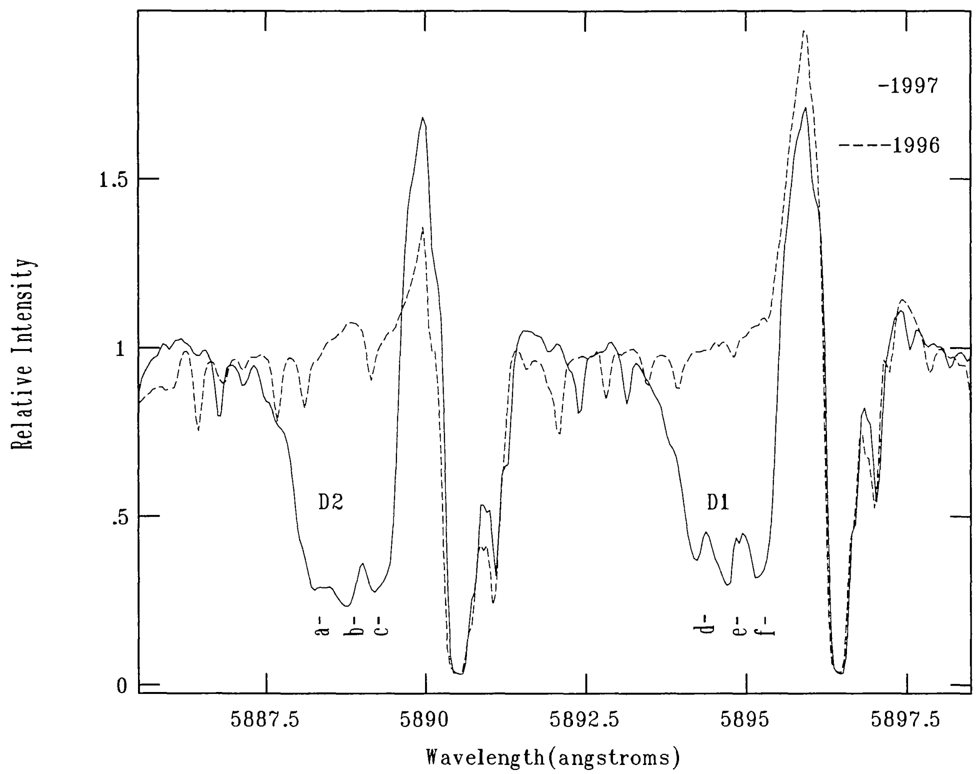

FIG. 4

The sodium *D* lines in the 1996 and 1997 spectra of XX Oph. In the 1997 spectrum the blue-shifted components of the *D* lines designated by a, b, c, d, e and f are at velocities of −131, −104, −82, −128, −112 and −76 km s^{-1}, respectively; similar absorption components are not noticed in the 1996 spectrum.

Other lines: Emission lines of ionized metals dominate the spectra. Mn, Ti, Si, Sc, Ca, Cr, S, *etc.*, are represented along with some neutral lines of He, Mg, Na, Ti, Fe, and Ni. Fig. 5 shows the spectral region around 4500Å in 1996 and 1997. We have estimated the average velocity of the best lines for direct comparison with Merrill's results[5] in Table I.

The *H* & *K* lines are complex with broad absorption components, while in 1949 they had several well-defined, strong, sharply-bounded absorption components having large negative displacements. N II at 6482Å, which is strong or moderate strength in Merrill's 1949 spectra, is not seen in our spectra. In Merrill's 1949 spectra, some lines, especially Ti II, had weak, narrow absorption components on their short-ward edges; in 1950 the emission lines were stronger and the absorption lines were absent. Among other strong emission lines are the infrared Ca II triplet: 8542·089Å and 8662·14Å appear in emission with significantly displaced absorption components. K I lines at 7664·907Å and 7698·979Å are clearly observed in emission in both 1997 and 1996; the average velocity measured from the central emissions of those lines is found to be ~ −35 km s^{-1} in 1997 and ~ −41 km s^{-1} in 1996. The blue-shifted absorption components have an average velocity ~ −63 km s^{-1} in 1997 and ~ −64 km s^{-1} in 1996. Merrill[5] noted that the stronger lines have P-Cygni profiles indicating an outflow velocity of 300–400 km s^{-1}.

