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(Albert-Einstein-Institut)

# Testbed for Validating Second-Generation TDI and Clock Noise Correction for LISA

Karin Kruuse

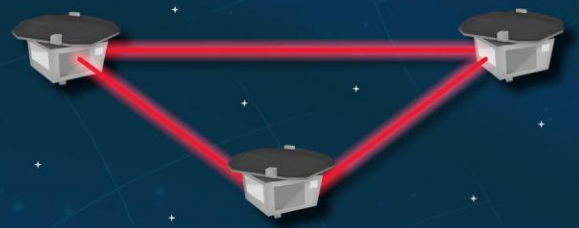
# THE SPECTRUM OF GRAVITATIONAL WAVES

esa

**Observatories & experiments**

Ground-based experiment

Space-based observatory



Pulsar timing array

Cosmic microwave background polarisation

**Timescales**

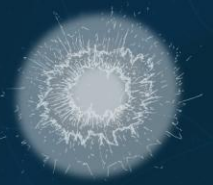
milliseconds | seconds | hours | years | billions of years

**Frequency (Hz)**

100 | 1 | $10^{-2}$ | $10^{-4}$ | $10^{-6}$ | $10^{-8}$ | $10^{-16}$

Cosmic fluctuations in the early Universe

**Cosmic sources**

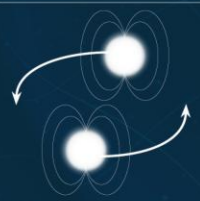


Supernova

Pulsar

Compact object falling onto a supermassive black hole

Merging supermassive black holes



Merging neutron stars in other galaxies

Merging stellar-mass black holes in other galaxies

Merging white dwarfs in our Galaxy

#lisa

ESA | NASA lisa

# The LISA Satellites

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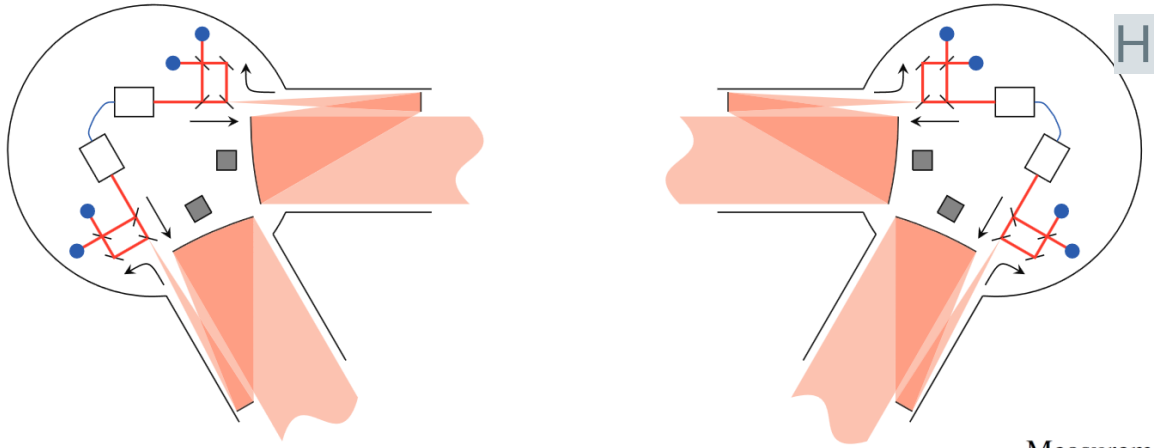
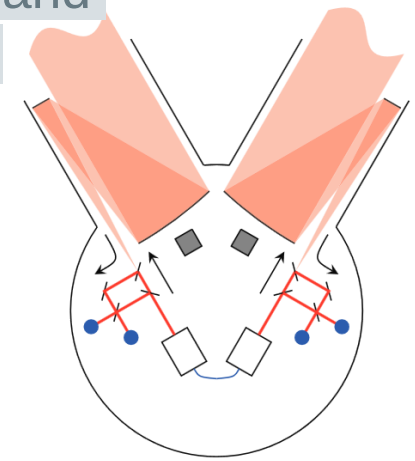
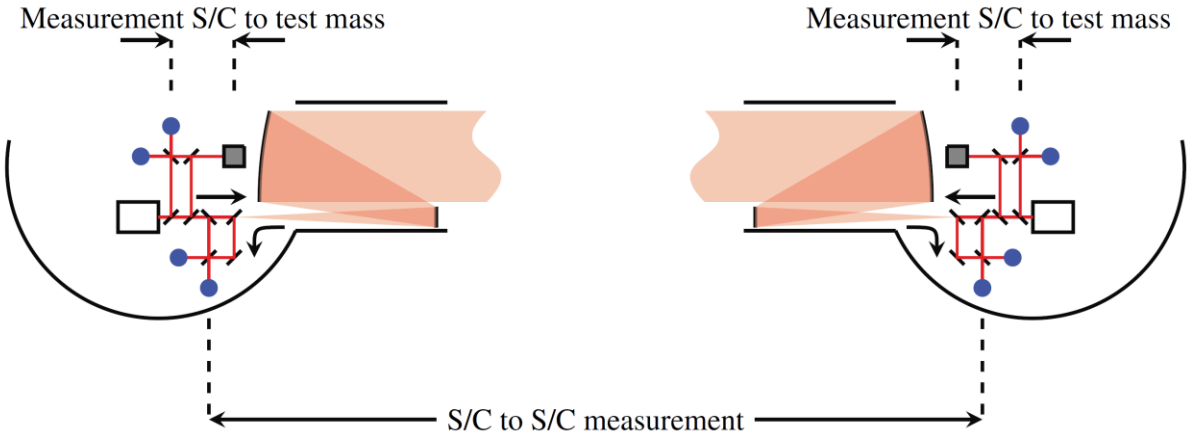


