Title: Intensity Interferometer Results on Sirius with 0.25 m Telescopes

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Collection/Series: Future Prospects of Intensity Interferometry

Subject: Cosmology

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Abstract:

We present the design and initial results of a stellar intensity interferometer using small 0.25 m Newtonian-style telescopes in an urban backyard setting. The primary purpose of the interferometer is to measure the angular diameters of stars. Recent advances in low jitter time-tagging equipment and Single Photon Avalanche Detectors have made the detection of second-order correlation signals, necessary for Intensity Interferometry as demonstrated by Hanbury Brown and Twiss in 1956, feasible with small telescopes. Using Sirius as a target star, we observe a strong second-order correlation spike with an integrated signal to noise ratio (SNR) ~7 after 13.55 h of integration over a three-night period using a 3.3 m baseline. The measured signal agrees with the theoretical estimates of both coherence time, □□coh = 0.74 ± 0.26 ps and SNR. We discuss the future expansion of this technique with multiple wavelengths simultaneously via a prism grating and multiple detectors.


Intensity Interferometry
With 10" backyard telescopes
Tom Mozdzen, Rick Scott, Phil Mauskopf
October 30, 2024

Background

- Work at ASU on intensity interferometry started in 2012
- Technology did not exist at the time
  - Developed CASPER ROACH-based time tagger
  - Started testing single photon counting detectors on telescopes
  - Tried Kitt Peak 90 inch – measured counts
- Paper by Pilyavsky, 2016
- Goal: Low cost, scalable interferomet small telescopes
- Status: Measured correlations with 1 elescopes from Sirius
  - SNR = 7 in 13.5 hours
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Equipment for an Intensity Interferometer

- Backyard Telescopes

3.3 m Baseline

10 m Baseline

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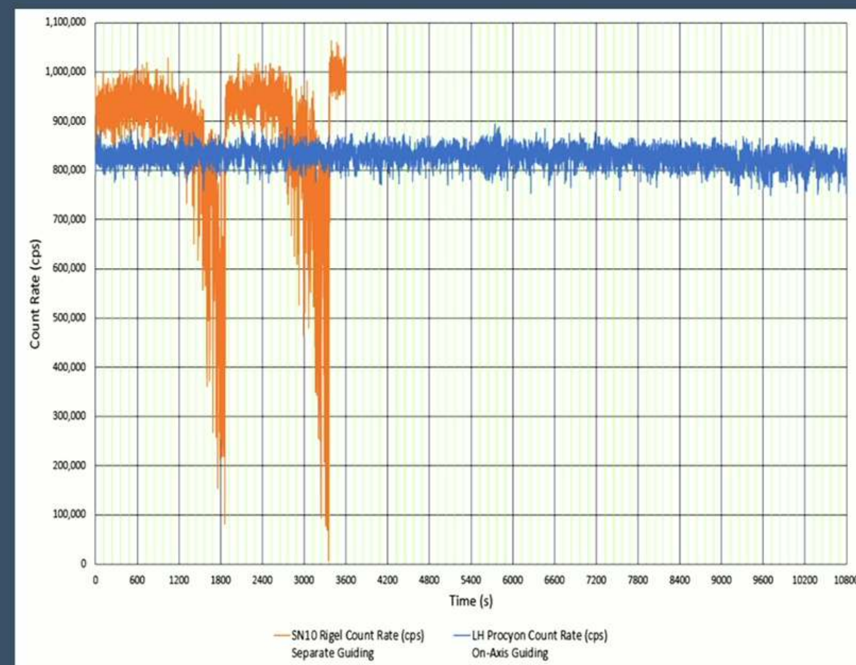
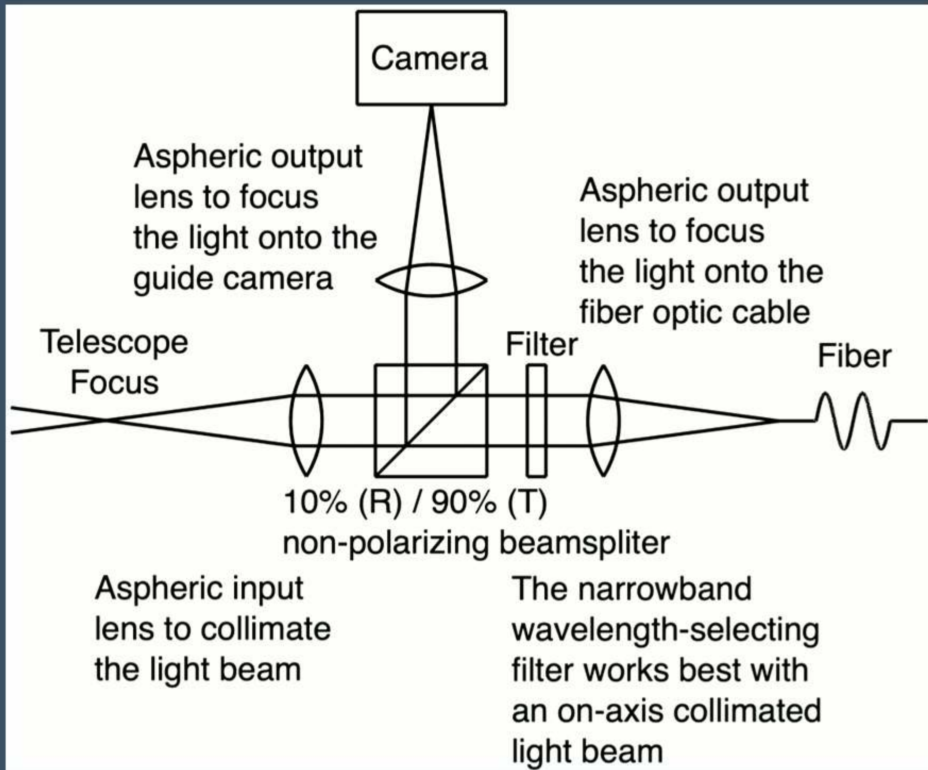
Equipment for an Intensity Interferometer

