Initial and Advanced LIGO Status

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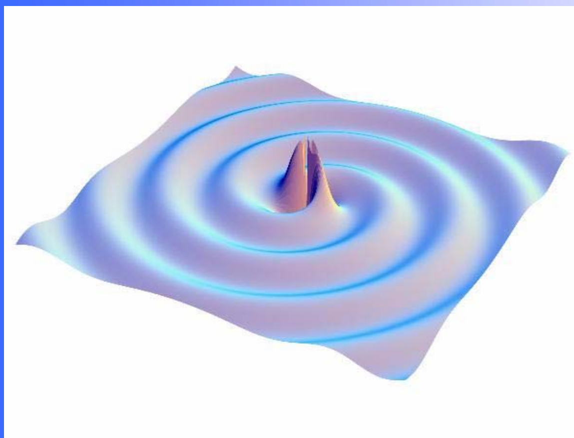
March 24, 2006
9th Eastern Gravity Meeting

G060669-00-R

LIGO and Gravitational Waves



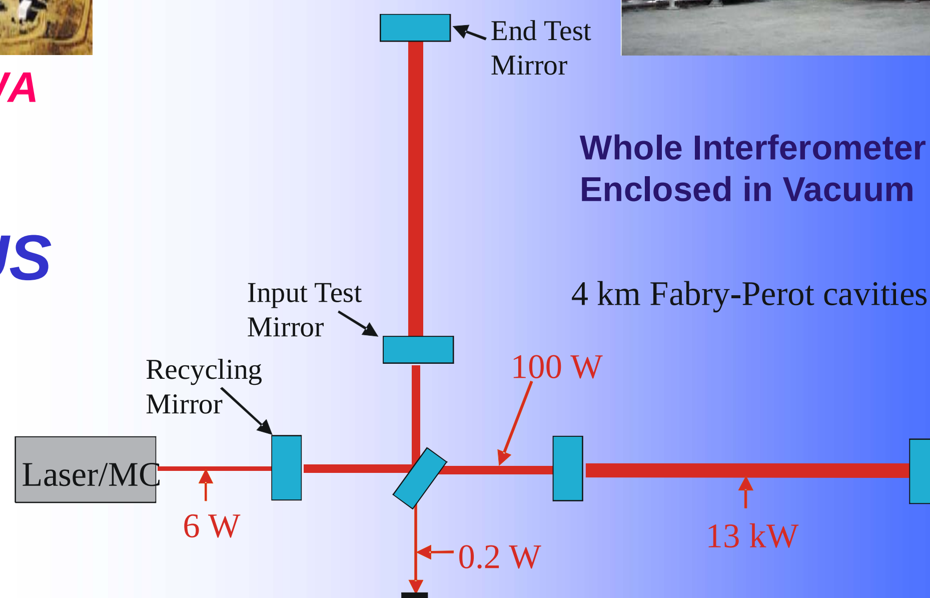
- Gravitational waves predicted by Einstein
- Accelerating masses create ripples in space-time
- Need astronomical sized masses moving near speed of light to get detectable effect

