Advanced LIGO

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LLO LSC

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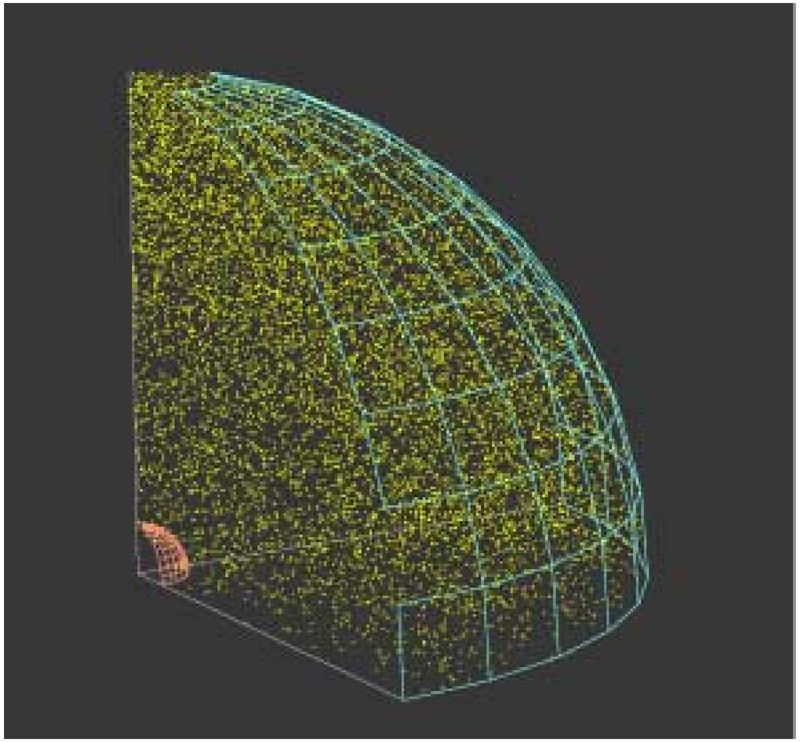
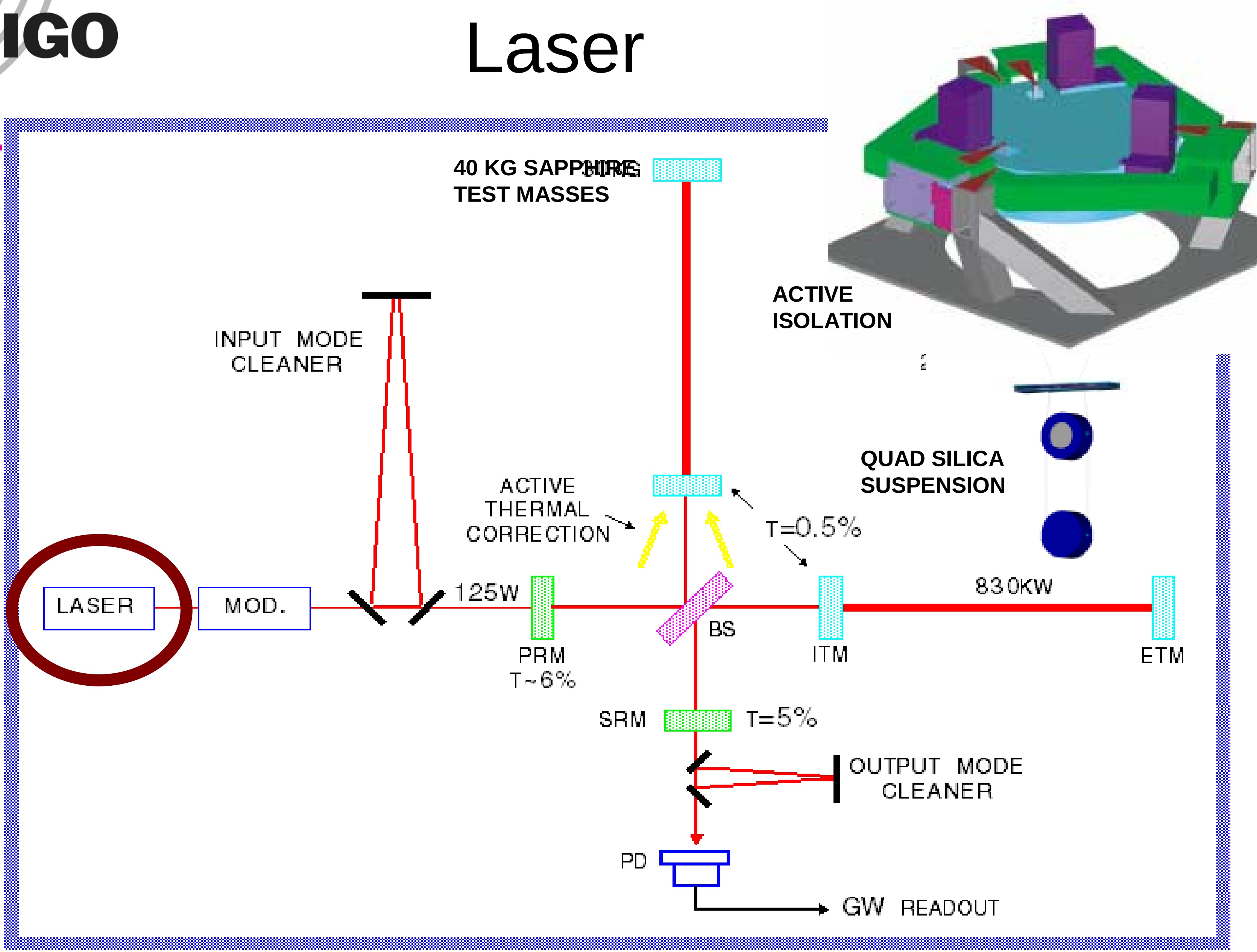
Advanced LIGO

- Advanced LIGO proposal submitted, end February
- Follows closely the baseline
  - » 3 interferometers, each 4km
  - » Signal recycled configuration
  - » ~180 W laser
  - » Sapphire substrates
  - » Quad monolithic suspensions
  - » Active isolation system
- More on organization etc. at end of talk
- What's new technically?