- Telescope Guiding Improvement
  - Piggyback mounted guide scope and camera
    - Long-term drift due to differential flexure
    - Needed to reset centering every 20 to 30 minutes
    - Orange on the plot is 1 hour of operation
  - On-axis guider built into the JaZeye
    - No long-term drift
    - Can operate for hours with no recentering
    - Blue on the plot is 3 hours of operation



Equipment for an Intensity Interferometer

- JaZeye Optical System



Equipment for an Intensity Interferometer

- JaZeye Narrowband Filter
  - We measured the narrowband filters we're currently using on stars with an Agilent Cary 5000 spectrophotometer
  - The filters have the following characteristics:
    - Center wavelength = 589.25 nm
    - Bandwidth = 1.2 nm
    - Overlapping bandwidth = 1.1 nm
    - t_{coh} = 0.78 ps

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Equipment for an Intensity Interferometer

- Single Photon Detectors: SPADs
  - Input is fed by a fiber optic cable to reduce loading on the JaZeye
  - Our old SPADs had a timing jitter of 350 ps vs 32 ps for our new SPADs

Old SPAD

New SPAD

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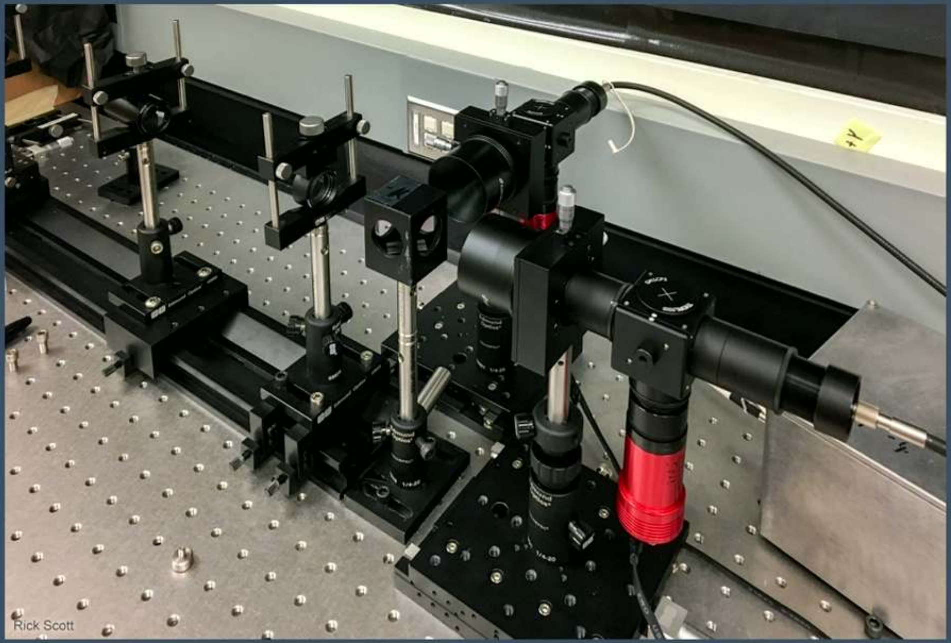
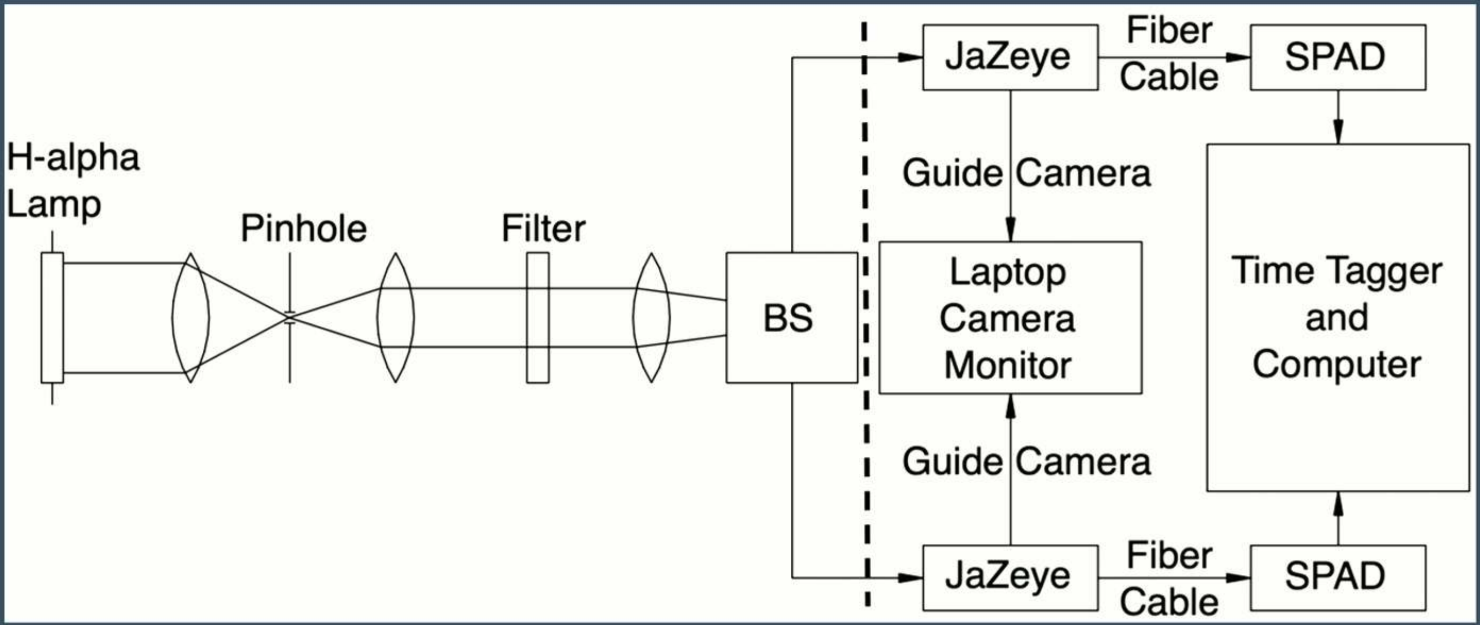
Equipment for an Intensity Interferometer

