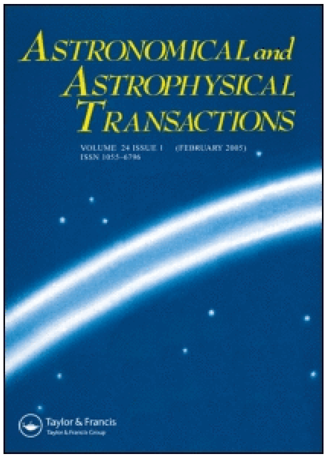

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Spectral and photometric observations of the B[e] stars MWC 314 and OY Gem

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In this paper the spectrophotometric and photometric data obtained for the sgB[e] star MWC 314 and the cPNB[e] star OY Gem during 2001–2004 at the high-mountain Assy-Turgen observatory are given. In the spectrum of MWC 314 the Hα, Hβ, He I and numerous Fe II intensity lines and the forbidden [N II] and [O I] lines are present. A variation in the intensity of the Hα lines relative to the continuum (from 24 to 33) is observed. During this time the equivalent width (EW) of the Hα line was changed in the limits 138–178Å, and the brightness magnitudes in the ranges $V = 9.82 - 9.96$, $B - V = 1.77 - 1.82$ and $V - R = 1.53 - 1.64$. The EW of the Hα is related to the star's colour index $B - V$; as the EW increases, the $B - V$ colour index is increased. In the spectrum of OY Gem the Hα, Hβ, He I and numerous Fe II intensity lines and the forbidden [Fe I], [N II], [O I], [O II], [O III] and [S II] lines are present. A variation in the intensity of the Hα lines relative to the continuum (from 100 to 138) is observed. During this time the EW of the Hα line was changed in the limits 700–955 Å, and the brightness magnitudes in the ranges $V = 11.05 - 11.36$, $B - V = 0.32 - 0.38$ and $V - R = 0.70 - 1.10$. No correlation between the brightness V with either the colour indices or the EW of the Hα has been observed.

Keywords: B[e] stars; Spectrophotometry; Photometry; MWC 314; OY Gem

1. Introduction

Most young stars are characterized by some kind of variability. Research on their sometimes regular and sometimes irregular behaviour enables us to investigate the processes occurring in these objects and their interaction with circumstellar matter. Such investigations need a large amount of observational data.

At the Fesenkov Astrophysical Institute, spectral and photometric observations are carried out on various types of young star: Hae–Be, B[e] and T Tau. The purpose of such research is the comparative analysis of spectral and photometric characteristics of these objects and, in particular, their change with time.This paper presents the observational results on two B[e] stars made during 2001–2004.

The investigation of B[e] stars (stars of B spectral type, for which forbidden emission lines are present in the visual spectrum) shows that it is a very non-uniform group, which include

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such objects as supergiants, compact planetary nebulae, symbiotic stars, stars evolved in the main sequence and stars with an as yet unknown mass and evolution stage. In many cases the uncertainty about the nature and evolution phase of B[e] stars originates because of the unknown distance to the object and, as a result, the unknown luminosity. In other cases, detailed spectroscopy and photometry have not yet been performed. Moreover, the mechanisms that produced the emission lines may be different in various objects.

In [1] it was also pointed out that grouping stars with different evolution stages into the same class called 'B[e] stars' is confusing. It was proposed that the classification criteria for B[e]-type stars should be overvalued because the observations show that these criteria may need to deal with various types of star of distinct masses and different evolutionary stages. It was also suggested that the term 'B[e] stars' should be substituted by the term 'B[e] phenomenon' and that five star classes that show the B[e] phenomenon should be defined as follows:

class 1: B[e] supergiants or 'sgB[e] stars';
class 2: pre-main sequence B[e]-type stars or 'Hae–B[e] stars';
class 3: compact planetary nebulae B[e]-type stars or 'cPNB[e] stars';
class 4: symbiotic B[e]-type stars or 'SymB[e] stars';
class 5: unclassified B[e]-type stars or 'unclB[e] stars'.

In the same paper [1] the primary and secondary classification criteria were specified for each of these groups.

The criteria for the presence of the B[e] phenomenon are the same as used earlier for B[e] stars and first introduced in 1976 by Allen and Swings [2]. They are as follows:

(i) the presence of strong Balmer emission lines;
(ii) the presence of permitted emission lines of low excitation (predominantly the low-ionization metals, *e.g.* Fe II);
(iii) forbidden emission lines [Fe II] and [O I] in the optical spectrum;
(iv) strong colour excesses in the near- and middle-infrared regions due to the hot circumstellar dust.

