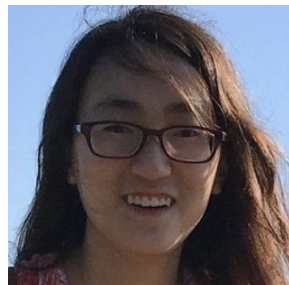# Pipeline for the Systematic Search of Transients Using ACT Data

Yaqiong Li – Cornell University
The Transient and Variable Universe 2023

Content and Collaborators

- Li, Biermann, Naess et al arxiv:2303.04767
- Instrument overview
- Data and maps
- Pipeline
- Results
- Discussion and Future

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Cornell University
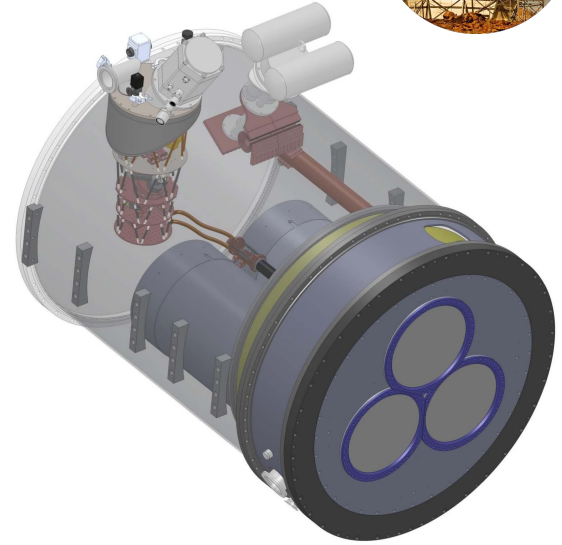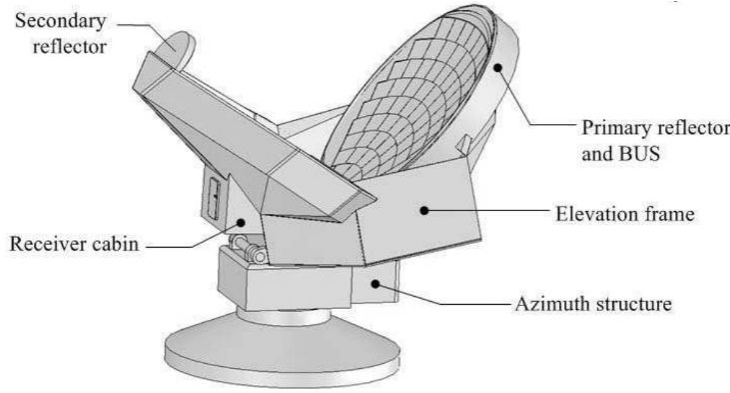
Emily Biermann
University of Pittsburgh

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Time domain science group
- Adam Hincks
- Arthur Kosowsky
- Carlos Hervias-Caimapo
- Yilun Guan

- Jack Orlowski-Scherer
- Cody Duell
- John Hood
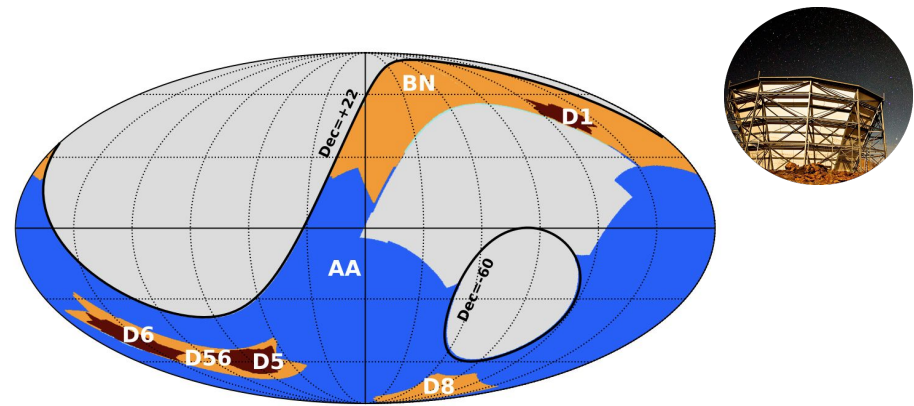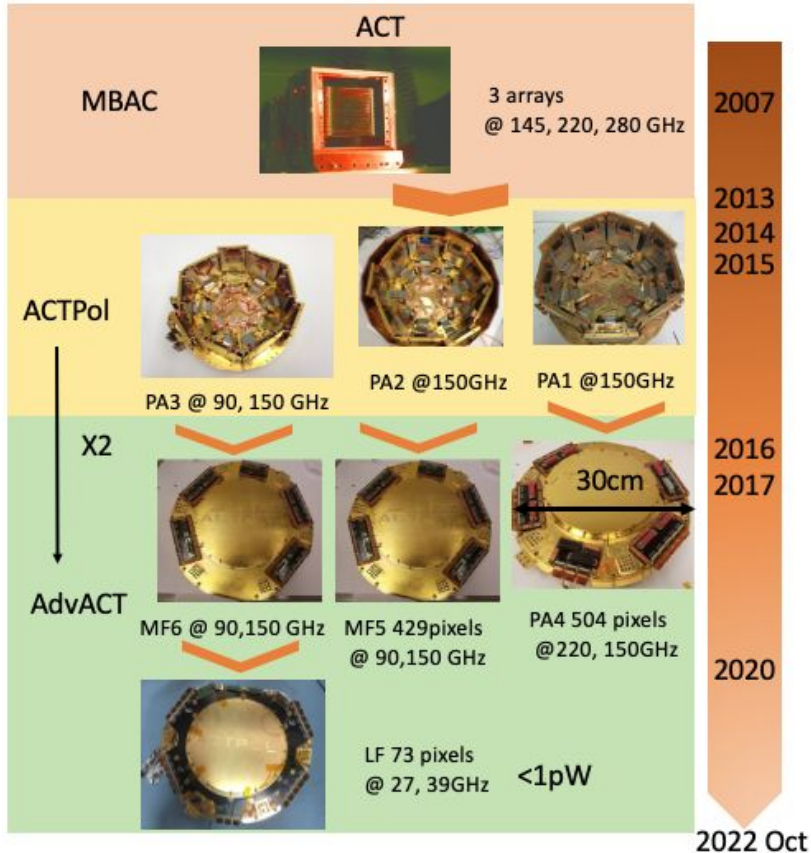- ….

