Qualification for space and roadmap towards spaceborne operation

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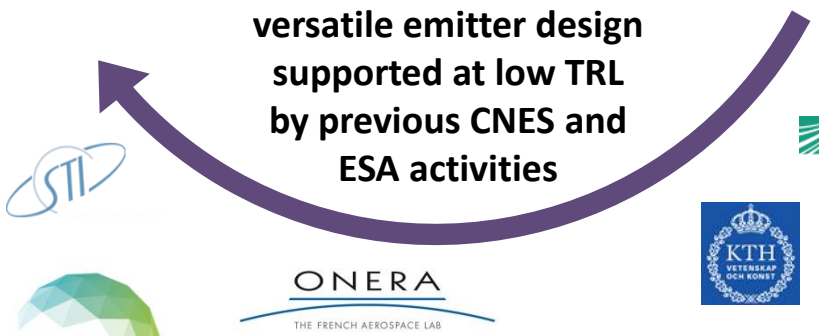
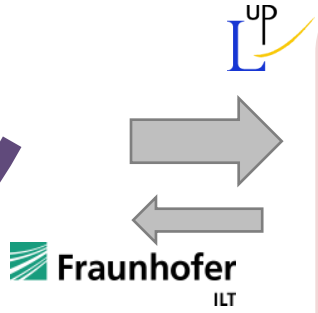
LEMON Final Public Workshop, 11 July 2023, Palaiseau, France

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 821868

Main objectives

- Radiation testing of components
  - Especially nonlinear components
- Preliminary vibration testing of some sub-units
  - For space
  - For airborne operation
- Identification of new solutions with potential for space
  - Low TRL BWOPO testing
  - New frequency reference (comb beating, new components (PIC) testing)
- Roadmap towards space



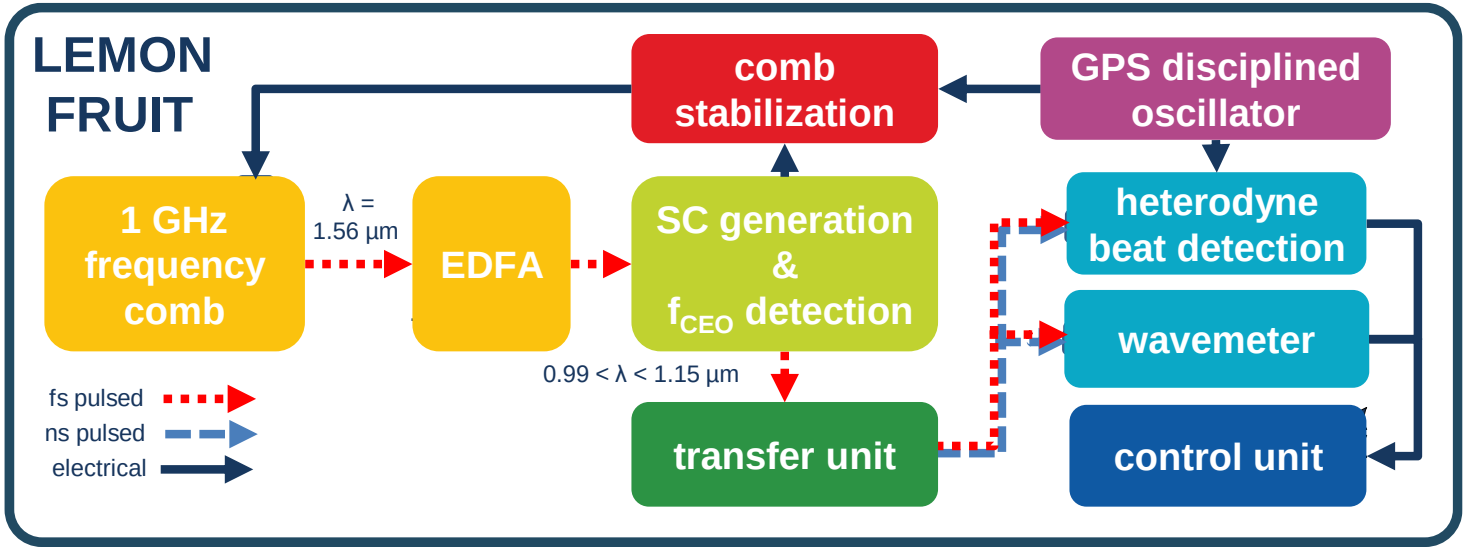


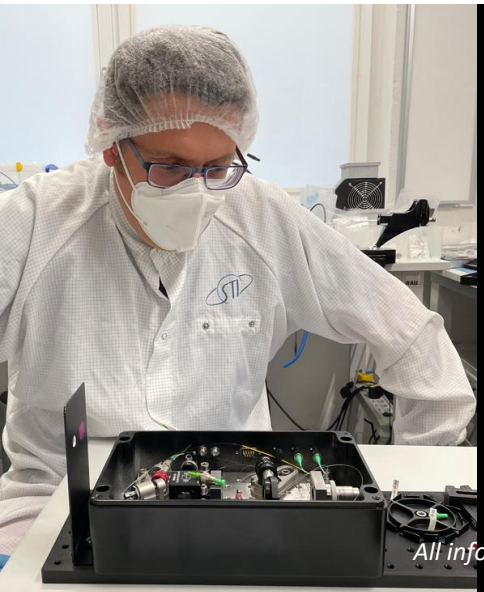
Impact

- Dissemination
- Exploitation
- **Toward a spaceborne DIAL**
- Emitter specs. (CO_2, H_2O, CH_4)
- Roadmaps analysis
- Sub-units environmental testing
- Critical comp. radiation testing
- Future mission proposals

