Gingin 80m research facility for Advanced Detectors

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Outline

- Summary of previous experiments
  - Thermal lensing and thermal compensation
  - Parametric instability
  - Sidles-Sigg instability
  - ***Advanced vibration isolators (Jean-Charles and Pablo on Tuesday)***
- Proposed experiments in the near future
  - Study of self-sustained instability
  - Demonstration of optical feedback control for suppressing the instability
  - Demonstration of double optical springs (DOS)
  - Demonstration of local readout scheme
- Conclusions

High optical power effects

- **Thermal lensing**

  The optical power absorbed by test masses induces thermal expansion and thermal optical coefficient change and leads to lensing effect inside the test mass.

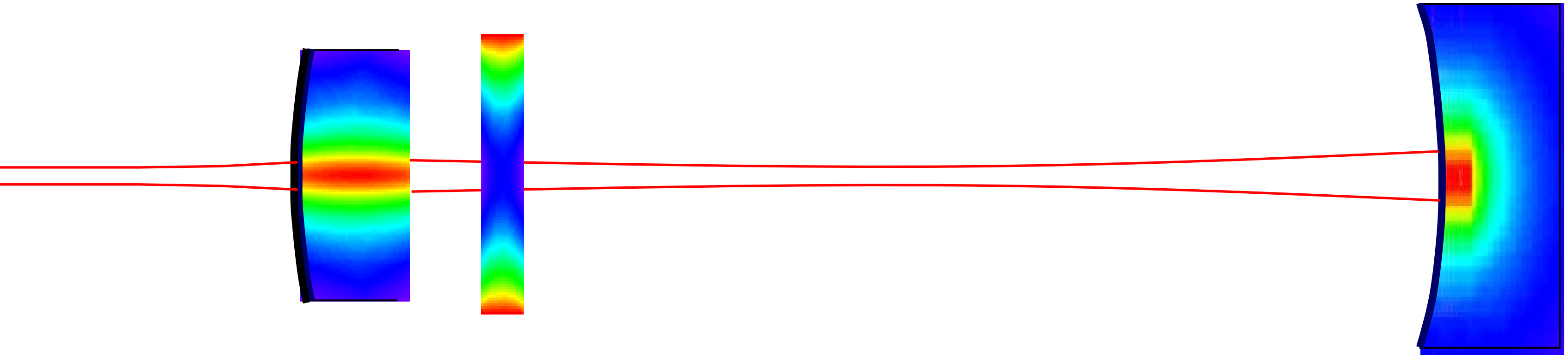
- **Parametric instability**

  Optoacoustic interactions between test mass acoustic modes and arm cavity optical modes mediated by radiation pressure force induces excitation of acoustic mode and instabilities

- **Sidles-Sigg Instability**

  Radiation pressure induced cavity alignment instabilities

Thermal Lensing and thermal compensation

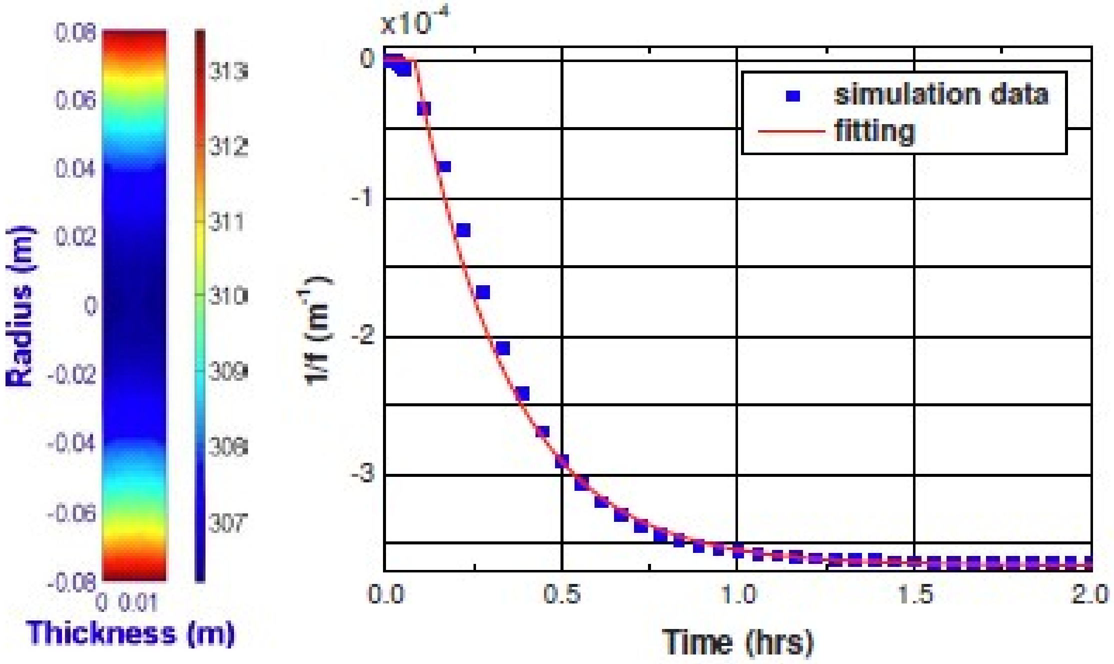


Input Test Mass
ROC = 2.5 km
Absorbed Power = ~0.5W

End Test Mass
ROC = 720m

Thermal Gradient: Jerome Degallaix

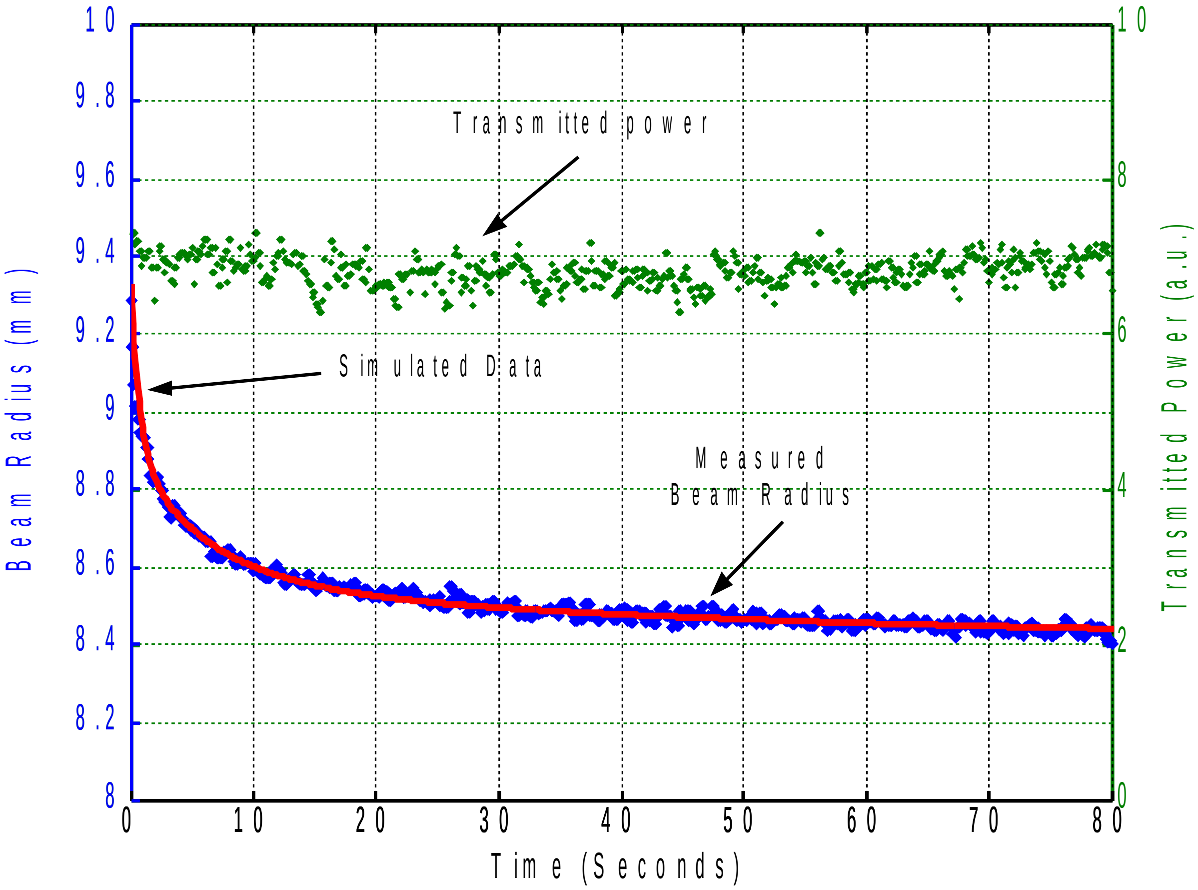
Thermal Lensing and thermal compensation



