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

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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 ≈ 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 $10\text{pm}/\sqrt{\text{Hz}}$

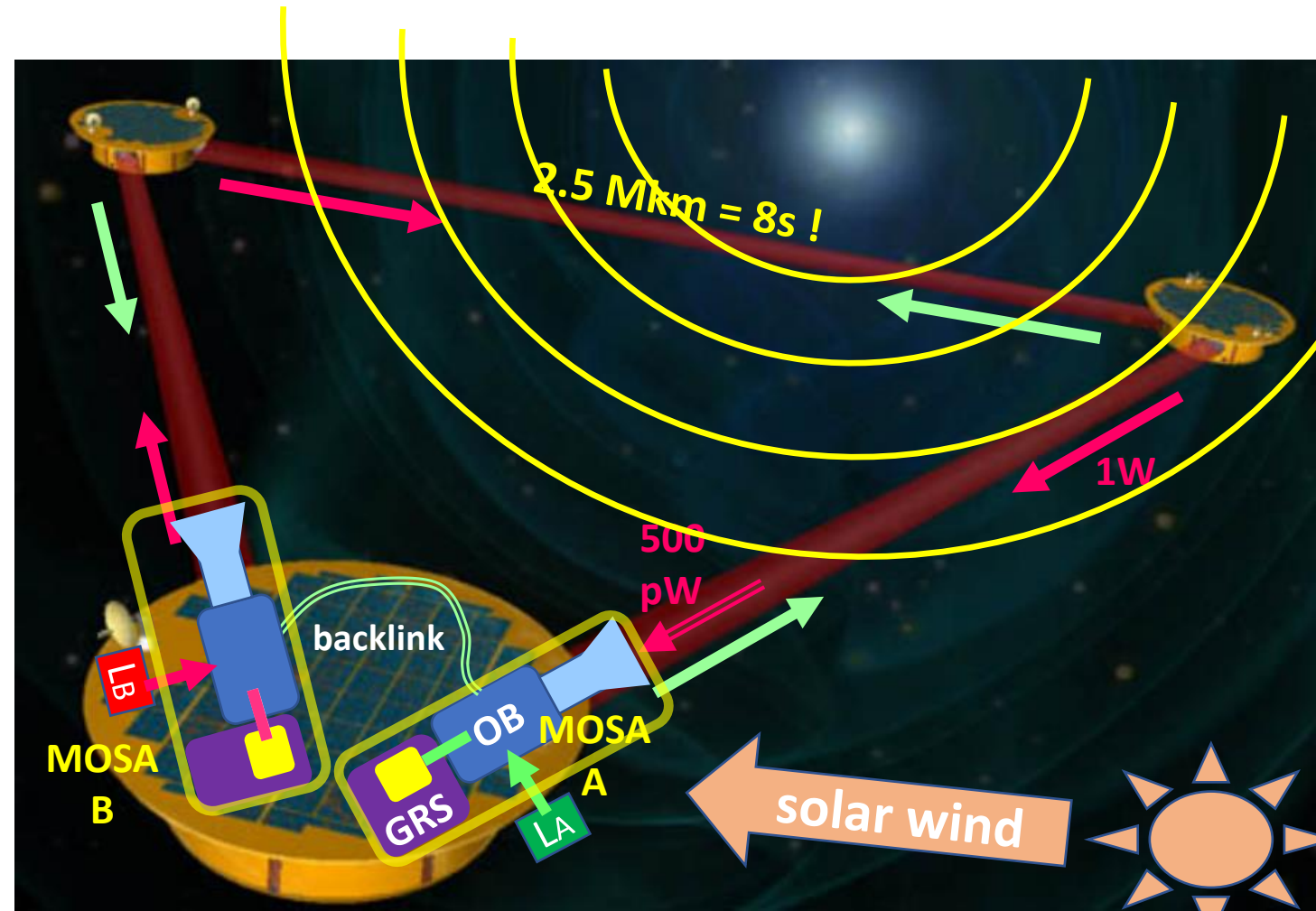
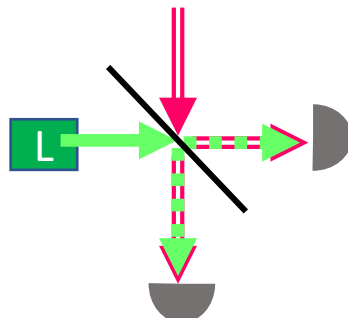
- records gravitational waves in the $20\mu\text{Hz}$ - 1Hz band
- trous noirs supermassive black holes, primordial universe,...