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Atacama Cosmology Telescope–Instrument Overview

- 6m Gregorian telescope in Atacama Desert with altitude of 5200m
- Aim to measure CMB intensity and polarization anisotropies from 30GHz-300GHz
- 1.4 arcmin beam at 150 GHz
- FOV spanning 1.5 deg
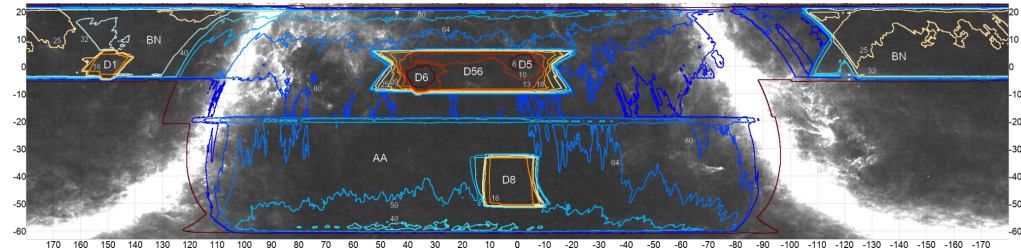- Three optics tubes, each housing a superconducting detector array at 100mK

- Azimuth rotation with Fixed elevation angle during scanning at 1.5 deg/s
- Each stripe takes 40 sec
- It takes 4 min for the sky to drift across one detector array

