
SOFIA@AAS 2019

HAWC+ Data Workshop

January 6, 2019

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Agenda

FORCAST:

- 08:30 – Introduction to FORCAST
- 09:00 – Introduction to FORCAST data pipeline and products
- 09:15 – DCS Archive demo for FORCAST
- 09:30 – *FORCAST Grism Data Recipe: Inspection and Assessment*
- 10:00 – Open time for exploration/break
- 10:30 – *FORCAST Grism Data Recipe: Basic Line Analysis*
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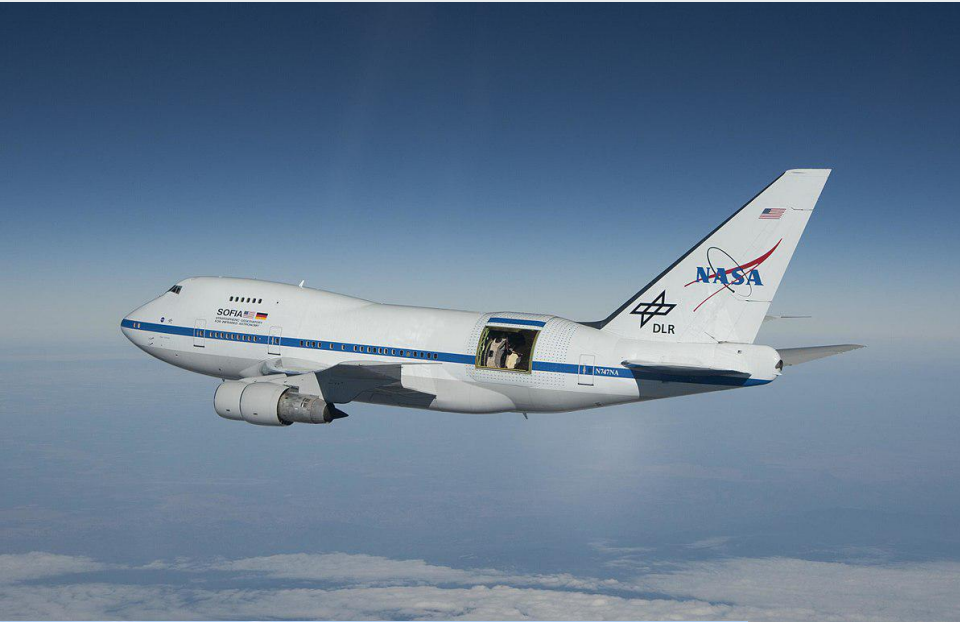
- 12:00 – Lunch break

HAWC+:

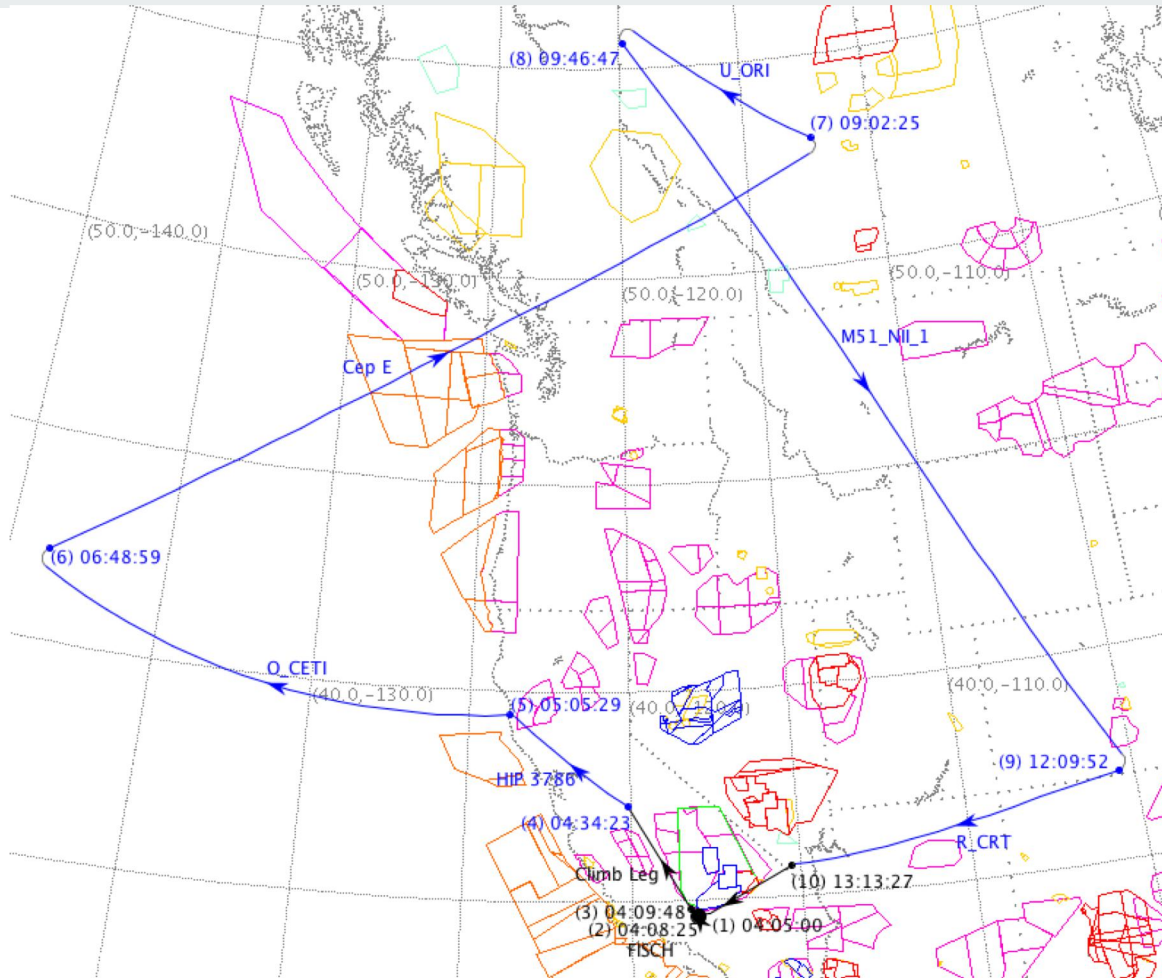
- 13:00 – Introduction to HAWC+ and polarimetry
- 13:30 – DCS Archive demo for HAWC+
- 13:45 – *HAWC+ Data Recipe*
- 15:15 – Break
- 15:45 – Open time for exploration
- 16:45 – Wrap up
- 17:00 – End

SOFIA Help Desk: sofia_help@sofia.usra.edu

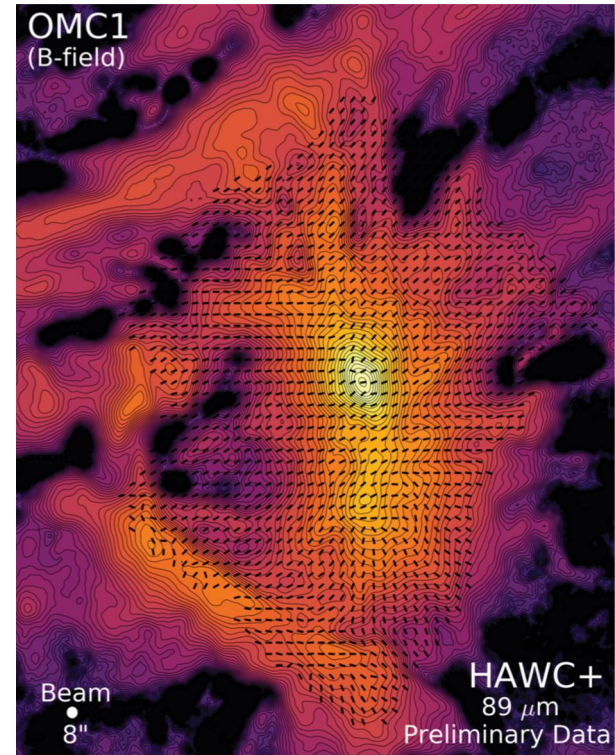
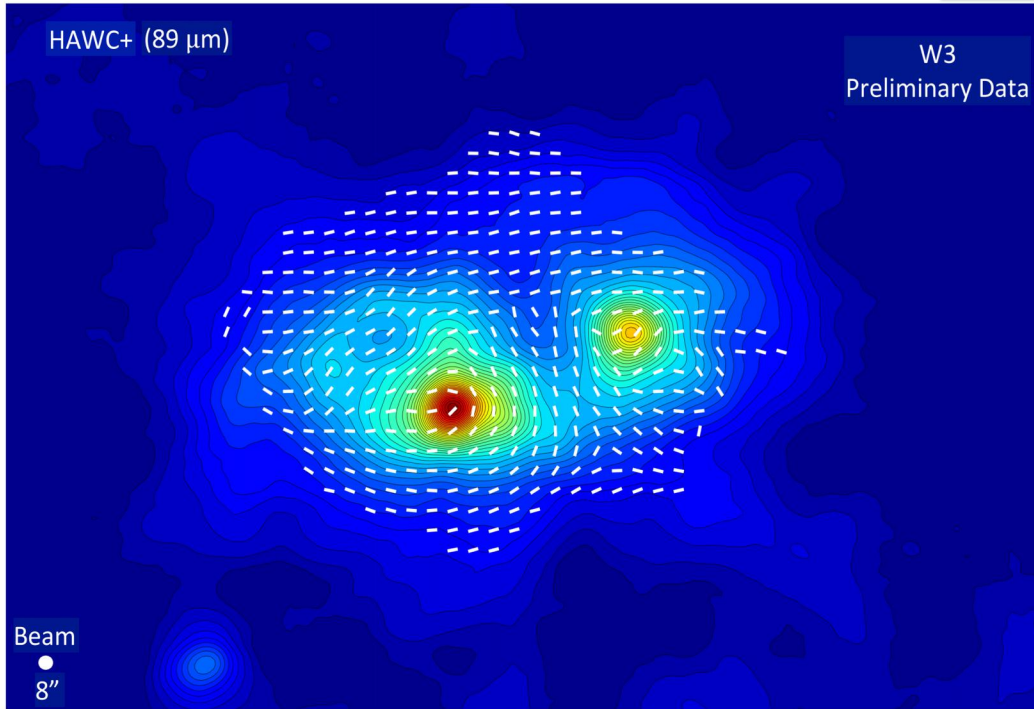
SOFIA and Far-Infrared Astronomy



