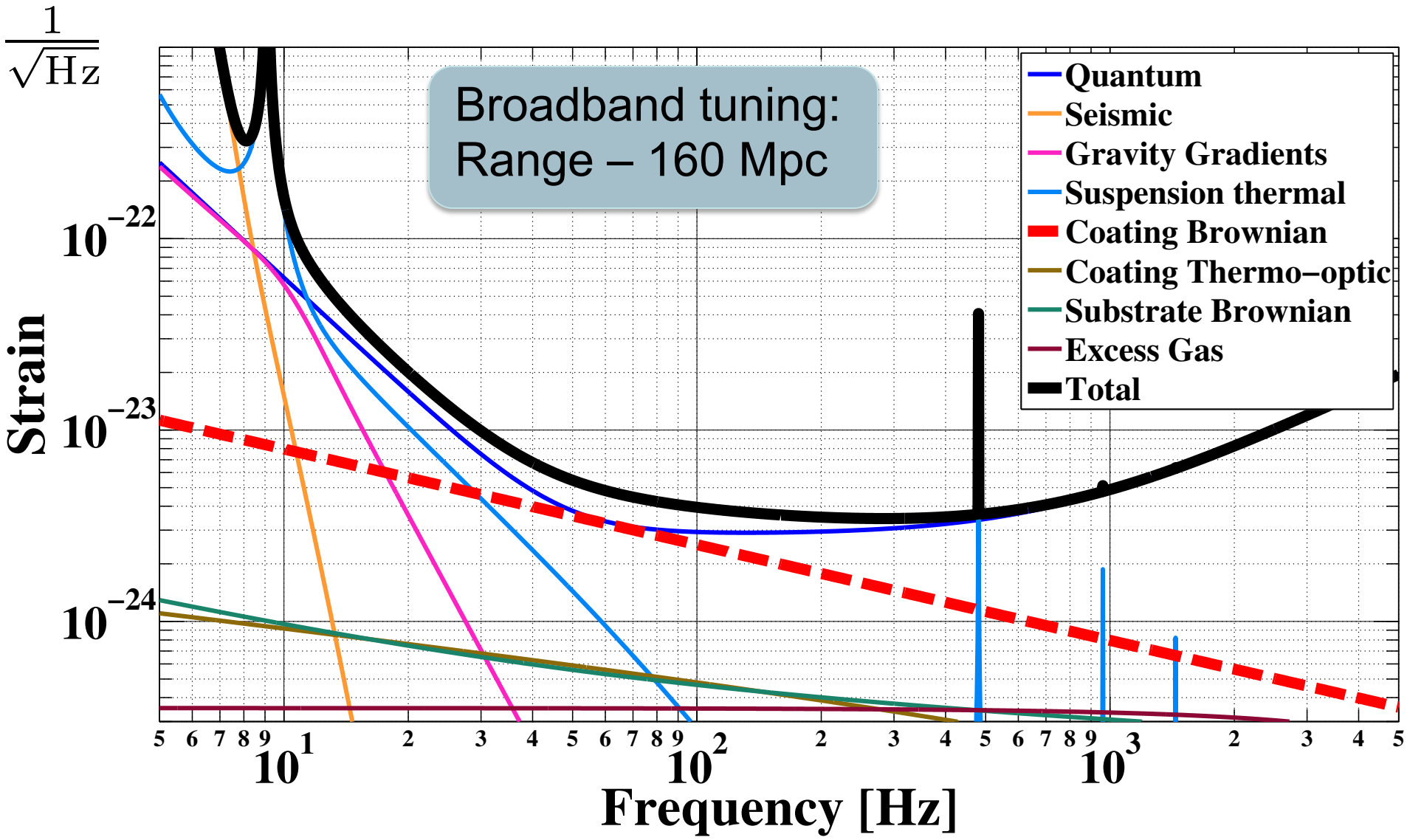
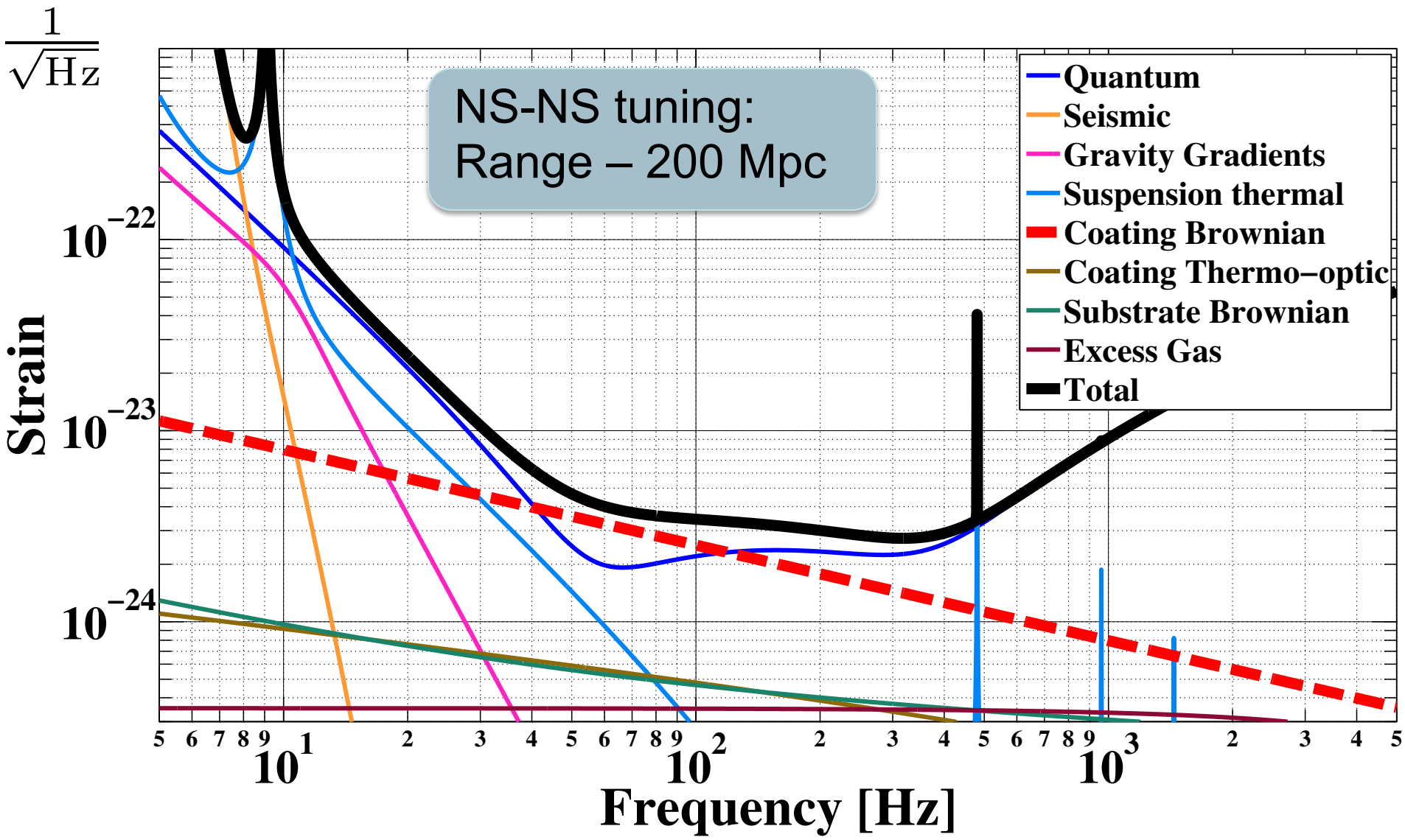
In short

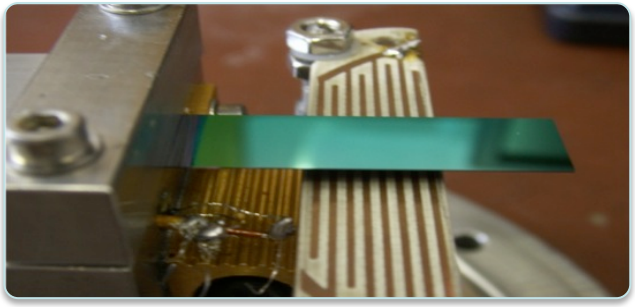
- Due to mirror surface roughness, adopting LG_{33} beams in the near future will be extremely challenging


Broadband tuning:
Range – 160 Mpc
Quantum
Seismic
Gravity Gradients
Suspension thermal
Coating Brownian
Coating Thermo−optic
Substrate Brownian
Excess Gas
Total
Strain
1/√Hz
10^−22
10^−23
10^−24
10^1
10^2
10^3
Frequency [Hz]

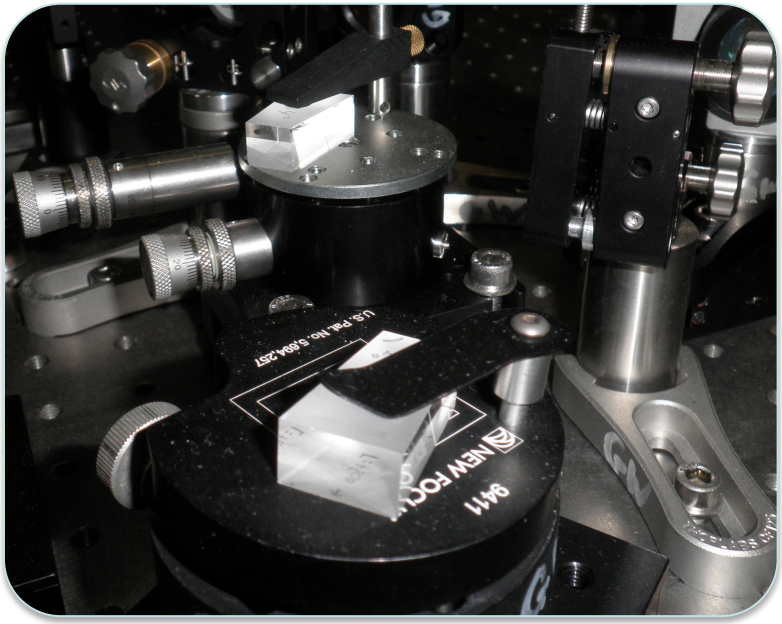

NS-NS tuning:
Range – 200 Mpc
Quantum
Seismic
Gravity Gradients
Suspension thermal
Coating Brownian
Coating Thermo−optic
Substrate Brownian
Excess Gas
Total
Strain
$\frac{1}{\sqrt{\mathrm{Hz}}}$
10^{-22}
10^{-23}
10^{-24}
10^{1}
10^{2}
10^{3}
Frequency [Hz]