Heterodyne interferometry

Unequal arm lengths and laser frequency noise



Split interferometry




Jennrich, 2010

# LISA Interferometric Metrology System

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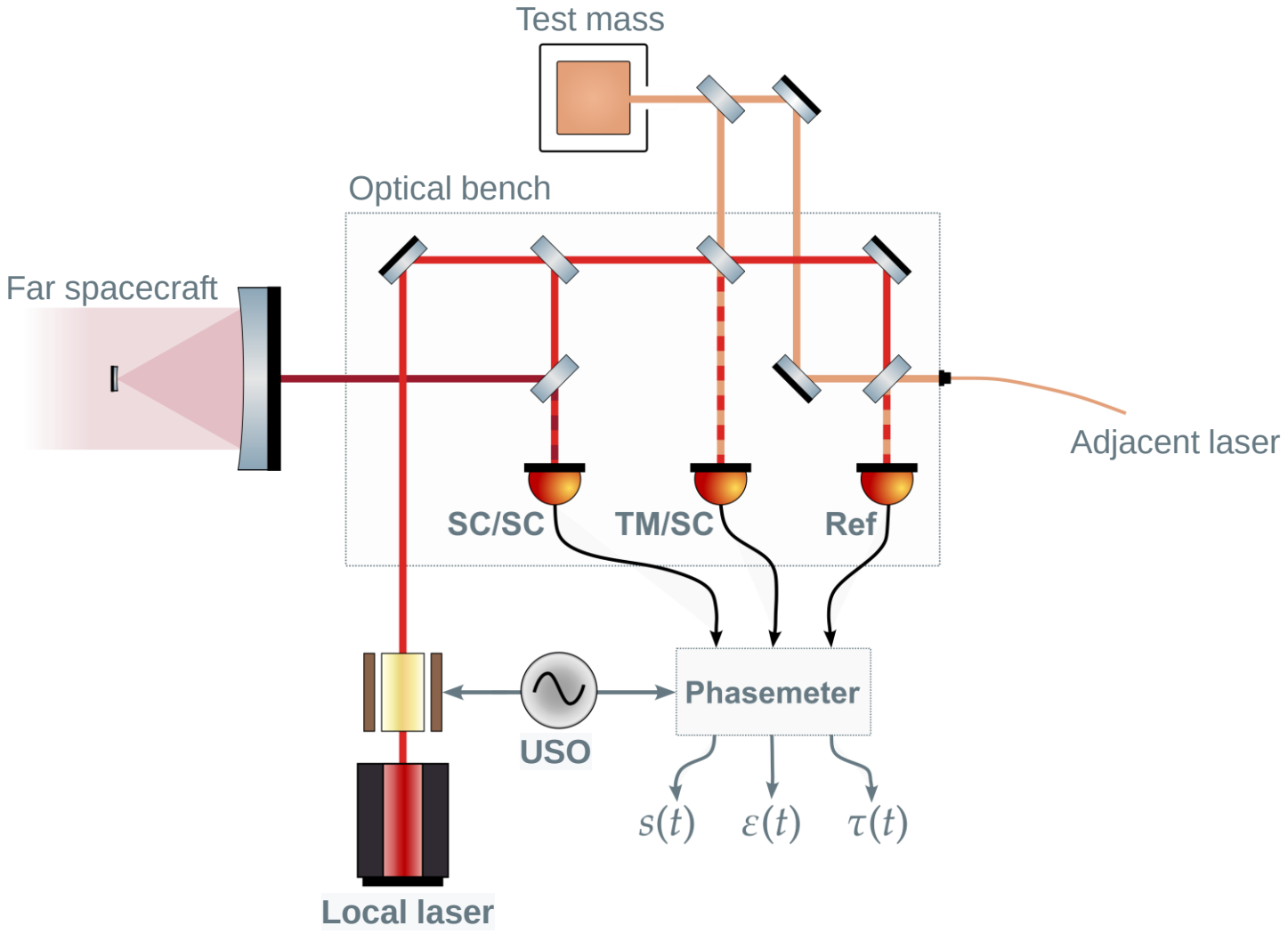


**USO** – Ultra Stable Oscillator
$s(t)$ – science beat note
$\varepsilon(t)$ – test mass beat note
$\tau(t)$ – reference beat note

