Laser systems for LISA and its precursor mission LISA Pathfinder

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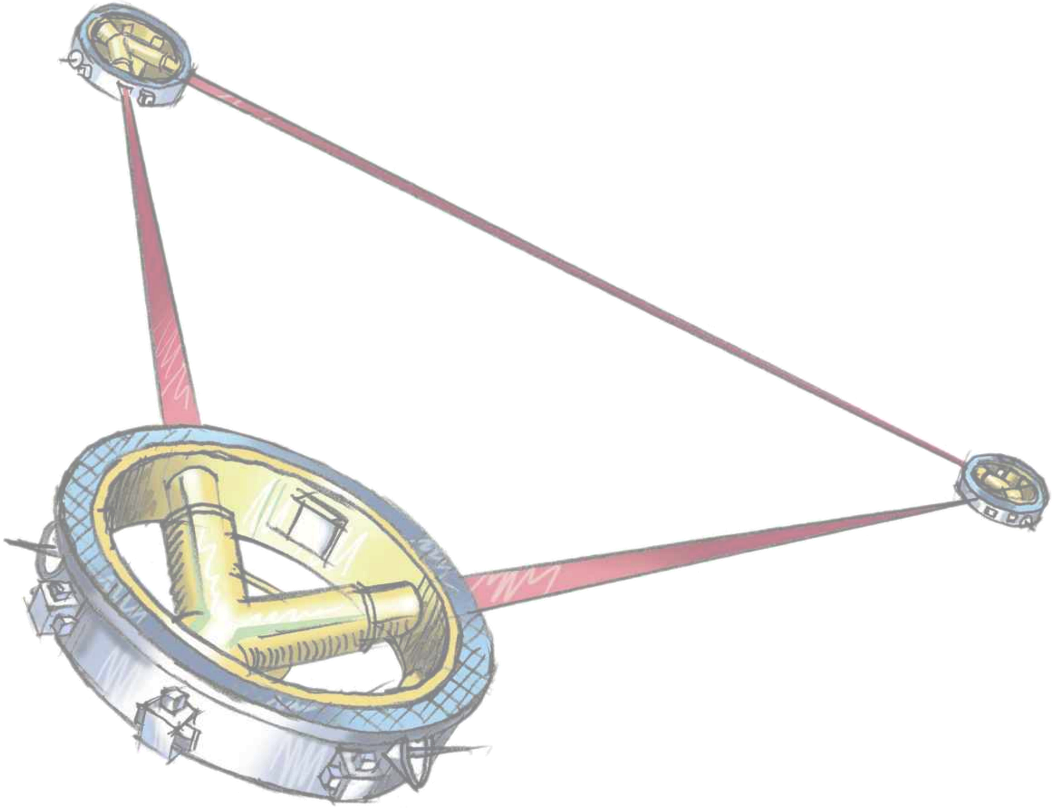
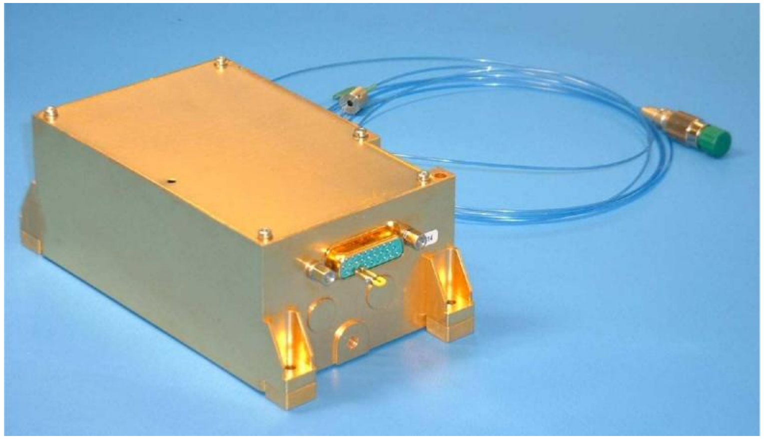


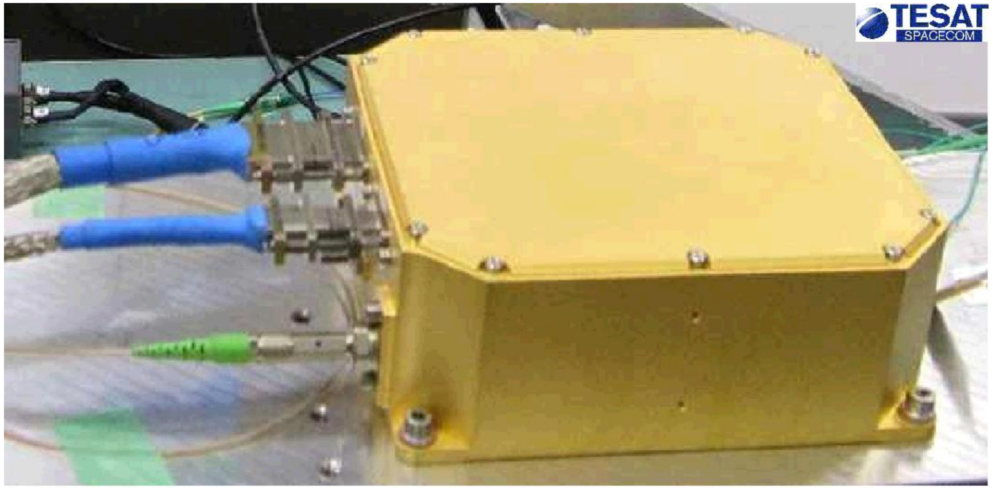
Lasers for LISA Pathfinder

breadboard model



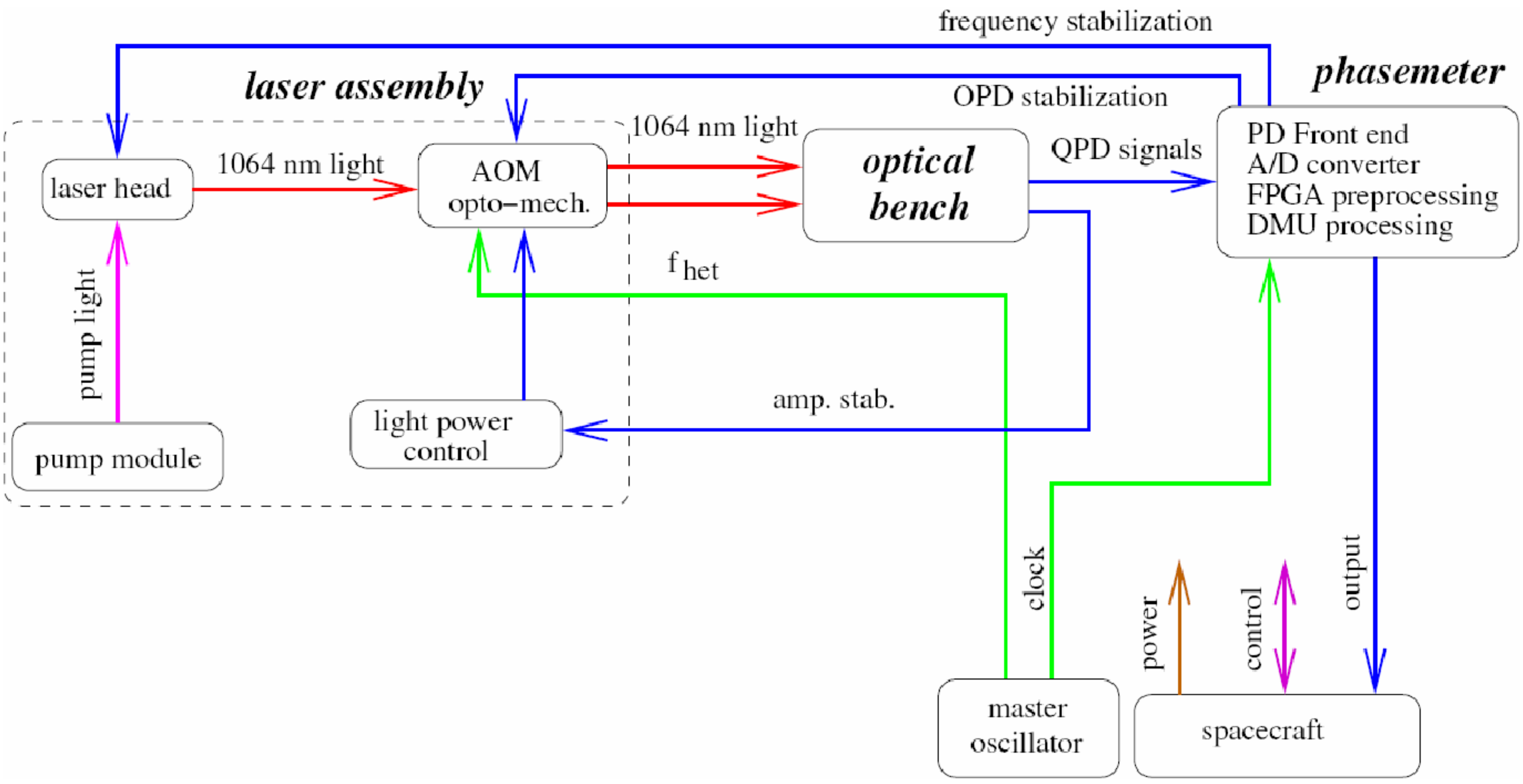
engineering model

flight model



- Lasers manufactured by Tesat Spacecom
- Flight model has space heritage already: TerraSar, NFire

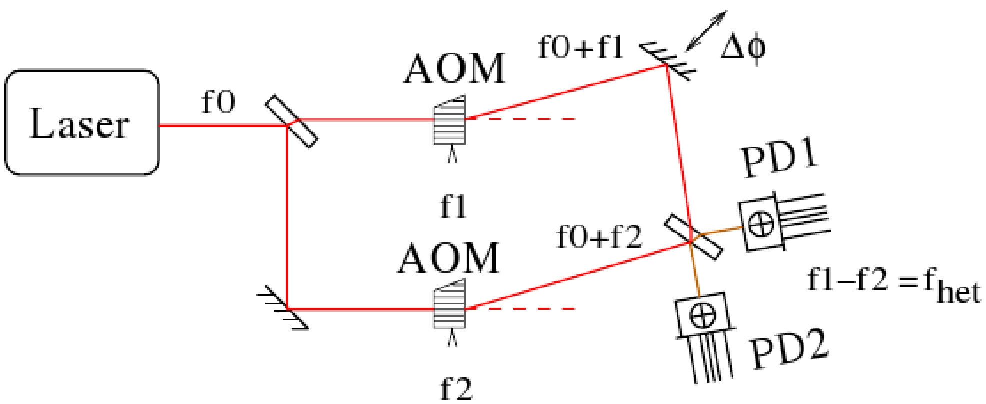
LISA Pathfinder optical metrology system

