# A Space-Based Gravitational-Wave Detector with Geometric Suppression of Spacecraft Noise (LAGRANGE)

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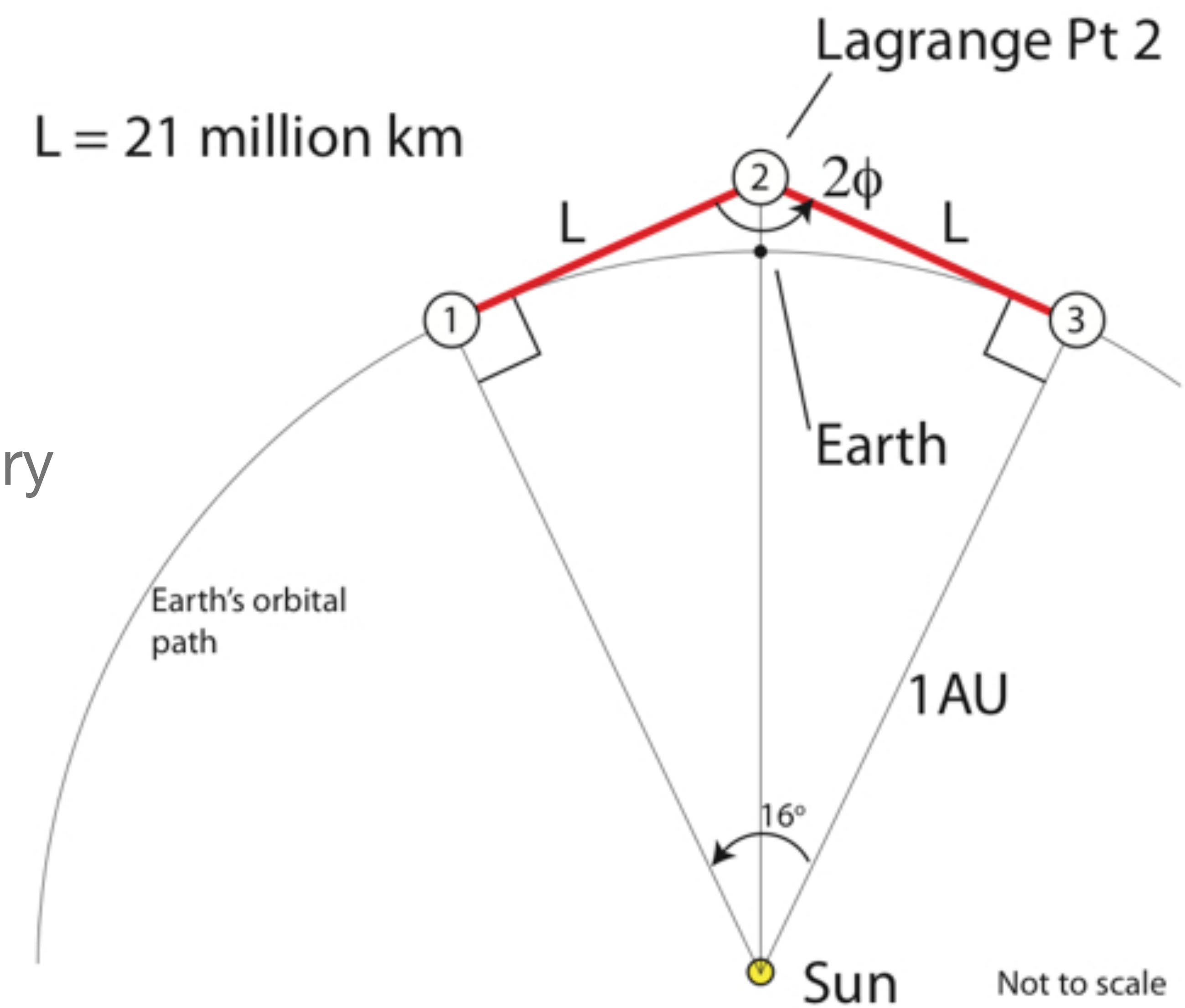
2011

# Gravitational Wave Detector with Geometric Suppression

- Remove: high-risk technologies; that drives spacecraft requirements
- Replace Drag-free
  (GRS + microNewton Thrusters)
  with radiometer + solar wind monitor
  (or GOCE accelerometer)
- 3 Spacecraft with LISA-like interferometry
  Separation is 4 x LISA separation
- Reduced (but interesting) science
  for reduced cost
- 4 rather than 6 interferometer links

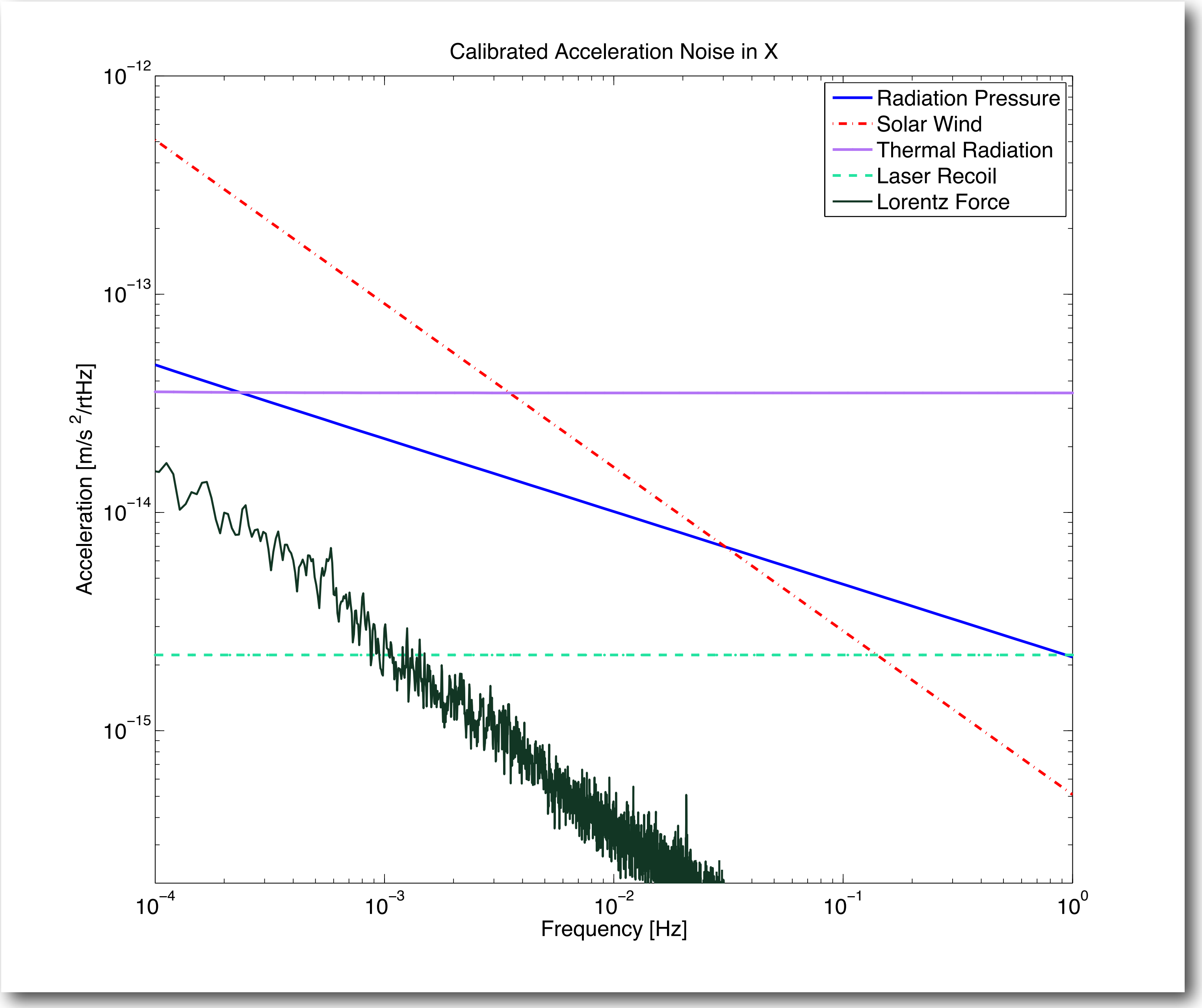


# Workshop Q's and A's 1.

- Q: What forces are you aware of that you are not measuring?

