Intensity Interferometry with SPADs

May 13, 2014

Genady Pilyavsky, Nathan Smith, Philip Mauskopf, Ed Schroeder, Ian Chute, Adrian Sinclair
Arizona State University (ASU)

What Is the Scientific Motivation?

- Small, hot, intense sources
  - Bright blue stars (OB)
  - BH accretion disks
- Proof of concept (SPAD)

Constraints/limitations for Astronomy:

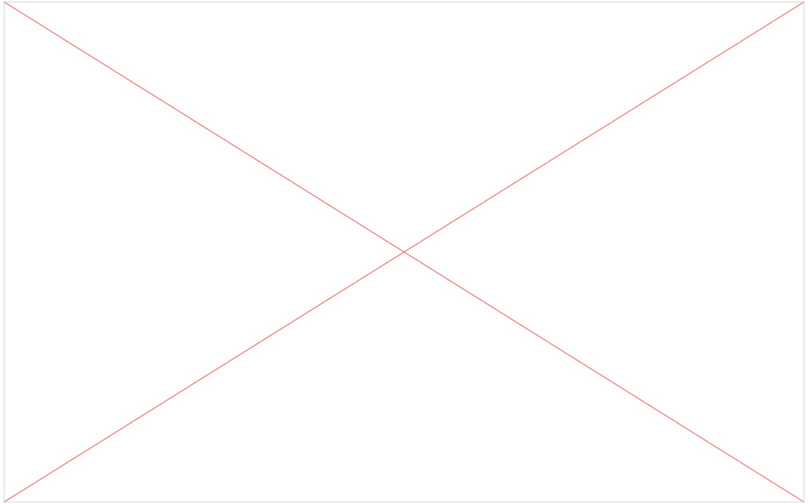
$$N_{mode} = \frac{(A)(\Omega)}{\lambda^2}$$

$$n_{occ} = \frac{N_{\text{modes}}}{e^{\frac{h\nu}{kT}} - 1}$$

$$\frac{S}{N} = \eta \cdot n_{occ} \cdot \sqrt{\frac{\tau_{\text{int}}}{\tau_{\text{det}}}} \cdot C_{(2)}(r_1, t_1 : r_2, t_2)$$

- Telescope size
- Integration time
- Detector time constant
- Count rate
  - Bandwidth
  - Source temperature

Example: Cygnus X-1



European Homepage for the NASA/ESA
Hubble Space Telescope

- Binary - OB star (9th magnitude) and black hole / accretion disk

- 5.6 day period

- Variation in brightness due to elongation of OB star

Cygnus X-1

The disk is far too small to resolve in any reasonable integration time with current detector capabilities.

