THE LISA GRAVITATIONAL WAVE MISSION

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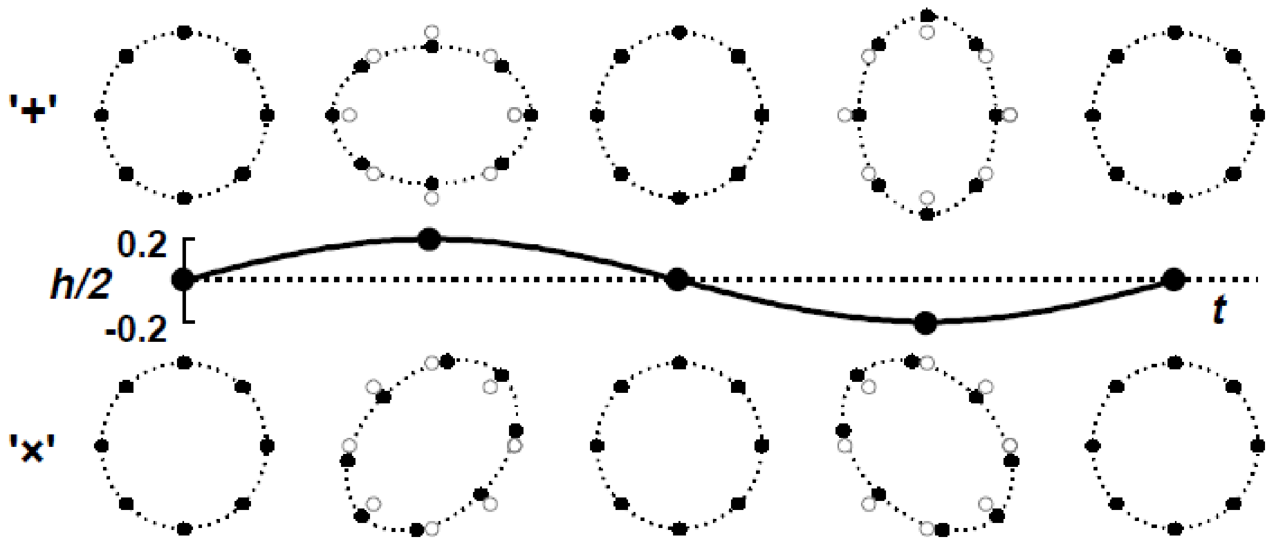
March 2010

Gravitational Waves

- Radiated by asymmetric changes in mass distributions (quadrupole moment or higher)
- Transverse, area preserving periodic strain in spacetime



$h \approx 10^{-20}$ near earth

Gravitational Waves

- Appear as time-dependent tidal forces in free-falling detector
- Fractional change in proper distance:

