LIGO and Advanced LIGO: Technical Issues

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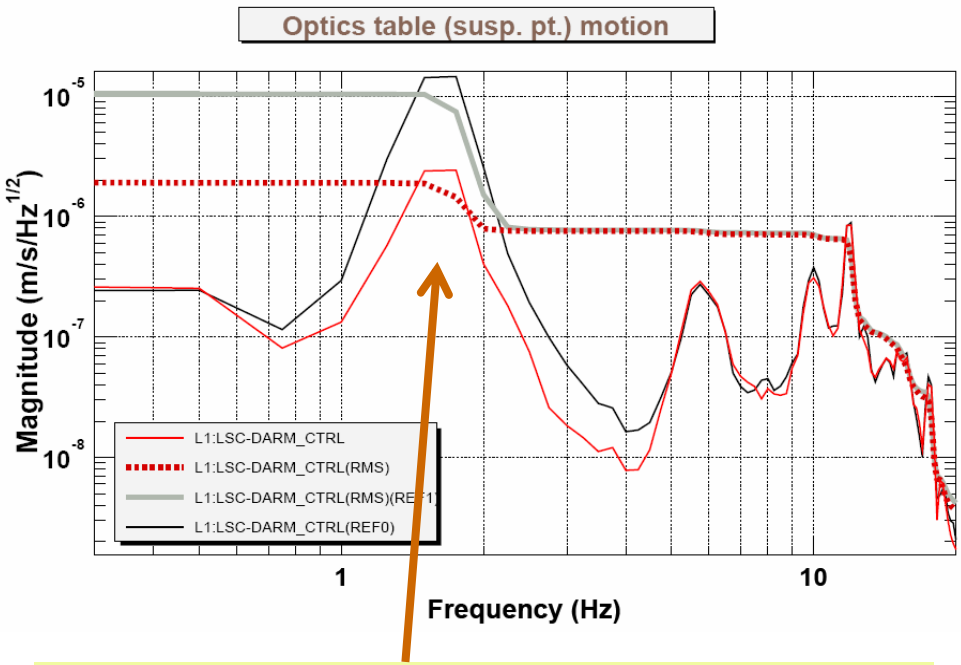
LIGO

Plan of talk

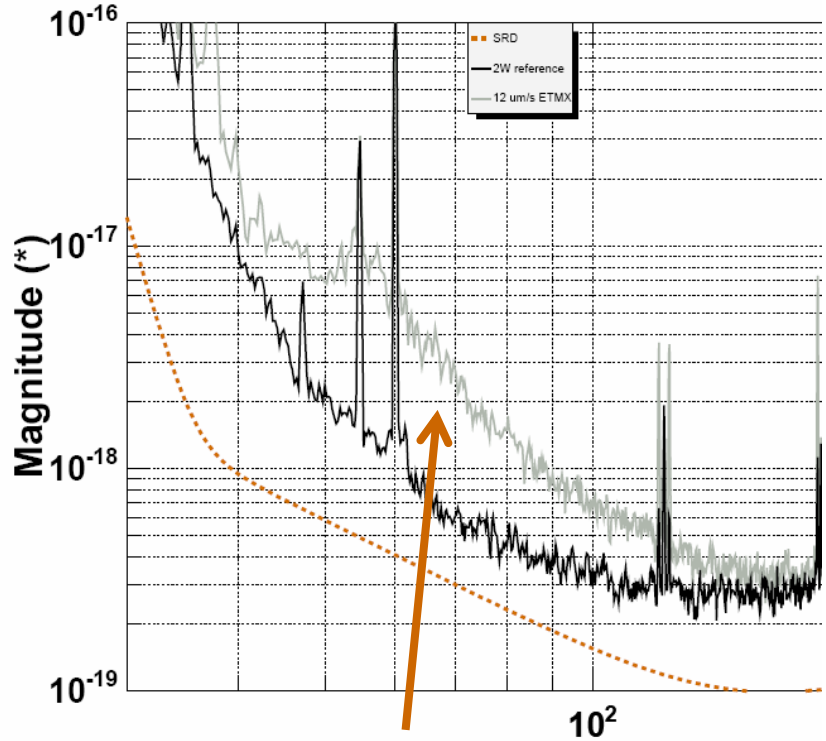
- Recent improvements and issues discovered in Initial LIGO with emphasis on things that have implications for Advanced LIGO
  - » Scattered Light, Thermal Compensation and Photo-detector Damage
- Potential Improvements to Initial LIGO
- Current status of Advanced LIGO of R and D.

Upconversion from stack motion has been observed

Effect first seen at LHO, & measured recently at LLO:*



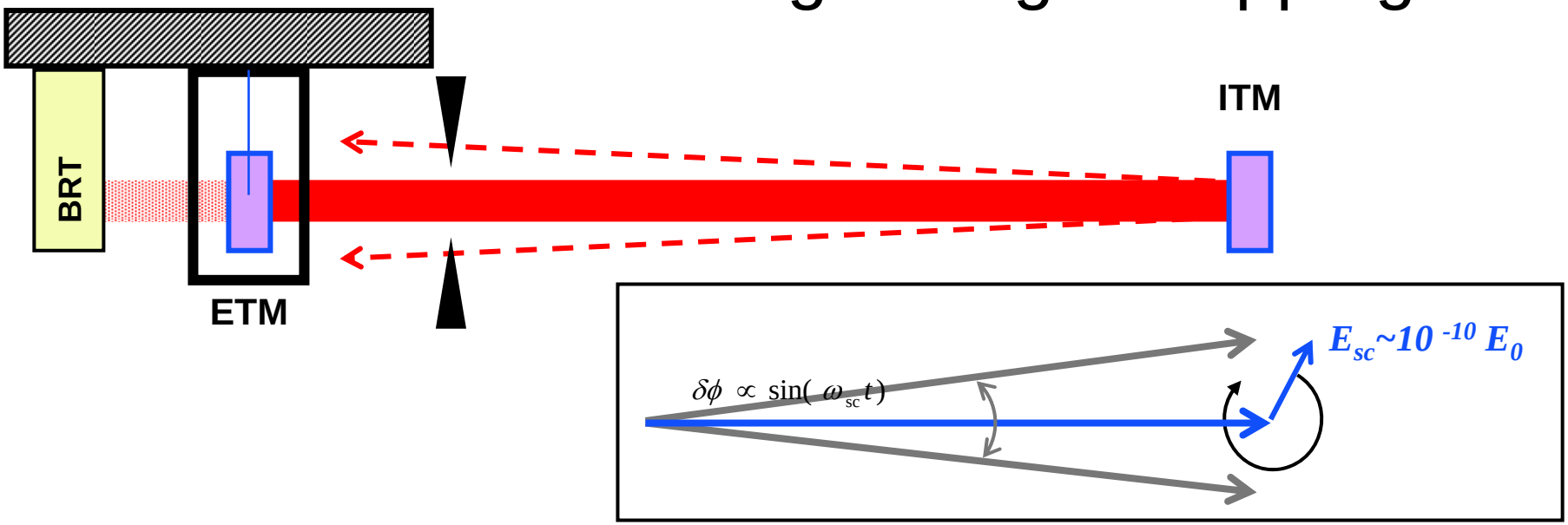
Using HEPI, increase the suspension point motion at 1.5 Hz by a factor of 5



