Toward LISA in the USA

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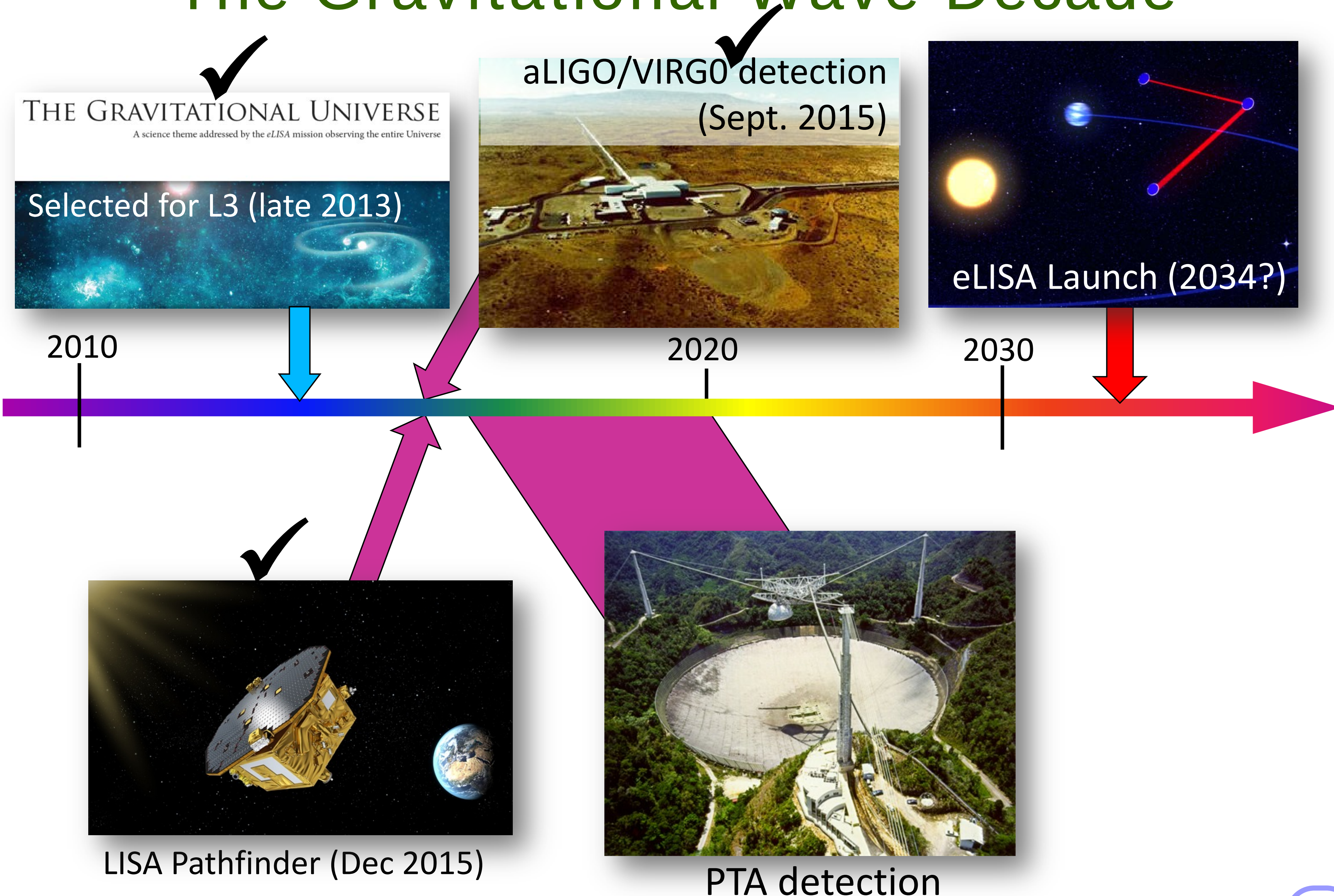
The Gravitational Wave Decade



Recent Developments in the U.S.

- Astronomy mid-decadal review (National Academy)
  - Congressionally mandated check on NASA's compliance with the 2010 decadal (NWNH)
  - Committee: 14 members (Rai Weiss, Neil Cornish, ...)
  - Held 3 meetings + 1 symposium (Danzmann): Oct 2015 - Feb 2016
  - Final report delivered to NASA now-ish
- NASA L3 Study Team

NASA L3 Study

- The L3 Study is:
  - Realization of the study promised in the plan for NWNH
  - Endorsed by the GWSIG, PhysPAG and Astrophysics Subcommittee

- Purposes of the study:
  - Phase 1 - FY16-17: Analyze the options for NASA participation in the L3 & work with the eLISA consortium on proposals to ESA
  - Phase 2 - FY17-18: Prepare report for 2020 decadal survey on NASA's participation in L3 as a minority partner

- 8th telecon was held last Friday

- 1st face-to-face meeting 19-20 April 2016, Salt Lake City

L3ST + TAG Members

L3ST

John Baker	GSFC
Peter Bender	U.C. Boulder
Emanuele Berti	U. Mississippi
John Conklin	U. Florida
Neil Cornish	Montana State U.
Curt Cutler	JPL
Kelly Holley-Bockelman	Vanderbilt U.
Scott Hughes	MIT
Shane Larson	Northwestern U.
Sean McWilliams	W. Virginia U.
Cole Miller	U. Maryland
Norna Robertson	Caltech
David Shoemaker (chair)	MIT
Ira Thorpe	GSFC
Michele Vallisneri	JPL

Technology Analysis Group

Jordan Camp	GSFC
William Klipstein	JPL
Jeffrey Livas	GSFC
Kirk McKenzie	JPL
Guido Mueller	U. Florida
John Ziemer	JPL

Working Groups

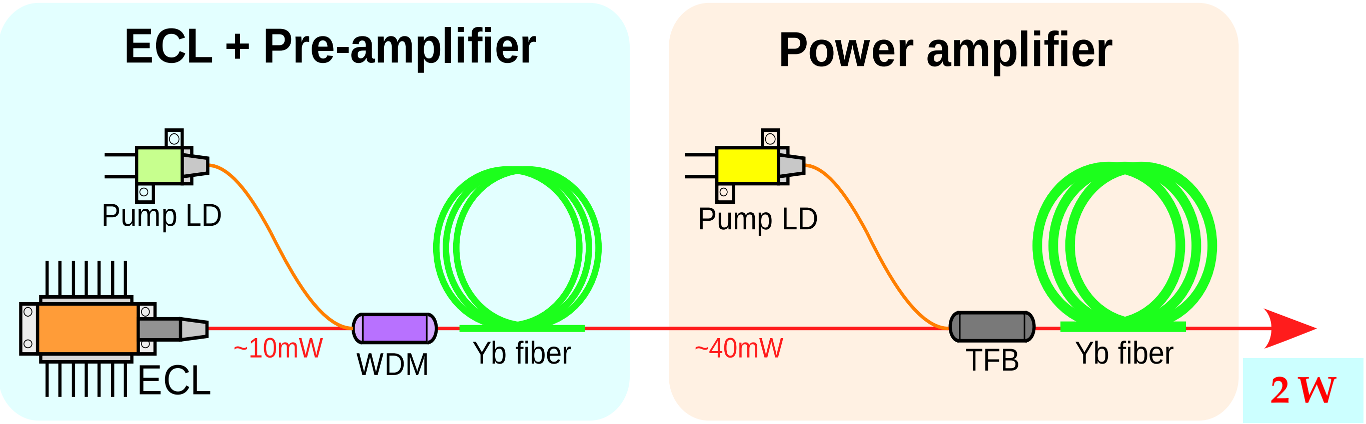
Astrophysical Sources	Shane Larson
Science Analysis	Scott Hughes
Instrumentation	John Conklin

- Study Scientist: Tuck Stebbins → Ira Thorpe
- Ex-Officio: Rita Sambruna, Ann Hornschemeier
- ESA appointed observer: Arvind Parmar

L3ST Technology Report

- 1st L3ST deliverable:
  - Analysis of candidate U.S. hardware contributions to L3
- Team has been focusing on various types of contribution
  1. 4 technologies with significant heritage & investment in the U.S.
     - Laser (GSFC)
     - Telescope (GSFC)
     - Phasemeter (JPL)
     - Thrusters (JPL/Busek)
  2. Other research activities in the U.S. that might benefit L3
     - Photoreceivers (GSFC)
     - Optical bench design/manufacturing (UF)
     - UV LED-based charge control (and torsion pendulum) (UF)

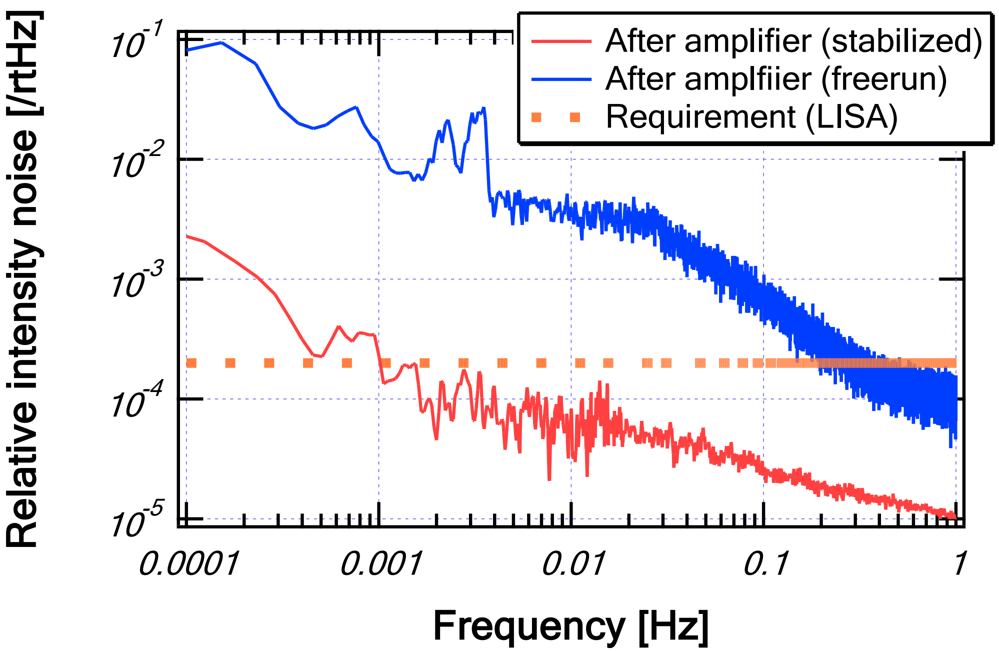
Fiber Laser, J. Camp (GSFC)

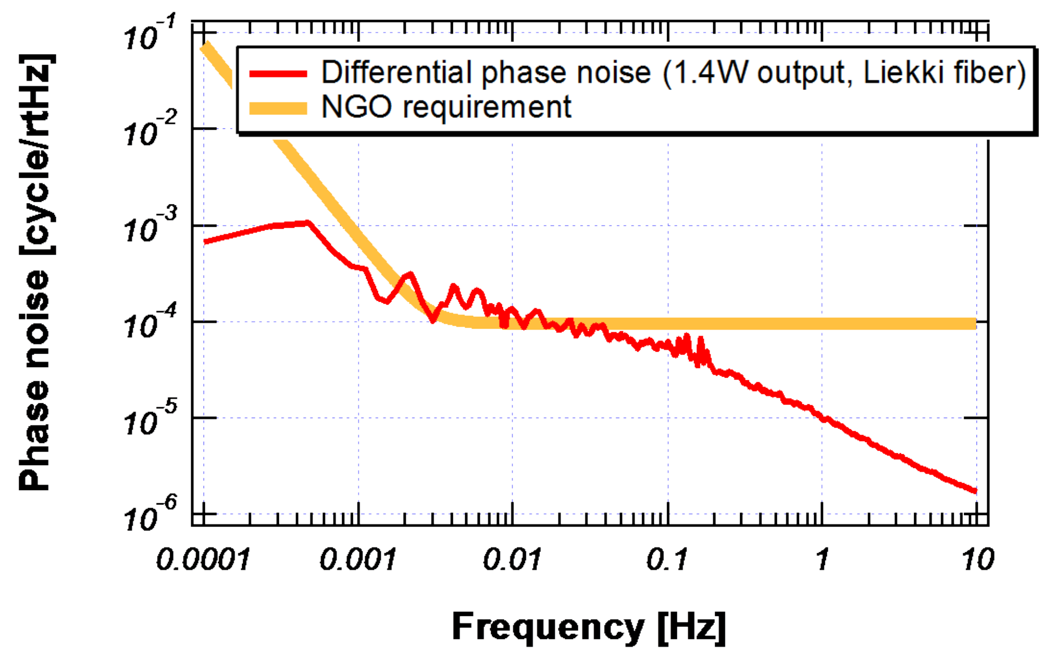


- Extended cavity laser diode (RIO)
- 1064 nm master oscillator power fiber amplifier design
  - Optimized for LISA
  - ~2 W output limited by fiber power density
- TRL 5 by FY2018

