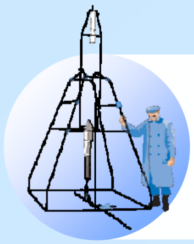
eLISA Laser Development in the US

Jordan Camp, Mike Krainak, Kenji Numata
NASA Goddard Space Flight Center

L3ST Meeting
March 25, 2016

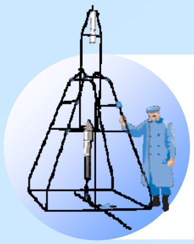


Why are we developing a LISA laser system at Goddard?

- **Europeans are working with TESAT (German Aerospace Company) to provide *commercial* LISA laser system**
  - **NPRO oscillator**
  - **5W amplifier used in non-standard configuration to produce 2W for LISA**

- **TESAT has been described as secretive and difficult to work with**

- **Karsten Danzmann has encouraged us to pursue an independent laser system at Goddard, so that a fully *transparent and optimized* laser system can be provided by LISA scientists**



eLISA laser program at Goddard

- **Provide TRL 5 laser system by FY2018**
  - **Fiber-based design, *optimized for LISA***
  - **Technical details to be made fully available to all LISA members**

- **R&D funding**
  - **$3.5M over 6 years: SBIR (Small Business Innovative Research), Goddard Internal R&D, LISA project funds, Strategic Astrophysics Technology grant**

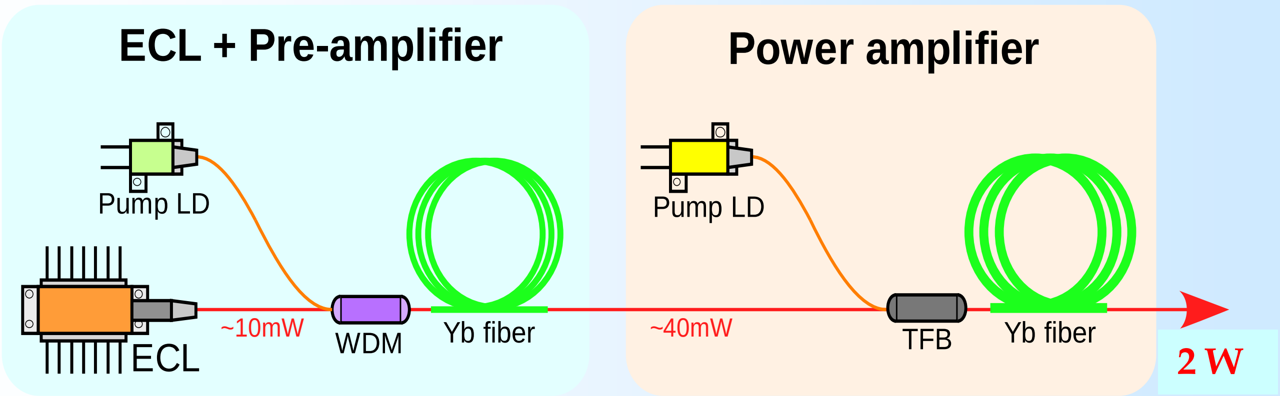
- **Cost for 12 LISA lasers (6 flight, 6 spare): $40M**

LISA laser requirements

Power	λ (nm)	Intensity Noise ($/Hz^{1/2}$)	Frequency Noise ($Hz/Hz^{1/2}$)	Differential Phase Noise ($rad/Hz^{1/2}$)	Lifetime
1.5 W	1064	10^{-4} (at 10^{-3} Hz) 10^{-8} (at 10^{7} Hz)	300 (at 10^{-2} Hz)	6×10^{-4} (at 10^{-2} Hz)	2.5 years

