SII on complex objects: Analysis of VERITAS-SII data on Spica

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VERITAS

The Ohio State University

Outline

- Lessons from the Gamma Cassiopeiae analysis
  - Difficulties in representing non-round sources
  - Attention to small details in the data

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- Pushing SII further
  - Dynamic systems: Spica

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  - Difficulties in representing non-round sources
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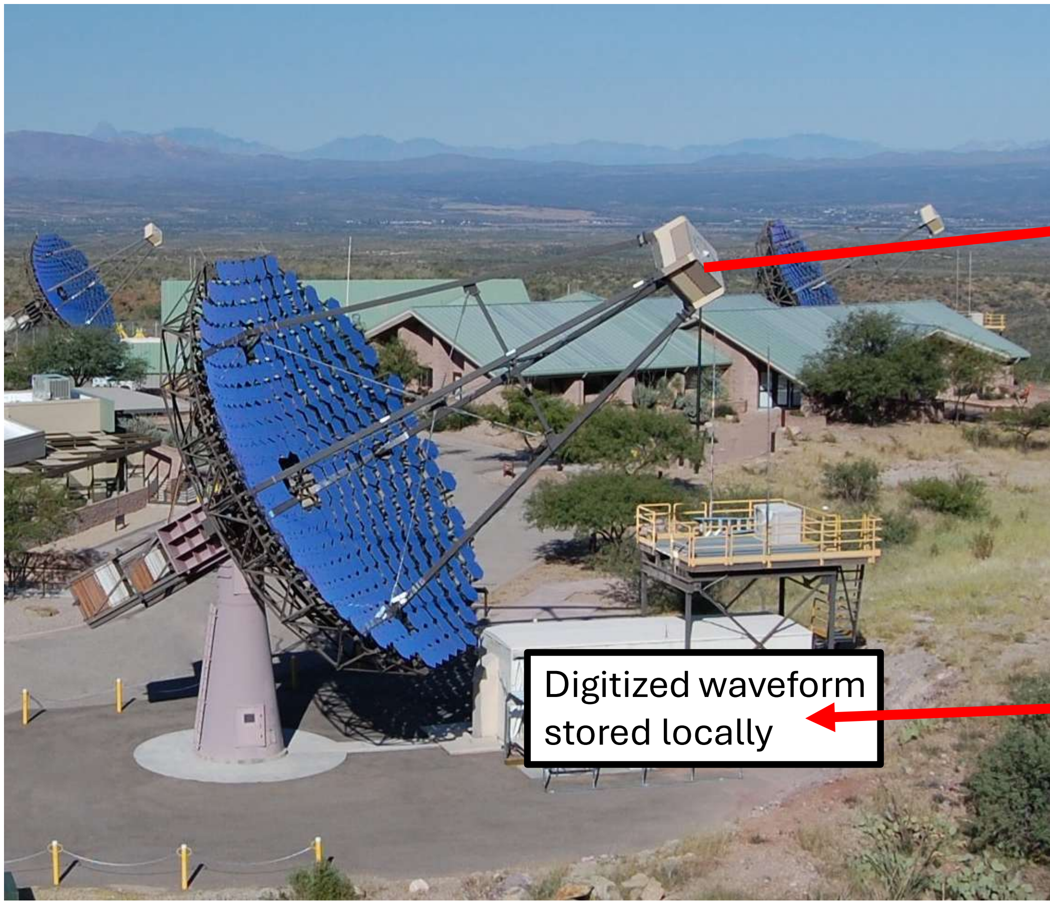
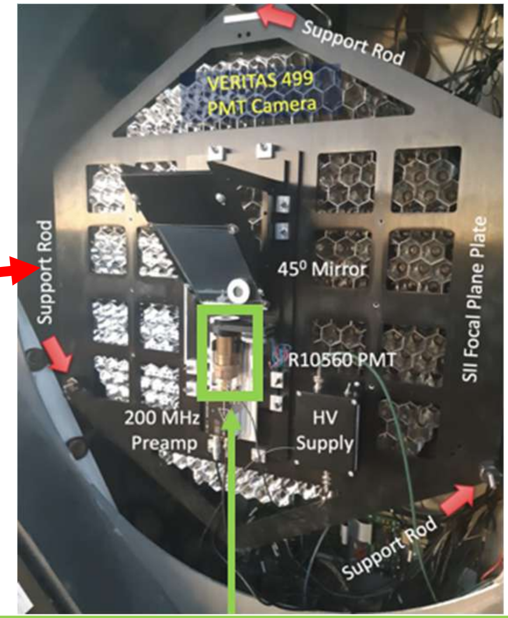
- Pushing SII further
  - Dynamic systems: Spica

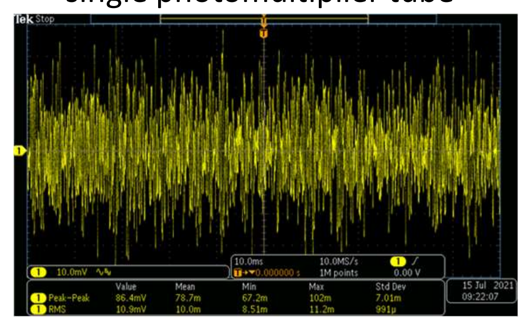
- Analysis procedures
  - Tracking corrections
  - 79 MHz
  - Splitting up runs

VERITAS SII

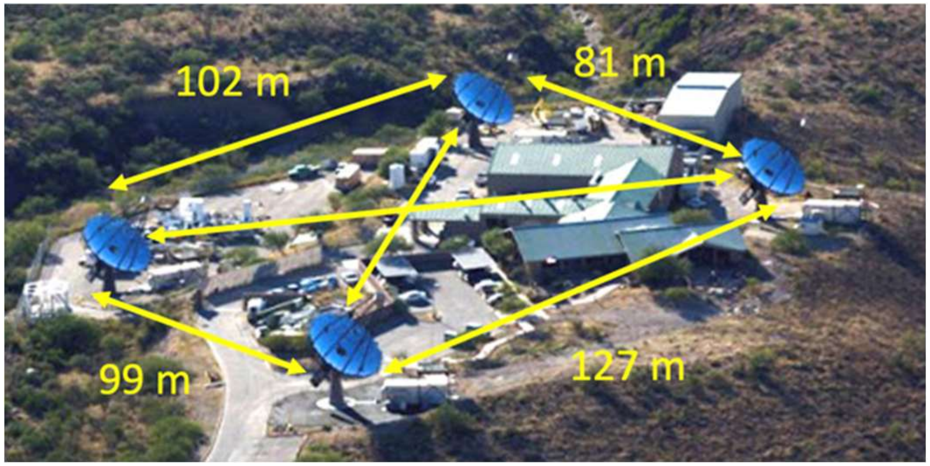


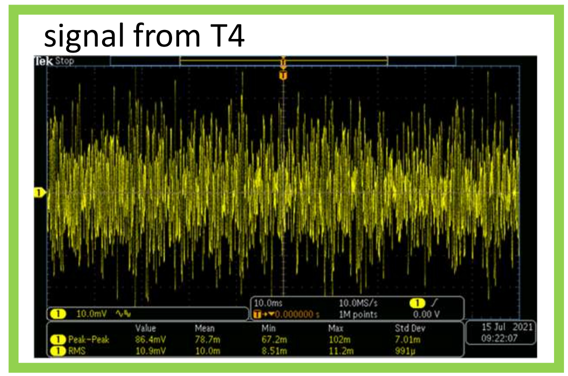


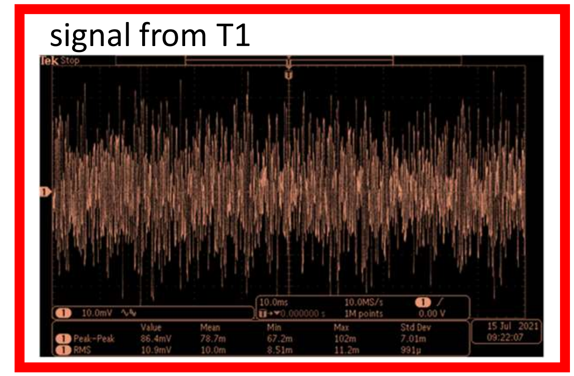
single photomultiplier tube



VERITAS SII

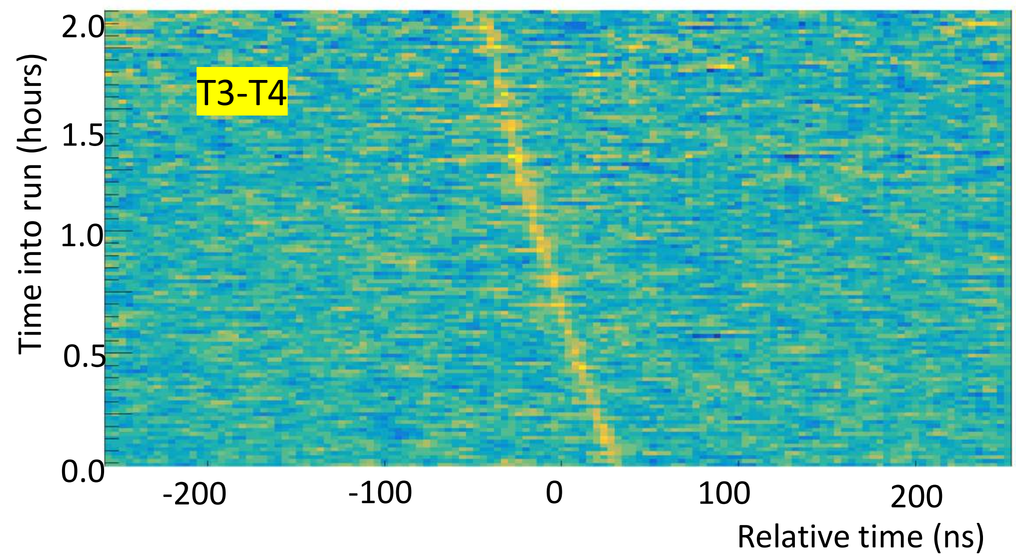






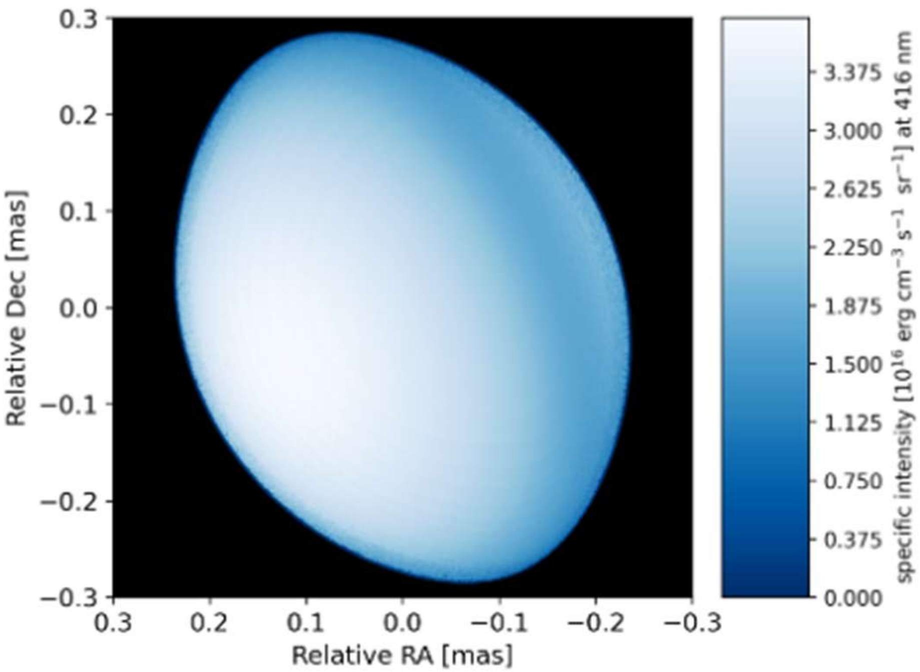
- 6 telescope pairs
- 30-175 meter projected baselines

2-hour observation → 6.5 TB of data stored to disk



Gamma Cassiopeiae Paper

- First oblate measurement with SII
- VERITAS (2025), DOI: 10.3847/1538-4357/ae0744



Measurement of the photosphere oblateness of γ Cassiopeiae via Stellar Intensity Interferometry with the VERITAS Observatory

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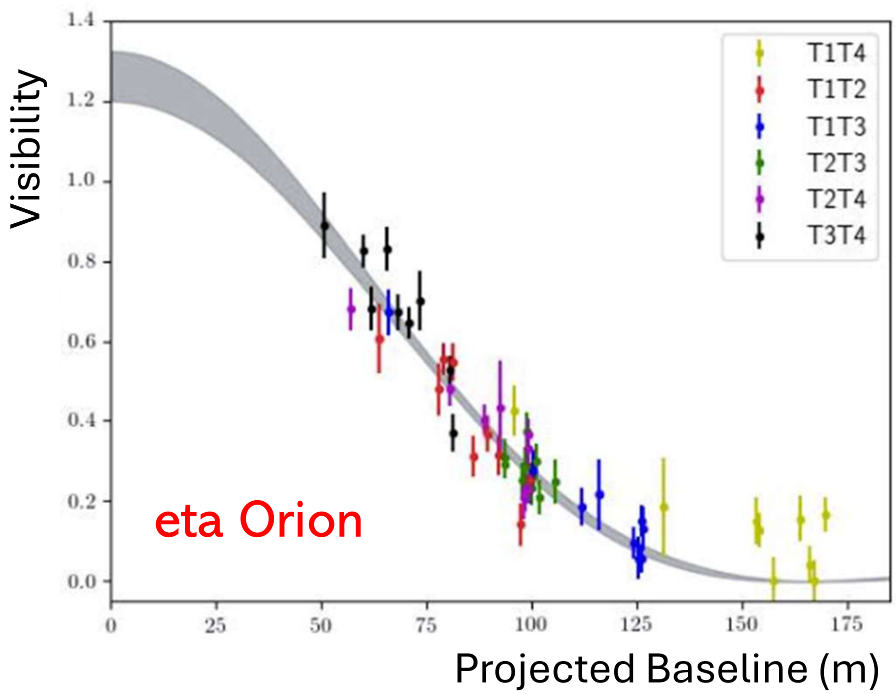
https://arxiv.org/pdf/2506.15027

Visibility vs Baseline

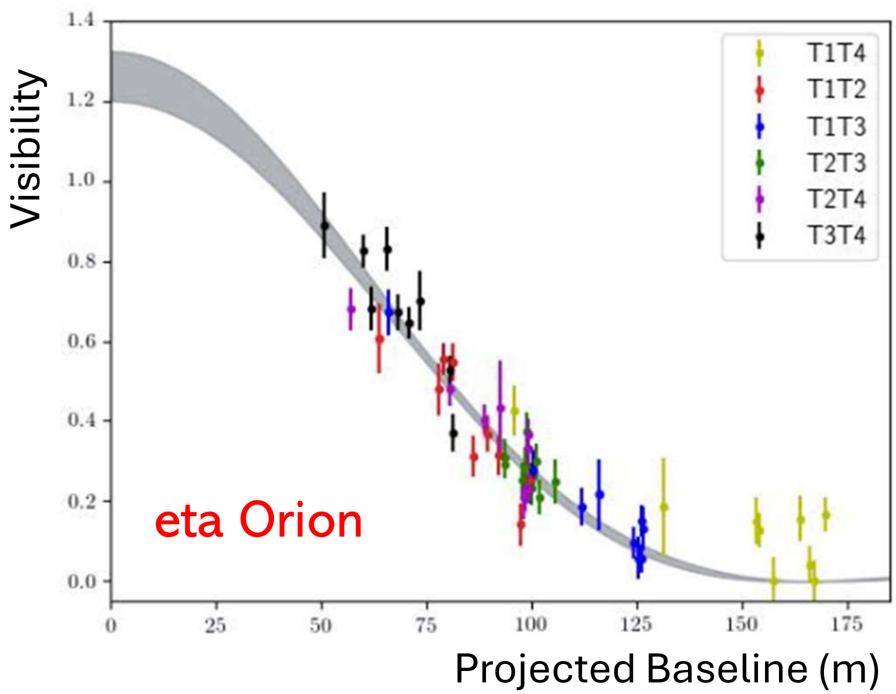
- For a round source, visibility only depends on the magnitude of the baseline



VERITAS (2020), DOI:10.1038/s41550-020-1143-y

Visibility vs Baseline

- For a round source, visibility only depends on the magnitude of the baseline
- For non round source, it depends on orientation of the baseline vector
- Poor representation of the data