NEW FREQUENCY REFERENCING SOLUTIONS

New frequency reference FRUit : Comb beating design

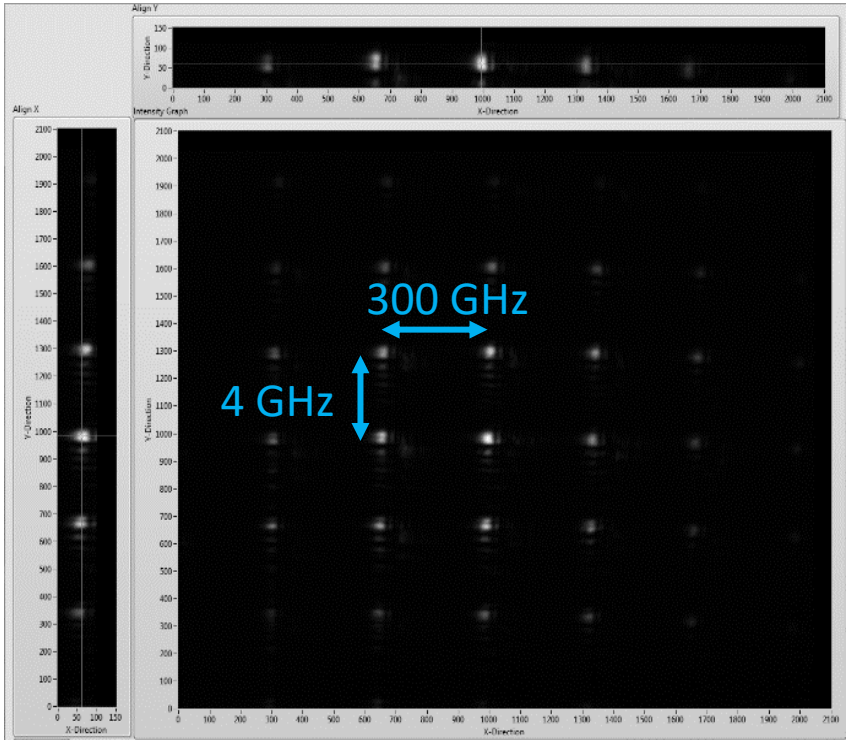


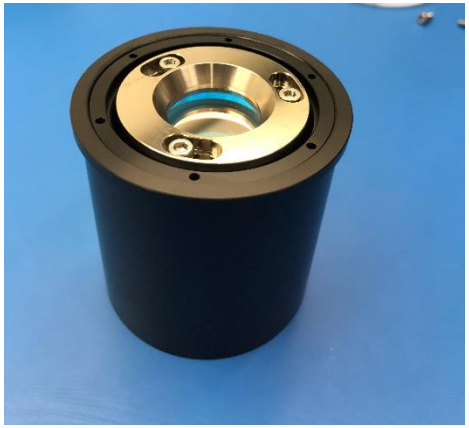


New frequency reference FRUit: Compact 2-D Wavemeter

- Integrated wide span wavemeter for space
  - Nearly same size as a single element wavemeter

CMOS camera | **Fizeau wedge assembly** | **Beam collimator**



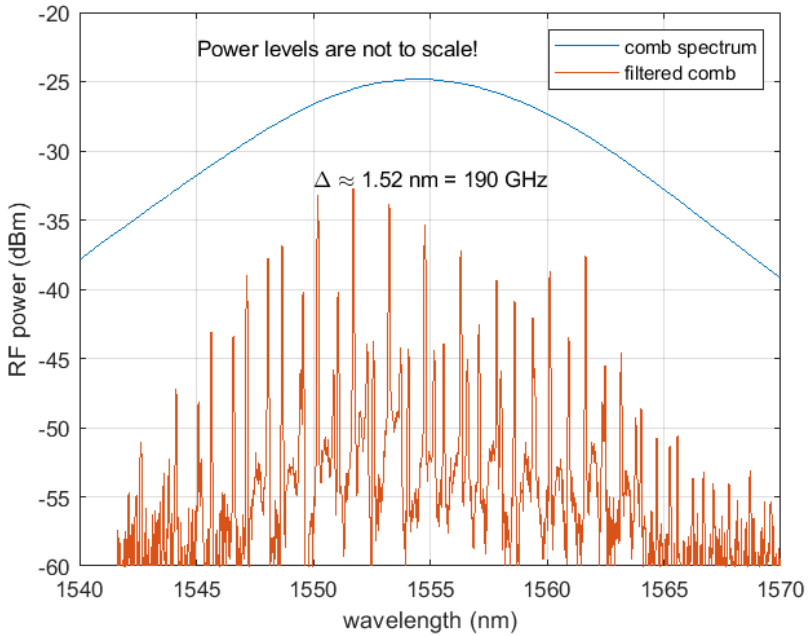


Comb frequency FRUit
SiN – Waveguide (PIC) evaluation

- Higher integration level of comb frequency reference
  - Supercontinuum generation
  - Mode Filtering
  - Light routing