DARM noise increases by a factor of ~5 over a wide band

LIGO

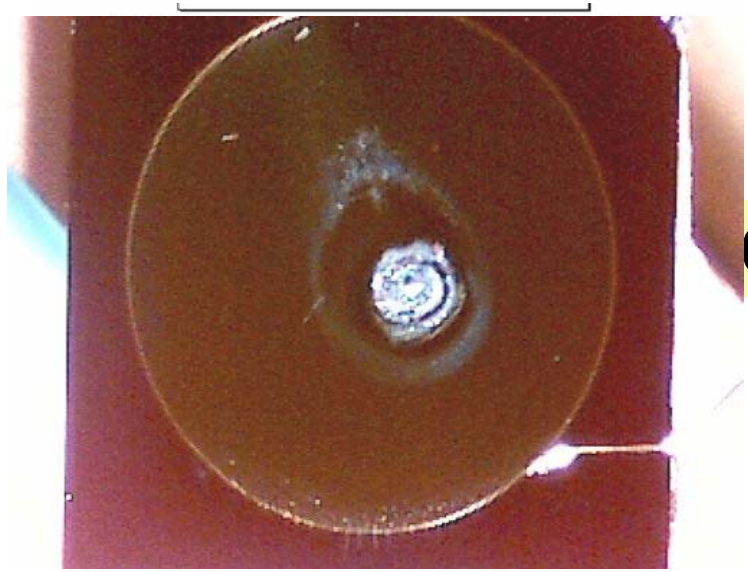
Scattered light fringe wrapping



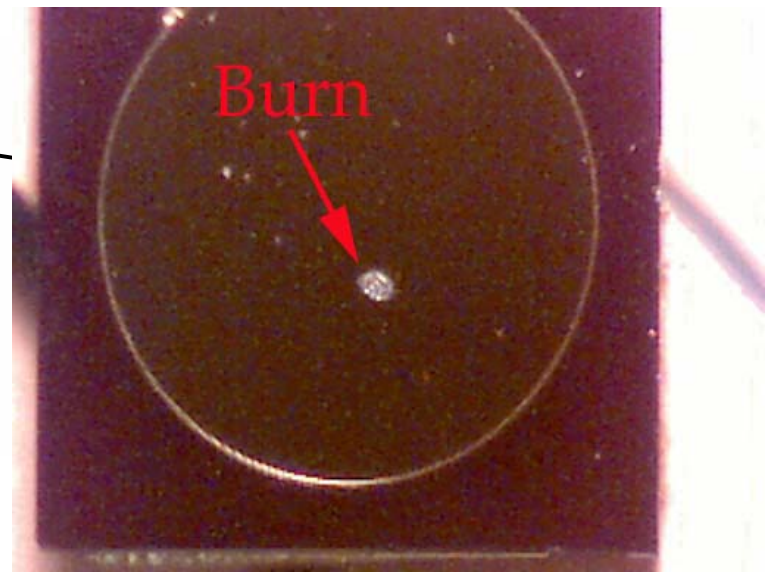
- Recent data looks a lot like what you'd expect from scattered light
- Scattered light is particularly important for low frequency performance – A serious issue for Advanced Detectors ??
- Beam tube baffles were made for this purpose
  - » Not currently installed in the beam (laid down in beam tubes)
  - » Considering the possibility of erecting ETM baffles, to begin with in one IFO

Photodiode damage a problem with high power operation

- Loss-of-lock: full beamsplitter power can be dumped out the AS port, in a ~10 msec width pulse
  - » Mechanical shutter cuts off the beam, with a trigger delay of about 6 msec
- PD damage due to
  - » Too high trigger level
  - » Shutter too slow (wrong type)
- Damaged PDs can be noisy
- Solution (in progress):
  - » All shutters of proper type
  - » Carefully set trigger level
  - » Looking at cutting off PD bias voltage on lock-loss
- Hopefully OMC will save the day for Advanced LIGO

