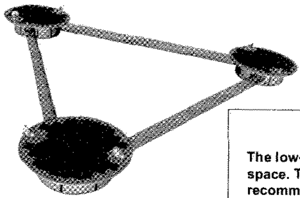
Concepts for a Space-based Gravitational-Wave Observatory (SGO)



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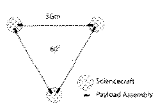
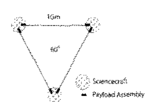
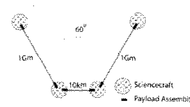
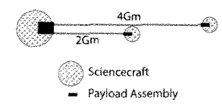
Abstract

The low-frequency band (0.0001 - 1 Hz) of the gravitational wave spectrum has the most interesting astrophysical sources. It is only accessible from space. The Laser Interferometer Space Antenna (LISA) concept has been the leading contender for a space-based detector in this band. Despite a strong recommendation from Astro2010, constrained budgets motivate the search for a less expensive concept, even at the loss of some science. We have explored the range of lower-cost mission concepts derived from two decades of studying the LISA concept. We describe LISA-like concepts that span the range of affordable and scientifically worthwhile missions, and summarize the analyses behind them.

Introduction

With the end of the formal NASA/ESA collaboration on the Laser Interferometer Space Antenna (LISA), teams in both the U.S. and Europe are studying new gravitational-wave mission concepts at lower price points, that is, less science for lower cost. The ESA science team has settled on a concept called Next Generation Space-based Gravitational-wave Observatory (NGO). See poster #146.26. In the U.S., NASA is conducting a study of mission concepts. The previous members of the LISA Project team have identified four LISA-like concepts, referred to as the Space-based Gravitational-wave Observatory (SGO), at different price points. This poster gives a comparative description of the science capabilities and mission parameters for SGO High, Mid, Low and Lowest.

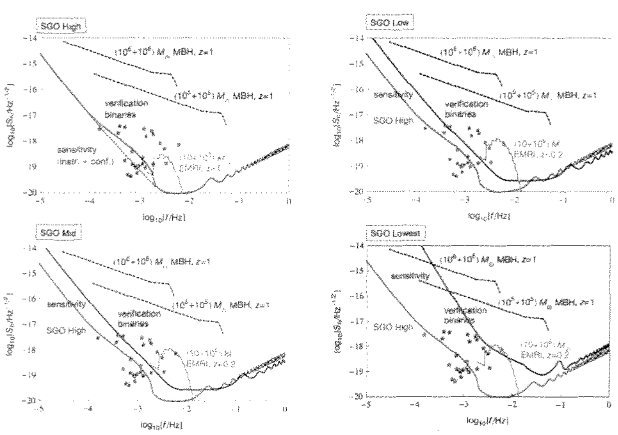
Concepts

	High	Mid	Low	Lowest
Design Goal	Capitalize on 20 years of NASA and ESA LISA studies and technology development. Lowest scientific technical and cost risk.	Reduce the LISA concept to the least expensive variant with six laser links, comprising three interferometer arms for simultaneously observing both polarizations, discriminating between some cosmological sources and instrumental noise, and redundancy.	Reduce the LISA concept to the least expensive variant with four gigameter-scale laser links. Based on four nearly identical SC with two of them located near one vertex and one at each of the other two vertices. The two corner SC, separated by ~10km, use a free-space optical link to compare their laser frequencies. Expect four identical SC are cheaper than three having two different designs.	Aim for the lowest cost gravitational mission that could achieve some minimal portion of LISA's science objectives. Collapse the Vee-constellation into a line, replacing two corner sciencecraft with one corner spacecraft that is nearly identical.
Changes (relative to the next higher concept)	• Single agency cost model • Lower launch costs	• Reduce detector arm length by a factor 5. • Reduce observation period from 5 to 2 years. • Reduce nominal starting distance from Earth by about factor of 2.5. • Reduce telescope diameter from 40 to 25 cm • Reduce laser power out of the telescope from 1.2 to 0.7 W (end of life). • In-field guiding is used instead of articulating the entire optical assembly.	• Add a fourth SC • A telescope, optical bench, laser, GRS, pointing mechanism and supporting structure and thermal subsystems is eliminated from each payload. • Two of the four SC have an optical pointing system (small telescope, 2-DOF pointing system) for exchanging laser beams.	• Two corner spacecraft combined into a single one with a single optical assembly using a similar optical bench capable of two outputs. 3 spacecraft instead of 4 • Elimination of the free-space laser link. • Elimination of propulsion modules.
Constellation Geometry				

