АСТРОФИЗИКА

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OXYGEN AND CARBON RICH COOL STARS IN THE CEPHEUS REGION: CLASSIFICATION OF SELECTED OBJECTS FROM KP2001 CATALOGUE. I

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We present moderate resolution CCD spectra and *R* photometry for seven KP2001 stars. We revised the spectral classification of the stars in the range $\lambda\lambda 4000-8700$ Å. Our photometric data confirmed the behaviour of the light curves downloaded from the NSVS (Northern Sky Variability Survey) database. For KP2001-32, presented as a Mira - type variable in NSVS, we estimated absolute bolometric M_b and *K* - band M_K magnitudes as well as the distance using the Period - Luminosity relations. We also estimated the mass loss rate using the calibration relations between mass loss rate and *K* - [12] index. From the position in infrared color-color diagrams we confirmed the photometric classification of KP2001-221 as a semi regular variable, based on the light curve of the NSVS database. For the N-type Carbon star KP2001-77 we estimated distance and absolute magnitude M_K using different calibration methods. For the remaining four objects we derived the absolute magnitudes and distances using our CCD spectra and published JHK_s magnitudes. We discuss the nature of these objects on the basis of the obtained results.

Key words: *stars:spectral classification:variability:absolute magnitudes:distances*

1. *Introduction*. Several regions in Cepheus have been formerly observed at the Byurakan Astrophysical Observatory (BAO) with 1m Schmidt telescope equipped with 1°.5 objective prism which gives a dispersion of 2500 Å/mm at Hβ. Each region covers on the sky 17 square degrees. The emulsion used was Kodak I-N which has a high spectral sensitivity in the range $\lambda\lambda 6800-8800$ Å.

On these plates M type stars are very well distinguished from other types of stars, showing bright and compact head in the near infrared; this feature is very well expressed especially in the late M subclasses.

Further investigations revealed that the selected regions are rich of M type stars, with a peak density at $\alpha = 23^h 32^m.7$ and $\delta = +67°$, where the partial density is approximately 20 stars per square degree.

Those results stimulated specific spectral observations of that dense region with the 4° objective prism which allows to classify M stars, using the same Kodak I-N emulsion. The first results were published in paper [1] by Kazaryan and Petrosyan; a list of 257 stars containing data of both types of candidate M giants and dwarfs is presently available in electronic form at CDS (http://vizier.u-strasbg.fr/viz-bin/VizieR?source=J/other/Ap/44.335). The selection criteria for our M stars were mainly based on the presence of the absorption bands at $\lambda\lambda$7054, 7589, 8300, 8432 Å of TiO and $\lambda\lambda$7400, 7900 Å of VO molecules and are extensively described in paper [1]. A more detailed analysis of the observational material revealed that 18 stars are variable and the results were presented in paper [2] by Kazaryan and Petrosyan.

Our next goal is to clarify the evolutionary state of our sample by defining more precisely their spectral subtype and luminosity class. We therefore decided to start a slit spectroscopic investigation of our objects. The present study is the first work of the new program and concerns a first set of stars selected from the KP2001 list.

2. *Spectroscopic and photometric observations*. We recently obtained moderate resolution CCD spectra for the first seven KP2001 stars in the range $\lambda\lambda$3940 – 8500Å, dispersion 3.9 Å/pixels, with the 1.52 m Cassini telescope of the Bologna Astronomical Observatory (Italy) at Loiano, equipped with the Bologna Faint Objects Spectrometer and Camera (BFOSC) and 1300x1340 pix EEV P129915 CCD. Photometric observations in *R*-band were also obtained with BFOSC in the same dates as for the spectra.

Table 1 presents the Journal of our observations, as well as the derived magnitudes and spectral types. The columns have the following meaning: column 1 - KP2001 number in the list [1]; column 2 - date of observation; column 3 - *R*-band magnitudes; column 4 - spectral type determination based on previous low-resolution spectra [1]; column 5 - new spectral subtype, revised from our CCD data, derived as described below.