- Bench Set Up
- Initial testing was performed on an optical bench in the lab
- The bench setup simulates a star from two telescopes
  - A beamsplitter is used to make a star for each JaZeye/detector system
  - No motion to track
  - No seeing effects



Equipment for an Intensity Interferometer

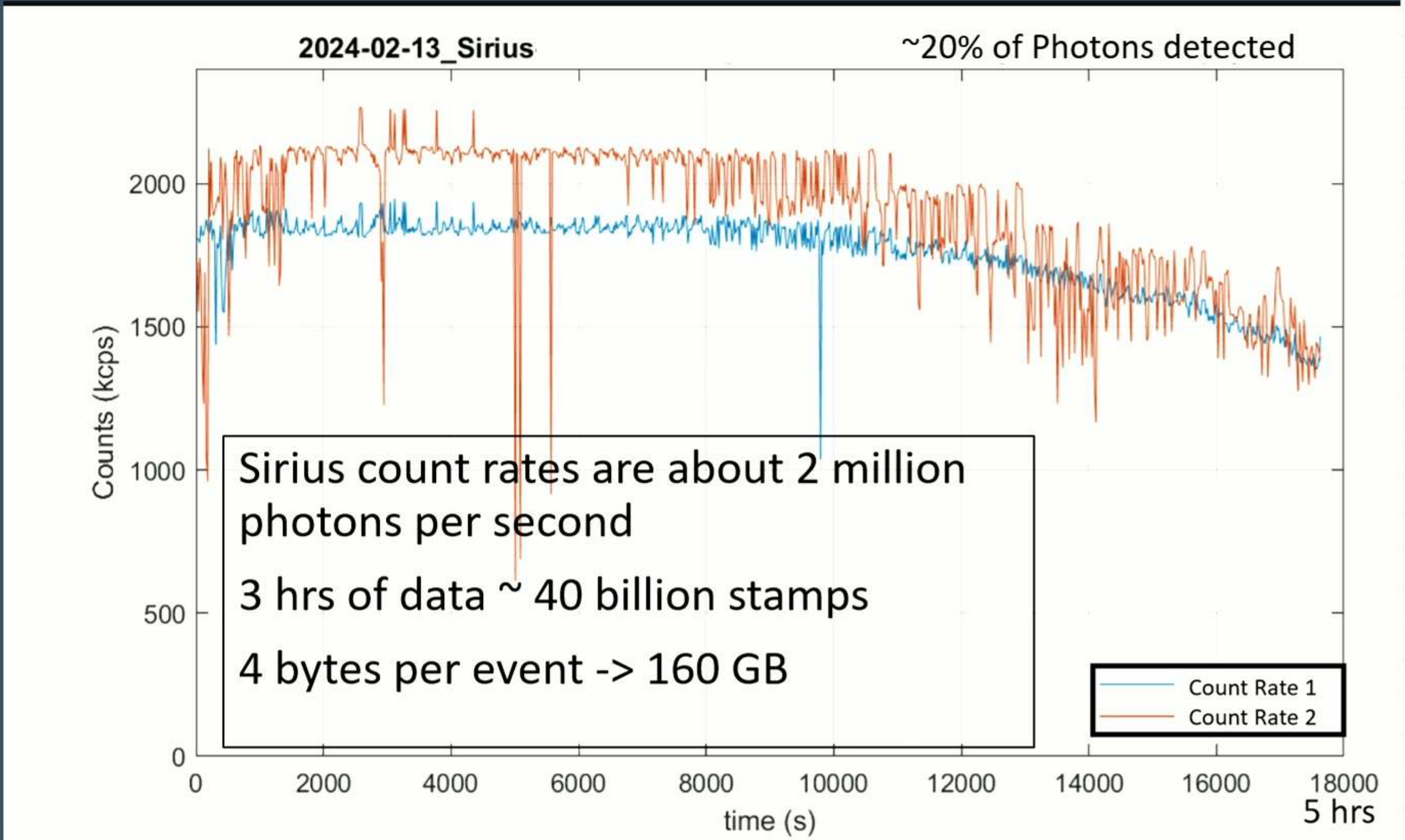
- Bench Set Up Block Diagram
  - Components to the right of the beamsplitter is the same as on the telescopes



