NEAR IR SPECTRA OF SYMBIOTIC STARS

Y. Andrillat
Observatoire de Haute Provence
04870 St Michel l'Observatoire (France)

It is very well known that symbiotic stars are displaying at the same time spectral characteristics of hot stars, cool stars (principally of M type), nebulae and circumstellar dust envelopes.
The investigation of the near IR is particularly interesting because one finds there important features of these different objects.

HOT STARS

In the near infrared region up to 1μ , the helium lines : He I λ 10830, He II λ10123, and the oxygen lines OIλλ 7772-8446 are very useful to construct theoretical models.

- Helium lines :

the quantitative observations are very crucial because they assign important constraints to the law for ionization distribution in the models.
He I λ 10830 ($2s^3S - 2p^3P$) - upper metastable level - is produced only by a highly excited state, and only at temperatures as high as 20 000°K. This lines has been found as a strong emission in WR stars and other early type emission line stars : Of, principally in the supergiants (Vreux, Andrillat 1979), Be stars (Andrillat, Swings 1976).
In the later type, it appears in absorption or in emission but with a weak strength (W = 100 - 1000 mA in a few G and early K stars).
It is not present with an appreciable intensity in the M stars (Vaughan, Zirin 1968).

He II λ10123 : This line is the first member of the Pickering serie ($n = 4 \longrightarrow n = 5$).
It has been observed to be in emission in WR, in absorption or in emission in O and Of stars (Andrillat, Vreux 1975 and Vreux, Andrillat 1979). Observations of this transition are extremely important to develop our understanding of helium line formation and the ratio I(10123) / I(4686) permits in particular to decide which mechanism produces He II λ4686 emission line (collisional desexcitation, pumping...).

M. Friedjung and R. Viotti (eds.), The Nature of Symbiotic Stars, 47–56.

https://doi.org/10.1017/S0252921100097414 Published online by Cambridge University Press

- Oxygene lines:

O I λ 8446 ($3^3S° - 3^3P$) is observed in emission in Be stars, novae and generally its intensity is very high compare to the one of the λ 7772 line.
In many cases, this anomalous strength is explained by a fluorescence mechanism due to Lβ absorption by O I atoms : for example, this process has been confirmed from observations of the other IR transitions λ 10295-302 in the spectrum of Nova Sct 1975 (Andrillat et al. 1975).

The λ 7772 line ($3^5S° - 3^5P$). This triplet appears in emission in novae and in a few Be stars (Andrillat, Houziaux 1967).
It cannot be excited by a fluorescence mechanism. It is visible in absorption in stars of the other types (A to M). It is an excellent criterion of luminosity (Parsons 1974).
Its intensity is temperature dependent because the high excitation potential (9.15eV) of the metastable $3s^5S$ lower level. It is particularly strong in Supergiants where the extended atmospheres allow low collisional desexcitation rates.

COOL STARS

In the near infrared, there are many characteristic TiO and VO bands which permit to classify the late type stars,principally the M stars. Several works on spectral classification have been done by different authors using a low dispersion who have described the appearance of the TiO and VO bands at various spectral types (Mavridis 1966 - McCarthy and al. 1966 - Wing 1966 - Albers 1974).
All their classifications are based upon the intensity of the principal bands of :
TiO : λλ 7054-7126-7589-8194-8300-8432-8859
VO : λλ 7900-10500.
The table 1 gives schematically the principal characteristics of the different spectral types of giant M stars.

Table 1

Spectral type	First appearance Ti O	VO
M0	7054-7126	
M2	7589	
M4	8432	
M5	8194-8859	7900
M6	8300	

a complex of VO bands around λ 10500 is very strong in the latest spectral types M8-M10.

It is important to note, among these bands, some are blended with some

https://doi.org/10.1017/S0252921100097414 Published online by Cambridge University Press

telluric bands situated at :
O_2 molecular bands : λ6870 (B) - λ 7593 (A)
H_2O " " : λ 7190 (a) - λ 8227 (Z) - λ 9060 (γ) - λ 9420 (ρ)
However, it is possible to recognize the molecular bands, because the modification due to the blending with the telluric bands are generally very typical.

Near infrared spectral features permit also to determine the luminosity criteria (Albers 1974 - Treanor, McCarthy 1966 - White, Wing 1978).

