Measurement of thermally induced test mass surface curvature changes in a LIGO 4-km interferometer

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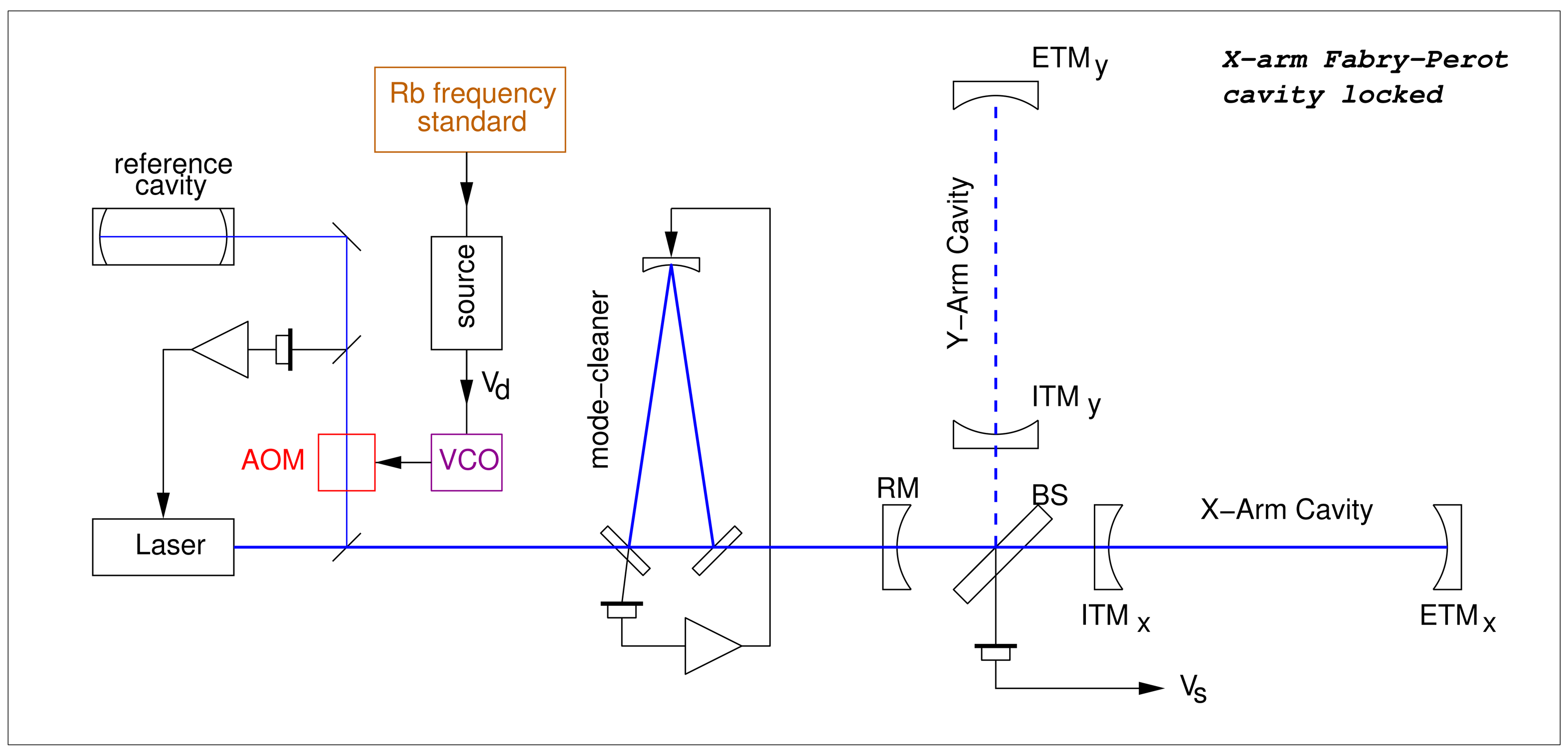
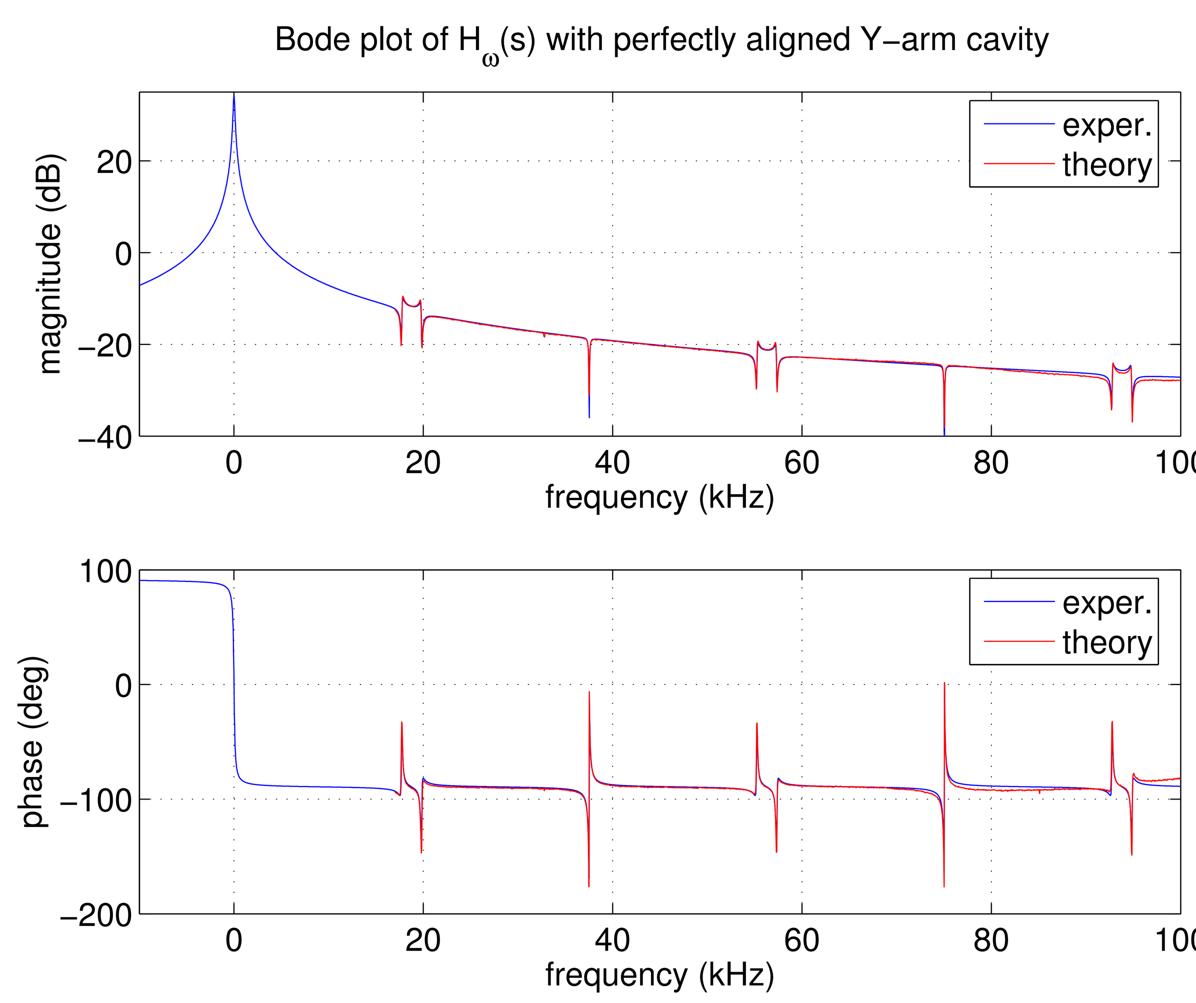
Abstract

