

LETTER TO THE EDITOR

# Detecting prolonged activity minima in binary stars<sup>★</sup>

## The case of $\zeta^2$ Ret

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### ABSTRACT

**Context.** It is well known that from 1645 to 1715 solar activity was notably low and the number of sunspots was extremely reduced. This epoch is known as the Maunder minimum (MM). The study of stars in prolonged activity minima such as the MM could help to shed light on this enigmatic epoch. However, to date, it is not easy to identify MM candidates among other stars. An original idea, which has hardly been explored, is to compare the activity levels of both components of binary systems.

**Aims.** Our goal is to explore if the star  $\zeta^2$  Ret, which belongs to a binary system, is in (or going to) a state similar to the MM. We have collected more than 430 spectra acquired between 2000 and 2019 with the HARPS, REOSC, UVES, and FEROS spectrographs.

**Methods.** We performed a detailed long-term activity study of both components using the Mount Wilson index, which is obtained from the Ca II H&K lines. To search for signs of an activity cycle, we analysed the resulting time series with the Generalised Lomb-Scargle and CLEAN periodograms.

**Results.** Our spectroscopic analysis shows a high activity level for  $\zeta^1$  Ret and a significant decrease in the magnetic activity cycle amplitude of  $\zeta^2$  Ret. Thus, the activity difference between both components has slightly increased ( $\Delta \log R'_{\text{HK}} \sim 0.24$  dex), when compared to the previously reported value. The long series analysed here allowed us to re-calculate and constrain the period of  $\zeta^2$  Ret to  $\sim 7.9$  yr. We also detected a long-term activity cycle of  $\sim 4.2$  yr in  $\zeta^1$  Ret, which has not been reported in the literature yet.

**Conclusions.** By analogy with the scenario that proposes a weak solar cycle during the MM, we suggest that activity signatures by  $\zeta^2$  Ret, that is to say a very low activity level when compared to its stellar companion, a notably decreasing amplitude ( $\sim 47\%$ ), and a cyclic behaviour, are possible evidence that this star could be in an MM state. To our knowledge, it is the first MM candidate star to have been detected through a highly discrepant activity behaviour in a binary system. Finally, we suggest that continuous observations of  $\zeta^2$  could help to better understand unusual periods such as the MM.

**Key words.** Stars: activity – binaries: general – Stars: chromospheres – Stars: individual:  $\zeta^1$  Ret – Stars: individual:  $\zeta^2$  Ret

## 1. Introduction

Pioneering research based on monitoring of H&K fluxes for 91 main-sequence stars showed that activity variations, including long-term cyclic behaviour similar to the 11-yr cycle of Sun, were also observed in other stars (Wilson 1978). Then, by us-

<sup>★</sup> Based on observations made with ESO Telescopes at the La Silla Paranal Observatory under programmes resumed in Table A.1, which is only available in electronic form at the CDS via an anonymous ftp to cdsarc.u-strasbg.fr (130.79.128.5) or via <http://cdsweb.u-strasbg.fr/cgi-bin/qcat?J/A+A/>.

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ing the Mount Wilson index ( $S_{\text{MW}}$ ) defined as the ratio between the flux in the optical Ca II H&K lines and the nearby continuum (Vaughan et al. 1978), Baliunas et al. (1998) analysed a sample of 2200 stars, finding different types of long-term activity behaviour. Those stars with a cyclic behaviour (with periods between 2.5 and 25 yr) showed intermediate activity levels, while those with erratic behaviour had higher activity levels. A third group presented flat activity levels, corresponding to inactive stars in general. These objects are particularly interesting because they could be in a state similar to the solar Maunder minimum (hereafter MM).

The MM was a phase between 1645 and 1715 when the Sun deviated from its usual 11-yr activity cycle (Eddy 1976); the number of sunspots was extremely reduced, although they did not disappear (Ribes & Nesme-Ribes 1993). In addition, some evidence, including other solar proxies, have suggested that the

solar cycle was still in progress although with reduced amplitude during the MM (e.g. Ribes et al. 1989; Ribes & Nesme-Ribes 1993; Beer et al. 1998; Usoskin et al. 2001; Soon & Yaskell 2003; Nagovitsyn 2007; Vaquero et al. 2015; Zolotova & Ponyavin 2015).

In particular, the study of MM analogue stars could be very useful to better understand the Sun’s magnetic field, especially its evolution in the past and future. It is also relevant to improve our knowledge about the current dynamo models (e.g. Saar & Baliunas 1992; Usoskin et al. 2006; Charbonneau 2010; Shah et al. 2018). However, the detection of an MM analogue state is a challenging task due to the long-term monitoring that is required, as well as to the lack of clear criteria to identify MM candidates (e.g. Wright 2004; Judge & Saar 2007).

Initial efforts to establish a criterion were carried out by Baliunas & Jastrow (1990) and Baliunas et al. (1995), which were based on the analysis of the relative variation of the  $S_{MW}$  index around its mean ( $\sigma_S/\bar{S}$ ). In this sense, the authors initially considered those stars with  $\sigma_S/\bar{S} < 1.5\%$ <sup>1</sup> as MM candidates. They were called ‘flat’ stars and were characterised by relatively constant and low activity levels.

Then, Henry et al. (1996) studied a sample of stars that belong to the Project Phoenix Survey. As a result, the authors defined a new class of inactive stars employing the chromospheric activity index  $\log R'_{HK}$ . According to their definition, stars with a  $\log R'_{HK} < -5.1$  dex (corresponding to  $S_{MW} < 0.15$  for solar type stars) could be considered as MM candidates. However, Wright (2004) showed that most of these stars were in fact evolved stars, with activity levels significantly lower than main-sequence objects, thereby concluding that low activity alone is not a sufficient discriminant of an MM state. Moreover, it has been suggested that the low activity level obtained by Henry et al. (1996) should be higher than  $-5.1$  dex and that the identification of MM candidates should not only be constrained to the visual part of the spectra. In this way, UV and X-ray data can also be used to identify MM candidates (e.g. Wright 2004; Judge & Saar 2007). Recently, Schröder et al. (2017) reported an average S-index of 0.154 for the unusually deep and long minimum in 2008-2009 of the solar cycle 24. The solar far-UV data also reveal a low activity behaviour during this period. Then, according to the analysis of the authors, the Sun could be entering into a new grand minimum phase.

To date, only very few firm MM candidates have been reported in the literature. For instance, Poppenhäger et al. (2009) analysed the exoplanet host star 51 Pegasi by using both X-ray and Ca II H&K data. A constant and low coronal flux in addition to a flat chromospheric activity suggest that this star could be in an MM state. Another example is the star HD 4915, which has been recently reported as an MM candidate by Shah et al. (2018). In that work, the authors studied the activity behaviour of the star by using a long-term database of the Ca II H&K optical lines, which was acquired between 2006 and 2018. They found a decrease in the magnetic activity over two cycles, which was revealed by the core flux variation in Ca II H&K lines. This fact could be a strong indication for a possible MM state in HD 4915.

An alternative way to identify MM candidates was proposed by Donahue (1998) (hereafter DO98) and Wright (2004). The authors pointed out that a remarkable difference in the activity behaviour among main-sequence binary components could be used as an MM star’s detector. In such systems, a similar MM

state could be associated to the star with lower activity. Following this interpretation, Flores et al. (2018b) suggested that the activity difference observed between the components of the  $\zeta$  Ret binary system could be attributed to an atypical activity of  $\zeta^2$  Ret. The  $F_X$  values estimated from XMM-Newton database for  $\zeta^1$  Ret and  $\zeta^2$  Ret are  $(5.11 \pm 0.08) \times 10^{-13}$  and  $(0.25 \pm 0.32) \times 10^{-13}$  erg s<sup>-1</sup> cm<sup>-2</sup>, respectively. This shows that  $\zeta^1$  Ret is more active than  $\zeta^2$  Ret in X-rays (see Flores et al. 2018b, for more details). In this way, as a feasible scenario, the star  $\zeta^2$  Ret is possibly emerging from (or going to) a state similar to the MM. In that work, we stress the need for additional spectroscopic data in order to verify or rule out this possible scenario. Fortunately, more spectroscopic ESO data were acquired for this remarkable binary system. Moreover, we count with additional spectra taken with the REOSC spectrograph at CASLEO observatory.

This binary system is comprised of two solar analogue stars that are physically connected (Shaya & Olling 2011), and their spectral types are classified as G2 V and G1 V according to the Hipparcos database (see Saffe et al. 2016, for details). Both stars have very similar stellar parameters ( $T_{eff}$ ,  $\log g$ , and [Fe/H]) and they are also similar to the Sun (see Saffe et al. 2016, for more details). Their empirical rotational periods obtained from the Mamajek & Hillenbrand (2008) calibration are  $13.2 \pm 2.8$  d and  $16.5 \pm 1.8$  d for  $\zeta^1$  Ret and  $\zeta^2$  Ret, respectively. This strong physical similarity could help to diminish or remove a possible dependence of the minimum Ca II H&K activity levels on gravity and metallicity (e.g. Schrijver et al. 1989; Wright 2004; Giampapa 2012), which is an additional advantage for the mutual comparison in this system. In addition, the large available data set ( $\sim 19$  yrs of observations) converts this system into a unique laboratory that allows us to carry out a detailed long-term activity study in order to explore the possible MM state of  $\zeta^2$  Ret, following the suggestion of DO98.

The paper is organised as follows: In §2, the observations and data reduction are described. In §3, our stellar activity analysis is presented. Finally, our discussion and main conclusions are provided in §4.

## 2. Observations and data reduction

Most of the stellar spectra of  $\zeta^1$  (=HD 20766) and  $\zeta^2$  Ret (=HD 20807) were downloaded from the European Southern Observatory (ESO) archive<sup>2</sup>. These observations were acquired with the HARPS spectrograph (resolving power  $R \sim 115\,000$ ), attached to the La Silla 3.6-m (ESO) telescope between 2003 and 2019. We also included some spectra taken with UVES (between 2002 and 2009) and FEROS (during 2010 and 2014) spectrographs ( $R \sim 80\,000$  and  $R \sim 48\,000$ , respectively), which are coupled to the Unit 8.2-m Telescope 2 (UT2) of the Very Large Telescope (VLT) and to the 2.2-m telescope located at La Silla, respectively. All ESO spectra were automatically processed by the corresponding pipelines<sup>3,4,5</sup>.

Additionally, our analysis was complemented with observations performed with the REOSC<sup>6</sup> spectrograph ( $R \sim 13\,000$ ), working at the 2.15-m Jorge Sahade telescope at the CASLEO in

<sup>2</sup> [http://archive.eso.org/wdb/wdb/adp/phase3\\_spectral/form?phase3\\_collection=HARPS](http://archive.eso.org/wdb/wdb/adp/phase3_spectral/form?phase3_collection=HARPS)

<sup>3</sup> <http://www.eso.org/sci/facilities/lasilla/instruments/harps/overview.html>

<sup>4</sup> <http://www.eso.org/sci/facilities/paranal/instruments/uves.html>

<sup>5</sup> <http://www.eso.org/sci/facilities/lasilla/instruments/feros.html>

<sup>6</sup> <https://casleo.conicet.gov.ar/reosc-ds-dc/>

<sup>1</sup> While those stars with an  $\sigma_S/\bar{S} \geq 2\%$  are considered variable or erratic.

