All-fibered, Compact and Transportable Iodine-based Optical Frequency Standard

➢ Main Objectives

- ❖ New generation of optical frequency standard
  - ✓ All-fibered
  - ✓ Compact & Transportable
  - ✓ Low power consumption

- ❖ Frequency stabilization on molecular iodine hyperfine line
  - ✓ ~ 10^{-14} for short term
  - ✓ ~ 10^{-15} for mid/long term
  - ✓ Long term reproducibility (accuracy) ~ kHz over years

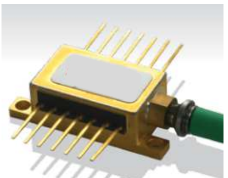
- ❖ Frequency stability transfer to other ranges of the optical domain
  IR (~ 1.5 µm and ~1 µm) & visible (from 800 nm to 700 nm) in same time

- ❖ Technological readiness level TRL4 for laboratory prototype

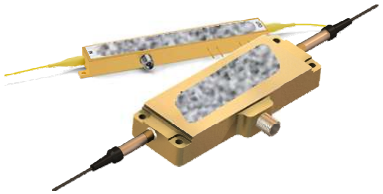
➢ Key points:

- ❑ Telecom laser sources exhibit very low intrinsic phase noise, unequaled at other wavelengths
- ❑ Optical amplifiers (EDFA) are powerful, compact & low amplitude/phase noise
- ❑ All other photonic components (EOM, AOM, nonlinear crystals, etc ..) have a superior TRL
- ❑ … and are space qualified or under tests (*)
- ❑ Iodine molecular references in the green range are intense, with high quality factor **(Q>10^9)**

Telecom band ~ 1.5 µm

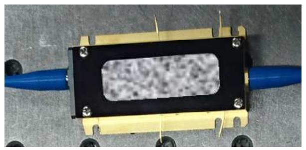


Laser Diode



EOM & AOM

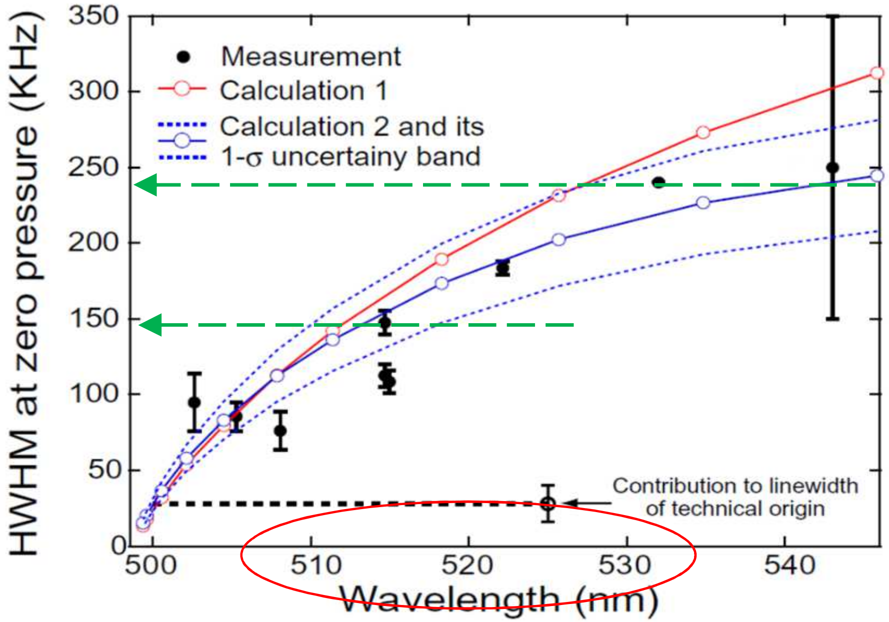
EDFA



Nonlinear Crystals

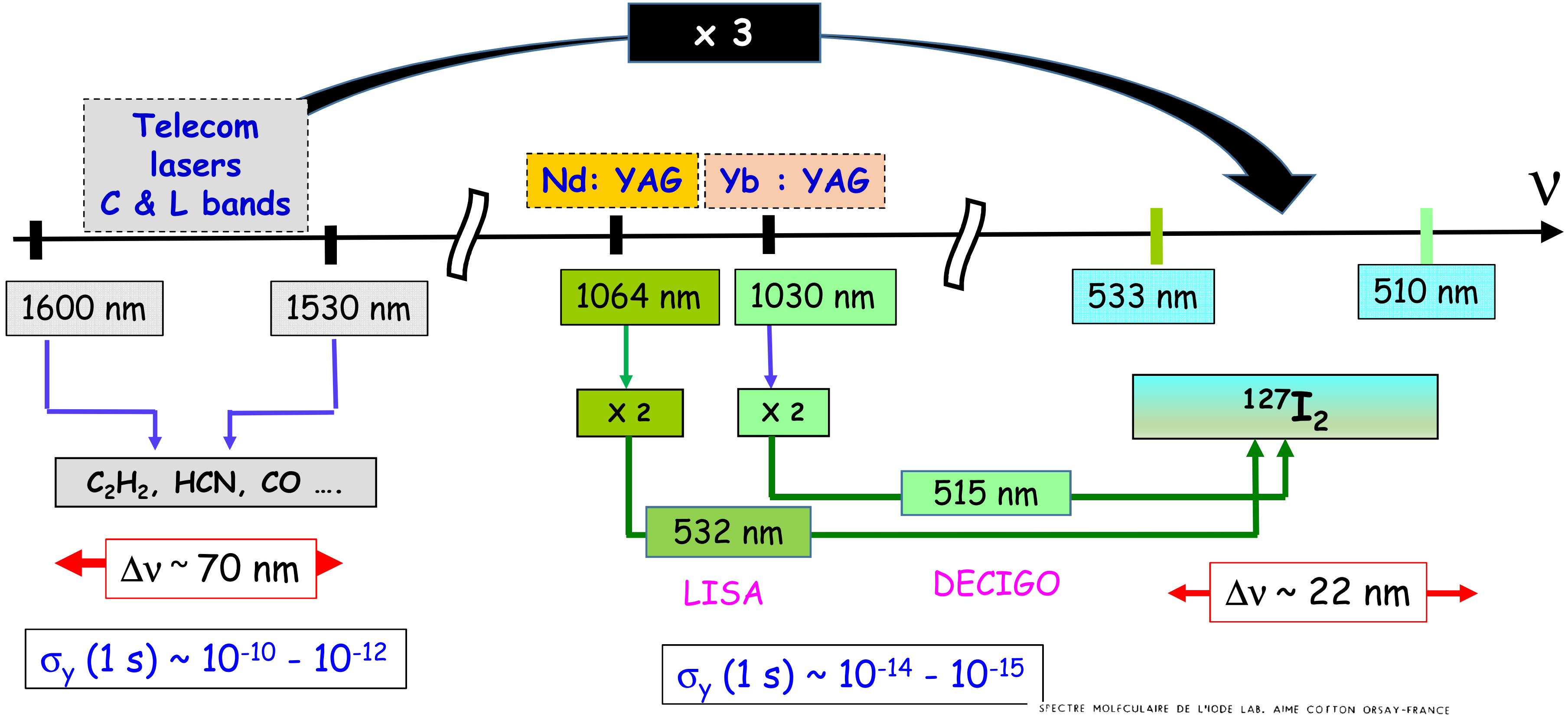
(*)
- V. Schkolnik et al., arXiv:1702.08330v1 (Feb. 2017)
- T. Lévèque et al., Applied Physics B, (2014)
- V. Menoret et al., Optics Lett., Vol. 36/ 21 (Nov. 2011)

