

V669 Cep: A new binary system with a B[e] star

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Abstract. We present the results of optical and near-IR spectroscopic and broadband multicolour photometric observations of the emission-line object V669 Cep. We find evidence that it contains a hot, low luminosity, B4–B6 star and a cool companion (most likely late-type giant). Significant variations of the H α line strength are detected on a timescale of months. The emission-line spectrum and strong IR-excess indicate a large amount of circumstellar gas and dust in the system. The spectral energy distribution in the near-IR region and the absence of late-type star features in the optical spectrum indicates that the cool star is heavily obscured by circumstellar dust, while the hot star is much less affected by reddening. The system is located at 1–1.5 kpc from the Sun in the local spiral arm. We suggest that V669 Cep is an evolved and probably mass exchanging binary system, a member of the group of Be stars with warm dust.

Key words. stars: emission-line – stars: individual: V669 Cep – techniques: spectroscopic; photometric

1. Introduction

Over the last few years we have been extensively studying IRAS sources with a steep flux decrease toward longer wavelengths in the region 12–100 μ m, associated with early-type emission-line stars. The presence of a very strong emission in the Balmer lines, many permitted and forbidden Fe II lines, and a significant near-IR excess indicate that they are surrounded by a significant amount of circumstellar gas and dust. This description is similar to that of B[e] stars, a group distinguished by Allen & Swings (1976). However, while the B[e] stars include objects of very different nature and evolutionary state, we limit ourselves to a subsample which we tentatively call *Be stars with warm dust* (Sheikina et al. 2000). They seem to be post-main sequence intermediate- and high-mass stars.

Some of the objects show evidence of the presence of a cool star in addition to the hot star. These studies resulted in a series of publications (Miroshnichenko et al. 2000, 2001, 2002), where we described the objects' properties in detail for the first time. In this paper we present the results of our observations of V669 Cep, another object which turned out to have similar features to those of our sample.

The object was found in the course of the Tonantzintla Observatory search for emission-line stars (Gonzales & Gonzales 1956, star No. 71) and then listed by Wackerling (1970) as 3g71. No brightness estimate for the object was reported in these catalogs. 3g71 was detected by two IR satellites, IRAS and MSX (Egan et al. 1999), and listed in their point source catalogs as IRAS 22248+6058 and MSX5_G106.3912+03.0922, respectively. The non-colour-corrected IRAS fluxes refined using the ADDSCAN procedure (co-addition of all IRAS scans; see Weaver & Jones

Table 1. Satellite IR photometry of V669 Cep.

IRAS	12 μm	25 μm	60 μm	100 μm
22248+6058	12.50 \pm 0.04	13.98 \pm 0.04	13.28 \pm 0.13	42.7 \pm 2.3
MSX	8.28 μm	12.13 μm	14.65 μm	21.34 μm
5C_G106.3912+03.0922	8.40 \pm 0.41	9.16 \pm 0.29	9.02 \pm 0.37	10.94 \pm 0.71

The fluxes are given in Janskys.

1992) along with those from the MSX survey are listed in Table 1. The IR position coincides with that of the Guide Star Catalog (Lasker et al. 1990) source GSC4264–0935 with an optical brightness of 12.2 mag.

Hang et al. (1999) obtained low-resolution (1.2 \AA pix^{-1}) optical spectra of 3g71 in 1993/5 and found a number of weak and moderately strong permitted and forbidden Fe II lines in emission, He I lines in absorption, a strong and variable emission in the $H\alpha$ line, and narrow emission components inside absorption wings of higher lines of the Balmer series ($H\beta$ and $H\gamma$). In 1997/8 Halpern et al. (2001) also obtained a few spectra of the object with a similar resolution (1.5 \AA pix^{-1}) in the course of identification of a possible optical counterpart for a γ -ray source 3EGJ2227+6122. 3g71 has occurred in the positional error circle of 3EGJ2227+6122, but was not identified as its counterpart. The 1997/8 spectra turned out to be very similar to those of 1993/5 and, in addition to the mentioned features, revealed the $H\delta$ and $H\epsilon$ lines without obvious emission components.

Hang et al. (1999) mentioned a tentative identification of 3g71 with an X-ray source 1H2214+589 (Tuohy et al. 1988), detected by HEAO-1 with an error box of about 2.5×0.5 degrees (Wood et al. 1984). Summarizing their spectroscopic data and taking into account the strong IR flux from 3g71 (see Table 1), Hang et al. suggested that the object is more likely a Herbig B5e star rather than a Be/X-ray binary. Even earlier Wood et al. (1984) listed another X-ray source, 4U2238+60 which is located almost at the border of the HEAO-1 error box for 1H2214+589, as a possible counterpart of the latter. This was supported by in't Zand et al. (2000), who discovered that the position of the weak transient X-ray source SAXJ2239.2+6116 coincided with that of 4U2238+60. The transient was found to show regular outbursts with a period of 232 days and have an optical counterpart, a 16-mag Be star. Thus, the association of 3g71 and 1H2214+589 was not confirmed.

Recently Kazarovets, Samus, & Durlevich (2001) included the object in the General Catalog of Variable Stars referring to Takamizawa¹, who obtained a few photovisual observations of 3g71 in 1994–1999 showing brightness variations from 11.9 to 12.4 mag (in a nonstandard passband close to the V -band). The star was denoted as V669 Cep with the variability type SR: (possible semi-regular variable).

No other ground-based photometric data have been published so far. All the information about V669 Cep = 3g71 mentioned above is not sufficient to make any definite conclusion about the nature and evolutionary state of this object. To clarify this issue we obtained new observations of V669 Cep and discuss them here.

2. Observations

The photometric $WBVR$ observations of V669 Cep were obtained on 2001 December 16 at the Tien-Shan Observatory (TSAO, Kazakhstan) using a 50-cm telescope with a standard pulse-counting single-channel photometer. The instrumental system, whose BVR bands are very close to the Johnson system, is described in Khaliullin et al. (1985). The errors of individual measurements were 0.02 mag in all the bands. HD 213530 (B9), whose $WBVR$ magnitudes are listed in Kornilov et al. (1991), was used as a comparison star. The instrumental system stability was controlled using other standard stars observed during the night. The Johnson $U - B$ colour-index of HD 213530 was calculated from the $W - B$ using a linear regression, derived for nearly 1000 B7-A9 non-supergiant stars from the Bright Star catalogue with $WBVR$ photometry ($U - B = (0.830 \pm 0.004)(W - B) - 0.006 \pm 0.001$). Its Johnson $R - I$ colour-index was calculated from the reddening ($E_{B-V} = 0.12$ mag) and a calibration of Wegner (1994).

