LIGO-G990079-13-M

Plans for LIGO II

David Shoemaker
LSC Stanford 20 July 99

- **Overview**
  - what are the constraints?
  - performance goals, astrophysical impact
  - lessons from LIGO I
  - strategies
- **Technical status**
  - configurations (Ken Strain)
  - lasers and optics (Eric Gustafson)
  - mechanical design - isolation and suspensions (David Shoemaker)
- **LIGO Laboratory view and role (Gary Sanders)**

Timeline

- **LIGO I data run starts: 2002**
  - unless detections made, instrument fully exploited after several years
- **LIGO II MRE support: 2002-2006**
  - assumes successful proposal in January 2001
  - assumes ~4 year funding cycle, ramp up in 2002, ramp down in 2006
- **LIGO II 'epoch': 2005 to ~2008**
  - ~two years required for installation and shakedown of a new configuration (change of optics, suspensions, isolation, control systems)
  - requires preparation, practice for installation
  - again, unless detections made, 2-3 years observation sounds right per significant technical step forward
  - could imagine a second 'non-invasive' improvement - e.g., adding a single optical component like an RSE mirror, or a switch to an alternative laser source

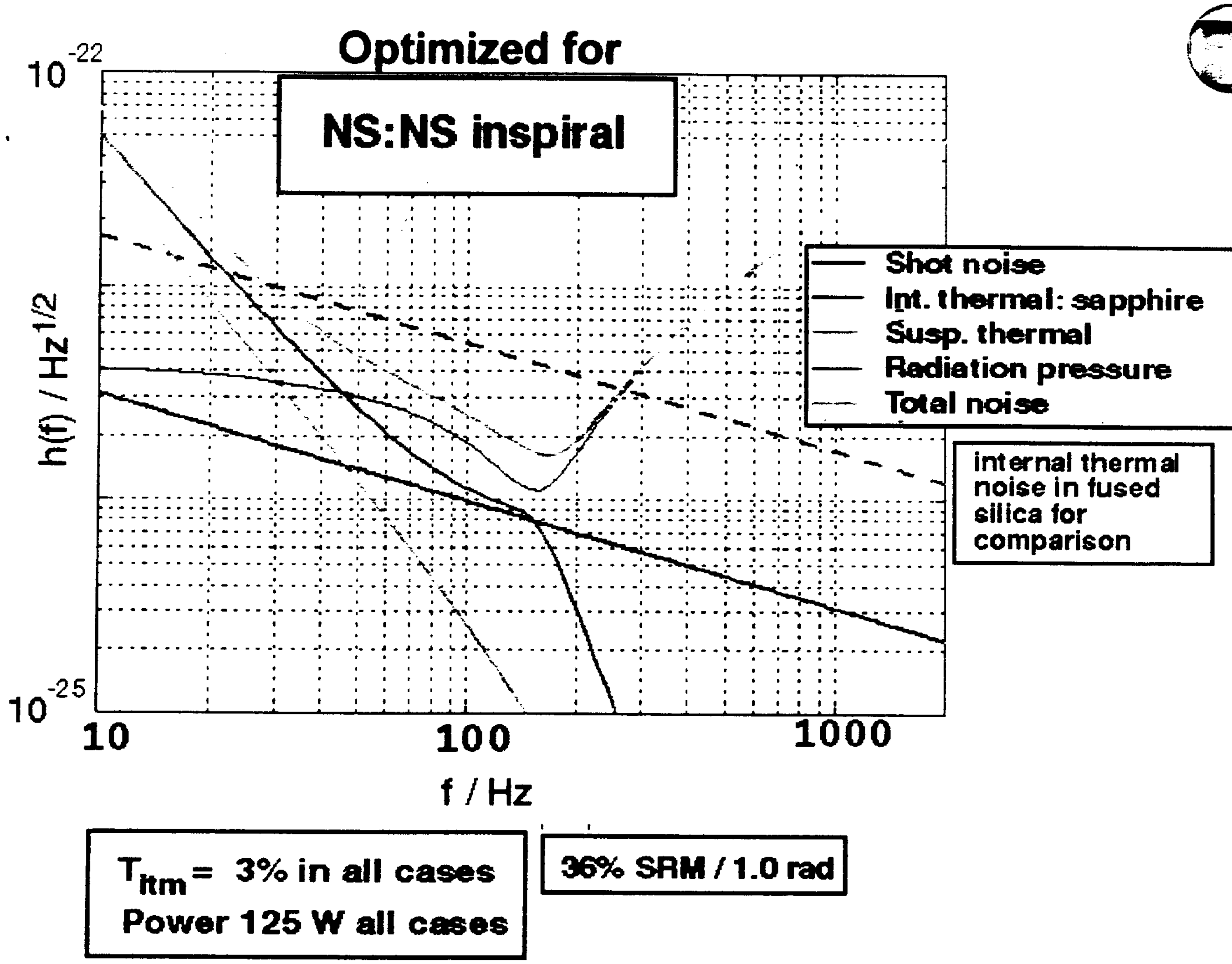
Goals

- **Make a significant change in 'Physics Reach'**
  - significantly improved probability of detecting foreseen sources
  - significantly improved overall sensitivity
- **Fully exploit basic configuration**
  - power/signal recycled Fabry-Perot Michelson
  - transmissive input optics
  - room-temperature pendulum suspension
- **Quantum limited at all useful frequencies**
  - optimize, not maximize, power
  - Newtonian background, thermal noise lurking below
- **Leave exotica for LIGO III (but absolutely critical to continue to pursue basic R&D)**
  - cryogenic and alternative approaches to reducing test mass thermal noise
  - diffractive optics, other basic changes in optical configurations to allow higher power, targeted searches
  - quantum-non-demolition techniques

Technologies

- **in the configuration**
  - addition of signal recycling