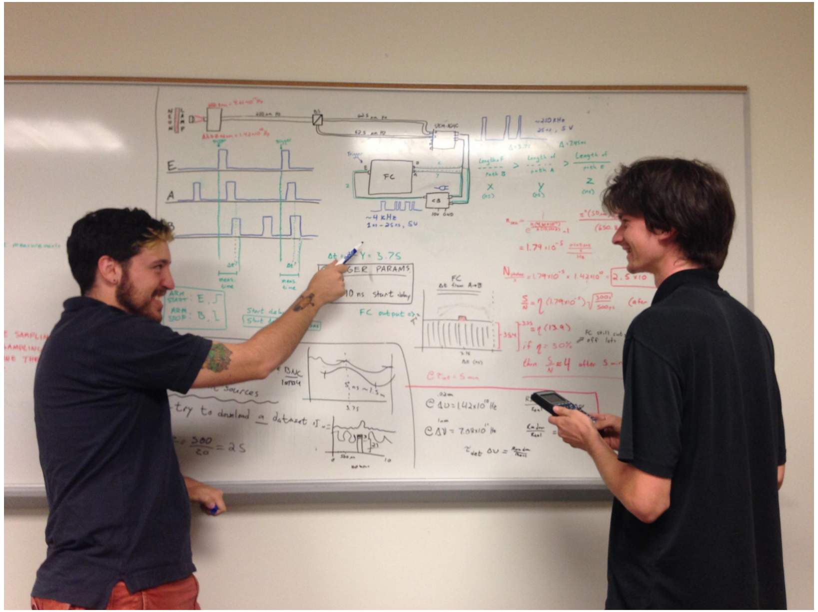
- N number of 1-m telescopes
- S/N=10

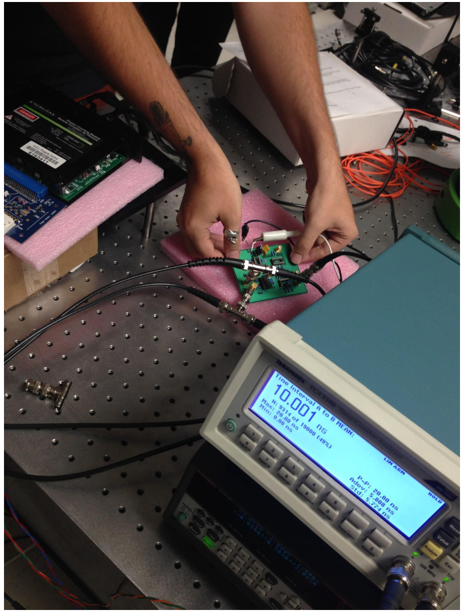
Integration Time				
N	*Cygnus X-1 (Star) (SNSPD)*	*Cygnus X-1 (Tail) (SNSPD)*	*Cygnus X-1 (Star) (SPD)*	*Cygnus X-1 (Tail) (SPD)*
1	5.48 days	4.17 years	8.13 days	6.19 years
5	5.26 hrs	60.88 days	7.80 hrs	90.28 days
10	1.32 hrs	15.28 days	1.95 hours	22.57 days
100	47.36 sec	3.65 hours	70.21 sec	5.42 hrs

What Is ASU's Approach?

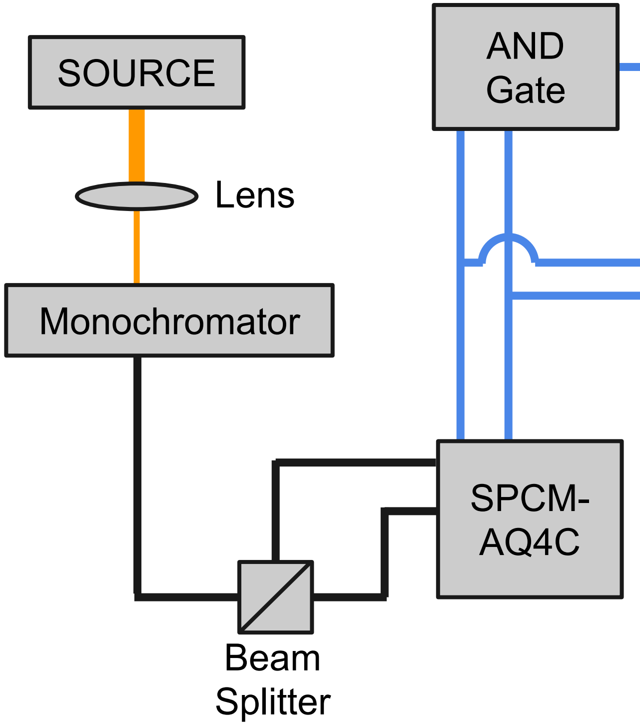
- Starting with off-the-shelf electronics
  - Excelitas SPCM-AQ4C
    - 500 ps
    - 4-Channel
    - ~ 65 % QE @ 650 nm
  - FCA 3100
    - 50 ps timing resolution
    - 1000 counts/sec (for time interval measurements)
- Small telescopes

