The SPT AGN Monitoring Program

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NSF

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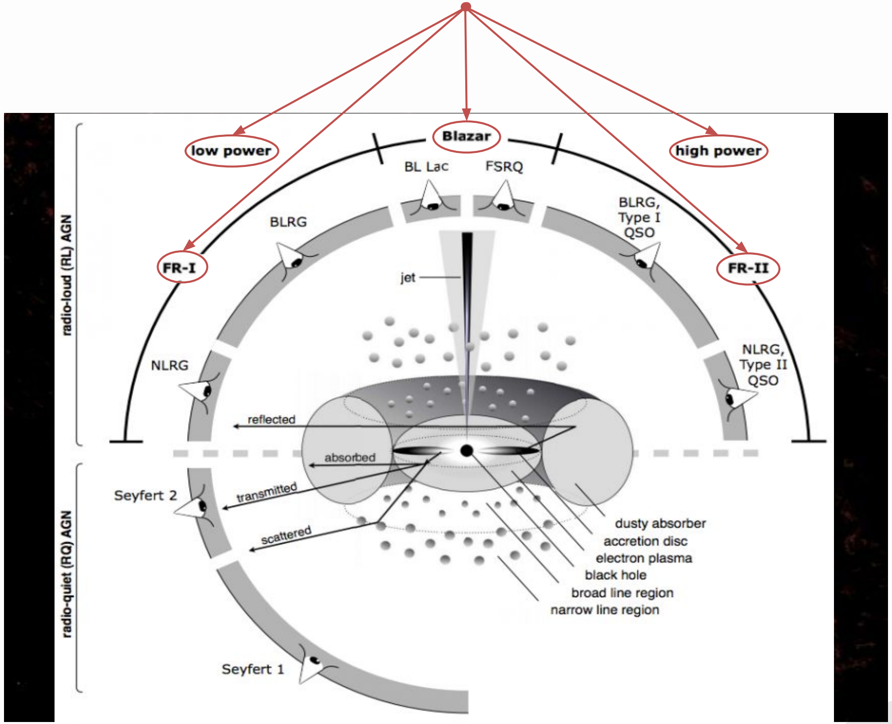
What are AGN?

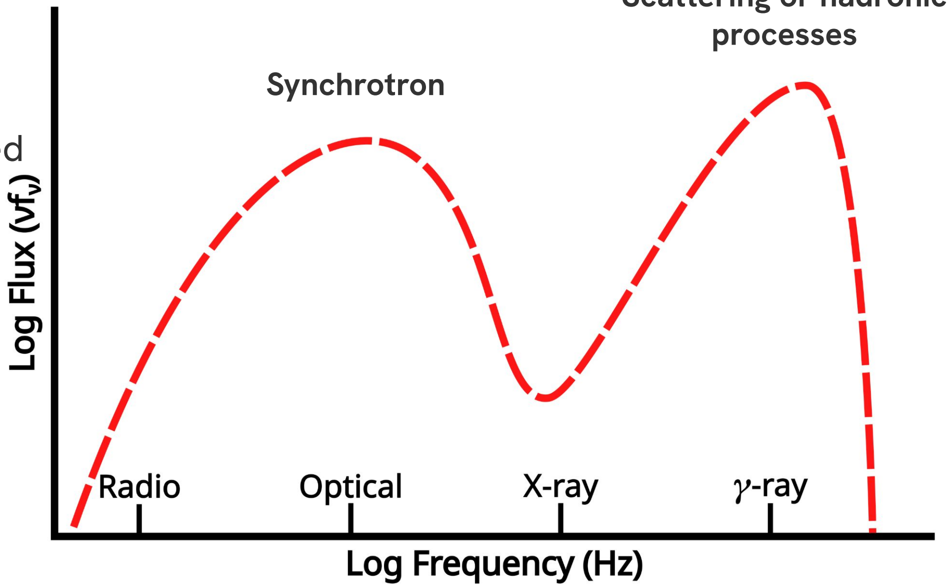
- Active Galactic Nuclei (AGN) are extremely luminous supermassive black holes at the very center of galaxies
- This luminosity is caused by the accretion of matter onto these black holes, and sometimes a relativistic jet
- What we observe is dependent on the properties of the AGN and the viewing angle
- When the jet of an AGN is pointed directly at us we observe a blazar
    - These are typically the brightest type of AGN in the millimeter wave (mm-wave)



