Two-velocity type mass outflow from the symbiotic binary Z And during its 2000 – 2002 outburst*

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Abstract. High resolution observations in the region of the lines He II λ4686 and Hγ of the spectrum of the symbiotic binary Z And were performed in the quiescent state of the system and during its outburst phase in 2000 – 2002 as well. During the active phase the behaviour of the radial velocity of the line He II λ4686 was similar to the orbital velocity of a secondary stellar component. The triplet lines of He I had P Cyg profiles indicating stellar wind with a velocity of 60 km s^{-1} from the hot secondary. The line He II λ4686 had broad emission component indicating optically thin stellar wind with a velocity of about 500 km s^{-1}. To explain the data of observations a model with an accretion disk (or dense material located in the orbital plane) in the system was proposed. In this model the wind originated from the accretor is slowing down in the orbital plane till velocity of 60 km s^{-1}. At higher stellar latitudes the wind is blowing out with a velocity of 500 km s^{-1}.

Key words: binaries: symbiotic - stars: activity - stars: winds, outflows - stars: individual: Z And

Двускоростен режим на изтичане на маса от симбиотичната двойна система Z And по време на избухването й през 2000 – 2002 г.

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Получени са данни с високо разрешение в областта на линиите He II λ4686 и Hγ от спектъра на симбиотичната двойна система Z And в спокойно състояние на системата и по време на избухването й през 2000 – 2002 г. По време на активната фаза поведението на лъчевата скорост на линията He II λ4686 беше типично за орбиталното движение на вторичен звезден компонент. Триплетните линии на He I имаха P Cyg профили, показващи звезден вятър от горещия компонент със скорост 60 km s^{-1}. Линията He II λ4686 имаше широк емисионен компонент, който показваше оптически тънък звезден вятър със скорост от около 500 km s^{-1}. Беше предложен модел на горещия компонент с акреционен диск (или вещество с висока плътност в орбиталната равнина). В този модел вятърът, възникващ от акретора, се забавя до скорост от 60 km s^{-1}в орбиталната равнина. На по-високите звездни ширини вятърът изтича със скорост от 500 km s^{-1}.

Introduction

The Z And binary system is a prototype of the classical symbiotic stars and consists of a normal cool giant of spectral type M4.5 (Mürset & Schmid 1999), a hot compact object with temperature higher than 10^5 K (Fernandez-Castro et al. 1988; Sokoloski et al. 2006) and an extended surrounding nebula partly photoionized by the hot component. Its orbital period is $758^{\mathrm{d}}.8$, which is based

* Based on observations collected at the Rozhen National Astronomical Observatory, Bulgaria

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on both photometric (Formiggini & Leibowitz 1994) and radial velocity (Mikolajewska & Kenyon 1996) data.

The quiescent spectrum of this binary resembles typical symbiotic star with TiO absorption bands and numerous emission lines of H I, He I, He II, N III, C III, Fe II, [O III], [Ne III], [Ne V] and [Fe VII]. The last active phase of Z And began at the end of August 2000 (Skopal et al. 2000) and the optical light reached its first maximum in December. After that it gradually decreased reaching its minimal value in August 2002. So the first outburst was realized which is a subject of our research.

In our previous work (Tomov et al. 2003, hereafter Paper I) we analyzed the continuum emission of Z And on the basis of photometric data obtained during this outburst and concluded that the hot companion has undergone a great expansion accompanied with a loss of mass and its photospheric radius has increased by a factor of about 40 compared with its quiescent value. The high resolution data taken during this phase show the presence of P Cyg type profiles of the helium lines indicating an expansion. Some of the emission lines whose width increased were also giving a reason to suppose a mass outflow from the companion. In the present work we analyze selected visual lines with the aim to form an overall picture of the outburst, combining the results of this analysis and the photometric research.

1 Observations and reduction

We observed the regions of the lines He II $\lambda4686$ and Hγ of the spectrum of Z And on ten nights with the Photometrics CCD camera mounted on the Coude spectrograph of the 2m RCC telescope at the National Astronomical Observatory Rozhen. The spectral resolution was 0.2 Å px^{-1}. Ever when we made more than one exposure per night, the spectra were added with the aim to improve the signal to noise ratio. Three of the nights were in 1999 when the star was at the quiescent state and the other ones – during the time of its 2000 – 2002 outburst (Fig. 1). The IRAF package [3] was used for data reduction as well as for obtaining the dispersion curve and calculating the radial velocities and equivalent widths.

