The Optical Limit of Phase Measurement in Space Based Interferometry

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This talk discusses a rigorous analysis of phasemeter behaviour in the ultra weak-light regime. We cover modelling, simulation and experimental analysis that aim to definitively answer the question: what is the fundamental limit in optical power at which heterodyne phase tracking measurements like that in the laser interferometer space antenna (LISA) [1] science measurement can be reliably performed.

LISA will measure gravitational signals by tracking optical laser links between satellites spaced millions of kilometres apart. The gravitational strain signal measured scales proportionally with the inter-satellite arm lengths, meaning that increase in arm length lowers dimensional stability requirements on the rest of the system. Improving the system in this way is generally considered infeasible, however, partly due to the associated decrease in received light (due to beam divergence). Our understanding of displacement measurements quickly erodes when the optical signal begins to enter the ultra weak signal regime, as linear tracking system approximations begin to break down. The control systems used to make this ultra-sensitive displacement measurement respond to this change in regime by exhibiting non-linear behaviour in the form of cycle slips, which ultimately corrupt any science measurement being performed.

Other space-based interferometers, such as the Gravity Recovery and Climate Experiment (GRACE) Follow-On [2] and the proposed Mass Change Mission (MCM), use a multi-dimensional acquisition scans to initially align the inter-satellite laser links. This process relies on being able to perform an optical measurement when the satellites are miss-aligned, making the detected signal extremely weak. Better understanding weak signal behaviour could improve acquisition and enable better understanding of tracking margins. Previous work in the field of weak-light phase tracking, e.g. Francis et al. [3], demonstrates phase tracking improves with stabilized lasers, so that lower optical powers can be reliably tracked without cycle-slips or loss of lock. This work adds to the understanding of how these systems behave in the weak-light regime and what the optical limit for effective tracking is.

[1] P Amaro-Seoane et al., *Laser Interferometer Space Antenna* (2017).

[2] B. S. Sheard et al., *Intersatellite laser ranging instrument for the GRACE follow-on mission*, (Journal of Geodesy, 2012).

[3] S. P. Francis et al., *Weak-light phase tracking with a low cycle slip rate*, (Optics Letters, 2014).