



# The European LISA Metrology System #2: Phasemeter Breadboard & Optical Testbed

Oliver Gerberding, Simon Barke, Nils Christopher Brause, Iouri Bykov, Juan Jose Esteban Delgado,  
Joachim Kullmann, Jens Reiche, Thomas Schwarze, Germán Fernández Barranco, Gerhard Heinzel,  
Karsten Danzmann



Centre for Quantum Engineering  
and Space-Time Research



Leibniz Universität Hannover  
Germany



Axcon ApS  
Lyngby, Denmark



European Space Agency  
ESA

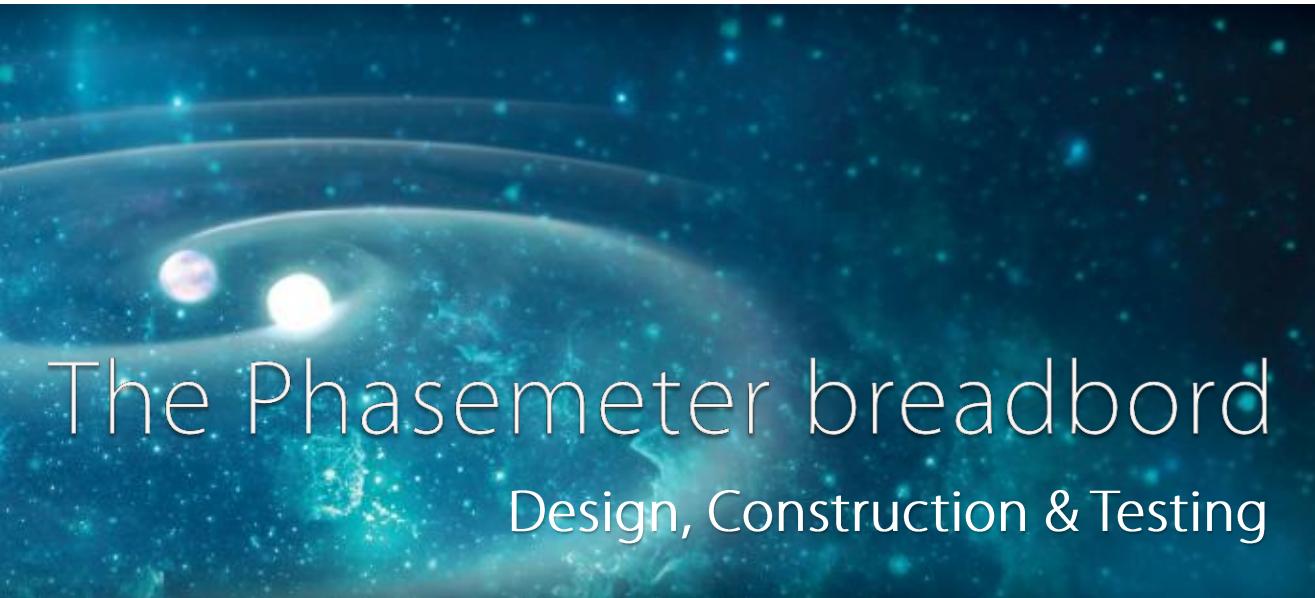


National Space Institute  
Denmark



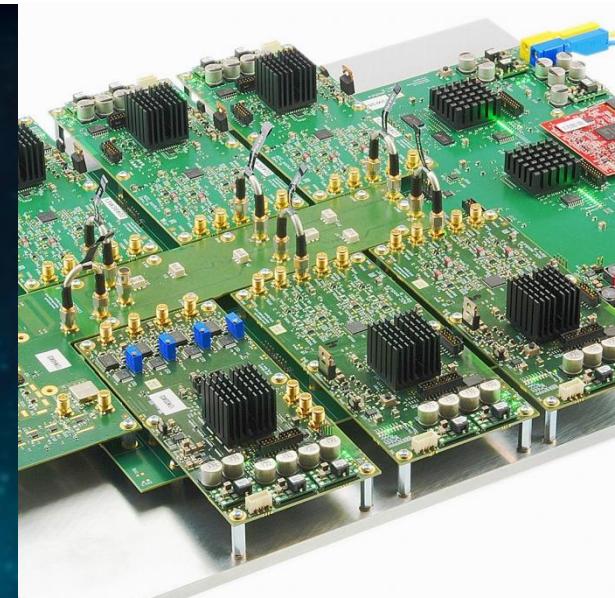
Max Planck Society  
Germany

We gratefully acknowledge support by the **European Space Agency** (ESA) (22331/09/NL/HB, 16238/10/NL/HB) and the **German Aerospace Center** (DLR) (50Q0601, 50Q1301) and thank the German Research Foundation for funding the **Cluster of Excellence QUEST** (Centre for Quantum Engineering and Space-Time Research).



# The Phasemeter breadboard

## Design, Construction & Testing



[facebook.com/  
LISAscience](https://facebook.com/LISAscience)



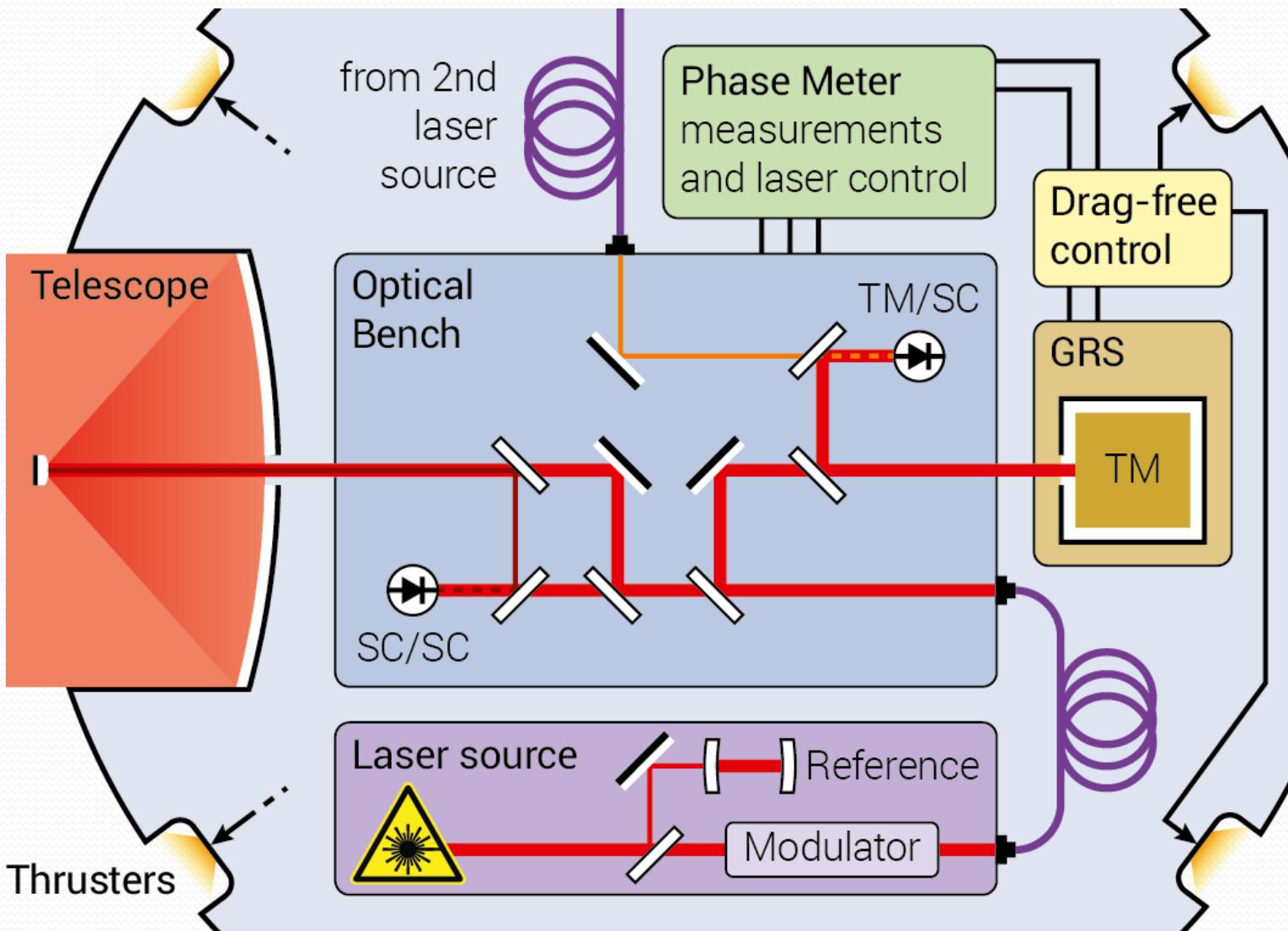
[@LISAscience](https://twitter.com/LISAscience)



[google.com/  
+LisaMissionOrg](https://google.com/+LisaMissionOrg)

[www.elisascience.org](http://www.elisascience.org)

# LISA Metrology Overview





# LISA Phase Measurement System

Contract with



Development of a breadboard model of the LISA Phase Measurement Subsystem (PMS) and of the Frequency Distribution System (FDS)

**DTU Space**  
National Space Institute

Allan Hornstrup

Søren Møller Pederson

**axcon**

The FPGA Power House

Anders Enggaard

Torben Vendt Hansen

Flemming Mortensen

Torben Rasmussen



Max-Planck-Institut  
für Gravitationsphysik  
(Albert-Einstein-Institut)

