About the chemical composition of δ Scuti - the prototype of the class of pulsating variables

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Abstract. We present chemical abundances in the photosphere of δ Scuti – the prototype of the class of pulsating variables – determined from the analysis of a spectrum obtained at Terskol observatory 2 meter telescope with resolution $R = 52,000$, signal to noise ratio 250. VLT and IUE spectra were used also. Abundance pattern of δ Sct consists of 49 chemical elements. The abundances of Be, P, Nb, Mo, Ru, Er, Tb, Dy, Tm, Yb, Lu, Hf, Ta, Os, Pt, Th were not investigated previously. The lines of third spectra of Pr and Nd also are investigated for the first time. The abundances of heavy elements show the overabundances with respect to the Sun up to 1 dex. The abundance pattern of δ Sct is similar to that of Am-Fm stars.

Keywords. stars: variables: delta Scuti, stars: abundances, stars: chemically peculiar, stars: individual (Delat Scuti)

1. Introduction

δ Sct type are pulsating variables located in the lower part of the instability strip. This type stars form the second most numerous group of pulsators in the Galaxy after the pulsating white dwarfs (Solano & Fernley 1997). New catalog (Rodriges & Breger 2001) has observational information available up to January 2000 about 636 stars of this type. The majority of δ Sct type stars belongs to Population I.

The chemical composition of δ Sct was investigated by Russell (1995), Rachkovskaya (2000). The most detailed abundance pattern was published by Erspamer & North (2003). They found the abundances of 30 elements.

The goal of this paper is to derive detailed abundances of chemical elements in the atmosphere of δ Sct – prototype of the numerous class of pulsating variables.
2. Observations and data reduction

High resolution spectrum of δ Sct was obtained using a coude-echelle spectrometer (Musaev et al. 1999) mounted on the 2-m “Zeiss” telescope at the Peak Terskol Observatory located near Mt. Elbrus (Northern Caucasus, Russia) 3,124 m above sea level.

We used the spectrograph in the mode with a resolving power of $R = 52,000$. The observed wavelength range, $\lambda \lambda 3610–10270 \, \text{Å}$, was covered by 86 echelle orders. In the observed spectrum, there are gaps between the orders in the wavelength region of $\lambda \geq 6705 \, \text{Å}$ and the width of each gap increases from 0.5 Å to 69 Å as the wavelength increases. The signal-to-noise reaches 250 or more in the red part of the spectrum.

The first-stage data processing (background subtraction, echelle vector extraction from the echelle-images, and wavelength calibration) was done using the latest version of PC-based DECH software (Galazutdinov 1992). For other processes including continuum placement, we use URAN software (Yushchenko 1998). The location of the continuum was determined taking into account the calculated spectrum.

The strongest lines of many chemical elements can be observed in the ultraviolet spectral region. To detect these lines we used three IUE spectra of δ Sct from INES archive – the spectra LWR10992HL, LWP18563HL, LWP18600HL. The wavelength coverage of these spectra is from 1850 to 3349 Å, spectral resolution is near 0.2 Å. The signal to noise ratio is sufficient for line identification and in some cases for deriving abundances with errors near 0.2-0.3 dex.

The spectra of δ Sct from VLT archive were also used. The spectral resolving power of this spectra are 80,000, S/N ratio more than 300, wavelength coverage 3860–4980 and 8661–9194 Å.

Short information about all used spectra can be found in Table 1. For abundance determinations the spectrum of Terskol observatory and IUE spectra were used, VLT spectrum was used for identification of faint line.

3. Atmosphere parameters

The information about previous determinations of effective temperature, surface gravity, rotation and microturbulence of δ Sct can be found in Table 2. We tried to find our values of atmospheric parameters. The values obtained from Geneva photometry and from the depth ratios of the iron lines, based on Kovtyukh & Gorlova (2000) method are listed at the end of the table.

