Optical Decoherence Studies

SURF 2019

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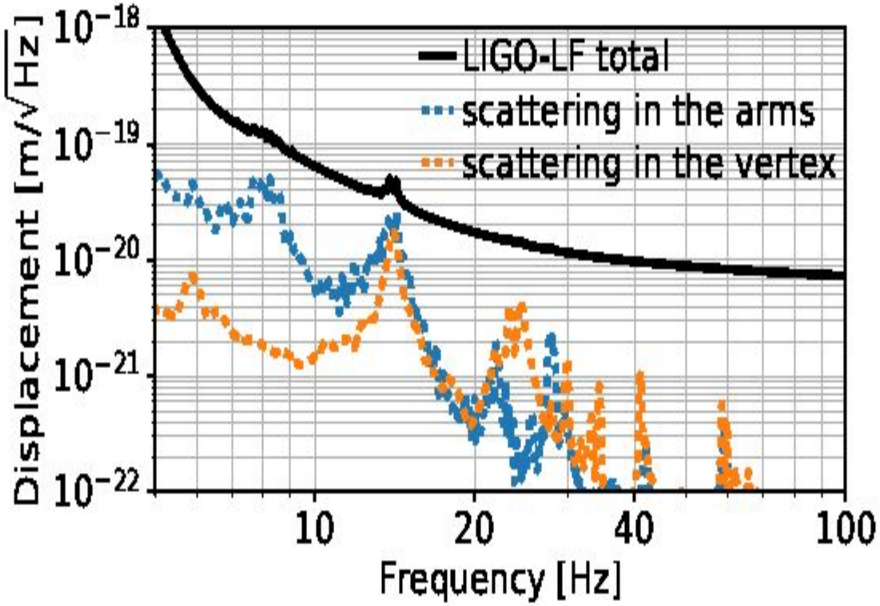
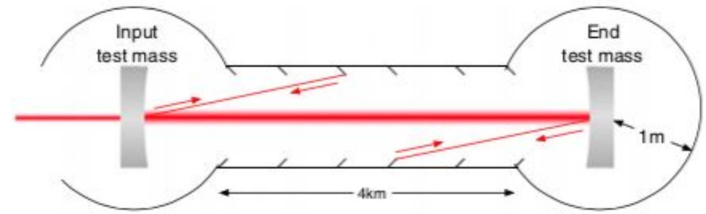
Overview

- In situ scatter measurements
- Camera setup
- Analysis of images
- Future work

Backscattered light noise

- Backscattered light modulates the phase and amplitude of main beam and introduces a random phase noise.
- Scattering is a critical noise source below 30 Hz.
- **Loss from scattered light reduces squeezing and will limit the sensitivity in the future upgrades.**



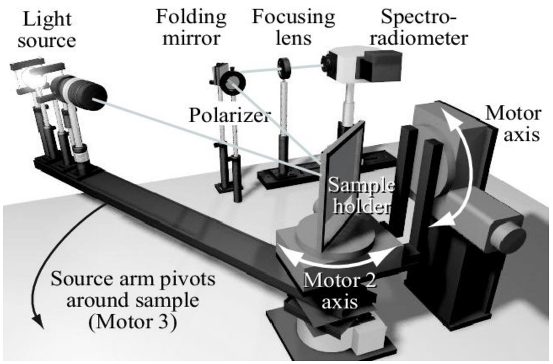


Scatter Measurements

- To further develop techniques to reduce the scatter losses from arm cavity mirrors, it is necessary to have *reliable methods* to -
    - **study scattering** due to surface imperfections, point scatters, coating, etc
    - **characterize the scatter loss** and
    - **understand the nature of scattered light**

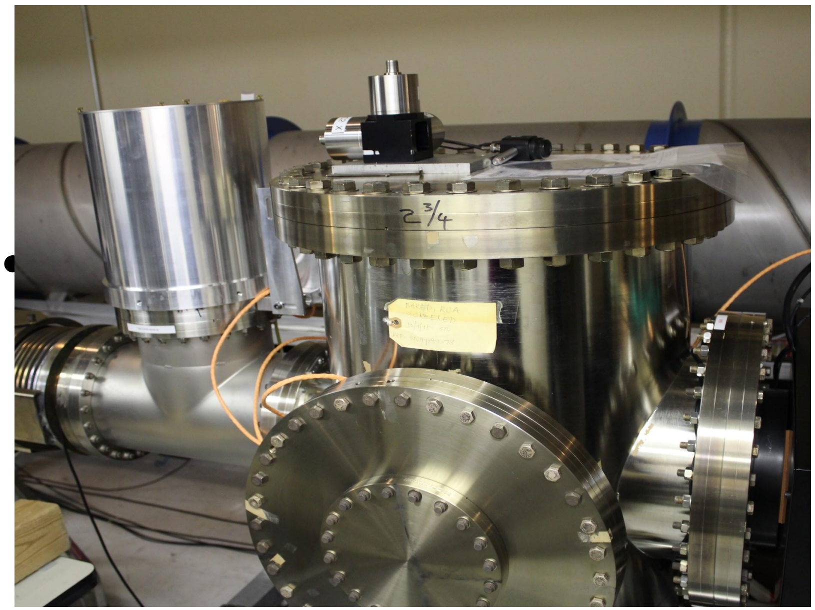
- To do all these, first off - **how to measure scattered light?**

