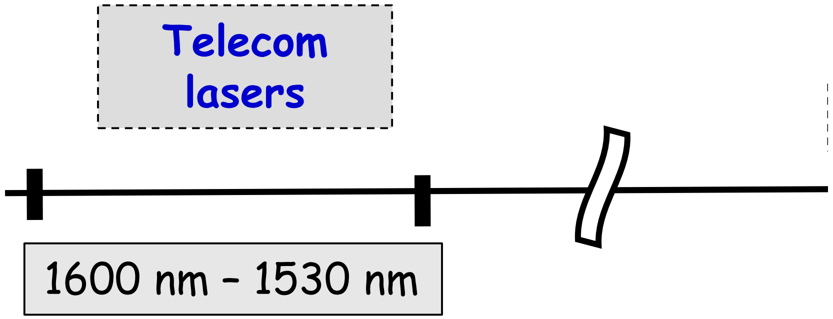
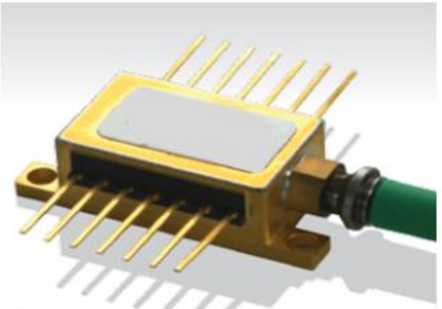
# Iodine based frequency stabilized laser

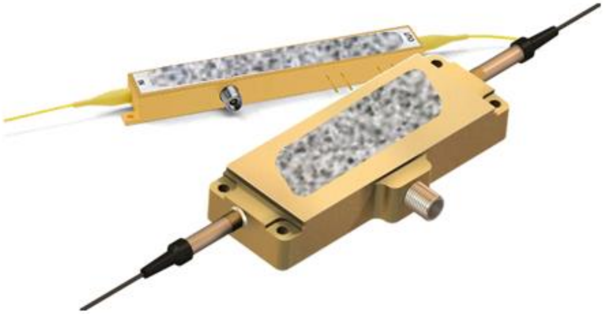
*Applying to the ground tests*
*of the payload of the LISA mission*

J. Barbarat Journée PhyGOG 21/05/2019



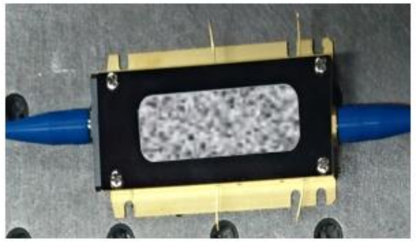
Laser Diode



EOM & AOM

ν

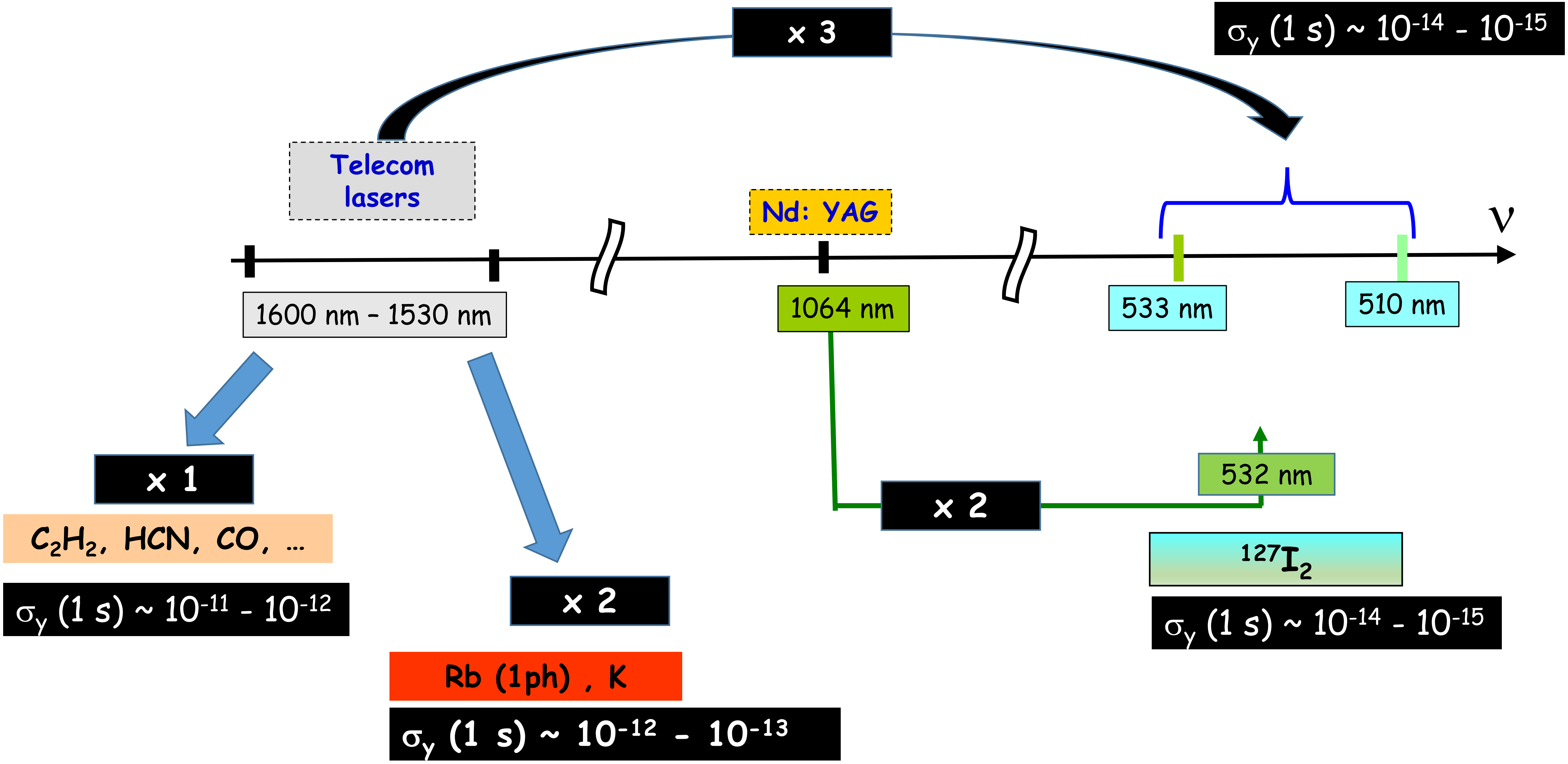
EDFA



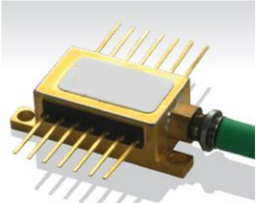
Nonlinear Crystals

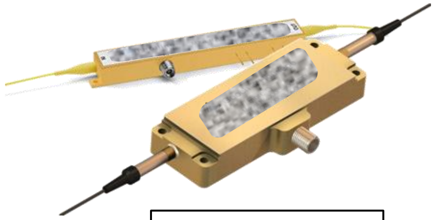
- Telecom lasers have very low intrinsic phase noise (line width ~kHz), compactness ($cm^3$)
- Optical amplifiers (EDFA) are powerful, compact and fibered
- Many optical devices exhibit high TRL (AOM, EOM, non linear crystals, …)
- Commercial solutions, low coast for laboratory development

All theses components are fibered and exhibit high TRL


× 3
σy (1 s) ~ 10-14 - 10-15
Telecom lasers
Nd: YAG
ν
1600 nm - 1530 nm
1064 nm
533 nm
510 nm
× 1
C2H2, HCN, CO, ...
σy (1 s) ~ 10-11 - 10-12
× 2
532 nm
127I2
σy (1 s) ~ 10-14 - 10-15
× 2
Rb (1ph) , K
σy (1 s) ~ 10-12 - 10-13

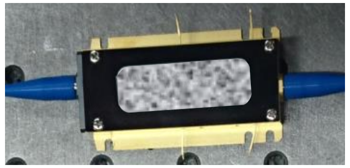
- More than 10 000 hyperfine iodine transitions –Intense and narrow – available in the green range
- Lines are only few GHz apart
- Opportunity to frequency stabilize “any” Telecom laser (C + L Telecom bands)





