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

**Michel Lintz**

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**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  $10\text{pm}/\sqrt{\text{Hz}}$

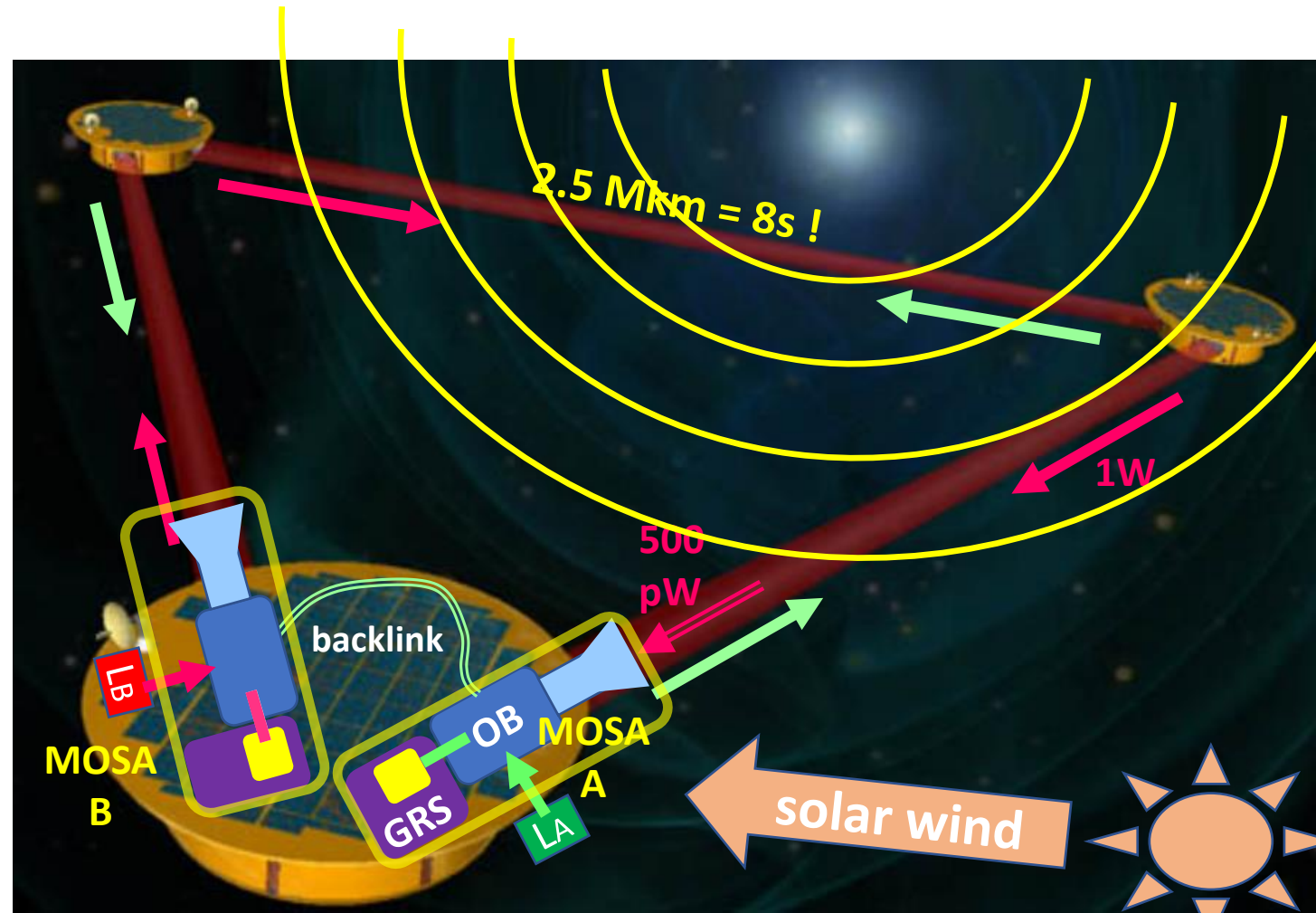
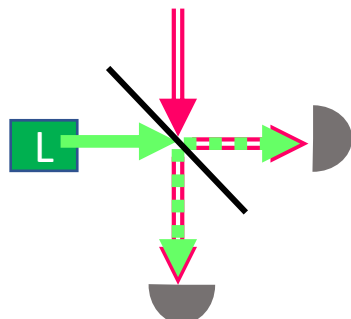
- records gravitational waves in the  $20\mu\text{Hz} - 1\text{Hz}$  band
- trous noirs supermassive black holes, primordial universe,...