Photodetector

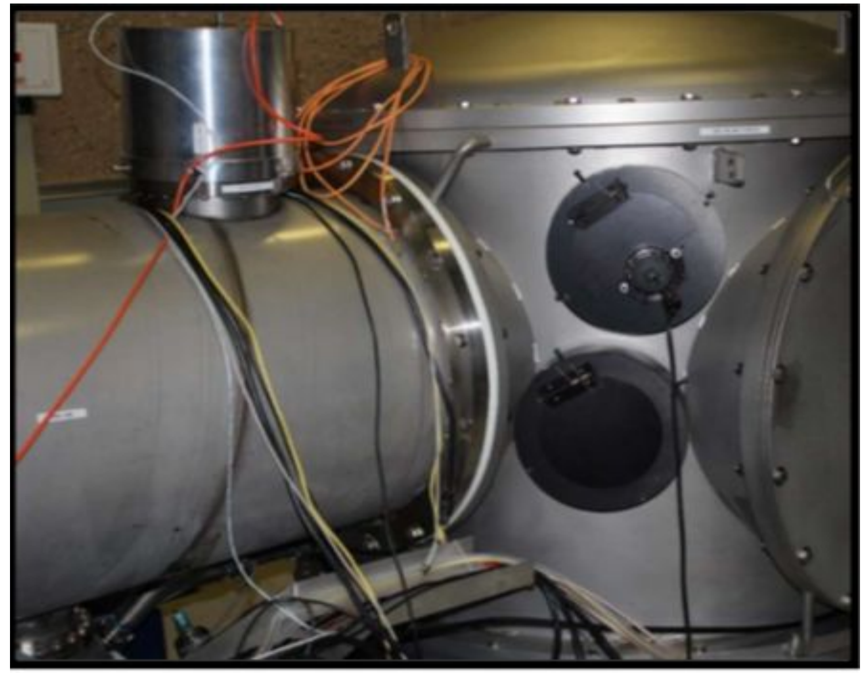


Scatterometer

How to measure scattered light in situ?