- A: Nothing significant

Laser recoil, Lorentz force analyzed:




Also small:

- transverse orbit coupling,
- s/c dipole coupling to magnetic field gradient

# Workshop Q’s and A’s 2.

- Q: What about internal distortions?

- A: Needs study, but expect these effects can be made small by palce the beamsplitter fiducial at spacecraft center.

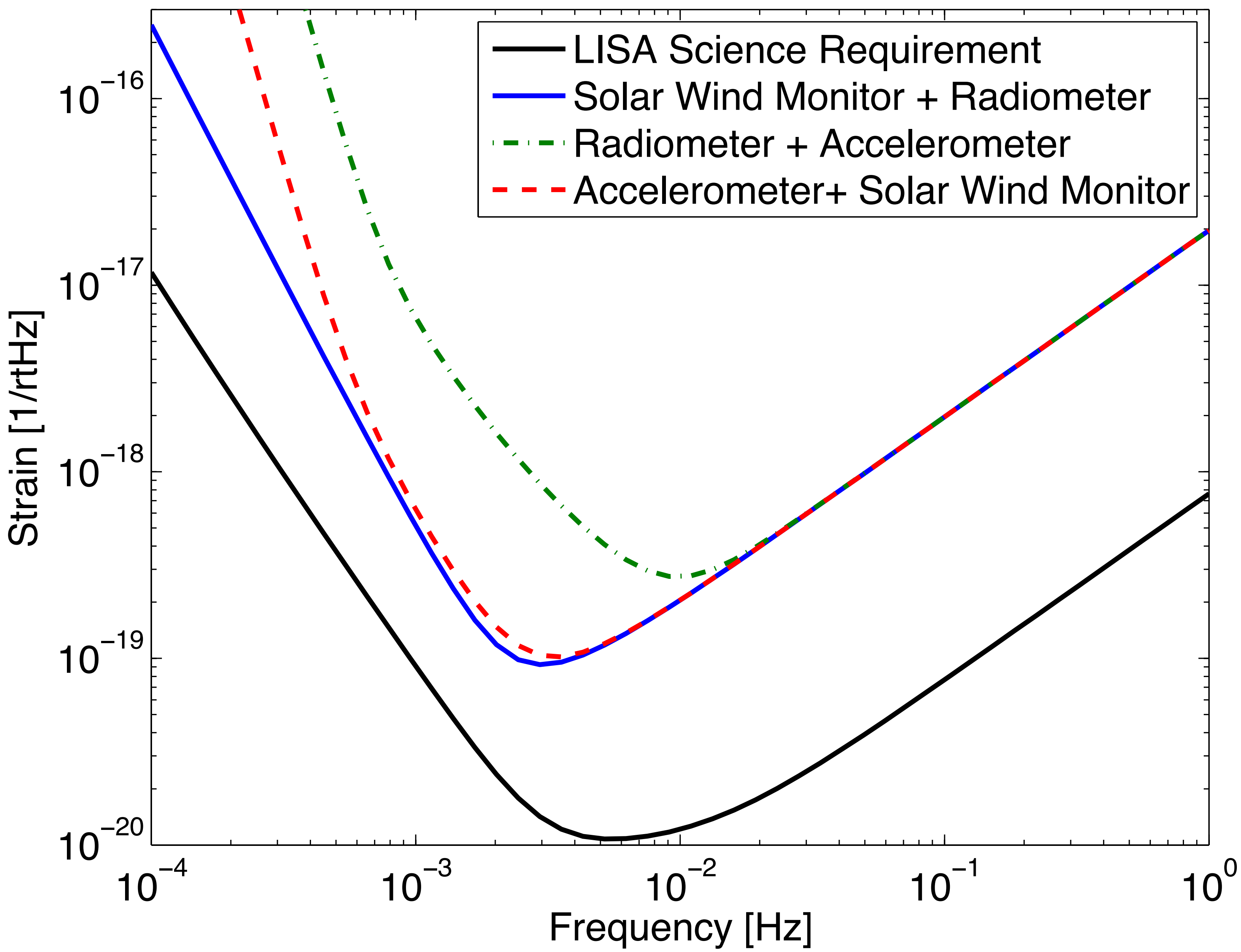
# Workshop Q's and A's  3 (performance risks).

- Q:  **Risk 1:** Unmodeled forces
- A: LAGRANGE s/c vs.  LISA's GRS:
  - Requirements relaxed a little
  - Benefit from larger mass (though smaller mass/area)
- Q:  **Risk 2:**  Inaccurate models
- A:  The noise couplings are simple enough that the risk seems low
- Q:  **Risk 3:** Sensor failures
- A:  Needs study, but the radiometer and solar wind monitors have very good reliability records.

# Workshop Q's and A's 4.

- Q: Is calibration with an on-board accelerometer critical?

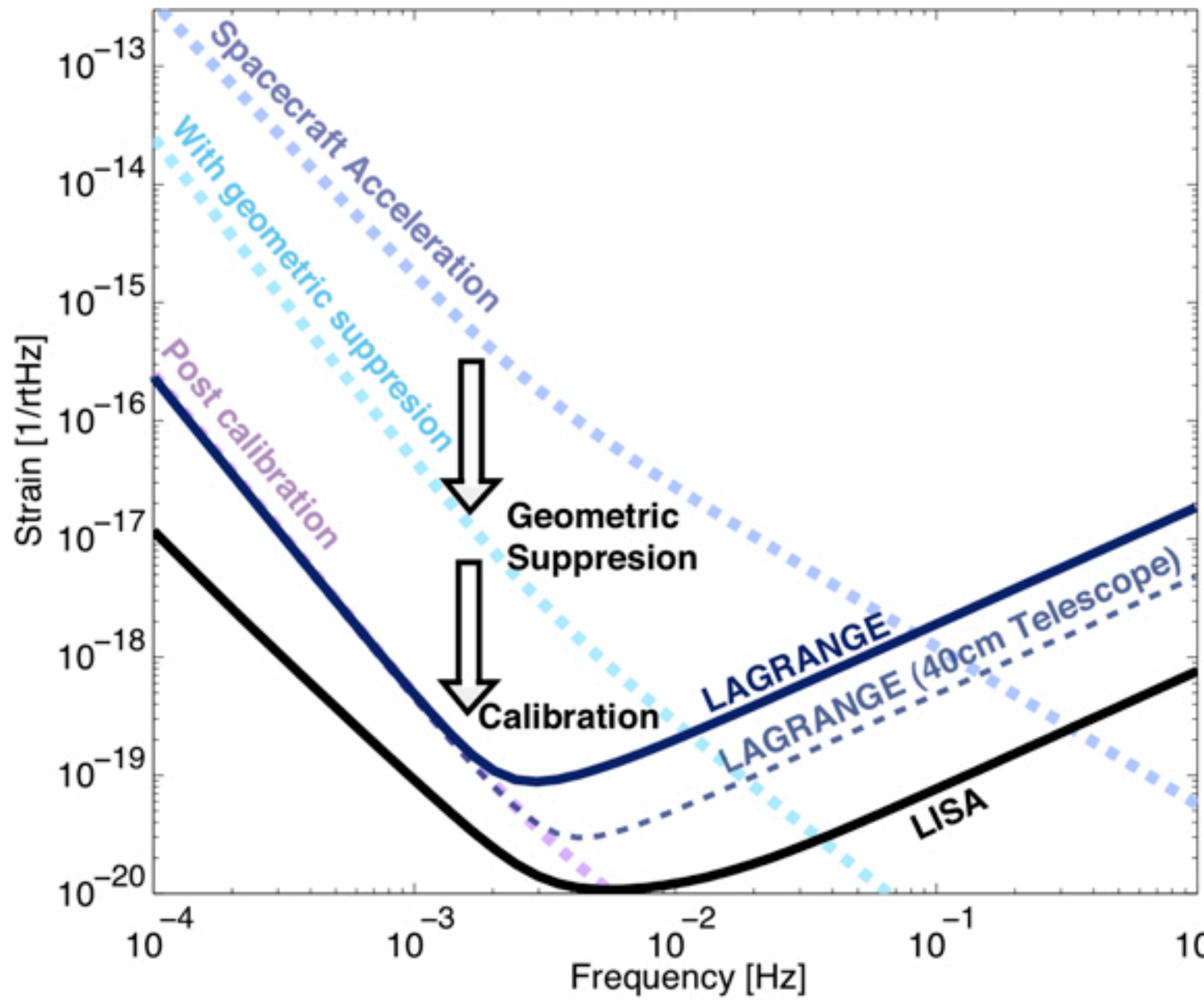
- A: No.



