Measuring Scatter In Silicon for Future LIGO Devices

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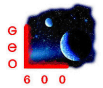
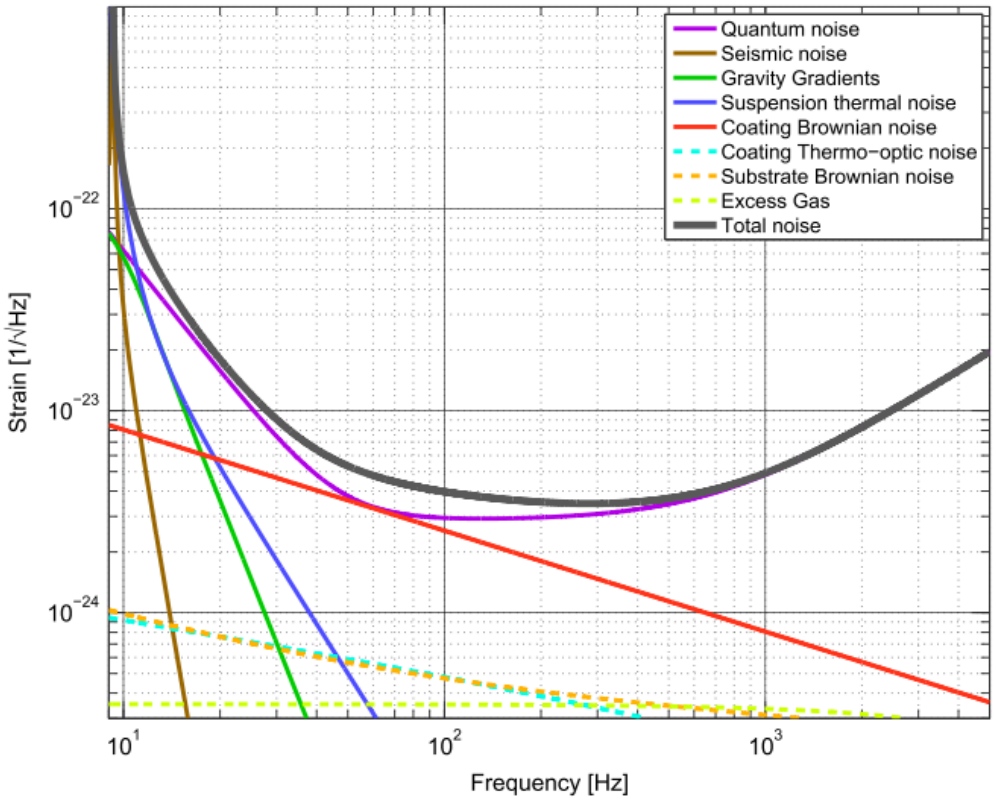
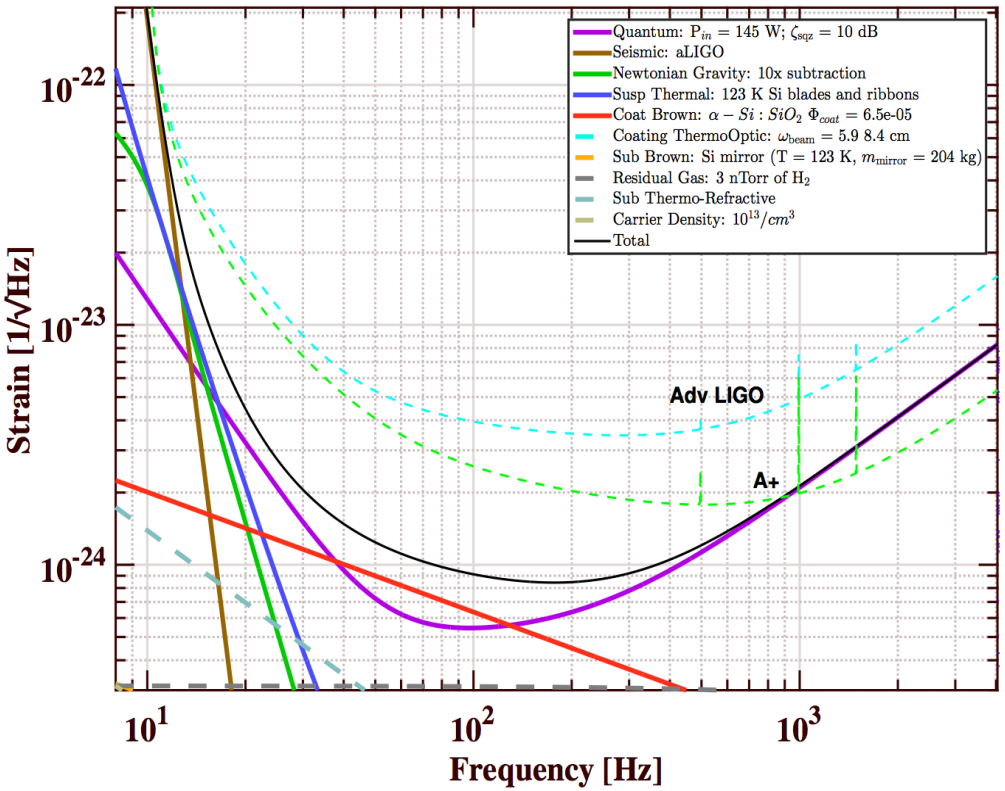


LIGO Noise Budget



- Limited by Quantum Noise (Squeezed Light)
- Limited by light scattering below a few 100Hz

Cryogenic LIGO



- Low Temperature (123K)
- Silicon Test Masses
- 1550-2100 nm laser
- Squeezed Light

Silicon

- Test masses need high optical and mechanical qualities
- Michael Czorchalski Magnetic Field Grown Silicon
- Low absorption
- Low defect concentration