Source: Beckmann & Shrader (2012)
Source: NRAO

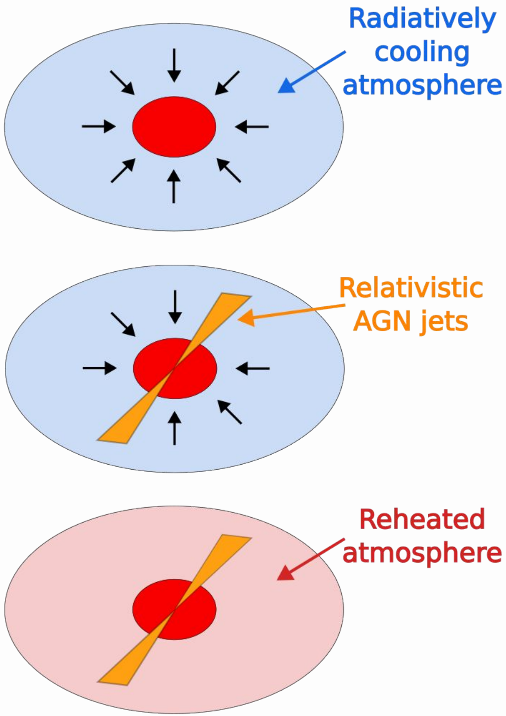
Blazar Emission Characteristics

- Blazars have a characteristic double humped spectrum caused by synchrotron radiation and inverse compton scattering/hadronic processes
- By studying these objects in the mm-wave we are probing synchrotron emission from the jet



Why Study Blazars in the mm-wave?

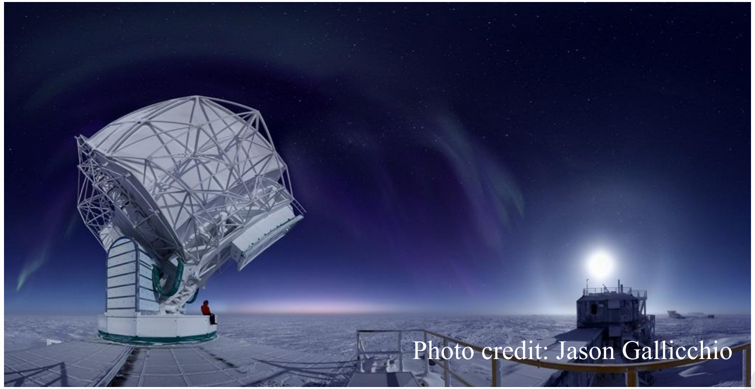
- AGN feedback plays a large role in galaxy formation, and has the capacity to reduce star formation and/or alter the kinematics and structure of the host galaxy
- Using our mm-wave data we can study the structure and activity of the jets which can drive feedback



Adapted from: A. C. Fabian

CMB Telescopes as AGN Monitors

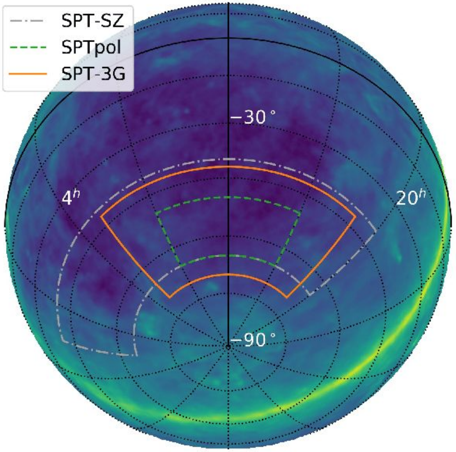
- “It has recently been recognized that cosmic microwave background (CMB) experiments have the potential to be used as AGN monitors” (e.g., Holder et al. 2019).
- high signal-to-noise ratio (S/N) in short observations.
- Good instantaneous point source sensitivity
- High-cadence observations of the same patch of sky over many years.
- Capable of building the first high cadence catalogs of AGN in mm-wave.