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

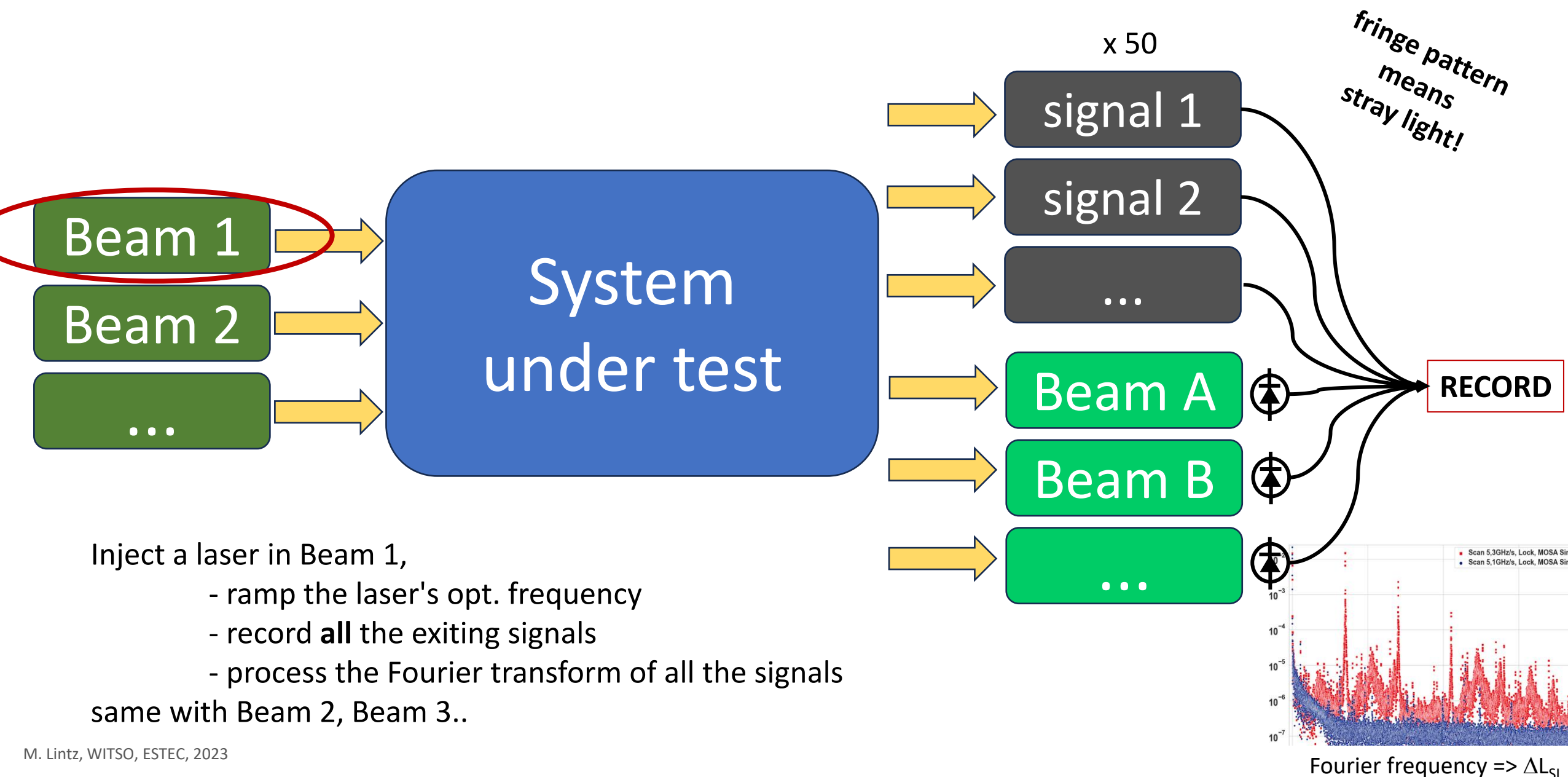
=> 2 MOSAs per spacecraft

=> 3 interferometers per MOSA

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

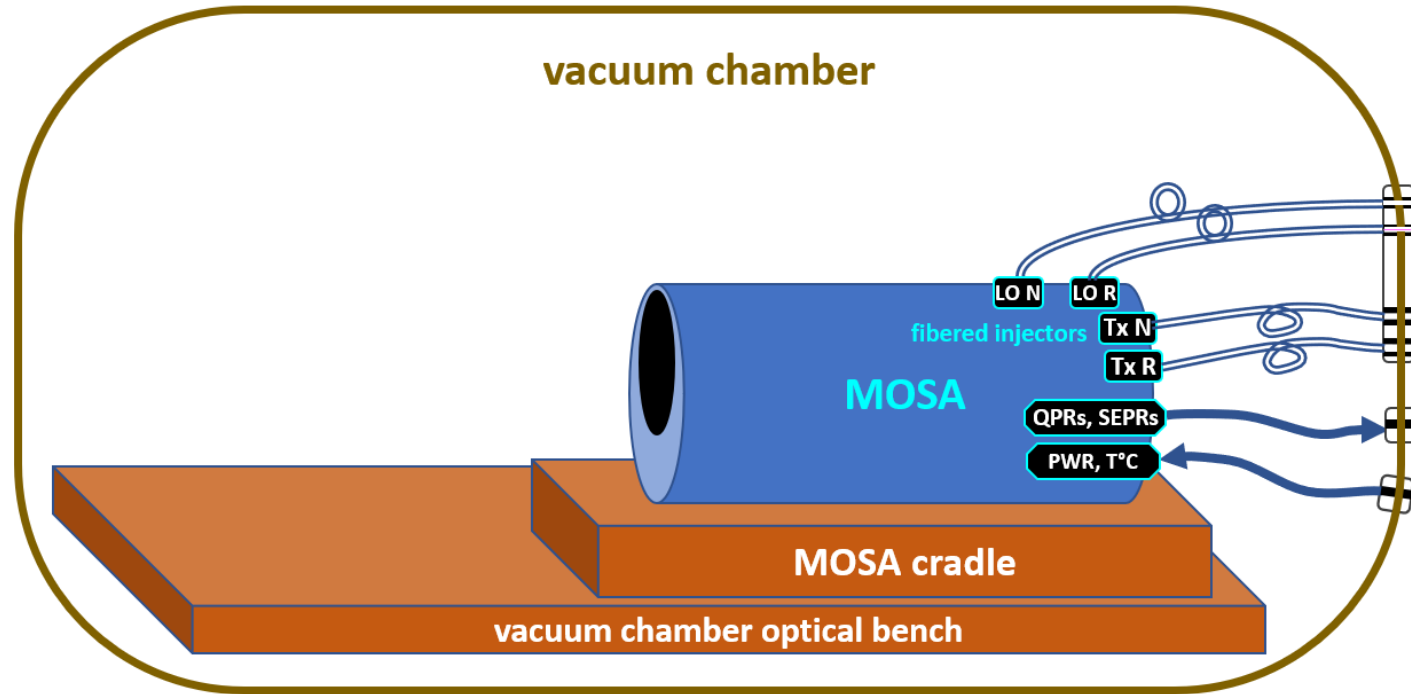


