Parametric instability and its control

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Outline:

1. Simulation results of dual recycling interferometers (*Slawek*)
2. Gingin experiments to demonstrate principle of optical feedback control of PI (*Lucienne and Fan*)
3. Tabletop experiments to study PI and its control (*Viet*)

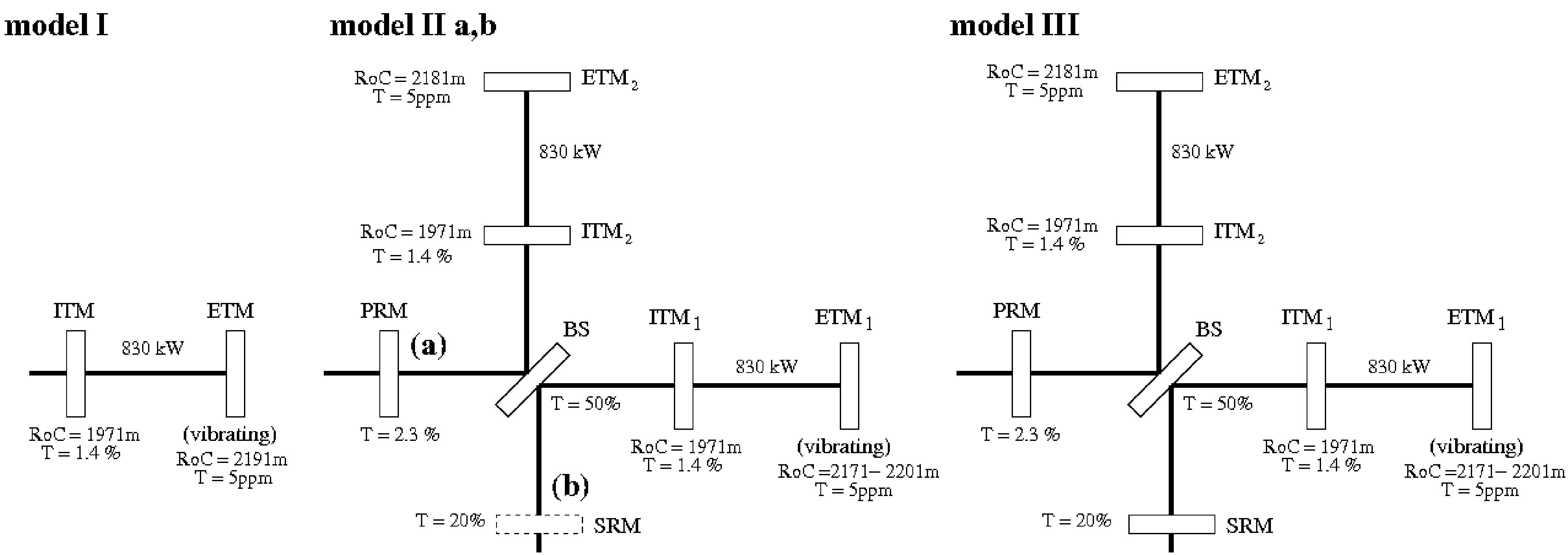
Parametric instability modeling for dual recycling interferometers

- Simulation done by *Slawek* based on the paper "Phys. Lett. A, 365, 10-16 (2007) " by S. E. Strigin and S. P Vyatchanin
- Two extreme cases are considered: all high order modes considered are exactly in-phase or out-of-phase with the carrier in PRC or SRC

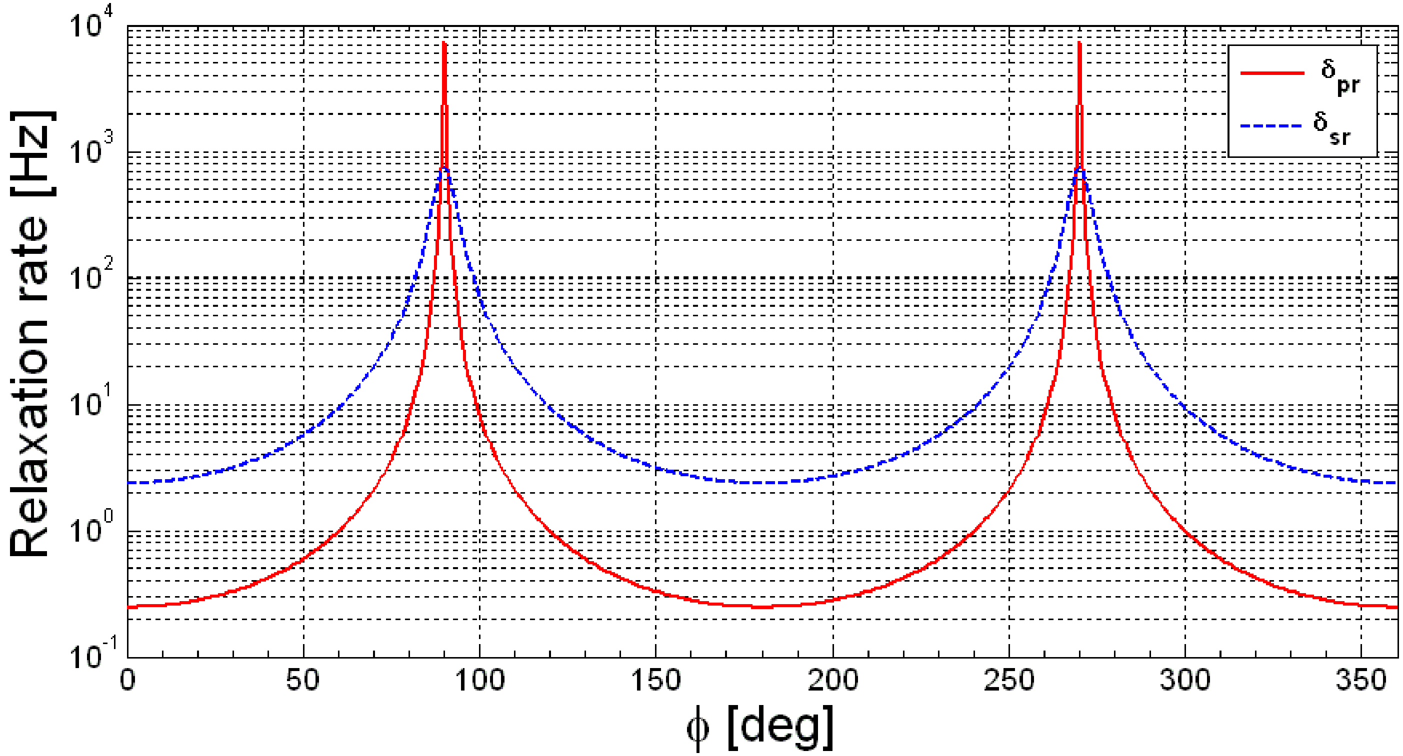
Parametric instability modeling for dual recycling interferometers