Laser



40 KG SAPPHIRE
TEST MASSES
ACTIVE
ISOLATION
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
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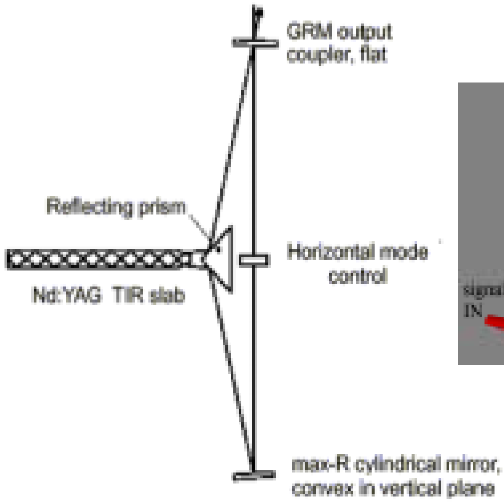
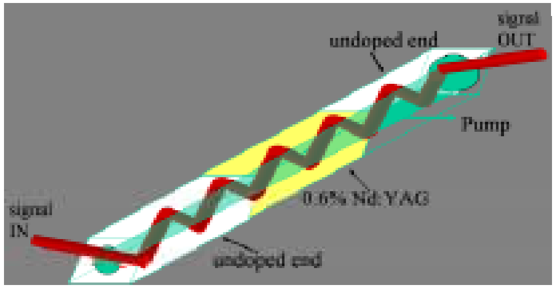
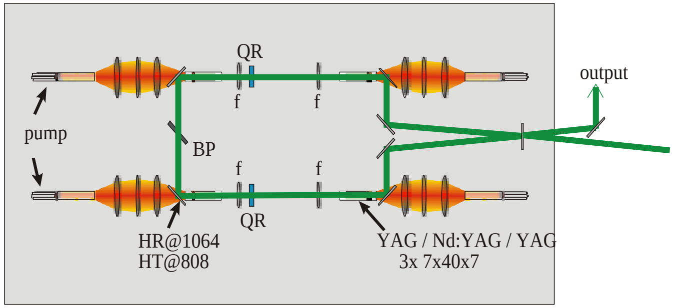
PD
GW READOUT

Pre-stabilized Laser

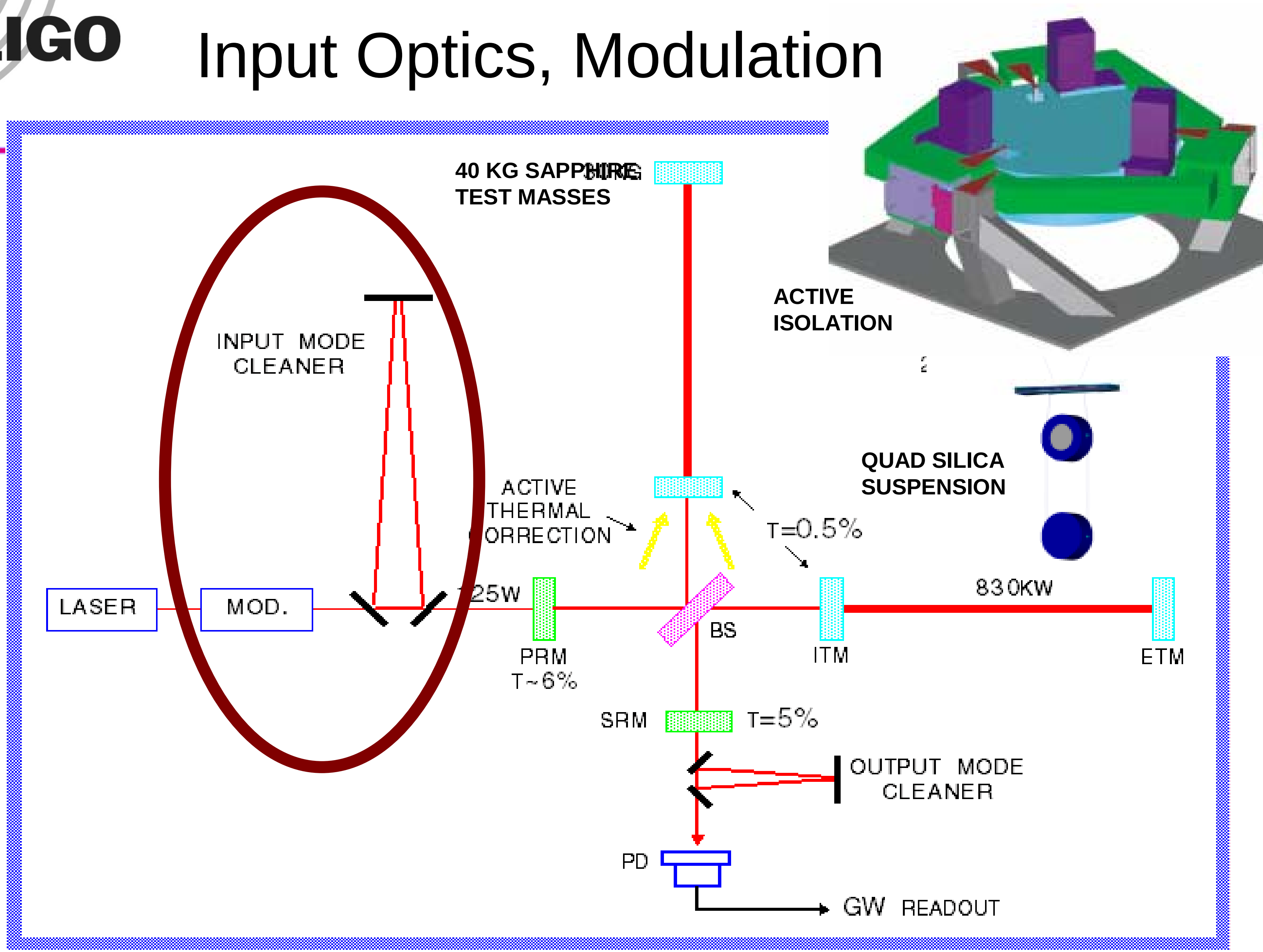
- Challenge is in the high-power ‘head’ (remaining design familiar)
  - » Coordinated by Univ. of Hannover/LZH
    Three groups pursuing alternate design approaches to a 100W demonstration
    - – Master Oscillator Power Amplifier (MOPA) [Stanford]
    - – Stable-unstable slab oscillator [Adelaide]
    - – Rod systems [Hannover]
  - » Concept down-select December 2002 → March 2003; presentations/discussion at this meeting
- Proceeding with stabilization, subsystem design







