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No evidence of a sudden change of spectral appearance or magnetic field strength of the O9.7V star HD 54879

G. A. Wade,[1★] S. Bagnulo,[2] Z. Keszthelyi,[3] C. P. Folsom,[4] E. Alecian,[5] N. Castro,[6] A. David-Uraz,[7] L. Fossati,[8] V. Petit,[7] M. E. Shultz[7] and J. Sikora[9]

[1]*Department of Physics & Space Science, Royal Military College of Canada, PO Box 17000 Station Forces, Kingston, ON K7K 0C6, Canada*
[2]*Armagh Observatory and Planetarium, College Hill, Armagh BT61 9DG, UK*
[3]*Anton Pannenkoek Institute for Astronomy, Universiteit van Amsterdam, Science Park 904, NL-1098 XH Amsterdam, the Netherlands*
[4]*IRAP, Université de Toulouse, CNRS, UPS, CNES, 14 Avenue Edouard Belin, F-31400 Toulouse, France*
[5]*Université Grenoble Alpes, IPAG, CNRS, F-38000 Grenoble, France*
[6]*Leibniz-Intitut für Astrophysik Potsdam, An der Sternwarte 16, D-14482 Potsdam, Germany*
[7]*Department of Physics and Astronomy, University of Delaware, 217 Sharp Lab, Newark, DE 19716, USA*
[8]*Space Research Institute, Austrian Academy of Sciences, Schmiedlstrasse 6, A-8042 Graz, Austria*
[9]*Department of Physics and Astronomy, Bishop's University, Sherbrooke, Québec J1M 1Z7, Canada*

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ABSTRACT

It was recently claimed that the magnetic O-type star HD 54879 exhibits important radial velocity variability indicative of its presence in a spectroscopic binary. More remarkably, it was furthermore reported that the star underwent a short, sudden variation in spectral type and magnetic field. In this letter, we examine new Narval and ESPaDOnS data of this star in addition to the previously published FORS2 data and conclude that both the reported velocity variations and the sudden spectral and magnetic changes are spurious.

Key words: binaries: spectroscopic – stars: massive – stars: rotation.

1 INTRODUCTION

HD 54879 is a late O-type star that was reported to be magnetic by Castro et al. (2015). They reported that the spectrum, characterized by very sharp lines, was very stable and essentially unperturbed by the presence of a magnetosphere. Shenar et al. (2017) reported multiwavelength (optical, UV, X-ray) observations of HD 54879, deriving an effective temperature $T_{\rm eff} = 30.5 \pm 0.5$ kK and a surface gravity of $\log g = 4.0 \pm 0.1$. Both Castro et al. (2015) and Shenar et al. (2017) concluded that the magnetic and spectral variability imply a rather long rotation period, likely around 5 yr. Hence, HD 54879 is inferred to be one of the most slowly rotating O-type stars known.

Hubrig et al. (2019a) described their analysis of an FORS2 spectropolarimetric time series of this star spanning 140 d. The essential conclusions of their study can be summarized as follows: (i) HD 54879 exhibits significant (of the order of 100 km s^{-1}) radial velocity variations on time-scales of days. (ii) On JD 2458166, HD 54879 underwent 'a sudden, short-term increase of the magnetic field strength' (from about −100 to −800 G), accompanied by a remarkable change in the star's spectrum corresponding to a significant change in spectral type (from late O to early B, accompanied by the complete disappearance of the He II lines). In a very recent follow-up paper and erratum, Hubrig et al. (2019b,c) appear to link both the sudden change of the spectral appearance of HD 54879 and the radial velocity variation to an insufficient S/N of the FORS spectra, and refer to putative instabilities of the pipelines they have attempted to use, but ultimately fail to give a satisfactory explanation on how 'an imperfect spectral extraction' could transform a O9.7V-type spectrum into a B2V-type spectrum.

In this letter, we examine these claims in the light of independent spectropolarimetric observations obtained using the high-resolution spectropolarimeters Narval and ESPaDOnS, as well as a re-examination of the FORS2 data studied by Hubrig et al. (2019a).