- Use AdvLIGO test mass parameters and
  - take into account coatings and flats on circumference.
  - 5500 acoustic modes considered
  - Cavity modes up to 9th order
  - Asymmetry in radius of curvature of the interferometer arm cavity test masses
  - Only one ETM acoustic modes are considered

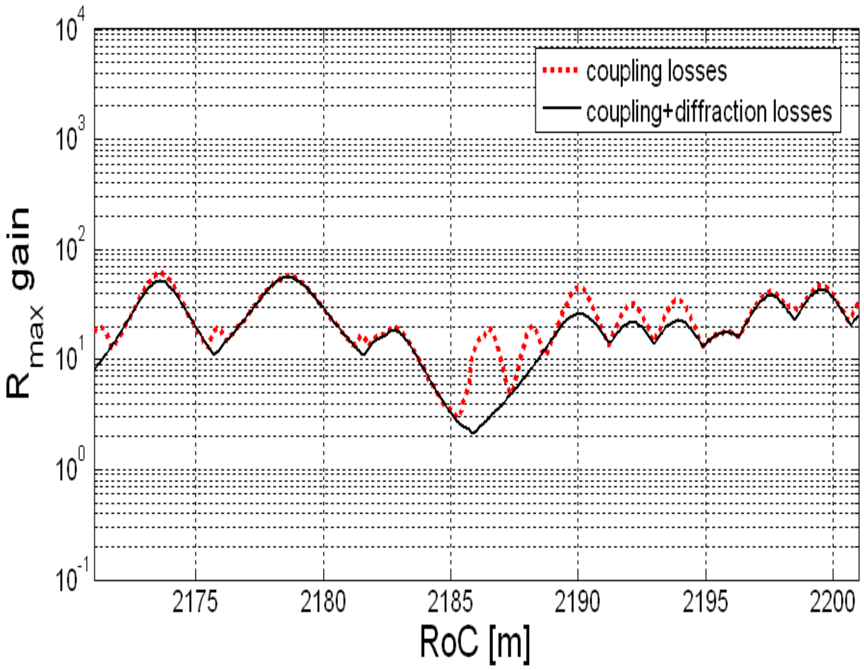
4 configurations are simulated

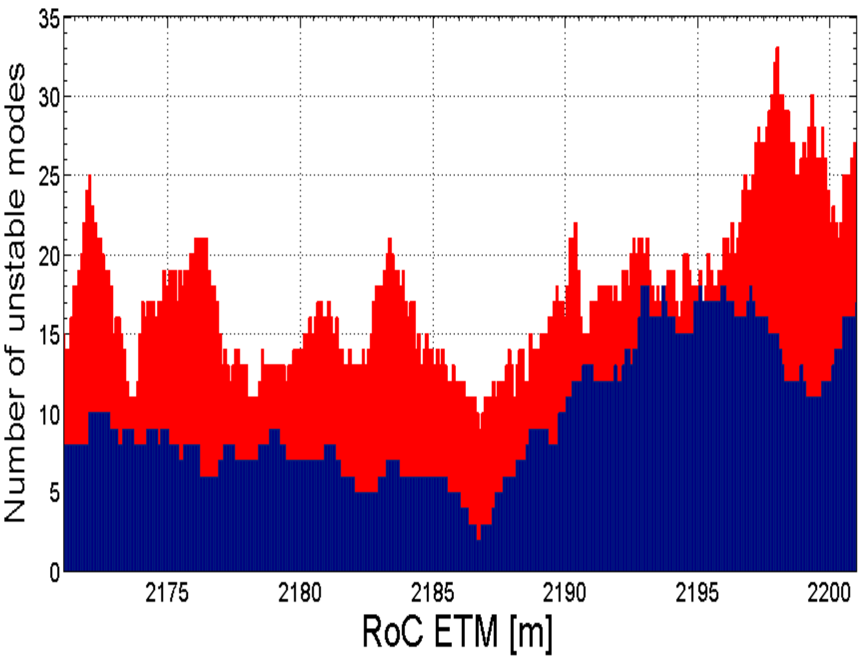


