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The ultraviolet variations of the post-AGB star HD 89353*

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Abstract. Based on an analysis of all low resolution spectra of HD 89353 (HR 4049) obtained with the International Ultraviolet Explorer (IUE) over several years and uniformly reprocessed, we report on large ultraviolet variations for this star whose amplitude increases towards long wavelengths. Ultraviolet maximum and minimum occur respectively at phase 0.52 and 0.92 of Waelkens et al. (1991) ephemeris which suggests that ultraviolet and optical variations occur in phase.

The ultraviolet energy distribution of HD 89353 is very deficient compared to that of the standard A6Ib star, HD 80404, and compared to the predictions of an ATLAS 9 model (T_{eff} = 7500K, $logg$ = 2.0 and [M/H]= -5.0) which bests fit the optical continuum. The ultraviolet flux deficiency scales as λ^{-1}, a trend already noted earlier (Waelkens et al. 1995). The most likely interpretation is that variable circumstellar extinction drives the ultraviolet and optical variations as proposed by Waelkens et al. (1991).

Key words: stars: atmospheres – stars: circumstellar matter – stars: individual: HD 89353 – stars: AGB and post-AGB

1. Introduction

High latitude A and F post-AGB supergiants are IRAS sources with far-IR colors similar to planetary nebulae with cold and/or warm circumstellar dust shells. These shells probably stem from severe mass loss experienced by these stars during the AGB (Parthasarathy and Pottasch, 1996). In the frame of a complete analysis of archival IUE data of these stars, we have confirmed large flux variations in the ultraviolet range for the bright post-AGB star, HD 89353 (HR 4049) (Waelkens et al. 1995) which we report on in this letter.

HD 89353 was first classified a B9.5 Ib-II supergiant by Houk and Cowley (1975). Abt (1984) stressed that the extreme weakness of the metallic lines precluded from ascribing an MK spectral type to this star. The star is located at high galactic latitude ($b = +22.9^0$) and is a photometric large amplitude and spectroscopic variable (Waelkens and Rufener, 1983; Waelkens et al., 1991). The H_α line has a P Cygni profile indicating current high mass loss. Lamers et al. (1986) report on a large infrared excess and an ultraviolet deficiency which they attribute to dust formed in the matter lost by the AGB star after leaving the AGB. In addition, Geballe et al. (1989) have reported on strong IR dust features and CO bands.

Lambert et al.'s (1988) LTE analysis of the line spectrum of HD 89353 revealed that the star is actually cooler (T_{eff} = 7500K, log g =1.0) than a B9.5 supergiant making it an A7II (later confirmed by Trams (1990)) and has very low metal abundances ([Fe/H] $\leq$ -3.0) but normal or overabundances of C,O,N,S. Waelkens et al. (1991) derived T_{eff} = 7600K, log g = 1.05 and [Fe/H] = -4.80. By extrapolating a Kurucz model, Waelkens et al. (1995) could fit the ultraviolet energy distribution with a model of parameters T_{eff} = 7500K, log g = 1.0 and Z = -2.5. Waelkens et al. (1991) found that the abundance pattern of HD 89353 to be very similar to that of another post-AGB star HD 52961. The abundance pattern in these stars is similar to the gas phase abundances of the interstellar medium. Venn and Lambert (1990) and Bond (1991) proposed that the peculiar abundance pattern in post-AGB stars is due to selective removal of the metals from the photosphere through grain formation and mass loss (dust fractionation). Van Winckel et al. (1992) and Waters et al. (1992) further specified that dust fractionation must take place in dust formed in matter ejected from the star and that the depleted gas is reaccreted onto the star forming a low metallicity photosphere. The presence of large amounts of dust around post-AGB stars certainly supports this scenario. Another conclusive evidence for the dust fractionation scenario was provided by Van Winckel et al. (1992) who derived the abundance of zinc in the extremely metal-poor post-AGB star HD 52961. HD 89353 is a binary with an as yet unseen companion as suggested by the length of the period of the photometric and spectroscopic variations of HD 89353 (429 days, Waelkens et al., 1995) and the amplitude of radial velocity variations (Waelkens et al. 1993, Van Winckel et al. 1995). In Sect. 2, we have redetermined the effective temperature and surface gravity of HD 89353 by fitting its energy distribution from the ultraviolet to the red with recent model atmospheres. The ultraviolet flux deficiency of HD 89353 previously established versus a hot B9 supergiant by Waters et al. (1989) is confirmed in two manners: first, by comparing the ultraviolet

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* Based on data from the International Ultraviolet Explorer

energy distribution to the model with the right effective temperature (significantly cooler than that of a B9.5I supergiant) and second by comparing it to the flux level of a standard star of similar spectral type. We also report on large ultraviolet variations from archival IUE data. In Sect. 3, we propose an interpretation of these variations in the frame of Waelkens et al.'s (1991, 1995) model of HD 89353.

