LETTER TO THE EDITOR

Magnetism and spin-orbit alignment in the young planetary system AU Mic *

Martioli, E.1,2, Hébrard, G.1,3, Moutou, C.4, Donati, J.-F.4, Artigau, É.5, Cale, B.6, Cook, N.J.5, Dalal, S.1, Delfosse, X.7, Forveille, T.7, Gaidos, E.8, Plavchan, P.6, Berberian, J.5, Carmona, A.7, Cloutier, R.13, Doyon, R.5, Fouqué, P.8,4, Klein, B.4, Lecavelier des Etangs, A.1, Manset, N.8, Morin, J.10, Tanner, A.11, Teske, J.12, and Wang, S.12

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ABSTRACT

We present high resolution near-infrared spectro-polarimetric observations using the SPIRou instrument at CFHT during a transit of the recently detected young planet AU Mic b with supporting spectroscopic data from iSHELL at IRTF. We detect Zeeman signatures in the Stokes V profiles, and measure a mean longitudinal magnetic field of $B_l = 46.3 \pm 0.7$ G. Rotationally modulated magnetic spots cause long-term variations of the field with a slope of $\frac{\Delta B_l}{\Delta t} = -108.7 \pm 7.7$ G/d. We apply the cross-correlation technique to measure line profiles and obtain radial velocities through CCF template matching. We find an empirical linear relationship between radial velocity and $B_l$, which allows us to calibrate out the radial velocity variations which stellar activity induces through rotational modulation of spots. We model the corrected radial velocities for the classical Rossiter-McLaughlin effect, using MCMC to sample the posterior distribution of the model parameters. This analysis shows that the orbit of AU Mic b is prograde and aligned with the stellar rotation axis with a sky-projected spin-orbit obliquity of $\lambda = 0^\circ \pm 5^\circ$. The aligned orbit of AU Mic b indicates that it formed in the protoplanetary disk that evolved to the current debris disk around AU Mic.

Key words. AU Mic b – radial velocity – SPIRou – extrasolar planets

1. Introduction

Detecting and characterizing planets around young stars is key to understanding the early stages of planetary evolution. Several mechanisms can produce strong misalignments between the planetary orbit and the stellar spin, including high eccentricity tidal migration, planet–planet scattering, and Kozai–Lidov cycles driven by a binary (e.g., Dawson & Johnson 2018; Triaud 2018). The resulting relative orientation of the planetary orbit and the rotation axis of the host star is a key discriminant between different formation and migration scenarios.

Here we report a measurement of the spin-orbit angle for the recently detected transiting super-Neptune planet AU Mic b (Plavchan et al. 2020). AU Mic is a young and active M1 star with a spatially resolved edge-on debris disk (Kalas et al. 2004), and a member of the $\beta$ Pictoris Moving Group (Torres et al. 2006). Its distance of only 9.7248 ± 0.0046 parsec (Gaia Collaboration 2018) and its estimated age of 22 ± 3 Myr (Mamajek & Bell 2014) make it both the closest and the youngest system with either a spatially resolved edge-on debris disk or a transiting planet. Table 1 summarizes the stellar and planetary parameters of the system.

Young systems with detected planets (e.g., V830 Tau b; Donati et al. 2016), and especially those with either a remnant debris disk like $\beta$ Pic b (Lagrange et al. 2009) or transiting planets (e.g., K2-33 b, DS Tuc Ab; David et al. 2016; Mann et al. 2016; Newton et al. 2019) are key probes of planetary formation. AU Mic has both a disk and at least one transiting planet, and it is also unique amongst debris disk hosts for being an M
star, the most numerous type of star in our Galaxy and the most promising spectral type to find habitable planets using current techniques.

2. Observations and data reduction

2.1. SPIRou

The Spectro-Polarimètre Infra Rouge (SPIRou) is a stabilized high resolution near infrared spectro-polarimeter (Donati et al., 2020, submitted) mounted on the 3.6 m Canada-France-Hawaii Telescope (CFHT) atop of Maunakea, Hawaii. SPIRou is designed to perform high precision measurements of stellar radial velocities to search and characterize exoplanets. It provides full coverage of the near infrared spectrum from 950 nm to 2500 nm, in a single exposure, without gaps, and at a spectral resolving power of 2.9 and ended at 1.8, with a minimum of 1.59. The condition remained nearly photometric, with the SkyProbe monitor measuring a maximum absorption of 0.12 mag. The image quality (seeing) measured by the SPIRou guider varies from 0.8 to 1.6 arc seconds, with a mean value of 0.96 ± 0.13 arc second. The Moon was almost full, with a 99% illumination, and was separated from our target by 40.3 degrees. The peak signal-to-noise ratio (SNR) per spectral bin (in the spectral order centered at ~ 1670 nm) of the individual exposures varies between 176 to 273, with a mean value of 242.

