Advanced LIGO Test Masses and Core Optics

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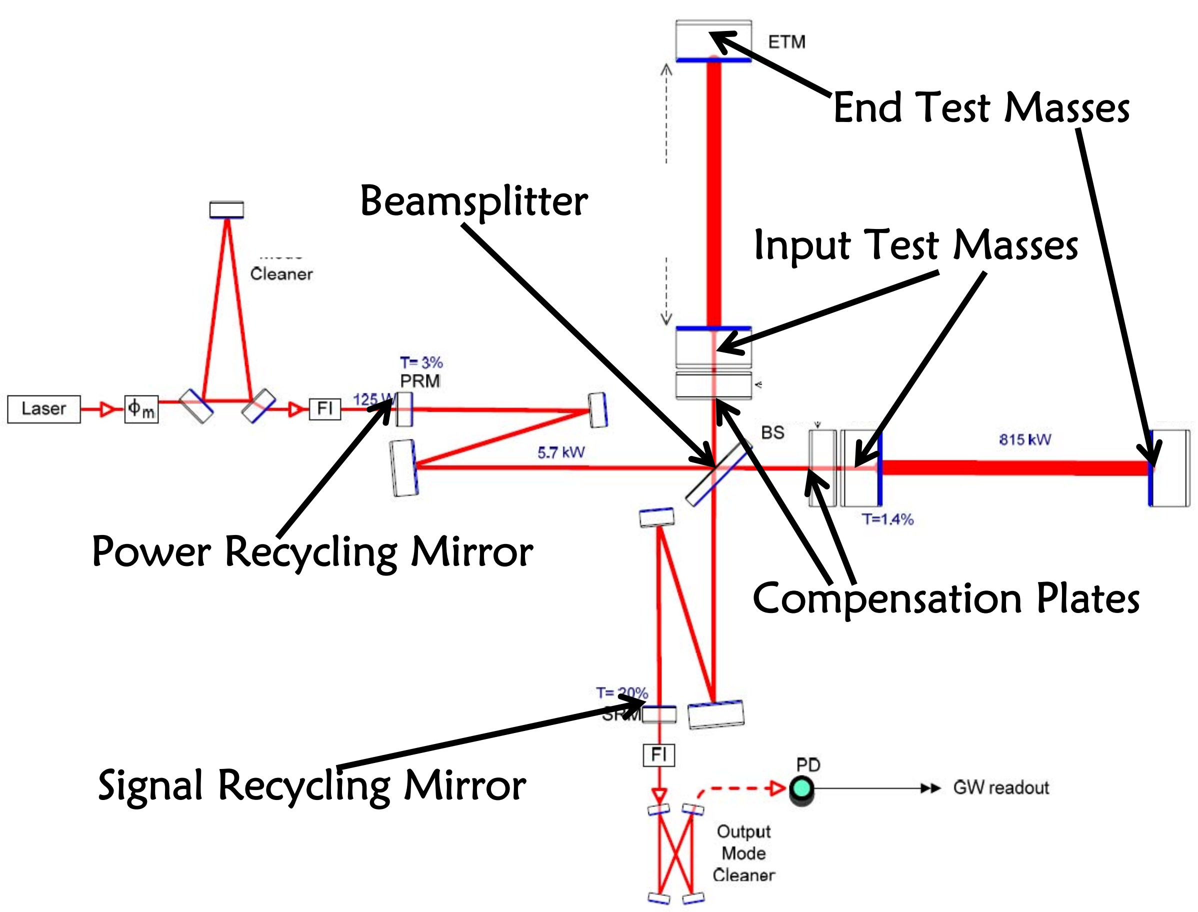
Optics Overview

