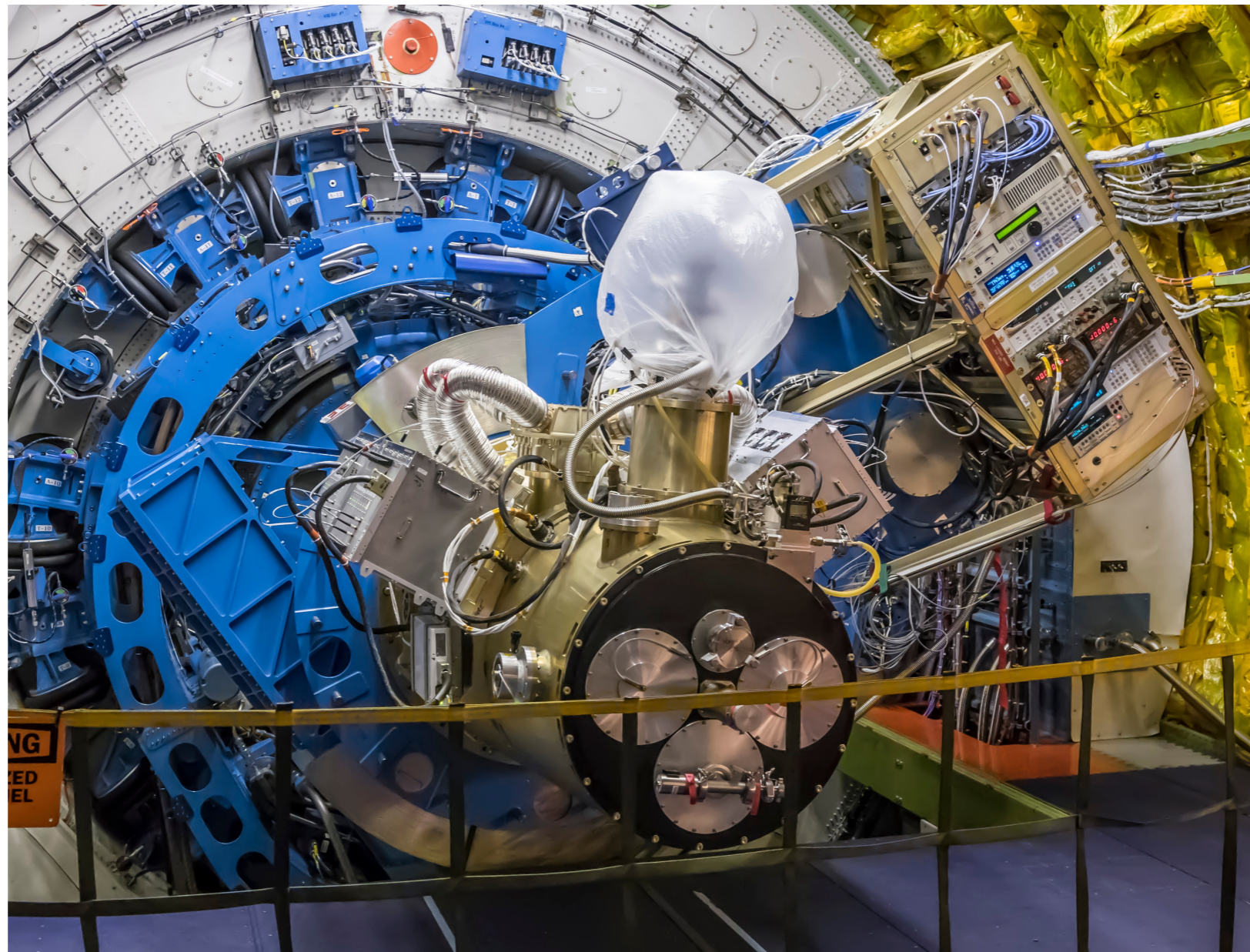
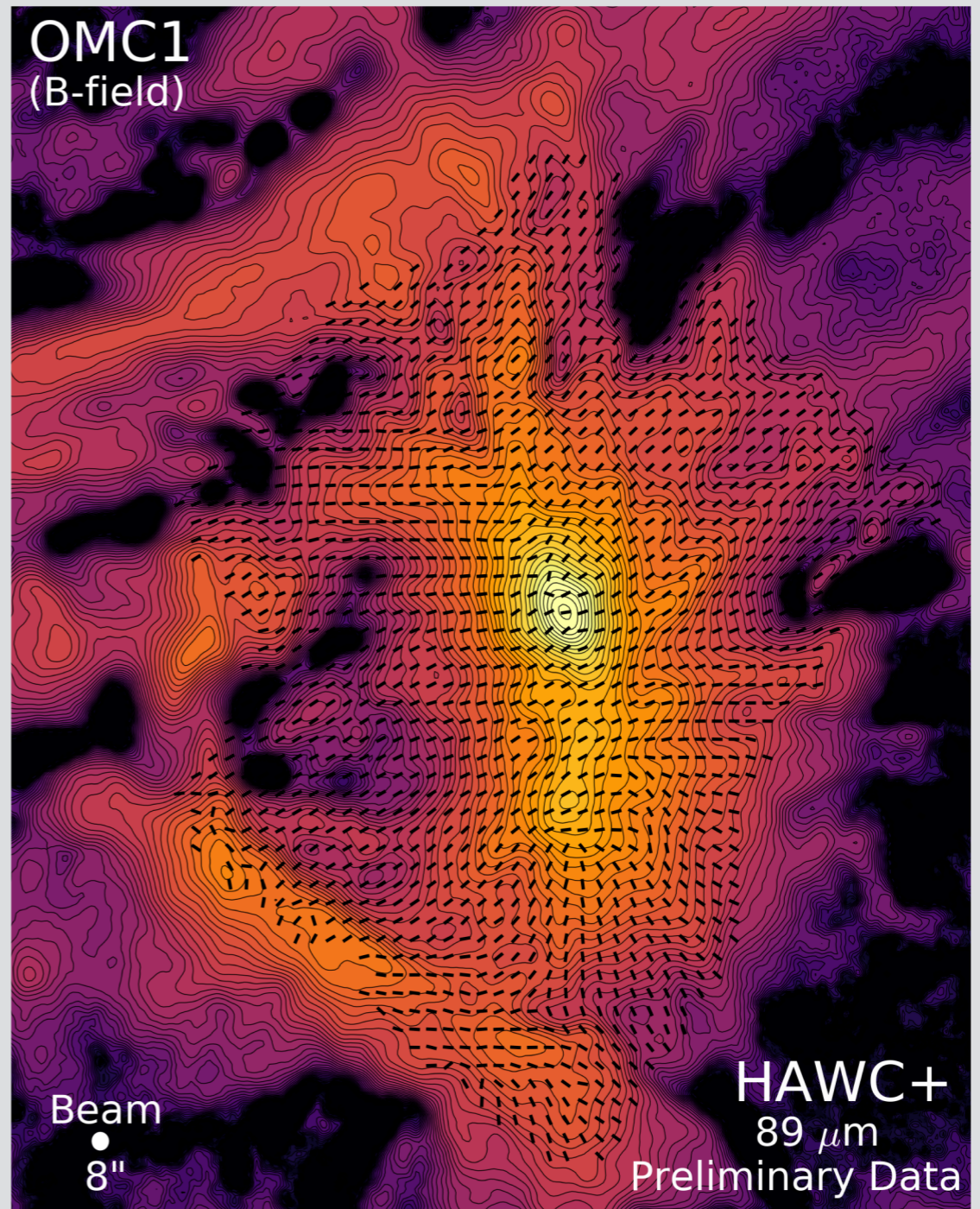
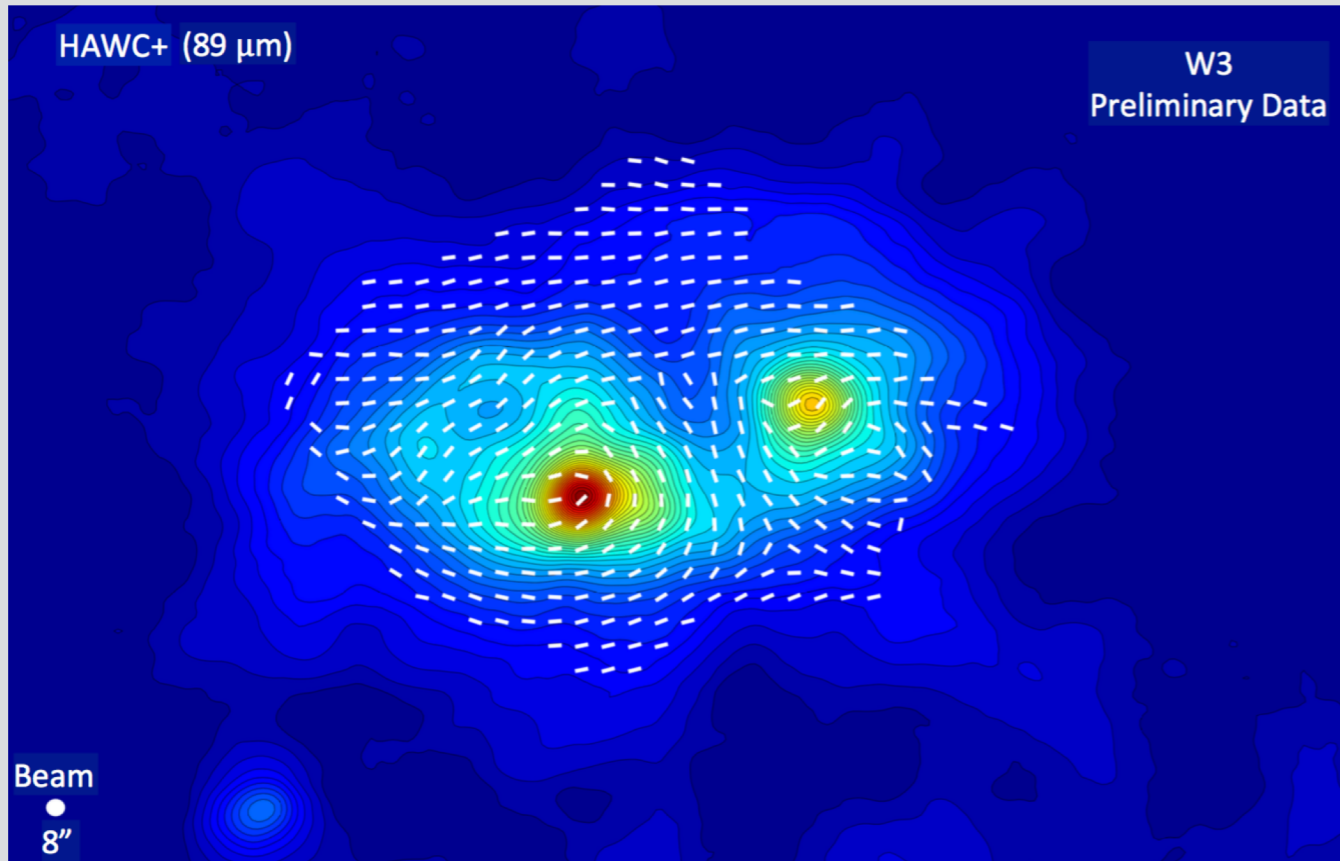