We adopted the values of effective temperature and surface gravity $T_{\text{eff}}=7000 \, \text{K}$, $\log g=3.5$. This parameters, Erspamer & North (2003) abundances and the values microturbulence and rotation velocities were used for initial calculation of synthetic spectrum in the whole observed region. This synthetic spectrum was used for identification of clean
Table 2. Atmospheric parameters of δ Sct

|                | Teff (K) | g log  | v sin i (km s⁻¹) | v micro (km s⁻¹) |
|----------------|----------|--------|------------------|------------------|
| Philip & Relyea 1979 | 7300     |        |                  |                  |
| Moon & Dvoretsky 1985 | 7200     |        |                  |                  |
| Lester et al. 1986  | 7100     |        |                  |                  |
| 7000            |          |        |                  |                  |
| Balona 1994      | 7267     |        |                  |                  |
| Russel 1995      | 7200     | 3.71   | 39               | 2.5              |
| Solano & Fernley 1997 | 7000     | 30.1   |                  |                  |
| 6900            |          |        |                  |                  |
| Rachkovskaya 2000| 7000     | 3.1    | 32               | 5.4              |
| 30              |          |        |                  |                  |
| Erspaner & North 2003 | 6776     | 3.47   | 25.51            | 2.8              |
| Geneva system    | 6772     | 3.45   |                  |                  |
| Iron lines depth ratios | 7064 |        |                  |                  |
| Adopted values   | 7000     | 3.5    | 25.5             | 3.8              |

iron lines in the spectrum. For these lines equivalent widths were found and the values of parameters were tested. It was necessary to change the microturbulence velocity to the value $v_{\text{micro}}=3.8$ km s\(^{-1}\).

The set of parameters ($T_{\text{eff}}=7000$ K, $g=3.5$, $v_{\text{micro}}=3.8$ km s\(^{-1}\)) and Erspaner & North (2003) abundances were used to produce individual atmosphere model using Kurucz (1995) ATLAS12 code. The dependencies of iron abundances on the equivalent widths and on the excitation levels of individual lines iron lines in the spectrum of δ Sct for our model show zero correlation. This model was used for abundance calculations.

4. Methodics

Differential spectrum synthesis method is used for all elements, except iron. For each line, we tried to find its counterpart in the solar spectrum atlas of Delbouille et al. (1973). Grevesse & Sauval (1999) solar photosphere model was used. This procedure frees us from uncertainties connected with oscillator strengths of spectral lines. The URAN code (Yushchenko 1998) and SYNTHE spectrum synthesis program (Kurucz 1995) are used to approximate the observed spectrum by the synthetic one.

A synthetic spectrum of δ Sct for the whole wavelength range helps us to identify spectral lines. Are included atomic and molecular lines from Kurucz (1995) as well as Morton (2000), Biemont et al. (2002) and partially from the VALD database (Piskunov et al. 1995).

Hyperfine structure and isotopic splitting are taken into account for Sc, V, Mn, Cu, Ba, Eu. The splitting data for Ba are taken from Francois (1996) and for other elements from Kurucz (1995). It should be noted that for all elements except Li, S, K, Ir, Th, U we found counterparts in the solar spectrum, so that the differential abundances are not strongly influenced by splitting effects. Holweger’s partition function for thorium is used (Morell et al. 1992).

5. The abundance pattern of δ Scuti

In Tables 3 and 4 the mean elemental abundances in the atmosphere of δ Sct are given. This tables contains data, obtained from the spectrum of Terskol observatory and IUE spectra respectively.
Figure 1. The observed spectrum of δ Sct (squares) and the synthetic spectra (solid lines) calculated with our final abundances. The axes are the wavelength in angstroms and relative fluxes. The positions of the spectral lines taken into account in the calculations are marked in the bottom part of the figure. For some of the strong lines the identification are given. The position of the Nd II $\lambda 5293.163$ Å line is marked by a vertical dotted line. The different synthetic spectra correspond to a Nd abundance lower or higher by 0.5 dex with respect to the abundance obtained from the optimum value. Nd II $\lambda 5293.163$ Å and Nd III $\lambda 5294.099$ Å lines show the example of the lines of the second and the third spectra of neodymium. The approximation of both spectra can be made with one value of abundance.

