AS 314: A dusty A–type hypergiant

By: A.S. Miroshnichenko, E.L. Chentsov , and V.G. Klochkova

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Abstract:
We present the results of our observations of the poorly-studied emission-line star AS 314 which include high-resolution spectroscopy, obtained at the 6 -meter telescope of the Russian Academy of Sciences, multicolor optical and near-infrared photometry. The strong Hα line, H*β* and H*γ* of moderate strength and a number of weak Fe ii lines were detected in emission. The Balmer lines and most of the Fe ii lines show narrow P Cyg-type pro-files which implies a very low terminal velocity of the stellar wind. Very weak signs of emission are found in Hδ. Photospheric lines detected for the first time allowed us to determine the object's spectral type, A0. The luminosity, $M_{bol} \sim -8.0$ mag was estimated using several methods and implies that AS 314 is a hypergiant, which is located at about 10 kpc from the Sun and has an initial mass of - 20 $M_\odot$. Modeling of the Balmer line profiles resulted in the following parameters of the stellar wind: $\dot{M}$ = 2 10^{-5} $M_\odot$ yr^{-1}, v_∞ = 75 $kms^{-1.}$ The star is located within the LBV strip in the HRD. Its noticeable far-IR excess is due to the circumstellar dust emission and is likely evidence of an LBV-type outburst in the past.
Key words: stars: emission-line — stars: supergiants — circumstellar matter — stars: mass-loss — stars: individual – AS 314

Article:

1. Introduction

Nearly several dozens of unusual high-luminosity stars in the Milky Way have been discovered so far. These objects exhibit bright emission lines, infrared (IR) excesses, and other features, which suggest the presence of a large amount of circumstellar matter. They are usually identified with massive ($M > 10$ $M_\odot$) evolved stars, such as B[e] supergiants (e.g., Zickgraf et al. 1986), Wolf-Rayet stars, or LBVs. The main feature of B[e] supergiants is a pronounced near-IR excess due to radiation of hot ($T \sim 1000$ K) circumstellar dust, while Wolf-Rayet stars are recognizable due to their bright and broad high-excitation emission lines of species indicative of a late stage of stellar evolution. The main characteristics of LBVs is their large- (~ 5 mag) and intermediate-amplitude (1 − 2 mag) photometric variability, which is accompanied by significant spectral variations. During these eruptive events, the star's photosphere increases its size, while its spectrum resembles those of supergiants with a decreasing temperature as the star's brightens (see Humphreys & Davidson 1994 for a review). However, such eruption events are rare, and LBVs spend a long time in quiescence (e.g., P Cyg) which makes it difficult to recognise them among other supergiants. Nevertheless, there are some indicators of quiescent LBVs which can be used in addition to their features of high-luminosity objects. For instance, a strong far-IR excess, which cannot be explained by free-free emission of the stellar wind, may point to a dust formation episode or an LBV-type outburst in the past (e.g., AG Car and HR Car).

Thus, observational monitoring of such objects is crucial in order to detect their possible eruptions and phase of activity, to constrain the evolution of the object and its circumstellar material, and to study their properties in more detail. Additionally, high signal-to-noise and high-resolution spectroscopic observations are needed to derive reliable physical parameters of these objects. The main aim of this paper is to present new observational data we recently obtained for an early-type emission-line star, AS 314, which has not been studied in detail so far.

AS 314 = LS 5107 = V452 Sct was discovered during the Mount Wilson spectroscopic search for emission-line stars in the Milky Way (Merrill & Burwell 1950).

Table 1. Optical photometry of AS 314

JD	V	$U-B$	$B-V$	$V-R$	$V-I$
[a]	9.86	0.13	0.92	–	–
2444025[b]	9.81	0.13	0.87	–	–
2444420[b]	9.87	0.11	0.89	–	–
2444426[b]	9.86	0.11	0.91	–	–
2449940.19[c]	9.84	0.07	0.91	0.89	1.47
2449941.18[c]	9.85	−0.05	0.95	0.92	1.58
2449944.17[c]	9.78	0.04	0.86	0.75	1.31
2451039.21[c]	9.89	−0.05	0.91	0.76	1.40
2451043.19[c]	9.97	−0.03	0.92	0.89	1.54

Data sources: [a] - Hiltner & Iriarte (1955) , [b] - Kozok (1985a), [c] - this paper.

Follow-up low-resolution spectroscopy obtained by Hiltner & Iriarte (1955) resulted in the spectral type A3: Ia, while Stephenson & Sanduleak (1971) listed it as B9 Ia. The *UBV* observations by Hiltner & Iriarte (1955) and Kozok (1985a), quoted in Table 1, revealed that the star is heavily reddened and that the spectral type, which can be de-rived from the photometry, is B9 ± 1. On the basis of the MK classification (A3 Ia), Humphreys (1970) estimated its distance from the Sun as 9.6 kpc, while Kozok (1985b) derived a value of 1.2 kpc from the color-indices analysis. These estimates suggest very different luminosities for the star.

Later Dong & Hu (1991) identified the star with an IRAS point source 18365−1353 with fluxes having a maximum at 60 μm. This identification made AS 314 a potentially interesting object as it points to cold dust associated with the star. AS 314 was also a HIPPARCOS target, HIP 91477, for which the parallax 3.58 ± 1.76 milliarcseconds was measured with a 2σ accuracy. This value can be translated into a distance larger than 280 pc (ESA 1997). A visual brightness variability of 0.2 mag was also detected during the HIPPARCOS mission. Recently Venn et al. (1998) obtained a high-resolution spectrum of AS 314 in the Hα region. These authors described the spectrum as a “disk-like” with “very sharp metallic lines” and concluded that the object is a Be star rather than a supergiant.

Below we discuss the results of our multicolor photometric and high-resolution spectroscopic observations of AS 314. The observations are described in Sect. 2, photometric characteristics and detected spectral lines in Sect. 3, the star’s fundamental parameters in Sect. 4. General discussion of our results is given in Sect. 5, while our conclusions are presented in Sect. 6.

2. Observations

The spectroscopic observations of AS 314 were obtained at the 6-meter telescope of the Special Astrophysical Observatory (SAO) of the Russian Academy of Sciences on 1997 July 23, 1998 June 16, and 1999 July 1.

The 1997 and 1999 spectra were taken with the CCD equipped échelle-spectrometer LYNX (Panchuk et al. 1999) mounted at the Nasmyth focus in the spectral ranges from 5370 to 6670 Å and from 5050 to 6635 Å. A 1140 *x* 1170 pixels CCD was employed. The pixel size is 16 *x* 16 μm. We used an échelle-grating 37.5 gr mm^{-1} with the blaze angle of 64.3° and the cross disperser with 300 gr mm^{-1} at first order. These observations were obtained under a poor weather conditions (seeing approximately 3 − 4″, clouds), therefore the slit size was enlarged to increase the signal-to-noise ratio. The average spectral resolution was equal to 0.35 Å per resolution element (0.07 − 0.10 Å pre pixel). The 1998 spectrum was obtained at the prime focus with the échelle-spectrometer PFES (Panchuk et al. 1998) with the same CCD detector in the range from 3998 to 7761 Å. The seeing was nearly 2″, while the spectral resolution was about 0.6 Å per resolution element (0.14 − 0.20 Å pre pixel).

