SGO Low: A LISA-like gravitational wave observatory with four links

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For the SGO Core Concept Team

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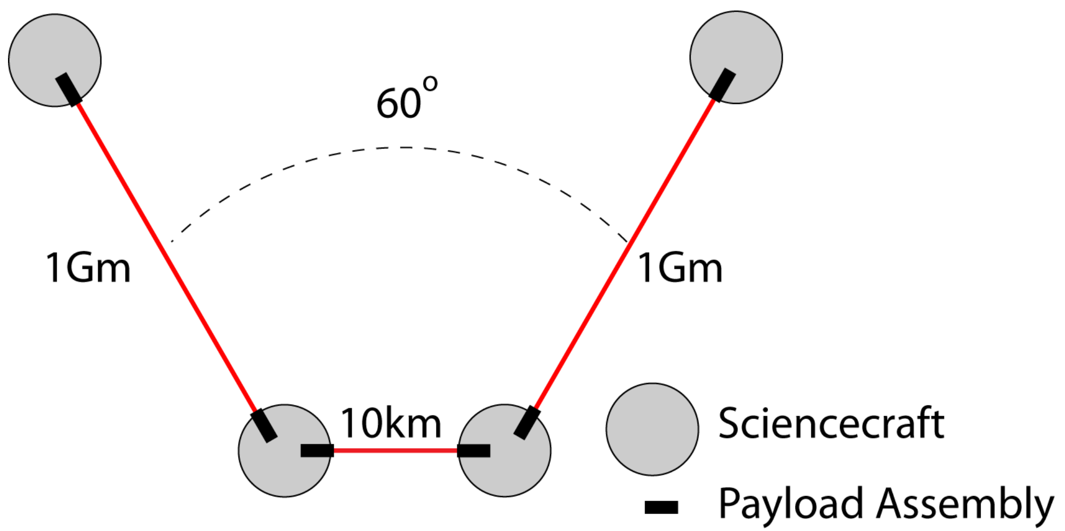
Overview

- Design Goal: Reduce LISA measurement concept to minimum four-link design while retaining primary science targets.
- Architecture: Four “identical” SC in 1Gm triangle, each with one payload assembly
- Two “corner” SC compare laser phase via 10km free-space link