# End of Q & A

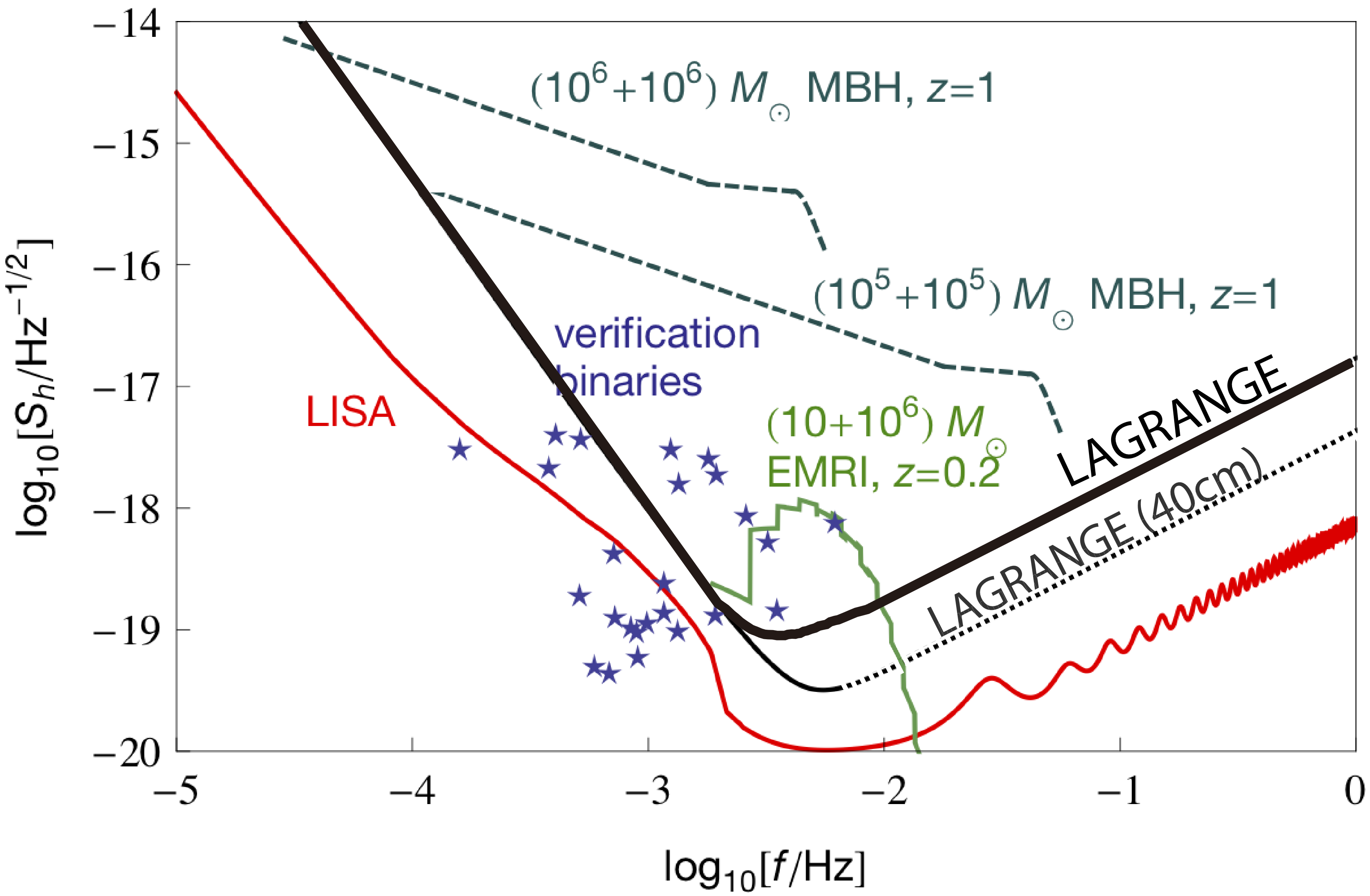
# Sensitivity

- Spacecraft noise is reduced through:
- Geometry (factor of 100)
- Calibration (factor of 100)
- Low frequency limit: Residual Solar-Wind Acceleration

