Current Status of the Anelastic Aftereffect Experiment

Prospects for Measuring the Internal Fiction in Fused Silica and Sapphire at $f = 1\text{–}10^3$ Hz

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REASONS FOR THE ANELASTIC AFTEREFFECT EXPT.

- Anelastic Aftereffect is a function of Dissipation in Bulk Mass in the 1 Hz – 1 kHz Frequency Range

  - Provides a Direct Measure of $\phi(f)$ in contrast to at Resonance: $\phi(f_0) = 1/Q_{f_0}$

  - Tests our Assumptions for Structural Damping, and Thermoelastic Damping

- For Glass Test Masses, Anelastic Aftereffect can be Measured using the Stress-Induced Birefringence (see *RSI* paper by M. Beilby, P. Saulson and A. Abramovici)

FLUCTUATION-DISSIPATION THEOREM

- $x^2_{\text{therm}}(f) = \dfrac{k_B T}{\pi^2 f^2} \quad (Y(f))$

  where $Y(f) = v(f)/F(f)$ and $\mathrm{Re}[Y(f)] = 2\pi f \phi(f)/k$

  and the spring constant is $k(1 + i\phi(f))$

- At resonance $\phi(f_n) = \dfrac{1}{Q_n}$

- For a test mass under an harmonic stress, ϕ is the phase shift in the strain.

- OR, we can derive ϕ from measurements of the anelastic aftereffect or creep

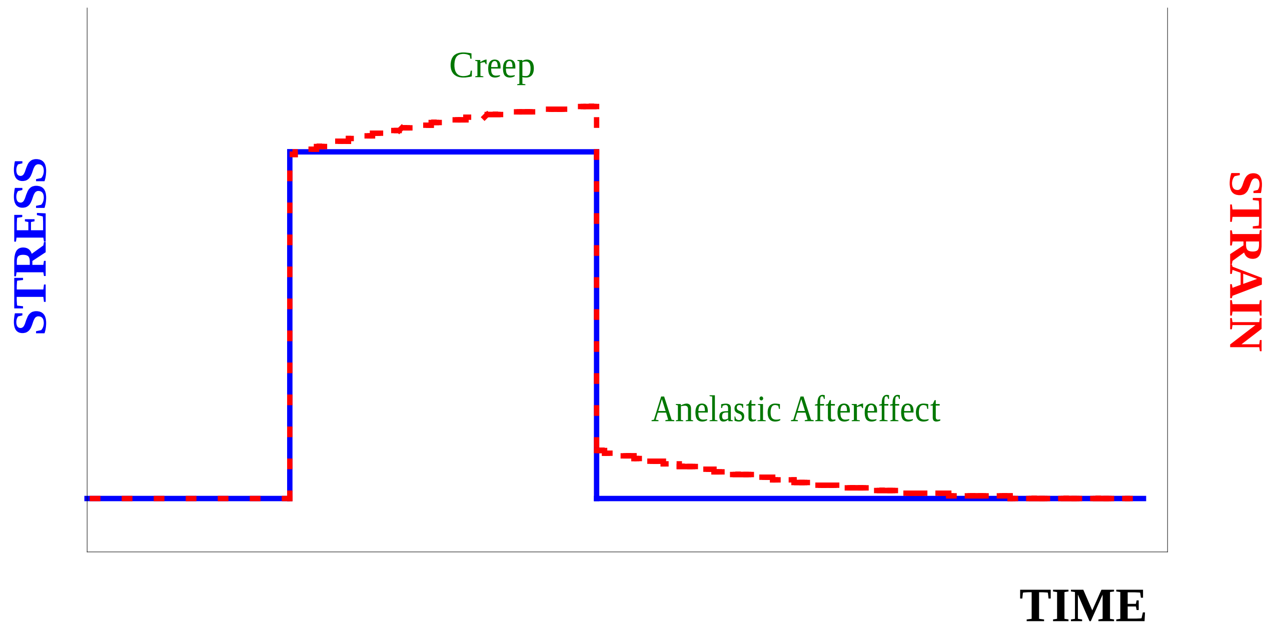
ANELASTIC AFTEREFFECT EXPERIMENT

MOTIVATION:

- Measure Loss, ϕ, in the Test Mass in the LIGO Frequency Range of Iinterest (1 Hz – 1 kHz)
- Resonant Q Measurements determine ϕ only at the resonant frequencies, (> 1 kHz)