SiN ring filter applied to comb to select 1 out of each 190 modes

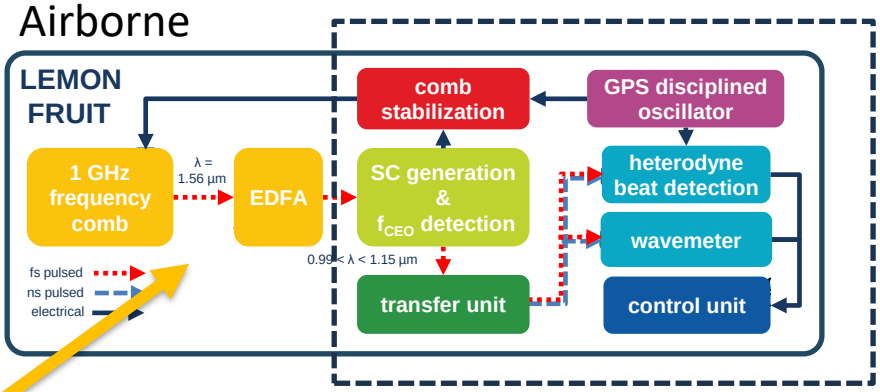
SiN waveguide chip placed in the holder



Goal → **Single Mode Filtering**

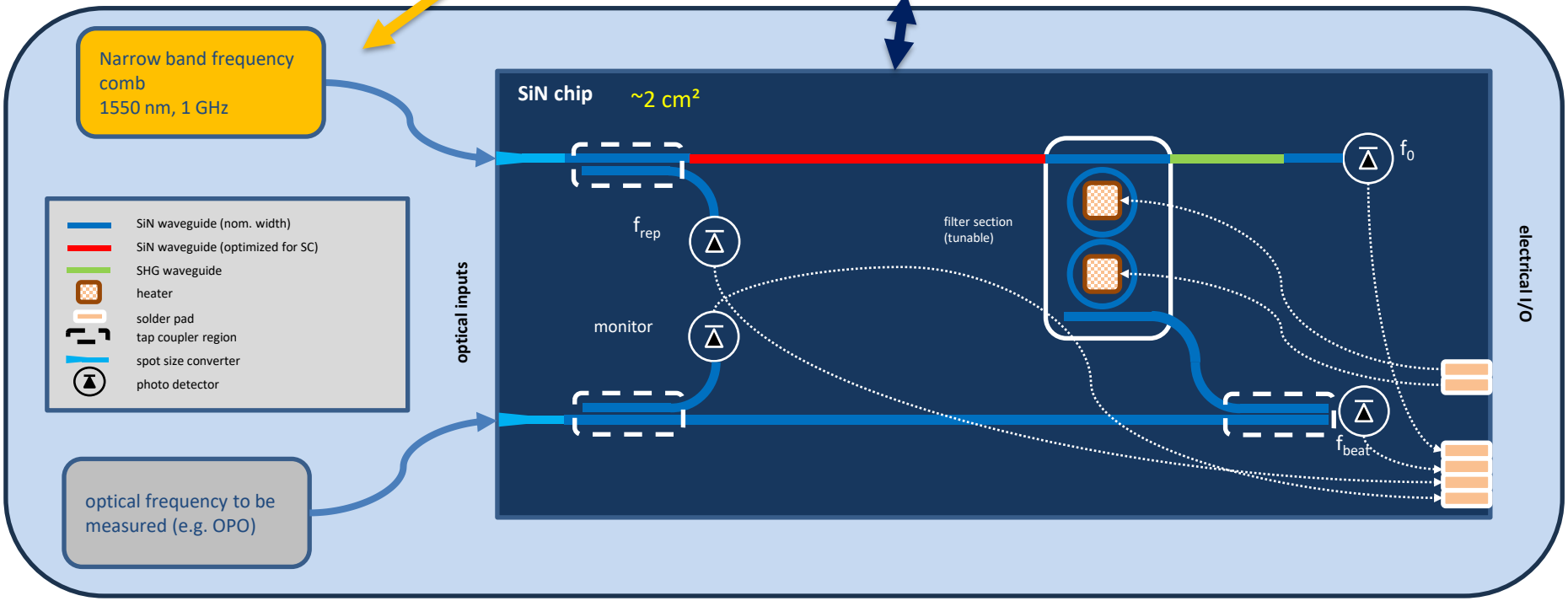
Comb frequency FRUit
SiN – Waveguide (PIC) evaluation

Airborne



Space development shall be taken to higher TRL level within the next GHG space lidar mission

Spaceborne



COMPONENT TESTING FOR SPACE

Radiation testing

- PPKTP nonlinear crystal for OPO / OPA
- Highly nonlinear fibers for SC generation
- SiN waveguide (PIC) for perspective of higher integration
- Reference comb laser crystals