The absolute fluxes of some selected lines in the observed regions were calculated with the use of their equivalent widths and the continuum fluxes at their positions based on BV photometric data.

The BV fluxes were corrected for the strong emission lines of Z And. The quiescent data and those, obtained after February 2001 were corrected in the same way as the quiescent data in the Paper I. The fluxes, related to the other epochs were not corrected because of the strong increase of the stellar and nebular continua and the relative decrease of the emission lines (Paper I).

All the fluxes were corrected for an interstellar reddening of $E(B-V) = 0.30$ using the extinction law of Seaton (1979).

As in Paper I we used the ephemeris Min(vis) = JD $2\,442\,666^{\mathrm{d}} + 758\overset{\mathrm{d}}{.}8 \times \mathrm{E}$, where the epoch of the orbital photometric minimum coincides with that of the spectral conjunction (Formiggini & Leibowitz 1994; Mikolajewska & Kenyon 1996; Fekel et al. 2000).

[3] The IRAF package is distributed by the National Optical Astronomy Observatories, which is operated by the Association of Universities for Research in Astronomy, Inc., under contract with the National Science Foundation.

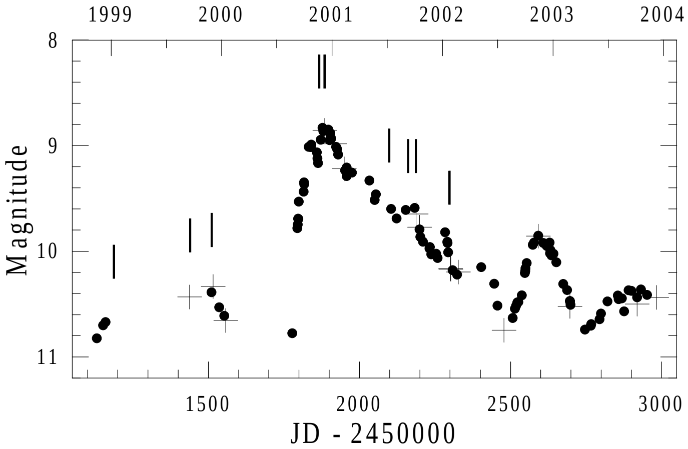

Fig. 1. The V light curve of Z And during its 2000 – 2002 outburst. The dots indicate the data of Skopal et al. (2002, 2004) and crosses our data. The vertical lines indicate the epochs of the spectral observations.

2 Analysis and discussion

2.1 The neutral helium lines

The triplet lines of helium He I $\lambda 4471$ and He I $\lambda 4713$ had purely emission profile and FWHM = 45 – 50 km s^{-1} in the quiescent state of the system. A blue-shifted absorption appeared in November and December 2000 during the time of the maximal light (Fig. 2). In November this absorption had two components. The He I $\lambda 4471$ line reached a residual intensity of 0.46 in November and 0.60 in December. Since the contribution of the cool giant's continuum at the same time was about 0.07 – 0.08 of the total continuum of the system at the wavelengths of these lines (Paper I), their appearance can be related to the hot companion. We observed the system at orbital phases close to the spectral conjunction, where the radial velocity of the companion is close to 0 km s^{-1} (Mikolajewska & Kenyon 1996) at that time. Then the velocity of the absorption components of about -60 km s^{-1} is related to the outflowing matterial from the companion. In this case the only supposition that the companion's photosphere has been expanded and we have observed a P Cyg stellar wind can be made.