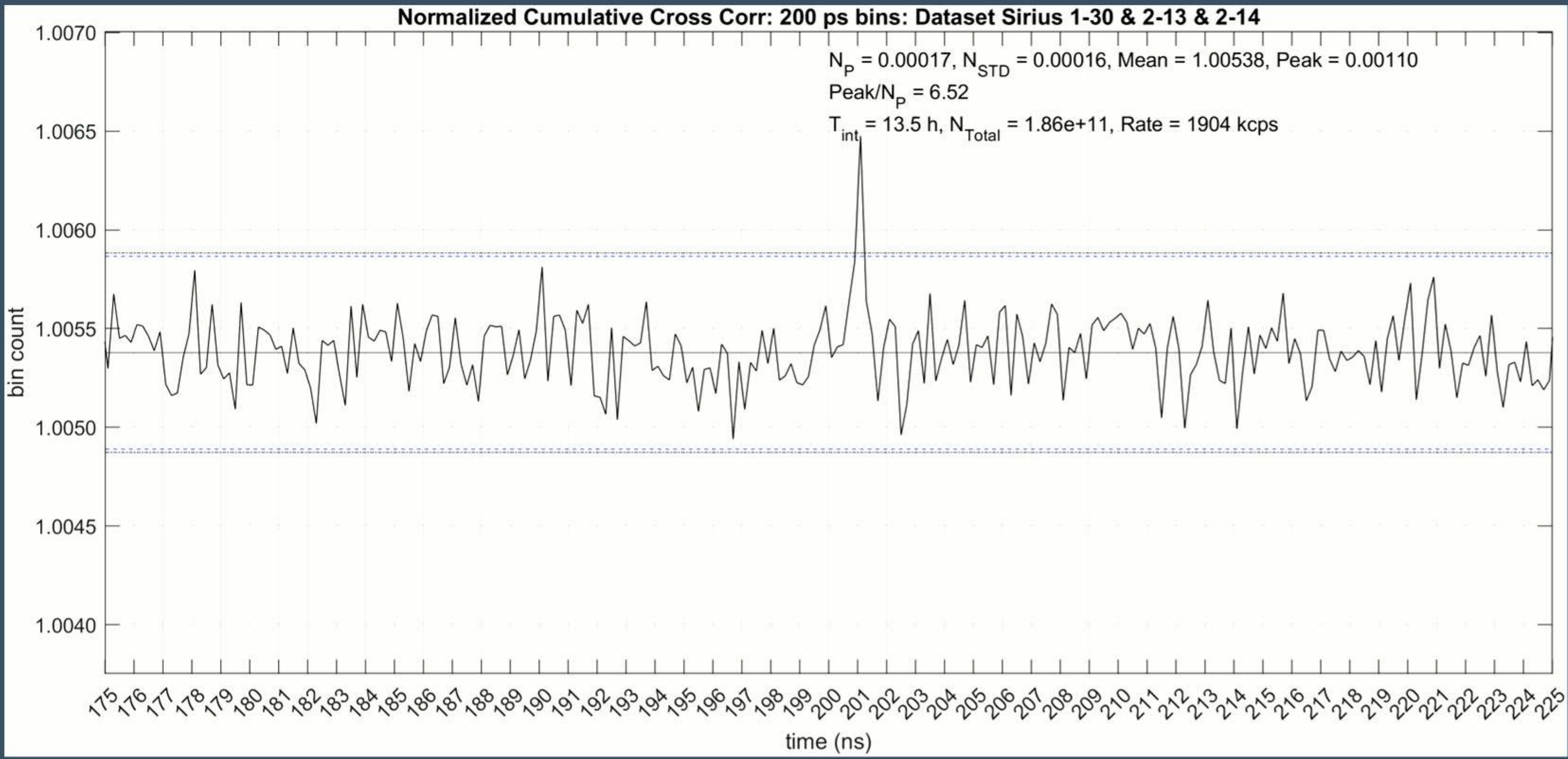
System Efficiency

Component Efficiency	Lurie-Houghton Telescope (%)	Meade SN10 Telescope (%)
Telescope Optics	71	72
Jazeye Optics	74	74
Fiber Optic Cable	92	92
Total Optics	49	49
Detector @ 589 nm	39	39
Total System	19	19