Differential $BVRI$ CCD photometry of V669 Cep was obtained with the 28-cm Beardsley Schmidt-Cassegrain telescope at the Lizard Hollow Observatory (LHO, Tucson, AZ, USA) on five nights, from December 2001 through January 2002. An SBIG ST-7E camera was used, and the frames were measured with the SBIG CCDOPS software. First-order extinction coefficients were determined for each night's observations. Standard stars, taken from Kornilov et al. (1991) and other literature sources, were observed from which transformation coefficients between the instrumental and Johnson system were derived. The primary comparison and check stars were, respectively, HD 213530 and HD 212776. Neither of those stars was used in determining the transformation coefficients. Frames of the primary comparison stars were not obtained each night. The magnitudes and colours of V669 Cep were measured with respect to HD 213530. V669 Cep did not show any brightness variations exceeding the internal observational errors, which were 0.03–0.1 mag in the B -band

¹ The light curve is accessible from <http://www.kusastro.kyoto-u.ac.jp/vsnet/LCs/index/CEPV669.html>

Table 2. Optical and near-IR photometry of V669 Cep.

JD2452000+	<i>V</i>	<i>U</i> − <i>B</i>	<i>B</i> − <i>V</i>	<i>V</i> − <i>R</i>	<i>V</i> − <i>I</i>	<i>J</i>	<i>H</i>	<i>K</i>	Remark
260.109	12.47	0.00	0.74	0.85					TSAO ^a
246–283	12.45	–	0.73	0.90	1.50				LHO ^b
118.65						9.98	9.04	7.61	CST
220.50						10.0	9.1	7.7	Palomar
	6.98	−0.20	0.03	0.07	0.09				HD 213530

^a $U - B$ was calculated from $W - B = -0.05$ mag using the same procedure as described for HD 213530.

^b The data were obtained between JD 2452246 and JD 2452283; the star is too weak in the U -band frames.

The near-IR photometric errors are 0.05 mag for the HK CST data, otherwise 0.1 mag.

and 0.01–0.03 mag in the VRI -bands. All our optical photometric data are presented in Table 2.

On 2001 July 27 we obtained JHK photometry of V669 Cep at the 1.55-m Carlos Sánchez Telescope (CST), operated by the Instituto de Astrofísica de Canarias at the Spanish Observatorio del Teide (Tenerife, Spain). We used a CVF infrared spectrophotometer equipped with an InSb photovoltaic detector, operating at the temperature of liquid nitrogen, with a photometric aperture of 15'' and a chopper throw of 30'' in the E-W direction to subtract the contribution from the background sky. The Teide photometric system is described in Arribas & Martínez-Roger (1987), as well as its relations with other standard photometric systems.

The infrared low-resolution spectroscopic observations of V669 Cep were acquired on 2001 July 29 at the 60-inch telescope of the Palomar Observatory with the CORMASS spectrograph (Wilson et al. 2001) in the region 0.75–2.5 μm ($R \sim 300$). The instrumental response and most of the effects of atmospheric absorption were removed by dividing the spectrum of V669 Cep by that of the calibrator star (HD 21338, G8 V, $V = 7.45$ mag). To remove the intrinsic spectrum of the calibrator from this ratio, a model from Kurucz (1994) appropriate to a G8 V star was used. The resulting spectrum was converted into magnitudes using passbands of the JHK photometric system from Bessell & Brett (1988). These magnitudes are presented in Table 2 along with the CST data. Both sets of magnitudes agree with each other rather well, justifying the reliability of the near-IR spectrum calibration. Additionally, from these data we estimated the Johnson I -band magnitude (10.9 mag) using a calibration by Straizys (1977). This turned out to be very close to our LHO data.

The high-resolution optical spectra of V669 Cep were obtained with the following telescopes and spectrometers:

1. 6-m telescope of the Special Astrophysical Observatory (SAO) of the Russian Academy of Sciences: on 2001 January 2 with the prime-focus échelle-spectrometer PFES (Panchuk et al. 1998) and a 1140×1170 pixel CCD detector in a spectral range 5000–6650 Å with a mean $R \sim 15000$; and on 2001 November 29 with the échelle-spectrometer Lynx (Panchuk et al. 1999), mounted in the Nasmyth-2 focus, and the same CCD

detector in a range 5030–6680 Å with a mean $R \sim 30000$. The SAO spectra were reduced using standard methods under MIDAS;

2. on 2001 September 7 at the 3.6-m CFHT (Mauna Kea, Hawaii, USA) with the Coudé échelle spectrometer Gecko and a 2048×4608 thinned back-illuminated EEV chip in the range 6505–6610 Å and with a $R \sim 60000$;
3. on 2001 October 10 at the 2.1-m Otto Struve telescope of the McDonald Observatory (Mt. Locke, Texas, USA) with the Sandiford échelle-spectrometer (McCarthy et al. 1993) in the range 5540–6915 Å and with a $R \sim 60000$. A 1200×400 pixel CCD was used.

The CFHT and McDonald spectra were reduced with IRAF².

3. Results

3.1. Spectrum

Both our high-resolution optical spectra and low-resolution near-IR spectrum of V669 Cep contain emission lines of neutral hydrogen, permitted and forbidden Fe II and O I lines. The emission-line spectrum is variable. Some iron lines at $\lambda\lambda 5150$ –5400 Å are seen only in the January 2001 spectrum, while others only in the November 2001 spectrum (Fig. 1a). This may be due in part to a low signal-to-noise ratio (~ 60 and ~ 40 in January and November, respectively), since all of these lines are weak. However, the variations are clearly seen in the [O I] lines and $H\alpha$.

The very weak emission lines of [N II] at 6548 and 6583 Å appeared in our high-resolution spectra. We also detected three He I lines with different profile shapes. The He I 6678 Å line has a pure absorption profile, the 5876 Å line exhibits a weak and variable emission component (Fig. 1b), while the 10830 Å line (observed at low resolution) is completely in emission. Other absorption features, seen in the spectra, are weak diffuse interstellar

² IRAF is distributed by the National Optical Astronomy Observatories, which are operated by the Association of Universities for Research in Astronomy, Inc., under contract with the National Science Foundation.