$$\frac{\delta L}{L} \approx \frac{h}{2}$$

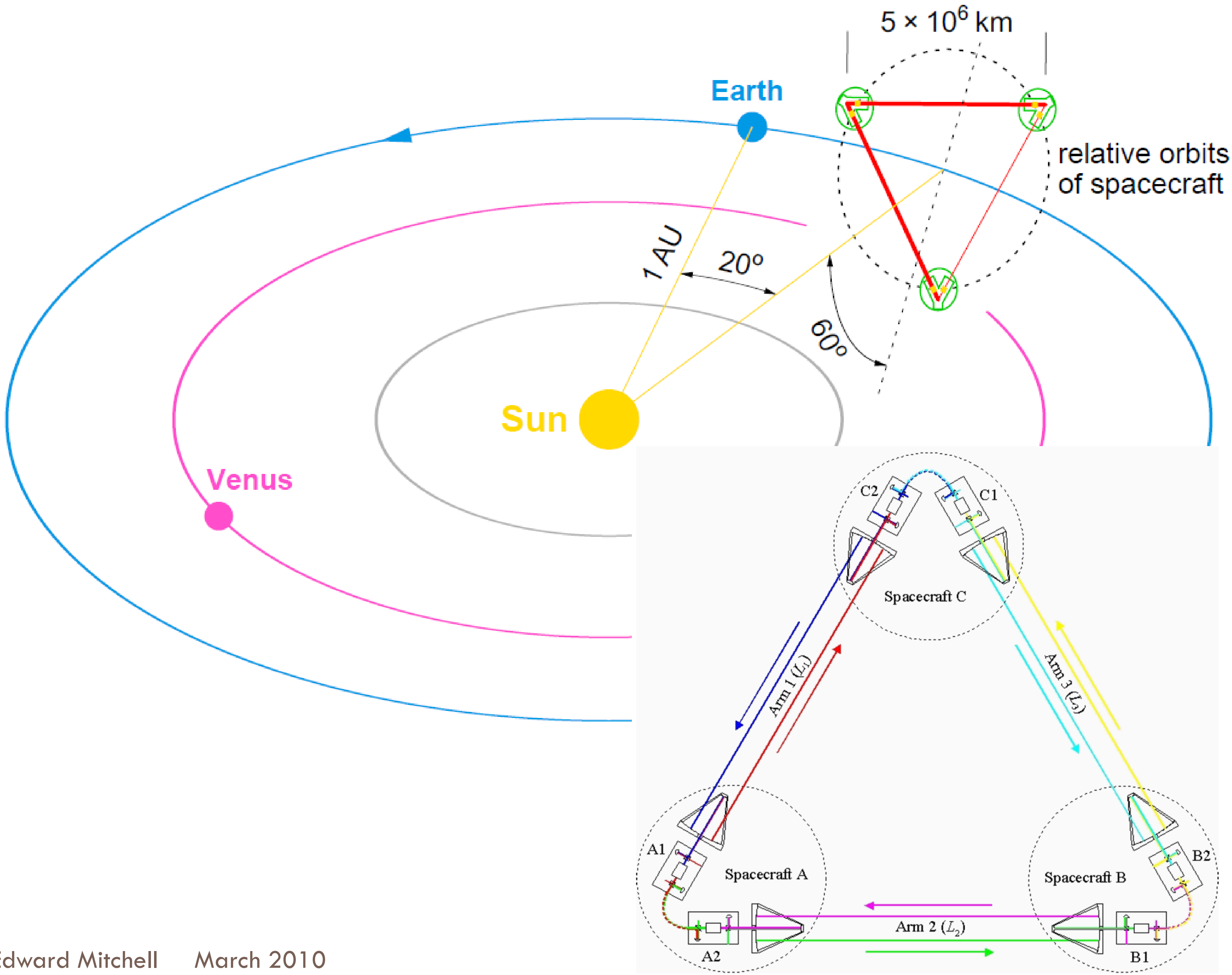
- Strain amplitude of binary source approximated as:

$$h_0 = 1.5 \times 10^{-21} \left(\frac{f}{10^{-3}\mathrm{Hz}}\right)^{2/3} \left