

OPTICAL SPECTROSCOPIC MONITORING OF 3 BE STARS FOR WHICH NO EVIDENCE OF A SECONDARY HAS BEEN FOUND: ψ PER, 25 ORI, AND 31 PEG

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Abstract: ψ Per, 25 Ori, and 31 Peg are Be stars for which no evidence of a secondary has been found. We conducted low-dispersion spectroscopic monitoring observations (resolving power (R)=500 $\sim$ 1000) of these 3 objects to investigate variations in $EW(H\alpha)$ and $EW(H\beta)$ (EWs), and the Balmer decrement ($=F(H\alpha)/F(H\beta)$, D_{34}). We also investigated variations in $FWHM$ and emission line peak intensity using medium-resolution spectroscopic data (BeSS, R is 10000 or 11000) from the same observation period. Significant variations in EWs and D_{34} were observed for 25 Ori during our 2006-2025 observation and for 31 Peg during our 2015-2025 observation. Analysis results of BeSS data for these objects show that the emission line profiles of the $H\alpha$ and $H\beta$ showed significant variations. On the other hand, the variations of the line profiles of He I (5876Å) and Mg I (5167Å) were minor.

1 Introduction

Classical Be stars are defined as B-type main sequence stars that have shown hydrogen emission lines at least once in the past. Be stars form circumstellar disks (known as “decretion disks”) around them. Since the early 1900s, photometric and spectroscopic monitoring observations have been conducted on many Be stars, and as a result, it has become clear that the disk is expanding and disappearing on various timescales. It has also become clear that Be stars give rise to viscous disks, and the pulsation and rapid rotation of Be stars are the cause of the ejection of disks from the central star (Carciofi 2011, Rivinius et al. 2013). On the other hand, Be stars include both binary systems and Be stars for which no evidence of a secondary has been found (many Be stars form binary systems), and it is not yet clear to what extent companion stars contribute to the expansion and disappearance of Be star disks.

Ishida et al. (2025) conducted low-dispersion spectroscopic observations (resolving power (R)=500 $\sim$ 1000) of Be stars known to be Be/white dwarf binary candidates (γ Cas and π Aqr) between 2005 and 2024, monitoring the Balmer decrement ($=F(H\alpha)/F(H\beta)$, D_{34}), for which observational reports are extremely few. Variations in D_{34} are thought to be related to variations in the effective temperature of the central star (Kogure, 2000). In their observations, Ishida et al. (2025) detected long-period variations in D_{34} for π Aqr. Furthermore, an analysis of medium-dispersion spectroscopic data (Be Star Spectra

database, BeSS¹) for π Aqr during the same observation period confirmed a phenomenon in which the *FWHM* of the $H\alpha$ line decreases in conjunction with an increase in D_{34} . However, it was unclear whether the cause of the variation in the disk of π Aqr lies in the central star or the companion star.

In this study, we will conduct monitoring observations specifically targeting Be stars for which no evidence of a secondary has been found. To the present day, it has become clear that many Be stars form binary systems. Miroshnichenko (2016) found that there are 13 binaries among the Be stars brighter than the visual magnitude $V \sim 4$, and 67 binaries among 245 Be stars brighter than $V \sim 8$ mag. Based on Hipparcos and Gaia data, Dodd et al. (2024) found that percentage belonging to binary systems of $28 \pm 1\%$ for B-type stars and $17 \pm 3\%$ for Be stars at separations between 0.02 arcsec and 0.2 arcsec.

We will then investigate the influence of the companion star on the disk by comparing our results with those from binary systems (γ Cas and π Aqr) observed and analyzed using the same method as Ishida et al. (2025). The target Be stars are 3 objects— ψ Per, 25 Ori, and 31 Peg—that can be observed from Japan, where our telescope is located.

ψ Per (HD 22192) is a Be star for which no evidence of a secondary has been found (Hutter et al. 2021). Its mass is $4.8 M_{\odot}$ (Sheikhi et al. 2016), its effective temperature is 15,654 K (Silaj & Landstreet, 2014), and its surface gravity ($\log g$) is 3.65 (Zorec et al. 2016). Emission lines of $H\alpha$ and $H\beta$ were first observed in 1890 (Fleming & Pickering, 1912). Although numerous spectroscopic observations have been conducted since then, the spectrum is considered to be nearly constant (Kitchin, 1970). There are also reports that the emission line profiles of $H\alpha$ and $H\beta$ vary on a cycle of several years (Krugov et al. 1986). Specific measured values for $H\alpha$ line equivalent width ($EW(H\alpha)$) have been reported as $-38.0 \text{ \AA}$ (Cote & Waters, 1987) and $-43 \pm 4 \text{ \AA}$ (Delaa et al. 2011). ψ Per is a “Be-shell star” in which the angle between the Be star’s rotation axis and the observer’s line of sight (i) is approximately $75^\circ \pm 8^\circ$ (the observer views it from the equatorial direction). The disk of ψ Per is estimated to extend to approximately 11 times the star’s radius (Delaa et al. 2011).

25 Ori (V1086 Ori, HD 35439) is a Be star for which no evidence of a secondary has been found located in OB1a in the constellation Orion, which contains many low-mass pre-main-sequence stars (Kharchenko et al. 2005, Kogure, 2002). Its mass is $11 \pm 2 M_{\odot}$ (Vieira et al. 2017), its effective temperature is 25300 ± 253 K, and $\log g$ is 3.50 ± 0.04 (Arcos et al. 2018). Spectroscopic observations of this object were first conducted in 1896 (Fleming & Pickering, 1912). Curtiss showed that there were cyclic variations in the V/R (the strengths ratio of the violet and red peaks), and it was found to vary from 1300 to 1890 days (McLaughlin, 1932). Subsequently, the hydrogen emission lines weakened; it was reported that $H\alpha$ became a faint emission line in 1961, and $H\beta$ became an absorption line in 1955 (Houziaux & Ringuelet-Kaswalder, 1968). 25 Ori is an “ordinary Be star” with $i \sim 55^\circ \pm 5^\circ$ (Cochetti et al. 2019). The major axis of its disk is estimated to be about 4.5 times the size of the star diameter when viewed through the $\text{Br}\gamma$ emission line ($2.165 \mu\text{m}$) (Cochetti et al. 2019).