The relaxation rates considering PRC and SRC as compound mirrors

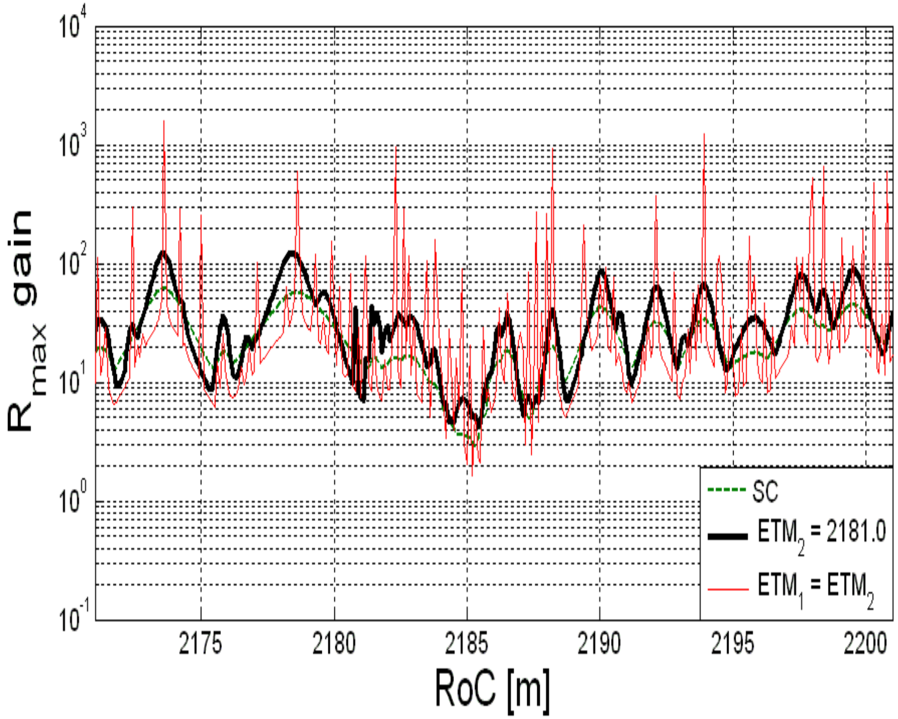


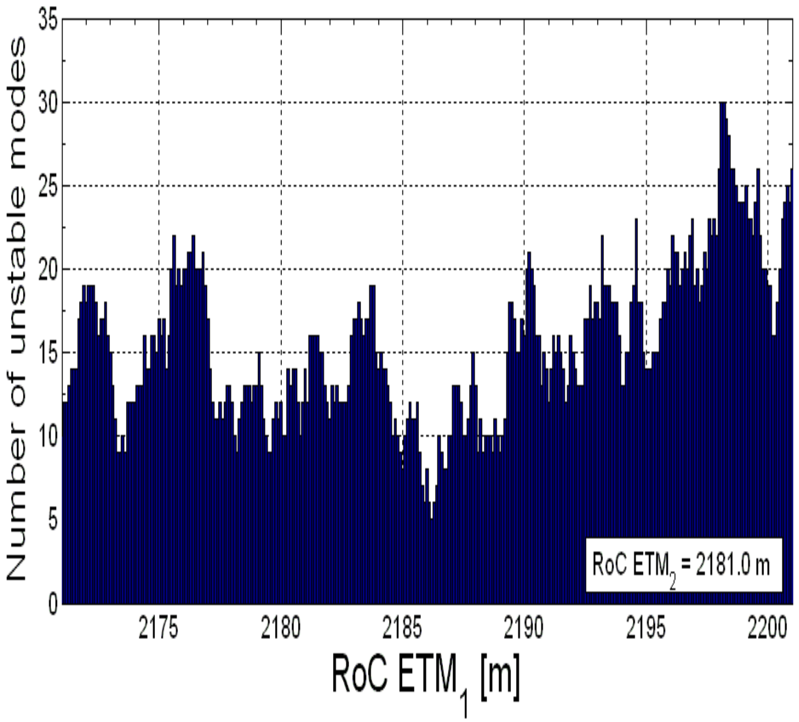
Single cavity case: high order mode diffraction losses make difference



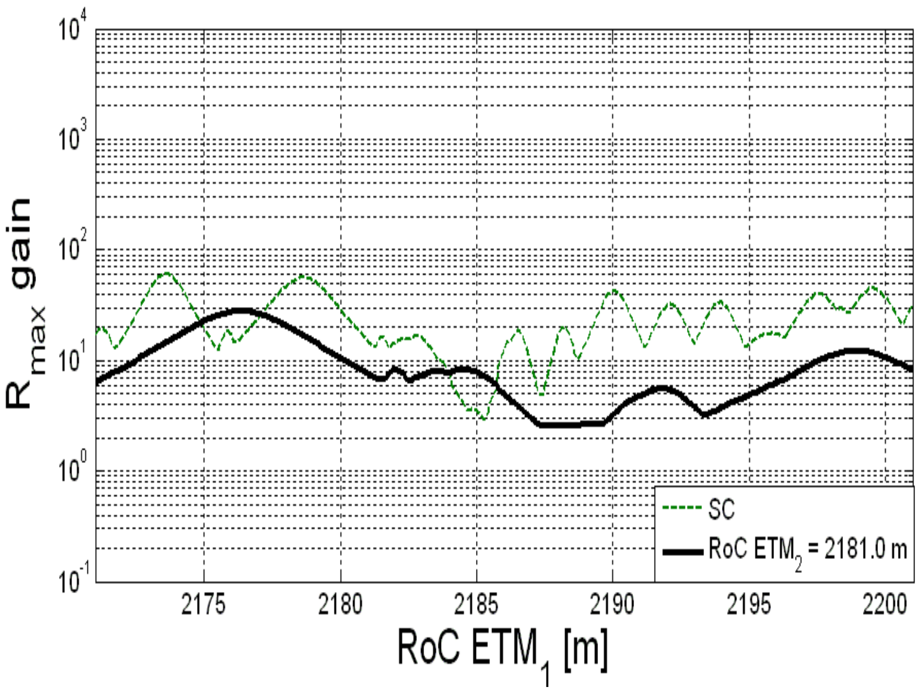


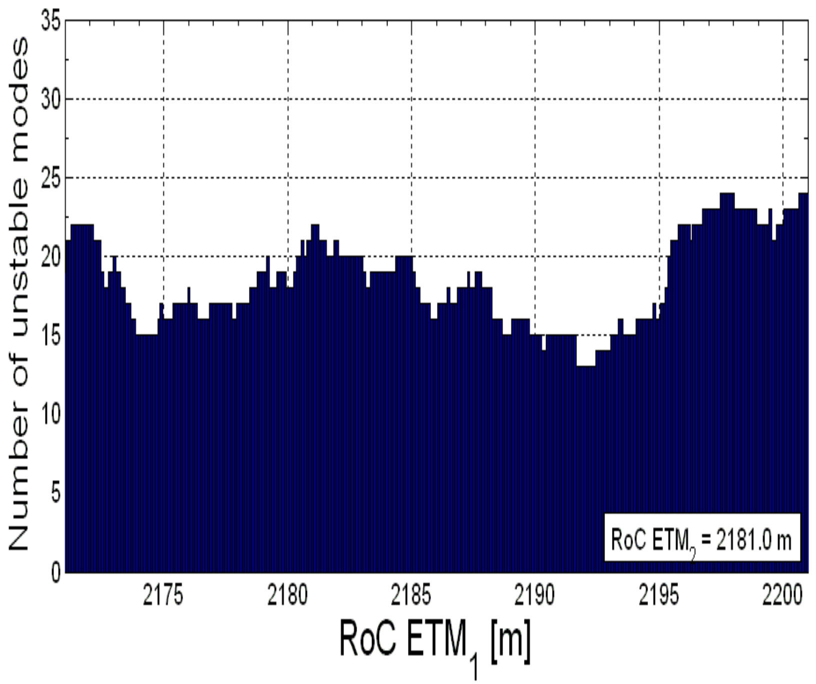
Power recycling interferometer, assuming all high order modes having low transmission through PRC