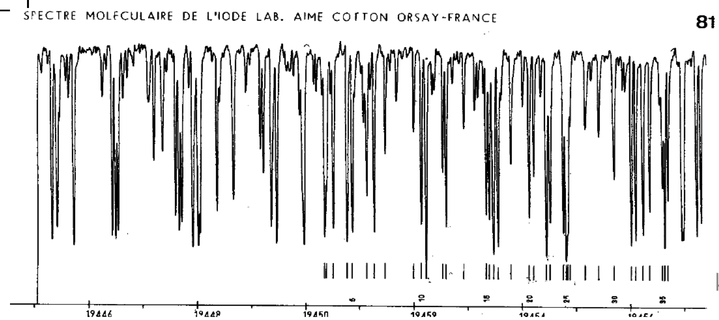
Green range ~ 515 nm



L. CHEN, «High-Precision Spectroscopy of Molecular Iodine", Thesis University of Colorado 2005,

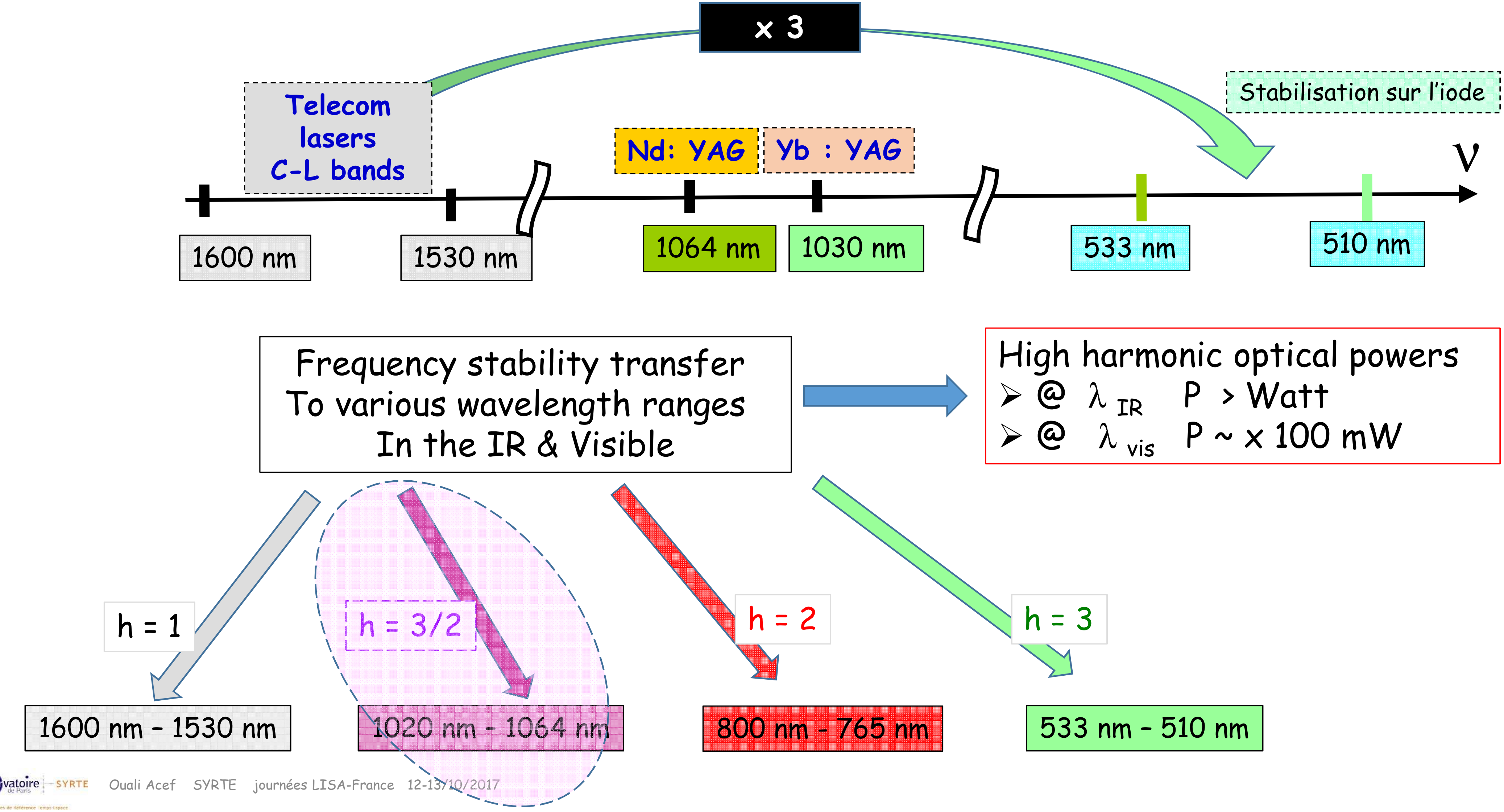
Opportunity to frequency stabilize any Telecom laser emitting in the C or L optical bands
Frequency step < 5 GHz in the IR