31 Peg (IN Peg, HD 212076) is a Be star for which no evidence of a secondary has been found Be star (Eggleton & Tokovinin, 2008). Its mass is $12.5 \pm 0.7 M_{\odot}$, its effective

¹(<http://basebe.obspm.fr/basebe/>)

temperature is $23,890 \pm 740$ K, and $\log g$ is 3.71 ± 0.15 (Zorec et al. 2016). The first observations of this star were conducted between 1890 and 1897, and observers at Harvard University confirmed that the $H\beta$ and $H\gamma$ lines were emission lines (Hubert, 1973). Subsequently, the $H\alpha$ emission line was also confirmed (Pickering, 1906); even when the emission intensity is at its minimum, the $H\alpha$ line always shines brightly, the $H\beta$ and $H\gamma$ emission lines repeatedly disappear and reappear approximately every 10–15 years (Hubert, 1973). Zorec et al. (1996) reported that the profiles of the $H\gamma$ line and the He I (4471 Å) line, which have formation regions within the photosphere, varied significantly over the course of approximately one year. 31 Peg is a “pole-on Be star” with $i \sim 26^\circ \pm 9^\circ$ (Schild, 1973, Zorec et al. 2016).

The spectral line shapes of Be stars are complex and depend on i . In the case of a “pole-on Be star,” a single peak is observed; in the case of an “ordinary Be star,” a double peak is observed; and in the case of a “Be-shell star,” a sharp absorption line is observed at the center of the double peak (Struve, 1931).

2 Observations and Objects

2.1 Low-dispersion spectroscopic observations

We have been observing ψ Per, 25 Ori, and 31 Peg since 2005 at the private Fujii Kurosaki Observatory located in Tamashima, Kurashiki City, Okayama, Japan (133.6°E , 34.5°N) and since 2019 at High school observatory located in Yokohama City, Kanagawa, Japan (139.6°E , 35.5°N). We used a 30-40 cm-aperture telescope. The spectrograph is a low-dispersion spectrograph, and resolving power (R)= $500 \sim 1000$ ($H\alpha$ line). All data are of good quality because all 3 objects are sufficiently bright (signal-to-noise ratios of at least 100 in nearly all spectra).

For data reduction, we used IRAF² (Image Reduction and Analysis Facility) or SUBARU Image Processor: MAKALI³ to perform primary processing (dark subtraction, flat-field correction, one-dimensional conversion, and wavelength calibration). We then fitted the detected $H\alpha$ and $H\beta$ lines with Gaussian functions and obtained the $EW(H\alpha)$ and $EW(H\beta)$ by integrating them in wavelength (Figure 1). The Balmer decrement was calculated from the obtained $EW(H\alpha)$ and $EW(H\beta)$. It is defined as the relative value of the Balmer emission line flux $F(Hn)$ ($n=3(\alpha)$, $4(\beta)$, $5(\gamma)$, etc.). Since the only hydrogen emission lines observed in this research were $H\alpha$ and $H\beta$, the Balmer decrement was calculated as the ratio of $F(H\alpha)$ to $F(H\beta)$, which we denote as D_{34} . D_{34} is expressed by the following formula (Kogure, 2000).

$$D_{34} = \frac{F(H\alpha)}{F(H\beta)} = G_\alpha \frac{W_e(H\alpha)}{W_e(H\beta)} \quad (1)$$

Here, G_α is the ratio of the radiative flux to the continuum flux, and is called “the conversion coefficient”. Based on a model atmosphere, Collins, Truax, & Cranmer (1991)

²IRAF is distributed by the National Optical Astronomy Observatories, operated by the Association of Universities for Research in Astronomy, Inc., under contract to the National Science Foundation of the United States.

³(<https://makalii.mtk.nao.ac.jp/index.html.en>)

Table 1: List of Observed 3 Be stars for which no evidence of a secondary has been found.

Name	Be Sp.type*	Magnitude (V)*	$V\sin i$ (km s ⁻¹)
ψ Per	B5III-Vn	4.17-4.28	275 ^a
25 Ori	B1V	4.92-4.96	260±5 ^b
31 Peg	B2V	4.85-5.05	100±2 ^b

*aavso (<https://www.aavso.org/>) or
GCVS database (<http://www.sai.msu.su/gcvs/cgi-bin/search.htm>)

^aZorec et al. (2016)

^bArcos et al. (2018)

Table 2: Observation log.

	ψ Per	25 Ori	31 Peg
Observation period (yr)	2011-2025	2006-2025	2005-2025
Exposure time (s)	20-60	30-60	30-60
Number of observation data	32	22	23

expressed G_α as a function of the B-type spectral subclass. W_e is the equivalent width of the emission lines only. Since the emission lines are thought to be superimposed on the absorption lines, the equivalent width of the photosphere absorption lines is W_s , and the observed equivalent width is W_{ob} , so

$$W_e = W_s - W_{ob} \quad (2)$$

W_{ob} is defined as positive below the continuum (absorption lines) and negative above the continuum (emission lines). W_s uses the calculated values for a model atmosphere by Fujii⁴. For details on the calculation method for D_{34} , please refer to Ishida et al. (2025). Slettebak, Collins, and Truax (1992) calculated the Balmer decrement based on observations of 41 bright Be stars in 1989. They reported that the electron density in the envelopes of Be stars with an effective temperature of 10,000 K ranges from 10^{11} - 10^{13} cm³, and that no clear correlation was observed between the Balmer decrement and $V\sin i$.

The observed objects of this study are shown in Table 1. Table 2 shows the observation log.