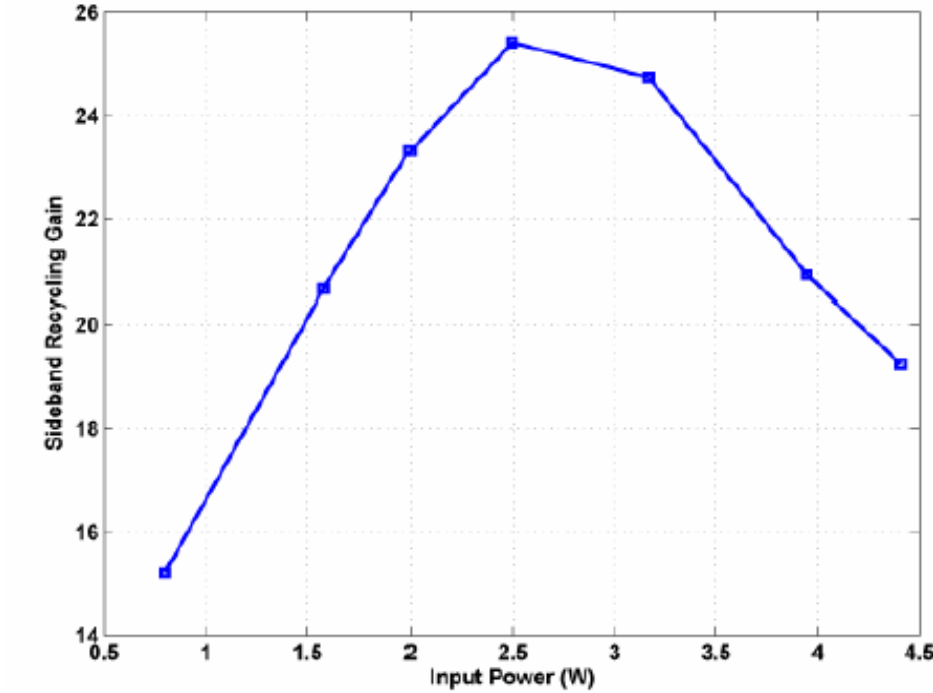


0 W



Initial LIGO: Excess Absorption at Hanford

- Input optics curved to match recycling mirror curvature at 8 W
  - Point design assumes a value for absorption
- Found best matching at 2.5 W
  - Additional absorption causes excess thermal lensing
- Excess absorption has to be in recycling cavity optic
  - Input mirrors or beamsplitter
- Other interferometers (2 K at Hanford and 4 K at Livingston) found to have much less absorption than expected



Sideband Recycling Gain
LIGO 4K Hanford IFO

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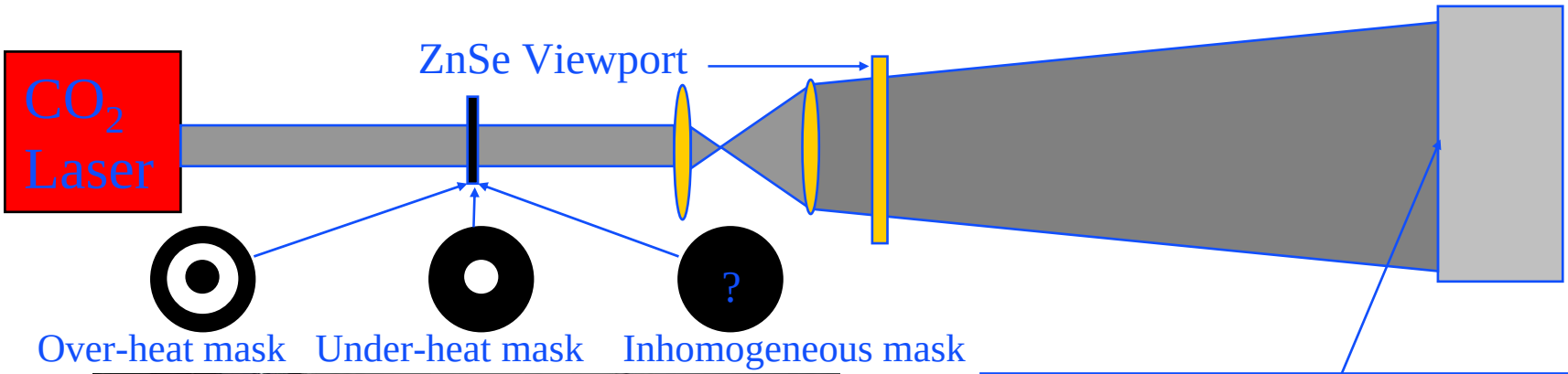
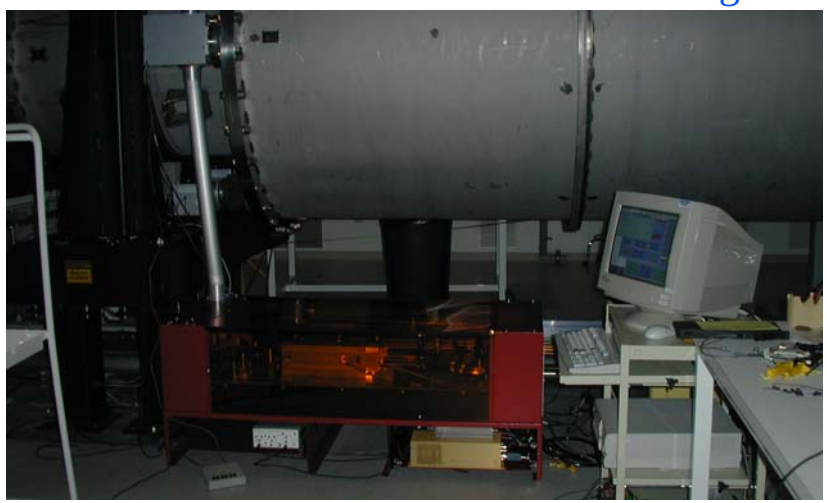
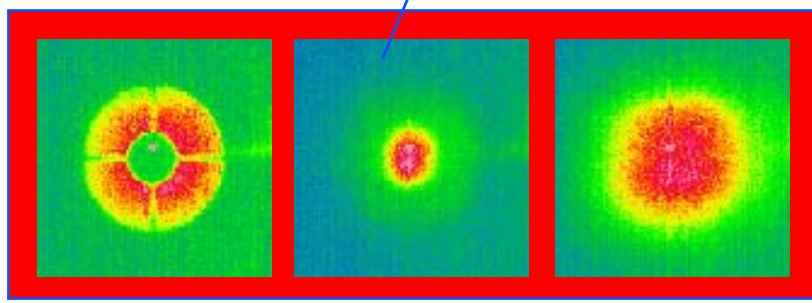
TCS Installed to Fix !!

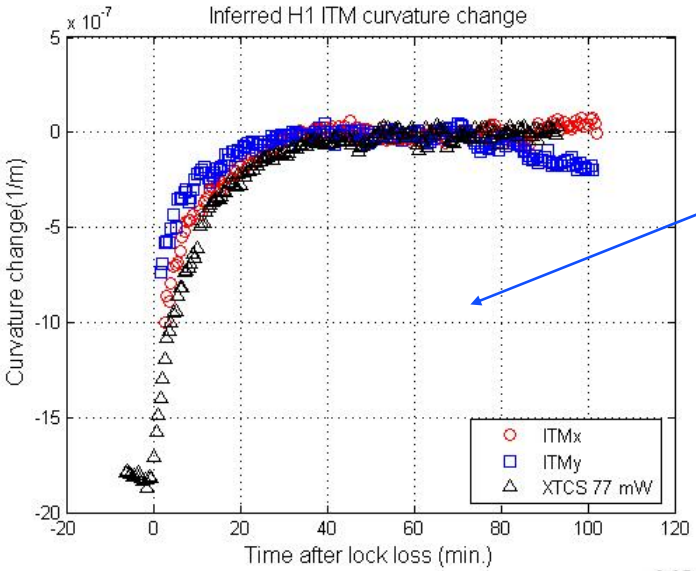






- TCS is very effective in correcting up to 75 mW of absorption in ITMs
- Improved masks and diagnostics required to fix higher absorption