Simon Barke

Nils Brause

Iouri Bykov

Juan J. E. Delgado

Karsten Danzmann

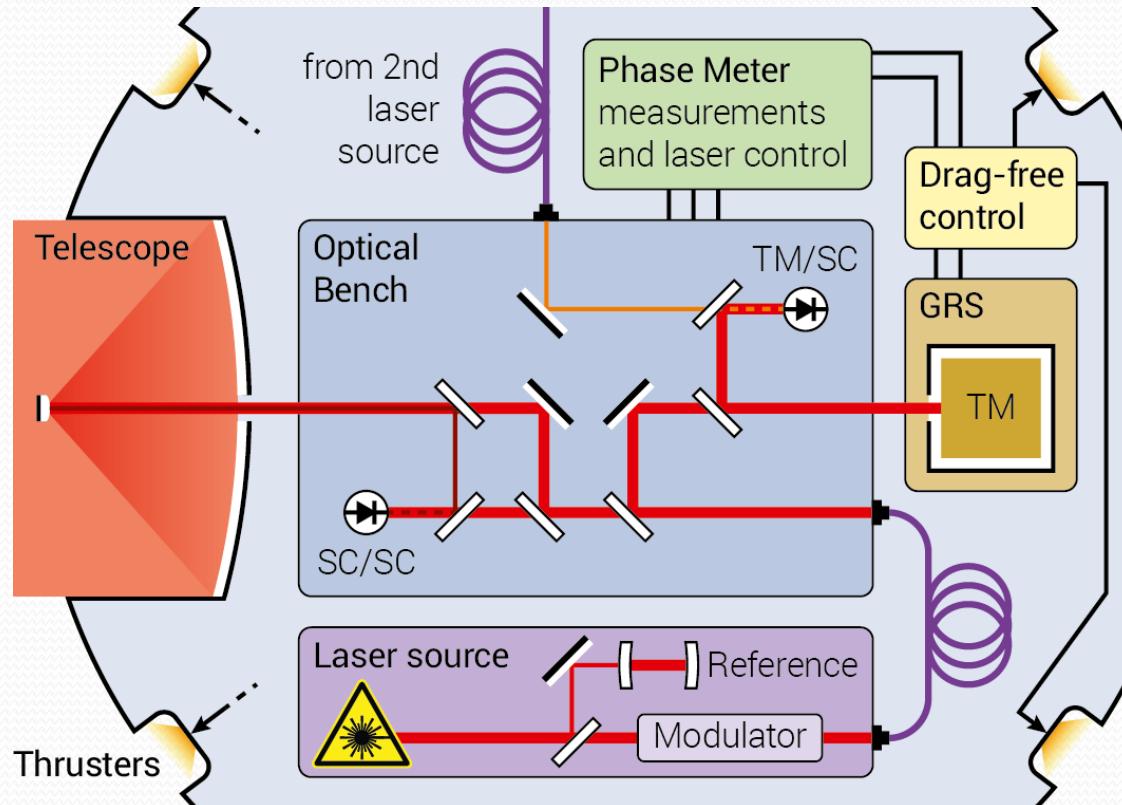
Oliver Gerberding

Gerhard Heinzel

Joachim Kullmann

Jens Reiche

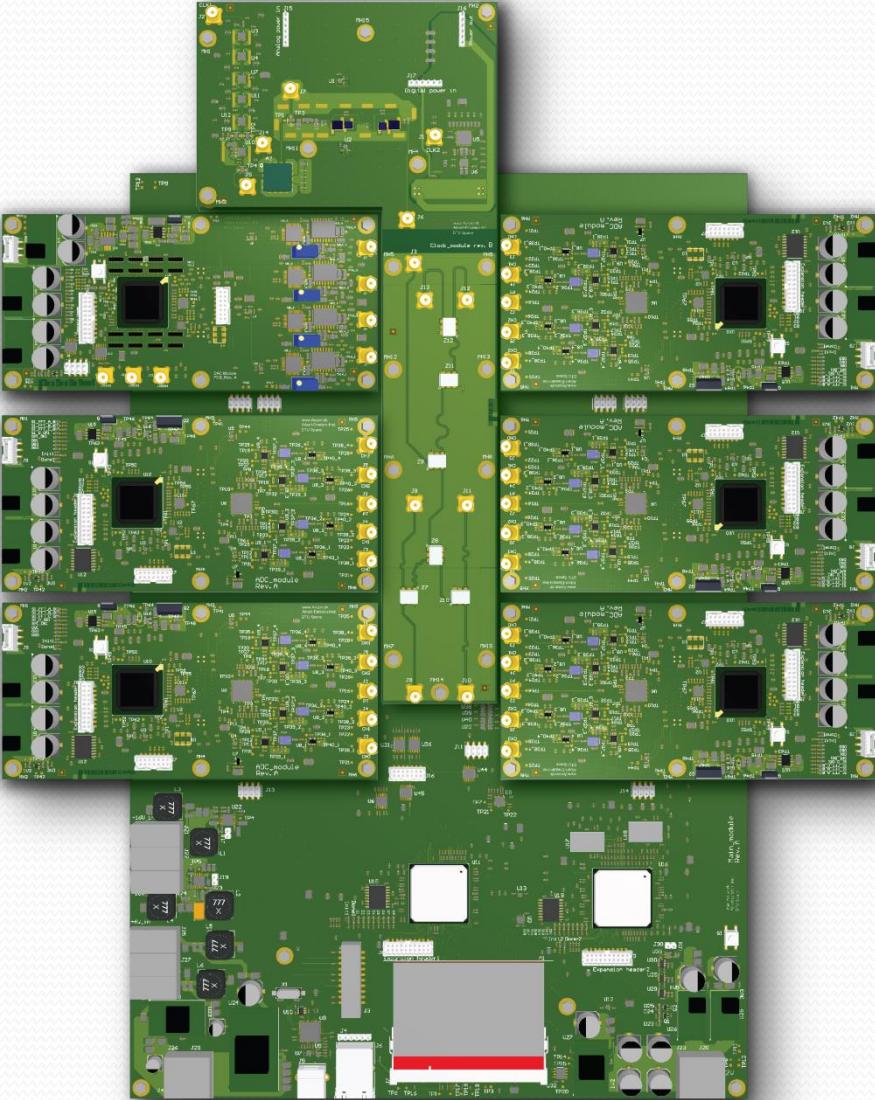
# LISA interferometry



- Interferometer
  - Phase readout
  - Angular readout
- Laser frequency noise
  - Ranging
  - Laser phase locking
- Independent satellites
  - Clock noise transfer
  - Data communication
  - Acquisition



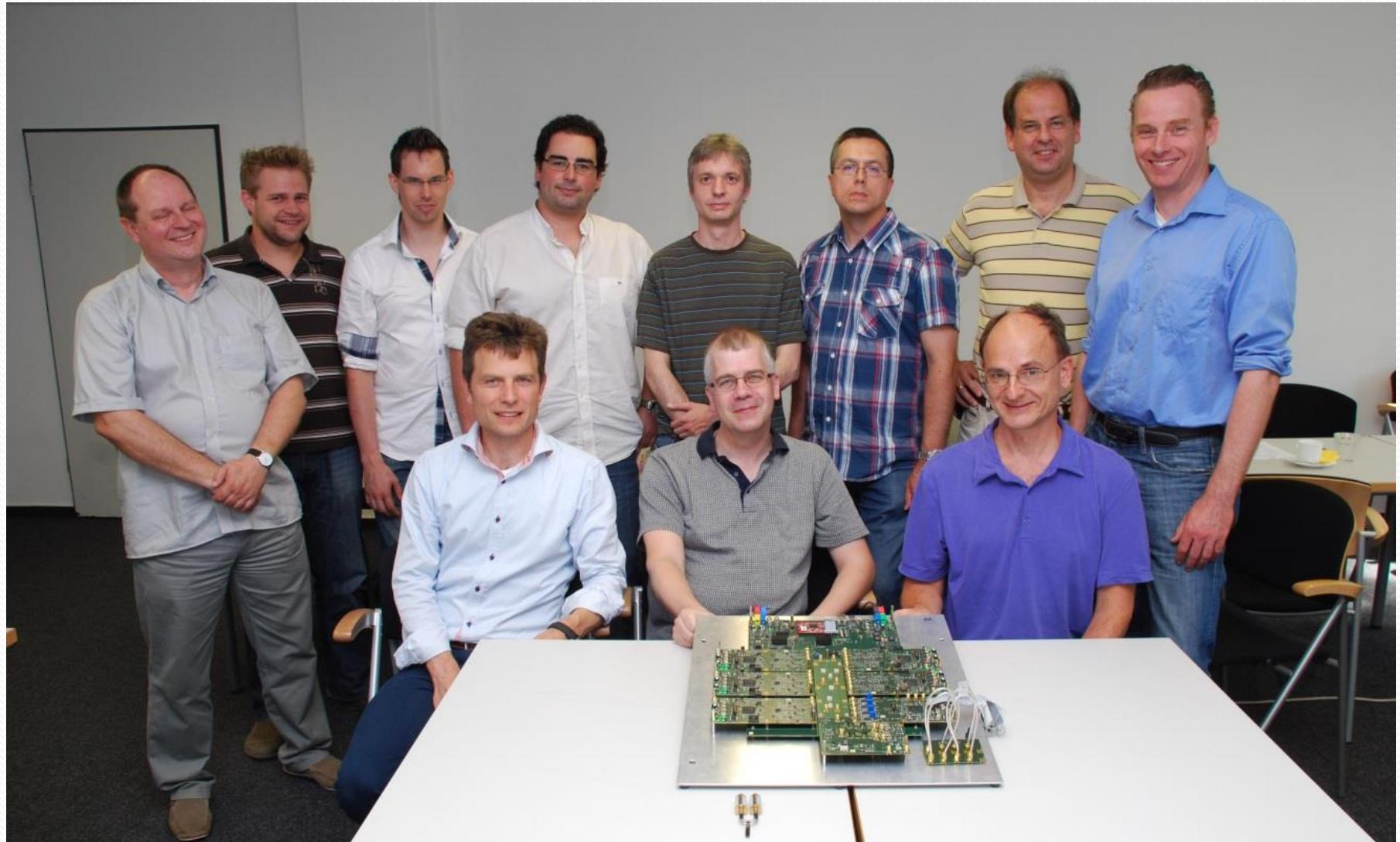
# Breadboard design



- 20 channel phasemeter
  - urad/sqrt(Hz) performance
  - readout of auxilliary functions
- Modular system
- Frequency control of two lasers
- Frequency distribution system
  - Sampling clock 80 MHz
  - Pilot tone 75 MHz
  - Clock tone sideband 2.4 GHz
- Generates ranging modulations
- Dedicated acquisition FPGA
- Temperature sensors
- CPU for data filtering and processing

