Cosmic Explorer Scattering Update

COSMIC EXPLORER

cosmicexplorer.org

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May 19, 2021

GWADW Virtual

Outline

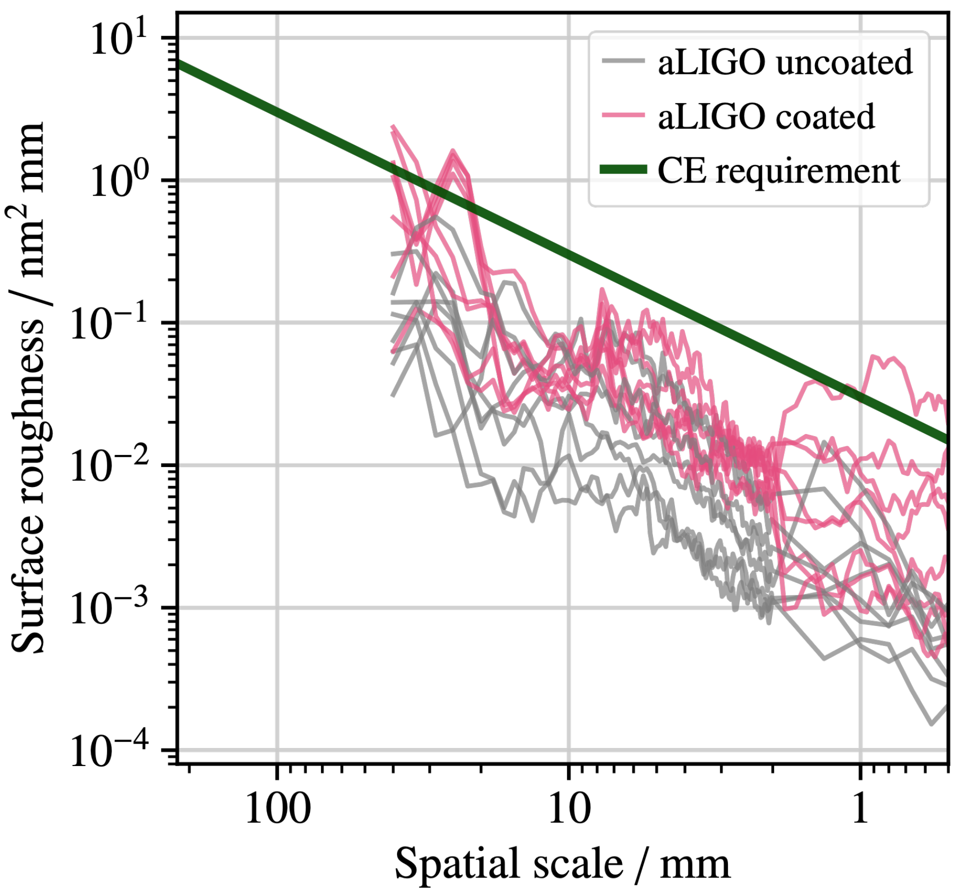
- Scattering from mirror roughness and defects
- Noise from beam clipping and diffraction at baffles

SCATTERING FROM MIRROR ROUGHNESS AND DEFECTS

Estimating CE Surface Roughness Requirements

- Roughness PSDs for installed aLIGO test masses:
  - Gray: before coating
  - Pink: after coating
- Green: requirement; simple power law that keeps scatter noise low enough
  - Must extend to larger spatial scale because of 70cm diameter CE test masses