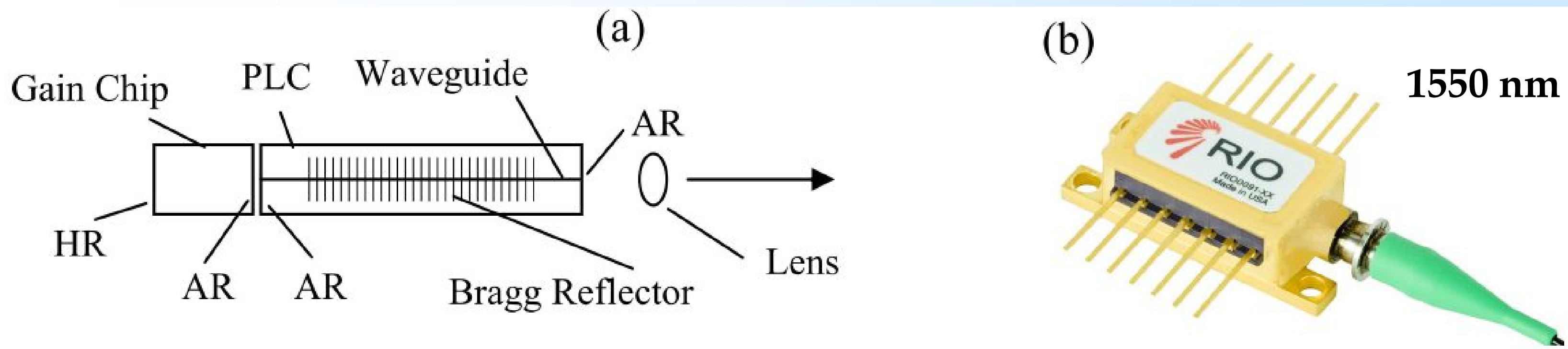
Table I. Laser requirements for eLISA

Goddard LISA laser design



Master Oscillator Power Amplifier (MOPA)
External Cavity Laser, fiber preamp, fiber amplifier
1064 nm wavelength
~ 2 Watt output (limited by fiber power density)

Oscillator: External Cavity Laser

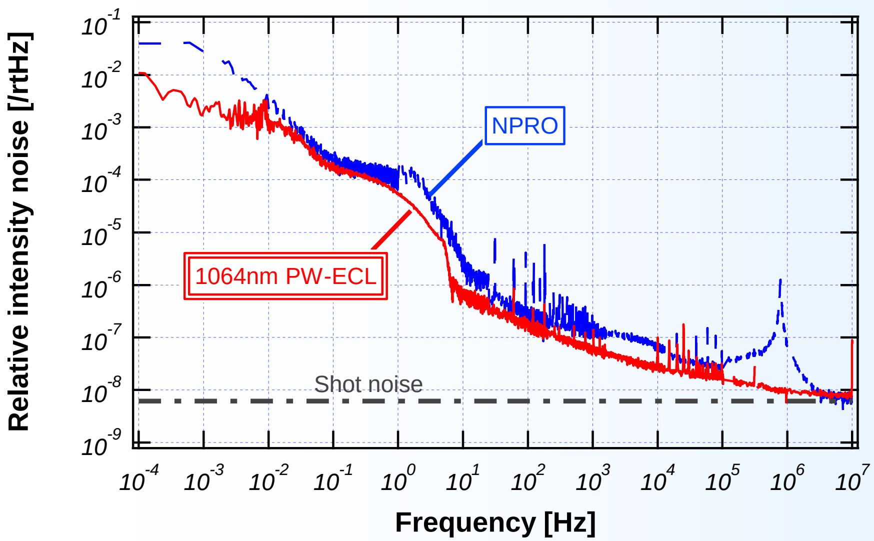


Simple, compact, low mass, highly reliable laser (butterfly package)

