Multiwavelength Cross-Correlation Using Millimeter AGN Light Curves from the Atacama Cosmology Telescope

Erika Hornecker, University of Toronto
mm Universe 2025, Chicago

Image credit: Jon Ward

Atacama Cosmology Telescope

Ground-based

Atacama Desert, Chile, 5200 m

Operated from 2007 - 2022

6-m primary mirror: 5 x Planck angular res.

3000 detectors

30GHz - 220GHz

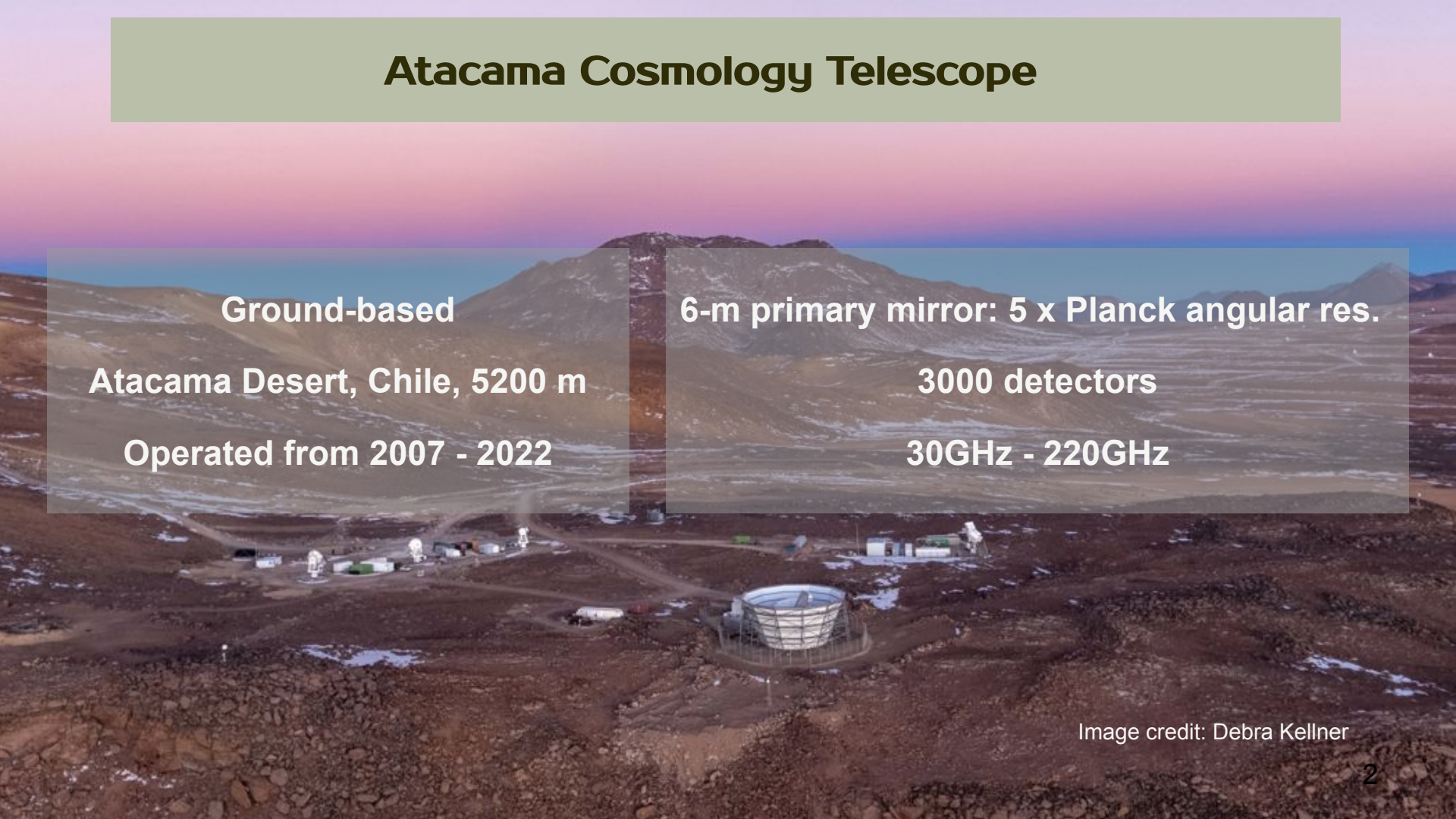
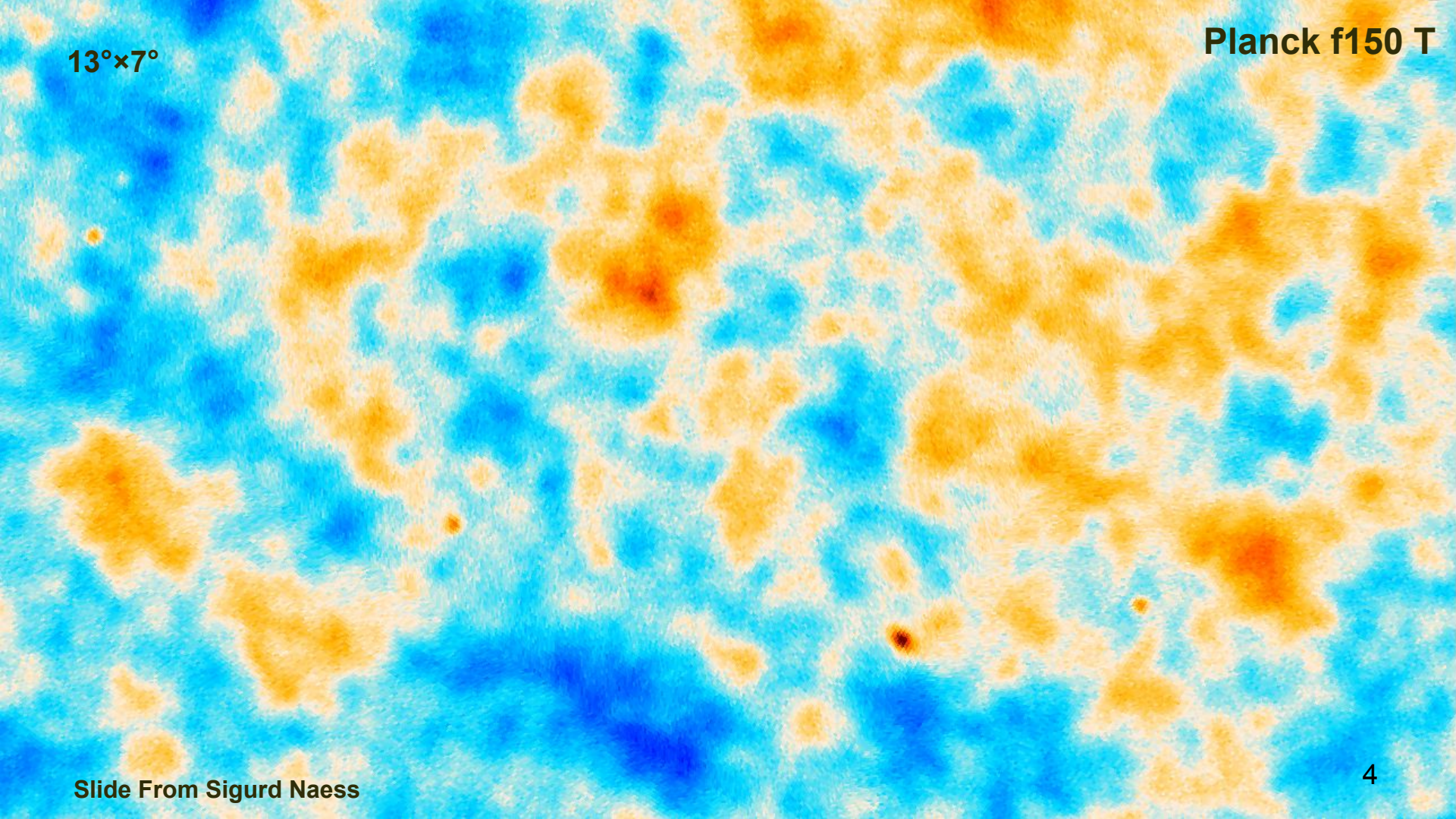