Table 1

JOURNAL OF OBSERVATIONS, PHOTOMETRIC RESULTS AND SPECTRAL CLASSIFICATION

KP2001 Number	Date of Observation	*R* band photometry mag.	Previous Sp. Subtype [1]	CCD Sp. Subtype
32	13.07.2007	13.0 ± 0.1	M10	M10
44	02.08.2007	13.52 ± 0.08	M2	M6
64	14.07.2007	12.20 ± 0.06	M3	M3
77	02.08.2007	13.7 ± 0.1	M2	N(C5-C6)
123	05.08.2007	11.61 ± 0.06	M6	M1
221	05.08.2007	11.92 ± 0.07	M6	M10
228*	10.10.2008	12.78 ± 0.1	M1	M3

Note to Table 1
*R-band photometry for KP 228 was obtained with the Celestron 925 telescope of the Roma University Physics Department with a CCD Camera StarlightXpress MX 916.

All the spectroscopic and photometric data were reduced by means of standard IRAF[1] procedures.

3. *Data analysis*. To clarify the nature of the observed objects, we

[1] *IRAF is distributed by the NOAO, which is operated by AURA under contract with NFTS.*

considered all possible photometric data from the modern astronomical databases together with our CCD spectra and photometry.

3.1. *Spectral types.* We determined spectral subtypes of our targets via side-by-side comparison with spectra of standard stars. To this purpose we collected a large number of comparison stars with known spectral subtypes (from M0 to M9, giants and dwarfs) with the same instrumental setup as for our target stars. The standard stars were selected from the paper by Kirkpatrick et al. [3], from the NLTT Catalogue [4] (Luyten, 1979 - http://cdsarc.u-

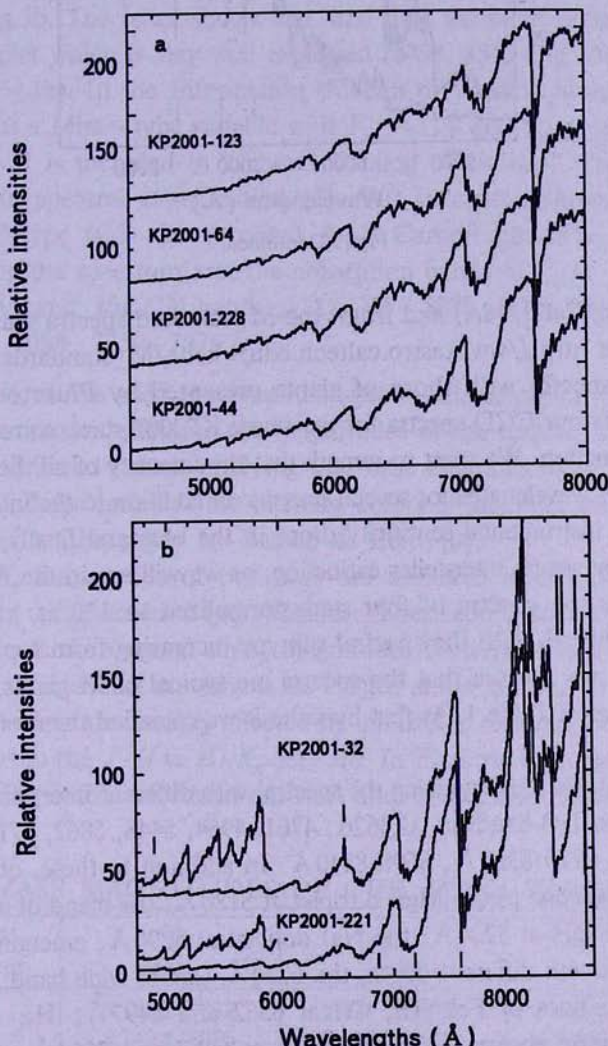

Fig.1(a, b, c). Spectra of the observed KP2001 stars, corrected for the atmospheric extinction, normalized to 100 at λ7600Å and then vertically shifted. For the stars in Fig.1a the spectral subtype is increasing from top to bottom. The atmospheric absorption bands are indicated by vertical bars. In Fig.1b the lines of the Ca II triplet visible in emission in the spectrum of KP2001-32, are also indicated. The Carbon star KP2001-77 is shown in Fig.1c.