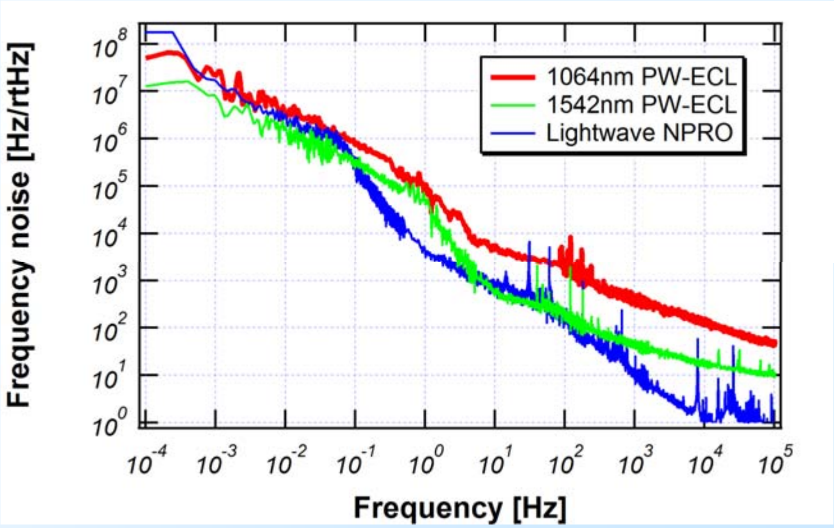
NPRO: $25K **ECL: $5K**

Wavelength → 1064 nm through SBIR contract

Intensity and Frequency Noise of 1064 nm ECL compared to NPRO



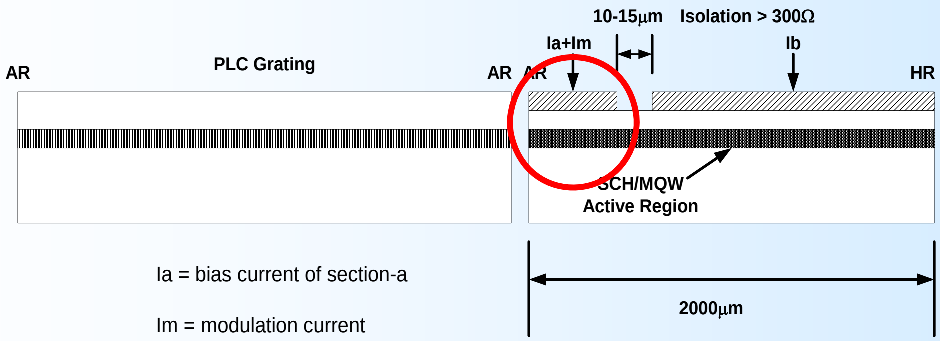
Intensity Noise

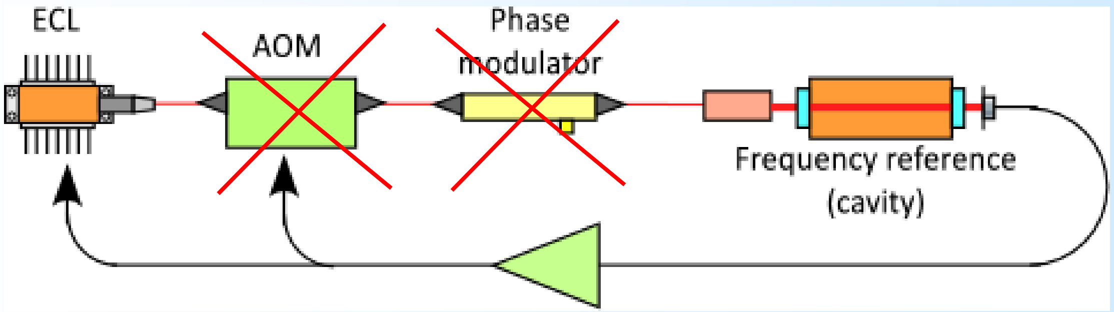


Frequency Noise

Frequency Modulation of ECL on laser chip (to be implemented in FY 17)

- ❑ Modulation of the effective refractive index inside the cavity, results in frequency modulation of the external wavelength up to 100 MHz
- ❑ FM section on the gain chip, separated from gain section by etching





ESA Interest in Goddard laser design

Subject: Re: LISA laser development at Goddard
From: <Frederic.Safa@esa.int>
Date: 5/13/2015 12:40 PM
To: Jordan Camp <Jordan.B.Camp@nasa.gov>

Dear Jordan,

Thanks for this mail. It was a real pleasure for me to visit Goddard Centre. I was impressed by the work done and the quality and commitment of the people I have met.

In particular, what you are doing on the laser for LISA is very promising and would be transformational (if successful, of course).

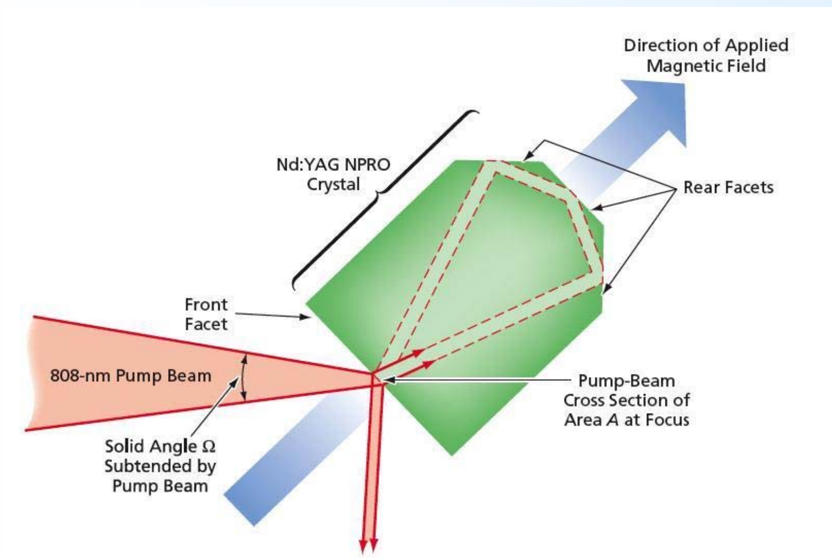
I am highly interested in getting from you further results.