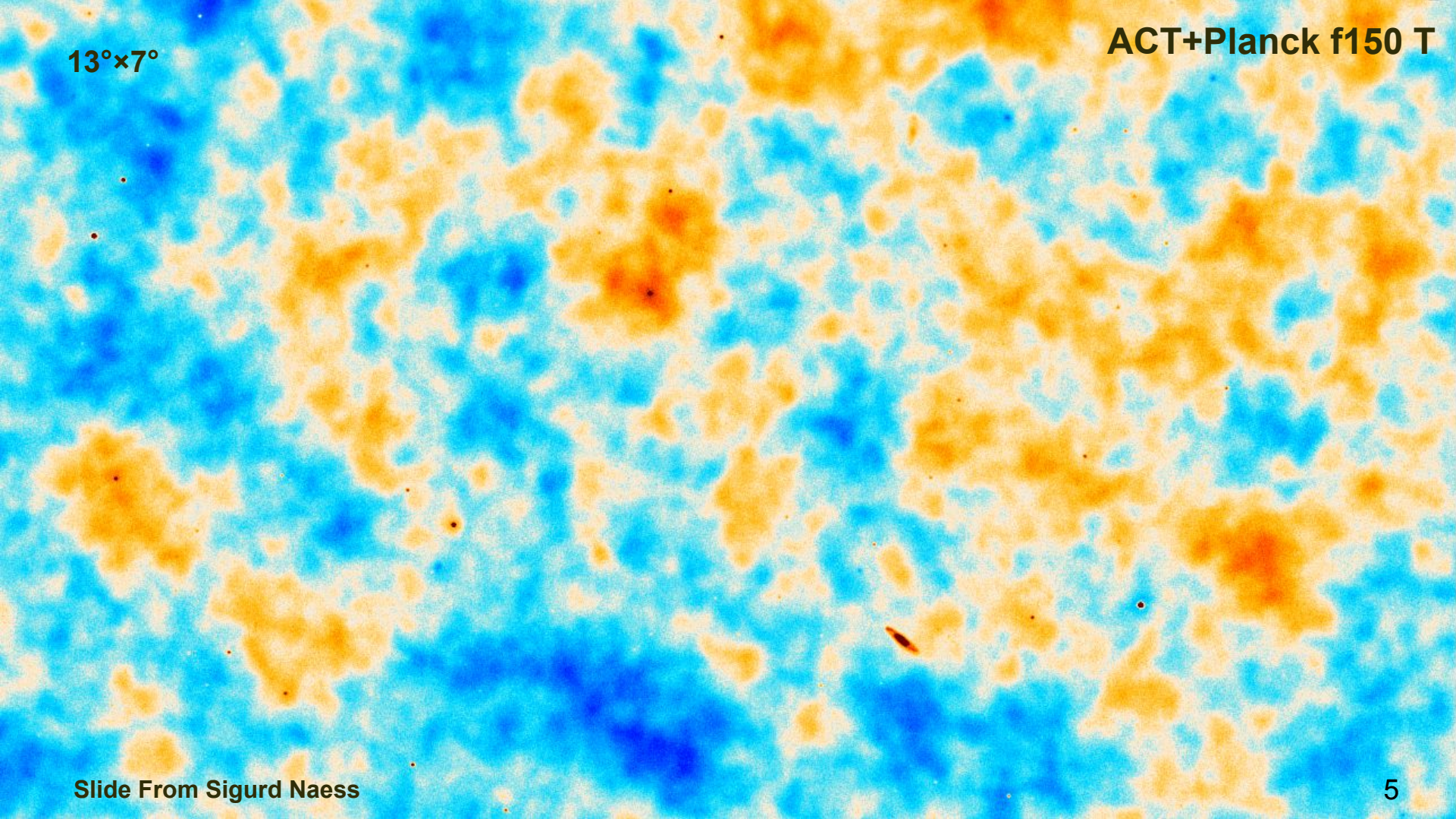
Image credit: Debra Kellner

The ACT Collaboration

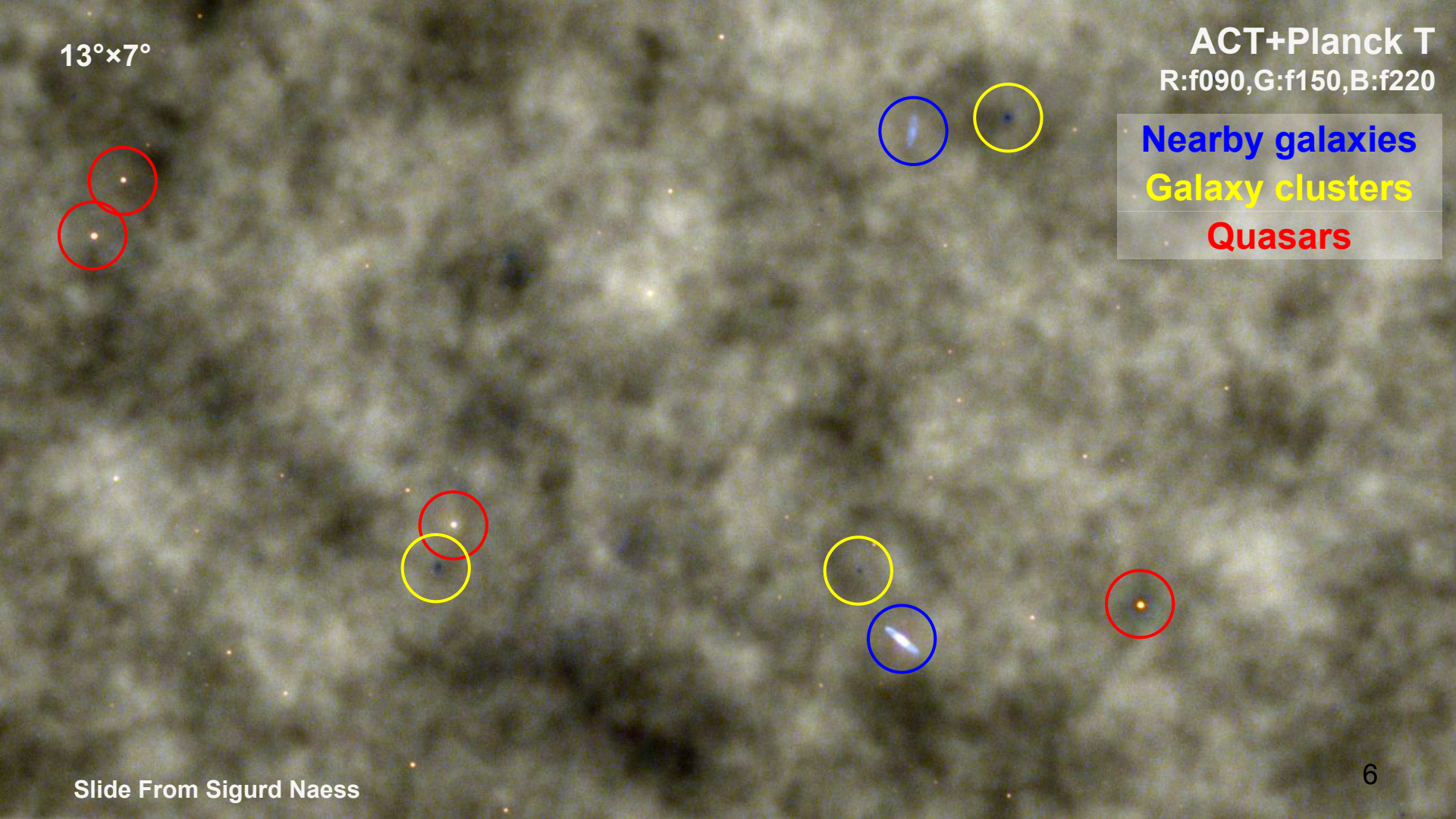
~160 collaborators at ~60 institutions



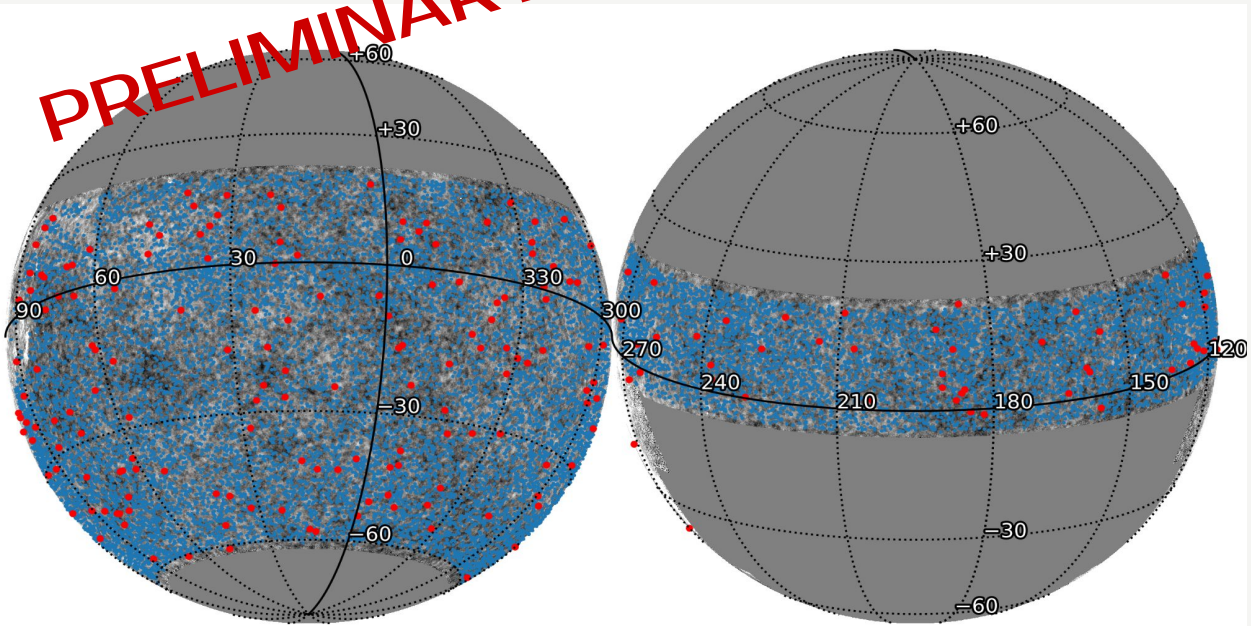
Slide From Sigurd Naess



Slide From Sigurd Naess


13°×7°
ACT+Planck T
R:f090,G:f150,B:f220
Nearby galaxies
Galaxy clusters
Quasars
Slide From Sigurd Naess