(\frac{r}{1\mathrm{kpc}}\right)^{-1} \left(\frac{\mathcal{M}}{\mathrm{M}_\odot}\right)^{5/3}$$

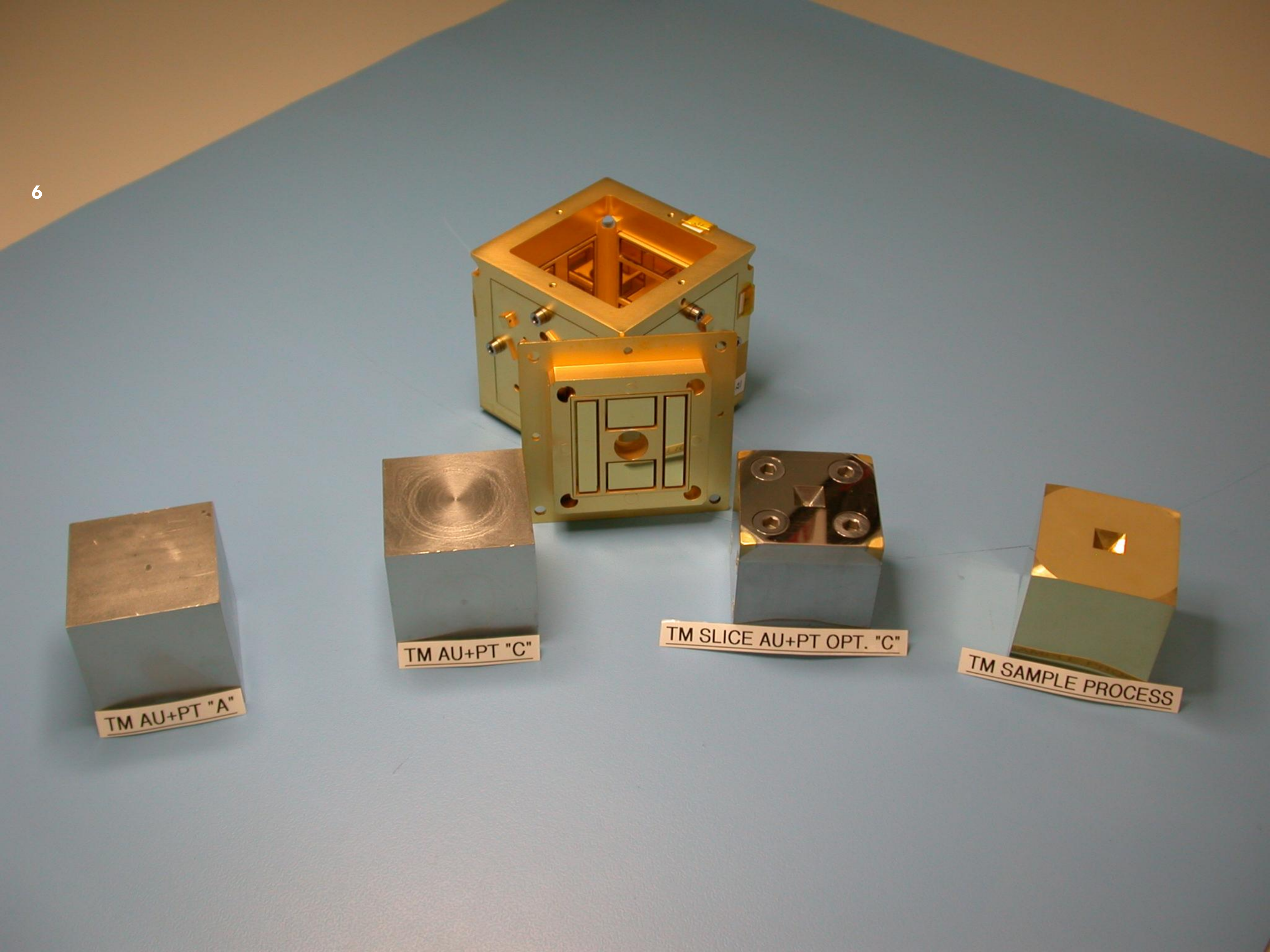
- Observation of increasing binary orbital frequency (eg. Hulse Taylor binary)

