



**HAL**  
open science

# A general method for the measurement of coherent stray light in optical systems and application to complex interferometers

Michel Lintz

► **To cite this version:**

Michel Lintz. A general method for the measurement of coherent stray light in optical systems and application to complex interferometers. WITSO Workshop on Innovative technologies in Space Optics, ESA, Nov 2023, Noordwijk, Netherlands. hal-04308611

**HAL Id: hal-04308611**

**<https://hal.science/hal-04308611>**

Submitted on 27 Nov 2023

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

# A general method for the measurement of coherent stray light in optical systems and application to complex interferometers

**Michel Lintz**

CNRS ARTEMIS / Observatoire de la Côte d'Azur

Nice, France



**Stray light = unwanted light** in an instrument, an experiment, ... A problem in:



- imaging
- spectroscopy
- polarimetry
- ...

Particularly with **coherent** stray light:  $\sim 2 \times \frac{A_{Stray\ Light}}{A_{Nominal\ Light}} = 2 \times \sqrt{\text{stray light power} / \text{nominal light power}}$

At component level, and at system level, in

- atomic clocks with optical pumping
- tests masses (added radiation pressure)
- interferometers in general
- in space missions with interferometers
  - GRACE-FO (interferometry over  $\approx 200$  km)
  - LISA mission and all the gravitational wave detectors (ground or space)
  - need for the measurement and identification of stray light at system level

# Stray light group at ARTEMIS:

Amaël ROUBEAU-TISSOT (PhD st.,  and )

Marco NARDELLO

Frédéric CLEVA

Michel LINTZ

# Measurement/identification of stray light at system level

**Time of flight techniques:**

- ultra-fast laser source
- ultra-fast detectors

**=> knowledge on the distance (hence the path) followed by stray light**

**...next talk !**

**Coherent techniques: can be implemented after the assembly of the system under test, using the system's detectors**

**Well-known method in radar techniques ("FMCW", frequency-modulated continuous wave)**

**Commercial reflectometers for the monitoring of faults in telecom networks**

**...but not adapted to measuring stray light in LISA**

- stray light in LISA is not just optical return (scattered light, diffraction, ghosts, .. to all the detectors)

# Plan

**The LISA mission in one slide**

**General approach for the measurement and identification of coherent stray light**

**Measurement of stray light in the LISA's "MOSA"**

**The frequency-ramped laser source, and the characterization of the instrument**

**Conclusion and perspectives**

# The "Laser Interferometer space Antenna" in one slide

Measures the variation of the 2.5 Mkm arm lengths  $10\text{pm}/\sqrt{\text{Hz}}$

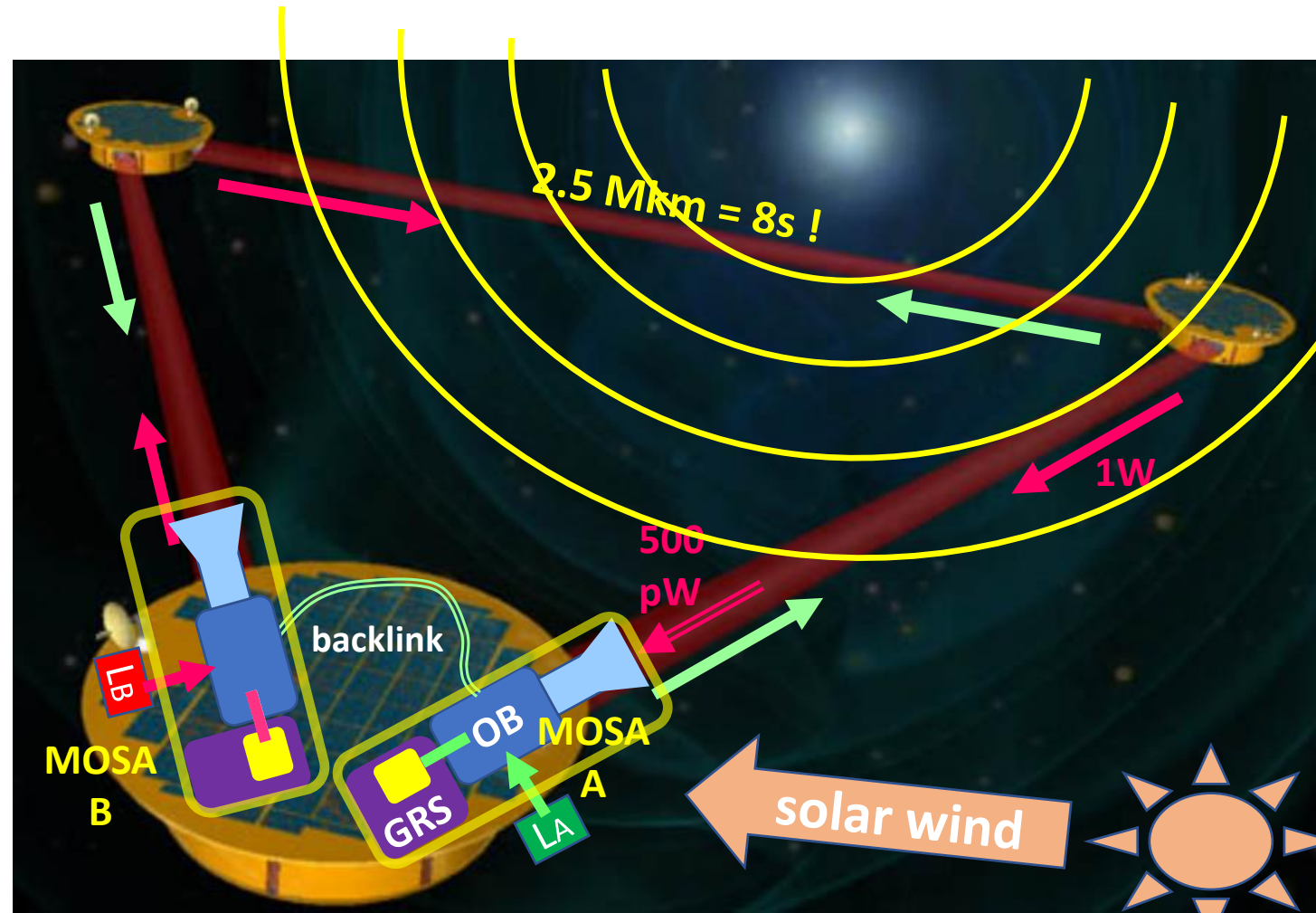
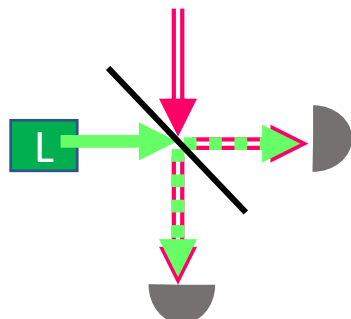
- records gravitational waves in the  $20\mu\text{Hz} - 1\text{Hz}$  band
- trous noirs supermassive black holes, primordial universe,...