PPKTP crystals

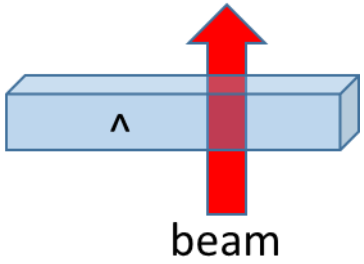
Sample 6B – low energy

- ❑ Proton Energy @ 10 MeV
- ❑ 1E10 p^+/cm^2 5.5 krad [SI]

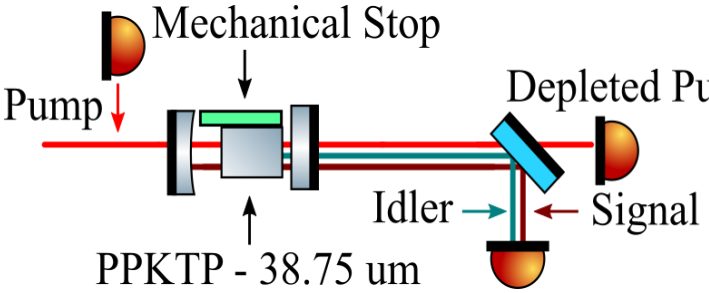
Sample 4C – high energy

- ❑ Proton Energy @ 60 MeV
- ❑ 4E10 p^+/cm^2 5.5 krad [SI]

PPKTP exposed along z+ axis (4C, 6B)



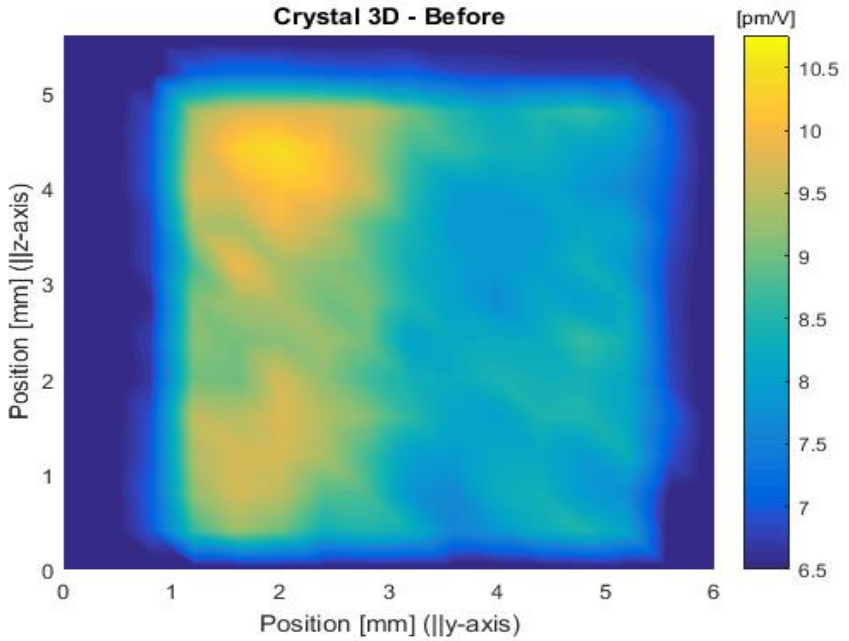
PPKTP crystals

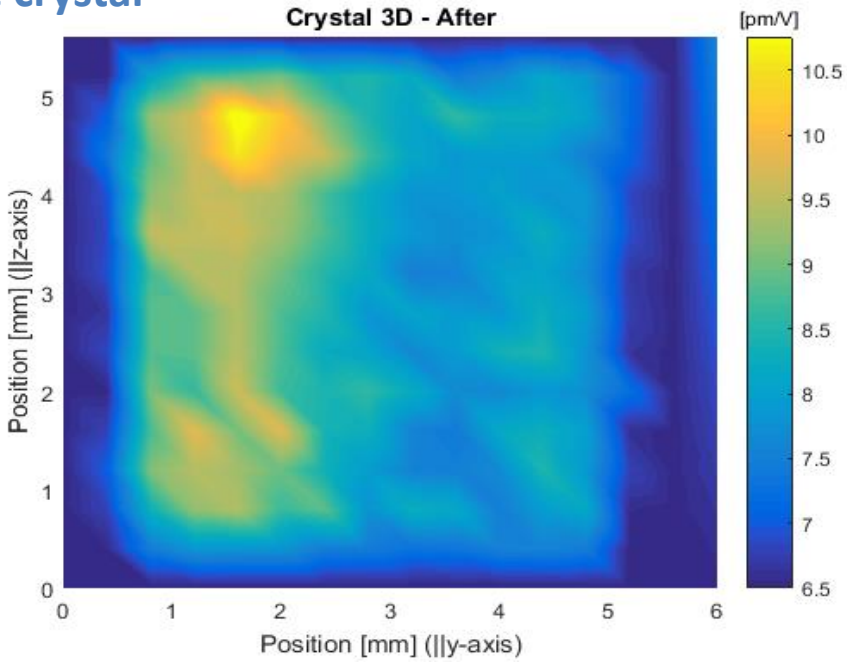


$$I_{th} = \frac{1.12}{\kappa g_s L_{eff}}\left(\frac{L_{cav}}{t_p c}\ln\frac{P_s}{P_n} + 2\alpha L_{cry} + \ln\frac{1}{\sqrt{R}} + \ln 2\right)$$

