POL-2 Polarimetry & Data Reduction

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James Clerk Maxwell Telescope
East Asian Observatory

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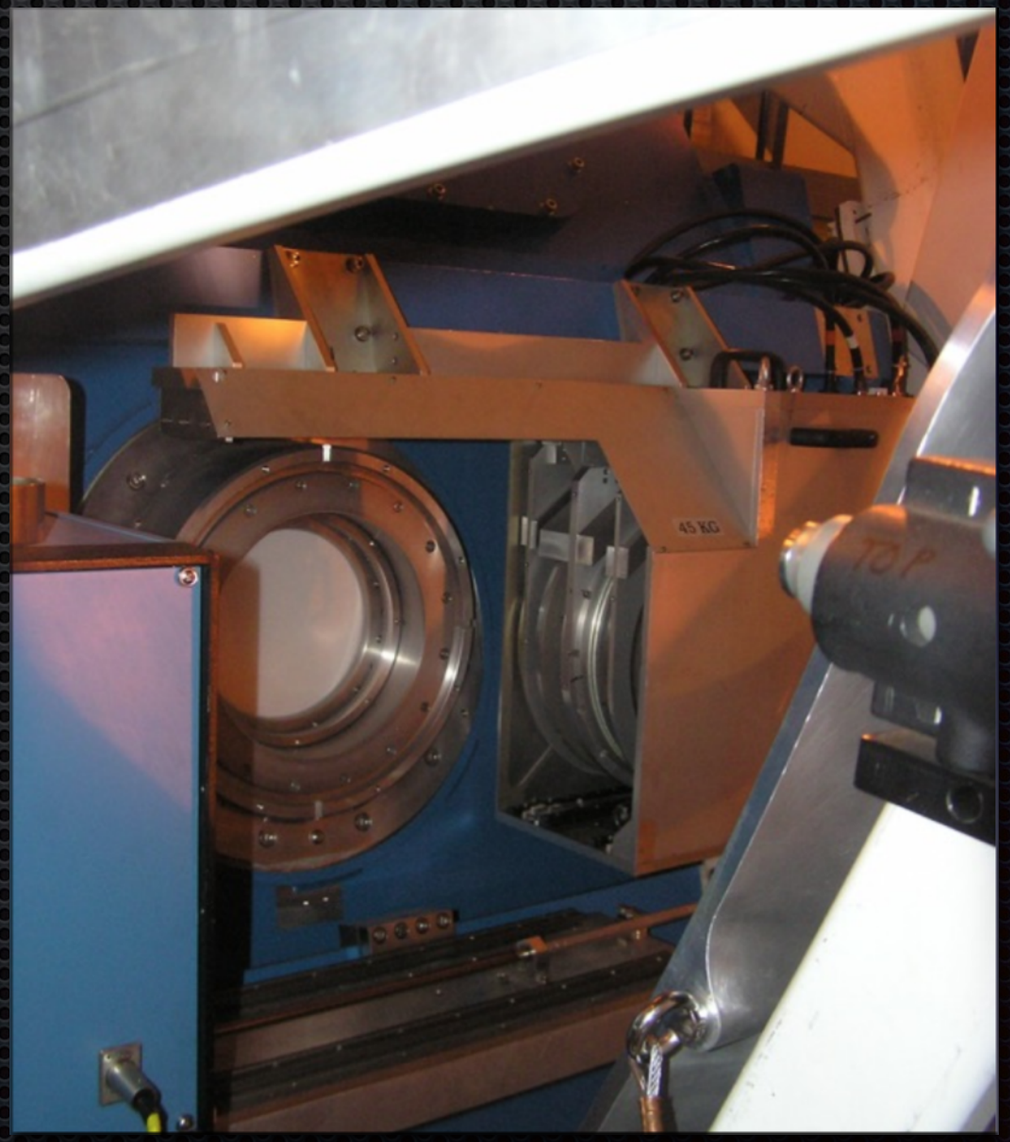
POL-2

