LIGO

Advanced LIGO

David Shoemaker

LLO LSC

19 Aug 2002

LIGO

Truths

- LIGO mission: detect gravitational waves and

  initiate GW astronomy

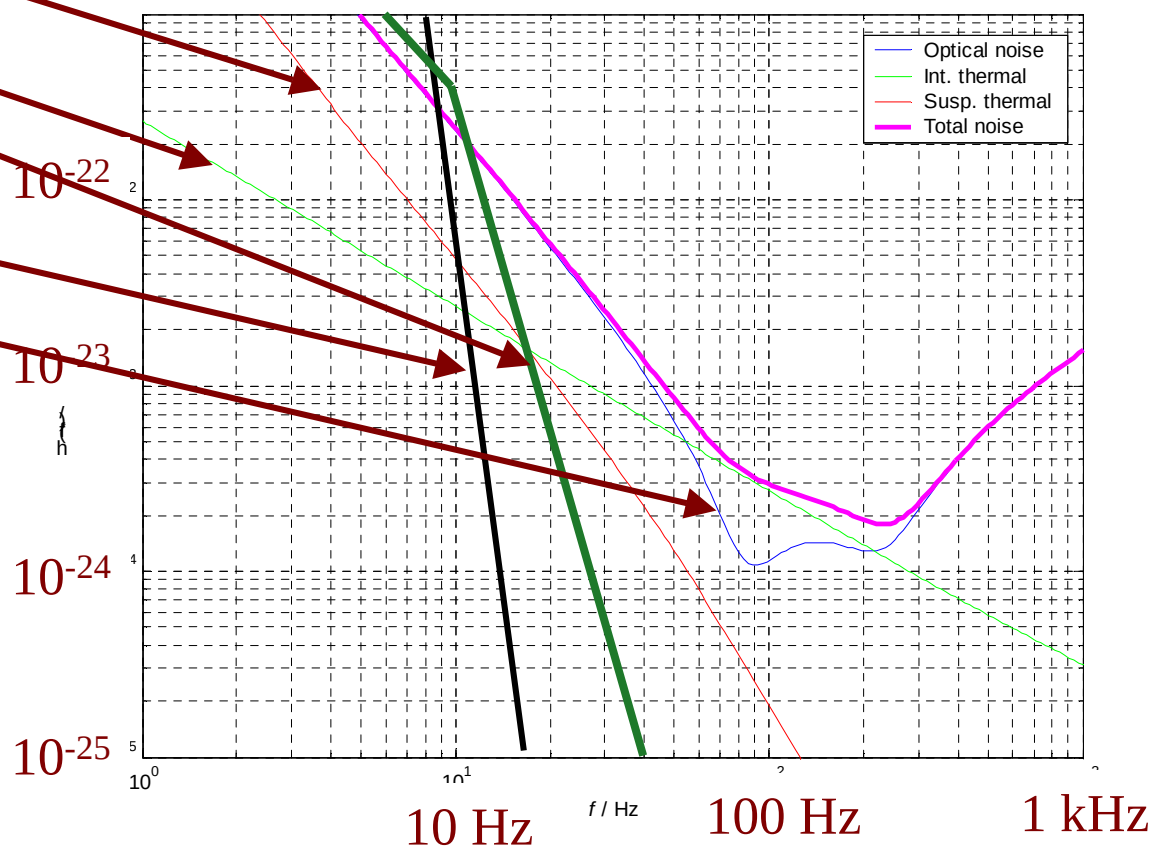
- Next detector
  - » Should be of significance for astrophysics if it observes GW signals (or if it does not)
  - » Should be at the limits of reasonable extrapolations of detector physics and technologies
  - » Should lead to a realizable, practical, reliable instrument
  - » Should come into existence neither too early nor too late

- An effort of the entire LIGO Scientific Collaboration (LSC)
  - » Amazing and delightful contrast with initial LIGO

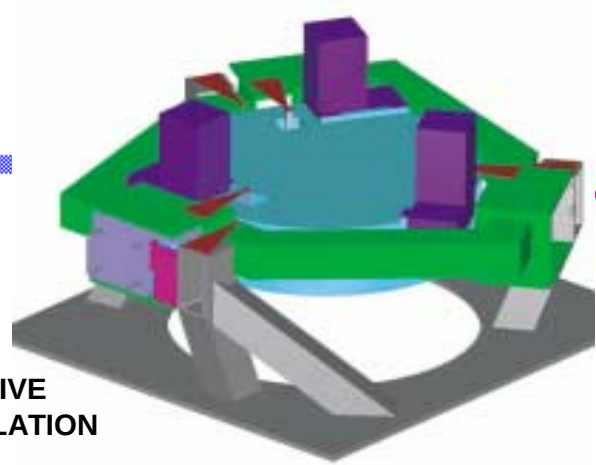
Anatomy of the projected Adv LIGO detector performance