Livingston LA

LIGO

Hanford WA

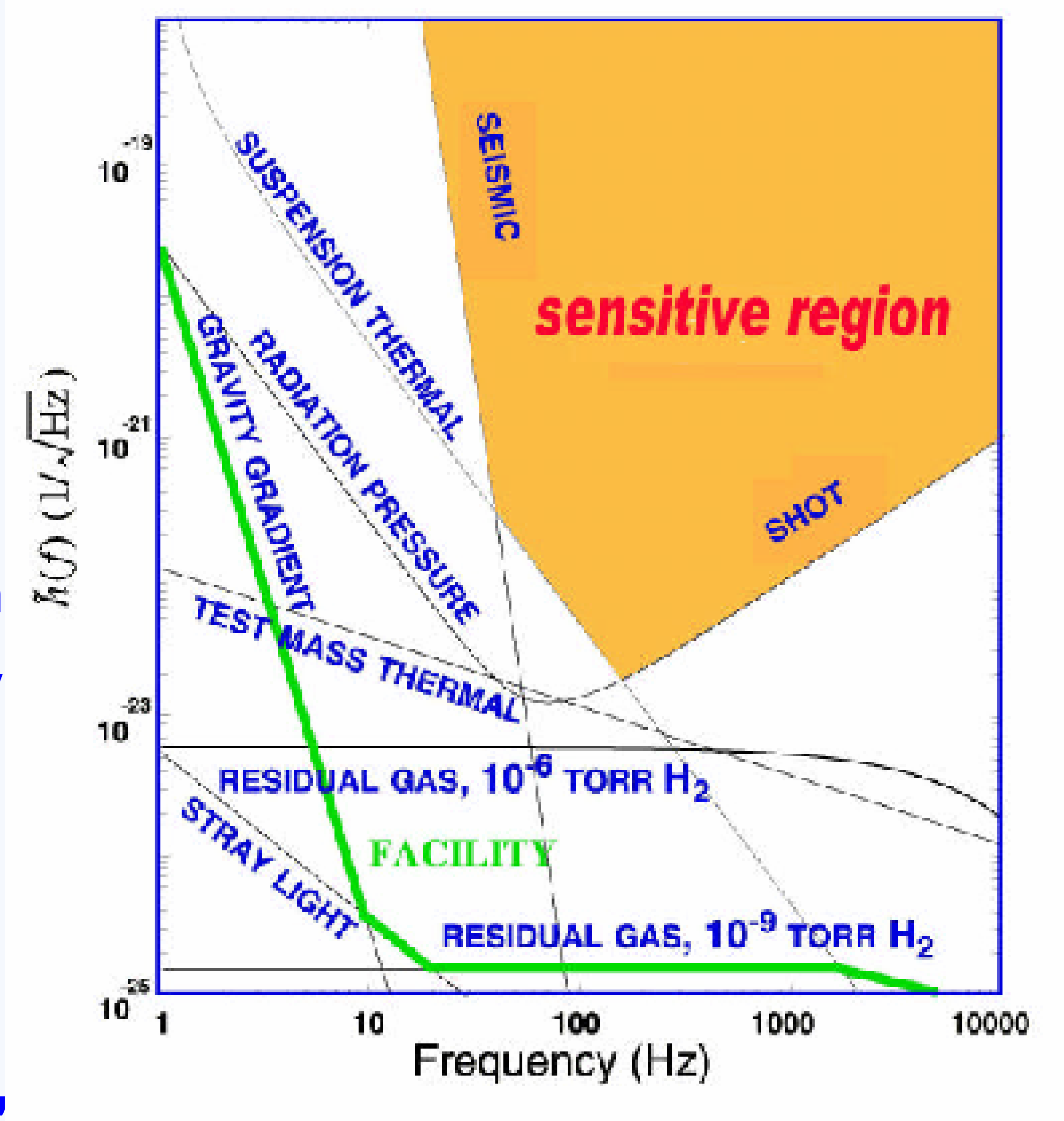
Whole Interferometer Enclosed in Vacuum



- **Two 4 km and 1 2 km long interferometers at 2 sites in the US**
- **Michelson interferometers with Fabry-Perot arms**
- **Optical path enclosed in vacuum**
- **Sensitive to strains around 10^{-21}**

Limiting Noise Sources

- **Seismic noise at low frequencies (<40 Hz)**
  - Optics hang as pendula
  - Vibration isolation between optics and outside
- **Thermal noise in intermediate frequency range (40 Hz - 200 Hz)**
  - k_B T energy in wire suspension
- **Shot noise at high frequency (> 200 Hz)**
  - 10 W laser
  - Optical cavities in arms
  - Power recycling
- **Sensitivity enough so detection of events possible, but perhaps not probable (?)**