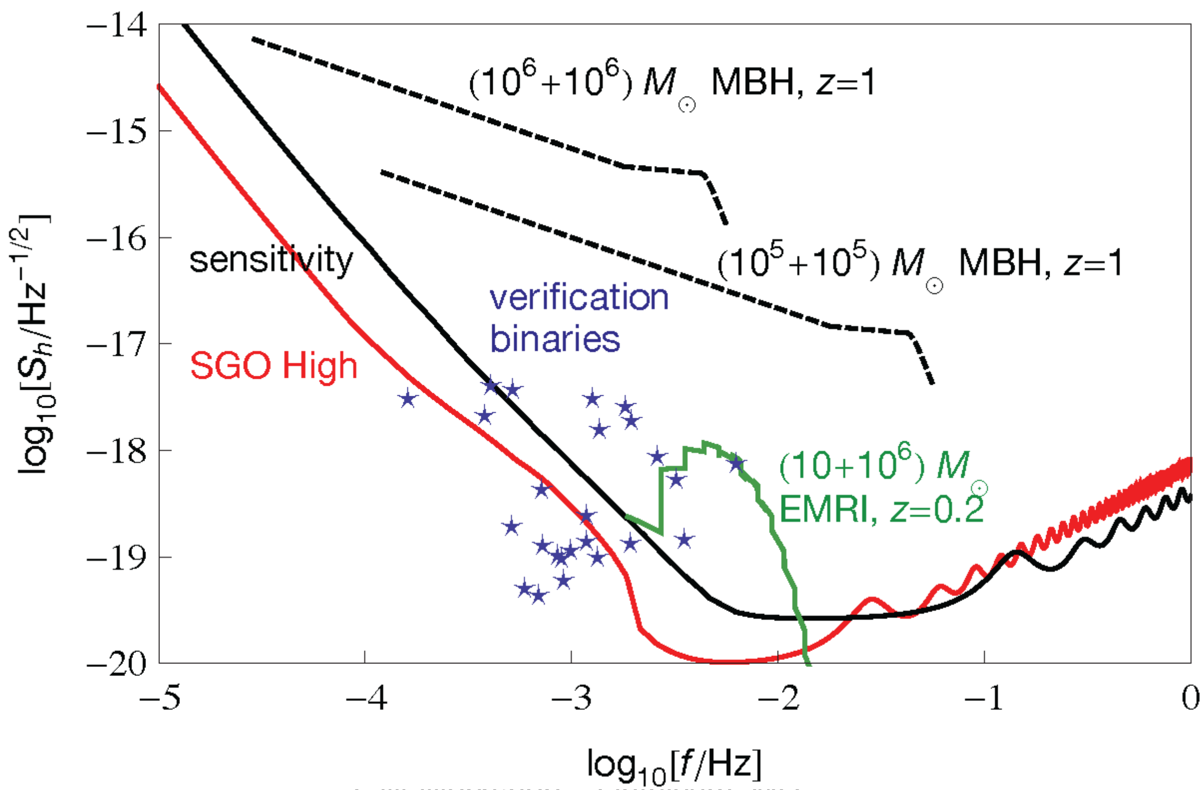


Design Parameters

- Arm Length: 1Gm
- Opening Angle: 60^o
- Orbit: Heliocentric drift-away at $\sim 9^o$ behind Earth
- Displacement sensitivity: $18x10^{-12}$ $m/Hz^{1/2}$
- Residual Acceleration Noise: 3x10-15 $m/s^2/Hz^{1/2}$
- Science Operations Duration: 2 years

Projected Sensitivity

- Above ~30mHz, sensitivity is equal or better than SGO High
- Below ~10mHz, instrumental sensitivity is ~10x worse
- No significant contribution from galactic foreground
- Sensitive to all three classes of LISA astrophysical sources



Measurement Performance

- Massive Black Hole Binaries
  - Detect ~12/yr with SNR ~ 100
  - median z ~ 5, max z ~ 12
  - Masses/spins ~ few %
  - Distance ~ 20%
  - Sky Location ~ 80deg^2
- Extreme Mass Ratio Inspirals
  - Detect ~20/yr @ z < 0.15
  - Masses/Spins ~ 10^{-4}
- Galactic Binaries
  - ~2x10^3 resolved sources
  - 7 verification binaries
  - Sky location ~ few deg

Massive Black Hole (MBH) Merger	
Detection Rate	~ 12/yr for 2 years
Characteristics	• Redshifts: $0 \lesssim z \lesssim 12$, $\tilde{z} \sim 5$ • Mass Range: $10^4 - 10^6?\ M_\odot$ • Signal Duration: $\sim$ weeks to months?
Observables	• Masses: $\frac{\sigma_M}{M} \sim 1\%$ @ $z = \tilde{z} \sim 5$; $\frac{\sigma_M}{M} \lesssim 1\%$ @ z=1; • Spins: $\frac{\sigma_S}{S} \sim 3\%$ @ $z = \tilde{z} \sim 5$; $\frac{\sigma_S}{S} \lesssim 1\%$ @ z=1 • Luminosity Distance: $\frac{\sigma_{D_L}}{D_L} \sim 20\%$ @ $z = \tilde{z} \sim 5$; $\frac{\sigma_{D_L}}{D_L} \sim 1\%$ @ z=1 • Sky Localization: $\sigma_\Omega \sim 80$ deg^2 @ $z = \tilde{z} \sim 5$; $\sigma_\Omega \lesssim 10$ deg^2 @ z=1
Science Payoffs	• History of MBH growth and galaxy mergers • Tests of General Relativity in strong-field, highly dynamical regime
Capture of Stellar Mass Compact Objects by MBH	
Detection Rate	Best estimate: ~ 20/yr; Pessimistic: < 1/yr
Characteristics	• Compact Object: mostly BH with $M \sim 10 M_\odot$ possibly some NSs and WDs • MBH Mass: $10^4 - 5 \times 10^6 M_\odot$ • Redshift Range: $z \lesssim 0.15$ • Orbital Period: $10^1 - 10^3$ s • Signal Duration: $\sim$ years
Science Payoffs	• History of MBH growth • Populations and dynamics of compact objects in galactic nuclei • Precision tests of General Relativity and Kerr nature of MBHs
Capture of IMBHs by MBH	
Characteristics	Detectable at $z \lesssim 10?$, rates uncertain
Ultra-Compact Binaries	
Characteristics	Primarily compact WD-WD binaries; mass transferring or detached Orbital periods: $\sim 10^2 - 10^4$ s
Detections	$\sim 2,000$ individual sources, including ≈ 7 known "verification binaries" Diffuse galactic background at $f \lesssim 2?$ mHz
Observables	Orbital frequency; Sky location to few degrees; Chirp mass and Distance from $\dot{f}$ for some high-f binaries
Science Payoffs	• $\sim$ 10−fold increase in census of short-period Galactic compact binaries • Evolutionary pathways, e.g. outcome of common envelope evolution • Physics of tidal interactions and mass transfer • WD-WD as possible SN Ia progenitors

