Testing Optical Configurations with the Glasgow 10m Prototype

B. Barr, A. Bell, M. Edgar, S. Hild, S. Huttner, J. Nelson, J. Macarthur, M. Plissi, B. Sorazu, K. Strain

GWADW meeting, Elba, May 2011

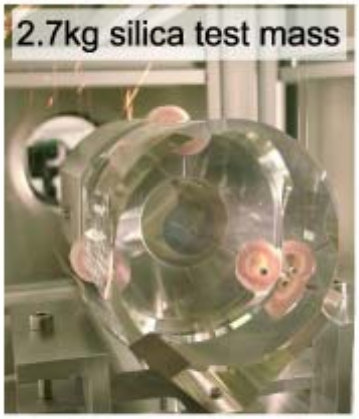
OVERVIEW

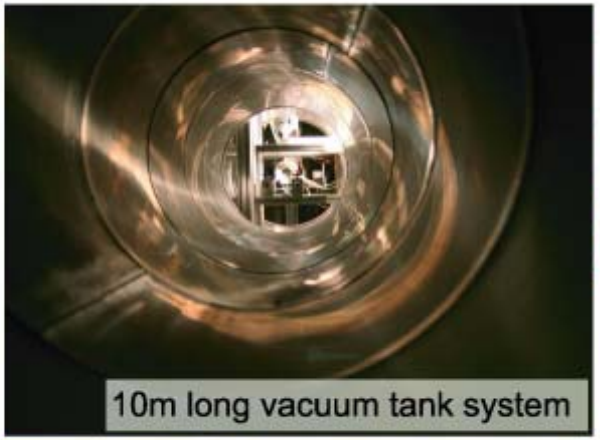
- **The Glasgow JIF laboratory**

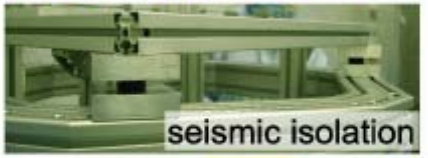
- **Recently…**
  - **Diffractive cavity** (2nd order Littrow)
    - Vibration, rotation and translation
  - **Optical springs** with a 100g mirror
    - Light suspension design and spring cavity control
  - **Suspended waveguide** cavity
    - Proof of principle
  - Interferometry with **Laguerre Gauss** modes
    - Investigating practical limits

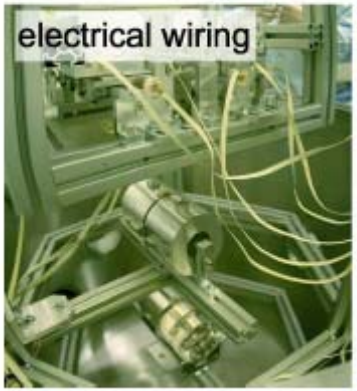
The Glasgow 10m prototype interferometer

- Ideal test bed for advanced interferometry concepts.
- Fast turn around for rapid, small-scale tests
- Timely validation of various innovative technologies
- Excellent training for students and postdocs



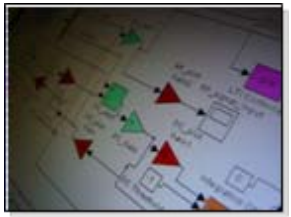




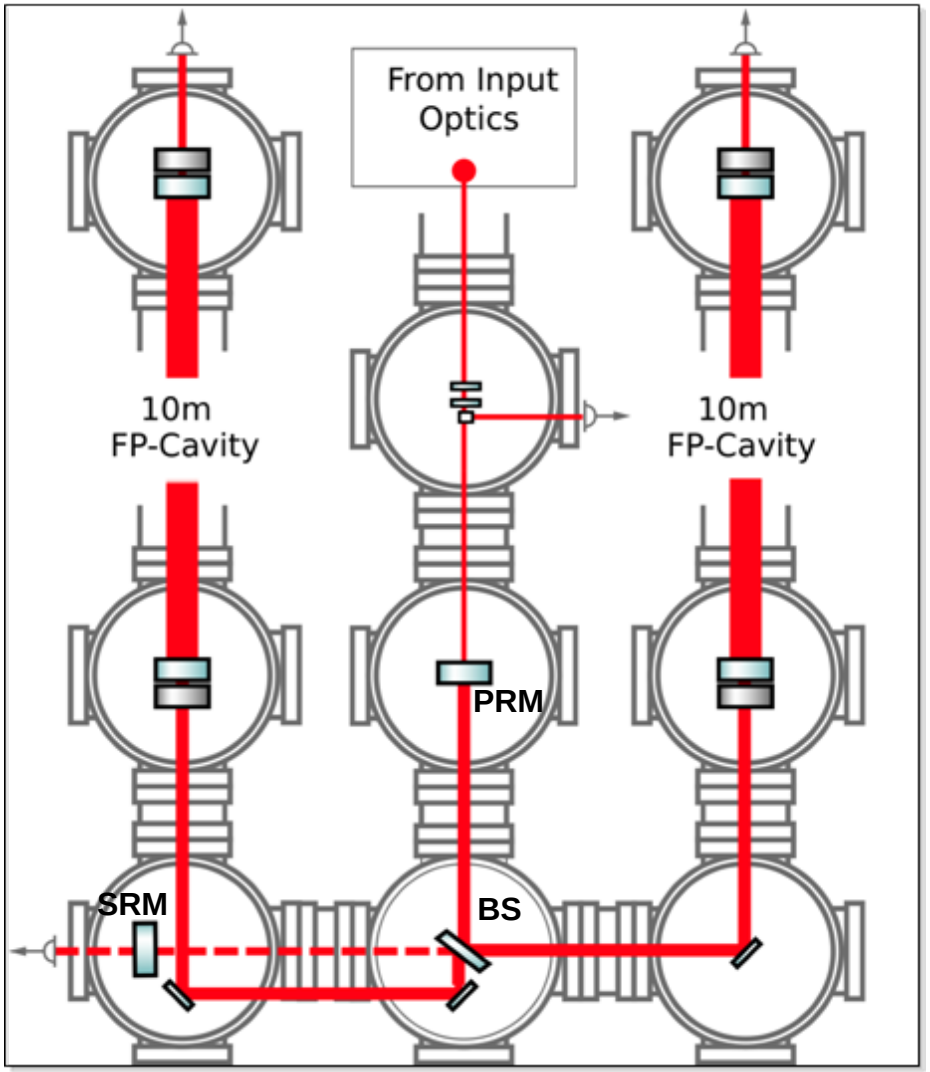


Facility overview

- **GEO-like Infrastructure:**
  - Triple stage GEO-suspensions
  - Same local control
- **Class 100 cleanroom + additional cleanroom tent around every tank.**
- **Analog and Digital Control**
  - aLIGO CDS – being phased in now