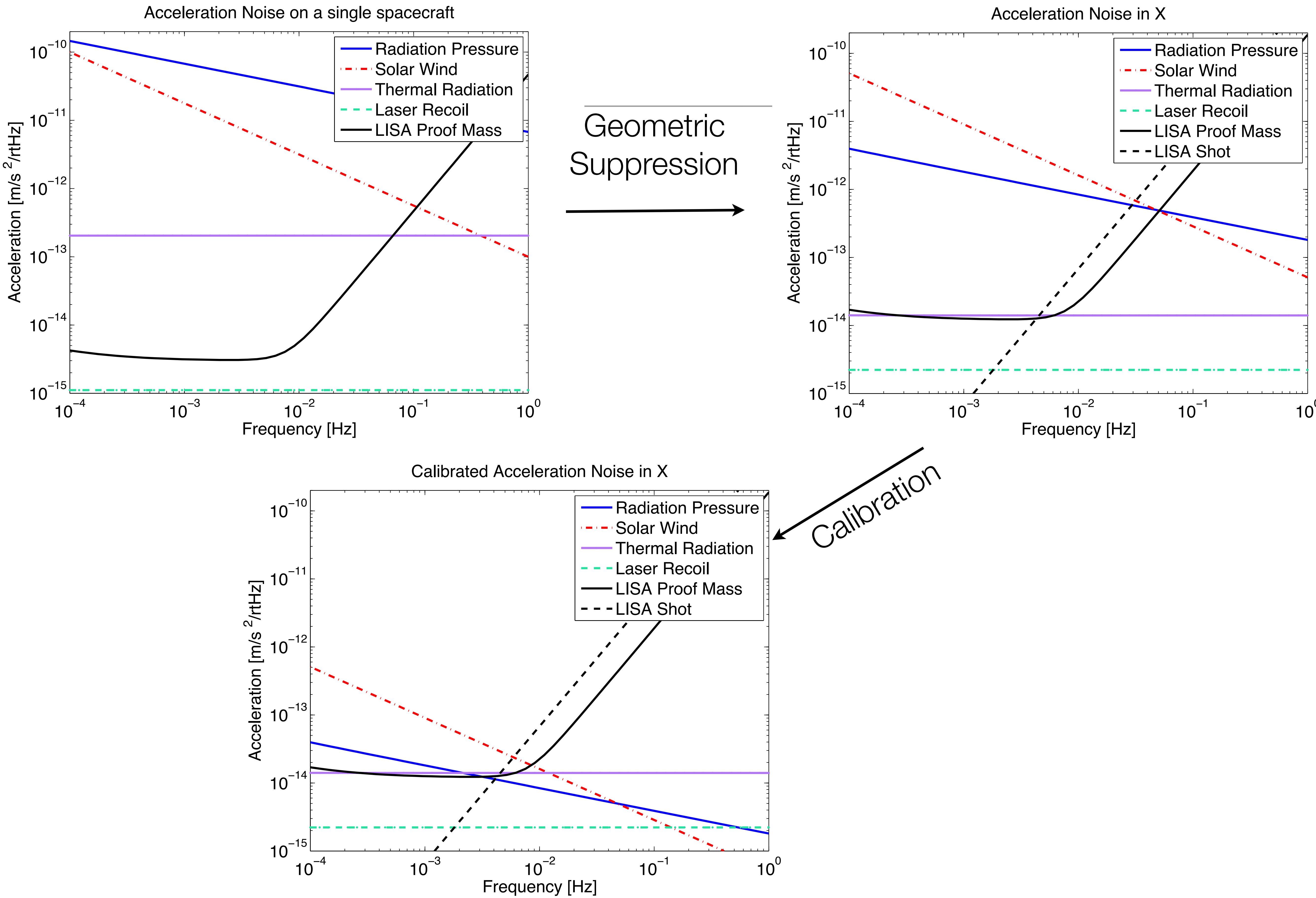


# Science

| Predicted Event Rates and Event Numbers | |
|---|---|
| Frequency band | 100 μHz to 0.1 Hz |
| Massive black hole mergers | 15 $yr^{-1}$ to 25 $yr^{-1}$, 2-5 with SNR > 100 |
| Extreme mass ratio inspirals | 10 $M_\odot$ + $10^6$ $M_\odot$ pair seen out to $z = 0.1$ |
| Detectable verification binaries | 6, (with SNR > 5). |
| Galactic binaries | 10000 detached binaries $yr^{-1}$ and 1400 Am CVns $yr^{-1}$ |



# Noise Budgets



# Instruments

- Solar wind monitor
- Radiometer
- Accelerometer

# SWEPAM


*Figure 11.* Photograph of the SWEPAM-I instrument. The large cylindrical housing is the sensor head; the rectangular electronics box behind it houses the high and low voltage power supplies and control electronics.

McCOMAS et al, Rev Sci Inst1998

SOLAR WIND ELECTRON PROTON ALPHA MONITOR

TABLE III
SWEPAM hardware parameters

| | SWEPAM-I | SWEPAM-E |
|---|---|---|
| Box size (L × W × H) (cm) | 36 × 24 × 30 | 25 × 18 × 19 |
| Mass (kg) | 3.7 | 2.5 |
| Power, average (W) | 3.1 | 2.7 |
| Power, peak (W) | 3.3 | 2.9 |
| Telemetry rate (b/s) | 540 | 460 |
| Number of CEMs | 16 | 7 |
| Temperature limits (°C) | | |
| Preferred operating | 0 to +20 | 0 to +20 |
| In calibration | −20 to +45 | −20 to +45 |
| Operating survival | −25 to +50 | −25 to +50 |
| Non-operating survival | −30 to +60 | −30 to +60 |
| EMC interference | | |
| DC magnetic | 0.01 nT @ 10′ | 0.03 nT @ 10′ |
| AC magnetic | BDL | BDL |
| AC electrical | BDL | BDL |
| Ordnance | 2 dimple motors | 2 dimple motors |
| Red tags (HV safe/arm) | 2 | 2 |

BDL: Below Detectable Levels.

# GOCE Accelerometer

- Only one axis needed

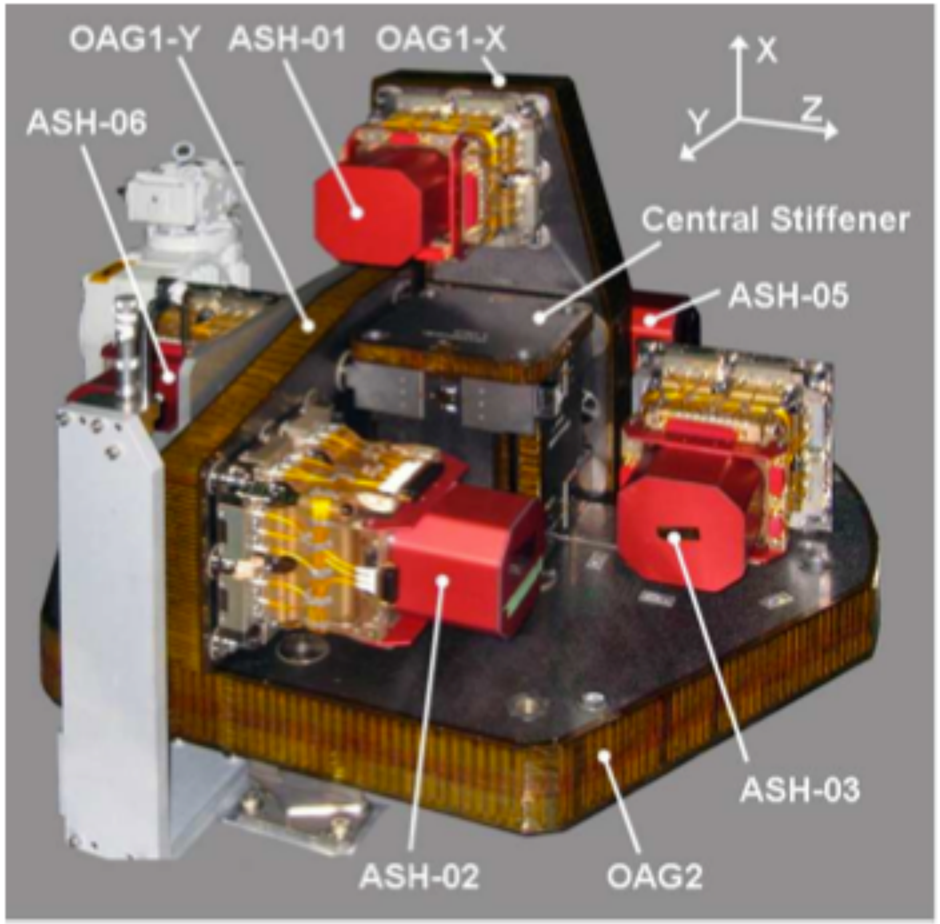
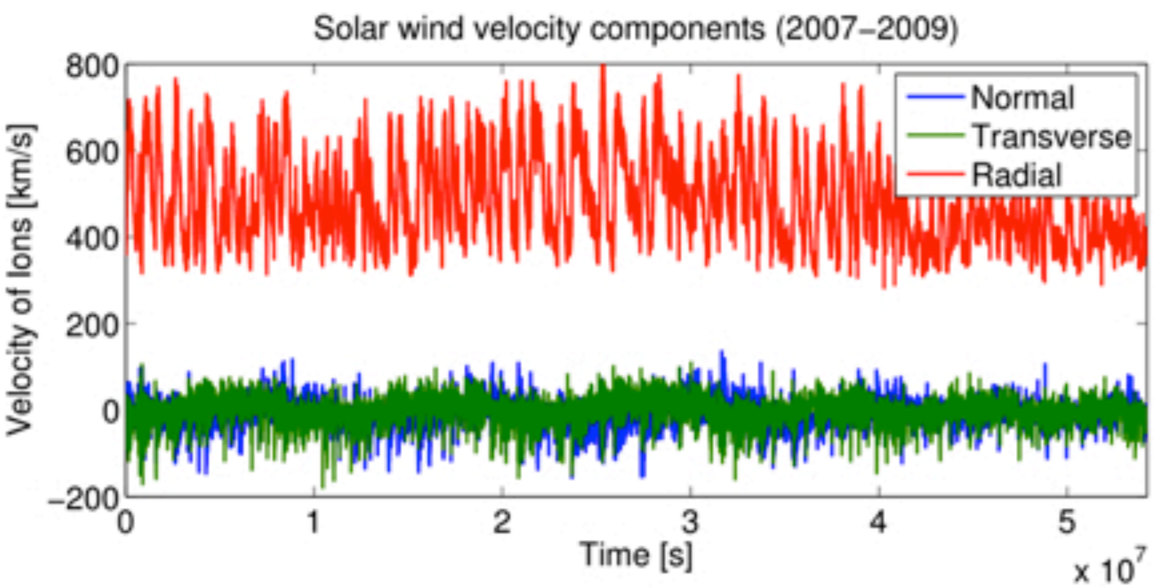
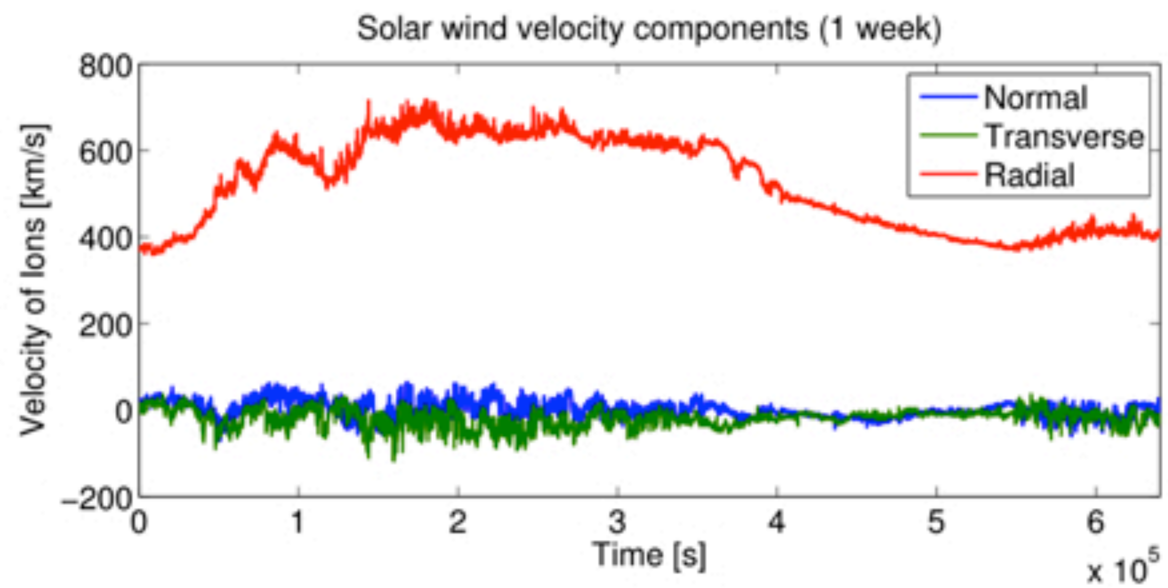