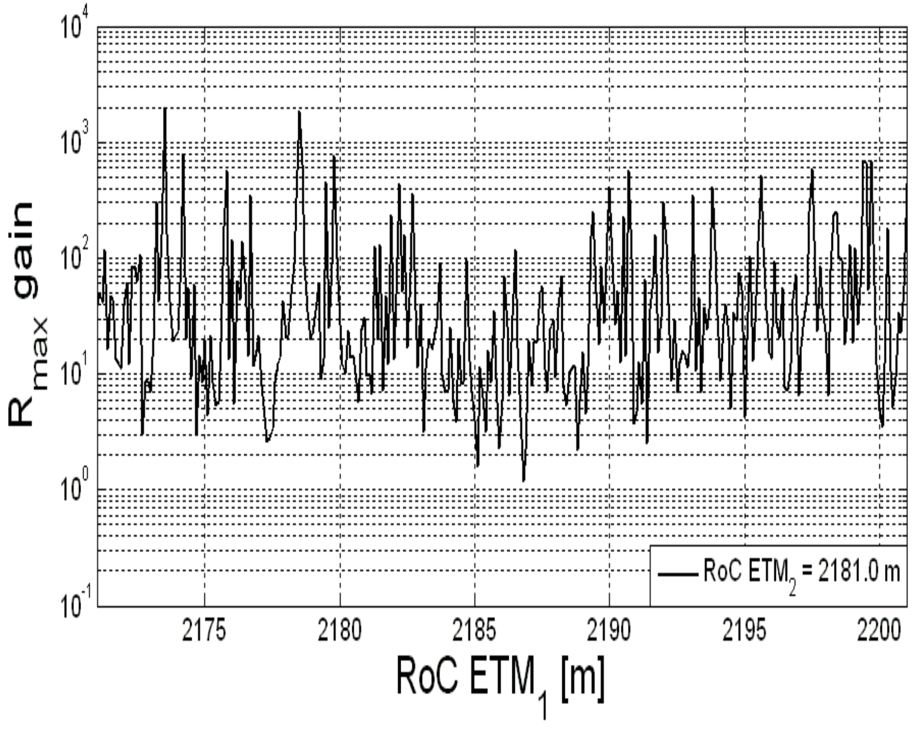


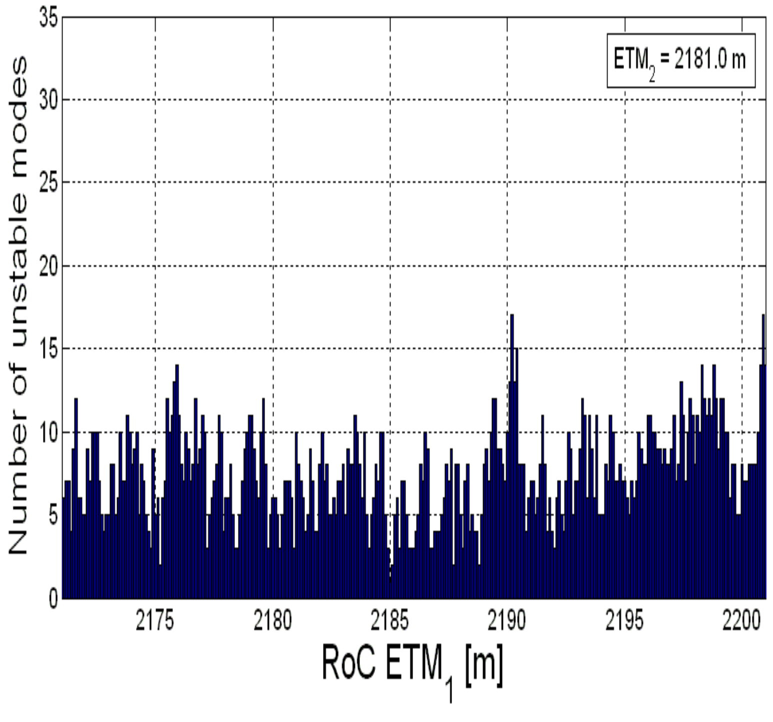
Power recycling interferometer, assuming all high order modes having high transmission through PRC



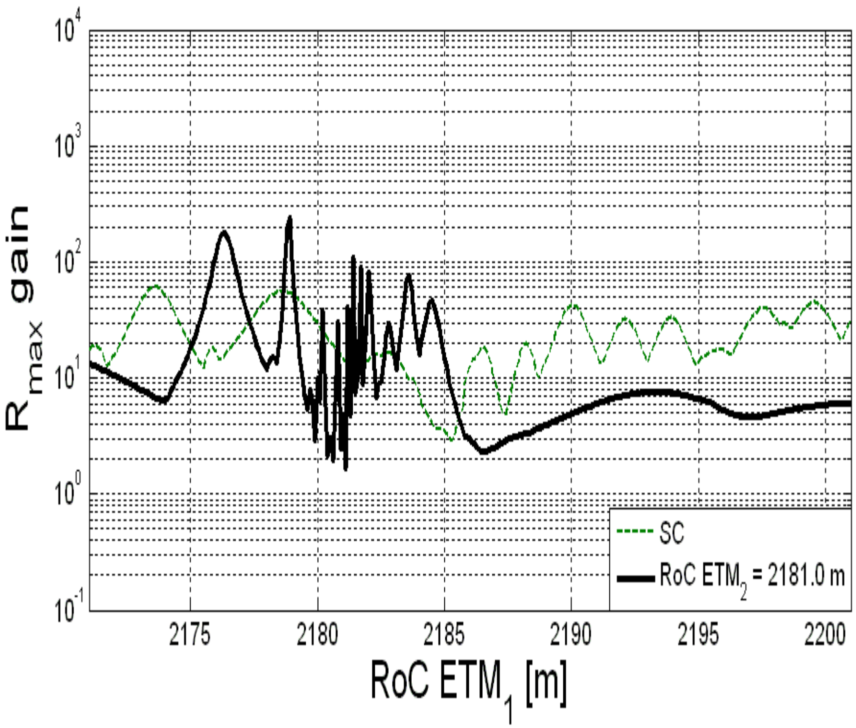


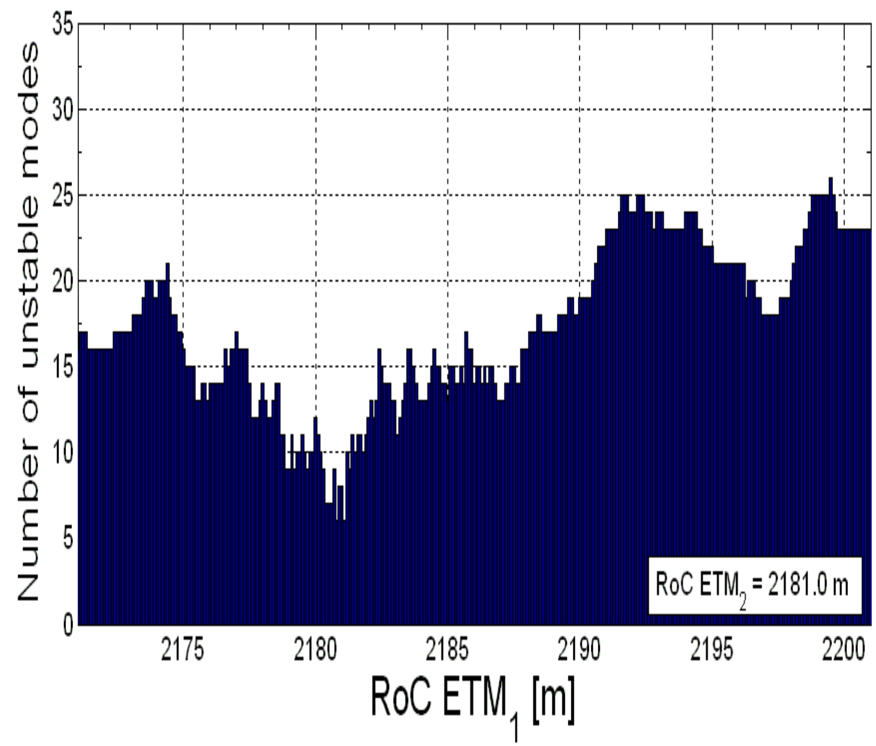
Dual recycling interferometer, assuming all high order modes having low transmission through PRC and high transmission through SRC



