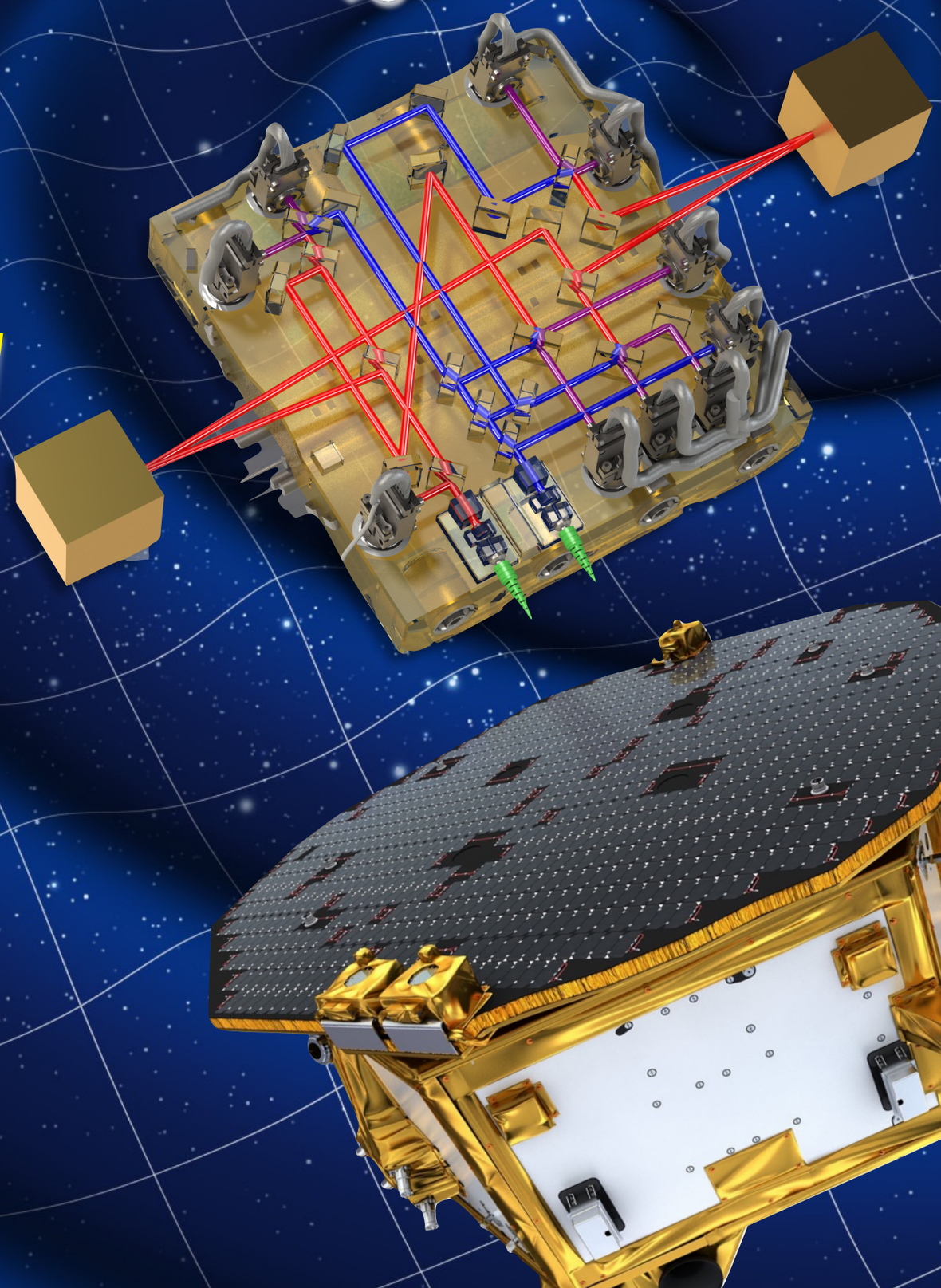
Albert Einstein Institute
Max Planck Institute for Gravitational Physics and
Leibniz Universität Hannover

lisa pathfinder

LISA Pathfinder

Optical Metrology at L1



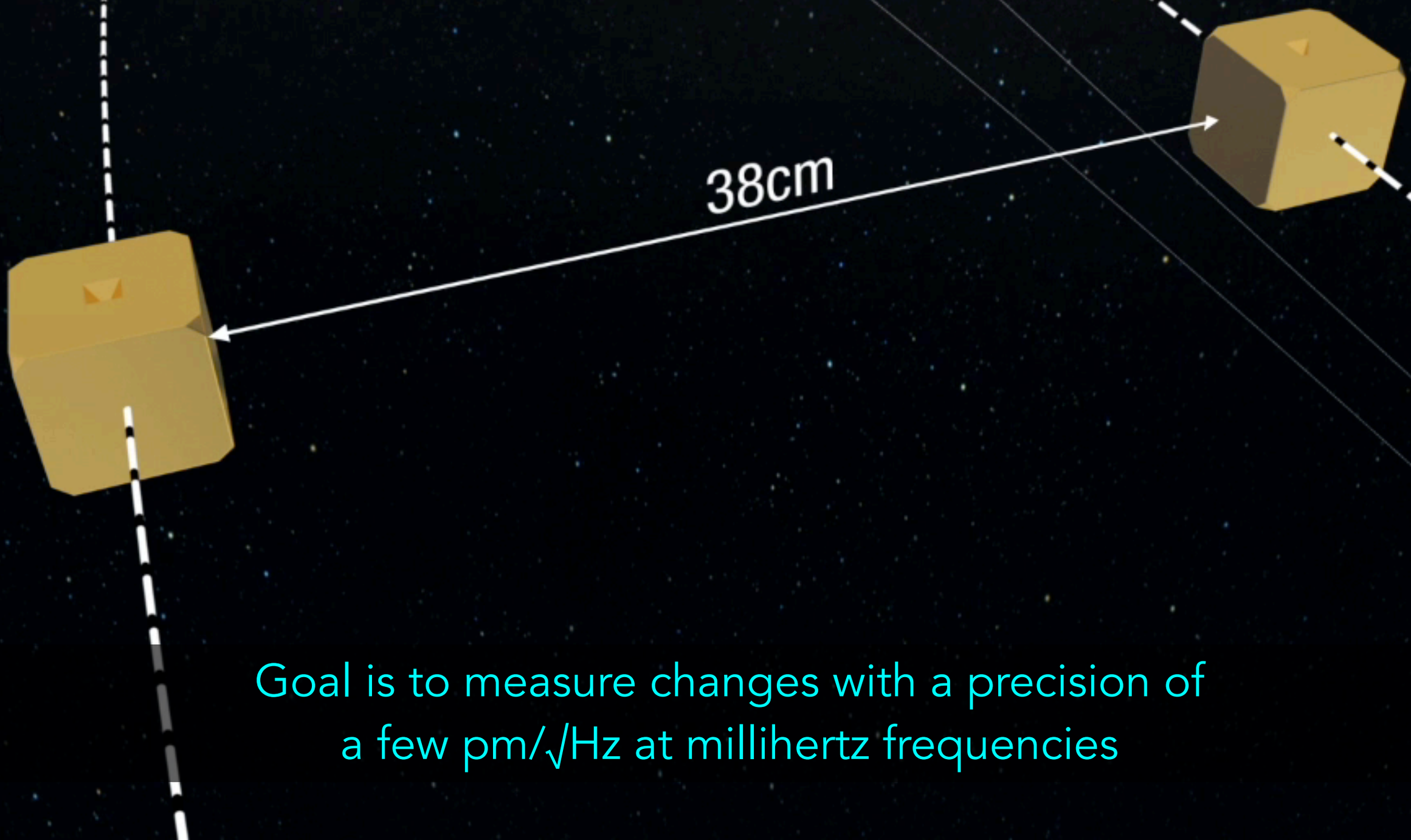
M Hewitson
for the LPF Team
LISA Symposium, Zurich
September 2016

Content

- OMS Introduction
- Commissioning
- Performance
- Noise budget
- Structural stability
- Long-term performance

The **O**ptical **M**etrology **S**ystem on LPF

Assess relative acceleration of test masses
by measuring their relative motion using an interferometer



Goal is to measure changes with a precision of
a few pm/√Hz at millihertz frequencies

The **O**ptical **M**etrology **S**ystem

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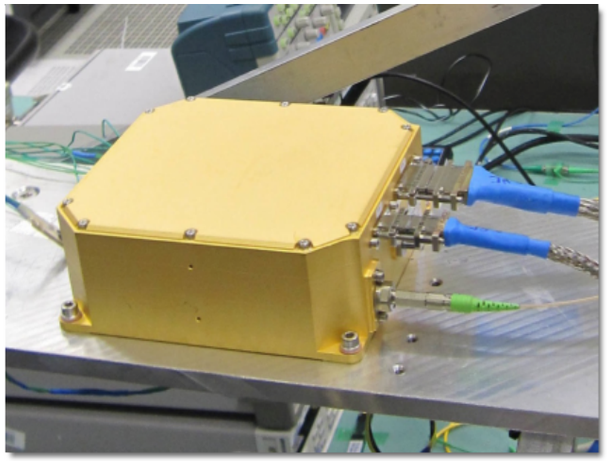
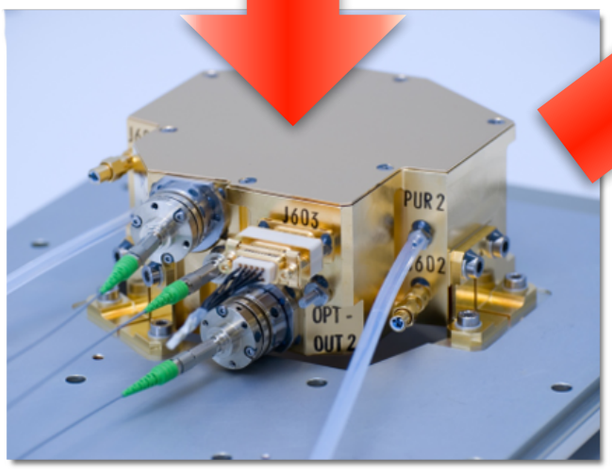
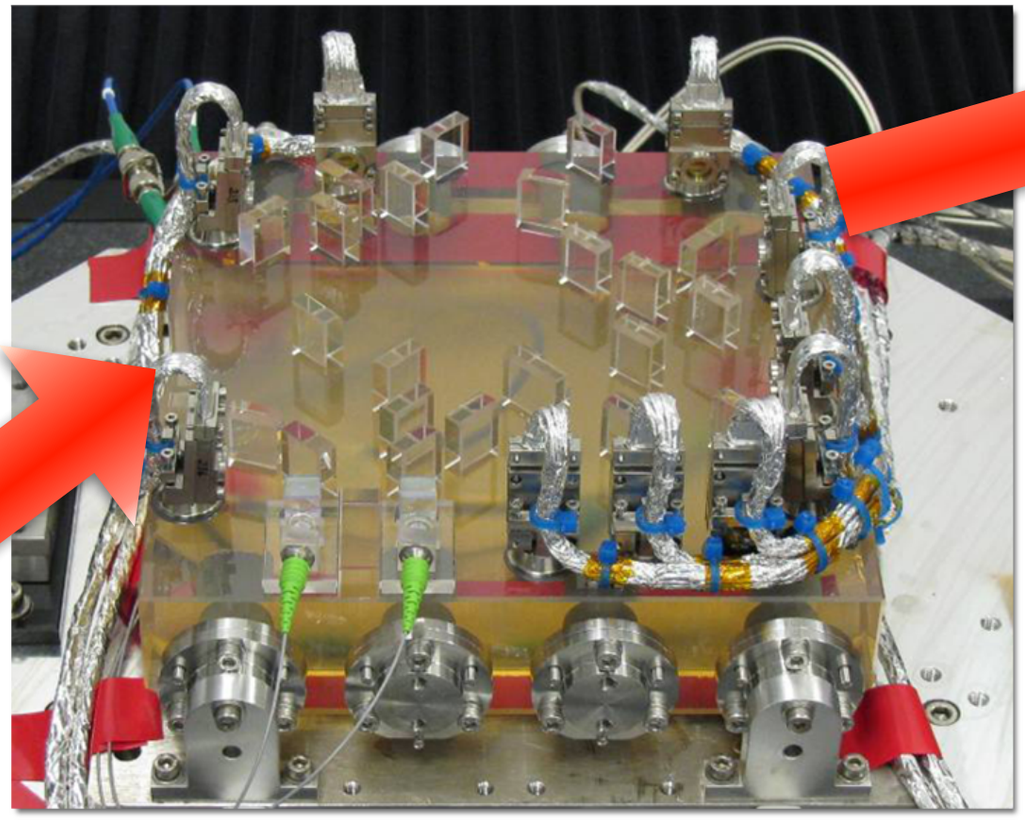


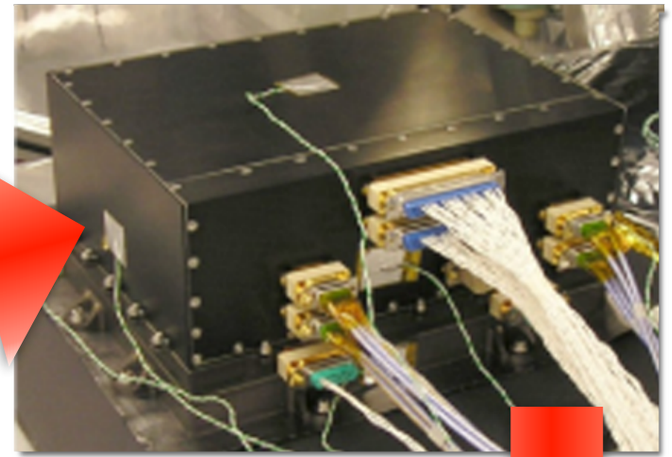
Reference Laser Unit



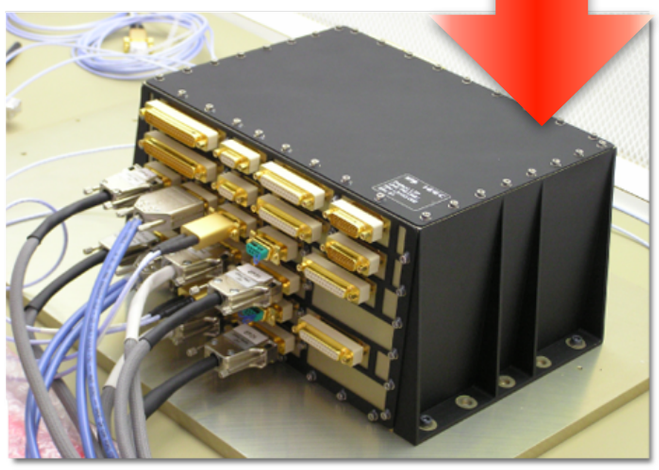
Laser Modulator



Optical Bench Interferometer



Phasemeter



Data Management Unit

Reference Laser Unit (RLU)