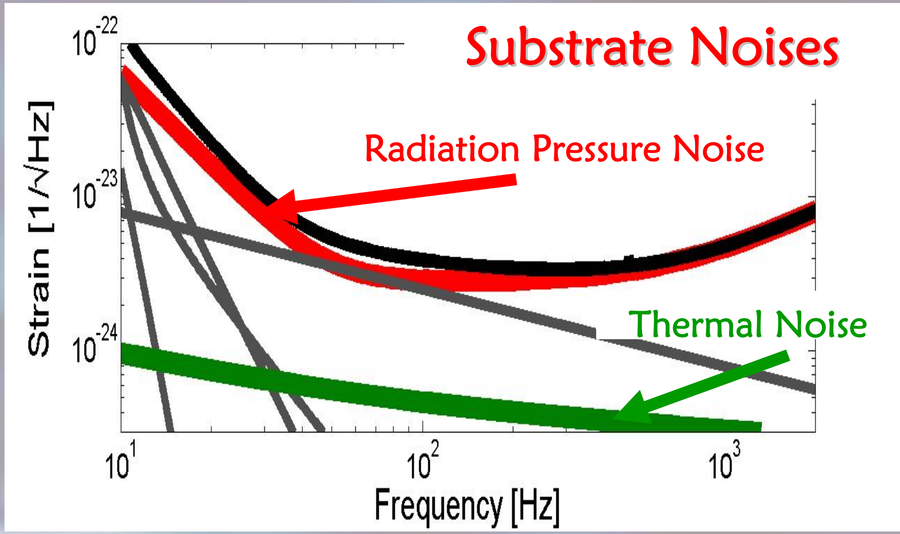
Core Optics

- Test Masses
  - –Input and End
  - –Define optical cavity
  - –Crucial to sensitivity
- Beamsplitter
- Compensation Plate
  - –Thermal lens control
- Power Recycling Mirror
  - –Increase optical power
- Signal Recycling Mirror
  - –Tune quantum noise



Advanced LIGO Optical Layout

Test Mass Substrate



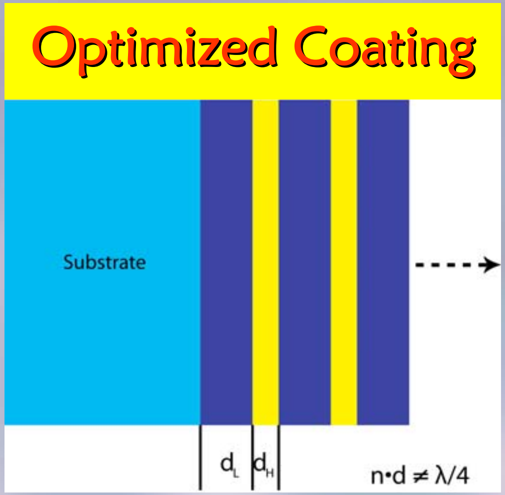
Silica

- Similar to Initial LIGO
- Thermal Noise
  - Technical noise source
- Different types for absorption
  - Very low: ITM, BS, CP
  - Low: Recycling mirrors
  - Average: ETM

aLIGO Silica Blank

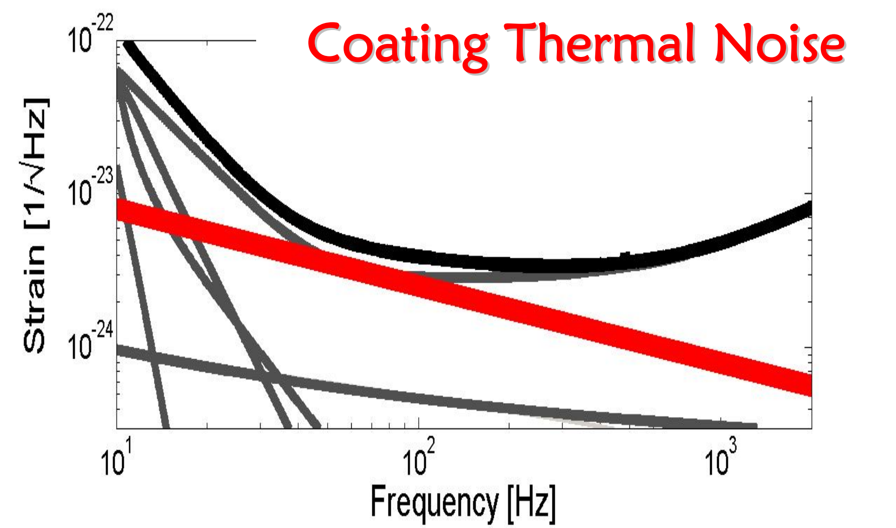
- Mass: 40 kilograms
  - Reduce radiation pressure noise
  - 4X as large as Initial LIGO
- 17 cm radius X 20 cm thickness
  - Practical to manufacture /suspend
  - Large beam, diffraction loss <2 ppm
  - Flats on side: suspension attachment