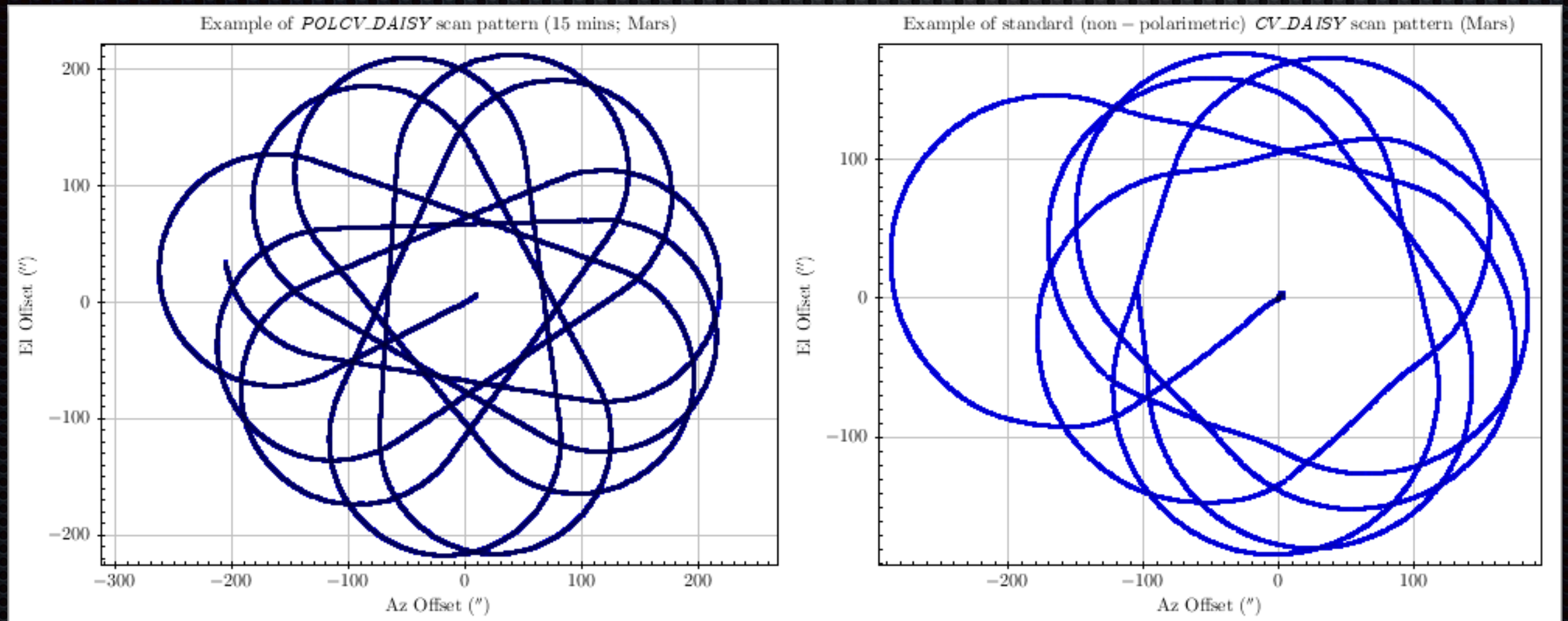
- Polarimetry module for *SCUBA-2:* enables large-field continuum sub-mm imaging polarimetry
- 3 optical components in “blades”:
  - Calibrator (~100% polarization)
  - Half-wave plate (HWP). Continuous rotation of this modulates polarization, allowing removal of atmospheric effects. Transmission at 850μm ~ 86%
  - Analyser
- **Total effective 850μm transmission ~ 74%**



POL-2 Observing Mode

- "***POLCV_DAISY***" mode - currently commissioned for **850μm only**
  - "*POLCV_DAISY*": Special case of "*CV_DAISY*" scan mode with a particular set of parameter settings different from standard, non-polarimetric scans
  - Telescope must scan slowly enough to obtain sufficient on-sky data for good Q & U values
- "Scan & Spin" mode: telescope moves with continuous velocity while *POL-2* HWP spins at 2 Hz
- ~200" in size; scan speed of 8" / s
- DR determines a pair of Q & U values for each 0.5s segment of data stream. Length of data segment = time taken for telescope to traverse 1 pixel in generated map
- Modulation generated by any polarization = 8 Hz at current HWP rotation speed => 4 complete modulation cycles (at 850μm)
- Pattern ~20× slower than standard non-polarimetric *SCUBA-2 Daisy* pattern

