eLISA Laser Development in the US

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NASA Goddard Space Flight Center

L3ST Meeting
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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

<table>
<thead>
<tr>
<th>Power (W)</th>
<th>( \lambda ) (nm)</th>
<th>Intensity Noise (/Hz(^{1/2}))</th>
<th>Frequency Noise (Hz/Hz(^{1/2}))</th>
<th>Differential Phase Noise (rad/Hz(^{1/2}))</th>
<th>Lifetime</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5</td>
<td>1064</td>
<td>(10^{-4}) (at 10(^{-3}) Hz)</td>
<td>300 (at 10(^{-2}) Hz)</td>
<td>(6 \times 10^{-4}) (at 10(^{-2}) Hz)</td>
<td>2.5 years</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(10^{-8}) (at 10(^{7}) Hz)</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

**Table I. Laser requirements for eLISA**
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)

Wavelength \(\rightarrow\) 1064 nm through SBIR contract

NPRO: $25K  
ECL: $5K
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

Diagram:
- AR = Active Region
- PLC Grating
- SCH/MQW
- Isolation > 300Ω
- 10-15μm
- 2000μm

Equations:
- $I_a =$ bias current of section-a
- $I_m =$ modulation current
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


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)

PW-ECL + preamp + power amp
PW-ECL: 6.5mW out
Preamp (counter pump): 64mW

Output power [W]
Backward power [mW]

Output [W]
Backward port [mW]

Pump power [W]

Graph showing the relationship between pump power and output power.
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
1550 nm ECL is space qualified

Other tests:
• Hermiticity
• Gamma-ray exposure
• Accelerated aging

→ Robust design suitable for space operation

Fig. 5 Reliability testing of ECL  a) thermal cycling  b) proton irradiation
### Conversion of ECL wavelength to 1064 nm

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

- 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