2.2 Medium-dispersion spectroscopic data

Data were obtained from the BeSS. Table 3 shows the observation log. The resolving power (R) is 10000 or 11000. We calculated the $FWHM$ from the obtained spectra. Because the emission line profiles were complicated, the measurements were taken as follows. The obtained spectra were normalized. Next, we measured the peak intensity of the emission line, then measured the wavelengths at which that intensity was half (on the long-wavelength side and the short-wavelength side), and calculated the result by

⁴<https://www.asj.or.jp/nenkai/archive/2008b/pdf/A68c.pdf>

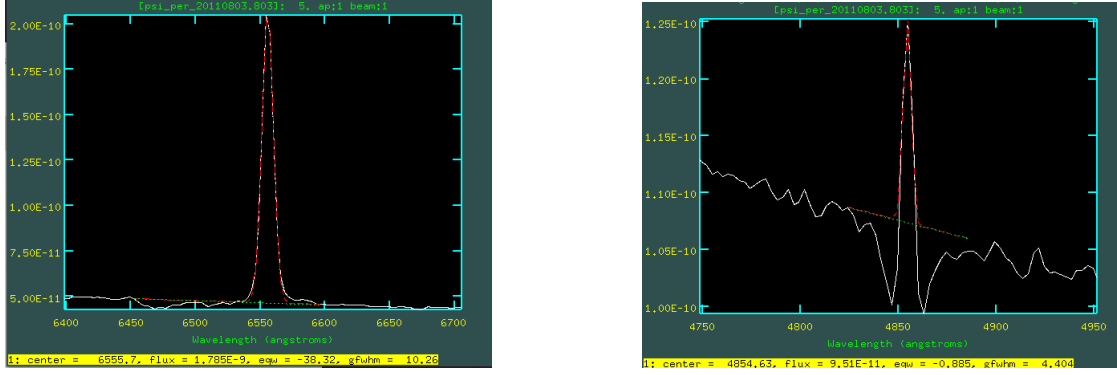


Figure 1: $H\alpha$ (Left) and $H\beta$ (right) emission lines obtained from low-dispersion spectroscopic observations (resolving power (R)=500 $\sim$ 1000) (e.g., ψ Per). White line indicates observational data, and red line indicates the model (Gaussian functions).

Table 3: Observation log (BeSS).

	ψ Per	25 Ori	31 Peg
Observation period (yr)	2010-2020	2012-2024	2011-2024
Exposure time (s)	1500-2700	1800-5440	2000-4500
Number of observation data	7	9	8

subtracting one wavelength from the other. For details on the calculation method for $FWHM$, please refer to Ishida et al. (2025).

3 Observation Results

3.1 ψ Per

Figure 2 (Table 5) shows the low-dispersion spectroscopic observation results of ψ Per. Figure 3 (Table 6) shows analysis results of medium-dispersion spectroscopic observation data (BeSS) of ψ Per. The $EW(H\alpha)$ for ψ Per has varied by approximately a factor of 1.3 during our 2011–2025 observations. The $EW(H\beta)$ has remained low throughout the observation period. A variation of approximately a factor of 1.3 is also observed in D_{34} , but this is thought to be influenced by the uncertainty in $EW(H\beta)$.

No significant variations in $FWHM$ or emission line peak intensity (intensity) were observed for $H\alpha$ and $H\beta$ over the observation period. However, for Mg I (5167Å), although the intensity remained nearly constant over the observation period, variations of approximately 1.5 times in $FWHM$ were observed. This phenomenon has also been observed in 31 Peg. He I (5876Å) showed faint absorption and was unclear throughout the observation period.

Overall, we interpreted the ψ Per disk as having shown little variation during our 2011–2025 observations.

Table 4: Low-dispersion spectroscopic observation results of ψ Per, 25 Ori, and 31 Peg. W_s is the equivalent width of the photosphere absorption lines calculated using a model atmosphere. G_α is the ratio of the radiative flux to the continuum flux. W_e is the equivalent width of the emission lines only. For details on the calculation method for these parameters, please refer to Ishida et al. (2025). Full table is available on the OEJVS's web site (https://oejv.physics.muni.cz/issues/table4_EW_D34.txt)

Name	Date	$EW(H\alpha)$	$EW(H\beta)$	$W_s(H\alpha)$	$W_s(H\beta)$	G_α	$W_e(H\alpha)$	$W_e(H\beta)$	D_{34}	Observer
ψ Per	2011/8/3	-38.3	-1.0	5.1	8.3	0.336	43.4	9.2	1.7	Fujii
ψ Per	2015/11/26	-41.2	-0.8	5.1	8.3	0.336	46.3	9.1	1.9	Fujii
ψ Per	2016/12/6	-40.8	-1.0	5.1	8.3	0.336	45.9	9.3	1.8	Fujii
...										
25 Ori	2006/12/2	-13.6	—	2.3	3.4	0.340	15.9	—	—	Fujii
25 Ori	2011/1/22	-19.4	-1.0	2.3	3.4	0.340	21.7	4.4	1.7	Fujii
25 Ori	2016/2/18	-26.8	-2.0	2.3	3.4	0.340	29.1	5.4	1.8	Fujii
...										
31 Peg	2005/11/1	-17.0	-0.5	3.0	4.6	0.346	19.9	5.1	1.4	Fujii
31 Peg	2012/10/12	-17.6	-0.5	3.0	4.6	0.346	20.5	5.1	1.4	Fujii
31 Peg	2015/11/4	-13.8	—	3.0	4.6	0.346	16.8	4.6	—	Fujii
...										

Table 5: Analysis results of medium-dispersion spectroscopic observation data (BeSS) of ψ Per, 25 Ori, and 31 Peg. Full table is available on the OEJVS's web site (https://oejv.physics.muni.cz/issues/table5_fwhm_int.txt)

Name	Date	$Fw(H\alpha)$	$Fw(H\beta)$	$Fw(Mg)$	$I(H\alpha)$	$I(H\beta)$	$I(Mg)$	Observer
ψ Per	2010/9/6	7.5	4.8	5.1	5.7	1.5	1.1	Christian Buil
ψ Per	2014/10/17	7.4	4.8	5.2	5.9	1.7	1.1	Michel Pujol
...								
25 Ori	2012/11/20	8.6	—	—	4.7	1.5	—	Thierry GARREL
25 Ori	2015/11/1	7.8	—	—	4.8	1.8	—	Olivier GARDE
...								
31 Peg	2011/8/5	3.5	2.6	—	5.4	1.6	—	Olivier Thizy
31 Peg	2015/7/22	3.5	2.3	3.9	3.9	1.3	1.1	Olivier Thizy
...								