LISA

- High power, predictable sources radiate below 10mHz
- Terrestrial gravity gradient/seismic noise limits earth based detectors to f>1Hz
- LISA target frequency range: 10^{-4}-10^{-1}Hz
  - Galactic binaries and extragalactic supermassive black hole binaries
- Laser interferometry – frequency analysis of phase differences reveals periodic path length changes

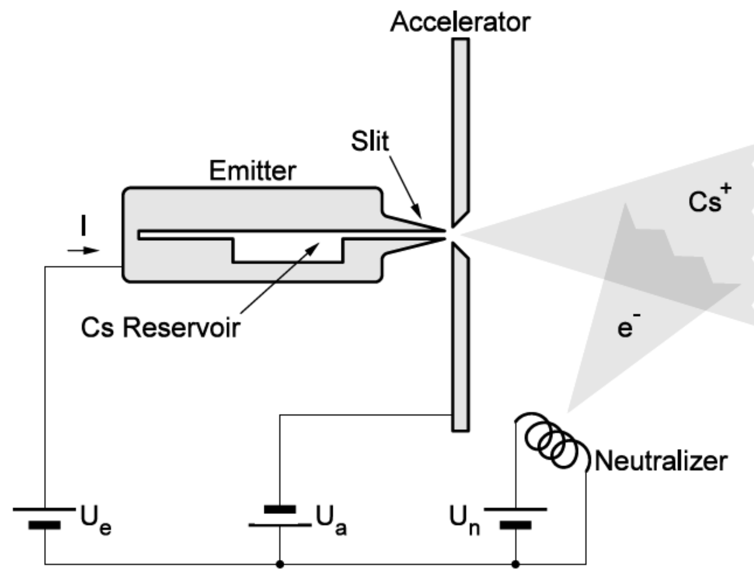


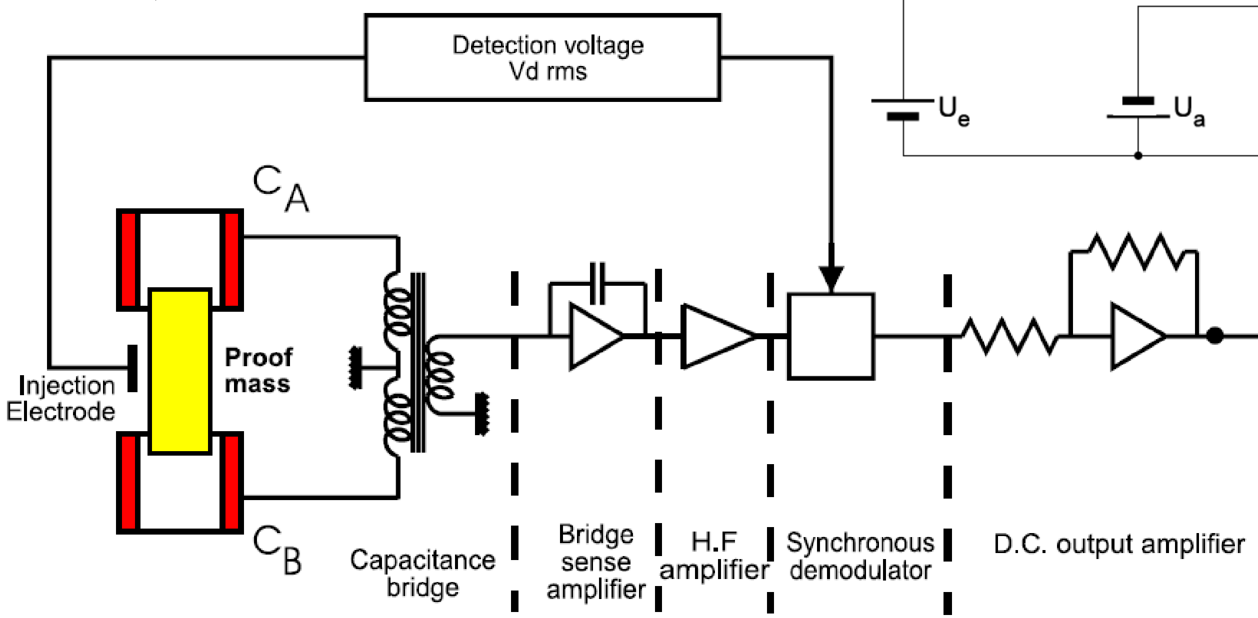
5 × 10^6 km
Earth
relative orbits
of spacecraft
1 AU
20°
60°
Sun
Venus
C2
C1
Spacecraft C
Arm 1 (L1)
Arm 3 (L3)
A1
Spacecraft A
Spacecraft B
B2
Arm 2 (L2)
A2
B1