2 OBSERVATIONAL MATERIAL

We obtained 22 high-resolution circularly polarized (Stokes V) spectra between 2014 November and 2018 January in order to confirm the detection of the star's magnetic field, and to measure the longitudinal field variation. The observations of HD 54879 were obtained using the ESPaDOnS and Narval spectropolarimeters located at the Canada–France–Hawaii Telescope (CFHT) and the Bernard Lyot Telescope (TBL), respectively. ESPaDOnS and Narval are essentially identical instruments consisting of high-resolution (resolving power $R \sim 65\,000$) Echelle spectrographs, which are fibre-fed from Cassegrain-mounted polarimetric modules. Each Stokes V observation consisted of a sequence of four sub-exposures, between which the polarimetric optics of the instruments were rotated, allowing for the removal of instrumental systematics (see

★ E-mail: gregg.wade@rmc.ca

Table 1. Log of high-resolution spectropolarimetric observations of HD 54879, including previously published HARPSpol observations (E = ESPaDOnS, N = Narval, H = HARPSpol). An integration range of +4 to + 50 km s^{-1} was used to measure the longitudinal magnetic field.

HJD-2450000	t_{exp} (s)	SNR (pix^{-1})	B_z (G)	N_z (G)	Inst.
6770.4993	2700	384	− 654 ± 11	− 15 ± 10	H
6971.0658	840	822	− 581 ± 11	− 2 ± 9	E
6971.1066	840	823	− 598 ± 11	19 ± 9	E
7030.5195	900	391	− 557 ± 17	− 7 ± 16	N
7032.5133	900	411	− 561 ± 16	− 10 ± 15	N
7033.5159	900	413	− 546 ± 16	9 ± 15	N
7092.5485	1800	212	− 523 ± 11	− 30 ± 11	H
7095.5057	900	130	− 543 ± 18	17 ± 17	H
7310.6113	590	211	− 516 ± 33	14 ± 32	N
7338.6680	590	239	− 464 ± 34	− 20 ± 34	N
7357.6202	590	200	− 467 ± 30	21 ± 29	N
7374.5860	590	224	− 463 ± 29	15 ± 28	N
7409.5524	590	227	− 495 ± 30	− 20 ± 30	N
7439.4167	590	165	− 556 ± 42	− 87 ± 41	N
7736.9843	475	556	− 418 ± 14	− 12 ± 13	E
7758.8779	656	542	− 427 ± 15	− 3 ± 14	E
7775.9878	840	606	− 435 ± 14	− 20 ± 13	E
7880.2244	712	558	− 369 ± 15	9 ± 15	E
8008.1272	880	626	− 229 ± 11	− 15 ± 10	E
8066.0351	880	526	− 185 ± 10	− 7 ± 10	E
8128.9253	880	406	− 138 ± 13	6 ± 13	E
8557.8753	880	506	74 ± 13	− 5 ± 13	E

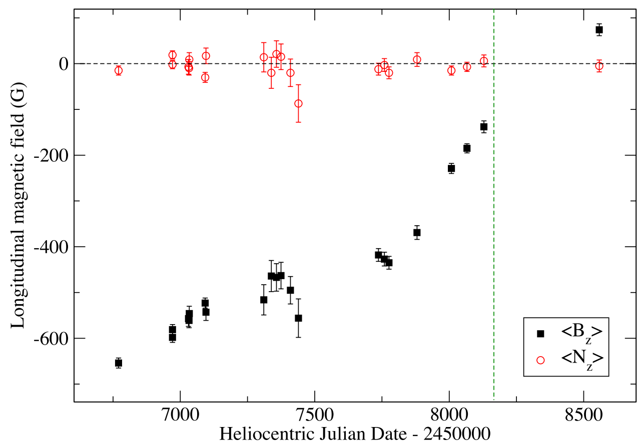

Figure 1. Longitudinal magnetic field of HD 54879 observed with the ESPaDOnS, Narval, and HARPSpol high-resolution spectropolarimeters during the period 2014 April to 2019 March (4.9 yr). The filled black squares represent the longitudinal field measured from the Stokes *V* profile. The open red circles represent the longitudinal field measured from the diagnostic null (*N*) profiles. The horizontal black line indicates $\langle B_z\rangle = 0$. The vertical green line indicates JD 2458165, the date on which HD 54879 was claimed to have undergone a qualitative change of its spectrum and magnetic field.