The basic LISA instrument is the "moving optical sub-assembly" (MOSA)

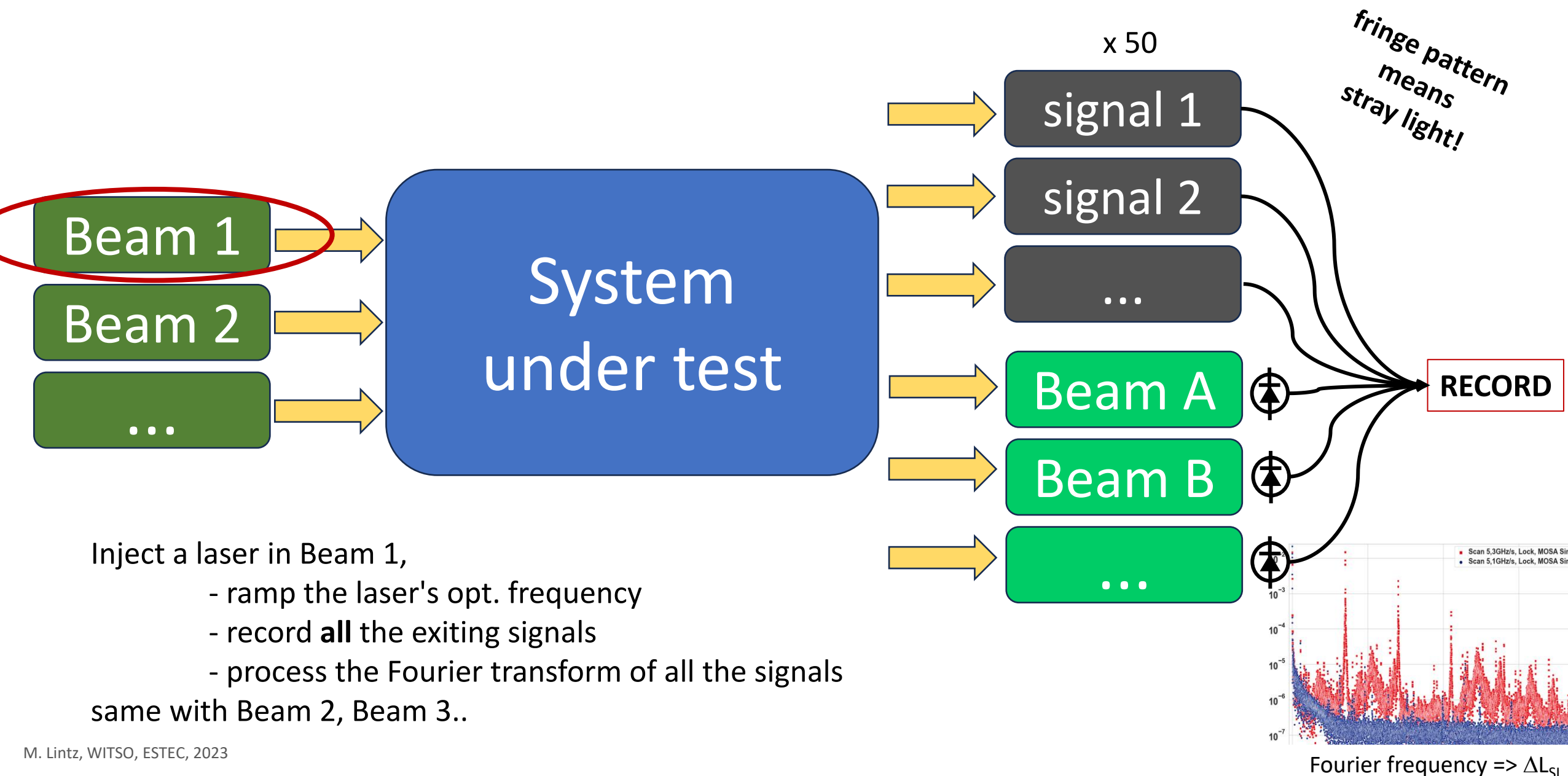
=> 2 MOSAs per spacecraft

=> 3 interferometers per MOSA

- "science" (long arm)
- "Test Mass"
- "reference"

