Signatures of Accretion: Pa α emission in HD 100546

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Abstract

Pa α is one of the intrinsically most valuable diagnostics of accretion in YSOs. However, it is based in a wavelength region (1.875 μm) which is heavily affected by absorption from water vapour in the earth''s atmosphere and thus generally only observed from space. We have taken advantage of the recent installation of a dedicated Particulate Water Vapour (PWV) monitor on Paranal observatory to use the CRIRES instrument at the VLT to observe the Pa α line in the Herbig Be star HD 100546 during an episode of particularly low PWV conditions. This constitutes the first spectroscopic detection of this line from the ground. We use the Pa α line to determine the accretion parameters of HD 100546 and present a comparison of this novel method to measure accretion with other methods.

Introduction

Fig. 1. 183 GHz L-HATPRO radiometer on Paranal.

The humidity in the earth's atmosphere is measured in the form of precipitable water vapour (PWV) — a measure of atmospheric water content. It is the amount (or depth) of water vapour in a column of the atmosphere if it were all to condense and fall as rain. PWV is one of the main, and variable, sources of opacity at infrared and (sub-)mm wavelengths. A 183 GHz radiometer (an L-HATPRO unit manufactured by Radiometer Physics Gmbh) has been operating on Cerro Paranal (altitude 2635 meter above sea level) since November 2012. This unit (Fig. 1) is capable of providing accurate measurements of the column of PWV above Paranal in real-time. Combined with the flexible scheduling of observations carried out at the VLT in service-mode, this new addition to the Paranal infrastructure allows us to successfully execute infrared observations at atmospheric windows which are normally only accessible from much higher altitude sites.

Table 1. PWV statistics on Paranal. Although the median PWV on Paranal is 2.3 mm, extremely dry conditions do occur on rare occasions when a finger of cold dry Antarctic air moves far North.

PWV ≤ 0.2 mm	PWV ≤ 0.5 mm	PWV ≤ 1.0 mm
0.6 % (2.2 nights/year)	1.9 % (6.9 nights/year)	13.6 % (49.6 nights/year)

Observations

As one of the lowest lying transitions of H I, Pa α is one of the intrinsically most valuable diagnostics of accretion in YSOs. However, it is based in a wavelength region (1.875 μm) which is heavily affected by absorption from water vapour in the earth's atmosphere and thus generally only observed from space.

A high-resolution spectrum of the Herbig Be star HD 100546 was obtained with CRIRES at the VLT in the Pa α line (1.875 μm) during an episode of low water vapour on June 22, 2013 (Fig. 3). The *R*=100,000 spectral resolution of the spectrum is high enough to see individual telluric lines from water vapour superimposed on the spectrum, which can be removed by dividing the spectrum by a model spectrum of the atmosphere over Paranal (Fig. 4).

