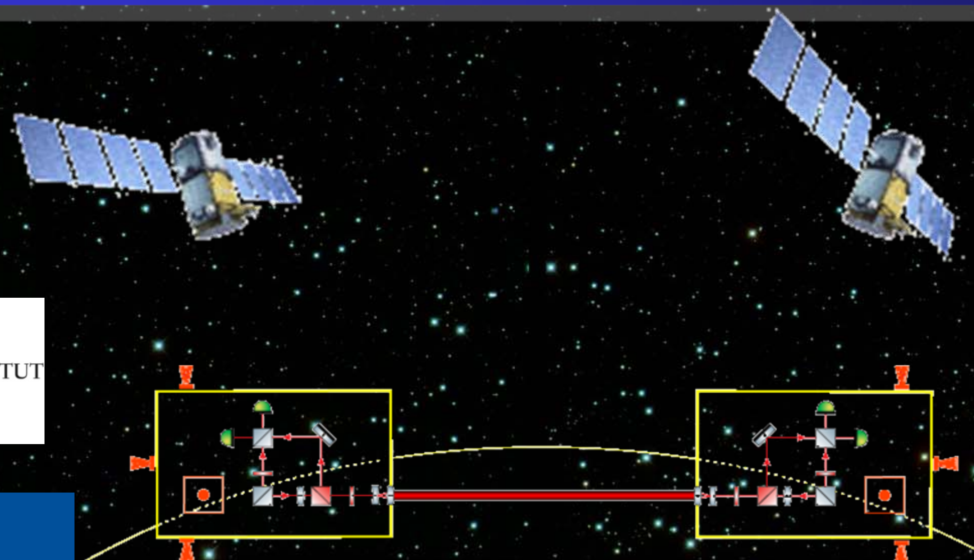
LISA technology for gravity-field missions



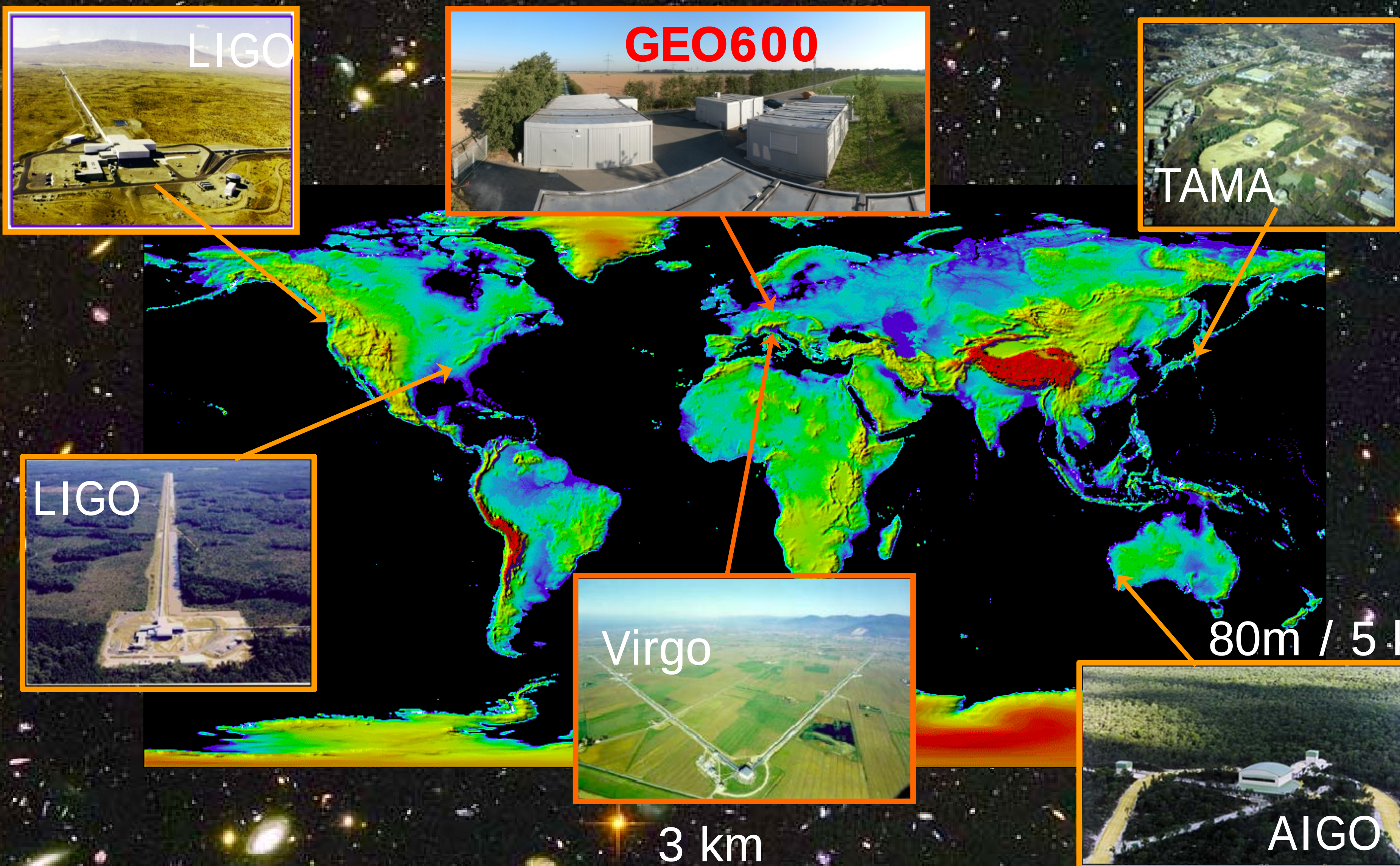
Max-Planck-Institut für Gravitationsphysik
Albert-Einstein-Institut

Leibniz Universität Hannover

quest

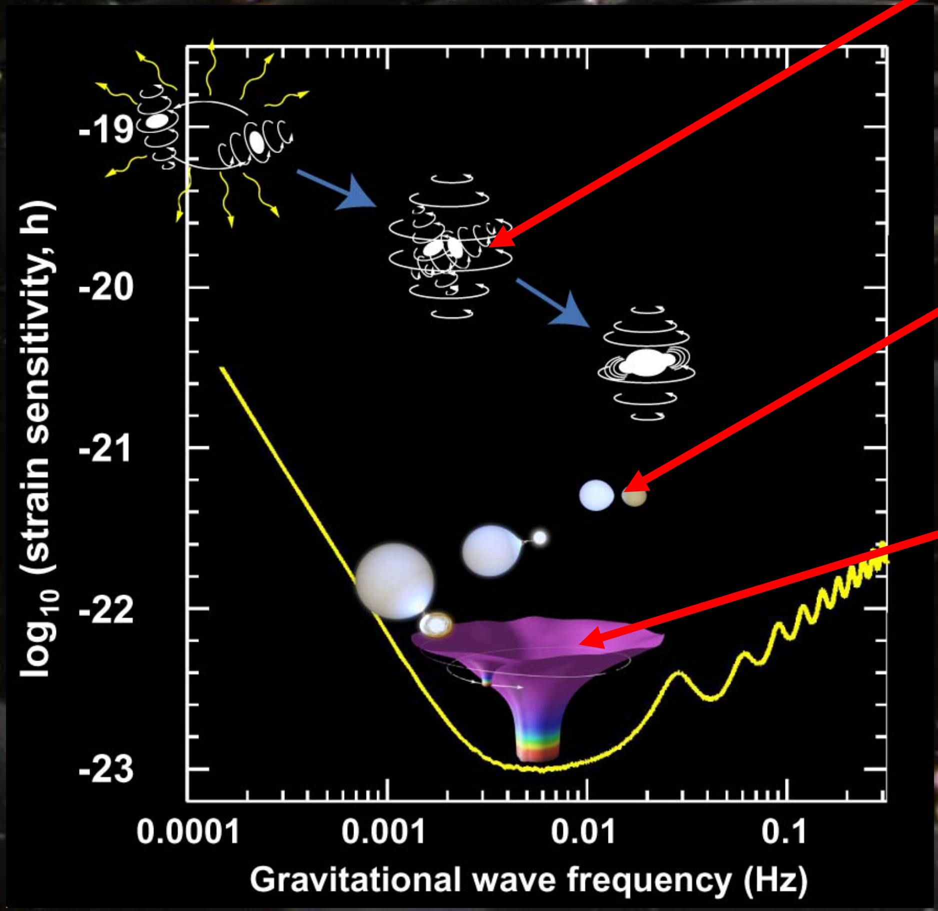
Gerhard Heinzel
AEI Hannover
Graz, September 30, 2009

