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# Optical spectroscopy of the infrared source IRAS 09276+4454

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**Abstract.**
The chemical abundance curve and main parameters of the infrared source IRAS 09276+4454 associated with the high latitude luminous cold star SAO 42901 have been determined using high–resolution optical spectra. The effective temperature, $T_e = 3400$ K, has been determined from band head intensity relations of the TiO $\alpha$–system. The abundances of 9 chemical elements in the atmosphere of IRAS 09276+4454 have been calculated by the model atmosphere method. Iron was found to be slightly deficient, $[Fe/H]_\odot = -0.34$dex. The abundance of iron group elements, V, Cr, Co, Ni, is slightly decreased relative to the iron abundance: $[X/Fe]_\odot = -0.15$, abundances of s–process elements, Y, Zr, Nd, are slightly increased relative to iron: $[X/Fe]_\odot = +0.10$. All the values obtained for the source IRAS 09276+4454 agree with its belonging to the evolution phase very close to AGB.
For 3 different observing moments strong variability of the radial velocity caused by binarity of the star studied is revealed.

**Key words:** stars: abundances – stars: evolution – stars: individual: IRAS 09276+4454

## 1. Introduction

Luminous stars with large IR–excesses are the first candidates for the stars at the post–AGB stage, evolving to the planetary nebula stage. Their chemical composition is of great interest as far as stellar evolution is concerned. High resolution spectroscopy of a sample of high latitude peculiar supergiants with large IR–excesses has been performed at the 6 m telescope over the last years (Klochkova, 1995; Začs et al., 1995; 1996; Klochkova, Panchuk, 1996; Klochkova et al., 1997abc). The main result of this research is the detection of overabundances of nuclei of s–process elements and an altered proportion of CNO elements in the atmospheres of 3 objects, IRAS 07134+1005 (Klochkova, 1995), IRAS 22272+5435 (Začs et al., 1995) and IRAS 04296+3429 (Klochkova et al., 1997c).

One of the bright stellar infrared objects, IRAS 09276 + 4454 = IRC + 40206 = AFGL 1355, with strong infrared radiation revealed both from the AFGL and IRAS–surveys is associated with the high–latitude luminous cold star HD 82040 = SAO 42901 (Grasdalen et al., 1983; Stencel, Backman, 1991). Using IRAS low–resolution spectra ($\lambda/\delta\lambda \approx 40$ in the region $8 - 15\,\mu$m and $\lambda/\delta\lambda \approx 20$ in the region $13 - 23\,\mu$m) Volk et al. (1991) referred this source to E–group with the 9.7 $\mu$m silicate dust emission detail.

Here we present new results for the source IRAS 09276+4454 derived from high–resolution optical spectra.

## 2. Observations and reduction

The first spectrum (JD=2450063.74) (Table 1) of the source IRAS 09276+4454 was taken at the Nasmyth focus of the 6 m telescope with the echelle spectrometer LYNX (Klochkova, 1995b) equipped with a CCD of 1040 × 1160 pixels developed by the Advanced Designs Laboratory of the Special Astrophysical Observatory.

Subsequent observations have been carried out at the prime focus of the 6 m telescope with the other spectral device – the echelle spectrometer PFES (Panchuk et al., 1998) in combination with the same CCD.

Observations have been carried out in the enviroment of OS Linux with the application of the NICE context (Knyazev, Shergin, 1995) of the MIDAS–ESO system. Two–dimensional echelle frames were processed using the ECHELLE context of the MIDAS. Drawing of a continuous spectrum level and determination of equivalent widths and radial velocity

Table 1: *The log of observations of IRAS 09276+4454 and $V_r$ measured using metallic lines. In the last line there is the $V_r$ value for the standard star $\alpha$ Tau.*

| Sp | JD, 2450... | $V_r$, km/s |
|---|---|---|
| s13012 | 063.74 | $20.9 \pm 1.9$ |
| s15736 | 505.58 | $36.3 \pm 8.3$ |
| s18512 | 767.73 | $161.4 \pm 4.8$ |
| $\alpha$ Tau | 763.77 | $54.0 \pm 2.5$ |

values were performed with the program DECH–20 (Galazutdinov, 1992). Equivalent widths of the lines W used in the chemical composition determination are presented in Table 2.