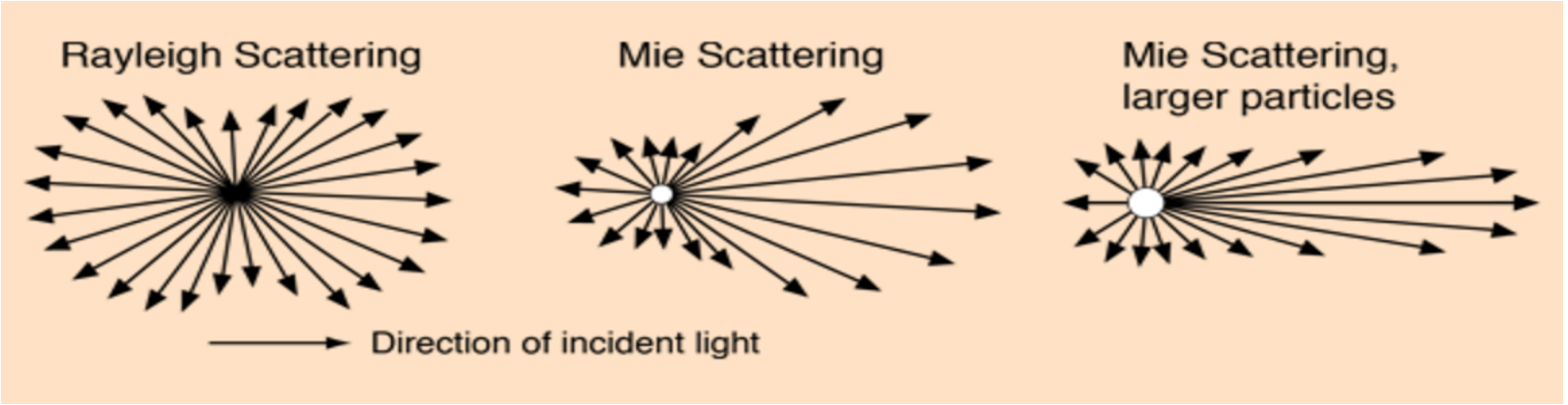
Scatter

- Direct measurement of scatter is important to characterize scatter from the bulk mirrors.
  - Scatter from the bulk can contribute to phase noise
  - Squeezing relies on photons entanglement, scattered photons aren't entangled
  - Scattered photons can be redirected into the vacuum chamber
- Measuring the scatter is a tool to measure the defects in Silicon, and give us a full picture of the optical absorption in the Silicon.

What Is Scatter

- Rayleigh Scattering causes blue light to be scattered strongly from molecules in atmosphere.
- Mie Scattering has no preference for wavelength, so causes the white glow near the sun, and white appearance of clouds.

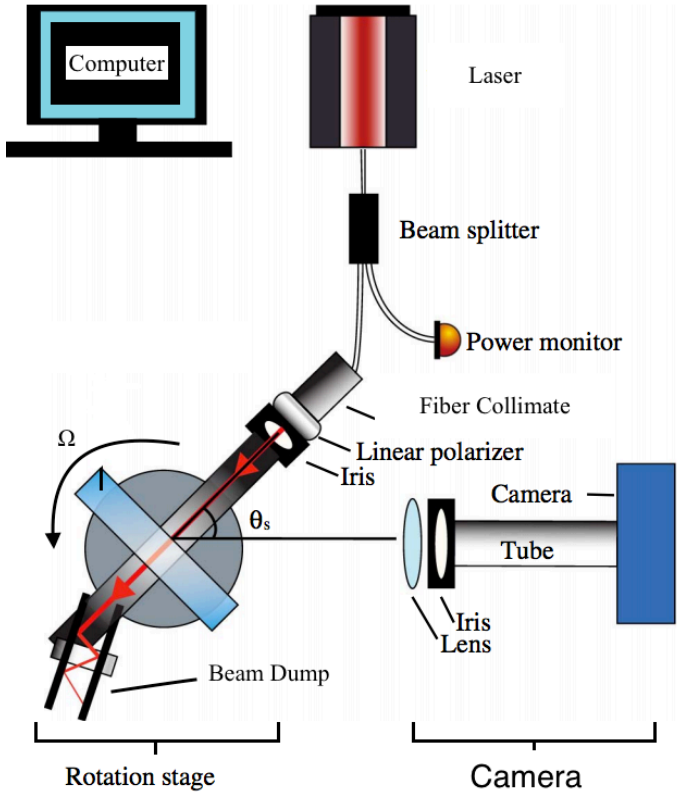
What Is Scatter



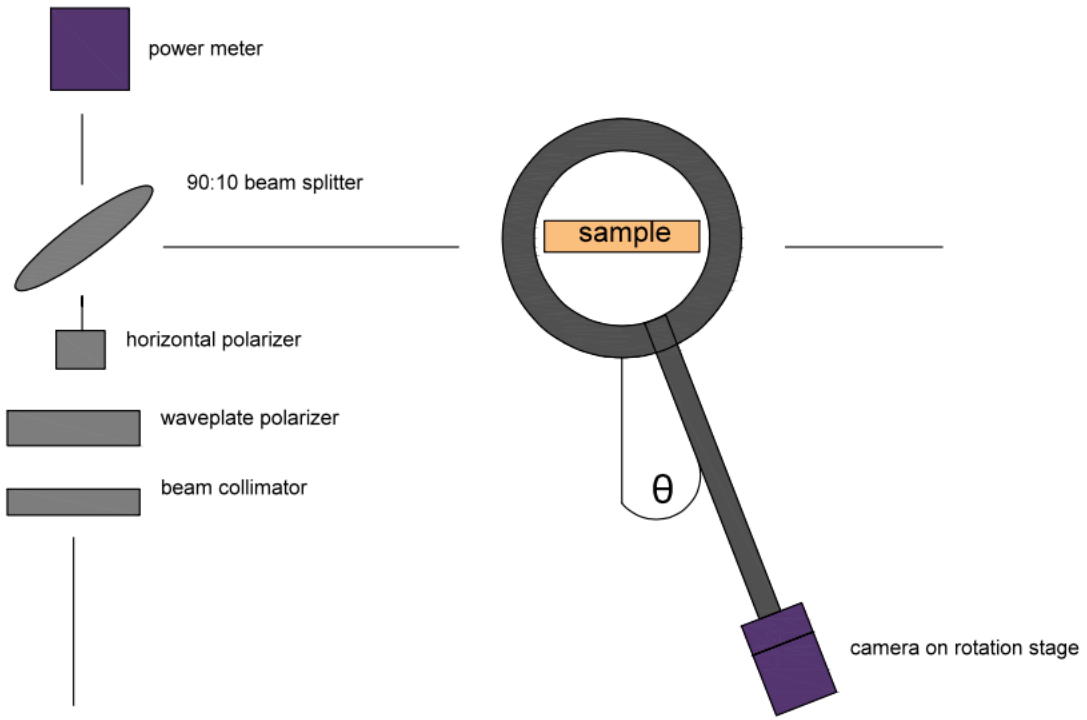
- Rayleigh scattering: $I = I_0 \frac{8\pi^4 N\alpha^2}{\lambda^4 R^2}$
- Mie scattering is mostly dependent on direction: $P_{ij} = \frac{\int_{r1}^{r1} P_{ij}(\theta,r)n(r)dr}{\int_{r1}^{r1} n(r)dr}$
- Why?

