# Development of a US Gravitational Wave Laser System for LISA


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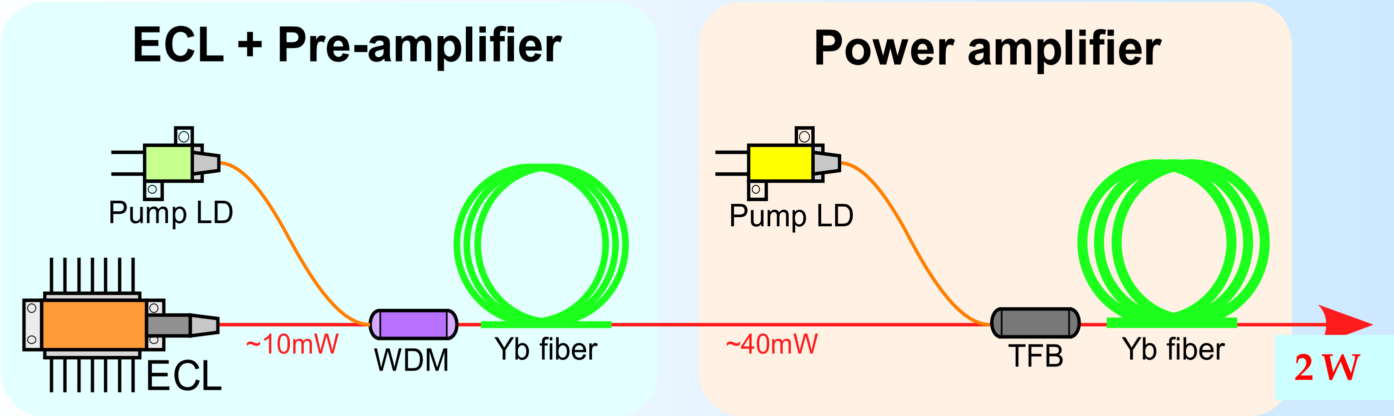
# eLISA laser program at GSFC

- Provide TRL 5 laser system by 2016
  - Modern, fiber-based design
  - Technical details to be made available to all LISA members
- Funding
  - SBIR (Small Business Innovative Research)
  - Internal GSFC R&D
  - LISA project funds
  - Strategic Astrophysics Technology award
  - ~ $3.5M over 6 years