e.g. Donati et al. 1997). Exposure times were adjusted for each observing run at either telescope, with sub-exposure times ranging between 475 and 900 s. The peak signal-to-noise ratio (S/N) per spectral pixel ranged from about 165 to 825. The log of observations is reported in Table 1. The data were reduced using pipelines specific to the CFHT and TBL, both feeding the same underlying reduction code, LIBRE-ESPRIT (Donati et al. 1997). We combined the new data with the three archival Stokes *V* spectra of HD 54879 obtained by Castro et al. (2015) using the HARPSpol instrument ($R \sim 115\,000$) of the European Southern Observatory (ESO) 3.6 m telescope at La Silla Observatory.

Each spectrum was processed using least-squares deconvolution (LSD; Donati et al. 1997) using the iLSD approach of Kochukhov, Makaganiuk & Piskunov (2010). The line mask was developed using a Vienna Atomic Line Database (VALD; e.g. Piskunov et al. 1995) EXTRACT STELLAR request that was then 'cleaned' and 'tweaked' to best match the spectrum of HD 54879 (e.g. Grunhut et al. 2017).

In addition, we have downloaded from the ESO archive the FORS2 observations discussed by Hubrig et al. (2019a). Data were reduced using dedicated IRAF and FORTRAN routines as explained for instance by Bagnulo & Landstreet (2018). We remind the reader that FORS2 is a Cassegrain-mounted instrument, and that FORS calibrations are obtained the day after the observations, with the telescope pointing at zenith. Because of unavoidable, variable flexures, radial velocity measurements require that FORS spectra be corrected for the resultant shifts using telluric lines, in particular sky emission lines. The FORS observations were obtained with grism 600B ($R \sim 2000$), and the observed spectral range includes only one appropriate calibration line, the O I line at 5577 Å. Therefore, only an approximate absolute wavelength calibration is possible. Nevertheless, using the ESO FORS pipeline (Izzo et al. 2010), we obtained 2D wavelength-calibrated frames, and measured the position of the telluric O I 5577 Å line on each individual frame to roughly correct (to a precision of the order of 10 km s^{-1}) for flexures and other instrument-related systematics.

3 RESULTS FROM THE ESPADONS AND NARVAL OBSERVATIONS

The observations summarized in Table 1 span nearly 5 yr, including the dates during which the FORS2 observations were obtained by Hubrig et al. (2019a). The derived values of the longitudinal magnetic field ($\langle B_z\rangle$) are reported in this table, and were measured using the procedure described by e.g. Wade et al. (2000). As illustrated in Fig. 1, $\langle B_z\rangle$ (shown as black, filled points) increases more or less monotonically over the 5 yr span of the observations, while the equivalent measurements from the diagnostic null profiles ($\langle N_z\rangle$) remain consistent with zero. From this figure, we draw the following conclusions:

(i) The slow, monotonic decrease of the star's longitudinal magnetic field (first reported by Hubrig et al. 2019a,b) shows clearly that the rotational period of HD 54879 must be significantly longer than 5 yr (according to the Oblique Rotator Model; Stibbs 1950). In fact, the most recent observation obtained with ESPaDOnS (in 2019 May) has (finally!) shown the reversal of sign of the Stokes *V* profile corresponding to our first view of the Northern magnetic hemisphere of the star (Fig. 2).

(ii) The high-resolution magnetic measurements show no evidence of any change of character either before or after the reported sudden change in magnetic field strength (the date of which is indicated by the vertical dashed green line in Fig. 1). The high-resolution measurements bracket this date, and show no departure from the long-term trend of increasing longitudinal field strength.