Input Optics, Modulation



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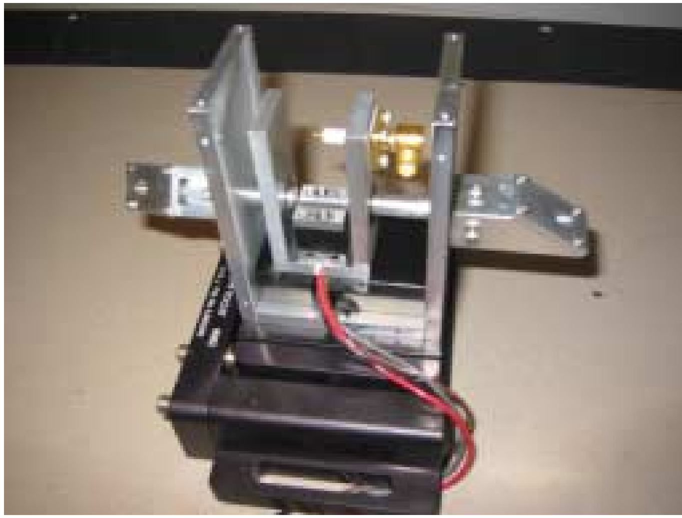
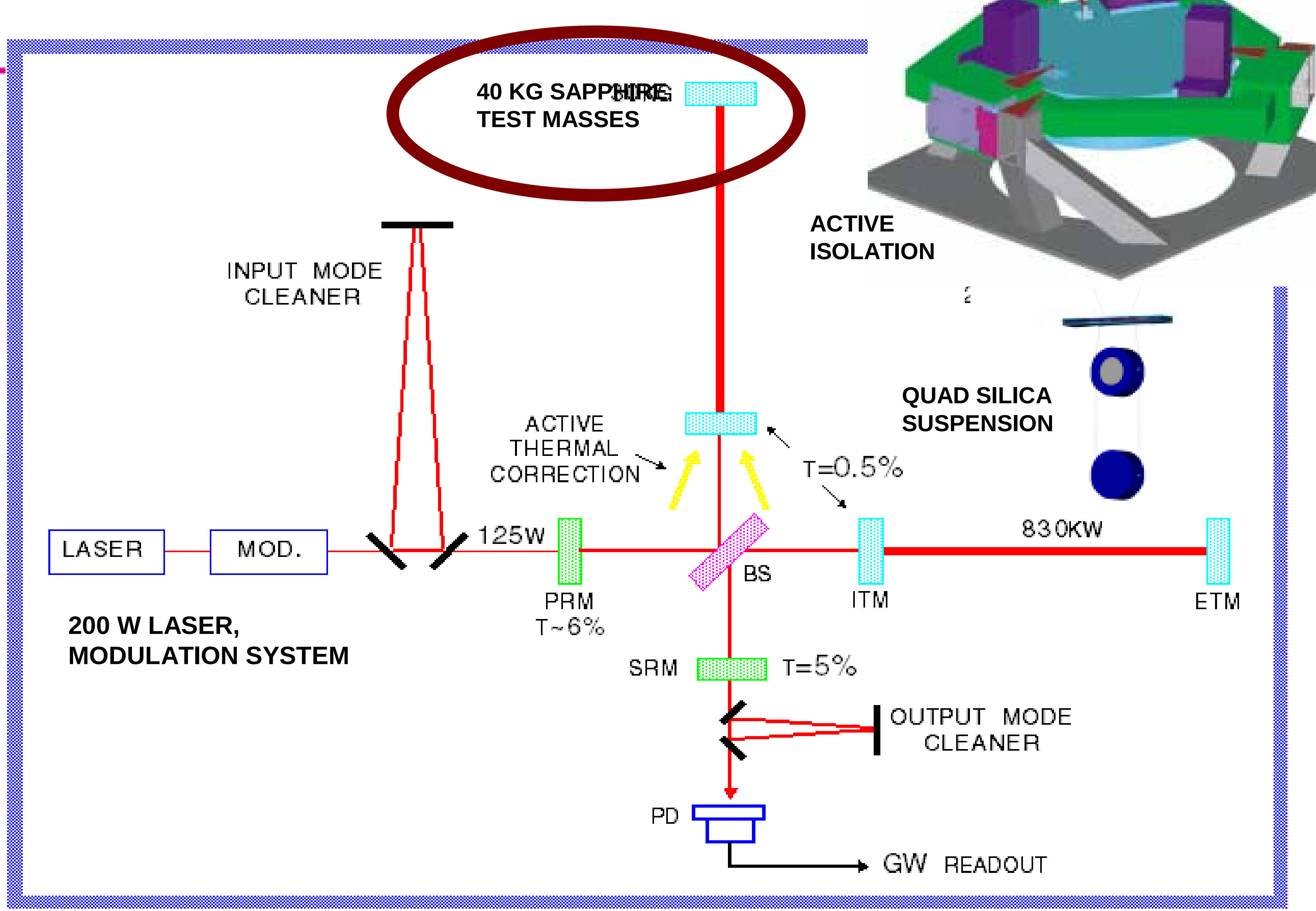


- University of Florida takes lead, preliminary design
- High power rubidium tantanyl phosphate (RTP) electro-optic modulator
  - constructed and tested prototype modulator
  - temperature-stabilization loop
  - medium-term (100 hr) exposure at Advanced LIGO power densities; no problems so far
- Prototype Faraday isolator from IAP
  - thermal birefringence compensated (> 40 dB)
  - delivered to LZH and Adelaide
  - thermal lensing compensation using negative temperature derivative FK51 Schott glass
  - absorption measurements to match TGG and FK51 for each individual FI; FK51 cut to length and polished
  - integrated lensing and birefringence FI prototype undergoing testing at UF
- Adaptive MMT for Advanced LIGO
  - no moving parts; in vacuo adjustment through intentional thermal lens
  - modeling indicates large adjustment range with no modal contamination
  - prototype table-top being tested at UF
- Setting up high-power testing lab at LLO – 100 W laser on order