Fw : FWHM, I : Intensity

3.2 25 Ori

Figure 4 (Table 5) shows the low-dispersion spectroscopic observation results of 25 Ori. Figure 5 (Table 6) shows analysis results of BeSS of 25 Ori. EWs has varied by approximately 2–3 times during our 2006–2025 observations, peaking from late 2023 to early 2024 (the intensity of $H\alpha$ also appears to peak in 2024). The peak of D_{34} occurred approximately one year after the peak of EWs . This was also confirmed in 31 Peg and π Aqr (Ishida et al. 2025). D_{34} varied by approximately 1.5 times, peaking from late 2024 to early 2025.

No significant variations in the $FWHM$ or the intensities of $H\alpha$ and $H\beta$ were observed between 2012–2024. On the other hand, the profiles of the $H\alpha$ and $H\beta$ emission lines have been changing approximately every year. Specifically, while the $H\alpha$ line clearly exhibited a double peak in some years, it showed a single peak in others, and in still others, it was difficult to determine which was the case. The $H\beta$ line exhibited a double peak in almost every year, but it varied irregularly—some years the intensity on the R-side was stronger than that on the V-side, while in other years it was weaker. We expect the asymmetry in the disk density varies significantly over short periods. He I (5876 Å) and Mg I (5167 Å) were unclear throughout the observation period.

3.3 31 Peg

Figure 6 (Table 5) shows the low-dispersion spectroscopic observation results of 31 Peg. Figure 7 (Table 6) shows analysis results of BeSS of 31 Peg. EWs has varied by approximately 3–5 times during our 2005–2025 observations, peaking from late 2023 to early 2024 (the intensities of $H\alpha$ and $H\beta$ have also varied by approximately 2–2.5 times). Although D_{34} differs among observers, on average, D_{34} varied by approximately 1.5 times, peaking between late 2022 and late 2024.

No significant variations in the $FWHM$ of $H\alpha$ and $H\beta$ were observed between 2011–2024. He I (5876 Å) exhibited a clear absorption line throughout the observation period.

4 Discussion

The 3 Be stars observed in this study was found exhibited different behaviors. However, when we included the 2 Be stars (γ Cas and π Aqr) that form a binary system observed by Ishida et al. (2025), similarities also became apparent. First, for ψ Per and γ Cas, where D_{34} did not vary during the observation period, the shapes of the spectral lines ($H\alpha$, $H\beta$, He I (5876Å), Mg I (5167Å)) and the $FWHM$ (for $H\alpha$ and $H\beta$) remained nearly constant. Next, for 25 Ori, 31 Peg, and π Aqr—where D_{34} varied (by approximately 1.5 times)—the emission line profiles of the $H\alpha$ and $H\beta$ showed significant variations. Regarding He I (5876Å) and Mg I (5167Å), the behavior differed between 25 Ori and 31 Peg (no evidence of a secondary) and π Aqr (a binary system). During the observation period, the 2 emission lines in 25 Ori remained unclear, and in 31 Peg, He I (5876Å) remained an absorption line and Mg I (5167Å) remained an emission line, showing little change in profiles. In contrast, the lines in π Aqr varied significantly in profiles throughout

the observation period (2010–2024), appearing at times as absorption lines and at other times as emission lines.

In conclusion, These monitoring observations could not explain the differences in disk behavior between no evidence of a secondary and binary systems. In the future, expanding the range of companion variations in binary systems (main-sequence stars, neutron stars, a wide range of eccentricities, etc.) and conducting longer-term monitoring may provide the key to solving this question.

5 Conclusions or Summary

In this paper, we present the results of low-dispersion spectroscopic observations (resolving power (R)=500 $\sim$ 1000) of 3 Be stars for which no evidence of a secondary has been found— ψ Per, 25 Ori, and 31 Peg—to investigate the variations in $EW(H\alpha)$ and $EW(H\beta)$ (EWs), and in Balmer decrement (D_{34}). We also analyzed variations in $FWHM$ and emission line peak intensity using medium-dispersion spectroscopic data (BeSS, R is 10000 or 11000) from the same observation period. In ψ Per, there have been no noticeable variations in the emission line profiles and the observation values. This characteristic is similar to that of γ Cas (Be/white dwarf binary candidates) reported in Ishida et al. (2025). On the other hand, Significant variations in EWs and D_{34} were observed for 25 Ori during our 2006–2025 observation and for 31 Peg during our 2015–2025 observation. Results from the analysis of BeSS data for these objects show that the emission line profiles of the $H\alpha$ and $H\beta$ showed significant variations. These characteristic is similar to that of π Aqr (Be/white dwarf binary candidates) reported in Ishida et al. (2025).

In conclusion, these monitoring observations were unable to clarify the purpose of this study: “to what extent companion stars contribute to the expansion and disappearance of Be star disks.”

