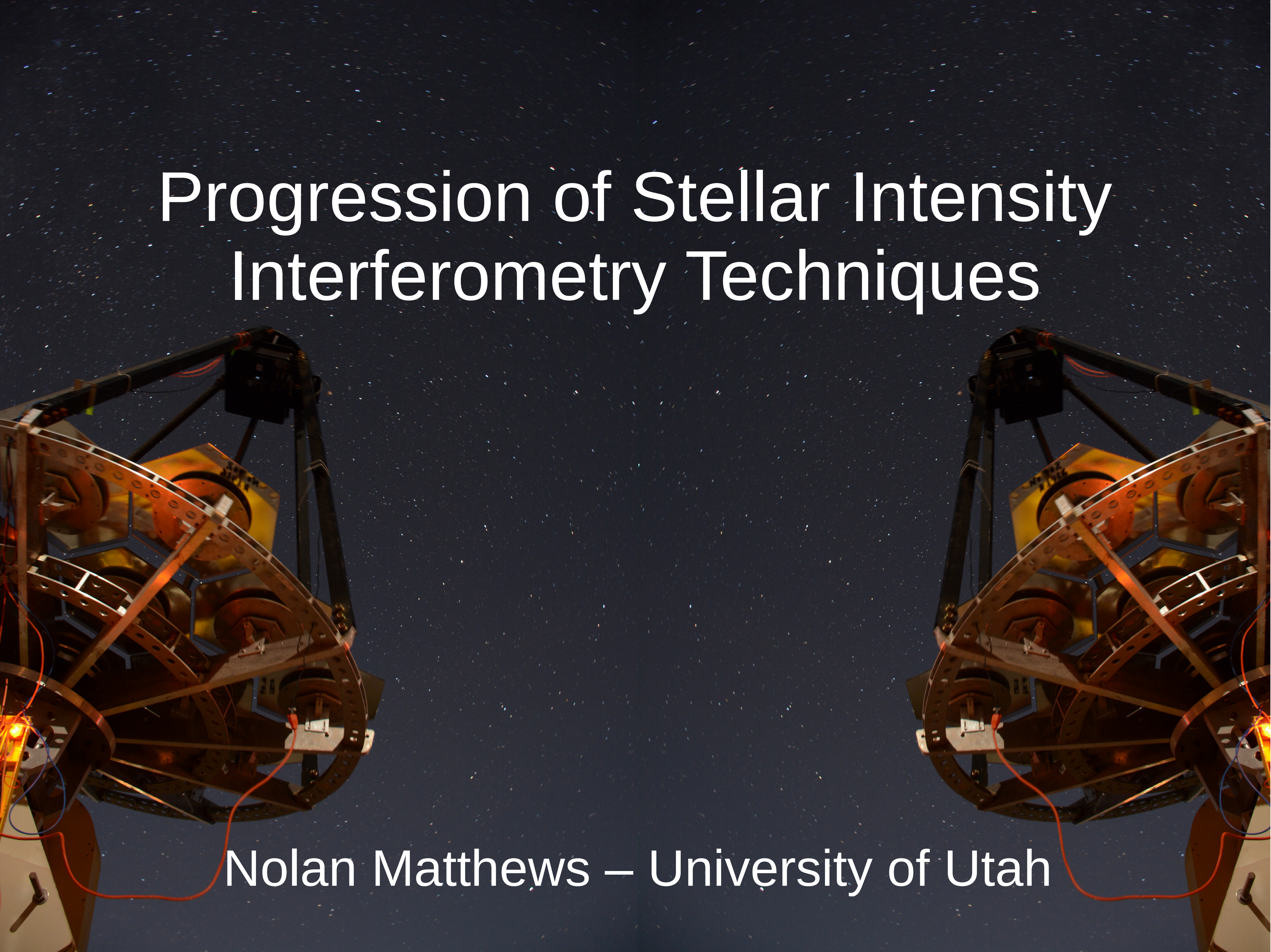
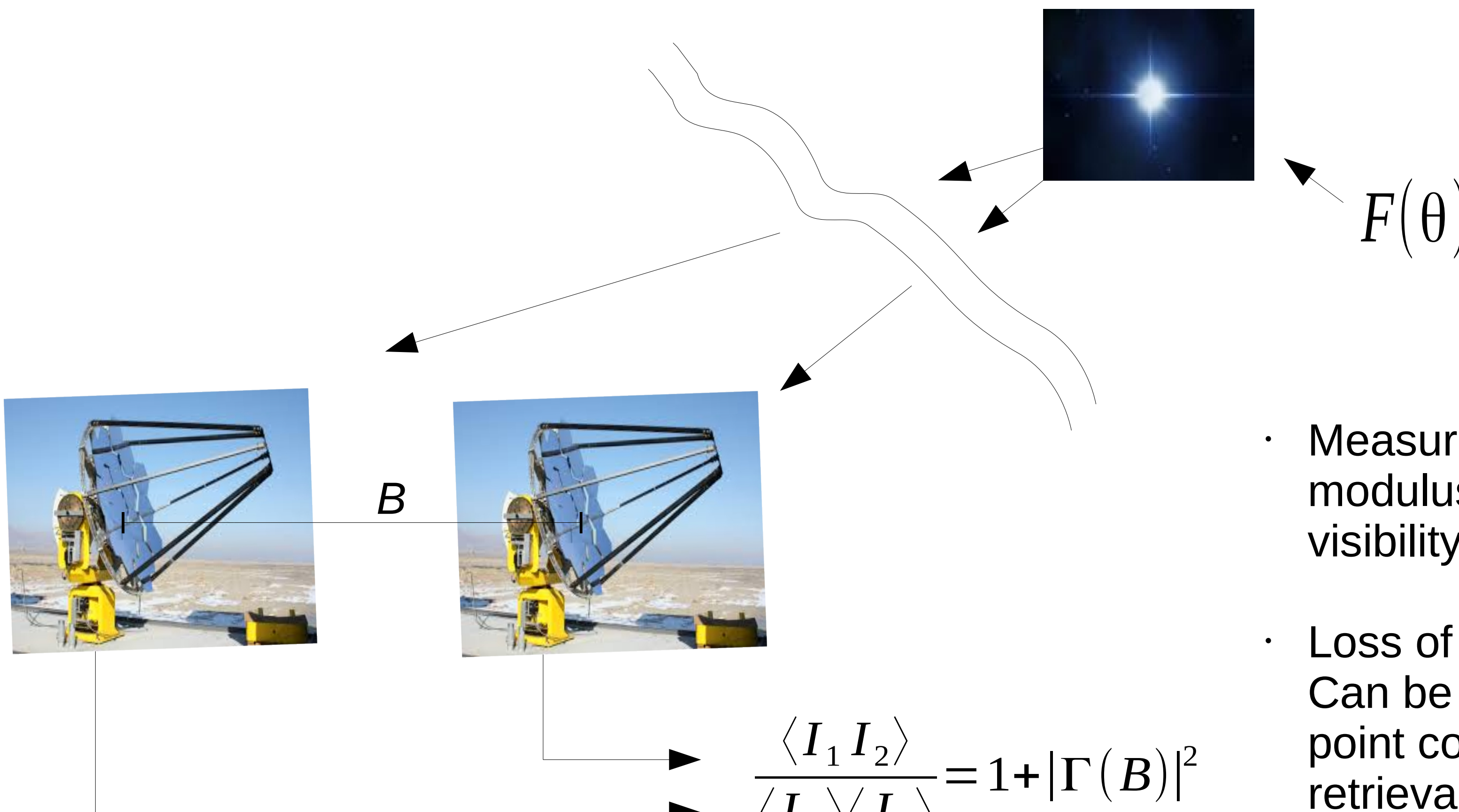
Progression of Stellar Intensity Interferometry Techniques



