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Auxiliary Optics System (AOS)

Technical Breakout Presentation
NSF Review of Advanced LIGO Project

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AOS Functions- a Grab Bag of Optics

- **Stray Light Control** (SLC)- baffles and beam dumps to prevent scattered light and ghost beams from interfering with interferometer performance
- **Thermal Compensation System** (TCS)- senses thermal lensing of core optics due to absorbed laser power and compensates using tailored heaters
- **Pickoff Mirrors and Telescopes**- collects a sample of the interferometer beam and reduces its size for transmission out of vacuum to the optical tables
- **Initial Alignment System** (IAS)- surveying and metrology used to install the in-vacuum optics in the correct positions with the correct orientations
- **Optical Lever System** (OpLev)- sensors to monitor the orientation of the optics as they swing in their suspensions
- **Photon Calibrator**- applies a known radiation pressure force to the End Test Masses for interferometer calibration
- **Output Mode-Matching Telescope** (OMMT)- reduces the dark port beam size and couples it into the Output Mode Cleaner
- **Viewports**- gets light into and out of the vacuum

What Ties AOS All Together

- AOS, broadly defined, is concerned with how light is maneuvered around the interferometer and into and out of vacuum:
  - scattered light
  - ghost beams
  - pickoff beams
  - output beams
  - optical levers
  - thermal compensators and compensator probes
  - photon calibrator beams
- The bulk of the optical layout inside the vacuum is defined by AOS

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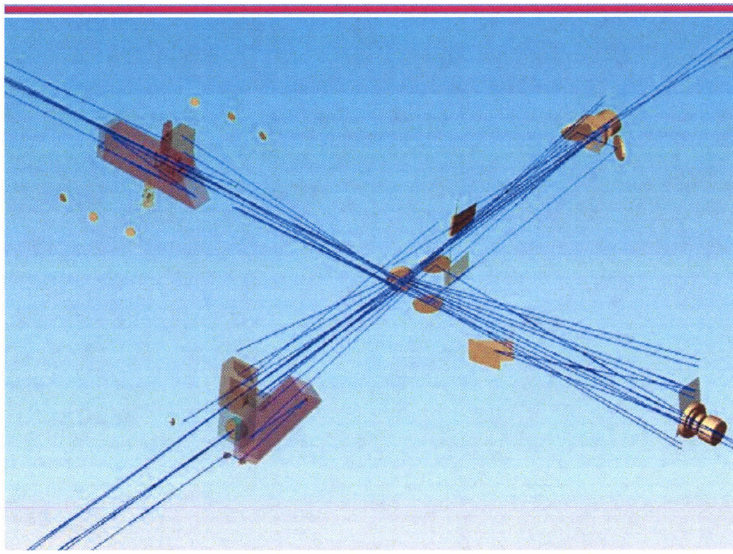
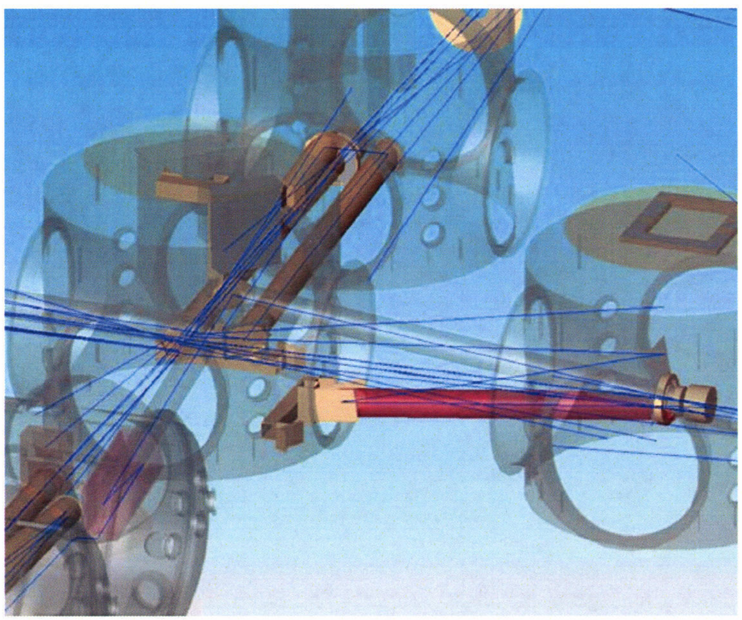
Stray Light Control





