ANALYSIS OF THE SPECTRAL ENERGY DISTRIBUTION OF THE COOLEST RCrB TYPE CARBON STAR DY Per

L.A.Yakovina[1], A.V.Shavrina[2], Ya.V.Pavlenko[3], A.F.Pugach[4]
Main astronomical observatory of the national academy of sciences of Ukraine, Kiev, Ukraine
[1]*yakovina@mao.kiev.ua,* [2]*shavrina@mao.kiev.ua,* [3]*yp@mao.kiev.ua,* [4]*pugach@mao.kiev.ua*

ABSTRACT. We analysed the spectral energy distribution of the evolved carbon star DY Per by spectral synthesis technique. The red giant shows the photometric features of R CrB type stars. We derived the atmosphere parameters of DY Per using three variants of molecular line lists. The range of T_{eff} estimations is $2900 < T_{eff} < 3300$ K. We adopted log g = 0. The star can be metal deficient and hydrogen deficient. The highest value of carbon abundance [C]=0.94 provides the combination of atmosphere parameters {T_{eff} =3100 K, [Fe/H] =0, log(C/O)=0.6, [N/Fe]=0, $(H/He)_{\odot}$} with Jorgensen's line lists for molecules C_2 and CN.

1. Introduction

The red giant DY Per shows photometric properties of R CrB type stars. Apparently, the star is the coolest among known stars of this type. DY Per is not typical R CrB type star and we cannot to classify one as a member of any known subclasses of C-stars.

Some authors estimate the effective temperature of DY Per $3500 < T_{eff} < 4740$ K by indirect methods (see Keenan & Barnbaum 1997). Yakovina et al. (2009) firstly determine $2900 < T_{eff} < 3000$ K for DY Per using fit of synthetic spectra to the observed spectral energy distribution (SED).

Molecular line lists in (Yakovina et al. 2009) were taken from database (Kurucz 1993-1994). This bank is the most full, but the accuracy of Kurucz's line lists is not always satisfactory. Because for some molecular systems are widely used data from other sources, it is possible to refine Kurucz's line lists. In this work we determine the atmosphere parameters of DY Per using the same observed material as in (Yakovina et al. 2009) and two other variants of line lists for molecules C_2 and CN.

The moderate resolution spectrum of DY Per was obtained 29.09.2003 with the spectrorgraph SPEM in Nesmith focus of 2.6-m telescope ZTSh of the Crimean astrophysical observatory. In the observed region $\lambda\lambda$ 400-730 nm the spectral resolution was $\sim$ 1.7 A/px, maximal S/N was about 280. Observed spectra reduction procedure is described in Yakovina et al. (2009).

Table 1: Systems of diatomic molecules accounted in computations of synthetic spectra. [1] - Urdahl et al. 1991, [2] - Huang et al. 1992, [3] - Tsuji 1973, [4] - Bernath et al. 1985.

Molecule	Transition	System	D_0 (eV)
$^{12}C^{12}C$	$d^3\Pi_g$ - $a^3\Pi_u$	Swan	6.297 [1]
$^{12}C^{12}C$	$A^1\Pi_u$ - $X^1\Sigma_g^+$	Phillips	6.297 [1]
$^{12}C^{14}N$	$B^2\Sigma^+$ - $X^2\Sigma^+$	Violet	7.738 [2]
$^{12}C^{14}N$	$A^2\Pi$ - $X^2\Sigma^+$	Red	7.738 [2]
^{12}CH	$A^2\Delta$ - $X^2\Pi$		3.47 [3]
^{12}CH	$B^2\Sigma^-$ - $X^2\Pi$		3.47 [3]
^{12}CH	$C^2\Sigma^+$ - $X^2\Pi$		3.47 [3]
^{24}MgH	$A^2\Pi$ - $X^2\Sigma^+$		1.27 [4]

2. Model atmospheres and synthetic spectra of DY Per

Model atmospheres of different T_{eff} and abundances (Pavlenko & Yakovina 2009) were calculated by SAM12 program (Pavlenko 2003). Microturbulent velocity $V_t = 3$ km/s was adopted. A reference set of the "solar" abundances we took from Gurtovenko & Kostik (1989).