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

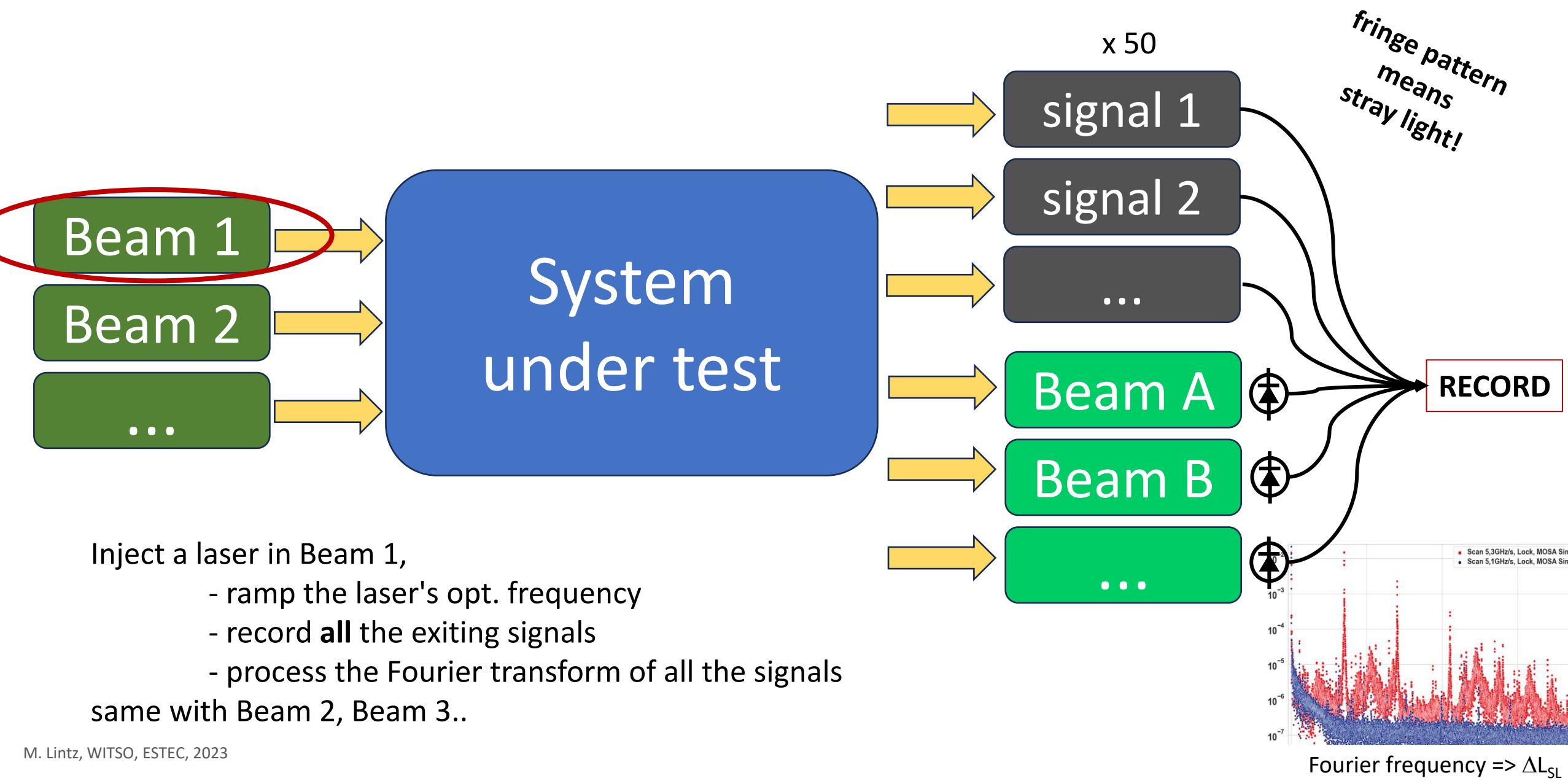
=> 2 MOSAs per spacecraft

=> 3 interferometers per MOSA

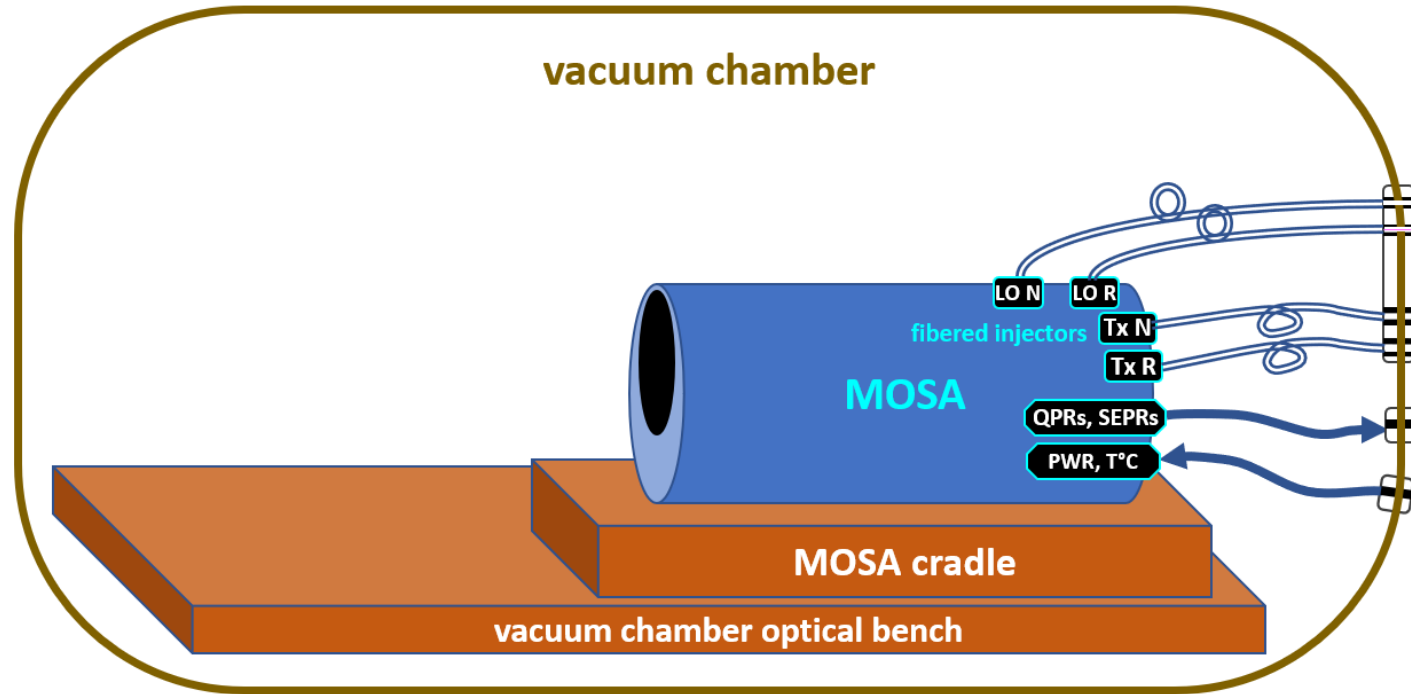