# GSFC LISA laser design



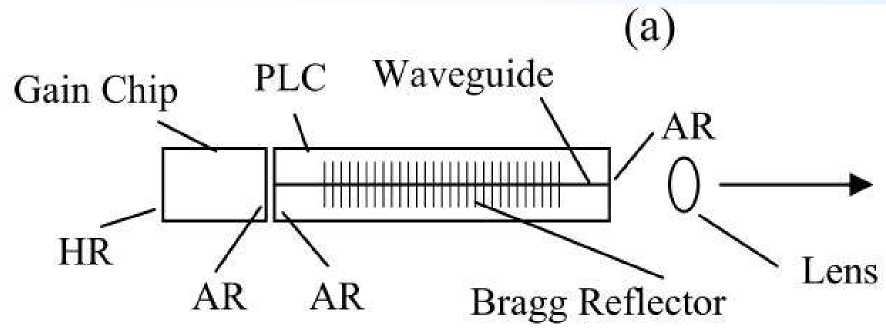

**MOPA design**

**External Cavity Laser, fiber preamp, fiber amplifier**

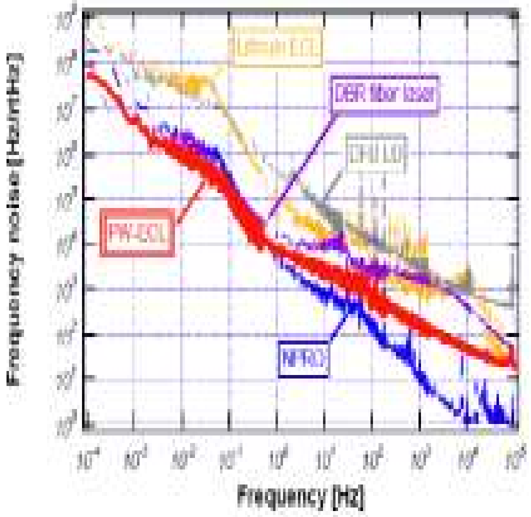
**1064 nm wavelength**

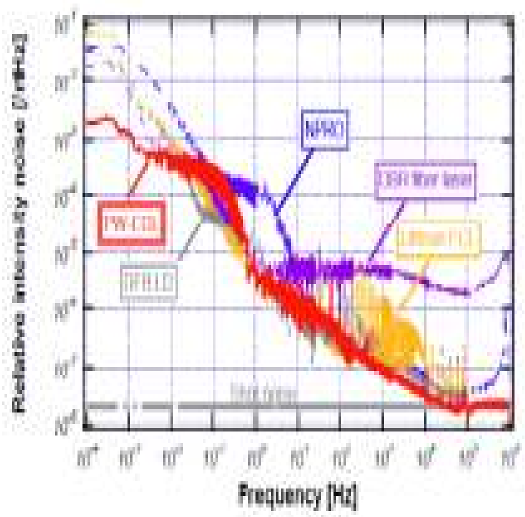
**2 Watt output**

# Oscillator: External Cavity Laser







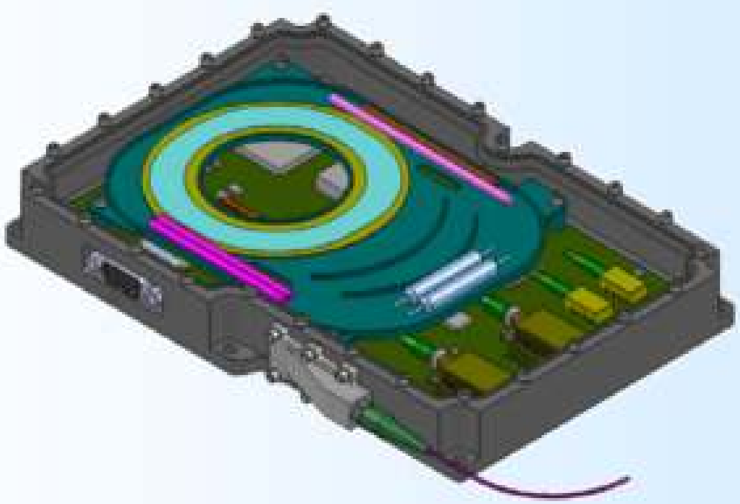




**Simple, compact, low mass, highly reliable laser (butterfly package)**

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