2. Ultraviolet variations

2.1. Observational material

All low resolution IUE spectra of HD 89353 obtained through the large apertures and properly exposed in the continuum have been retrieved in NEWSIPS (New Spectral Image Processing Software) format. Compared to IUESIPS (IUE spectral image processing system), NEWSIPS provides a uniform reprocessing of IUE data, eliminates the fixed pattern of noise (which amounts to 50% of the noise in IUE data) and results in an improvement of the signal to noise ratio of 15% or more. The FES counts obtained by the Fine Error Sensor on board IUE before each exposure measure the brightness of the star around 5000 Å contemporary to the IUE spectrum. We have converted them into magnitudes, V_{FES}, using Perez and Loomis' algorithm (1991) which takes into account corrections for the FES dead time, focus variations, time sensitivity degradation. Image numbers, observing dates, Fine Error Sensor (FES) magnitudes V_{FES} and orbital phases as computed from Waelkens et al. (1991) ephemeris are collected in Table 1. A few spectra miss the corresponding FES magnitudes as the star was on a few occasions acquired as a blind offset from a nearby brighter star. Note that the FES magnitudes differ by more than 1 magnitude from the V magnitudes recorded in Waelkens et al. (1991). The V_{FES} are indeed not V magnitudes and cannot be used as reliable absolute photometry but they help identifying the brightening or faintening of the star. All spectra have been corrected for interstellar extinction using Savage and Mathis (1979) law for our Galaxy and adopting $E(B-V) = 0.10$. Indeed, Buss et al. (1989) have derived from the nearby stars HD 89391, HD 84567 and HD 86612 that the interstellar extinction towards HD 89353 must verify $0.07 \leq E(B-V) \leq 0.17$.

Table 1. Log of the observations used

Spectrum	V_{FES}	Date	Orbital phase
SWP 25474	6.58	850317	0.48
SWP 30942	6.95	870510	0.29
SWP 30943	6.99	870510	0.29
SWP 31256	6.92	870626	0.40
SWP 33577	7.75	880520	0.15
SWP 40218	6.29	901128	0.28
SWP 40379	6.27	901218	0.32
SWP 44702	6.63	920518	0.52
SWP 46405	6.91	921204	0.99
SWP 49375	–	931130	0.81
SWP 50506	7.09	940409	0.11
SWP 54309	–	950406	0.94
SWP 56349	–	951226	0.55
LWP 12311	7.88	871219	0.80
LWP 12674	8.70	880216	0.94
LWP 13274	–	880519	0.15
LWP 23119	6.59	920518	0.52
LWP 24405	6.89	921204	0.99
LWP 26840	–	931130	0.81
LWP 26841	6.49	931130	0.81
LWP 27854	7.06	940409	0.11
LWP 27855	7.10	940409	0.11
LWP 30391	–	950406	0.94
LWP 31839	–	951226	0.55

2.2. Effective temperature and ultraviolet flux deficiency

Waters et al. (1989) established that the ultraviolet energy distribution of HD 89353 is deficient with respect to a model of effective temperature T_{eff} = 10000K corresponding to a B9.5I supergiant. Waelkens et al.'s (1991) analysis of the line spectrum of HD 89353 revealed the star is actually much cooler (T_{eff} = 7600K, log g =1.0), we first decided to redetermine the effective temperature and surface gravity by fitting the optical spectral energy distribution (SED) of HD 89353 to the predictions of recent improved model atmospheres calculated with ATLAS 9 (Kurucz, 1992) and second to confirm the ultraviolet flux deficiency respect to the model at the right temperature.

In order to construct the energy distribution of HD 89353, we have used the ultraviolet spectrum obtained at maximum UV light, Geneva photometry retrieved from Trams et al. (1991) which we converted into absolute fluxes. The observed SEDs were further corrected for interstellar reddening using Savage and Mathys (1979) extinction law.

The theoretical energy distributions are ATLAS 9 LTE, RE, line blanketed models (Kurucz, 1992). Molecular opacity was not taken into account. Grids of models were calculated for various effective temperatures, surface gravities and most likely metallicities ([M/H] = -1.0 and -5.0 in agreement with Trams et al. (1991)) and the observed and theoretical energy distributions were normalized at 5500 Å to allow for comparison. The effective temperature and surface gravity were determined by adjusting the photospheric continuum in the optical range. Indeed, the Balmer Jump is sensitive to the effective temperature and surface gravity whereas the Paschen continuum is sensitive to temperature.