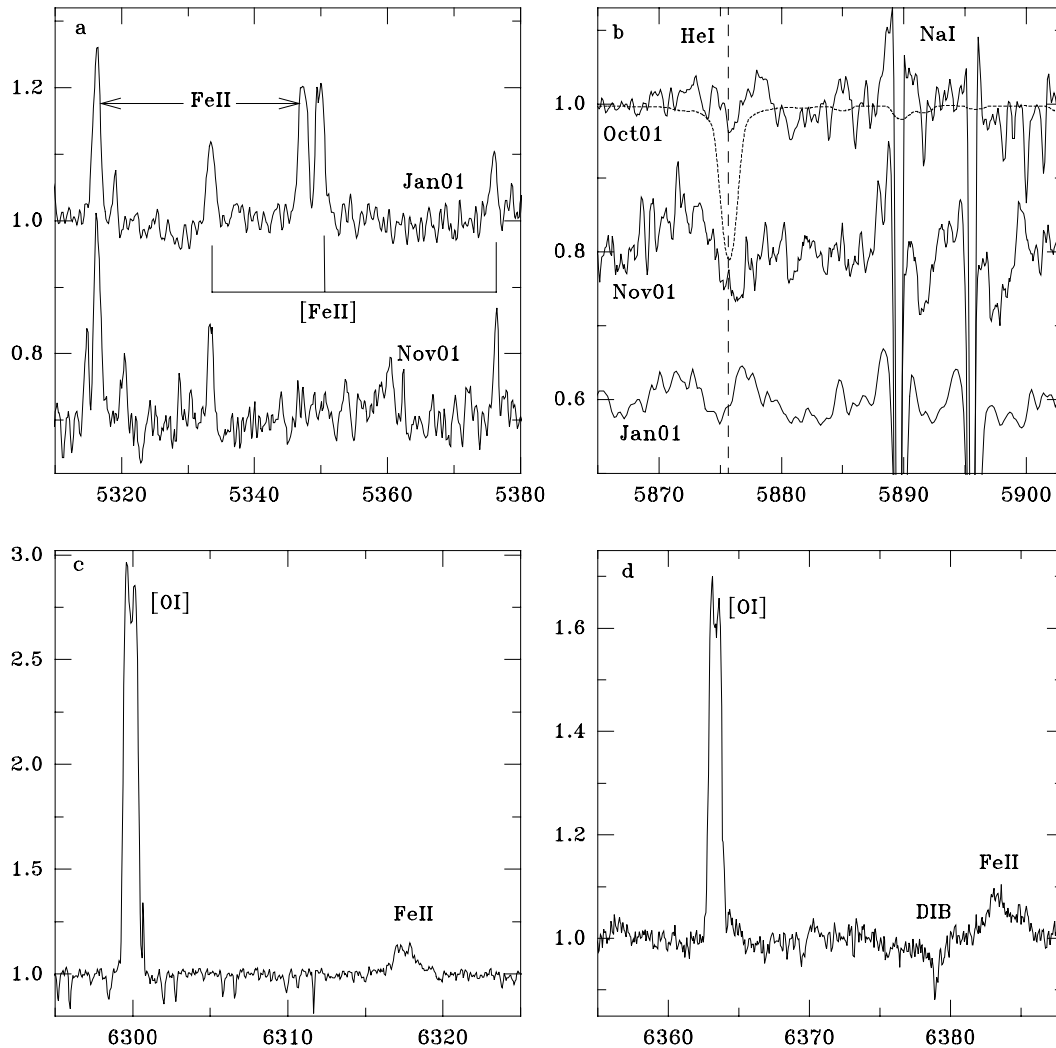


Fig. 1. Portions of the spectrum of V669 Cep. **a)** The SAO January and November 2001 spectra shifted by $0.2 I_c$ with respect to each other. **b)** The He I and Na I lines region. The vertical line represents the laboratory wavelength of the 5876 Å line. A synthetic spectrum for $T_{\text{eff}} = 15\,000$ K, $\log g = 4.0$, and a rotation velocity of 50 km s^{-1} is shown by the dotted line. **c)** and **d)** Portions of the McDonald spectrum in the regions of [O I] lines. Heliocentric wavelengths are given in Å, while the intensities are normalized to the continuum.

bands (DIBs), and a group of features at $2.29\text{--}2.39 \mu\text{m}$. The latter can be identified with the CO (2–0), (3–1), (4–2), and (5–3) bands. The only Fe II lines, seen in the near-IR spectrum, are those at 9997 and 10501 Å (Rudy et al. 2000 and references therein). These lines, although much stronger, are also observed in the spectra of luminous B[e] stars (Lopes et al. 1992).

The list of lines identified in the spectrum of V669 Cep with the help of a catalogue by Coluzzi (1993) is presented in Tables 3 (optical range) and 4 (near-IR range). Parts of the spectra are shown in Figs. 1–4.

Overall, our optical spectra are similar to the low-resolution spectra of Hang et al. (1999). The only Balmer line from our spectral range, H α , is extremely strong and rather narrow (full width at half maximum, $FWHM \sim 120 \text{ km s}^{-1}$; Fig. 2). The intensity of its central peak varies dramatically with time (Fig. 2a). The signal registered in the underlying continuum was high (≥ 1000 counts) in all

our spectra, while the line’s peak was not saturated. This excludes significant normalization errors. The existing H α EW data are presented in Table 5. Due to a higher resolution and signal-to-noise ratio, we detected the absorption wings of the H α line in the CFHT spectrum. Their slope is consistent with an effective temperature (T_{eff}) of $\sim 15\,000$ K and a $\log g \geq 3$.

The DIBs are weak, indicating a low reddening. For example, the equivalent width of the strongest DIB at 5780 Å (0.23 Å) corresponds to $E_{B-V} \sim 0.5 \text{ mag}$ (Herbig 1993). Rudy et al. (1991) have used the IR O I lines to estimate the reddening when the 8446 and 11 287 Å lines are produced mainly by Ly β fluorescence, and continuum fluorescence can be treated as a perturbation. In V669 Cep, however, it is clear from the observed ratios that continuum fluorescence makes a large contribution. The difficulty is that for continuum fluorescence the relative strengths of the three lines depend on the UV spectral

Table 3. Lines identified in the optical spectrum of V669 Cep.

Line ID	λ_{lab} Å	I/I_c	RV km s ⁻¹	EW Å	Rem.	Line ID	λ_{lab} Å	I/I_c	RV km s ⁻¹	EW Å	Rem.
1	2	3	4	5	6	1	2	3	4	5	6
Fe II(42)	5018.44	1.3	-34	0.54	Jan01	He I(11)	5875.72	0.95	-		
[Fe II](19F)	5158.78	1.2	-24:		Nov01	Na I(1)	5889.95	0.49	-16	0.41	
[Fe II](35F)	5163.95	1.1	-17:		Nov01	Na I(1)	5895.92	0.57	-16	0.43	
Fe II(42)	5169.03	1.3	-21	0.26		Fe II(74)	6147.74	1.02	-	0.02	
[Fe II](19F)	5220.06	1.1	-24:		Nov01	DIB	6195.96	0.94	-13	0.08	
Fe II(49)	5234.62	1.1	-22	0.08	Jan01	DIB	6203.08	0.94	-14	0.04	
Fe II(41)	5238.58	1.1	-20	0.15:	Jan01	Fe II(74)	6247.55	1.08	-	0.07:	+f
Fe II(41)	5256.89	1.1	-30:	0.10:	Jan01	Fe II()	6248.9	1.08	-		
[Fe II](19F)	5261.61	1.2	-16:	0.05		[O I](1F)	6300.3	2.9-4.0	-18	2.0-3.1	
[Fe II](18F)	5273.38	1.1	-21:	0.14		Fe II	6317.99	1.1	-25:	0.3	
Fe II(49)	5276.00	1.1	-26:		Nov01	[O I](1F)	6363.78	1.7-1.9	-18	0.7-1.0	
Fe II(49,48)	5316.61	1.3	-22	0.34		Fe II	6383.72	1.1	-	0.24	
[Fe II](19F)	5333.65	1.1	-16	0.18		[N II](1F)	6548.03	1.04	-25	0.04	CFHT
Fe II(49)	5346.56	1.2	-23	0.27	+f	H α	6562.81	var.	-25		
[Fe II](18F)	5347.67	-	-	-	Jan01	[N II](1F)	6583.45	1.1	-23	0.07	CFHT
[Fe II](19F)	5376.47	1.1	-28:	0.09		DIB	6613.56	0.85	-15	0.15	
DIB	5780.37	0.85	-10	0.23		He I(46)	6678.15	0.95	-		Oct01
DIB	5796.96	0.91	-10	0.08							

Comments to the line list in the optical spectrum of V669 Cep.