## 3. Determination of model parameters and chemical composition

The effective temperature has been derived from the spectral type Sp — $T_e$ calibrations. The spectral type has been derived by the technique given in the paper of Boyarchuk (1969). The method is supposed to use the intensity ratios of a spectrum on the long–wave side from the edge of the strip to the short–wave side of the $\alpha$ system head band strips of TiO ($I_{\lambda+}/I_{\lambda-}$). We employed $I_{\lambda+}/I_{\lambda-}$ at 4761(2,0), 4804(3,1), 4955(1,0), 5000(2,1), 5167(0,0), 5240(1,1), 5448(0,2), 5759(0,2) ÅÅ for spectral class determination. To illustrate this we present part of the IRAS 09276+4454 spectrum (Fig. 1) near the band (0;0) of TiO $\alpha$–system. The values $I_{\lambda+}/I_{\lambda-}$ and the results of the Sp determination for each criterion are presented in Table 3. The average value of spectral class of IRAS 09276+4454 is equal to M5. Different calibration relations Sp – $T_e$ give the following results: a) 3220 K (Flower, 1975); b) 3420 K (Ridgway, 1980), c) 3470 K (Dyck et al., 1996), d) 3450 K (Fabbroni, Richichi, 1997).

The surface gravity of IRAS 09276+4454 has been estimated from its luminosity assigned from the effective temperature using the evolutionary track calculations from Boothroyd and Sackmann (1988) and the standard formula

$$\log(g/g_{\odot}) = 4\log(T_e/T_{e\odot}) - \log(L/L_{\odot}) + \log(M/M_{\odot}),$$

where the solar parameters, $T_e = 5770$ K and $\log g = 4.40$, have been adopted. The mass value for the object studied was assumed to be $1.2\,M_{\odot}$. The obtained value of the surface gravity is $\log g = 1.2$.

The microturbulent velocity $V_t$ was determined by forcing the abundance of individual Fe I lines to be independent of equivalent width. The accuracy of the microturbulent velocity determination is $\pm 0.3$ km s$^{-1}$, $\Delta T_e = \pm 100$ K, $\Delta \log g = \pm 0.3$ dex.

Table 2: *Data ($\lambda$, identification X, excitation potential EP and equivalent width W) for lines used for chemical composition calculation.*

| $\lambda$ | X | EP | W (mÅ) |
|---|---|---|---|
| 7357.73 | TI | 1.44 | 270.8 |
| 7489.57 | TI | 2.25 | 145.0 |
| 7471.21 | TI | .81 | 115.6 |
| 7496.11 | TI | 2.24 | 91.1 |
| 7580.41 | TI | 2.23 | 66.9 |
| 7338.94 | V | 2.14 | 140.0 |
| 7355.93 | CR | 2.89 | 240.0 |
| 7400.23 | CR | 2.90 | 212.0 |
| 7401.69 | FE | 4.19 | 30.0 |
| 7411.15 | FE | 4.28 | 118.0 |
| 7418.67 | FE | 4.14 | 81.0 |
| 7430.54 | FE | 2.59 | 81.0 |
| 7443.02 | FE | 4.19 | 60.0 |
| 7445.75 | FE | 4.26 | 150.0 |
| 7447.38 | FE | 4.96 | 21.0 |
| 7447.96 | FE | 5.52 | 8.0 |
| 7454.00 | FE | 4.19 | 23.0 |
| 7461.52 | FE | 2.56 | 97.0 |
| 7473.55 | FE | 4.61 | 13.0 |
| 7476.38 | FE | 4.80 | 15.0 |
| 7484.30 | FE | 5.09 | 12.0 |
| 7491.65 | FE | 4.30 | 93.0 |
| 7495.06 | FE | 4.22 | 188.0 |
| 7498.53 | FE | 4.14 | 33.0 |
| 7506.01 | FE | 5.06 | 20.0 |
| 7507.26 | FE | 4.42 | 74.0 |
| 7477.51 | FE | 3.88 | 18.3 |
| 7511.01 | FE | 4.18 | 155.6 |
| 7568.89 | FE | 4.28 | 123.2 |
| 7583.79 | FE | 3.02 | 144.3 |
| 7586.01 | FE | 4.31 | 155.2 |
| 7437.14 | CO | 1.96 | 23.0 |
| 7385.24 | NI | 2.74 | 64.0 |
| 7393.60 | NI | 3.61 | 95.0 |
| 7422.28 | NI | 3.64 | 108.0 |
| 7414.50 | NI | 1.99 | 130.0 |
| 7555.60 | NI | 3.85 | 121.0 |
| 7574.04 | NI | 3.83 | 72.8 |
| 7439.86 | ZR | .54 | 112.1 |
| 7553.00 | ZR | .51 | 40.6 |
| 7554.70 | ZR | .51 | 90.4 |
| 7558.45 | ZR | 1.54 | 10.3 |
| 7450.20 | Y + | 1.75 | 26.2 |
| 7513.77 | ND | .93 | 51.4 |
| 7538.26 | ND | 1.44 | 31.4 |
| 7577.49 | ND | .20 | 53.4 |