2.2. Observations

We observed the June 16, 2019 transit of AU Mic b as part of the Work Package 2 (WP2) of the SPIRou Legacy Survey (Donati et al., 2020, submitted) CFHT large program (id 19AP42, PI: Jean-François Donati). The observations were carried out in the Stokes V spectro-polarimetric mode of SPIRou. They started at UT 2019-06-17T10:56 and finished at UT 2019-06-17T15:45, and consist of 116 individual flux spectra of AU Mic with a 122.6 s exposure time. They correspond to 29 Stokes V polarimetric spectra (with 4 individual exposures per polarimetry sequence). Our observations started with an airmass of 2.9 and ended at 1.8, with a minimum of 1.59. The condition remained nearly photometric with the SkyProbe monitor (Cuillandre et al., 2003) measuring a maximum absorption of 0.12 mag. The image quality (seeing) measured by the SPIRou guider varies from 0.8 to 1.6 arc seconds, with a mean value of 0.96 ± 0.13 arc second. The Moon was almost full, with a 99% illumination, and was separated from our target by 40.3 degrees. The peak signal-to-noise ratio (SNR) per spectral bin (in the spectral order centered at ~ 1670 nm) of the individual exposures varies between 176 to 273, with a mean value of 242.

2.3. Data reduction

The data have been reduced with version v.0.6.082 of the APERO SPIRou data reduction software (Cook et al., 2020, in prep). APERO first combines the sub-exposures at the read-out level, correcting for the non-linearity in the pixel-by-pixel response. The 1D spectral fluxes are optimally extracted following Horne (1986). The individual spectral orders are processed and saved separately, providing a 2D frame with about 4088 spectral pixels for 48 orders. SPIRou uses two optical fibers to collect light from the two images formed by a Wollaston prism. For pure spectroscopy, APERO merges the spectra of the two beams, whereas for polarimetry the fluxes of the two channels are individually saved for later polarimetric analysis. APERO also calculates for each channel a blaze function from daytime flat-field exposures. The pixel-to-wavelength calibration is obtained from a combination of daytime exposures of a UNe hollow-cathod lamp and of a thermally-controlled Fabry-Pérot etalon (FP). The FP also feeds a third fiber during science exposures to monitor instrument drifts. APERO calculates a telluric absorption spectrum for each exposure, using an extensive library of telluric standard stars observed nightly with SPIRou over a wide range of air mass and atmospheric conditions. APERO uses the PCA-based correction technique of Artigau et al. (2014) to produce a telluric absorption corrected spectrum. APERO also calculates the Cross Correlation Function (CCF) with a set of line masks optimized for different stellar types and systemic velocities.

2.4. iSHELL data

We include in our analysis simultaneous RV measurements from 47 in-transit spectra of the June 16, 2019 transit of AU Mic obtained with the iSHELL spectrometer on the NASA Infrared Telescope Facility (IRTF, Rayner et al., 2016). Their 2-minute exposure time results in a photon signal-to-noise ratio of ~ 60-70 per spectral pixel at 2.4 μm (the approximate peak of the blaze function for the center order), and in turn in a RV precision of 15-27 m/s (median 21 m/s) per measurement. These spectra were reduced and their RVs extracted using the methods outlined in Cale et al. (2019).

3. Spectropolarimetry

SPIRou Stokes-V spectra are obtained from sequences of 4 exposures with distinct positions of the Fresnel rhombs (we com-
Fig. 1. Median of all LSD profiles in the AU Mic time series. The top panel shows Stokes I LSD (red points) with a a Voigt profile model fit (green line); the middle panel shows Stokes V (blue points) and a double Voigt profile model fit (blue line); the bottom panel shows the null polarization profile (orange points).

pute the Stokes parameter using the "ratio" method (Donati et al. 1997; Bagnulo et al. 2009). Since the order of the exposures within the successive AU Mic polarimetric sequences is identical, we can obtain higher time sampling by calculating polarimetric spectra in every set of four adjacent exposures. With this method we obtain a total of 113 (non-independent) polarimetric spectra in every set of four adjacent exposures. With this processing alternative, we apply a median filter (MF) to the CCF.