# Measurement + identification of stray light in a complex optical system

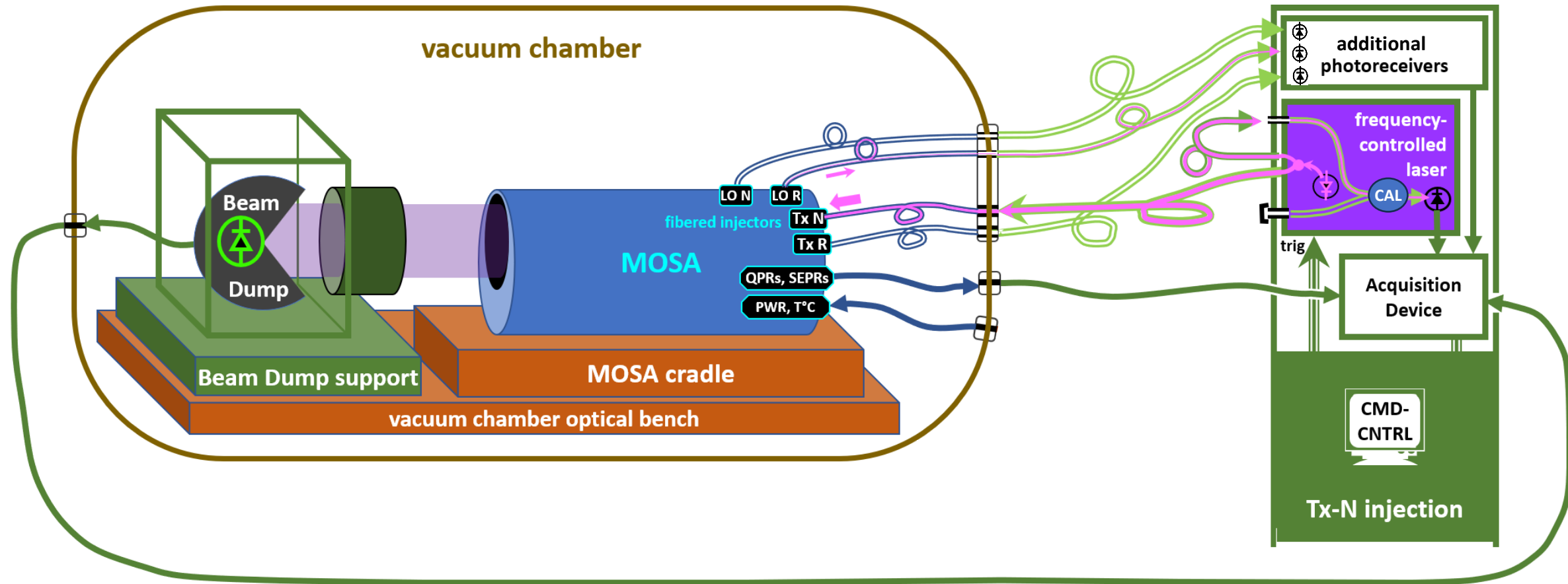




# The stray light measurement in LISA's MOSA



# 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

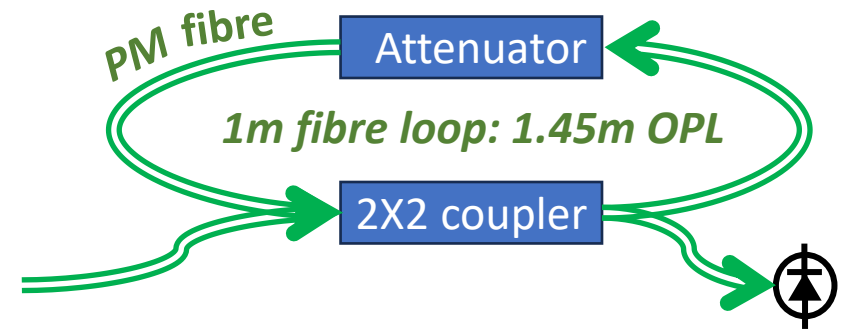
# The frequency-ramped laser source: monitoring the ramp