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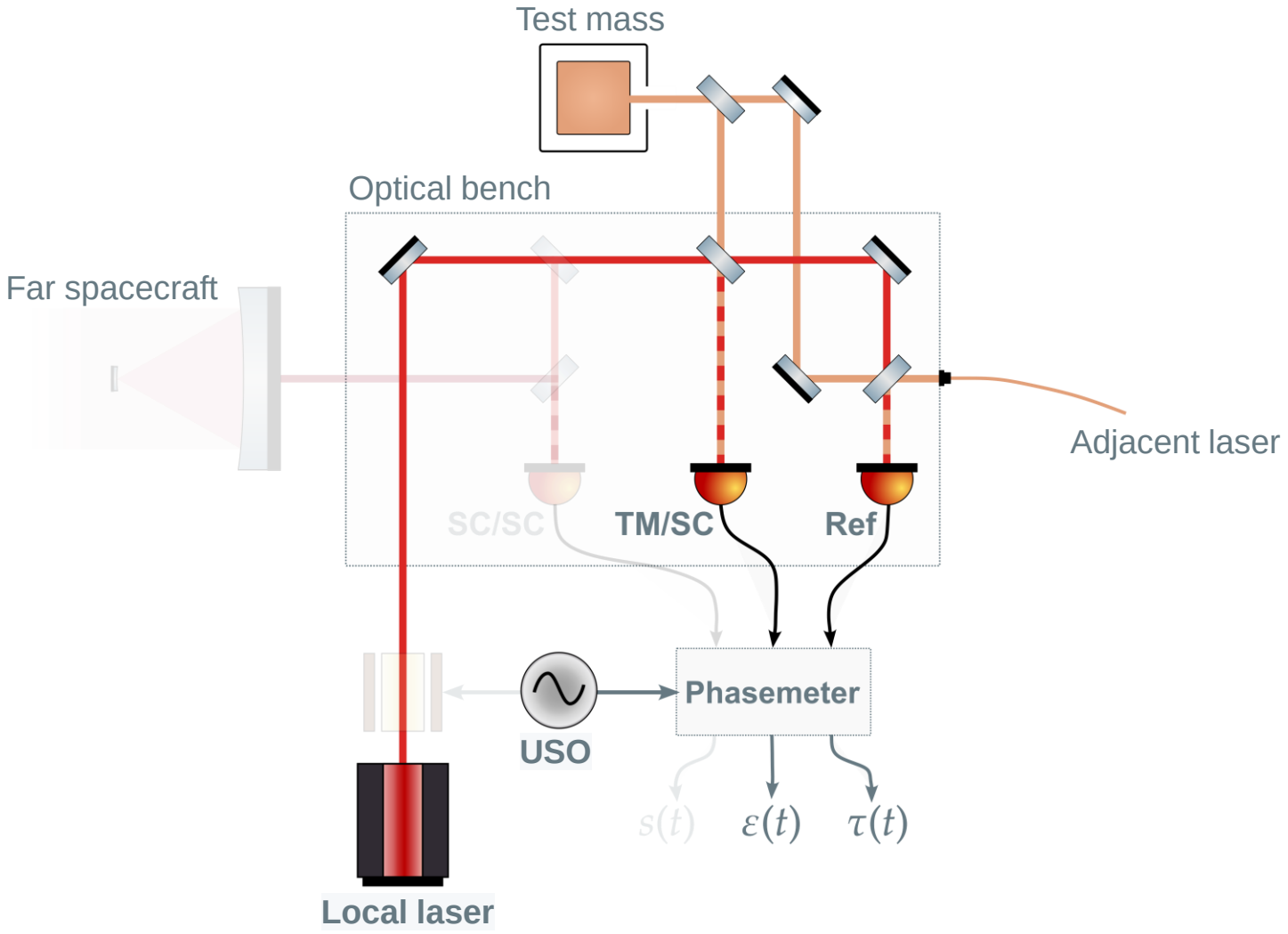


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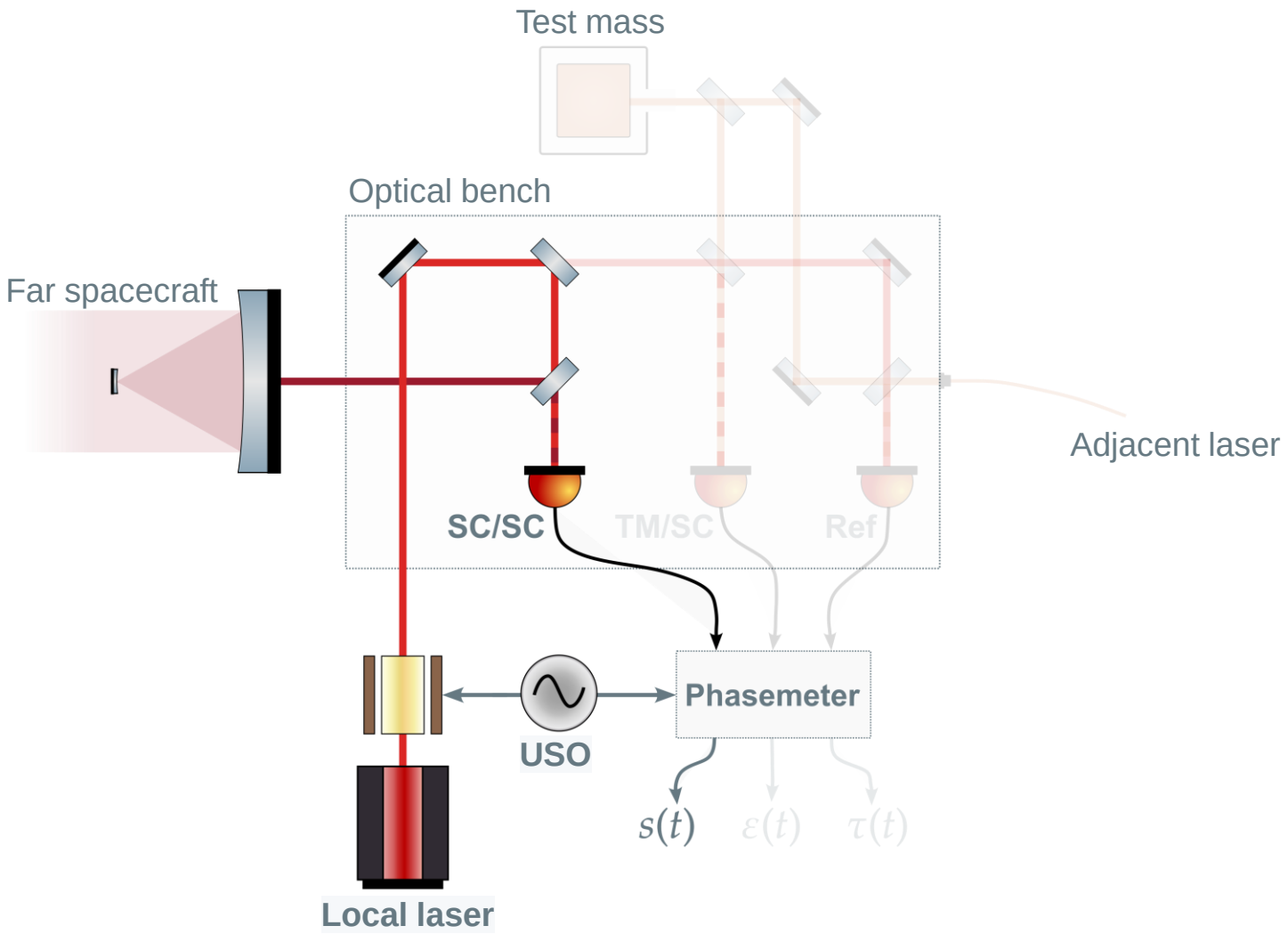


