Major International Collaboration in Advanced LIGO R&D

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LIGO

Major International Roles in Advanced LIGO

From Shoemaker talk

- GEO (UK, Germany) project has joined the LSC
  - » advanced LIGO involvement includes leading roles in suspensions, configurations, prestabilized laser.
  - » GEO is proposing a capital contribution/partnership in construction of advanced LIGO
- ACIGA project has joined LSC
  - » advanced LIGO involvement includes laser development, sapphire development and high power issues
- Recent discussions have begun with Virgo on collaboration in coating development and in joint data taking and data analysis

Proposal Table of LSC Institutions

From proposal

- GEO
  - » Suspensions
  - » Mechanical losses
  - » Configurations
  - » Prestabilized laser
  - » Data analysis
  - » Proposed capital partners
- ACIGA
  - » Sapphire
  - » High power lasers
  - » Configurations
  - » Handling high power
  - » Data analysis

Table 8 List of LSC Institutions.

Institution
ACIGA
Caltech - CACR
Caltech - CaRT
Caltech - CEGG
Cal. State Dominguez Hills
Carleton University
Cornell
GEO 600
Harvard-Smithsonian
Inst. of Applied Physics - Russia
Inter-University Centre for Astronomy and Astrophysics (India)
Iowa State University
JILA (Univ. of Colorado)
Louisiana Tech
LSU
Moscow State University
NAOJ - TAMA
Oregon University
Penn State
Southern University/A&M College
Stanford University
Syracuse University
University of Florida
University of Michigan
University of Texas - Brownsville
University of Wisconsin-Milwaukee
LIGO Hanford
LIGO Livingston
LIGO MIT
LIGO Caltech

From proposal

LIGO-M000352-00-M

Area Activity	Deliverable	Participant **Lead**	Role	Milestones
Suspension (SUS)				
Test Mass Materials Development (Mechanical)	Q measurements and modeling for coated optics; loss (phi) measurements of coatings & substrate materials; measurements of different coaters; measurements of the effect of polishing & chemical treatment	GEO	Glasgow will explore coating materials and annealing	4Q00: Initial Impact of Coating on TM Q Initial loss of target materials 4Q01: Final FS & Sapphire Q, with optical coatings 2Q02: Selection of test mass material 4Q02: Characterization of selected materials
		Iowa	Iowa leads the coating mechanical modeling work	
		LIGO (MIT)	MIT will perform ring down measurements for variations in coating thickness & coater	
		MSU	MSU will investigate chemical and flame polishing effects on substrate Q	
		Stanford	Stanford will lead the effort and study effect of coaters/processes, measure substrate an coated optic Q	
		Syracuse	Syracuse investigate surface polishing & chemical treatment, direct phi measurement of substrate materials (anelastic aftereffect)	
Test Mass Mechanical Integration	hydroxy catalysis bonding procedure; welding technique/procedure; surface preparation requirements; strength characterization; interface geometry definition	LIGO (CIT)	CIT will study & optimize the strength of FS-FS and FS-sapphire bonds, determine surface preparation/cleaning requirements	✓ 3Q00: Bonding/welding technique defined 4Q02: Characterization of specific techniques
		GEO	GEO will lead the effort and study the effects of welding FS and bonding on Q, bond strength	
		Stanford	Stanford will study the effects of welding FS and bonding on Q, bond strength	
		Syracuse	Syracuse will measure the effect of bonded attachments on composite Q	
Suspension Fiber & Ribbon Development	Initial design, fabrication technique development and performance prediction for suspension fibers	LIGO (CIT)	CIT is developing repeatable & characterized production process and exploring dynamics of twisted ribbons	✓ 2Q00: Ribbon conceptual design 4Q00: Basic silica ribbon/fiber research enables fabrication process research 2Q01: Fiber fabrication process established 4Q02: Characterization of production fibers
		GEO	Glasgow leads effort and defines initial design & processes	
		MSU	MSU will measure and optimize fiber Q	
		Syracuse	SYR will measure FS fiber and rod Q	

From Proposal Appendix: All MOU's Summarized

From proposal

GEO 600

Areas of Research. Initial LIGO: Implementation and exploitation of the Initial LIGO detector and physics through the initial science data run, and software development, prototyping, coding and testing.
Advanced LIGO: Seismic isolation, suspensions, thermal noise, future isolation and suspension improvements, advanced subsystems for initial LIGO interferometers, entirely new advanced interferometers, lasers and optics, future high power lasers, required improvements in optics for use in advanced subsystems, and advanced detector configurations.