An argon-filled thorium hollow-cathode lamp was used as the source of comparison spectrum. Control and correction of instrumental displacement of the comparison and object spectra were done in using the telluric lines of O_2 and H_2O. We tested focusing with the spectra obtained over the observing night using telluric lines and the comparison lamp.

Additionally, 5 *UBVRI* broad-band observations of AS 314 in the Johnson photometric system were obtained at the 1-meter telescope of the Tien-Shan Observatory (Kazakhstan) in August 1995 and August 1998. One *JHKL* observation was taken at the 0.75-meter telescope of the South-African Astronomical Observatory on 9 July, 1997 (JD 2450639.49). The optical photometry along with the previously published data are presented in Table 1 with typical errors not exceeding 0.02 mag. The near-IR photometry was obtained for the first time with the following results: $J = 7.94 \pm 0.03$, $H = 7.60 \pm 0.03$, $K = 7.36 \pm 0.03$, $L = 6.99 \pm 0.10$ mag.

3. Results

3.1. Photometric characteristics

The available photometric data show that the optical brightness of AS 314 varied within 0.25 mag during the last 40 years. The HIPPARCOS photometry (67 observations in 17 dates between March 1990 and March 1993) from Table 2 along with the results from Table 1 give the following range of the variations: $9.97 \leq V \leq 9.73$ mag. The *V*-band light curve is shown in Fig. 1. The amount of the data obtained so far is insufficient for a periodicity analysis. Note that our *BV* data are close to those published before, while our $U - B$ is nearly 0.1 mag bluer. The latter may be due in part to the $U - B$ difference of the object and its comparison star (HR6989, $U - B = -0.19$ mag). However, in the sky they are located close enough to each other (0.5°) and were usually observed with an air mass difference not exceeding 0.1. Besides that our instrumental photometric system is very close to the Johnson one (Bergner et al. 1988). Thus, we do not expect systematic errors in the observed $U - B$ to be larger than $0.02 - 0.03$ mag. Perhaps, the difference is mainly due to the deviation of the *U*-band transmission curve in our and other authors' filter sets.

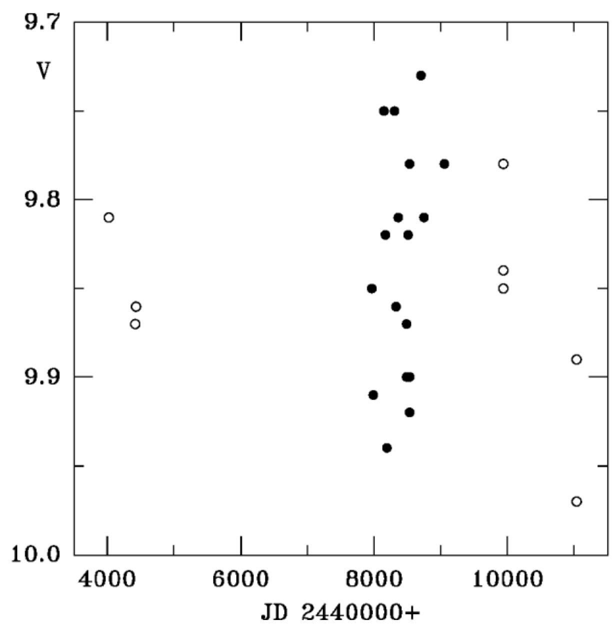

Fig. 1. ***Light-curve of AS 314 in the V-band from 1979 to 1998. Data from Table 1 are shown by open circles, while the HIPPARCOS data from Table 2 by filled circles***

Table 2. HIPPARCOS photometry of AS 314

JD	V	n	JD	V	n
2447963.83	9.85 ± 0.01	4	2448492.08	9.87 ± 0.01	3
2447990.58	9.91 ± 0.02	4	2448504.85	9.82 ± 0.02	2
2448143.67	9.75 ± 0.02	2	2448532.82	9.90 ± 0.02	9
2448166.70	9.82 ± 0.01	2	2448533.29	9.92 ± 0.01	2
2448191.02	9.94 ± 0.01	2	2448537.35	9.78 ± 0.02	4
2448311.40	9.75 ± 0.01	7	2448703.71	9.73 ± 0.02	4
2448329.24	9.86 ± 0.01	3	2448749.75	9.81 ± 0.02	4
2448357.58	9.81 ± 0.02	4	2449060.63	9.78 ± 0.01	4
2448491.91	9.90 ± 0.02	4			

The data are averaged within the observing date and translated from the HIPPARCOS photometric system to the Johnson V-band system using formulae from Harmanec (1998). The mean observing dates are given in Cols. 1 and 4, the number of observations during each date are given in Cols. 3 and 6.

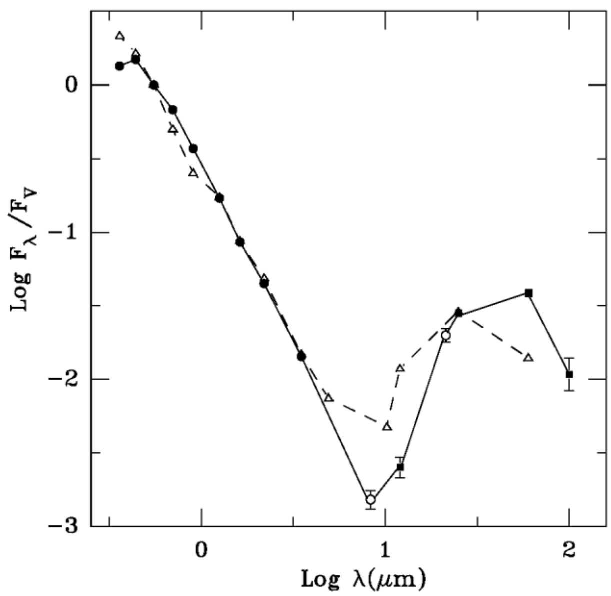

Fig. 2. ***SEDs of AS 314 and the LBV HR Car (open triangles) in the range from 0.3 to 100 μm. Our ground-based data for AS 314 are shown by filled circles, those of MSX by open circles, while those of IRAS by filled squares***