**Numata, Camp, Krainak, Stolpner, OE 18, 22781**

# Packaging of ECL and Preamp



2 ECLs
2 Preamp Diodes

10 cm x 5 cm x 1 cm
50 mW output

**Redundant ECL and Preamplifier package**

# 1550 nm ECL is space qualified

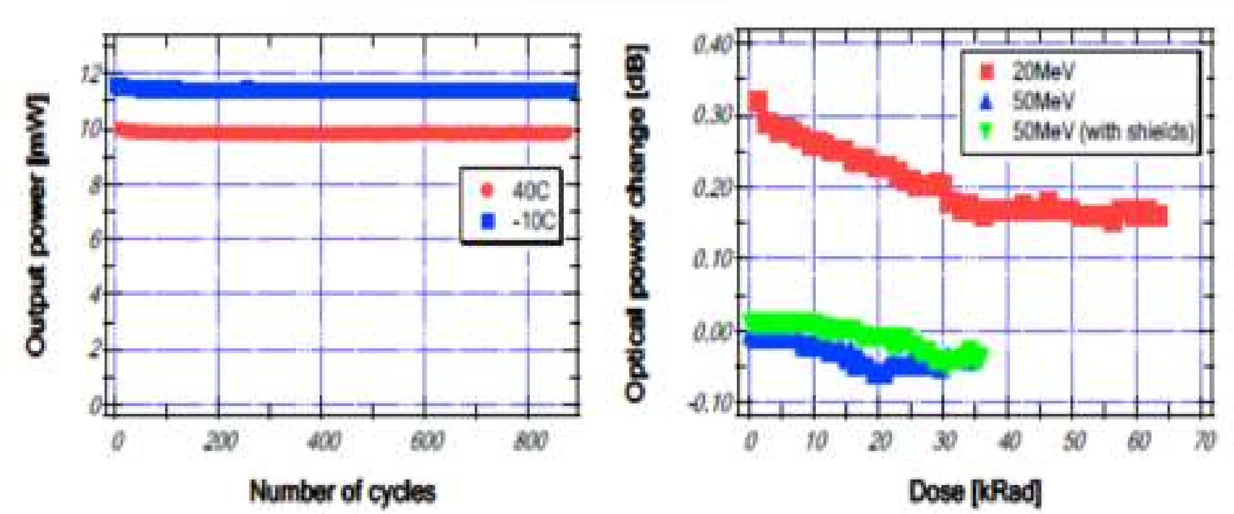



Fig. 5 Reliability testing of ECL a) thermal cycling b) proton irradiation

**Other tests:**

- Hermiticity
- Gamma-ray exposure
- Accelerated aging

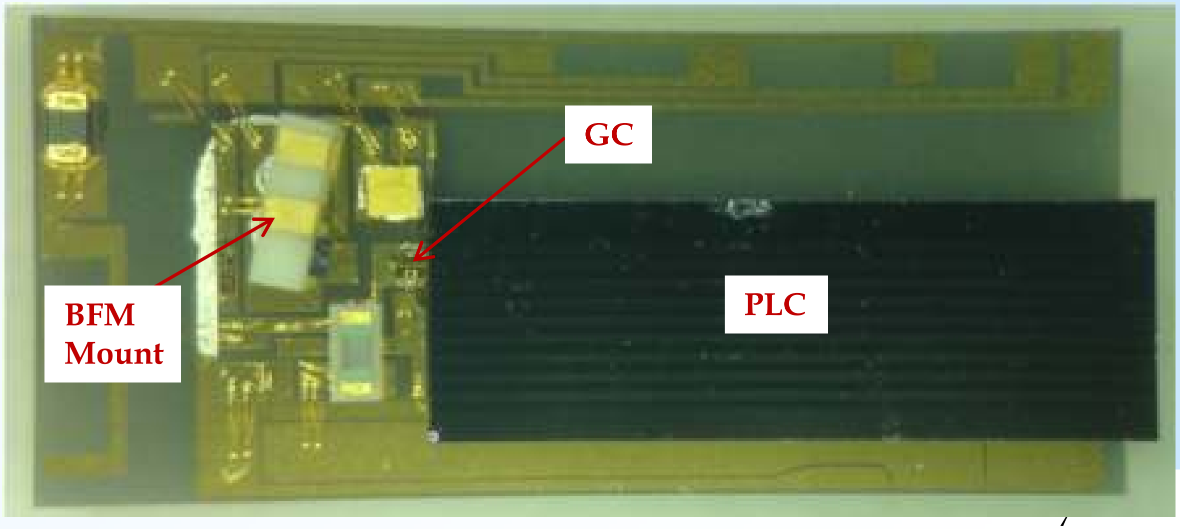
**→ Robust design suitable for space operation**