- "science" (long arm)
- "Test Mass"
- "reference"



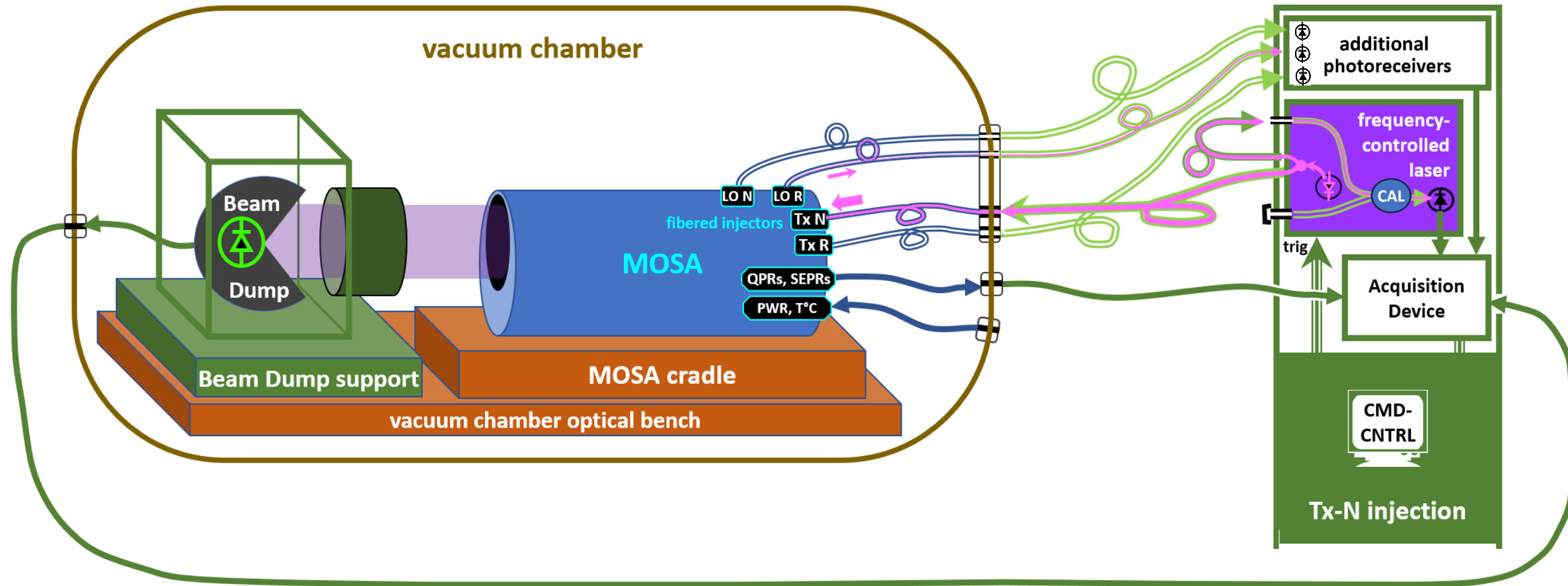
Measurement + identification of stray light in a complex optical system



