NASA/GSFC 滞在 帰朝報告

穀山 渉

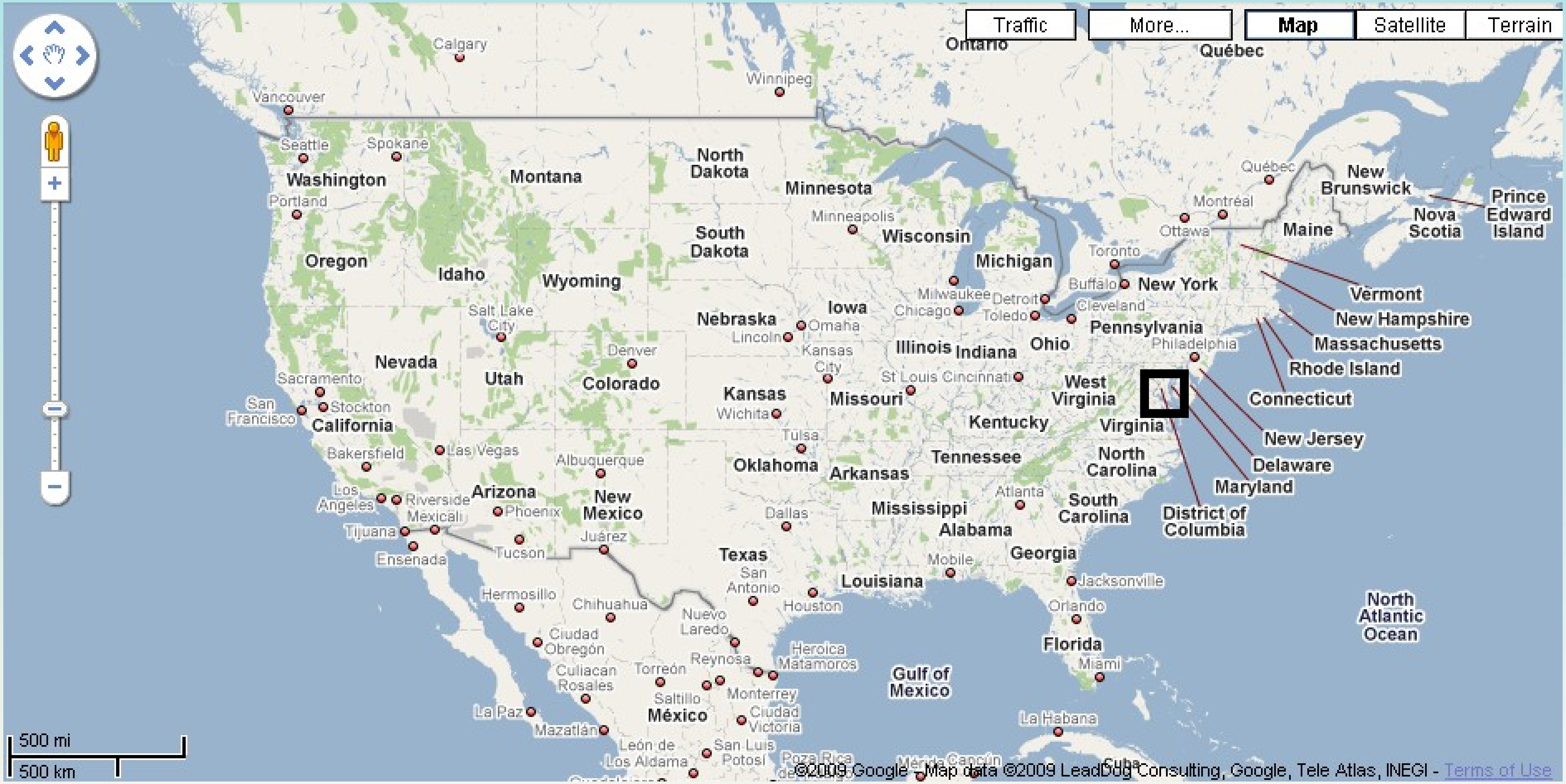
Building 34 (沼田さんの実験室が入っている)

Contents

- NASA/GSFC 訪問
- 沼田さんの実験
  - Fiber Laser Development for LISA
  - Laser Development for Earth Science Missions
- My Activity
  - Iodine Wavemeter
  - Others
- Miscellaneous

NASA/GSFC 訪問

- **訪問**
  - 10/1～12/17 (11**週間**)，12/6-8 Caltech**出張**
  - NASA Goddard Space Flight Center – Gravitational Astrophysics Lab



NASA/GSFC 訪問

- NASA Goddard Space Flight Center
  - 米国メリーランド州グリーンベルト
  - 1959年開設、サイエンスの拠点(地球、惑星・太陽系、天文学)

Iodine Wavemeter

- 12/7 に Caltechで開かれた、LISA WG meetingに行ってきました。
  - WG 2: PD, Laser, Phasemeter, Telescope, Interferometry Frequency Stabilization
  - WG 3: Proof Mass 関係?

そのスライドを流用しながらお話しします。

- **沼田さんの実験**
  - Fiber Laser Development for LISA (50%)
  - Laser Development for Planetary Science Missions (50%)

LISA

Beyond Einstein: From the Big Bang to Black Holes

Fiber Laser Development

Kenji Numata

Department of Astronomy, University of Maryland, CRESST

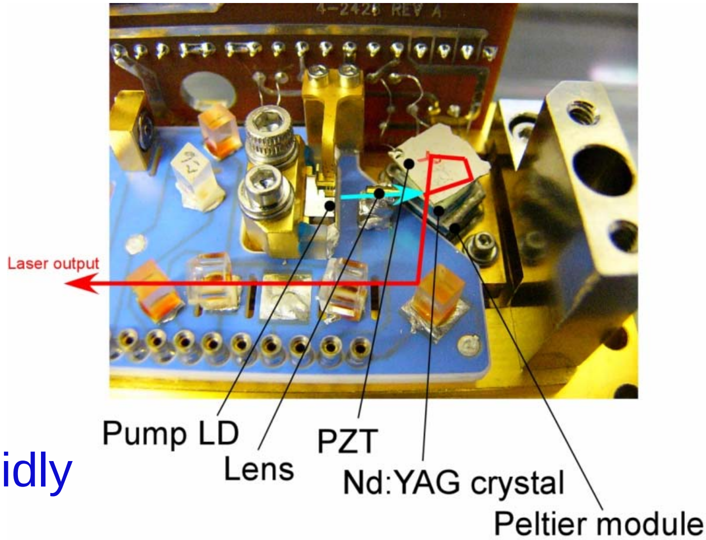
Gravitational Astrophysics Laboratory (Code 663), NASA/GSFC

GSFC - JPL

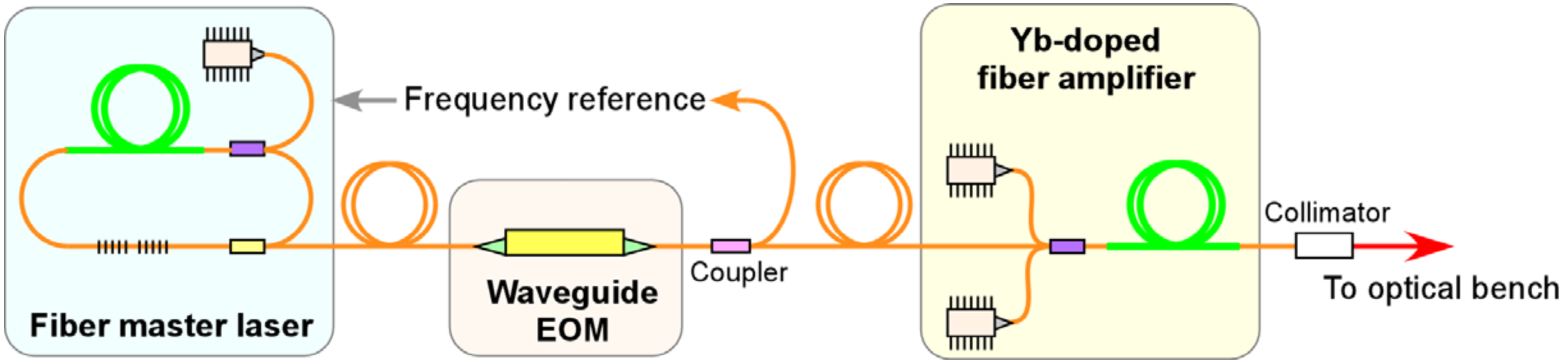
esa

1. Introduction

- NPRO (Non-planar ring oscillator) has been used traditionally.
  - Compact crystal cavity gives high stability.
  - LISA needs low noise laser.
  - “Black box” in many cases
    - E.g.) TESAT NPRO for LPF

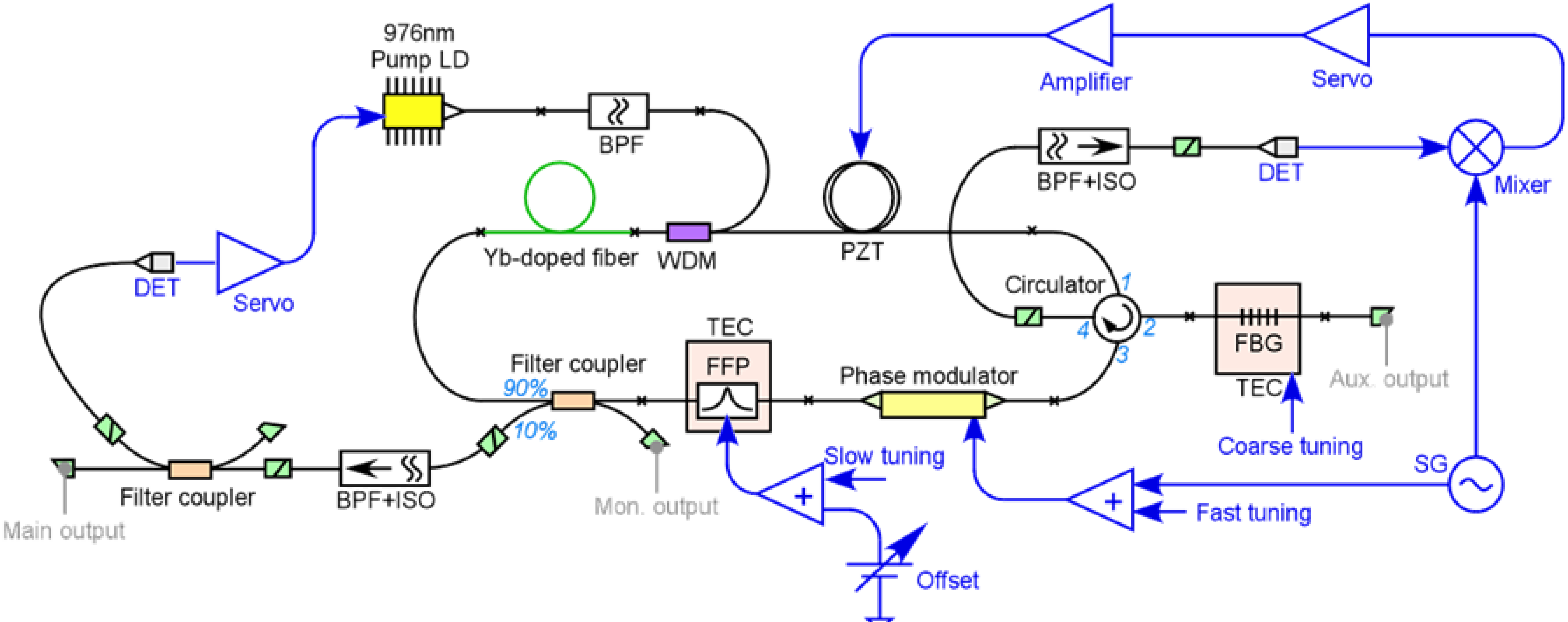


- All fiber/waveguide solution
  - Fiber laser/amplifier technologies matured rapidly
  - Higher robustness, cleaner output
  - No strong magnet



