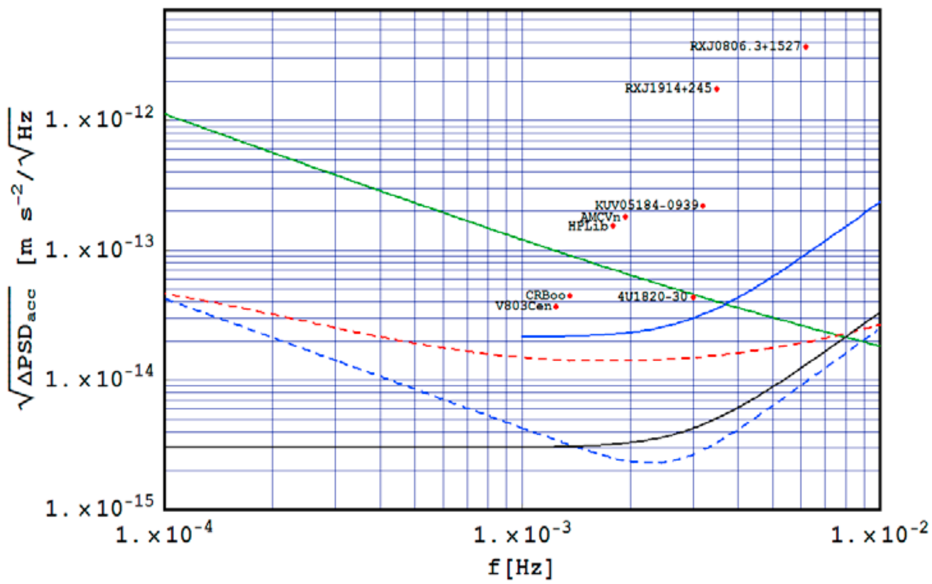

Figure 5: Upper limits on non-modeled surface effect related acceleration noise in LISA. Green solid line: upper limit from Trento pendulum measurements of a full GRS replica. Dashed red line: upper limit from high sensitivity Seattle torsion pendulum measurements using a gold-coated silicon plate.

Also shown are: LISA requirements (black solid line), LISA Pathfinder requirements (blue solid line), and LISA Pathfinder projected upper limit on all (surface and volume) non modeled forces (Dashed blue line). The red dots represent galactic binaries that would be seen with one year of integration if the corresponding acceleration noise level would be achieved in LISA.

The Mock LISA data challenges

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Mock data challenges are widely used in the development and validation of scientific experiments characterized by complex data flows, large collaborations, extensive use of information technology, and difficult or unproven data-analysis techniques. They involve the generation of mock data sets that impersonate the future output of measurements, at varying levels of realism. The data sets are then used to exercise select parts of the data collection and analysis chain. For example, a mock data challenge for a particle collider might be used to verify that the data storage system is fast enough to record all triggers, or to validate the statistical analysis of event backgrounds.

At the December 2005 meeting of the LISA International Science Team (LIST), the Data Analysis Working Group resolved to sponsor a series of Mock LISA Data Challenges (MLDCs) centered on LISA science data analysis, with dual purposes of encouraging early development of LISA-specific data-analysis methods and tools, and demonstrating the extent to which the gravitational-wave research community is technically ready to distill a rich science payoff from the LISA data output.

As described in detail in the LISA U.S. Mission Science Office's "AMIGOS" planning document for the development of data-analysis methods [1], the MLDCs can also generate other useful byproducts. In the course of the challenges, the state of knowledge for specific types of analyses is inventoried, and idealized procedures are cast into forms that can be implemented in practice. Prototypes of software tools and architectures are created that may later evolve into production software or inform its design. And perhaps most important, a common data-analysis testing ground becomes available to all research groups, allowing them to compare approaches, exchange components, and verify each other's results.

The MLDCs are organized in rounds of increasing complexity and realism, which are released and evaluated in sequence. Each round includes several data sets, which contain simulated LISA noise and gravitational waveforms from one or more expected LISA sources, with source parameters drawn randomly from plausible ranges. Each data set is distributed in two versions: a blind challenge set whose source parameters are not disclosed, and a training set with its source parameters provided (and, of course, different from those used in the challenge set). Challenge participants are asked to respond with the maximum amount of information about the sources that they can extract from the challenge sets, and to provide a technical documentation of their work. One of the greatest scientific benefits of the challenges will come from quantitative comparisons of results, analysis methods, and implementations: thus, the challenges are truly blind tests, not contests, although a spirit of friendly competition can benefit scientific output.