The difference in temperature between δ Sct and that of the Sun is quit large and we were not able to find the counterparts in the solar spectrum for all investigated lines. That is why in Table 3 we give both relative and absolute abundances of the chemical elements in the atmosphere of δ Sct.

The first two columns are the atomic number and identification of investigated species. The next two are the number of lines with counterparts in the solar spectrum and the relative abundance, obtained from these lines, with the last figures of errors in brackets. The fifth column is the total number of lines of given element or ion. Two subsequent triplets of columns are the mean abundances in the atmosphere of δ Sct for three sets or atmospheric parameters: the best values, and effective temperature and surface gravity shifted by -0.2 dex and +100 K respectively. There are absolute values of abundances in the second triplet and relative, with respect to Grevesse & Sauval (1998), in the first.

Table 4 contains the similar values for lines, investigated using IUE spectra. Only absolute abundances and relative values with respect to Grevesse & Sauval (1998) are shown in this table. Fig. 2 illustrates the relative abundances in the atmosphere of δ Sct.

The analysis of the tables shows the relative abundances calculated with respect to the absolute solar photosphere abundances are very close to the direct differential abundances.
Figure 2. The abundances of chemical elements and ions in the atmosphere of δ Scuti with respect to their abundances in the solar atmosphere. Filled circles – Terskol observatory observations. Open circles – IUE data. Crosses – Erspamer & North (2003). Open square – lithium (Russel 1995)

6. Conclusions

- The abundance pattern of δ Scuti consists of 49 chemical elements. The lines of eight of them are found only in ultraviolet spectrum.
- The abundances of Be, P, Ge, Nb, Mo, Ru, Er, Tb, Dy, Tm, Yb, Lu, Hf, Ta, Os, Pt, Th were not investigated previously.
- The lines of the third spectra of Pr and Nd are observed. The values of abundances of these elements obtained from the lines of second and third spectra are equal.
- The abundances of heavy elements shows the overabundances with respect to the Sun up to 1 dex.
- The abundance pattern of δ Scuti is similar to that of Am-Fm stars.

