Optical Intensity Interferometry Using SNSPDs

Faith Beall

Supervisor: Albert Stebbins

Overview

1. Intensity Interferometry: History and Concept
2. Preliminary calculations
3. Experimental design – Current progress
4. Future work

Intensity Interferometry: History and Concept

Hanbury Brown and Twiss with the Narrabri Stellar Intensity Interferometer

- Pioneered by Robert Hanbury Brown and Richard Twiss – initially used in radio-astronomy to measure angular sizes of two prominent radio sources: Cygnus A and Cassiopeia A

Hanbury Brown and Twiss with the Narrabri Stellar Intensity Interferometer

- Pioneered by Robert Hanbury Brown and Richard Twiss – initially used in radio-astronomy to measure angular sizes of two prominent radio sources: Cygnus A and Cassiopeia A
- They developed a theory of intensity interferometry using light waves, leading to the development of the Narrabri Stellar Intensity Interferometer from 1963-1974
  - It produced reliable measurements and displayed the potential for astronomical interferometry – measured angular size of stars down to 2.5 magnitude

Picture retrieved from: https://www.astronomaestro.com/2020/06/the-power-and-potential-of-stellar.html

Hanbury Brown and Twiss with the Narrabri Stellar Intensity Interferometer

- Pioneered by Robert Hanbury Brown and Richard Twiss – initially used in radio-astronomy to measure angular sizes of two prominent radio sources: Cygnus A and Cassiopeia A
- They developed a theory of intensity interferometry using light waves, leading to the development of the Narrabri Stellar Intensity Interferometer from 1963-1974
  - It produced reliable measurements and displayed the potential for astronomical interferometry – measured angular size of stars down to 2.5 magnitude
- With the implementation of modern technology, sensitivity can be improved

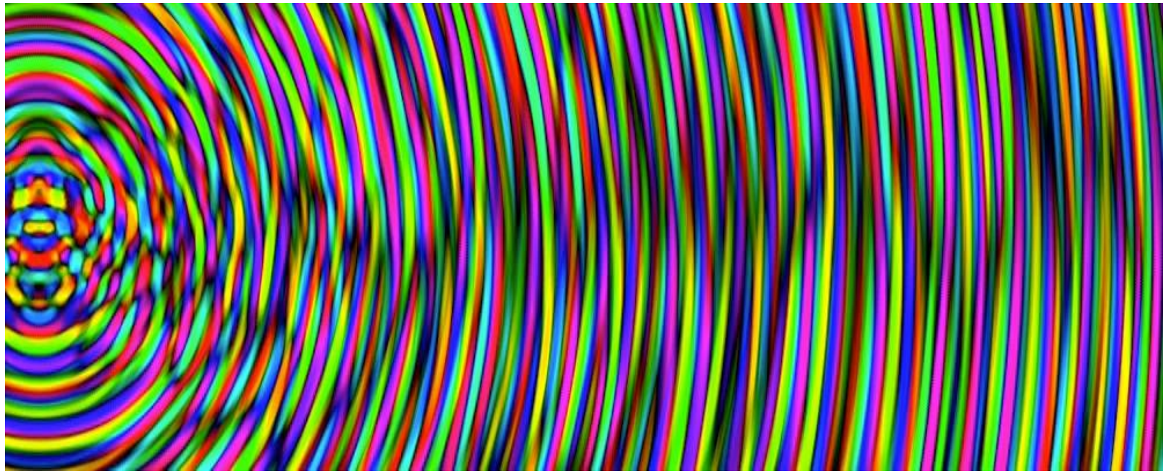
Picture retrieved from: https://www.astronomaestro.com/2020/06/the-power-and-potential-of-stellar.html

Intensity Interferometry

- Uses two light detectors with extremely long baselines pointed at a single astronomical source to measure excess rate of photon arrivals

Intensity Interferometry

- Uses two light detectors with extremely long baselines pointed at a single astronomical source to measure excess rate of photon arrivals
- Stars: spatially incoherent

