

LISA Pathfinder: Optical Metrology System Noise Sources

Sarah Paczkowski for the LPF collaboration

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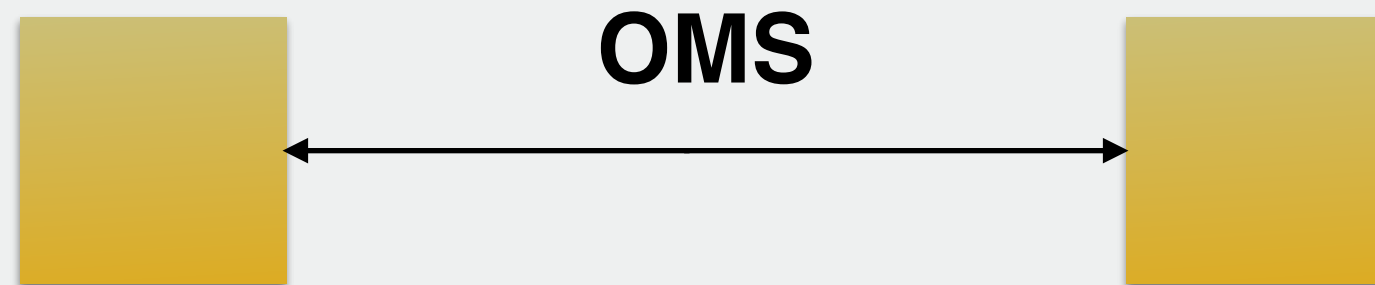
Overview

- LISA Pathfinder **O**ptical **M**etrology **S**ystem (OMS)
- selected OMS noise sources investigated
 - laser frequency noise
 - common mode **P**ath **L**ength (PL) noise
 - **R**elative **I**ntensity **N**oise (RIN)
- conclusions & outlook



LPF **O**ptical **M**etrology **S**ystem (**O**MS)

LPF measurement: acceleration of free-falling test mass

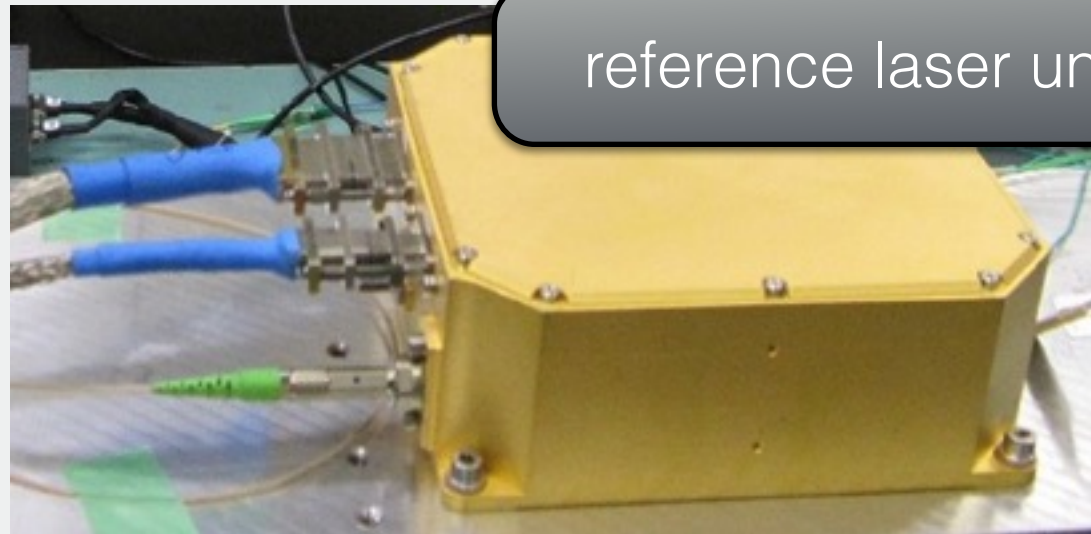


OMS: measure distance with respect to quiet reference mass
with required accuracy of

$$S_{\delta x} \leq 9 \frac{\text{pm}}{\sqrt{\text{Hz}}} \left(1 + \left(\frac{3 \text{ mHz}}{f} \right)^2 \right)$$

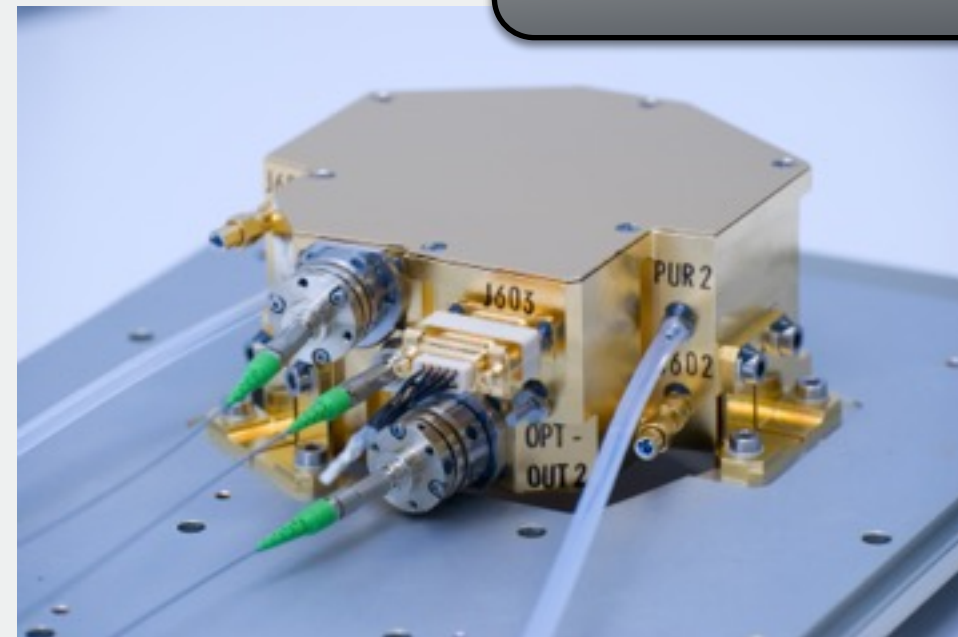


LPF **O**ptical **M**etrology **S**ystem (**O**MS)



