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 1983 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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Final report: http://pcos.gsfc.nasa.gov/studies/gravitational-wave-mission.php

Mission Concept Comparison

Parameter	NGO	SGO Mid (This poster)	LISA (Best)
Measurement arm length	1 x 10^6 km	1 x 10^6 km	5 x 10^6 km
Number & type of spacecraft	1 corner (2 optical assemblies, 2 end (single optical assembly	3 corner (2 optical assemblies)	3 corner (2 optical assemblies)
Number of measurement arms, one-way links	2 arms, 4 links	3 arms, 6 links	3 arms, 6 links
Constellation	Vee	Triangle	Triangle
Gravitational-wave polarization measurement	Single instantaneous polarization, second polarization by orbital evolution	Two simultaneous polarizations continuously	Two simultaneous polarizations continuously
Orbit	Heliocentric, earth-trailing, drifting-away 9° - 21°	Heliocentric, earth-trailing, drifting-away 9° - 21°	22° heliocentric, earth-trailing
Trajectory	Launch to Geosynchronous Transfer Orbit, transfer to escape, 14 months	Direct injection to escape, 18 months	Direct injection to escape, 14 months
Duration of science observations	2 years	2 years	5 years
Launch vehicle	Two Soyuz-Fregat	Single Medium EELV (e.g., Falcon 9 Block 3)	Single Medium EELV (e.g., Atlas V 551)
Optical bench	Low-CTE material, hydroxy-catalysis construction	Low-CTE material, hydroxy-catalysis construction	Low-CTE material, hydroxy-catalysis construction
Laser	2 W, 1064 nm, frequency and power stabilized	1 W, 1064 nm, frequency and power stabilized	2 W, 1064 nm, frequency and power stabilized
Telescope	20 cm diameter, off-axis	25 cm diameter, on-axis	40 cm diameter, on-axis
Gravitational Reference Sensor	46 mm cube Au:Pt, electrostatically controlled, optical readout	46 mm cube Au:Pt, electrostatically controlled, optical readout	46 mm cube Au:Pt, electrostatically controlled, optical readout

Science Comparison

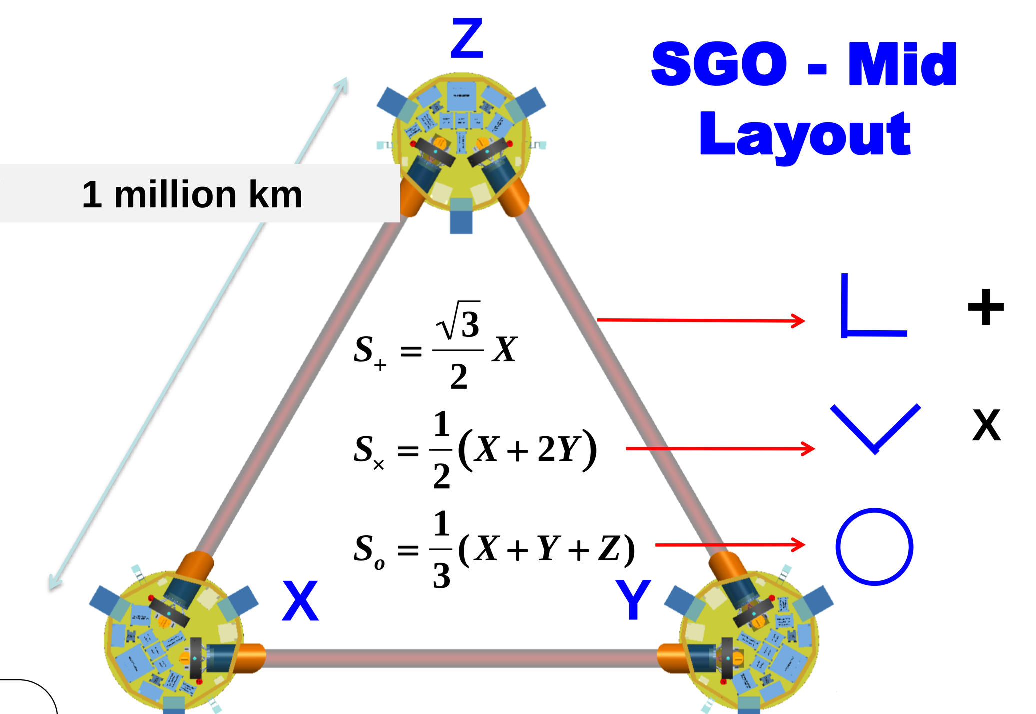
	NGO	SGO Mid (This poster)	LISA (Best)
Massive Black Hole Binary Totals	40-47	41-52	108-220
Detected z > 10	1-3	1-4	3-57
Both mass errors < 1%	13-30	18-42	67-171
One spin error < 1%	3-10	11-27	49-130
Both spin errors < 1%	<1	<1	1-17
Distance error < 3%	3-5	12-22	81-108
Sky location < 1 deg^2	1-3	14-21	71-112
Sky location < 0.1 deg^2	<1	4-8	22-51
Extreme Mass-Ratio Inspirals	12	35	800
Resolved Compact WD Binaries	3,889	7,000	40,000
Interacting	50	100	1,300
Detached	5,000	8,000	40,000
Sky location < 1 deg^2	1,053	2,000	13,000
Sky location < 1 deg^2, distance error < 10%	533	800	8,000
Stochastic Background (normalized)	0	0.2	1