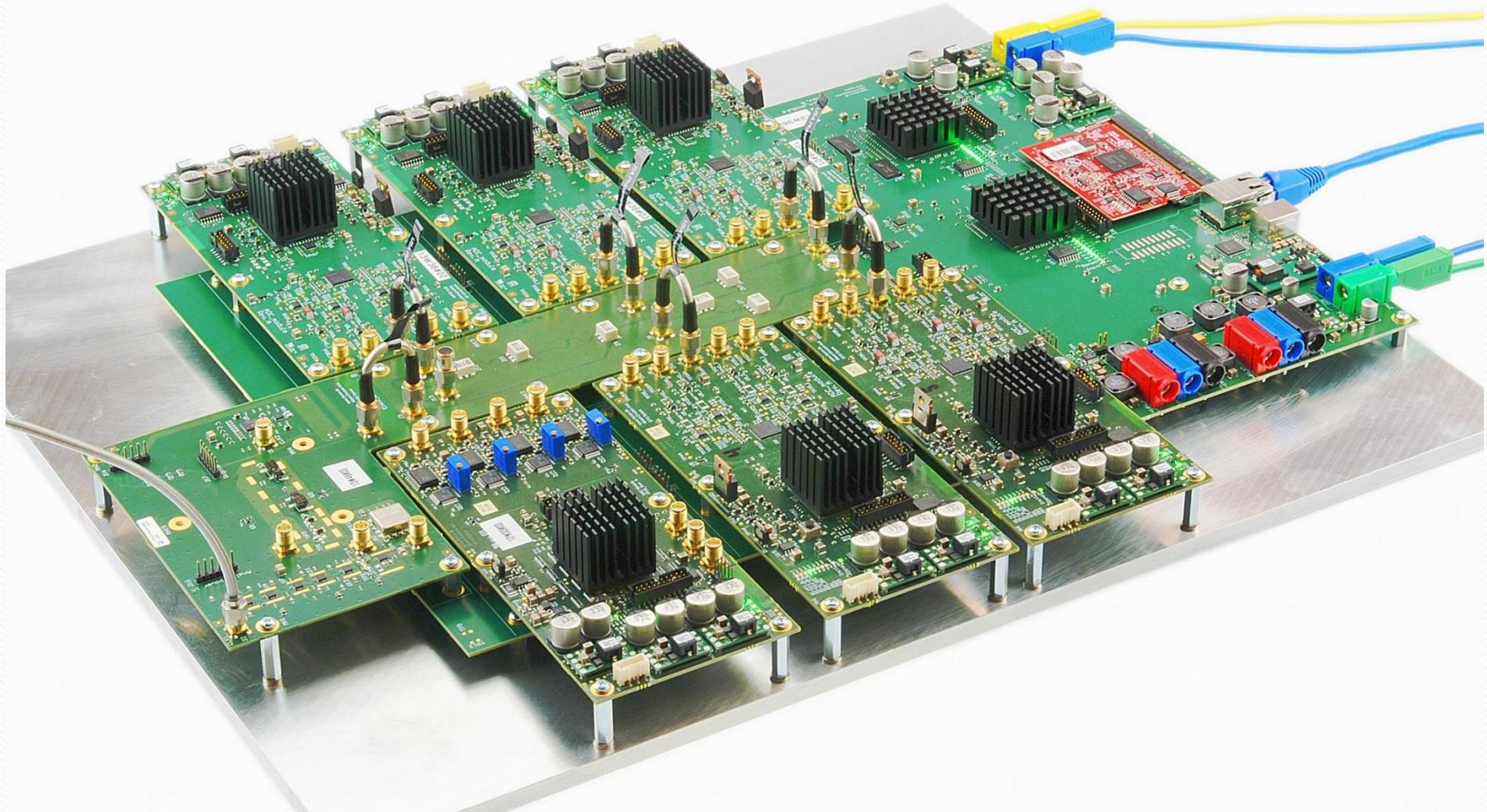


# Hardware delivery August 2012



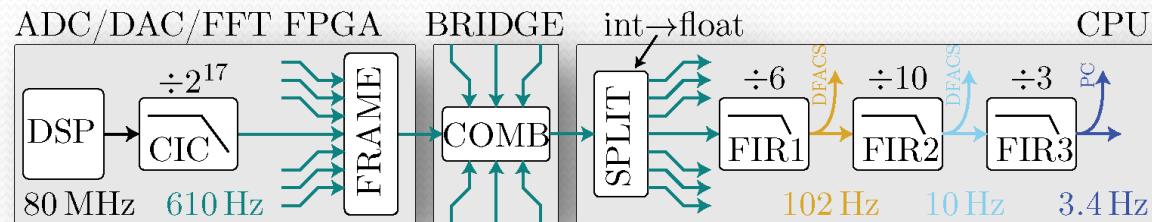
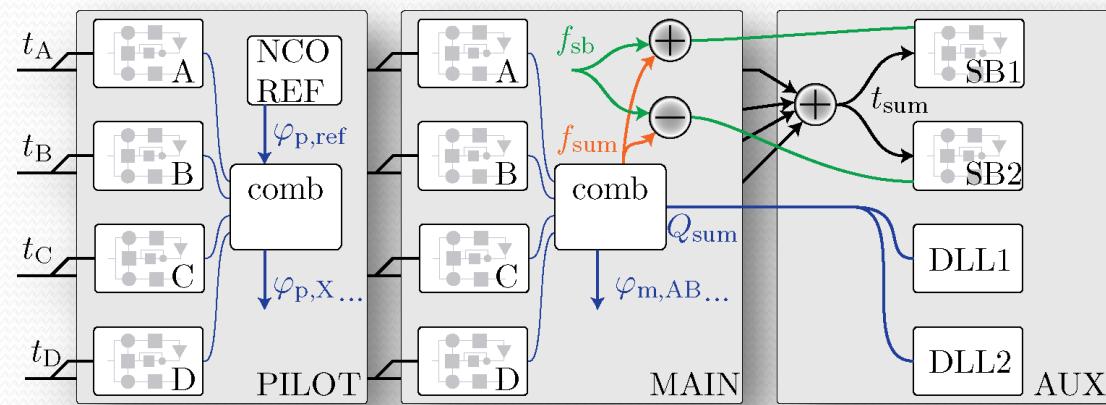
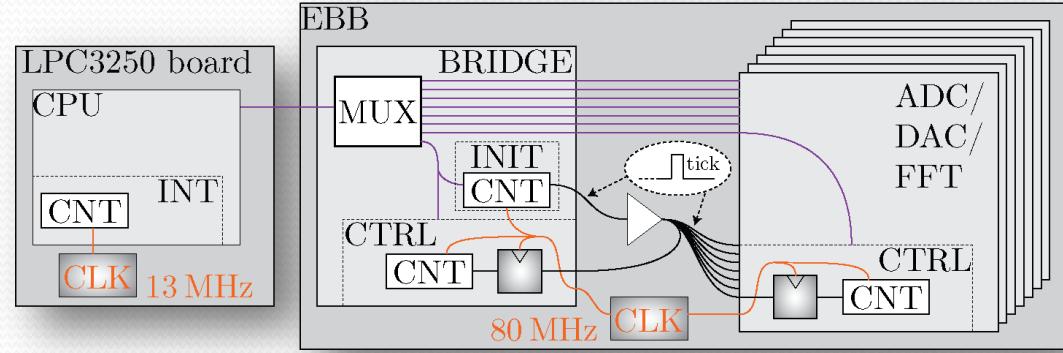


# The phasemeter



# Algorithm implementation

- FPGA synchronisation
- Interfaces  
(FPGAs, CPU, PC)
- PLLs
- DLLs
- Decimation filters  
(CIC, FIR)
- FFTs
- Data storage
- System control
- Laser control

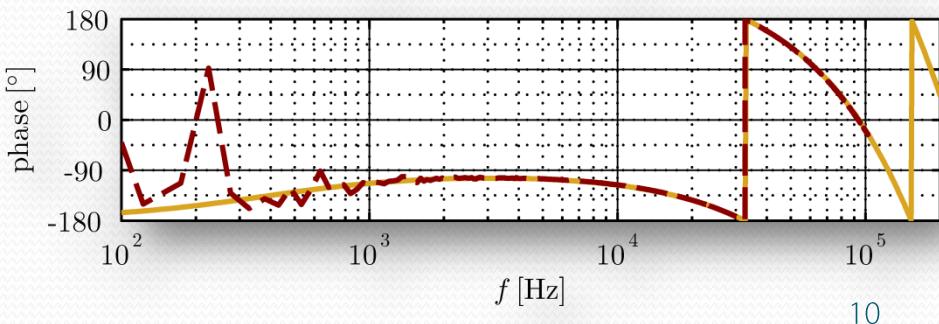
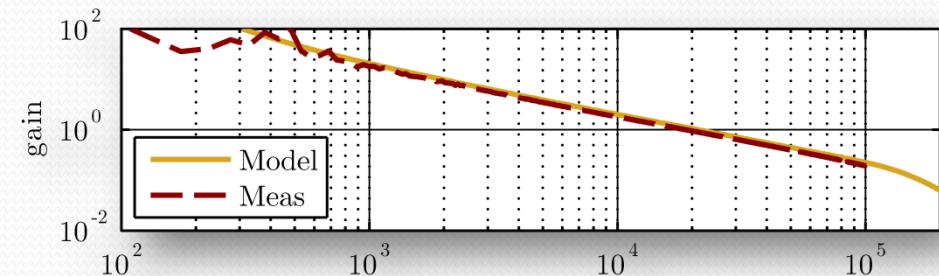
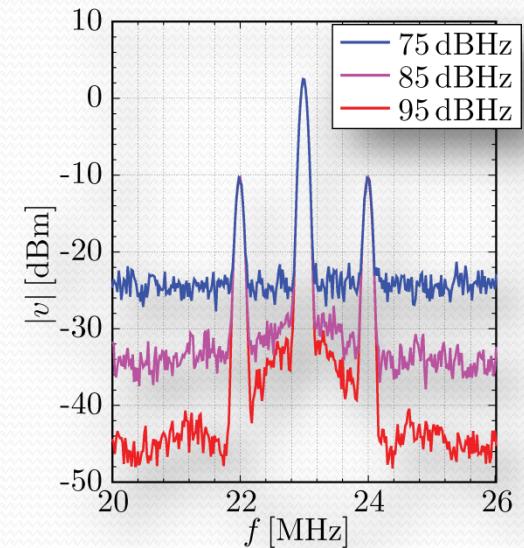