Detector Arrays and Data

ACT

MBAC	3 arrays @ 145, 220, 280 GHz	2007

ACTPol

PA3 @ 90, 150 GHz

PA2 @150GHz

PA1 @150GHz

2013
2014
2015

X2

30cm

2016
2017

AdvACT

MF6 @ 90,150 GHz

MF5 429pixels @ 90,150 GHz

PA4 504 pixels @220, 150GHz

2020

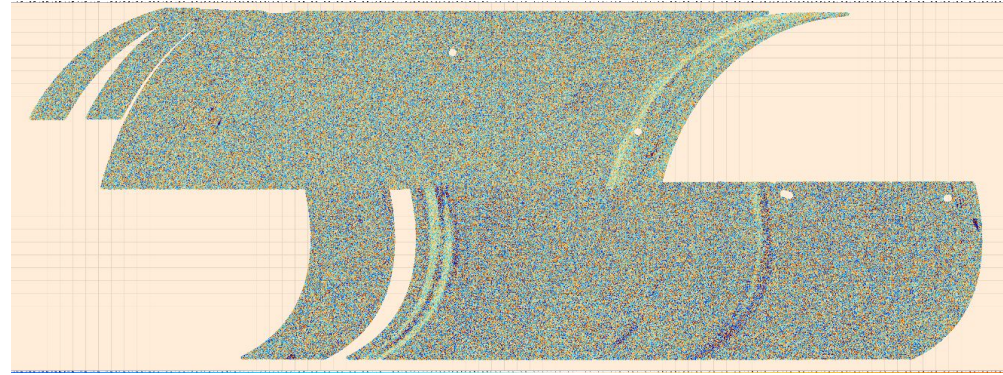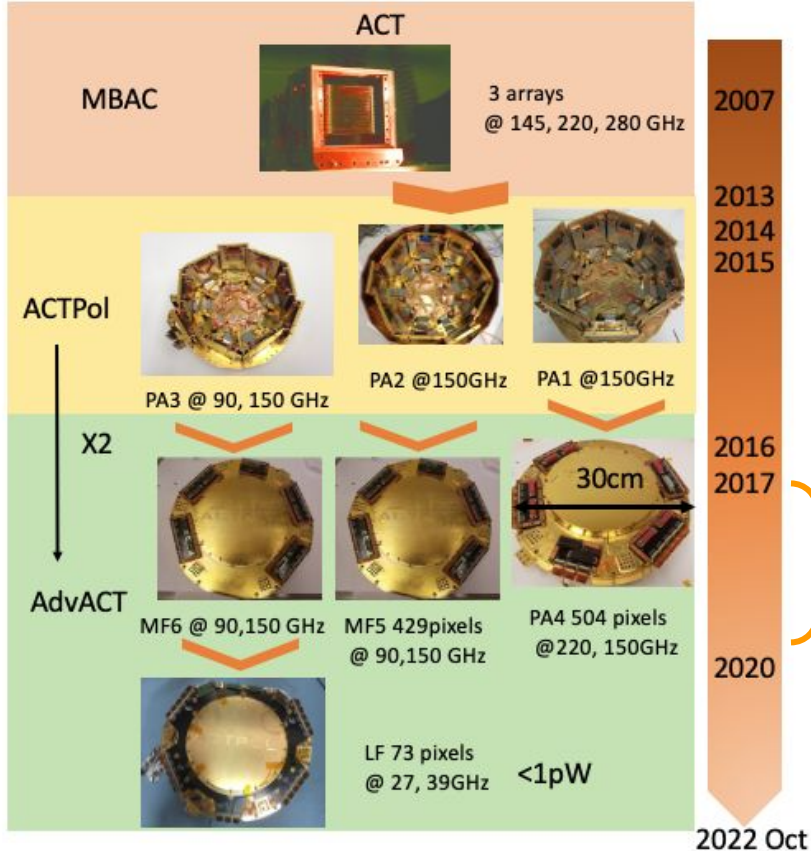LF 73 pixels @ 27, 39GHz   <1pW

2022 Oct

Sky coverage in galactic coordinates

Aiola et al, 2020

- ~18,000 square degree in total, >40% of sky
- ~ weekly scanning cadence

Detector Arrays and Data

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PA4 504 pixels @220, 150GHz

LF 73 pixels @ 27, 39GHz   <1pW

2020

2022 Oct

2017-2019
PA4 f220, PA4 f150
PA5 f150, PA5 f090
PA4 f150, PA6 f090

- 3-day maps from search of Planet 9. Naess et al, arXiv:2104.10264
- 3 transients found serendipitously. Naess et al, arXiv:2012.14347

Maps, Filtering Strategies and Data Cuts

- 3-day maps with maximum likelihood mapmaking process

  - Subtracted by a 7-year mean map to leave only time dependent signal

  - Day and night (UTC 23-11) maps

- Matched filtering process

$$\boldsymbol{\rho} = \mathbf{B}^T \mathbf{U}^{-1} \hat{\mathbf{m}}_T$$
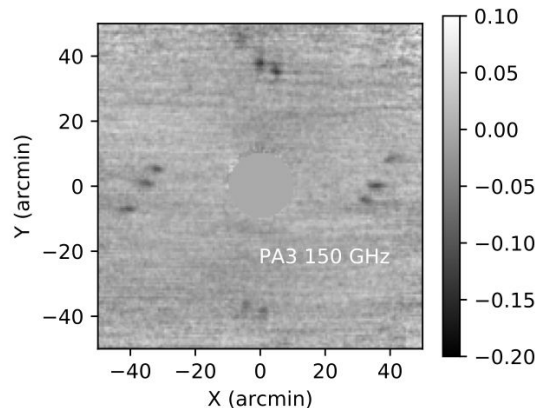$$\boldsymbol{\kappa} = diag(\mathbf{B}^T \mathbf{U}^{-1} \mathbf{B})$$
$$\kappa_i \approx \alpha B_{ji}^2 \omega_j$$

$$\mathbf{f} = \boldsymbol{\rho}/\boldsymbol{\kappa}$$
$$S/N = \boldsymbol{\rho}/\sqrt{\boldsymbol{\kappa}}$$
$$Var(\mathbf{f}) = 1/\boldsymbol{\kappa}$$

- Cuts (moving objects)

  - Area within 3 arcmin of bright asteroids (Vesta, Pallas, Ceres, Iris, Eros, Hebe, Juno, Melpomene, Eunomia, Flora, Bamberga, Ganymed, Metis, Nausikaa and Malasslia) is removed

 - Area within 0.8 degree of Venus, Mars, Jupiter, Saturn, Uranus or Neptune is removed.