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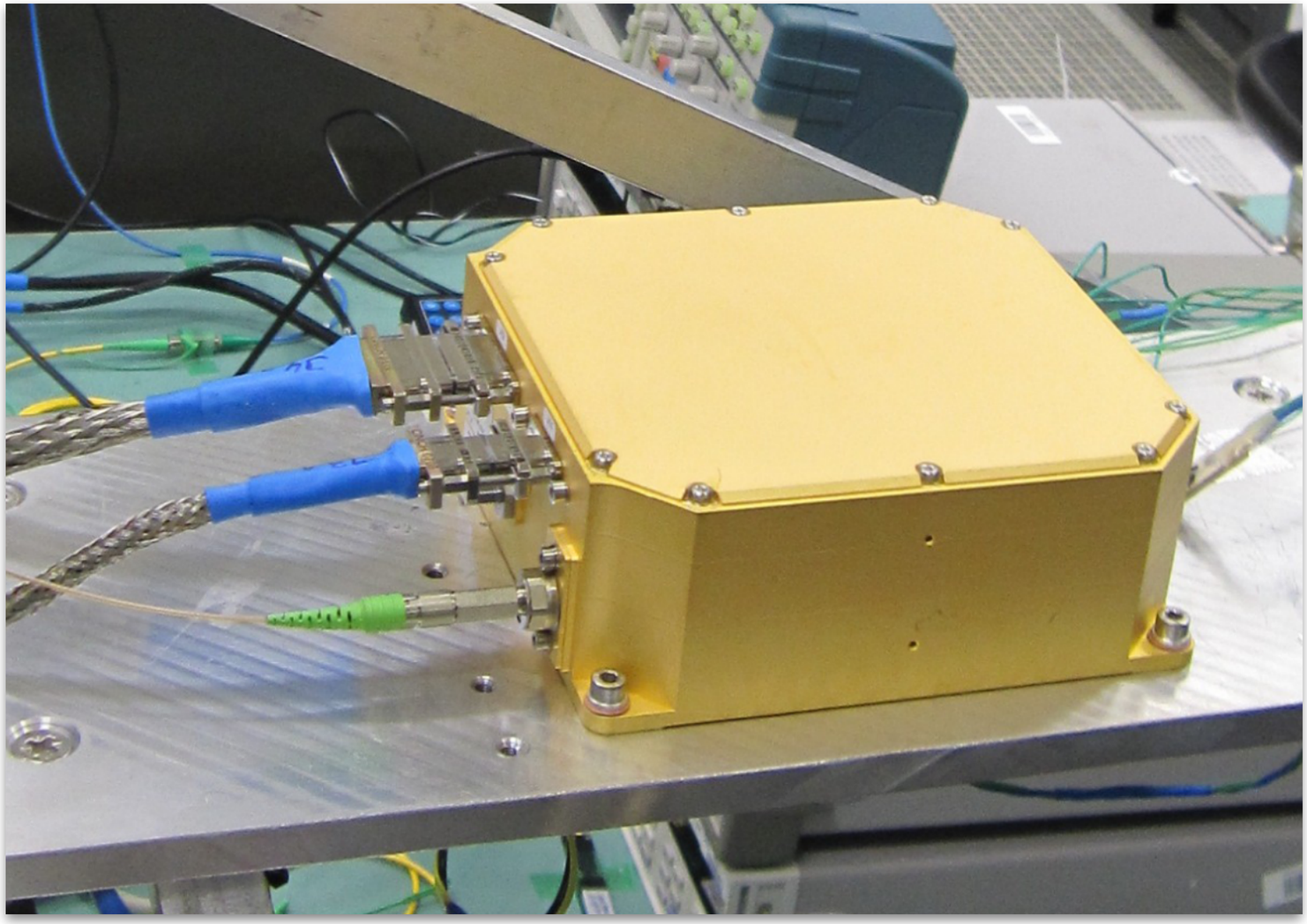
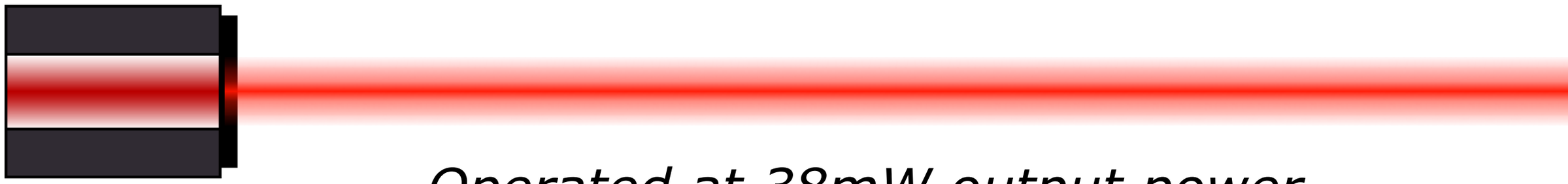
Nd:YAG laser

λ: 1064 nm

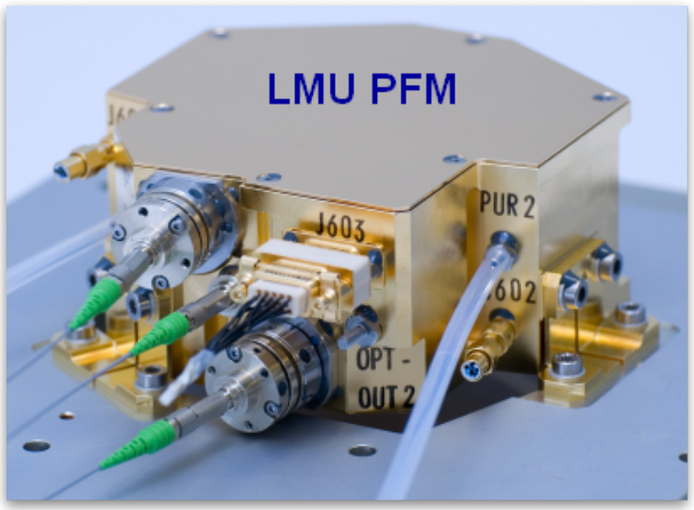
Power: 45 mW



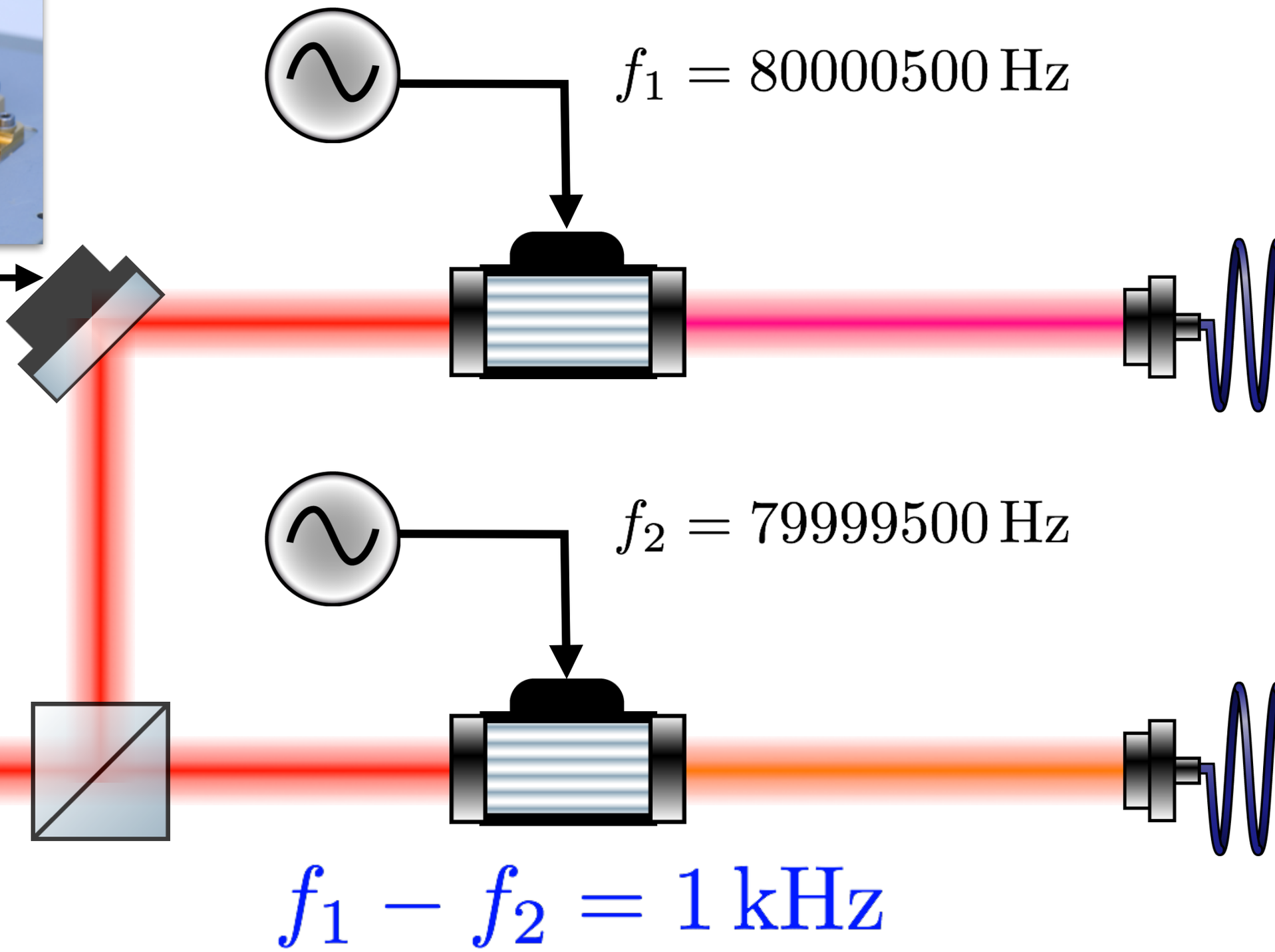


Operated at 38mW output power

Modulation



Optical Path Length Difference Correction



On the optical bench…

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←power stabilisation

few %

α

in flight:
$\alpha \approx 4.5°$

Phase measurement

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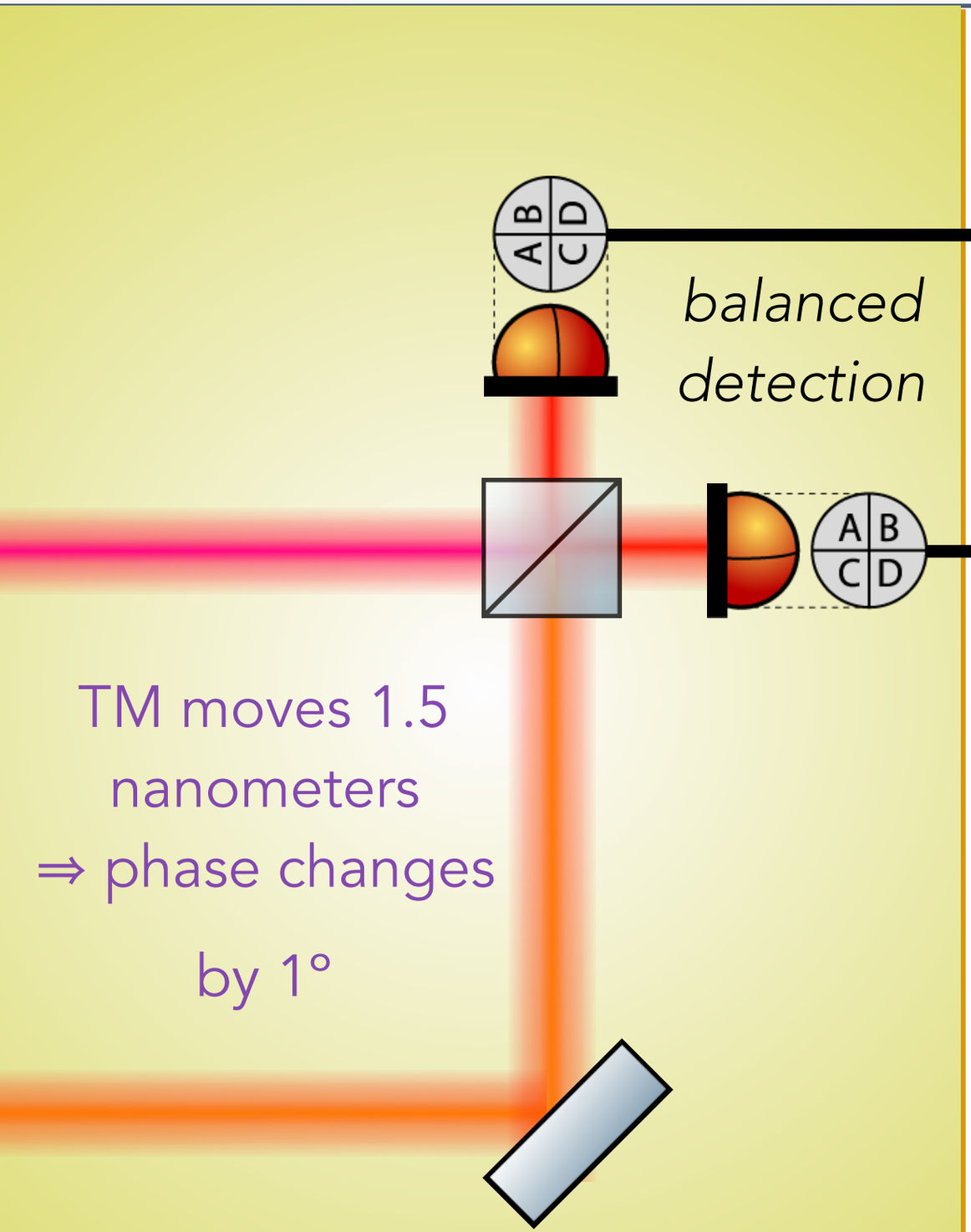