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



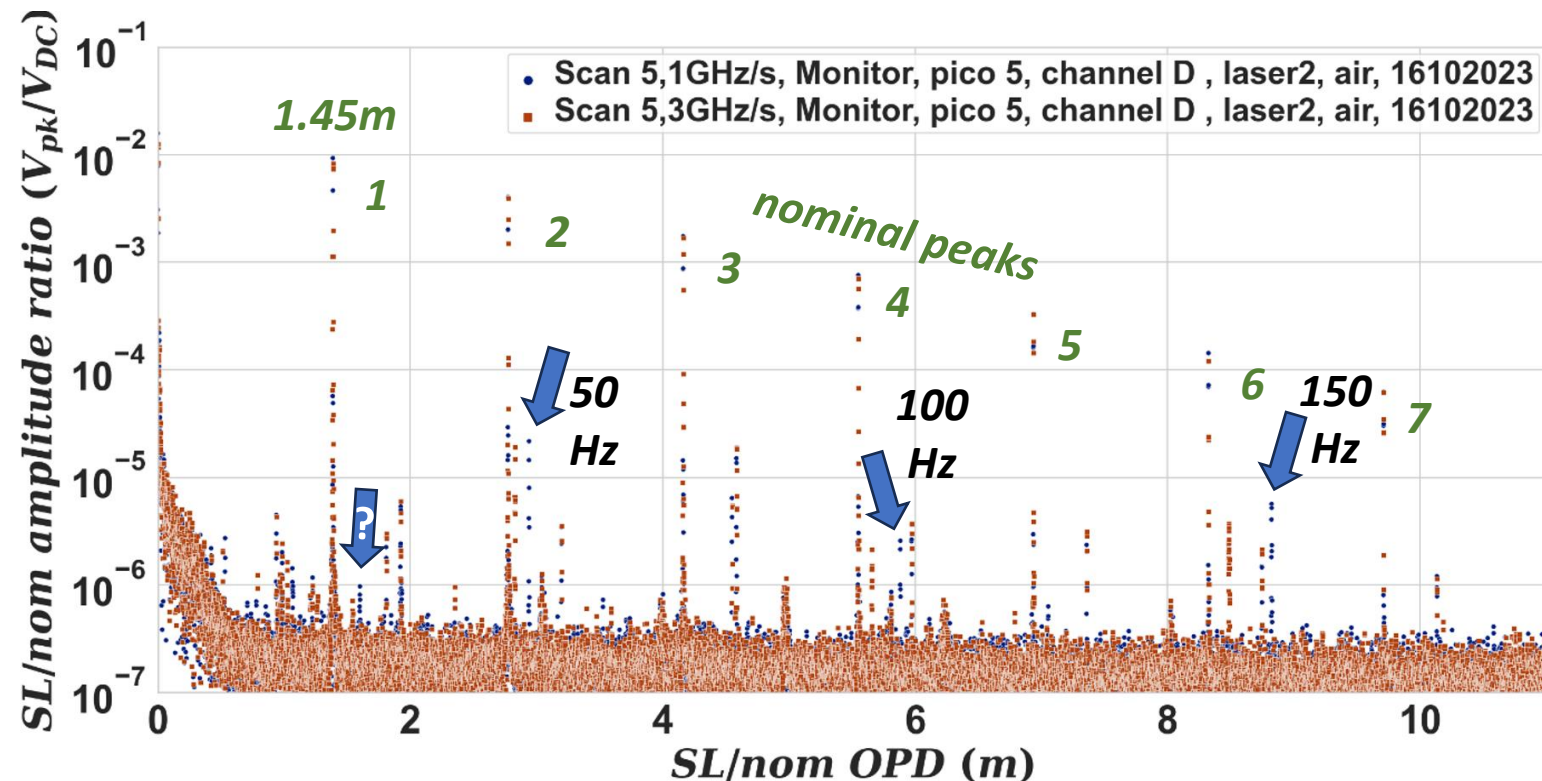
=> 7 nominal peaks

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

