Analysis of DG Tau polarimetry data collected in Feb. 2007

Giles Novak, May 28 2007 (updated May 29)

I. INTRODUCTION AND OVERVIEW OF DATA

In this document, I analyze the DG Tau data to get (1) a preliminary science result, and (2) an assessment of how well SHARP does on faint sources during good weather, for comparison with the figure of merit given in the Table of Specifications on our web page.

One test that I've done is to break the data up into five bins of roughly equal statistical significance and then compute a reduced chi squared (χ_r^2) for these five bins. χ_r^2 is a comparison of the dispersion of the Stokes parameters for the five bins with the dispersion that would be expected given the nominal uncertainties of the Stokes parameters, which are propagated from the frame-rate errors given by sharp-integ.

χ_r^2 turns out to be very close to unity ($\chi_r^2 = 1.07$, for 8 degrees of freedom). This is described in section VI below.

Furthermore, the errors calculated by sharp-integ are themselves in rough agreement with the figure of merit given on the Table of Specifications. Specifically, they are about 25% too high. This is described in Section III below.

So I think we can use the figures of merit in the Table of Specifications with confidence, with an accuracy of plus-or-minus 25% or so.

The result for DG Tau is P = (1.3 +/- 0.6)% at Phi_Sky = (124 +/- 13) degrees. An i.p. correction has been applied but no polarization efficiency correction has been applied yet.

All analysis was done on zamin.

The excel logbook is posted on the web page. Data were collected on Feb 12 (tau ~ 0.035; ~ 1.5 hours of observations; five arcminute chop), Feb. 13 (tau ~ 0.07; ~ 4 hours; two arcminute chop), and Feb. 14 (tau ~ 0.08; ~ 3 hours; two arcminute chop).

I discarded the following scans because of notations in the logbook, or for other reasons:

Feb. 12:
36089 - glitch

Feb. 13:
36197-200 - "beam appears really broad" (too close to zenith?)
36216 – bad hwp move

Feb. 14:

36322-29 – very low statistical weight as signal is very low (tau rising & source setting)

II. SHARP-INTEG RESULTS

I used sharpinteg 2.3, with the posted rgm (rgm0702.dat), and with the following additional flags: "–f 1 –w –sil ".

I examined all of the I, q, and u maps for the Feb. 12 cycles, and also the associated error maps. For the Feb. 13 and 14 data, I examined representative maps (but not all maps). The results are:

The source is clearly visible in all I maps. The I maps have large DC offsets, often comparable with the source brightness. The Q and U maps also sometimes have offsets, but at a much lower level (almost a full order of magnitude lower). Structure in the Q and U maps is described further in Section IV.

The peak signals are typically one pixel away from the nominal peak locations which are: (5.5, 5.5), (7.5,7.5), (7.5, 5.5), (5.5, 7.5)

On Feb. 12, the peak signal (after background subtraction) is about 0.0034, on average. For cases where DG Tau has approximately equal flux in each of four pixels, that flux is about 0.0025.

Pixel [4,8] is flakey. Rows 10, 11, and 12 are noisier, and maybe 9 also. Row 2 sometimes has problems.

The efficiencies fluctuate a lot, but here are some recorded values:

Date	chop efficiency	data-taking efficiency	total efficiency
Feb. 12	39%	66%	26%
Feb. 13	68%	starts low, but rises to 81%	55%, by the end
Feb. 14	60%	some files as high as 81%	as high as 49%

III. SHARP-INTEG RESULTS FOR THE SIGNAL-TO-NOISE

This analysis was done for the data of Feb. 12 only. For pixels near the center of the array, the Q-error and U-error maps tell us that the rms error in Q and U is about 0.00015-0.00017, which is about 7% of the flux of DG Tau for the case where DG Tau has equal flux in four pixels (this flux is 0.0025, see section II). Thus, a single cycle would give errors in q and u of 3.5%, by combining four pixels. Scaling to 1% errors, we would require 12.25 cycles. Each cycle lasts 7.25 minutes, so achieving 1% errors requires 1.48 hours.