(a) (b)

Time evolution of the inverse of the focal length of the compensation plate

Thermal Lensing and thermal compensation



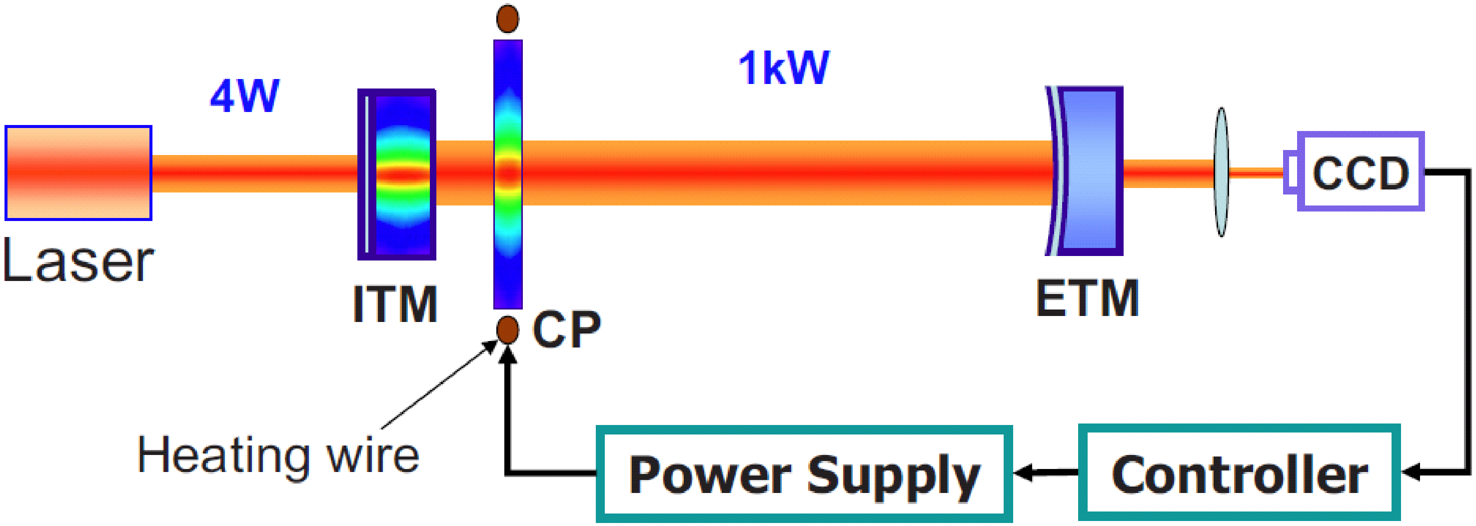
C. Zhao, et al, PRL **96, 231101 (2006)**

Results confirmed predictions by Vinet and Hello

Real time thermal lensing monitoring using Adelaide’ s Hartmann sensor

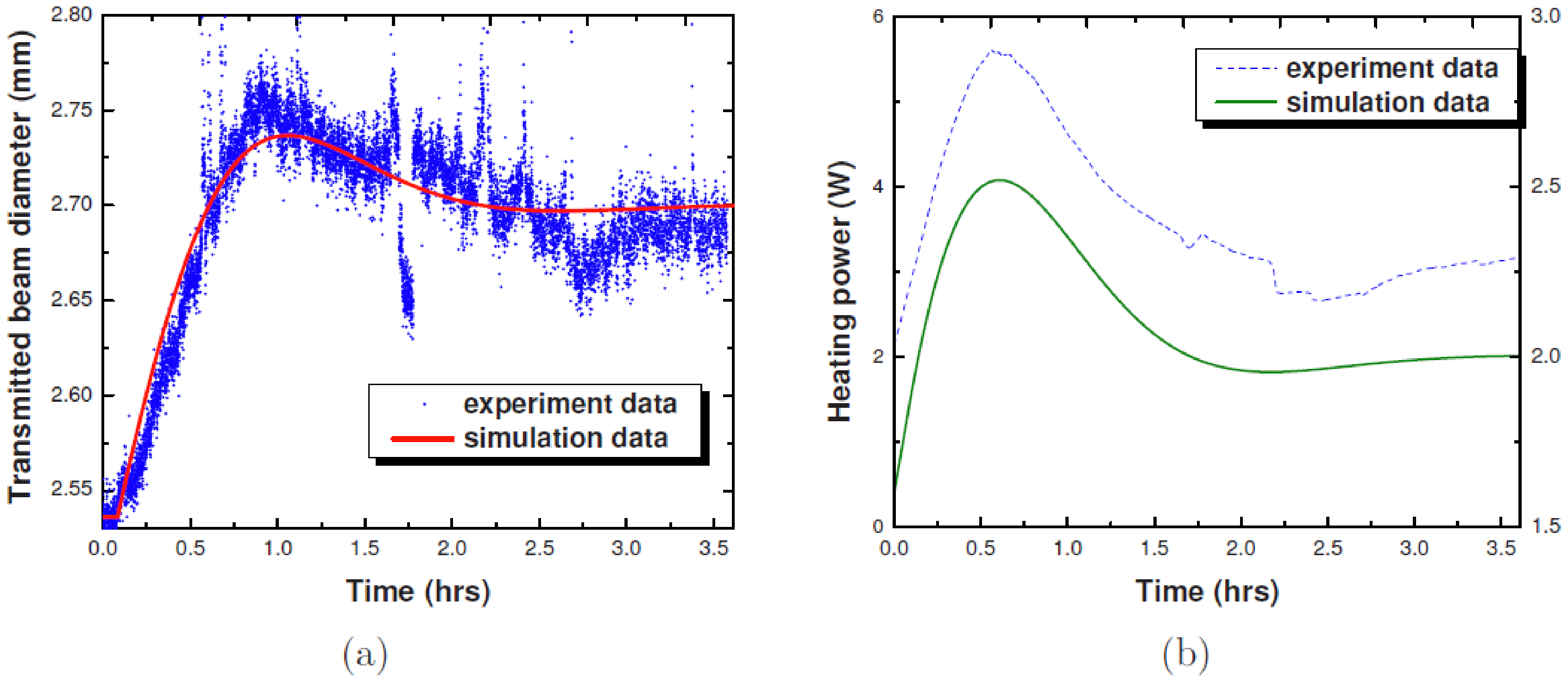
A. Brooks, et al, Applied Optics Vol. 48, Iss. 2, pp. 355–364 (2009)

Feedback Control of Thermal Lensing



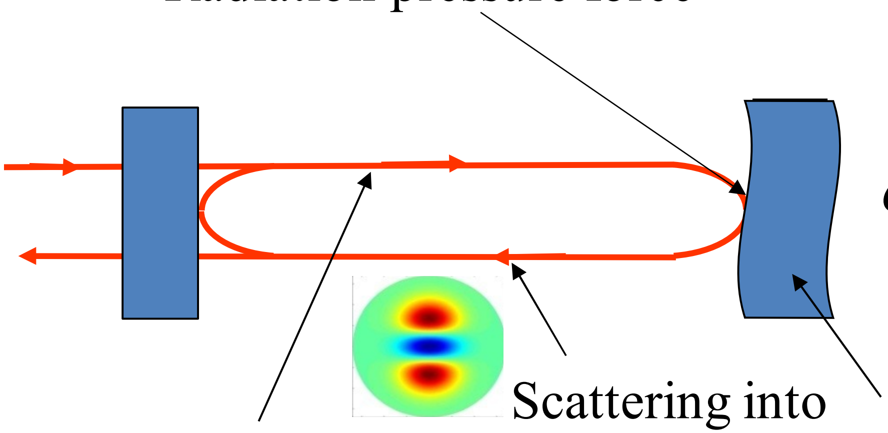
Y. Fan, et al, Rev. Sci. Instrum. **79, 104501 (2008)**