Science Performance

- *Understand the formation of massive black holes*
  - Not likely to directly detect seed BH
  - May constrain seed population by observing their progeny
- ***Trace the growth and merger history of massive black holes and their host galaxy (NWNH)***
  - By measuring mass/spin and rough redshift of MBH mergers, BH growth is traced
  - EMRI's give very precise measurements in local universe
  - Sky localization insufficient for identifying host galaxy
- *Explore stellar populations and dynamics in galactic nuclei*
  - EMRI events help characterize immediate environments of MBH in the local universe
  - Some risk that no EMRI's are detected if pessimistic event rate estimates are assumed

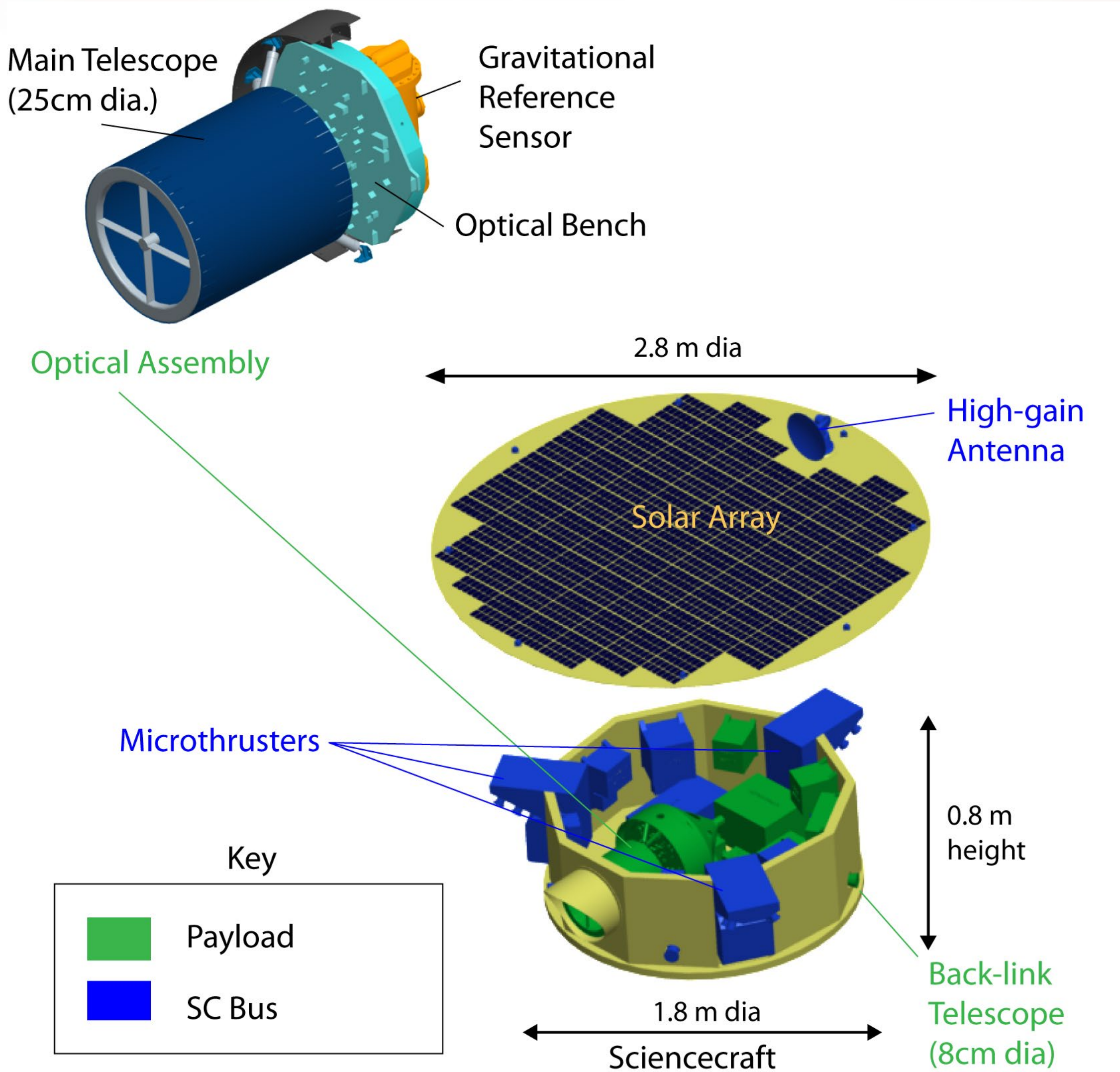
Science Performance - Continued

- *Survey compact stellar-mass binaries and study the structure of the galaxy*
  - Few thousand individual binaries with measured mass & spin will provide information on the demographics of compact objects in the Milky Way.
- *Confront General Relativity with observations*
  - Compare MBH waveforms with numerical relativity
  - **Map spacetime of individual MBH with EMRI and compare to Kerr solution (NWNH)**
  - Compare EM and GW observations of galactic binaries
- ***Probe new physics and cosmology, and search for unforseen sources of gravitational waves (NWNH)***
  - Limited by four-link design, which does not allow cross-checks

Instrument Design

- **Simplifications from SGO High / LISA**
  - Single GRS per SC, 12-DOF control system
  - No Optical Assembly Tracking Mechanism
  - Reduced laser power (0.7W)
  - Reduced telescope size (25 cm)
  - No on-board frequency reference (arm-locking)
  - UV-LED charge control
  - Reduced point-ahead angle and angle rate
  - Reduced component count
- **Additional Components**