Nolan Matthews – University of Utah

Brief Review of Intensity Interferometry

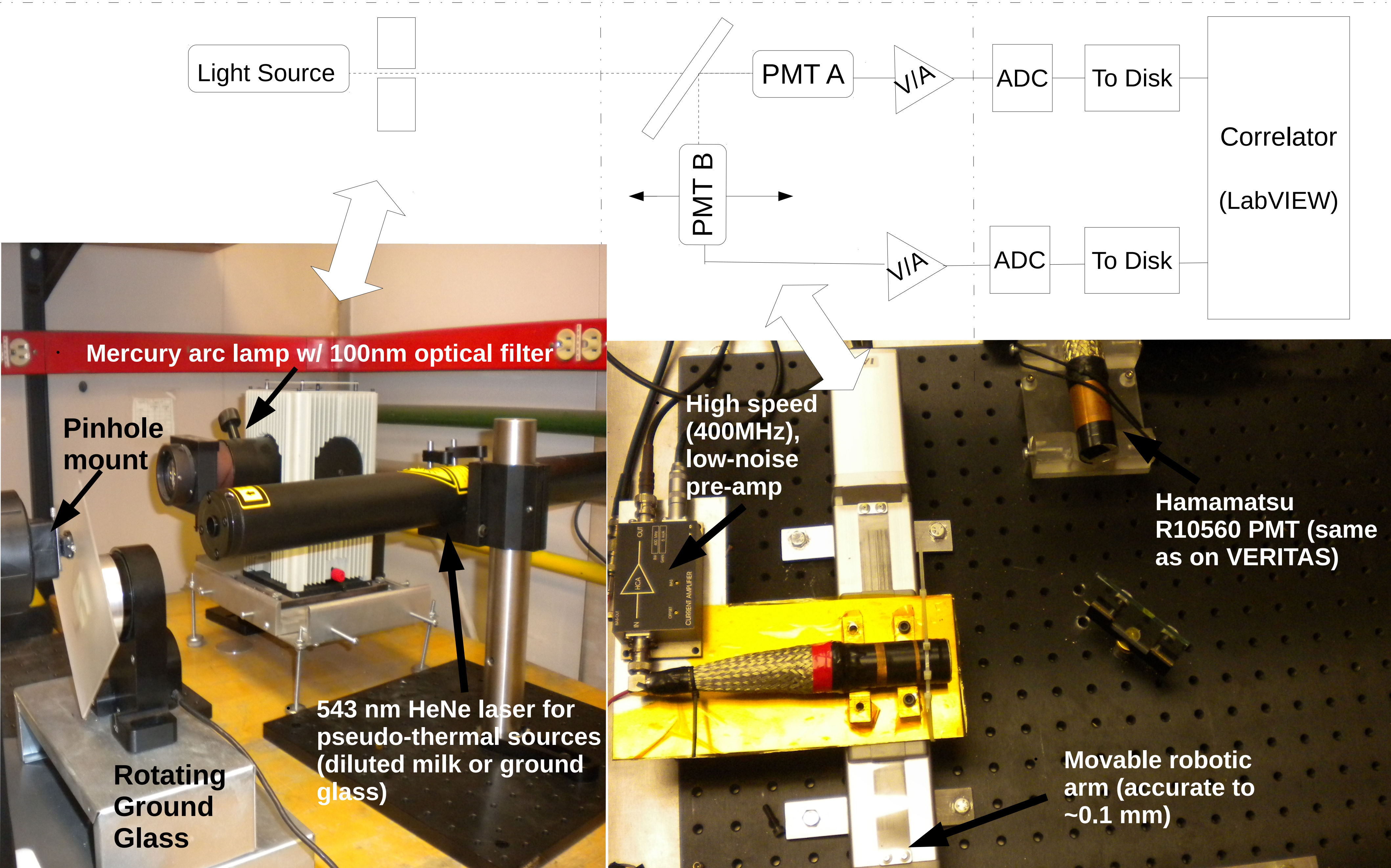


$$\frac{\langle I_1 I_2 \rangle}{\langle I_1 \rangle \langle I_2 \rangle} = 1 + |\Gamma(B)|^2$$

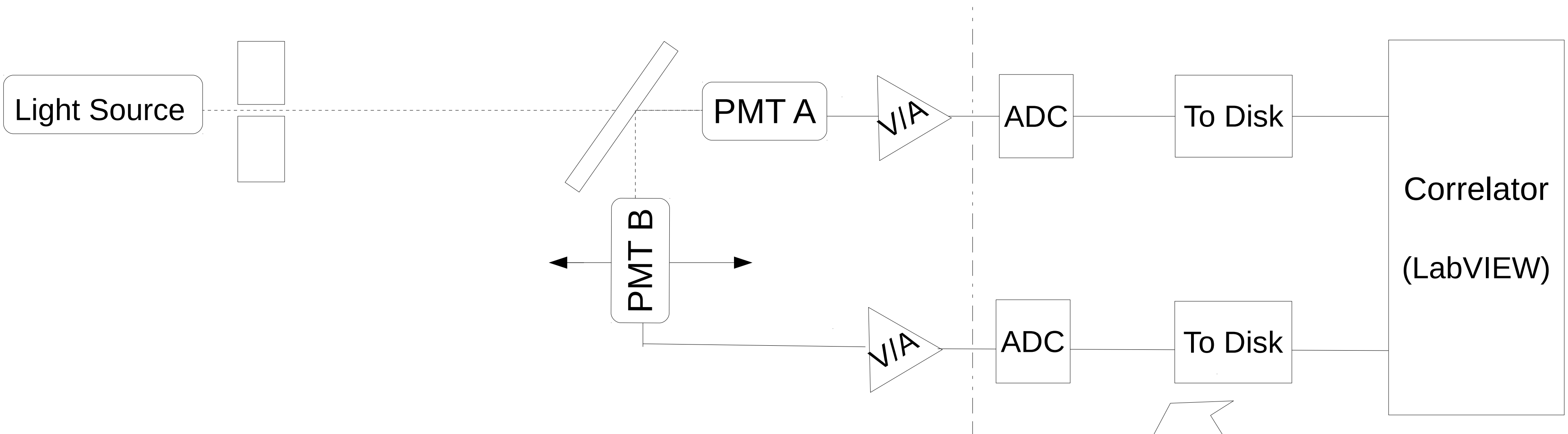
$$\Gamma(B) \propto \int F(\theta) e^{ikB\theta} d\theta$$

- Measures the squared modulus of the complex visibility of the source.
- Loss of phase information. Can be found through three-point correlation and phase retrieval techniques [Nunez 2012]
-

Lab Setup → Sources & Detectors

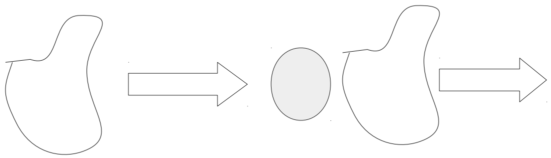


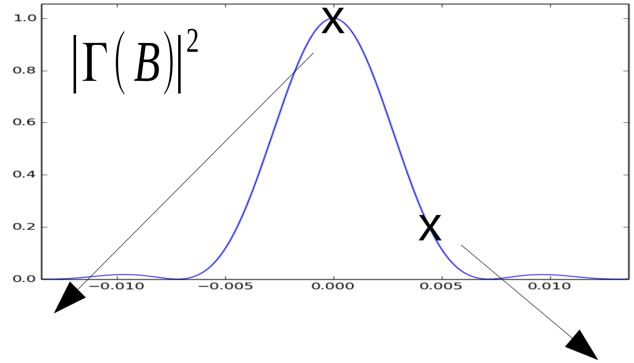
Lab Setup → DAQ System

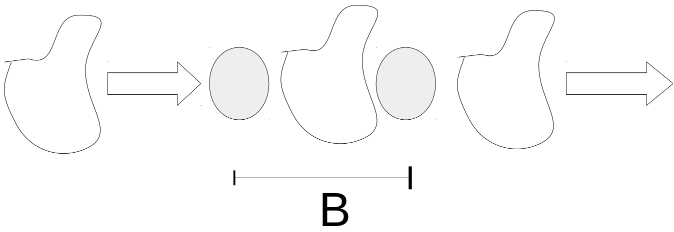


- Digitize data at 250 MHz (4ns/sample)
- Stream data to disk at 500MB/sec.
- Dynamic capabilities of FPGA
- Data analyzed in LabVIEW