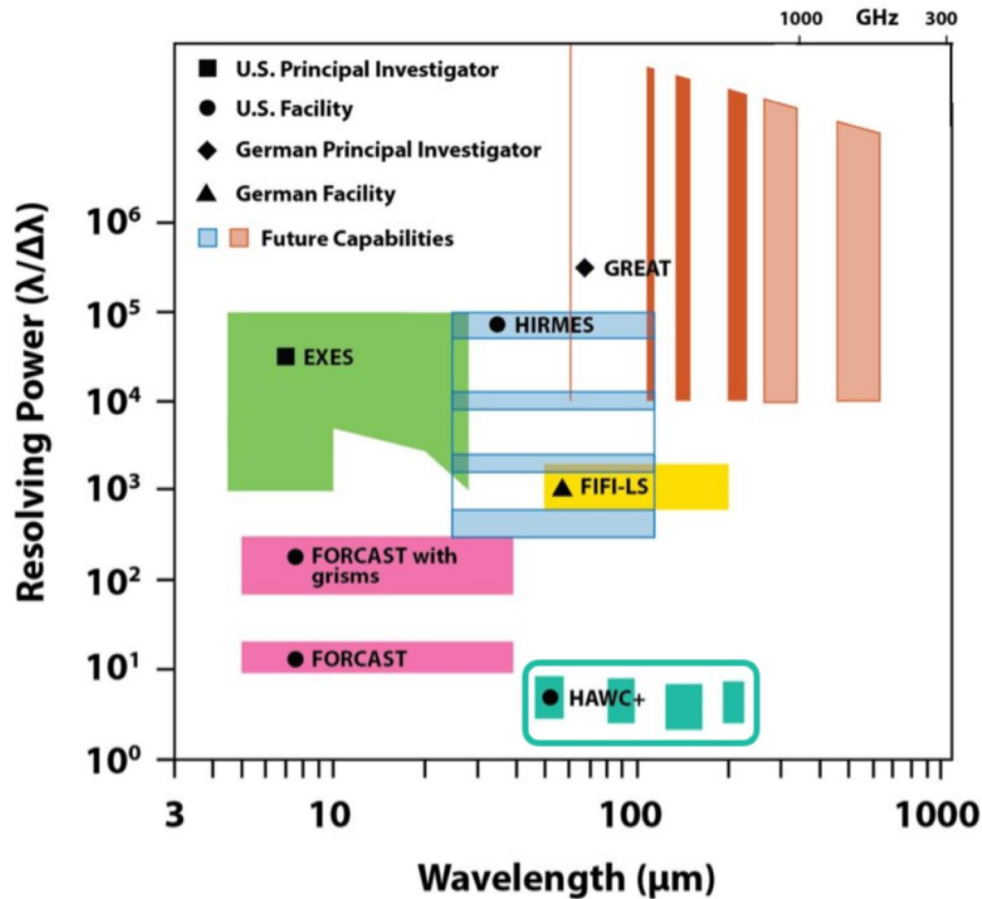
Observing on SOFIA



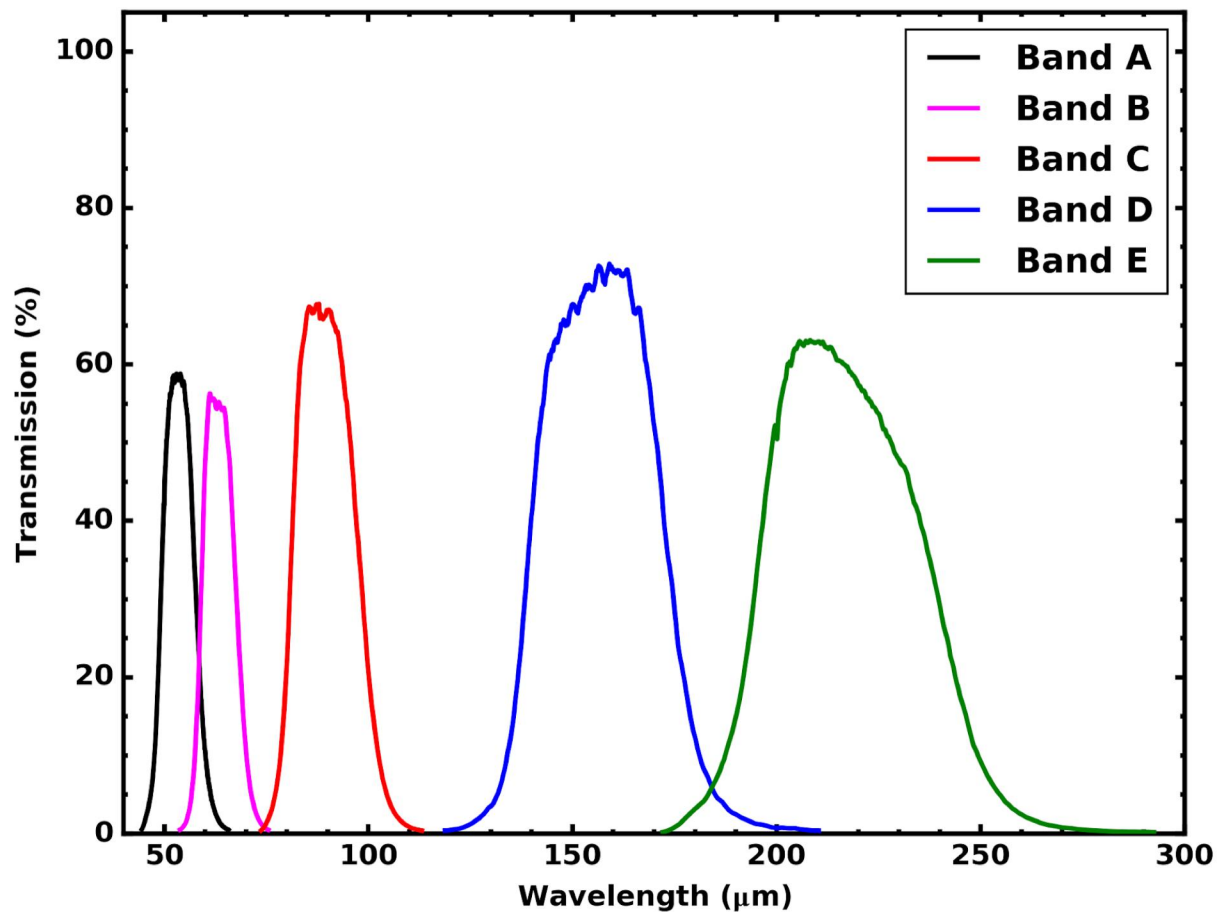
Imaging and Polarimetry with HAWC+



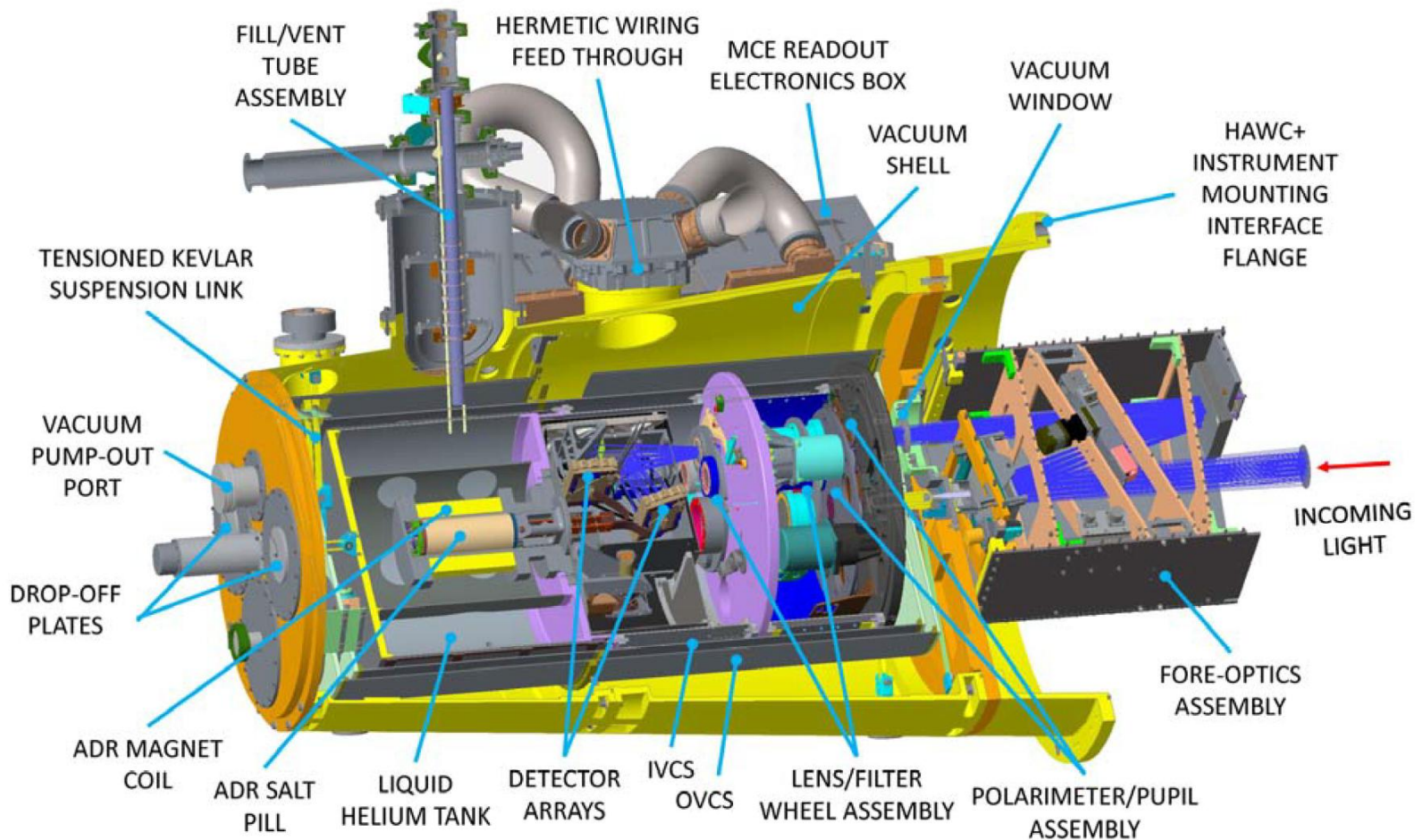
