OPTICAL SPECTROSCOPIC MONITORING OF THE CARBON–RICH POST–AGB STAR HD 56126 :

Pulsation and Shock Waves

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Abstract. A spectroscopic monitoring of the post–AGB star HD 56126 was performed as regularly as possible over a 14–month interval in order to study atmospheric motions that could be associated with shock wave propagation through the stellar atmosphere. Some spectral features are strongly variable on a timescale of a few days. Radial velocity variations are also good evidence for complex atmospheric dynamics, in agreement with the recently found photometric variability. The data point to a pulsating nature for HD 56126, with a main period of 27.3 days.

1. Introduction

In order to investigate internal structure and atmospheric motions in post–AGB stars, we performed regular spectroscopic observations of HD 56126 = SAO 96709 = IRAS 07134+1005. Parthasarathy et al. (1992) and Klochkova (1995) have analysed its atmospheric chemical composition. Both derive a moderate metal deficiency ([Fe/H] = –1.0) and a large excess of *s*–process and CNO elements. The object displays a strong excess in the IRAS bands and was later found to have peculiar mid–infrared features including the 3.3 μm band often attributed to PAH (Kwok et al. 1990), emissions in the 6–8 μm region (Buss et al. 1990), and very strong emission bands near 21

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and 30 μm (Kwok et al. 1989; Omont et al. 1995). These bands are seen in objects with carbon-rich material. Zuckerman et al. (1986) and Bujarrabal et al. (1992), from molecular observations of the circumstellar envelope of HD 56126 (CO, HCN), also infer such a C–rich nature. All these findings on photospheric abundances, envelope dust and molecules support the case for a genuine post–AGB star.

Until very recently, this F5 I star was not considered to be variable. Bogaert (1994) discovered the first evidence for the photometric variability of HD 56126, presenting a light curve with a very small and irregular amplitude ($\Delta V = 0.06 - 0.15$) and a period of about 50 days, although it is very difficult to estimate the period confidently from these data.

A few optical spectroscopic studies have already been devoted to hydrogen lines in HD 56126. Oudmaijer and Bakker (1994) obtained high-signal-to-noise observations taken at a two-month interval and showed that long-term (but not very fast) variability of the Hα line is present, in agreement with an expected period in the range 30–96 days.

2. The Spectroscopic Monitoring

We present the first high-resolution optical spectroscopic monitoring of HD 56126, performed over a 14 month period (January 1991 to April 1992) with as regular intervals as possible. This work is based on observations carried out at the 1.52-m telescope of the Observatoire de Haute Provence (CNRS), France and a more detailed report is given in Lèbre et al. (1996). The AURELIE spectrometer was used at coudé focus with a 1800 line/mm grating blazed at 5000 Å. Twenty–one spectra at the Hα line and seventeen of the Na D doublet were secured, with central wavelengths of 6582 and 5885 Å and resolving power $R = \lambda/\Delta\lambda$ of 41 000 and 36 000, respectively (i.e. about 8 km s^{-1} in velocity resolution). All our spectra are presented after reduction to the stellar rest frame (SRF), for which we adopted the value of 86.1 km s^{-1} on the heliocentric scale (centroid velocity of molecular CO and HCN emissions: $V_{LSR} = 72.0$ km s^{-1}), obtained by Bujarrabal et al. (1992).

3. The Spectral Line Profile Variations

In Figure 1, we present the results of our Hα monitoring over 14 months. The Hα line is strongly variable (on timescales of the order of days) and presents several types of profiles: P–Cygni profile, reverse P–Cygni profile, shell–type profile, or asymmetric absorption. Within only a few days, the Hα line can change from one type of profile to another. Our time resolution (about 5–15 days) seems a bit too coarse to follow the evolution of these variations with good accuracy, especially the appearance/development/dis-