$J \quad 1 \quad A / J_0$

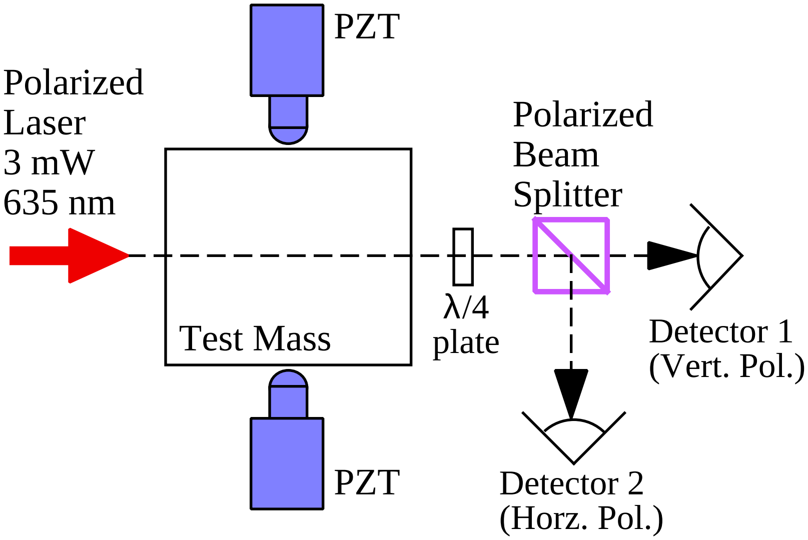
- For a material under constant stress, ϕ can be extracted from the Anelastic Aftereffect (A) or the Creep



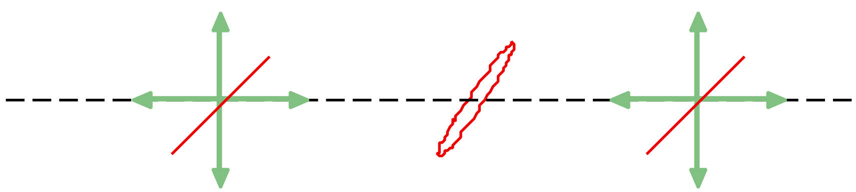
$$\phi\left(f = \frac{1}{2\pi\tau}\right) \approx \frac{\pi}{2}\,\frac{d\,J(\tau)}{d\ln\tau}$$

We measure the Anelastic Aftereffect in Optically Transparent Test Masses via Stress-Induced Birefringence.

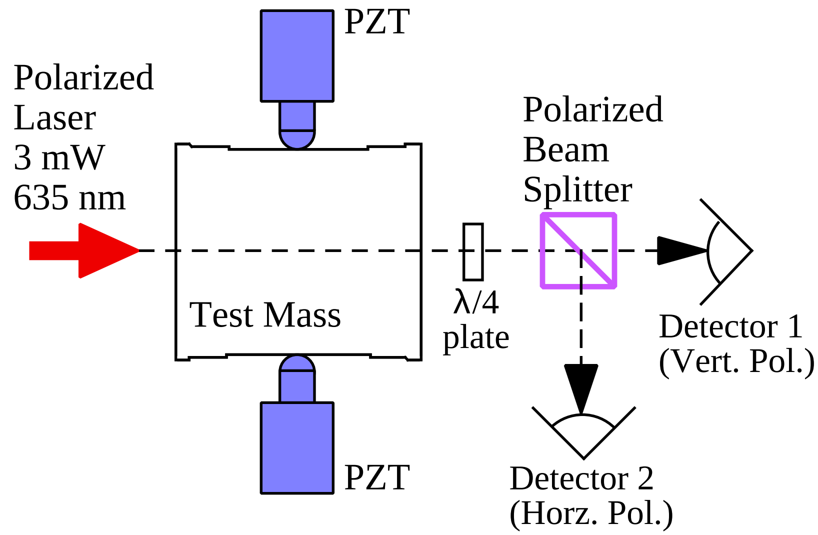
UN-SQUEEZED STATE



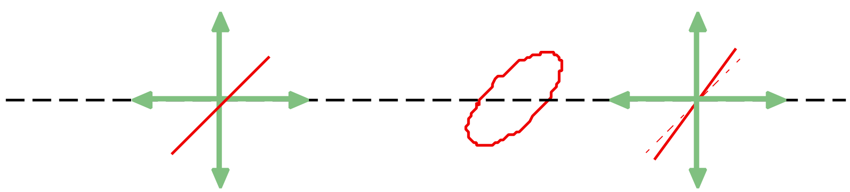
Polarization (looking downstream)