South Pole Telescope

Photo credit: NSF

- 2007: SPT-SZ
  - Temp
- 2012: SPTpol
  - Temp + Pol
- 2017: SPT-3G
  - Temp + Pol
- ~1 arc minute res.

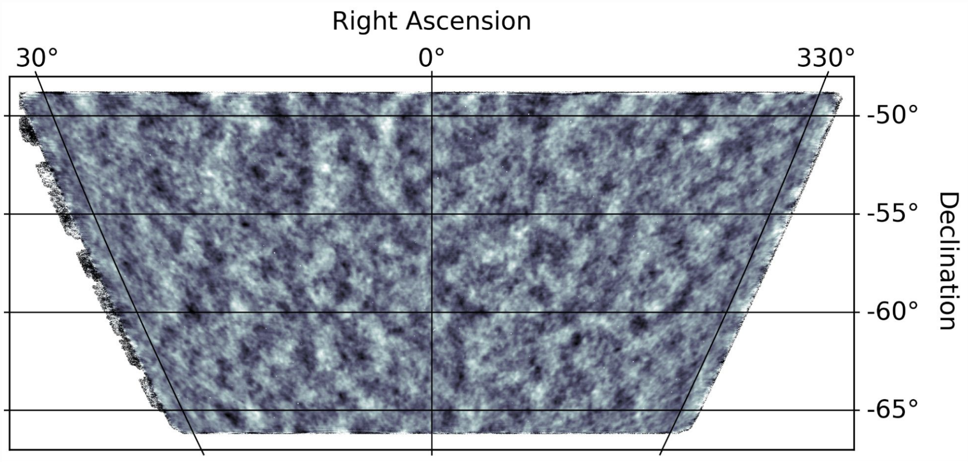


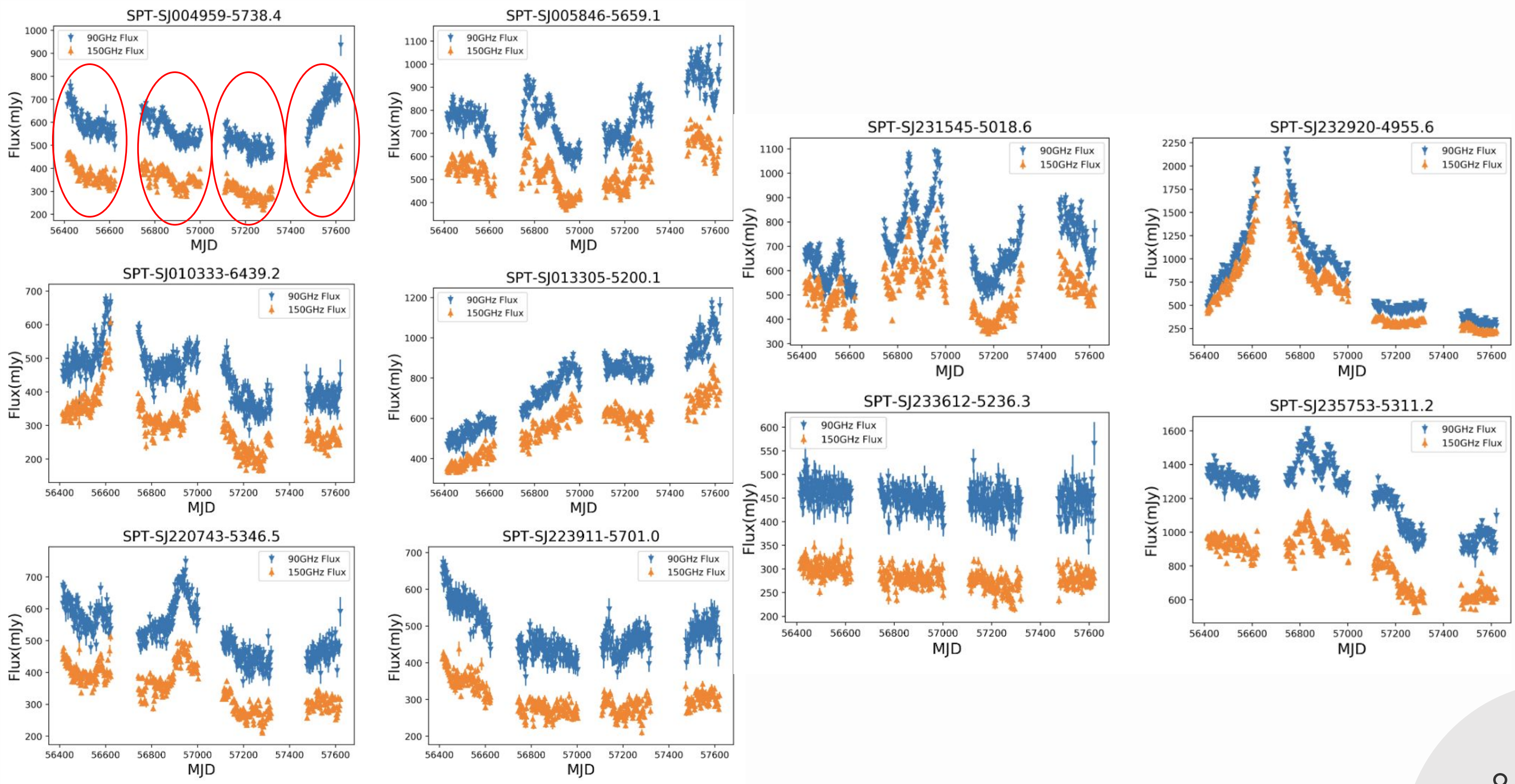
Dutcher et. al. 2021

	# detectors	Area (deg^2)	95 GHz (uK-arcmin)	150 GHz (uK-arcmin)	220 GHz (uK-arcmin)
SPT-SZ (main)	960	2500	40	17	80
SPTpol (main)	1600	500	13	6	-
SPT-3G (main)	16,000	1500	3.0	2.2	8.8

SPTpol 500 deg ^{2} Survey

- SPTpol: second generation camera used to observe the CMB intensity and polarization
- ~3500 observations over ~9000 hours, covering 22^h to 2^h in right ascension and -65° to -50° in declination.
- Two frequencies observed:
  - 90 GHz