- **Stray Light Control uses baffles and beam dumps to safely discard scattered light and ghost beams before they can interfere with IFO operation.**
- ***Requirement: the phase noise resulting from stray light scattered back into the IFO from moving surfaces must not exceed 1/10th the Advanced LIGO sensitivity.***
- **Estimates of the coupling paths and sensitivity of the interferometer to scattered light are underway.**
- **Technical challenges under control.**

cost: $661k

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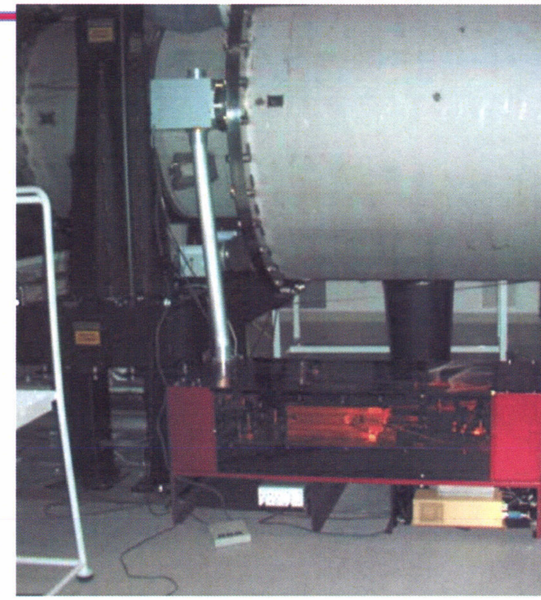
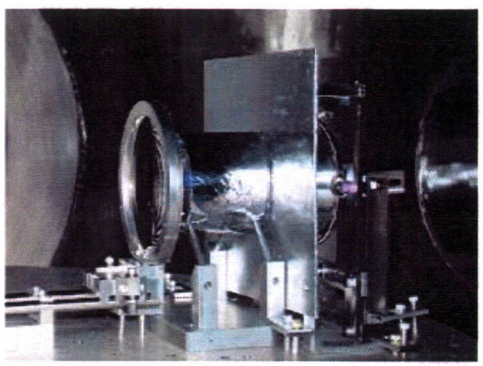
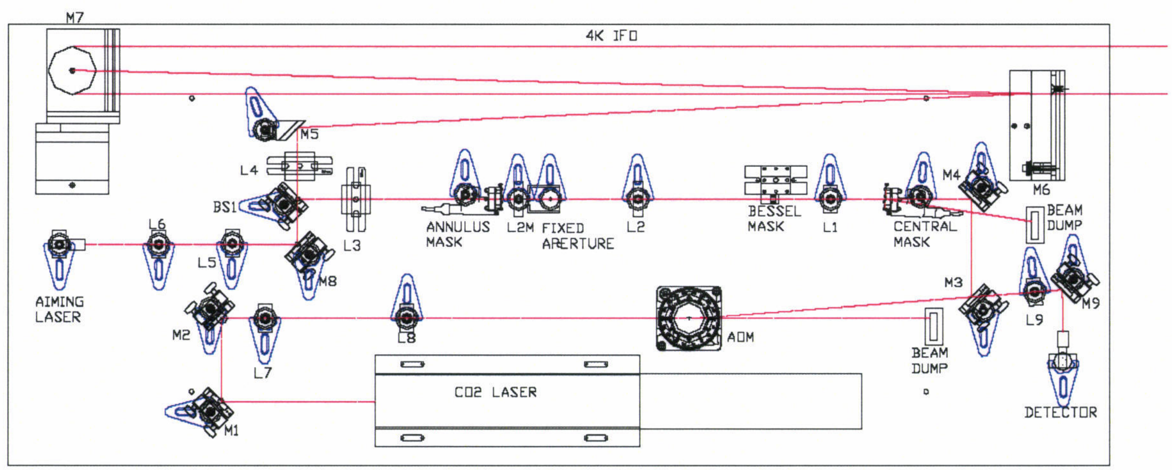
Thermal Compensation System (TCS)