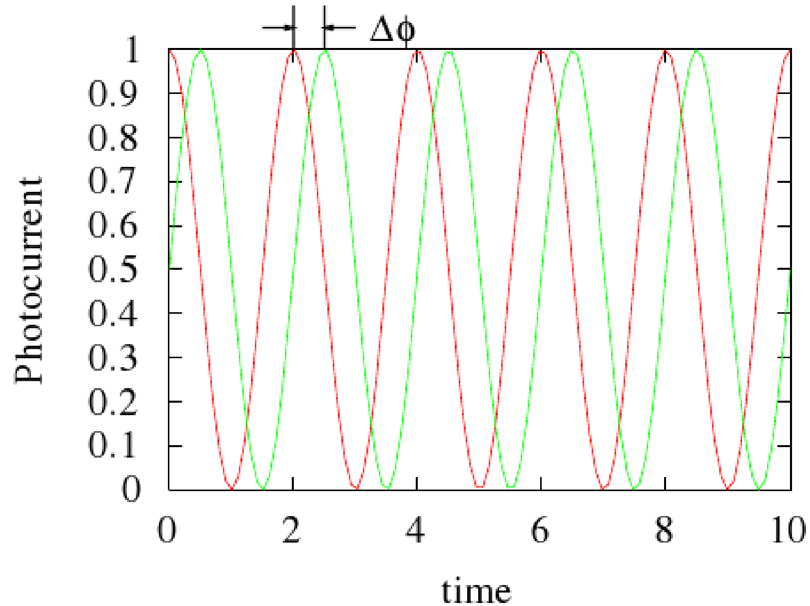


- Laser delivers light to laser modulator (LM)
- LM produces light at two frequencies to operate optical bench
- Frequency, power, optical pathlength difference stabilization active

LISA Pathfinder interferometry concept

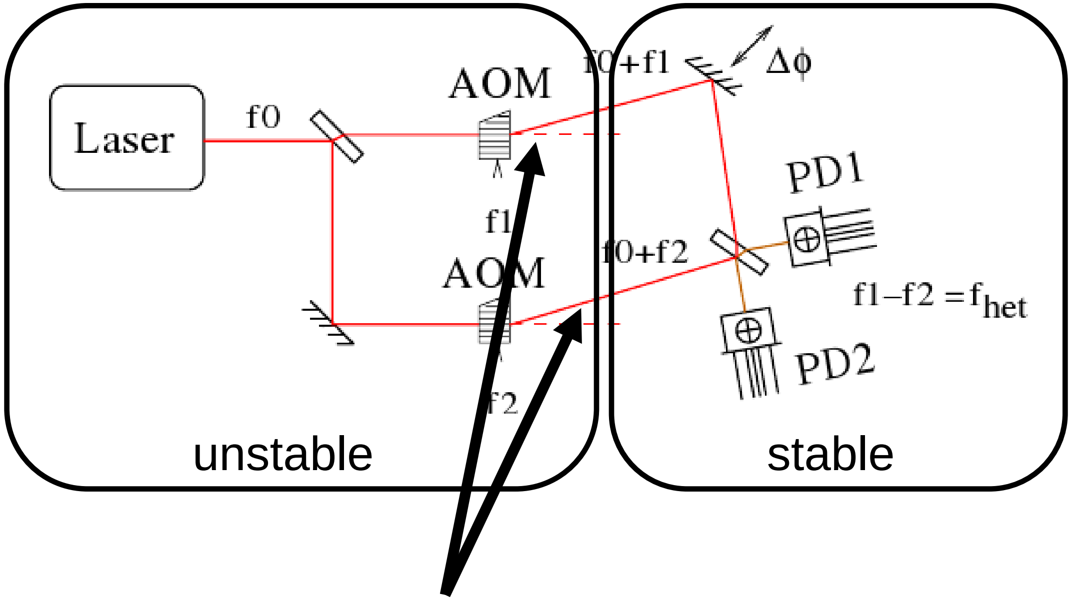
- Locking to dark fringe not possible due to large motion of test masses – no actuators available with pm accuracy
- Use heterodyne inteferometer





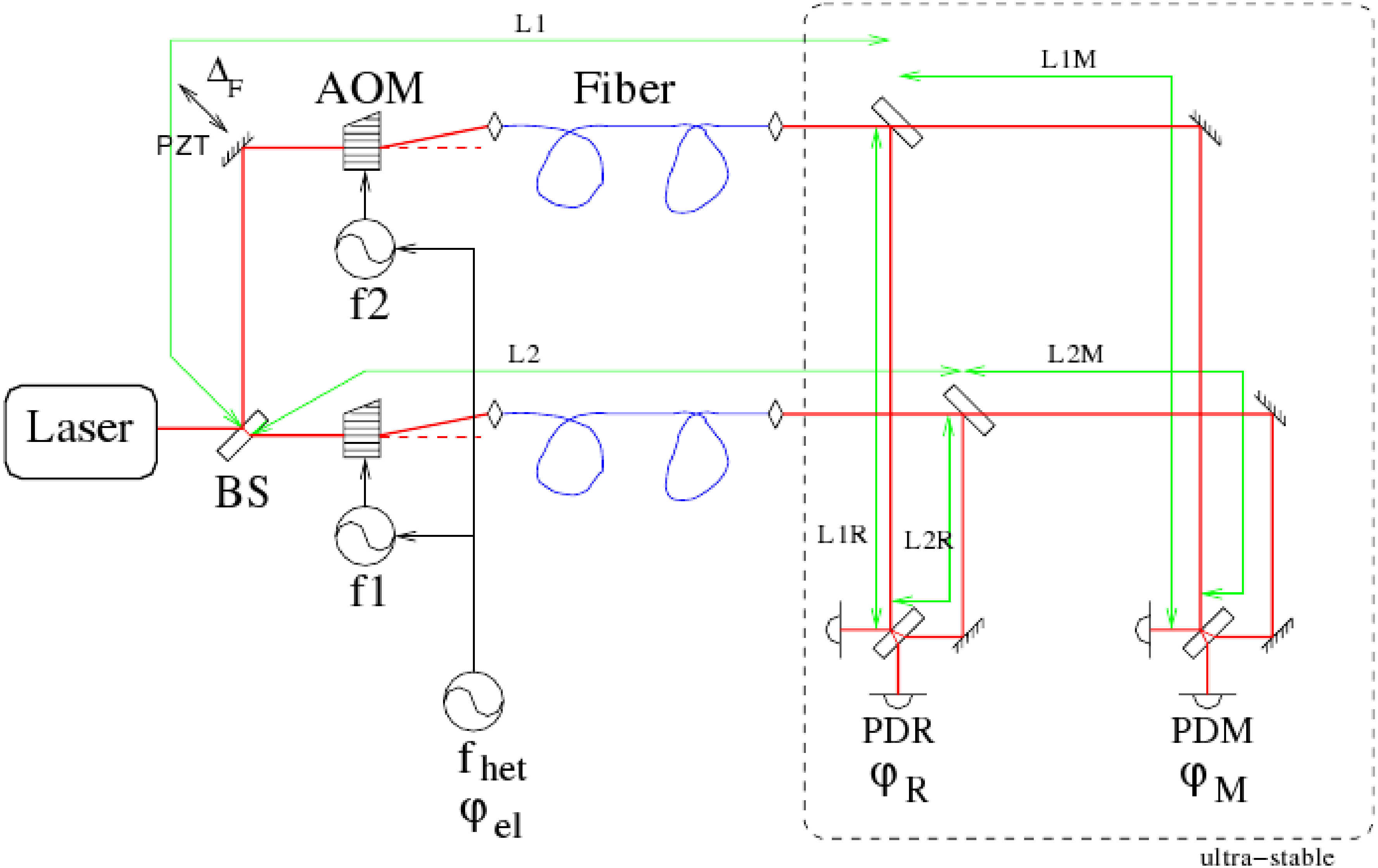
Heinzel et al. CQG vol. 20 pp. S153 (2003)

LISA Pathfinder interferometry concept



- Fibres used behind AOMs
  - as spatial mode cleaner
  - to separate AOMs from the optical bench and test masses
- reference interferometer required

LISA Pathfinder Interferometry concept



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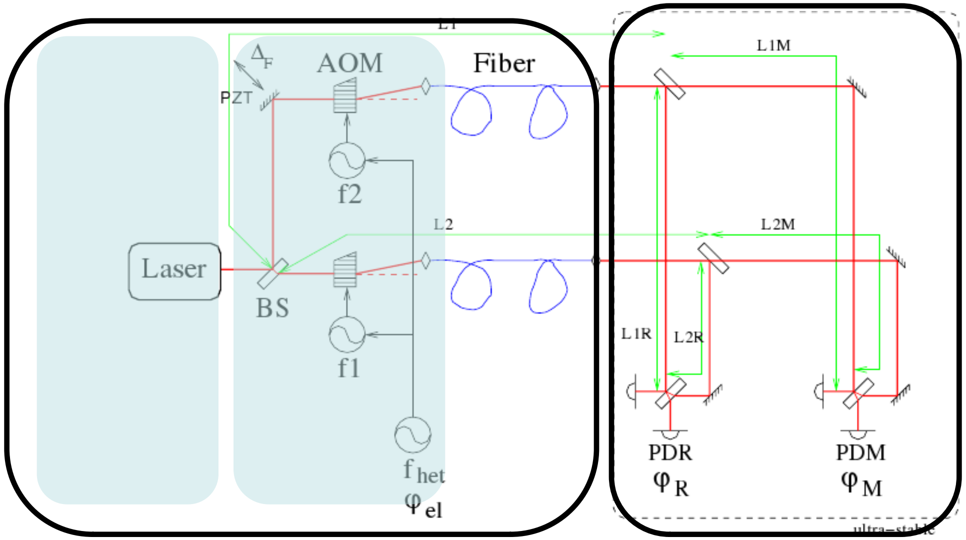
reference interferometer