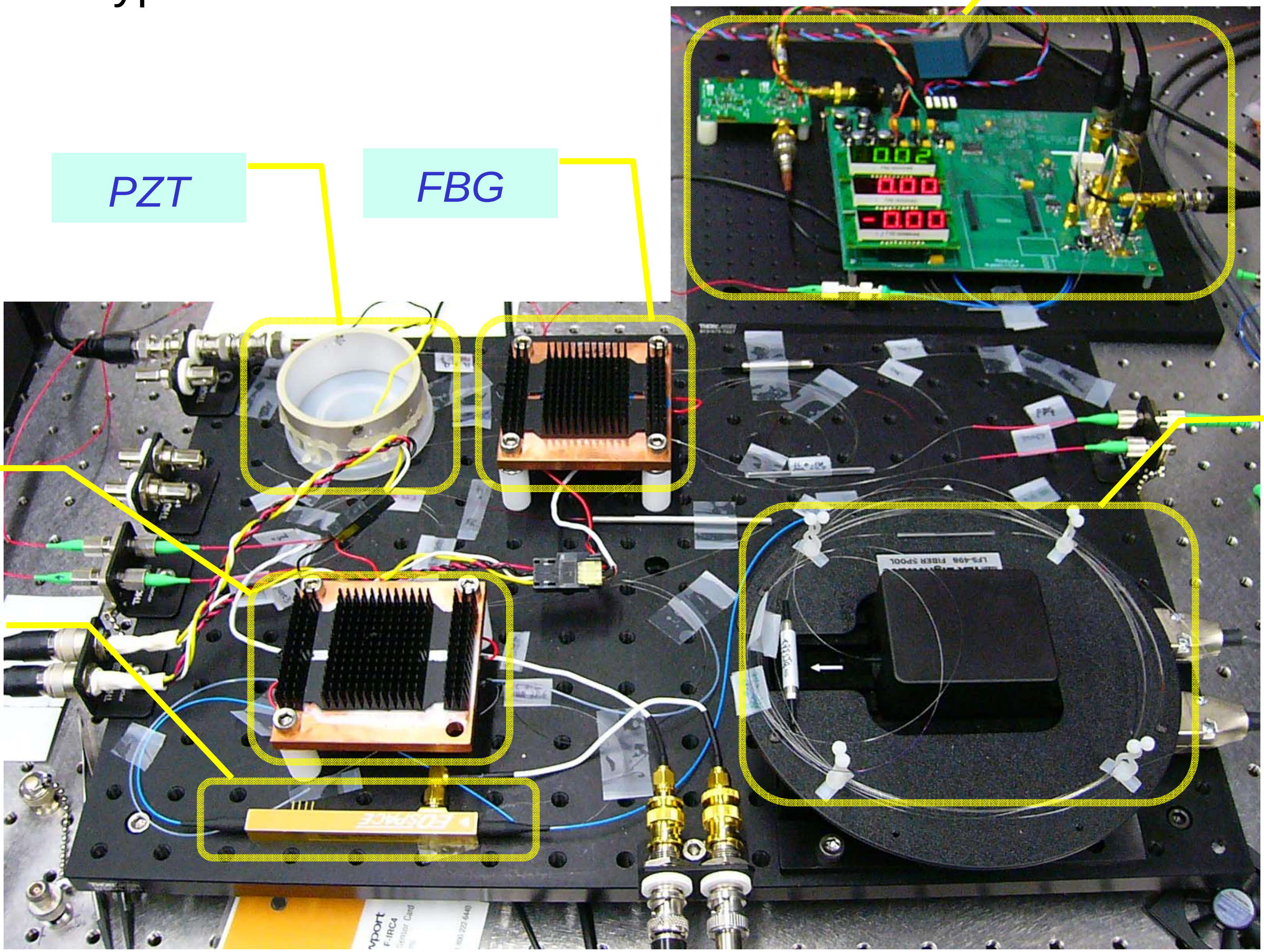
2. Experimental Setup

- Ring configuration adopted over linear configuration
  - More flexible, no spatial hole-burning, etc.
  - Single-mode selection by filters (50MHz FSR)
    - Fiber Bragg Grating (FBG) 34GHz BW + Fiber Fabry-Perot (FFP) 85MHz BW
  - All PM components: single polarization operation
    - Fast axis has much larger insertion loss.



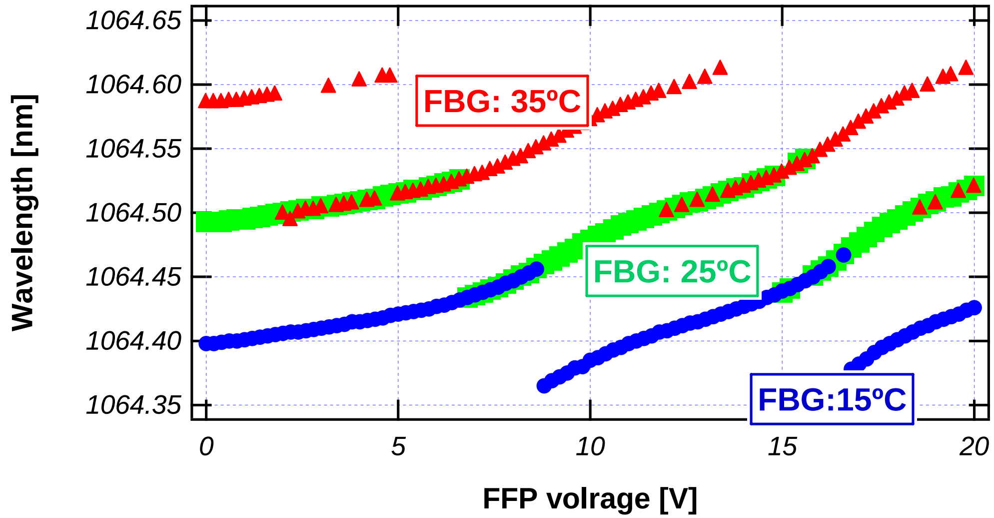
Setup photo

- Prototype on a breadboard

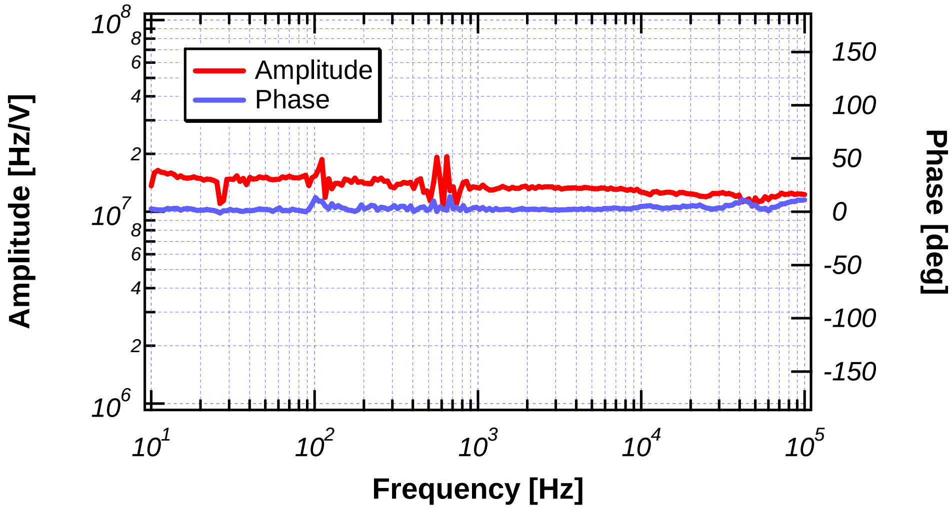


3. Experimental Results

- Coarse tuning
  - FBG temperature
  - FFP voltage (separation)
  - 0.25nm (66GHz) range
    - +-10V/+-10degree

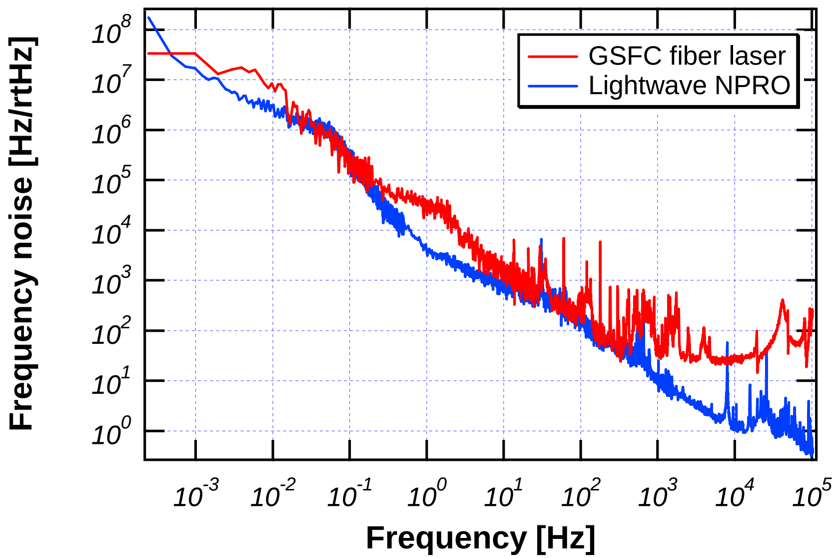


- Fine tuning
  - Voltage on phase modulator
    - Effectively changes laser cavity length
  - Flat frequency response
    - At least up to 100kHz
    - Wider BW than commercial lasers

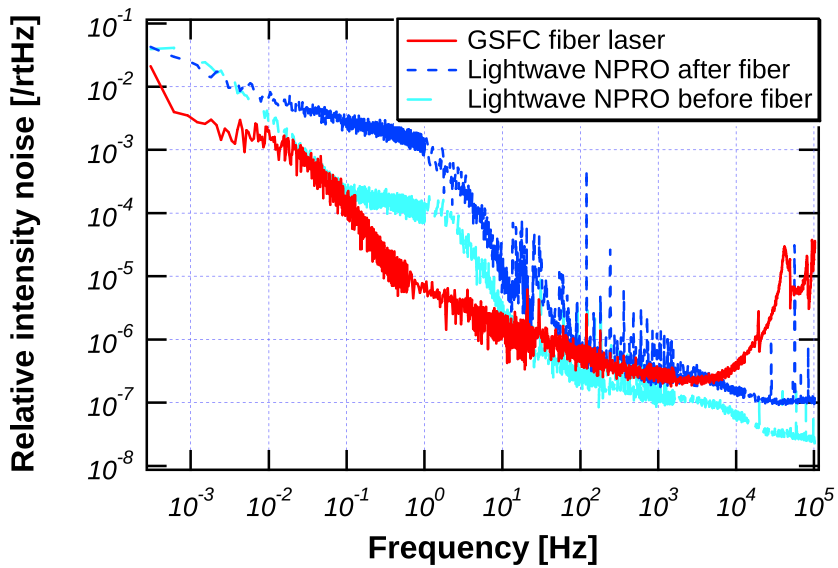


Noise of fiber laser

- Frequency noise



- Intensity noise



– Low frequency: comparable to (better than) NPRO

– High frequency: increased noise due to relaxation oscillation

– Stabilization experiments

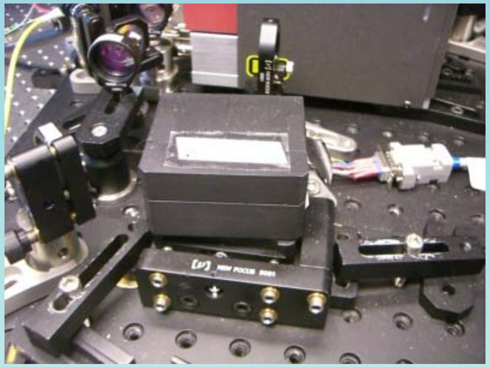
  - Frequency: Planned using iodine or cavity.
  - Intensity: Done after Yb amplifier and satisfied LISA requirement at low frequency.