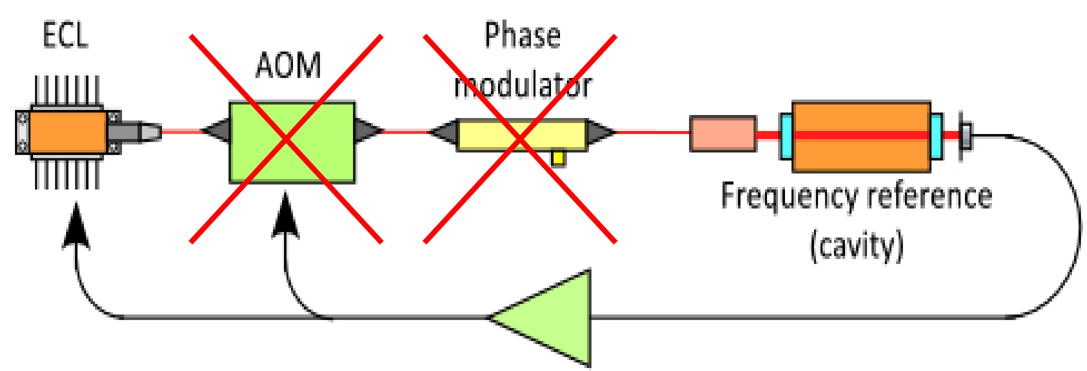
Fiber Laser Performance & Plans

- RIN and phase noise close to LISA specifications



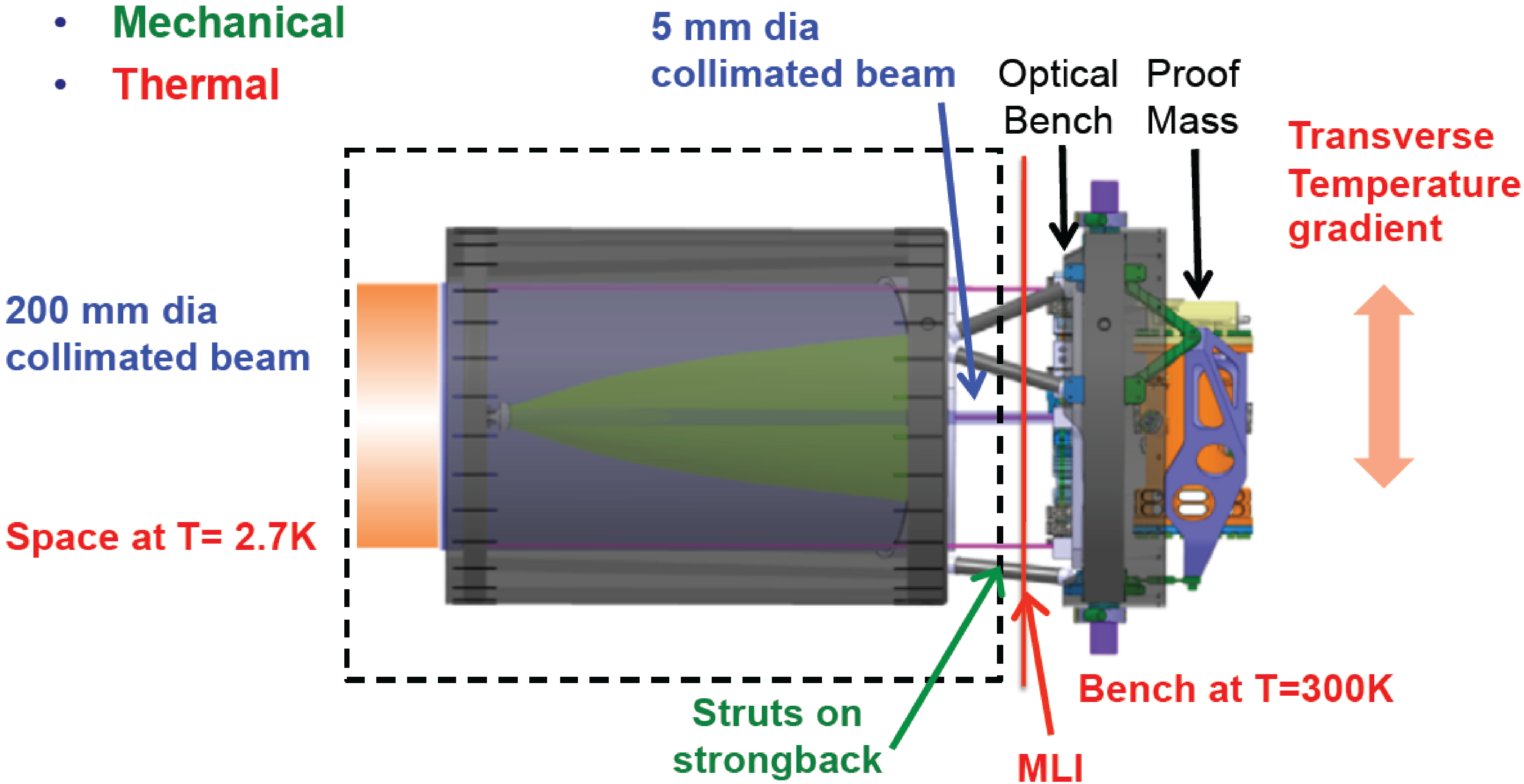


- Plans for FY2017
  - Integrated frequency mod. on diode gain chip
  - Accelerated aging tests



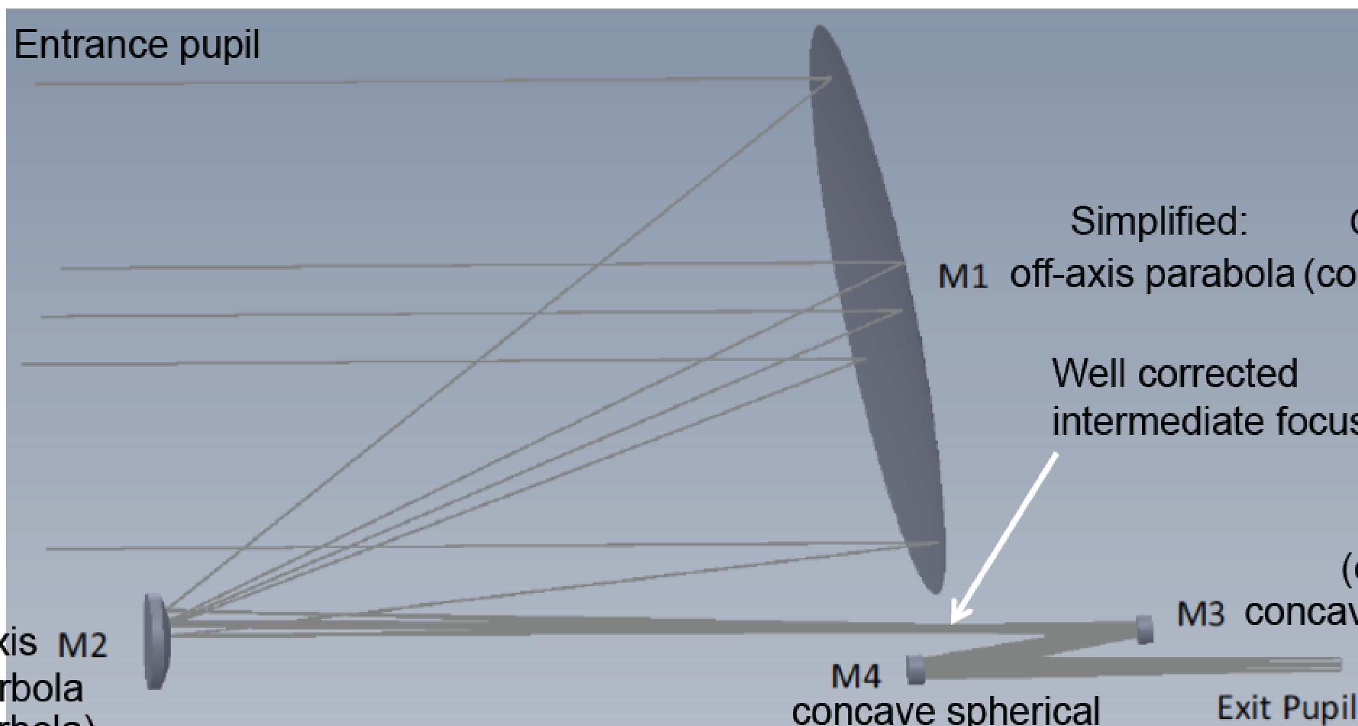
Telescope Development, J. Livas (GSFC)

- Goal: complete design meeting optical, mechanical, thermal, and stability requirements
  - Optical
  - Mechanical
  - Thermal