HD 100546

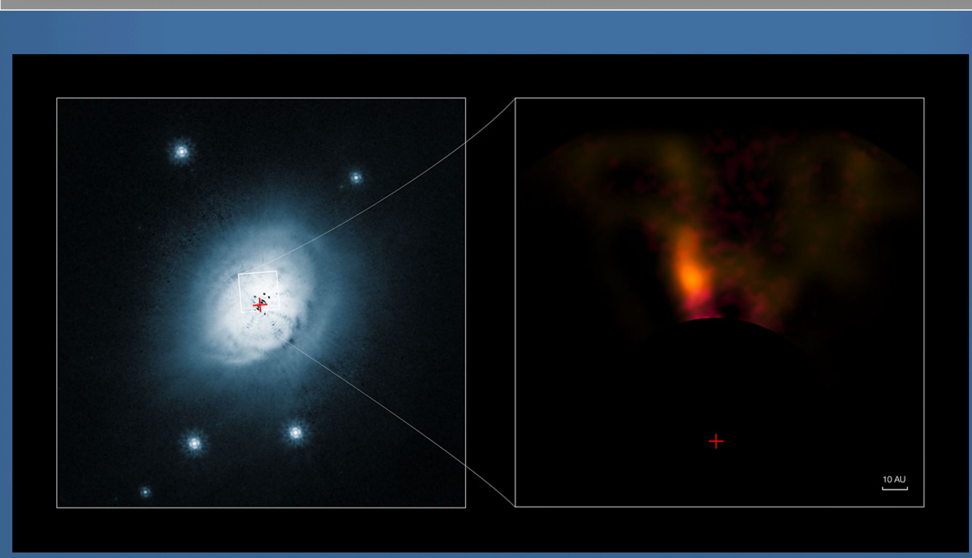

Fig. 2. HST (Ardila et al. 2007) and VLT/NACO (Quanz et al. 2013) coronographic images of HD 100546. The Hubble visible-light image (left) shows the outer disc of gas and dust around the star. The NACO picture of a small part of the disc (right) shows a candidate protoplanet located at ~47 AU from the star. The position of the star is marked with a red cross in both panels [Photo credit: ESO/NASA/ESA/Ardila et al.].

HD 100546 is a well-known, relatively evolved (age > 5 Myr), Herbig Be star surrounded by a highly processed dusty disk (Malfait et al. 1998). Images in scattered light (e.g. Fig. 2) show a large (*R* > 300 AU) circumstellar disk with an inclination of 42°. The shape of the spectral energy distribution, as well as infrared CO and optical [O I] line profiles, provide evidence for an inner gap ranging from approximately 4-13 AU (Bouwman et al. 2003, Acke & van den Ancker 2006, van der Plas et al. 2009, Hein Bertelsen et al. 2014). A massive planet was suggested to be orbiting within this gap. A bright and compact feature within the disk at ~47 AU from the star was detected in the near-infrared by Quanz et al. (2013) and was interpreted as a second planet currcently forming within the disk (Fig. 2).

Results

The Pa α line in HD 100546 shows a strong (peak.continuum ratio: 8.6) single-peaked profile with FWHM ~ 480 km s^{-1}. Comparison with the profiles of Ly α and H α (Fig. 5) shows large differences in the line profiles: whereas Pa α is single-peaked, H α and Ly α are double peaked. The absorption components in the H α and Ly α line profiles can be interpreted as due to H I absorption in our line of sight due to interstellar and circumstellar material (McJunkin et al. 2014).

