POL-2 Instrumental Polarization

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Summary

This document summarizes the instrumental polarization (IP) signal detected by the POL-2 polarimeter on the SCUBA-2 receiver. A model for the IP signal is presented, along with a method to measure the IP model parameters using skydips and the results from 2015 POL-2 commissioning data. Finally, the python code used to fit the IP model parameters is presented.

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1 POL-2 and Instrumental Polarization

The POL-2 instrument is a polarimeter composed of a spinning half-wave plate (HWP) and an analyser grid [1]. It is designed for use in the 850 μm and 450 μm SCUBA-2 observing bands and is installed on the James Clerk Maxwell Telescope (JCMT). The polarimeter is designed such that any polarized signal is modulated to 4× the rotation frequency of the HWP. Each SCUBA-2 detector will simultaneously measure the Stokes' Q and U parameters, which characterize the polarization signal of incoming light. The oblique reflections of light along the optics train of the JCMT, as well as absorption and emission from the gore-tex wind screen placed across the telescope dome, introduces a small IP signal to data. The large field-of-view (FOV) of SCUBA-2 and the high sensitivity targets of POL-2 requires the IP signal be understood and removed.

2 The IP model

The IP model was developed by Doug Johnstone and described in an IPT model brief [2]. This analysis extends the original model to include an elevation independent offset in the measured Q and U signals. Furthermore, the IP signals have been found to vary across the FOV, requiring a unique IP correction for each channel in the SCUBA-2 focal plane.

The IP model accounts for a fixed IP component, due to the POL-2/JCMT optics, and an elevation-dependent IP component caused by the JCMT wind screen. The latter component is further divided up into an IP component caused by the polarization-dependent absorption of sky signal by the wind screen, and an IP component caused by the polarized emission from the wind screen. The emissive component is expected to be 90° from the absorptive component.

When applied to an unpolarized sky with a brightness of N_s and a wind screen brightness of W_s, the IP Q and U signals are given in equations 1 and 2 respectively.

$$\begin{aligned} Q_f &= p_f * N_s \cos(2\theta_{ip}) \\ Q_a &= p_s * N_s \cos(2(\theta_{ip} + el + C_o)) \\ Q_e &= W_s \cos(2(\theta_{ip} + el + C_o + 90)) \\ Q_{IP} &= Q_f + Q_a + Q_e + C_Q \end{aligned} \tag{1}$$

$$\begin{aligned} U_f &= p_f * N_s \sin(2\theta_{ip}) \\ U_a &= p_s * N_s \sin(2(\theta_{ip} + el + C_o)) \\ U_e &= W_s \sin(2(\theta_{ip} + el + C_o + 90)) \\ U_{IP} &= U_f + U_a + U_e + C_U \end{aligned} \tag{2}$$

The parameters are the percentages of sky signal that becomes polarized by the optics and wind screen, p_f and p_s, the angle of the fixed IP θ_{ip}, an offset between this angle and the polarized signal from the wind screen C_o, and constant offsets (C_Q, C_U)

The wind screen emission and offsets do not depend on the brightness of the source, making them spatially large in the FOV and easily filtered in the data. Therefore, the IP affecting an astronomical source of brightness N_s is given by equation 3

$$\begin{aligned} Q_{AS} &= p_f * N_s \cos(2\theta_{ip}) + p_s * N_s \cos(2(\theta_{ip} + el + C_o)) \\ U_{AS} &= p_f * N_s \sin(2\theta_{ip}) + p_s * N_s \sin(2(\theta_{ip} + el + C_o)) \end{aligned} \tag{3}$$

3 IP measurements from Skydips

Skydips provide a method for measuring the IP model parameters with many positive qualities; The sky is assumed to be unpolarized, so any measured polarization during a skydip can be attributed to IP; skydips cover a wide range of elevations; the brightness (with the dome opened or closed) can be measured with the calibrator; and the change in sky brightness is a function of elevation and τ, both of which are known (or measured). This section presents a brief overview of the IP measurements from skydips. Further details are presented in POL-2 meeting documentation [3, 4, 5, 6].

The fixed IP components P_f and θ_{IP} can be measured using skydips taken with the dome closed. In this setup, the absorption and emission by the wind screen cancel out. Then, with the dome open, the remaining IP model parameters can be measured.

3.1 Dome Closed, Calibrator In

With the calibrator in place, the Q and U signals are given by equation 4. The calibrator angle and dome brightness can be measured from the combination of Q and U data.

$$\begin{aligned} Q_{cal} &= 0.5 * N_{dome} \cos(2\theta_{cal}) \\ U_{cal} &= 0.5 * N_{dome} \sin(2\theta_{cal}) \end{aligned} \tag{4}$$

3.2 Dome Closed, Calibrator Out

Once the dome brightness measured, the fixed IP components are measured from skydips taken with the dome closed. The IP model is given by the equation 5.

$$\begin{aligned} Q_{IP} &= p_f * N_{dome} \cos(2\theta_{ip}) \\ U_{IP} &= p_f * N_{dome} \sin(2\theta_{ip}) \end{aligned} \tag{5}$$

3.3 Dome Open

The normalization of the sky brightness, N_s, is measured using the calibrator, as was done to measure the dome brightness. Once the normalization of the sky brightness is N_s is known, then the sky brightness at a given elevation (el) and τ is given by $N_s(1 - \exp(-\tau \csc(el)))$[1]

Using the sky brightness, p_f and θ_{IP} measured above, and equations **??**, the remaining IP parameters cane be measured for each channel. Figure 1 shows an example of Q and U skydip data from a single channel, and the corresponding IP model components. Figure 2 shows the variations of the best fit IP parameters across the focal plane for the 850 μmdata.