  - 150 GHz
- Observes same patch every 2 hours
- Using CMB maps for time domain study
  - 4 year coadd → 36 hour bundles
  - 450+ observations
    - Observes flux variability





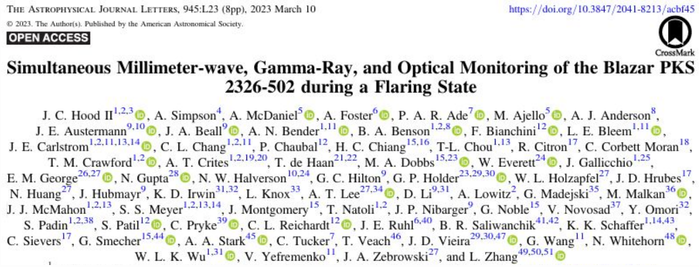
SPT-SJ004959-5738.4
SPT-SJ005846-5659.1
SPT-SJ010333-6439.2
SPT-SJ013305-5200.1
SPT-SJ220743-5346.5
SPT-SJ223911-5701.0
SPT-SJ231545-5018.6
SPT-SJ232920-4955.6
SPT-SJ233612-5236.3
SPT-SJ235753-5311.2
90GHz Flux
150GHz Flux
Flux(mJy)
MJD

AGN Variability Pilot Study

- Long time scale correlations with Fermi and SPT.
- Short time scale correlations with Fermi and optical.
- Short time scale correlations with Fermi and SPT.
- No measurable correlation with SPT and optical.