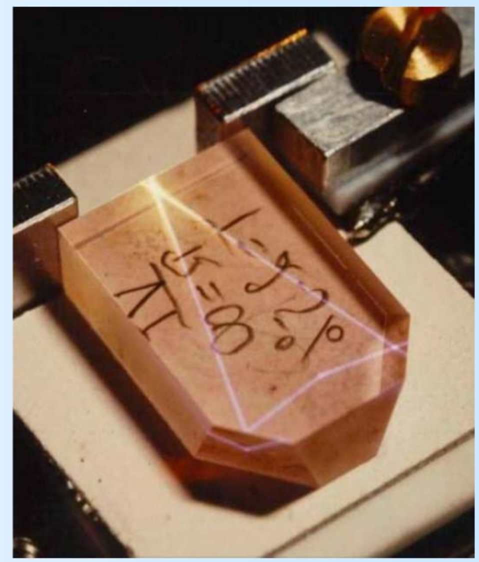
kind regards
Frederic

Frederic Safa is ESA Head of Mission Design Studies

Backup Oscillator: Building a Space-Qualified NRPO

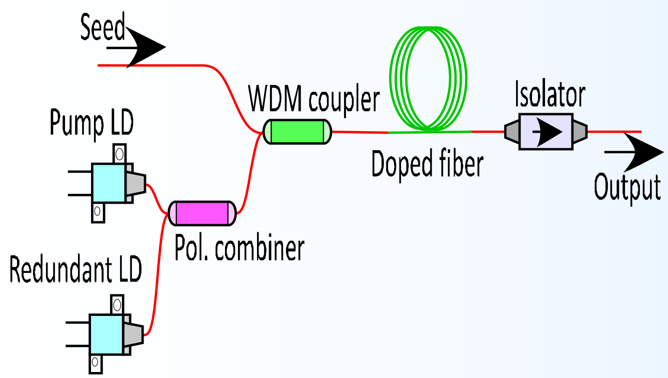
Leverage NASA-Goddard space-flight laser experience and processes (in-house build of Geoscience Laser Altimeter System (GLAS-1998), Mercury Laser Altimeter (MLA-2003), Lunar Orbiting Laser Altimeter (LOLA-2009), Laser Communication Relay Demonstration (LCRD-present) , Global Ecosystem Dynamics Investigation (GEDI-present) laser transmitters



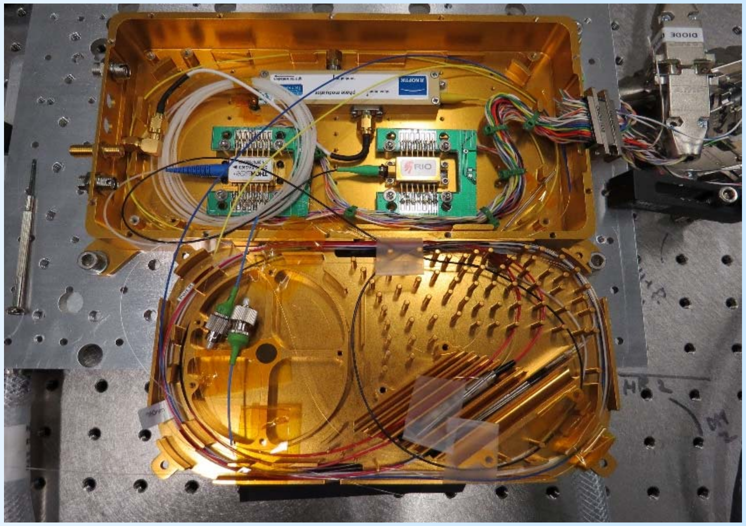


Steve Li (Laser Branch) holds patent on NRPO construction

Preamp Design and Fabrication

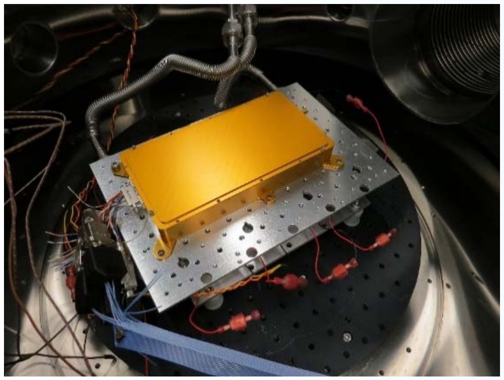


Preamp design

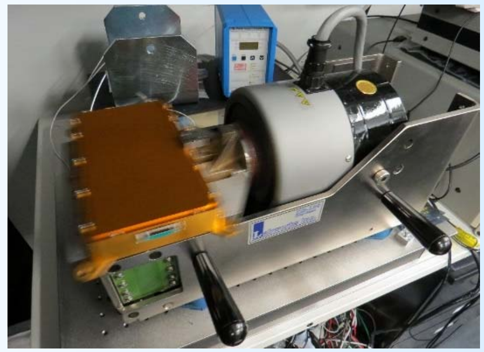


Preamp Fabrication
(chassis includes ECL)