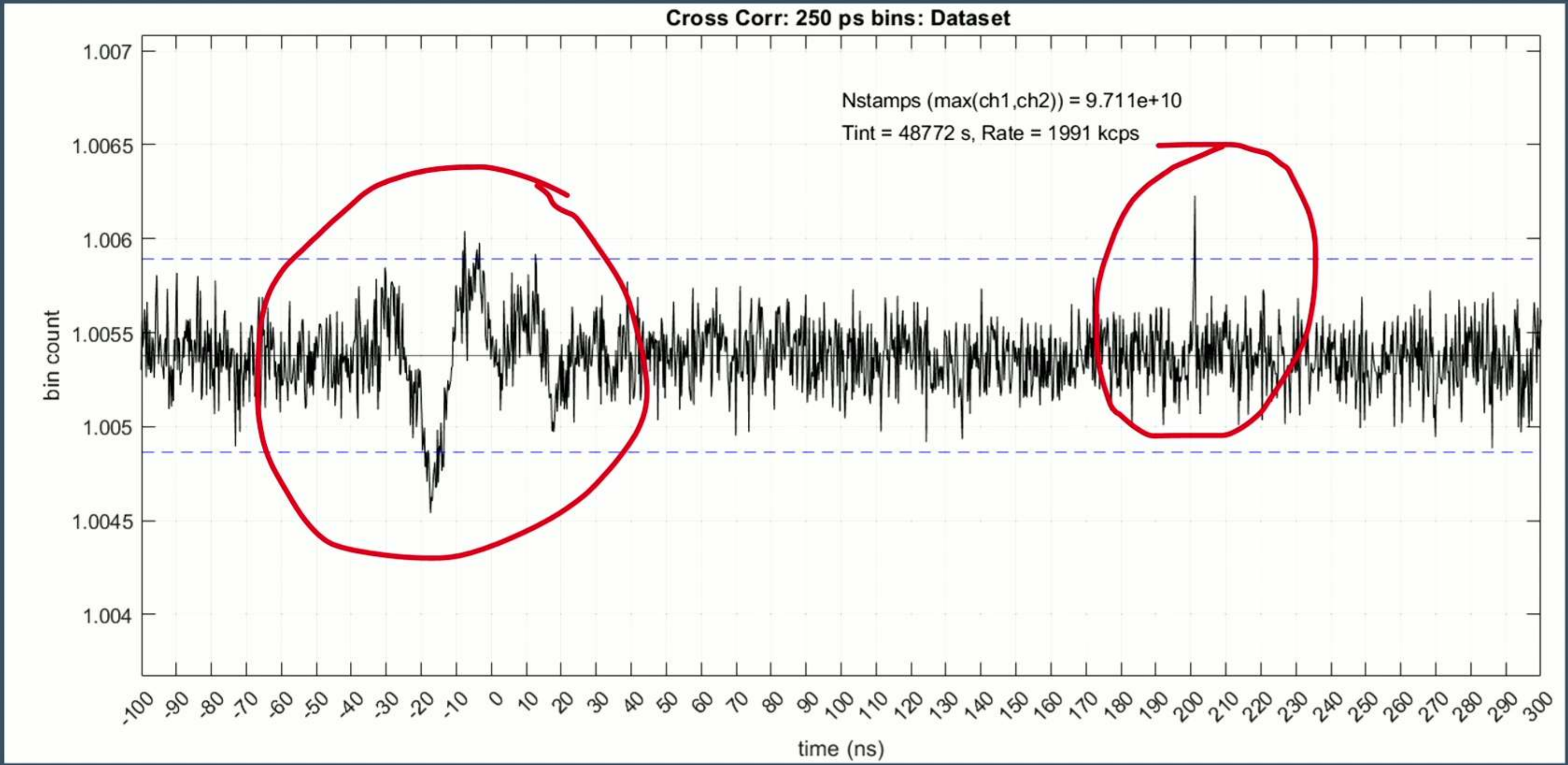
Typical Data – counts and timestamps



Time Stamp (ps)	Scope Number
0	2
269,843	2
653,358	1
1,874,472	1
1,935,303	2
2,135,445	1
2,651,378	2
2,829,997	2
3,022,721	1
4,073,462	1
4,578,386	1
5,094,998	2
5,521,825	1
5,694,721	2
8,053,649	1
8,350,105	2
8,708,926	2
10,082,938	2
10,595,984	2
10,942,030	2
11,266,221	2
11,431,180	2
11,474,172	1
11,795,308	1
12,079,465	2


Normalized Cumulative Cross Corr: 200 ps bins: Dataset Sirius 1-30 & 2-13 & 2-14
N_P = 0.00017, N_{STD} = 0.00016, Mean = 1.00538, Peak = 0.00110
Peak/N_P = 6.52
T_{int} = 13.5 h, N_{Total} = 1.86e+11, Rate = 1904 kcps
bin count
time (ns)

Shift the correlation away from t = 0



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Our Favorite Equations

$$g^{(2)}(\tau) = 1 + |V_{12}(d)|^2 |\gamma_{11}(\tau)|^2$$

$$g^{(2)}(\tau) = 1 + \frac{1}{n_M \tau_{res}} |V_{12}(d)|^2 \left[|g^{(1)}(\tau)|^2 * |M_{11}(\tau)|^2 \right]$$