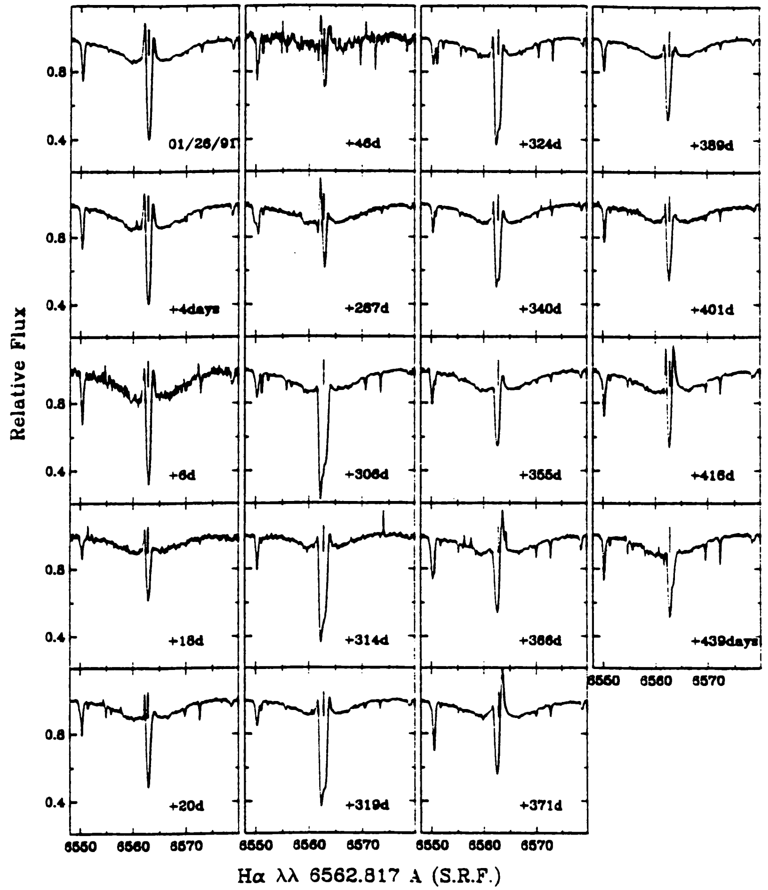

Figure 1. Spectroscopic observations of the Hα line region. The laboratory wavelength is indicated by the short straight line. The date of the observation is indicated through the progression in days from the first spectrum.

appearance of emission in the blue and/or red wings of the hydrogen line. It is consequently difficult to derive a reliable period for that Hα variability.

One of the most striking observational features is the permanent presence of the Hα emission component. Because the emission width is narrow, it is probably not a shell type emission, which would be formed in a very extended volume far away from the photosphere. Instead, it is better explained by a strong shock wave propagating in the atmosphere. In this case, the emission would be formed within the de-excitation region of the shock wake, i.e. in a very narrow shell above the photosphere. Because at some phases the blueshifted emission component, or the redshifted one, or both, are clearly above the continuum, we expect that we have a single broad shock emission mutilated by an almost central absorption. Depending on