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# Laser Noise Reduction via TDI

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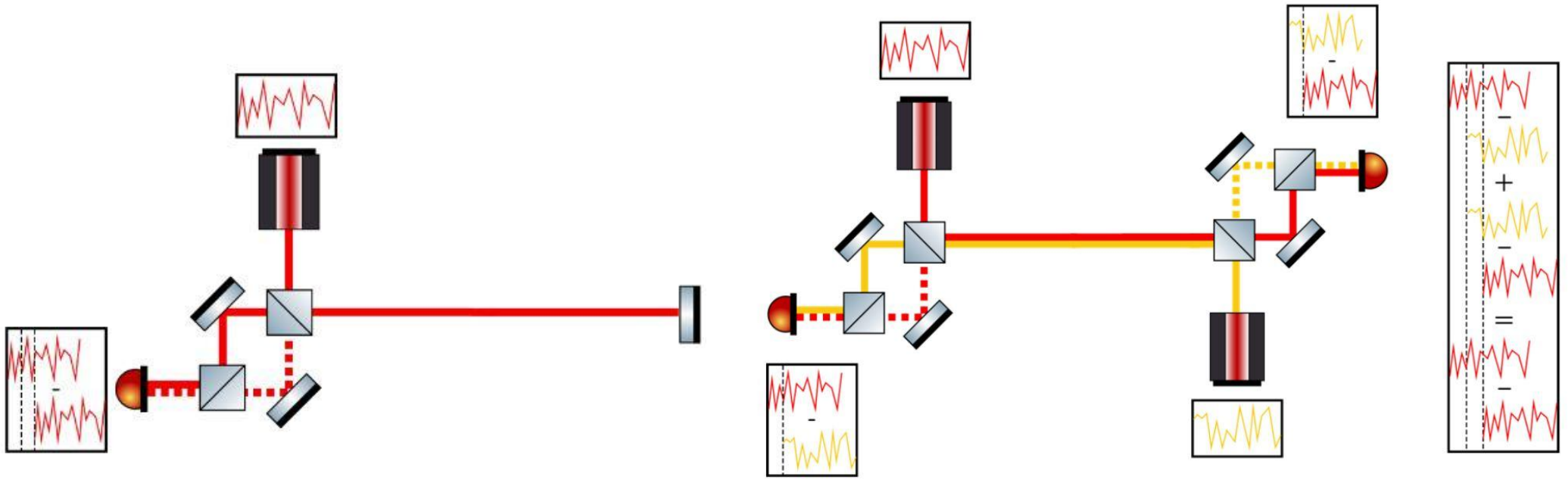
Time Delay Interferometry (TDI) is a cluster of methods to construct virtual equal arms in post-processing.