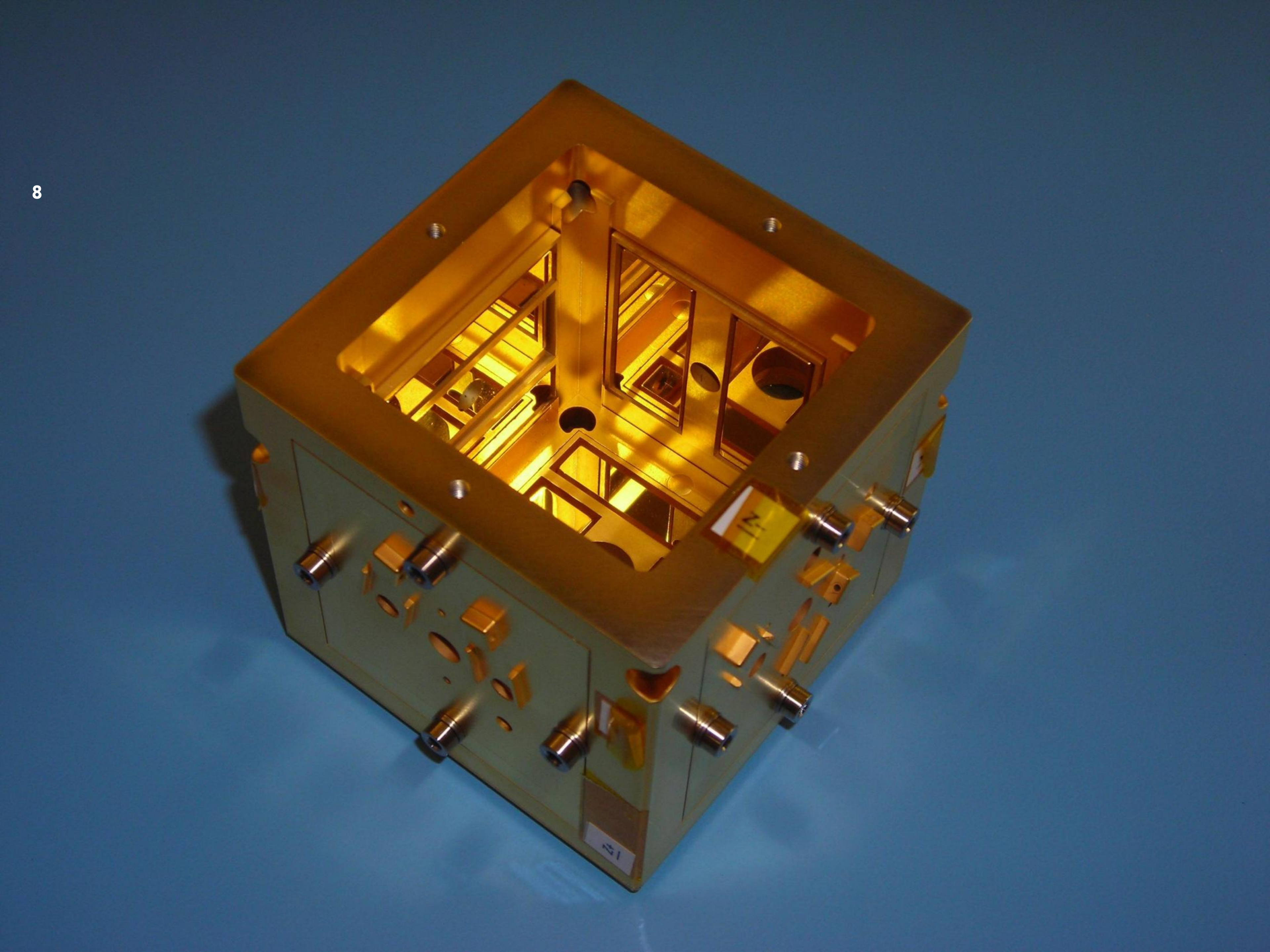

TM AU+PT "A"
TM AU+PT "C"
TM SLICE AU+PT OPT. "C"
TM SAMPLE PROCESS

Gravitational Reference Sensor

- Test mass follows geodesic path in spacetime
- TM position detected by capacitance measurements
- Micro-Newton thrusters maintain central TM





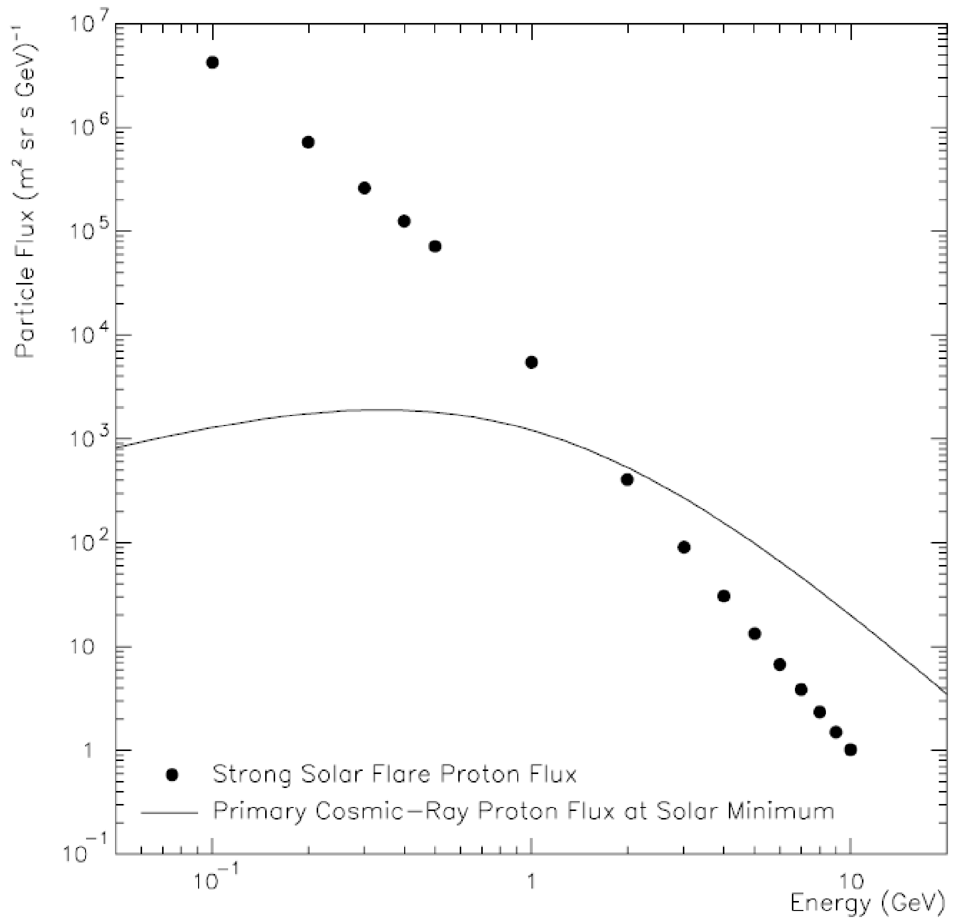


Instrument Noise

- Optical path noise
  - Eg. Laser shot and phase noise
  - Mimics change in arm length
- Acceleration noise
  - Real arm length changes due to spurious forces
  - Dominates at low frequency ($f<2mHz$), scaling as $1/f$
  - A major component is due to Coulomb and Lorentz forces caused by test mass charging

