ATLAS OF M7III SPECTRAL FEATURES IN THE OPTICAL

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(Received 9 January 2002; accepted 17 August 2002)

Abstract. The difficulties encountered in attempts to study the spectra of very late stars inspired us to prepare this spectral atlas containing essentially spectral features of M7III stars in the optical spectral region. As representative star we took the cool component of the binary symbiotic CH Cygni during one of its quiescent phases. Total number of 920 atomic lines and molecular bands have been identified with different degrees of reliability.

Keywords: atlases – stars: late type-line: identification – molecular data – atomic data

1. Introduction

In conjunction with our studies of symbiotic stars in quiescence we have made an extended analysis of the optical spectrum of CH Cygni obtained at the Haute Provance Observatory from 1987 to 1989.

This atlas can be taken as an essential guide for identification of late M type spectra though it originates from our study of the binary star CH Cygni. Namely, CH Cygni is a symbiotic star consisting of two components, both of them contributing to the symbiotic spectrum during active phases (Mikolajewski et al., 1990) But in quiescence, during which the spectrograms used have been taken, the spectral features of the cool component dominate the spectrum (Kotnik-Karuza et al., 1992).

This work was done initially for our own use but we have since organized parts of it into atlas form. Since the electronic version from which the plots have been obtained has been lost in the several computer/media passages over the last decade we made hand-draw identifications on a clean version of the plot and scanned them in order to make them electronically available. We have had numerous requests for both the paper as well as the electronic version of this atlas. So we have summarized this material here to make it widely and permanently available. The laborious and extensive identification work has been done by searching the old and up to date literature on atomic data (Moore, 1959), NIST (Atomic Spectra Database) and molecular data (Davis, 1947; Jorgensen, 1994)

Astrophysics and Space Science **288:** 269–277, 2003.

2. Cool Component of CH Cyg

2.1. OPTICAL SPECTRUM

It is well known that the spectral features of the cool component dominate the spectrum of CH Cygni out of its active phases (Mikolajewski et al., 1990). The extreme complexity of these spectra in the optical region is to a great extent a result of overlapping atomic absorption lines and molecular bands belonging to different molecular species and their isotopes. These phenomena lead to a considerable truncation of the continuum which introduces additional difficulties regarding line identification. There are also some emission lines which can be assigned either to the remnants of the symbiotic phenomenon or to the intrinsic characteristic of the M type star atmosphere.

It has been generally accepted that shock waves created by the pulsations in the extended atmosphere of M giant stars are mainly responsible for the excitation of emission lines observed in the spectra (Hinkle et al., 1982). However in our case strong arguments speak in favour of symbiotic phenomenon being at least partly responsible for the appearance of the emission lines. For example, comparison of radial velocity curves of Fe II (permitted and forbidden) lines and of photospheric lines suggests that the Fe II lines might be associated to the hot companion (Kotnik-Karuza et al., 1992). Radial velocities of the Balmer lines give evidence that the Balmer region is a slowly expanding shell of material ejected by the cool component. The time evolution of Balmer profiles during the observed 1987–89 quiescent phase seems to reflect the variable rate of the mass flow via stellar wind onto the hot component. The λ5007[OIII] line is formed in nebula supplied by mass loss of the cool component via stellar wind and ionized by the radiation from the hot component (Kotnik-Karuza and Jurdana-Šepić, 1998).

In any case the emission lines do not disturb the pure spectrum of the M type star but represent a valuable extra information.

2.2. SPECTRAL CLASSIFICATION

The cool component of CH Cyg was observed since the early twenties and adopted as an MKK spectroscopic standard for the spectral type M7III (Tomov et al., 1996). Since then a lot of work has been done regarding its classification (Table I) which is seriously complicated by an insufficient number of standards for spectral classes later than M6 as well as the fact that probably all stars of such late spectral types are Miras or semiregular type variables. The classification is primarily based on the strength of the TiO bands which are the most outstanding features in the optical and near IR spectral region.

Particularly relevant for this work is the classification of Mikolajewski et al. (1990) which is based on observations of CH Cyg made during the same quiescent phase as ours. The graphical representation in Figure 7 of Mikolajewski et al.