Test Mass Coatings: Thermal Noise



- High Index Material
  - Titania doped tantala
  - Lower ϕ than tantala in initial LIGO
  - Same *Y*, higher *n*
  - *dn/dt* not problematic
- Low Index Material
  - Silica, same as Initial LIGO
  - Low *ϕ, Y* well matched to substrate

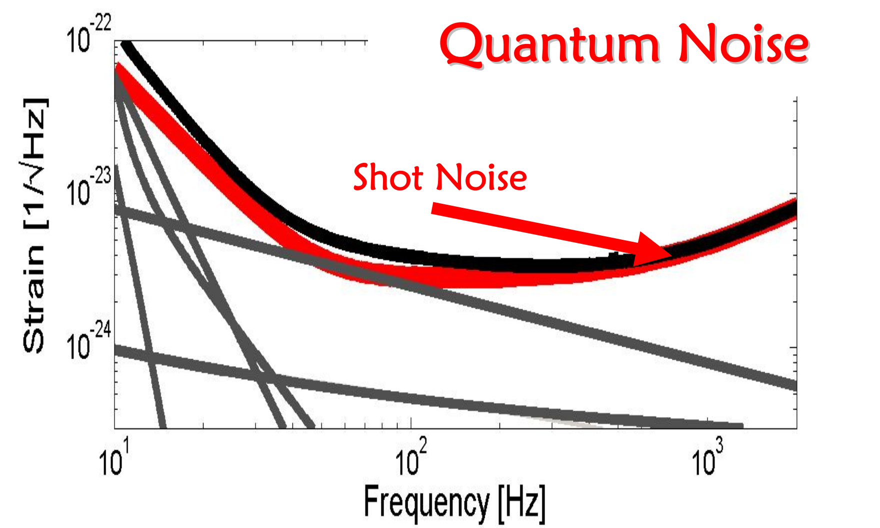
- Laser Spot Size
  - 5.5 cm on ITM, 6.2 on ETM
  - ~3 cm in Initial LIGO
  - Reduces thermal noise
- Optimized thickness
  - Reduce amount of high index material
  - Preserve reflectivity
  - Allows for dichroic behavior



