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Chemical composition of HD 179821 (IRAS 19114+0002)*

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Abstract. A LTE analysis of medium resolution spectra of HD 179821 has been made. Derived atmospheric parameters of HD 179821 are $T_{\rm eff} = 5660$ K, $\log g = -1.0$ and [Fe/H]=-0.5. The position of the star in the H-R diagram, its high radial velocity (V_r=100 km s^{-1}), its far infrared excess similar to PNe and its chemical composition suggest that HD 179821 is a low mass post-AGB carbon-poor supergiant and not a population I massive red supergiant. The underabundance of carbon and of the s-process element zirconium shows that HD 179821 has not gone through the third dredge-up. We emphasize the similarity of the chemical pattern of the post-AGB star HD 179821 and the C-poor halo PN DDDM-1.

Key words: stars: abundances – stars: fundamental parameters – stars: individual: HD 179821 – stars: AGB and post-AGB

1. Introduction

1.1. Post-AGB stars

The chemical composition of bright post-AGB stars has been recently reviewed by Bond (1991) and Luck (1993). In these reviews they discussed the chemical composition of luminous (low gravity) high latitude supergiants which were found to show detached cold dust shells with far-IR colors similar to planetary nebulae (Parthasarathy & Pottasch 1986) and high latitude low gravity A type supergiants with warm dust shells (Lamers et al. 1986; Waelkens et al. 1992). Bond (1991) and Parthasarathy et al. (1992) concluded that the photospheric CNO abundance pattern in such stars are distinctly atypical of normal population I supergiants, and clearly indicate that these stars have burned helium. There are few post-AGB supergiants (HR 4049, HD 52961 and HD 44179, see Waelkens et al. 1991, 1992) which were found to show extreme underabundance of Fe and other refractory elements, and nearly normal (solar) abundances of CNO. Bond (1991) proposed dust grain formation as the depletion mechanism.

IRAS spectra are useful tool for searching new post-AGB stars; the optically bright post-AGB stars indeed show a double-peaked energy distribution in their spectra from the UV to the IR emission. The IRAS emission feature at 21μm occur in spectra of C-rich post-AGB stars such as in IRAS 05341+0852. High-resolution spectroscopy of these 21μm stars support an efficient 3rd dredge-up. Van Winckel (1999) has used the [Zr/Fe] abundance ratio as a measure of the dredge-up efficiency versus metallicity for post-AGB stars showing a double-peaked energy distribution. In his Figure 1, there is a clear separation between the enriched objects (the 21μm stars) and the other stars which are very similar objects but without chemical enrichment due to the 3rd dredge-up.

Some post-AGB candidate stars also show the presence of a hot dust component making the IR excess very broad. Waters at al. (1997) have discovered among post-AGB candidates a tight correlation between the occurrence of hot dust and binarity. On the other hand, Van Winckel et al. (1995) have emphasized a strong connection between depletion and binarity. According to these authors, the gas-dust separation needed to account for the depletion pattern is likely to take place in a circumbinary dusty disc.

Detailed chemical composition analysis is available for only a few post-AGB stars. In order to further understand the abundance pattern of post-AGB F and G supergiants, we carried out chemical composition analysis of bright post-AGB candidate HD 179821 (Pottasch & Parthasarathy 1988).

1.2. HD 179821

Having nearly the coldest IRAS colours (12 μm=31 Jy, 25 μm=650 Jy, 60 μm=520 Jy and 100 μm=170 Jy) among evolved stars, HD 179821 has gained considerable attention in recent literature as it displays many unusual properties.

This is a V=8.4 star of spectral type G5 I_a (Buscombe 1984; Hrivnak et al. 1989). In the CO survey of cold IRAS objects, Zuckerman & Dyck (1986) have detected CO molecular emission in HD 179821. It has large CO radial velocity (V_r=100 km s^{-1}) with respect to local standard of rest and also it has large out flow velocity (V_{exp}= 32 km s^{-1}). Based on its kinematical properties, large IRAS fluxes and out flow velocity, they suggested that the star might once have been a runaway O-type