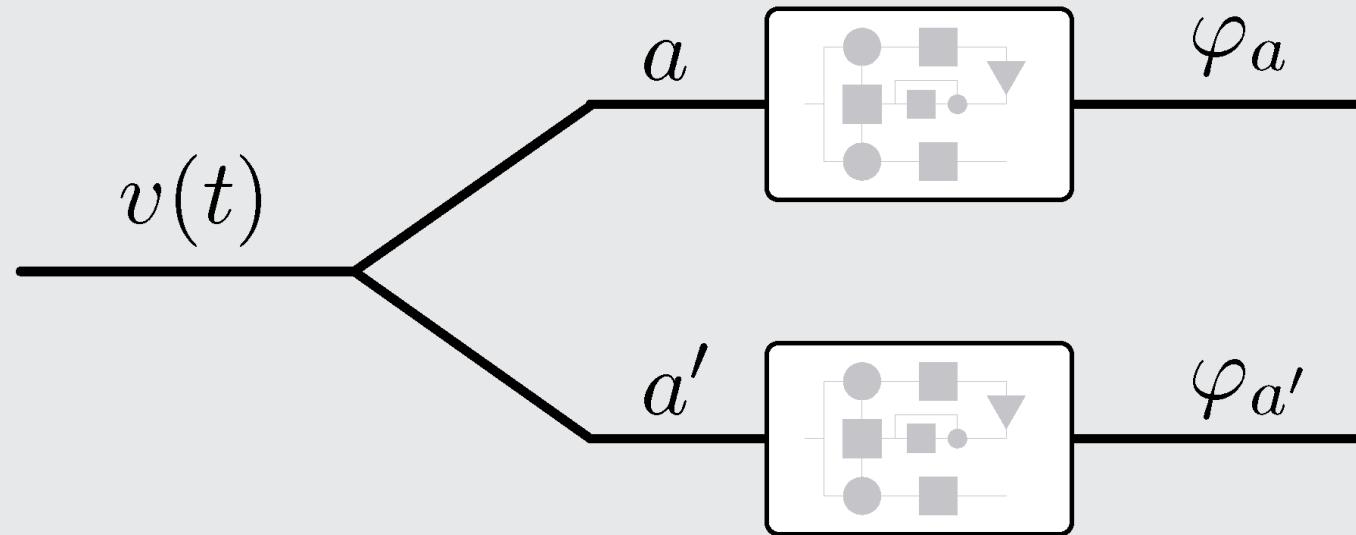
# Test campaign

Only electronic signals:

- Phase readout performance (with realistic signals)
- Ranging
- DWS readout for DFACS
- Laser control
- Generation of PRN codes
- Acquisition
- Phase stability of Frequency Distribution System