Scatterometer

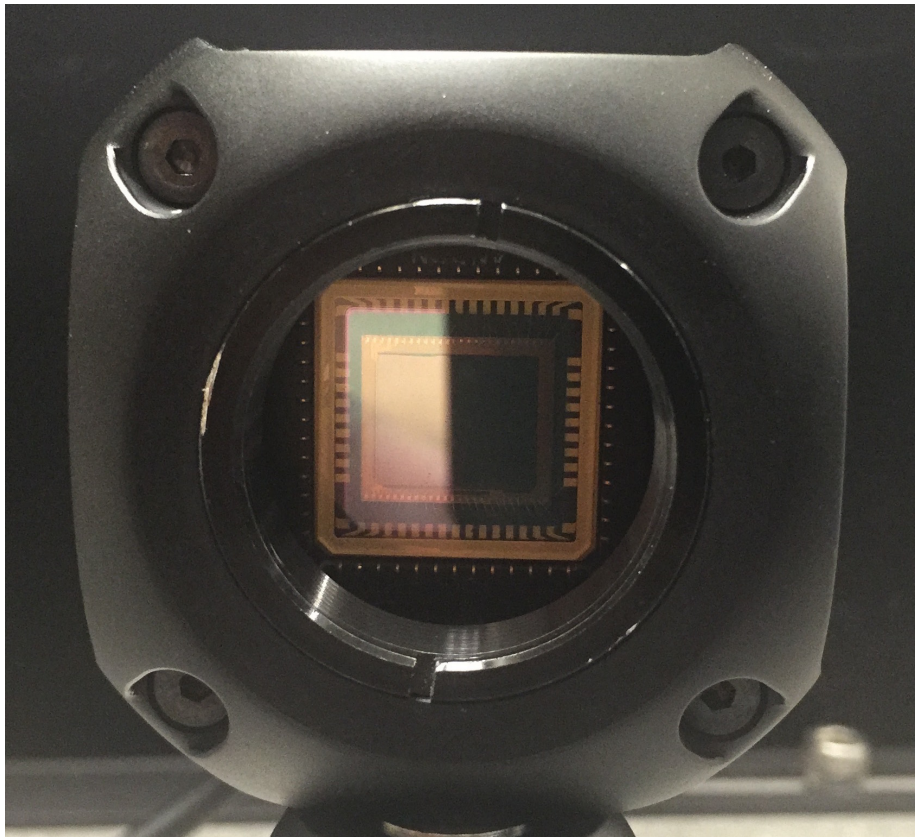
- How do we measure the scattered field?



My Set Up

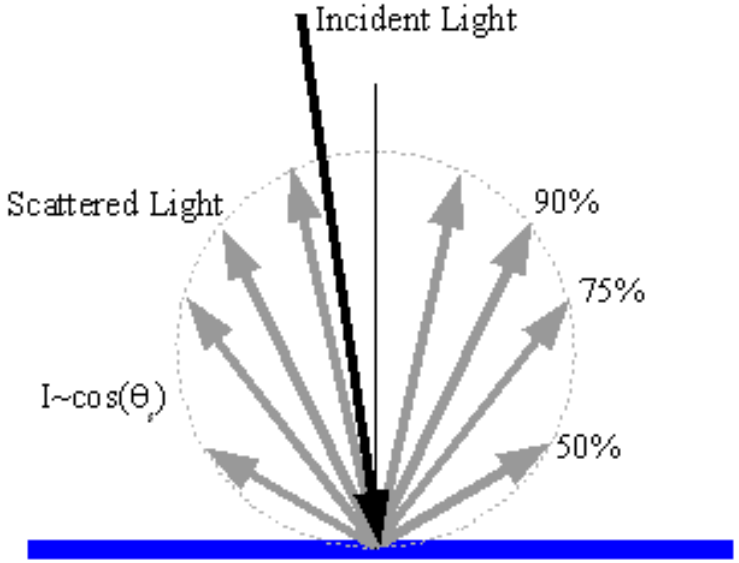

power meter
90:10 beam splitter
sample
horizontal polarizer
waveplate polarizer
beam collimator
θ
camera on rotation stage

My Set Up



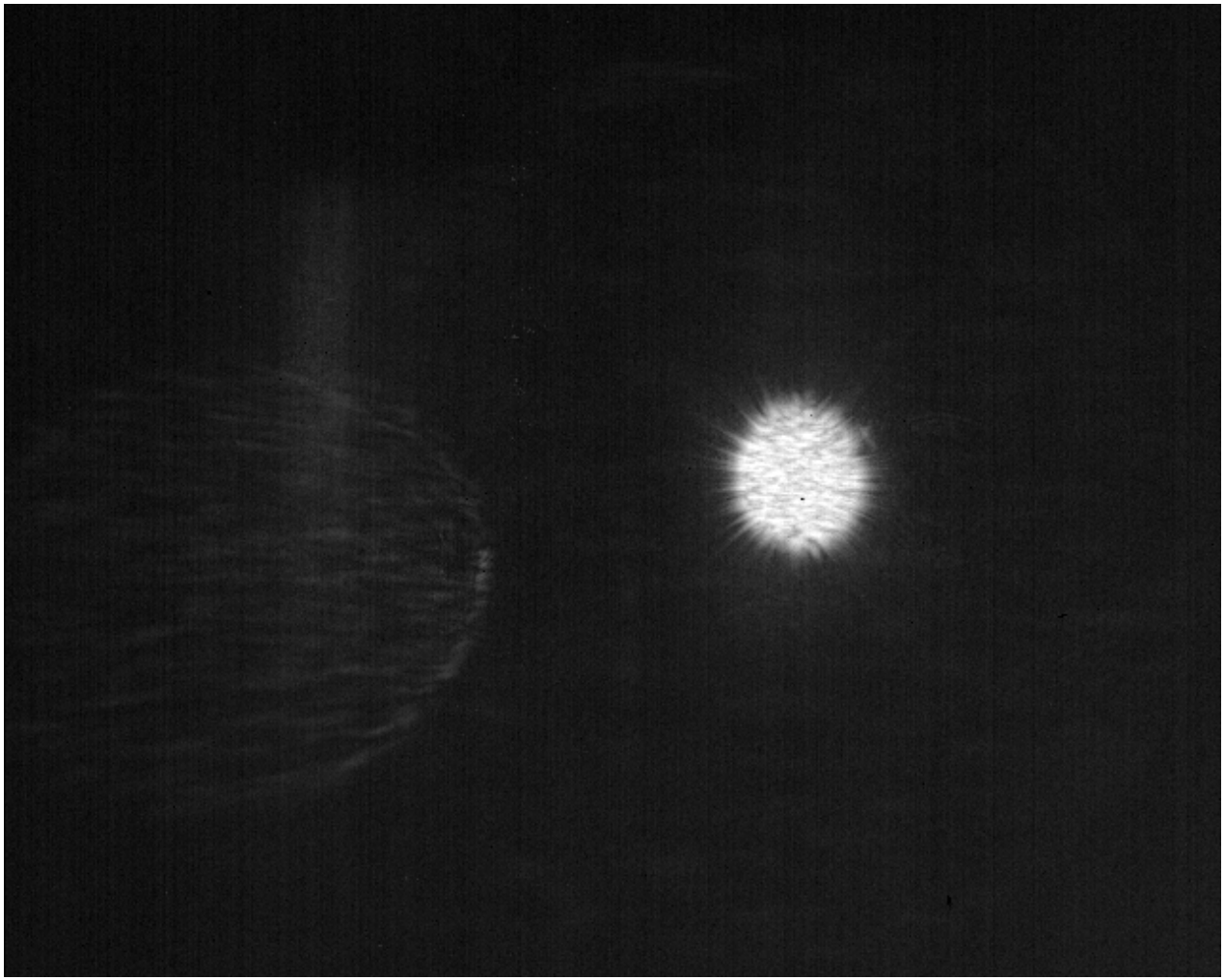
- InGaAs Infrared Camera
- Can see 900nm – 1700nm
- Large dynamic range
- Low dark noise