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* Based on observations obtained at the Observatoire de Haute-Provence, France

star. Pottasch & Parthasarathy (1988) were the first to discuss the post-AGB nature of this star based on its IRAS fluxes. The spectral energy distribution (SED) of this source closely resembles that of the high latitude post-AGB candidate HD 161796 (Parthasarathy & Pottasch 1986) and its IRAS colours are similar to planetary nebulae. The large far infrared excess of this star has been attributed to large scale mass-loss in the AGB phase of evolution. The studies of SED from 0.4 μm to 100 μm (Pottasch & Parthasarathy 1988; Hrivnak et al. 1989; van der Veen et al. 1989, 1994) points out that the star has a detached cold ($\approx$ 130 K) dust shell and no hot dust component indicating recent cessation of mass-loss. However very recently Hawkins et al. (1995) discovered an extended nebula around HD 179821 at near-IR wavelengths and they suggested that it is an extremely massive star which has recently undergone an enormous mass-loss. They estimate mass of the circumstellar envelope to be around 8$M_{\odot}$. Polarimetric and coronagraphic near-IR images (Kastner & Weintraub 1995) revealed the presence of extended dust reflection nebula around HD 179821. Under the assumption that the star lies at its kinematical distance (6 kpc), Kastner & Weintraub (1995) suggested that its circumstellar envelope has a dynamical lifetime of 5000 yr, and a mass of $\approx$ 5 $M_{\odot}$ of gas and dust. Thus HD 179821 is either classified as a post-AGB star descended from a low-mass progenitor or as a very massive red supergiant.

2. Observations

In this paper we use spectra obtained during the night 20-21 July 1998 at the Observatoire de Haute-Provence (France) at medium resolution (1 pixel=0.2 Å implying a resolution of ≈ 8000) centered on the BaII λ4554 Å with a total range of 430 Å. The *Aurélie* spectrograph (Gillet et al. 1994) installed on the 1.52m telescope at Observatoire de Haute Provence uses a cooled 2048 photo-diode detector forming a 13μm pixel linear array, a grating with 600 grooves mm^{-1} giving a mean dispersion of 16.3Å mm^{-1}. The choice of the resolution was indicated for this star by its known strong macroturbulence (Začs et al. 1996).

Thorium lamps were observed before and after each stellar observation for wavelength calibration. At the beginning, the end and the middle of the night, a series of flat-fields was obtained using a calibration lamp (tungsten). Flat-field corrections and wavelength calibrations of the 1-dimensional images were performed at Montpellier using the MIDAS package. HD 179821 was observed two times during the night at JD 2 451 015.39 and 2 451 015.51. Nine spectrophotometric flux standards recommended by Massey et al. (1988), Breger (1976) and Taylor (1984) were observed during the night in order to check any variations of the atmospheric absorption and to calibrate all spectra in flux. The absorption and seeing being better in the second half of the night, we selected in this work the second spectrum of HD 179821 which was exposed 2 hours; the standard star HR 7950 was observed just before HD 179821, and HR 8634 and HR 9087 just after. The response curves of the three standard stars are very similar: the relative differences are lower than 0.5% between 4480λ and 4580λ and differ at the maximum of 4% at the edges of the spectral range. Then, we calibrated the spectrum of HD 179821 with each of the three response curves, and divided the obtained spectra by their flux value at a wavelength of 4510Å. After this normalization, the three calibrated spectra are similar within 4%. In the following (Sect. 3) we used a spectrum of HD 179821 calibrated in flux with the averaged response curve of the three standard stars, and normalized at 4510λ. We are confident that the normalized flux of this spectrum is known with a relative error of $\pm2\%$ implying an approximated spectral slope $87.10^{-5} \pm 8.10^{-5}$. Such uncertainty on the normalized flux is not able to change the derived effective temperature by more than 70 K, which is less than the uncertainty adopted on the temperature.

3. Analysis and results

As a first step, we derived values of the fundamental parameters of the star, T_{eff}, log g and [M/H] by using a technique described in Thévenin & Jasniewicz (1992). In this technique we compare observed spectrum with synthetic spectra computed using the Bell et al.'s grid (1976) degraded at the resolution of the observed spectrum. We recall that for comparison we divided both observed and computed spectra by their flux value at a wavelength of 4510 Å. With this technique there is no placing of any continuum. This technique is close to the one developed by Cayrel et al. (1991). Note that we had to decrease the resolution of the synthetic spectra until they fit profiles of observed spectra. We first concluded that the macroturbulence of HD 179821 is very high, leading to a value of 21.5 ± 4km.s^{-1} in the blue spectral range which is typically larger than the macroturbulence found in supergiant stars. This velocity is in agreement with those deduced by Začs et al. (1996) and Reddy & Hrivnak (1999). There is no important influence of interstellar absorption on the results of this technique of synthetic spectrum analysis because we used a narrow spectral range. In a last iteration, temperature was fixed by a perfect fit of the slope of the observed spectrum. Another iteration was done to improve the value of the surface gravity by comparing a spectral range dominated by lines of neutral elements with other ones dominated by lines of ionized elements, realizing as perfect as possible the ionization equilibrium of the stellar photosphere. In a last iteration, we perfect the fit by changing the abundances of some elements. The microturbulent velocity had to be increased until $11\,\mathrm{km.s}^{-1}$ to fit the spectral range of blended lines sensitive to this parameter, e.g. blend of saturated lines. This value is probably overestimated due to poor description of this velocity in a so extended atmosphere. A variation of this parameter with the optical depth is probably more realistic.