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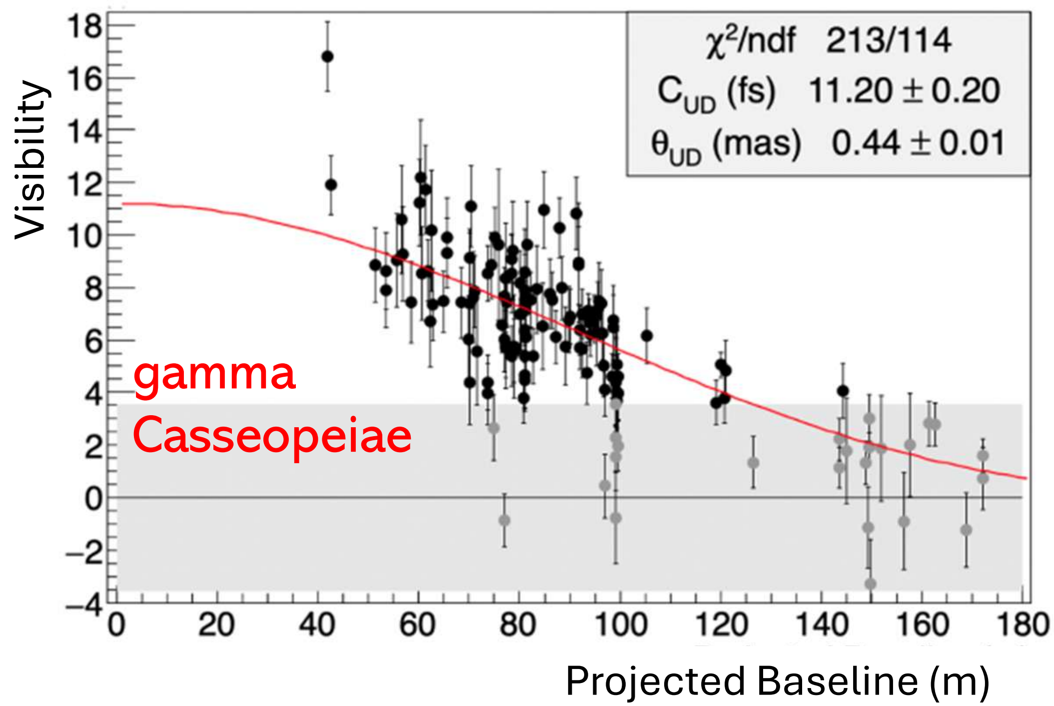
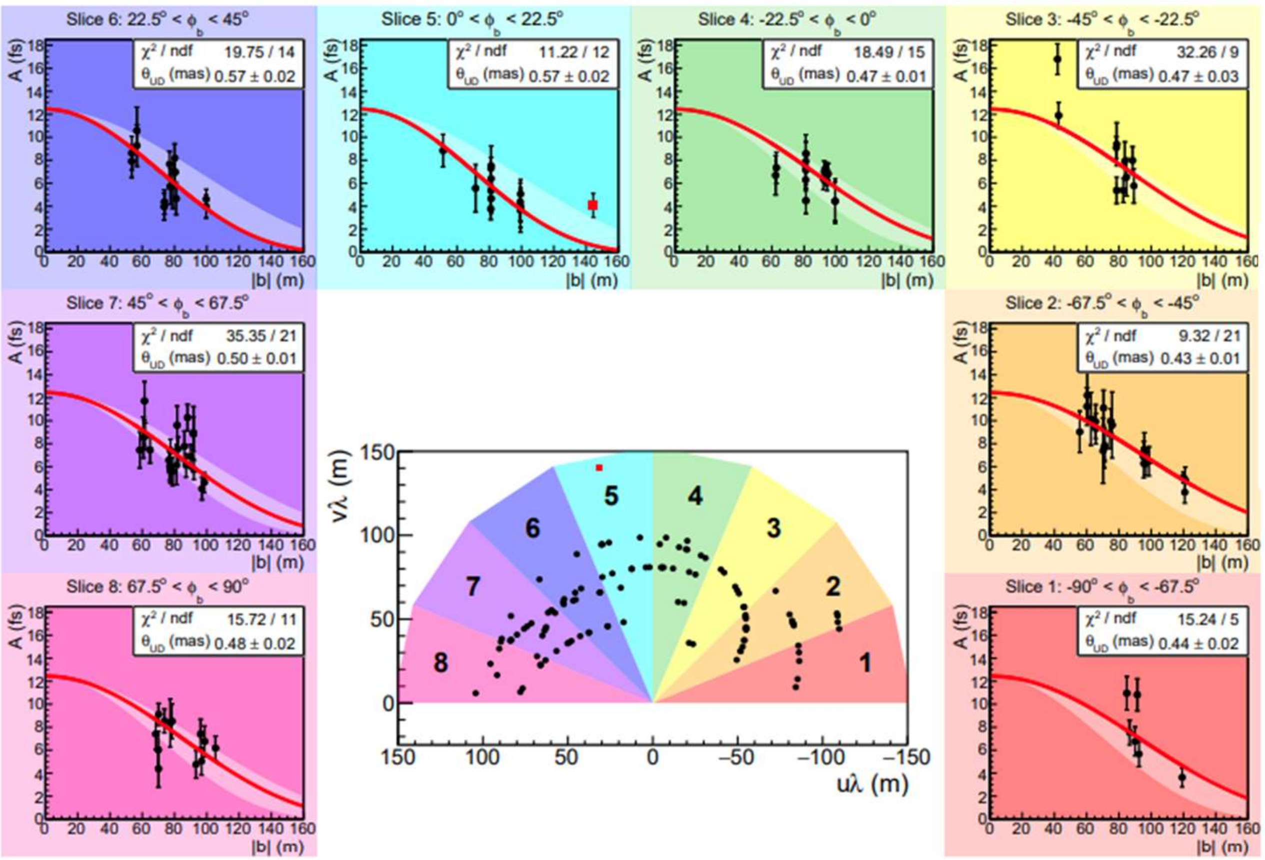


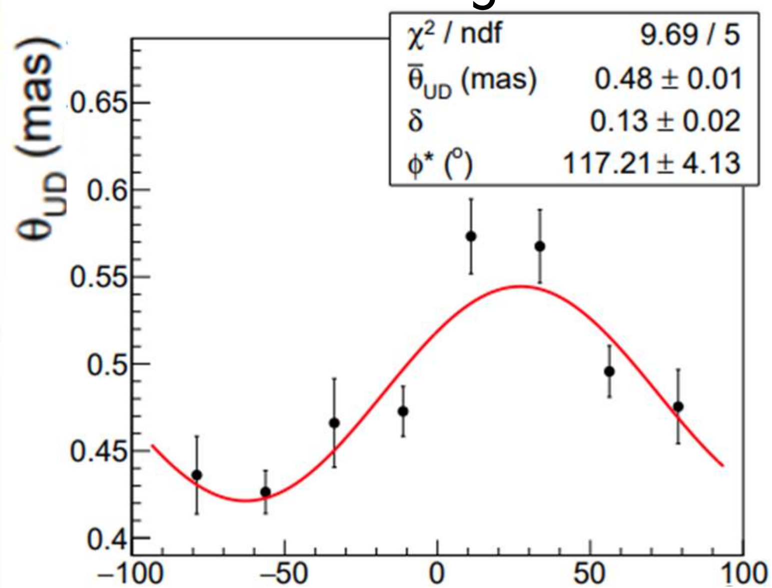
VERITAS (2025), DOI 10.3847/1538-4357/ae0744

Intuitive way to plot non-round sources

- A more intuitive way to plot: “slices” of the UV plane



Clear evidence of anisotropy at the 6 sigma level



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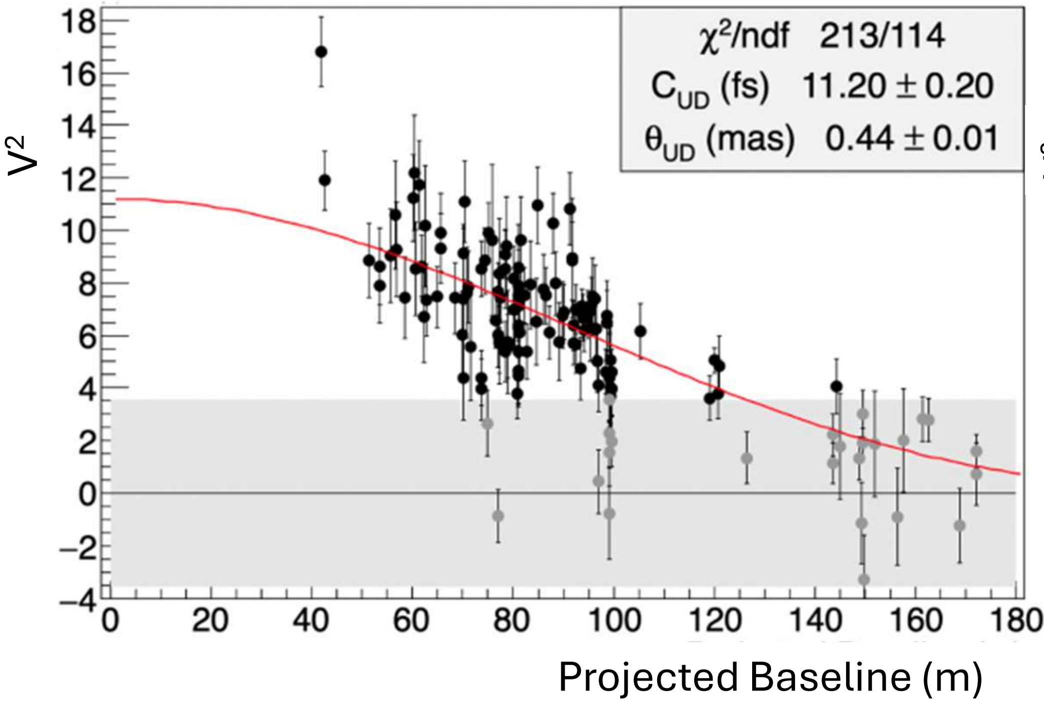
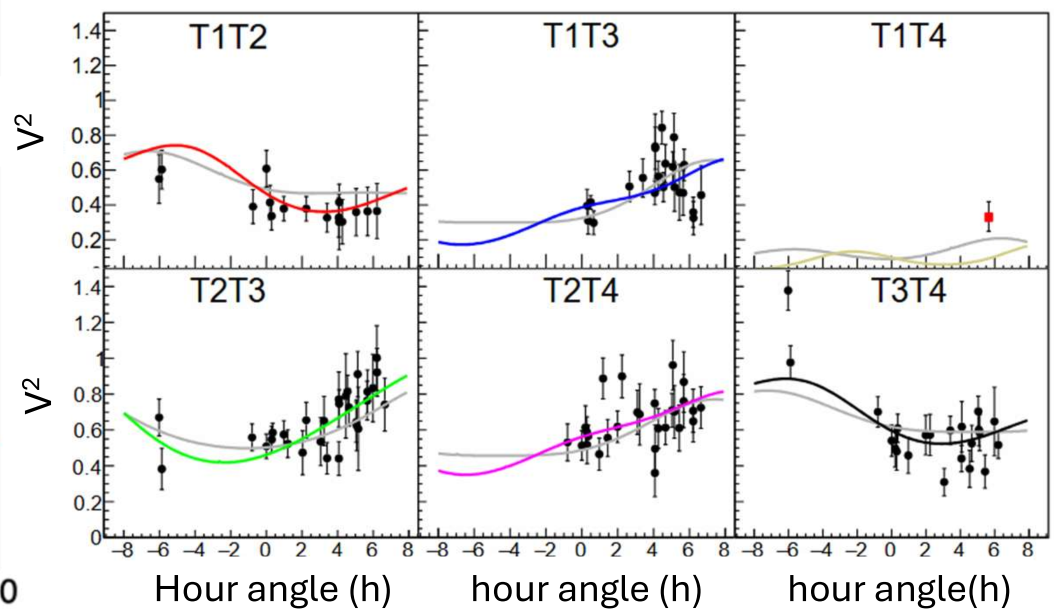
More correct way to plot

- Separate by pair and hour angle
- For a given telescope pair and hour angle, one unique visibility



Uniform Ellipse Model

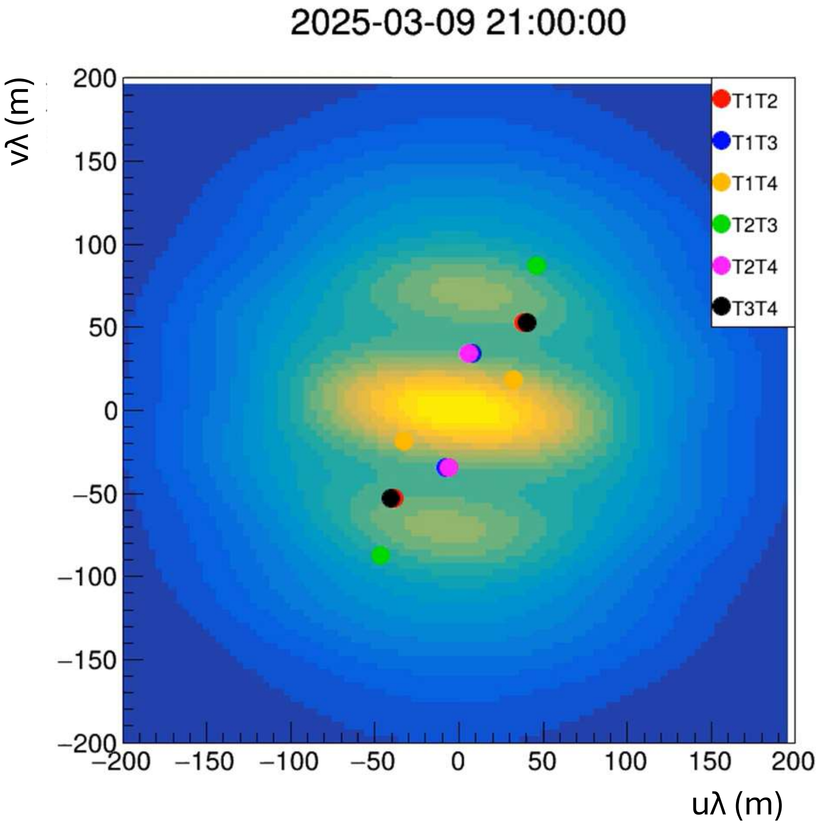


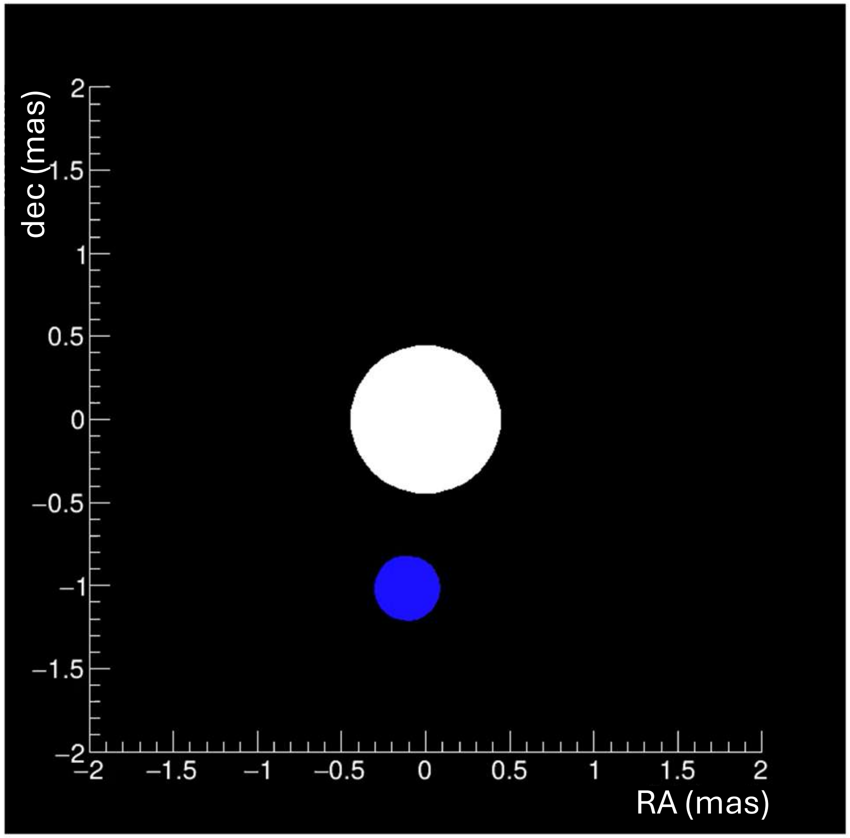
- Gray curves = round model

VERITAS (2025), DOI 10.3847/1538-4357/ae0744

alpha Virginis (Spica)

- Binary star with a period of 4.01 days
- Milestone for modern SII
- Fringe and UV tracks change independently