Unreliable identifications and less accurate measurements are denoted by colons. Intensities at line peaks in units of the underlying continuum are given in Col. 3, heliocentric RV in Col. 4, equivalent widths in Col. 5, and Remarks in Col. 6.

“f” refers to the following line; lines detected in a particular spectrum are referred by dates; Intensities, RV s and EW s are averaged if detected in more than one spectrum; the H α equivalent widths are given in Table 5.

Table 4. Lines identified in the near-IR spectrum of V669 Cep.

λ_{lab}	ID	I/I_c	λ_{lab}	ID	I/I_c
8446.35	O I (4)	1.24	13 164.00	O I	1.12
9229.017	P9	1.18	15 556.45	Br16	1.03
9545.974	P8	1.10	15 700.66	Br15	1.05
9997.58	Fe II	1.07	15 880.54	Br14	1.04
10 049.38	P7	1.21	16 109.31	Br13	1.07
10 501.00	Fe II	1.05	16 407.19	Br12	1.09
10 830.34	He I (1)	1.16	16 806.52	Br11	1.10
10 938.09	P6	1.44	17 362.11	Br10	1.09
11 287.00	O I	1.13	21 655.29	Br γ	1.16
12 818.05	P5	1.95			

Table 5. The existing H α line equivalent width data for V669 Cep.

JD2400000+	$EW, \text{Å}$	Ref.
49297	103	1
50006	75	1
50720	88	2
51001	93	2
51912	181	3
52160	67	3
52192	123	3
52243	187	3

References: 1 – Hang et al. (1999), 2 – Halpern et al. (2001), 3 – this work.

energy distribution of the exciting source (Grandi 1975, 1976). The reddening can be estimated, but the uncertainty is greater than the case where Ly β fluorescence is the primary source and the intrinsic 8446/11 287 intensity ratio is well known. The relative photon flux ratios for continuum illumination by a B-type star are approximately 1/0.06/0.5 for the lines at 8446, 11 287, and 13 164 Å, respectively. Using this and allowing for a contribution from Ly β fluorescence gives $E_{B-V} = 1.2 \pm 0.3$ mag. For this we have corrected the strength of the 11 287 Å line for telluric absorption assuming a $FWHM$ for the line of 90 km s⁻¹ and a heliocentric radial velocity (RV) of -22 km s⁻¹ (values derived from our high-resolution optical measure-

ments) in the manner described in the appendix of Rudy et al. (1991).

The emission lines of [O I] at 6300 and 6363 Å have RV s close to those of other emission lines and are formed in the object’s envelope. In the McDonald spectrum ($R = 60\,000$) they appear double-peaked (as well as the Fe II lines at 6317 and 6383 Å) with a mean peak separation of 25 km s⁻¹.

The Na I D_{1,2} lines consist of a rather deep interstellar absorption component (not split even at $R = 60\,000$) superposed on a weak, circumstellar emission (see Fig. 1b). Another absorption component at +90 km s⁻¹ is clearly seen in both D-lines only in the November 2001 spectrum.

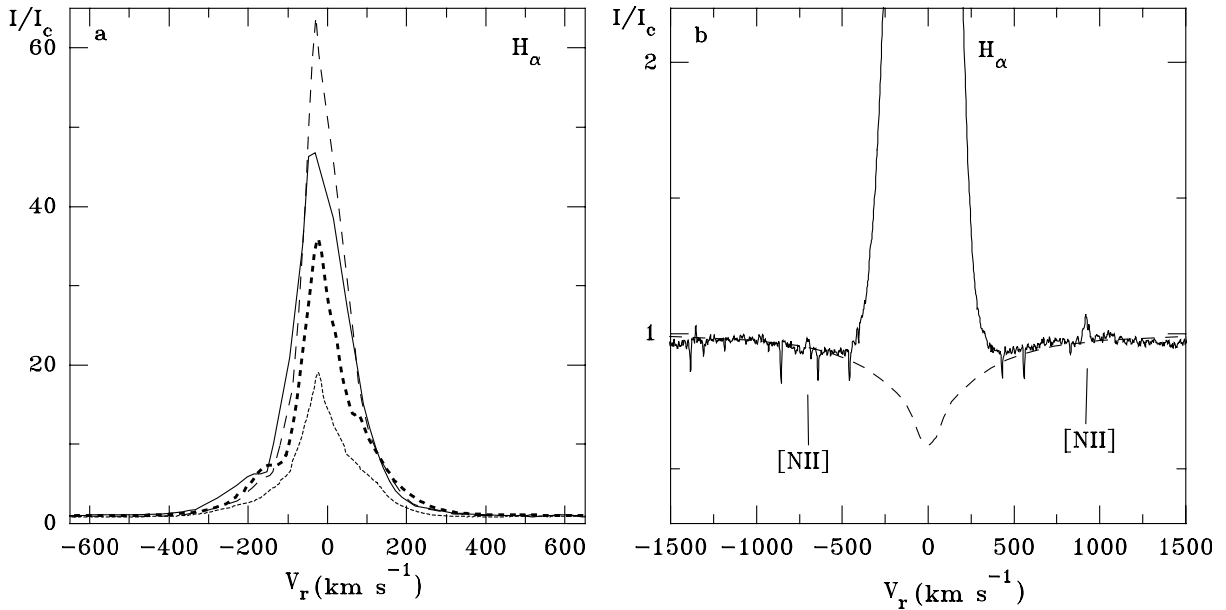


Fig. 2. The H α line profiles of V669 Cep. **a)** The SAO January 2001 (solid line), CFHT (short-dashed line), McDonald (dotted line), and SAO November 2001 (long-dashed line) spectra. **b)** The lower part of the CFHT profile (solid line) with a theoretical profile for $T_{\text{eff}} = 15000$ K, $\log g = 4.0$ and a rotation velocity of 50 km s^{-1} (dashed line). The RV s are heliocentric, while the intensity scale is the same as in Fig. 1. Telluric lines were not removed from the spectrum.

