Science impact of improved instrumentation in space-based gravitational-wave detection

Authors: Ira Thorpe, Jeff Livas, and Tuck Stebbins

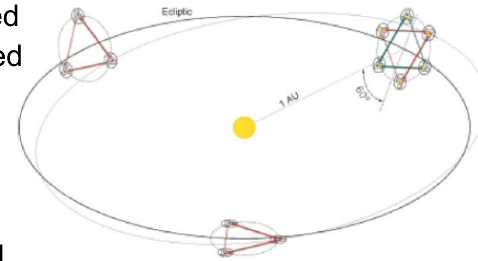

Figure 1: A network of instruments would enhance multi-messenger astronomy through improved source localization.

The tremendous scientific potential of “first-generation” space-based gravitational wave detectors such as LISA has long been recognized by the scientific community. Here we consider what additional science would be enabled by follow-on instrumentation with enhanced capabilities and briefly comment on the technology development efforts that would be required to achieve these capabilities. Broadly speaking, there are two approaches that could be taken to improve upon a LISA-like instrument. The first is to increase the instantaneous sensitivity to gravitational-wave strain in one or more frequency bands. This is analogous to building electromagnetic detectors with higher sensitivity or broader bandwidth. The second is to improve the instrument’s ability to measure the wavefront of the gravitational waves passing through the solar system. This is analogous to building a an electromagnetic instrument with more pixels. In a gravitational-wave detector, wavefront information can be improved by building a network of instruments in separate locations, adding additional links to an instrument, or placing the instrument in a more complex orbit so that it samples different components of the waveform for long-duration signals. Which combination of spectral sensitivity and wavefront sensitivity would be most beneficial depends on the science goals in question. Some specific examples are:

- **Multi-messenger astronomy:** Coordinated observations with gravitational waves and electromagnetic instruments benefit from improved source localization offered by a network of GW instruments. In this case, the technology development effort would be focused on building multiple units and reducing size and mass while maintaining, or maybe even relaxing, sensitivity levels.
- **Cosmic Evolution through observations of BH mergers:** Extending sensitivity to lower frequency bands would allow observation of higher mass and higher redshift systems compared with first-generation instruments. This would require improved drag-free systems and better control of small forces on the test mass.
- **Cosmological Background:** As with the CMB, direct detection of the cosmological GW background requires subtracting astrophysical foregrounds. This is made easier by working in a frequency band with fewer astrophysical sources, such as the band around ~100mHz, at the upper end of the LISA band. Improving sensitivity here would require improved distance metrology systems: larger and more stable optics, more powerful and more stable lasers, and better phase measurement systems.
- **Galactic Nuclei:** The EMRI sources lie in the “bucket” of the LISA instrument, at peak sensitivity. Improving sensitivity here would require *both* improved drag-free systems and improved interferometry.