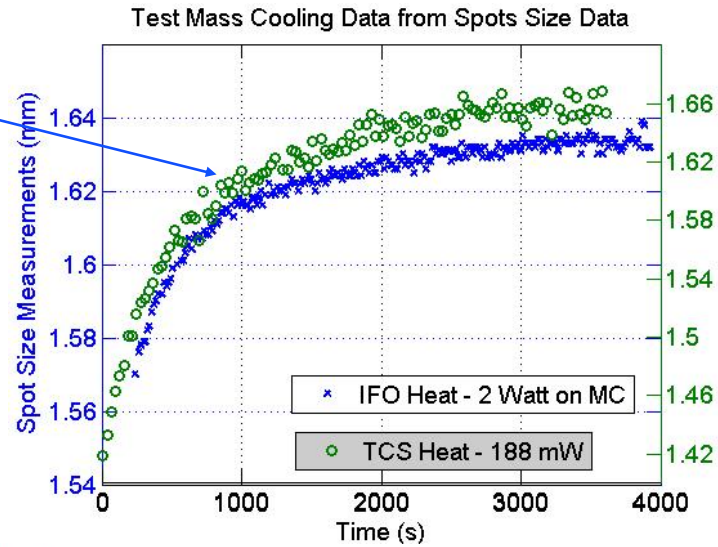
Diagnosing the overheat problem in LIGO Hanford Observatory

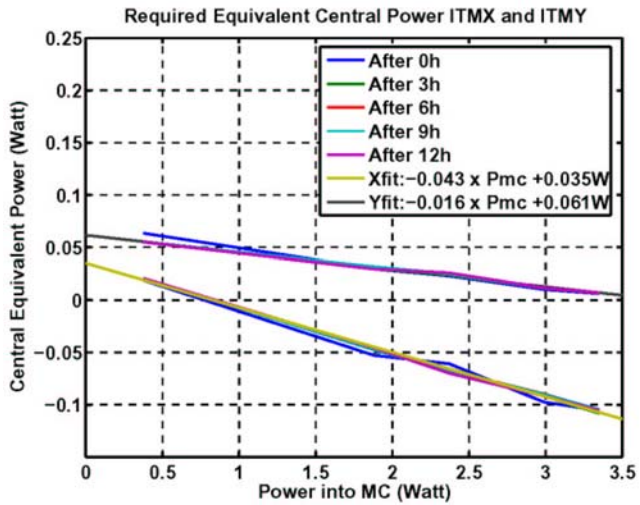


Spot Size Data

G factor data

TCS Correction Data





Measurement Summary

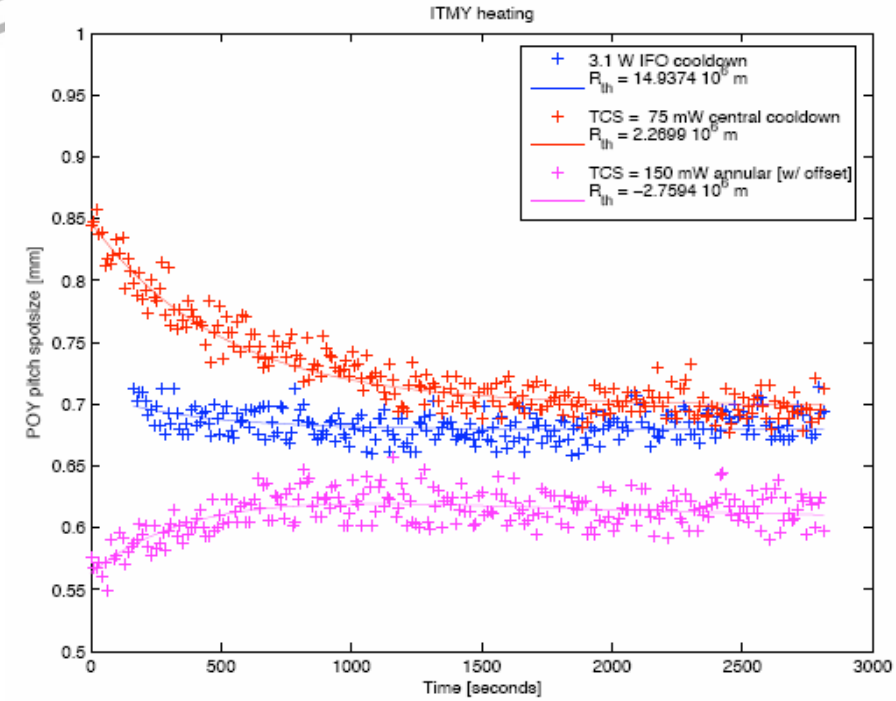
-3 Different measurements performed

- TCS used for calibrations of absorption

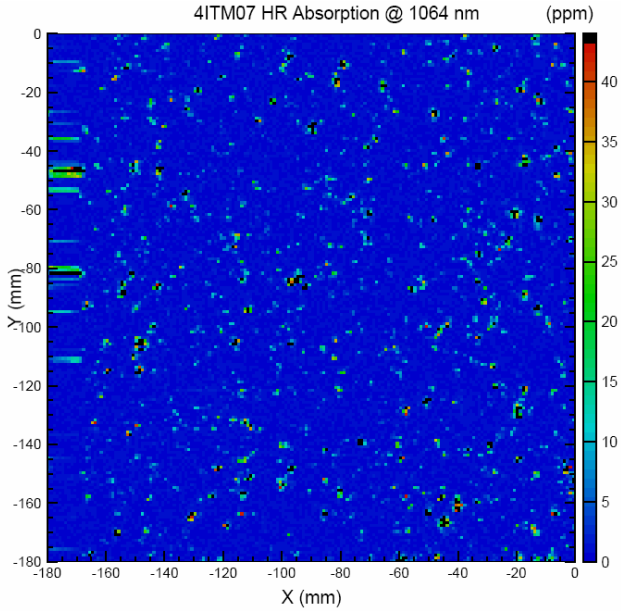
Results Summary

- [36+/-5, 13 +/- 2] mw per W of power on the MC for [ITMX, ITMY]
- Correspond to 26 ppm absorption in the ITMX
- All other IFO mirrors are considerably less