- **Maximise the potential of the Glasgow 10m by carrying out several strands of experiments in parallel**



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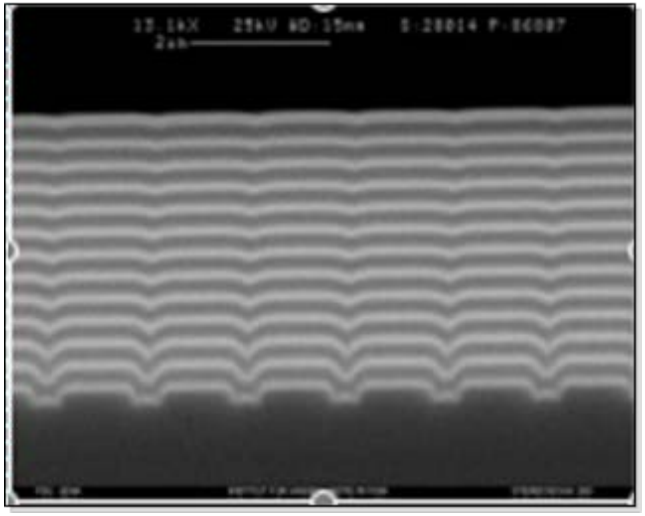
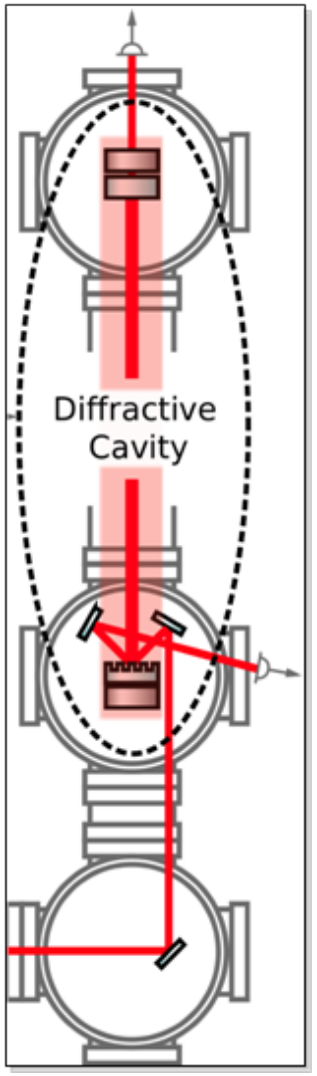
Diffractively coupled cavity

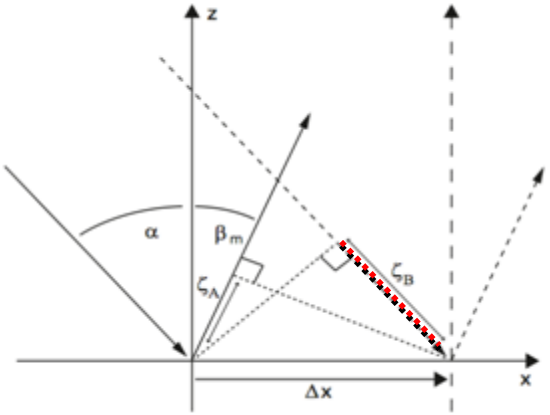
- Motivation: Gratings can be used to **replace transmissive optics** => can decrease thermal problems and some thermal noise contributions.
- First demonstration of a **suspended cavity using a 3-port grating** as cavity incoupler (2nd order Littrow).
- Collaboration with **Universities of Hannover, Jena and Birmingham.**
- Using an grating etched into a fused silica substrate then over-coated with multi-layers of Ta_2O_5 and SiO_2.
- Achieved cavity finesse of about **1100.**





Diffractively coupled cavity

- **Experimental confirmation of phase noise from grating side-motion into the cavity length-sensing signal**
- **In contrast to a normal mirror, side-motion of a grating, introduces additional phase noise** (Freise et al, *New J Phys*, 2007, 9, 433-+)