MC2 chamber

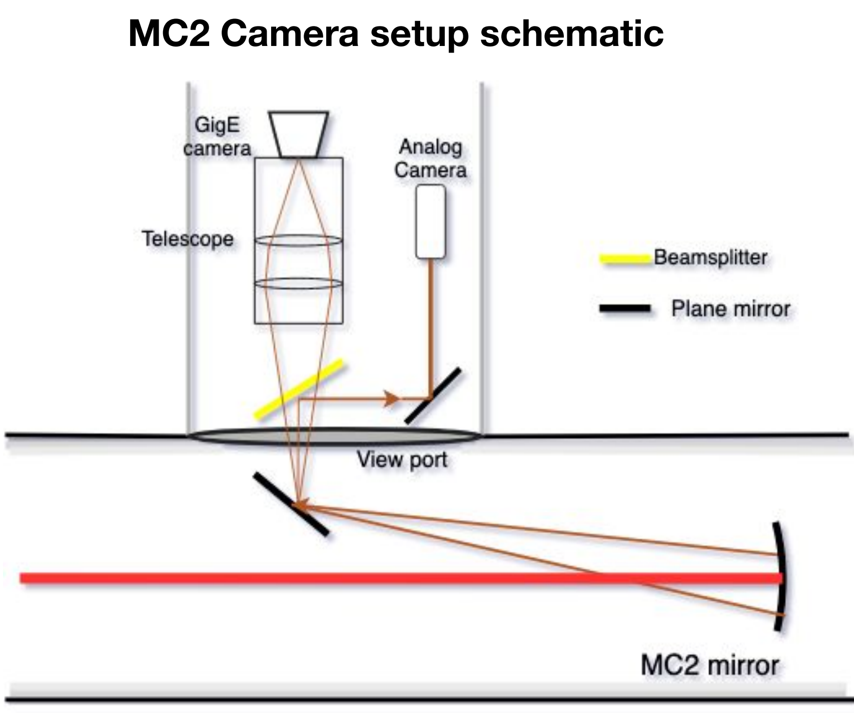


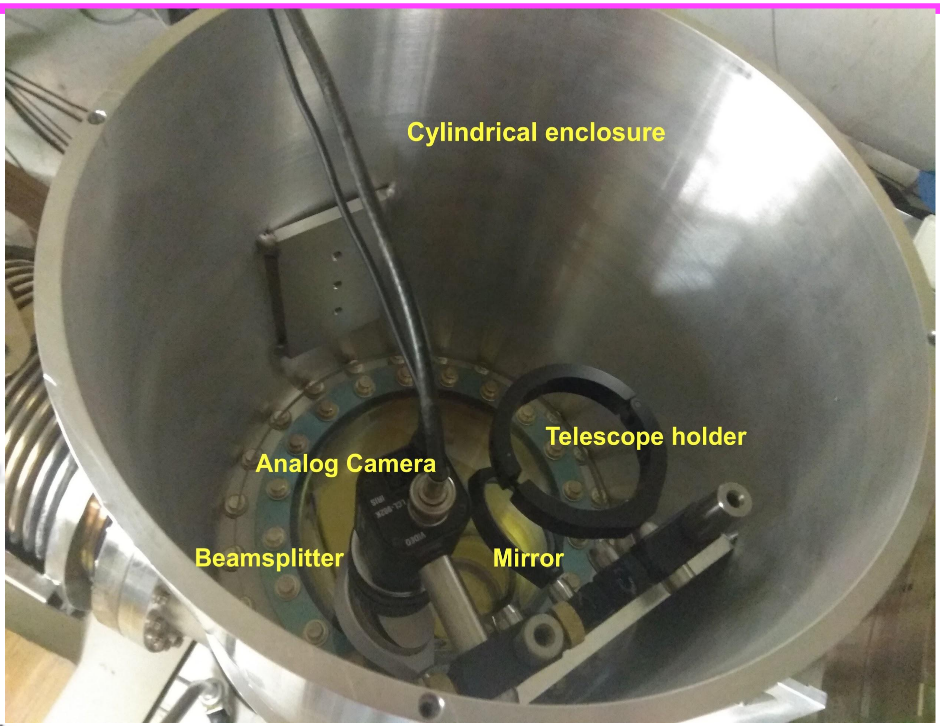
ETMX Chamber

→ Mirrors/test masses are inside the vacuum chamber. Limited access!

→ Make the best use cameras!

Camera setup





- Study point scatterers, nature of scattered light, etc
- Estimate scattered light power (loss)