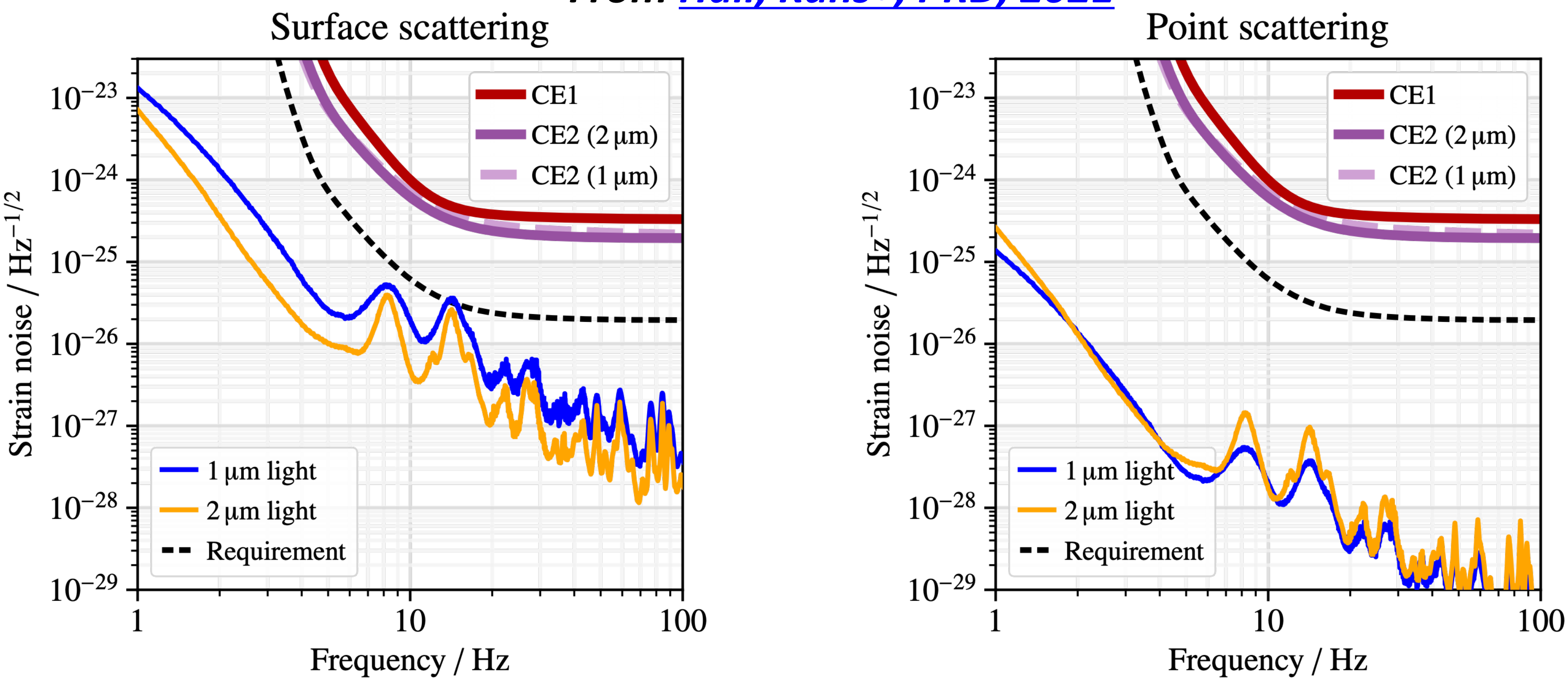
From Hall, Kuns+, PRD, 2021



Estimating CE Surface Roughness Requirements

- Backscattering estimates carried out by Yuntao Bai (Caltech) https://dcc.ligo.org/LIGO-T1900854
- surface roughness: mostly scattering to narrow angles (using green power law)
  - point defects: scattering to wide angles (using BRDF=1e-4 1/Sr)