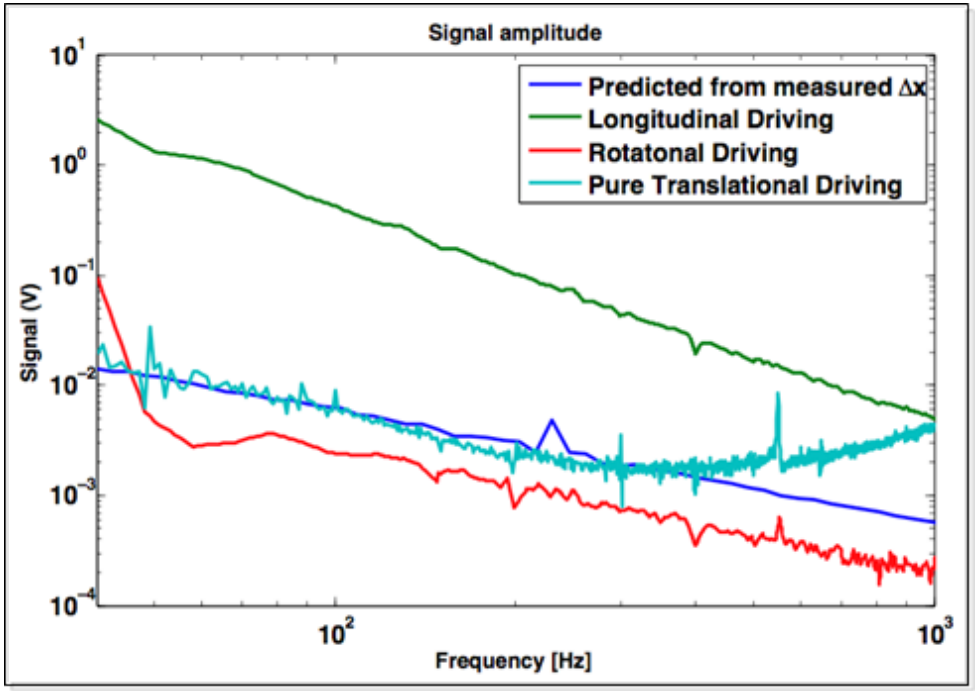


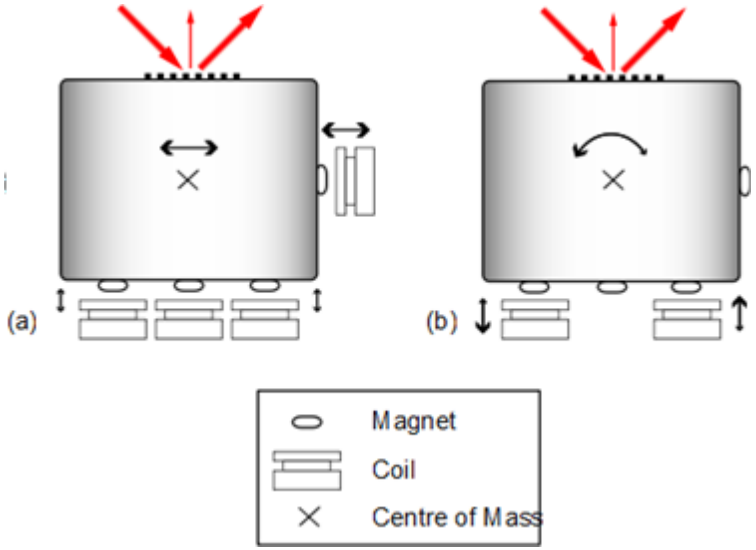
$$\zeta_m = \zeta_B - \zeta_A = -\Delta x \frac{m\lambda}{d}$$

- **Working through the field equations predicts a 1/f response in the length sensing signals for a cavity** (Hallam et al, *J. Opt. A*, 2009, 11, 085542)
- **Testing this in our freely suspended system, by driving the optic from side-to-side produced something rather interesting…**

Diffractively coupled cavity

- **Translational motion behaves as expected**