TABLE I
Spectral classifications of the cool component of CH Cyg

Spectral type	Reference
M6	Graff, 1924 a,b
close to M7	Yamashita, 1967
M7	Gusev and Caramish, 1970
close to M7 rather than M6	Gusev, 1976
M6.5 ± 0.3	Kenyon and Fernandez-Castro, 1987
M6.9 ± 0.4	Taranova and Shenavrin, 1989
M6.5–M7.2	Mikolajevski et al., 1990
M8	Huang et al., 1994
M7.5	Mürset and Schmidt, 1999
M6.7	Zhu et al., 1999
later than M7	Kotnik-Karuza and Jurdana-Šepić, 2000

TABLE II
Details of the spectrum

Spectrogram	Date	JD 2440000+	Reciprocal linear dispersion (Å/mm)	Wavelength range (Å)
GA 7576	1. 6. 1987.	6947	20	3750-4950
GA 7577	2. 6. 1987.	6948	20	4840-6800

(1990) which compares observations of CH Cyg with the M6III and M7III standard spectra, clearly speaks in favour of M7III type.

3. Spectrograms

The presented spectral atlas of CH Cygni is based on resolution R $\approx$ 15000 photographic observations extending from 3750-6800 Å. The observations were made with Coudè spectrograph at the 152 cm telescope of the Haute Provance Observatory. The spectrograph was operated at reciprocal linear dispersion of about 20 Å/mm, the spectrograms were digitized with the PDS microphotometer and the intensity vs. wavelength tracings have been obtained by means of the ELSPEC program at the ASTRONET pole of the Trieste Observatory.

TABLE III

Number and type of identified spectral features

Total number of features: 920			
Absorption: 882		emission: 38	
molecular bands	atomic lines	forbidden	permitted
135	747	30	8

The details of the spectrum are given in Table II. It can bee seen that the atlas is composed from the data originating from two spectrograms covering different optical spectral regions and observed on two succeeding days. The time difference should not affect the cool component's spectrum during quiescence.

4. Atlas Contents

The atlas contains 45 pages with the total number of 920 identified features, the types of which have been summarized in Table III.

The spectral content of atomic features is displayed in Table IV and that of molecular ones in Table V. Due to insufficient resolution of our spectra we could not resolve the rotational structure of molecular bands, so that only identified molecular bands and subbands of the corresponding electronic transitions are given. Although the TiO molecular features dominate the spectrum, several molecular bands belonging to ZrO and ScO molecules have also been observed.

Figure 1 gives an example of the observed spectrum with identifications added. Each identified line is characterised by its chemical symbol, degree of ionisation, multiplet number and wavelength in angströms. The identification of molecular bands refers to their heads: it contains the symbol of the molecule, electronic system, vibrational quantum numbers of the upper and the lower electronic state, subband designation and wavelength in angström in air. The shading has not been specified since it is unique for all observed bands which are red shaded.

The position of atomic spectral lines on the wavelength scale are plotted by taking into account the heliocentric radial velocities, determined with an error of $\pm$ 5 km/s (Kotnik-Karuza et al., 1992) and given in Table VI. Lines with central depths stronger than a few percent have been identified. The ordinate in each plot is a logarithm of the relative flux.

On the whole plot, the identifications are displayed as labels on the top of the spectrum. Lines above the spectrum point precisely to the exact position of the spectral lines on the wavelength scale. A full line stands for a reliably identified unblended spectral line. A dashed line represents an absorption line with a

TABLE IV
Identified atomic lines

Atom	Number of lines	Wavelength range (Å)
H I	5	4340–6563
He II	1	4100
O I	2	6300–6363
O III	3	4363–5007
Ne III	1	3868
Na I	2	5889–5896
Mg I	5	3829–4168
Al I	4	3931–3945
Si I	1	4102
S II	1	4068
Ca I	9	3948–6573
Ca II	1	3933
Sc I	6	3907–5550
Sc II	13	4246–4717
Ti I	103	3752–5907
Ti II	10	3759–4601
V I	123	3793–5735
V II	10	3945–4206
Cr I	154	3790–5574
Mn I	17	3790–5433
Mn II	1	4345
Fe I	175	3758–5507
Fe II	28	4231–5019
Co I	37	3841–4392
Ni I	16	3772–4463
Ni II	1	6467
Sr II	2	4077–4216
Y I	1	4142
Y II	1	3967
Zr I	14	3780–4278
Zr II	4	4277–4496
Cb I	6	4058–4169
Ba II	3	4934–4555
La II	20	3759–3937
Ce II	1	4113
Gd II	4	4292–4338