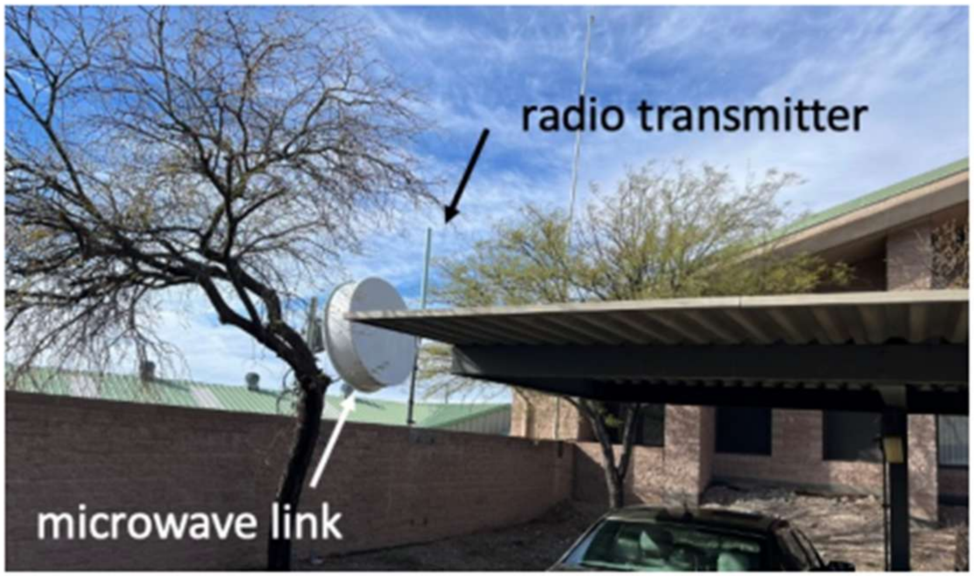
alpha Virginis

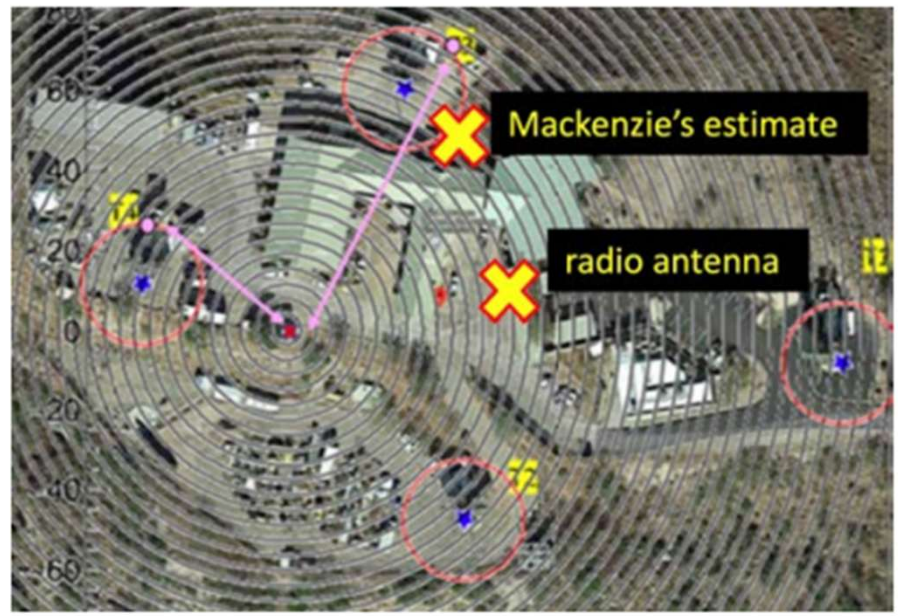
- 4 observation campaigns between February 2024 and May 2025
- ~40 hours of observations
  - ~225 pair hours

UTC Date	Active Telescopes	79 MHz?	Observation Length (hours)
2024-02-22	T1, T2, T3, T4	Yes	5.41
2024-02-24	T1, T2, T3, T4	Yes	5.66
2024-05-17	T1, T2, T3, T4	Yes	0.98
2024-05-23	T2, T3, T4	Yes	1.80
2024-05-24	T2, T3	Yes	2.71
2024-05-25	T1, T2, T3, T4	Yes	3.85
2024-05-26	T1, T2, T3, T4	Yes	2.05
2025-03-10	T1, T2, T4	No	5.17
2025-03-11	T1, T2, T4	No	6.40
2025-05-07	T1, T3, T4	No	5.41
2025-05-15	T1, T2, T3, T4	No	4.92
2025-05-16	T1, T2, T3, T4	No	5.17

79 MHz Removal

- Extraneous noise from onsite communication radios

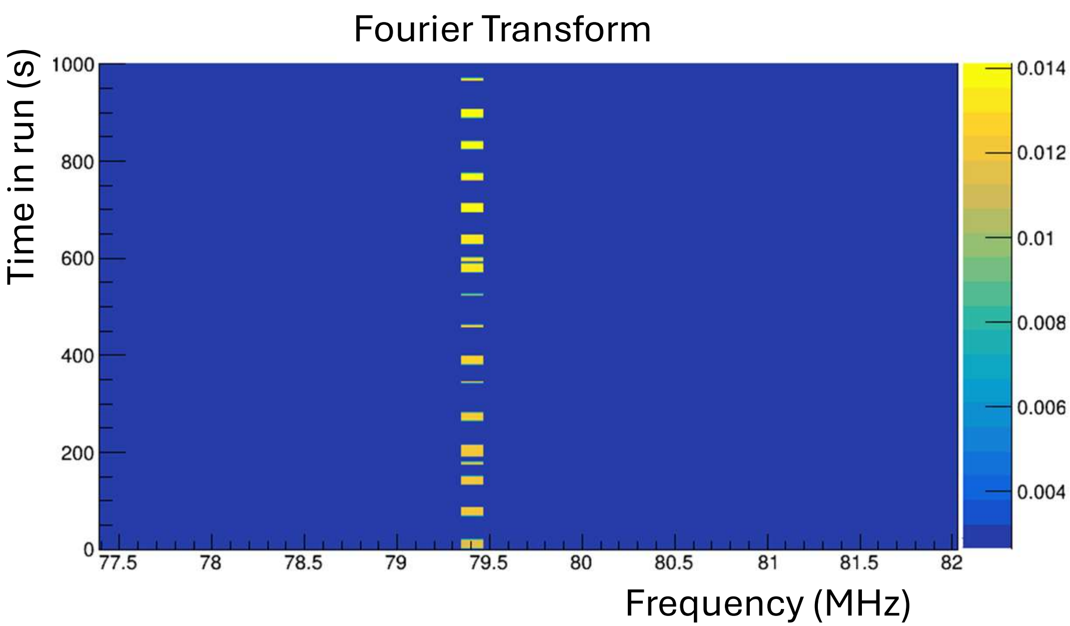


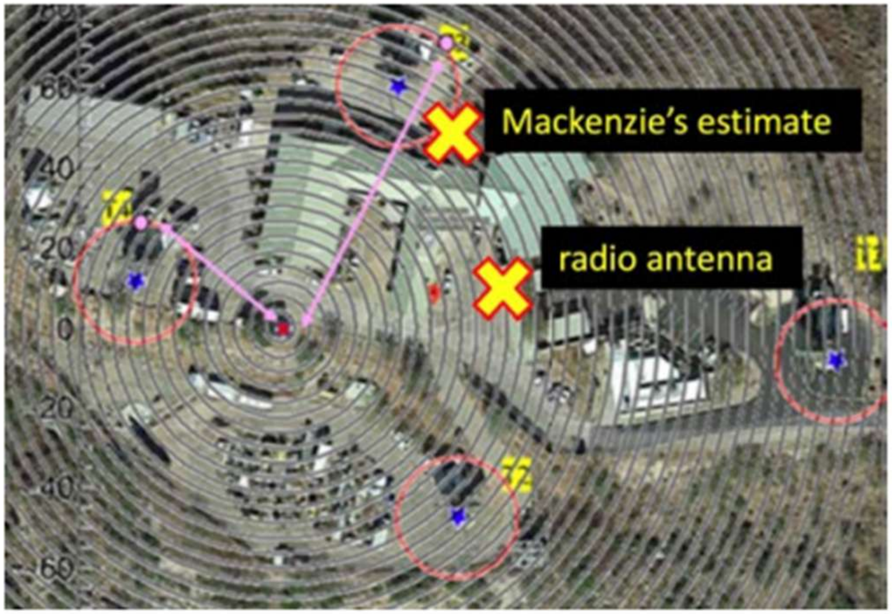


Results of 2021 study by Mackenzie (Scott)
Ticoras very close to actual source of noise

79 MHz Removal

- Extraneous noise from onsite communication radios
- ~30% of the data is contaminated





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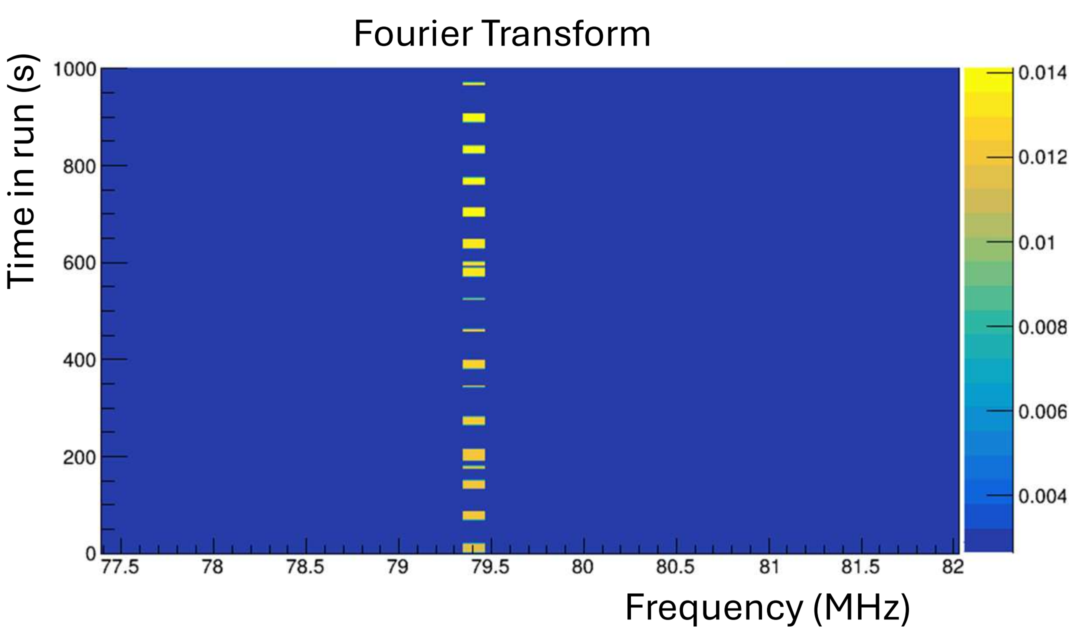
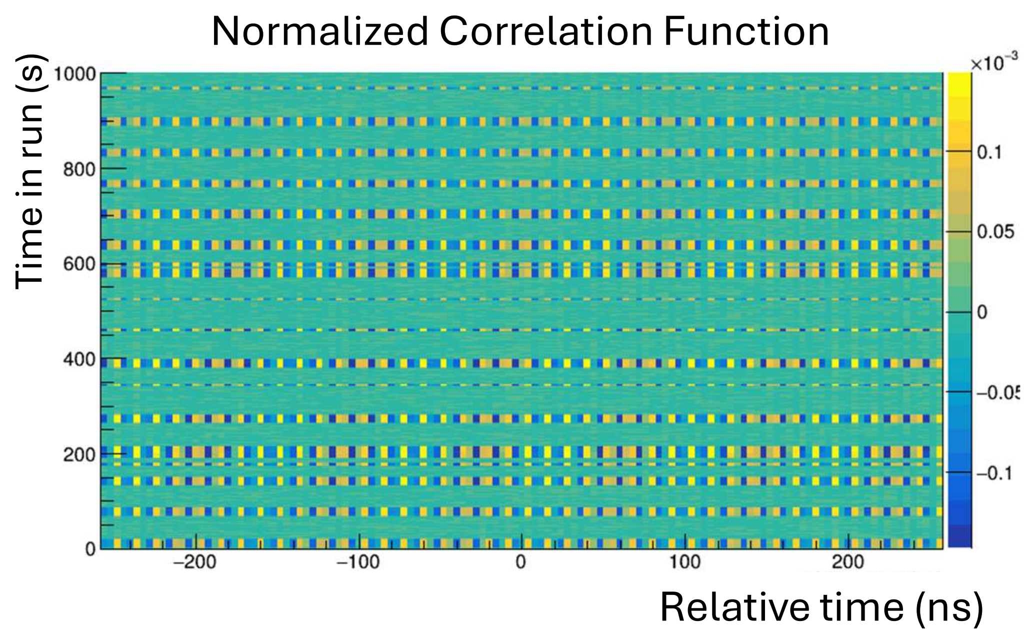
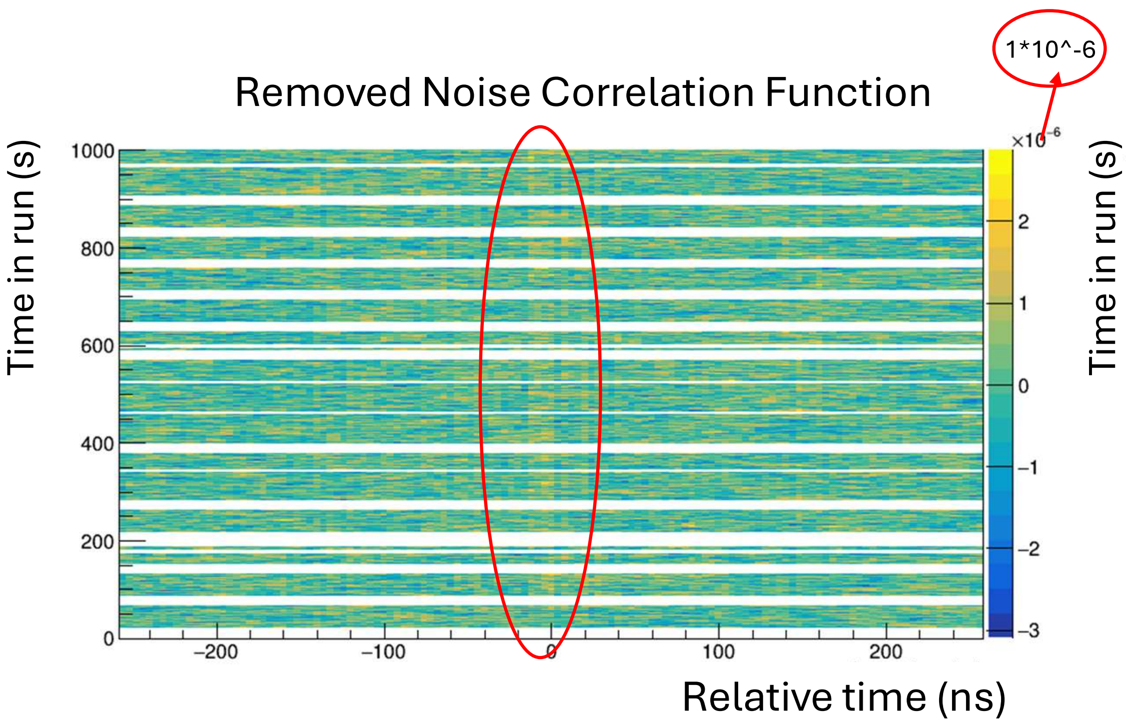
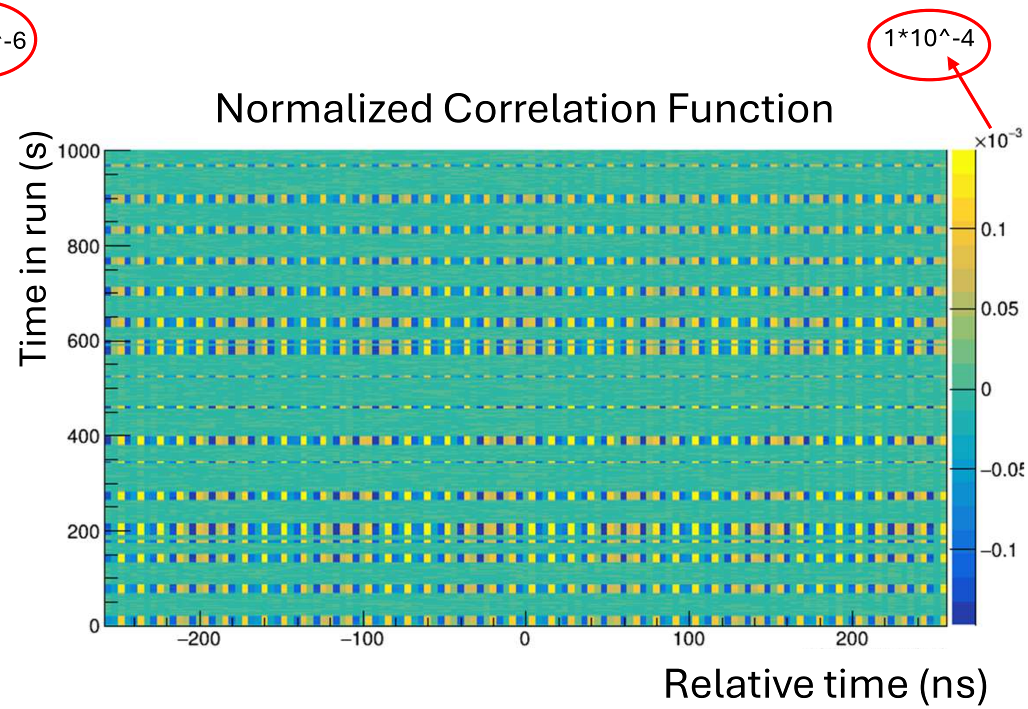