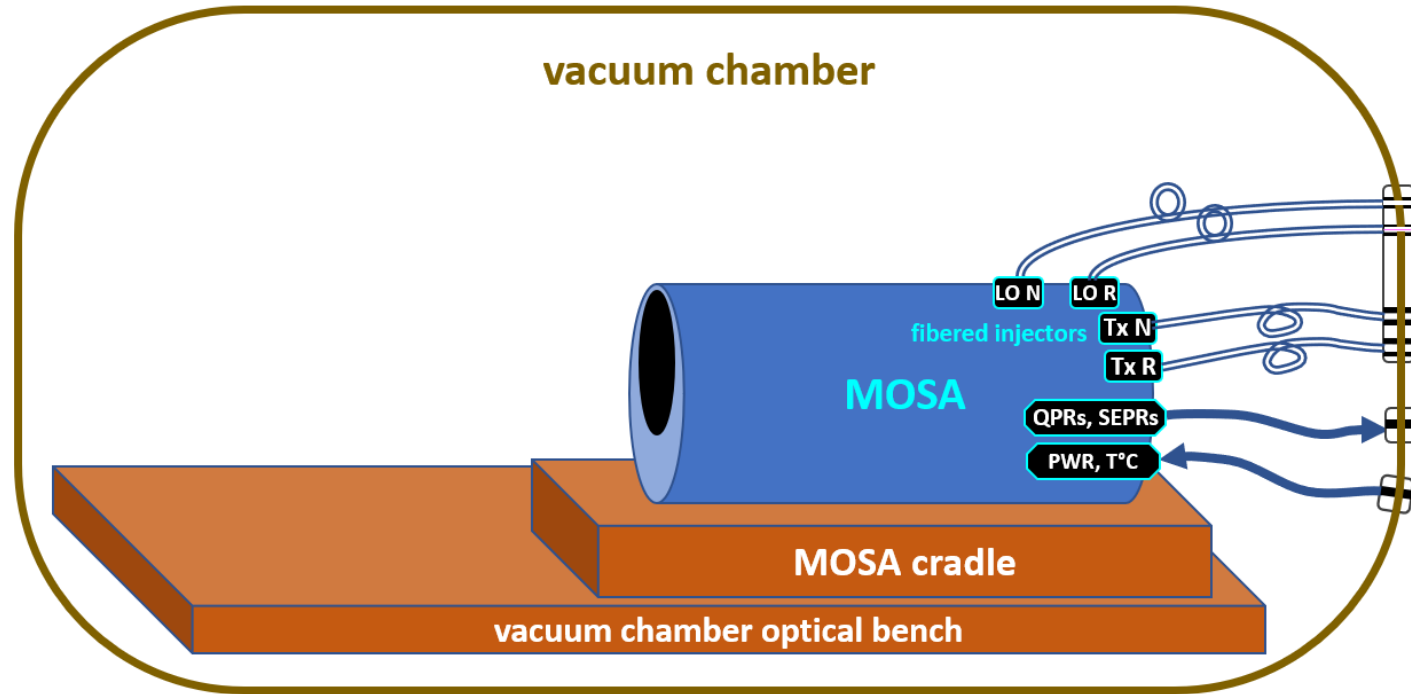


# Measurement + identification of stray light in a complex optical system

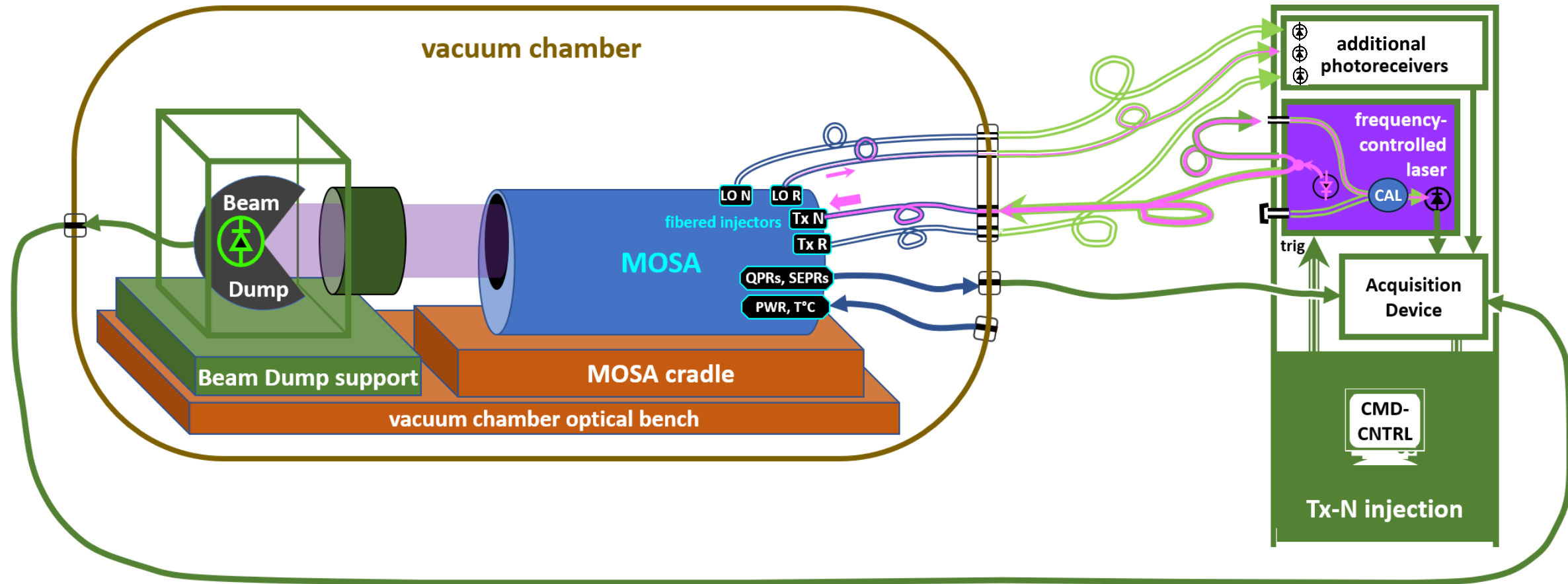




# The stray light measurement in LISA's MOSA



# The stray light measurement in LISA's MOSA



- Laser source produces **two** beams:
  - one powerful,
  - the other  $\approx 1\text{mW}$ , low power
- beam emitted => **beam dump required**

Need for the "calibrator" unit and signal

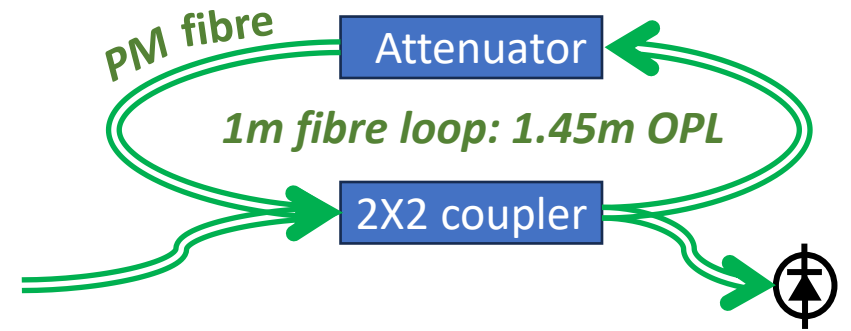