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

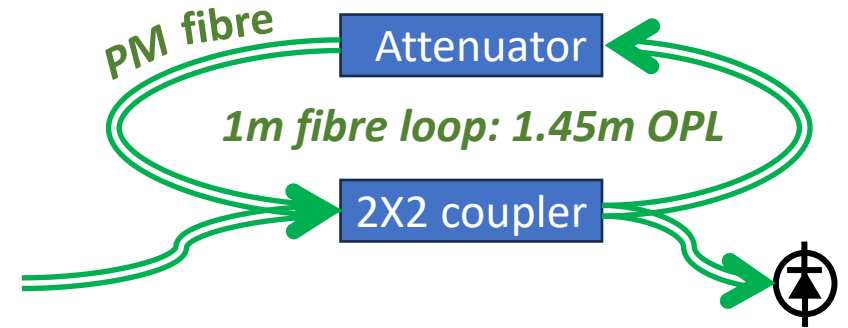
The frequency-ramped laser source: monitoring the ramp

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



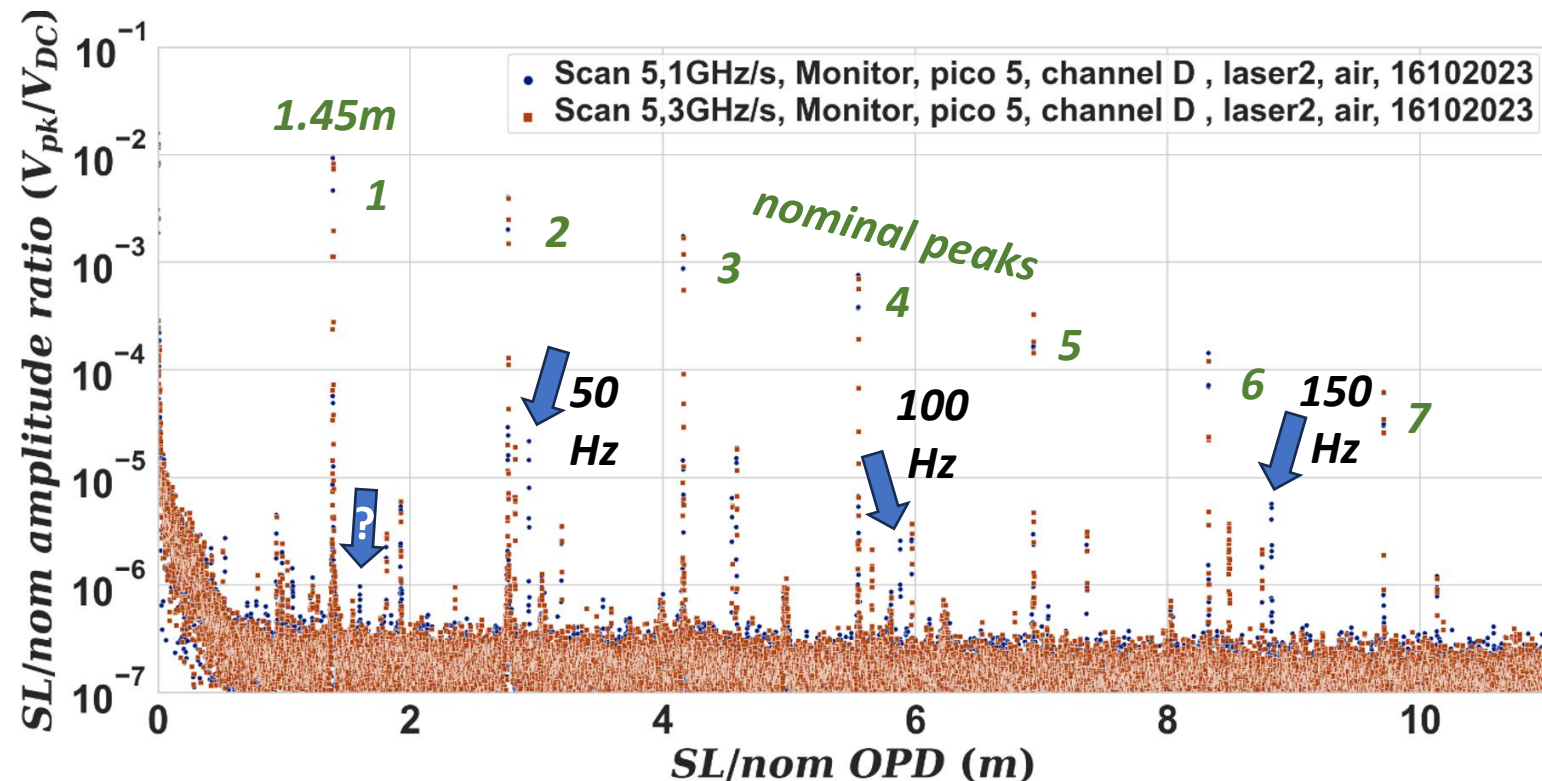
=> 7 nominal peaks

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

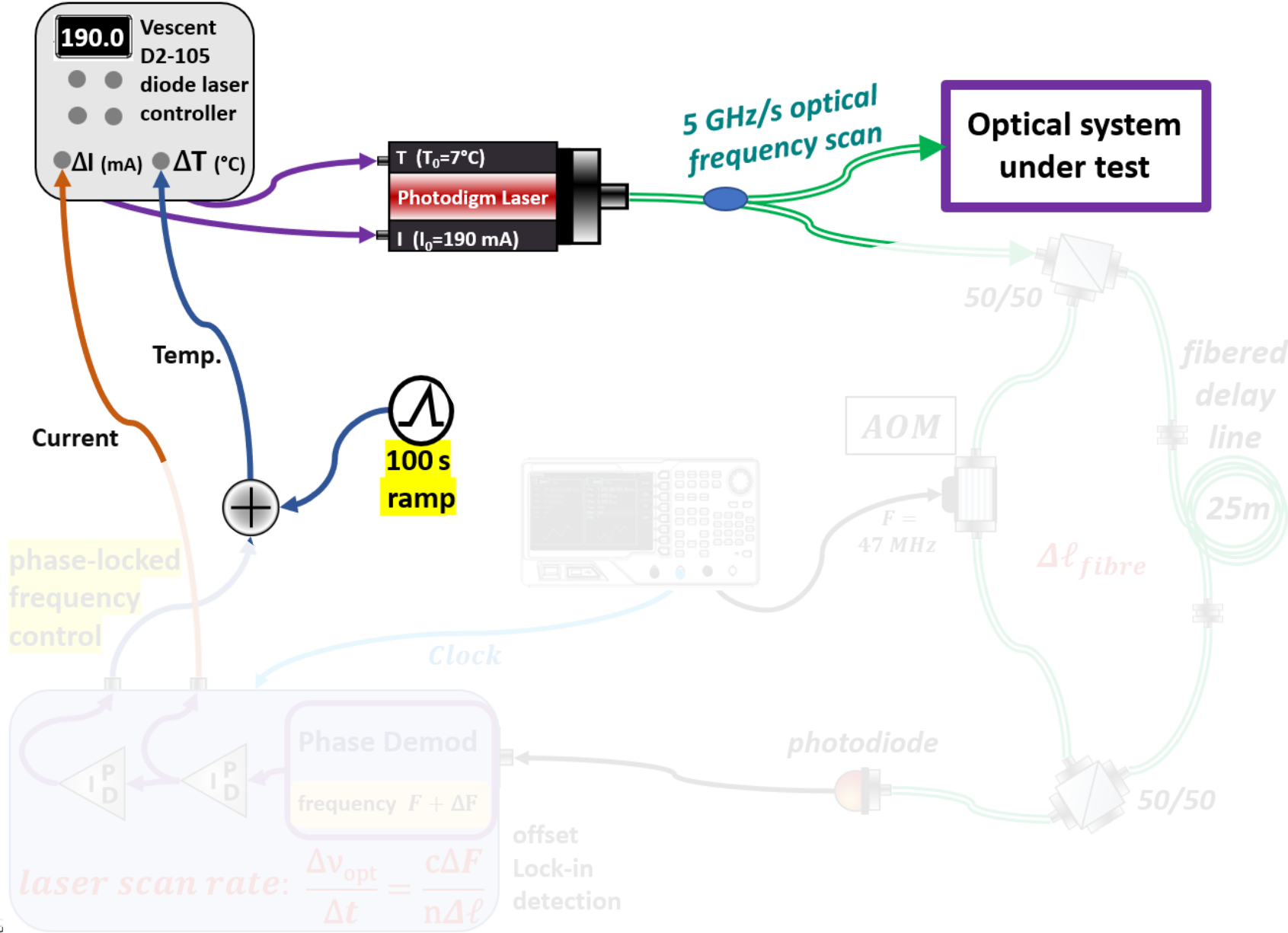
Trick to identify parasitic peaks:

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

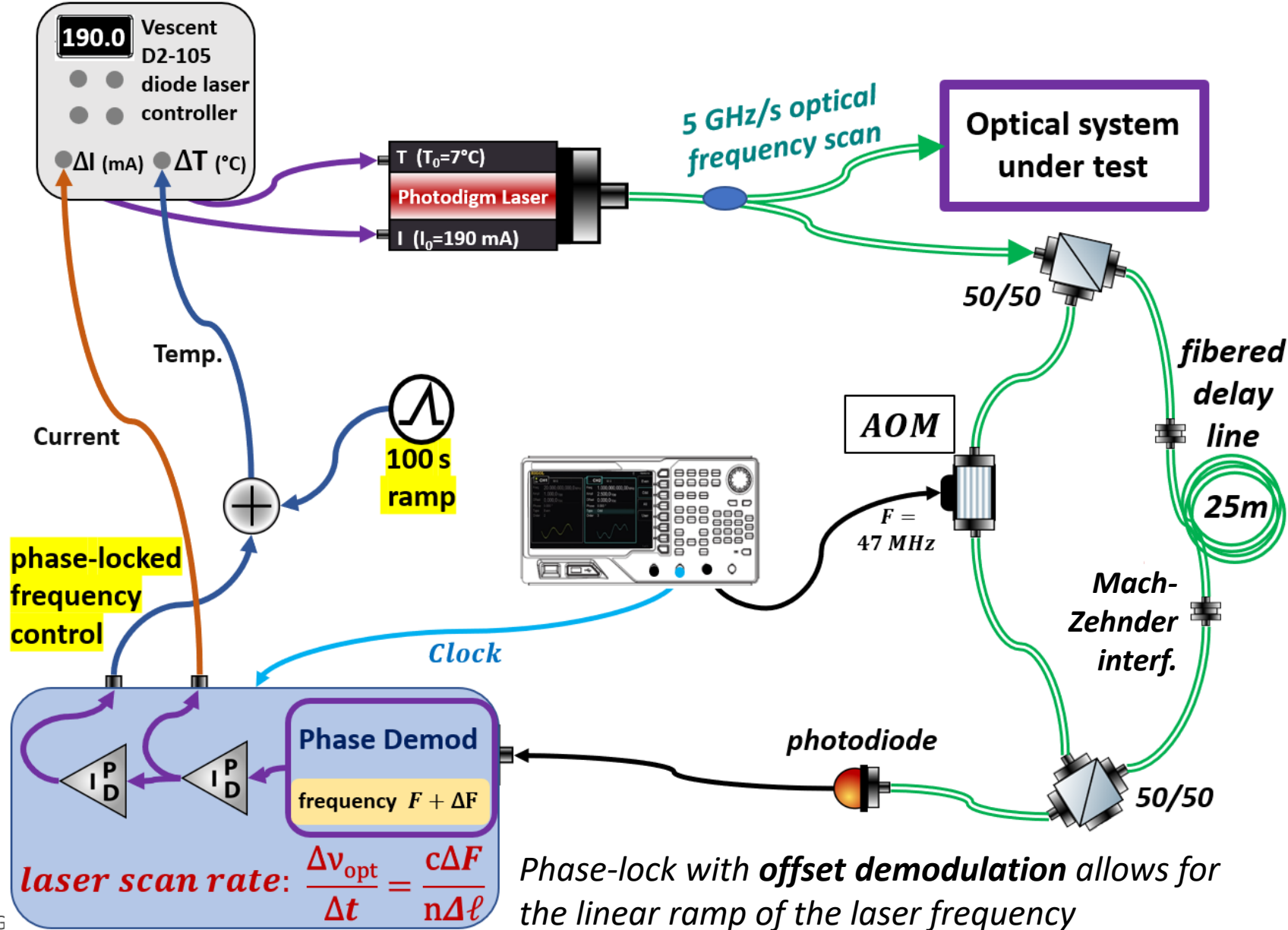
=> only true optical contributions
give overlapping peaks !