79 MHz Removal

- Extraneous noise from onsite communication radios
- ~30% of the data is contaminated
- Remove times where the radios were active

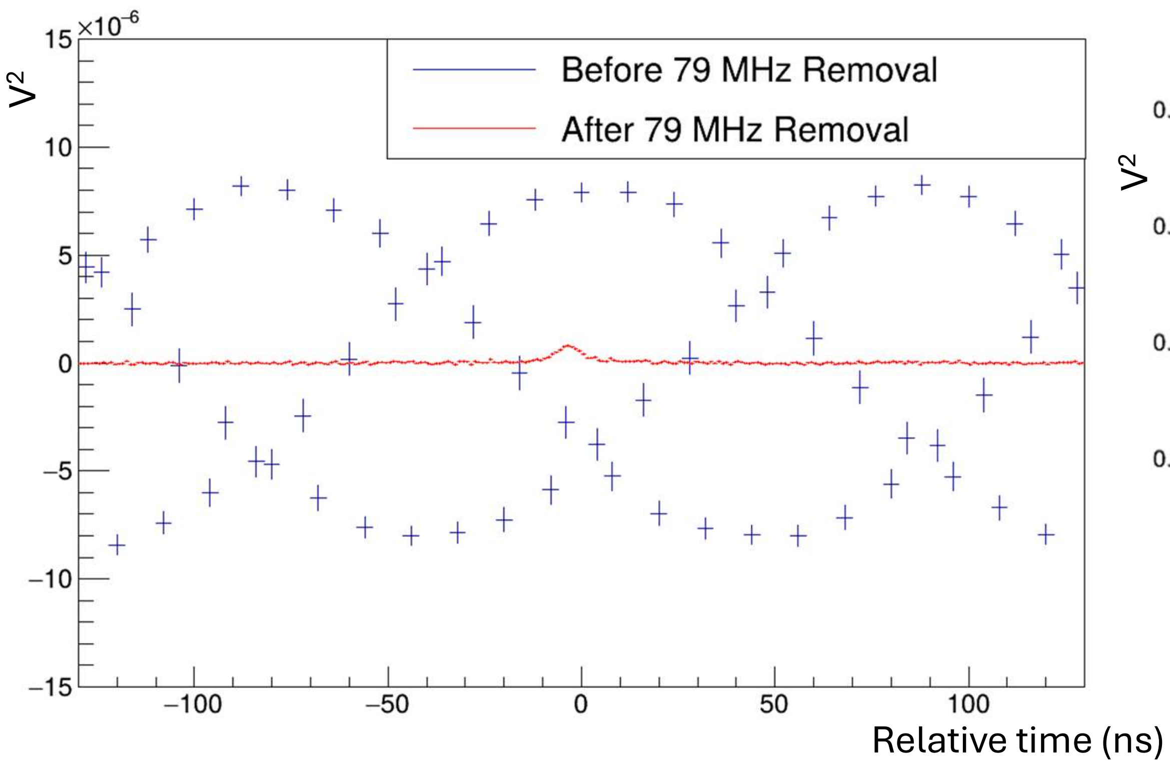




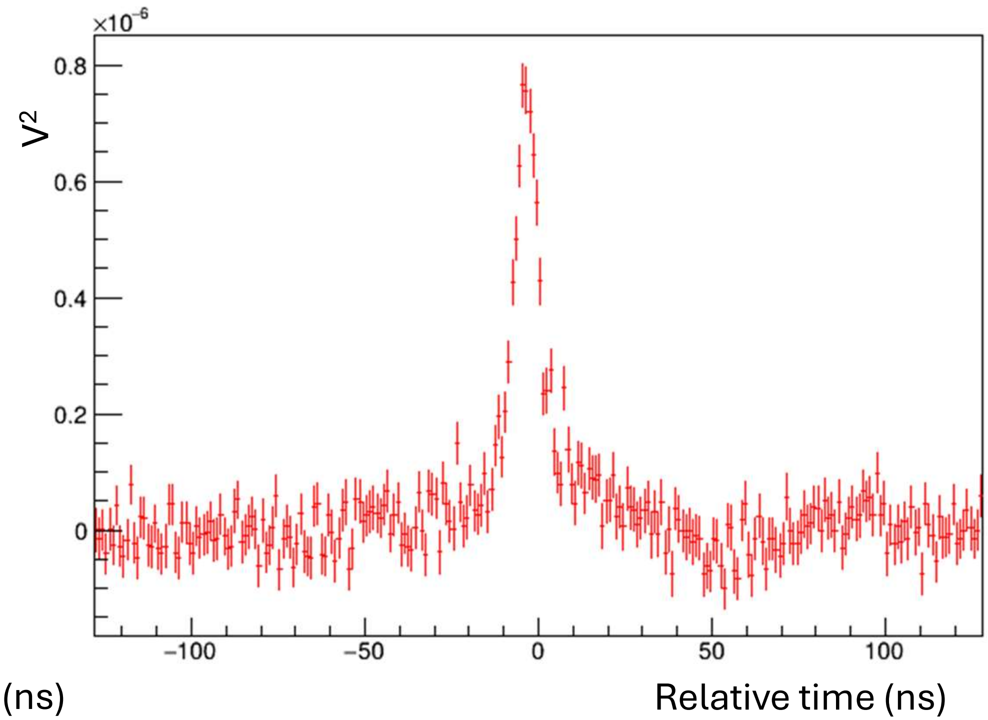
79 MHz Removal

- Data unusable until it's removed

Projected Correlation Function

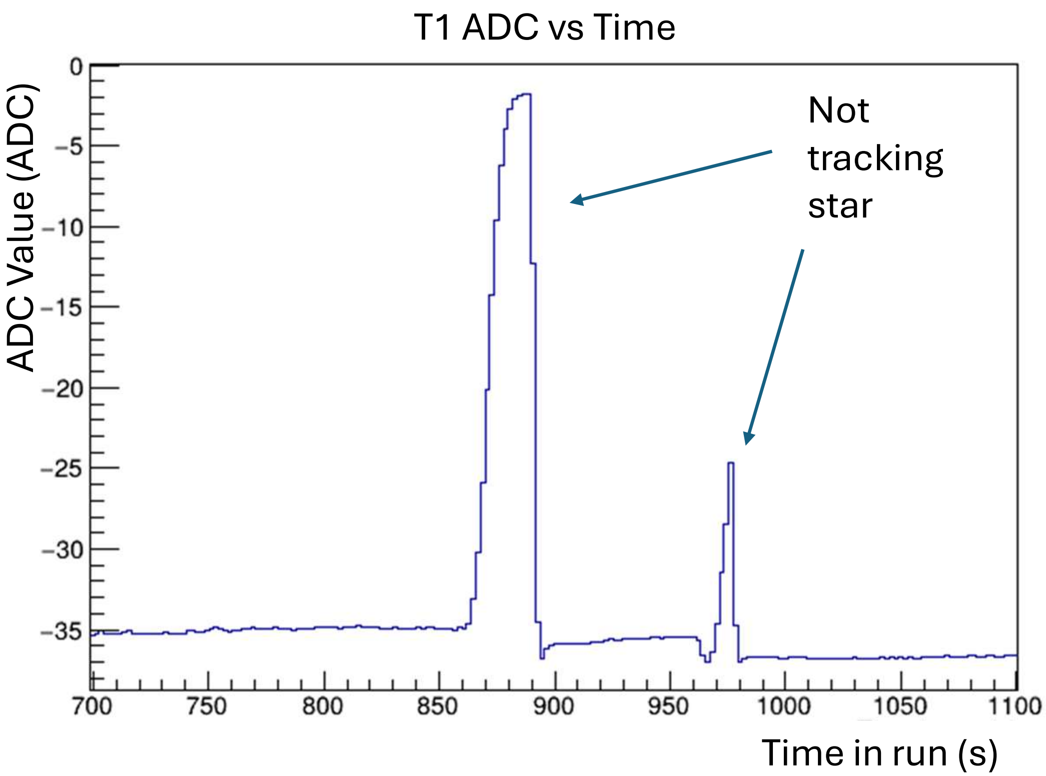


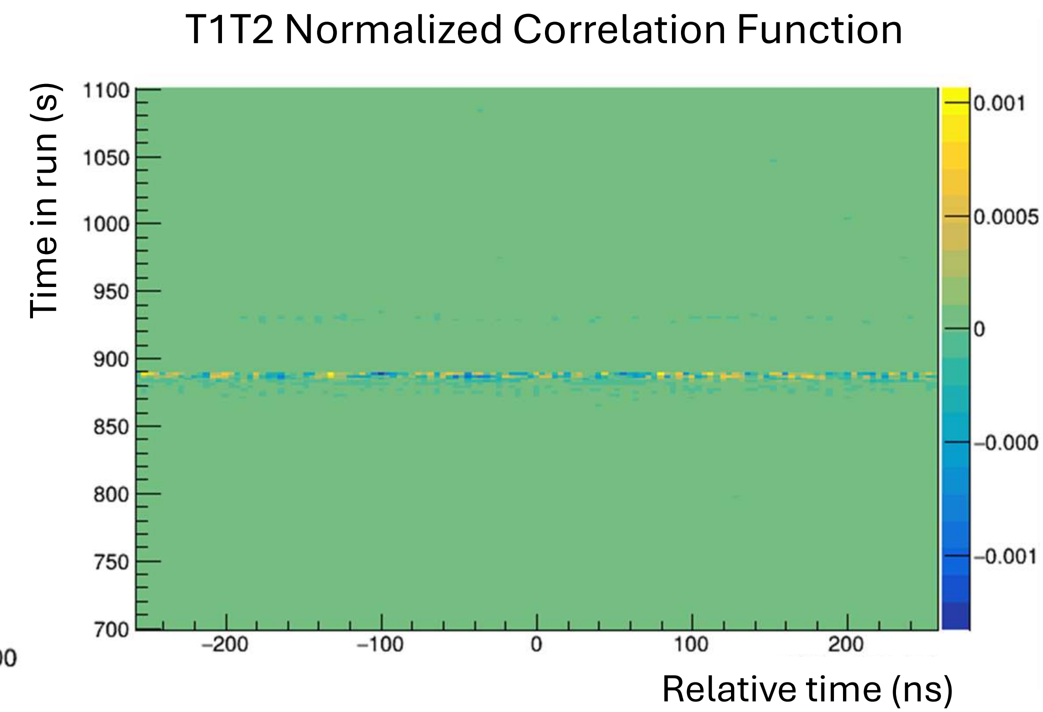
After 79 MHz frames removed



Tracking Frame Removal

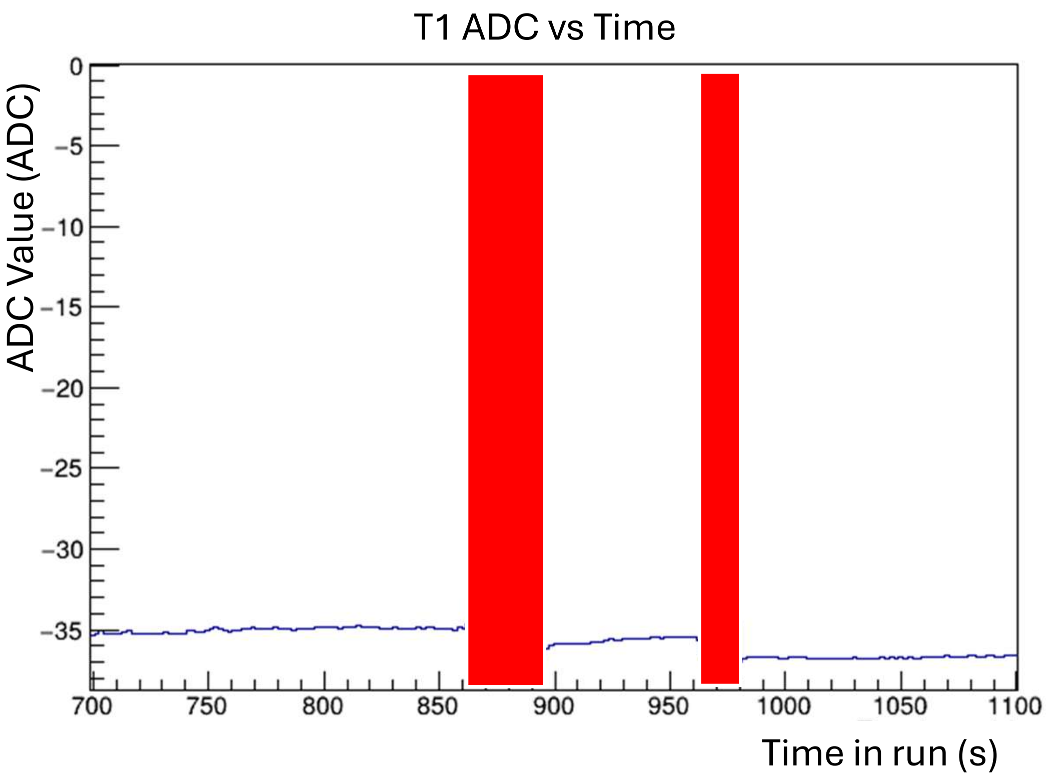
- Corrections to tracking software cause discrepancies in the normalization of the correlation function
- Seen in severe drops in ADC counts
  - Note that our ADC values are negative, so a spike upwards corresponds to a drop in signal