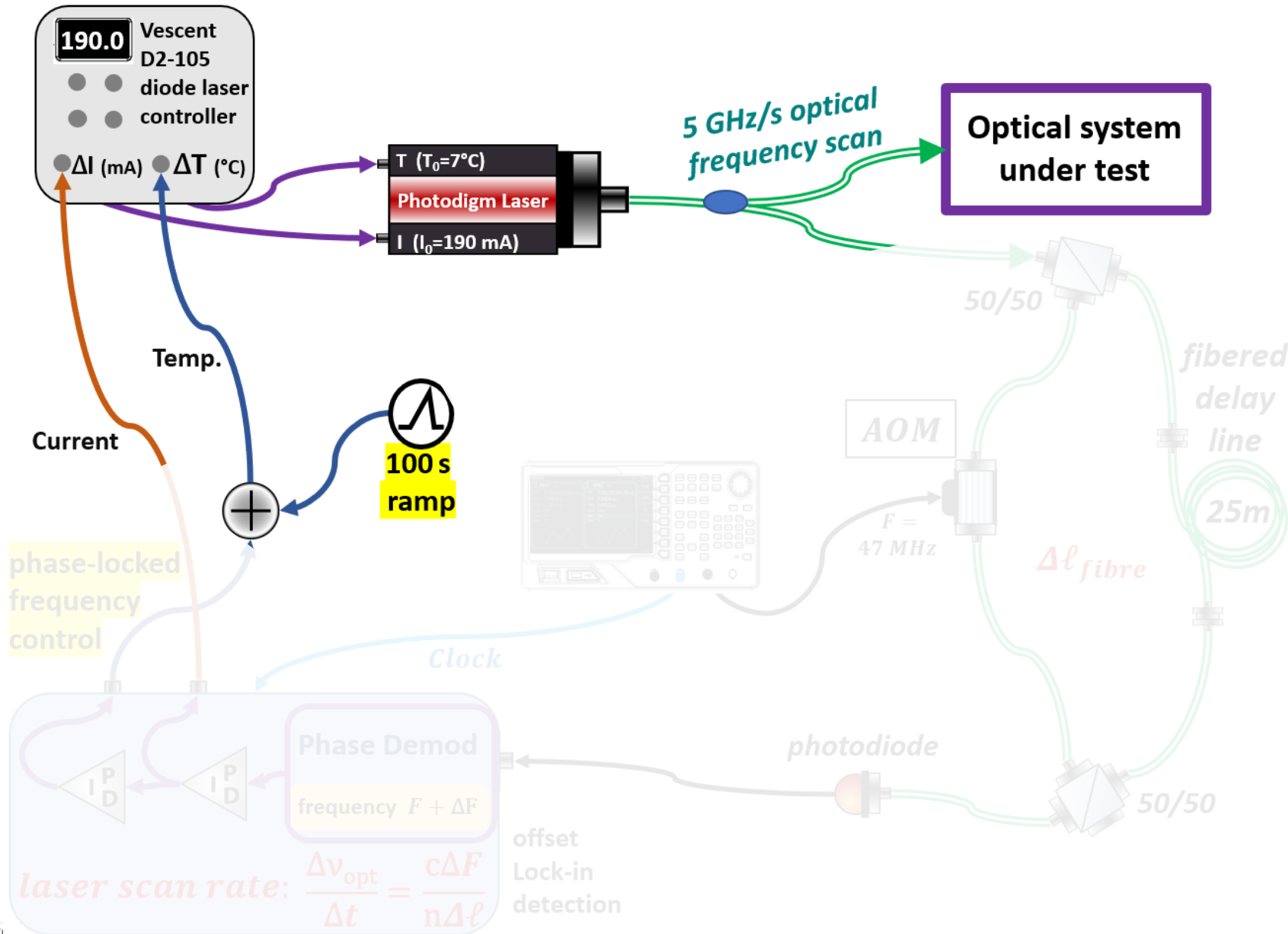
Trick to identify parasitic peaks:

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

=> only true optical contributions  
give overlapping peaks !