Synthetic spectra were calculated by WITA6 program (Pavlenko 1997). Due to the high $^{12}C/^{13}C$ value in atmosphere of DY Per (Keenan & Barnbaum 1997), molecules contained ^{13}C were not accounted in our computations. We used the atomic line list from VALD (Kupka et al. 1999). The list of molecular systems accounted in synthetic spectra calculations we set in Table 1. Dissociation potentials are shown too.

In work (Yakovina et al. 2009) the line lists of all molecular systems had been taken from CD-ROM N18 of database (Kurucz 1993-1994). In this work we used two another versions:

First, we update line list of the Swan system of C_2 molecule from (Kurucz 1993-1994). For other molecular band systems we used the original Kurucz's line lists. The original Kurucz's list and modified one we name K18 and K18n, respectively.

Second, line lists of CN red system and C_2 (without dividing into the systems) were taken from Jorgensen's site http://stella.nbi.dk, other lists were taken from (Kurucz 1993-1994).

Line list of the CN red system on Jorgensen's site is well known list from tape SCAN-CN (see Jorgensen & Larsson 1990). Lists C_2 are the lists of Querci, described in (F.Querci et al. 1971, F.Querci et al. 1974). Jorgensen transformed Querci's lists to the SCAN-CN format. He updates oscillator strength (gf) when come new molecular data.

We updated Kurucz (1993-1994) line list of Swan band system using the Kuznetsova & Shavrina (1996) data and programs. The new values of gf for Swan system were calculated using information from databank RADEN (Kuznetsova et al. 1993) and the MOLEC program, developed in the Main astronomical observatory of NASU.

C_2 and CN spectra computed with three versions of molecular line lists are shown in Fig. 1. All theoretical spectra shown in this paper are convolved by gaussian of FWHM = 1.2 nm.

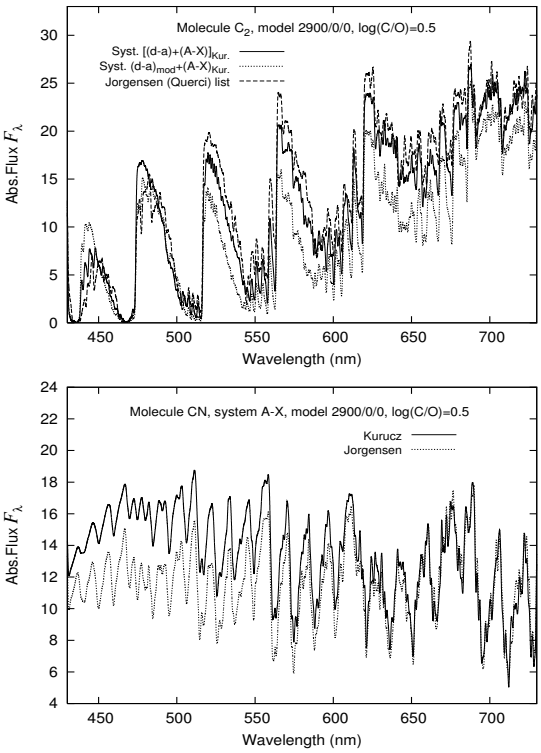

Figure 1: Theoretical spectra of C_2 and CN molecules computed with different molecular line lists. We computed gf-values for C_2 (d-a)$_{mod}$ lines following a procedure by Kuznetsova & Shavrina (1996)

3. Results

From the best fits of theoretical SEDs to observed fluxes of DY Per at $\lambda\lambda$ 430-730 nm we determined the atmosphere parameters $T_{\rm eff}$, [Fe/H], C/O, [N/Fe] and H/He.

To compare the observed and synthetic spectra we follow the next procedure.