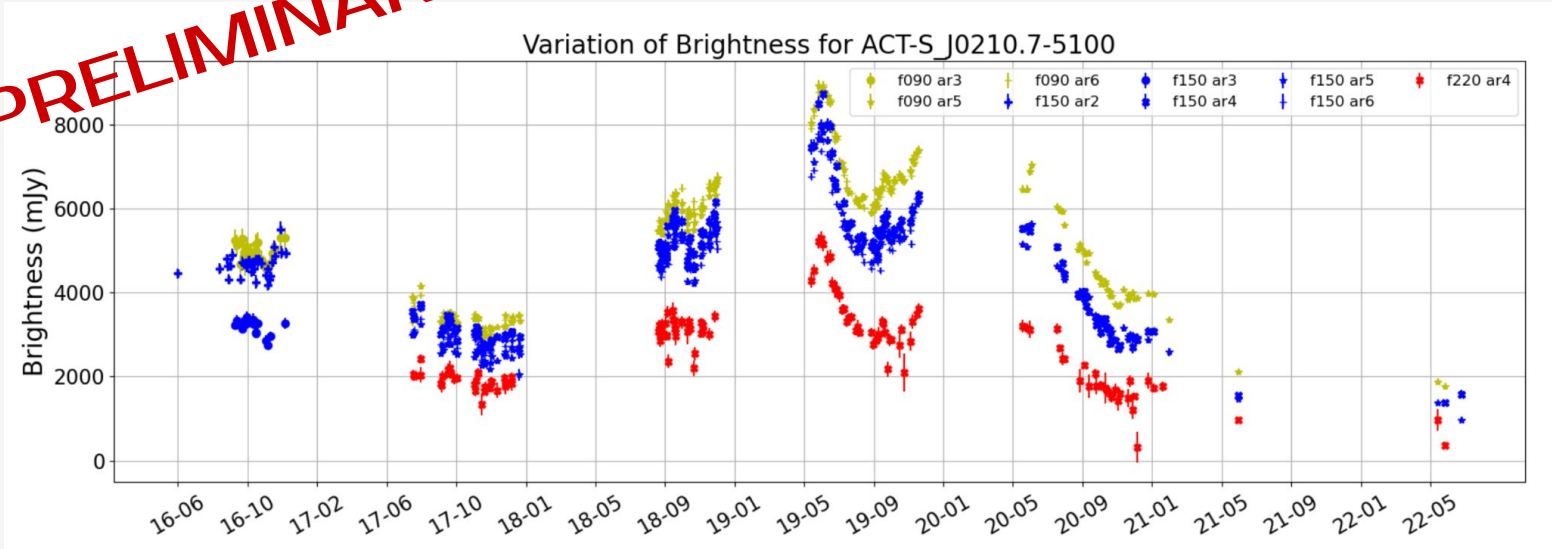
ACT footprint



From Cristian Vargas

ACT AGN Light curves

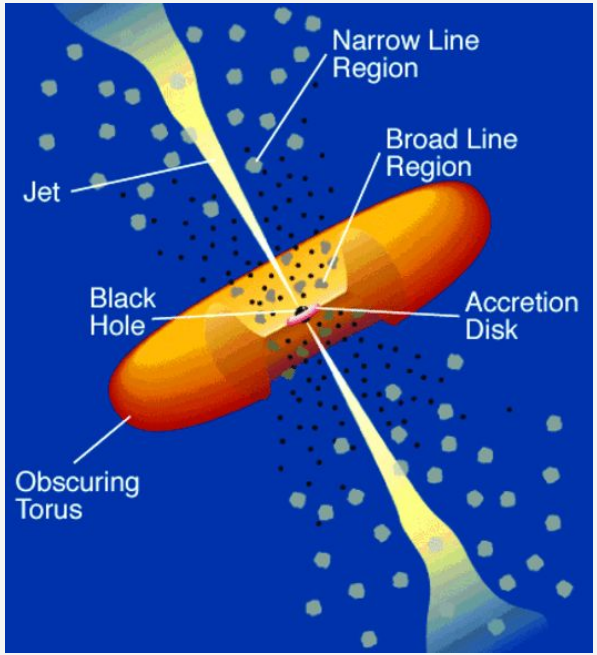
PRELIMINARY



Xiaoyi Ma, Adam Hincks, Sigurd Naess

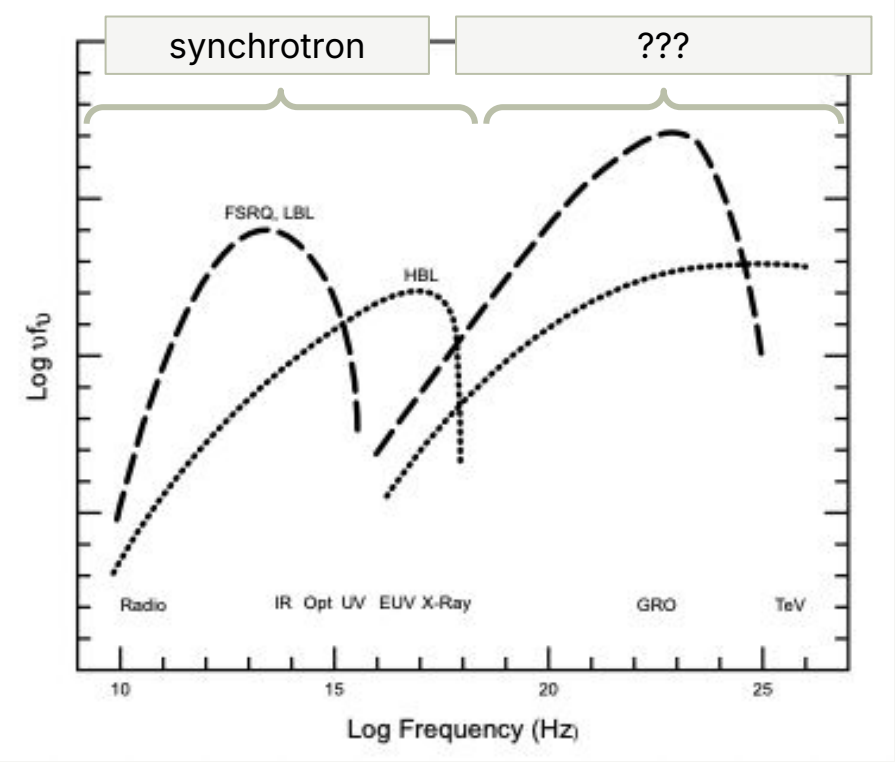
Blazars

- Doppler boosted
- Emission across the entire spectrum
- Highly variable on timescales from minutes to years



From Urry & Padovani (1995)

Blazars



From Urry (1998)

Origin of gamma-ray emission?

Leptonic

IC scattering of soft photons by relativistic electrons

“synchrotron self-Compton”

“external radiation Compton”
- Accretion disk
- BLR
- Torus ...

Hadronic

Proton-synchrotron radiation

Photo-pion production
- Pion decay: pairs, high E photon, neutrinos

Origin of gamma-ray emission?

Leptonic

IC scattering of soft photons by relativistic electrons

↓

correlated variability:
radio-UV + gamma-ray

Hadronic

Proton-synchrotron radiation/
Photo-pion production

↓

un-correlated variability
orphan flares?

Multiwavelength cross-correlation

Correlation between mm/optical/gamma-ray ?

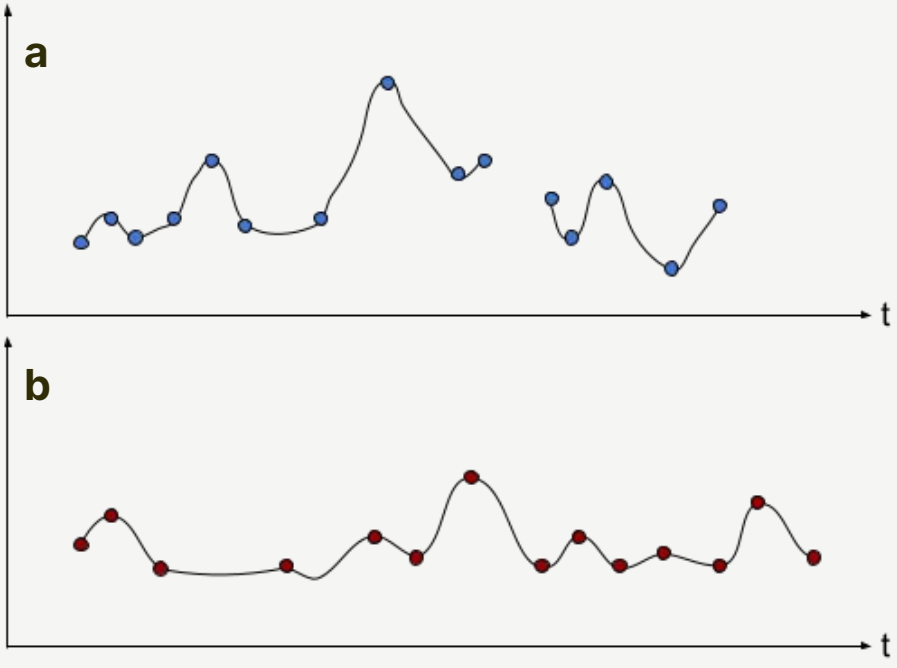
Does this support leptonic/hadronic models?