Adopted atmospheric parameters are: $T_{\rm eff} = 5660\,\mathrm{K}$, $\log g = -1.00$, [Fe/H] = -0.5, $\xi_{turb} = 11.0\mathrm{km.s}^{-1}$. The sensibility of the fit to the different parameters gives a precision of ± 100 K on the effective temperature, ± 0.5 dex for the logarithm of the surface gravity g, ± 0.2 dex for chemical abundances and $\pm 1.0\mathrm{km.s}^{-1}$ for ξ_{turb}. Abundance results of peculiar elements are given in Table 1. Solar abundance reference values are from

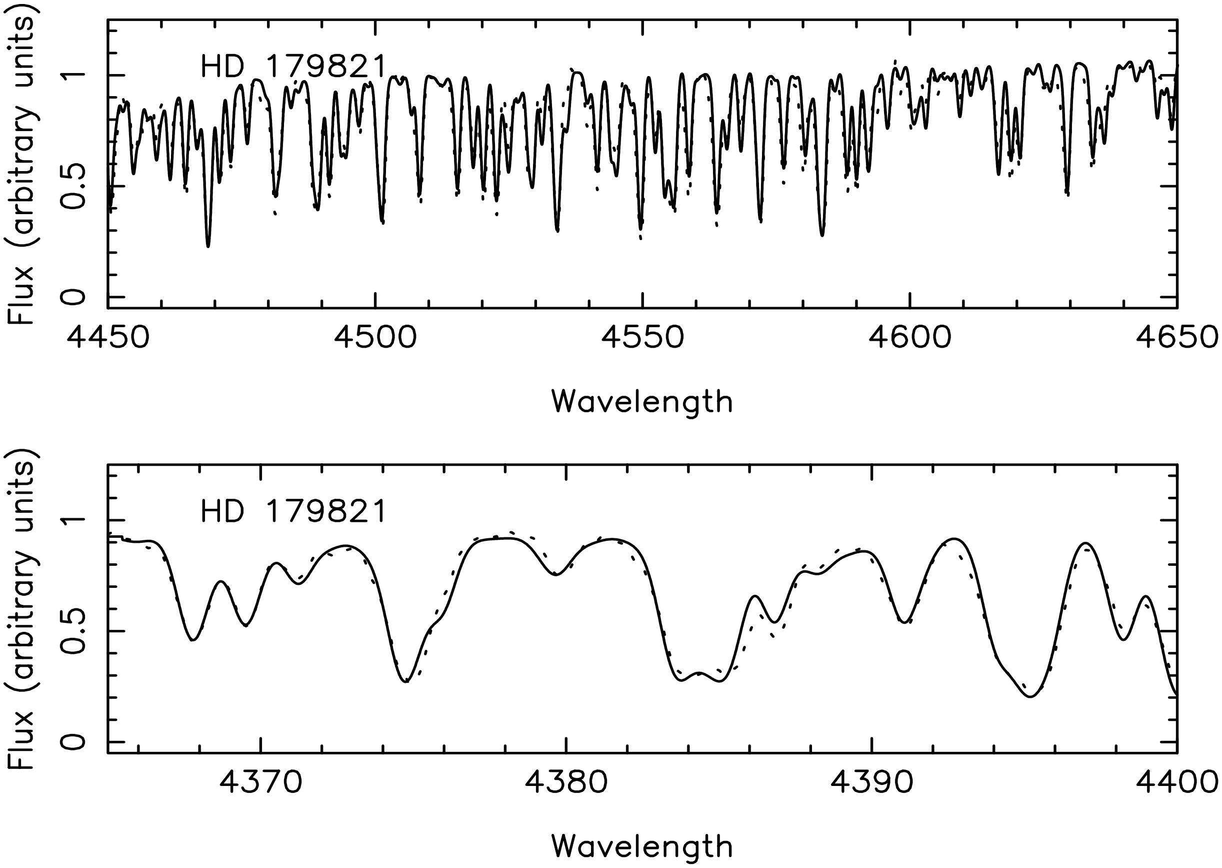

Fig. 1. Medium-resolution spectrum of HD 179821 (dashed line). The stellar spectrum computed is with parameters described in Sect. 3 ($T_{\rm eff} = 5660\,{\rm K}$, $\log g = -1.00$, [Fe/H] = -0.5, $\xi_{turb} = 11.0$km.s^{-1}). Wavelengths are given in Å