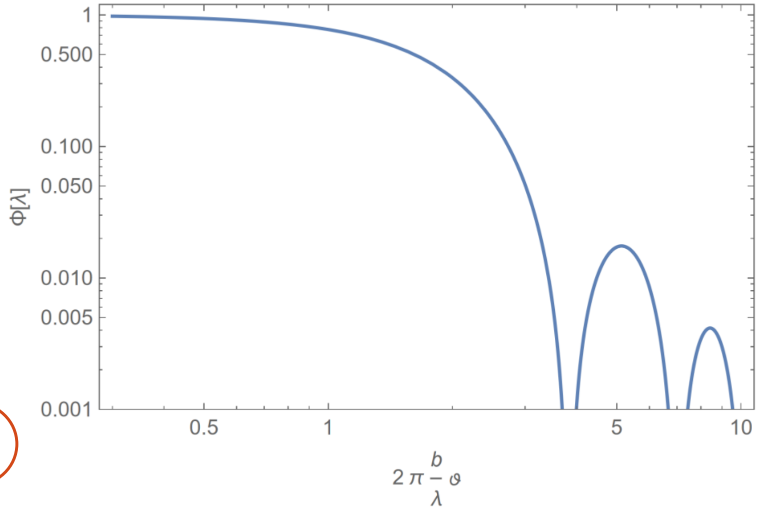


- The length of the transverse correlations coming from an incoherent source contains information about the angular size of that source.
- There will be a measurable excess correlation of photons arriving at the two counters.

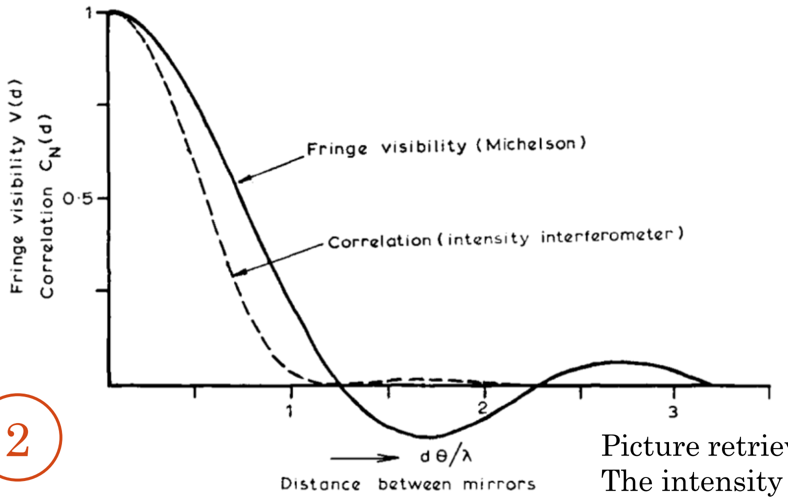
Intensity Interferometry

- Measures the excess correlation of simultaneously recorded photons as a function of:
  - baseline separation of the two detectors ***b***
  - wavelength $\boldsymbol{\lambda}$
- Excess correlation provides:
  1. Measure of uniform brightness of star (coherence function/intensity power spectrum)
  2. Angular size of the source

1



2



Picture retrieved from: R. H. Brown, The intensity interferometer: its application to astronomy (1974)

Advantages

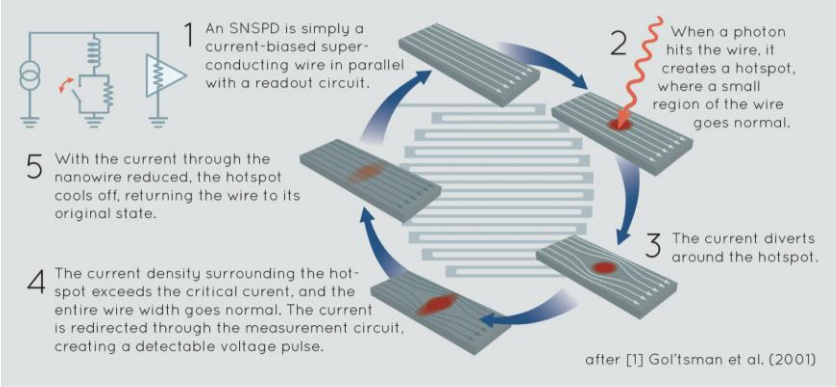
- ✓ No need for mutually coherent local oscillators at different telescope stations – only need digital electrical components
- ✓ Easily scalable for long baselines and multiple telescopes
- ✓ High optical angular resolution – dependent on baseline length which can be arbitrarily large
- ✓ Rapid development in single photon detector technology can provide increased sensitivity

Goal?