San Juan, Argentina. These data, taken between 2000 and 2015 under the HK $\alpha$  project<sup>7</sup>, were reduced following the standard procedures with IRAF<sup>8</sup> tasks, that is to say by performing bias subtraction, flat fielding, sky subtraction, order extraction, and wavelength calibration. See Table A.1 for details on observation logs.

Before the calculation of the standard  $S_{MW}$  index defined by Vaughan et al. (1978) at the Mount Wilson Observatory (MWO), we first discarded those spectra with low a signal-to-noise ratio ( $S/N \leq 100$ ). As a result, we obtained 79 spectra for  $\zeta^1$  Ret and 352 for  $\zeta^2$  Ret. These spectra, with a mean  $S/N \sim 175$  at 6070 Å, were corrected by radial velocities using standard IRAF tasks. Then, we integrated the flux in two windows centred at the cores of the Ca II H&K lines (3968.47 Å and 3933.66 Å, respectively), weighted with triangular profiles of 1.09 Å full width at half-maximum (FWHM), and computed the ratio of these fluxes to the mean continuum flux, which was integrated in two passbands of  $\sim 20$  Å width centred at 3891 and 4001 Å. As a result, we obtained the S-index corresponding to each one of the instruments used in this work, which were then converted to the  $S_{MW}$  following the calibration procedures of Lovis et al. (2011), Cincunegui et al. (2007), and Jenkins et al. (2008) for HARPS, REOSC, and FEROS spectroscopic data. For the case of UVES spectra, there is no calibration available. These data were intercalibrated to the rest of the time series.

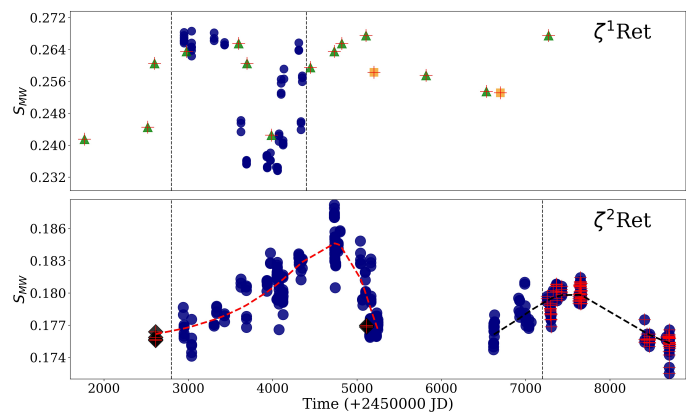
### 3. Stellar activity analysis

In order to search for clear signatures of a possible MM state in the binary system  $\zeta$  Ret, as suggested in Flores et al. (2018b), we show the time series of the  $S_{MW}$  indexes for both components in Fig. 1 ( $\zeta^1$  Ret and  $\zeta^2$  Ret are plotted in the upper and lower panels, respectively). We have included all spectroscopic data from HARPS, REOSC, FEROS, and UVES. As a result, we have an extensive database for each component of approximately 19 years. Vertical dashed lines were plotted to highlight the time coverage of our current series from those published in Flores et al. (2018b).

A direct comparison of these new time series shows a clear decrease in the amplitude of the chromospheric activity of the  $\zeta^2$  Ret component (from the first peak to the last one). To quantify this decrease in activity, in Fig. 1 we fitted the corresponding time series assuming a typical solar activity shape  $f(t)$  for each peak (see Eq. 8 in Egeland et al. 2017, for more details). The first cycle fit (red dashed line) is given by the following parameters:  $A = 0.0104$ ,  $B = 1.32$  yr,  $\alpha = -0.24$  yr<sup>-2</sup>,  $t_m = 2008.67$  yr (xJD=4711.72 days), and  $f_{min} = 0.17422$ , while the corresponding parameters for the second cycle (black dashed line) are  $A = 0.0053$ ,  $B = 1.59$  yr,  $\alpha \sim 2 \times 10^{-26}$  yr<sup>-2</sup>,  $t_m = 2016.42$  yr (xJD=7542.22 days), and  $f_{min} = 0.1746$ . As a result, both fits show an amplitude of  $\Delta S_{MW} = 0.0084$  and  $\Delta S_{MW} = 0.0045$ , meaning a decrease of  $\sim 47\%$  in the activity cycle amplitude. To classify each component according to their variability type, we considered the criteria adopted by Baliunas et al. (1995). Then,  $\zeta^1$  Ret can be classified as a variable star (with  $\sigma_S/\bar{S} \sim 4.3\%$ ), while  $\zeta^2$  Ret would be classified as a ‘flat star’ ( $\sigma_S/\bar{S} \sim 1.4\%$ ),

<sup>7</sup> The main aim of the HK $\alpha$  project consists in the systematic observation of main sequence stars to carry out long-term activity studies (see Cincunegui & Mauas 2004, for more details).

<sup>8</sup> IRAF is distributed by the National Optical Astronomical Observatories, which is operated by the Association of Universities for Research in Astronomy, Inc. (AURA), under a cooperative agreement with the National Science Foundation.

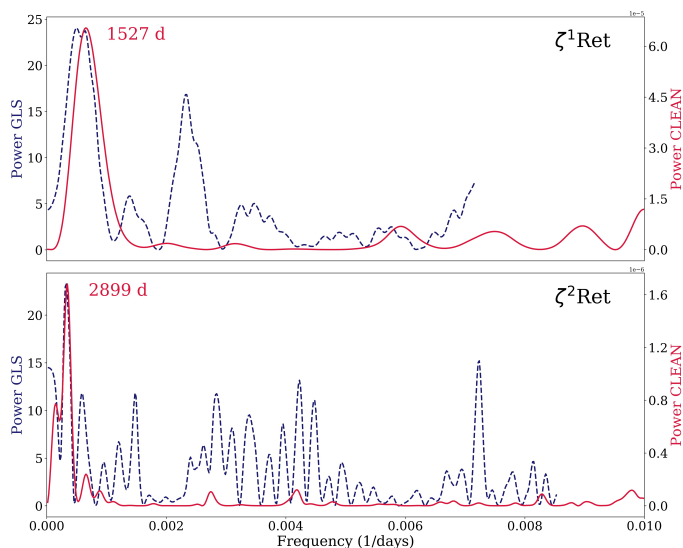


**Fig. 1.** Upper panel:  $S_{MW}$  index variation of  $\zeta^1$  Ret. HARPS data are indicated with blue circles (for both panels), while REOSC and FEROS data are indicated with green triangles and orange squares, respectively. Lower panel: Activity variation for  $\zeta^2$  Ret. Here, UVES data are indicated with black diamonds. Both vertical dashed lines in each panel represent the time coverage of those series that were initially reported, while the new data are indicated with red crosses. Red and black dashed lines show the fitted activity maxima  $f(t)$  for both peaks.

although its stellar activity shows a clear variation. For comparative purposes, we also computed the  $\log R'_{HK}$  index by subtracting the photospheric contribution following the prescription given in Noyes et al. (1984), resulting in a mean activity difference of  $\sim 0.24$  dex, which is slightly higher than the previous value of 0.22 dex reported in Flores et al. (2018b).

In order to explore the components of the Ca II H&K line-core fluxes responsible for the low  $S_{MW}$  index in  $\zeta^2$  Ret, we computed its basal level of activity. Schrijver et al. (1989) concluded that the line-core emission in the Ca II lines is composed by a photospheric component, a basal flux probably related to acoustic heating, and a third component associated with purely magnetic activity. In this sense, we estimated the Ca II photospheric component using a synthetic spectra calculated with SYNTH3 and ATLAS9 model atmospheres (Kurucz 1993), accounting for a photospheric Mount Wilson index of  $S_{phot} = 0.149$ . Following Mittag et al. (2013), we converted this index to the Ca II line-core photospheric fluxes of  $(2.539 \pm 0.017) \times 10^6$  erg cm<sup>-2</sup> s<sup>-1</sup>, which are higher than the photospheric flux derived in Noyes et al. (1984) for a star of  $B - V = 0.60$ . Mittag et al. (2013) revised this historical work and determined that the photospheric flux was underestimated. They also computed an excess basal flux non-photospheric in erg cm<sup>-2</sup> s<sup>-1</sup> given by  $\log(F'_{HK}) = 6.42 - 1.03(B - V)$ . Considering this contribution,  $F'_{HK} = (5.65 \pm 0.51) \times 10^5$  erg cm<sup>-2</sup> s<sup>-1</sup> and the photospheric flux derived from  $S_{phot}$  for  $\zeta^2$  Ret, the entire basal contribution  $F'_{HK} + F_{HK}^{phot} = (3.10 \pm 0.07) \times 10^6$  erg cm<sup>-2</sup> s<sup>-1</sup> is associated to a Mount Wilson index of  $S_{MW} \sim 0.180$ . The mean activity level of  $\zeta^2$  Ret between 6658.5 and 8849.5 days is slightly lower in less than  $1.5\sigma$ , thus it is mainly related to a basal chromospheric heating. Although a remaining magnetic contribution is still evident in the activity cycle.

To search for long-term activity cycles in this binary system, we first calculated the monthly means of all data. This procedure, which has been applied in previous works (e.g. Baliunas et al. 1995; Metcalfe et al. 2010; Gomes da Silva et al. 2011; Flores et al. 2018a), enables us to reduce the rotational scatter originated by individual active regions. Following Zechmeister & Kürster (2009), we computed the Generalised Lomb-Scargle periodogram (hereafter GLS) and the false-alarm probability (here-



**Fig. 2.** GLS (blue dashed line) and CLEAN (red continuous line) periodograms for the means of the Mount Wilson indexes plotted in Fig. 1. The upper and lower panels correspond to  $\zeta^1$  Ret and  $\zeta^2$  Ret, respectively. The most significant CLEAN periods are indicated in each panel.

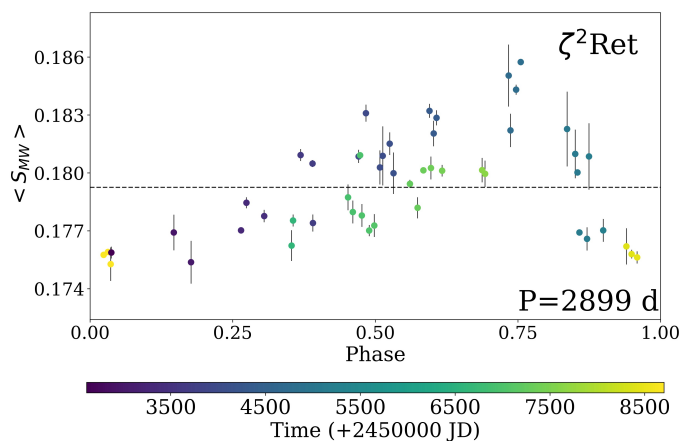
after FAP, see their equation 24) of each significant peak present in the periodograms. In the upper and lower panels of Fig. 2, we show the GLS (blue dashed line) for  $\zeta^1$  Ret and  $\zeta^2$  Ret, respectively. Both stars seem to be periodic. In the case of  $\zeta^1$ , we found two prominent peaks which can be associated with activity cycles, one of them has a period of  $1548 \pm 62$  d with an FAP of  $1 \times 10^{-14}$ . While, the second peak is  $431 \pm 6$  d with an FAP of  $2 \times 10^{-08}$ . For the  $\zeta^2$  Ret component, the large data set collected in this work allowed us to re-calculate its previously reported period ( $3670 \pm 170$  d). A prominent peak of  $3047 \pm 134$  d with an FAP of  $4 \times 10^{-12}$  was detected in the GLS periodogram (see the lower panel of Fig. 2). Therefore,  $\zeta^2$  Ret also satisfies the Baliunas et al. (1995) criteria for a cycling star (i.e.  $\text{FAP} \leq 10^{-02}$ ).