Transponder signal

Synthesized transponder signal

Hartwig, 2021

# Clock Noise Reduction

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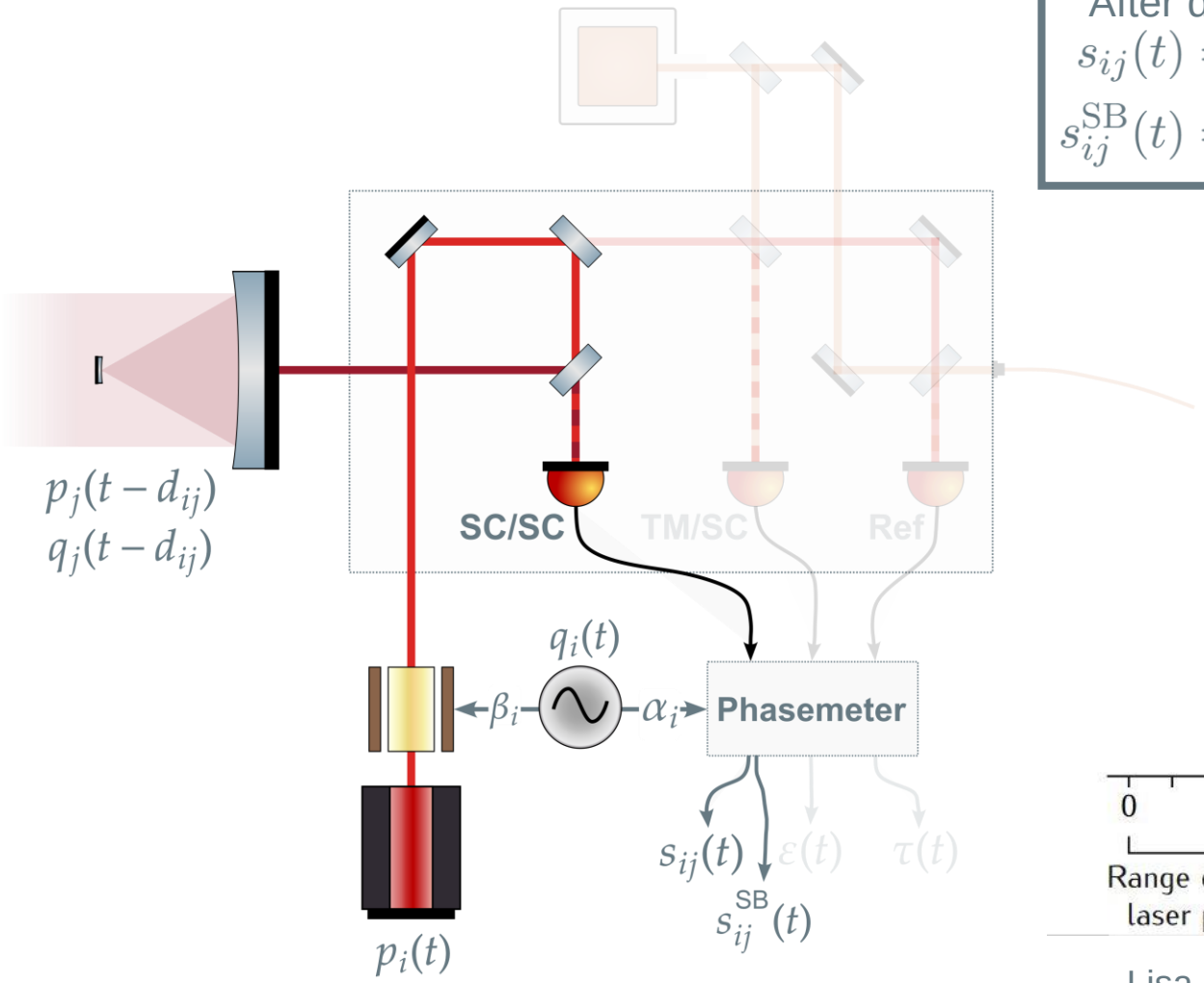
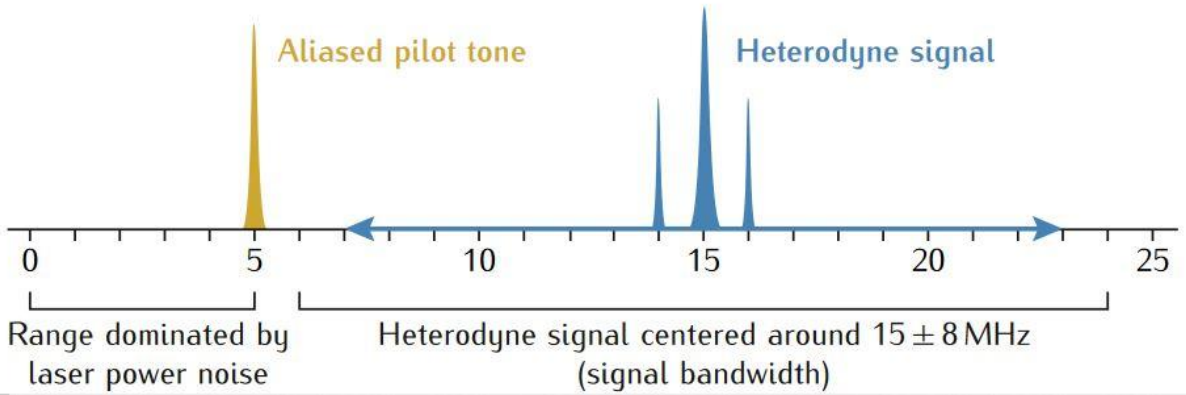
After demodulation, considering laser noise and clock jitter:

$$s_{ij}(t) = p_i(t) - p_j(t - d_{ij}) + \alpha_i q_i(t)$$

$$s_{ij}^{\mathrm{SB}}(t) = p_i(t) - p_j(t - d_{ij}) + \beta_i q_i(t) - \beta_j q_j(t - d_{ij}) + \alpha_i^{\mathrm{SB}} q_i(t)$$