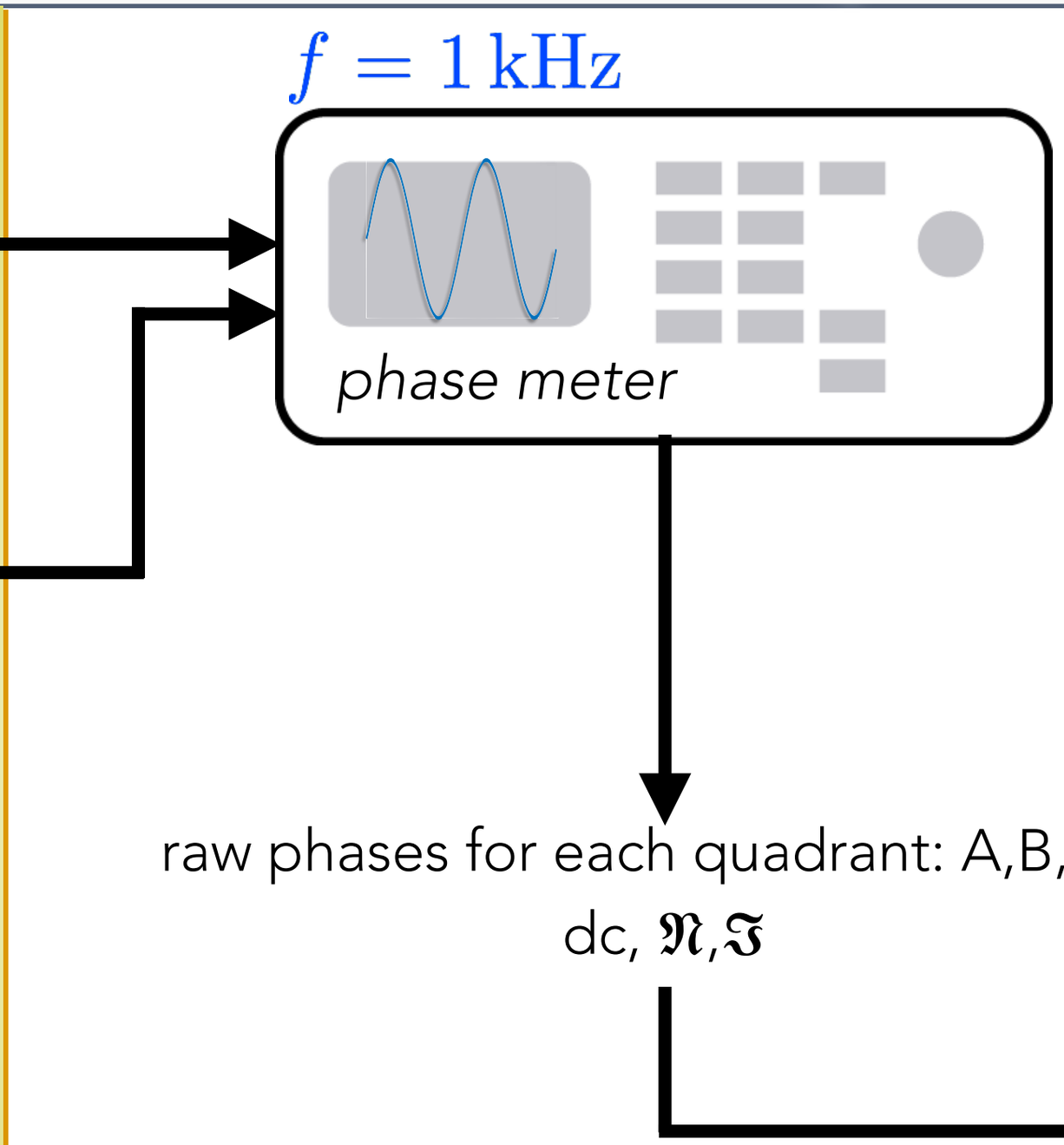

Computing science measurements

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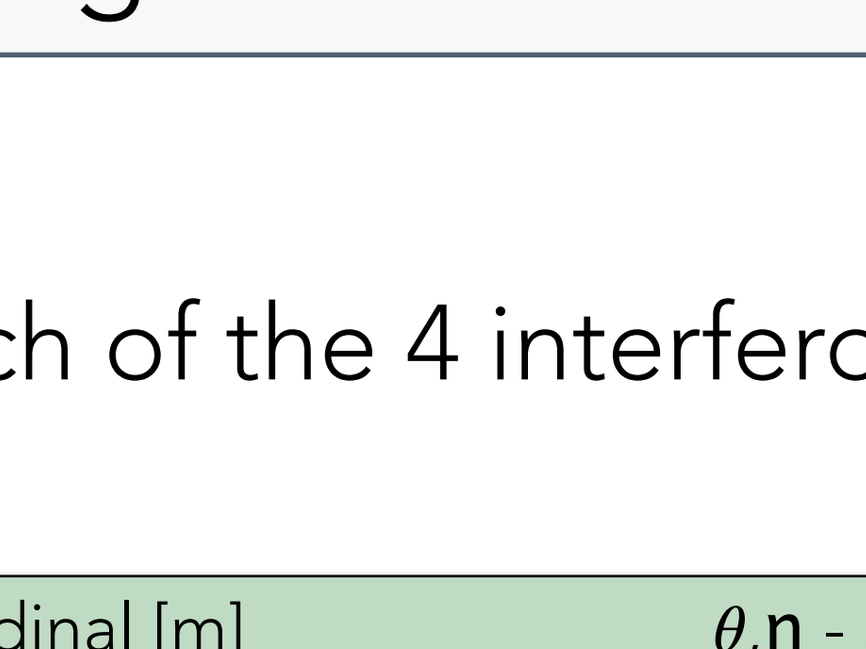
for each of the 4 interferometers…

x - longitudinal [m]

θ,η - angular [rad]

to DFACS…



***D**ata **M**anagement **U**nit*

control feedback signals

modulation unit & laser…

The 4 Interferometers of the OMS

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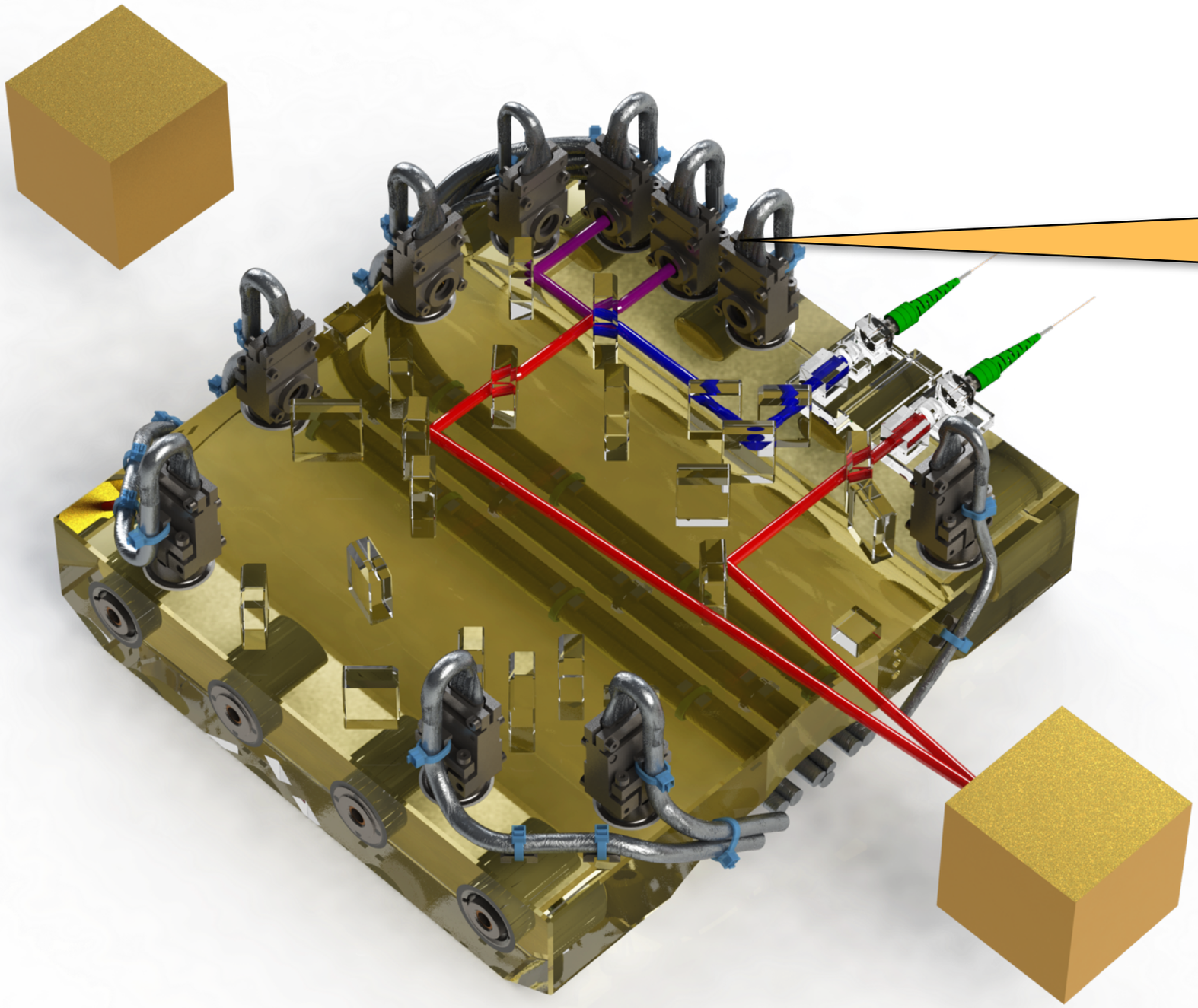

X1 Interferometer

Measures position and orientation of TM1 w.r.t. OB (SC)

The 4 Interferometers of the OMS

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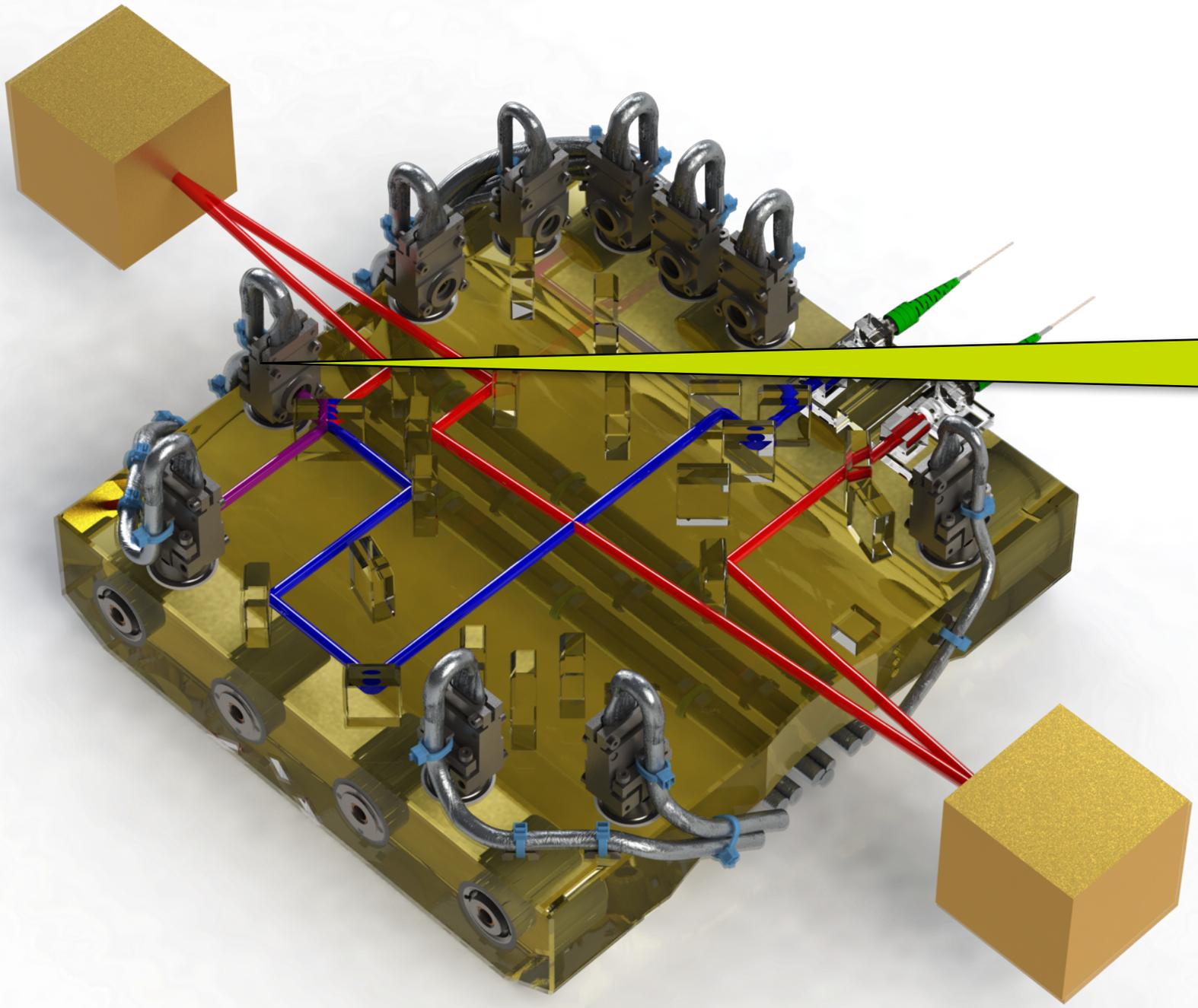

X12 Interferometer

Measures position and orientation of TM2 w.r.t. TM1

The 4 Interferometers of the OMS

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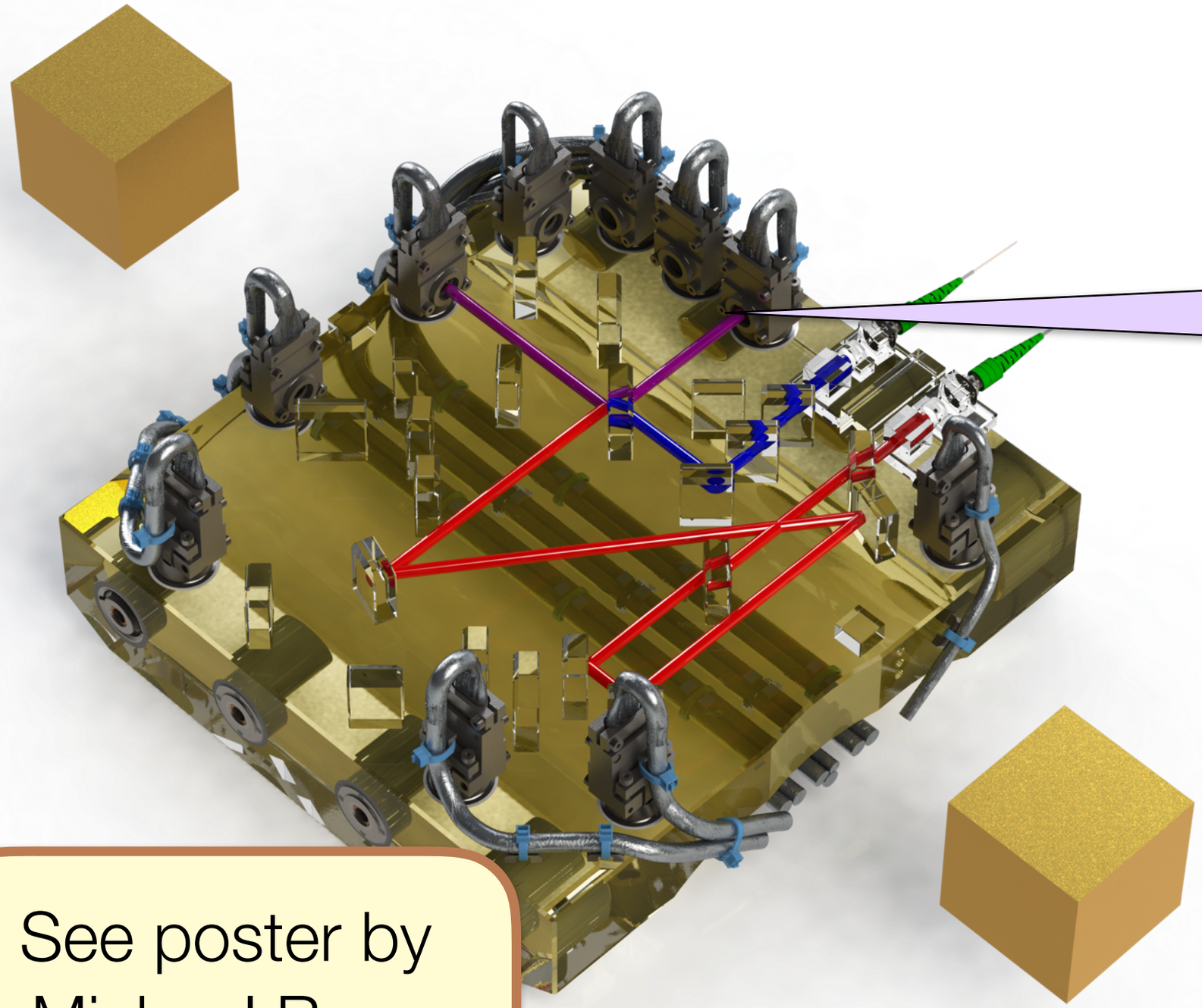

Reference Interferometer

Measures phase fluctuations common to both optical fibres.