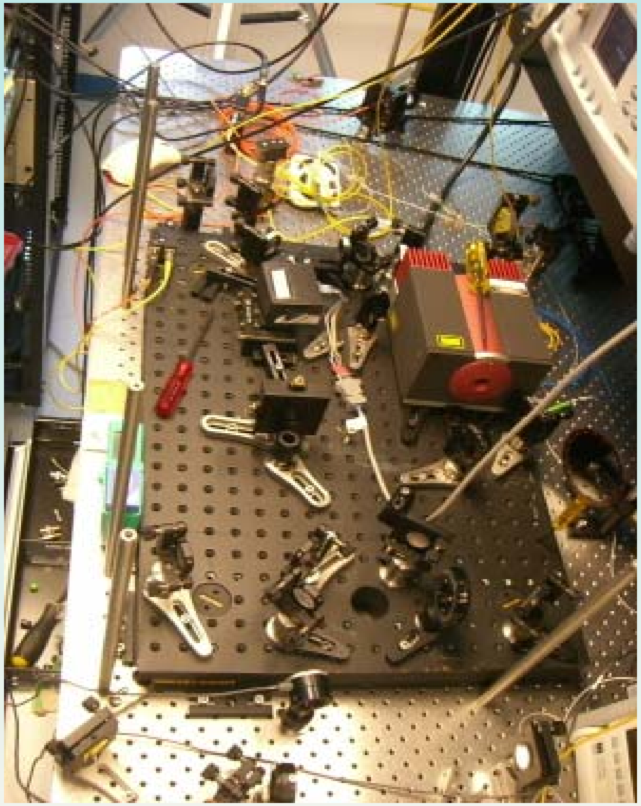
4. Summary

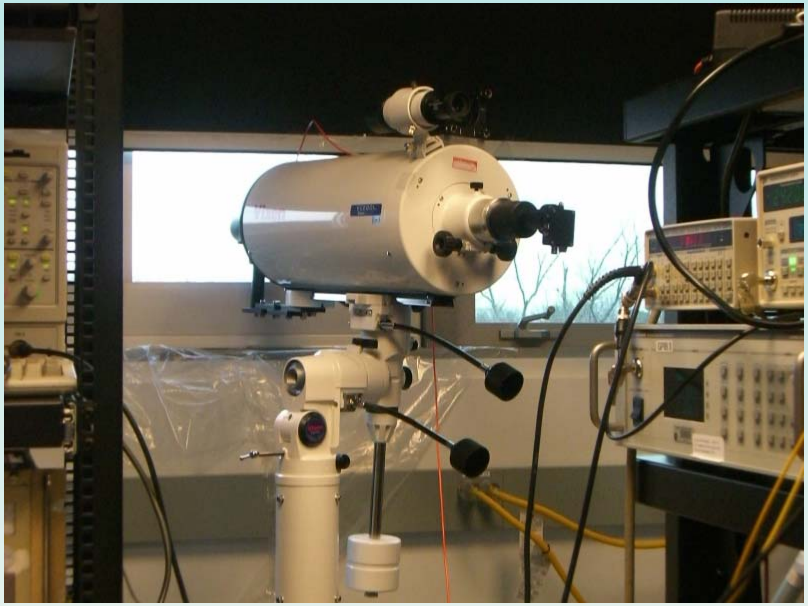
- Fiber laser has significant advantages over traditional NPRO.
  - Higher robustness, cleaner output, no strong magnet, etc.
- Now we can make single-mode, single-polarization laser.
  - Fully custom-made laser possible
  - No special gain fiber, standard components only
  - Single-mode lasing achieved
  - Comparable frequency/intensity noise to NPRO
  - Wider frequency control bandwidth than NPRO
- Current activities
  - Trying new configurations and filters to improve efficiency
  - Starting component space qualifications
  - Stabilization experiments

Laser Development for Planetary Science Missions

- OPAを用いた火星探査Lidar用レーザー光源
  - OPA (Optical Parametric Amplifier)：Seeded OPG
  - 3270.4nm (for CH4) と 1578.2nm (for CO2)を生成
  - 1064nm Q switch Laser (3ns, 300mW ave., 5kW peak, E_{pulse}~60μJ)



