Laser Frequency Stabilisation and Interferometer Path Length Differences on LISA Pathfinder

Sarah Paczkowski on behalf of the LISA Pathfinder collaboration

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background

interferometer as our measurement stick

$$\Delta s = \frac{\lambda}{2\pi}\Delta\phi$$

rewrite using

$$c = \lambda f$$

path length difference

phase noise

$$\delta\phi = 2\pi\frac{\Delta s}{c}\delta f$$

frequency fluctuations

background

path length difference or arm length mismatch

phase noise

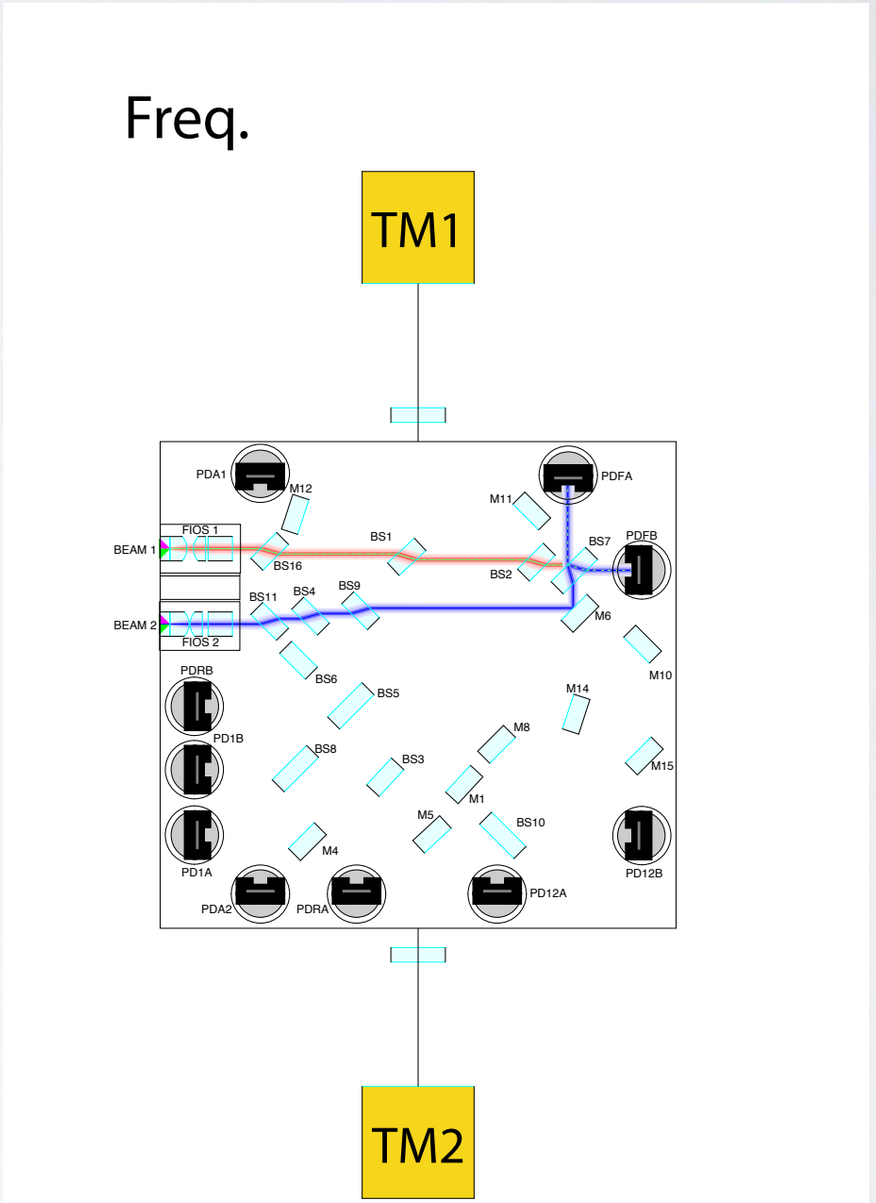
$$\delta\phi = 2\pi \frac{\Delta s}{c} \delta f$$

frequency fluctuations

- laser frequency noise is important because
  - with a non-zero path length difference, laser frequency noise couples into our measurement
- how to measure it: with a dedicated interferometer!