LIGO

Understanding the image

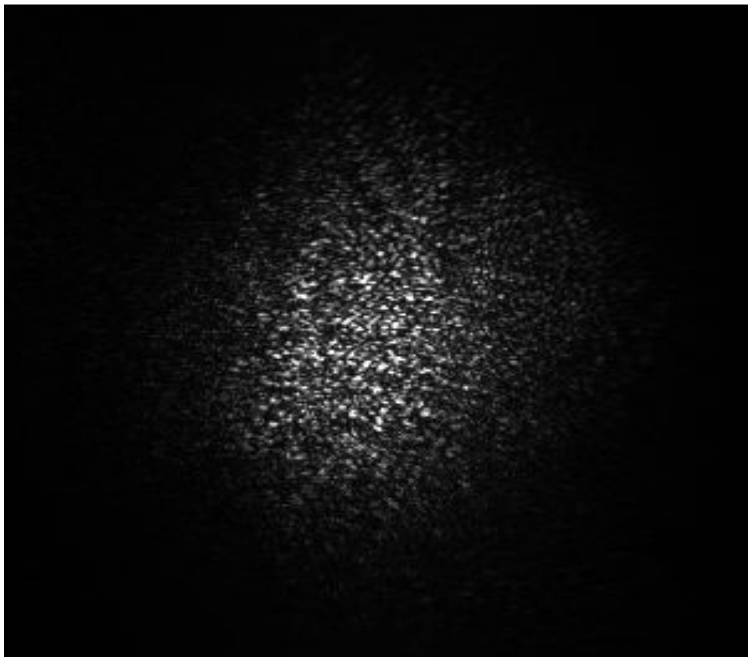


Image of beamspot on MC2 mirror

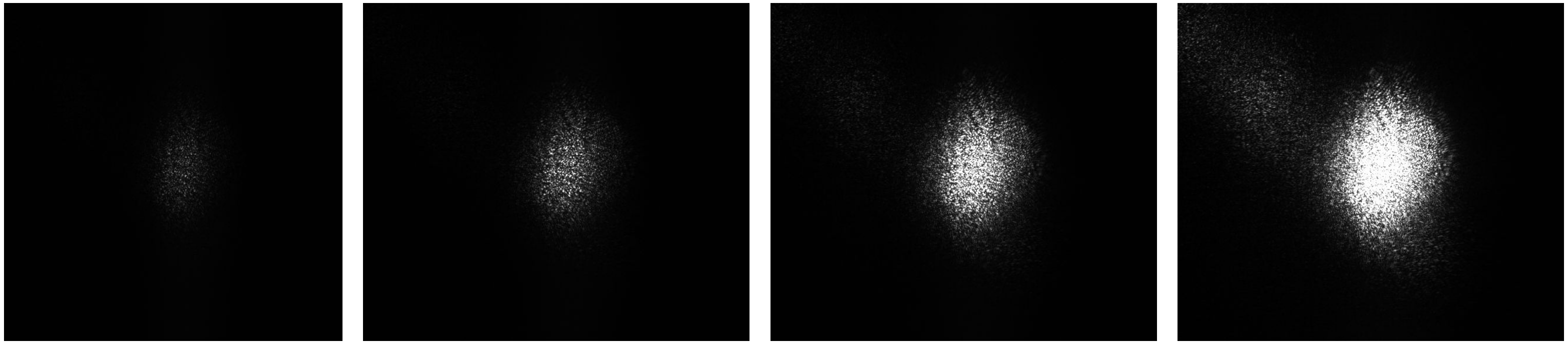
- **Studies on point scatterers:**
  - **Size vs number** of point scatterers
  - **Spatial distribution** of point scatterers
  - What **fraction of scattering** is due to these point scatterers?
- **Other studies:**
  - Can we get some info about the **coherence of scattered light** from these images?
  - Understanding how effective our **cleaning methods** are
  - Can we get some info about how **different coatings** affect scattering?

High Dynamic Range Images

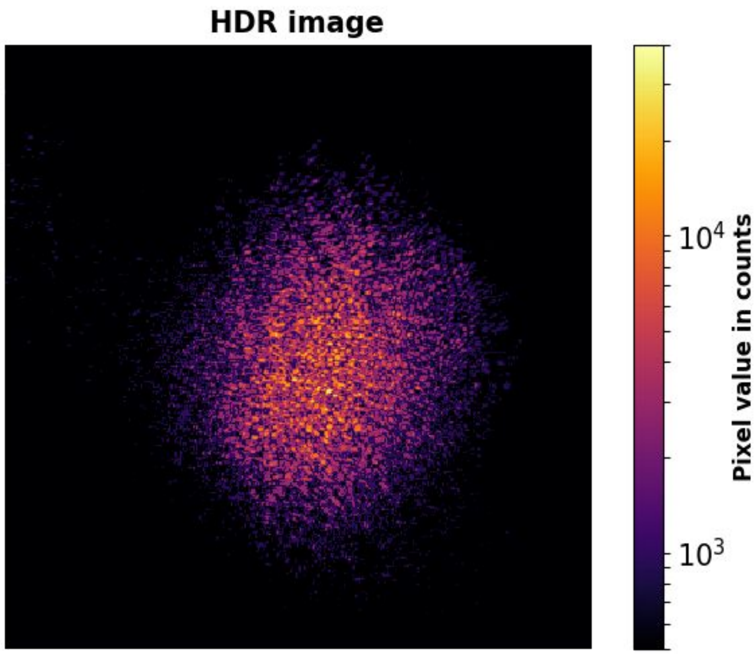
- Dynamic range is the ratio of intensity corresponding to the brightest region of the image and to the darkest.

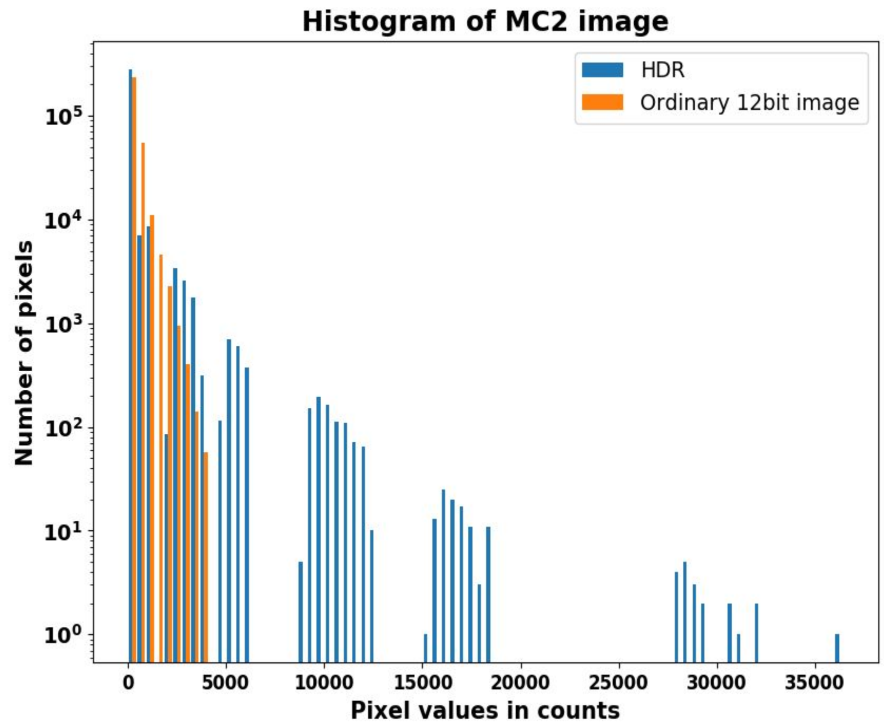
- HDR image resolves the **contrast** and **image details** much better than an ordinary image which might be limited by **pixel saturation.**

