The solar-like ”Second Spectrum” and the polarised metal lines in emission of the post-AGB binary 89 Herculis.

F. Leone¹,², M. Gangi¹,², M. Giarrusso¹,², C. Scalia¹,², M. Cecconi³, R. Cosentino³, A. Ghedina³, M. Munari², S. Scuderi²

¹Università di Catania, Dipartimento di Fisica e Astronomia, Sezione Astrofisica, Via S. Sofia 78, I–95123 Catania, Italy
²INAF - Osservatorio Astrofisico di Catania, Via S. Sofia 78, I–95123 Catania, Italy
³INAF - Fund. Galileo Galilei, Rambla José Ana Fernández Perez 7, 38712 Breña Baja (La Palma), Canary Islands, Spain

ABSTRACT

We studied the polarised spectrum of the post-AGB binary system 89 Herculis on the basis of data collected with the high resolution Catania Astrophysical Observatory Spectropolarimeter, HARPS-North POlarimeter and Echelle SpectroPolarimetric Device for the Observation of Stars. We find the existence of linear polarisation in the strongest metal lines in absorption and with low excitation potentials. Signals are characterized by complex Q and U morphologies varying with the orbital period. As possible origin of this ”Second Solar Spectrum”-like behaviour, we rule out magnetic fields, continuum depolarisation due pulsations and hot spots. The linear polarisation we detected also in the Ca ii 8662Å line is a clear evidence of optical pumping polarisation and it rules out the scattering polarisation from free electrons of the circumbinary environment. In the framework of optical pumping due to the secondary star, the observed periodic properties of the spectral line polarisation can be justied by two jets, flow velocity of few tens of km s⁻¹, at the basis of that hour-glass structure characterising 89 Herculis. We also discovered linear polarisation across the emission profile of metal lines. Numerical simulations show that these polarised profiles could be formed in an undisrupted circumbinary disk rotating at ≤ 10 km s⁻¹ and whose orientation in the sky is in agreement with optical and radio interferometric results. We conclude that the study of those aspherical envelopes, whose origin is not yet completely understood, of PNe and already present in the post-AGB’s, can benefit of high resolution spectropolarimetry and that this technique can shape envelopes still too far for interferometry.

Key words: circumstellar matter - stars: post-AGB - techniques: polarimetric

1 INTRODUCTION

Photopolarimetry by Kruszewski et al. (1968) has shown that the Mira variable stars are characterised by a certain degree of linear polarisation changing with wavelength and time. By means of spectropolarimetry at low resolution, McLean & Coyne (1978) has pointed out a high polarisation degree, up to 7%, across Balmer lines of Mira itself. Harrington & Kuhn (2009b,a) and Lèbre et al. (2011) have shown that such a property is often present in the Balmer lines of evolved stars. The existence of linearly polarisation across individual metal lines in absorption has been reported for the Mira star χ Cygni by Lèbre et al. (2014) and for the red supergiant Betelgeuse by Aurière et al. (2016). Using the Least Squares Deconvolution (LSD, Donati et al. 1997), Tessore et al. (2015) found evidence of linear polarisation in the spectral lines of the RV Tau variable R Scuti and Sabin et al. (2015) in the lines of the RV Tau variable U Monocerotis as well in the post-AGB star 89 Herculis.

It appears that evolved stars can be characterised by the so called Second Solar Spectrum consisting of spectral lines partially in absorption and partially in emission when observed at high resolution linear spectropolarimetry (Stenflo 1982). This spectrum in polarised light has represented the observative basis for the comprehension of the most external layers of the Sun and now its discovery in evolved stars opens new perspective for the understanding of stellar evolution. In general, polarisation across spectral lines is expected to trace and shape the envelopes of the final stellar stages whose departure from the spherical symmetry is still a matter of discussion. Despite many theories invoke magnetic fields to explain the rich variety of aspherical compo-
Figure 1. All 15 ESPaDOnS Stokes $I$, $Q/I$, $U/I$ profiles and polarisation ($P = \int \sqrt{|Q/I|^2+(U/I)^2} d\lambda$) for the Fe\textsc{ii} 4508.288 Å, Cr\textsc{ii} 4558.783 Å and Ti\textsc{ii} 4805.085 Å lines. Data collected, between 2005 and 2009, present a clearly linear polarisation and a significant morphological variability in time.