Systems under development for GEO 600 and of relevance to Advanced LIGO include: a 12 Watt injection-locked Nd:YAG laser with a control topology similar to LIGO I PSL, frequency control with respect to suspended 8 meter modecleaners and an outer frequency stabilization loop with the power recycling cavity as the reference, an intensity stabilization loop with feedback to the injection-locked slave pump diode, mode cleaners for measuring cross coupling introduced by spatial filtering, a dual-recycled interferometer using four-pass delay lines in the 600 meter arms, signal recycling (as opposed to power recycling, considered standard for all current detectors), and Resonant Sideband Extraction (RSE) with many configurational similarities with signal recycling.

Specific Tasks. Initial LIGO: Coding, using the Hough hierarchical algorithm, of all main routines necessary to run the search on a single node, with most routines being LAL compliant.

Preparation of a set of packages aimed at handling the data analysis requirements to search for backgrounds with energy spectral density that follows a broken power-law behavior.

Development, testing and prototyping and improving the coherent line removal package.

Development of time-frequency methods for unmodeled GW sources including concretization of the idea of detecting the signal through a search in a time-frequency representation based on the so-called "Signal track Search" algorithm.

Development and implementation of adaptive methods for interferometric gw data denoising. This includes development of adaptive filtering techniques to separate and extract gravitational wave signature from the stationary Gaussian background noise.

Transient testing, improvement/adding new functionalities and maintenance of the C++ code.

Development of a Median Based Line Tracker (MBLT), a new line removal method. MBLT promises to be insensitive to the presence of broadband transients and can work on line features in any part of the spectrum since no prior models for the line noise are required.

Development of a likelihood based test for the presence of a common source in event data from two different instruments. This algorithm will allow scanning over coincidence window size which is currently being fixed by hand in the standard analysis.

Exploration of ways to improve the performance of the Kalman filter algorithm for removal of violin modes.

Application of time series modeling (both linear and non-linear) to interferometer data with line features removed.

Obtaining of a robust statistic for detecting gravitational waves from inspiraling compact binaries in order to search for gravitational waves from inspiraling compact binaries on the presence of non-Gaussian and non-stationary detector noise. Template-placement algorithms for single detectors as well as detector-networks are being explored.

Advanced LIGO: Development of suspensions relevant to Advanced LIGO and future LIGO enhancements, including: evaluation of the performance of triple pendulum system in GEO 1200 meter single arm test interferometer and feed back of information relevant to Advanced LIGO, development of suspension designs and local controls for Advanced LIGO, and installation of the first fused silica suspensions in GEO.

Materials research relevant to Advanced LIGO and future LIGO enhancements, including: work on ribbon strength and quality factors, and effects of welding to silicate bonded attachments (in collaboration with Caltech), investigation of hydroxy-catalysis bonding of silica to crystalline materials (in collaboration with Stanford and Caltech), investigation of loss factors of crystalline material with bonded attachments (in collaboration with Stanford), investigation of losses associated with dielectic coatings on silica and sapphire test masses, and development of methods to achieve the direct measurement of off-resonance thermal noise in small mirrors.

Advanced Laser development, including: cross-coupling between laser stabilization control loops in a Nd:YAG laser system relevant to Advanced LIGO interferometers with emphasis on the amplification process (injection-locking vs. MOPA), design and development for the Advanced LIGO prestabilized laser (PSL), investigation of noise performance of a suspended reference cavity with respect to the suspended GEO modecleaners, design and construction of an NPRO pumped with a single-mode laser diode (in collaboration with InnoLight, a local laser manufacturer), intensity stabilization of the12 Watt system, experimental comparison of performance of injection-locked and MOPA designs (in collaboration with Stanford), characterization and long term-performance evaluation of the final GEO 12 Watt laser system, investigation of signal recycling, demonstration of resonant sideband extraction in a suspended interferometer, and implementation and modification of sensing and control systems.