Laser Diode

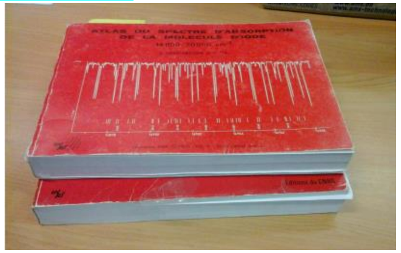
EOM & AOM

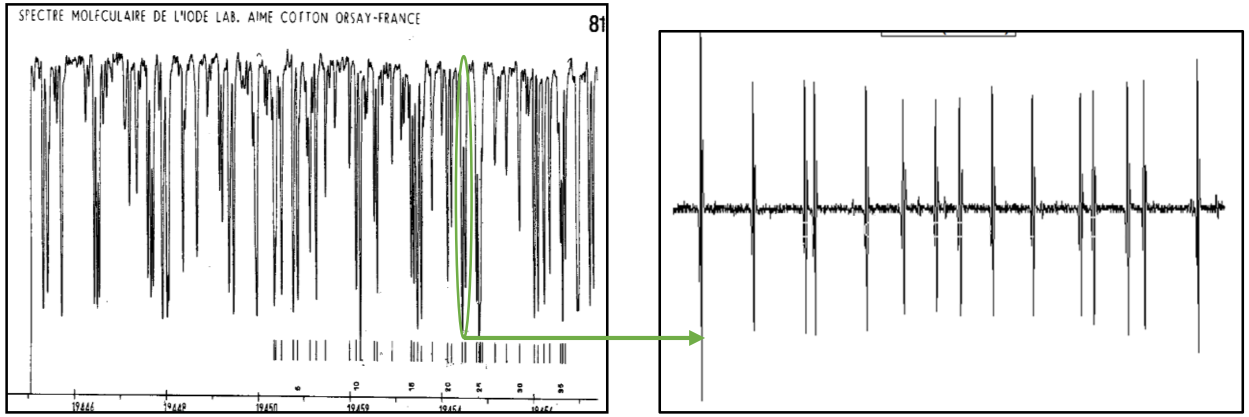


EDFA

Nonlinear Crystals

Frequency tripling process is required

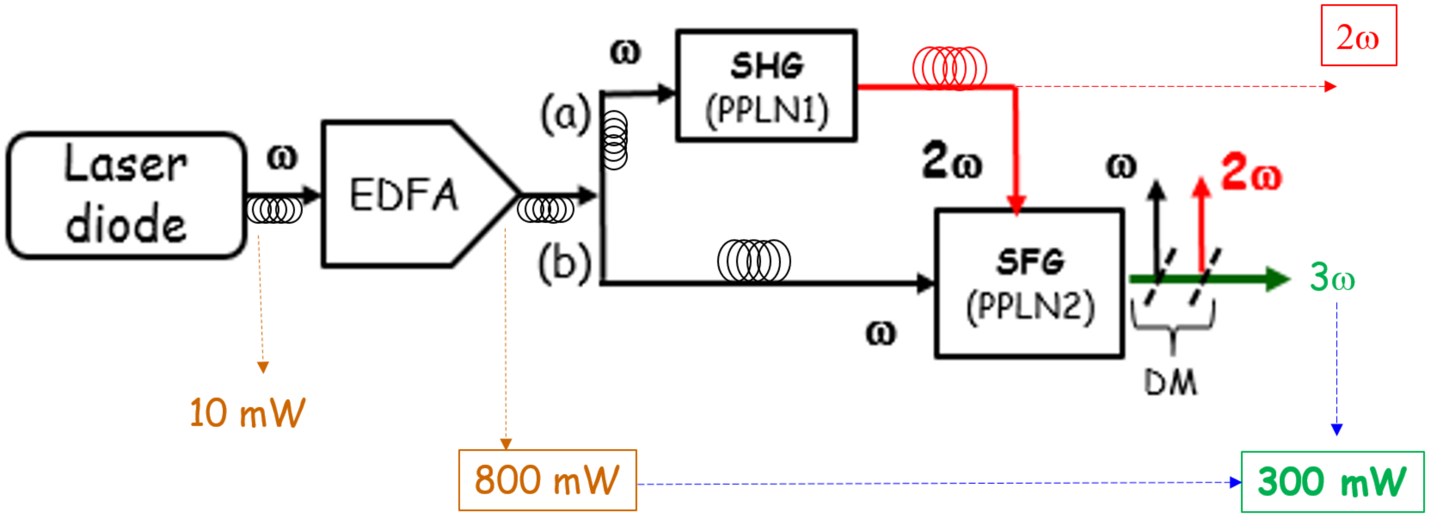


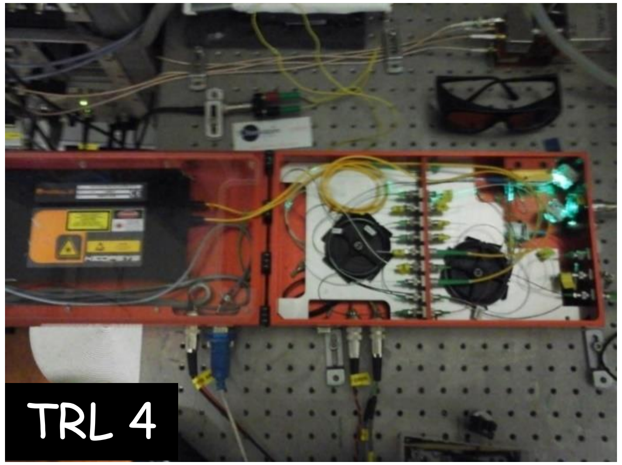


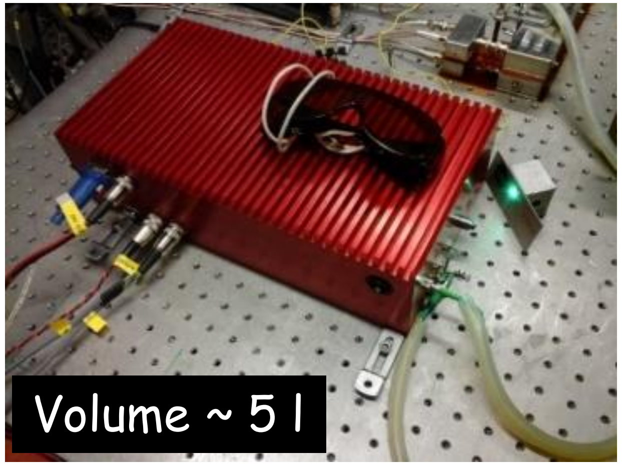

$$\sigma \propto \frac{1}{S/_{N} * Q}$$

- ❖ Are **narrow** ($Q = \frac{\nu}{\Delta\nu} > 10^9$), $\Delta\nu$ ~ 300 kHz
- ❖ Exhibit high S/N ratio (~$10^5$ in 1 Hz bandwidth)
- ❖ Frequency stability ~$10^{-14}$ @ 1s

# Frequency tripling 1



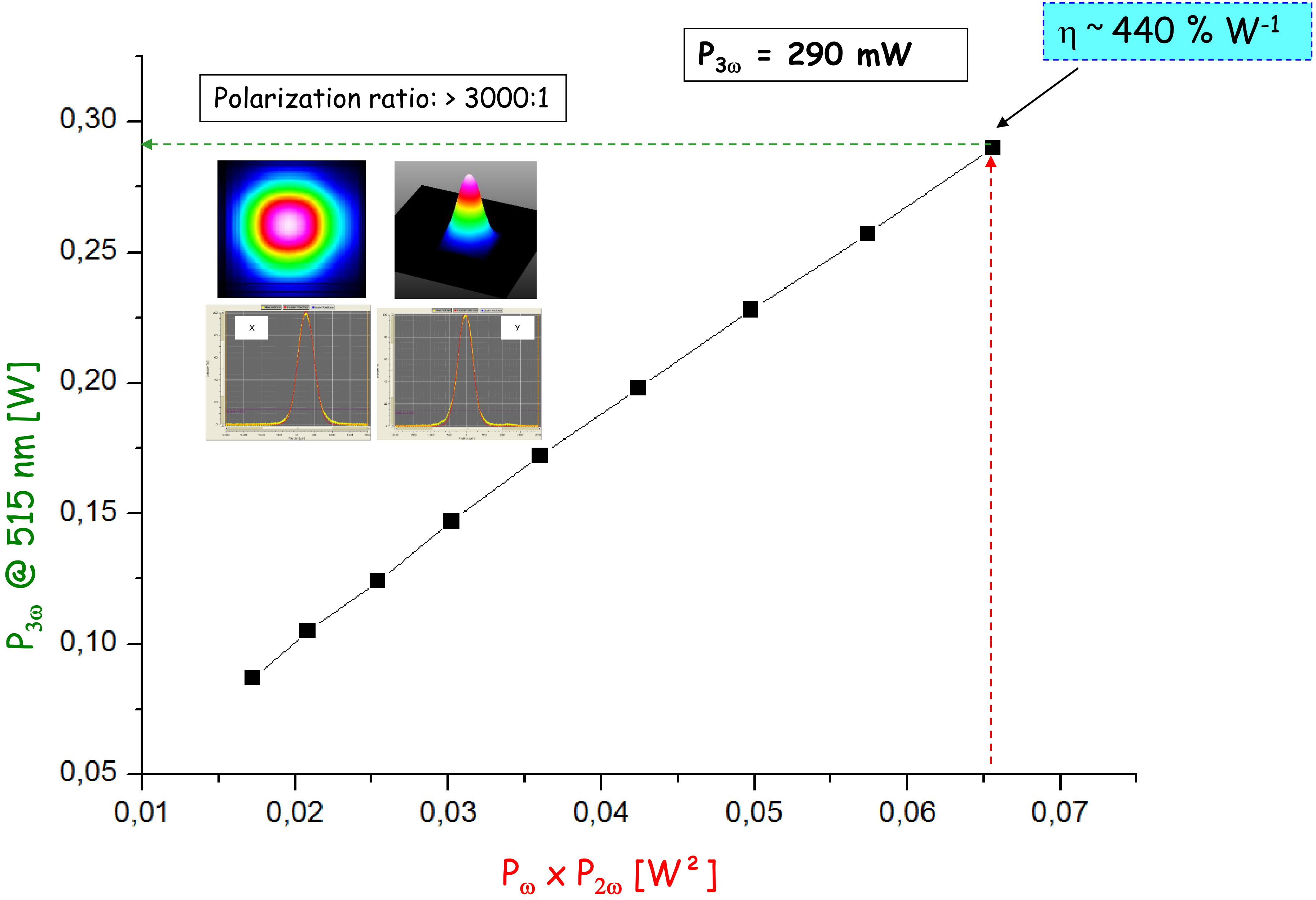



No linear optical conversion
IR – Vert :

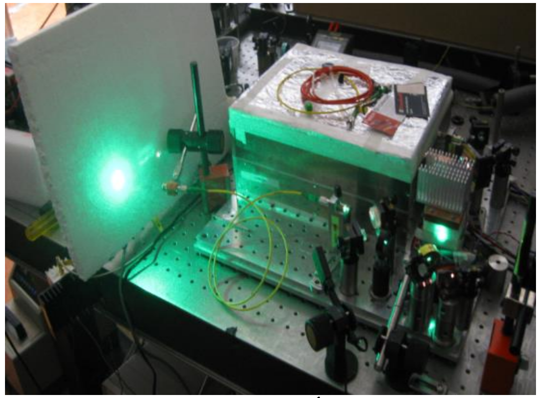
800 mW à 1542 nm
**290 mW à 514 nm**

$P_{3\omega}/P_{\omega} \sim 36\%$



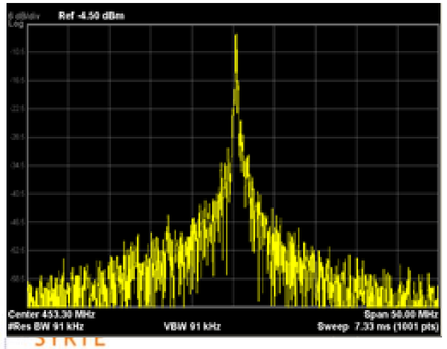
THG demonstrator

Lab experiment



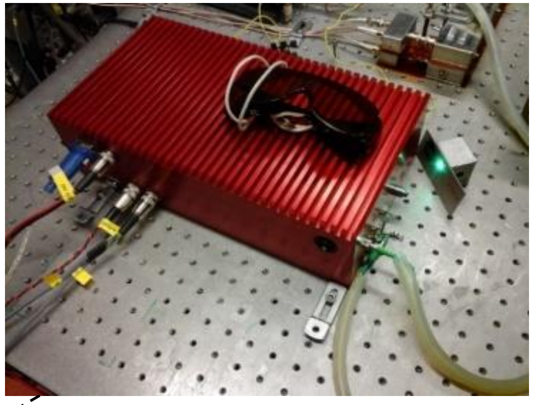
$P_{3\omega}$ = 30 mW
$P_{\omega}$ = 1 W