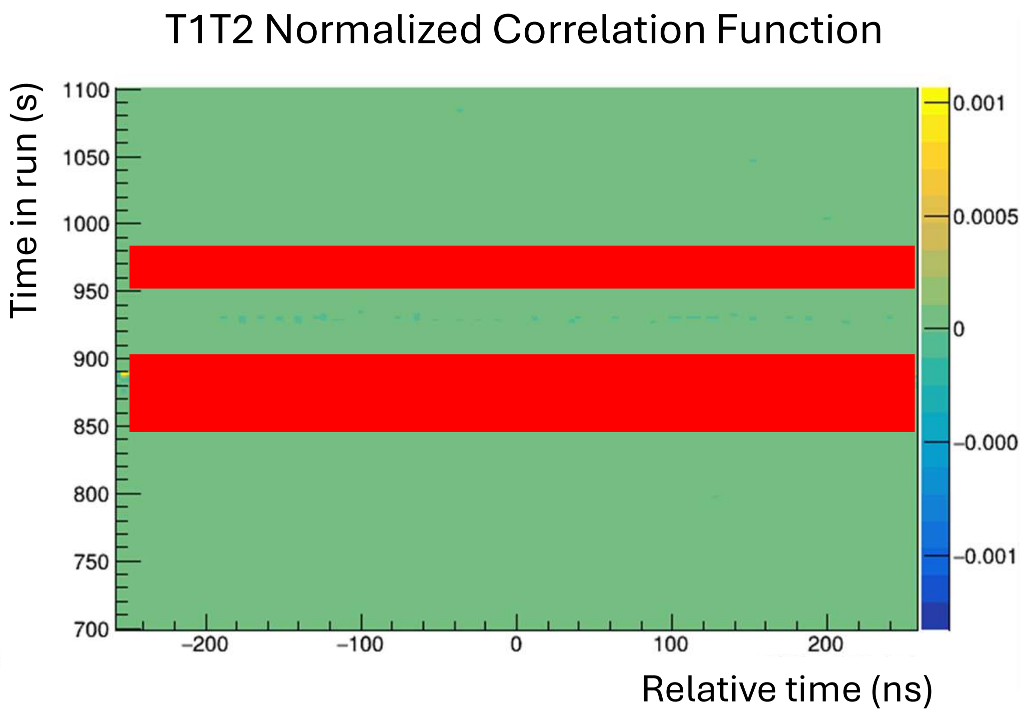




Tracking Frame Removal

- Identify bad tracking corrections using the average ADC versus time





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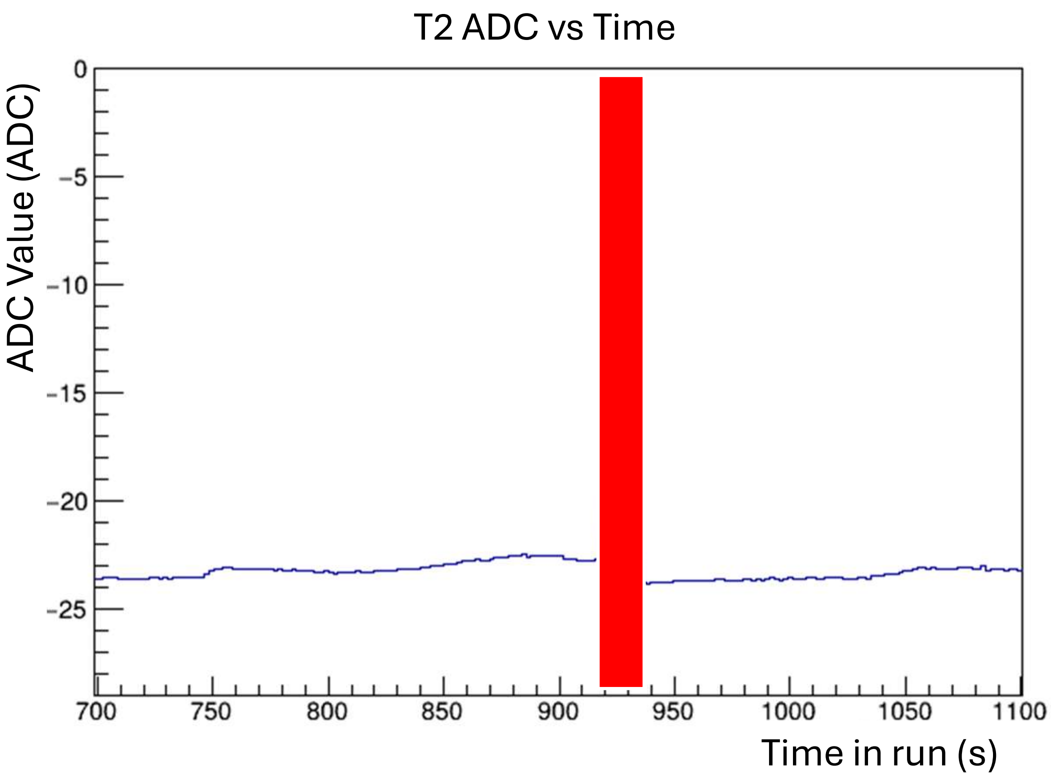
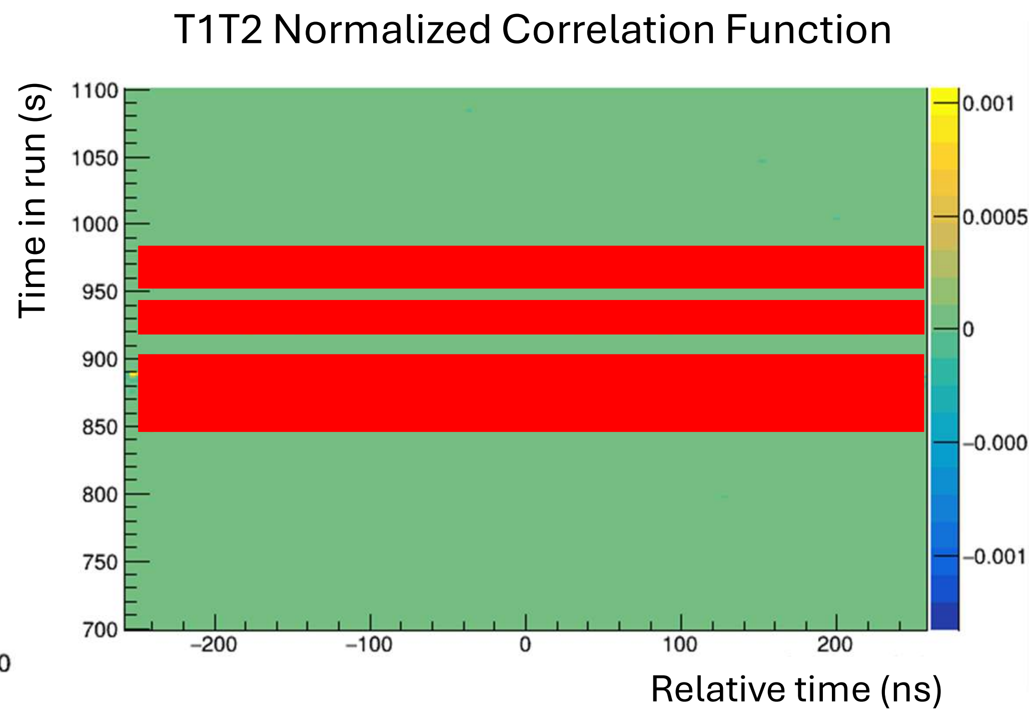
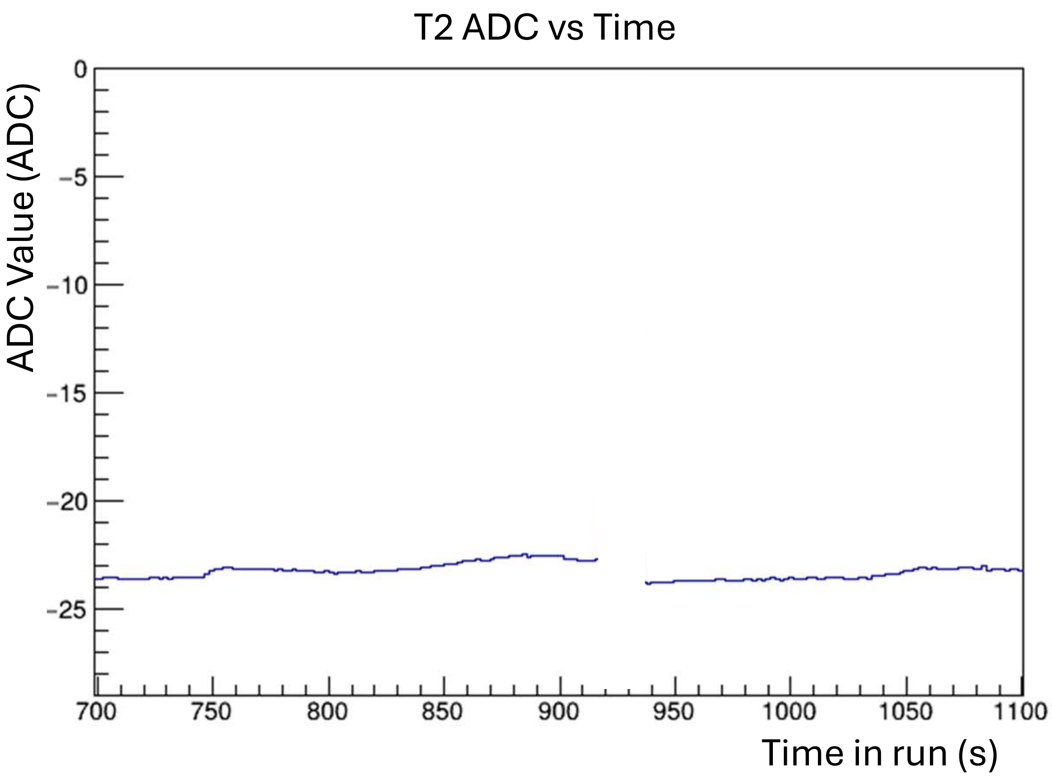
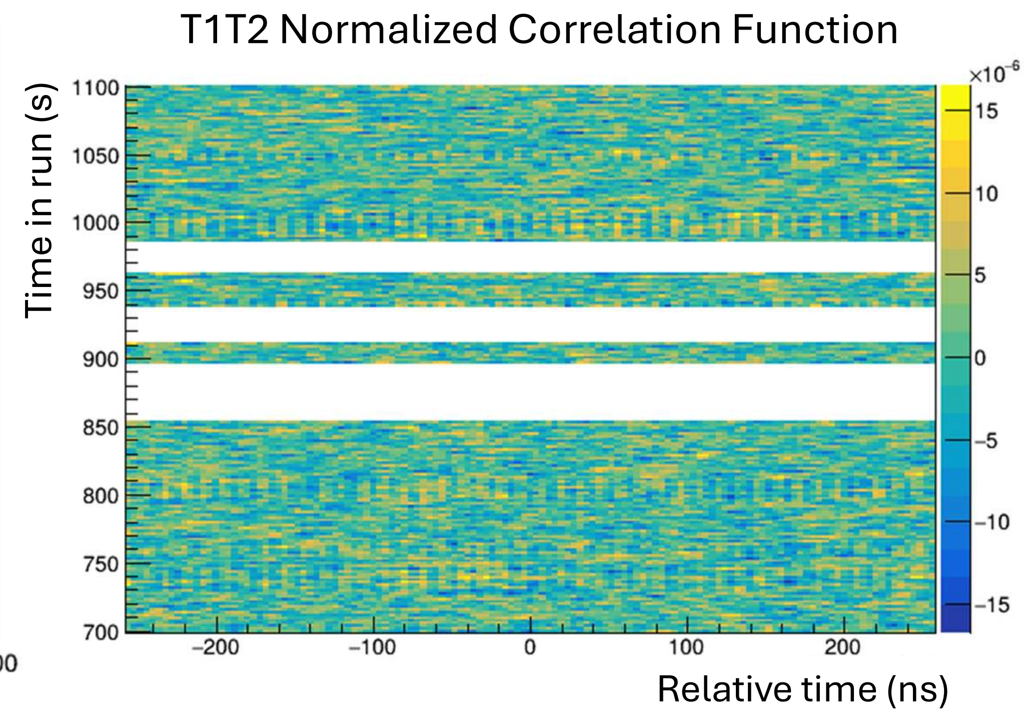




Tracking Frame Removal

- Identify bad tracking corrections using the average ADC versus time
- Completely remove those moments of our data

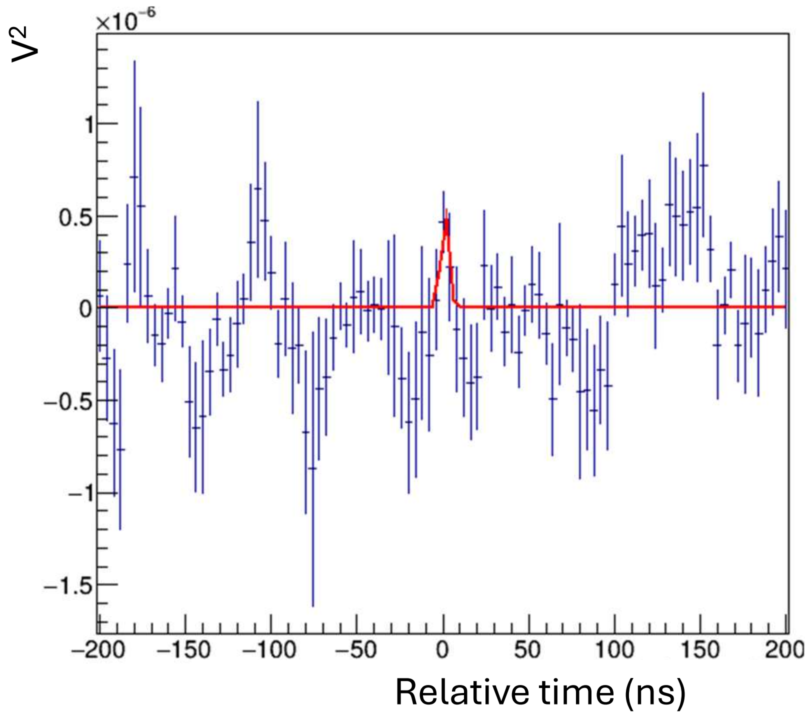




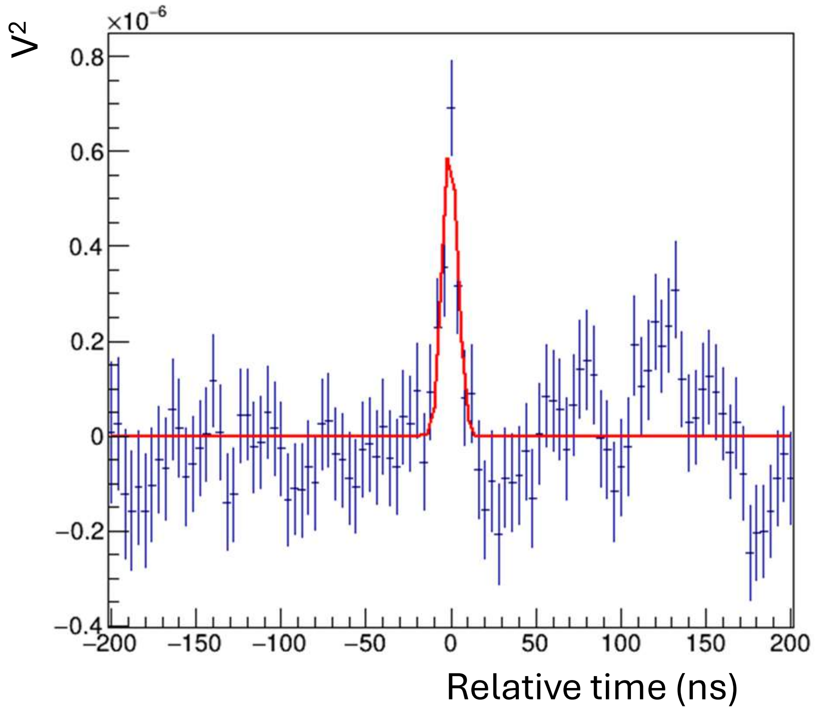
Tracking Frame Removal

- Corrections to the telescope tracking cause large dips in the ADC output
- Removing necessary to the analysis
    - Extreme example, but always necessary

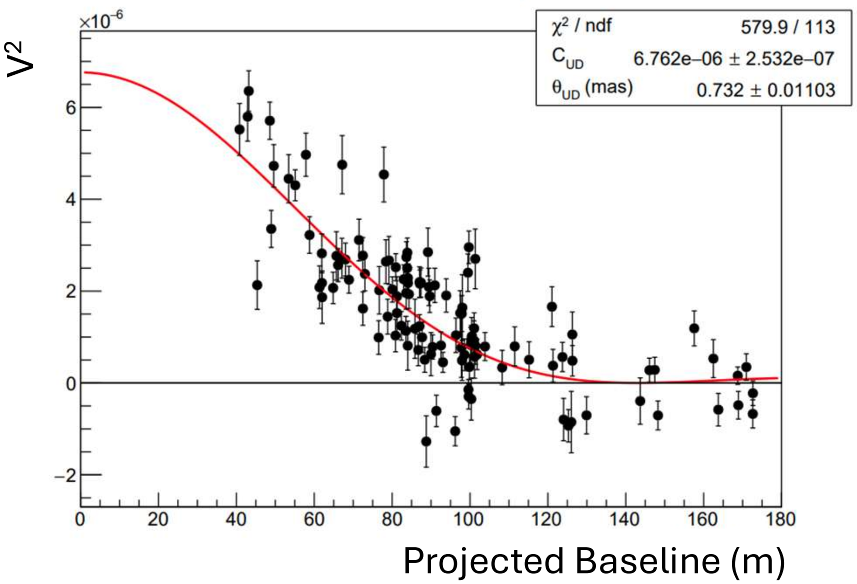
Without Removing Tracking Correction



After Removing Tracking Correction

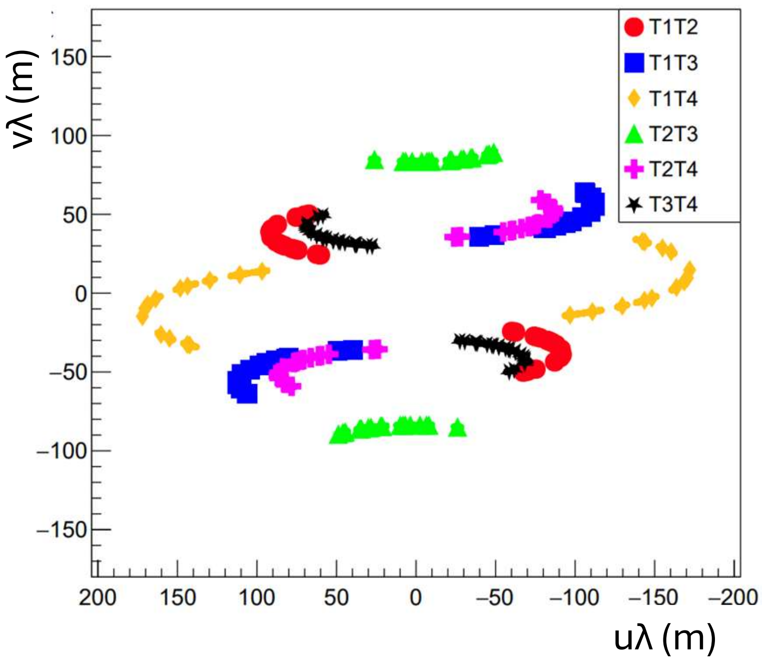


Spica Data

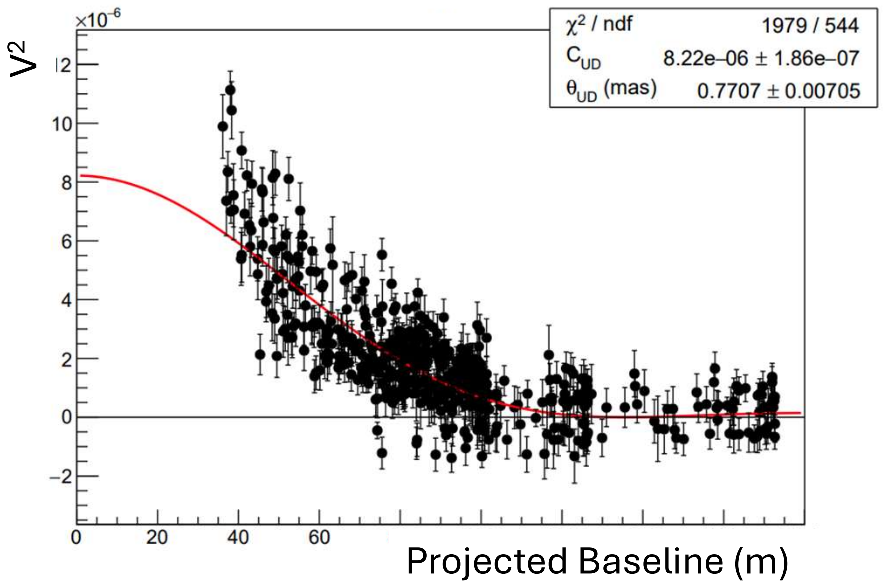


- 4 observation campaigns
- ~40 hours of data
    - ~225 pair hours
- 115 points that pass quality cuts
- ~1 hour long runs