Measurements of Pseudo-Thermal Source Intensity Correlations







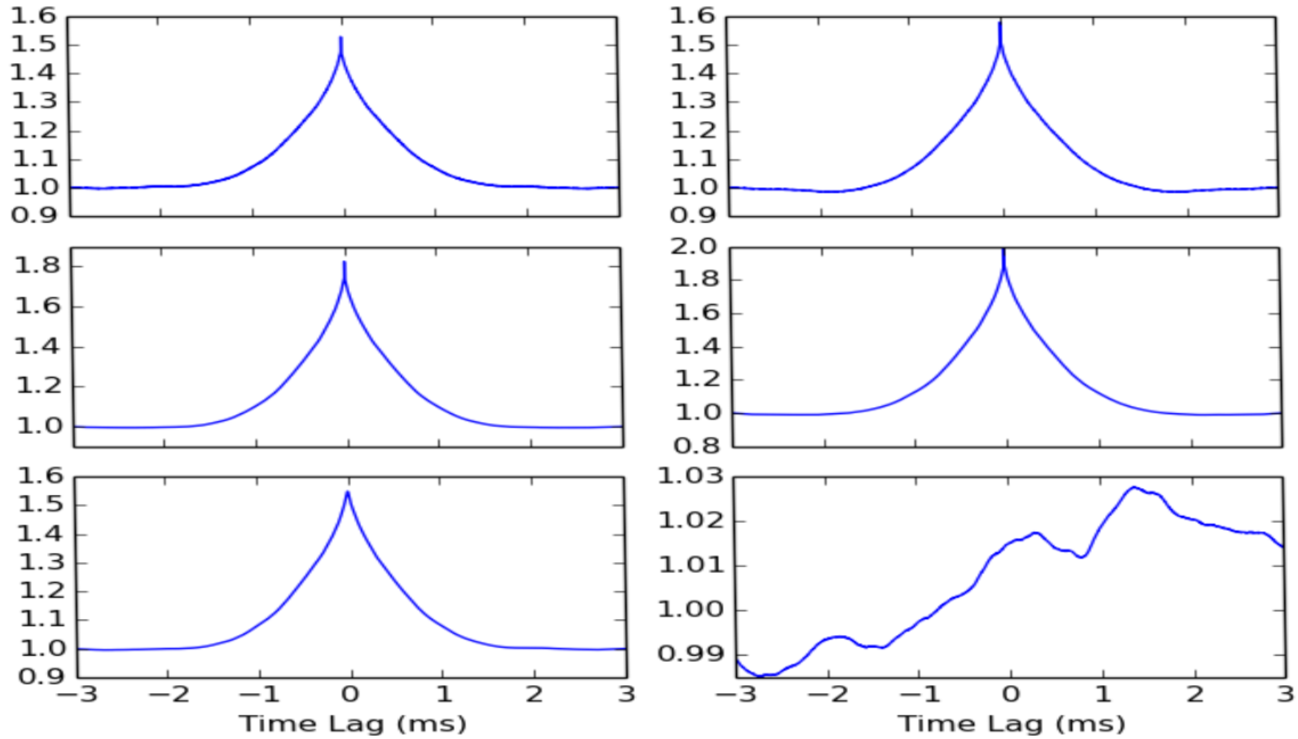
Zero Baseline Separation

Large Baseline Separation

$$\frac{\langle I_1 I_1(\tau)\rangle}{\langle I_1\rangle^2}$$

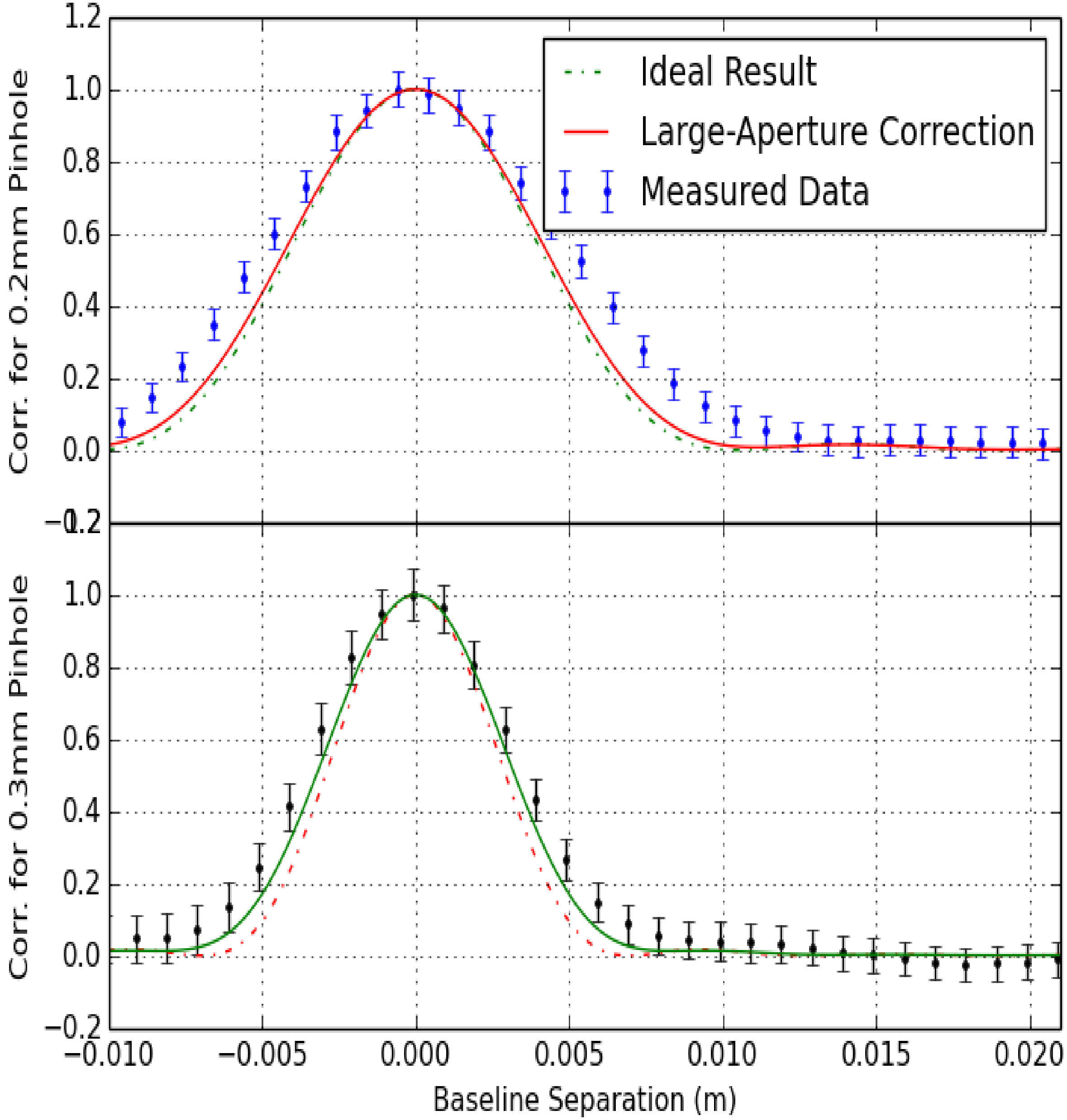
$$\frac{\langle I_2 I_2(\tau)\rangle}{\langle I_2\rangle^2}$$