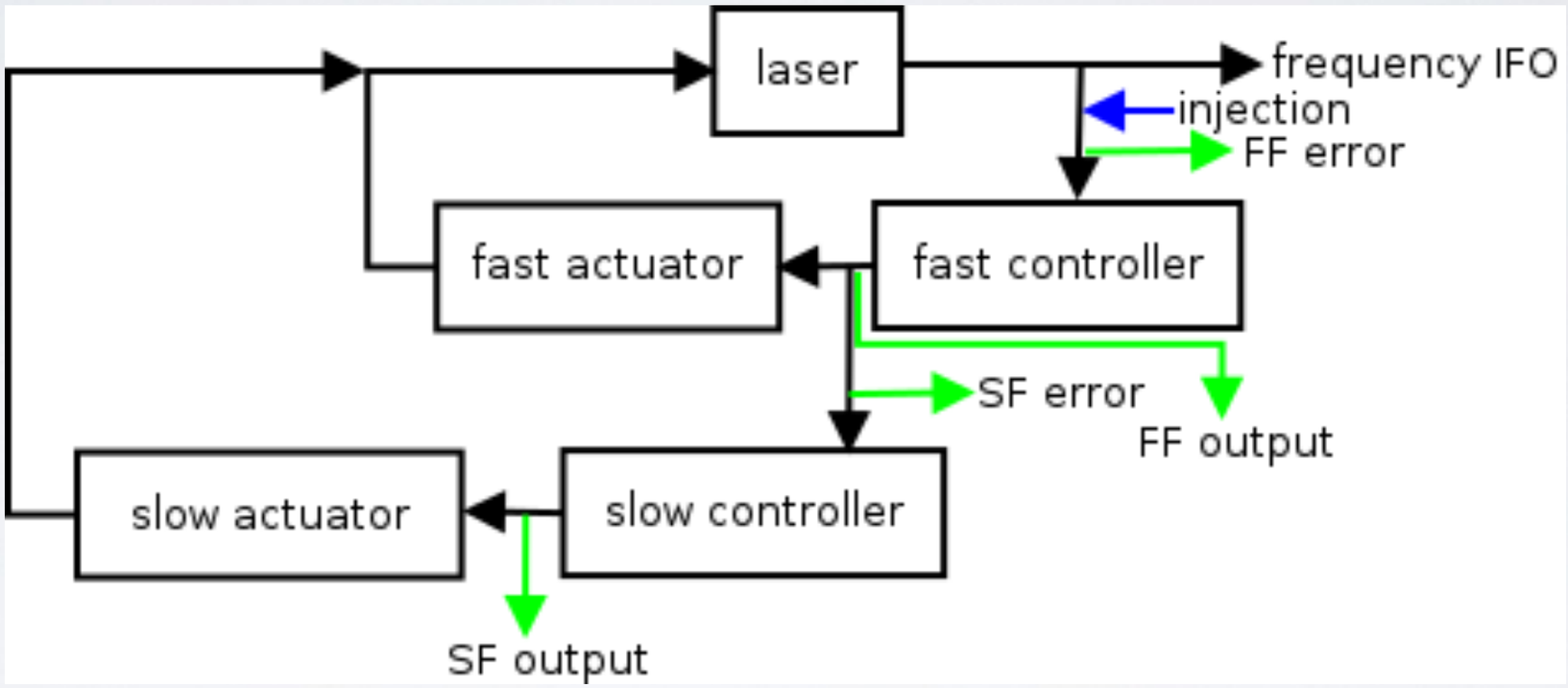
frequency IFO

- total: 4 interferometers (IFO) on LPF optical bench (OB)
- frequency interferometer allows us to measure the laser frequency noise
- intentional path length difference of 0.3821m in optical fibres before OB
- input to laser frequency control loop