The spectral energy distribution (SED) of AS 314 in the region $0.3 - 1.2$ μm constructed from our averaged optical and near-IR data is consistent with what is expected for a B9-type supergiant (e.g., Wegner 1994) affected by the interstellar reddening A_V = 2.8 mag assuming the total-to-selective extinction ratio R = 3.1. The assumption that the star is a dwarf would result in a much earlier spectral type (B2–B3) which is not consistent with the earlier spectroscopic determinations described above (see Sect. 1) and our own results (see Sect. 3.2). There is a small excess radiation in the *HKL*-bands (*EHK* = 0.1 mag, *EKL* = 0.2 mag) which can be explained by free-free emission from the stellar wind. However, the excess radiation is much larger at longer wavelengths ($\lambda \geq 10$ μm) indicating the presence of cool circumstellar dust in the system. In addition to the IRAS data quoted above (see Sect. 1), we identified AS314 with the source 019.2440−03.6636 from the recently released mid-IR survey carried out by the MSX satellite in 1996/7 (Egan et al. 1999). The star was detected in two bands centered at 8.28 and 21.34 μm with the fluxes 0.12 and 4.31 Jy, respectively. The MSX fluxes are in good agreement with those of IRAS indicating no noticeable variations of the dusty envelope radiation on a time scale between the surveys (13 years). Furthermore, the MSX result provides more confidence in identification of the optical and IR objects because of a high accuracy of the MSX positional measurements (~$2 - 3''$). Despite both the IRAS and MSX positions are very close to the optical one ($4.8''$ and $4.1''$ offset respectively), the IRAS positional error box is much larger ($35'' \times 6''$) than the MSX one. Dereddened SEDs of AS 314 and of a galactic LBV HR Car (e.g. de Winter et al. 1992) shown in Fig. 2 are very close to each other. The same kind of far-IR excesses have also planetary nebulae, but below we will show that AS 314 is not related to this particular type of objects.

Table 3. Characteristics of the Balmer lines. I_{max} and V_{max} are the intensity and heliocentric radial velocity of the emission peak, respectively; I_{abs} and V_{abs} are the minimum intensity of the absorption component and its radial velocity; V_{sec} is the radial velocity of the secondary emission peak. All intensities are normalized to the continuum

Line	I_{max}	I_{abs}	V_{max}	V_{abs}	V_{sec}
Hα[a]	11.84	0.18	−21	−105	−150
Hα[b]	7.88	0.16	−23	−120	−175
Hα[c]	10.48	0.20	−28	−105	−150
Hβ	2.66	0.09	−24	−105	−170
Hγ	1.17	0.05	−28	−100	
Hδ	–	0.01	–	− 96	

[a] - July 1997, [b] - June 1998, [c] - July 1999.

3.2. Spectrum

The spectrum of AS314 is not dominated with emission lines. It contains a rather strong and narrow Hα (equivalent width, EW, ~ 14 Å) line showing a P Cyg-type profile. The line appeared slightly variable in our spectra which is in part due to different dispersions. However, a physical reason for the variations, such as variable mass loss rate cannot be excluded as well. The Hβ and Hγ lines also show noticeable emission components, while in Hδ only weak signs of emission are seen.

Identification of the spectral lines was done on the basis of a catalog of Coluzzi (1993) and a compilation of Johansson (1978) for Fe II lines. In total 351 lines were identified in the spectral range between 4002 and 7743 Å. Characteristics of the Balmer lines are presented in Table 3, averaged radial velocities of the lines of different species in Table 4, while the overall information including laboratory wavelengths, identifications, peak intensities, equivalent widths, and radial velocities of all identified lines (except for those of the Balmer lines) are given in Table 5. The measured line characteristics were averaged for those lines detected in different spectra. The most informative parts of the 1998 spectrum are shown in Figs. 3 and 4.

Many Fe II lines of low excitation with P Cyg-type profiles are present in the spectrum. At the same time, nearly 30 Fe II lines with excitation energy higher than 10 eV are seen in absorption. The only forbidden emission lines seen in the spectra ([O I] 5577 and 6300 Å) are presumably telluric.

Absorption lines of He I, C II, N I, N II, Ne I, Na I, Mg I, Mg II, Si II, Si III, S II, Ti II, Cr II, and Fe II were found in the spectrum. Comparison of the strengths of some of them with those of other supergiants gives a spectral type of A0.2 ± 0.3, which is consistent with the above photometric estimate. The classification criteria and the basic system of equivalent widths were taken from Kopylov (1960a, 1960b) and Chentsov & Luud (1989) for the blue and red spectral region, respectively. The absorption lines, which are usually used for the quantitative classification of supergiants (e.g., He I 4471, Mg II 4481 Å), in the spectrum of AS 314 look the same as those in those of normal supergiants. The resulting spectral type is the average of the estimates derived from using different criteria (EW ratios). For example, the EW ratio of the He I 4471 and Mg II 4481 Å lines gives the spectral type B9.8, while that of Si II 4128/30 and He I 4471 Å gives A0.5.

The absolute visual magnitude estimate, $M_v = -7.3 \pm 0.5$ mag, is less reliable, since the Hδ and Hγ profiles are distorted by the stellar wind emission, while the O I 7771/5 Å triplet was beyond our spectral range. A direct comparison of the spectra of AS 314 and HD 223960 (A0.1, Bartaya et al. 1994) suggests that the temperature of the former is not higher and the luminosity is not lower than those of the latter.

Since only a few lines of O I and no O II lines have been found in our spectra of AS 314, one can suggest a N/O overabundance. This is also found for the LBV's AG Car, HR Car (Hutsémekers & van Drom 1991), and the high-luminosity supergiant/LBV candidate MWC 314 (Miroshnichenko et al. 1998).

The sodium D1,2 lines consist of three absorption components. The strength of the interstellar components is consistent with the high reddening evident from the photometry. The other two components have radial velocities of about −90 and −121 kms^{-1} (see Fig. 4b) and are most likely of circumstellar origin. A significant number of diffuse interstellar bands (DIB) is found in the spectrum of AS 314. The strength of some DIBs in stellar spectra display a good correlation with the star's reddening (e.g. Herbig 1993). We use this property to obtain an independent estimate of the latter. The equivalent widths of the DIBs at 5780 and 5797 Å, 0.39 and 0.15 Å, respectively, correspond to $E_{B\text{-}V} = 0.9$ (Herbig 1993), which is in good agreement with the dereddened optical color-indices. The interstellar features (DIBs and Na I D lines) have radial velocities of about −6 km s^{-1}, which is most likely due to absorption in a nearby interstellar cloud Lynds 410 (Lynds 1962).

The mean radial velocities of the He I, C II, S II, and Ne I pure absorption lines in the 1997 and 1999 spectra differ significantly (+16 ± 3 kms^{-1}) from those in the 1998 spectrum. The difference exceeds the measurement errors and points to the existence of real variations in the radial velocity of the star. The same effect was found for the high-excitation Fe II lines and circumstellar components of the Na I lines (see Table 4).