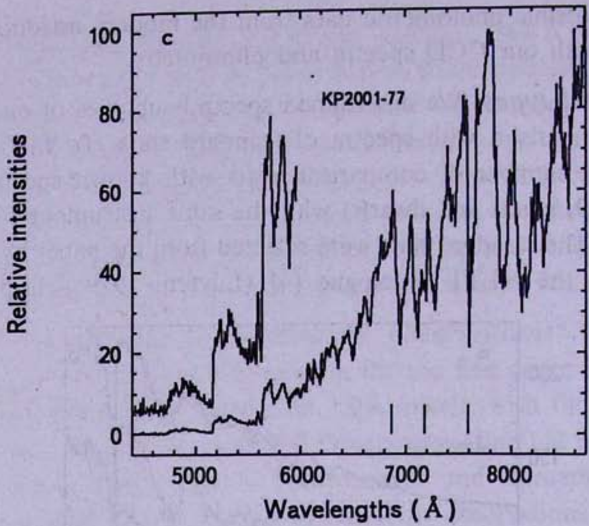

Fig.1. Continued.

strasbg.fr/viz-bin/Cat?I/98A) and from the M standard spectra made available by Kelle Cruz at http://www.astro.caltech.edu/~kelle/M_standards. We finally compared our spectra with those of giants presented by Fluks et al. [5].

Fig.1 presents our CCD spectra for the seven KP2001 stars, corrected for the atmospheric extinction. We want to remark that the intensity of all the spectra are very faint at short wavelengths for several reasons: in addition to the intrinsic colors of the stars, the instrumental sensitivity drops in the blue and finally, the objects are all affected by strong interstellar extinction, as we will see in the next section.

Fig.1a shows the spectra of four stars normalized to 100 at λ7600Å and then vertically shifted, with the spectral subtype increasing from top to bottom. From the figure we can see that the spectra are typical of M giants, as written in the last column of Table 1. As first hypothesis we classified them of luminosity class III.

The main features characterizing the spectra, with different intensities from one to another are the TiO bands at λλ4626, 4761, 4954, 5448, 5862, 6714 Å, 7060-7200 Å, 7907 Å, 8270-8330 Å, 8500-8540 Å. In addition to these, other important absorptions are due to the MgI, b triplet at 5180 Å; the blend of atomic lines (FeI, TiI, CrI)+MgH at 5206 Å; the NaI doublet at 5890 Å, emerging from the TiO band though with different depth; the 6230 Å CaOH wide band; the blends of several atomic lines of FeI, TiI, CrI at 6362 and 6497 Å; Hα at 6562 Å.

The atmospheric absorption bands of O_2 at 6867 and 7594 Å and of H_2O at 7186 Å are indicated by vertical bars.

In KP2001-123 the 4761 Å TiO band is barely visible and the 6714 Å TiO band is weak, indicating an early M subtype. The luminosity class is either compatible with M1 III or M2 Ib.

In KP2001-64 and 228 these two bands are stronger; the stars are very similar and their spectrum appears of a later subtype. The luminosity class can be either II or III.

KP2001-44 is weak in the blue part of the spectrum, but starting from 4800 Å presents very well expressed TiO absorption bands, particularly the 6714 Å which is much stronger than in the other stars. The NaI doublet almost disappears, drowned in the strong TiO band. Overall this spectrum can be classified as belonging to a middle M6 subtype star.