Lisa metrology system-final report, 2014

# Previous Experiment

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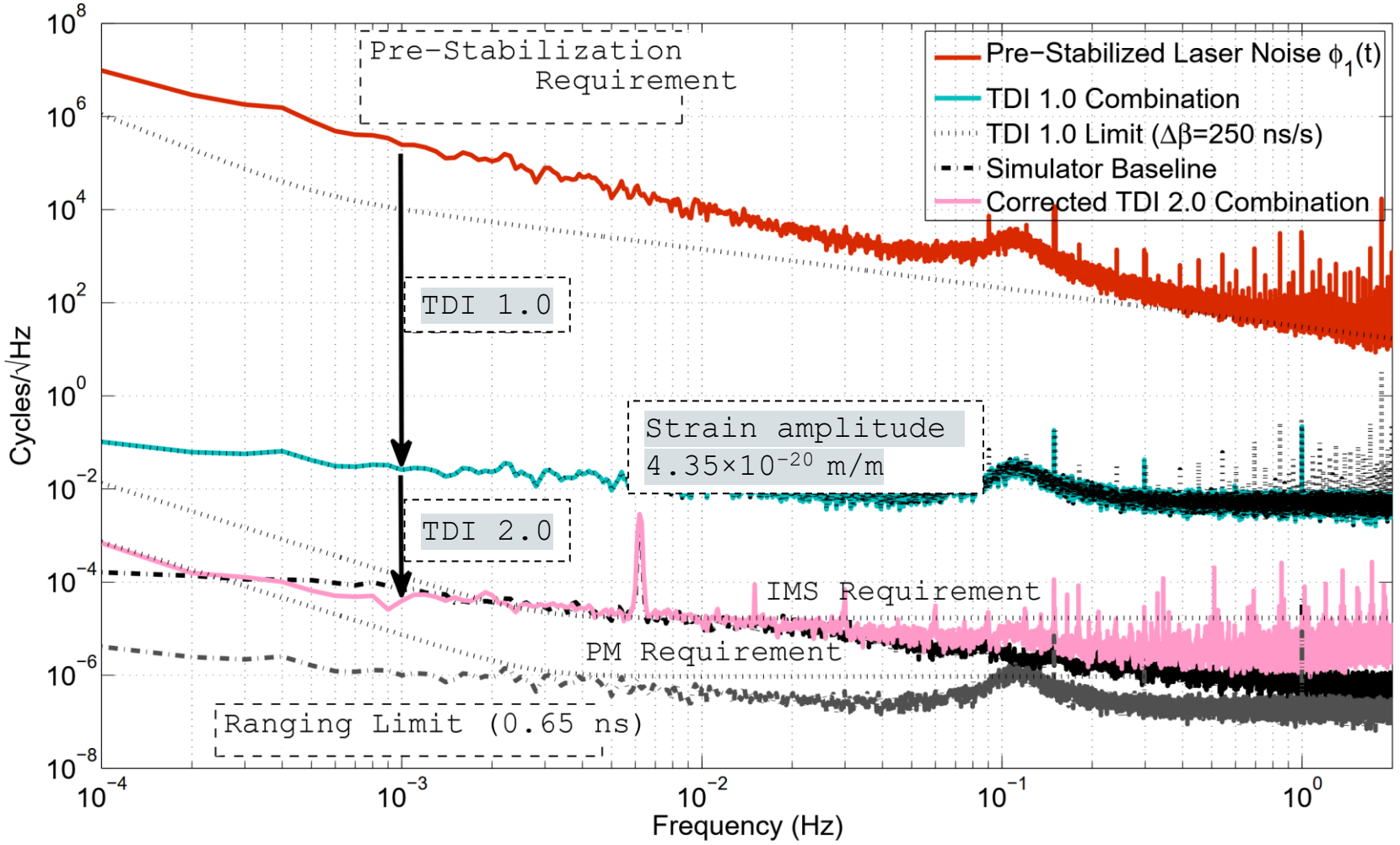


Mitryk, 2012

# miniLISA

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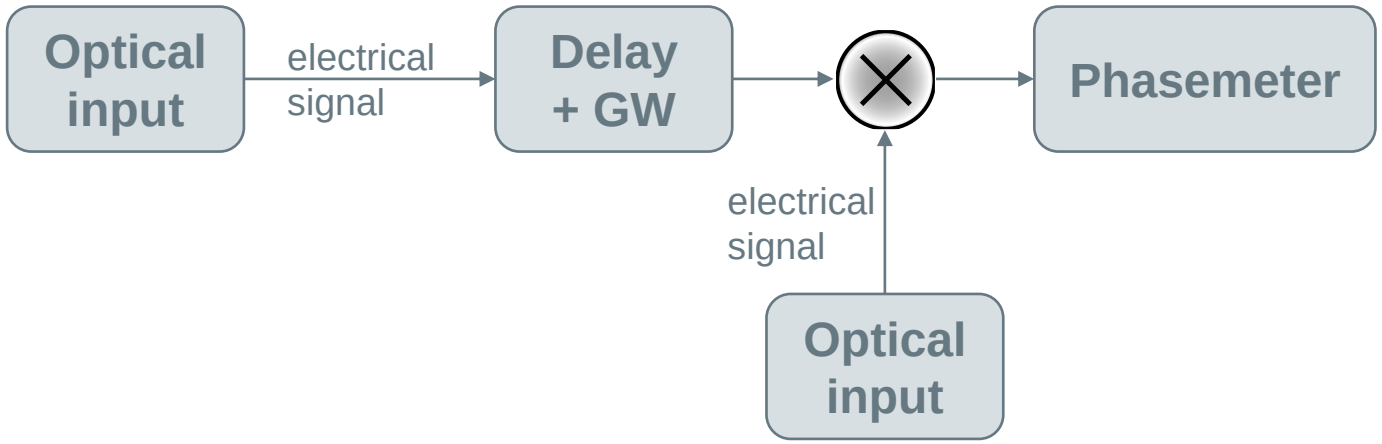
miniLISA is a hardware testbed that aims to simulate LISA's signal chain and test whether we can recover a gravitational wave signal from a realistic, noisy system.

To start with, we want to test the combination of second generation TDI and the clock noise removal post-processing methods on experimental data.