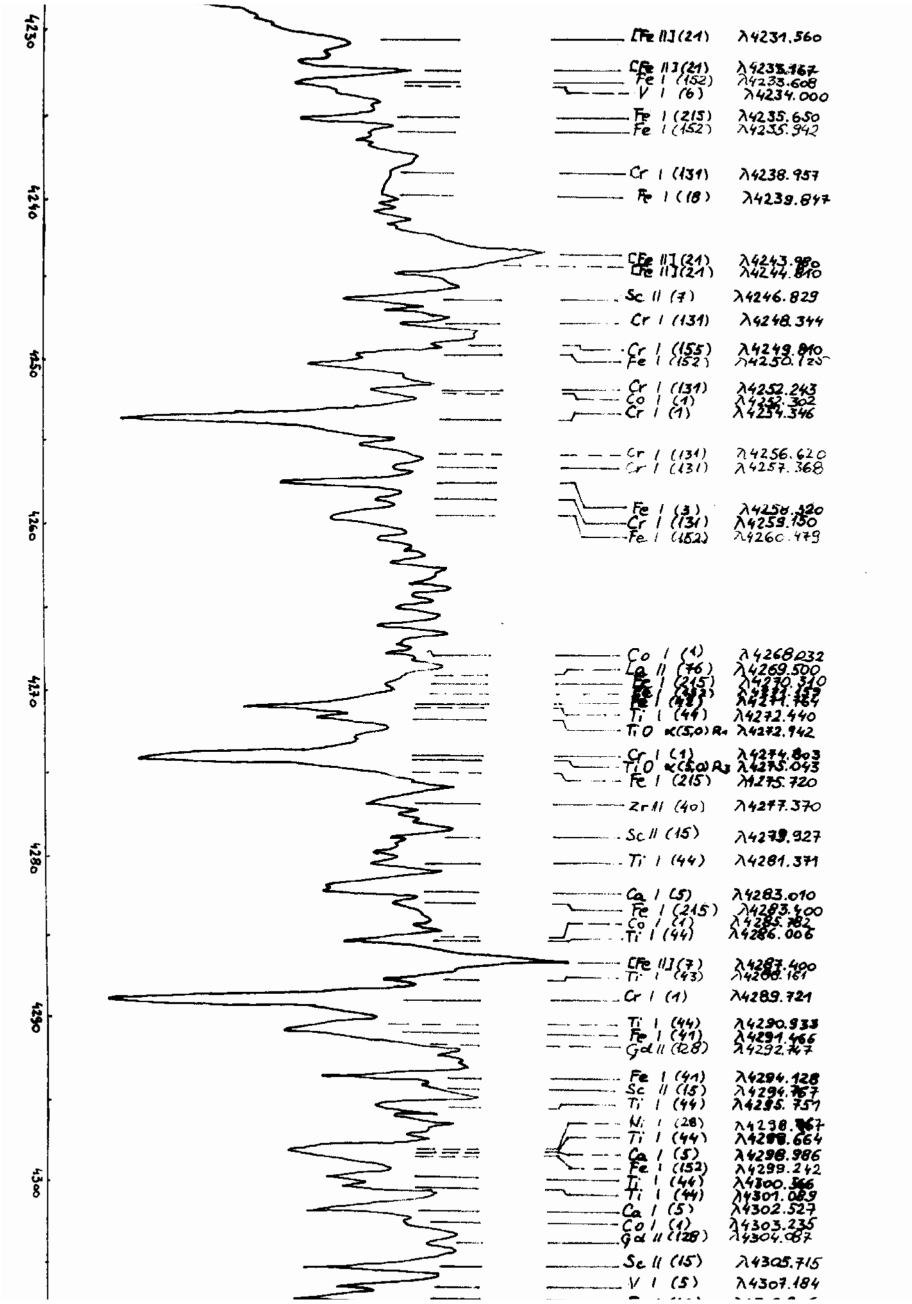

Figure 1.

