Mechanical Loss of Epoxies

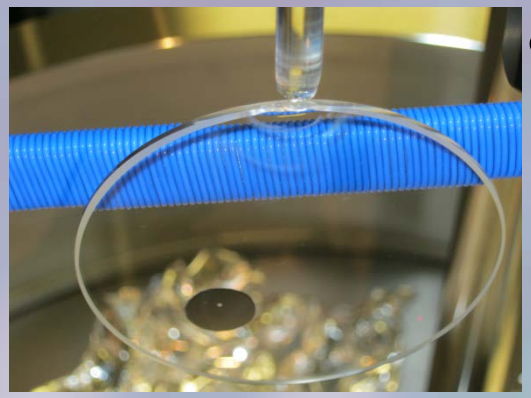
Gregory Harry

Department of Physics, American University

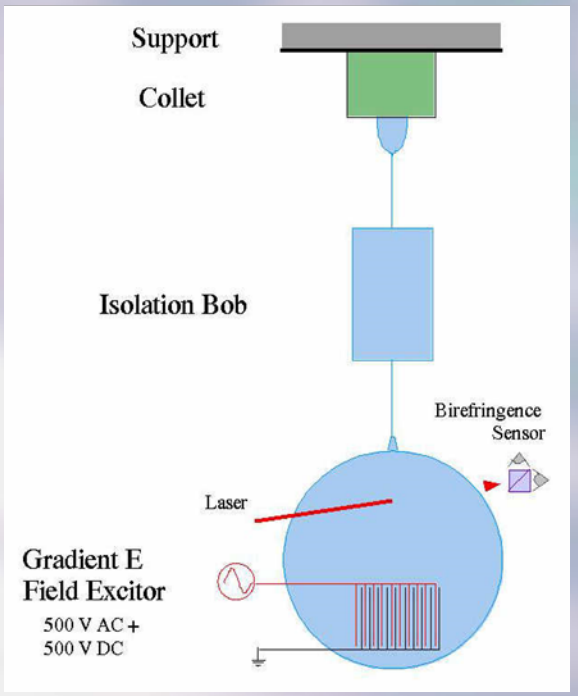
May 20, 2014

G1400597

LIGO Q Measuring Technique



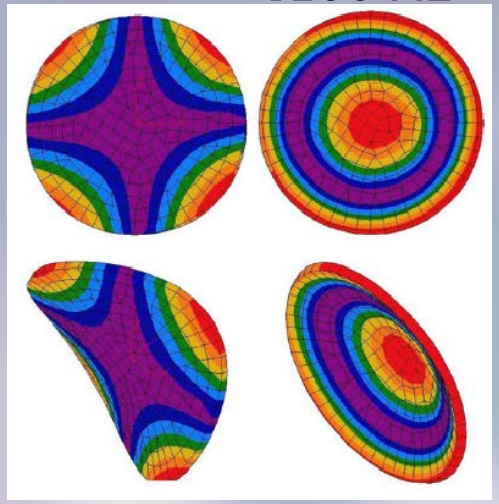
- Epoxy applied to 3 inch fused silica disk sample
  - Thin disk 0.5 inch diameter
  - 1.75 cm from center of large disk
  - 100 μm thick silica disk on top



- Welded to silica fiber/bob isolation
- Suspended in vacuum
- Excite normal modes using comb capacitor
- Modes at 2.7 – 10 kHz
  - Some high frequency pure shear modes