100 μs **300 μs** **1000 μs** **3000 μs**



HDR images





- Increased dynamic range and bit depth

→ Better resolution of intensity of points on the image

Scatter loss measurements

- **How to measure scattered power from the images?**

→ take pixel sum of the image and convert it into physical measure - power incident on our camera

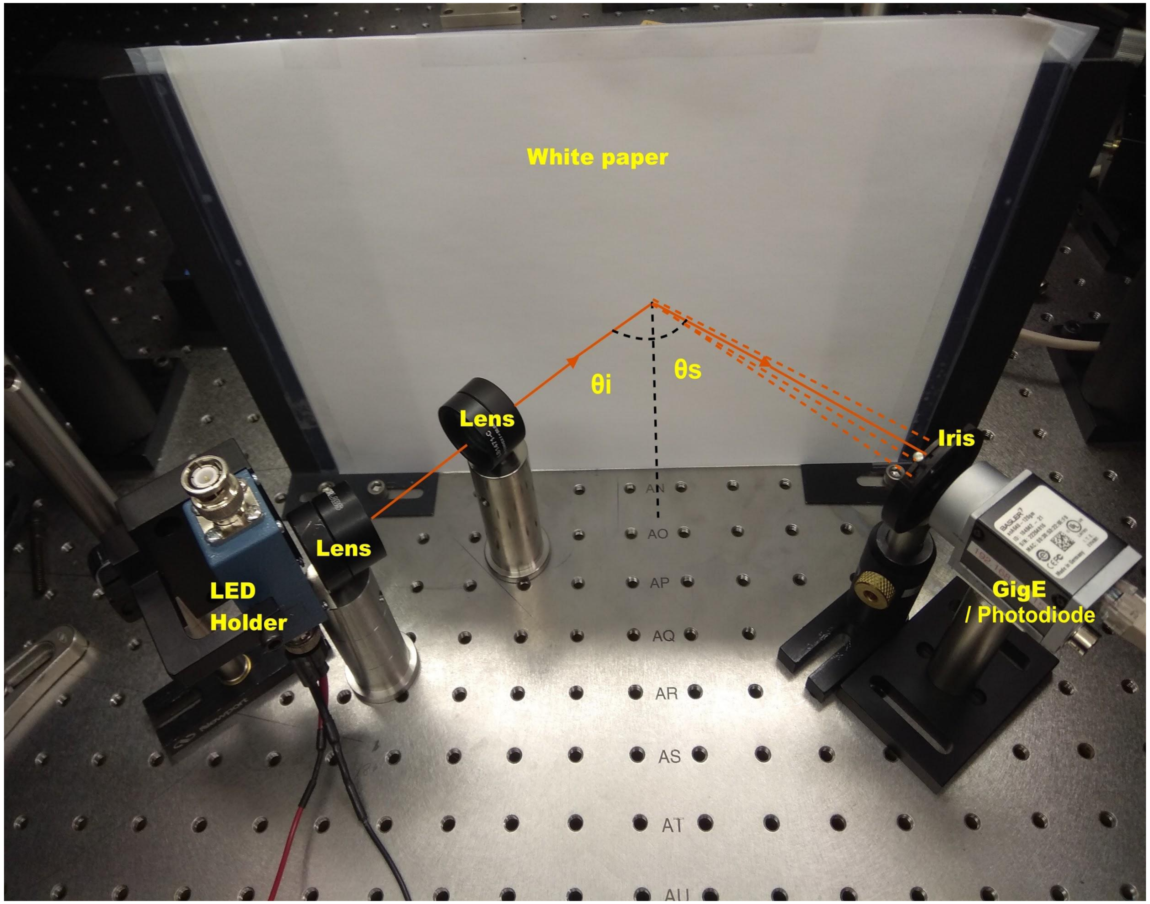
- Pixel sum is a function of both **incident power** and **exposure time**!

