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

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2011

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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 placing 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

<table>
<thead>
<tr>
<th>Predicted Event Rates and Event Numbers</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Frequency band</strong></td>
</tr>
<tr>
<td><strong>Massive black hole mergers</strong></td>
</tr>
<tr>
<td><strong>Extreme mass ratio inspirals</strong></td>
</tr>
<tr>
<td><strong>Detectable verification binaries</strong></td>
</tr>
<tr>
<td><strong>Galactic binaries</strong></td>
</tr>
</tbody>
</table>

![Graph showing event rates and event numbers](image)
Noise Budgets

Acceleration Noise on a single spacecraft

Frequency [Hz]

Acceleration [m/s²/√Hz]

Radiation Pressure
Solar Wind
Thermal Radiation
Laser Recoil
LISA Proof Mass

Acceleration Noise in X

Frequency [Hz]

Acceleration [m/s²/√Hz]

Radiation Pressure
Solar Wind
Thermal Radiation
Laser Recoil
LISA Proof Mass
LISA Shot

Calibrated Acceleration Noise in X

Frequency [Hz]

Acceleration [m/s²/√Hz]

Radiation Pressure
Solar Wind
Thermal Radiation
Laser Recoil
LISA Proof Mass
LISA Shot

Geometric Suppression

Calibration
Instruments

- Solar wind monitor
- Radiometer
- Accelerometer
SWEPAM

Table III
SWEPAM hardware parameters

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

BDL: Below Detectable Levels.

McCOMAS et al, Rev Sci Inst 1998

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.
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:**

![Graphs showing solar wind velocity components](image)
The highly variable solar wind (2)

Angle of the solar wind - Histogram
Orbits, 2 year data

![Graphs showing S/C separation, relative S/C velocity, Michelson angle, and Sun-Link angle over time.](image)
Orbits, 5 year data
## Cost Estimate

### Table 4: Cost Estimate ($M FY12)

<table>
<thead>
<tr>
<th>Cost Differences between SGO-Mid and LAGRANGE</th>
<th>Cost (FY12$M)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GSFC Space Gravitational Observatory - Mid (SGO-Mid)</td>
<td>1,400</td>
</tr>
<tr>
<td>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.</td>
<td>(196)</td>
</tr>
<tr>
<td>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</td>
<td>(105)</td>
</tr>
<tr>
<td>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.</td>
<td>17</td>
</tr>
<tr>
<td>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.</td>
<td>17</td>
</tr>
<tr>
<td>Accelerometer: $13M cost increase for adding three units. Estimated for GRACE.</td>
<td>13</td>
</tr>
<tr>
<td>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.</td>
<td>(40)</td>
</tr>
<tr>
<td>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.</td>
<td>10</td>
</tr>
<tr>
<td>LAGRANGE</td>
<td>1116</td>
</tr>
</tbody>
</table>
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: $\Delta \rho$, $\Delta v$, $\Delta \theta$, hold other terms constant, calculate acceleration spectrum

- Density noise is largest.