- Suspension thermal noise
- Internal thermal noise
- Newtonian background, estimate for LIGO sites
- Seismic 'cutoff' at 10 Hz
- Unified quantum noise dominates at most frequencies for full power, broadband tuning

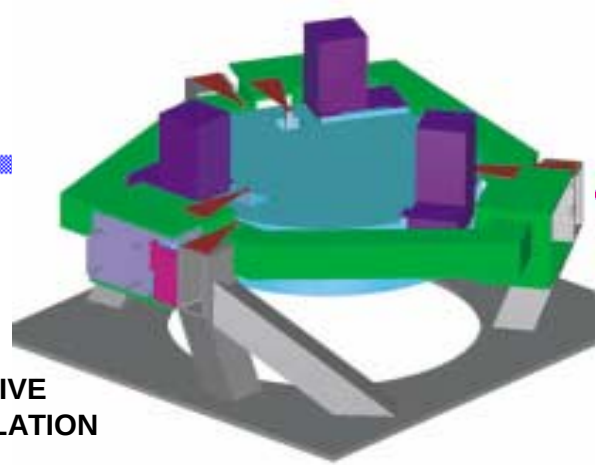
- NS Binaries: for two LIGO observatories,
  - » Initial LIGO: ~20 Mpc
  - » Adv LIGO: ~300 Mpc
- Stochastic background:
  - » Initial LIGO: ~3e-6
  - » Adv LIGO ~3e-9



Design overview



ACTIVE
ISOLATION



ACTIVE
ISOLATION

40 KG SAPPHIRE
TEST MASSES

INPUT MODE
CLEANER

QUAD SILICA
SUSPENSION

ACTIVE
THERMAL
CORRECTION

T=0.5%

LASER

MOD.