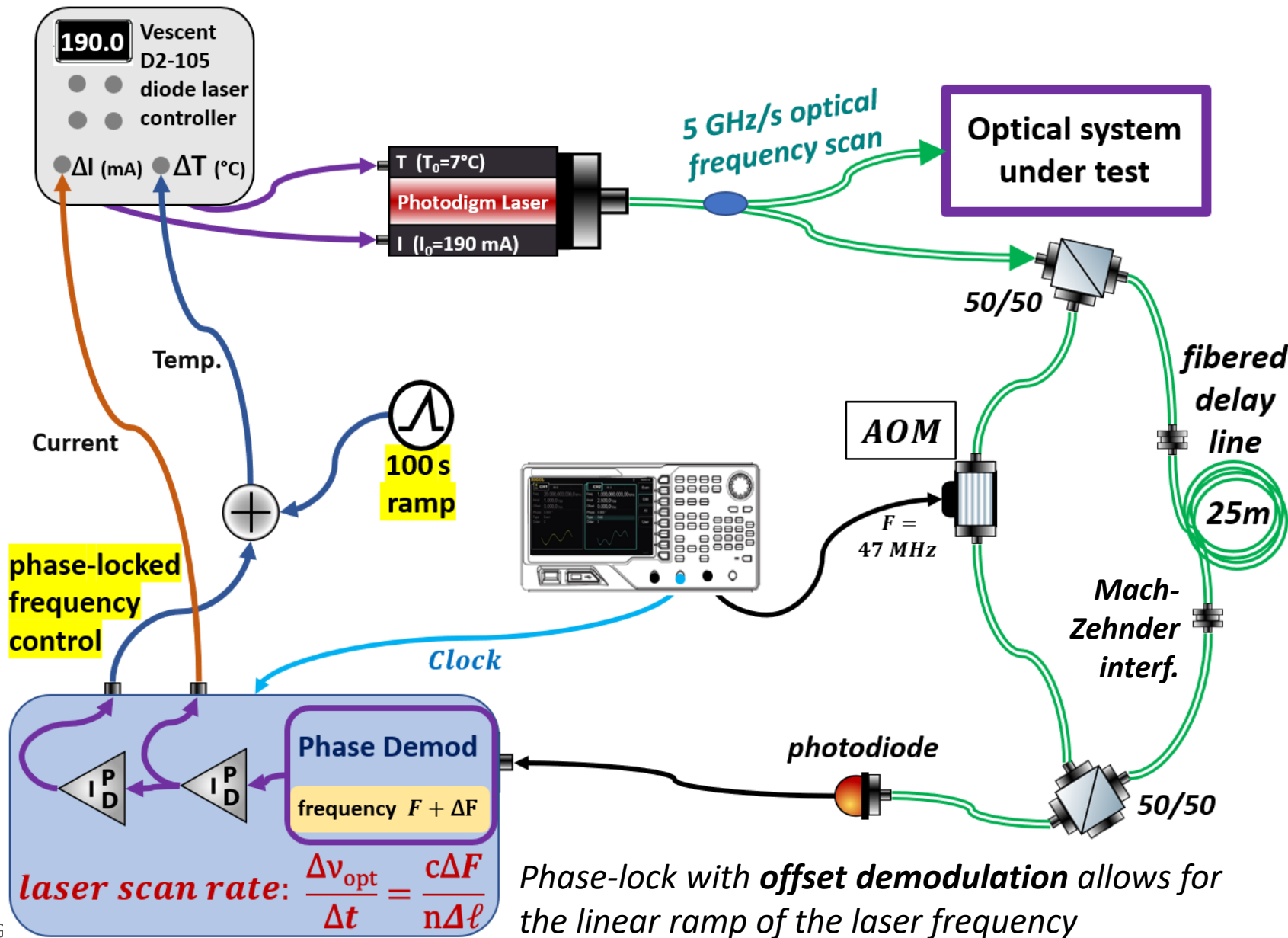


# Implementation of the laser



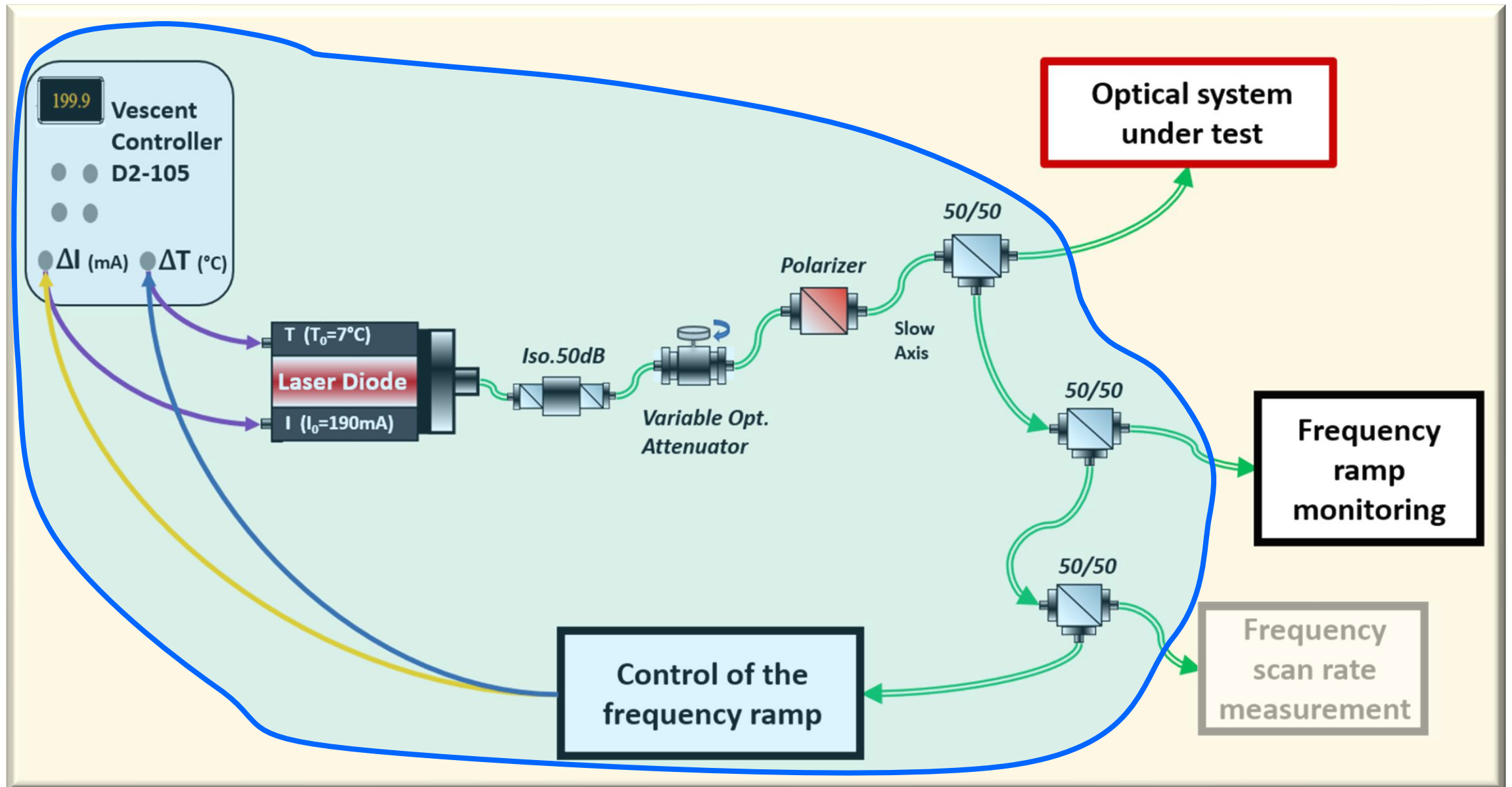
2nm-span optical frequency-scanned laser source