Methods of reducing thermal noise

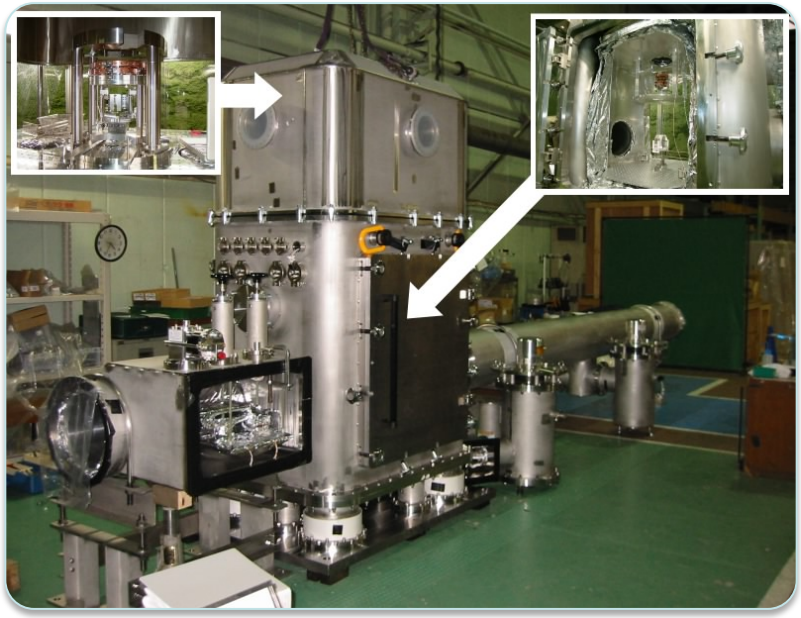
- Materials
- Cooling
- BEAM SHAPE



M. Abernathy, IGR, U. of Glasgow

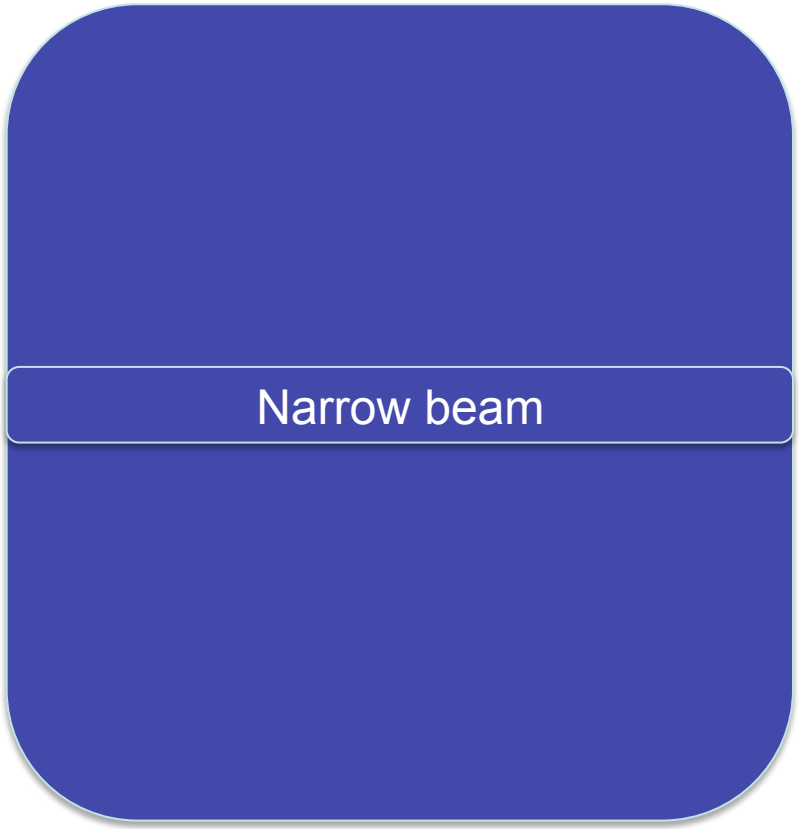


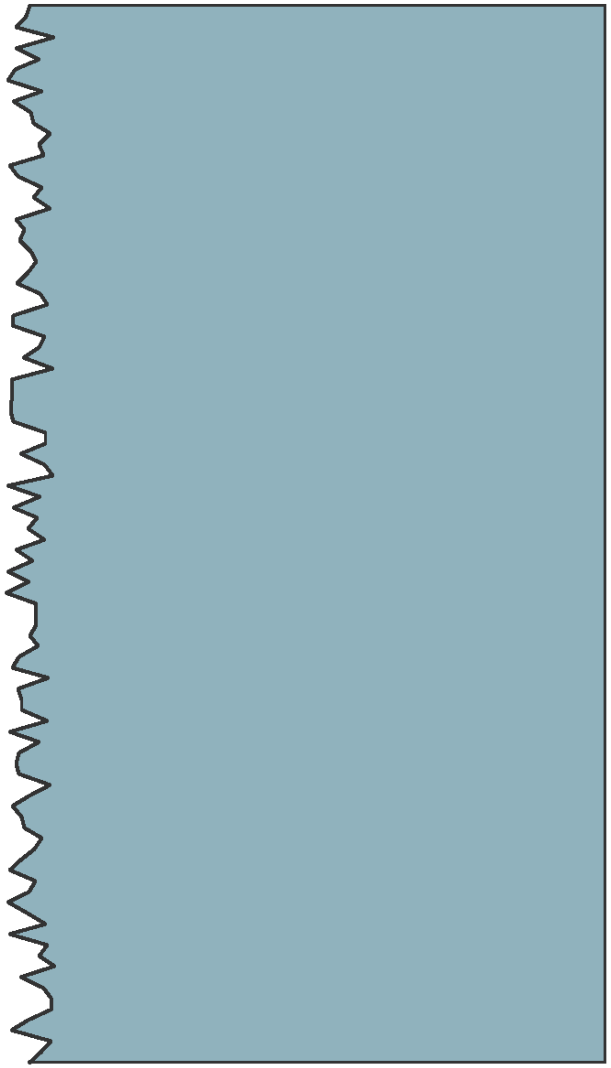
Undergraduate coating-free mirror project, ANU



http://www.icrr.u-tokyo.ac.jp/gr/lcgt/lcgt2010e.html

Bigger is better

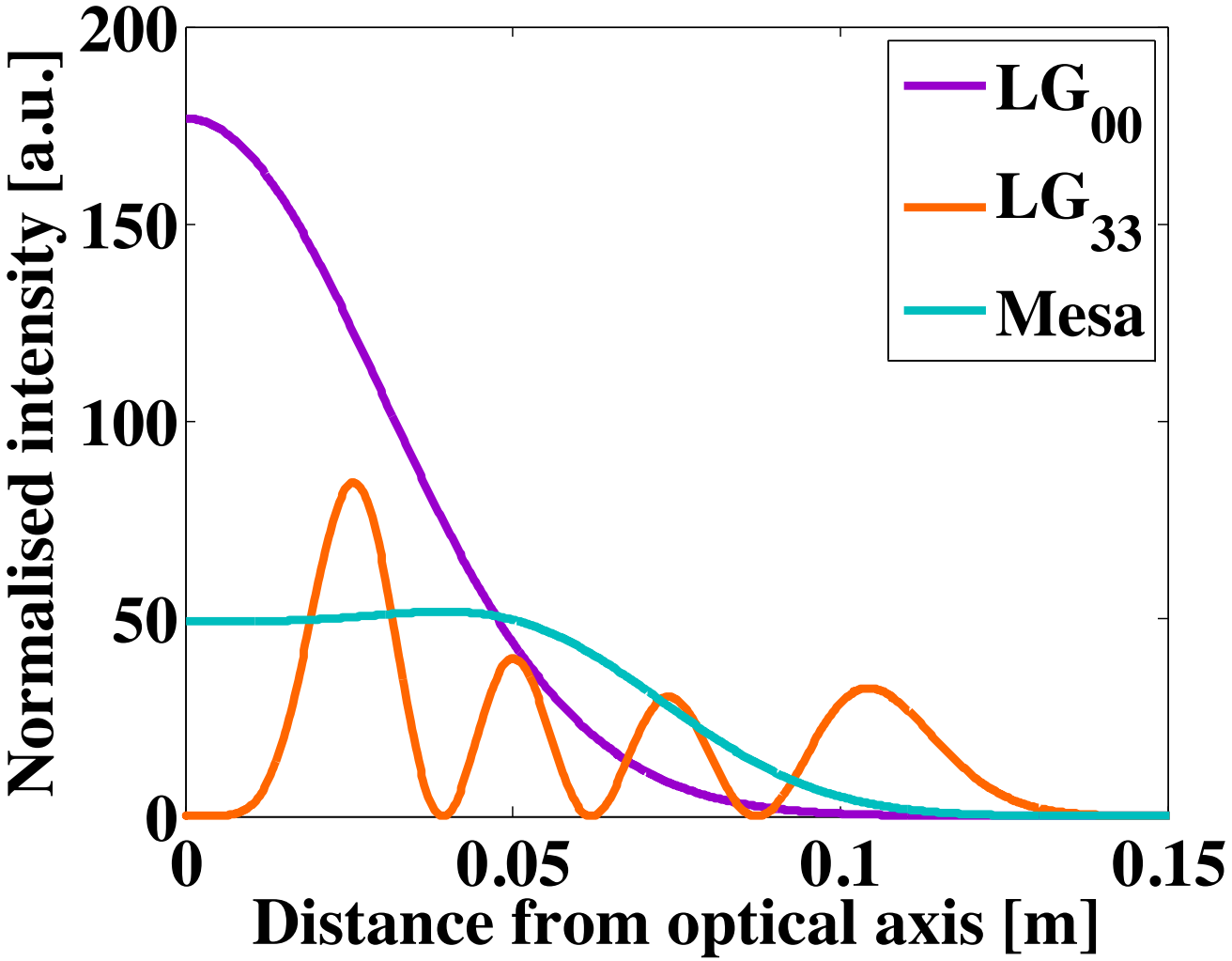




$$S_{CB} \propto \frac{1}{\omega^2}$$

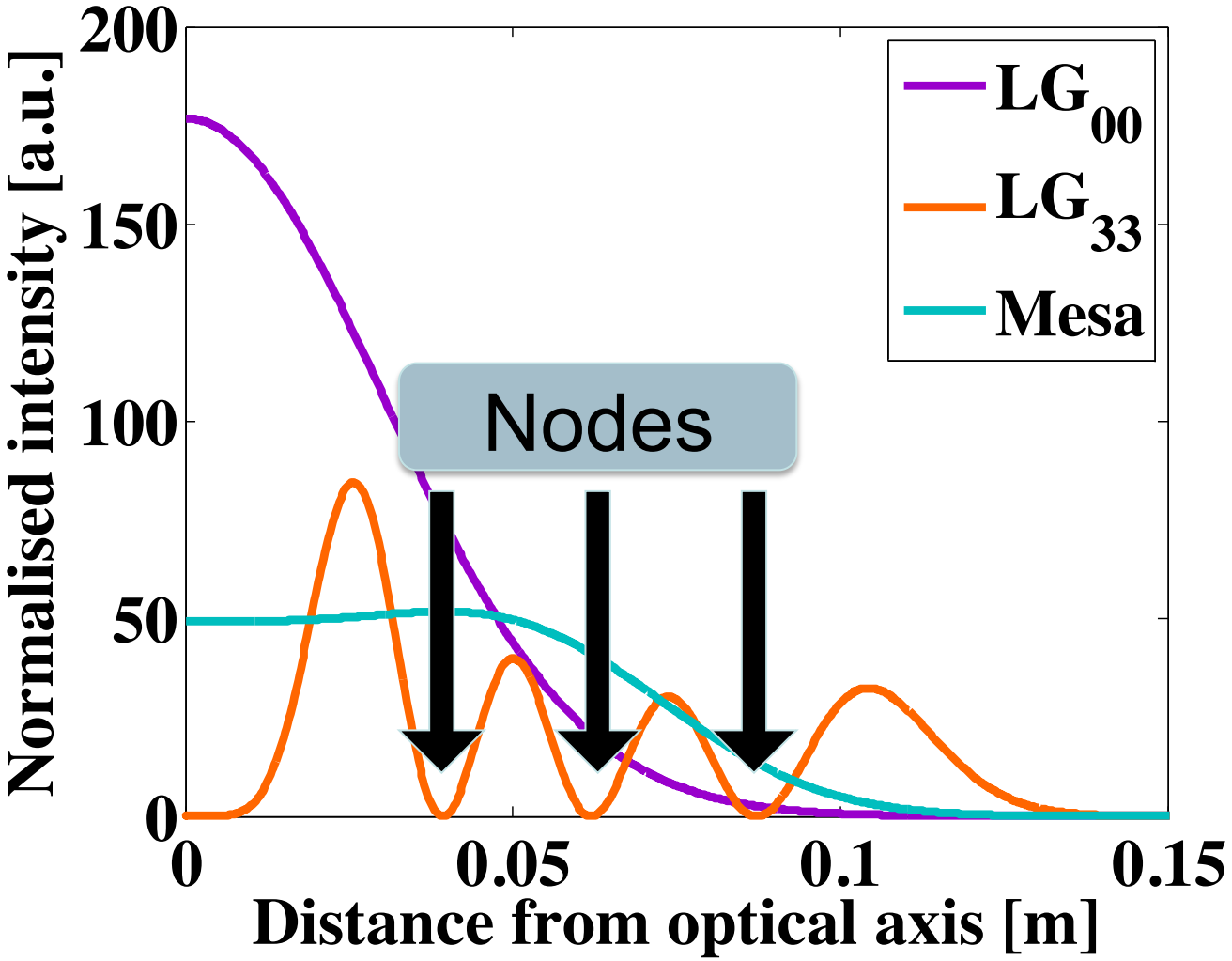
Pierro et al., Phys. Rev. D 76, 122003 (2007)

New beam shapes for GW III – LG_{33}



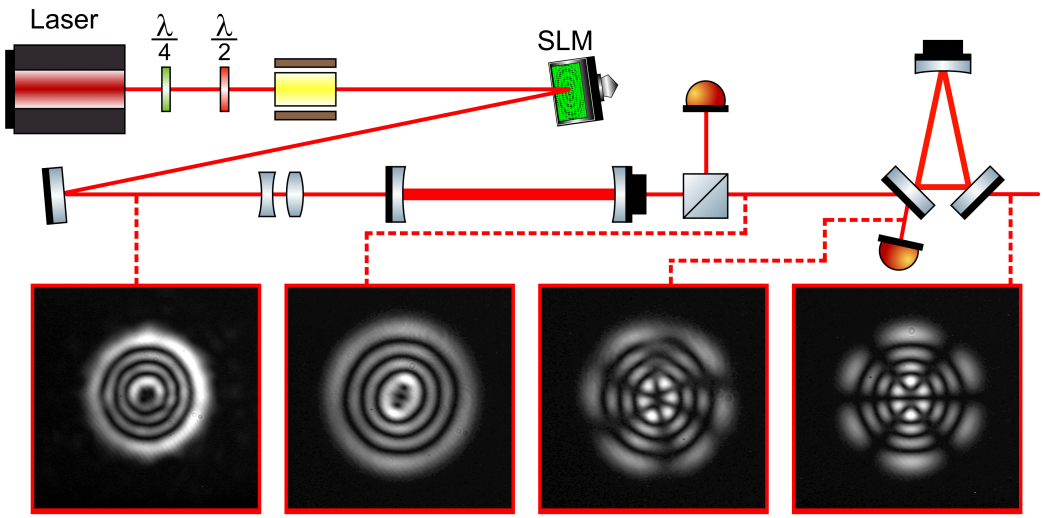
Mours et al.,Class. Quantum Grav. 23, 5777–5784 (2006)

