#### **Albert Einstein Institute**

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# Transportable setup for amplifier phase fidelity measurements

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# Breadboard laser for LISA 10 years ago

 NPRO 1.2 W output power, 30 Hz/rtHz, fiber-coupled pump module



# LISA laser concept today

- Master oscillator fiber amplifier
- Developments ongoing at
  - Lusospace / LZH
  - GSFC
- Hardware with flight heritage



LTP RLU FM



Amplifier for laser com. terminal



- Phase modulator between seed laser and amplifier for
  - Clock noise transfer
  - Ranging
  - Data communication



Phase modulator between seed laser and amplifier for

- Clock noise transfer
- Ranging
- Data communication

# USO clock tone transfer chain

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# USO clock tone transfer chain

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![](_page_6_Picture_2.jpeg)

# **USO phase noise measurement**

![](_page_7_Figure_1.jpeg)

![](_page_7_Figure_2.jpeg)

![](_page_8_Figure_0.jpeg)

$$\begin{array}{ll} \text{Phase read-out:} & \Delta\phi_{1\,\text{pm}} \leq \frac{1\,\text{cycle}}{1064\,\text{nm}} \cdot \frac{1\,\text{pm}}{\sqrt{\text{Hz}}} \cong \frac{1\,\mu\text{cycle}}{\sqrt{\text{Hz}}} \cong \frac{6\,\mu\text{rad}}{\sqrt{\text{Hz}}} \\ \text{Ancillary Modulation Error:} & \Delta\phi_{AME} \leq \Delta\phi_{1\,\text{pm}} \cdot \frac{f_{EOM}}{f_{het}} \cong \frac{2.4\,\text{GHz}}{24\,\text{MHz}} \cdot \frac{6\,\mu\text{rad}}{\sqrt{\text{Hz}}} \\ \text{LISA frequency band:} & \Delta\phi_{AME} \cdot (f) \leq 0.6 \cdot \sqrt{1 + \left(\frac{2.8\,\text{mHz}}{f}\right)^4} \frac{\text{mrad}}{\sqrt{\text{Hz}}} \end{array}$$

# **Requirements – EOM frequency**

# • Shot noise limit of both sideband-sideband beats combined: $93.2 \text{ pm}/\sqrt{\text{Hz}}$

![](_page_9_Picture_2.jpeg)

$$\Delta \phi_{correction} = \Delta \phi_{combined} \cdot \frac{f_{\text{het}}}{f_{\text{EOM}}}$$

• For 
$$\Delta \phi_1 \text{ pm} \leq \frac{1 \text{ pm}}{\sqrt{\text{Hz}}} \rightarrow \frac{f_{\text{het}}}{f_{\text{EOM}}} \leq 1/100$$

# **Requirements – EOM frequency**

# • Shot noise limit of both sideband-sideband beats combined: 93.2 $pm/\sqrt{Hz}$

![](_page_10_Figure_2.jpeg)

$$\Delta \phi_{correction} = \Delta \phi_{combined} \cdot \frac{f_{\text{het}}}{f_{\text{EOM}}}$$

• For 
$$\Delta \phi_1 \text{ pm} \leq \frac{1 \text{ pm}}{\sqrt{\text{Hz}}} \rightarrow \frac{f_{\text{het}}}{f_{\text{EOM}}} \leq 1/100$$

#### Sources of differential phase noise in amplifiers

- amplifier length changes ΔL due to
  - changes in ambient temperature
  - pump power changes
  - seed power changes

$$\Delta \varphi = \frac{2\pi \cdot f_{\rm EOM}}{c} \cdot \Delta L$$

combined effect measured
ΔL≤12 µm/√Hz

 nonlinear dispersion and laser frequency changes

![](_page_11_Figure_8.jpeg)

 Effect measured for passive fiber and found to be negligible

#### 5 W flight-representative amplifier by Tesat tested

![](_page_12_Picture_1.jpeg)

#### **Tesat amplifier results**

![](_page_13_Figure_1.jpeg)

- Seeded by LISA-like signal (narrowband carrier + two sidebands with 17% power each)
- No sign of SBS visible in backscattered signal (was monitored live)

#### **Tesat amplifier results**

![](_page_14_Figure_1.jpeg)

- Relative power noise (RIN) was measured at 2.2 W output power
- RIN compatible with LISA requirements

# EOM phase fidelity

![](_page_15_Figure_1.jpeg)

- Phase fidelity of waveguide EOM fulfills LISA requirements
- Space-qualified version available

# Breadboard amplifier phase fidelity

![](_page_16_Figure_1.jpeg)

# Breadboard amplifier phase fidelity

![](_page_17_Figure_1.jpeg)

![](_page_18_Figure_0.jpeg)

#### Setup to measure phase noise introduced by fiber amplifier

![](_page_19_Figure_1.jpeg)

- Breadboards, modular setup, and electronics in rack ensure transportability
- room temperature fluctuations  $\rightarrow$  passive thermal isolation
- power dependent phase shift in mixers  $\rightarrow$  active amplitude stabilizations

![](_page_20_Picture_0.jpeg)

![](_page_21_Picture_0.jpeg)

![](_page_21_Picture_1.jpeg)

![](_page_22_Picture_0.jpeg)

![](_page_22_Picture_1.jpeg)

![](_page_22_Picture_2.jpeg)

![](_page_23_Picture_0.jpeg)

![](_page_24_Picture_0.jpeg)

![](_page_25_Figure_0.jpeg)

## Sensitivity of test setup

![](_page_26_Figure_0.jpeg)

## Sensitivity of test setup

### Summary

- Laser system with flight heritage available
- TEAT

![](_page_27_Picture_3.jpeg)

 Transportable test setup is in place\*

![](_page_27_Picture_5.jpeg)

- Next measurement windows are
  - end June mid July
  - end August mid October

![](_page_28_Picture_0.jpeg)

![](_page_28_Picture_1.jpeg)

![](_page_28_Picture_2.jpeg)

g+ LISAcommunity

![](_page_28_Picture_4.jpeg)

www.elisascience.org