Another peculiar property detected is that all the radial velocities are negative, being rather unusual for this direction in the Galaxy. In general, stars in the vicinity of AS 314 show positive radial velocities as it is expected from the galactic rotation curve (Dubath et al. 1988). For example, for the two LBV candidates, HD 168607 and HD 168625, that are both located within 5° from the object, the radial velocities are about +10 km s^{-1} (Chentsov & Luud 1989). However, there is a discrepancy for AS 314 ranging from 70 km s^{-1} assuming a distance D = 1 kpc to 130 kms^{-1} for D = 10 kpc. These estimates are based on the averaged radial velocity of AS 314 of —50 ± 10 km s^{-1} (see Table 4) and on calculations using formulae from Dubath et al. (1988) for the direction towards the star. Such a difference indicates that the star has a large peculiar velocity.

Table 4. Radial velocities for groups of lines in the spectrum of AS 314. The averaged velocity in km s^{-1} and the number of lines (N) used to derive these values are listed for each spectrum. In the last column χ is the excitation potentials in eV, while r is the residual intensity with respect to the continuum

Element	1997		1998		1999		Comment
	R.V.	N	R.V.	N	R.V.	N	
abs He I, C II	−41 ± 3	4	−60 ± 2	8	−43 ± 1	3	
abs S II, Ne I	−46 ± 4	8	−60 ± 2	12	−44 ± 2	15	
abs Fe II			−61 ± 2	29	−42 ± 3	16	$\chi \geq 10$
abs Si II, Mg II	−54 ± 3	5	−57 ± 3	8	−58 ± 1	2	
em Fe II	−57 ± 2	18	−57 ± 2	35	−48 ± 2	18	$\chi \leq 4$, $r \geq 0.85$
abs Fe II	−97:	8	−98 ± 3	25	−85 ± 3	16	$\chi \leq 4$, $r \geq 0.85$
em Fe II			−28 ± 2	4	−28	1	$\chi \leq 4$, $r \leq 0.55$
abs Fe II			−106 ± 2	6	−91 ± 1	2	$\chi \leq 4$, $r \leq 0.55$
abs Na I	−68 ± 1	2	−88	2	−66 ± 1	2	
I.S. Na I	−6	2	−6	2	−3 ± 1	2	
I.S. DIB	−8:	5	−8 ± 2	12	−4 ± 3	14	

Some emission line profiles were found slightly different in our spectra. This could be due to different dispersions and/or possible variations of the stellar wind (see Fig. 5). The observed pure absorption line profile shape variations are mainly instrumental, as the line equivalent widths are essentially the same in all three spectra.

4. Physical parameters

Let us now constrain fundamental parameters of the star and its wind. The luminosity of AS 314 may be estimated in different ways. Photometry of nearby stars with known MK spectral types shows that the interstellar extinction is distributed in this direction unevenly. For example, ac-cording to Neckel & Clare (1980) A_V reaches 3 mag at already 0.3 — 0.5 kpc from the Sun. However, their statistics is limited by 9 stars for a region of at least 10 square degrees around the star position. This region is projected on the cloud Lynds 410, which is the main source of inter-stellar extinction here. Lahulla & Hilton (1992) obtained *UBV* observations of about 100 stars in a 4° *x* 4° region near Lynds 379 centered in 4° SW from the position of AS 314. However, only a few stars from this survey are inside the boundaries of Lynds 410. Combining the results of these two papers for stars within Lynds 410, we found that in the ~2.5° *x* 2.5° region centered on AS 314 *AV* reaches 3.0 ± 0.5 mag at 2 ± 1 kpc, while no further extinction rise is seen until at least 6 kpc. This allows us to suggest that AS 314 is located behind Lynds 410 with a lower limit of log $L_{bol}/L_\odot \geq 3.7$. We should note here that this luminosity estimate is very uncertain, but it provides evidence that AS 314 is not a classical Be star. The latter objects of a similar spectral type have luminosities at least 2 orders of magnitude smaller than the lower limit derived for AS 314 (e.g., Zorec & Briot 1991).

A luminosity calibration for B9–A2 supergiants by Rosendhal (1974) based on the strength of the Si ii lines at 6347 and 6371 Å gives log $L_{bol}/L_\odot > 4.9$. A similar value, log $L_{bol}/L_\odot = 4.9 \pm 0.2$, follows from our spectroscopic estimate (Sect. 3.2). As a consequence the star is located close to the line of LBVs in the Hertzsprung-Russell diagram (Stothers & Chin 1994). The bright Hα line also suggests a high luminosity for the star as was pointed out by Talavera & Gómez de Castro (1987). Indeed, only those A-type supergiants with $M_V \leq -8$ mag, such as HD 160529 and HD 168607, display so strong (EW ≥ 10 Å) H*α* lines in emission (Fig. 6a).

As it is seen in Fig. 6b, the wings of the H*δ* line in AS 314 are narrower than those of the Kurucz (1994) model atmospheres for $T_{eff} = 9000$ K and log $g = 1.5$ and wider than those of HD 160529 (log $g = 0.55$, Stahl et al. 1995). These two values can be adopted as initial estimates for an upper and lower level of the surface gravity for AS314. Since the star displays small photometric and spectroscopic variations, these estimates seem to be reliable.

Our result for the spectral type determination, which comes mainly from the quantitative spectroscopy as the most reliable method, in combination with such a high luminosity lead to the MK type A0 Ia+ for AS 314. de Jager & Nieuwenhuijzen (1987) give $T_{eff} = 9100$ K for stars of such a spectral type. Thus, summarizing all the above estimates, we finally adopt the object's $M_V = -8.0 \pm 0.5$ mag, which corresponds to log $L_{bol}/L_\odot = 5.2 \pm 0.2$, $R_* = 160 \pm 30 R_\odot$, and implies D ~10 kpc. These T_{eff} and L_{bol} match the evolutionary track of a 20 $M_\odot$ star (Schaller et al. 1992) and imply log $g = 1.3$, which is located within the above limits.

In order to determine the temperature of the dusty envelope we model the overall observed SED with the DUSTY code (Ivezić et al. 1999), which solves the radiation transfer problem in spherical dusty envelopes. In the model we used the optical properties of amorphous carbon (Hanner 1988), which is expected to form around evolved luminous stars (Bjorkman 1998). The density distribution was assumed to be proportional to the inversed square distance from the star. A good fit to the observed SED was obtained for a dust temperature of 100 K at the inner envelope boundary and the overall optical depth of the envelope of 0.03. The corresponding distance of the hottest grains from the star was found to be 0.2 pc.