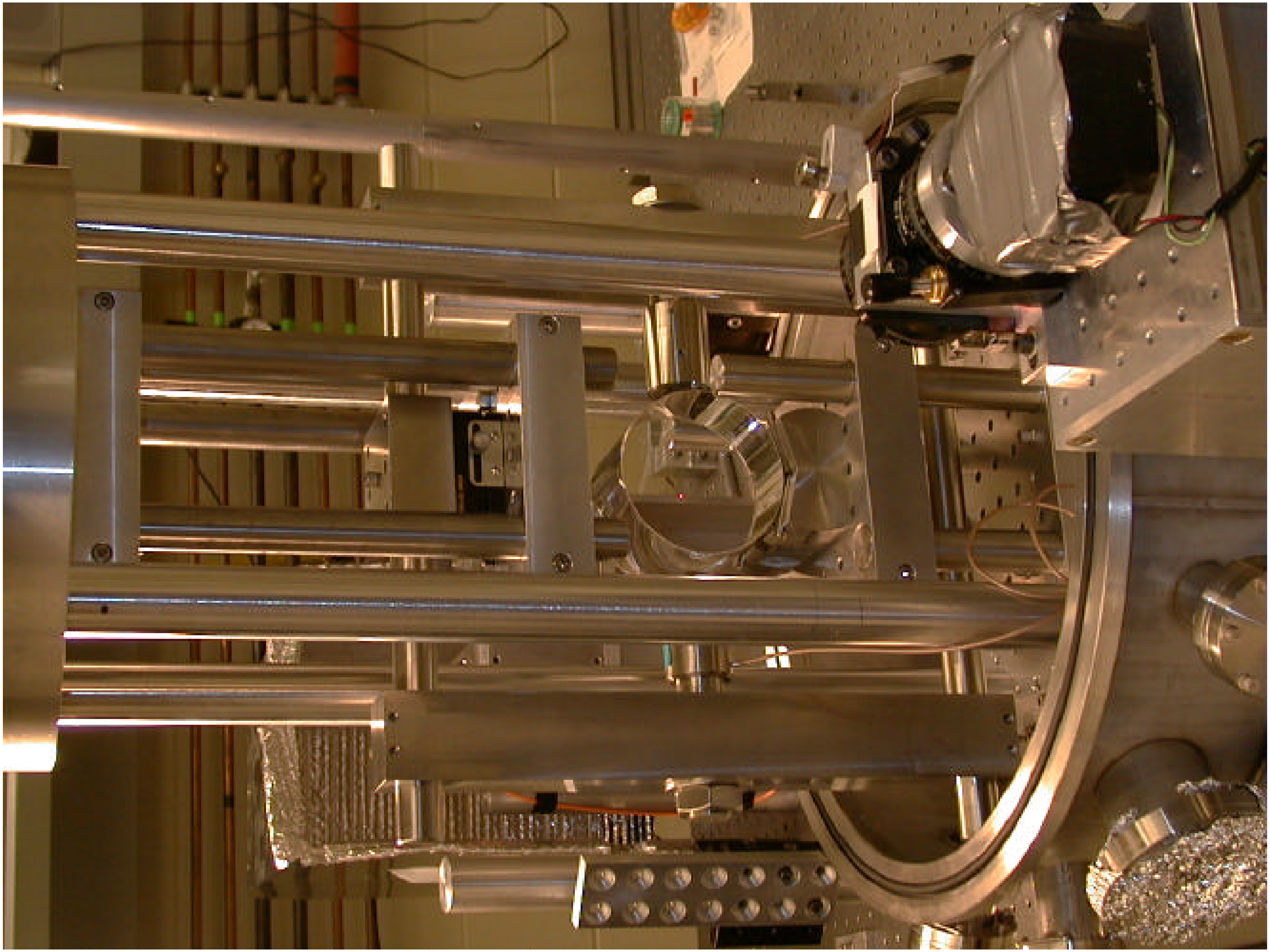
SQUEEZED STATE

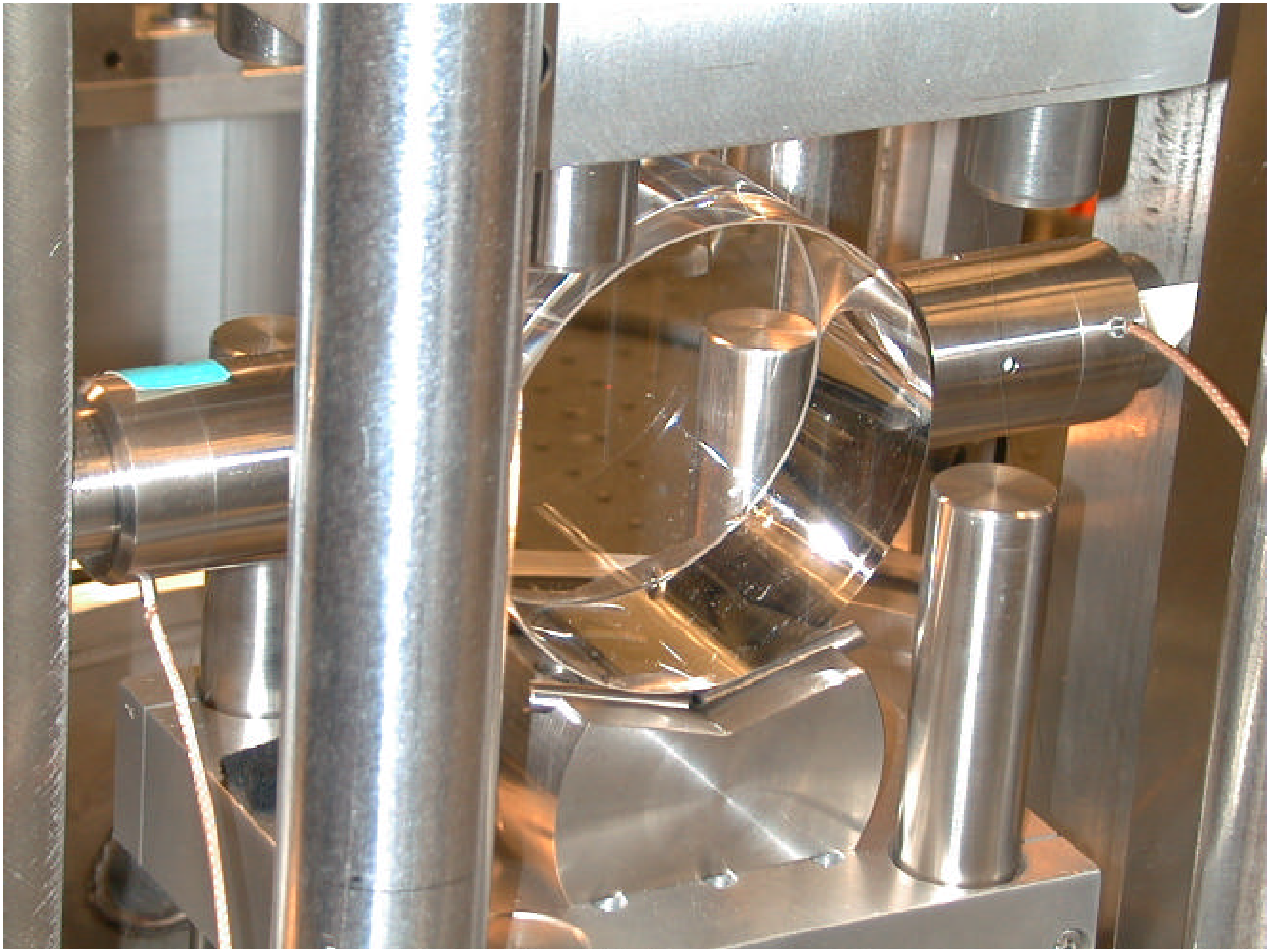


Polarization (looking downstream)



Where the Detector Difference Signal is proportional to the Stress in the Test Mass

