Analysis of LIGO Test Mass Internal Modes as a Measure of Coating Absorption

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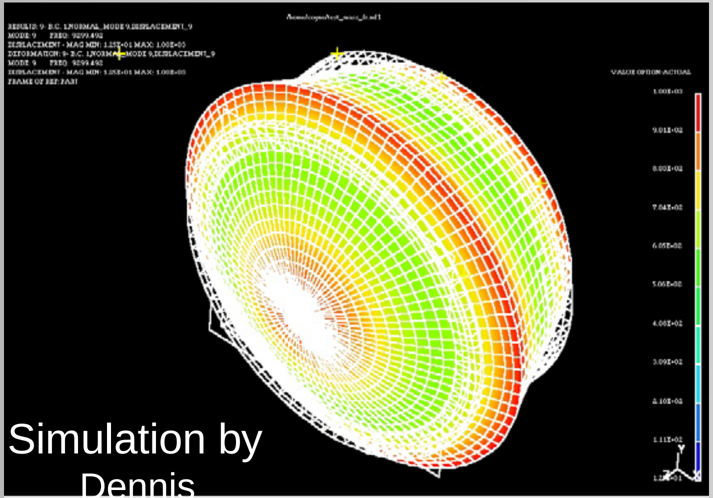
LIGO DetChar Telecon

Test Mass Body Modes

- 25 cm diameter, 10 cm thick, 10 kg, fused silica
  - Calculate modes using finite element analysis
- Frequency of modes changes with temperature
  - Temp dependence of Young's modulus
  - df / f = 70 ppm / K