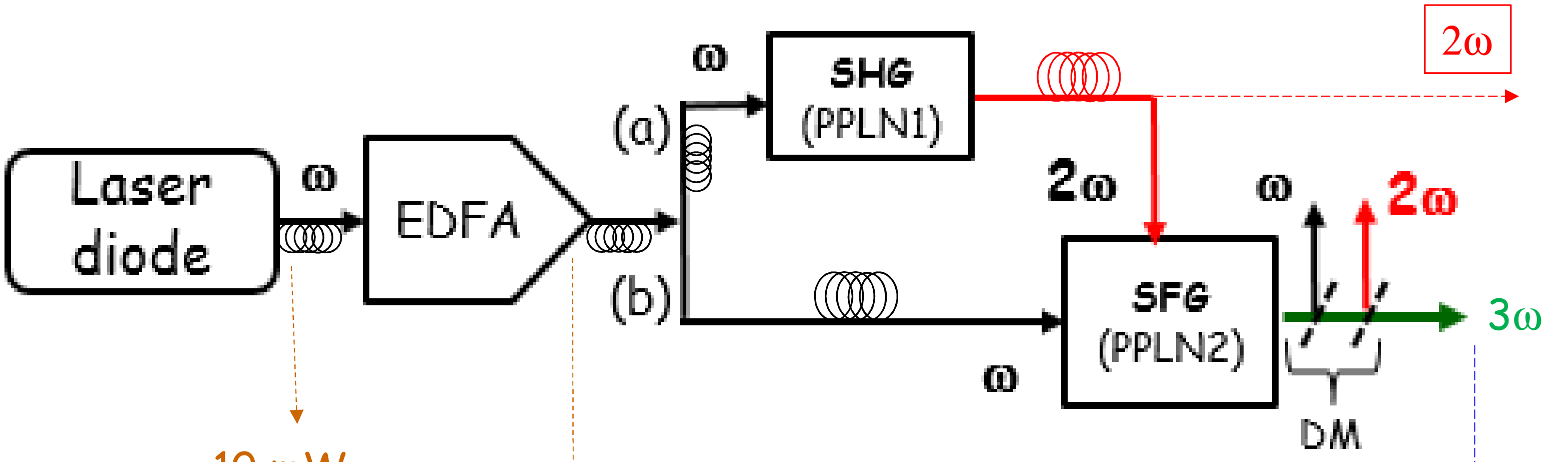
Dense iodine absorption spectrum in the green range
> 10^5 hyperfine lines of $^{127}I_2$

Opportunity to frequency stabilize any Telecom laser emitting in the C or L optical bands
Frequency step < 5 GHz in the IR



Frequency tripling process

Volume and power consumption not optimized



10 mW

800 mW

300 mW

High optical efficiency

$\eta_{\omega \to 3\omega} = P_{3\omega}/P_{\omega}$

$\eta > 36\ \%$

Low power consumption

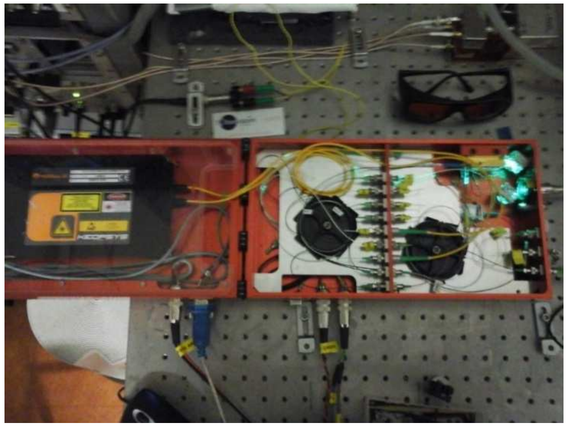
< 20 Watt

(Non-optimized)

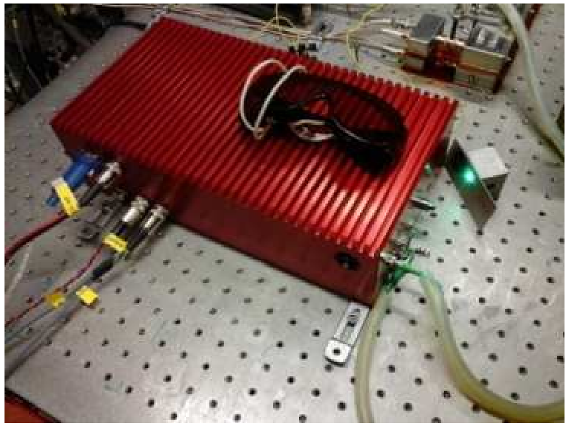
$\rho = P_{opt}/P_{elect}$

$= 1{,}5\ \%$

Frequency stabilization purpose needs **Less** than 20 mW of green optical power **(@ 3ω)**