Table 1. Logbook of observations. The achieved Signal-to-Noise (S/N) is determined from null LSD spectra.

| HJD     | S/N | Instr. | HJD     | S/N | Instr. |
|---------|-----|--------|---------|-----|--------|
| 53604.753 | 11300 | ESP    | 55102.832 | 5200 | ESP    |
| 53775.115 | 10500 | ESP    | 55109.823 | 12400 | ESP    |
| 53777.096 | 19400 | ESP    | 56816.515 | 3000 | CAOS   |
| 53961.777 | 21800 | ESP    | 56862.456 | 2300 | CAOS   |
| 54372.821 | 23900 | ESP    | 56863.347 | 2400 | CAOS   |
| 54877.099 | 4300  | ESP    | 56876.340 | 3500 | CAOS   |
| 54878.132 | 10700 | ESP    | 56894.309 | 4200 | CAOS   |
| 54880.076 | 14700 | ESP    | 56897.301 | 4100 | CAOS   |
| 54954.125 | 12900 | ESP    | 56898.274 | 4300 | CAOS   |
| 54955.849 | 10600 | ESP    | 56904.313 | 3700 | CAOS   |
| 54958.121 | 14000 | ESP    | 57582.248 | 3700 | CAOS   |
| 54959.874 | 8000  | ESP    | 57666.248 | 2900 | CAOS   |
| 55081.874 | 3000  | ESP    | 57900.100 | 4300 | HANPO  |

Figure 2. Examples of spectral lines with equal depth showing that, within errors, polarisation does not depend on wavelength.

asymmetry already present in the post-AGB phase before the PNe phase. In Section 4, we present the Second Stellar Spectrum of 89 Her and its periodic variability. In Section 6, we analyse the possible origins of this polarisation. In Section 5, we present the polarisation of metal lines in emission from the circumbinary envelope and relate their properties to the geometry and dynamic of the emitting region. Finally, we resume our conclusions in the last Section 7.

2 89 HERCULIS

Classified as an F2 Ib C supergiants by Gray & Garrison (1989), 89 Herculis (HR 6685, HD 163506) is the prototype of the new class, introduced by Waters et al. (1993), of post-AGB binaries surrounded by a circumbinary dust disk. The ephemeris of this binary system was determined by Waters
and coworkers from Radial Velocities (RV):

$$JD(RV_{\text{max}}) = 2446013.72(\pm 16.95) + 288.36(\pm 0.71) \text{ days}$$ (1)

Furthermore, the primary component of 89 Her pulsates with a period of 63.5 days (Arellano Ferro 1984).

Interferometric data of 89 Her have been interpreted by Bujarrabal et al. (2007) with two nebular components: an expanding hour-glass structure and an unresolved circumbinary Keplerian disk. Bujarrabal and coworkers concluded that the hour-glass axis is tilted with respect to the Line-of-Sight (LoS) of $\theta_{\text{LoS}} = 15^\circ$ with a Position Angle $\theta_{\text{PA}} = 45^\circ$.

From the basis of time resolved broad-band photopolarimetry, Akras et al. (2017) concluded that 89 Her is an intrinsic unpolarised source in the visible range.

3 OBSERVATIONAL DATA

From June 2014 to October 2016, we have performed high resolution linear spectropolarimetry of 89 Her with the high resolution *Catania Astrophysical Observatory Spectropolarimeter* (CAOS, $R = 55000$, Leone et al. 2016a) at the 0.91m telescope of the stellar station of the Catania Astrophysical Observatory (G. M. Fracastoro Stellar Station, Serra La Nave, Mt. Etna, Italy). A spectrum in linearly polarised light was acquired on May 27, 2017 with the HArps-North PolArimeter (HANPO, $R = 115000$, Leone et al. 2016b) of the Telescopio Nazionale Galileo (Roque de Los Muchachos Astronomical Observatory, La Palma, Spain). Data were reduced and Stokes $Q/I$, $U/I$ and null spectra $N$ obtained according to the procedures described in Leone et al. (2016a). The null spectra check the presence of any spurious contribution to the polarised spectra and errors in the data reduction process.