$$\frac{\langle I_1 I_2(\tau)\rangle}{\langle I_1\rangle\langle I_2\rangle}$$

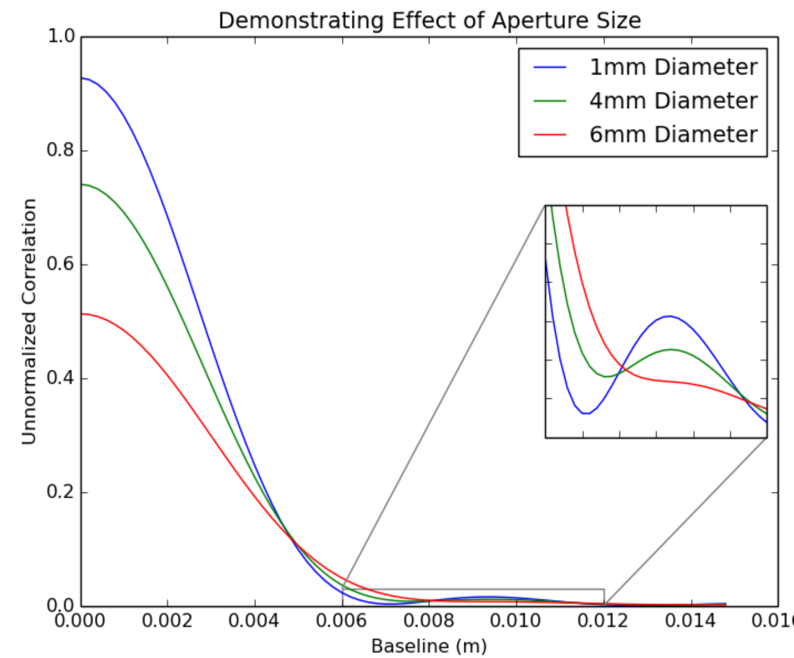


τ τ

Pseudo-thermal source measurements over many baselines



Incorporating Large Aperture Sizes



$$|\Gamma(B)|^2_{corr} \propto \frac{1}{A_1 A_2} \int dA_1 \int dA_2 |\Gamma(B)|^2$$

[HBT 1974, J. Rou et al. 2013]

$$\Gamma(B) = 2 \frac{J_1\left(\frac{\pi\theta}{\lambda} B\right)}{\frac{\pi\theta}{\lambda} B}$$

θ → Angular diam. of source

λ → Wavelength of light source

Thermal Light Progress (some background)

For sources where the coherence time << sampling rate, the cross-correlation at the PMT photo-cathode is given by: [Mandel 1963; HBT 1974]

$$c(d) = \langle \Delta i_1(t) \Delta i_2(t) \rangle = e^2 \dot{N}_{p.e.}^{\,2} |\gamma_d(0)|^2 \frac{\Delta f}{\Delta \nu}$$

- $\dot{N}_{p.e.}$ → Photo-electon count rate
- $\Delta\nu$ → Optical Bandwidth ~1/Tcoh
- Δf → Electronic Bandwidth ~1/Tsamp

<u>Lab</u>

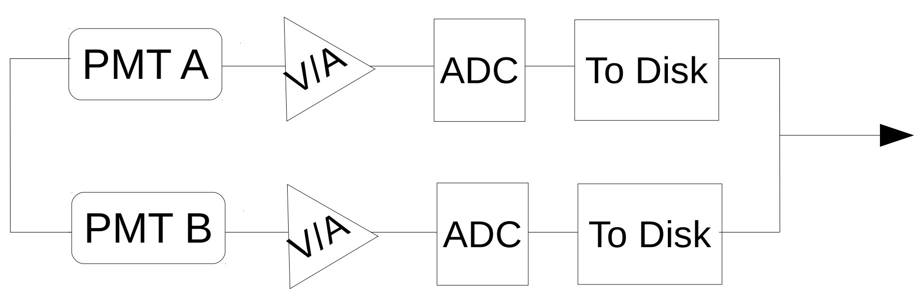
$\Delta\nu$ ~10^7 MHz

Δf ~100MHz

$$\frac{\Delta f}{\Delta \nu} = 10^{-5}$$

Why intensity interferometry w/ thermal sources is hard!

$c(d)$



$$c_m = c(d) G_{pmt\,A} G_{pmt\,B} G^2_{pre-amp} G^2_{ADC}$$

G_{pmt}	$G_{pre-amp}$	G_{ADC}
~10^5	5 kV/A	~0.5 dig.cts/mV

For source:

$\dot{N}_{p.e.}$ ~ 2 x 10 ^9;

c_m ~ 0.02 (dig.cts)^2

Tracking Noise Levels

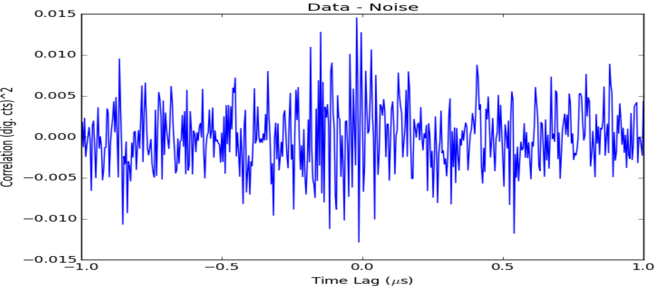
- Noise follows:

$$N(T) = \frac{\beta}{\sqrt{T}}$$

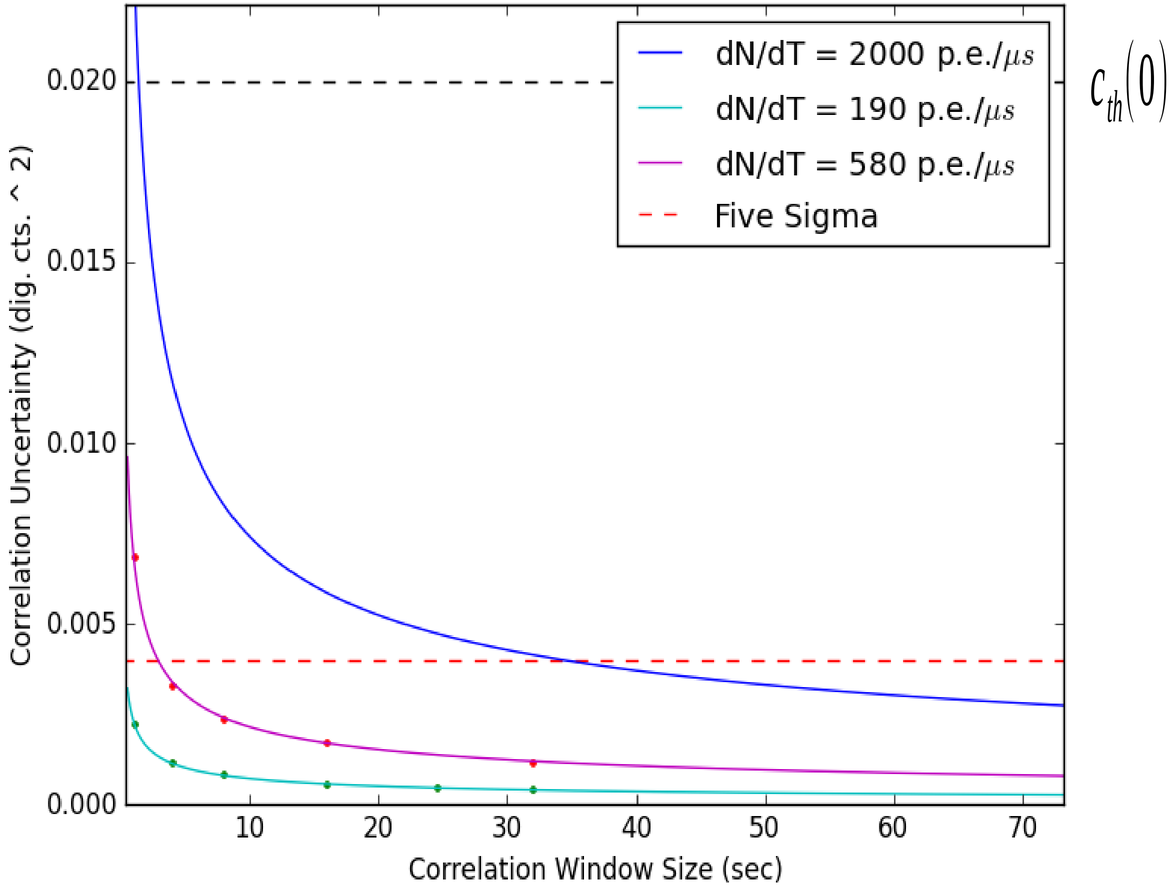
$$\beta = \sqrt{2} e^2 \dot{N}_{p.e.} \sqrt{\Delta f}$$

$$\beta \propto \dot{N}_{p.e.}$$

Define noise by scatter at different time lags:

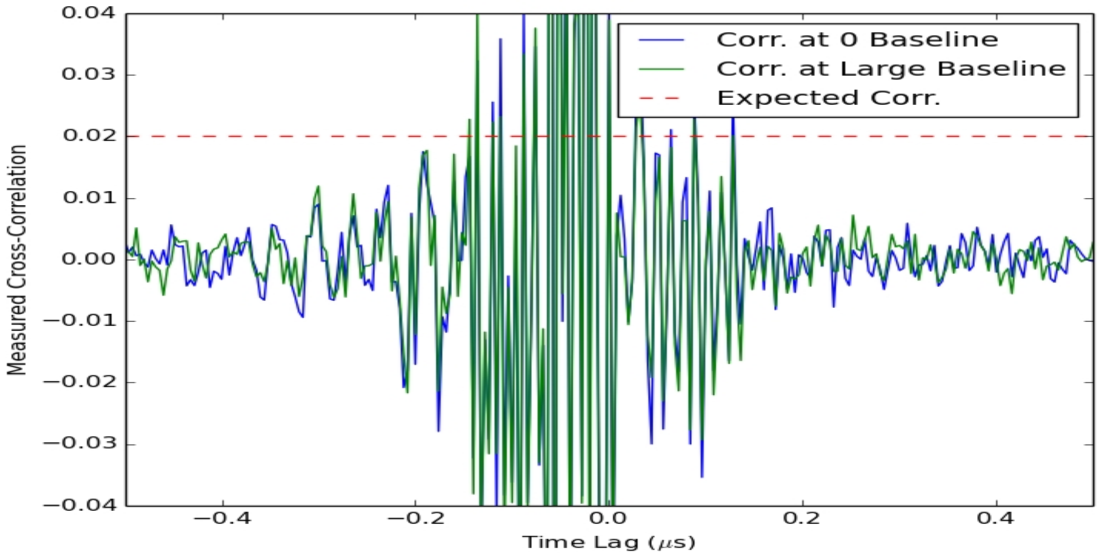


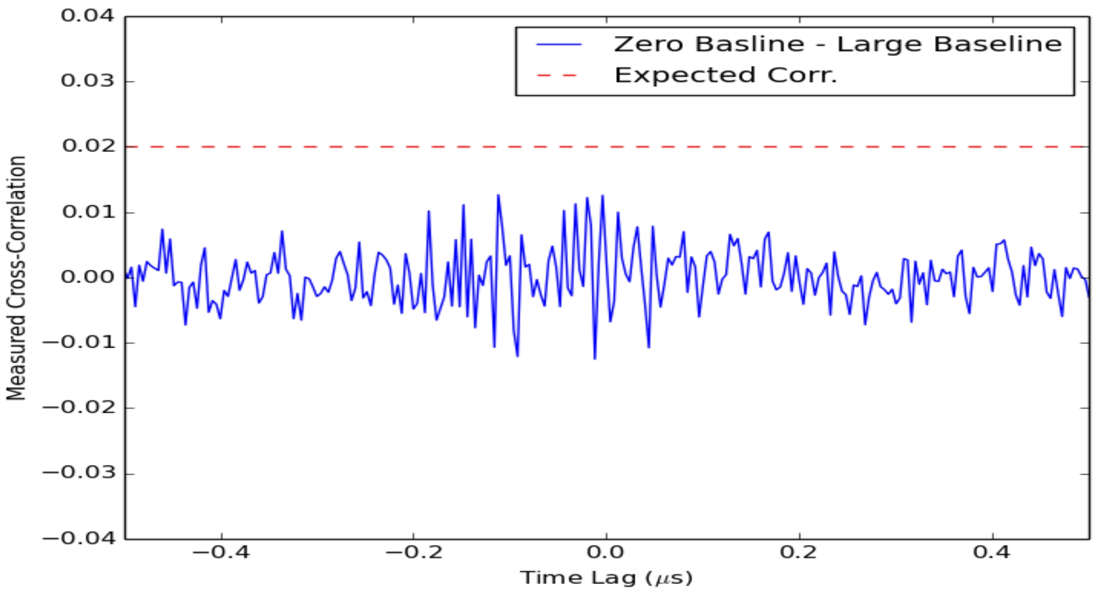
} σ



Track noise for known rates, extract β
Scale to different rates.

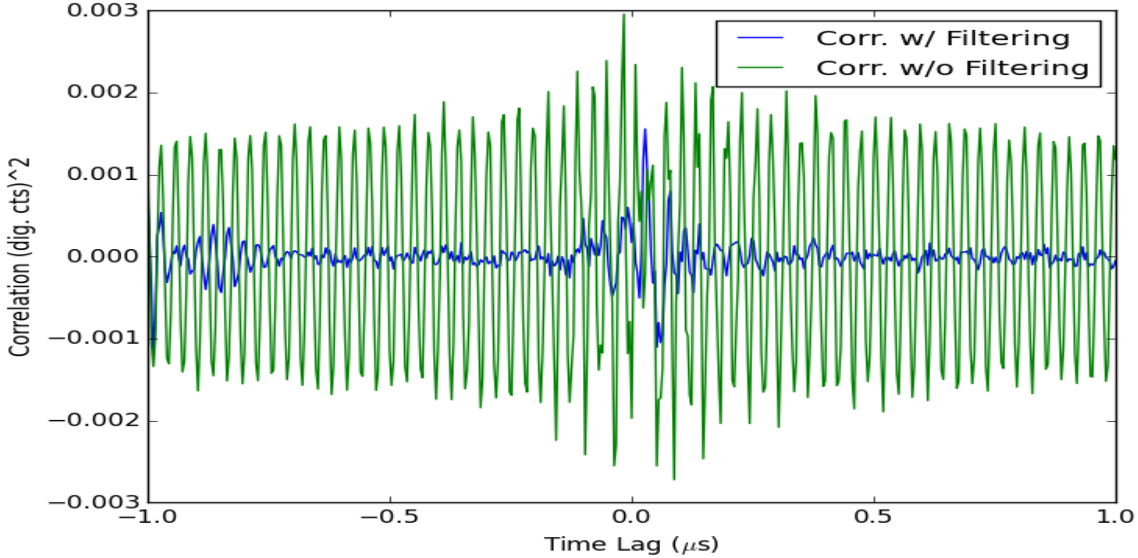
Initial Observations of Thermal Sources

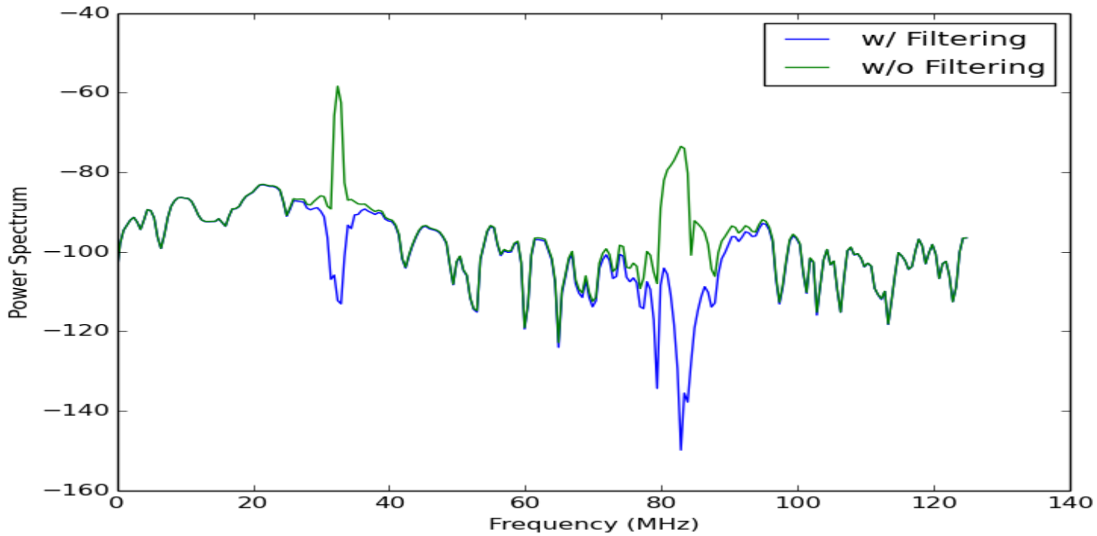




- Even with shielding noise will be present; most obvious at short (< 200 ns) timescales.
  - PMT cross-talk, simultaneous RF pickup, correlated DAQ noise..
- Removal may be possible by subtracting noise correlation from the signal correlation.
- Assumption: Noise pickup is the same at small/large baselines.