Light Curve Statistics

Dataset	zero-lag correlation	zero-lag p-value
SPT x Fermi year one (smoothed)	0.75	2.9×10^{-2}
SPT x Fermi year one (smoothed & detrended)	-1.3×10^{-2}	0.52
Smarts x Fermi year one (smoothed)	0.92	3.0×10^{-4}
Smarts x Fermi year one (smoothed & detrended)	0.92	$< 10^{-4}$
SPT x Smarts year one (smoothed)	0.48	0.16
SPT x Smarts year one (smoothed & detrended)	2.6×10^{-2}	0.47
SPT x Fermi year two (smoothed)	0.23	0.32
SPT x Fermi year two (smoothed & detrended)	0.67	1.0×10^{-3}
Smarts x Fermi year two (smoothed)	0.54	7.4×10^{-2}
Smarts x Fermi year two (smoothed & detrended)	0.34	8.7×10^{-2}
SPT x Smarts year two (smoothed)	0.32	0.26
SPT x Smarts year two (smoothed & detrended)	9.7×10^{2}	0.36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https://doi.org/10.3847/2041-8213/acbf45

Simultaneous Millimeter-wave, Gamma-Ray, and Optical Monitoring of the Blazar PKS 2326-502 during a Flaring State

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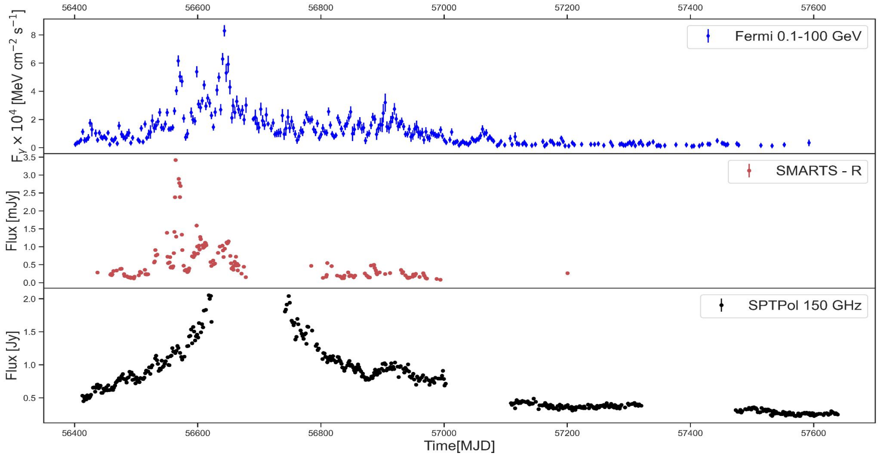
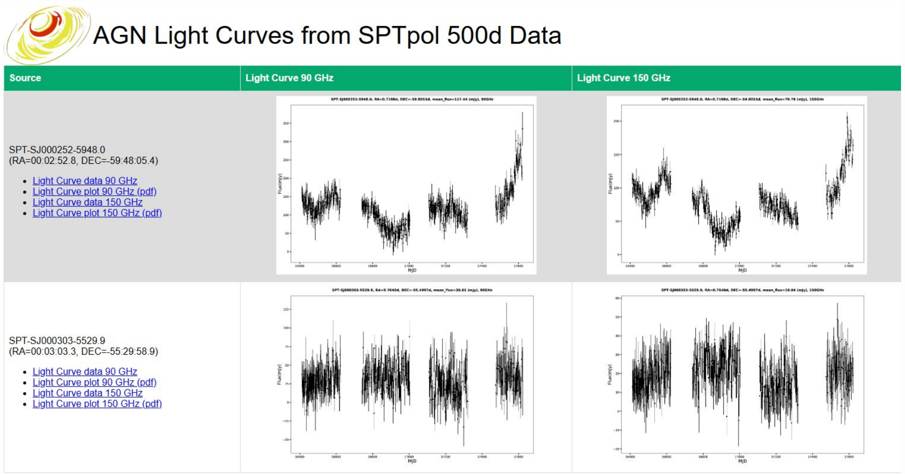