The 350 micron flux of DG Tau is 5.2 Jy (from Megan's tables in her proposals). This is 1.8 times brighter than the reference flux used in the Table of Specifications. But the Table assumes 60% efficiency, and we achieved only 26% on Feb. 12th. This represents a penalty of a factor of 1.52 in sensitivity. The tau recorded in the excel logsheet was 0.03 – 0.04, and the airmass was about 1.1. The "tau sec z" is thus about 0.0385, which should be compared with the reference "tau sec z" of 0.065. The result is we should gain a factor of 1.94 (= exp[25*[0.065-0.0385]]). Combining these three factors, we should have an advantage of a factor of 2.30 relative to the atmospheric, source flux, and efficiency conditions assumed in the Table of Specifications. This is a factor of 5.3 advantage in time. So we should be able to achieve a 1% error in 0.94 hours instead of the 5 hours stated in the Table of Specifications.

Comparing the value 0.94 hours with the value 1.48 hours shows that our errors are about 25% higher than expected. This discrepancy is probably within the uncertainties of the various calculations used here and in making the Table of Specifications.

IV. SHARP-INTEG RESULTS FOR Q AND U MAPS

I noticed that the maps of Q and U sometimes have the appearance of random Gaussian noise with zero mean, and amplitude consistent with the information given in the Q-error and U-error maps. (Note that in section III I showed that the Q-error and U-error maps show levels of error consistent with photon noise, or perhaps very slightly higher). Not all the Q and U maps show this nice appearance, however. More typically, there appear to be DC offsets and large-scale gradients superimposed. Such effects usually have amplitudes equal to or less than the amplitude of the photon noise, so its not clear how much trouble they could cause. But note that if we were trying to combine all of the flux from a 12x12 pixel map into one polarization measurement, the effects I am describing will be a major limitation on the accuracy of SHARP.