HAWC+ in Context



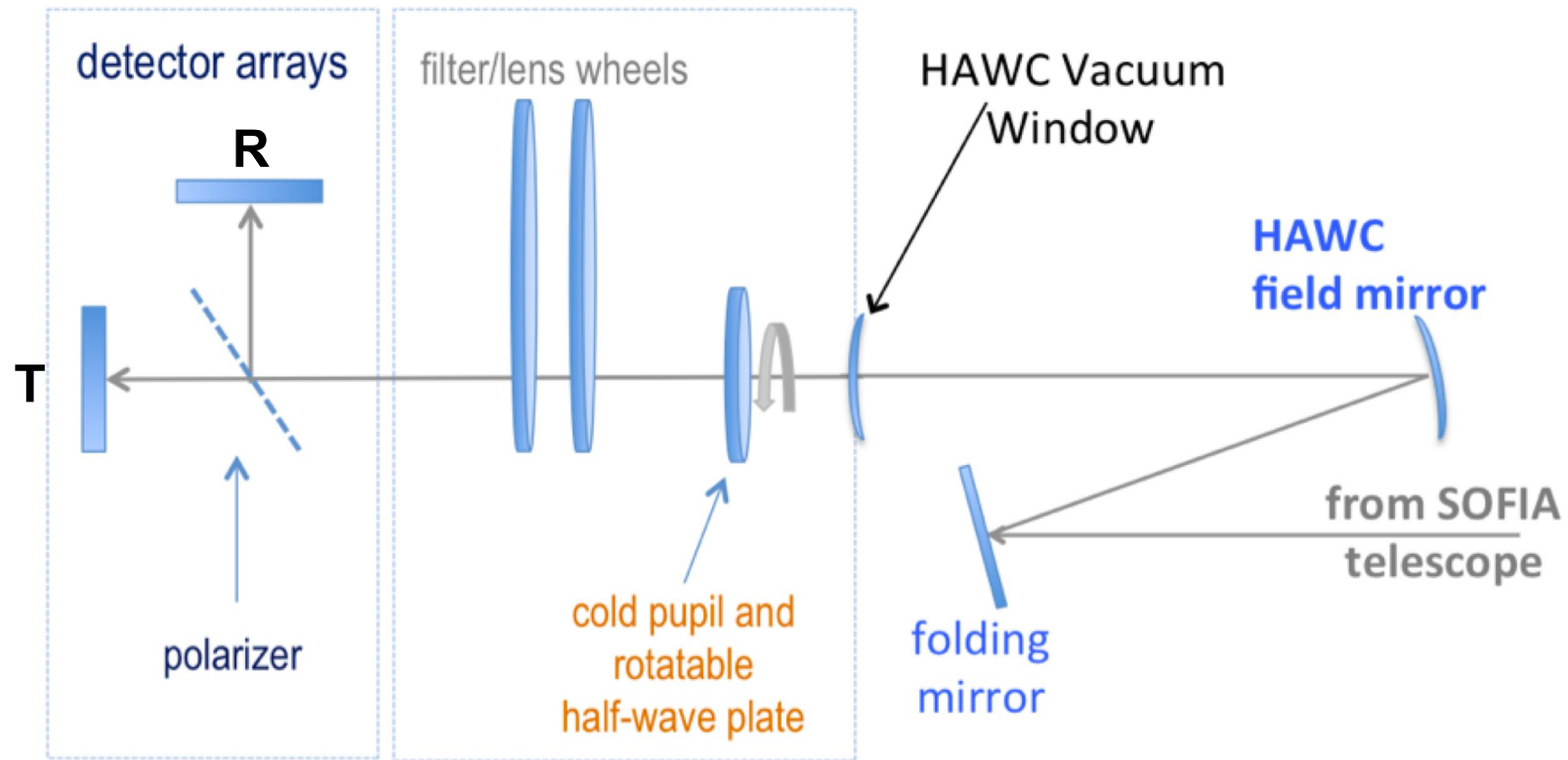
HAWC+ Filters



Inside HAWC+



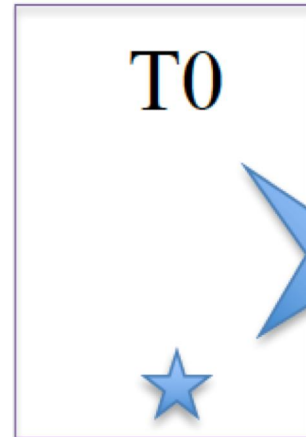
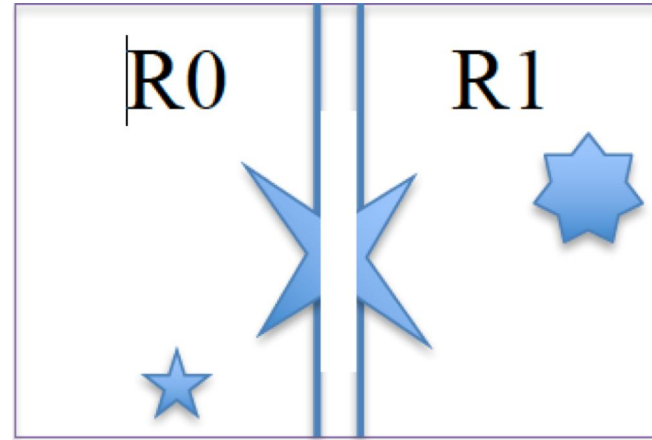
Optical Path