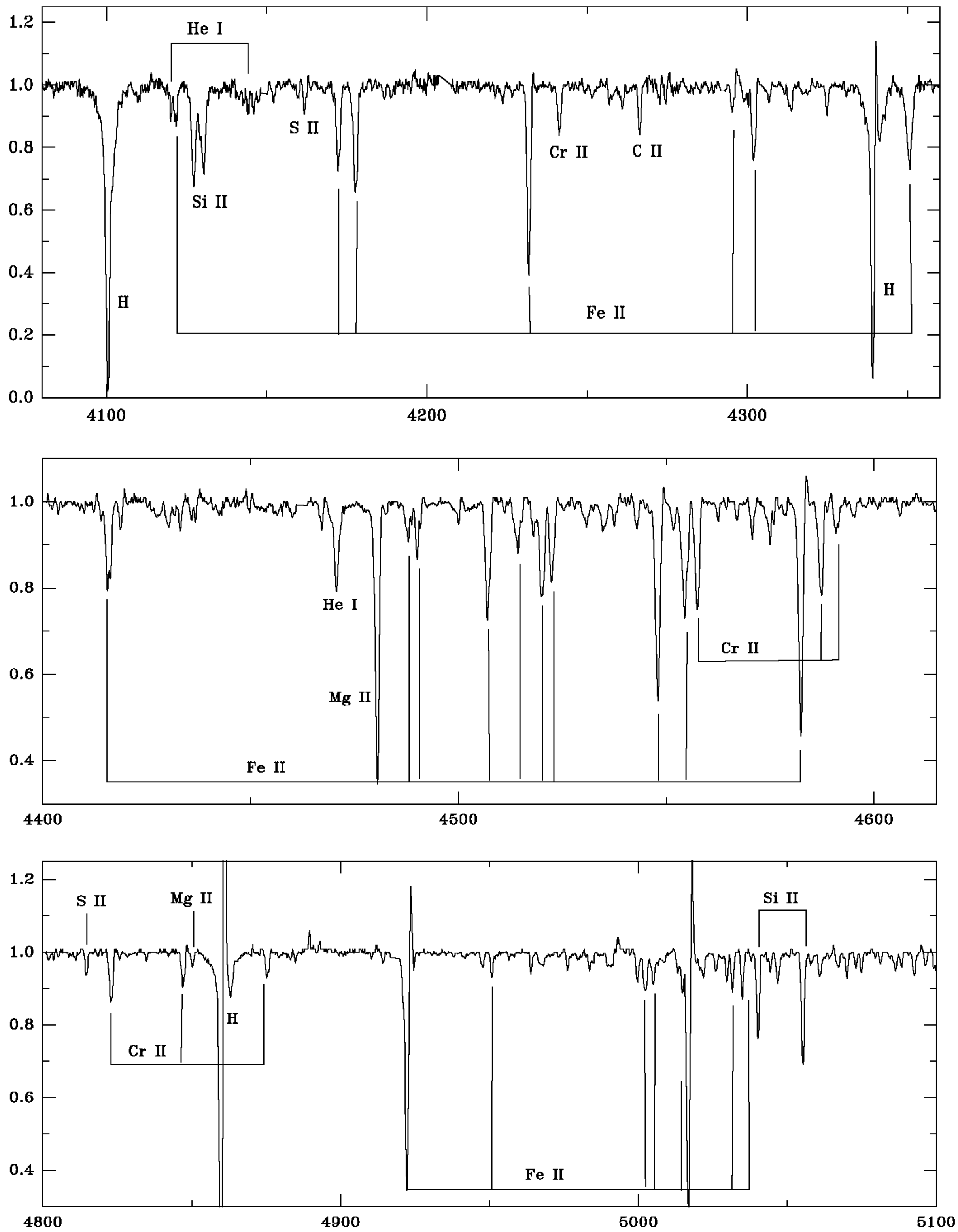

Fig. 3. ***The blue part of the 1998 spectrum of AS 314***

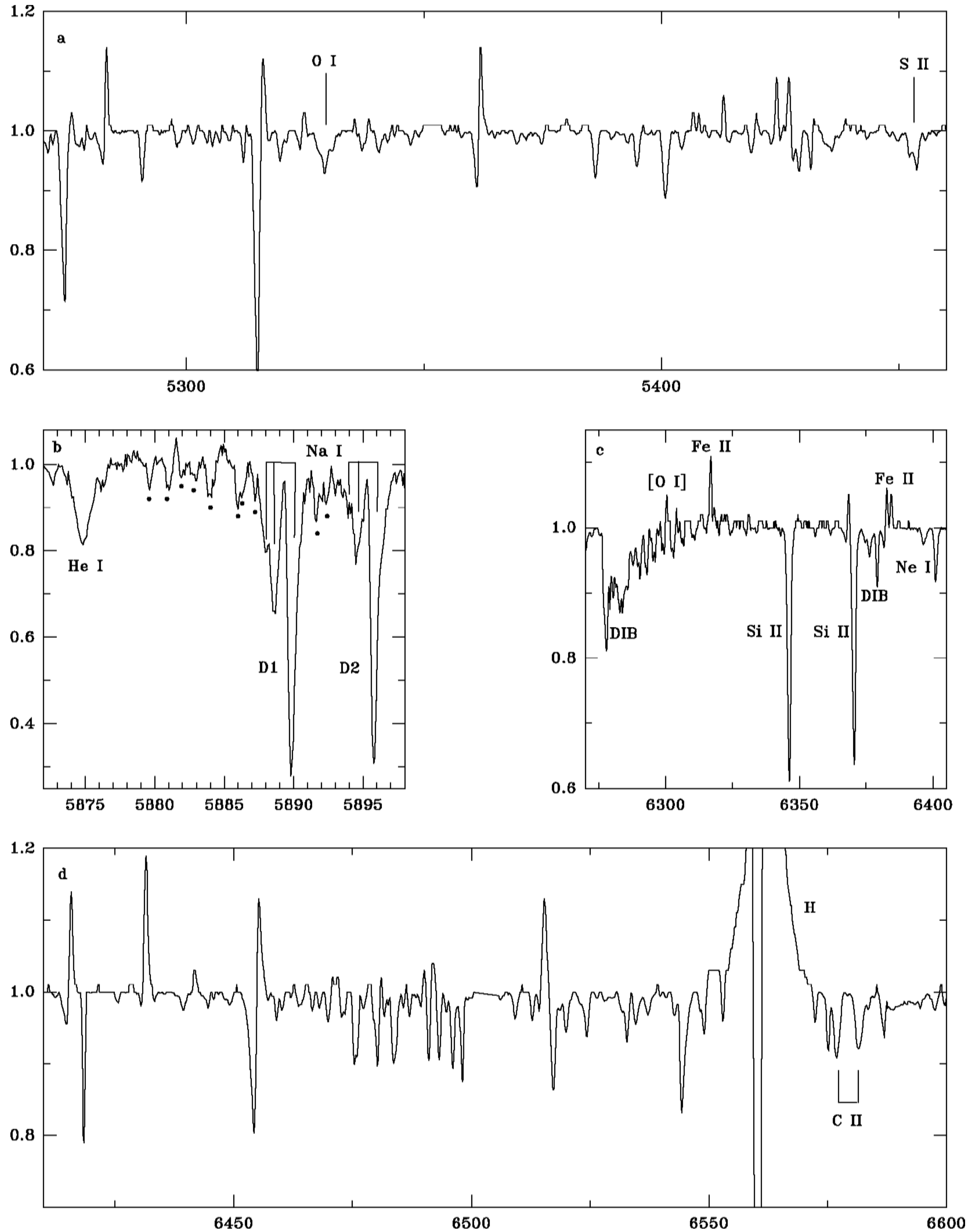

Fig. 4. ***The yellow-red part of the 1998* (a,c,d) *and 1999* (b) *spectra of AS 314.* a) *all noticeable unmarked lines seen are those of Fe* II; b) *the absorption components of the sodium D lines are marked by solid lines, telluric water vapour lines are marked by dots;* d) *all the lines with P Cyg-type profiles are those of Fe* II, *while the pure absorption lines are telluric***

The calculated SED virtually passes through the ob-served data points and is, therefore, not displayed in Fig. 2. However, the lack of the IR data (such as information about the spectral properties in the 10 μm region) does not allow us to constrain the envelope model better. The dust temperature is close to that derived for the galactic LBVs HR Car (170 K), AG Car and WRA 751 (130 K, de Winter et al. 1992). The lower temperature found for AS 314 suggests that an event (perhaps, an outburst), which might have led to the dust formation occurred earlier than in the other quoted LBVs.

The first three lines of the Balmer series in AS 314 have P Cyg-type profiles, which may be interpreted as a con-sequence of spherical mass loss, while their broad wings suggest a noticeable amount of electron scattering in the stellar wind. Comparison of the object's Hα line profile with those of other LBVs with similar $T_{\rm eff}$ shows that both red wing and the absorption component are narrower in AS 314 (see Fig. 6a). This implies a smaller terminal velocity (v_∞) and a smaller electron scattering optical depth ($T_{\rm e}$) for AS 314. Since v_∞ for HD 160529 is about 90 km s^{-1} (Sterken et al. 1991), this value may be suggested as an upper level of v_∞ for AS 314.

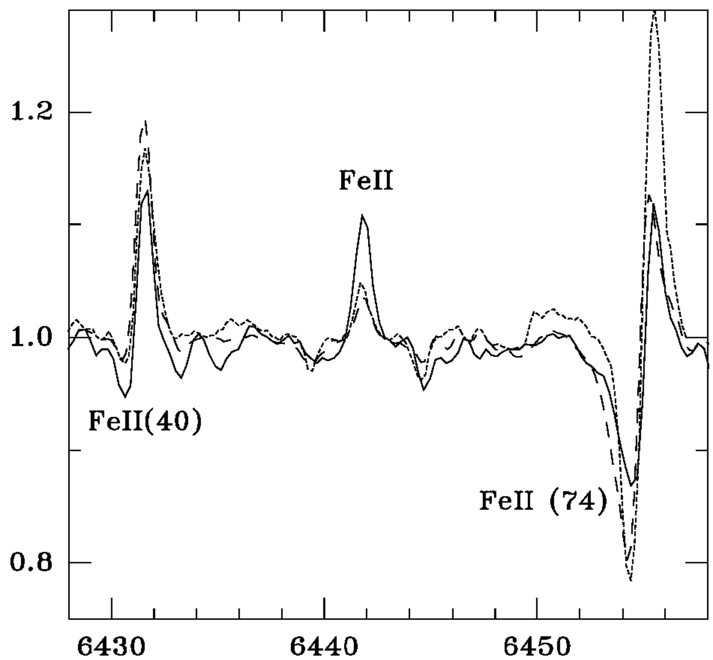

Fig. 5. ***Spectral line variations in different spectra of AS 314. The 1997 spectrum is shown by a solid line, the 1998 spectrum by a long-dashed line, the 1999 spectrum by a short-dashed line***

The relationship between the wind momentum and luminosity for supergiants (Kudritzki 1998) being applied to the parameters of AS 314, as derived above, gives an estimate of the mass loss rate, $M \sim 10^{-5}\ M_\odot\ {\rm yr}^{-1}$. In order to constrain the parameters of the object's stellar wind we tried to model its Balmer line profiles under assumptions of spherical geometry and β-velocity law using a radiation transfer Sobolev code by Pogodin (1986). Electron scattering was treated in a simplified way as described in Castor et al. (1970), which is reasonable given a small expected $T_{\rm e}$.