Other Analysis Techniques





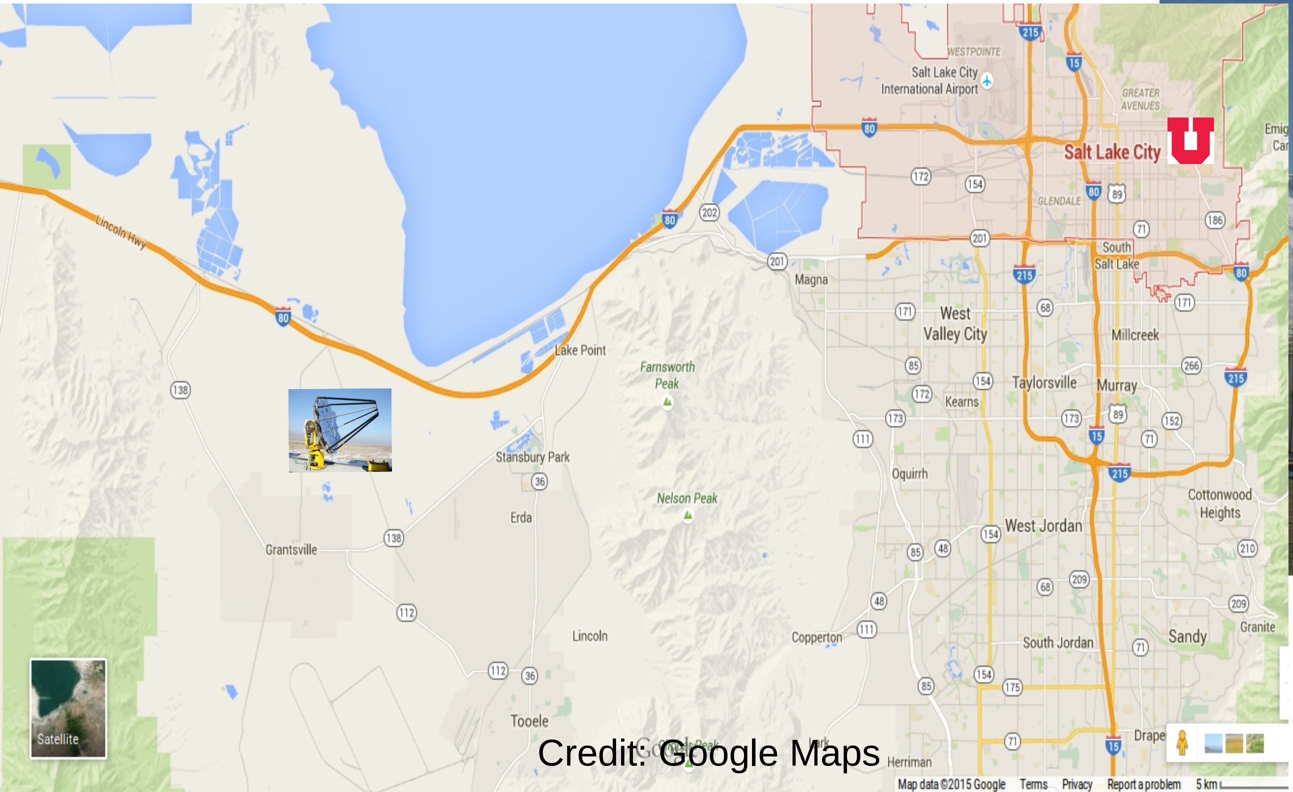
- Apply digital filtering to further reduce noise for non-broadband signals.
- Trade-off → Reduces desired correlation signal.
- Opportunity to lower noise levels at small scales

SII at StarBase-Utah

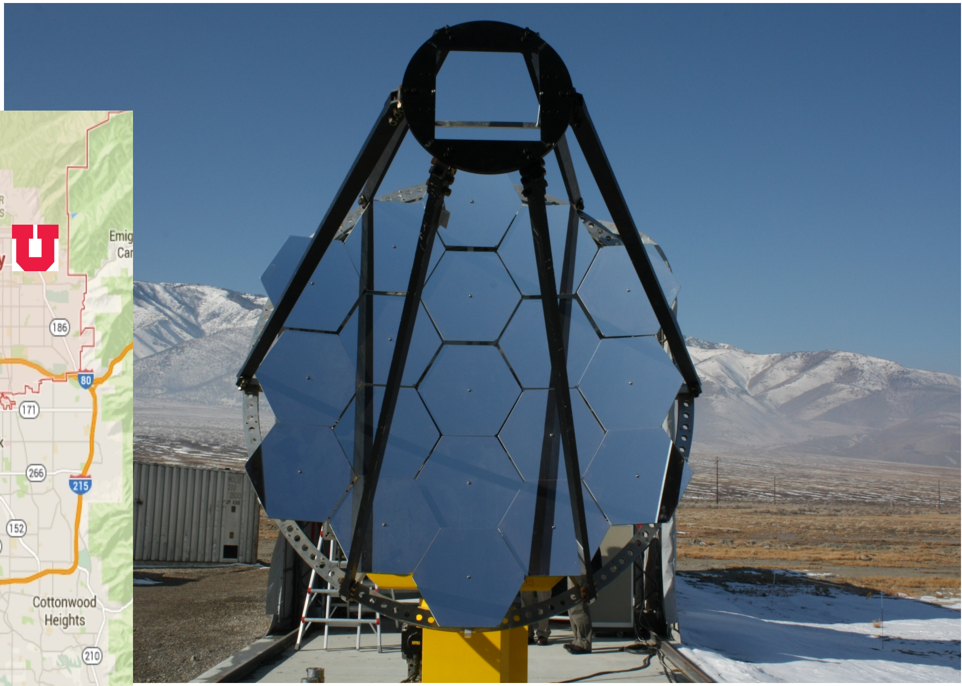
- University of Utah operates two 3m diameter telescopes separated by 23m located in Grantsville, UT. (~45 min west of Salt Lake City)

- Target stars with ~1-5 mas angular diameter.

- Testbed for II observations!



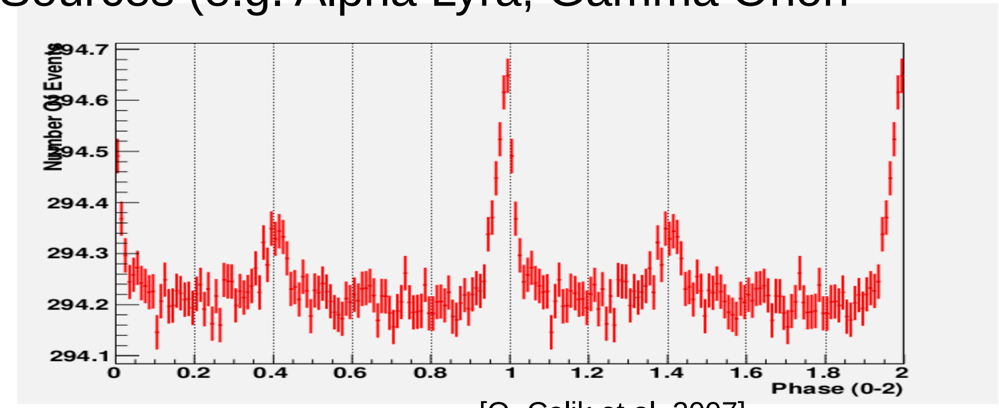
Credit: Google Maps



Looking Forward

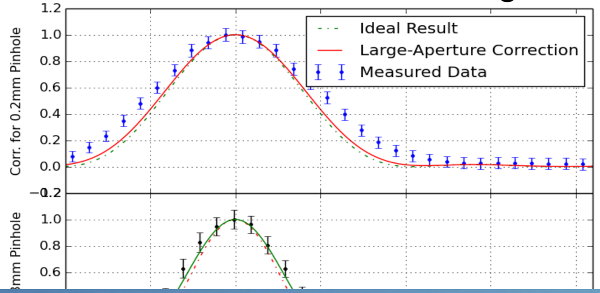
StarBase telescopes in operation

Observations of Crab Pulsar in Winter + Unresolved Sources (e.g. Alpha Lyra, Gamma Orion