    (increased sensitivity in narrow band or other optimization)
- **in the optical system**
  - broad-band improvement due to increase in circulating power (to 170 W, increased optical efficiency)
- **in thermal noise**
  - pendulum thermal noise improvement through change to fused silica (factor 6 reduction), design of fibers (~factor 5 reduction): factor 30 less than LIGO I
  - test mass thermal noise: change to crystalline masses (factor 12 less than LIGO I)
- **in seismic noise**
  - improved filtering to ~10 Hz 'brick wall'
    (touching Newtonian background)

Sample sensitivity curve



CW sources: addition of 10-30 Hz, RSE
Bursts: broad 'sweet spot'
Stochastic sources: l0 Hz cutoff
Binaries: 15-20x further seeing than LIGO I

Inputs to upgrade strategies

- **Physics reach**
  - as much as quickly as possible
- **Impact on observation:**
  - how much of present system to be removed?
  - any rework of infrastructure? how much 'shakedown'?
  - Leave one interferometer running one shift (e.g., 2k)?
- **Ability to test in advance:**
  - performance to requirements,
  - ease of installation,
  - reliability
- **Costs**
  - cost of new elements: R&D, design, materials, installation
  - cash flow: integral from 2002-2004 might not suffice for some expensive changes or long-lead items in 2004

Inputs to upgrade strategies con't

- **Some technologies close to 'available'**
  - fused silica pendulums, higher power lasers, thermal 'defocussing'
- **Some technologies challenging but require no 'breakthroughs'**
  - seismic attenuation, with some mix of active and passive elements
  - modification of suspensions for work at low frequencies
  - associated control problems
- **Some technologies show promise but need significant R&D**
  - crystalline masses/optics (significant industry development needed)
  - signal-tuned recycling (hard long lab work, multiple prototypes)
- **Risk evaluation**
  - some risk appropriate for long-range plans
  - must have a fallback for all high-risk elements
- **Manpower limits**
  - can we really support all development in parallel?
  - Can we maintain the schedule?