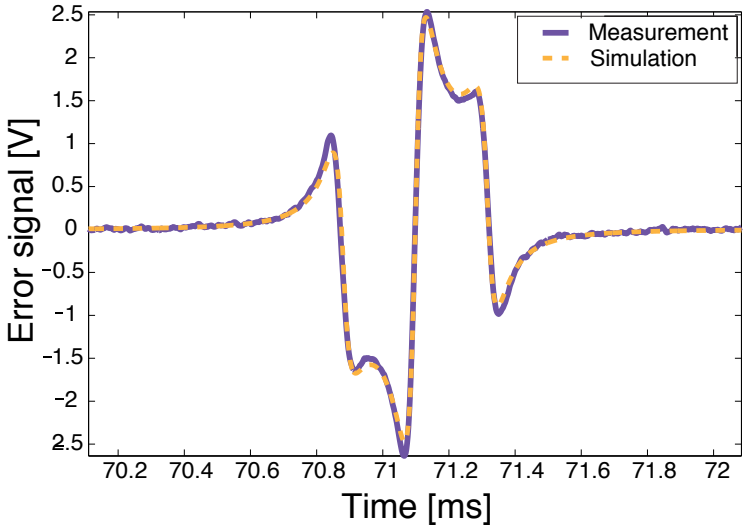
New beam shapes for GW III – LG_{33}

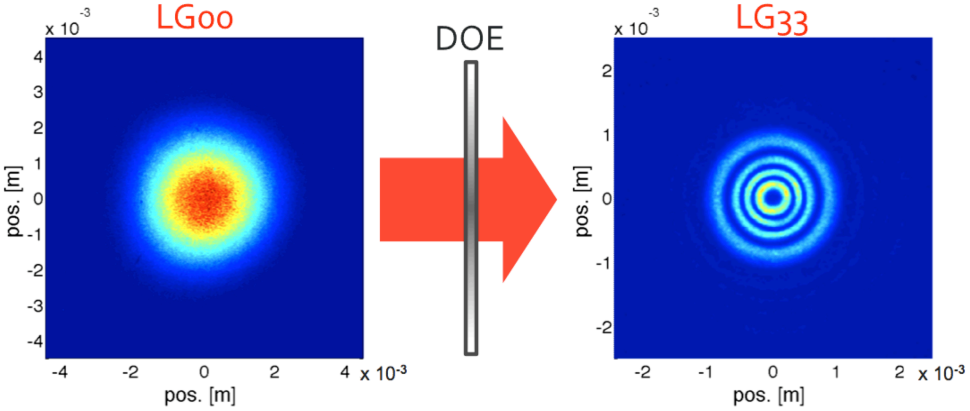


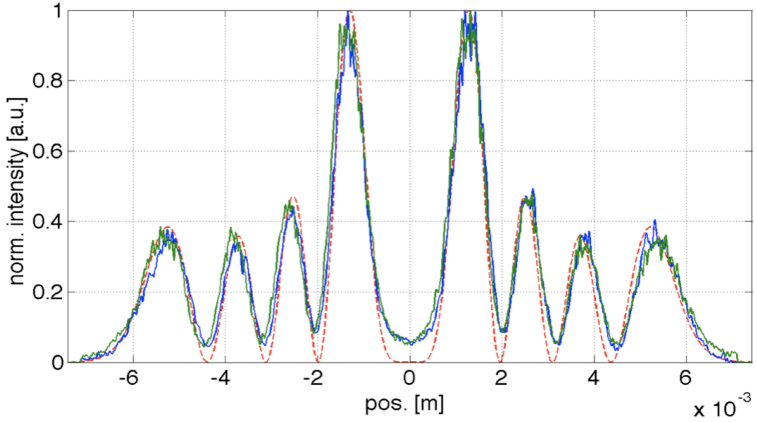
Mours et al.,Class. Quantum Grav. 23, 5777–5784 (2006)

Experimental work









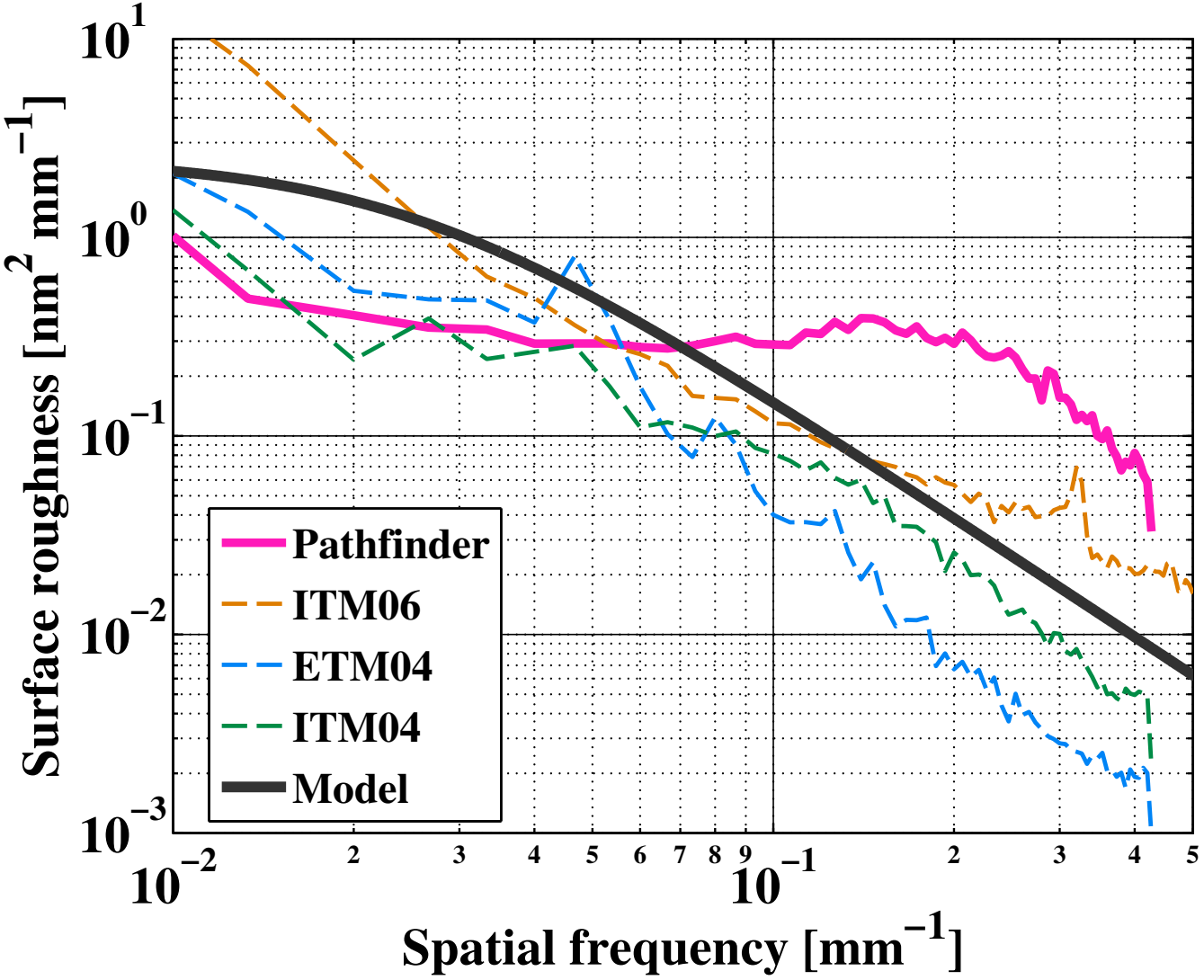
Fulda et al., Phys. Rev. D 82, 012002 (2010)
Granata et al., Phys. Rev. Lett. 105, 231102 (2010)

FFT simulations of LG_{33}

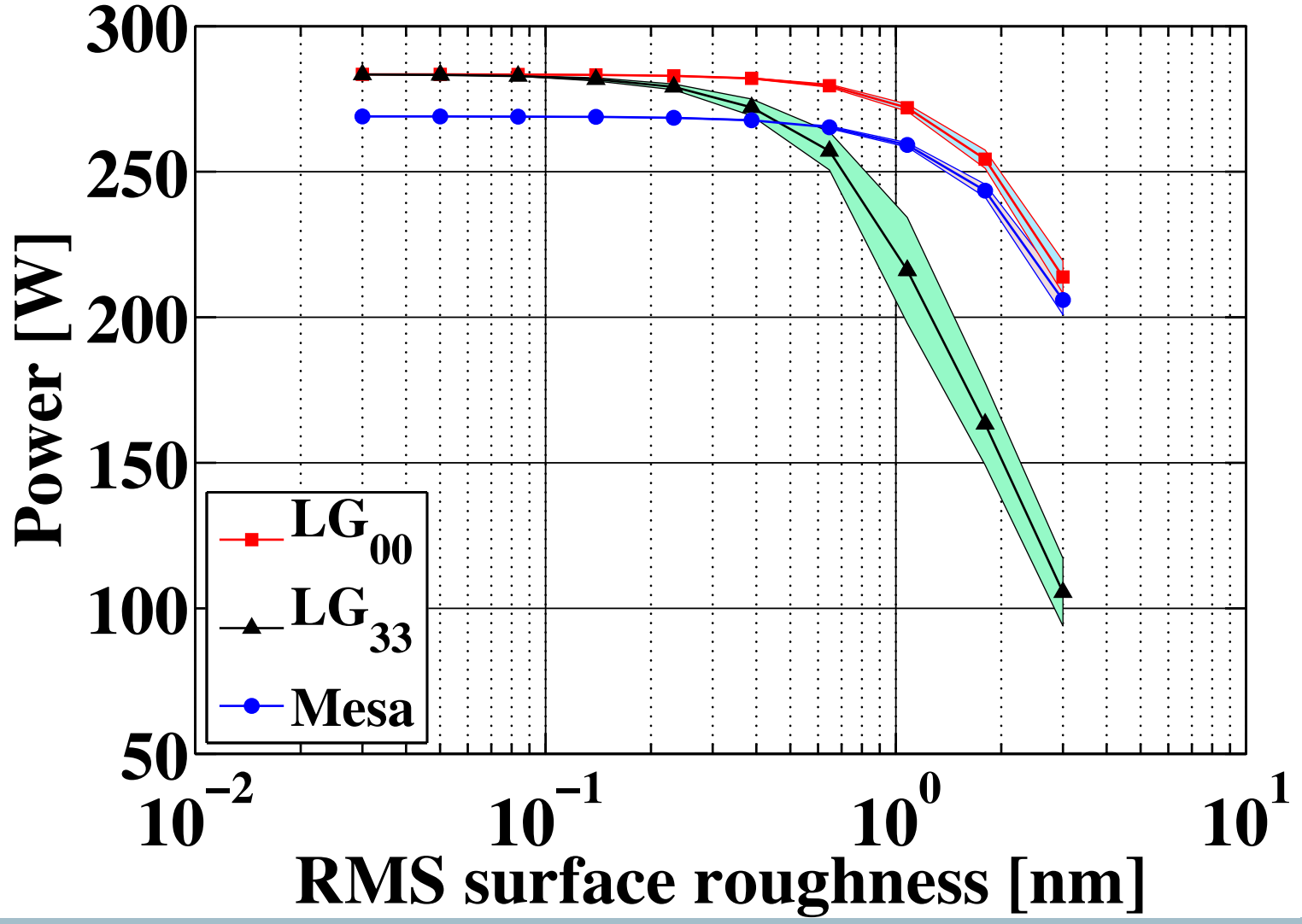
- Evaluate performance in real IFO
- SIS tool (H. Yamamoto)
- Simulate single 2nd generation style arm cavity
  - ROCs chosen to give diffraction loss equal to that of LG_{00}
- Assume input is pure LG_{33}

Yamamoto, LIGO Document T070039-v6 (2011)