Actions, results and forensics



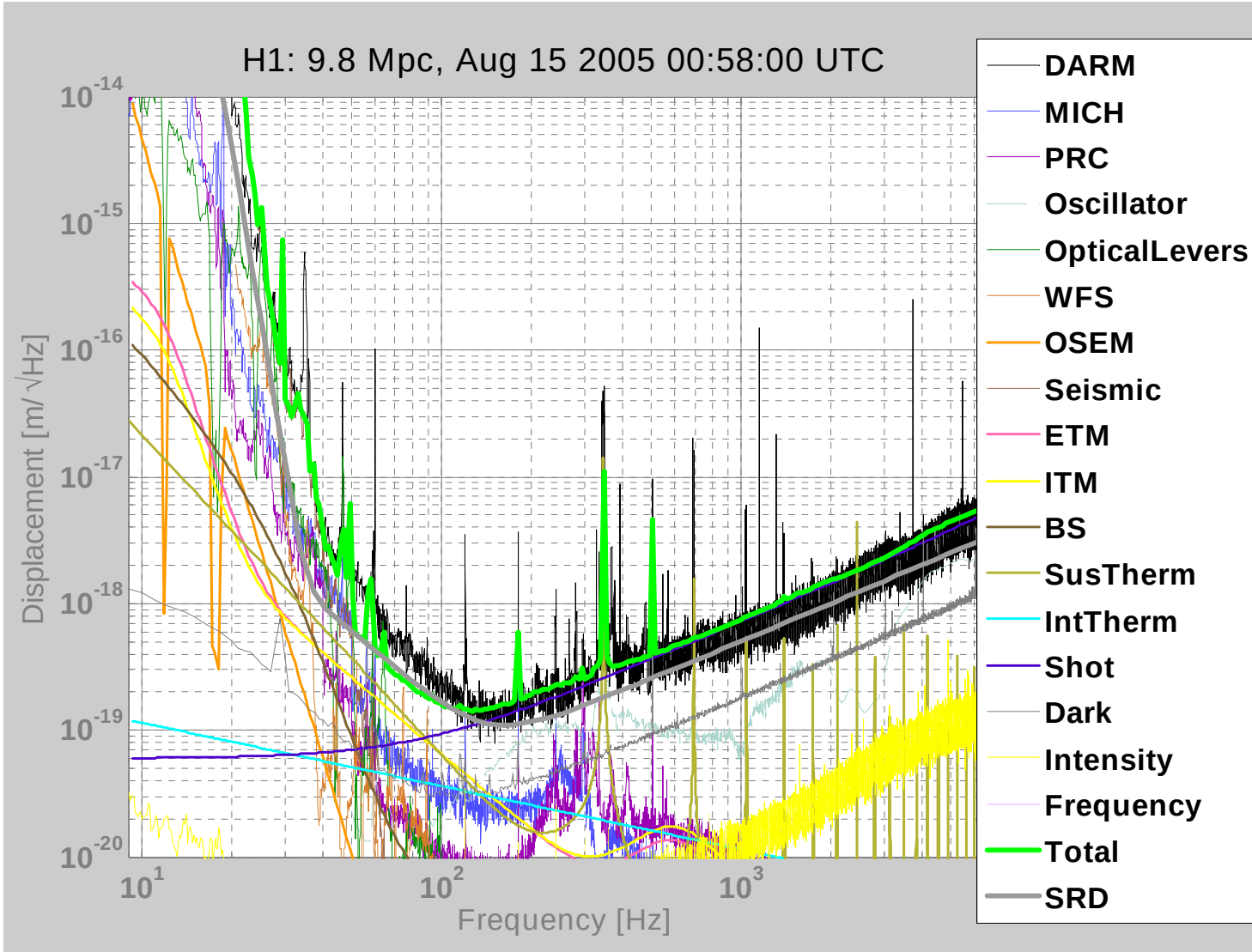
- LHO vacuum space was vented
- Film on the AR surfaces and the BS
- H1 ITMX replaced, ITMY was drag wiped



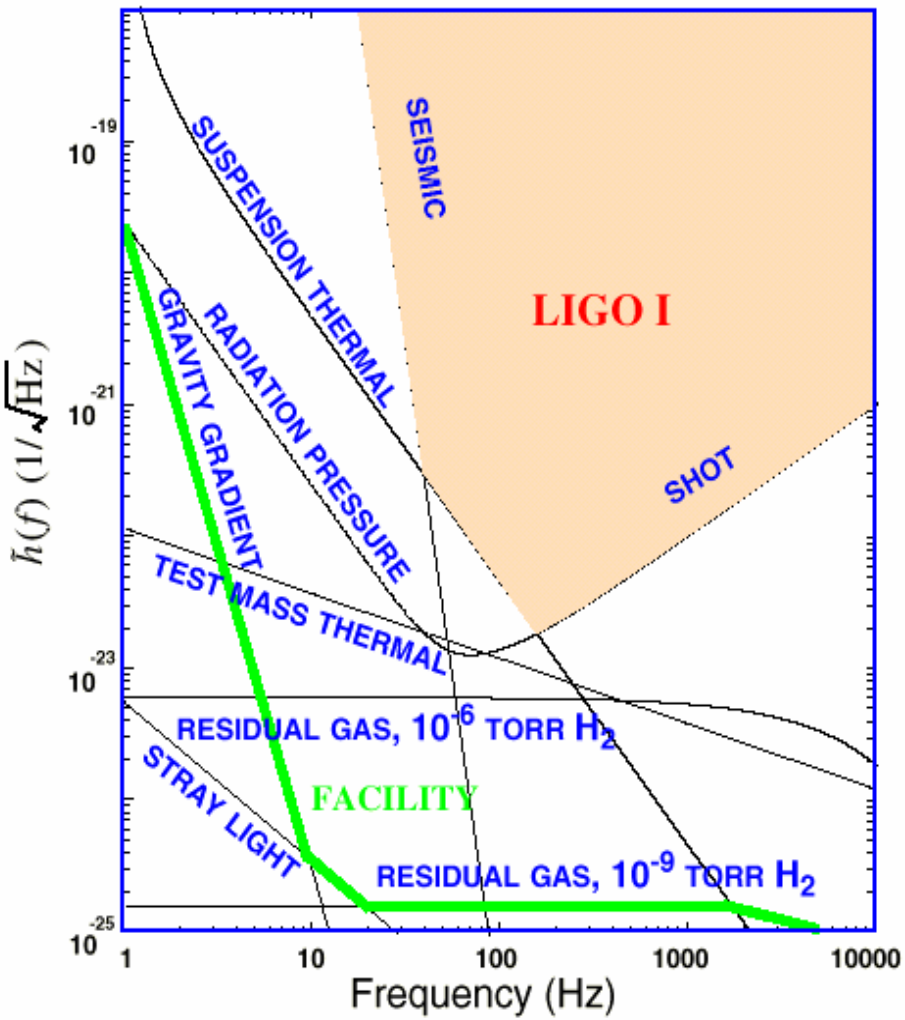
- An upper limit on the absorption in the H1 optics has been placed of 3 mW per Watt or approximately 3ppm
- TCS now good to 40 Watts of Input
- Forensics at Caltech found over 200 point absorbers on the HR surface of the optics