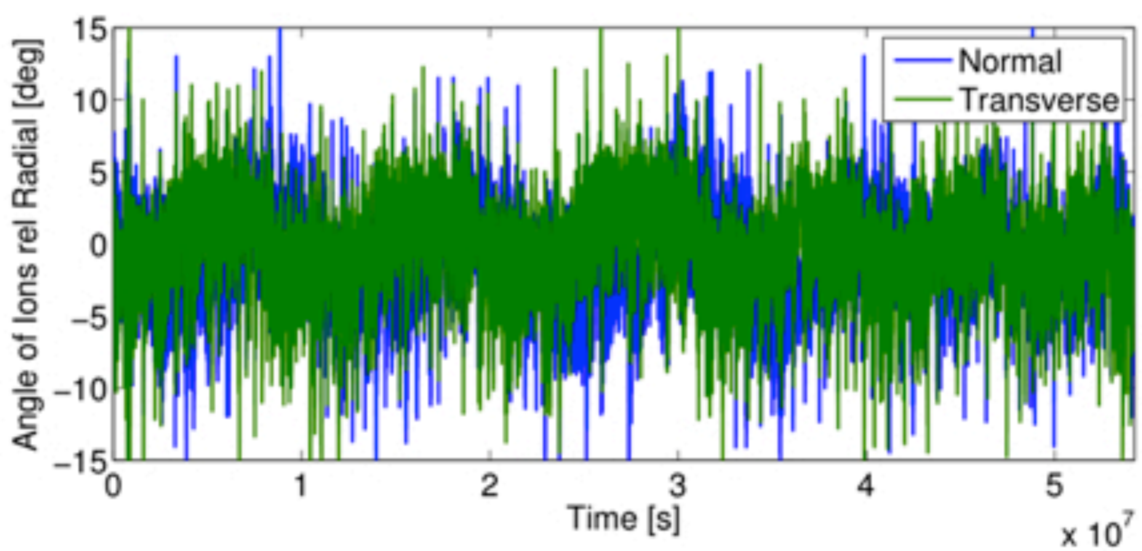

*Figure 2: View of the FM Gradiometer core with accelerometer sensor heads (ASH) on the carbon-carbon structure (Photo from Thalès Alenia Space).*

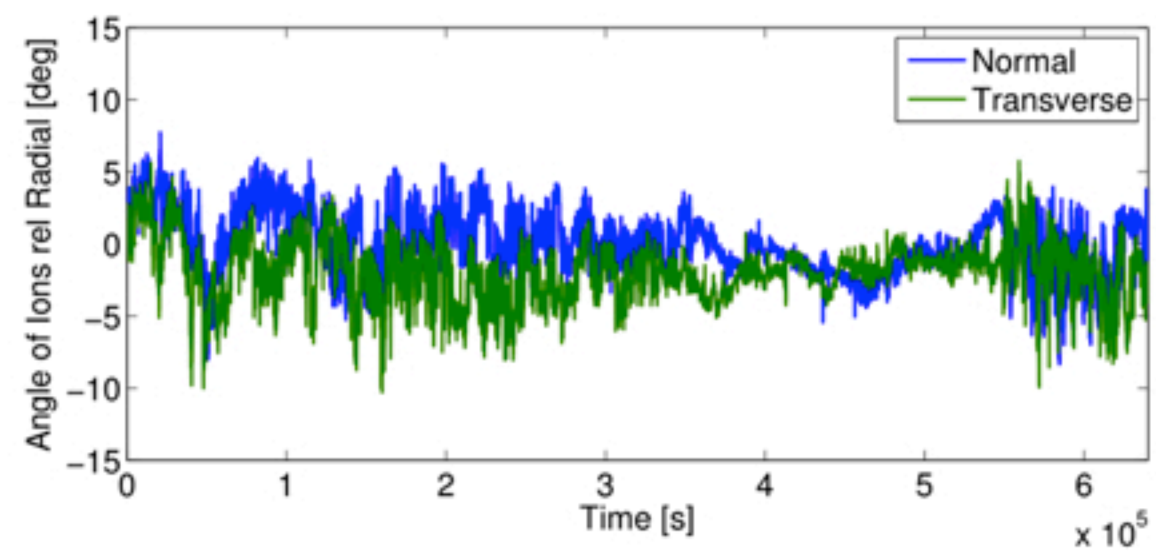
# The highly variable solar wind (1)