- **Vibrational coupling noticed due to internal mass modes driving grating surface in translation (rising response on pure translational trace)**
- **Rotational motion also scans the surface across the beam**





More details: B.Barr et al, "Translational, rotational and vibrational coupling into phase in diffractively-coupled optical cavities", in review – Optics Letters

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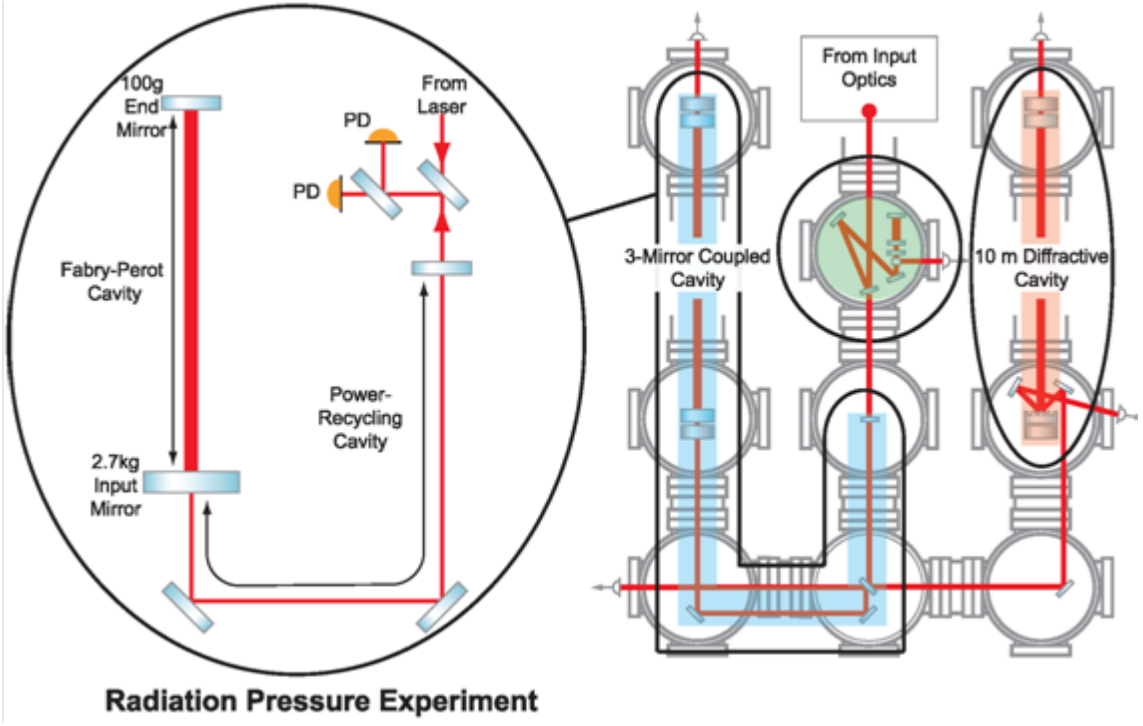
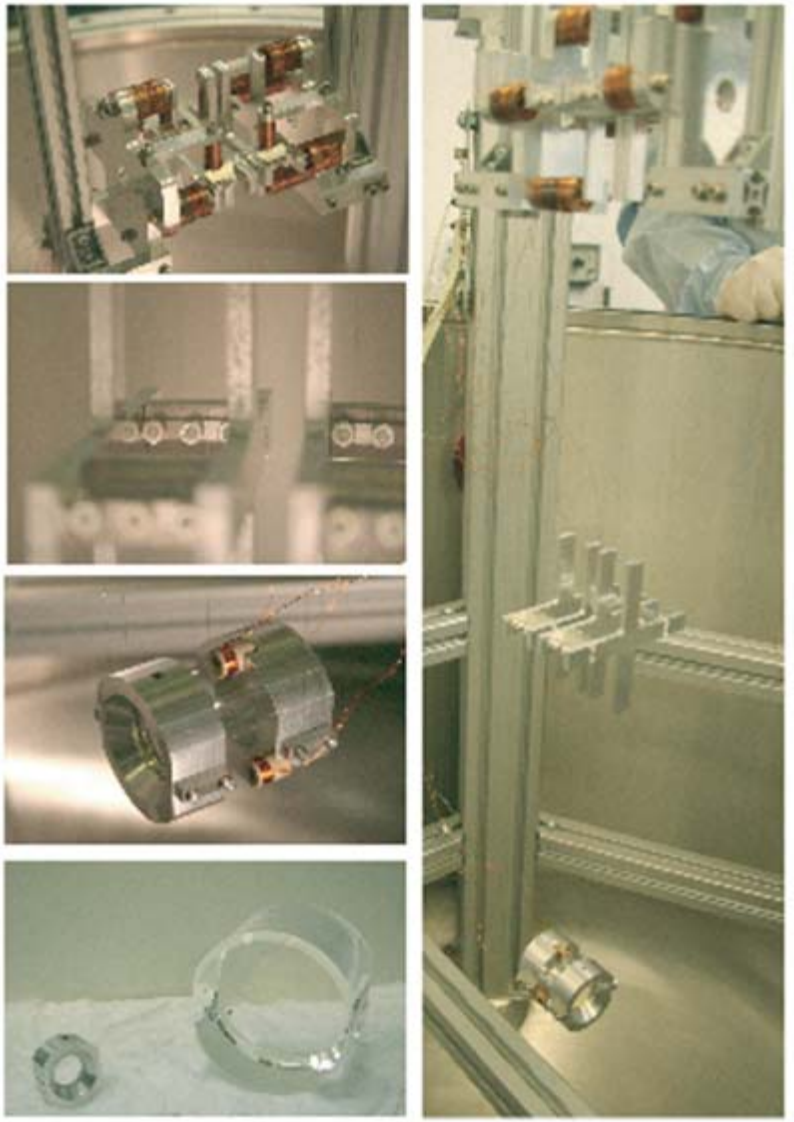
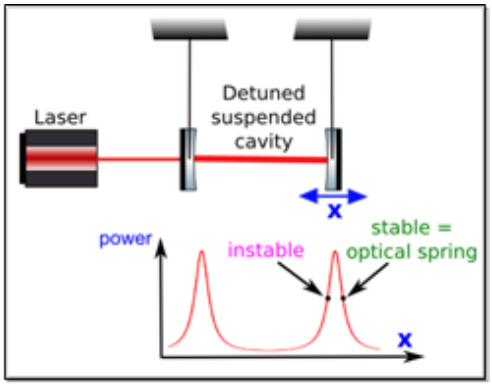
Optical spring with a 100g mirror