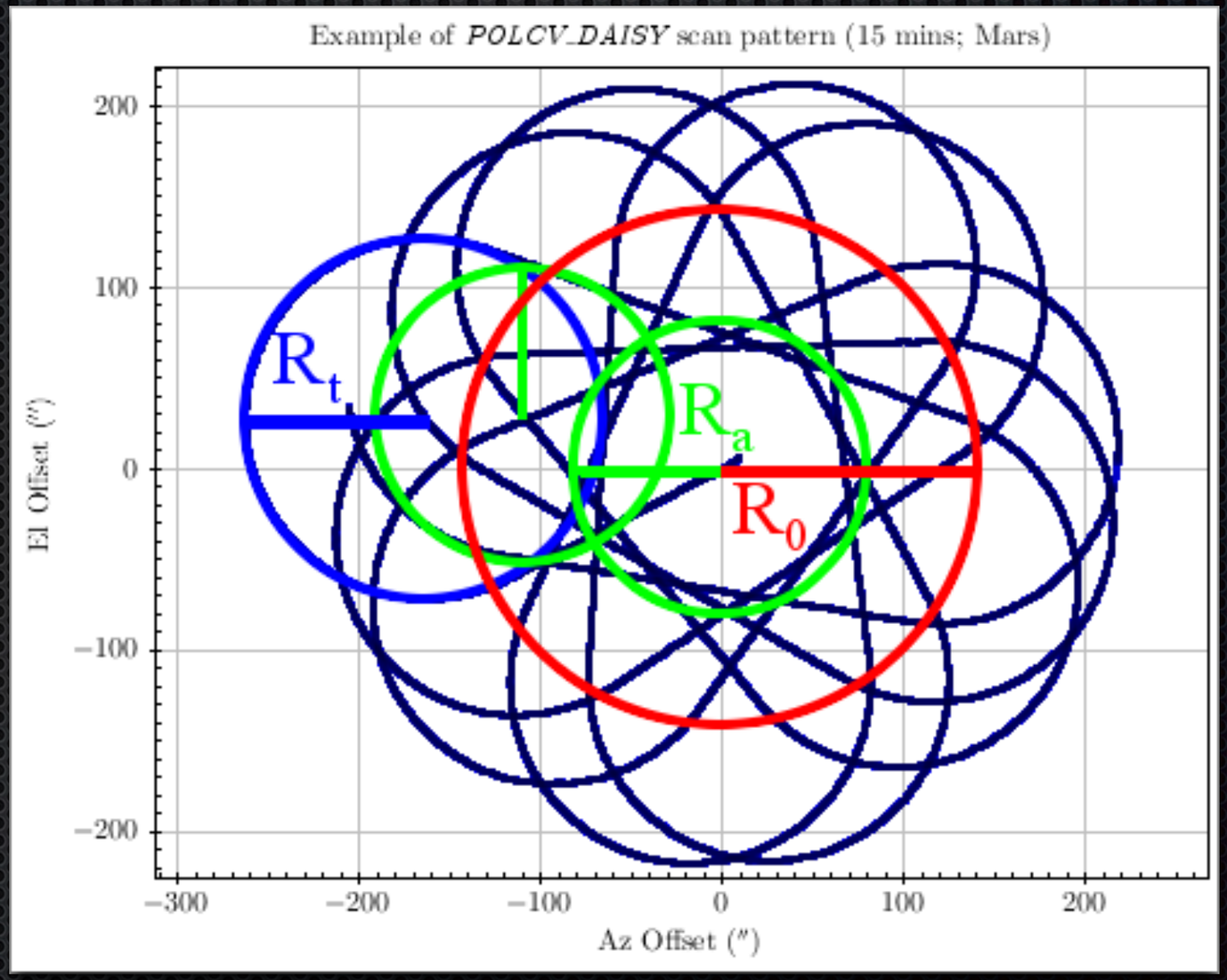
POLCV_DAISY Scan Pattern



POLCV_DAISY scan pattern (15 mins; Mars; left, dark blue) vs. standard (non-polarimetric) *CV_DAISY* scan pattern (Mars; first few scans only for clarity; right, light blue). In addition to differences in shape, scan patterns differ slightly in overall size.