(iii) An ESPaDOnS observation of HD 54879 was obtained on JD 2458129, approximately 1 month prior to the reported episode. As illustrated in Fig. 3, the spectrum obtained on that date is fully compatible with the high-resolution spectrum observed at all earlier dates, modulo very weak variations of the line profile depth and

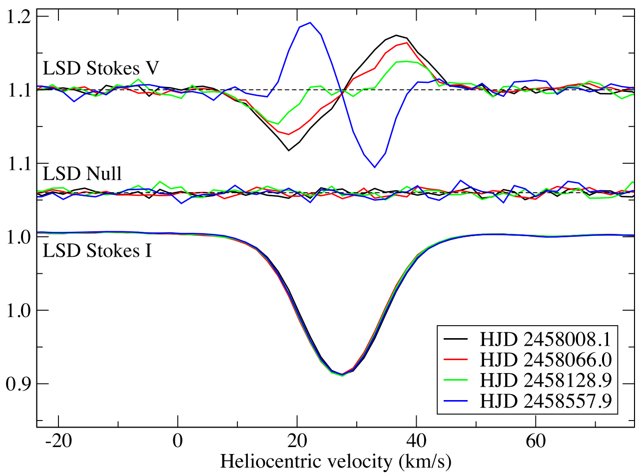

Figure 2. Stokes I and V, along with null N LSD profiles of HD 54879 obtained in 2017–2019, illustrating the recent change of polarimetry of the Stokes V signature. These spectra correspond to the final four longitudinal field measurements shown in Fig. 1.

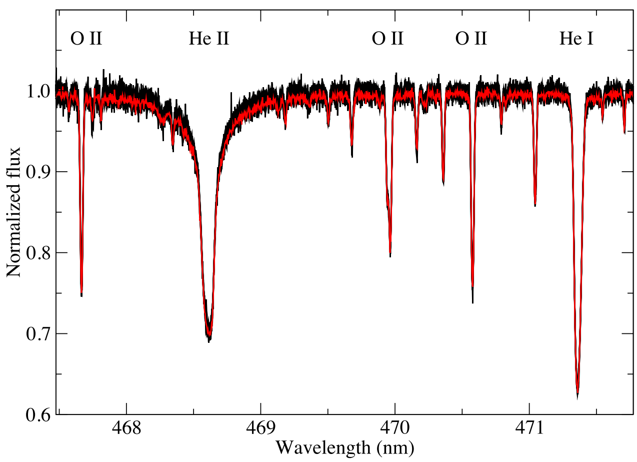

Figure 3. Selected ESPaDOnS and Narval spectra of HD 54879 obtained between 2014 November and 2019 March (in black), showing an arbitrary region containing various absorption lines. No strong RV variability comparable to that reported by Hubrig et al. (2019a) is observed. The spectrum shown in red corresponds to JD 2458128.9, and was acquired about 1 month before the remarkable spectrum reported by Hubrig et al. (2019a).

morphology (variations that are observed throughout the 5 yr of monitoring). In particular, we note the lack of any measurable variation of the radial velocity, in the ESPaDOnS and other high-resolution spectra (some of which were acquired less than one night apart), larger than about 1 km s^{-1}. In addition, the following ESPaDOnS spectrum (obtained on HD 2458557) is also in good agreement with the earlier data. These results are fully consistent with the initial report by Castro et al. (2015).

4 RE-ANALYSIS OF THE FORS2 SPECTRA

The major result of our re-analysis of the FORS2 spectra is that, in contrast to the claims of Hubrig et al. (2019a), there is no evidence of any significant change in the spectrum obtained on 2018 February 17 with respect to all the other spectra of the same star, and that, consistent with what we have found with ESPaDOnS observations, there is no indication of any remarkable change of the star?s radial velocity. In Fig. 4, we have tried to reproduce the dramatic spectral difference shown in fig. 4 of Hubrig et al. (2019a). Our figure clearly shows that, not only there is no remarkable difference between the line profiles obtained at different epochs (including those obtained on 2018 February 17, shown in bold red), but that there is no significant change in radial velocity, once corrections due to the heliocentric velocity and instrument flexures are properly taken into account. We have also re-calculated the longitudinal magnetic field from all FORS2 observations using the methodology of e.g. Bagnulo et al. (2012). We found that our uncertainties are often two times larger than those published by Hubrig et al. (2019a), but the field measurements appear consistent within the error bars. The only exception, of course, is the field estimate obtained from the observations of 2018 February 17, for which we have measured a longitudinal field value of -250 ± 140 G, instead of -880 ± 120 G as reported by Hubrig et al. (2019a).