HAWC+ TES detectors

Two arrays of co-aligned TES bolometers

- 32 x 40 pixel subarrays
- Total intensity:
 - R0 + R1
- Polarimetry
 - R0 + T0
- 0.3 K transition
- >12 hour hold time



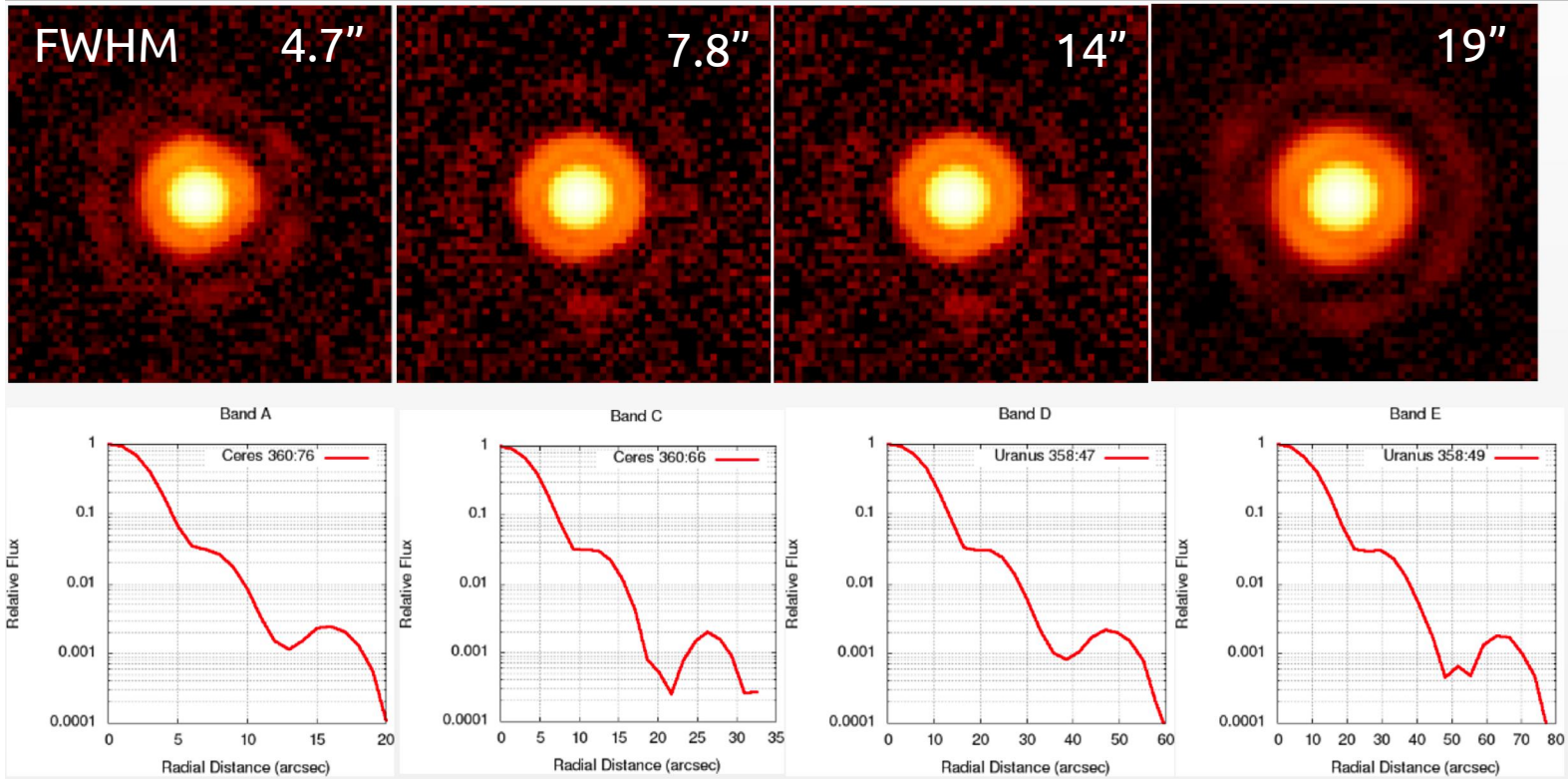
Instrument Parameters

Band / Wavelength	$\Delta\lambda/\lambda$	Angular Resolution	Total Intensity FOV (arcmin)	Polarization FOV (arcmin)
A / 53 μm	0.17	4.7" FWHM	2.7 x 1.7	1.3 x 1.7
B ^a / 63 μm	0.15	5.8" FWHM	4.2 x 2.6	2.1 x 2.6
C / 89 μm	0.19	7.8" FWHM	4.2 x 2.6	2.1 x 2.6
D / 154 μm	0.22	14" FWHM	7.3 x 4.5	3.6 x 4.5
E / 214 μm	0.20	19" FWHM	8.0 x 6.1	4.0 x 6.1



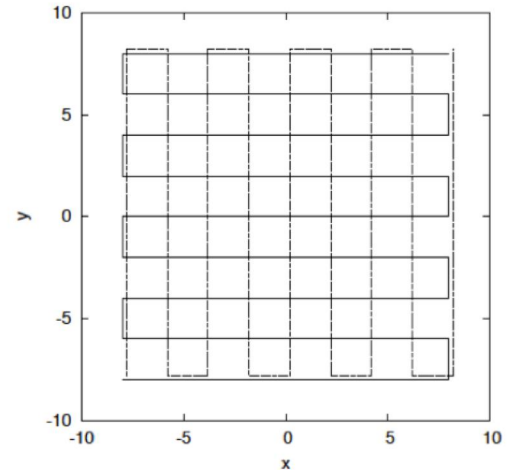
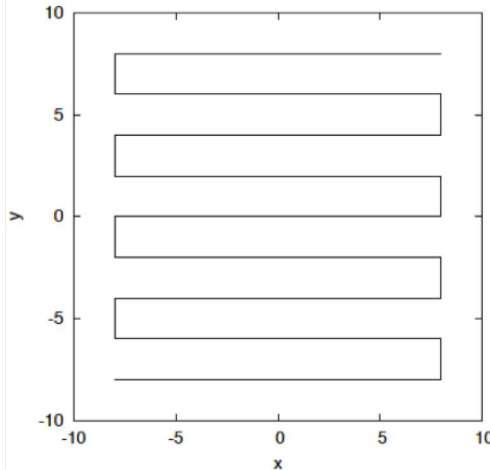
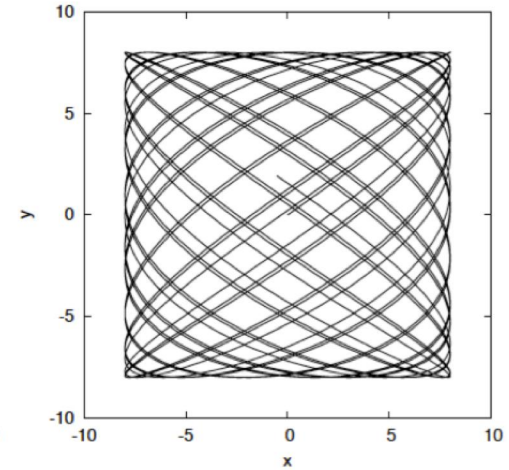
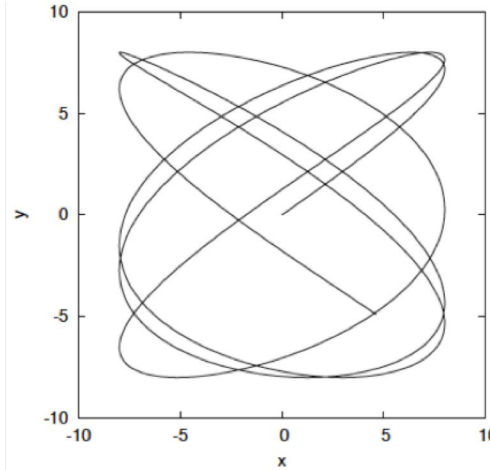
HAWC+ PSF