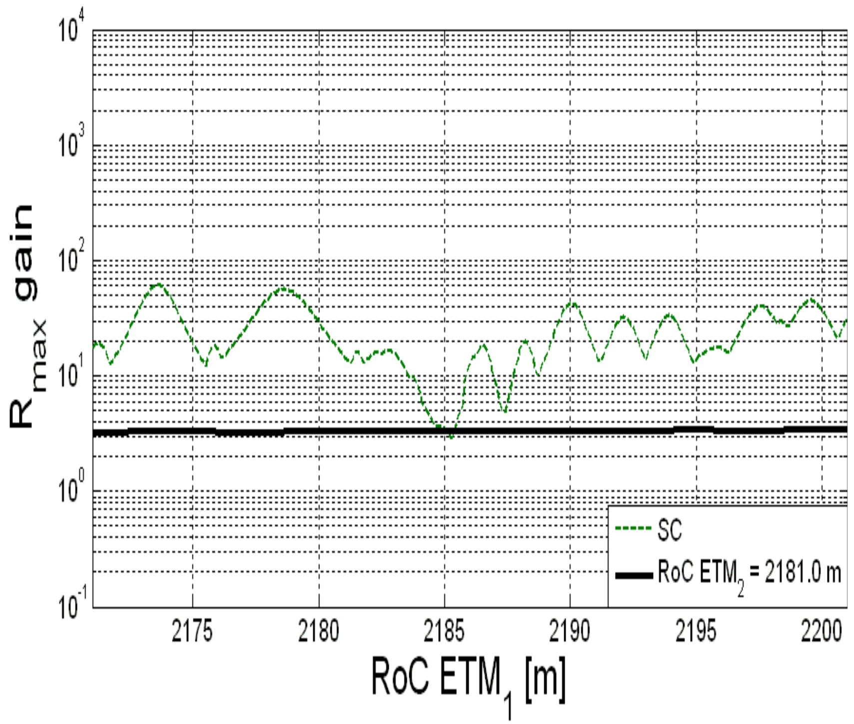


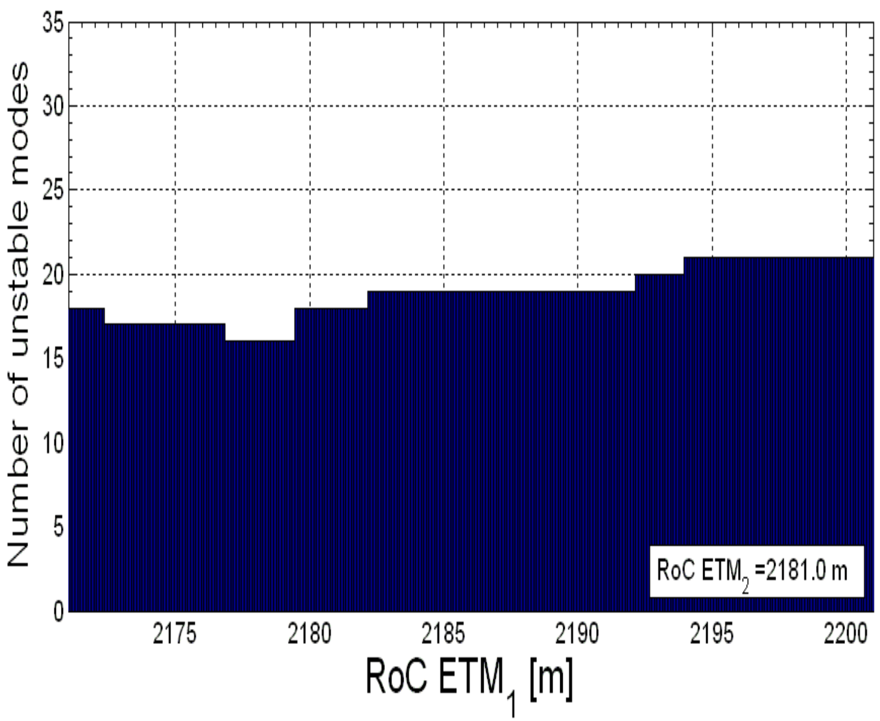
Dual recycling interferometer, assuming all high order modes having high transmission through PRC and low transmission through SRC