Hubrig et al. (2019b,c) also seem to come to conclusions similar to our own: namely that the reports of the sudden spectral and magnetic change and the large velocity variations are erroneous. However, they state that low S/N of the data is the culprit, and claim that this phenomenon is a reproducible, albeit spurious consequence of a problem with the reduction pipelines used. Their fig. 8 shows a ~300 Å region of two FORS2 observations obtained on 2019 January 1 separated by just 25 min. One of the spectra, extracted using a proprietary MIDAS pipeline, completely lacks various absorption lines that are clearly visible in the other spectrum. While the data obtained in 2019 January are not publicly available, it seems unlikely that low S/N affects spectral extraction in a way that absorption lines are filled to the continuum; moreover, a Stokes*I*spectrum with an S/N of about 1000 cannot be considered to be 'low'. In their fig. 10, Hubrig et al. (2019b) show some details of Stokes I spectra extracted using the ESO pipeline, in which the He I 4921 Å line appears at different wavelengths, offset by several angstroms, during a full sequence of sub-exposures obtained on a time-scale of tens of seconds. Their stated conclusion is that 'the ESO FORS pipeline has issues with wavelength stability even for higher S/N data' and that 'in its current form [it] is not delivering proper results'. We do not have access to the raw data presented in their figs 8 and 10, nor do the authors provide details about how they have set up or employed the pipeline. All we can say is that, to the best of our knowledge and based on extensive experience, it is unlikely that the ESO pipeline changes the applied wavelength solution between observations obtained sequentially, unless specifically set to do so by the user. In fact, using the spectra that are already available in the ESO archive, we have verified that the ESO FORS pipeline does not produce the spurious results presented by Hubrig et al. (2019b). We also note that each of the spectra obtained on 2018 February 17 have typically a peak ADU count of 20 000 per CCD pixel, and that the combined spectrum reaches an S/N of 1600 per Å. It is totally unclear how this spectrum could be defined having a 'low S/N', especially considering that the spectrum must have been repeatedly and carefully re-examined by Hubrig et al. (2019b,c).

5 CONCLUSIONS

Motivated by the report of remarkable magnetic and radial velocity behaviour of the magnetic O-type star HD 54879 by Hubrig et al. (2019a), we have examined magnetic and spectral measurements of this object obtained with multiple instruments over a 5 yr period. While we confirm the slow increase of the longitudinal field reported