SOFIA is diffraction-limited at all wavelengths

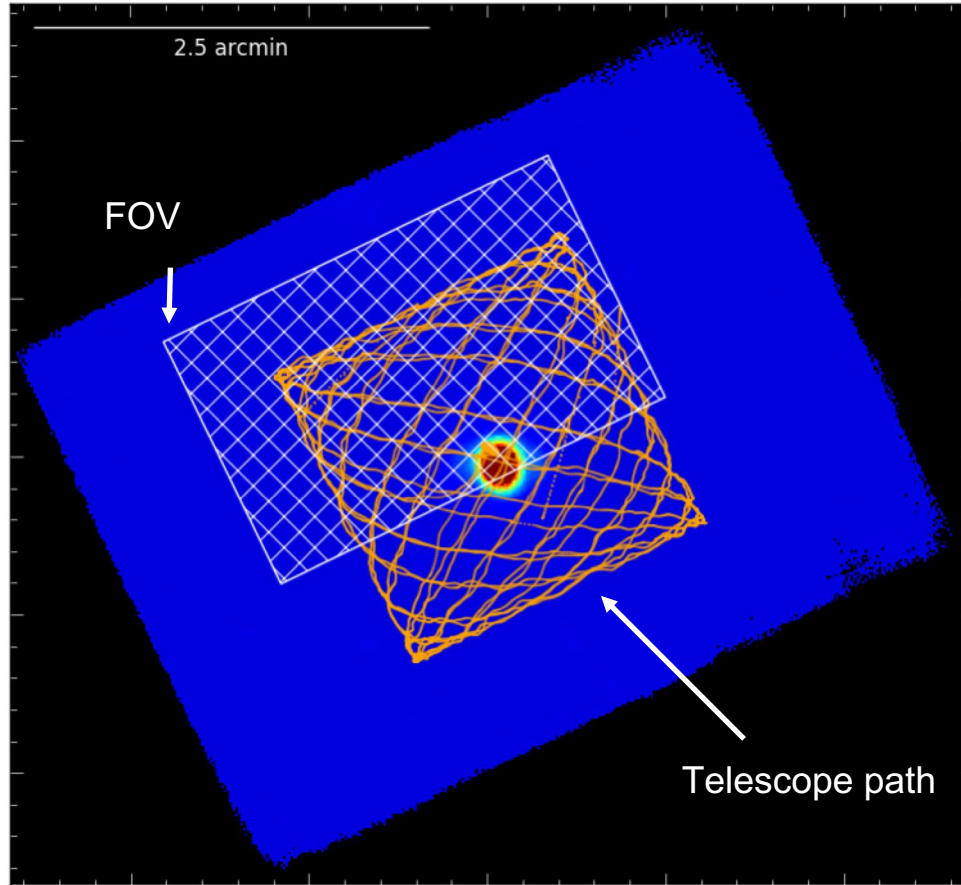


Observing Modes

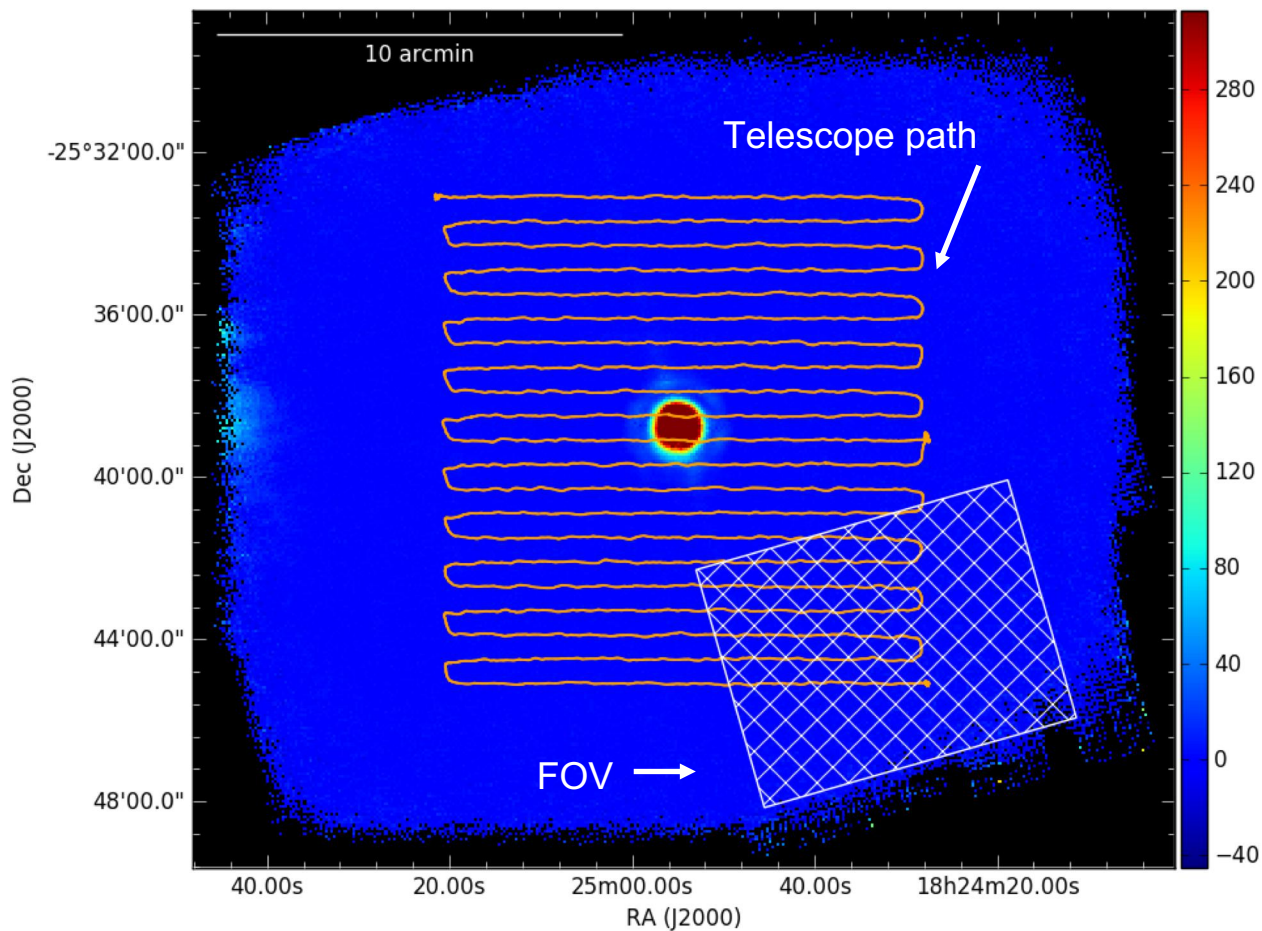
- Symmetrical Chop/Nod for polarimetry
- Total intensity scan mapping has two modes:
 - Lissajous: for small fields comparable to the FOV
 - Raster: for large mapping areas
- Part of the map should include regions with no extended emission



Lissajous Scanning



Raster Scanning



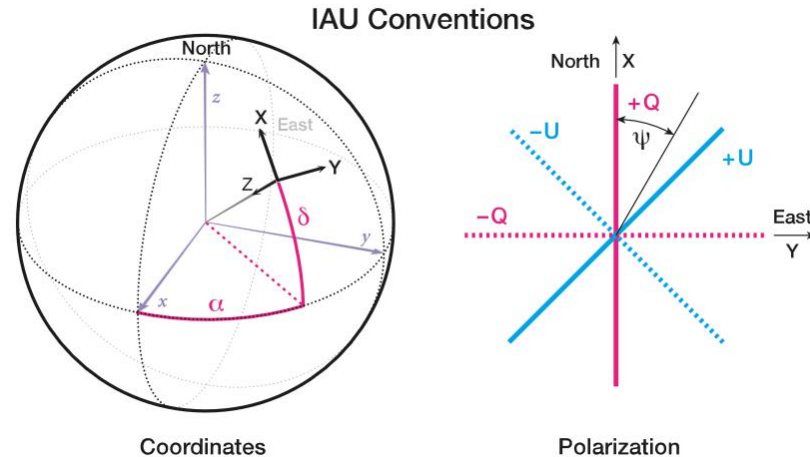
Polarization Basics

- Polarized light:
 - Stokes I is the total intensity of the incoming light;
 - P is the fraction of the light that is polarized;
 - θ is the angle of the polarization relative to celestial North.