Test Mass Coatings: Optical Properties

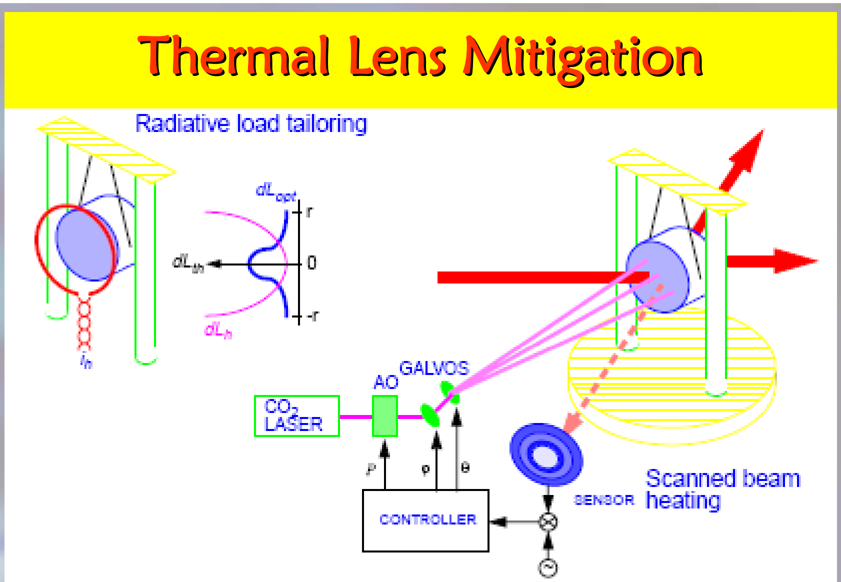
Initial LIGO Scatter

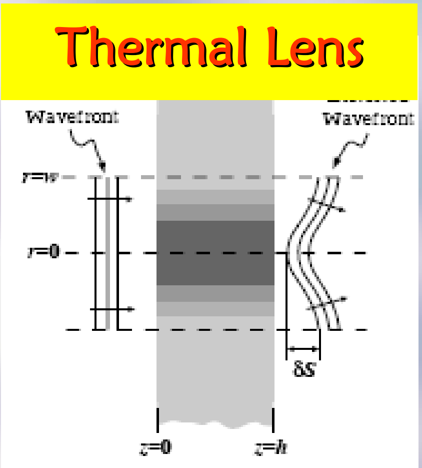
- Wavelength: 1.064 µm
  - Same as initial LIGO
  - Some efficacy at 532 nm for lock acquisition interferometer
- Scatter: < 10 ppm
  - Requires microroughness <0.16 nm RMS
  - Polish done with ion beam for figure control
  - 10- 70 ppm in initial LIGO, point scatterers
- ETM Transmission: < 6 ppm
  - Initial LIGO 12 ppm
  - Thicker coating than ITM
- ITM Transmission: 1.4 %
  - Initial LIGO 2.7%
  - Match between arms to 0.2%
  - Determines cavity pole frequency



Test Masses - Thermal Lensing

- Coating absorption: <0.5 ppm
  - ~ 1 ppm initial LIGO
- Cavity power: 800 kW
  - Initial LIGO 10 kW
- Substrate absorption: ~ 4 ppm
- Silica *dn/dT* ~ 10^{-5}
  - Large in Initial and Advanced

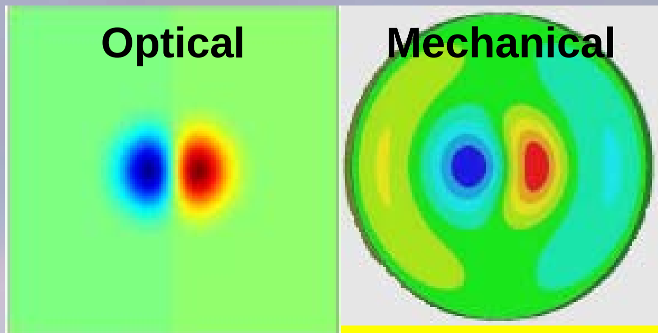




Thermal Lensing Mitigation

- Ring Heaters on Compensation Plate
  - Adds heat to outside rim
- Projected CO_2 laser
  - Similar to Initial LIGO
  - Adds heat where needed
  - Possible to scan laser for more controlled heating

Test Masses – Other Issues



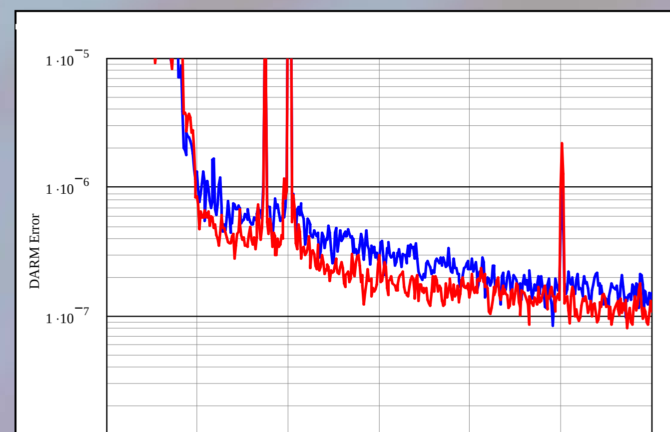
Overlapping Modes

Other Concerns

- Parametric instabilities
  - Control problems/lock loss
- Silicate bonding
  - Connection to suspension
- High optical power
- Non-Gaussian noise
  - Limiting for iLIGO searches