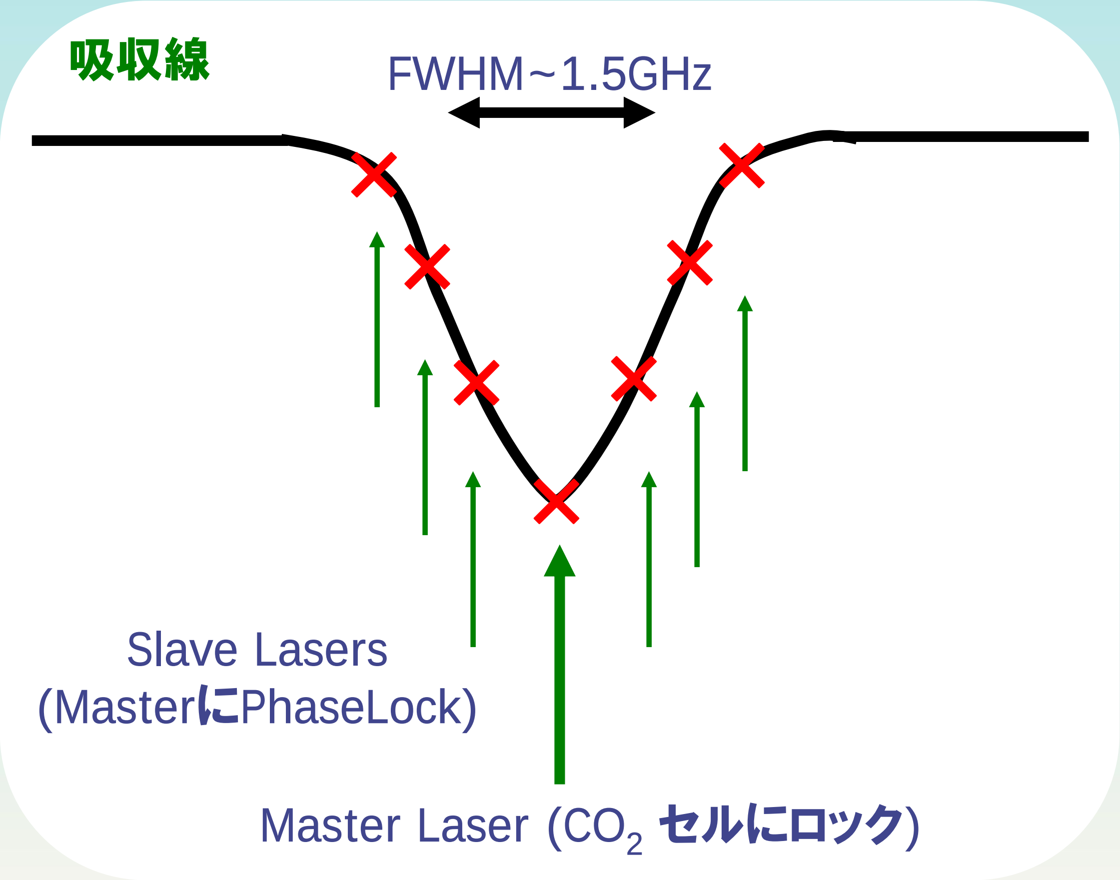


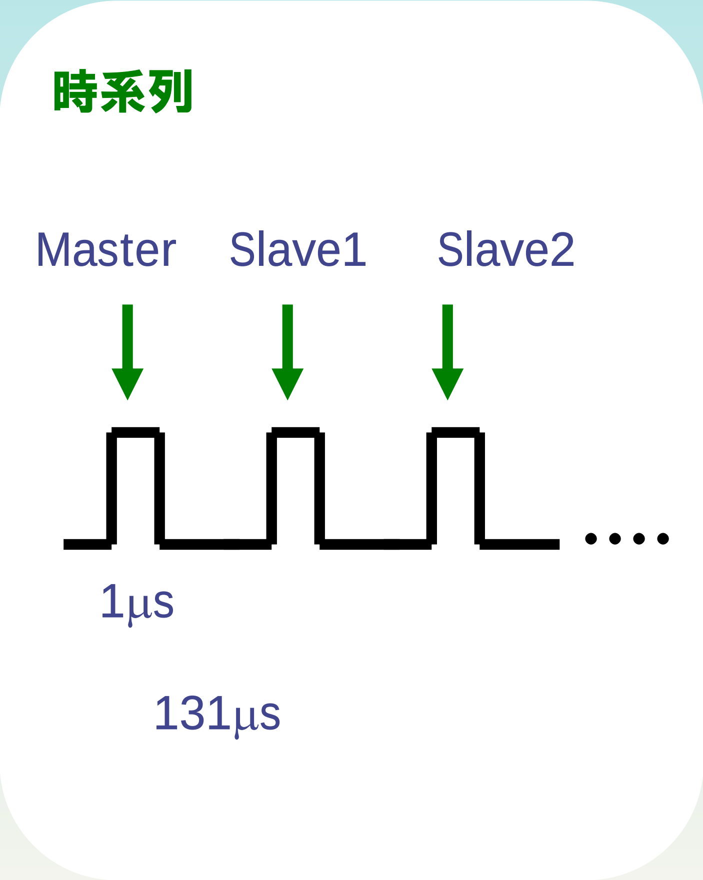


Telescopeで発射
携帯電波塔に取り付けた反射板で見る

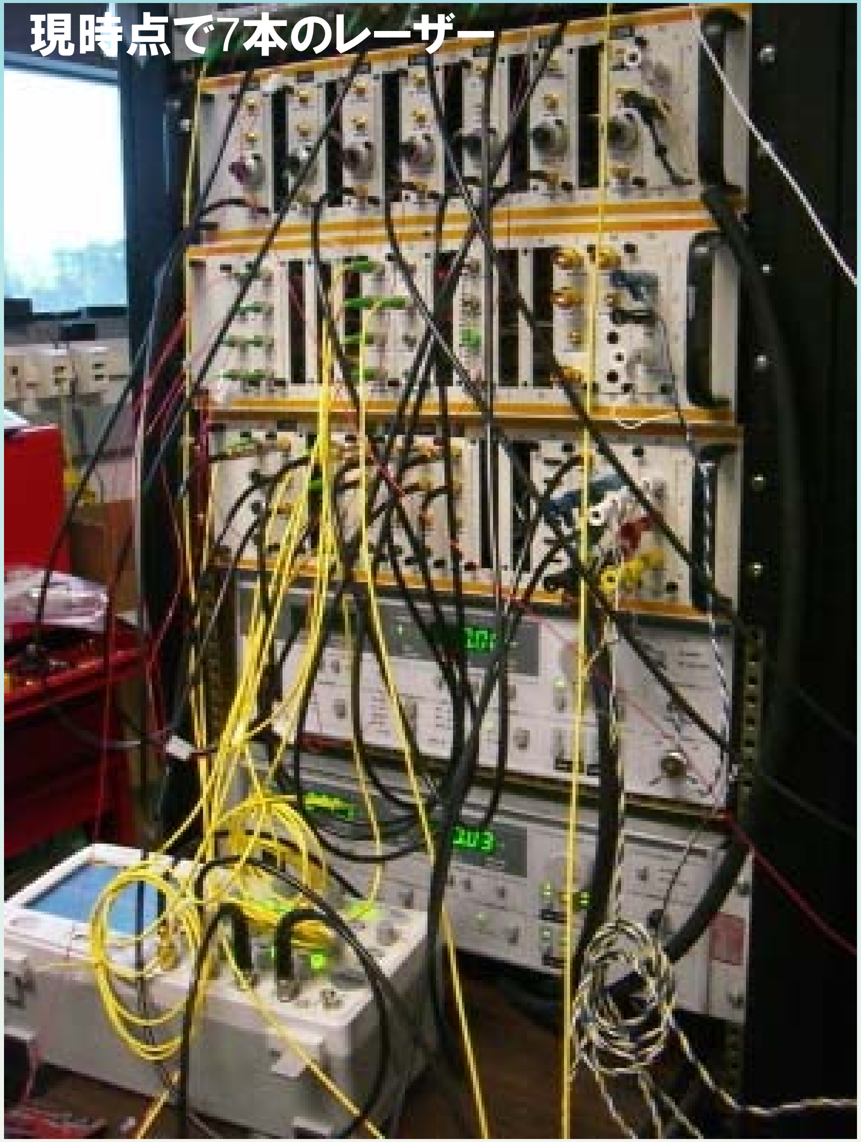
- (ASCENDSミッションその他)でのCO_2観測用安定化レーザー光源
  - CO2の 1572.335nm 吸収線を観測し、CO_2濃度の1ppm単位での測定を目指す → 安定化が必要

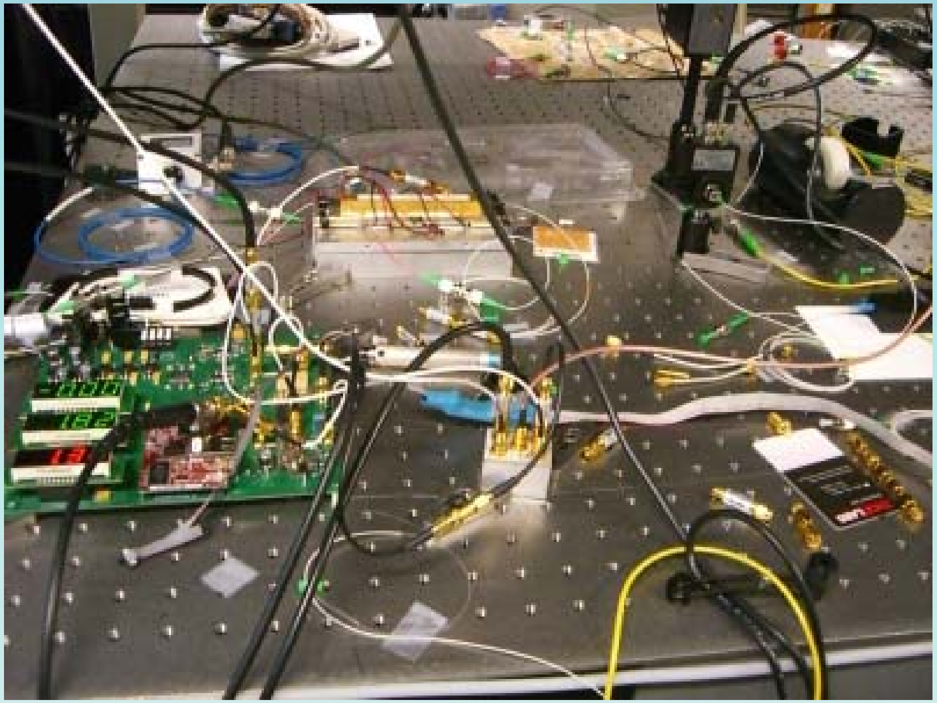
概念図





■ 実験装置





My activity at Goddard

- Iodine Wavemeter

LISAの現在のデザインでは、キャビティを使った周波数安定化を行う。

その場合、2機のS/Cのレーザー間でビートを取るときに絶対周波数を知らないので、周波数を振ってサーチすることになる。

ヨウ素セルを用いて**絶対周波数を知る装置(Wavemeter)**があるとリスク低減につながるのでうれしいのではないか。

衛星に搭載することを考えて、**なるべくシンプルなセットアップで、レーザーのPZTに変調もかけず、ヨウ素吸収線を見るだけ**で絶対周波数を合わせる実験をした。

その結果、20MHz (LISA搭載 PD の BW)以内に独立な2つのレーザーを追い込むことや、オフセット周波数 **4MHz の Phase Lock** のデモンストレーションができた。

Iodine Wavemeter

Wataru Kokuyama

Department of Physics, University of Tokyo

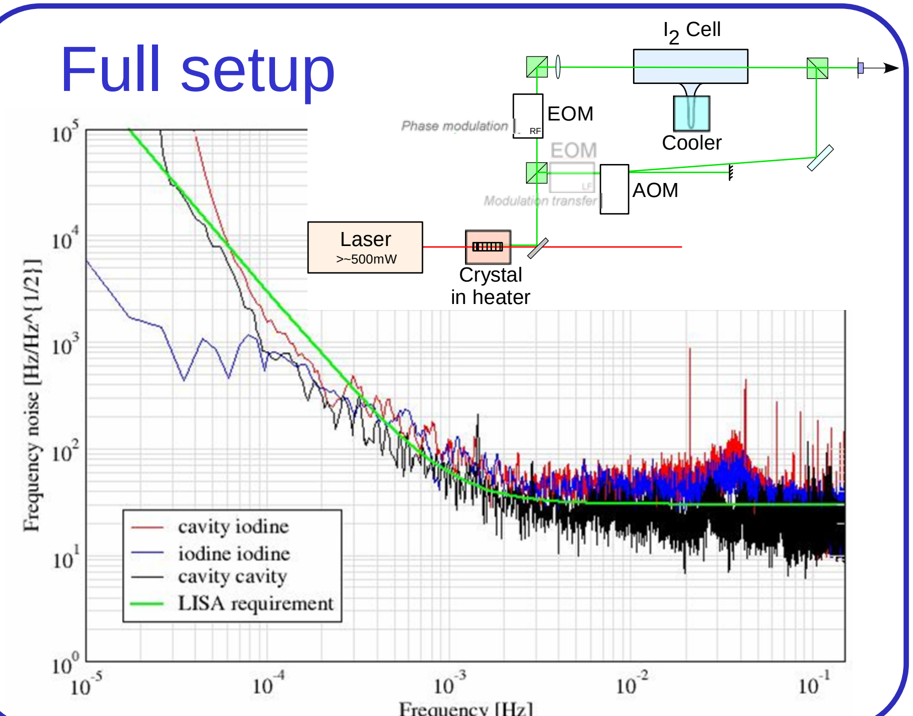
(Visiting NASA/GSFC)

Background

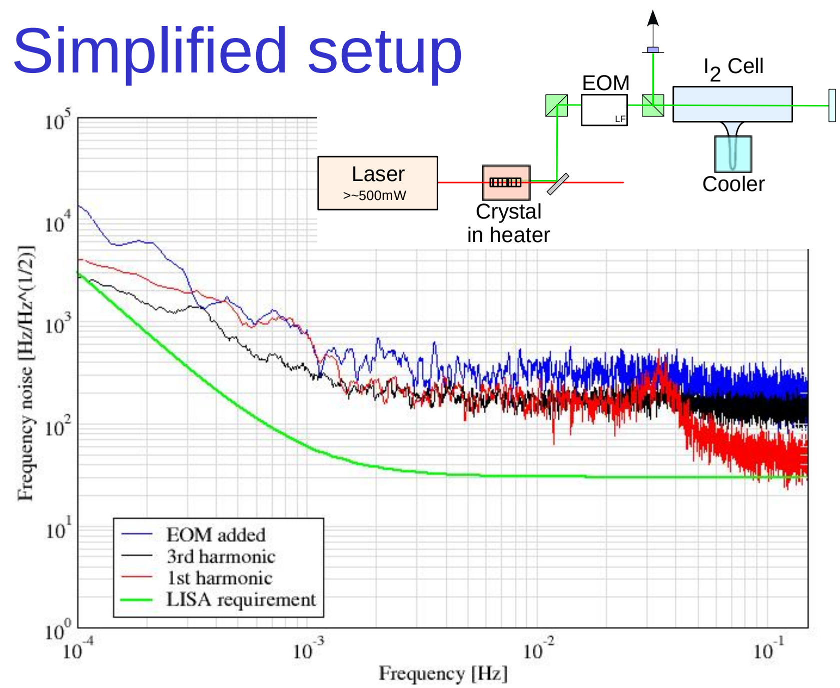
- Iodine stabilization demonstration completed (~3 years ago)
  - LISA pre-stabilization requirement achieved
  - Radiation test on doubling crystal, measurement of alignment sensitivity, etc.
  - Involved bulk crystal in oven, modulations, cooler for cell, etc.

→ **Other use of iodine with simpler setup?**

Full setup



Simplified setup



Motivation

- Lock acquisition of the constellation is a challenge for LISA
- Lower risk for “unknown unknowns” of laser frequency acquisition
  - Independent frequency reference on each spacecraft
  - The simpler, the better.