# The frequency-ramped laser source: monitoring the ramp

Frequency ramp must be linear ( $<10^{-4}$ ), with a known and reproducible value

=> The "calibrator" is a fibered interferometer which monitors

- the linearity of the frequency ramp
- the reproducibility of the ramp rate
- the absence of stray frequency modulations

and more



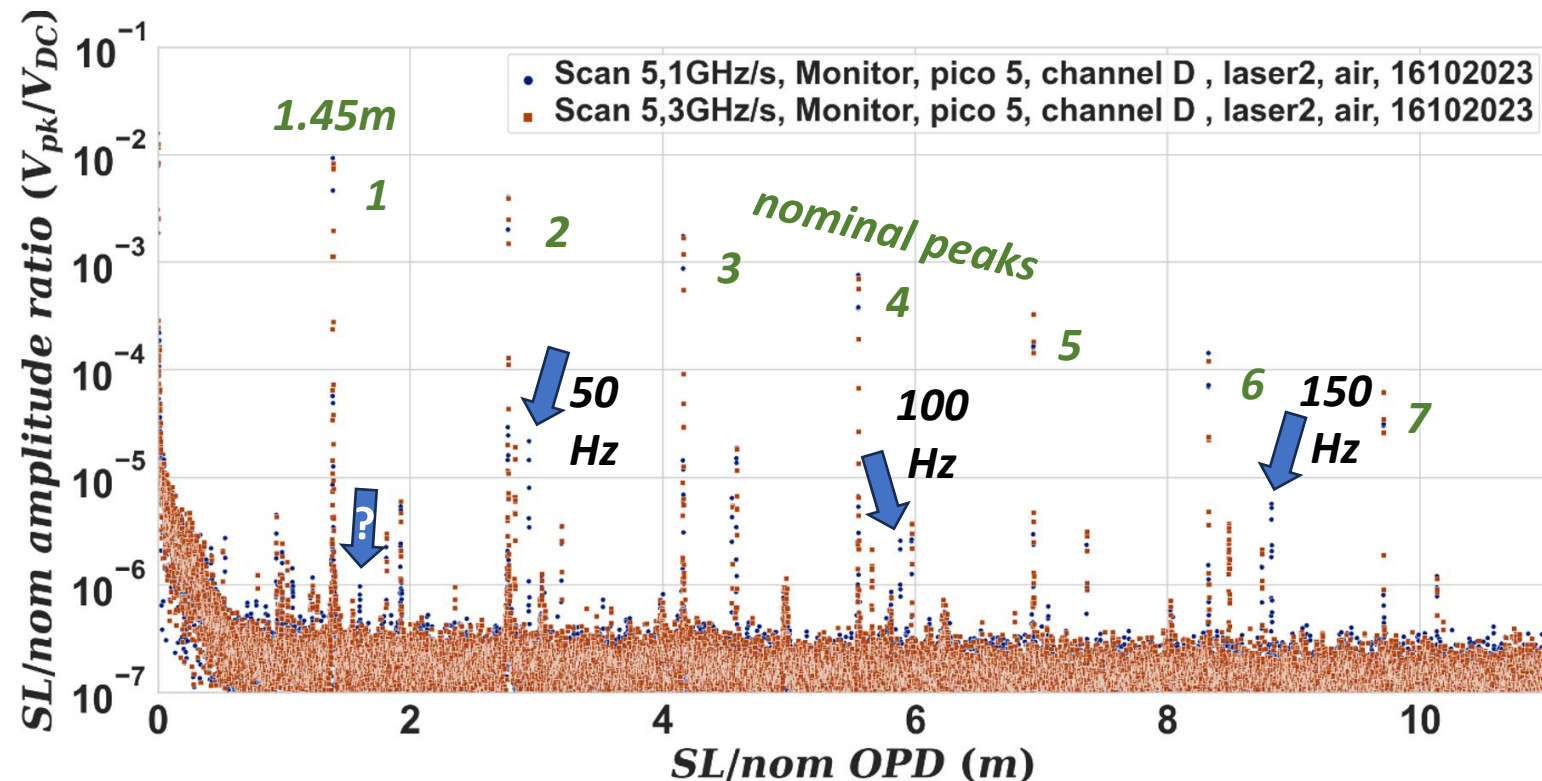
=> 7 nominal peaks

sharp enough to appreciate the ramp to  $\ll 10^{-4}$   
allows real-time fine monitoring of the ramp