First of all, we analyse the fit of synthetic spectrum to the selected narrow spectral regions of maximums or minimums in observed SED. Maximums of flux determine the gradient of SED in the investigated region. We found that gradient of SED is the important indicator of $T_{\rm eff}$. All selected regions we show on Fig. 2. We used them for determination of the next parameters:

– Swan bands were the main indicators of carbon abundance,

– bands of CH A-X system with Δv =-1 were the main indicators of the hydrogen abundance,

– resonance Na I doublet was the main indicator of atomic spectrum intensity,

– the band 3-0 of CN red system was the main indicator of nitrogen abundance.

In Fig.3 we show some fits of synthetic spectra, computed with different line lists, to the DY Per SED. These fits are rather similar.

We show in the Table 2 some new results combined with Yakovina et al. (2009) data.

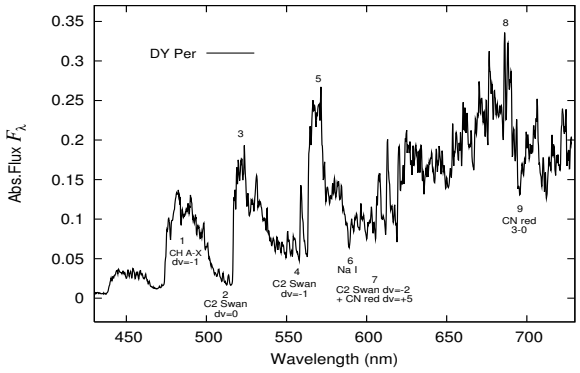

Figure 2: The main indicators for determination of atmosphere parameters in spectrum of DY Per. Here Δv =v'-v", v' and v"- vibrational quantum numbers of upper and low levels of transition, accordingly

Table 2: Sets of atmosphere parameters that provide the good fits of synthetic spectra to spectrum of DY Per. We adopt log g=0.0, $(H/He)_{\odot}$= 0.911/0.089 ≈ 9/1

T_{eff}	[Fe/H]	log C/O	[N/Fe]	H/He	[C]	Line list
2900	-0.5	0.3	0.0	Sun	+0.14	K18
2900	-1.0	0.5	0.2	7/3	-0.16	K18
2900	-1.5	0.6	0.4	3/7	-0.56	K18
2900	-2.0	0.6	0.5	1/9	-1.01	K18
3000	-0.5	0.4	0.0	Sun	+0.24	K18
3000	-1.0	0.5	0.3	Sun	-0.16	K18
3000	-1.0	0.5	0.2	8/2	-0.16	K18
3000	-1.5	0.8	0.5	5/5	-0.36	K18
3000	-2.0	1.0	0.8	3/7	-0.66	K18
3000	0.0	0.4	0.0	Sun	+0.74	Jorgensen
3100	0.0	0.6	0.0	Sun	+0.94	Jorgensen
3100	-0.5	0.4	0.0	4/6	+0.24	Jorgensen
3200	-2.0	1.2	1.5	Sun	-0.46	K18n
3200	-2.5	1.4	1.8	5/5	-0.76	K18n
3300	-2.0	1.6	1.4	Sun	-0.06	K18n
3300	-2.5	1.6	1.6	7/3	-0.56	K18n

Table 2 shows some ambiguousness of our DY Per parameters estimations. Values of effective temperature of DY Per are 2900 < T_{eff} < 3000 K if use line list K18 (Kurucz 1993-1994), 3000 < T_{eff} < 3100 K if use data of Jorgensen (http://stella.nbi.dk) and 3200 < T_{eff} < 3300 K if use K18n list.

In general, the uncertainty of other atmosphere parameters estimations - [Fe/H] , log(C/O), [N/Fe] and H/He - is considerably higher. We fixed the upper limits of metallicity for every T_{eff} and molecular line list:

$[Fe/H]_{max}$= -0.5 for K18 line list,

$[Fe/H]_{max}$= -2.0 for K18n list,

$[Fe/H]_{max}$= 0.0 for Jorgensen's data.