Subtracted from all other IFOs in the DMU.

See poster by Michael Born

The 4 Interferometers of the OMS

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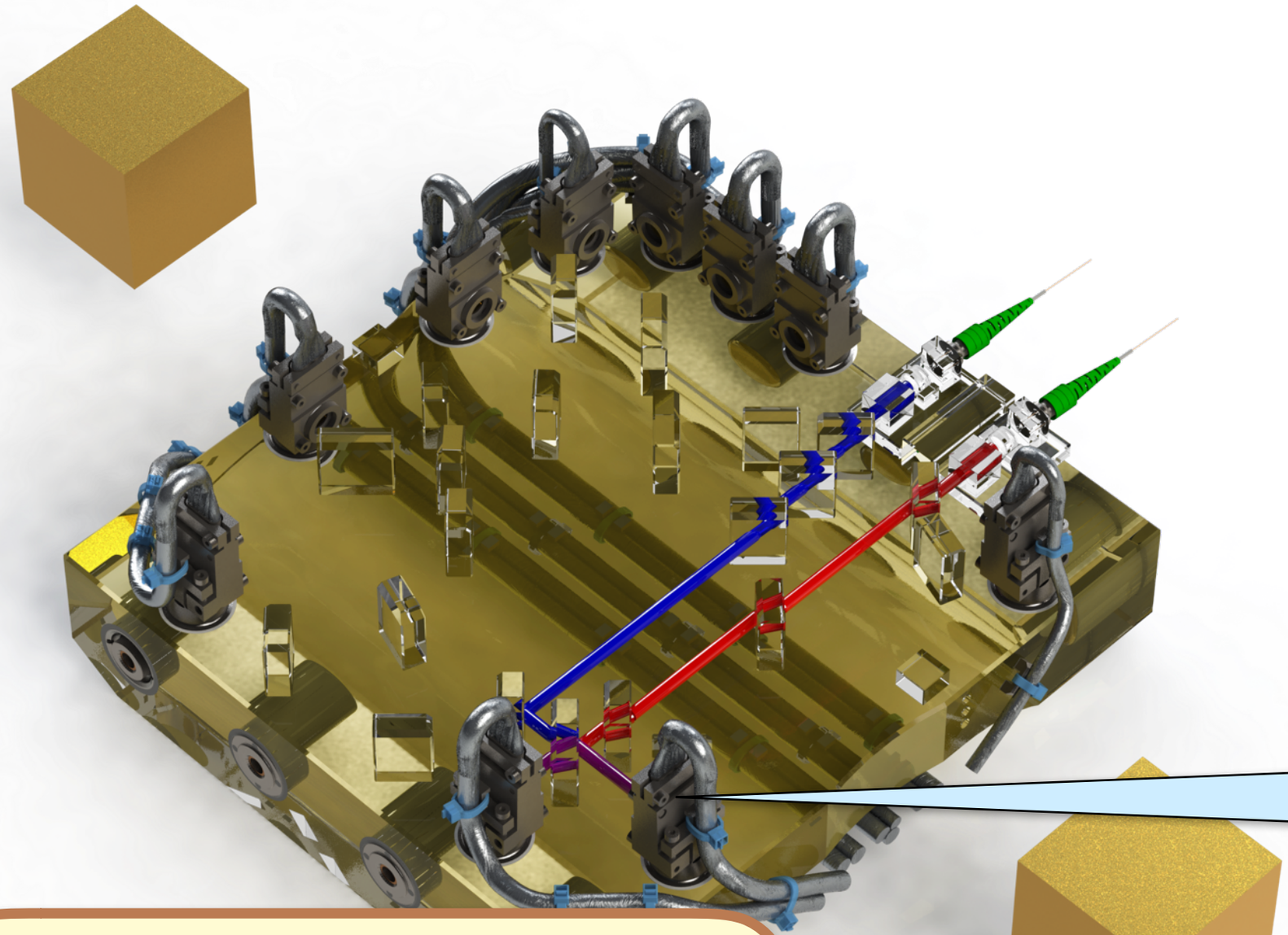
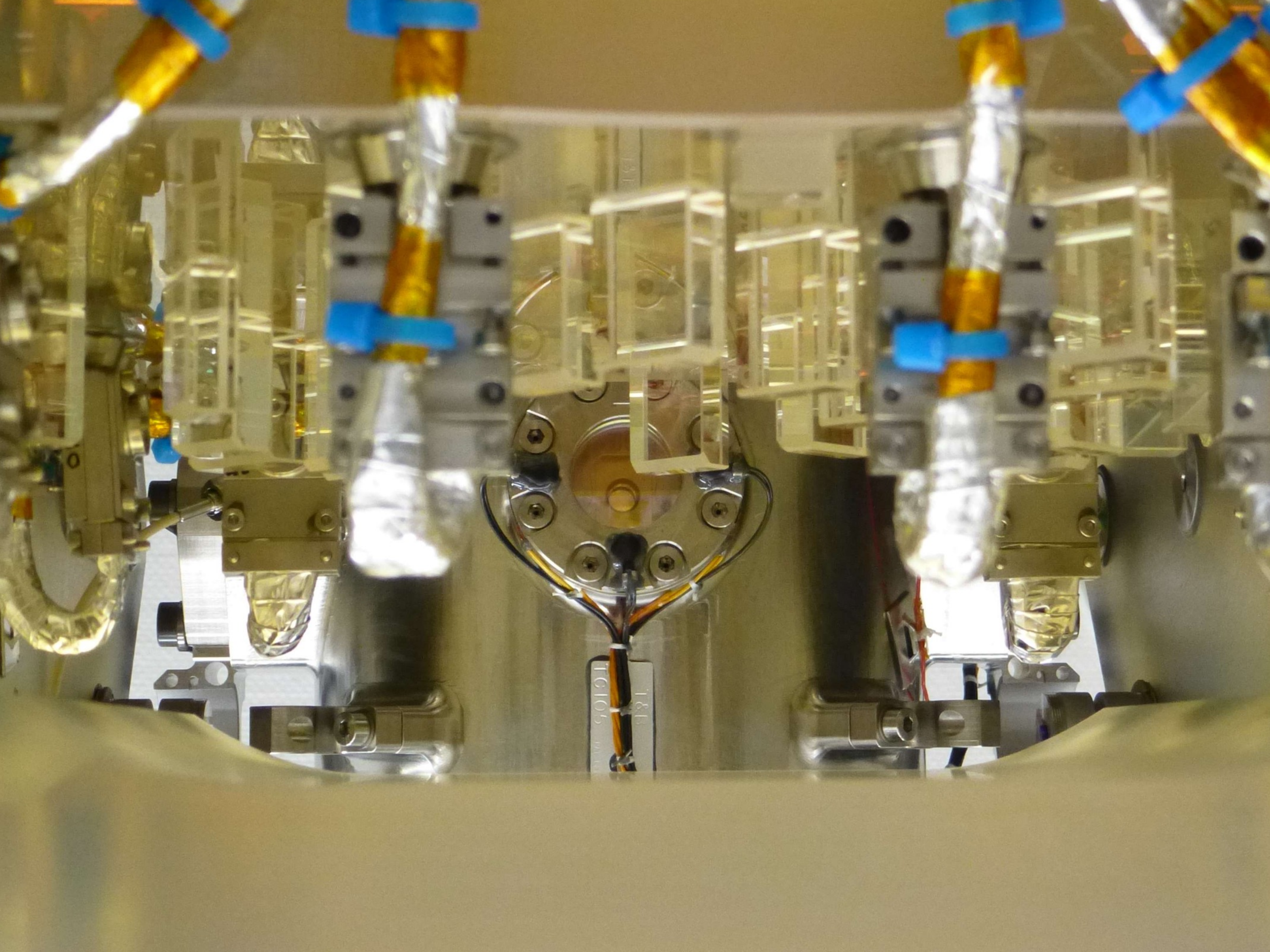


Frequency Interferometer

Measures fluctuations of laser frequency.

Used to stabilise laser frequency.

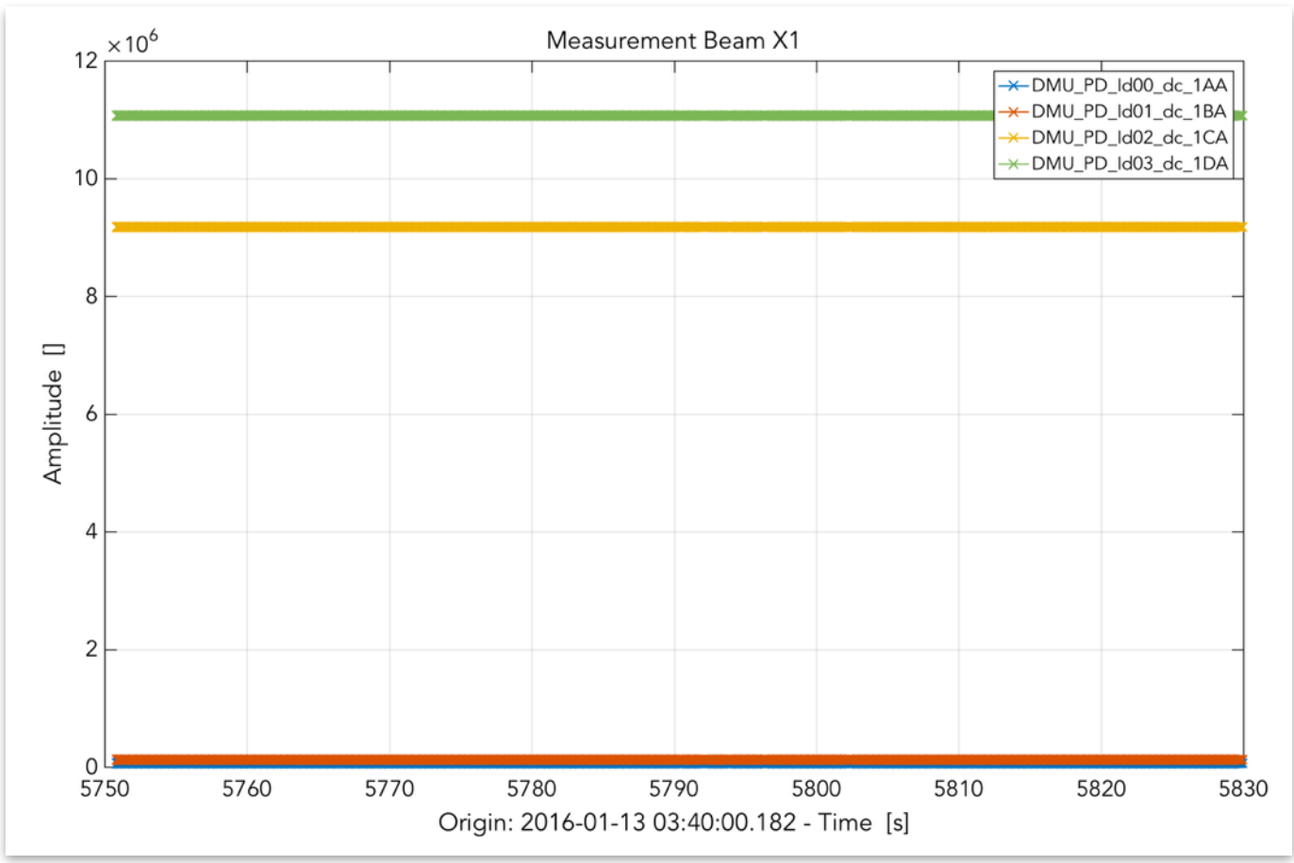
See talk by Sarah Paczkowski



Commissioning - first light

It was a cold, dark night in early January…

- DMU calibration coeffs updated in DMU
- RLU + **L**aser **A**ssembly redundant chain checkout
  - LA Electronics, B-side, activated
  - DMU to operational mode, OMS processing on
  - Pump diode bench B activated
  - 40 mW RLU output
  - Light detected on some quadrants
- RLU + LA prime chain
  - LA Electronics, A-side, activated
  - Pump diode bench A activated
  - 40 mW RLU output
  - Light detected on some quadrants



OMS Activities - Phase 1

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1. Switch on and checkout of all units
2. Actuator scans
3. Single beam measurements (spot positions)
4. Stabilisation Loops checkout
5. RLU performance and operating point
6. Initial performance with low contrasts

