Analysis of POL-2 SkyDips at 850 Microns

In order to try and understand the sources of instrumental polarization of POL-2, I have investigated the eight SkyDip observations that Per has reduced. Here I write-up the various steps that I have taken to understand the observations and my final thoughts on how best to proceed with scientific data reduction.

Steps in the Analysis:

1) Determination of sky brightness relation

With the Calibrator in the beam, half of the brightness of the (originally) unpolarized sky should be made polarized (assuming a perfect Calibrator) and therefore one should expect that the polarized intensity of the atmosphere will vary with elevation according to the formula for the optical depth through a slab.

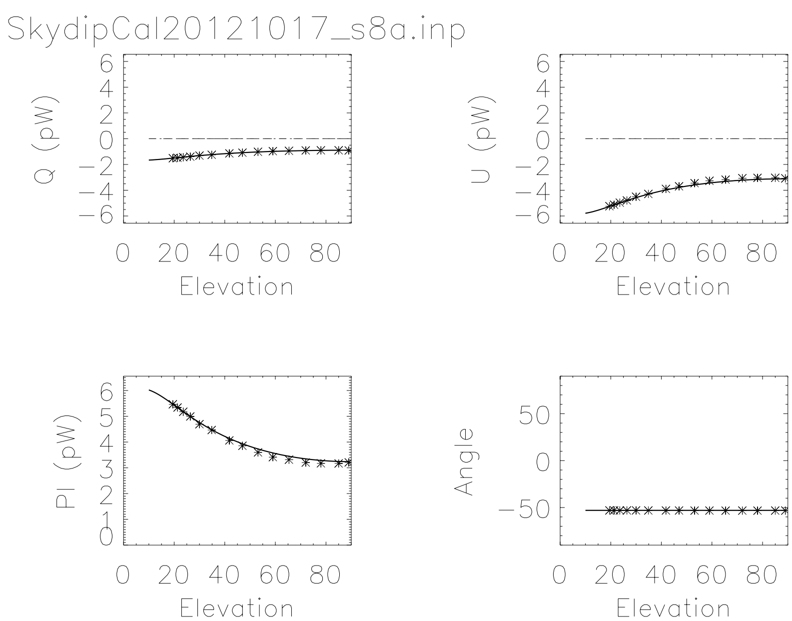
Thus, we expect:

Q = 0.5 * N * [1 - exp(- Airmass * Tau0)] * cos(2. * Angle_C)
and
U = 0.5 * N * [1 - exp(- Airmass * Tau0)] * sin(2. * Angle_C),

where N is the intensity normalization (in picoWatts), Airmass is the standard equation which varies as a function of elevation, Tau0 is an observed quantity, and Angle_C is the orientation of the Calibrator on the fixed grid defined by the detector.

A good fit is found to observation SkyDipCal20121017 (see below) by fixing N=12.2 picoWatts, Tau0 = 4.7 * CSO_Tau (where I have since been told the calibration should be 4.6 and is not quite linear), and Angle_C = -53.

In the figure below the stars represent the observations and the thick solid line denotes the model Q, U, PI, and observed angle.