Organization

- **LIGO Laboratory evidently responsible for the Observatories**
  - LIGO II project organization to be in LIGO Lab
- **LSC central to success for a LIGO II upgrade**
  - LIGO I using most Lab personnel, especially with experience in interferometer design and prototyping
  - LSC has wealth of resources; also busy, but unique and numerous
- **Lab anticipates significant participation from LSC**
  - continuing basic R&D
  - directed R&D (interactions with industry, structured prototype testing)
  - subsystems responsibility possible through MOU with Lab; fabrication/installation
    (LIGO I: Univ. Fla. and the IO subsystem)
- **GEO playing a special role**
  - very strong technical partner
  - also likely to contribute materially
- **GEO, VIRGO, TAMA provide valuable technology tests**
  - high-sensitivity tests of real hardware
  - beneficial for Lab to stay close to these projects; exchanges

Steps along the Path

- **R&D has lead to Strawman design**
  - presentation to follow
- **Selection of a Reference Design**
  - LSC makes proposal as input for the Lab draft Project Plan (some options allowed) by the close of this meeting
- **Costing, manpower, reality check by Lab in August**
  - close LSC- Lab working session
  - capitalization of Lab scientific and engineering expertise
- **Detailed LSC R&D plan to NSF in early September**
  - update and focussing of 1998 R&D Whitepaper
  - tightly organized around Reference Design for LIGO II