2.2 The He II λ4686 line

All of our spectra showed the He II $\lambda 4686$ line has single-peaked core and extended low intensity variable wings, indicating velocity of several hundreds km s^{-1}. The behaviour of the wings differed from that one of the core during all time of observations. The intensity of the wings correlated with the light variations, whereas the intensity of the core anticorrelated. Moreover the wings displayed rapid variability on a timescale of about one day and the core did

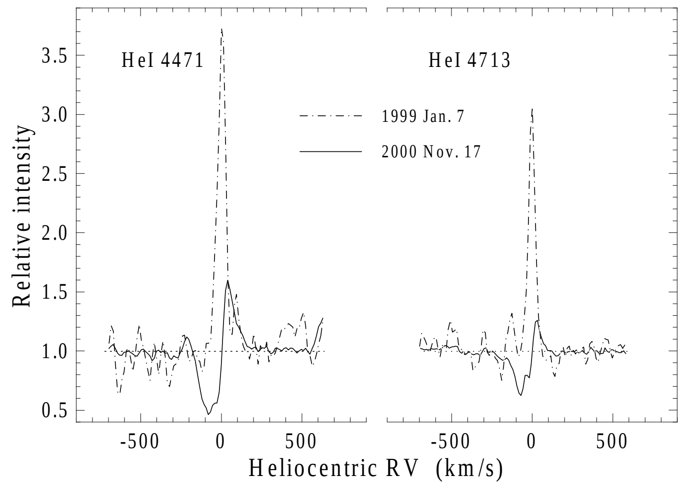

Fig. 2. The profiles of the He I triplet lines during quiescent and active phase.

not (see below). These facts gave us a reason to suppose that the core and the wings were two different components of the line. We named them a narrow central component and a broad component with a low intensity.

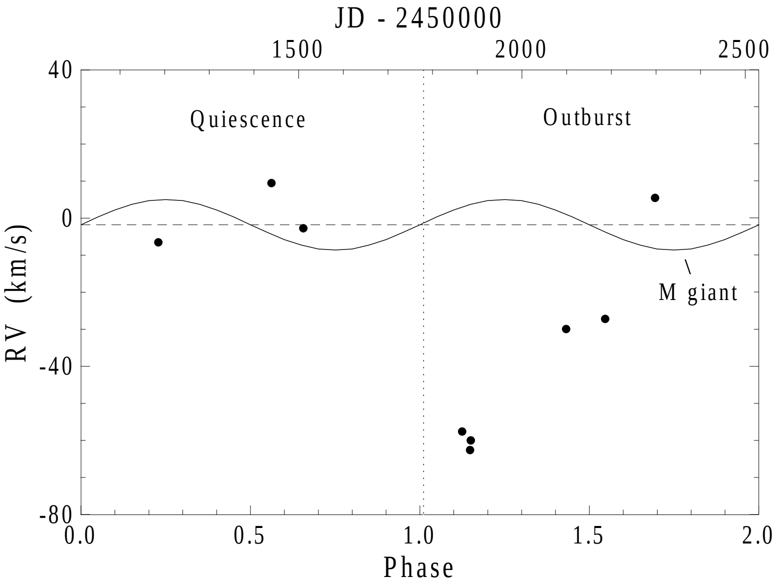

Fig. 3. The variations of the radial velocity of the He II $\lambda 4686$ line. For comparison the behaviour of the velocity of the cool giant in the system is shown as well, according to the orbital solution of Formiggini & Leibowitz (1994).

In the quiescence the radial velocity of the narrow component was close to the velocity of the mass center of the system. During the active phase, however, the behaviour of this velocity was typical for a secondary stellar component (Fig. 3) but its amplitude was great. This behaviour as well as the increased width of the line propose that it has probably emitted in the expanding shell of the companion. The emission region of the line most probably was decreased and was related only to the close vicinity of the companion since its flux became smaller.