2) Determination of the Dome brightness

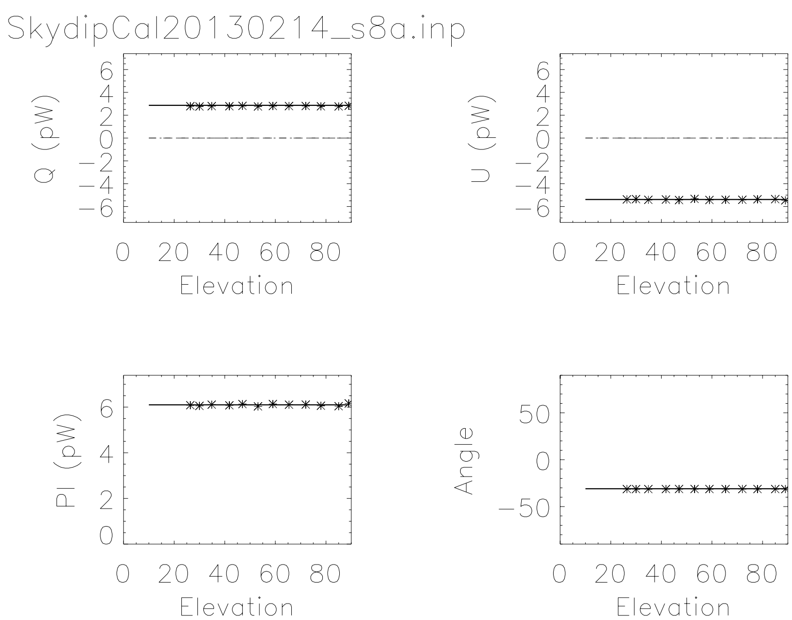
With the calibrator in the beam and the dome closed, the polarized intensity is fixed, which from the above discussion suggests that to first order the dome has a constant brightness, independent of elevation.

Indeed, when fitting SkydipCal20130214, it is possible to use the same scaling factor N=12.2 picoWatts as for the atmosphere and further assuming an infinite optical depth, ie exp(-Airmass*Tau0)=0.
Therefore one gets for this data set:

Q = 0.5 * N * [1 - 0] * cos(2. * Angle_C)
and
U = 0.5 * N * [1 - 0] * sin(2. * Angle_C)

Note, however, that Angle_C = -31 degrees (rather than -53 degrees). This is likely due to an error in the the knowledge of the wave plate phase on 20130214 since only observations on that day require Angle_C = -53 degrees, while all others require -31 degrees.

[However, it is concerning that there is almost exactly 22.5 degrees between the two …]



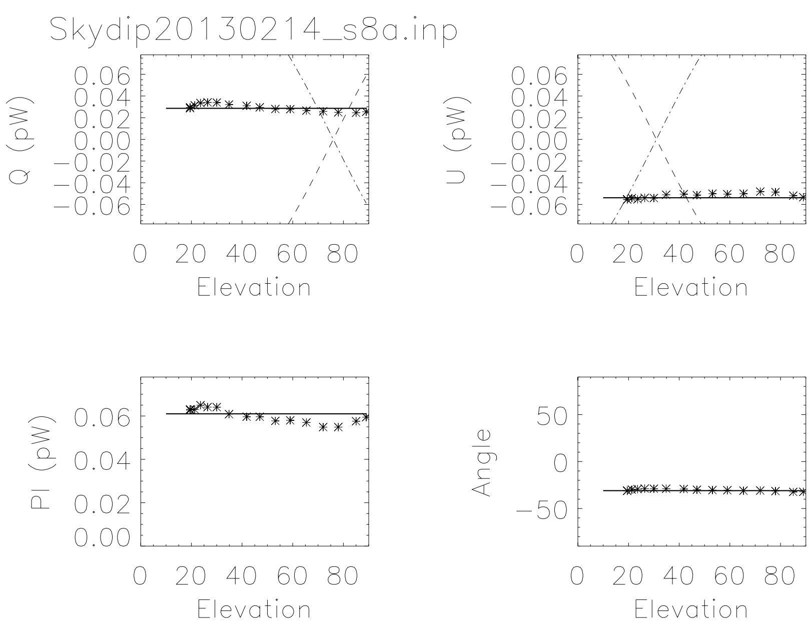
3) Determination of the 'fixed' instrumental polarization percentage

With the calibrator out of the beam but the dome closed we see a constant polarization angle which suggests that the polarized absorption of the dome through the wind screen and the polarized emission of the wind screen cancel out very cleanly. Assuming this, and using our knowledge from above as to the expected intensity of the originating unpolarized flux (N=12.2 pW), we can estimate the polarization of the 'fixed' part of the instrument (i.e. the HWP, the analyser, and the mirrors fixed in position with respect to SCUBA-2).