KP2001-221 and KP2001-32 (V0531 Cep) have a very late spectrum, presented in Fig.1b. The latter shows Hα and Hβ visible in emission as well as Ca-II IR triplet which is very well expressed (8498, 8542 and 8662 Å, indicated by bars in Fig.1b). In the Information Bulletin of Variable Stars [6] this object is indicated as a Mira - type variable with $V_{max}=11.9$ and $V_{min}=16.1$ magnitudes.

KP2001-77 is included in General Catalog of Galactic Carbon Stars No 5870, without spectral classification [7]. Our spectrum, shown in Fig.1c, is typical of N-type (C5 - C6 subclass) AGB Carbon star. The main features characterizing the spectrum are: the absorption bands of C_2 at λλ4737, 5165, 5636, 6191 Å, and the CN bands at λλ5225, 5730, 5878, 6013, 6206, 6478, 6631, 6925, 7088, 7259, 7876 Å.

3.2. *Colors*. We used the obtained spectral classification to measure the interstellar extinction affecting the magnitudes of the targets. To this purpose we used the infrared colors, applying the same diagrams as in the papers [8-12]. A detailed discussion of the intrinsic colors of late type giants and dwarfs can be found in the paper by Bessell & Brett [8].

The JHK_s magnitudes of our stars are available in literature only from 2MASS (direct online access at http://irsa.ipac.caltech.edu/applications/BabyGator). Table 2 presents the original JHK_s magnitudes from 2MASS catalogue.

We want to stress that our targets are located at low galactic latitude; therefore the observed colors are strongly affected by interstellar reddening as evident from their positions in the $J-H$ vs $H-K_s$ diagram. In Fig.2 we reproduced the Figure A3 of paper [8], where we added our stars after having transformed the original

Table 2

2MASS MAGNITUDES OF OUR KP2001 TARGETS

KP2001 Number	J mag.	H mag.	K_s mag.
32	6.156±0.032	5.027±0.042	4.345±0.029
44	8.742±0.026	7.540±0.069	7.056±0.026
64	7.382±0.029	6.085±0.027	5.601±0.020
77	8.534±0.027	6.914±0.044	6.080±0.018
123	7.161±0.024	5.927±0.047	5.410±0.026
221	4.961±0.017	4.116±0.250	3.612±0.350
228	8.263±0.027	7.056±0.034	6.589±0.027

2MASS values to the Bessel & Brett system using the formulae given in the Explanatory Supplement to the 2MASS Second Incremental Data Release at http://www.ipac.caltech.edu/2mass/releases/second/doc/sec6_3.html and in Appendix A by Carpenter [22]. We report the $J-H$ and H-K_S colors also in columns 2 and 4 of Table 3. From the spectral classification we deduced the expected intrinsic

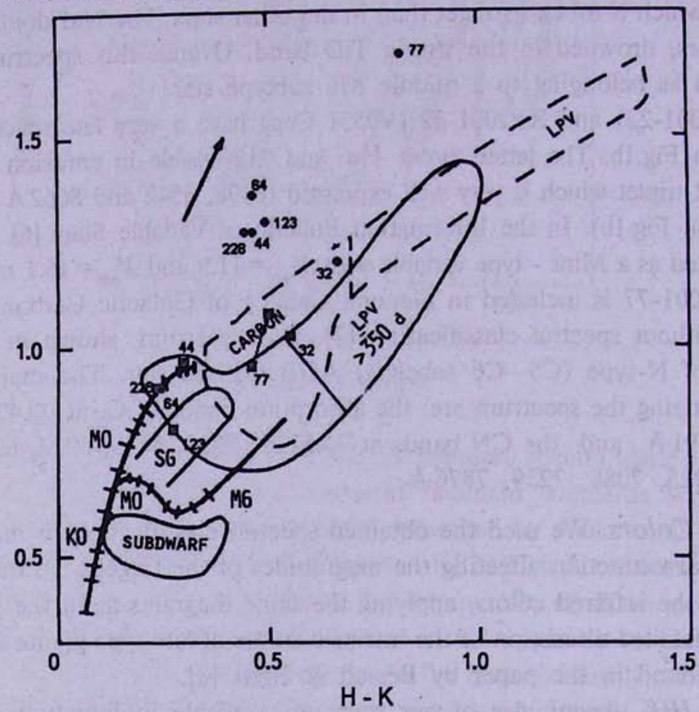

Fig.2. Infrared colour-colour diagram from Fig.A3 of Bessel & Brett [8]. Dots indicate the observed positions of our stars, squares indicate the positions after reddening correction.