Calibration

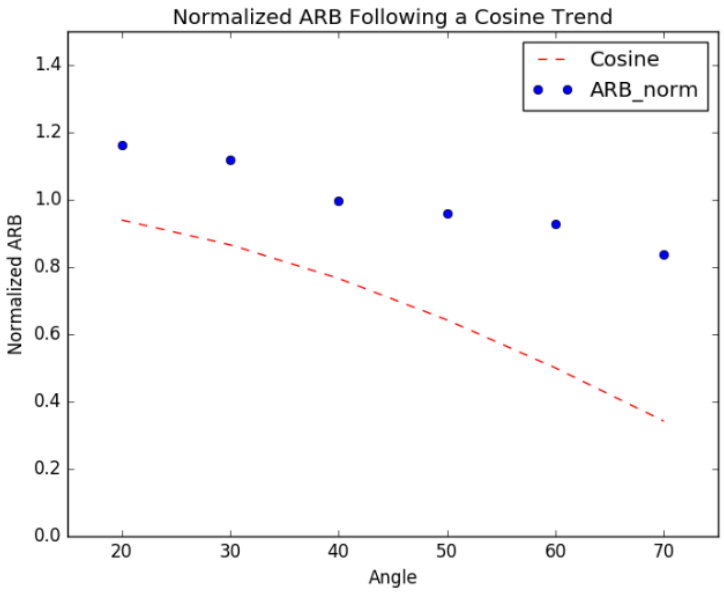


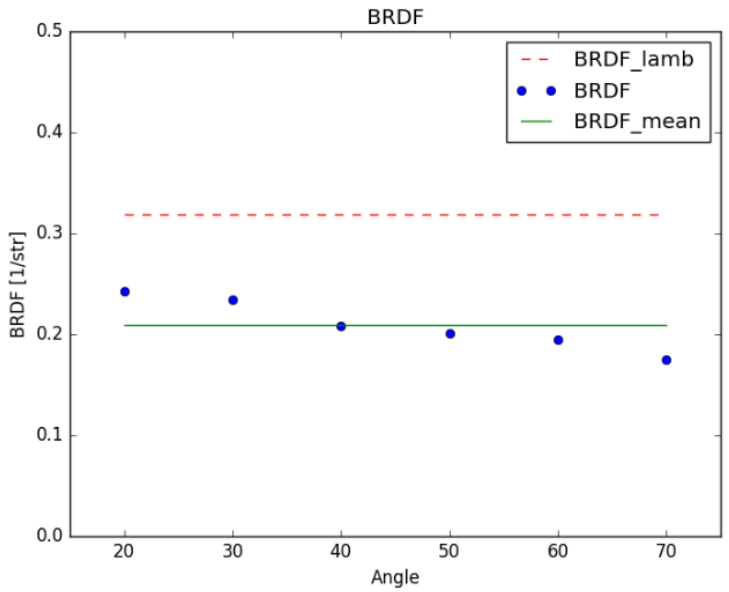
- Make measurements of a known scattered field: Lambertian Scatter.
- $\frac{L_0}{E_i} = \frac{\rho}{\pi} = 1/\pi$
- $ARB_{camera} = \frac{\sum_k V_k}{T_{exp} P_i}$
- $F_c = \frac{1/\pi}{ARB_{camera}}$
- Expect : $\frac{1}{\pi} = F_c ARB_{camera}$
- Expect ARB to follow the Lambertian Cosine relation