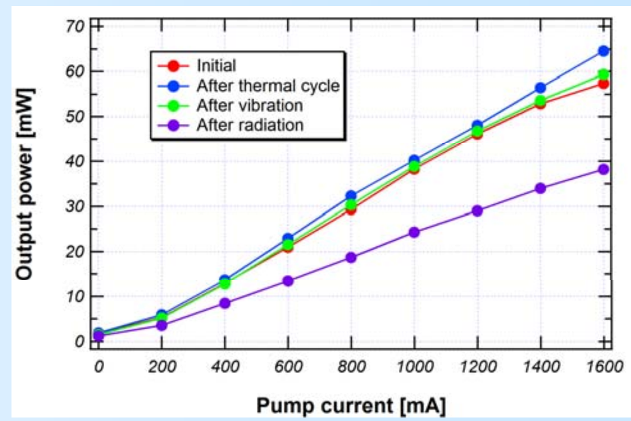
ECL + Preamp Environmental Testing

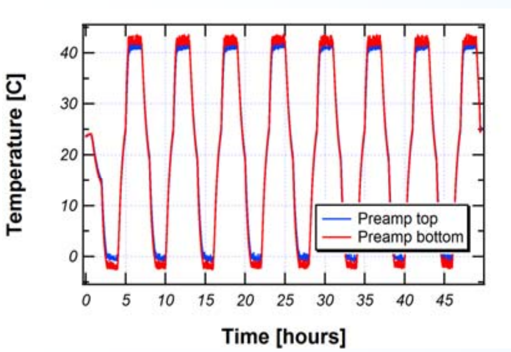


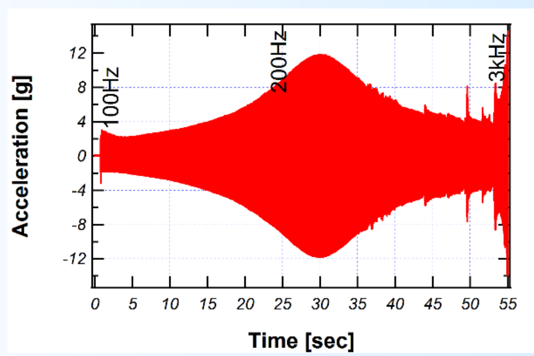
Vacuum thermal cycling



Vibration



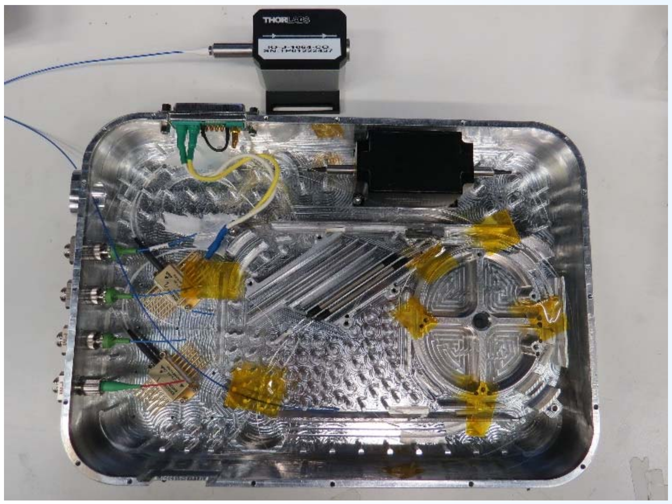




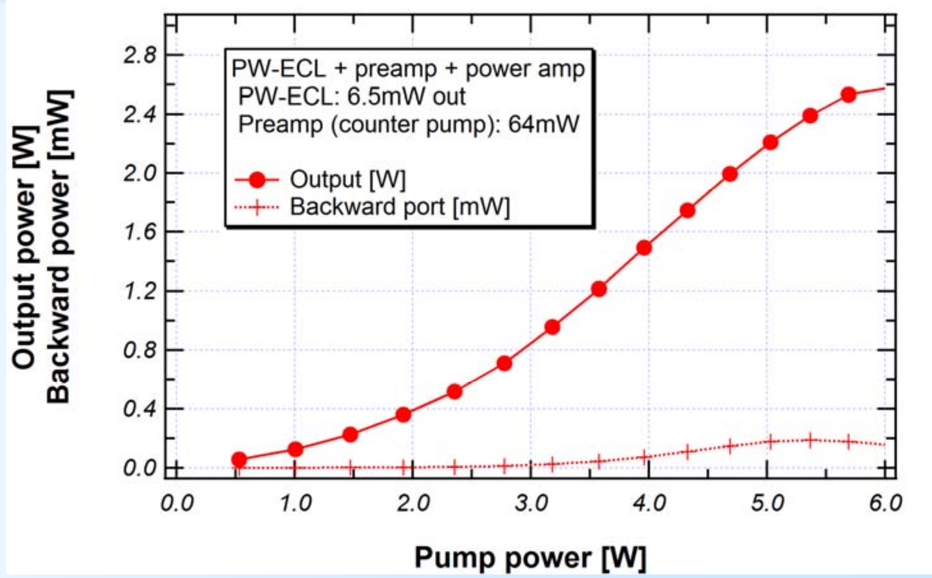
Results

- Thermal vac: no effect
- Vibration: no effect
- Radiation: 30% power drop (10^4 LISA dose rate)