Source: Hood et al 2023

STRAWHAT Catalog and Expansion

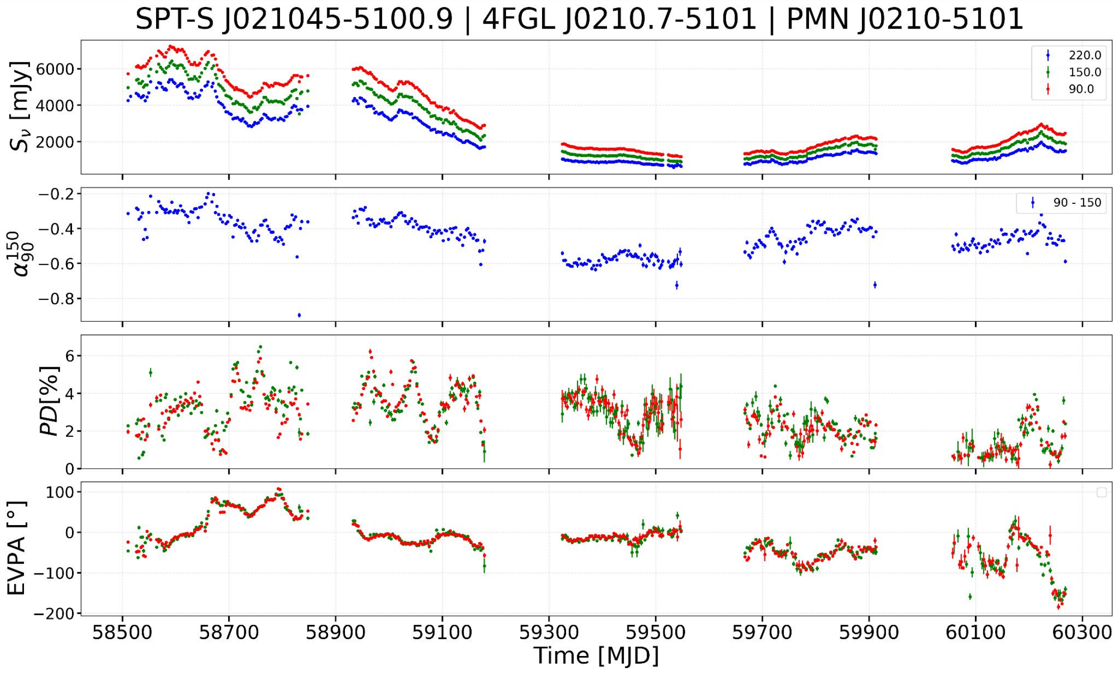
<u>Proposed Expansion</u>:

- ❖ SPT Treasury Record of AGN With Historical Activity and Time-series
- ❖ Includes SPTPol 90 and 150 temperature data
- ❖ Include SPT-3G 90, 150, and 220 flux and polarization data for bright AGN
- ❖ Build joint AGN catalog including data from SO and ACT and CMB-S4

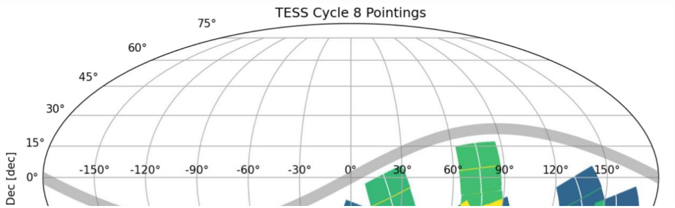


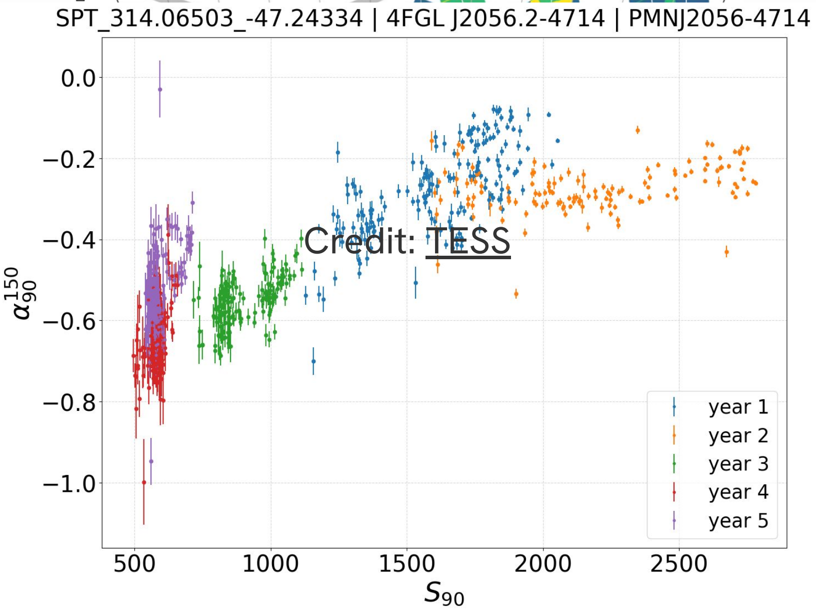
https://spt3g.ncsa.illinois.edu/datasets/spt_agn_lightcurves/