Charging

- Earthquake stops
  - Silica tipped, viton in iLIGO
- Electrostatic Drive (ESD)
  - Can be used as charge sensor
- Mitigation
  - UV, Ion guns, venting



Charging Noise in iLIGO

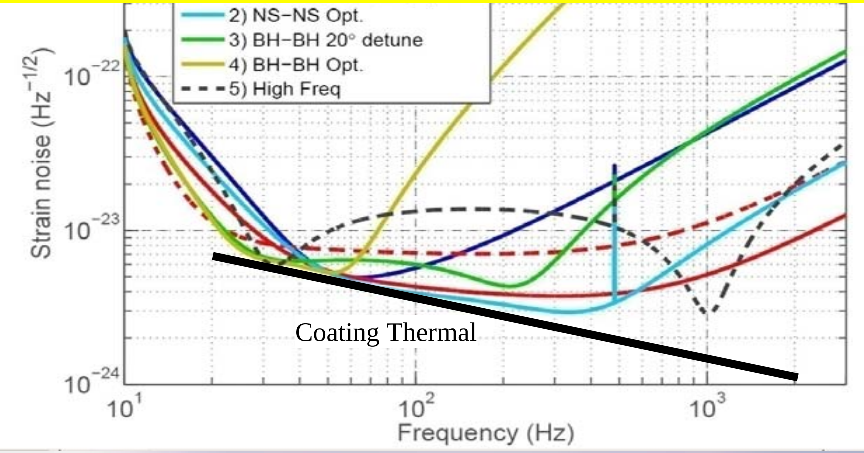
Other Core Optics

Beamsplitter

- 75 cm diameter X 6 cm thick
- Low absorption silica
- Beamsplitter ratio – 50/50
  - Equal power to 1%
- Wire loop suspension
- Tantala/silica coating

Beamsplitter

Different Signal Recycling Modes



Recycling Mirrors

- 15 cm diameter X 7.5 cm thick
- Power recycling mirror
  - Increases optical power
- Signal recycling mirror
  - Tune optical noise by changes in transmission and position

Advanced LIGO Core Optics Status

- All silica blanks have been received
- Polishing in progress on all core optics
- Coating in progress on test masses
  - ITM coating design approved, coating to start at LMA, Lyon, France
  - ETM coating design in progress at LMA
  - Other core optics to be coated at CSIRO, Sydney, Australia
- Connection to silica suspensions being tested
  - LASTI prototype at MIT
  - Silicate bond and welding
- Metrology to be done at Caltech & coating vendors
- Delivery to sites begins winter 2011

Comparison to Other 2nd Generation Detectors

Advanced Virgo

- Similar to Advanced LIGO
- Different silicate bond geometry

Large Cryogenic Gravitational Telescope

- Sapphire masses: 30 kg
- Cryogenic: 20 K
- Tantala/Silica coatings

GEO HF

- Focus on high frequency
- 14 kg test masses
- Tantala/Silica coatings
- Small beam (0.8 and 2.5 cm)
- Signal recycling 1st generation