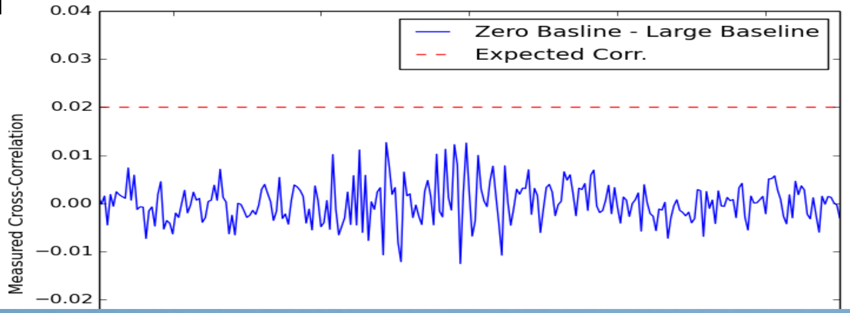


[O. Celik et al. 2007]

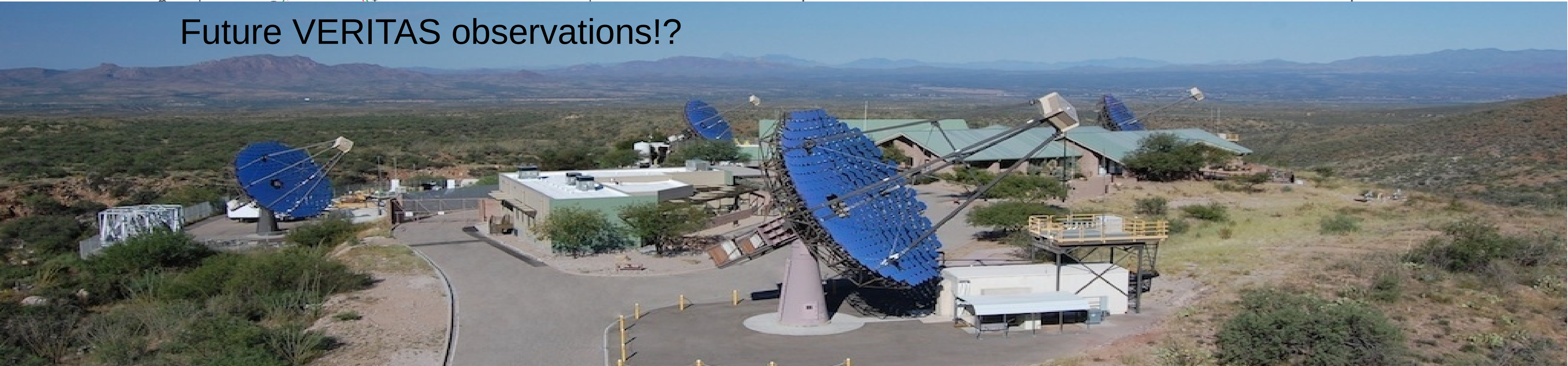
Continue to refine psuedo-thermal source measurements. Work towards image reconstruction



Observe Thermal Correlations



Future VERITAS observations!?



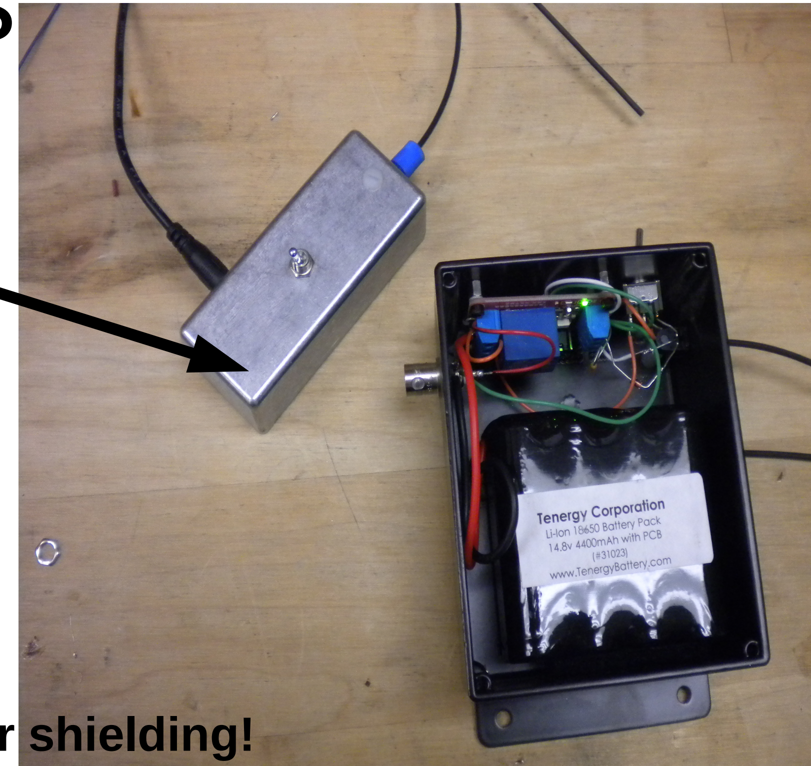
Acknowledgements

National Science Foundation
WHERE DISCOVERIES BEGIN

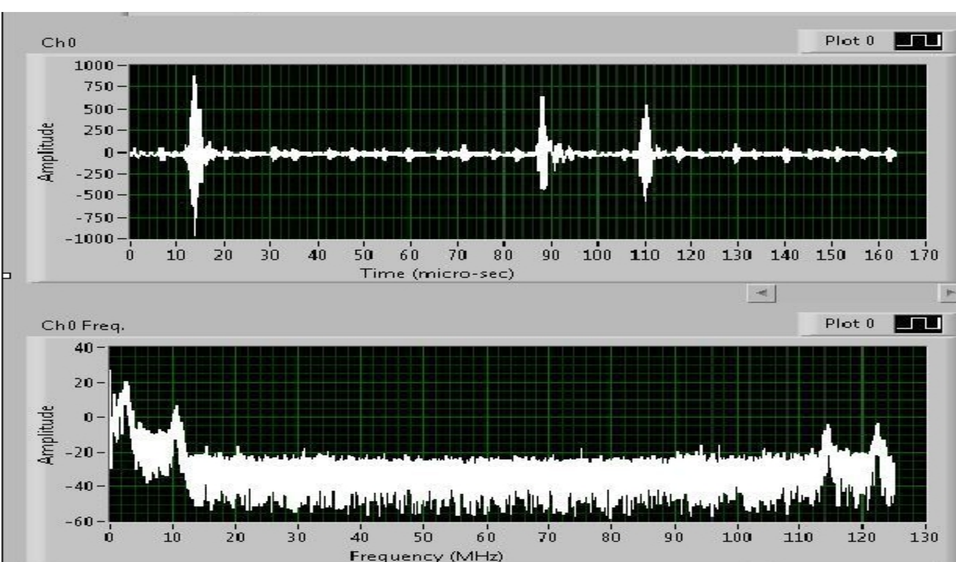
Left Picture: Dr. Dave Kieda (PI), Abigail McBride, Patty Bolan, Dr. Udara Abeysekara, (me), Dave Rosen,
Right Picture: Dr. Stephan Lebohec