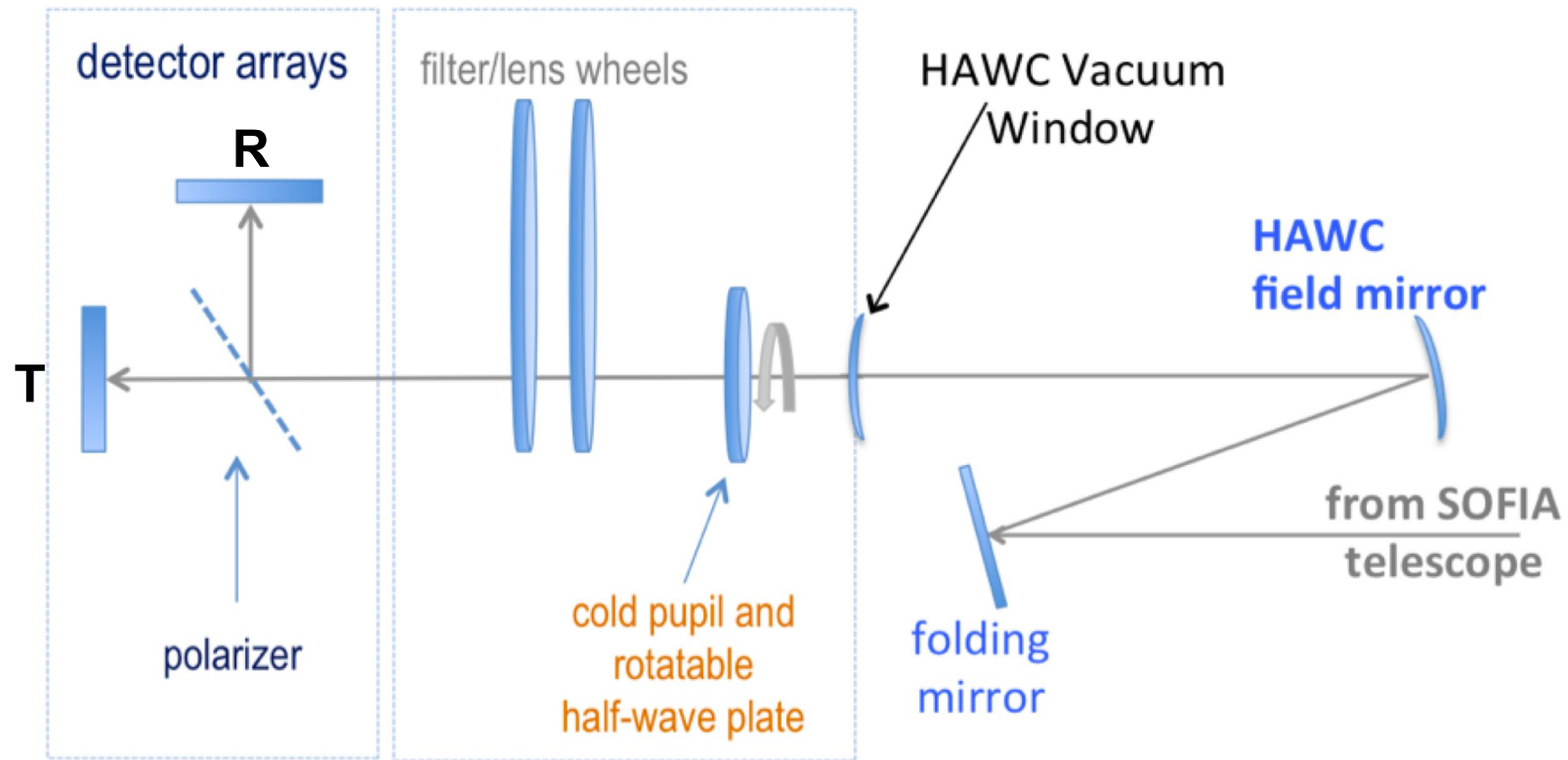
- Linear Stokes parameters:

- $Q = I P \cos(2\theta)$

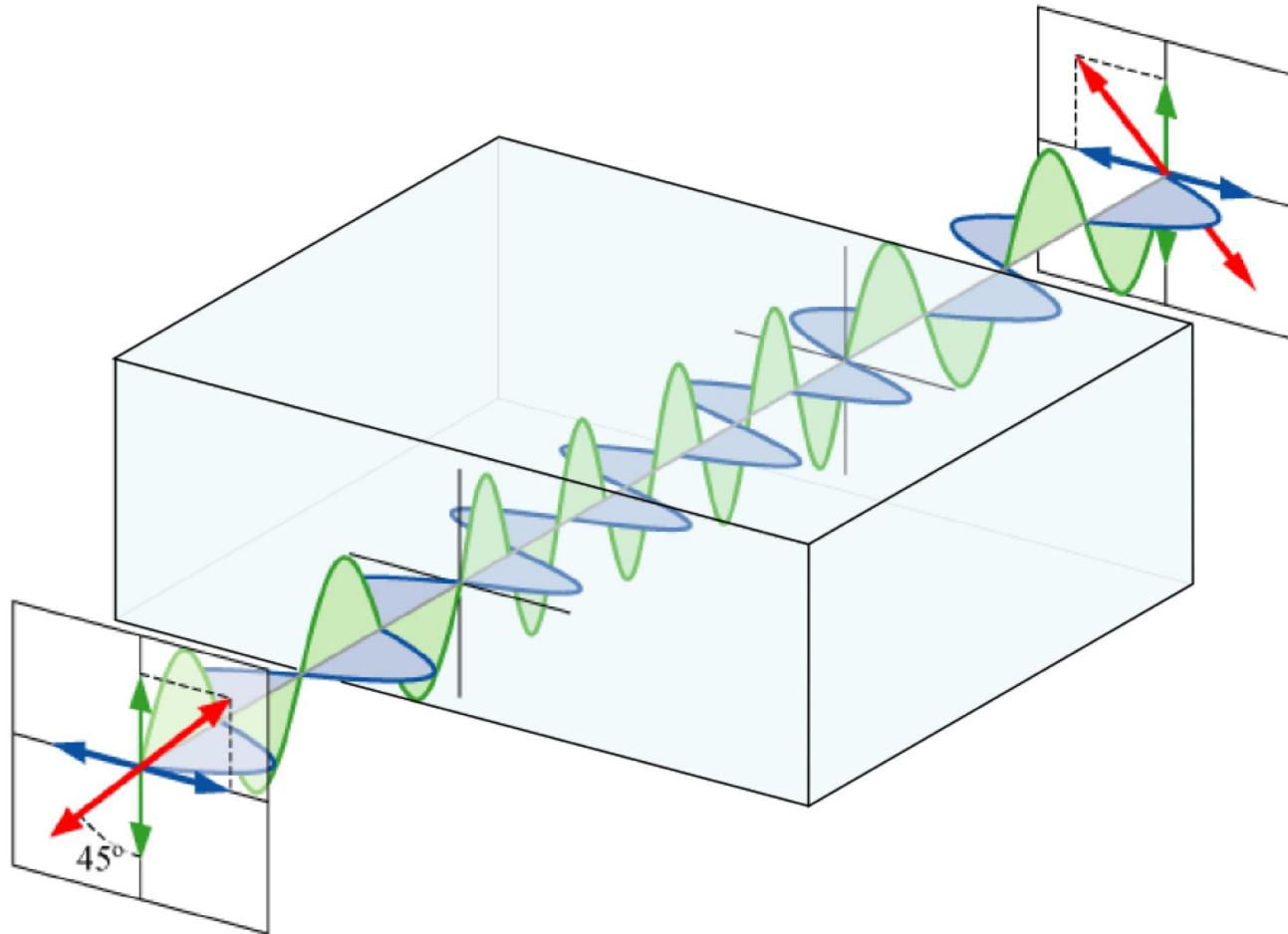
- $U = I P \sin(2\theta)$



Optical Path



Half-wave Plate



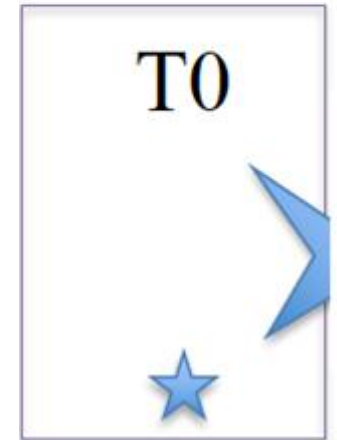
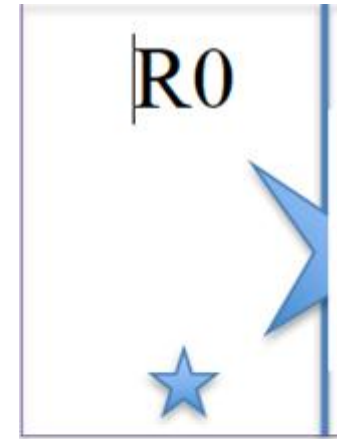
Measuring Q & U with HAWC+