We also executed the CLEAN deconvolution algorithm (Roberts et al. 1987) to explore whether the 431-day period which appears in the GLS periodogram of  $\zeta^1$  Ret is due to sampling. A comparison between GLS (blue dashed line) and CLEAN (red continuous line) periodograms is shown in Fig. 2. For the case of  $\zeta^1$ , we found that the only predominant peak is around  $1527 \pm 43$  d, while for  $\zeta^2$  we obtained a single significant period of  $2899 \pm 139$  d. The errors of the periods detected with the CLEAN algorithm depend on the finite frequency resolution of the periodograms  $\delta\nu$  as given by Eq.(2) in Lamm et al. (2004),  $\delta P = \frac{\delta\nu P^2}{2}$ . Therefore, the periods found for the binary system employing the CLEAN algorithm correspond to those associated with the GLS method.

Finally, in Fig. 3 we show the monthly average values of the  $S_{MW}$  index for  $\zeta^2$  Ret phased with the period derived with the CLEAN algorithm. The errors of these data were calculated as their standard deviation; whereas for those bins with a single measurement, we considered the typical dispersion of other bins.

#### 4. Discussion and conclusions

Following the aim of this study, we carried out a long-term activity of the  $\zeta$  Ret binary system employing several spectroscopic data obtained over a span of 19 years. We detected long-term activity cycles of  $1527 \sim 43$  d ( $\sim 4.2$  yr, not yet reported in the literature) and  $2899 \sim 139$  d ( $\sim 7.9$  yr) for  $\zeta^1$  and  $\zeta^2$  Ret, respec-



**Fig. 3.** Monthly means of the Mount Wilson indexes for  $\zeta^2$  Ret phased with a period of  $\sim 7.9$  yr. The observing seasons are represented by coloured circles. The error bars of HARPS data and the corresponding mean activity level (dashed horizontal line) have been included.

tively. In particular, the new data included in this work allowed us to make a better estimation for the period obtained in Flores et al. (2018b) for  $\zeta^2$  Ret.

Flores et al. (2018b) propose two possible scenarios to explain the large difference in activity between the stars  $\zeta^1$  and  $\zeta^2$  Ret. In the first scenario, the stars possibly present different rotational periods<sup>9</sup>, which could result in different average activity levels. The second scenario suggests that the star  $\zeta^2$  Ret is possibly in an MM state. In the present work we collected new evidence, including more than 430 spectra acquired with the HARPS, REOSC, FEROS, and UVES spectrographs, which support the idea that  $\zeta^2$  Ret is possibly in an MM state due to the following reasons.

- There is a large difference in the average activity levels between both stars (hereafter  $\Delta$ ). DO98 and Wright (2004) suggested that binary systems, presumably co-eval stars, with significant  $\Delta$  levels could point to an MM state of the most inactive star. In particular, DO98 suggest that an age difference (estimated using an activity-age calibration) greater than  $\sim 1$  Gyr could indicate an MM state. Using the DO98 calibration, we estimate ages of 1.5 and 3.3 Gyr for  $\zeta^1$  Ret and  $\zeta^2$  Ret, that is to say a notable difference of  $\sim 1.8$  Gyr. An age difference greater than 1.0 Gyr is also obtained through the Mamajek & Hillenbrand (2008) and Lorenzo-Oliveira et al. (2016) calibrations.
- In fact, the value of  $\Delta = 0.24$  dex we found in the present work for most recent years has increased from the value  $\Delta = 0.22$  dex reported in Flores et al. (2018b)
- The cycle amplitude of  $\zeta^2$  Ret decreased notably, from  $\Delta S_{MW} = 0.0084$  to  $\Delta S_{MW} = 0.0045$  in the last cycle, that is to say it decreased by  $\sim 47\%$ . We caution that, until now, there is no clear agreement about the solar cycle behaviour during the MM state. Initially, sunspot records suggested that the cycle was interrupted (e.g. Spoerer & Maunder 1890; Eddy 1976; Wilson 1994). However, different works using counts of sunspots and cosmogenic isotopes indicate a weaker but persistent cycle (e.g. Ribes & Nesme-Ribes 1993; Beer et al. 1998; Miyahara et al. 2004; Poluianov

<sup>9</sup> The analysis of these new spectroscopic data does not reveal the presence of any reliable rotational modulation for both stars.



et al. 2014; Vaquero et al. 2015). In addition to the Sun, Shah et al. (2018) show that the G5V star HD 4915, which is a candidate to present an MM state, also reveals a cycle still in progress with decreasing amplitude, similar to  $\zeta^2$  Ret.

- The current activity level of  $\zeta^2$  Ret is very low ( $\langle F_{HK} \rangle \sim 3 \times 10^6 \text{ erg cm}^{-2} \text{ s}^{-1}$ ). This value is even lower within the statistical error than the theoretical basal level for this object ( $F_{HK} = (3.10 \pm 0.07) \times 10^6 \text{ erg cm}^{-2} \text{ s}^{-1}$ ). The basal value was determined by estimating the sum of the non-photospheric basal flux  $F'_{HK}$  for B-V = 0.60 (Mittag et al. 2013), and the photospheric contribution was estimated using a synthetic spectra calculated with SYNTHE and ATLAS9 model atmospheres (Kurucz 1993). The stellar parameters of  $\zeta^2$  Ret were taken from the high-precision analysis of Saffe et al. (2016).

Finding an unambiguous example of an MM candidate is a very difficult task, which is due in part to the fact that an MM state in general is not totally clear, and it requires a large observational time span. To date, only very few MM candidates have been reported in the literature, HD 4915 being one of them (Shah et al. 2018). For the case of  $\zeta^2$  Ret, we profit from the fact that this star belongs to a binary system, which makes it a very valuable candidate. In fact, to our knowledge,  $\zeta^2$  Ret is the first MM candidate to have been detected through the activity differences in a binary system, as suggested by DO98.

Finally, we strongly recommend searching for valuable MM candidates in those binary systems with high activity differences. They can be used as good laboratories to address many questions related to solar and stellar MM, which have yet to be subjected to intense scrutiny (see Zolotova & Ponyavin 2015; Vaquero et al. 2015; Carrasco et al. 2019, for more details).

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## References

Baliunas, S. & Jastrow, R. 1990, *Nature*, 348, 520  
 Baliunas, S. L., Donahue, R. A., Soon, W., & Henry, G. W. 1998, 154, 153  
 Baliunas, S. L., Donahue, R. A., Soon, W. H., et al. 1995, *ApJ*, 438, 269  
 Beer, J., Tobias, S., & Weiss, N. 1998, *Sol. Phys.*, 181, 237  
 Carrasco, V. M. S., Vaquero, J. M., Gallego, M. C., et al. 2019, *ApJ*, 886, 18  
 Charbonneau, P. 2010, *Living Reviews in Solar Physics*, 7, 3  
 Cincunegui, C., Díaz, R. F., & Mauas, P. J. D. 2007, *A&A*, 469, 309  
 Cincunegui, C. & Mauas, P. J. D. 2004, 414, 699  
 Donahue, R. A. 1998, in *Astronomical Society of the Pacific Conference Series*, Vol. 154, *Cool Stars, Stellar Systems, and the Sun*, ed. R. A. Donahue & J. A. Bookbinder, 1235  
 Eddy, J. A. 1976, *Science*, 192, 1189  
 Egeland, R., Soon, W., Baliunas, S., et al. 2017, *ApJ*, 835, 25  
 Flores, M., González, J. F., Jaque Arancibia, M., et al. 2018a, *A&A*, 620, A34  
 Flores, M., Saffe, C., Buccino, A., et al. 2018b, *MNRAS*, 476, 2751  
 Giampapa, M. S. 2012, in *IAU Symposium*, Vol. 286, *IAU Symposium*, ed. C. H. Mandrini & D. F. Webb, 257–267  
 Gomes da Silva, J., Santos, N. C., Bonfils, X., et al. 2011, *A&A*, 534, A30  
 Henry, T. J., Soderblom, D. R., Donahue, R. A., & Baliunas, S. L. 1996, *AJ*, 111  
 Jenkins, J. S., Jones, H. R. A., Pavlenko, Y., et al. 2008, *A&A*, 485, 571  
 Judge, P. G. & Saar, S. H. 2007, *ApJ*, 663, 643  
 Kurucz, R. 1993, 13  
 Lamm, M. H., Bailer-Jones, C. A. L., Mundt, R., Herbst, W., & Scholz, A. 2004, *A&A*, 417, 557  
 Lorenzo-Oliveira, D., Porto de Mello, G. F., & Schiavon, R. P. 2016, *A&A*, 594, L3  
 Lovis, C., Dumusque, X., Santos, N. C., et al. 2011, *ArXiv e-prints* [arXiv:1107.5325]