We have developed a new technique for measuring the g factor of a resonant Fabry-Perot cavity and have applied it to the 4-km-long arm cavities of the LIGO H1 interferometer. The technique involves modulating the frequency of the laser light incident on the cavity and measuring the response of the Pound-Drever-Hall error signal used to lock the cavity on resonance. When a misalignment between the incident light and the cavity axis is introduced, the laser-frequency-to-PDH-signal transfer function exhibits features localized at frequencies related to the transverse spatial mode frequency separation. Comparison with theory yields an estimate of the arm cavity g factor, $g = g_1 g_2$ where $g_i = 1 - L/R_i$ with L being the length of the arm cavity and R_i the test mass surface curvature. We have used this technique to monitor changes in the g-factor of the arm cavities as they are heated by the laser radiation in the interferometer and thus investigate optical absorption in the test masses. Comparison between the two arm cavities has been utilized in efforts to identify the source of anomalously high absorption in the LIGO H1 interferometer.

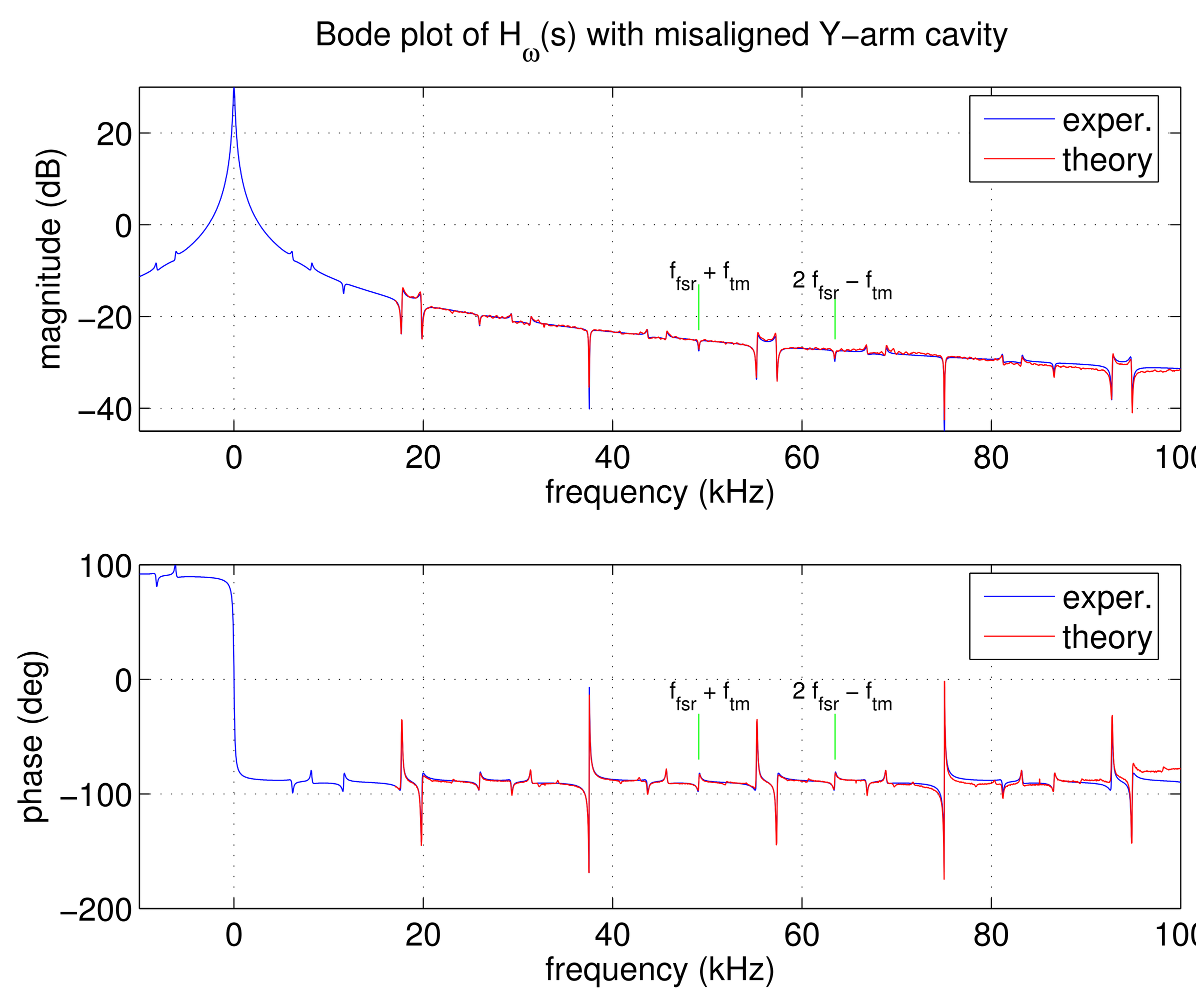
Measurement technique



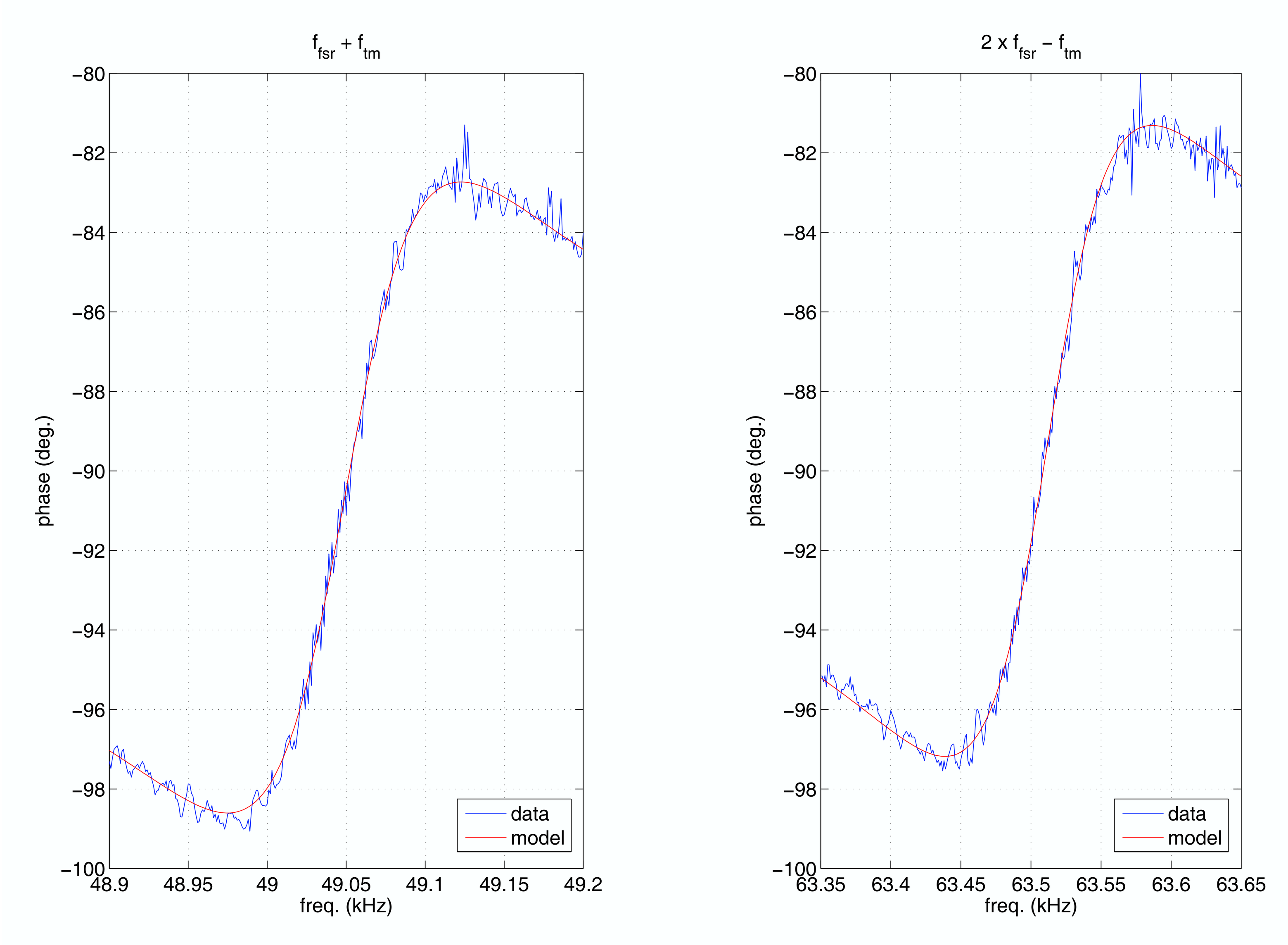
The laser frequency to PDH signal transfer function, $H_\omega(s)$, has cusps at multiples of the cavity free spectral range frequency (37.52 kHz) as well as features at frequencies related to the modulation sideband frequency.



When the cavity input beam is misaligned, features appear at frequencies dictated by the cavity transverse mode spacing frequency, f_{tm}. $f_{tm} = (f_{fsr}/\pi)\arccos(g_1 g_2)^{1/2}$ where $g_{1,2} = 1 - L/R_{1,2}$. R_1 and R_2 are the test mass radii of curvature. We thus infer the mirror radii of curvature by measuring the frequency of the related features in $H_w(s)$. This technique was first proposed by F. Bondu in 2002 (Rakhmanov, Bondu, Debieu, and Savage, *Class. Quantum Grav.* **21** (2004) S487-S492).