In addition, reduced spectropolarimetric data of 89 Her have been retrieved from the Canadian Astronomy Data Centre. Spectra were collected from 2005 to 2009 at the 3.6m Canadian-France-Hawaii Telescope with the "Echelle SpectroPolarimetric Device for the Observation of Stars" (ESPaDOnS, $R = 68000$, Donati et al. 2006).

The logbook of observations is given in Table 1.

4 POLARISATION OF METAL LINES IN ABSORPTION

Sabin et al. (2015) discovered evidence of linear polarisation in the Stokes $Q/I$ and $U/I$ LSD profiles of 89 Her spectra recorded with ESPaDOnS on Feb. 8, 2006. We found that all the archived ESPaDOnS spectra of 89 Her, spanning about 1400 days, are characterised by metal lines in absorption whose Stokes $Q/I$ and $U/I$ profiles are not null and variable in time. Figure 1 provides an example of such variable signals for transitions of Fe $\text{ii}$, Cr $\text{ii}$ and Ti $\text{ii}$. In any spectrum, Stokes profiles scale with the line depth irrespective of wavelength (Fig. 2). We have then selected in the 400–700 nm range, common to the three spectropolarimeters, a set of about 1000 metal lines whose Stokes $I$ residual is larger than 0.2 to obtain Stokes $Q/I$ and $U/I$ LSD profiles. Fig. 3 shows the comparison between the ESPaDOnS-LSD and Fe $\text{ii}$ 4508.288 Å profiles at three different dates.

In CAOS spectra of 89 Her, we don’t find any direct evidence of polarisation. After numerical simulations showing that ESPaDOnS Stokes $Q/I$ and $U/I$ profiles would be hidden in the Signal-to-Noise (S/N) of CAOS spectra, we have successfully constructed the CAOS-LSD profiles from the spectral line list we selected for the ESPaDOnS-LSD. For consistency, also the HANPO-LSD Stokes profiles were based on the same list of spectral lines. The complete collection of the variable Stokes $Q/I$ and $U/I$ LSD profiles is shown in Fig. 4. S/N values achieved in null LSD profiles is given in Table 1.

We have then performed a time analysis of the total polarisation measured across the LSD profiles. The Scargle (1982) periodogram, CLEANED following Roberts et al. (1987), presents the highest peak at 294±5 days that is coincident within errors with the orbital period (Fig. 5). For this reason hereafter we will adopt the ephemeris by Waters et al. (1993) (Eq. 1). Fig. 5 shows how the total polarisation changes with the orbital period. A similar variability cannot be statistically confirmed for the Equivalent Widths, whose sinusoidal fit gives an amplitude of $10 \pm 9$ mÅ.
5 POLARISATION OF METAL LINES IN EMISSION

Discovered by Osmer (1968), more than 300 weak metal lines in emission have been identified by Kipper (2011) in the spectrum of 89 Her. Kipper pointed out that these lines: 1) present the velocity of the binary system, 2) are due to neutral metals with a rather low (<6 eV) excitation levels, and 3) are not due to forbidden and ionic transitions. Kipper concluded that these emission lines are formed in the circumbinary disk. Already Waters et al. (1993) have interpreted these weak, neutral or low-excitation-level emission lines of metals as a proof of the collisionally excited interaction between the stellar wind and the circumbinary disk.

We have analysed the polarisation properties of the emission metal lines crowding the spectrum of 89 Her and found as a general rule that they present, left panel of Fig. 6, an about 1% polarisation fully stored in the Stokes U/I profile. However, few emission lines appear to show the opposite behavior, right panel of Fig. 6, to be confirmed with further observations.