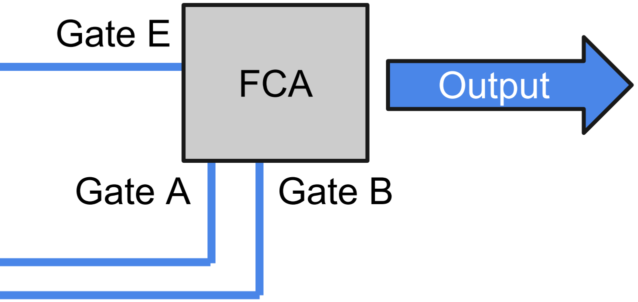
Lab testing

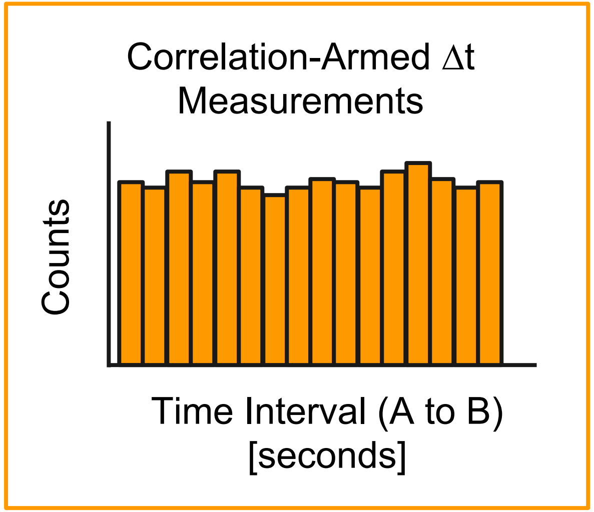




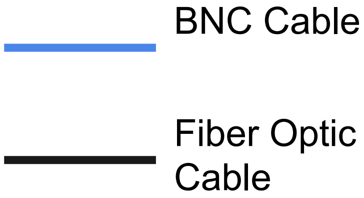
Lab Testing







- Signal Path
  - Gate E: 0.0 ns
  - Gate A: 7.75 ns
  - Gate B: 11.50 ns
- Correlations from AND Gate are used to arm sampling regions in FCA

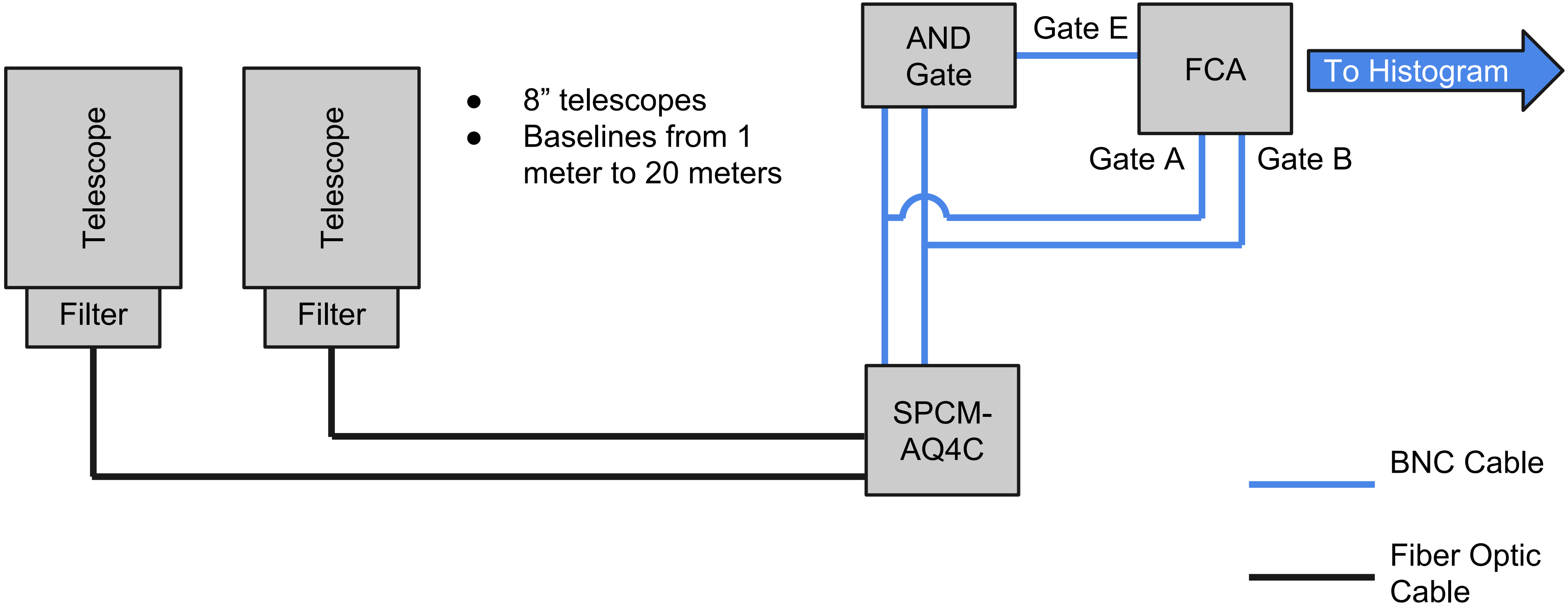


Limitations

- Maximum single detector count rate ~ 2 MHz
- Number of measurements per second is limited to about 15,000 to internal data buffer
- Dead time effectively reduces this to ~1,000 per second
  - Use AND gate as trigger to maximize efficiency