  - milestones and responsibilities explicit!
  - not forgetting LIGO III
- **Conceptual Draft Project Plan to NSF in early September**
  - Reference Design, Cost/Schedule, Lab plans
  - where possible, indications of institutional commitments for subsystems

LIGO II: Suspension/Isolation

David Shoemaker - LSC - 20 Jul 99

Suspension

- requirements
- technical solution

Isolation

- requirements
- technical solution(s)

Suspension: Requirements

Thermal noise

- must realize potential of best known materials
- noise not to be degraded by more than 10% from expectation based on best measurements available
- excess noise must be demonstrated not to significantly impact sensitivity

Actuation

- provide points for longitudinal, angle control
- not compromise thermal noise performance (above)

Attenuation of external stochastic forces

- seismic noise (jointly designed with seismic isolation to meet '10 Hz brick wall' attenuation requirement)
- controller noise (hierarchy of ranges/forces, noise) to be <10% of thermal noise
- thermal noise of previous isolation stages to be <10% of thermal noise

Suspension: Materials

Substrate materials (shared with Lasers & Optics)

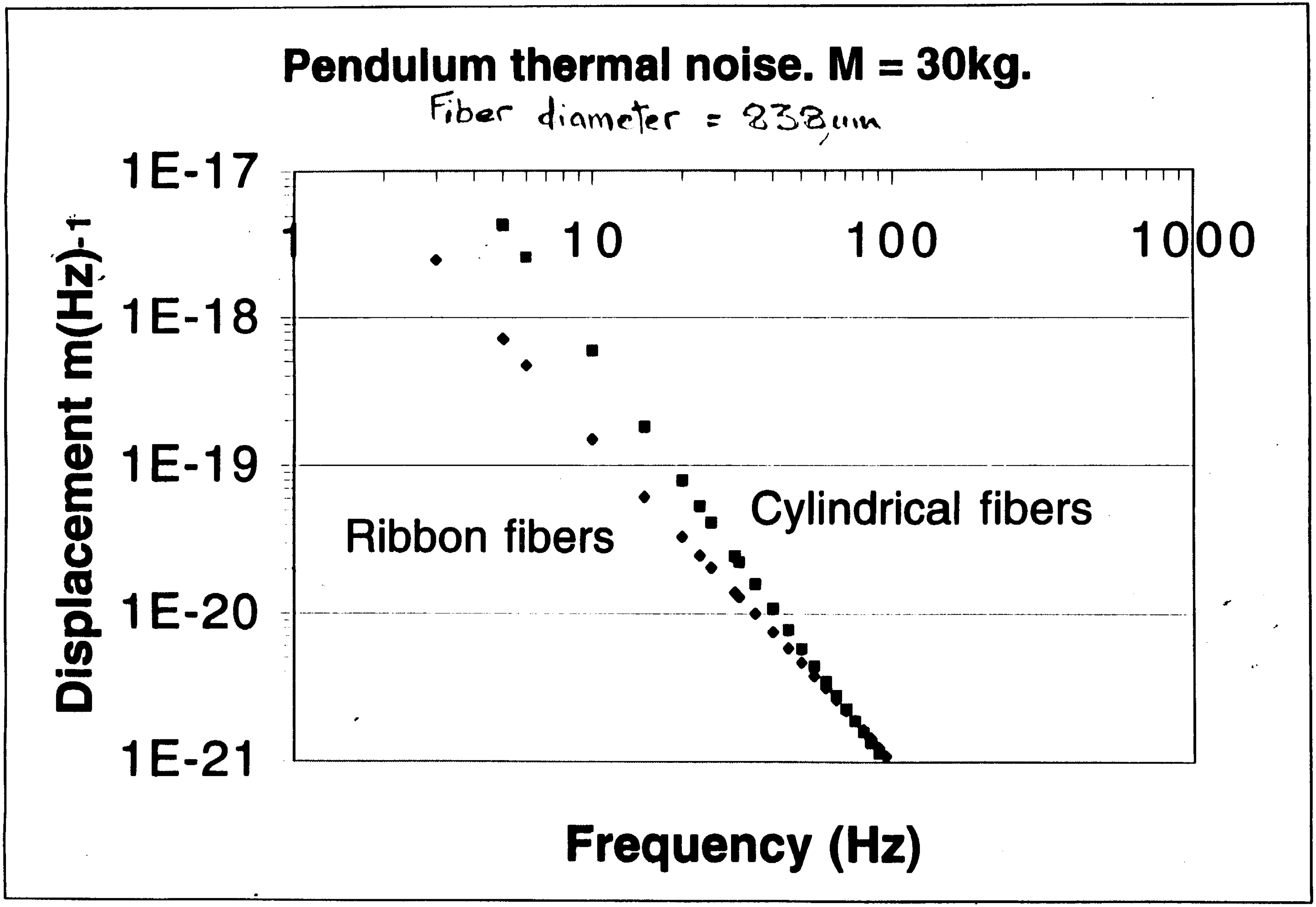
- fused silica
  - familiar; lowest loss 10^-7
  - near-term or fall-back solution
- crystalline materials, typified by Sapphire
  - lower loss (10^-8), higher density, higher speed of sound - net thermal noise ~6x better
  - requires extensive development for size, optical properties (L&O)