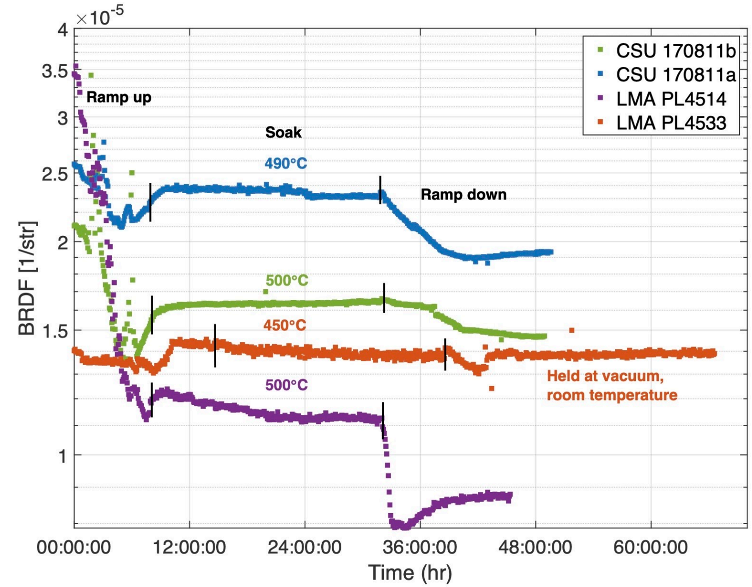
From Hall, Kuns+, PRD, 2021

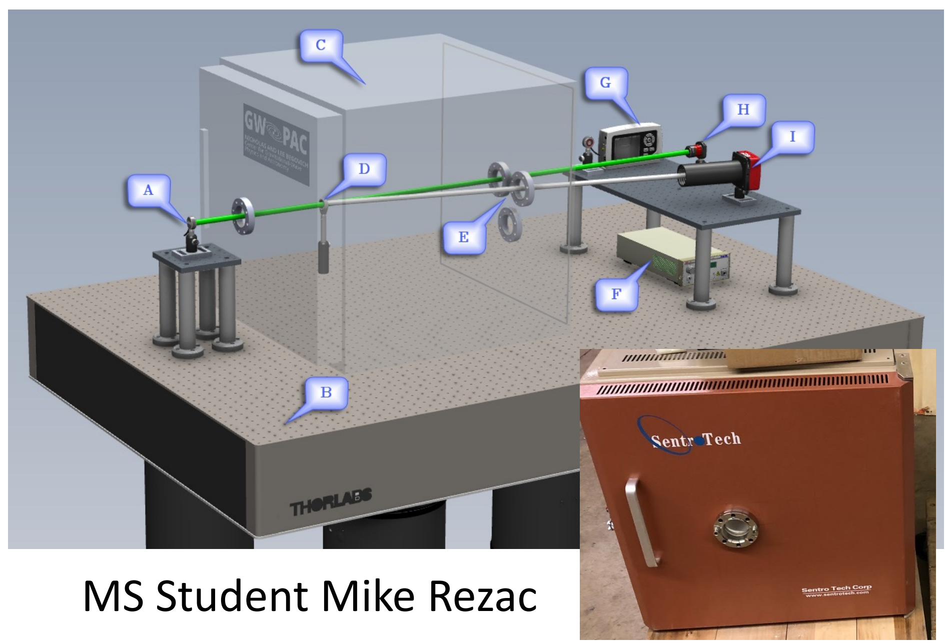


A+/CE Scatter Experiments

At Cal State Fullerton

- **In-situ scatter versus annealing**
  - Scatter versus annealing of (Ti):Ta2O5 in vacuum [Capote+, JOSAA] showed decreasing scatter to 500C
  - Repeat and extend this work, but in air, using latest coatings and annealing prescriptions
  - Sentrotech oven purchased, electrical in lab being upgraded