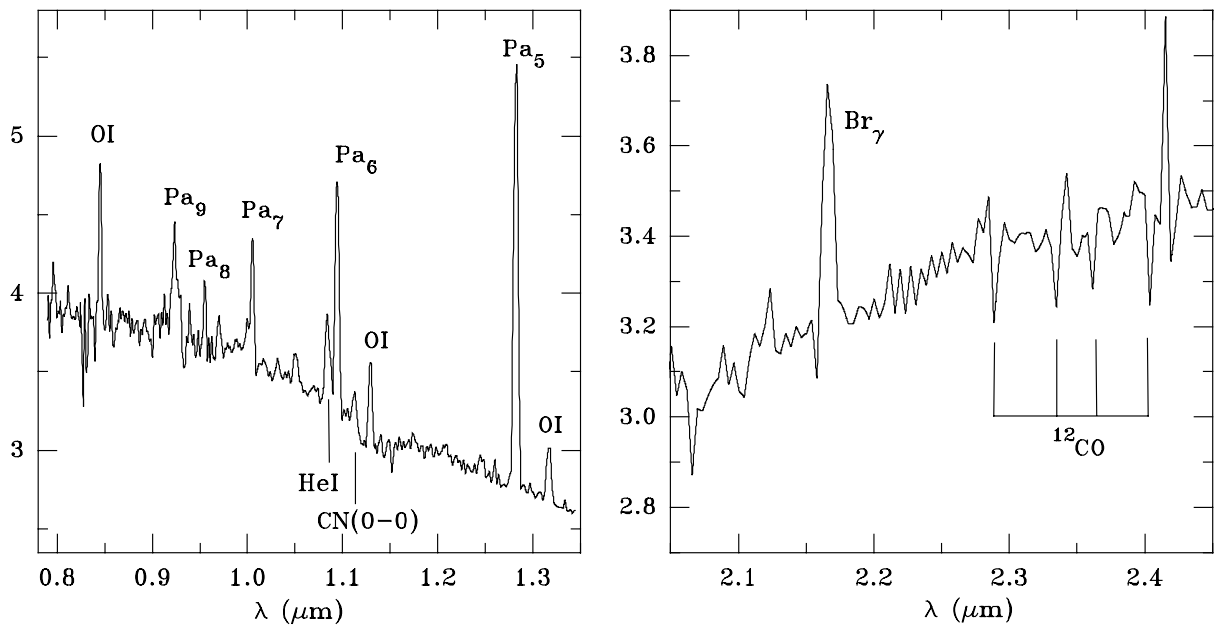


Fig. 3. Parts of the low-resolution near-IR spectrum of V669 Cep. Wavelengths are given in microns, while the fluxes are given in units of $10^{-17} \text{ W cm}^{-2} \mu\text{m}^{-1}$.

Unfortunately, it is affected by a telluric line (seen in the McDonald spectrum, the upper plot in Fig. 1b). However if real, it is definitely circumstellar and variable. In the November 2001 spectrum the appearance of this component is accompanied by a positive velocity shift of the He I 5876 \AA line. The explanation of these phenomena is not clear yet and requires follow-up high-resolution spectroscopy.

The mean RV of the Na I D interstellar components is -16 km s^{-1} , that of the DIBs is $-12 \pm 3 \text{ km s}^{-1}$, while that

of the emission lines is $-22 \pm 3 \text{ km s}^{-1}$ and $-20 \pm 2 \text{ km s}^{-1}$ (January and November 2001, respectively). Both the structure of the interstellar Na I components and the RV values suggest that the object belongs to the local spiral arm, whose outer edge is located at a distance (D) of ~ 1 – 1.5 kpc from the Sun (Efremov 1989). Additional absorption components, formed in the more distant Perseus arm, appear in the spectra of stars in this direction at RV s $\sim -45 \text{ km s}^{-1}$ and $D \geq 2$ kpc (e.g., Munch 1957). This sets an upper limit for D toward V669 Cep at 1.5 kpc, consid-

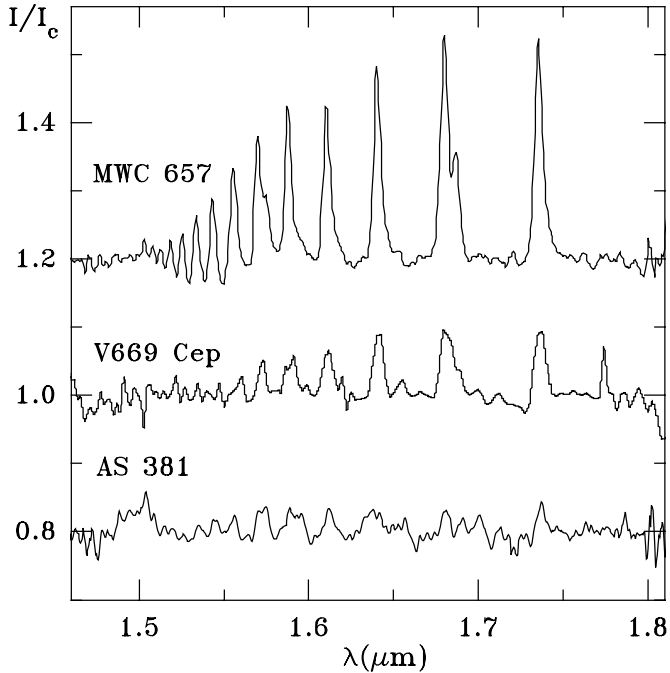


Fig. 4. The normalized H -band spectra of several Be stars with warm dust. The spectra of MWC 657 and AS 381, obtained at Lick in July of 2000 with a similar resolution (see Miroshnichenko et al. 2002 for details), are shown for comparison.

ering that the object is unlikely to reside in the inter-arm space.

There is also a continuum jump at $1.1 \mu\text{m}$ (see Fig. 3), which appears in the spectra of stars later than G5 of luminosity types I–III (Wallace et al. 2000) and is attributed to the CN 0–0 band. Along with the presence of the CO absorption bands, this suggests the presence of a late-type component in the system. The absence of late-type star features shortward of 6800 \AA does not allow us to constrain its spectral type, and indicates that the cool star is significantly fainter than the hot one.

3.2. Photometry and spectral energy distribution

The optical photometry indicates that V669 Cep is a reddened B-type star. From the existing UBV data for stars in a $1^\circ \times 1^\circ$ region around the object a colour-excess ratio $E_{U-B}/E_{B-V} = 0.60$ can be derived. Its application to the colour-indices of V669 Cep gives a spectral type of B5 and $E_{B-V} = 0.9$ mag (Wegner 1994). The colour-excess is consistent with the estimate from the IR line strengths and larger than that derived from the DIBs strength. The latter is less reliable as showing significantly different relationships in different directions (see Herbig 1993). The nearby stars reddening also indicates that $E_{B-V} \geq 0.7$ mag corresponds to $D \geq 1$ kpc, which is in agreement with our estimate from the Na I lines and can be adopted as a lower limit for the distance toward V669 Cep.