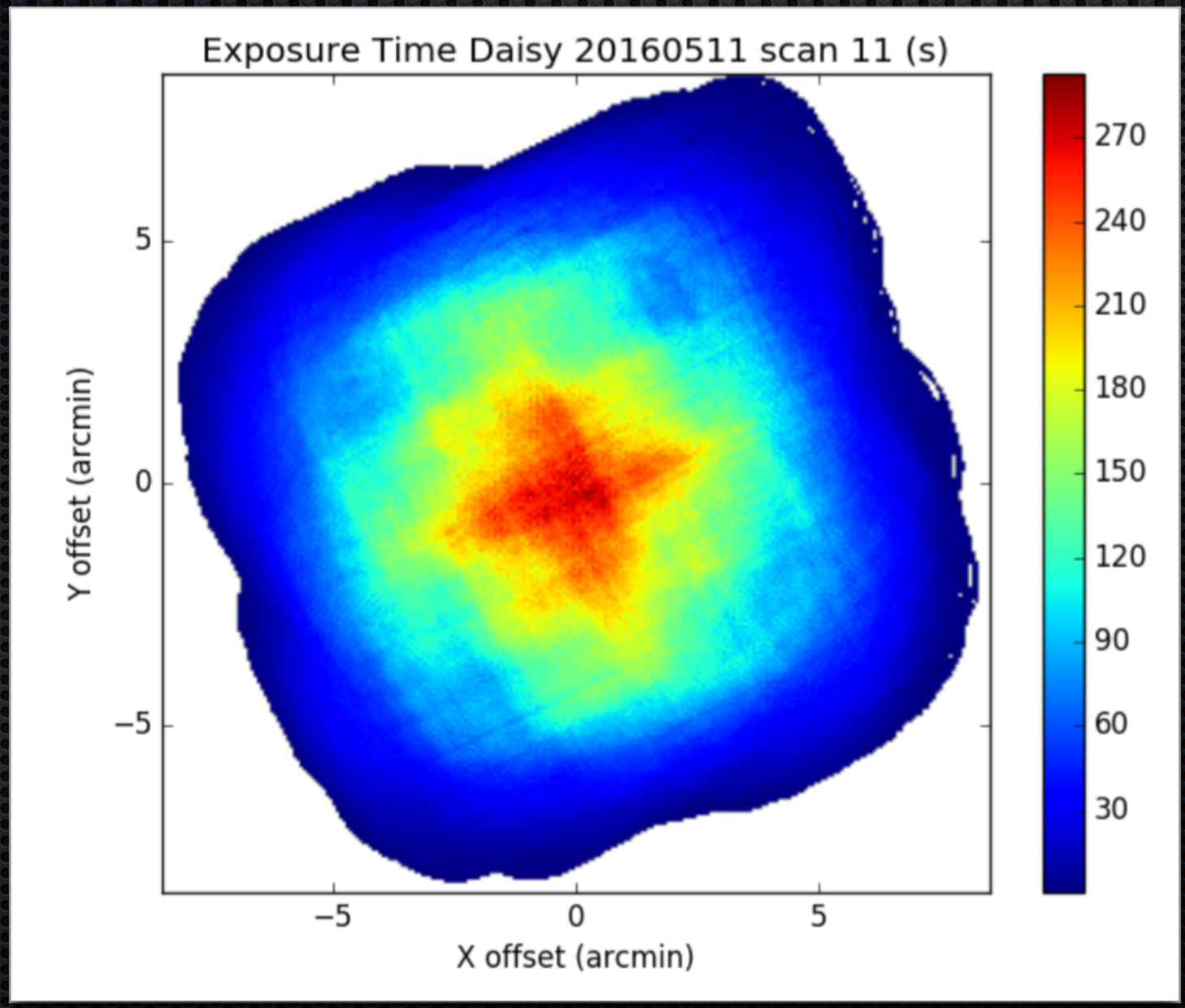
POLCV_DAISY Details

Parameter	Value
HWP Rotation Frequency	2 Hz
Antenna Scanning Speed	8” / s
R_0 (Map Pattern Radius)	133”
R_1 (Turn Radius)	99”
R_a (Nominal Avoidance Radius)	77”



Smaller *POLCV_DAISY* patterns may be technically possible in future, yielding superior performance for small sources (< 1’)

Typical *POLCV_DAISY* Exposure Time Map



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SCUBA-2 ITC

Input

Source and Conditions

Source position: 40 ° declination

225 GHz opacity: Band 2: 0.05 < τ ≤ 0.08 | 0.065 ?

Observation

Map type: POL-2 daisy (~3 arcmin) ?

Matched filter ?