If the star satisfies these criteria, the star shows the B[e] phenomenon.

2. Observations

The spectroscopic and photometric observations were carried out with the 1 m telescope of the Assy-Turgen high-mountain observatory of the Fesenkov Astrophysical Institute of the National Academy of Science of the Kazakhstan Republic in September 2001–November 2004.

The spectral observations were made with a UAGS spectrograph and a charge-coupled device (CCD) camera ST-8 (1530×1020 pixels). The inverse dispersion was 0.5 Å per pixel. The spectral investigations of MWC 314 and OY Gem were mainly carried out in the regions of the Hα and Hβ lines. The flat field for spectrophotometry was obtained from the cupola, illuminated by the usual tungsten lamp. No reductions for instrumental contours were made. The equivalent width (EW) of the Hα line is defined without taking into account the fact that it can overlap absorption lines. For the investigated star the exposure was 30 min.

The photometric *BVRI* data were obtained with an ST-7 CCD camera. All photometric observations were corrected for the flat field, which was obtained using the twilight sky.

3. MWC 314

MWC 314 (BD + 14°3887) was discovered by Merril [3], who found hydrogen and Fe II emission in its spectrum. The star belongs to the class of sgB[e] stars and satisfies the criteria of [1] for B[e] supergiants. This group includes objects of extremely high luminosity, located in the upper part of the Hertzsprung–Russell diagram.

In 1998, Miroshnichenko *et al.* [4] determined the radial velocity for the emission lines of ionized metals, which was about $+55\,\mathrm{km\,s^{-1}}$; this agrees with a distance to the object of 3.0 ± 0.2 kpc in accordance with the Galaxy rotation curve. The effective temperature T_{eff} is nearly 25 000 K. The other stellar parameters are $\log(L_{\mathrm{bol}}/L_0) = 6.1 \pm 0.3$ and $R^* = 60(90 - 50)R_0$ [4]. According to the results of [4], MWC 314 is one of the highest-luminosity stars in the Milky Way.

Up to 1990 the photometric observations of MWC 314 were only represented by three measurements in the *UBV* Johnson system [5–7] and infrared observations [8] in the *HKL* bands. In 1995, Bergner *et al.* [9] published the *UBVRIJHK* and *UBVRI* photometric observations of this star during 1990–1994. Analysis of these measurements was carried by Miroshnichenko [10]. He noted that during this observational period the object was variable in all bands with a mean amplitude magnitude of nearly 0.3. In 1992–1993, the star was weaker with a magnitude of approximately 0.2; the colour index $B - V$ became smaller for a magnitude of 0.2, and the index $V - R$ became larger for a magnitude of 0.1 than in other observational periods. The object location in the $U - B$ versus $B - V$ diagram unambiguously indicates that this is substantially a reddened star, because it is located in the region of early B supergiants with a high value of reddening [10].

The photometric and spectral data obtained for MWC 314 during 2001–2004 are given in table 1. The columns of table 1 contain the following data from left to right: the date of observations; the universal time (UT); the EW(Hα) of the Hα emission line; the full width FW(0.1) at a maximum intensity of 0.1; the intensity of the line maximum relative to the continuum; the magnitude of V; the colour index $B - V$; the colour index $V - R$. As can be seen from table 1, during the observations the magnitude of the object brightness in the V band changed in the range $9.82 - 9.96$, and the magnitudes of the colour indices changed in the ranges $B - V = 1.77 - 1.84$ and $V - R = 1.53 - 1.64$.

Our photometric BVR measurements of MWC 314 cover the period from 2002 to 2004. During 2002–2003 the star changed its brightness and colour indices slightly, which provides evidence about the relative stability of the object on a timescale of years, as has already been mentioned in [10]. In 2004, MWC 314 was approximately weaker with a magnitude of 0.1 in the V band relative to the data obtained earlier. The colour indices remained almost unchanged.

In figures 1 and 2 the results of our observations (indicated by crosses) and the results of [9] (indicated by full circles) are given. As can be seen, as the brightness of V increases, $B - V$ increases and $V - R$ decreases.

Figure 3 illustrates the dependence of the EW of the Hα line on the $B - V$ colour index. As can be seen, there is a correlation of EW with $B - V$; on increase in the EW, $B - V$ increases on the average. During the observational period, no other correlations were observed.

