SPECTROSCOPIC STUDY OF PLEIONE IN 1977-1979

Ryuko Hirata, Jun'ichi Katahira*, and Jun Jugaku†
DEPEG, Observatoire de Paris, Meudon,
on leave from Department of Astronomy, University of Kyoto.
*Science Education Institute of Sakai City, Osaka, Japan.
†Tokyo Astronomical Observatory, Tokyo, Japan,
guest observer with the International Ultraviolet Explorer Satellite.

Abstract Shell spectra of Pleione in 1977-1979 are characterized by further increase in their strengths and by the development of the blue-winged profiles without noticeable variation of their radial velocities. The MgII resonance lines at λ2800A have the blue-shifted components with a velocity of -35 km/s relative to the other shell lines. The development of the shell structure is derived. The mass loss rate was $7X10^{-11}$ $M_{\odot}$/yr.

1. INTRODUCTION

We here report the spectroscopic behavior of Pleione(B8e, Vsini=340km/s) in 1977-1979. Our studies on this star in 1972-1976 are found in Hirata and Kogure (1977,1978), and Higurashi and Hirata (1978, hereinafter HH). The reciprocal linear dispersion of our spectrograms is 10A/mm. We also obtained the IUE spectra in high dispersion mode in October 1978, and January 1979.

2. GENERAL DESCRIPTION

The strengths of shell lines have increased further in 1977-1979. Their profiles have still kept their characteristics in 1973-1976, that is, the higher the ionization potential is, the narrower the line becomes. The most striking characteristics in 1977-1979 is the development of the blue-winged profiles without noticeable variation of their radial velocities. Mean radial velocities of the Balmer shell lines(H6-H20) were +10.7±0.2, +10.6±0.5, and +8.0±0.5 km/s in October 1977, August and November 1978, respectively. The CaII K line has still a very broad component.

The rich shell lines are also seen in the far-ultraviolet region. Preliminary identification shows these rich shell lines are composed of the relatively low-ionized metals, just as expected from the visual region. The blue-winged profiles are also seen in the far-ultraviolet region. There is no clear evidence of the existence of CIV and SiIV ions.

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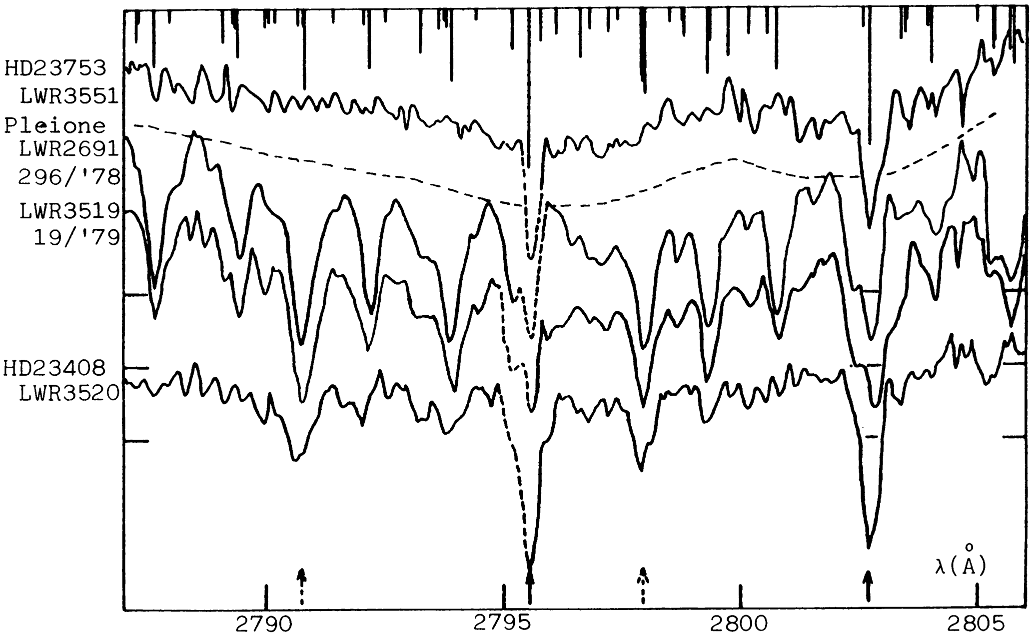

Fig.1. λλ2787-2806 Å region of HD23753, Pleione, and HD23408.