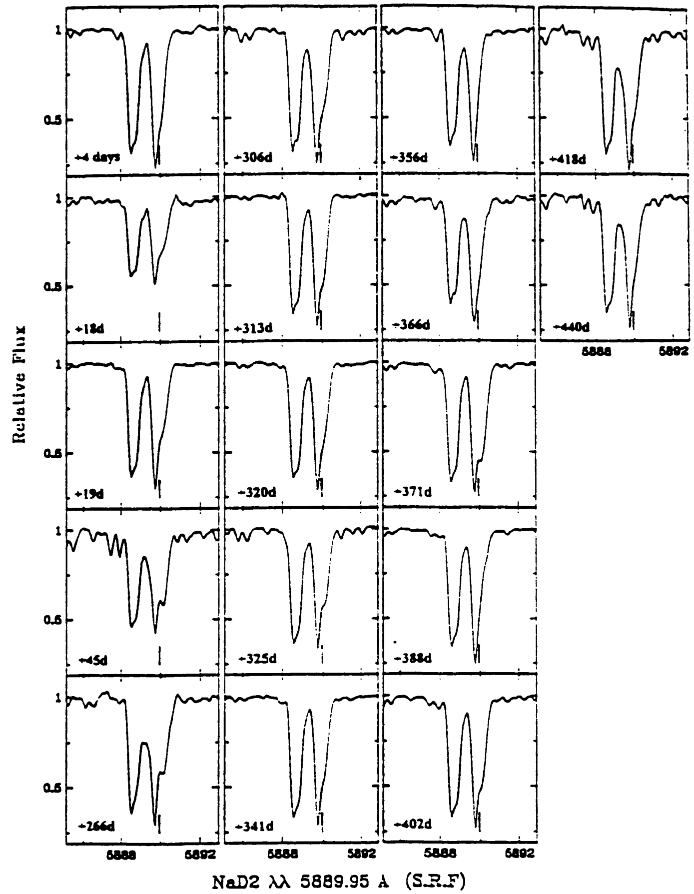

Figure 2. Spectroscopic observations of the Na D2 line. The short straight line indicates the line wavelength (5889.95 Å) in the stellar rest frame.

the wavelength position of absorptions with respect to the shock emission, the observed double-peak emission can appear with a stronger blueshifted component or *vice versa.* This kind of double-peaked profile is well observed in RV Tauri and W Virginis stars as reported by Lèbre & Gillet (1991 and 1992, respectively). Fokin (1991) has calculated similar double-peak emissions for the pulsating star W Vir. He shows that absorption components are caused by a self-absorption mostly due to scattering in the pre-shock layers and confirms that the emission is formed behind the shock front. Since HD 56126 is a post–AGB star, we can also expect that it is an irregular pulsating star, probably showing large variations from one cycle to another.

In Figure 2 we show the profile variations of the Na D2 line at 5889.95 Å (the same profile structure and variation being observed at D1). The most blueshifted component (around 5888.65 Å) is centered at $V_{LSR} = 6$ km s^{-1} ± 2 km s^{-1} with a full width of about 50 km s^{-1}. It is probably of interstellar origin because no significant profile variation is seen and an interstellar CO radio emission at V_{LSR} = 10 km s^{-1} has been detected along the line of sight (Zuckerman et al. 1986).

The other component located near the rest velocity has at least a partially stellar origin. Obviously, this blended line shows a profile that varies in time, but on the other hand its bluest absorption peak (around 5889.77 Å) remains very stable in shape and radial velocity (V_{SRF} = −10 km s^{-1}, or a V_{LSR} of 62 km s^{-1}) and is thought to be of circumstellar origin.

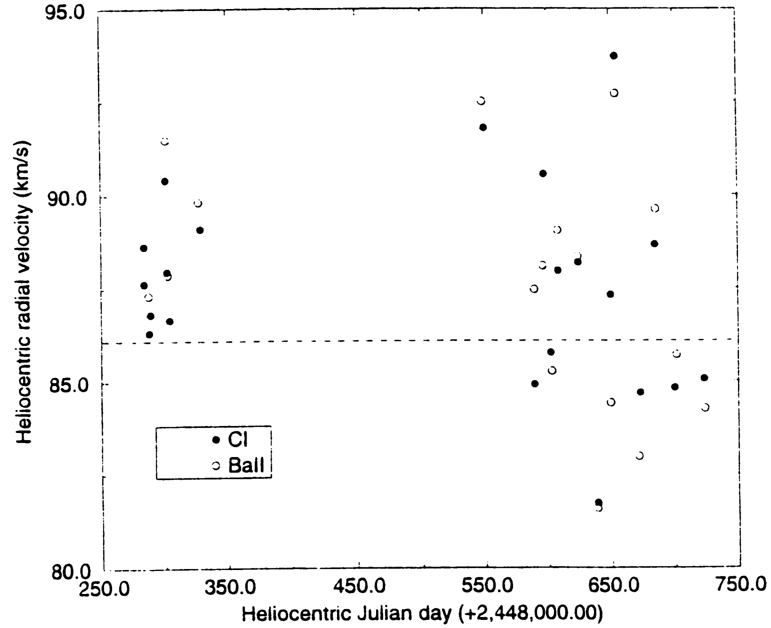

Figure 3. Heliocentric radial velocity curves for the C I and Ba II lines. The centroid radial velocity of molecular circumstellar profiles, V_{LSR} = 72 km s^{-1} (V_{helio} = 86 km s^{-1}), is indicated by the horizontal dashed line.