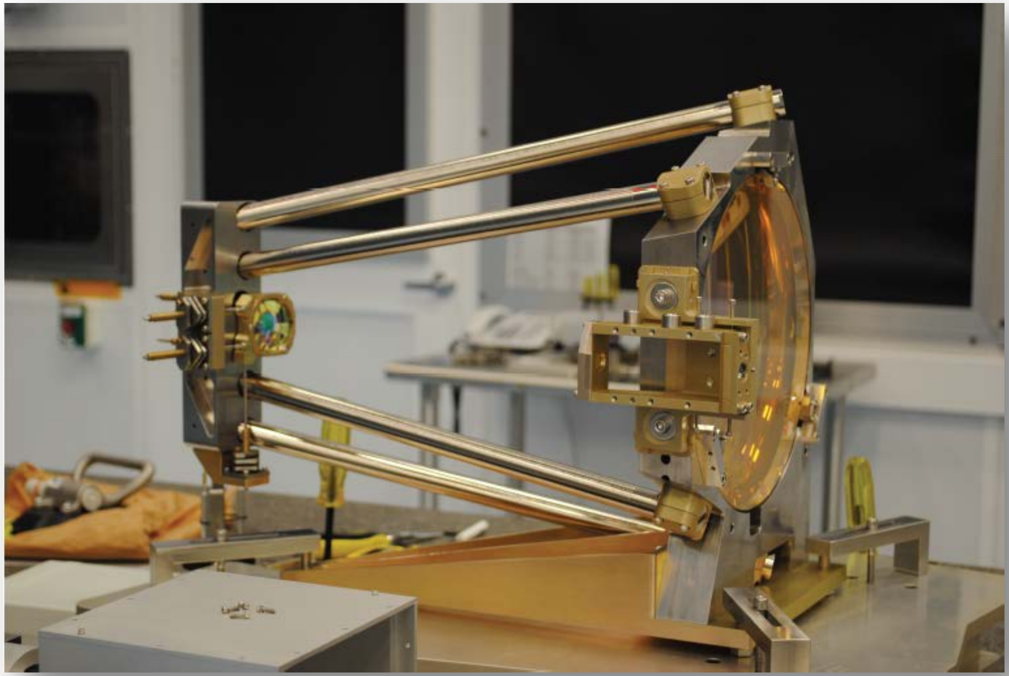


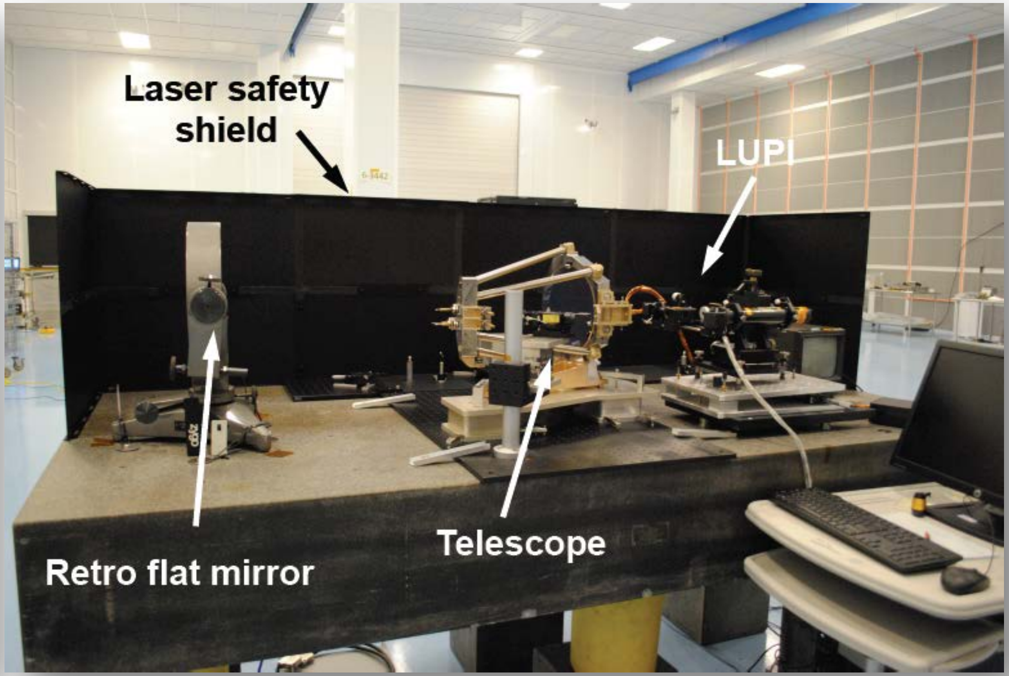
Telescope Design

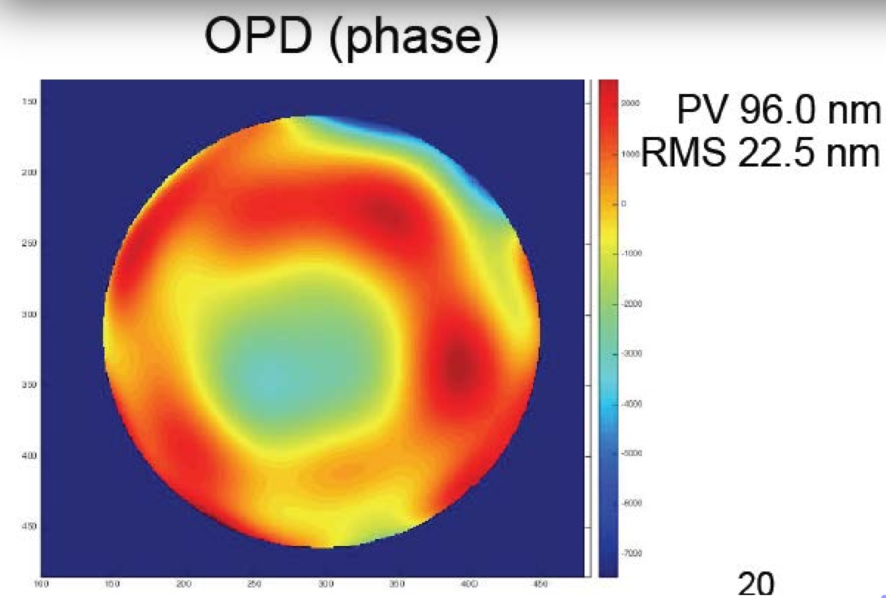
- SiC QuadPod spacer met pm/Hz$^{1/2}$ stability requirement (GSFC/UF)
- Scattered light requirement → off-axis
- Design: Off-axis Cassegrain+pupil extender



Telescope Prototype Testing







- "Diffraction limited"
  $\lambda/30$ @ 1064 nm = 35 nm
- Prototype meets spec
  - But OPD is wavelength dependent

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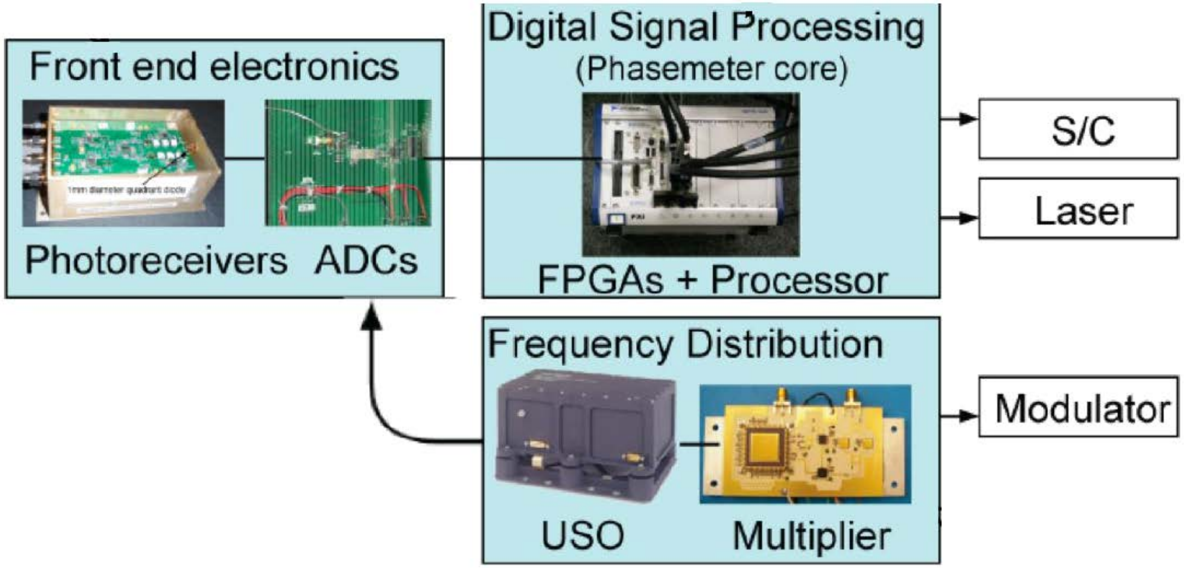
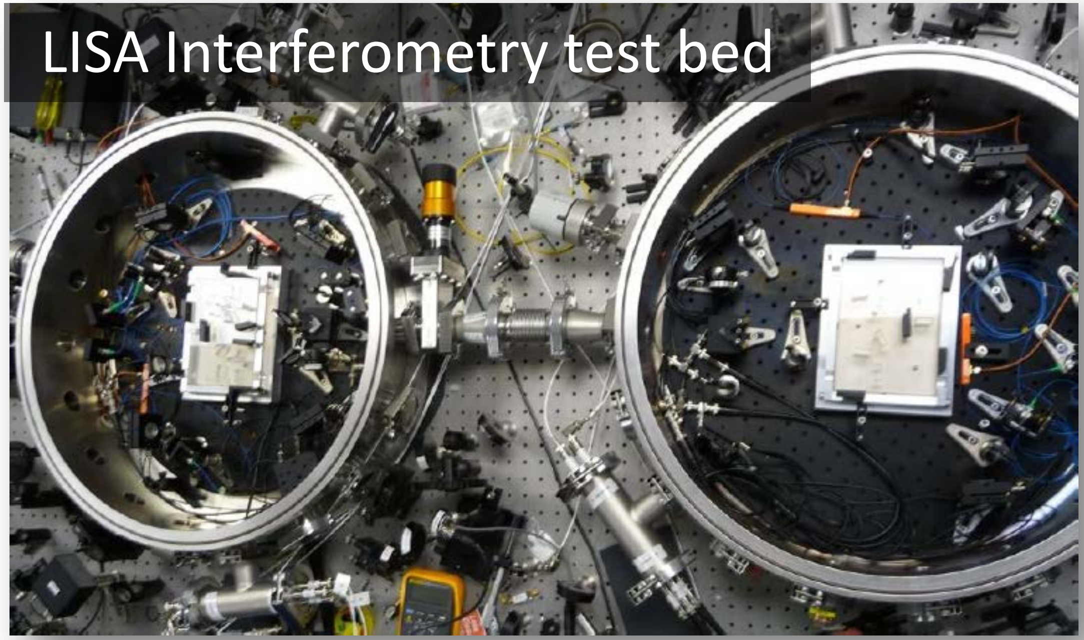
Phasemeter, W. Klipstein (JPL)

- Phasemeter functionality
  - Interferometer readout
    - mHz phase modulation on MHz Doppler beat
  - Stabilizes master laser to reference cavity
  - Offset phase locks slave laser to received signal
  - Differential wavefront sensing for pointing
  - Clock sidebands
  - Intersatellite range to 1 m for TDI
- All functions at TRL 4/5
  - Some TRL 9 from LRI

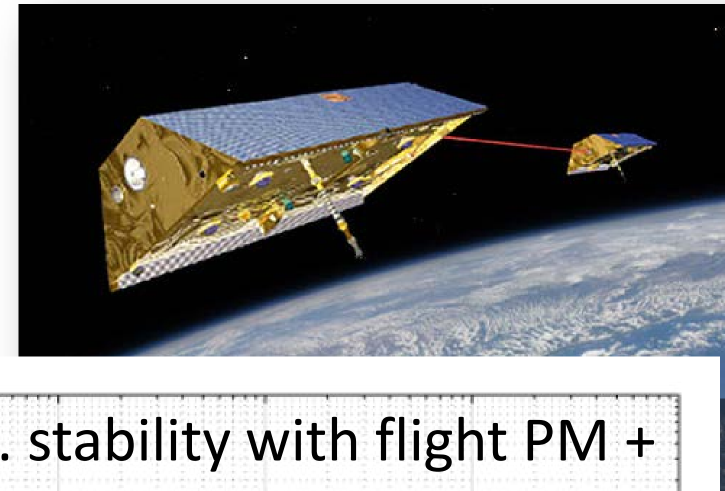


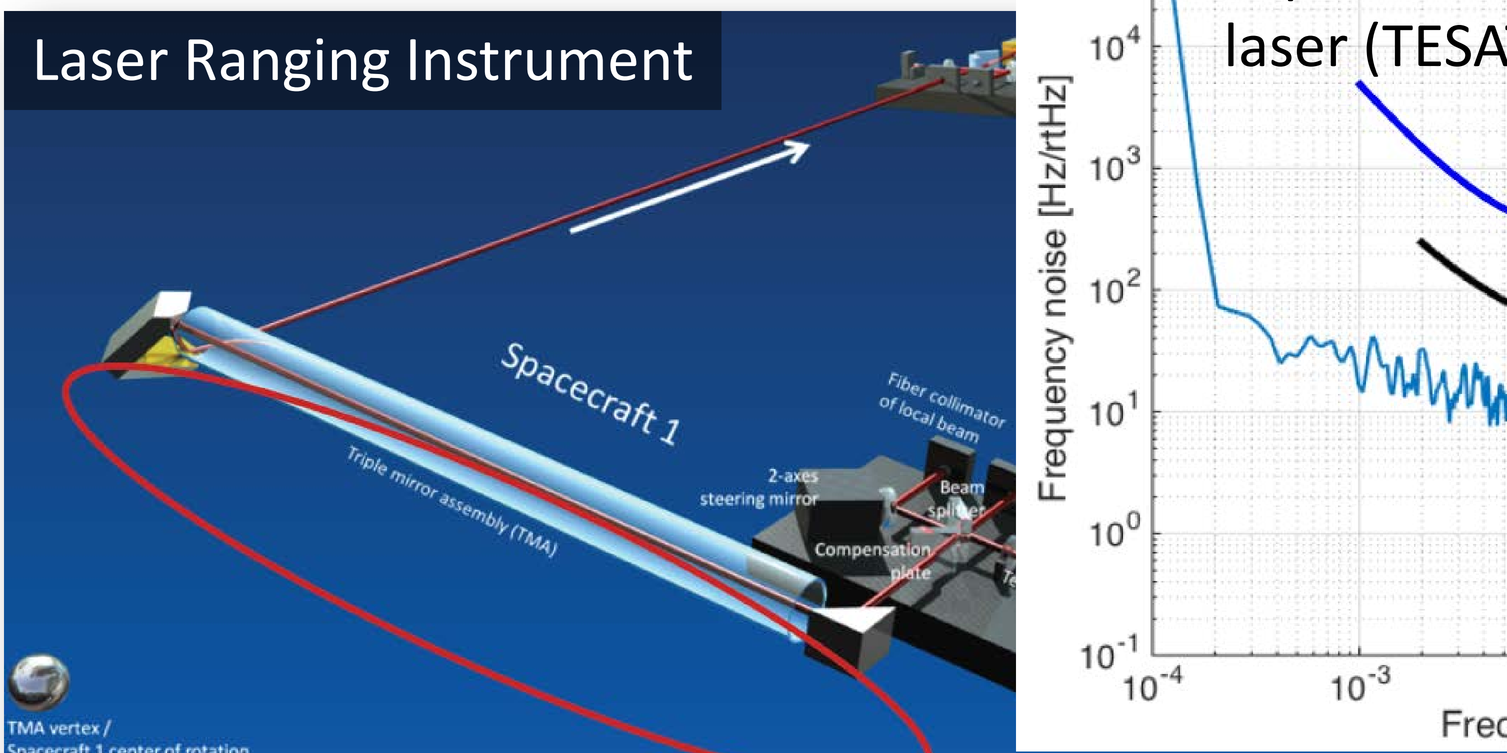


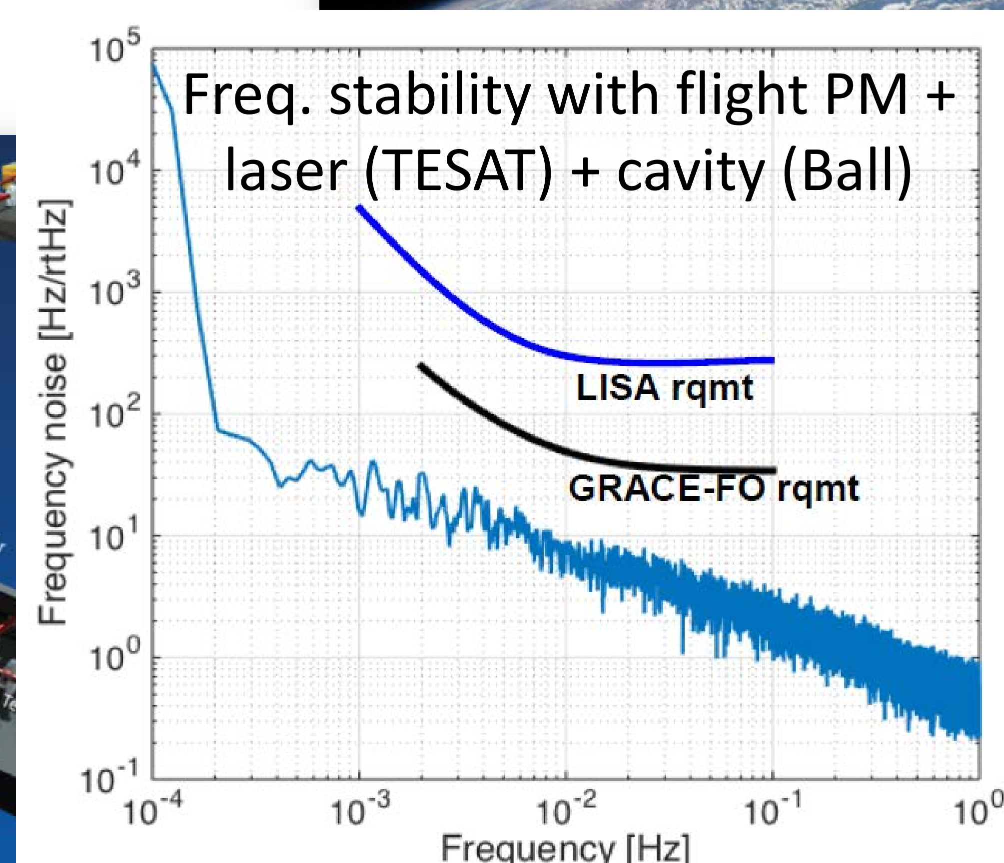
GRACE-FO Laser Ranging IFO

Klipstein (JPL), Heinzel (AEI), ...