Resources Provided by GEO 600. Personnel dedicated to LIGO includes fifty-seven collaborators, of this fifty are involved in the Initial LIGO and thirty-three in the Advanced LIGO effort. The Full Time Equivalent (FTE) level of effort is 47.6, of this 30.5 is dedicated to the Initial LIGO and 17.1 to the Advanced LIGO.

GEO 600 Project…

- UK/German project to build and operate a 600 meter arm interferometer
  - » Glasgow, Cardiff, Hannover (Univ. and Max Planck Institute of Quantum Optics), Garching (MP), AEI (Potsdam)
  - » 600 meter delay line arms
  - » Signal recycling is included
  - » Multiple pendulum silica fiber suspensions
  - » Prestabilized laser system built on in-house injection locked laser

GEO Project Status

- A double bounce 2400 meter long arm cavity has already been locked
- Silica fiber suspensions have been built
- 10 Meter Glasgow prototype is in preparation for signal recycling research
- Data sharing and joint analysis with LIGO planned

GEO will measure the controls properties of the multiple pendulum suspensions and the real noise floor in a sensitive interferometer as part of their observations program

GEO – Suspensions R&D

- Lead design role through Preliminary Design of multiple pendulum suspensions
- Provide some of the prototyping
- Developed silicate bonding of fibers to test masses
- Perform Q measurements of fibers/optics
- Develop fiber/ribbon pulling
- Develop initial local controls design
- Apply results of GEO 600 experience
- Participate in LASTI tests
- Caltech's Willems in Glasgow this year
- Glasgow's Robertson in Stanford/Caltech next year

GEO – Configurations R&D

- Glasgow's Ken Strain leads the LSC Working Group on Advanced Interferometer Configurations
- Glasgow 10 Meter prototype is being prepared for a proof of principle recycling experiment which will be used to guide the 40 Meter experiment at Caltech
- Glasgow leads in the use of the Penn State Bench model of the interferometer design and is applying the Stanford Melody thermal model

GEO – Prestabilized Laser Subsystem

- LIGO selected the GEO/Hannover proposal to lead the development of the 180 watt PSL system
- Hannover (Univ. + MPQ) group works closely with Laser Zentrum Hannover to develop the GEO laser
  - » This team will lead the advanced LIGO development together with Caltech, Stanford, Adelaide
  - » Front end laser technology will be selected from among Stanford, GEO, Adelaide approaches

GEO as "Capital" Partners

- PPARC funding is supporting Glasgow work on suspensions for advanced LIGO
- Glasgow has discussed a PPARC contribution of about $6 million to constructing advanced LIGO.
- Max Planck Gesselschaft is ~doubling the institute at Hannover
  - » New funding is supporting the laser system development
- Hannover group will also seek about $6 million in total contributions toward advanced LIGO
- Proposed $12 million contribution depends upon NSF decision to construct Advanced LIGO

Australian Consortium for Interferometric Gravitational Wave Astronomy (ACIGA)

- ACIGA has joined the LSC
- University of Western Australia, Australia National University, University of Adelaide
- High power 80 Meter Test Interferometer under construction near UWA
- Configurations research
- Sapphire and suspensions research
- High power stable-unstable resonator laser research

ACIGA is interested in a larger role in Advanced LIGO

TAMA

- Only the TAMA group at National Astronomical Observatory (NAO) has joined LSC
  - » Joint research in configurations (resonant sideband extraction experiment just completed at Caltech
  - » Thermal Noise Interferometer
- But TAMA 300 project has an MOU with LIGO
  - » Modeling
  - » 40 Meter coincidence run
- LIGO/Caltech just provided new isolation system prototypes to TAMA for testing in a TAMA test interferometer
- Growing collaboration in cryogenic interferometer technology

Russian collaborators

- Braginsky – Moscow State
  - » The leading group studying thermal noise, materials properties, quantum sensing
- Institute of Applied Physics (Nizhny Novgorod)
  - » Nonlinear and high power optics and metrology research done in collaboration with Florida group

Virgo

- Virgo has not joined the LSC
- Several collaborative peer to peer efforts have taken place
  - » Optics
  - » Beam tube technology
- Coating advanced LIGO optics at the Virgo facility in Lyon is being explored
- Virgo has proposed
  - » Coating should be done as a collaboration
  - » Virgo and LIGO should develop ability to run our detectors as a coordinated phased array with joint publication of results.