We applied the least squares deconvolution (LSD) method of Donati et al. (1997) to each Stokes I, Stokes V, and null polarization spectrum to obtain LSD profiles for each. The line mask used in our LSD analysis was obtained from the VALD catalog (Piskunov et al.1995) based on a MARCS model atmosphere (Gustafsson et al. 2008) of effective temperature 3500 K and surface gravity log g = 5.0 cm s^{-2}. Figure 1 presents the medians of the 113 profiles, and its Stokes-V panel shows a clearly detected Zeeman signature.

4. Radial Velocities

We measure the radial velocity of AU Mic using the cross-correlation function (CCF) between the telluric-corrected stellar spectrum and a line mask (Pepe et al. 2002). The broad nIR bandpass of SPIRou covers thousands of atomic and molecular lines, which greatly improves the precision in the determination of the CCF. The line mask plays an important role in the CCF method, since it determines the spectral regions that are probed and the statistical weight for each of these regions. We use the “M2 weighted RV -5.mas” line mask from the set of empirical masks delivered by the APERO pipeline. This mask is based on the observed spectra of the M2V star Gl 15A and is a good match to the M1V spectral type of AU Mic. Even though SPIRou spectra are corrected for telluric absorption, this mask blanks out those lines with more than nominal telluric absorption at a systemic radial velocity of -5 km/s, which is close to the -4.5 km/s systemic velocity of AU Mic. The mask has 3475 lines, but we further filter it using the approach of Moutou et al. (2020, submitted), eliminating those lines which are not detected in the mean Stokes-I spectrum of AU Mic, for a final set of 2277 retained lines.

Table 2. Fit parameters of AU Mic b. T_{i} is in units of BJD - 2458330, \lambda is in degrees, \nu_{c} \sin \iota_{c} and \gamma are in km/s, and \alpha is in m s^{-1} d^{-1}.

| Parameter | Prior | Posterior |
|-----------|-------|-----------|
| T_{c}     | \mathcal{N}(0.39153, 0.00070) | 0.3882^{+0.011}_{-0.013} |
| R_{p}/R_{*}| \mathcal{N}(0.0514, 0.0013) | 0.058^{+0.010}_{-0.004} |
| \lambda   | \mathcal{U}(-90, 90) | -0.1^{+18.2}_{-9.4} |
| \nu_{c} \sin \iota_{c} | \mathcal{N}(7.8, 0.3) | 7.70^{+0.26}_{-0.53} |
| \gamma    | \mathcal{U}(-\infty, \infty) | -4.386^{+0.015}_{-0.008} |
| \alpha    | \mathcal{U}(-\infty, \infty) | 141^{+1}_{-3} |

The 48 orders delivered by SPIRou have different noise levels, depending mostly on the instrumental throughput (Donati et al., 2020, submitted) and on the telluric absorption. We compute a separate CCF for each spectral order, and combine some of those into a sum CCF to improve precision. We obtain individual RV measurements for each spectral order and calculate the RV dispersion \sigma_{RV} throughout the time series. The mean dispersion between all orders is \sigma_{RV} = 97 \pm 90 m/s. Given the variable RV precision between orders, we decided to restrict our analysis to the 1512 nm to 1772 nm range in the H-band, where the mean RV dispersion is \sigma_{RV} = 28 \pm 7 m/s. Our CCF mask has a total of 842 lines within this spectral range.

We measure radial velocities from the CCF by least-square fitting for the velocity shift \Delta v_{i} that best matches the CCF of an individual exposure, CCF_{i}, to the median of the CCFs of all exposures, \overline{CCF}_{m}. The shifted template \overline{CCF}_{m}(\nu + \Delta v) is calculated by cubic interpolation. We also measured RVs by fitting a Gaussian to each CCF, which is the most usual method. That gives similar results but shows stronger systematics correlated with the air mass of the observations, and we therefore adopt the CCF matching (CM) method in our analysis. In yet another processing alternative, we apply a median filter (MF) to the CCF time series before calculating RVs through template matching, using a 3 x 3 window along the time and velocity axes.