Linewidth of experiment line (in the green)
Measure by two distinct laser setup
Linewidth < 10 kHz




$3\omega$ high power CW generation demonstrator

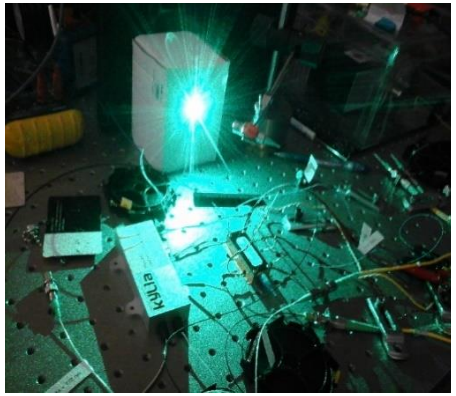
Technologic maturation (lab development)

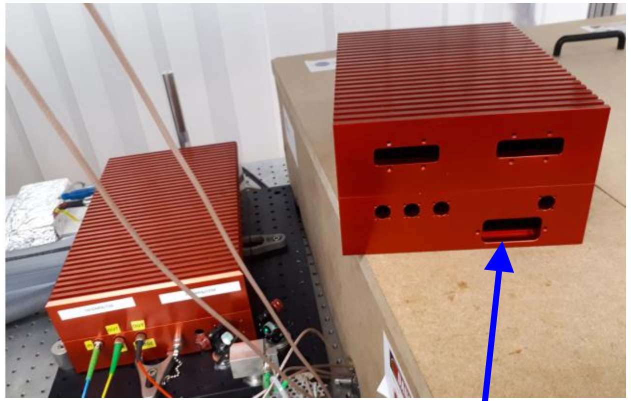


$P_{3\omega}$ = 300 mW
$P_{\omega}$ = 800 mW
$\eta$ = 36 %
Electrical consuption = **21 W**
**Freespace** $3\omega$ output

Very stable power of $3\omega$
Continuous working from July 2014

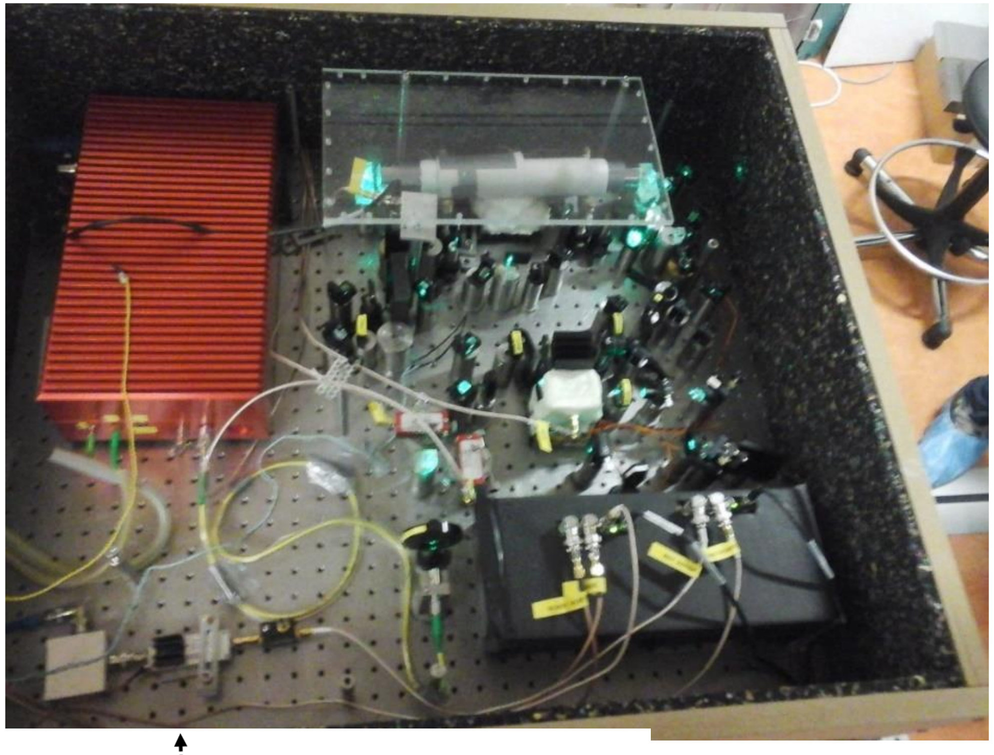
- Low optic power @ $3\omega$
- Low electric consumption
- Low volume
- Bording of electronic control

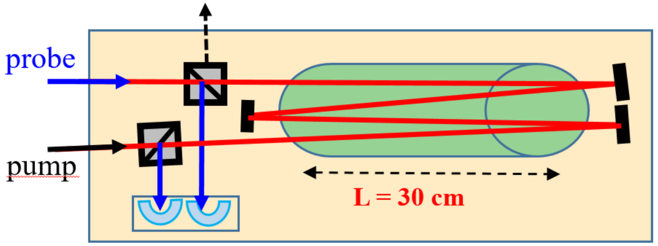




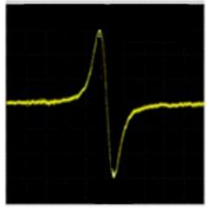
$P_{3\omega}$ = 110 mW
$P_{\omega}$ = 700 mW
$\eta$ = 16 %
Electrical consuption = **20 W**
**PM fibred** $3\omega$ output
Phase modulation included

Planed development based on
New crystal SFG PPLN-Bulk crystal
supported by PhyFOG + PN GRAM






Overall optical bench dimensions :
80 x 80 x 20 cm$^3$ ( ~ 130 litres)



First derivative
of the iodine line
Is used to frequency
Stabilize the IR laser

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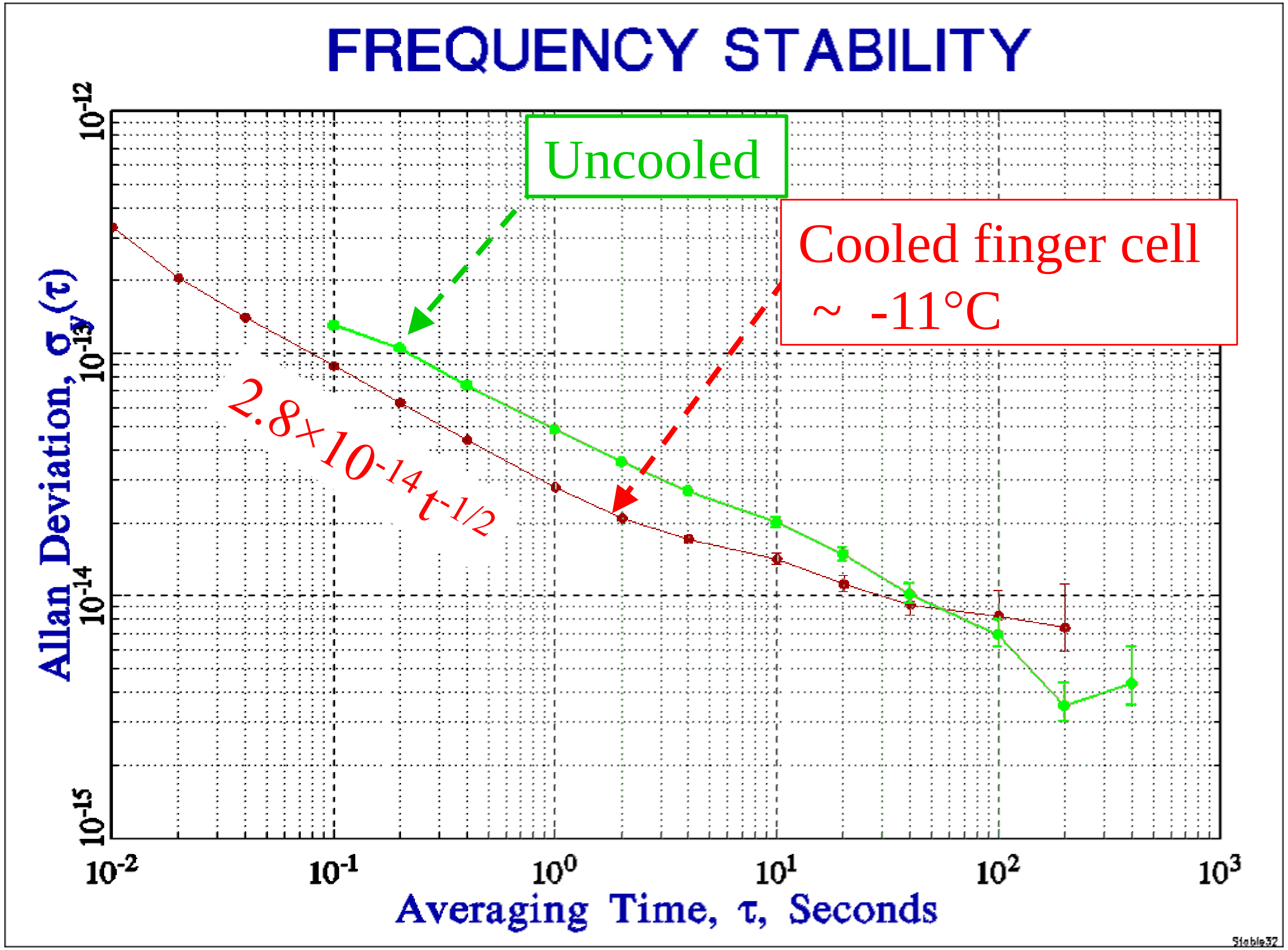
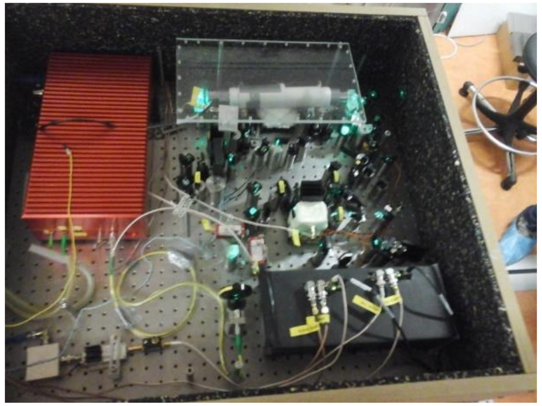
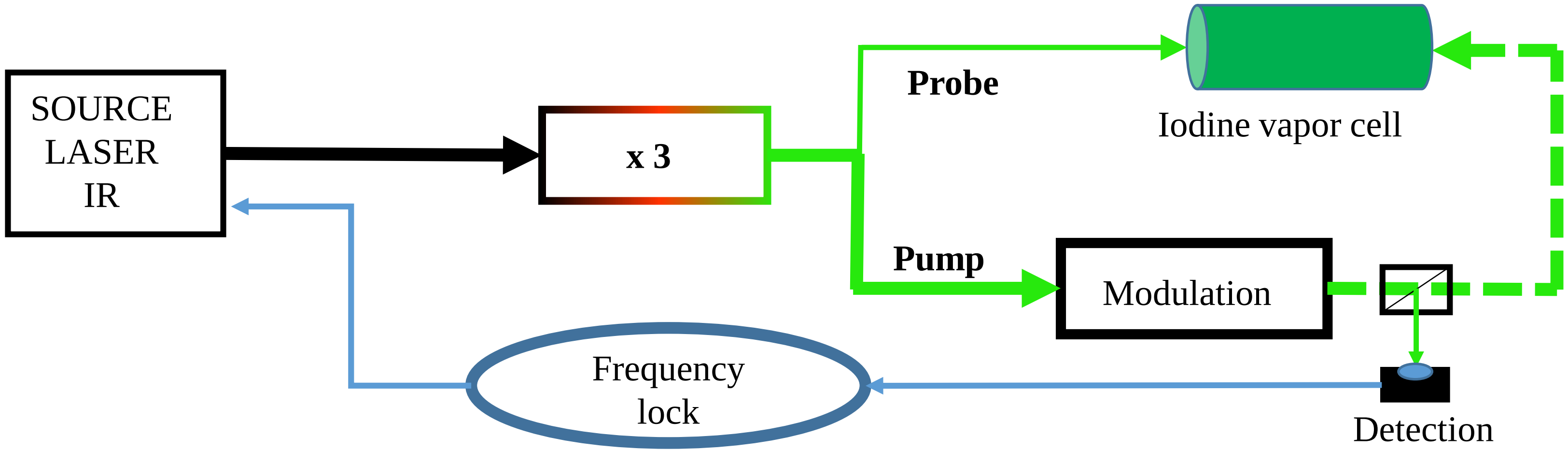
Systèmes de Référence Temps-Espace