Let’s use our light curves to find out

Lightcurves:

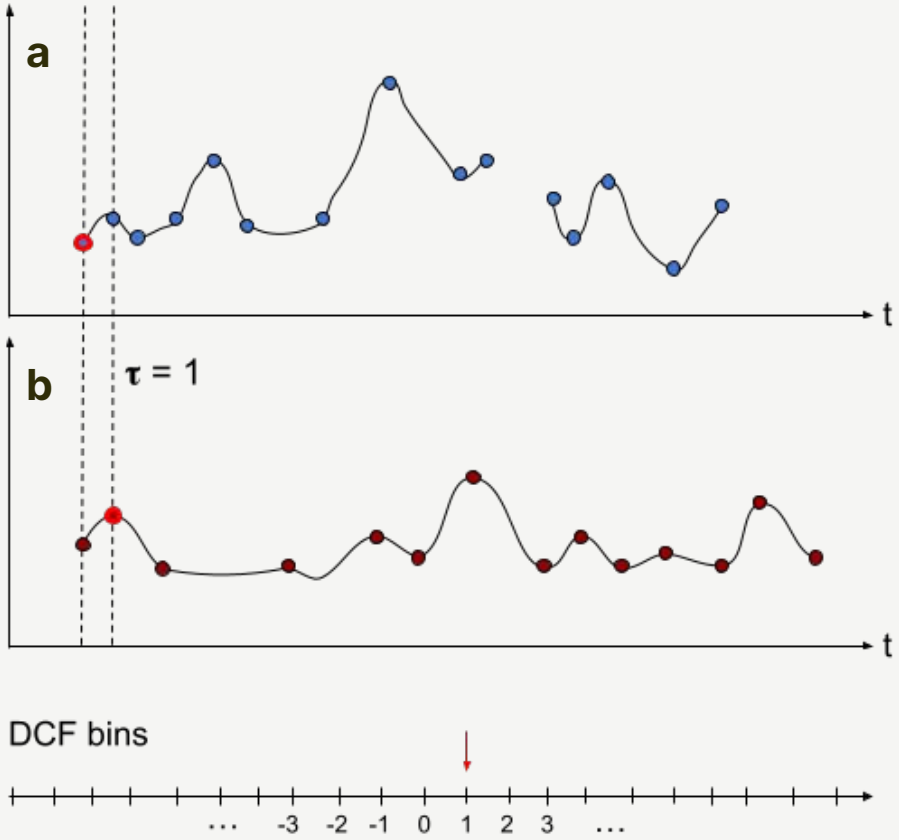
- Gamma-ray : Fermi-LAT LCR
- Optical : ASAS-SN

Discrete correlation function



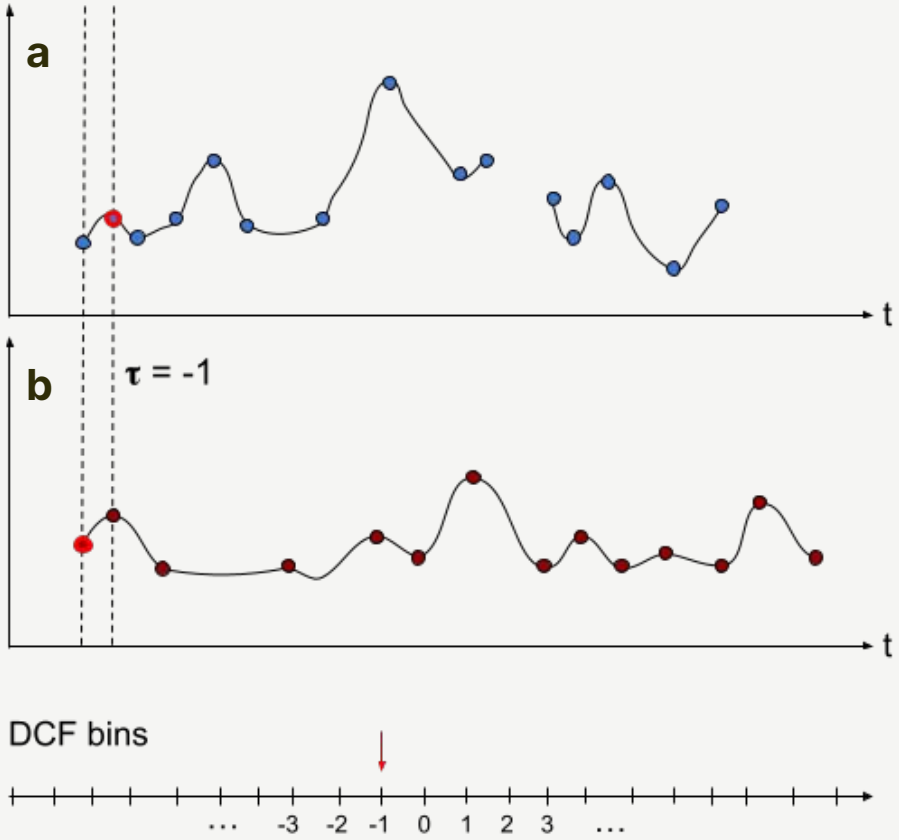
$$\mathrm{UDCF}_{ij} = \frac{(a_i - \bar{a})(b_j - \bar{b})}{\sqrt{(\sigma_a^2 - e_a^2)(\sigma_b^2 - e_b^2)}},$$

Discrete correlation function



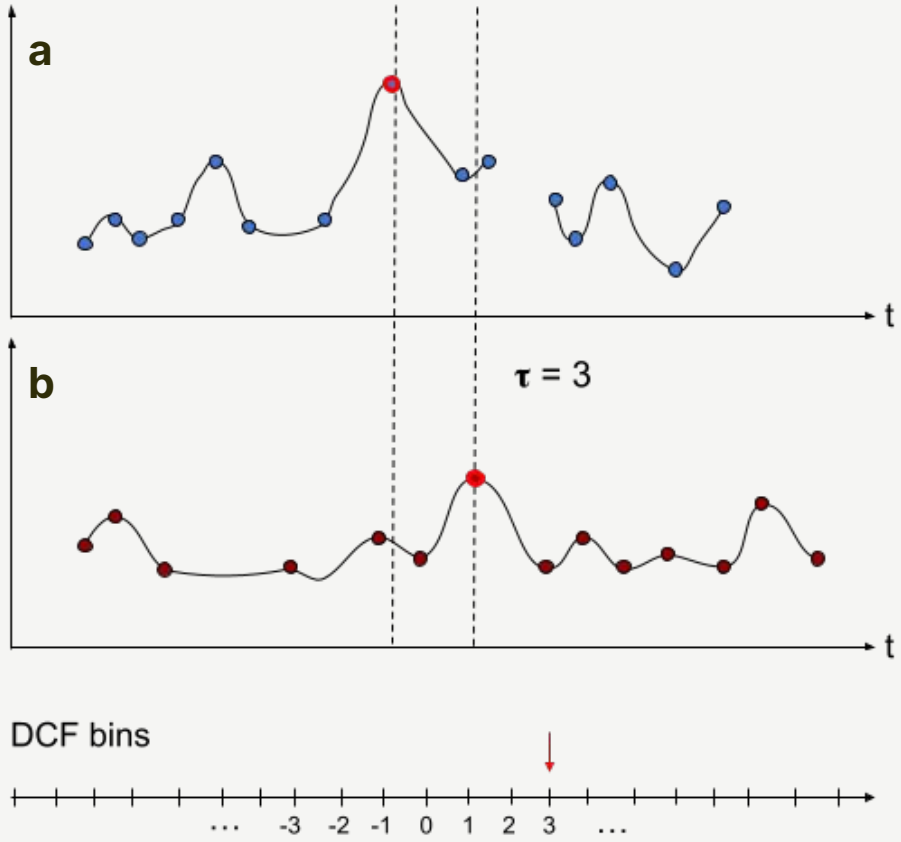
$$\mathrm{UDCF}_{ij} = \frac{(a_i - \bar{a})(b_j - \bar{b})}{\sqrt{(\sigma_a^2 - e_a^2)(\sigma_b^2 - e_b^2)}},$$

Discrete correlation function



$$\mathrm{UDCF}_{ij} = \frac{(a_i - \bar{a})(b_j - \bar{b})}{\sqrt{(\sigma_a^2 - e_a^2)(\sigma_b^2 - e_b^2)}},$$