These polarised line profiles are expected for rotating disks (Vink et al. 2005). We have numerically computed polarised profiles with the STOKES code and found that observations are justified by an opened undisrupted disk slightly tilted towards the line of sight and rotating at \( \leq 10 \) km s\(^{-1}\), Fig. 7. A value in agreement with Bujarrabal et al. (2007) conclusion that the characteristic rotation would be \( \sim 8 \) km s\(^{-1}\). We adopted a density of scattering electrons equal to \( 10^{10} \) cm\(^{-3}\), an external radius of 10 AU and a PA of the circum-binary disk equal to 45°.

In the literature, an indirect evidence of free electrons in the circum-binary disk of 89 Her is the necessity of the H\(^-\) continuum opacity to justify the observed spectral energy distribution (Hillen et al. 2013). We note that the mass loss (\( \sim 10^{-8} M_{\odot} \) yr\(^{-1}\), Osmer 1968) from the primary star, responsible for the observed H\(_\alpha\) P Cygni profile, could be a continuously source of free electrons for the low temperature circum-binary disk.

We note that the observed Stokes U/I profiles are slightly variable with the orbital period. It could be that the STOKES assumption of central symmetry of the disk...
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6 ORIGIN OF LINEAR POLARISATION OF METAL LINES IN ABSORPTION

Spectral lines in absorption with linearly polarised profiles are not common and, as a consequence, available theoretical explanations and literature are rather limited. Starting from the consideration that the polarisation of metal lines in emission is not variable with the orbital period, the phenomenon responsible for the polarisation of metal lines in absorption is on a smaller scale than the circumbinary disk and related to the presence of the secondary.

6.1 Magnetic Fields

Since Wade et al. (2000) and Bagmulo et al. (2001), linearly polarised metal lines are observed in the spectra of magnetic chemically peculiar stars (Wolff 1983, still offers a complete and gentle introduction to this class of stars) and it is ascribed to the Zeeman effect. As to 89 Her, this possibility has been ruled out by Sabin et al. (2015) who detected no Stokes V signal across the LSD line profile (see their figure 1) and established an upper limit of 10 G to the effective magnetic field, that is by definition the average over the visible stellar disk of longitudinal components of the field (Babcock 1947).

With CAOS, we have also performed circular spectropolarimetry of 89 Her on HJD56853.535 and an upper limit of 50 G has been estimated for the effective field from the Stokes V and I LSD profiles. The field has been measured with the moment technique as in Leone & Catanzaro (2004). In principle, a linear polarisation in spectral lines associated to a null circular polarisation is possible for a purely transverse field. However, for a large scale organised stellar magnetic field of a rotating star even if the average of the longitudinal components across the visible stellar disk is null, Stokes V profiles are different than zero. We then agree with Sabin et al. (2015) conclusion and exclude the possibility we are recording the linear polarisation of Zeeman components.

6.2 Stellar Continuum Polarisation

Stellar Pulsations

Odell (1979) firstly introduced the idea that stars with non-radial pulsations show a periodically variable polarisation due to the photospheric electron-scattering opacity and then he observed the linked photopolarimetric variability with an amplitude of 0.045% in the star BW Vul (Odell 1981). Fabas et al. (2011) have associated the variable polarisation presented by the Balmer lines of the pulsating o Ceti to the propagation of shock waves. Later, Lèbre et al. (2014) observed a variable polarisation in the metal lines of the Mira star χ Cygni and the RV Tauri star R Sct and they related the polarisation to the global asymmetry at the photospheric level induced by pulsations.

We can rule out that the metal line polarisation of 89 Her is a consequence of pulsations simply because the observed polarisation is not variable with the 63.5 day pulsation period but rather with the orbital period, Fig. 5.
Figure 8. Spectral line polarization as a function of θ angle (bottom panel) and anisotropy factor $w$ (Landi Degl’Innocenti & Landolfi 2004) normalized to the Sun value ($w'' = 0.37$) at 2$''$ (top panel).