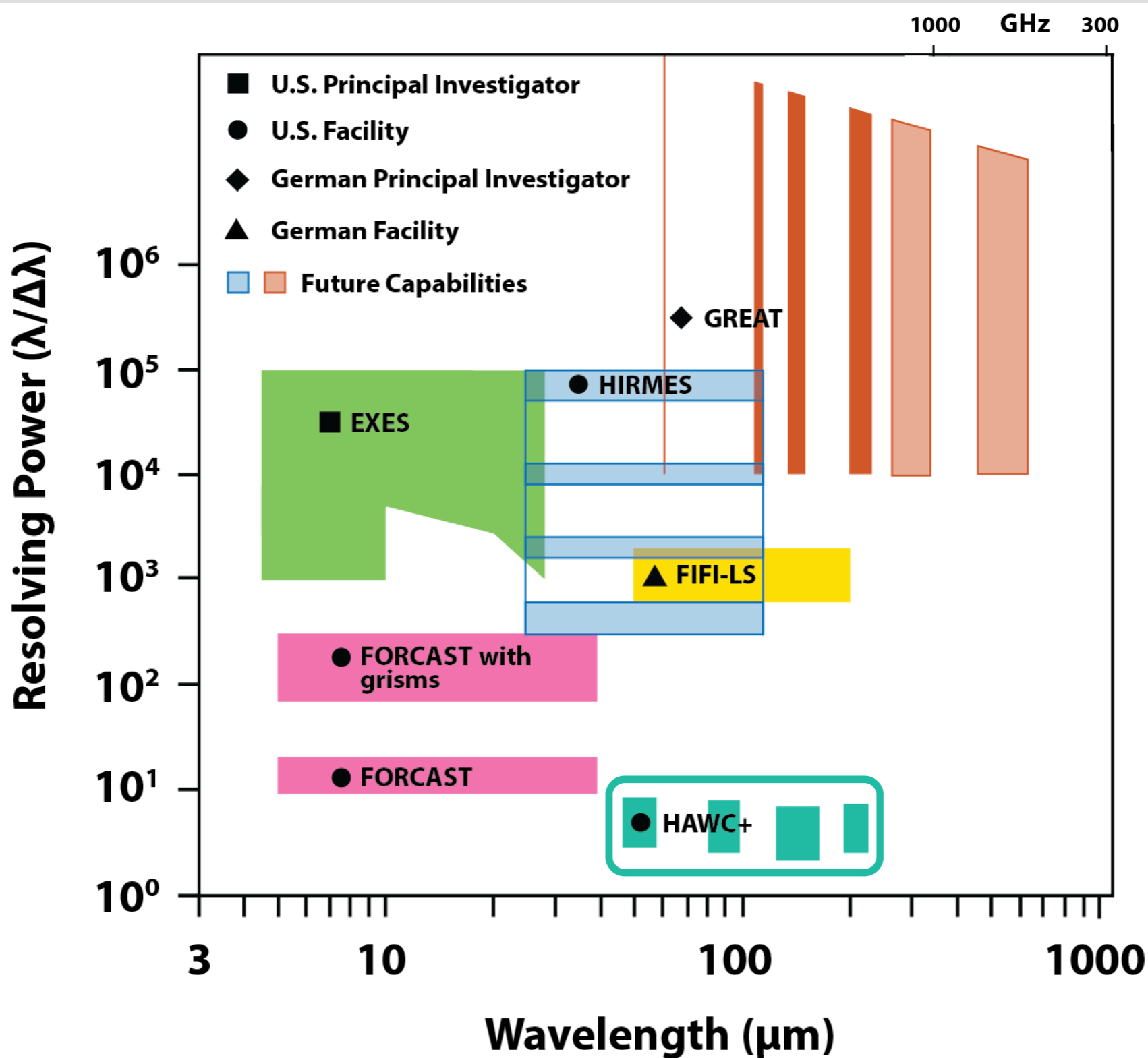
# SOFIA Instruments: HAWC+



# Imaging and Polarimetry HAWC+



# HAWC+

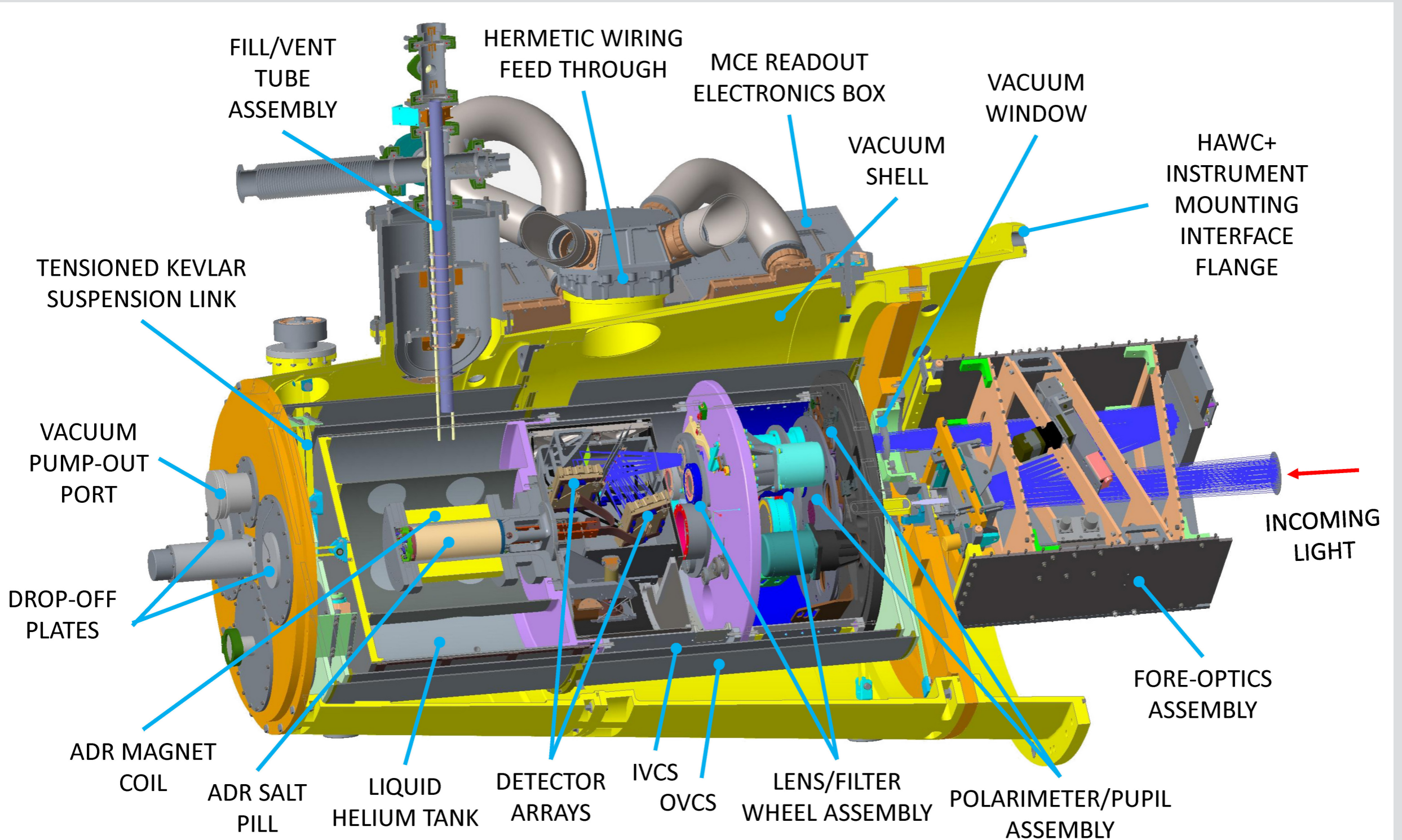


# HAWC+ Specifications

- PI: C. Darren Dowell (JPL)
- Imaging and Polarimetric capabilities

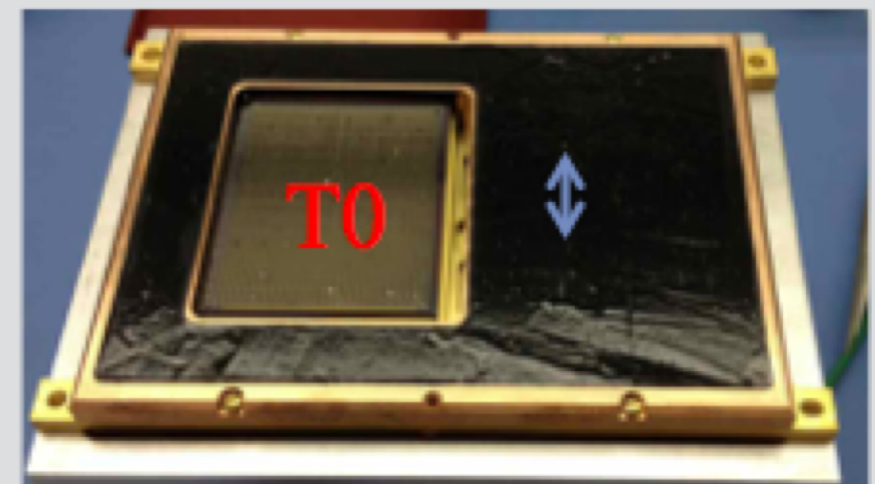
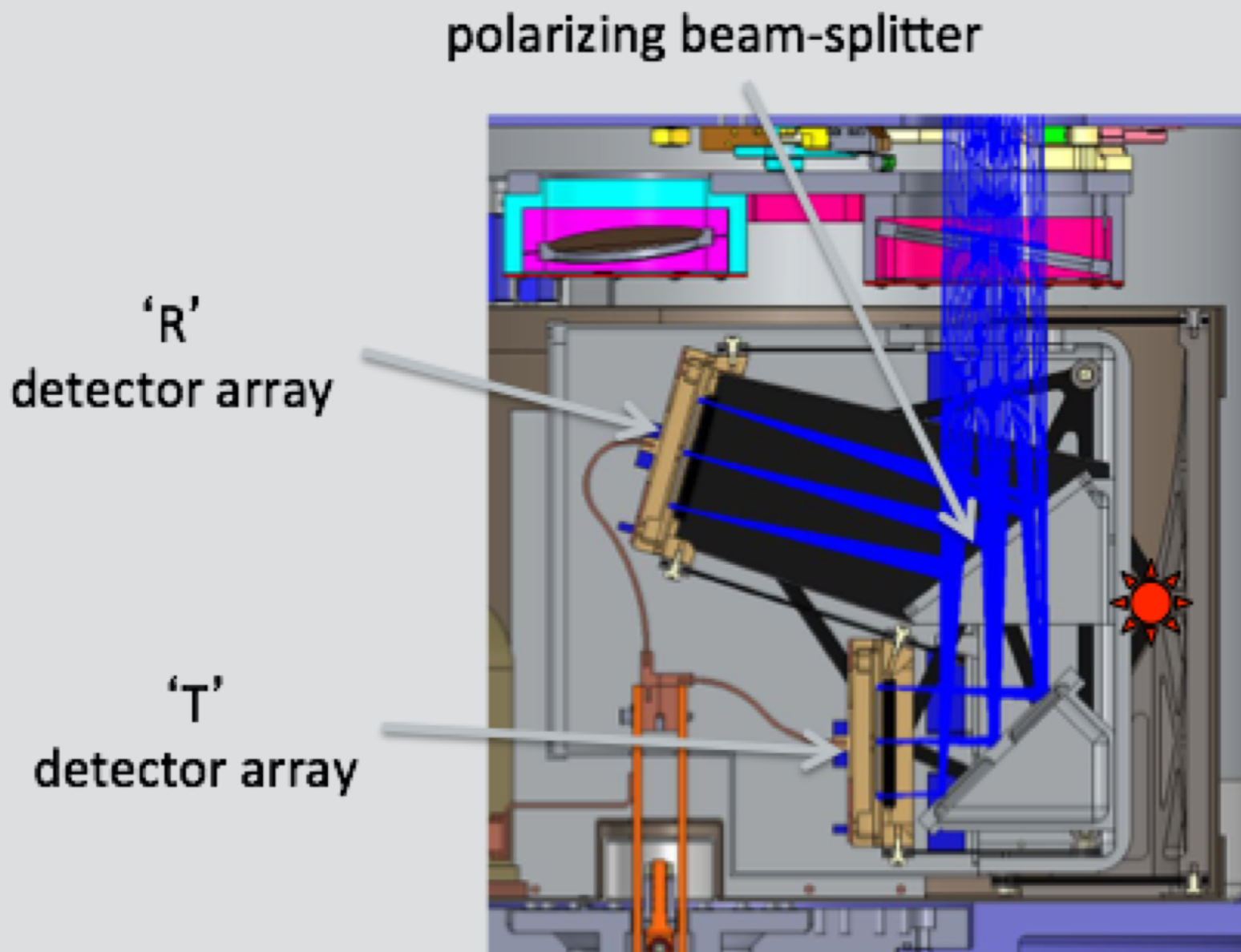
Band / Wavelength	$\Delta\lambda/\lambda$	Angular Resolution	Total Intensity FOV (arcmin)	Polarization FOV (arcmin)