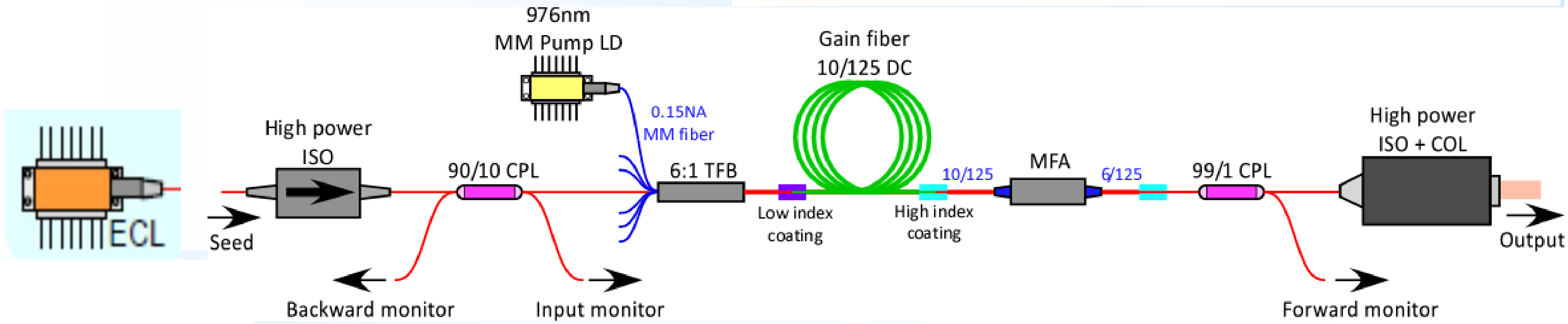
Operation of Laser Amplifier



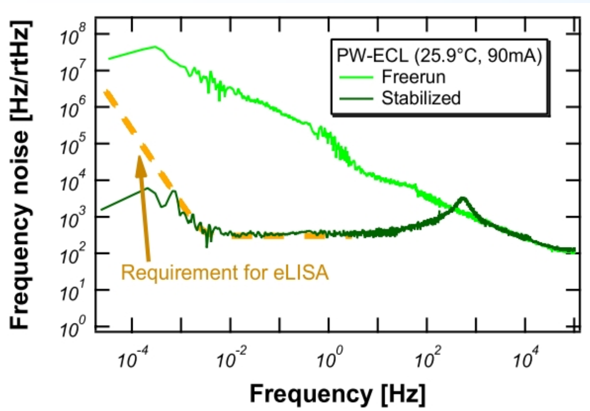
Fiber Amplifier



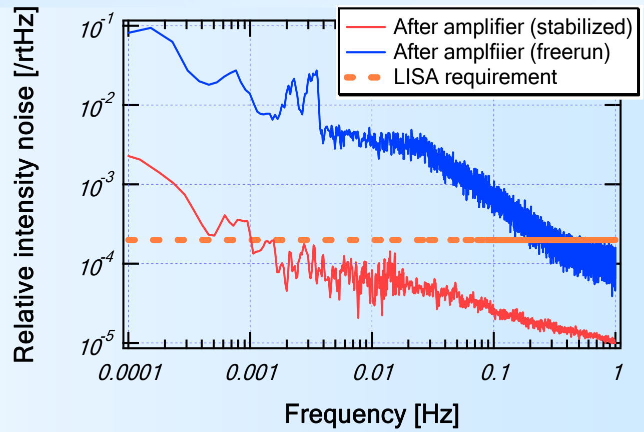
Laser System output
(flat backward port power → no SBS)



