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# Investigating the Effect of Lenses in a Long Interferometer Arm

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# Why should we go bigger?

$$h = \frac{\Delta L}{L}$$

- Gravitational wave – h
- Displacement noise – ΔL
- Displacement from gravitational wave increases
- Strain from noise decreases

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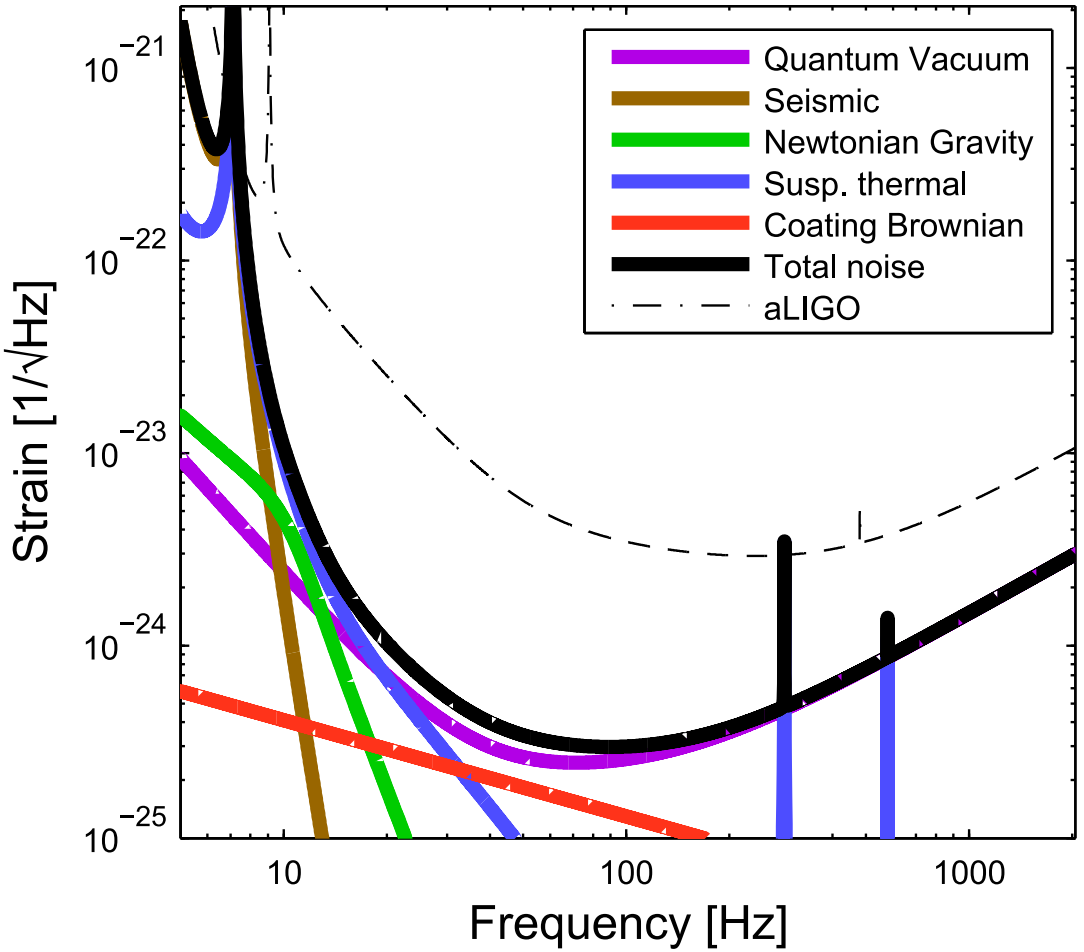
# Preliminary noise budget



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# What's the problem?