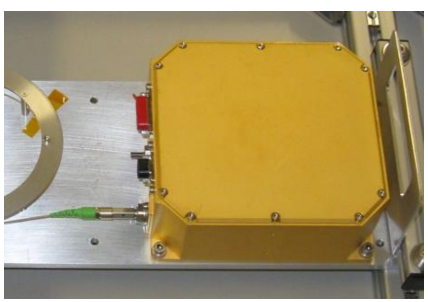
measurement interferometer

LISA Pathfinder hardware implementation

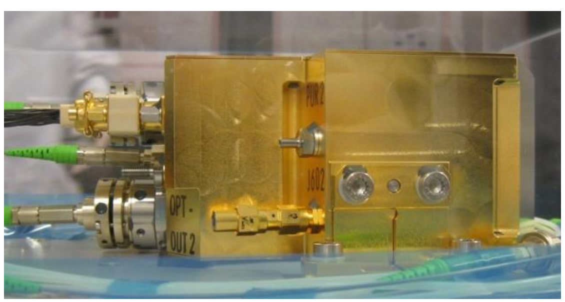
unstable



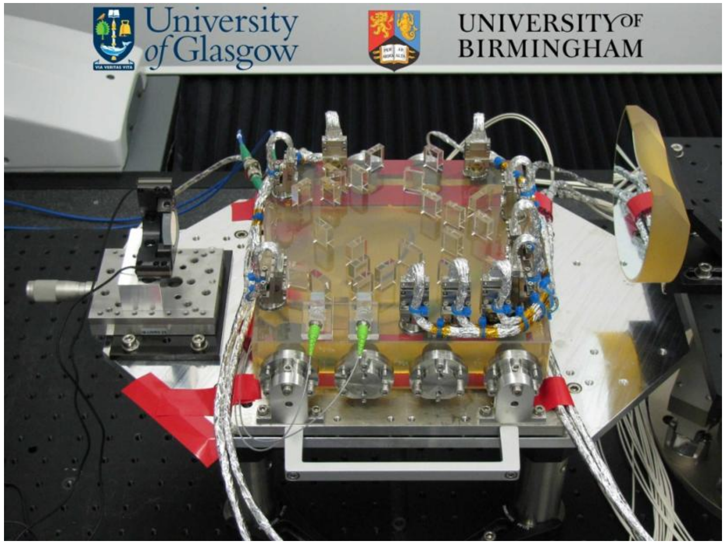
stable



Laser

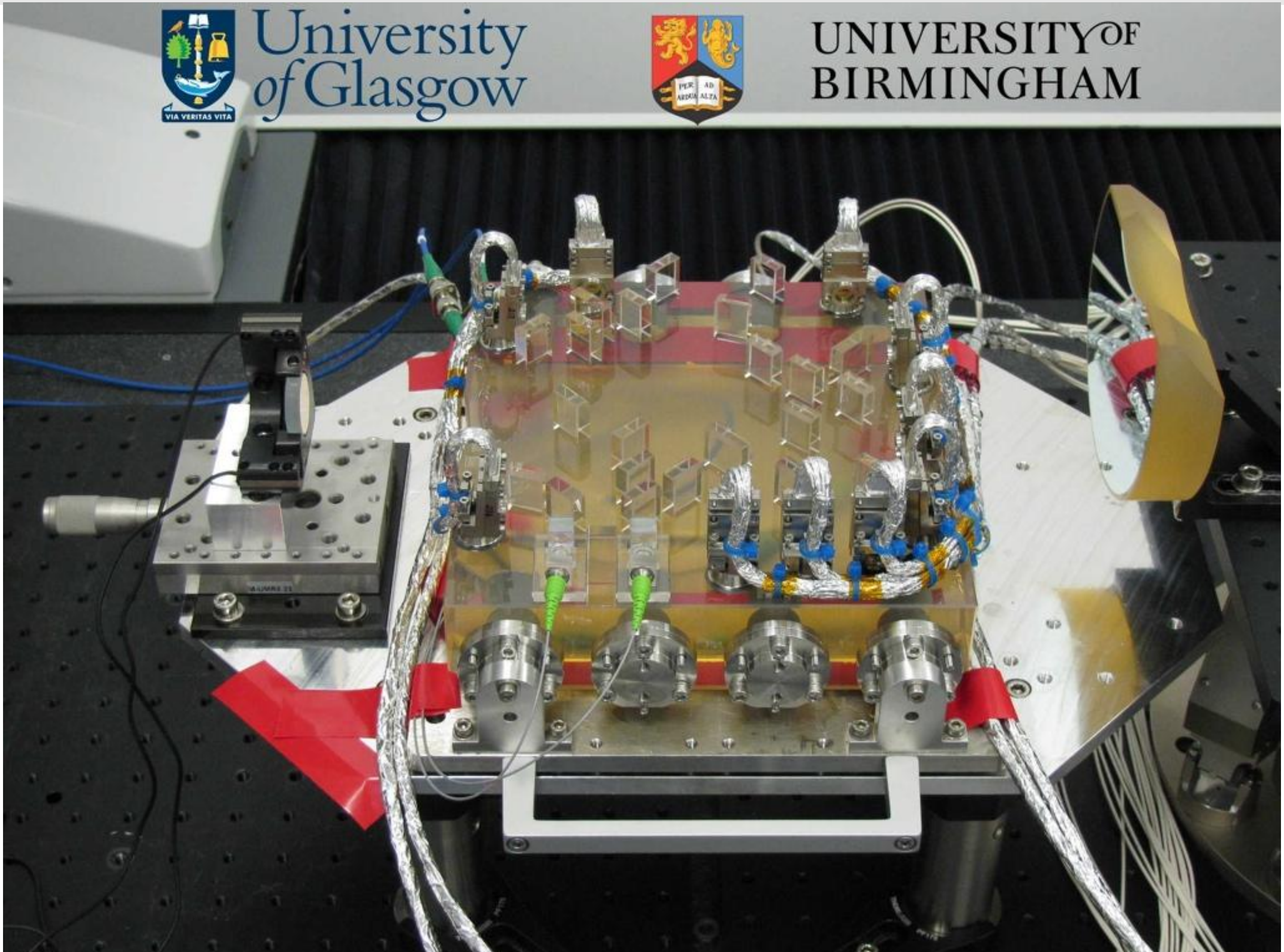


Laser modulator

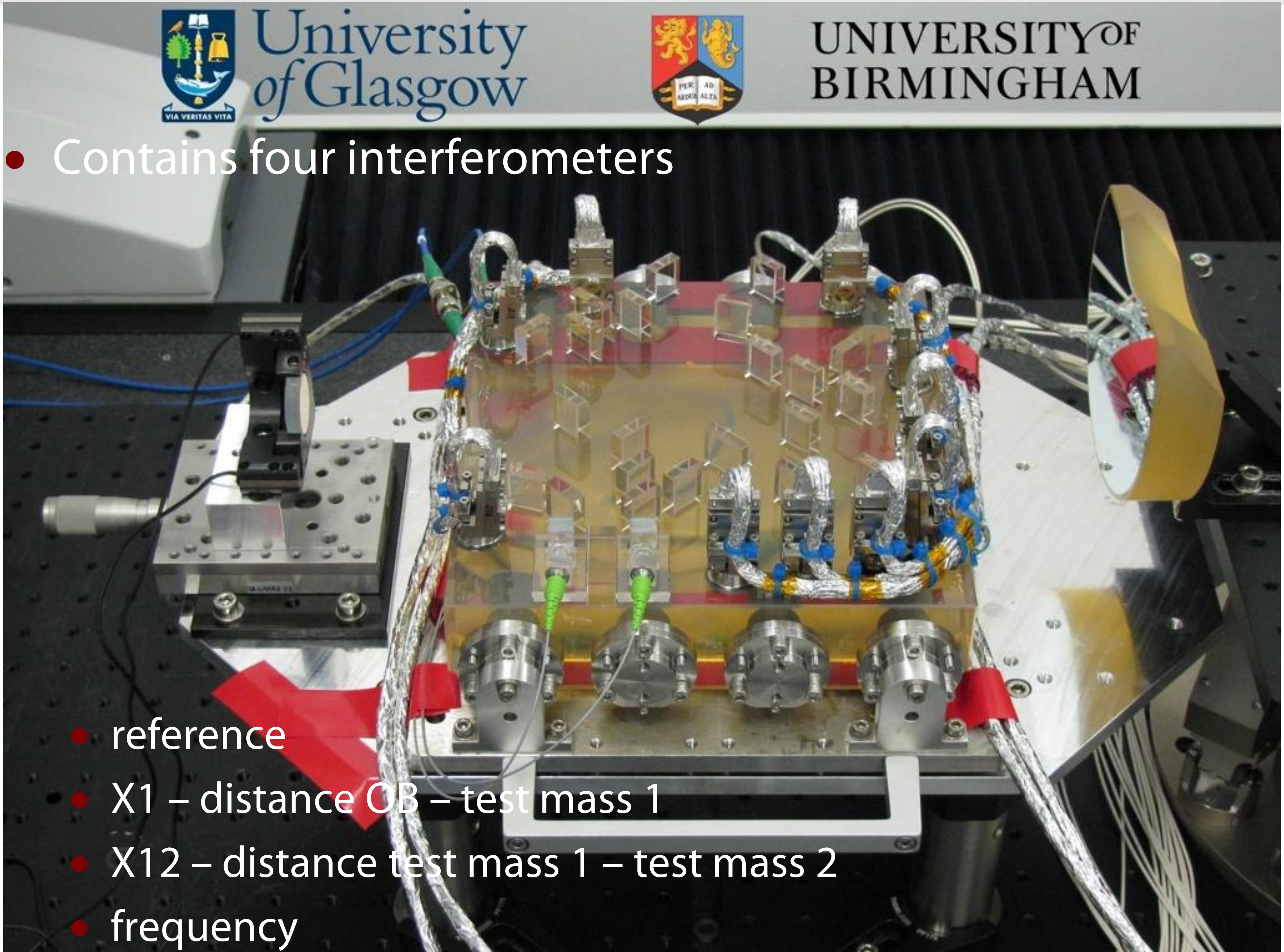


Optical bench

LISA Pathfinder optical bench PFM



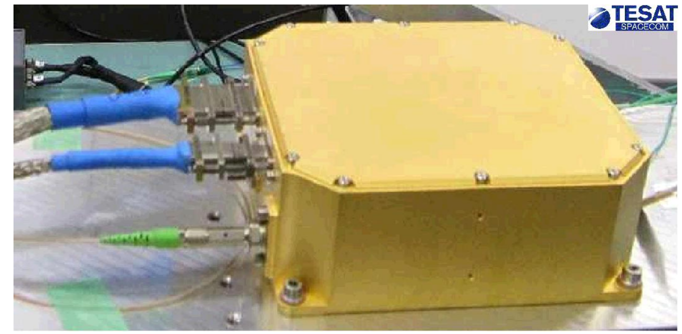
LISA Pathfinder optical bench PFM

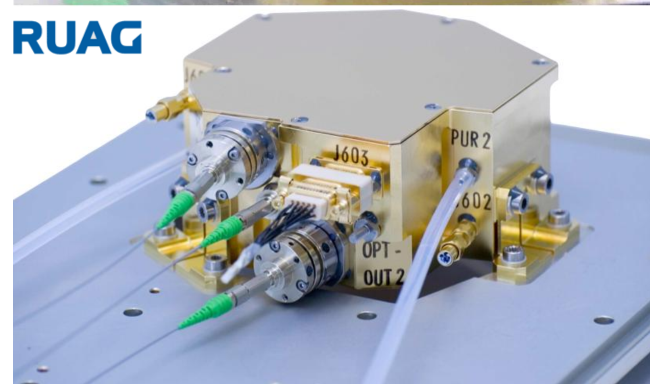


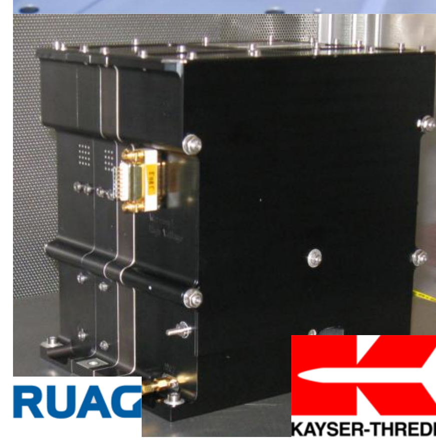
- Contains four interferometers
  - reference
  - X1 – distance OB – test mass 1
  - X12 – distance test mass 1 – test mass 2
  - frequency

Laser system for LISA Pathfinder

- Consists of
  - Reference laser unit
    - 40 mW @ 1064 nm
    - Actuators: slow power, slow and fast frequency
  - Laser modulator unit
    - Beam splitter
    - Two AOMs
    - Two optical pathlength actuators
  - Laser control unit
    - Power supply
    - actuates frequency, power, OPD