# Conversion of ECL wavelength to 1064 nm

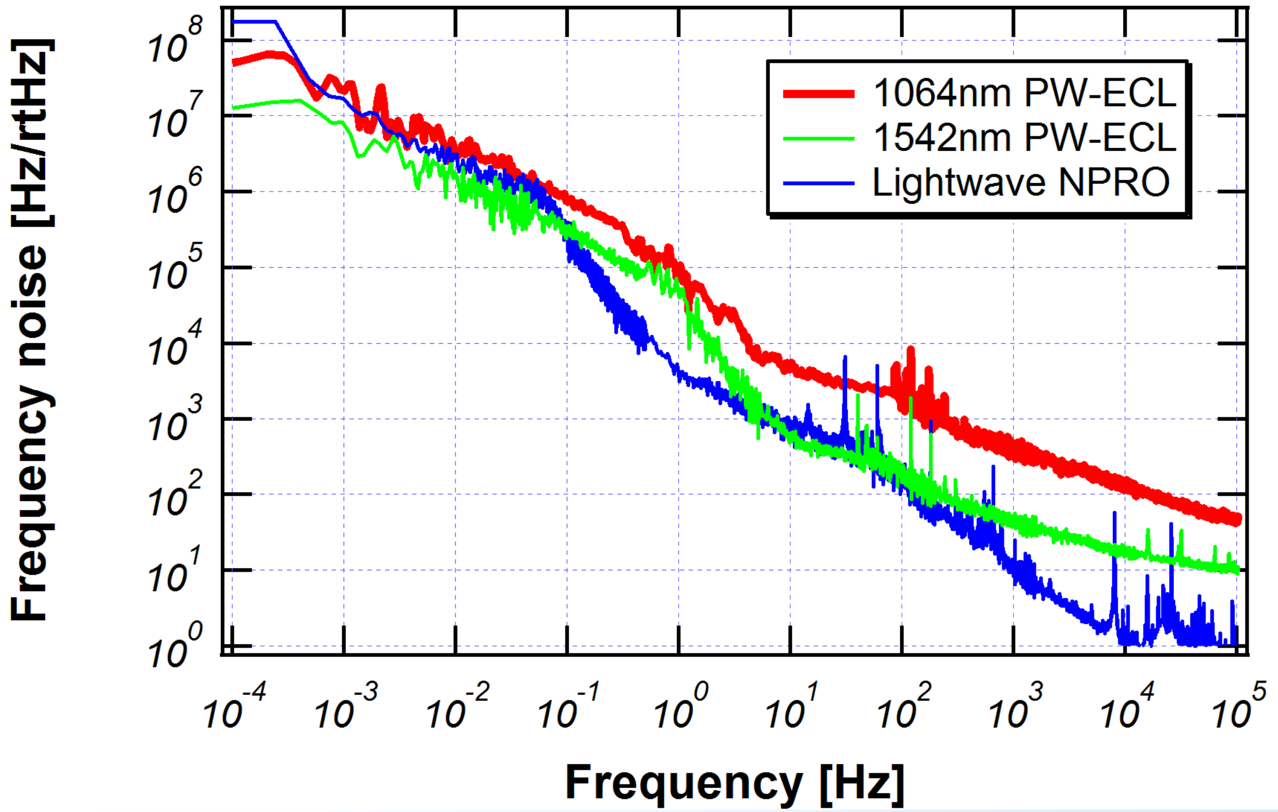
| Gain Chip | | |
|---|---|---|
| | RWG (1064nm) | BH (1550nm) |
| 1 | Complex epi design | epi design is decoupled from mode size converter |
| a | Use special design to expand beam size | Beam defined by BH and mode size converter |
| | | |
| 2 | Waveguide defined by RWG | Waveguide defined by BH |
| 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 |

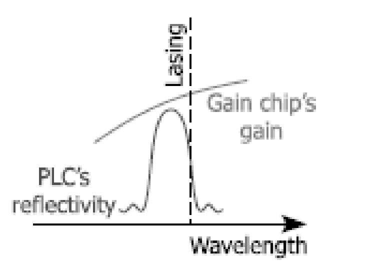
- PLC = Planar linear cavity
- GC = gain chip
- BFM = back facet monitor