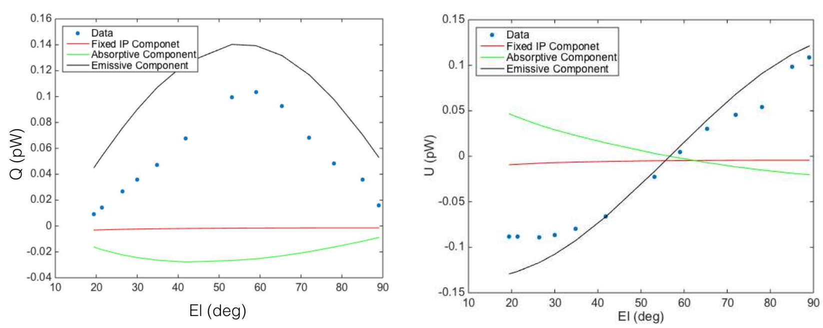

Figure 1 The Q and U signals from a skydip plotted with the three IP model components. **Left:**The Q data. **Right:** The U data.

[1] This is derived assuming a plane-parallel sky. This assumption is generally good at elevations between 20° - 90°.

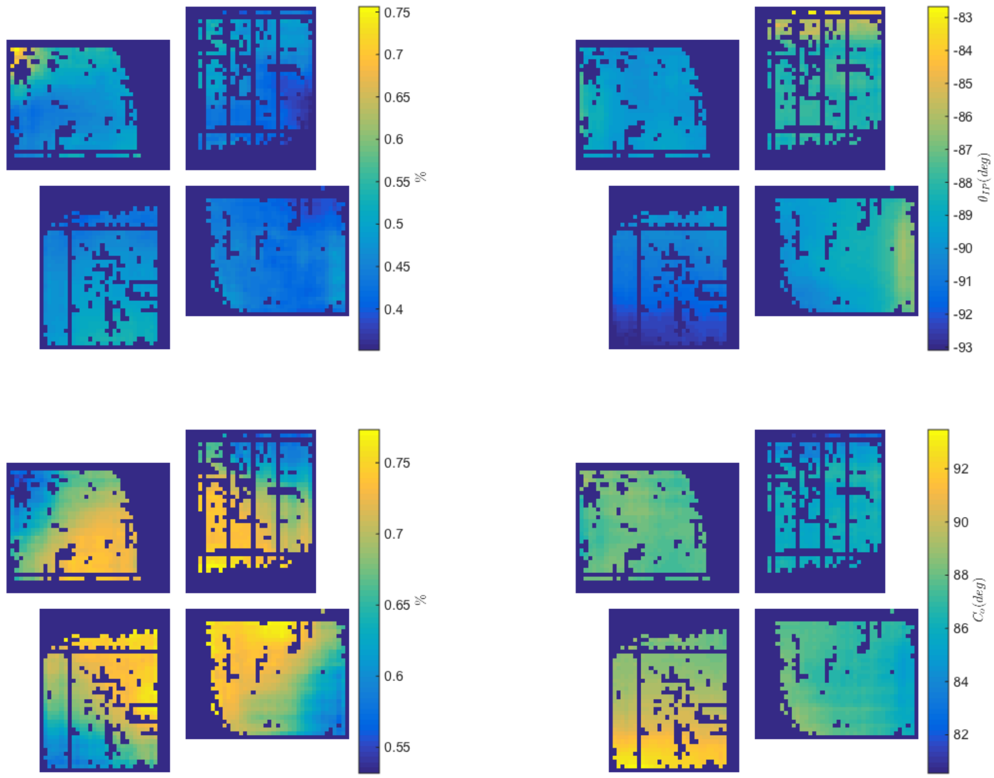

Figure 2 The IP model parameters across the SCUBA-2 850 μmfocal plane. **Top Left:** The fixed polarization percentage, p_f. **Top Right:** The fixed IP angle θ_{IP}. **Bottom Left:** The wind screen polarization percentage, p_s. **Bottom Right:** The angle offset between the fixed polarization and the wind screen polarization.

4 Python IP Fitting Code

The IP model fitting code has been written in python and is available in the starlink software collection. The code pol2_ipdata.py requires the numpy, pylab, scipy, starutil and pyndf python packages.

The required inputs are the full pathnames to

- domeclosedcalin = skydips taken with the dome closed and the calibrator in
- domeclosedcalout = skydips taken with the dome closed and the calibrator out
- domeopencalin = skydips taken with the dome open and the calibrator in
- in = skydips taken with the dome open and the calibrator out

and the output is an ndf file which contains the IP model parameters for each channel in each array. This ndf file is used in POL2 reductions by pol2cat.py and pol2scan.py.

An example of a command line call the pol2_ipdata.py is given below:

```
>> export STARLINK_DIR=/stardev
>> ~/stardev/bin/smurf/pol2_ipdata.py out=‘ipdata.sdf’ in=/skydip/2015_skydips/s*
   domeclosedcalin=/skydip/Dome_Closed_Calibrator_In/s*
   domeclosedcalout=/skydip/Dome_Closed_Calibrator_Out/s*
   domeopencalin=/skydip/Dome_Open_Calibrator_In/s*
```

5 Conclusions

The POL-2 IP model, the method for measuring the IP model parameters, and the code for fitting the IP model parameters has been presented.

References

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