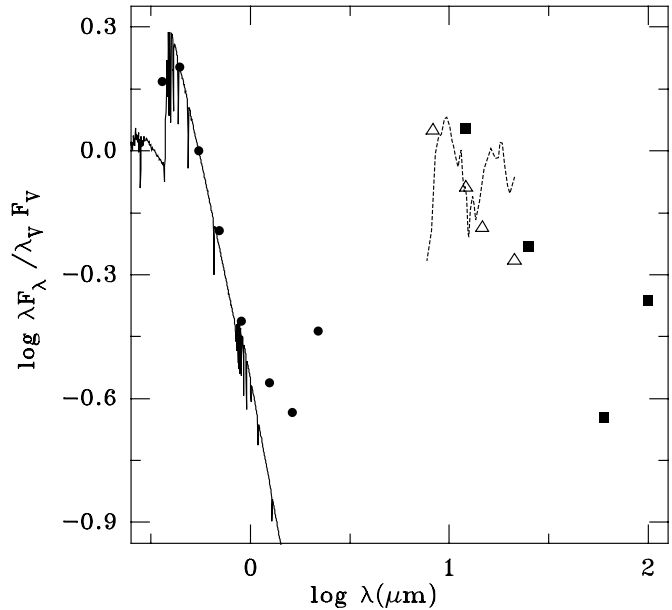


Fig. 5. The SED of V669 Cep. The solid line represents the synthetic spectrum for $T_{\text{eff}} = 15000 \text{ K}$ and $\log g = 4.0$ from Kurucz (1994). The $UBVR IJHK$ fluxes are shown by filled circles, the IRAS data by filled squares, the MSX data by open triangles, and the IRAS LRS spectrum (rescaled to the $12 \mu\text{m}$ flux) by the dashed line. A reddening of $E_{B-V} = 0.9$ mag and $V = 12.4$ mag were assumed.

Our near-IR photometry and spectrum show the presence of circumstellar dust, as the colour-indices ($\overline{J-H} = 0.94 \pm 0.11$, $\overline{H-K} = 1.43 \pm 0.07$) are much larger than those expected from a stellar photosphere and the low reddening estimated above. Moreover, the IRAS and MSX data show even stronger mid- and far-IR excesses. The IRAS LRS spectrum, which is rather noisy due to the closeness of the object’s flux to the threshold of the spectrometer, was cleaned with a numerical high-frequency filter. This procedure revealed the presence of the silicate emission features at 9.7 and $18 \mu\text{m}$, indicating that the circumstellar dust is oxygen-rich and is optically thin at these wavelengths. The $100 \mu\text{m}$ IRAS flux is most likely contaminated by the interstellar IR cirrus emission, because the 2D coadded image of the source is extended, and the parameter $\text{CIR3} = 114 \text{ MJy sr}^{-1}$ (the total $100 \mu\text{m}$ sky surface brightness around the object) is much larger than the object’s $60 \mu\text{m}$ flux (Ivezić & Elitzur 1995). Hence the $100 \mu\text{m}$ IRAS flux of V669 Cep is not reliable.

The dereddened spectral energy distribution (SED) of V669 Cep (see Fig. 5) shows that an excess radiation above the photospheric spectrum already exists at $\lambda \sim 1 \mu\text{m}$ and rises drastically longward of $\lambda \sim 1.5 \mu\text{m}$. The excess maximum, located at $\sim 10 \mu\text{m}$, suggests that the bulk of circumstellar dust has temperatures $\sim 300 \text{ K}$. The steep flux decrease longward of $20 \mu\text{m}$ and the spectral features discussed above make V669 Cep similar to objects from the group of Be stars with warm dust, recently defined by us (Sheikina et al. 2000).

The 12 μm IRAS flux is 1.5 times higher than the corresponding MSX flux. In part this may be due to the broader IRAS bandpass. The colour-correction factor for this wavelength (1.41), suggested in The IRAS Explanatory Supplement (1985) and based on an A0-type photospheric underlying spectrum, would remove this difference. However, the SED of V669 Cep in the mid-IR is certainly much flatter than that of an A0-type star implying a smaller flux reduction. Nevertheless, the IRAS and MSX fluxes of V669 Cep, obtained 13 years apart, are close to each other. This fact along with the high positional accuracy of the MSX mission provide evidence that the IR excess does belong to V669 Cep and the near-IR flux rise with wavelength is real.

4. Discussion

The results of our observations suggest that V669 Cep is most likely a binary system with a hot and a cool stellar component and gas-and-dust circumstellar envelope. Its emission-line spectrum and SED in the IR region are similar to those of other binary Be stars with warm dust, MWC 623 (Zickgraf 2001) and AS 381 (Miroshnichenko et al. 2002). Let us consider different hypotheses about the nature and evolutionary state of the V669 Cep system.

From the object's mean brightness and our estimates for D and A_V one can derive an absolute visual magnitude of the hot companion, $M_V = -0.9 \pm 0.4$ mag, assuming no contribution of the cool companion to the V -band brightness. The latter suggestion is justified by the absence of noticeable late-type star features in the observed parts of the optical spectrum. According to a calibration of Straizys & Kuriliene (1981), such an M_V corresponds to main-sequence B4–B6 stars. The same range of spectral types follows from our UBV data. Thus, we confirm the conclusion of Hang et al. (1999) about a mid B-type underlying star in this source. Comparing V669 Cep with AS 381, in whose spectrum lines of the cool companion are seen redward of ~ 5800 Å and for which we estimated the companions' brightness ratio of $\Delta V \sim 2.2$ mag, we can suggest that the brightness ratio in the V669 Cep system is even larger. In this case the cool companion should be a late-type subgiant or even a dwarf. Thus, taking the suggestion of Hang et al. (1999) that the hot companion is a pre-main-sequence Herbig Be star, it is natural to assume that the cool companion is a T Tau star.

The optical colour-indices (Table 1) and the bluest part of the near-IR spectrum (Fig. 3) indicate that the overall (inter- and circumstellar) reddening is rather low. At the same time, the steep rise of the observed flux from ~ 1.5 to ~ 10 μm is consistent with a large amount of dust in the system. It also indicates that the dust is most likely optically thick in the optical region. Two different explanations for this situation can be considered.

The first explanation concerns the presence of individual non-spherical envelopes around each companion or a circumbinary disc. Such a circumstellar matter distribution can be deduced from the double-peaked optical line

profiles (Fig. 1). The disc (or discs) should be inclined to the line of sight at an intermediate angle, because the line profiles are narrow and the central depressions are shallow. We have already shown that the Brackett emission lines strength in the close to pole-on object AS 381 are much weaker than in the more equator-on MWC 657 (Miroshnichenko et al. 2002) both of which display properties, similar to those of V669 Cep. The line strength difference is mainly due to a stronger continuum, coming from a larger surface of a more inclined disc (if both the lines and continuum are formed in the same envelope). In V669 Cep the Brackett lines are a little stronger than those in AS 381 (see Fig. 4). Thus if the gas-and-dust envelope of V669 Cep is a disc viewed close to pole-on, it can obscure both companions a little. This does not contradict a possible pre-main-sequence nature of the system.

