GALILEO

Advanced Interferometric Gravitational Wave Receivers and their Subsystems

Stanford University

LIGO-G970015-00-R

GALILEO Faculty

Director

Robert Byer – Applied Physics

Associate Director

Peter Michelson – Physics

Daniel DeBra – Aeronautics and Astronautics

Martin Fejer – Applied Physics

Jonathan How – Aeronautics and Astronautics

Associated Faculty

James Harris – Electrical Engineering

Yoshi Yamamoto – Electrical Engineering and Applied Physics

Richard Taylor – Physics

Chronology

12/89 – NSF Support for Byer Group Laser Development Begins

12/95 – GALILEO Proposal Submitted to NSF

5/96 – Site Review of GALILEO, NSF Special Emphasis Panel

6/96 – Revised GALILEO Proposal to NSF Submitted

6/96 – LIGO White Paper on Advanced Detectors

6/96 – McDaniel Committee on the Long Range Use of LIGO
recommended "open collaboration with broad community participation"

8/96 – Funding for Revised GALILEO Program Begins

10/96 – "Proposal for a Research and Development Program for Advanced LIGO Detectors by the LIGO MIT/Caltech Groups" Submitted

10/96 – "A Supplemental Proposal for the GALILEO Program for a Collaboration with LIGO On Advanced Interferometer Development" Submitted

GALILEO Research Areas

Table Top Interferometers

Martin Fejer
- Optics
- Interferometry

Robert Byer
- Lasers
- Optics

Laser Development

Robert Byer
- Lasers
- Optics
- Nonlinear Optics

Jonathan How
- Adaptive Optics
- MIMO Control

Martin Fejer
- Materials
- Optics
- Nonlinear Optics

Suspensions, Thermal Noise and Control

Peter Michelson
- Vibration Isolation
- Thermal Noise

Daniel DeBra
- Controls
- Vibration Isolation

Jonathan How
- Vibration Isolation
- MIMO Control

Martin Fejer
- Materials

GALILEO Funded Program and Work Proposed in Supplement

Funded Program	Proposed in Supplement
Laser Noise Reduction (GEO)	Laser Amplifier Power Scaling (LIGO)
Table Top Intereferometers and Control	Thermal Effects in Table Top Interferometers
Active Strut Development with Feed-Forward	Advanced Active Isolation System and MIMO Control (JILA, LIGO)
Advanced Materials for Testmasses and Suspensions (Syracuse, GEO)	Double Pendulum and Control (LIGO, GEO)

Advanced Interferometry

Goals

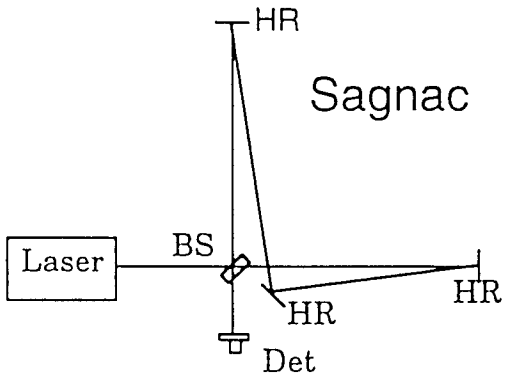
Sensitivity

High Interferometer Availability

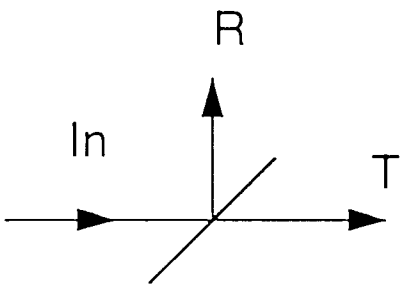
Issues

- Signal Extraction
- Power Scaling
- Robust Control
- Laser Engineerability
- Scattered Light