125W

830KW

BS

PRM
T~6%

ITM

ETM

SRM

T=5%

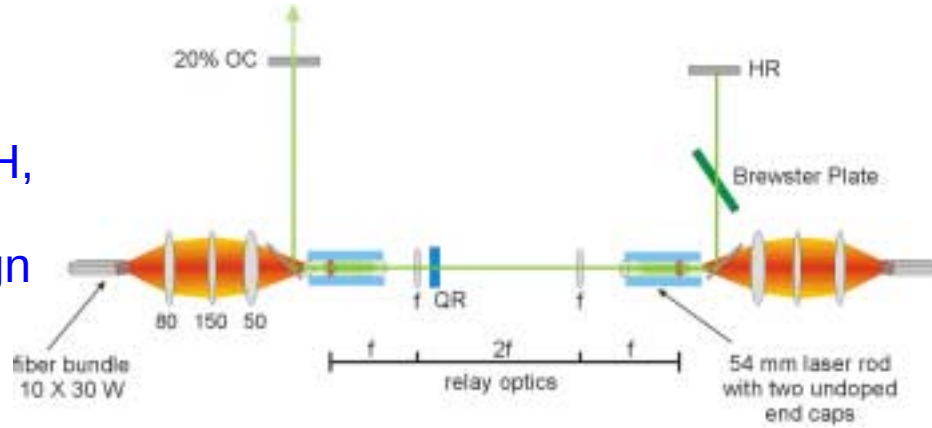
OUTPUT MODE
CLEANER

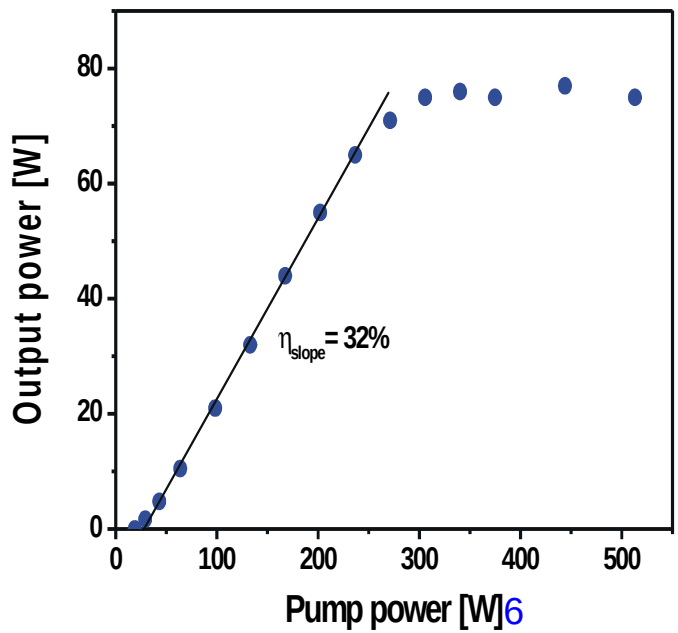
PD

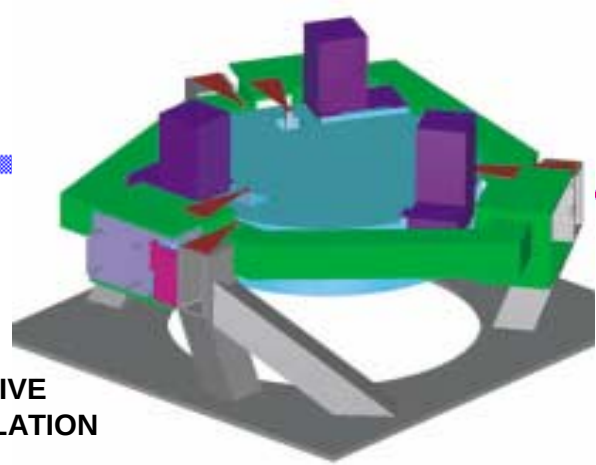
GW READOUT

Pre-stabilized Laser

- Pre-Stabilized Laser (PSL)
  - » Coordinated by Univ. of Hannover/LZH, will lead subsystem
  - » Three groups pursuing alternate design approaches to a 100W demonstration
    - – Master Oscillator Power Amplifier (MOPA) [Stanford]
    - – Stable-unstable slab oscillator [Adelaide]
    - – Rod systems [Hannover]
  - » All three have had difficulties, mix of trivial and serious
  - » All have reached ‘about’ 100 W, but not to their satisfaction, and without learning what is needed to make a choice
  - » Concept down-select December 2002
    - – Delayed by ~9 months; no impact on schedule, though
  - » Proceeding with stabilization, subsystem design



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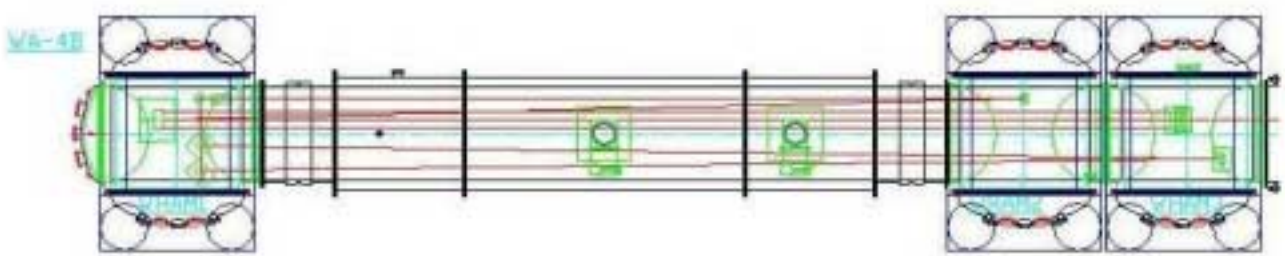
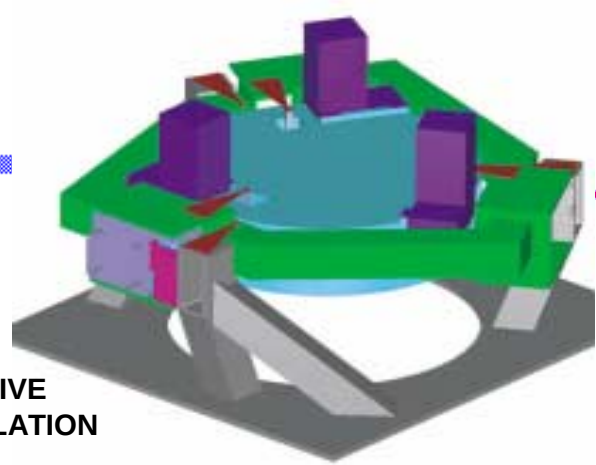
GW READOUT

Input Optics

- Design is based on initial LIGO system
- Design Requirements Review held in May 2001: very successful
- Many incremental innovations due to
  - » Initial design flaws (mostly unforeseeable)
  - » Changes in requirements LIGO 1 → LIGO II
  - » Just Plain Good Ideas!
- New Faraday isolator materials: 45 dB, 150 W
- Larger masses (radiation pressure), vacuum tubes (layout)
- Thermal mode matching
- Preliminary design underway