- TCS was developed for Advanced LIGO, but retrofit to initial LIGO and has proven itself essential.
- *Requirements: TCS must…*
  - » *prevent RF sideband power buildup in the recycling cavities from saturating due to aberration losses*
  - » *keep GW sideband amplitude loss through the signal cavity below 5%*
  - » *keep dark port contrast defect light below 1 mW level*
- TCS could also adjust static curvature errors and control acoustic parametric instability by tuning the arm cavity mode spectrum.
- TCS will employ two types of actuator:
  - » Incandescent ring heaters for homogeneous absorption
  - » Carbon dioxide laser heaters for inhomogeneous absorption
- TCS will employ two types of sensor:
  - » Dedicated probes for individual optic phase profiles
  - » Phase cameras for IFO beam structure



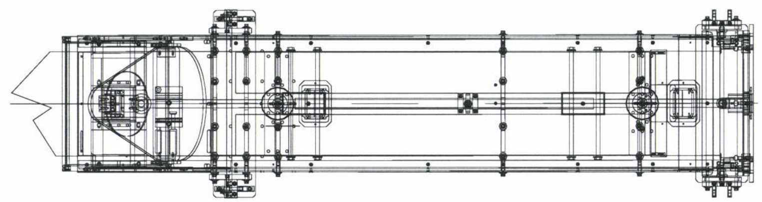


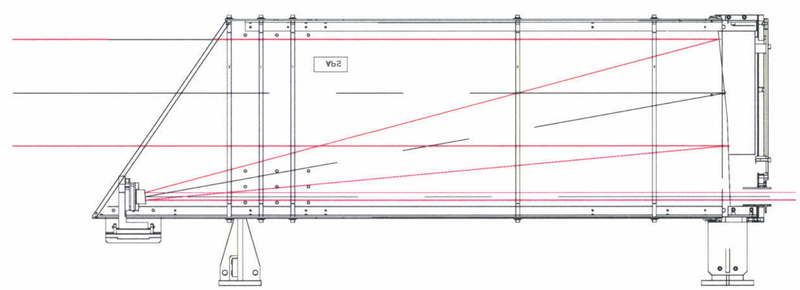


$1,959k

Pickoff Mirrors and Telescopes

- Pickoff mirrors reflect a small fraction of IFO beam out of the main beam to be sensed for IFO control; telescopes reduce the beam size to fit through viewports to sensing tables.
- *Requirements: TBD, but conservative estimate is to scale up proportional to the increase in beam size from LIGO to Advanced LIGO.*
- All basic optics and not technically demanding.