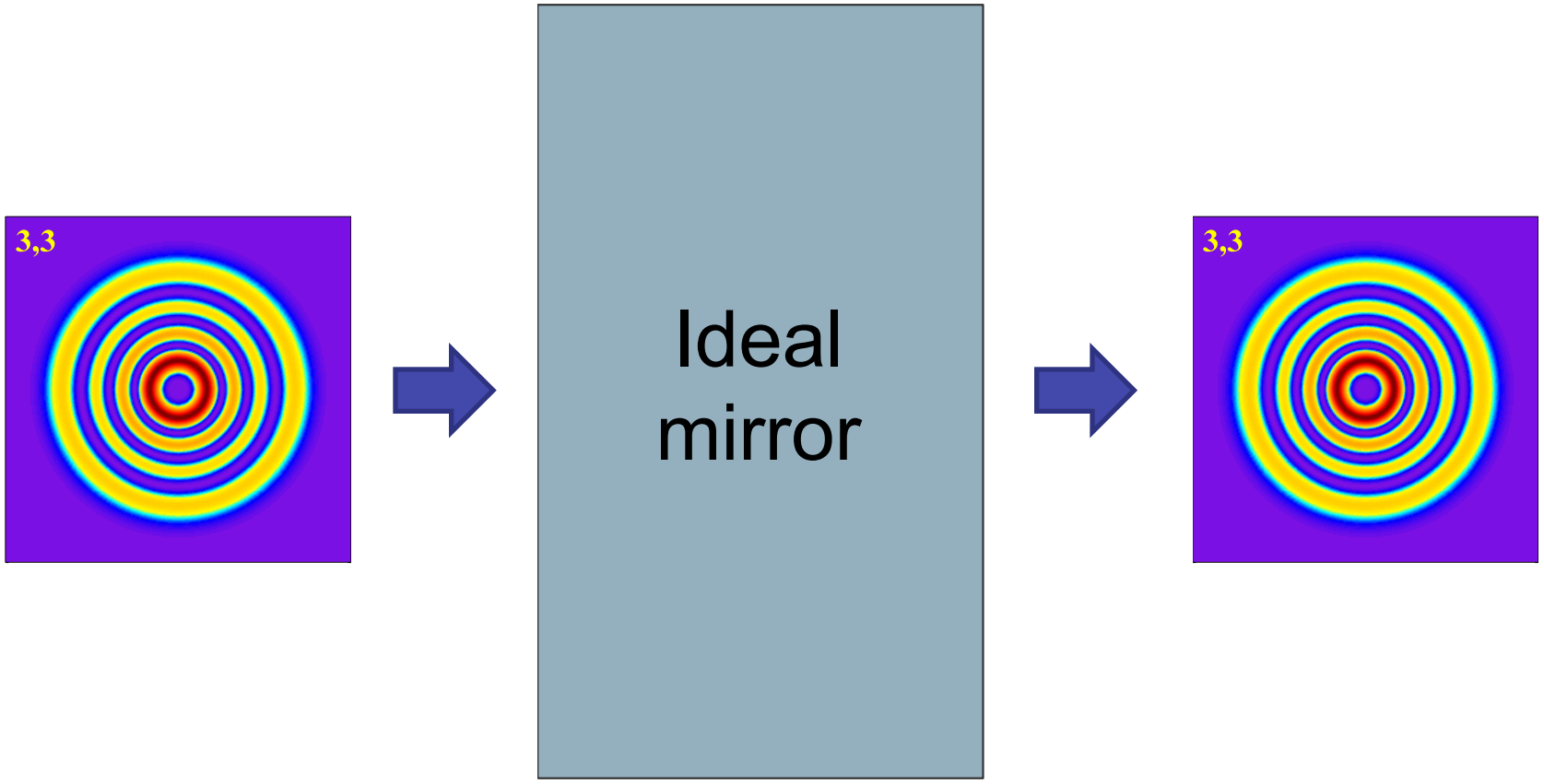
Mirror surface roughness



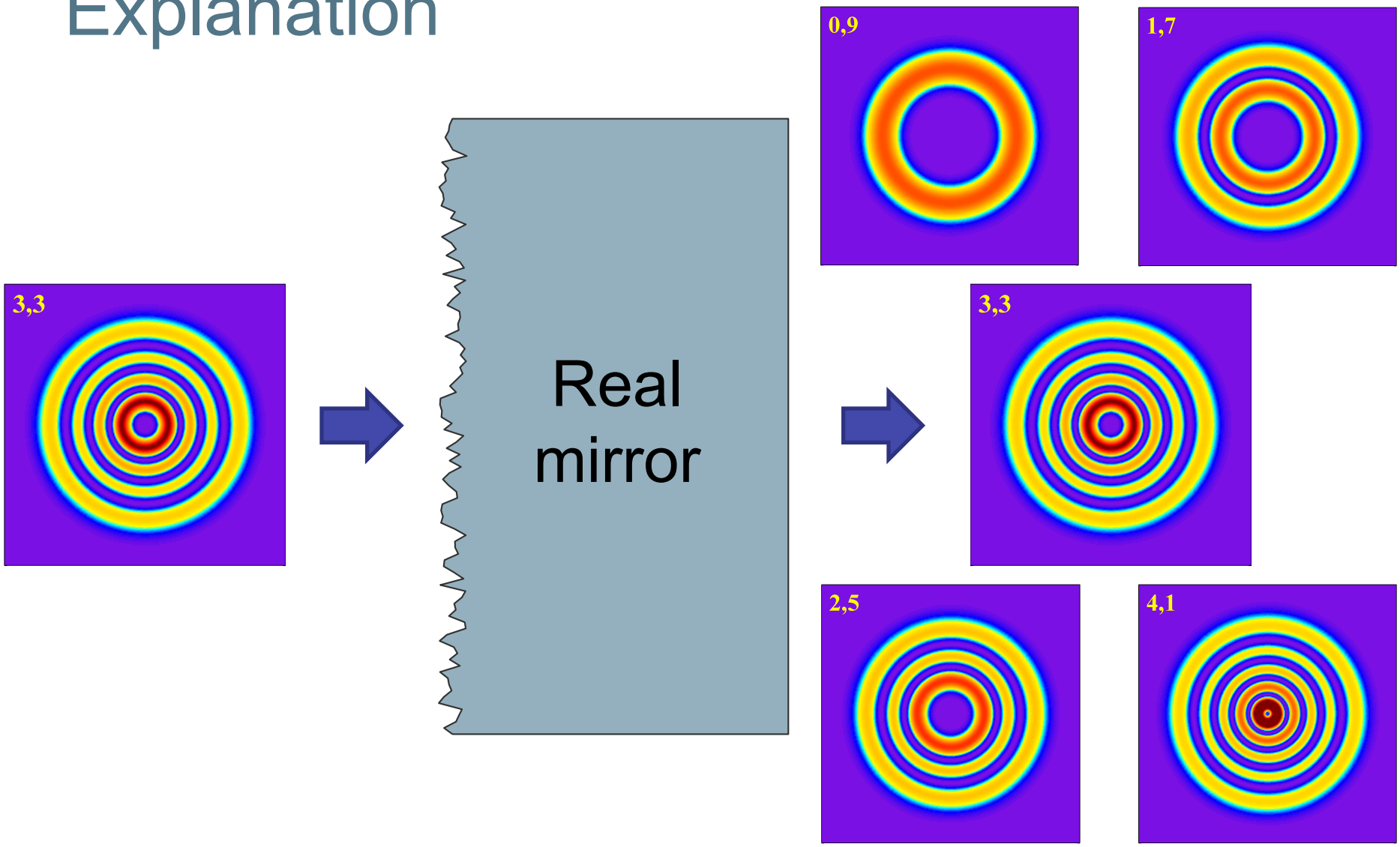
Circulating power



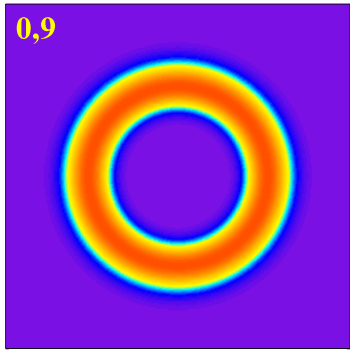
Explanation



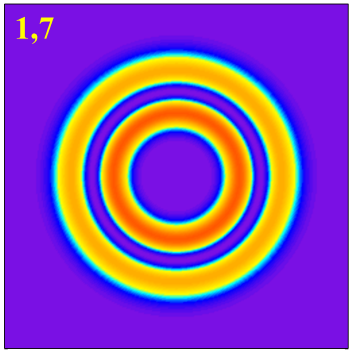
Explanation



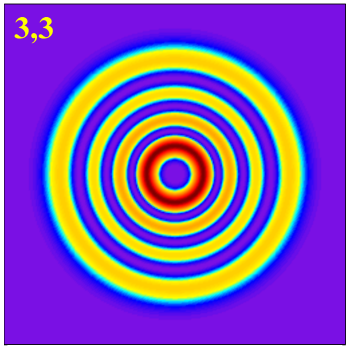
Modal contamination



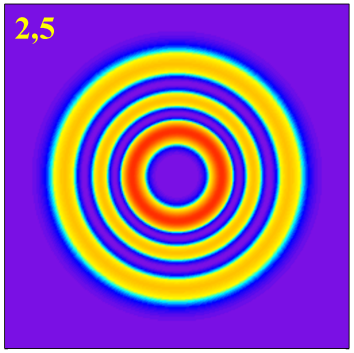
0,±9: 0.3 %



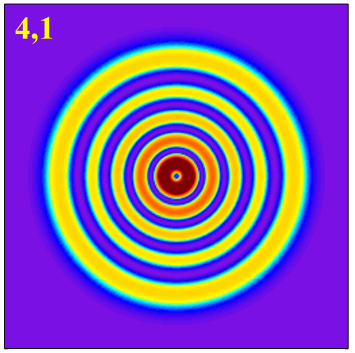
1,±7: 0.2 %



3,-3: 0.7 %

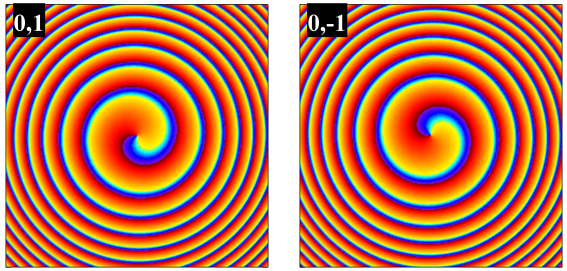


2,±5: 0.1 %



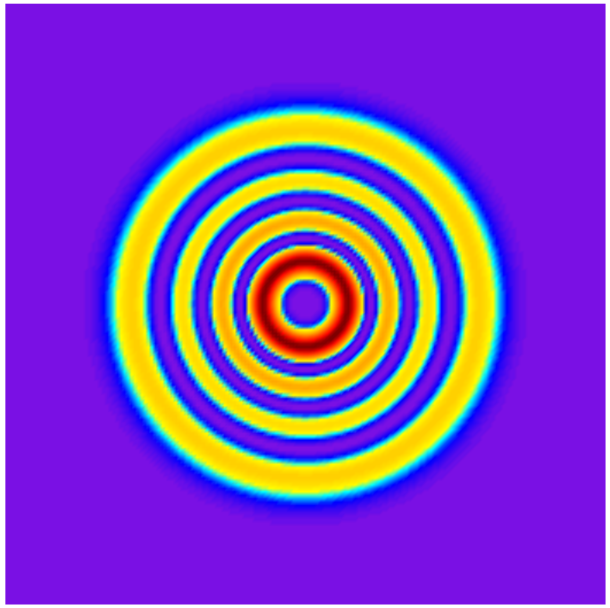
4,±1: 0.2 %

Total contamination: 1.5 %

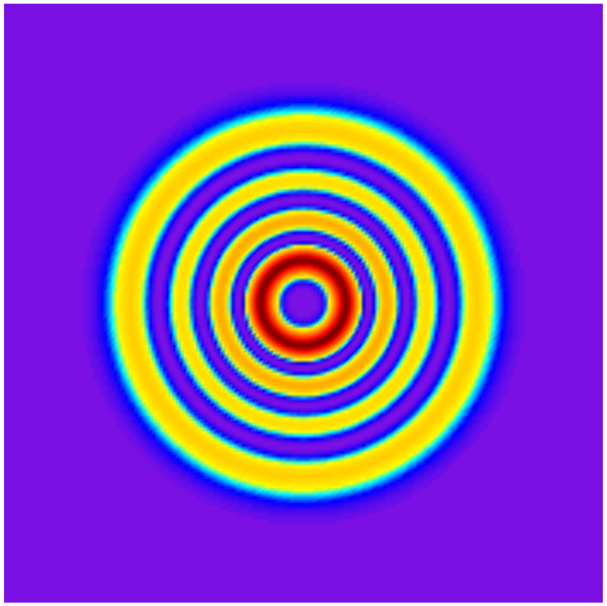


± modes have opposite helicity

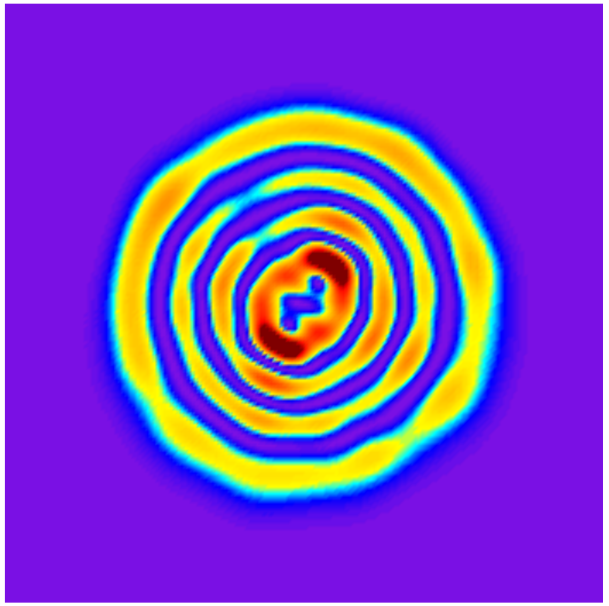
Output modes – LG_{33}



Input

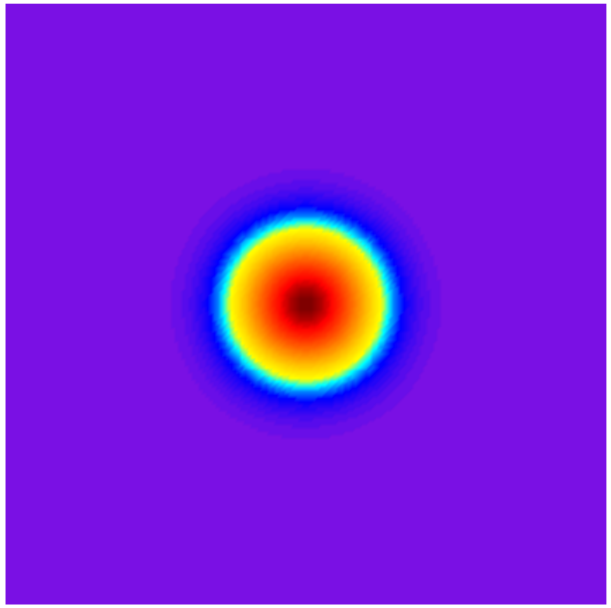


Reflected with ideal mirrors