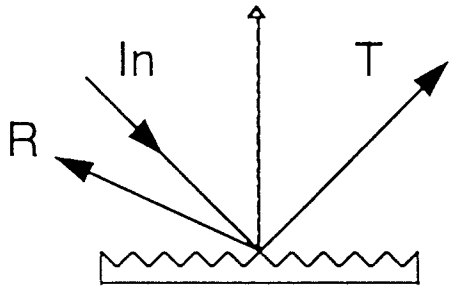
Approaches



Transmissive Beamsplitter



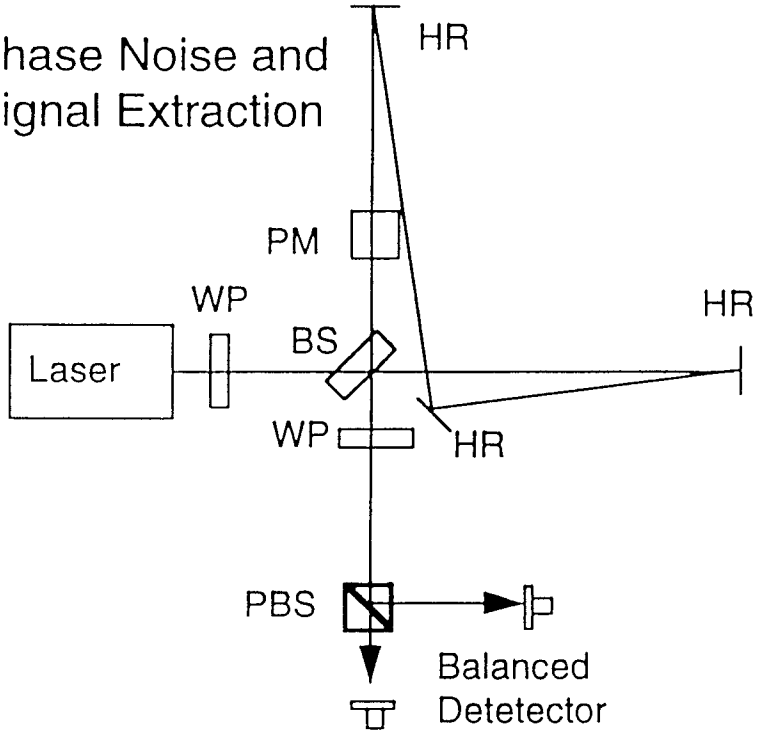
Reflective Beamsplitter



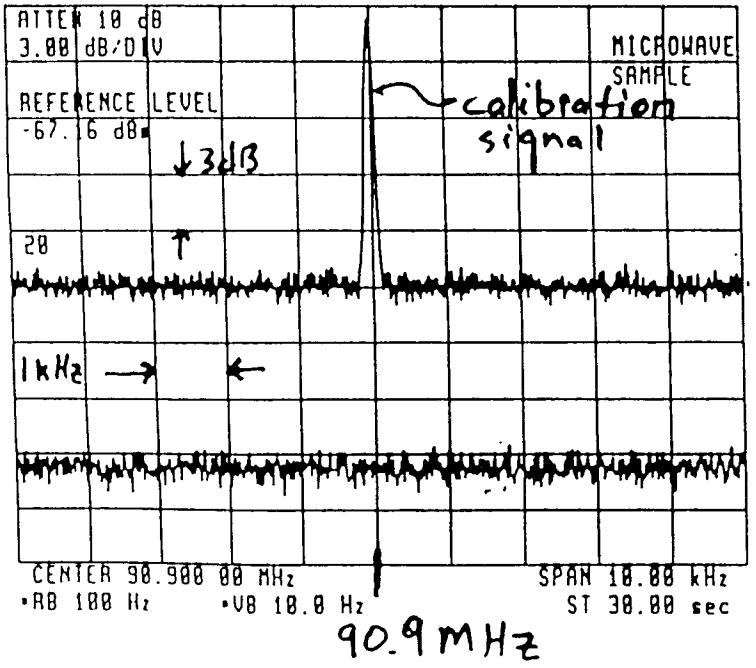
Progress on Table Top Interferometers

Ke-Xun Sun

Phase Noise and Signal Extraction

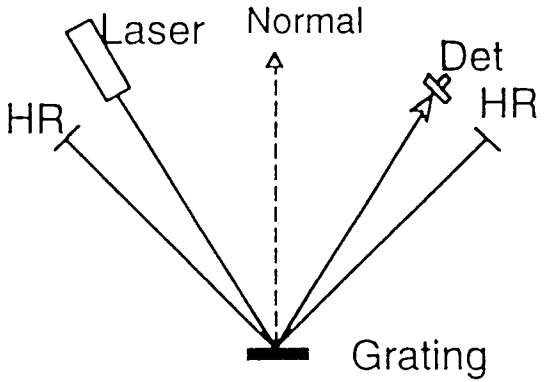


Phase Sensitivity

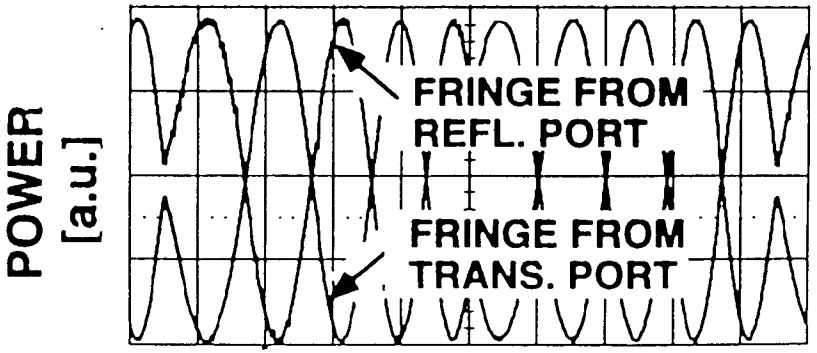


8×10^{-10} rad/$\sqrt{Hz}$