We find that the SED of HD 89353, corrected for E(B-V) = 0.10 cannot be reproduced by models of temperature near 10000K and low gravity. Instead, a model with T_{eff} = 7500K, $logg$ = 2.0 and [M/H]= -5.0 best reproduces the optical SED (Fig. 1). The found effective temperature and surface gravity and metallicity agree quite well with the determinations by Waelkens et al. (1991) who derived $T_{eff} = 7600K$, log g = 1.00 and [Fe/H] = -4.8 from the analysis of optical lines. Fig. 1 clearly shows that the SED is deficient with respect to the model in the ultraviolet range, a feature which we further confirmed by comparing the ultraviolet SED of

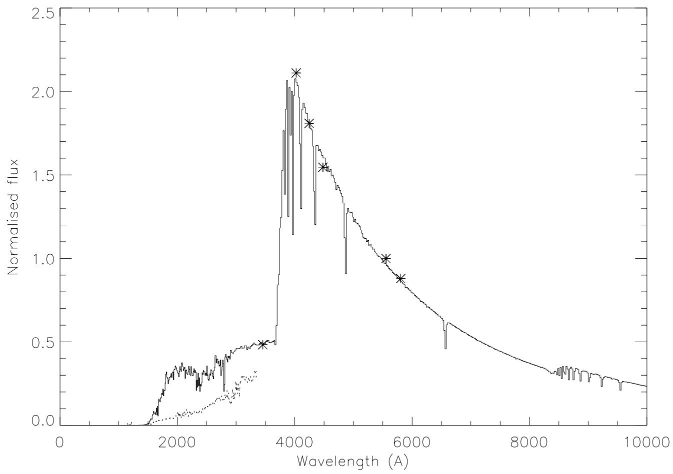

Fig. 1. Comparison of the SED of HD 89353 displayed as dots in the UV and stars in the optical with its best fit model. Observed and theoretical fluxes normalised at 5556 Å

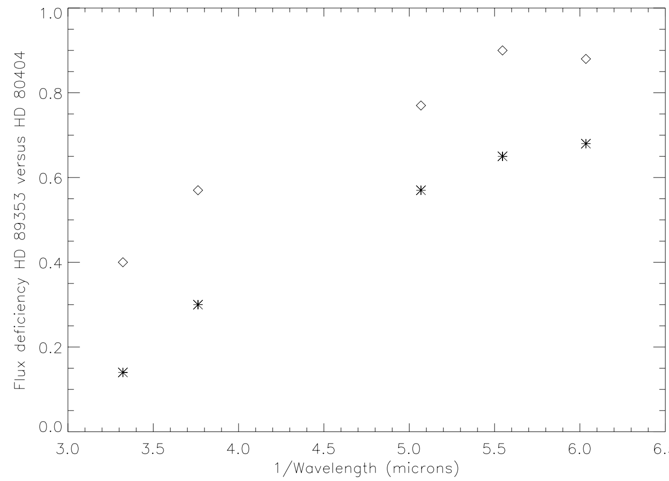

Fig. 2. Ultraviolet deficiency of HD 89353 respect to the standard star HD 80404 at phases ϕ = 0.52 (UV max, stars) and ϕ = 0.95 (UV min, diamonds). Fluxes are normalised at 5556 Å.

HD 89353 with that of the standard A7II star, HD 80404. Fig. 2 displays the large flux deficiency in the ultraviolet, measured as $\log(\frac{f_\lambda(HD\,80404)}{f_V(HD\,80404)}) - \log(\frac{f_\lambda(HD\,89353)}{f_V(HD\,89353)})$, at two different orbital phases of the system (ultraviolet maximum $\phi = 0.52$ and minimum $\phi = 0.95$ respectively). We find that the deficiency has the same shape at maximum and minimum UV and roughly scales as λ^{-1}. The fairly large difference in deficiencies between maximum and minimum partly stems from the fact that we could not normalise each SED to the corresponding V flux. We do know that the SED at phase 0.95 (minimum) corresponds to $V = 5.8$ as this spectrum was simultaneous to one of Waelkens measurements but we do not know the V magnitude corresponding to the spectrum taken at phase 0.52 (maximum). Normalising each SED to the proper V magnitude would reduce the difference between the deficiencies.