5. Rossiter-McLaughlin effect

We first model the SPIRou radial velocities of AU Mic as the combination of its reflex orbital motion caused by planet b, assuming a circular orbit and the Plavchan et al. (2020) orbital parameters, and the classical Rossiter-McLaughlin (RM) effect, with the stellar limb darkening accounted for as described in Ohta et al. (2005). We adopt a linear limb darkening model and fix the H-band coefficient to \mu_{H} = 0.2432 from Claret & Bloemen (2011). We adopt as free parameters the time of conjunction \text{c}, the planet to star radius ratio R_{p}/R_{*}, the sky projected obliquity angle \lambda, the projected stellar rotation velocity \nu_{c} \sin \iota_{c}, the systemic velocity \gamma, and we include a slope of the RVs as a function of time, \alpha, to account for both stellar activity trends and a planetary signal.

Table 2 shows the priors which we adopt for each parameter. We sampled the posterior distributions using the emcee Markov chain Monte Carlo (MCMC) package (Foreman-Mackey et al. 2013), using 32 walkers and 300 MCMC steps of which we discard the first 50. The best-fit values in Table 2 are the medians of the posterior distribution, and the errorbars enclose 34% on each side of the median.

Figure 2 shows as blue triangles the SPIRou AU Mic RVs obtained by CCF matching the original CCFs, whereas the filled circles show those obtained from the median filtered CCFs. We identify two anomalous regions in the time series, marked in red
in the figure, where the RV residuals are above 2.5 × σ. We interpret these regions as stellar activity events, such as spot-crossing by the planet and/or flares. The corresponding data were masked out in the final model fit. Our best fit RM model includes a RV slope of 141\pm 18 \text{ m s}^{-1} \text{ d}^{-1} and the dispersion of its residuals is 5.1 m/s outside the mask. For illustration of the stability of SPIRou, we also show the instrumental drifts obtained from the spectrum of the FP calibrator which is simultaneously observed through the reference fiber, with a dispersion of just 0.51 m/s.

The sky projected obliquity angle of \( \ell = -0.1 + 9.4 \) degrees shows that the orbit of AU Mic b is prograde and close to aligned with the rotation axis of the parent star. Our best fit value of \( \nu_c \sin \iota_e = \SI{7.70 \pm 0.26}{km/s} \) agrees well with the Table 1 value calculated from the stellar radius and rotation period, as well as with independent measurements of \( \nu_c \sin \iota_e \) (Lavail et al. 2018). Our analysis also shows that the conjunction occurred about 5 minutes (\( \sim 3 \times \sigma \)) earlier than predicted, and favors a slightly larger planetary radius, though within 1\( \sigma \), \( \ell \). These parameters are however not well constrained by our data, since we did not reach full convergence when increasing the number of MCMC iterations, most likely because we lack any pre-transit baseline and our post-transit baseline is affected by stellar activity.

6. Magnetic activity

As amply illustrated by its TESS light curve, AU Mic is an active star, with a surface largely filled by spots and plages, and with frequent flares (Plavchan et al. 2020). The \( \sim 5 \) hr SPIRou time series covers 4.5% of the 4.863-day rotation period of AU Mic . The non-uniform brightness distribution of the AU Mic disk has therefore probably changed, slowly through rotation of the visible hemisphere, and rapidly through flaring and spot evolution. Planet AU Mic b can additionally transit spots and plages, also causing fast variability. These brightness variations change the rotation profile of AU Mic and strongly affect our RV measurements. Batley et al. (2012) reported a 124.74-m/s dispersion for their nIR RV measurements of AU Mic. Klein et al. (2020, in prep.) analyze longer term SPIRou spectropolarimetric observation and reconstruct a Zeeman Doppler Imaging (ZDI) model, from which they predict a \( \pm 150 \text{ m/s} \) RV variability from stellar activity, which approximately matches the Batley et al. (2012) dispersion. Klein et al. additionally predict median and maximum slopes of respectively \( \sim 50 \text{ m s}^{-1} \text{ d}^{-1} \) and \( \sim 200 \text{ m s}^{-1} \text{ d}^{-1} \), making the \( \alpha = 141 \pm 18 \text{ m s}^{-1} \text{ d}^{-1} \) linear trend in our RM analysis fully compatible with the expected activity signal.