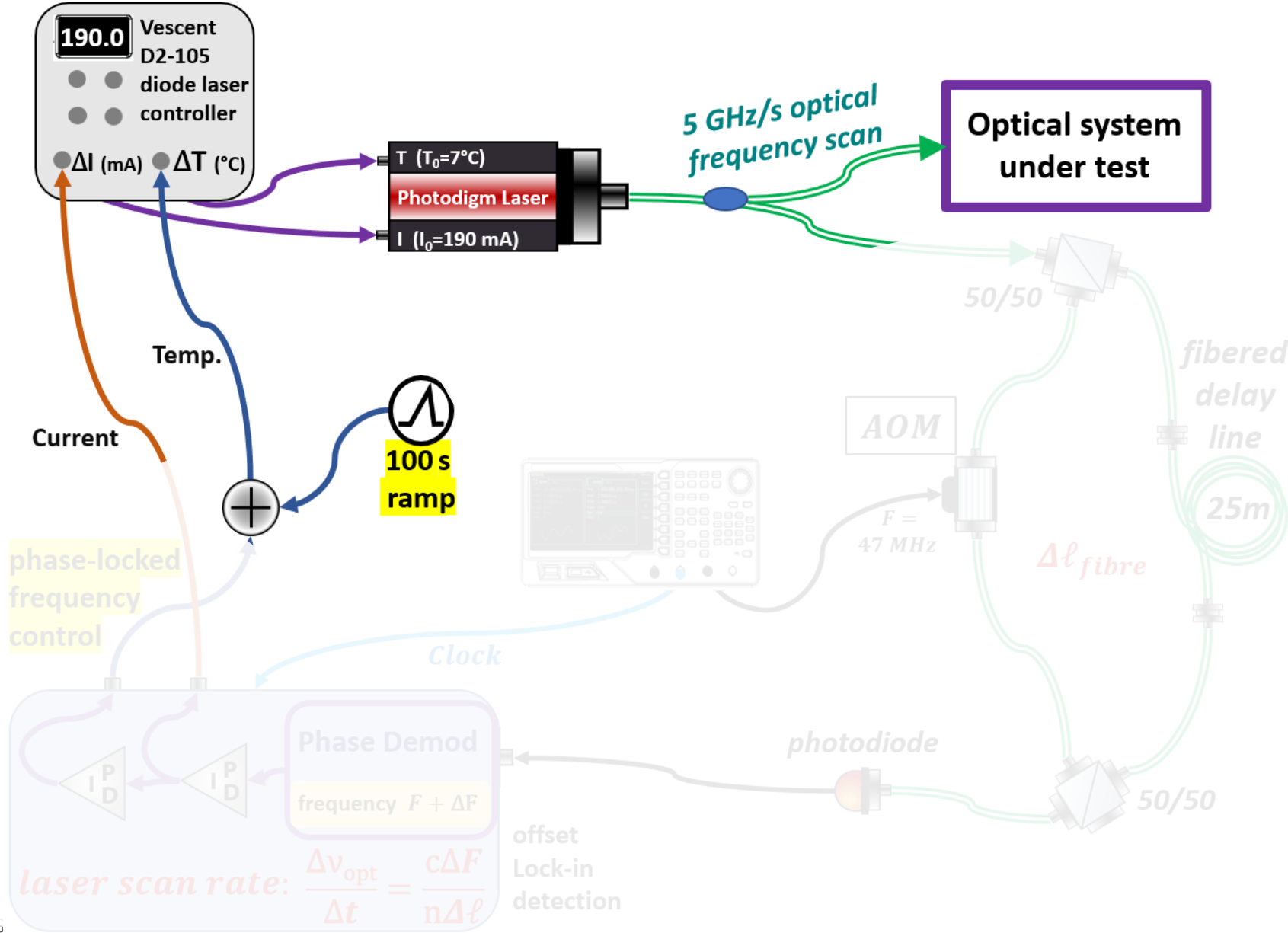
Trick to identify parasitic peaks:

- first scan with scan rate SR1
- second scan with rate SR2

=> only true optical contributions  
give overlapping peaks !