values, listed in Table III of paper [8] in order to move the experimental values to the intrinsic positions and compute the extinctions to the stars. Having obtained the color infrared excess (Table 3, columns 3 and 5), we computed $E(B-V)$, A_V and A_K (Table 3, columns 6,7,8) using the reddening relations given in the Appendix B of paper [8]:

$$E(J-H) = 0.37\,E(B-V); \quad E(H-K_S) = 0.19\,E(B-V) \tag{1}$$

$$A_V = 3.12\,E(B-V); \quad A_K = 0.34\,E(B-V). \tag{2}$$

2MASS gives only one photometric point of the two variables KP2001-32 and 221; therefore we cannot infer an accurate value of the color excess and extinction; for the former star we report the only value compatible with the expected location in Fig.2 for a long period Mira variable.

The magnitudes of the semiregular variable KP2001-221 are given with very large uncertainties, in addition the apparent position in the color-color diagram seems not to be affected by interstellar extinction.

On the contrary KP2001-77 is very far from the location of typical carbon stars and a large correction is necessary to bring the star inside the area occupied by carbon stars; in Table 3 we give the maximum and minimum values of the colors compatible with those of N type stars (see also Fig.3 of Totten et al. [21]) and the derived parameters.

Table 3

INFRARED COLORS AND COLOR EXESS OF OUR KP2001 TARGETS TRANSFORMED TO THE BESSEL & BRETT SYSTEM

KP2001 Number	$J-H$ mag.	$E(J-H)$ mag.	$H-K_s$ mag.	$E(H-K_s)$ mag.	$E(B-V)$ mag.	A_V mag.	A_K mag.
32	1.20 ± 0.05	0.18	0.66 ± 0.05	0.10	0.52	1.70	0.19
44	1.27 ± 0.07	0.31	0.46 ± 0.07	0.16	0.85	2.65	0.29
64	1.36 ± 0.04	0.46	0.46 ± 0.03	0.22	1.18	3.68	0.40
77	1.70 ± 0.05	0.75	0.81 ± 0.05	0.35	1.9	5.9	0.6
		0.62		0.31	1.65	5.1	0.3
123	1.30 ± 0.05	0.50	0.49 ± 0.05	0.22	1.21	3.77	0.41
221	0.91 ± 0.25		0.48 ± 0.43				
228	1.27 ± 0.04	0.37	0.44 ± 0.04	0.20	0.97	3.00	0.33

For KP2001-123 we reported the values obtained assuming the star being a supergiant; this correction also better agrees with the direction of the dereddening vector.