The best fit parameters are as follows: $M = 2\ 10^{-5}\ M_\odot {\rm yr}^{-1}$, $\beta = 1.3$, $v_\infty = 75$ kms^{-1}, $w_0 = 0.02$ (wind velocity at the photospheric level in units of v_∞), and $T_{\rm e} = 0.4$. The agreement of the calculated and observed profiles is not perfect (see Fig. 7) and reflects the simplifications adopted (spherical symmetry, the electron scattering treatment) as well as difficulties of using the Sobolev method for small velocity gradients. Nevertheless, the derived wind parameters are in reasonable agreement with those of the other hypergiants quoted here.

5. Discussion

The above analysis shows that AS 314 is a distant and a high-luminosity star. Its emission in the Hα line is only comparable to those of the most luminous galactic stars of similar spectral types, HD 160529 (Stahl et al. 1995) and HD 168607 (Chentsov & Luud 1989), which are considered LBV candidates. AS 314 is certainly not a Be star, as was suggested by Venn et al. (1998), because the line emission in Be stars arises in a quasi-Keplerian disk (e.g., Hanuschik et al. 1995), which gives double- or single-peaked, but not P Cyg-type, profiles. The narrow wings and cores of the Hγ and Hδ lines in AS 314 points to a low gravity and a low rotational velocity of the star which is common in A-type supergiants (Verdugo et al. 1999), while Be stars have gravities at least 2 order of magnitude larger and are rapid rotators.

Furthermore, the IR-excess of AS 314 is certainly due to thermal emission of circumstellar dust. Our analysis of the high-resolution IRAS maps of its environments constructed by means of the Maximum Correlation Method (Aumann et al. 1990) and obtained from the Infrared Processing and Analysis Center in Pasadena (California, U.S.A.) shows that in all four IRAS bands the source is point-like and its position coincides with the optical position of AS 314 (see Fig. 8). The star's $T_{\rm eff}$ is small enough to effectively heat interstellar dust. Therefore, the dusty particles responsible for the IR excess in AS 314 are certainly connected to the star. One possible explanation of their existence is an LBV-type outburst occurred in the past. Otherwise the dust may be a remnant of the red supergiant evolutionary phase. In both cases AS314 is a more evolved object than HD 160529 and HD 168607 quoted above, as the latter do not display any noticeable far-IR excess.