- **Aim: optical spring with 100g mirror**
- **Triple-stage suspension + reaction chain.**
  - Much of this design serves as a reference for suspensions for the AEI-10m
- **Three mirror coupled cavity configuration**

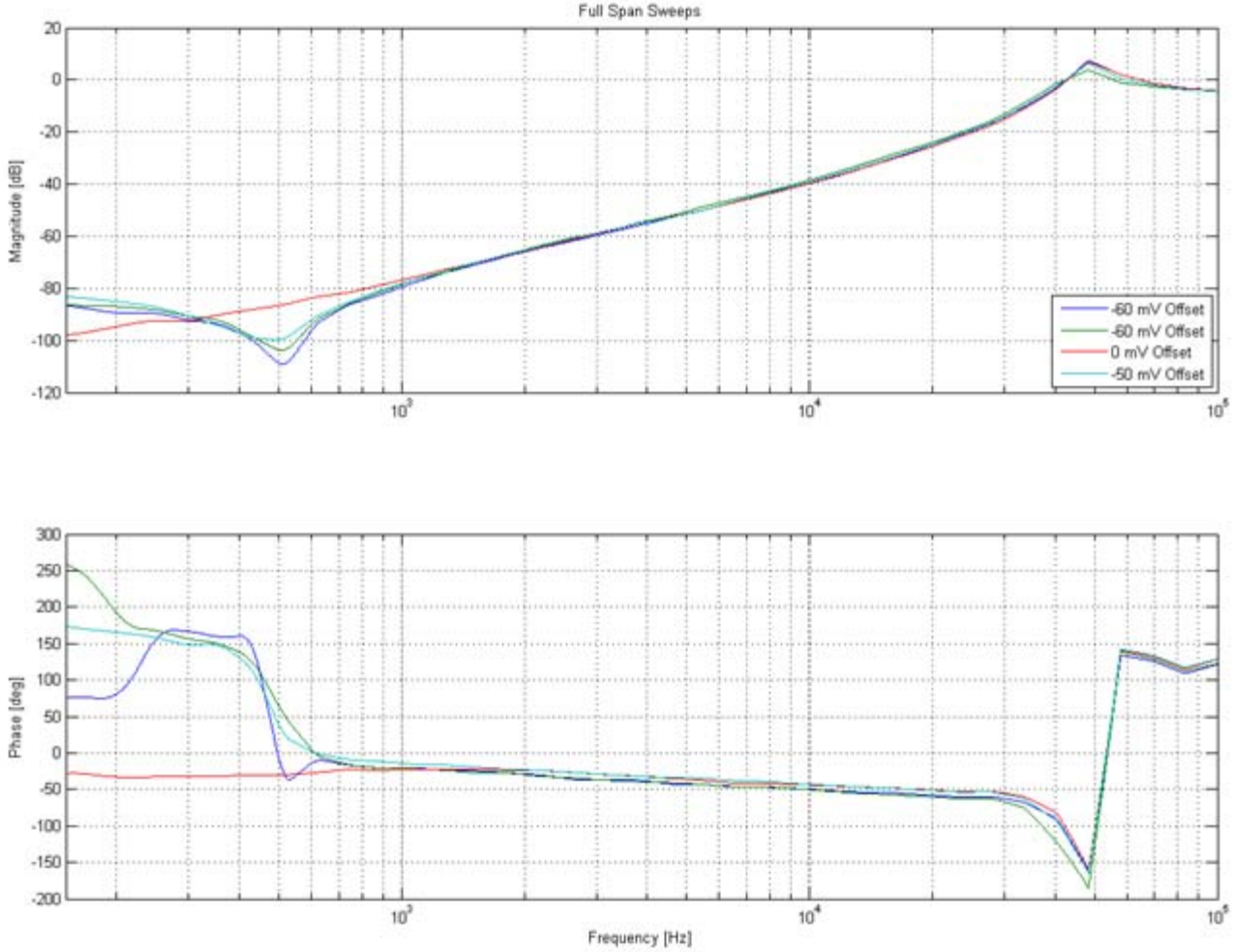




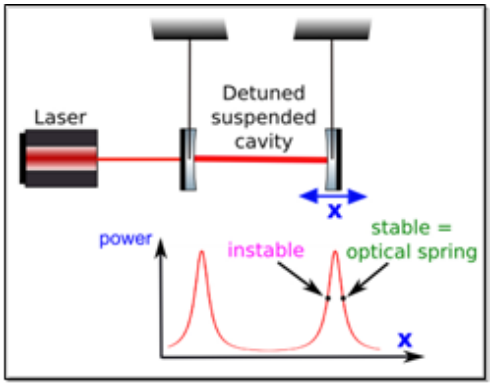
Optical spring with a 100g mirror



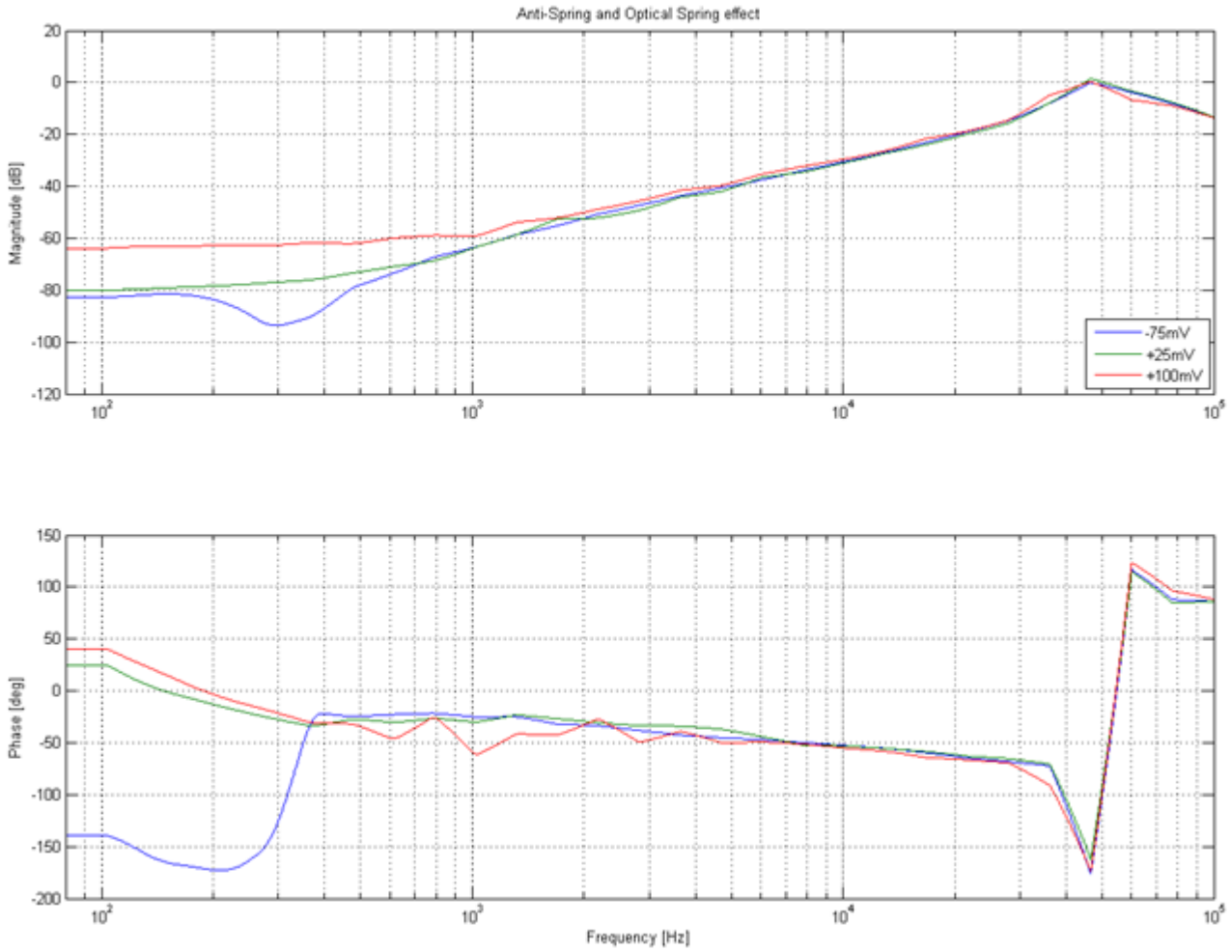
- **Clear optical spring effect with cavity detuning**
  - **In-loop measurements – lower magnitude = higher gain**
  - **In theory opposite offsets should give less gain…**



Optical spring with a 100g mirror



- **Clear reduction in gain with opposite detuning**



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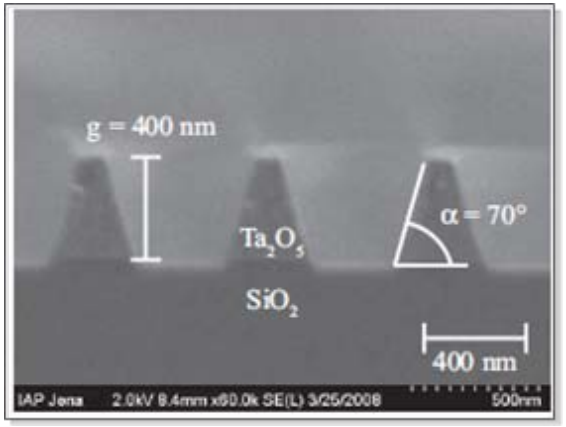
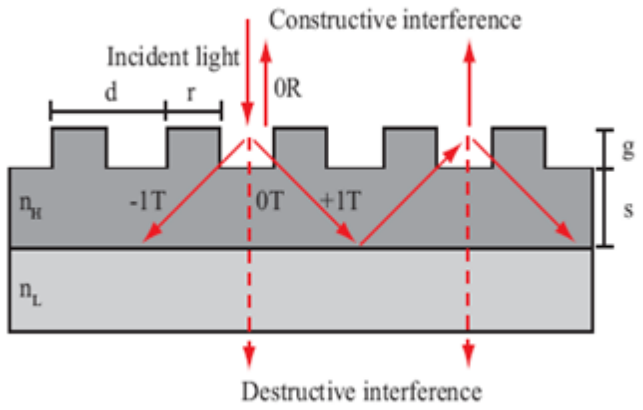
Waveguide cavity