  - 8 cm back-link telescope with tip/tilt control

Spacecraft Design



Mission Design

- **Launch Stack**
  - Each SC mates with propulsion module
  - Four SC/PM pairs stack in fairing
  - Total wet stack mass of ~4300kg
- **Launch Vehicle Possibilities**
  - Atlas V (531), 650kg margin
  - Falcon 9 Heavy, 9200kg margin. Shared launch?
- **Trajectory:**
  - Direct insertion into drift-away
  - Total $\Delta v \sim 130$m/s
- **Orbit Stability**
  - $\Delta L/L \sim 0.6\%$, Doppler ~ 2 MHz, interior angle variation $\sim 0.6^{o}$

Cost Estimate

- **Basis**
  - LISA Project costs from multiple epochs
  - LISA Pathfinder development costs
  - LV cost data
  - 70% success probability and 20% reserves
  - Credit taken for non-recurring engineering costs

SGO High estimate	**1.66**
Launch vehicle savings	0.00
Optical assembly count reduction	-0.03
Payload mass or redundancy reduction	-0.10
Mission duration reduction	-0.12
SGO Low total	**$1.41B**

ROM Cost Estimate: $1.41B (FY12)

Schedule

- Schedule based on LISA project schedule with some savings during I&T and operations
- 9 years pre-launch, 22 months transfer & commissioning, 2 years operations
- Extended mission limited by constellation stability & communication

Phase		Duration (months)
A		12
B		30
C/D		66
E	transfer	18
	commissioning	4
	Science ops	24

Summary

- The SGO Low concept addresses 2 of the 3 science priorities for space-based gravitational wave detection identified in the NWNH report.
- Low technical risk due to heritage from LISA Pathfinder and past LISA technology development and risk-reduction activities.
- No cost savings relative to SGO Mid despite moderate loss of science performance
- Small cost savings relative to SGO High with significant loss of science performance

SGO Core Concept Team

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