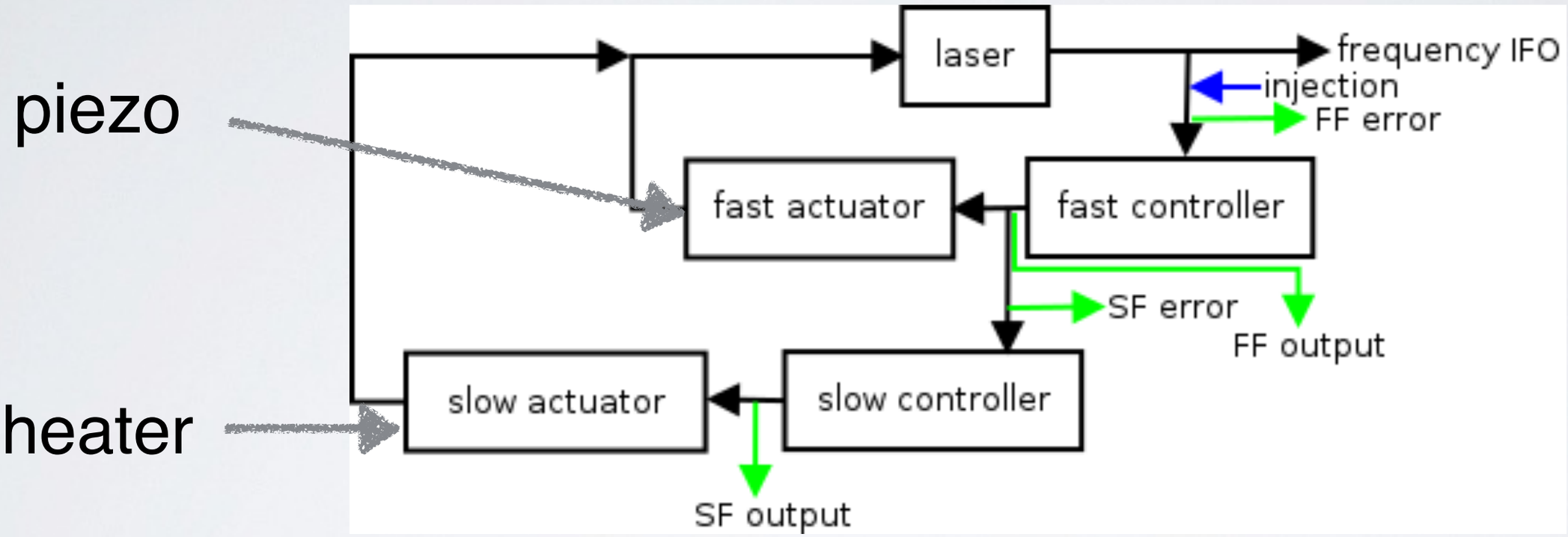
picture courtesy of ASD & IGR

laser frequency control loop(s)



- nested control loop
- implemented at 100 Hz inside data management unit

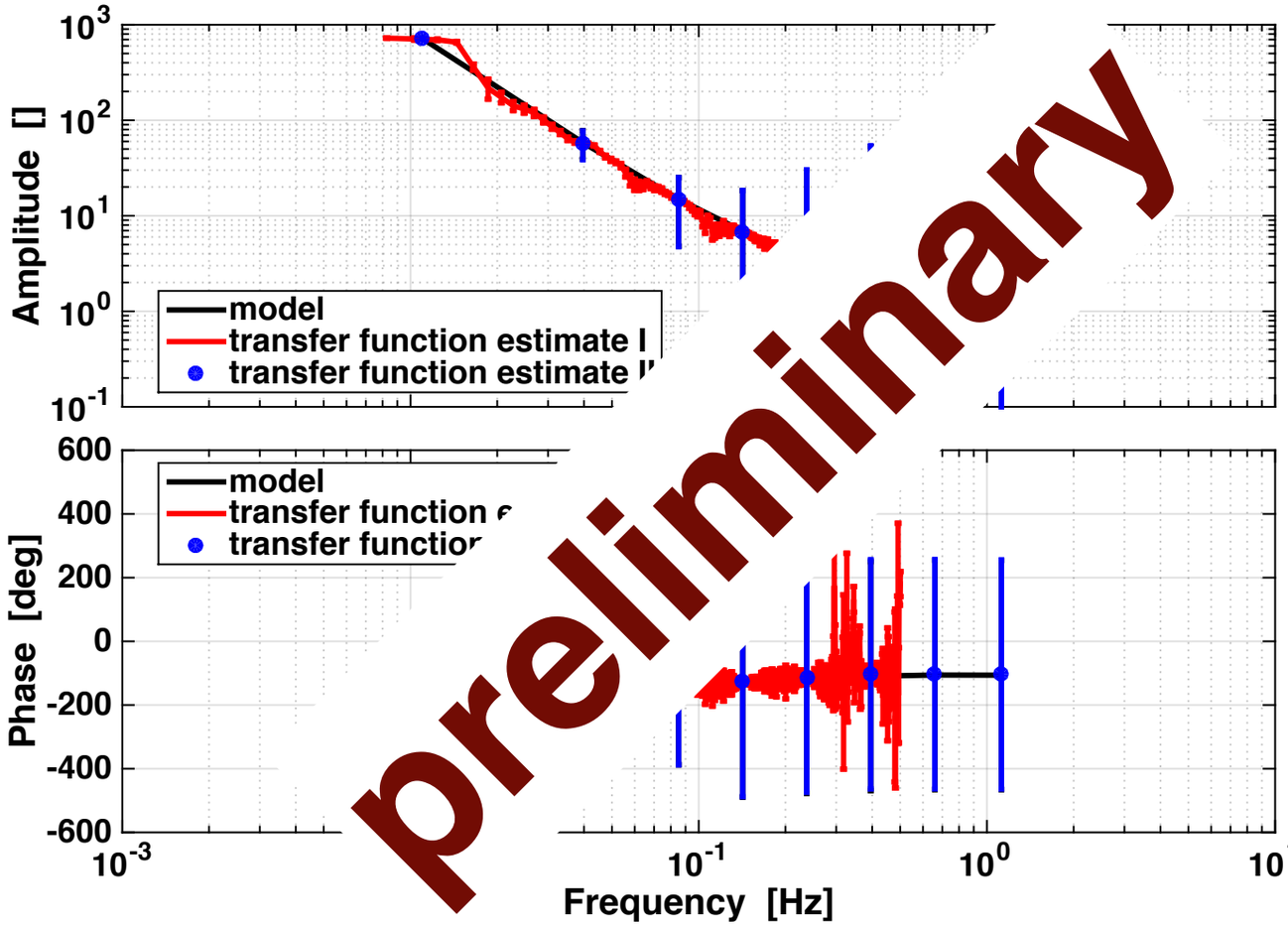
laser frequency control loop(s)