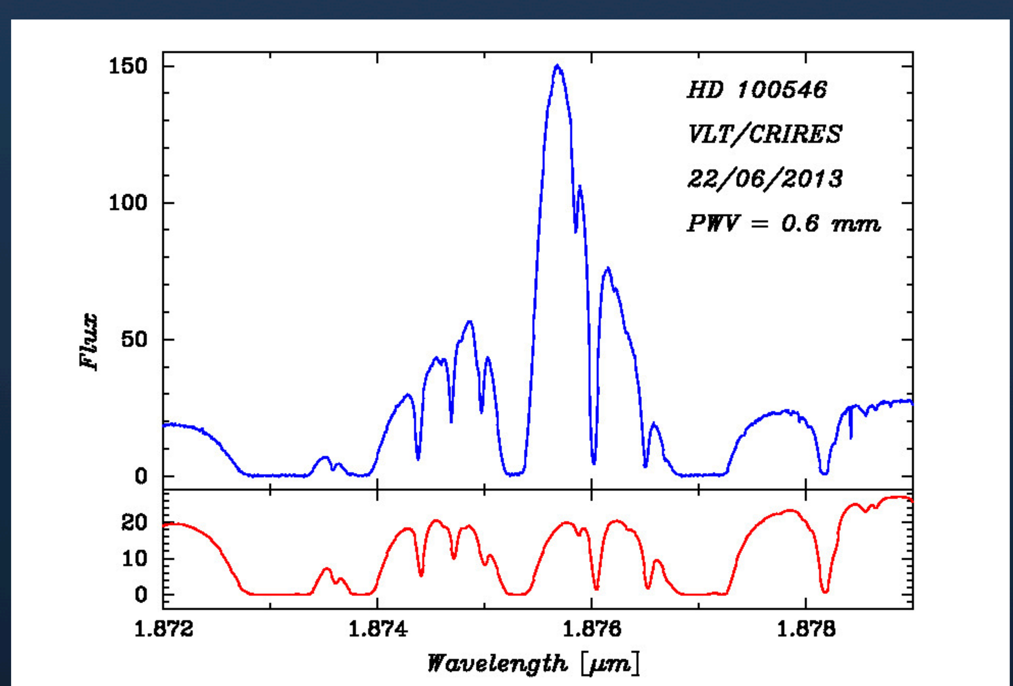

Fig. 3. Non extinction-corrected VLT/CRIRES spectrum of HD 100546 (top panel) in the wavelength region of the Pa α line. Effective PWV (measured by the L-HATPRO radiometer, corrected to the airmass of our observation) was 0.6 mm. Superimposed on the spectrum deep absorption lines due to residual water vapour in the earth's atmosphere can be seen. The bottom panel shows a model transmission for the atmosphere above Paranal for PWV = 0.6 mm.

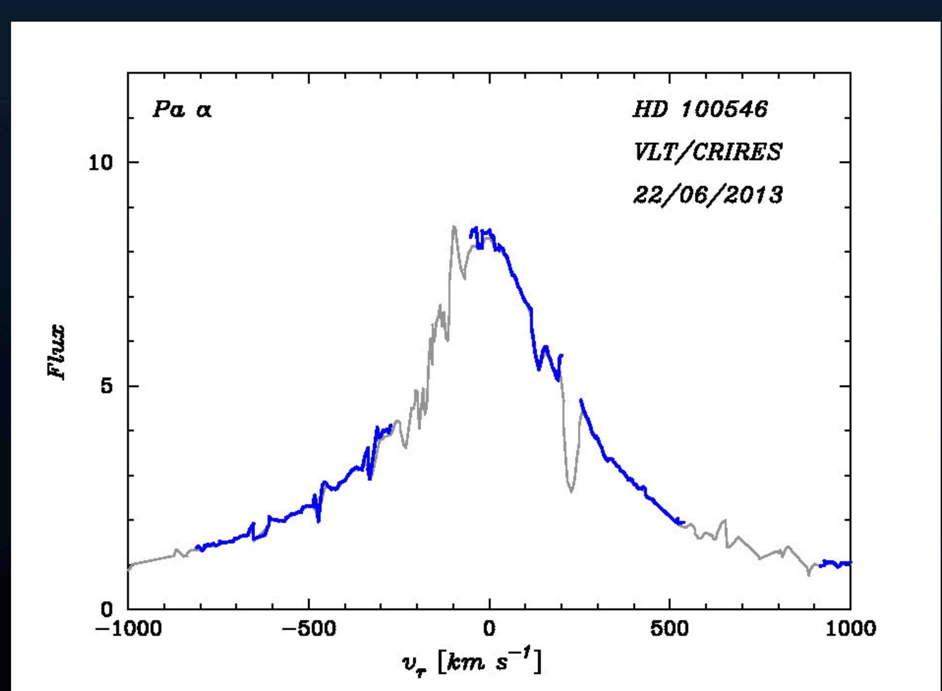

Fig. 4. Spectrum of HD 100546 in the Pa α line corrected for telluric absorption. The spectral regions plotted in blue have flux > 0.5 (relative to the continuum in the non-extinction corrected, whereas the spectral regions plotted in grey have low flux in the original spectrum, so the spectral shape is less reliable.

Results (continued)