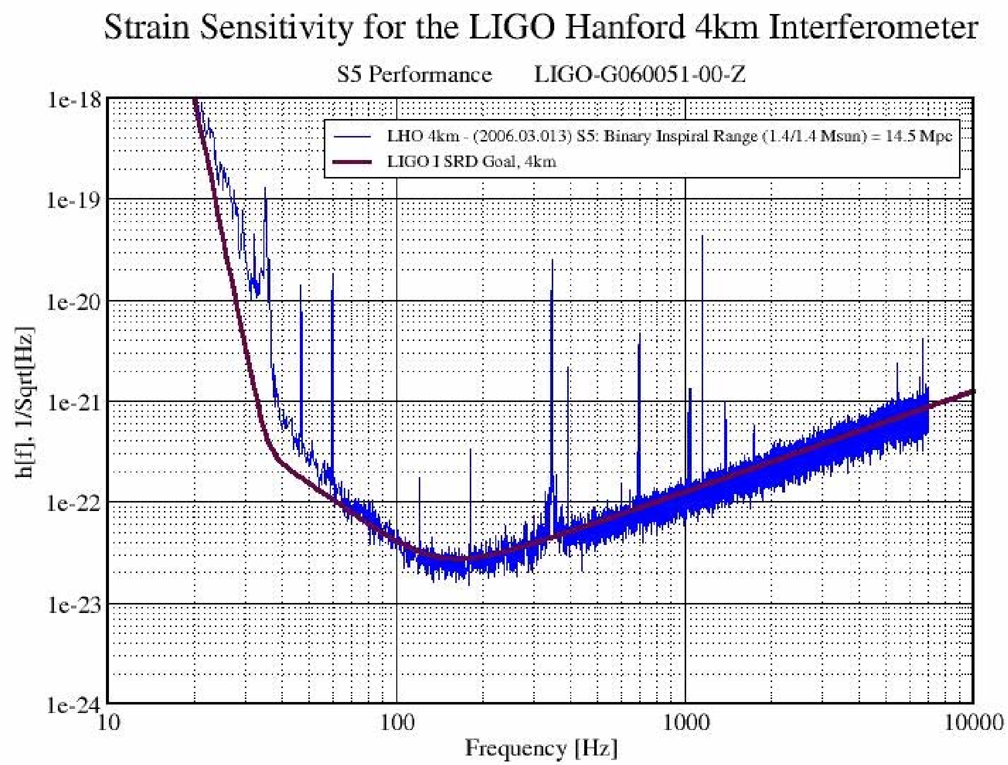
Current LIGO Noise

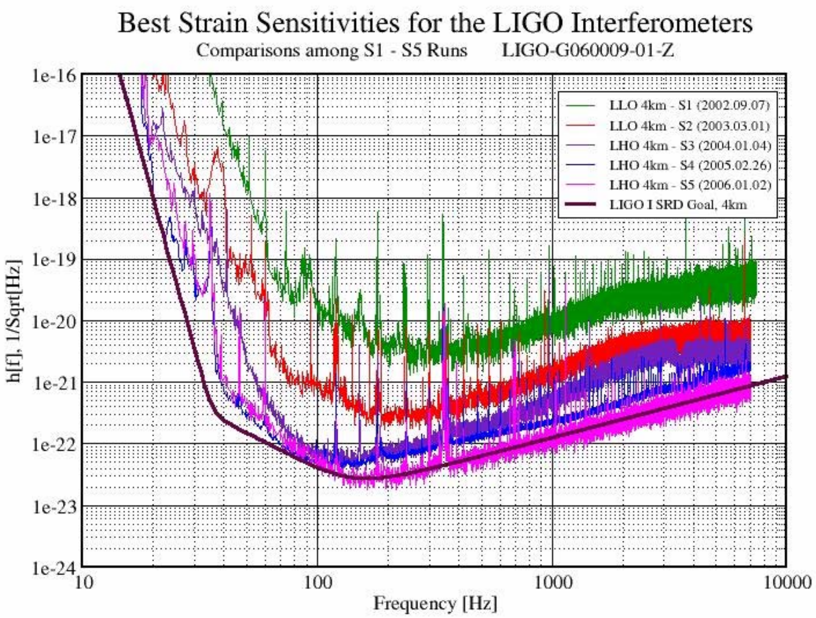
Present noise at design value in all three interferometers

- Some excess noise < 50 Hz
- Noise reduction during breaks

Currently taking data

- Will collect 1 years worth of triple coincidence
- Began in November 2005
- Extensive data analysis ongoing





Hanford 4 K sensitivity

- Neutron star inspirals 14.5 Mpc
- 10 M_O black hole inspirals to 50 Mpc
- Stochastic background 7.5 10^{-6}
- Crab pulsar ε 2.8 10^{-5}
- Sco X-1 ε 3.0 10^{-7}