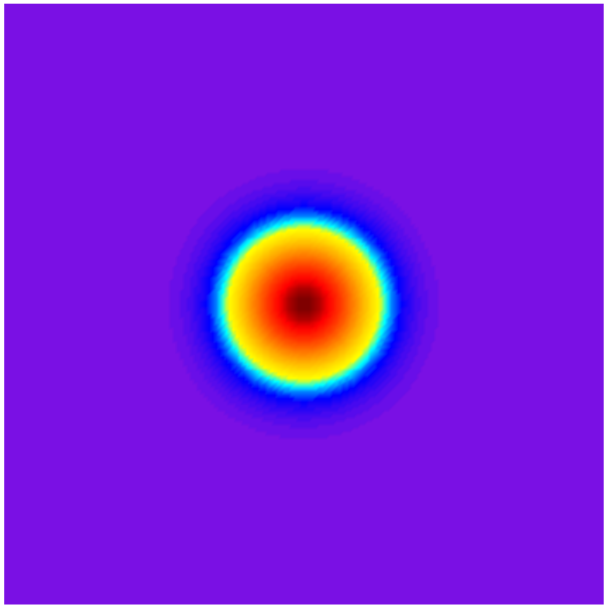


Reflected with real mirrors

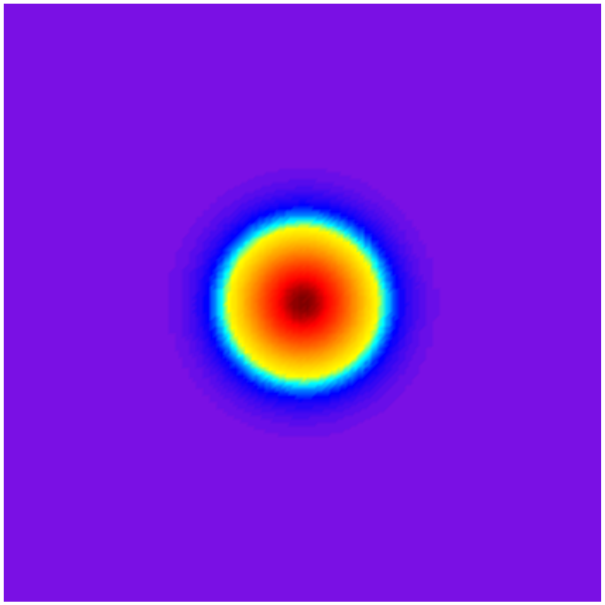
Output modes – LG_{00}



Input



Reflected with ideal mirrors

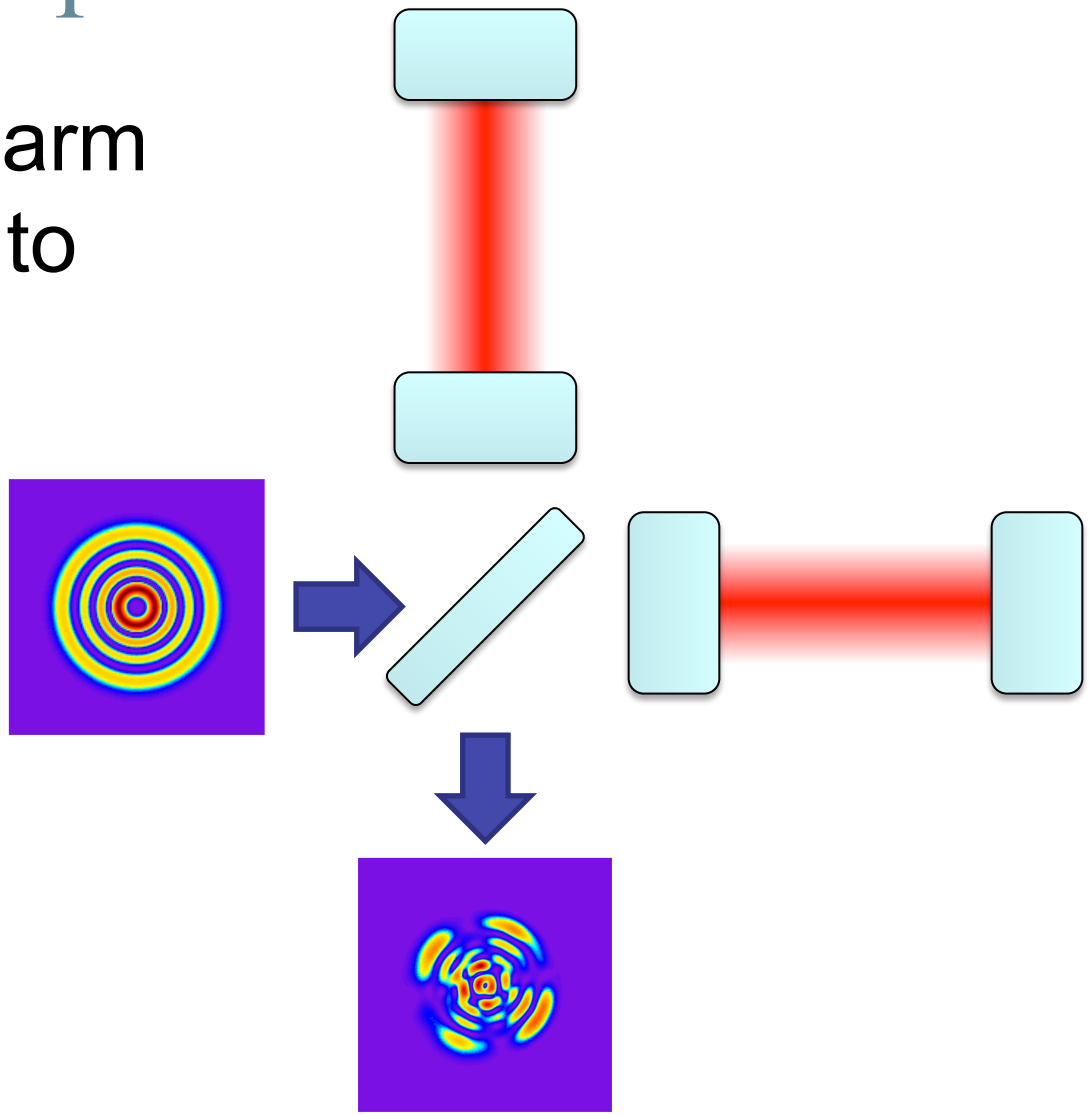


Reflected with real mirrors

Contrast defect - I

- Combine discrete arm cavity simulations to create IFOs

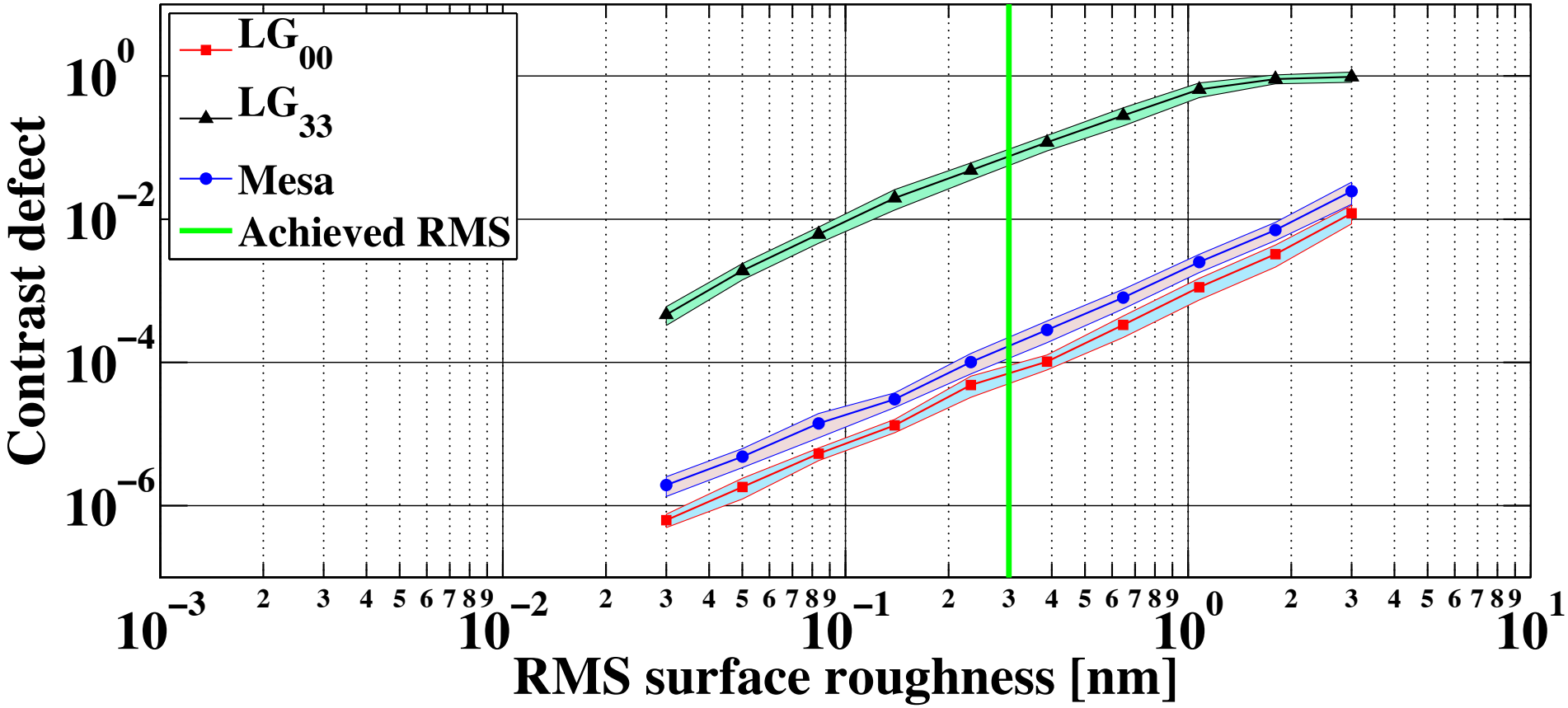
$$\begin{pmatrix} n \\ 2 \end{pmatrix}$$



- Estimate contrast defect

$$C = \frac{P_{AS}}{P_X + P_Y}$$

Contrast defect - II



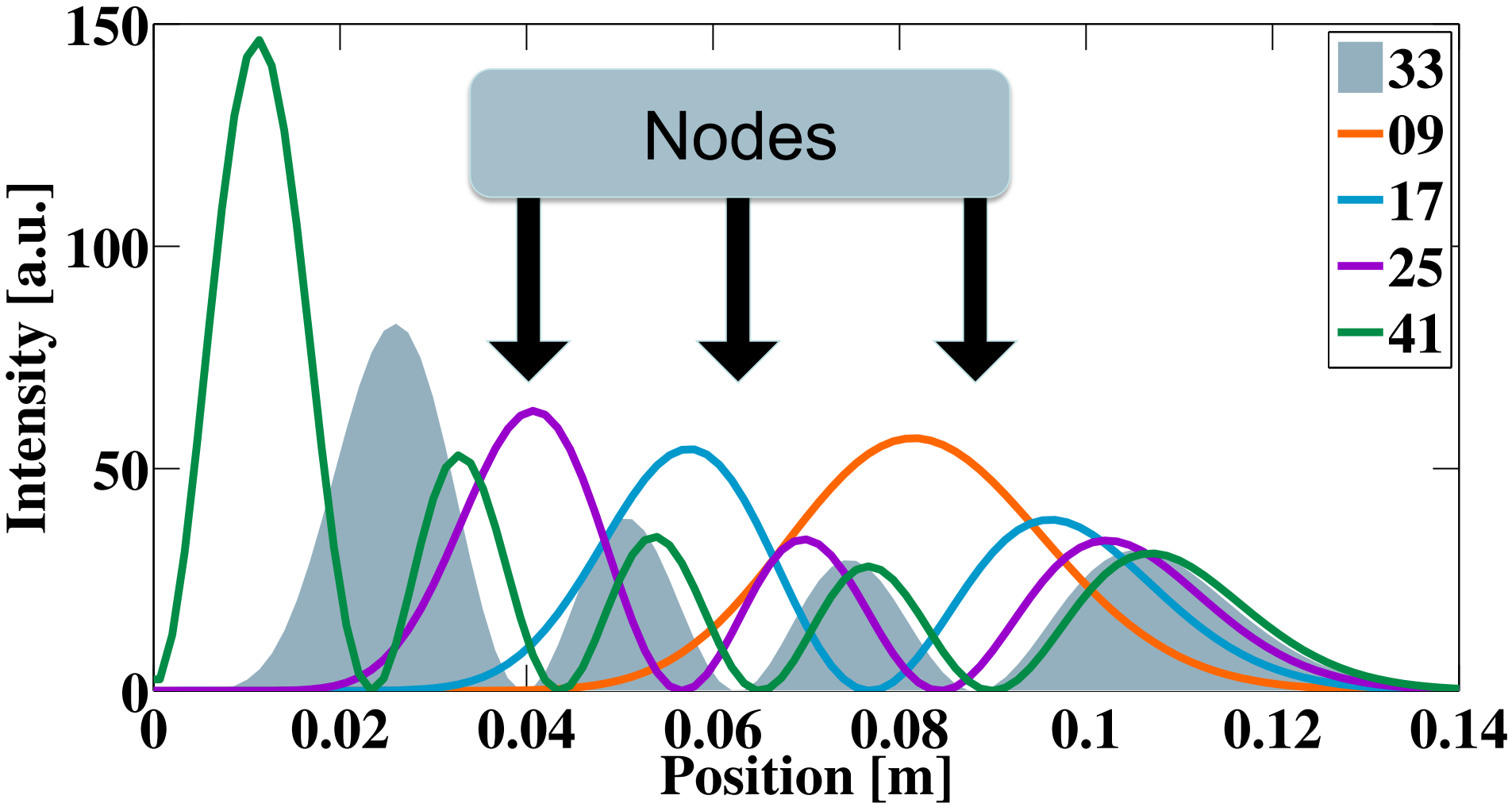
Mitigation – better polishing/ tuning

- Polishing needs to be around 10 times better to match Gaussian
  - State of the art not quite good enough
- Frequency tuning
  - Mirror imperfections break degeneracy
  - HOMs have discrete resonance frequencies
  - Tune f_{input} to optimise