Coverage of the UV Plane



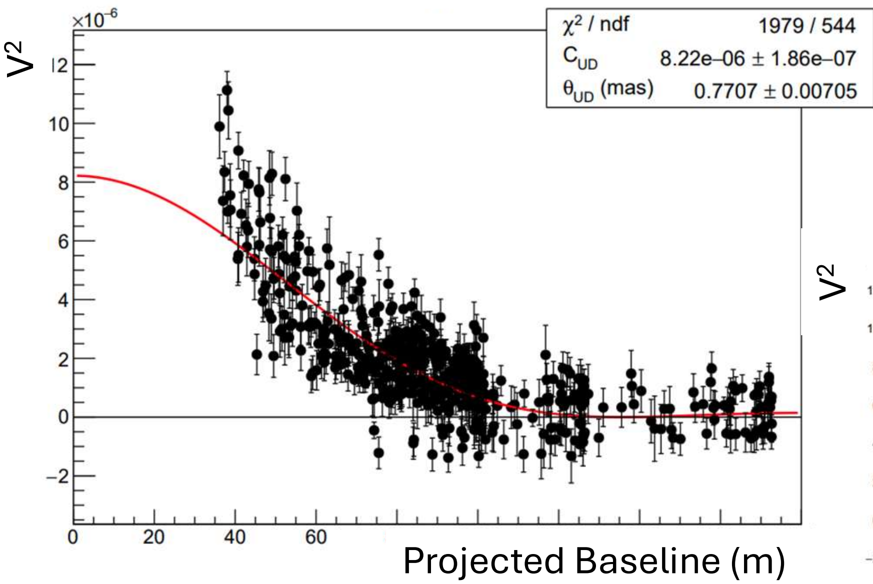
Split Data



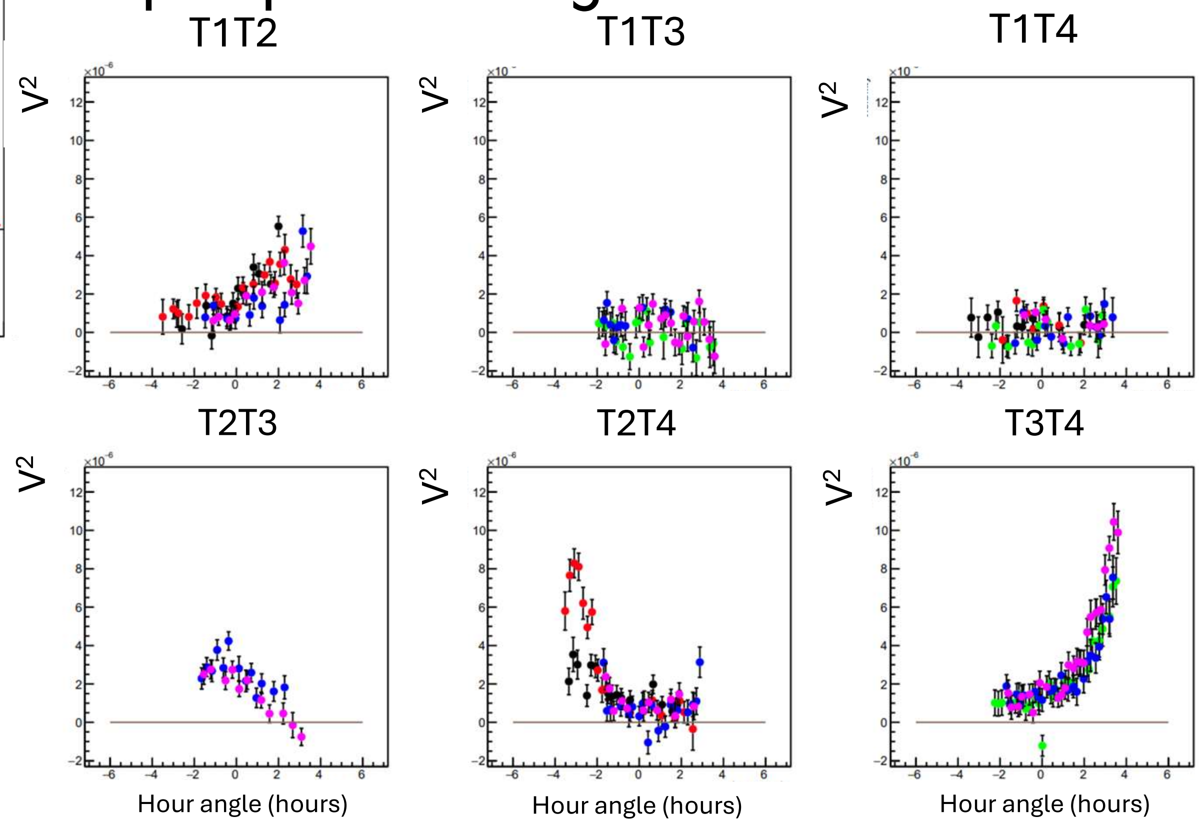
- Brightness and short baselines allow us to split significantly
  - ~15 minute segments

Split Data

- 15 minute segments of data
- Dynamic system, no unique visibility per pair per hour angle

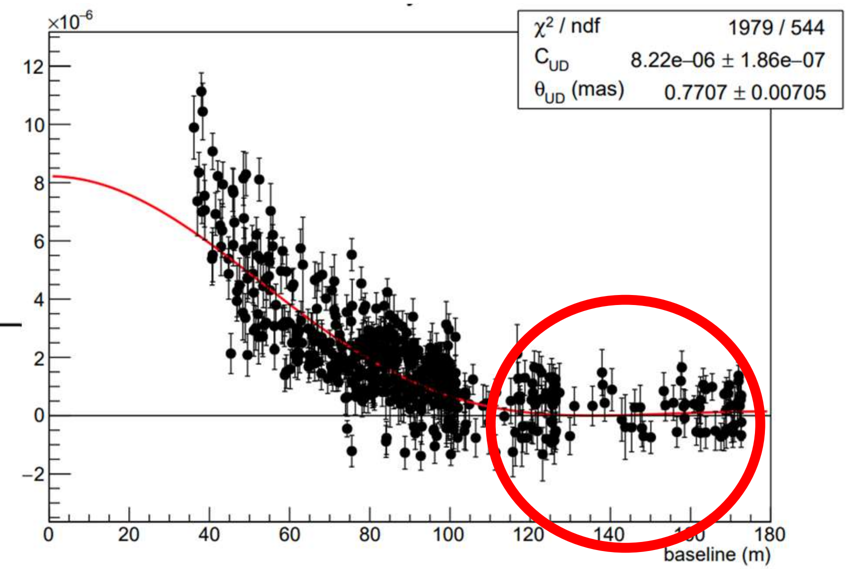


2025 Data
- March 10
- March 11
- May 7
- May 15
- May 16

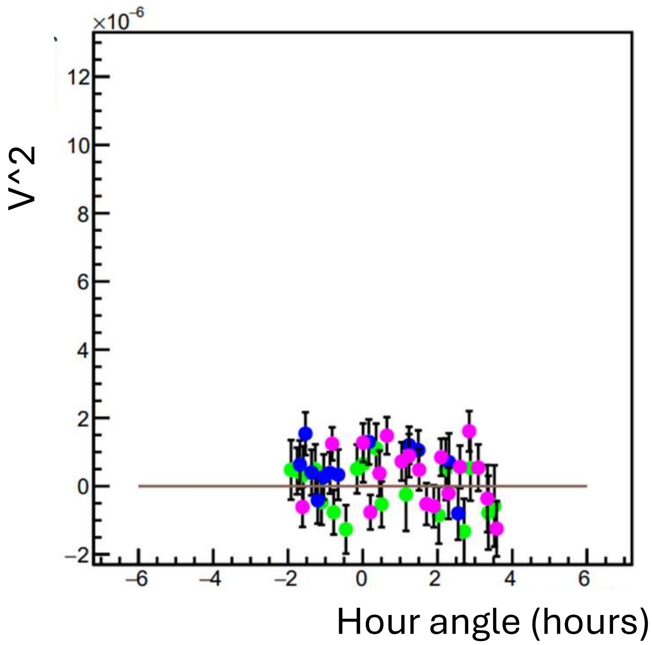


Measuring near zero visibilities

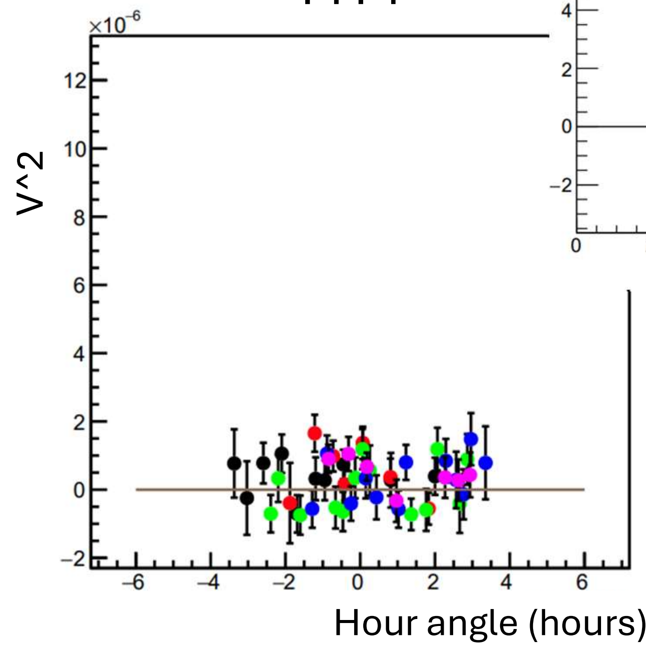
- Large number of points gives us clear evidence of near zero visibility
- Large baselines, no expected visibility



T1T3



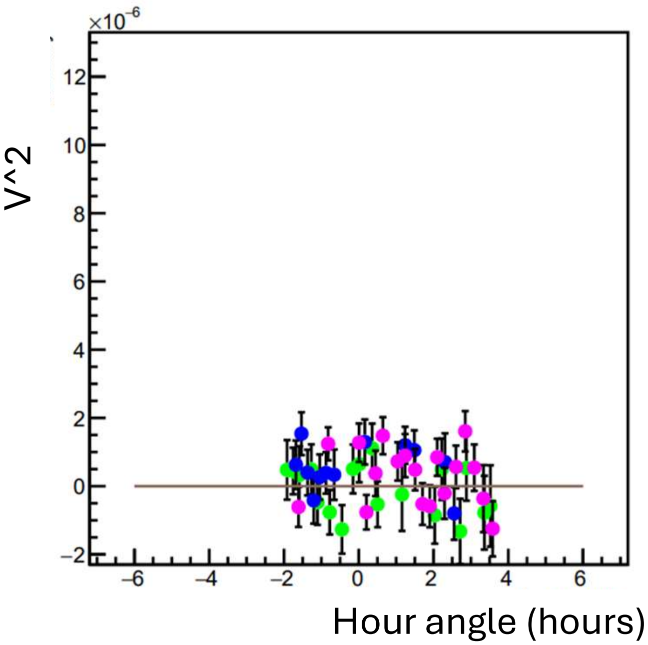
T1T4



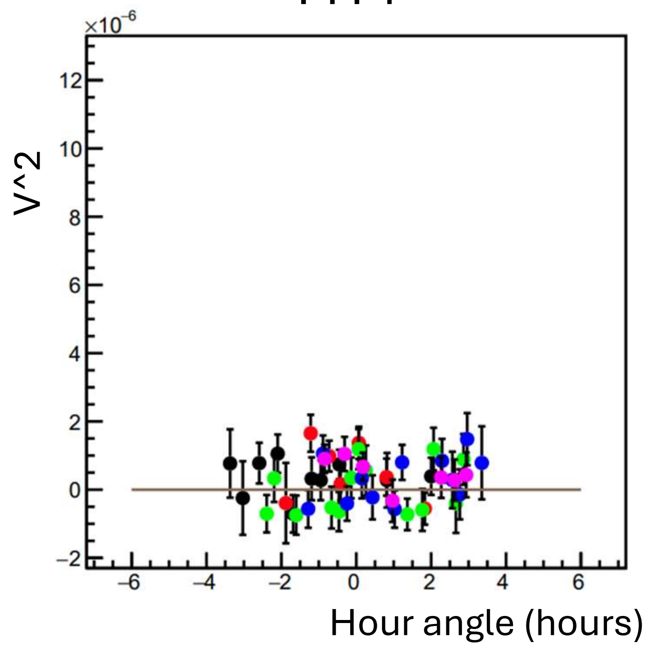
Measuring near zero visibilities

- Fits to the "off peak" region yield visibilities where there is zero correlation
- Rarely get back zero measurement
  - VERITAS (2024), DOI 10.3847/1538-4357/ad2b68
  - VERITAS (2025), DOI 10.3847/1538-4357/ae0744

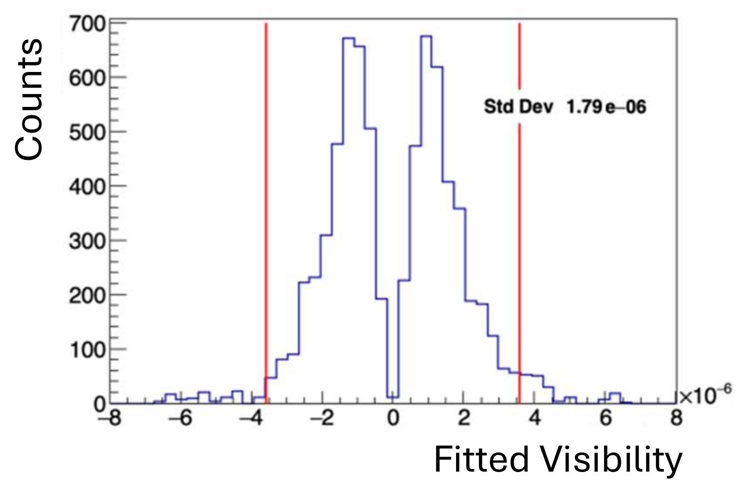
T1T3



T1T4



Fits to off peak region = "branching distribution"



Gamma Casseopeiae

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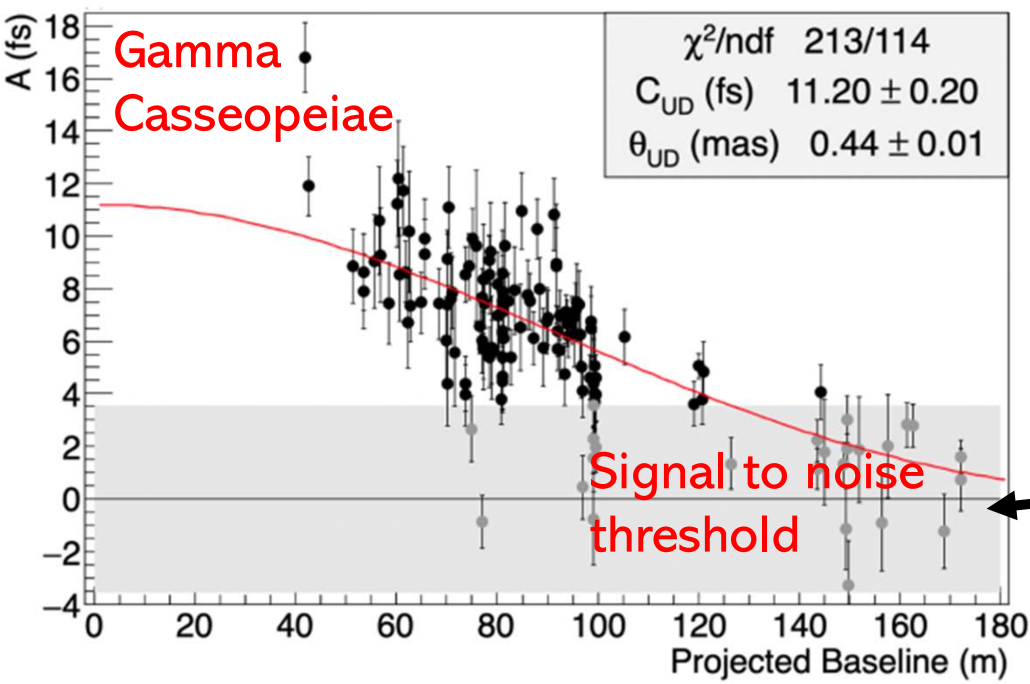