The MgII resonance lines at λ2800 A have the blue-shifted components. Figure 1 shows two spectra in this spectral region, together with those of HD23753(B8V,Vsini=280 km/s), and HD23408(20 Tau,B7III,Vsini=40 km/s), all belong to the Pleiades cluster. The spectrum of HD23753 is composed of the broad photospheric features around the MgII resonance lines at λλ 2795.5, 2802.7A, and sharp interstellar components of these lines, while HD23408 shows the subordinate lines of the MgII λλ2790.8, 2797.9 A(broken arrows in the figure), and other photospheric lines of FeII and CrII, in addition to the MgII resonance lines(solid arrows). Rich shell lines are seen in the spectra of Pleione. The broken line for LWR2691 is the background photospheric feature implied from the spectrum of HD23753. In the uppermost part of the figure, we show the expected line depths of the shell lines in an arbitrary scale, which are approximated by the root of the caluculated equivalent widths. The equivalent widths of the shell lines were computed by the curve-of-growth technique for the parameters derived from the FeII lines in the visual region. Cosmic abundance was assumed, and the dilution factor was introduced in the ionization equilibrium. We used gf-values of Kurucz and Peytremann (1975). It is seen that our result of calculation coincides well with the observed spectra. The MgII resonance lines at λ2802.7A and λ2795.5A have blue-shifted components, whose radial velocities relative to the nearby FeII, CrII shell lines are -34±1, and -36±1 km/s, respectively. These values were obtained from four spectra in October 1978, and two spectra in January 1979. The value for λ2795.5A should be less weighted, because the line is contaminated by the reseau, and also the non-shifted MnII λ2795.2 line is expected to contribute appreaciably from our calculation. From the fact that no blue-shifted component is seen in the MgII subordinate lines, we conclude that the blue-shifted components are originated in the less dense part of the envelope.

3. ANALYSIS

We measured the equivalent widths, half half-widths, and central depths of the metallic shell lines in the spectral region, λλ3800-5020A, for six plates obtained in November 1978. The method of analysis is the same as in HH. We determined the reciprocal excitation temperature θ_{exc}, the column density <Nl>, and the microscopic velocity ξ from the curve-of growth. From the half half-widths, we can guess the outer radius of the absorbing region, r, in units of stellar radius(we assumed the conservation of angular momentum in the envelope). From the central depths, we get the fractional area of the stellar disk, β, which is screened by the velocity zone for the line center, and the effective optical thickness of the velocity zone, τ. Figure 2 shows the variation of these parameters in 1973-1978. Typical errors(2σ) are shown in the right bottom

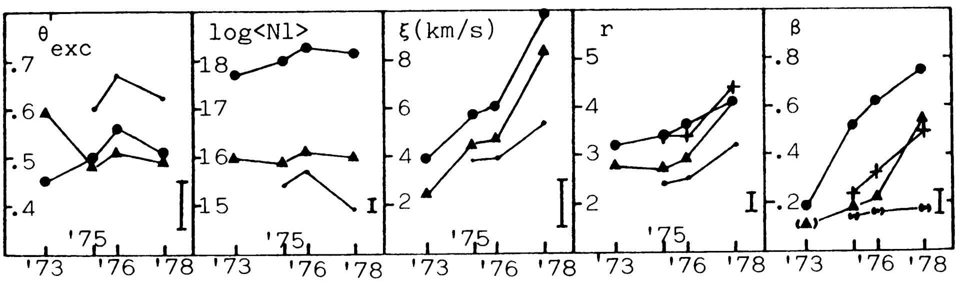

Fig.2 Variation of θ_{exc}, <Nl>, ξ, r, and β in 1973-1978. The symbols are FeI(·), FeII(●), TiII(▲), and CrII(+).

corners. The excitation temperatures and column densities of various ions did not change so greatly, while the radii r and the fractional areas β have increased further, as a smooth extension in 1973-1976. The structure of the shell in 1978 is the same as in 1973-1976, i.e., a cold dense core is surrounded by a hotter, tenuous envelope. The microscopic velocity ξ increased remarkably. For example, ξ of the FeII lines increased from 6 km/s in 1976 to 10 km/s in 1978. Recalling the development of the blue-winged profiles in 1977-1979, we can conceive that the outflow became conspicuous, and this made the apparent values of ξ greater (HH, Mihalas 1979). The increase in ξ affects the widths of shell lines, though we made no correction for the estimate of r in figure 2. For example, the outer radius of the FeII formation region in 1978 increases from $4.1R_*$ to $4.6R_*$ when both ξ- and instrumental broadenings are corrected. This is an extreme case, and such an effect is not so great in the other ions.