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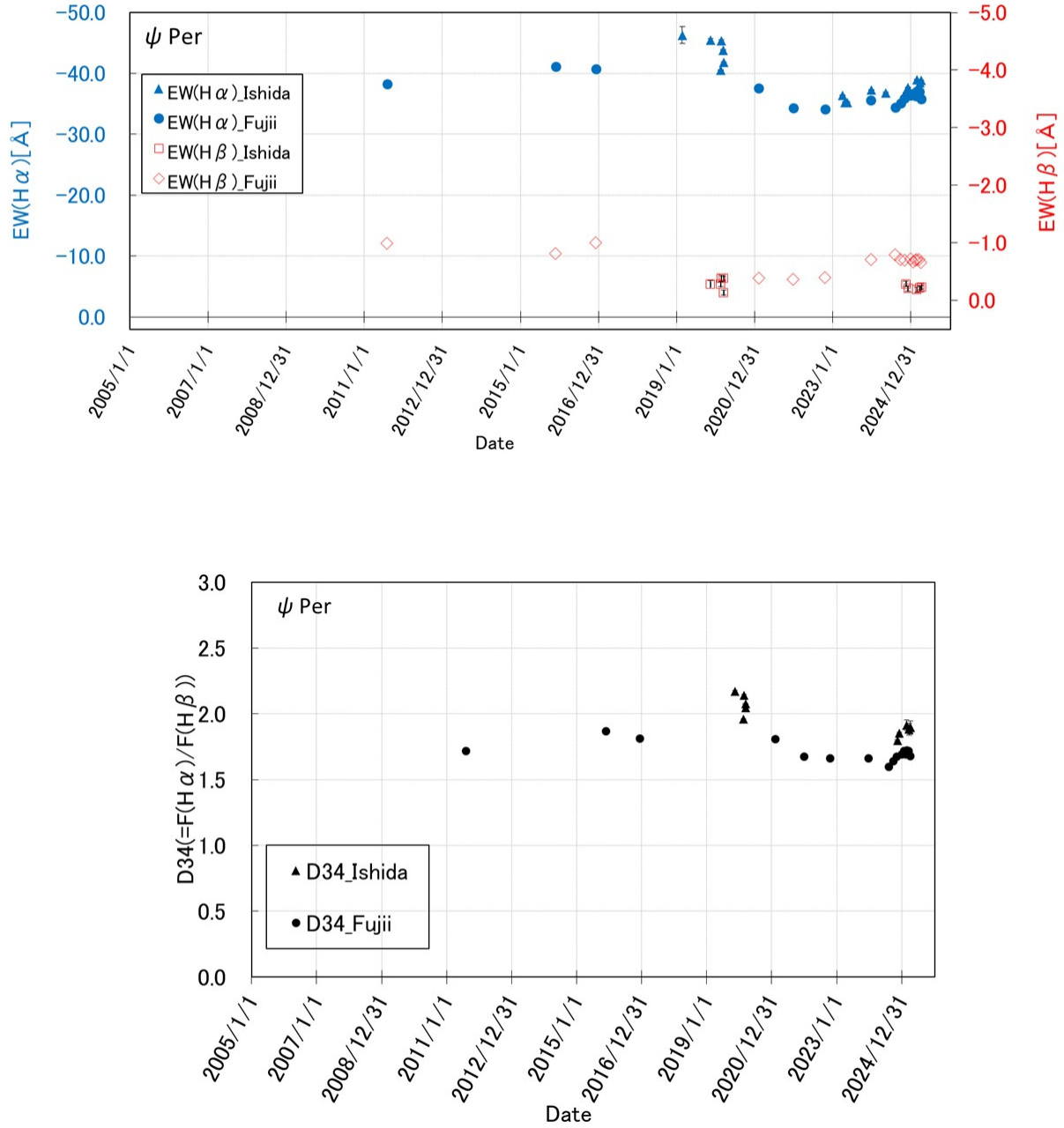


Figure 2: Low-dispersion spectroscopic observation results of ψ Per. The top panel shows EW s and bottom panel shows D_{34} .