# Split measurement concept



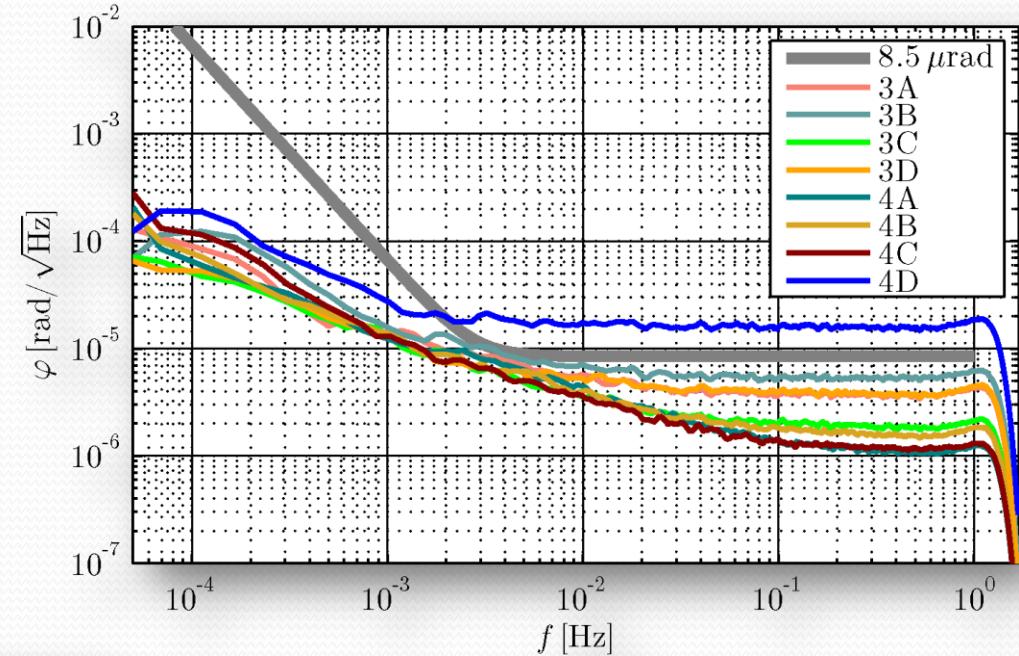
$$a = a'$$

$$\varphi_a - \varphi_{a'} \approx 0$$

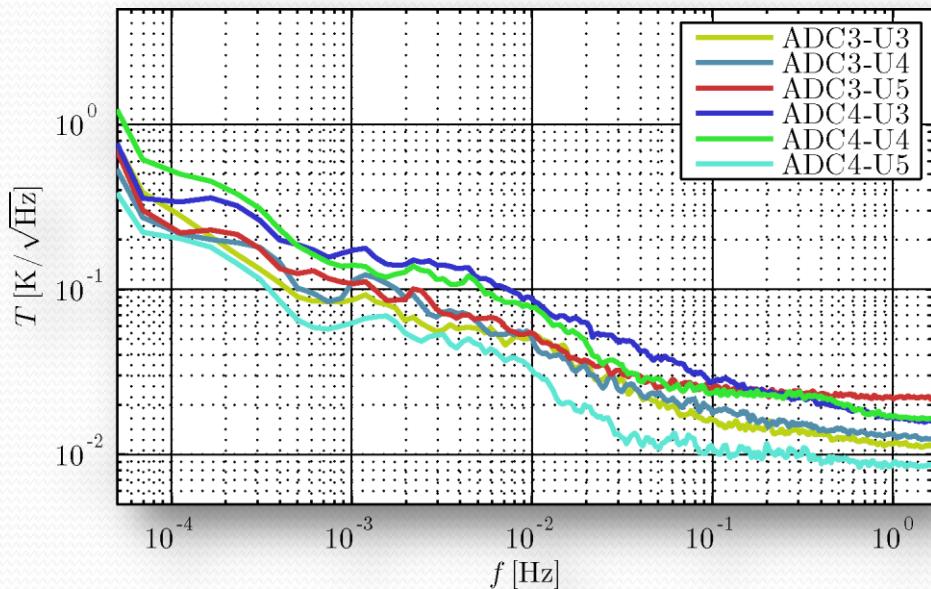


# Phase performance

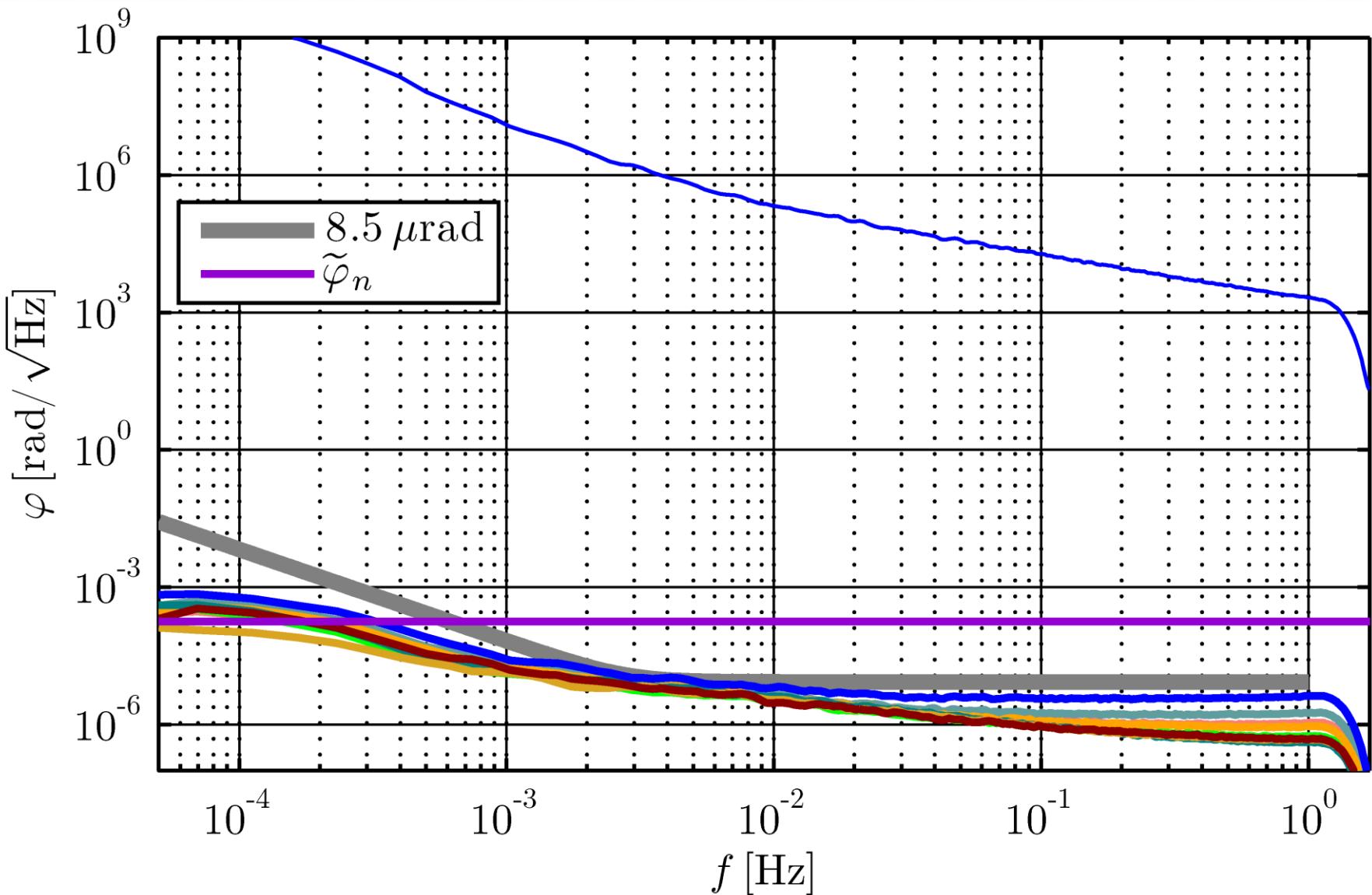
- Required active temperature control
- Unknown noise coupling related to impedance matching



- Realistic LISA-like input signal
- $f = 25 \text{ MHz}$
- Frequency, and shot noise
- Sidebands
- PRN phase modulations



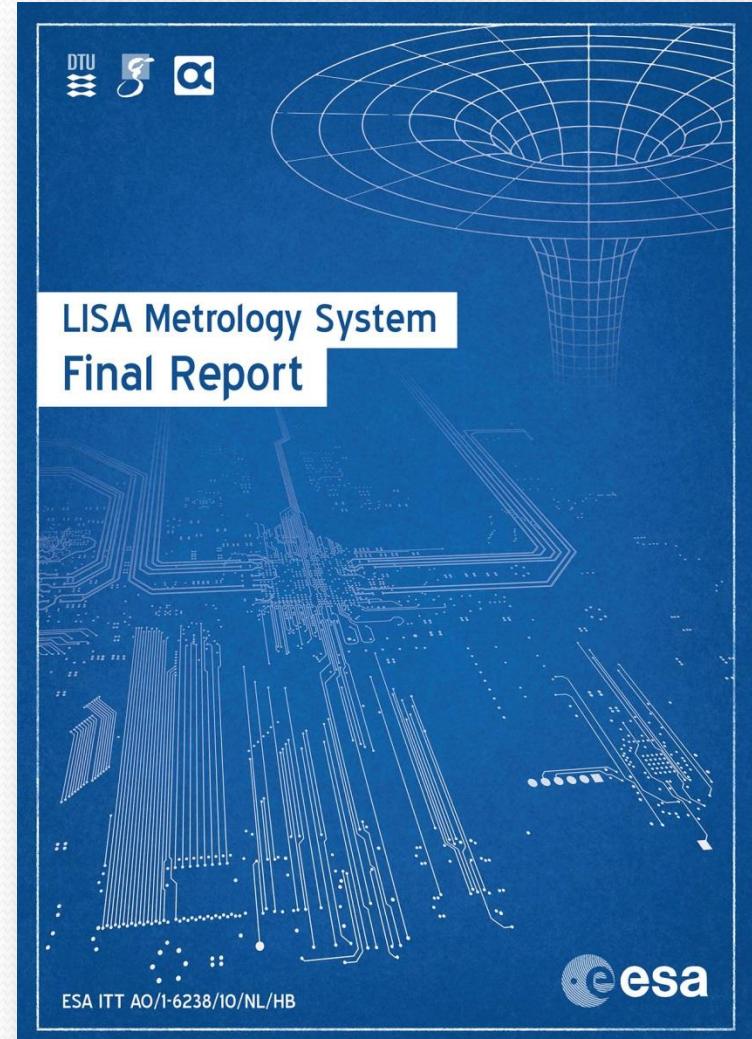
# Performance in perspective





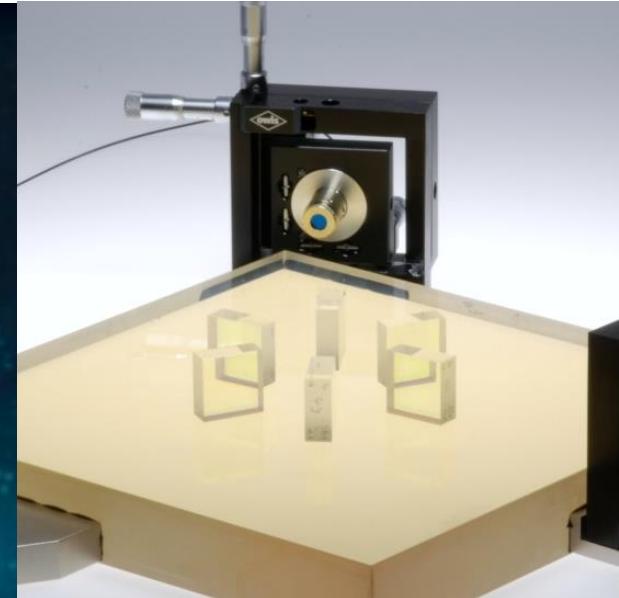
# Project finished

- Test campaign successfull
  - All functionalities were demonstrated
  - Met all requirements
- Project was concluded with final presentation on March 7, 2014.
- Final report will be available soon



# The Optical Testbed

The ultimate metrology test with three signals



[facebook.com/  
LISAscience](https://facebook.com/LISAscience)



[@LISAscience](https://twitter.com/LISAscience)



[google.com/  
+LisaMissionOrg](https://google.com/+LisaMissionOrg)

[www.elisascience.org](http://www.elisascience.org)