- Maintaining a narrow beam
  - » Large beam means larger optics and larger beam tube
  - » Expensive and difficult to manufacture
- Solution: Add lenses to beam tube

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# Lens problems

- Find a lens configuration
- Find the noise introduced by lenses
- Find a way to create the lenses

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# Finding a Lens Configuration

# Transverse mode spacing

- Examine transverse mode spacing (TMS) of cavity
- Cavity has eigenmodes $TEM_{mn}$
- Only $TEM_{00}$ should resonate
- Additional Gouy phase $(m + n + 1)\eta$
- Define $TMS = \frac{\eta}{2\pi}$
- $TEM_{mn}$ resonant if $(m + n)TMS \in \mathbb{Z}$

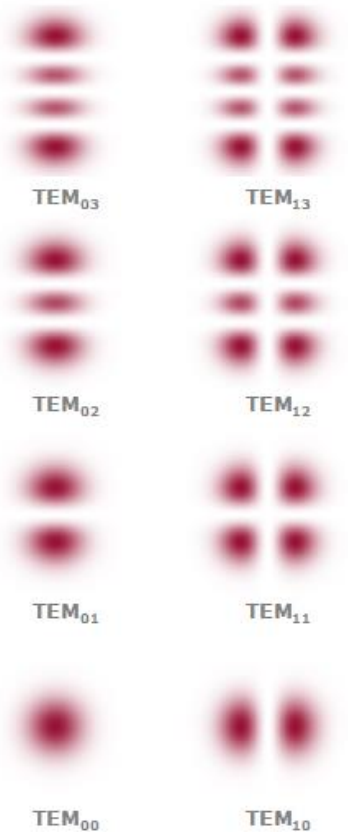


Image from RP Photonics Encyclopedia:
http://www.rp-photonics.com/resonator_modes.html

