Time resolved spectroscopy of the post-AGB star HD 56126

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ABSTRACT
We have investigated the report of Tamura and Takeuti that the Hα line of the F-type post-AGB star HD 56126 is variable on time scales of minutes. To this end, HD 56126 was observed on two occasions with the William Herschel Telescope. Seventeen, respectively thirty spectra were taken within time span of 1.5 hours in order to detect any short term variations. We find that the Hα line profile changed strongly over the two month interval, but no evidence is found for short term variability. The variability Tamura and Takeuti claim to find is probably due to the low signal-to-noise in their spectra.

Keywords: stars: AGB and Post-AGB – stars: circumstellar matter – stars: evolution of – stars: mass-loss – stars: individual: HD 56126

1 INTRODUCTION
HD 56126 (F5I, 7h13m25.3s +10°05′09″) belongs to the class of the so-called high latitude supergiants that are thought to be in the post-Asymptotic Giant Branch (post-AGB) phase of their evolution. These stars are supergiant spectral types, but are located at unexpectedly high Galactic latitudes. After it was found that most of these stars show far-infrared excess emission due to thermally re-radiating dust (Parthasarathy and Pottasch 1986; Trams et al. 1991; Oudmaijer et al. 1992; Kwok 1993) the post-AGB phase. The evolved status makes the objects less luminous and older compared to massive supergiants, placing them closer to the plane and allowing them more time to get there, solving the high latitude problem.

During the AGB phase, carbon rich material from the helium burning shell was dredged up to the photosphere of HD 56126. This is suggested by the detection of the 3.3 μm, infrared “PAH” feature by Kwok et al. (1990), and the detection of C2 and CN absorption lines in the optical spectrum by Bakker et al. (1995). A study by Parthasarathy et al. (1992) showed that HD 56126 is metal deficient by a factor of ten with respect to solar metalicities, although C, N, O and S appeared solar. This photospheric abundance pattern resembles that of interstellar gas, where the metals have been condensed onto grains (Lambert et al. 1988; Bond 1991; Van Winckel et al. 1992).

One of the main problems in the study of late stages of stellar evolution of low to intermediate-mass stars is whether there is mass-loss during the post-AGB phase, and if there is, the magnitude of the mass-loss rate. After the core mass, the post-AGB mass-loss rate is the most important parameter governing the time scale of the evolution of these objects from the AGB to the Planetary Nebula (PN) phase. For example the transition of a star with a core mass 0.546 M⊙, having a Reimers mass-loss of 10⁻⁸ M⊙ yr⁻¹ takes 100,000 years (Schönberner 1981 and 1983). A period in which the AGB wind has dispersed into the interstellar medium long before the central star has reached a temperature high enough to ionize its circumstellar shell and become observable as a PN. However, as pointed out by Trams et al. (1989), increasing the mass-loss rate to 5 × 10⁻⁷ M⊙ yr⁻¹ accelerates this transition to only 5000 years, which would make a PN readily observable. It is difficult however to determine post-AGB mass-loss rates. All “classic” tracers of mass-loss rates such as circumstellar CO millimeter emission, far infrared excesses etc. trace the former AGB wind rather than the present-day mass-loss in post-AGB stars.

Most of the post-AGB stars exhibit mild Hα emission. Some objects show strong P-Cygni type emission, while most of the stars have shell type profiles. In the recent literature the Hα emission has been interpreted as the star undergoing a post-AGB mass-loss (Trams et al. 1989; Parthasarathy et al. 1992; Slijkhuis 1992). In fact, the Hα emission is, next to the near-infrared excess observed in some of the objects (Trams et al. 1989), the only diagnostic suggested for post-AGB mass-loss. Although a P-Cygni type emission can be understood with a simple expanding wind model, the double peaked shell type profiles require somewhat more com-
plicated geometries as for example rotating disks (Waters et al. 1993). The mass-loss interpretation gets more into difficulties when considering the fact that many of the stars show variable Hα profiles. Some of the stars have shell type Hα lines where the ratio between the blue and the red peaks varies on time scales of months (Arellano Ferro 1985; Waelkens et al. 1991, Waters et al. 1993). Only in the case of HR 4049 the Hα variability could be correlated with radial velocity variations and the orbital phase of the star in a binary system (Waelkens et al. 1991). Although the number of binary stars in the sample of post-AGB stars under consideration is relatively high (Waelkens and Waters 1993), not all stars that exhibit Hα variations are yet identified as members of a binary system.

Another interpretation that can give rise to variable Hα emission of post-AGB stars stems from stellar pulsation theory. The F-G type post-AGB stars are located in a part of the HR diagram where the photosphere is subject to instabilities (Sasselov 1993; Zalewski 1992). A consequence of such instabilities has been pointed out by Lèbre and Gillet (1991a+b, 1992) in their work on RV-Tauri and W-Virgins stars, objects that resemble post-AGB stars very closely. These stars show variable Hα emission during their pulsation cycle. Lèbre and Gillet showed that inward and outward moving shocks within the photosphere can produce line profiles remarkably similar to those observed in the post-AGB stars discussed above.