However, the $H\alpha$ emission line is too strong for a mid B-type Herbig star, if we assume that the bulk of the circumstellar gas is illuminated by the hot companion alone (or the absence of the cool companion). Even more massive pre-main-sequence objects (such as HD 200775, Miroshnichenko et al. 1998, or MWC 297, Drew et al. 1997) rarely have a stronger $H\alpha$ emission. If we attribute the line emission to the much fainter T Tau companion, this contradiction would become even stronger. The equivalent width of the $H\alpha$ line would be ≥ 1000 Å, that is not observed in any of such objects (see Cohen & Kuhl 1979). Other arguments against the pre-main-sequence nature of the object include the following:

1. both Herbig Ae/Be and T Tau stars usually have much flatter IR SED due to the presence of distant and cold circumstellar dust of protostellar origin. If the companions have the same age, the T Tau star, which evolves much slower than the intermediate-mass hot companion, has to be extremely young and exhibit a significant far-IR excess with a flux rising longward of ~ 10 μm .
2. The CN (0–0) 1.1 μm absorption band is a feature of luminous stars.

The second explanation assumes that the companions are obscured differently. Since we observe no significant obscuration of the hot companion (from the low optical reddening), the dust might obscure only the cool companion. The hot companion can even have no dust around it, because its relatively high UV flux prevents the dust condensation in its Roche lobe. This interpretation is supported by the fact that we see only very weak [N II] nebular lines in the spectrum of V669 Cep (see Fig. 2b). Such a faint phenomenon implies that the circumstellar gas distribution around the hot star is rather compact, and its average density is relatively high. Therefore, the optical nebula around the object noticed by Hang et al. (1999) on the Palomar Sky Survey plate may represent the scattered light off the dust around the cool companion, which in this case can be intrinsically much brighter. It can be a giant as in the MWC 623 system (Zickgraf 2001). Since the dust condensation radius is very low for a cool star, all the dust in the system can be confined to the cool companion's Roche

lobe. Such a model has been considered for some symbiotic systems (e.g., V1016 Cyg, Taranova & Bogdanov 2001). This idea can be applied to other Be stars with warm dust and, hence, be used to correct the brightness ratios in known and suspected binaries. At the same time, we should note that these binaries cannot be fully identified with symbiotic systems. The former seem to have less evolved hot companions than the latter. Nevertheless, the evolutionary state of the Be stars with warm dust is not constrained yet and requires further investigation, which is out of this paper scope.

A suggestion that V669 Cep is an optical (projected) pair can easily be ruled out. None of the companions alone seem to take all the object's features without a contradiction, as we explained above. The probability of a positional coincidence of two stars, surrounded by a significant amount of circumstellar matter, in a relatively unpopulated field is extremely low.

The shape of the $H\alpha$ profile (Fig. 2a) is suggestive of the presence of a broader double-peaked structure (at $I/I_c \sim 10$) in addition to the strong and variable central peak. The double-peaked emission profile is a gaseous disc feature, while the central peak may be formed in a ring, close to the Roche lobe boundary of the hot companion and in a region of the mass transfer. The suggestion about mass transfer is justified by the presence of an extremely strong $H\alpha$ emission, which seems to be too strong for a reasonable mass loss rate from a mid B-type star (as we mentioned above).

We can roughly estimate the parameters of the system and its stellar companions. The hot companion's luminosity $\log L/L_\odot = 2.7 \pm 0.2$ can be derived from the above M_V , a B4–B6 spectral type ($T_{\text{eff}} \sim 15\,000 \pm 2000$ K, Straizys & Kuriliene 1981), and a bolometric correction of ~ -1 mag (Miroshnichenko 1997). This leads to the star's radius $R_* \sim 3 R_\odot$ and mass $M_* \sim 4 M_\odot$. Then, if the companions have the same luminosities and masses (as in MWC 623, Zickgraf 2001), and the cool star has a K spectral type (the CO bands are too faint for an M-type star, as in AS 381, Miroshnichenko et al. 2002), the minimum orbital period would be about 5 days (assuming that the stars touch each other). Since there is a large amount of circumstellar matter in the system, both companions need some space for its storage. This will make their separation and orbital period larger.

A very sparse light curve obtained by Takamizawa contains 2 brightenings of the object in early 1998 and mid 1999 (~ 1.5 years apart) by 0.3–0.4 mag. These are probably not related to the orbital rotation in the system, which does not seem to be eclipsing (see above arguments). However if the cool companion is more massive, has a larger Roche lobe, and the dust is distributed around it mostly spherically (as in the case of V1016 Cyg), then the dust can obscure the hot star at certain orbital phases even at relatively large inclinations ($\geq 30^\circ$) of the orbital plane to the line of sight. The absence of detailed RV variation data does not allow us to give an accurate estimate for the orbital period. The existing $H\alpha$ data (Table 5) show

that significant intensity variations occur on a timescale of a few months. If mass loss or transfer is relatively stable in the system, these variations may be due to the projection or other effects, related to the orbital motion. From the fact that classical Be and Be/X-ray binaries with the strongest emission-line spectra have orbital periods of 150–250 days (Reig et al. 1997) and that the $H\alpha$ line in V669 Cep is extremely strong, we can suggest that its orbital period is of the order of a few hundred days. Such a period implies an angular separation of a few milliarcseconds at $D = 1$ kpc, that can be detected by the next generation satellites, such as SIM, or ground-based speckle interferometers (e.g., IOTA).

As we discussed in our previous papers (Miroshnichenko et al. 2000, 2002), the steep decrease of the far-IR flux probably implies that the system is still evolving redward from the main-sequence and is too young to produce a pronounced SED peak at 25–60 μm , which is observed in the IRAS data for post-AGB stars or LBVs. The presence of forbidden lines in the spectrum of V669 Cep allows us to classify it as a B[e] object, a new member of the group of Be stars with warm dust. We note here that despite our conclusion that the dust is most likely located around the cool companion, there is no contradiction with the B[e] type definition (the presence of forbidden lines and dust, Allen & Swings 1976), which does not specify the dust origin. In fact, the B[e] star list contains a number of symbiotic stars, which are observationally similar to V669 Cep except for the reversed companions' brightness ratio.