- Partnership btw NASA & DLR
  - NASA/JPL: Phasemeter, laser, cavity
  - AEI/DLR/STI: Optical bench, photodetectors, TMA, baffles
- LRI PM is LISA-lite PM
- 2017 launch



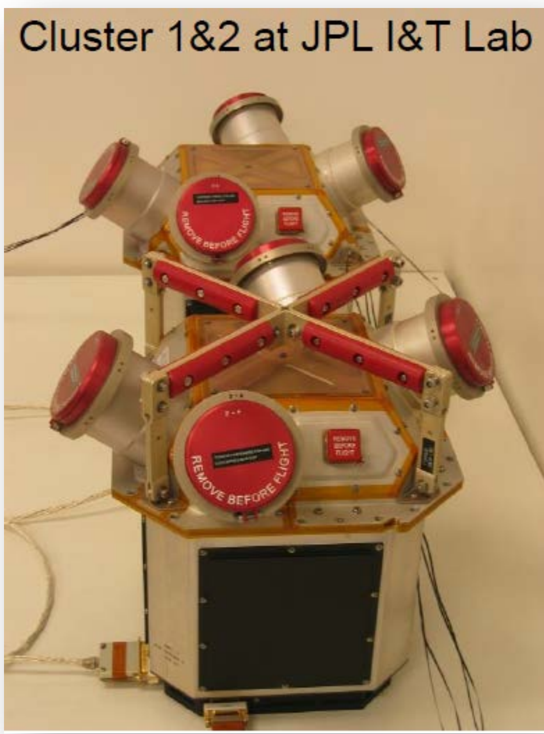


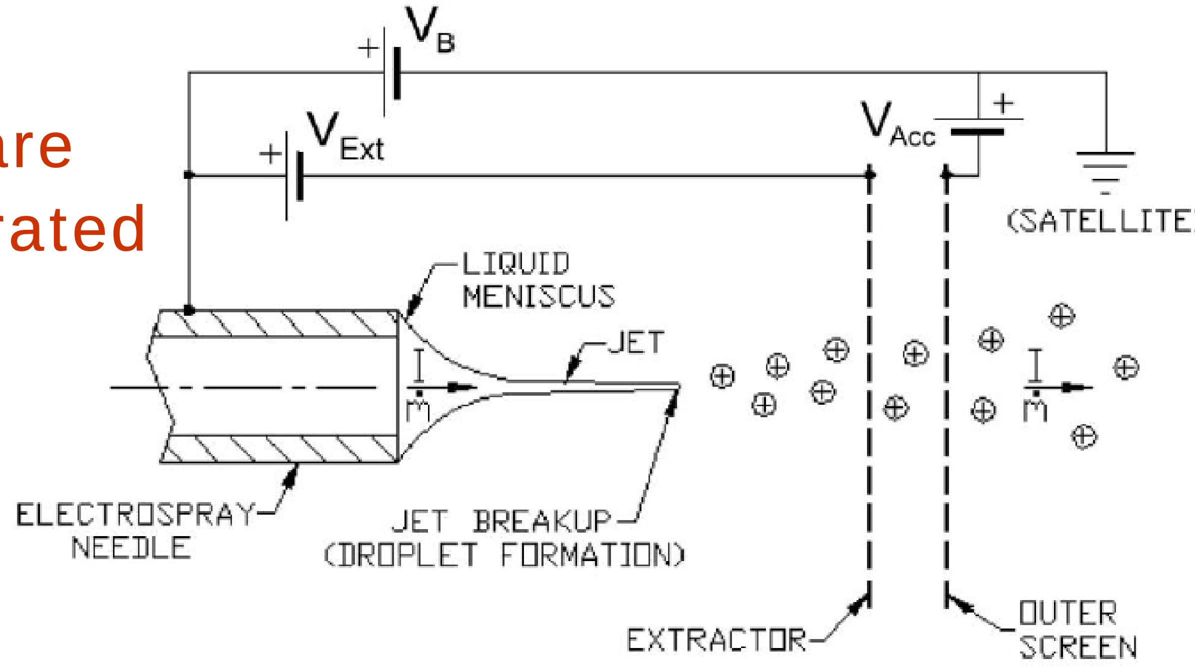


Colloid Micronewton Thrusters

J. Ziemer (JPL)

- Colloid thrusters emit charged droplets that are electrostatically accelerated
  - $Thrust \propto I_B^{3/2}\, V_B^{1/2}$





Images courtesy of Busek Co.

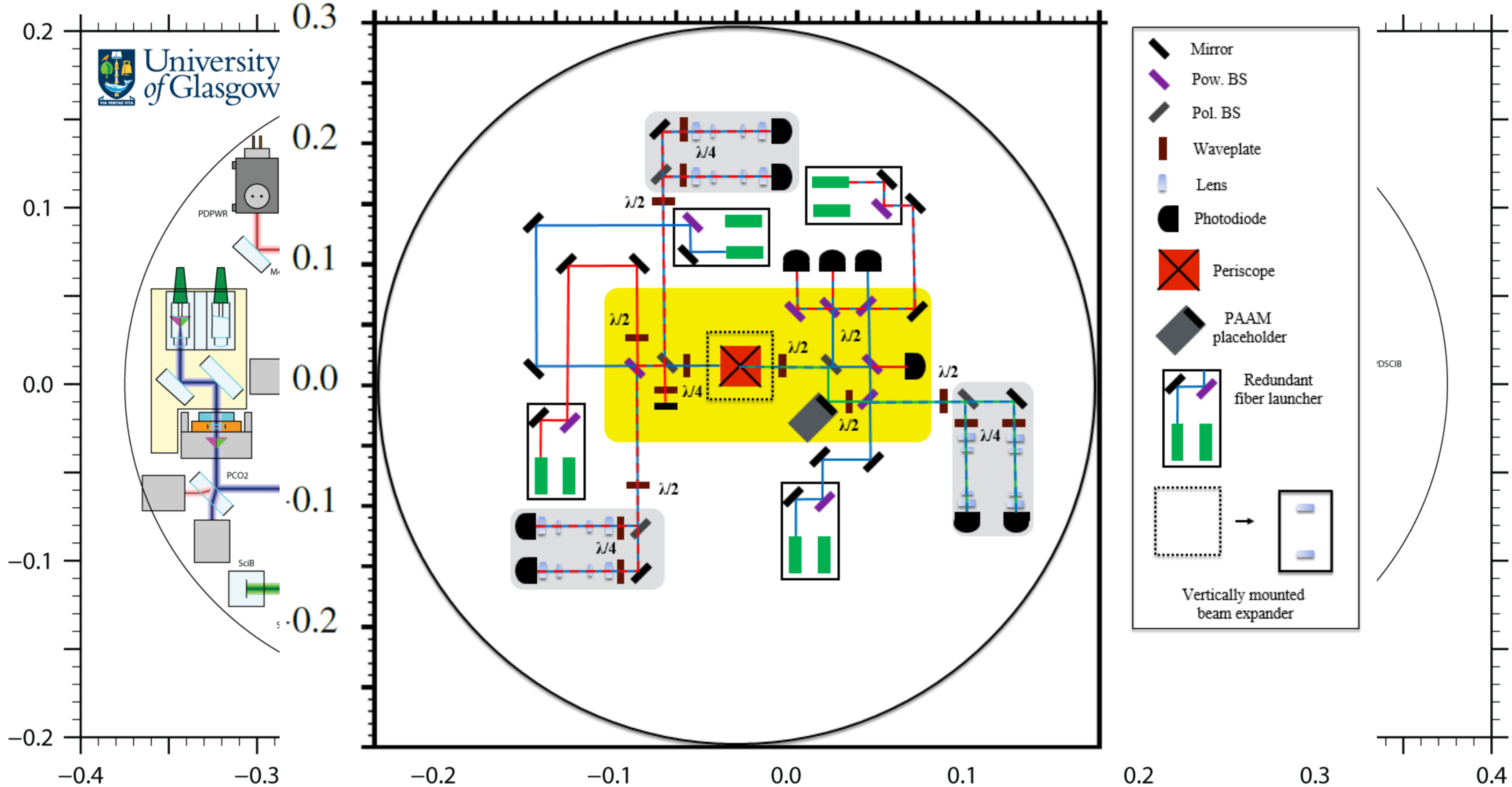
- Two LISA Pathfinder flight units
  - Maximum thrust: 30 µN
  - Thrust precision: 0.1 µN
  - Delivered in 2008

Status of Colloid Micronewton Thrusters

- CMNT at TRL 7
- LISA Pathfinder experience:
  - Thrusters stored with propellant loaded for 8 years
  - Startup took longer than expected for one thruster
  - Bubble dissipation took longer than expected, but progressed
  - All thrusters passed functional test and were considered as viable backup to cold gas for post-separation, de-spin, tip-off cancelation
- CMNT capable of meeting all LISA requirements
- To meet LISA lifetime:
  - Larger propellant tanks and full redundancy
  - Configuration and propellant loading to prevent bubbles
  - Lifetime model validation and verification with long-term testing

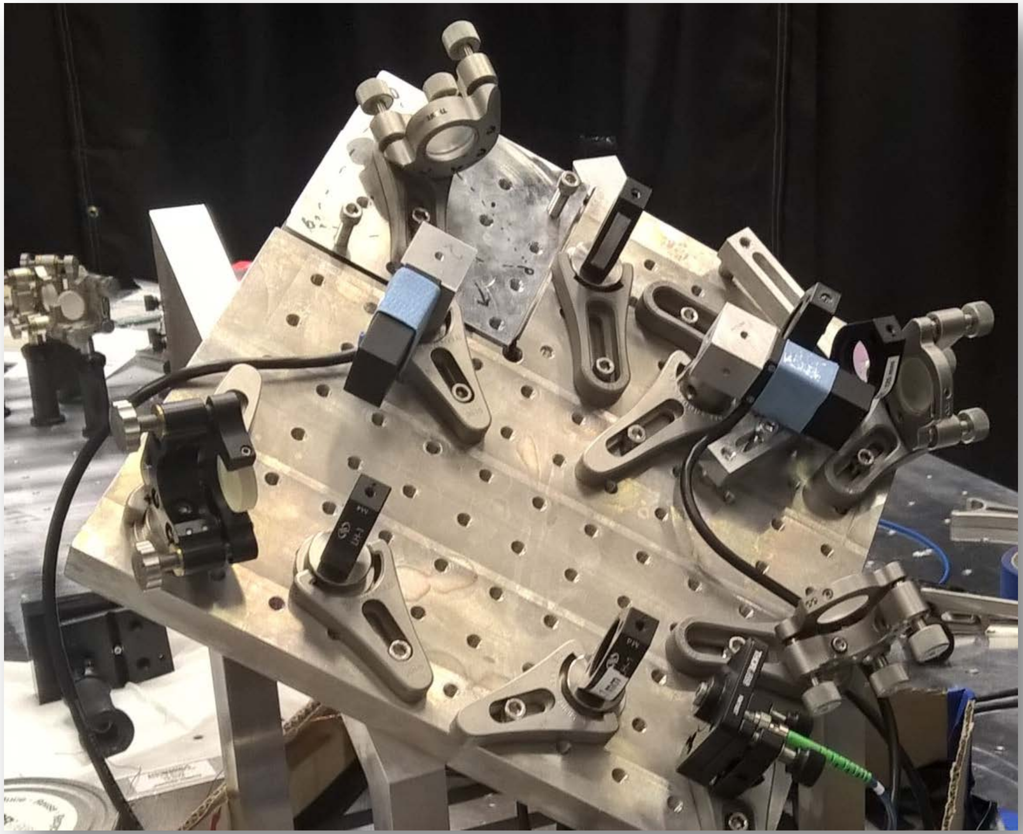
Modular Optical Bench G. Mueller (UF)