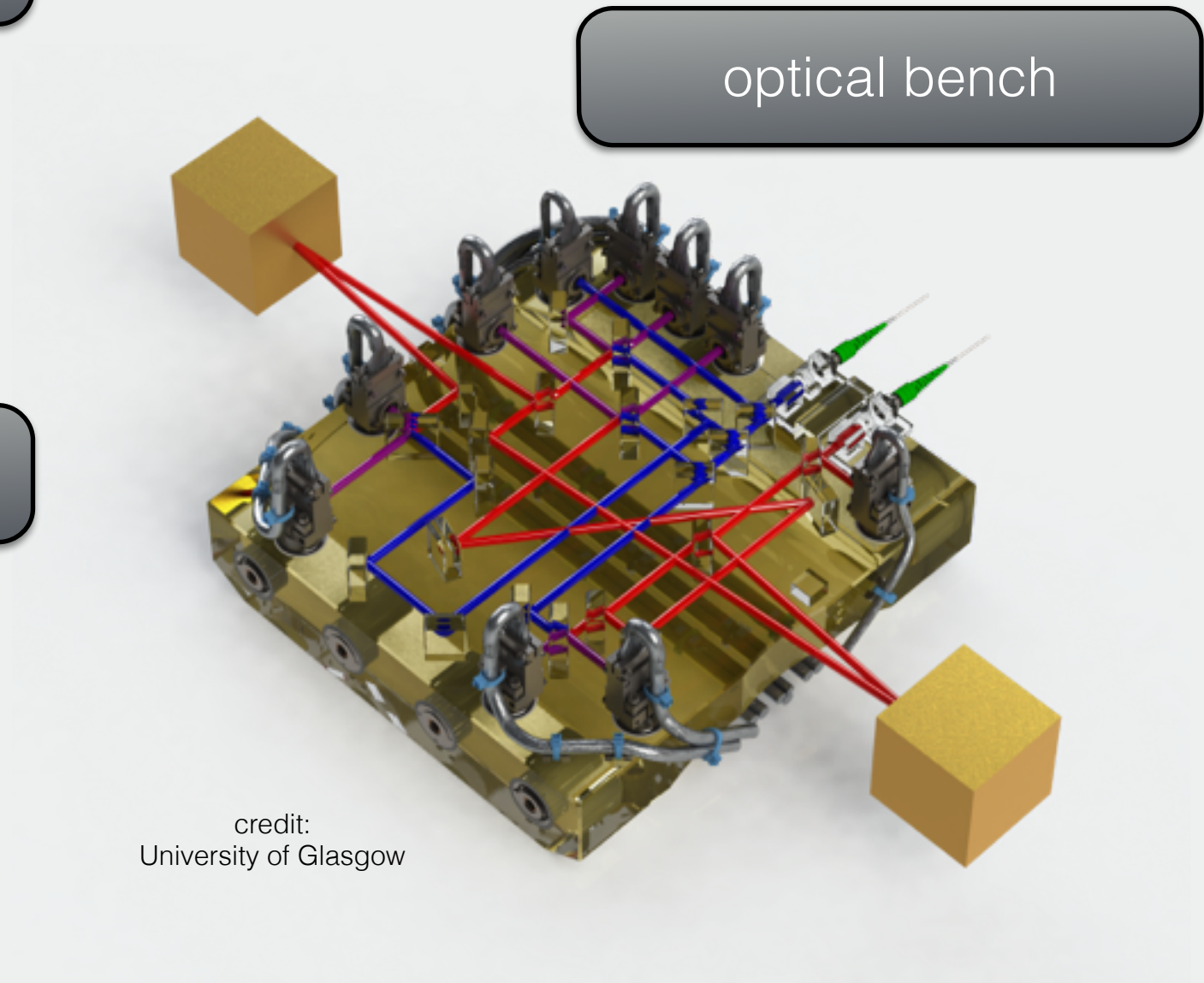
reference laser unit

credit: TESAT



laser modulator unit

credit: RUAG

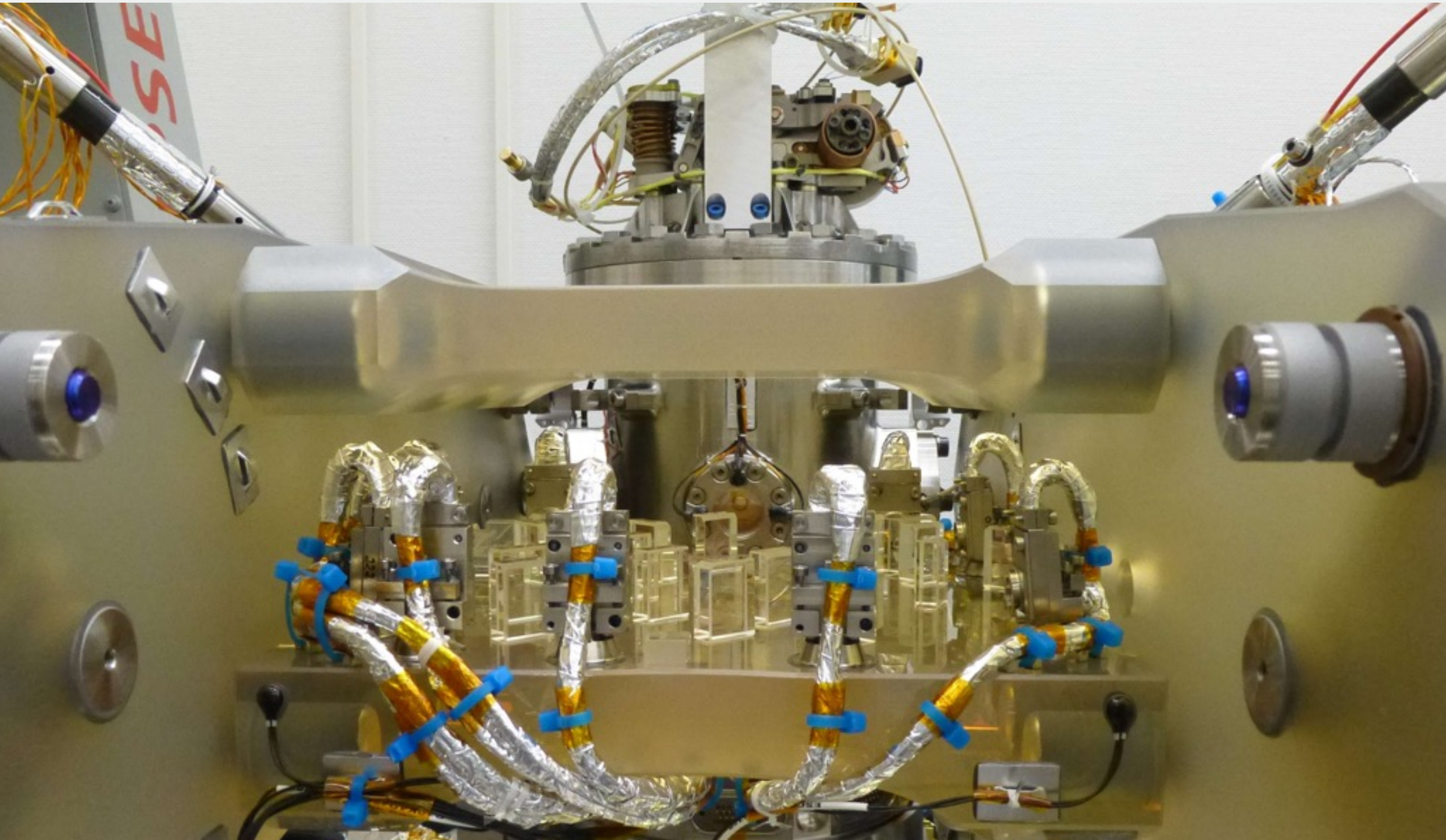


optical bench

credit:
University of Glasgow



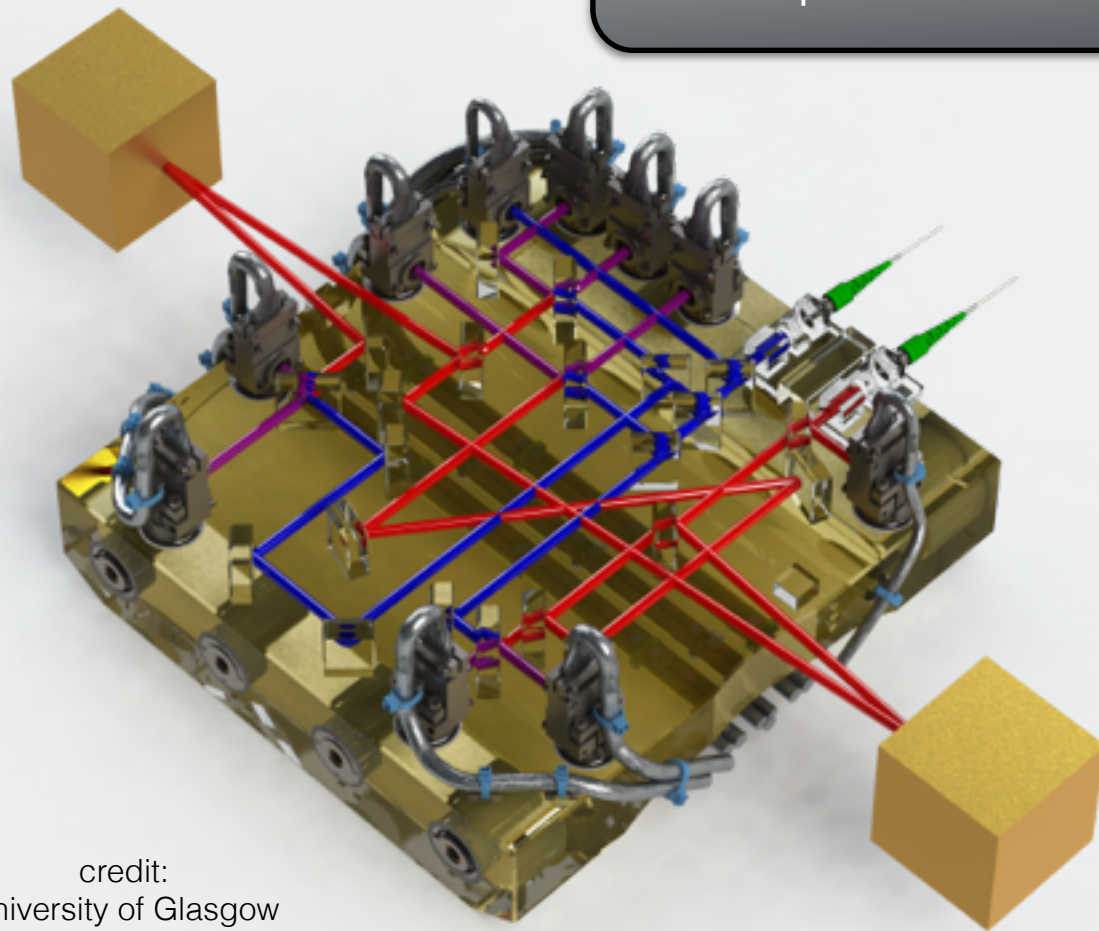
LPF **O**ptical **M**etrology **S**ystem (**O**MS)





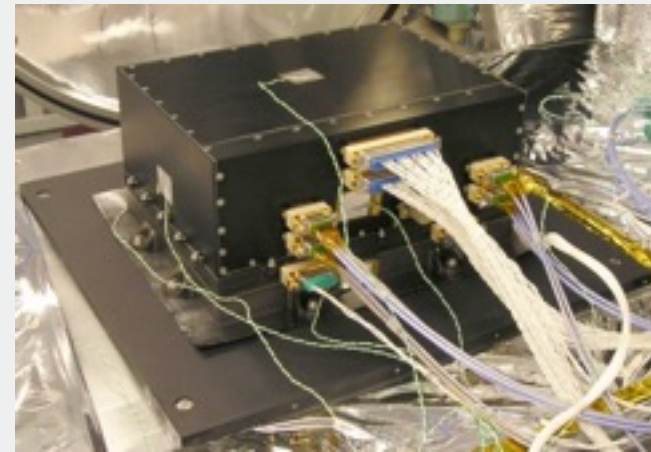
LPF Optical Metrology System (OMS)