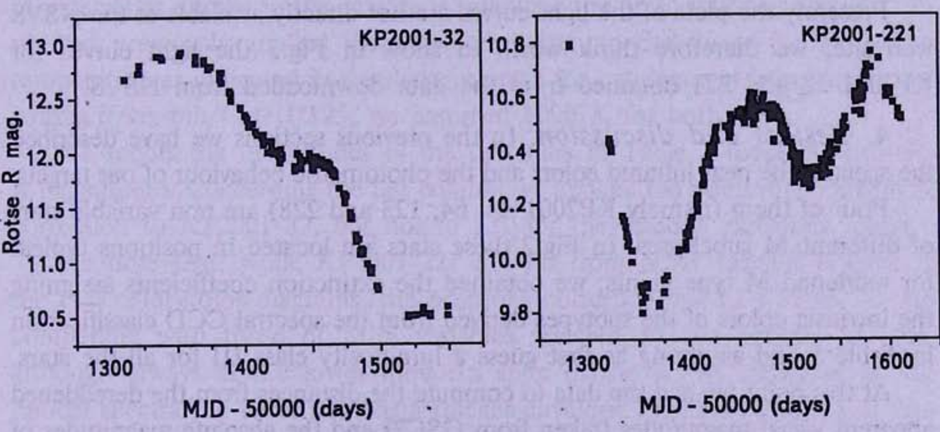

Fig.3. Light curves of KP2001-32 and 221 downloaded from NSVS database.

The $E(B-V)$ derived from the two infrared excess of all the stars agree quite well. In Table 3 we give the mean value for $E(B-V)$ and the derived extinctions. As expected these latter are quite high, given the low galactic latitude of our targets.

3.3. *Variability*. We considered the Northen Sky Variability Survey

(NSVS)[14] to investigate the variability for observed KP2001 stars. This survey monitored several fields during more than one year providing light curves for sources with visual magnitude from 8 to ~15.5. All seven KP2001 stars have detections in that database. The photometric band of the ROTSE experiment is similar to the Johnson Red, for this reason we decided to obtain the R magnitudes to check the variability of our targets.

The light curves showed practically constant values for KP2001-44 ($R_{Rotse}=13.2$), KP2001-64 ($R_{Rotse}=11.9$), KP2001-123 ($R_{Rotse}=11.5$) and KP2001-228 ($R_{Rotse}=12.6$). From a comparison of NSVS data with our magnitudes listed in Table 1, it results that the red luminosities of these stars remained stable also after the end of the monitoring by ROTSE.

The Carbon star KP2001-77 shows a quasi periodical modulation of very small amplitude around $R_{Rotse}=13.5$.

Finally KP2001-32 and KP2001-221 have shown strong and modulated luminosity variability. Actually these two stars are present in the catalogue of "Red variables in NSVS" [15] which gives information concerning the variability types of the monitored stars (the electronic form of the catalog is available at http://visier.u-strasbg.fr/vis-bin/VizieR?-source=J/AJ/128/1265). In this catalogue KP2001-32 (V0531 Cep) is reported as a Mira-type variable (amplitude 2.45, mean $R_{Rotse}\sim 11.8$, period ~401 days, computed by the automatic NSVS code). We note that in L.Dahlmark [6] the quoted period for V0531 Cep is 366 days.

KP2001-221 is classified as a Semi-Regular (SR) variable with amplitude 0.92, mean $R_{Rotse}\sim 10.448$ and period ~152 days.

Presently the plots of the light curves are not directly available at the NSVS web site; we therefore think worth to show in Fig.3 the light curves for KP2001-32 and 221 obtained from the data downloaded from NSVS.

4. ***Results and discussion***. In the previous sections we have described the spectra, the near infrared colors and the photometric behaviour of our targets.

Four of them (namely KP2001-44, 64, 123 and 228) are non variable stars of different M subclasses. In Fig.2 these stars are located in positions typical for reddened M type giants; we obtained the extinction coefficients assigning the intrinsic colors of the subtypes derived from the spectral CCD classification in Table 1 and assuming as first guess a luminosity class III for all the stars.

At this point we had the data to compute the distances from the dereddened apparent visual magnitudes (taken from GSC2) and the absolute magnitudes of the assumed spectral types and luminosities ($M_V(1)$ column in Table 4). We found the unexpected result that the distances $D(1)$ listed in Table 4, derived with the classical formula $M=m+5-5\log D$, decrease with increasing experimental A_V revealing a non perfect classification, essentially in the luminosity class. We therefore decided to iterate the calculations: we firstly computed approximate distances by applying the average relation between A_V and distance (see eg. Bradt