Balmer shell lines were analyzed for all plates obtained in October

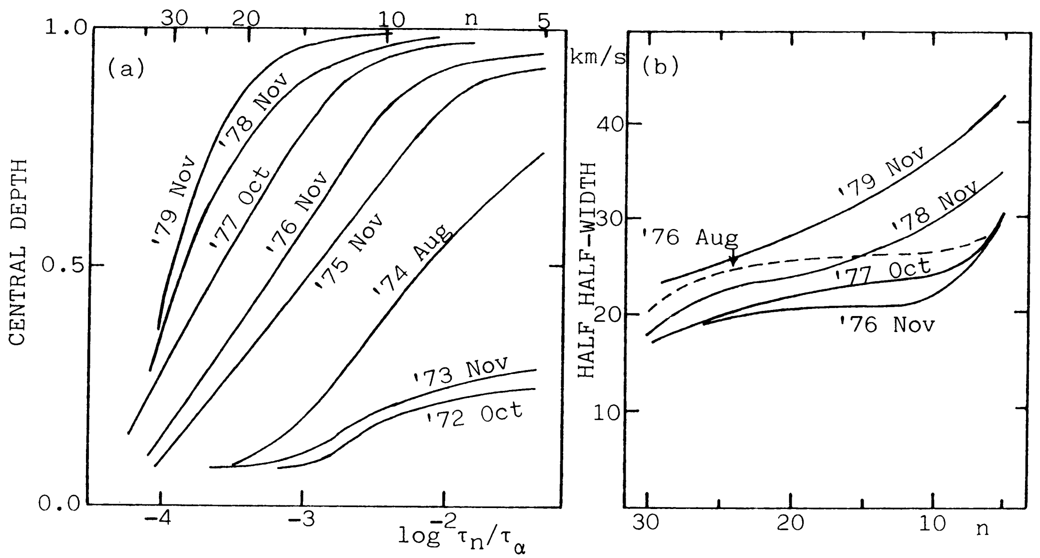

Fig.3 Variation of Balmer shell lines, a) central depths, b) half half-widths.

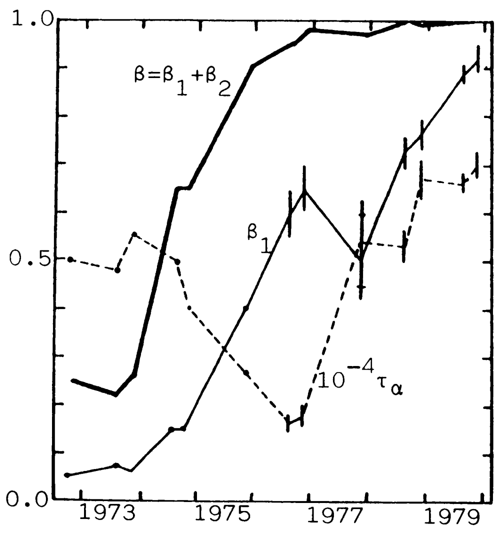

Fig.4 Variation of β and τ_α for the Balmer shell lines.

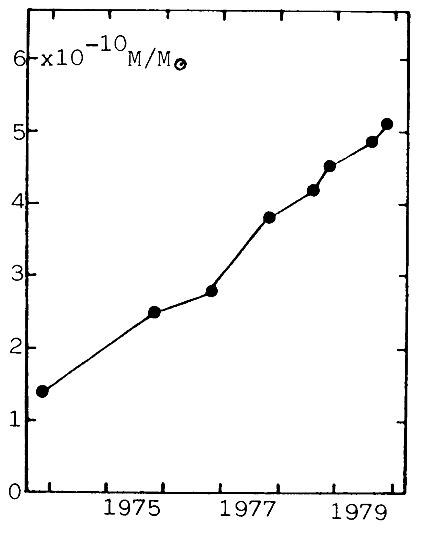

Fig.5 Variation of the envelope mass.

1977, August, November 1978, and August, November 1979. Figure 3a shows the variation of their central depths in 1972-1979, and figure 3b shows the variation of their half half-widths in 1976-1979. The central depths have increased steadily, and reached to unity even in the intermediate members in 1979, while the half half-widths decreased untill Novemver

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1976, then turned to increase since then. The flat part in the H10-H20 lines disappeared at the same time. This behavior of the half half-widths is in contrast with that of the metallic lines. The equivalent widths of Balmer shell lines increased steadily in 1972-1979. These observational facts indicate that the saturation effect influences even in the intermediate members of the Balmer shell lines in 1977-1979. Nevertheless, we applied our central depth method to the data in 1977-1979. Two-layer approximation was also adopted. The results are shown in figure 4, together with those in 1972-1976. The fractional area and the optical thickness in Hα for the first layer are designated by β_1, and τ_α, respectively. It is seen that the fractional area increased steadily, while the optical thickness decreased in 1972-1976, and turned to increase since then. This indicates the growth of dense core, accompaning the outflow, after the the phase of diffusing-out in 1972-1976. We must note, however, that the saturation effect in 1977-1979 casts some doubts on the simple application of our central depth method. The mass of the envelope was estimated from the column density and the outer radius, under the same assumptions as in HH. We assume the outer radius is $4R_*$ in 1977-1979, as indicated from FeII, because the half half-widths of Balmer lines give no more the radius of the hydrogen envelope, due to the saturation effect. Fortunately, the value of the outer radius does not affect the resultant mass so seriously. For example, the mass of the envelope increases by 15% for $5R_*$. Figure 5 shows the variation of envelope mass. The mass loss rate is estimated as $7X10^{-11}$ $M_\odot$/yr in 1977-1979, slightly larger than $5X10^{-11}$ $M_\odot$/yr in 1973-1976.

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