LIGO

Proposal to the NSF: Low Noise Suspensions and Readout Systems for Future LIGO Interferometers

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LIGO Program Advisory Committee Meeting

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LIGO Hanford Observatory

Overview

- Collaborative proposal between Caltech and Moscow State University
  - » Most work under this grant performed at MSU
  - » Support for group at MSU
  - » Travel funds for visits to Caltech and LSC
  - » Equipment transferred to MSU
- Willems (suspensions) and Whitcomb (general) act as primary Lab contacts for MSU group
- Interaction with the LIGO Lab and LSC

Quick History of MSU GW Research

- MSU group active in GW detection since 1970's
  - » Pioneered extremely high Q oscillators for GW detection (cryogenic sapphire bar)
  - » Invented QND detectors (in collaboration with Thorne group)
- Shift to LIGO-related research ~1990
  - » Pioneered all-fused silica suspensions
  - » Identification of noise sources for Initial and AdvLIGO
  - » Development of readout schemes to beat the Standard Quantum Limit
- Research support provided from Caltech funds 1991-2
- Funded by NSF since 1993
  - » Initially as a supplement to Thorne grant
  - » Separate grant with Whitcomb as PI from 1995
- Charter member of LSC

MSU Group Members

- Vladimir Braginsky (Professor)
  - » Overall supervision, interface with LIGO
- Valery Mitrofanov (Full Professor)
  - » Development of damping for high Q test mass and suspension modes, study electric charges on test masses
- Farid Khalili (Full Professor)
  - » New readout schemes to beat the Standard Quantum Limit
- Sergey Vyatchanin (Full Professor)
  - » Analysis of nonlinearities, analysis of new readout schemes
- Igor Bilenko (Docent, ~ Associate Professor)
  - » Experimental studies of excess noise in fused silica suspensions
- Alexander Stepanov (Docent)
  - » Thermoelastic and excess noise in mirror coatings
- Technician, postdoc, 4-8 graduate students

Results from Prior Grant— Suspensions and Thermal Noise

- Factors affecting Q of fused silica suspensions
  - » Achieved Q ~ 2.5 x 10^8
- Studies of noise due to electric charges on test mass optics
  - » Slow charging ~10^4 e/cm^2/day
  - » Occasional large jumps (cosmic rays?)
- Placed limits on excess noise in fused silica suspension fibers
  - » No excess noise observed up to 15% breaking stress
- Identification and study of thermal noise sources
  - » Thermoelastic noise in sapphire
  - » Thermorefractive noise in fused silica
  - » Coating thermal noise (independently identified by Stanford/Glasgow collaboration)

Results from Prior Grant— QND interferometers

- Use of frequency dependent squeeze angles to beat the Standard Quantum Limit (SQL)
- Speedmeters – measure momentum, not position
  - » Ideas leading to practical designs by Purdue/Chen
- “Optical bar” and “optical lever” configurations
  - » Use radiation pressure to transfer the motion of end masses to vertex for local readout
- Intra-cavity readout interferometers
  - » Potential to operate at high sensitivity with much lower power than conventional interferometers

Results from Prior Grant

- Twenty-four papers published or in review during current grant
  - » P.Willems, V.Sannibale, J.Weel, V.Mitrofanov, "Investigation of the dynamics and mechanical dissipation of a fused silica suspension," *Physics Letters A*, vol. 297, pp. 37–48, 2002.
  - » V.B.Braginsky, S.P.Vyatchanin, "Thermodynamical fluctuations in optical mirror coatings," *Physics Letters A*, vol. 312, pp. 244-255, 2003.
  - » H. J. Kimble, Yuri Levin, Andrey B. Matsko, K. S, Thorne, S. P. Vyatchanin, "Conversion of conventional gravitational-wave interferometers into QND interferometers by modifying their input and/or output optics", *Phys. Rev. D*, vol. 65, p. 022002, 2002.
  - » F.Ya.Khalili, "Frequency-dependent rigidity in large-scale interferometric gravitational-wave detectors," *Physics Letters A*, vol. 288, pp. 251–256, 2001.
  - » S.L.Danilishin, F.Ya.Khalili, "Stroboscopic Variation Measurement," *Physics Letters A*, vol. 300, p. 547, 2002.

Proposed Research— Suspensions and Thermal Noise

- Continued study of electric charges on optics
  - » Improved time resolution
  - » Improved sensitivity
  - » Correlation with cosmic rays?
- Excess noise in suspension
  - » Excess noise in highly stressed fused silica fibers
  - » Non linear noise and dynamic instabilites
- Low noise damping of high Q modes
  - » Electrostatic
  - » Optical

Proposed Research— QND Interferometers

- Analysis of different speedmeter configurations
- Intra-cavity readout schemes
  - » Analysis of known schemes aimed at controlling dynamic instabilities
  - » Search for new schemes without instabilities
  - » Development of practical design for local meter
- New methods for preparation of squeezed light (pondermotive squeezing)

Interactions with the LIGO Lab and LSC

- Important component of this grant
- Regular visits to LIGO Lab
  - » Vladimir Braginsky, two visits per year, one month each
  - » Valery Mitrofanov, one visit per year, two weeks
  - » Farid Khalili, one visit per year, two weeks
  - » Sergey Vyatchanin, one visit per year, two weeks
- All visits timed to allow participation in LSC meetings
- Other visits to LSC institutions as needed
  - » Willems visit to MSU to work with Mitrofanov and Bilenko
  - » Mitrofanov and Tokmakov visit to Glasgow for interchange on fused silica fibers
- Side comment: Increasingly difficult for physical scientists to get visas for visits to US

Training and Outreach

- Senior MSU staff use LIGO and GW detection as examples in classes
  - » Numerous graduate students involved with research
- Several MSU group members now working in US
  - » Vladimir Ilchenko, JPL
  - » Andrey Matsko, JPL
  - » Anatoly Savchenkov, JPL
  - » Alexander Ageev, postdoc, Syracuse University (Saulson)
  - » Ivan Grudinin, graduate student, Caltech-LIGO
- Four public lectures during current grant
  - » Including 30 minute lecture by Braginsky broadcast by Russian TV network

Conclusion

- Highly motivated and productive group with a long history and commitment to gravitational wave detection
- Exploring important areas for the future that are not being studied by the rest of the community
- As effective an interaction plan as is possible with a group 11 timezones away in a country with the history that Russia has