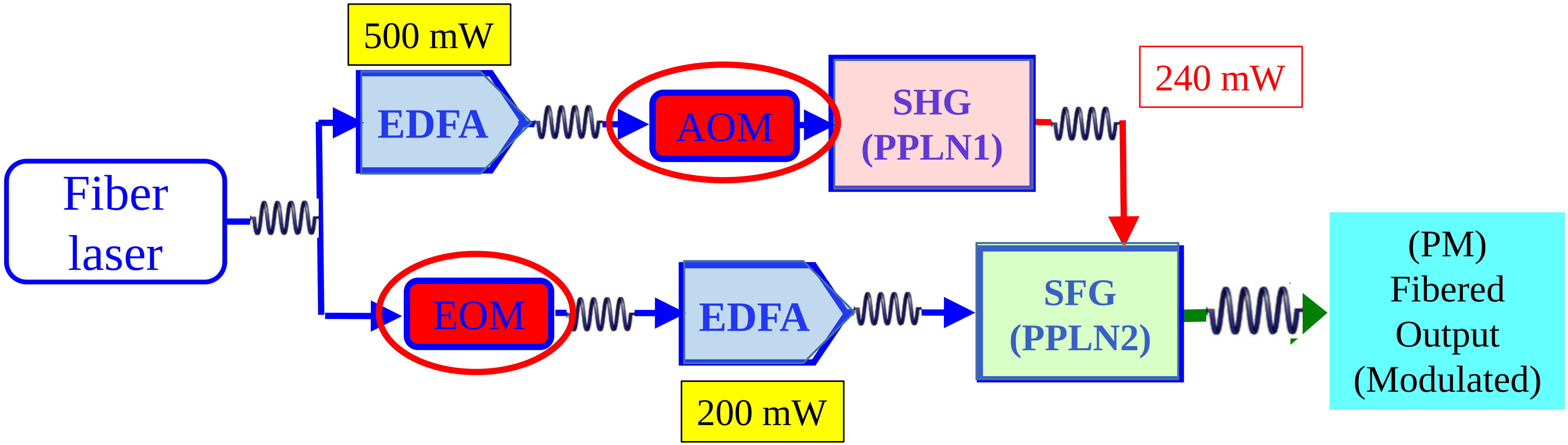





Development of a new frequency stabilized setup
Compact and fibered configuration

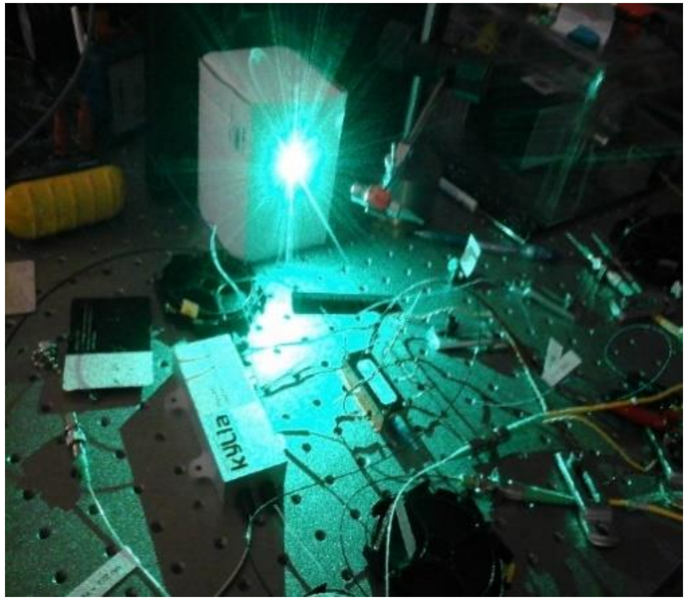
needs to operate in the IR domain :
- the phase modulation (with EOM)
- the power stabilization (with AOM)

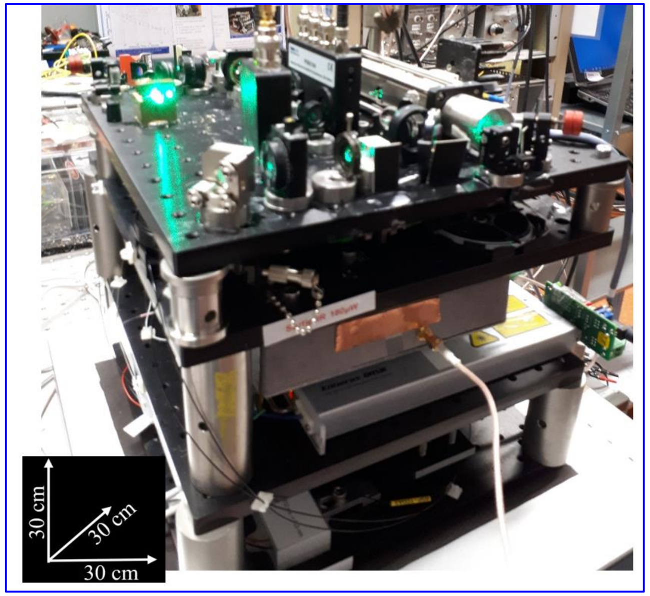
# New generation of frequency stabilized compact and fibered laser




**110 mW @ 514.5 nm**

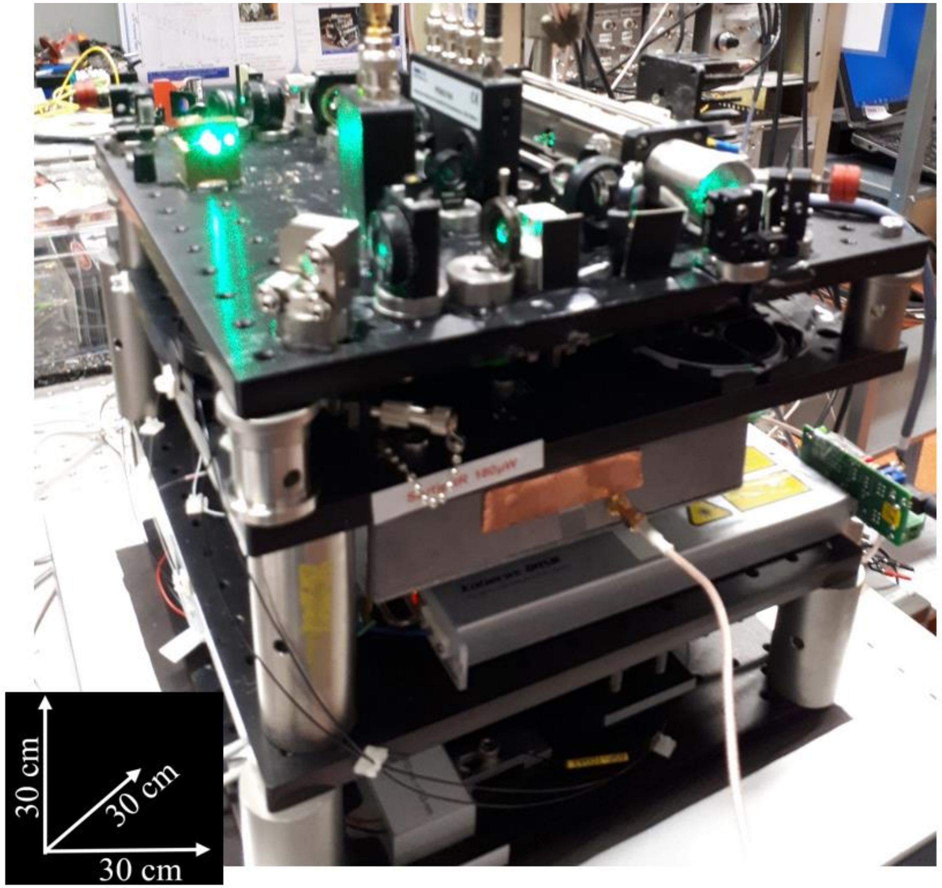
$\eta = P_{3\omega}/P_{\omega} = 15\ \%$