# Implementation of the frequency swept laser source



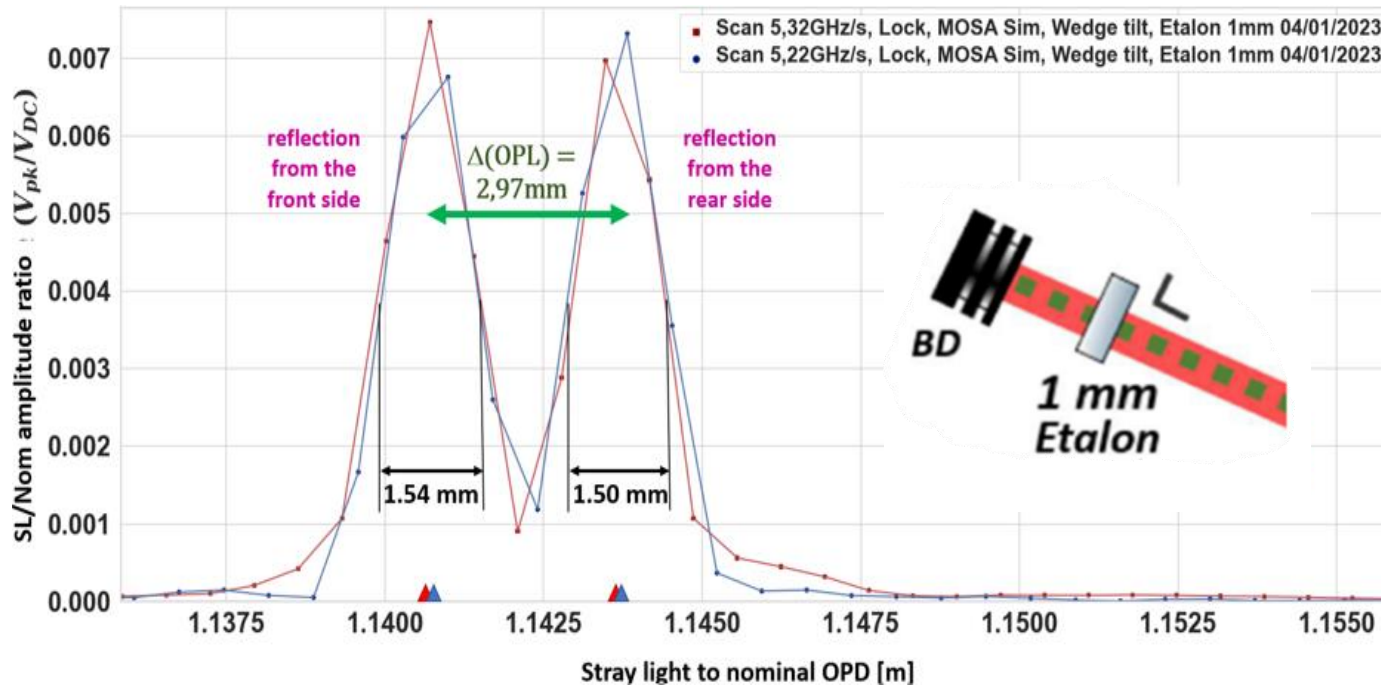
2nm-span optical frequency-scanned laser source