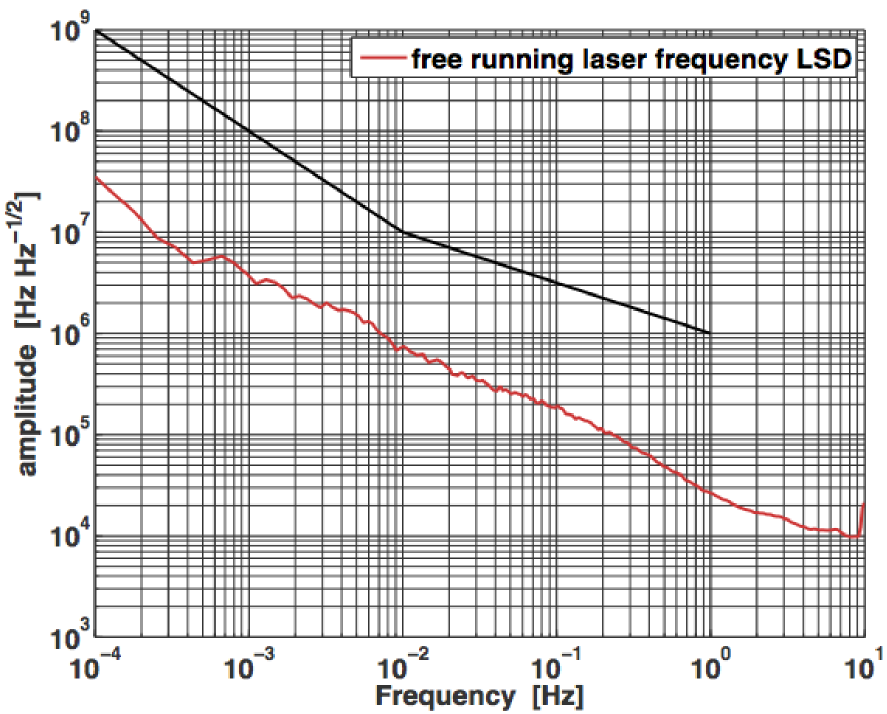




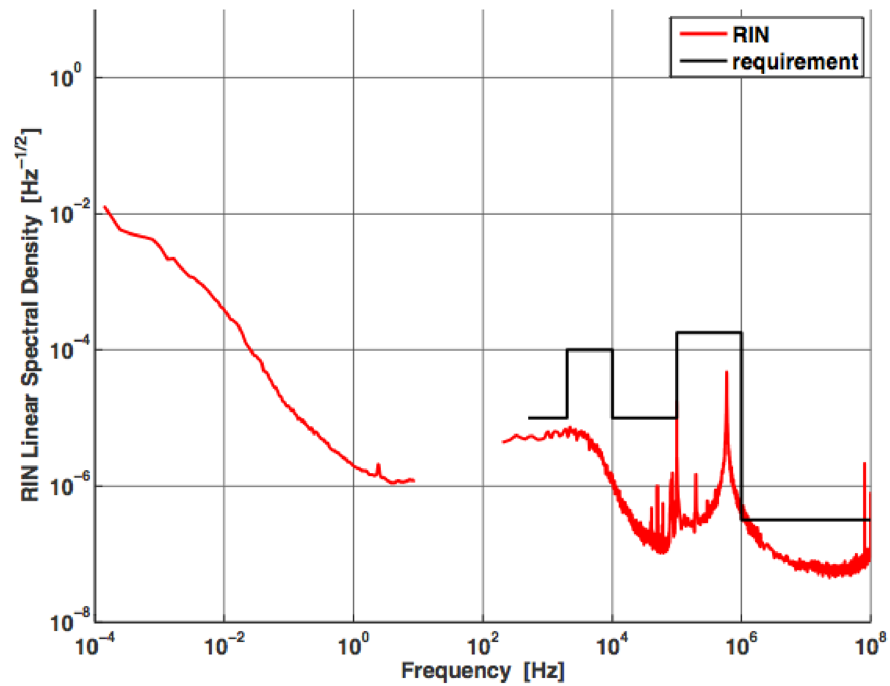


Reference laser unit FM free-running noise

- Nominal 40 mW output power
- 30 kHz/√Hz @ 1 Hz freq. noise



Frequency noise



Relative power noise

Laser frequency stabilization

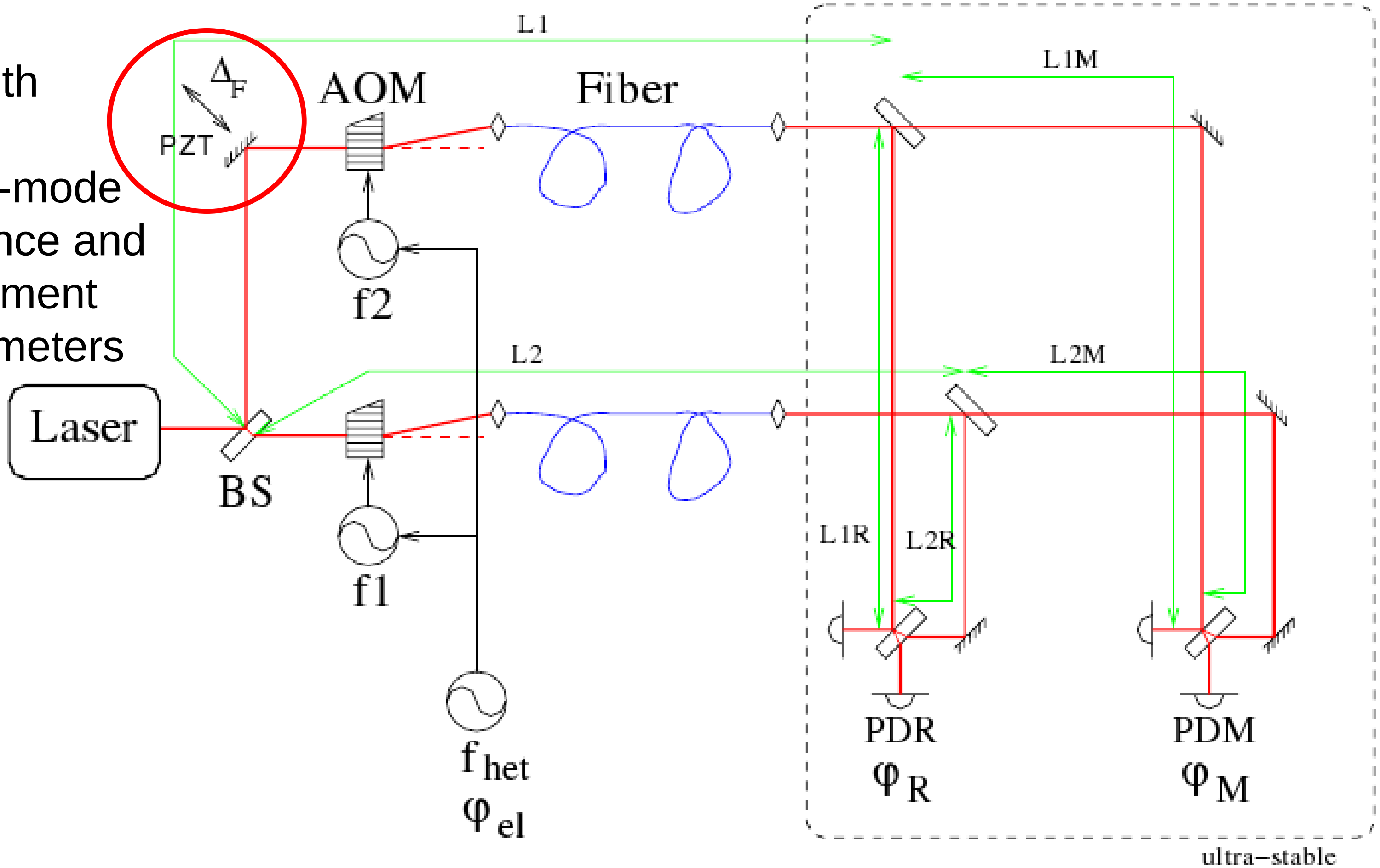
- Pathlength differences up to 1 cm in interferometers
- 28 kHz/√Hz frequency noise required to keep impact on length measurement below 1 pm/√Hz
- Two nested digital loops (100 Hz sampling frequency) running in data management unit (DMU)
- Inner loop acting on fast frequency actuator (PZT on laser crystal)
- Outer loop acting on slow frequency actuator (temperature of laser crystal)

Laser power stabilisation

- Two reasons for laser power stabilisation
  - Limit radiation pressure noise at test masses in measurement band
  - Limit power noise at heterodyne frequency
- Two control loops
  - inner fast analog loop acting on RF power applied to individual AOM
  - Outer slow loop acting on laser power