A / 53 $\mu\text{m}$	0.17	4.7" FWHM	2.7 x 1.7	1.3 x 1.7
B <sup>a</sup> / 63 $\mu\text{m}$	0.15	5.8" FWHM	4.2 x 2.6	2.1 x 2.6
C / 89 $\mu\text{m}$	0.19	7.8" FWHM	4.2 x 2.6	2.1 x 2.6
D /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

# HAWC+ Specifications



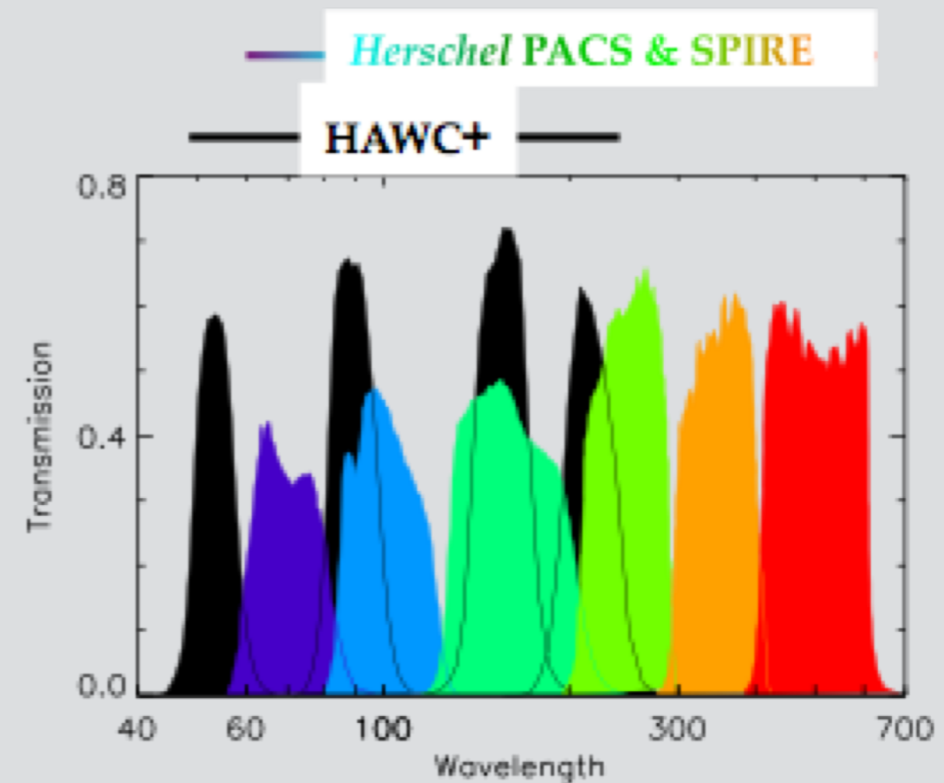
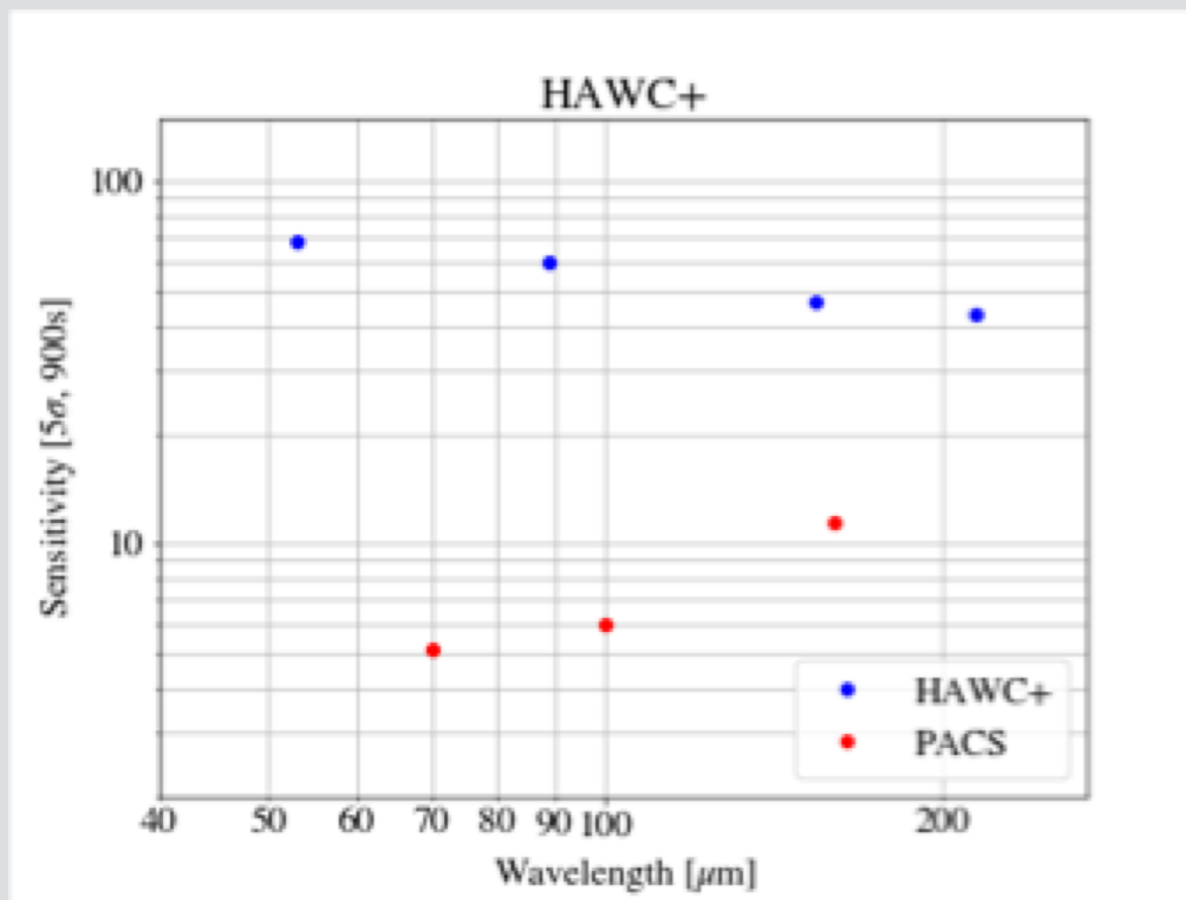
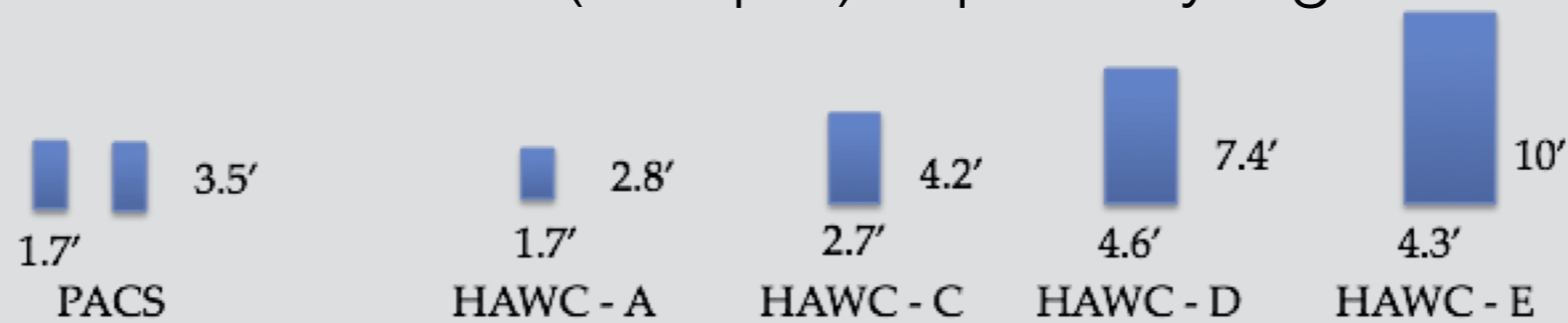
# HAWC+ Field Of View