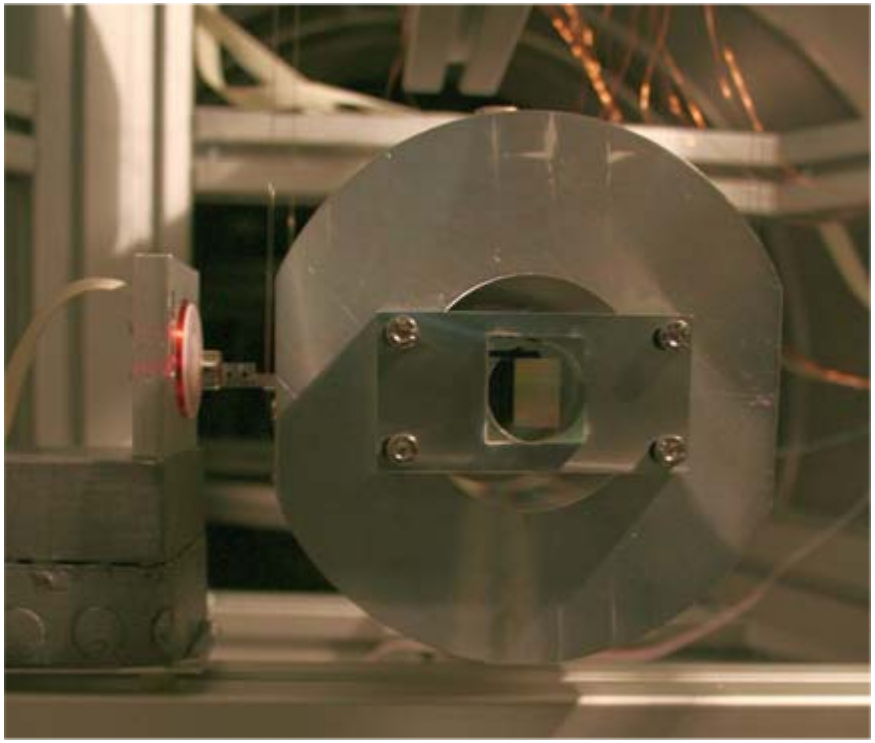
- Motivation: **Waveguide coatings might provide very low thermal noise**.
  - A.Bunkowski et al: *CQG,* **2006***, 23*, 7297-7303
  - F.Brückner et al: *Opt. Lett., OSA,* **2008***, 33*, 264-266
  - F.Brückner et al: *Optics Express,* **2008***, 17*, 163-
- Aim: Demonstrate **suspended cavity** with **waveguide mirror**
- Collaboration with **AEI-Hannover** and **Jena University.** Main actors: **D.Friedrich** (Hannover) and **F.Brueckner** (Jena).
- Jena produced a batch of waveguide mirrors (1064nm) for use in the Glasgow 10m prototype**.**
- Tested reflectivities and put the best one (around 99.5%) into the vacuum system…

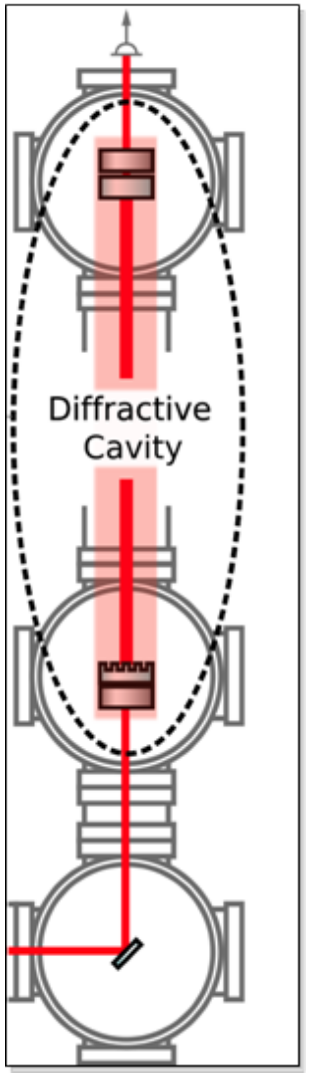




Waveguide cavity

- Locking – conventional Pound Drever Hall set-up
- Finesse = **790**
- Waveguide reflectivity of **R = 99.2%** - a bit lower than previously measured
  - Homogeneity?
  - Clipping loss?
- Translational effects
  - Nothing seen as yet…
  - …as expected!





More details: D. Friedrich et al, “Waveguide grating mirror in a fully suspended 10 meter cavity”, accepted for publication – Optics Express