Optical pathlength difference stabilisation

Pathlength changes common-mode in reference and measurement interferometers

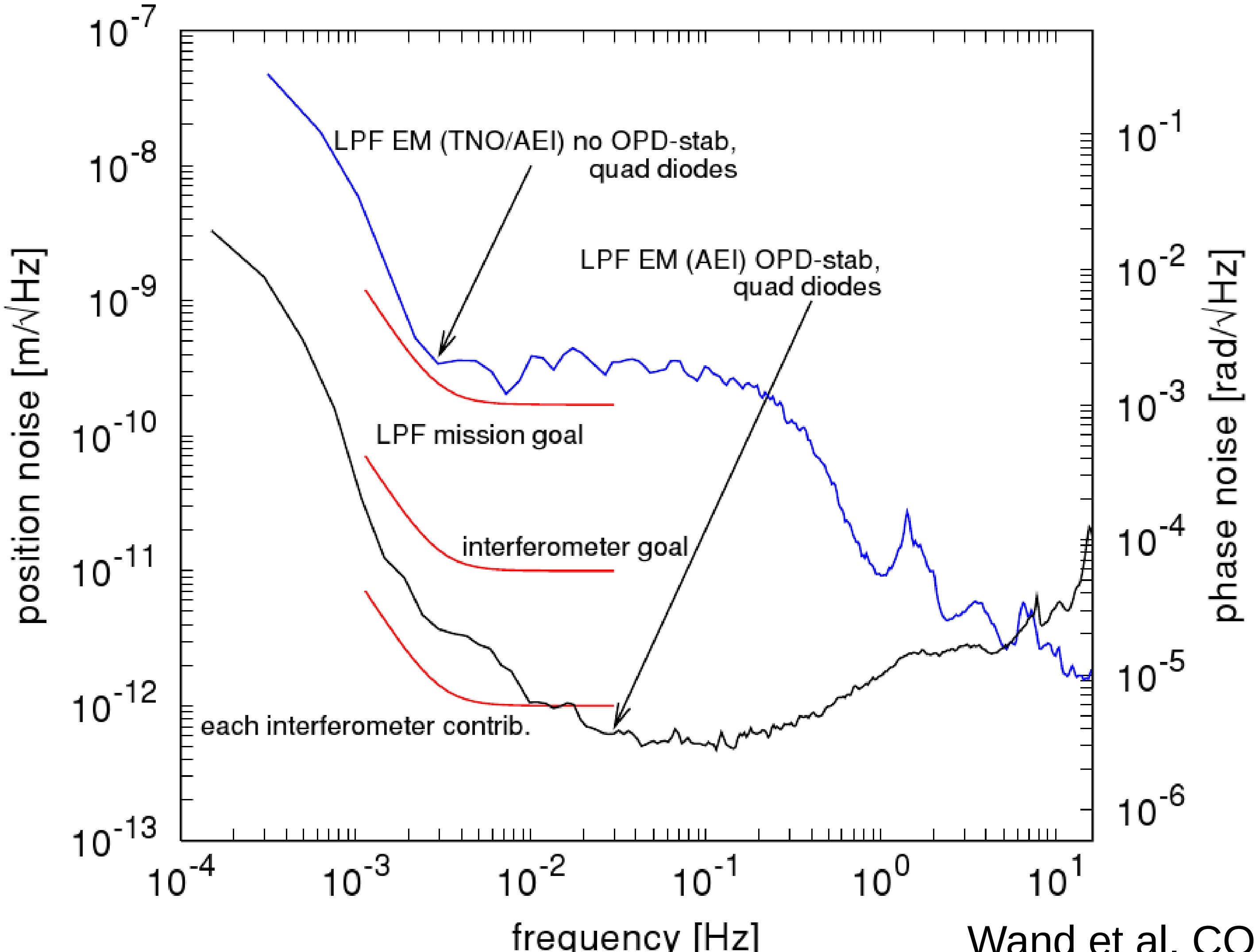


reference interferometer

measurement interferometer

Common-mode noise suppression only works down to nm/√Hz

Optial pathlength difference stabilisation



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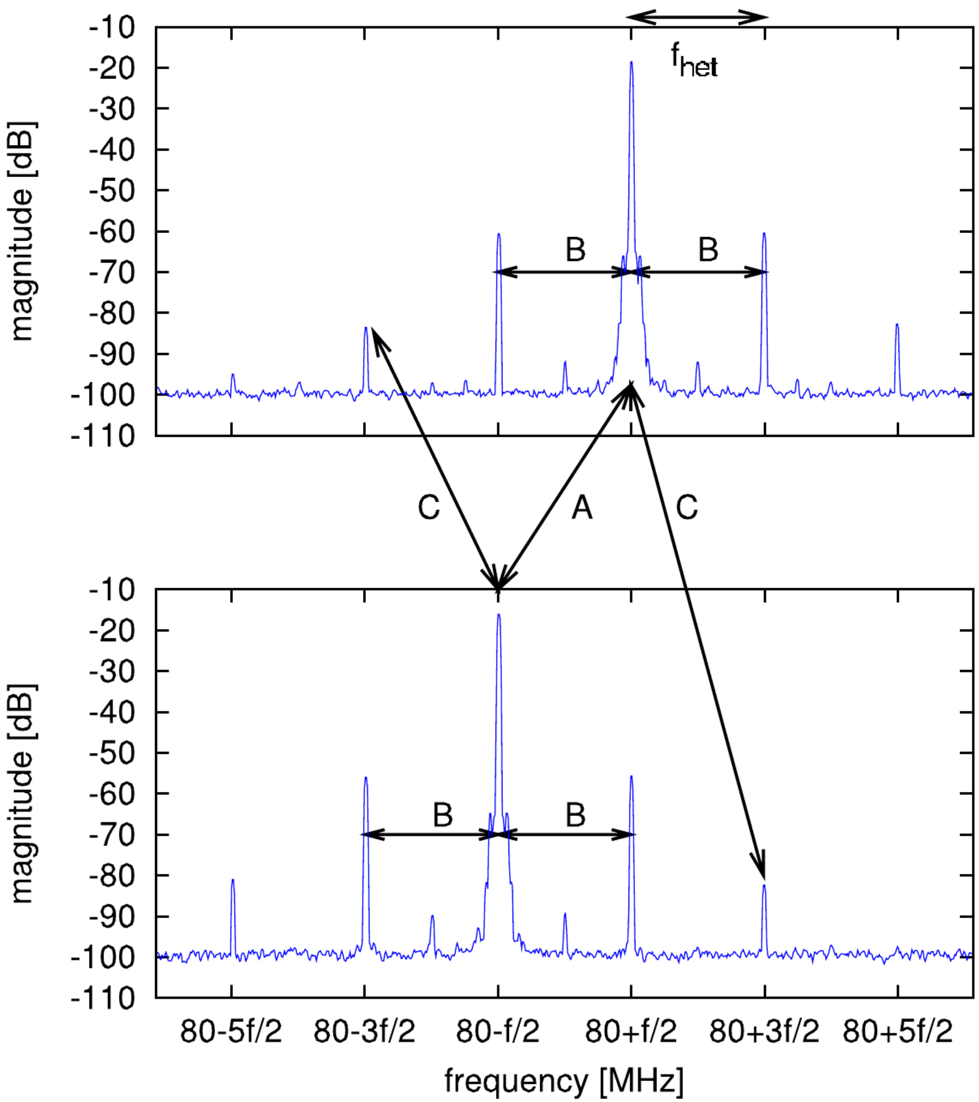
- Noise mitigation works, nm/√Hz without stabilisation, pm/√ Hz with stab.

Optical pathlength difference stabilisation

- AOM driving signals show parasitic sidebands spaced at the heterodyne frequency caused by electro-magnetic coupling between AOM drivers
- A denotes the nominal heterodyne signal
- B,C denote parasitic heterodyne signals
- parasitic phase depends on sum and difference of measurement and reference phase
- both phases are dominated by external disturbances
- mitigation of noise effect: keep reference phase constant
- achieved by PZT actuators in laser modulator unit



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LISA laser

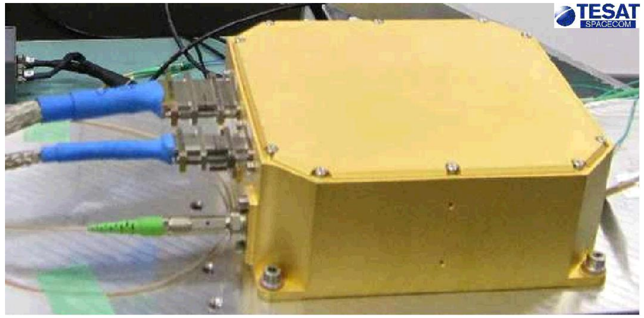
- Breadboard demonstrated
  - 1.2 W out-of-fiber
  - 30 Hz/√Hz frequency noise
  - $2x10^{-4}$/√Hz relative power noise

EADS ASTRIUM
LZH
INNOLIGHT WHEN STABILITY MATTERS
Contraves Space
Alenia SPAZIO A FINMECCANICA COMPANY

- ESA has issued ITT for engineering model
  - 2 W @ 1064 nm
  - actuators for stabilization
- Concept
  - Master oscillator power amplifier
  - EOM in-between for clock-noise transfer, ranging

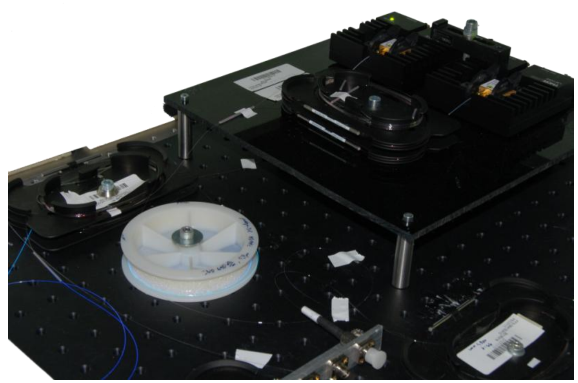
LISA laser system components

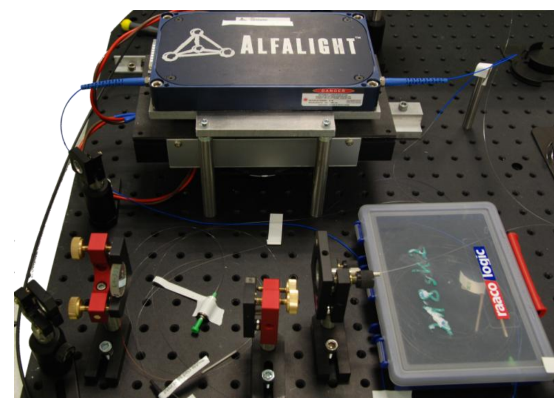
- Seed laser
  - NPRO
  - fiber laser



- EOM (clock-noise transfer, ranging)

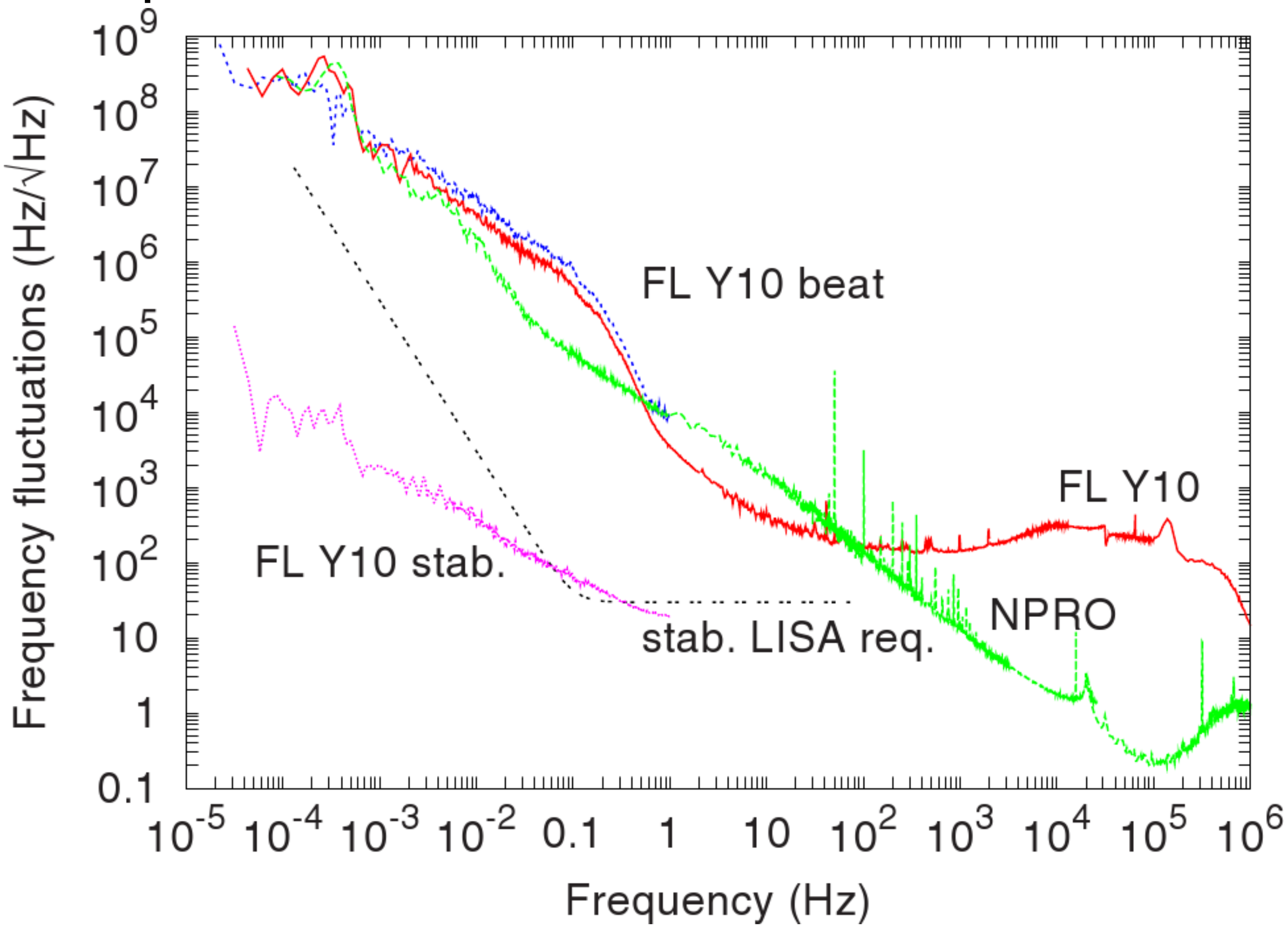
- fiber amplifier
  - core-pumped
  - cladding pumped