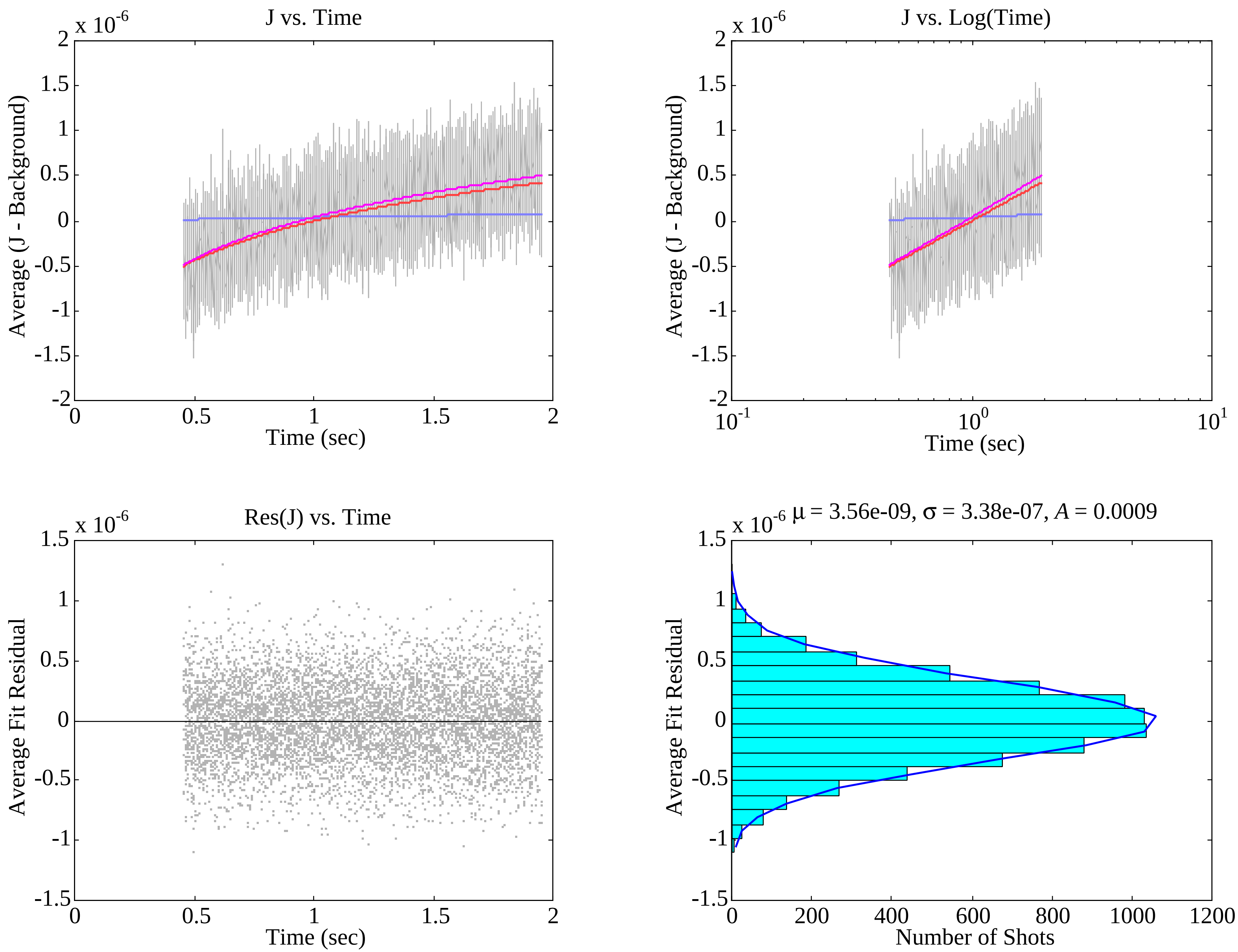


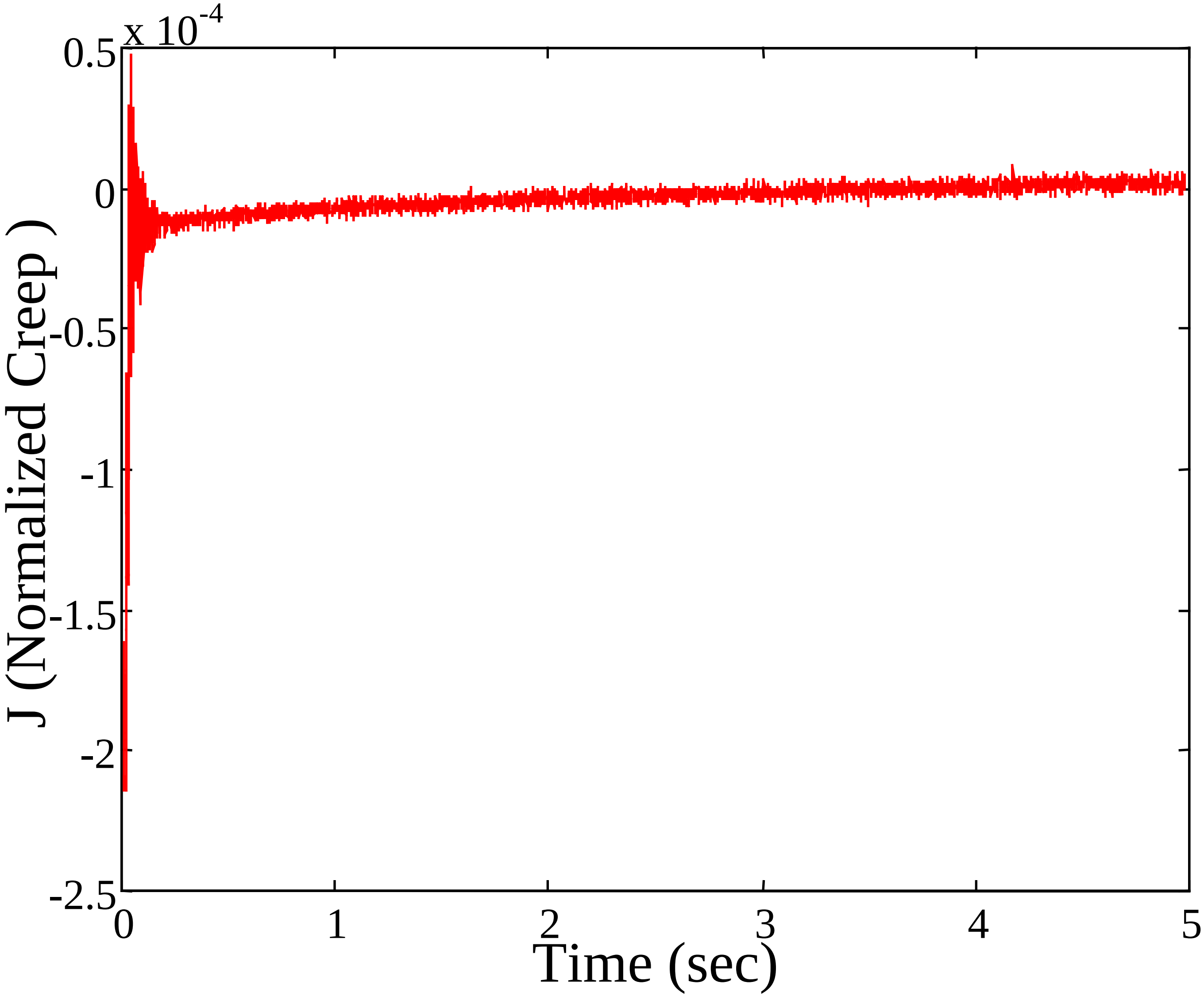


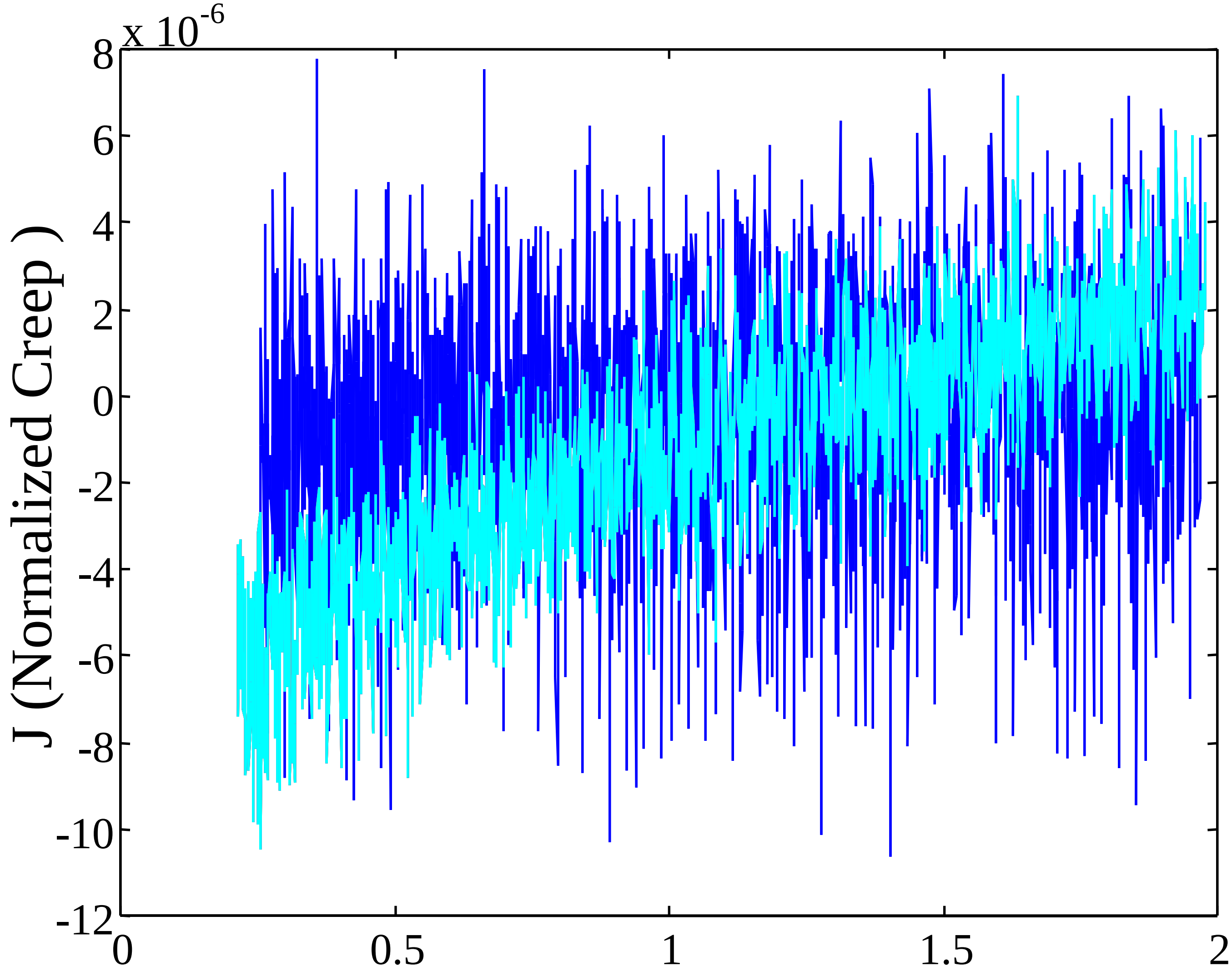
RECENT IMPROVEMENTS IN THE ANELASTIC AFTEREFFECT EXPERIMENT

- PZT Frame is more rigid (for greater squeeze), self-centering (better alignment)
- PZTs individually controlled to correct for individual hysteresis
- PreAmp (10^4 amplification) and detectors now battery powered (no 60 Hz)
- New Quieter Higher Power Laser should bring us close to shot noise (Temperature controlled, Low Noise Current Supply, Single-mode polarized-preserving optical fiber)
- Insulated experimental shelter minimizes thermal fluctuations