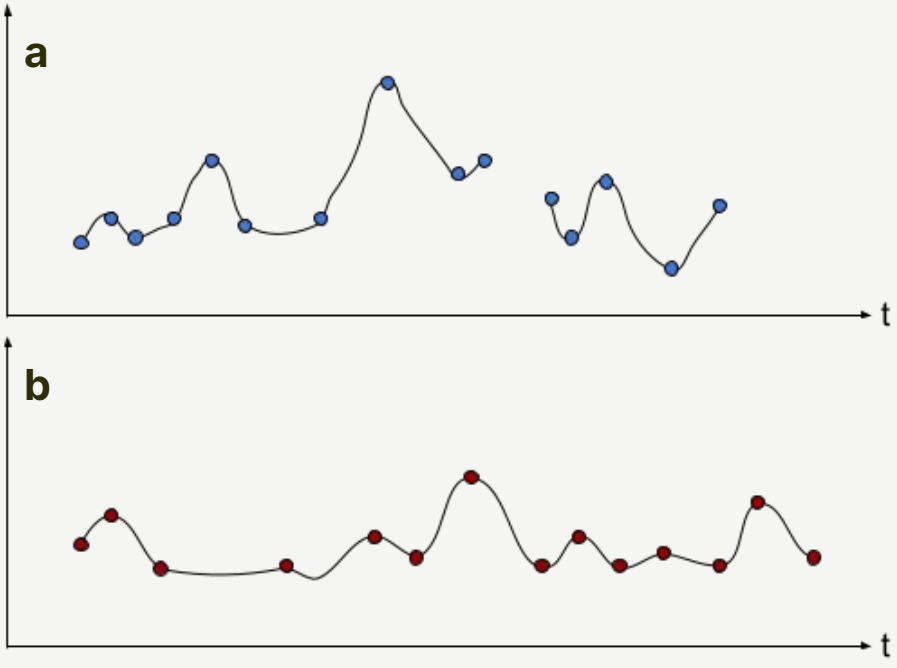
Discrete correlation function



etc...

$$\mathrm{UDCF}_{ij} = \frac{(a_i - \bar{a})(b_j - \bar{b})}{\sqrt{(\sigma_a^2 - e_a^2)(\sigma_b^2 - e_b^2)}},$$

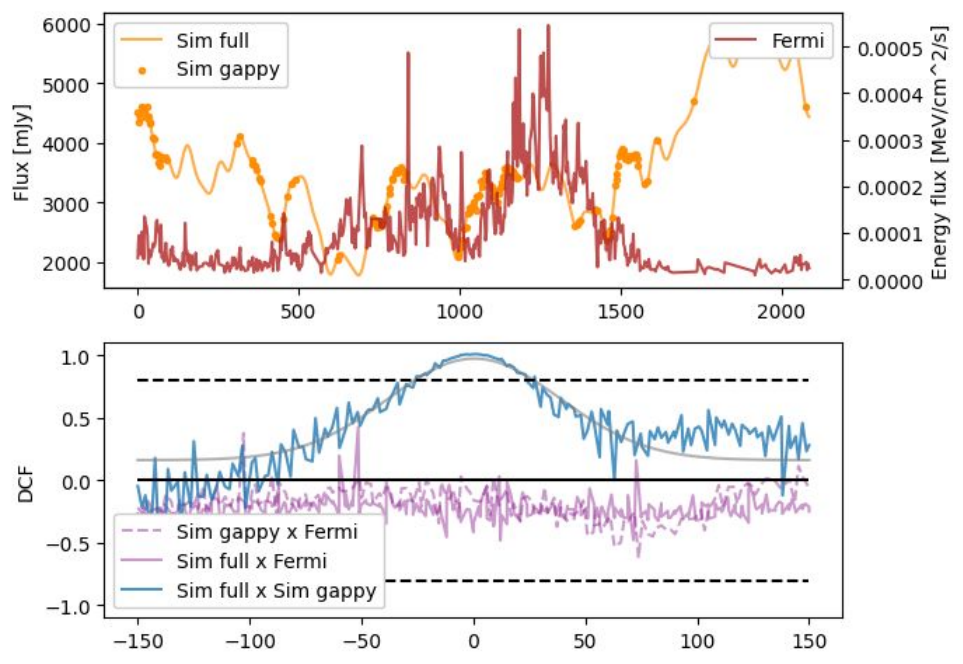
Discrete correlation function



$$\mathrm{UDCF}_{ij} = \frac{(a_i - \bar{a})(b_j - \bar{b})}{\sqrt{(\sigma_a^2 - e_a^2)(\sigma_b^2 - e_b^2)}},$$

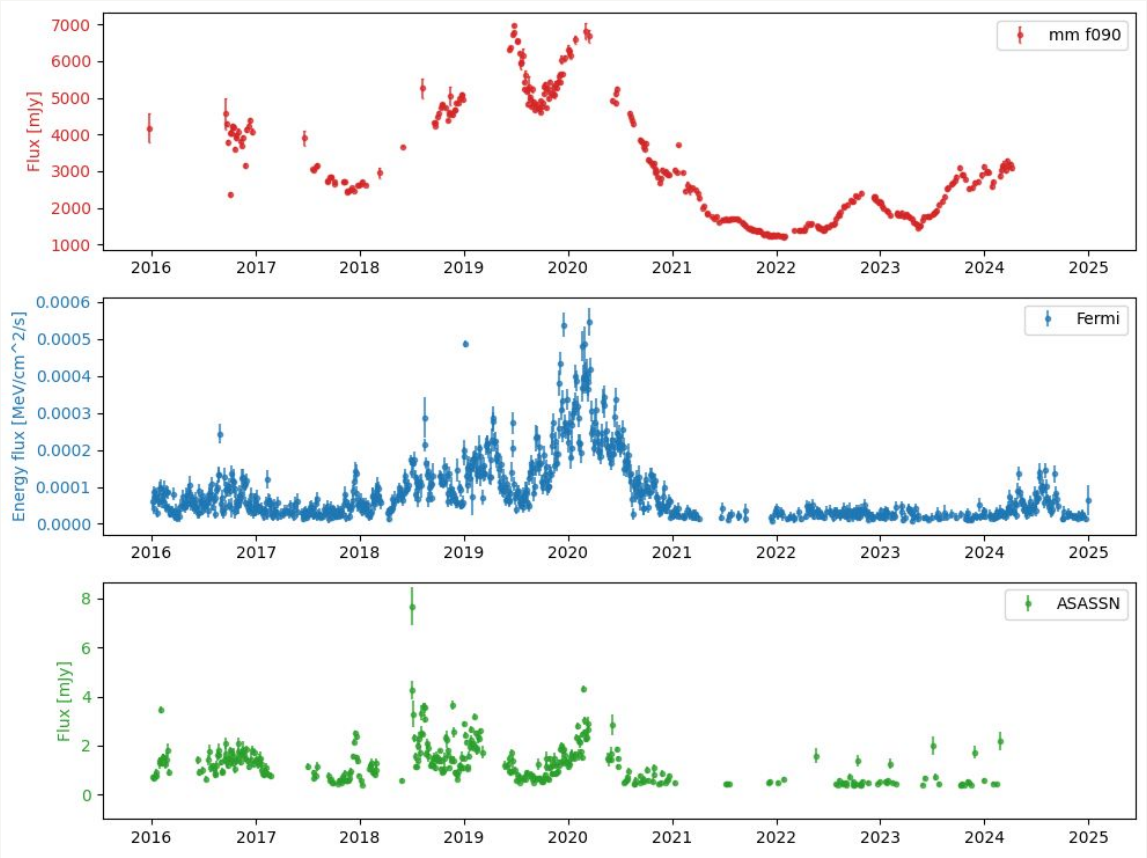
$$\mathrm{DCF}(\tau) = \frac{1}{M} \mathrm{UDCF}_{ij}\,.$$