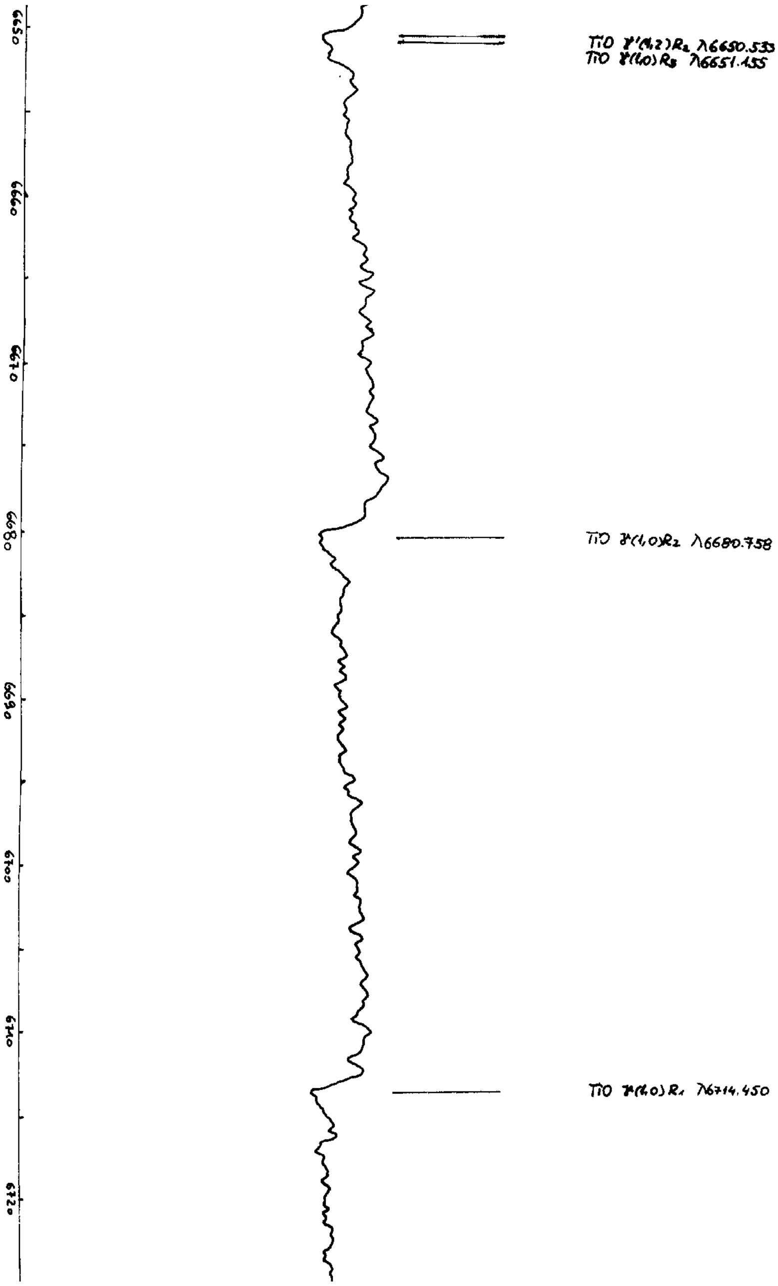

Figure 1. Part of the observed photospheric spectrum of CH Cygni: a) section of the blue spectrum containing atomic absorption and emission lines; b) section of the red spectrum clearly showing the TiO molecular bands of the γ and γ' system. The γ system is represented by the three subbands of the (1,0) band.

TABLE V
Identified molecular bands

Molecule	Electronic system	Number of bands	Wavelength range (Å)
TiO	α	62	4272–6664
TiO	β	8	5115–6103
TiO	γ	41	5853–6715
TiO	γ'	13	5200–6663
ZrO	α	1	4850
ZrO	β	2	5629–5717
ZrO	γ	3	6412–6543
ScO	III	4	6063–6092
ScO	V	1	6115

TABLE VI
Radial velocities of identified spectral lines

Spectral lines	RV(km/s)
photospheric absorption lines of neutral metals and metalic ions	–55
emission lines Fe II, [Fe II]	–68
emission lines H I	–60
emission lines [S II], [O I], [O III], [Ne III]	–65

not well defined dip. A question mark added to the dashed line means unreliable identification which can be due to the following reasons:

– its radial velocity lies outside the given error limits ($\pm$ 5 km/s)
– the multiplet itself contains only one line
– only one identified line of a multiplet falls in the observed wavelength range
– certain element is represented by a too small number of identified spectral lines.

5. Availability of the Atlas

The paper version of the atlas is available from the Astronomy Department, University of Trieste. Atlas files in EPS and GIF format, README file and a file with line identification list are available in electronic form through the www:http://www.phy.pefri.hr/ATLASM7III.

6. Conclusion

After a thorough study of complete bibliography on late M giants we have not found any similar identified spectral record. The work of Davis (1947) dealing with β Pegasi refers to earlier M types. So we hope that this atlas will provide a useful material for future research of the spectra of the coolest M giants.

Acknowledgements

Thanks are due to all our collegues who inspired and encouraged us to publish this work, particularly to M. Hack, K. Pavlovski and V. Vujnović. We also express our sincere gratitude to P. Bonifacio from the Astronomical Observatory of Trieste who kindly assisted with the preparation of the atlas. We are greatly indebted to the anonymous referee for encouraging us to bring this work to its final version.

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