optical bench



credit:
University of Glasgow

phaser unit



credit: University of Birmingham

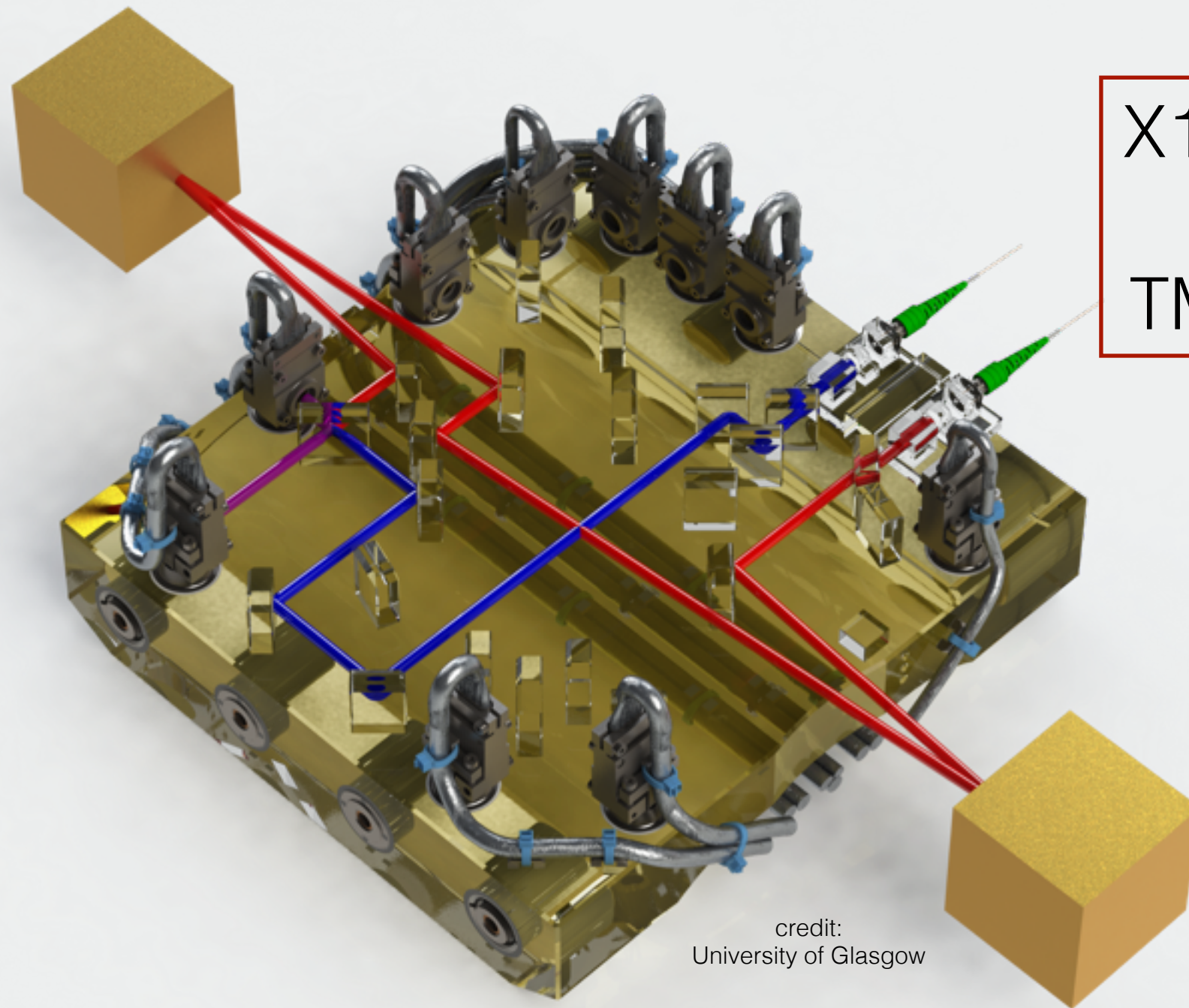
data management unit



credit: NTE-SENER



LPF optical bench: X12 interferometer

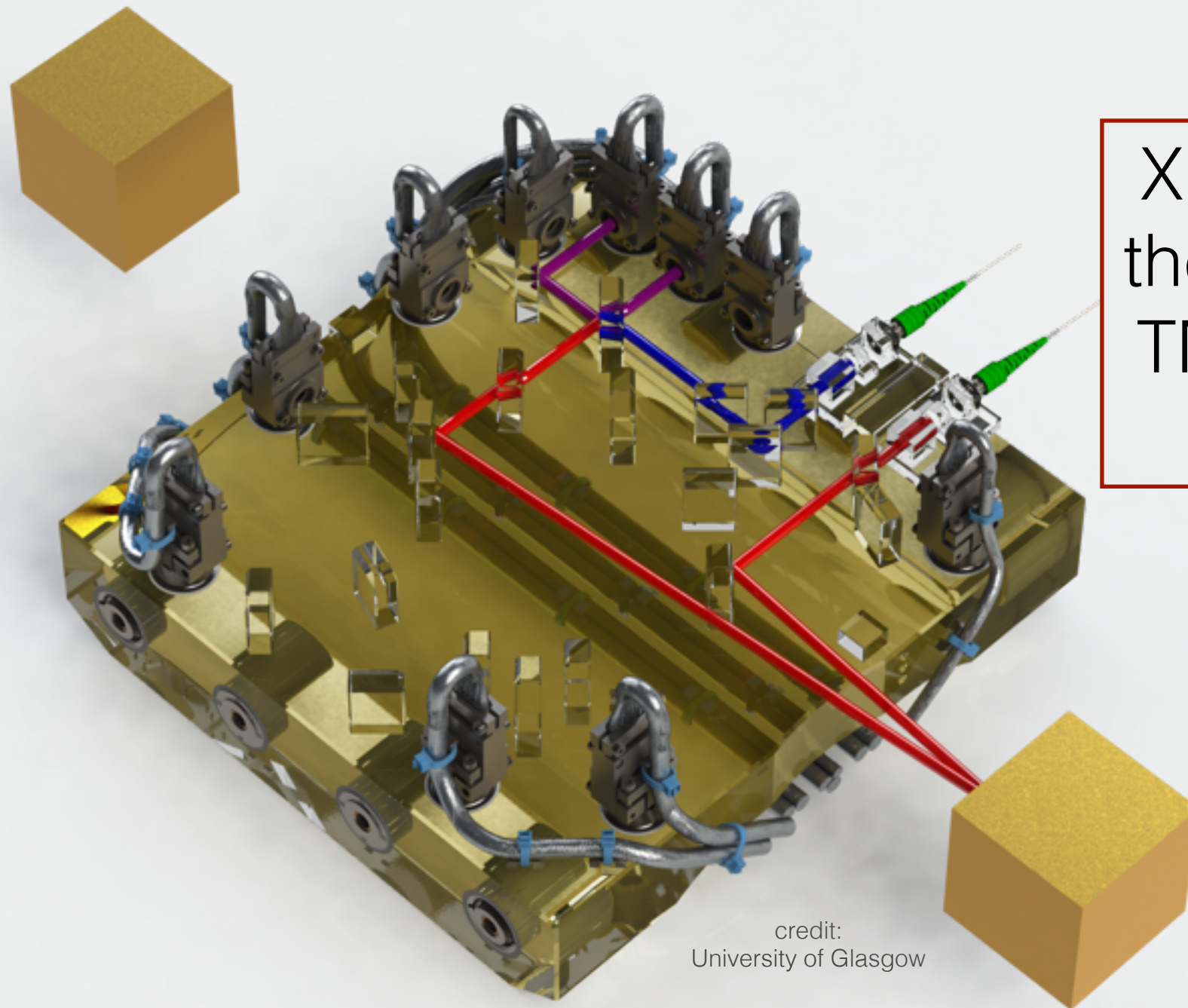


X12 measures
position of