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| Z | Ident. | $\Delta \log N$ | $\Delta \log N$ | logN | $\log N$ |
|---|---|---|---|---|---|
| C I | 6 | 0.00(06) | 0.00(06) | 0.02(09) | 0.01(09) | 8.52(12) |
| N I | 7 | 0.04(11) | 0.15(06) | 0.04(11) | 0.02(11) | 8.07(06) |
| O I | 8 | 0.23(18) | 0.21(17) | 0.15(17) | 0.17(17) | 9.04(17) |
| Na I | 11 | 0.07(12) | 0.04(07) | 0.04(07) | 0.04(15) | 6.34(02) |
| Mg I | 12 | 0.04(15) | 0.07(10) | 0.05(12) | 0.03(11) | 7.51(10) |
| Al I | 13 | 0.03(01) | 0.02(00) | 0.01(01) | 0.00(02) | 7.60(00) |
| Si I | 14 | 0.07(12) | 0.01(02) | 0.04(07) | 0.04(15) | 6.34(02) |
| K I | 19 | -0.32 | -0.30 | -0.28 | 4.80 | 4.82 |
| Ca I | 20 | -0.19(12) | -0.09(11) | -0.17(11) | -0.14(11) | 6.27(11) |
| Sc II | 21 | 0.00(09) | 0.03(00) | 0.02(10) | 0.01(09) | 6.39(00) |
| Ti II | 22 | 0.06(07) | 0.06(02) | 0.16(06) | 0.15(05) | 4.06(02) |
| Cr I | 24 | -0.02(10) | -0.02(10) | 0.04(05) | 0.08(09) | 5.69(10) |
| Mn I | 25 | -0.03(12) | -0.03(12) | 0.00(09) | 0.07(09) | 5.69(10) |
| Fe I | 26 | -0.02(10) | -0.02(10) | 0.03(10) | 0.08(09) | 5.69(10) |
| Co I | 27 | 0.27(04) | 0.14(06) | 0.24(08) | 0.28(07) | 5.06(06) |
| Cu I | 28 | 0.05 | 0.25(07) | 0.27(03) | 0.32(01) | 4.46(07) |
| Zn I | 29 | 0.35(13) | 0.22(15) | 0.36(13) | 0.36(15) | 4.82(15) |
| Se I | 30 | 0.15(08) | 0.02(10) | 0.15(08) | 0.17(07) | 7.35(10) |
| Sr II | 38 | 0.38(10) | 0.38(10) | 0.34(10) | 0.45(04) | 3.35(10) |
| Y II | 39 | 0.66(11) | 0.58(13) | 0.61(13) | 0.69(14) | 2.82(13) |
| Zr II | 40 | 0.37(12) | 0.36(20) | 0.33(18) | 0.24(15) | 2.96(20) |
| Ba II | 56 | 0.07 | 0.56(24) | 0.53(20) | 0.49(08) | 2.69(24) |
| Ce II | 58 | 0.72(08) | 0.14(14) | 0.16(16) | 0.26(11) | 4.21(14) |
| Pr II | 59 | -0.04(10) | -0.04(10) | 0.09(08) | 0.12(05) | 5.35(10) |
| Nd II | 60 | 0.07(09) | 0.07(09) | 0.03(10) | 0.08(09) | 5.69(10) |
| Sm II | 62 | 0.27 | 0.27 | 0.27 | 0.27 | 5.17 |
| Eu II | 63 | 0.52(04) | 0.52(04) | 0.55(05) | 0.63(10) | 1.23(04) |
| Tb II | 65 | 0.50(02) | 0.50(02) | 0.50(02) | 0.55(07) | 1.21(02) |
| Dy II | 66 | 0.52(04) | 0.52(04) | 0.55(05) | 0.63(10) | 1.23(04) |
| Er II | 68 | 0.66 | 0.66 | 0.66 | 0.66 | 1.77 |
| Tm II | 69 | 0.51(11) | 0.51(11) | 0.53(10) | 0.58(13) | 2.01(11) |
| Yb II | 70 | 0.68 | 0.68 | 0.68 | 0.68 | 2.01 |
| Lu II | 71 | 0.51 | 0.51 | 0.51 | 0.51 | 1.52 |
| Hf II | 72 | 0.84(16) | 0.84(16) | 0.89(18) | 0.93(18) | 1.77(16) |
| Th II | 90 | 0.89 | 0.89 | 0.89 | 0.89 | 0.79 |

Table 3. Mean abundance of chemical elements in the atmosphere of $\delta$ Sct. Terskol observatory observations.
**Table 4.** Mean abundance of chemical elements in the atmosphere of δ Sct. IUE observations

| Z  | Ident. | n  | *GS98 | logN  |
|----|--------|----|-------|-------|
| 4  | Be II  | 2  | -0.29(11) | 1.06(11) |
| 32 | Ge I   | 2  | 0.49(03) | 3.90(03) |
| 41 | Nb II  | 2  | 0.47(00) | 1.89(00) |
| 42 | Mo II  | 4  | 0.72(24) | 2.64(24) |
| 44 | Ru II  | 1  | 0.53    | 2.37    |
| 72 | Hf II  | 2  | 0.99(01) | 1.87(01) |
| 73 | Ta II  | 1  | 1.18    | 1.05    |
| 76 | Os II  | 2  | 0.92(03) | 2.37(03) |
| 78 | Pt I   | 1  | 0.83    | 2.63    |