Feedback Control of Thermal Lensing



(a) The time evolution of the transmitted beam size as the feedback control system was applied. The blue dots are experimental data while the solid curve is the simulated result . (b) A dash plot of measured time dependence of the heating power applied onto the compensation plate

Parametric Instability



Radiation pressure force

Input light
frequency ω_o

$$\omega_0 - \omega_1 = \pm\omega_m$$

Cavity Fundamental mode
(TEM$_{00}$, frequency ω_o)

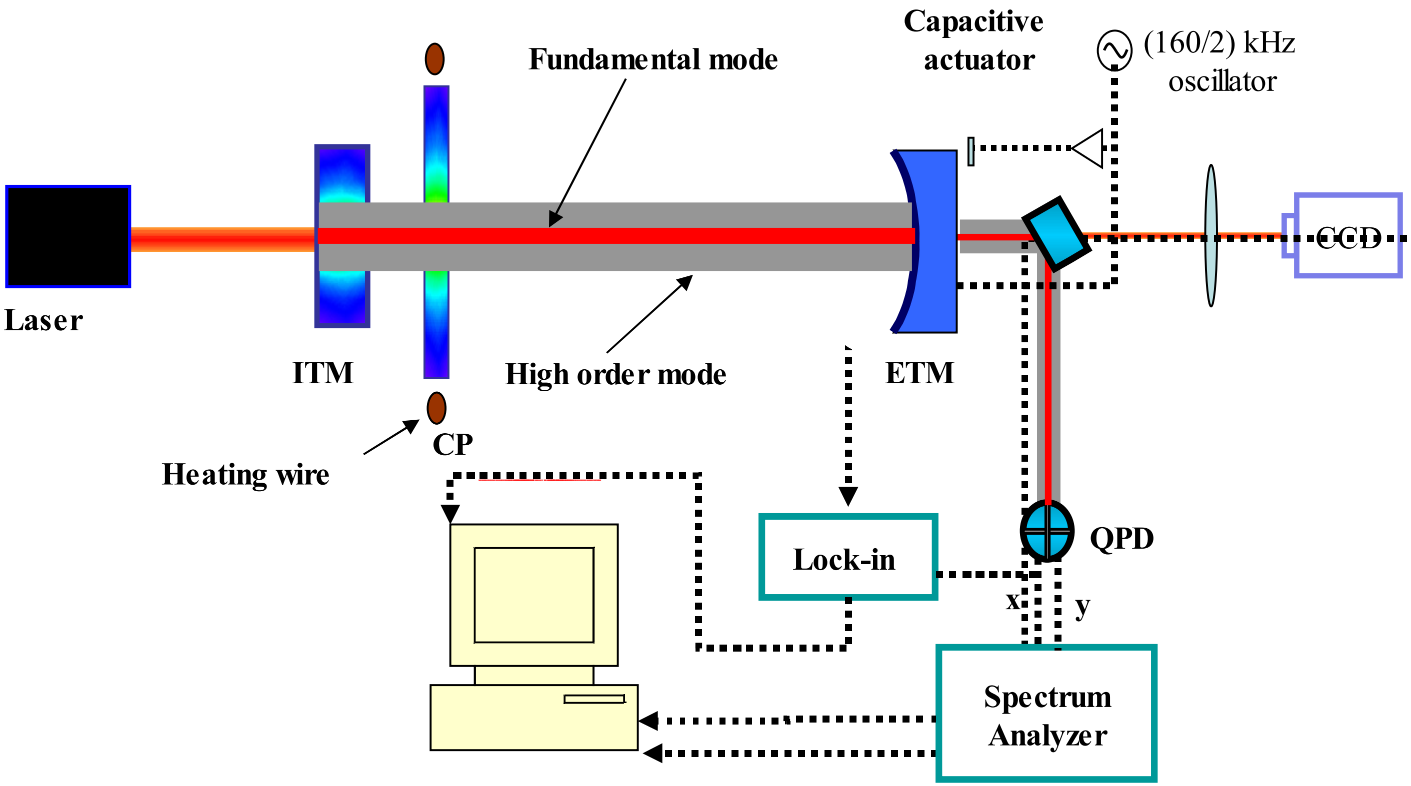
Scattering into
TEM$_{mn}$,
frequency ω_1

Acoustic mode ω_m

3-mode interaction requires **frequency matching** and **spatial overlap** of acoustic and optical modes

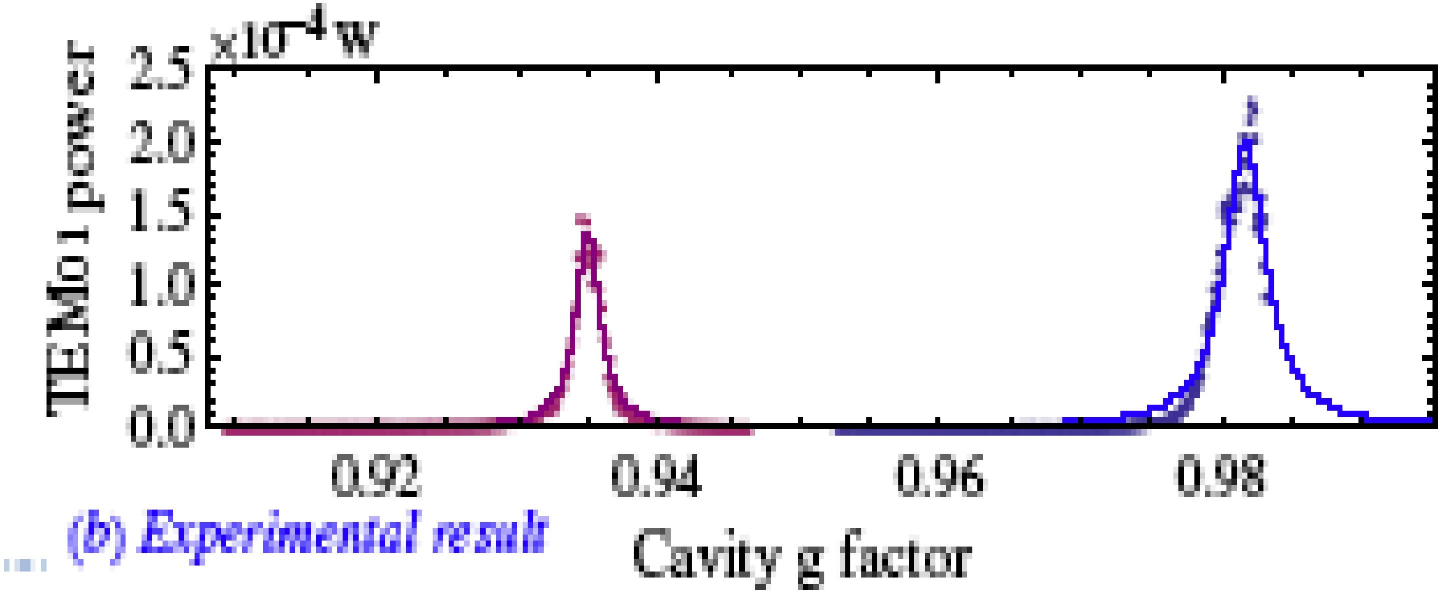
V. B. Braginsky, S. E. Strigin, & S. P. Vyatchanin, Phys. Lett. A, ***287**, 331-338 (2001)*
C. Zhao, et al, Phys. Rev. Lett. **94**, 121102/1-4 (2005)
L. Ju, et al, Phys. Lett. A, **354**, *360-365* (2006)

Parametric instability experiments: Observation of 3-mode Parametric Interactions