Suspension fibers: fused silica

- no competition for room-temperature performance

Fiber cross-section

- round
  - near-term or fall-back solution
- rectangular
  - increases 'dilution' (amount of energy stored in gravitational field)
  - moves thermo-elastic damping peak
  - requires more development, low-noise test



Pendulum thermal noise. M = 30kg.
Fiber diameter = 238μm
1E-17
1E-18
1E-19
1E-20
1E-21
Displacement m(Hz)-1
1
10
100
1000
Ribbon fibers
Cylindrical fibers
Frequency (Hz)

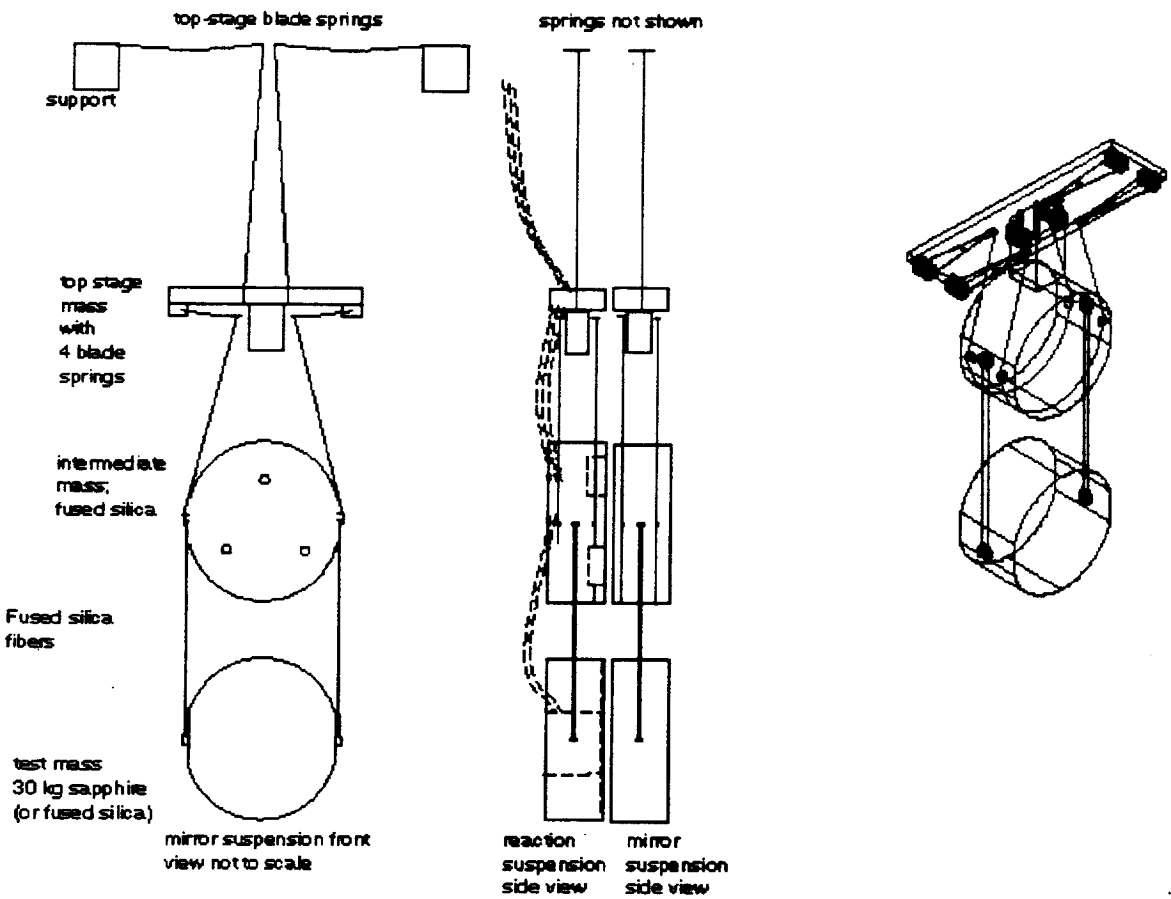
Suspension: Design

Based on GEO600 design

- many aspects tested in Glasgow 10m interferometer
- presently in production/installation for GEO

Triple pendulum

- bottom test mass (and reaction mass for end test mass)
- intermediate mass: angular and longitudinal control
- top mass/cantilever spring: positioning, vertical isolation



Suspension: Technology

Assembly techniques

- tabs attached to test mass and intermediate mass using hydroxy-catalysis
  - works for fused silica and sapphire test masses
- fibers welded to tabs at bottom and top

Sensors

- none for test mass (damping from levels above)
- occultation (LED/PD) for upper stage; possibly electrostatic

Actuators

- photon pressure on test mass for operation
- electrostatics for acquisition (if needed); and fallback if photon pressure not needed or possible
- magnets/coils for upper stages, varying force requirements, wide dynamic range in all cases

Isolation: Requirements

Seismic attenuation

- The 'brick-wall' cutoff is to be significantly below the frequencies of best overall sensitivity (~100 Hz): thus, 10 Hz cutoff.
- The rms motion of the test mass while the interferometer is locked is to be less than 10^{-14} meters.
- The rms velocity of the test mass is to be small enough and the test mass control is robust enough that the interferometer can acquire lock.
- The system will fit into the existing vacuum chambers and can be tested in the LIGO/MIT Advanced System Test Interferometer Facility.

