



First-light imaging polarimetry of auroral emissions with the Polaribotn camera

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Abstract. We present first-light observations of auroral imaging polarimetry with the Polaribotn camera, a monochrome micropolarizer-based instrument equipped with narrowband filtering at the O(¹S) 557.7 nm green line. The instrument was operated simultaneously with the Corbel Cru polarimeter during a campaign in Skibotn, Norway, allowing a direct comparison with the existing narrow-field reference framework. The common field of view was identified empirically from the intensity time series, and the Polaribotn measurements show good agreement with Corbel Cru in both degree and angle of linear polarization. Extending the analysis to 63 regions of interest across the full image reveals that DoLP and AoLP do not respond in the same way to auroral structures: DoLP decreases in the brightest arc regions, whereas AoLP often remains coherent over a large fraction of the field of view. The corresponding (q, u) analysis points to a strong scene-wide polarization component with local intensity-dependent perturbations. Although the present dataset does not yet allow a definitive interpretation of the physical origin of the polarization, it demonstrates that auroral imaging polarimetry is feasible and provides spatial information not accessible to previous narrow-field instruments.

1 Introduction

Upper-atmospheric emissions have been studied for more than a century, yet many questions remain unanswered. In the visible range these emissions are mainly produced by the atomic oxygen O, which is abundant in the thermosphere together with molecular nitrogen N₂ and oxygen O₂, and also by the ionized molecular nitrogen N₂⁺, a major component of the ionosphere. One of the main mechanisms driving these emissions is the excitation of these species through the collision and ionization with energetic electrons precipitating from the solar wind and the magnetosphere (called primary electrons) or with secondary electrons produced during the ionization process. These collisions excite and ionize atoms and molecules in the upper atmosphere, which subsequently emit light during de-excitation. The precipitating electrons follow the Earth's magnetic field lines, generating field aligned currents which couple the magnetosphere and the ionosphere. These currents are connected



to Pedersen horizontal currents flowing in the ionospheric E region, at altitudes around 110 km.

Duncan (1959) was the first to study and report the polarisation of upper-atmospheric emissions, linking it to the anisotropic velocity distribution of precipitating electrons. However, the observed Degree of Linear Polarisation (DoLP) reached values as high as 30%. Chamberlain (1959) later showed that such values were theoretically impossible and likely caused by instrumental effects. Interest in the topic subsequently declined for several decades, while our technology and comprehension of the upper atmosphere continued to improve.

Lilensten et al. (2006) proposed revisiting the measurement of the polarisation of the upper-atmospheric emissions using more sensitive instruments specifically designed for low-light and low-polarisation observations. Several positive detections of the polarisation in the red atomic oxygen line at 630 nm were reported (Barthélémy et al., 2011; Lilensten et al., 2013, 2015, 2016), with DoLP values reaching up to 10%, although typical values were closer to 2%. These observations were carried out in the polar cap where a permanent precipitation of low-energy electrons originating directly from the solar wind occurs. Bommier et al. (2011) proposed a theoretical model for the impact polarization of the red line based on a semi-classical approach, predicting DoLP values significantly higher than those previously observed and suggesting the existence of competing depolarizing effects. Using the same model, they also concluded that the auroral green-line emission at 557.7 nm could not be polarized by impact with precipitating electrons. These theoretical results motivated investigations of polarisation in other upper-atmospheric emissions, including the green (557.7 nm), blue (427.8 nm), and purple (391.4 nm) lines (Barthelemy et al., 2019; Bosse et al., 2020). These observations were carried out in the auroral oval and surprisingly, a similar amount of polarisation was reported in the green line, raising questions about its origin. In particular, light pollution scattered in the atmosphere from indirect sources, such as street lamps, is itself polarized and may contaminate the observations. This possibility challenged the interpretation of the observed polarization as being intrinsic to auroral emissions.

Subsequent studies therefore focused on understanding the origin of the night-sky polarisation observed in both urban and remotes areas, under conditions ranging from intense auroral activity to faint nightglow. Two main strategies were employed: light pollution models (Bosse et al., 2023) and multi-instrument observations (Bosse et al., 2020, 2022a). These studies show that (i) all main auroral emissions exhibit polarization levels of up to a few percent, (ii) scattering of artificial light pollution cannot be neglected, although it is insufficient to fully explain the observations, and (iii) light pollution contamination may still be present even in remote observing sites. In parallel, Bourgeois et al. (2022) demonstrated through controlled laboratory experiments that auroral polarisation originates at the source, i.e. that each atmospheric constituent emission is polarized. This study could rule out the assumption from which the emission would not be polarized and the polarization would occur while the light crosses the ionospheric currents.

This series of results were obtained with a family of instruments called "Cru" whose operating principle is described in section 2. The main limitation of these instruments is their narrow field of view (FoV) of 2° and the lack of spatial resolution. As a consequence, although they are capable of detecting rapid temporal variations in polarization, they cannot resolve spatial variations across or around an auroral arc at a given moment. Mapping polarisation parameters over a large FoV was therefore not possible. This limitation made the identification of polarisation sources more difficult and significantly reduced the amount of information that could be extracted from the observations.



Auroral imaging polarimetry is only beginning to emerge. Very recently, Stockmans et al. (2026) introduced the "Polarization of the Aurora in the North Imaging Camera" (PANIC) instrument, an RGB polarization camera combined with additional broad-band filters and a rotating half-wave plate. Their work demonstrated that compact multi-band auroral imaging polarimetry is feasible in principle, but also highlighted how challenging such observations remain in practice. In particular, the first PANIC dataset did not reveal a clear auroral polarization signal during bright arc activity, despite sub-percent polarimetric sensitivity, and the authors discussed important limitations related to thermal stability, dark-current control, and the complexity of separating weak auroral polarization from background and instrumental effects.

In this paper, we present observations carried out with a new instrument called Polaribotn, an imaging polarimeter designed to overcome the spatial-resolution limitations of the Cru instruments, but also to address the limitation from PANIC. The strategy adopted here is deliberately simpler: a monochrome polarized sensor used with narrowband filtering targeting the green line from O(¹S) at 557.7 nm, operating simultaneously with the Corbel Cru instrument for cross-validation. Section 2 provides a detailed description of the instruments used during the campaign. Section 3 presents the observations and their direct comparison. Section 4 is devoted to the data-analysis methods and the calibration of the polarization measurements. Results are presented in section 5, followed by a discussion in Section 6 and a conclusion to outline the requirements and prospects for future observational campaigns.

2 Instrumentation

2.1 The Cru instruments

Over the last years, we developed a series of instruments dedicated to the measurement of the auroral polarisation, known as the Cru instruments. The first prototype was called Petit Cru and described in detail by Bosse et al. (2020). Two additional versions, called Corbel Cru and Grand Cru, were built in the following years and used in Bosse et al. (2022b). All three instruments are built on the same operating principle, briefly recalled here. For a complete description, the reader is referred to Bosse et al. (2020).

First, the light passes through a polarising element, the analyser, which continuously rotates at frequencies up to 20 Hz. A converging lens then defines the instrument FoV to approximately 2°. An interference filter subsequently selects the wavelength of interest, with a bandwidth of 2 nm around the red line at 630 nm and 10 nm around the other emission lines. Finally, the transmitted light flux is measured using a photomultiplier.

This optical setup forms a channel, which can be replicated two times (for Corbel Cru) or four times (for Grand Cru) within the same instrument. This configuration allows simultaneous observations at different wavelengths by using different interference filters per channel. Variations of the measured flux during one rotation of the analyser provide access to the polarisation properties of the incoming light through Malus' Law using a lock-in amplifier (Collett, 2005). To improve the signal-to-noise ratio, the signal can be integrated over several rotations of the analyser. This increases the accuracy of the polarisation measurements, but relies more strongly on the assumption that the polarisation state varies slowly compared to the rotation period of the analyser.