Goal?

To test the efficacy of optical intensity interferometry using SNSPDs

SNSPD: Superconducting Nanowire Single Photon Detector



- SNSPDs have high resolution and good quantum efficiency in the infrared, making them advantageous in intensity interferometry.
- SNSPDs have not been applied to intensity interferometry before.

Picture retrieved from:
https://indico.physics.lbl.gov/event/815/attachments/1750/2119/APH_110_2018.pdf

Key Components

- 35-inch-long dark box
- An LED light source (artificial star) with aperture in front
- Two optical fibers with collimators attached for focusing light at 1 micron into nanowire – one stationary and one mobile for baseline adjustment
- All components mounted on optical breadboard

Preliminary Calculations

Thermal Load

- Determine the photon flux of source (artificial star)

$$flux = \frac{\Omega\, B_\lambda\, \Delta\lambda}{\varepsilon[\lambda]}$$

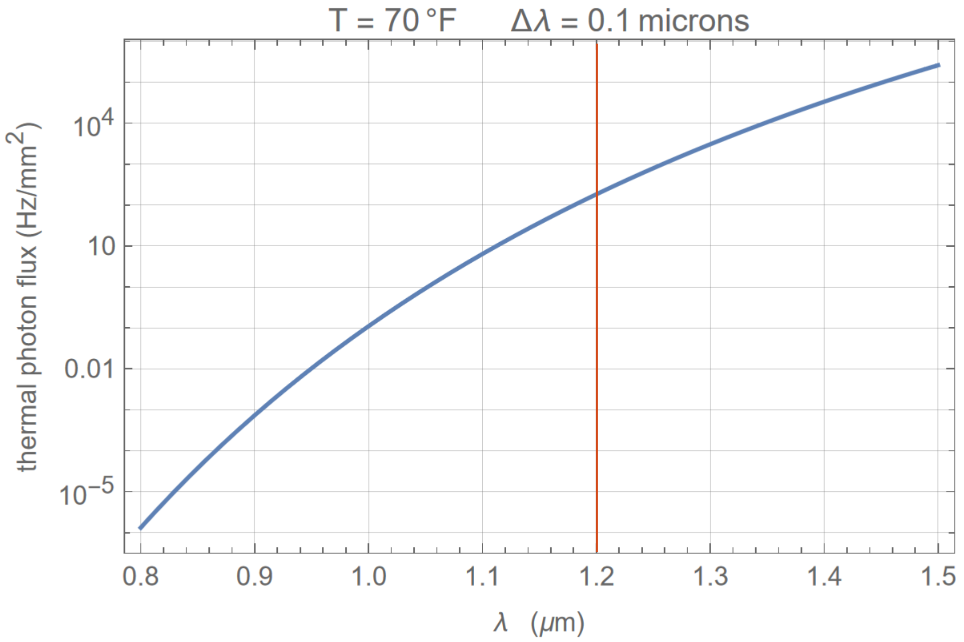
  - Ω: solid angle
  - B_λ: spectral radiance of blackbody, given by Planck's Radiation Law
  - $\Delta\lambda$: wavelength bandwidth (assumed small)
  - $\varepsilon[\lambda]$: energy per photon (hc/λ)

Thermal Load

- Determine the photon flux of source (artificial star)

$$flux = \frac{\Omega \, B_\lambda \, \Delta\lambda}{\varepsilon[\lambda]}$$

  - Ω: solid angle
  - B_λ: spectral radiance of blackbody, given by Planck's Radiation Law
  - $\Delta\lambda$: wavelength bandwidth (assumed small)
  - $\varepsilon[\lambda]$: energy per photon (hc/λ)
- As to not oversaturate the nanowire, we are restricted to $\lambda < 1.2 \ \mu m$.