Scan of Saturn showing sidelobes that rea 47 arcmin away from the planet

Initial Detection and Cross Matching between Arrays

- 7.8 billion of pixel searched for each of the six combinations of array and frequency
  - 28k 5-sigma false detections in total assuming a gaussian distribution
- Initial detection
  - SNR>5
  - Center of mass evaluated by flux
  - 332,333 initial detections found
- Cross match between arrays
  - Matching distance of 1.5 arcmin
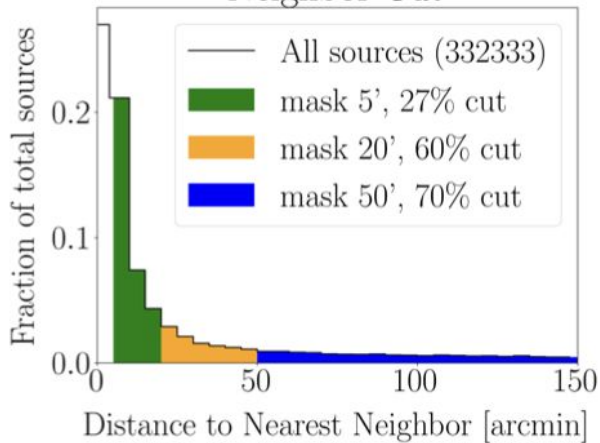 - 76% of candidates are cut
  - Potential overcut

SNR map | Mask selecting pixels with S/N>5.0 | Center of mass weighted by flux

PA6
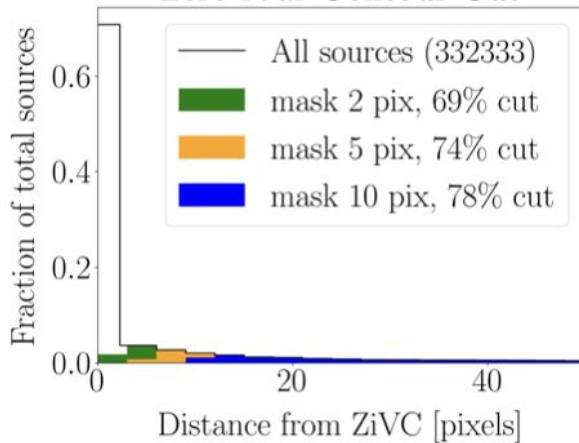PA4   PA5
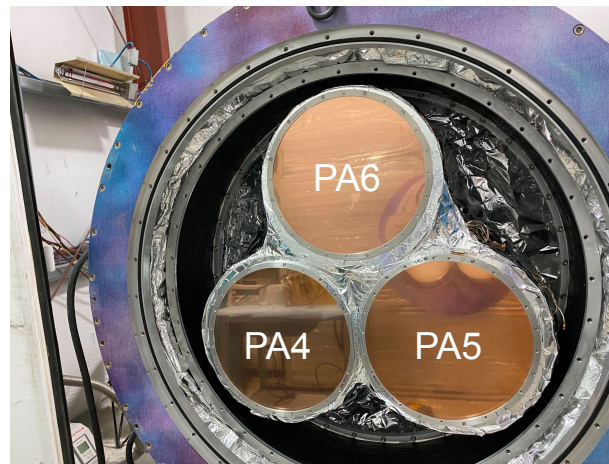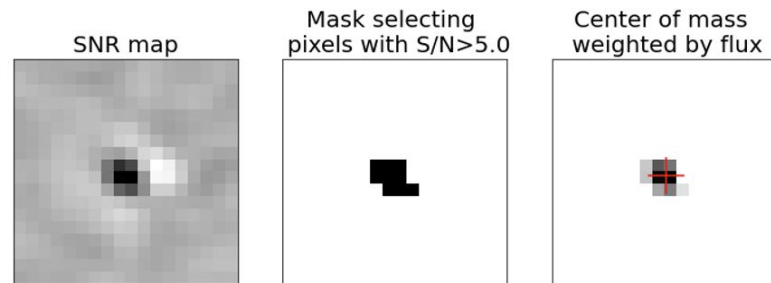
Geometry Cuts
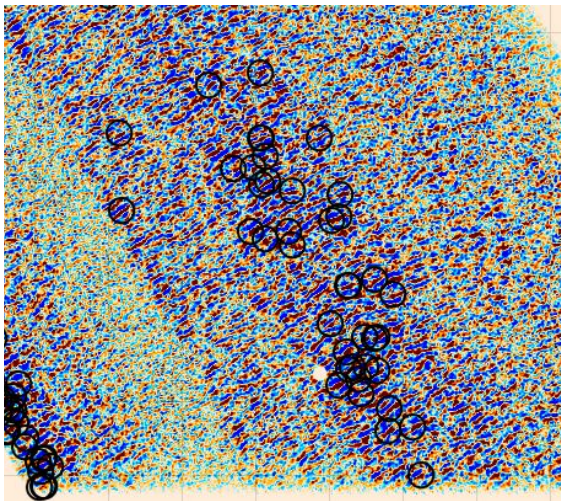
- Edge area is considerably noisy
- Uneven scanning coverage with low hit counts
  - Stripy pattern of candidates along the scanning directions
  - Zero ivar contour cut
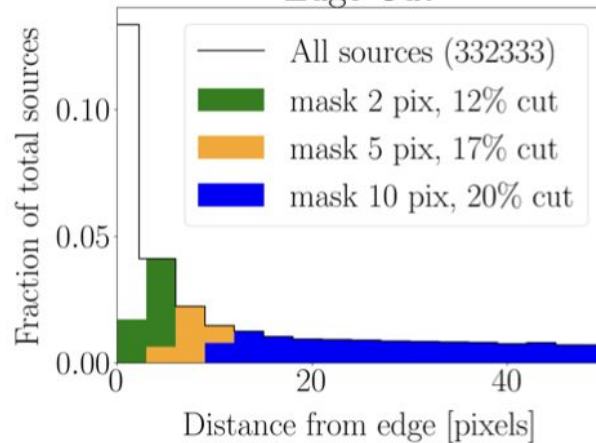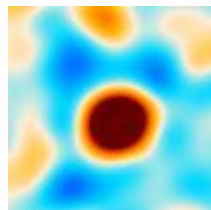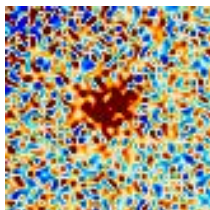- 96% of spurious sources are cut in total