Two other strong lines, Ba II λ 5853.688 Å and C I λ 6587.622 Å, are useful. They are not blended with any other spectral feature and seem always very symmetric. We first noted a strong agreement in the Doppler shifts of the Ba II, C I, and stellar sodium lines, all being strongly blueshifted or redshifted at the same dates. More quantitatively, we achieved Gaussian fits on both the Ba II and C I lines, and we measured a total of 38 independant radial velocities which are plotted versus time in Figure 3. The Ba II and C I measurements made on the same night generally agree within 1.5 km s^{-1}, suggesting synchronous dynamics for the atmospheric layers where

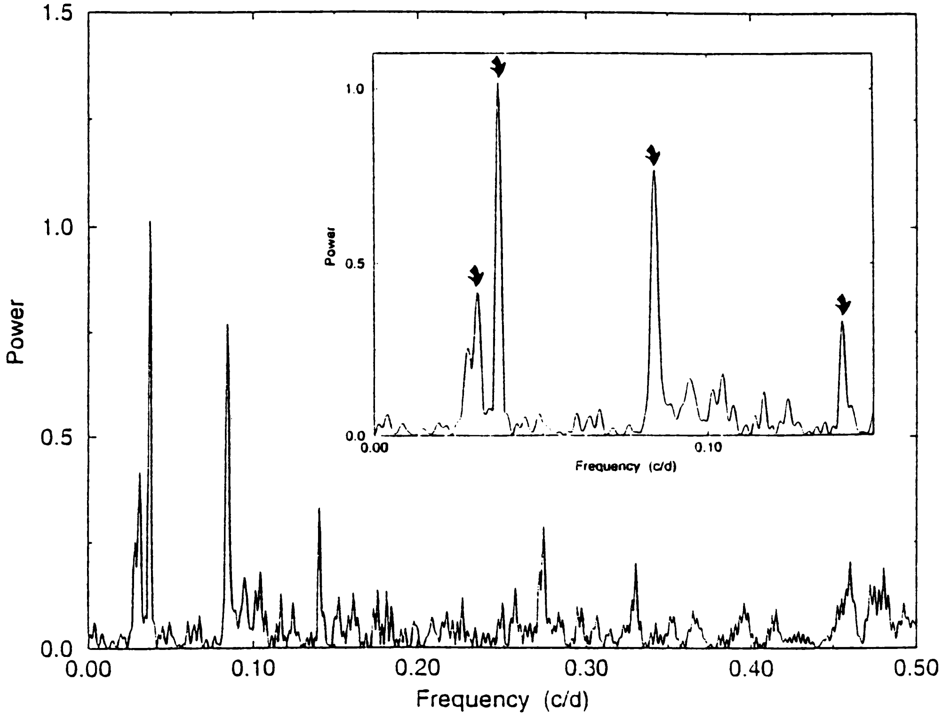

Figure 4. CLEAN power spectrum from the heliocentric radial velocity measurements on the C I and Ba II lines. The relevant frequencies (see text) are indicated with arrows.

these lines are formed. The peak-to-peak amplitude of the radial velocity variations is ~ 15 $\mathrm{km\,s^{-1}}$.