Calibration



Calibration



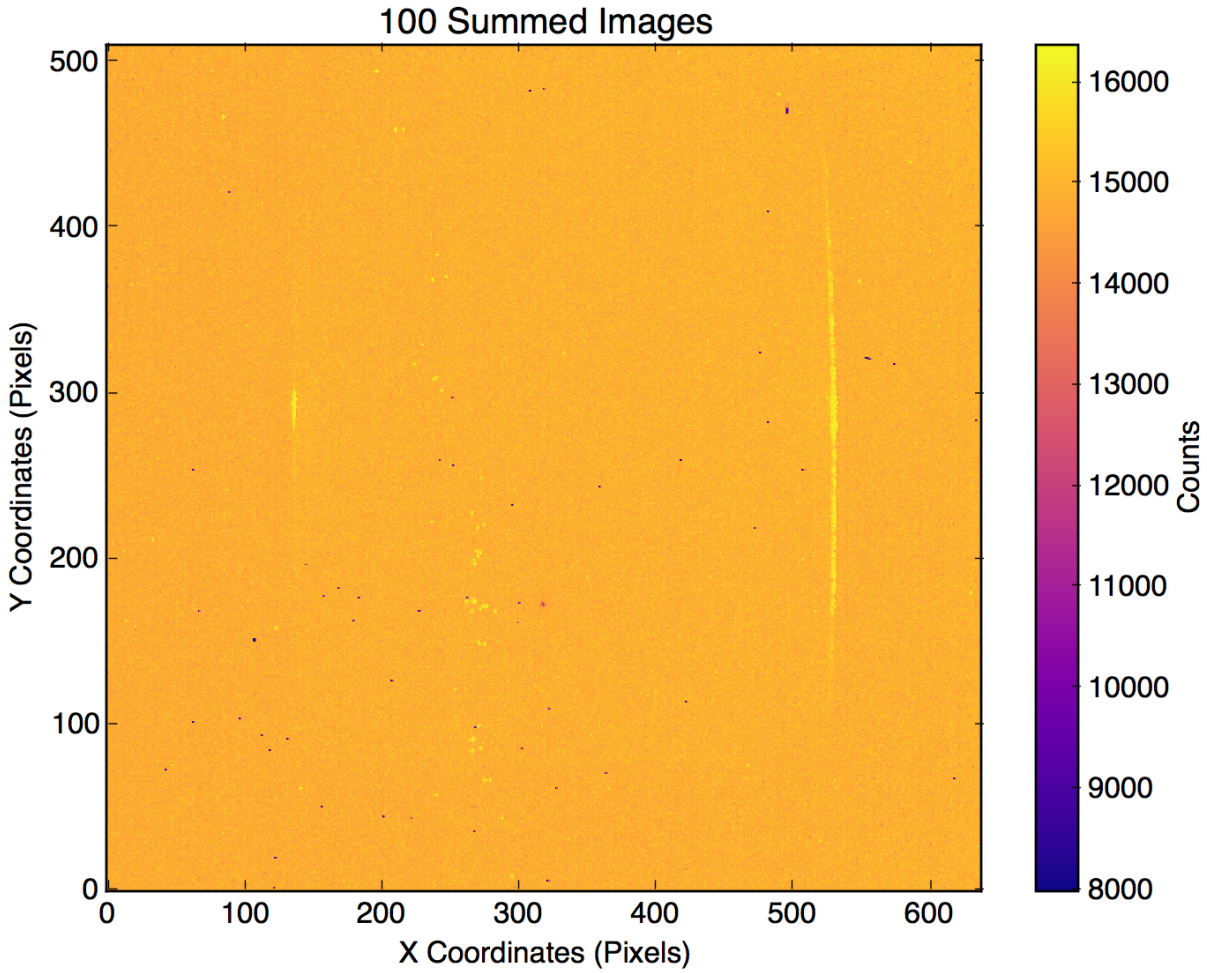


$$F_c = 2.99 * 10^{-12}\, W * \frac{sec}{counts * str}$$

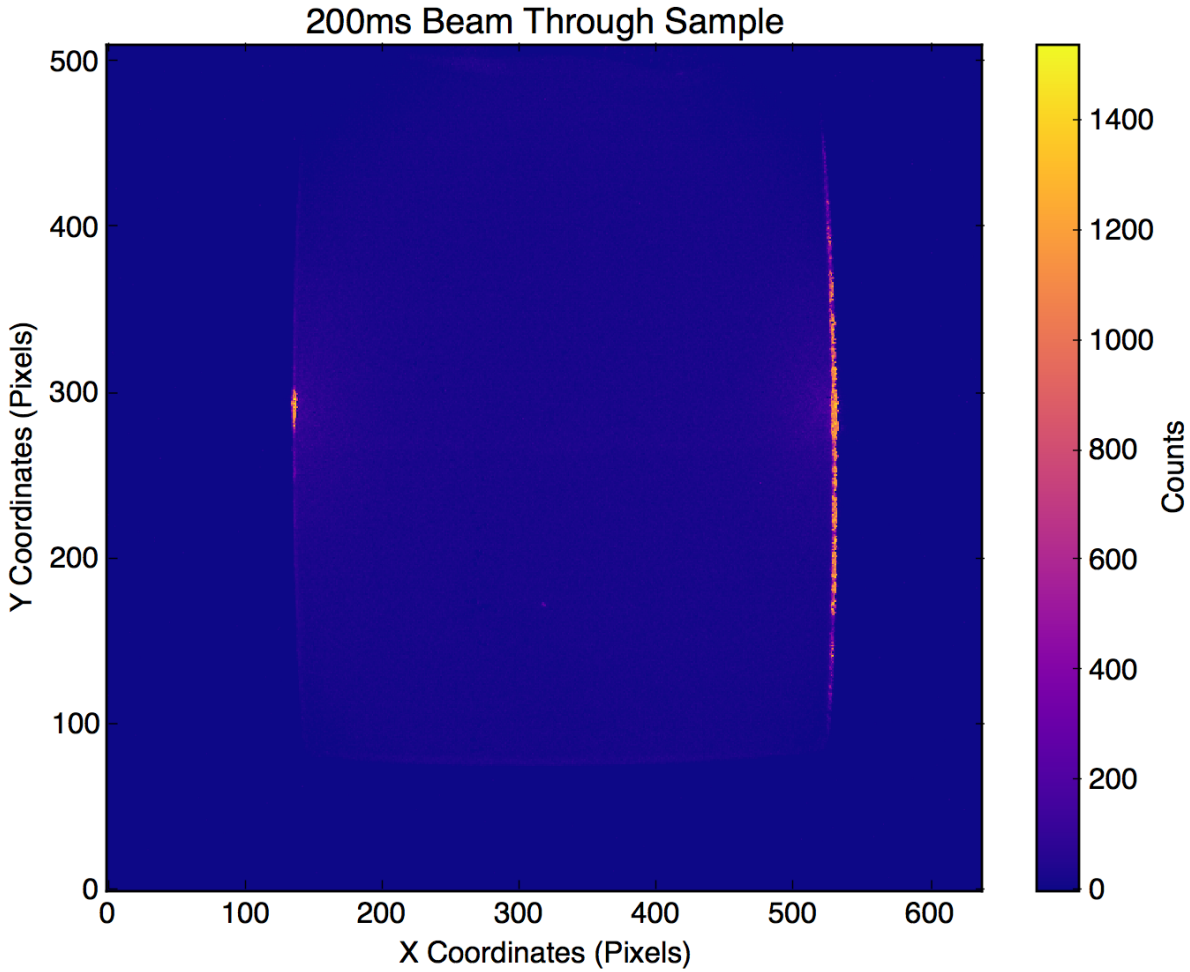
Imaging!