All Reflective Michelson



Fringe Contrast



99% fringe contrast

Laser Development and Laser Noise Reduction

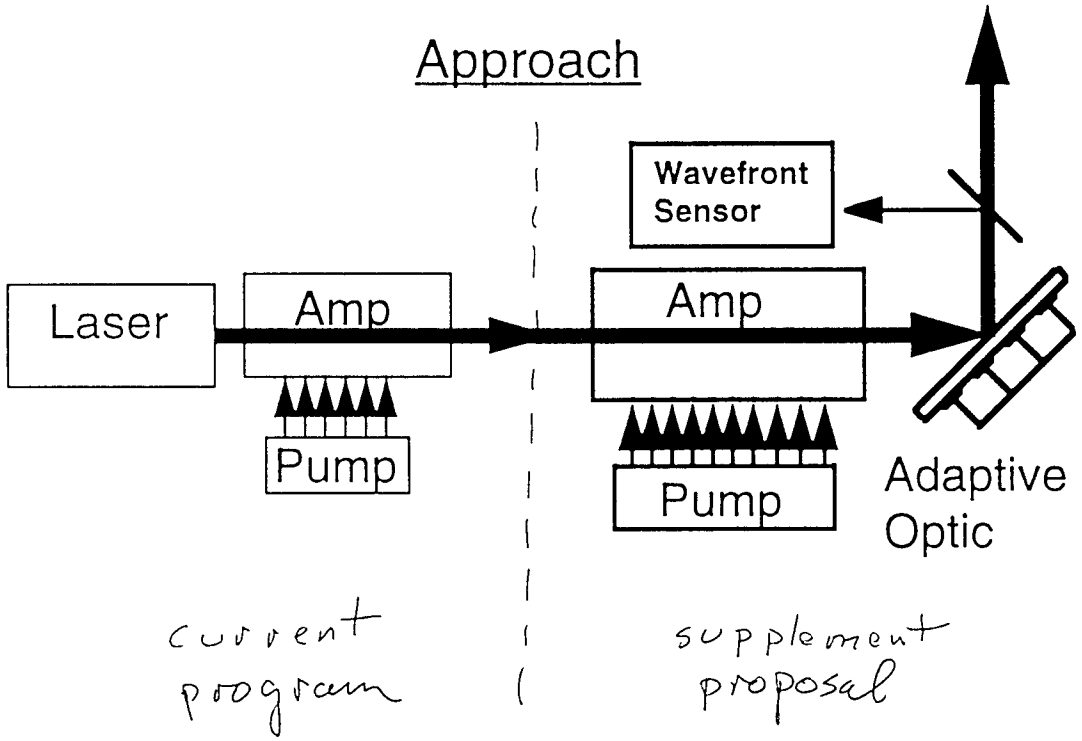
Issues

- Power 10W→100W
- Laser Noise
- Spatial Mode Quality

Supplemental Program

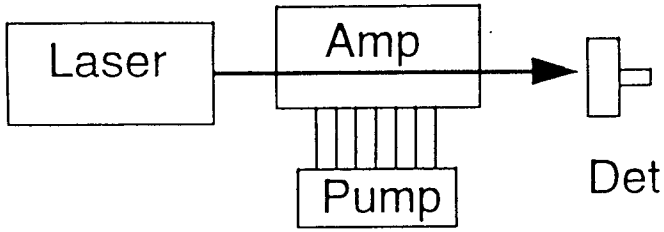
- 100 Watt Saturated Amplifier
- Adaptive Optic
- Temporal and Spatial Noise
- System Integration and Phase Noise Demo (LIGO)