In this work we aim at confirming the rapid changes of the Hα profile of HD 56126 described by Tamura and Takeuti (1993, hereafter TT93). These authors reported Hα line profile variations on time scales of the order of minutes. If the variability on minute time scales is real, it will prove very hard to attribute the observed Hα emission to mass-loss. In principle it may be possible to have short “puffs” of mass ejected from the photosphere and falling back again, giving rise to blue and red emission peaks respectively. Such “puffs” are then indicative of a turbulent photosphere, so the mass-loss and stellar pulsation should be closely intertwined. It would then be more reasonable to explain the rapid Hα variability in terms of pulsation solely than a combination of mass-loss and pulsation together. Realizing the important implications caused by the short term variability reported by TT93, we decided to obtain a set of high quality spectra with short exposure times of HD 56126. For this purpose the Utrecht Echelle Spectrograph mounted on the 4.2m WHT telescope on La Palma was employed.

2 OBSERVATIONS AND DATA REDUCTION

2.1 Observations

The first set of observations was carried out on December 21st 1993 in service time with the Utrecht Echelle Spectrograph (Unger 1994) mounted on the Nasmyth platform of the 4.2 m William Herschel Telescope, La Palma, Spain. The weather was fair, but the seeing was larger than 2′′, which, compared with the slit width of 1′′, resulted in a somewhat lower signal-to-noise of the spectra than could have been possible. The detector was a 1124 × 1124 TEK CCD. Wavelength calibration was performed by observing a Thorium-Argon lamp. The central wavelength of the setting was 5587 Å, resulting in a wavelength coverage from 4700-7200 Å. In order to make a compromise between signal-to-noise and time resolution, it was decided to make exposures with increasing integration times.

A second set of data was obtained during a run on the WHT in the night of February 26-27 1994. The settings were the same as for the December run, except for the central wavelength (7127 Å), resulting in a wavelength coverage from 5500 Å, 1 μm. This time the strategy was aimed at searching for time variations within minutes. Thirty exposures of 60 seconds and 30 seconds were taken consecutively. The sky was cloudy, resulting in many telluric features in the spectra. The spectral resolution as measured from telluric absorption lines (full width at half maximum) is 8.5 km s⁻¹. The logs of the observations and the resulting signal-to-noise ratios (measured in the Hα order) are provided in Tables 1 and 2.

| Time | texp [sec] | Airmass | SNR |
|------|------------|---------|-----|
| 23:24:39 | 60 | 1.465 | 50 |
| 23:27:58 | 60 | 1.446 | 52 |
| 23:30:56 | 90 | 1.430 | 62 |
| 23:37:41 | 90 | 1.394 | 63 |
| 23:41:05 | 90 | 1.378 | 63 |
| 23:44:40 | 180 | 1.361 | 87 |
| 23:49:35 | 180 | 1.339 | 89 |
| 23:54:29 | 180 | 1.318 | 83 |
| 23:59:23 | 180 | 1.299 | 82 |
| 00:05:25 | 240 | 1.276 | 98 |
| 00:11:19 | 240 | 1.256 | 90 |
| 00:17:10 | 240 | 1.237 | 99 |
| 00:23:09 | 240 | 1.219 | 95 |
| 00:29:12 | 240 | 1.202 | 103 |
| 00:35:08 | 240 | 1.186 | 100 |
| 00:41:11 | 240 | 1.171 | 90 |
| 00:47:11 | 240 | 1.158 | 94 |

The SNR has been calculated in the line free region between 6533-6540 Å.
correct within 15%. The SNR spectra calculated in this way will be used further in this study.

3 IS THERE VARIABILITY?

3.1 Time scales of minutes

In Fig. 1 all individual spectra around Hα obtained December 1993 are plotted. In order to decide whether there are any variations in the spectra we adopt the simple, yet powerful statistical formalism presented by Fullerton (1990) and Henrichs et al. (1994). With this method the variability can be expressed in a temporal variance spectrum (TVS, Eq. 1):

\[(TVS)_{\lambda} \approx \frac{1}{N-1} \sum_{i=1}^{N} \left( \frac{F_i(\lambda) - F_{av}(\lambda)}{\sigma_i(\lambda)} \right)^2 \] (1)

where \(N\) is the number of spectra, \(F_{av}(\lambda)\) represents the constructed average spectrum, \(F_i(\lambda)\) the individual spectra, and \(\sigma_i(\lambda) = F_i(\lambda)/(SNR)\) of each individual pixel of the spectra.

Following Henrichs et al. (1994) and Fullerton (1990) the temporal sigma spectrum (TSS = √TVS) is calculated. This quantity represents approximately \((\sigma_{obs}/\sigma_{av})\), that is the standard deviation of the variations of the individual spectra with respect to the average spectrum divided by the standard deviation of the average spectrum. If no significant variations are present in the spectra, the value will be close to one, significant deviations are directly represented in units of the noise level, that is to say a peak “Temporal Sigma Spectrum” of three corresponds to a variability at a 3σ level.