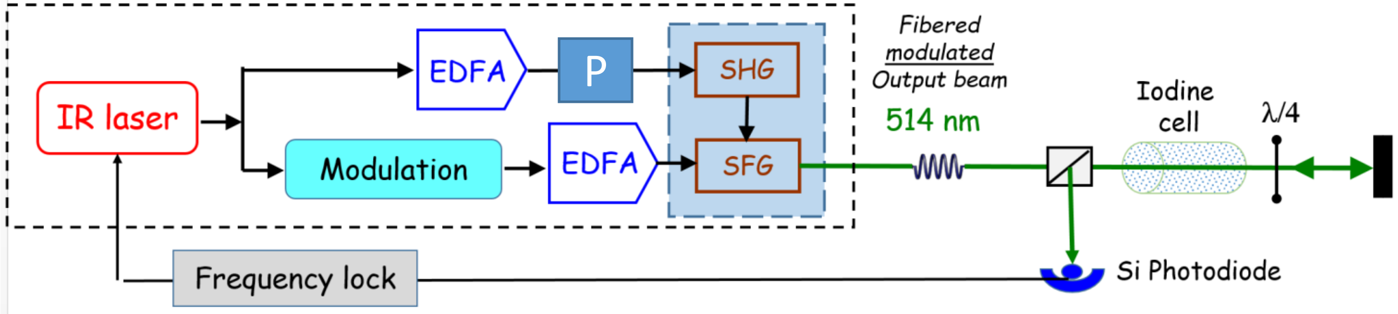




# New generation of frequency stabilized compact and fibered laser

PoC




- Compact setup : 30 x 30 x 30 $cm^3$

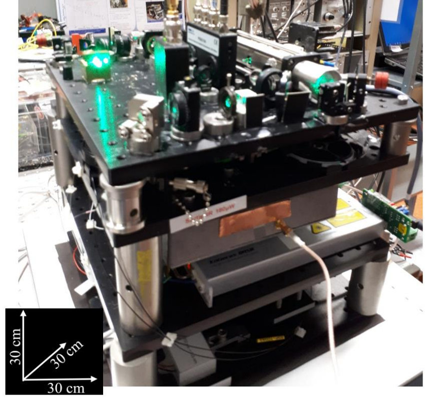
Fibered:

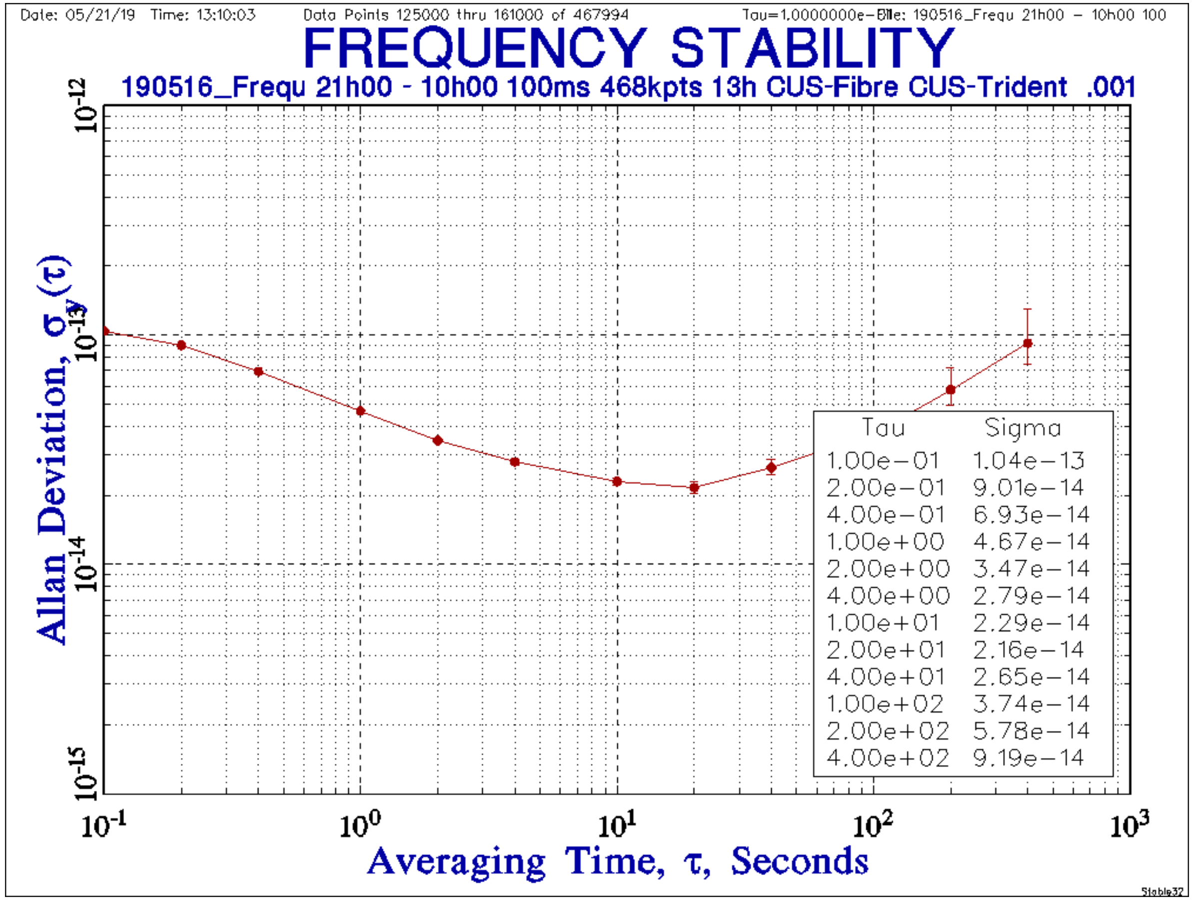
- Fiber laser
- 2 x EDFA
- 2 x LiNbO3 NL crystals (THG process)
- 1 x EOM (Phase modulation)
- 1 x AOM power stabilization in the green

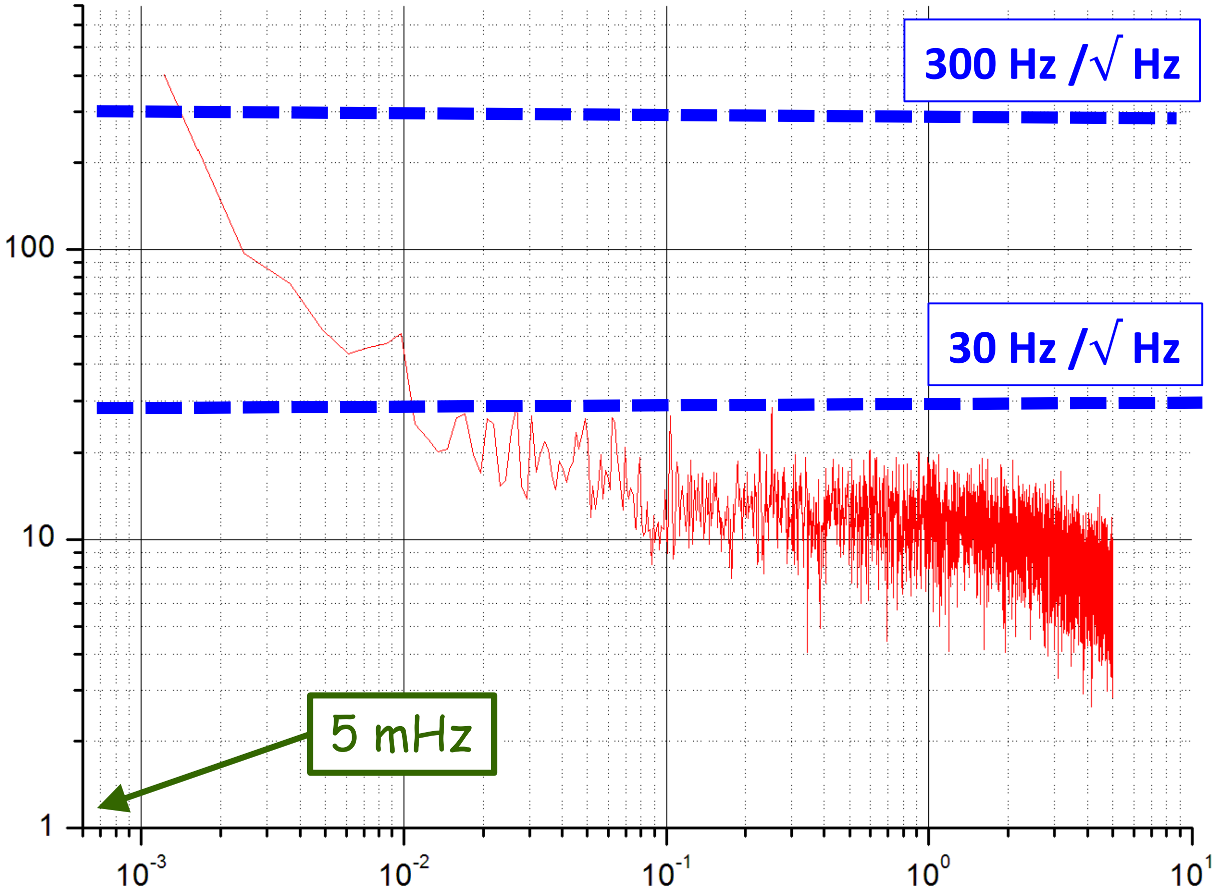
Free space:

- 1 x Iodine cell
- 2 x Photodiodes

# New generation of frequency stabilized compact and fibered laser

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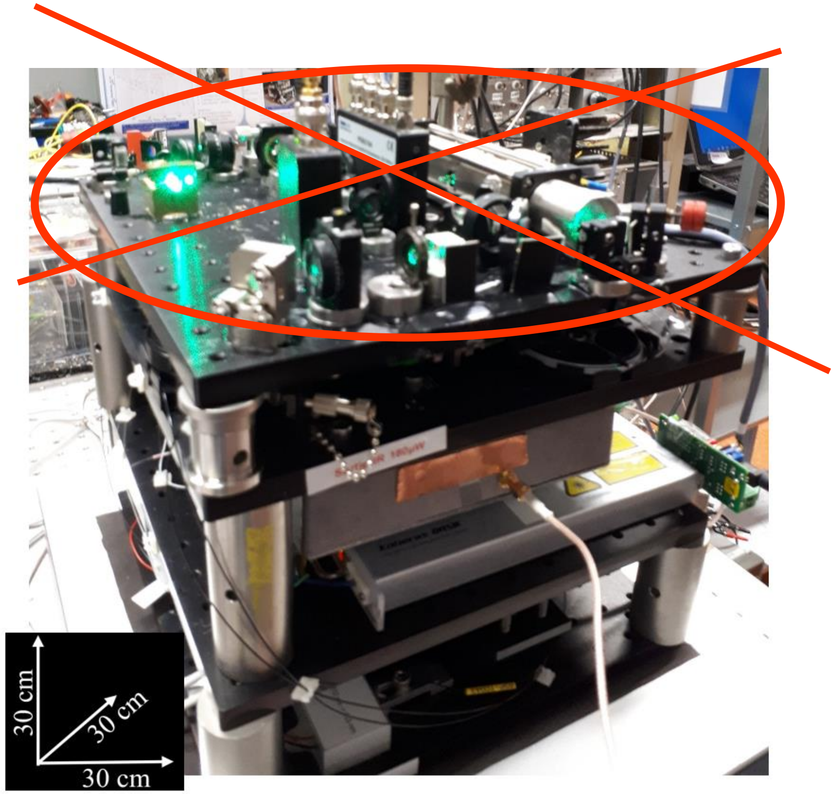
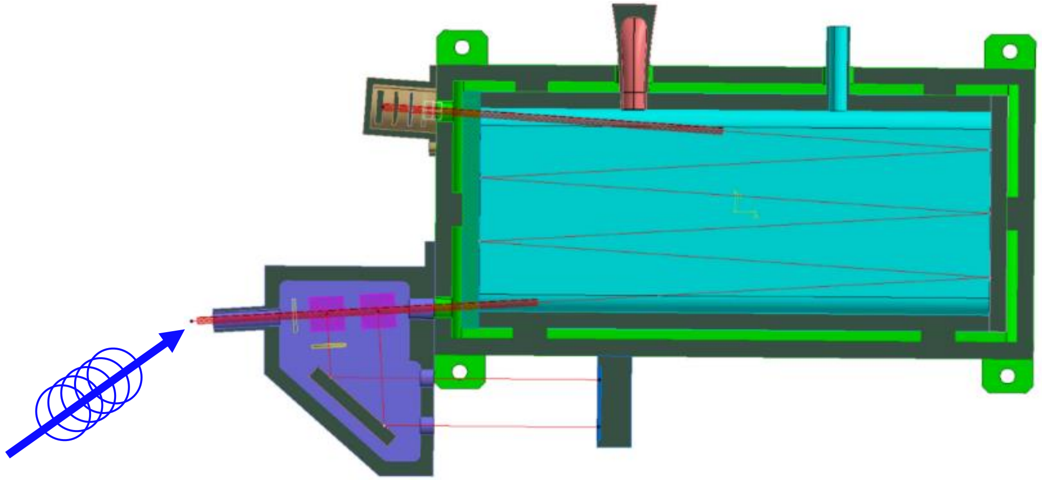
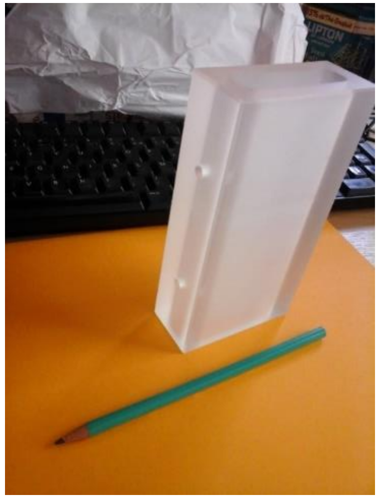
# New generation of frequency stabilized compact and fibered laser

Next step → develop a fibered iodine cell module



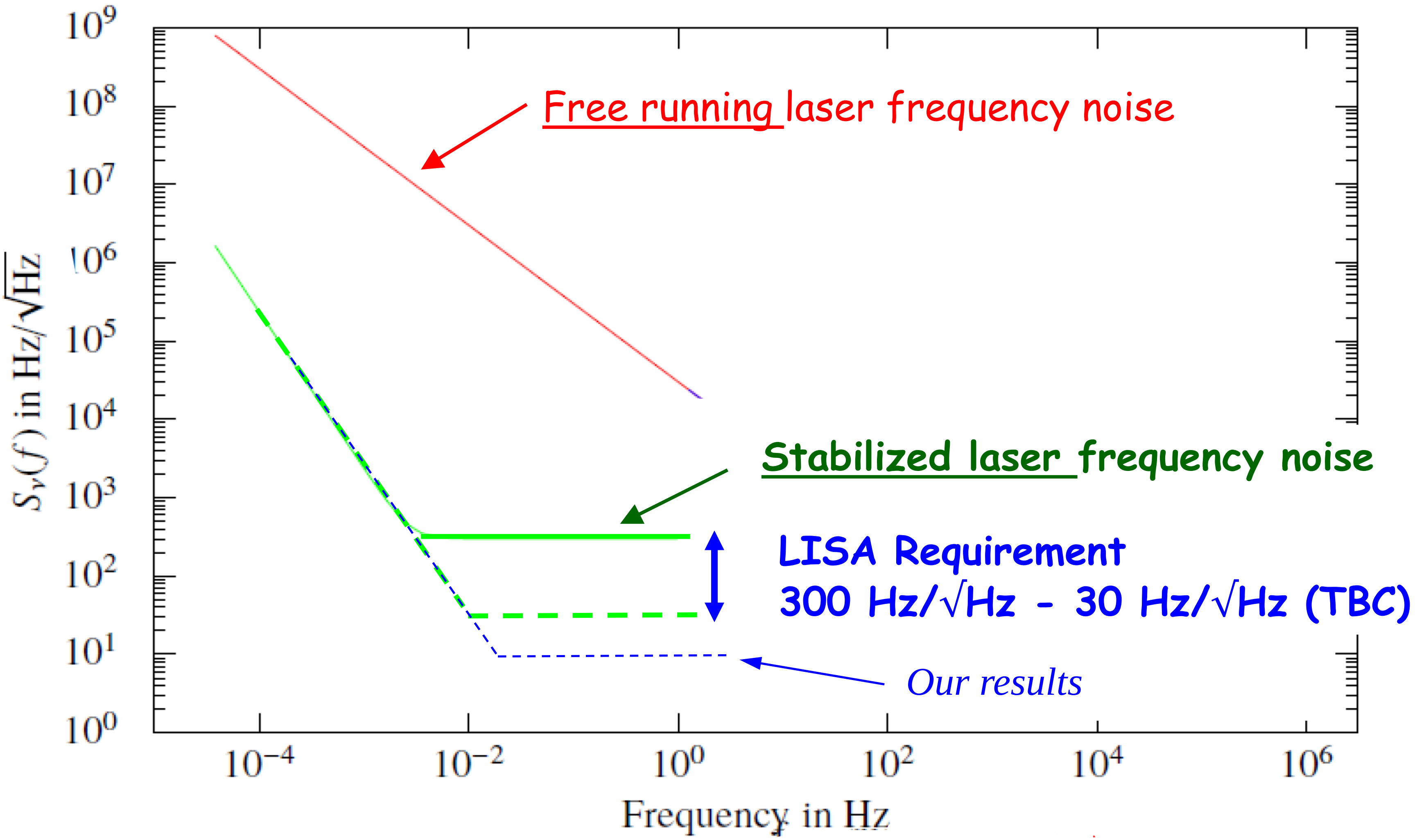





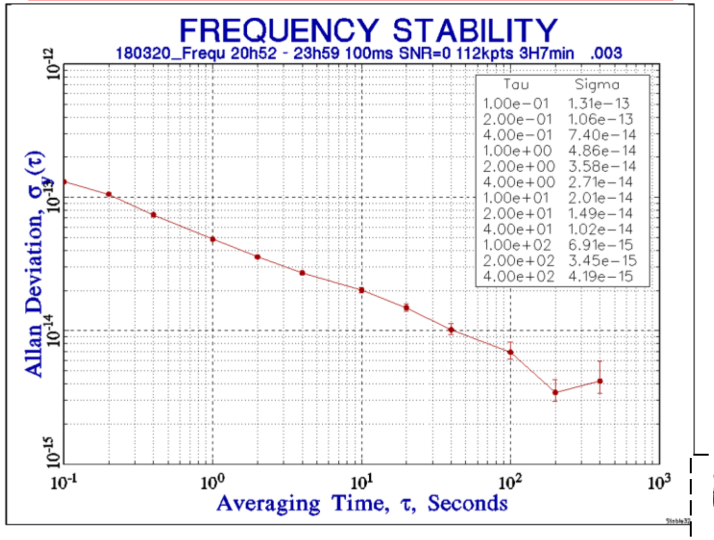
# Application to the ground tests of the payload of the LISA mission