Mamajek, E. E. & Hillenbrand, L. A. 2008, *ApJ*, 687, 1264  
 Metcalfe, T. S., Basu, S., Henry, T. J., et al. 2010, *ApJ*, 723, L213  
 Mittag, M., Schmitt, J. H. M. M., & Schröder, K. P. 2013, *A&A*, 549, A117  
 Miyahara, H., Masuda, K., Muraki, Y., et al. 2004, *Sol. Phys.*, 224, 317  
 Nagovitsyn, Y. A. 2007, *Astronomy Letters*, 33, 340  
 Noyes, R. W., Hartmann, L. W., Baliunas, S. L., Duncan, D. K., & Vaughan, A. H. 1984, *ApJ*, 279, 763  
 Poluianov, S. V., Usoskin, I. G., & Kovaltsov, G. A. 2014, *Sol. Phys.*, 289, 4701  
 Poppenhäger, K., Robrade, J., Schmitt, J. H. M. M., & Hall, J. C. 2009, *A&A*, 508, 1417  
 Ribes, E., Merlin, P., Ribes, J. C., & Bartholot, R. 1989, *Annales Geophysicae*, 7, 321  
 Ribes, J. C. & Nesme-Ribes, E. 1993, *A&A*, 276, 549  
 Roberts, D. H., Lehar, J., & Dreher, J. W. 1987, *AJ*, 93, 968  
 Saar, S. H. & Baliunas, S. L. 1992, in *Astronomical Society of the Pacific Conference Series*, Vol. 27, *The Solar Cycle*, ed. K. L. Harvey, 150–167  
 Saffe, C., Flores, M., Jaque Arancibia, M., Buccino, A., & Jofré, E. 2016, *A&A*, 588, A81  
 Schrijver, C. J., Dobson, A. K., & Radick, R. R. 1989, *ApJ*, 341, 1035  
 Schröder, K. P., Mittag, M., Schmitt, J. H. M. M., et al. 2017, *MNRAS*, 470, 276  
 Shah, S. P., Wright, J. T., Isaacson, H., Howard, A. W., & Curtis, J. L. 2018, *The Astrophysical Journal*, 863, L26  
 Shaya, E. J. & Olling, R. P. 2011, *ApJS*, 192, 2  
 Soon, W. W.-H. & Yaskell, S. H. 2003, *The Maunder Minimum and the Variable Sun-Earth Connection* ((Singapore: World Scientific Publ. C.))  
 Spoerer, F. W. G. & Maunder, E. W. 1890, *MNRAS*, 50, 251  
 Usoskin, I. G., Mursula, K., & Kovaltsov, G. A. 2001, *J. Geophys. Res.*, 106, 16039  
 Usoskin, I. G., Solanki, S. K., Taricco, C., Bhandari, N., & Kovaltsov, G. A. 2006, *A&A*, 457, L25  
 Vaquero, J. M., Kovaltsov, G. A., Usoskin, I. G., Carrasco, V. M. S., & Gallego, M. C. 2015, *A&A*, 577, A71  
 Vaughan, A. H., Preston, G. W., & Wilson, O. C. 1978, *PASP*, 90, 267  
 Wilson, O. C. 1978, *ApJ*, 226, 379  
 Wilson, P. R. 1994, *Cambridge Astrophysics Series*, 24  
 Wright, J. T. 2004, *AJ*, 128, 1273  
 Zechmeister, M. & Kürster, M. 2009, *A&A*, 496, 577  
 Zolotova, N. V. & Ponyavin, D. I. 2015, *The Astrophysical Journal*, 800, 42

**Appendix A: Observational data and derived Mount  
Wilson indexes for  $\zeta$  Ret.**

**Table A.1.** Observational data and derived  $S_{MW}$  indexes for the binary system  $\zeta$  Ret.

| HD 20766       |         |            |                     | HD 20807 |                |         |            |                     |          |
|----------------|---------|------------|---------------------|----------|----------------|---------|------------|---------------------|----------|
| Observing date | xJD     | Instrument | Observing programme | $S_{MW}$ | Observing date | xJD     | Instrument | Observing programme | $S_{MW}$ |
| 2000-08-12     | 1769    | REOSC      | 0800(B)             | 0.242    | 2002-12-05     | 2613.50 | UVES       | 266.D-5655(A)       | 0.176    |
| 2002-08-01     | 2519    | REOSC      | 0802(C)             | 0.244    | 2002-12-05     | 2613.50 | UVES       | 266.D-5655(A)       | 0.176    |
| 2002-11-21     | 2600    | REOSC      | 1102(A)             | 0.260    | 2002-12-05     | 2613.50 | UVES       | 266.D-5655(A)       | 0.177    |
| 2003-11-06     | 2949.25 | HARPS      | 072.C-0513(B)       | 0.266    | 2002-12-05     | 2613.50 | UVES       | 266.D-5655(A)       | 0.177    |
| 2003-11-06     | 2949.26 | HARPS      | 072.C-0513(B)       | 0.266    | 2003-10-27     | 2939.26 | HARPS      | 072.C-0488(E)       | 0.179    |
| 2003-11-06     | 2949.26 | HARPS      | 072.C-0513(B)       | 0.266    | 2003-10-30     | 2942.23 | HARPS      | 072.C-0488(E)       | 0.178    |
| 2003-11-06     | 2949.26 | HARPS      | 072.C-0513(B)       | 0.267    | 2003-11-06     | 2949.27 | HARPS      | 072.C-0513(B)       | 0.176    |
| 2003-11-06     | 2949.26 | HARPS      | 072.C-0513(B)       | 0.268    | 2003-11-06     | 2949.27 | HARPS      | 072.C-0513(B)       | 0.176    |
| 2003-11-06     | 2949.27 | HARPS      | 072.C-0513(B)       | 0.268    | 2003-11-06     | 2949.27 | HARPS      | 072.C-0513(B)       | 0.176    |
| 2003-12-05     | 2979    | REOSC      | 1203(A)             | 0.264    | 2003-11-06     | 2949.27 | HARPS      | 072.C-0513(B)       | 0.177    |
| 2004-02-04     | 3039.11 | HARPS      | 072.C-0513(D)       | 0.262    | 2003-11-06     | 2949.28 | HARPS      | 072.C-0513(B)       | 0.177    |
| 2004-02-04     | 3039.12 | HARPS      | 072.C-0513(D)       | 0.264    | 2003-11-06     | 2949.28 | HARPS      | 072.C-0513(B)       | 0.177    |
| 2004-02-04     | 3039.12 | HARPS      | 072.C-0513(D)       | 0.265    | 2004-02-04     | 3039.13 | HARPS      | 072.C-0513(D)       | 0.174    |
| 2004-02-04     | 3039.12 | HARPS      | 072.C-0513(D)       | 0.265    | 2004-02-04     | 3039.13 | HARPS      | 072.C-0513(D)       | 0.174    |
| 2004-02-04     | 3039.13 | HARPS      | 072.C-0513(D)       | 0.266    | 2004-02-04     | 3039.14 | HARPS      | 072.C-0513(D)       | 0.175    |
| 2004-02-04     | 3039.13 | HARPS      | 072.C-0513(D)       | 0.269    | 2004-02-04     | 3039.14 | HARPS      | 072.C-0513(D)       | 0.175    |
| 2004-10-28     | 3306.33 | HARPS      | 074.C-0012(A)       | 0.266    | 2004-02-04     | 3039.14 | HARPS      | 072.C-0513(D)       | 0.176    |
| 2004-10-28     | 3306.33 | HARPS      | 074.C-0012(A)       | 0.267    | 2004-02-04     | 3039.15 | HARPS      | 072.C-0513(D)       | 0.178    |
| 2004-10-28     | 3306.33 | HARPS      | 074.C-0012(A)       | 0.268    | 2004-10-28     | 3306.33 | HARPS      | 074.C-0012(A)       | 0.177    |
| 2005-03-01     | 3430.06 | HARPS      | 074.C-0012(B)       | 0.265    | 2004-10-28     | 3306.33 | HARPS      | 074.C-0012(A)       | 0.177    |
| 2005-03-01     | 3430.07 | HARPS      | 074.C-0012(B)       | 0.265    | 2004-10-28     | 3306.34 | HARPS      | 074.C-0012(A)       | 0.177    |
| 2005-03-01     | 3430.07 | HARPS      | 074.C-0012(B)       | 0.266    | 2004-11-26     | 3335.20 | HARPS      | 072.C-0488(E)       | 0.178    |
| 2005-08-14     | 3597.82 | REOSC      | 0805(A)             | 0.266    | 2004-11-26     | 3335.20 | HARPS      | 072.C-0488(E)       | 0.178    |
| 2005-09-11     | 3624.40 | HARPS      | 60.A-9036(A)        | 0.243    | 2004-11-26     | 3335.20 | HARPS      | 072.C-0488(E)       | 0.179    |
| 2005-09-11     | 3624.41 | HARPS      | 60.A-9036(A)        | 0.245    | 2004-11-26     | 3335.21 | HARPS      | 072.C-0488(E)       | 0.179    |
| 2005-09-11     | 3624.41 | HARPS      | 60.A-9036(A)        | 0.246    | 2005-03-01     | 3430.05 | HARPS      | 074.C-0012(B)       | 0.177    |
| 2005-11-15     | 3689.15 | HARPS      | 60.A-9036(A)        | 0.236    | 2005-03-01     | 3430.06 | HARPS      | 074.C-0012(B)       | 0.178    |
| 2005-11-15     | 3689.16 | HARPS      | 60.A-9036(A)        | 0.236    | 2005-03-01     | 3430.06 | HARPS      | 074.C-0012(B)       | 0.178    |
| 2005-11-15     | 3689.16 | HARPS      | 60.A-9036(A)        | 0.236    | 2005-09-11     | 3624.42 | HARPS      | 60.A-9036(A)        | 0.181    |
| 2005-11-16     | 3690.26 | HARPS      | 076.C-0878(A)       | 0.235    | 2005-09-11     | 3624.42 | HARPS      | 60.A-9036(A)        | 0.181    |
| 2005-11-16     | 3690.26 | HARPS      | 076.C-0878(A)       | 0.235    | 2005-09-11     | 3624.43 | HARPS      | 60.A-9036(A)        | 0.181    |