- 3 detectors are available: R0, R1 and T0
- Imaging and Polarimetric capabilities



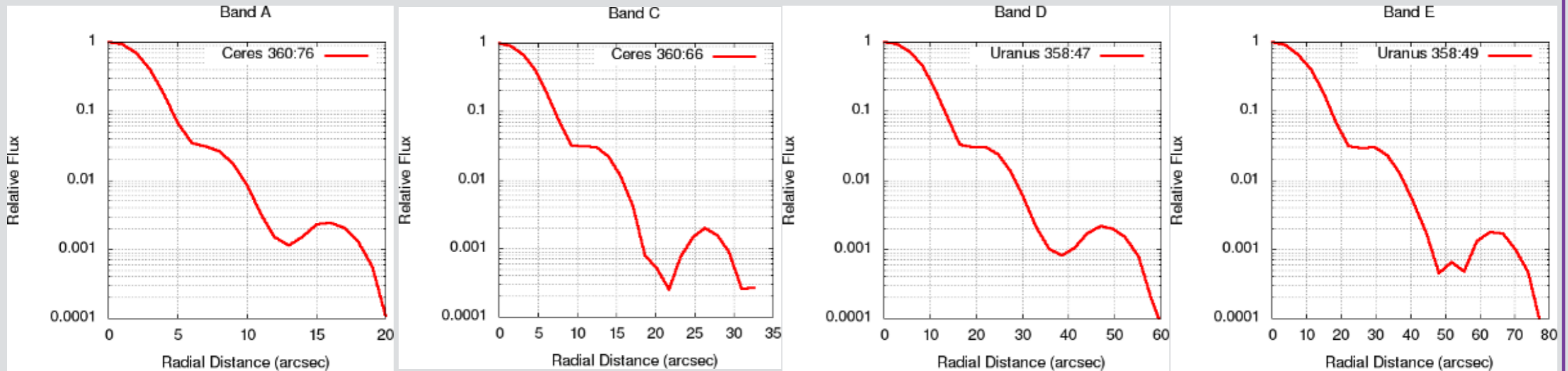
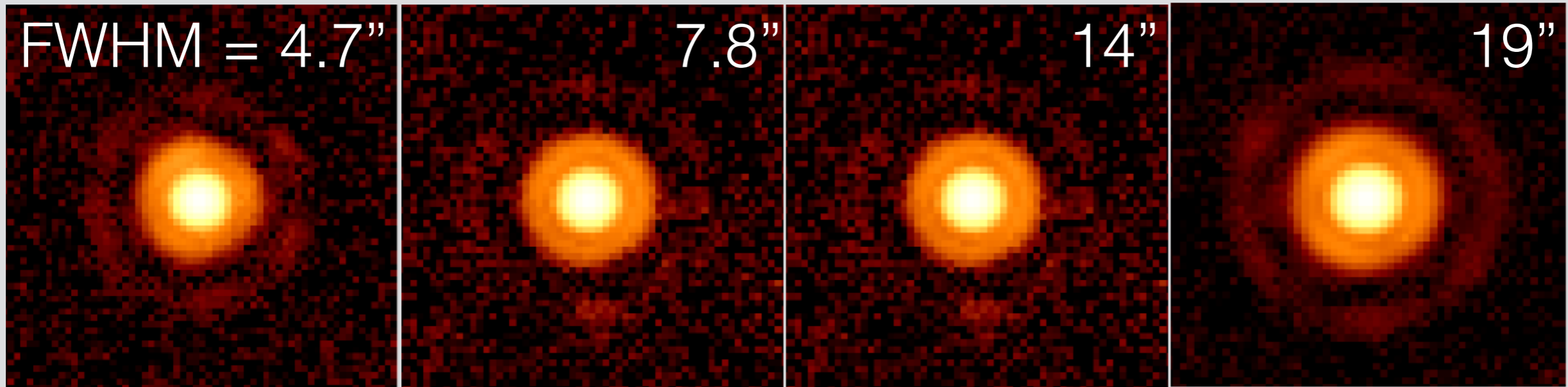
# HAWC+ Sensitivities

- HAWC+ total power is less sensitive than PACS, considering that HAWC+ bands are narrower than HERSCHEL's.
- However, the HAWC+ FOV is wider than PACS at long wavelengths. Note that the FOV of Band E (214  $\mu\text{m}$ ) is partially vignettted.



# HAWC+ PSF

SOFIA is diffraction limited at all HAWC+ wavelengths.