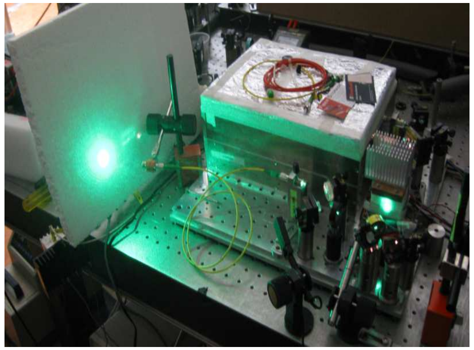
Volume ~ 5 l



TRL 4

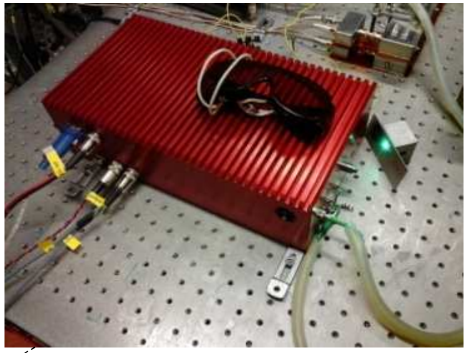
Ch. Philippe et al., « Efficient third harmonic generation of a CW-fibered 1.5 µm laser diode", Appl. Phys. B 122 (10) 265 (2016)

THG process demonstration



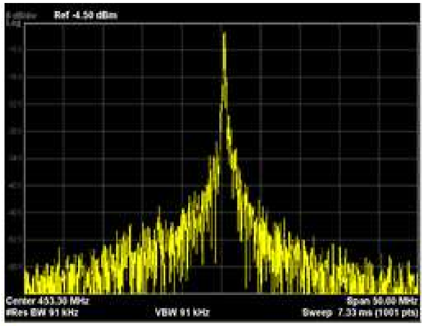
$P_{3\omega}$ = 30 mW
P_{ω} = 1 W

High efficiency THG



$P_{3\omega}$ = 300 mW
P_{ω} = 800 mW

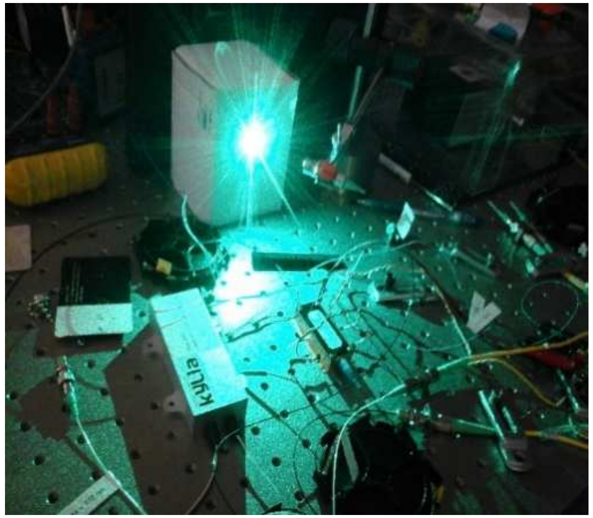
Experimental linewidth
< 10 kHz (@ 3ω)
(between two independent systems)