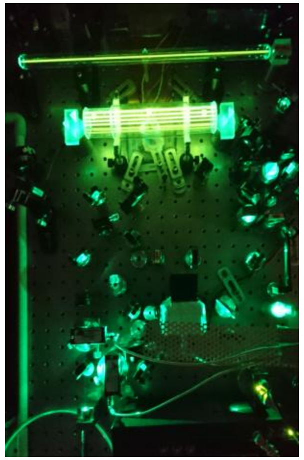
Nominal LISA-laser wavelength = 1064 nm

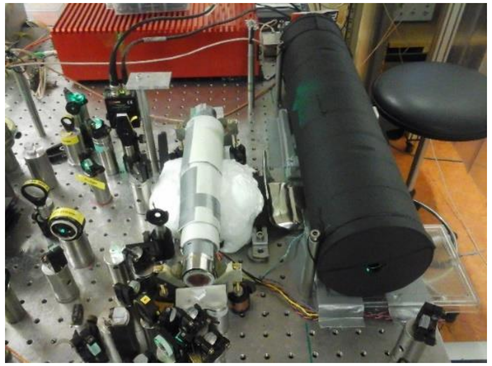
LISA - Laser frequency stability



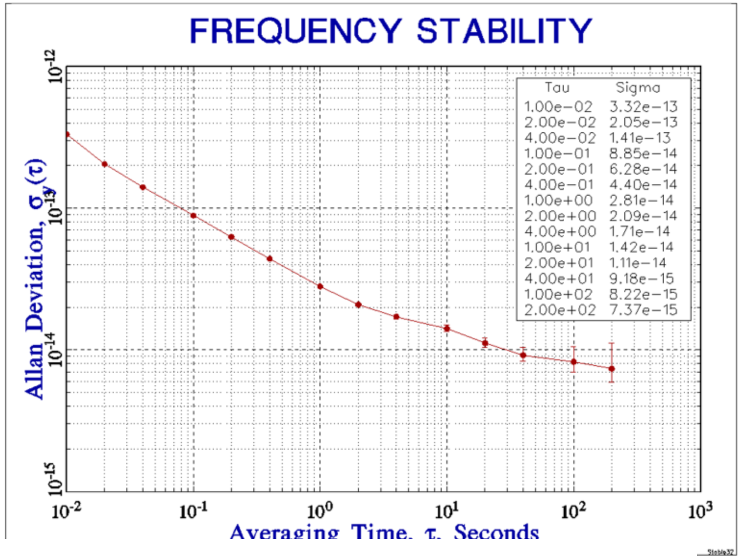
Room temperature iodine cell
& Magnetic shield



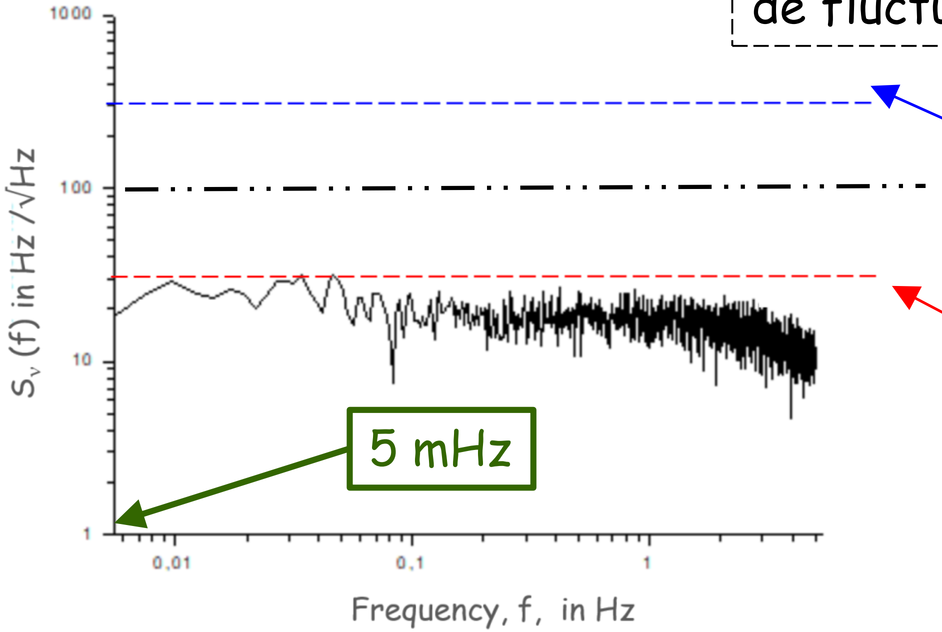





Cooled iodine cell (-11°C )
No magnetic shield

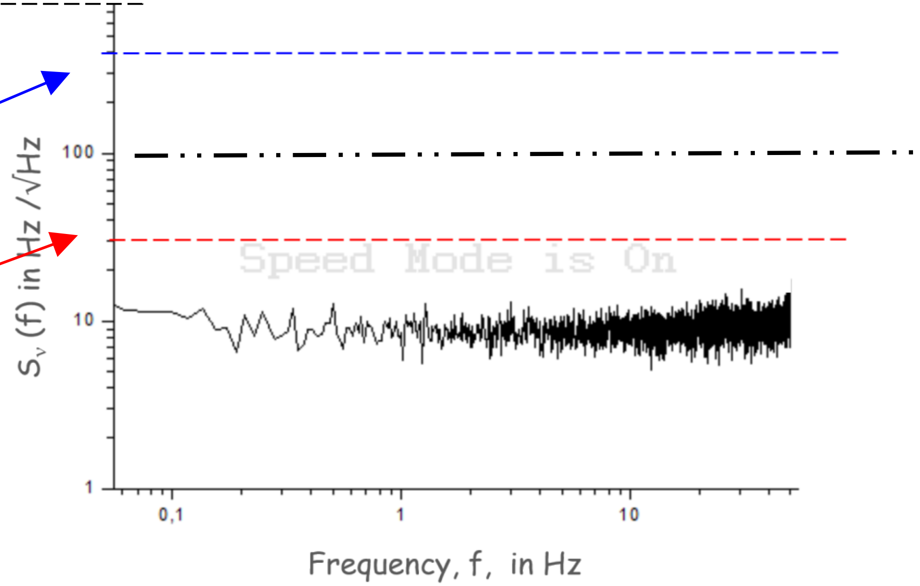



Exprimées en termes de densité spectrale
de fluctuations résiduelles de fréquence




**300 Hz /√ Hz**

**30 Hz /√ Hz**

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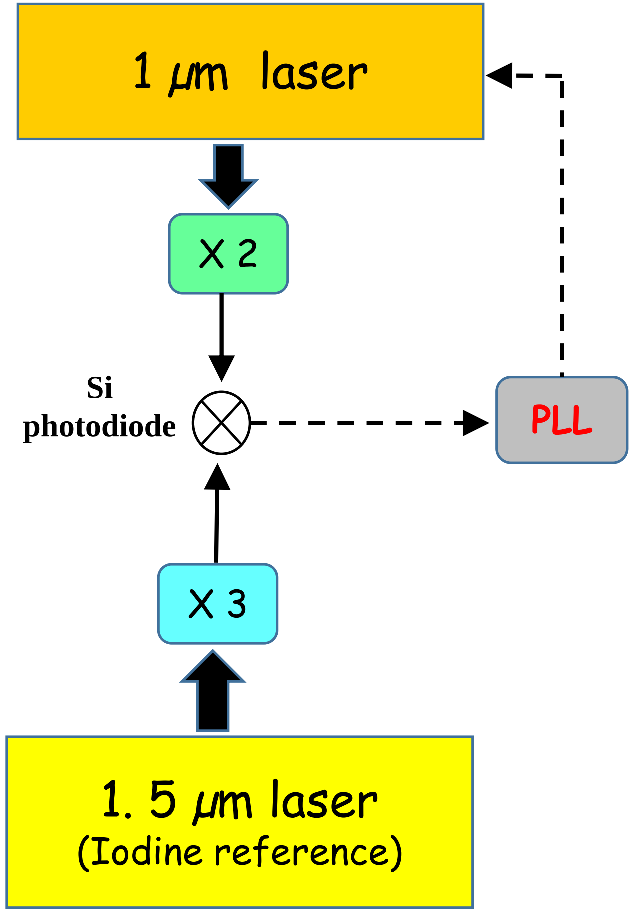


2936 OPTICS LETTERS / Vol. 39, No. 10 / May 15, 2014

# Optical phase locking of two infrared continuous wave lasers separated by 100 THz

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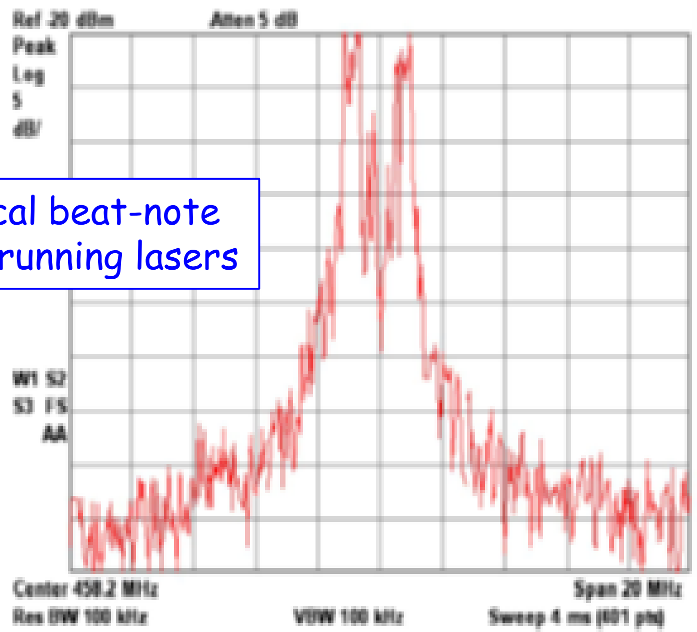
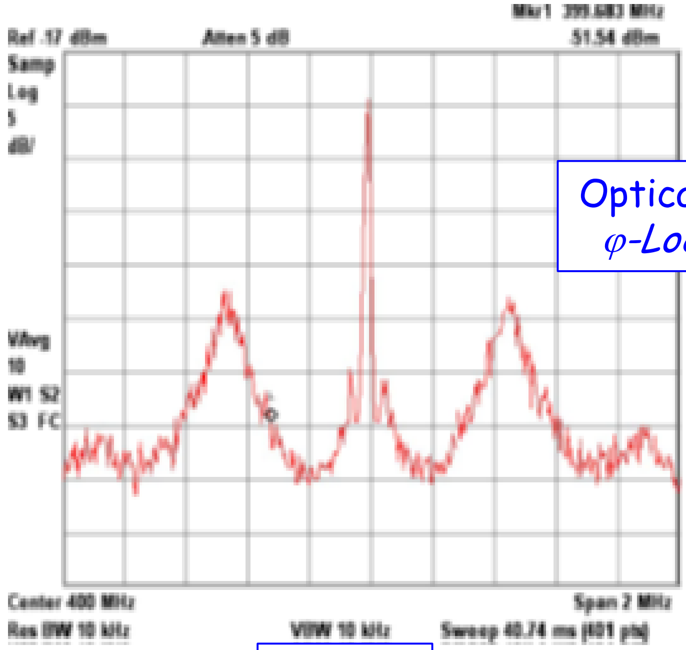
Received December 20, 2013; revised March 28, 2014; accepted March 30, 2014;
posted April 11, 2014 (Doc. ID 203532); published May 9, 2014