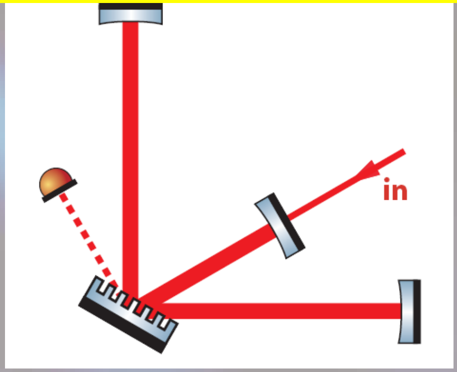
Third Generation Ideas

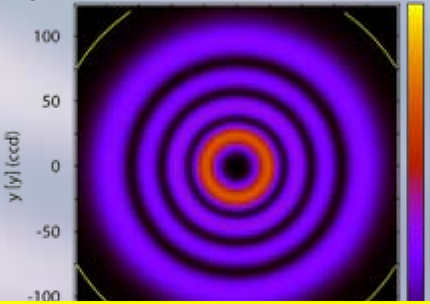
Thermal noise

- New substrates
  - Sapphire, silicon
- New coating materials
- Beam shaping
  - Mesa, Gauss-Laguerre
- Khalili cavities
- Change wavelength
  - Thinner coating
- Corner reflectors
- Cryogenics

Sapphire Optic

Diffractive Beamsplitter





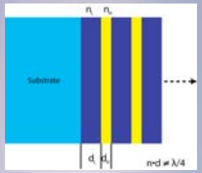
Gauss-Laguerre Mode

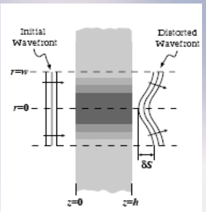
Quantum Noise

- Diffractive optics
  - All reflective
  - Higher optical power
  - Lower shot noise
- Larger substrates
  - Lower Heisenberg uncertainty
  - Lower radiation pressure noise

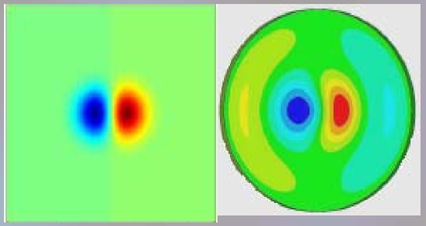
Conclusions

- Advanced LIGO test mass low noise design
  - Larger mass for radiation pressure
  - Low absorption/scatter for shot noise
  - Improved coatings for thermal noise

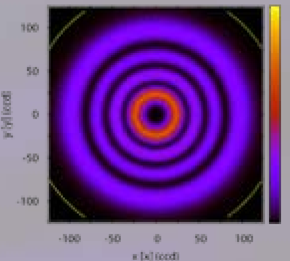




- Concerns for test masses
  - Thermal lensing
  - Charging
  - Parametric instability
  - Non-Gaussian noise, silicate bonding, high power, etc.



- Other core optics also have strict optical requirements
- All Advanced LIGO core optics being made
- Other designs in other 2nd generation detectors
- Research in progress for 3rd generation ideas