850 μm pixel size: 4 "

450 μm pixel size: 2 "

SCUBA-2 offers two types of standard observing mode: “daisy” for compact sources (≲ 3 arc-minutes) and “pong” patterns of various sizes.

An additional observing mode is offered for polarimetry with POL-2.

SCUBA-2 observing modes

Requirement

Wavelength: 850 μm

Target sensitivity: 2.000 mJy/beam

Calculate

Calculator Mode

Mode: Time required for target RMS

Change mode

Help on this calculator | Contact us

SCUBA-2 ITC (*Hedwig*) *POL-2 Daisy* supported (since 16B)

Steps for Reduction & Analysis of Raw POL-2 data - *pol2scan* (see tutorial)

- Creation of Q & U time-streams from raw analyses intensity time-stream data (using *SMURF calcqu* command)
  - Clean up time-streams: flat-field, convert to pW, fix any bolometer DC offsets in time-streams, remove any bolometer transients in time-streams, remove bolometer constant offsets, etc.
  - Cleaned 180 Hz time-streams converted into down-sampled 2 Hz Q & U time-streams
    - Sets of Q & U values generated from short sections of time-streams
    - Models applied - Fits & notional variances (used for subsequent weighting) derived
- Creation of Q & U maps from Q & U time-stream data (using *SMURF makemap* command with special configuration file)
  - Factors in low scan speed, uses PCA for sky background removal, skips FLT model component, applies weights, applies correction for Instrumental Polarization (IP) effects
- Creation of vector catalogues from Q & U maps (using *POLPACK polvec* command)
- Display & analysis of final vector catalogues (using *Starlink GAIA* &/or *POLPACK* packages)

https://www.eao.hawaii.edu/~dberry/pol2-dr.htx/pol2-dr.html

Starlink SMURF pol2scan Usage

- Available as part of **recent** Starlink public software release (**2016A or newer**)
- Typically invoked from shell as follows:

> smurf

> pol2scan in=<Input polarimetry files to be reduced>

ipref=<Input non-polarimetric reference map>

qudir=<Target directory to which resultant Q & U time series will be written>

q=<Output NDF in which to return Q intensity map>

u=<Output NDF in which to return U intensity map>

cat=<Output FITS file containing resultant vector catalog>

ipfcf=<FCF value to be used>

mapdir=<Target directory in which to return Q & U maps made from each individual observation supplied via "in" parameter, before co-adding them>

- Many other parameters available: *> pol2scan --help*

POL-2 Data - Error Calculation

- As for non-polarimetric *SCUBA-2* data, datasets also contain array of uncertainties
- First, re-bin Q & U maps so pixel size = beam size (e.g. using *Starlink KAPPA "COMPAVE"* command)
- Several possible ways to obtain noise estimates for Q & U maps:
  - Use *GAIA* "*Image Regions / Image Analysis*" menu to measure pixel data value standard deviation for flat part of image
  - Examine "*Variance*" values stored in final Q & U mosaics generated by *pol2scan* with *GAIA* (or a script), or use "*Error*" button in *GAIA* NDF display selection window to display standard deviations. These "*Variance*" values are created by *makeup* (run automatically as part of *pol2scan*), & measure spread of background-subtracted bolometer values that fall in each pixel
  - If many observations of science field available & Q & U maps for all observations used same reference intensity map, can estimate noise in a pixel by looking at range of values at that pixel among those observations. *Starlink CCDPACK "MAKEMOS"* command with "*GENVAR*" parameter can be used for this, e.g. (with "*qlist*" containing all input filenames):

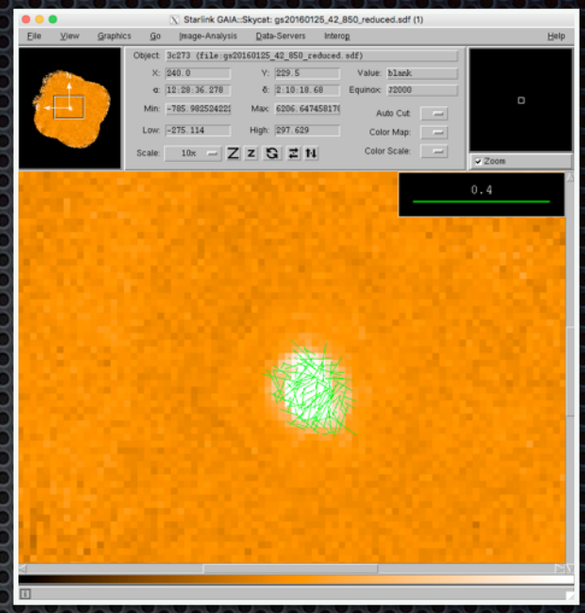
```
> makemos in=^qlist out=qmosaic method=mean usevar=no genvar=yes
```