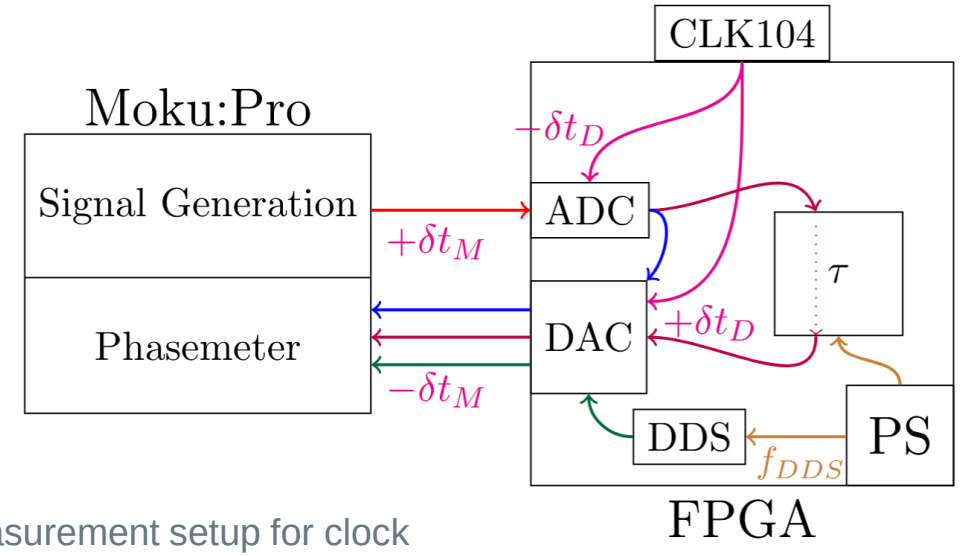
miniLISA could also offer a substitute to modelled noise sources included in current data analysis.



# Current Status

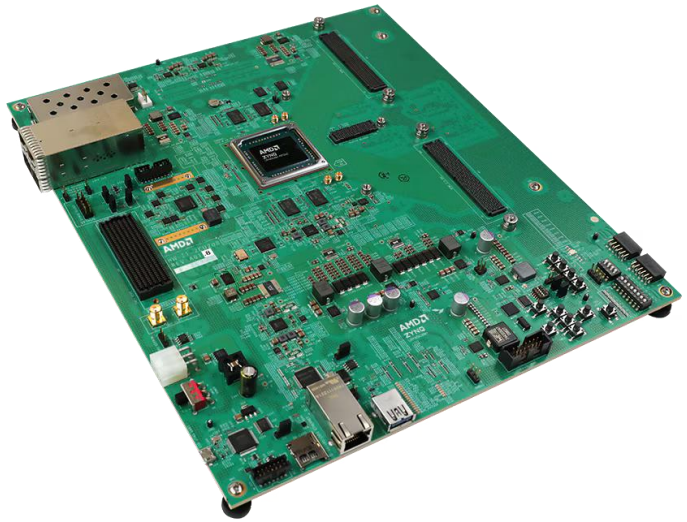
A fully electronic implementation of the interferometry system together with a delay and gravitational wave injection has already been developed and is being tested.

- Time varying delays
- Doppler shifts for both the carrier and sidebands
- Gravitational wave injection




Measurement setup for clock jitter analysis in the delay line

Ferguson, 2025



AMD Zynq™ UltraScale+™ RFSoC ZCU208 Evaluation Kit

# One-arm Phase Measurement

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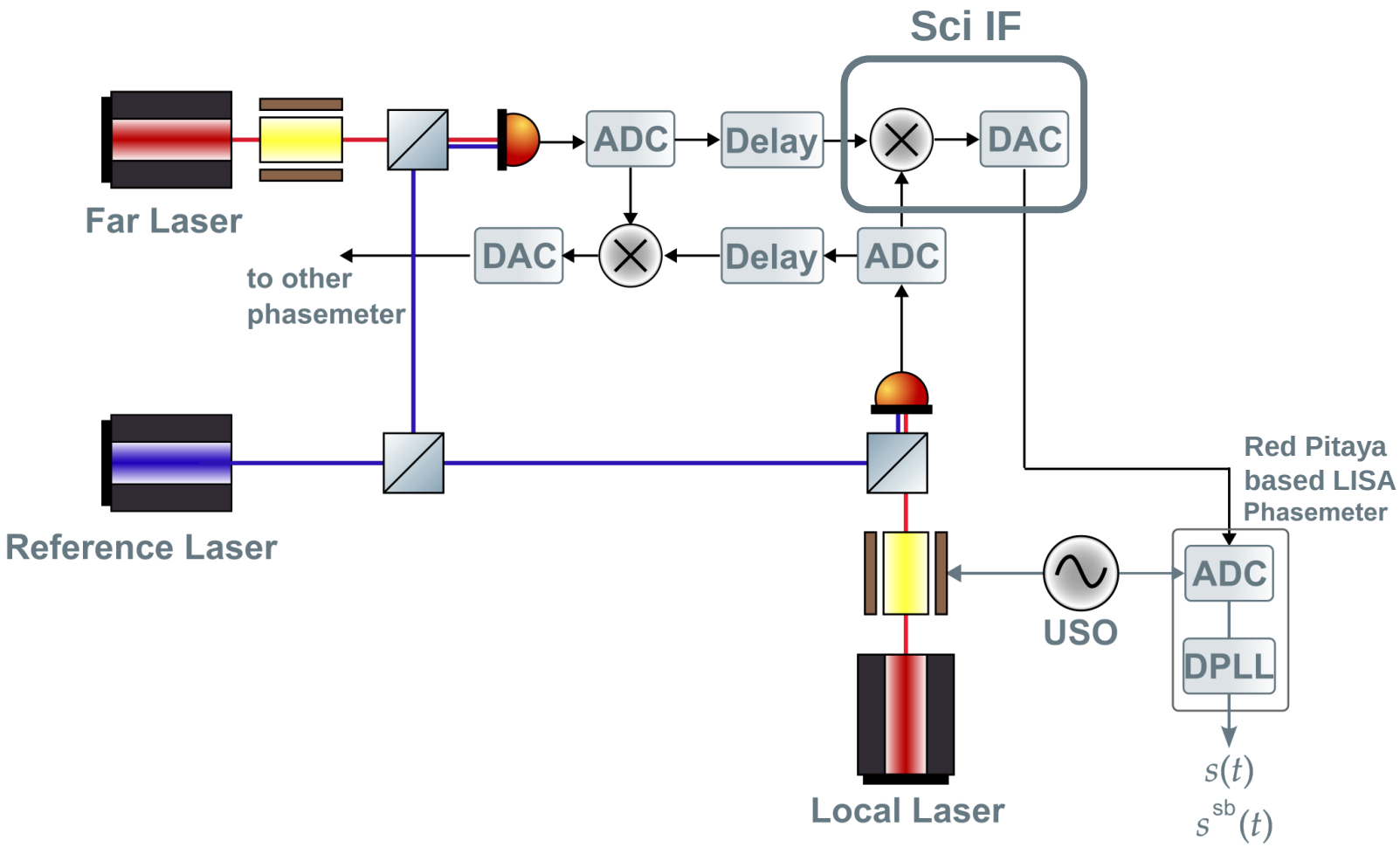
Set up for generating one LISA-like arm link.