| 2005-11-16     | 3690.26 | HARPS      | 076.C-0878(A)       | 0.236    | 2005-11-14     | 3688.15 | HARPS      | 60.A-9036(A)        | 0.180    |
| 2005-11-22     | 3697.68 | REOSC      | 1105(A)             | 0.260    | 2005-11-14     | 3688.15 | HARPS      | 60.A-9036(A)        | 0.181    |
| 2006-07-14     | 3930.44 | HARPS      | 077.C-0530(A)       | 0.237    | 2005-11-14     | 3688.16 | HARPS      | 60.A-9036(A)        | 0.181    |
| 2006-07-14     | 3930.44 | HARPS      | 077.C-0530(A)       | 0.237    | 2005-11-16     | 3690.26 | HARPS      | 076.C-0878(A)       | 0.177    |
| 2006-07-14     | 3930.44 | HARPS      | 077.C-0530(A)       | 0.237    | 2005-11-16     | 3690.27 | HARPS      | 076.C-0878(A)       | 0.178    |
| 2006-07-20     | 3936.33 | HARPS      | 077.C-0530(A)       | 0.234    | 2005-11-16     | 3690.27 | HARPS      | 076.C-0878(A)       | 0.178    |
| 2006-07-20     | 3936.33 | HARPS      | 077.C-0530(A)       | 0.234    | 2006-07-16     | 3932.41 | HARPS      | 077.C-0530(A)       | 0.180    |
| 2006-07-20     | 3936.34 | HARPS      | 077.C-0530(A)       | 0.235    | 2006-07-16     | 3932.41 | HARPS      | 077.C-0530(A)       | 0.181    |
| 2006-08-26     | 3973.34 | HARPS      | 077.C-0530(A)       | 0.236    | 2006-07-16     | 3932.41 | HARPS      | 077.C-0530(A)       | 0.181    |
| 2006-08-26     | 3973.35 | HARPS      | 077.C-0530(A)       | 0.236    | 2006-07-20     | 3936.33 | HARPS      | 077.C-0530(A)       | 0.181    |
| 2006-08-26     | 3973.35 | HARPS      | 077.C-0530(A)       | 0.238    | 2006-07-20     | 3936.33 | HARPS      | 077.C-0530(A)       | 0.181    |
| 2006-09-07     | 3985.80 | REOSC      | 0906(A)             | 0.243    | 2006-07-20     | 3936.33 | HARPS      | 077.C-0530(A)       | 0.181    |
| 2006-11-04     | 4043.12 | HARPS      | 078.C-0044(A)       | 0.234    | 2006-08-26     | 3973.34 | HARPS      | 077.C-0530(A)       | 0.183    |
| 2006-11-18     | 4057.13 | HARPS      | 078.C-0044(A)       | 0.234    | 2006-08-26     | 3973.34 | HARPS      | 077.C-0530(A)       | 0.183    |
| 2006-11-19     | 4058.07 | HARPS      | 078.C-0833(A)       | 0.234    | 2006-08-26     | 3973.34 | HARPS      | 077.C-0530(A)       | 0.184    |
| 2006-11-19     | 4058.07 | HARPS      | 078.C-0833(A)       | 0.234    | 2006-11-08     | 4047.17 | HARPS      | 072.C-0488(E)       | 0.181    |
| 2006-11-19     | 4058.07 | HARPS      | 078.C-0833(A)       | 0.234    | 2006-11-10     | 4049.19 | HARPS      | 072.C-0488(E)       | 0.179    |
| 2006-12-07     | 4076.07 | HARPS      | 078.C-0044(A)       | 0.241    | 2006-11-12     | 4051.20 | HARPS      | 072.C-0488(E)       | 0.181    |
| 2006-12-07     | 4076.10 | HARPS      | 078.C-0833(A)       | 0.242    | 2006-11-12     | 4051.21 | HARPS      | 072.C-0488(E)       | 0.182    |
| 2006-12-07     | 4076.10 | HARPS      | 078.C-0833(A)       | 0.243    | 2006-11-14     | 4053.25 | HARPS      | 072.C-0488(E)       | 0.182    |
| 2006-12-31     | 4100.08 | HARPS      | 078.C-0044(A)       | 0.253    | 2006-11-14     | 4053.26 | HARPS      | 072.C-0488(E)       | 0.182    |
| 2006-12-31     | 4100.25 | HARPS      | 078.C-0833(A)       | 0.253    | 2006-11-14     | 4053.26 | HARPS      | 072.C-0488(E)       | 0.183    |
| 2006-12-31     | 4100.25 | HARPS      | 078.C-0833(A)       | 0.256    | 2006-11-16     | 4055.23 | HARPS      | 072.C-0488(E)       | 0.182    |
| 2006-12-31     | 4100.25 | HARPS      | 078.C-0833(A)       | 0.257    | 2006-11-16     | 4055.23 | HARPS      | 072.C-0488(E)       | 0.182    |
| 2007-01-24     | 4124.10 | HARPS      | 078.C-0044(A)       | 0.240    | 2006-11-16     | 4055.24 | HARPS      | 072.C-0488(E)       | 0.183    |
| 2007-01-24     | 4124.10 | HARPS      | 078.C-0833(A)       | 0.240    | 2006-11-19     | 4058.07 | HARPS      | 078.C-0833(A)       | 0.179    |
| 2007-01-24     | 4124.10 | HARPS      | 078.C-0833(A)       | 0.241    | 2006-11-19     | 4058.07 | HARPS      | 078.C-0833(A)       | 0.180    |
| 2007-01-24     | 4124.10 | HARPS      | 078.C-0833(A)       | 0.241    | 2006-11-19     | 4058.07 | HARPS      | 078.C-0833(A)       | 0.181    |
| 2007-02-02     | 4133.14 | HARPS      | 078.C-0044(A)       | 0.259    | 2006-12-07     | 4076.09 | HARPS      | 072.C-0488(E)       | 0.180    |
| 2007-02-03     | 4134.10 | HARPS      | 078.C-0044(A)       | 0.257    | 2006-12-07     | 4076.09 | HARPS      | 072.C-0488(E)       | 0.181    |
| 2007-07-29     | 4310.42 | HARPS      | 079.C-0681(A)       | 0.264    | 2006-12-07     | 4076.09 | HARPS      | 072.C-0488(E)       | 0.181    |
| 2007-07-29     | 4310.42 | HARPS      | 079.C-0681(A)       | 0.264    | 2006-12-07     | 4076.24 | HARPS      | 072.C-0488(E)       | 0.181    |
| 2007-07-29     | 4310.43 | HARPS      | 079.C-0681(A)       | 0.266    | 2006-12-07     | 4076.24 | HARPS      | 078.C-0833(A)       | 0.177    |
| 2007-08-23     | 4335.32 | HARPS      | 079.C-0681(A)       | 0.244    | 2006-12-07     | 4076.25 | HARPS      | 078.C-0833(A)       | 0.179    |
| 2007-08-23     | 4335.32 | HARPS      | 079.C-0681(A)       | 0.246    | 2006-12-07     | 4076.25 | HARPS      | 078.C-0833(A)       | 0.180    |
| 2007-08-23     | 4335.32 | HARPS      | 079.C-0681(A)       | 0.246    | 2006-12-31     | 4100.25 | HARPS      | 078.C-0833(A)       | 0.182    |
| 2007-09-07     | 4350.38 | HARPS      | 079.C-0681(A)       | 0.256    | 2007-01-15     | 4115.08 | HARPS      | 072.C-0488(E)       | 0.182    |
| 2007-09-07     | 4350.38 | HARPS      | 079.C-0681(A)       | 0.257    | 2007-01-20     | 4120.11 | HARPS      | 072.C-0488(E)       | 0.179    |
| 2007-09-07     | 4350.39 | HARPS      | 079.C-0681(A)       | 0.257    | 2007-01-20     | 4120.11 | HARPS      | 072.C-0488(E)       | 0.179    |
| 2007-12-13     | 4448.69 | REOSC      | 1207(B)             | 0.259    | 2007-01-20     | 4120.12 | HARPS      | 072.C-0488(E)       | 0.179    |
| 2008-09-22     | 4730.76 | REOSC      | 0908(D)             | 0.264    | 2007-01-20     | 4120.12 | HARPS      | 072.C-0488(E)       | 0.179    |
| 2008-12-20     | 4821.61 | REOSC      | 1208(C)             | 0.266    | 2007-01-20     | 4120.12 | HARPS      | 072.C-0488(E)       | 0.180    |
| 2009-12-02     | 5188    | REOSC      | 1009(B)             | 0.268    | 2007-01-21     | 4121.08 | HARPS      | 072.C-0488(E)       | 0.180    |
| 2010-01-05     | 5201.03 | FEROS      | 084.A-9004(B)       | 0.258    | 2007-01-21     | 4121.08 | HARPS      | 072.C-0488(E)       | 0.181    |
| 2011-09-14     | 5819.76 | REOSC      | 0911(B)             | 0.258    | 2007-01-21     | 4121.09 | HARPS      | 072.C-0488(E)       | 0.182    |
| 2013-08-31     | 6535.88 | REOSC      | 0813(A)             | 0.253    | 2007-01-23     | 4123.08 | HARPS      | 078.C-0833(A)       | 0.178    |
| 2014-02-11     | 6699.03 | FEROS      | 092.A-9002(A)       | 0.253    | 2007-01-23     | 4123.08 | HARPS      | 078.C-0833(A)       | 0.180    |
| 2015-09-08     | 7273    | REOSC      | 0915(C)             | 0.268    | 2007-01-23     | 4123.08 | HARPS      | 078.C-0833(A)       | 0.180    |
|                |         |            |                     |          | 2007-07-29     | 4310.43 | HARPS      | 079.C-0681(A)       | 0.183    |
|                |         |            |                     |          | 2007-07-29     | 4310.43 | HARPS      | 079.C-0681(A)       | 0.184    |
|                |         |            |                     |          | 2007-07-29     | 4310.43 | HARPS      | 079.C-0681(A)       | 0.184    |