Vector catalogues created by *pol2scan* also include estimates of errors on vector lengths & angles

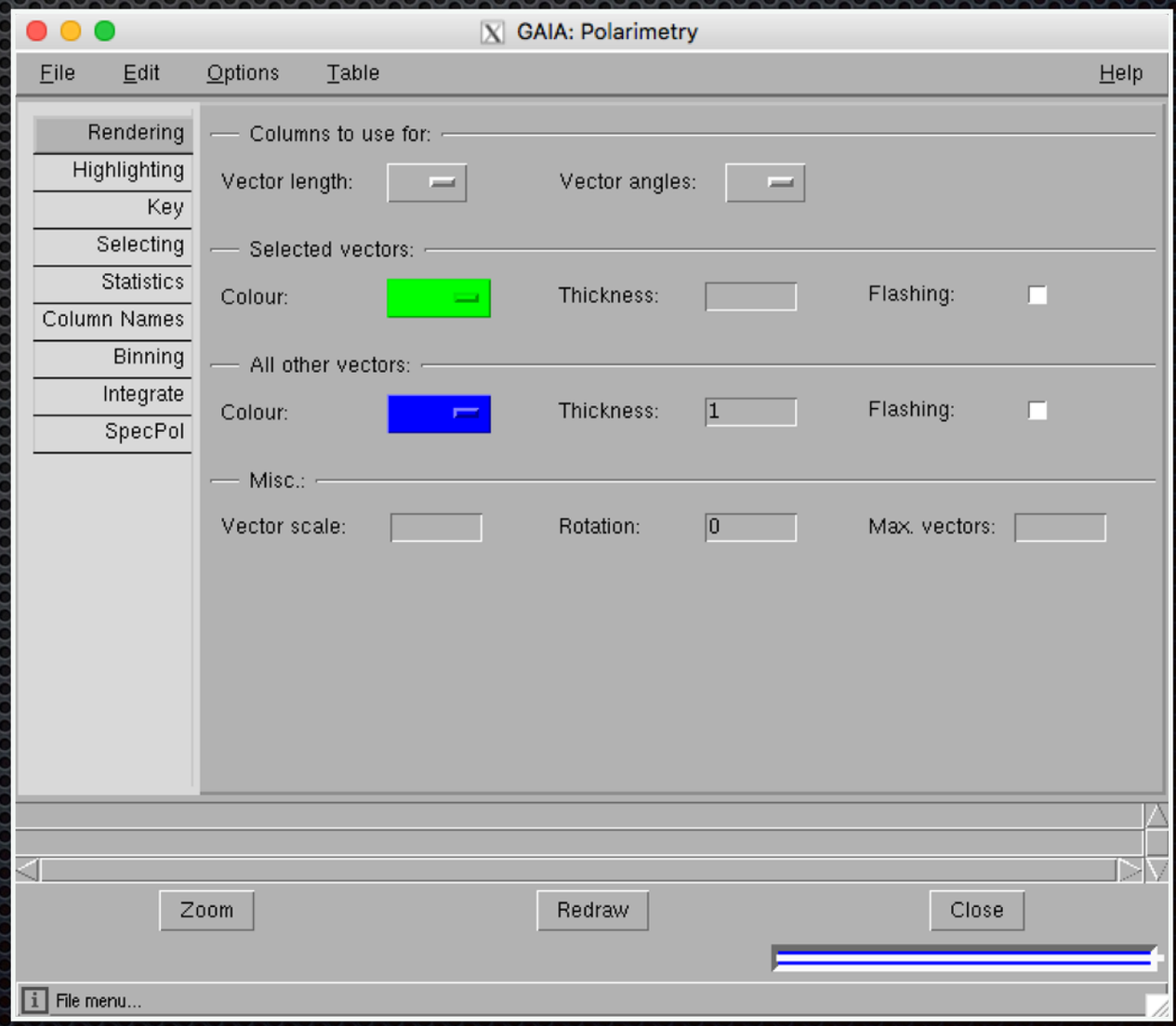
POL-2: Covering Larger Areas

- Use a “Daisy Chain”
- Multiple *POLCV_DAISY* observations with suitable spacing to provide adequate sampling
- Current recommendation (subject to change):
  - Triangular grid with *Daisy* centres spaced 250” apart
  - IP reference maps: Matching non-pol *Daisy* scans for small areas. *Pong* scans may be better for larger areas?