The Particle Environment

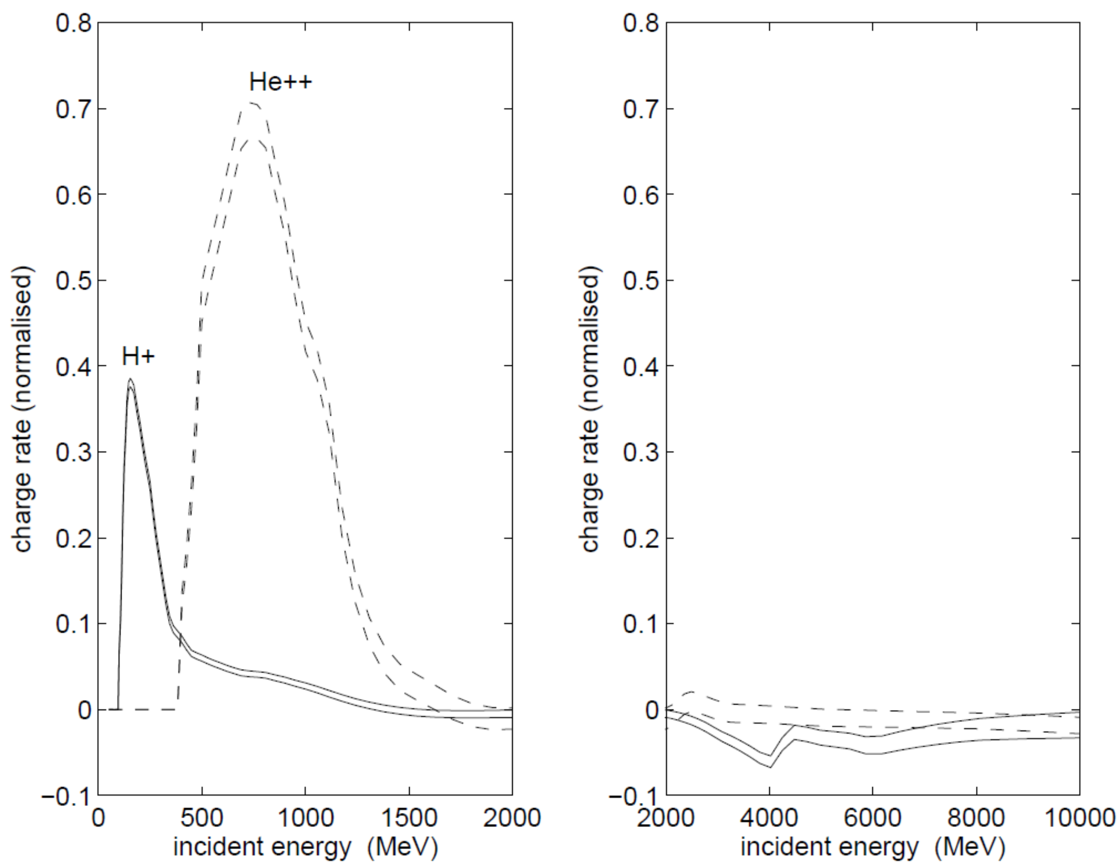
- Galactic Cosmic Rays (GCRs) and Solar Energetic Particles (SEPs) penetrate the test mass
- Particles are stopped/ejected, leaving a net charge
- GCRs have nearly isotropic, steady flux
- SEP events (flares, CMEs) increase charging by factor of 10^3



[Grimani et al. Class. Quantum Grav. **21** (2004) S629-S633]