Test Masses



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Core Optics: Sapphire

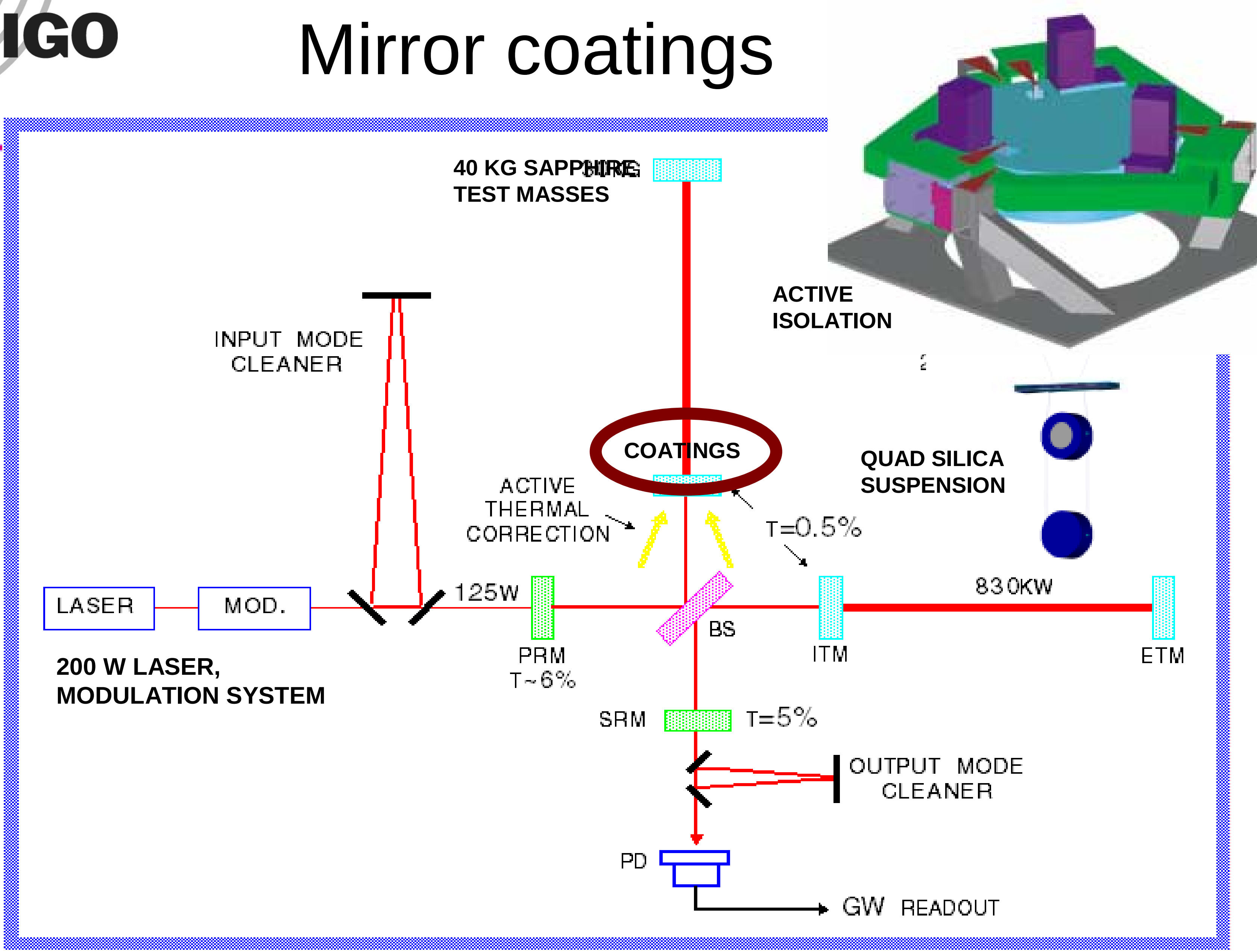
- Focus is on developing data needed for choice between Sapphire and Fused Silica as substrate materials
- Fabrication of Sapphire: 4 full-size Advanced LIGO boules grown, 31.4 x 13 cm; two acquired (one ‘nice’ and one ‘not so nice’)
- Many aspects of material development successfully tested
- Substrate mechanical losses: recently measured at 200 million, meets requirement
- Still lots to be done – know how to do it, but it will take time
- Downselect Sapphire/Silica (further) delayed to July-August 2003
  - » Uses all slack in schedule

Core Optics: Fused Silica

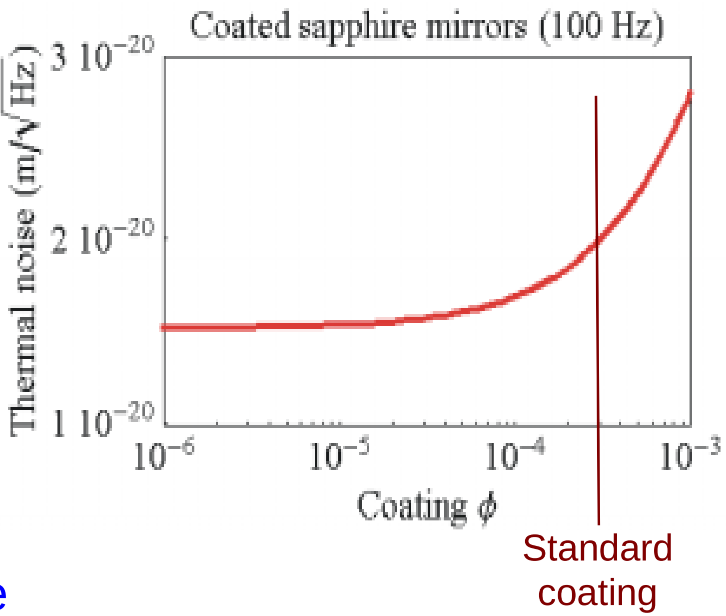
- Recent measurements of annealed Fused Silica rods show Q of 200 million
- IF
  » this can be realized in a full-sized Fused Silica test mass, and
  » IF the coating losses can be made 10x lower than present average, and
  » IF the Young’s modulus of low-loss coatings can (or must) be low,

  THEN better low-frequency sensitivity for silica than sapphire
- Effort underway to refine annealing, realize procedure for polished optics