Table 1. Adopted abundances

[C/Fe]	[Mg/Fe]	[S/Fe]	[Ca/Fe]	[Ti/Fe]
< -1.0	0.55	0.10	-0.40	0.05
[Cr/Fe]	[Ni/Fe]	[Zn/Fe]	[Zr/Fe]	[Ba/Fe]
-0.05	0.00	-0.25	-0.70	-0.85
[La/Fe]	[Ce/Fe]	[Eu/Fe]		[Fe/H]
-0.40	-1.00	-1.10		-0.50

Holweger (1979). Abundance fits were done using spectral regions where most of the lines are weak. A poor estimate of the microturbulence velocity has a small influence on derived abundances which can be overestimated. An error of $+3{\rm km.s}^{-1}$ on the microturbulent velocity gives a correction around -0.05 dex on the abundances derived by the spectral fit. Some parts of the spectral fit are shown in Fig. 1.

In Fig. 2 we show that if we adopt an effective temperature of 6500 K as proposed by Začs et al. (1996) and more recently by Reddy & Hrivnak (1999) and log g = 1.3, it is impossible to reproduce the slope of the spectra and line profiles. This high temperature is definitively rejected.

Our calculations are done using an LTE assumption. Non-LTE effects could exist because the surface gravity is very low and therefore electronic collisions are less important. The under-abundance derived is also a source of Non-LTE effects, because the UV-flux becomes more important and it can result in an over-ionization of the elements like iron. If such effects exist, they are relatively small for supergiant stars moderately metal-poor as demonstrated by Thévenin & Idiart (1999). For supergiant stars of the Small Magellanic Cloud, an overionization of ≈ 0.05 dex is derived for [FeI/FeII]. Therefore this effect has no consequence on the derived surface gravity which is constrained by the ionization equilibrium. Most of the small blended lines reproducing a great part of the aspect of the spectrum are formed in the range $-1.3 < \tau < -1.9$. Stronger lines reproducing few per cents of the total spectrum are formed in layers above $\tau = 0.4$. In consequence both strong and small lines are not concerned by the extreme layers of the model atmosphere which can poorly reproduce the intensity of the lines.

Note that to perfect the fit we had to use all ionized lines present in the Kurucz (1993) data basis. The presence of so many neutral and ionized lines per Å of spectrum contributing considerably to the blends therefore strictly forbidden to measure accurate equivalent width of lines and in consequence forbidden to use the classical detailed analysis by the technique of the curve of growth. We do not understand how Začs et al. (1996) have been able to measure equivalent widths as small as 7 mÅ on spectra dominated by a large macroturbulence even in the red part of the spectrum.

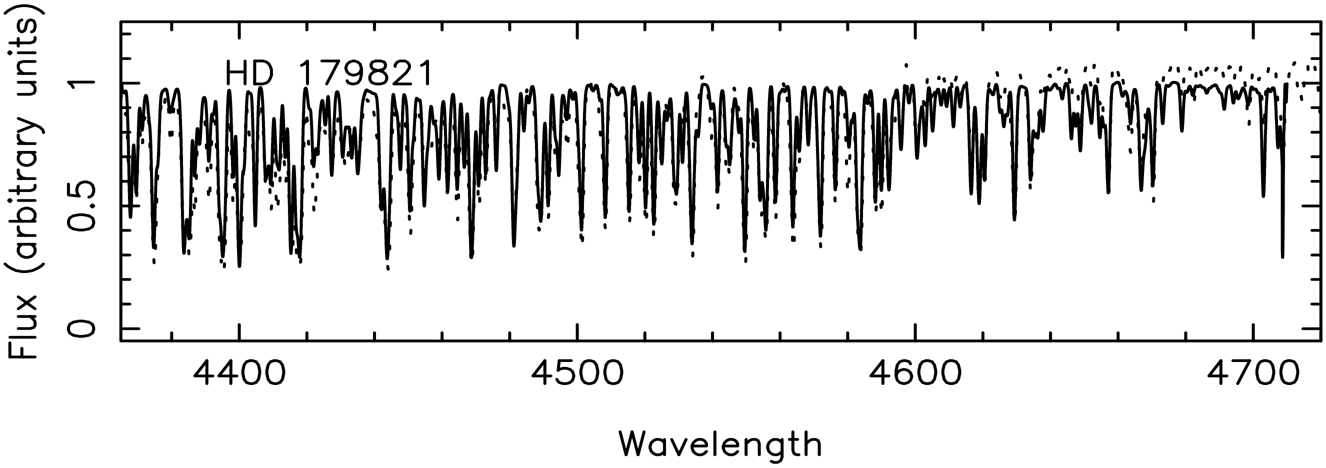

Fig. 2. Medium-resolution spectrum of HD 179821 (dashed line). The stellar spectrum is computed with parameters done by Začs et al. (1996) ($T_{\rm eff} = 6800\,{\rm K}$, $\log g = 1.3$, [Fe/H] = 0.0). Wavelengths are given in Å