Projected Optical Powers on the bench

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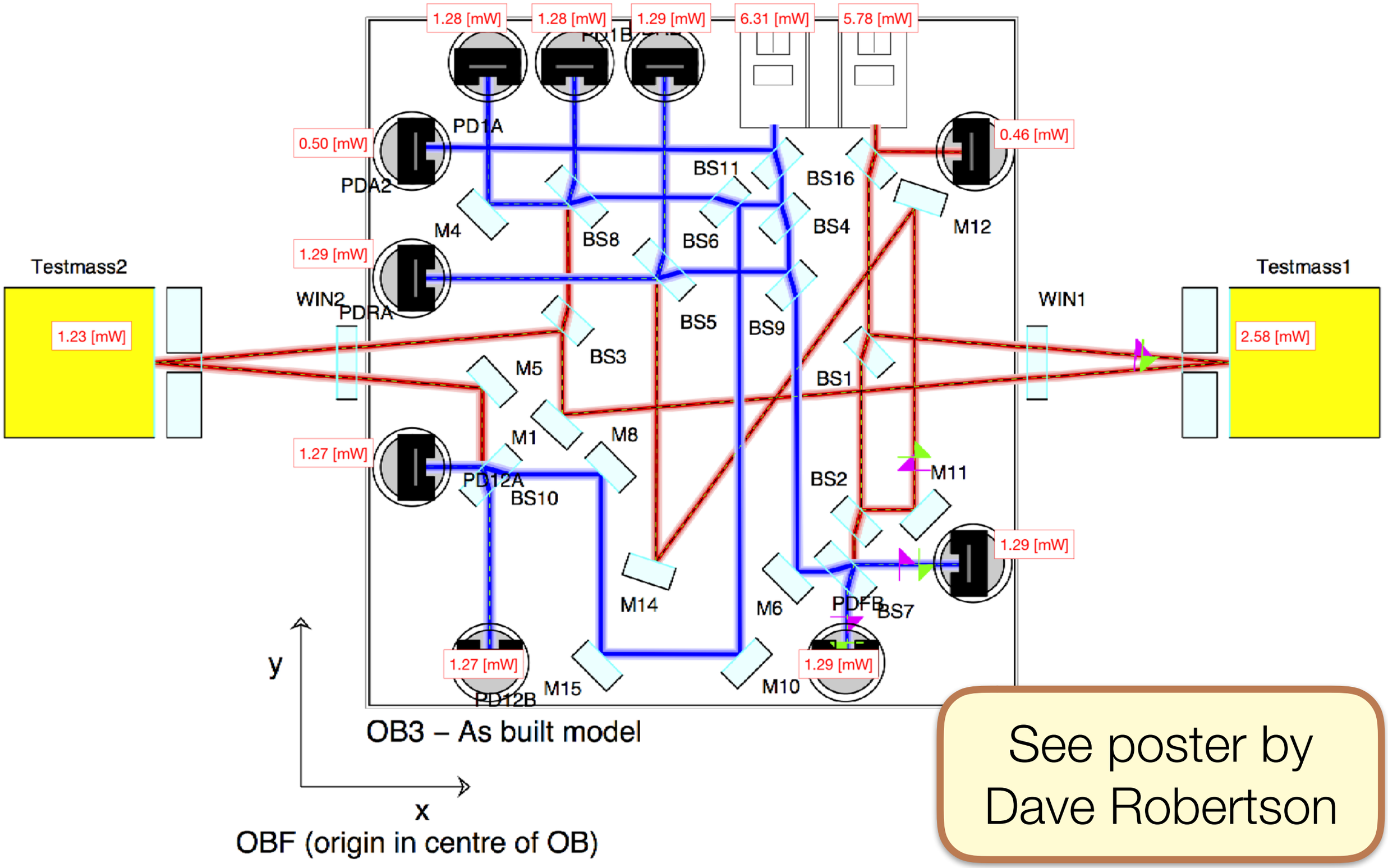

See poster by Dave Robertson

Performance with minimal contrast…

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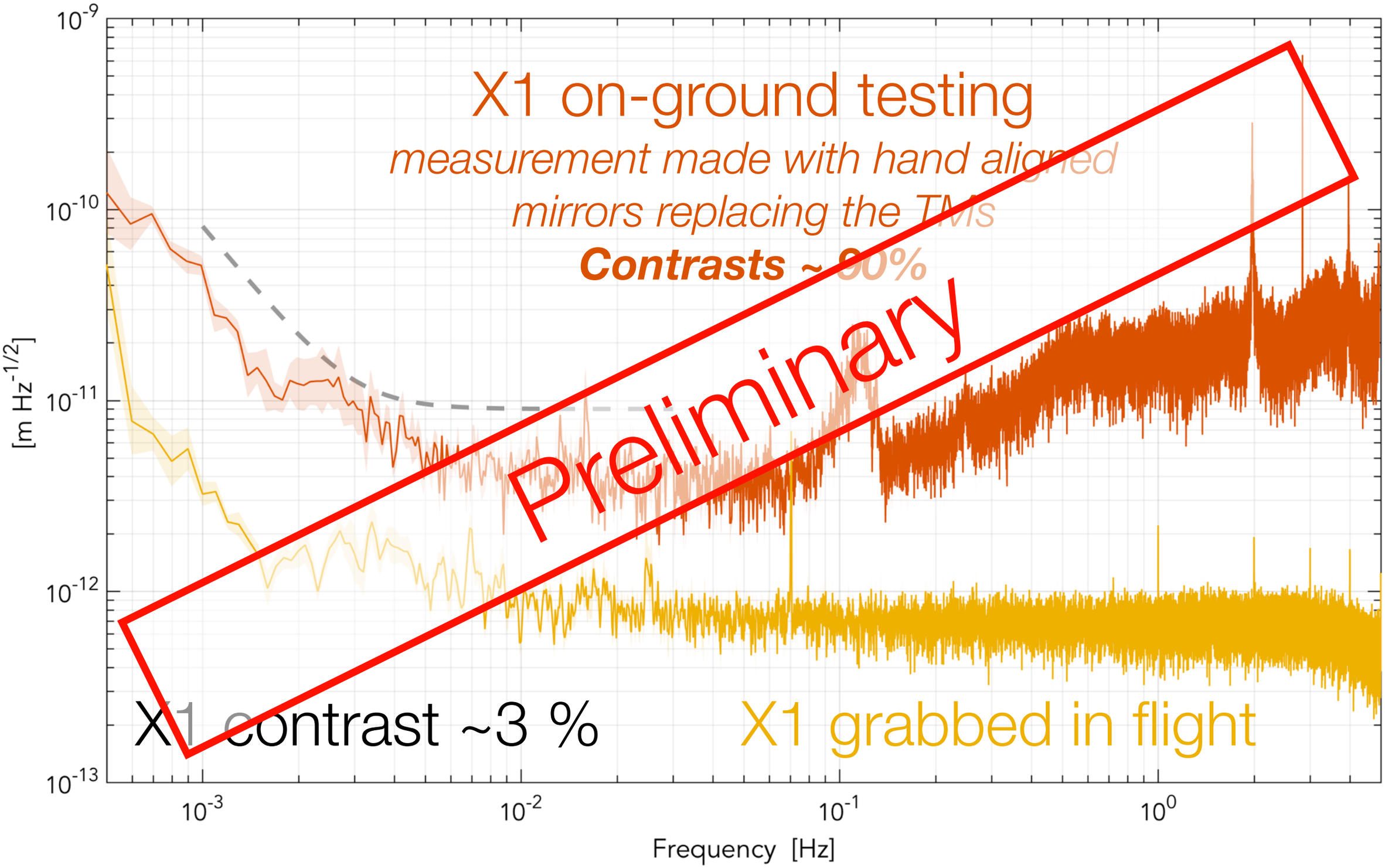

OMS Activities - Phase 2

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1. TM optical alignment after release
2. Polarity and gain tests
3. Trimming of powers on the bench
4. Performance with aligned test masses

Alignment of the optical system

	Offset [μrad]
η_1	-730
ϕ_1	-170
η_2	-186
ϕ_2	+628

- Account for offsets between the inertial sensor and optical reference frames
  - mechanical tolerances build up during the integration procedure
- Switched to optical angular control for TM1 on Feb 18th
- Switched to TM2 optical angular control on Feb 18th

Contrasts before and after alignment

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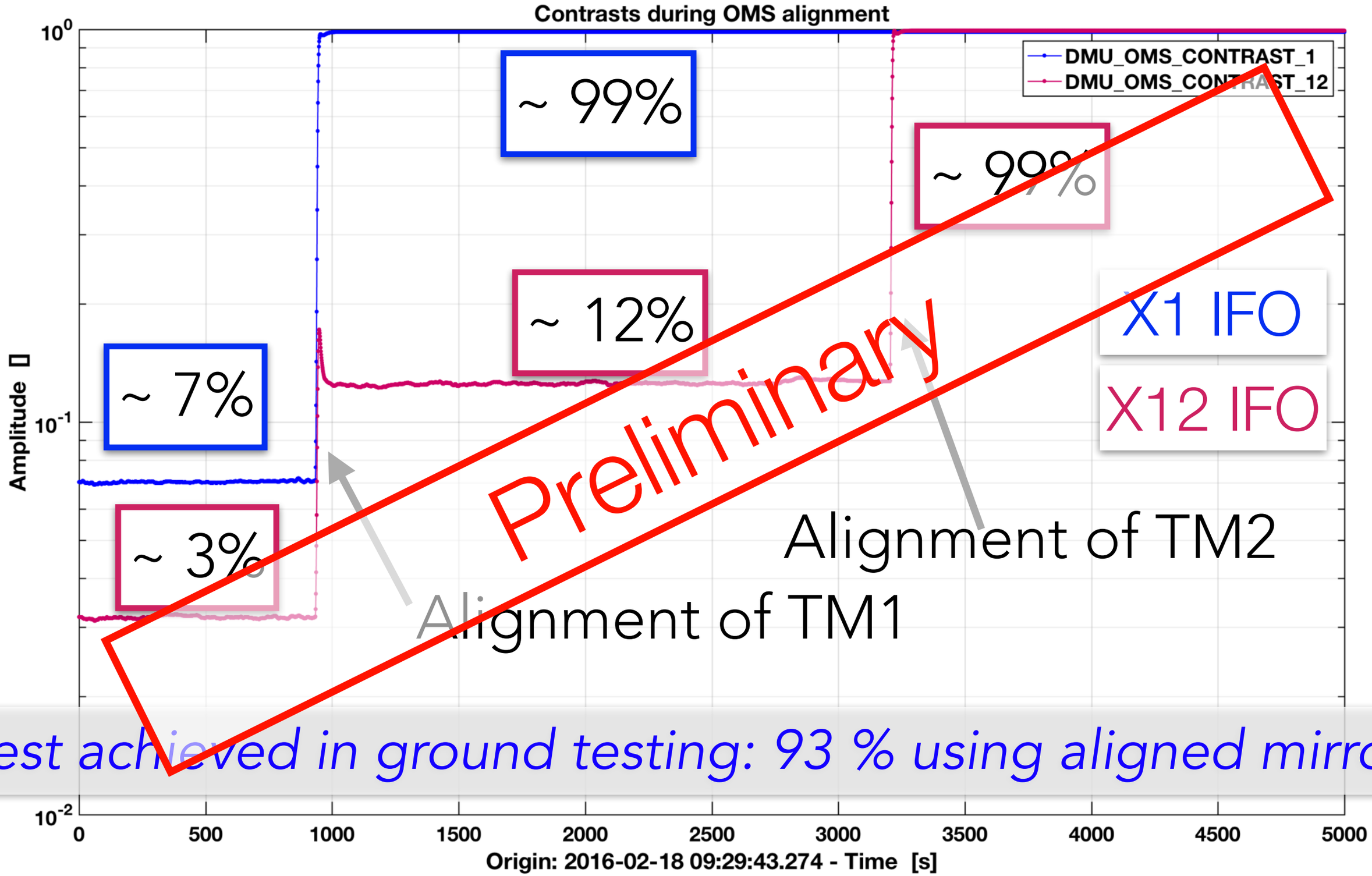

best achieved in ground testing: 93 % using aligned mirrors

X12: Initial performance with aligned TMs

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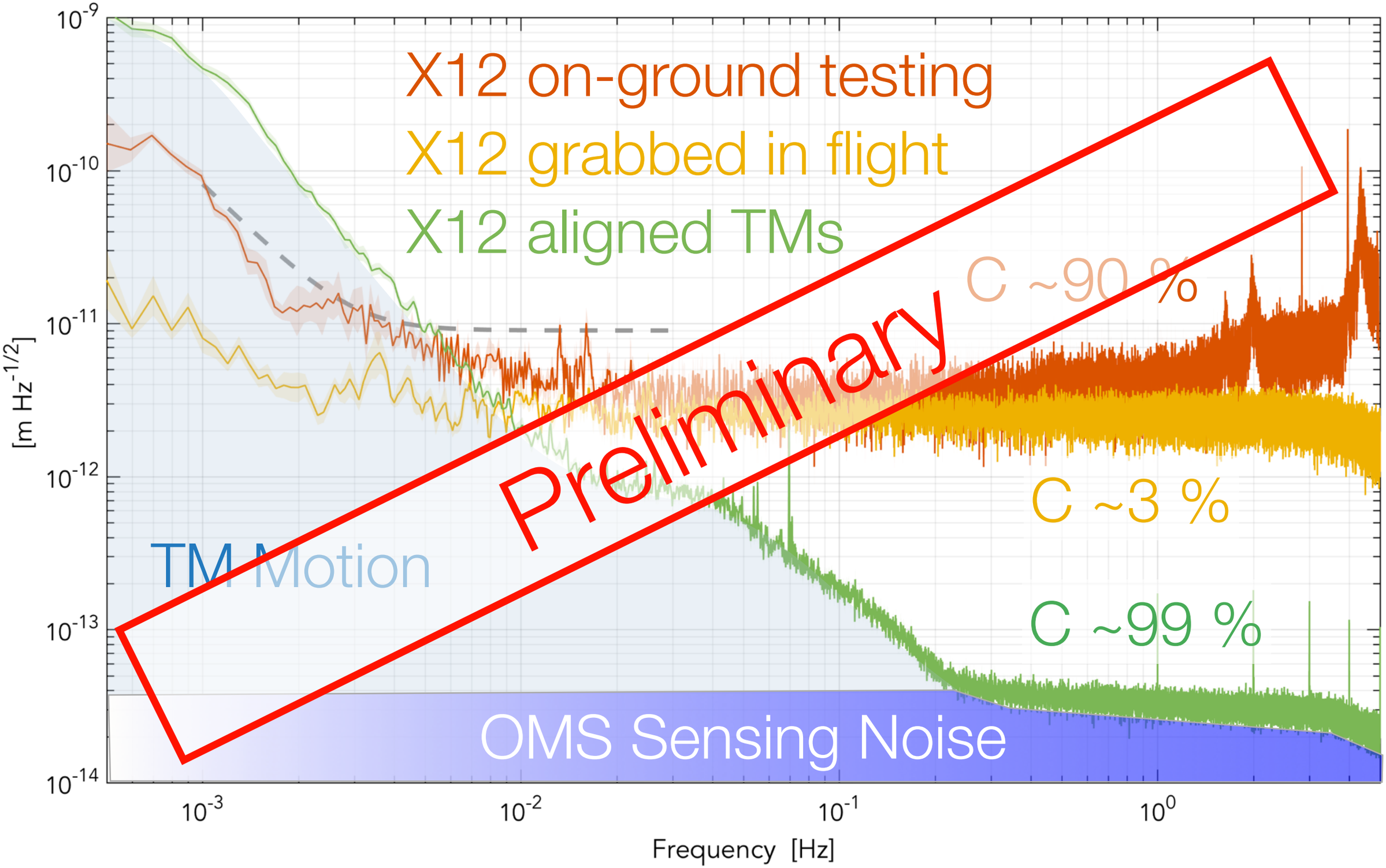