Hot spots

Schwarz & Clarke (1984) and Clarke & Schwarz (1984) have shown that the variable photopolarimetric data of Betelgeuse with particular reference to the TiO band can be consequence of a wavelength independent (e.g. Thomson) scattering and temporal evolution of hot spots. Extending Clarke and Schwarz’s interpretation, Aurière et al. (2016) suggested that the linear polarization observed in the spectral line of Betelgeuse is indeed an effect of the depolarisation of the continuum set to zero.

Schwarz & Clarke (1984) have computed the expected polarization of the continuum in the 400 - 700 nm range due to hot spots. It appears that, whatever the temperature and extension of hot spots are, polarization decreases with the wavelengths. We can then conclude that in the case of 89 Her the observed polarization across metal lines is not due to hot spots as these have been theorised for Betelgeuse. We have found a polarization degree that is independent on the wavelength, Fig. 2.

6.3 Scattering polarisation from circumbinary electrons

In section 5 we explained the polarisation of metal lines in emission with the presence of the circumbinary disk. Despite Hillen et al. (2013) detection of a 35-40% optical circumstellar flux contribution to the 89 Her luminosity, the polarisation from free electrons of the circumbinary envelope is certainly not at the origin of the polarisation of metal lines in absorption. We have always clearly detected linear polarisation across the Ca\textsc{ii} 8662 Å line profile (Fig. 10), that, as pointed out by Kuhn et al. (2011), cannot be due to scattering (Manso Sainz & Trujillo Bueno 2003).

Nevertheless, we have carried out numerical tests with the STOKES code to understand the role of scattering polarisation from free electrons of the circumstellar environment. Polarised line profiles at the observed 1% level are predicted if the Hillen et al. (2013) bipolar outflow with an appropriate ($n_e \sim 10^{10} - 10^{11}$ cm$^{-3}$) electron density is assumed. However, the ensuing 6% polarised continuum is not compatible with Akras et al. (2017) finding of no polarisation. In addition, we were not able to adapt the outflow properties in order to justify the polarisation variability across spectral lines with the orbital period.

6.4 Anisotropic Radiation Pumping

Kuhn et al. (2007) suggested that the linearly polarised continuum of Herbig Ae/Be stars is due to the anisotropic radiation pumping. At our knowledge, this mechanism has not yet been suggested as origin of polarisation in metal spectral lines of stars other than the Sun.

The here observed linear polarisation across the Ca\textsc{ii} 8662 Å line profile, ruling out the scattering polarisation, is the clear evidence of optical pumping (Kuhn et al. 2011). As to 89 Her, the presence of a very close (0.31 AU, Bujarrabal et al. 2007) companion justifies, at least in principle, the assumption of a not isotropic radiation field responsible of the observed polarised metal lines be seen variable with the orbital period. A quantitative evaluation based on the anisotropy factor $w$ (Landi Degl’Innocenti & Landolfi 2004), that is zero for an isotropic radiation field and 1 for an unidirectional radiation beam, confirms the presence of a not isotropic field between the two components of 89 Her. We obtain $w_{5500\text{nm}} \sim 0.8$ if a) the stellar parameters by Waters et al. (1993), who found that the primary component presents $T_{\text{eff}} = 6500$ K, log $g = 1.0$ and $R = 41 R_\odot$, while the secondary is a 0.6 $M_\odot$ main sequence star: that is an M0V star with $T_{\text{eff}} = 4045$ K, log $g = 4.6$ and $R = 0.6 R_\odot$ (Gray 2008), and b) the surface fluxes by Kurucz (2005) and limb-darkening by Diaz-Cordoves et al. (1995) are adopted.

To numerically explore the possibility we are really in...
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Figure 10. Stokes parameters of the Ca\textsuperscript{ii} 8662Å line as observed, from left, on HJD 53777, 53961 and 54372. According to Kuhn et al. (2011) the very existence of the polarisation in this calcium line rules out the scattering polarisation from free electrons. It is compatible with optical pumping instead.