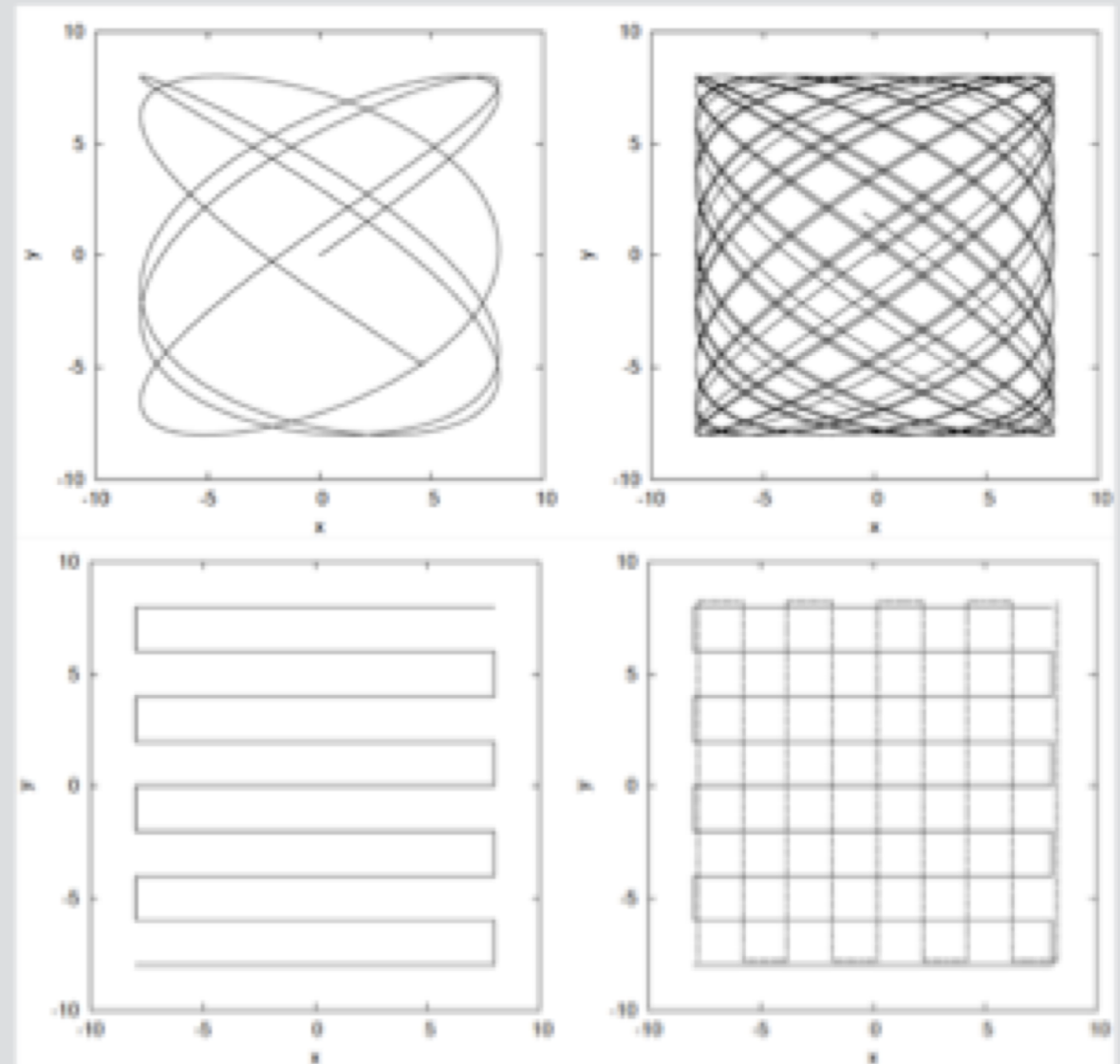




# HAWC+ Lissajous & Rasters

- Chop-nod is only available with the polarimetric mode.
- Total Intensity scan mapping is used with two available patterns:

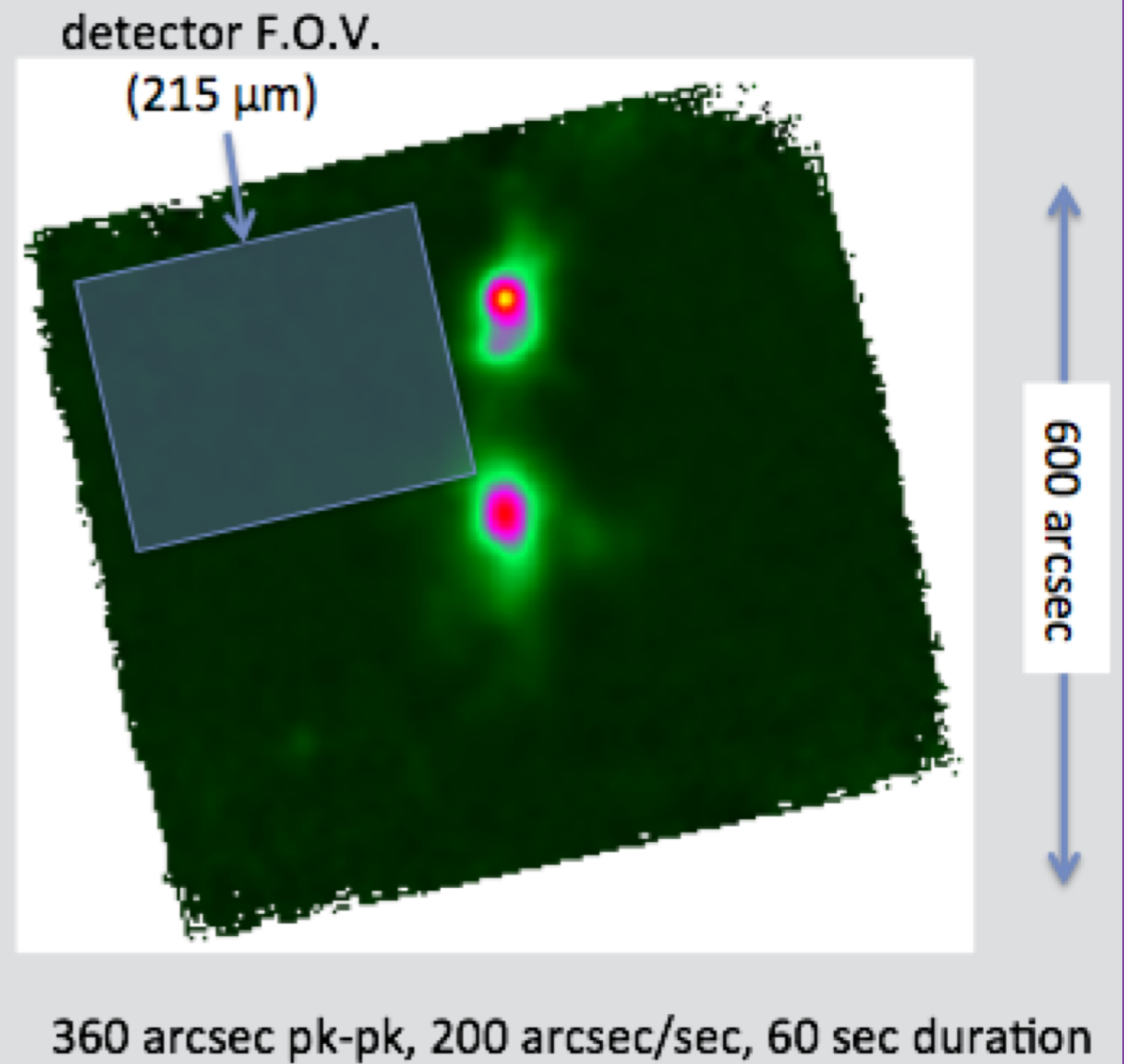
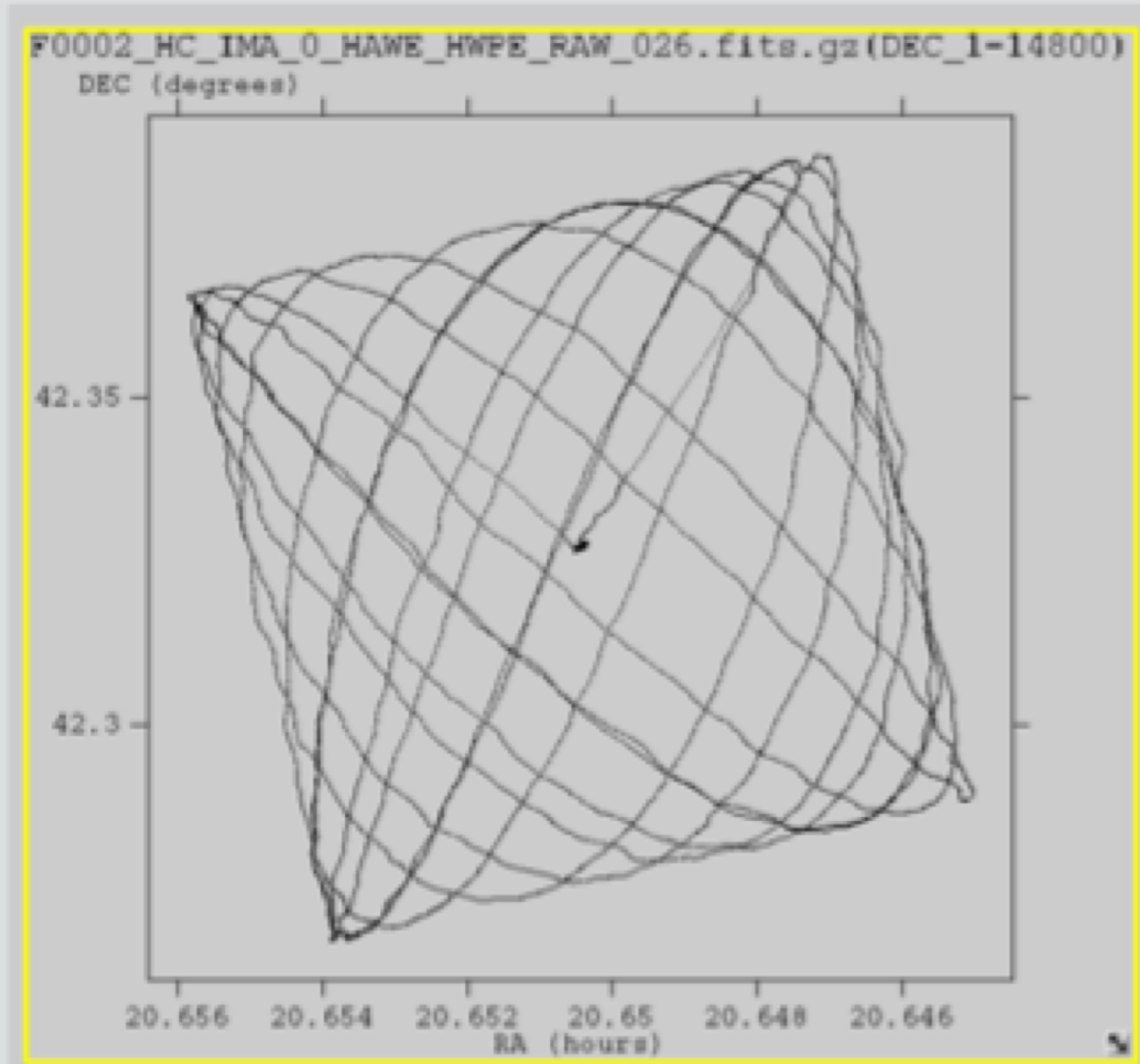
- Lissajous for small fields. Use this mode for fields comparable to the FOV of HAWC+