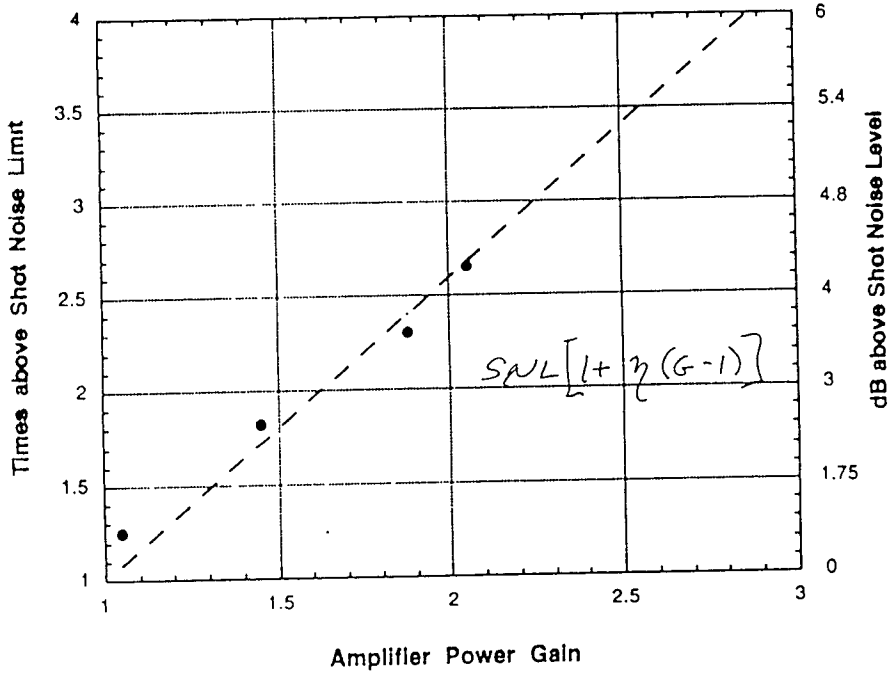
Approach



Progress in Laser Development

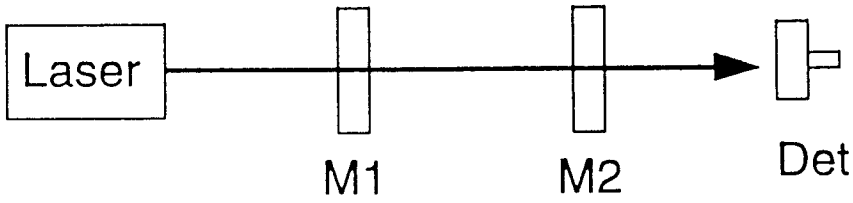
Laser Amplifier Noise

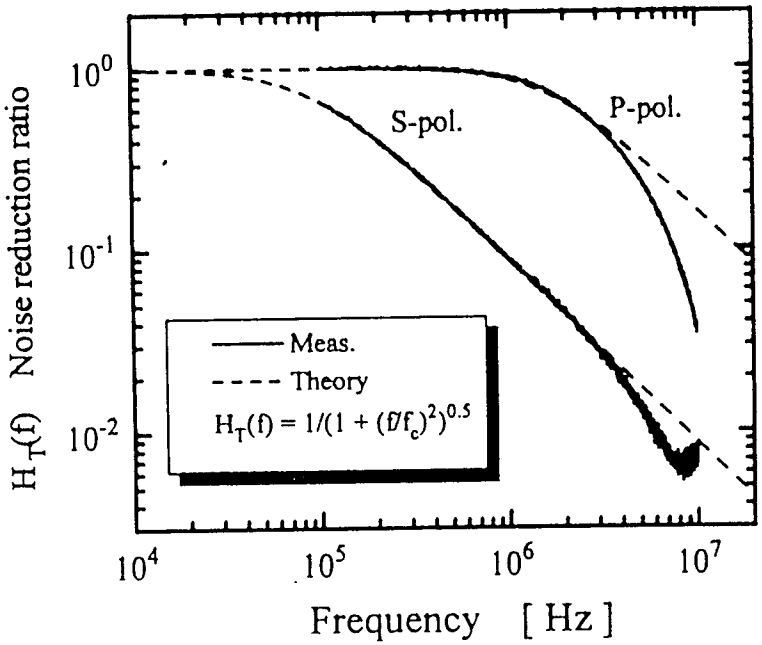




W. Tulloch, S. Rowan (GEO)

Fabry-Perot Pre-Mode Cleaner