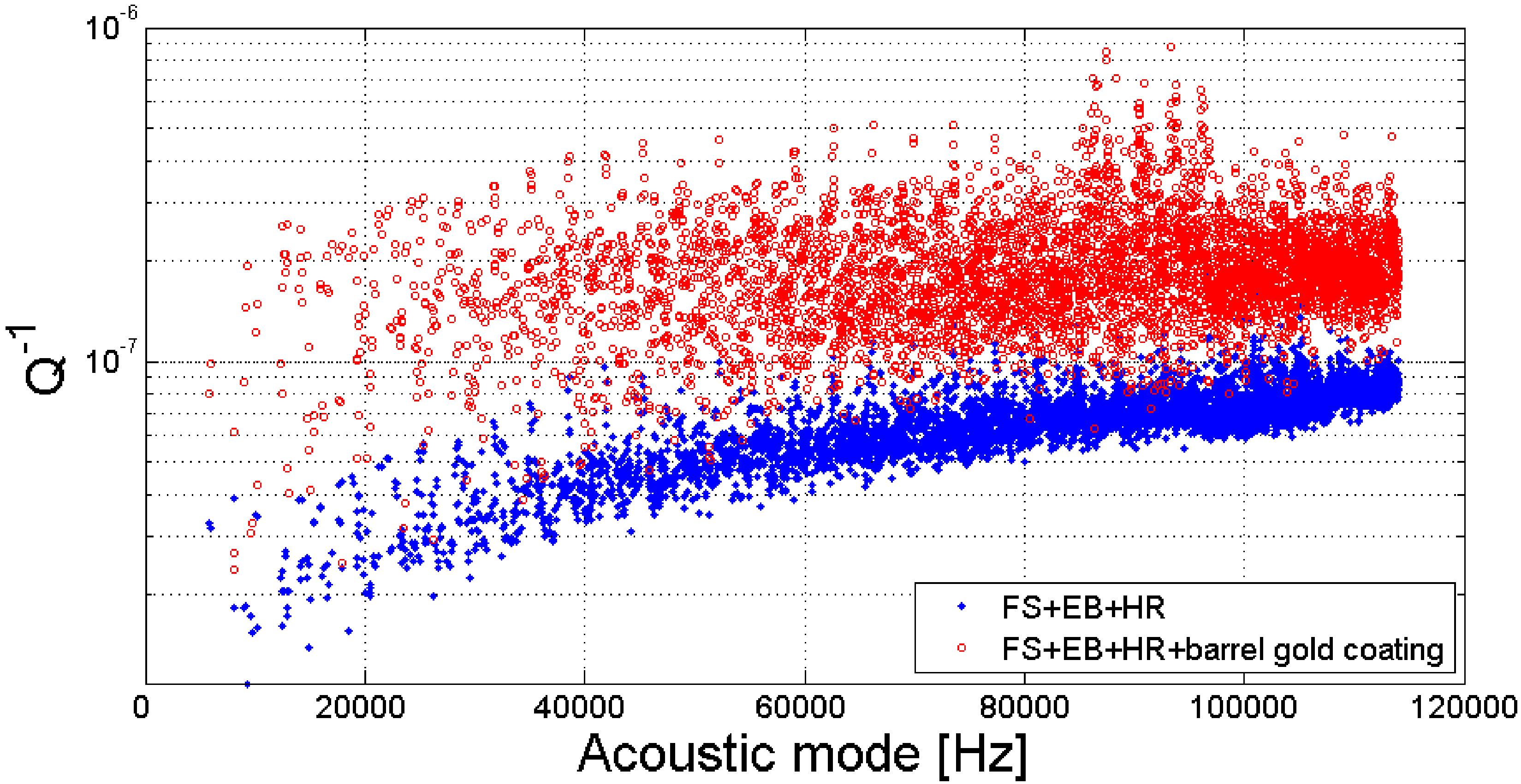


Dual recycling interferometer, assuming all high order modes having high transmission through both PRC and SRC



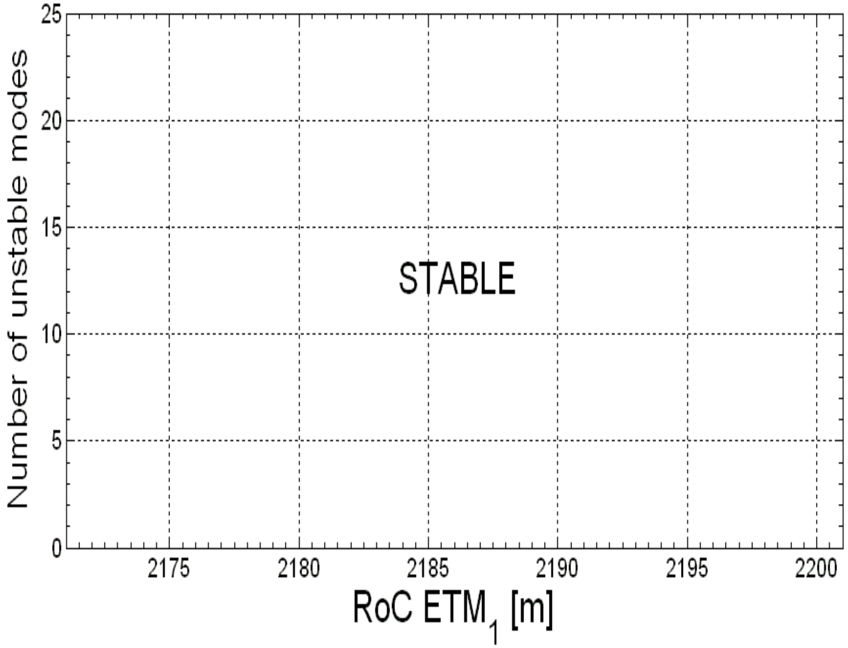


Acoustic mode suppression due to the barrel gold coating on ETM

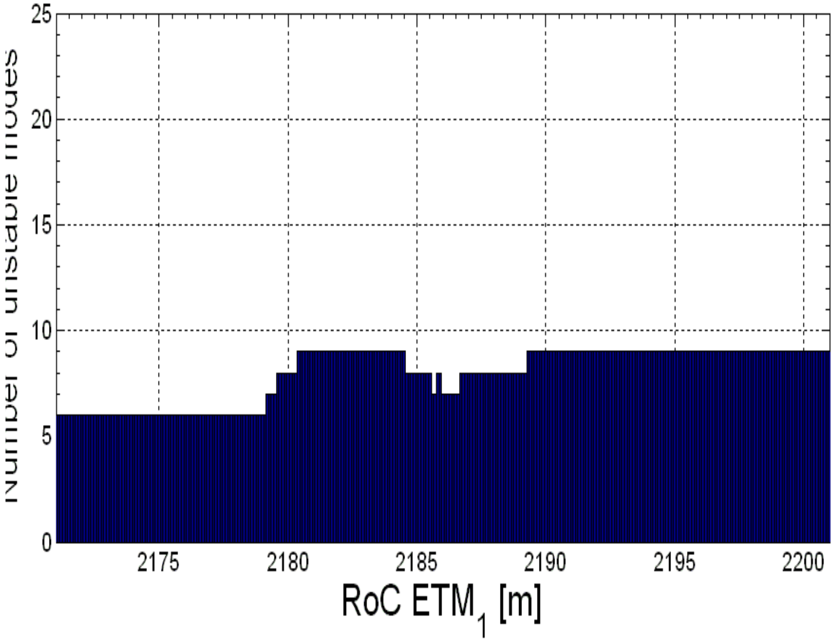


Dual recycling interferometer with barrel gold coating test masses, assuming all high order modes having highest transmission through PRC and SRC

415kW



830 kW



Summary:

- Two extreme cases are considered in the simulation that represents the best and worst situations in terms of PI
- The real interferometers will sit in between
- IF we could design such stable PRC and SRC that have high transmission for most lower order high order modes, the PI gain will be close to the best situation

How to Control PI

Reduce Q_1 with minimum sensitivity deterioration

Reduce Q_m with minimum noise: dampers

Parametric Gain: $$R = \frac{8 P_{in} Q_0 Q_1 Q_m}{L^2 \omega_0 \omega_m^2} \frac{\gamma B_1 / m_{eff}}{1 + \left(\Delta\omega / \delta_1 \right)^2}$$

$Q_{0,1,m}$: Q-factors of the cavity modes, TEM_{00} and TEM_{mn}, and the acoustic mode respectively