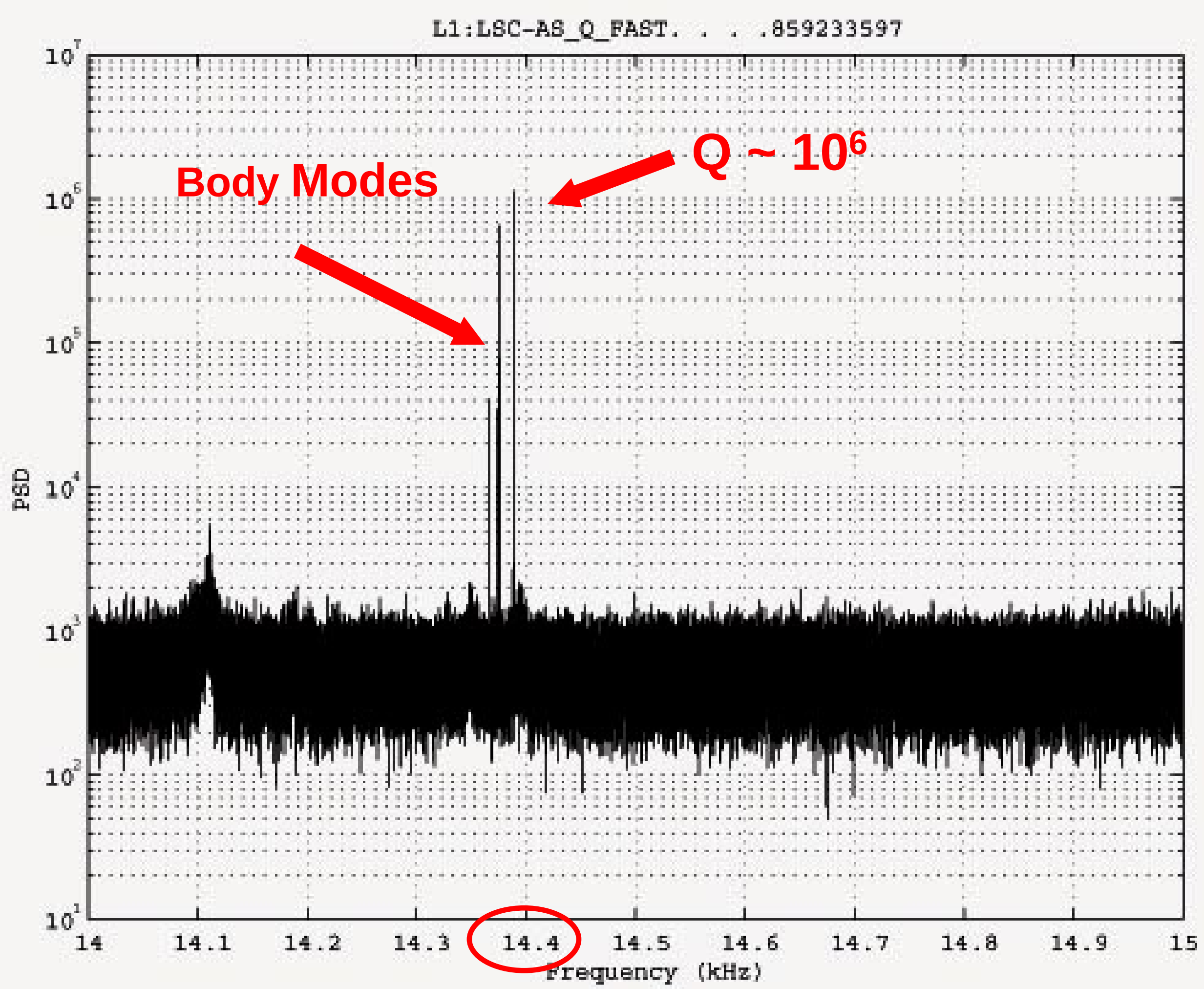
"Drumhead" Mode



Simulation by Dennis

- Frequency shift of the test mass body modes gives a measure of the temperature of the mirrors
  - Temperature change due to absorption driven by IFO / TCS power step
  - Coating absorption seems to be larger (by factor of ~5-10) than when initially measured in the lab at CalTech
  - Track motion of modes vs. time throughout S5 data