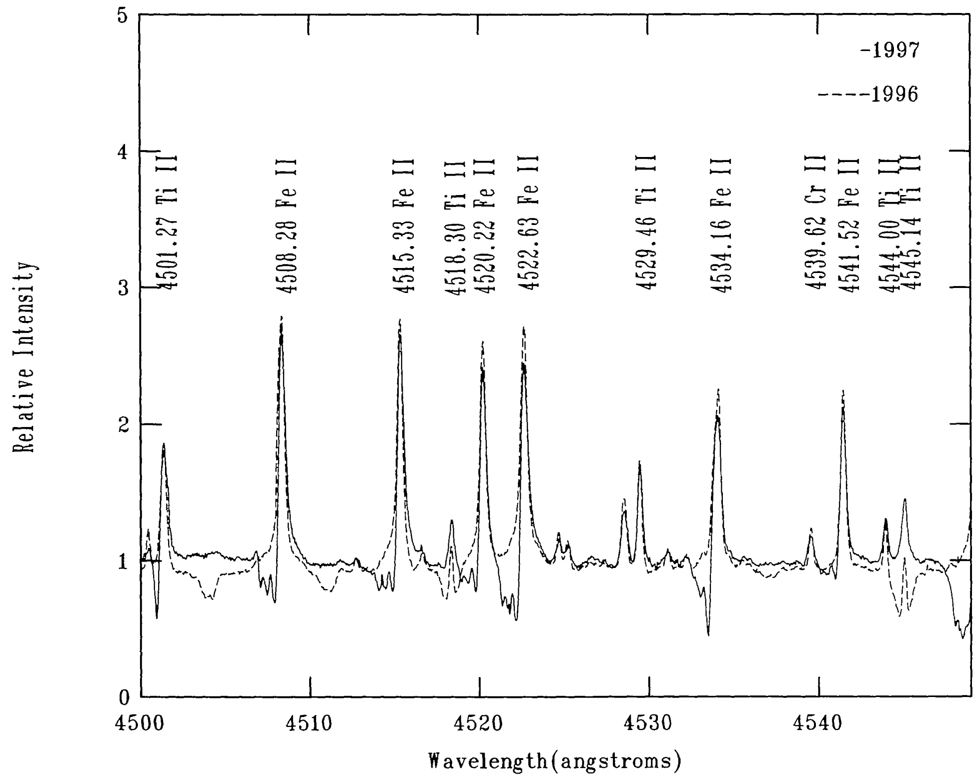

FIG. 5

The region around 4500Å in the 1996 and 1997 spectra of XX Oph.

Lockwood *et al.*[10] reported a depression at 0·78 μm and attributed it to TiO, while showing that the energy distribution is dominated by the hot star at the shorter wavelengths. We could not trace any evidence in our spectra for TiO bands in the 7700–7800Å range, which are strong in middle- and late-M-type stars. It may be that the continuum from the hot star is too strong, veiling the molecular bands in our spectrum.

Forbidden lines: The [O I] lines at 5577, 6300, and 6363Å are sharp and clearly present. Since these lines are most probably optically thin, the profiles reflect the velocity distribution of the emitting gas; such forbidden lines are good diagnostic tools. A flux ratio of F[O I]= (F(6300) + F(6363))/F(5577) = 1·7 ± 0·3 is estimated, with $F(\lambda) = W(\lambda)F_C(\lambda)$, where $F(\lambda)$ is the flux in the line, $W(\lambda)$ is the equivalent width, and $F_C(\lambda)$ is the continuum flux corrected for interstellar reddening. The measured equivalent widths of the emission lines have been converted to line fluxes using *UBVRI* colours from de Winter & Thé[14] to define the continuum flux, with a reddening correction of $E(B-V) = 1{\cdot}30$.

The forbidden lines of [Fe II] varied in intensity from 1996 to 1997 but were never very strong. They yield an average velocity of ~ -44 km s^{-1}, which is comparable to those of the permitted lines. [S II] at 4068Å is definitely present while the 4076Å line is weak or absent.