Neighbor Cut
- All sources (332333)
- mask 5', 27% cut
- mask 20', 60% cut
- mask 50', 70% cut

Distance to Nearest Neighbor [arcmin]

Zero iVar Contour Cut
- All sources (332333)
- mask 2 pix, 69% cut
- mask 5 pix, 74% cut
- mask 10 pix, 78% cut

Distance from ZiVC [pixels]

Edge Cut
- All sources (332333)
- mask 2 pix, 12% cut
- mask 5 pix, 17% cut
- mask 10 pix, 20% cut

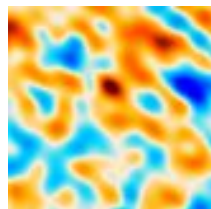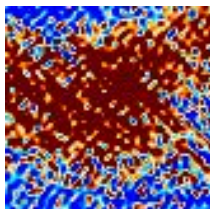Distance from edge [pixels]

Final Candidate Confirmation

- Mean flux density cut
  - Candidates with mean flux <-50mJy and >50mJy
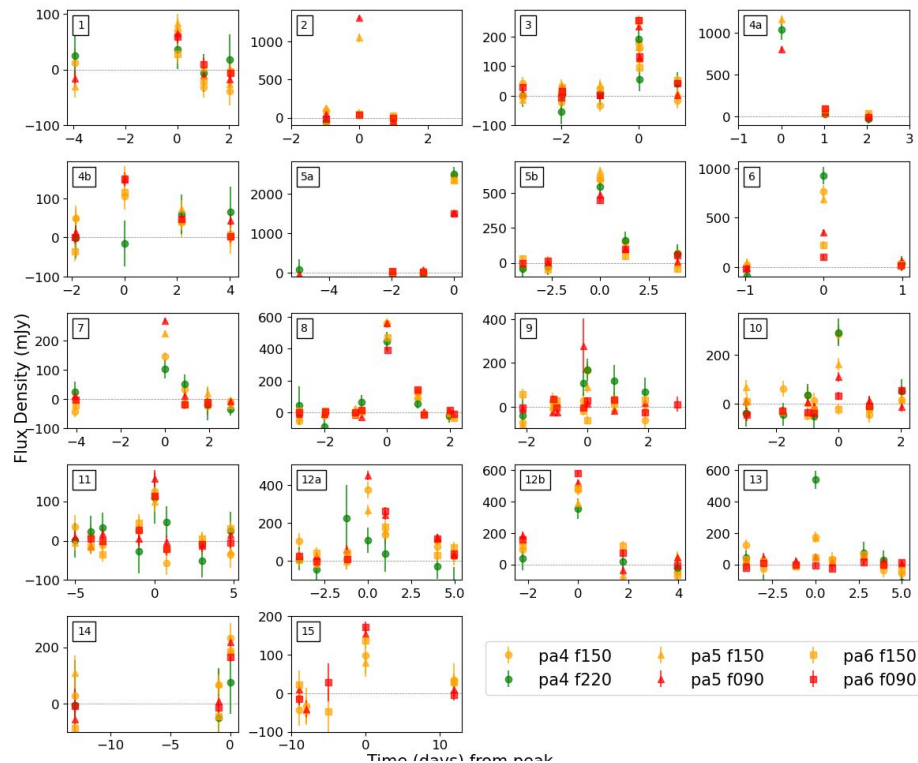- Light curves
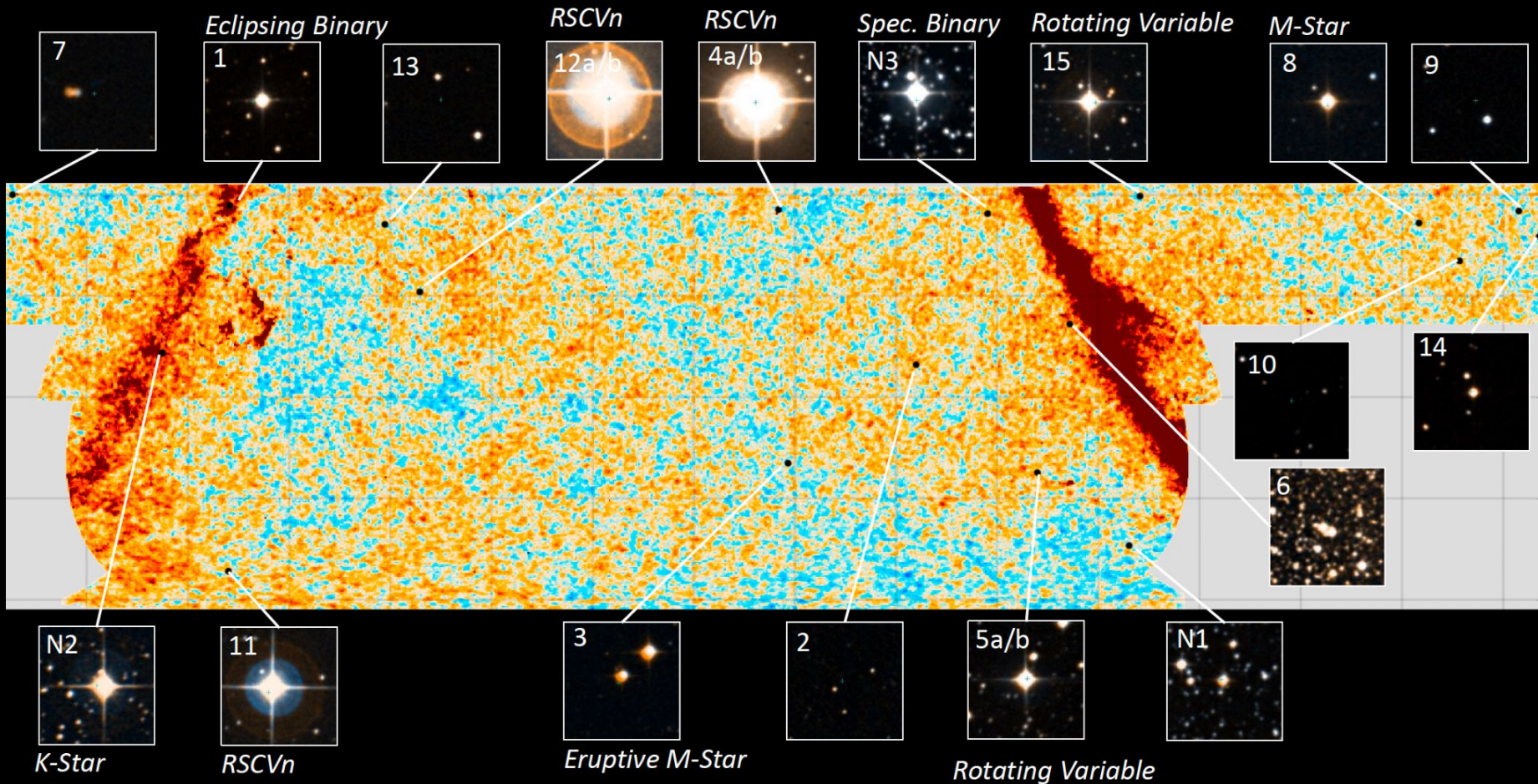- Thumbnail maps