Imaging!

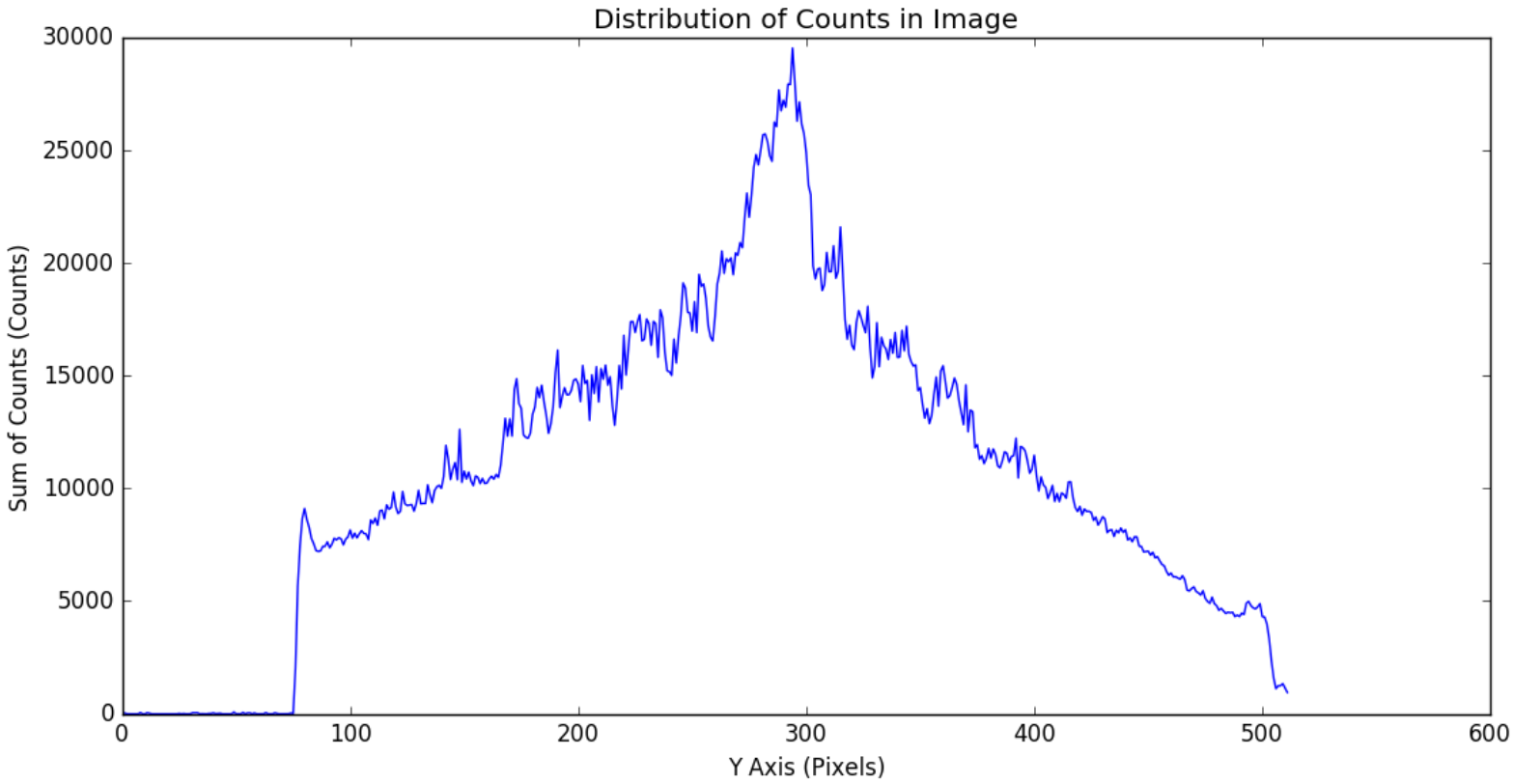
Processing!


100 Summed Images
Y Coordinates (Pixels)
X Coordinates (Pixels)
0
100
200
300
400
500
600
Counts
16000
15000
14000
13000
12000
11000
10000
9000
8000

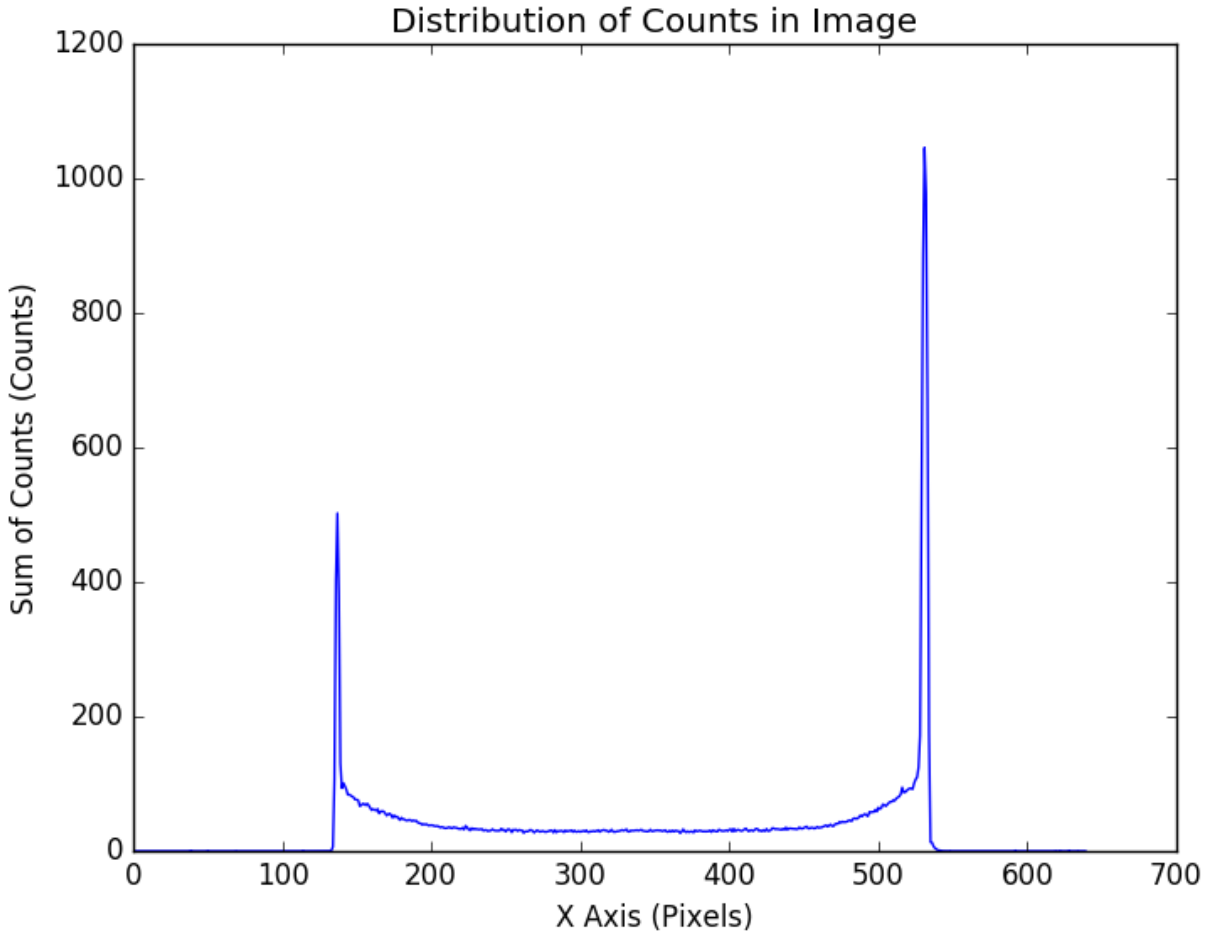
Processing!