World-Wide Laser Interferometric Gravitational Wave Detector Network



Source: A. Lazzarini, modified

A Universe Full of Strong Low-f Gravitational Wave Sources



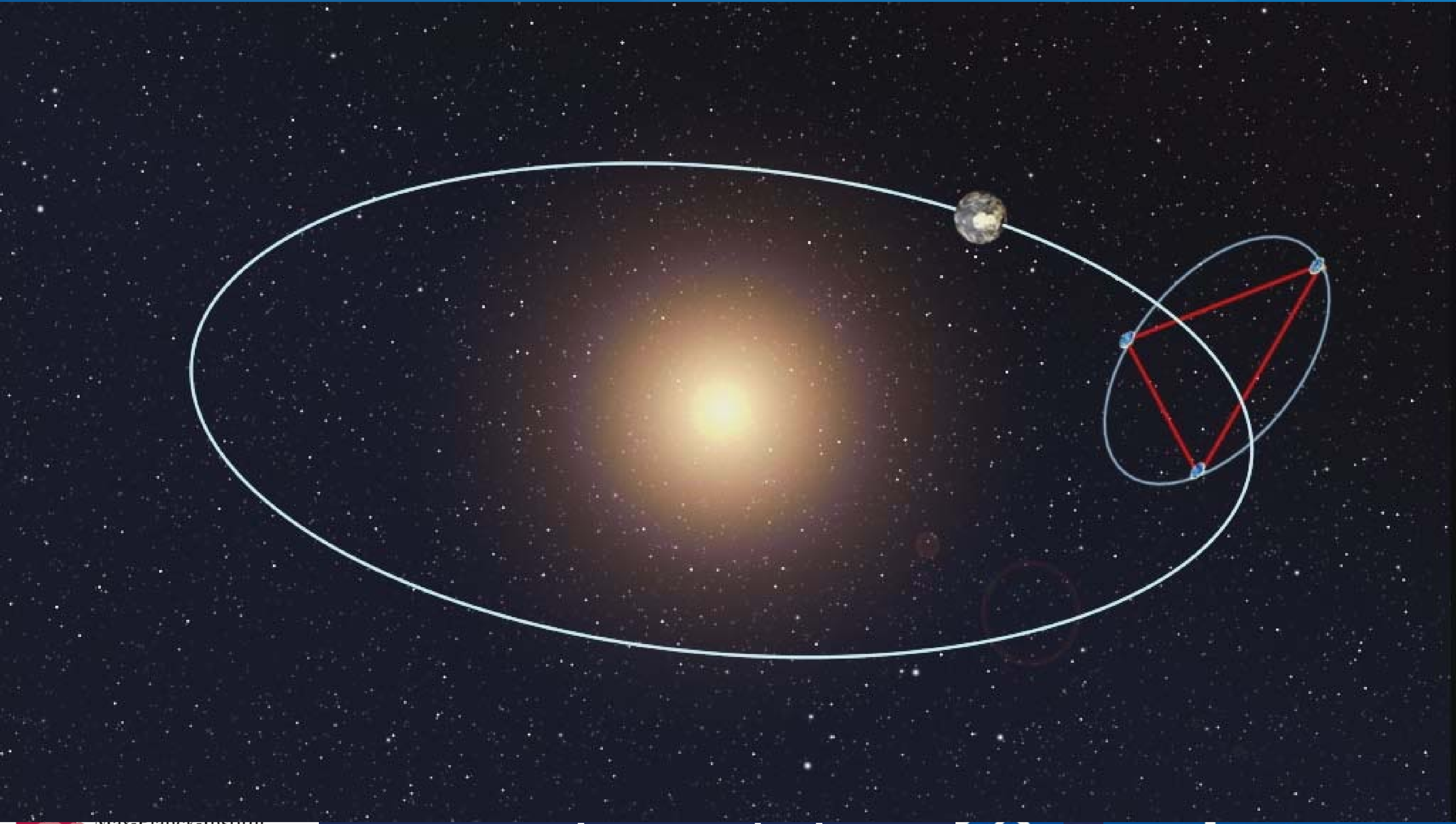
Massive Black Hole Binary (BHB) inspiral and merger

Ultra-compact binaries

Extreme Mass Ratio Inspiral (EMRI)

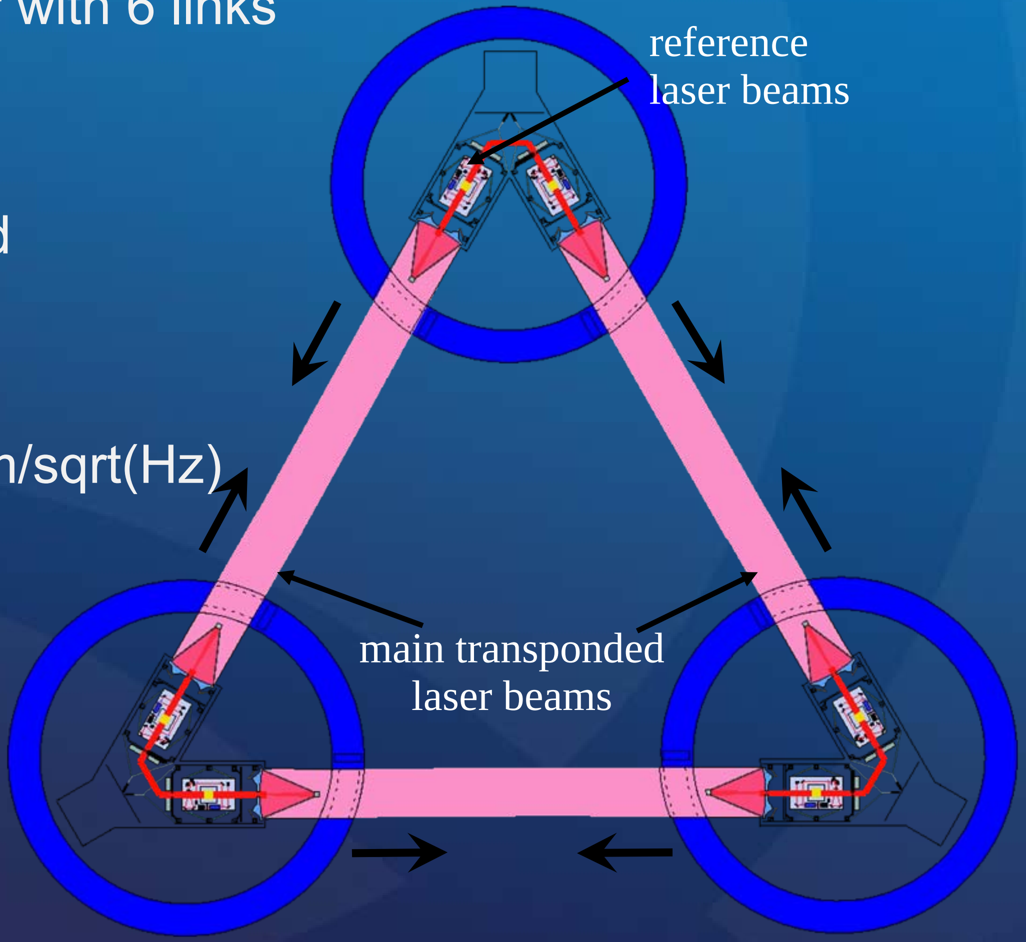
Cosmic backgrounds, superstring bursts?