Considering Skydip20130214, we get 0.5% for the 'fixed' instrumental polarization. That is:

Q = 0.005 * N * [1 - 0] * cos(2. * Angle_C)
and
U = 0.005 * N * [1 - 0] * sin(2. * Angle_C)

Note that Angle_C is again -31 degrees.



4) Determination of the 'elevation dependent' instrumental polarization percentage

The final five SkyDip observations were all taken with Calibrator out of the beam and the dome open. Additionally, all these observations have independent calculations of the optical depth to the zenith (Tau0).

We begin our investigation by assuming a functional form for Q and U that takes into account the 'fixed' polarization as described above:

Qf = 0.005 * 12.2 * [1 - exp(- Airmass * Tau0)] * cos(2. * Angle_C)
and
Uf = 0.005 * 12.2 * [1 - exp(- Airmass * Tau0)] * sin(2. * Angle_C).

We then add a component due to absorption of the intensity from the atmosphere by the wind screen, where the angle C_0 denotes the offset between the 'fixed' instrumental polarization and the wind screen polarization when the telescope is pointed at the horizon:

Qa = p1 * 12.2 * [1 - exp(- Airmass * Tau0)] * cos[2. * (Angle_C + elevation + C_0)]
and
Ua = p1 * 12.2 * [1 - exp(- Airmass * Tau0)] * sin[2. * (Angle_C + elevation + C_0)].

Finally we add a constant intensity component due to emission from the wind screen (which should be 90 degrees out of phase with the polarized absorption).

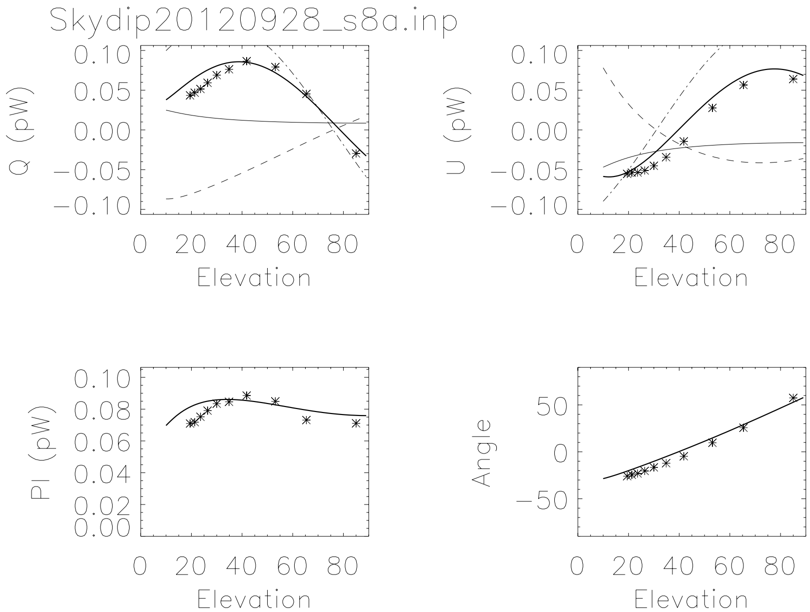
Qe = p2 * 12.2 * [1 - 0] * cos[2. * (Angle_C + elevation + C_0 + 90)]
and
Ue = p2 * 12.2 * [1 - 0] * sin[2. * (Angle_C + elevation + C_0 +90)].