If we assume a lower limit of the dusty grains velocity of 5 $\mathrm{kms^{-1}}$, then the kinematic age of the object's dusty envelope is less than 3 10^4 years. The evolutionary time passed since the end of the main-sequence phase is an order of magnitude larger for a 20 $M_\odot$ star (Schaller et al. 1992). Therefore, the envelope may be formed on the object's way from the main-sequence. On the other hand, Stothers & Chin (1994) noted that low-luminosity LBVs (log Lbol/$L_\odot$ ~5) might have reached their present positions in the HRD after a violent mass loss during the red supergiant phase. In this case their initial masses are much larger than it is follows from the current theoretical evolutionary tracks. However, since a far-IR excess similar to that of AS 314 is not observed in HD 160529 and HD 168607, which have almost the same fundamental parameters of the underlying stars and stellar winds, the red supergiant scenario seems not to be justified enough.

The discrepancy between the measured radial velocity of AS 314 and that expected from the galactic rotation curve might suggest that it is a runaway star and/or a member of a binary system. The proper motion of the star measured by HIPPARCOS, μ = 7.4 ± 2 milliarcseconds, at D = 10 kpc gives the tangential velocity 350 ± 100 km $\mathrm{s^{-1}}$. Thus, taking into account the radial velocity of nearly 100 $\mathrm{kms^{-1}}$, one can estimate the total linear velocity of about 365 km $\mathrm{s^{-1}}$ for AS 314. The distance from the galactic plane turns out to be about 600 pc at D = 10 kpc. These values are consistent with those expected for a run-away star ejected from a cluster (Leonard 1993).

In the Hertzsprung-Russell diagram (Fig. 9) AS 314 is located close to the positions of the LBVs in quiescence as well as to the instability line suggested by Stothers & Chin (1994). This instability is due to the decrease of helium in the star's core during steady helium burning phase. Stothers & Chin also suggested that such a type of instability cannot be encountered by stars with initial masses $\leq$30 $M_\odot$. Less massive stars may only become dynamically unstable through mass exchange in a close binary system. The latter possibility may well be the case for AS 314 because of its radial velocity variations. However, the data obtained so far are still insufficient to derive certain conclusions about binarity of the object. Nevertheless, since the usual uncertainty in determination of the LBVs fundamental parameters is of the order of 20 − 30 per cent, the position of AS 314 is very close to those of HD 160529 and HD 168607, taking into account these uncertainties. This suggests that binarity may not be crucial for AS 314 in order to encounter the instability phase.

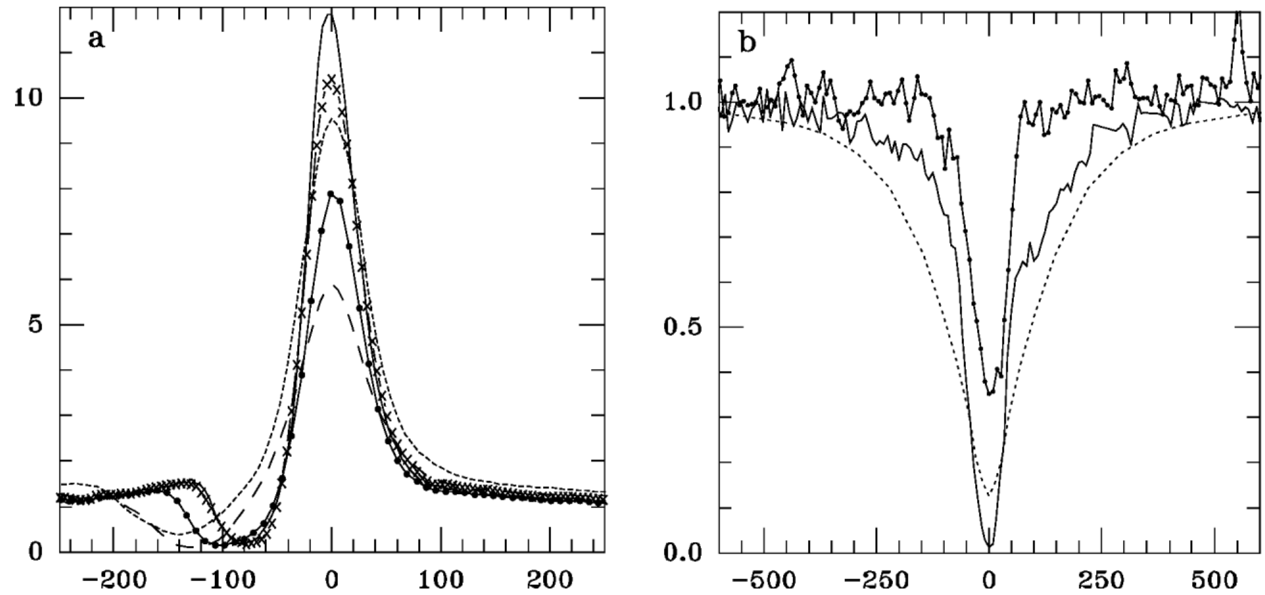

Fig. 6. ***a) Comparison of the Hα profiles of AS 314 and of two LBV candidates. The profiles of AS 314 are shown by solid lines with no additional symbols (the 1997 spectrum), with circles (1998), or with crosses (1999). The profile of HD 160529 (Stahl et al. 1995) is shown by a long-dashed line, while that of HD 168607 (Chentsov & Luud 1989) by a short-dashed line. b) Hδ line profiles of AS 314 (solid line), HD 160529 (solid line with dots), and that of the Kurucz (1994) model atmosphere for T_{eff} = 9000 K, log g = 1.5 (dashed line). Extrema of all the line profiles are shifted to the zero velocity. The velocity is given in kms^{-1}, while the intensity is normalized to continuum***

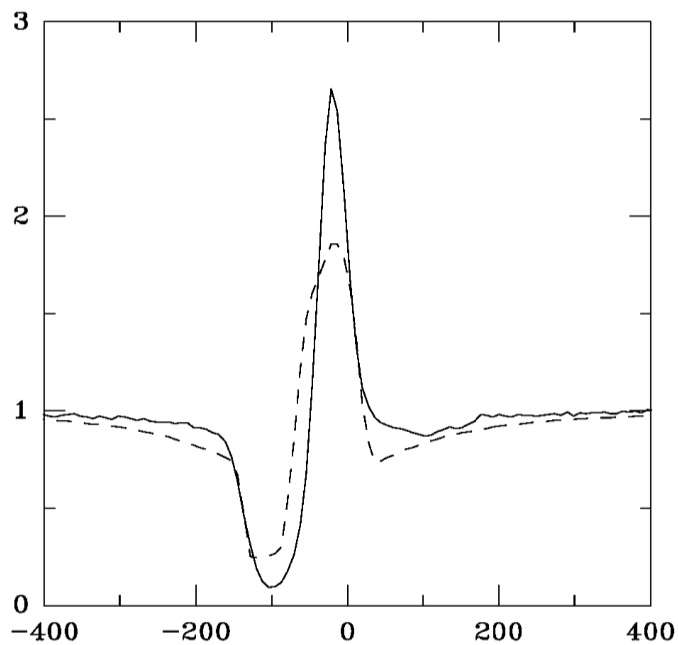

Fig. 7. ***Theoretical fit (dashed line) to the Hβ line profile of AS 314 (solid line) obtained in 1998. The fit parameters are presented in the text. The velocity and intensity are given in the same units as in Fig. 6***