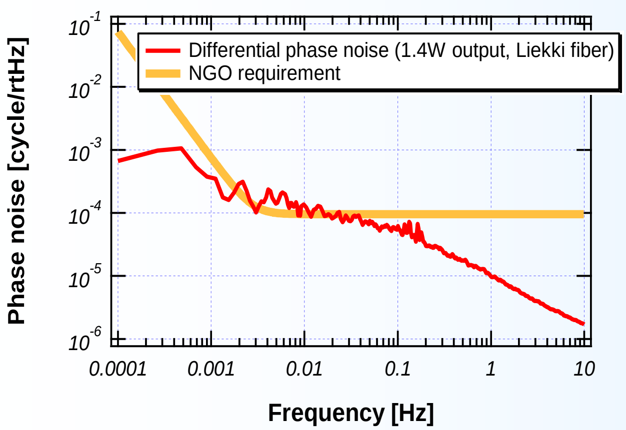
Laser System Noise



Stabilized frequency noise



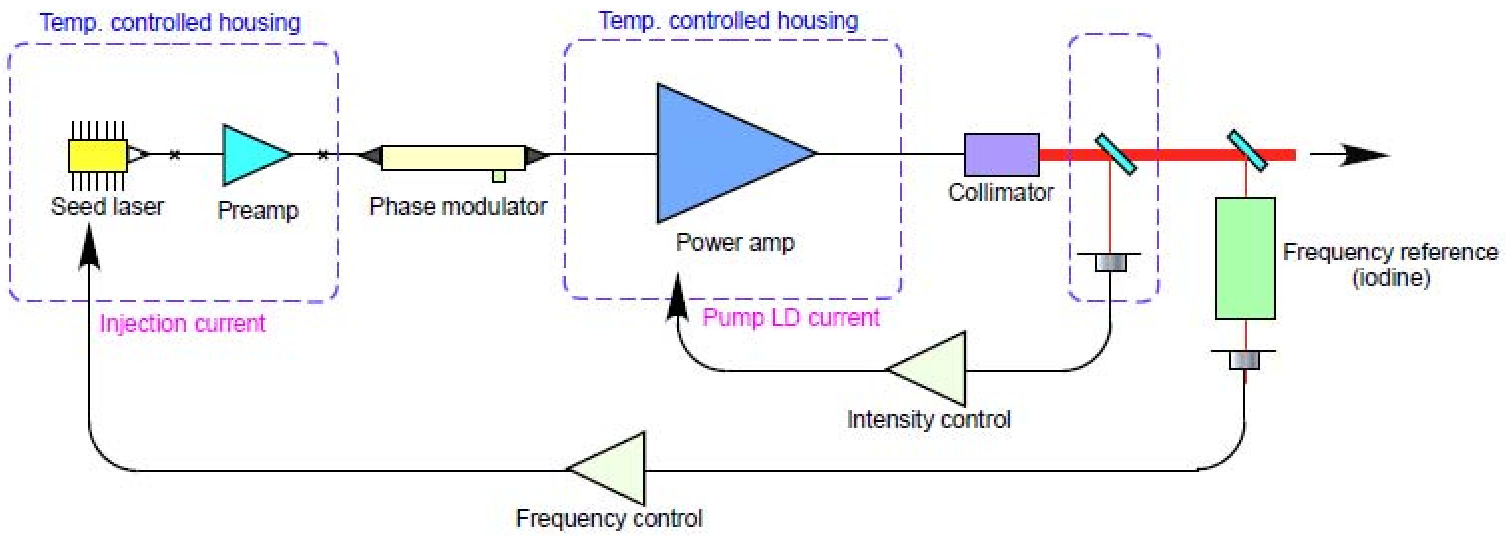
Stabilized intensity noise



Differential phase noise

Laser system noise very close to requirements

Accelerated Aging Tests for FY 2017



1064 nm ECL, preamp + power amplifier
Temperature stabilized environment
Accelerated aging → verify laser lifetime

Laser Development Schedule

- **FY 2016**
  - **Amplifier environmental testing**
  - **Start space qualified NPRO build**

- **FY 2017**
  - **Complete NPRO build**
  - **Accelerated aging tests to verify laser lifetime**
  - **Implement ECL on-chip frequency modulation**

- **FY 2018**
  - **Finalize oscillator: ECL or NPRO**

- **FY 2019**
  - **Deliver TRL 5 laser system**

Summary

- We are well along to produce a TRL 5 LISA laser system
  - Oscillator (ECL or NPRO), Preamp, Amplifier
- Laser System very close to meeting noise goals
  - Intensity, Frequency, Differential Phase Noise
- Environmental testing done on oscillator and preamp
  - Thermal vacuum cycling, vibration, radiation
- Remaining work
  - Amplifier environmental testing, NPRO backup, ECL FM, laser system accelerated aging