- Supergiant M stars

The CN bands λλ7800-8000 are enhanced in the spectra of M stars of high luminosity (Sharpless 1956). In the supergiant M stars, the λλ 8308-8330 features due to the blend of titanium and iron lines are very well visible.

- Giant M stars

In luminosity class III, the CN bands λλ 7800-8000 are extremely weak or absent. The Ca II triplet (λλ 8498-8543-8663) is strong.

- Dwarf M stars

The Ca H bands near λ6385 and λ6880 are prominent (Ohmen 1936).
The Na I doublet (λλ 8183-8195) is clearly present.
The sodium lines and the Ca H bands are good luminosity criteria for the dwarf stars over the range M0-M5.

NEBULAR LINES

In the near IR, one finds several interesting forbidden lines which are present in novae (nebular phase), Be[ ] stars, planetary nebulae and which are used to determine the physical parameters (Te, Ne)

- [S III] λλ9532-9069, the strongest lines in PN
- [S II] λλ10284-10370 which permit access to reddening problems by comparison with the blue doublet (λλ 4068-4076).
- [C I] λλ 8727-9823, [S I] λ7726, [O II] λλ7319-7331, [Cl III] λλ8196-8580, [Cl IV] λλ7530-846, [A III] λλ7136-7751, [A IV] λλ7237-7263, [A V] λ7006
- Some lines of [Fe II] λλ7155-7452, [Fe IV] λλ7189-7221-7923 have been found in Be[ ] (Swings 1969).

Taking into account the precedent remarks, it appears that the near infrared study will bring interesting informations in particular concerning the spectral classification and the luminosity class of the "cool spectrum". As far as the "hot spectrum" is concerned, it will be possible to precise the formation mechanisms of the helium and oxygen . Nevertheless, there are very few obervations in this region.

SPECTRA OF THE SYMBIOTIC STARS BETWEEN λλ 8000-11000

A first glance permits to distinguish 2 kinds of near infrared

https://doi.org/10.1017/S0252921100097414 Published online by Cambridge University Press

spectra of the symbiotic stars:
- Relatively poor spectra which correspond to "old and classical symbiotics" very well known from several decades (RY Sct, EG And, CH Cyg, AG Dra, AG Peg...). (Fig.1)
- Spectra very rich in emission lines and molecular bands corresponding to stars in evolution which had a recent outburst (RX Pup, V1016 Cyg (1964), HM Sge (1975), HBV 475 = V1329 Cyg (1969)). (Fig.2).
In July and August 1981, we have obtained the spectra of these objects (Haute Provence Observatory - 193 cm Telescope - Spectro ROUCAS + Image Tube - spectral range λλ 8000-11000 - dispersion 230 A.mm^{-1}).

RY Sct

The spectrum of RY Sct shows [Fe III] emission lines which are currently found in the spectra of some novae and a few symbiotic stars (BF Cyg for example in the blue visible spectrum).
The spectra obtained by Cowley and Hutchings (1976) do not confirm a possible relation with these objects. These authors proposed a model consisting of 2 massive stars embedded in an unusual nebulosity showing strong [Fe III] emissions. RY Sct has been identified as a radio binary source.
- Our spectrum obtained the 3.7.1981 (Fig.1) does not present the characteristics of symbiotic stars. The dominent features are the strong λλ9532-9069, [S III] and λ10830 He I emission lines.
No molecular bands are visible.

EG And = HD 4174 = BD 39°167

From 0.8 to 1.1μ , the spectrum of August 11, 1981 shows only one emission : He I λ10830. (Fig.1).
- Wilson (1950) describes the blue spectrum of October 12, 1949, but he does not identify this element.
- The presence of He I λ10830 permits to assign a temperature to the hot companion : T $\geqslant$ 20 000°, which is in good agreement with the value 20 000° < T < 40 000° indicated by Smith (1980).
The IR observations by Swings and Allen (1972) indicate an absence of any large scale IR excess, as in the case of AG Peg.
Smith suggests that analogous processes are occuring in EG And and AG Peg and gives 20 000° < T < 40 000°.
-Smith proposes a binary model consisting of a M2 III semi regular variable and a hot secondary one, surrounded by a common envelope.
- In the near IR, we do not observe molecular bands : the absence of TiO λ8432 band is compatible with a M2-M4 type star.
- Moreover, we observe a strong Ca II triplet without the CN band 7900 in absorption which characterizes a giant star.
Thus, our IR observations confirm the spectral type proposed by Smith. This author observes changes in the equivalent width, radial velocity and line profile of Hα . He founds a good correlation with a pulsation period of 470 days.
It was interesting to know which phase the He I λ10830 emission corresponds to. In this aim , we have observed the Hα profile pratically