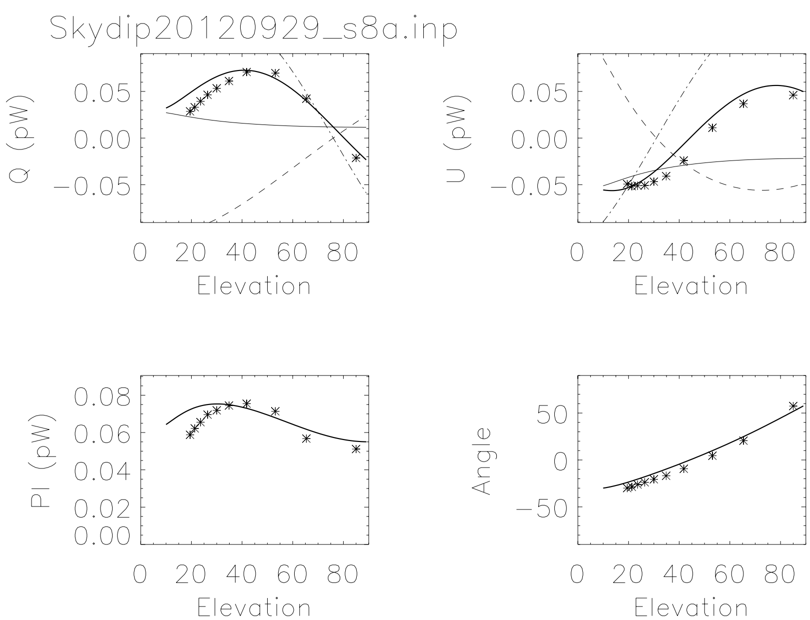
Put together we get

Q = Qf + Qa + Qe
U = Uf + Ua + Ue

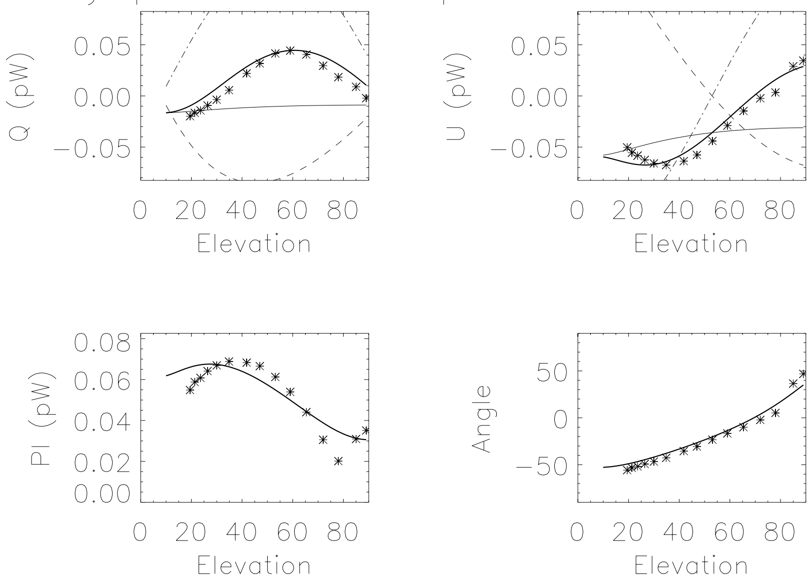
We assume that Angle_C = -31 degrees, except for the observations taken on 20121017 for which we assume Angle_C=-53. Thus, there are three unknowns to find - p1, p2, C_0. Furthermore, we expect that p1 ~ p2, since when the dome is closed and we expect the same intensity from the dome and the wind screen, we see no evidence of varying polarized angle with elevation.

Below are fits to all five Skydip observations assuming that p1 = 0.011, p2 = 0.011, and C_0 = 90 degrees. The fits are not great but definitely provide the main features that are observed. The thin solid lines are Qf/Uf, the dashed lines are Qe/Ue, and the dash-dotted lines are Qe/Ue.