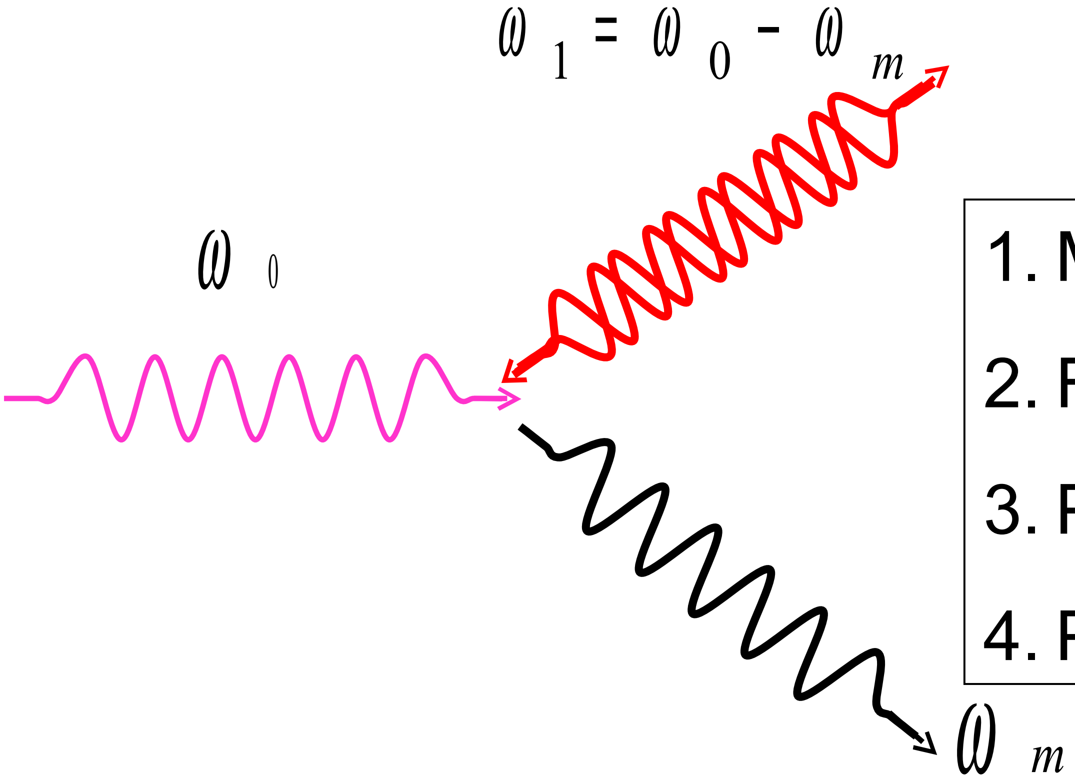
C. Zhao, et al, Phys. Rev. A **78, 023807 2008**

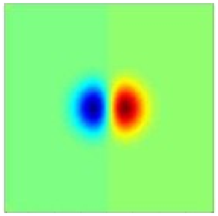
Parametric instability experiments: Observation of 3-mode Parametric Interactions



- Witnessed two high order transverse modes corresponding to two different mechanical modes of the mirror parametric gain ~ 0.01

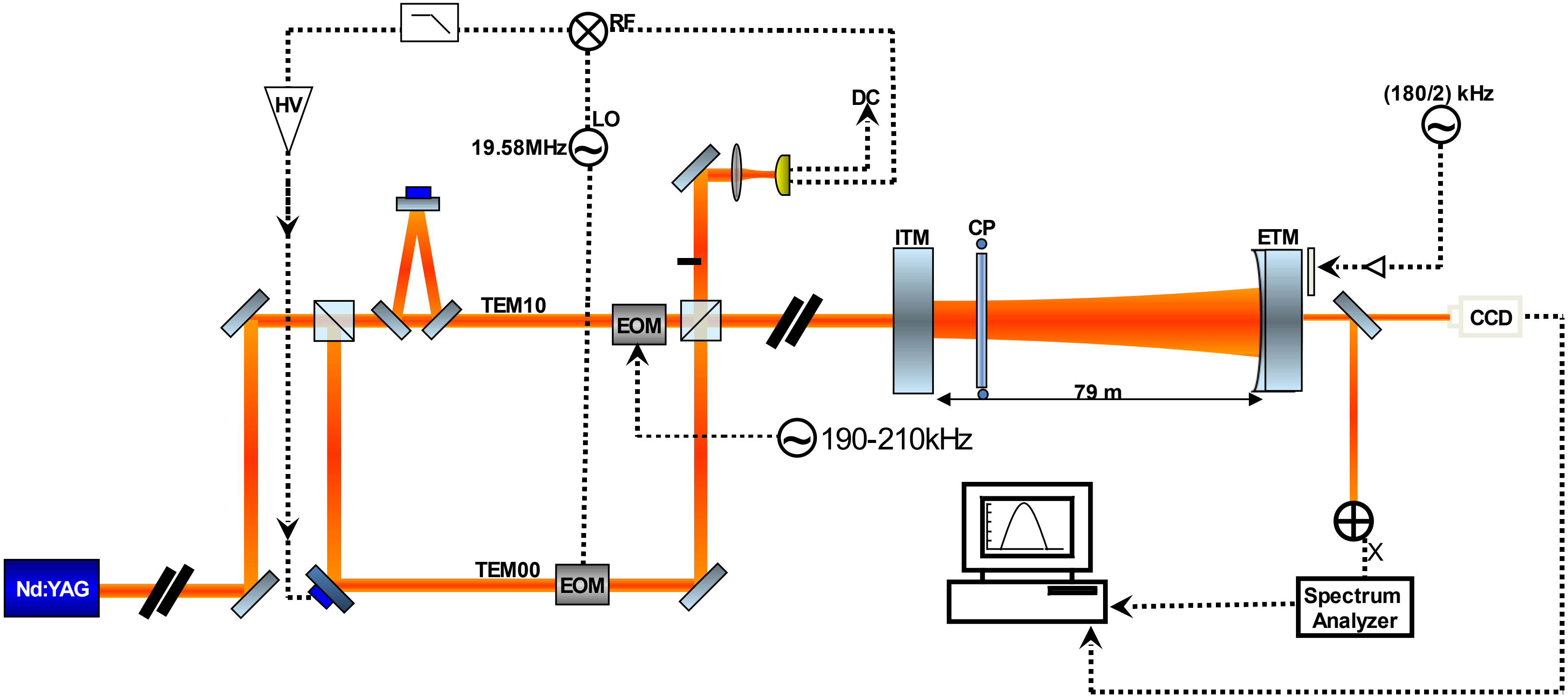
Optical feedback control





1. Mode shape
2. Frequency
3. Phase
4. Power

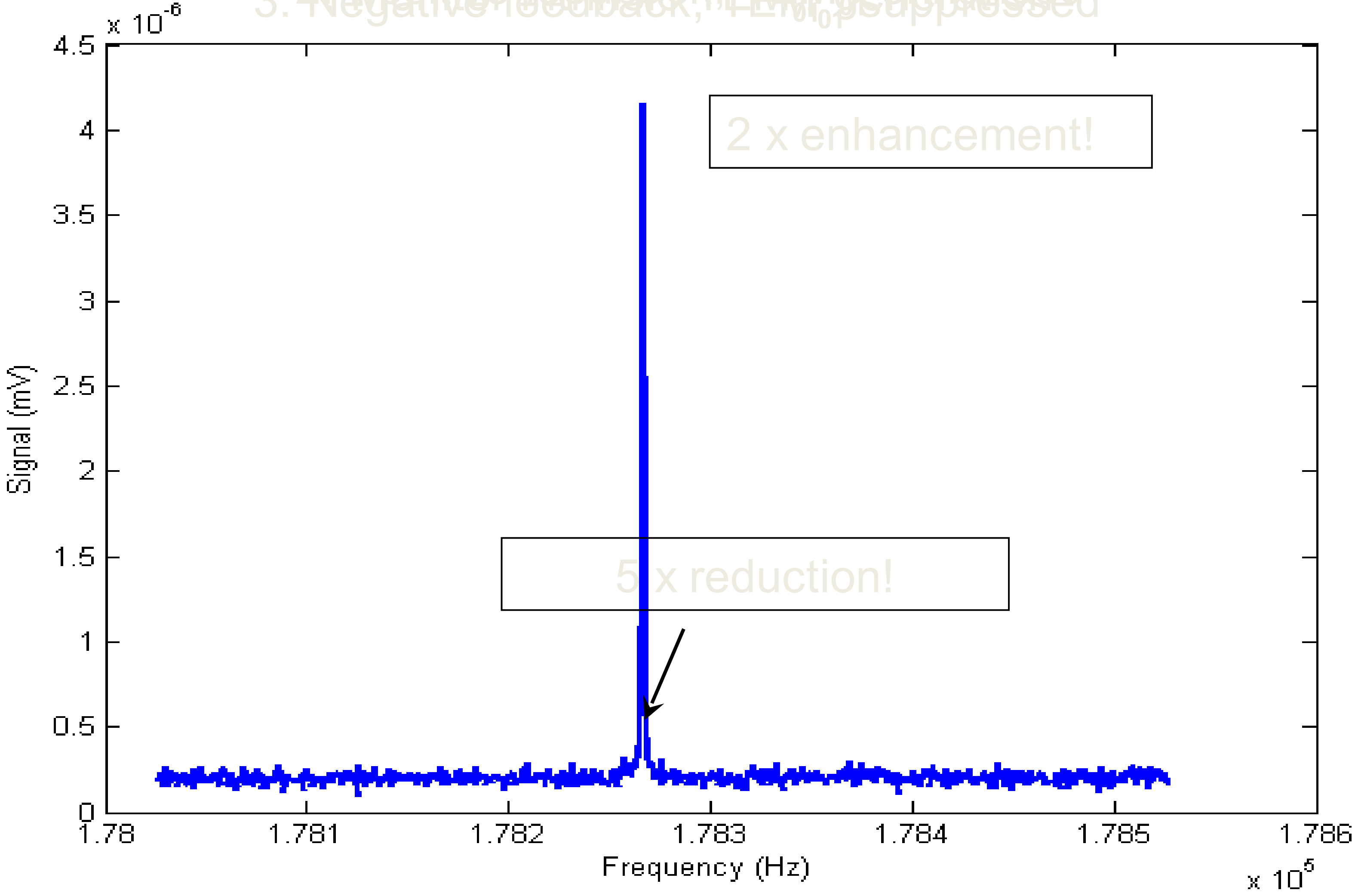
Demonstration of optical feedback control principle