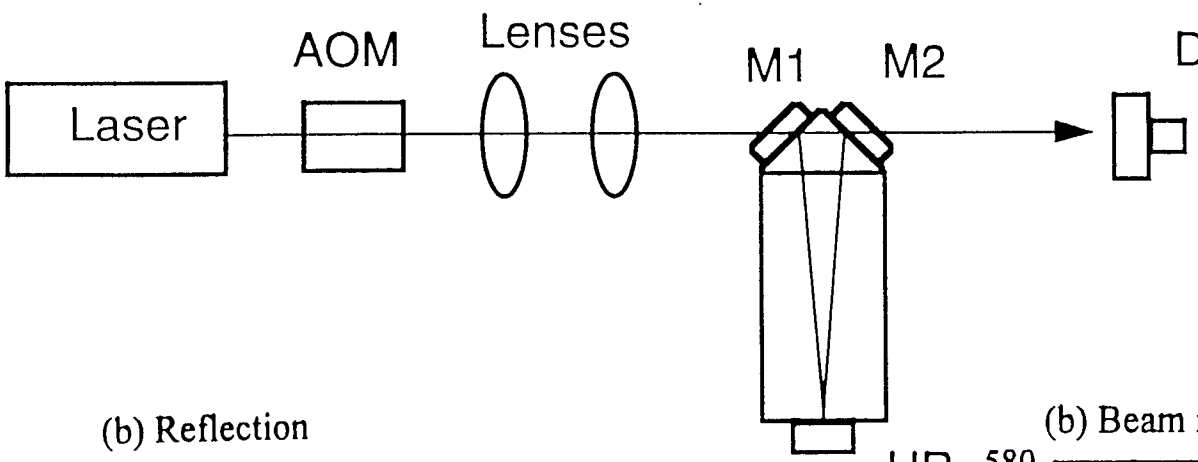


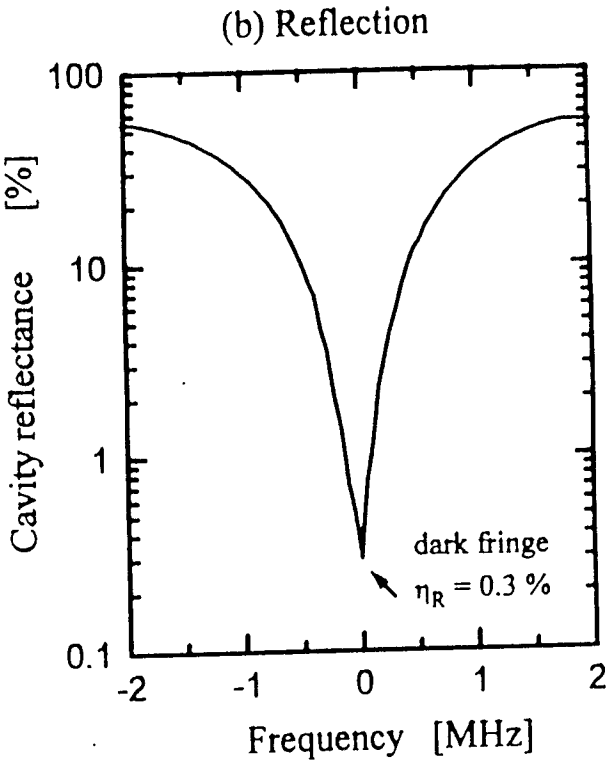


N. Uehara

Progress on Laser Pre Mode Cleaner

N. Uehara

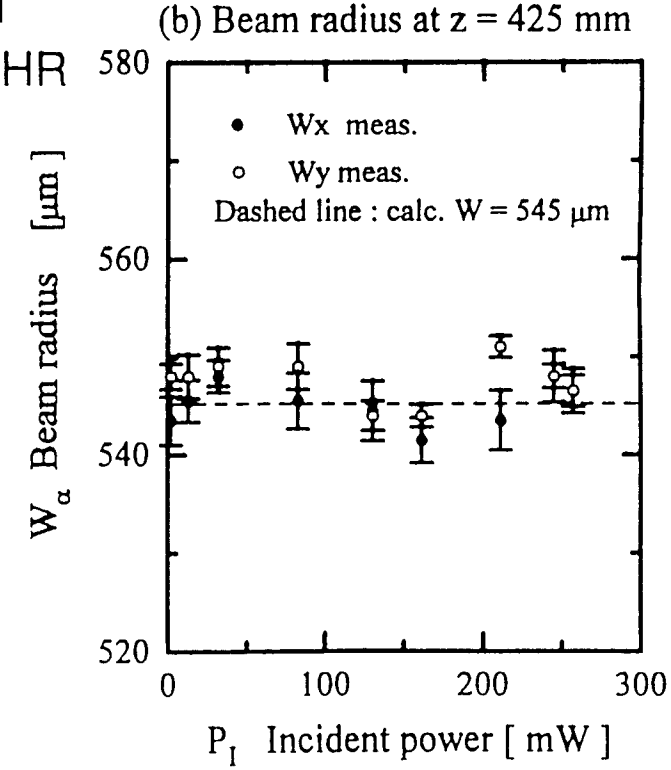




$\frac{P_{00}}{P_{tot}} = 0.998$