TABLE I

Displacement velocities in km s⁻¹

Sp. feature		1997⁺	1996⁺	1960*	1959*	1945*	1926*
Hα 6562·817	absorption	—	−332	−357	−397	−407	−336
	emission	−6	−20	−23	−20	−23	−6
Hβ 4861·342	absorption	−96	−334				
	emission	−23	−19				
Hγ 4340·468	absorption	−147	−332				
	emission	−23	−21				
Metals[a]	absorption	−74	−327	−356	−393	−446	−358
	emission	−46	−41	−43	−39	−35	−34
[Fe II]	emission	−32	−44	−45	−39		
K I 7664·907	absorption	−67	−61				
	emission	−36	−42				
K I 7698·979	absorption	−62	−64				
	emission	−35	−40				
Na I 5889·925	absorption	(a) −131	—				
		(b) −104	—				
		(c) −82	—				
	emission	−43	−38				
Na I 5895·925	absorption	(d) −128	—				
		(e) −112	—				
		(f) −76	—				
	emission	−40	−36				

* from Merrill[5]
⁺ present work
[a] average displacement velocity of neutral and ionized lines in 1996 and 1997 spectra are calculated for direct comparison with Merrill's results.
a–f: see Fig. 4

Fe I and Fe II lines: We have identified a large number of Fe I and Fe II lines in both 1996 and 1997. It is well known that if the emitting gas is optically thin, the left hand side of the following equation giving the line flux,

$$\log\,(W(\lambda)F_C(\lambda)) - \log gf + 3\log\lambda = \log N_2/g_2 + \log C$$

should be fairly constant within a multiplet unless the gas is optically thick or the excitation is very peculiar. In the above equation $W(\lambda)$ is the equivalent width, $F_C(\lambda)$ is the continuum flux corrected for interstellar reddening, C is a constant, N_2 is the upper level population, and g_2 is the statistical weight of that level. We found that for both Fe I and Fe II lines, within a multiplet, the left-hand side of the above expression does not give constant values, implying that the lines are coming from optically thick gas for which the line flux may be almost independent of the *gf* value. Fe I and Fe II lines give similar velocities, an average of ~ -41 km s^{-1}.

Discussion and conclusions

The spectral nature of XX Oph changes distinctly between different epochs and to trace its history requires continuous monitoring of the star, following its behaviour from when it is in emission to the state when its spectrum exhibits both emission and absorption. Close observation of these gradual changes is likely to reveal valuable information regarding the star's physical environment. It is possible that the unique structure and mass loss from XX Oph can be understood in terms of the evolution of a closely-interacting binary. In particular, Bath[23] has suggested that, in certain cases, mass transfer may lead to dissipation of the convective member of the binary (thus the system becomes a single star) and to mass outflow from the system through the formation of an 'excretion disc'.

The peculiar emission-line star MWC 560 is known to show great similarity to XX Oph as far as spectroscopic behaviour is concerned[21]. Both exhibit highly blue-shifted absorption components of the hydrogen lines and also, in a few cases, of other metals. The maximum velocities observed in blue-shifted absorption components in XX Oph are, however, much smaller, almost by an order of magnitude, than those of MWC 560. Both exhibit TiO absorption bands, at 8470, 8880, and 9350Å, which are characteristic of M0-M5 giants[25]. Although the natures of both the stars are difficult to establish, a physical scenario of a binary system consisting of an M giant and a compact secondary star, where a variable mass-transfer rate from the giant onto the compact secondary star causes its rapid photometric flickering[26], could perhaps be true for XX Oph also.

The strong emission lines of XX Oph indicate a large emitting atmosphere, but the cause of such an extended atmosphere is not yet clear. As both permitted and forbidden lines of various atoms and ions yield similar velocities, the emitting regions seem relatively quiescent. As the absorbing layers seem to be more active, high-dispersion spectra of XX Oph, with its strong and numerous displaced absorption lines, are likely to provide vital information.