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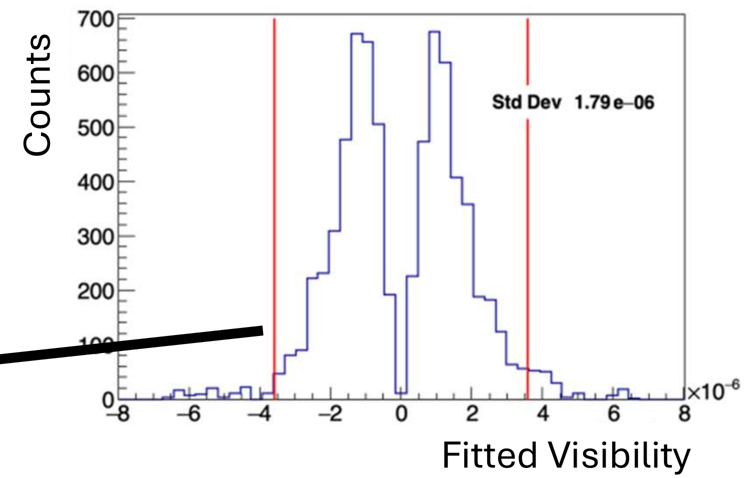
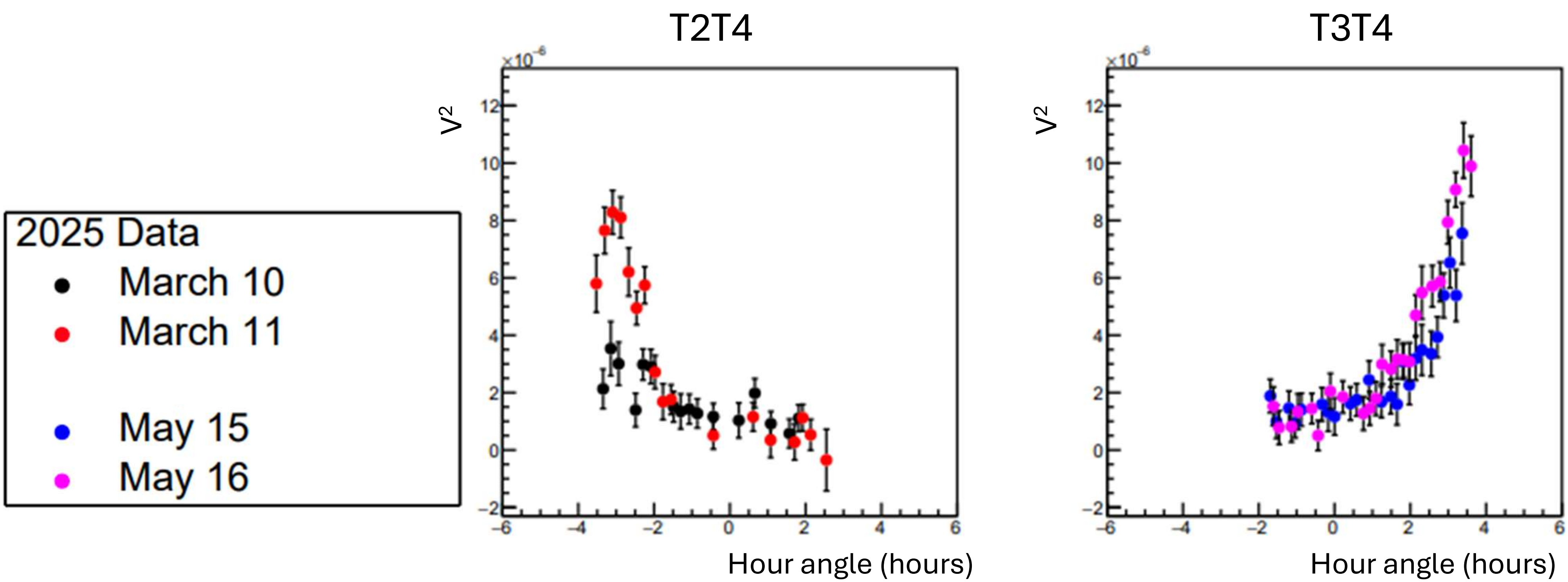


Gamma Casseopeiae

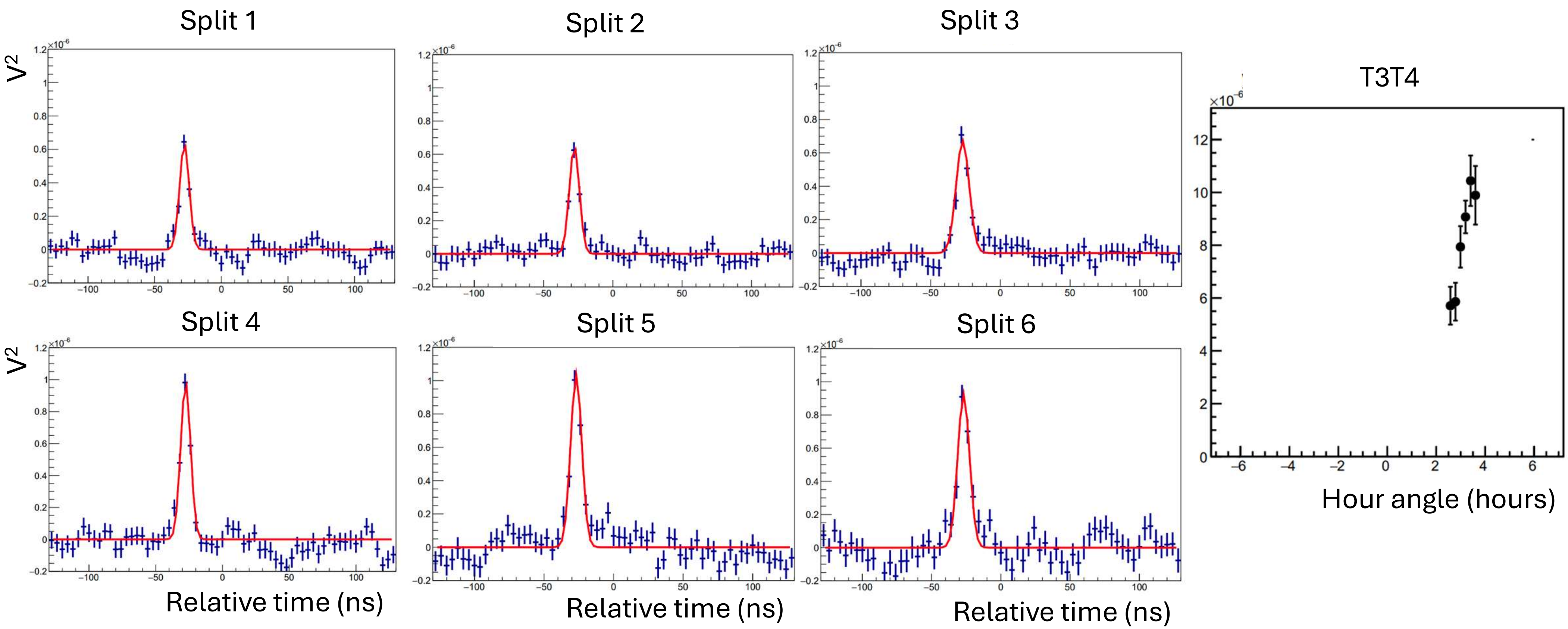
Dynamic Features

- Splitting is necessary to pick up on the sensitive areas of a dynamic system
- Clear evidence of dynamic system
  - No unique visibility per hour angle per pair



Visibility changes fast

- ~12-minute segments of data



Summary and outlook

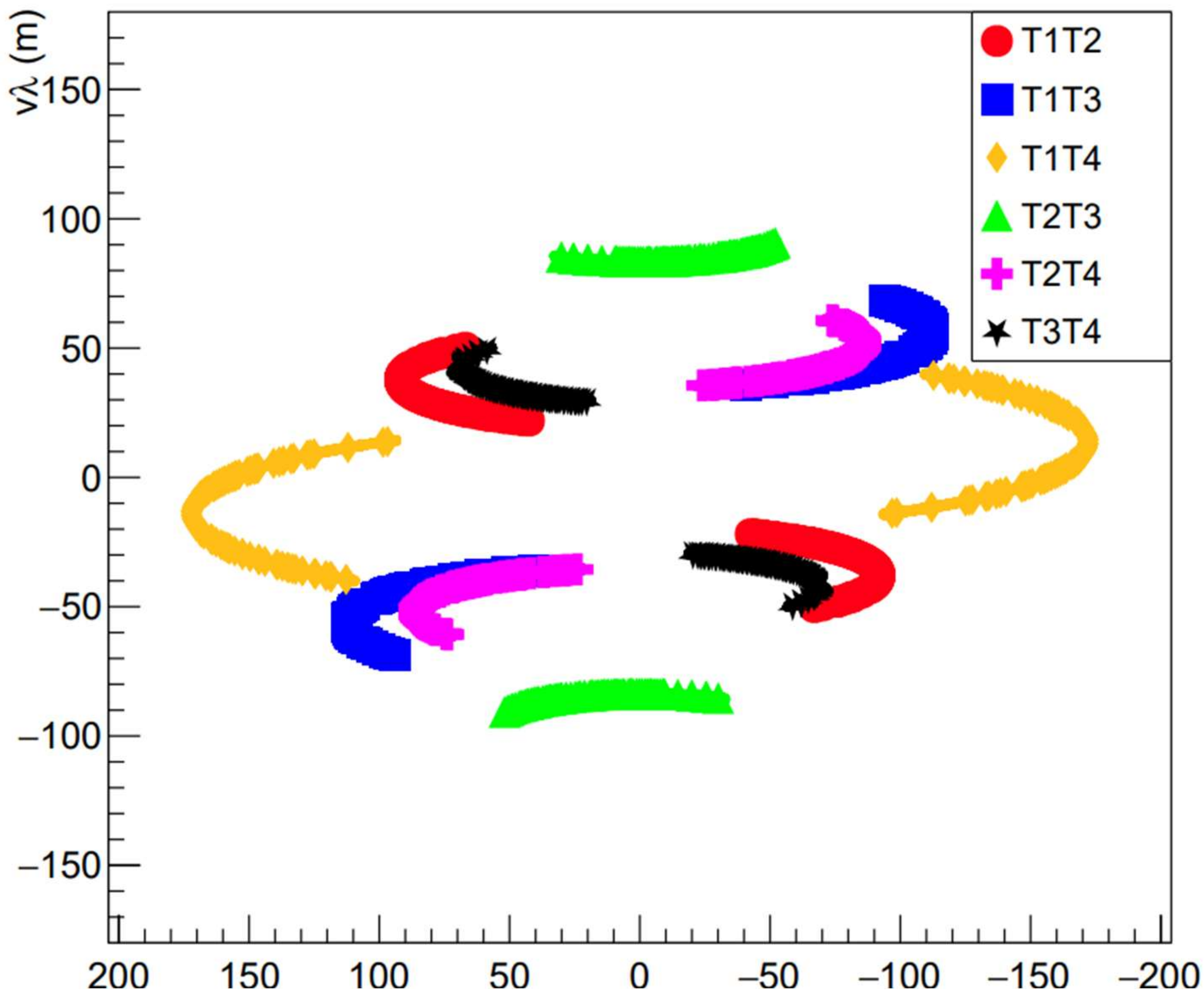
- What we learned from the gamma Cassiopeiae analysis
  - How to represent non round sources
  - Small details in the data have large effects
- What we are learning from alpha Virginis
  - We now must represent a non-round source that's also dynamic
  - Capturing rapidly changing visibilities is key to complex sources
- Next
  - Extracting orbital parameters
  - Complete analysis of the full data set

Questions?

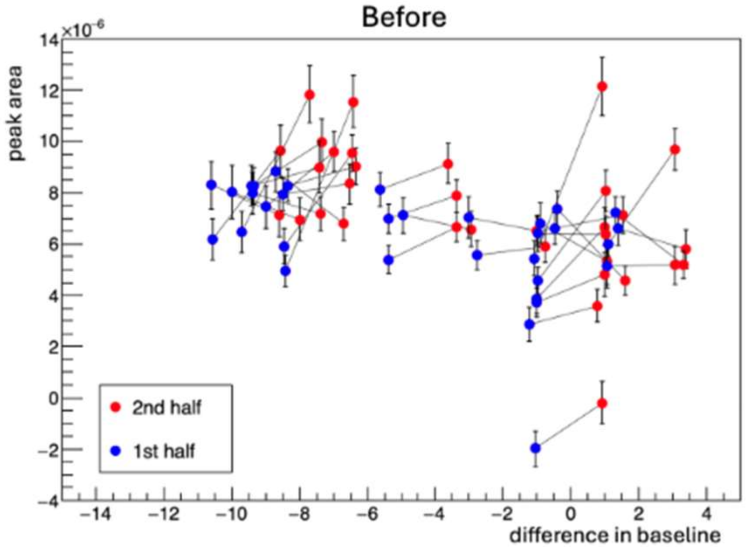
THE OHIO STATE UNIVERSITY

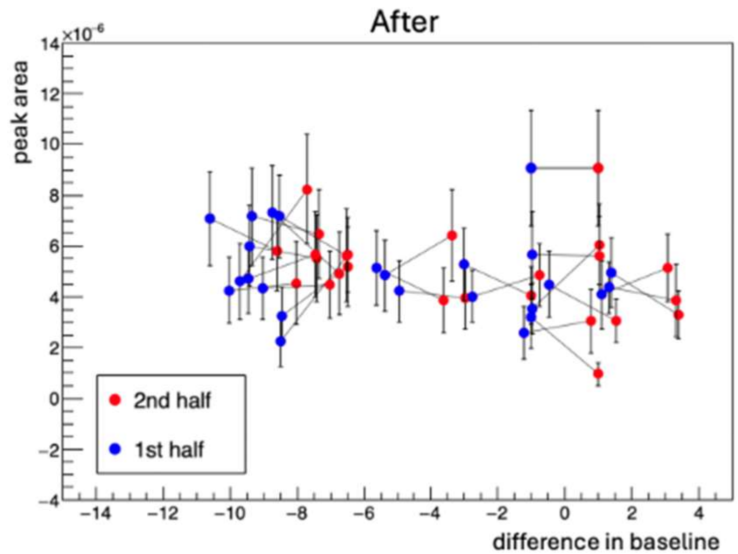
VERITAS

backup



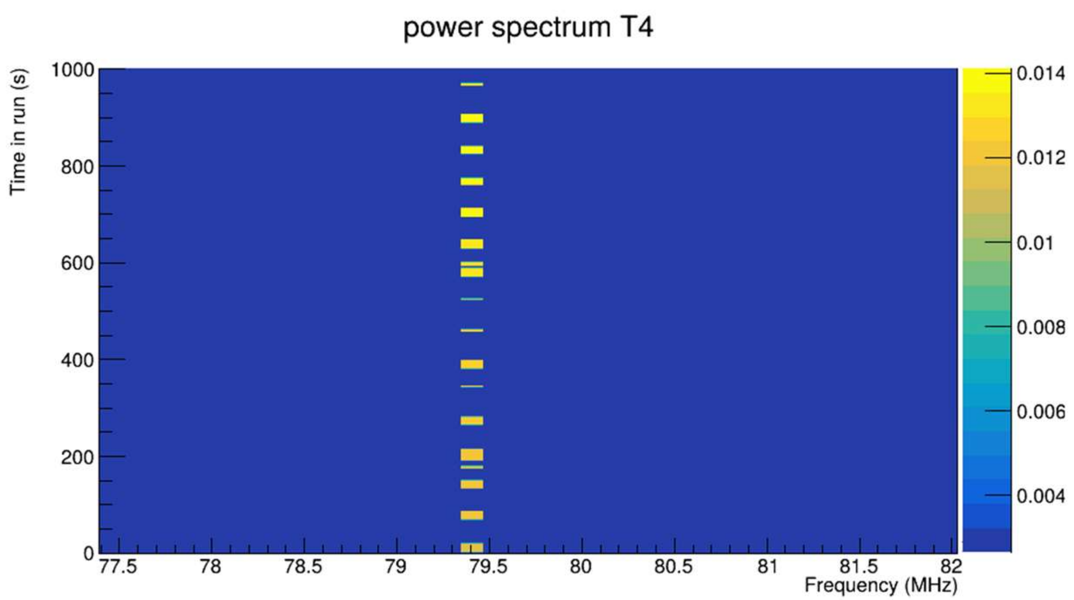
vλ (m)
150
100
50
0
−50
−100
−150
200
150
100
50
0
−50
−100
−150
−200
T1T2
T1T3
T1T4
T2T3
T2T4
T3T4