Stable harmonic power @ 3ω
Continuous operation since July 2014

Ongoing development

- Low optical power @ 3ω
- Low power consumption
- Reduced optical volume



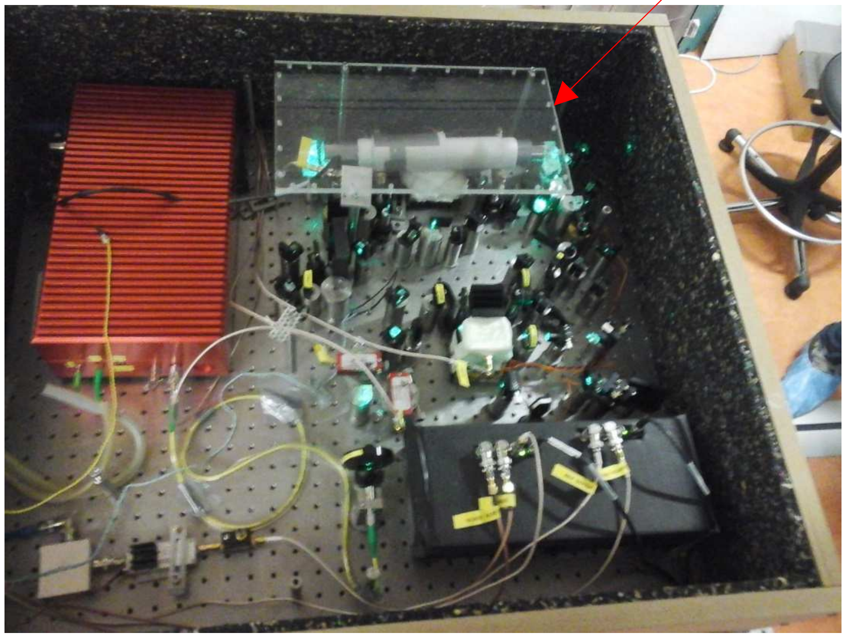
$P_{3\omega}$ = 110 mW
P_{ω} = 0,5 W

EDFA
Volume / 4
Mass / 3

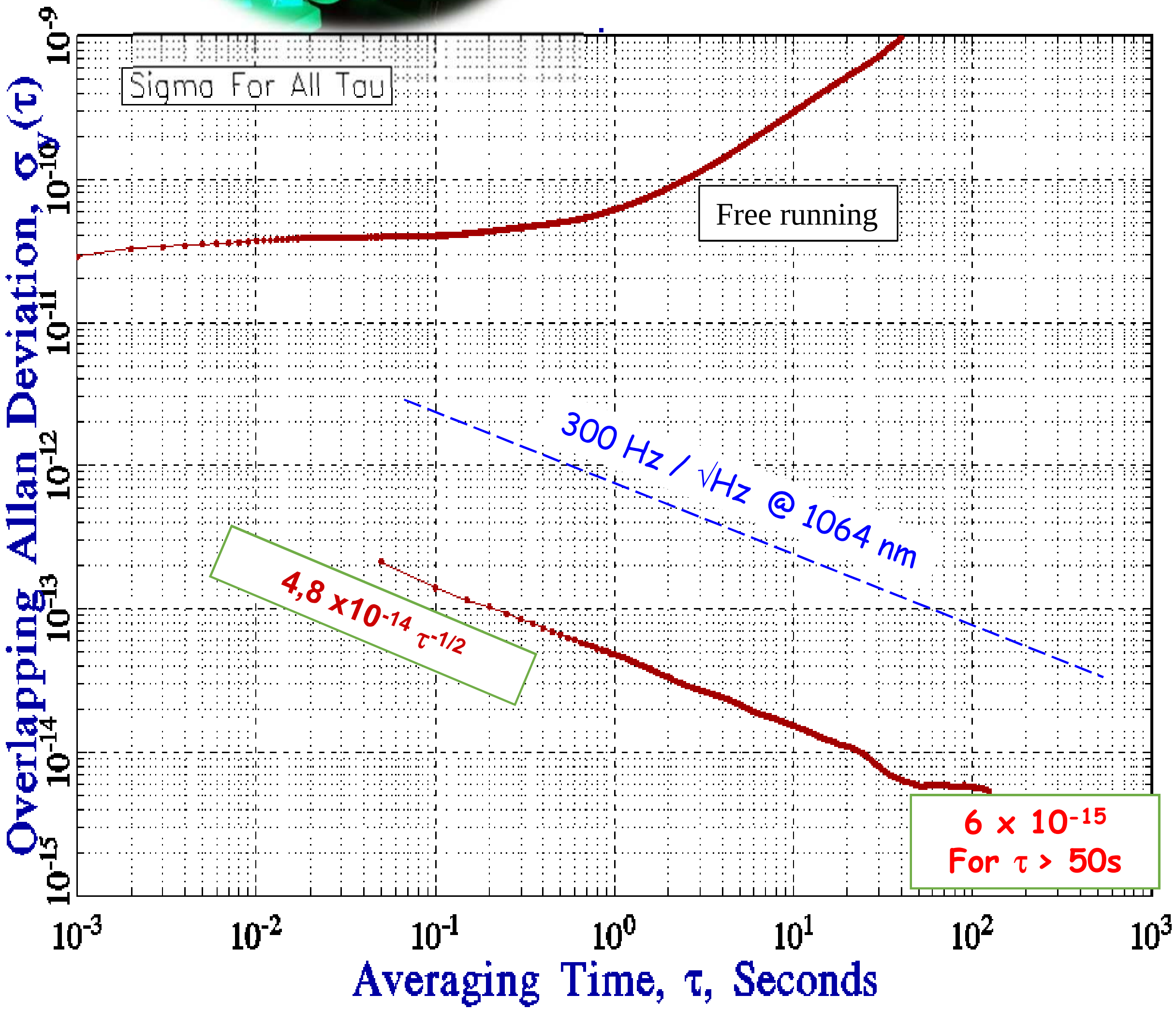
R&T CNES – 2017/2018

Free space iodine stabilization setup

Cellule d'iode
Longueur 20 cm



Ch. Philippe et al., "Frequency tripled 1.5 µm telecom laser diode stabilized to iodine hyperfine line in the 10–15 range", **DOI:** [10.1109/EFTF.2016.7477827](https://doi.org/10.1109/EFTF.2016.7477827)