Current LIGO Sensitivity Curve

- Best Sensitivity Achieved is 12 MPc
- Automated Noise Analysis
- Close to SRD over all band
- Significant improvements are difficult



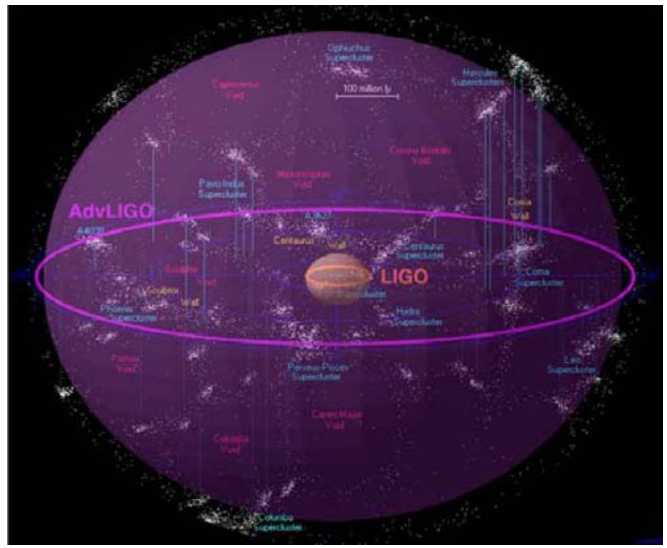
What can we do to improve on Initial LIGO ???

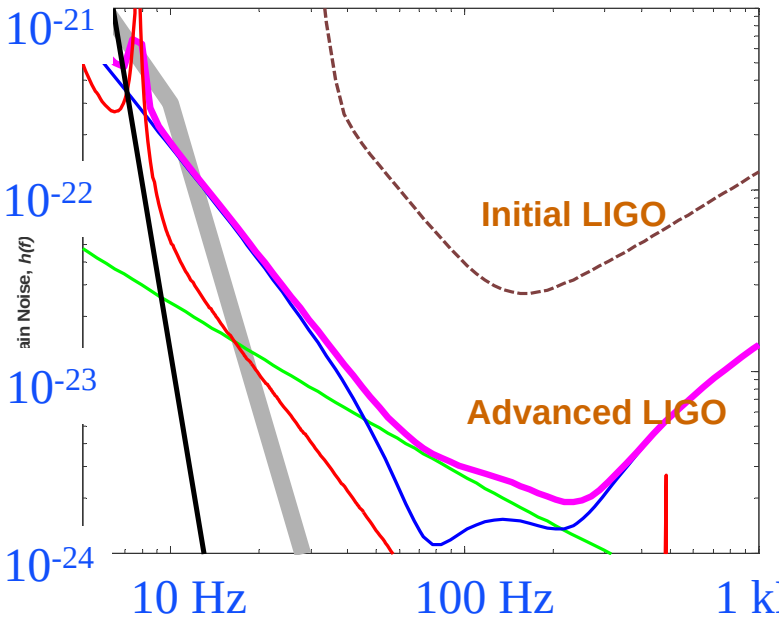


- Increase the Laser Power
  - 50 Watt New Target
  - Early delivery of LZH technology
  - Commercial Rod Amplifiers
  - TCS should be able to handle it with minor tweaks
- Suspension thermal noise can be improved by moving spot on mirrors and better than anticipated
- Incorporate Advanced LIGO Technologies - Output MCs and DC readout

Advanced LIGO Overview

- **LIGO infrastructure designed for a progression of instruments**
  - Nominal 30 year lifetime
- **Initial LIGO planned (and required) to run at design sensitivity for one integrated year**
  - Will begin end of 2005





- **Second generation interferometer**
- **Quantum noise limited in much of band**
- **Signal recycling mirror for tuned response**
- **Thermal noise in most sensitive region**
- **About factor of 10 better sensitivity**
- **Sensitive band down to ~ 10 Hz**
- **Detect neutron star inspirals out to about 200 Mpc**

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Advanced LIGO – What Changes

Subsystem	Initial LIGO	Advanced LIGO
Interferometer	Power recycling	Power and Signal Recycling
Output	RF read-out	DC read out with output mode cleaner
PSL	10 Watt MOPA	180 W Injection-Locked Oscillator
	$\Delta P/P \sim 10^{-8}$ 1/√Hz at 100 Hz	$\Delta P/P \sim 2\ 10^{-9}$ 1/√Hz at 10 Hz
Input Optics	300 g single suspension	3 Kg triple suspensions
		Adaptable optics, better isolators and EOMs
Core Optics	Fused Silica (10 Kg)	Sapphire / Fused Silica Optics (40 Kg)
	g1 g2 = (0.71)(0.43) = 0.3	g1 g2=(1-4/2.08)(1-4/2.08)=0.85
Coatings	Phi ~4 10^{-4} Si O_2/Ta O_5	Phi ~ 5 10^{-5} Coating material TPD
Seismic	Passive attenuation	Active 6 dof system with HEPI (Init. LIGO extra)
Suspensions	Single loop wire	Quad Suspensions with fused silica fibers
ATC	Added later ?	Full thermal compensation system