Implementation of the laser

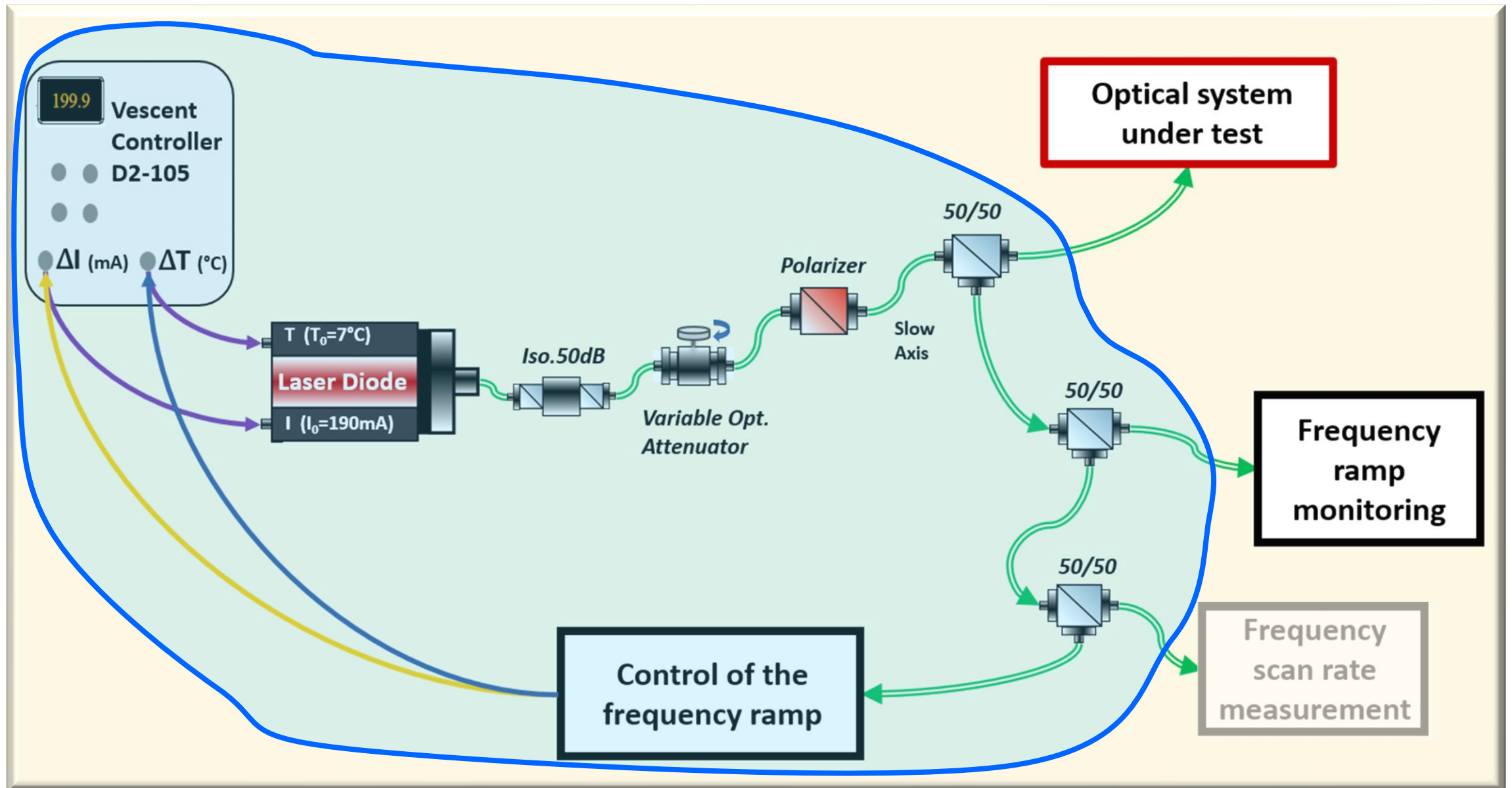


Implementation of the frequency swept laser source



2nm-span optical frequency-scanned laser source

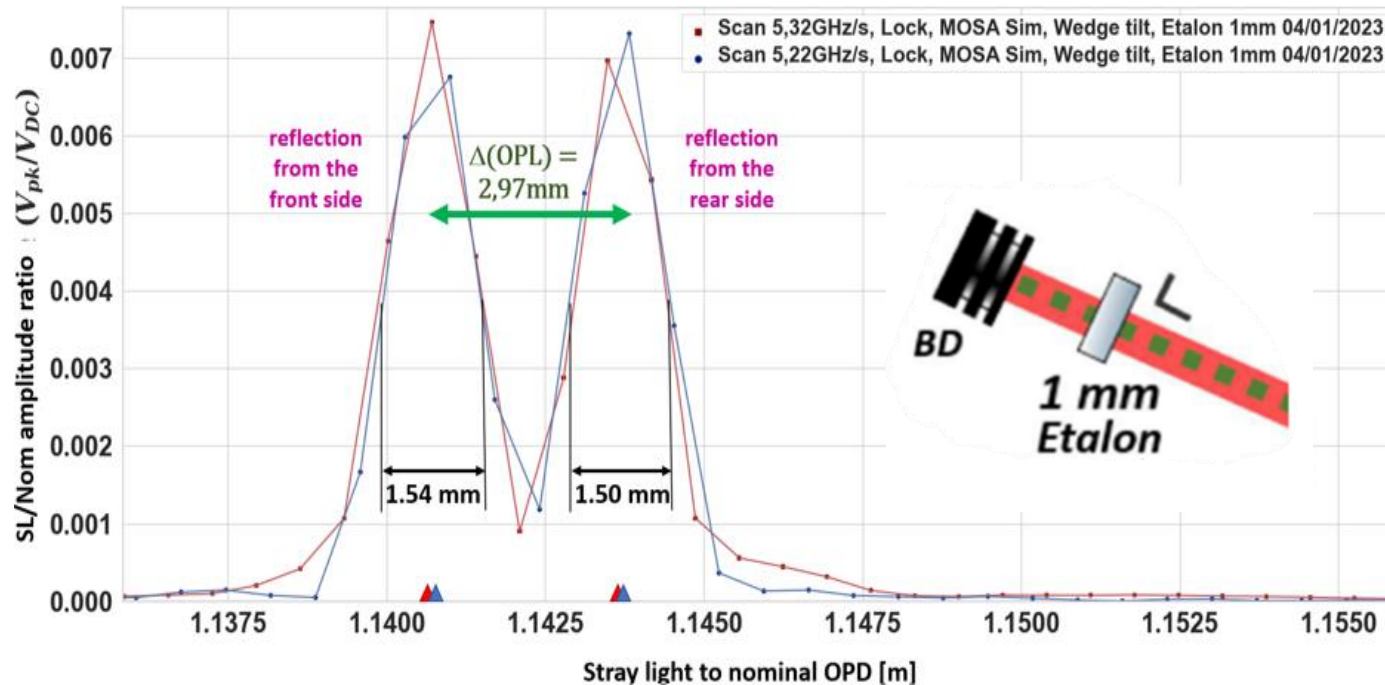
Implementation of the frequency swept laser source