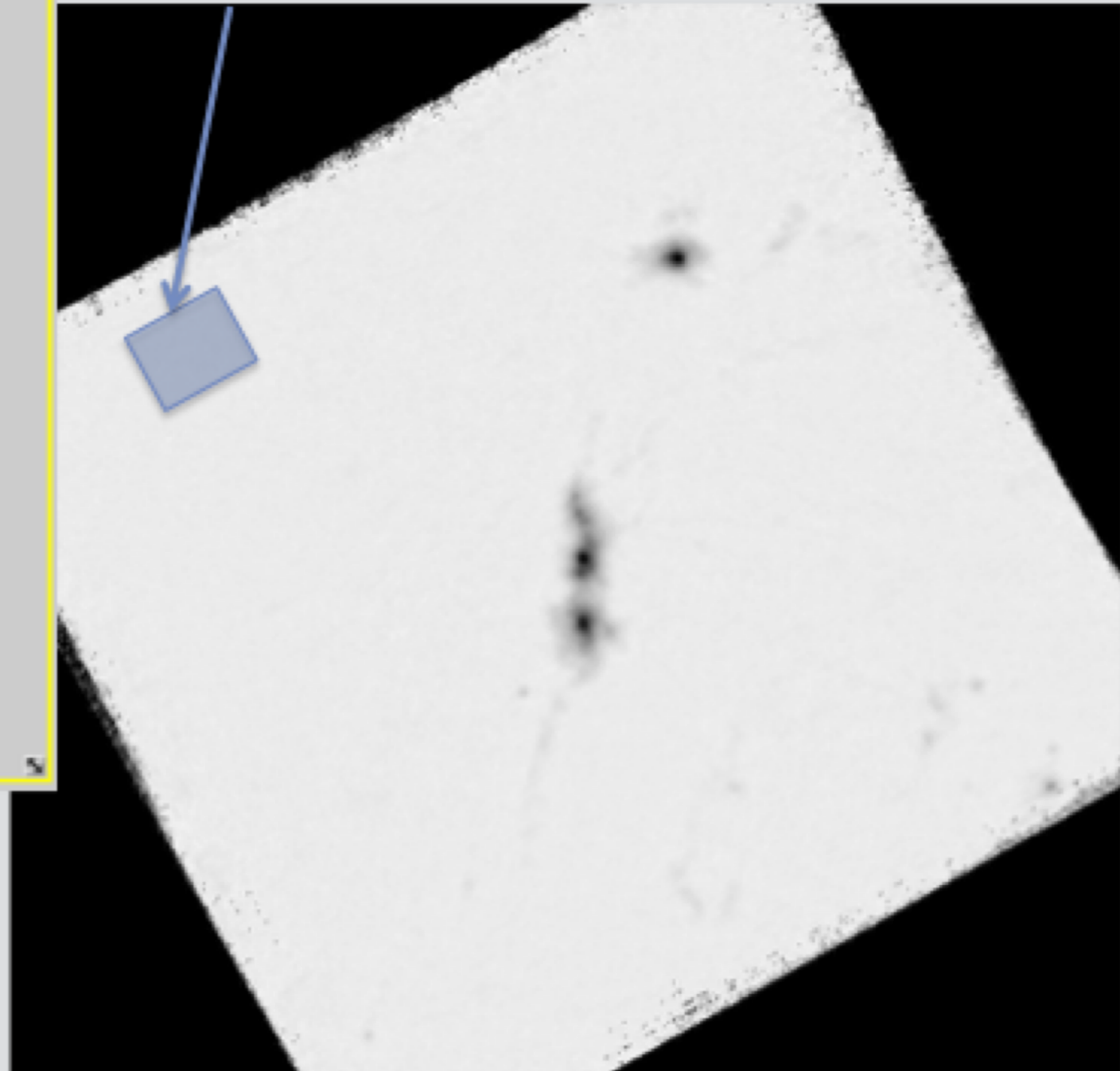
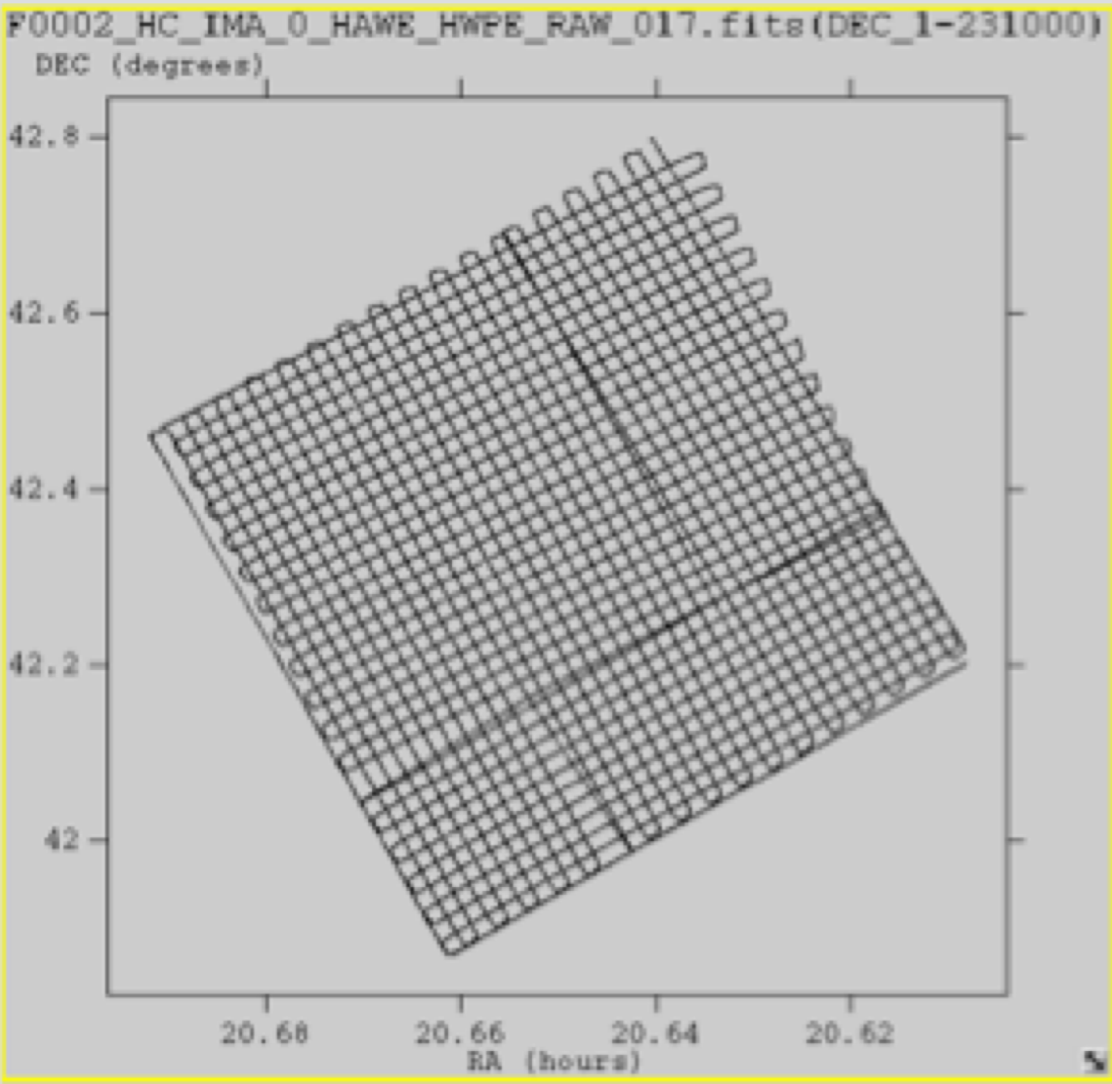
- Rasters to map large fields.

- In both cases, two scans are required to avoid striping.
- To obtain an absolute flux calibration, part of the map should include regions with no extended flux.

# HAWC+ Lissajous



# HAWC+ Raster



200 arcsec/sec, 19 min. duration  
5 pauses to cross-check gyros vs.  
star tracking

3000 arcsec



2018  
Community Days  
Workshops



# HAWC+ Total intensity

Band name	Band center (microns)	FWHM Bandwidth (microns)	Pixel Size (arcsec)	Beam Size (arcsec FWHM)	Polarimetry Field of View* (arcmin)	Photometry Field of View* (arcmin)	Instantaneous Point-Source Sensitivity** (Jy s <sup>0.5</sup> )
A	53	8.7	2.55	4.85	1.4 x 1.7	2.8 x 1.7	1.9
B	62	8.9	4.02	***	2.1 x 2.7	4.2 x 2.7	***
C	89	17	4.02	7.8	2.1 x 2.7	4.2 x 2.7	2.3
D	154	34	6.90	13.6	3.7 x 4.6	7.4 x 4.6	2.0
E	214	44	9.37	18.2	4.2 x 6.2	8.4 x 6.2	1.7

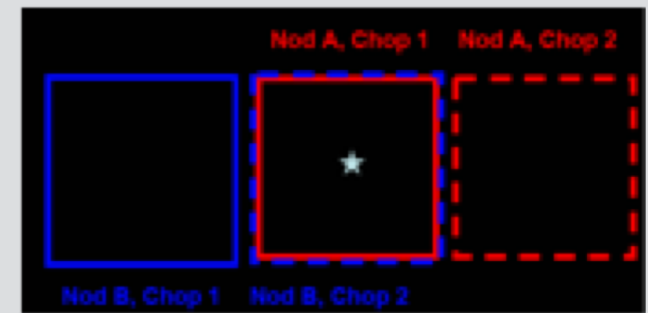


# HAWC+ Polarimetry



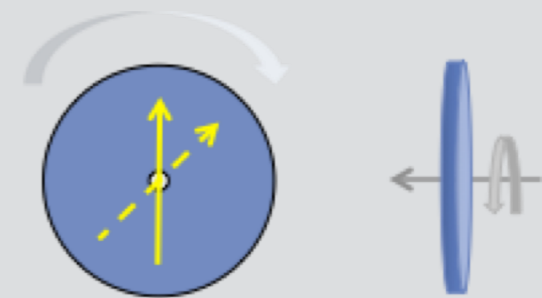
## 1) Chop-nod:

- Nod parallel to chop, symmetric only
- Chop-throw < 8 arcmin, Chop-freq. 5-20 Hz



## 2) Half-WavePlate (HWP) rotation:

- 4 HWP positions:  $0^\circ$ ,  $45^\circ$ ,  $22.5^\circ$  and  $67.5^\circ$
- Chop-nod at each HWP angle

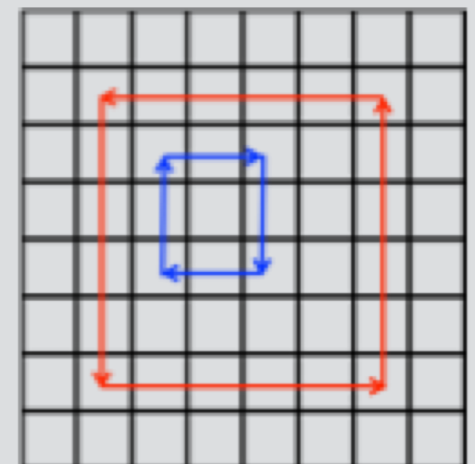


## 3) Dithering:

- 4 dither positions within the FOV
- Repeat chop-nod and HWP rotation at each dither position

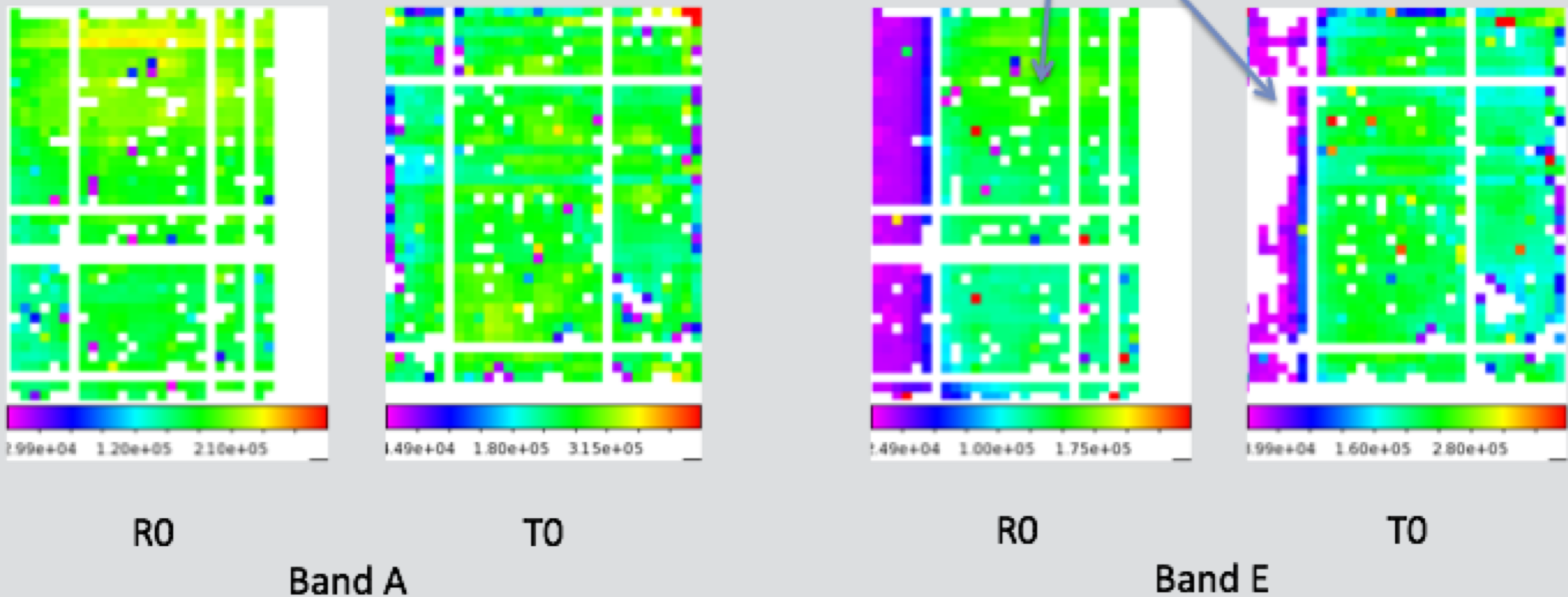
## 4) Mosaics:

- Steps 1 to 3 are repeated for a new sky position



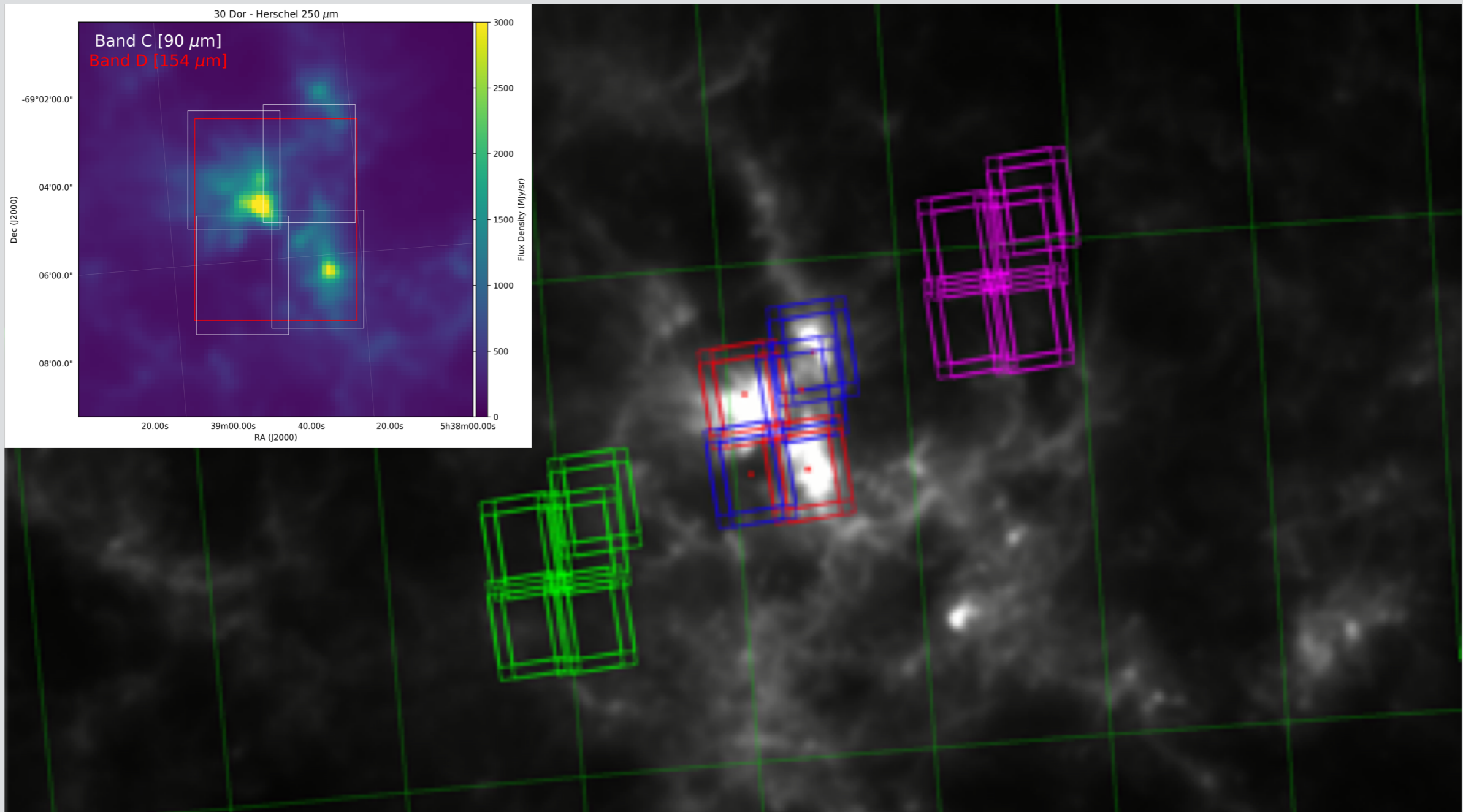
# HAWC+ Dithering

- Bad and missing pixels in the detector of HAWC+ require dithering to have images without holes.
- Band E (214  $\mu\text{m}$ ): Vertical vignetting on the left and right of the array. Usable FOV  $\sim 2' \times 6'$ .



# HAWC+ Chop-Nod

- Mosaic and Chop-nod polarimetric observations of 30 Dor
- These observations will be publicly available.
- 8h total time of observation.
- No proprietary time on 30 Dor polarimetric data!



# HAWC+ Polarimetry

- Polarization efficiency

Band	Quartz Half-Wave Plate Thickness (mm)	Measured System Polarization Efficiency* (%)
A 53 $\mu\text{m}$ (B 62 $\mu\text{m}$ )	0.55 (0.55)	84
C 89 $\mu\text{m}$	0.89	94
D 154 $\mu\text{m}$	1.55	98
E 214 $\mu\text{m}$	2.16	98

- Instrumental polarization (IP)

Band	q (%) May 2017	u (%) May 2017	q (%) Oct-Nov 2017	u (%) Oct-Nov 2017
A	-1.55 +/- 0.05	-0.35 +/- 0.02	-1.60 +/- 0.07	-0.38 +/- 0.02
C	-1.67 +/- 0.09	0.87 +/- 0.06	-1.64 +/- 0.08	0.82 +/- 0.07
D	0.27 +/- 0.12	1.98 +/- 0.09	0.14 +/- 0.14	1.89 +/- 0.11
E	-1.00 +/- 0.18	-1.51 +/- 0.09	-1.09 +/- 0.16	-1.41 +/- 0.11

The IP is corrected by the pipeline.  
Systematic errors in IP  $\sim 0.3\%$ .