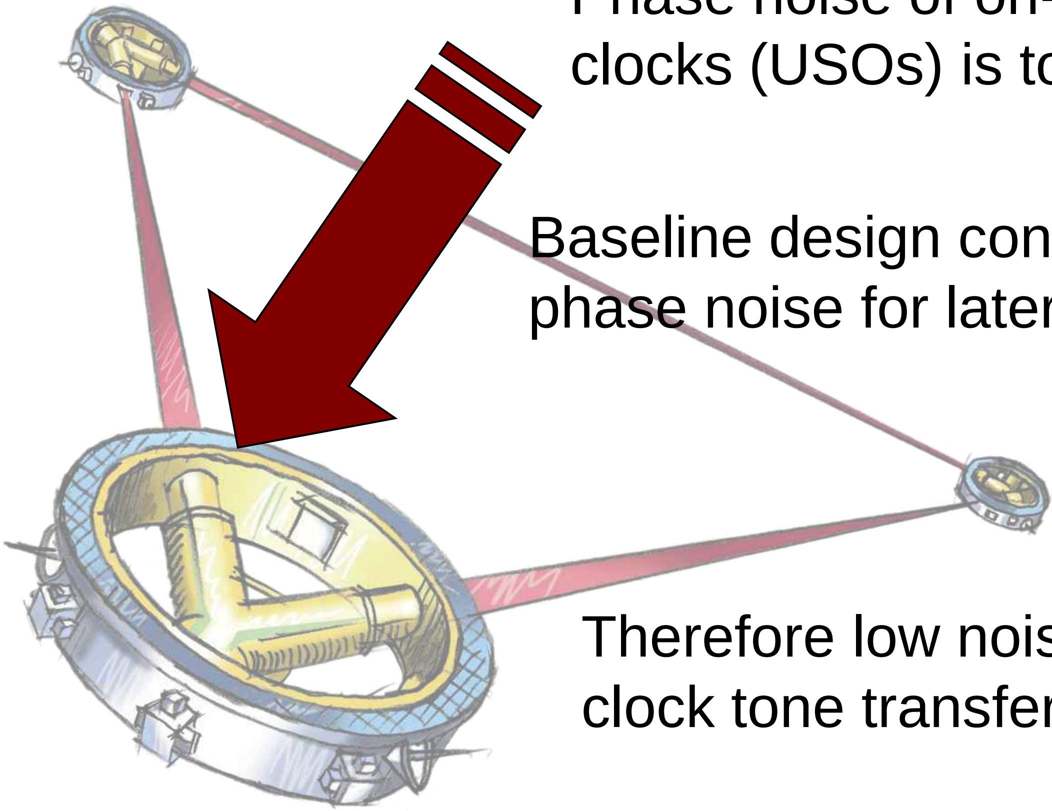
Seed lasers for LISA

- Frequency noise of commercial fiber laser (Boostik by Koheras, labelled FL Y10) comparable to NRPO below 100 Hz



Tröbs et al. JOSAB 26 pp. 1137 (2009)

Ultra Stable Oscillator (USO) phase noise

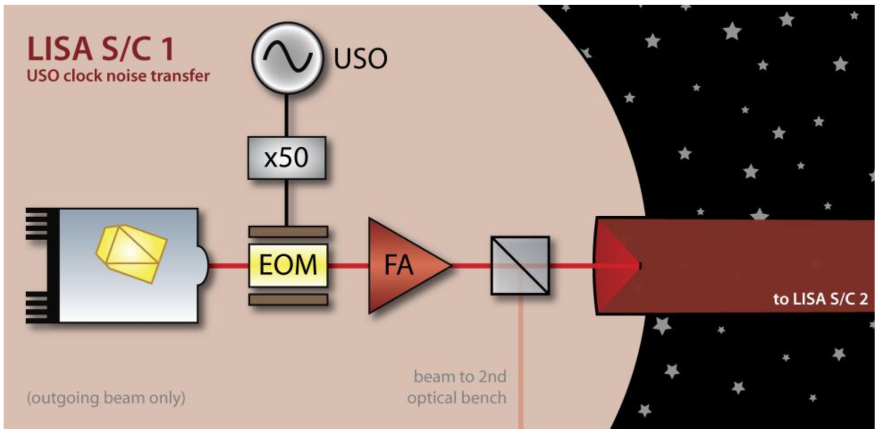


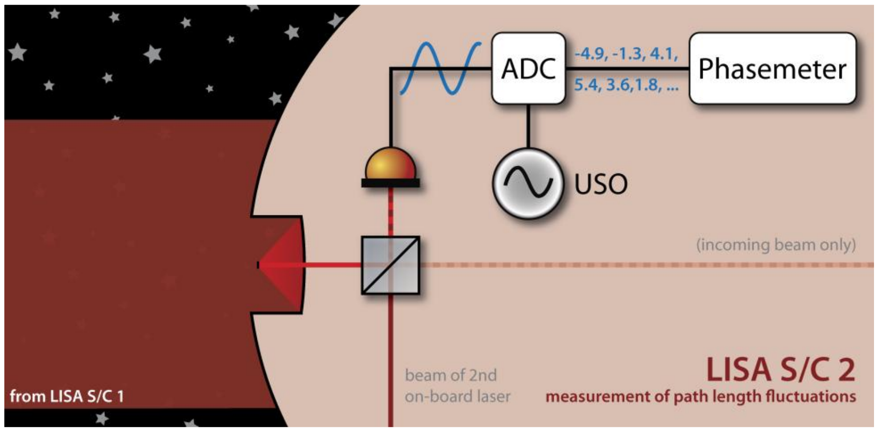
Phase noise of on-board clocks (USOs) is too high!

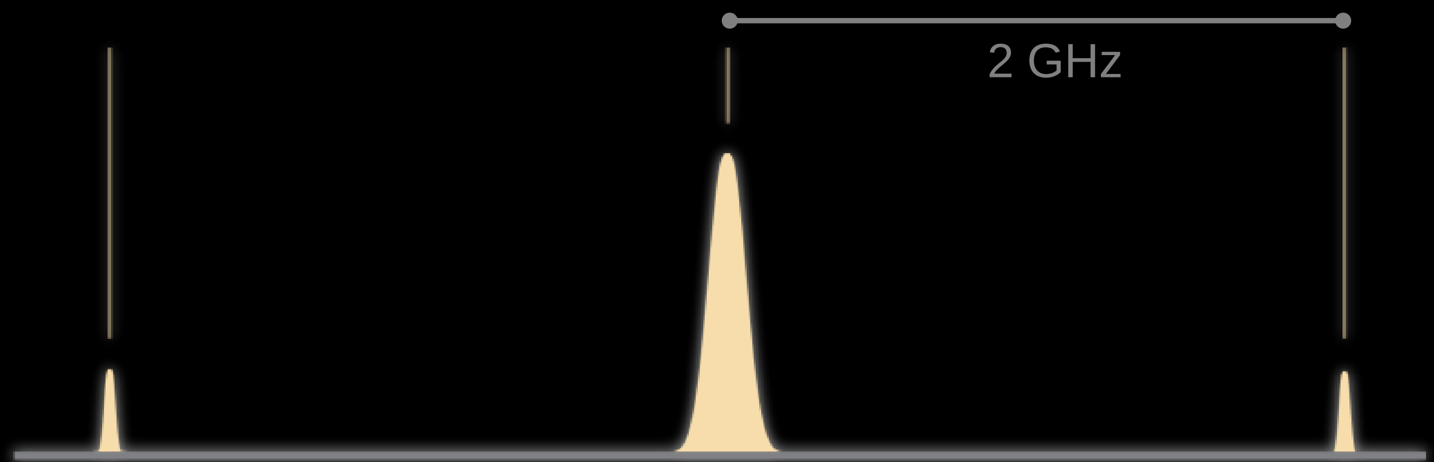
Baseline design concept: measure phase noise for later cancellation.