Mirror coatings

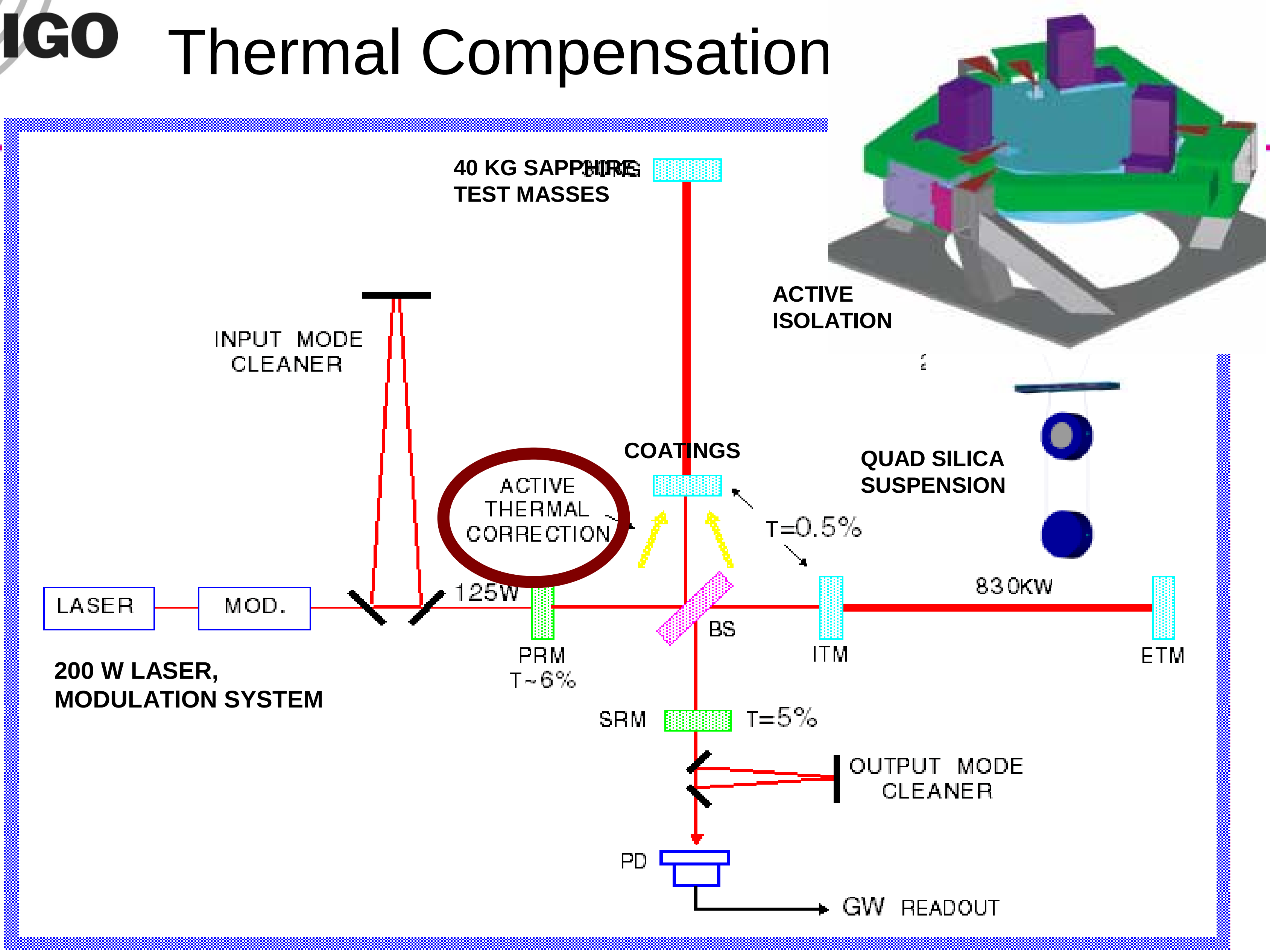


Coatings



- Optical absorption (~0.5 ppm), scatter look acceptable for conventional coatings
- Thermal noise due to coating mechanical loss is the challenge
- No breakthroughs, although some alternative coatings show somewhat reduced loss
  - » Annealed Silica/Alumina
  - » Doped Silica/Tantala
- Analysis also advancing – thermoelastic noise
- Need ~<factor 3 in loss; also need more complete characterization of present coatings (esp. Young's modulus)
- Interaction with substrate properties, but want to choose substrate well before coating – may force a choice of materials for the coatings
- Expanding the coating development program
- Pursuing means to get better values for thermophysical properties of coatings
- First to-be-installed coatings needed in ~2.5 years – sets the time scale