Graph 5: *Summary:* SUMslowfs$_e$.m, *Data:* slowfs.m, *Time:* 17-Mar-2000 01:56:10




x 10^-4
0.5
0
-0.5
-1
-1.5
-2
-2.5
J (Normalized Creep)
0
1
2
3
4
5
Time (sec)


x 10^-6
8
6
4
2
0
-2
-4
-6
-8
-10
-12
J (Normalized Creep)
0
0.5
1
1.5
2

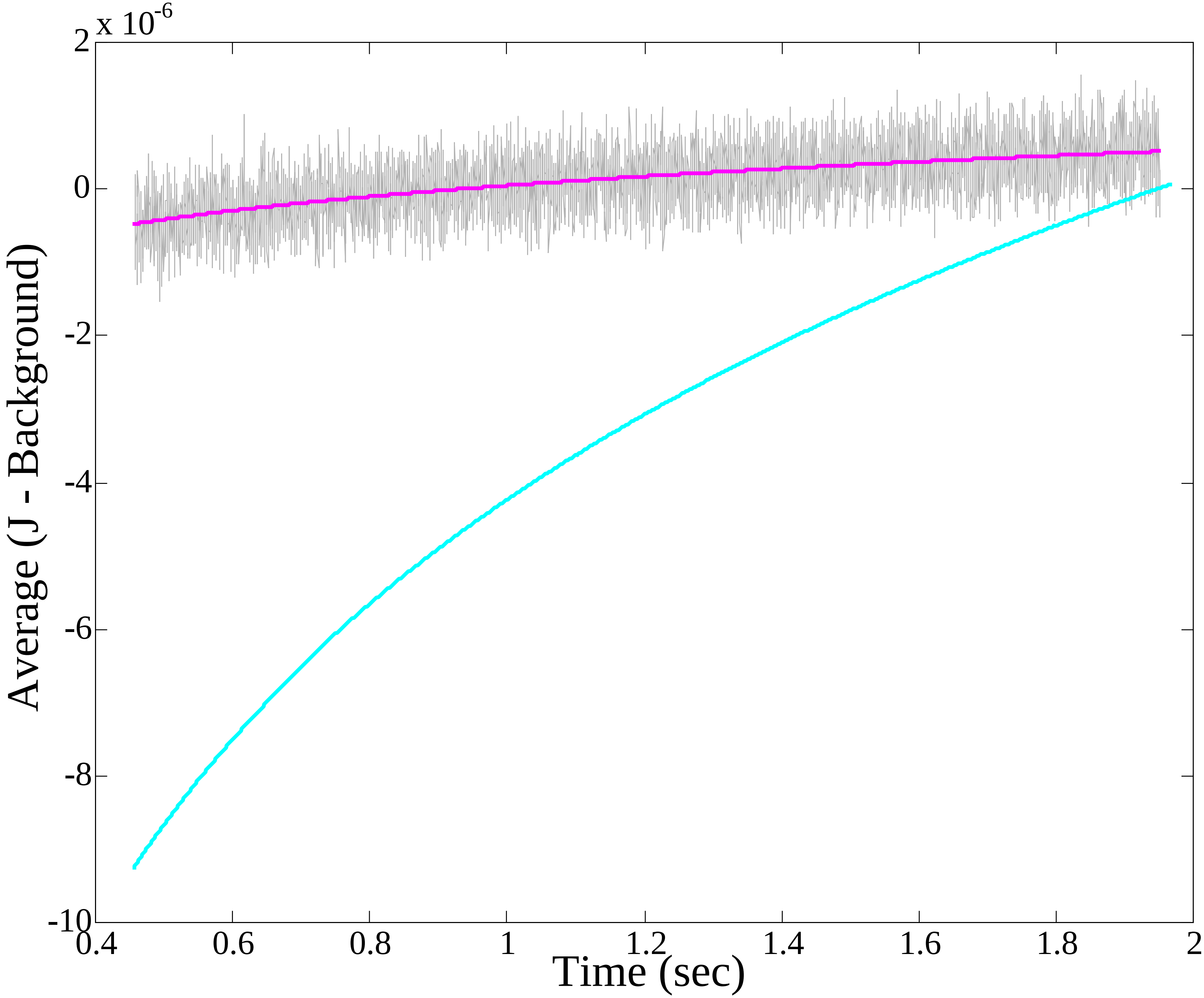
Prospects for Measuring ϕ of Sapphire with Anelastic Aftereffect

- Fused silica $\phi < 10^{-6}$ but systematics from the test mass mount limit our sensitivity