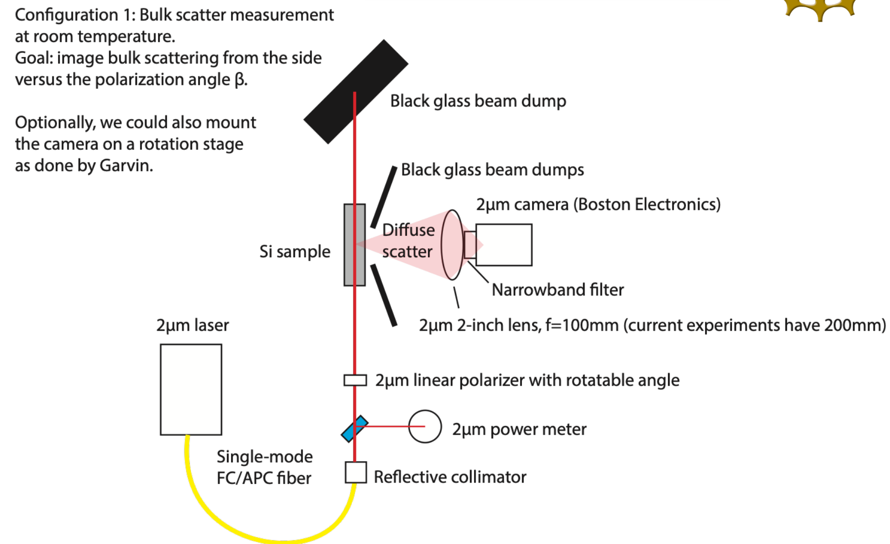


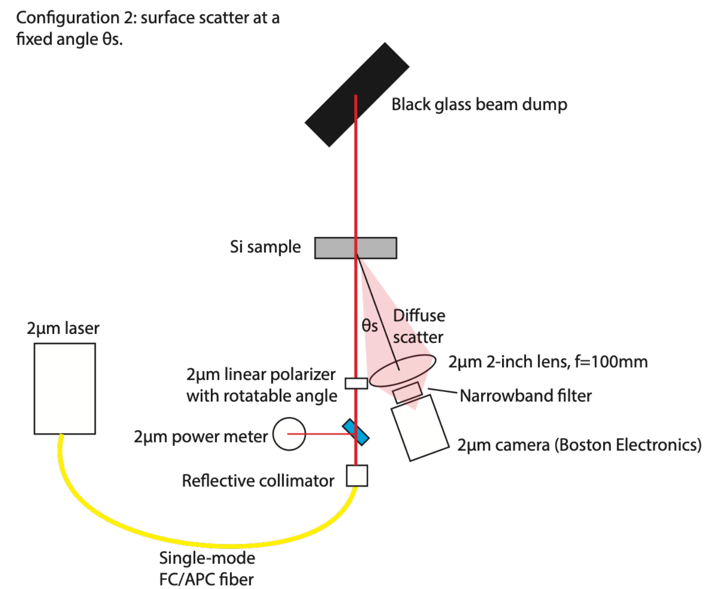
MS Student Mike Rezac

Voyager/CE2 Scatter Experiments

At Cal State Fullerton

- **Scatter of silicon and coatings at 2um and 123K**
  - Would verify Zeno Tourasi's (Glasgow) silicon scatter measurements (bulk scatter and surface scatter), but at new wavelength and temperature
  - Coordinating with Caltech (Chris Wipf) on samples
  - GM cryostat purchased from ColdEdge
  - 2um laser and cameras purchased
  - Extendable to birefringence (i.e. repeat [Krüger CQG 2016] at 2um, 123K





MS Student Alexandra Gruson

NOISE FROM BEAM CLIPPING AND DIFFRACTION AT BAFFLES

Noise from clipping and diffraction

- The Cosmic Explorer beam is much larger than 2nd generation beams
- Baffles clip a larger amount of the propagating field
- This might lead to
  - Changes in the shape of the cavity eigenmode
  - Noise due to modulated diffraction due to baffle motion
- How to address the problem?
  - Numerically difficult: high dynamic range since the Gaussian tails are very small at the baffle edge
  - FFT propagation is ideal for capturing the sharp edge of the baffles, but not great at the dynamic range
  - Modal approach is numerically more stable with the dynamic range, but need very large number of modes