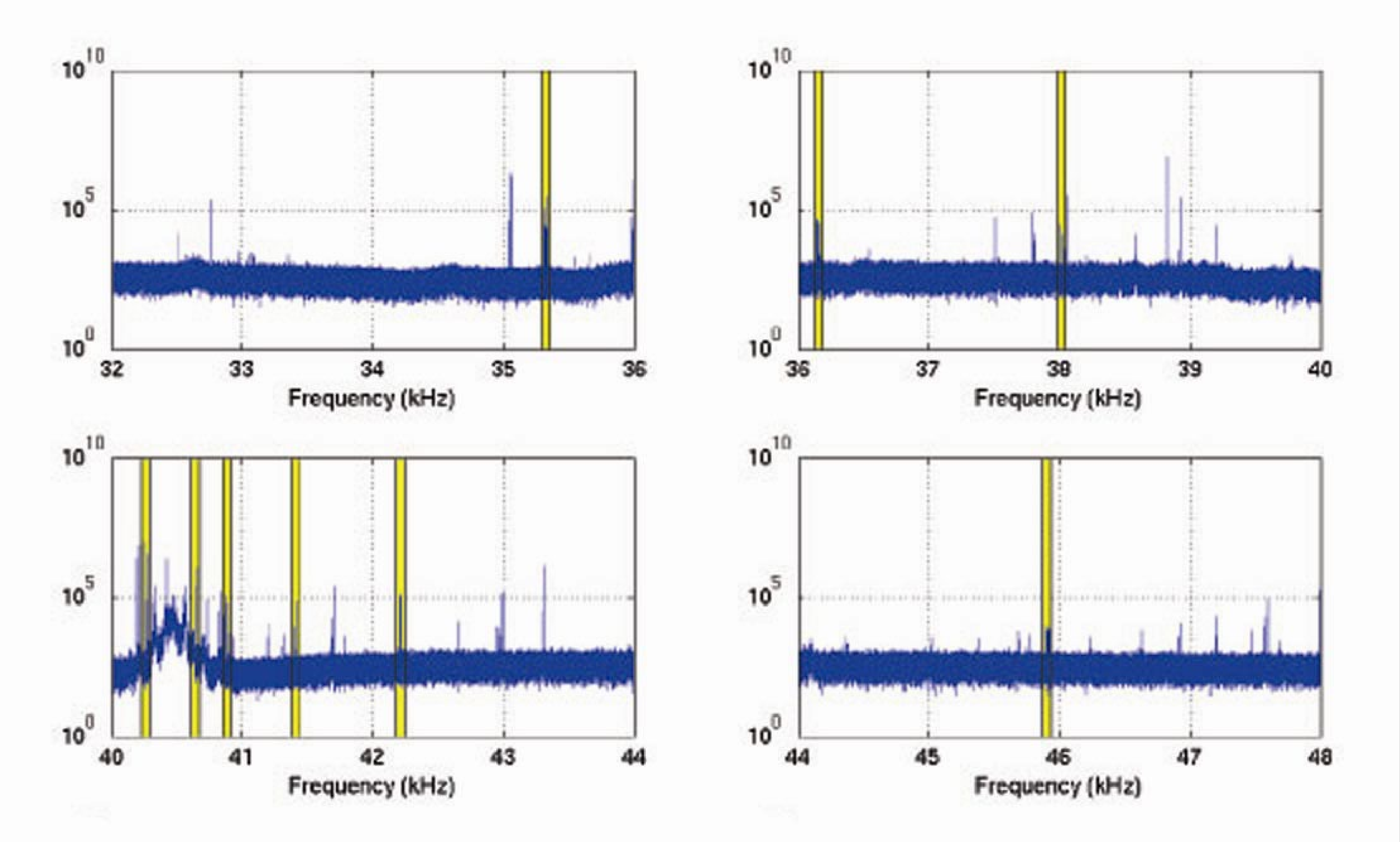
Visible in LIGO data



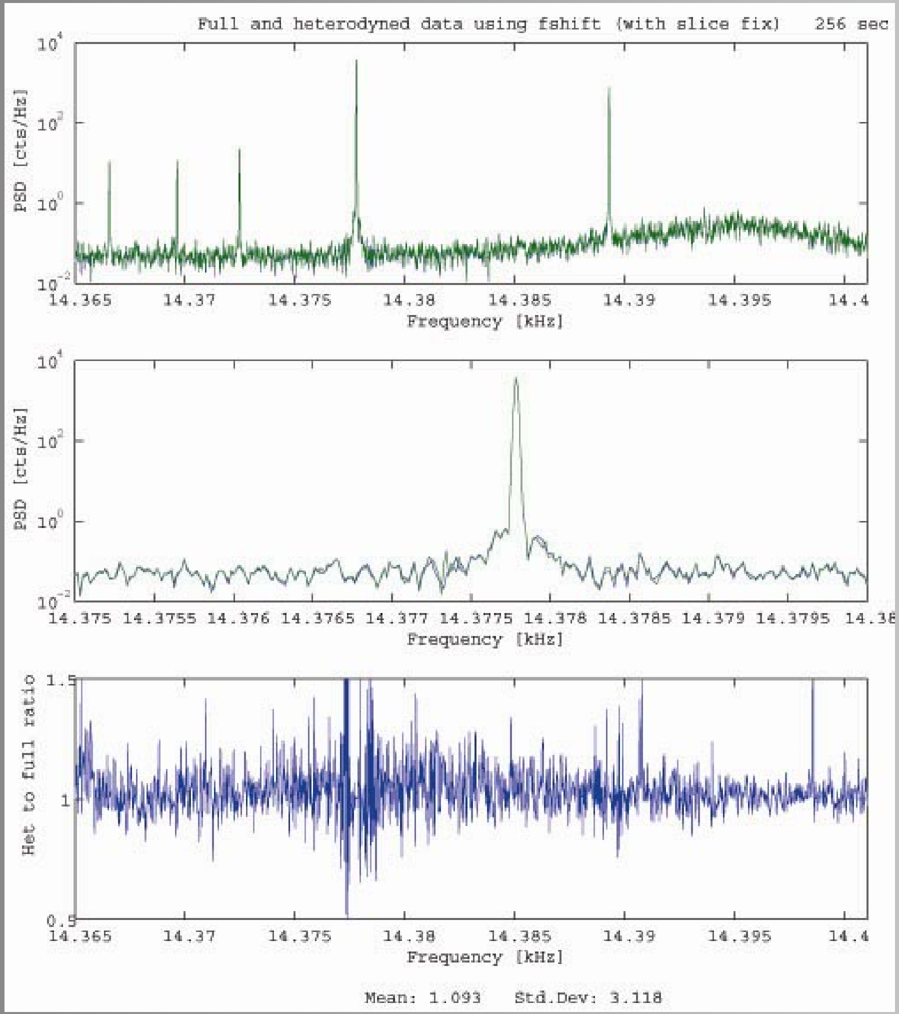
Computational Issues

- ~2 Years of Data, stored on tape
  - Slow to access
- Want to extract only the 256kHz “FAST” Channel
  - Store data on disk to perform analysis
- 256kHz sample rate yields huge amount of data
  - Need to reduce amount of data stored
- Solution: heterodyne and downsample time series
  - Generate “reduced” frame files