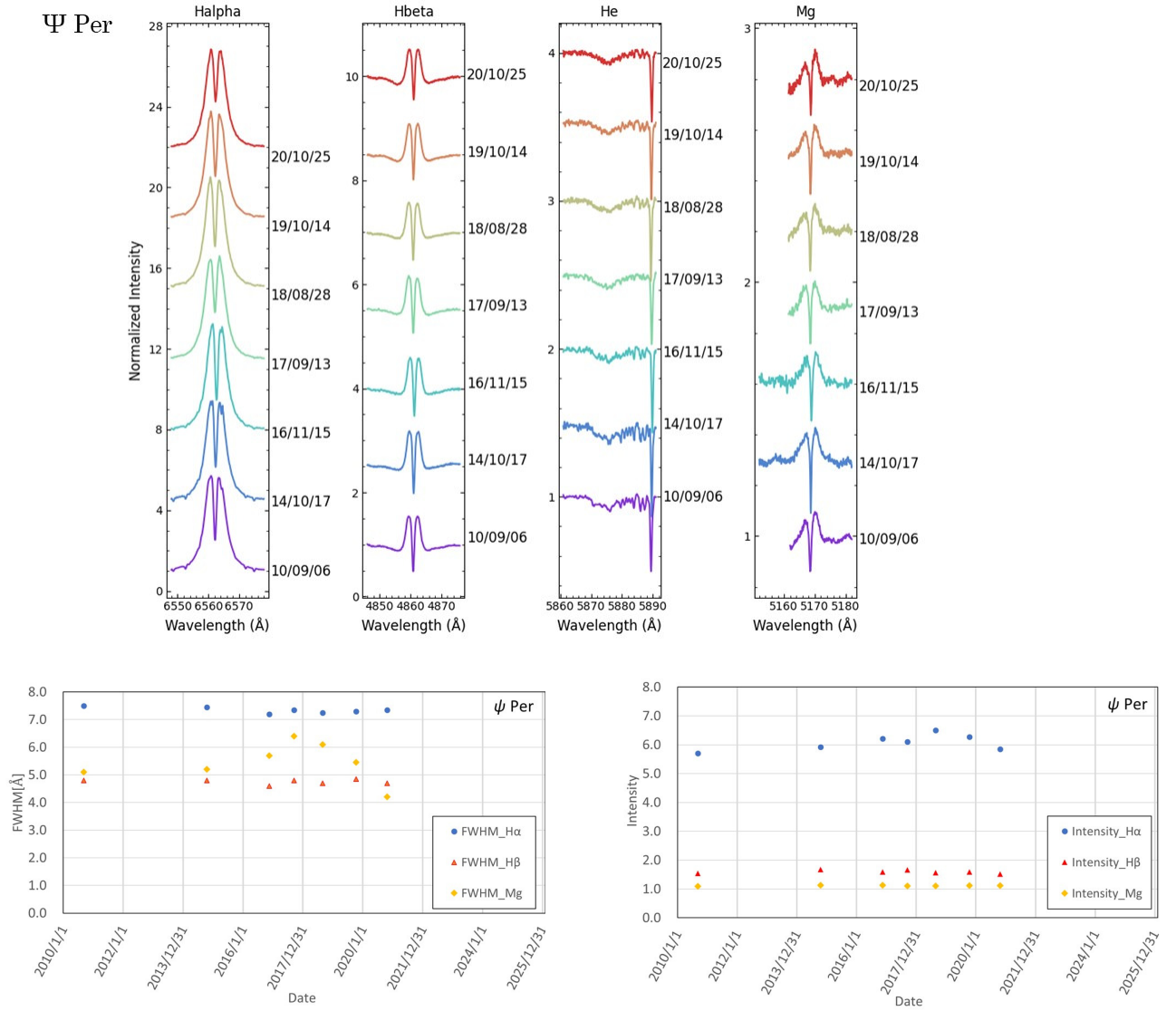


Figure 3: Analysis results of medium-dispersion spectroscopic observation data (BeSS) of ψ Per. The top panel shows evolution of the emission line profile of BeSS from 2010 to 2020. The bottom panel shows the time variations in $FWHM$ and emission line peak intensity.

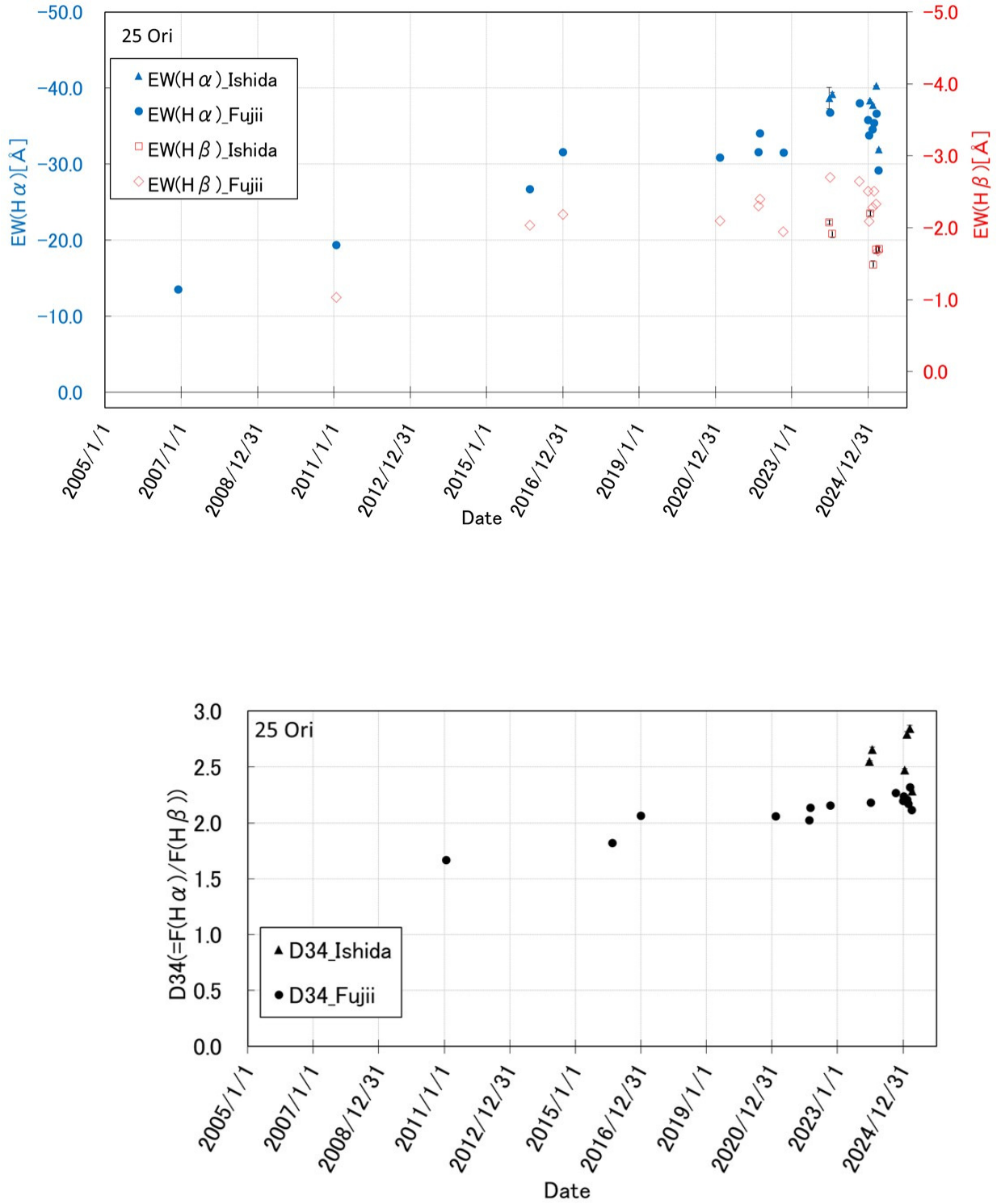


Figure 4: Low-dispersion spectroscopic observation results of 25 Ori. The top panel shows EW s and bottom panel shows D_{34} .