Work plan

DONE

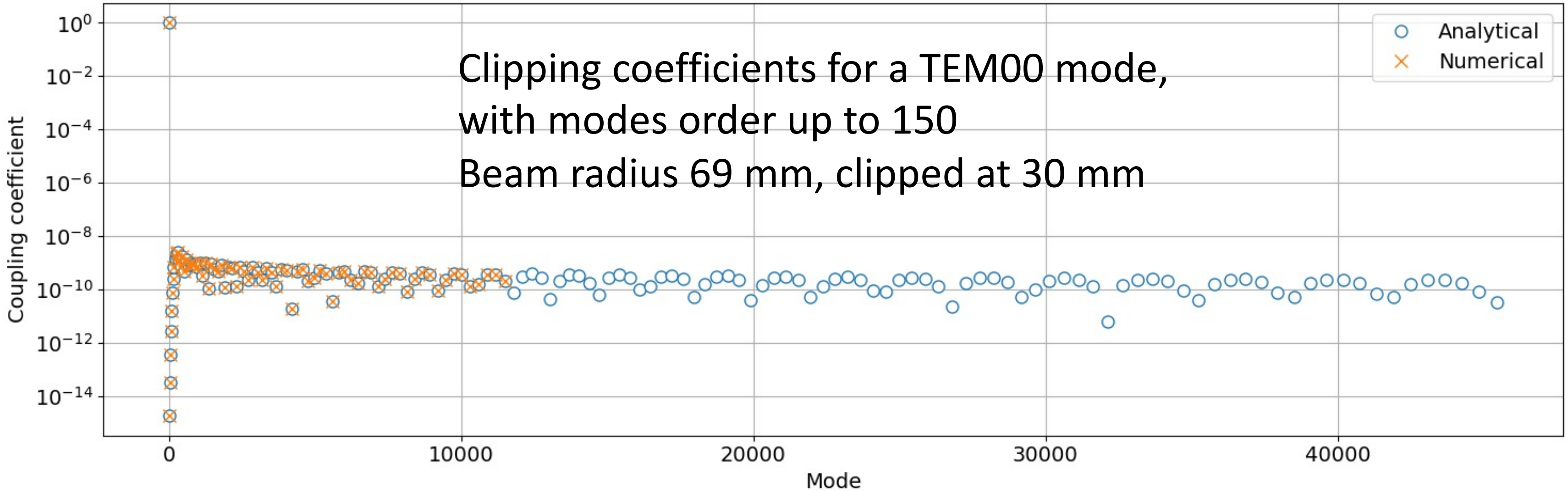
1. Develop a model model of baffle clipping
2. Compute the cavity eigenmode with baffles (centered and with random lateral displacements)

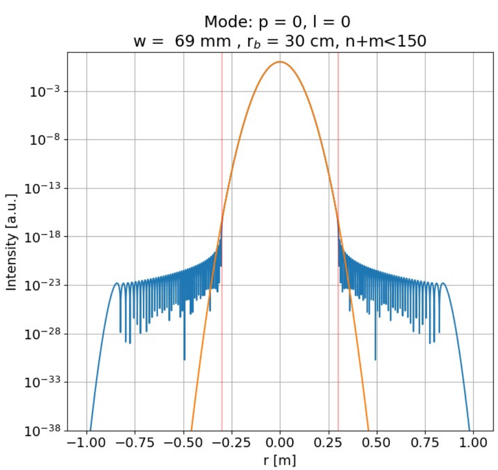
IN PROGRESS

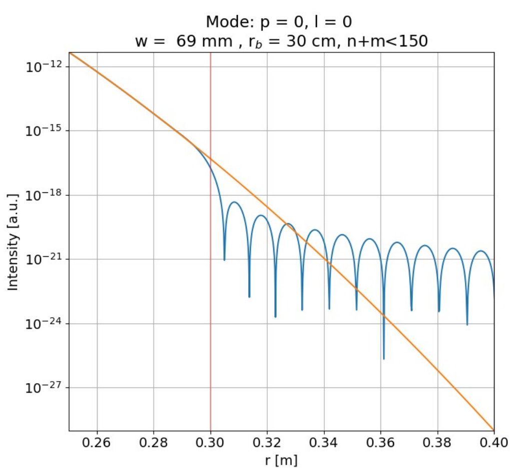
3. Compute the effect of a lateral and longitudinal motion of each baffle on the circulating mode and compute phase and radiation pressure noise
4. Study the dependency on number of baffles
5. Derive some requirements on baffle seismic isolation