Heterodyne Windows



Full / Heterodyned Comparison



Computational Procedure

- FFT heterodyned time series stored in new frames
  - Repeat for each channel

- Fit peaks with Lorentzian
  - Accurately determine center frequency

$$L(x) = \frac{A}{2\pi}\frac{\Gamma}{(x-x_0)^2+(\frac{1}{2}\Gamma)^2}+y_0$$

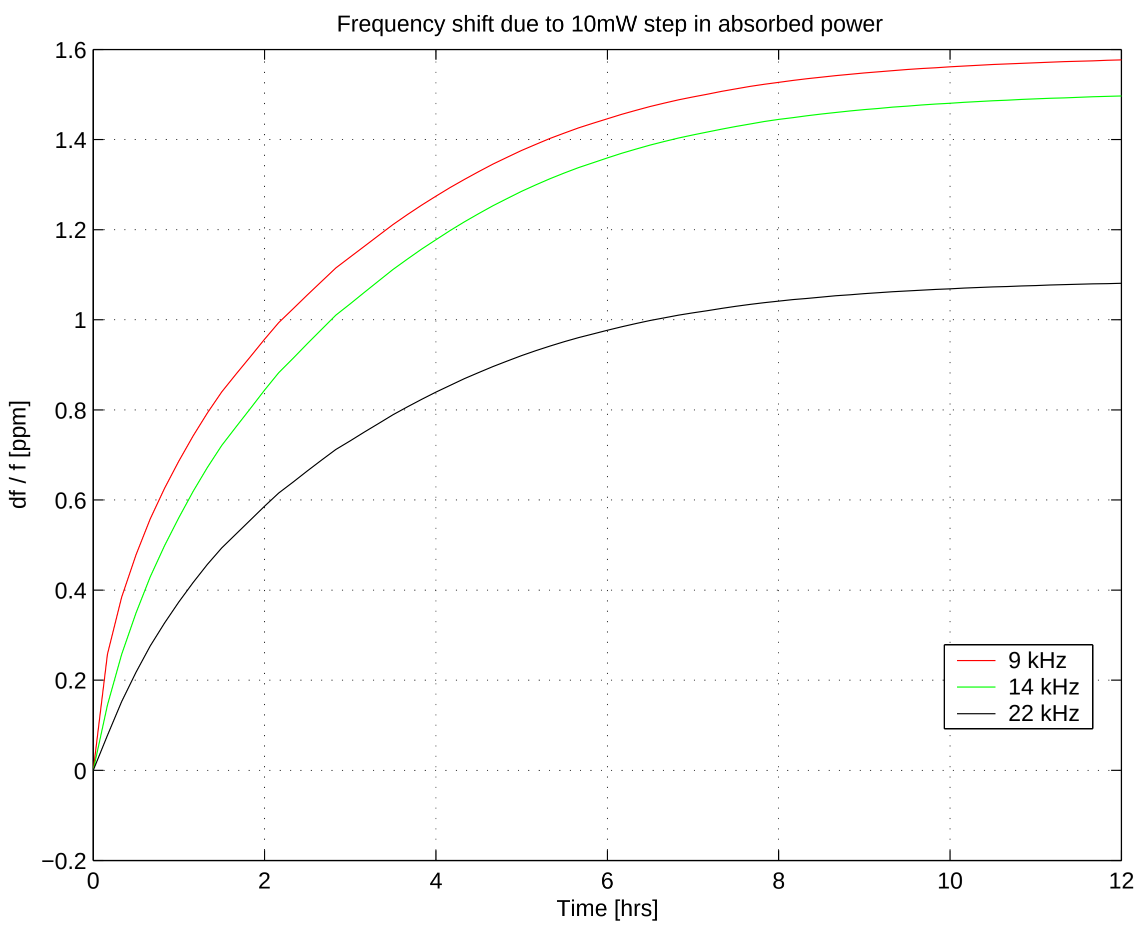
Γ - Full Width Half Max
x_0 - Center Frequency
A - Overall Scale Factor
y_0 - Vertical Shift

Toolboxes used / Bugs Found

- Use GDS libraries for frame generation
  - Libframe – frame access / generation
    - Found N+1 Bug
  - fShift – heterodyne time series
    - Long time series accumulate error from FIR filter
  - DecimateBy2 – downsample heterodyned time series

- Use Matlab for peak finding / analysis
  - Pwelch() – 8 averaged overlapping FFT with Hamming window
  - Fmincon() – fit Lorentzian using least squares minimization