Therefore low noise in clock tone transfer chain required

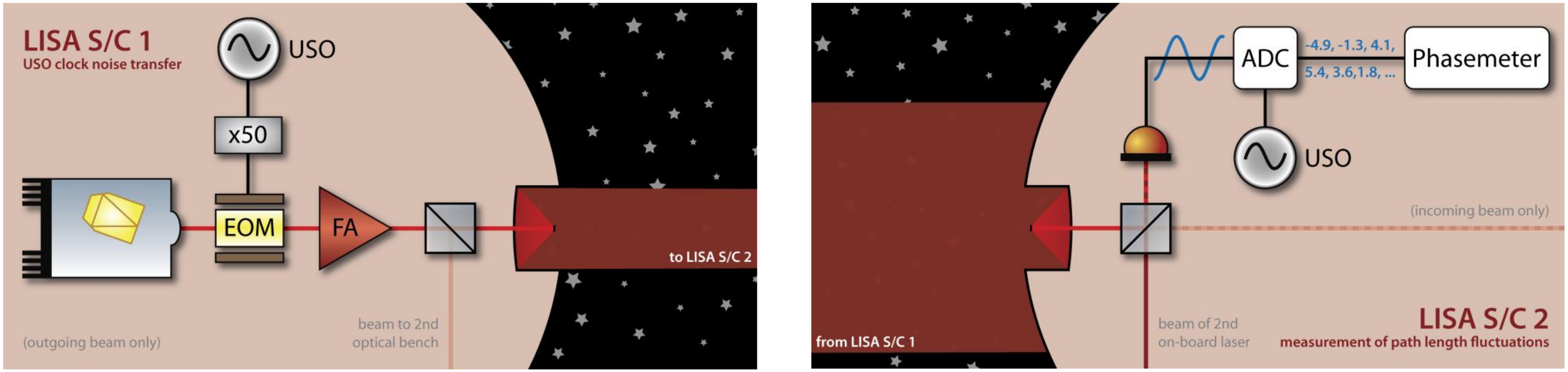
USO clock tone transfer chain

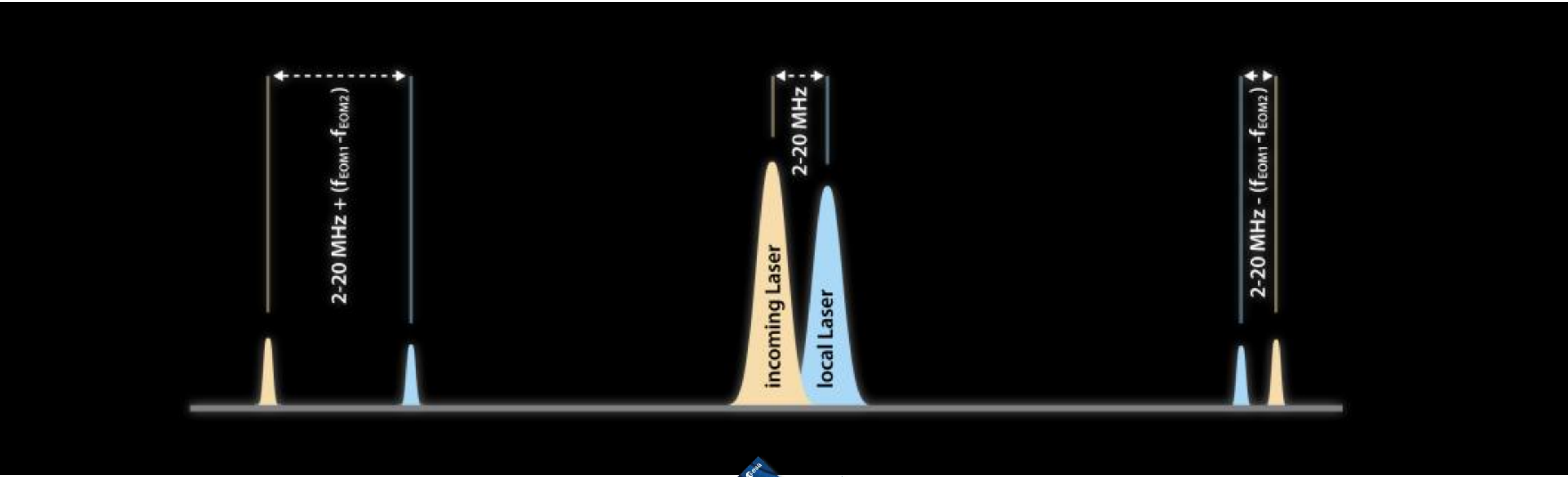




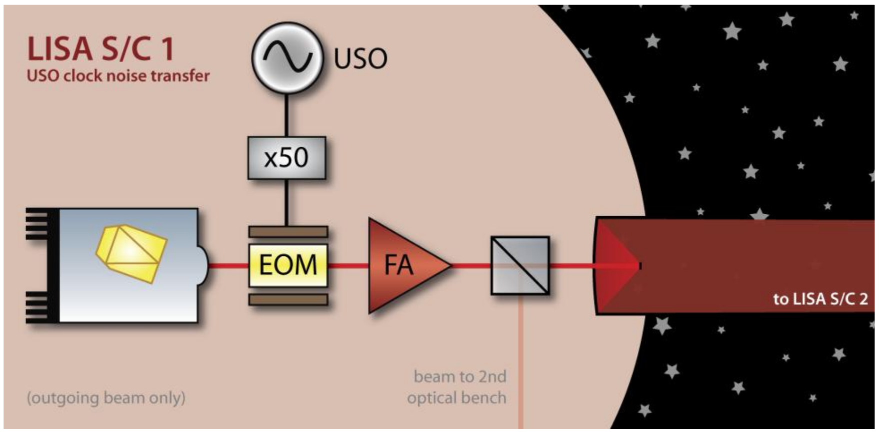


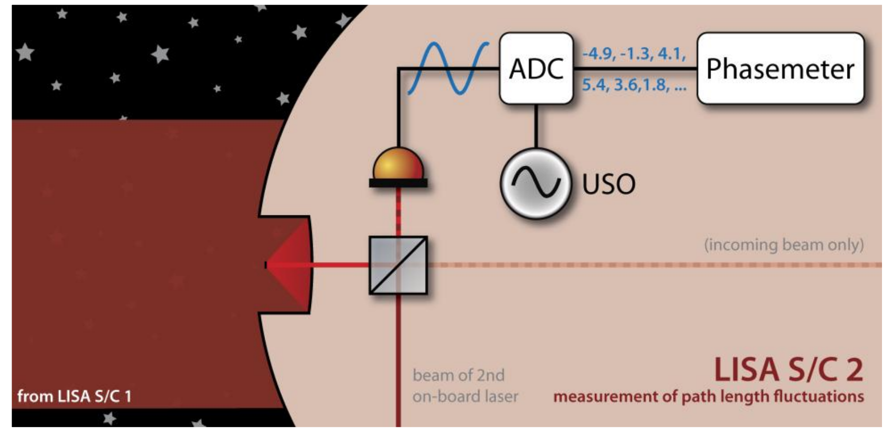
USO phase noise measurement





Requirements





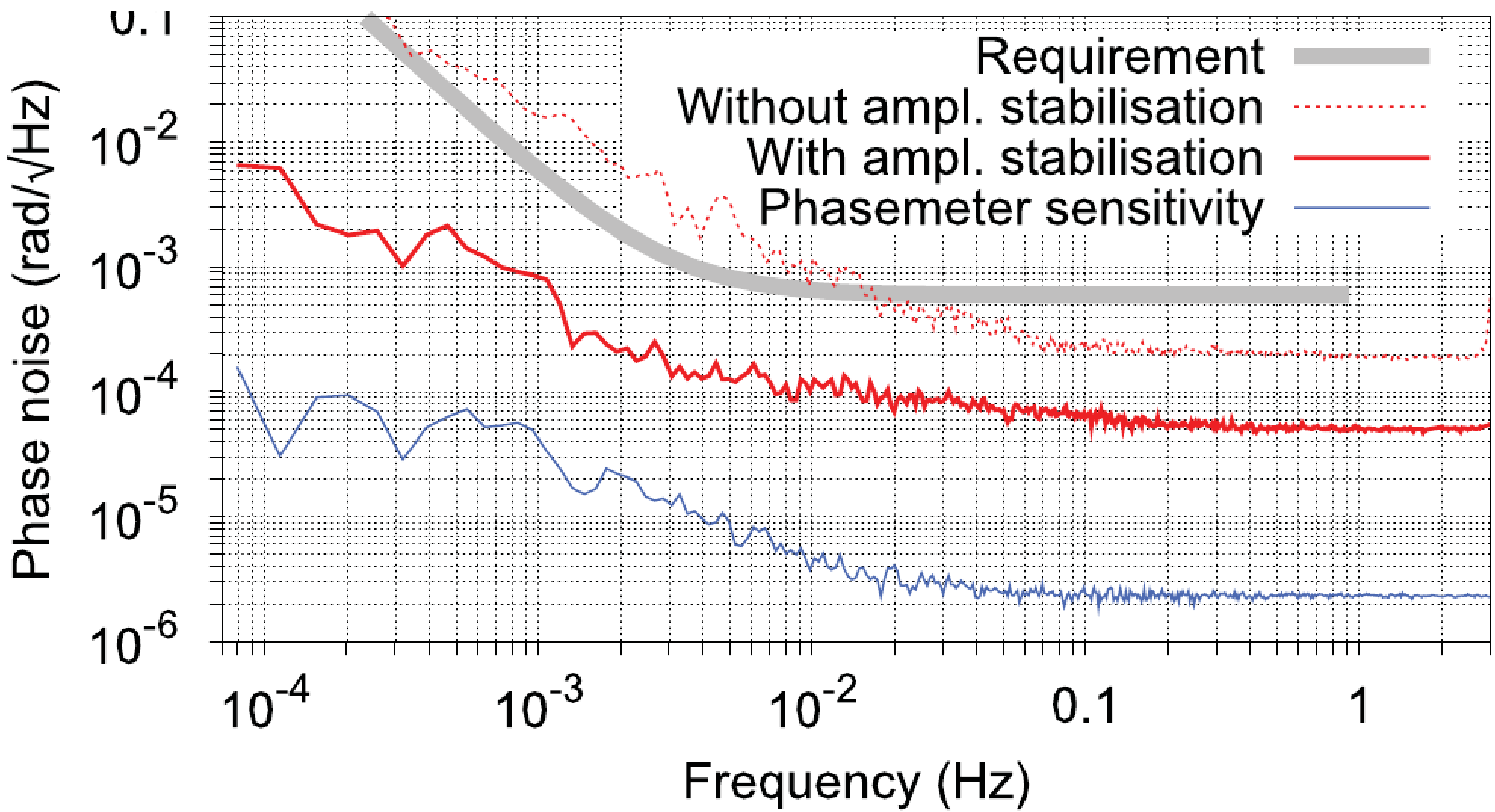
Phase read-out: $$\Delta\phi_{1\mathrm{pm}} < \frac{1\,\mathrm{cycle}}{1064\,\mathrm{nm}} \cdot \frac{1\,\mathrm{pm}}{\sqrt{\mathrm{Hz}}} \approx 1\,\frac{\mu\mathrm{cycles}}{\sqrt{\mathrm{Hz}}} \approx 6\,\frac{\mu\mathrm{rad}}{\sqrt{\mathrm{Hz}}}$$

Ancillary Modulation Error: $$\Delta\phi_{\mathrm{AME}} < \Delta\phi_{1\mathrm{pm}} \cdot \frac{f_{\mathrm{USO}}}{f_{\mathrm{het}}} \cdot \frac{f_{\mathrm{mod}}}{f_{\mathrm{USO}}} \approx 6 \cdot \frac{2\,\mathrm{GHz}}{20\,\mathrm{MHz}}\,\frac{\mu\mathrm{rad}}{\sqrt{\mathrm{Hz}}}$$

LISA frequency band: $$\Delta\phi_{\mathrm{AME}'}(f) = 0.6 \cdot \sqrt{1 + \left(\frac{2.8\cdot 10^{-3}\,\mathrm{Hz}}{f}\right)^4}\,\frac{\mathrm{mrad}}{\sqrt{\mathrm{Hz}}}$$

EOM phase fidelity

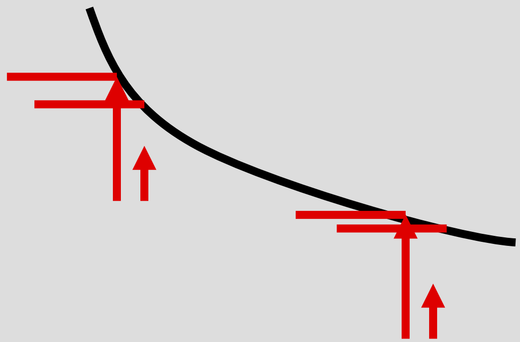
- Phase fidelity of waveguide EOM fulfills LISA requirements
- Space-qualified version available



Barke et al. Appl Phys B (2010) 98: 33–39

Potential sources of differential phase noise in amplifiers

- nonlinear dispersion and laser frequency changes



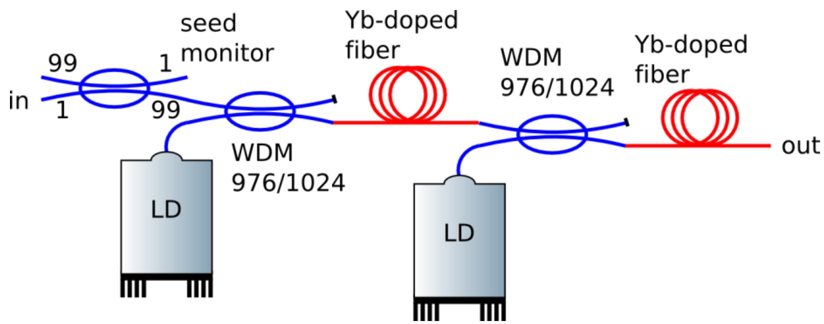
- first measurements show tiny effect
- should be negligible in LISA

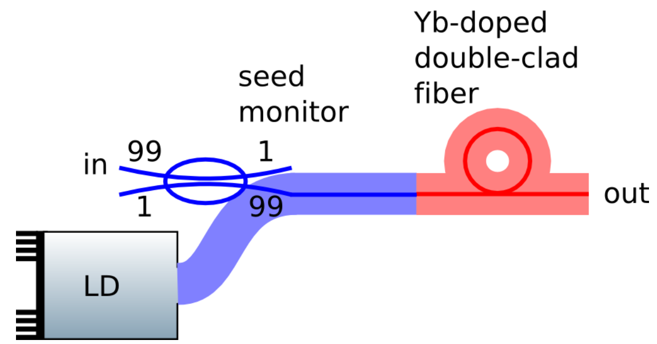
- amplifier length changes due to
  - changes in ambient temperature
  - pump power changes
  - seed power changes

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

- combined effect measured

Optical amplifiers under test





Core-pumped amplifier

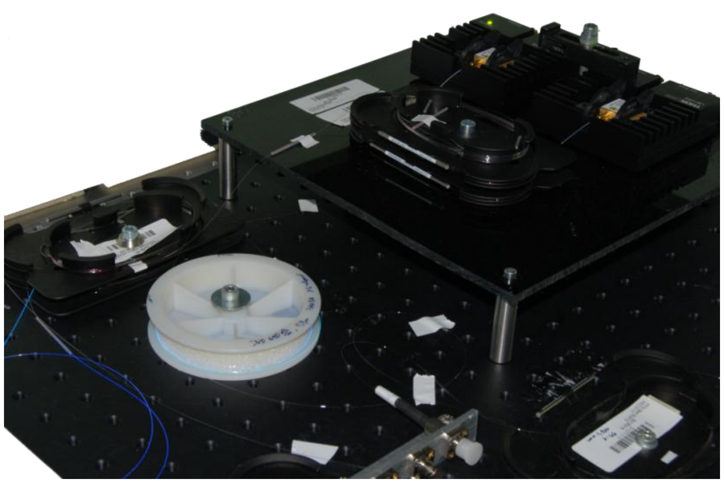
- Two identical stages
- Pumping directly the core of a single-mode fiber
- 2 x 0.4 m active fiber
- 1 W output power

Cladding-pumped amplifier

- Single stage
- Pumping in the multi-mode cladding
- 3 m active fiber
- 1 W output power

Amplifiers supplied by Laser Zentrum Hannover e. V.