The instrument is not calibrated for absolute radiometric measurements. Its output consists of electron counts recorded at a sampling frequency of 1 kHz, meaning that the measured flux intensity is expressed in arbitrary units. However, the instrument was calibrated for DoLP using a light source of known polarisation developed at the Laboratoire d'Optique Atmosphérique in Lille (Bosse et al., 2020). Depending on the brightness of the observed light source, the instrument is capable of measuring DoLP with an accuracy down to 1% for faint auroras and 0.5% for brighter ones. These sensitivity limits also define the practical detection threshold for the Angle of Linear Polarization (AoLP). Below these DoLP threshold, the AoLP becomes poorly constrained and in practice undefined.

2.2 The Polaribotn camera

In order to overcome the limitations associated with the narrow FoV and the absence of spatial resolution of the Cru instruments, the Royal Belgian Institute for Space Aeronomy acquired and deployed a new imaging polarimeter called Polaribotn. This instrument is based on a QHY550P thermoelectrically cooled CMOS camera equipped with Sony's polarized IMX250MZR monochrome sensor (Lane et al., 2022). The detector is a global-shutter sensor with $3.45\ \mu\text{m}$ pixels and a focal-plane micropolarizer mosaic, in which adjacent pixels sample four linear polarization orientations (0° , 45° , 90° , and 135°), as depicted in Figure 1 of Lane et al. (2022). This architecture provides some snapshot measurements of the linear polarization state through a super-pixel approach, without any moving optical element. In the Sony Polarsens design, the polarizer is formed on chip under the lens layer, which improves the extinction ratio and the dependence on incidence angle compared with more conventional realizations.

The camera was operated with a Canon 24 mm lens at $f/2.8$. Calibration studies of this polarization image sensor show that larger ray angles, i.e. lower F-number than 2.8, can become an additional source of polarimetric error for micropolarizer-based detectors (Lane et al., 2022). As an astronomical camera, the detector temperature can be actively regulated during the observations, which is an important advantage for low-light polarimetric measurements because it stabilizes the dark current. The useful field covered by the reconstructed polarimetric images is approximately $20^\circ \times 17^\circ$ on the sky, as shown in Figure 1. A narrowband interference filter, integrated within a filter wheel, centered on the green auroral line at 557.7 nm, with a full width at half maximum of about 3 nm, is used. This configuration was chosen to isolate the main auroral O^1S emission while preserving a sufficiently wide FoV for imaging. The intensity has not been radiometrically calibrated and is therefore expressed in digital units (ADU).

3 Observations

3.1 Observing configuration

The dataset analyzed in this paper was acquired in Skibotn, Norway, on 15 February 2026, during an interval extending approximately from 18:00 to 19:10 UT. The all-sky camera at Skibotn (Nanjo et al., 2022) showed weak but dynamically evolving auroral arcs, with cloud or cirrus contamination becoming more significant after 18:40. This visual activity occurred

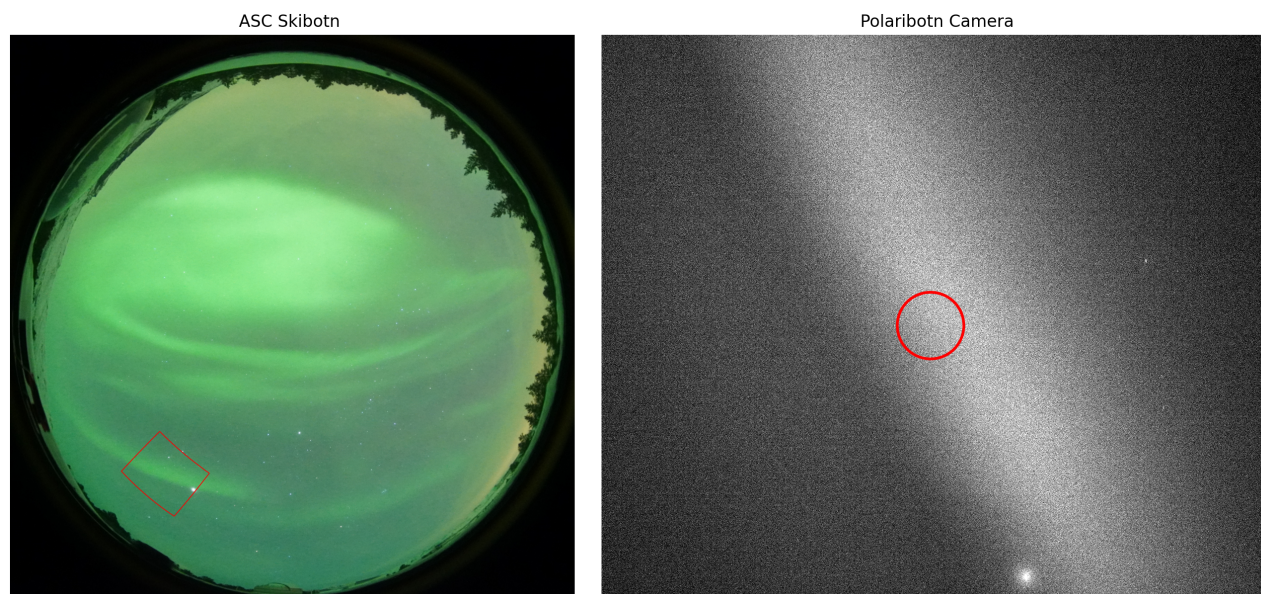


Figure 1. Left: image acquired by the all-sky camera located at the Skibotn Observatory at 18:17:19 UT (Nanjo et al., 2022), with the Polaribotn camera FoV indicated by the red square. Right: Polaribotn camera FoV at 18:17:21 UT, with the approximate FoV of the Corbel Cru instrument indicated by the red circle.

120 under moderate planetary geomagnetic conditions, with $H30/Hp30 = 3.667$ for the considered period. In contrast, the Tromsø magnetometer response remained modest: after subtracting the quiet horizontal field, the amplitude stayed within approximately -60 to +87 nT, with no pronounced negative period or sharp onset-like decrease.

To collect sufficient auroral signal, the camera was operated with an exposure time of 20 s, with the detector temperature set at -20°C, and a gain setting of 400. Although necessary for this weak event, this relatively high gain strongly reduced the
125 useful detector dynamic range.

Simultaneous observations were also carried out with the Corbel Cru instrument, which was used here as a reference. In the present study, we primarily use the 557.7 nm channel for comparison with the Polaribotn measurements. The Corbel Cru data were acquired with a native time resolution of 0.5 s. For the present analysis, however, the time series were smoothed over 15 s in order to improve the signal-to-noise ratio.

130 3.2 Definition of the common FoV with Corbel Cru

Because the Corbel Cru instrument does not provide imaging capabilities and has no dedicated pointing system, the common FoV between both instruments had to be identified empirically. To achieve this, the Corbel Cru intensity time series was compared with the Polaribotn intensity measured in different circular regions of interest within the image, each corresponding to a nominal diameter of 2°. This procedure defined a small set of plausible common FoVs with very similar intensity
135 correlations. Among these nearly equivalent solutions, the region giving the best agreement in DoLP was retained as the



best estimate of the common FoV. The AoLP time series was not used during this selection procedure. The resulting region is indicated by the red circle in Figure 1, and the associated intensity comparison is shown in Figure 2. Over the common interval, the correlation coefficient reaches $R = 0.996$, supporting the identification of a common FoV suitable for comparison. This empirical definition should nevertheless be regarded as approximate.