Finite Element Modeling

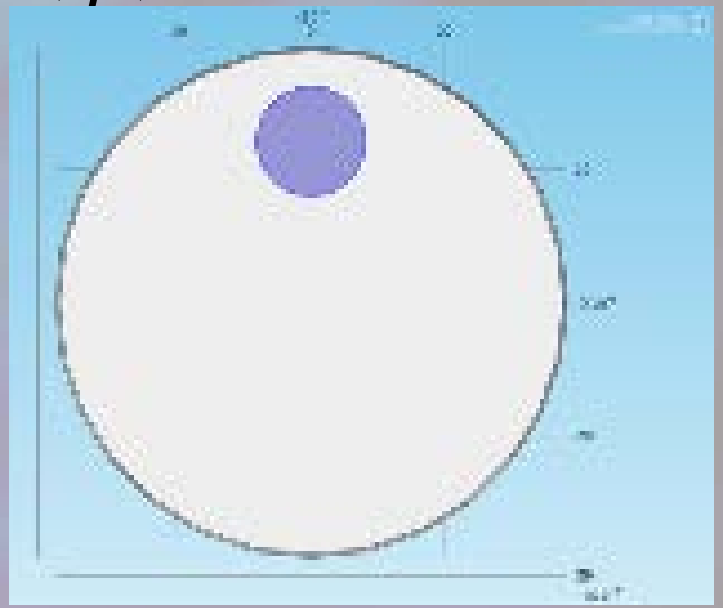
Butterfly 2700 Hz Drumhead 4100 Hz



- COMSOL model for each mode
  - Silica disk with epoxy/silica button
- Calculate energy distribution
- Use standard values of epoxy parameters Y, σ, ρ, d

$Y = 5 \times 10^5$ Pa, $\sigma = 0.4$,
$\rho = 1.5$ g/cm^3, $d = 20$ μm

- Scale energies to account for different properties



LIGO

Epoxies of Interest

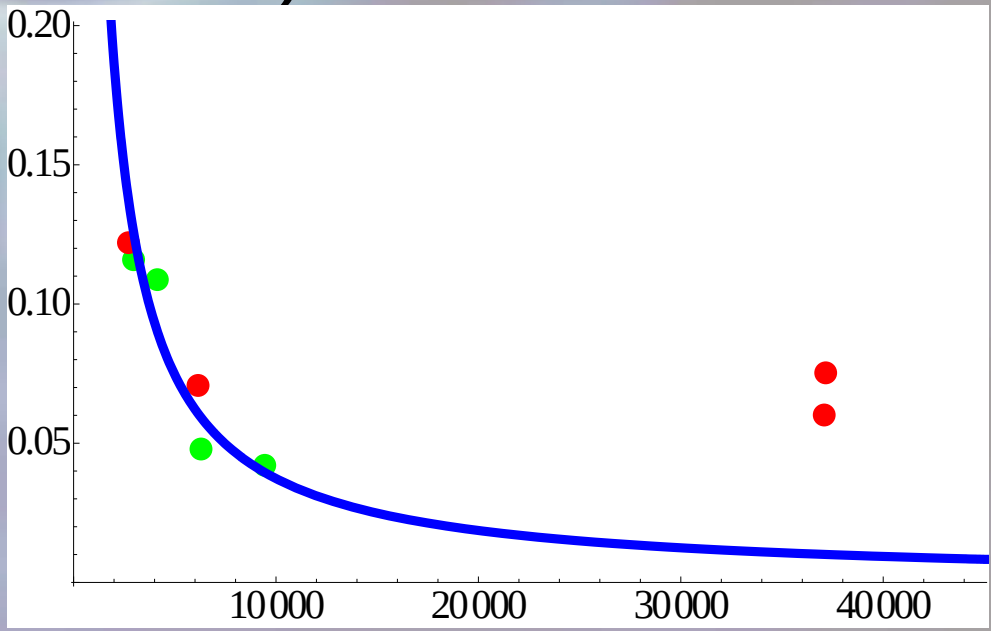
- **Hysol Tra-Duct 2902**: Conducting, LHV* approve
- **EMI Optocast 3553LV**: aLIGO OMC, LHV approve
- **Masterbond EP30**: aLIGO replacement for VacSeal, TM standoffs, LASTI AMD tests, E1000386
- **Epotek 353ND**: T. Bodiya suggestion, not LHV
- **Hysol EA9313**: LISA Optical Bench use, not LHV
- **EP1730-1**: aLIGO connectors, LHV approve
- **Cyanoacrylate**: Superglue