Table A.1. continued.

| HD 20766       |     |            |                |                 | HD 20807       |         |            |                |                 |
|----------------|-----|------------|----------------|-----------------|----------------|---------|------------|----------------|-----------------|
| Observing date | xJD | Instrument | Obs. programme | S <sub>MW</sub> | Observing date | xJD     | Instrument | Obs. programme | S <sub>MW</sub> |
|                |     |            |                |                 | 2007-08-03     | 4315.36 | HARPS      | 072.C-0488(E)  | 0.183           |
|                |     |            |                |                 | 2007-08-03     | 4315.37 | HARPS      | 072.C-0488(E)  | 0.183           |
|                |     |            |                |                 | 2007-08-03     | 4315.37 | HARPS      | 072.C-0488(E)  | 0.183           |
|                |     |            |                |                 | 2007-08-23     | 4335.31 | HARPS      | 079.C-0681(A)  | 0.181           |
|                |     |            |                |                 | 2007-08-23     | 4335.31 | HARPS      | 079.C-0681(A)  | 0.182           |
|                |     |            |                |                 | 2007-08-23     | 4335.32 | HARPS      | 079.C-0681(A)  | 0.183           |
|                |     |            |                |                 | 2007-09-07     | 4350.41 | HARPS      | 079.C-0681(A)  | 0.182           |
|                |     |            |                |                 | 2007-09-07     | 4350.41 | HARPS      | 079.C-0681(A)  | 0.183           |
|                |     |            |                |                 | 2007-09-07     | 4350.41 | HARPS      | 079.C-0681(A)  | 0.183           |
|                |     |            |                |                 | 2008-09-22     | 4731.29 | HARPS      | 072.C-0488(E)  | 0.187           |
|                |     |            |                |                 | 2008-09-22     | 4731.29 | HARPS      | 072.C-0488(E)  | 0.187           |
|                |     |            |                |                 | 2008-09-22     | 4731.29 | HARPS      | 072.C-0488(E)  | 0.187           |
|                |     |            |                |                 | 2008-09-22     | 4731.30 | HARPS      | 072.C-0488(E)  | 0.187           |
|                |     |            |                |                 | 2008-09-22     | 4731.30 | HARPS      | 072.C-0488(E)  | 0.187           |
|                |     |            |                |                 | 2008-09-22     | 4731.30 | HARPS      | 072.C-0488(E)  | 0.188           |
|                |     |            |                |                 | 2008-09-22     | 4731.30 | HARPS      | 072.C-0488(E)  | 0.188           |
|                |     |            |                |                 | 2008-09-27     | 4736.22 | HARPS      | 072.C-0488(E)  | 0.183           |
|                |     |            |                |                 | 2008-09-27     | 4736.22 | HARPS      | 072.C-0488(E)  | 0.184           |
|                |     |            |                |                 | 2008-09-27     | 4736.22 | HARPS      | 072.C-0488(E)  | 0.184           |
|                |     |            |                |                 | 2008-09-27     | 4736.23 | HARPS      | 072.C-0488(E)  | 0.184           |
|                |     |            |                |                 | 2008-09-28     | 4737.31 | HARPS      | 072.C-0488(E)  | 0.183           |
|                |     |            |                |                 | 2008-09-28     | 4737.32 | HARPS      | 072.C-0488(E)  | 0.183           |
|                |     |            |                |                 | 2008-09-28     | 4737.32 | HARPS      | 072.C-0488(E)  | 0.184           |
|                |     |            |                |                 | 2008-09-28     | 4737.32 | HARPS      | 072.C-0488(E)  | 0.184           |
|                |     |            |                |                 | 2008-09-28     | 4737.32 | HARPS      | 072.C-0488(E)  | 0.184           |
|                |     |            |                |                 | 2008-09-28     | 4737.32 | HARPS      | 072.C-0488(E)  | 0.185           |
|                |     |            |                |                 | 2008-09-28     | 4737.32 | HARPS      | 072.C-0488(E)  | 0.185           |
|                |     |            |                |                 | 2008-09-29     | 4738.32 | HARPS      | 072.C-0488(E)  | 0.183           |
|                |     |            |                |                 | 2008-09-29     | 4738.33 | HARPS      | 072.C-0488(E)  | 0.184           |
|                |     |            |                |                 | 2008-09-29     | 4738.33 | HARPS      | 072.C-0488(E)  | 0.184           |
|                |     |            |                |                 | 2008-09-29     | 4738.33 | HARPS      | 072.C-0488(E)  | 0.184           |
|                |     |            |                |                 | 2008-09-29     | 4738.33 | HARPS      | 072.C-0488(E)  | 0.185           |
|                |     |            |                |                 | 2008-09-29     | 4738.34 | HARPS      | 072.C-0488(E)  | 0.185           |
|                |     |            |                |                 | 2008-09-29     | 4738.34 | HARPS      | 072.C-0488(E)  | 0.186           |
|                |     |            |                |                 | 2008-10-03     | 4742.25 | HARPS      | 072.C-0488(E)  | 0.180           |
|                |     |            |                |                 | 2008-10-07     | 4746.22 | HARPS      | 072.C-0488(E)  | 0.183           |
|                |     |            |                |                 | 2008-10-07     | 4746.23 | HARPS      | 072.C-0488(E)  | 0.183           |
|                |     |            |                |                 | 2008-10-07     | 4746.23 | HARPS      | 072.C-0488(E)  | 0.183           |
|                |     |            |                |                 | 2008-10-07     | 4746.23 | HARPS      | 072.C-0488(E)  | 0.183           |
|                |     |            |                |                 | 2008-11-04     | 4774.20 | HARPS      | 072.C-0488(E)  | 0.184           |
|                |     |            |                |                 | 2008-11-04     | 4774.21 | HARPS      | 072.C-0488(E)  | 0.184           |
|                |     |            |                |                 | 2008-11-04     | 4774.21 | HARPS      | 072.C-0488(E)  | 0.184           |
|                |     |            |                |                 | 2008-11-06     | 4776.23 | HARPS      | 072.C-0488(E)  | 0.184           |
|                |     |            |                |                 | 2008-11-06     | 4776.23 | HARPS      | 072.C-0488(E)  | 0.184           |
|                |     |            |                |                 | 2008-11-06     | 4776.24 | HARPS      | 072.C-0488(E)  | 0.185           |
|                |     |            |                |                 | 2008-11-06     | 4776.24 | HARPS      | 072.C-0488(E)  | 0.185           |
|                |     |            |                |                 | 2008-11-06     | 4776.24 | HARPS      | 072.C-0488(E)  | 0.185           |
|                |     |            |                |                 | 2008-11-30     | 4800.15 | HARPS      | 072.C-0488(E)  | 0.186           |
|                |     |            |                |                 | 2008-11-30     | 4800.16 | HARPS      | 072.C-0488(E)  | 0.186           |
|                |     |            |                |                 | 2009-07-27     | 5039.43 | HARPS      | 183.C-0972(A)  | 0.185           |
|                |     |            |                |                 | 2009-07-29     | 5041.38 | HARPS      | 183.C-0972(A)  | 0.183           |
|                |     |            |                |                 | 2009-07-29     | 5041.38 | HARPS      | 183.C-0972(A)  | 0.183           |
|                |     |            |                |                 | 2009-07-29     | 5041.38 | HARPS      | 183.C-0972(A)  | 0.183           |
|                |     |            |                |                 | 2009-07-29     | 5041.39 | HARPS      | 183.C-0972(A)  | 0.184           |
|                |     |            |                |                 | 2009-08-21     | 5064.40 | HARPS      | 183.C-0972(A)  | 0.179           |
|                |     |            |                |                 | 2009-08-21     | 5064.40 | HARPS      | 183.C-0972(A)  | 0.179           |
|                |     |            |                |                 | 2009-08-27     | 5070.36 | HARPS      | 183.C-0972(A)  | 0.179           |
|                |     |            |                |                 | 2009-09-24     | 5098.26 | HARPS      | 183.C-0972(A)  | 0.181           |
|                |     |            |                |                 | 2009-09-24     | 5098.26 | HARPS      | 183.C-0972(A)  | 0.182           |
|                |     |            |                |                 | 2009-09-24     | 5098.27 | HARPS      | 183.C-0972(A)  | 0.182           |
|                |     |            |                |                 | 2009-09-29     | 5103.29 | HARPS      | 183.C-0972(A)  | 0.180           |
|                |     |            |                |                 | 2009-09-29     | 5103.30 | HARPS      | 183.C-0972(A)  | 0.180           |
|                |     |            |                |                 | 2009-09-29     | 5103.30 | HARPS      | 183.C-0972(A)  | 0.180           |
|                |     |            |                |                 | 2009-10-09     | 5113.75 | UVES       | 266.D-5655(A)  | 0.176           |
|                |     |            |                |                 | 2009-10-09     | 5113.75 | UVES       | 266.D-5655(A)  | 0.176           |
|                |     |            |                |                 | 2009-11-16     | 5151.20 | HARPS      | 183.C-0972(A)  | 0.176           |
|                |     |            |                |                 | 2009-11-16     | 5151.20 | HARPS      | 183.C-0972(A)  | 0.176           |
|                |     |            |                |                 | 2009-11-16     | 5151.21 | HARPS      | 183.C-0972(A)  | 0.176           |
|                |     |            |                |                 | 2009-11-16     | 5151.21 | HARPS      | 183.C-0972(A)  | 0.176           |
|                |     |            |                |                 | 2009-11-20     | 5155.15 | HARPS      | 183.C-0972(A)  | 0.176           |
|                |     |            |                |                 | 2009-11-20     | 5155.15 | HARPS      | 183.C-0972(A)  | 0.176           |
|                |     |            |                |                 | 2009-11-20     | 5155.15 | HARPS      | 183.C-0972(A)  | 0.176           |
|                |     |            |                |                 | 2009-11-20     | 5155.15 | HARPS      | 183.C-0972(A)  | 0.176           |
|                |     |            |                |                 | 2009-11-20     | 5155.16 | HARPS      | 183.C-0972(A)  | 0.177           |
|                |     |            |                |                 | 2009-11-20     | 5155.16 | HARPS      | 183.C-0972(A)  | 0.177           |
|                |     |            |                |                 | 2009-11-22     | 5157.13 | HARPS      | 183.C-0972(A)  | 0.178           |
|                |     |            |                |                 | 2009-11-22     | 5157.13 | HARPS      | 183.C-0972(A)  | 0.178           |
|                |     |            |                |                 | 2009-11-22     | 5157.14 | HARPS      | 183.C-0972(A)  | 0.178           |
|                |     |            |                |                 | 2009-11-28     | 5163.11 | HARPS      | 183.C-0972(A)  | 0.182           |
|                |     |            |                |                 | 2009-11-28     | 5163.12 | HARPS      | 183.C-0972(A)  | 0.183           |
|                |     |            |                |                 | 2009-11-28     | 5163.12 | HARPS      | 183.C-0972(A)  | 0.183           |
|                |     |            |                |                 | 2009-12-01     | 5166.06 | HARPS      | 183.C-0972(A)  | 0.179           |



Table A.1. continued.