$\frac{P_{out}}{P_{in}} = 0.992$

p-polarization, finesse = 200



s-polarization
finesse ~ 4000

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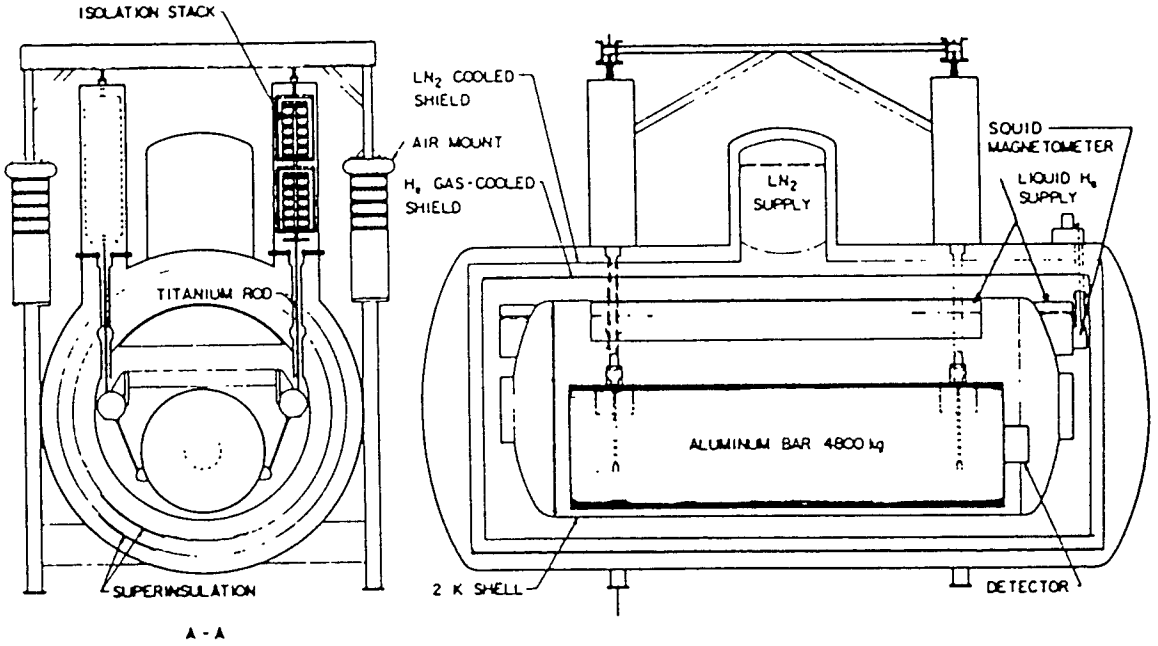
Suspensions, Thermal Noise, and Interferometer Control