# HAWC+ Polarimetry

- Sensitivities

Band name	Band center (microns)	MDCF (Jy), 4 $\sigma$ in 900 sec	Mapping Speed (arcmin <sup>2</sup> hr <sup>-1</sup> (MJy sr <sup>-1</sup> ) <sup>-2</sup> )	MDCPF (% Jy), 4 $\sigma$ in 900 sec	MIfP (MJy/sr), $\sigma(P) = 0.3\%$ in 1 hr for beam area
A	53	0.25	0.0027	40	28,000
C	89	0.30	0.029	20	6000
D	154	0.26	1.1	21	2000
E	214	0.23	7	24	1300

The MDCPF for Band A of 40 % Jy (Table 3) indicates that the polarization of a 40 Jy, 1 % polarized point source could be detected with 4 $\sigma$  significance in 900 sec

# Preparing HAWC+ observations

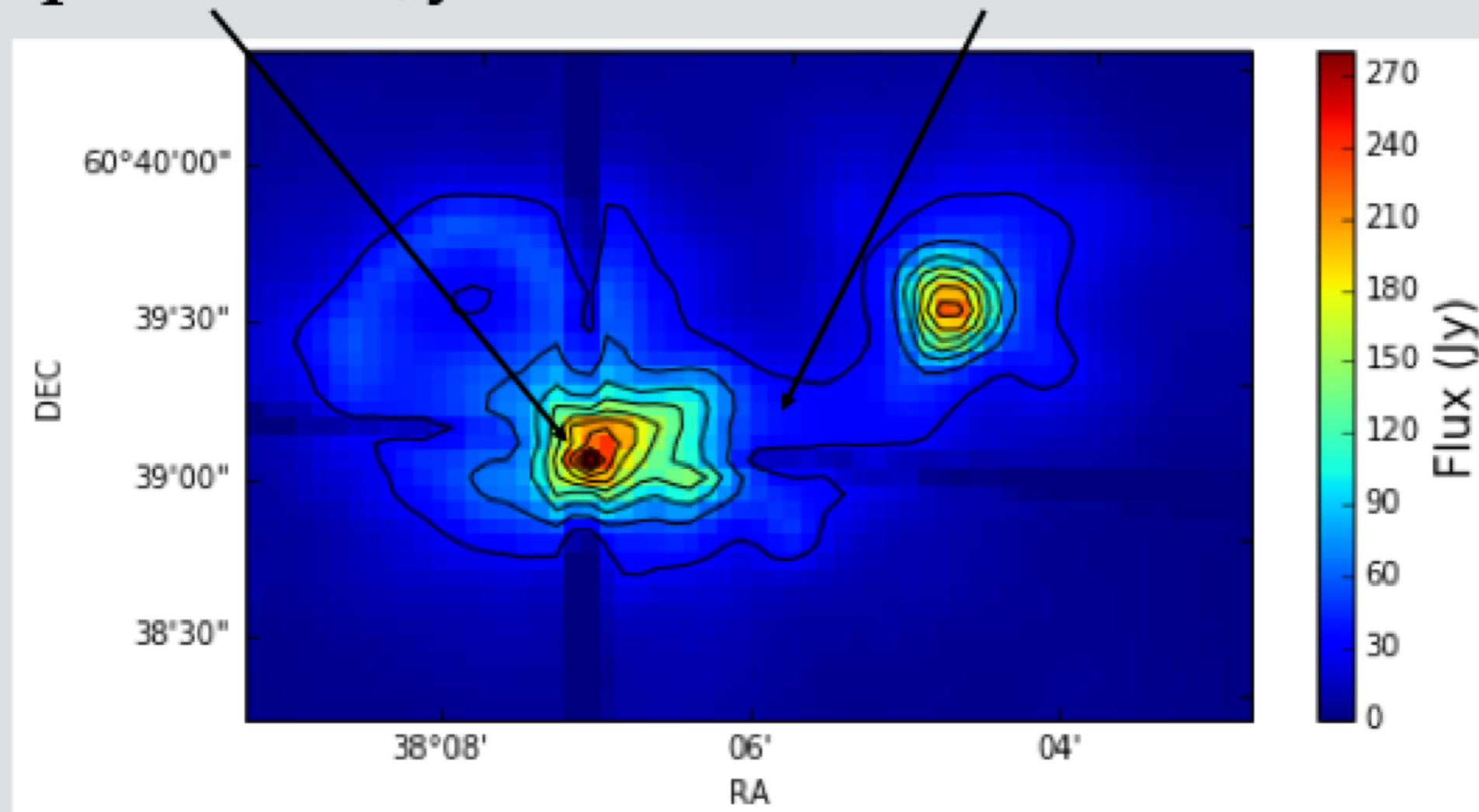
- Key instruments/observation parameters:
  - 1) Expected Total flux at desired wavelength
    - [use Herschel or SED modeling]
  - 2) Expected degree of polarization at desired wavelength
    - [use SED modeling or polarization models]
  - 3) Expected polarization accuracy.
    - It depends on your scientific goals
  - 4) Go to ETC and estimate the observing time given your requirements.



# Preparing HAWC+ observations: Example

Peak pixel: 305 Jy

Faint region: ~30 Jy



W3 was observed during HAWC+ science verification. Using a 70  $\mu\text{m}$  Herschel observation, the faint region has a flux density of  $\sim 30$  Jy. in a 4" pixel, this corresponds to  $1.87 \text{ Jy/arcsec}^2$

# Preparing HAWC+ observations: Polarimetry

## - Assumptions

### 1) Expected Total flux at desired wavelength:

- $1.87 \text{ Jy/arcsec}^2$

### 2) Expected degree of polarization at desired wavelength

- $P = 1 \%$

### 3) Expected polarization accuracy.

- Polarization accuracy of 0.2%, then  $S/N = 1\%/0.2\% = 5$



# Preparing HAWC+ observations: ETC inputs



Instrument

Instrument properties: [\(more info\)](#)

Filter: [more info](#)

Band C and HWP C

## Calculation Method

Calculation method: [\(more info\)](#)

Select the calculation method

- S/N ratio resulting from a Total Integration Time of  secs
- Total Integration Time to achieve a S/N ratio of

P with S/N = 5

## Astronomical Source Definition

Spatial profile and continuum brightness: [\(more info\)](#) Choose point or extended source.

- Point source (nominal spatial profile) with spatially integrated brightness  Jy  
Polarization  Percent
- Extended source having uniform surface brightness  Jy / sq arcsec  
Polarization  Percent

Expected Flux

Emission line: [\(more info\)](#) in addition to the above continuum. The output SNR or observing time will be for the sum of continuum plus line.

Single emission line at wavelength  microns with line flux  W/m<sup>2</sup>/sq arcsec

Expected P

## Observing Condition Constraints

Note: You can read the [explanatory notes](#) for more information on the water vapor overburden.

- Elevation Angle:  20°  40°  60°
- Altitude in 1000's of feet:  35  36  37  38  39  40  41  42  43  44  45
- Zenith Water Vapor Overburden (microns):  26.7  16.9  12.8  11.0  9.6  8.4  7.3  6.3  5.5  4.8  4.2

# Preparing HAWC+ observations: ETC outputs

## *SOFIA Instrument Time Estimator (SITE)*

### **HAWC\_Plus**

#### Outputs

Relative atmospheric transmission	0.99779	
Total Integration Time	8	seconds

#### User Inputs

Filter name	HAW_C+HAW_HWP_C	
Band center	88.700	microns
Band width	17.200	microns
Source type	extended	
Total continuum flux	1.87	Janskys/sq arcsec
Percent Polarization	1.0	
Elevation angle	40.0	degrees
Zenith water vapor	7.3	microns
Aircraft Altitude	41.0	microns
Signal to noise per pixel	5.0	

#### Instrument Parameters

Instrument pixel size ( X direction )	4.000	arcseconds
Instrument pixel size ( Y direction )	4.000	arcseconds

# Preparing HAWC+ observations: Overheads

- ETC provides on-source integration time to achieve a specific S/N.
- Enter on-source integration time in USPOT. Then USPOT will add overheads.

HAWC PLUS Polarization [AOR ID: N/A]

Unique AOR Label:

Target: W 3 Type: SOFIA Fixed Single  
36.767080, 61.874190 Equ J2000 or 2h27m04.0992s, +61d52m27.084s Equ J2000

Observing Condition & Acquisition / Tracking

HAWC\_PLUS

Observation Order:

Total Exposure Time (sec):

AOR Repeats:

Time per full nod pattern (ABBA) (sec):

HWP Angle Sequence:

Initial HWP angle (deg):

Example Rotation Angle (deg):

HWP:

Passband:

Dither Offset

Dither Coordinate System:

Dither Offset X:

Dither Offset Y:

Dither Offset Unit:

Dither Scale (arcsec):

Dither Pattern:

Number	Offset East/Row/Perpen...	Offset North/Column/Pa...
1	12.0	12.0
2	-12.0	12.0
3	-12.0	-12.0
4	12.0	-12.0

Nod & Map

Chop / Nod

Nod/Chop Style:

Nod Throw (arcsec):

Nod Angle Coordinate:

Nod Angle (deg):

Chop Type:

Chop Throw (arcsec):

Chop Angle (deg):

Chop Angle Coordinate Reference:


Chop Angle Coordinate Reference Type Unit:

Chop Frequency:

Chop Sync Source:

Chop on or off chip:

Information



calculateEstimate: **Calculate Duration (seconds):**

$(\text{expTimePerCycle} * \text{repeat}) = (320.0 * 1) = 320.0$

$a=2.0 \ b=300.0 \ \text{overhead} = 1,480.0 \ \text{duration} = 1,800.0$

OMC-1 (E-Field, CRUSH background)