Additional - Instrumentation of Telescopes

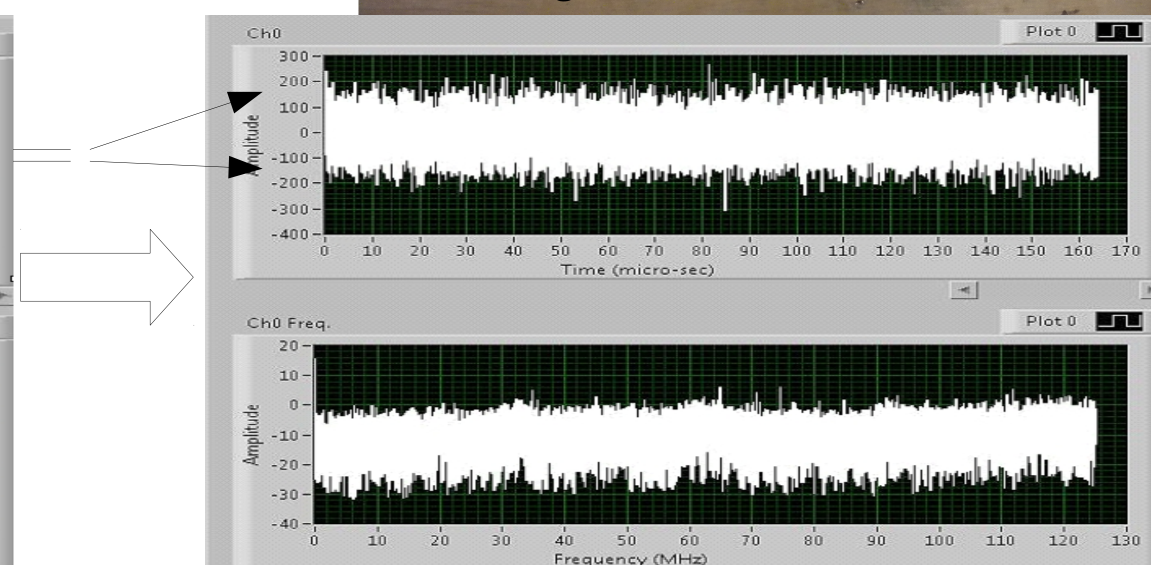
- Using shielded coax cable – previously used optical fiber link.
- Introduce optical fiber relay for switching HV on/off
- Using copper shield for PMT's/braided cable over coax
  - Rejection of RF noise from telescope motors



Before shielding



After shielding!



Additional - Goals for StarBase

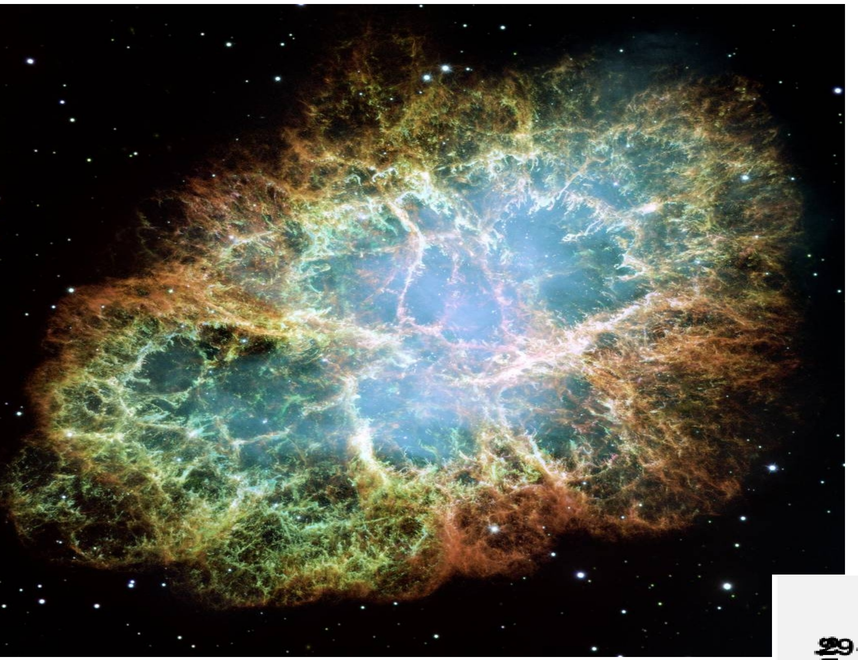
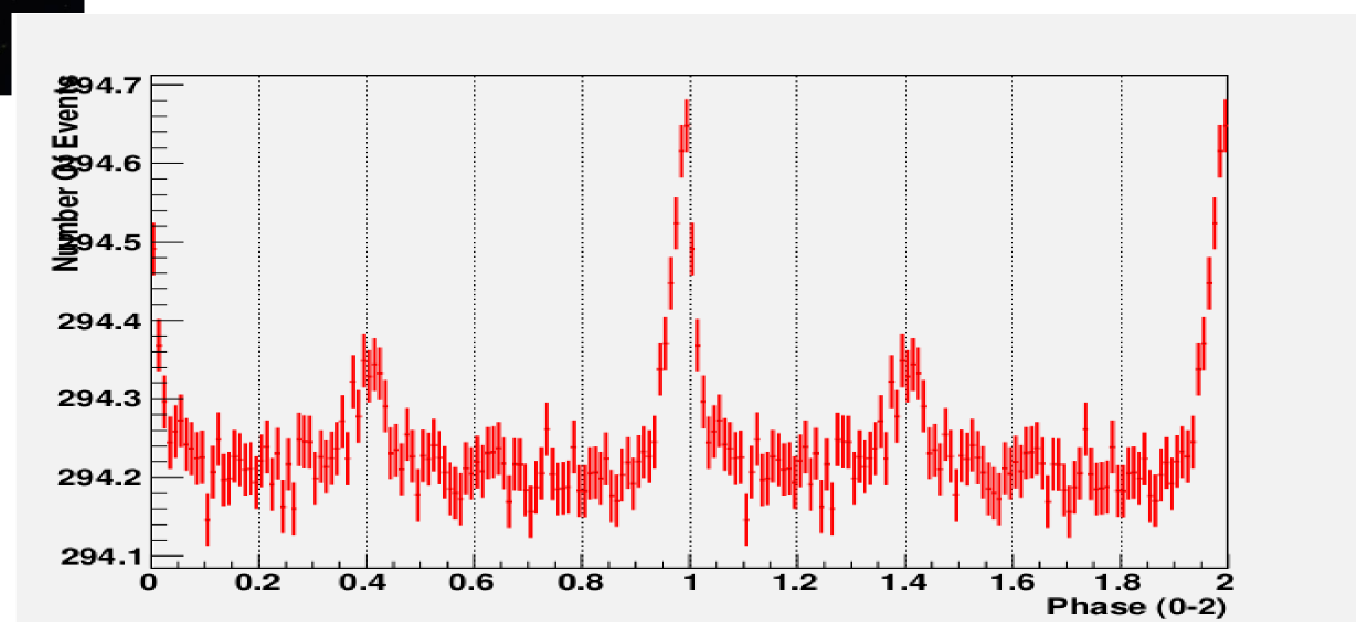


Image Credit: NASA, ESA, J. Hester, A. Loll (ASU)

- Carry out observations of Crab Pulsar (Nov 2015 – Mar 2016)
  - Verifies electronic capabilities as well as telescope operation.
  - If successful, would be smallest known ACT to observe optical crab pulses!
  - Signal rate ~ 1/1000th of the background (~10^8 p.e./sec) [Ona-Wilhelmi, Cortina, and Fonseca 2004]

- After verifying techniques in lab on thermal sources begin observations of bright stellar sources.

- First step.. making thermal observations in the lab!



Additional - Thermal Light Progress (some background)

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$$\dot{N}_{p.e.} = A \alpha n \Delta \nu$$

- A → Collection Area (m^2)
- α → Quantum Efficiency (p.e./photon)
- n → Source Flux (photons * sec^-1 * Hz ^ -1 m^-2)
- $\Delta \nu$ → Optical Bandwidth (Hz) ~ 1/Tcoh
- Δf → Electronic Bandwidth (Hz) ~ 1/Tsamp

	Lab
$\Delta \nu$	~10^7 MHz
Δf	~100MHz

$$\frac{\Delta f}{\Delta \nu} = 10^{-5}$$

→ Why intensity interferometry w/ thermal sources is hard!