- **How to do convert pixel sum to power?**

→ Radiometric calibration

Radiometric Calibration

- Light source - **1050 nm LED** (to avoid any effect due to coherence of laser light)
- **Comparative measurement** between camera and photodetector
- **Uniform secondary source** - White paper (an approximation to Lambertian scatterer)



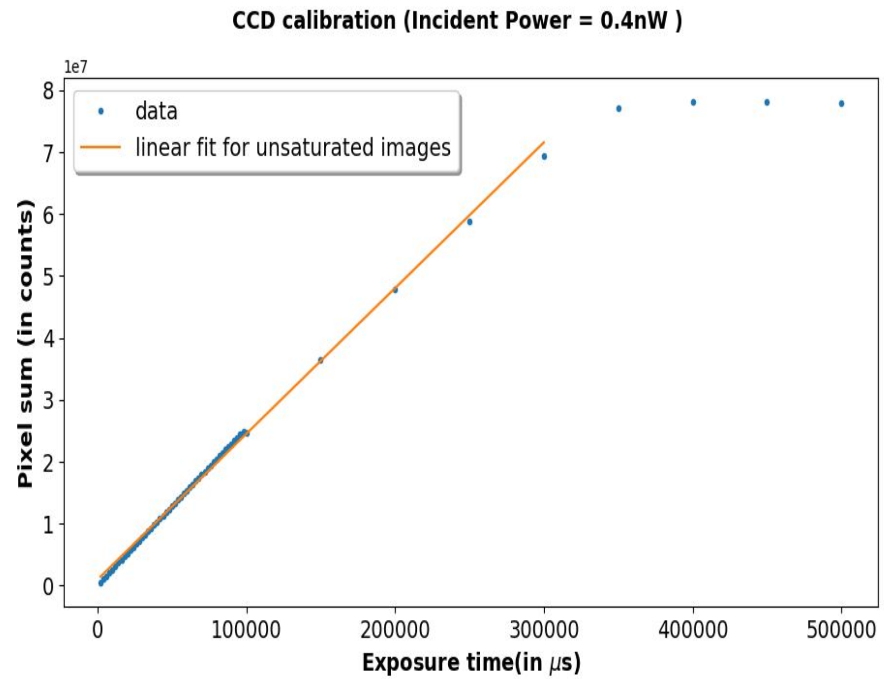
Calibration factor

- Calibration factor converts **pixel counts** to **power**

- For unsaturated images,

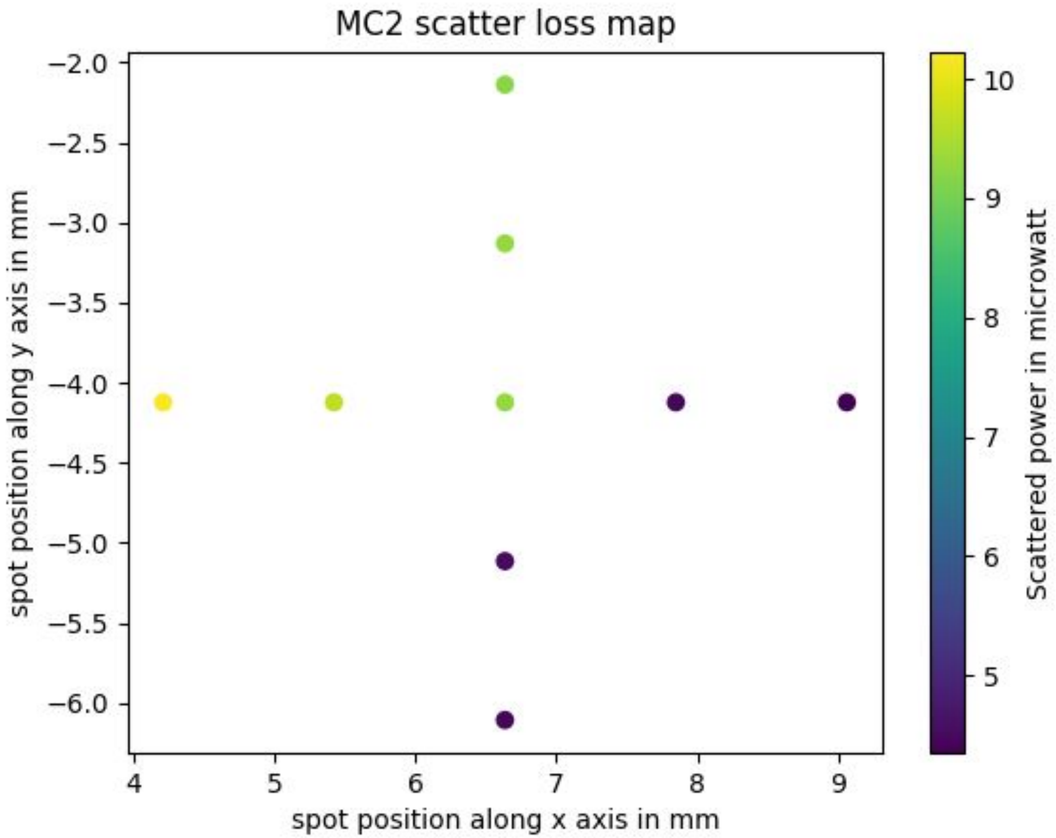
$$Scattered\ power\ (P_s) = CF * \frac{Pixel\ sum}{Exposure\ time}$$