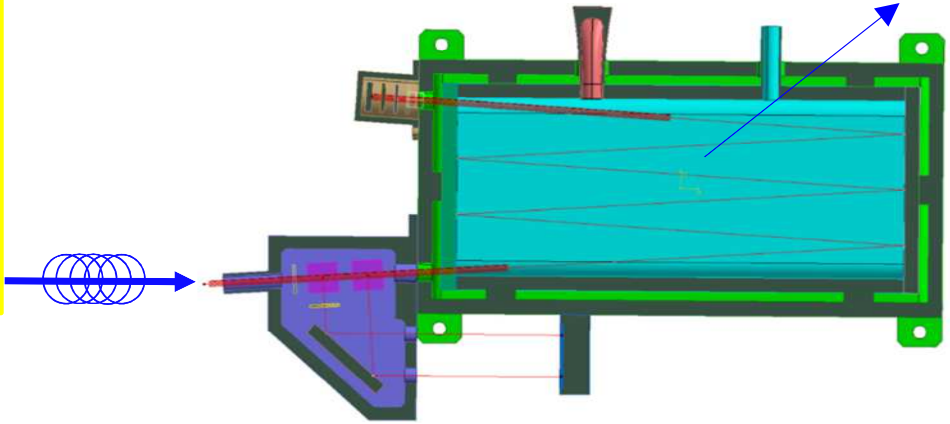


Transportable optical frequency standard
Prototype under development

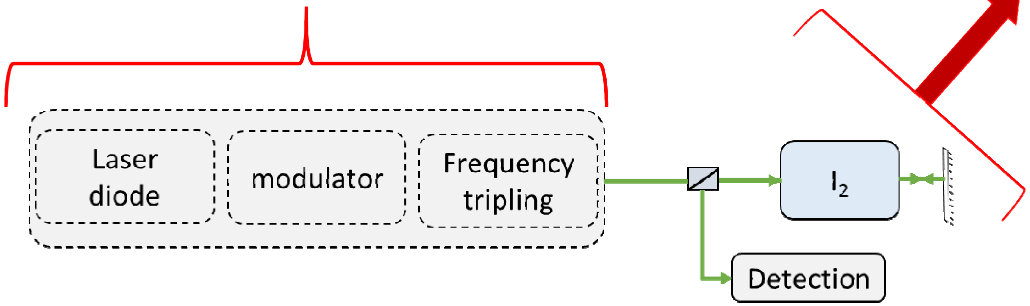
Banc laser fibré

Développé

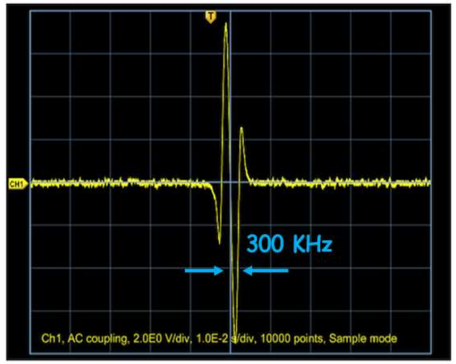
Compact Iodine cell
15 x 8 x 4 cm^3



Intégration
opto-mécanique
en cours



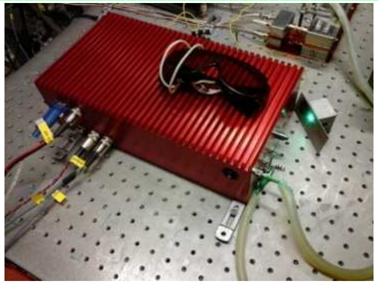
Approach already
demonstrated

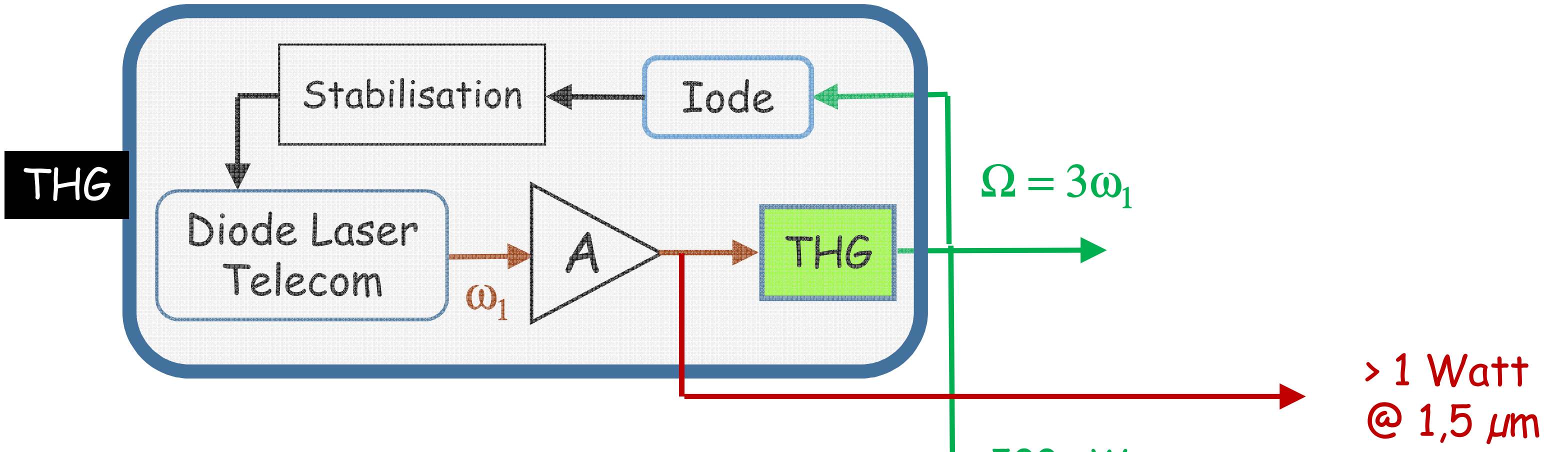


Composante hyperfine a_{15} de la raie R46(44-0) au voisinage de 1543. nm

Frequency stability transfer from 1542 nm → 1030 nm

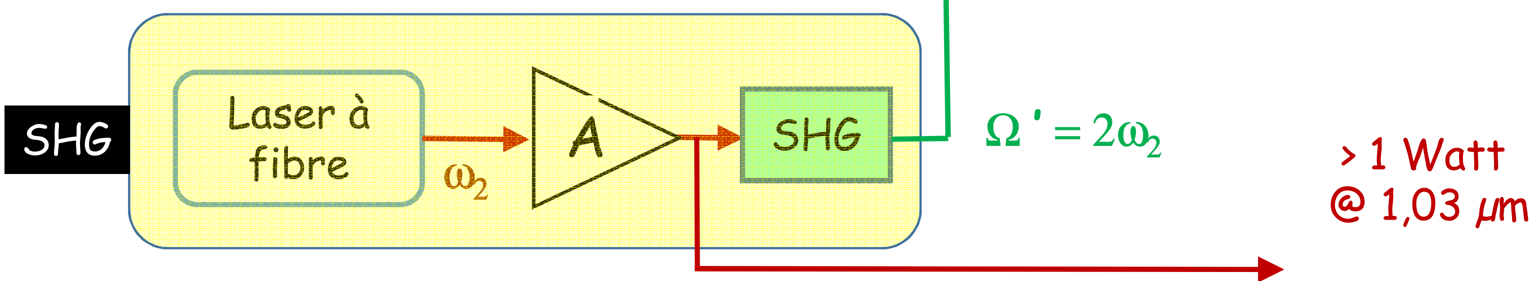
Frequency tripled
1542 nm laser diode





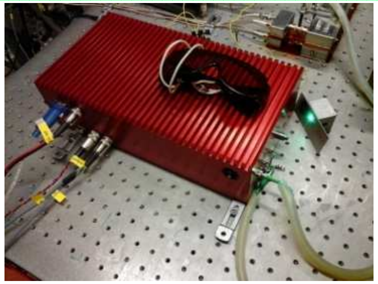
- THG process with Telecom laser diode (1542 nm)
- SHG process with fiber laser (1030 nm)