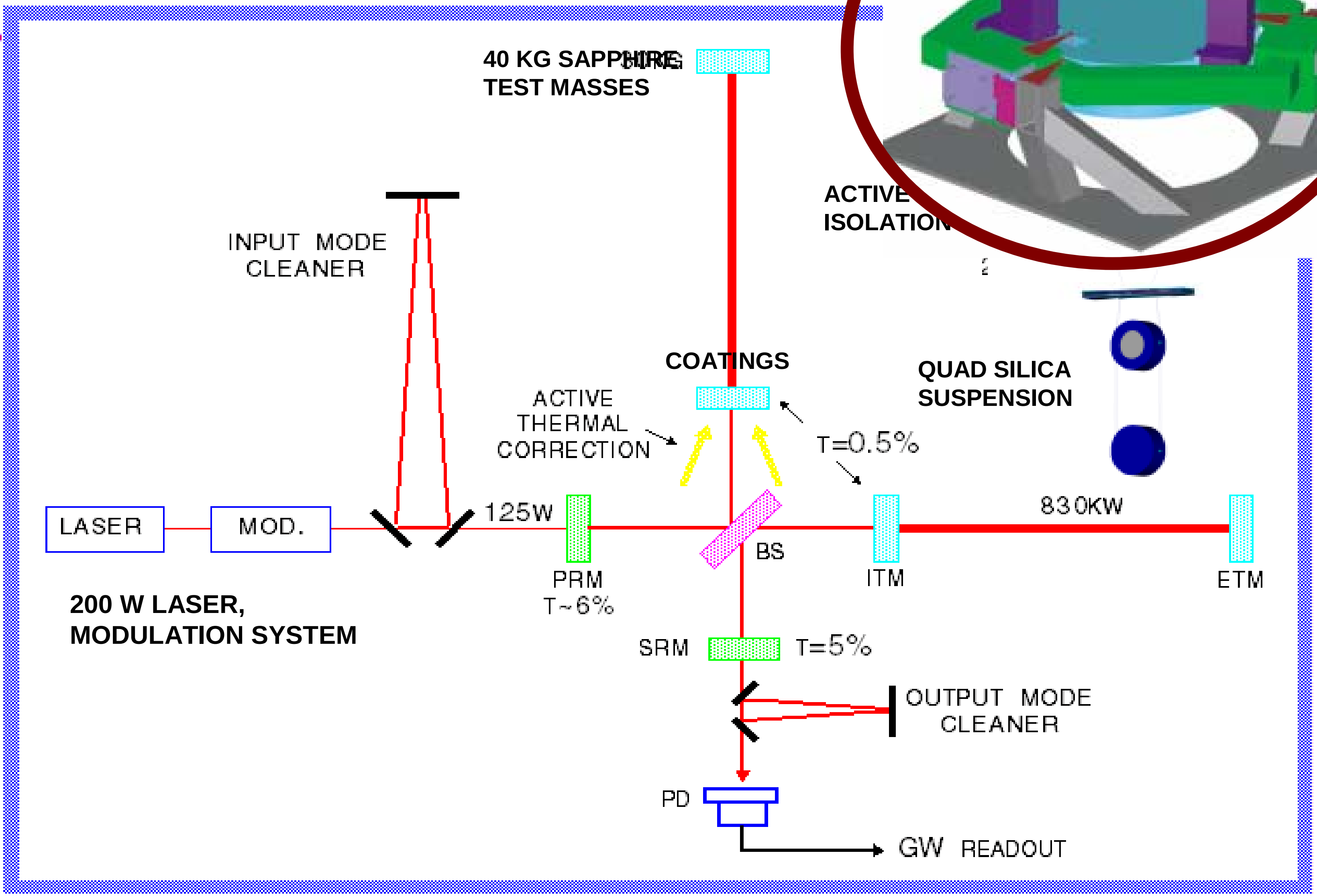
Thermal Compensation



Active Thermal Compensation

- Removes excess ‘focus’ due to absorption in coating, substrate
- Initial R&D successfully completed
  - » Quasi-static ring-shaped additional heat
  - » Scan (raster or other) to complement irregular absorption
  - » Ryan Lawrence graduated
- Plans, construction for tests ACIGA Gingin moving along well
- Modeling for surface absorption/compensation underway
  - » GEO-600 using this technique to correct for ROC difference
- May have a role in initial LIGO – optimization for available power

Seismic Isolation



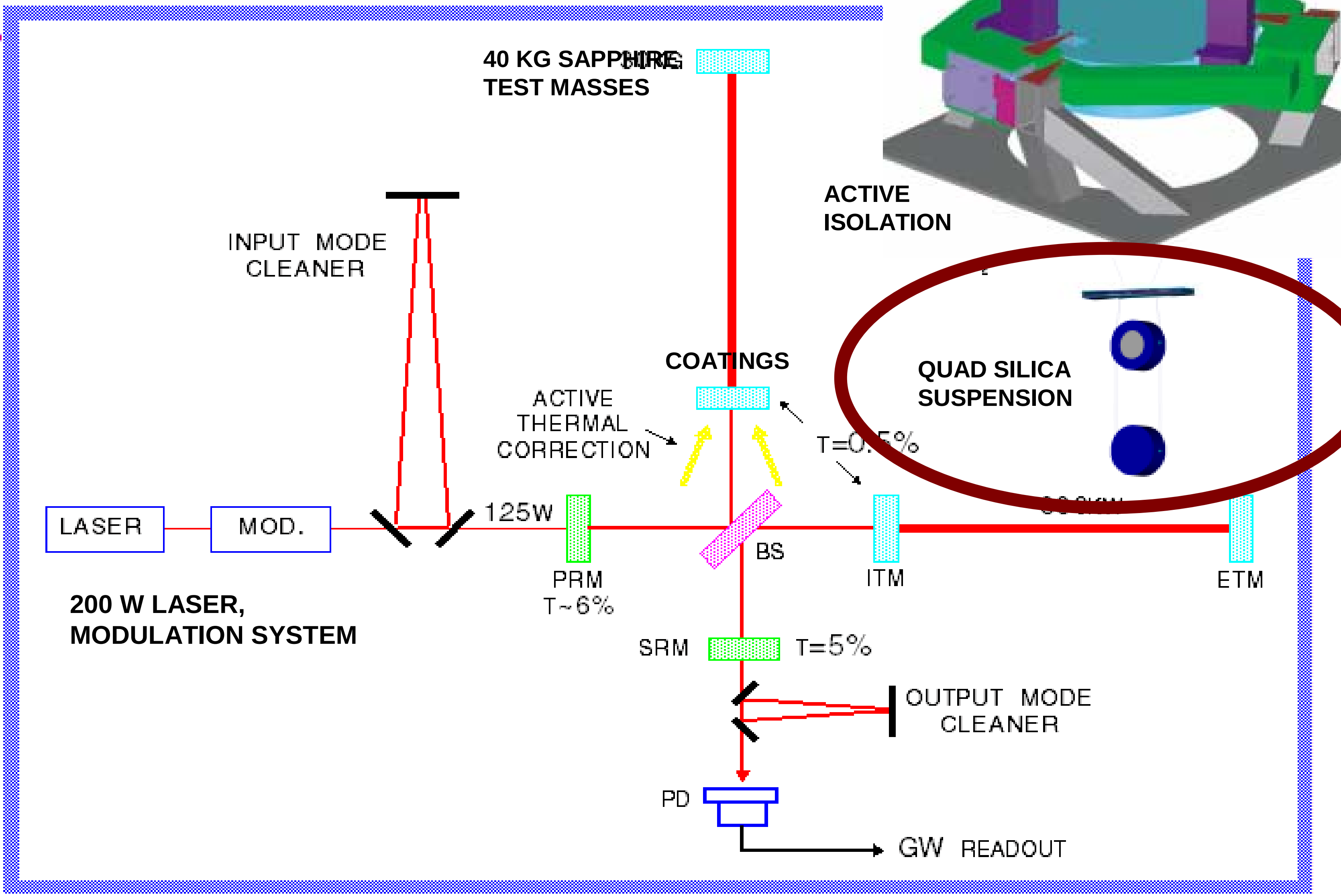
Isolation I: Pre-Isolator

- Element of Adv LIGO – although LIGO I requires much higher performance than Adv LIGO
- Aggressive development of hardware, controls models
- Prototypes in test
- Dominating Seismic Isolation team effort, until Mid-year

Isolation II: Two-stage platform

- Stanford Engineering Test Facility Prototype characterization starting
- Initial indications are that the design is a good success
  - » Observe extremely small tilt for horizontal excitation
  - » High structural resonant frequencies
- Bid package ready for LASTI prototypes – should identify vendors for actual production!