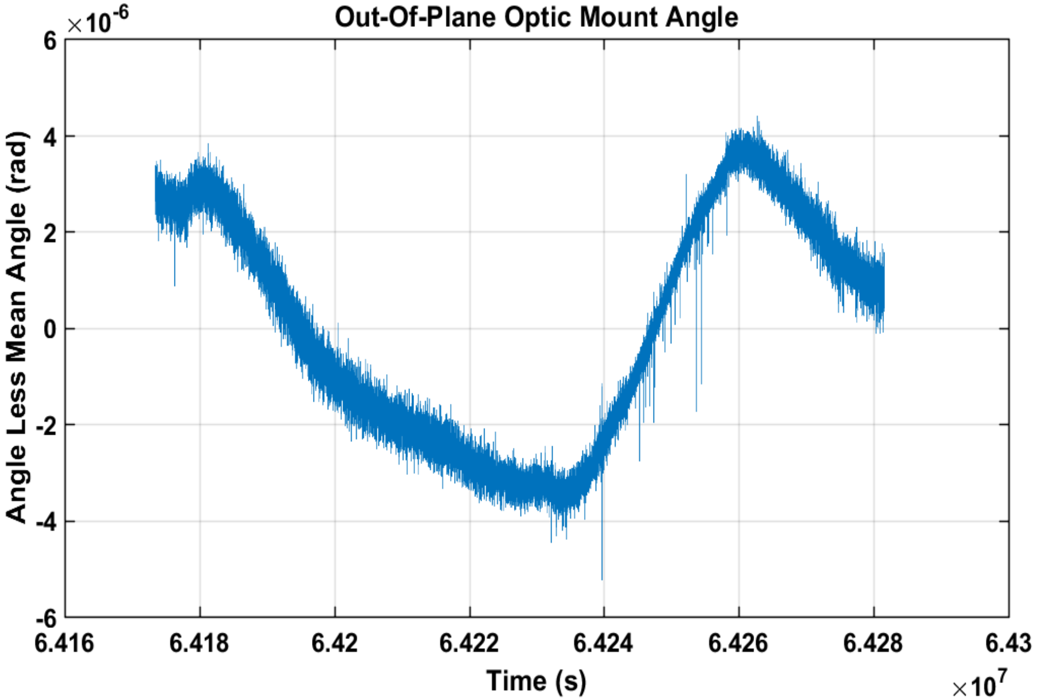
- 1 pm/√Hz stable regions clamped to 10 µm, 10 µrad base
- Functional blocks (i.e. local IFO) developed, tested and integrated separately



Testing Commercial Optics & Mounts

- Aluminum bench → molybdenum bench (few months)
- Test optic remove/replace with 0.3 µm, ~µrad repeatability
- Position sensor measures optic displacement & orientation



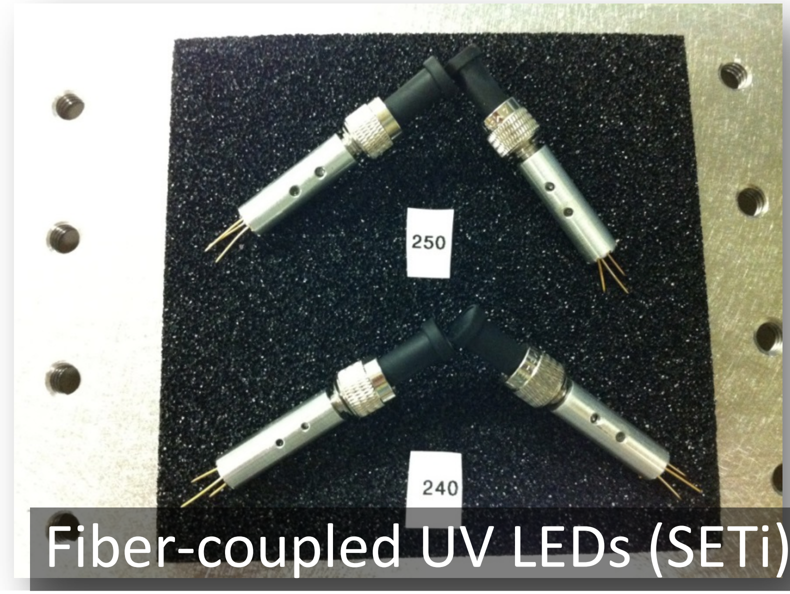


Orientation stability: ~5 µrad (temperature correlated)

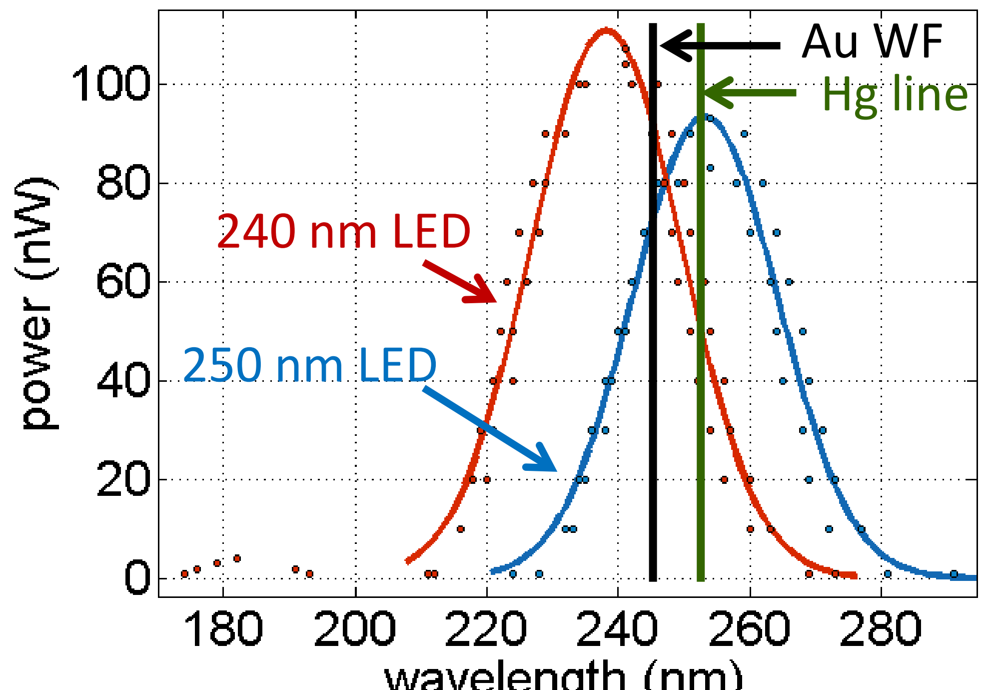
Position stability: ~0.3 µm

UV LED-based Charge Control J. Conklin (UF)

- TM charges due to release after launch & cosmic rays (50 e/s)
- Charge increases electrostatic stiffness & interacts with *E* fields
- TM Charge control via UV photoemission demoed by GP-B
- UV LEDs are attractive alternate to Hg lamps
  - 240 ± 10 nm UV LED
    < Au work function 243 nm
  - ~10x reduction in SWaP
    (~150 mW in → 25 μW out)
  - Enables AC charge control

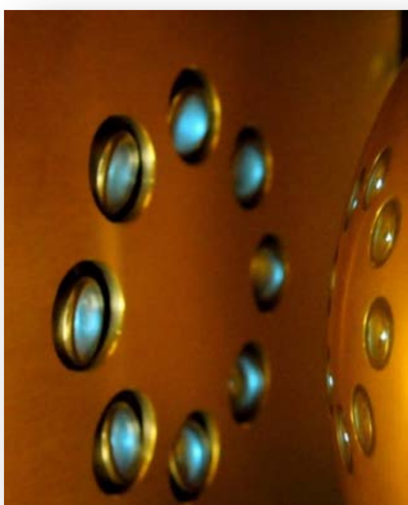


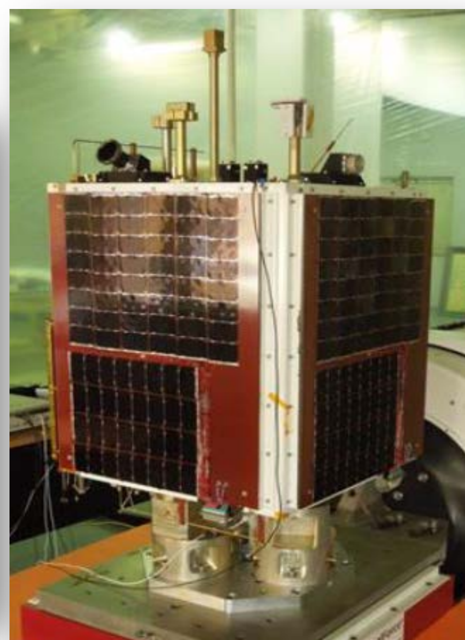
Fiber-coupled UV LEDs (SETi)



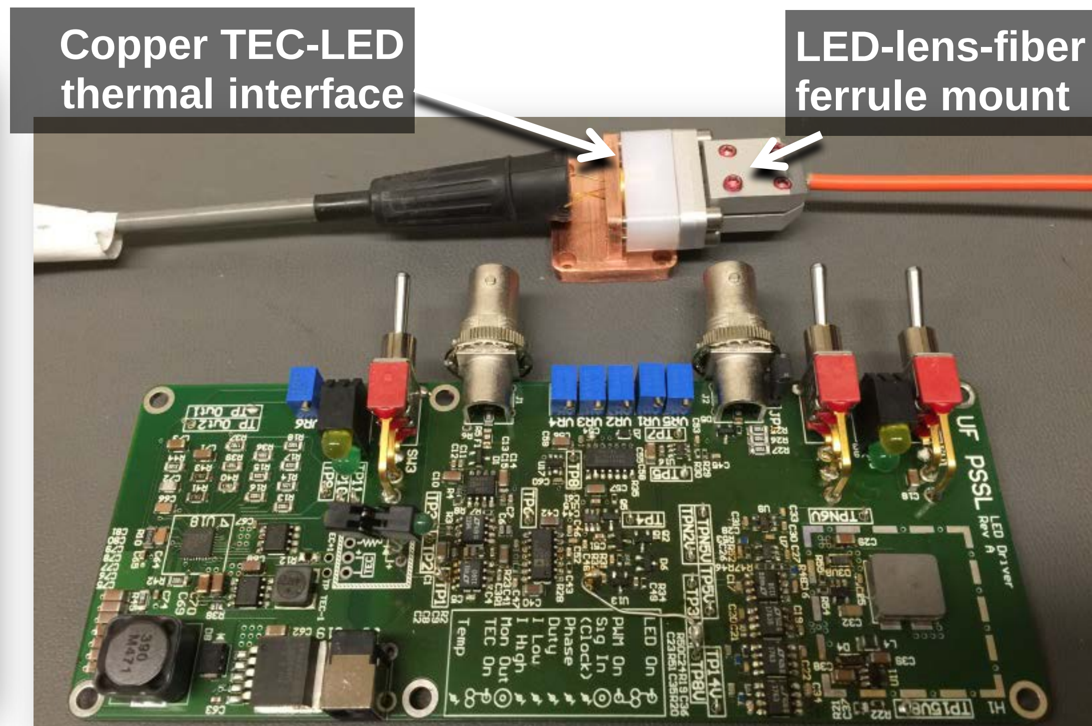
UV LEDs in Space

- UV LED Small Satellite – 19 June 2014 launch
  - Stanford, NASA Ames, KACST collaboration
  - Successful demo of UV LED-based charge transfer in space
- Space capable UV LED driver electronics / fiber coupler (UF)