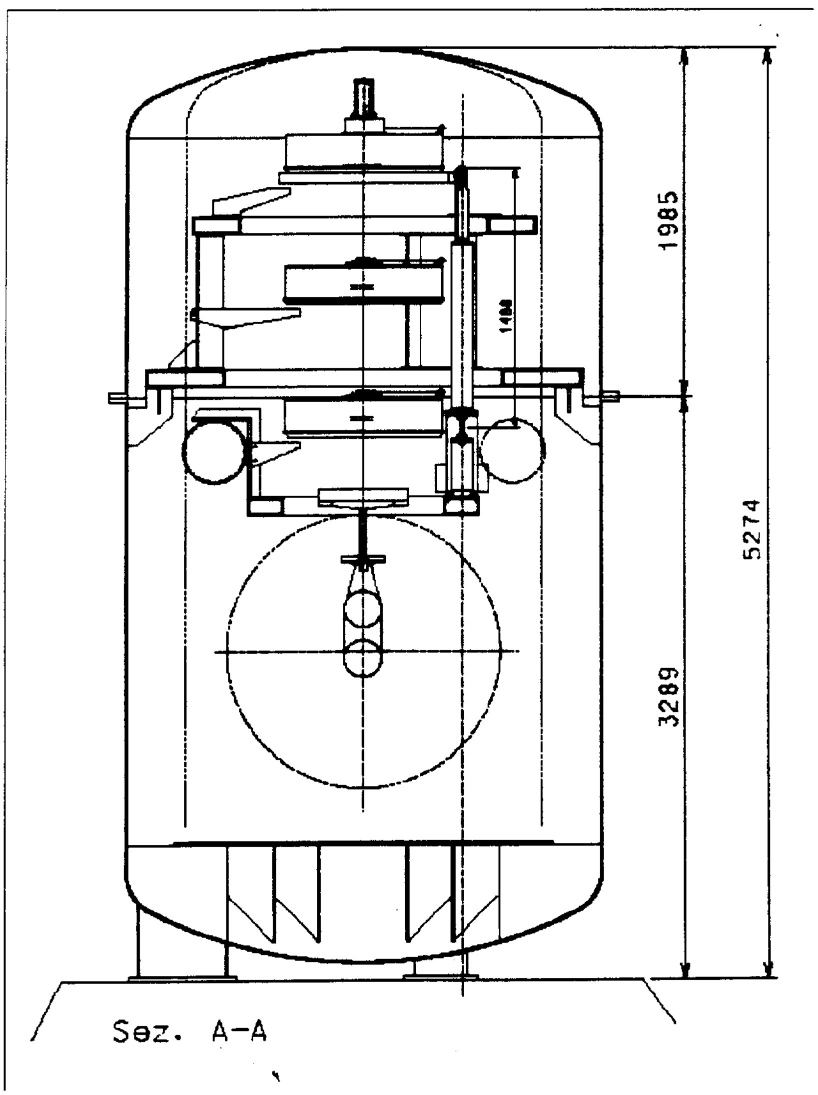
Actuation

- The mirror control system must have a large enough control range to allow the interferometer to remain locked for at least 1 week (or month?)

Isolation systems

Solution 1: 'passive' attenuation - low natural frequencies

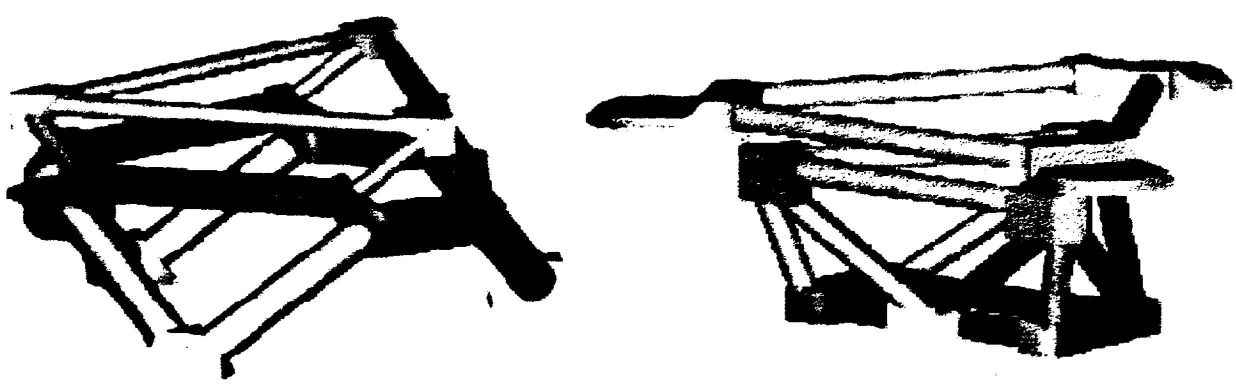
- inverted pendulum with ~.03 Hz horizontal resonance
- spring-counterspring approach with ~0.1 Hz vertical resonance
- control systems to establish/maintain position, damp internal modes; and for some active suppression