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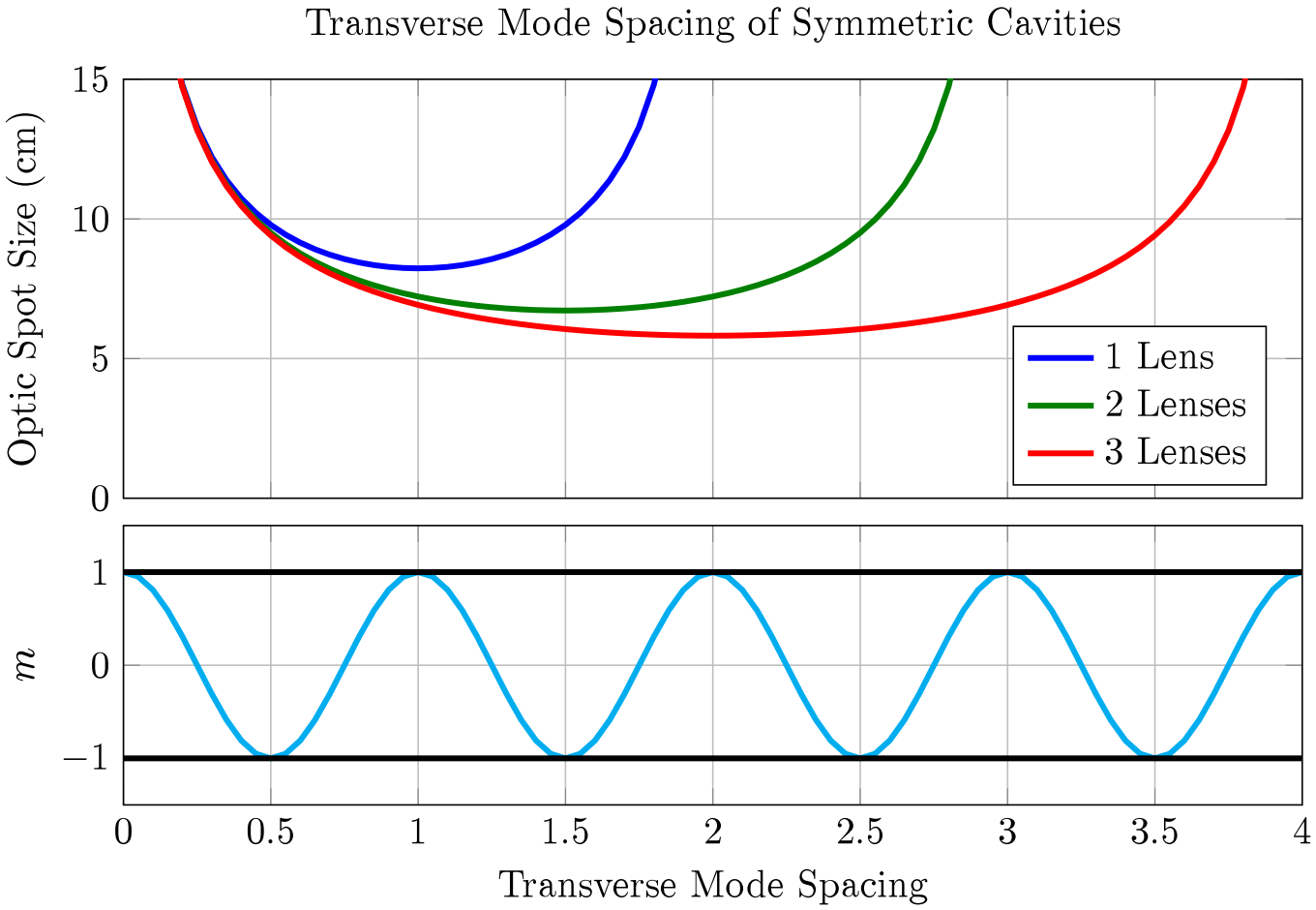