* LHV –LIGO High Vacuum E960050

Hysol Tra-Duct 2902

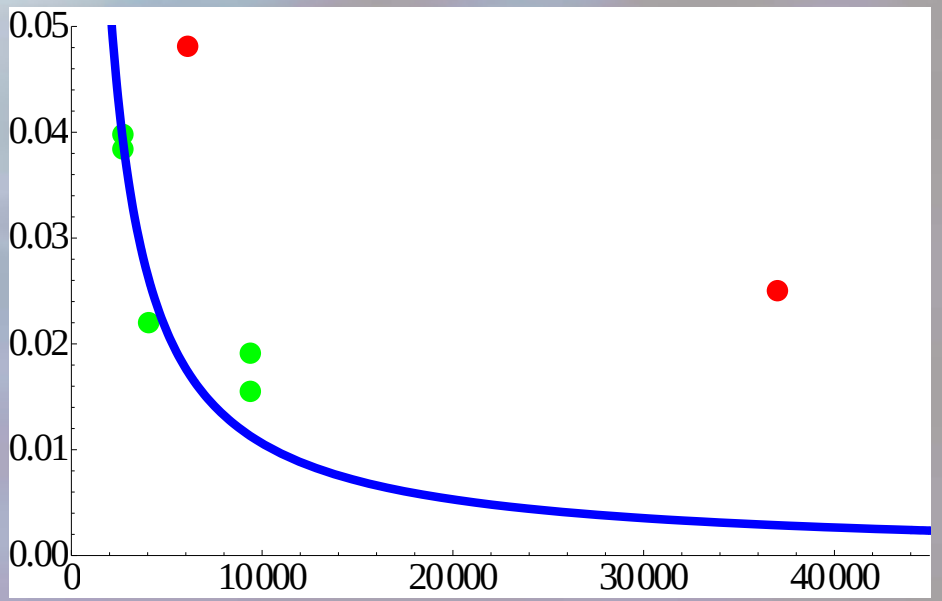
- Conductive, suggested by Slawek Gras
- Reported in G1301138, G1300207, G1300163
- Thickness $d = 47\ \mu\mathrm{m}$, modulus $Y = 4.8\ \mathrm{Gpa}$
  - NRL report w/ 17% silver, 83% epoxy
- Viscosity 20 Pa s (data sheet)
- Very lossy

  $0.05 < \varphi < 0.1$
- Log fit (green) gives slope -1.002
- High thermal noise, low damping