Understanding the performance: noise sources

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Source	Coupling	Contribution
Frequency Noise	via arm-length mismatch between measurement and reference beam	~300 um mismatch ⇒ 20 fm/√Hz @ 1Hz
Phasemeter Noise	Quantisation, front-end electronics, etc	~650 nrad/√Hz per channel ⇒ 28 fm/√Hz
RIN	Couples at 2x f_{het}	~0 for correct operating point
RIN @ DC	Not relevant for OMS performance, but creates fluctuating forces on TMs	~2 fm s^{-2} / √Hz @ 0.1 mHz

+ other, less significant sources

Relative **I**ntensity **N**oise coupling

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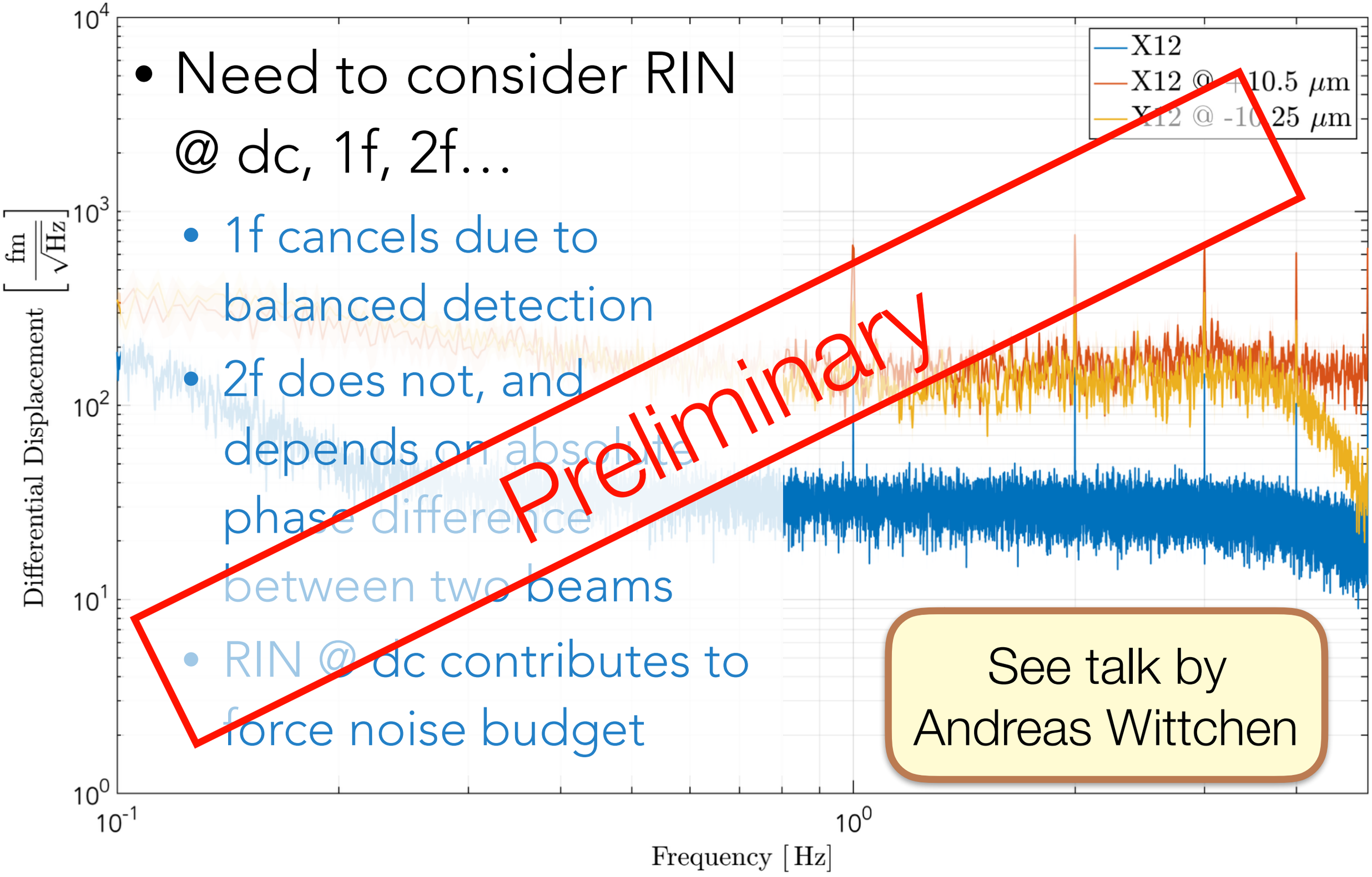
- Need to consider RIN @ dc, 1f, 2f…
  - 1f cancels due to balanced detection
  - 2f does not, and depends on absolute phase difference between two beams
  - RIN @ dc contributes to force noise budget



Preliminary

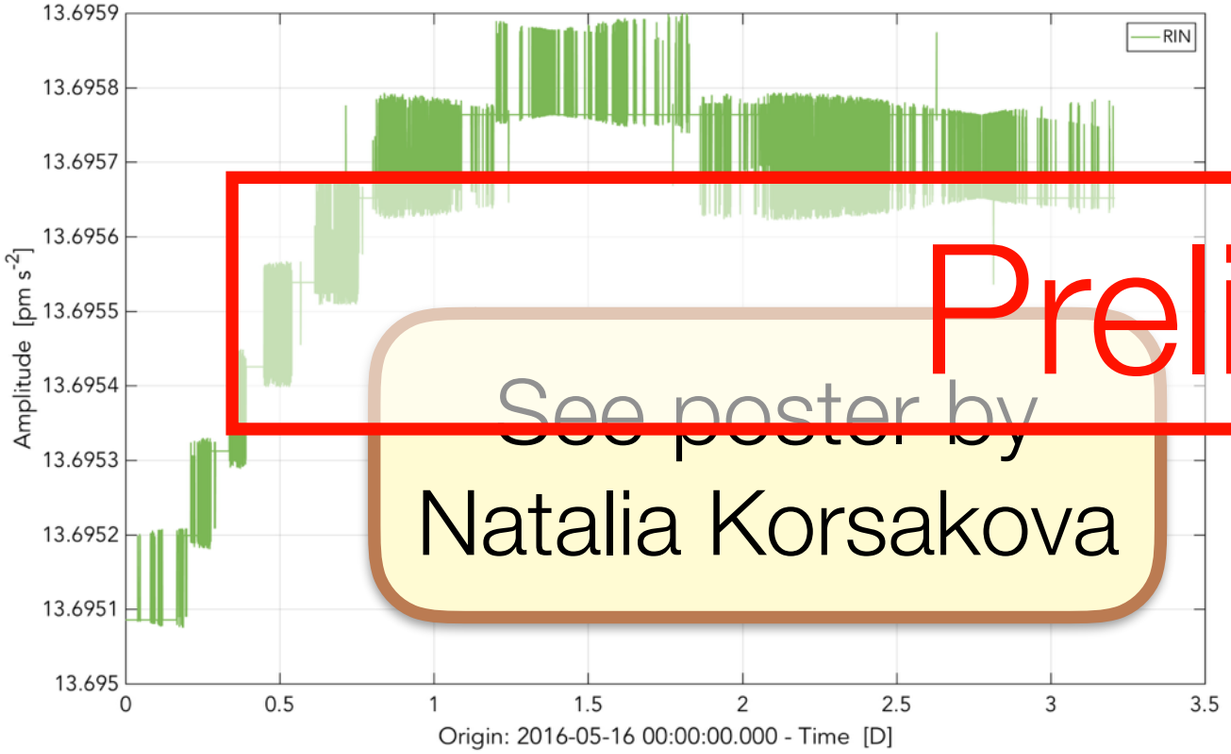
See talk by Andreas Wittchen

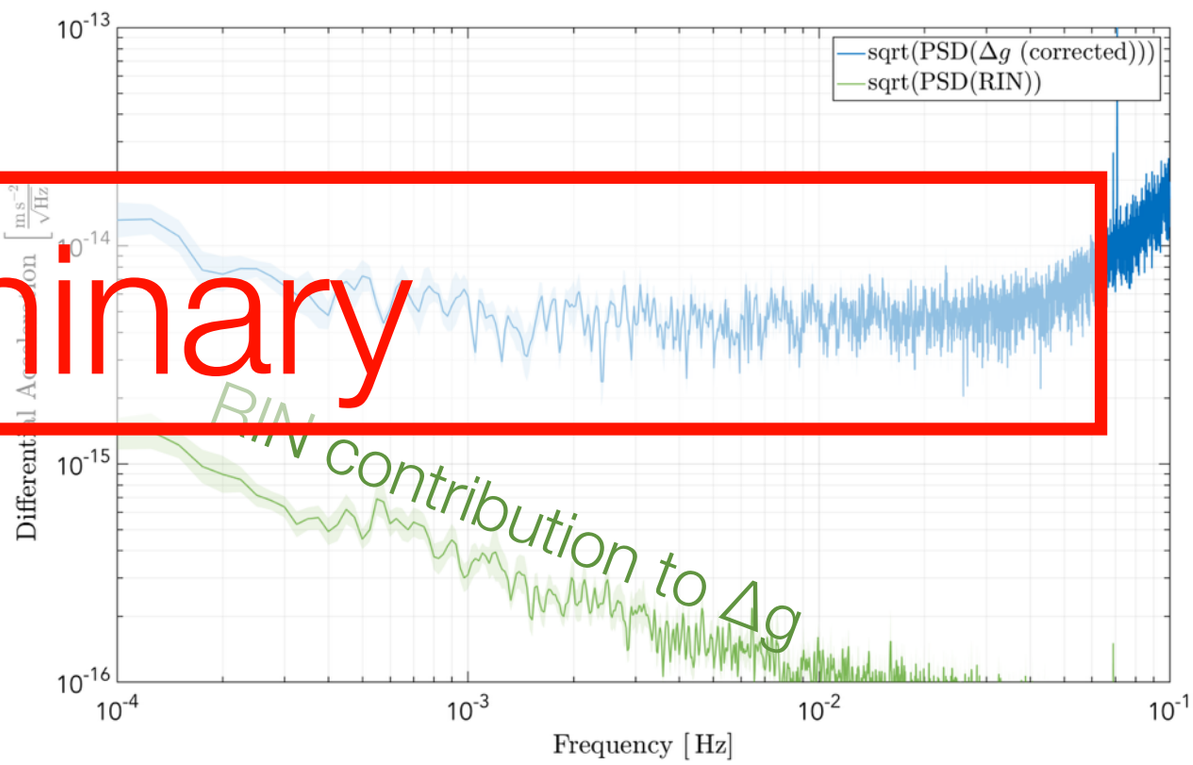
RIN @ dc - photon pressure

- RIN @ dc imparts a force on the TMs via momentum transfer from reflected and absorbed photons
- Fluctuations in the laser intensity result in a fluctuating force

$$\Delta g_{\mathrm{dc}}^{\mathrm{RIN}} = 2 \times \frac{2.6\,\mathrm{mW} + 1.25\,\mathrm{mW}}{M_{\mathrm{TM}} \times c} \approx 13\,\mathrm{pm\,s^{-2}}$$