Since both spot and flare events are connected to the magnetic field (Lavail et al. 2018), we search for an empirical correlation between the measured RVs and the longitudinal magnetic field \( B_{L} \), in an attempt to mitigate the effects of stellar activity on our RV data. The longitudinal magnetic field \( B_{L} \) is calculated for each AU Mic polarized spectrum using the following equation from Donati et al. (1997):

\[
B_{L} = -2.14 \times 10^{11} \frac{\int V(v)dv}{\lambda_0 \cdot g_{eff} \cdot c \cdot \int [I_e - I(v)]dv}
\]  

where \( c \) is the speed of light, \( I(v) \) and \( V(v) \) are the Stokes I and V profiles as functions of velocity \( v \) in the star’s frame, \( I_e \) is the continuum of the Stokes I profile, \( \lambda_0 = 1515.38 \) nm is the mean wavelength, and \( g_{eff} \) = 1.24 is the mean Landé factor of the lines included in the mask. The bottom panel of Figure 3 illustrates our measurements of \( B_{L} \) for AU Mic showing values obtained both from the original Stokes V profiles (black points with errorbars) and from the median filtered profiles (black line). The mean longitudinal field of AU Mic during our time series is \( B_{L} = 49.7 \pm 8.1 \text{ G} \), with a linear trend of slope \( -108.7 \pm 7.7 \text{ G/d} \) which is likely due to rotational modulation of spots. The field measured from the median LSD profile of figure 3 is \( B_{L} = 46.3 \pm 0.7 \text{ G} \) and therefore closely matches the mean longitudinal field of the sequence.

We least-square fit (Figure 3 top panel) the following linear function to the RM-subtracted RV data:

\[
v_p(t) = [B(t) - B_0] a + v_0,
\]

where \( B_0 \) is an arbitrary reference magnetic field, \( a \) is the scaling factor between the two quantities, and \( v_0 \) is a constant velocity. The best fit scaling factor is \( a = -1.31 \pm 0.12 \text{ m s}^{-1} \text{ G}^{-1} \), significant at the 9σ level. The Pearson-r correlation coefficient between our measured RVs and the predicted \( v_p \) is \( r = 0.72 \), showing a significant correlation between the two quantities, mainly because stellar rotation modulates both the RVs and \( B_{L} \). Subtracting a linear fit from both \( B_{L} \) and RVs to eliminate the long term variations reduces \( r \) to 0.19, showing some possible smaller correlation between the short time-scale variations of the RVs and \( B_{L} \). Subtracting only the fitted \( B_{L} \) slope however produces less dispersed RV residuals than subtracting the full empirical model \( v_p \). The short time scale structure is likely due to spot evolution, flares, and the planet transiting spots and plages. Each of these phenomena unfortunately has a different relationship between its RV variation and \( B_{L} \), which makes our linear model much too simple to account for the short-term RV variability. A future paper will investigate these issues in much more detail and with an extended observational dataset.

7. Results and Discussion

Our preferred SPIRou RVs of AU Mic are obtained by subtracting from the measured RVs the linear component of the empirical model, a \( 142 \pm 17 \text{ m s}^{-1} \text{ d}^{-1} \) slope which mostly removes the stellar activity signal discussed above. We then adjust the RM model of section 6 to both the iSHELL and corrected SPIRou data, using 50 MCMC walkers and 2000 steps with the first 500 discarded. Our only free parameters are the projected obliquity angle \( \lambda \) and two systemic velocities \( \gamma_{SPIRou} \) and \( \gamma_{iSHELL} \), to account for different instrumental zero points. We fix \( T_0, R_p, R_{star}, \) and \( \nu_c \sin \iota_e \) to their literature values because our data do not constrain them as well. Nevertheless and as a consistency test, we perform an alternate fit using our Table 2 fitted values for the fixed parameters, instead of the literature values of Table 1.

Using the literature values of the fixed parameters, we obtain \( \lambda = -0.1 \pm 0.5 \) degrees and 5.7-m/s and 11.9-m/s dispersions for the SPIRou (masked data excluded) and iSHELL residuals. Using instead our previously fitted values of the fixed parameters produces slightly smaller dispersions of the residuals of both instruments, 5.0 m/s and 11.6 m/s, and a fitted obliquity angle of \( \lambda = 0.3 \pm 7.2 \) degrees. The fitted \( \lambda \) has \( \sim 40 \% \) smaller uncertainties when using the literature values, which suggests that these literature values contribute significant information to the measurement of \( \lambda \). One important consideration is that all data selection and analysis choices affect the errorbars to some extent but have little effect on the central value, which is therefore robust. \( \lambda \) is for instance practically unchanged when including or not the SPIRou data points that we masked as affected by short
Fig. 2. SPIRou radial velocities of AU Mic. Blue triangles show the RVs obtained from CCF matching the original CCFs, and filled circles show the RVs obtained from CCF matching the median-filtered CCFs. Red circles show data masked by our 2.5σ clip. Vertical lines show the predicted start, center, and end of the transit. The green line shows the best fit model and the thin red lines show models for 100 randomly selected MCMC samples. The grey dashed line shows best fit slope of $141^{+13}_{-31}$ m s$^{-1}$ d$^{-1}$ with an arbitrary vertical offset for visualisation, and the orange points show the SPIRou instrumental drift (also with an arbitrary offset), and illustrate its dispersion of just 0.51 m/s.