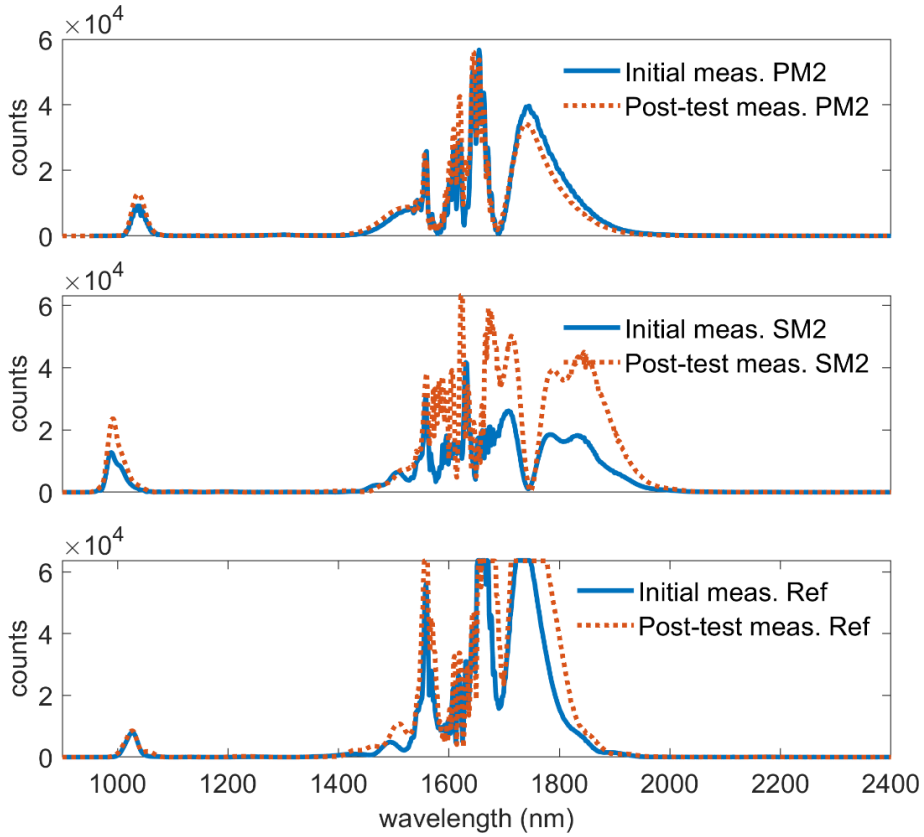
$$g_s = \frac{1}{1+\left({}^{w_s}/_{w_p}\right)^2} \qquad \kappa = \frac{8\pi^2 d_{eff}^2}{\lambda_i \lambda_s n_s n_i n_p \varepsilon_0 c}.$$

Reference crystal





Highly nonlinear fibers

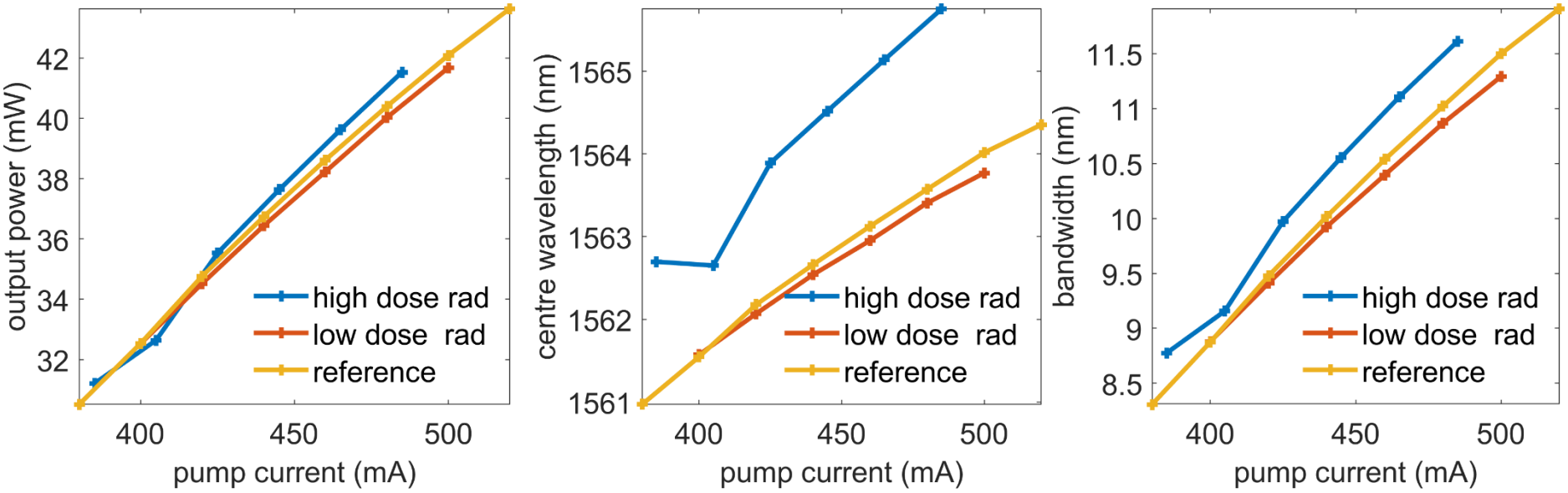


- Supercontinuum of 3 different HNFs
- 2 × HNFs irradiated, 1 × HNF reference
- Absolute count variations due to coupling loss into spectrometer