AGN in the SPT-3G 1500 deg^2 Main Field

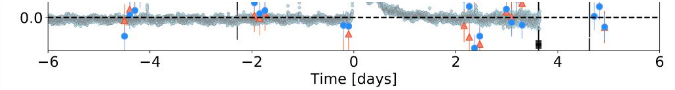


- ❖ 5 years of data spanning from 2019-2023
- ❖ The SPT-3G survey is significantly more sensitive at all frequencies than SPTpol, particularly 90 GHz
- ❖ The field is larger meaning more bright sources
- ❖ SPT-3G unlocks polarization data for a large number of sources





Credit: TESS



Stellar Flare, Credit: Guns et al. 2021

Science Goals for AGN in SPT-3G

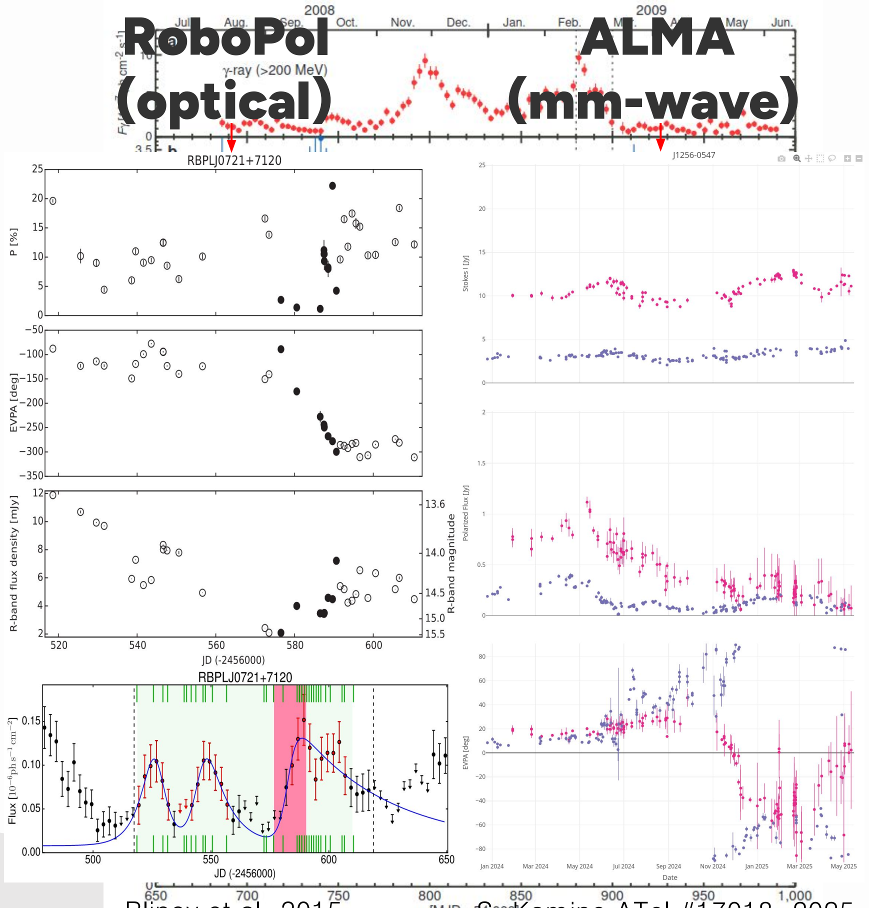
- ❖ Characterize emission types and states with spectral variability *(jet activity)*
- ❖ Investigate the disk-jet connection with simultaneous X-ray data *(jet launching)*
- ❖ Investigate short timescale variability mechanisms with TESS *(jet structure & activity)*
- ❖ Search for Electric Vector Polarization Angle (EVPA) rotations *(jet structure & activity)*