The velocities derived from metallic lines appear essentially the same as those found by Merrill on several occasions, as shown in Table I. An interesting feature of Table I is two very distinct Hα emission régimes characterized by different velocities: while the years 1945, 1959, 1960, and 1996 show a velocity ~ -20 km s^{-1}, the two years 1926 and 1997 have a very different value of ~ -6 km s^{-1}. Further observations are critically needed to understand the nature of this unusual object.

References

(1) W. P. Fleming, *Harvard Circ.* No. 143, 1908.
(2) P. W. Merrill, *PASP*, **36**, 225, 1924.
(3) P. W. Merrill, *PASP*, **38**, 45, 1926.
(4) P. W. Merrill, *ApJ*, **75**, 133, 1932.
(5) P. W. Merrill, *ApJ*, **133**, 503, 1961.
(6) S. Beljawsky, *Beobachtungszirkular der Astron. Nachrichten* No. 24, 1924.
(7) H. Shapley & I. E. Woods, *Harvard Circ.* No. 292, 1926.
(8) R. Prager, *Harvard Bull.* No. 912, 1940.
(9) D. Kilkenny *et al.*, *SAAO Circ.*, No. 9, 55, 1985.
(10) G. W. Lockwood *et al.*, *ApJ*, **195**, 385, 1975.
(11) S. L. Geisel, *ApJ*, **161**, L105, 1970.
(12) S. Kleinmann & L. V. Kuhi, *PASP*, **84**, 766, 1972.
(13) P. Kuan & L. V. Kuhi, *ApJ*, **199**, 148, 1975.
(14) D. de Winter & P. S. Thé, *Ap&SS*, **166**, 99, 1990.

(15) R. M. Humphreys & J. S. Gallagher, *PASP*, **89**, 182, 1977.
(16) Y. Andrillat & J. P. Swings, *ApJ*, **204**, L123, 1976.
(17) T. A. Lee, *PASP*, **82**, 765, 1970.
(18) P. N. Kholopov, *General Catalogue of Variable Stars* (Moscow Pub. House, Moscow), 1990.
(19) D. A. Allen, *Proc. Astr. Soc. Australia*, **5**, 369, 1984.
(20) S. J. Kenyon, *The Symbiotic Stars* (Cambridge University Press), p.148, 1986.
(21) A. G. Michalitsianos *et al.*, *ApJ*, **371**, 761, 1991.
(22) R. G. Tull, *PASP*, **107**, 251, 1995.
(23) C. Jaschek & M. Jaschek, *The Classification of Stars*, (Cambridge University Press), 1987.
(24) G. T. Bath, *MNRAS*, **171**, 311, 1975.
(25) D. K. Lynch *et al.*, *IAU Circ.*, No. 5009, 1990.
(26) H. Bond *et al.*, *BAAS*, **16**, 516, 1984.

CORRESPONDENCE

To the Editors of 'The Observatory'

NavPac to the Rescue

Further to my review (**120**, 404, 2000) of *NavPac and Compact Data 2001–2005*, I shipped this publication on a recent Atlantic crossing *via* high latitudes (seeking and finding a bay in the Arctic ice close to 80 degrees North which possibly marked the end of the Gulf Stream, which we had approximately followed from the latitude of Long Island).

During our passage — near the Grand Banks in strong winds and thick fog — we realized that our large-area charts of the North Atlantic were not on the gnomonic projection as we expected but on Mercator's (US Nos 121 & 126). Moreover, our new GPS gave bearing and distance to our next landfall but nowhere stated whether the bearing was great circle or rhumb line, either in memory or handbook; we repeatedly explored both in mounting frustration. Finally I booted *NavPac* on the laptop and I had the answer in 30 seconds.

As we proceeded onwards it became clear that the sensible way to organize the operation of the GPS (which the manufacturer has now done) is to update the great circle continually, thus updating and improving the traditional technique I learned many years ago. However, I must commend the clarity of the *NavPac* package, which always explains what it does in an instantly understandable way. Moreover, one always has the confidence that should all the electronics go down the raw data are available for pencil and paper navigation using the trusty sextant!

Yours faithfully,
JOHN MAGRAW

The Bungalow,
Townend
Ardington
Oxon, OX12 8PY

2000 November 23