- nested control loop
- implemented at 100 Hz inside data management unit

loop characterisation experiment

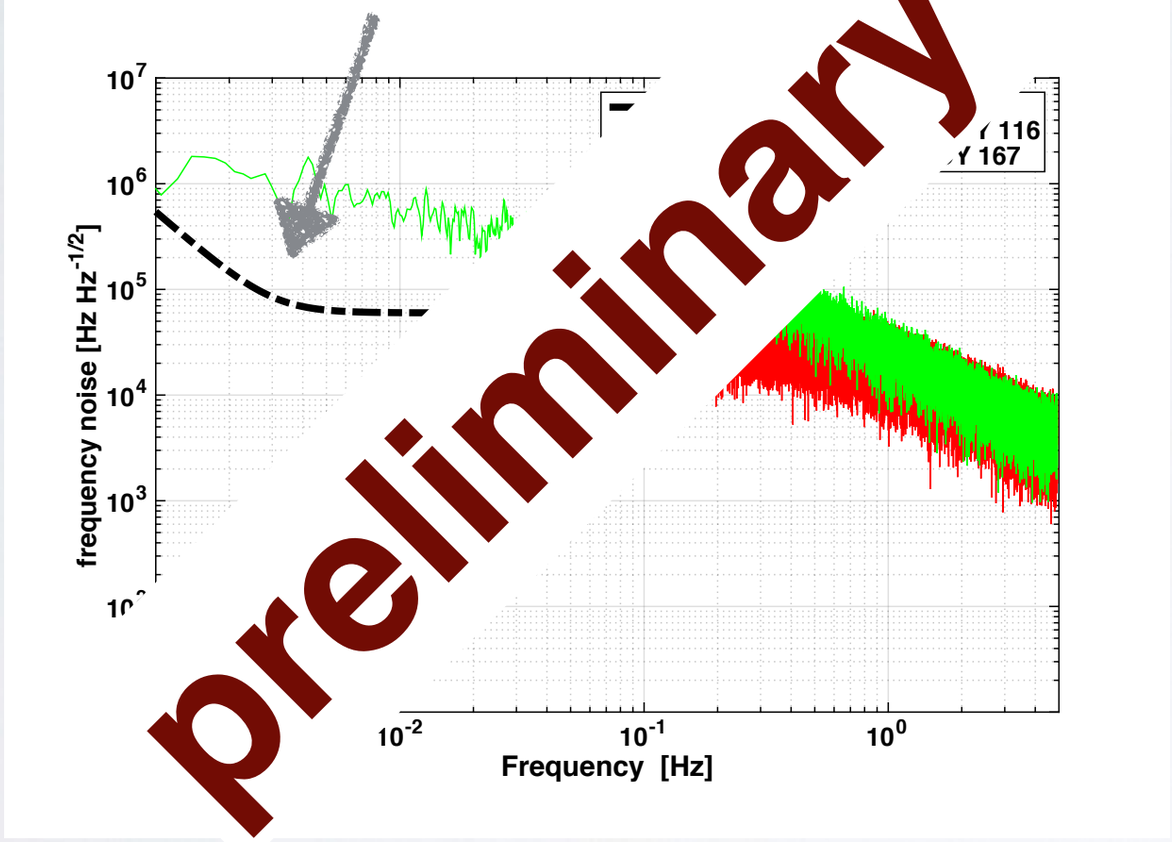
- measured either only at injection frequencies (transfer function estimate II) or including also the noise (transfer function estimate I) at all frequencies in between injection frequencies
- model with flight model test campaign parameters
- unity gain frequency Hz & phase margin