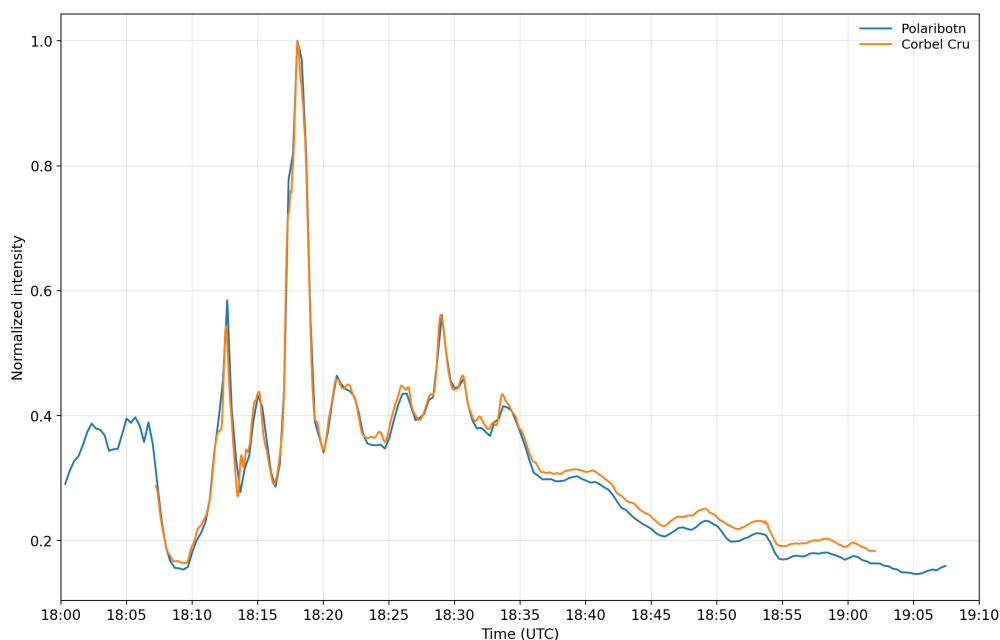


Figure 2. Normalized auroral intensity measured by the Corbel Cru instrument (orange) and by the Polaribotn camera (blue) for the region of interest from Figure 1 providing the closest match to the Cru FoV.

140 4 Data reduction and calibration

4.1 Polarimetric reconstruction and first-order calibration

The calibration procedure was designed to place the Polaribotn measurements on a basis directly comparable to those of the Corbel Cru reference instrument.

For each raw frame, the four polarization channels were extracted from the detector micropolarizer mosaic according to the sensor geometry. In the native camera convention, these four channels correspond to polarization orientations of 0° , 45° , 90° , and 135° . Because these four channels are sampled at slightly different positions on the focal-plane micropolarizer mosaic, such detectors are in principle affected by spurious polarization signals caused by instantaneous field-of-view (IFOV) sampling errors in the presence of spatial intensity gradients (Tyo et al., 2009). This effect is expected to be more critical for sharp structures and point-like sources than for extended auroral and sky emissions. In the present study, however, the main



150 observables are derived from 20 s exposures and from spatial integration over circular regions of 2° diameter, so these local sampling effects are expected to be substantially reduced, although not strictly eliminated.

The linear Stokes parameters (Goldstein, 2011; Tinbergen, 2005) were then reconstructed as

$$I = I_0 + I_{90}, \quad (1)$$

155 $Q = I_0 - I_{90}, \quad (2)$

$$U = I_{45} - I_{135}. \quad (3)$$

Before the polarimetric reconstruction, each frame was corrected using a master dark acquired with the same exposure time and gain settings as the auroral observations.

160 For the comparison with Corbel Cru, the analysis was restricted to a circular region of interest (ROI) corresponding to the approximate 2° FoV defined above. Let $\mathcal{R}$ denote the set of pixels p belonging to this ROI. The integrated Stokes parameters are

$$I_{\mathcal{R}} = \sum_{p \in \mathcal{R}} I(p), \quad Q_{\mathcal{R}} = \sum_{p \in \mathcal{R}} Q(p), \quad U_{\mathcal{R}} = \sum_{p \in \mathcal{R}} U(p). \quad (4)$$

The corresponding degree and angle of linear polarization are

165 $\text{DoLP}_{\mathcal{R}} = \frac{\sqrt{Q_{\mathcal{R}}^2 + U_{\mathcal{R}}^2}}{I_{\mathcal{R}}}, \quad (5)$

$$\text{AoLP}_{\mathcal{R}} = \frac{1}{2} \arctan\left(\frac{U_{\mathcal{R}}}{Q_{\mathcal{R}}}\right), \quad (6)$$

taking the correct quadrant into account.

To estimate the instrumental polarization bias under conditions as close as possible to the auroral measurements, we acquired
170 a series of integrating-sphere frames using the same optical setup, exposure time, gain, and analysis ROI. A 12-inch-diameter integrating sphere (model US-120-SF, Labsphere Inc., USA) was used here as a quasi-unpolarized source, illuminated at 557.7 nm with a double monochromator (model DTMc300, Bentham Instruments Ltd, UK) combined with a 1000 W quartz-halogen lamp. The measurements were performed at the Belgian Radiometric Characterization Laboratory (B.RCLab) located at BIRA-IASB. Because of laboratory constraints, the detector temperature during this calibration was set to -15°C instead
175 of -20°C during the observations. According to the manufacturer specifications, the detector dark current varies only weakly over this temperature range, so this mismatch is expected to have only a minor impact on the calibration.

In full generality, the instrumental response can be described by a Mueller matrix relating the incident and measured Stokes vectors. In the present work, however, the analysis is restricted to linear polarization and to ROI-integrated quantities. We



therefore adopt a first-order reduced description involving only I , Q , and U , and assume that the dominant instrumental effect
180 is a weak leakage of total intensity into the linear polarization channels:

$$\begin{pmatrix} I \\ Q \\ U \end{pmatrix}_{\text{meas}} \approx \begin{pmatrix} 1 & 0 & 0 \\ q_{\text{inst}} & 1 & 0 \\ u_{\text{inst}} & 0 & 1 \end{pmatrix} \begin{pmatrix} I \\ Q \\ U \end{pmatrix}_{\text{true}}. \quad (7)$$

This first-order model neglects higher-order couplings such as $Q \leftrightarrow U$ cross-talk, depolarization terms, and any contribution involving circular polarization. Under this approximation,

$$I_{\text{meas}} \approx I_{\text{true}}, \quad Q_{\text{meas}} \approx Q_{\text{true}} + q_{\text{inst}} I_{\text{true}}, \quad U_{\text{meas}} \approx U_{\text{true}} + u_{\text{inst}} I_{\text{true}}. \quad (8)$$

185 Assuming the integrating sphere radiance to be unpolarized, the residual fractional biases are estimated over the same ROI as

$$q_{\text{inst}} = \frac{Q_{\mathcal{R}}^{\text{sphere}}}{I_{\mathcal{R}}^{\text{sphere}}}, \quad u_{\text{inst}} = \frac{U_{\mathcal{R}}^{\text{sphere}}}{I_{\mathcal{R}}^{\text{sphere}}}. \quad (9)$$

The quantities q_{inst} and u_{inst} are dimensionless fractional biases, so that the corresponding contamination in Q and U scales with the measured intensity level.

190 The corrected ROI-integrated Stokes parameters are then obtained as

$$Q_{\mathcal{R}}^{\text{corr}} = Q_{\mathcal{R}}^{\text{raw}} - q_{\text{inst}} I_{\mathcal{R}}^{\text{raw}}, \quad (10)$$

$$U_{\mathcal{R}}^{\text{corr}} = U_{\mathcal{R}}^{\text{raw}} - u_{\text{inst}} I_{\mathcal{R}}^{\text{raw}}. \quad (11)$$

This correction should therefore be interpreted as a first-order removal of intensity-to-polarization leakage, rather than as a full
195 Mueller-matrix inversion (Azzam, 2016).