Demonstration of optical feedback control principle

2. Positive feedback, TEM_{01} enhanced

3. Negative feedback, TEM_{01} suppressed

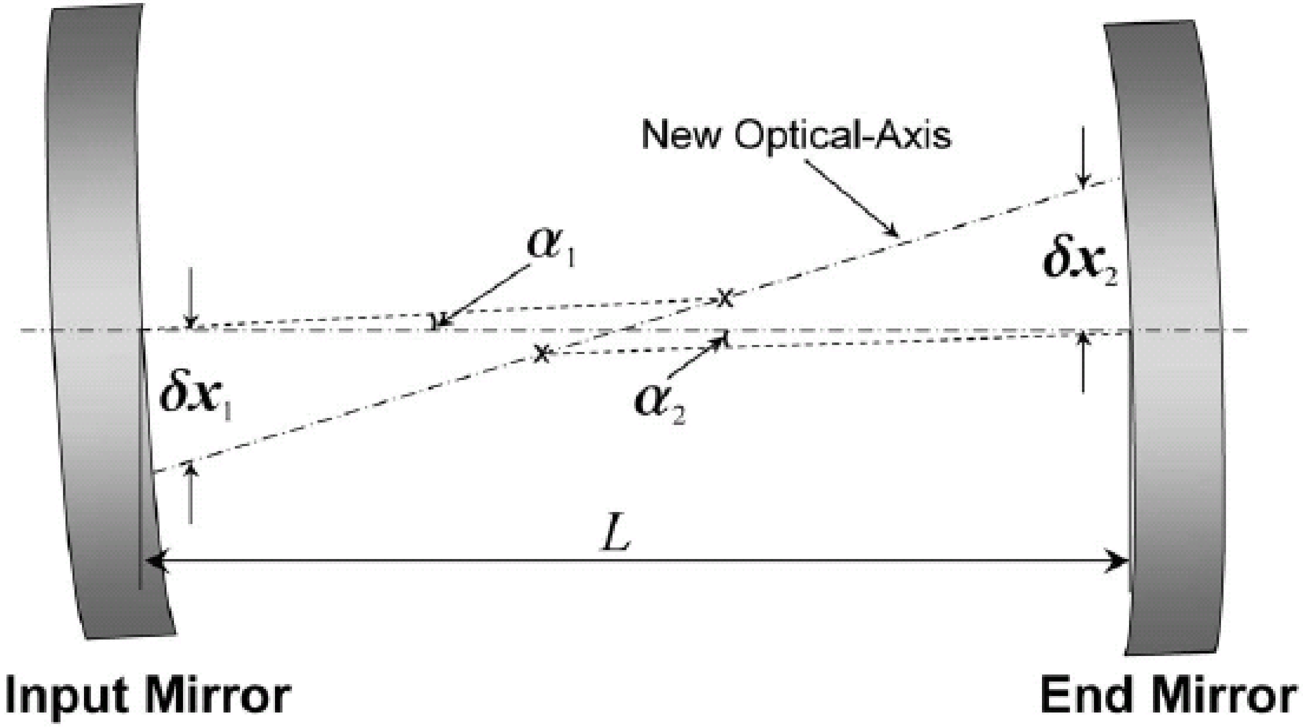


2 x enhancement!

5 x reduction!

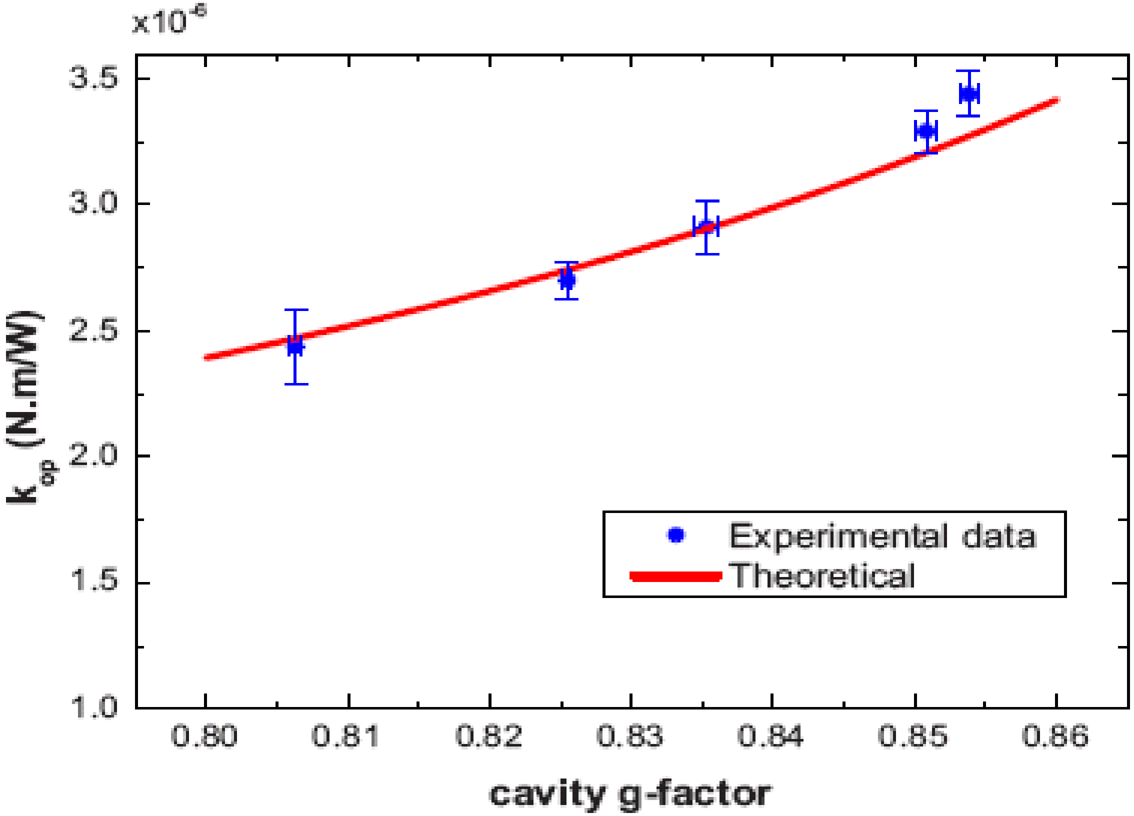
Sidles-Sigg Instability

Mirror tilting induces cavity mode position offset on the mirror and radiation pressure torque