$\Delta\omega = \omega_0 - \omega_1 - \omega_m$

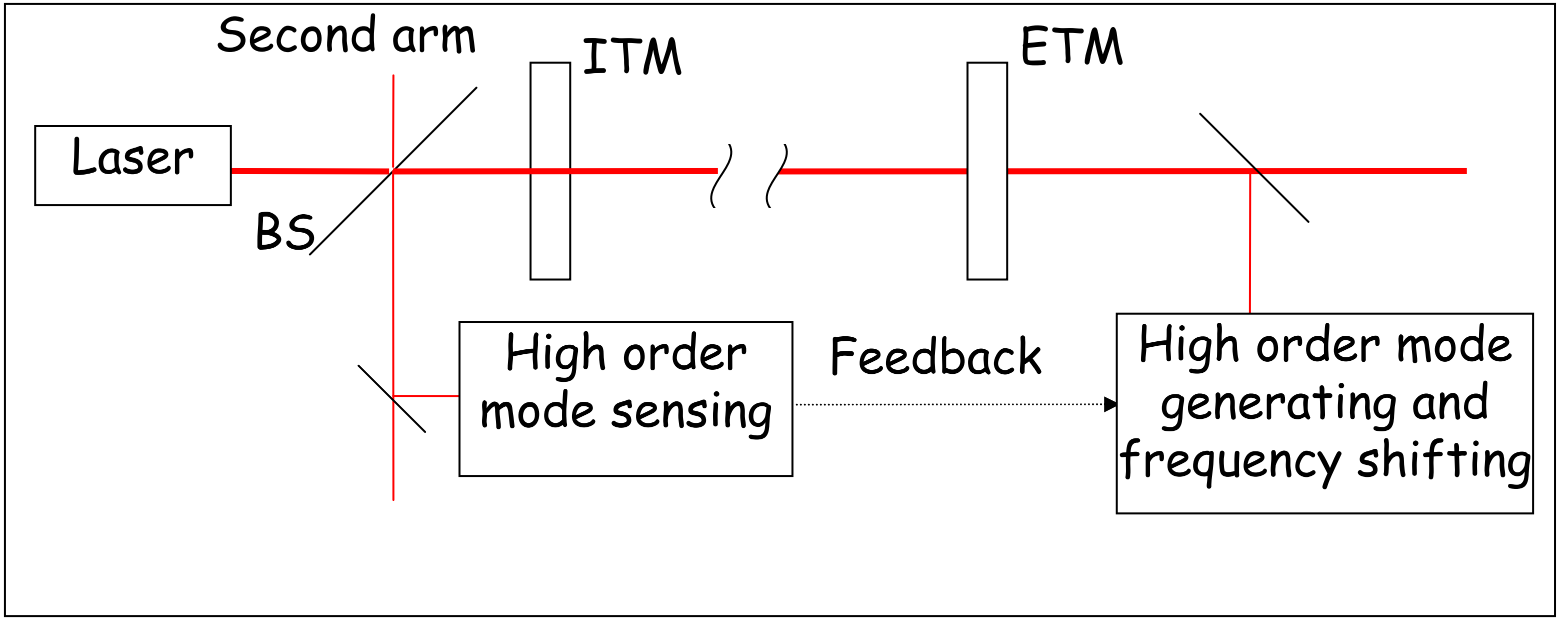
ω_0 : the frequency of the TEM_{00} mode

ω_1 : the frequency of the TEM_{mn} mode

$\delta_1 = \omega_1 / 2Q_1$

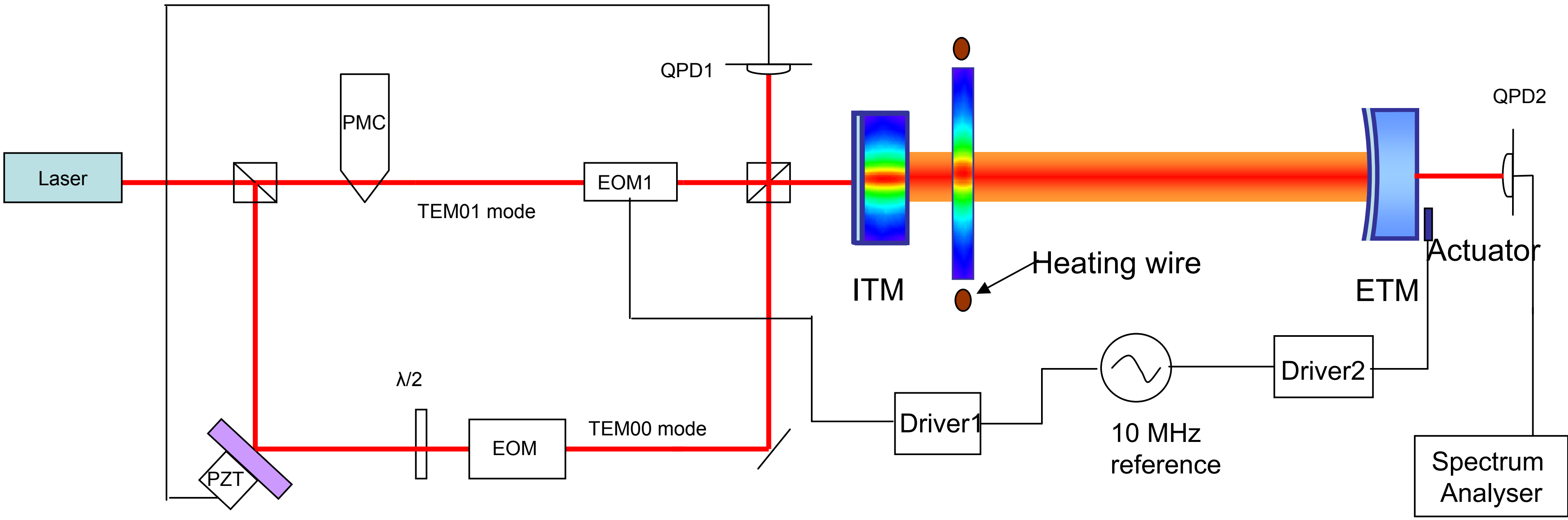
*V. B. Braginsky, S. E. Strigin, & S. P. Vyatchanin, Phys. Lett. A, **287**, 331-338 (2001)*

Proposed ETM injection schematic



- ETM transmission to be re-injected into the cavity
- Two AOMs create right frequency shift
- Deformable mirror generates suitable high order mode pattern

Gingin South Arm Experiments



•The TEM00 mode and TEM01 mode beams are phase locked with a Mach-Zehnder and injected to the cavity simultaneously.

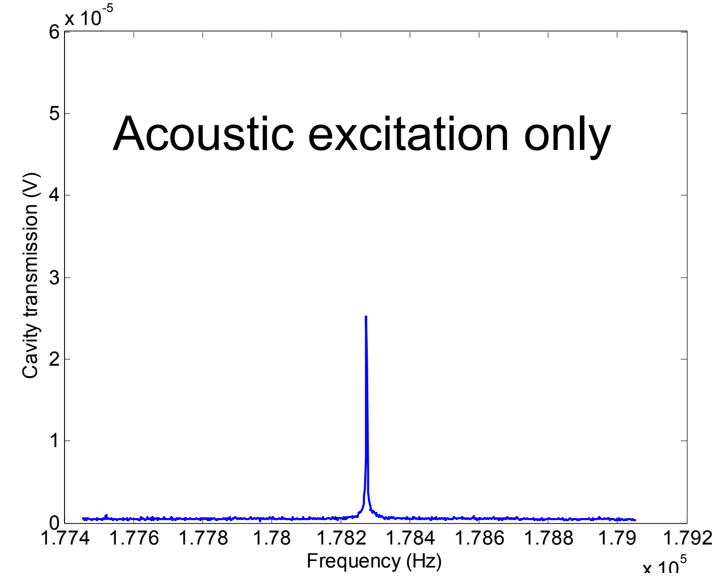
•Driver1 and Driver2 are two function generators synchronized by a 10 MHz reference signal.