4.2 Alignment to the CRU angle convention

An additional calibration step was required to express the retrieved polarization angles in a convention consistent with the Corbel Cru reference framework, which considers the 0° of the AoLP as the local vertical. The alignment was determined empirically from a Malus-law test performed with a flat-screen setup and a rotating polarizer in front of the Polaribotn camera.
200 The comparison indicated that the Polaribotn convention required an angular offset correction of approximately 92.5° , together with a sign reversal of U . After applying this correction, the AoLP is expressed in the Cru convention, in which 0° corresponds to the local vertical and the angle is wrapped within the interval $[-90^\circ, +90^\circ)$.

5 Results

The ROI-integrated formulation introduced above is first used for the comparison with Corbel Cru in the common 2° FoV, and
205 then extended in Section 5.2 to a grid of 63 sky-defined ROIs of identical size covering the full Polaribotn image.



5.1 Validation against the Corbel Cru reference

Figure 3 compares the degree and angle of linear polarization measured by Polaribotn and by the Corbel Cru instrument over the common FoV. The agreement between the two datasets is good overall, although not strictly point-by-point at all times. The DoLP time series exhibit the same main temporal behavior, with a correlation coefficient of about 0.90. As already discussed by Bosse et al. (2020), the DoLP tends to decrease when the auroral intensity increases. In the present dataset, the sudden decrease from about 2% to 0.3% around 18:18 UT corresponds to the passage of a bright auroral arc through the common FoV. Small residual differences remain, for instance around 18:27 UT, where the Polaribotn DoLP is slightly higher than the Cru one by about 0.3%. This discrepancy occurs nevertheless during a faint-emission interval, when no clear arc is visible in the common FoV as discussed later in section 5.2.2.

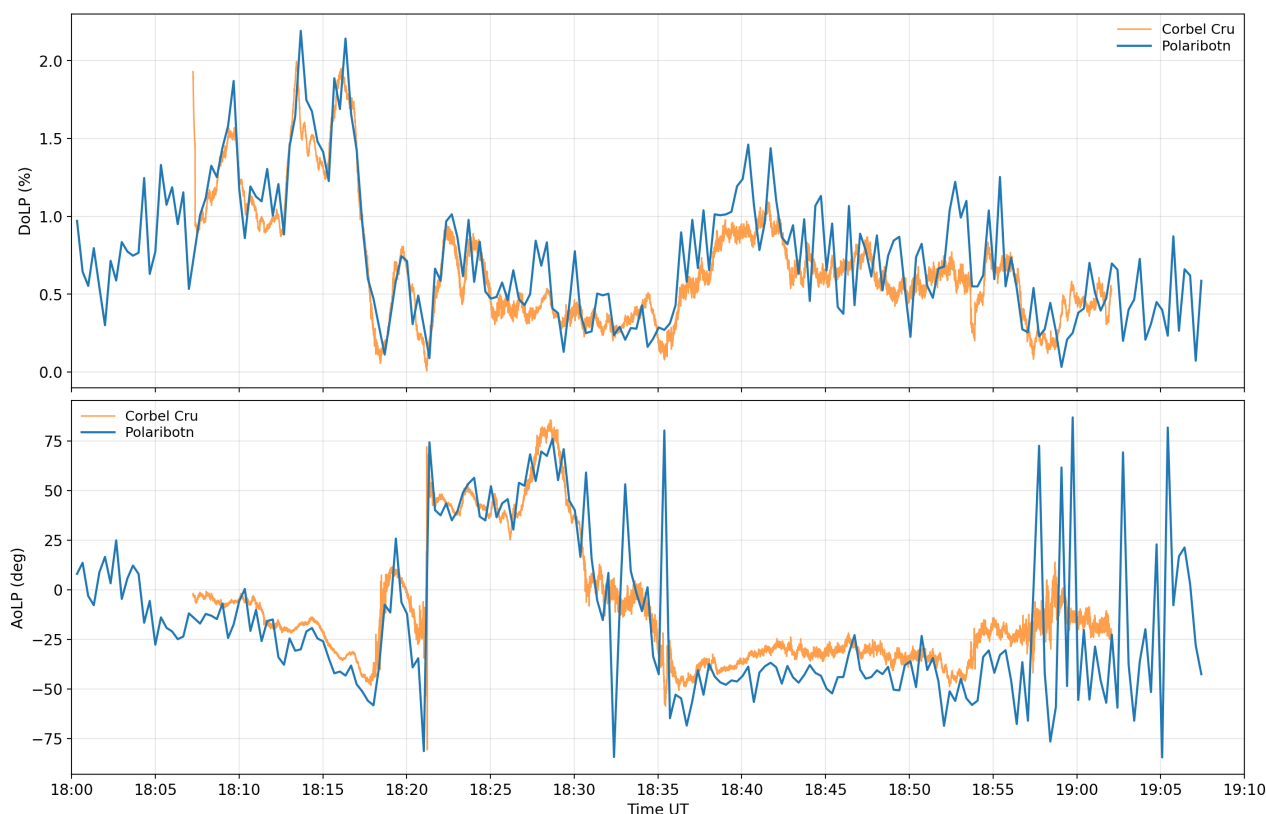


Figure 3. Comparison of the degree (top) and angle (bottom) of linear polarization measured by the Polaribotn instrument and by the Corbel Cru instrument over the common FoV.

The corresponding AoLP comparison is shown in the bottom panel of Figure 3. Both instruments exhibit a similar overall temporal evolution, including the main angle reversals around 18:18 UT, 18:22 UT, and 18:28 UT, followed by a marked decrease after about 18:30 UT. The consistency between the two measurements remains clearly visible even after about



18:40 UT, when cloud contamination begins to affect the FoV, and can still be recognized up to about 18:55 UT. Beyond that time, the Polaribotn AoLP becomes markedly noisier and the agreement deteriorates. This behavior is not unexpected given the weak auroral signal, the 20 s integration time and the empirical definition of the common FoV. In addition, the intensity comparison in Figure 2 reveals a small residual mismatch after about 18:35 UT, with Polaribotn decreasing slightly faster than Cru. This suggests that the two instruments do not weight the scene in exactly the same way, which may also contribute to the remaining differences in DoLP and AoLP. The comparison involves two fundamentally different instrumental concepts, and the effective Corbel Cru angular response may differ slightly from an ideal 2° aperture. The agreement should therefore be interpreted as a strong validation of the main polarization signatures rather than as an exact equivalence at every time step.

5.2 Spatial behavior of DoLP and AoLP

Figure 4 summarizes the temporal evolution of the ROI-based quantities over the full Polaribotn field of view. For intensity and DoLP, the central curve shows the median across the 63 circular ROIs of 2° diameter defined on the sky, while the shaded band indicates the 5th-95th percentile range of the ROI values. The spread is quantified using the 5th-95th percentile range of the values across the 63 ROIs, rather than a standard deviation, because these field-wide distributions are often non-Gaussian.

For AoLP, the central value is not a median of wrapped angles, but the mean polarization angle derived from the mean normalized Stokes parameters, $\langle q \rangle$ and $\langle u \rangle$, as

$$\text{AoLP}_{\text{mean}} = \frac{1}{2} \arctan\left(\frac{\langle u \rangle}{\langle q \rangle}\right),$$

with the appropriate quadrant convention. The shaded band in the AoLP panel represents the 5th-95th percentile range of the angular deviations of the individual ROI polarization vectors around that mean direction. This choice avoids ambiguities related to the circular nature of AoLP and provides a more robust description of the field-wide angular coherence.

The vertical markers identify the intervals selected for detailed inspection in Figures 5 and 6. We first consider an arc-dominated interval, corresponding to cases a)-d), during which successive auroral arc structures cross the FoV while the mean polarization angle evolves smoothly over several minutes. Cases e)-h) document a later angular transition associated with a fainter arc event and its subsequent evolution toward a more diffuse auroral background. The corresponding all-sky camera images are presented in Appendix A.