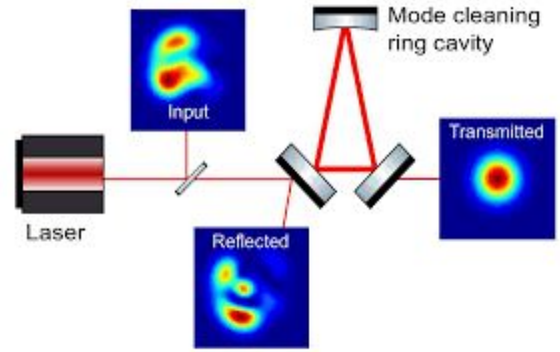
- In saturated images some information about the power is lost!



$$Calibration\ factor\ (CF) = \frac{Power}{slope\ of\ pixel\ sum\ vs\ exposure\ time}$$

Scatter loss map of MC2





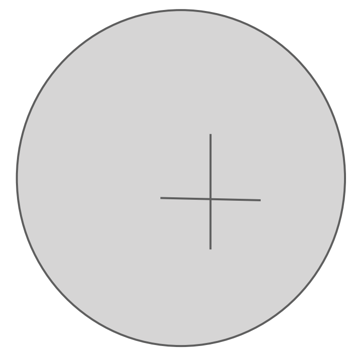
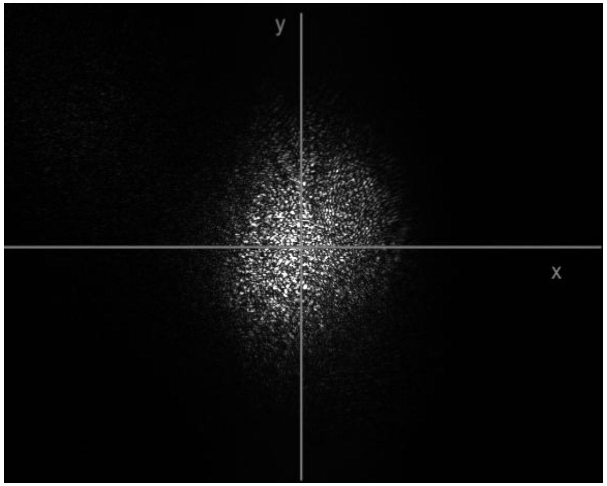


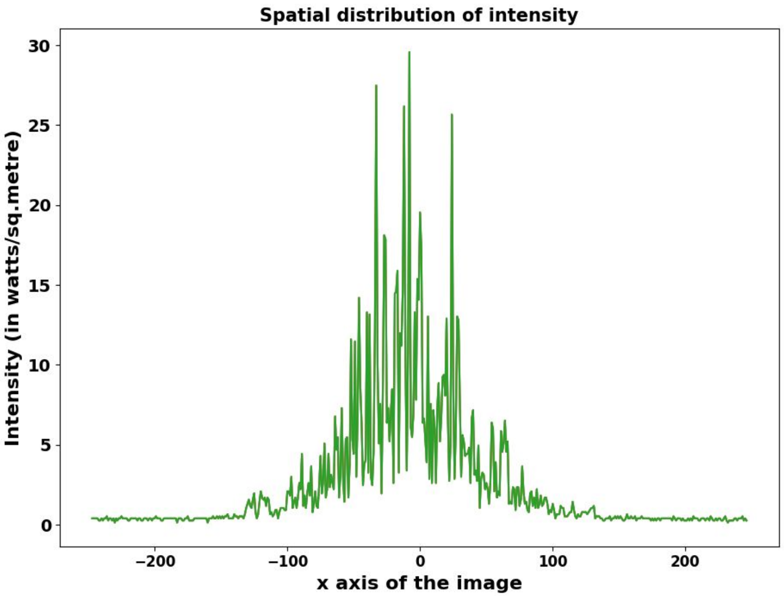
Diagram of MC2 mirror
(not to the scale)

- **Combining this kind of map with Transmission and Reflection maps of the cavity helps us estimate total optical loss**

Intensity analysis of the image



MC2 beamspot image



- Beamspot is not quite a Gaussian - due to scattering effects
- Needs more analysis to quantify the deviation

Summary

- Importance of scattering studies
- HDR images and their uses
- Measuring scattered power/ scatter loss

Future work

- Installation of GigE cameras for all cavities
- Design for real time BRDF measurements at small angles
- Studies with a scatterometer