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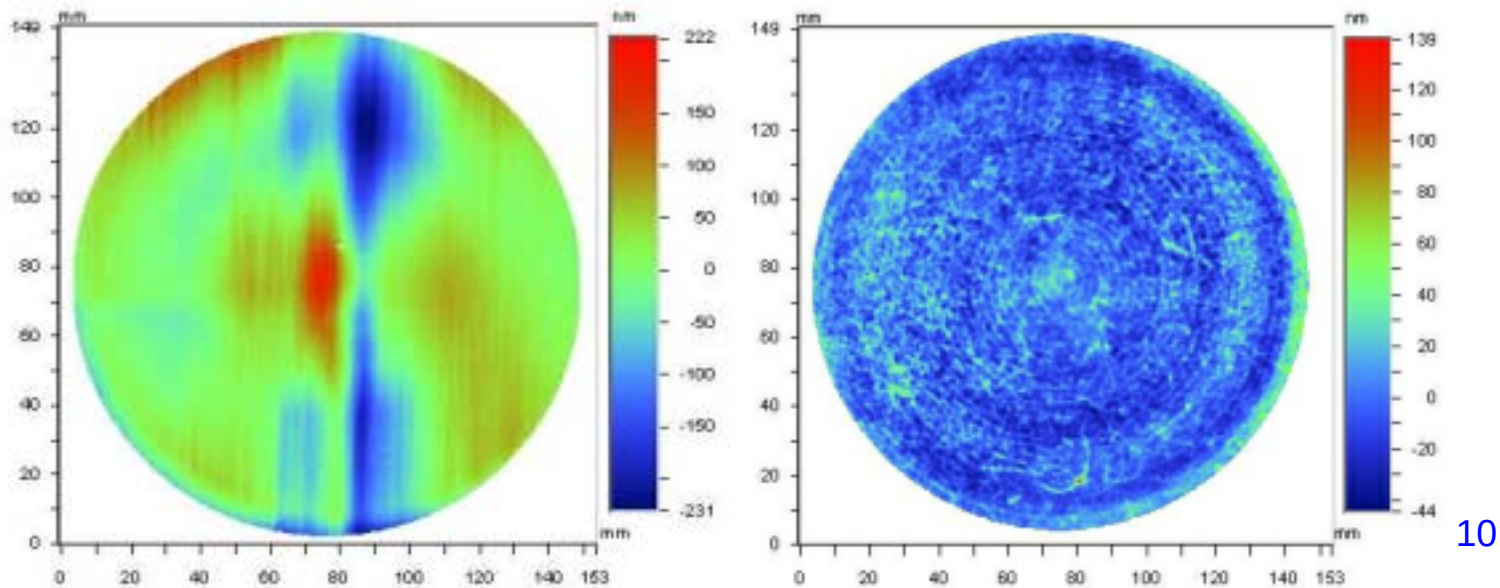
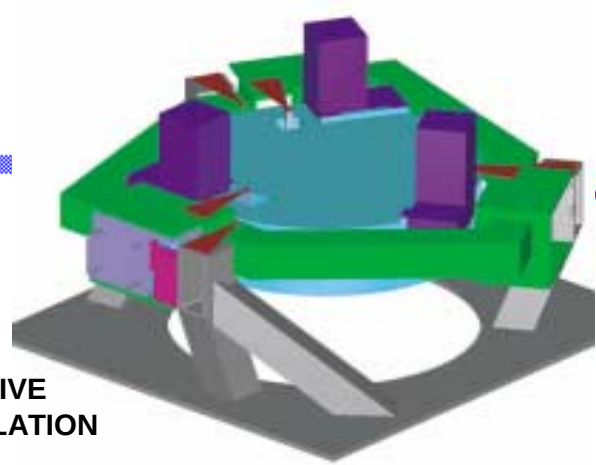
GW READOUT

Sapphire Core Optics

- Focus is on developing data needed for choice between Sapphire and Fused Silica as substrate materials
  - » Sapphire looks like better performance, lower cost; feasibility is question
- Progress in fabrication of Sapphire:
  - » 4 full-size Advanced LIGO boules, 31.4 x 13 cm, grown
  - » Delivery in October – destined for LASTI test optics
- Homogeneity compensation by polishing: RMS 60 nm → 15 nm