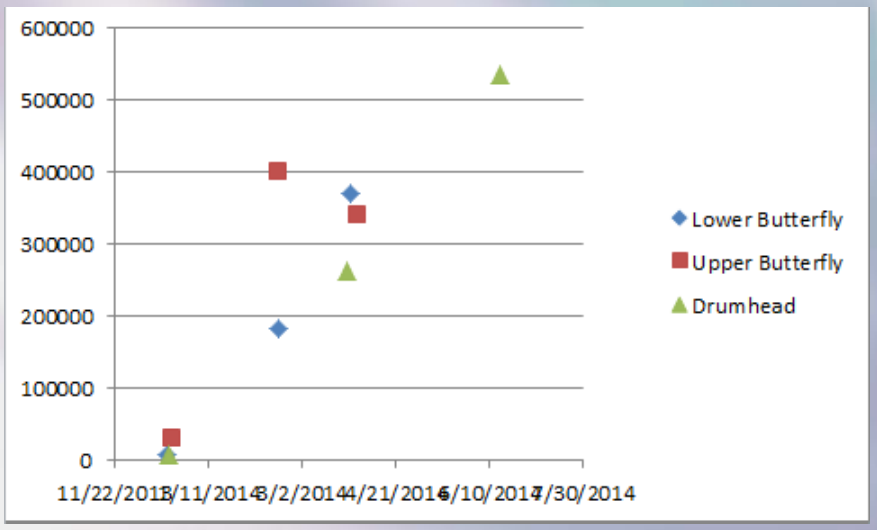
EMI Optocast 3553LV

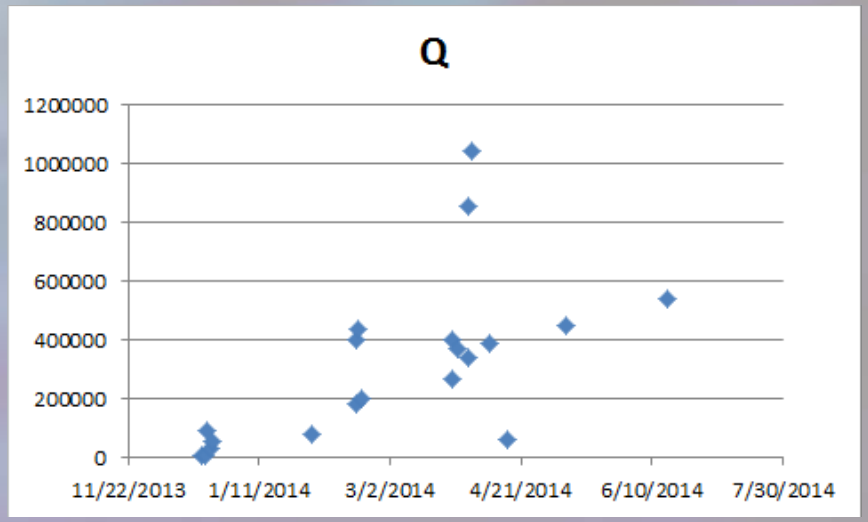
- Used in aLIGO
- Different geometry, epoxy directly below center, 1.5 cm offset
- Thickness $d = 10\ \mu\mathrm{m}$, modulus $Y = 3.4\ \mathrm{Gpa}$
  - Engineer at Electronics Materials Inc.
  - Viscosity 0.5 Pa s
- $0.01 \leq \varphi \leq 0.05$
- Partial trend towards lower φ at high frequency



Optocast Curing

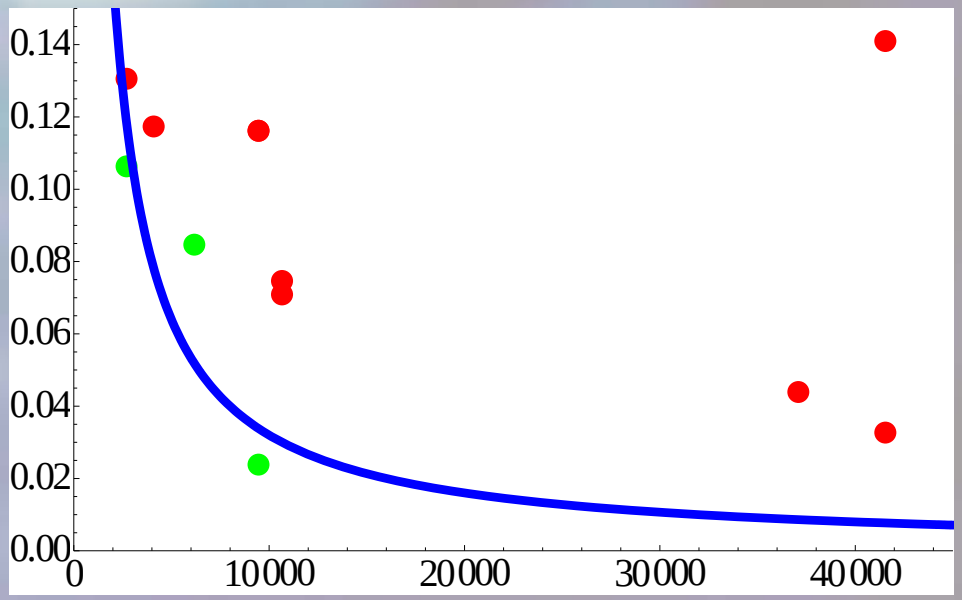
- Optocast was cured with heat rather than UV
  - Unclear what exactly EMI suggests
- Used PID controlled oven at 90° C for 2 hours
- Q data suggests curing may not have completed before hanging in vacuum