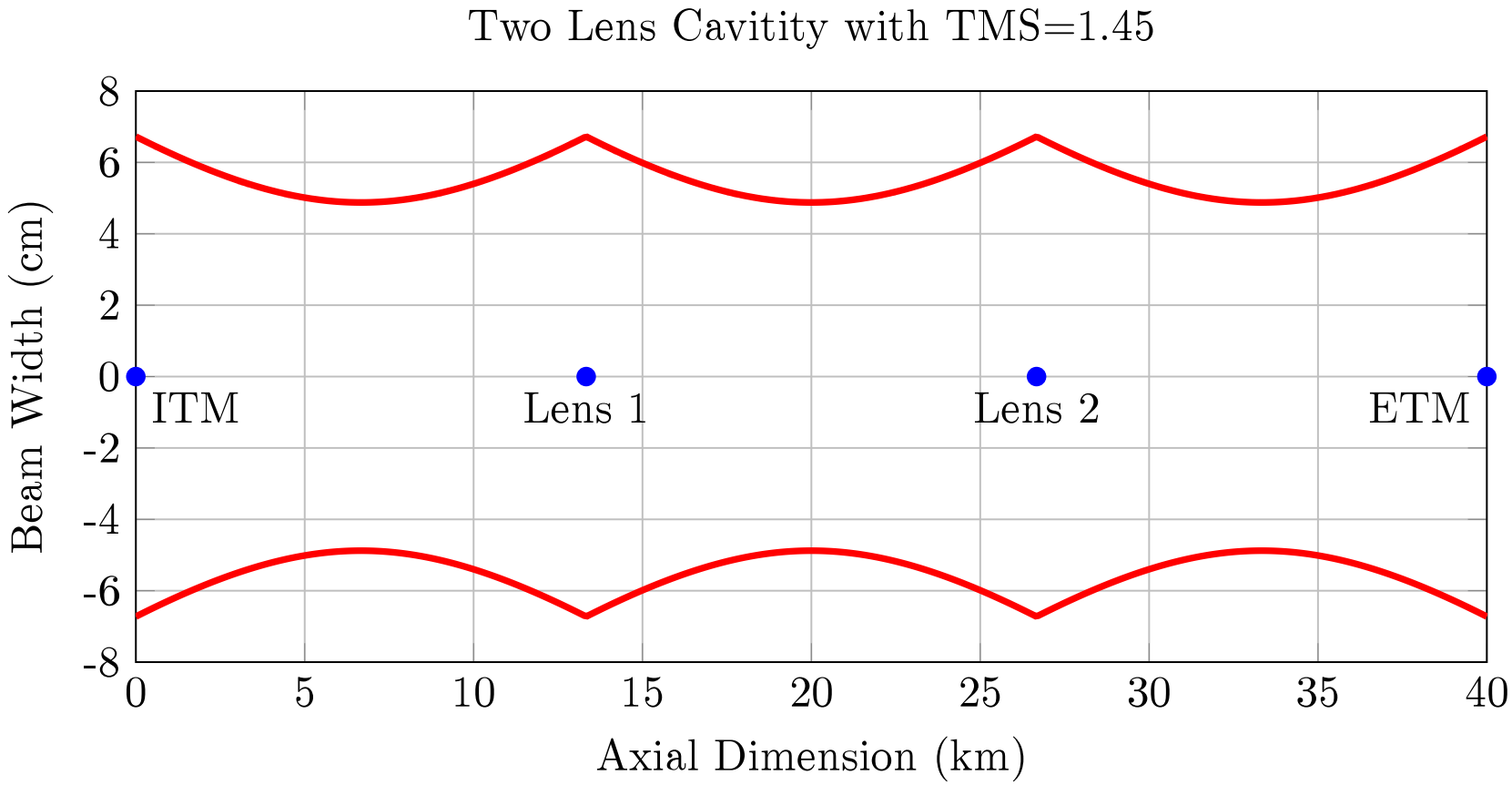
# Choosing a configuration