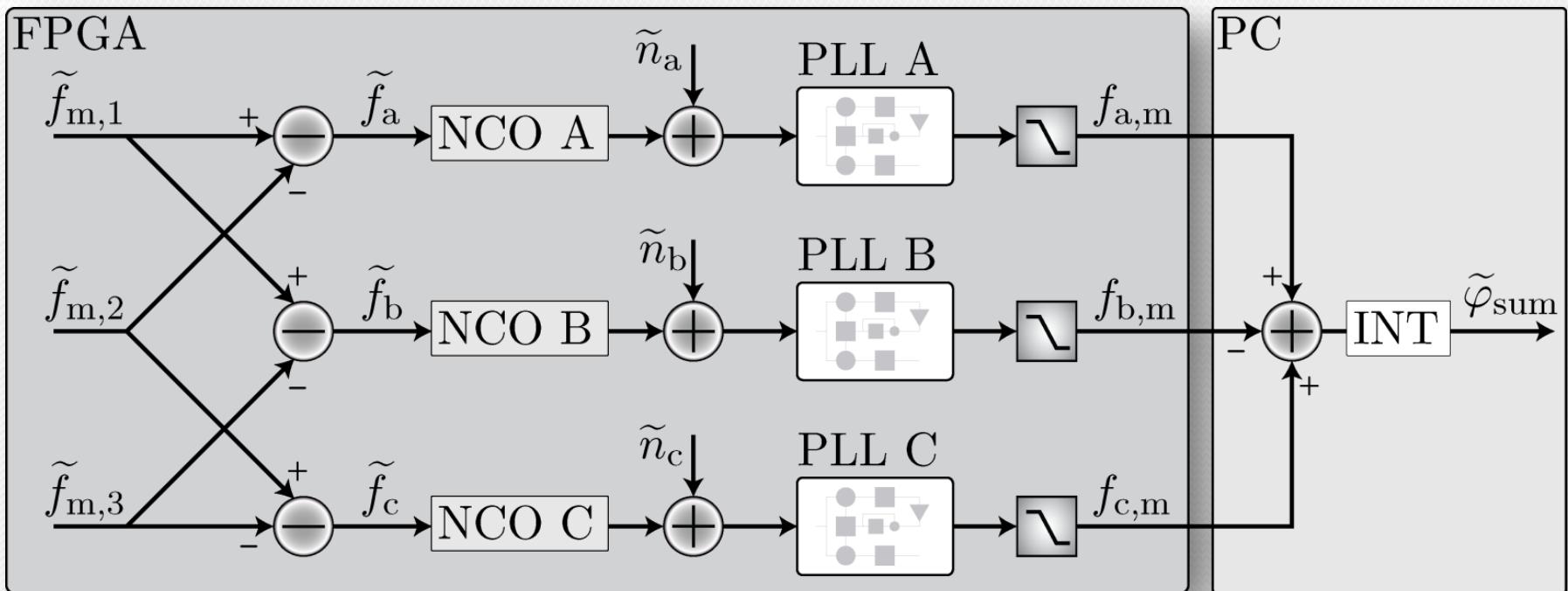
# Concept of a three signal test

$$a \neq b \neq c$$

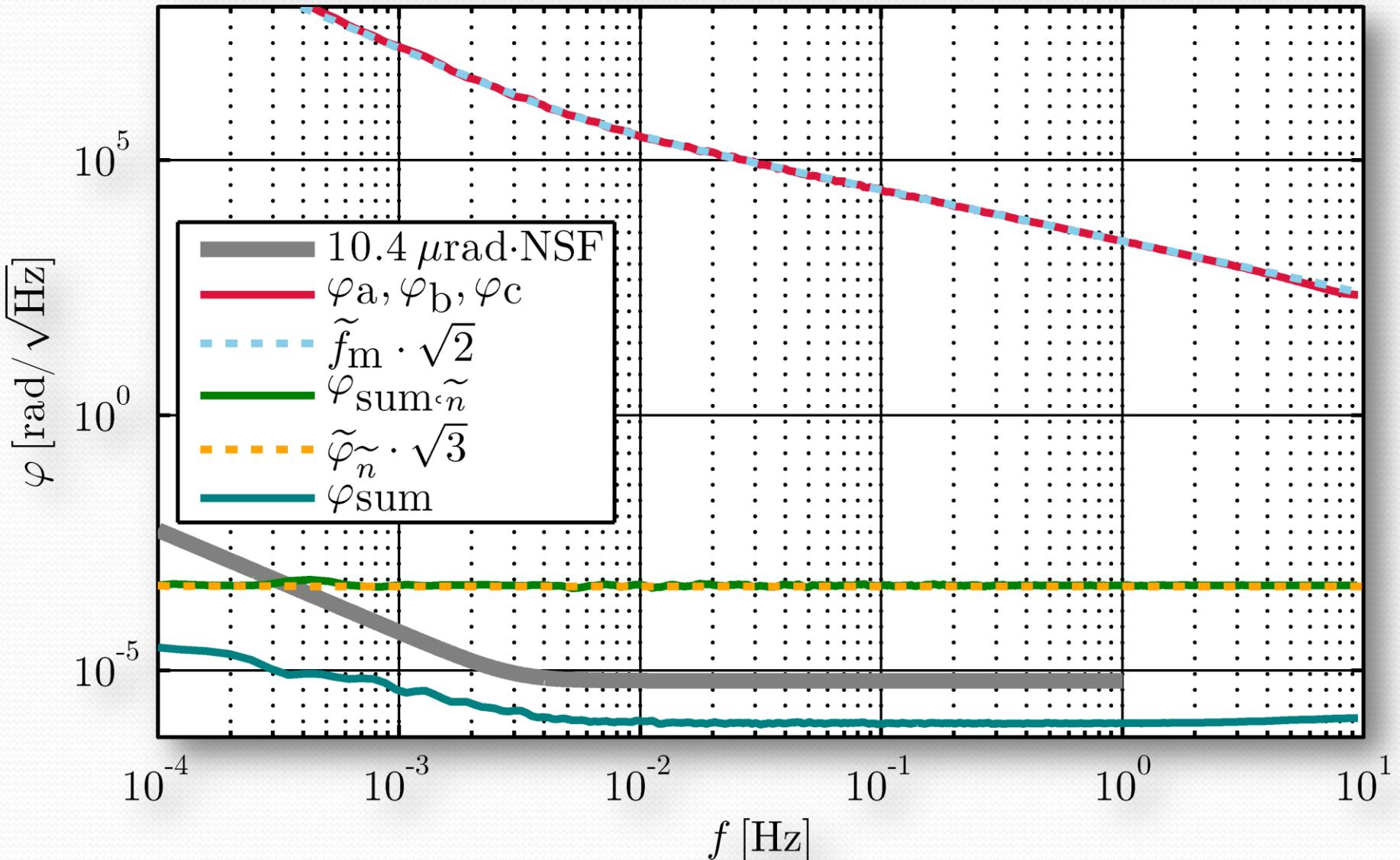
$$\varphi_a + \varphi_b + \varphi_c \approx 0$$

- The LISA phase measurement has a very large dynamic range due to the high initial laser frequency noise
- A three signal test is required to investigate non-linear noise sources that are relevant at such levels