| HD 20766       |     |            |                |                 | HD 20807       |         |            |                |                 |
|----------------|-----|------------|----------------|-----------------|----------------|---------|------------|----------------|-----------------|
| Observing date | xJD | Instrument | Obs. programme | S <sub>MW</sub> | Observing date | xJD     | Instrument | Obs. programme | S <sub>MW</sub> |
|                |     |            |                |                 | 2009-12-01     | 5166.06 | HARPS      | 183.C-0972(A)  | 0.179           |
|                |     |            |                |                 | 2009-12-01     | 5166.07 | HARPS      | 183.C-0972(A)  | 0.179           |
|                |     |            |                |                 | 2009-12-01     | 5166.07 | HARPS      | 183.C-0972(A)  | 0.180           |
|                |     |            |                |                 | 2010-01-31     | 5227.06 | HARPS      | 183.C-0972(A)  | 0.178           |
|                |     |            |                |                 | 2010-02-03     | 5230.05 | HARPS      | 183.C-0972(A)  | 0.176           |
|                |     |            |                |                 | 2010-02-03     | 5230.05 | HARPS      | 183.C-0972(A)  | 0.176           |
|                |     |            |                |                 | 2010-02-03     | 5230.06 | HARPS      | 183.C-0972(A)  | 0.176           |
|                |     |            |                |                 | 2010-02-03     | 5230.06 | HARPS      | 183.C-0972(A)  | 0.177           |
|                |     |            |                |                 | 2010-02-07     | 5234.03 | HARPS      | 183.C-0972(A)  | 0.178           |
|                |     |            |                |                 | 2010-02-07     | 5234.03 | HARPS      | 183.C-0972(A)  | 0.178           |
|                |     |            |                |                 | 2010-02-18     | 5245.03 | HARPS      | 183.C-0972(A)  | 0.177           |
|                |     |            |                |                 | 2010-02-18     | 5245.04 | HARPS      | 183.C-0972(A)  | 0.177           |
|                |     |            |                |                 | 2010-02-18     | 5245.04 | HARPS      | 183.C-0972(A)  | 0.177           |
|                |     |            |                |                 | 2010-02-19     | 5246.01 | HARPS      | 183.C-0972(A)  | 0.177           |
|                |     |            |                |                 | 2010-02-19     | 5246.01 | HARPS      | 183.C-0972(A)  | 0.177           |
|                |     |            |                |                 | 2010-02-19     | 5246.01 | HARPS      | 183.C-0972(A)  | 0.177           |
|                |     |            |                |                 | 2010-02-19     | 5247.00 | HARPS      | 183.C-0972(A)  | 0.177           |
|                |     |            |                |                 | 2010-02-20     | 5247.00 | HARPS      | 183.C-0972(A)  | 0.177           |
|                |     |            |                |                 | 2010-02-20     | 5247.01 | HARPS      | 183.C-0972(A)  | 0.178           |
|                |     |            |                |                 | 2010-02-21     | 5248.00 | HARPS      | 183.C-0972(A)  | 0.177           |
|                |     |            |                |                 | 2010-02-21     | 5248.01 | HARPS      | 183.C-0972(A)  | 0.177           |
|                |     |            |                |                 | 2010-02-21     | 5248.01 | HARPS      | 183.C-0972(A)  | 0.177           |
|                |     |            |                |                 | 2013-11-23     | 6619.11 | HARPS      | 192.C-0852(A)  | 0.175           |
|                |     |            |                |                 | 2013-11-23     | 6619.12 | HARPS      | 192.C-0852(A)  | 0.175           |
|                |     |            |                |                 | 2013-11-24     | 6620.11 | HARPS      | 192.C-0852(A)  | 0.175           |
|                |     |            |                |                 | 2013-11-24     | 6620.11 | HARPS      | 192.C-0852(A)  | 0.175           |
|                |     |            |                |                 | 2013-11-24     | 6620.11 | HARPS      | 192.C-0852(A)  | 0.175           |
|                |     |            |                |                 | 2013-11-27     | 6623.19 | HARPS      | 192.C-0852(A)  | 0.176           |
|                |     |            |                |                 | 2013-11-27     | 6623.19 | HARPS      | 192.C-0852(A)  | 0.177           |
|                |     |            |                |                 | 2013-11-27     | 6623.19 | HARPS      | 192.C-0852(A)  | 0.177           |
|                |     |            |                |                 | 2013-11-27     | 6623.19 | HARPS      | 192.C-0852(A)  | 0.177           |
|                |     |            |                |                 | 2013-11-27     | 6623.19 | HARPS      | 192.C-0852(A)  | 0.177           |
|                |     |            |                |                 | 2013-11-27     | 6623.19 | HARPS      | 192.C-0852(A)  | 0.177           |
|                |     |            |                |                 | 2013-11-27     | 6623.19 | HARPS      | 192.C-0852(A)  | 0.177           |
|                |     |            |                |                 | 2013-11-29     | 6625.14 | HARPS      | 192.C-0852(A)  | 0.177           |
|                |     |            |                |                 | 2013-11-29     | 6625.14 | HARPS      | 192.C-0852(A)  | 0.177           |
|                |     |            |                |                 | 2013-12-02     | 6628.09 | HARPS      | 192.C-0852(A)  | 0.176           |
|                |     |            |                |                 | 2013-12-02     | 6628.10 | HARPS      | 192.C-0852(A)  | 0.176           |
|                |     |            |                |                 | 2013-12-02     | 6628.10 | HARPS      | 192.C-0852(A)  | 0.177           |
|                |     |            |                |                 | 2013-12-05     | 6631.07 | HARPS      | 192.C-0852(A)  | 0.177           |
|                |     |            |                |                 | 2013-12-05     | 6631.08 | HARPS      | 192.C-0852(A)  | 0.177           |
|                |     |            |                |                 | 2013-12-05     | 6631.08 | HARPS      | 192.C-0852(A)  | 0.178           |
|                |     |            |                |                 | 2014-09-16     | 6916.36 | HARPS      | 192.C-0852(A)  | 0.180           |
|                |     |            |                |                 | 2014-09-19     | 6919.37 | HARPS      | 192.C-0852(A)  | 0.178           |
|                |     |            |                |                 | 2014-09-27     | 6927.27 | HARPS      | 192.C-0852(A)  | 0.179           |
|                |     |            |                |                 | 2014-09-27     | 6927.28 | HARPS      | 192.C-0852(A)  | 0.179           |
|                |     |            |                |                 | 2014-09-29     | 6929.26 | HARPS      | 192.C-0852(A)  | 0.178           |
|                |     |            |                |                 | 2014-09-29     | 6929.26 | HARPS      | 192.C-0852(A)  | 0.178           |
|                |     |            |                |                 | 2014-10-20     | 6950.38 | HARPS      | 192.C-0852(A)  | 0.178           |
|                |     |            |                |                 | 2014-11-28     | 6989.22 | HARPS      | 192.C-0852(A)  | 0.181           |
|                |     |            |                |                 | 2014-11-28     | 6989.23 | HARPS      | 192.C-0852(A)  | 0.181           |
|                |     |            |                |                 | 2014-12-02     | 6993.11 | HARPS      | 192.C-0852(A)  | 0.178           |
|                |     |            |                |                 | 2014-12-02     | 6993.11 | HARPS      | 192.C-0852(A)  | 0.179           |
|                |     |            |                |                 | 2014-12-08     | 6999.12 | HARPS      | 192.C-0852(A)  | 0.178           |
|                |     |            |                |                 | 2014-12-08     | 6999.13 | HARPS      | 192.C-0852(A)  | 0.178           |
|                |     |            |                |                 | 2014-12-12     | 7003.13 | HARPS      | 192.C-0852(A)  | 0.177           |
|                |     |            |                |                 | 2014-12-12     | 7003.13 | HARPS      | 192.C-0852(A)  | 0.177           |
|                |     |            |                |                 | 2015-01-15     | 7037.11 | HARPS      | 192.C-0852(A)  | 0.177           |
|                |     |            |                |                 | 2015-01-15     | 7037.12 | HARPS      | 192.C-0852(A)  | 0.178           |
|                |     |            |                |                 | 2015-01-16     | 7038.05 | HARPS      | 192.C-0852(A)  | 0.177           |
|                |     |            |                |                 | 2015-01-16     | 7038.05 | HARPS      | 192.C-0852(A)  | 0.177           |
|                |     |            |                |                 | 2015-01-16     | 7038.06 | HARPS      | 192.C-0852(A)  | 0.177           |
|                |     |            |                |                 | 2015-02-12     | 7065.06 | HARPS      | 192.C-0852(A)  | 0.177           |
|                |     |            |                |                 | 2015-08-21     | 7255.37 | HARPS      | 192.C-0852(A)  | 0.179           |
|                |     |            |                |                 | 2015-08-21     | 7255.38 | HARPS      | 192.C-0852(A)  | 0.179           |
|                |     |            |                |                 | 2015-08-21     | 7255.38 | HARPS      | 192.C-0852(A)  | 0.180           |
|                |     |            |                |                 | 2015-09-28     | 7293.29 | HARPS      | 192.C-0852(A)  | 0.178           |
|                |     |            |                |                 | 2015-09-28     | 7293.29 | HARPS      | 192.C-0852(A)  | 0.178           |
|                |     |            |                |                 | 2015-09-28     | 7293.30 | HARPS      | 192.C-0852(A)  | 0.178           |
|                |     |            |                |                 | 2015-09-28     | 7293.30 | HARPS      | 192.C-0852(A)  | 0.179           |
|                |     |            |                |                 | 2015-09-28     | 7293.30 | HARPS      | 192.C-0852(A)  | 0.179           |
|                |     |            |                |                 | 2015-09-29     | 7294.25 | HARPS      | 192.C-0852(A)  | 0.178           |
|                |     |            |                |                 | 2015-09-29     | 7294.25 | HARPS      | 192.C-0852(A)  | 0.178           |
|                |     |            |                |                 | 2015-09-29     | 7294.26 | HARPS      | 192.C-0852(A)  | 0.179           |
|                |     |            |                |                 | 2015-09-29     | 7294.26 | HARPS      | 192.C-0852(A)  | 0.179           |
|                |     |            |                |                 | 2015-09-29     | 7294.26 | HARPS      | 192.C-0852(A)  | 0.179           |
|                |     |            |                |                 | 2015-10-05     | 7300.32 | HARPS      | 192.C-0852(A)  | 0.177           |
|                |     |            |                |                 | 2015-10-05     | 7300.32 | HARPS      | 192.C-0852(A)  | 0.178           |
|                |     |            |                |                 | 2015-10-05     | 7300.33 | HARPS      | 192.C-0852(A)  | 0.178           |
|                |     |            |                |                 | 2015-10-09     | 7304.34 | HARPS      | 192.C-0852(A)  | 0.177           |
|                |     |            |                |                 | 2015-10-09     | 7304.34 | HARPS      | 192.C-0852(A)  | 0.178           |
|                |     |            |                |                 | 2015-11-01     | 7327.18 | HARPS      | 192.C-0852(A)  | 0.180           |
|                |     |            |                |                 | 2015-11-01     | 7327.19 | HARPS      | 192.C-0852(A)  | 0.180           |

Table A.1. continued.