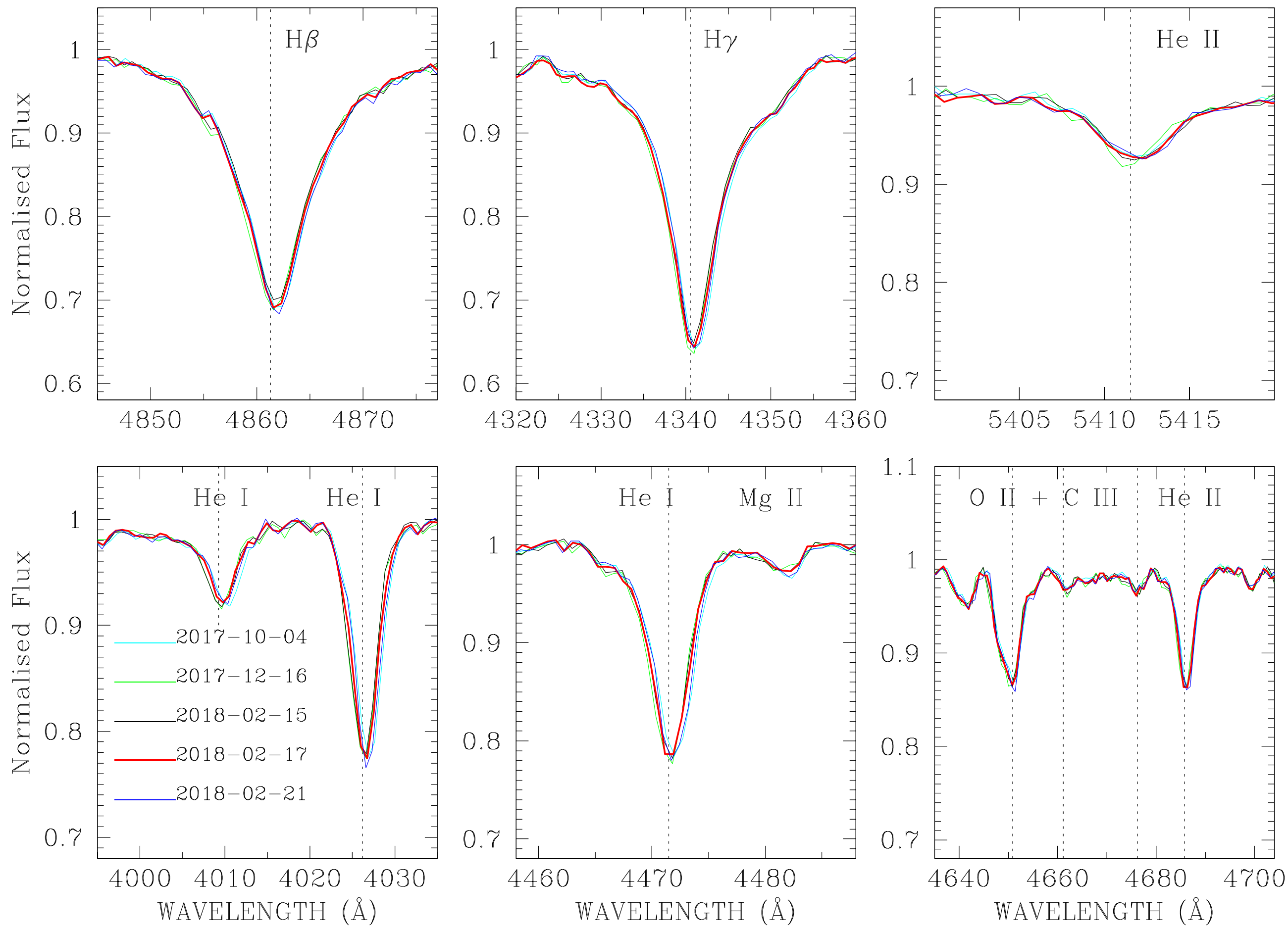

Figure 4. Profiles of various spectral lines in the FORS2 spectra of HD 54879 after heliocentric correction and correction for instrumental systematics using the O I 5577 Å line.

by Hubrig et al. (2019a,b), we are unable to confirm the reported velocity variations, nor the sudden spectral and magnetic changes.

Hubrig et al. (2019b) also appear to conclude that the reports of the sudden spectral and magnetic change and the large velocity variations are erroneous. However, they ascribe this to a serious problem that they claim affects the FORS data reduction pipelines that they employed. Although we are unable to reproduce their experiment due to the proprietary nature of their data, we consider it highly unlikely that the large RV shifts and significant spectral distortions that they illustrate can result from the pipeline if it is properly used. Moreover, we point out that if these phenomena were indeed a consequence of a problem with the pipeline, this would strongly affect the magnetic measurements derived from all of their spectra of HD 54879. Apart from the observation obtained on 2018 February 17, this is not observed. Given this, in addition to the lack of detail about the data reduction and investigation into the purported problems, it seems that the simplest explanation is that human error, rather than the data reduction pipeline, is at fault.

The FORS2 spectrum from 2018 February 17, reported by Hubrig et al. (2019a) to correspond to that of an early B star, is effectively identical to all of the other spectra of HD 54879 in our re-reduced data, i.e. that of a late O-type star. In addition, the longitudinal magnetic field measured from the re-reduced spectrum, equal to -250 ± 140 G, is fully compatible with the field measured from the other spectra of this star. Examining figs 4 and 6 of Hubrig et al. (2019a) (in the latter of which they illustrate the remarkable similarity of the affected spectrum with that of the known magnetic B2 star CPD -57° 3509), it seems reasonable to speculate that the spectrum of another object (in particular a rapidly rotating magnetic B-type star) may well have been mistakenly substituted by those authors.

The new high-resolution spectropolarimetric observations of HD 54879 presented here paint a clear picture of a very slowly rotating, strongly magnetized object, the general behaviour of which is compatible with the known sample of hot, magnetic stars. In particular, our most recent ESPaDOnS observation reveals a change of polarity of the longitudinal magnetic field implying that the Northern magnetic hemisphere has now become visible.

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