Figure 11. HAZEL parameters best matching the Stokes LSD profiles are folded with the orbital ephemeris given in Eq. 1. Symbols are as in Fig. 5. The saw-tooth variation of the $\gamma$ angle, due to its definition in 0-180° range, is indicative of a closed loop of the polarisation vector along the orbital motion of the secondary star. The longitude of periastron $\omega = 359.3^\circ$ (Waters et al. 1993) implies that the polarisation vector is North-South oriented ($\gamma = 0^\circ$) in conjunctions and East-West oriented ($\gamma = 90^\circ$) in quadratura. Single and double wave variations have been assumed to match the parameter changes but for the $\gamma$ one that has been assumed linear in time.

Figure 12. HAZEL parameters best matching the Stokes LSD profiles are folded with the orbital ephemeris given in Eq. 1. Symbols are as in Fig. 5. The saw-tooth variation of the $\gamma$ angle, due to its definition in 0-180° range, is indicative of a closed loop of the polarisation vector along the orbital motion of the secondary star. The longitude of periastron $\omega = 359.3^\circ$ (Waters et al. 1993) implies that the polarisation vector is North-South oriented ($\gamma = 0^\circ$) in conjunctions and East-West oriented ($\gamma = 90^\circ$) in quadratura. Single and double wave variations have been assumed to match the parameter changes but for the $\gamma$ one that has been assumed linear in time.

presence of a spectral line polarisation induced by a periodically variable anisotropic radiation field due to the orbiting secondary, we compare synthetic Fe\textsuperscript{II} 4508.288 Å Stokes profiles computed with the HAZEL code (Asensio Ramos et al. 2008) with the observed LSD profiles. For calculations, observed profiles have been corrected for the Doppler shift due to the orbital motion of the primary component. Magnetic fields, that are not necessary to induce a population imbalance (Trujillo Bueno & Landi Degl’Innocenti 1997), have been neglected to minimise the free parameters to the: 1) slab velocity $v_{sl}$, 2) thermal velocity $v_{th}$, 3) strength of the Stokes I line $\eta_0$, 4) angle $\theta$ between the LoS and the normal $\mathbf{n}$ to the slab and 5) polarisation angle $\gamma$ representing the azimuth of the polarisation vector with respect to
the North-South direction. Fig. 8 shows how the anisotropy factor \( w \) and the \( \theta \) angle contribute to the polarisation level, again with the aim to minimise the number of free parameters, the anisotropy factor has been arbitrarily fixed equal to the solar value \( (w^{\odot} = 0.37) \) at \( 2^\circ \).

Three slabs are required to fit the variable Stokes \( Q/I \) and \( U/I \) LSD profiles of 89 Her with HAZEL. A stationary feature in absorption (hereafter LINE 2 and due to SLAB 2) and two oppositely Doppler shifted features, the blue-shifted LINE 1 of SLAB 1 and the red-shifted LINE 3 of SLAB 3. Fig. 9 shows an example of the fit for two of CAOS-LSD profiles. With the exception of the thermal velocity \( v_{th} \) that is constant in time, all fit parameters present a well defined variability with the orbital period (Fig. 11).

According to the adopted ephemeris (Eq. 1), the radial velocity of the primary component of the 89 Her binary system presents its maximum at the orbital phase \( = 0 \) when it moves away from us and the system is in quadratura. Thus the less massive secondary is before the primary (inferior conjunction) at phase \( = 0.25 \), while the superior conjunction is at phase \( = 0.75 \). Waters et al. (1993) measured a longitude of periastron \( \theta = 359.3^\circ \) orienting the main axis of the elliptical \( (e = 0.189) \) orbit with the East-West direction. Moreover, 89 Her is characterised by an hour-glass structure that is orthogonal to the orbital plane, elongated in a direction that forms an angle of \( 15^\circ \) with respect to the LoS and with a Position Angle of \( 45^\circ \) (Bujarrabal et al. 2007). Fig. 12 shows a sketch of 89 Her.