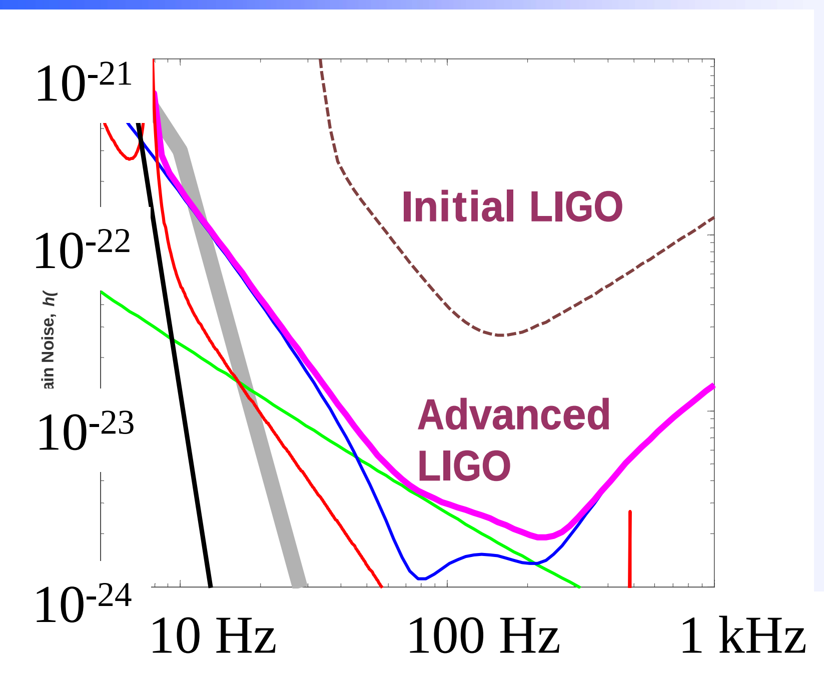
Advanced LIGO Overview

LIGO infrastructure designed for a progression of instruments

- Nominal 30 year lifetime

All subsystems to be replaced and upgraded

- More powerful laser
- Larger core optics
- More aggressive seismic isolation



- **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**
- **Expected sensitivity**
  - Neutron star inspirals to about 175 Mpc
  - 10 M_O black hole inspirals to 775 Mpc
  - Stochastic background 1 10^{-9}
  - Crab pulsar ε 8.5 10^{-7}
  - Sco X-1 ε 5.3 10^{-8}

Laser and Optics

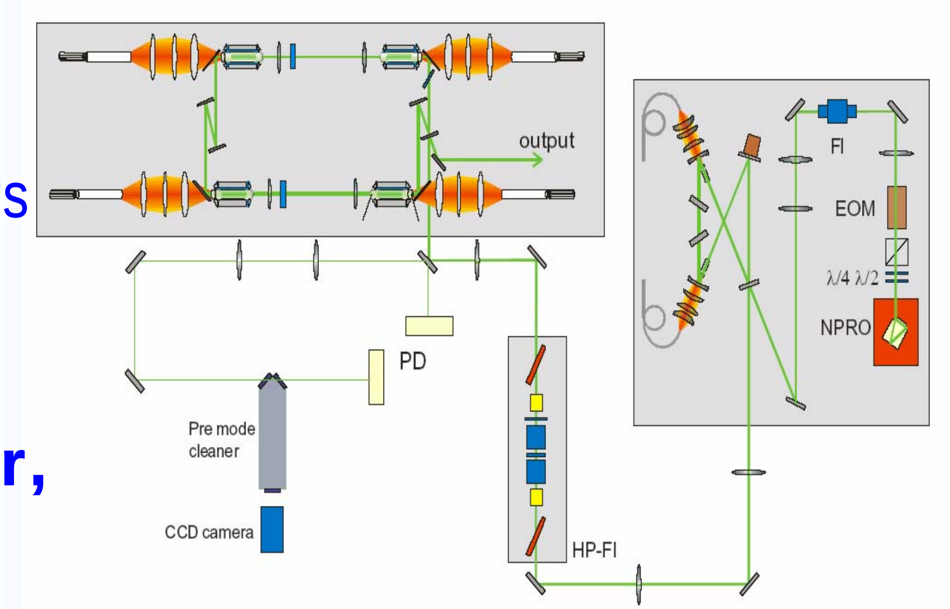
180 W end-pumped Nd:YAG rod injection locked needed