LIGO

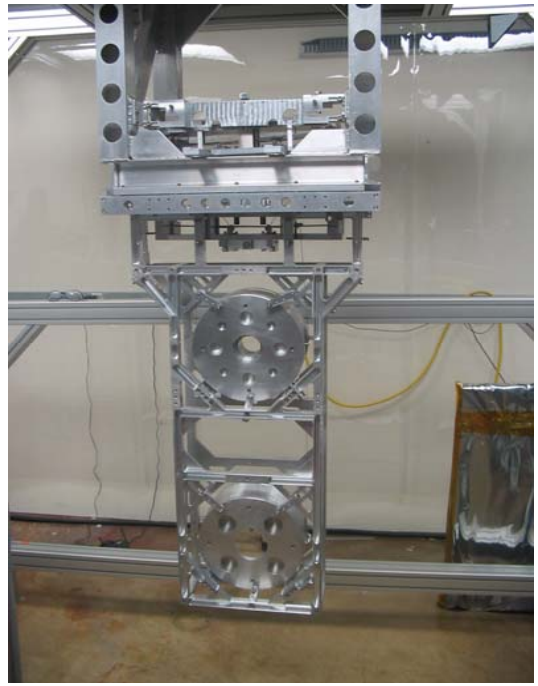
Progress on Sub-Systems

- Significant Progress Made on All Sub-systems
- In the interest of time will review
  - » Seismic
  - » Suspensions
  - » Coatings
  - » Prototyping and Test Facilities
- Please ask about any others at the end

Suspensions

- **Extend GEO600 monolithic suspension**
  - Funded and developed by our UK partners

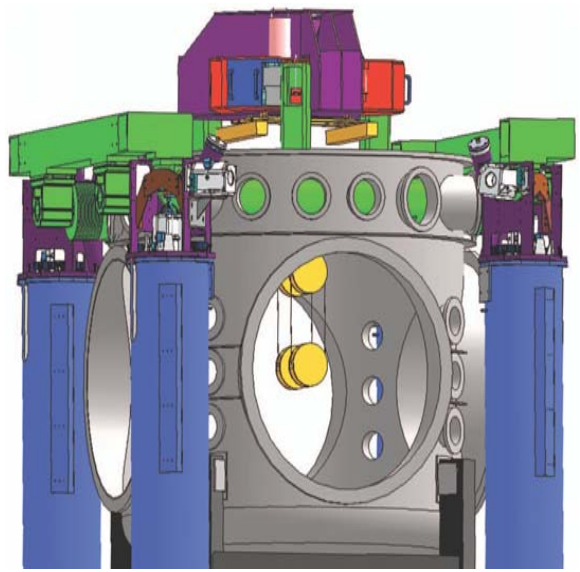
  Requirements:
  - minimize suspension thermal noise
  - Complement seismic isolation
  - Provide actuation hierarchy
- **Quadruple pendulum design chosen**
  - Fused silica ribbons or fibers, bonded to test mass
  - Leaf springs (VIRGO origin) for vertical compliance

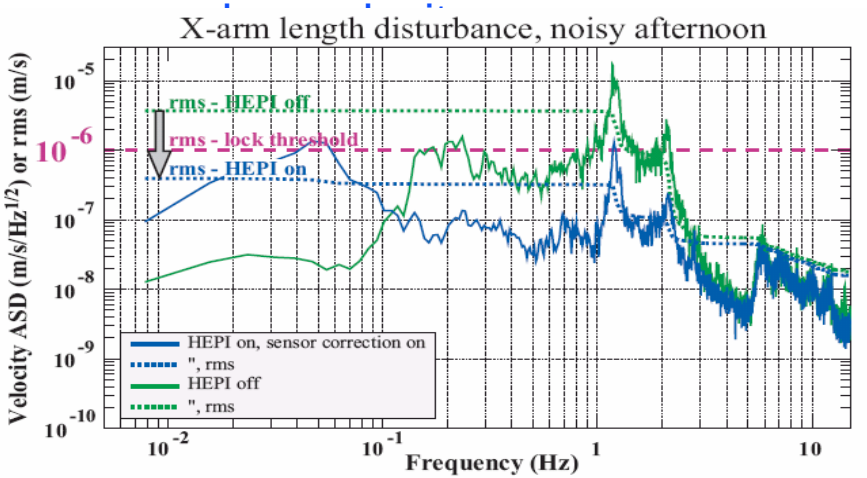


- **Mode Cleaner (triple) control prototype installed in LASTI**
  - Performance as expected, some model improvements
  - New Estimator Controls Strategy
- **Controls prototype assembled at Caltech**
  - LASTI in Late 2005
- **CO_2 laser fiber/ribbon drawing apparatus being developer**
  - Laser welds being characterized for strength/Q etc.
  - No problems seen

Seismic Isolation

- Choose an active approach for BSC
  - High-gain servo systems, two stages of 6 degree-of-freedom each
  - External hydraulic actuator pre-isolator
  - Allows extensive tuning of system after installation, operational modes
- HAM design being reviewed
  - Stanford prototype is baseline
  - Studying single-stage system for lower cost