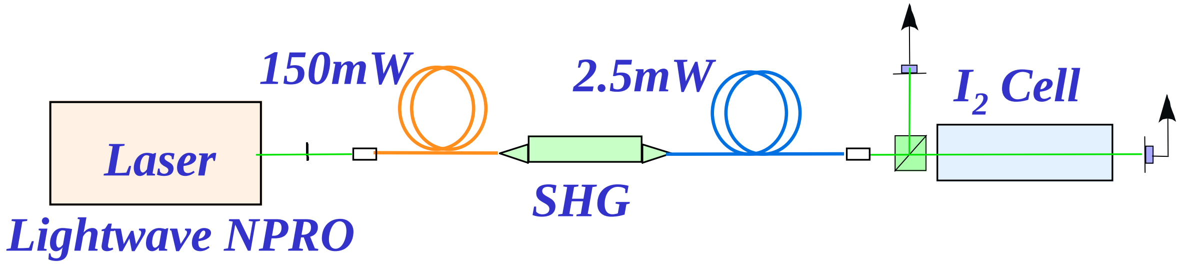
- Iodine wavemeter
  - Information on absolute laser frequency
  - Onboard laser diagnostics
  - Less sensitive to environmental disturbances

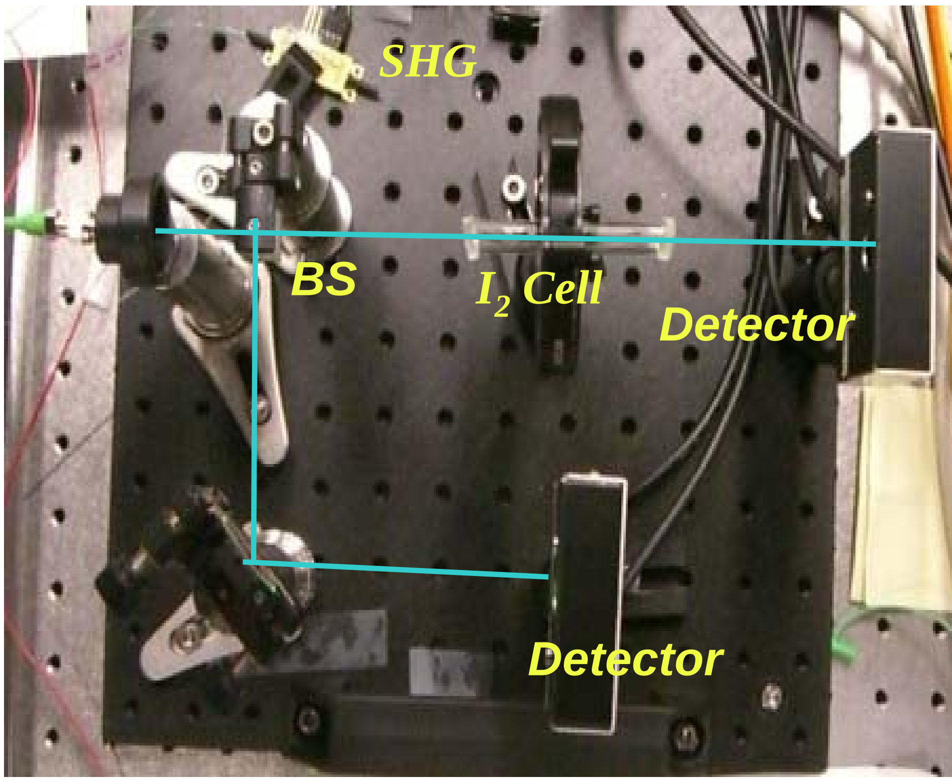
⇩

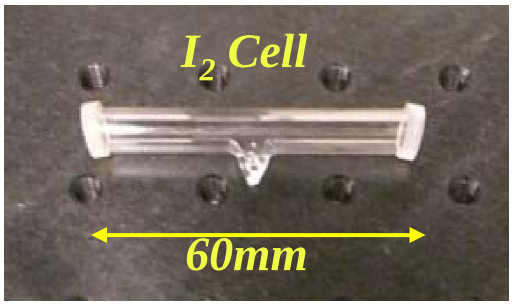
Easier initial lock acquisition and robust onboard laser system

- **We demonstrated ~10MHz accuracy and automatic phase lock with very simple setup**

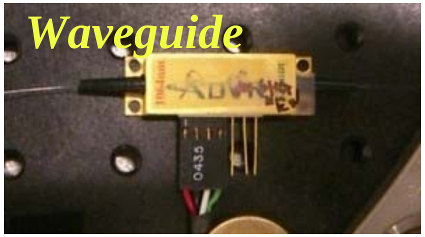
Experimental Setup







Iodine cell w/o cooler for pressure control



fiber-coupled waveguide PPKTP
For LISA, SHG w/o heater available

<u>No heater (for LISA), No cooler, No modulator</u>

Method

- How to tune lasers
  - Program written in LabView

1. Sweep laser frequency

- All frequency range

2. Identify Doppler broadened line

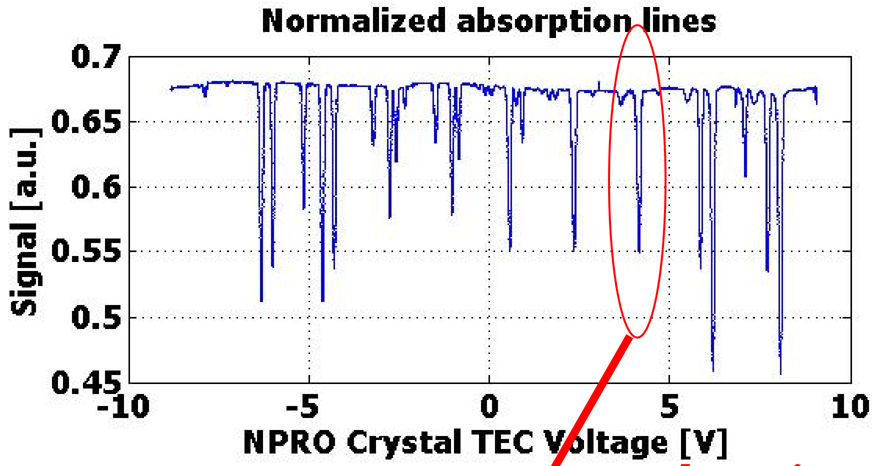
- Remove mode-hop regions

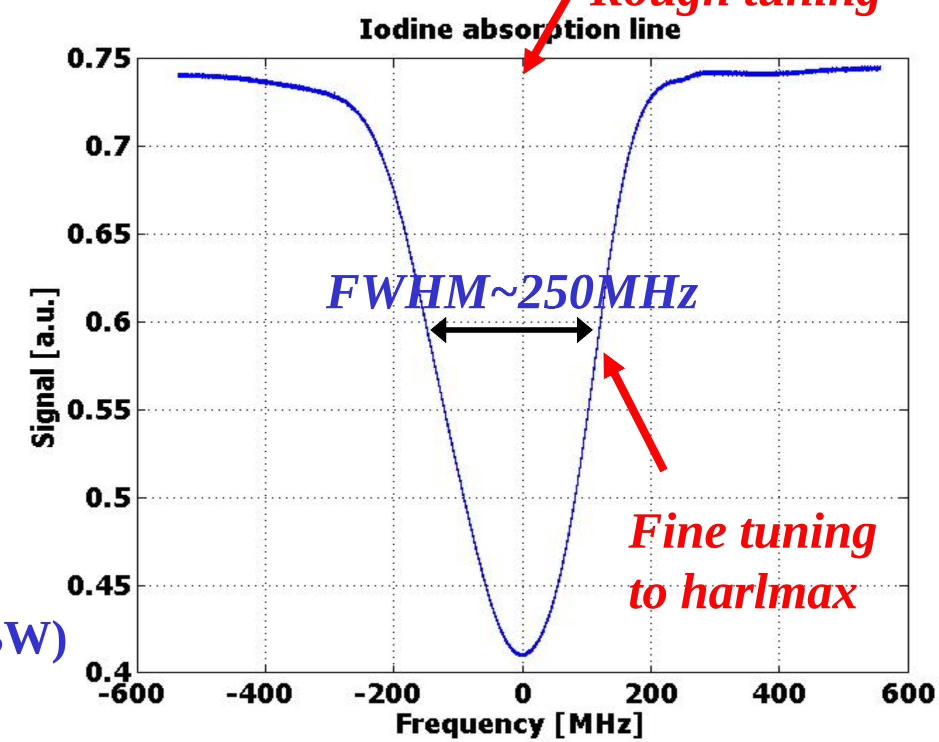
3. Tune laser to identified line (Rough tuning)

4. Sweep again on the peak and go to halfmax (Fine tuning)

⬇

10MHz accuracy achieved; Beatnote of two lasers is < 20MHz (LISA's Detector BW)



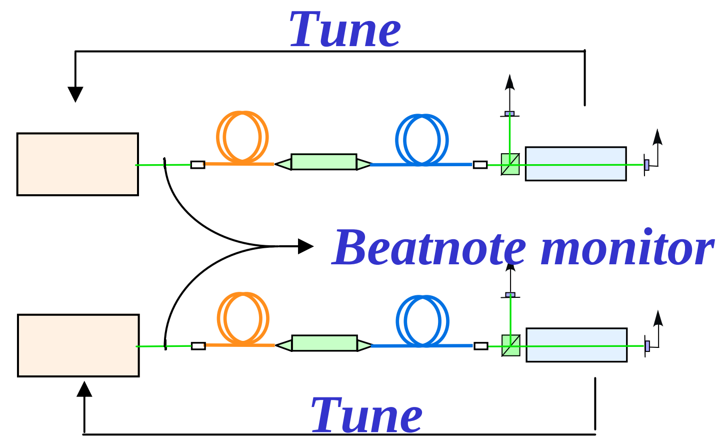


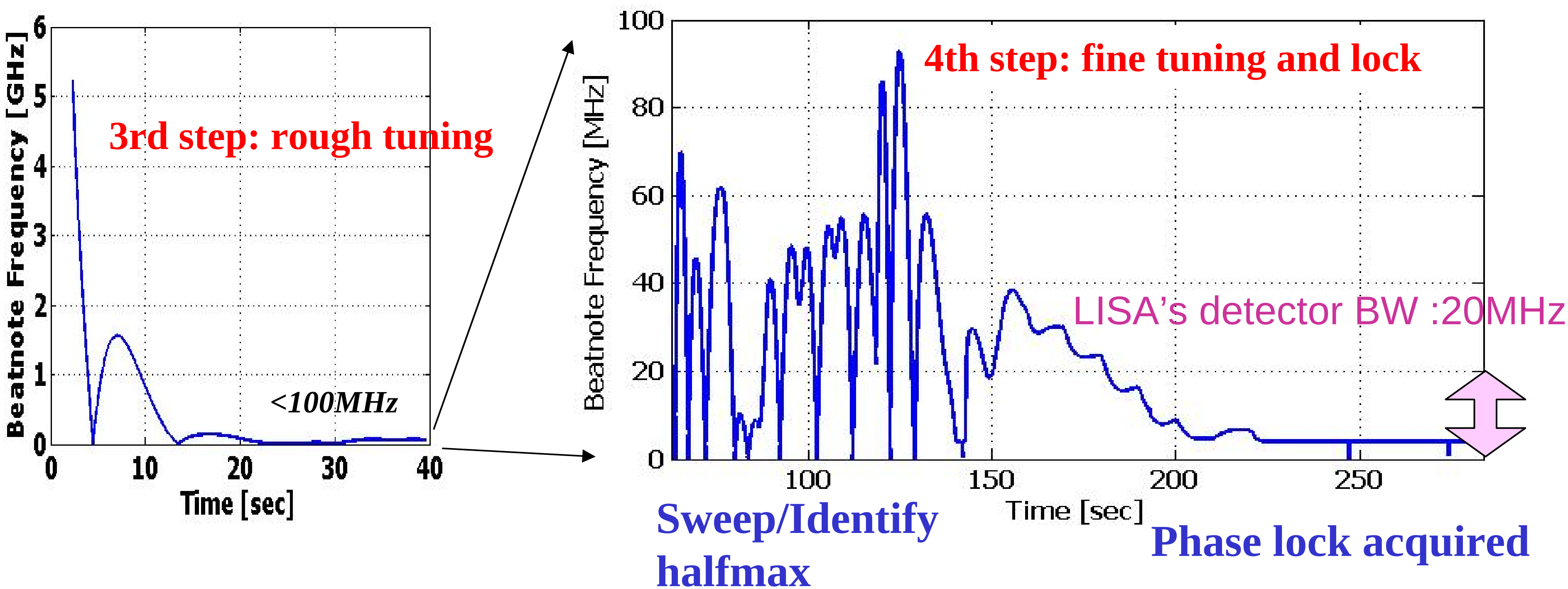
Results

- < 10MHz accuracy of absolute frequency
- 4MHz phase lock with two independently-tuned lasers