TM2 w.r.t TM1

credit:
University of Glasgow

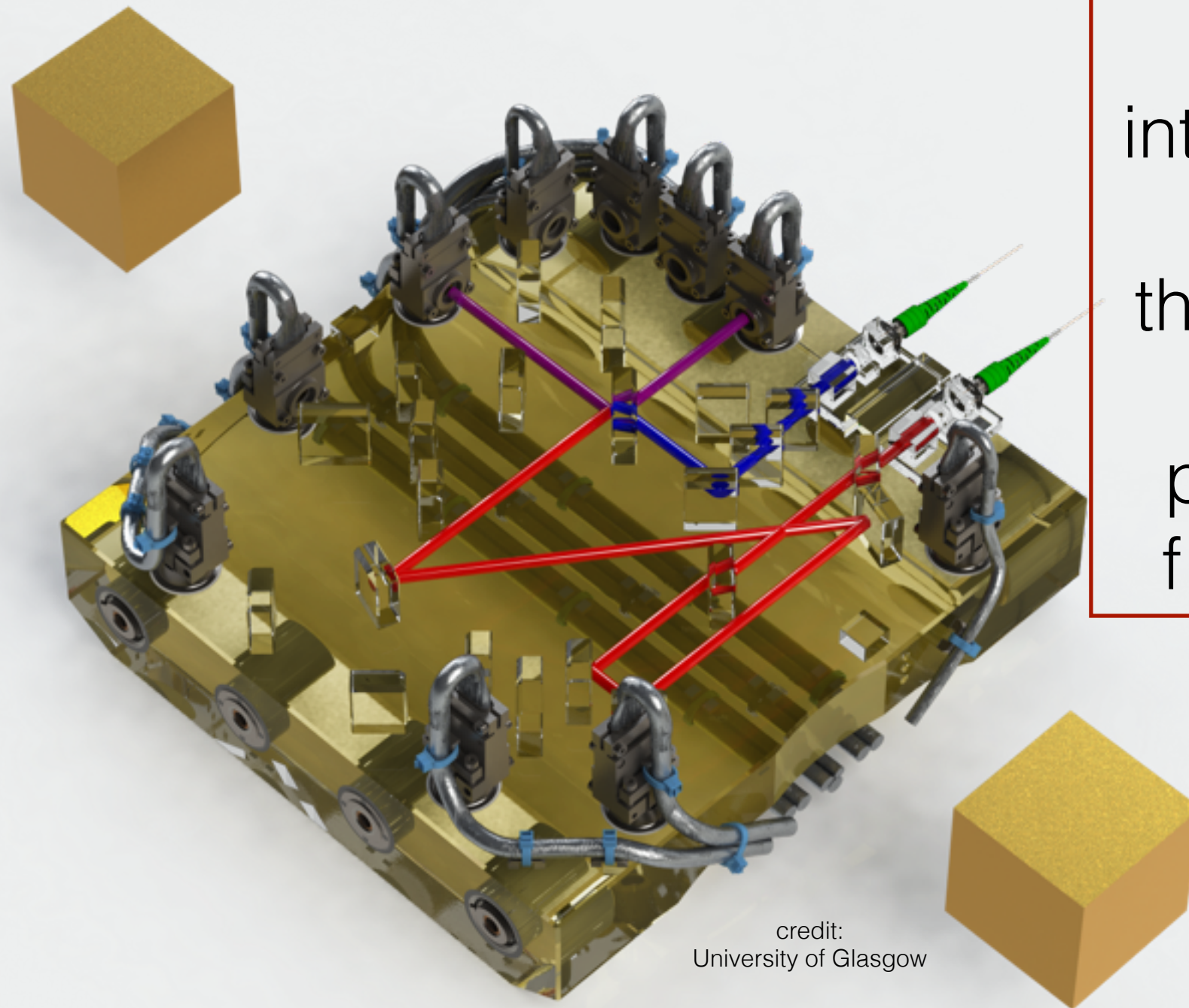


LPF optical bench: X1 interferometer





LPF optical bench: reference interferometer



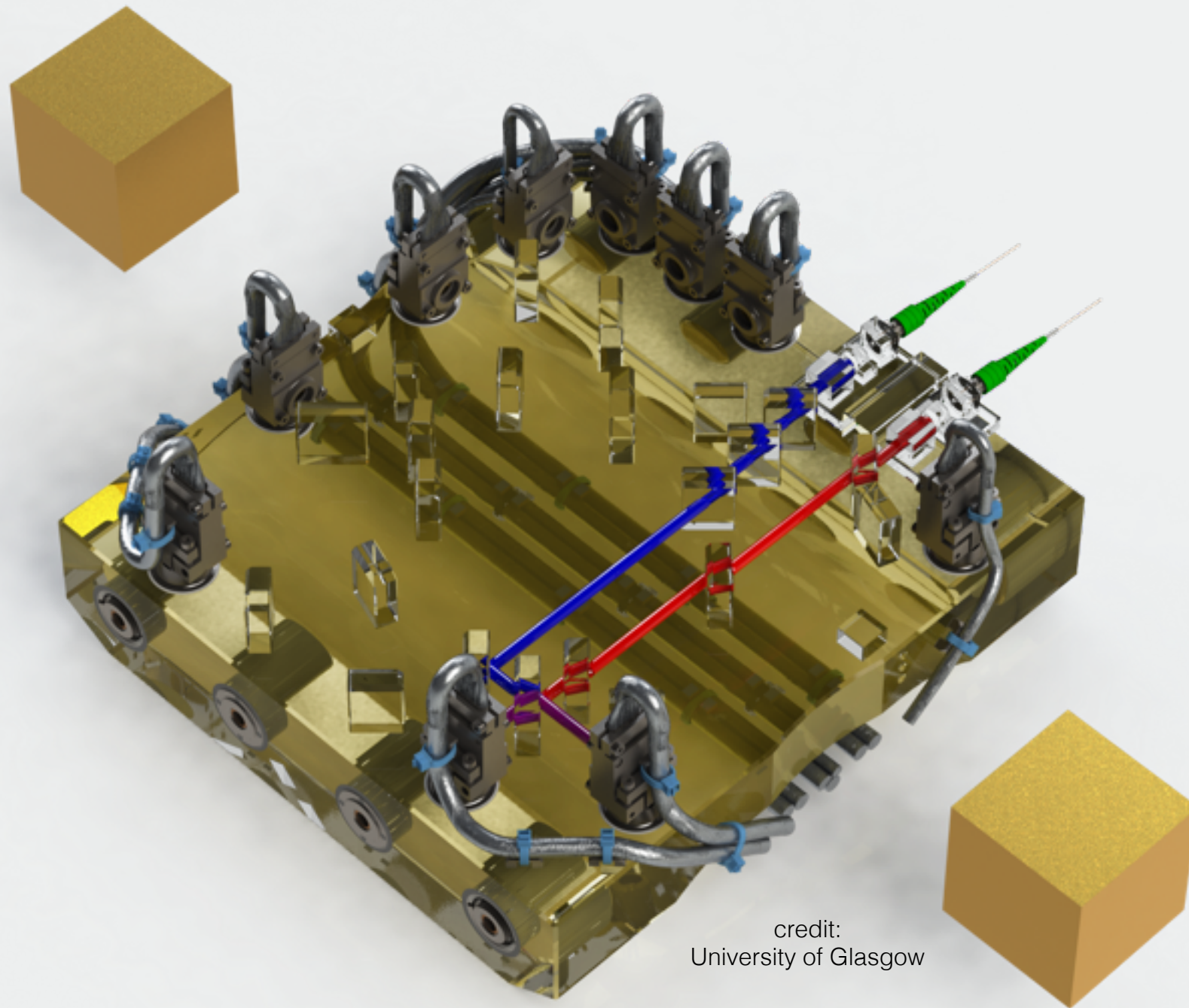
reference
interferometer
measures
the common-
mode
path length
fluctuations