Mitigation - rings

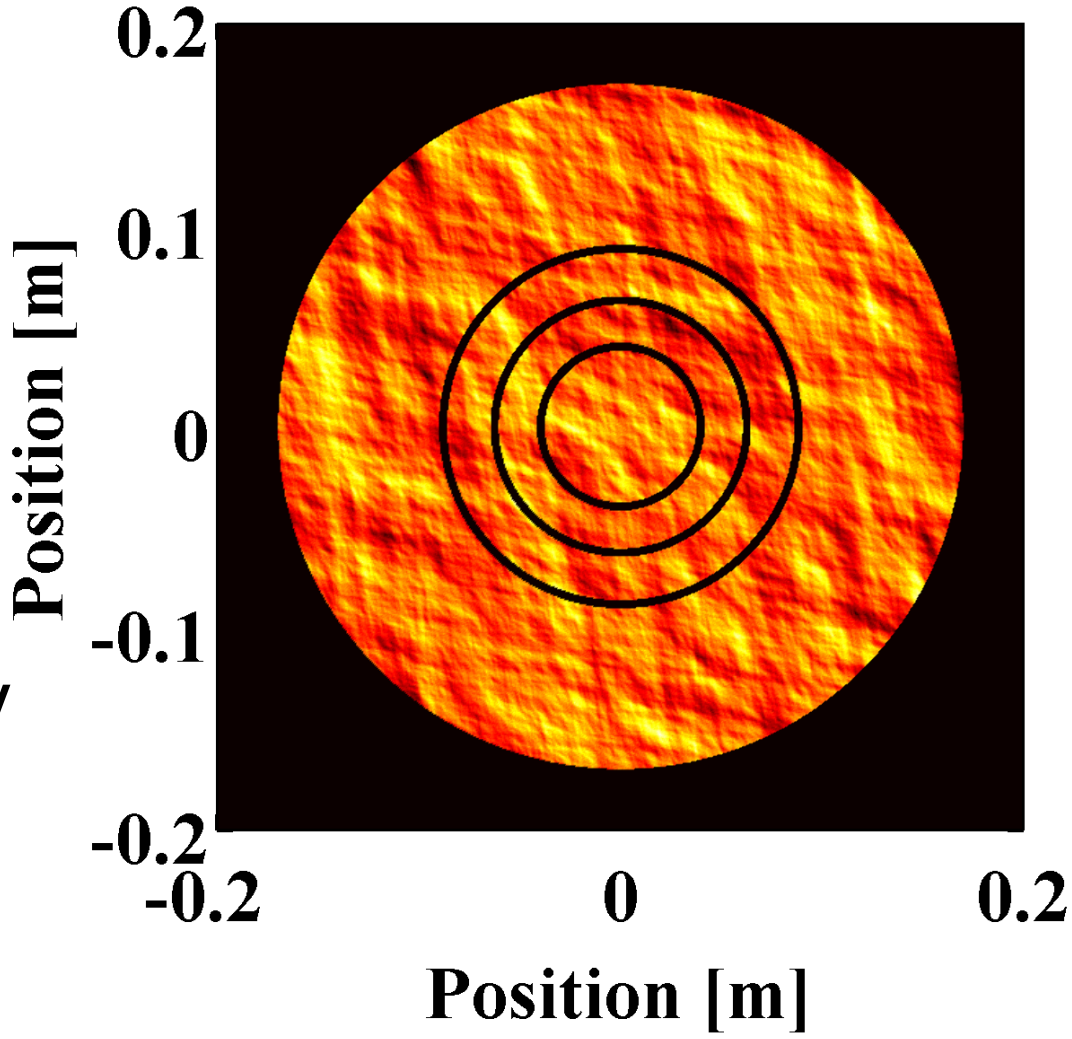
R. Glauber and W. Rueckner (Harvard Natural Sciences Lecture Demonstrations, Photo by Laura Wulf)

Degenerate modes

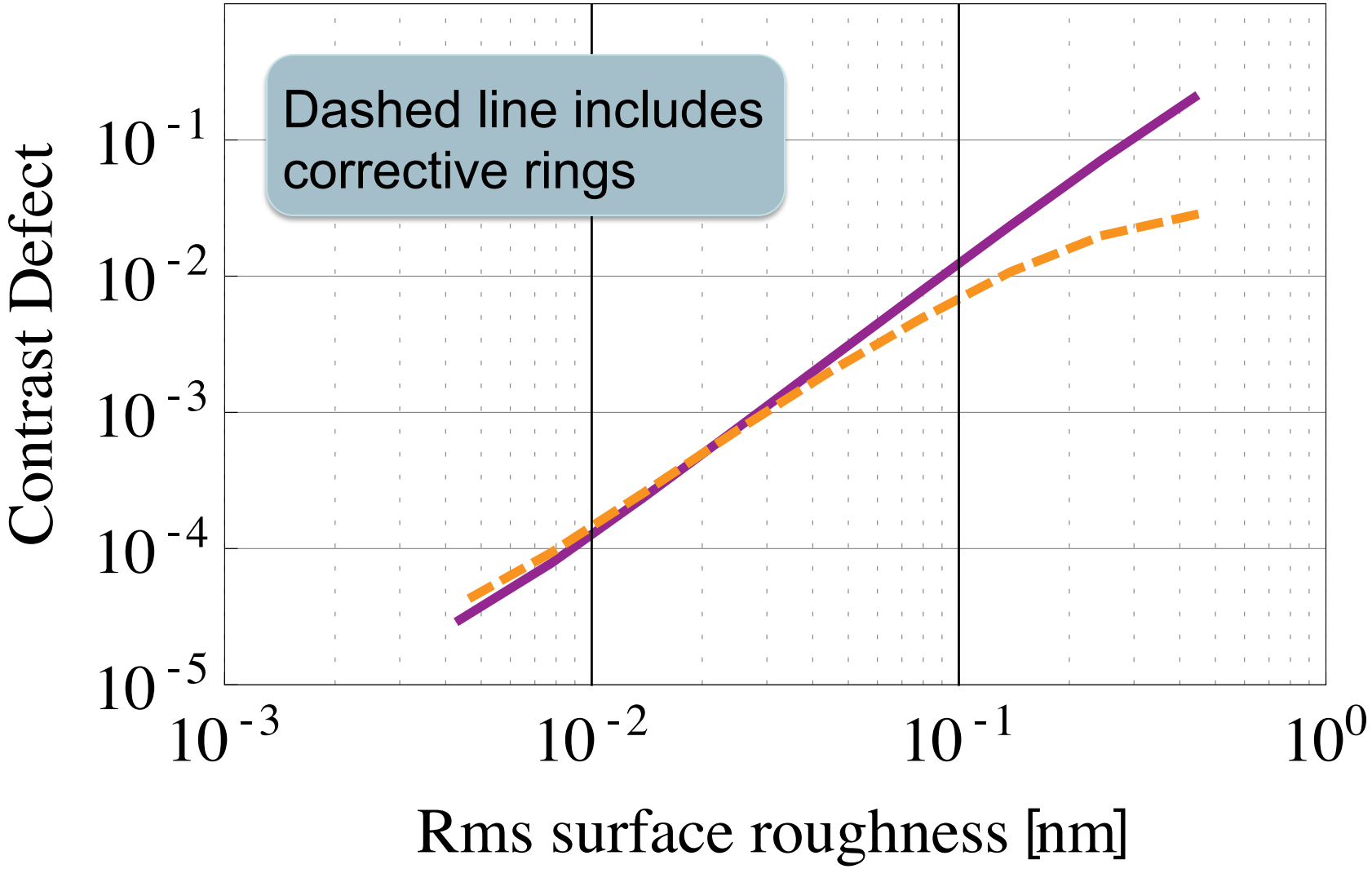


Mitigation - rings

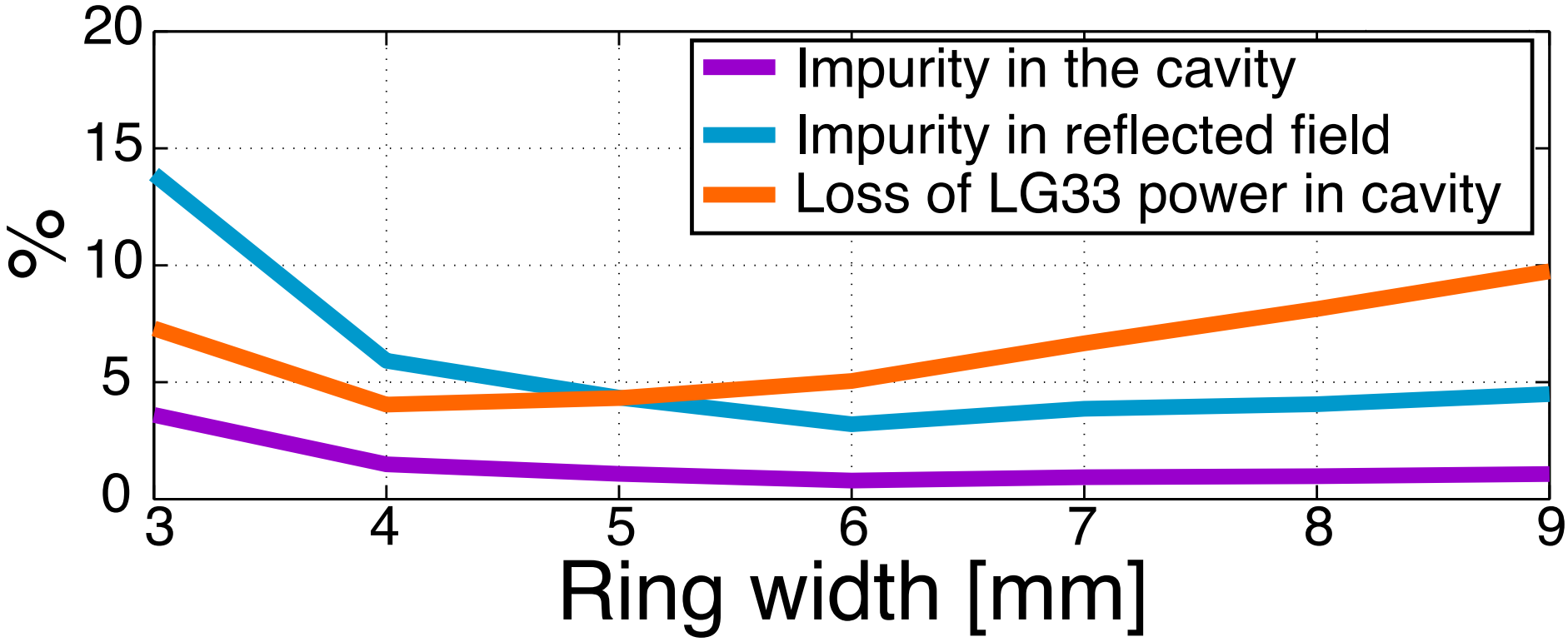
- Modify mirror at nodes of LG_{33} to `damp' other modes
- Add material or reduce reflectivity



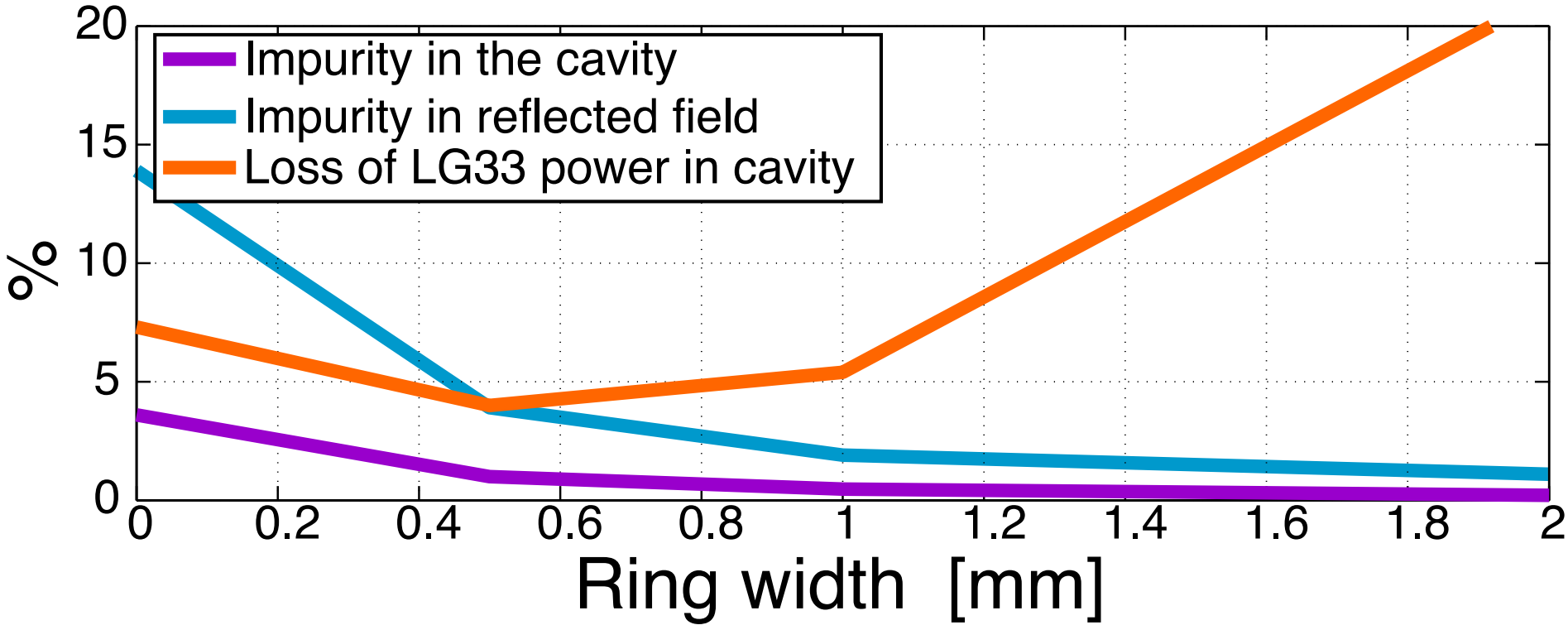
Mitigation – Rings (Hong)