LISA Smart Orbits



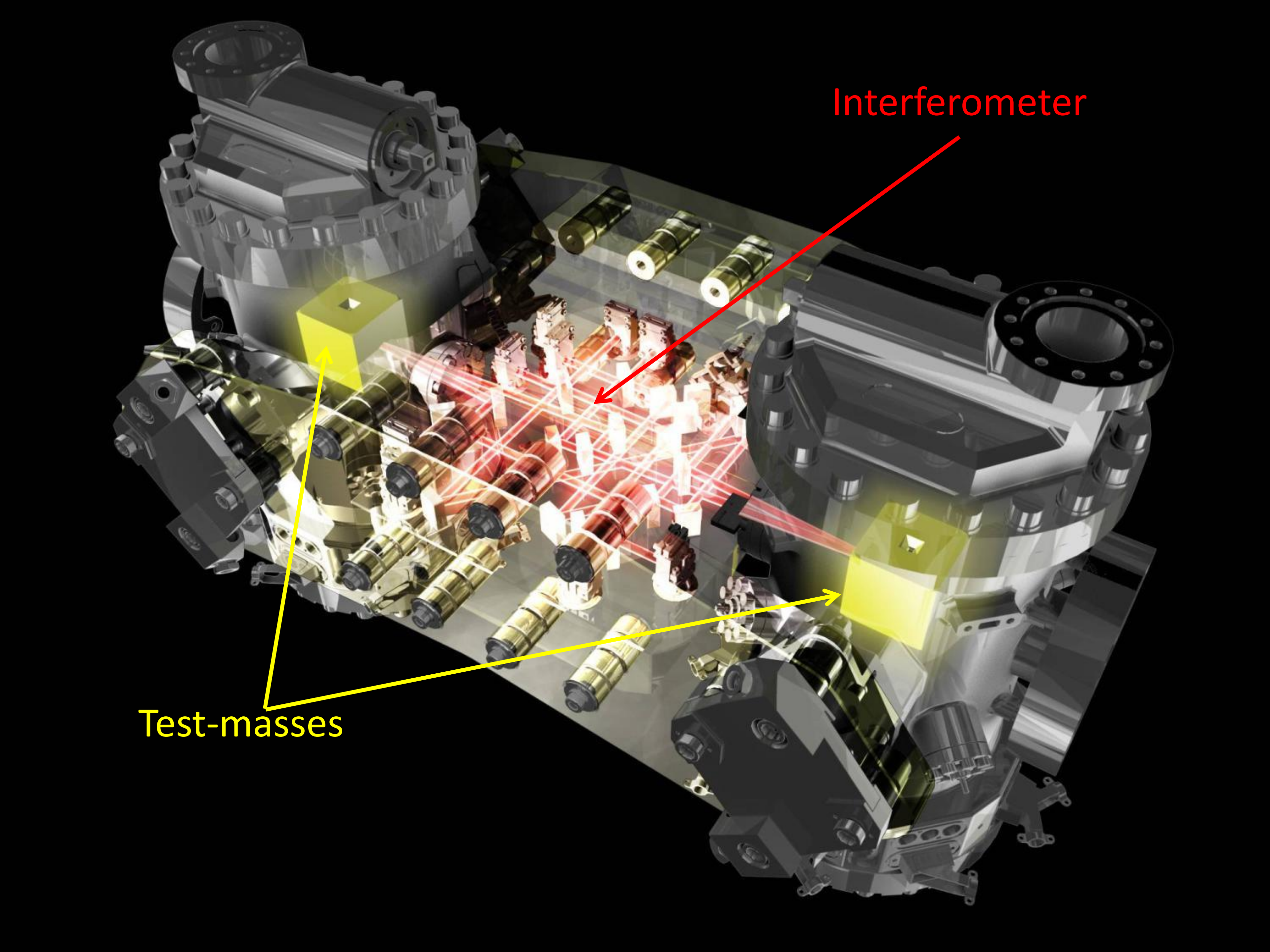
LISA Layout

- Laser heterodyne transponder with 6 links
- Diffraction widens the laser beams to many kilometers
  - 1 W sent, 100 pW received by 40 cm Telescope
- Doppler shift up to 15 MHz
- Single-link noise budget 12 pm/sqrt(Hz)