    (factor ~ 1 us/20ns ~ 50)
  - 1 us ~ average random time interval
  - 20 ns = width of single pulse

ASU Astronomy System Set Up



- 8” telescopes
- Baselines from 1 meter to 20 meters

How Does ASU's Data Analysis Program Will Work?

- Save the timestreams
- Induce a time shift
- Fit a curve to the distribution
  - Temperature is known
  - Distance is known

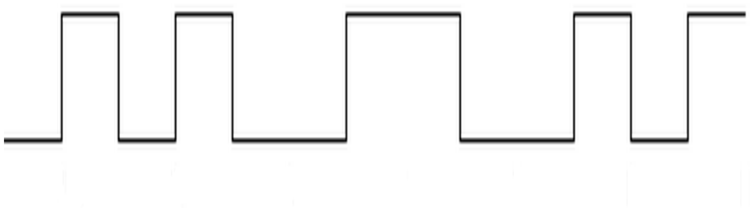
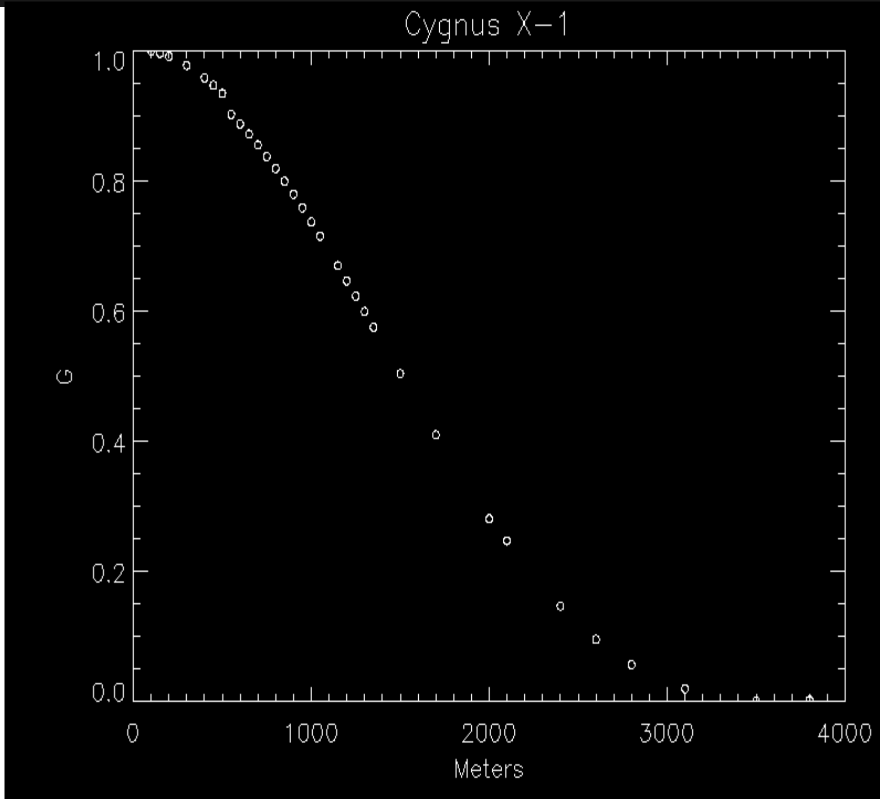