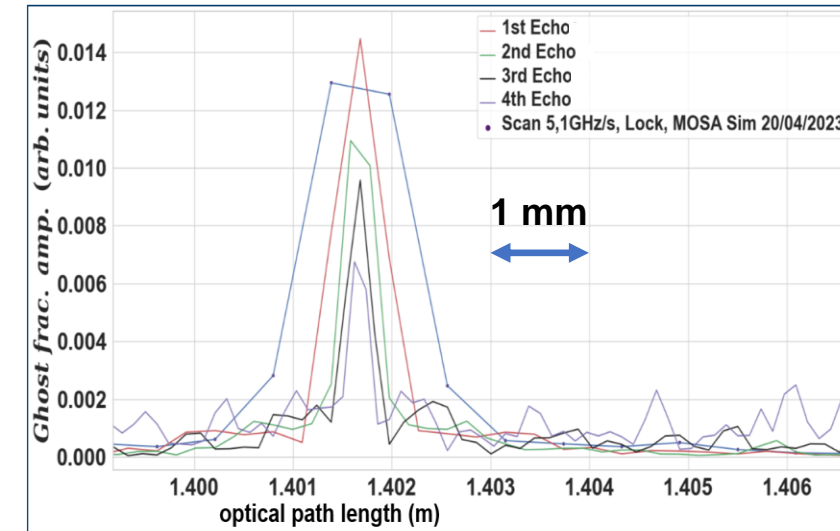
Characterization of the SL measurement: OPD resolution

- Spectroscopist's resolution

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



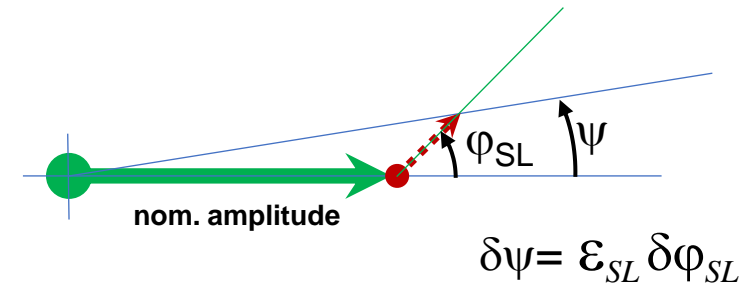
- Metrologist's resolution:
Reproducibility/consistency
at the 0.1 mm level in the
OPD measurements



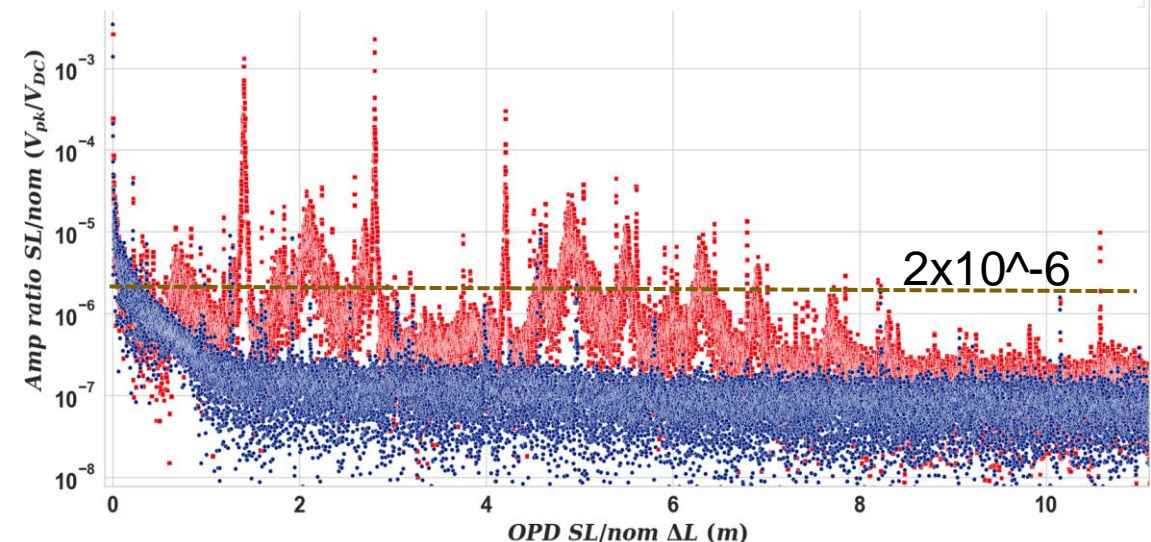
What noise floor for the SL optical amplitude measurement ?

- For each component the "acceptable fractional SL amplitude" $\varepsilon_{\text{accept-SL}}$ stems from the performance model:
 - noise in the LISA measurement should not exceed 10 pm/ $\sqrt{\text{Hz}}$ with less than ≈ 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

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



- Then the measurement floor must be $< [\varepsilon_{\text{accept-SL}}]_{\text{smallest}}$ with a margin (SNR) of 30
- Presently this leads to a fractional noise floor of 2×10^{-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** <=