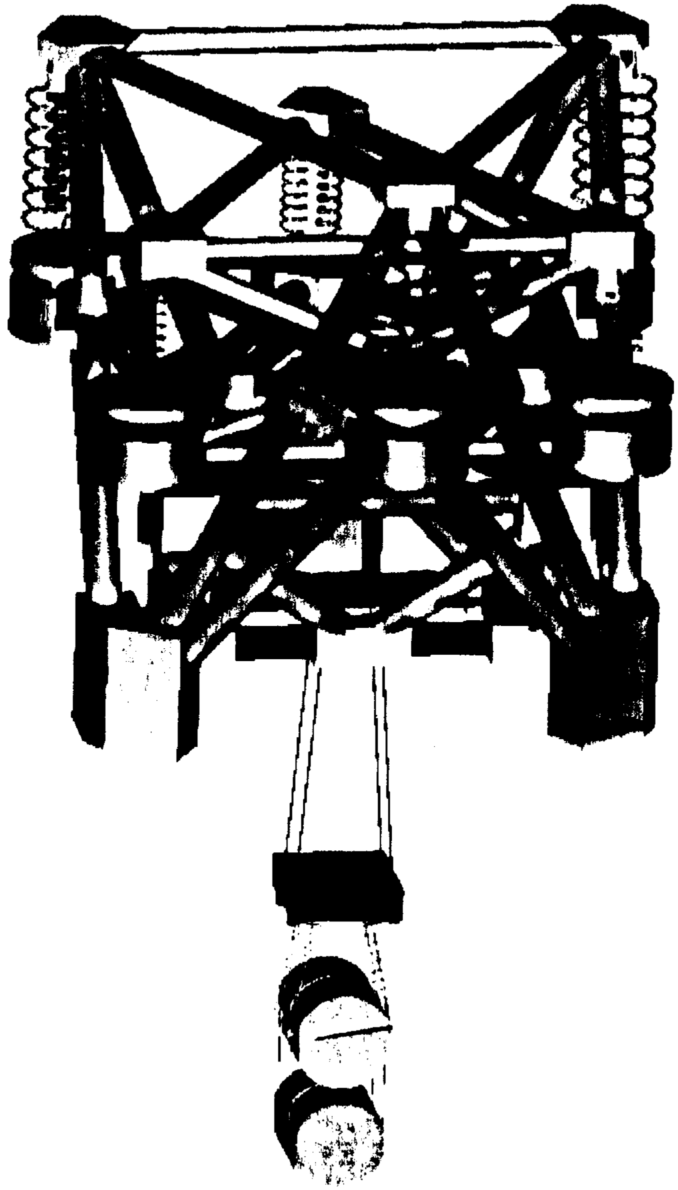
Isolation systems

Solution 2: 'active' attenuation - high natural frequencies

- external hydraulic actuator for positioning, some LF attenuation
- spring layer with ~5 Hz horizontal and vertical resonance
- low noise accelerometer to sense motion
- one or two 'high gain' active system to reduce motion (possibly to sensor limit)
- final passive stage