An international MLDC task force, charged with administering the challenges, started work in February 2006. Its main responsibilities are the generation of challenge data sets and evaluation of challenge results. These involve several subtasks:

• Choosing the content of the challenge data sets, both gravitational-wave sources and instrument noise. These are chosen so as to target the specific aspects of LISA data analysis considered to present the major challenges. For example, one data set that has been chosen for the first round of challenges addresses the problem of detecting the signal from an isolated massive–black-hole (MBH) binary.

• Specifying data standards for the LISA sources. This includes selecting theoretical models for the waveforms (*e.g.*, black-hole binary inspirals are assumed to be circular and adiabatic, with radiation computed in the restricted 2PN approximation), and choosing standard sets of source parameters.

• Describing standard models for critical aspects of LISA, collectively called a "pseudo-LISA", including such as things as the LISA orbits (*e.g.*, locations of LISA spacecraft at t=0), instrument noise sources (*e.g.*, their spectra), and phase measurements (*e.g.*, choices for TDI combinations).

• Developing a standard file format to represent the data sets, with input–output libraries for several computational environments.

• Collecting or creating software to generate the gravitational waveforms and the pseudo-LISA instrument noise sources, and to assemble the LISA phase measurements and encode them in the standard format. All software is made available to the challengers, who can reproduce the MLDC pipelines to generate any number of additional training sets.

• Generating the challenge and training data sets, and storing the key files containing the answers to the challenges. The task of storing the answers is entrusted to two task force members who are sworn to secrecy and who will not take part in the MLDCs as challengers.

• Providing all participants in the MLDCs with any technical support required.

The MLDC task force was able to fulfill all of these tasks in time for the first round of challenge data sets to be presented to and endorsed by the LIST at their June 2006 meeting. Challenge-1 data sets were released publicly shortly thereafter; they are available online at ***astrogravs.nasa.gov/docs/mldc***. Results are due on or before 01 December 2006. They will be presented at the 11th Gravitational Wave Data Analysis Workshop (GWDAW11) in Golm, Germany later that month.

From the viewpoint of data analysis, these Challenge-1 problems are relatively easy. They focus on galactic binaries and massive black-hole inspirals—the GW sources considered high enough in priority to be retained even in a hypothetical minimum-science LISA mission [2]. These sources are represented by simple, idealized theoretical waveforms, and the data sets do not include the "confusion background" of galactic white-dwarf binaries. This simplification has allowed the task force to concentrate first on the development of the basic tools and common conventions that will be used for subsequent, more complex challenges. It also gives the competing research groups time to learn and understand the tools and conventions without the added complexity of more realistic waveforms.

Challenge-2 data sets will be released at December's GWDAW11, with results due back to the task force in June 2007. Training sets for Challenge 2 will be released earlier as they become available. Challenge 2 will focus on data sets characterized by many overlapping and interfering GW signals from multiple source types. This is known as the "global-fit problem" of LISA data analysis. When sources overlap like this in the time and frequency domains, it can become difficult or impossible to distinguish them without skewing estimates of their parameters. A strong signal may even obscure a weaker signal entirely. Challenge-2 data sets will include radiation from a background of about 30,000 galactic binaries, with parameters drawn from population-synthesis simulations. Extreme–mass-ratio inspirals will also be featured more prominently in this second round.

The third round of challenges will be released in June 2007 for evaluation the following December, and the fourth in December 2007 for evaluation in June 2008. The content for these data sets has not been decided yet, but they will include additional LISA sources such as bursts and stochastic backgrounds, as well as more realistic models of instrument noise and operation (*e.g.*, noise nonstationarity, data gaps and disturbances, etc.).

We encourage all interested groups and individuals to take part in the mock LISA data challenges. Participants should subscribe to the MLDC challenge mailing list (***gravity.psu.edu/mailman/listinfo/lisatools-challenge***) and register with one of the MLDC task force co-chairs (Michele Vallisneri at ***vallis@caltech.edu*** or Alberto Vecchio at ***av@star.sr.bham.ac.uk***). The standards, conventions, and signal-generation pipelines used to generate Challenge-1 data sets are documented extensively in the Challenge-1 omnibus document [3]. The activities of the task force can be tracked at their wiki (***tapir.caltech.edu/dokuwiki/list-wg1b:home***), while the MLDC software is collected in the LISAtools SourceForge project (***sourceforge.net/projects/lisatools***), which also hosts documentation, bug tracking, and user forums.

We are very excited about the progress and results to date of the MLDC effort, and are confident that it will help bring together research groups from around the world working on LISA data analysis. It will serve as an excellent first step toward coordinating international efforts in this area, and ultimately toward advancing the leading edge of LISA scientific research and demonstrating its full potential.

References

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