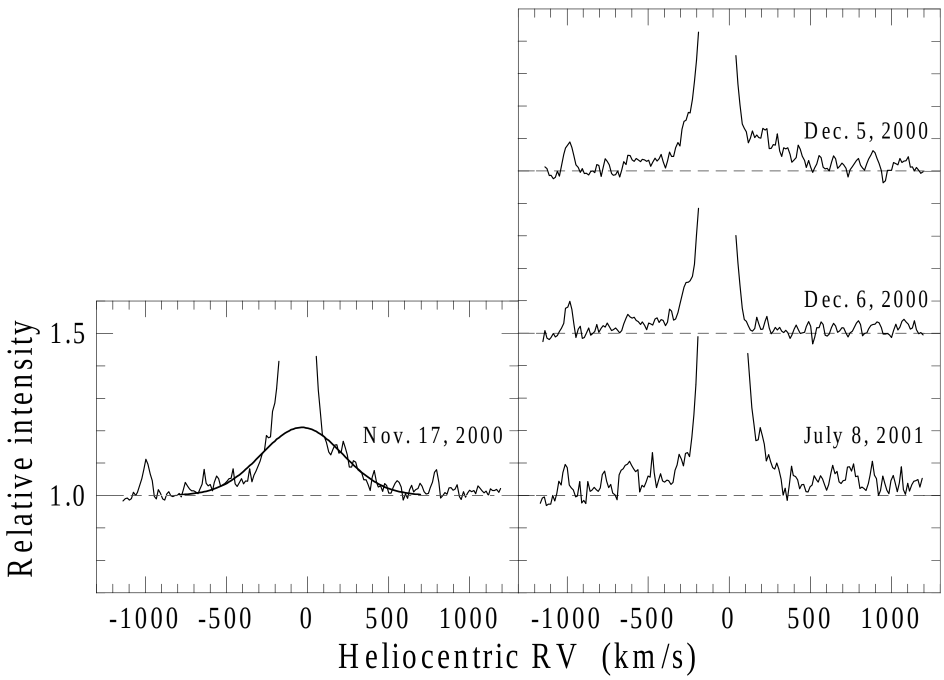

Fig. 4. The area of the wings of the He II $\lambda4686$ where the Gaussian fit of its broad component is seen. The spectra show the rapid variability of the broad component. The level of the local continuum is marked with a dashed line.

In the quiescent state the broad component of the He II $\lambda4686$ line was very weak. Its existence was concluded on the basis of the presence in its wavelength region of an emission exceeding the level of the local continuum. This emission is associated with a number of details which are related neither to the noise of the detector nor to nebular spectral lines. However, since this emission is too weak, it can not be measured with an adequate accuracy. In regard to its possible origin, we can not exclude the possibility for electron scattering in the surroundings of the compact companion as far as it is a hot high luminosity object.

During the active phase the broad emission increased and its height above the level of the local continuum reached up to 0.2. We analyzed this emission by fitting with Gaussian function (Fig. 4). Its FWHM obtained with this procedure is listed in Table 1. The equivalent width was obtained with an error reaching up to 25 per cent, which depends mainly on the level of the local continuum. However, since the broad emission is not good seen because of blending with the central narrow component and its profile is actually not Gaussian, the error of the equivalent width is greater than this value.

Table 1. The He II λ4686 line data.

Date	Orb. phase	RV ($\mathrm{km\,s^{-1}}$)	FWHM(N) ($\mathrm{km\,s^{-1}}$)	F(N)	FWHM(B) ($\mathrm{km\,s^{-1}}$)	FWZI(B) ($\mathrm{km\,s^{-1}}$)	v_{fast} ($\mathrm{km\,s^{-1}}$)	F(B)
1999 Jan. 7	0.228	−6.59	71.0	32.84				
1999 Sept. 17	0.562	9.47	64.0	39.35				
1999 Nov. 27	0.656	−2.75	71.0	37.15				
2000 Nov. 17	0.125	−57.58	119.6	14.54	590 ± 40	1240	620	7.198
2000 Dec. 5	0.148	−62.57	132.4	14.93	560 ± 43	1180	590	7.234
2000 Dec. 6	0.150	−60.01	119.6	15.78				
2001 July 8	0.432	−29.94	123.5	30.17	680 ± 150	1340	670	3.489
2001 Sept. 7	0.512		108.8	34.96	500 ± 80	980	490	2.988
2001 Oct. 3	0.547	−27.19	104.9	29.35	500 ± 50	950	480	3.055
2002 Jan. 23	0.694	5.44	83.2	30.31	390 ± 35	730	370	1.394

N – narrow component
B – broad component
F = F × 10^{-12} $\mathrm{erg\,cm^{-2}\,s^{-1}}$

The broad component of the He II λ4686 line indicate a high velocity and since it is emitted in the close vicinity of the hot companion, most probably the high velocity is related to nebular material ejected by the companion. In some cases the broad component was undergone strong variations on the time scale of about one day. For example its red wing was much weaker on December 6, 2000 than December 5, 2000 (Fig. 4). That is why we propose that the broad component was due to variable stellar wind with a high velocity (Table 1). The velocity was obtained on the basis of the full width of the zero intensity (FWZI) of the line.