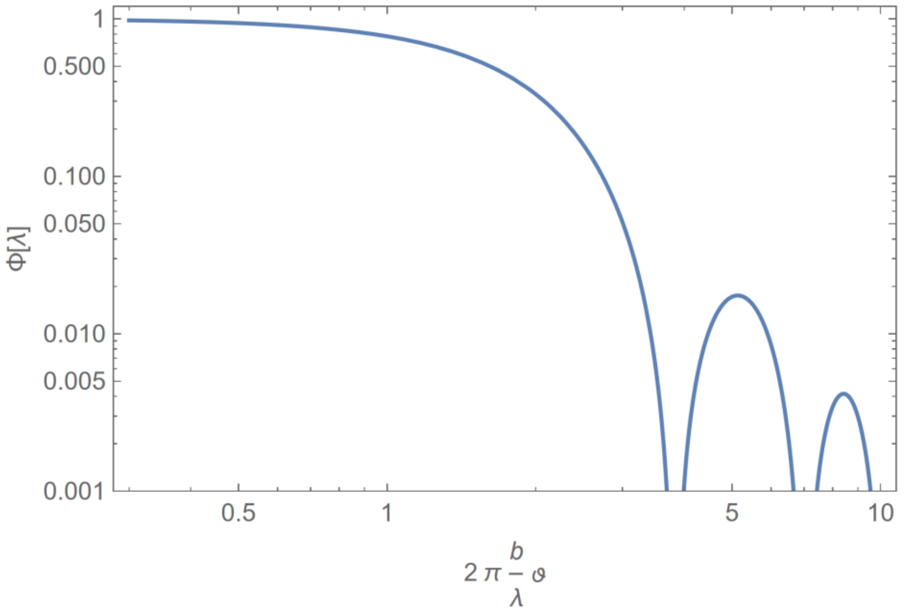
Coherence Function

- Provides a quantitative measure of the uniform brightness of the star

$$\Phi = \left[\frac{2\,J_1[x]}{x}\right]^2 \; where\; x = 2\pi\frac{b}{\lambda}\theta$$

  - J_1: Bessel function of the first order
  - b: baseline
  - λ: source wavelength
  - θ: angular size of source seen from fibers

$$\frac{\frac{1}{2}\, aperture}{distance\ between\ fibers\ and\ LED}$$

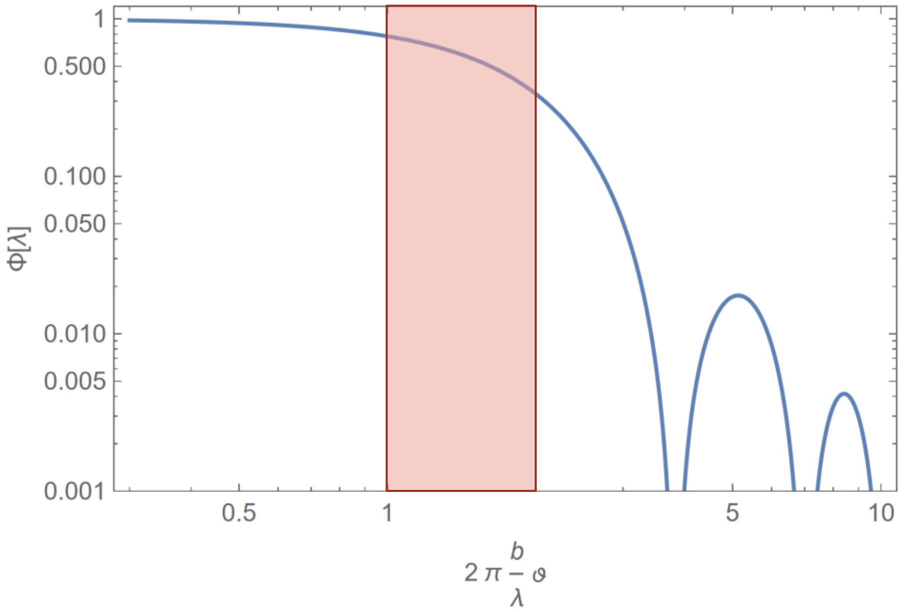


Coherence Function

- Ideal $x \cong 1$ for resolved source

$$\Phi = \left[\frac{2\,J_1[x]}{x}\right]^2 \; where\ x = 2\pi \frac{b}{\lambda}\theta$$

- Limited to: distance between LED and fibers ($\sim 30\ in$)
- Adjustable parameters to achieve $x \cong 1$:
  - Smaller baseline
  - Larger LED wavelength in IR range
  - Smaller aperture