- Variable in **magnitude** and **direction:**



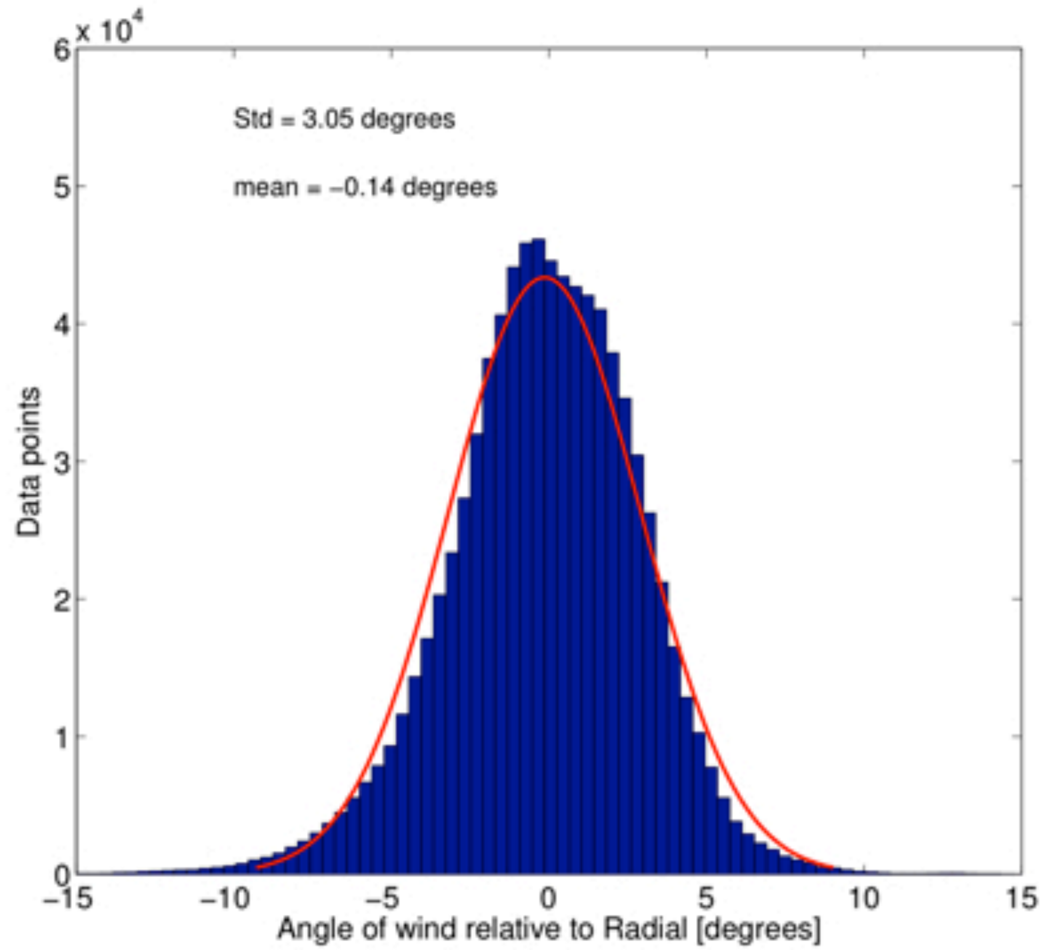



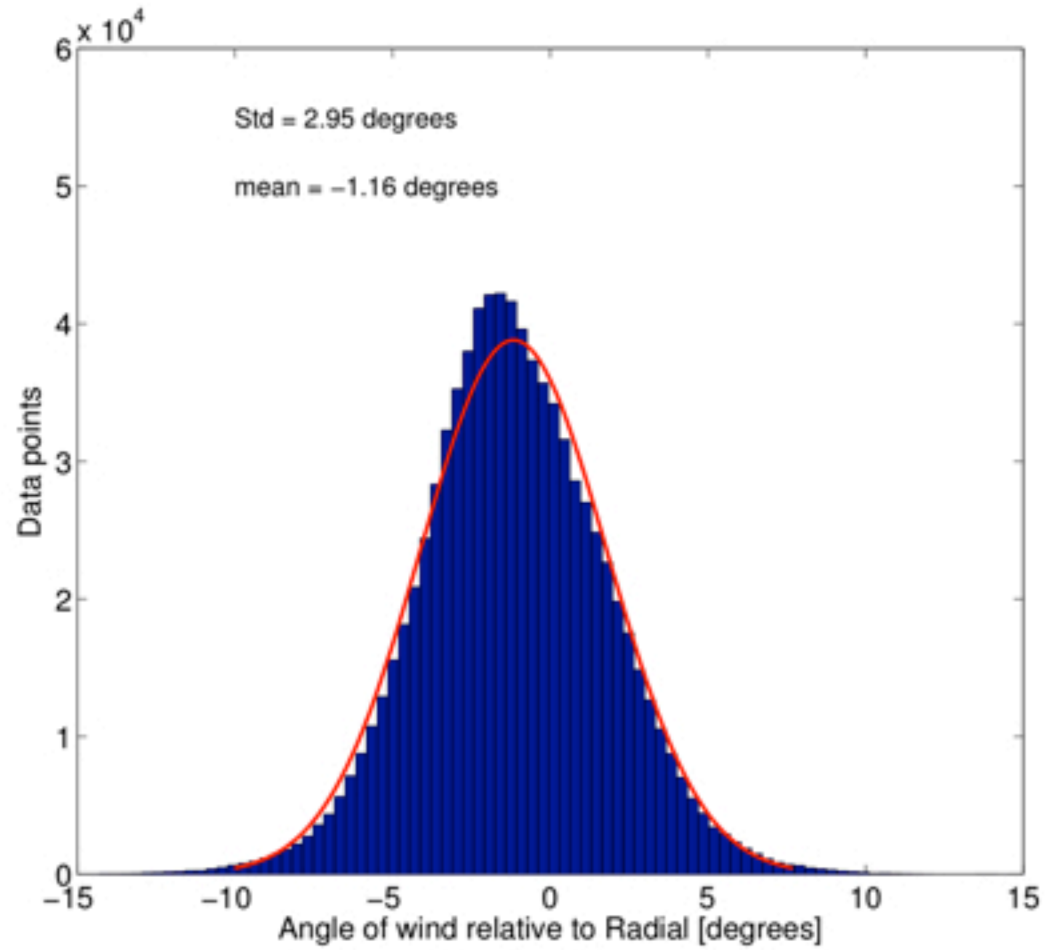



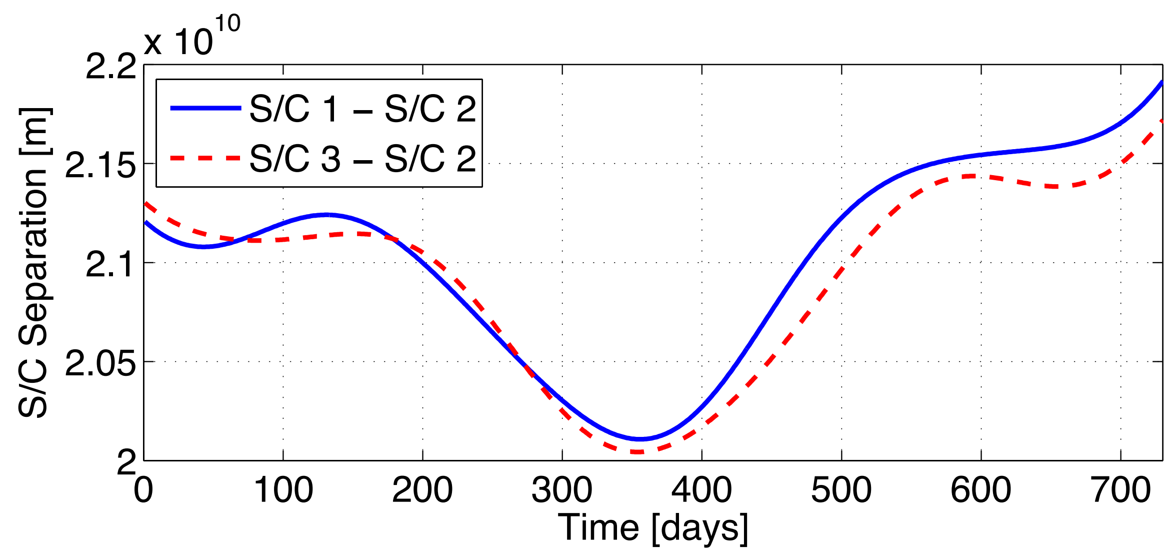
# The highly variable solar wind (2)