Simulation



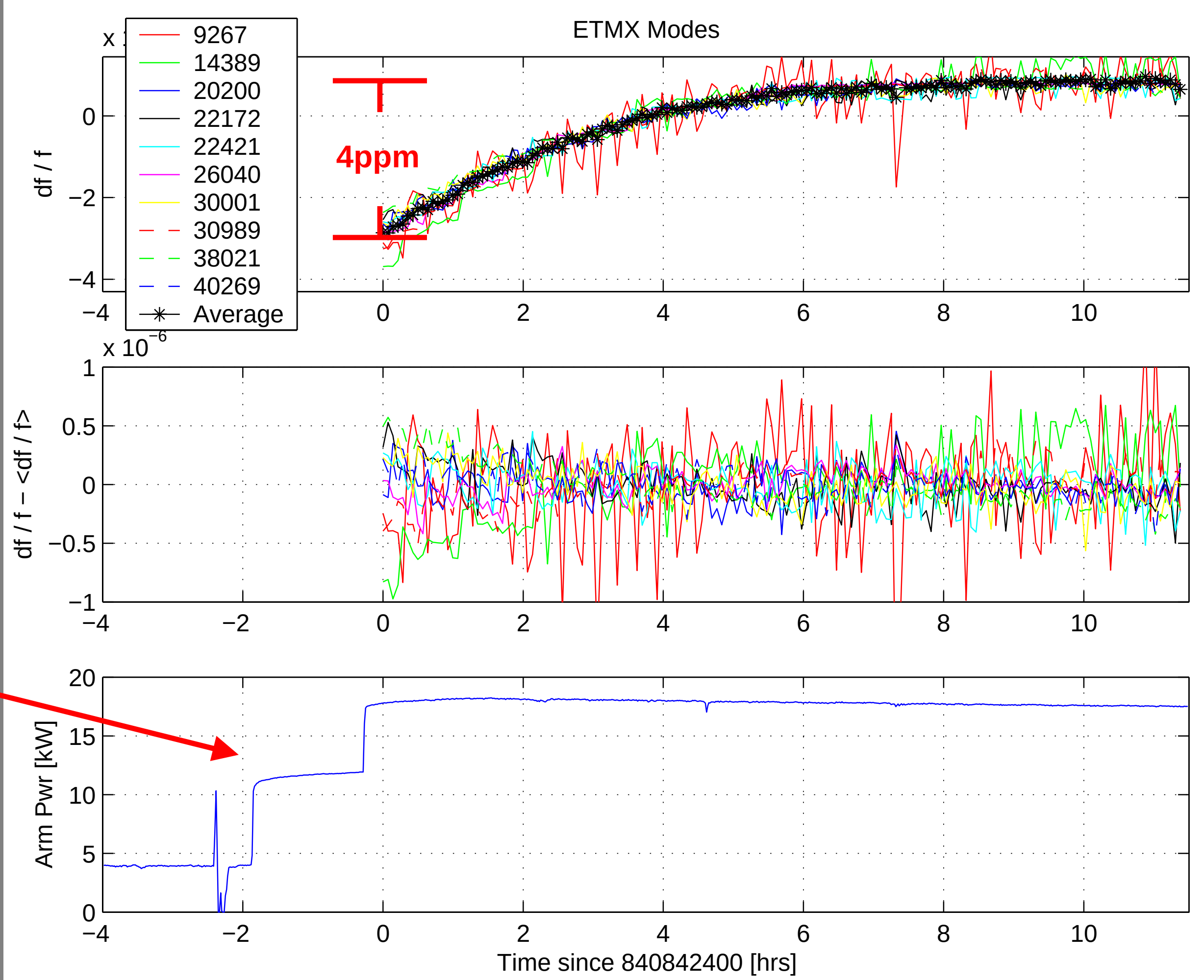
Comsol finite element analysis simulation by Phil Willems