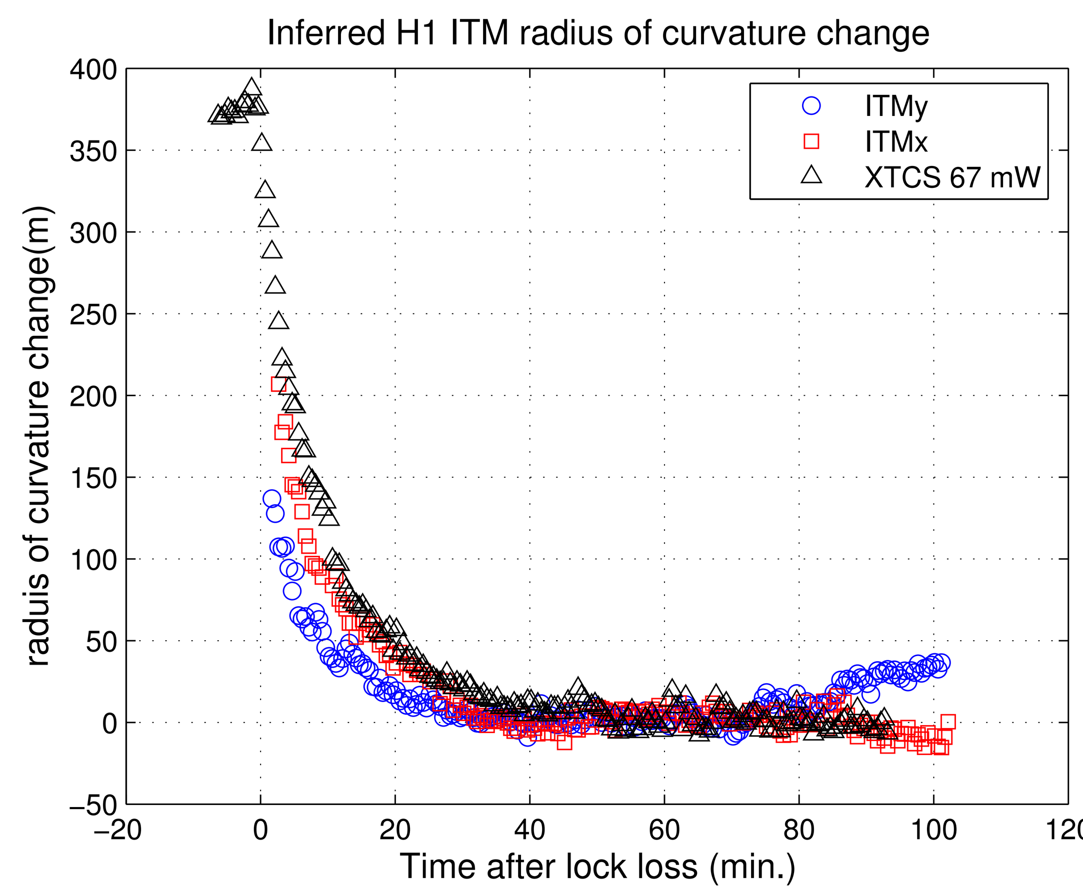


For these measurements, we lock a single arm of the interferometer, misalign the input beam, modulate the laser frequency and measure the response of the demodulated output of one of the anti-symmetric port photodetectors. We simultaneously measure the feature near 49 kHz ($f_{fsr} + f_{tm}$) and the feature near 63.5 kHz ($2 \times f_{fsr} - f_{tm}$). These features move in opposite directions as the cavity g factor changes.



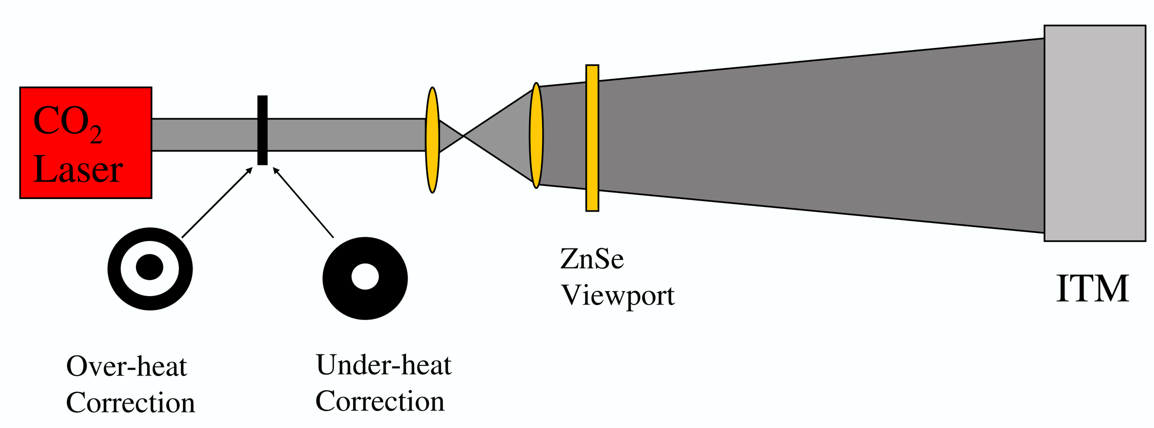
Thermal relaxation after breaking interferometer lock state