Integrate

$$|V_{12}(d)|^2 = \frac{2}{\tau_{coh}} \text{x Integrated Signal}$$

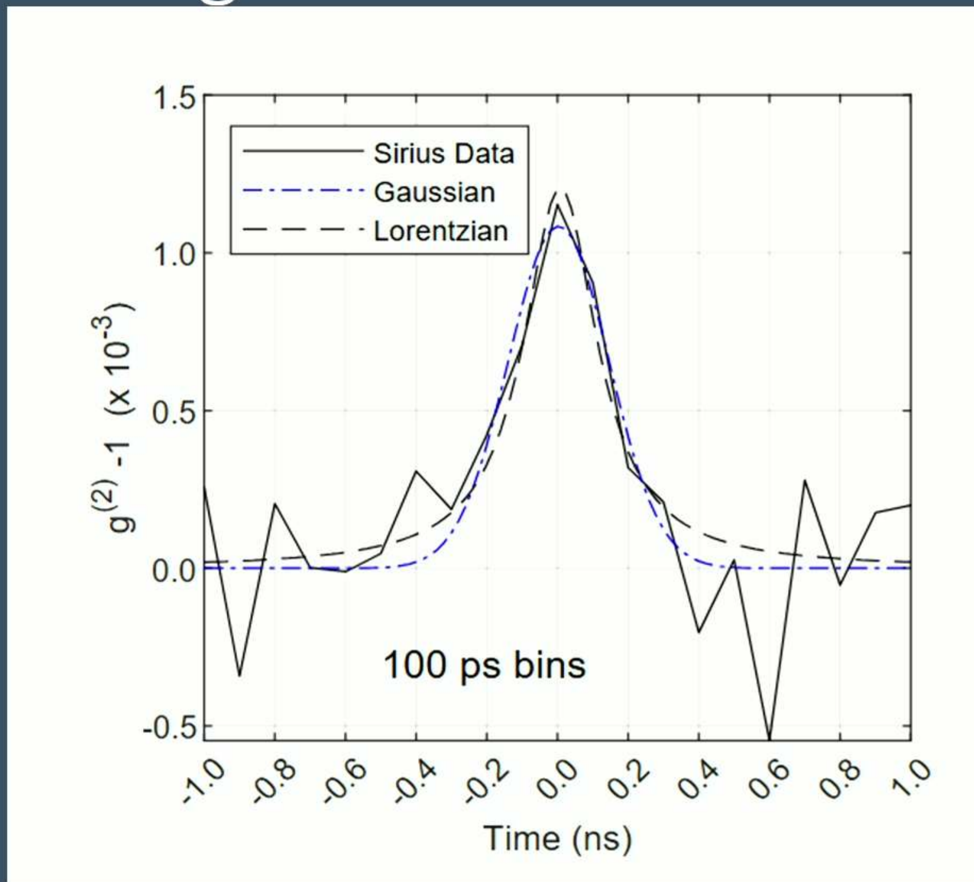
$$\tau_{coh} = \int_{-\infty}^{+\infty} |g^{(1)}(\tau)|^2 d\tau$$

$$\tau_{res} = \int_{-\infty}^{+\infty} |M_{11}(\tau)|^2 d\tau$$

$$\sigma_{res} = \tau_{res}/\sqrt{2\pi}$$

$$SNR = \frac{\tau_{coh}}{2} \left(\frac{R_1 R_2 T_{int}}{2^{1/2} \tau_{res}} \right)^{1/2} |V_{12}(d)|^2$$

Coherence Signal



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Gaussian Fitting Results

Source	2x Fit Area (ps)	Fit Height (10^{-3})	Sigma Fit (ps)	τ_{res} derived (ps)	$\lvert V_{12}(3.3\ m)\rvert^2$
Sirius	0.74 +/- 0.26	1.1 +/- 0.2	138 +/- 26	346 +/- 65	0.95 +/-0.33

With:

T_{coh} = 0.78 ps from the filter shape

SNR ~ 7.0

Expected $\lvert V_{12}(3.3\ m)\rvert^2 = 0.94 +/- 0.01$

Bonus Equations

$$\Delta\nu_{\mathrm{FWHM}} = \frac{1}{\tau_{\mathrm{coh}}} = \frac{1.00}{\tau_{\mathrm{coh}}} \text{ Top Hat}$$

$$\Delta\nu_{\mathrm{FWHM}} = \left(\frac{2\ln(2)}{\pi}\right)^{1/2} \frac{1}{\tau_{\mathrm{coh}}} = \frac{0.66}{\tau_{\mathrm{coh}}} \text{ Gaussian}$$

$$\Delta\nu_{\mathrm{FWHM}} = \frac{1}{\pi\tau_{\mathrm{coh}}} = \frac{0.32}{\tau_{\mathrm{coh}}} \text{ Lorentzian}$$

IV. Future Plans

- Collection time reduction
  - More baselines simultaneously
  - Multiple Telescopes
  - Spectrometers – use multiple wavelengths to reduce collection time
  - Use both polarizations
  - Slightly larger telescope
    - 12" to 14" would still be low cost
  - Lower system jitter – 6x
    - 2.4x less collection time

- Measure exotic objects
  - Quasars
    - Accretion discs around black holes

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