For all $[Fe/H]_{max}$ estimations of H/He are solar. If [Fe/H]decreases appears hydrogen deficiency, C/O and [C/Fe] increases but carbon abundance relatively solar value [C] decreases.

We cannot choose definitely the best variant of synthetic spectrum in frames of our spectral synthesis technique only. Qualitative analysis of observations of DY Per (Keenan & Barnbaum 1997, Zacs et al. 2007) shows that DY Per is of normal metallicity or slightly metal deficient star and, possibly, hydrogen deficient. From another hand, it is obviously that carbon abundance in atmosphere of DY Per is quite high. We see from Table 2 that only Jorgensen's molecular line lists support [C] values close to observed in atmospheres of R CrB type stars ([C]=1-2). The highest carbon abundance [C]=0.94 we get for model atmosphere {T_{eff} =3100 K, [Fe/H] =0, log(C/O)=0.6, [N/Fe]=0, $(H/He)_{\odot}$}. We note that these values of parameters are not in contradiction with rough estimations of other authors. The fit of theoretical fluxes to the observed SED of DY Per for this case is shown on Fig. 3c.

4. Discussion and conclusions

Results of this work and Yakovina et al. (2009) allows make the next conclusions:

- The effective temperature of DY Per is in range 2900 < T_{eff} < 3300 K. Our estimations of T_{eff} are below of estimations by indirect methods. So we confirm that DY Per is the coolest R CrB type star.
- For every value of T_{eff} spectral synthesis technique gives the large ambiguousness in the [Fe/H] , log(C/O), [N/Fe], H/He atmosphere parameters estimations. However, if account the qualitative analysis provided by some authors and physical constrains, the most real combination of atmosphere parameters of DY Per is {T_{eff} =3100 K, [Fe/H] =0, log(C/O)=0.6, [N/Fe]=0, $(H/He)_{\odot}$} with Jorgensen's line lists for molecules C_2 and CN.

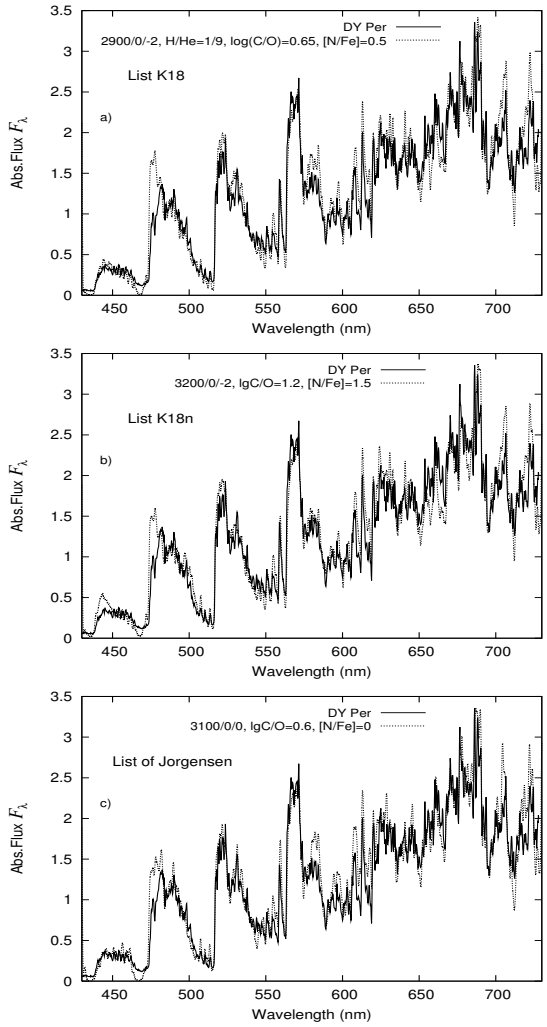

Figure 3: Fit of synthetic spectra computed with different line lists of C_2 and CN to the observed fluxes of DY Per.

- We believe that new observations of DY Per in wider spectral region, high resolution spectra of this star and independent methods of analysis allow us to increase a confidence of determination of atmosphere parameters of DY Per.

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