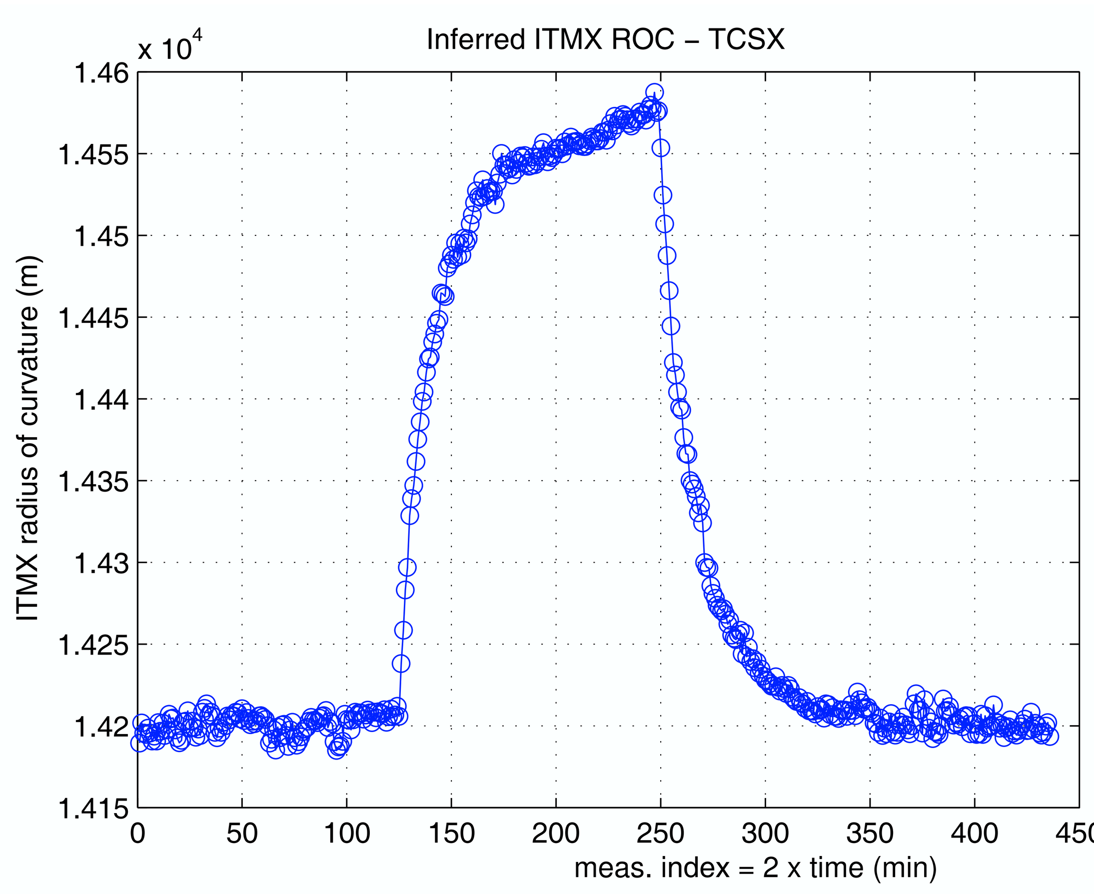
After allowing the fully-locked interferometer to reach thermal equilibrium (several hours) we break lock, lock a single arm, misalign the input beam, and measure the temporal evolution of the cavity g factor. If we assume that the end test mass curvature does not change (we suspect anomalously high absorption in the input test masses) we can infer an *effective* ITM curvature and compare it with the *cold* ITM curvature. This difference is the thermally-induced curvature change due to absorption of the 1064 nm laser light in either the surfaces or the substrate of the optic.



TCS calibration

The Thermal Compensation System (TCS) utilizes CO_2 lasers to compensate for mirror curvature changes. The 10 μm radiation is incident upon and absorbed at the high-reflecting surface of the input test masses. We utilize the TCS lasers to calibrate the curvature changes with a known amount of absorbed power.





TCS switched on at ~ index = 125. Laser power ~ 67 mW in annular heating pattern. TCS switched off at ~ index = 250 (one hour after turn on).

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