Mitigation – Rings (Yamamoto)



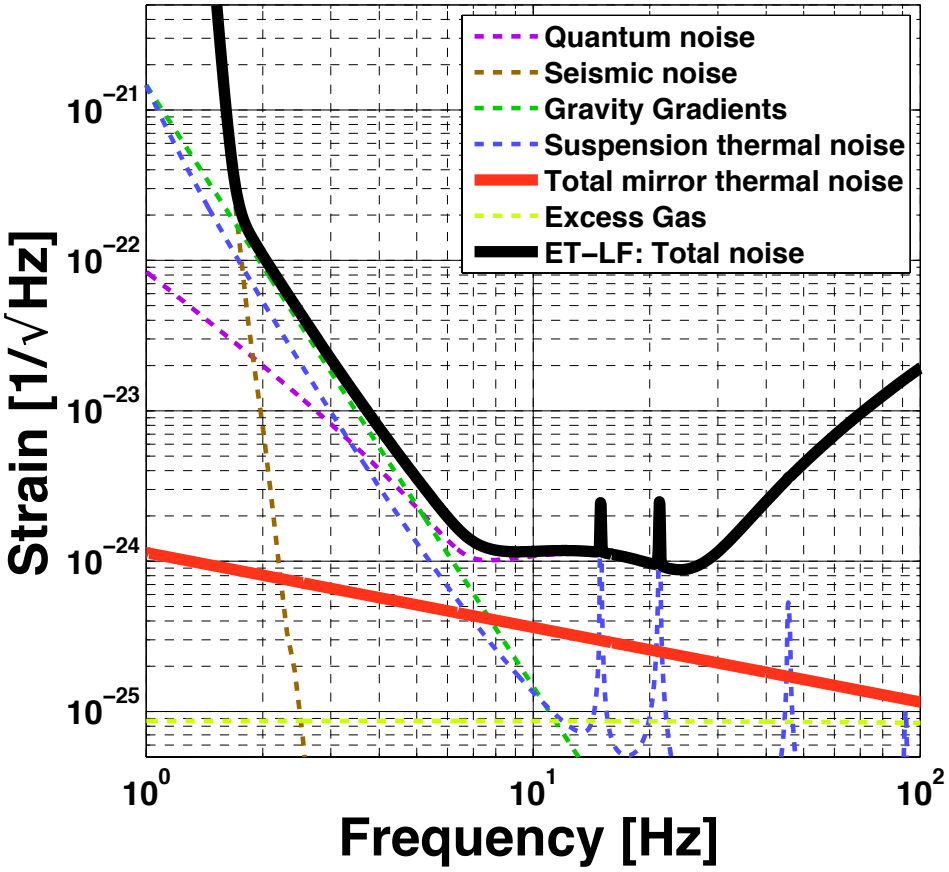
Mitigation – R=0 Rings (Yamamoto)

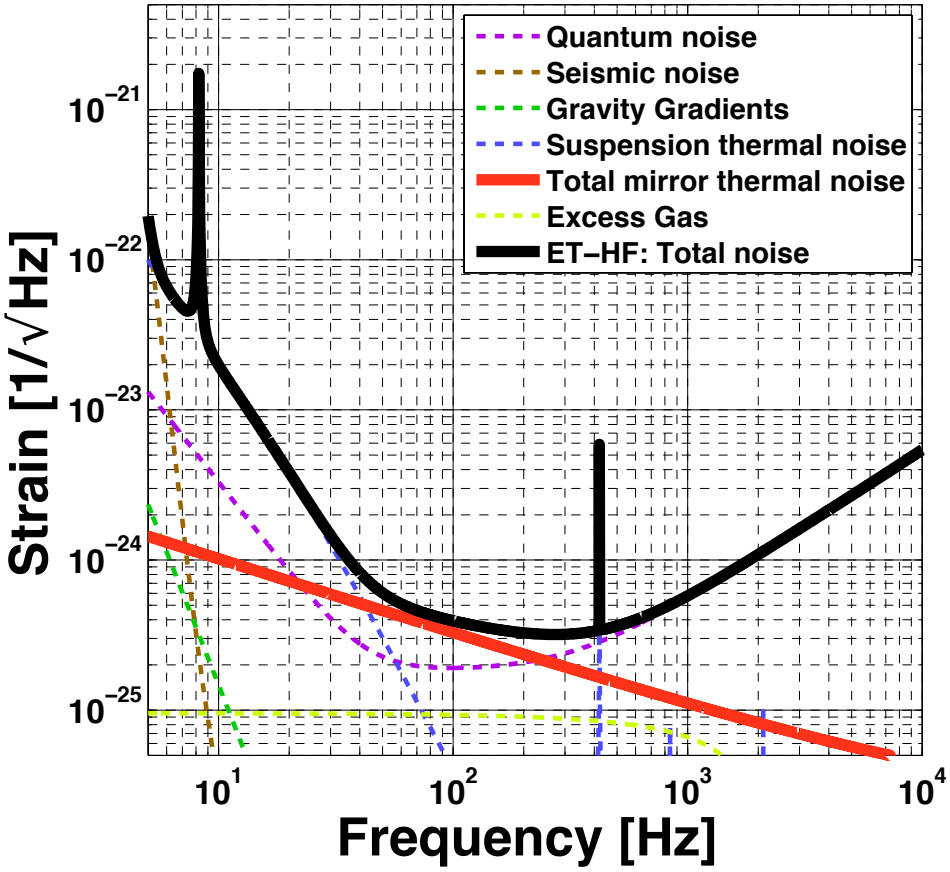


In short

- Due to mirror surface roughness, adopting LG_{33} beams in the near future will be extremely challenging

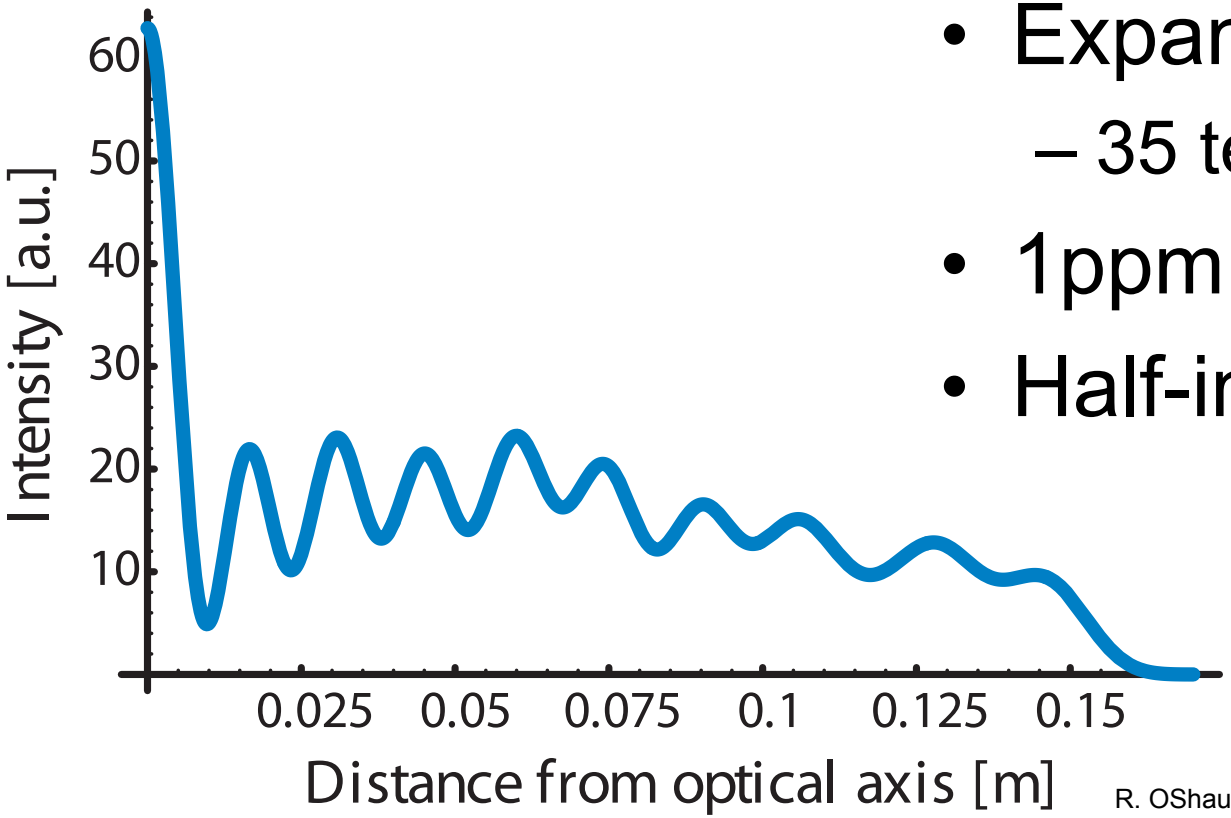
Designing the `ultimate' beam





Hild et al., Class. Quantum Grav. 28, 094013 (2011)

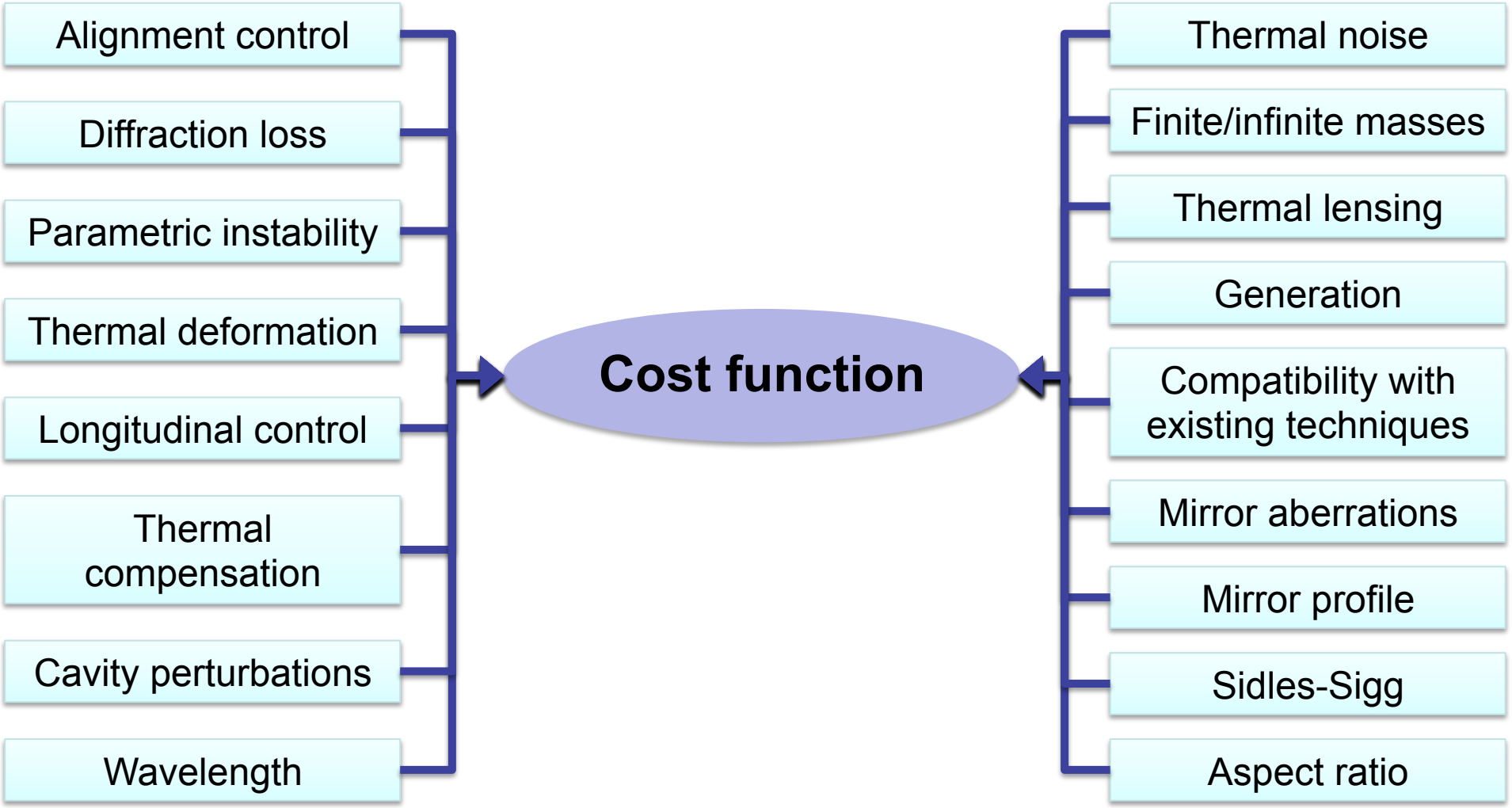
Designing the `ultimate' beam



- Lovelace scaling law
- Expansion in LG basis
  - 35 terms
- 1ppm per bounce
- Half-infinite mass