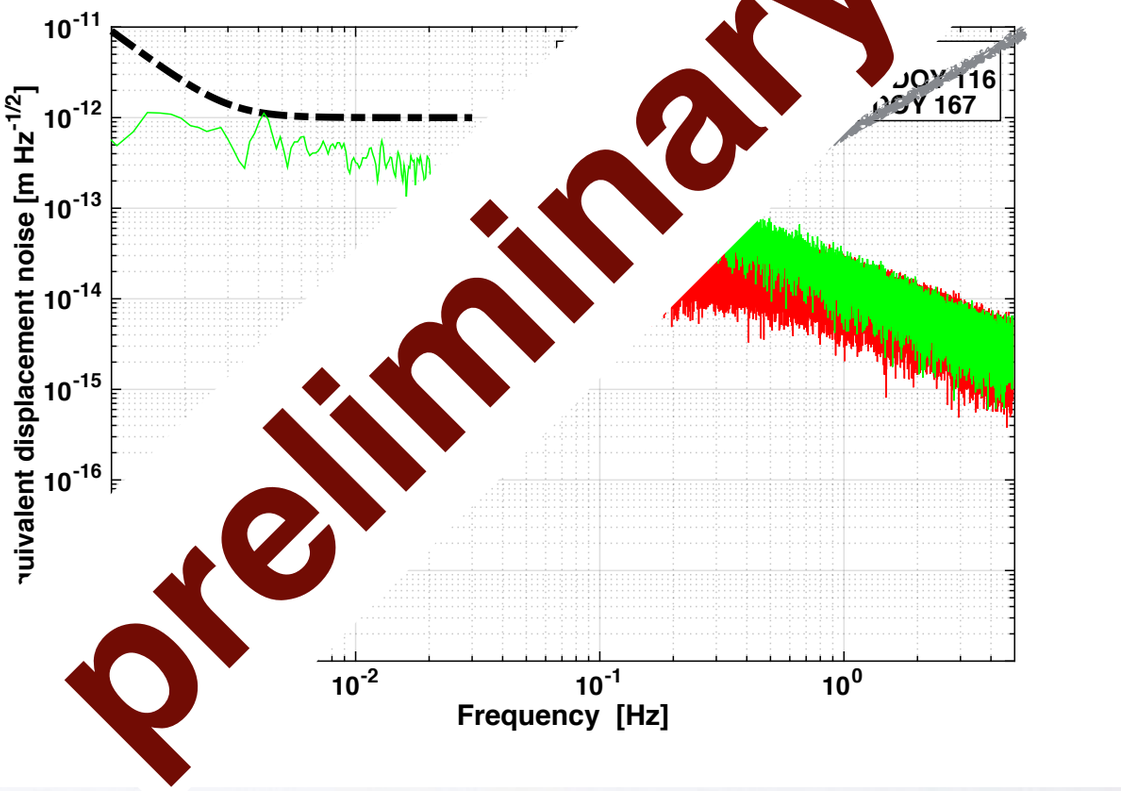
open - loop transfer function results from DOY 164