External hydraulic pre-isolator installed on initial LIGO at Livingston

- Increases initial LIGO duty cycle
- Exceeds advanced LIGO requirements

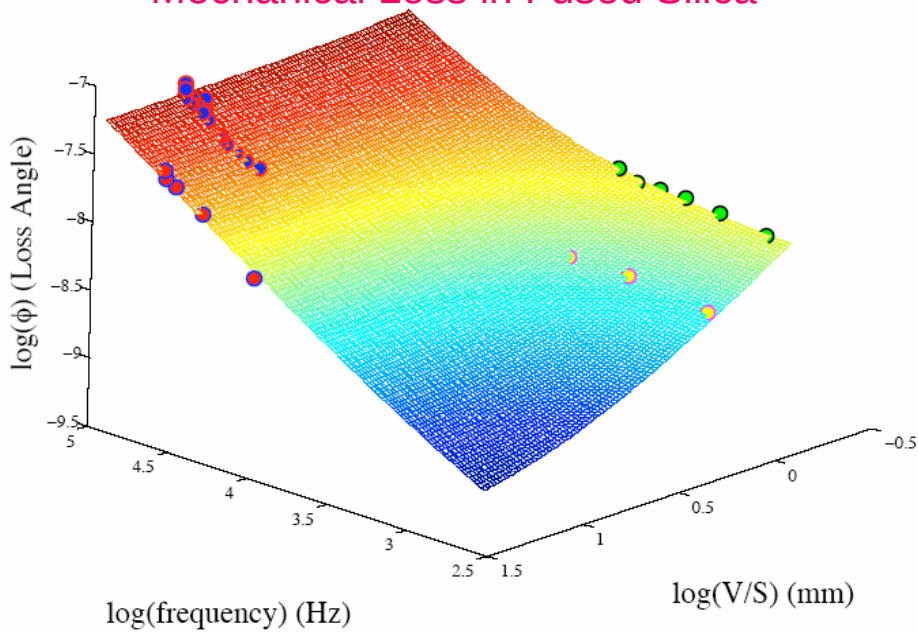
Seismic Isolation II

- Results from Stanford Seismic isolation prototype
  - » Significant progress
  - » 1000x Isolation in-and demonstrated
  - » 1-10 Hz performance in progress
  - » Sensor limited around 10 Hz
- Design virtually completed for the BSC prototype
  - » Bids being currently sort for component manufacture
  - » Assembly to start in early Summer 06
- HAM SAS Prototype
  - » Design complete
  - » Bidders conference soon
  - » Test in LASTI in May 05

Core Optics

- Fused silica chosen as substrate material
  - Improved thermal noise performance from original anticipation
  - Some concerns about unknowns with sapphire
- Coating will dominate thermal noise and absorption
  - Progress reducing ϕ with doping
  - Doped Coating Noise improvement observed in TNI
- Parametric instabilities
  - Have been identified as a potential problem
  - May have to spoil modal Q's of optics
- Other issues
  - Thermal compensation working on initial LIGO
  - Noise effects of charging being pursued

Mechanical Loss in Fused Silica



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Prototypes - I

LASTI - MIT

- Test full scale components & verify installation
- Explore seismic/low frequency noise
- Already used for initial LIGO - HEPI
- Triple control suspension prototype testing now
- Quad control suspension prototype starting in Dec 2005
- Exploring seismic noise enhancement near 10 Hz – Now understood

LASTI - MIT

40 m - Caltech

40 m Interferometer - Caltech

- Sensing/controls tests of readout
  - Locking of dual recycled interferometer
- Engineering model for data acquisition, software, electronics
- Testing DC read-out
- Exploring modulation techniques
  - Mach-Zehnder design

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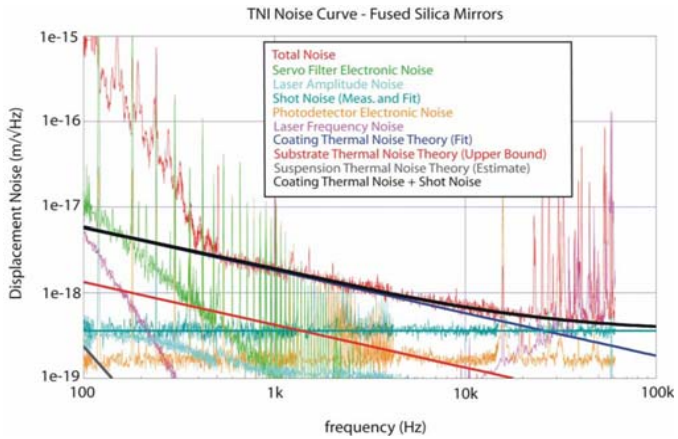
Prototypes - II

Engineering Test Facility -Stanford

- Seismic isolation prototype



TNI Results

Thermal Noise Interferometer – Caltech

- Brownian noise in silica/tantala coatings
- Thermoelastic noise in sapphire
- Brownian noise of silica/titania-doped tantala coatings in progress

GinGin – HPTF

Gingin – Western Australia

- High power tests
- Thermal lens compensation
- Hartmann off axis wavefront sensor
- Parametric instability tests planned

Mexican Hat Mirrors – Caltech

- Testing Mesa Beam Cavities

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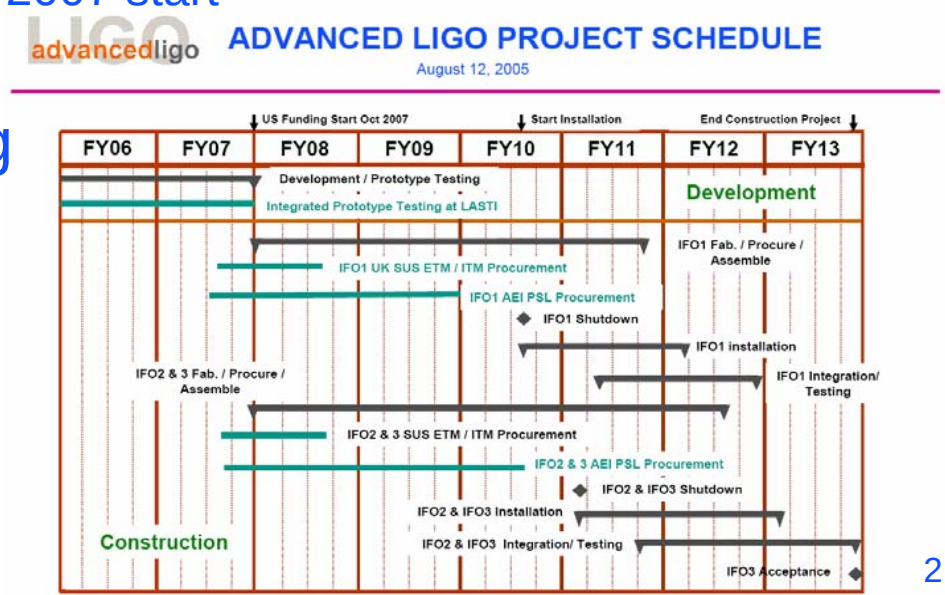
Advanced LIGO Project Status

- National Science Board endorsed the Advanced LIGO construction proposal in October 2004
  - Contingent upon an integrated year of observation with Initial LIGO
- National Science Foundation & Presidential Budget includes LIGO
  - LIGO is one of 3 proposed new start projects in the next 3 years
  - President's budget calls for October 2007 start
  - Hope Katrina will not effect this !!!!!!!
- Baseline plan calls for shutting down first initial LIGO interferometer mid 2010
  - Finish installing third advanced LIGO interferometer end 2013



LIGO

Conclusions

- Initial LIGO is virtually at the Science Requirements
- 5th Science Run (S5) due to start in November
- Significant Progress has been made in Advanced LIGO R and D
- A year of testing full scale prototypes is ahead of us