- Stokes Q :

$$Q = \frac{1}{2} [(R - T)_0 - (R - T)_{45}]$$

- Stokes U :

$$U = \frac{1}{2} [(R - T)_{22.5} - (R - T)_{67.5}]$$



Polarization Basics

- Polarization fraction P :

$$P = 100 \sqrt{\left(\frac{Q}{I}\right)^2 + \left(\frac{U}{I}\right)^2}$$

- Uncertainty σ_P :

$$\sigma_P = \frac{1}{I} \sqrt{\sigma_{Q,U}^2 + \sigma_I^2 P^2}$$

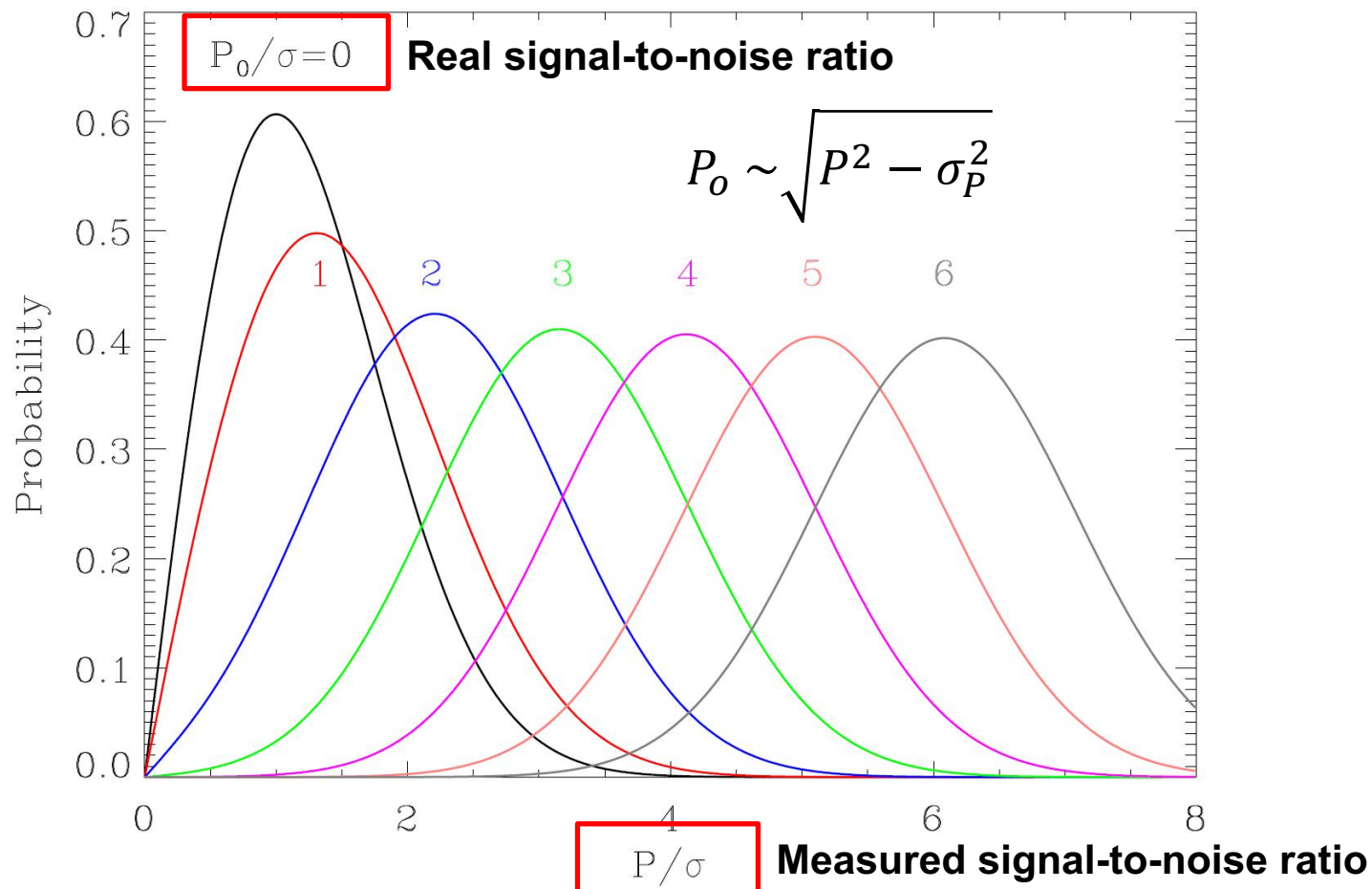
- Polarization angle θ :

$$\theta = \frac{90}{\pi} \tan^{-1} \left(\frac{U}{Q} \right)$$

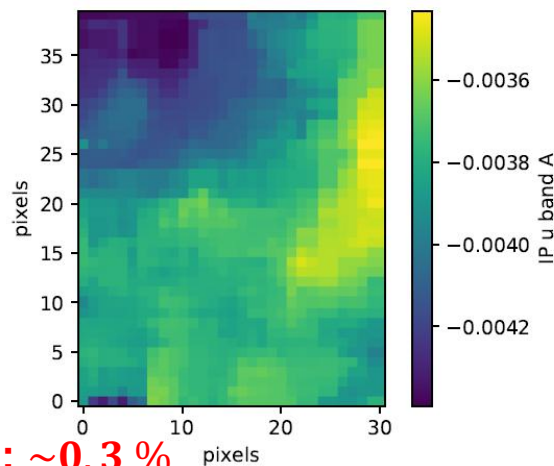
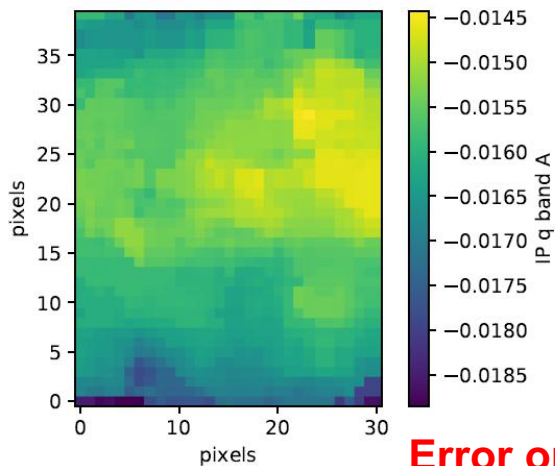
- Uncertainty σ_θ :

$$\sigma_\theta = \frac{180^\circ}{\pi} \frac{\sigma_P}{2P}$$

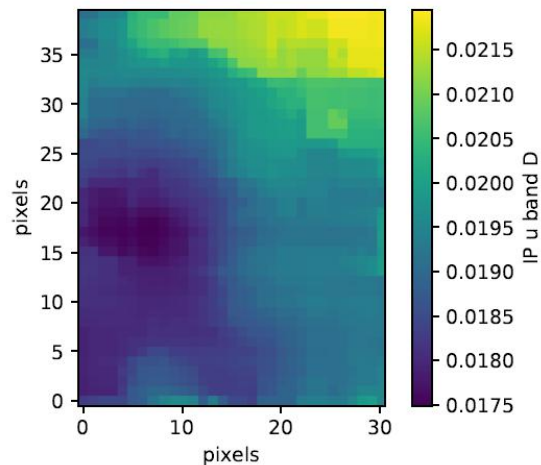
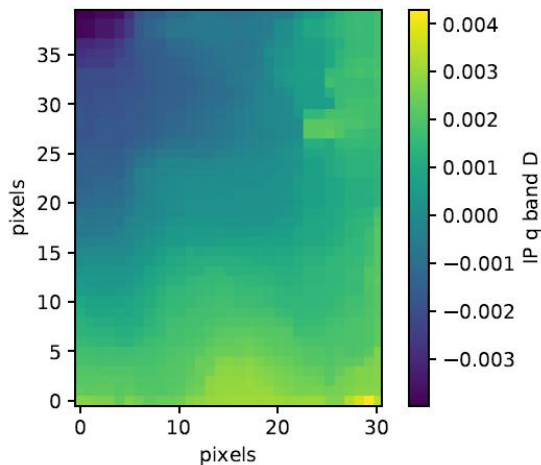




Instrumental Polarization



Error on IP: ~0.3 %



Data Products

Ext #	Ext Name	Type	Units	Description
0	STOKES I	img	Jy/pix	Stokes I (total intensity)
1	ERROR I	img	Jy/pix	Error in I
2	STOKES Q	img	Jy/pix	Stokes Q
3	ERROR Q	img	Jy/pix	Error in Q
4	STOKES U	img	Jy/pix	Stokes U
5	ERROR U	img	Jy/pix	Error in U
6	IMAGE MASK	img	...	Weighted # of input pixels combined into output pixels
7	PERCENT POL	img	%	Polarization percent $p = 100\sqrt{(Q/I)^2 + (U/I)^2}$
8	DEBIASED PERCENT POL	img	%	Debiased polarization percent $p' = \sqrt{p^2 - \sigma_p^2}$
9	ERROR PERCENT POL	img	%	Error in p'
10	POL ANGLE	img	deg	Polarization angle (θ) in sky coordinates
11	ROTATED POL ANGLE	img	deg	Polarization angle (θ_{90}) rotated by 90°
12	ERROR POL ANGLE	img	deg	Error in θ
13	POL FLUX	img	Jy/pix	Polarized intensity $I_p = I \times p/100$
14	ERROR POL FLUX	img	Jy/pix	Error in I_p
15	DEBIASED POL FLUX	img	Jy/pix	Debiased polarized intensity $I_{p'} = I \times p'/100$
16	MERGED DATA	tab	...	Detector info from all merged images in cube
17	POL DATA*	tab	...	Polarization data for each pixel
18	FINAL POL DATA†	tab	...	Subset of POL DATA with quality cuts