Results

Calculated absorption: < 5ppm

Up to 30% error

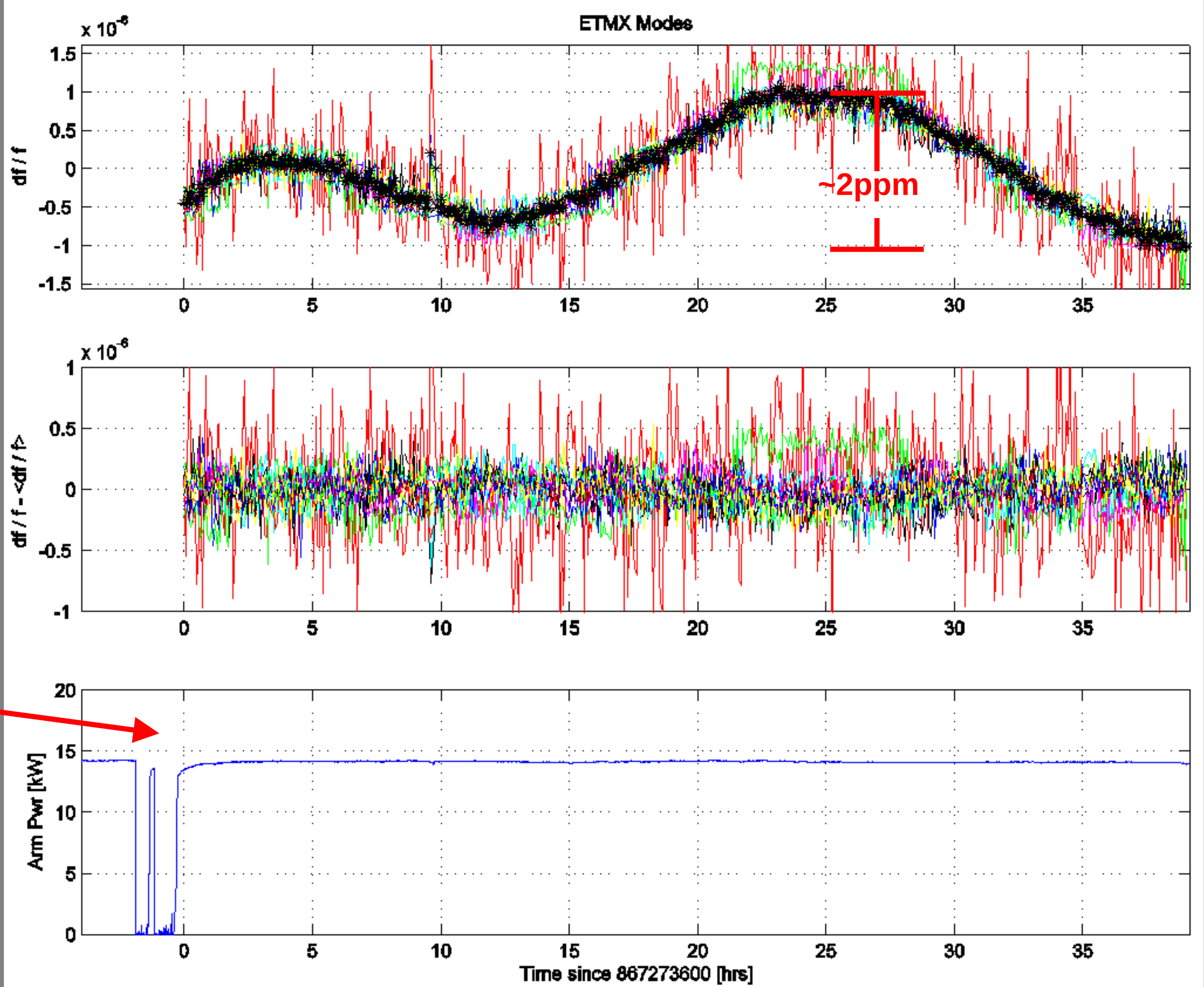
Complicated initial conditions



Ambient Temperature Drift

30 mK Temperature Shift

Steady State

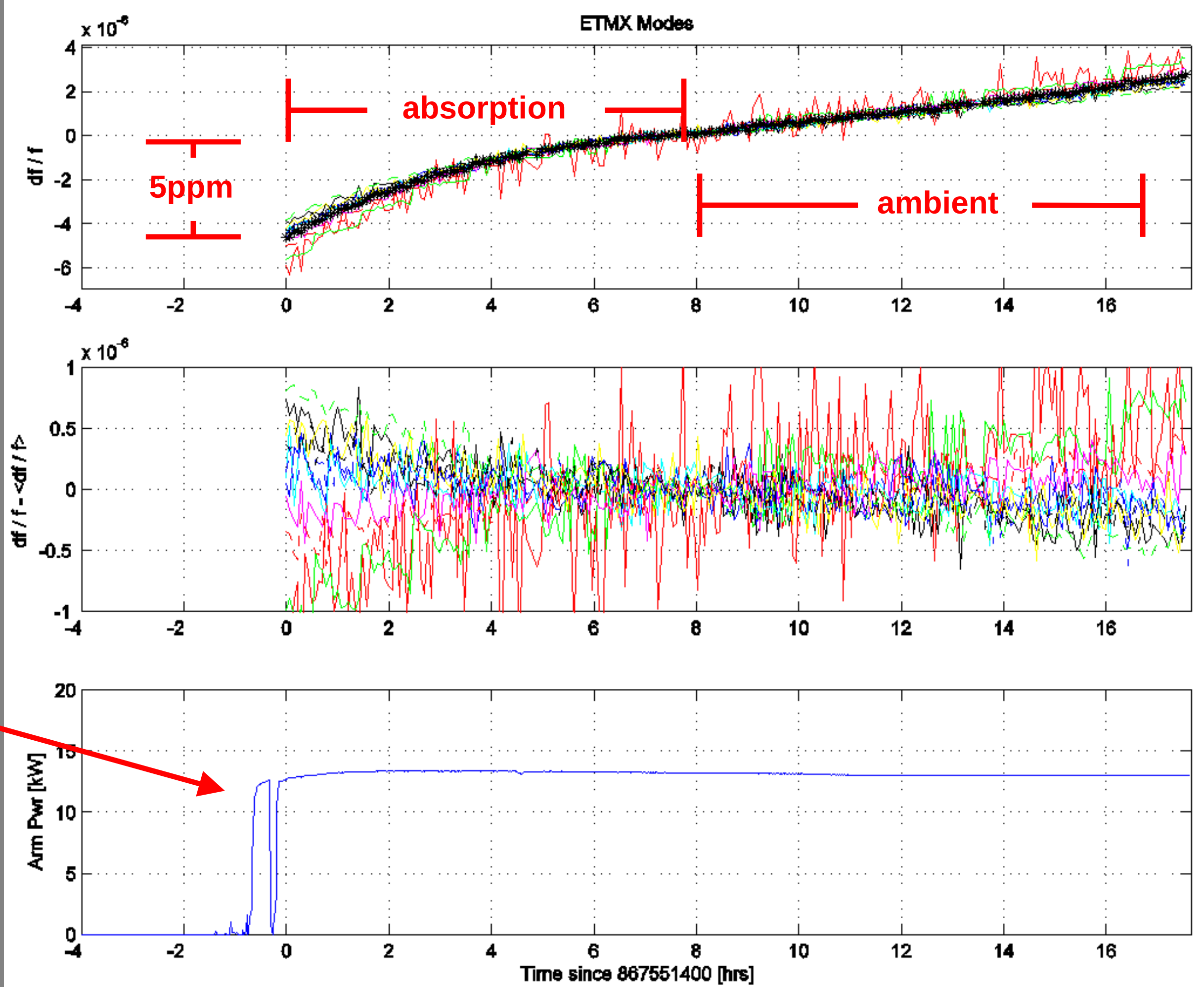


Absorption / Ambient

Calculated absorption: < 3.5 ppm

Up to 10% error

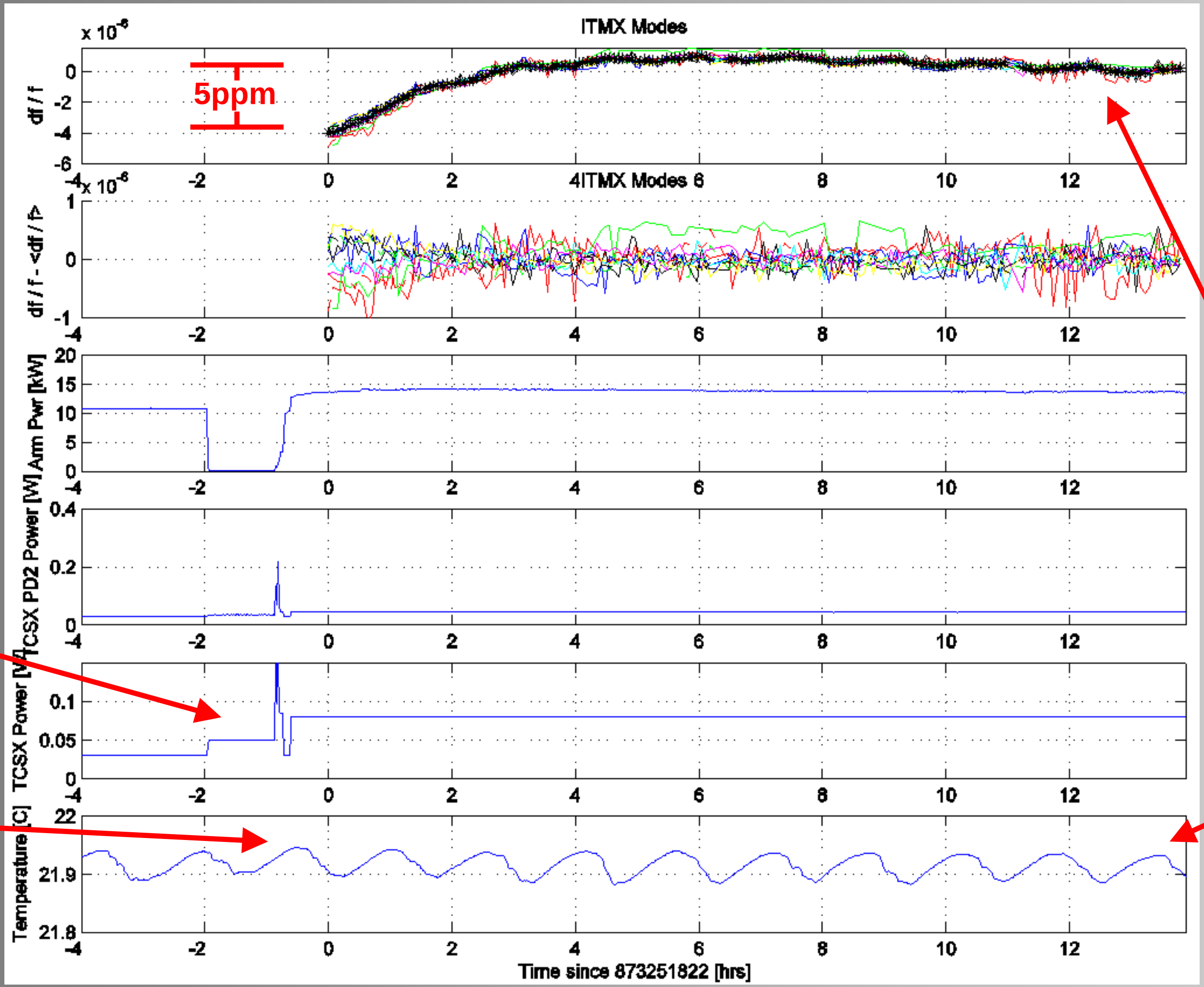
Good power step



Temperature Data

Calculated absorption: < 3.5 ppm

Up to 30% error

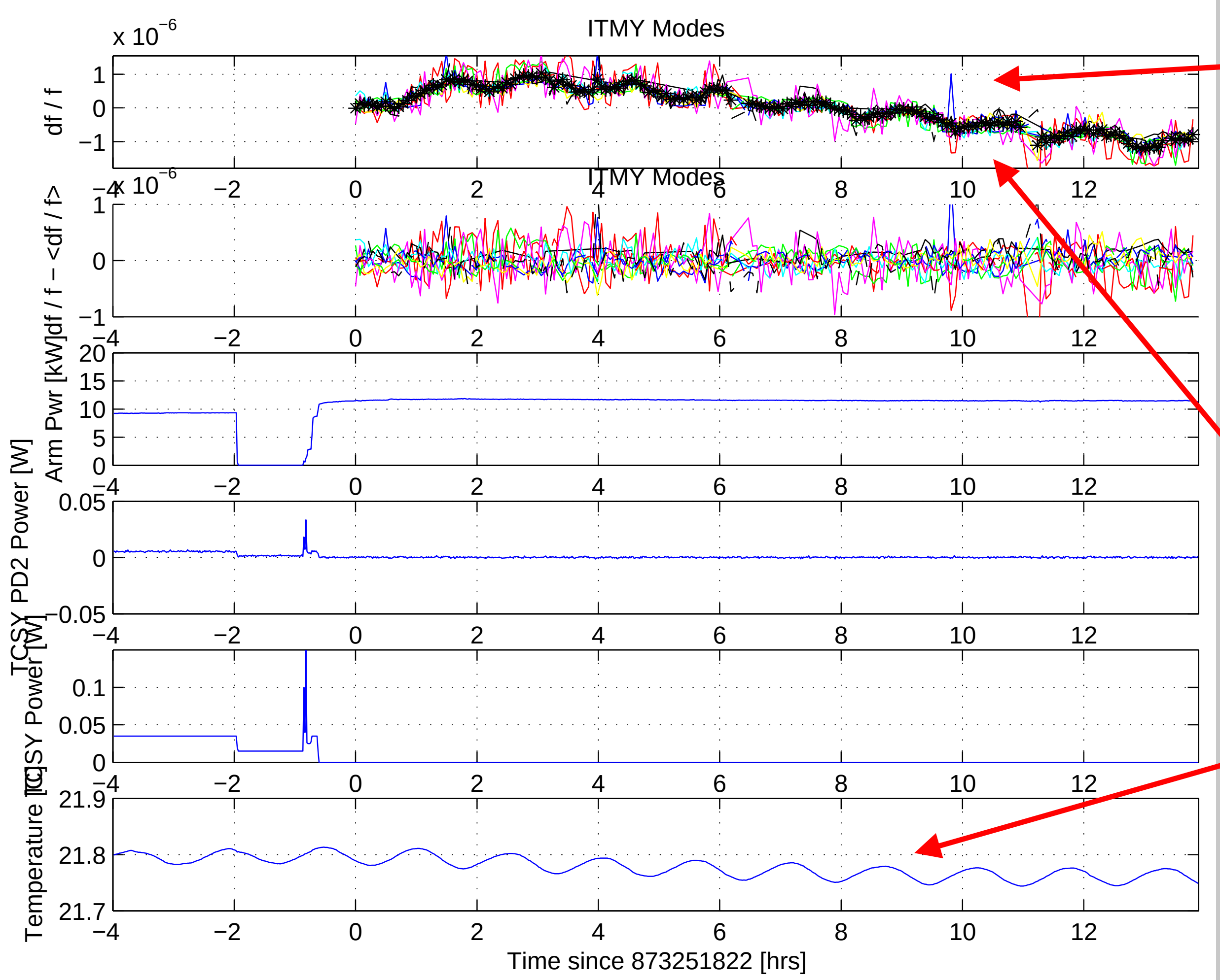


TCS step

Steady avg. Temp

~1.5 hr Temp fluctutaions

Temperature Data



Temp induced shift:

~ 1.5 ppm

Decreasing avg. Temp

~ 20 mK

Post S5 Commissioning

- New temperature sensors installed at LLO by Phil allow for removal of ambient temperature induced frequency shift
  - ITM sensors recently connected
  - ETM temperature sensors still need to be connected!
- Need >5 hour lock segments for good absorption measurement
  - 1W Mode cleaner power step
- Vary TCS power for verification
  - Use Annulus / Central Heating for mode spectroscopy
- Perform analysis on H2 while upgrade in progress
  - Before / after each vent

Summary

- Analysis of internal mode frequency shift can yield very accurate measure of absorption
  - limited by systematic error
- Need long lock segment with power step
  - Post S5 commissioning perfect opportunity
- Ambient temperature induced shifts can be removed for ITM
  - Need ETM temperature sensors
- Absolutely necessary to understand for AdLIGO
  - Power in arms 50x larger than initial LIGO
- Changing absorption would be serious problem