LED selection

- Need to achieve an optimal rate of photons for coincidence counting
- Number of photons per second exiting LED found by:

$$\gamma_{rate} = E_e \cdot \frac{1}{\varepsilon[\lambda]} \cdot a$$

  - E_e: Maximum Irradiance – radiant flux received per unit area measured at a distance of 200 mm
  - $\varepsilon[\lambda]$: energy per photon (hc/λ)
  - a: area of aperture hole –

    $\pi \left(\frac{D}{2}\right)^2$ *where D is the aperture*

LED selection

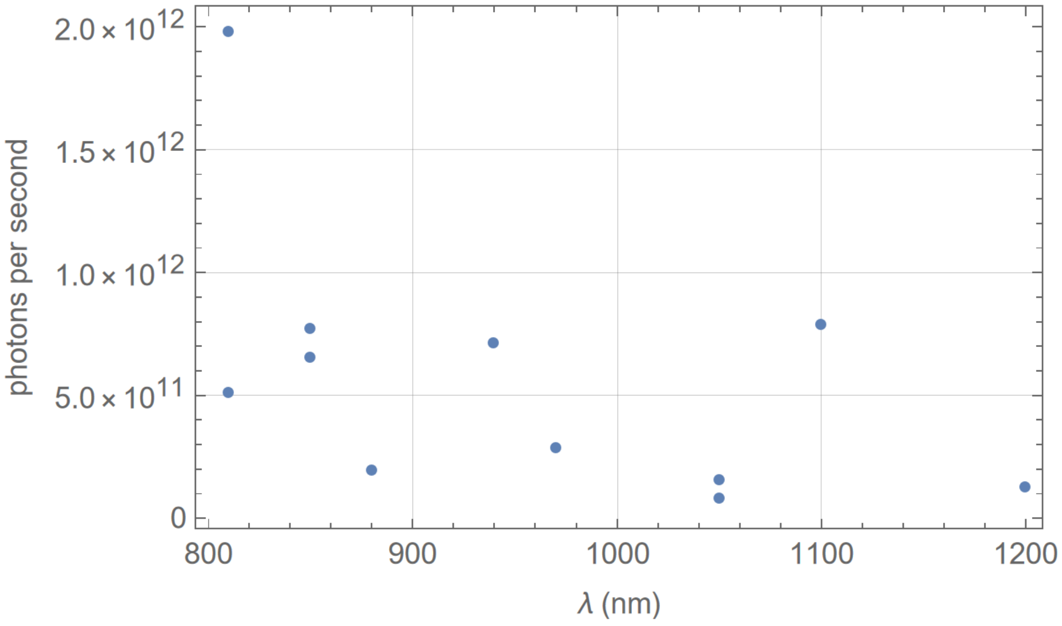
- Need to achieve an optimal rate of photons for coincidence counting
- Number of photons per second exiting LED found by:

$$\gamma_{rate} = E_e \cdot \frac{1}{\varepsilon[\lambda]} \cdot a$$

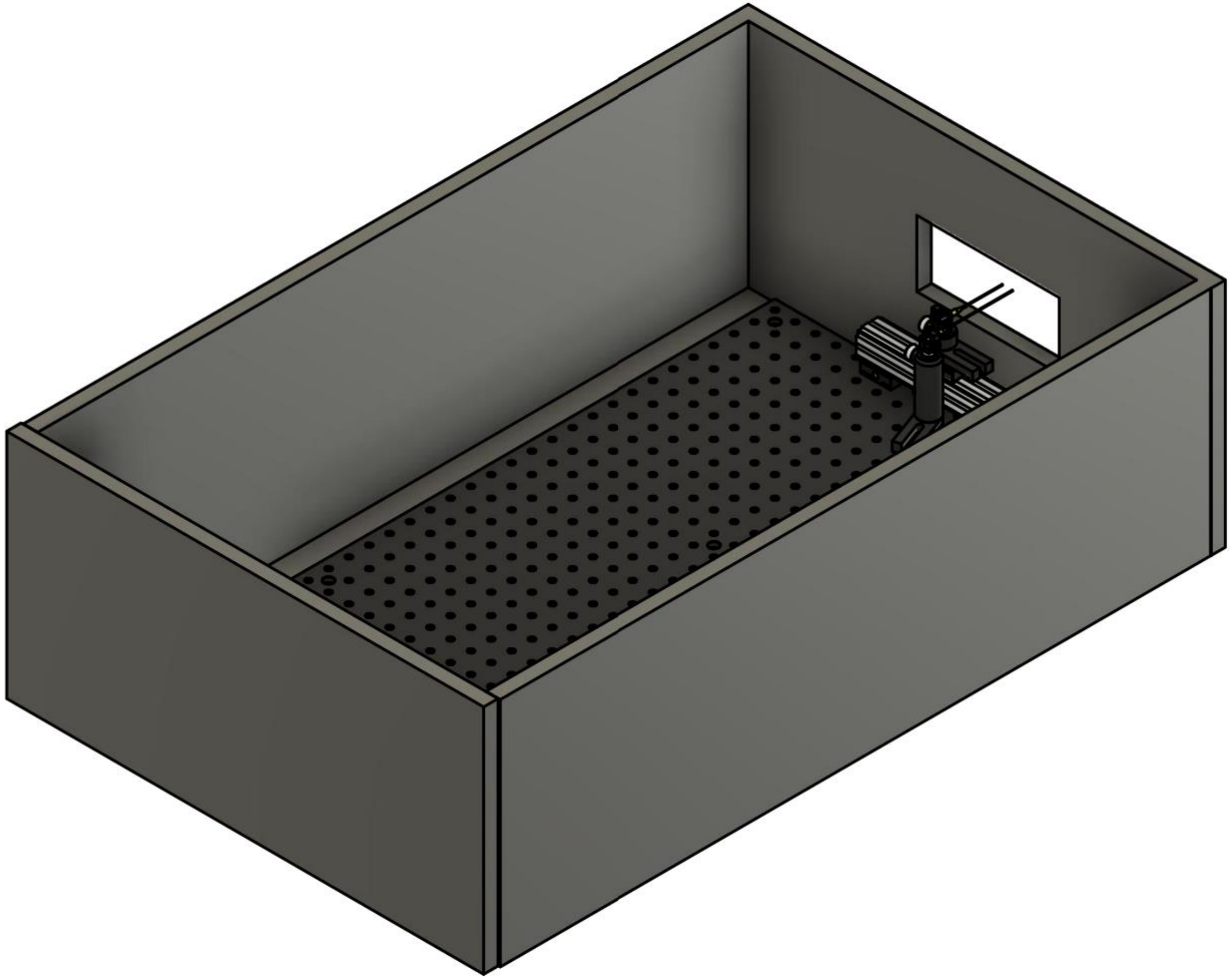
  - E_e: Maximum Irradiance – radiant flux received per unit area measured at a distance of 200 mm
  - $\varepsilon[\lambda]$: energy per photon (hc/λ)
  - a: area of aperture hole –

    $\pi\left(\frac{D}{2}\right)^2$ *where D is the aperture*

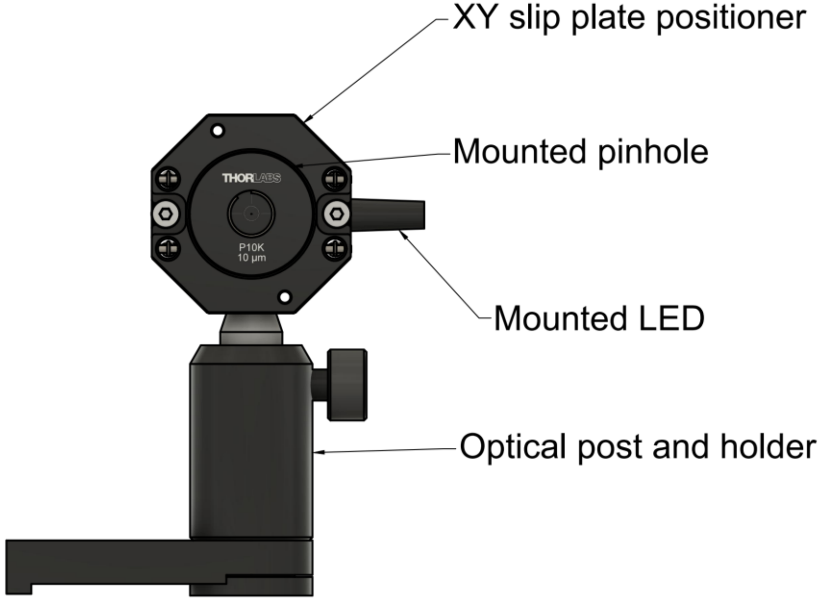
- Nearly all LEDs have similar magnitudes, any wavelength is acceptable