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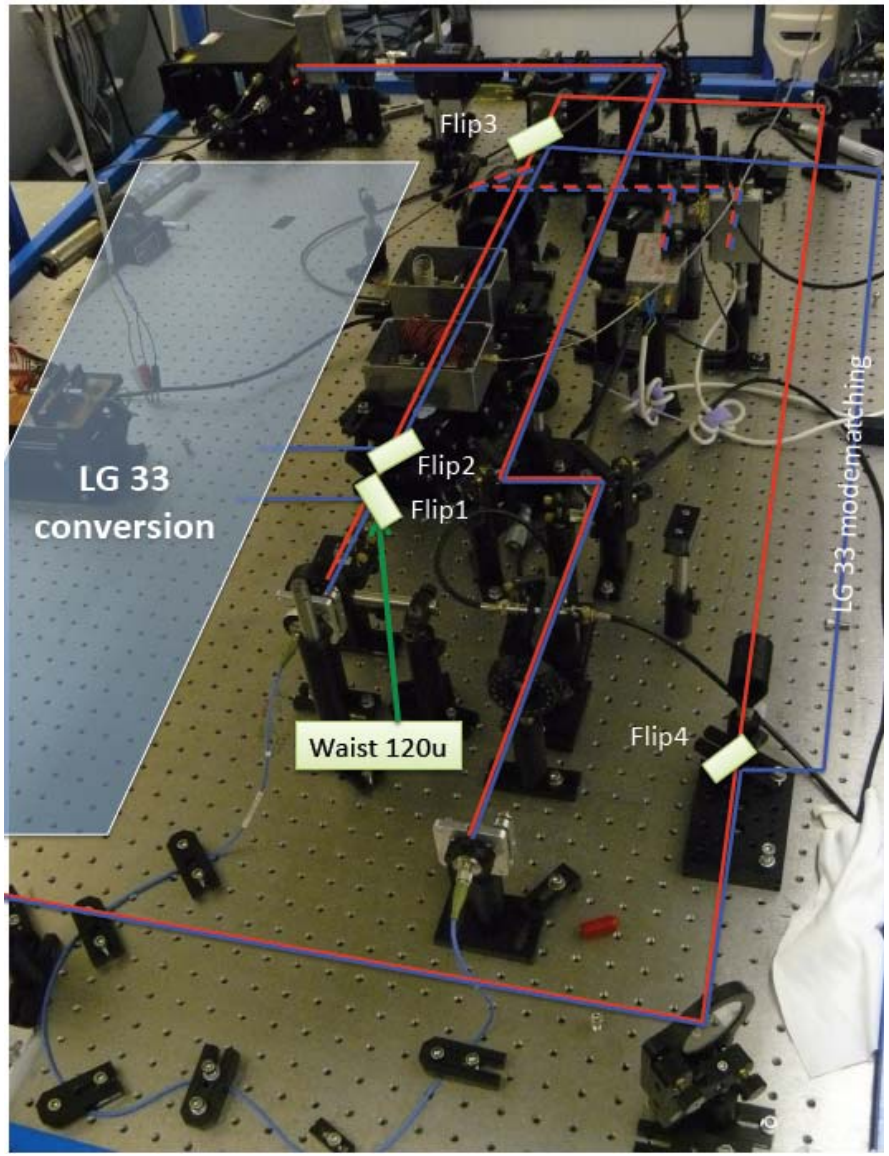
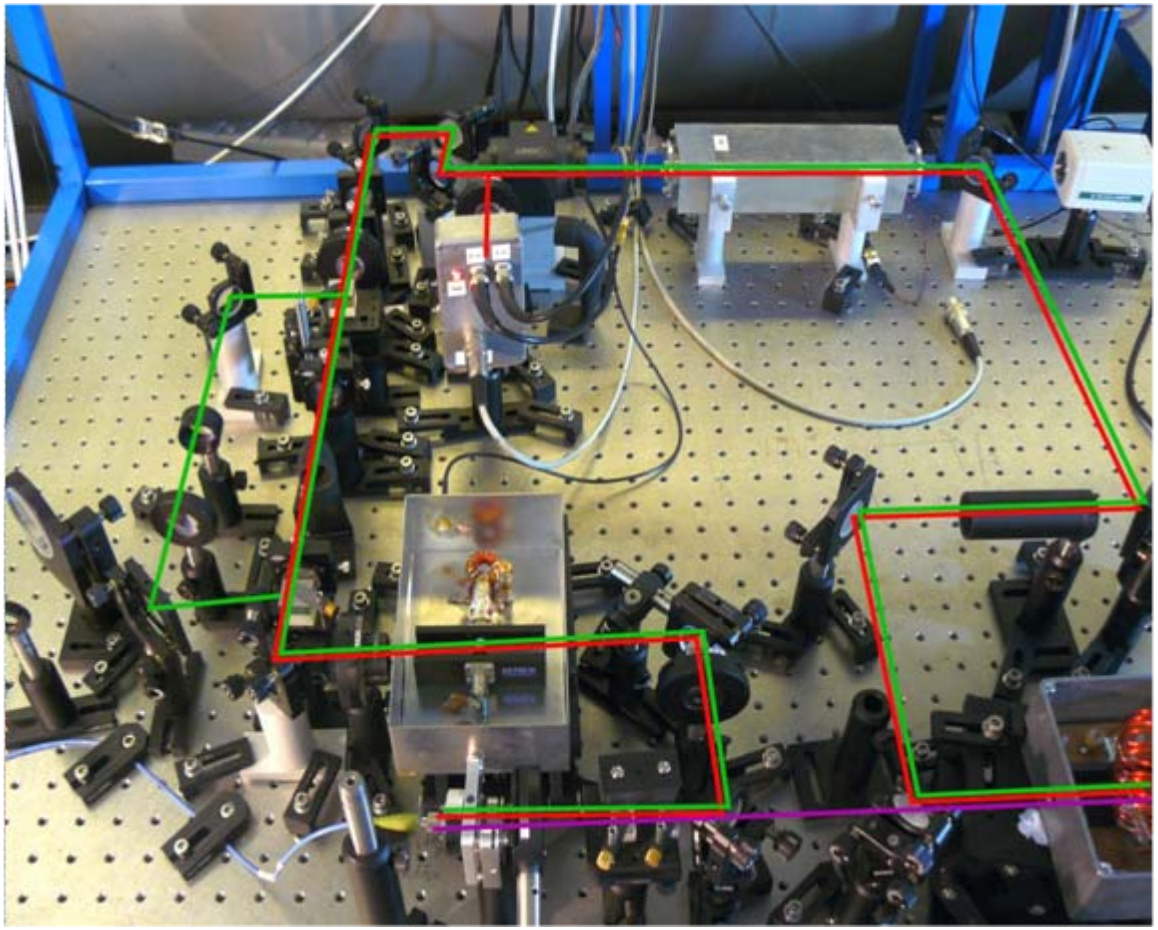
LG-modes