5.2.1 Arc-dominated interval

We first consider an interval corresponding to the passage of auroral arc structures through the FoV of the Polaribotn camera, illustrated by cases a)-d) in Figure 5. For each selected frame, the associated (q, u) diagram is shown below the image. Each of the 63 ROIs is represented by one point in the (q, u) plane, color-coded according to the auroral intensity measured in that ROI. The distance from the origin corresponds to the DoLP: the farther a point lies from the origin, the larger the DoLP. The cyan annulus indicates the 5th-95th percentile range in radial distance, i.e. the spread in DoLP across the FoV, while the green sector represents the 5th-95th percentile range of the angular deviations around the mean AoLP direction, defined as in Figure 4.

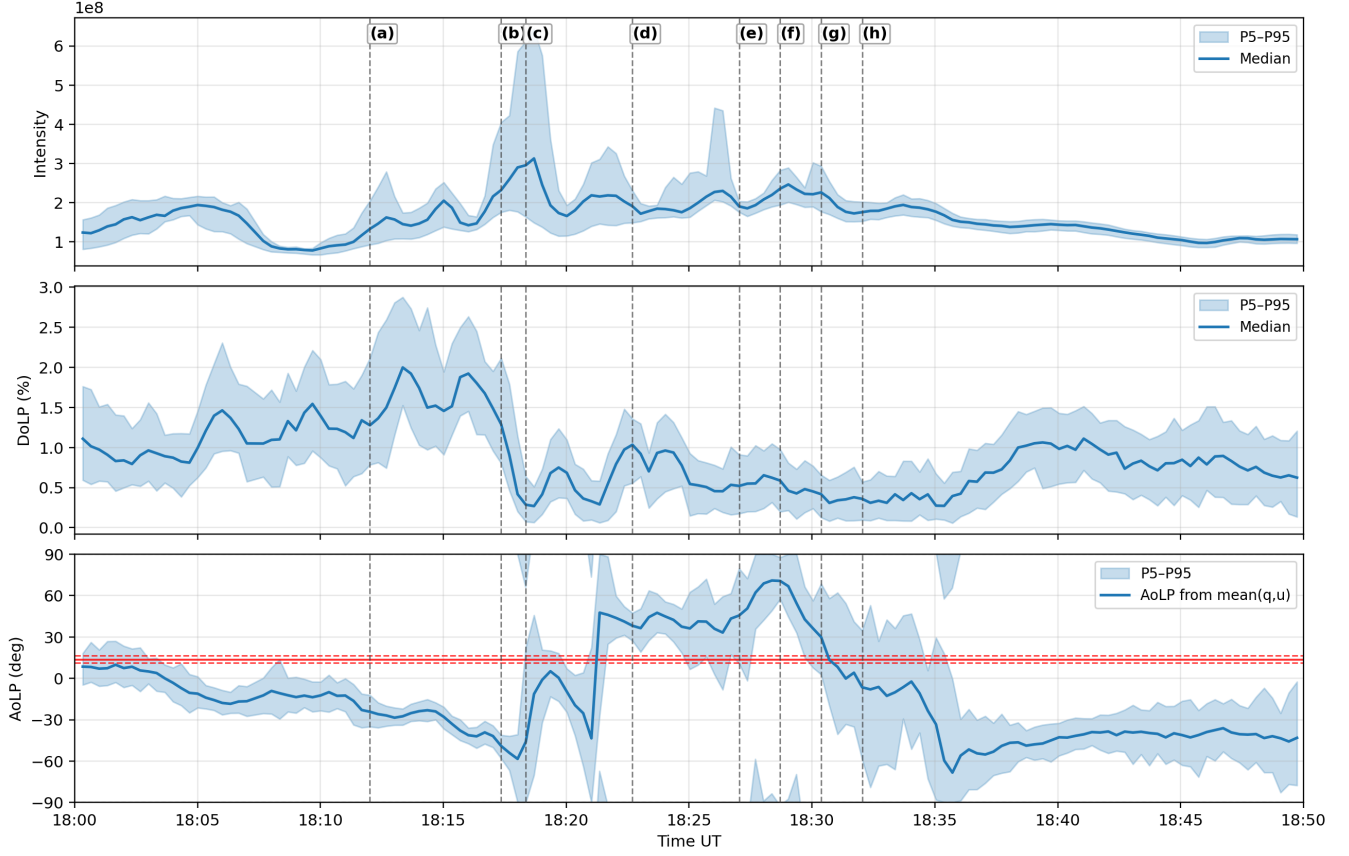


Figure 4. Temporal evolution of the median intensity (in ADU) and median DoLP across the 63 ROI. For AoLP, the central curve shows the mean angle derived from the mean normalized Stokes parameters, $\langle q \rangle$ and $\langle u \rangle$, while the shaded band indicates the 5th-95th percentile angular deviations of the ROI polarization vectors around that mean direction. Vertical dashed lines mark the case studies discussed in Section 5.2. In the bottom panel, the projected magnetic-field direction in the sky plane (equivalently, in the detector plane) is also shown as a reference angle in red. The associated upper and lower curves indicate the range of projected magnetic-field angles across the Polaribotn FoV, taking into account its finite extent of $20^\circ \times 17^\circ$.

250 The mean DoLP shown in the (q, u) panels is computed from the mean normalized Stokes vector as

$$\text{DoLP}_{\text{mean}} = \sqrt{\langle q \rangle^2 + \langle u \rangle^2}.$$

It is therefore not identical to the median DoLP shown in Figure 4, which instead characterizes the typical polarization amplitude across the 63 ROI. By contrast, $\text{DoLP}_{\text{mean}}$ measures the coherence of the polarization state over the full ROI set: if the individual ROI polarization vectors remain similarly oriented in the (q, u) plane, $\text{DoLP}_{\text{mean}}$ stays close to the typical local
255 DoLP, whereas it decreases when the ROI orientations become more dispersed and partly cancel each other. In practice, these

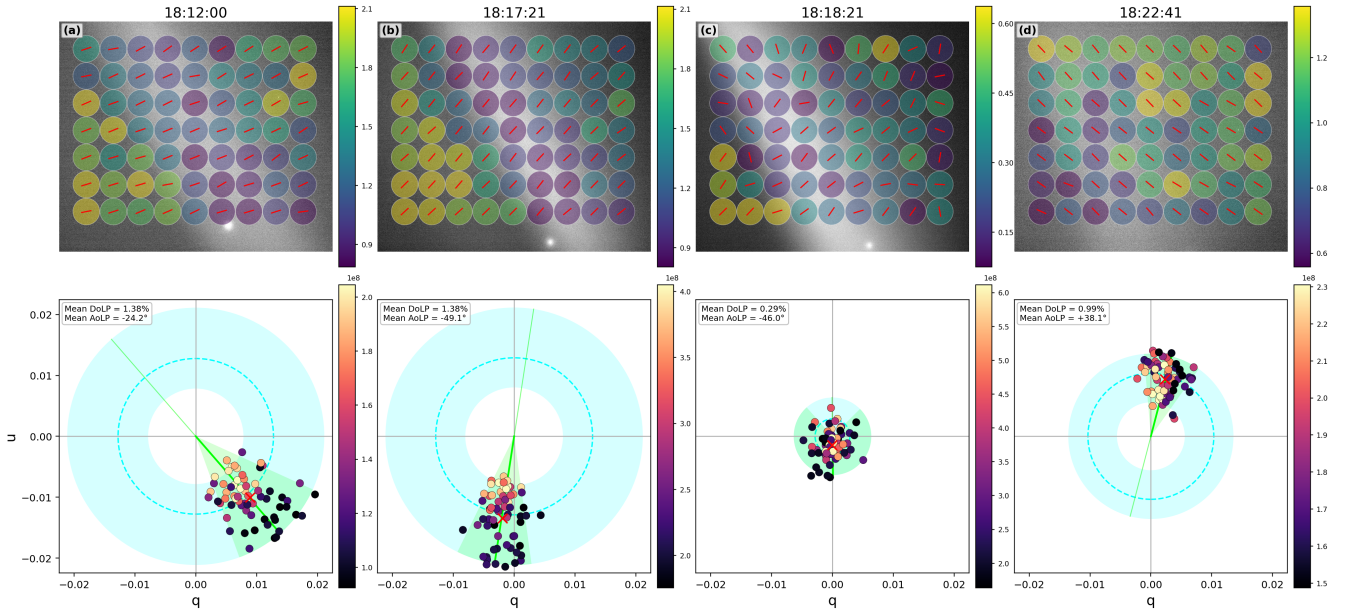


Figure 5. Selected frames during an arc-dominated interval in the Polaribotn FoV. Top: ROI-based polarization maps overlaid on the reduced raw images; the colour scale gives the DoLP in %, and the red segment gives the AoLP direction in each ROI. Bottom: corresponding (q, u) diagrams, with one point per ROI, colour-coded by the intensity integrated over the ROI (in ADU). The distance to the origin gives the DoLP, and the polar angle gives the AoLP. The cyan annulus and green sector indicate the 5th-95th percentile spreads in DoLP and AoLP, respectively.