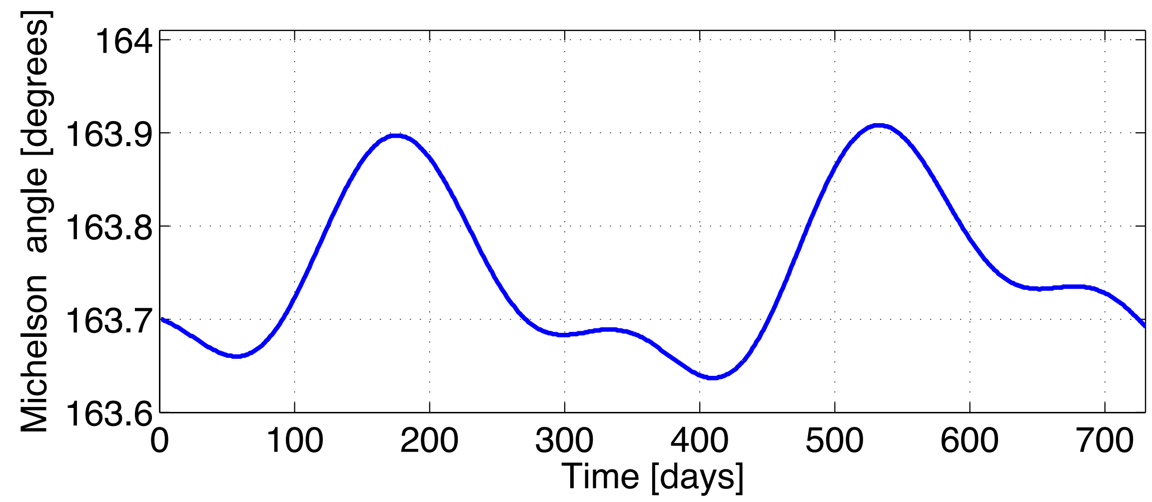
## Angle of the solar wind - Histogram

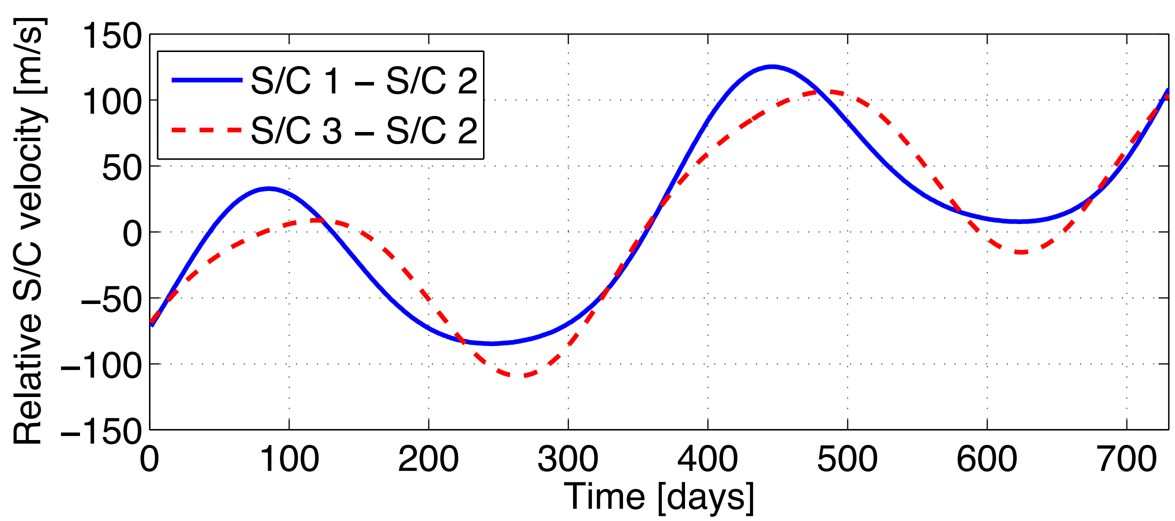


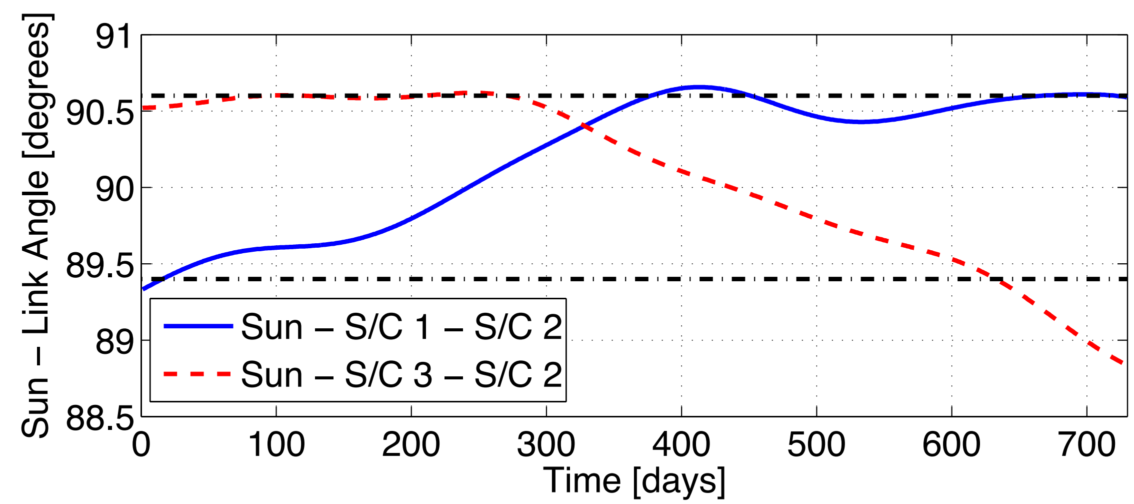



# Orbits, 2 year data

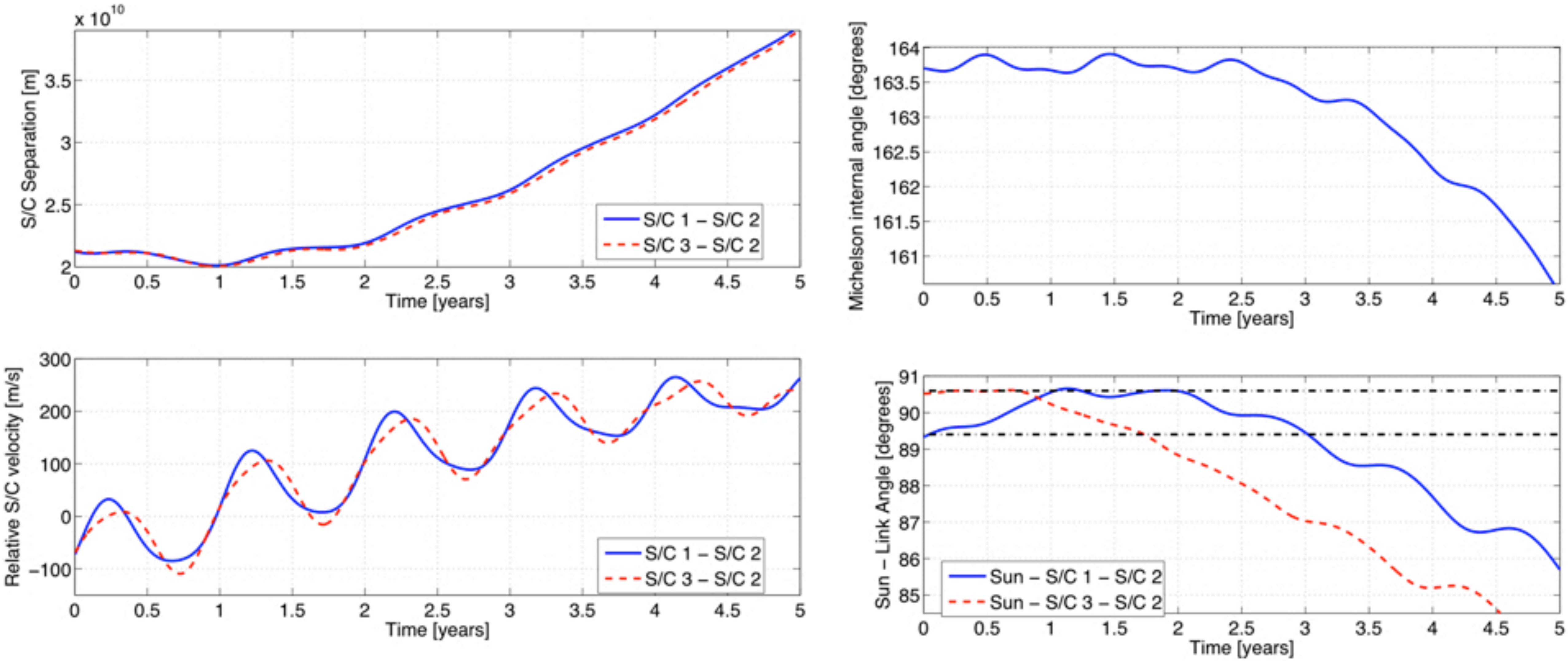


# Orbits, 5 year data



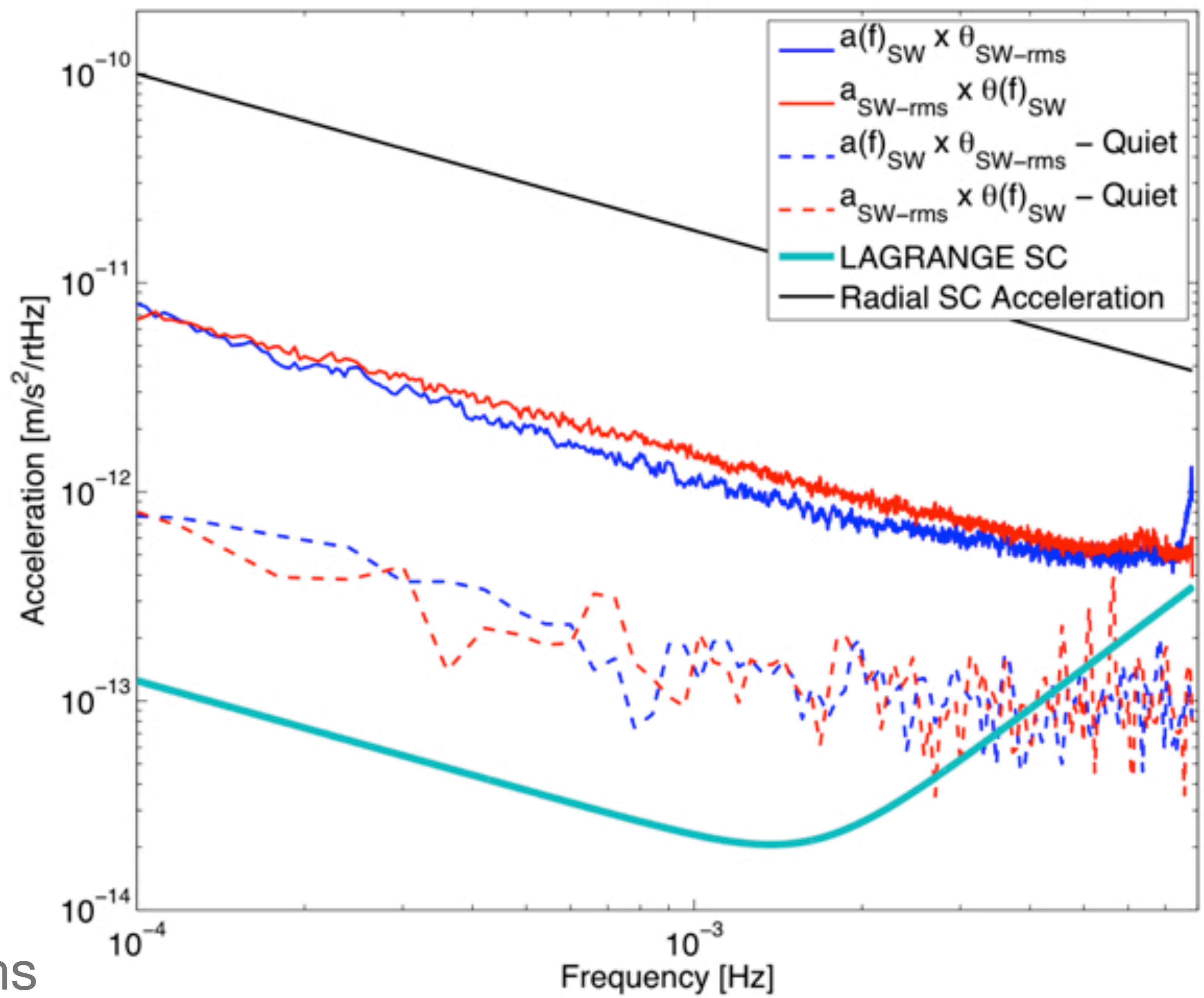
# Cost Estimate

Table 4: Cost Estimate ($M FY12)

| Cost Differences between SGO-Mid and LAGRANGE | Cost (FY12$M) |
|---|---|
| GSFC Space Gravitational Observatory - Mid (SGO-Mid) | 1,400 |
| Gravitational Reference System: $196M cost reduction for removing six GRS units. A single GRS is estimated at $53M using a parametric mass-based modeling tool. This estimate aligns with the SGO-Mid estimate of $50 Million, which is used as a basis for the six-unit reduction. | ( 196) |
| Two telescope assemblies and optical benches: $90M cost reduction. (LAGRANGE requires 4; SGO-Mid requires 6). Removal of laser pre-stabilization on each spacecraft:$15M | ( 105) |
| Solar Wind Monitor: $17M cost increase for three additional units. A single solar wind monitor is estimated at $7M using a parametric mass-based modeling tool and is the basis for the two-unit increase. | 17 |