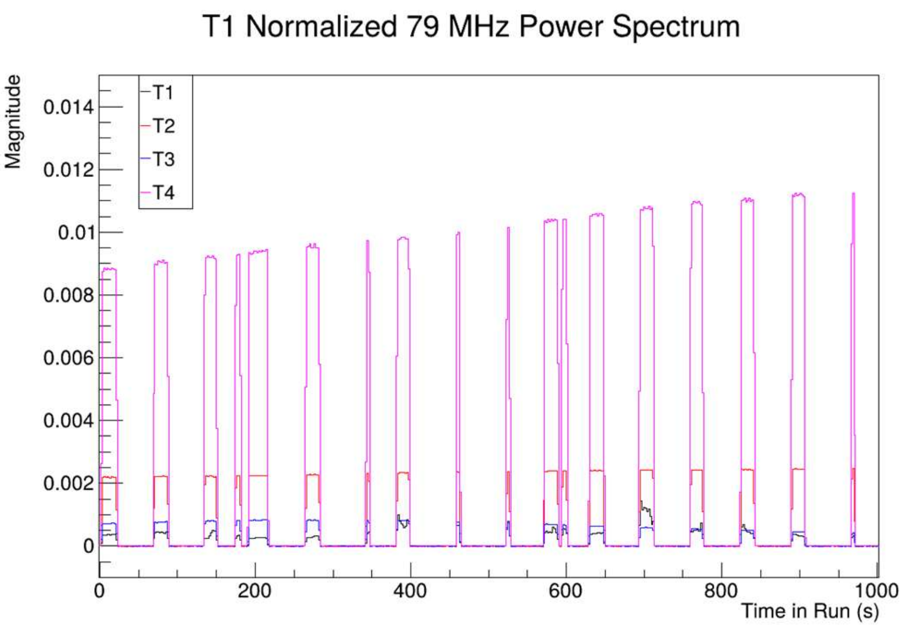

Before
×10⁻⁶
14
12
10
8
6
4
2
0
−2
−4
peak area
2nd half
1st half
−14
−12
−10
−8
−6
−4
−2
0
2
4
difference in baseline


After
×10⁻⁶
14
12
10
8
6
4
2
0
−2
−4
peak area
2nd half
1st half
−14
−12
−10
−8
−6
−4
−2
0
2
4
difference in baseline

79 MHz Removal

- Take the average of neighboring bins and subtract to normalize
  - Zero when radios are off
  - Large magnitude when on





79 MHz Removal

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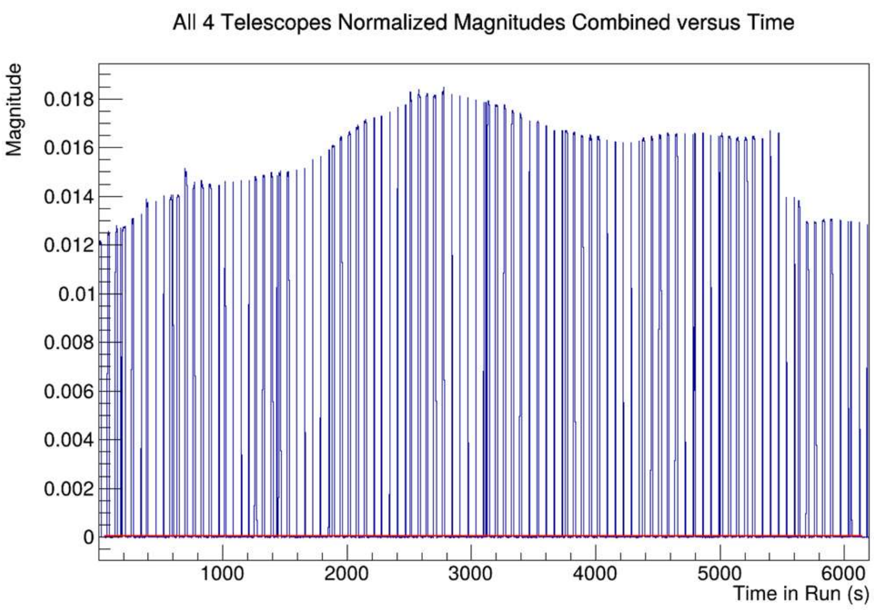
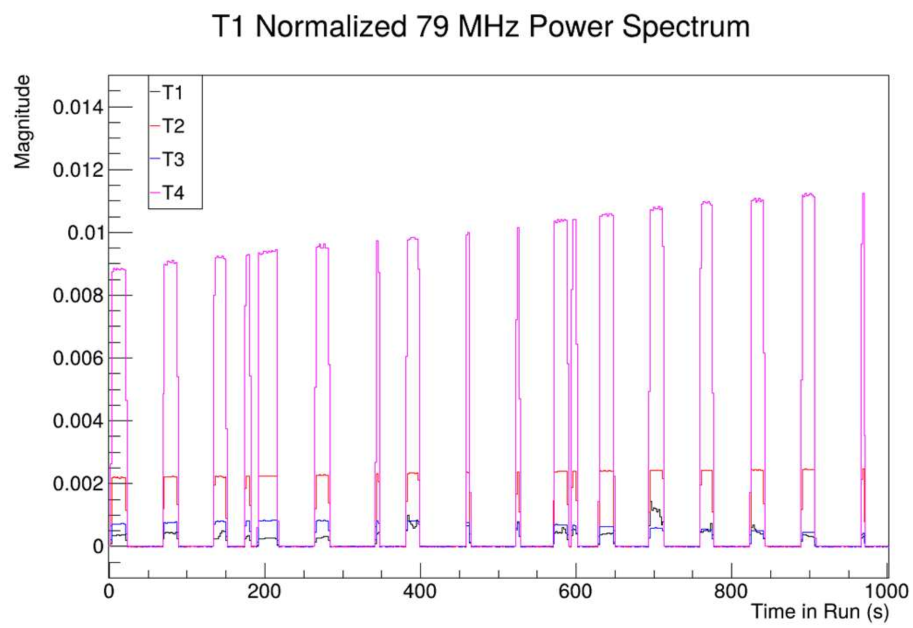




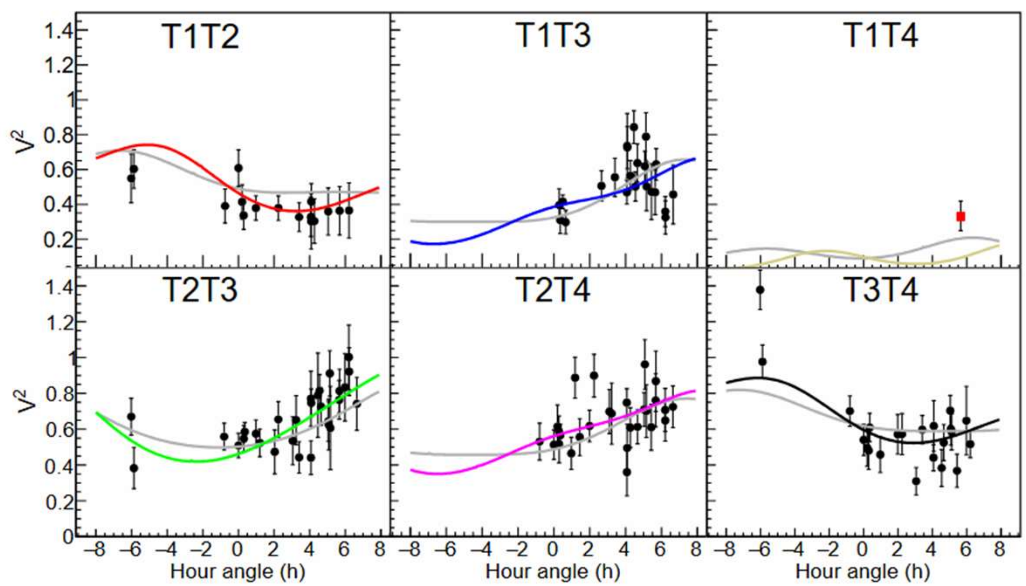
Paper measurements

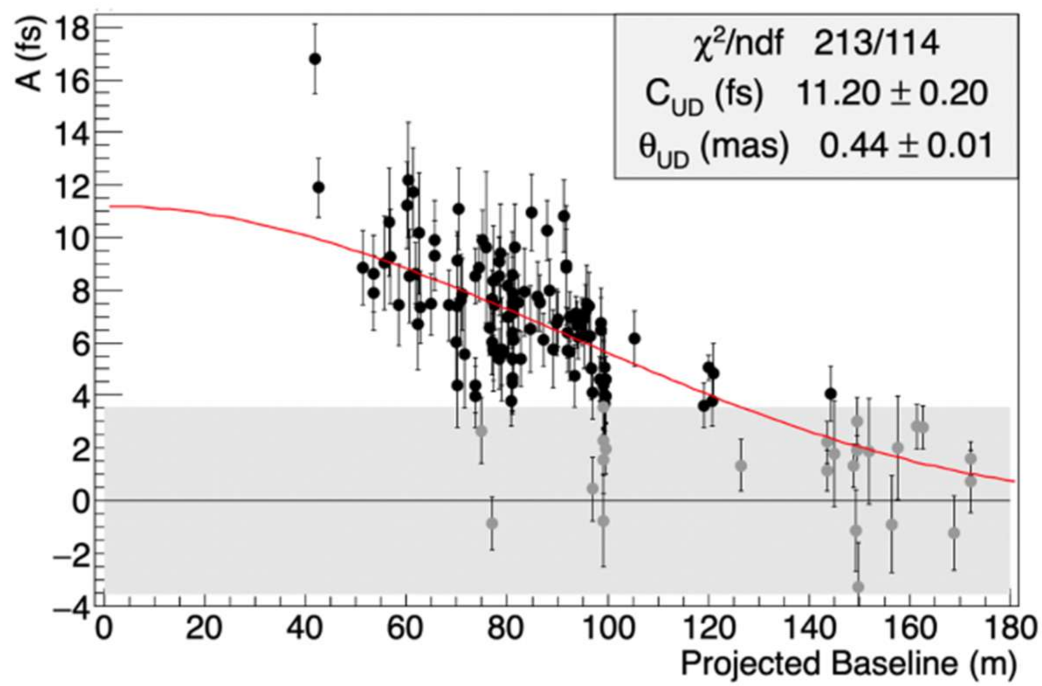
T1T4 point	Model	ϕ^* (º)	θ_{min} (mas)	$\theta_{\text{maj}}/\theta_{\text{min}}$	C_{norm} (fs)	χ^2/ndf
Excluded	Uniform Disk	-	$0.44 \pm 0.01 \pm 0.03$	(1)	$11.2 \pm 0.2 \pm 0.5$	213/114
	uv slices	$117 \pm 4 \pm 6$	$0.42 \pm 0.02 \pm 0.02$	$1.30 \pm 0.05 \pm 0.03$	12.4*	9.69/5
	Uniform Ellipse	$116 \pm 5 \pm 7$	$0.43 \pm 0.02 \pm 0.02$	$1.28 \pm 0.04 \pm 0.02$	$12.4 \pm 0.5 \pm 0.5$	170/112
Included	Uniform Disk	-	$0.43 \pm 0.01 \pm 0.02$	(1)	$11.0 \pm 0.2 \pm 0.5$	215/115
	uv slices	$118 \pm 4 \pm 6$	$0.41 \pm 0.01 \pm 0.02$	$1.27 \pm 0.05 \pm 0.04$	12.2*	7.39/5
	Uniform Ellipse	$117 \pm 5 \pm 8$	$0.42 \pm 0.02 \pm 0.02$	$1.27 \pm 0.05 \pm 0.03$	$12.2 \pm 0.5 \pm 0.5$	178/113

NOTE—note that χ^2/ndf for the uv slices analysis is based on sinusoidal fit to round model fits of the 8 "pizza slice" sections.

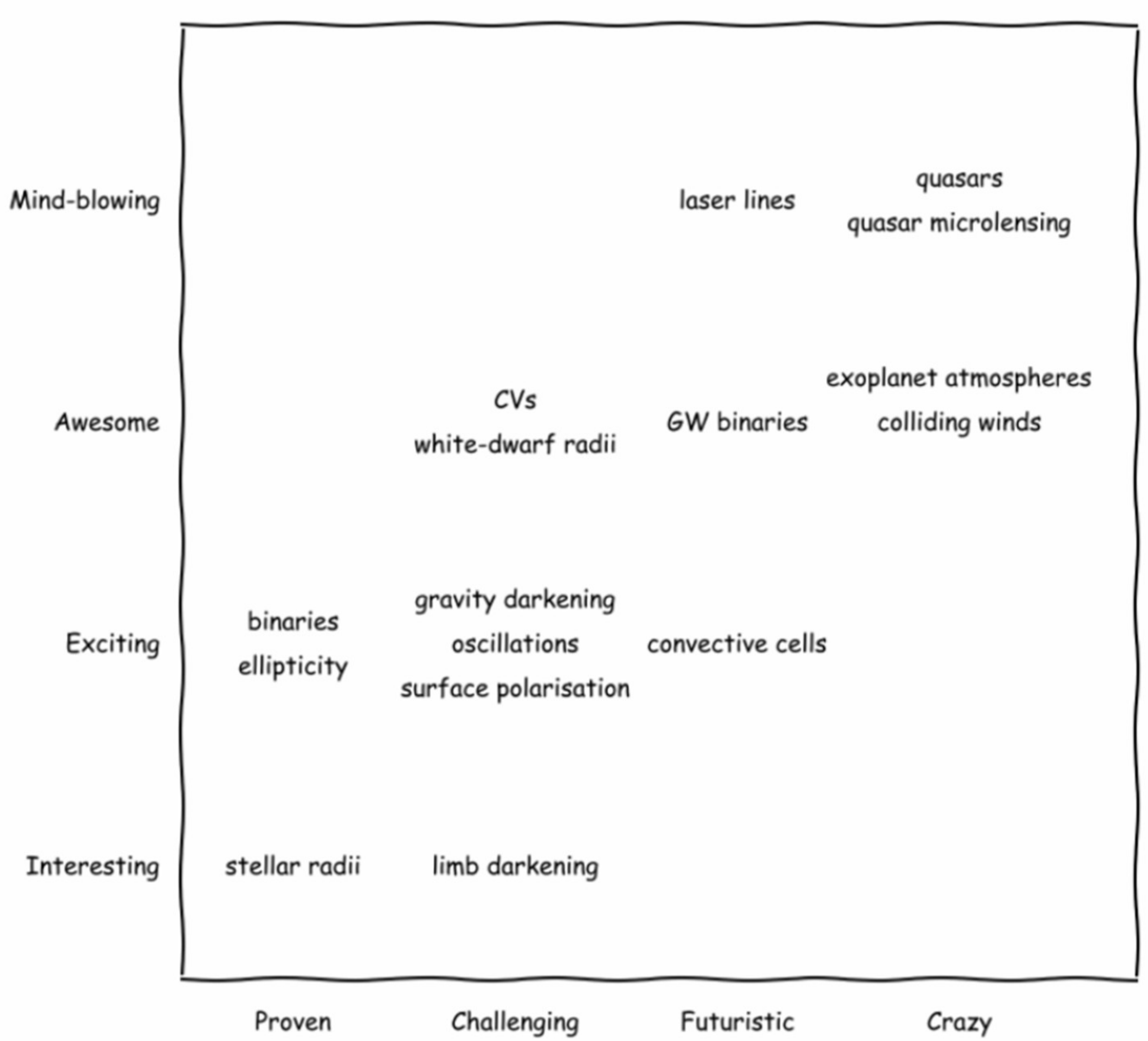
*C_{norm} for the uv slice model is fixed to C_{norm} from the Uniform Ellipse model fit.

Errorbars are reported as $\pm(stat) \pm (syst)$.


T1T2
T1T3
T1T4
T2T3
T2T4
T3T4
V²
Hour angle (h)
1.4
1.2
1
0.8
0.6
0.4
0.2
0
−8 −6 −4 −2 0 2 4 6 8



χ²/ndf 213/114
C_UD (fs) 11.20 ± 0.20
θ_UD (mas) 0.44 ± 0.01
A (fs)
18
16
14
12
10
8
6
4
2
0
−2
−4
0
20
40
60
80
100
120
140
160
180
Projected Baseline (m)


Mind-blowing
Awesome
Exciting
Interesting
laser lines
quasars
quasar microlensing
CVs
white-dwarf radii
GW binaries
exoplanet atmospheres
colliding winds
binaries
ellipticity
gravity darkening
oscillations
surface polarisation
convective cells
stellar radii
limb darkening
Proven
Challenging
Futuristic
Crazy