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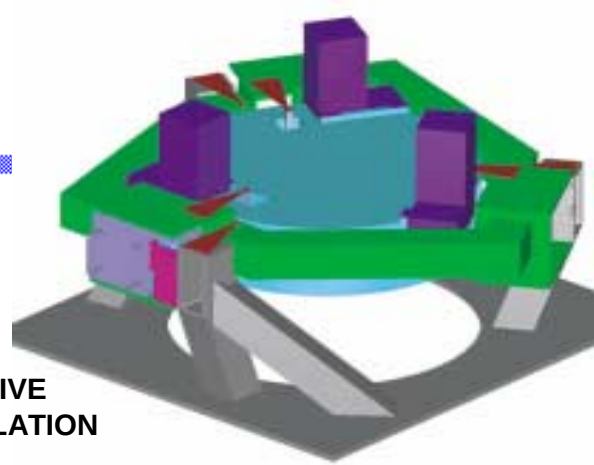
LIGO

Coatings

- Evidently, optical performance is critical –
  - » ~1 megawatt of incident power; ~2000 Nbounce (instead of 200)
  - » Very low loss in scatter and absorption required
- Thermal noise due to coating mechanical loss also significant
- More confirmation that principal source of loss is Ta2O5, not SiO2
  - » ‘Same’ coating by different coaters has different loss…
- Looking for alternatives
  - » Niobium coatings made, optically ok, mechanical losses TBD
  - » Doped Tantalum, annealing, etc.
- Need ~10x reduction in lossy material to have coating make a negligible contribution to noise budget – not obvious



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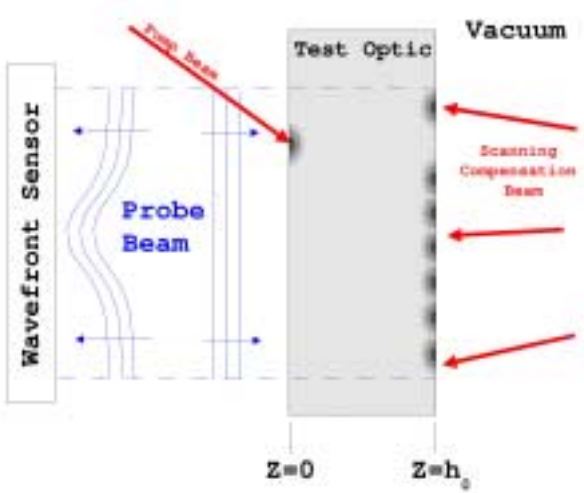
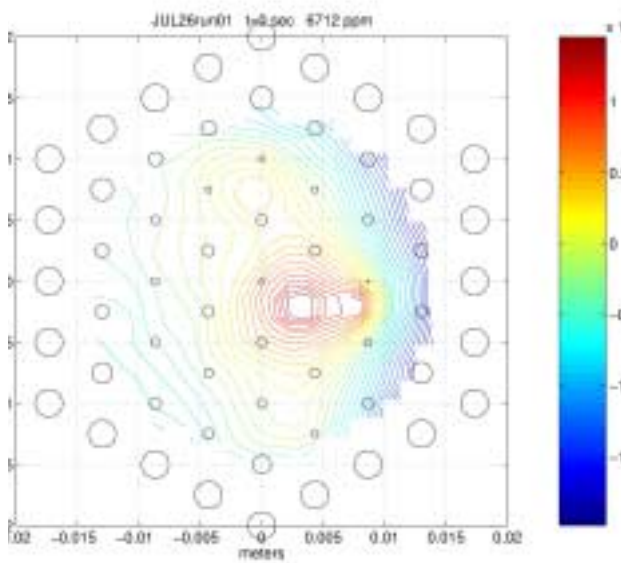
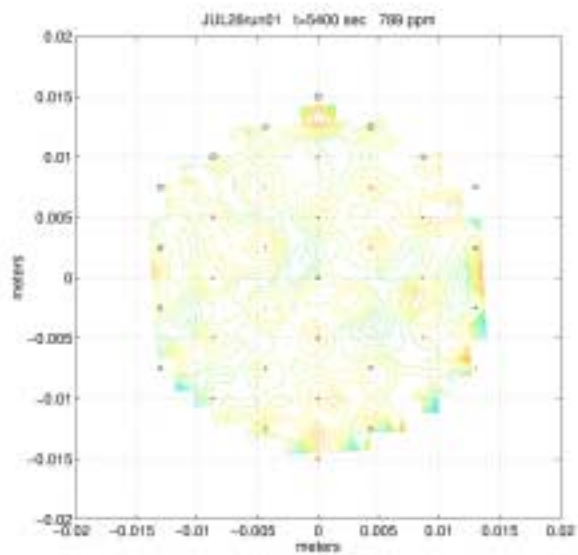
GW READOUT