# Implementation of the frequency swept laser source

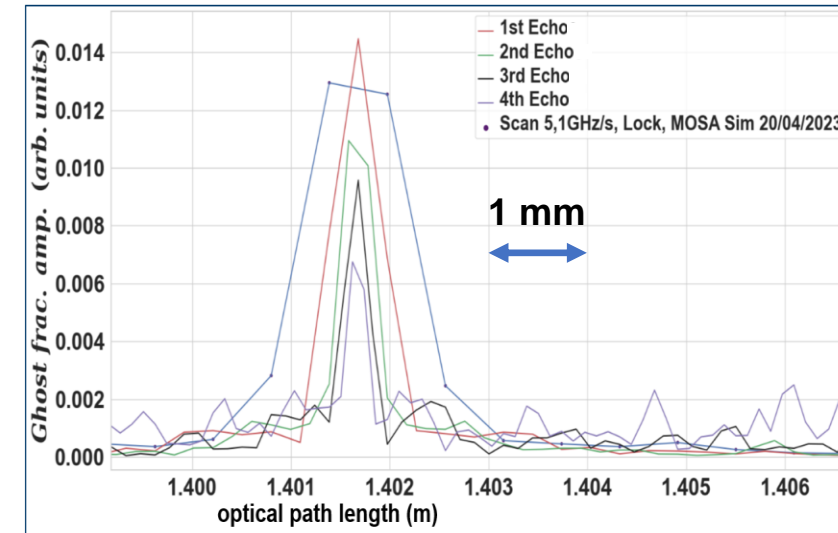


# Characterization of the SL measurement: OPD resolution

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



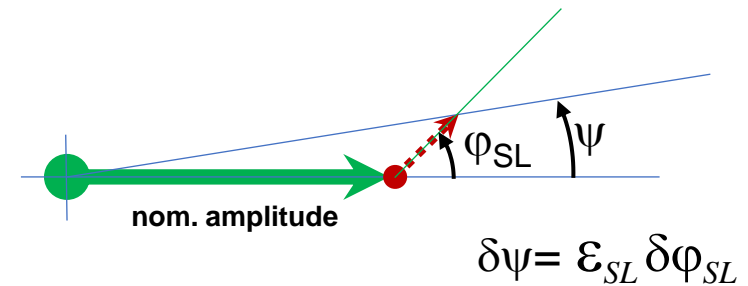
- Metrologist's resolution:  
Reproducibility/consistency  
at the 0.1 mm level in the  
OPD measurements



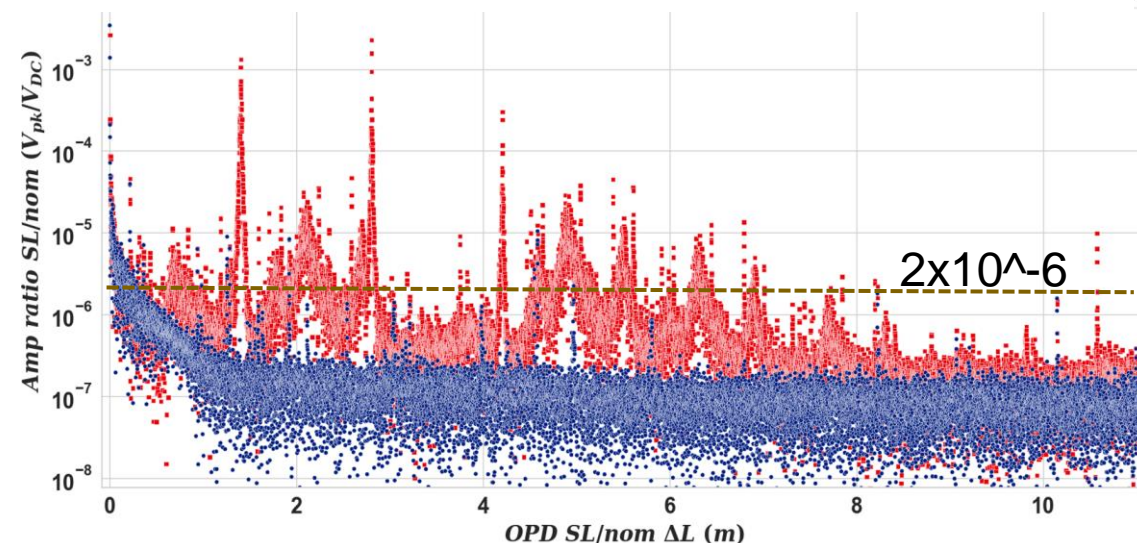
# What noise floor for the SL optical amplitude measurement ?

- 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** <=