SGO-Mid Mission Summary

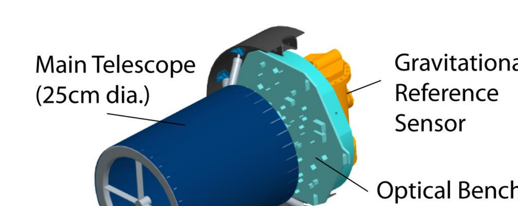
- Mission Design
  - 10^6 km arm-length, 3 arms, 60 deg triangle
  - 3 identical spacecraft
  - LISA-like payload
    - 25 cm telescope/1 W laser
  - 9-21 degree drift away heliocentric orbit
  - Direct injection to escape, 18 mo transfer
    - Single EELV (e.g. Falcon 9 Block 3)
  - Baseline 2 year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

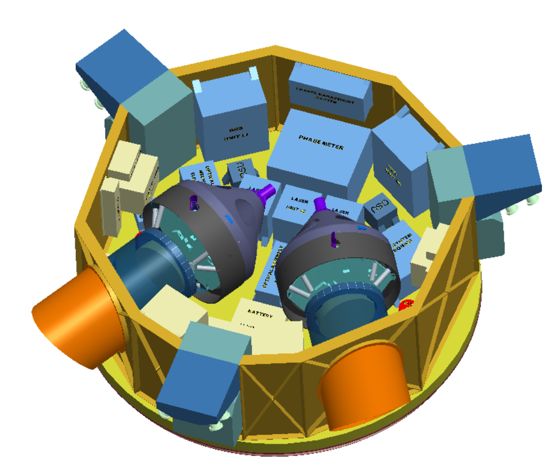
SGO - Mid Layout



Sciencecraft

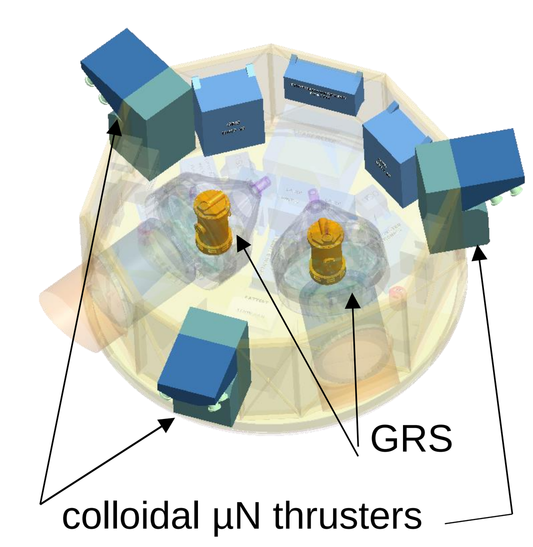