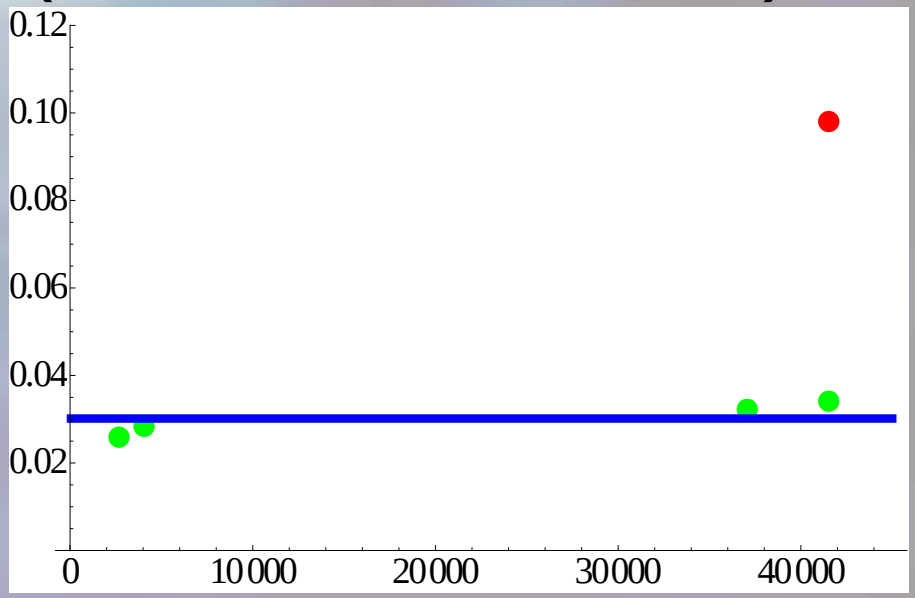
Masterbond EP30

- Used in aLIGO in TM standoffs
- Suggested by Janeen Romie
- Thickness $d = 10\ \mu\mathrm{m}$, modulus $Y = 2.9\ \mathrm{Gpa}$
  - Engineer at Masterbond
  - Viscosity 0.02 Pa s (very thin)
- Higher loss $0.02 \leq \varphi \leq 0.14$
- Slope -0.62
- Fit to $1/f$
- Something of trend



Epotek 353ND

- Used in Mavalvala lab, sample supplied by Tim Bodiya
- Thickness $d = 10\ \mu\mathrm{m}$, modulus $Y = 3.7\ \mathrm{Gpa}$
  - Epotek 301-2, Ferminlab-TM-2366-A
- Viscosity $\approx$ 12.5 Pa s (353 ND data sheet)
- $\varphi \approx 0.03$
- Limited frequency data
- Possible(?), slight increase with f