credit:
University of Glasgow



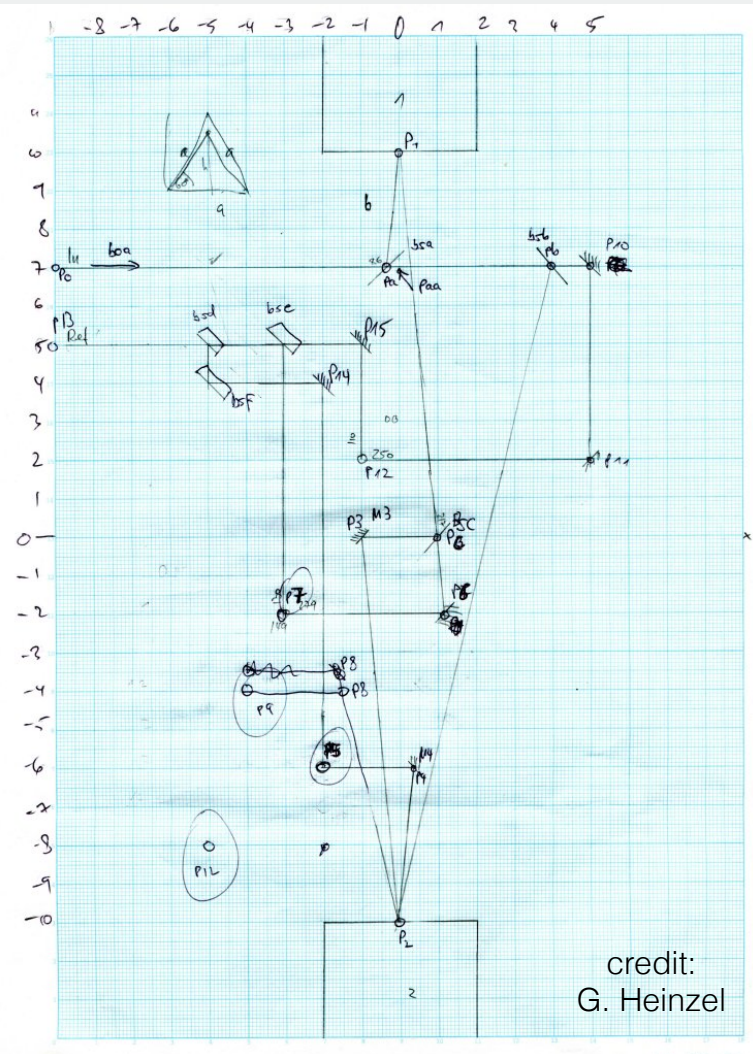
LPF optical bench: frequency interferometer

measures
the laser
frequency
fluctuations





LPF Optical Metrology System (OMS)



Idea (2001) ...

construction
and
development





LPF **O**ptical **M**etrology **S**ystem (**O****M****S**)