1st step: Sweep starts from frequency difference > 10GHz

2nd step: Identify peak automatically





Summary

- Iodine wavemeter offers significant advantages for LISA.
  - Absolute frequency reference will simplify lock acquisition of spacecrafts.
  - Risk reduction

- We demonstrated automatic 4MHz phase lock, laser diagnosis, and ~10MHz accuracy wavemeter with very simple configuration.
  - No heater, No cooler, No modulator
  - Fiber-coupled waveguide, small cell only
  - The small package can be put on anywhere in spacecraft.

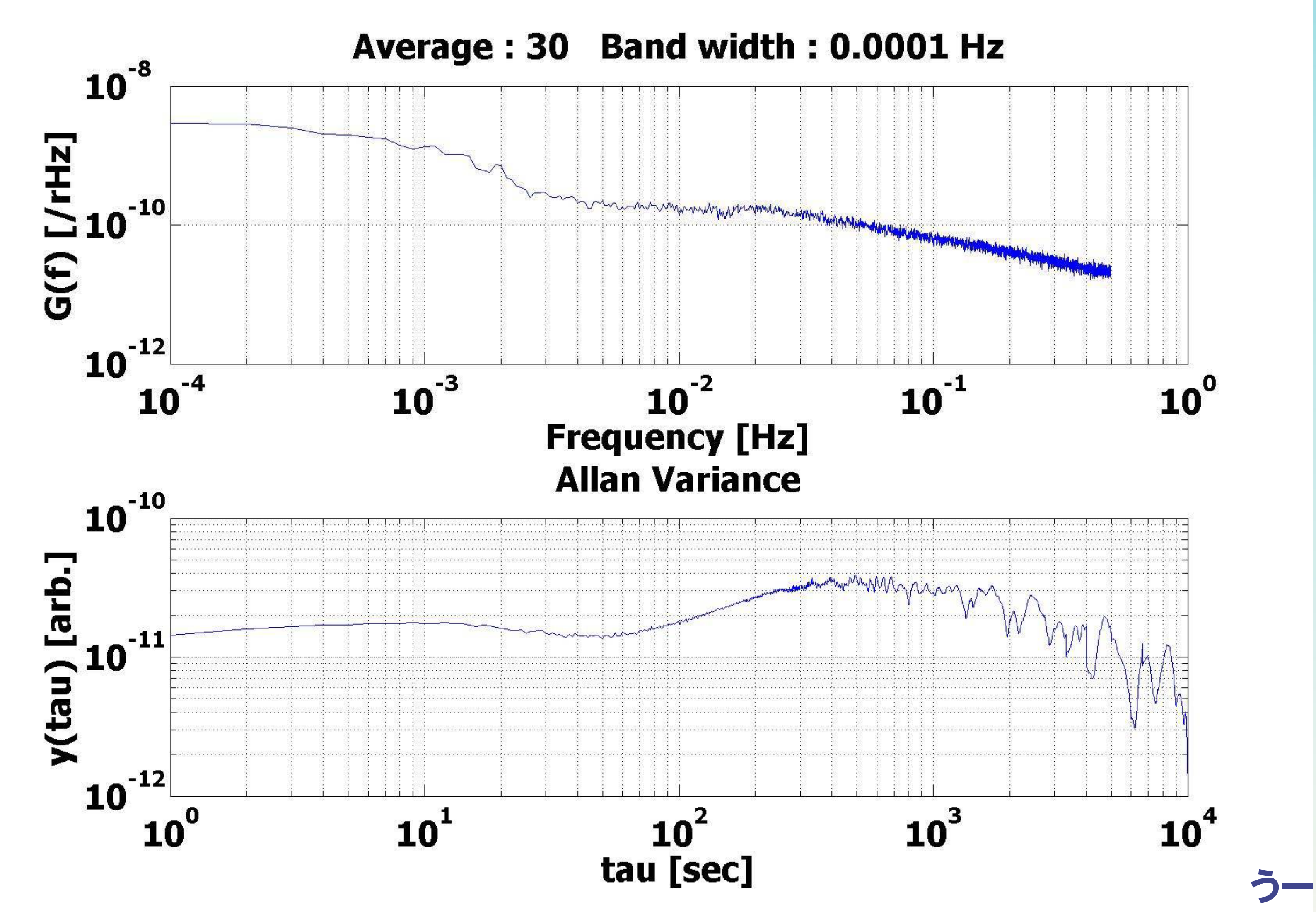
Goddardに帰ってから追加実験: IR:4mW (Green:1.6mW)でもOK！


前から見た写真
ヨウ素セル
セットアップ
レーザー(2台)
絶対周波数
リファレンス


後ろから見た写真
レーザー(2台)
ヨウ素セル
セットアップ
絶対周波数
リファレンス
Labveiw DAQ Box

その他 ちょこっとやったこと(1)

沼田さんのところにあった、ヨウ素周波数安定化装置を動かしてみた (2台のビート)

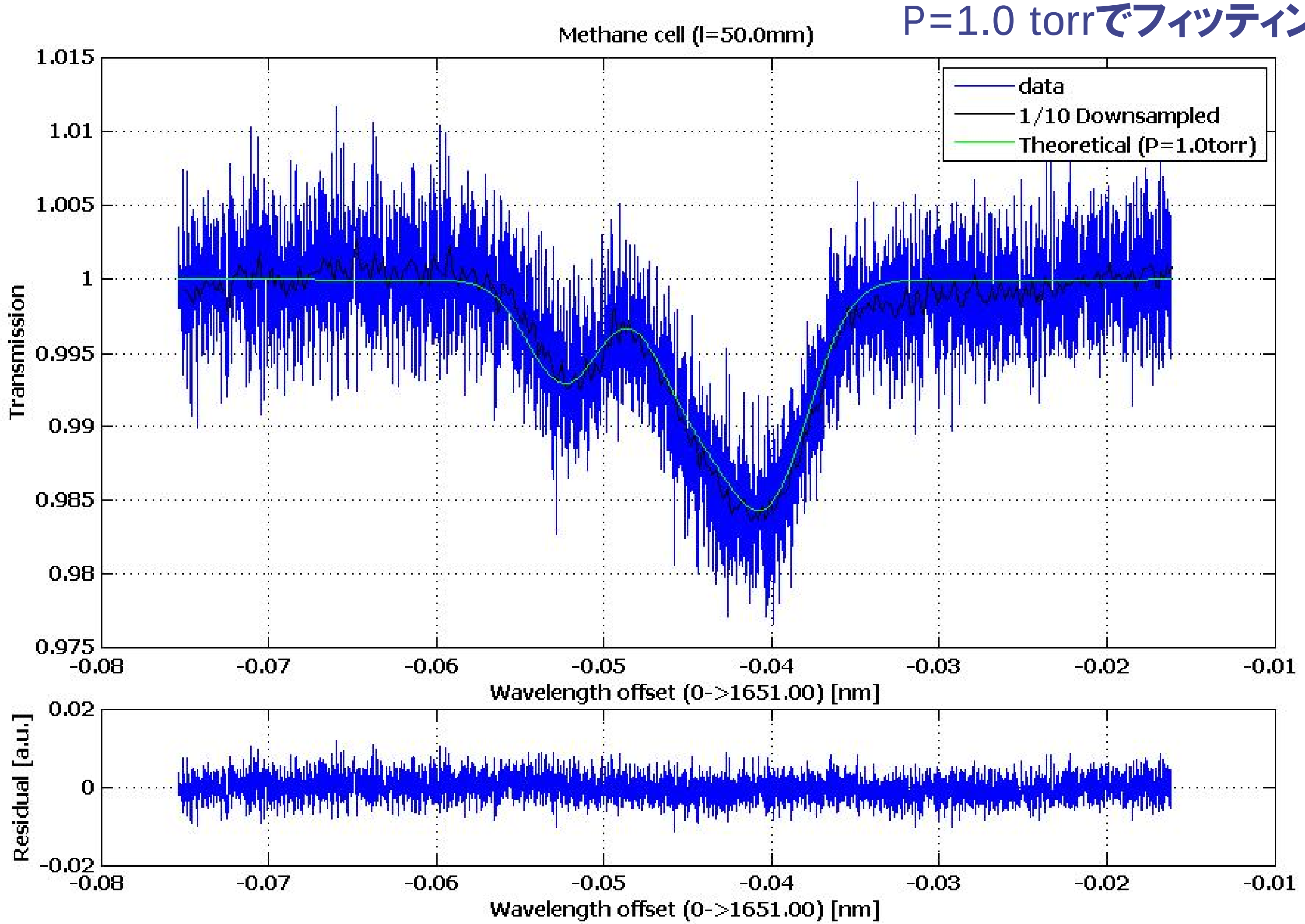


うーん…

その他 ちょこっとやったこと(2)

新しく買ったメタンセルの内圧を吸収率でキャリブレーションしてみた

P=1.0 torrでフィッティング



I_2は吸収が強いから楽。弱い吸収線は大変ですね…

引越し

- **沼田さんの実験室の引越し**(11/13-14)