Suspension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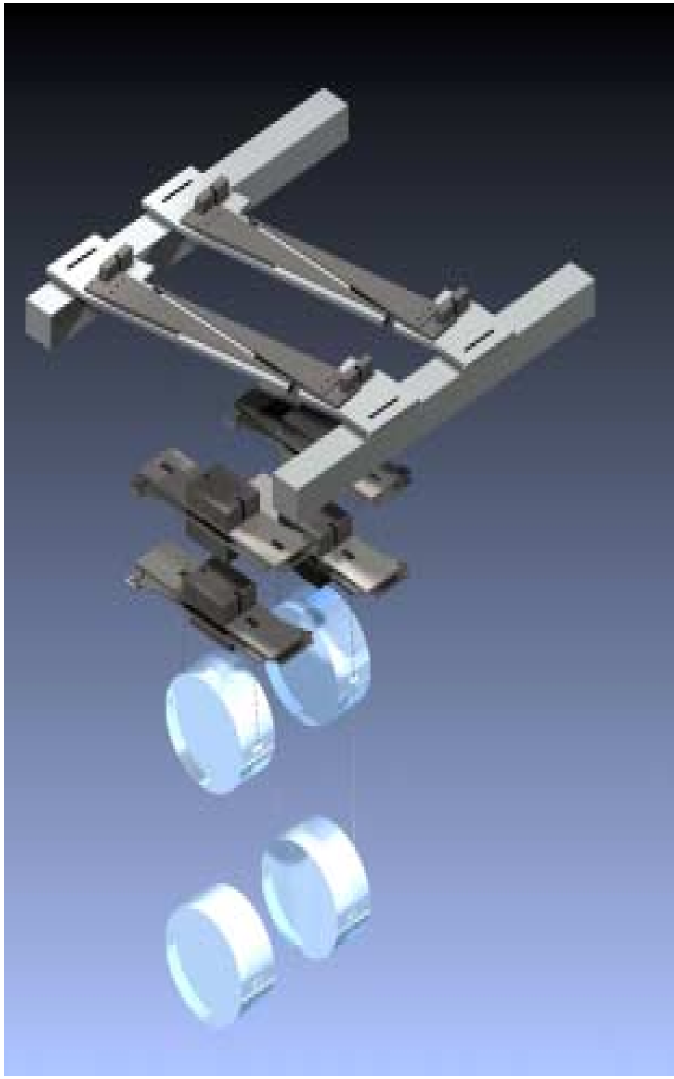
Suspensions I: Test Mass Quads

- Success of GEO600 a significant comfort
  - » All suspensions now installed
- Design advancing; working on weight
- Requires downselect Sapphire/Silica for further refinement
- Challenge: developing means to damp solid body modes quietly; maybe use a combination:
  - » Eddy current damping
  - » Split actuator path (VIRGO)
  - » Along with standard ‘OSEM’
  - » Interferometric local sensor another option
  - » Allow higher ‘Q’ in operation
- PPARC proposal: significant financial and technical contribution; quad suspensions, electronics, and some sapphire substrates
  - » U Glasgow, Birmingham, Rutherford Appleton

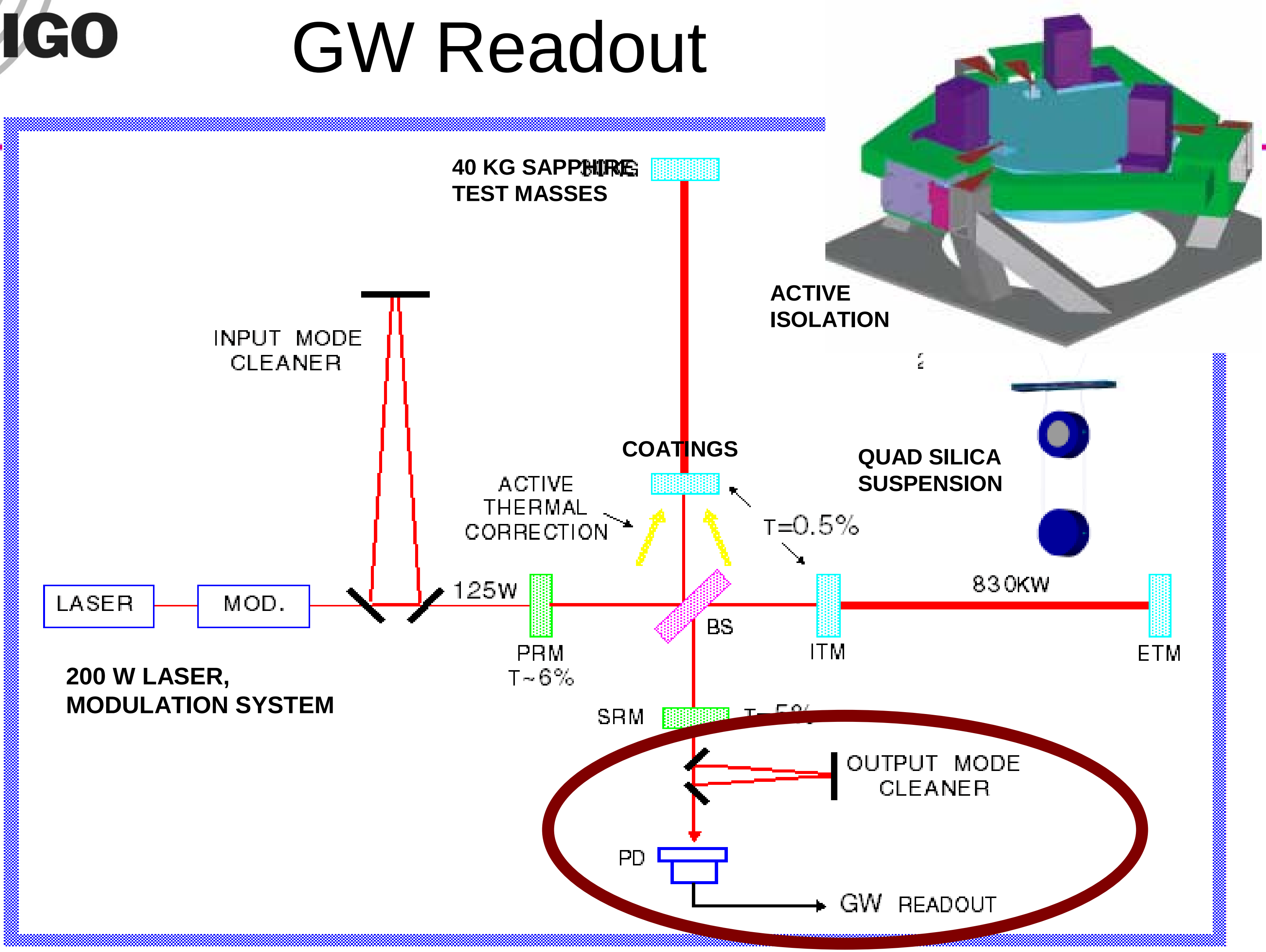


Suspensions II: Triples

- Prototype of Mode Cleaner triple suspension now complete
- In testing at Caltech, basic dynamics, damping
- OSEM design being refined
- To be installed in LASTI mid-2003
- Recycling mirror design underway