Good candidate example

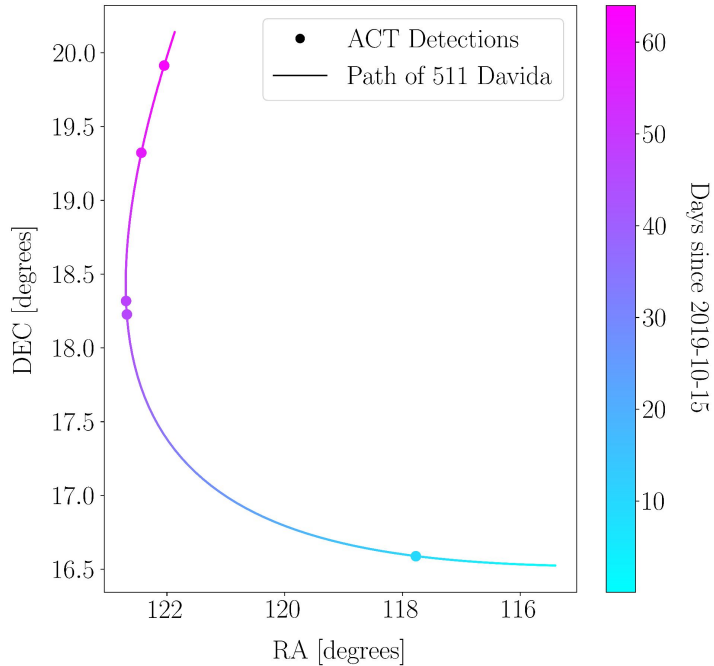Bad candidate example

Intensity
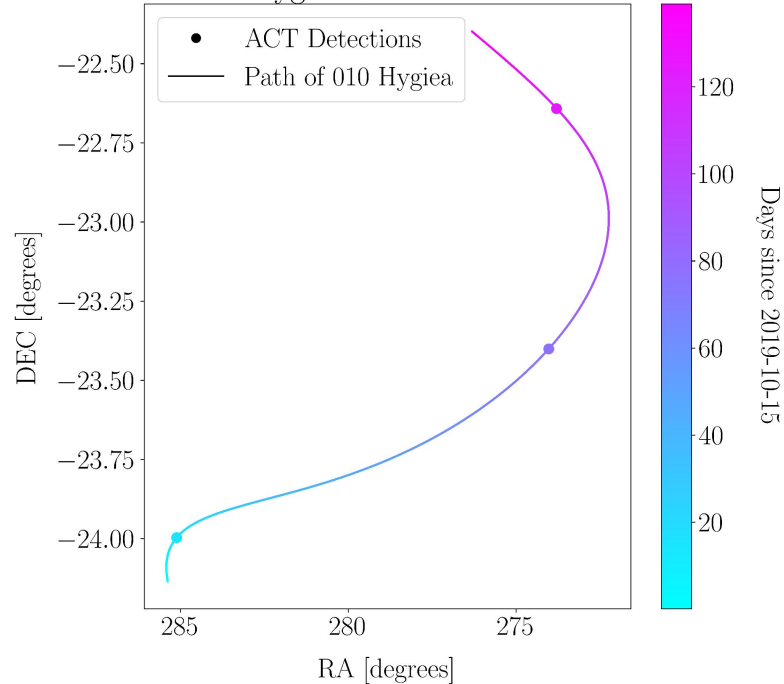
SNR map after matched filtering