Image : http://www.erg.abdn.ac.uk/~gorry/eg3567/images/manenc.gif



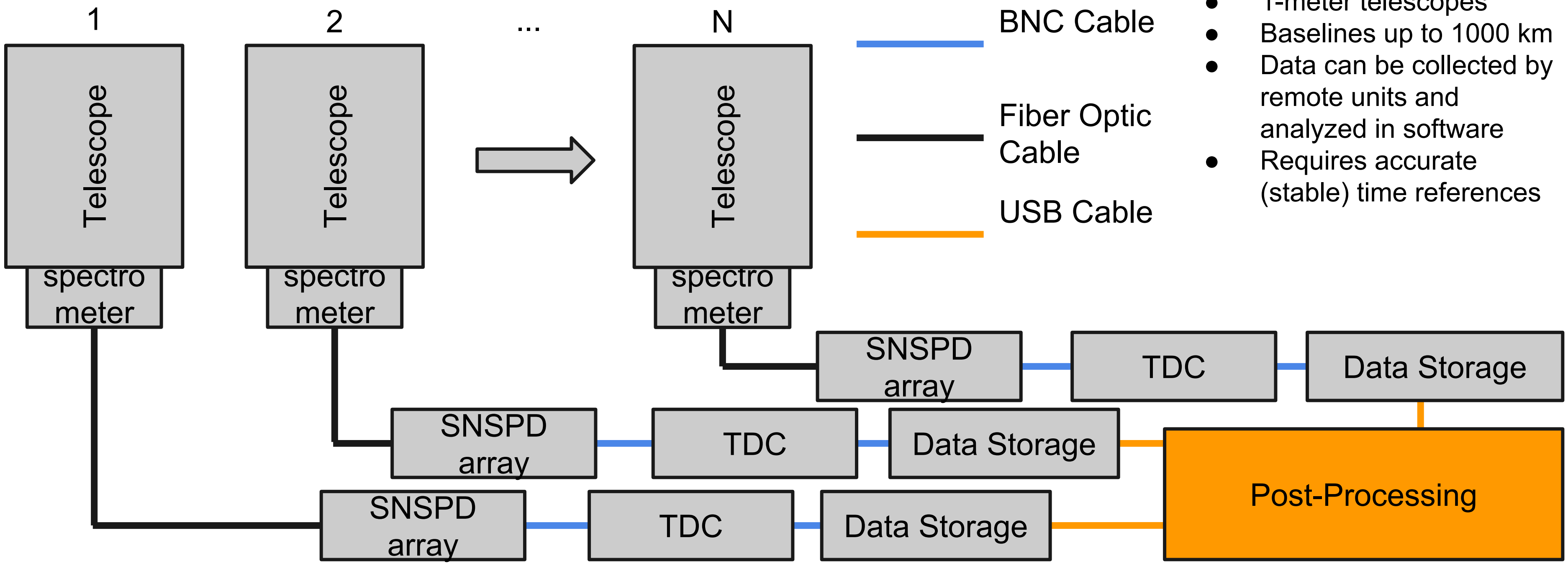
What Are the Constraints of Our System?

- Parameters
  - Collecting area = 0.0324 sq. meters
  - Bandwidth = 709.6 GHz
  - Wavelength of highest efficiency = 650 nm
  - Detector time constant = 500 ps
- Expected Performance
  - Betelgeuse (T = 3300 K, Angular Area = 4.08 x 10^-14 sq. deg)
    - Integration time = 1 minute, S/N = 0.80
    - Integration time = 5 hours, S/N = 13.8
    - Integration time = 300 hours, S/N = 107
  - Proxima Centauri (M-dwarf) (T = 3042 K, Angular Area = 1.87 x 10^-17 sq. deg)
    - Integration time = 1 minute, S/N = 0.01
    - Integration time = 5 hours, S/N = 0.18
    - Integration time = 300 hours, S/N = 1.13
- Clearly, current experimental parameters must be improved in order to measure small, dim stellar objects

What Are ASU’s Future Plans?

- Better detectors
  - SNSPDs
    - Faster detector time constant (< 150 ps)
    - Longer wavelengths (higher occupation number)
    - Improved performance characteristics
      - Proxima Centauri
        - Integration time = 1 minute, S/N = 0.25
        - Integration time = 5 hours, S/N = 4.25
        - Integration time = 300 hours, S/N = 33.0
- Simultaneous multiwavelength measurements
    - Arrays of SNSPDs
    - Integration time → 1/N

How Will ASU's Future System Be Set Up?



- 1-meter telescopes
- Baselines up to 1000 km
- Data can be collected by remote units and analyzed in software
- Requires accurate (stable) time references

Thank You

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