Modal model – Laguerre Gauss

- Clipping matrix for a centered baffle can be computed analytically in Laguerre Gauss basis.
- Precise and efficient implementation, allows the use of a very large number of modes







Report / paper in preparation
for the analytical clipping model

We finally get the following closed-form, analytical expression for the coupling coefficient

$$C_{qm,pl} = \delta_{lm}\sqrt{q!p!(q+|l|)!(p+|l|)!}\sum_{j=0}^{\min(p,q)} \frac{\rho_B^{2|l|+4j+2}\,{}_1F_1\left[\begin{matrix}p+q+|l|+1\\ |l|+2j+2\end{matrix}\right](-\rho_B^2)}{j!(p-j)!(q-j)!(|l|+j)!(|l|+2j+1)!} \qquad (10)$$

This coupling matrix depends only on one parameter $\rho_B = \frac{r_B\sqrt{2}}{w}$ that is the ratio of the baffle radius to the beam radius.

Modal model – miscentered baffles

- Move to Hermite-Gauss basis
  - Analytical base change matrix

I. Kimel and L. R. Elias, *Relations Between Hermite and Laguerre Gaussian Modes*, IEEE Journal of Quantum Electronics 29, 2562 (1993)

- Translate beam basis and then use the centered clipping matrix
  - Analytical expressions for beam translation

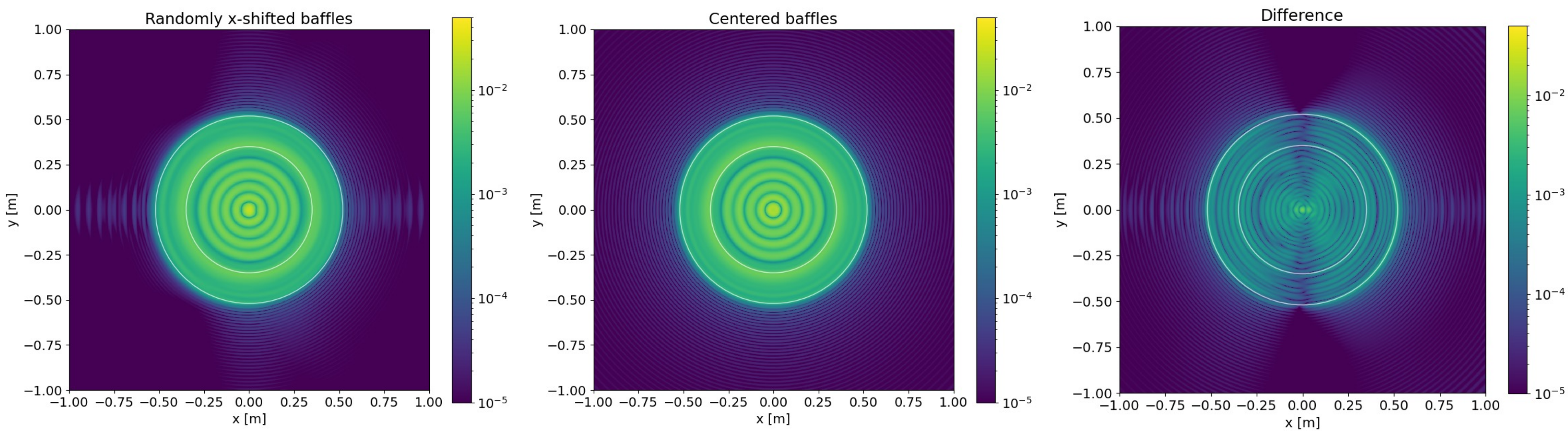
J.-Y. Vinet, *Virgo Physics Book - Optics and related topics*,

- There are a lot of implementation details to make it work
  - Use arbitrary precision arithmetic
  - Use sparse matrix implementation
  - Use FFT-inspired accelerated convergence