Testing on simulations

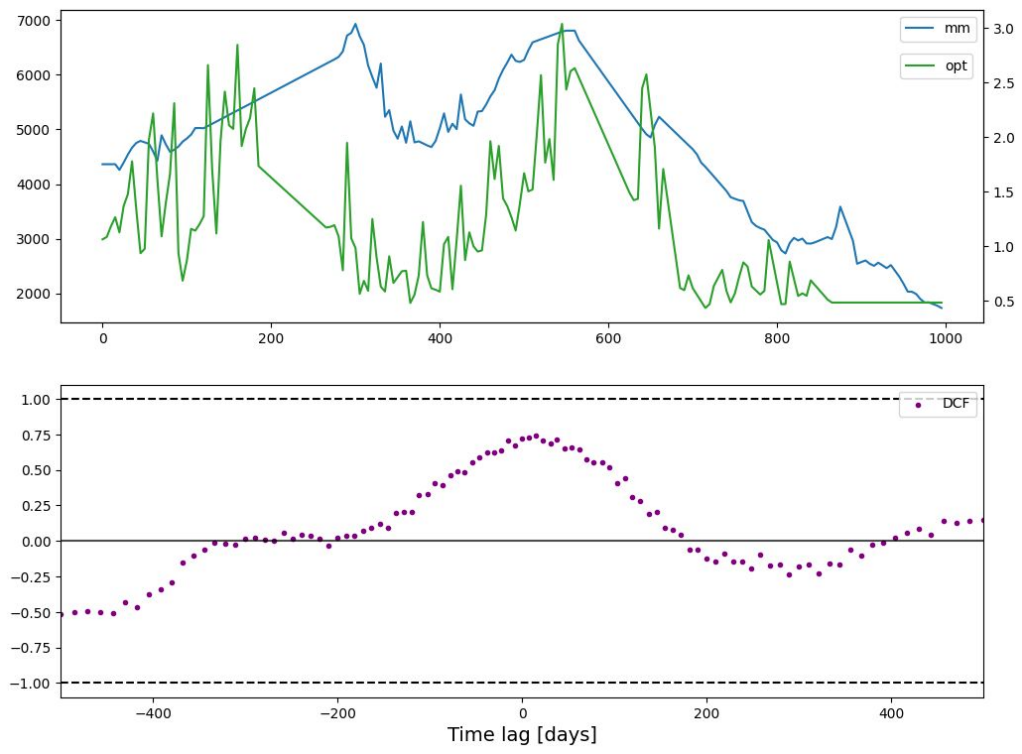


Let’s use a real light curve

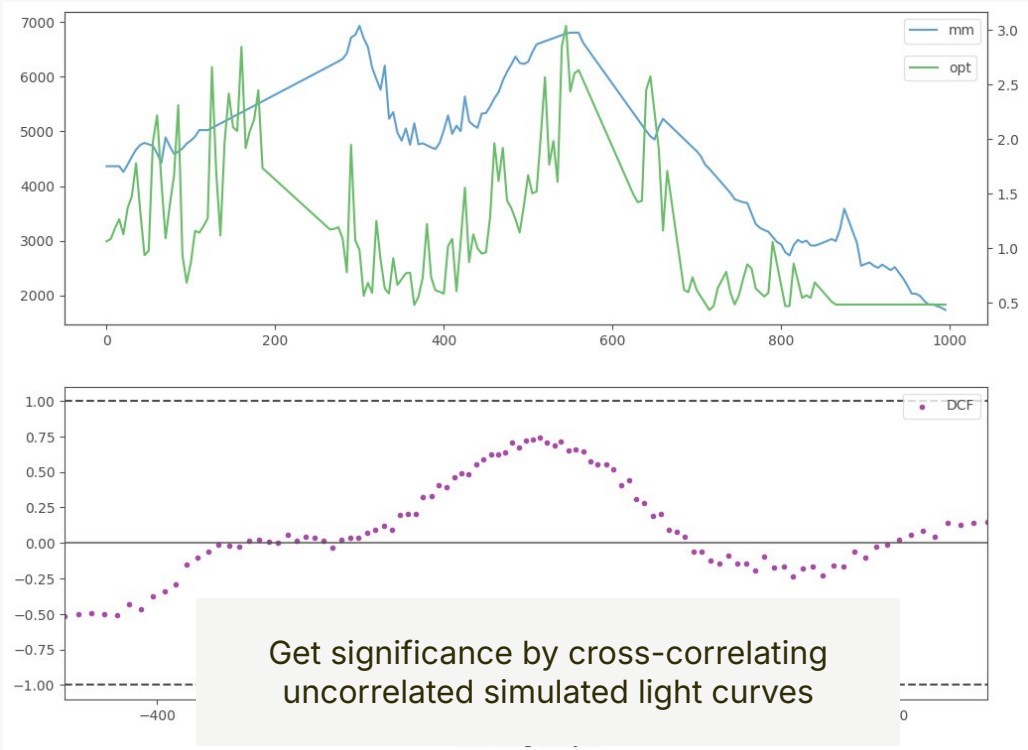
PKS 0208-512



Let’s use a real light curve



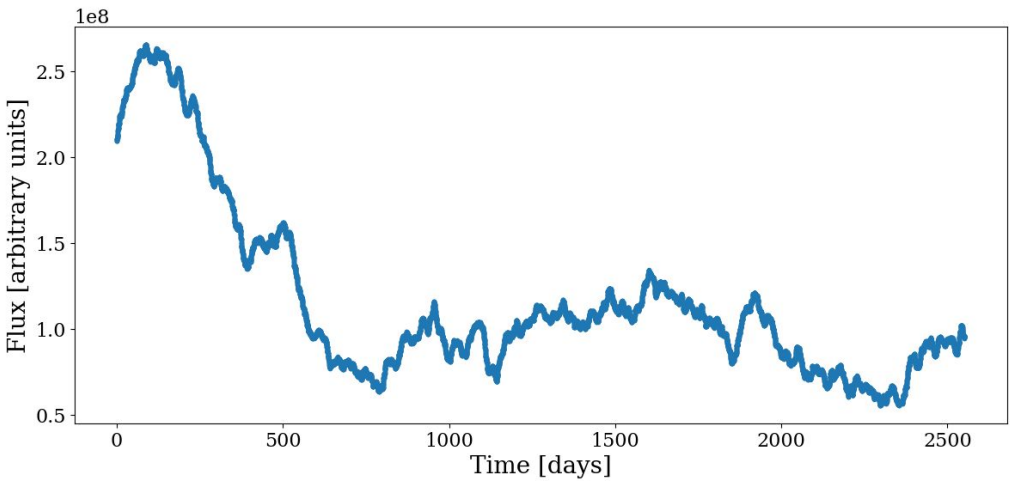
Let’s use a real light curve



Using lcsim for simulations

PSD

$$P(\nu) = A\left(\frac{\nu}{\nu_0}\right)^{-\beta}$$



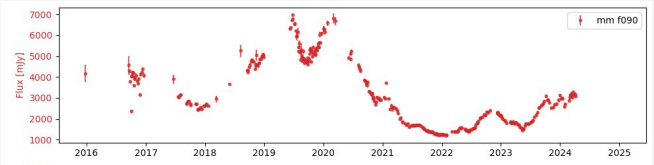
Using lcsim for simulations

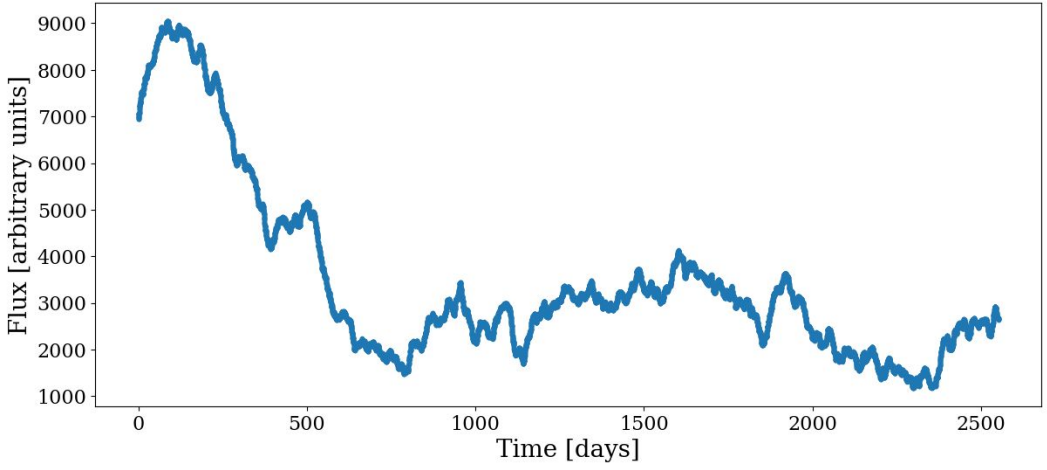
PSD

$$P(\nu) = A\left(\frac{\nu}{\nu_0}\right)^{-\beta}$$

Scale

Mean and STD





Using lcsim for simulations

PSD

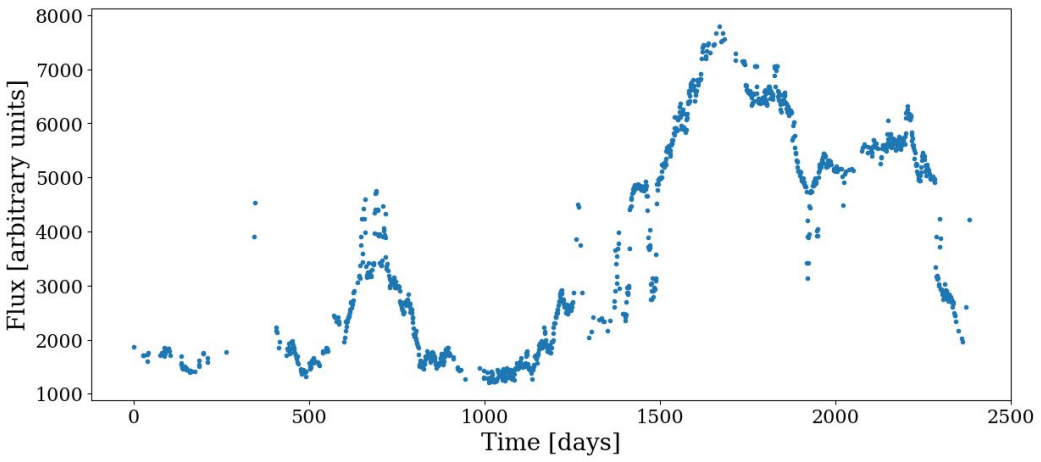
$$P(\nu) = A\left(\frac{\nu}{\nu_0}\right)^{-\beta}$$

