Possible Space-based Gravitational-wave Observatory Mission Concept

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Abstract

The existence of gravitational waves was established by the discovery of the Binary Pulsar PSR 1913+16 by Hulse and Taylor in 1974, for which they were awarded the 1993 Nobel Prize. However, it is the exploitation of these gravitational waves for the extraction of the astrophysical parameters of the sources that will open the first new astronomical window since the development of gamma ray telescopes in the 1970's and enable a new era of discovery and understanding of the Universe. Direct detection is expected in at least two frequency bands from the ground before the end of the decade with Advanced LIGO and Pulsar Timing Arrays. However, many of the most exciting sources will be continuously observable in the band from 0.1-100 mHz, accessible only from space due to seismic noise and gravity gradients in that band that disturb ground-based observatories. This poster will discuss a possible mission concept, Space-based Gravitational-wave Observatory (SGO-Mid) developed from the original Laser Interferometer Space Antenna (LISA) reference mission but updated to reduce risk and cost.

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Mission Concept Comparison

<table>
<thead>
<tr>
<th>Parameter</th>
<th>NGO</th>
<th>SGO Mid</th>
<th>LISA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measurement arm length</td>
<td>1 x 10(^3) km</td>
<td>1 x 10(^5) km</td>
<td>5 x 10(^5) km</td>
</tr>
<tr>
<td>Number &amp; type of spacecraft</td>
<td>3 corner (2 optical assemblies, 2 end single optical assembly)</td>
<td>3 corner (2 optical assemblies)</td>
<td>3 corner (2 optical assemblies)</td>
</tr>
<tr>
<td>Number of measurement arms, one-way links</td>
<td>2 arms, 6 links</td>
<td>3 arms, 6 links</td>
<td>3 arms, 6 links</td>
</tr>
<tr>
<td>Constellation</td>
<td>Viasat</td>
<td>Triangle</td>
<td>Triangle</td>
</tr>
<tr>
<td>Gravitational-wave polarization measurement</td>
<td>Single instantaneous polarization, second polarization by orbital evolution</td>
<td>Two simultaneous polarizations continuously</td>
<td>Two simultaneous polarizations continuously</td>
</tr>
<tr>
<td>Orbit</td>
<td>Heliocentric, earth-trailing, drifting-away 9° - 21°</td>
<td>Heliocentric, earth-trailing, drifting-away 9° - 21°</td>
<td>Heliocentric, earth-trailing</td>
</tr>
<tr>
<td>Trajectory</td>
<td>Launch to Geosynchronous Transfer Orbit, transfer to escape, 14 months</td>
<td>Direct injection to escape, 18 months</td>
<td>Direct injection to escape, 14 months</td>
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<tr>
<td>Duration of science observations</td>
<td>2 years</td>
<td>2 years</td>
<td>5 years</td>
</tr>
<tr>
<td>Launch vehicle</td>
<td>Two Soyuz-Fregat</td>
<td>Single Medium EELV (e.g., Falcon 9 Block 3)</td>
<td>Single Medium EELV (e.g., Atlas V 551)</td>
</tr>
<tr>
<td>Optical bench</td>
<td>Low-CTE material, hydroxy-catalyzed construction</td>
<td>Low-CTE material, hydroxy-catalyzed construction</td>
<td>Low-CTE material, hydroxy-catalyzed construction</td>
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<tr>
<td>Laser</td>
<td>2 W, 1064 nm, frequency and power stabilized</td>
<td>1 W, 1064 nm, frequency and power stabilized</td>
<td>2 W, 1064 nm, frequency and power stabilized</td>
</tr>
<tr>
<td>Telescope</td>
<td>46 mm cube Au/Pt, electrostatically controlled, optical readout</td>
<td>46 mm cube Au/Pt, electrostatically controlled, optical readout</td>
<td>46 mm cube Au/Pt, electrostatically controlled, optical readout</td>
</tr>
</tbody>
</table>

Science Comparison

<table>
<thead>
<tr>
<th>Parameter</th>
<th>NGO</th>
<th>SGO Mid</th>
<th>LISA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Massive Black Hole Binary Totals</td>
<td>40-47</td>
<td>45-52</td>
<td>108-220</td>
</tr>
<tr>
<td>Detected &gt; 10</td>
<td>1-1</td>
<td>1-1</td>
<td>1-1</td>
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<tr>
<td>Both mass errors &lt; 1%</td>
<td>13-30</td>
<td>18-42</td>
<td>67-171</td>
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<tr>
<td>One spin error &lt; 1%</td>
<td>3-10</td>
<td>11-27</td>
<td>49-130</td>
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<tr>
<td>Both spin errors &lt; 1%</td>
<td>&lt;1</td>
<td>&lt;1</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Distance error &lt; 3%</td>
<td>3-5</td>
<td>12-22</td>
<td>81-108</td>
</tr>
<tr>
<td>Sky location &lt; 1 deg^2</td>
<td>1-3</td>
<td>14-21</td>
<td>71-112</td>
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<tr>
<td>Sky location &lt; 0.1 deg^2</td>
<td>&lt;1</td>
<td>4-8</td>
<td>22-51</td>
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<tr>
<td>Extreme Mass Ratio Insirals</td>
<td>12</td>
<td>35</td>
<td>800</td>
</tr>
<tr>
<td>Resolved Compact WD Binaries</td>
<td>3,889</td>
<td>7,000</td>
<td>40,000</td>
</tr>
<tr>
<td>Interacting</td>
<td>50</td>
<td>100</td>
<td>1,300</td>
</tr>
<tr>
<td>Detached</td>
<td>5,000</td>
<td>8,000</td>
<td>40,000</td>
</tr>
<tr>
<td>Sky location &lt; 1 deg^2</td>
<td>1,053</td>
<td>2,000</td>
<td>13,000</td>
</tr>
<tr>
<td>Sky location &lt; 0.1 deg^2, distance error &lt; 10%</td>
<td>533</td>
<td>800</td>
<td>8,000</td>
</tr>
<tr>
<td>Stochastic background (normalized)</td>
<td>0</td>
<td>0.2</td>
<td>1</td>
</tr>
</tbody>
</table>

SGO-Mid Mission Summary

- **Mission Design**
  - 10^6 km arm-length, 3 arms, 60 degree triangle
  - 3 identical spacecraft
- **LISA-like payload**
  - 25 cm telescope/1 W laser
  - 9-21 degree drift away heliocentric orbit
- **Direct injection to escape, 18 mo transfer**
  - Single EELV (e.g. Falcon 9 Block 3)
  - Baseline 2 year lifetime + 2 years
  - Limited by communications bandwidth

3 identical arms enables simultaneous measurement of both polarizations of gravitational waves, which is essential for parameter extraction, particularly of transient events such as mergers.

Sciencecraft

Full Sciencecraft Bus

Disturbance Reduction System Detail

Laser

Optical Bench

Launch Stack in 5 Meter Fairing

Mission Timeline

Pre-Launch 24 months science operations: orbits optimized for 48 months

Summary

The LISA-like mission concept SGO-Mid is based on the baseline LISA mission design, but has been updated to reduce risk and cost. The main differences with the baseline are the shorter armlength (1 million km instead of 3) and the mission lifetime (2 years instead of 5). Science return is maximized by keeping three arms to allow simultaneous measurement of both polarizations as well as a Sagnac configuration that allows careful measurement of the noise. Drift away orbits offer graceful degradation as the constellation moves out of communications range.