Experimental Design – Current Progress

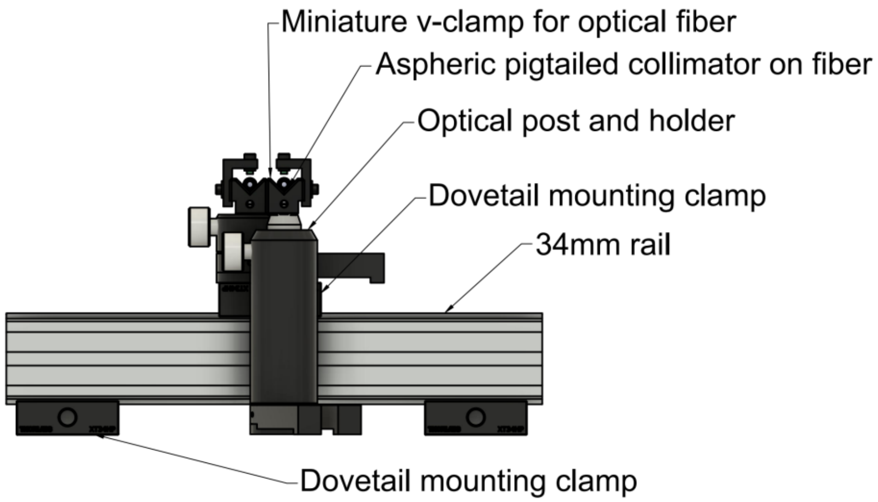


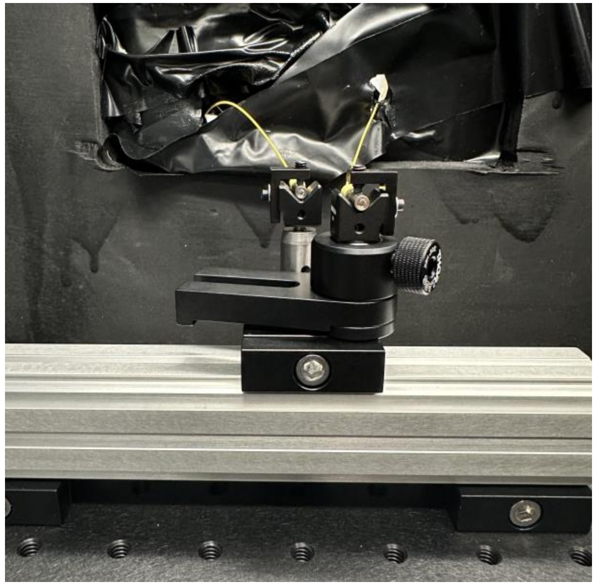
Fusion 360 3D rendering


XY slip plate positioner
Mounted pinhole
THORLABS
P10K
10 µm
Mounted LED
Optical post and holder