V. SHARP-COMBINE: TESTS OF BACKGROUND SUBTRACTION, SMOOTHED-TAU APPLICATION, AND POINTING CORRECTIONS

The version I used was 3.702

The default syntax I used was

```
sharp_combine bl combine.fits –hwp 91 –l 51 51 –sm 2 –ma 5 –ps 6 –pm 6 –q –bg 10 0
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A link to the file list ("bl", standing for "biglist") that I used to analyze the data is posted on the analysis logbook right next to this memo. (The pointing corrections and smoothed tau values that appear in this "bl" file were obtained from the SHARP web page.)

I experimented with background subtraction, smoothed tau, and pointing corrections, using a subset of the data consisting of the first 5 cycles of Feb. 12 (files 78-83). This subset is referred to as "Group A" (see section VI).

Without background correction, the edges of the I map have flux values equal to half of the peak flux. With background subtraction, the contrast is much better (10:1). I tried 1, 3, 10, and 50 iterations. 1 iterations is too few, but 3, 10, and 50 are no different from one another.

Results for Group A (q and u given in percent):

Conditions	smoothed I pk flux	smthd I pk loc	q	sig-q	u	sig-u
No bckgnd sub			0.0	1.3	0.6	1.3
Add bckgnd sub	0.0072	(27, 25)	+0.3	1.3	-0.8	1.3
Add smoothed tau	0.0070	(27, 25)	+0.1	1.2	-0.7	1.2
Add pointing corr.	0.0073	(26, 26)	0.0	1.2	-0.1	1.2

Note that the application of the pointing correction brings the source into the center of the map. Note that the background correction does change the polarization a bit, as does the application of the pointing correction.

In order to test the effects of the number of iterations of background subtraction on the results, I analyzed the complete data set with 0, 3, 10, and 20 iterations. These tests used smoothed tau and included pointing corrections. Here are the results (values in percent):

Number of iterations	q	sig-q	u	sig-u
0	-0.7	0.6	-1.5	0.6
3	-0.6	0.6	-1.3	0.6
10	-0.6	0.6	-1.3	0.6
20	-0.6	0.6	-1.3	0.6

VI. SHARP-COMBINE: BINNING THE DATA

The data were divided into 5 groups that seemed likely to have roughly equal statistical weight:

Group A: first 5 files of Feb. 12th
Group B: last 6 flies of Feb 12th
Group C: first 7 files of Feb 13th
Group D: last 19 files of Feb 13th

Group E: all 20 files of Feb 14th

Sharpcombine was run and the results for Q and U were obtained by multiplying q and u, respectively, by smoothed-I. The Q and U values have all been multiplied by 1,000,000.

Group	Q	sig-Q	U	sig-U
A	0	88	-7	88
B	-76	84	+27	95
C	-60	143	+90	150
D	+44	97	-238	97
E	-90	102	-204	102

The weighted average is (Q,U) = (-34 +/- 44, -94 +/- 45)

The average value of I for the five bins is 6500 x 10^{-6}

The reduced chi squared obtained by comparing the ten values with the two mean values is 1.07. For 8 degrees of freedom you have a 38% chance of getting this from a random distribution. So there is no evidence for any errors above the photon noise influencing our data.

VII. INSTRUMENTAL POLARIZATION CORRECTION

I estimate the i.p. that must be subtracted from the DG Tau results reported above as follows:

John's recent memo, not yet posted, shows that the normalized Stokes parameters corresponding to the 350 micron i.p. are consistent from run to run at the 0.2% level, for the July, Feb, and late April runs. (Note that for these three runs, the value of hwp is within a degree or two of 90 degrees.) Rounding the average for the three runs to the nearest 0.1%, I get:

q_i = 0.3%, u_i = 0.0%
q_t = 0.3%, u_t = 0.0%

Definitions are given in John's posted i.p. memo (analysis log May 21 2007)

To rotate onto the sky plane, I need to know the parallactic angle (P.A.) and the elevation (EL). I divide the data into six groups, each having values of parallactic angle and elevation that don't vary internally by more than +/- 33 degrees:

Group AB – groups A and B together
Group C

Group D
Group E1 – first 6 files of group E
Group E2 – next 6 files of group E
Group E3 – last 8 files of group E

The relative weights are computed from the error-bars in Q and U given above. (Equal weights are assigned to E1, E2, and E3, each thus getting (1/3) of the weight that would be given to group E.)

From the excel logsheet, I obtained the following:

Group	P.A.	EL + P.A.	P.A. variations	EL+P.A. variations
AB	-112	-37	less than +/- 15	less than +/- 15
C	+113	+10	between 15 and 33	between 15 and 33
D	+93	+147	between 15 and 33	less than +/- 15
E1	-150	-70	less than +/- 15	less than +/- 15
E2	+150	+40	between 15 and 33	between 15 and 33
E2	+120	+10	between 15 and 33	between 15 and 33

Next I rotate the two instrumental polarization vectors (for "telescope" and "instrument") as defined above, onto the sky plane, using the formulas in John's memo. I set hwp=90 as it is very close to this value. P.A. is needed to rotate the telescope polarization onto the sky and EL+P.A. is needed to rotate the instrument (fixed) component onto the sky.

Note that where the angle variations are large (see table above) there will also be a reduction in the magnitude of the vector, due to averaging of vectors pointing in different directions. To estimate the magnitude of this effect, I did a Taylor expansion and found that for a total angular spread of +/- 1 radian in stokes space, the polarization should get reduced to (2/3) of its value. Thus, for the cases where the values of P.A. (or EL+P.A.) vary by somewhere between +/- 15 and +/- 33 degrees, I reduce the polarization magnitude from 0.3% to 0.2%. Otherwise I leave the polarization at 0.3% when rotating it to sky coordinates. The error introduced in this way will be of order a few hundredths of a percent.

After rotating (and sometimes reducing, as described above) the polarization vectors, I take the weighted mean over the six bins, to get, in sky coordinates:

q_t = -0.18%, u_t = +0.07%
q_i = +0.09%, u_i = -0.17%
And finally, rounding to 0.1%, we get a total instrumental polarization of :

(q_t+i, u_t+i) = (-0.1%, -0.1%)

VIII. RESULT FOR DG TAU

I subtract the i.p. of section VII from the DG Tau result of section V, to obtain:

(q, u) = (-0.5 +/- 0.6, -1.2 +/- 0.6)%

or

P = (1.3 +/- 0.6)% at 124 +/- 13 degrees.

For comparison, here is the 800 micron result of Tamura et al. (1999)

P = (3.0 +/- 0.9)% at 25 +/- 8 degrees

The disk long axis is at 99 degrees, according to Tamura et al.

The two polarization results are in strong disagreement. One must either have 90 flip or a sharp drop in polarization toward the shorter wavelength.