All spectra were obtained in the region of the Hα and Hβ lines. The spectrum of the Hα line region is given in figure 4, and the lines are as follows.

Hydrogen. The hydrogen Hα and Hβ lines of the Balmer series are fairly strong. The Hα line has a reasonably symmetric single profile. During observations the EW of the Hα line changed within the limits $\mathrm{EW} = 138 - 179$ Å, FW(0.1) was in the range $471 - 544\,\mathrm{km\,s^{-1}}$, and the maximum intensity relative to the continuum was in the range from 24 to 33. Some features of P Cyg absorption are absent for the Hα and Hβ lines.

Table 1. The spectral and photometric data for MWC 314.

Date	UT	EW(Hα) (Å)	FW(0.1) ($km\,s^{-1}$)	I_{max}	V	$B-V$	$V-R$
16 September 2001	15:46	151.55	527.7	25.96			
20 September 2001	17:35	143.50	516.6	25.16			
20 September 2001	17:46	152.08	516.6	26.45			
21 September 2001	14:33	158.53	544.0	26.91			
18 October 2001	13:27	178.07	530.3	31.17			
16 November 2001	12:55	158.82	507.4	27.96			
18 November 2001	13:38	153.23	512.0	27.12			
21 November 2001	12:35	152.32	525.7	26.42			
5 August 2002	17:34	178.22	498.3	32.55			
6 August 2002	17:33	160.35	498.3	28.54			
8 August 2002	16:08	157.97	512.0	28.18			
9 August 2002	16:24	161.77	507.4	29.06			
5 September 2002	15:18	156.48	539.4	28.11	9.84	1.79	
7 September 2002	14:45	163.67	512.0	29.87	9.85	1.81	1.59
8 September 2002	14:39	158.10	530.3	27.88	9.84	1.80	1.58
9 September 2002	14:43	158.83	512.0	28.31	9.85	1.80	1.58
10 September 2002	14:40	151.03	494.7	27.69	9.83	1.80	1.60
5 October 2002	13:27	166.13	502.8	30.48	9.87	1.82	1.58
9 October 2002	15:07	169.96	512.0	31.22	9.86	1.80	1.58
6 November 2002	12:52	162.36	516.6	29.90	9.82	1.84	1.64
28 August 2003	15:07	144.20	470.8	28.94	9.88	1.80	1.58
29 August 2003	15:28	154.65	516.6	28.44	9.84	1.81	1.58
31 August 2003	15:10	148.85	498.3	28.55	9.88	1.78	1.56
24 September 2003	14:11	140.28	498.3	25.54	9.84	1.79	1.56
25 September 2003	14:22	151.08	516.6	27.70	9.82	1.80	1.53
28 September 2003	14:05	147.44	484.6	26.86	9.83	1.80	
29 September 2003	13:33	149.39	494.7	27.63	9.84	1.81	1.55
30 September 2003	13:37	144.64	494.7	26.92	9.86	1.80	1.57
13 August 2004	15:26	151.99	521.1	24.05	9.96	1.78	1.62
12 September 2004	14:29	140.06	521.1	25.49			
13 September 2004	14:42	146.38	530.3	26.07	9.95	1.77	1.61
8 October 2004	13:49	142.75	512.0	25.89	9.93	1.80	1.58
11 October 2004	14:04	138.86	512.0	25.20			
14 October 2004	13:43	137.78	512.0	25.76	9.94	1.77	1.60
10 November 2004	12:45	138.57	512.0	25.62	9.94	1.77	1.60

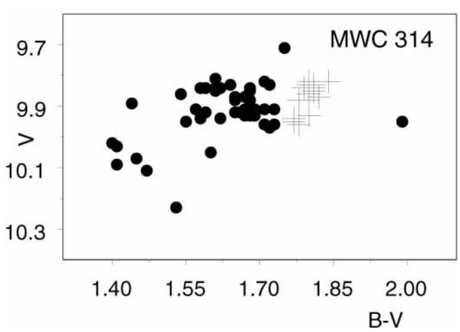

Figure 1. The dependence of V on $B-V$ for MWC 314.

Helium. The spectrum contains strong He I lines: $\lambda = 4922$, 5016, 6678 and 7066 Å. The $\lambda = 4714$ Å line is weak. The He I lines have the typical P Cyg profile with absorption displaced to the blue region.