200ms Beam Through Sample
Y Coordinates (Pixels)
X Coordinates (Pixels)
Counts
0
100
200
300
400
500
600
1400
1200
1000
800
600
400
200
0

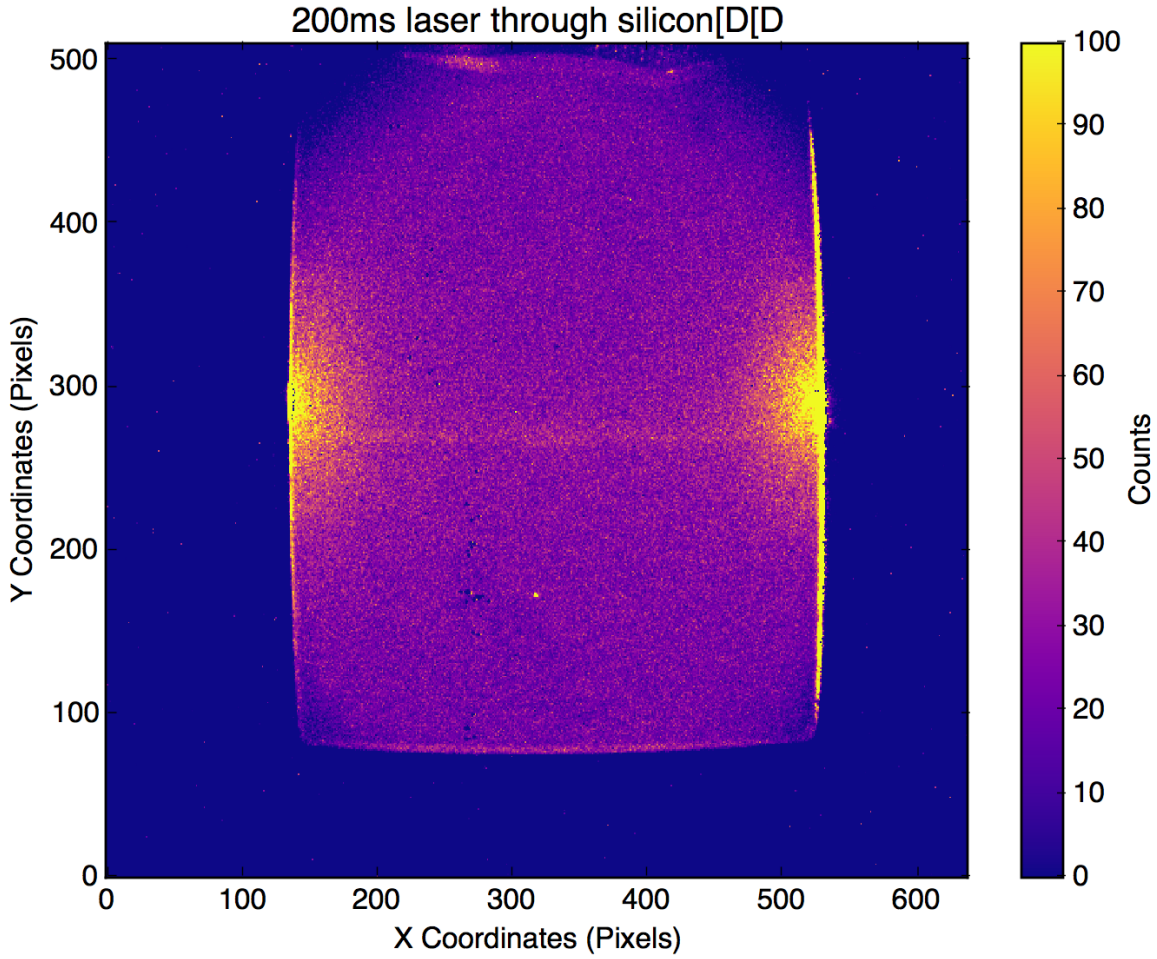
Processing


Distribution of Counts in Image
Sum of Counts (Counts)
Y Axis (Pixels)
0
5000
10000
15000
20000
25000
30000
0
100
200
300
400
500
600