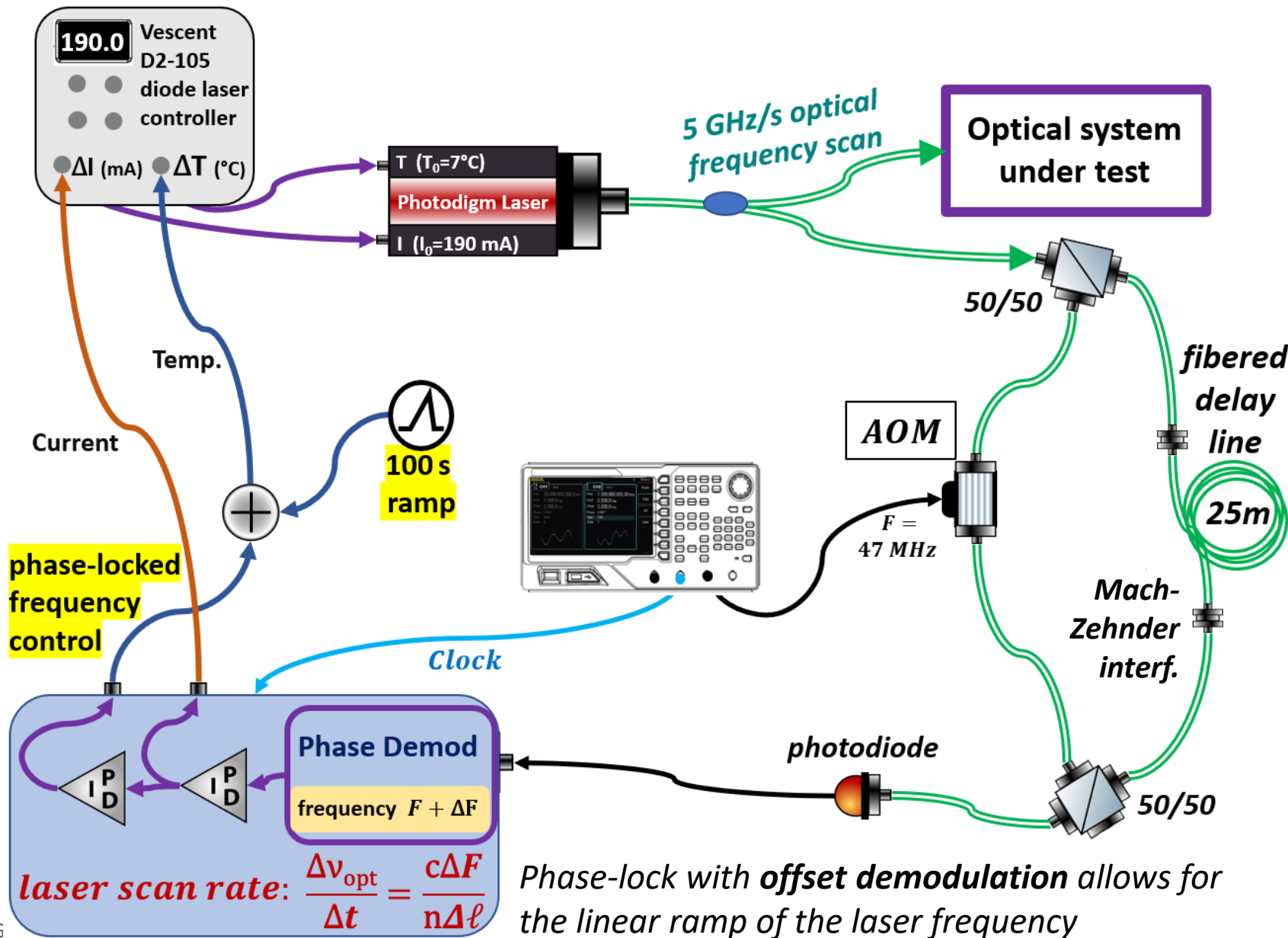


# Implementation of the laser



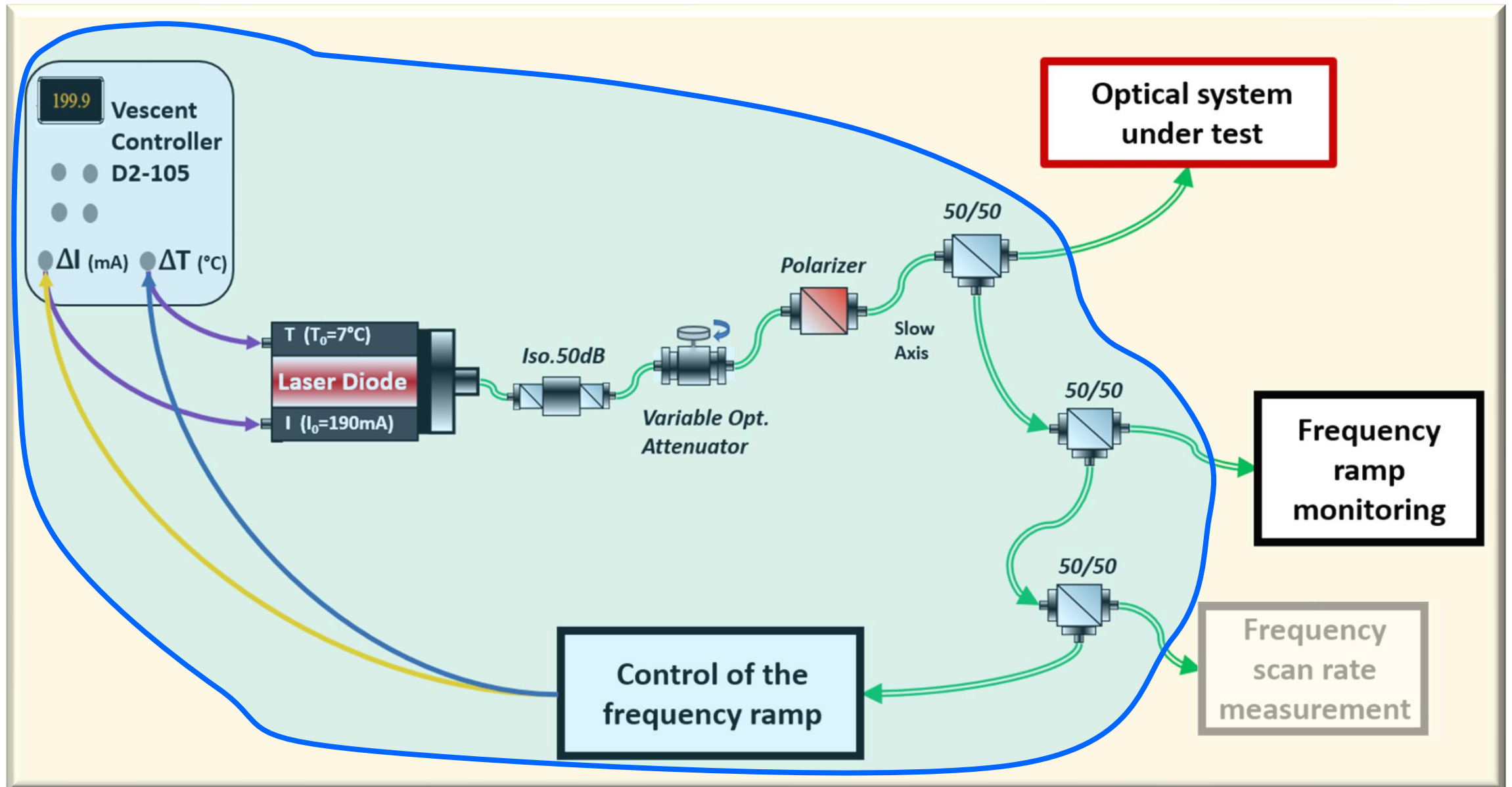
2nm-span optical frequency-scanned laser source