[23]), with $A_v = 1.2$ mag/kpc which is reasonably correct at low galactic latitudes in the Cepheus direction. We then derived the new expected absolute magnitudes M_v ($M_v(2)$, column 7 in Table 4) and improved spectral type and luminosity class (SP in the same Table). With the improved intrinsic positions in the diagram

Table 4

VISUAL MAGNITUDES, DISTANCES AND CLASSIFICATION OF THE FOUR NON VARIABLE GIANTS

KP2001 Number	m_v(GSC2) mag	m_v der mag	M_v (1) mag	D (1) kpc	D (2) kpc	M_v (2) mag	SP Type
44	15.1	12.45	-0.2	3.4	2.65	+0.73	M6 III/IV
64	13.7	10.04	-0.6	1.3	3.68	-2.4	M2/M3 II
123	13.2	9.03	-0.5	0.8	3.77	-3.4	M1 II/Ib
228	14.3	11.3	-0.6	2.4	3.0	-0.7	M2/M3 III

we recalculated the extinction and finally obtained reasonable values for the distances $D(2)$ in Table 4.

KP2001-32 and 221 have a very late spectral type and are strongly variable. Both are located in the Miras region in the $J-H$ vs $H-K$ diagram of Fig.3 of paper [16], while they occupy quite different positions in the far infrared color-color diagrams (K-[12]) vs ([12]-[25]) and ([25]-[60]) vs. ([12]-[25]) (Fig.5 and 6 of the same paper).

Here [12], [25] and [60] are the IRAS magnitudes, calculated from the flux densities quoted in the catalogue following the prescriptions given in [17]; we had previously applied the color correction to the fluxes for the stellar temperature as indicated in the description of the catalogue at http://cdsarc.u-strasbg.fr/viz-bin/Cat?II/125; we assumed 1000 K for both stars.

We report the magnitudes of the two stars in Table 5 together with the K magnitudes. Concerning the last column we applied the interstellar extinction correction to KP2001-32, but not to 221 for the reasons explained above.

We note that, while KP2001-221 lies far from other variable objects in the two color-color diagrams, the positions corresponding to KP2001-32 are compatible with those of Mira variables selected by the authors of [16], although always at the lower limit. In spite of the strong similarity of the optical spectra the latter star has a thicker envelope than KP2001-221 as also indicated by the hydrogen Balmer emission lines.

With the data available for KP2001-32 we can estimate the absolute K-band magnitude M_K and the bolometric magnitude M_{bol} by adopting the Period-Luminosity relations valid for O-rich Mira type variables (equations 1 and 2 in [16] and references therein):

$$M(bol) = 2.80 - 3.00 \log P \tag{3}$$

Table 5

IRAS MAGNITUDES OF THE TWO KP2001 VARIABLES STARS IN OUR SAMPLE

KP2001 Number	[12] μm	[25] μm	[60] μm	K mag
221	2.50	2.10	0.88	3.61
32	2.49	1.80	1.11	4.15

$$M(K) = 0.93 - 3.47 \log P \quad (4)$$

We can also determine the apparent bolometric (m_{bol}) magnitude for KP2001-32 by applying the bolometric correction $BC(K)$ to the $m(K)$ reddening corrected magnitude (see [19] for details):

$$m_{bol} = m_K + BC(K) \quad (5)$$

In equation (5) we adopted the value $BC(K) = 2.8$ obtained using the calibration $BC(K)$ vs. (K - [12]) index for O-rich Miras given in Figure A3 of the same paper [19].

Having the absolute and apparent magnitudes we can finally give an estimate of the distance to the star. When applying the equations above we must remember the two different periods quoted for this star, 366 and 401 days from two different sources; we therefore report in Table 6 the calculated parameters using both values, also to have an indication of the uncertainties.

We have finally computed a raw estimate of the mass loss - rate for KP2001-32. We derived the value reported in column 7 of Table 6 from the calibration based on the K - [12] index (Fig.21 of [16]).