two DoLP diagnostics remain close during most of the sequence, which is consistent with a rather homogeneous evolution of the polarization angle across the image and with limited vector cancellation in the (q, u) plane.

These four frames show that DoLP and AoLP do not respond in the same way to the passage of arc structures through the FoV. The arcs mainly affect the DoLP: the degree of polarization decreases within the brightest regions, while larger DoLP values are generally found in the fainter surrounding areas. By contrast, the AoLP remains spatially coherent over most of the FoV in cases a), b), and d), despite the clear intensity modulation introduced by the auroral structures. The arc activity therefore modulates the polarization amplitude more clearly than the polarization angle.

The (q, u) diagrams support this view. In cases a), b), and d), the ROI cloud remains elongated along a preferred direction, showing that most ROIs share a similar polarization orientation. At the same time, the cloud is radially structured, with part of the spread correlated with intensity. This is consistent with a partial separation between brighter arc regions and fainter background regions. The displacement of the cloud centroid from one frame to the next further indicates that the dominant polarization state evolves globally with time, rather than being controlled only by the local arc morphology. The (q, u) analysis therefore points to a strong scene-wide component, while the auroral structures appear mainly as intensity-dependent perturbations superimposed on that global behaviour.



270 Case c) at 18:18:21 is particularly intriguing. In this frame, the mean DoLP drops to only $\sim 0.29\%$, and the ROI cloud collapses close to the origin in the (q, u) plane. In this low-DoLP regime, the AoLP becomes poorly constrained and its apparent dispersion should not be interpreted as a robust physical pattern. However, the frame reveals a puzzling behavior: although the image is dominated by a brighter auroral arc, the DoLP decreases across all ROIs, including regions containing only faint background emission. This suggests that the mechanism responsible for the observed depolarization operates over a larger area than the visible arc itself. The origin of this behavior remains unclear and deserves further investigation.

Quantitatively, the AoLP distribution remains narrow in cases a), b), and d): the mean AoLP derived from $\langle q \rangle$ and $\langle u \rangle$ is -24.2° , -49.1° , and $+38.1^\circ$, respectively, and the corresponding 5th-95th percentile angular deviations remain within about $\pm 9^\circ$ to $\pm 12^\circ$. By contrast, case c) is associated with a collapse of the mean DoLP to only $\sim 0.29\%$, together with a dramatic broadening of the AoLP distribution, reaching about -69° to $+67^\circ$ in 5th-95th percentile deviations. This confirms that the angular information is robust in cases a), b), and d), but no longer reliable in case c).

Before case c), the mean polarization angle evolves smoothly across the full detector. Between about 18:10 and 18:17 UT, the mean AoLP derived from $\langle q \rangle$ and $\langle u \rangle$ decreases quasi-monotonically from roughly -10° to -60° , while its spatial dispersion remains limited. This behaviour, already visible in Figure 4, shows that the angular coherence is not tied to a single arc. Several arc structures succeed one another within the FoV, yet the dominant polarization angle still follows a continuous large-scale evolution; this succession is more clearly seen in the supplementary movie.

Case c) marks a different regime. Around 18:18 UT, the DoLP collapses and the AoLP becomes poorly constrained, as shown by the very large 5th-95th percentile angular spread. After this transition, the AoLP stabilizes again around $+40^\circ$ in case d), with a much narrower dispersion. The sequence therefore indicates an angular transition of about 100° , but one that occurs through a low-DoLP phase in which the angle is temporarily not robust. Visually, the same arc appears to remain in the FoV after case c), although with a strongly varying brightness.

5.2.2 Sharp AoLP transition during a later arc event

A sharp AoLP transition is also observed between 18:27 and 18:30 UT, corresponding to cases e)-h) in Figure 4. The corresponding intensity maps and (q, u) diagrams are shown in Figure 6. According to the all-sky images presented in Appendix A, case e) does not show any clear arc within the Polaribotn FoV, or at most a very faint diffuse auroral signal. The DoLP remains weak and only weakly structured across the image. The AoLP is also poorly constrained, with a large spread ranging from about -33° to $+36^\circ$, as shown in Figure 6.

At 18:28:42 UT (case f), a faint arc appears in the FoV. In contrast with the previous case study, this structure does not produce a clear DoLP signature. The AoLP, however, becomes much more organized across the FoV, with a mean value of about 70° and a narrower spread of roughly -12° to $+18^\circ$. The corresponding (q, u) cloud is more compact and more clearly offset from the origin, indicating that the polarization state is better defined than in case e).

The arc is still visible in case g), while the mean AoLP decreases toward about 30° . The angular spread increases again, reaching about -27° to $+39^\circ$, so that the angle is less tightly constrained than in case f). Based on the all-sky sequence, the



arc also appears to weaken at this stage and to transition toward a more diffuse auroral background, as suggested by case h) and by the supplementary movie. In this later regime, both DoLP and AoLP are less constrained.

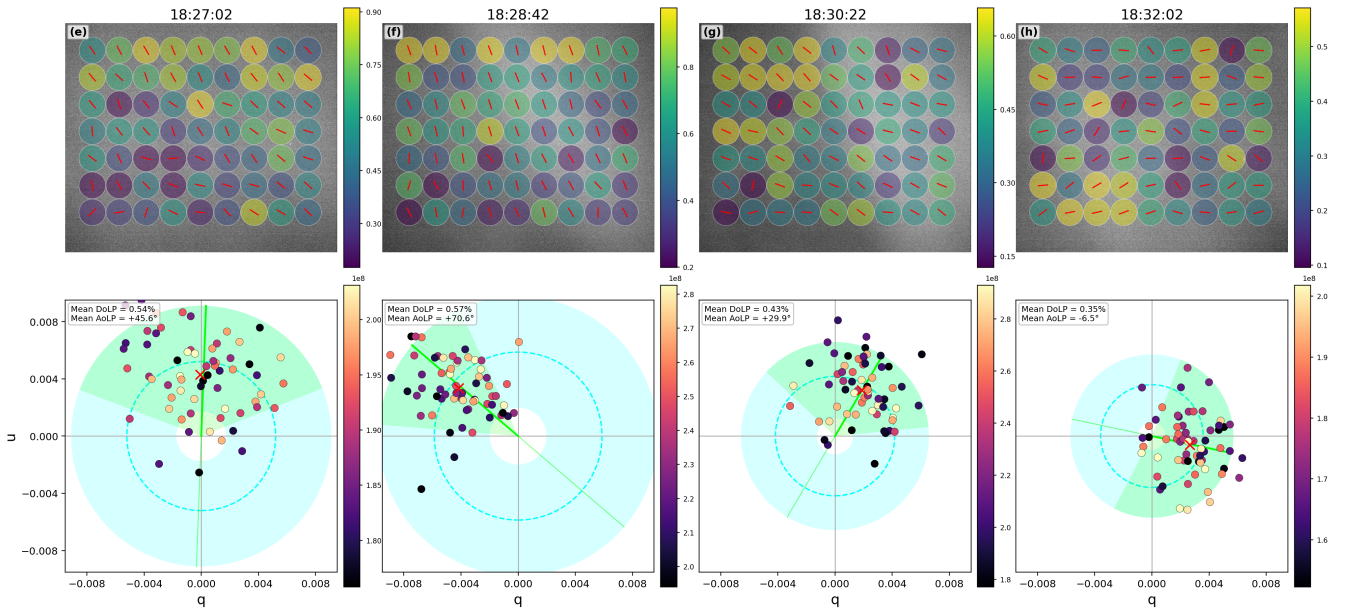


Figure 6. Same as for Figure 5 for the cases e) to h).