Besides a high velocity wind, a mass flow with a low velocity of about 60 $\mathrm{km\,s^{-1}}$ from the companion was observed in the P Cyg lines of He I during the active phase. Then several outflow velocities were detected and we suppose that the lowest one is related to latitudes close to the orbital plane, and the highest one is realized in a direction perpendicular to the orbital plane. (If we suppose the other situation when the highest velocity is related to the orbital plane, in the region close to this plane the shell will be optically thin and will provide possibility to observe the high temperature compact object as in the quiescent state. The results of the continuum analysis (Paper I; Skopal et al. 2006), however, do not support this supposition. Some theoretical results (Bisikalo et al. 2006) show that an accretion disk is possible to exist in some periods of time in the system. We will suppose that during the outburst such a disk (or nebular material with increased density in the orbital plane) exists, which prevents the flow in the plane of the orbit.

We will also suppose that the velocity of the wind of the compact object is the same in all directions being initially about 500 $\mathrm{km\,s^{-1}}$, but in the region close to the orbital plane it decreases as a result of preventing by the disk. Probably for this reason reduced outflow velocities were observed which, in addition, covered one appreciable range of $0 \div 300$ km s^{-1}. This range was indicated by the P Cyg line P V λ1117, whose absorption component reached its maximal depth at velocity about 50 km s^{-1} (Sokoloski et al. 2006) like the He I lines. In this case the observed photosphere of the companion forms as a result of a growth of the density of the outflowing material because of prevention by the disk.

The density of the expanding shell depends on the velocity and when several flows with different velocities are related to different stellar latitudes, the level of the photosphere at these latitudes will be at different distances from the center of the star. For example the high velocity wind is optically thin and the level of the observed photosphere in its region is probably more close to the star than in the other region. Consequently, the expanding shell will not be spherical, but rather disk-like one. Since the bolometric luminosity is the same, the photosphere related to the greatest radius will have lower temperature. Then the low effective temperature of the observed photosphere of the companion of about 30 000 K, obtained from the analysis of the continuum energy distribution (Paper I; Skopal et al. 2006) can be related to this disk-like shell.

At the time of the maximal light the width of the He II λ4686 narrow component doubled, compared with its quiescent value and reached about 130 km s^{-1}. Most probably this width is determined first of all by the expansion of the shell but the gas turbulence can have also same contribution in it. Then the expansion velocity indicated by this line is close to the velocity of the absorption components of the lines of He I which are related to the observed photosphere. This photosphere, however, has an effective temperature of about 30 000 K (Paper I; Skopal et al. 2006) and its emission can not ionize He II. Then we can suppose that the narrow component of the He II λ4686 line is emitted above this photosphere, but its region is heated mainly by shock ionization when outflowing material meets the accretion disk. This conclusion provides possibility to explain the great negative velocity of this line. It can be due to an occultation of the back side of its emission zone by the disk-like slowly-expanding shell (Skopal et al. 2006). The model of the hot compact component is shown in Fig. 5.

Conclusion

We present results of high resolution observations of selected lines of He I and He II of the spectrum of the symbiotic binary Z And during its active phase 2000 – 2002. The triplet lines of helium He I λ4471 and λ4713 Å of this binary had P Cyg profile indicating stellar wind from the hot compact object with a velocity of about 60 km s^{-1} in November and December 2000 at the time of the maximal light.

During the active phase the behaviour of the radial velocity of the line He II λ4686 was typical for a secondary stellar component. That is why we concluded that it excites probably in the expanding atmosphere of the compact companion and reflects its orbital motion.

During the active phase the line He II λ4686 contained broad emission component with low intensity indicating stellar wind with a velocity of about 500 km s^{-1}.

