Joint Research Efforts in Low-Noise Materials

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1. Abstract

The pursuit of fundamental physics through precision measurement is often limited by the properties of the materials that make up the core components of such experiments. Some examples include: the coatings of LIGO's mirrors, surface patch effects and machinability of test masses in short-range gravitational inverse square law tests, thermal mechanical noise in searches for 5th forces, and thermal magnetic noise in searches for CP violation, CPT violation and dark matter that rely on magnetic read-out systems and low surface conductivity cells for EDM tests. Since practically every precision measurement will ultimately be limited by material properties, it is expected that many more will be discovered during the SnowMass discussions. By definition improvements in the critical material properties will translate directly to sensitivity improvements in tests for new fundamental physics. However, the technical and high-risk nature of research into improved materials, the need to maintain manufacturing capabilities, and the desire to share the techniques among groups, make it a research area better suited to a long-term community effort than left to isolated induvidual research groups.

2. Surfaces and Coatings

2.1. **Inverse-square Law and Patch Effects.** Measuring gravity at short distances is important for understanding fundamental physics. An intrinsic part of such measurements is putting relatively large masses as close as possible. At separations below 50 microns, patch effects on the conducting surfaces of testbodies and shielding foils, combined with the effects of ambient vibrations, dominate the noise of the measurements [1]. Additionally, the masses need structure on the order of 50 microns with uniformity and flatness below 1 micron, necessitating the extension of micro-fabrication techniques to high-density materials, Developing techniques for bulk micromachining of high-density materials and better surface preparation techniques would benefit all experiments working on these difficult but important measurements. The long time frames needed to develop and perform these experiments mean that graduate students and post-docs are not a suitable repository for this knowledge.

2.2. **LIGO mirrors.** LIGO's detection of gravitational waves, and the variety of astrophysics and fundamental physics that can be discovered studying these events, has been one of the cardinal discoveries of this decade. LIGO is photon-shot-noise limited in certain frequency ranges, requiring them to implement squeezed light techniques to improve their sensitivity. However, LIGO can not run at full laser power because losses in the mirror surface would cause too much heating of the mirrors. For improvements to LIGO the mirror coatings must also be improved.

3. Thermal Noise

3.1. **Mechanical noise.** Mechanical accelerometers are used in some of the most sensitive searches for very weak new long-range forces [2]. The noise in such systems is often limited by mechanical thermal motion and would be reduced by continued improvements in low loss materials.

3.2. **Magnetic field noise.** Several measurements of fundamental physics take advantage of the great sensitivity of modern magnetic field sensors, including EDM searches, tests of CPT and Lorentz symmetry, searches for new pseudo-goldstone bosons via spin-dependent forces and a wide range of axion dark matter direct-detection. Magnetometers are based on quantum effects

– SQUIDs and SERF magnetometers in particular – are sensitive enough that the noise is dominated by magnetic field noise generated by the magnetic shielding needed to isolate the system under study. Some success has been had in making low-noise shielding, but those approaches have either required very large shielded rooms, or the manufacturing was tricky and the capabilities no longer exists [3]. Reducing eddy-currents through insulating high-permeability or micro-fabbed shielding would help several experiments but the expertise and manufacturing capabilities need to be maintained.

References

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