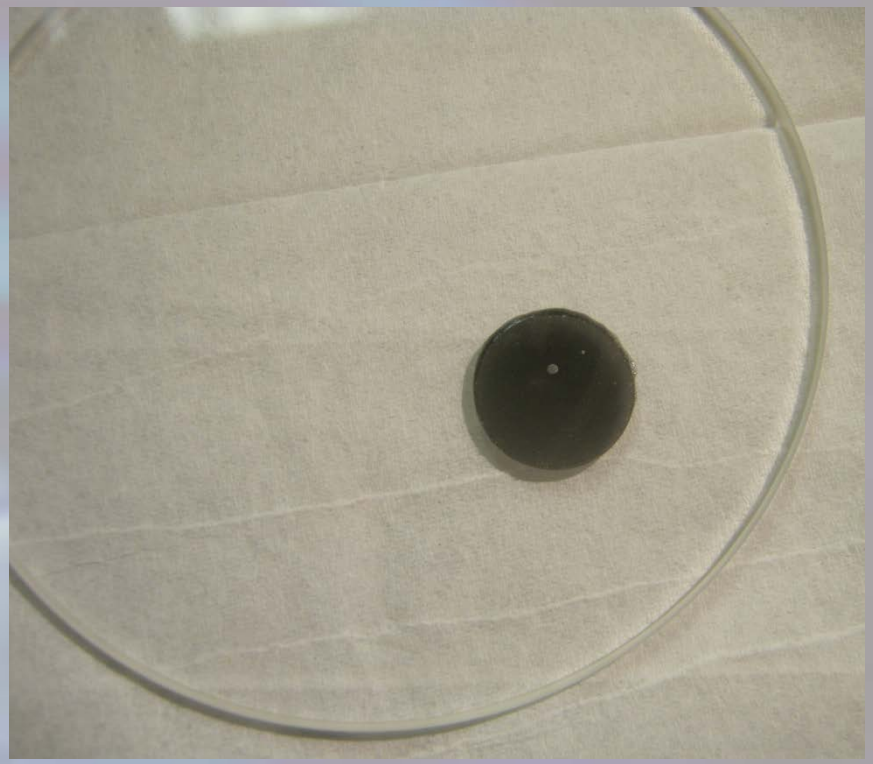
Hysol EA 9313

- Epoxy applied at center of sample
  - Not ideal, poor energy coupling to modes
- Viscosity 1.2 Pa s
- Need better FEA model for this geometry
- Have Q data
  - $f = 2692\ \mathrm{Hz}\ \ Q = 4.5 \times 10^5$
  - $f = 6114\ \mathrm{Hz}\ \ Q = 1.2 \times 10^6$
  - $f = 6115\ \mathrm{Hz}\ \ Q = 1.1 \times 10^6$
  - $f = 9370\ \mathrm{Hz}\ \ Q = 1.2 \times 10^6$