https://doi.org/10.1017/S0252921100097414 Published online by Cambridge University Press

at the same date (2 days after the observation of He I λ10830).
We have used a spectrum recording system by analogic TV mounted on the Echelle spectrograph of the 152 cm Telescope. The dispersion was 55 $A.mm^{-1}$ and the spectral range $\lambda\lambda$6250-6925.
Hα is a single emission without structure. The radial velocity of the peak is - 44 $km.s^{-1}$ and the equivalent width : 2,4 A. These values correspond to the 0,80 phase (Smith 1980).

CH Cyg

During the last recent outburst (sept.1977), we observed CH Cyg in the near IR region. Spectral features were visible (Andrillat, Faraggiana 1977):
- many strong TiO molecular bands, in particular $\lambda\lambda$7054-7126-8344-8432-8859, these 3 later bands being characteristic of M6,5 type stars or even of a later type.

This result is compatible with the one obtained by Morris (1977) which attributed a M7 type from the blue spectrum.
- 2 absorption lines of the Ca II triplet were visible, the third was blended with a TiO band. The presence of these lines indicated that the M7 star is a giant.

The observations by Smith and Bopp (1977) in the spectral range 5800-8700 show a 2 components emission profile of Hα, the blue one being several times stronger than the red one.
These authors did not note any emission features visible in the red.
Then, it seems that the He I lines, 5875-6678-7065, are absent : in the near infrared, we have not observed the He I λ 10830 emission line.
In July 1981 (Fig.1): we have again observed CH Cyg in the spectral range 0,8-1,1 μ
- The TiO molecular bands have disappeared
- It is the same for the Ca II triplet
- Only P7 λ 10049 is visible as a broad absorption. P13 is also visible.

CI Cyg

In the spectral range 0,8-1,1 μ, the spectrum of CI Cyg is poor. However, we have observed some changes between 1974 and 1981.
- 5.8.1974 { He I λ 10830 is a strong emission; O I λ 8446 is a moderate emission }
- 26.8.1975 { He I λ 10830 is absent; O I λ8446 ? is not visible but our spectrum is overexposed }
- 4.7.1981 (Fig.1) : the spectrum is analogous to that of the 5.8.1974.

At this date, C.C.Huang has observed CI Cyg in the blue region : the He I spectrum is strong. The He II λ 4686 is strong but λ 3203 is absent.
We do not observe He II λ 10123 line. These 2 lines have the same upper level and it would be interesting to determine the ratio of their intensities in order to determine an intrinsec possible reddening.
It is the case for AG Dra.

AG Dra

It is very well known that the intensity of the H and He emission lines

https://doi.org/10.1017/S0252921100097414 Published online by Cambridge University Press

are variable.
In the spectral range 0,8-1,1μ, the spectrum observed on July 4,1981 (Fig.1) is characterized by :
- a strong continuum
- intense emission lines of He I λ10830 and He II λ10123

At the same date, C.C.Huang has observed the UV recombination lines of He II λ3203 and also the He II λ4686 line.
The P7 λ10049 Paschen line is a weaker emission than He II λ10123.
- O Iλ8446 is also present in emissinn.
- No molecular bands are visible.

This remark permits to assign a spectral type earlier than M2 (we have no observations below 0,8μ).
The result is in good agreement with the K3 III classification proposed by Doroshenko and Nikolov (1967) from a study of the energy distribution in the continuum observed in 1961-1962.
During this period, these authors noted also the presence of emission lines : He II λ4686, and He I λ3889, this later being analogous to that of He I λ10830 (metastable level).

AG Peg

In the near IR, the continuum is very strong (Fig.1).
- He I λ10830 is a strong emission
- He II λ10123 is very well visible and its intensity is comparable to that of P7 λ10049.