305 6 Discussion

The present study shows that the Polaribotn camera can recover a structured polarization signal consistent with the Cru reference framework. This validates the instrumental concept, the first-order bias correction, and the convention alignment required for imaging polarimetry of auroral emissions. It also provides the first independent confirmation of the Cru polarization measurements using a fundamentally different instrumental concept. This independent cross-validation is particularly important because it alleviates a recurrent concern in auroral polarimetry, namely that similar signatures measured in laboratory and field configurations could still be affected by systematics shared by the same instrumental concept (Bourgeois et al., 2022). Here, the agreement is obtained between two fundamentally different implementations observing the same auroral scene simultaneously.

The imaging capability of Polaribotn opens the possibility of investigating spatial AoLP variations across auroral structures. However, the data do not reveal such a unique local AoLP signature directly tied e.g. to the instantaneous morphology of a given arc. Instead, DoLP and AoLP behave differently across the FoV: DoLP is more closely linked to intensity and tends to decrease in the brightest arc regions, whereas AoLP often remains coherent over a large fraction of the FoV, except when the DoLP becomes too small for the angle to remain robust. The (q, u) analysis further points to a strong scene-wide component, with additional intensity-dependent clustering in some frames.



Within the framework proposed by Bosse et al. (2022b), the AoLP transition can be discussed by comparing the measured polarization angle with simple geometrical reference directions. In their green-line study, Bosse et al. (2022b) showed that the AoLP was generally closer to the apparent angle of the horizontal equivalent current, while becoming temporarily closer to the projected magnetic-field direction during a short angular jump. In the present work, our aim is not to reconstruct the horizontal equivalent current system for this single one-hour dataset. Instead, we adopt a more limited approach and examine whether the measured AoLP becomes close to the projected magnetic-field direction or not. This does not provide a full interpretation of the current system, but it offers a first-order test of whether a simple field-aligned scenario could explain the observed angular transition.

In our case, the projected magnetic-field angle is nearly uniform across the Polaribotn FoV, with a value of about $13.5^\circ \pm 2.5^\circ$, as shown in Figure 4. The associated upper and lower curves indicate the range of projected magnetic-field angles across the Polaribotn FoV, taking into account its finite extent of $20^\circ \times 17^\circ$. The observations do not reveal a simple regime in which the measured AoLP would become clearly field-aligned. Indeed, except for a short interval at the beginning of the sequence, around 18:00 UT, the AoLP remains far from the projected magnetic-field angle. This suggests a more complex situation, likely involving persistent horizontal-current contributions, possible field-aligned contributions, and scene-wide or propagation-related effects. In that sense, the present results seem more consistent with a modulation of the polarization state by the horizontal current system than with a purely field-aligned state. This interpretation must remain cautious, but the observed variability is too rapid and too well correlated with auroral activity to be reduced to a stationary background alone.

These observations are coherent with previous Cru observations and the conclusion that light pollution from scattered sources can not explain entirely the polarization. In the case of a polarized background with bright unpolarized auroral arc, the polarization would also decrease when the intensity increases, which is observed. However here the DoLP drops close to zero only once in case c), and similar values are found during low- and high-intensity intervals. A scattering polarization background should be dominant with a stable AoLP during faint auroral periods, which is not the case for cases e-h). In the case of a polarized background with bright unpolarized auroral arcs, the DoLP would indeed be expected to decrease when the intensity increases, which is observed. However, this simple picture does not explain the significant temporal variations of the AoLP observed during periods of weak auroral activity. A scattering-polarization background would instead be expected to maintain a relatively stable polarization angle over time.

The comparison with the Cru instrument shows that the lower time resolution of the Polaribotn camera is not a problem to observe the polarization of auroral arcs. We are able to retrieve all main features observed by the Cru instruments. This might of course not be the case for more dynamic auroral events.

The present observations are nevertheless limited by the conditions of this first campaign. The auroral activity remained relatively weak, and the camera was operated at a gain of 400, which strongly reduced the effective dynamic range. The effective full-well capacity decreased from about $12,000\text{ e}^-$ to about 350 e^- . As a consequence, the usable intensity range was severely compressed, making the analysis less informative for weak auroral structures and reducing the contrast between faint and bright regions. Future campaigns will therefore require a better compromise between sensitivity and dynamic range. In



addition, the FoV was probably too small to include a sufficiently quiet background region. Cloud or cirrus contamination also became more significant later in the sequence.

355 7 Conclusion

This study presents the first-light demonstration of the Polaribotn camera for auroral imaging polarimetry. The agreement with Corbel Cru validates the instrumental concept as well as the calibration strategy and provides an independent confirmation of the polarization signatures previously reported with the Cru instruments. Furthermore, the data demonstrate that auroral imaging polarimetry provides access to spatial information that is not available from narrow-field measurements. Introducing
360 a polarization instrument, which does not contain moving part as for the Cru instrument, thus being more rugged, is also an important step in the direction of establishing autonomous and continuous polarization measurements throughout the whole auroral season. This allows for an observation program which will secure the acquisition of a large and statistical significant dataset.

The present observations do not yet allow us to determine the physical origin of the polarization. However, they show
365 that the method is sensitive to structured, time-dependent auroral signals and can therefore provide stronger constraints than narrow-field measurements alone.

Future campaigns should target stronger auroral events under cleaner observing conditions, allowing the camera to operate at lower gain, over a larger dynamic range, and with shorter exposure times than the 20 s used in the present study. A wider FoV would help separate scene-wide and arc-related contributions while better characterizing the surrounding background.
370 The planned overwintering deployment in Skibotn will increase the statistical basis of the study and enable observations at additional auroral wavelengths, in particular 630.0 nm and 427.8 nm. Such observations will be essential for testing the wavelength dependence of the polarization signal and moving from this first-light demonstration toward a more physical interpretation.



Data availability. All-sky color camera images are available at http://darndeb08.cei.uec.ac.jp/~nanjo/public/skibotn_imgs/.

375 *Video supplement.* An all-sky color movie from the images from UT 18:00 to 19:10 is available in the supplementary materials.

Author contributions. GC carried out the Polaribotn observations in Skibotn. GC and DB performed the in-house Polaribotn calibration. JL, LB, and AG carried out the observations with the Corbel Cru instrument. GC led the analysis and manuscript writing. All co-authors contributed to the interpretation of the results and to the revision of the manuscript.

Competing interests. The authors declare that they have no conflict of interest.

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385 **Appendix A: All Sky Camera Pictures**

We present here the all-sky camera images from Skibotn (Nanjo et al., 2022), corresponding to the case studies identified in Figure 4, from a) to h).