Test Mass Charging

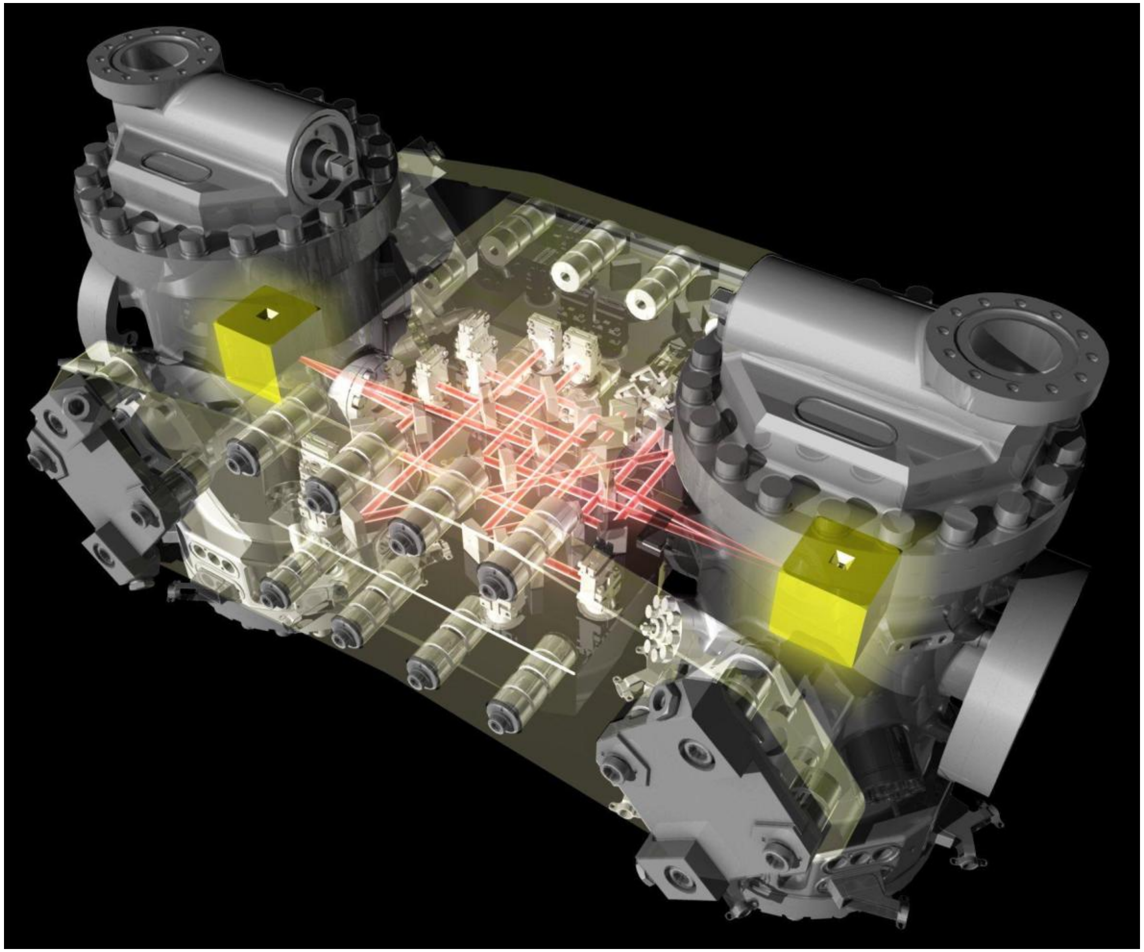
- E<100MeV/n
  - Primaries do not reach test mass (TM)
- 100-400MeV/n
  - Primaries stop in TM
- 400-2000MeV/n
  - Primaries pass through, secondary protons stop in TM
- E>2000MeV/n
  - Primary & secondary protons pass though, secondary electrons stop



Test mass charging modelled with GEANT

LISA Pathfinder

- Technology demonstrator for launch in 2012
- Single spacecraft at the L1 Lagrange point
- Observe charging and monitor particle fluxes



LISA Technology Package [ESA]