The dereddened colors of the carbon star KP2001-77 lie well inside the locus of N-type stars in Fig.2. To derive absolute magnitude and distance to the star we applied two different methods and used all the minimum and maximum values of the color excess and extinctions (see Table 3). We want to remember that this star showed only very small photometric variations during the ROTSE monitoring.

In the first case we used Fig.4 of the paper by Totten et al [21] to have an estimate of M_K; we therefore reduced the 2MASS data to the SAAO system. In our case the differences SAAO - 2MASS are 0.06 in the K magnitude and

Table 6

ABSOLUTE MAGNITUDES, DISTANCES AND MASS-LOSS OF KP2001-32

Period days	m_{bol} mag.	M_{bol} mag.	M_K mag.	D (kpc) from M_{bol}	D (kpc) from M_K	m - loss ($M_\odot$/yr)
401	6.95	-5.0	-8.10	2.5	2.8	~7.0 x 10^{-8}
366	6.95	-4.89	-7.96	2.3	2.6	~7.0 x 10^{-8}

0.11 in the color $J-K$; we obtained the corrected mean value $\langle J-K \rangle = 1.66 \pm 0.02$ mag, from which we derived $M_K \approx -7.8 \pm 0.2$ mag. Finally from the two extreme values of A_K and therefore of the dereddened K, we computed the distance to the star $D = 4.9 \pm 0.3$ kpc.

The second distance determination was obtained from the two extreme visual extinctions, assuming as above the extinction coefficient 1.2 mag/kpc. The mean value of the distance is $D = 4.6 \pm 0.3$ kpc. The resulting mean value of the absolute K magnitude is $M_K \approx -7.7 \pm 0.2$ mag.

The very good agreement between the optical and infrared magnitudes and between different distance estimates indicates that cold dusty shells surrounding the central star are absent or negligible. The IRAS far infrared fluxes of this star support this hypothesis.

In the future we plan a long term monitoring of KP2001-32 to determine the true value of the photometric period and to verify the existence of a unique periodicity.

For the Carbon star the very small amplitude oscillations with a period of about 140 days, seem to be real in spite of the big uncertainties in the Rotse-magnitudes; a long and accurate monitoring will be necessary to confirm the regularity of these variations.

We intend to apply the same analysis to all the 257 KP 2001 stars in the Cepheus region with the purpose to clarify their nature and compare the ratio of Carbon to Oxygen-rich giant stars in this region of the Milky Way.

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ХОЛОДНЫЕ ЗВЕЗДЫ БОГАТЫЕ КИСЛОРОДОМ И УГЛЕРОДОМ В ОБЛАСТИ ЦЕФЕЯ: КЛАССИФИКАЦИЯ ОТОБРАННЫХ ОБЪЕКТОВ ИЗ KP2001. I

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Приводятся CCD-спектры со средним разрешением и *R*-фотометрия для семи звезд из KP2001. Пересмотрена спектральная классификация звезд в диапазоне $\lambda\lambda 4000-8700$Å. Наши фотометрические данные подтвердили поведение кривых яркости, взятых из базы данных NSVS (Northern Sky Variability Survey). Для KP2001-32, представленная в NSVS как переменная типа Мира, мы оценили абсолютную болометрическую величину M_b и величину M_K в полосе *K*, а также расстояние, используя соотношение период - светимость. Оценили также степень потери массы, используя отношение калибровки между степенью потери массы и индекса *K* - [12]. На основе цветовых диаграмм в инфракрасных лучах мы подтвердили фотометрическую классификацию KP2001-221 как полуправильную переменную, основанную на базе данных NSVS. Для углеродной звезды KP2001-77, N-типа, мы оценили расстояние и абсолютную величину M_K, используя различные методы калибровки. Для остальных четырех объектов мы получили абсолютные величины и расстояния, используя CCD-спектры и опубликованные JHK_s величины. На основе полученных результатов обсуждена природа этих объектов.

Ключевые слова: ***звезды:спектральная классификация:переменность: абсолютные величины:расстояния***

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