- Examine a symmetric cavity
- Length L
- N lenses evenly spaced
- Mirror radius of curvature R
- Lens focal length R/2
- Can solve for spot size w(L,N,TMS)

# Transverse mode spacing results



# A possible solution



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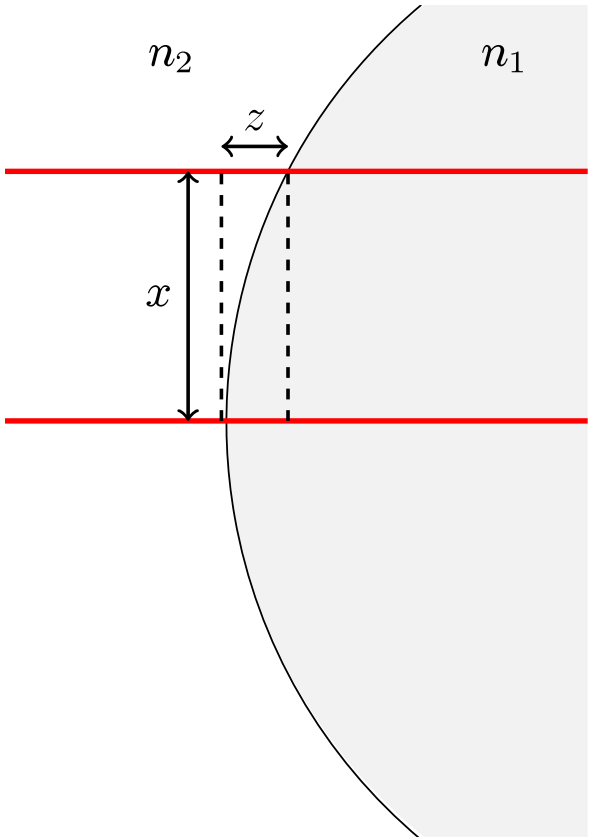
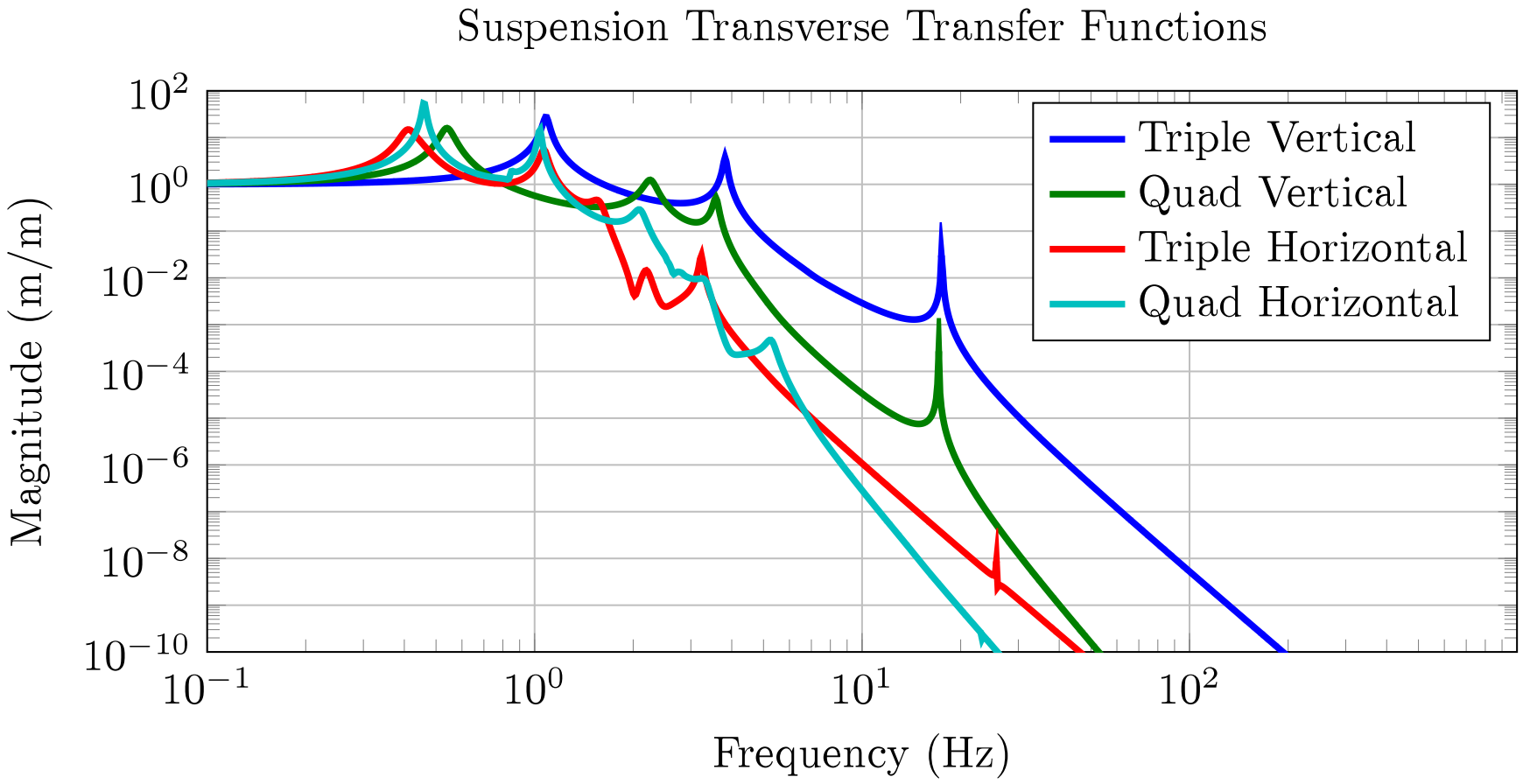
# Finding the Noise Introduced by the Lenses

# Transverse motion coupling

- An off-center beam travels through lens a shorter distance
- Lens and vacuum have different indices of refraction
- Lens motion changes optical path length