Iron. The lines presented in the spectrum are the Fe II permitted lines.

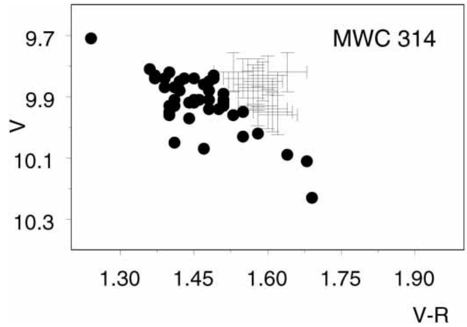

Figure 2. The dependence of V on $V-R$ for MWC 314.

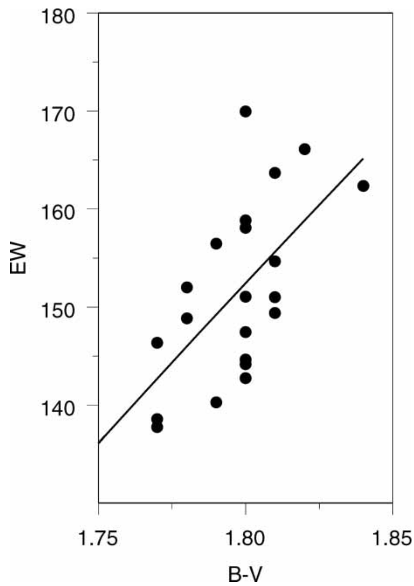

Figure 3. The dependence of EW on $B-V$ for MWC 314.

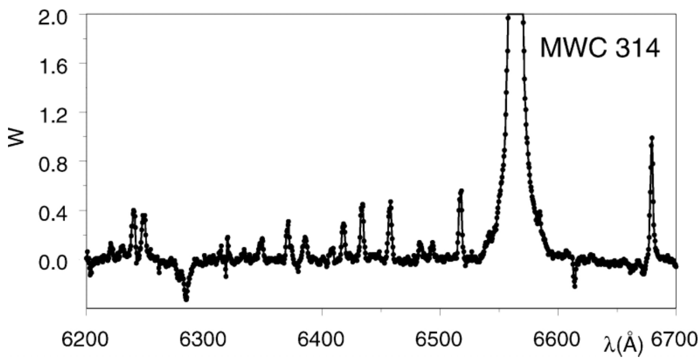

Figure 4. The Hα region for MWC 314.

Oxygen. In the spectrum there is the weak [O I] (λ = 6300 Å) line.

Silicon. There are the two Si II permitted lines: the λ = 6347 Å line and the λ = 6370 Å line, which overlaps the Fe II line.

Nitrogen. The forbidden [N II] (λ = 6584 Å) line appears on the red wing of the Hα line.

Also, in all spectra there are the strong circumstellar absorption lines λ = 4763, 6284 and 6616 Å.

4. OY Gem

The cPNB[e] stars are the group that show the B[e] phenomenon and are in the evolutionary phase of low-mass stars which will became planetary nebulae. In [12] the affinity of stars with the B[e] phenomenon and spectra of planetary nebula was pointed out. The optical spectra of many compact planetary nebulae show strong Balmer emission lines and Fe II emission lines, and also the [Fe II] and [Ca II] forbidden lines. Moreover, there may be forbidden lines of more highly ionized states, such as [O III], [S III] and [Ne III]. Known examples are the Butterfly Nebula M2-9 and the protoplanetary infrared source Hen3-1475. Many of these objects show strong infrared excesses.

The cPNB[e] stars have the following features.

(i) Forbidden lines with a low ionization potential are present; the spectrum may also show forbidden emission lines of higher excitation, such as [O III], [S III], [Ne III], [Ar III] and [Ar V].
(ii) There is an enhancement in the nitrogen abundance with an abundance ratio [N]/[C] > 1 or an enhancement [He]/[H] ratio, which is characteristic of the evolved evolutionary stage.
(iii) The energy distribution can show the presence of cold dust ($T_d < 100$ K), which can be the wind remnant of an asymptotic giant branch.