→ **No damage detectable**

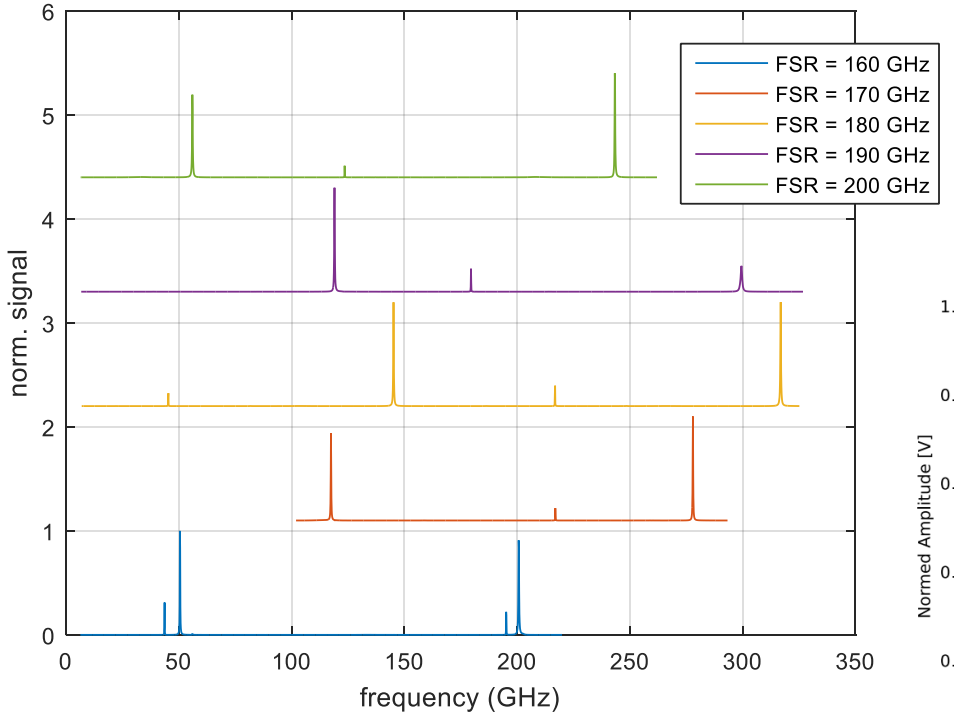
Laser Gain and Mode Locking Device

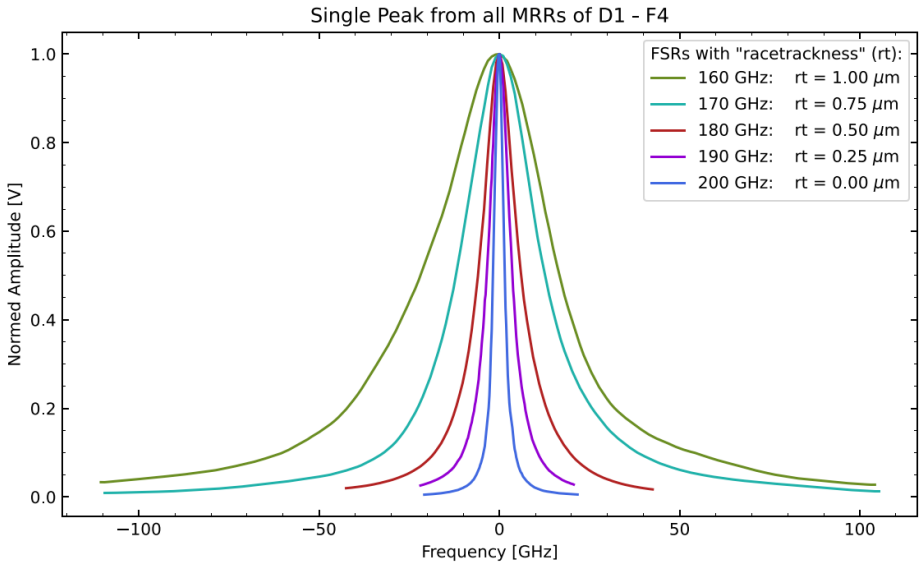
- ❑ Laser built with non irradiated reference samples
- ❑ Subsequent removal of reference samples and insertions of test samples
- ❑ Realignment kept minimal
- → **Laser re-built with radiated samples within specification**