It clearly appears that the He II λ10123 line is broader than P7.
This broadening confirms the presence of a WR companion star in the spectroscopic binary AG Peg which consists of a normal M3 III star and a hot WN6 star (Boyarchuk 1968).
- The absence of the TiO λ 8432 molecular band and the presence of the strong TiO λλ 7054-7126 (Andrillat, Houziaux 1982) and the moderate 7589 bands are in good agreement with the type M3.
- The presence of the strong Ca II triplet in absorption indicates the class luminosity is III. Finally, the spectral IR features confirm the classification proposed by Boyarchuk.
- O I λ 8446 is also present in emission.

Swings and Allen (1972) found no indication of an infrared excess in AG Peg (H-K = 0,23 mag).
In the case where dust is present : H-K $\geqslant$ 0,4.
However, Boyarchuk found that AG Peg has a circumstellar envelope with Te $\sim$ 17 000K).Perhaps, the hot component provides sufficient energy to heat the circumstellar material to such high temperatures as large scale grain formation cannot occur (Smith 1980).
The temperature of the hot component T = 40 000° has been determined by Gallagher and al. 1979).

RX Pup

From 1940, this star has shown some spectral changes
- 1940 : the spectrum presented an obviously symbiotic character but without any evidence of a late type companion (Swings,Struve 1941).

- From 1972 to 1975 : the high excitation emission lines have disappeared or have a weak strength.
The spectrum in the spectral range λλ 3658-8542 is similar to that of a Be[ ]star (Swings, Klutz 1976).
Moreover, Swings and Allen (1972) discovered a large infrared excess which they attributed to a circumstellar dust shell.
- Between march and december 1979, Klutz and Swings (1981) observe, between λλ 3558 and 5010, an important spectral evolution with an increase of the excitation degree : broad and strong emission lines of He II, N III, O III, [O III] are present. The N III λ 4640 and He II λ 4686 lines intensities are similar to the ones found in WN7-8 stars. The spectrum is comparable to that of 1940.
- 30 november 1980: In the near IR (λλ 5875-10850), one spectrum has been performed at the 3,60 m ESO telescope with the Boller Chivens Spectrograph equipped with a RETICON (dispersion 228 $A.mm^{-1}$) (Fig.3).
We are observing (Swings 1981) an important increase of the low excitation emission lines, principally :
- He I lines λλ5875, 6678, 7065 : we observe also the λ 10830 line.
- O I λ 8446 which is very strong while λ 7772 is a moderate emission. λ8446 is probably excited by a fluorescence mechanism from Lβ .
In 1979, λ 8446 is a moderate emission and λ 7772 is in absorption (Swings, Klutz 1976).
The Ca II triplet is a strong emission.
Paschen lines are visible up to P17.
Many Fe II lines are present : they are indicated by points (Fig.3).
For the first time, molecular absorption bands are clearly detected : TiO λλ7589-8432 are strong.
These bands permit to attribute a spectral type later than M5 to the cool component.
Moreover, it seems that the λ7900 VO band is present. In this case, the spectral type is M6.
Thus, this observation in the near IR confirms the symbiotic character of RX Pup and precises the spectral type M5 or M6 for the cool companion.

V1016 Cyg, HM Sge

In the near IR, the spectra of these 2 stars are similar and characterized by many strong emission lines (Fig.2).
The He I λ10830 line is dominent.
The Paschen lines are visible up to P19.
He II λ10123 is strong.
O I λ 8446 is present but stronger in V1016 Cyg than HM Sge.
The sulfur forbidden lines are also intense.
Important spectral variations have been observed for these 2 stars. They will be described in the papers concerning the individual stars.

HBV 475

The spectrum obtained on August 8, 1981 shows a strong continuum cut by intense molecular TiO absorption bands (Fig.2).

O I λ8446 is very faint because this line is blend with the strong TiO λ8432 which prevents from seing the Ca II triplet line. Spectral variations of the object will be given in the section relative to the individual stars.