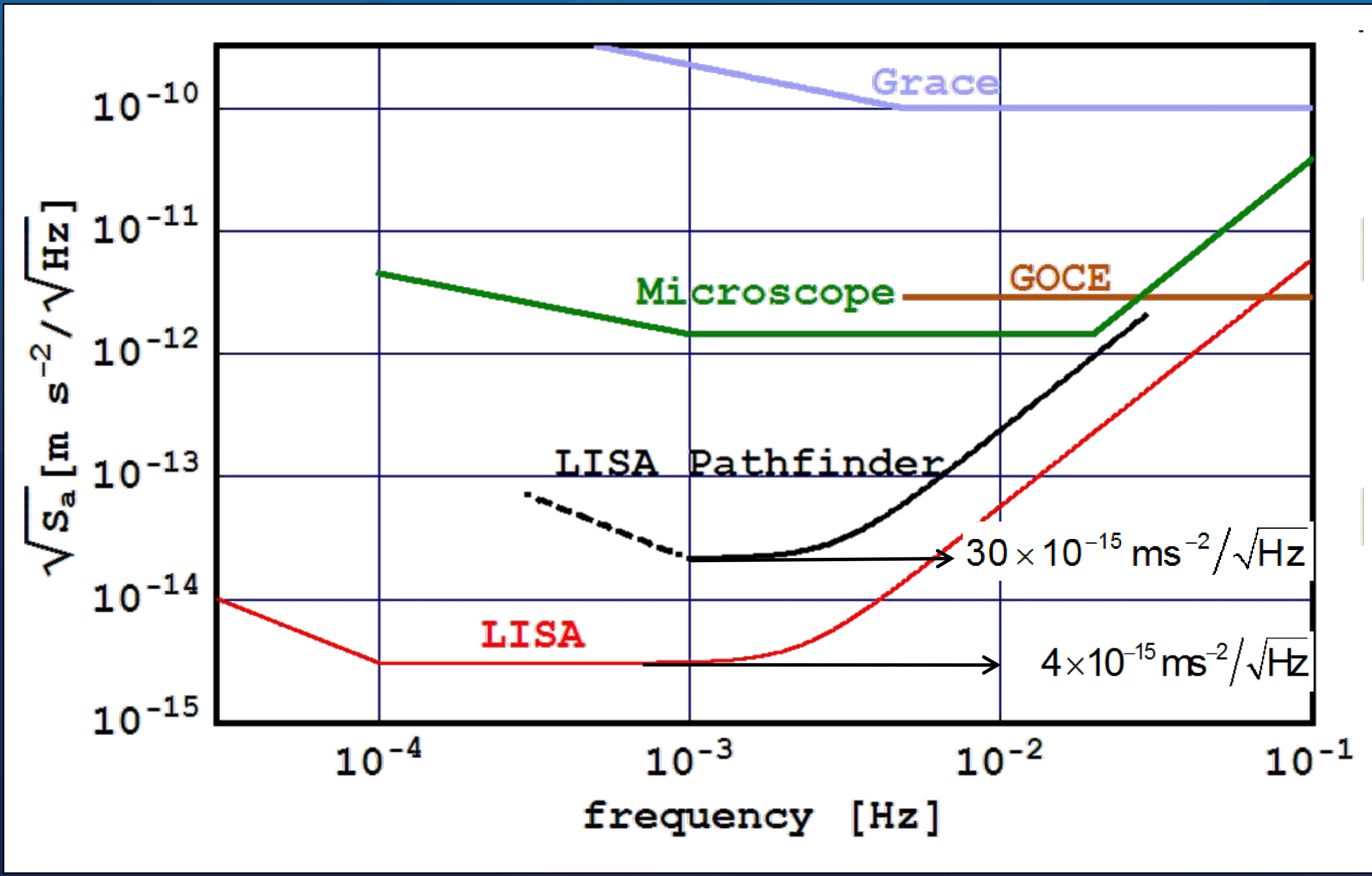


LISA Pathfinder

- Take one LISA link
- Squeeze it into one spacecraft


Interferometer
Test-masses

LISA and LPF requirements



LISA Basic Design Items

- Free flying test mass subject to very low parasitic forces:
  - Drag free control of spacecraft (non-contacting spacecraft)
  - Low noise microthruster to implement drag-free
  - Large gaps, heavy masses with caging mechanism
  - High stability electrical actuation on cross degrees of freedom
  - Non contacting discharging of test-masses
  - High thermomechanical stability of S/C
  - Gravitational field cancellation
- Precision interferometric local ranging of test-mass to spacecraft:
  - pm resolution ranging, sub-mrad alignments
  - High stability monolithic optical assemblies
- Precision interferometric 5 Mio km spacecraft to s/c ranging:
  - High stability telescopes
  - High accuracy phase-meter
  - High accuracy frequency stabilization
  - Constellation acquisition
  - Precision attitude control of S/C

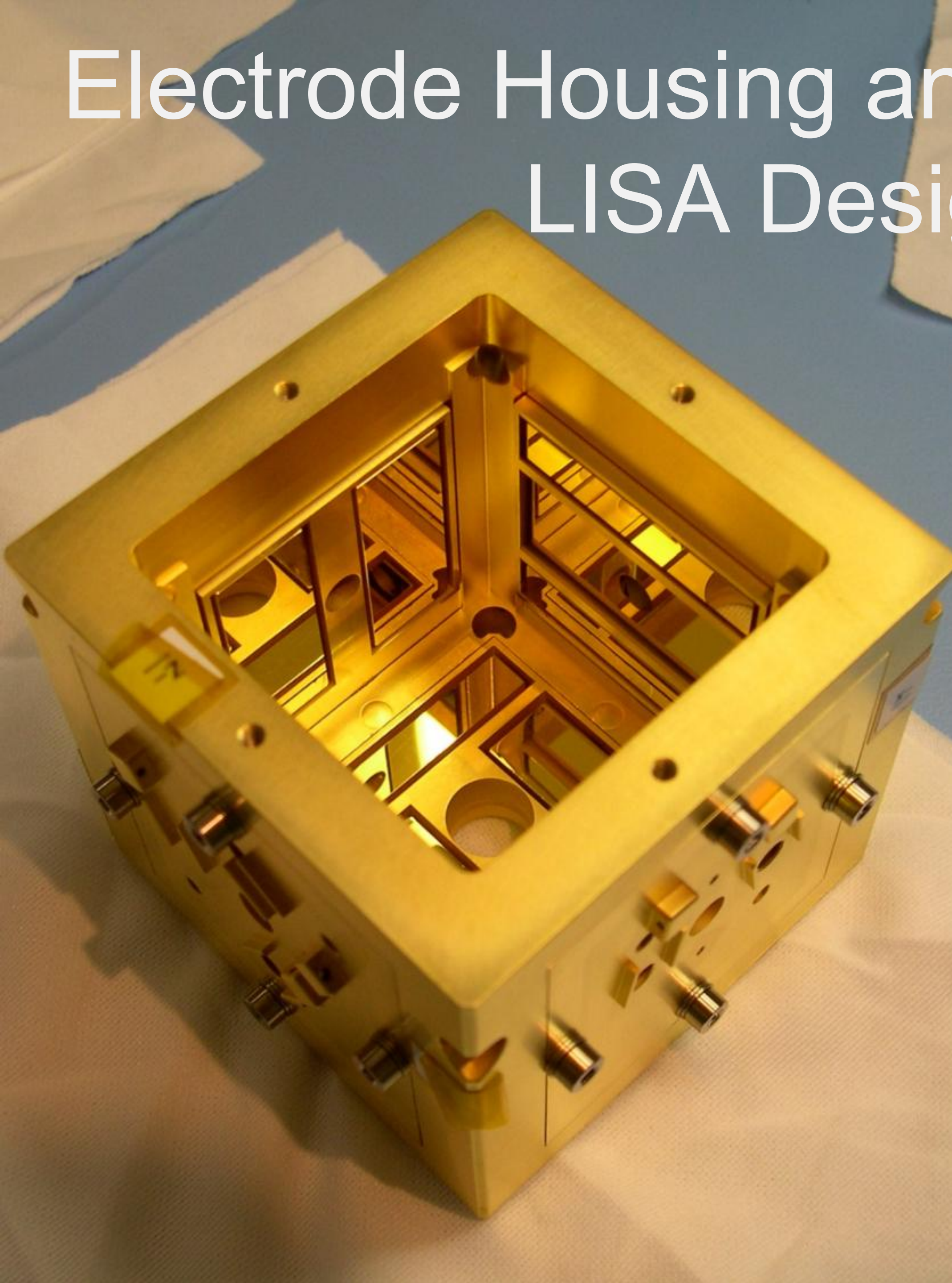
Spacecraft Follows Test Mass → Drag-Free

Position of spacecraft relative to test-mass is measured by the local interferometer
Spacecraft is kept centered on test-mass by acting on micro-Newton thrusters.

Test masses

- LISA Pathfinder and LISA are drag-free in different conditions than GRACE/GOCE:
  - far away from Earth, quiet surroundings, no atmospheric drag, stable thermal conditions
  - $3 \cdot 10^{-15}$ ms^{-2} performance
- New mission will have either accelerometer or drag-free, in any case a free floating test mass
- GRACE-type formation plus gradiometers?