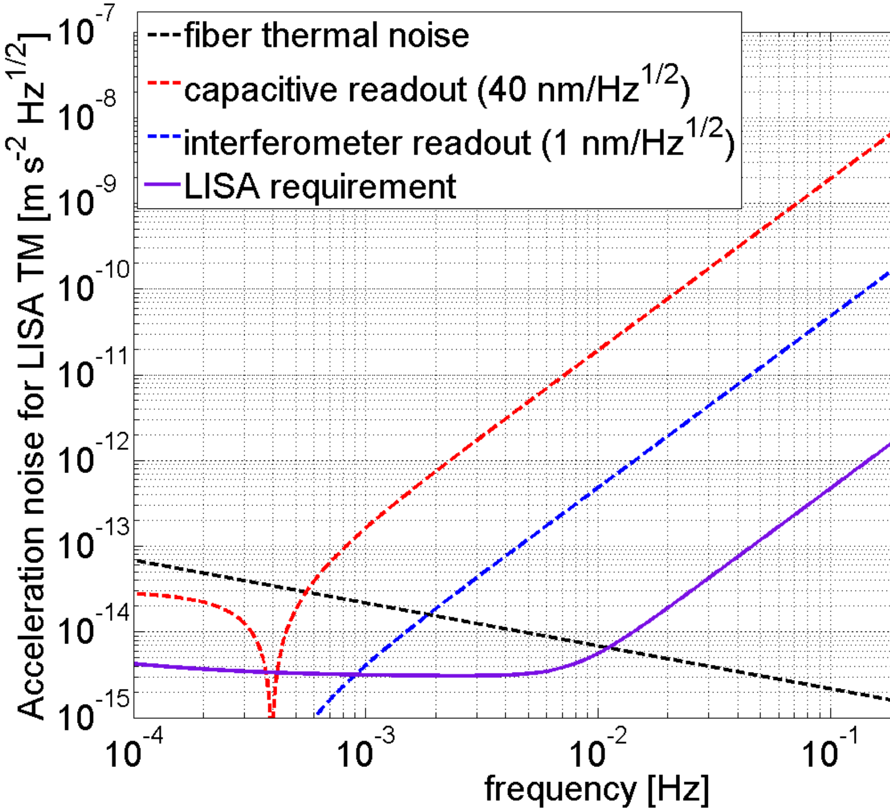
UV LED payload & Saudi-Sat4



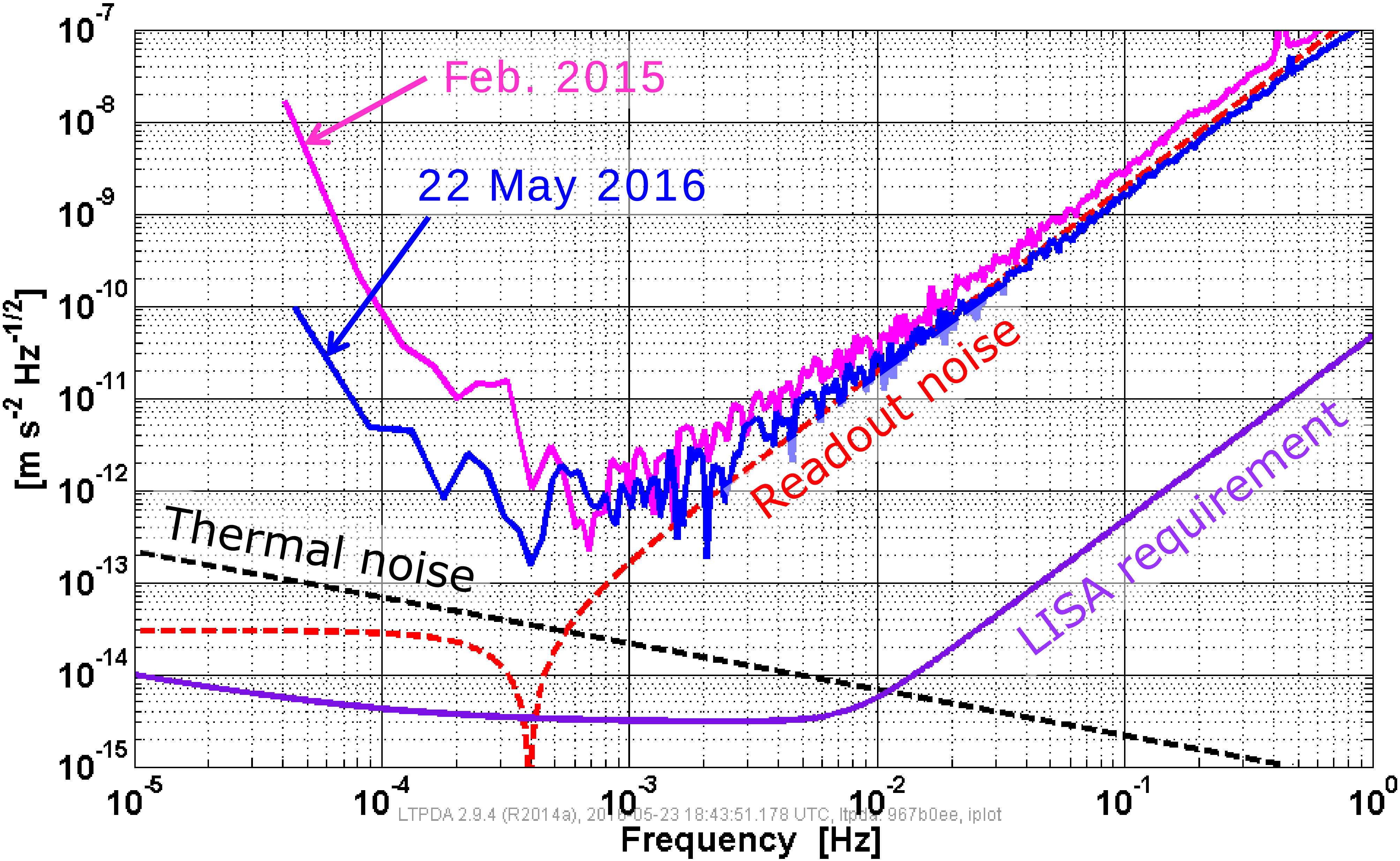
Initial UV LED driver & fiber coupler

UF Torsion Pendu

- Follows 4TM Trento pend
  - Fiber supports cross bar w
    4 hollow TMs (rotation → t
  - Light weight (0.46 kg) Al s
    reduces needed fiber diam
  - Measures surface forces



Equivalent LISA TM Acceleration Noise

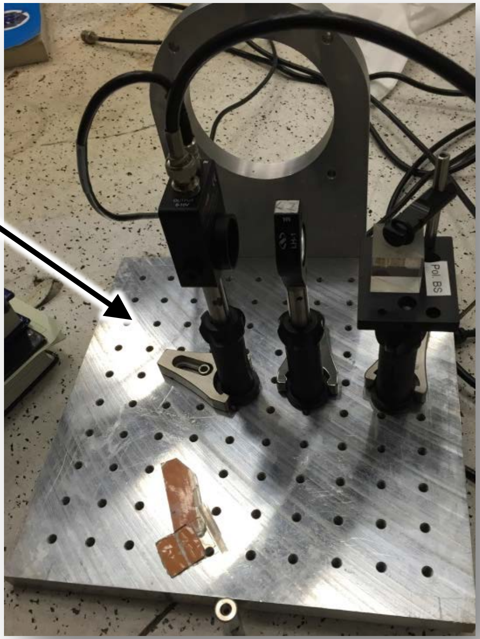


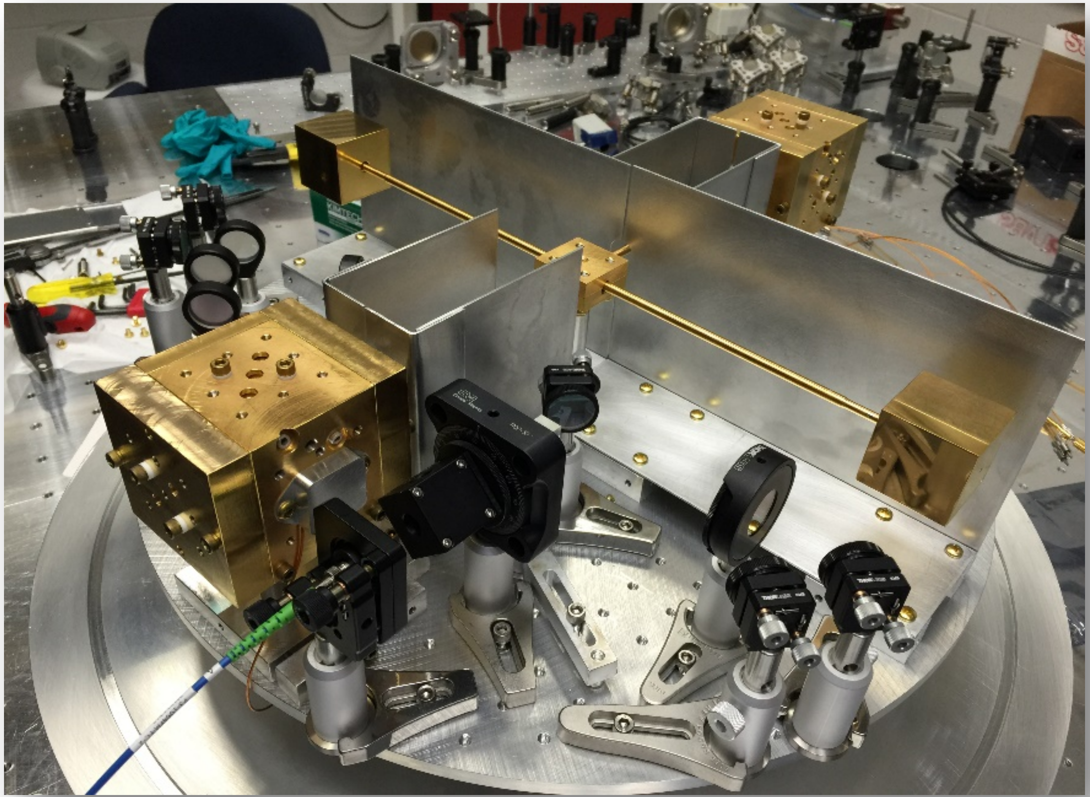
Interferometer Readout

- Polarization multiplexed Mach-Zehnder interferometer measures differential displacement of two test masses
- Light delivered by fiber feedthrough
- Recombined beam sensed outside chamber (free-space)
- Typical sensitivity:

  250 pm/Hz$^{1/2}$

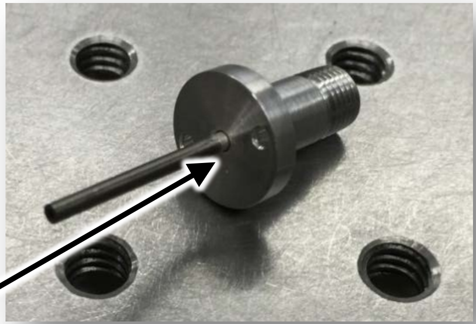
External bench



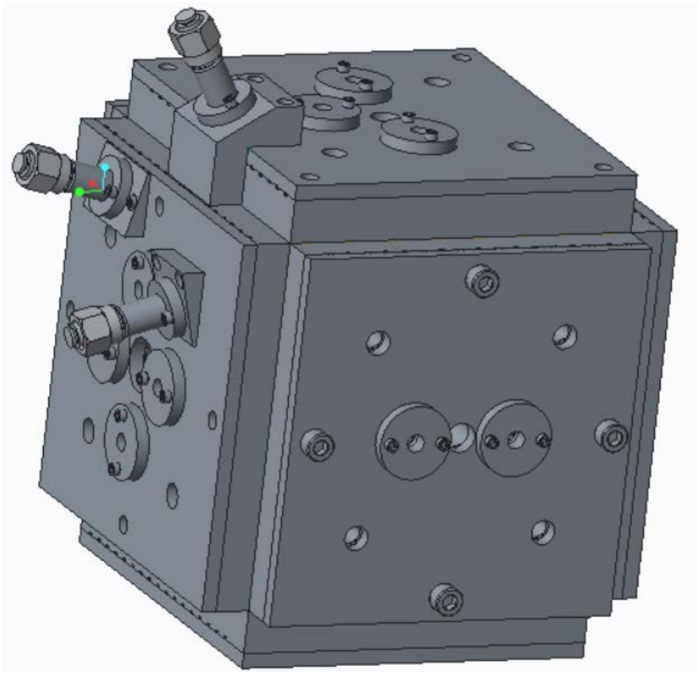


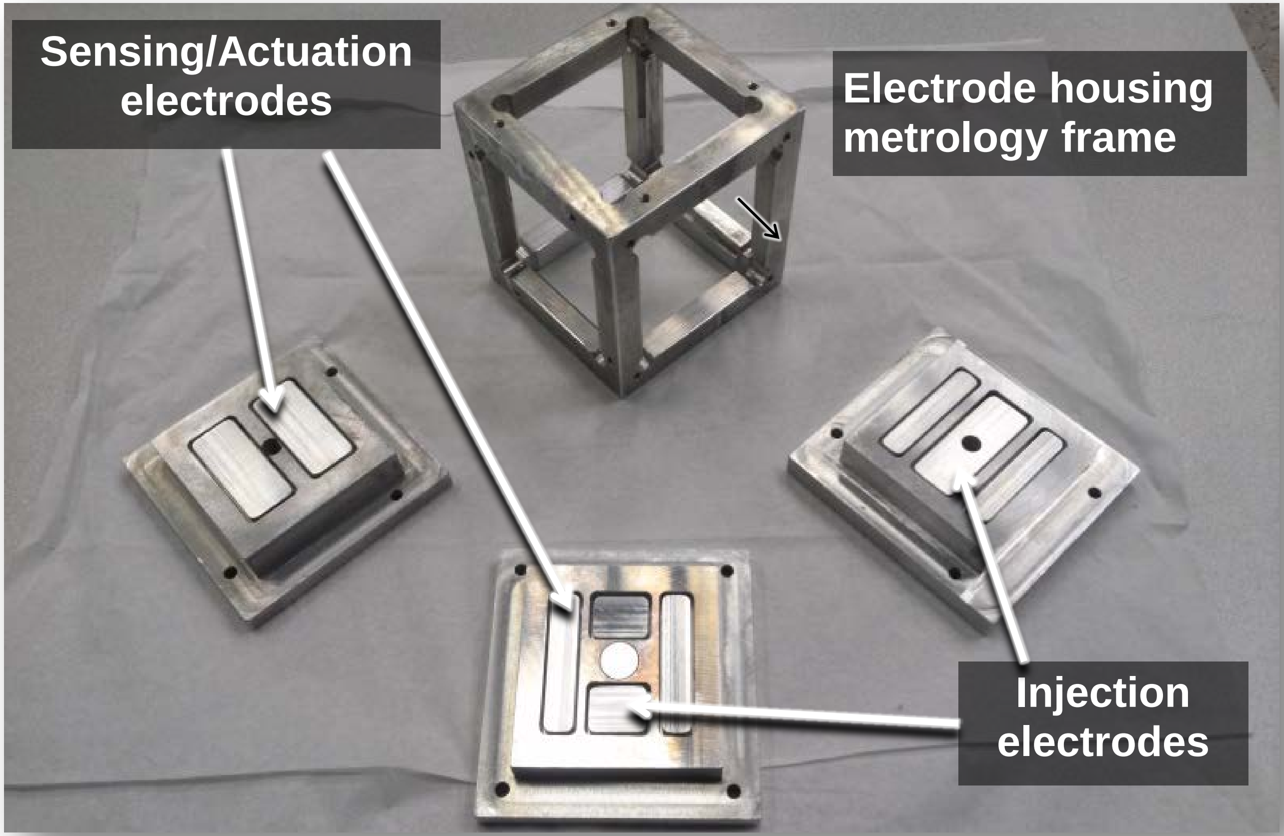
Updated GRS Model

- Internal geometry same as Pathfinder
- 3 UV light injection ports
- Prototype: Aluminum + PEEK
- Integrated into pendulum late summer