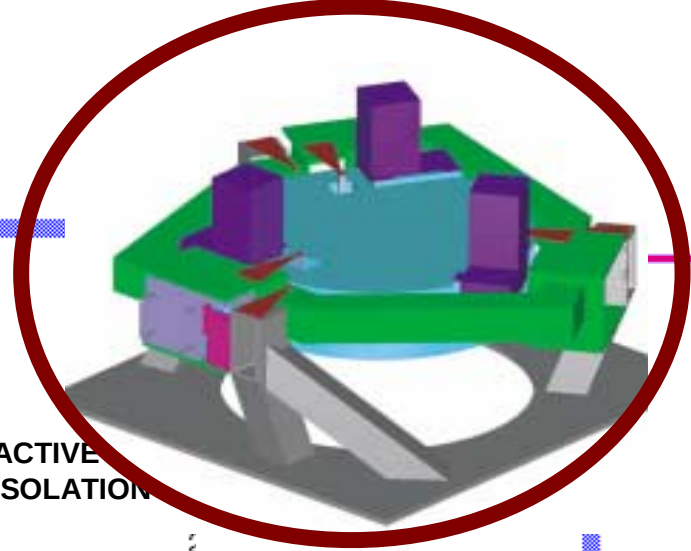
Active Thermal Compensation

- Removes excess ‘focus’ due to absorption in coating, substrate
- Two approaches possible, alone or together:
  - » quasi-static ring-shaped additional heat (probably on compensation plate, not test mass itself)
  - » Scan (raster or other) to complement irregular absorption
- Recent success: directed energy approach









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GW READOUT

Isolation I: Pre-Isolator

- Need to attenuate excess noise in 1-3 Hz band at LLO
- Using element of Adv LIGO
- Aggressive development of hardware, controls models
- Prototypes in fabrication
- Being installed at LASTI on HAM as we speak
- Plan: install at LLO after S2, April ‘03