Polarization Angle Rotations

- In 2009 a change in optical polarization angle was seen coincident with a optical flare and gamma-ray flare
- The low time delay between the gamma-ray flare and the change in optical polarization angle suggests that the emission originated from the same region of the jet
- Still many open questions:
  - What physical process causes these events?
  - Are the gamma-ray flares physically connected to the rotations?
  - Is it the same for every event in every AGN?

RoboPol (optical)

ALMA (mm-wave)



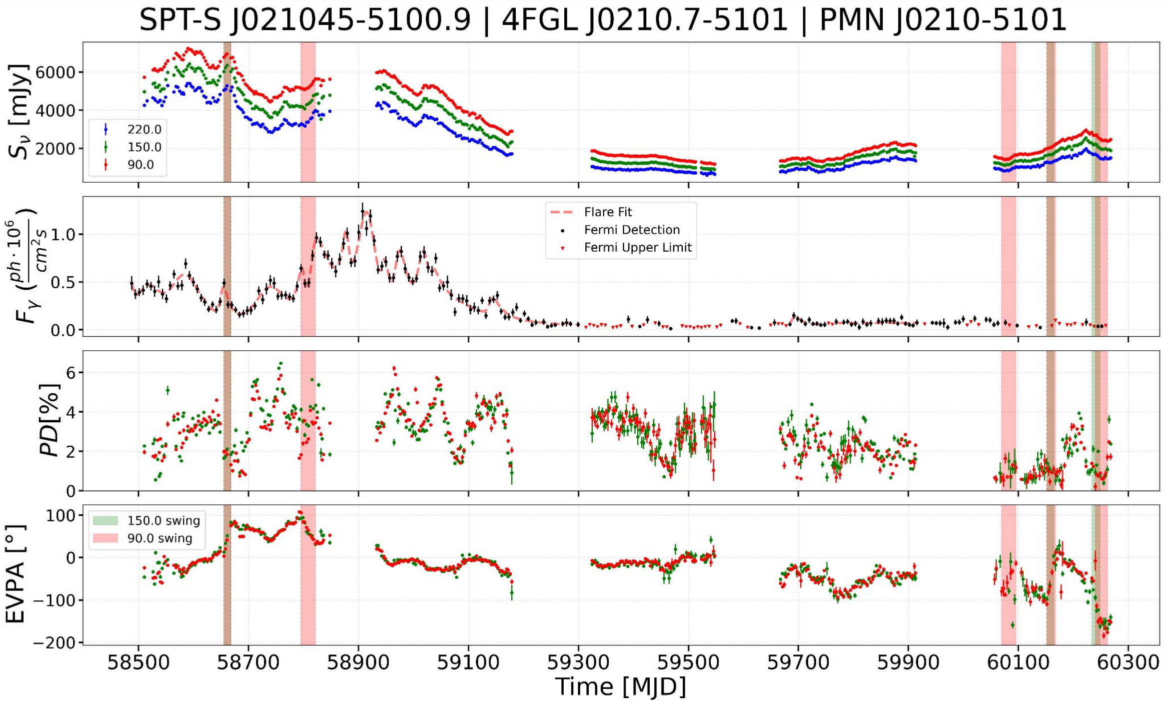
Blinov et al. 2015

S. Kamino ATel #17018, 2025

Adobo et al. 2010

Polarization Angle Rotations in SPT-3G

- We see large polarization angle rotations in many of our sources
- With enough of these events we hope to assemble a sample that can distinguish between different models:
  - Stochastic (random changes within the jet)
  - Deterministic (physical mechanisms)



Summary

- CMB experiments are a good tool for AGN monitoring in the mm-wave
- We have a SPTpol and an even better SPT-3G sample
  - If you have any neat ideas for this data let us know!
- In the era of time-domain astronomy, CMB experiments like SPT serve a crucial role in complementing telescopes such as Vera Rubin