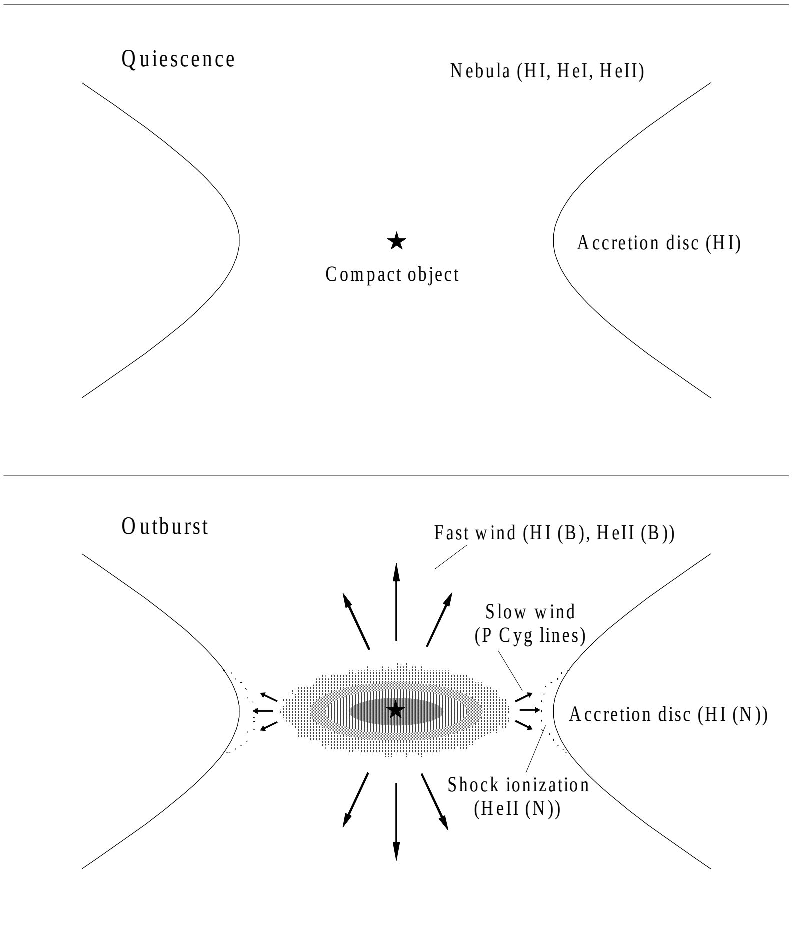

Fig. 5. Schematic model of the hot component of the system Z And in a plane, perpendicular to the orbital plane.

To explain the obtained data a model with an accretion disc (or dense material located in the orbital plane) in the system was proposed. During the active phase massoutflow from the compact companion at velocity equal to that indicated by the broad emission components is realized. This outflow is slowing down in the orbital plane till the velocity of the P Cyg wind due to interaction with the disk and an optically thick disk-like shell forms. The narrow component of the He II $\lambda 4686$ line is probably excited in the collisional region, whose back side is occulted by the disk-like shell. The great negative velocity of this line at orbital phases close to the quadrature is thus explained.

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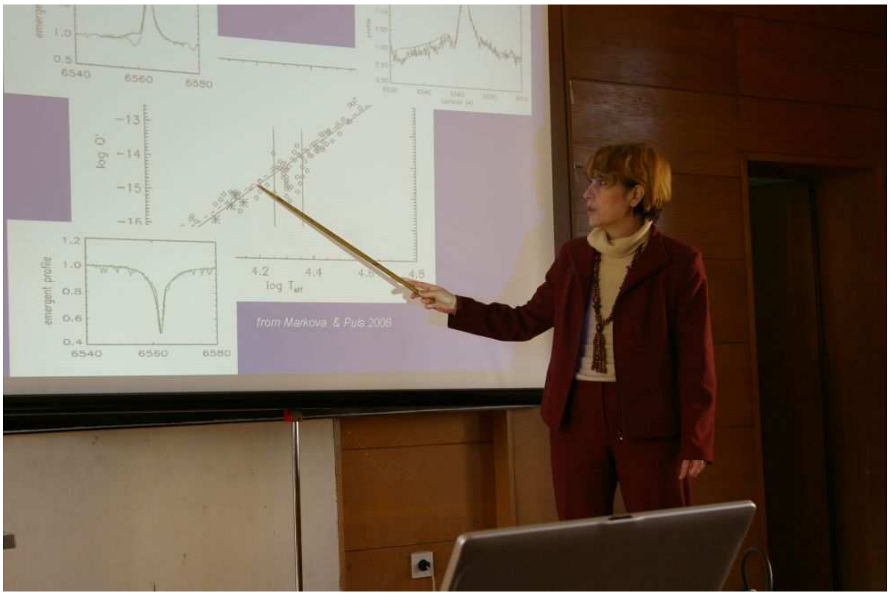
log Q'
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emergent profile
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