Electrode Housing and Test Mass: LISA Design



Interferometer technology overlap

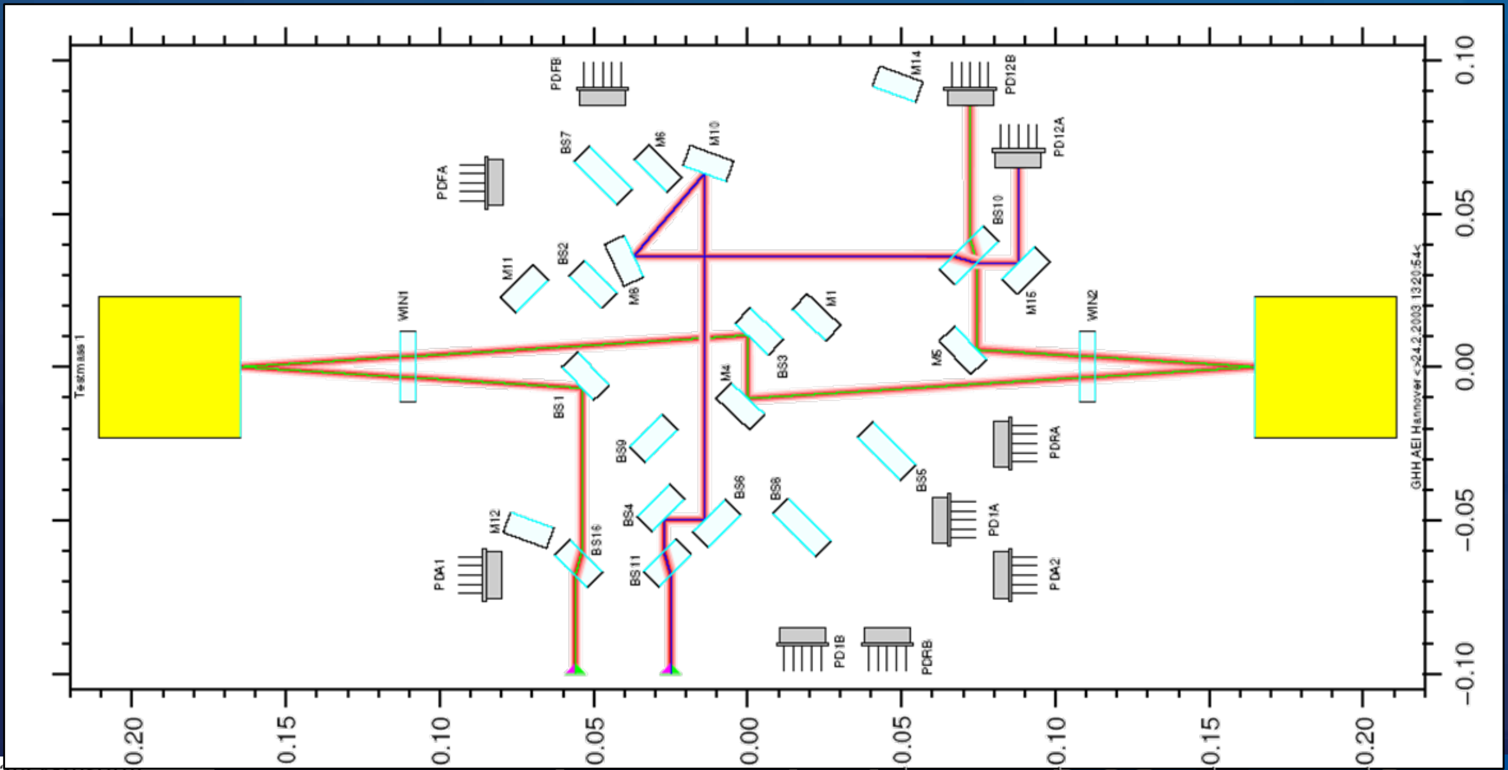
- Heterodyne laser interferometry on long distances with telecsopes
- Same frequency range (mHz)
- Stable optical benches
- Lasers, Frequency stabilization and Offset phase locking
- Phase measurement system
- Absolute ranging and clock syncronisation
- Optical sensing of a free floating test mass
- Data transfer on the optical link
- Alignment tracking and autonomous acquisition

Local Optical sensing

- local sensing of test mass: heterodyne with DWS
  - use AOMs for kHz heterodyne frequency as in LISA Pathfinder OR
  - use existing MHz heterodyne frequencies like LISA
- gravity gradient sensor with optical readout ???

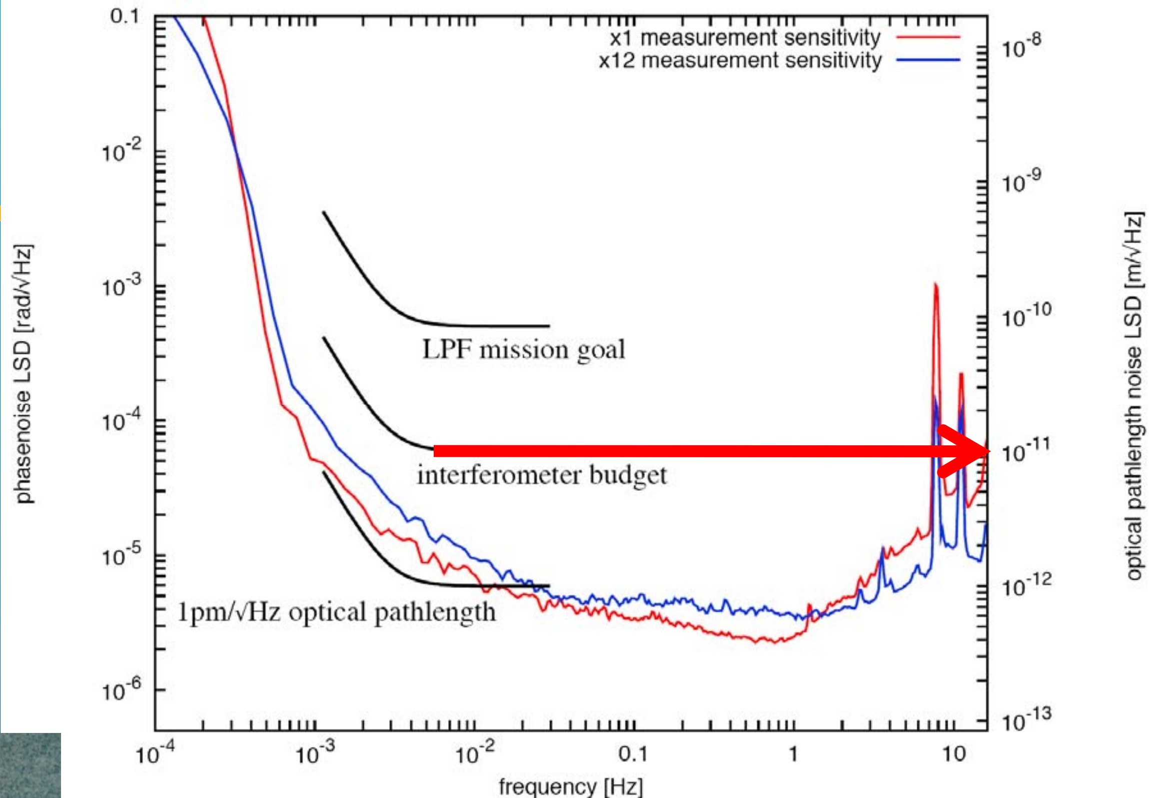
Test Mass ↔ (Spacecraft)↔ Test Mass Link <10 pm/√Hz

- Heterodyne Mach-Zehnder interferometer
- Sensitive orientation/pointing measurement (nrad/sqrt(Hz))
- High-rate output possible
- Cross couplings due to misalignment well understood and mitigated