The individual spectra and the resulting TSS are plotted around Hα in Fig. 1. It is clear from the temporal sigma spectrum that no significant variability is present. The spikes in the TSS spectrum correspond to cosmic ray hits that resulted in higher count levels and consequently higher signal-to-noise ratios. These cosmic ray events are still a bit present in the spectra, and provide an independent check whether the method is indeed capable of detecting variability. Another way to demonstrate the adequacy of the method can be found in Fig. 2 where we have plotted the first and last taken spectrum around 6875 Å during the December run. The effect of the decreasing airmass on the strength of telluric absorption lines is seen.

Similar calculations were performed for spectra with the same integration times, and for the rest of the UES spectrum. Except for strong telluric absorption lines (see Fig. 3) no variations are present.
3.2 Time scales of months

Average spectra were computed by adding all spectra before the continuum correction, resulting in spectra with a high SNR ($\geq 300$ and $\leq 175$ for the December and February observations respectively). The radial velocity is not significantly variable, the heliocentric velocity we derive from strong metallic lines are $87 \pm 2$ km s$^{-1}$, and $84 \pm 2$ km s$^{-1}$ for the December and February spectra respectively.

In Fig. 1 the H$\alpha$ lines at both occasions are shown. The profiles are different; whereas in the December spectrum the H$\alpha$ profile shows a central absorption at $103$ km s$^{-1}$, it has shifted to $94$ km s$^{-1}$ in February, the peaks around the H$\alpha$ absorption have increased in strength. The true shape of the emission is hard to determine, but considering the red-shifted center of the H$\alpha$ absorption, there appears to be a rather broad emission component blue-shifted by more than $20$ km s$^{-1}$.

Not only the H$\alpha$ lines differ, a preliminary comparison of the individual spectra shows that all spectral lines are broader by more than 40% at their full width half maximum, while the depression relative to the continuum decreased in the February spectra relative to the December spectrum. Interestingly, except for the strongest metallic lines (depression $\leq 50\%$) where a blue-shifted absorption wing is visible, all lines appear symmetric. The interstellar component in the profiles of the NaI D1 & D2 lines do not change in velocity nor in shape between the two spectra, indicating that changes in other lines are not due to observational errors.

For the FeI and FeII lines we note that the equivalent width of the FeI lines decreased, while the equivalent width of the FeII lines has increased. The fact that the ionization degree of Fe has changed indicates an increase of the effective temperature, the broader lines are probably the result of a higher surface gravity. The deeper central absorption in the H$\alpha$ line is also due to an increase of the effective temperature which gives a higher population of the $n = 2$ level for hydrogen according to the Boltzmann law.
In Sect. 3.1 it was shown that no short term variability is found in the Hα line of HD 56126. In Sect. 3.2 it was argued that, due to the broadening of most stellar lines and the change in ionization degree of Fe, the star has become hotter over a time interval of 65 days. This indicates that the star is variable, consistent with the findings of Bogaert (1994), who found photometric variability of HD 56126.

It is still hard to identify the mechanism responsible for the emission observed in Hα. It can be due to mass-loss, where the stronger emission in the February spectrum is simply due to the increased temperature of the star, it could also be due to a shock wave ploughing through the photosphere. It may be worthwhile to monitor post-AGB stars on time scales of days and weeks to appreciate the true temporal changes in their spectra.

Finally we consider whether the absence of any short term variability can be expected based on simple arguments; in principle the fastest time scale in which a wave can propagate in a stellar atmosphere is the scale height \( h \) divided by the speed of sound \( v_s \):

\[
h = \frac{kT R^2}{\mu m_H MG} \text{[m]} \quad (2)
\]

\[
v_s \sim \sqrt{\frac{kT \mu}{m_H}} \text{[km s}^{-1}] \quad (3)
\]

With \( M \) the mass of the star and \( R \) its radius, \( \mu \) is the mean molecular weight which is taken to be 1. Adopting typical parameters for a F-type post-AGB star, \( M = 0.6 M_\odot \), and \( R = 60R_\odot \), we obtain a shortest possible time scale of 1.8 days.

One can also estimate the pulsation period of a typical post-AGB star:

\[
\tau_p = Q \times \left( \frac{R}{R_\odot} \right)^3 \left( \frac{M}{M_\odot} \right) \text{[days]} \quad (4)
\]

Where \( Q \) is the pulsation constant in days. Adopting the same stellar parameters as above, and noting that \( Q \) ranges from 0.04 for classical Cepheids to 0.16 for W-Virginis stars (Allen 1973) we obtain an expected period of 30 – 96 days. This simple exercise tells us that variations on time scales shorter than days are not really to be expected in post-AGB stars. It is consistent with the change observed over a period of two months.

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