measured frequency noise

derived before OB build using 1pm req. & pessimistic 1cm mismatch assumption

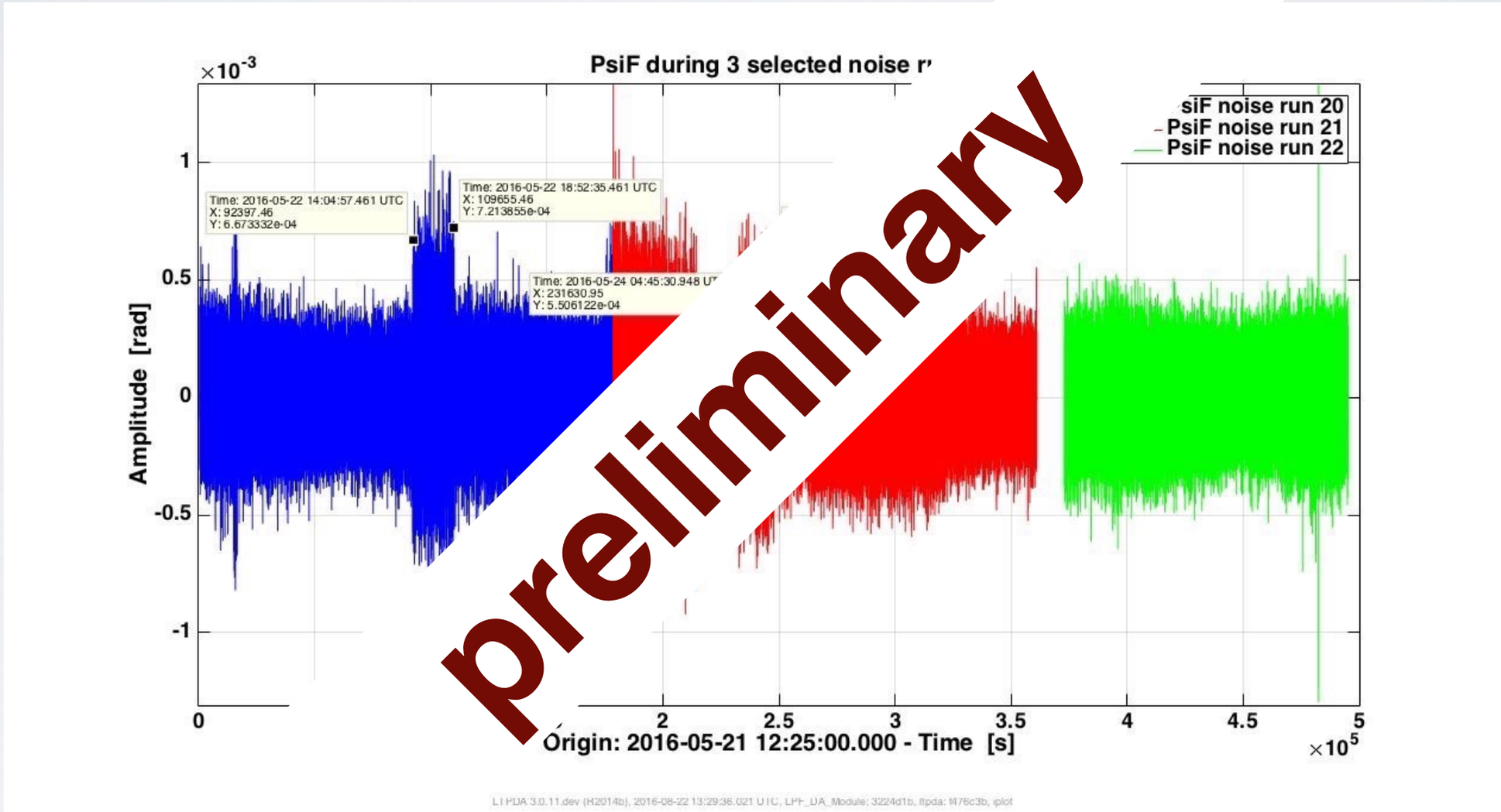


path length noise achieved with estimated mismatch



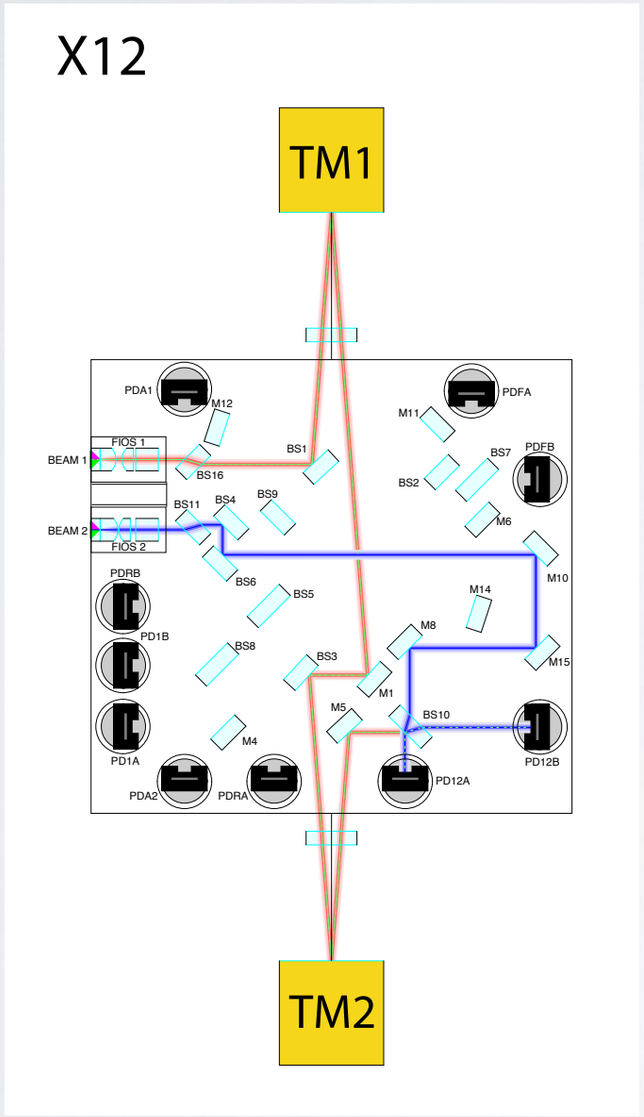
- fulfil frequency noise requirement with stabilisation
- due to small arm length difference, displacement requirement fulfilled in both cases