Viewing POL-2 Maps: GAIA Polarimetry Toolbox



- Included as part of *Starlink GAIA* package
  - "*Image-Analysis*" drop-down menu option
- Enables import & manipulation of vector tables
  - Binning, vector map overlays, specific area selection, generation of statistics, etc.



Producing Hardcopy Vector Plots: *POLPACK*

- *POLPACK*: *Starlink* Imaging Polarimetry Reduction Package

  > polpack

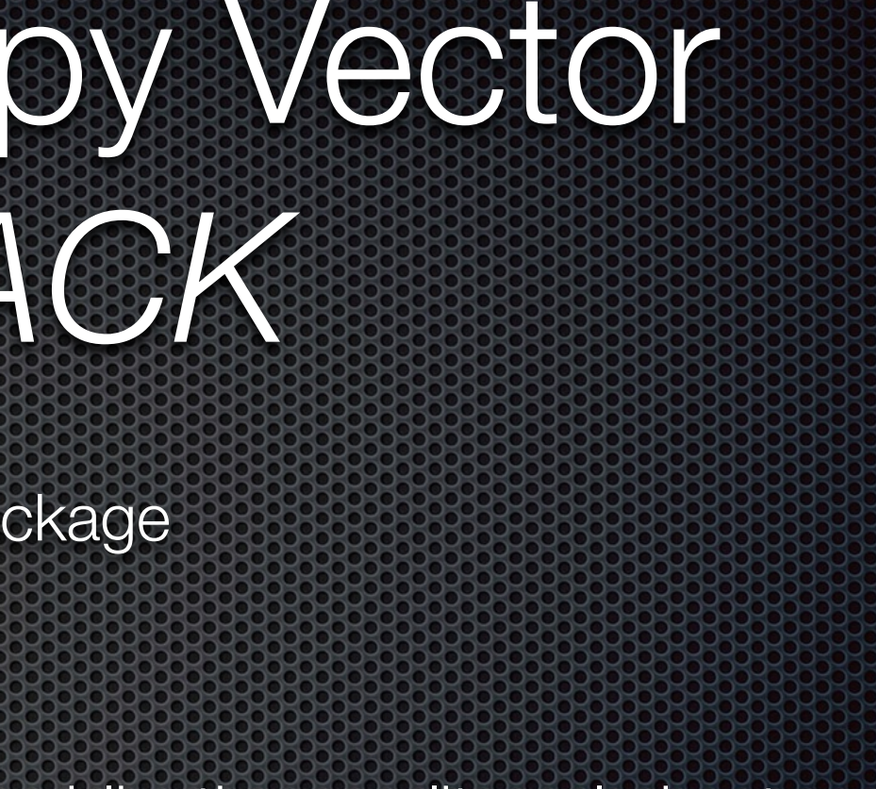
- Together with *KAPPA*, can be used to (e.g.) generate publication-quality polarimetry maps
- Documentation:

  http://starlink.eao.hawaii.edu/docs/sun223.htx/sun223.html

- Help:

  > polhelp

  > showme sun223



Nothing is Permanent But Change...

- *Starlink POL-2* data reduction still undergoing development
- New command currently being tested: ***pol2map***
  - Total intensity map (used for IP correction & to normalize polarized intensity values into fractional polarizations) created from same *POL-2* observations used to generate Q & U maps
  - Produces flatter backgrounds
  - Produces lower noise levels
  - Q & U map-making procedure same as for I - better matching of spatial scales & FCF
  - 2-Pass approach used to generate total intensity map
  - Change of models used:
    - *pol2map* uses (COM, GAI, PCA, EXT, FLT, AST, NOI)
    - *pol2scan* uses (PCA, EXT, AST, NOI)

BOTTOM LINE: ALL PRESENTED INFORMATION IS SUBJECT TO CHANGE!

POL-2 DR Tutorial…

http://www.eaobservatory.org/jcmt/science/reductionanalysis-tutorials/pol-2-dr-tutorial-1/