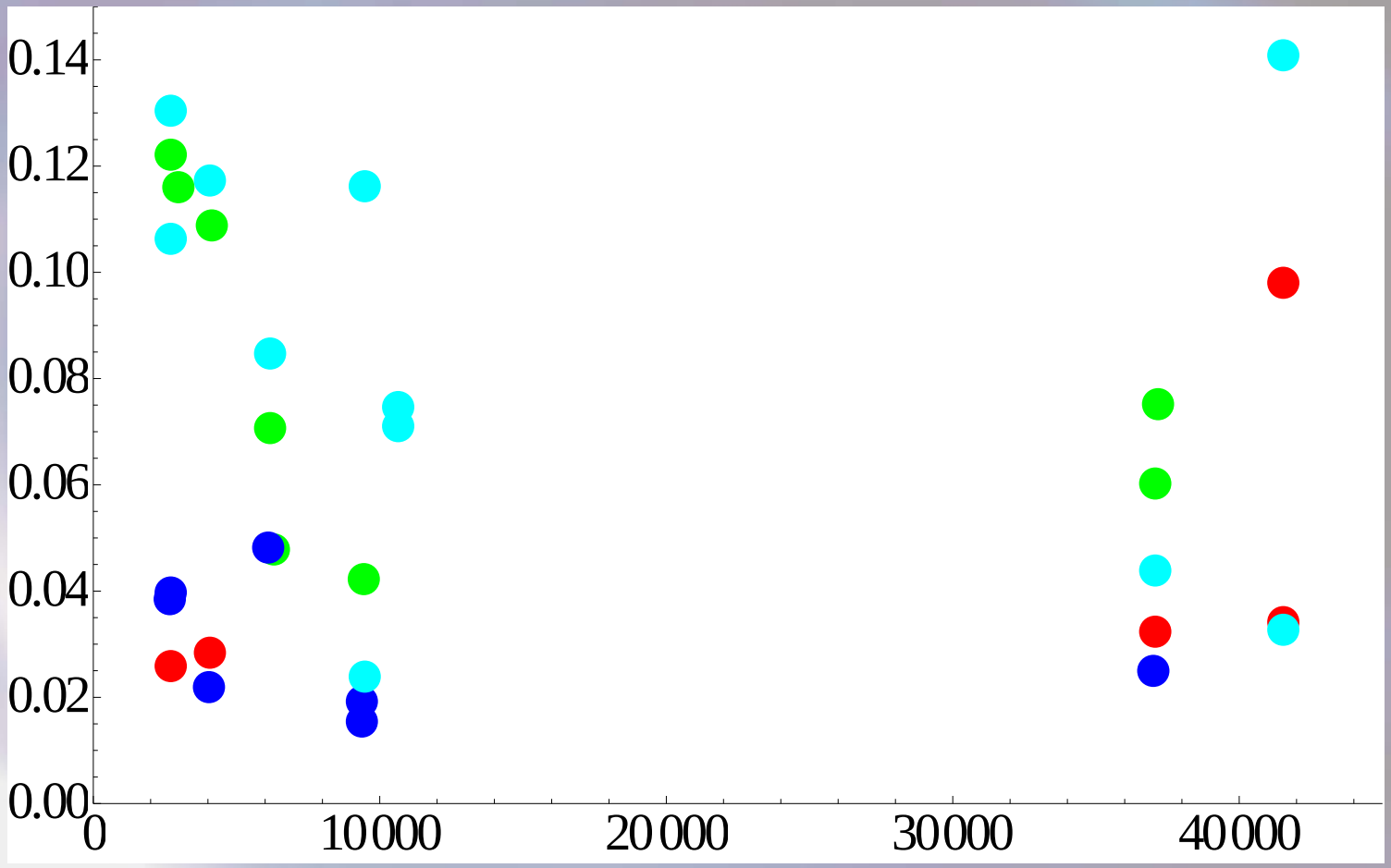
LIGO

EP 1730

- Being measured now
- Measured some Q's
  - $f = 2683\ \mathrm{Hz}\ \ Q = 35{,}000$
  - $f = 4077\ \mathrm{Hz}\ \ Q = 300$
  - $f = 9367\ \mathrm{Hz}\ \ Q = 14{,}000$
- Trying to find Young's modulus value
- Viscosity 25 Pa s
- Thickness and density data to be analyzed



Combined Data



Green – Tra-Duct 2902 Red – Epotek 353ND

Blue – Optocast 3553LV Cyan – EP 30

Other Issues and Future Plans

- Did measure cyanoacrylate (super glue)
  - Found that super glue does not stick to glass
  - Very lossy, probably rubbing
- Viscosity important for thickness
- Glass transition temperature TRA-DUCT 52^{o} C, EPO-TEK 353ND 90^{o} C

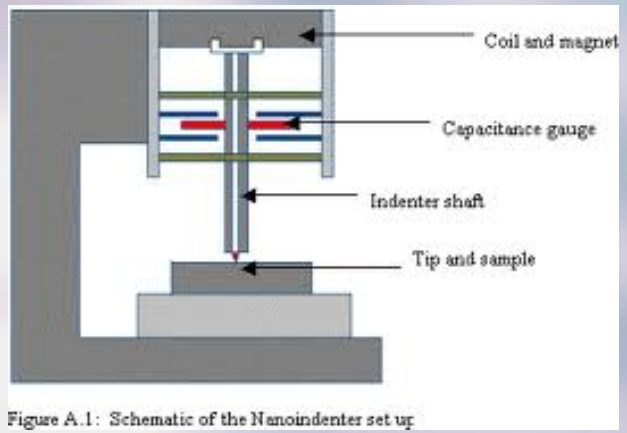


Figure A.1: Schematic of the Nanoindenter set up

- Remeasure key mode Q's
- Finish EA 9313 and EP 1730
- Divide energy into bulk and shear
- Measure Young's modulus
  - M. Abernathy at Caltech/M. Zanolin at ERAU
- Calculate thicknesses from epoxy volume

LIGO

Conclusions

- Typical mechanical loss $0.01 \leq \varphi \leq 0.14$
- Epotek 353ND and Optocast 3553LV have lower loss $0.01 \leq \varphi \leq 0.05$
- Some evidence of frequency dependence against us
  - High loss at thermal noise frequencies
  - Lower loss at test mass mode frequencies
- Some sweeping up corners work to be done
- Can do more detailed study of particular epoxies, frequency ranges, shear vs. bulk