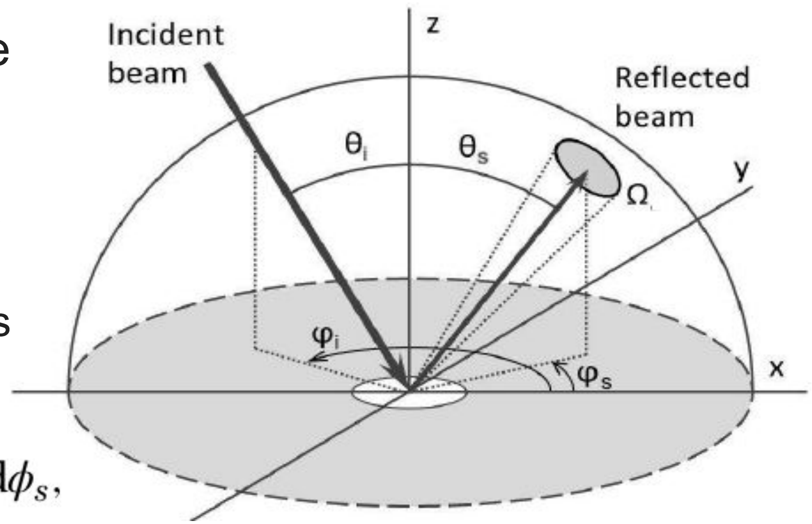
Thank you!

Supplementary - BRDF

- Bidirectional reflectance distribution function (BRDF)

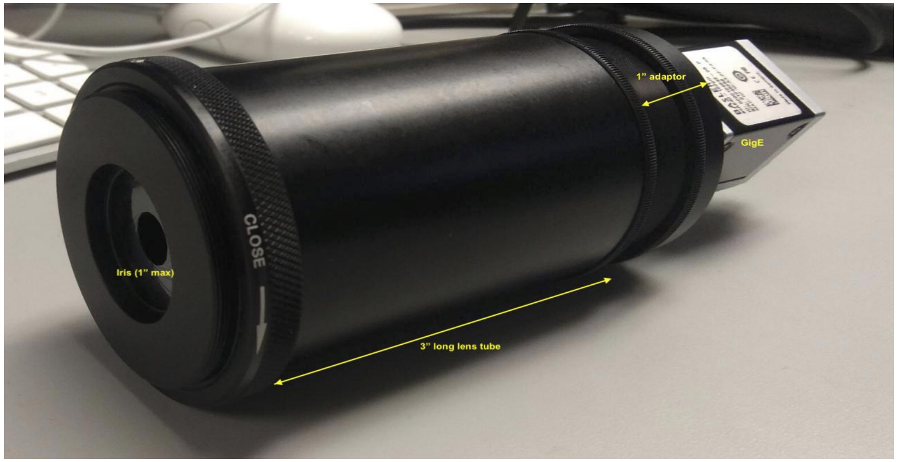
$$BRDF\,(\theta_i\,,\phi_i\,,\theta_s\,,\phi_s\,,\lambda,x,y) = \frac{P_s}{P_i\;cos(\theta_s)\;\Omega}$$

- BRDF models are used to characterize anisotropy of a surface
- BRDF can be used to estimate the total integrated scattering (TIS). Knowing the incident power(P_i) and reflectivity of the surface, we can get the total scatter loss (P_s)



$$\frac{P_s}{P_i} = R\,\mathrm{TIS} = \int_0^{2\pi}\int_0^{\pi/2} \mathrm{BRDF}\cos\theta_s\sin\theta_s \mathrm{d}\theta_s \mathrm{d}\phi_s,$$

Supplementary - Telescope



- Why use telescope?
- Telescope parameter optimization

Supplementary - Lambertian Scatterer

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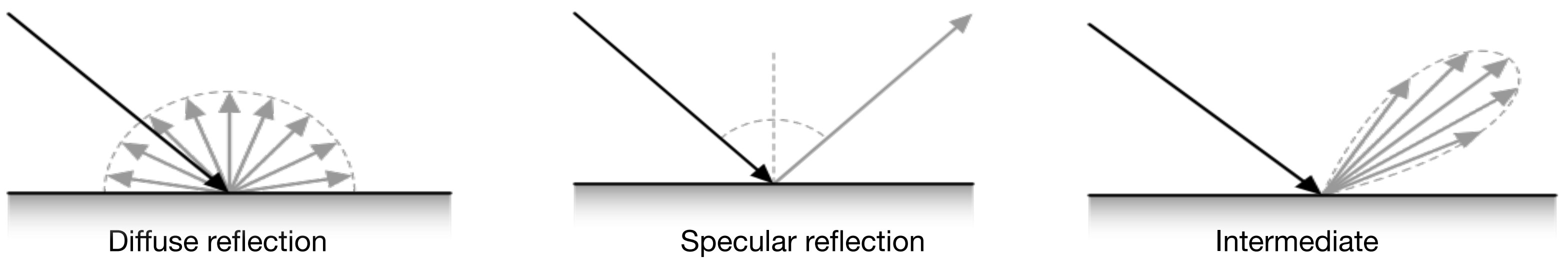

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