$$S_{\Delta g}^{\mathrm{RIN}} = 2\frac{S_{\mathrm{P}}}{Mc}$$





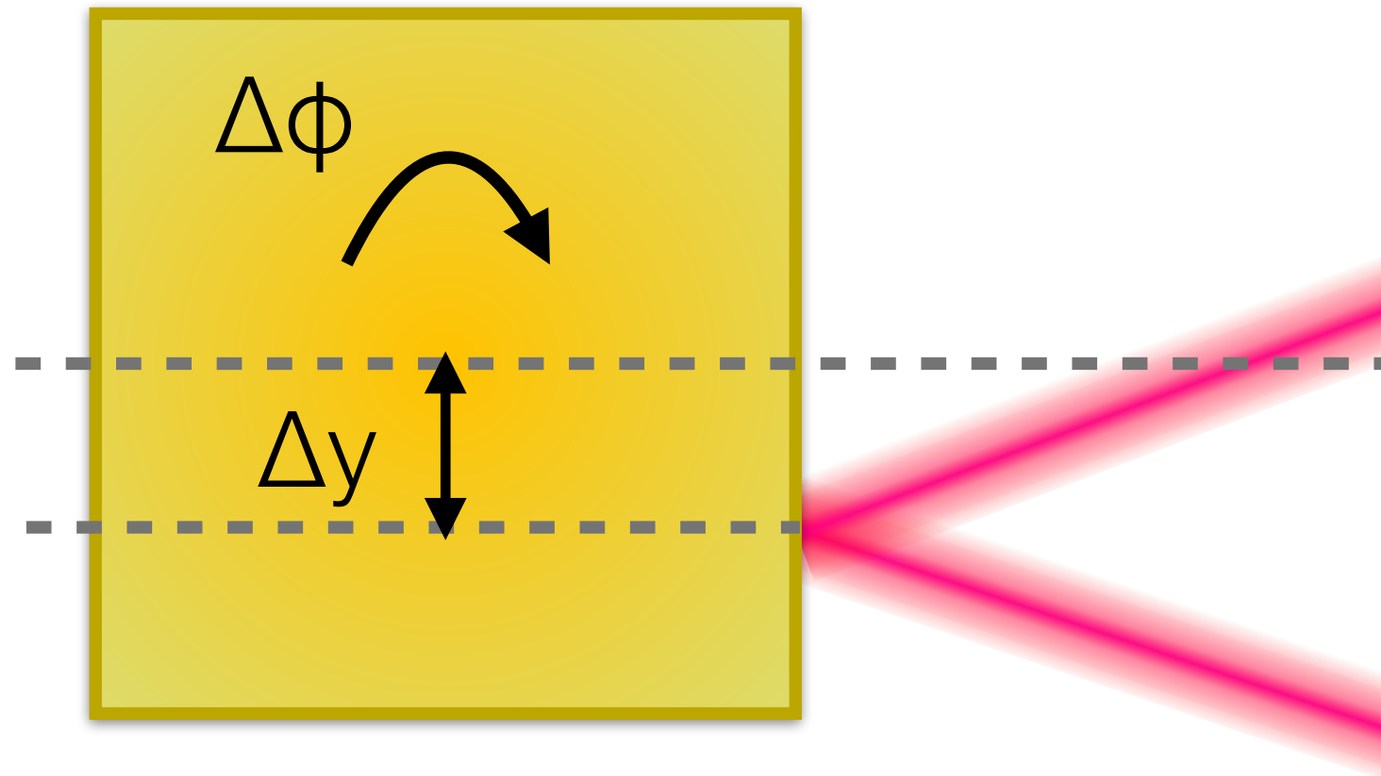
Preliminary

See poster by Natalia Korsakova

Sensing cross-talk

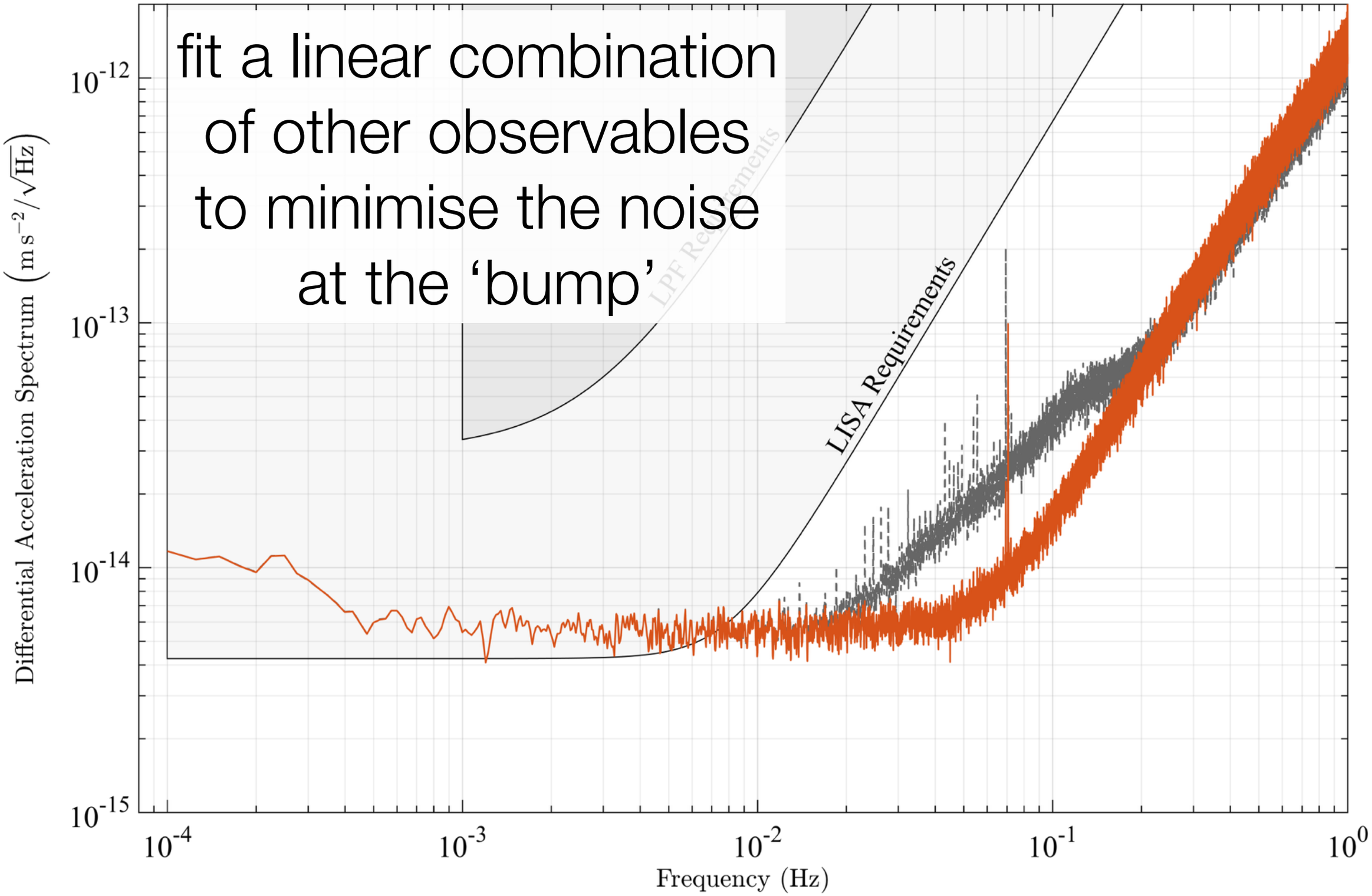
- coupling of TM/SC jitter to differential readout via:
  - TM alignment
  - beam properties
  - PD construction (slits)
  - …
- minimise by:
  - subtracting on ground
    - ad-hoc fit, or physical model
  - alignment of TMs

See poster by Gudrun Wanner



$$\Delta x \approx \Delta\phi \, \Delta y$$

Cross-talk in Δg - software subtraction



Cross-talk in raw Δg - TM alignment

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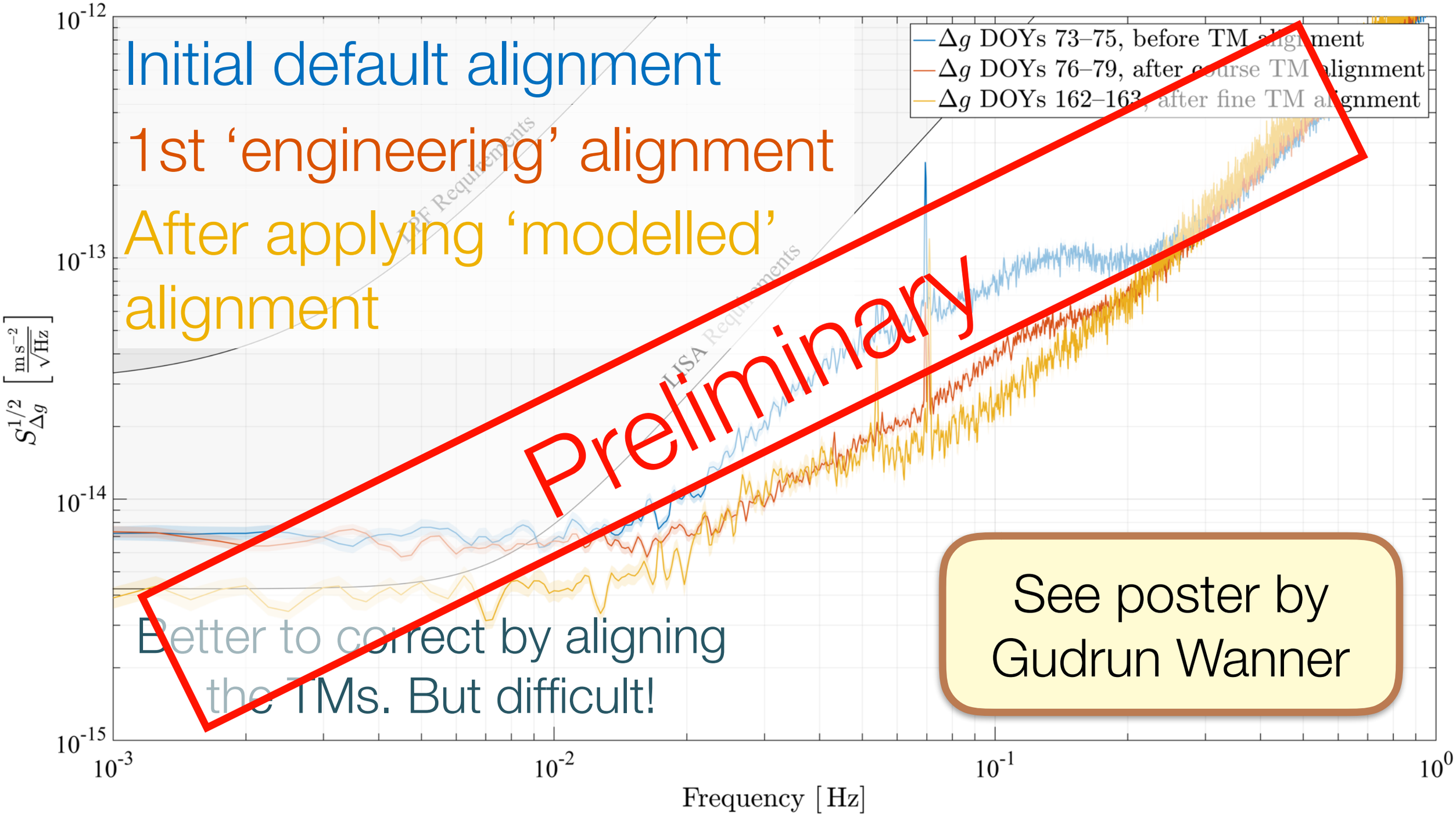
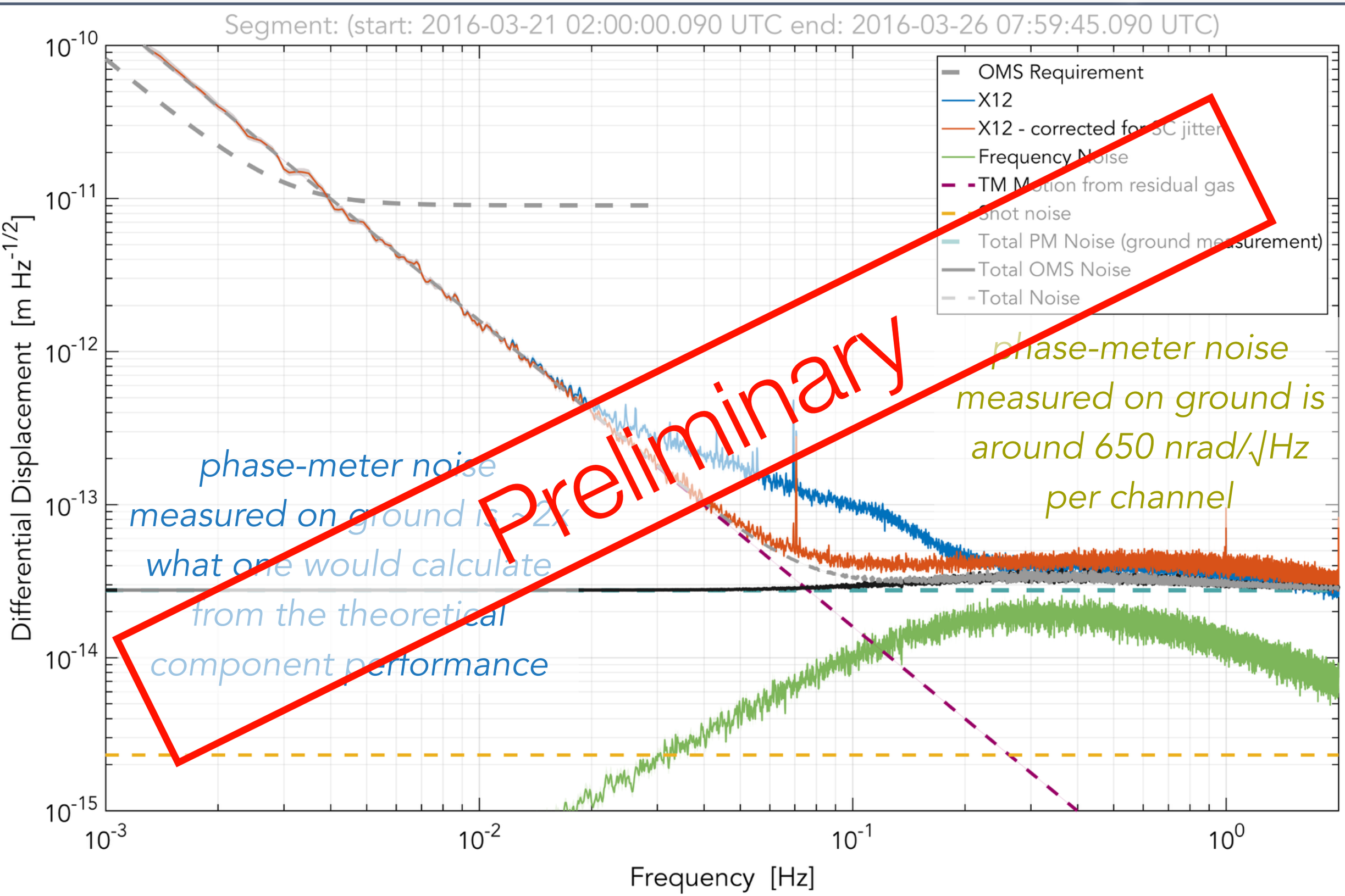