| HD 20766       |     | HD 20807   |                |                 |                |         |            |                |                 |
|----------------|-----|------------|----------------|-----------------|----------------|---------|------------|----------------|-----------------|
| Observing date | xJD | Instrument | Obs. programme | S <sub>MW</sub> | Observing date | xJD     | Instrument | Obs. programme | S <sub>MW</sub> |
|                |     |            |                |                 | 2015-12-08     | 7364.24 | HARPS      | 192.C-0852(A)  | 0.180           |
|                |     |            |                |                 | 2015-12-08     | 7364.24 | HARPS      | 192.C-0852(A)  | 0.181           |
|                |     |            |                |                 | 2015-12-08     | 7364.24 | HARPS      | 192.C-0852(A)  | 0.181           |
|                |     |            |                |                 | 2015-12-11     | 7367.22 | HARPS      | 192.C-0852(A)  | 0.181           |
|                |     |            |                |                 | 2015-12-11     | 7367.23 | HARPS      | 192.C-0852(A)  | 0.181           |
|                |     |            |                |                 | 2015-12-17     | 7373.19 | HARPS      | 192.C-0852(A)  | 0.179           |
|                |     |            |                |                 | 2015-12-17     | 7373.20 | HARPS      | 192.C-0852(A)  | 0.179           |
|                |     |            |                |                 | 2016-02-08     | 7426.05 | HARPS      | 192.C-0852(A)  | 0.180           |
|                |     |            |                |                 | 2016-02-08     | 7426.05 | HARPS      | 192.C-0852(A)  | 0.180           |
|                |     |            |                |                 | 2016-02-09     | 7427.06 | HARPS      | 192.C-0852(A)  | 0.180           |
|                |     |            |                |                 | 2016-02-09     | 7427.07 | HARPS      | 192.C-0852(A)  | 0.180           |
|                |     |            |                |                 | 2016-02-11     | 7429.07 | HARPS      | 192.C-0852(A)  | 0.180           |
|                |     |            |                |                 | 2016-02-11     | 7429.08 | HARPS      | 192.C-0852(A)  | 0.181           |
|                |     |            |                |                 | 2016-09-01     | 7632.37 | HARPS      | 196.C-1006(A)  | 0.179           |
|                |     |            |                |                 | 2016-09-01     | 7632.37 | HARPS      | 196.C-1006(A)  | 0.179           |
|                |     |            |                |                 | 2016-09-01     | 7632.38 | HARPS      | 196.C-1006(A)  | 0.179           |
|                |     |            |                |                 | 2016-09-01     | 7632.38 | HARPS      | 196.C-1006(A)  | 0.179           |
|                |     |            |                |                 | 2016-09-01     | 7632.38 | HARPS      | 196.C-1006(A)  | 0.180           |
|                |     |            |                |                 | 2016-09-01     | 7632.38 | HARPS      | 196.C-1006(A)  | 0.180           |
|                |     |            |                |                 | 2016-09-11     | 7642.38 | HARPS      | 196.C-1006(A)  | 0.181           |
|                |     |            |                |                 | 2016-09-11     | 7642.38 | HARPS      | 196.C-1006(A)  | 0.181           |
|                |     |            |                |                 | 2016-09-11     | 7642.38 | HARPS      | 196.C-1006(A)  | 0.181           |
|                |     |            |                |                 | 2016-09-11     | 7642.38 | HARPS      | 196.C-1006(A)  | 0.181           |
|                |     |            |                |                 | 2016-09-12     | 7643.34 | HARPS      | 196.C-1006(A)  | 0.180           |
|                |     |            |                |                 | 2016-09-12     | 7643.35 | HARPS      | 196.C-1006(A)  | 0.180           |
|                |     |            |                |                 | 2016-09-12     | 7643.35 | HARPS      | 196.C-1006(A)  | 0.180           |
|                |     |            |                |                 | 2016-09-12     | 7643.35 | HARPS      | 196.C-1006(A)  | 0.180           |
|                |     |            |                |                 | 2016-09-13     | 7644.33 | HARPS      | 196.C-1006(A)  | 0.180           |
|                |     |            |                |                 | 2016-09-13     | 7644.33 | HARPS      | 196.C-1006(A)  | 0.180           |
|                |     |            |                |                 | 2016-09-13     | 7644.34 | HARPS      | 196.C-1006(A)  | 0.181           |
|                |     |            |                |                 | 2016-09-17     | 7648.39 | HARPS      | 196.C-1006(A)  | 0.181           |
|                |     |            |                |                 | 2016-09-17     | 7648.39 | HARPS      | 196.C-1006(A)  | 0.181           |
|                |     |            |                |                 | 2016-09-17     | 7648.39 | HARPS      | 196.C-1006(A)  | 0.181           |
|                |     |            |                |                 | 2016-09-17     | 7648.40 | HARPS      | 196.C-1006(A)  | 0.181           |
|                |     |            |                |                 | 2016-09-19     | 7650.29 | HARPS      | 196.C-1006(A)  | 0.181           |
|                |     |            |                |                 | 2016-09-19     | 7650.29 | HARPS      | 196.C-1006(A)  | 0.181           |
|                |     |            |                |                 | 2016-09-19     | 7650.29 | HARPS      | 196.C-1006(A)  | 0.181           |
|                |     |            |                |                 | 2016-09-19     | 7650.30 | HARPS      | 196.C-1006(A)  | 0.181           |
|                |     |            |                |                 | 2016-09-23     | 7654.29 | HARPS      | 196.C-1006(A)  | 0.179           |
|                |     |            |                |                 | 2016-09-23     | 7654.29 | HARPS      | 196.C-1006(A)  | 0.179           |
|                |     |            |                |                 | 2016-09-23     | 7654.29 | HARPS      | 196.C-1006(A)  | 0.179           |
|                |     |            |                |                 | 2016-09-23     | 7654.30 | HARPS      | 196.C-1006(A)  | 0.180           |
|                |     |            |                |                 | 2016-09-25     | 7656.22 | HARPS      | 196.C-1006(A)  | 0.179           |
|                |     |            |                |                 | 2016-09-25     | 7656.22 | HARPS      | 196.C-1006(A)  | 0.179           |
|                |     |            |                |                 | 2016-09-25     | 7656.22 | HARPS      | 196.C-1006(A)  | 0.180           |
|                |     |            |                |                 | 2016-09-25     | 7656.23 | HARPS      | 196.C-1006(A)  | 0.180           |
|                |     |            |                |                 | 2016-09-27     | 7658.26 | HARPS      | 196.C-1006(A)  | 0.180           |
|                |     |            |                |                 | 2016-09-27     | 7658.26 | HARPS      | 196.C-1006(A)  | 0.180           |
|                |     |            |                |                 | 2016-09-27     | 7658.26 | HARPS      | 196.C-1006(A)  | 0.180           |
|                |     |            |                |                 | 2016-09-27     | 7658.26 | HARPS      | 196.C-1006(A)  | 0.181           |
|                |     |            |                |                 | 2016-09-29     | 7660.24 | HARPS      | 196.C-1006(A)  | 0.179           |
|                |     |            |                |                 | 2016-09-29     | 7660.24 | HARPS      | 196.C-1006(A)  | 0.180           |
|                |     |            |                |                 | 2016-09-29     | 7660.24 | HARPS      | 196.C-1006(A)  | 0.180           |
|                |     |            |                |                 | 2016-09-29     | 7660.25 | HARPS      | 196.C-1006(A)  | 0.181           |
|                |     |            |                |                 | 2016-10-01     | 7662.28 | HARPS      | 196.C-1006(A)  | 0.179           |
|                |     |            |                |                 | 2016-10-01     | 7662.28 | HARPS      | 196.C-1006(A)  | 0.179           |
|                |     |            |                |                 | 2016-10-01     | 7662.28 | HARPS      | 196.C-1006(A)  | 0.180           |
|                |     |            |                |                 | 2016-10-01     | 7662.28 | HARPS      | 196.C-1006(A)  | 0.180           |
|                |     |            |                |                 | 2018-10-18     | 8409.18 | HARPS      | 0102.C-0584(A) | 0.178           |
|                |     |            |                |                 | 2018-10-21     | 8412.26 | HARPS      | 0102.C-0584(A) | 0.175           |
|                |     |            |                |                 | 2018-10-22     | 8413.21 | HARPS      | 0102.C-0584(A) | 0.176           |
|                |     |            |                |                 | 2018-11-15     | 8437.23 | HARPS      | 0102.C-0584(A) | 0.176           |
|                |     |            |                |                 | 2018-11-18     | 8440.11 | HARPS      | 0102.C-0584(A) | 0.176           |
|                |     |            |                |                 | 2018-11-18     | 8440.12 | HARPS      | 0102.C-0584(A) | 0.176           |
|                |     |            |                |                 | 2018-11-18     | 8440.12 | HARPS      | 0102.C-0584(A) | 0.176           |
|                |     |            |                |                 | 2018-12-15     | 8467.10 | HARPS      | 0102.C-0584(A) | 0.175           |
|                |     |            |                |                 | 2018-12-15     | 8467.10 | HARPS      | 0102.C-0584(A) | 0.175           |
|                |     |            |                |                 | 2018-12-17     | 8469.07 | HARPS      | 0102.C-0584(A) | 0.176           |
|                |     |            |                |                 | 2018-12-17     | 8469.07 | HARPS      | 0102.C-0584(A) | 0.176           |
|                |     |            |                |                 | 2018-12-17     | 8469.08 | HARPS      | 0102.C-0584(A) | 0.176           |
|                |     |            |                |                 | 2018-12-19     | 8471.21 | HARPS      | 0102.C-0584(A) | 0.175           |
|                |     |            |                |                 | 2018-12-19     | 8471.21 | HARPS      | 0102.C-0584(A) | 0.176           |
|                |     |            |                |                 | 2018-12-19     | 8471.22 | HARPS      | 0102.C-0584(A) | 0.176           |
|                |     |            |                |                 | 2019-07-02     | 8666.42 | HARPS      | 0103.C-0206(A) | 0.176           |
|                |     |            |                |                 | 2019-07-02     | 8666.42 | HARPS      | 0103.C-0206(A) | 0.176           |
|                |     |            |                |                 | 2019-07-25     | 8689.34 | HARPS      | 0103.C-0206(A) | 0.176           |
|                |     |            |                |                 | 2019-07-25     | 8689.35 | HARPS      | 0103.C-0206(A) | 0.176           |
|                |     |            |                |                 | 2019-08-06     | 8701.44 | HARPS      | 0103.C-0206(A) | 0.176           |
|                |     |            |                |                 | 2019-08-06     | 8701.45 | HARPS      | 0103.C-0206(A) | 0.176           |
|                |     |            |                |                 | 2019-08-06     | 8701.45 | HARPS      | 0103.C-0206(A) | 0.176           |
|                |     |            |                |                 | 2019-08-06     | 8701.45 | HARPS      | 0103.C-0206(A) | 0.176           |
|                |     |            |                |                 | 2019-08-06     | 8701.45 | HARPS      | 0103.C-0206(A) | 0.176           |
|                |     |            |                |                 | 2019-08-06     | 8701.45 | HARPS      | 0103.C-0206(A) | 0.176           |

**Table A.1.** continued.

| HD 20766       |     |            |                |                 | HD 20807       |         |            |                |                 |
|----------------|-----|------------|----------------|-----------------|----------------|---------|------------|----------------|-----------------|
| Observing date | xJD | Instrument | Obs. programme | S <sub>MW</sub> | Observing date | xJD     | Instrument | Obs. programme | S <sub>MW</sub> |
|                |     |            |                |                 | 2019-08-07     | 8702.27 | HARPS      | 0103.C-0206(A) | 0.175           |
|                |     |            |                |                 | 2019-08-07     | 8702.27 | HARPS      | 0103.C-0206(A) | 0.175           |
|                |     |            |                |                 | 2019-08-07     | 8702.28 | HARPS      | 0103.C-0206(A) | 0.175           |
|                |     |            |                |                 | 2019-08-07     | 8702.28 | HARPS      | 0103.C-0206(A) | 0.175           |
|                |     |            |                |                 | 2019-08-07     | 8702.28 | HARPS      | 0103.C-0206(A) | 0.176           |
|                |     |            |                |                 | 2019-08-07     | 8702.28 | HARPS      | 0103.C-0206(A) | 0.176           |
|                |     |            |                |                 | 2019-08-08     | 8703.35 | HARPS      | 0103.C-0206(A) | 0.173           |
|                |     |            |                |                 | 2019-08-08     | 8703.36 | HARPS      | 0103.C-0206(A) | 0.173           |
|                |     |            |                |                 | 2019-08-08     | 8703.36 | HARPS      | 0103.C-0206(A) | 0.174           |
|                |     |            |                |                 | 2019-08-08     | 8703.36 | HARPS      | 0103.C-0206(A) | 0.175           |
|                |     |            |                |                 | 2019-08-09     | 8704.28 | HARPS      | 0103.C-0206(A) | 0.175           |
|                |     |            |                |                 | 2019-08-09     | 8704.28 | HARPS      | 0103.C-0206(A) | 0.175           |
|                |     |            |                |                 | 2019-08-09     | 8704.28 | HARPS      | 0103.C-0206(A) | 0.175           |
|                |     |            |                |                 | 2019-08-09     | 8704.28 | HARPS      | 0103.C-0206(A) | 0.176           |
|                |     |            |                |                 | 2019-08-09     | 8704.29 | HARPS      | 0103.C-0206(A) | 0.177           |
|                |     |            |                |                 | 2019-08-13     | 8708.27 | HARPS      | 0103.C-0206(A) | 0.175           |
|                |     |            |                |                 | 2019-08-13     | 8708.27 | HARPS      | 0103.C-0206(A) | 0.175           |
|                |     |            |                |                 | 2019-08-13     | 8708.27 | HARPS      | 0103.C-0206(A) | 0.175           |
|                |     |            |                |                 | 2019-08-13     | 8708.28 | HARPS      | 0103.C-0206(A) | 0.175           |
|                |     |            |                |                 | 2019-08-13     | 8708.28 | HARPS      | 0103.C-0206(A) | 0.175           |
|                |     |            |                |                 | 2019-08-13     | 8708.28 | HARPS      | 0103.C-0206(A) | 0.176           |

**Notes.** Columns 2 and 7: Julian day xJD=JD-2 450 000. Columns 4 and 9: ID programmes corresponding to ESO and REOSC observations.