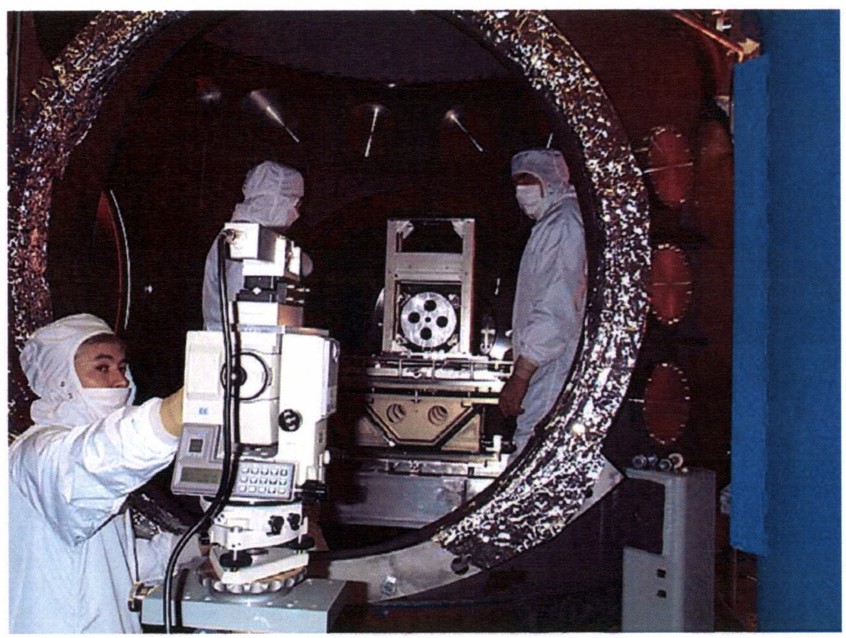




$2,757k

Initial Alignment System

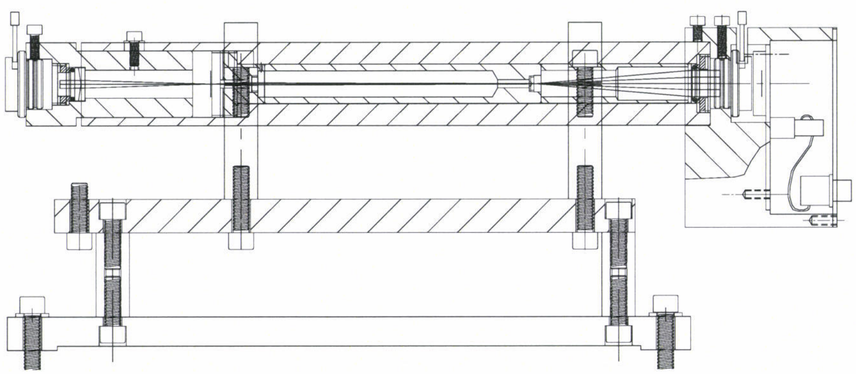
- **Surveying and metrological equipment for positioning and orienting core optics during initial installation.**
- ***Requirements: same as those for initial LIGO-***
  - » ***+-0.1 mrad pitch and yaw***
  - » ***+- 1mm transverse positioning***
- **Essentially no difference from initial LIGO.**



$136k

Optical Lever System

- Monitors orientation of suspended optics by sensing reflected laser beam with quadrant photodetectors.
- *Requirements: angular noise, .002-10Hz- <10^{-8}rad RMS*
- These are used in initial LIGO and work well, but would work a little better with position-insensitive receiver lenses. Prototype lenses have been tested.
- Only small changes to existing hardware here.



$1,007k

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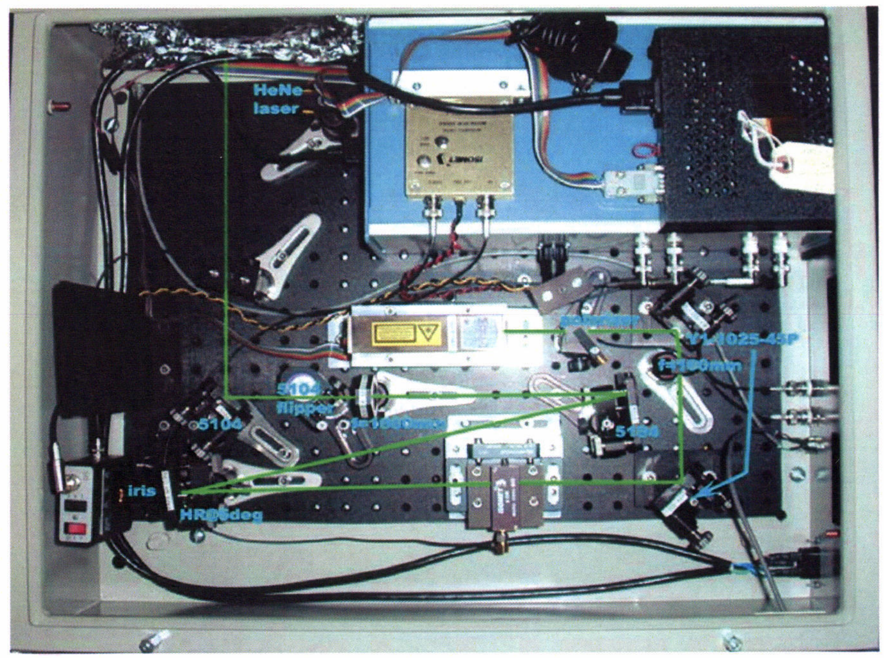
Photon Calibrator Status, Development