Sidles-Sigg Instability

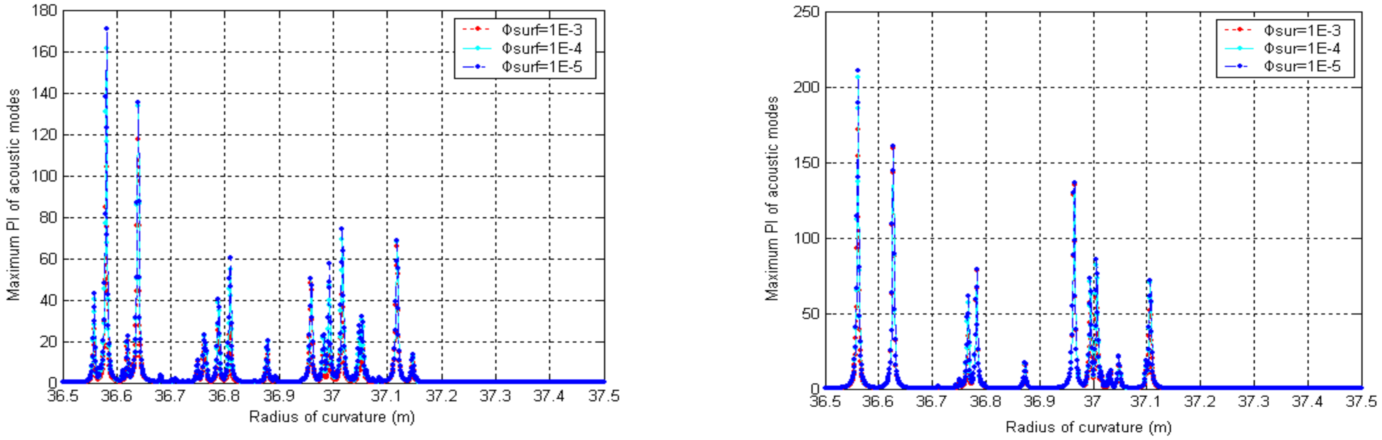
Measured optical torsion stiffness as a function of cavity g-factors



Y. Fan, et al, Appl. Phys. Lett. **94, 081105 (2009)**

Proposed experiments: (1) Observation of Self-sustained instability

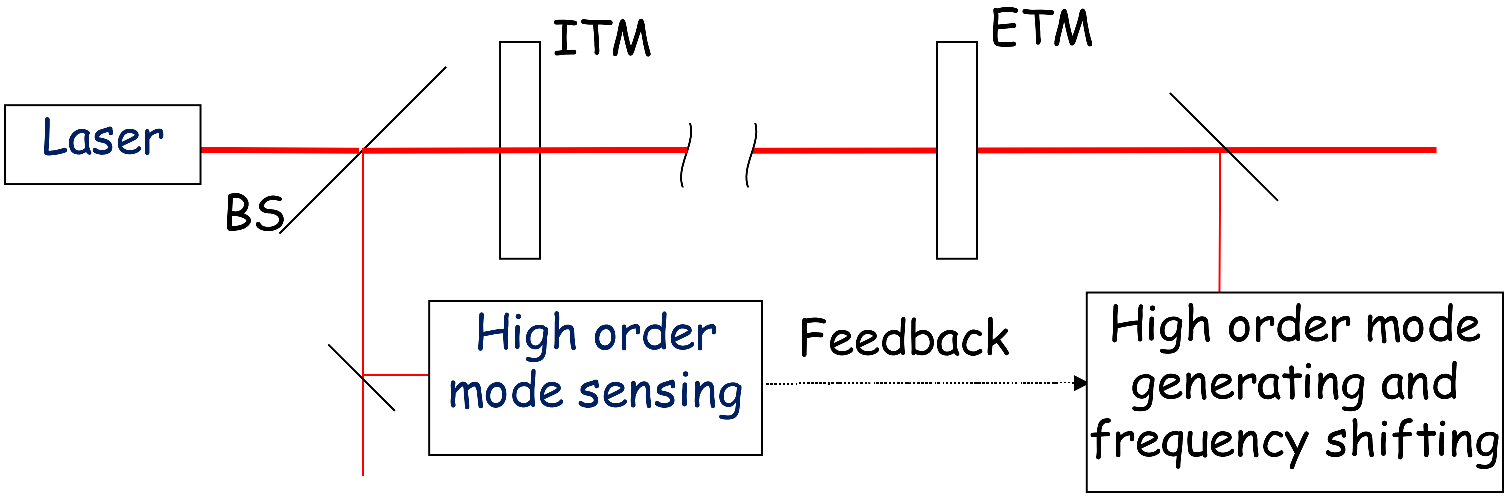
- High finesse (~15000) cavity
- High optical power (~50W laser)
- Assuming mechanical Q-factor, ~10^6
- CO2 laser heating to tune the test mass radius of curvature



(a) (b)

Maximum parametric gain vs. RoC
(a) for TEM_{01}; (b) for TEM_{10};

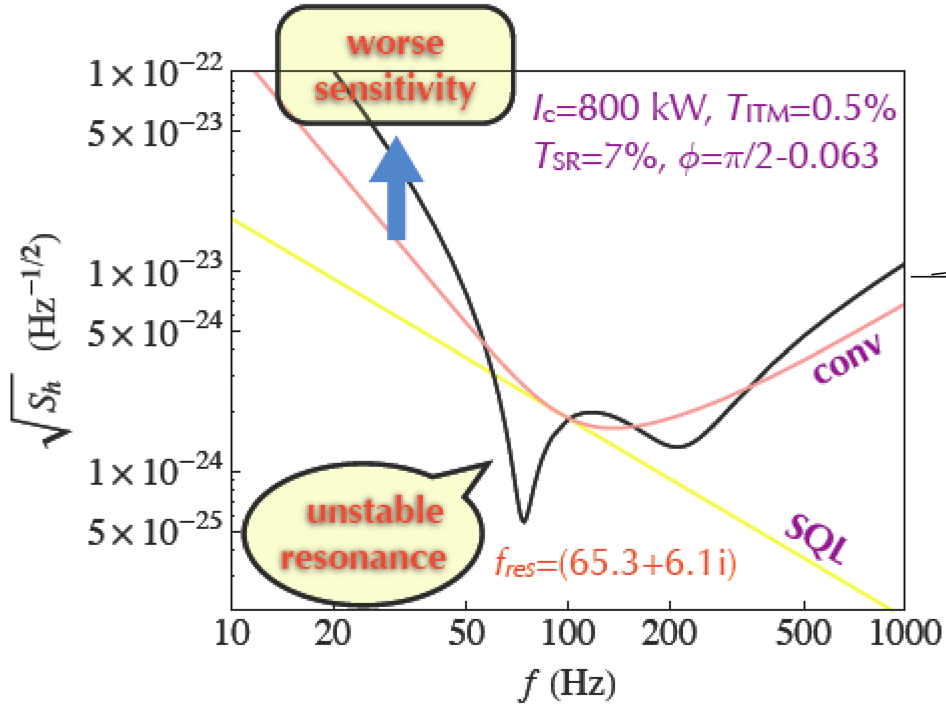
Proposed experiments:
(2) Optical feedback for suppressing instability

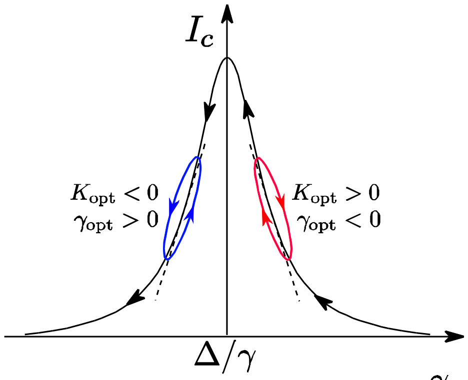


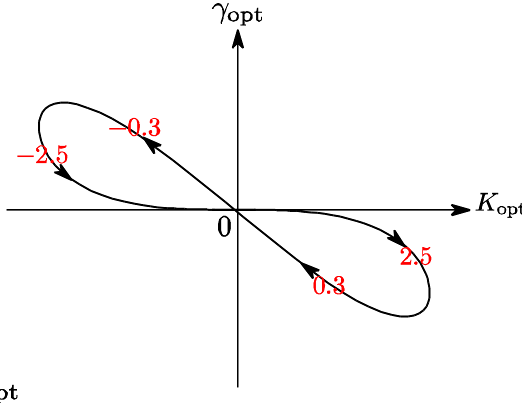
- ETM transmission to be re-injected into the cavity
- Two AOMs create right frequency shift
- Deformable mirror generates suitable high order mode patterns