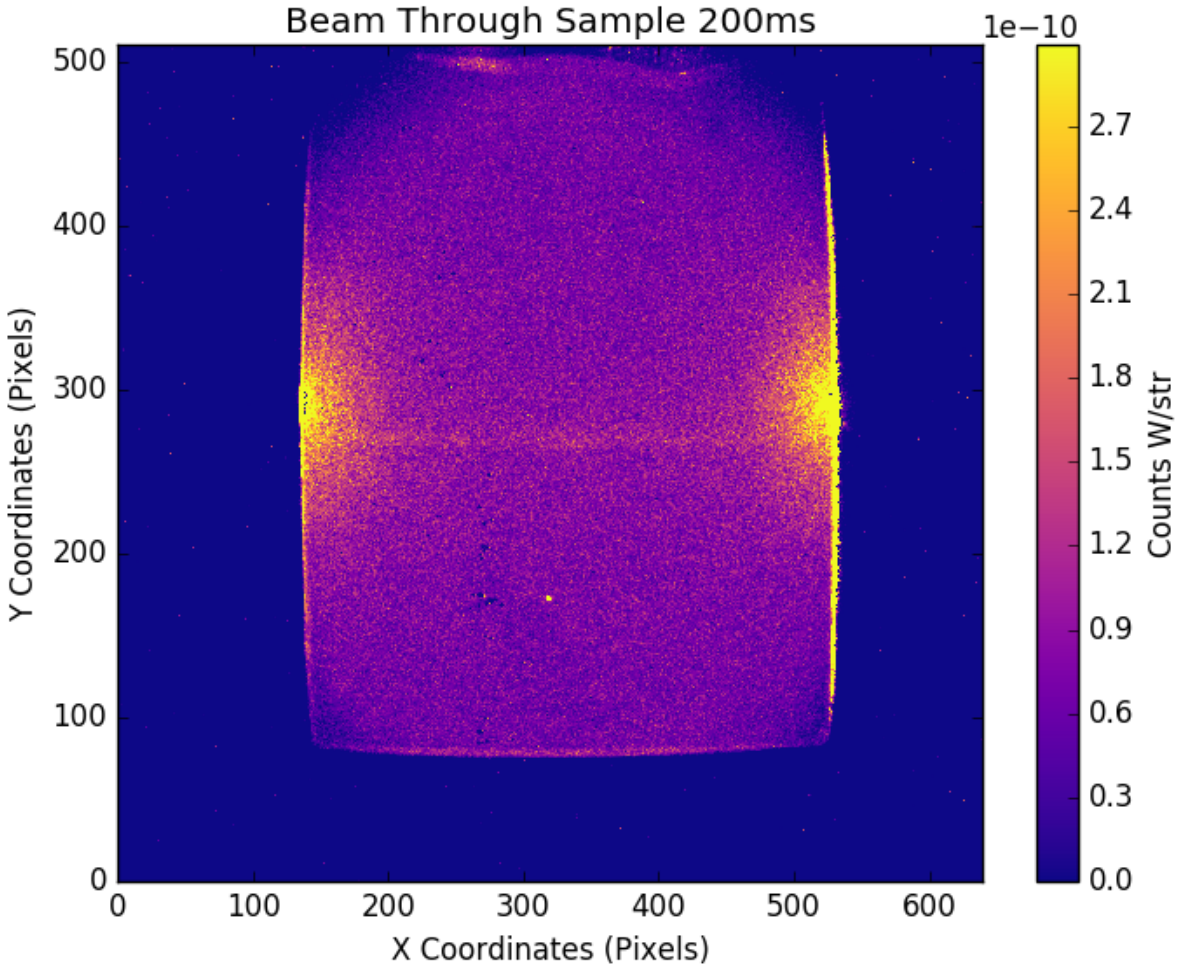
Processing


Distribution of Counts in Image
Sum of Counts (Counts)
X Axis (Pixels)
0
200
400
600
800
1000
1200
0
100
200
300
400
500
600
700

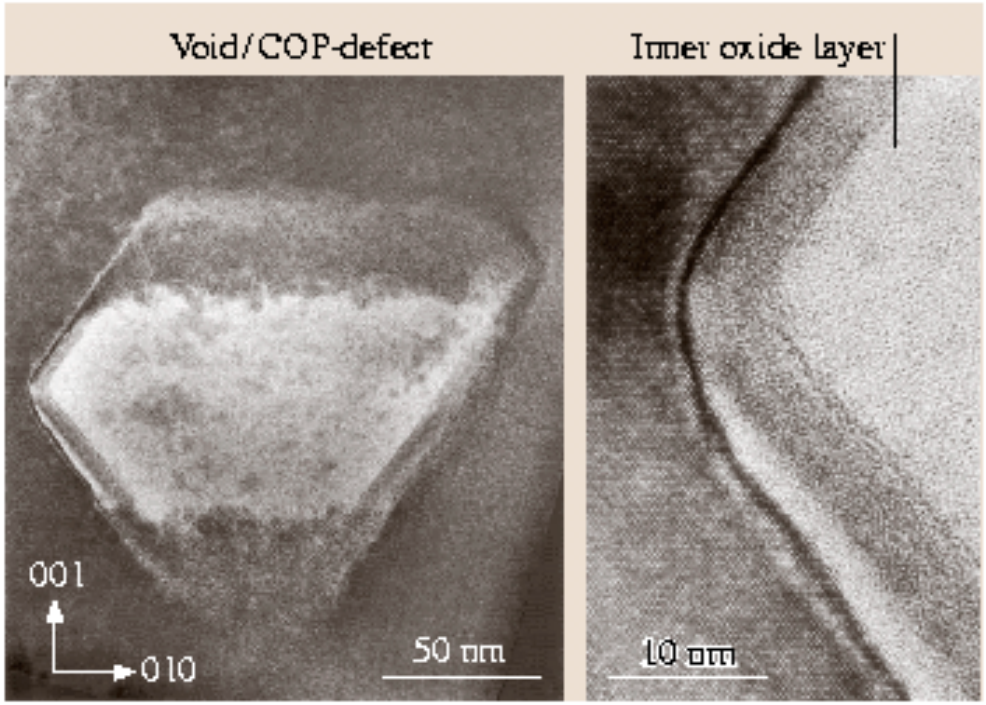
Processing!


200ms laser through silicon[D[D
Y Coordinates (Pixels)
X Coordinates (Pixels)
Counts
0
100
200
300
400
500
600
10
20
30
40
50
60
70
80
90

Imaging!


Beam Through Sample 200ms
1e−10
Y Coordinates (Pixels)
X Coordinates (Pixels)
Counts W/str
0
100
200
300
400
500
600
0.0
0.3
0.6
0.9
1.2
1.5
1.8
2.1
2.4
2.7

What Is Causing This Beam?



- Culprits:
  - SiO2
  - Octahedral Voids
- Magnitude: 70-200nm

What Now?

- Image the Scattered Field with the scatterometer!
- Better angular resolution with stepper motor!
- Test for Rayleigh or Mie scattering!

A Thought

my dad told me that the
sky was blue
because it wanted to be
closer to the ocean
no one told me
that blue was my own doing
color my mind's creation
light has no preference
only interaction
and at night
the sky would change
from blue to orange
from rayleigh to mei