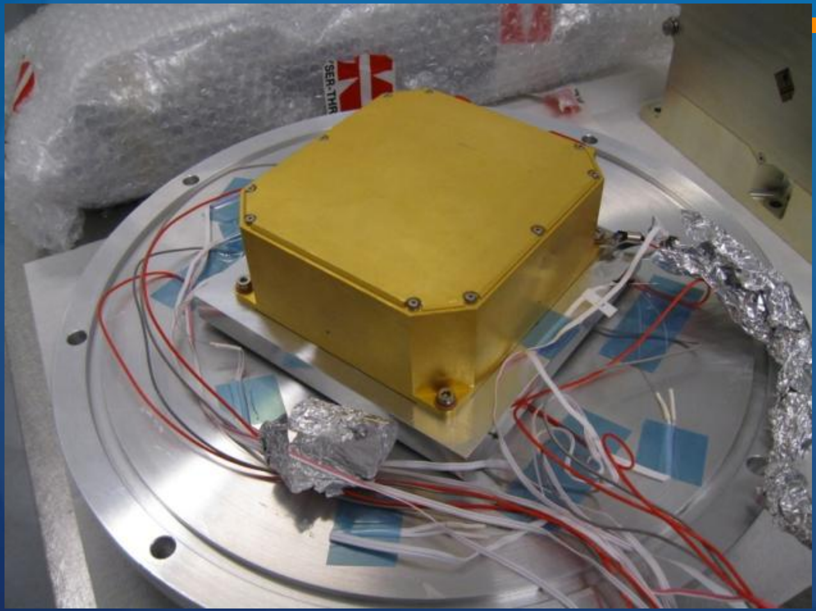
Demonstrated Performance

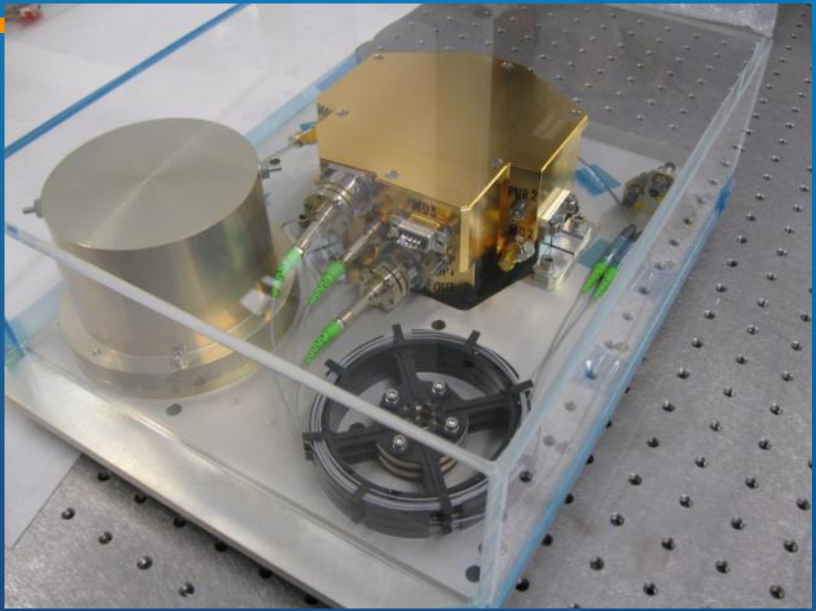
LISA’s 10 pm/√Hz

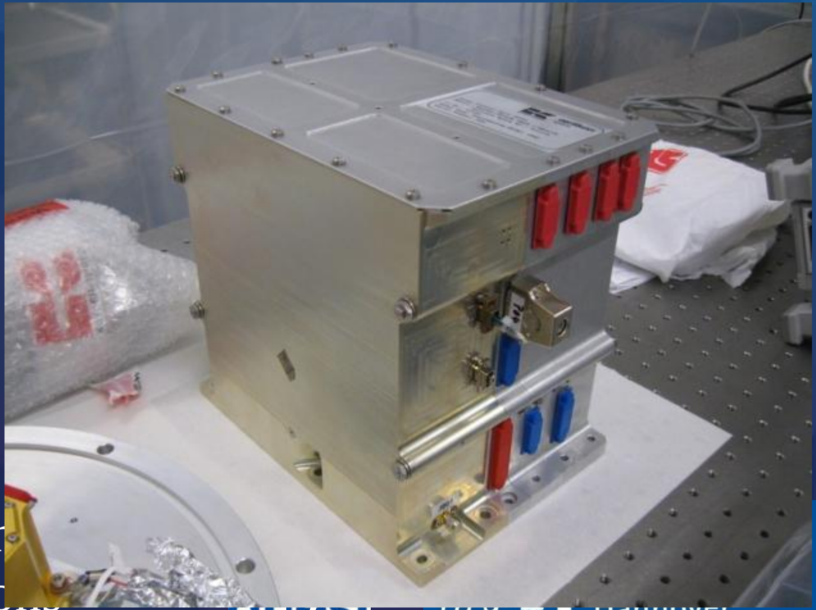


- Engineering model of the full interferometer system of LISA Pathfinder:
  - Local test mass to spacecraft interferometer
  - Test mass to test mass interferometer