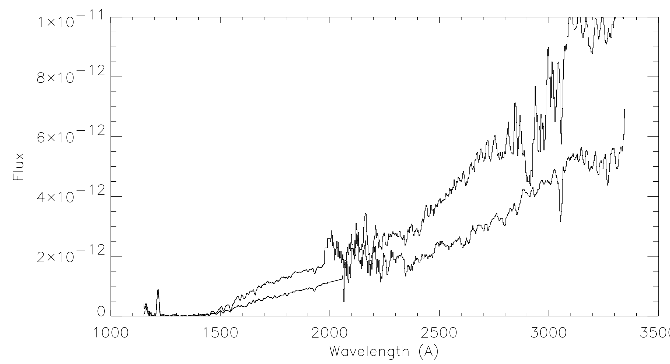

Fig. 3. Ultraviolet spectral energy distribution of HD 89353 at phases ϕ = 0.52 (UV max) and ϕ = 0.95 (UV min)

2.3. Ultraviolet variations and their relationship to the variations in the V band

The SED at maximum and minimum UV flux are displayed in Fig. 3. Large variations are clearly observed whose amplitude increases towards longer wavelengths. In order to obtain the ultraviolet light curves of HD 89353 at various wavelengths, we rebinned the spectra into 50 Å wide bands and calculated the integrated flux in these spectral bands. In Fig. 4, we show the variation of the integrated flux in 1 band free from absorption lines centered at 1600 Å. Although the IUE data do not fully sample the period (many phases between 0.6 and 1.0 are missing), precluding to establish the shape of the lightcurve, we do observe however that the far ultraviolet lightcurve displays a broad maximum around phases 0.40–0.5, ie at the phase of V maximum (see Fig. 3 in Waelkens et al. (1991)). Moreover, the coincidence of phases of UV minimum with the deep optical minimum observed by Waelkens et al. (1991) further suggests that UV and optical variations may occur in phase.

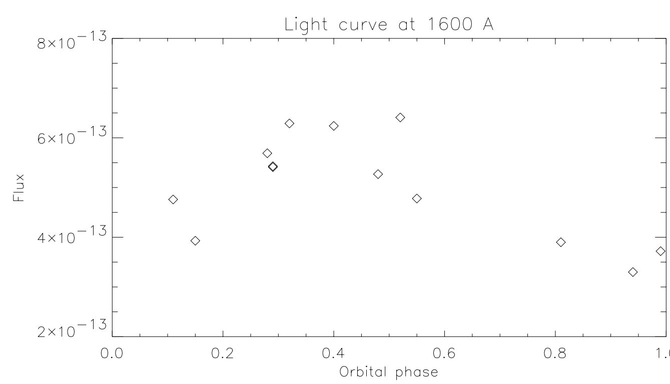

Fig. 4. Lightcurve of HD 89353 at 1600 Å

3. Interpretation

Our investigation of the archival spectra of HD 89353 clearly shows large variations in the ultraviolet whose amplitude increases with wavelength. As the ultraviolet variations seem to occur in phase with the variations in the V band, we suggest that a common physical process drives the flux variations of the star in the ultraviolet and optical range. Waelkens et al. (1991)

proposed that circumstellar dust around HD 89353 must be confined in a circumstellar ring inclined with respect to the observer and that periodic obscuration of the starlight by the ring causes the photometric variations of HD 89353 in the optical range. More specifically, Waelkens et al. (1995) propose that at inferior conjunction the obscuration must be maximal while it is minimal when the star passes above or below the ring when it is at maximum distance from the observer. This periodic obscuration will also alter the flux level in the ultraviolet range as the star will periodically be seen through the dust (ultraviolet flux minimum) and outside the dust (ultaviolet flux maximum). Thus the photometric variations in the ultraviolet and in the optical range can be accounted for by a geometry effect.

Our investigation of the ultraviolet spectra of HD 89353 also allows us to address the putative presence of a white dwarf in this system. Indeed, Waelkens et al. (1991) suggested that the invisible companion of the system might be a white dwarf or more likely a low-mass star still evolving on the main sequence. We fail to detect the spectrum of a hot companion in any of the longest SWP exposures shortwards of 1500 Å where HD 89353 does not emit any photospheric flux. The exposure times were long enough to allow detection of a V=11 to 12 mag white dwarf of effective temperature higher than 20000K. Whereas we cannot rule out the presence of a fainter and somewhat cool atypical white dwarf, we rather propose as Waelkens et al. (1991) did that the companion might be a cool dwarf with no emission in the ultraviolet.

The wavelength dependence of the variable ultraviolet deficiency of HD 89353 as λ^{-1} suggests that small dust grains optically thick in the ultraviolet are present around the system. Their size should be smaller than the UV wavelength. Muci et al. (1994) have compared the circumstellar extinction derived by Buss et al. (1989) for HD 89353 to the laboratory spectrum of freshly formed amorphous carbon grains condensed in hydrogen rich atmospheres. The good fit they find confirms that the particles responsible for the extinction are small compared to the UV wavelength and must be hydrogen rich.

As a conclusion, we suggest that the observed ultraviolet variations can be accounted for in the frame of Waelkens et al. (1993, 1995) variable obscuration model: ultraviolet minimum occurs when the starlight is obscured by circumstellar dust in the ring, conversely ultraviolet maximum occurs when the star is seen unobscured.

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