We find that the overall behavior of the fit parameters of the three slabs (Fig. 11) can be understood within the present picture of 89 Her, if the stationary SLAB 2 presents the average optical and physical properties of the primary component in reflecting and reprocessing the radiation from the orbiting secondary, correspondingly the blue-shifted SLAB 1 represents the jet pointing towards us and the red-shifted SLAB 3 represents the receding jet. In such hypothesis, it is straight to explain:

- the always negative SLAB 1 velocity and the always positive SLAB 3 velocity, both of the order of the hour-glass expansion velocity equal to \( \sim 6-7 \text{ km s}^{-1} \) (Bujarrabal et al. 2007).
- the constant thermal broadening, as it is expected for a phenomenon not due to a change of physical properties of the source, as for example because of pulsations or spots.
- the synchronous saw-tooth variation of \( \gamma \) angles for the three slabs with the orbital period. The continuous variation of \( \gamma \), defined in the \( 0-180^\circ \) range, shows that the polarisation vector describes a closed loop in the sky, that is the scattering plane rotates around the LoS with the secondary star. The orientation of the polarisation vector with the East-West direction in conjunctions and with the North-South direction in quadratura is due to the East-West orientation of the major axis of the elliptical orbit (Fig. 11 and Fig. 12).

A quantitative evaluation of the fit parameters and a description of their variability would require a not yet available 3-D version of HAZEL and a detailed knowledge of 89 Her environment. Qualitatively, the variability of fit parameters is due to the not perfect symmetry with respect to the LoS, to the not null eccentricity of the orbit and to absorption and occultation phenomena. For example, the weak modulation of the SLAB 2 in \( v_{ad} \) and \( \theta \) could be due to orbit eccentricity, or the large modulation of the SLAB 3 \( \theta \) angle with respect the SLAB 1 could be a consequence of partial occultation of the receding jet by the primary star (Fig. 12).

**Figure 12.** A not in scale sketch of 89 Her. The binary system presents the major axis aligned with the East-West direction (Waters et al. 1993). An hour-glass structure is centered on the primary component and normal to the orbital plane (Bujarrabal et al. 2007). In the framework of the anisotropic radiation pumping, the variable Stokes LSD profiles (Fig. 11) can be synthesised with the HAZEL (Asensio Ramos et al. 2008) code assuming three slabs: the stationary SLAB 2 presents the average optical and physical properties of the primary component in reflecting and reprocessing the radiation from the orbiting secondary, correspondingly the blue-shifted SLAB 1 represents the jet pointing towards us and the red-shifted SLAB 3 represents the receding jet. \( \theta \) is the angle between the normal \( n \) to the slab and the LoS, \( v_{n} \) the velocity of the slab towards the LoS. In Section 5.3 is the complete description and definition of fit parameters.

7 CONCLUSIONS

On the basis of high resolution spectropolarimetry, we have found that the metal lines of the binary system 89 Her are polarised as in the Second Solar Spectrum. These absorption metal lines with low excitation potentials present a linear polarisation varying in time with the orbital period.

Because of the variability with the orbital period, we rule out as origin of the variability the pulsations. Moreover, we can also rule out hot spots as possible origin the continuum depolarisation because of the not dependence of polarisation on wavelength.

According to Kuhn et al. (2011), the linear polarisation we detected in the CaII 8662Å line rules out the scattering polarisation from free electrons of the circumbinary environment and it suggests that the origin of the Second Solar Spectrum we observed in 89 Her is the anisotropic radiation field due to the secondary star. In this framework, the periodic variability of polarised profiles, particularly the closed loop described by the polarisation angle, can be ascribed to...
the jets at the basis of the hour-glass structure differently illuminated by the secondary orbiting around the primary.

A further unexpected properties of 89 Her is the polarisation across the emission metal lines. Numerical simulations show that polarised profiles are consistent with electron scattering in an undisrupted rotating disk. Such a disk appears to be clockwise rotated of 45° (clockwise) from the North-South direction as it was observed by interferometric observations.

If it is possible to generalise the result of our observational campaign of 89 Her, we conclude that the inner regions of stellar envelopes can be probed via high resolution spectropolarimetry and that this appears the only diagnostics for stars still too far for interferometric studies.

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