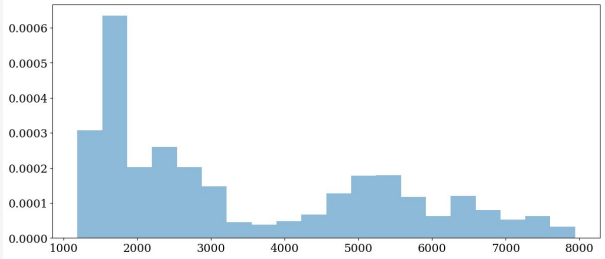
Scale

Mean and STD

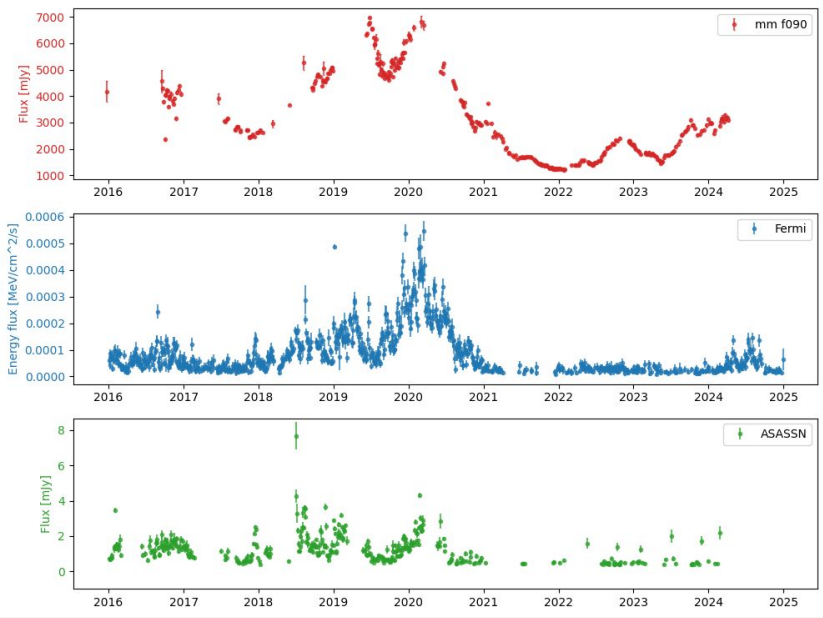
PDF

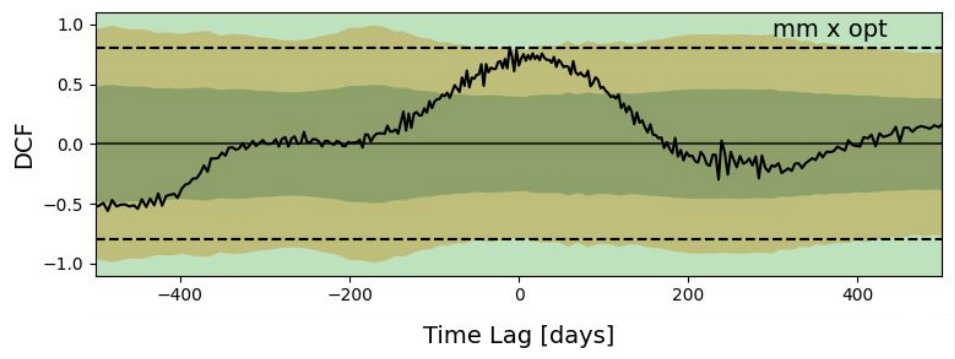
Resample





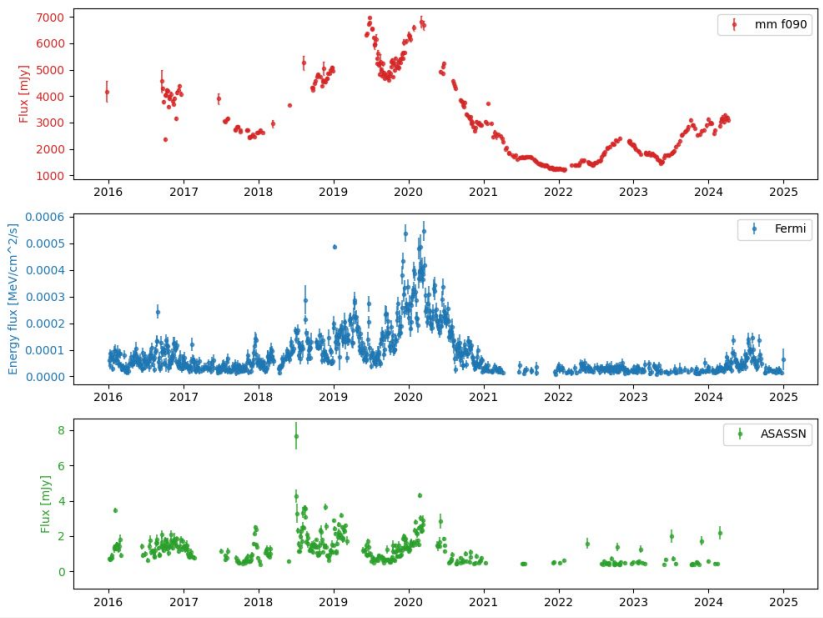
Results: mm x optical

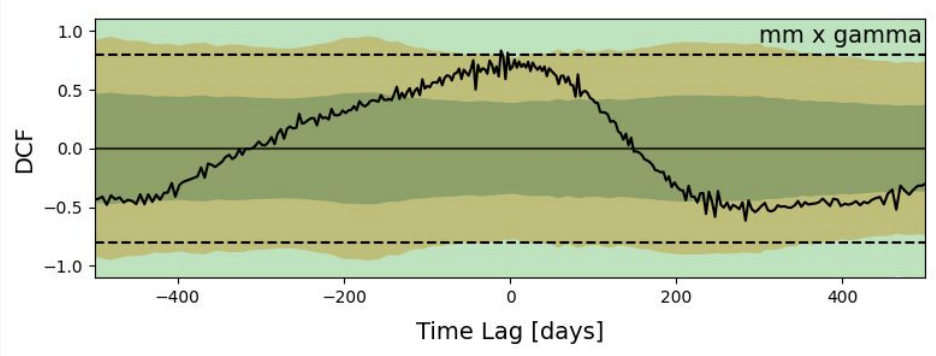




Lag = ~ 30 days

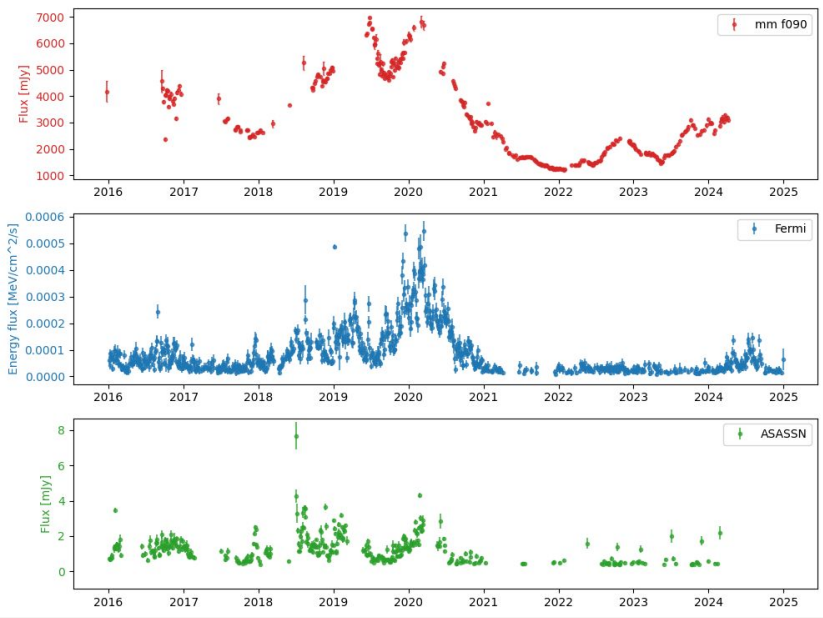
Results: mm x gamma

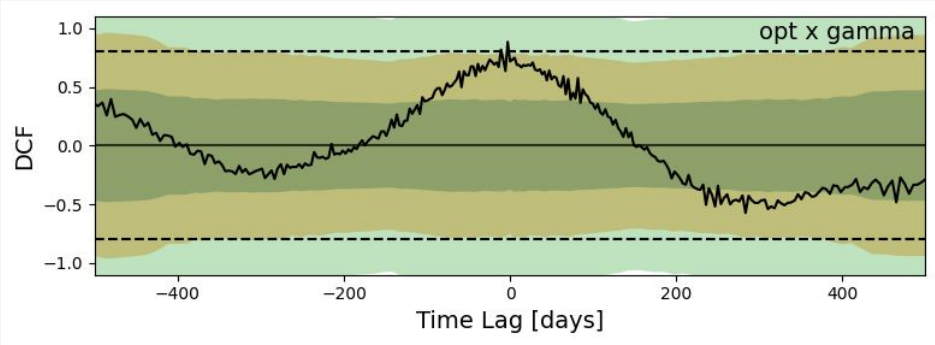




Lag = ~ 25 days

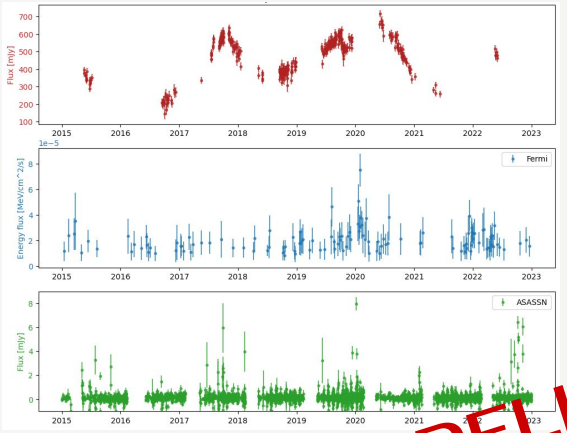
Results: optical x gamma

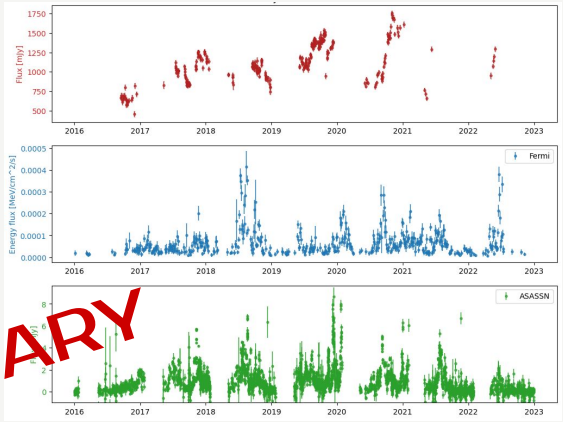




Lag = ~ 3 days

Examples of other interesting light curves





PRELIMINARY

Thank you

- Measured correlation for PKS 0208-512
- Refine analysis of time lag
- Include more light curves from our sample
- Let’s collaborate/chat !