5. Conclusions

We obtained and analysed optical and near-IR spectroscopic and photometric observations of the emission-line star V669 Cep = 3g71 associated with the IR source IRAS 22248+6058. The optical spectrum is dominated by weak permitted and forbidden Fe II emission lines in addition to the strong and double-peaked [O I] lines and extremely strong and variable $H\alpha$ ($66 \leq EW \leq 187$ Å). Both our optical photometry and spectrum suggest that a mid B-type (B4–B6) low-luminosity star, surrounded by a non-spherical gaseous envelope, is responsible for the observed features and SED in the optical domain. The absorption bands of CN and CO, seen in the near-IR spectrum, as well as a steep rise of the observed flux in the 1.5–10 μm region indicate the presence of a cool (probably K-type) star in the system. The dusty envelope seems to be located mostly around the cool companion, reducing its brightness. The flux decrease longward of 10 μm provides evidence that the dusty envelope is rather compact and may be confined within the Roche lobe of the cool companion. The $H\alpha$ line strength suggests an ongoing mass exchange in the system, probably through the companions' circumstellar matter. The binary belongs to the local spiral arm at a distance of 1–1.5 kpc from the Sun.

The described properties of V669 Cep rule out the hypothesis by Hang et al. (1999) that it is a pre-main-sequence Herbig Be star. Instead, we argue that it is a post-main-sequence intermediate-mass binary, although probably less evolved than symbiotic systems. Further optical and IR observations of V669 Cep are very desirable in order to study its brightness and spectral variations in more detail.

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References

- Allen, D. A., & Swings, J.-P. 1976, *A&A*, 47, 293
- Arribas, S., & Martínez-Roger, C. 1987, *A&AS*, 70, 303
- Bessell, M. S., & Brett, J. M. 1988, *PASP*, 100, 1134
- Cohen, M., & Kuhl, L. V. 1979, *ApJS*, 41, 743
- Coluzzi, R. 1993, *Bull. Inf. CDS*, 43, 7
- Drew, J. E., Bushfield, G., Hoare, M. G., et al. 1997, *MNRAS*, 286, 538
- Efremov, Yu. N. 1989, in *Sites of Star Formation in Galaxies*, Moscow (Nauka)
- Egan, M. P., Price, S. D., Moshir, M. M., et al. 1999, *The Midcourse Space Experiment Point Source Catalog Version 1.2, Explanatory Guide*, AFRL-VS-TR-1999-1522
- Gonzales, G., & Gonzales, G. 1956, *Bol. Obs. Tonantzintla y Tacubaya*, No. 15, 16
- Grandi, S. A. 1975, *ApJ*, 196, 465
- Grandi, S. A. 1976, *ApJ*, 206, 658
- Halpern, J., Gotthelf, E. V., Leighly, K. M., & Hefland, D. J. 2001, *ApJ*, 547, 323
- Hang, H.-R., Liu, Q.-Z., & Xia, J.-P. 1999, *A&A*, 344, 614
- Herbig, G. H. 1993, *ApJ*, 407, 142
- in't Zand, J. J. M., Halpern, J., Eracleous, M., et al. 2000, *A&A*, 361, 85
- IRAS Explanatory Supplement to the Catalogs and Atlases 1985, ed. C. A. Beichman, G. Neugebauer, H. J. Habing, P. E. Clegg, & T. J. Chester, NASA RP-1190
- Ivezić, Ž., & Elitzur, M. 1995, *ApJ*, 445, 415
- Kazarovets, E. V., Samus, N. N., & Durevich, O. V. 2001, *Inform. Bull. Var. Stars*, No. 5135
- Khaliullin, Kh., Mironov, A. V., & Moshkaliyov, V. G. 1985, *Ap&SS*, 111, 291
- Kornilov, V. G., Volkov, I. M., Zakharov, A. I., et al. 1991, *Sternberg Astron. Inst. Proc.*, v.63
- Kurucz, R. L. 1994, *Smithsonian Astrophys. Obs.*, CD-ROM No. 19
- Lasker, B. M., Sturch, C. R., McLean, B. J., et al. 1990, *AJ*, 99, 2019
- Lopes, D. F., Damini Neto, A., & Freitas Pacheco, J. A. 1992, *A&A*, 261, 482
- McCarthy, J. K., Sandiford, B. A., Boyd, D., & Booth, J. 1993, *PASP*, 105, 881
- Miroshnichenko, A. S. 1997, In *Fundamental Stellar Parameters*, ed. T. R. Bedding (Publ. School of Physics, Univ. of Sydney, Australia), *Proc. IAU Symp.*, 189, 50
- Miroshnichenko, A. S., Mulliss, C. L., Bjorkman, K. S., et al. 1998, *PASP*, 110, 883
- Miroshnichenko, A. S., Chentsov, E. L., Klochkova, V. G., et al. 2000, *A&AS*, 147, 5
- Miroshnichenko, A. S., Levato, H., Bjorkman, K. S., & Grosso, M. 2001, *A&A*, 371, 600
- Miroshnichenko, A. S., Bjorkman, K. S., Chentsov, E. L., et al. 2002, *A&A*, 383, 171
- Munch, G. 1957, *ApJ*, 125, 42
- Panchuk, V. E., Najdenov, I. D., Klochkova, V. G., et al. 1998, *Bull. Spec. Astrophys. Obs.*, 44, 127
- Panchuk, V. E., Klochkova, V. G., Najdenov, I. D., et al. 1999, *Preprint of the Special Astrophys. Observ.*, No. 139
- Reig, P., Fabregat, J., & Coe, M. J. 1997, *A&A*, 322, 193
- Rudy, R. J., Erwin, P., Rossano, G. S., & Puetter, R. C. 1991, *ApJ*, 383, 344
- Rudy, R. J., Mazuk, S., Puetter, R. C., & Hamman, F. 2000, *ApJ*, 539, 166
- Sheikina, T. A., Miroshnichenko, A. S., & Corporon, P. 2000, in *The Be-phenomenon in Early-Type Stars*, ed. M. A. Smith, H. F. Henrichs, & J. Fabregat, *ASP Conf. Ser.*, 214, 494
- Straizys, V. 1977, in *Multicolour photometry of stars* (Vilnius, Mokslas Publ.)
- Straizys, V., & Kuriliene, G. 1981, *Ap&SS*, 80, 353
- Taranova, O. G., & Bogdanov, M. B. 2001, *Astron. Rep.*, 45, 461
- Tuohy, I. R., Buckley, D. A. H., Remillard, R. A., et al. 1988, in *Physics of Neutron Stars and Black Holes*, ed. Y. Tanaka (Universal Academy Press Inc., Tokyo), 93
- Wackerling, L. R. 1970, *Mem. RAS*, 73, 153
- Wallace, L., Meyer, M. R., Hinkle, K., & Edwards, S. 2000, *ApJ*, 535, 325
- Weaver, Wm. B., & Jones, G. 1992, *ApJS*, 78, 239
- Wegner, W. 1994, *MNRAS*, 270, 229
- Wilson, J. C., Skrutskie, M. F., Colonno, M. R., et al. 2001, *PASP*, 113, 227
- Wood, K. S., Meekins, J. F., Yentis, D. J., et al. 1984, *ApJS*, 56, 507
- Zickgraf, F.-J. 2001, *A&A*, 375, 122