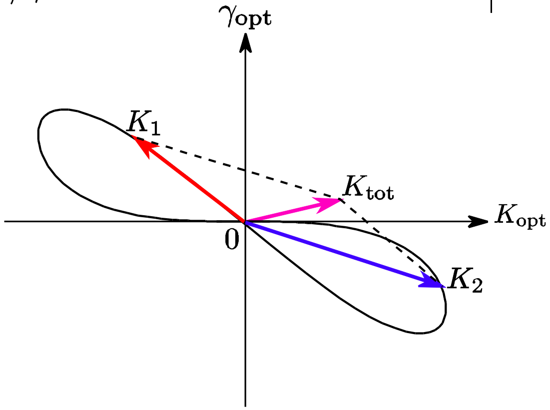
Proposed experiments:
(3) Double optical springs for creating optical “negative inertial”

Brief introduction:









Y. Chen: Parametric Instability Workshop, July 17, 2007

Buonanno & Chen:

PRD, VOLUME 65, 042001

PRD, VOLUME 64, 042006

H. Rehbein, et al: PRD ,78, 062003 (2008)

T. Corbitt, et al, PRL 98, 150802 (2007)

Proposed experiments:

(3) Double optical springs for creating optical “negative inertial”

Motivation:

The SQL in terms of GW strain sensitivity:

$$h_{\mathrm{SQL}} = \frac{1}{L}\frac{\sqrt{S^{F}_{\mathrm{SQL}}(\Omega)}}{m\Omega^2} = h^{\mathrm{fm}}_{\mathrm{SQL}}\sqrt{\frac{|\chi^{-1}(\Omega)|}{\Omega^2}}$$

A system with larger mechanical susceptibility (χ/m) has smaller SQL than the free mass SQL

Y. Chen, et al, LIGO-T1000069-v1

Proposed experiments:
(3) Double optical springs for creating optical "negative inertial"

Considering the test mass dynamics with double optical springs (DOS)

$$x(s) = \frac{\chi(s)F(s)}{m} \quad \Longrightarrow \quad \chi^{-1}(s) = s^2 + \frac{K_1(s)+K_2(s)}{m},$$

$$K_{1,2} = \frac{mJ_{1,2}\delta_{1,2}}{s^2+2\gamma s+\Delta_{1,2}^2}, \quad J_{1,2} = \frac{4\omega_{1,2}I_{1,2}}{mcL}, \quad \Delta_{1,2} = \sqrt{\gamma^2+\delta_{1,2}^2}.$$

with $s=-i\Omega$;
F is the force applied on the test mass, x is the displacement ,
γ *is the cavity linewidth,* $\delta_{1,2}$ *is cavity detuning for carrier ,* $\omega_{1,2}$

Proposed experiments: (3) Double optical springs for creating optical "negative inertial"

If we could impose the following constrains,

$$K_1(0) + K_2(0) = 0\,,$$

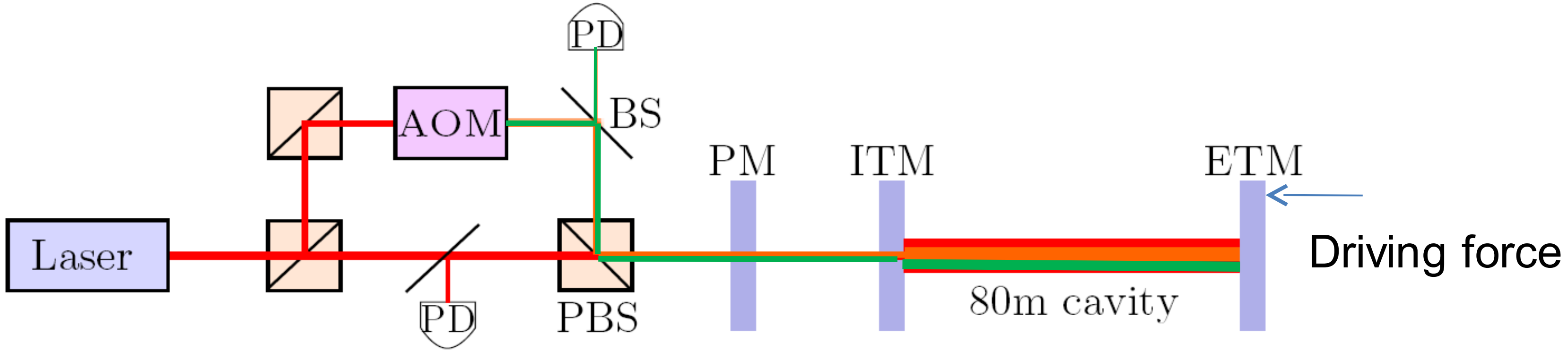
$$\frac{\partial[K_1(s) + K_2(s)]}{\partial s}\bigg|_{s=0} = 0.$$

$$\frac{1}{2}\frac{\partial^2[K_1(s) + K_2(s)]}{\partial s^2}\bigg|_{s=0} + m = 0$$

Then, $\chi^{-1}_{(s)} \approx O(s^3)$

Proposed experiments:
(3) Double optical springs for creating optical "negative inertial"

This is actually achievable at Gingin with a 3-mirror cavity:



PM: power recycling mirror; PBS: polarization beam splitter; BS: beam splitter; PD: photodetector; ITM: input test mass; ETM: end test mass.

Proposed experiments: (3) Double optical springs for creating optical "negative inertial"

Test mass, m=0.8 kg, cavity length L=80m, cavity circulating power:

I_1= 3kW, I_2=10kW

Cavity detuning:

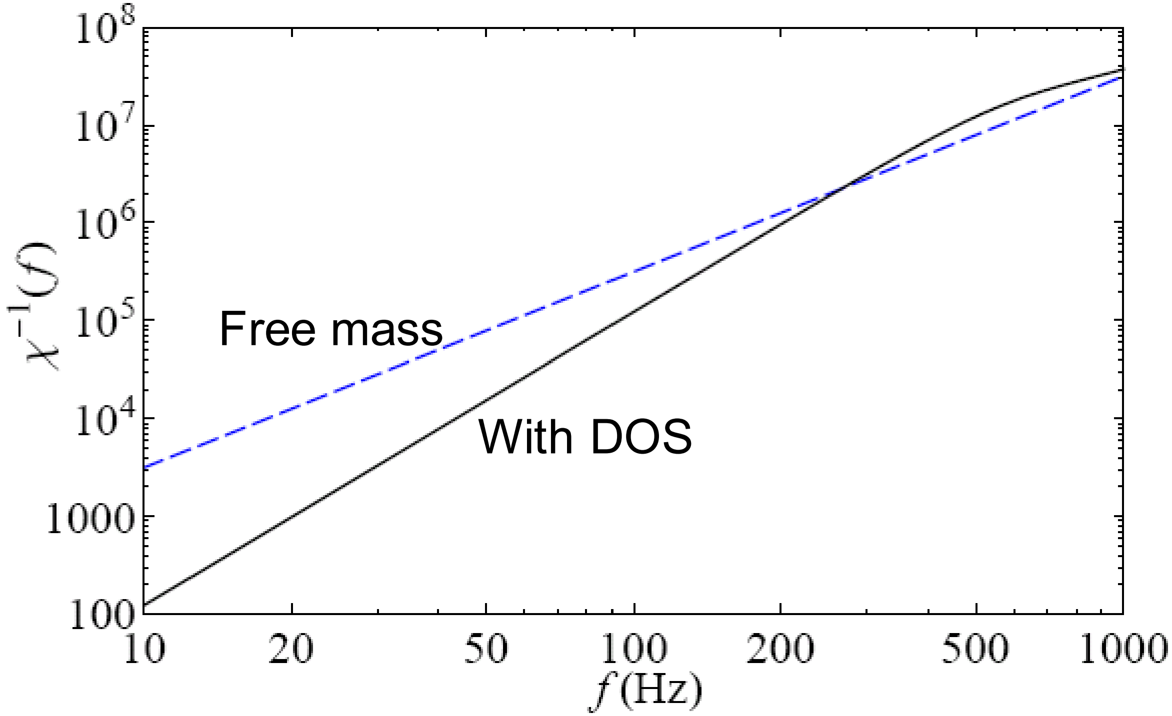
$\delta_1/2\pi$=200 Hz

$\delta_2/2\pi$=-500 Hz

Cavity linewidth:

$\gamma_1/2\ \pi$=36 Hz;