LIGO

GW Readout



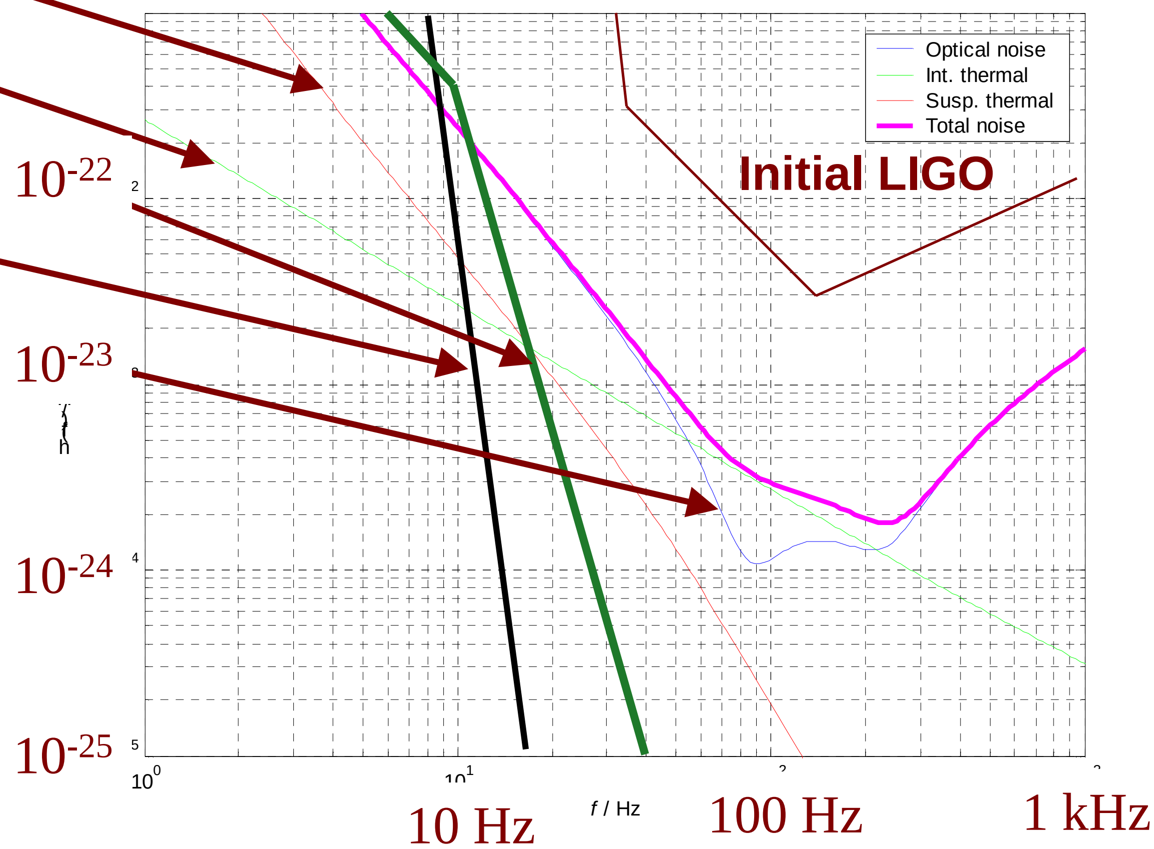
GW readout, Systems

- GEO-600 starting to lock (no cavities in arms, though)
- Glasgow 10m prototype
  - SR experiment control matrix elements confirmed, near diagonal, fit models
  - RSE - all optics in, light soon
- Caltech 40m prototype in construction, early testing
- Calculations continue for best strain sensing approach
  - DC readout (slight fringe offset from minimum) or ‘traditional’ RF readout
  - Analysis of the RF readout system done, so framework in place to make RF/DC comparison
- Tracking several efforts to improve on the baseline Adv LIGO sensing system (through upgrades, conceivably baseline changes if merited):
  - Mexican-Hat beams which better fill mirrors, reduce thermal noise
  - Variable-transmission signal recycling mirrors (ACIGA proposed contribution)
  - Injection of squeezed vacuum into output port

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



The Proposal

- Three interferometers, each signal recycled
  - » Two 4km ‘wideband’ instruments, pretty flexible actually
  - » Extension of present LHO 2km to 4km, potentially HF optimized
- Can be used at full or reduced power for LF searches
- Leaves open substrate choice, specifics of Laser technology
- Subsystem leads LSU, GEO (UK, Hannover), UFlorida, ACIGA, Caltech, MIT
- Fiduciary responsibility is with the LIGO Lab
- Proposal to NSF is $122 M; additional support from international partners (GEO and ACIGA), current and future LIGO Lab operating budget

Proposed Plan

- Initial LIGO Observation 2002 – 2006
  - » 1+ year observation within LIGO Observatory
  - » Significant networked observation with GEO, LIGO, TAMA, VIRGO
  - » No plans to make significant upgrades to Initial LIGO system
- Structured R&D program to develop technologies
  - » Cooperative Agreement carries R&D in Lab to Final Design, 2005
- Proposal just submitted for fabrication, installation
- Anticipate NSF review in early May 2003
- Long-lead purchases planned for 2004
  - » Sapphire Test Mass material, seismic isolation fabrication
  - » Prepare a ‘stock’ of equipment for minimum downtime, rapid installation
- Start installation in 2007
  - » Baseline is a staged installation, Livingston and then Hanford
  - » Two 4km instruments at Hanford, one 4km instrument at Livingston
- Start coincident observations in 2009

LIGO

Advanced LIGO

- A lot of nice analysis, detailed design, and test underway
- Some important steps forward
- Still a few good problems to solve
- A broad community effort, international support
- Start with making the transition from R&D to Project
  (hopefully with impetus from an NSF go-ahead!)
- Present instruments, data establishing the field of interferometric GW detection
- Advanced LIGO can lead the field to maturity