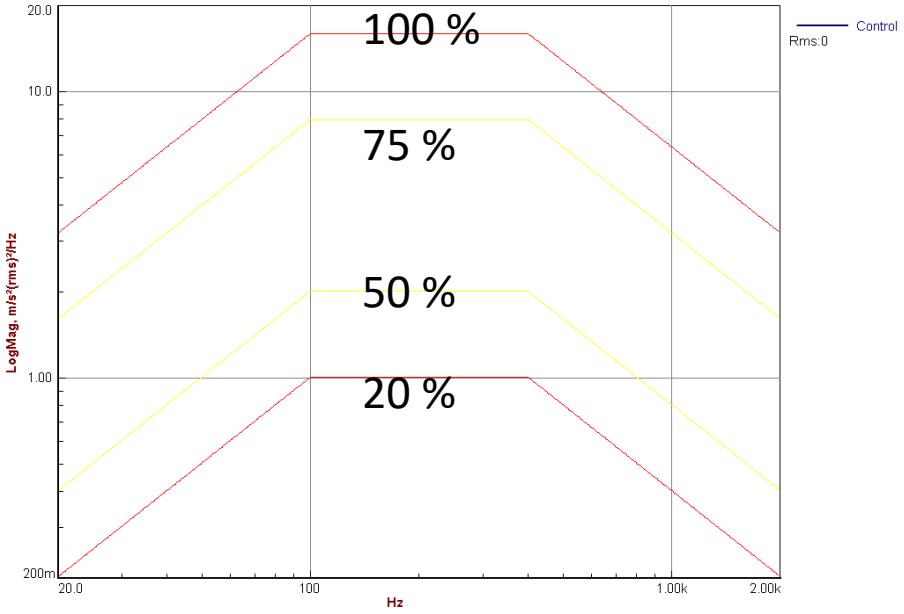
SiN post radiation testing

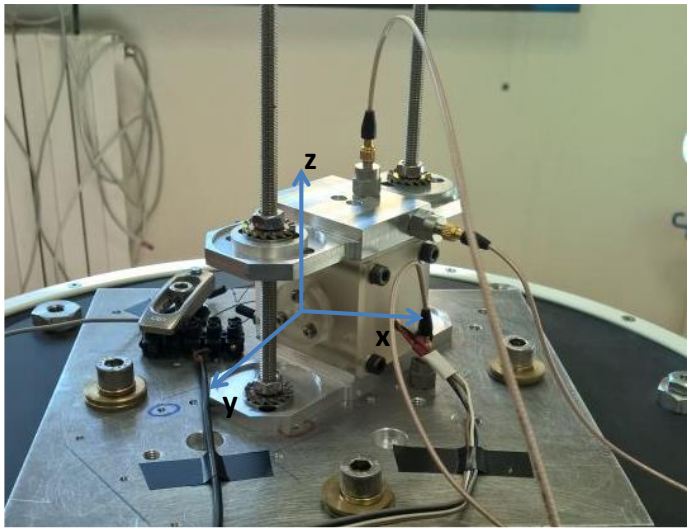
- Large range measurement via temperature tuning to obtain FSRs
- High resolution measurement via current tuning to measure FWHM of resonance

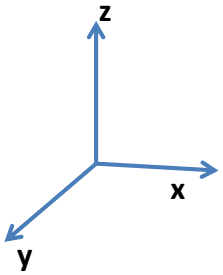




Preliminary vibration testing of NesCOPO







Frequency (Hz)	Test level random
below 100*	3 dB/Oct
100 – 400	> 0.4 g²/Hz
Above 400	-3 dB / Oct

Frequency (Hz)	Test level sinus
5-20	11.6 mm (0-pk)
20-75	10 g
57-150	2.5 g

*due to limited displacement of the shaker the levels might be lower at low frequencies

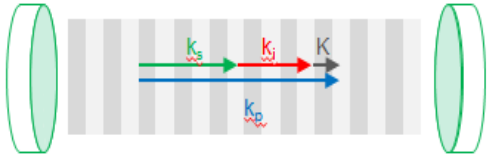
ROADMAP TOWARDS SPACE

Conclusion from activities

- No radiation critical topics discovered
- A new type of OPO configuration to be further assessed for space *(see next slide)*
- Evaluation of some PIC components: integration of low power branches (e.g. FRUit) in SiN well suitable for compactness
- Frequency referencing by comb beating is a suitable method for < MHz accuracy

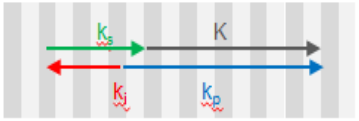
Backward wave OPO development

- Preliminary testing of a zero-cavity OPO concept (BWOPO) for Lidar
  - BWOPO => no cavity, narrow-linewidth,
  - But difficult tunability => pump tuning



Oscilation obtained thanks to a cavity optical feedback

Classical OPO configuration with classical quasi-phase matching in a non-linear crystal



Backward phase-matching with contra-propagating waves

The oscillation can be obtained with no cavity

  - Tests of a hybrid fiber/solid 1µm laser (CNRS LCF + Onera) with BWOPO crystals (KTH Royal Institute of Technology)