Peter Michelson, Daniel DeBra, Martin Fejer, and Jonathan How

- Extensive experience with Gravity Wave Experiments



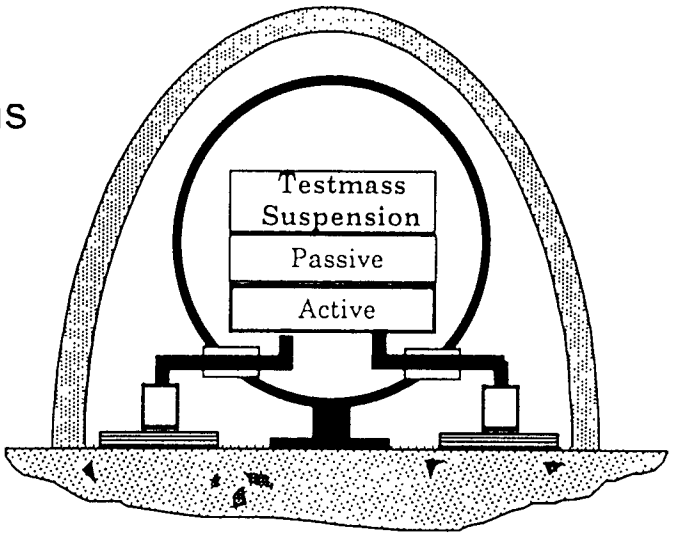
- Control and mechanical design for Gravity Probe B
- Isolation and control for space based stellar interferometers

Suspensions, Thermal Noise and Control (Current)

Goals: - Low thermal noise
- Large seismic isolation

Issues

- Low loss testmass
- Low loss suspensions
- Fabrication
- Non-Gaussian noise
- Violin modes
- Vacuum compatible active isolation



Approaches

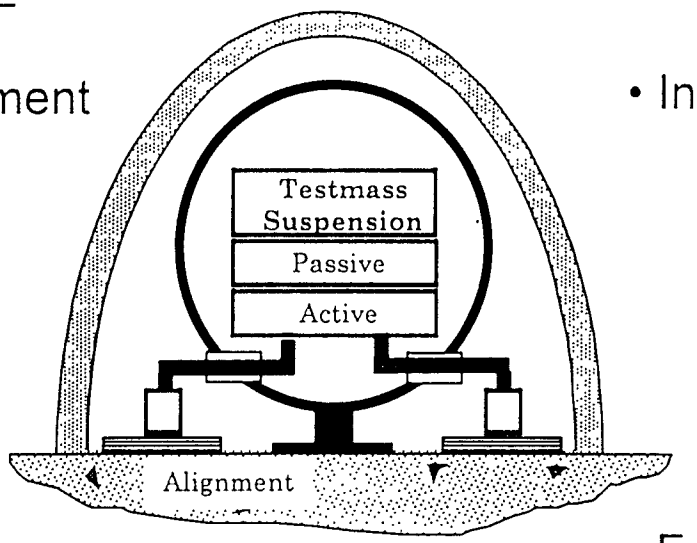
- Testmass (w/Syracuse)
  - sapphire
  - silicon
- Fibers and flexures (w/GEO)
  - sapphire
  - silicon
- Diffusion bonding
- Low strain designs
- Struts and shells
- Active strut

Double Pendulum and Active Isolation (Supplemental)

Goals: - Improved **low** frequency isolation
- Improved interferometer **availability**
- Reduced thermal **noise**

Further Issues

- Isolation and alignment control architectures
- Robust control
- Dynamic range
- Sensor noise
- Low loss suspension