Full Sciencecraft Bus

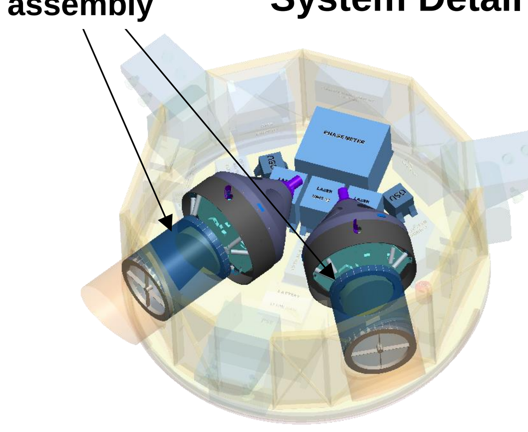


Solar array not shown for clarity

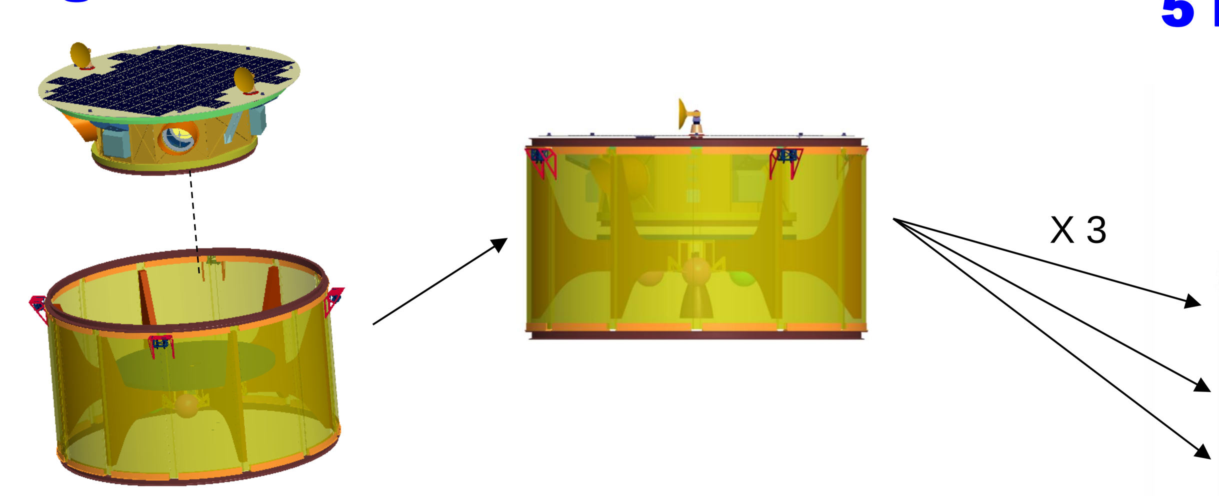
Disturbance Reduction System Detail



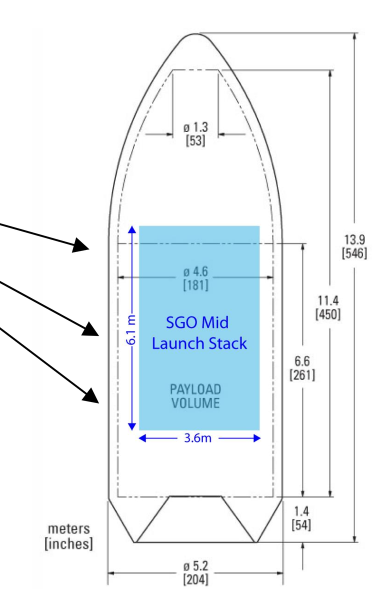
Interferometry Measurement System Detail



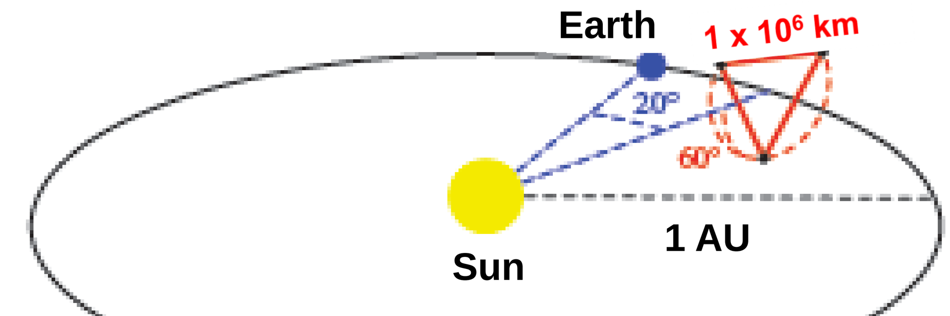
Propagation Module



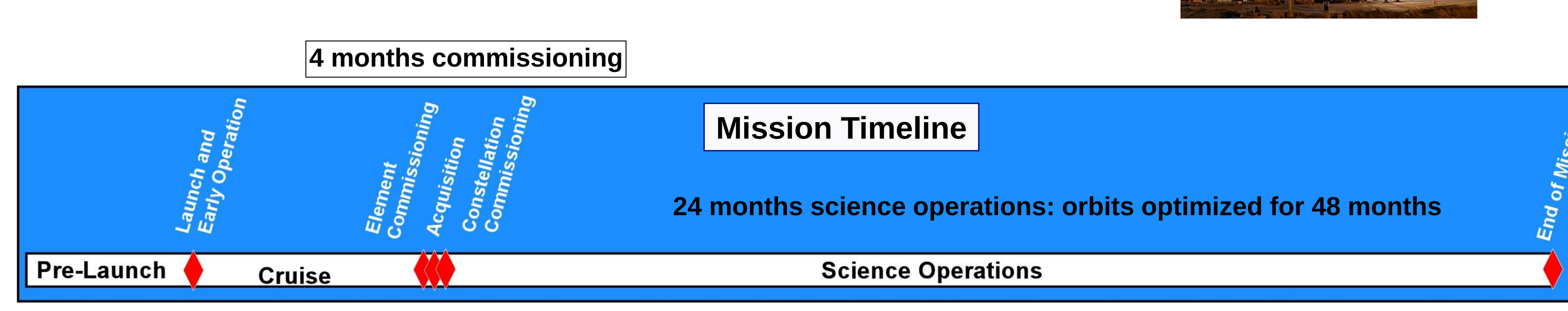
Launch Stack in 5 m Fairing



Science Orbits



Falcon Heavy EELV



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 5) 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.