OMS noise sources: **L**aser **F**requency (**LF**) noise

phase noise
in X12, X1 or R

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

path length
difference
or arm length
mismatch

frequency
fluctuations

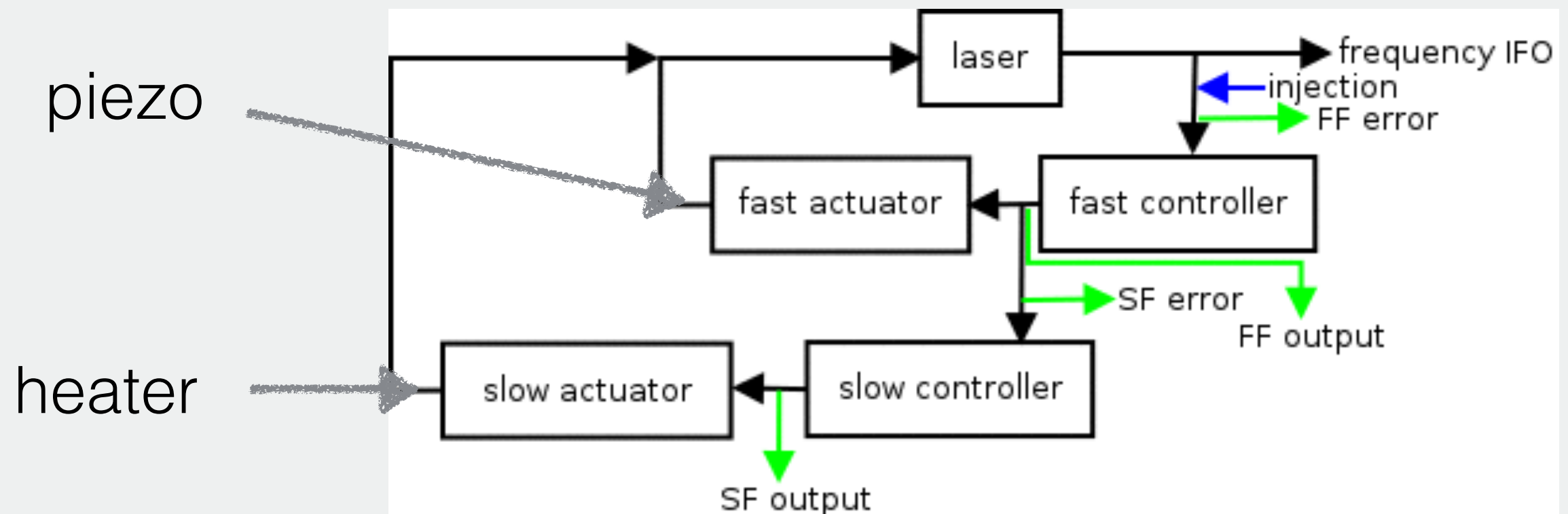


OMS noise sources: **L**aser **F**requency (**LF**) noise

functioning of loop
also verified by dedicated
characterisation experiments



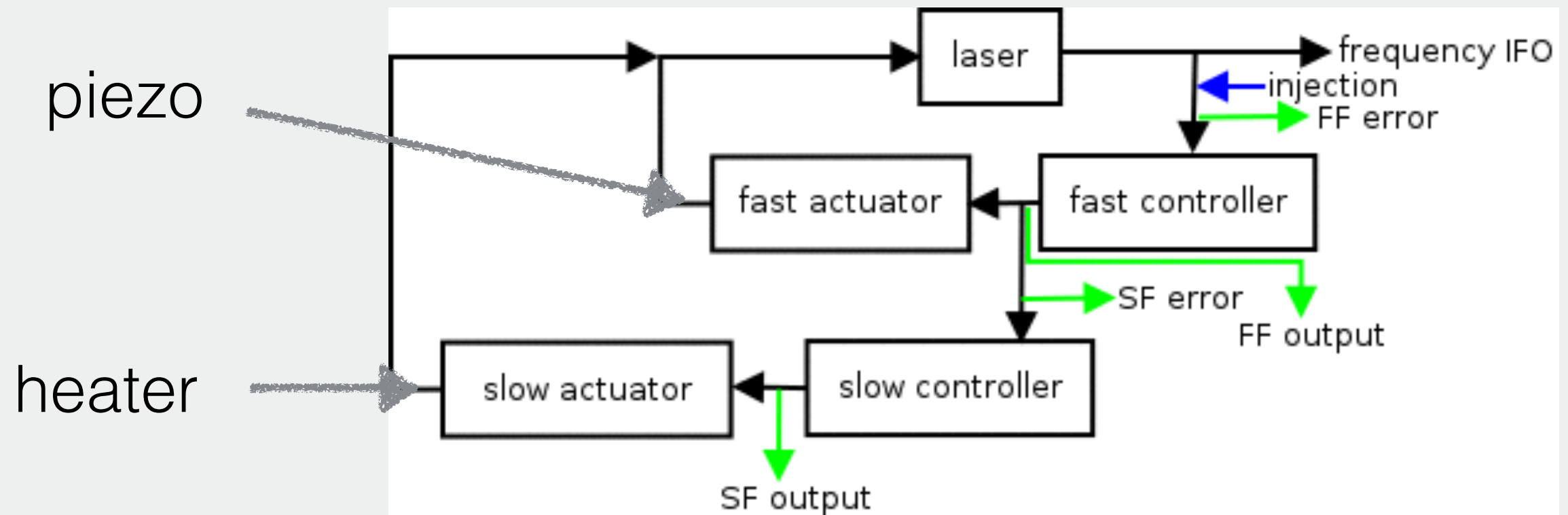
OMS noise sources: LF control loop experiments



- nested control loop
- implemented at 100 Hz inside DMU
- **green** = housekeeping data, frequency IFO = science data



OMS noise sources: LF control loop experiments



- experiment **idea**:

inject signals at different frequencies → estimate transfer functions



OMS noise sources: LF control loop experiments

science data

housekeeping
data

- timing between the two channels: different and varies over time
- processes started by different commands
- science data is synchronised to OBC time, HK to DMU time, low-priority task



OMS noise sources: LF control loop experiments

- problem specific to OMS loop analysis
- basic idea of approach: generate 1 Hz data from 10 Hz data with different offsets → compare correlations
- IDL = buffer to record HK data with sampling frequency above 1 Hz → different to laboratory on ground

date	satellite configuration	IDL use
DOY 027: 27-01-2016	TMs grabbed	x
DOY 164: 12-06-2016	TMs drag-free	✓
DOY 022: 22-01-2017	TMs drag-free	(✓)
DOY 096: 05-04-2017	TMs grabbed	✓



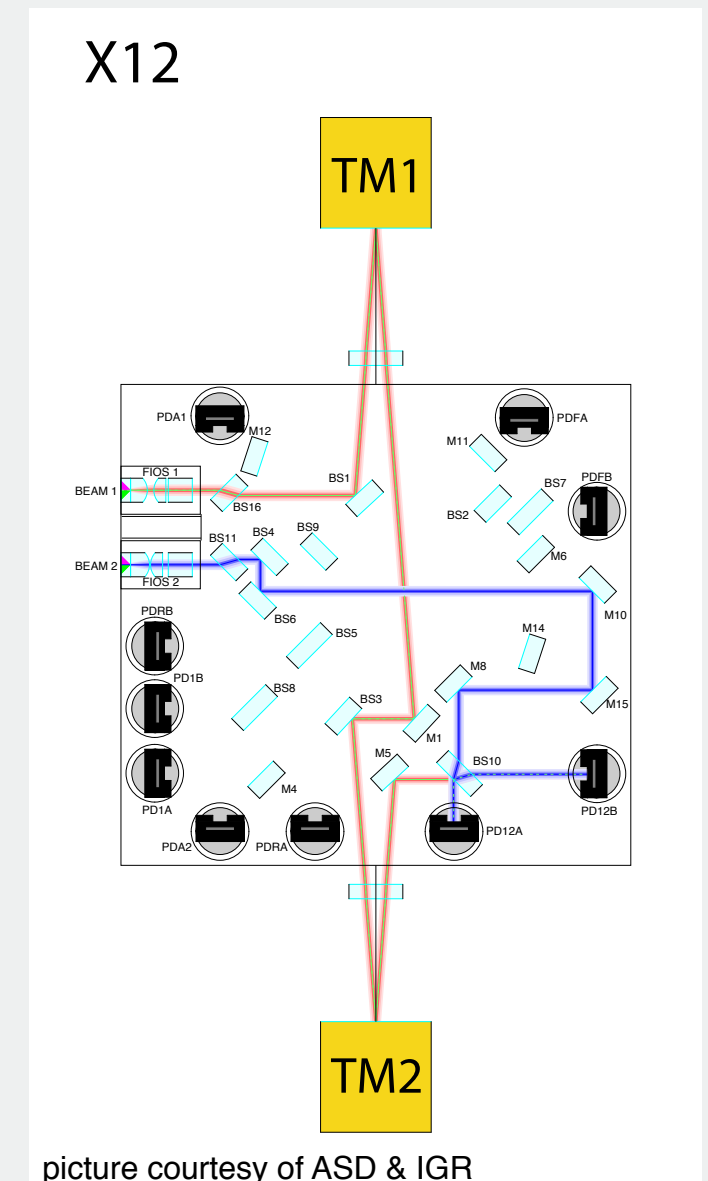
OMS noise sources: LF control loop experiments

- current results confirm solid performance



OMS noise sources: LF noise

- coupling of laser frequency noise allows us to estimate path length mismatch
- interesting because
 - measures **quality of integration**
 - needed for **OMS noise budget**
- applicable to X12, X1 and reference interferometer





OMS noise sources: LF noise: PL mismatch in X12

1. We move a TM \rightarrow PL mismatch changes accordingly
2. measured PL mismatch is independent of laser frequency modulation amplitude and frequency
3. PL mismatch for free-falling test masses varies between



OMS noise sources: common mode PL noise

investigation lead:
Michael Born

in addition:
optical
path length
difference
(OPD)
control loop

- actuators adjust PL of fibres in modulation unit



OMS noise sources: common mode PL noise

- OPD loop experiments similar to LF loop experiments
- With loop closed: suppression of PL fluctuations ...