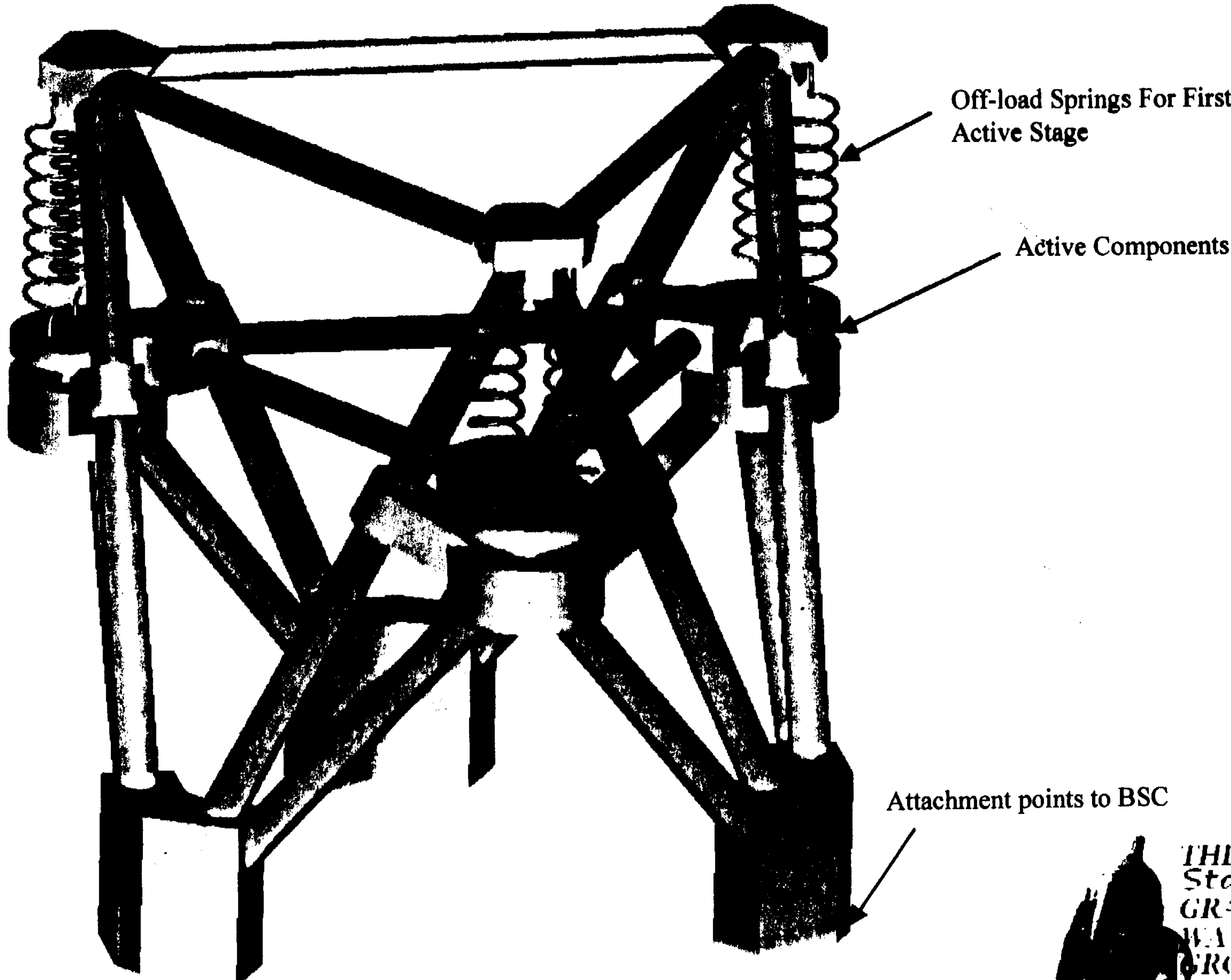


1 Hz - Two Stage Active Isolation



THE
Stanford
GRAVITY
WAVE
GROUP

1 Hz - Two Stage Active Isolation



THE Stanford GRAVITY WAVE GROUP

Isolation: Decisions

Multiple solutions are better than none

- both appear to be viable
- elements from both solutions very likely to appear in final design
- questions are what natural frequency and how much gain

What is the least we could possibly do?

- LIGO I stack with GEO pendulum: minimally invasive, ok performance, possibly short 'down-time'
- apply to 2k ifo as first step?

Process

- draw up explicit list of objective measures of systems, work through for both systems
- establish rough costing for both systems
- develop scenarios for design, fabrication, and installation
- all to be done in timely fashion for final LIGO II proposal

Timeline

Isolation

- downselect to one design (no later than spring 2000)

Suspension

- refinement of design for 10 Hz
- tests in GEO 600 in 2000

Fabrication of prototypes 2000-2001

- tests of bits and pieces

Prototype test 2001-2003

- displacement sensitivity comparable to LIGO II
- frequencies comparable to LIGO II
- work on steady state, excess noise, reliability
- go/nogo according to results (excess noise....)

Fabrication of production systems 2003-2005

- fit test for first article, installation practice

Note 1, Linda Turner, 08/17/99 07:50:02 PM
LIGO-G990079-13-M