- Backup efforts in slabs & fiber lasers

Frequency stabilization

- 10 Hz/Hz$^{1/2}$ at 10 Hz required

Development at Max-Planck Hannover, Laser Zentrum Hannover



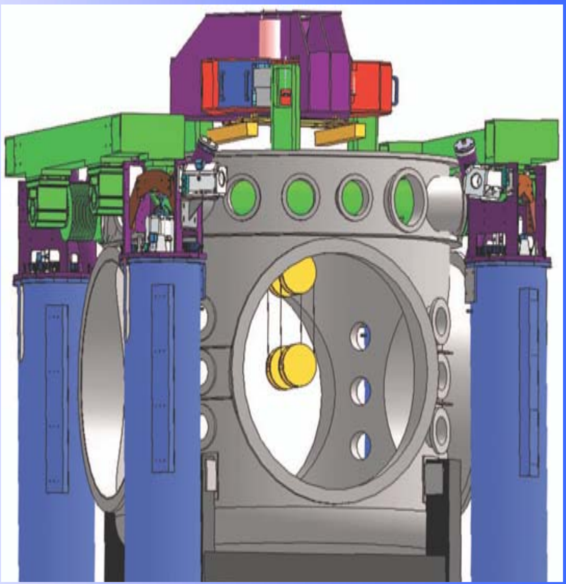
Silica chosen as substrate material

- Improved thermal noise performance from original anticipation
- Some concerns about unknowns with sapphire (absorption, construction,…)

Coatings dominate thermal noise & optical absorption

- Progress reducing ϕ with doping
- See talk by Matt Abernathy

Seismic Isolation and Suspensions



Active isolation in large chambers

- High-gain servo systems, two stages of 6 degree-of-freedom each
- External hydraulic actuator pre-isolator
- Extensive tuning of system after installation

Hydraulic pre-isolator installed at Livingston

- Increases initial LIGO duty cycle
- Exceeds advanced LIGO requirements

Adopt GEO 600 silica suspension design

- Multi-stage suspension, final stage fused silica
- Ribbons baseline design, fibers as fallback

Quadruple pendulum design chosen

- Ribbons silicate bonded to test mass
- Leaf springs (VIRGO origin) for vertical compliance

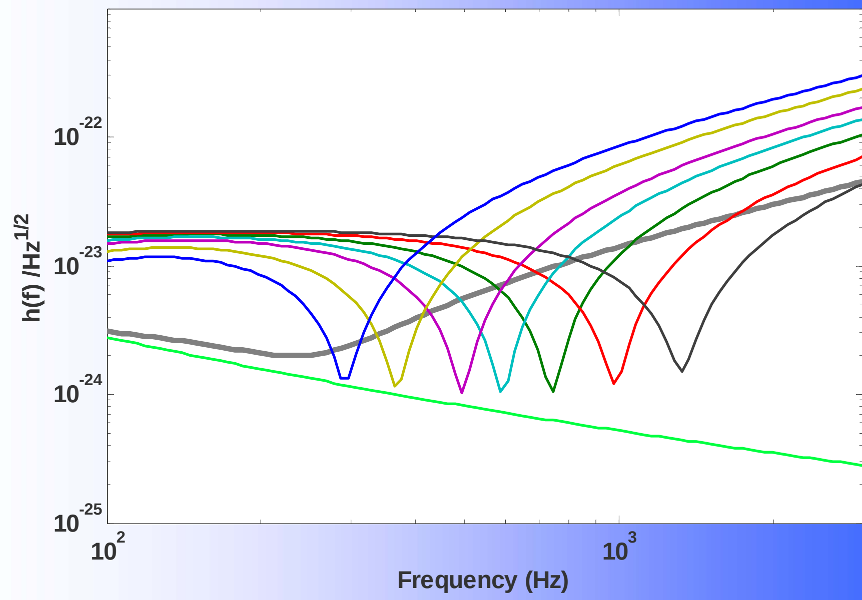
Laser fiber/ribbon drawing apparatus developed

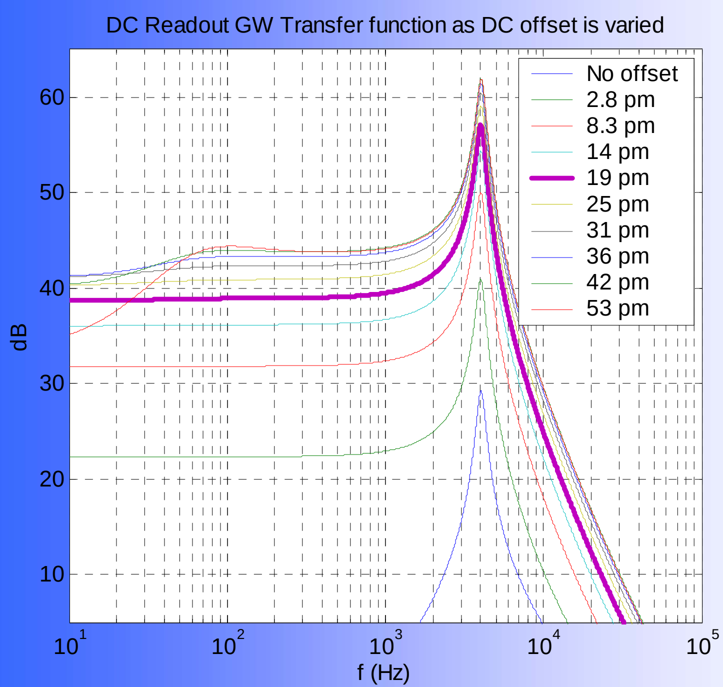
- Welds being characterized for strength/Q etc.