| Radiometer: $17M cost increase for adding three units. A single radiometer is estimated at $7M using a parametric mass-based modeling tool and is the basis for building three-units. | 17 |
| Accelerometer: $13M cost increase for adding three units. Estimated for GRACE. | 13 |
| Attitude Control: $40M cost savings due to a different ACS design. SGO-Mid uses Micro-Newton thrusters, whereas this mission uses reaction wheels and desaturation thrusters. An estimate of the total cost of colloidal thrusters for LISA is $80 Million, while an estimate for the total cost of hydrazine thrusters and reaction wheels on this mission is $40 Million. | ( 40) |
| Laser Power: $10M cost increase due to the 1.2 Watt higher power (LISA-like) laser compared to the SGO-Mid 0.7 Watt laser. | 10 |
| LAGRANGE | 1116 |

# Solar wind - SWEPAM instrument minimum performance

- Look for when the wind is quite - plot spectra
- This appears to occur when the wind is low velocity (~330km/s vs 800km/s max)
- This gives worse case level for SWEPAM measurement performance, but may still be actual wind.
- This level is less than a factor of 10 from LAGRANGE assumptions



# SW Noise Components

- Look at: Δrho, Δv, Δtheta, hold other terms constant, calculate acceleration spectrum
- Density noise is largest.