The spectral region $\lambda\lambda$7350 – 7580 ÅÅ is relatively free from the molecular line blanketing and it has been used to obtain abundances from atomic lines of Ti I, V I, Cr I, Fe I, Co I, Ni I, Zr I, Y II and Nd II. A synthetic spectrum of atomic lines has been calculated with the oscillator strengths log gf from Gurtovenko and Kostyk (1989) and the solar model

Table 3: *Determination of spectral type of IRAS 09276+4454*

| λ, Å | $I_{\lambda+}/I_{\lambda-}$ | Sp |
|---|---|---|
| 4761 | 0.20 | M5.0 |
| 4804 | 0.37 | M5.0 |
| 4955 | 0.13 | M4.7 |
| 5000 | 0.43: | M5.5: |
| 5167 | 0.13 | M5.2 |
| 5240 | 0.56: | M6: |
| 5448 | 0.30 | M4.5 |
| 5759 | 0.76 | M4.5 |

from a new grid model by Kurucz (1993) and compared with the Atlas of the Sun. A synthetic spectrum has been calculated using the program STARSP (Tsymbal, 1996). As a result, the lines, correctly describing the solar spectrum, have been selected. For compilation of the line list the lines from the papers of Klochkova and Panchuk (1996), Whitmer et al. (1995), Smith and Lambert (1990) have also been involved. Thus 23 neutral iron lines and 1–6 lines of other elements have been selected (Table 2).

The level of the continuous spectrum was located by the standard method for cold stars — by intensity peaks in the wide region of the spectrum. To check the continuous spectrum level location and estimate the contribution to absorption of TiO a synthetic spectrum was calculated for the selected regions.

Determination of chemical element abundances in the atmosphere of the object has been carried out by the programme WIDTH-9 of Kurucz using the model with the following values of the parameters $T_e = 3400$ K, log g = 1.0 , $V_t = 3$ km/s and with the solar metallicity from the grid of atmosphere models by Brown et al. (1989). This grid of LTE, plane-parallel hydrostatic atmosphere models covers a range of $T_e = 3000 - 4000$ K and surface gravilty log g = 0.0 – 2.0. These models make allowance for absorption by numerous types of molecules: CO, $H_2O$, TiO, SiO, CN, $C_2$, CH, NH, OH, MgH, SH.

The oscillator strengths are taken from Gurtovenko and Kostyk (1989), for the lines of Zr I and Y II - from Kurucz, Peytremann (1975) and for Nd II - from Plez et al. (1993).