different levels of frequency noise



- obse e two different levels
- systematic analysis pending

arm length mismatch



picture courtesy of ASD & IGR

$$\delta\phi = 2\pi \frac{\Delta s}{c} \delta f$$

path length difference

frequency fluctuations

- arm length mismatch: path length of measurement and reference beam in same interferometer is not equal
- dependent on absolute TM positions
- 2 x mechanical mismatch ~ optical path length difference

arm length mismatch

- mismatch is interesting because
  - quality assessment of LPF Core Assembly (LCA)
  - parameter is needed to estimate the frequency noise contribution to total OMS noise
- in LPF: measure frequency noise (Freq IFO) & displacement in IFOs (o12 or o1 IFO)

→ deduce mismatch

arm length mismatch

two principles to calculate:

- transfer function
- noise minimisation

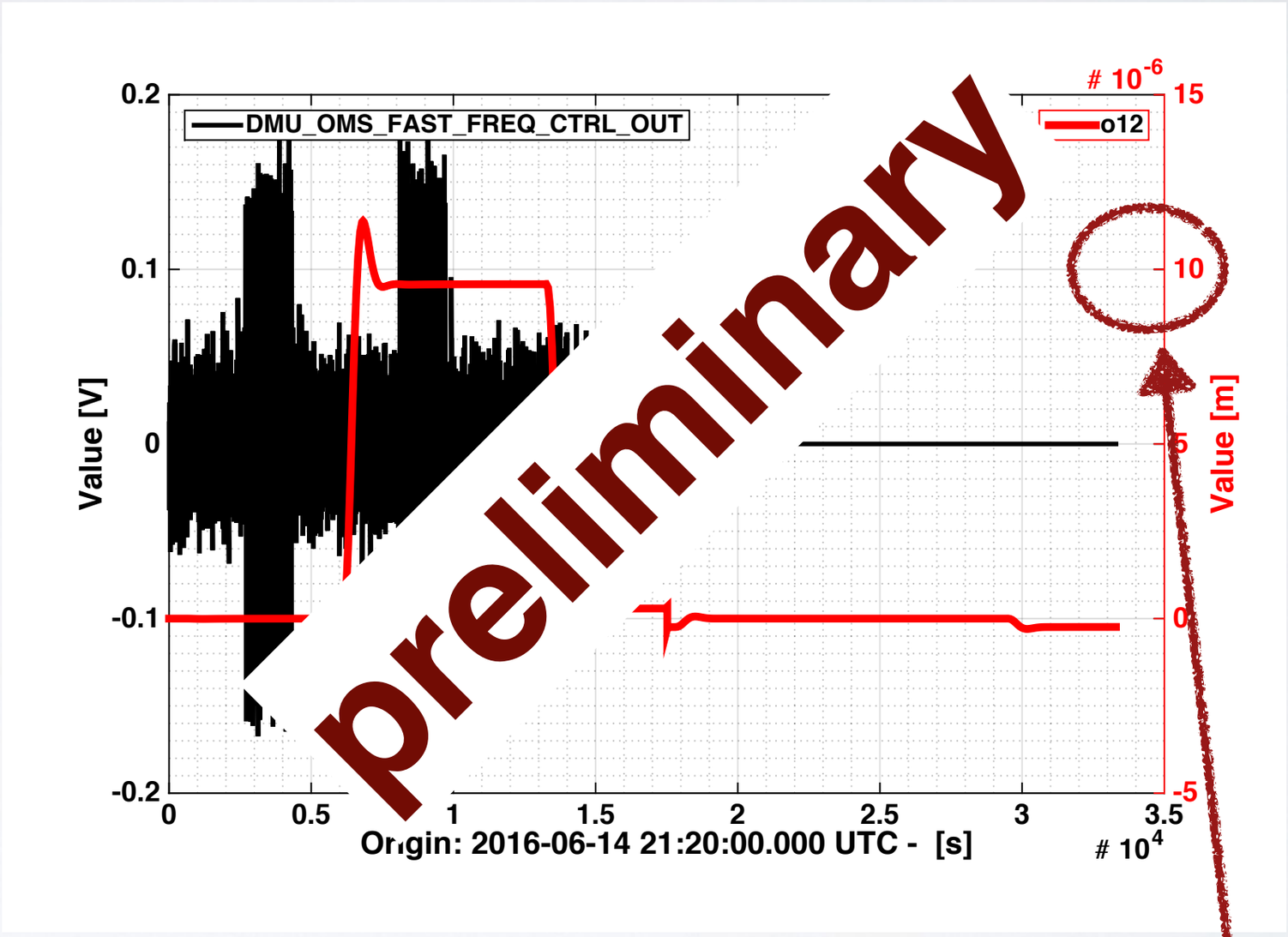
three ways to measure on LPF

1. arm-length mismatch experiment
2. from frequency loop characterisation experiment
3. during noise measurement

arm length mismatch experiment - design

steps of experiment:

1. injection @ nominal position
2. injection @ offset position
3. open-loop noise measurement



commanded offset: 9.576 um
TM 2 moved towards centre of satellite

arm length mismatch experiment - results

- **the measurements are consistent with each other**
- **we know the sign of the mismatch**