Backup Slides

1550 nm ECL is space qualified

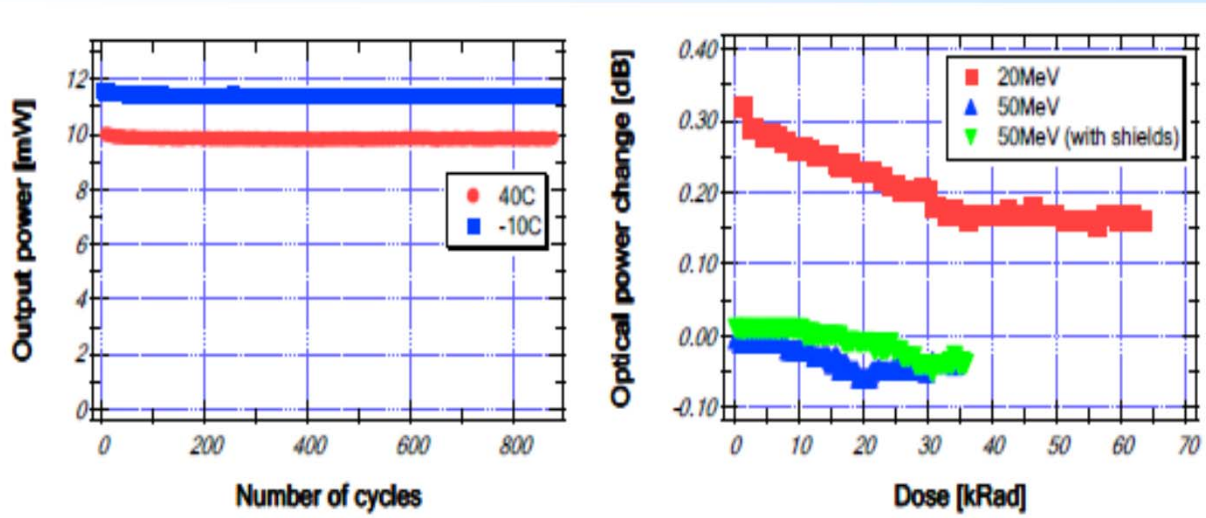


Fig. 5 Reliability testing of ECL a) thermal cycling b) proton irradiation

Other tests:

- **Hermiticity**
- **Gamma-ray exposure**
- **Accelerated aging**

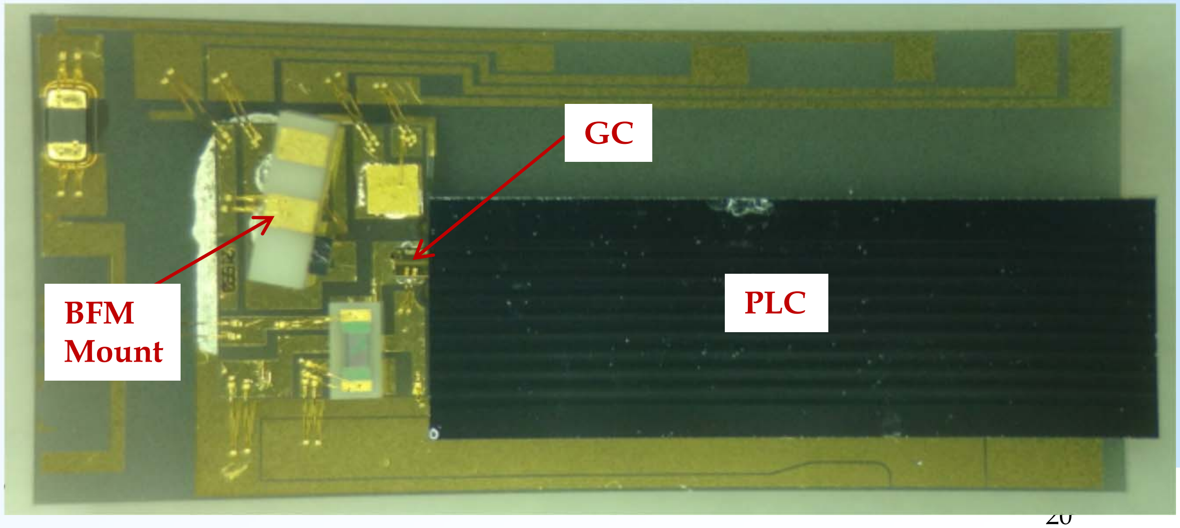
→ Robust design suitable for space operation

Conversion of ECL wavelength to 1064 nm

Gain Chip		
	RWG (1064nm)	BH (1550nm)
1	Complex epi design	epi design is decoupled from mode size converter
a	Use special design to expand beam size	Beam defined by BH and mode size converter
2	Waveguide defined by RWG	Waveguide defined by BH
a	Weak index guiding	Strong index guiding
b	Thermal and carrier lensing affect beam profile	No thermal and carrier lensing
c	Beam profile dependes on operating current	Beam profile does not depend on operating current
d	Excitation of TEM_{01} could degrade noise	Only TEM_{00}
f	High ellipticity	Almost circular
g	High GC-PLC coupling loss	Low GC-PLC coupling loss
h	Requires facet passivation	Does not require facet passivation
i	One-step growth	Two-step growth

- PLC = Planar linear cavity
- GC = gain chip
- BFM = back facet monitor

Numata, Alalusi, Stolpner, Camp, Krainak, OL 39, 2101 (2014)



RF Intensity Noise of NPRO and ECL