Optical amplifiers under test



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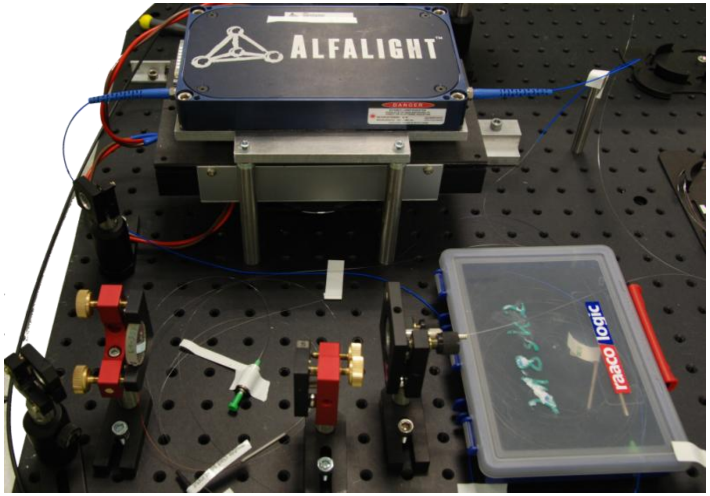

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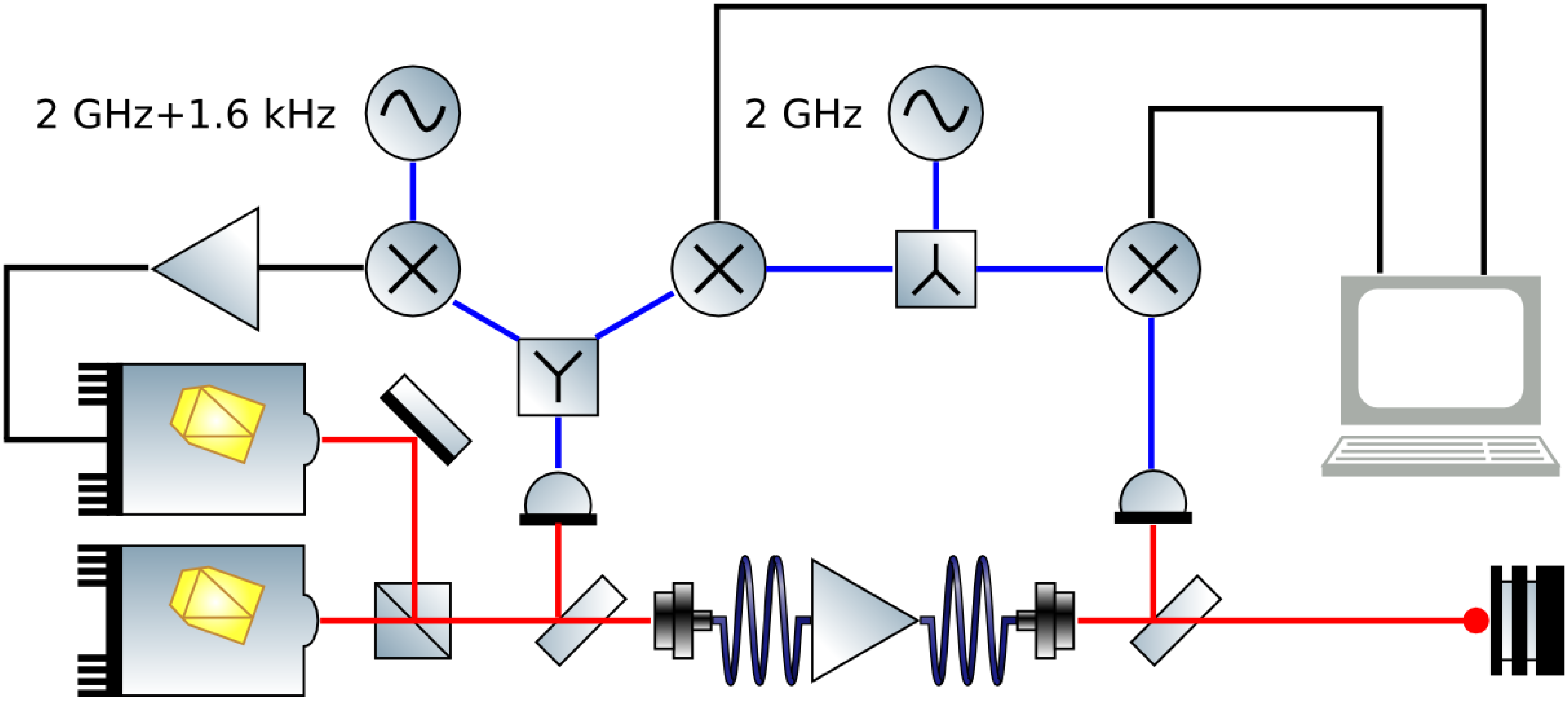
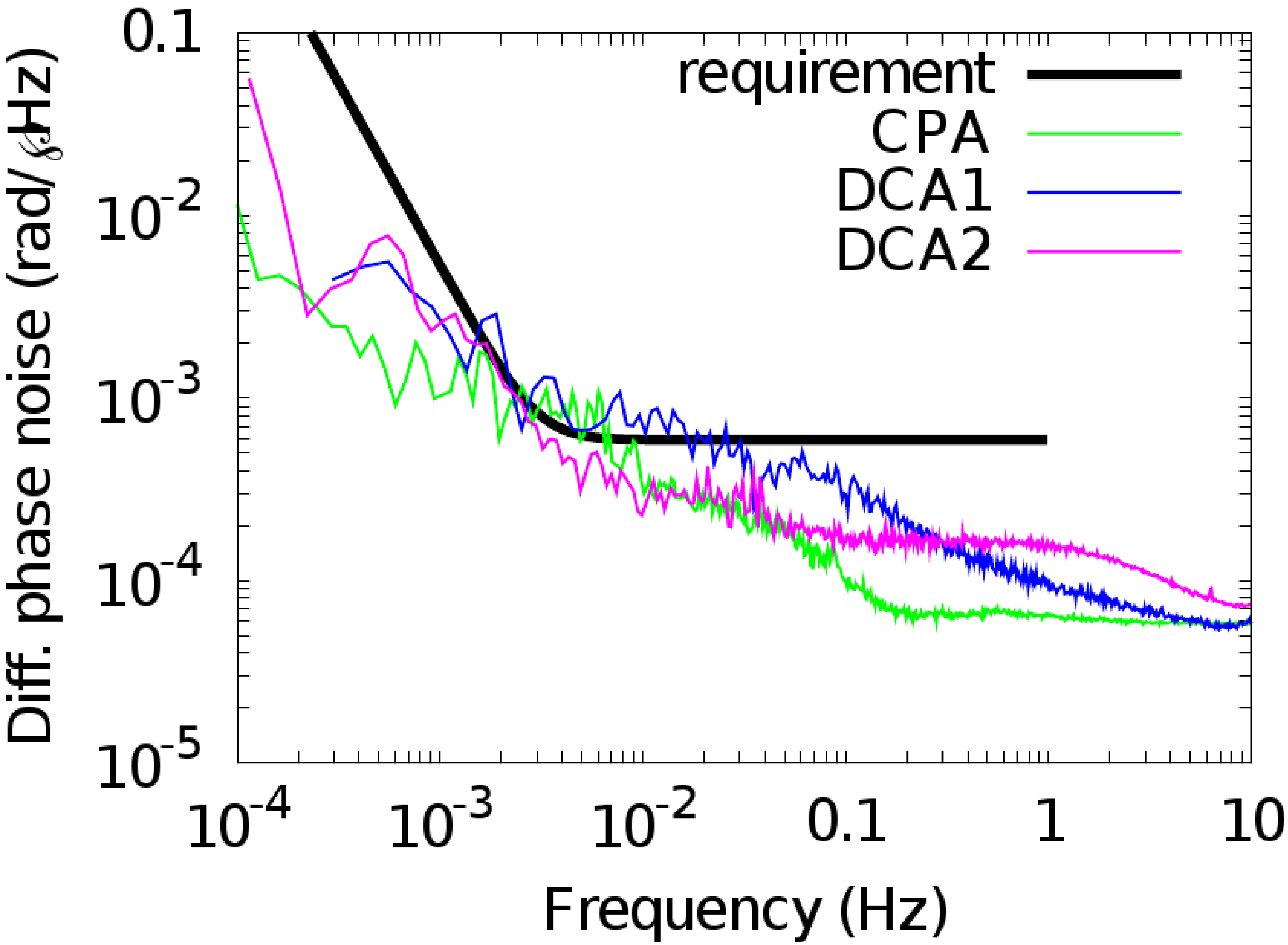
Measurement setup



Differential phase noise of amplifiers

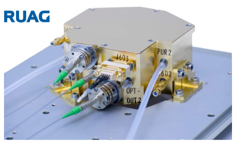


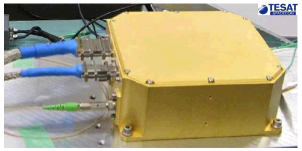
Tröbs et al. JPCS (2010) 208: 012042

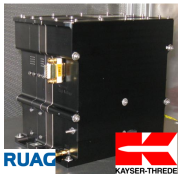
- 1 W output power
- Within LISA requirement
- 2 GHz sideband frequency

Summary

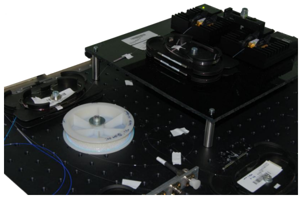
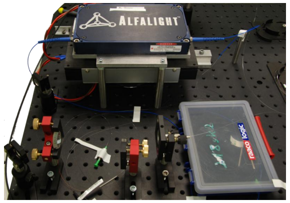
- Laser system for LISA Pathfinder
  - laser unit, laser modulator unit, laser control unit
  - FMs finished and extensively tested
- Laser system for LISA
  - breadboard demonstrated pre-stabilisation
  - components for EM are available
  - phase fidelity of EOM and fiber amplifiers was verified









Thank you

- J Reiche, A Garcia & LTP team
- HSL team

LISA Pathfinder in acoustic test chamber at ESA