G. Lovelace, Class. Quant. Gravity 24, 4491 (2007).
R. OShaughnessy, S. Strigin, S. Vyatchanin, arXiv:gr-qc/0409050.

Optimisation parameters/constraints



Requirements

- Experience required to define weighting/ veto/constraints
  - What can polishers/TCS/control systems do?
    - What are critical parameters?
- Modular code with compatible input/output
  - Analytical/modal/FFT
- Clever optimisation – avoid local minima

Thoughts

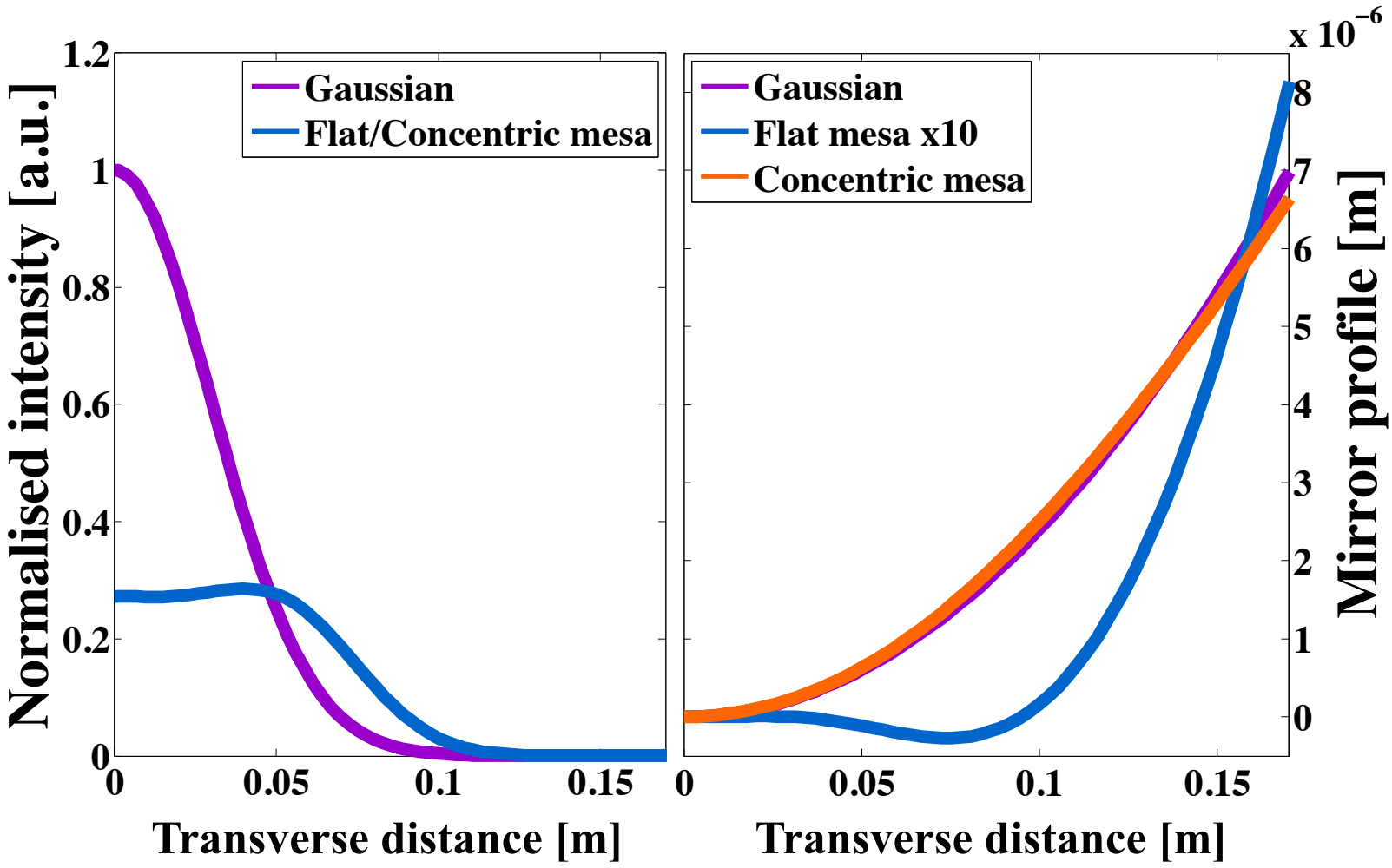
- Difficult problem – start small
- How much improvement is available?
- Other ideas
  - unstable cavities
  - delay lines
  - coating-free cavities

Summary

- Higher order LG beams appear to be hampered by mirror surface aberrations
- Efforts are ongoing to solve this problem
- Coating thermal noise will remain a significant problem in future detectors
- In the meantime we should think about methods of devising the optimal beam

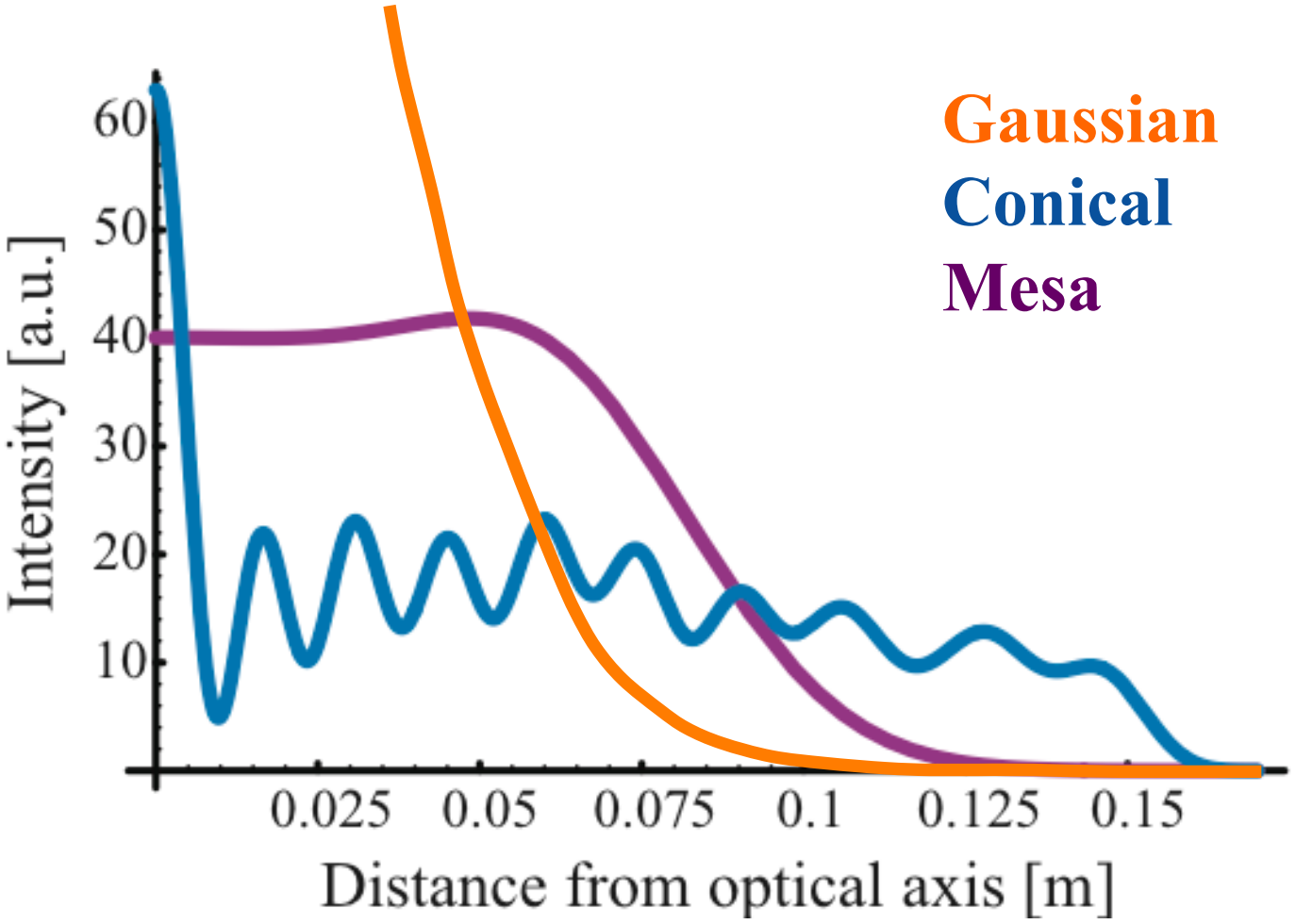
Contact details

New beam shapes for GW I - Mesa



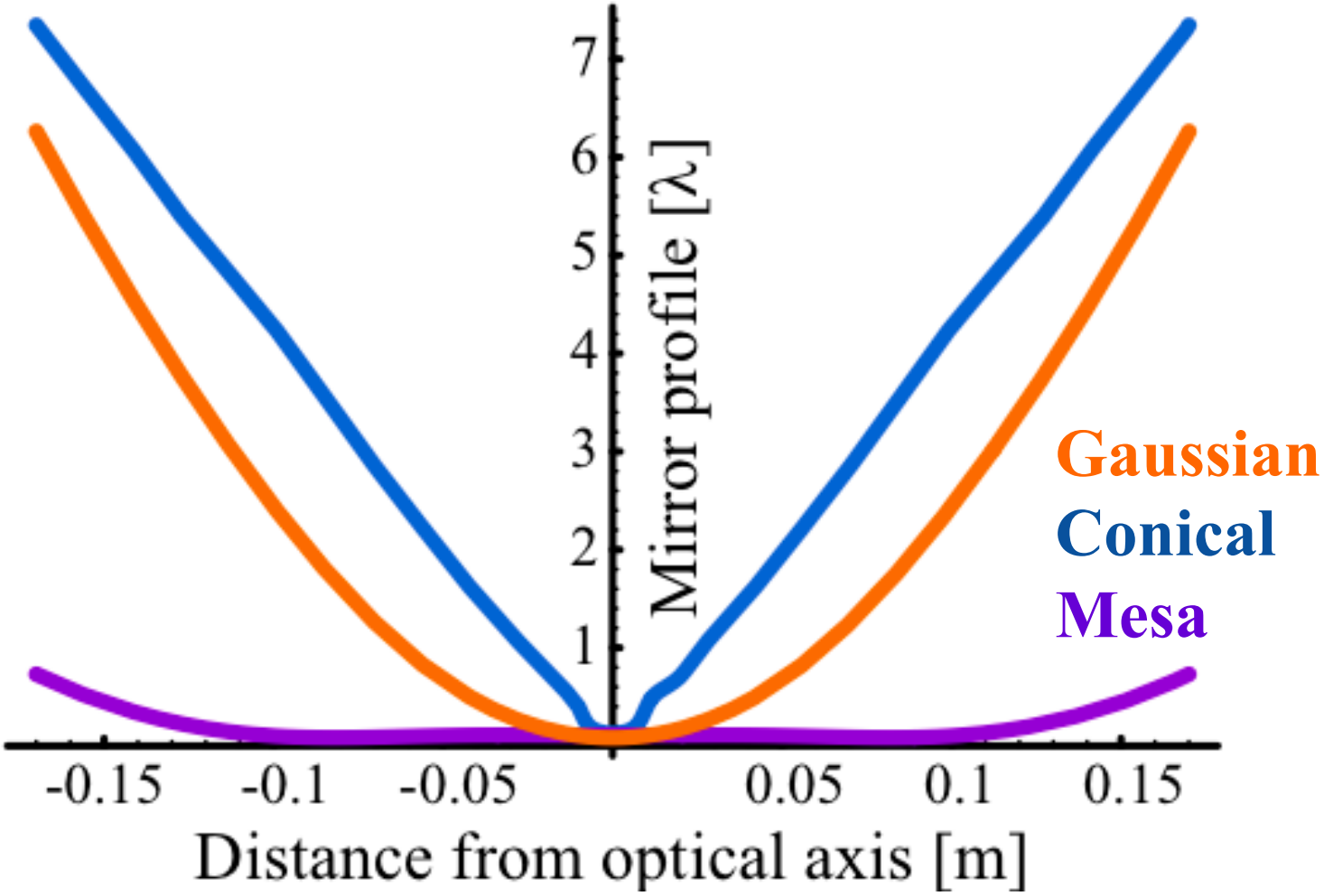
Bondarescu et al., Phys. Rev. D 74, 082003 (2006).

New beam shapes for GW II - Conical



Bondarescu et al., Phys. Rev. D 78, 082002 (2008).

New beam shapes for GW II - Conical



Bondarescu et al., Phys. Rev. D 78, 082002 (2008).

New beam shapes for GW - comparison

	Mesa	Conical	LG_{33}
Thermal noise	✓ ✓	✓ ✓ ✓	✓ ✓
Creation/coupling	✓ ✓	✗	✓
Perturbations	✗	✗ ✗ ✗	✓
Control	✓	?	✓ ✓
Thermal effects	✓ ✓	?	✓ ✓ ✓
Mirror shape	✗	✗ ✗	✓ ✓ ✓ ✓ ✓ ✓