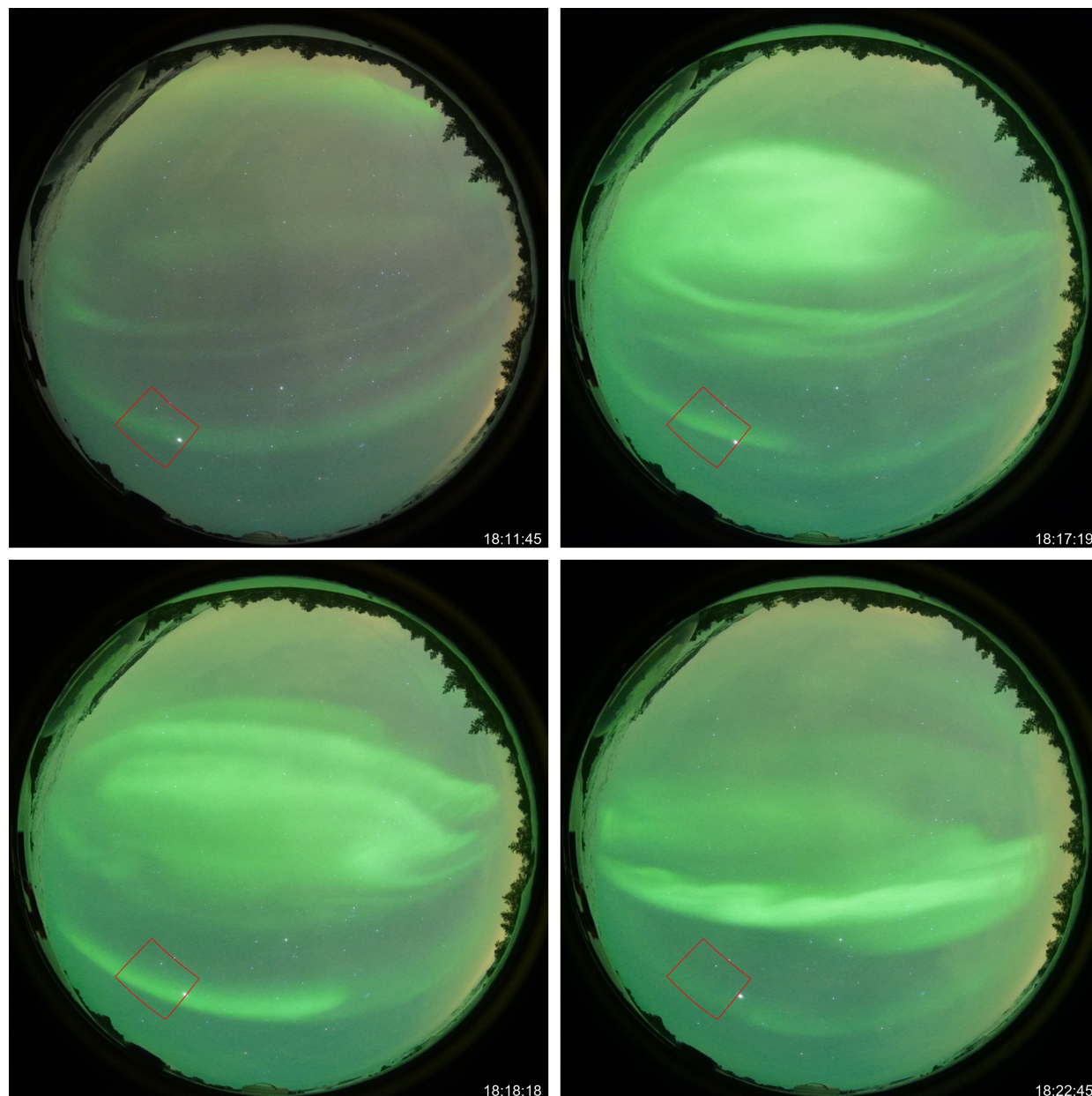


Figure A1. All-sky camera images from Skibotn corresponding to cases a)- 18h11m45s, b)-18h17m19s, c)-18h18m18s, and d)-18h22m45s discussed in Section 5.2.1. These frames illustrate the succession of auroral arc structures during the arc-dominated interval analyzed with the Polaribotn camera.

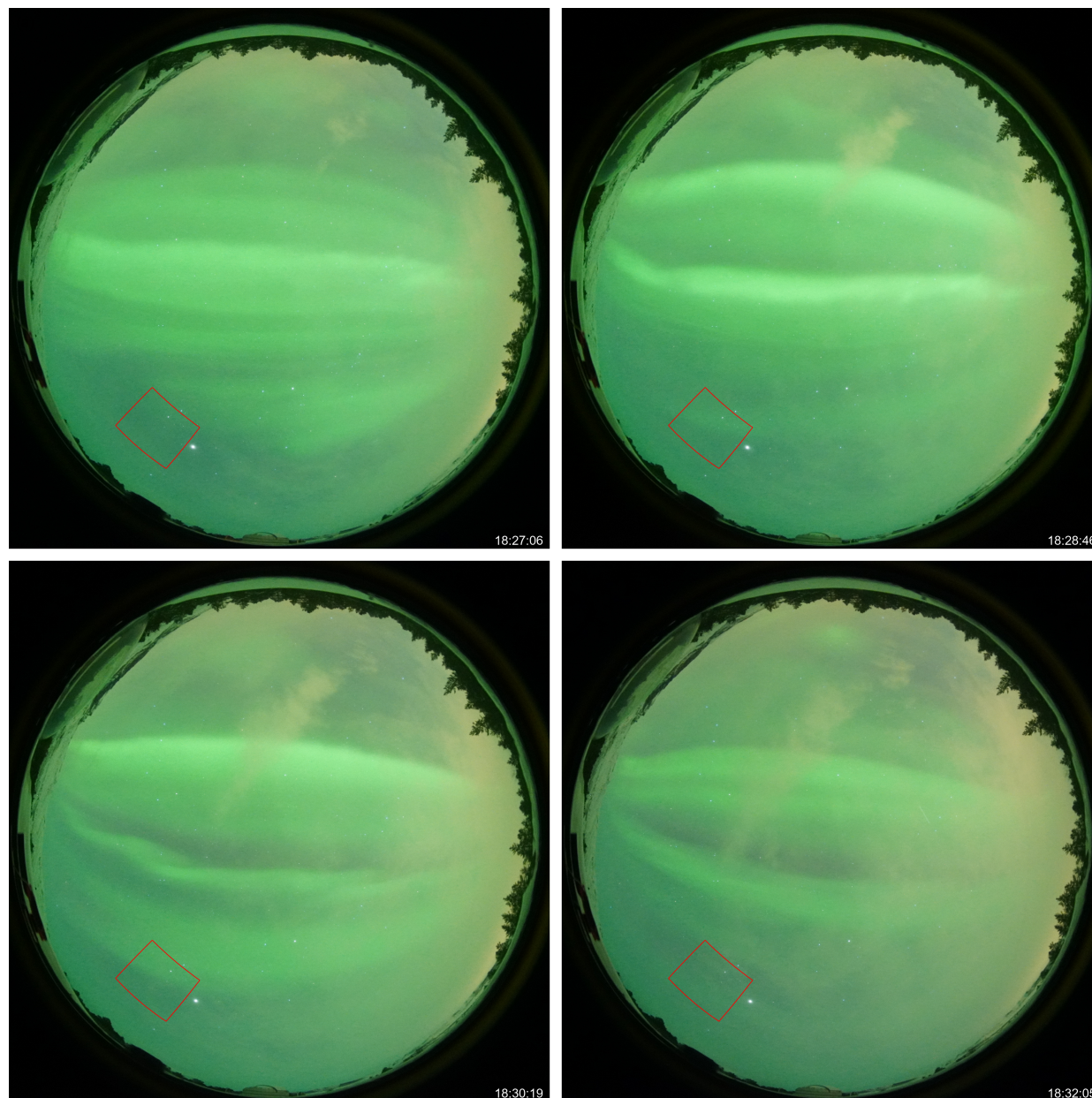


Figure A2. All-sky camera images from Skibotn corresponding to cases e)-18h27m06s, f)-18h28m46s, g)-18h30m19s, and h)-18h32m05s discussed in Section 5.2.2. These frames illustrate the later angular transition, from a faint arc event to a more diffuse auroral background.

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