📧 erika.hornecker@mail.utoronto.ca

Extra slides

AGN Schematic

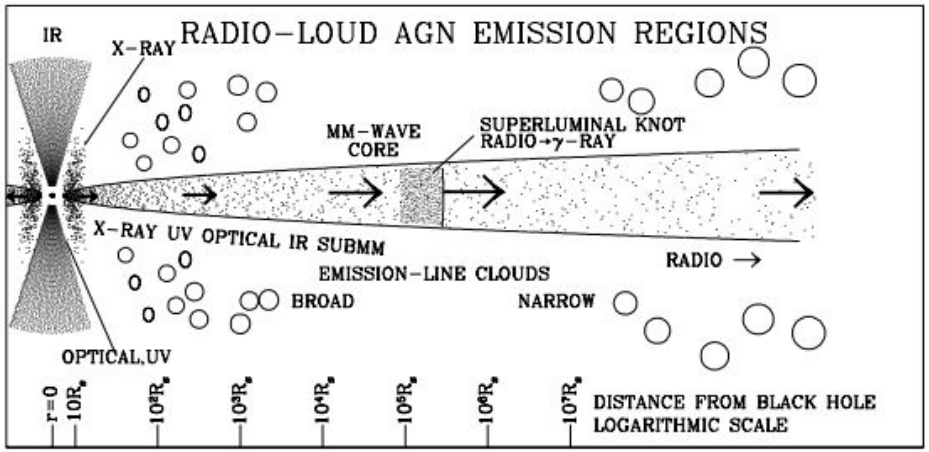
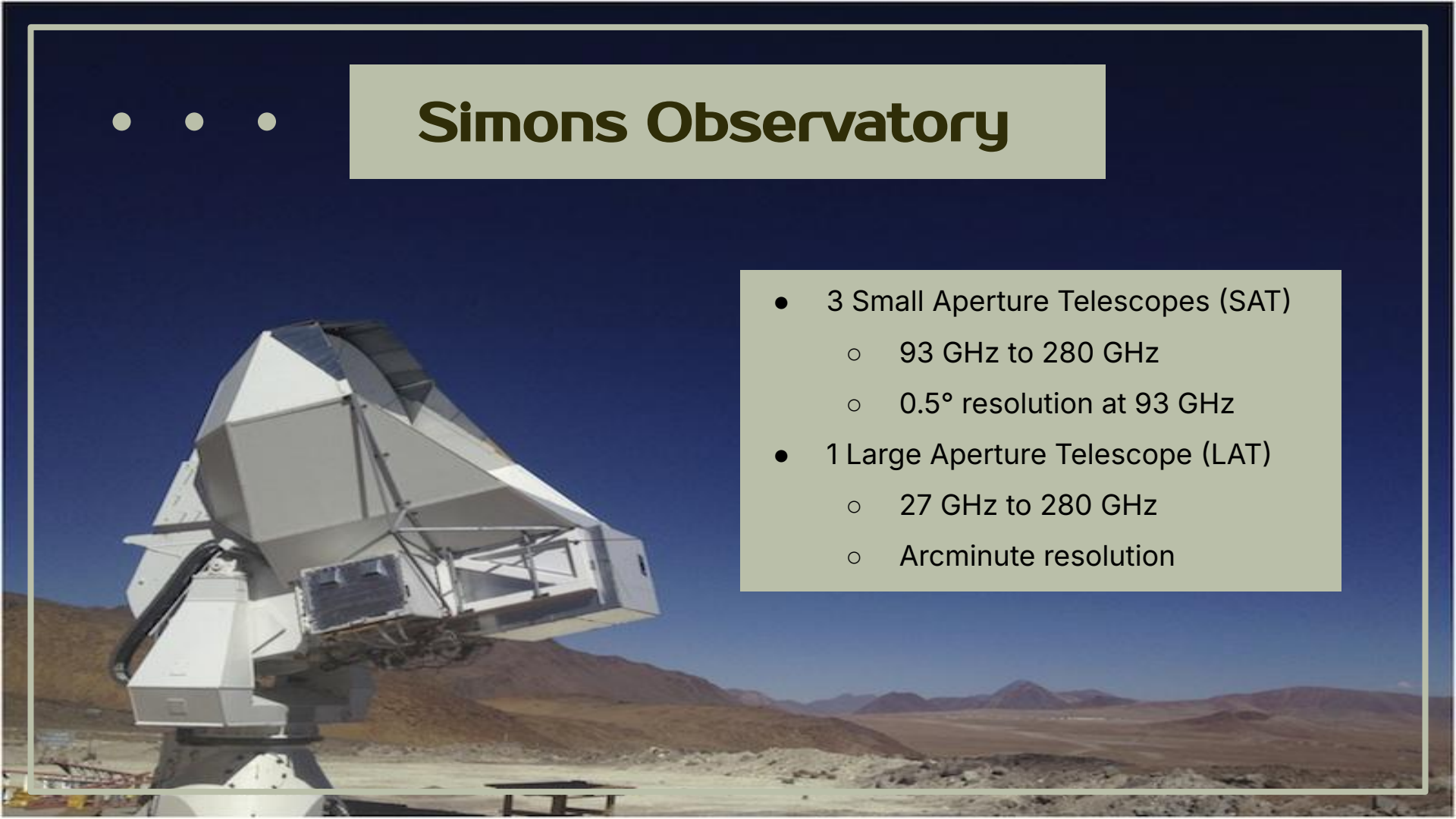


FIGURE 1. Sketch of the various sites of emission in an active galactic nucleus with a relativistic jet. The density of dots signifies in a qualitative way the intensity of the emission. The radiation produced in the jet is relativistically beamed, while the emission from outside the jet is not. It is not clear whether the emission from the ambient jet between the black hole (small black circle near the base of the jet) and the core is visible. The length of the arrows indicates the Lorentz factor of the flow. Note the logarithmic scale of approximate distance from the black hole, measured in Schwarzschild radii. (Adapted from Marscher, 2005)

From Marscher (2006)

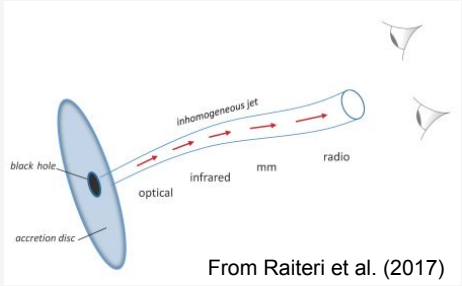
Simons Observatory



- 3 Small Aperture Telescopes (SAT)
  - 93 GHz to 280 GHz
  - 0.5° resolution at 93 GHz
- 1 Large Aperture Telescope (LAT)
  - 27 GHz to 280 GHz
  - Arcminute resolution

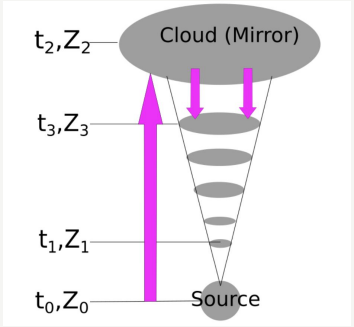
Variability models

Jet geometry



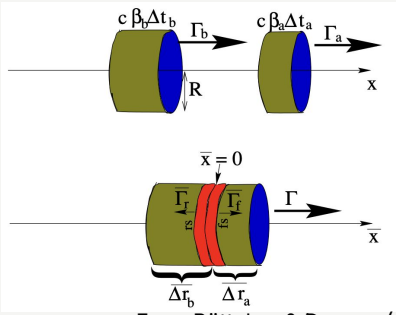
From Raiteri et al. (2017)

Synchrotron mirror model



From Oberholzer & Böttcher (2019)

Internal shock models



From Böttcher & Dermer (2010)

Multiwavelength cross-correlation

Correlation between mm/optical/gamma-ray ?

A Hadronic Synchrotron Mirror Model for the "Orphan" TeV Flare in 1ES 1959+650

Markus Böttcher[1]

Lightcurves:

- Gamma-ray : Fermi-LAT LCR
- Optical : ASAS-SN

Does this support leptonic/hadronic models?

IMPLICATIONS OF THE ANOMALOUS OUTBURST IN THE BLAZAR PKS 0208–512

Ritaban Chatterjee[1], Krzysztof Nalewajko[2], and Adam D. Myers[1]

Published 2013 June 21 •

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

J. C. Hood II,[1,2,3] A. Simpson,[4] A. McDaniel,[5] A. Foster,[6] P. A. R. Ade,[7] M. Ajello,[5] A. J. Anderson,[8]