# Implementation of the frequency swept laser source



2nm-span optical frequency-scanned laser source

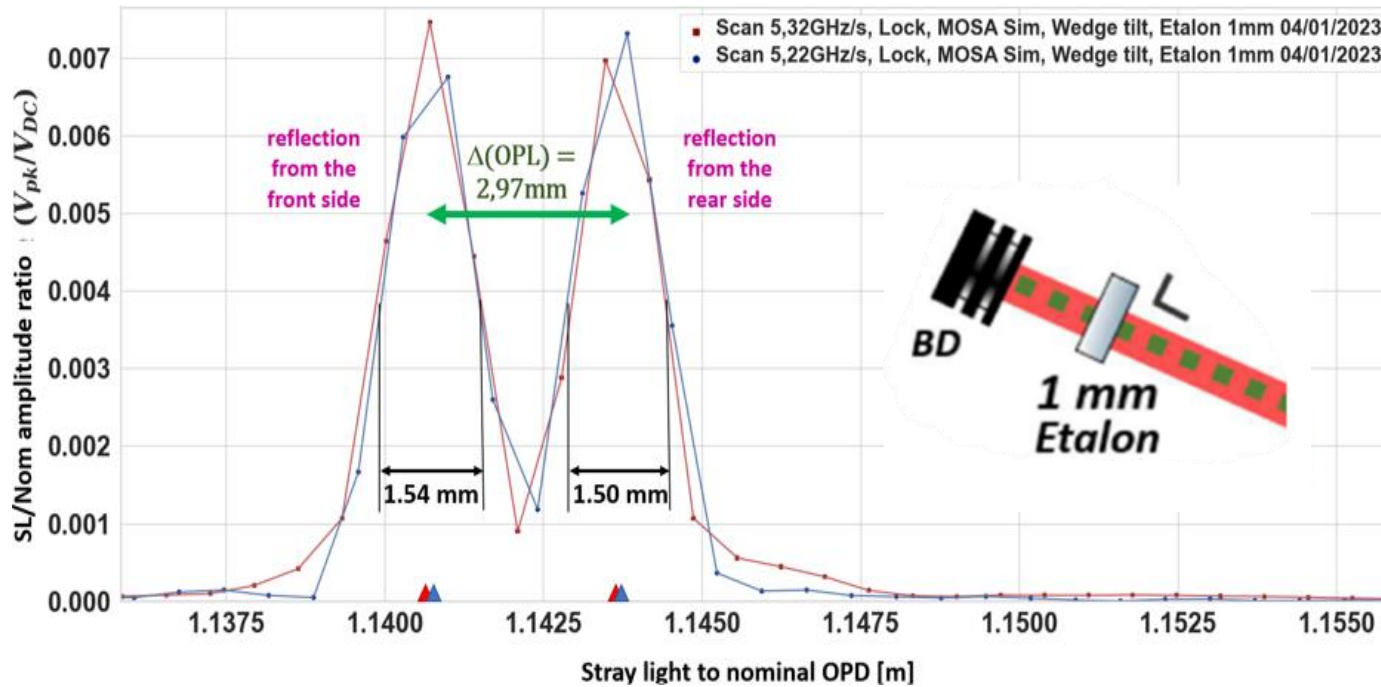
# Implementation of the frequency swept laser source