OY Gem (MWC 162 = HD 51585 = IRAS 06556 + 1623) was first discovered by Merrill and Burwell [13], who found hydrogen and Fe II emission in its spectrum. Allen and Swings [2] classified it as belonging to a small class of hot emission stars with high infrared excess and forbidden lines of high excitation, resembling planetary nebulae. Spectral line identification in the visual and near-infrared regions was made by a number of researchers [8, 14–21]. The spectral class of OY Gem was estimated as B0–B1 from the intensities of the hydrogen and He I emission lines, from the energy distribution in the continuum and also from the star location in the two-colour diagram of $U - B$ versus $B - V$ on the assumption that the colour excess $E(B - V)$ is of magnitude 0.5–0.6 [11, 14, 22, 23]. Arkhipova [22] suggested the hypothesis that OY Gem is an evolved star of intermediate initial mass, moving to the left on the Hertzsprung–Russell diagram, and also that it is a possible protoplanetary object. Arkhipova and Ikonnikova [21] reached the conclusion that the energy distribution in the star's spectrum shows the availability of three sources of radiation: a star with a temperature of 28 000 K, hot dust with a temperature of 1100 K and cold dust with a temperature of 180 K. They made estimations of the following stellar parameters: $M = 0.62\mathrm{M}_0$; $L = 6190L_0$; $\log g = 3.42$; distance $D = 2.1$ kpc; rate of mass loss, $\dot{M} = 1.4 \times 10^{-8}\,\mathrm{M}_0\,\mathrm{year}^{-1}$.

Some *UBV* photometric observations of OY Gem are collected in table 1 of [22] and are represented by some measurements in 1968, 1973, 1987 and 1988. Our *BVR* observations of this star cover the period from 2002 to 2004 and are given in table 2.

The columns of table 2 contain the following data from left to right: the date of observations; the universal time (UT); the EW(Hα) of the Hα emission line; the full width FW(0.1) at a

Table 2. The spectral and photometric data for OY Gem.

Date	UT	EW(Hα) (Å)	FW(0.1) (km s^{-1})	I_{max}	V	$B-V$	$V-R$
19 November 2001	22:30	864.2	781.7	119.75			
22 November 2001	22:05	857.0	786.2	116.87			
11 December 2001	20:02	865.4	809.1	113.53			
12 December 2001	19:28	881.4	781.7	121.17			
15 January 2002	16:27	895.0	795.4	123.22			
8 February 2002	18:17	836.6	777.1	116.53			
9 February 2002	16:41	847.5	777.1	118.09			
10 February 2002	18:19	879.1	768.0	125.85			
11 February 2002	18:40	865.6	786.2	120.80			
10 November 2002	23:10	870.6	777.1	122.87	11.24	0.34	0.77
6 December 2002	21:44	845.4	754.3	121.73	11.26	0.30	0.77
6 January 2003	18:28	952.7	758.8	138.51	11.26	0.34	0.76
8 January 2003	18:37	955.7	768.0	136.59	11.24	0.35	0.74
28 January 2003	17:00	884.8	749.7	131.47	11.34		0.70
1 February 2003	17:08	893.9	731.4	134.91	11.27	0.34	0.76
3 February 2003	16:08	929.1	777.1	133.35	11.25	0.34	0.73
27 December 2003	20:02	753.5	772.5	111.67	11.15	0.33	1.09
18 January 2004	17:49	789.2	740.5	116.71	11.16	0.32	1.08
12 November 2004	21:50	765.0	786.2	115.11	11.17	0.32	1.10
13 November 2004	21:30	703.6	777.1	100.06	11.05	0.38	0.98

maximum intensity of 0.1; the intensity of the line maximum relative to the continuum; the magnitude of V; the colour index $B-V$; the colour index $V-R$. During the observations the magnitude of the object brightness in the V band changed in the range $11.05-11.34$, and the magnitudes of the colour indices changed in the ranges $B-V=0.30-0.38$ and $V-R=0.70-1.10$.

As can be seen from table 2, during October 2002–February 2003 the star changed its brightness and colour indices slightly. In December 2003–November 2004, OY Gem showed an increase in the brightness magnitude of the V band to approximately 0.1 in comparison with data obtained earlier. The colour index $B-V$ remained almost the same, and the index $V-R$ increased to a magnitude of nearly 0.3. At the same time, substantial decreases in the EWs of the Hα and Hβ lines were observed. Perhaps this behaviour is connected with increases in the optical depths in lines due to the envelopes produced. During the period of our observations, no distinct correlation between the brightness V with either the colour indices or the EW of the Hα line is observed.

All spectra were obtained in the region of the Hα and Hβ lines. Typical spectra of these regions are given in figures 5 and 6, and the lines are as follows.