4. Period Searching

From the radial velocity measurements on the Ba II and C I lines we have searched for characteristic periods through Fourier analysis. The CLEAN power spectrum (Roberts et al. 1987) is displayed in Figure 4. With a high degree of confidence, four peaks are detected, corresponding to a primary period of 27.3 days and three secondary periods of 32.9, 11.9, and 7.1 days. The frequency accuracy is about 4×10^{-4} c/d for each peak, that is ± 0.3 days on the 27.3 days period. The dominant period ($P = 27.3$ days) is half as large as the one we can roughly derive from the photometric data (~ 50 days). This indeed is reminiscent of the atmospheric dynamics of the RV Tauri star R Sct, with two shock waves propagating through the stellar atmosphere over a light cycle of 142 days.

5. Conclusions

In order to look for variations in the Hα and Na D line profiles that could be related to the propagation of a shock wave through the stellar atmosphere, we performed a spectroscopic monitoring on the well-known carbon–rich infrared post–AGB candidate HD 56126. On a timescale of days we observed important changes in the Hα profile as well as synchroneous radial-velocity variations in the Na D, Ba II and C I photospheric lines. Searching for periods with the CLEAN procedure yields a main period of 27.3 ± 0.3 days and three other probable ones around 32.9, 11.9, and 7.1 days. From the recently-found photometric variability of this star (V amplitude of 0.15 mag), and from our results, we infer that HD 56126 has atmospheric dynamics which remind us of those observed for RV Tauri stars. Linear and non-linear modelling of HD 56126 (Jeannin et al. 1996) also reconciles strong shock-wave propagation in the stellar atmosphere with the small light amplitude, suggesting that HD 56126 is a first-overtone pulsator with a period of 30 days.

Clearly, more photometric and spectroscopic observations are needed to investigate the evolutionary phase of HD 56126 and related objects. For that purpose, we have undertaken with the 1.93-m telescope of OHP a second spectroscopic monitoring covering a wider spectral region (from 3800 to 6800 Å) with better resolution ($R = 42\,000$) and better timescale sampling (one observation per week from October 1995 to April 1996). We hope to report new results soon, with improvement on the period determination.

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Discussion

Luttermoser: Is the Hα line *optically* thin or *effectively* thin? This will be very important when trying to deduce velocity fields from this line. The technique of deducing macroscopic gas velocities by noting velocity "widths" and velocity "shifts" from fitted Gaussian profiles over a "two-peaked" emission line, as has been done for past Mira observations, is only valid if the line is *optically* thin. *Effectively* thin lines typically display "two-peaked" emission features in their cores (e.g. Ca II in late-type stars), even if the atmosphere is static and plane parallel (e.g. the solar Ca II lines).

Lèbre: Following the work of Dr. Fokin, we expect that the hydrogen lines are produced in atmospheric regions of high opacity. Consequently the observed Hα profile is very probably composed of a single broad emission with an almost central absorption caused by re-absorption of the cool hydrogen located in the high atmospheric layers. The resulting profile is a two-peaked visible emission. The optically thin emitting possibility is certainly not acceptable, but only a quantitative modeling of hydrogen profiles can provide the definitive answer. This needs a full nonlinear non-adiabatic pulsating model of post-AGB stars.

Cherchneff: With shock strengths of $47\,\mathrm{km\,s^{-1}}$, you should expect the formation of a precursor in the pre-shock gas. Do you have evidence for such a phenomenon?

Lèbre: Indeed a strong shock is a radiative shock, with a precursor in the pre-shock gas. But we do not have any observational features or typical variations that could be associated with it as direct evidence.

Van Winckel: How do you generate a shock when the photometry does not give evidence for pulsation?

Lèbre: Photometric observations of HD 56126 have a very small amplitude. This can be reconciled with the presence of strong shocks in the atmosphere when taking into account a radiative shock and at the limit an isothermal shock. Consequently we must expect that the stellar luminosity L_* always dominates over the shock luminosity (by a factor of 10), independently of the weak amplitude variation of L_*. Nevertheless, some luminosity contribution from the shock can be envisaged in the blue spectral range at some phases because the "effective" temperature of the recombination region of the shock wake is around 15,000 K.