Backward wave OPO development

- Preliminary testing of a zero-cavity OPO concept (BWOPO) for Lidar

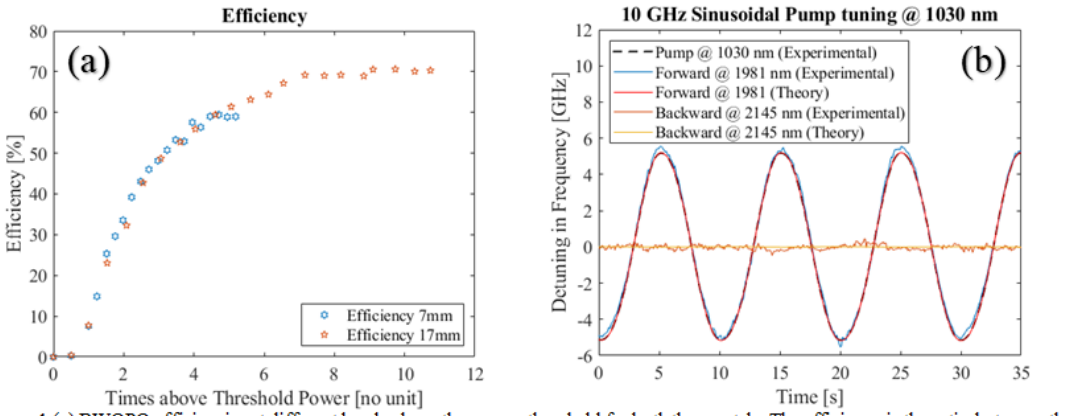


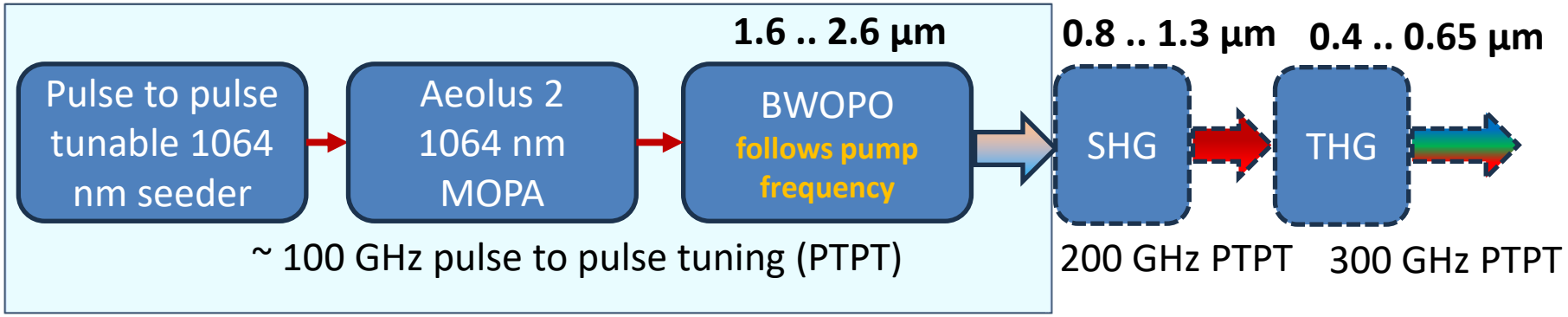
Figure 1 (a) BWOPO efficiencies at different levels above the energy threshold for both the crystals. The efficiency is the ratio between the parametric energies and the pump (b) BWOPO tuning for forward and backward traveling waves as the pump is tuned by±5 GHz.

- Preliminary tests successful
  - ✓ Submitted to 2 Optica conferences (CLEO, MICS)
  - ✓ Further models to estimate the purity levels achievable, tests to be performed
  - ✓ To be included in the roadmap for future developments towards space

Generic space emitter concept

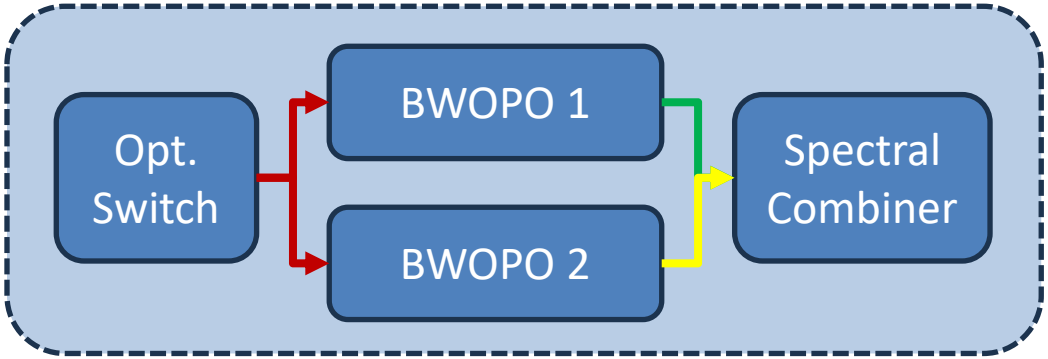
Output WL can be designed with crystal to

Standard configuration



Development Options for larger spectral coverage

Yb:YAG 1030 nm MOPA
500 GHz PTPT



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This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 821868