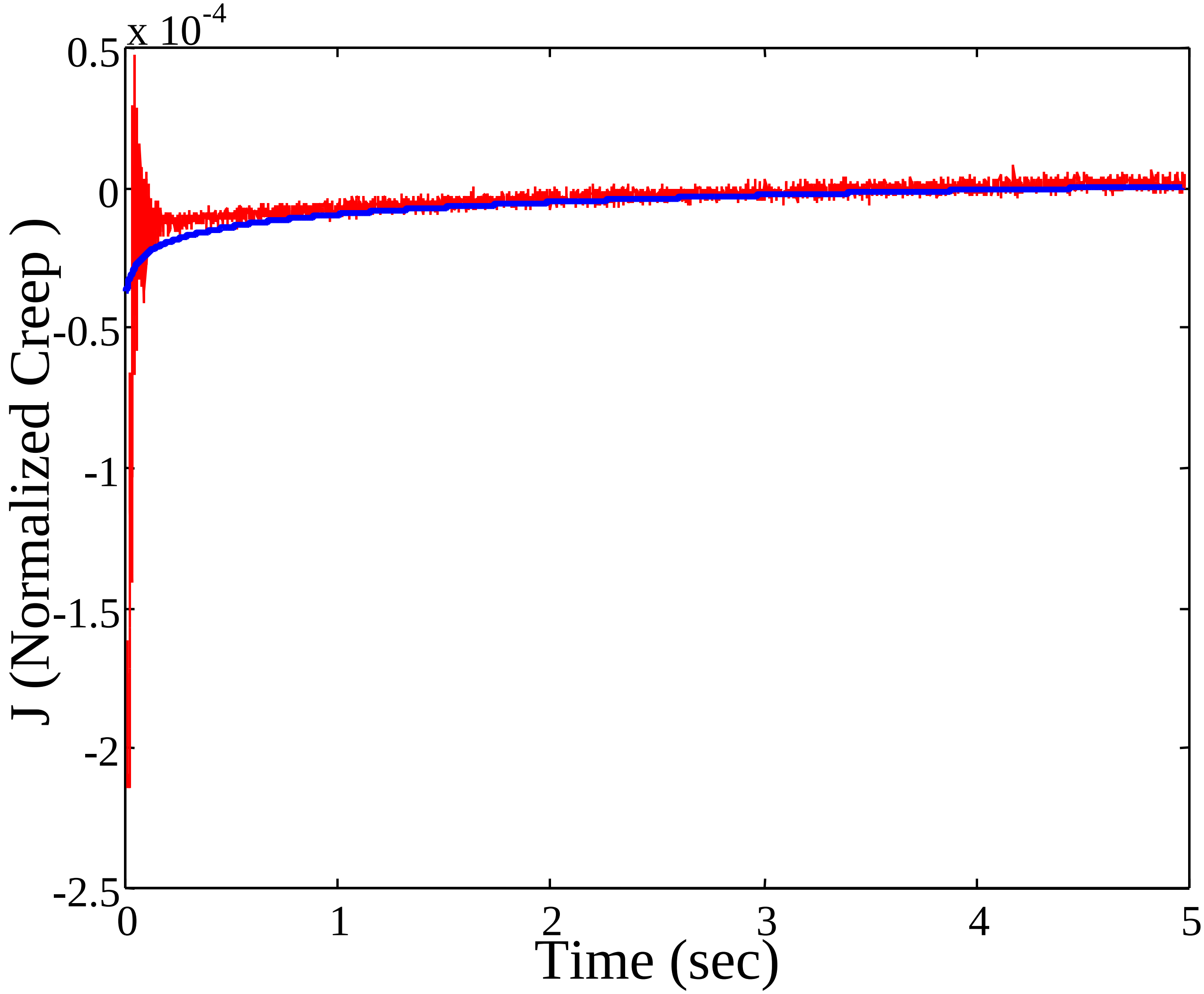
- Thermoelastic Noise in Sapphire is calculated to be $\phi(f = 1\text{ Hz}) \approx 10^{-5}$ (quite detectable?)

- Inherent Birefringence may prove troublesome for our suspended mounts

- Large Stress-induced birefringence must be achievable with our PZT vise



x 10^-6
2
0
-2
-4
-6
-8
-10
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Average (J - Background)
Time (sec)



x 10^-4
0.5
0
-0.5
-1
-1.5
-2
-2.5
J (Normalized Creep)
0
1
2
3
4
5
Time (sec)

CURRENT STATUS OF THE ANELASTIC AFTEREFFECT EXPT.

- Statistical error at $\approx 10^{-8}$, but Systematic errors from the mounts are on the 10^{-7} level.

- Sapphire ϕ should be easily measurable barring any problems with birefringence.

- Fused Silica has been just beyond our reach. Mounting and alignment difficult with vise which squeezes with 10^{4} N and 1 mil clearance on either side. Two new mounts ready to be tested. Ultimately we could resort to silicate bonding.