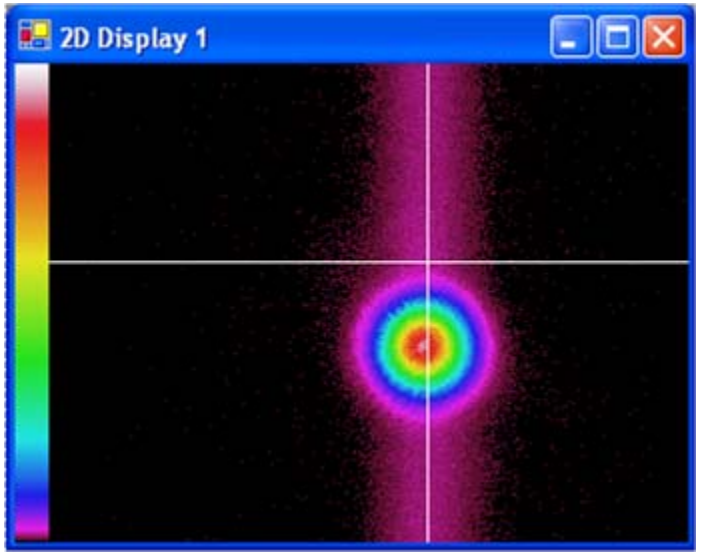
- Motivation: **LG modes can provide a reduction in thermal noise.**
- Simulations and benchtop experiment
  - S.Chelkowski et al: "Prospects of higher-order Laguerre-Gauss modes in future gravitational wave detectors", *PRD,* **2009***, 79*, 122002
  - P.Fulda et al: "Experimental demonstration of higher-order Laguerre-Gauss mode interferometry", *PRD,* **2010***, 82*, 012002
- Time for testing in an environment similar to a GW detector!
- Collaboration with **University of Birmingham.**
- Main aims:
  - **Study of control signals**
  - **Investigate effects from mode-degeneracy**

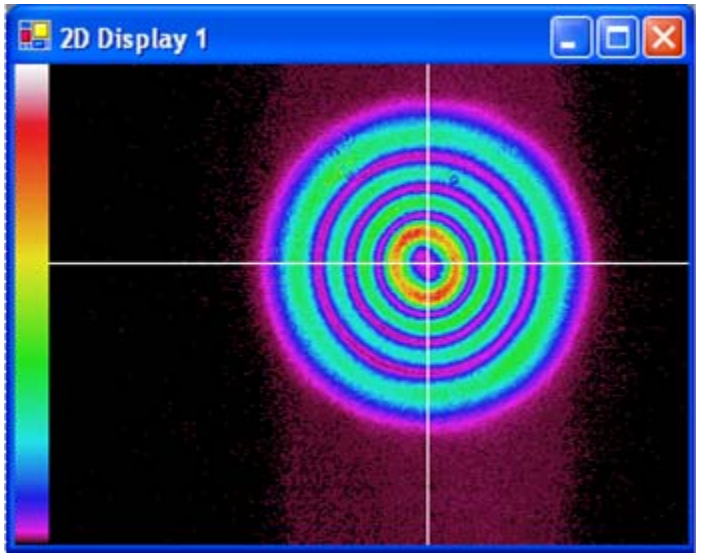


LG-modes

- Fully functioning **LG00** / **LG33** mode generation set-up

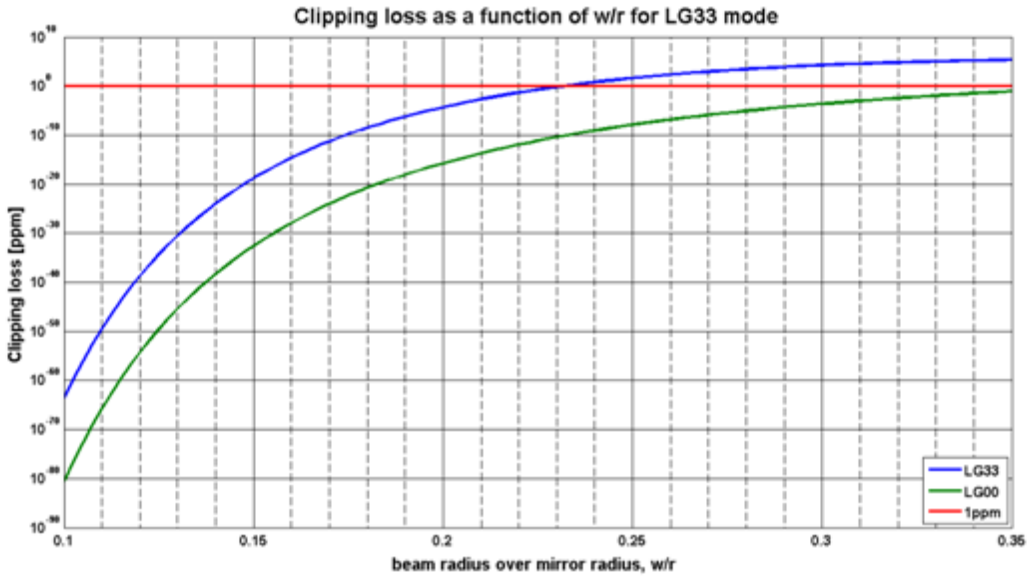


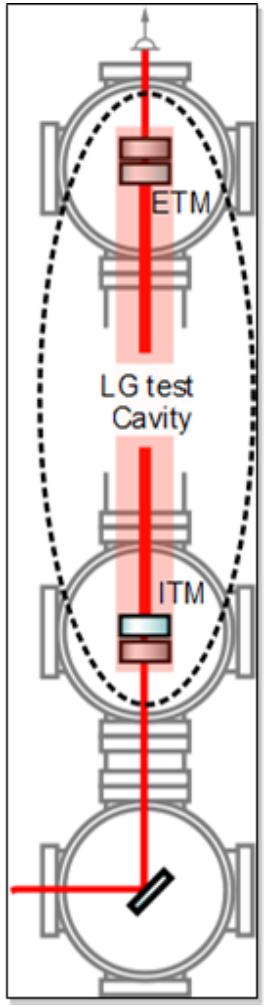




LG-modes

- Upgraded in-vacuum steering mirrors to larger, 2-inch optics to facilitate passage of wider beam
- Swapped waveguide optic for conventional mirror (with larger reflective aperture)
- Initial alignment is complete
- Suspended cavity investigations begin soon
  - **Locking**
  - **Mode analysis**





Summary

- **The Glasgow 10m Prototype is a fully operational Multi-Experiment facility**
- **Lots of interesting interferometry concepts under investigation**
- **Lively exchange of PhD-students. Everybody is welcome to join …**

… END