Hydrogen. The Hα and Hβ lines of the Balmer series are very strong. Both lines have a double-peaked profile with central absorption. Both for the Hα line and for the Hβ line the red component has a greater intensity than the blue component. The intensity ratio R/V of red component to blue component has a tendency to increase with time. So, for the Hα line the R/V value was 2.23 in November–December 2001, 2.38 in January–February 2002, 2.40 in November 2002–February 2003 and 2.62 in December 2003–November 2004. For the Hβ line, greater changes in R/V were observed: from 4.0 in November–December 2001 to 6.2 in November 2004. For the Hα line the peak separation is nearly 180 km s^{-1} and for the Hβ line approximately 125 km s^{-1}. It must be emphasized that the double-peaked profiles of the Balmer series from Hα to Hδ with a peak separation of 150 km s^{-1} and the P Cyg profiles for high members of the series were only pointed out in the paper by Klutz and Swings [20] for their observations made between 1971 and 1976.

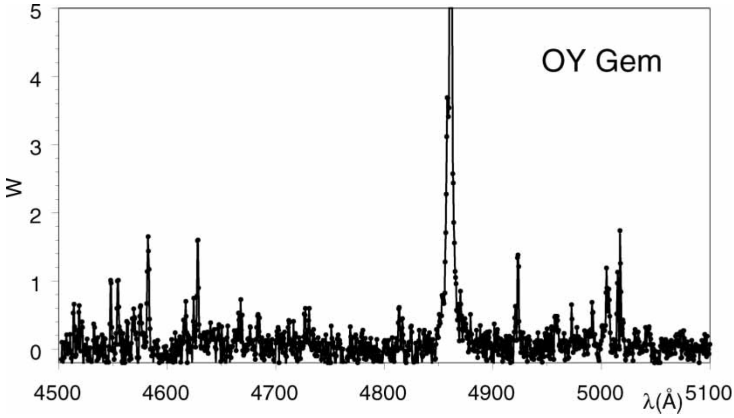

Figure 5. The Hβ region for OY Gem.

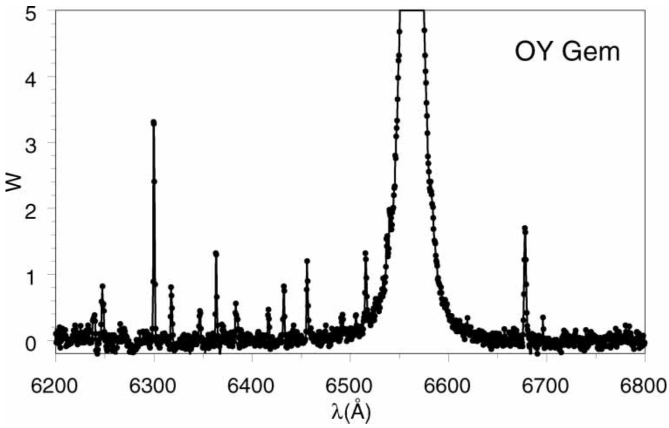

Figure 6. The Hα region for OY Gem.

Helium. The spectrum contains strong He I lines: $\lambda = 4922$, 5016, 6678 and 7066 Å. The $\lambda = 4714$ Å is weak. The He I lines have a typical P Cyg profile with absorption displaced to the blue region. In the spectra, weak lines of ionized He II ($\lambda = 4686$ and 6234 Å) are present.

Iron. The lines present in spectrum are the Fe II permitted and forbidden lines.

Oxygen. In the spectrum there are the [O I], [O III] and O I lines. The [O I] ($\lambda = 6300$ and 6363 Å) lines are fairly strong.

Silicon. There are two Si II permitted lines: the $\lambda = 6347$ Å line and the $\lambda = 6370$ Å line, which overlaps the Fe II line.

Nitrogen. The forbidden [N II] ($\lambda = 6584$ Å) line is present on the red wing of the Hα line.

Sulphur. The [S II] forbidden lines sometimes emerge in the red part of the spectrum with $\lambda = 6717$ and 6731 Å.

5. Results

The results of spectral and photometric observations obtained for the sgB[e] star MWC 314 and the cPNB[e] star OY Gem during 2001–2004 at the high-mountain Assy-Turgen observatory are given in tables 1 and 2. The spectral and photometric features of these objects are briefly discussed.

It should be noted that this work is part of an extensive programme of investigation on Hae–Be, B[e] and T Tau young objects, which will be performed in the near future.

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