Polarimetry

1. Chop-nod:

Nod parallel to chop, symmetric only

Chop-throw <8 arcmin, Chop-freq. 5-20 Hz

2. Half-WavePlate (HWP) rotation:

4 HWP positions: 0° , 45° , 22.5° , and 67.5°

Chop-nod at each HWP angle

3. Dithering:

4 dither positions within the FOV

Repeat chop-nod and HWP rotation at each dither position

4. Mosaics:

Steps 1 to 3 are repeated for a new sky position



Symmetric Chop/Nod

Nod Match Chop:

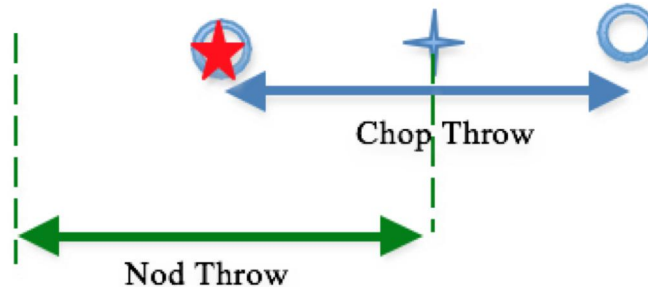
Nod A:

Chop position 1 Boresight position 2

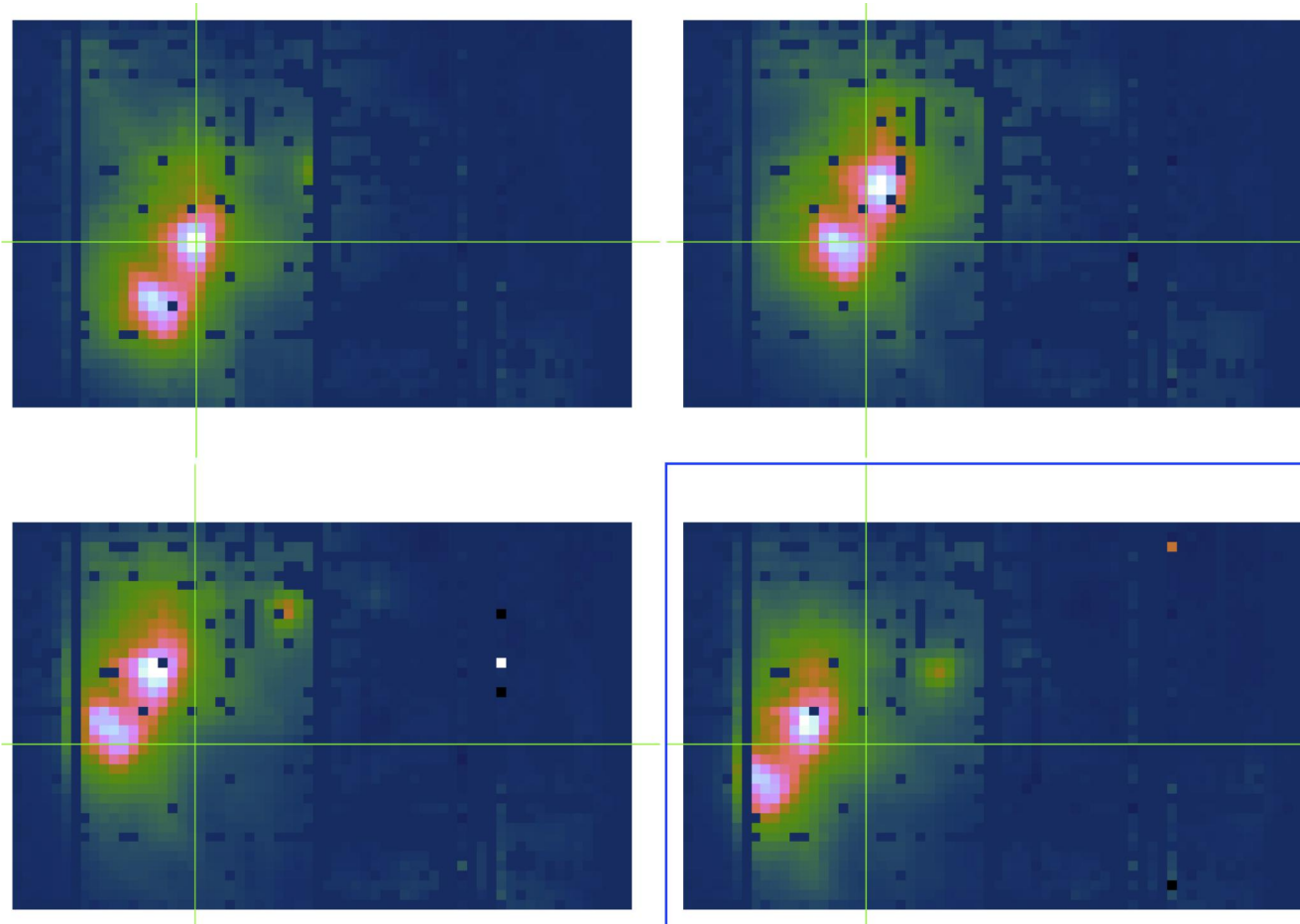


Nod B:

Chop Position 1 Boresight Position 2

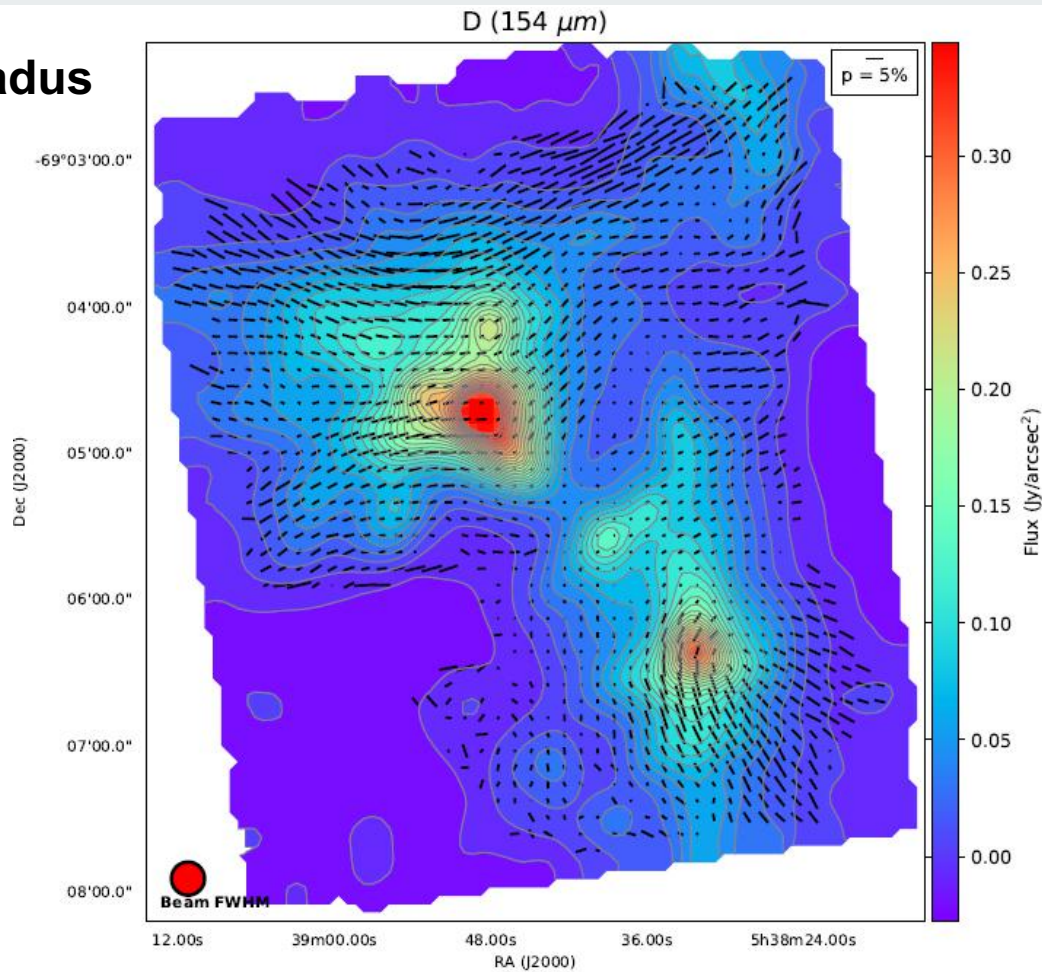


Polarimetry Dithering



Resulting Polarization Maps

30 Doradus



Conclusion



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