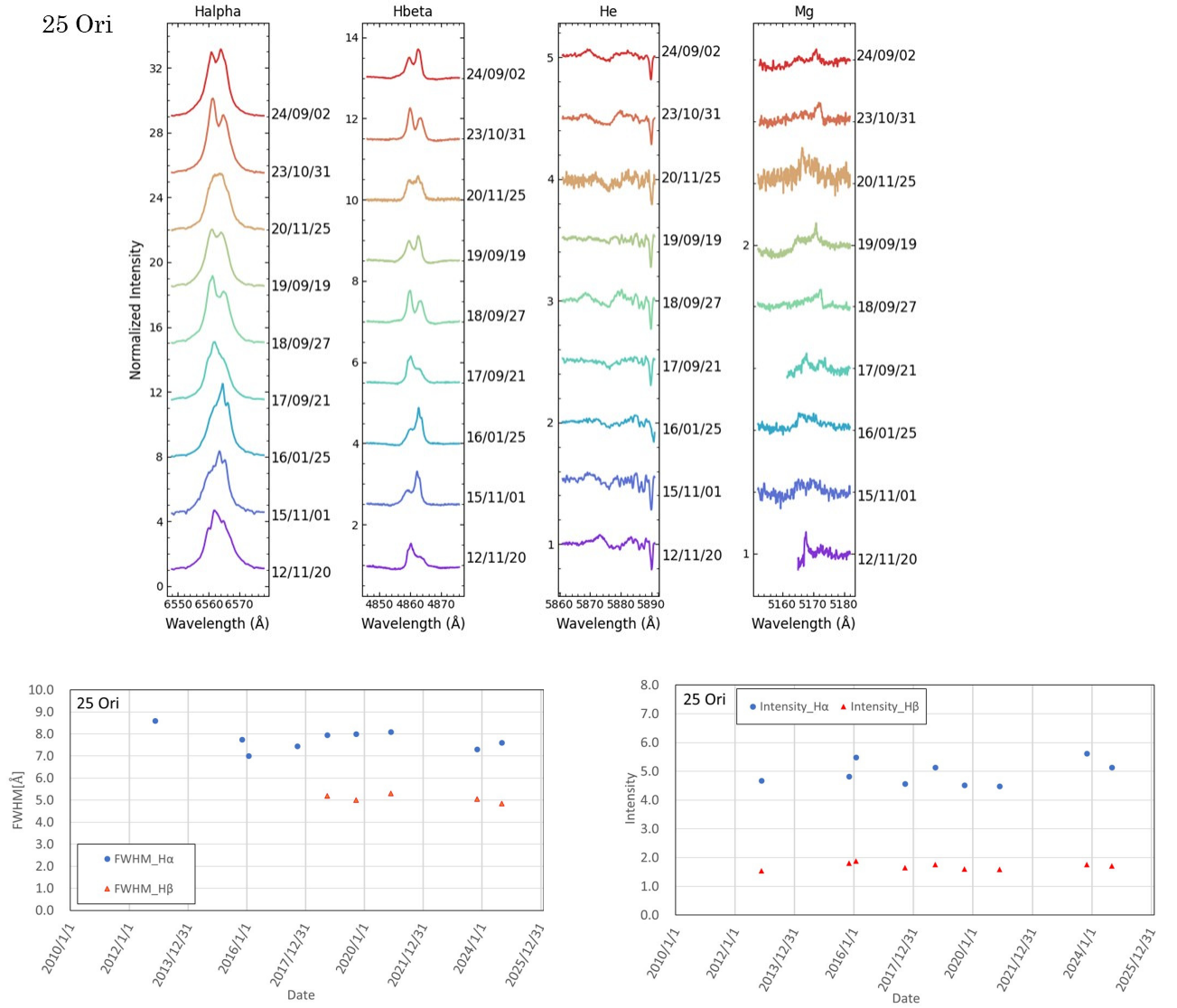


Figure 5: Analysis results of medium-dispersion spectroscopic observation data (BeSS) of 25 Ori. The top panel shows evolution of the emission line profile of BeSS from 2010 to 2020. The bottom panel shows the time variations in $FWHM$ and emission line peak intensity.