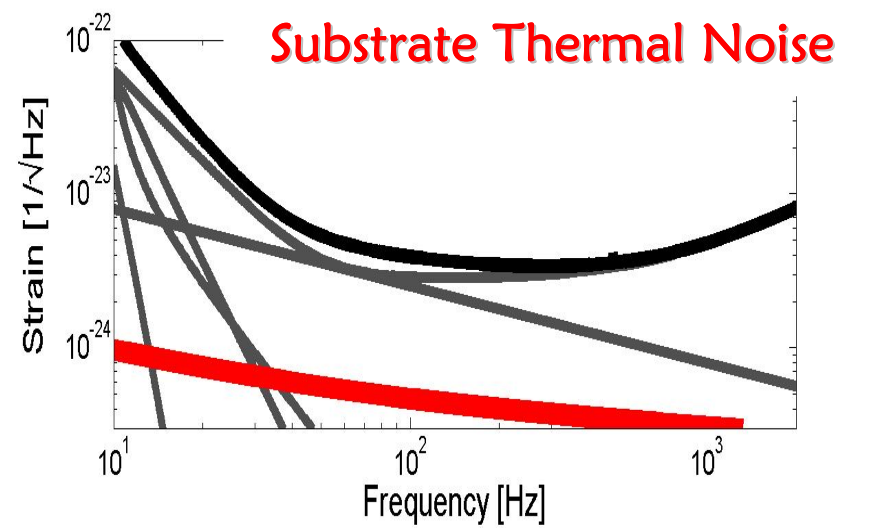
Optics Issues

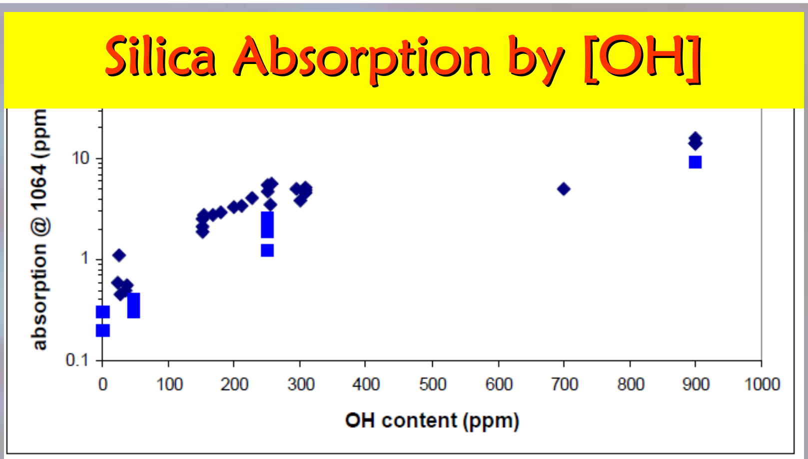
- Thermal Noise
  - Substrate
  - Coating
    - Material
    - Design
  - Spot Size
  - Temperature
- Thermal Lensing
  - Absorption
  - Optical Power
  - Mitigation
- Optical Properties
  - Polish and Scatter
  - Spot Size and Diffraction
  - Transmission Matching
- High Power
  - Parametric Instabilities
  - Damage
- Miscellaneous
  - Charging
  - Connection to Suspension
  - Non-Gaussian Noise

Test Mass Substrate Material

Silica

- Same as Initial LIGO
  - Experience, availability
- Thermal Noise
  - Technical noise source
  - Brownian: Model of mechanical loss
  - Thermoelastic: Depends on well known parameters



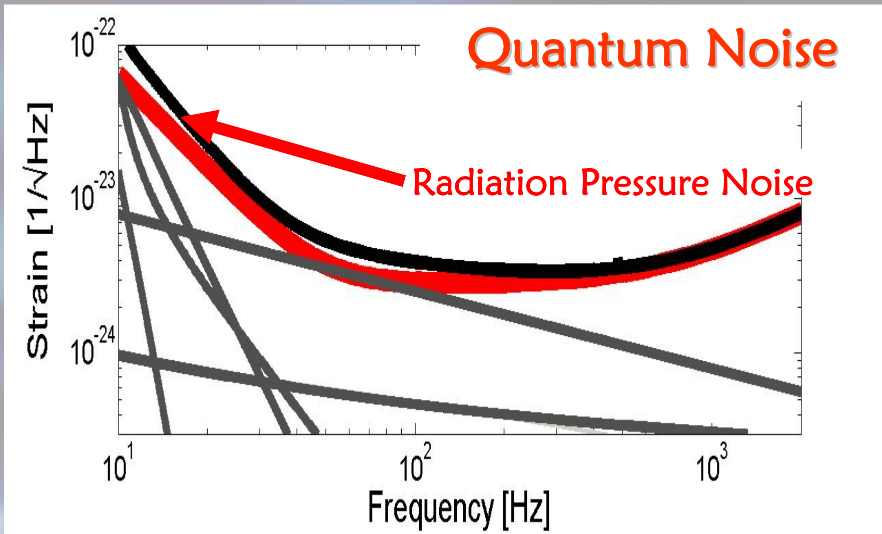


Types

- Heraeus 3001 Low OH
  - ITM, BS, CP
  - Absorption < 0.2 ppm/cm
- Corning 7980 0C
  - Recycling Mirrors
- Corning 7980
  - ETM