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



# Frequency noise of world's 1st 1064 nm ECL (in Butterfly package)

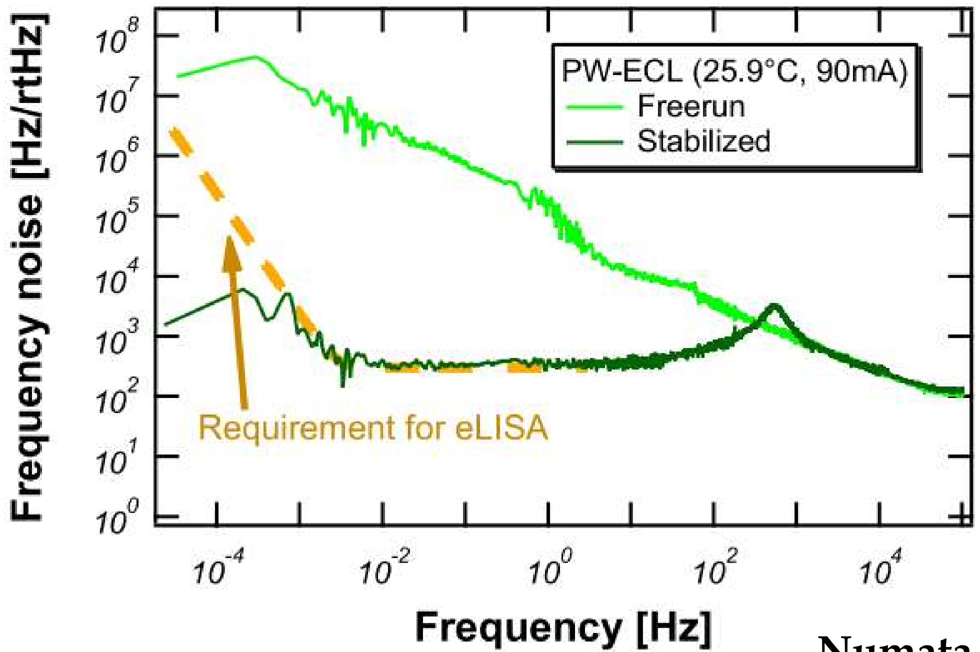



**<u>Lowering phase noise:</u>** 1) optimize optical cavity reflectivity slope → strong feedback→ low noise 2) optimize gain chip for low loss → low noise 3) select gain chip for lowest 1/f noise

# Frequency stabilization with iodine

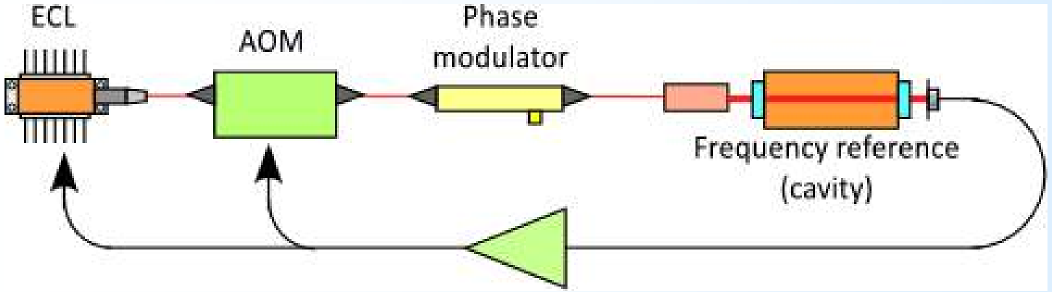
- **1064nm PW-ECL + Yb fiber amp + Waveguide doubler**