# Seismic motion damping



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# Transverse motion results

- Interested in noise at 10 Hz
- Want noise $\leq 10^{-24}\sqrt{Hz}^{-1}$
- Quad suspension: $h = 6.3 \times 10^{-26}\sqrt{Hz}^{-1}$
- Triple suspension will not be sufficient

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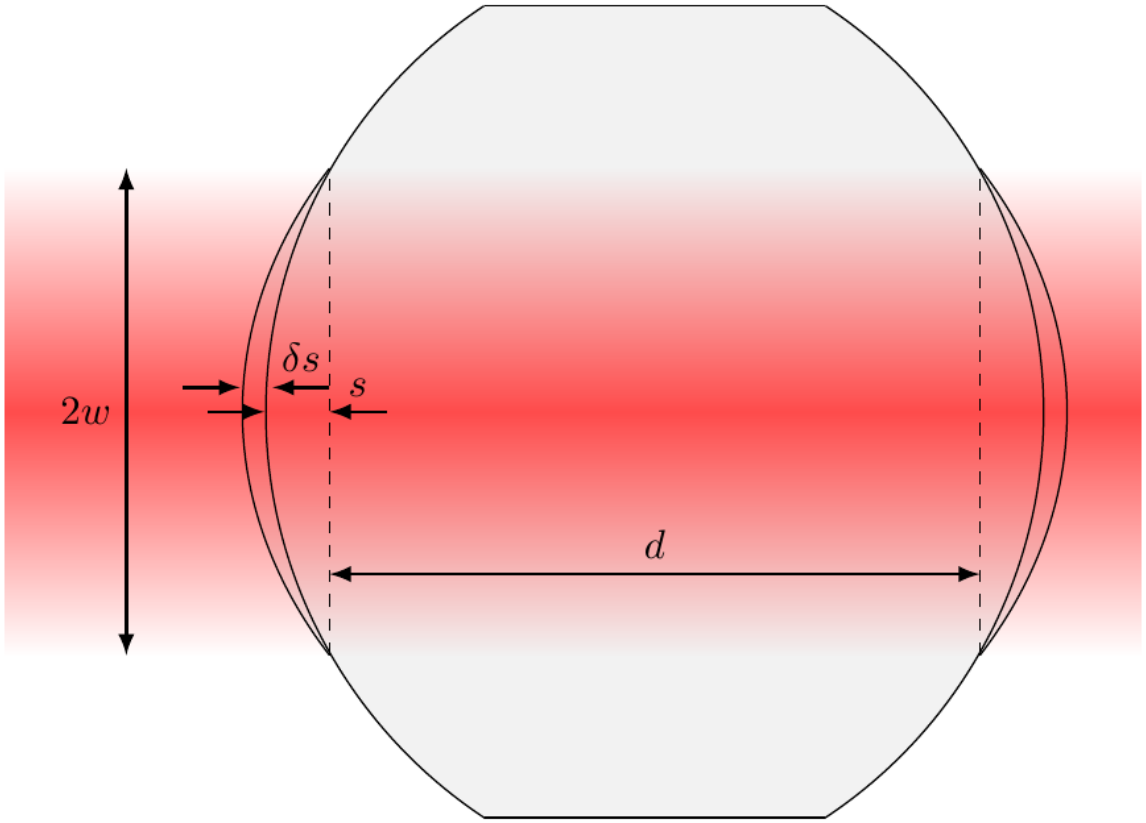
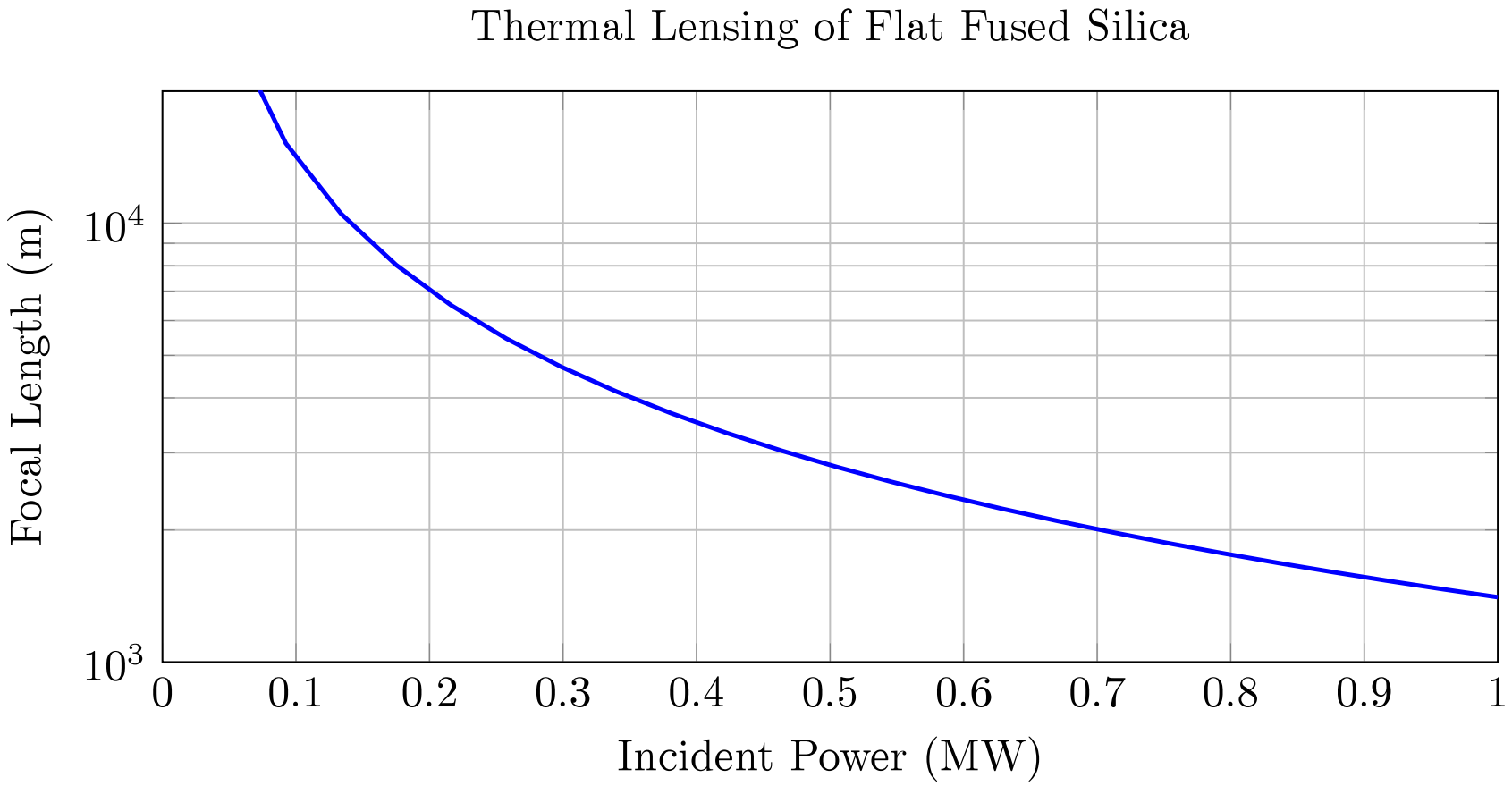
# How to Create the Lenses

# Thermal lensing



# Thermal lensing results



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# Conclusions

- A narrow beam can be propagated 40km with as few as 2 lenses
- Motion of the lenses will not be a limiting factor with a quad suspension system
- TCS will be required to reduce thermal lensing to the required focal lengths

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# Acknowledgements


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# Questions?