We report on phase locking of two continuous wave IR laser sources separated by 100 THz emitting around 1029 and 1544 nm, respectively. Our approach uses three independent harmonic generation processes of the IR laser frequencies in periodically poled $MgO:LiNbO_3$ crystals to generate second and third harmonics of those two IR sources. The beat note between the two independent green radiations generated around 515 nm is used to phase lock one IR laser to the other, with tunable radio frequency offset. In this way, the whole setup operates as a mini-frequency comb




Optical beat-note
Free running lasers

20 MHz

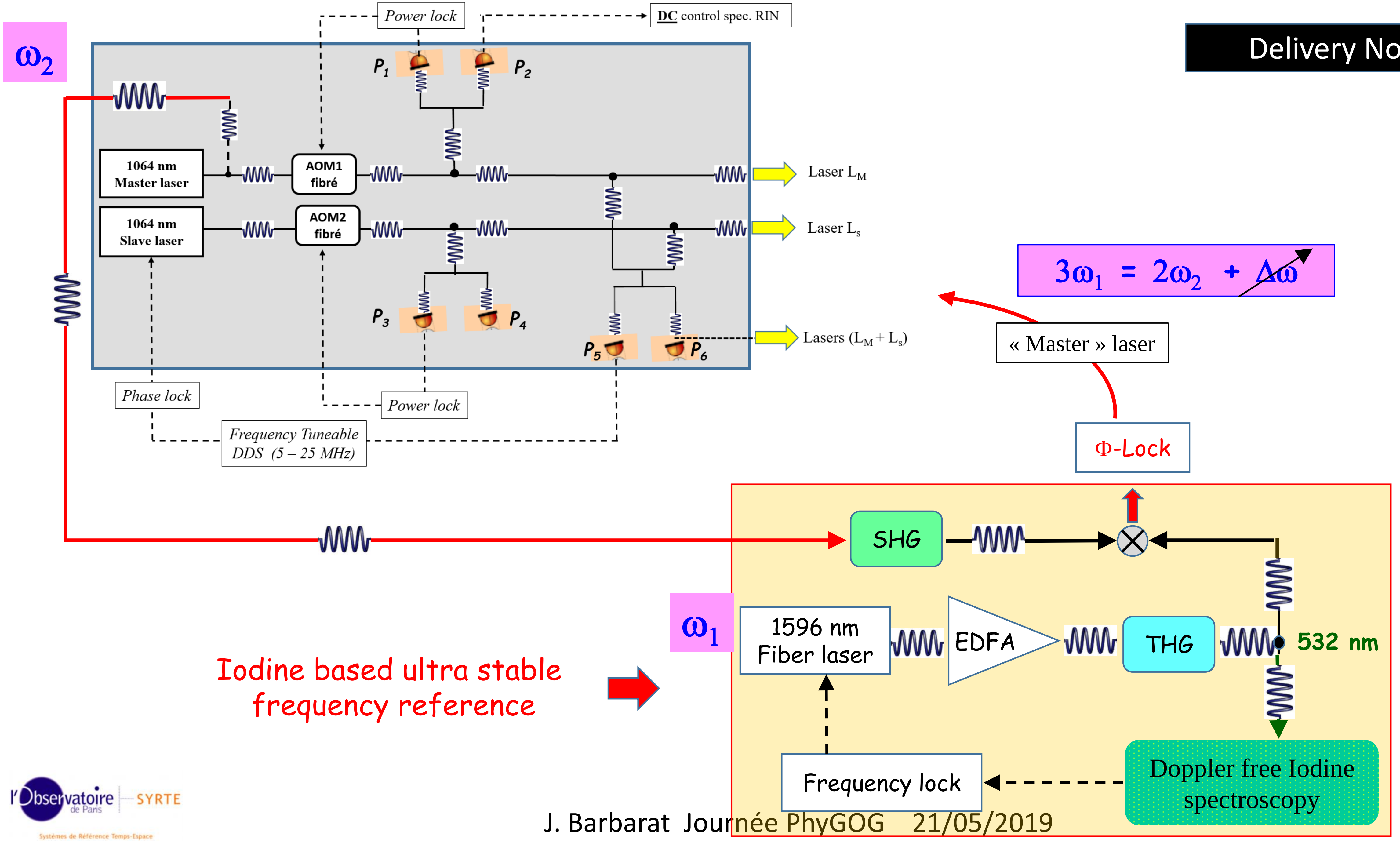



Optical beat-note
*φ-Locked* lasers

2 MHz

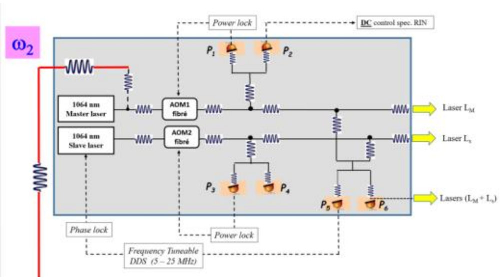
N. Chiodo et al., Optics Lett. 29, 2014

Delivery Nov. 2019

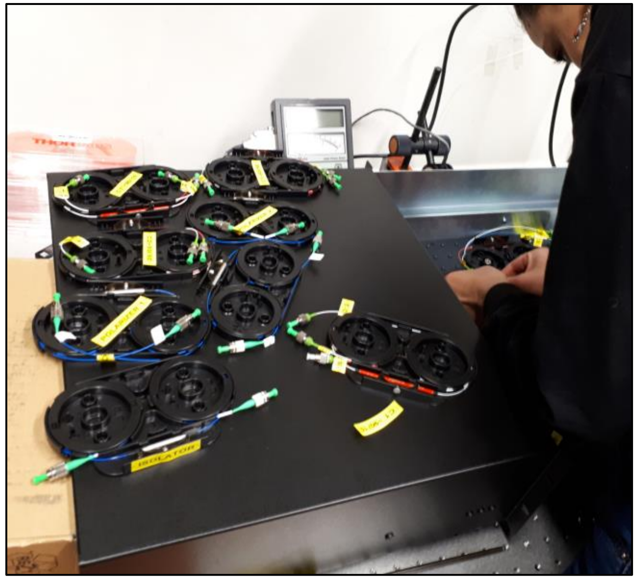



Delivery > 2020

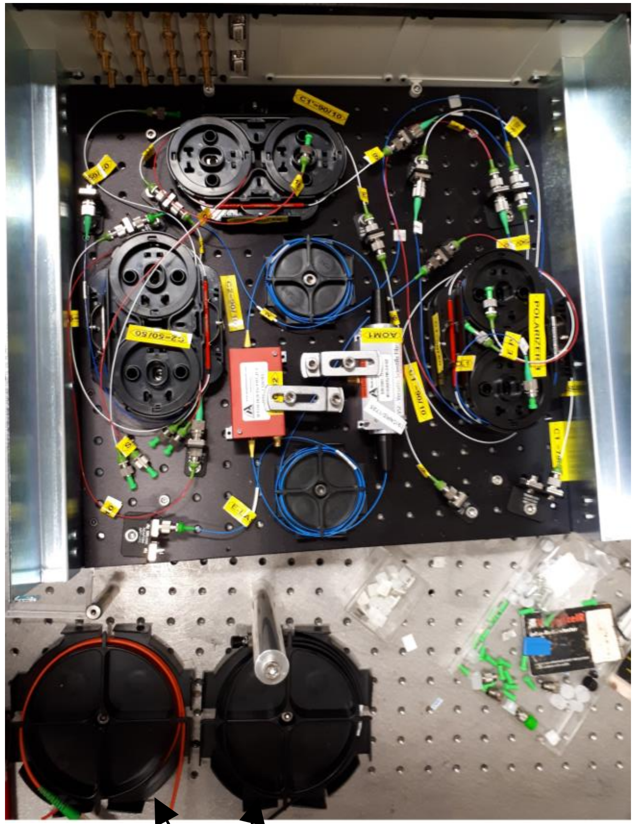
# Optical bench under development (Phase A / LISA-France activities)

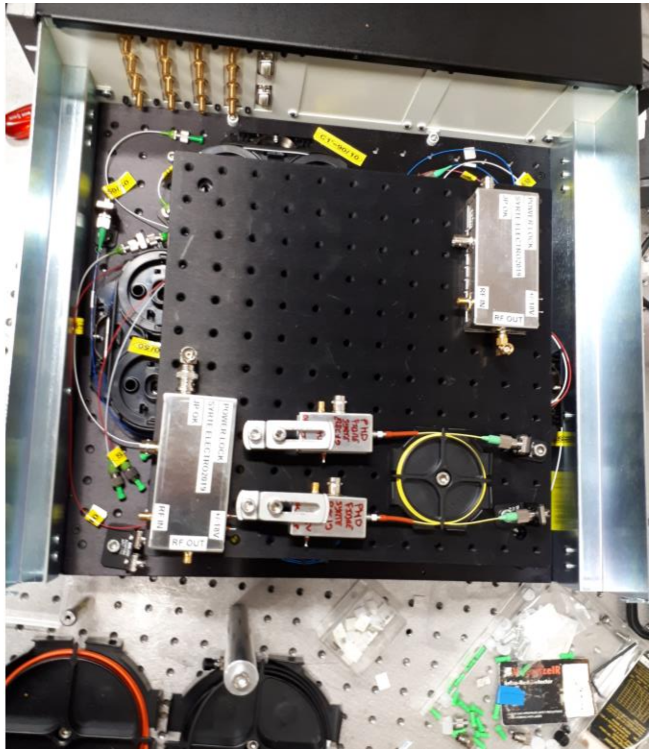






*K. Zahar's Master internship*





The whole setup will be provided in 19'' rack

Input 1064 nm lasers

- Photodiodes
- Power stabilization
- ….

# Conclusion

- Efficient frequency tripling process of a CW Telecom laser diode (~1.54 µm) is demonstrated
- Compact, fibered and low electrical consumption devices
- We have demonstrated frequency stability in the $10^{-15}$ range using Iodine atomic vapor in a sealed cell.
- Possibility to operate a frequency stability transfer at others wavelengths (near IR, visible)

## Applications

- Ultra-stable optic link, Laser ranging, ground-space or inter- satellites links, LISA
- New generation ground detectors at 1. 5 µm
- Atmospheric spectroscopy, femtosecond laser frequency stabilization, LIDAR control
- Underwater optical telecommunications

Thank you for your attention