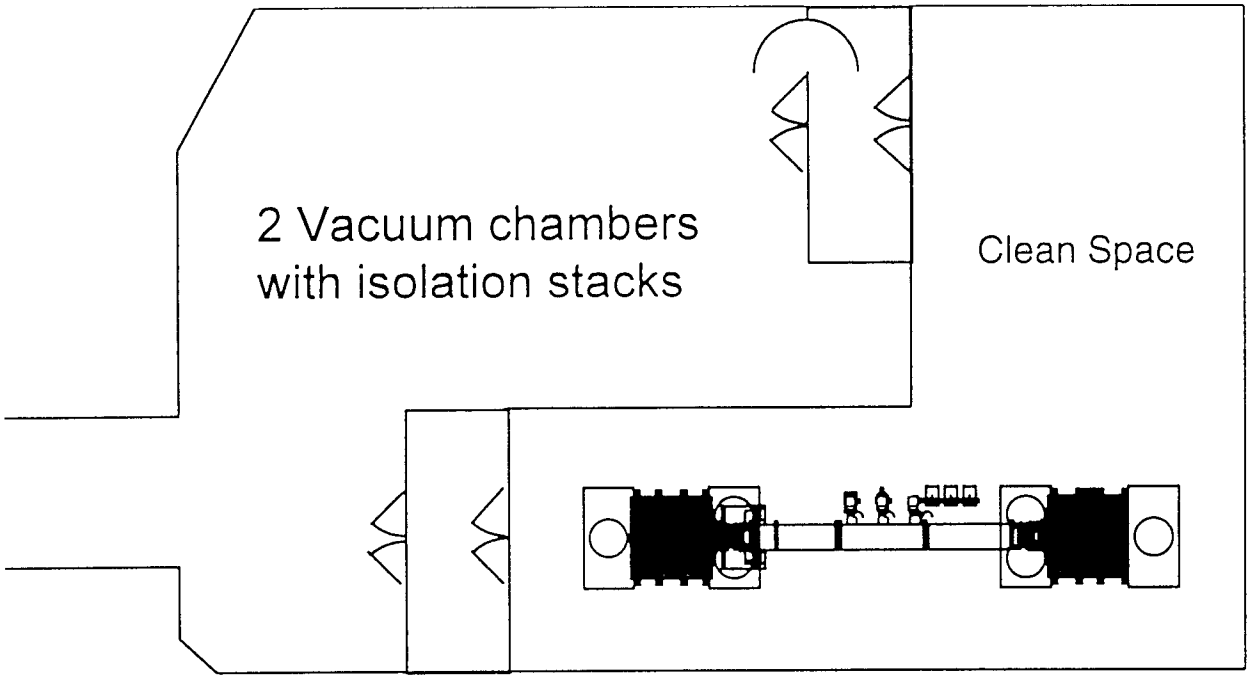


Approaches

- Integrated engineering (w/JILA)
  - active/passive tradeoff analysis
  - MIMO control
  - integrated alignment and isolation
  - automated system ID
- Feedforward control (w/JILA)
- Double pendulum (w/LIGO, GEO)
  - non-collocated control

Engineering Test Facility

- End Station II of High Energy Physics Lab at Stanford
  - 4000 sq foot high bay space
  - 2500 sq foot "clean space"
  - two 15 ton cranes



- ETF is a crucial element of a strong collaborative effort
  - dedicated to engineering analysis of the isolation/alignment control

Engineering Test Facility

- Facility for testing multiple full size active control systems
  - Fabry-Perot interferometer mirrors on independent isolators
  - relatively poor displacement and phase sensitivity compared to 40m (reduced cost)
  - clean vacuum system
- Designed to facilitate rapid prototyping
  - easy access and turn around
  - available to LRC
- Versatile and functional
  - verify tools to enhance interferometer availability (ID & robustness)
  - maintain lock while correcting for large scale disturbances
  - dynamic range compensation for fine actuators

Summary of Proposal Supplement

- GALILEO is a **multidisciplinary** effort among Stanford Faculty
- GALILEO is **collaborative** with LIGO, GEO, JILA and Syracuse
- High-power Laser amplifier development (LIGO)
  - build and test a high gain saturated amplifier
  - incorporate an active mirror into the amplifier
  - amplify the 10W LIGO Laser
  - measure frequency, amplitude and modal noise
  - collaborate with LIGO on a phase noise measurement at 3×10^{-11} rad/sqrt(Hz) if required

Summary of Proposal Supplement

- Double pendulum
  - assess LIGO disturbance environment to determine design requirements (w/LIGO)
  - analysis of GEO600 double pendulum (w/GEO)
  - tabletop double pendulum experiments to study stability and control
    - » incremental prototyping (w/LIGO, GEO)

- Vibration isolation and control
  - investigate redesign options for the passive/active vibration isolation systems (w/JILA, LIGO)
  - design and implement an integrated control strategy in the Engineering Test Facility (w/JILA, LIGO)
  - vacuum compatibility studies of active vibration isolation (w/LIGO)
  - analyze candidate control configurations in the ETF
    - » select those for high sensitivity tests