# Two-arm Testbed

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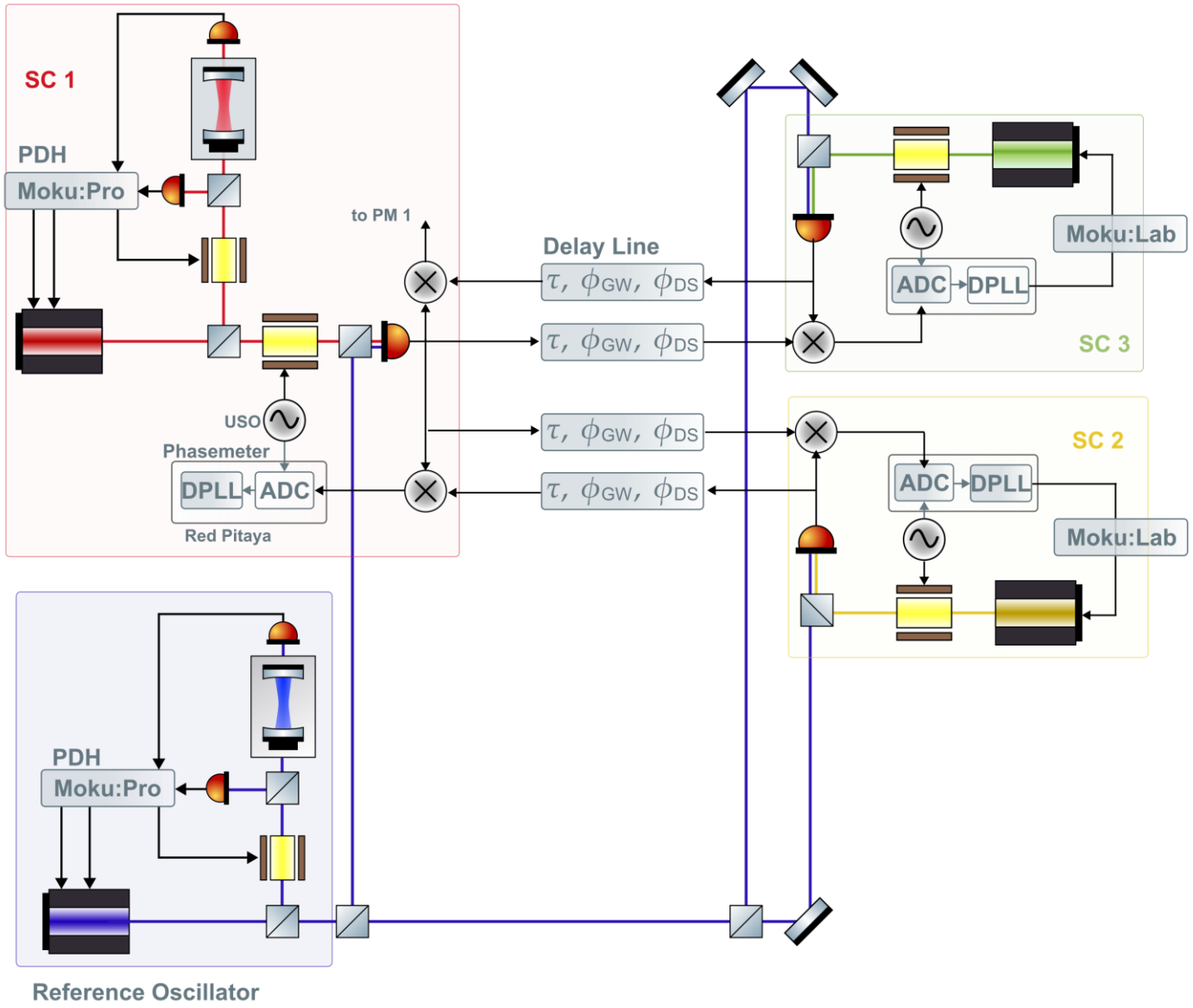

# Possible Additions

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- Third arm connection
  - for better peremeter estimation and data analysis
- More elaborate clocking system
  - To better replicate the clock noise removal in LISA


Thank you for listening!