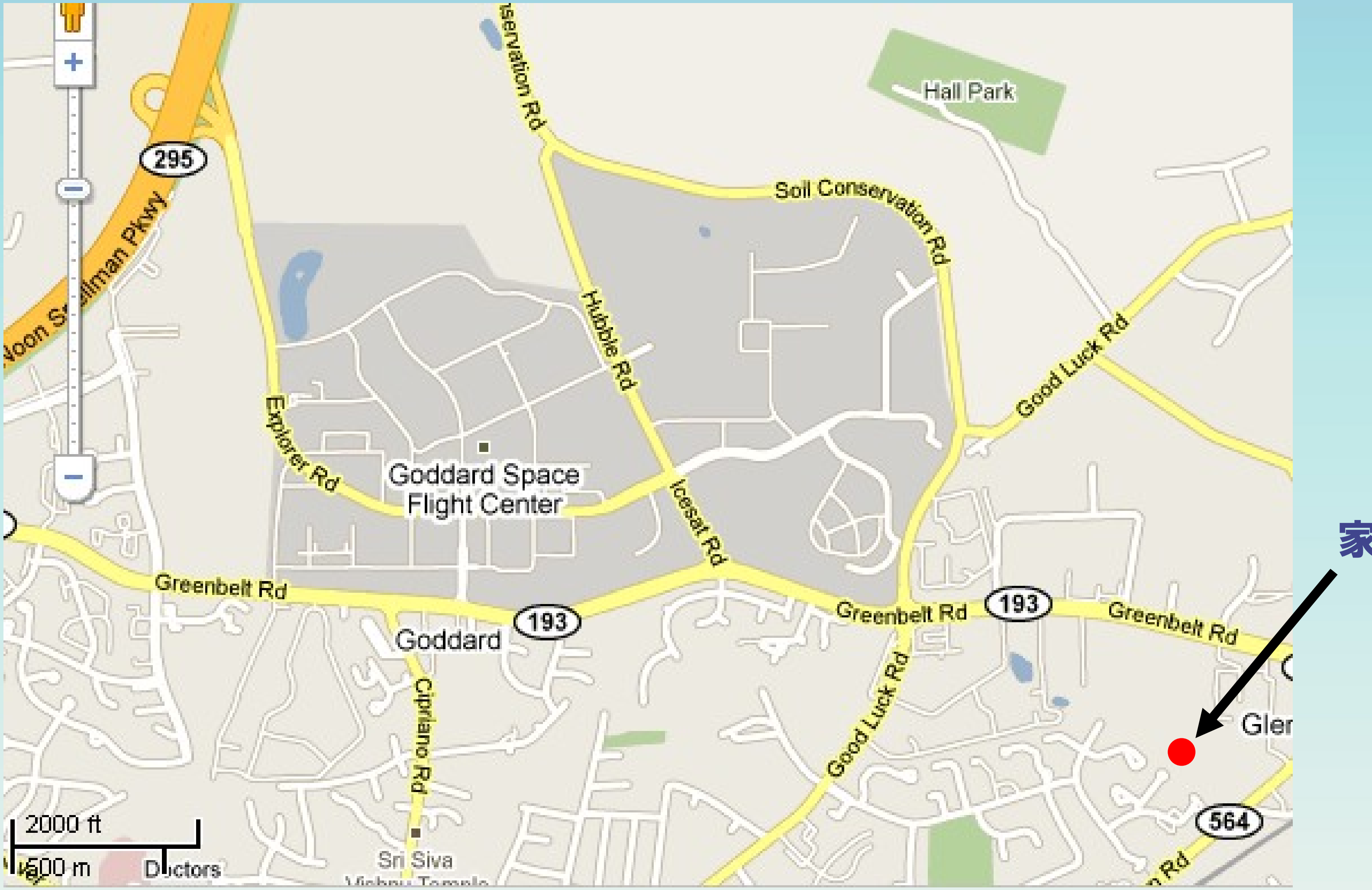
Before

After

セットアップをブレッドボード上に→引越し後2日くらいで実験開始

- Miscellaneous
  - **メリーランドでの暮らし**
  - **観光**
  - **お金＆**Visa

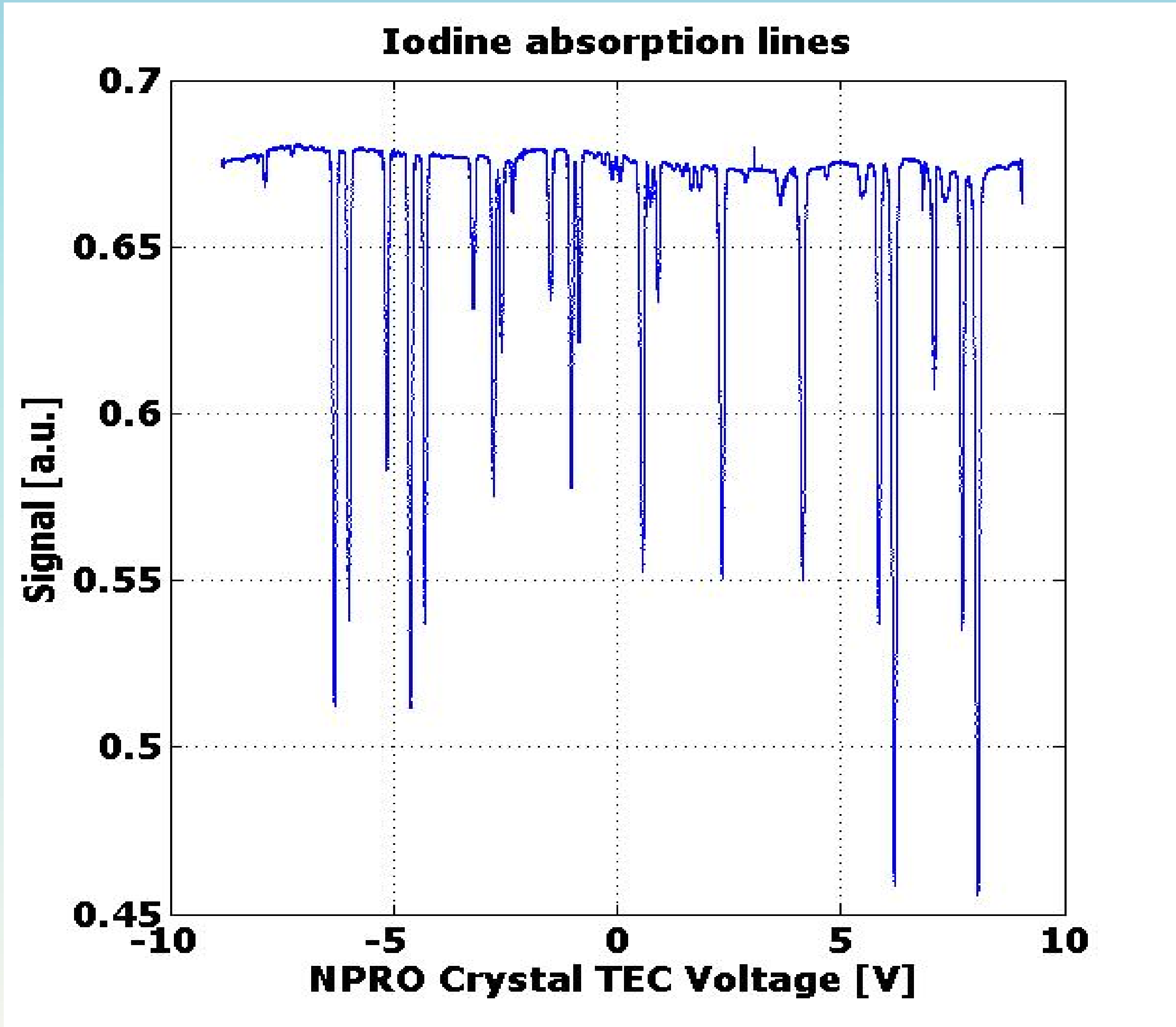
メリーランドでの暮らし

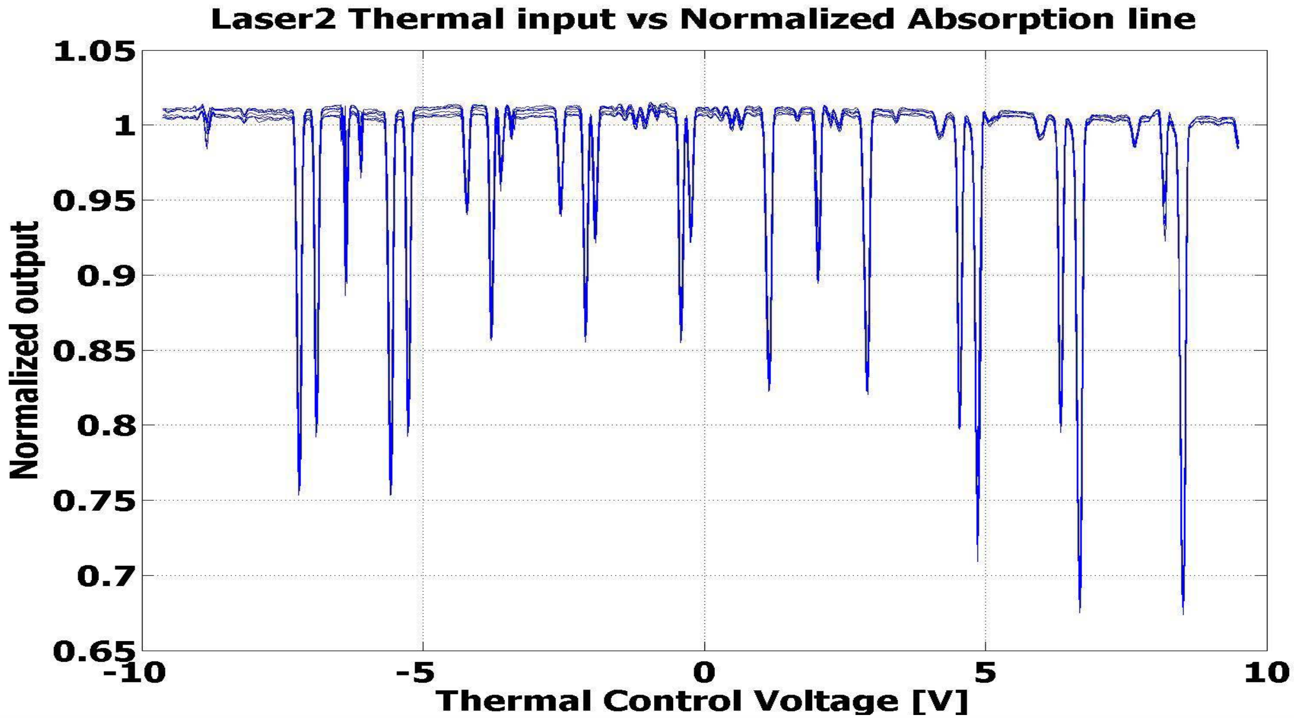


家から毎日車を運転して「通勤」: 8時半～9時半に来て、19時半ごろ帰る

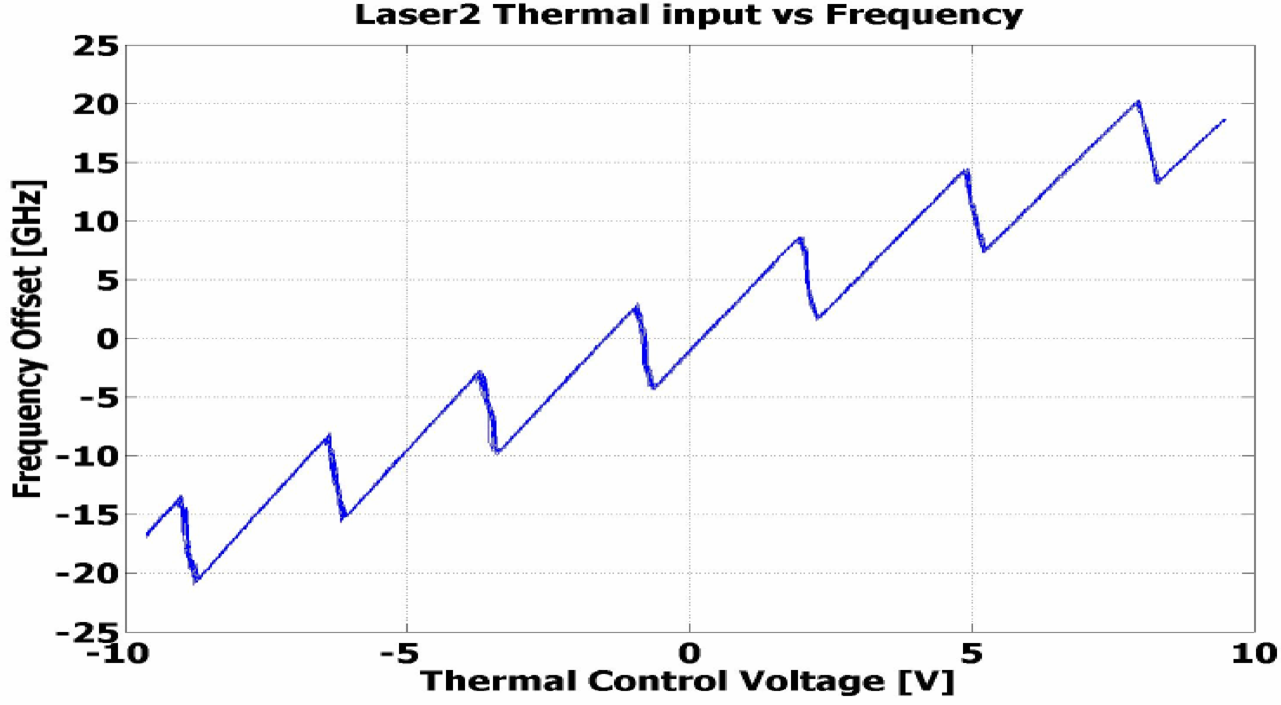
朝ごはん：家、昼ごはん：Goddardのカフェテリア/外、 晩ごはん：家

おわり

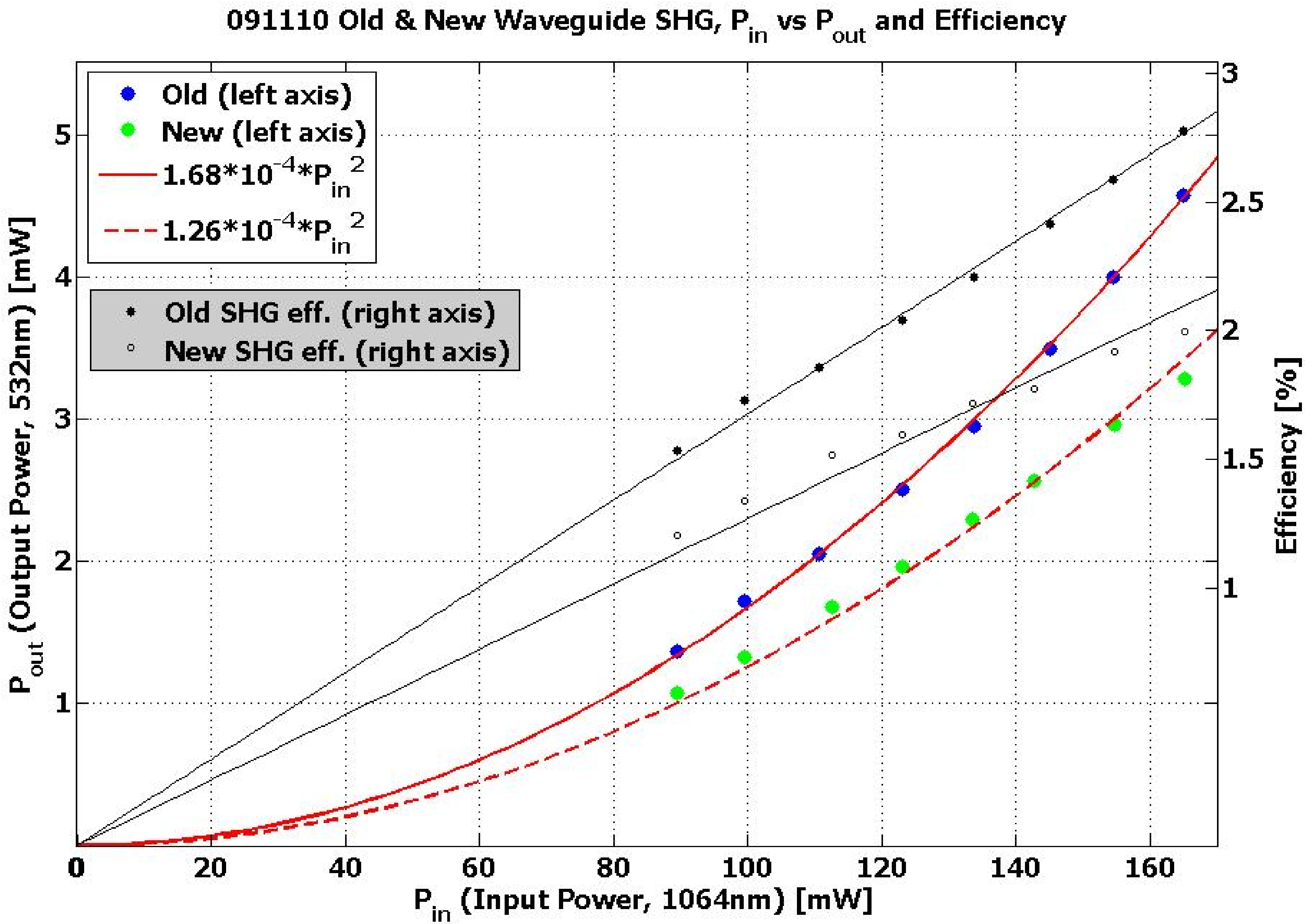

Iodine absorption lines
0.7
0.65
0.6
0.55
0.5
0.45
Signal [a.u.]
-10
-5
0
5
10
NPRO Crystal TEC Voltage [V]

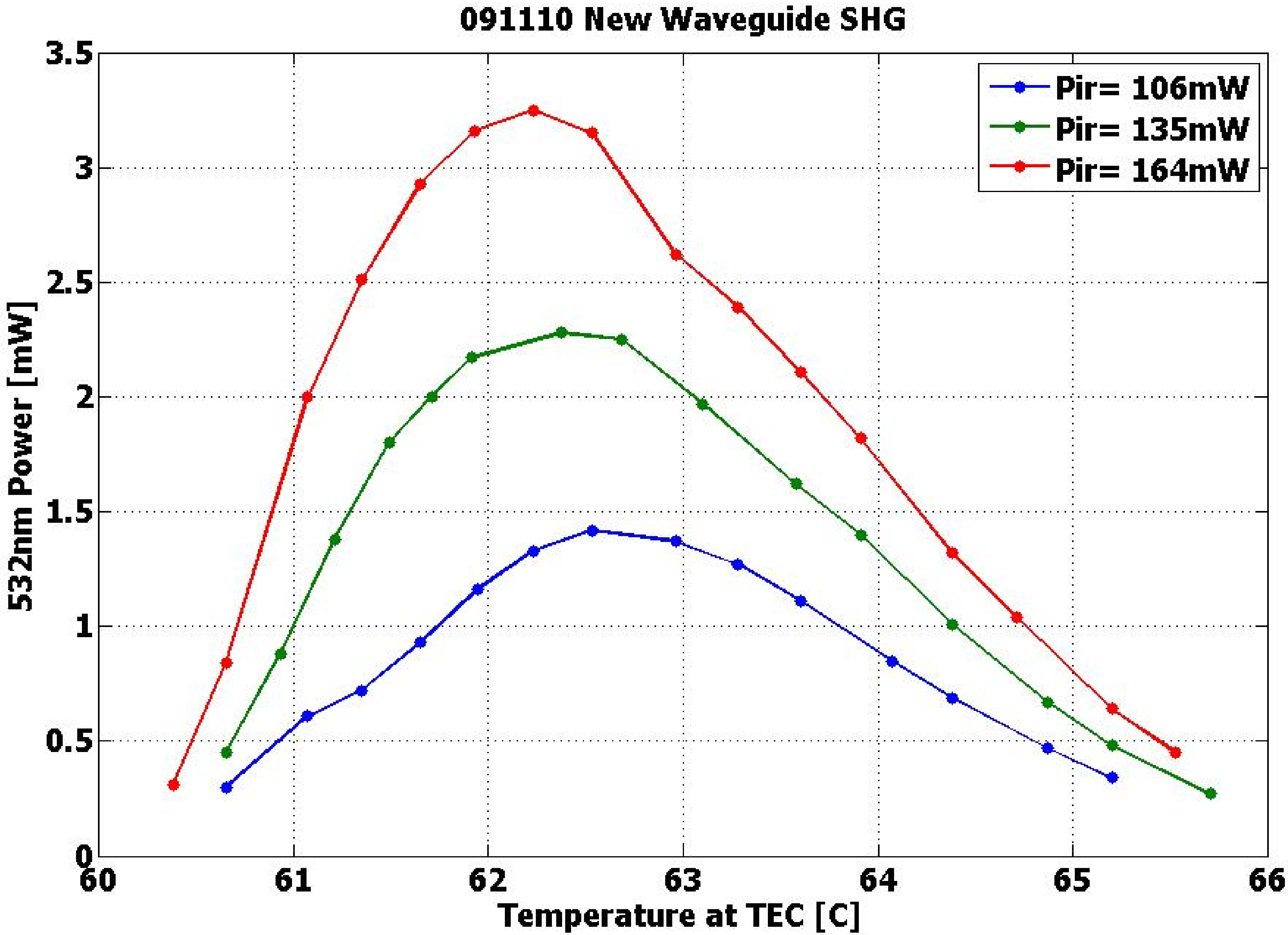


Laser2 Thermal input vs Normalized Absorption line
Normalized output
1.05
1
0.95
0.9
0.85
0.8
0.75
0.7
0.65
-10
-5
0
5
10
Thermal Control Voltage [V]



Laser2 Thermal input vs Frequency
Frequency Offset [GHz]
25
20
15
10
5
0
-5
-10
-15
-20
-25
-10
-5
0
5
10
Thermal Control Voltage [V]


091110 Old & New Waveguide SHG, P_{in} vs P_{out} and Efficiency
Old (left axis)
New (left axis)
$1.68*10^{-4}*P_{in}^2$
$1.26*10^{-4}*P_{in}^2$
Old SHG eff. (right axis)
New SHG eff. (right axis)
P_{out} (Output Power, 532nm) [mW]
Efficiency [%]
P_{in} (Input Power, 1064nm) [mW]
0
20
40
60
80
100
120
140
160
1
2
3
4
5
1.5
2.5


091110 New Waveguide SHG
Pir= 106mW
Pir= 135mW
Pir= 164mW
532nm Power [mW]
Temperature at TEC [C]
0
0.5
1
1.5
2
2.5
3
3.5
60
61
62
63
64
65
66