Readout

Dual recycled (signal & power) Michelson with Fabry-Perot arms

- Offers flexibility in instrument response
- Can provide narrowband sensitivity
- Critical advantage: can distribute optical power in interferometer as desired
- Output mode cleaner





DC rather than RF sensing

- Offset ~ 1 pm at interferometer dark fringe
- Best signal-to-noise ratio
  - Simplifies laser, photodetection requirements
  - Perfect overlap between signal & local oscillator
  - Easier to upgrade to quantum non-demolition in future

Advanced LIGO Project Status

National Science Board (NSB) endorsed Advanced LIGO proposal in October 2004

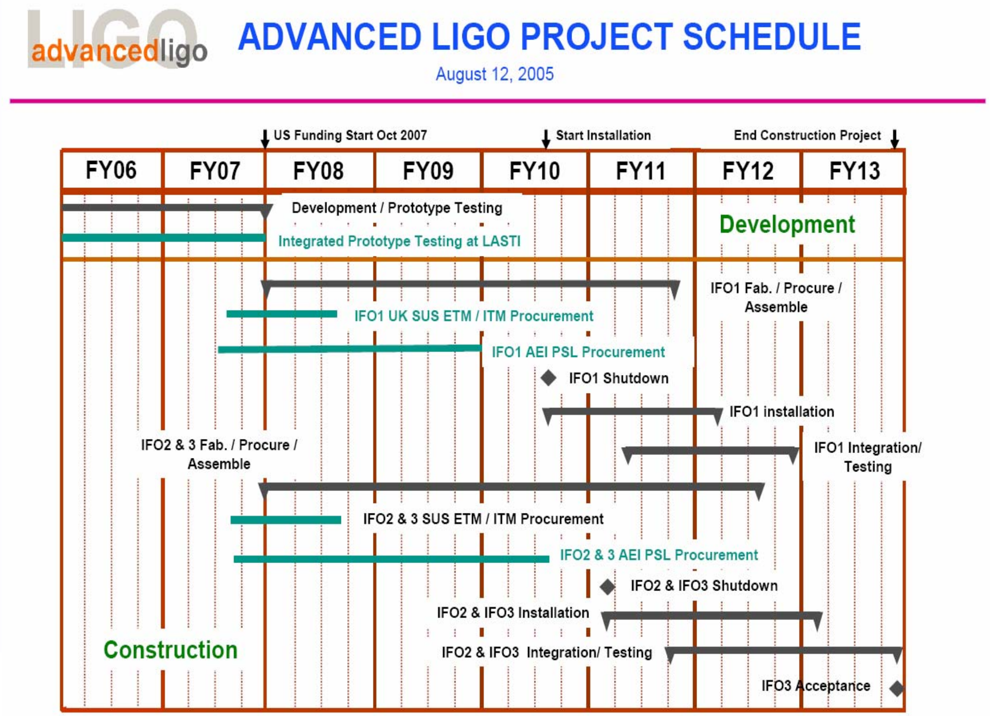
- Contingent upon integrated year of observation with Initial LIGO

National Science Foundation & Presidential Budget for 2006 includes Advanced LIGO

- One of 3 new projects to start in next 3 years
- October 2007 start date

Shut down first initial LIGO interferometer mid 2010

- Finish installing 3rd interferometer end 2013



NSF review of costs, manpower & schedule in June 2006

- Fresh analysis→updates of technology
- Current best estimates comparable with NSB-approved costs

Conclusions

- **Initial LIGO working as designed**
  - Upper limits on gravitational wave sources
  - Working towards a confirmed detection
- **Advanced LIGO will have ~ 10 X sensitivity of initial LIGO**
  - 1000 X rate for homogeneously distributed sources
  - Detection of events probable
- **Laser will have 180 W of power**
- **Fused silica substrates for core optics**
  - Coating crucial and still under development
- **Fused silica ribbon suspensions**
- **More aggressive seismic isolation**
- **DC readout of dual-recycled configuration**
- **Budget situation hopeful for 2007 start**
  - No check in hand yet