Test Mass Geometry

- 40 kg mass
  - Reduce radiation pressure noise
    - Reduce Heisenberg uncertainty
  - 4X as large as Initial LIGO
- 17 cm radius X 20 cm thickness
  - Practical to manufacture /suspend
  - Large beam
    - diffraction loss <2 ppm
  - Flats on side: suspension attachment



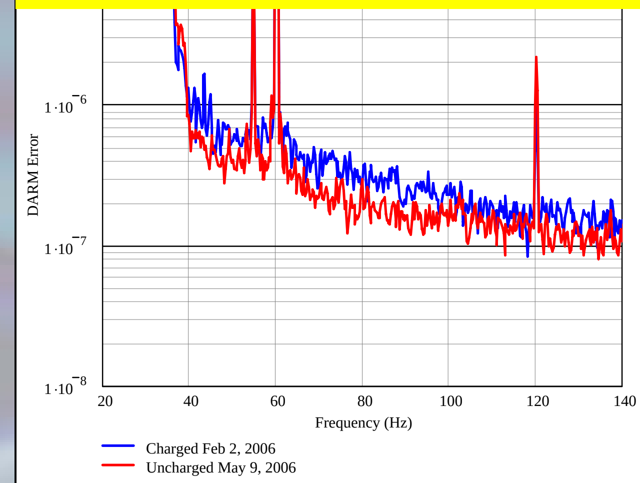
aLIGO Silica Blank

- Radius of curvature
  - ~2 kilometers
  - 7 km (ITM), 15 km (ETM) in Initial LIGO
- Wedge angle
  - <0.1° on back side
  - Back reflected beam out of optical path
  - Reflected beams used as pickoff

Test Masses – Charging

- Source of low frequency noise
- Earthquake stops
  - Silica tipped
  - Viton in initial LIGO
  - Reduces charge transfer
- Electrostatic Drive (ESD)
  - On compensation plate
  - Can be used as charge sensor
  - Possible interactions with charge

Charging Noise in iLIGO



Advanced LIGO ESD

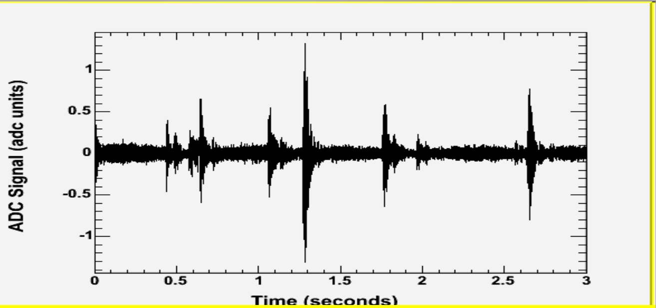
Charge Mitigation

- Nothing in Initial LIGO
- Ultraviolet light
  - Increased coating absorption
- Low energy ion gun
- Venting – air, argon, etc

Test Masses – Other Issues

Parametric Instabilities

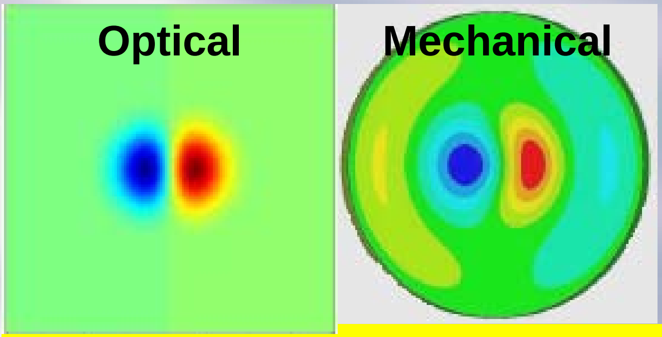
- Exchange of energy between optical and mechanical modes
  - Overlap of mode shapes
- Control problems /lock loss
- Mitigation being studied



Glitch Noise in iLIGO

Other Concerns

- Silicate bonding
  - Connection to suspension
  - High ϕ but far from beam
- High optical power
- Non-Gaussian noise
  - Limiting for iLIGO searches
  - Coating defects, thermal stresses, mechanical stress in bonds, etc.



Overlapping Modes