Fig. 3. The top panel shows as a function of time the RM-subtracted RVs of AU Mic in green and their best fit Equation 2 linear model in dark blue. The vertical dashed lines show the predicted transit center (blue) and end (red). The bottom panel shows the longitudinal field derived from the original LSD profiles (black circles) and from the median filtered LSD profiles (black line). We also present a linear fit to the values of $B_L$ (dashed grey line in bottom panel) and the corresponding trend in velocity space (dashed grey line in top panel).

Fig. 4. Simultaneous fit to the corrected SPIRou RVs (filled circles) and iSHELL RVs (hollow circles) of the model of Rossiter-McLaughlin effect (green line). Red circles show SPIRou data masked by our 2.5σ clip. The vertical dashed lines show the predicted transit center (blue) and end (red). Bottom panel shows the residuals of the fit with respective dispersions of 5.7 m/s and 11.9 m/s for SPIRou and iSHELL.

RM model independently of SPIRou, but the two data sets are fully mutually compatible. The agreement between the data sets from these two different instruments using independent techniques for data analysis is remarkable and shows that both instruments are stable and can provide RVs with precisions of a few m/s for an active star.

In addition to the analysis presented here, we performed extensive tests adopting different model assumptions, and obtaining radial velocities with different methods including RV measurements from an analysis of CCF bisector and measuring RVs term stellar activity. We adopt as our preferred value of $\lambda$ that obtained with the fixed parameters set to their literature values and without masking the SPIRou velocities for activity, $\lambda = 0^\circ \pm 5^\circ$. This result confirms that the planet is on a prograde orbit and that the orbital and rotation spins are closely aligned. Figure 4 shows this final fit model to the RV data for both instruments.

Since iSHELL only observed a partial transit of AU Mic and no out-of-transit baseline, its data alone do not constrain a full

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from LSD profiles produced by an independent pipeline (Donati et al., 2020, submitted). All RM model fits persistently prefer a \( \lambda \) value consistent with aligned rotation and orbital angular momenta.

8. Conclusions

1. We present observations of a transit of the recently detected planet of the nearby young M1 star AU Mic with a resolved edge-on debris disk with the SPIRou high resolution near infrared spectro-polarimeter at CFHT and the iSHELL high resolution near infrared spectrograph at IRTF.

2. We cross-correlate the spectra with numerical masks and employ the CCF matching method to obtain radial velocities of AU Mic with \( \sim 5\text{m/s} \) precision.

3. We obtain Stokes I and V spectra of AU Mic and perform a LSD analysis to obtain average Stokes I and V profiles, and strongly detect a Zeeman signature in the Stokes V profile. The corresponding mean longitudinal magnetic field is \( B_L = 46.3 \pm 0.7 \text{G} \) and varies at a global rate of \( dB_L / dt = -108.7 \pm 7.3 \text{G/d} \).

4. We use the correlated variability of the longitudinal magnetic field and radial velocity, with a scaling factor \( \alpha = -1.31 \pm 0.12 \text{ m s}^{-1} \text{G}^{-1} \text{to} \) empirically correct a linear RV trend of \( 141 \pm 17 \text{ m s}^{-1} \text{d}^{-1} \). This trend is consistent with the slope of \( 141 \pm 31 \text{ m s}^{-1} \text{d}^{-1} \) found in our RM analysis and compatible with the activity level of AU Mic.

5. We fit a classical Rossiter-McLaughlin effect model to the SPIRou and iSHELL data, and find a sky projected spin-orbit obliquity angle for AU Mic of \( \lambda = 0^\circ \pm 5^\circ \).

6. AU Mic b is therefore on a prograde and closely aligned orbit, which is evidence that the planet likely formed in the proto-planetary disk that evolved to the current AU Mic debris disk, provided that the star-disk-planet components of the system share the same angular momentum orientation.

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