- expected: , measured: , agrees within errors of of the offset position
- the error at the offset position is larger because mismatch and thus coherence is smaller
- mismatch during noise measurement averaged over 5 min segments, worst case error estimate

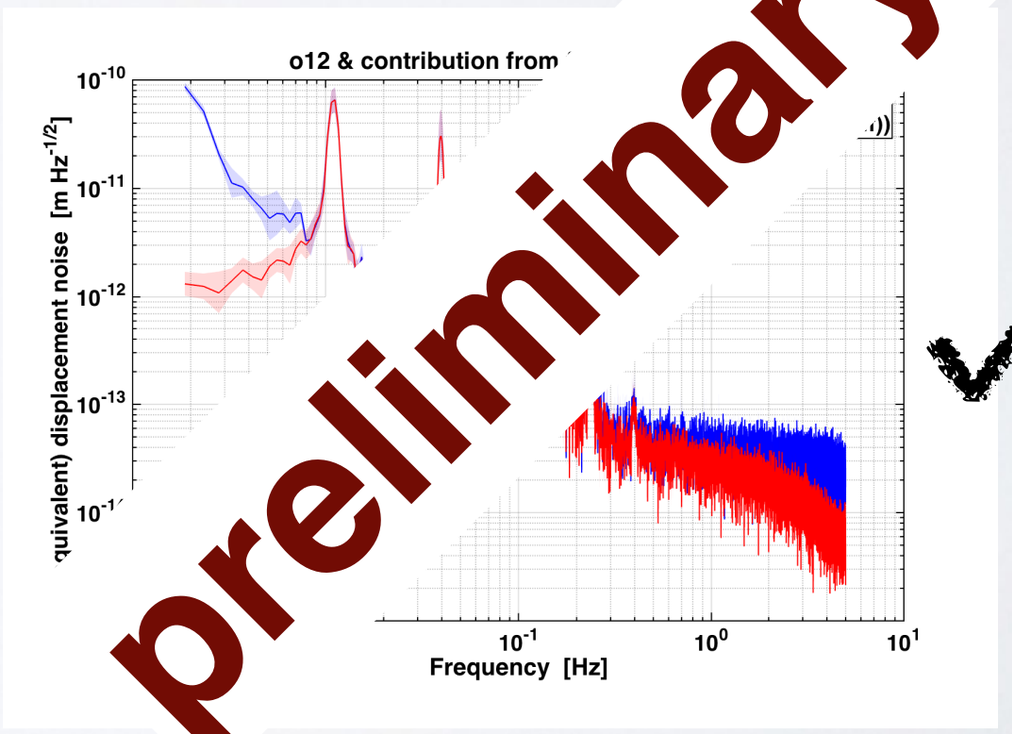
- result agrees to the estimates from the frequency characterisation experiment on DOY164:
- not inconsistent with ground measurement where OB was measured individually
- **well below the requirement of 1mm**

arm length mismatch over time

- **we want:** arm length mismatch estimate over noise runs
- **required:** TM motion low, high coherence between the channels
- **caveat I:** phase tracking is reset after every station keeping
- **caveat II:** accordance between the different methods and their errors

already in best case with injections, different implementations provide different errors

check: during injection measurement: equivalent displacement noise from frequency noise should explain t… peaks in o12:



contribution to total OMS noise

mismatch:

frequency noise relevant from

max ~
@

summary

- in an interferometer where the two beams travel not the same path length, frequency noise is relevant
- on LPF, laser stabilised with nested feedback control
- deduce the arm length mismatch in o12 IFO
- the integration of LCA is better than required