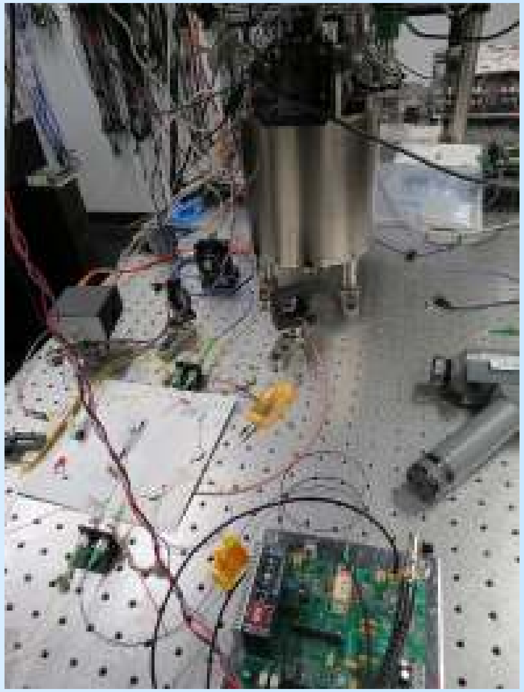



**Numata et al., Opt. Lett 39, 2101**

**Satisfies the freq. noise requirement for eLISA at low frequency**

# Frequency stabilizing the ECL

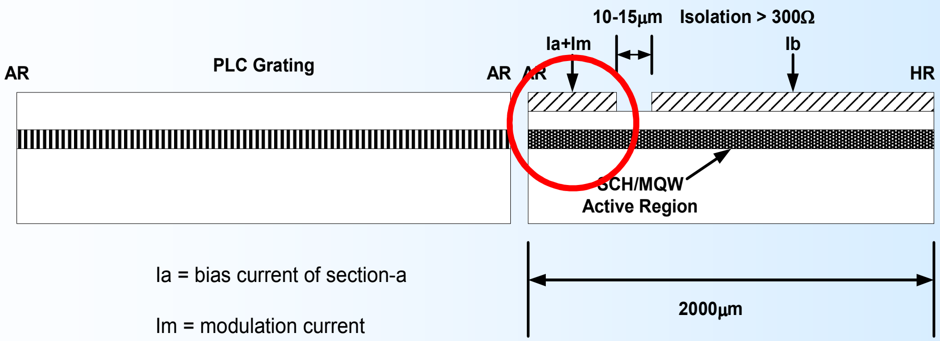


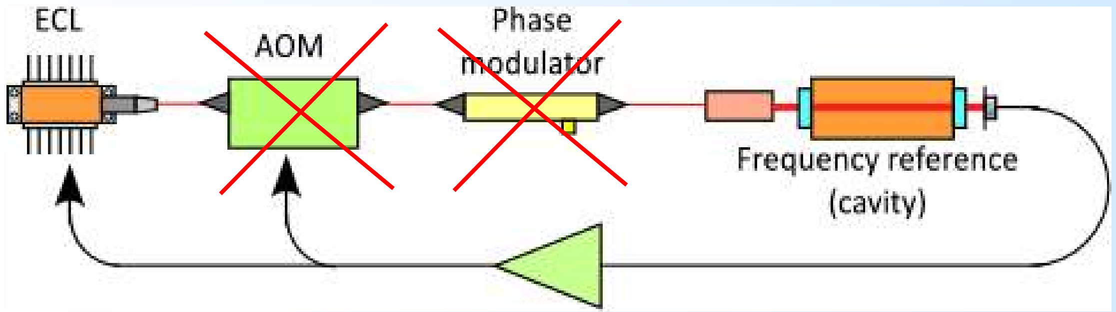



**External AOM as frequency actuator to suppress frequency noise at high frequency**

# Frequency Modulation of ECL on laser chip (to be implemented)

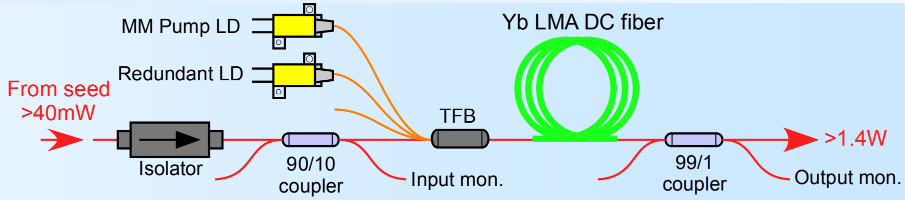
- ❑ Modulation of the effective refractive index inside the cavity, results in frequency modulation of the external wavelength up to 100 MHz
- ❑ FM section on the gain chip, separated from gain section by etching