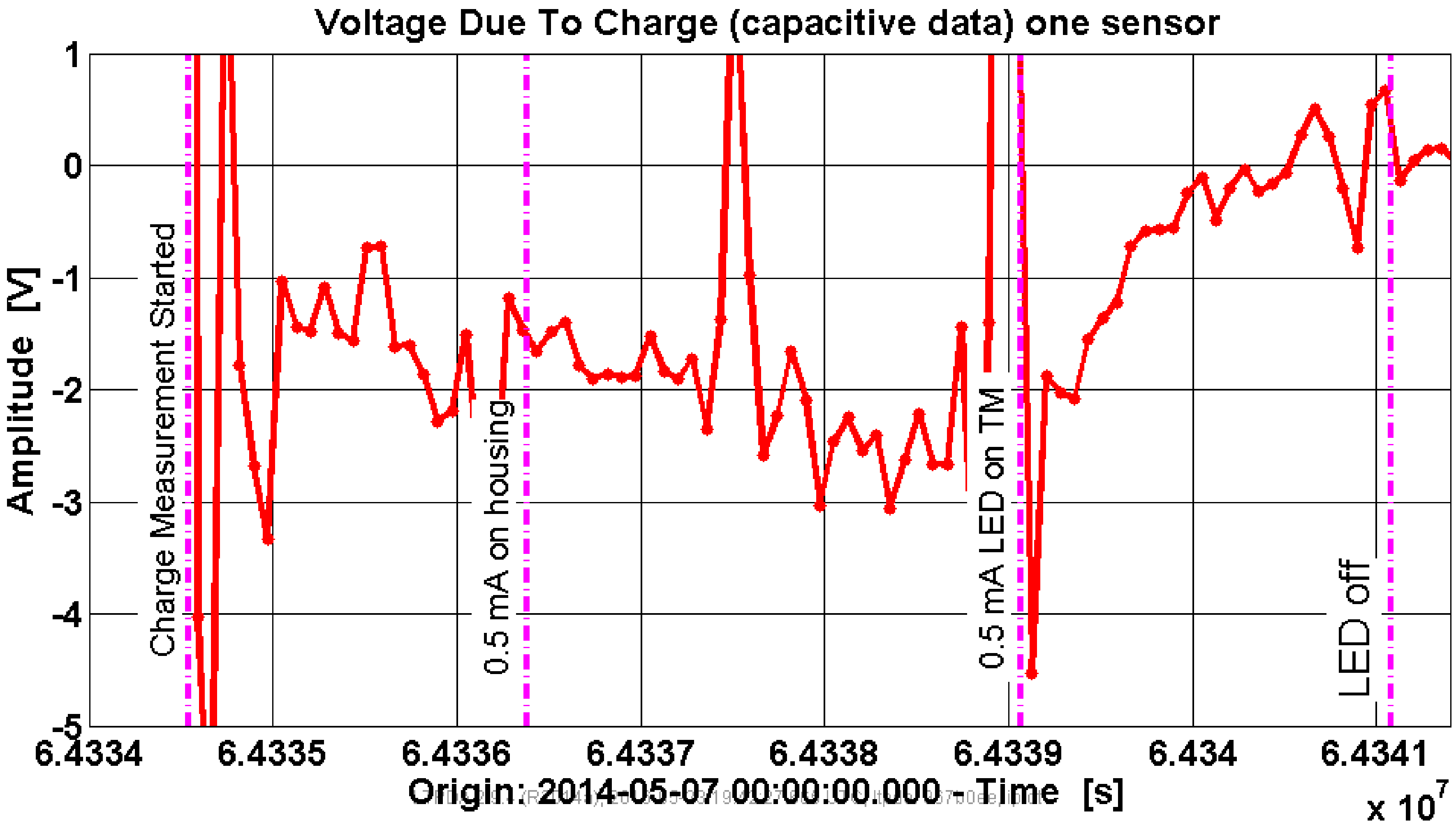
UV injector
(Ti ferrule + UV fiber + SMA connector)





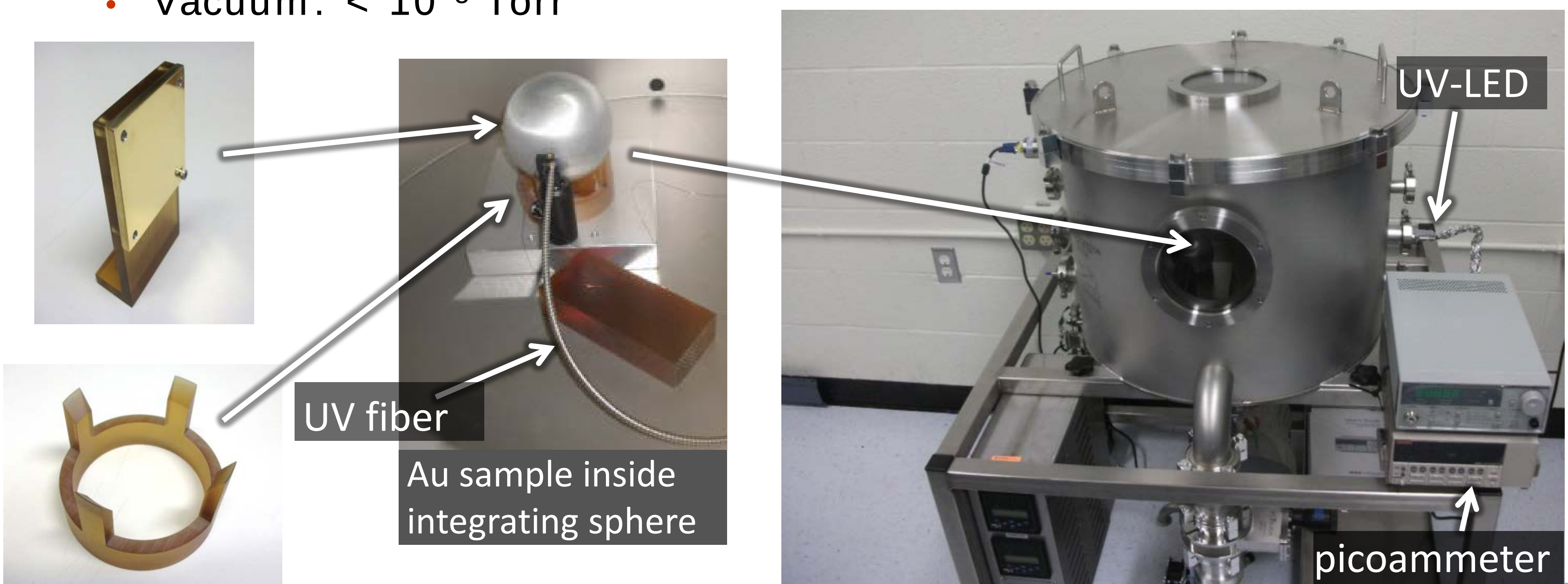
DC Charge Control on Pendulum

- Applied AC field drives pendulum with amplitude $\propto q$
- Illuminating the housing drives electrons to the TM
- Illuminating the TM drives electrons to the housing

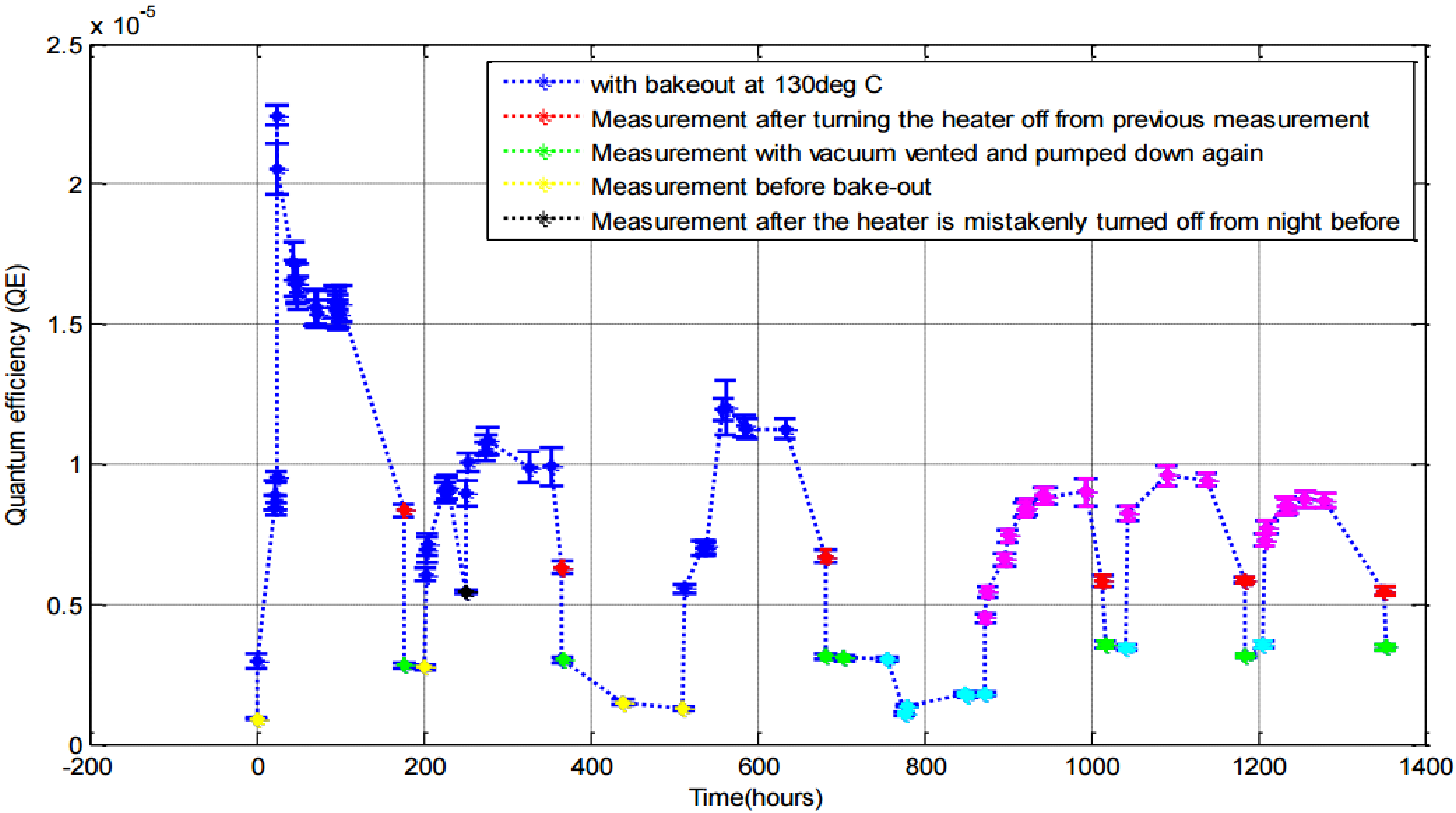


QE Measurements

- # liberated electrons / # incident photons (typ. ~10^{-5} for Au)
- Drives charge control performance (want $R < \mathrm{QE}_1/\mathrm{QE}_2 < R^{-1}$)
- Measurement technique:
  - Fiber-coupled UV LEDs illuminate coated sample
  - Samples (-9 V), sphere (+9 V)
  - Picoammeter measures current flow from sample to sphere
  - Vacuum: < 10^{-5} Torr