OMS noise source: **Relative Intensity Noise (RIN)**

heterodyne interferometry:

investigation lead:
Andreas Wittchen

$$P(t) = P_{\text{Laser}}(t) (1 \pm c \cos(\omega_{\text{het}} - \varphi))$$

power impinging
on
photodiode

insert
fluctuations

contrast

heterodyne
frequency



OMS noise source: **Relative Intensity Noise (RIN)**

phasemeter: only
terms at
heterodyne frequency



RIN @
DC
heterodyne frequency
2x heterodyne frequency



OMS noise source: RIN experiment concept



OMS noise source: RIN experiment results

- noise at different test mass positions:



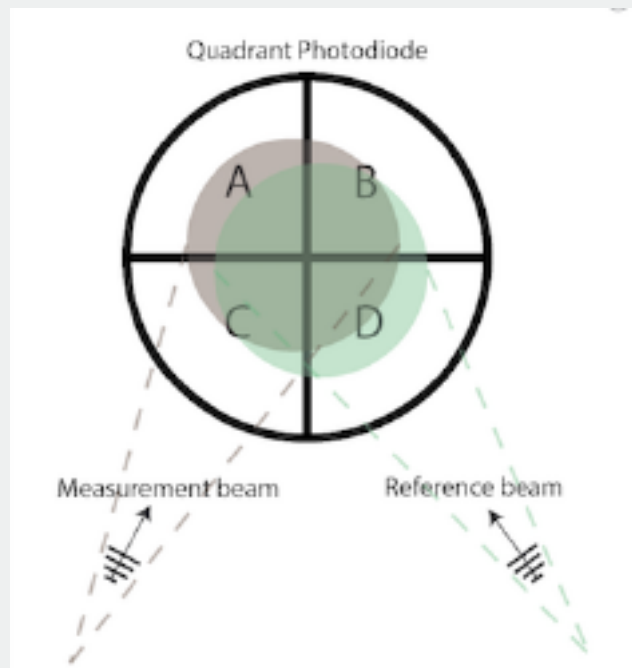
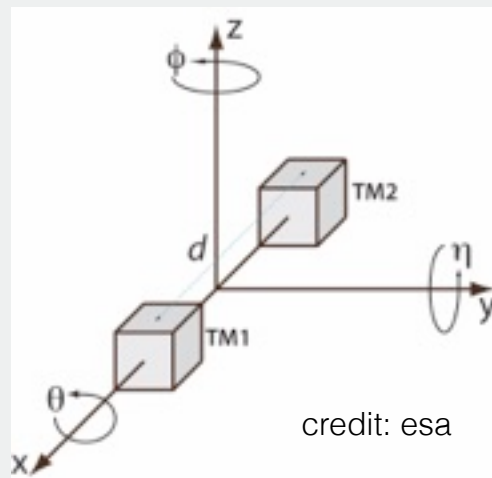
OMS noise source: RIN experiment results



OMS angular measurements: Differential **W**avefront **S**ensing (DWS)

measure 2 rotations
per test mass

investigation lead:
Lennart Wissel





OMS angular measurements: DWS step experiments

- how does the noise level change with rotation of test masses?



OMS noise budget

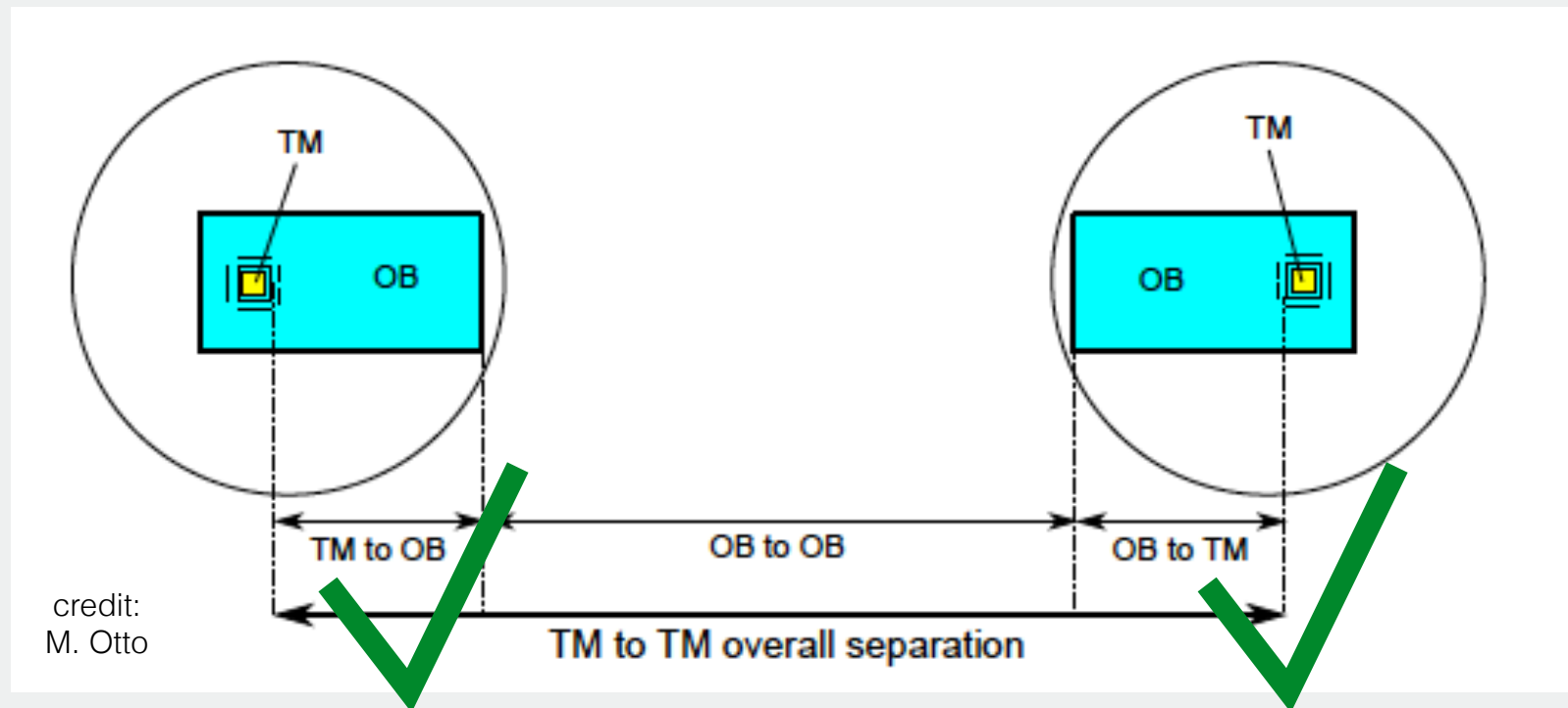


summary & conclusions

- excellent performance
 - more than 100x better than on ground
 - in-depth analysis for future interferometer development
 - OMS performance limited by phasemeter noise
- other main noise sources
 - laser frequency noise
 - relative intensity noise (RIN)



Outlook: LISA and the split-interferometry concept



- high precision local interferometry at the core of LISA
- **successfully tested by LISA Pathfinder OMS**
- long-arm interferometry: (some) insight from Grace Follow-On Laser Ranging Instrument expected

Thank you for your attention!