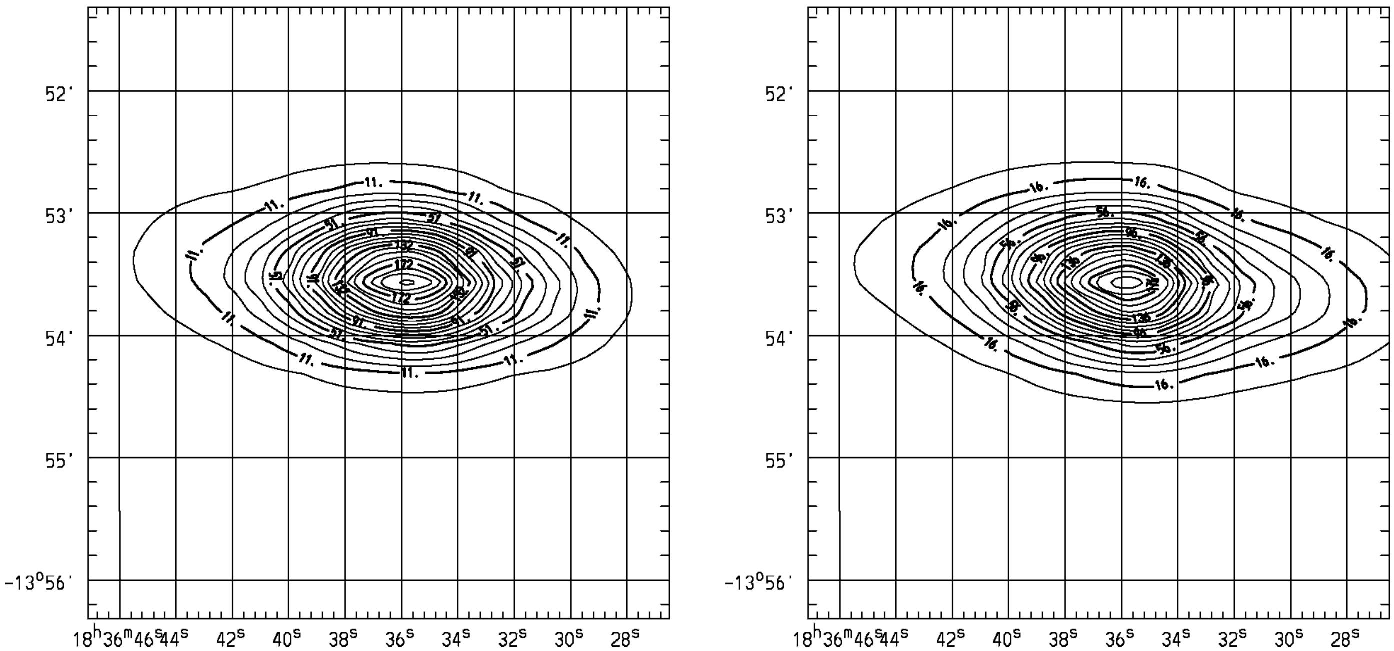

Fig. 8. ***IRAS high-resolution maps of AS 314 (top) and an artificial point-like source of the same integrated intensity (bottom) at 60 µm***

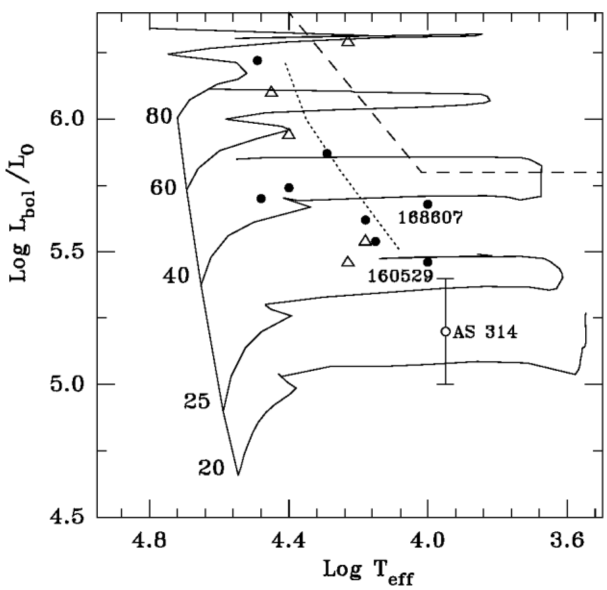

Fig. 9. ***Hertzsprung-Russell diagram. The zero-age main-sequence and evolutionary tracks from Schaller et al. (1992) for stars of different initial masses (denoted by the numbers in M⊙ near corresponding tracks) are shown by solid lines, the Humphreys-Davidson limit by a dashed line, while the Stothers & Chin instability line by a dotted line. Positions of LBVs and candidate LBVs collected from literature are shown by filled circles, those of some high-luminosity B[e] supergiants by triangles. HD numbers of the LBVs, which have fundamental parameters and spectral properties closest to those of AS 314, mark the corresponding positions. The position of AS 314 is shown by the open circle***

6. Conclusions

The new spectroscopic observations of a reddened A0-type hypergiant, AS 314, resulted in constraining its intrinsic parameters and evidence that it is a candidate LBV in quiescence. Its wind seems to have the lowest terminal velocity among similar objects, while the mass loss rate is among the highest for the galactic high-luminosity stars. The far-IR excess is found to be due to the emission of circumstellar dust, which was probably formed in an event occurred after the star left the main-sequence but not during the red supergiant evolutionary phase. A general conclusion, which can be drawn from the observed radial velocity variations, is that the photospheric lines display a different behaviour from that of the wind lines, and the variations are real. We are not able to interpret them be-cause of the small number of the spectra obtained. To make further progress in understanding its properties the following observations are desirable:

1. A more thorough study of the radial velocity variations through high-resolution spectroscopy;

2. Infrared observations to constrain properties of the circumstellar dust;

3. Photometric monitoring is worthwhile as the star may show significant brightness variations.

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