Improved QE Consistency with Bake-out

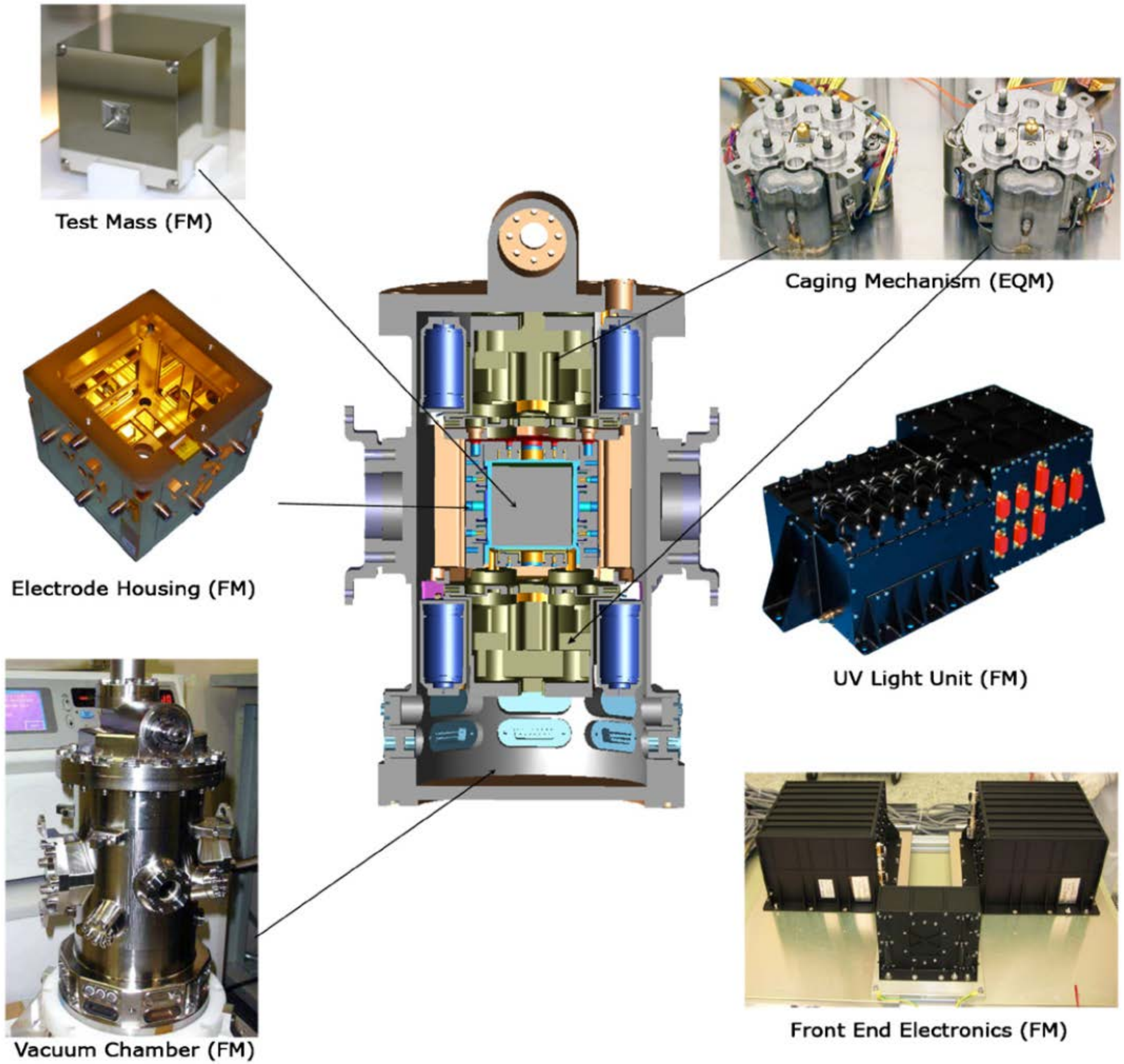


Thanks

- To follow along:
- NASA GWSIG Email list: http://pcos.gsfc.nasa.gov/sags/gwsag/gwsag-maillist.php
- L3ST website: http://pcos.gsfc.nasa.gov/studies/L3/

Backup slides ...

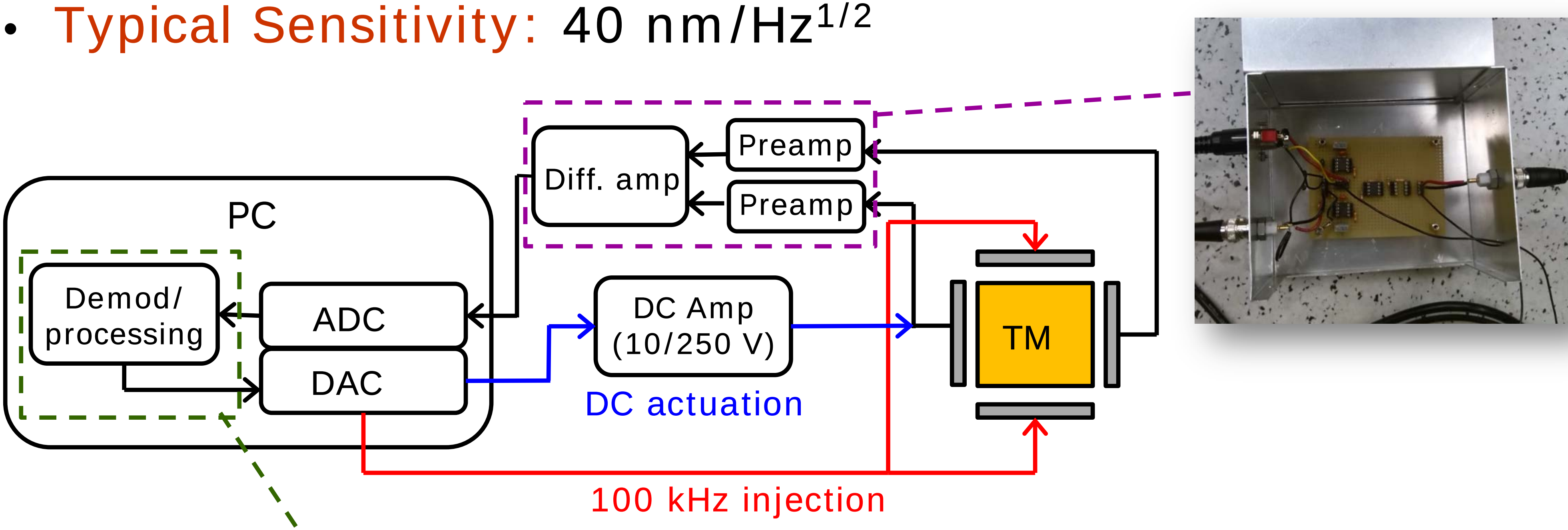
LISA Gravitational Reference Sensor

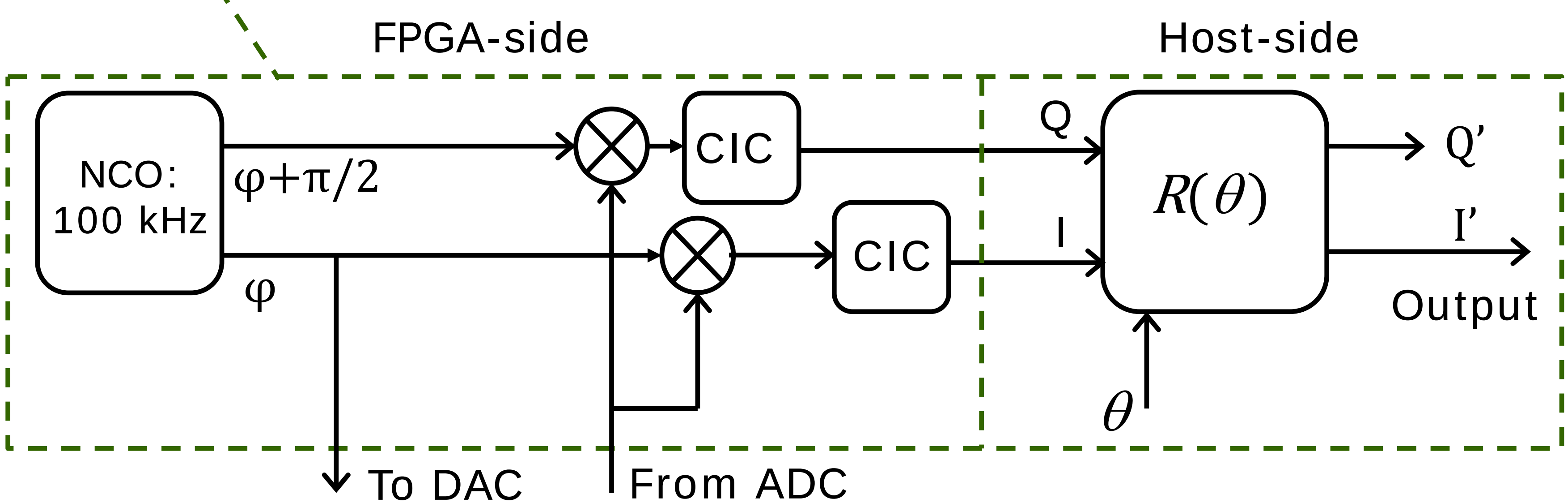


*F. Antonucci et al (2011)

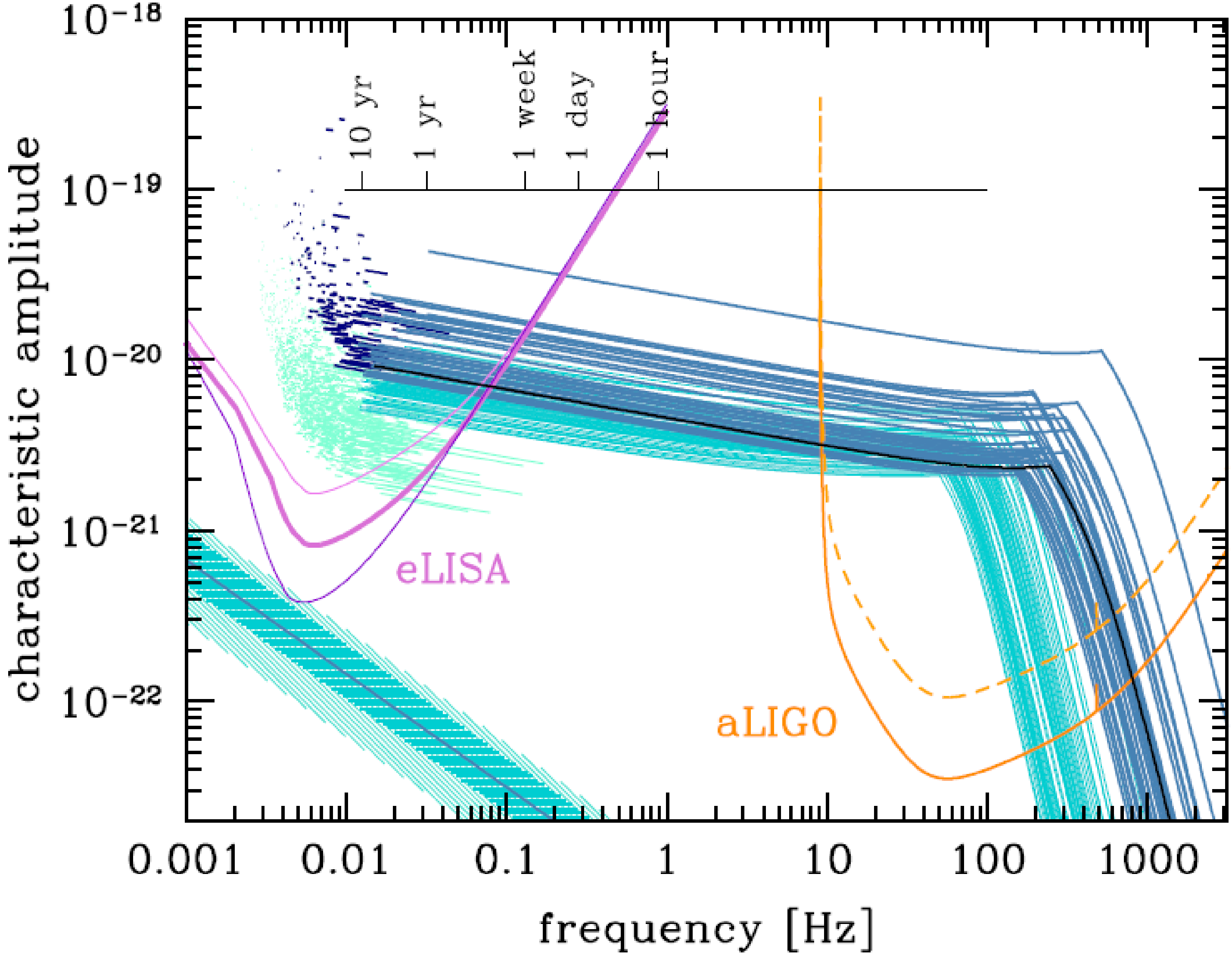
AC Capacitive Readout & DC Actuation

- Typical Sensitivity: 40 nm/Hz$^{1/2}$





Multi-band GW Astronomy



[Sesana arXiv:1602-06951 (2016)]