- **Basic design for initial LIGO works, but Nd:YLF lasers used are not quite as reliable as we'd like.**
- ***Requirements: 1W pk-pk sinusoidal power output to 2 kHz, noise injection <1/10th Advanced LIGO sensitivity***
- **New design will use Nd:YAG lasers, offset locked from main IFO beam to prevent scattered light injection.**
- **New laser and offset locking are well-known technologies- technical challenges are modest.**
- **If electrostatic actuators in SUS are insufficiently quiet, the Photon Calibrator will be upgraded to Photon Drive- same basic design, but with more powerful laser.**



$1,071k

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Output Mode-Matching Telescope

- **Main interferometer beam of 6 cm spot size is reduced for input to output mode cleaner and detection.**
- **If stable signal recycling cavity is adopted, this telescope will be incorporated into signal recycling cavity and have more stringent displacement noise requirements (comparable to signal recycling mirror).**
- ***Requirements: TBD***
- **In initial LIGO, this was another Pickoff Telescope. For Advanced LIGO it will be a long suspended telescope similar to the Input Mode-Matching Telescope.**
- **Technical challenges under control.**

$828k

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Viewports

- **All light enters and exits the vacuum through viewports**
  - » **BK7 and fused silica for visible and Nd:YAG light**
  - » **Zinc selenide for carbon dioxide laser light**
- **Viewports need good but not spectacular flatness, AR coatings**
- ***Requirements (for Nd:YAG viewports):***
  - » ***clear aperture >2.75"***
  - » ***wavefront distortion $\lambda/10$ @ 633nm***
  - » ***transmittance >99.9%***
- **Basic optics, similar to initial LIGO, no difficulties expected.**

$386k

Why We Think We Can Build All This

- **SLC-** same as initial LIGO
- **TCS-**
  - » Carbon dioxide laser projector used on initial LIGO
  - » Ring heaters tested/used at MIT, GEO600 and Gingin
  - » Sensors developed and tested at Gingin and IAP (Nizhny Novgorod)
- **Pickoff Mirrors and Telescopes-** same as initial LIGO
- **IAS-** same as initial LIGO
- **OpLev-** same as initial LIGO, with position-insensitive receiver tested at Caltech.
- **Photon Calibrator-** similar to initial LIGO, but with same laser we use in all our tabletop experiments
- **OMMT-** same as input mode-matching telescope, except potentially with AdLIGO triple suspensions
- **Viewports-** same as initial LIGO

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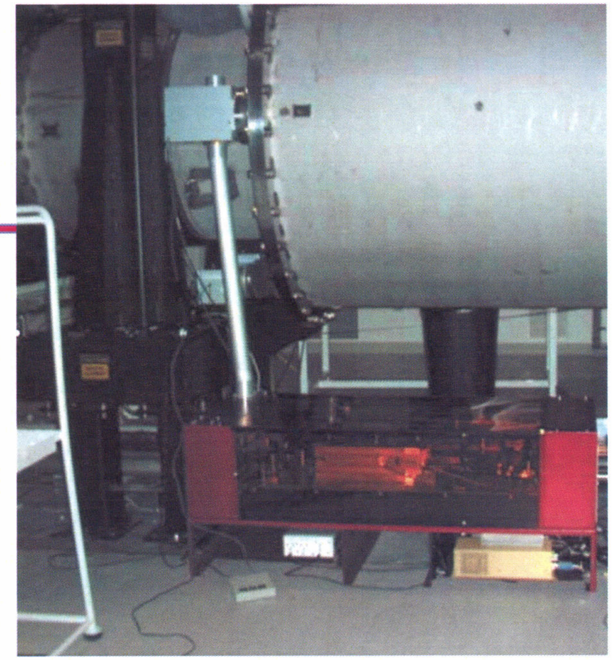
AOS Safety Considerations



- AOS includes lasers
  - » Class IV: TCS carbon dioxide projector, Photon Calibrator Nd:YAG
  - » Class IIIb: IAS autocollimator, TCS sensors, OptLevs
- Fixed installations (TCS, OptLev, Photon Calibrator) employ beam tubes, enclosures, keyed entry interlocks, safety protocols
- Temporary installations (IAS) employ strict safety protocols
- Lock loss involves release of ≤22J of light per arm in 30 μs- Stray Light Control includes baffles to keep this light from damaging in-vacuum equipment or escaping vacuum.
- 'Standard' safety issues: ergonomics, electrical, weight, pressure