Results–Counterparts

Eclipsing Binary

RSCVn

RSCVn

Spec. Binary

Rotating Variable

M-Star

K-Star

RSCVn
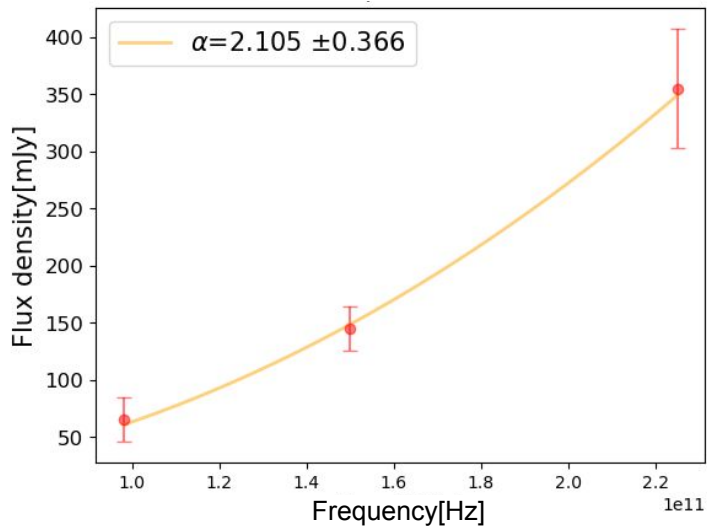
Eruptive M-Star

Rotating Variable

Byproduct Result of Asteroids

Dedicated study of asteroids:
Orlowski-Scherer et al,
arxiv:2306.05468

Results – Light Curves and Spectra Indices

- Fit for spectra indices using flux density from light curve $\quad S_\nu \propto \nu^\alpha$
  - Peak flux evaluated inverse variance average of PA4 and PA5
- Subarray light curves by separating detectors into 4 subgroups with respect to scanning time to study the rise and fall time
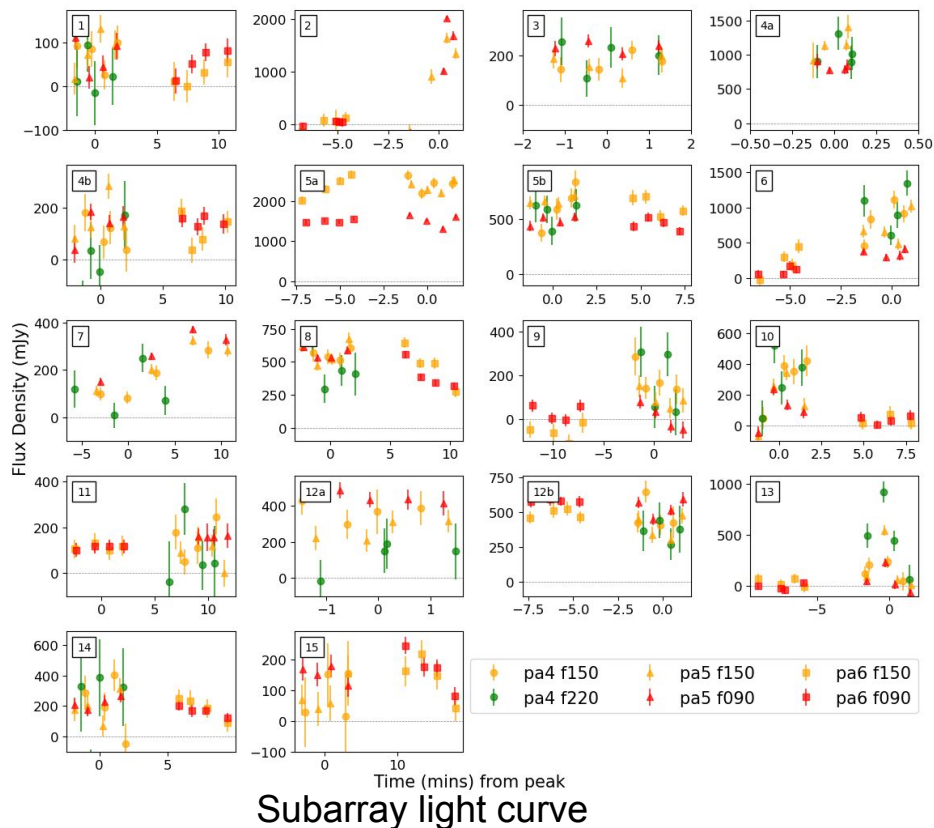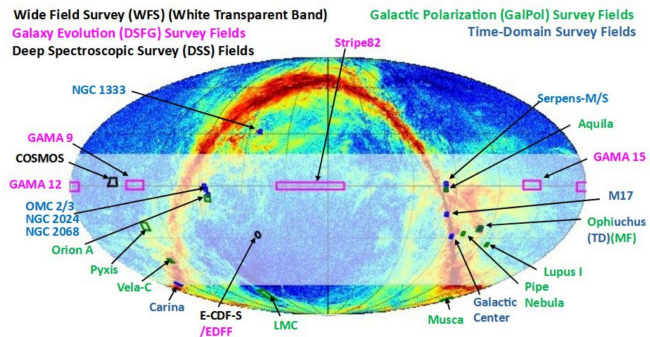

Subarray light curve

Summary and Future Work/Instruments

- We have demonstrated a pipeline for systematic search of transients using ACT data
- Depth-1 map
  - New seasons of data
  - Single scan with more consistent sensitivity and freedom of stacking data with different scale of time
- Search of transients near galactic plane
- Future CMB instruments
  - Simons Observatory
    - 10 times mapping speed
    - Depth versus cadence?
  - CCAT-prime
    - Deep and spectroscopic scans
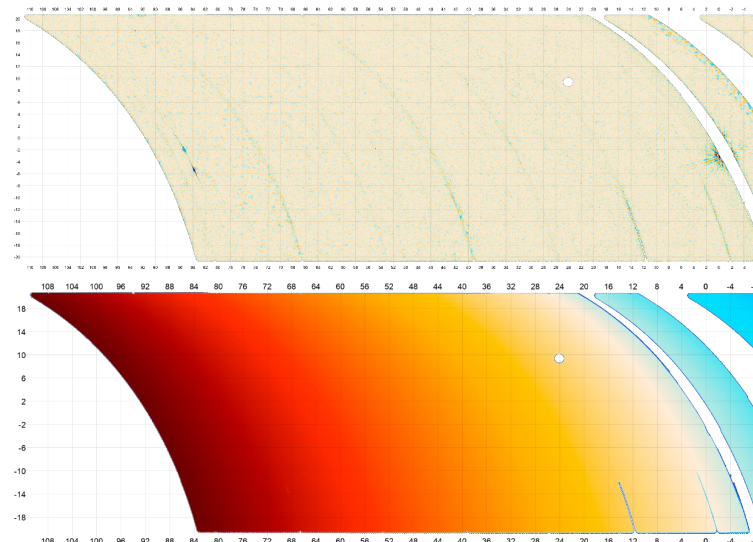
Depth-1 map, figure courtesy of Sigurd Naess

Thanks!