RERERENCES

Albers,H.: 1974, Astrophys.J.189, 463.
Andrillat, Y., Houziaux,L.: 1967, J.Obs.50, 107.
Andrillat, Y., Fehrenbach, Ch., Vreux,J.M.: 1975, IAU Circ.n°2798
Andrillat, Y., Vreux, J.M.: 1975, Astron.Astrophys.41, 133.
Andrillat, Y., Swings,J.P.: 1976, Astrophys.J.204,L123.
Andrillat, Y., Houziaux, L.: 1982, IAU Coll.70 "The nature of symbiotic stars", this volume, p. 57.
Boyarchuk, A.A.: 1968, Soviet Astronomy 11, 818.
Cowley, A.P., Hutchings, J.B.: 1976, PASP 88, 456.
Doroshenko, V.T., Nikolov, N.S.:1967, Soviet Astronomy 11, 453.
Faraggiana, R., Andrillat, Y.: 1977, IAU Circ.3102.
Gallagher, J.S., Holm, A.V., Anderson, C.M., Webbink, R.F.: 1979, Astrophys.J.229, 994.
Klutz, M., Swings, J.P.: 1981, Astron.Astrophys.96, 406.
McCarthy, M.F., Treanor, P.J., Kent Ford, W.: 1966, Coll.on late type stars, Ed.M.Hack, 100.
Mavridis, L.N.: 1966, Coll.on late type stars, Ed.M.Hack, 420.
Morris, S.C.: 1977, IAU Circ.3101.
Ohman, Y.: 1936, Stockholm Annaler Bd.12 n°3.
Parsons, S.B.: 1964, Astrophys.J.140, 853.
Sharpless, S.: 1956, Astrophys.J.124, 342.
Smith, S.E.: 1980, Astrophys.J.237, 831.
Smith, S.E., Bopp, B.W.: 1977, IAU Circ.3113.
Swings, J.P.: 1969, Thèse Université de Liège.
Swings, J.P., Allen, D.A.: 1972, PASP 84, 523.
Swings, J.P., Klutz, M.: 1976, Astron.Astrophys.46, 303.
Swings, J.P.: 1981, IAU Circ.3560.
Swings, P., Struve, O.: 1941, Astrophys.J.94, 291.
Treanor, J.J., McCarthy, M.F.: 1966, Coll.on late type stars, Ed.M.Hack, 109.
Vaughan, A.H., Zirin, H.: 1968, Astrophys.J.152, 123.
Vreux, J.M., Andrillat, Y.: 1979, Astron.Astrophys.75, 93.
Vreux, J.M., Andrillat, Y.: 1979 , Astron.Astrophys.76, 221.
White, N.M., Wing, R.F.: 1978, Astrophys.J.222, 209.
Wilson, R.E.: 1950, PASP 62, 14.
Wing, R.F.: 1966, Coll.on late type stars, Ed.M.Hack, 231.