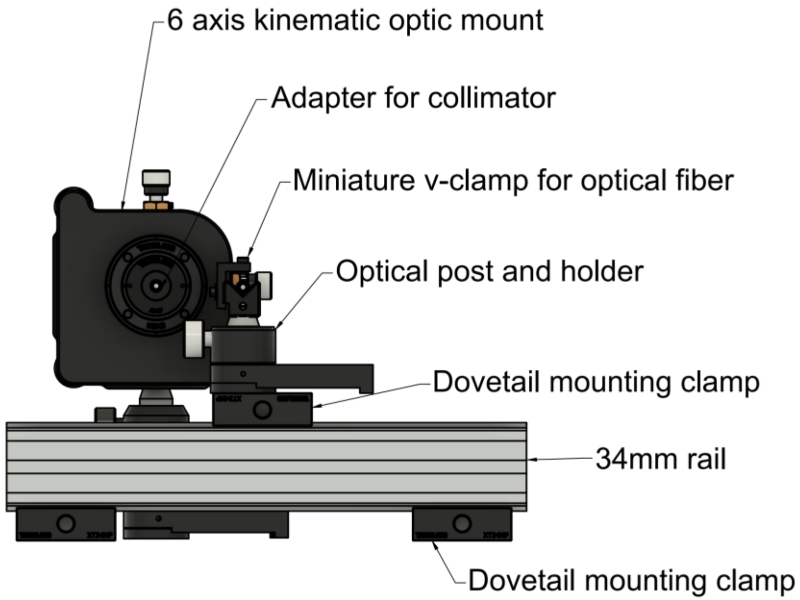
LED

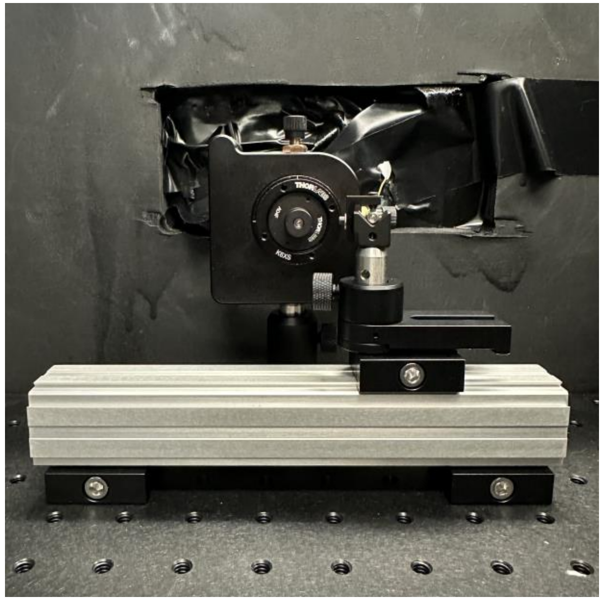
Fibers: Option 1





Fibers: Option 2

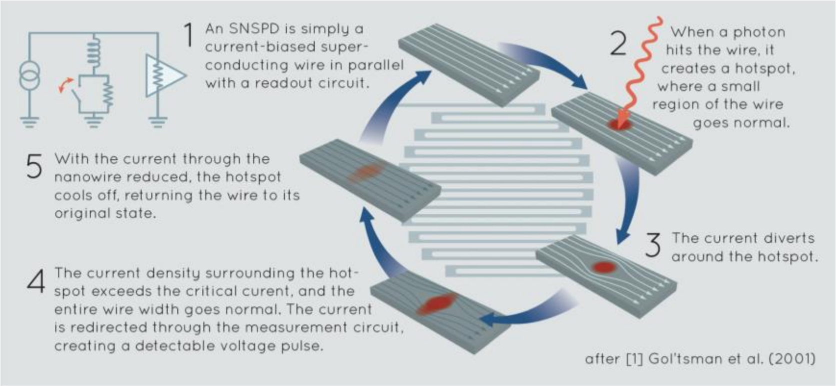




- Assembly nearly complete: need precise alignment of collimator with beam via laser

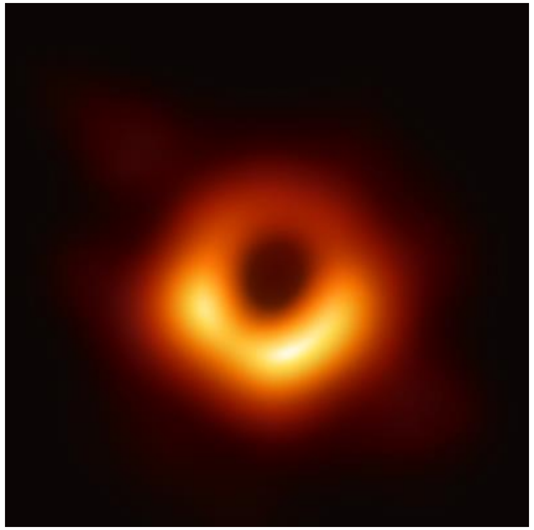
Future Work

- Utilize SNSPDs to see expected excess simultaneous photon rate



Picture retrieved from:
https://indico.physics.lbl.gov/event/815/attachments/1750/2119/APH_110_2018.pdf

- Intensity interferometry has potential to provide high angular resolution to image objects that appear small in the sky.
- Continued study into implementing modern photon counters is needed to achieve success.



Picture retrieved from:
https://www.nasa.gov/mission_pages/chandra/news/black-hole-image-makes-history

Thank you!