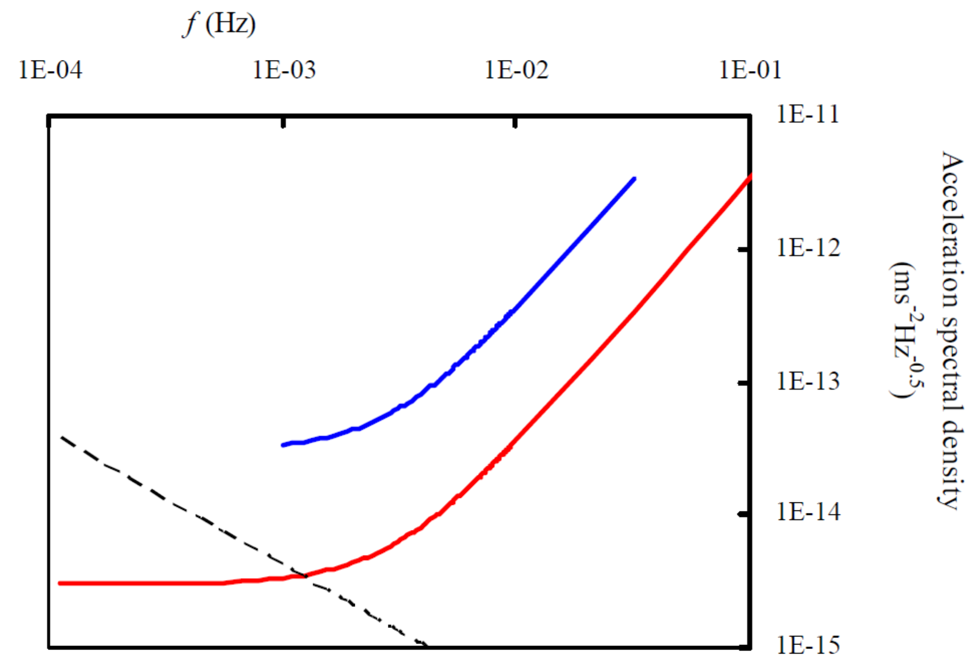
Charge Management

- UV photoelectron emission to maintain $Q < 10^5$e
  - Two discharge modes: rapid/continuous
- Charge fluctuations in time domain have coherent Fourier components in frequency domain
- Minimise $\dot{Q}$ through continuous discharge, matching charge/discharge rate (within 0.1% for LISA)
- Charge rate varies due to stochastic arrival of particles:

$$Q(t) = \bar{\dot{Q}}t + \delta Q(t)$$

LISA Pathfinder: Charge Management

- Measure $\overline{\dot{Q}}$ and Q over 1 hour periods
- Charging shot noise and rate fluctuations not resolvable
- Expected to exceed LISA noise budget



Noise resulting from a net charging rate, for 1 day integration period, matching rates to $\pm10es^{-1}$ and maintaining $Q<10^5e$

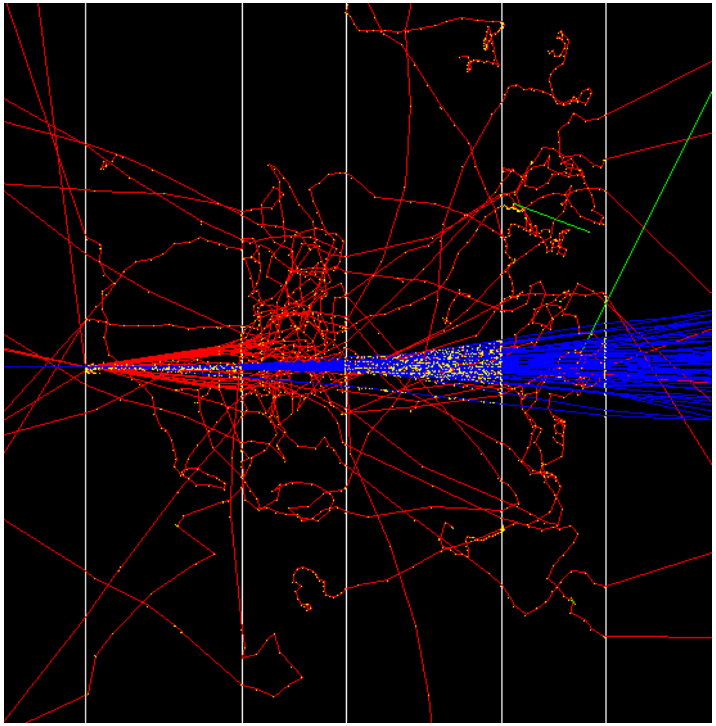
Dashed line = largest coherent Fourier component

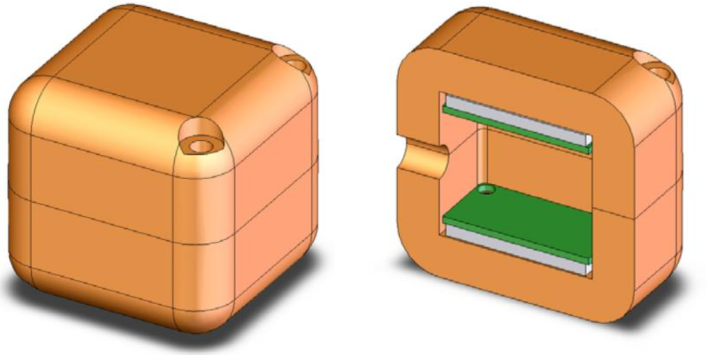
Red line = LISA noise target

Blue line = LISA Pathfinder noise target

LISA Pathfinder: Radiation Monitor

- Use radiation monitor to validate models and track short term flux changes
- Try to characterise transfer function between monitor data and test mass charge rate
- Develop radiation monitors and charge management for LISA





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