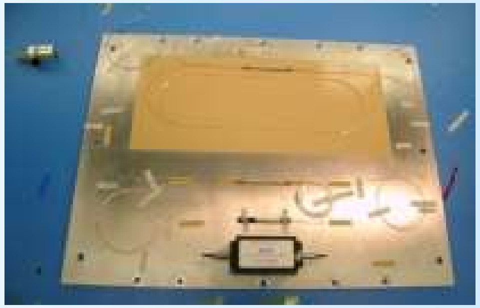


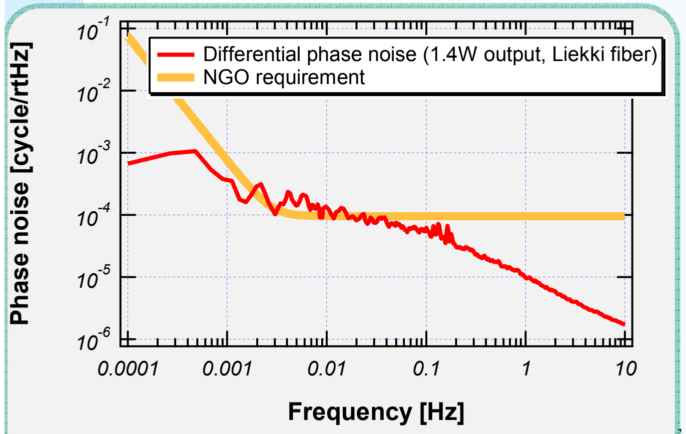



# Power Amplifier

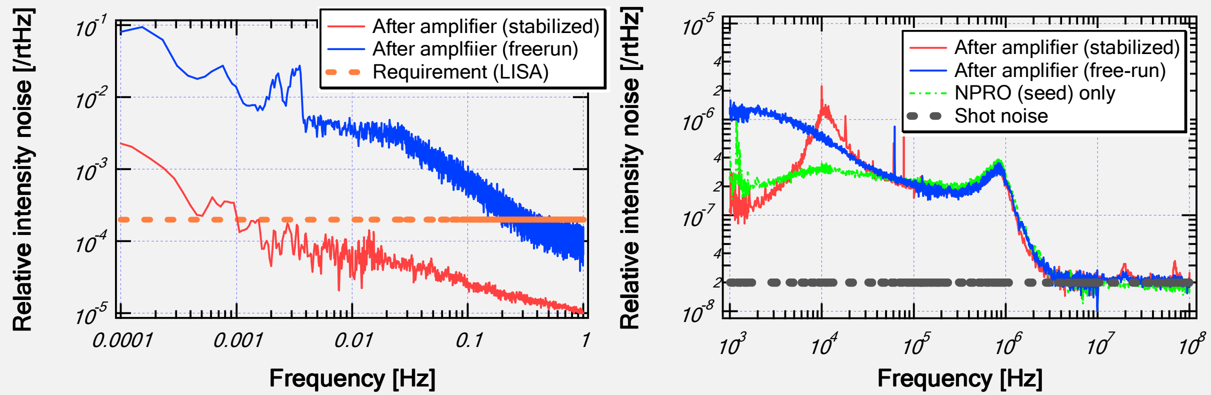
- **Design**
  - All fiber coupled
  - Large mode area, double-clad Yb fiber
  - Forward pump to avoid risk and noise sources
- **Noise performance**
  - No additional frequency noise
  - eLISA requirement level
    - Differential phase noise (@2GHz)
    - Stabilized low frequency RIN with feedback to pump diode



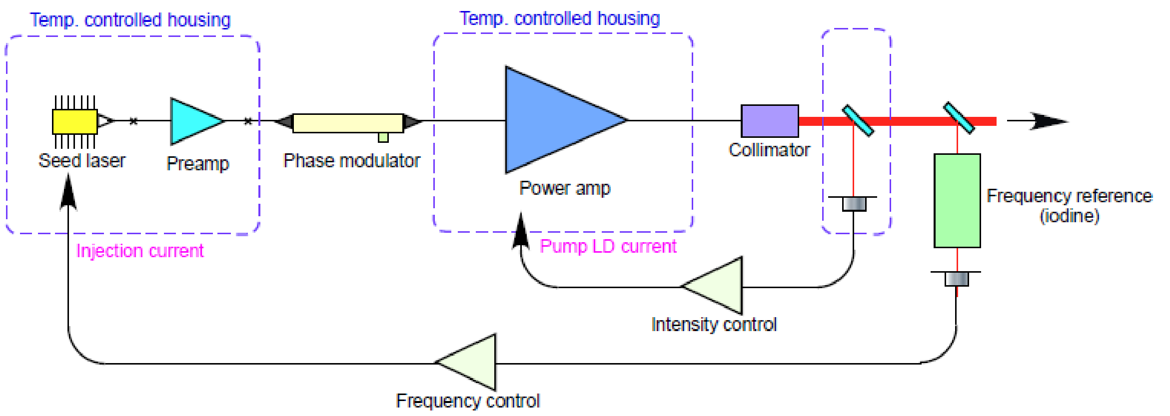



Differential phase noise




RIN and its stabilization (low/high frequency ends)

# Planned Systems Tests for FY 2015




**1064 nm ECL oscillator, rebuilt power amplifier**
**Temperature stabilized environment**
**Tests: noise, accelerated aging, etc.**

# Laser Development Schedule

- **FY 2014 - 2015**
  - **Iterate design of 1064 nm ECL gain chip, planar cavity**
- **FY 2015**
  - **Laser system testing with 1064 nm ECL**
  - **Achieve final frequency noise performance**
- **FY 2016**
  - **Reliability testing of 1064 nm ECL**
    - **Low risk since same packaging as 1550 nm, also Eagleyard data indicates reliable 1064 nm gain chips**
  - **Implement on-chip frequency modulation**