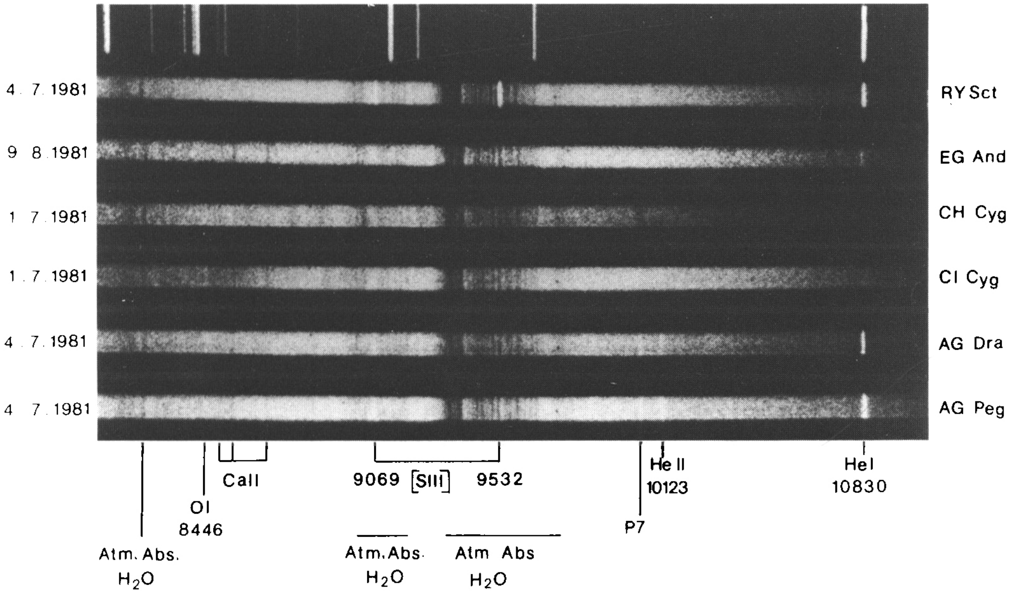

Fig.1

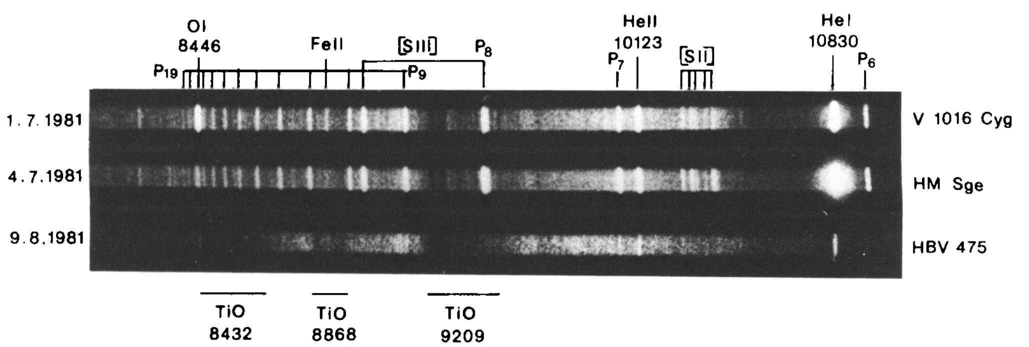

Fig.2

https://doi.org/10.1017/S0252921100097414 Published online by Cambridge University Press

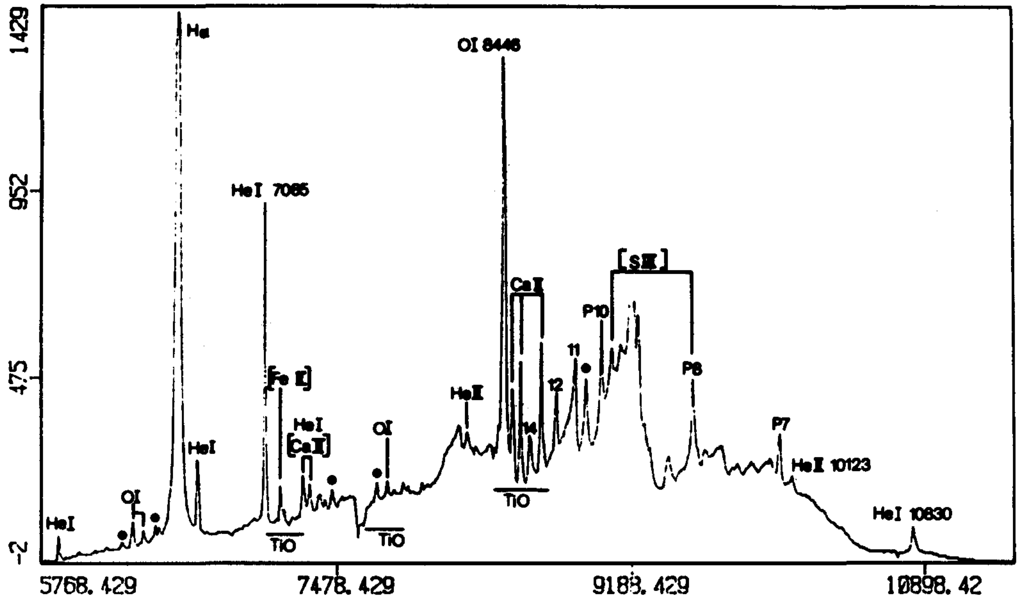

Figure 3. The near infared spectrum of RX Pup on 30 November 1980.

DISCUSSION ON NEAR INFRARED OBSERVATIONS

Hack: I was surprised to see that no emission of OI λ 8446 has been observed in CH Cyg, since the λ1300 lines are present and very strong in emission, and both are expected to be the results of the Lyβ excitation mechanism.

Andrillat: OI 8446 is not visible in our spectrum. The continuum is strong can mask weak emissions. In any case if this is the reason, OI λ 8446 should be very weak.

https://doi.org/10.1017/S0252921100097414 Published online by Cambridge University Press