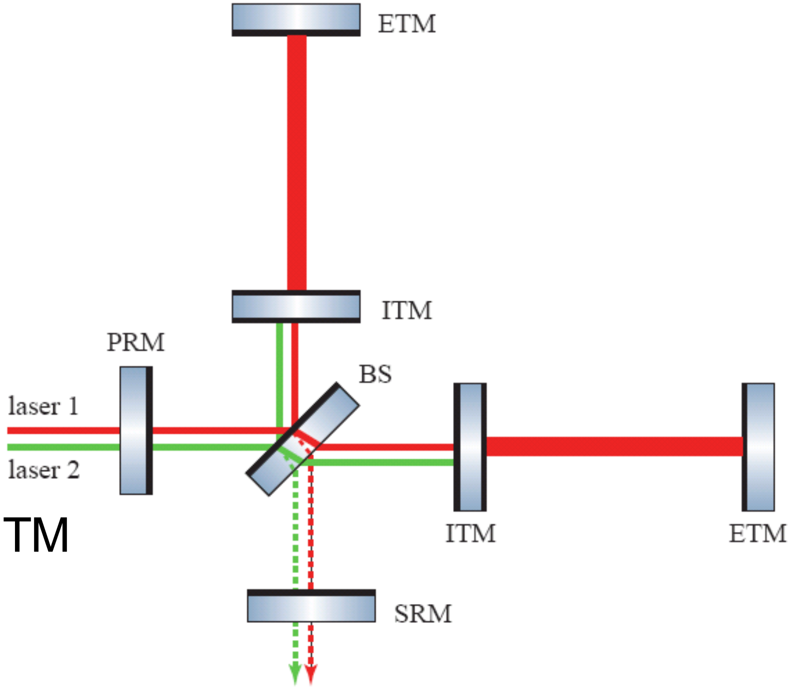
$\gamma_1/2\ \pi$=400 Hz;



Proposed experiments:
(4) Demonstration of Local readout scheme

Brief introduction:

Detuned signal recycling -> optical spring, f_{os}~ detection band (~100Hz)
-> Improved quantum noise at around f_{os},
But, reduced sensitivity at frequencies below f_{os}

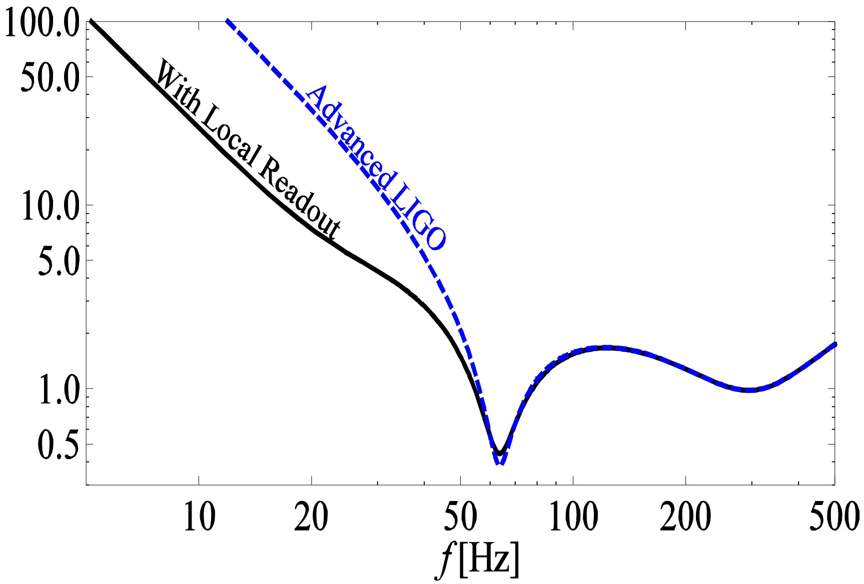


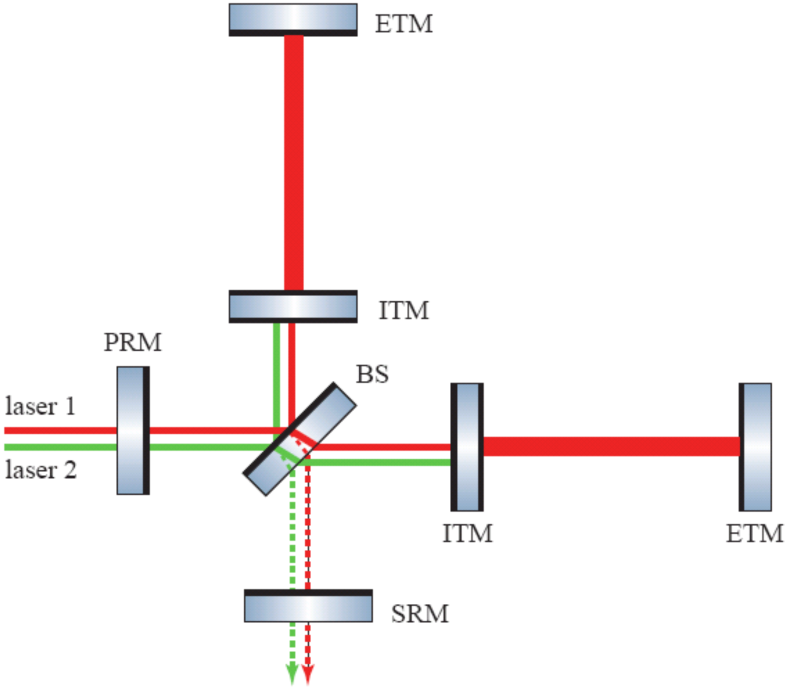
Below $f_{os,}$ ITM and ETM are connected together
-> optical "bar"-> ITM follows ETM motion
In BS inertial frame:
Gravitational Waves-> tidal force applied on the ETM
-> less sensitivity

The second laser beam to sense the ITM motion -> recover low frequency sensitivity

Henning Rehbein, Helge Müller-Ebhardt, Kentaro Somiya, Chao Li, Roman Schnabel, Karsten Danzmann, and Yanbei Chen
Phys. Rev. D **76**, 062002 (2007)

Proposed experiments:
(4) Demonstration of Local readout scheme

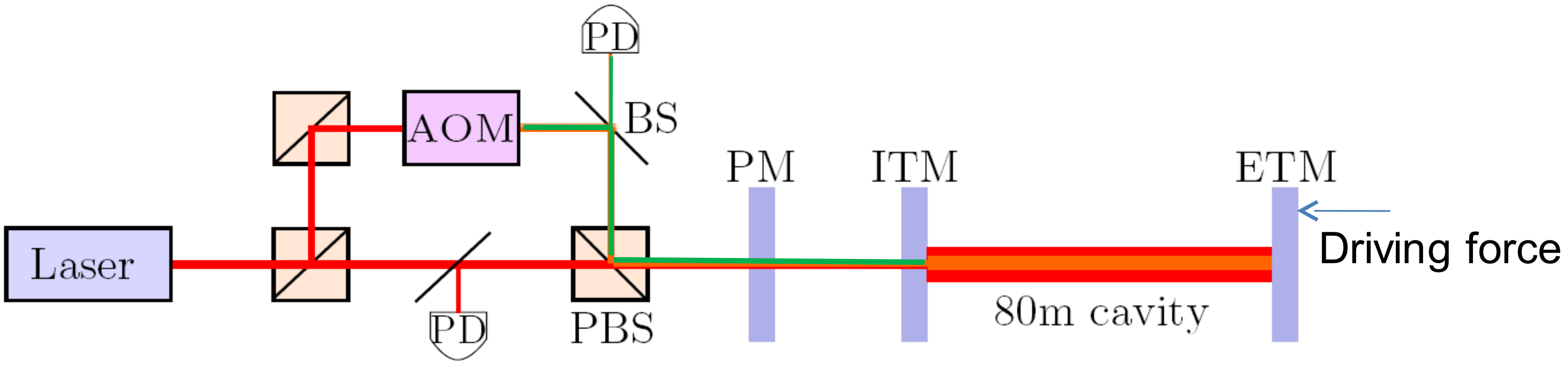




Sensitivity divided by SQL of detuned AdvLIGO
with and without local readout, (Haixing Miao)

Proposed experiments:
(4) Demonstration of Local readout scheme

Optical layout for demonstration at Gingin



PM: power recycling mirror; PBS: polarization beam splitter; BS: beam splitter; PD: photodetector; ITM: input test mass; ETM: end test mass.

Conclusions

Possible experiments at next stage Gingin facility:

- Observation of self-sustained PI instability
- Demonstration of PI control schemes
- Demonstration of optical “negative inertial”
- Demonstration of local readout.

Thank you !