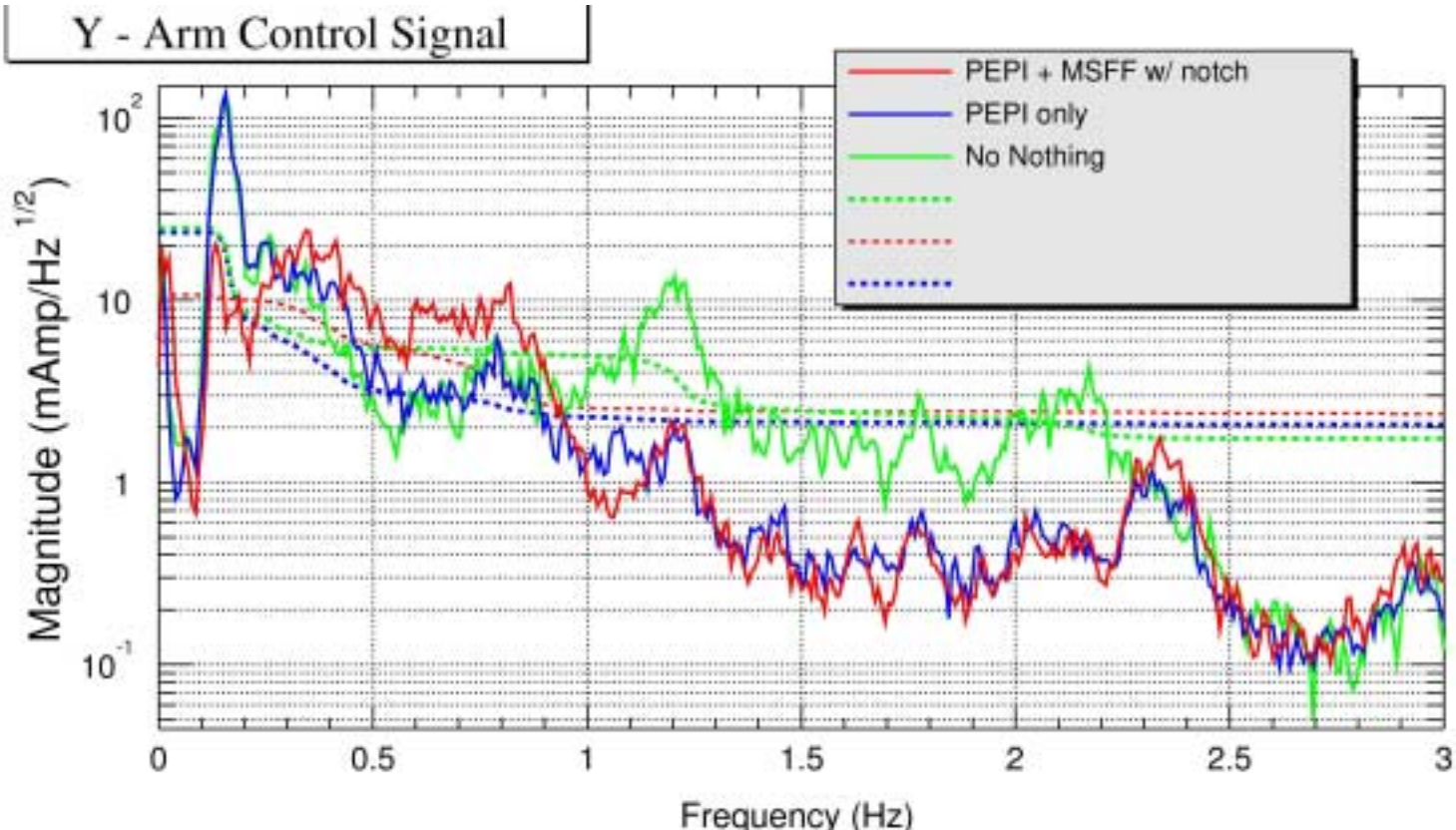
Advanced LIGO

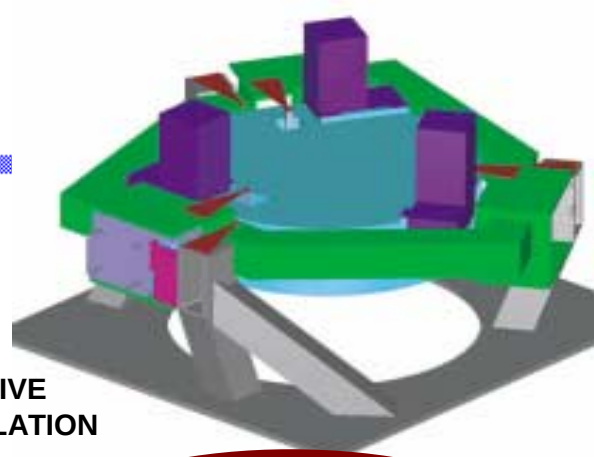
Isolation II: Two-stage platform

- Huge effort is focussed on pre-isolator, so slow going
- Stanford Engineering Test Facility Prototype progressing
  - » Mechanical system complete
  - » Instrumentation being installed for modal characterization
- The original 2-stage platform continues to serve as testbed in interim
  - » Recent demonstration of sensor correction and feedback over broad low-frequency band

Isolation III: PEPI

- Pre-pre-isolator, using initial LIGO PZT 'Fine Actuators', some velocity sensors, and some digital control techniques
- Had been demonstrated on LLO existing end station BSCs
- Has now been installed on Input Test Masses
  - » One of a number of silver linings to S1 delay
- Significant reduction in motion; net effect on Duty Cycle TBD





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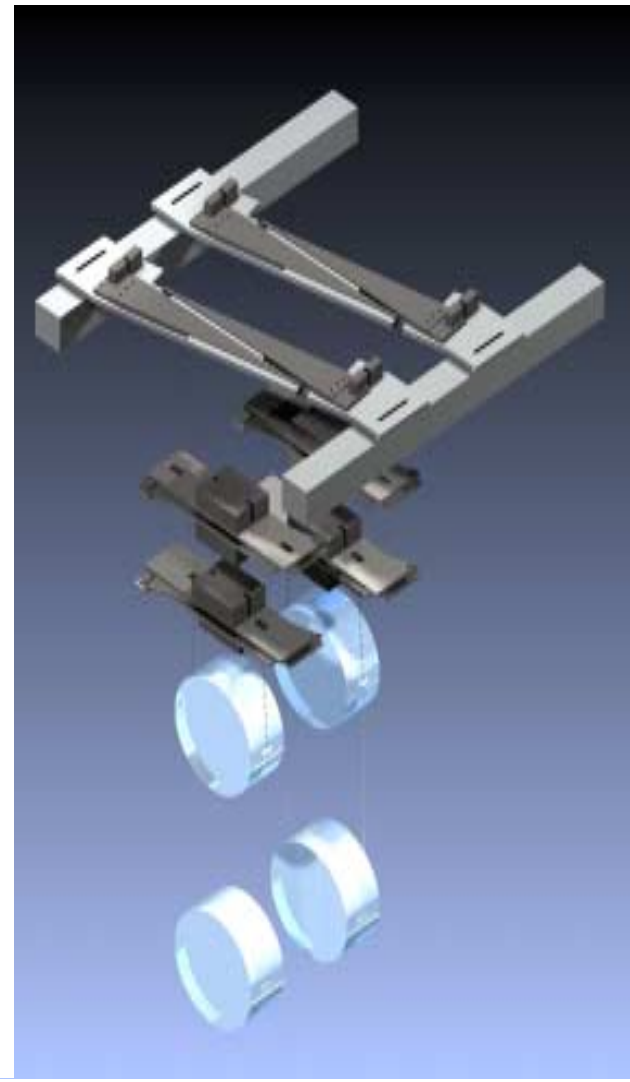
Suspensions