Noise budget



DWS Noise Budget

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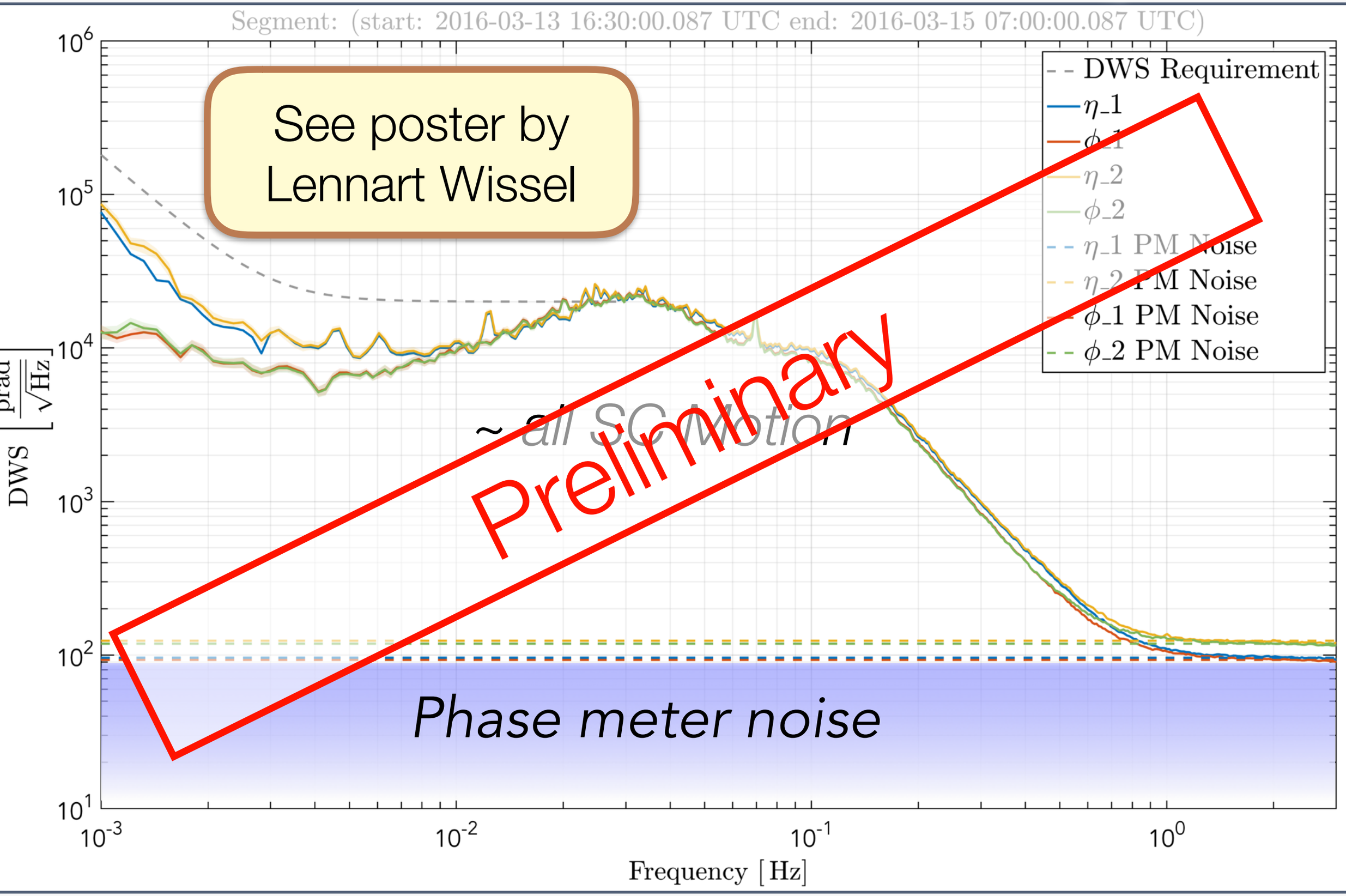
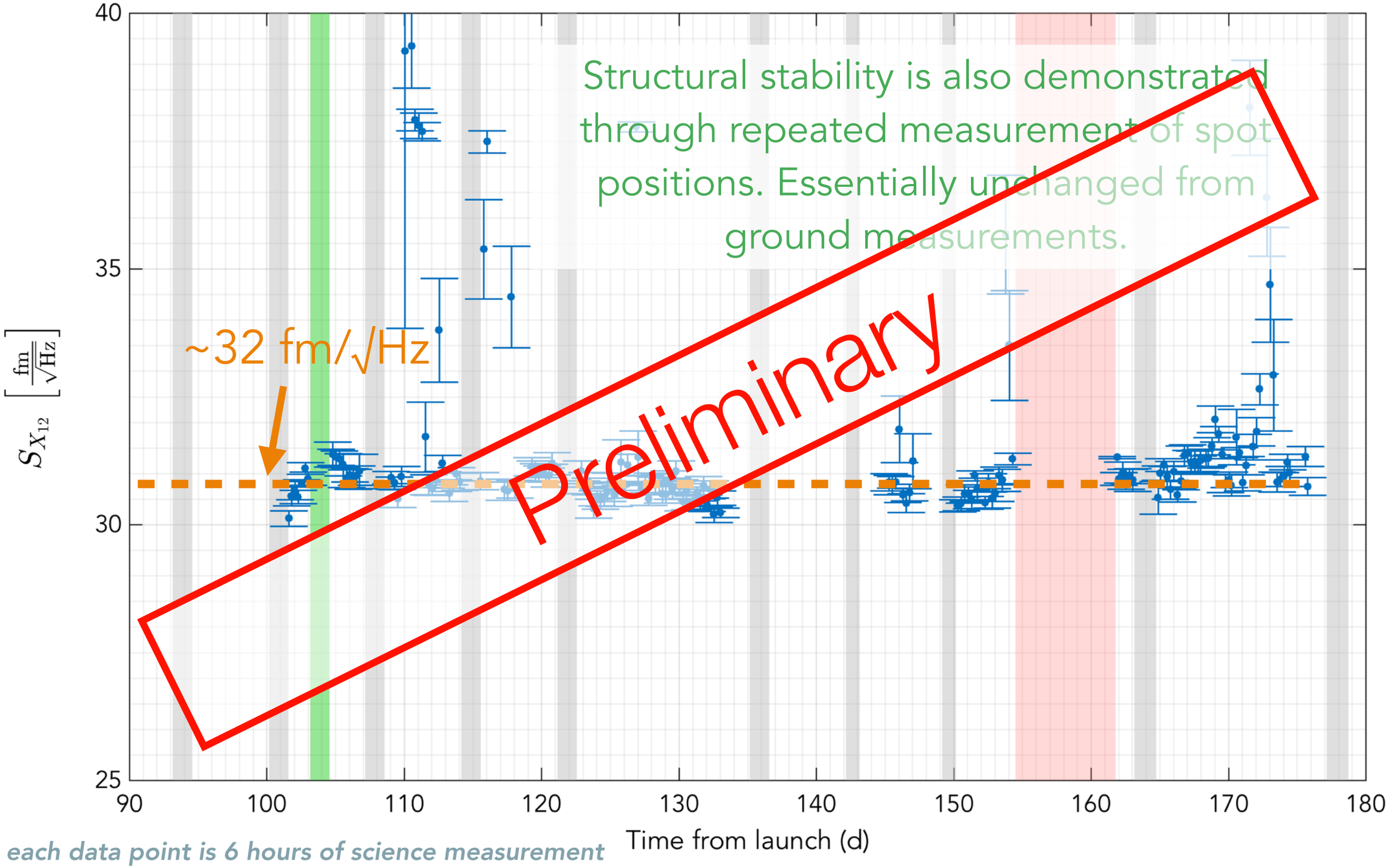


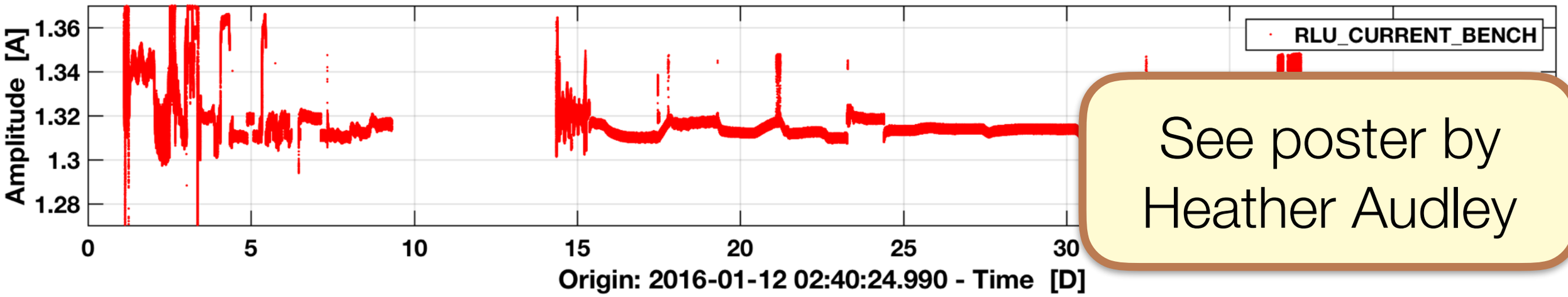
See poster by Lennart Wissel

Stability of OMS performance

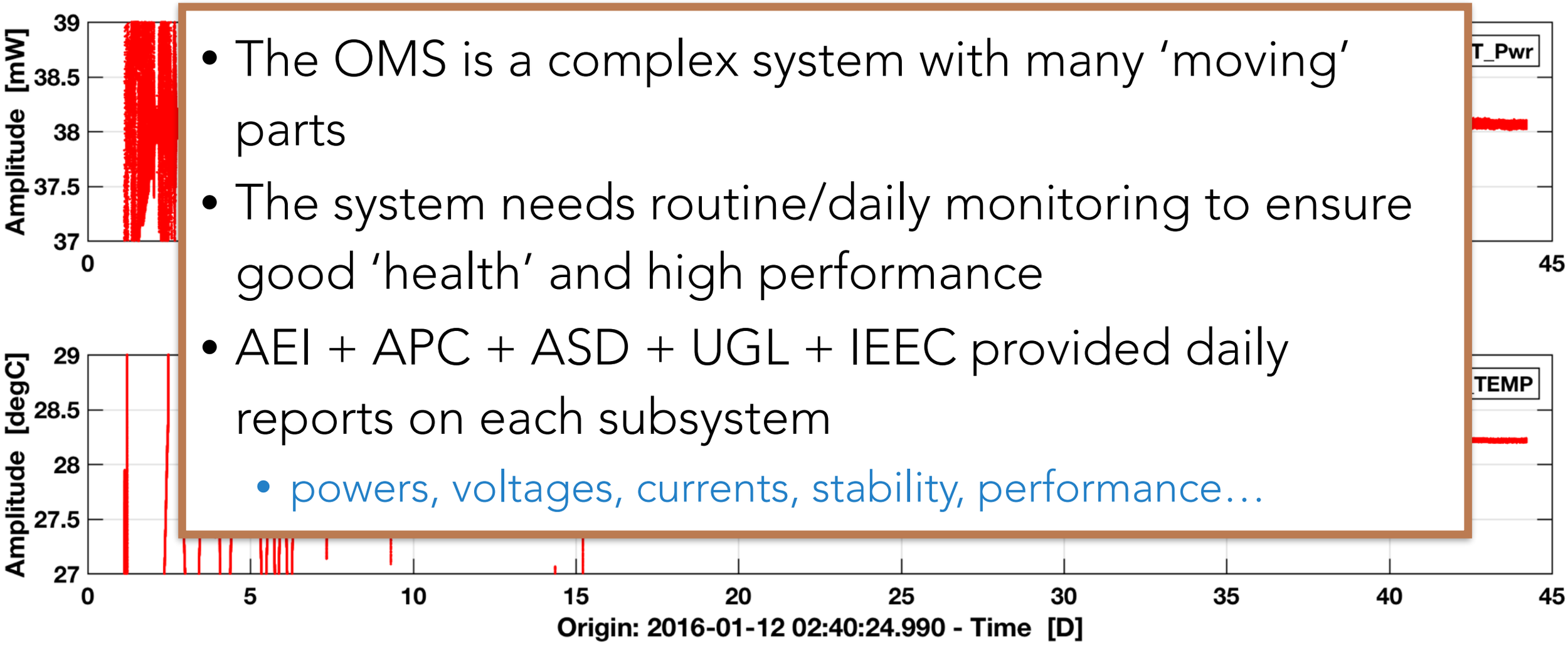


each data point is 6 hours of science measurement

Long-term monitoring



See poster by Heather Audley



- The OMS is a complex system with many 'moving' parts
- The system needs routine/daily monitoring to ensure good 'health' and high performance
- AEI + APC + ASD + UGL + IEEC provided daily reports on each subsystem
  - powers, voltages, currents, stability, performance…

Summary

- The optical metrology system on-board LPF is a **resounding success**
- Performance about x100 better than achieved on ground
- High-stability and reliability
- Very little maintenance required
- High-performance allowed us to explore cross-talk at unexpected levels
- Concepts and design techniques are proven and ready for use in LISA

Thanks to all LPF Team

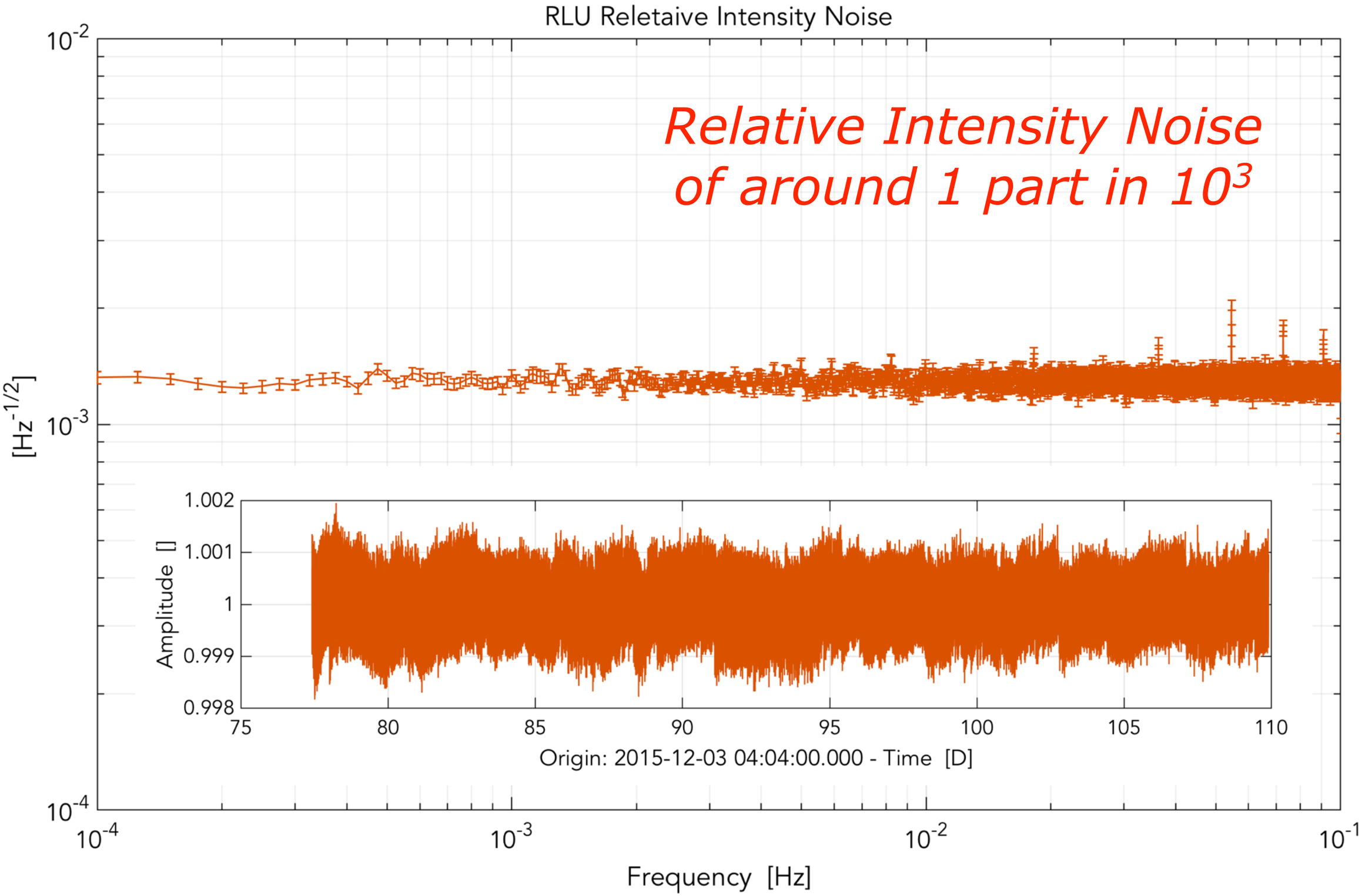
Supported by:

Federal Ministry
for Economic Affairs
and Energy

on the basis of a decision
by the German Bundestag

additional material

RIN @ the laser



Noise budget from theoretical considerations

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