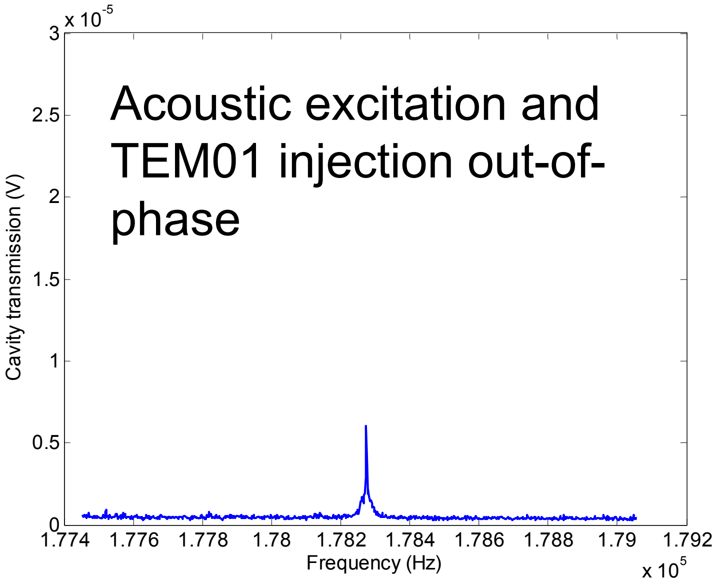
•Driver2 drives the ETM acoustic mode at resonance frequency of ~ 178kHz. The spectrum analyser detects signal from the split photodiode QPD2

•Driver1 drives the EOM at the same frequency as Driver2 to creates sidebands at the same frequency as the scattering by the ETM acoustic mode.

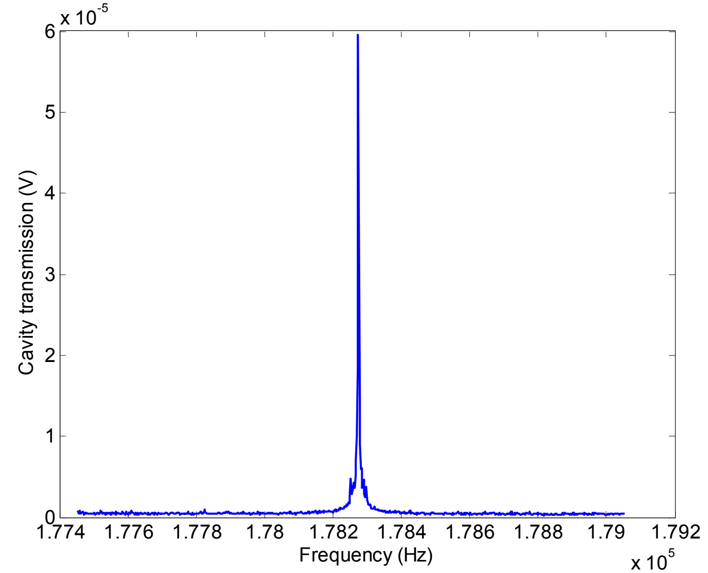
•By manually tuning the phase difference between Drver1 and Driver2 outputs we can observe the signal on the spectrum analyser at ~178 kHz being increased or suppressed as shown in the next slide.

Beating signal at the cavity transmission





Acoustic excitation and TEM01 injection in-phase



Gingin east arm experiments

Received two fused silica test masses with following parameters:

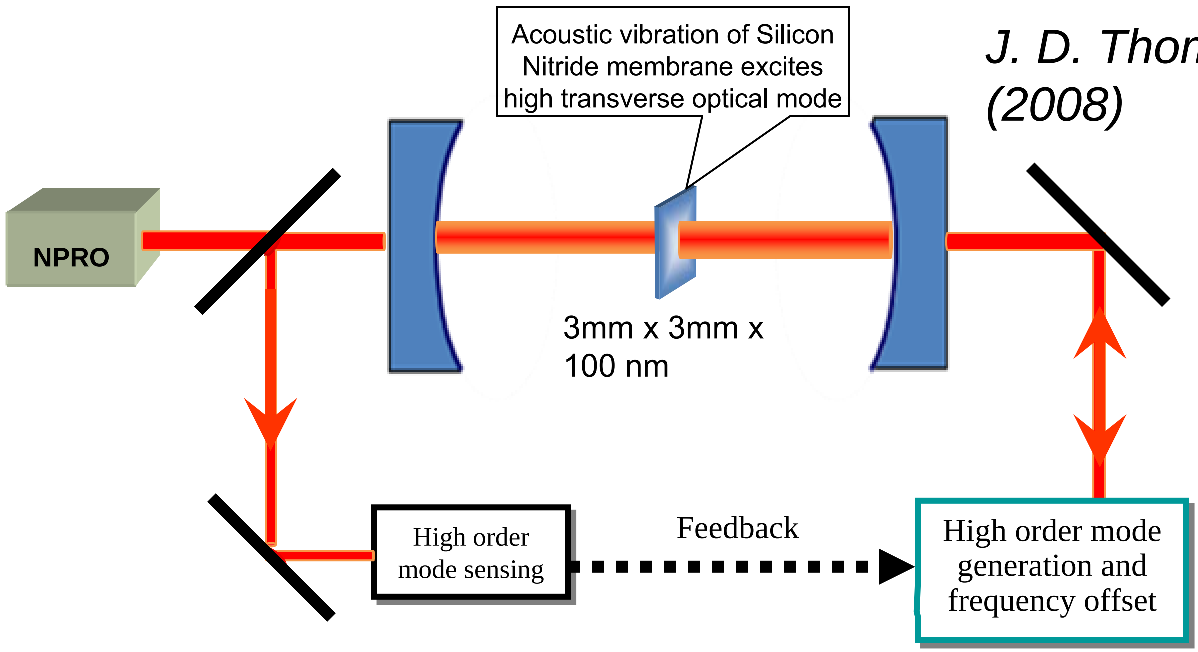
ITM: R>=99.97%; T>=200 ppm; RoC=37.4 m; 100mm in diameter, 50mm thick.
ETM: R>=99.99%; 37.5 m Concave, 100mm in diameter and 50mm thick.

Cavity length: ~73.4 M

Aim to observe PI of gain ~20 at 50 W input power and test various control schemes.

Tabletop experiments

J. D. Thompson, Nature06715 (2008)



- A ~0.5 meter cavity plus a 3mm by 3mm by 100nm membrane have been setup in a vacuum chamber.
- The cavity has been locked to the TEM00 mode, The cavity bandwidth ~100kHz.
- With offset locking we observed the self-oscillations at ~ 60 kHz which is the drum mode frequency of the membrane (2-mode instability).
- The next step is to tune the cavity length and make the high order mode resonance simultaneously with TEM00 mode and hopefully to see the 3-mode instability soon.