LPF Laser: same as LISA Master Laser

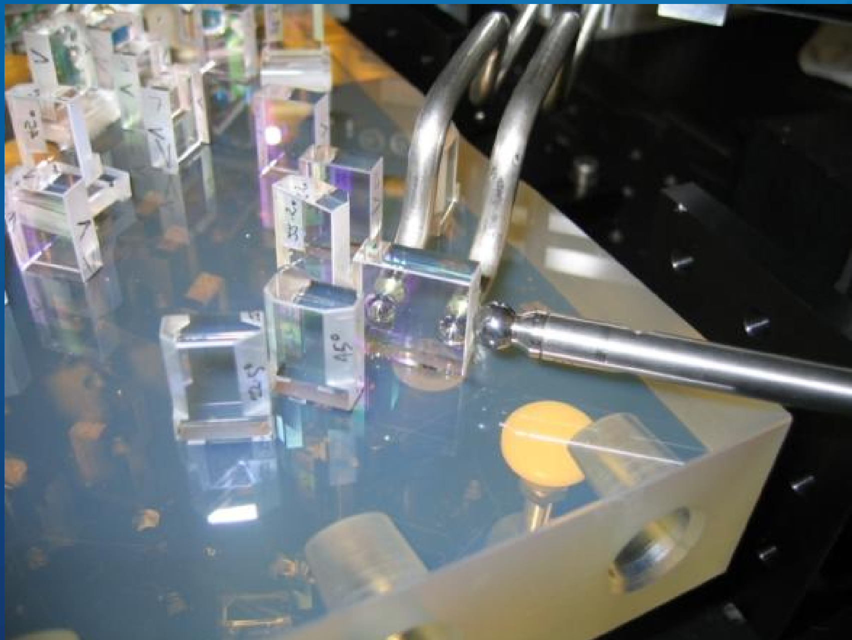


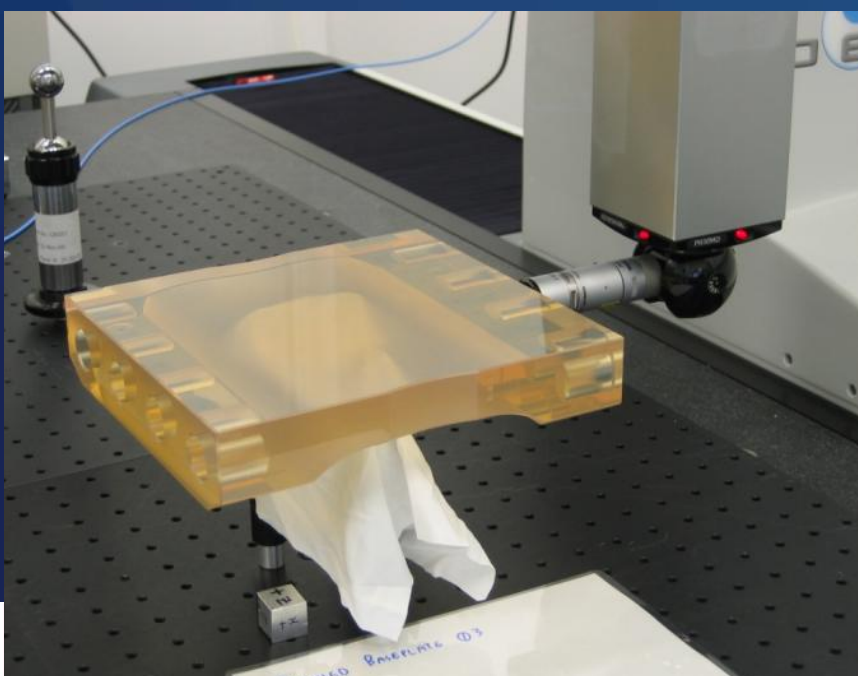


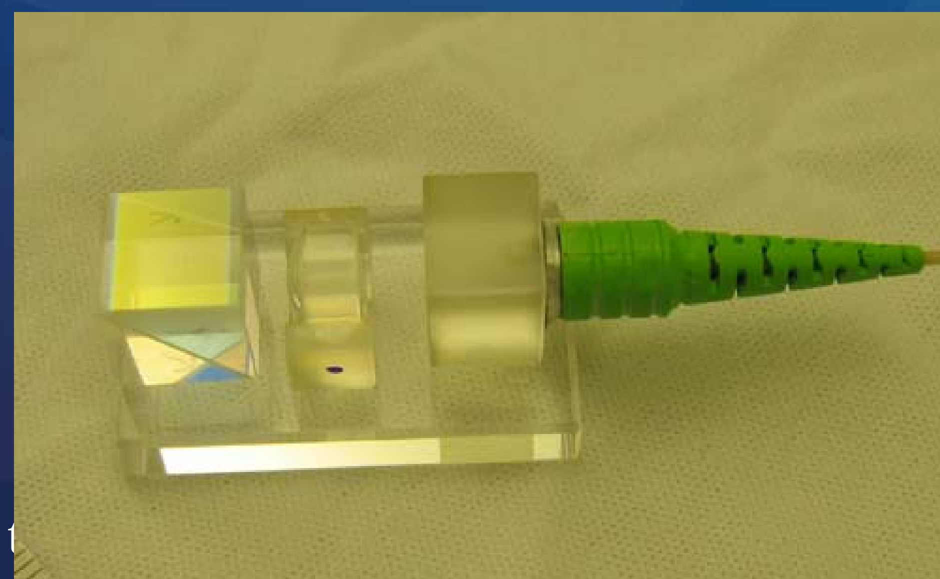


- 25…50 mW
- Nd:YAG (1064 nm)
- Redundant pump module
- Actuators for frequency and anplitude stabilization

High Stability Monolithic Optical Structures: Same Technology as for LISA

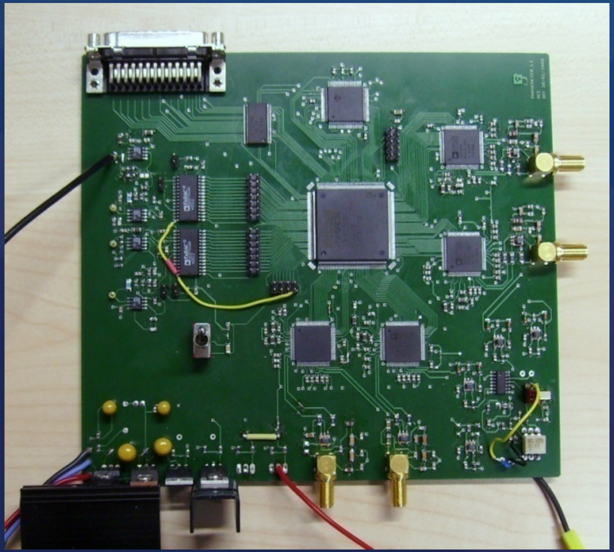


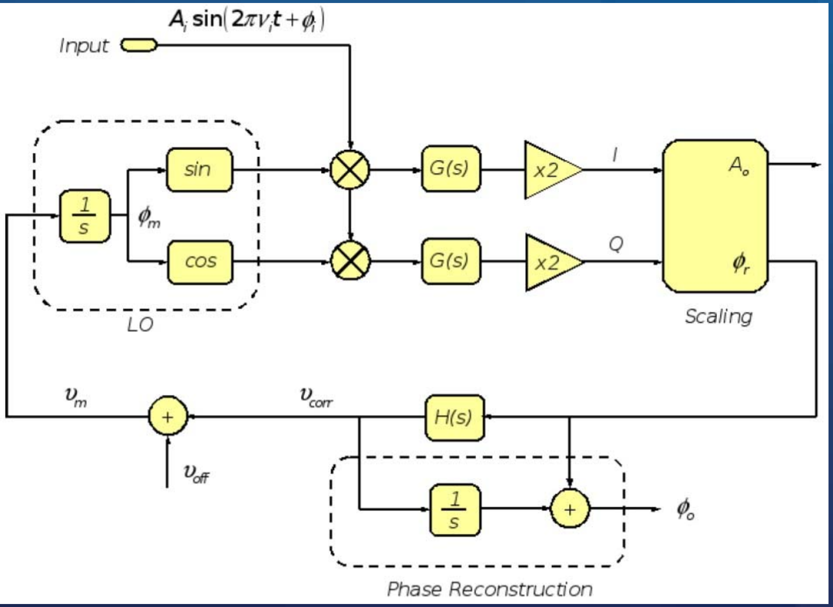




phasemeter

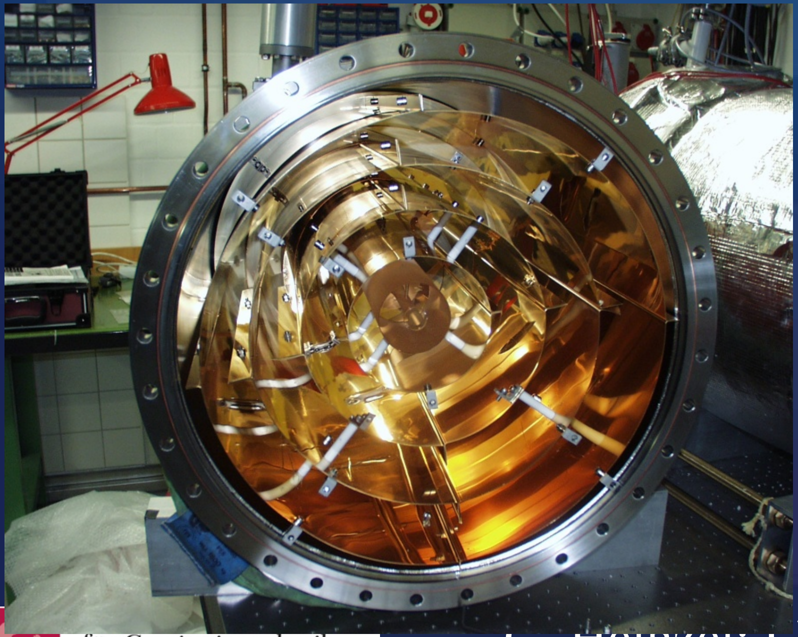
- Same as LISA: Digital PLL
- Fast ADC samples beatnote, servo makes NCO (numerically controlled oscillator) track the input
- Breadboards for LISA exist and work fine.
- Extra functions: data transfer, ranging timestamps and clock synchronization