Characteristics

Parameter	LISA Concept	SGO High	SGO Mid	SGO Low	SGO Lowest
Arm length (meters)	5 x 10^9	5 x 10^9	1 x 10^9	1 x 10^9	2 x 10^9
Constellation	Triangle	Triangle	Triangle	Triangle (60-deg Vee)	In-line: Folded SyZyGy
Orbit	22° heliocentric, earth-trailing	22° heliocentric, earth-trailing	Heliocentric, earth-trailing, drifting-away 9°- 21°	Heliocentric, earth-trailing, drifting-away 9°- 21°	≤9° heliocentric, earth drift-away
Trajectory	Direct injection to escape, 14 months	Direct injection to escape, 14 months	Direct injection to escape, 18 months	Direct injection to escape, 18 months	Direct injection to escape, 18 months
Interferometer configuration	3 arms, 6 links	3 arms, 6 links	3 arms, 6 links	2 arms, 4 links	2 unequal arms, 4 links
Launch vehicle	Medium EELV (e.g., Atlas V 431)	Medium EELV (e.g., Falcon Heavy shared launch)	Medium EELV (e.g., Falcon 9 Block 3)	Medium EELV (e.g., Falcon 9 Heavy shared launch)	Medium EELV (e.g., Falcon 9 Block 2)
Baseline/Extended Mission Duration (years)	5/3.5	5/3.5	2/0	2/0	2/0
Telescope Diameter (cm)	40	40	25	25	25
Laser power out of telescope end of life (W)	1.2	1.2	0.7	0.7	0.7
Measurement system modifications	Baseline/Reference	Baseline/Reference (Same as LISA Concept)	In-field guiding, UV-LEDs, no pointing	4 identical spacecraft with one telescope each, In-field guiding, free space backlink, UV-LEDs, arm locking	3 spacecraft with one telescope each, episodic thrusting, in-field guiding, next gen micronewton thrusters, no prop module
Motivation:	Science performance, two agencies	LISA performance with all known economies	Lowest cost 6 links	Lowest cost with viable science return	Lowest cost
Approximate Cost (FY12 $B)	1.82	1.66	1.40	1.41	1.19

Science Performance



Comparison of Science Performance for different versions of SGO				
Concept	SGO High	SGO Mid	SGO Low	SGO Lowest
Nominal Lifetime	5 yrs	2 yrs	2 yrs	2 yrs
MBH mergers				
Total # Detections	$70 \sim 150$	$25 \sim 35$	$25 \sim 35$	~ 4
Median Redshift	$\bar{z} \sim 5$	$\bar{z} \sim 5$	$\bar{z} \sim 5$	$\bar{z} \sim 4$
Mass Precision @ $z = \bar{z}$	$\frac{\sigma_M}{M} \sim 0.2\%$	$\frac{\sigma_M}{M} \sim 1\%$	$\frac{\sigma_M}{M} \sim 1\%$	$\sim 3\%$
Spin Accuracy @ $z = \bar{z}$	$\sigma\chi \sim 0.3\%$	$\sigma\chi \sim 2\%$	$\sigma\chi \sim 3\%$	-
Distance Accuracy @ $z = \bar{z}$	$\frac{\sigma_{D_L}}{D_L} \sim 3\%$ (WL)	$\frac{\sigma_{D_L}}{D_L} \sim 3\%$ (WL)	$\frac{\sigma_{D_L}}{D_L} \sim 20\%$	-
Sky Localization @ $z = \bar{z}$	$\sim 1\ \text{deg}^2$	$\sim 1\ \text{deg}^2$	$\gtrsim 100\ \text{deg}^2$	-
# Detections @ $z < 2$	~ 7	$1 \sim 2$	$1 \sim 2$	< 1
Mass Precision @ $z = 1$	$\frac{\sigma_M}{M} \lesssim 0.1\%$	$\frac{\sigma_M}{M} \lesssim 0.1\%$	$\frac{\sigma_M}{M} \lesssim 0.3\%$	-
Spin Accuracy @ $z = 1$	$\sigma\chi \lesssim 0.1\%$	$\sigma\chi \lesssim 0.1\%$	$\sigma\chi \lesssim 1\%$	-
Sky Localization @ $z = 1$	$\lesssim 0.1\ \text{deg}^2$	$\lesssim 0.1\ \text{deg}^2$	$\lesssim 10\ \text{deg}^2$	-
EMRIs				
# Detections	$40 \sim 4000$, to $z \sim 1.0$	$2 \sim 200$, to $z \sim 0.2$	$\lesssim 40$, to $z \sim 0.15$	0
Mass Accuracy	$\frac{\sigma_M}{M} \sim 0.01\%$	$\frac{\sigma_M}{M} \sim 0.01\%$	$\frac{\sigma_M}{M} \sim 0.01\%$	-
MBH Spin Accuracy	$\sigma\chi \sim 0.01\%$	$\sigma\chi \sim 0.01\%$	$\sigma\chi \sim 0.01\%$	-
Compact Binaries				
# Verification binaries	10	8	7	0
# Resolvable binaries	$\sim 20,000$	$\sim 4,000$	$\sim 2,000$	~ 100
Discovery Space				
Detects early-universe Ω_{gw}	$\gtrsim 10^{-10}$	$\gtrsim 10^{-9}$	-	
Can Detect+Verify Bursts?	✓	✓	-	-