4. Discussion

The chemical composition of HD 179821 clearly differs from the average chemical composition of yellow supergiants (Barbuy et al. 1996) and dwarfs stars (Wheeler et al. 1989). Yellow supergiants have elemental abundances [Fe/H]=0.0, [C/Fe]=-0.2, [N/Fe]=0.1, [O/Fe]=-0.2 (Barbuy et al. 1996). However HD 179821 is found to be moderately metal-deficient indicating that it is not a massive population I supergiant. The large radial velocity coupled with low-metallicity implies that HD 179821 is not a massive supergiant.

Recently Kastner & Weintraub (1995) and Hawkins et al. (1995) suggested that HD 179821 may be a massive yellow supergiant caught in between RGB and Wolf Rayet phase. They estimated mass of the circumstellar dust shell to be 5-8$M_{\odot}$. Another important point to be noted is the non-detection of HCN toward HD 179821 attributed to the recent cessation of mass-loss (Hrivnak et al. 1989) which is also suggested by its low IRAS variability index VAR=0. Presence of strong HCN is the characteristic of heavily mass losing supergiants (Bujarrabal et al. 1992; Nercessian et al. 1989).

Recently Začs et al. (1996) reported the chemical composition analysis of HD 179821. They discussed two possible effective temperatures ($T_{\rm eff}$=6800K and 5500K) and finally used the atmospheric parameters as being $T_{\rm eff}$=6800K, log g=1.3 and [Fe/H]=-0.10. They find overabundance of C, Ni, Ti, Sc and s-process elements. From our analysis of the spectrum of HD 179821, such overabundances are not found. More recently Reddy & Hrivnak (1999) adopted the same atmospheric parameters derived the same typical abundances. They discussed this hot deduced temperature as to be a consequence of excitation balance of lines having low excitation values. This temperature could be wrong because of Non-LTE effects masking the real excitation balance. Consequently their temperature do not fit the one derived by the Balmer line H_{δ} and by the photometry ($\sim 5000\,{\rm K}$), invoking possible emission which masks the absorption feature. Emission is detected in H_{α} but could not be a reasonable explanation of this large temperature discrepancy. The fact that our spectra show a flux slope incompatible with those deduced by Začs et al. and Reddy & Hrivnak eliminate this hot $T_{\rm eff} = 6800$K (see Fig. 2). Their hot adopted temperature is responsible of the wrong ionization equilibrium balance deduced (e.g. $\log g = 1.3$ and 0.5) and therefore of their wrong abundances.

4.1. Comparison with DDDM-1 and HII-SMC

Note that our derived abundances of HD 179821 (Table 1) are remarkably resembling to those deduced for the halo-PN DDDM-1 (see Clegg et al. 1987). Iron is moderately underabundant with carbon and s process elements underabundant. Same situation is found for the object Barnard 29 (see Conlon et al. 1994). As evidence these objects, HD 179821, DDDM-1 and Barnard 29 did not undergo a 3rd dredge-up. By these abundance aspects these objects have similar abundances as the HII regions of the Small Magellanic Cloud and the same iron abundances as supergiant stars also belonging to the SMC. Did they have the same material origin of a C-poor halo gas similar to the present SMC?

5. Conclusions

We have analyzed a spectrum of a post-AGB candidate HD 179821. Our abundance analysis results of HD 179821 suggests that this is a low-mass evolved object but not a run away population I supergiant ejected from the disc. The high radial velocity, large displacement (Z=200 pc) from the galactic plane, low [Fe/H], far-IR excess and its position in the H-R diagram suggest that HD 179821 is a post-AGB star. Our abundances of HD 179821 shows that it has left the AGB before the third dredge-up. It is having chemical composition similar to that of high latitude hot post-AGB stars. Therefore HD 179821 is a cooler analogue of high latitude hot post-AGB star. As HD 179821 evolves to higher temperatures it may become a hot post-AGB star with underabundance of carbon similar to that of high latitude hot post-AGB stars and Barnard 29.

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