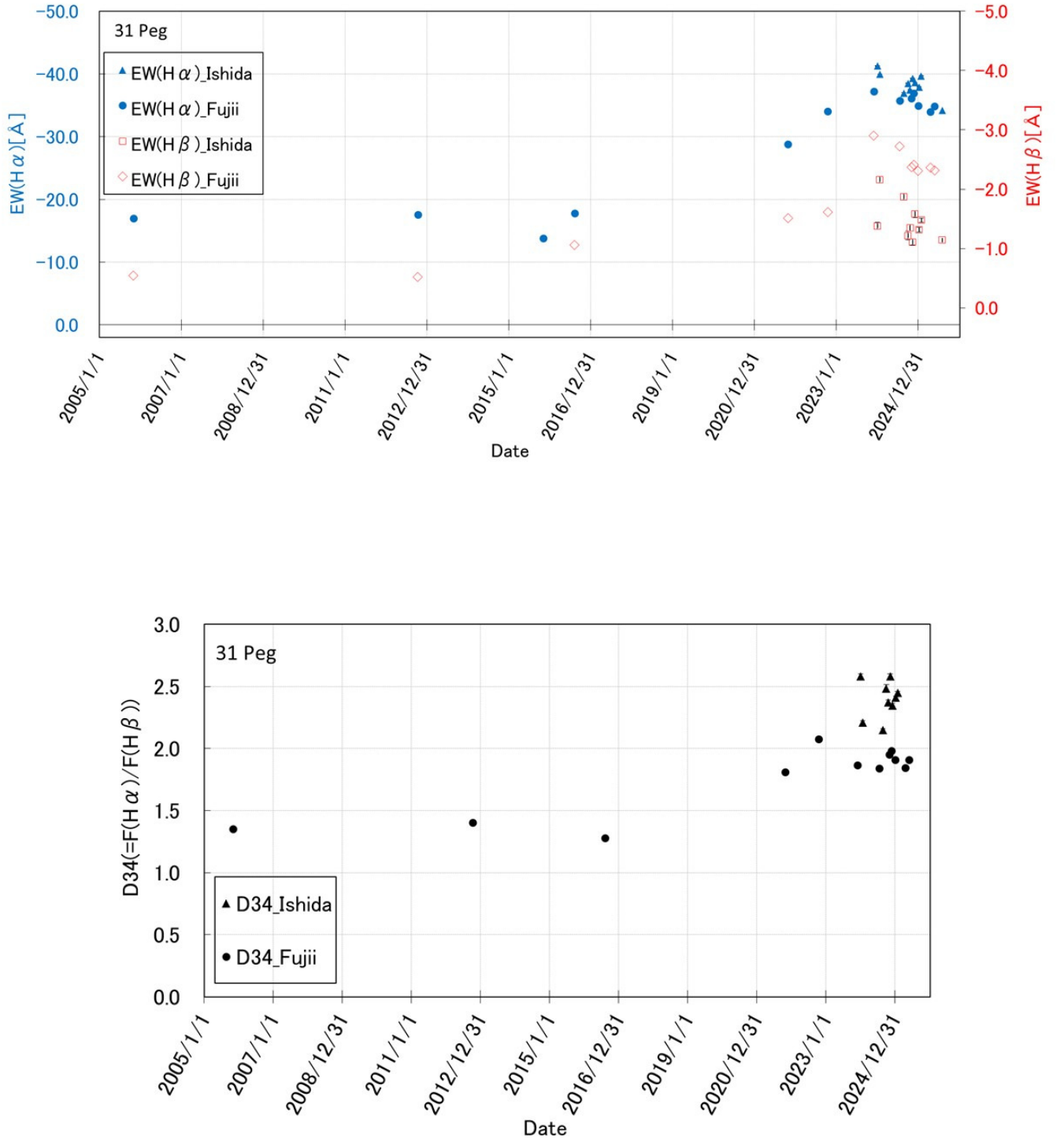


Figure 6: Low-dispersion spectroscopic observation results of 31 Peg. The top panel shows EW s and bottom panel shows D_{34} .

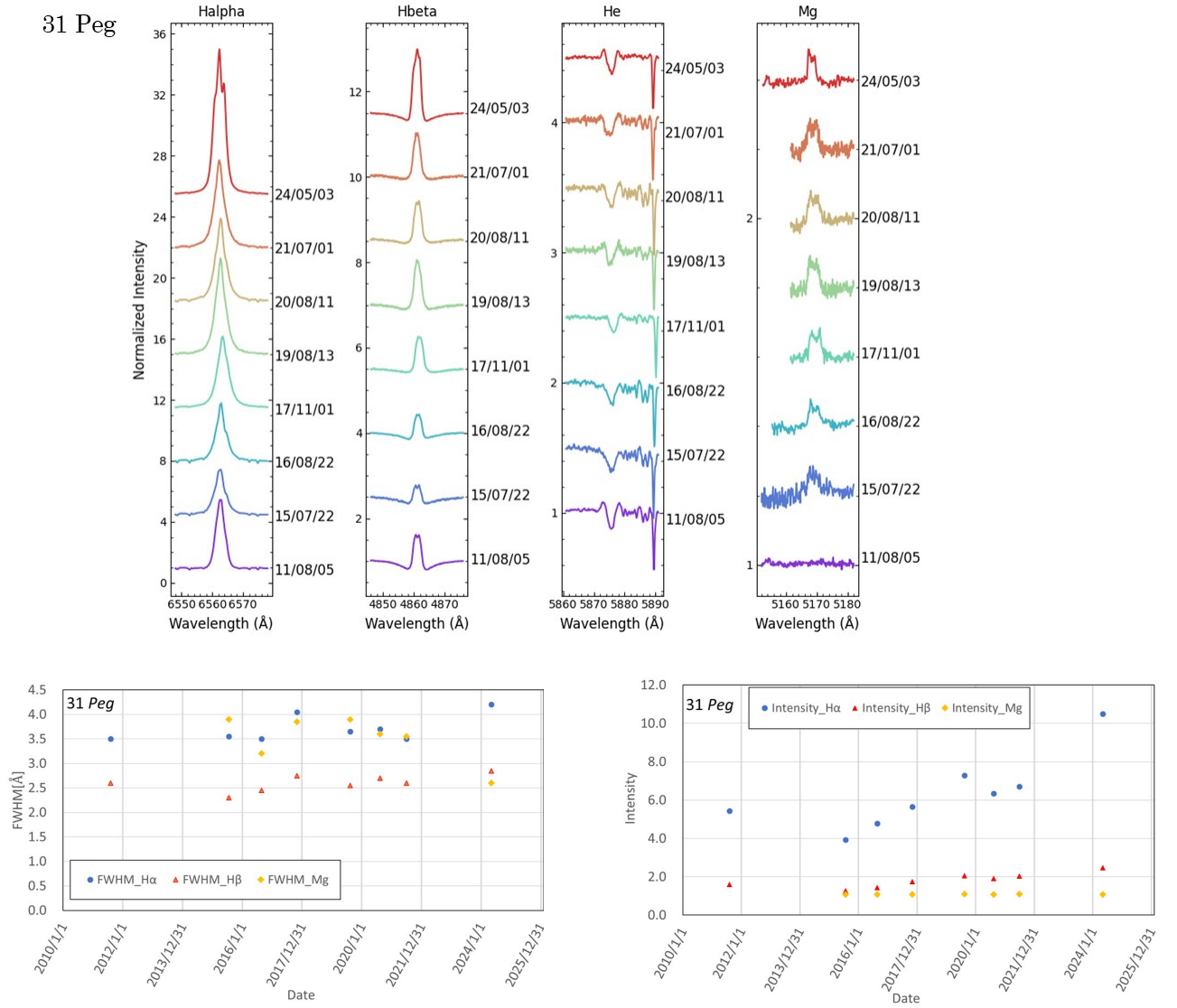


Figure 7: Analysis results of medium-dispersion spectroscopic observation data (BeSS) of 31 Peg. The top panel shows evolution of the emission line profile of BeSS from 2010 to 2020. The bottom panel shows the time variations in $FWHM$ and emission line peak intensity.