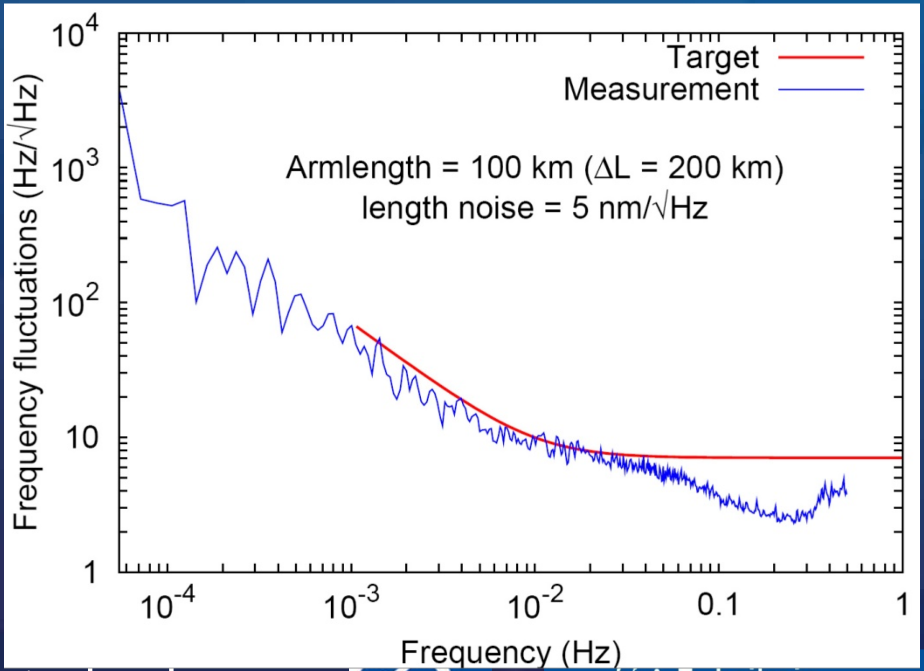




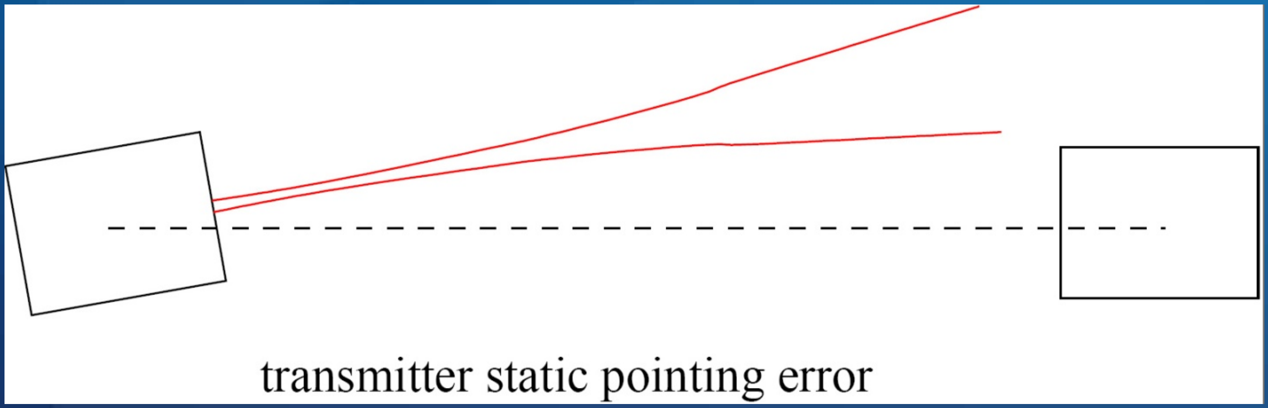
Laser frequency stabilization

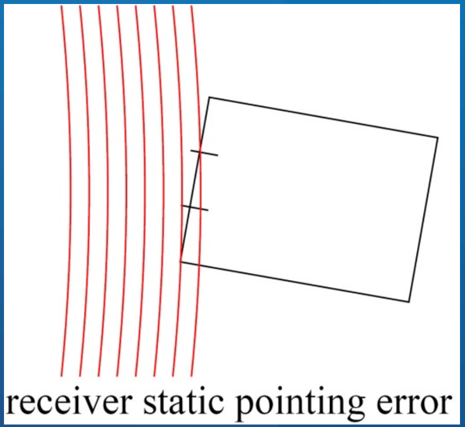
- Armlength is effective pathlength difference
- Direct coupling of laser frequency noise into length measurement
- LISA tricks not applicable here
- Required stability is achievable but not easy

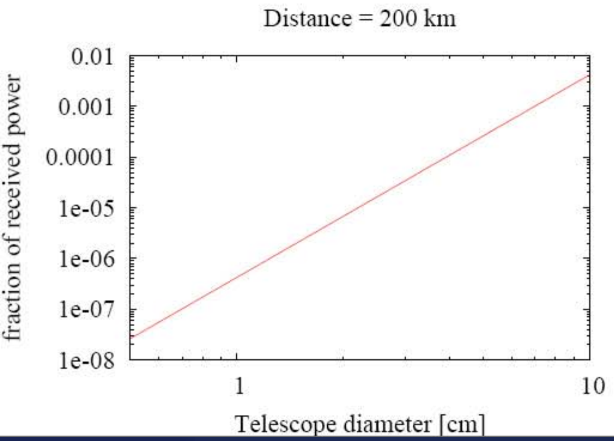


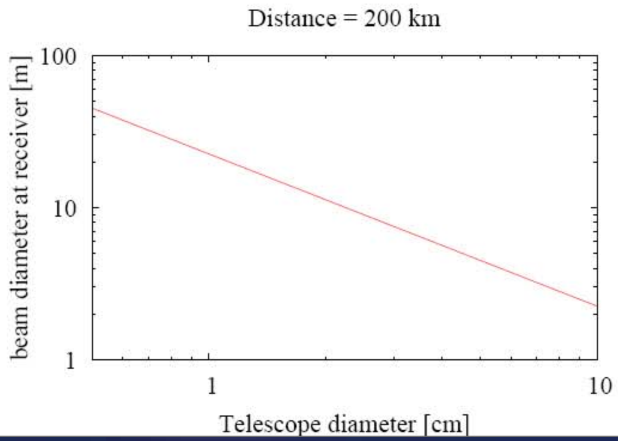


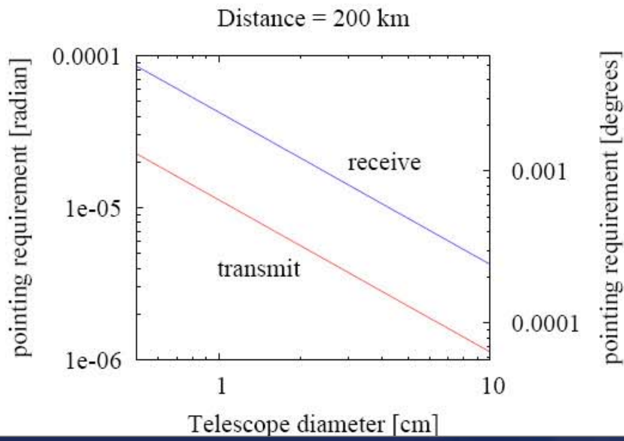
Pointing requirements



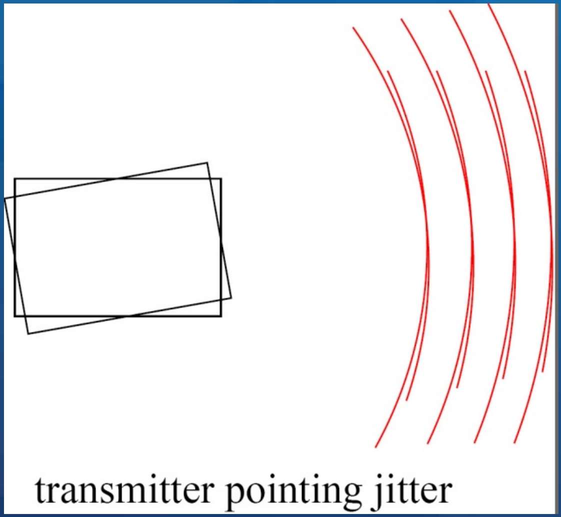


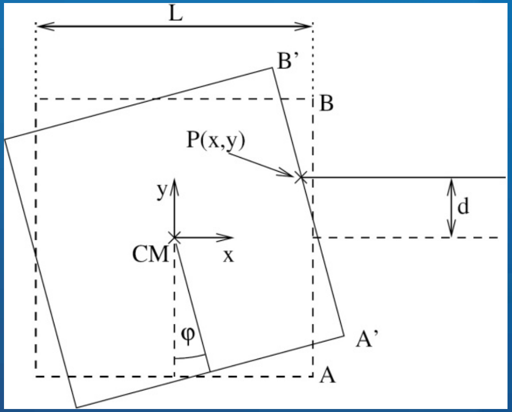






Ponting jitter causes length noise





- Interferometer gives excellent error signal (receiver)
- Need fast, wide-range actuator to react
- Some compensation by optical design possible
- THE main design challenge in our view.

Thank you for your attention!