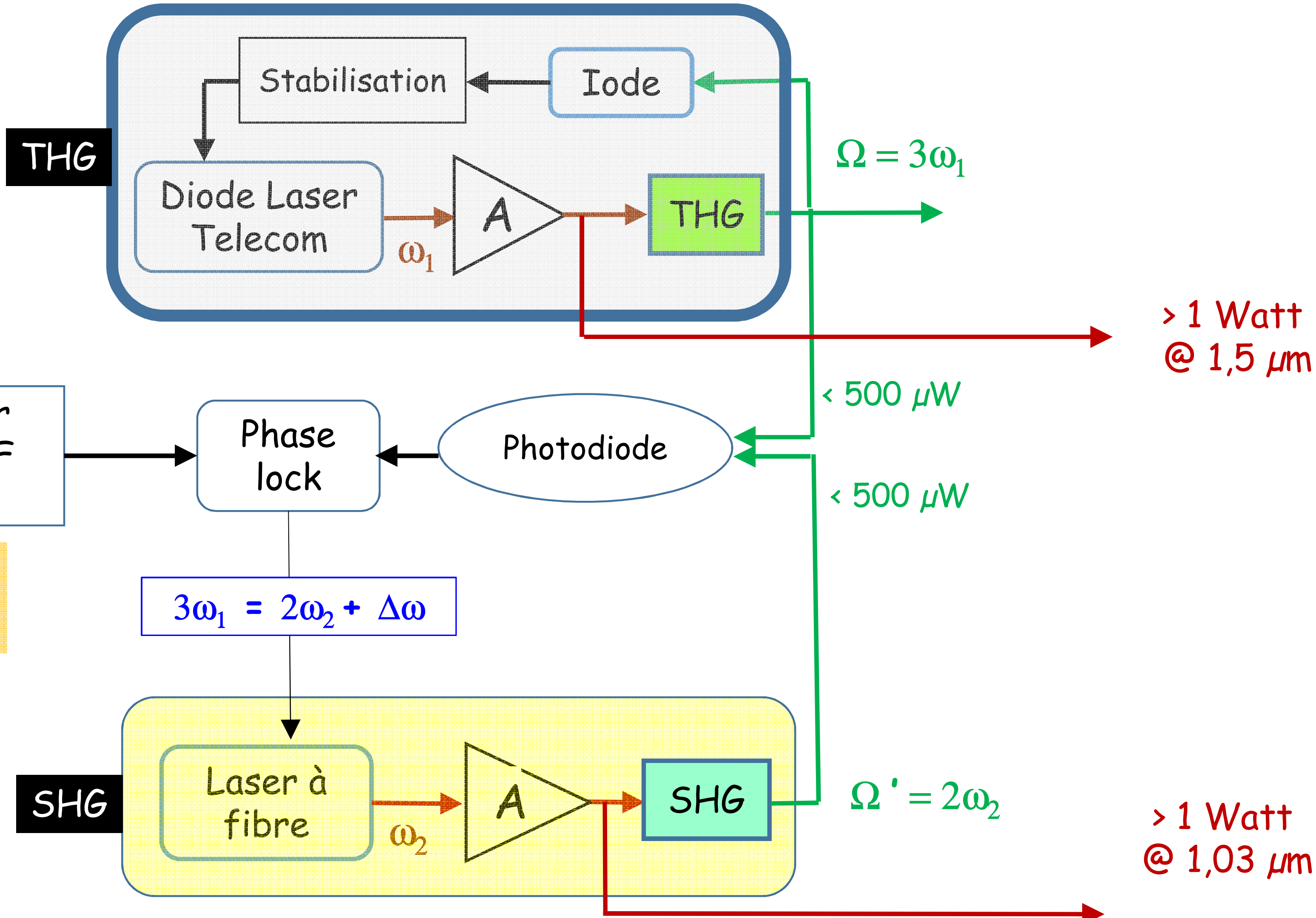
Frequency doubled
1030 nm fiber laser



Frequency stability transfer from 1542 nm → 1030 nm

Frequency tripled
1542 nm laser diode





Frequency doubled
1030 nm fiber laser

Laser 1,54 µm triplé en fréquence + Laser 1,03 µm doublé en fréquence

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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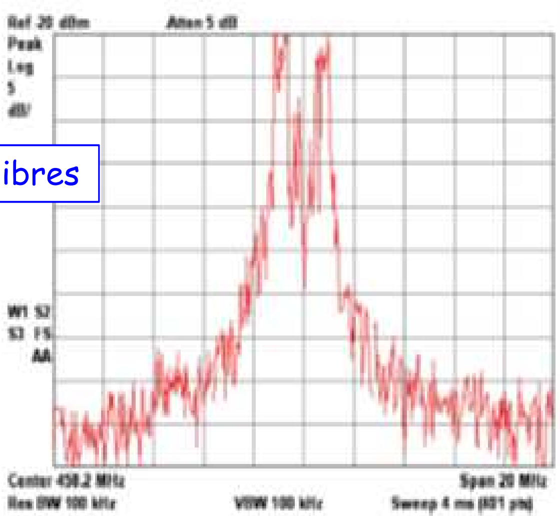
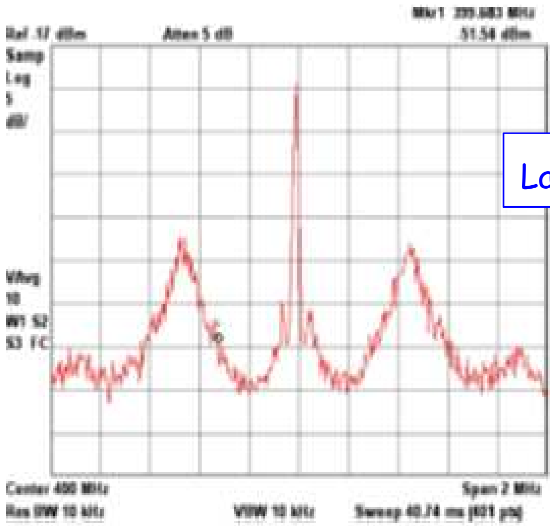
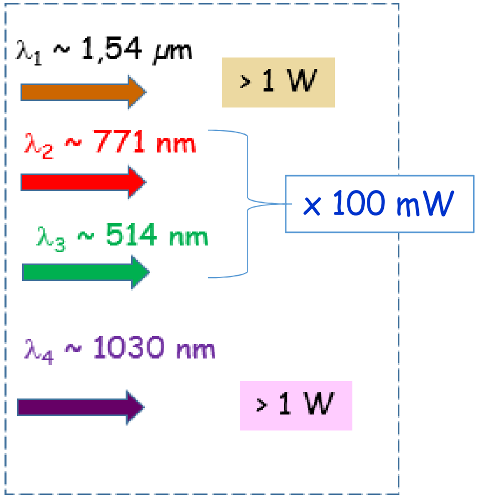
We report on phase locking of two continuous wave IR laser sources separated by 100 THz emitting around 1029 and 1544 nm, respectively. Our approach uses three independent harmonic generation processes of the IR laser frequencies in periodically poled MgO:LiNbO$_3$ crystals to generate second and third 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