- PPARC proposal: significant financial and technical contribution; quad suspensions, electronics, and some sapphire substrates
  - » U Glasgow, Birmingham, Rutherford Appleton
- LF cut-off decision: working trade issues
  - » 10 – 10.5 Hz looks most likely for ‘bounce’
- A mode cleaner triple suspension prototype now being built for LASTI
- Both fused silica ribbon and dumbbell fiber prototypes are now being made and tested
- Eddy current damping has been tested favorably on a triple suspension
  - » Alternative to (noisy) local sensing system



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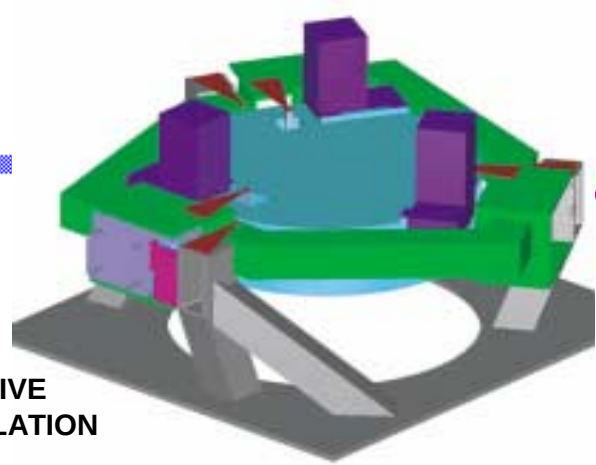

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GW READOUT

GW readout, Systems

- Glasgow 10m prototype, Caltech 40m prototype in construction, early testing
  - » Mode cleaner together and in locking tests at 40m
- Calculations continue for best strain sensing approach
  - » DC readout (slight fringe offset from minimum) or ‘traditional’ RF readout
  - » Hard question: which one shows better practical performance in a full quantum-mechanical analysis with realistic parameters?
- Technical noise propagation also being refined
- Progress on photodiode development (Stanford)

- Systems (or larger!) trade: the Third Interferometer – what kind of astrophysics does this additional detector bring us?

Summary of technical status

- A great deal of momentum and real progress in every subsystem
- No fundamental surprises as we move forward; concept and realization remain intact with adiabatic changes

- Note that the Instrument Science sessions at this meeting are largely Plenary –
  - » This afternoon from 13.30 to 16.30
  - » Tomorrow morning from 9.00 to 10.45

- …now, when and how to turn this into instruments?

Instrument Science Plenary Sessions

13:30 Plenary Instrument Science Session I

- Configurations:
  - » David Tanner: sensing scheme 5/5 min
  - » David Tanner: brief update on AIC 5/5 min
  - » Alessandra Buonanno/Yanbei Chen: readout considerations 20/5 min
- Suspensions/Isolation
  - » Joe Giaime/Brian Lantz: seismic isolation, pre isolator 25/5 min
  - » Sheila Rowan/Gregg Harry: thermal noise in substrate and coatings 25/5 min

- 15:00 – 15:15 Break/Snack
- Lasers
  - » Maik Frede: Status of Laser Zentrum Hannover Laser Program 15/5 min
  - » Shally Saraf: Status of Stanford High Power Laser Program 15/5 min
  - » Benno Willke: Adelaide Laser Program 10/5 min
  - » Benno Willke : Update on Adv. LIGO PSL program 10/5 min
- 16.30 session closed

Tuesday August 20 09:00 Plenary Instrument Science Session II

- Optics
  - » Roger Route/Marty Fejer: sapphire material development 20/5 min
  - » Dave Reitze: sapphire/silica downselect update 15/5 min
  - » Norna Robertson/Phil Willems: suspensions 25/5 min

Additional technical sessions
(of which I am aware…)

Tuesday August 20

- Optics Working Group session in depth discussions:
  - » Coating mechanical losses 13:15-14:15
  - » Advanced LIGO High Power Techniques 14:15-15:45

- 15.45 Break/Snack

- Suspension/Working Group session in depth discussion:
  - » Low frequency Isolation and Tilt Control for Active Platforms 16:00-16.30

Wednesday August 21

- 09:00 40m Technical Advisory Group meeting 09:00-09.45