# Digital three signal test

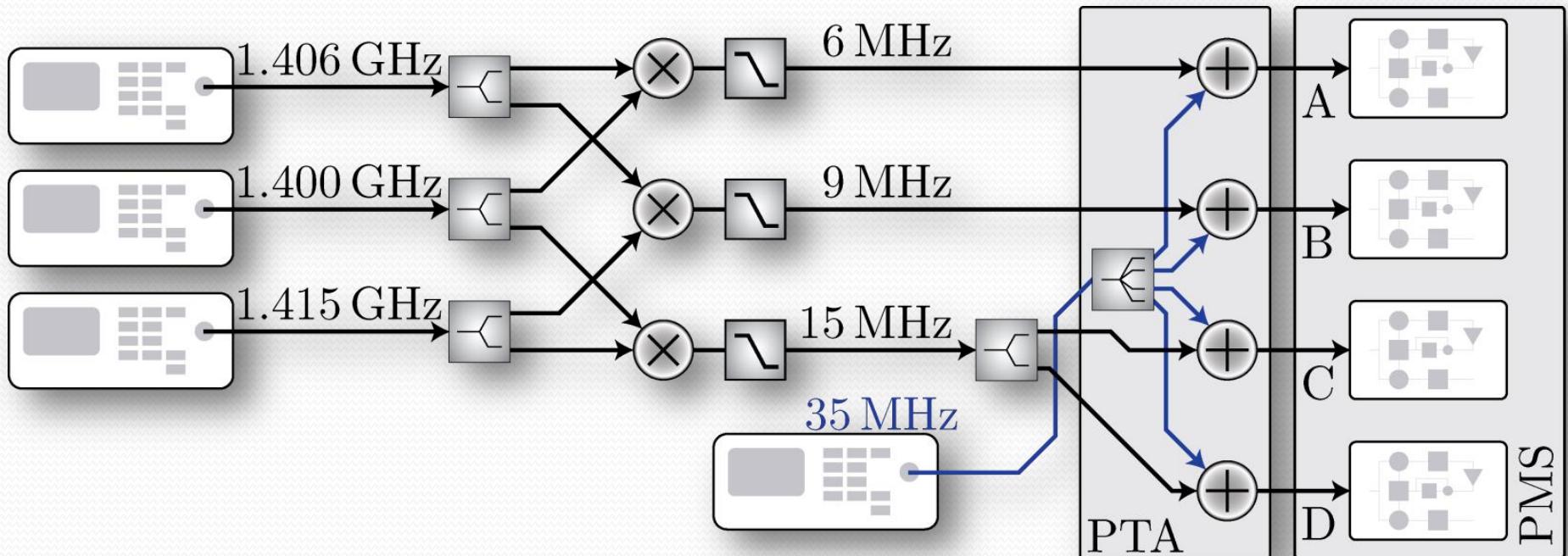


# Digital three signal test: results

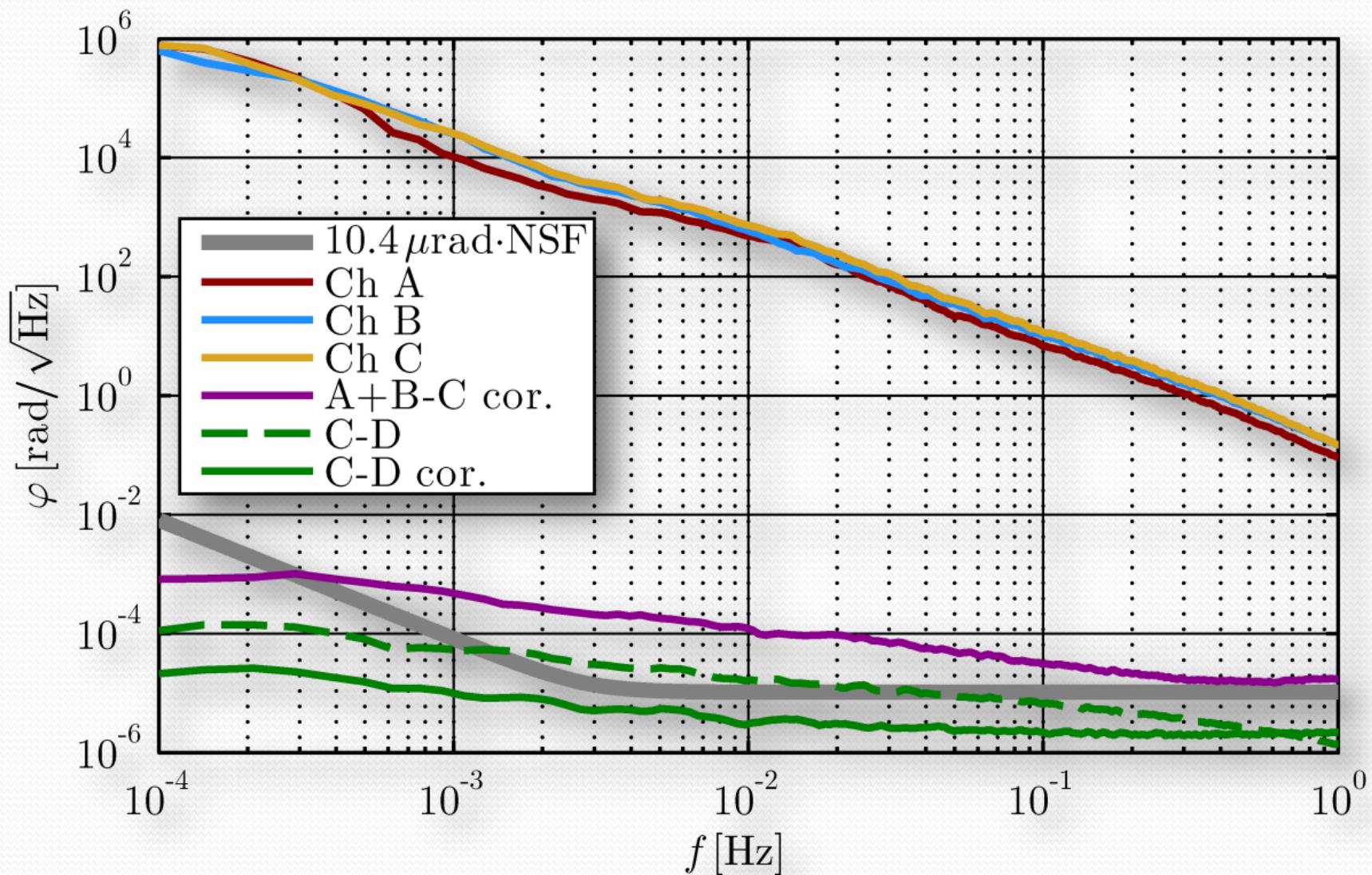




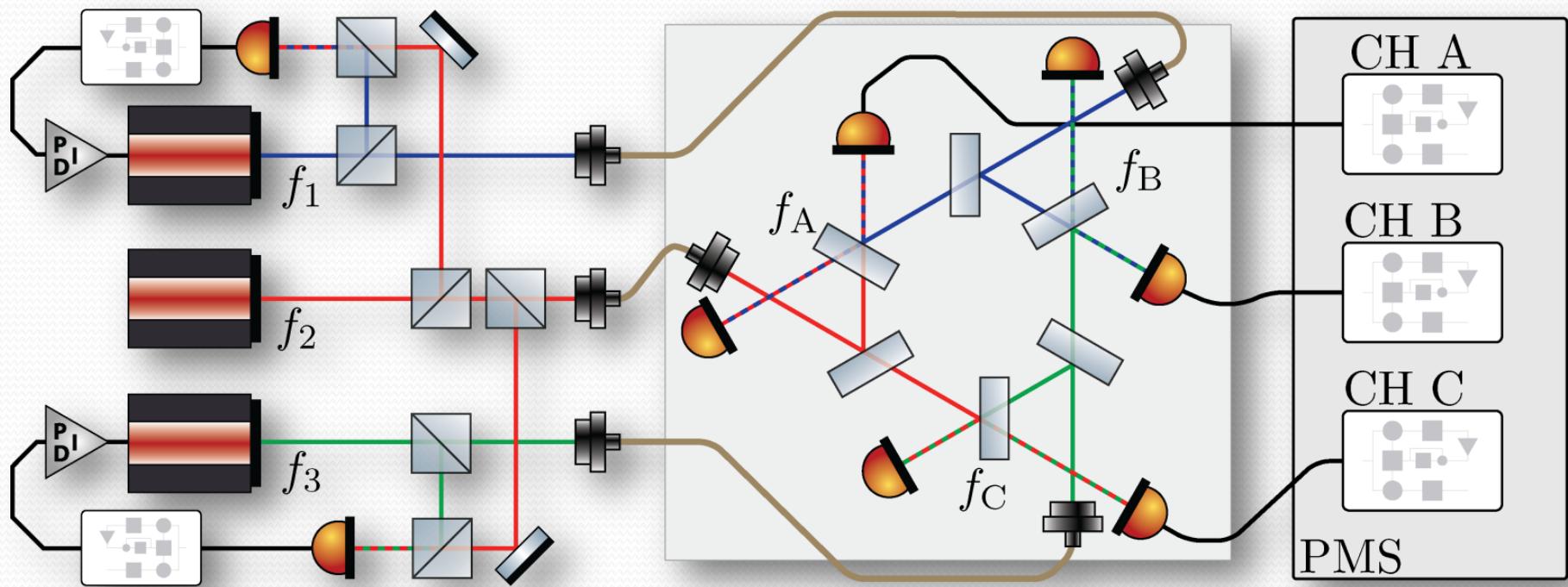
# Analogue three signal test



# Analogue three signal test: results

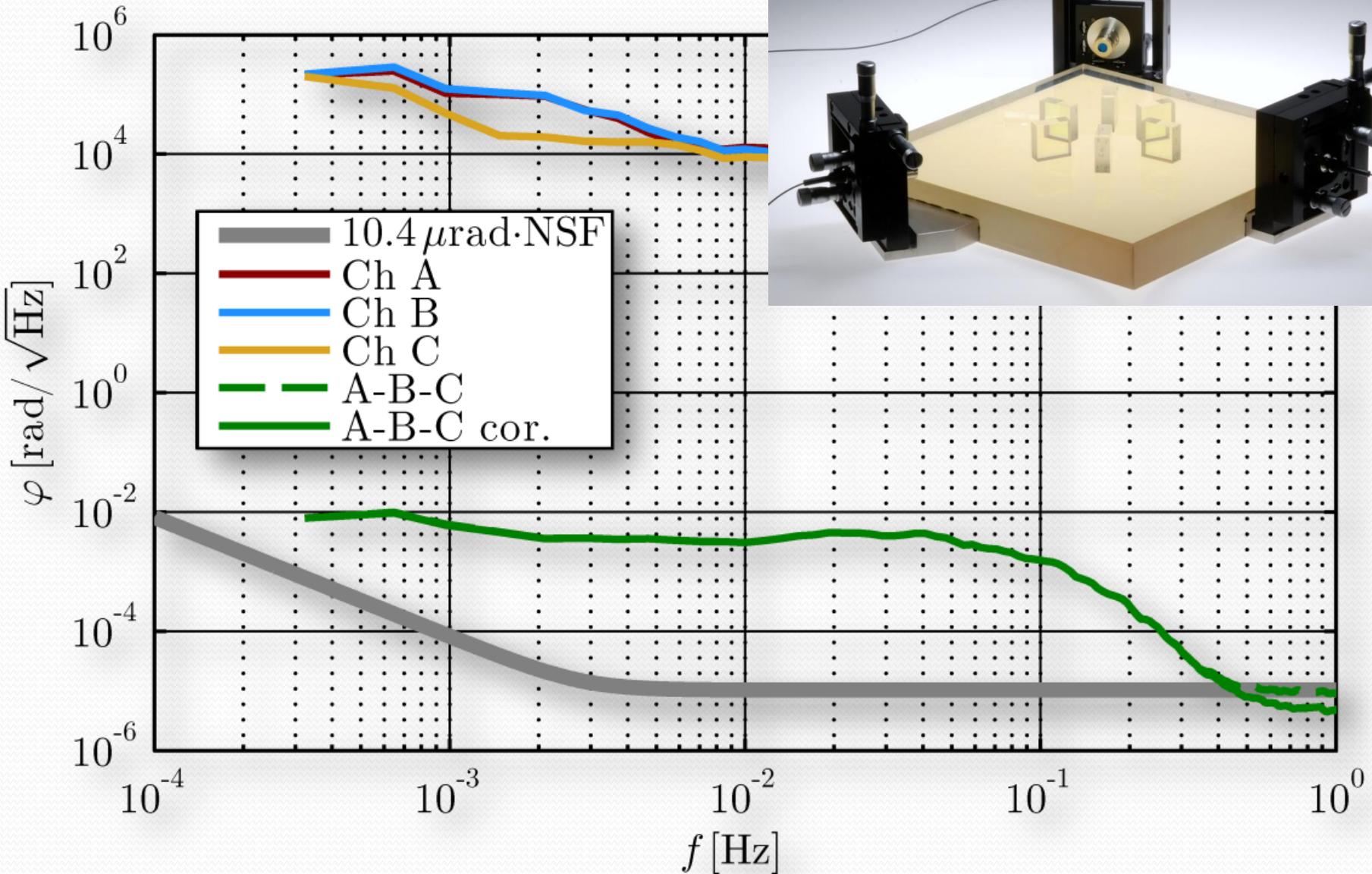


# Optical three signal test



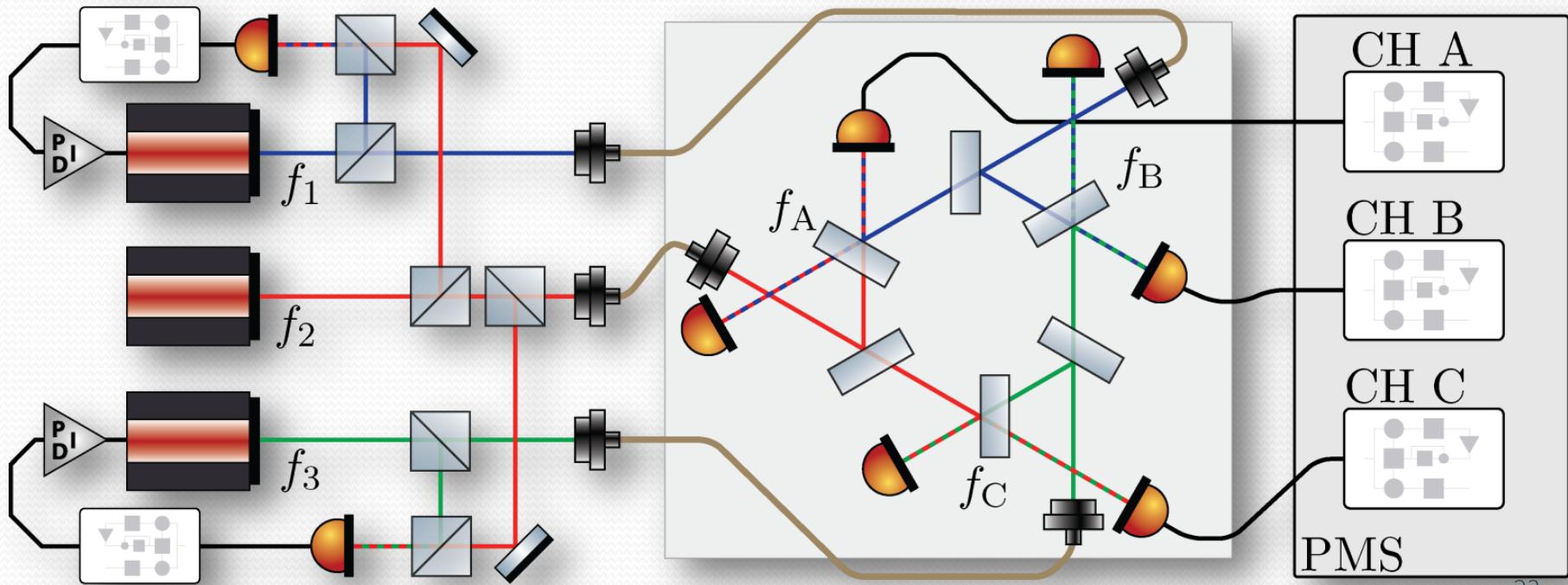


# Optical three signal test: first results



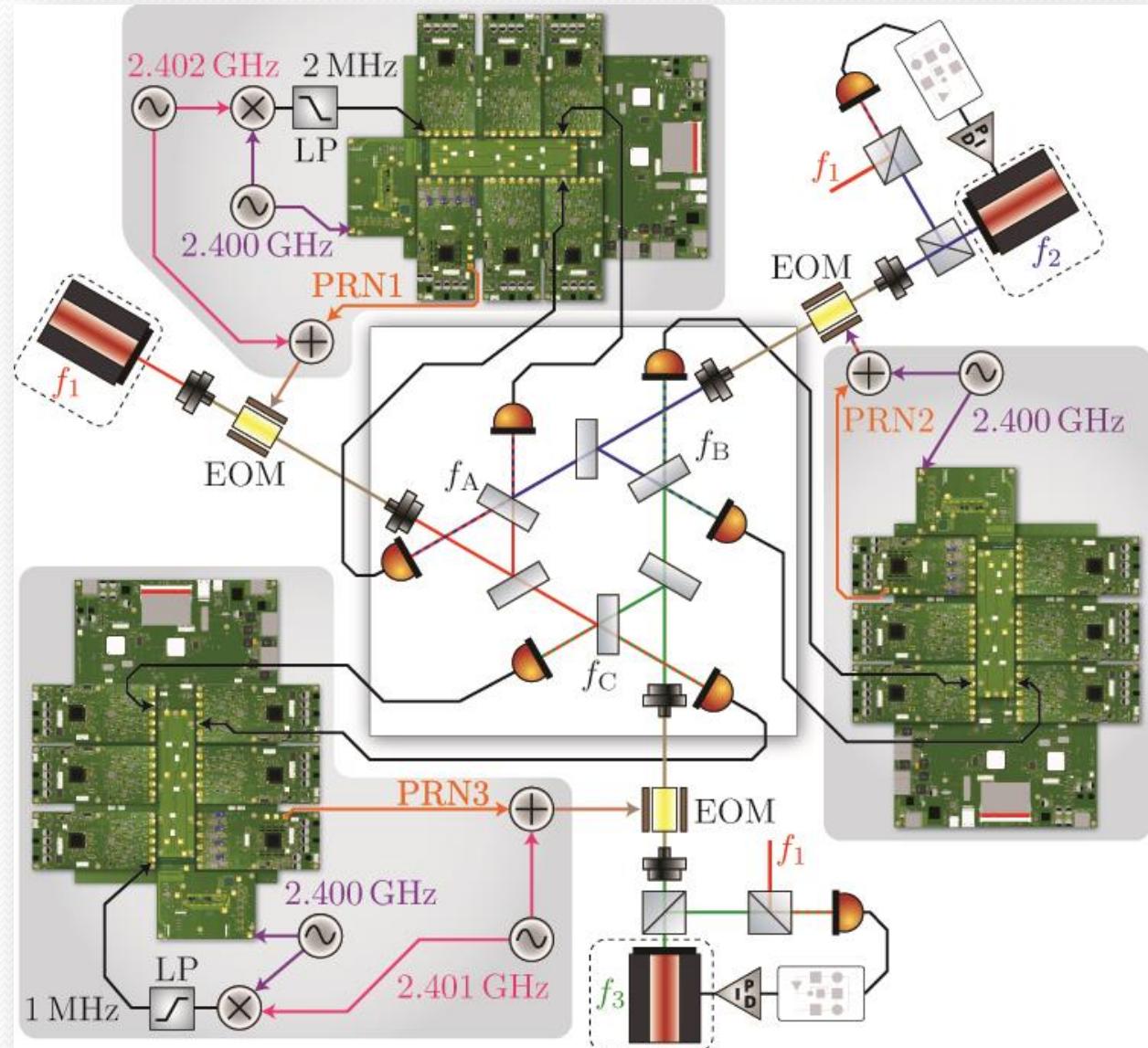
# Hexagon IFO: The next steps

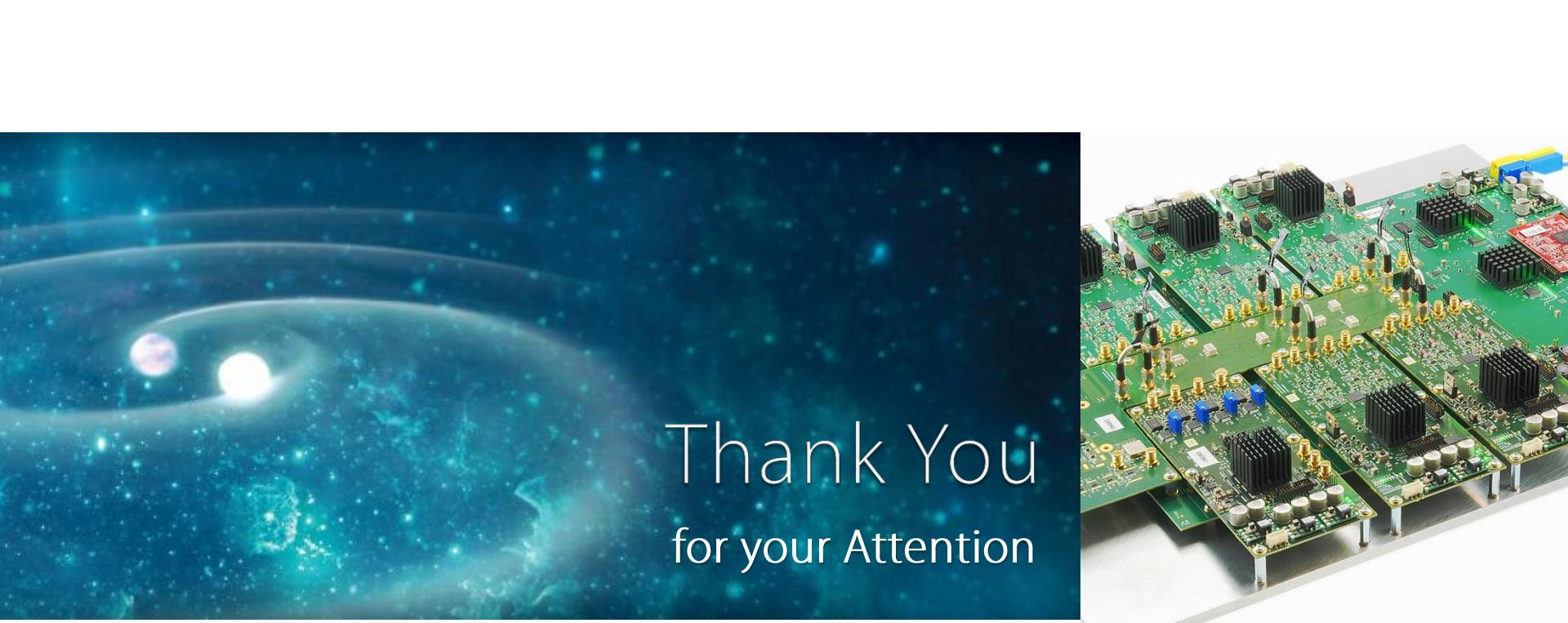
- Go to vacuum
- Monolithic fibre injectors to reduce beam jitter
- ESA phasemeter breadboard
- Dedicated photoreceivers (see poster #16 by Germán Fernández Barranco)



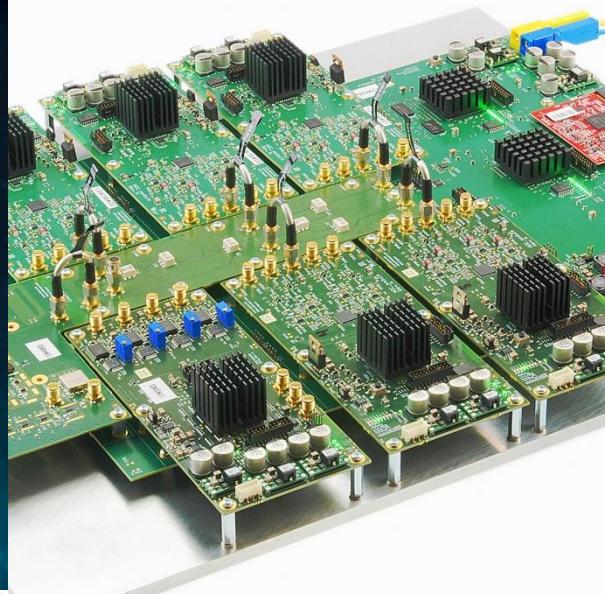
# Hexagon IFO: The Goal

- 1) Achieve urad/sqrt(Hz) performance
- 2) Achieve performance with three independent phasemeters
  - Clock noise transfer
  - Ranging & data communication
  - Timing correction in post-processing via Kalman-Filter
  - Demonstration of all functionalities and the full dynamic range required for TDI
- 3) Testbed for all metrology sensitiv components





# Thank You for your Attention



Centre for Quantum Engineering  
and Space-Time Research



Leibniz Universität Hannover  
Germany



Axcon ApS  
Lyngby, Denmark



European Space Agency  
ESA



National Space Institute  
Denmark



Max Planck Society  
Germany



[facebook.com/  
LISAscience](https://facebook.com/LISAscience)



[twitter.com/  
LISAscience](https://twitter.com/LISAscience)



[google.com/  
+LisaMissionOrg](https://google.com/+LisaMissionOrg)

[www.elisascience.org](http://www.elisascience.org)