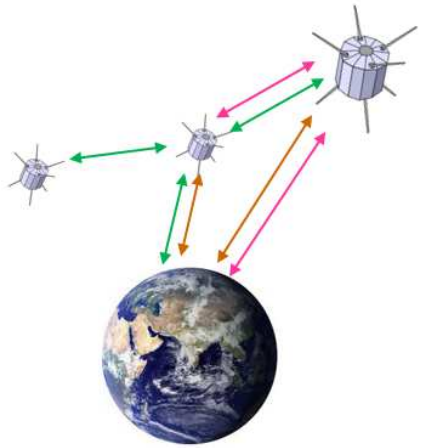
Lasers libres





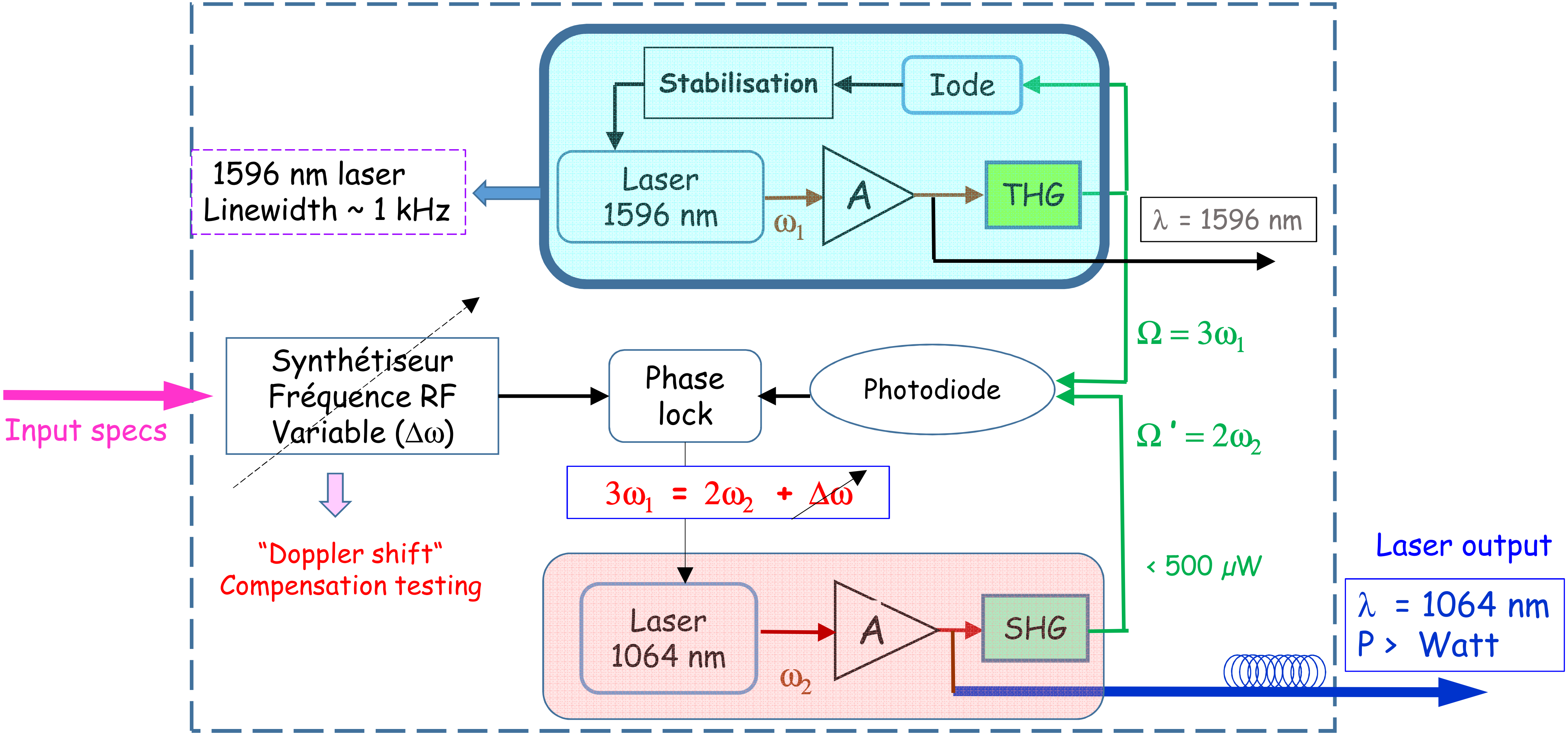
Lasers φ-Lockés





- Long distance optical links (up/down)
- Multi-λ accurate laser ranging
- ….

Frequency stabilized laser @ 1064 nm for LISA-AIV/T (SYRTE Lab proposal)



CONCLUSION

- All-fibered frequency stabilized laser source operating @ λ = 1064 nm
- Compact and low power consumption setup
- Low noise (analog/digital) electronics for the frequency stabilization purpose
- Frequency stability better than 300 Hz / √Hz
- Long term frequency reproducibility (accuracy) ~ kHz level
- Compensation testing of Doppler frequency shift due to the satellites motion

❑ Project follow-up and expertise