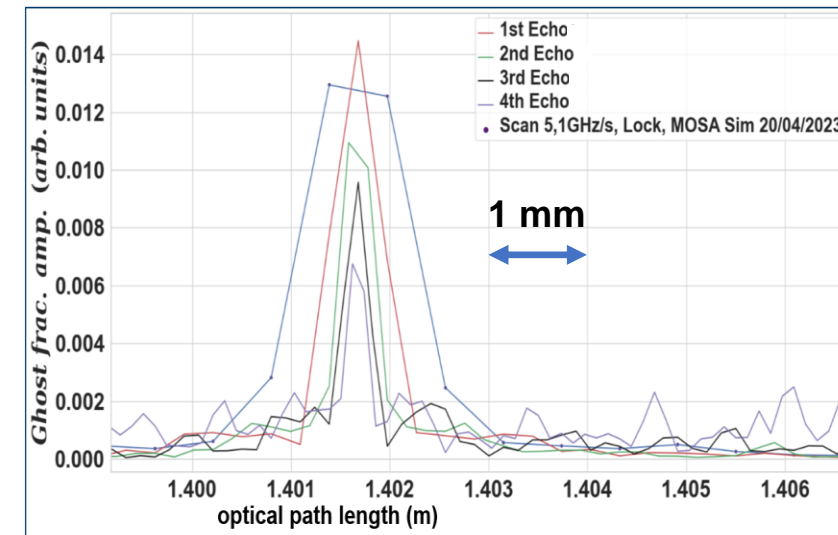


# Characterization of the SL measurement: OPD resolution

- Spectroscopist's resolution  
Resolution between nearby peaks,  
characterized with a 1mm silica etalon  
optical frequency scan: 530GHz ( $\approx 2\text{nm}$ )



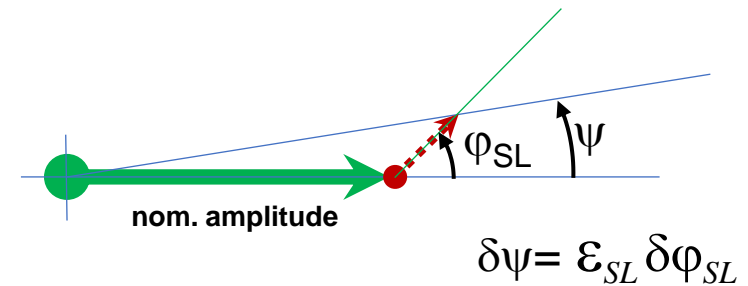
- Metrologist's resolution:  
Reproducibility/consistency  
at the 0.1 mm level in the  
OPD measurements



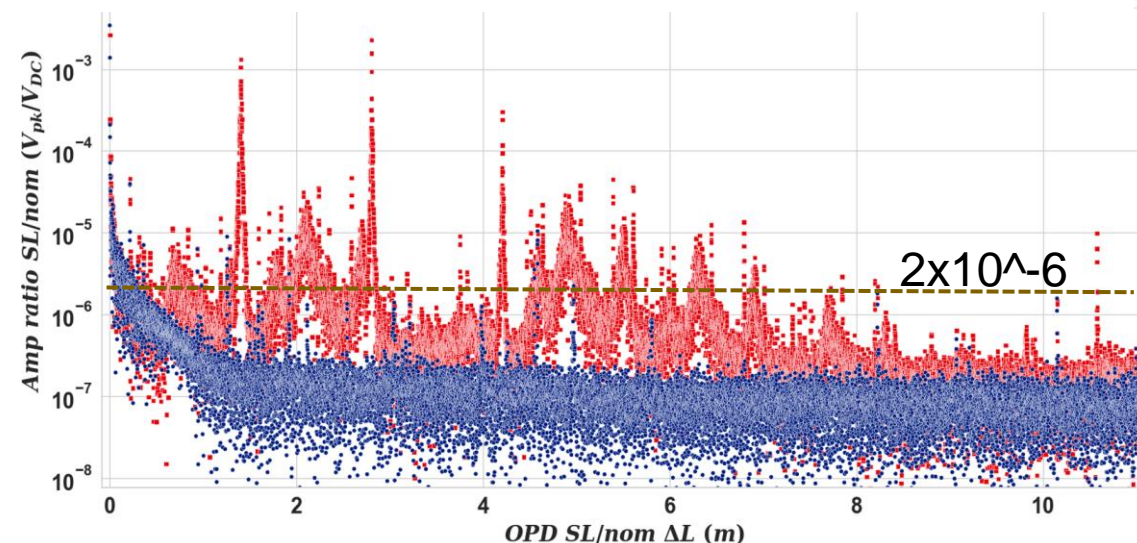
# What noise floor for the SL optical amplitude measurement ?

- For each component the "acceptable fractional SL amplitude"  $\epsilon_{\text{accept-SL}}$  stems from the performance model:
  - noise in the LISA measurement should not exceed 10 pm/ $\sqrt{\text{Hz}}$  with less than  $\approx 1$  pm/ $\sqrt{\text{Hz}}$  from stray light
  - the allocation can be broken to 0.1 pm/ $\sqrt{\text{Hz}}$  for each contribution to stray light
- Then the acceptable fractional amplitude is given by

$$\epsilon_{\text{accept-SL}} = [\text{Allocation for stray light}] / [\text{SL path length noise}]$$



- Then the measurement floor must be  $< [\epsilon_{\text{accept-SL}}]_{\text{smallest}}$  with a margin (SNR) of 30
- Presently this leads to a fractional noise floor of  $2 \times 10^{-6}$  in the Fourier transform data.
- If an excess is observed with one component, the final check is globally, at MOSA level, against the Performance Model





# Conclusions and outlook

- Presently no showstopper with the prototype
- OK for the measurement of scattered light
- Noise floor at OPD < 1m to be improved by normalization of the signals
- "Polarization wobbling" reduces the effective dynamics
- Residual modulation in the laser's optical frequency scan (=> small, reproducible stray peak) to be reduced
- The large number of signals can lead to tedious, slow interpretation of the signals' Fourier transforms
  - how far the post-processing can be automated is an open question
- The prototype was recently coupled to a LISA-similar optical interferometer
  - to deal with more representative signals (20 simultaneous signals)
  - => develop automatic post-processing routines
  - => check for the difference **tests in vacuum** vs **tests in ambient air**
    - No striking difference apart from the index of air => **preliminary** <=