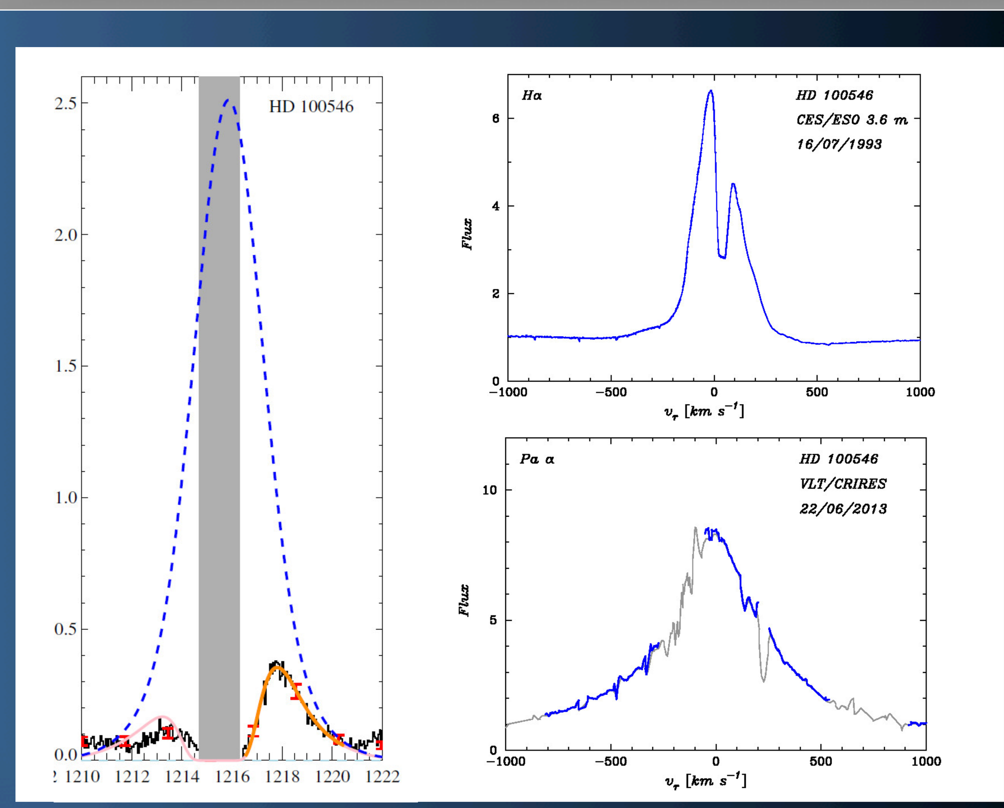

Fig. 5. Comparison of H I lines profiles of HD 100546. **Left panel:** Ly α (taken from McJunkin et al. 2014). The grey area shows the region affected by geocoronal Ly α emission. Blue dashed and orange solid lines show the unabsorbed and foreground-absorbed model line profiles. **Top right:** H α spectrum of HD 100546 obtained at the ESO 3.6 m telescope. **Bottom right:** Pa α spectrum of HD 100546 obtained with CRIRES at the VLT.

The Pa α line has the highest line luminosity of any line within the UV-near-IR spectrum of HD 100546. It is one of the dominant contributors to the total line luminosity – an often used proxy for accretion luminosity in YSOs (e.g. Alcala et al. 2014). Converting accretion luminosity to a mass accretion rate using $M_{acc} = 1.25\ L_{acc}\ R_*/GM_*$, we derived an accretion rate of 3 × 10^{-8} M$_{\odot}$yr^{-1} for HD 100546.

Conclusions

- As demonstrated by the pilot study of Pa α in HD 100546 shown here, it is possible, under dry conditions, to do spectroscopy of the Pa α line using ground-based observatories.
- The Pa α line has a number of properties which make it an interesting diagnostic of accretion in Herbig Ae/Be stars:
  - At 1.875 μm extinction is low, allowing the detection of Pa α even in embedded objects.
  - Low continuum emission from dust, allowing high line/continuum ratios.
  - Wavelength suitable for Adaptive Optics observations with high Strehl ratios.
- In HD 100546, Pa α is the line with the highest intrinsic peak/continuum flux ratio.
- Whereas Ly α and H α show absorption components, the profile of Pa α in HD 100546 show a smooth profile, dominated by emission.
- The accretion rate derived from the Pa α line in HD 100546 (3 × 10^{-8} M$_{\odot}$yr^{-1}) is a factor of 30 higher than previous estimates. From the single example presented here it is unclear whether this represents a systematic difference in accretion rates derived from different methods or could be due to temporal variability of the accretion in HD 100546.

References

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