The well studied cold supergiant α Tau has been used as a standard star and we have determined the abundances of the star studied relative to this standard (see Table 4). The abundances of α Tau have been calculated with the atmosphere model from the models grid of Brown et al. (1989) and parameters $T_e = 4000$ K, log g = 1.0, $V_t = 2$ km/s. The results of determination of chemical composition of IRAS 09276+4452 and α Tau are given in Table 4. Here log ϵ (X) is the result of calculation of average

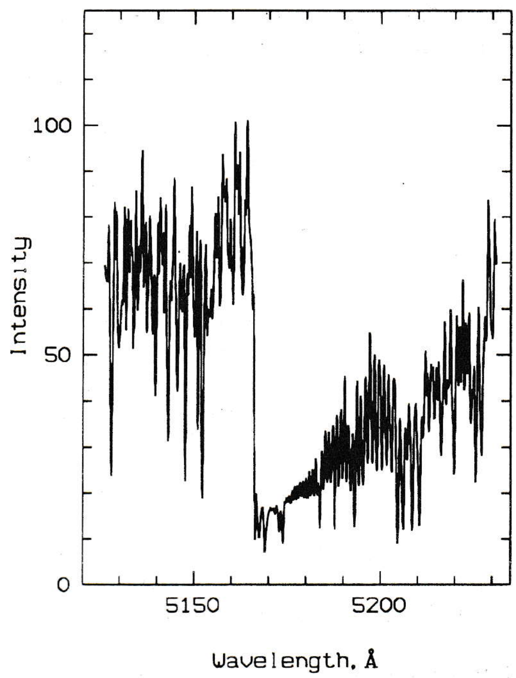


Figure 1: *The IRAS 09276+4454 spectrum near the band (0;0) of TiO α–system.*

abundances; "n" is the number of spectral lines used for calculation of the average value, σ is the error of this average. The values of [X/Fe] are given relative to the Sun (column 5) and to the standard star α Tau (column 6). The solar composition is taken from the paper by Grevesse and Noels (1993).

## 4. Results

As seen from Table 4, a slight deficiency of iron, $[Fe/H]_\odot = -0.34$, has been found for the peculiar supergiant SAO 42901 = IRAS 09276+4454. The abundances of the iron group elements, Cr, Co, Ni, are decreased relative to the iron abundance: for these elements $[X/Fe]_\odot = -0.15$.

The s–process elements, Y, Zr, Nd, show an abundance slightly enhanced than that of iron: $[X/Fe]_\odot = +0.10$.

We, apparently, observe this object at a phase very close to AGB. But the presence of the IR–excess suggests that the object evolves to the early PPN–phase. Volk, Kwok (1989) have also noted that the object IRAS 09276+4454 is of a very late spectral type (M6) and is unlikely to be PPN.

It should be noted that 3 observing nights gave

Table 4: *Chemical composition of IRAS 09276+4454* $\log \epsilon(X) \pm \sigma$ *(at log (H) = 12.0), n — the number of lines used for calculation.*

| | | IRAS 09276+4454 | | | | $\alpha$Tau |
|---|---|---|---|---|---|---|
| X | n | $\log \epsilon(X)$ | $\sigma$ | $[X/H]_{\odot}$ | $[X/H]_{\alpha Tau}$ | $\log \epsilon(X)$ |
| Ti I | 5 | 4.58 | 0.13 | -0.44 | 5.16 | -0.58 |
| V I | 1 | 3.56 | | -0.44 | 4.06 | -0.50 |
| Cr I | 1 | 5.21 | | -0.46 | 5.77 | -0.56 |
| Fe I | 23 | 7.16 | 0.24 | -0.34 | 7.80 | -0.64 |
| Co I | 1 | 4.36 | | -0.56 | 5.08 | -0.72 |
| Ni I | 6 | 5.70 | 0.20 | -0.55 | 6.27 | -0.57 |
| Zr I | 4 | 2.41 | 0.22 | -0.19 | 2.94 | -0.53 |
| Y II | 1 | 2.63 | | -0.39 | 3.34 | -0.68 |
| NdII | 3 | 1.65 | 0.06 | -0.15 | 1.91 | -0.26 |

different values of $V_r$. Such a difference is caused by binarity nature of the object IRAS 09276+4454 which associated with binary star ADS 7403 A.

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