R. Day et al, *Accelerated convergence method for fast Fourier transform simulation of coupled cavities*, J.Opt.Soc.Am. A 31, 652 (2014)

Example result

- Cosmic Explorer cavity, 100 baffles equally spaced, radius 52 cm
- ITM T=1.4%, ETM T=5ppm
- No mirror maps, mirror radius 35 cm



Inner circle: test mass size
Outer circle: baffle size

Example result

- Cosmic Explorer cavity, 100 baffles equally spaced, radius 52 cm
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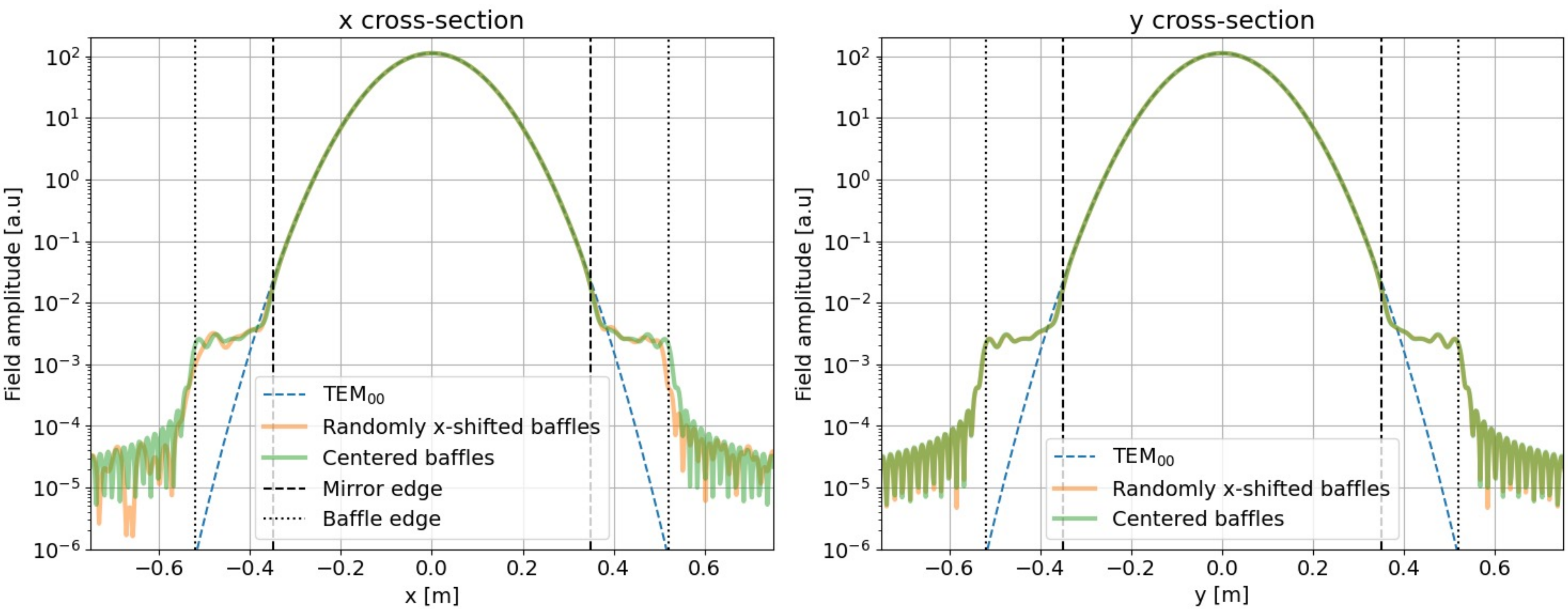

Conclusions

- Mirror roughness
  - Computed for points and roughness
  - Points seem ok
  - Roughness requirement comparable PSDs for aLIGO for spatial scales < few cm
  - Must extend to 70-80cm diameter and larger spatial scale
- Noise from baffle clipping
  - Developed a modeling framework
  - Computed distortion of the intra-cavity fields due to the baffle clipping and diffraction
  - Noise and coupling to be computed