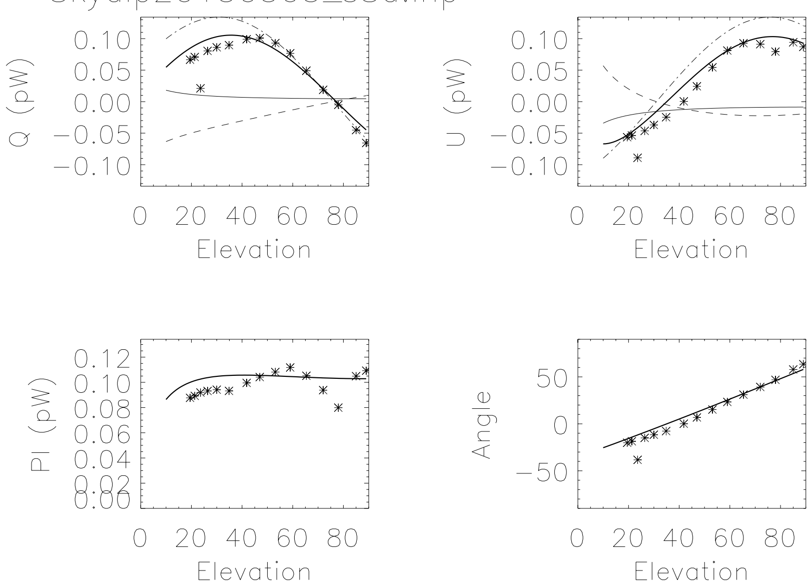

Skydip20120928_s8a.inp
Q (pW)
U (pW)
PI (pW)
Angle
Elevation

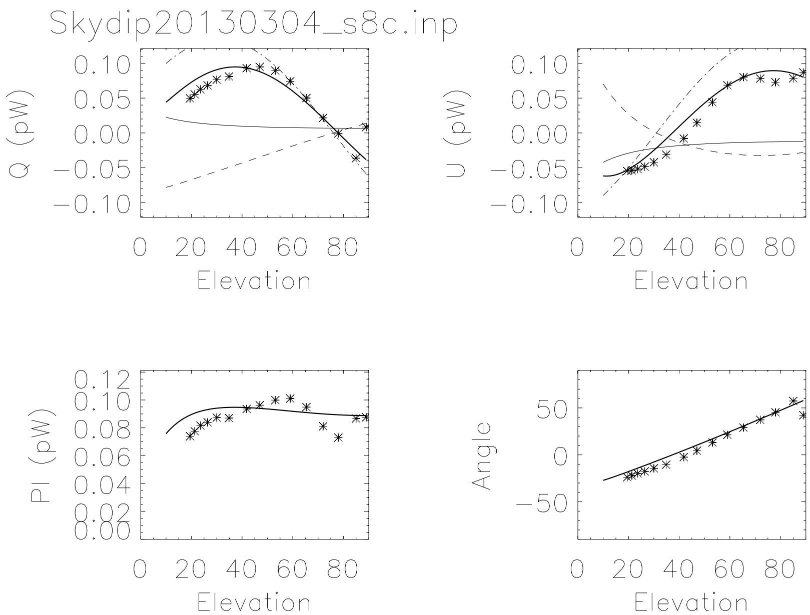

Skydip20120929_s8a.inp
Q (pW)
U (pW)
PI (pW)
Angle
Elevation

Skydip20121017_s8a.inp



Skydip20130303_s8a.inp





5) Some thoughts:

First, it would appear that my simple model is not sophisticated enough to catch all of the features in these data sets. I suspect that this may be due in part to assuming that the wind screen is both a constant temperature and has a constant polarization signature with elevation. It is unclear whether we can capture enough of these nuances to be able to use these relations to remove the incident polarized signal to the level required in order to uncover the faint astronomical signal (remember we are trying to get from ~40 Jy down to mJys).

It seems more likely that we should continue to utilize a differential approach like that which David Berry has been implementing. However, it might be quite useful to look at the 25 independent stares in any given observations as if they were a mini-skydip in order to see if there are additional systematic effects we can uncover.

What I am mostly hoping is that we can use the information provided above to estimate the instrumental polarization of the astronomical source. It would appear to me that we should expect an astronomical source instrumental polarization of about

Q_A = 0.005 * N_A * cos(2. * Angle_C) + 0.011 * N_A * cos[2. * (Angle_C + elevation + 90)]
and
U_A = 0.005 * N_A * sin(2. * Angle_C) + 0.011 * N_A * sin[2. * (Angle_C + elevation + 90)],

where N_A is the strength of the astronomical source.