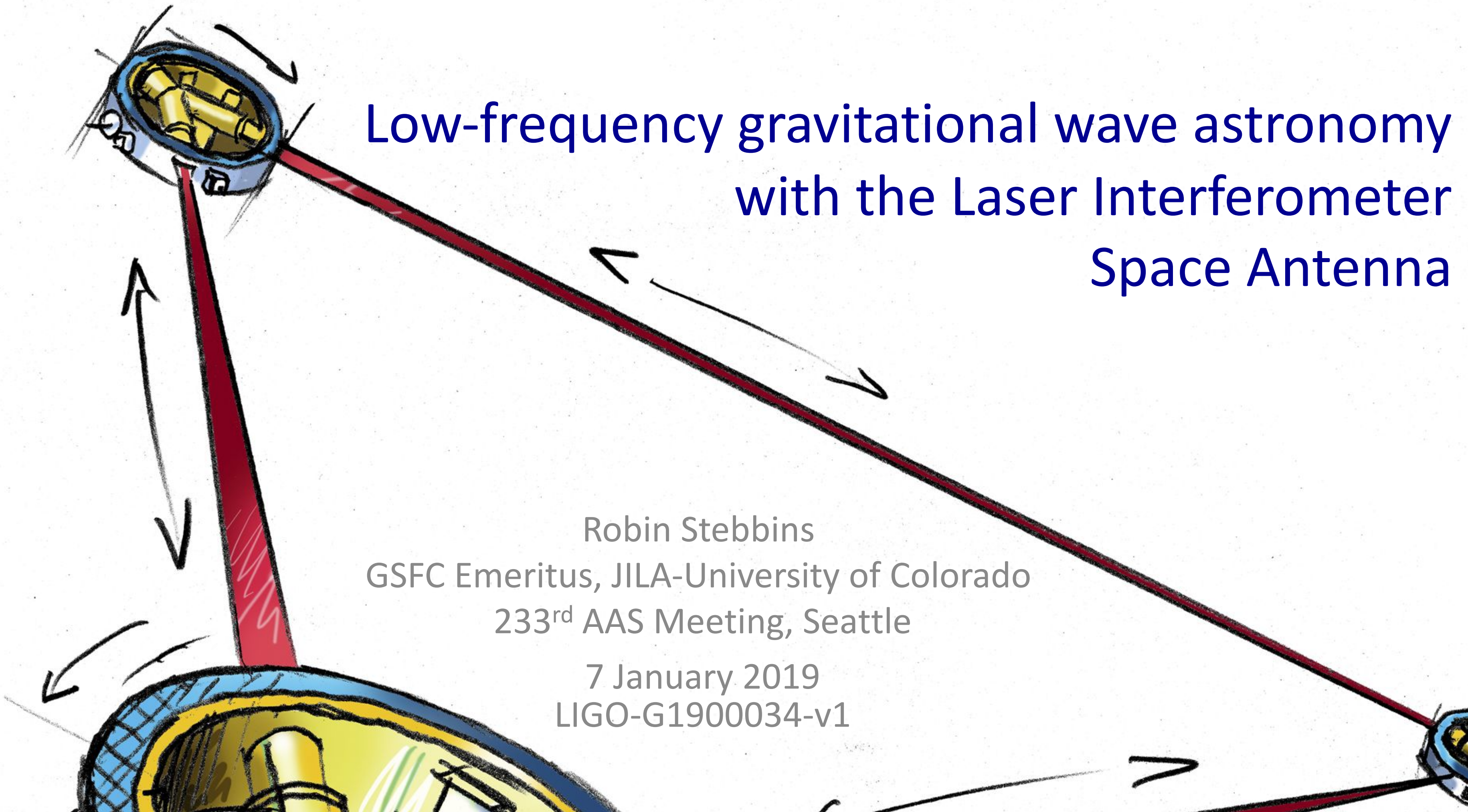


Low-frequency gravitational wave astronomy with the Laser Interferometer Space Antenna

Robin Stebbins
GSFC Emeritus, JILA-University of Colorado

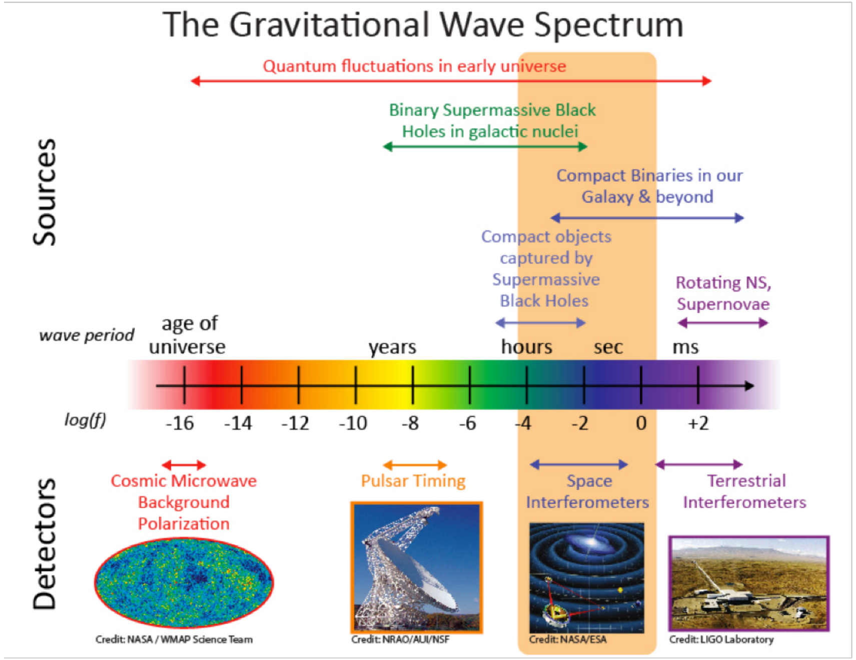
233rd AAS Meeting, Seattle

7 January 2019

LIGO-G1900034-v1

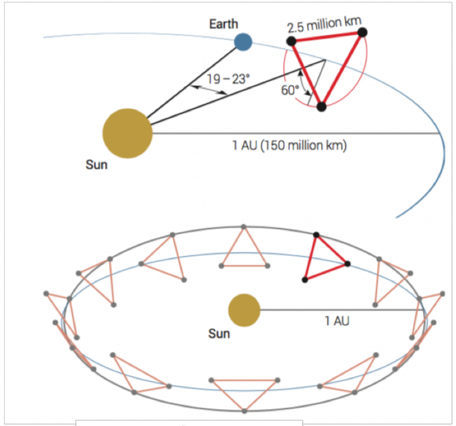
LISA is complementary to next-gen ground observatories

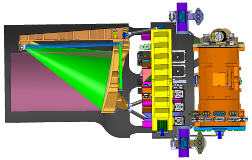
- A first-gen space observatory, but with spaceflight heritage
- Shared principles: laser interferometry, template fitting, etc.
- But, a really different detector
- A complementary measurement band in the GW spectrum
- Different source types and numbers
- Different detection, signals and data analysis
- A space mission: no upgrades, constrained lifetime, slight improvements at best
- Mid-2030's with Cosmic Explorer, Voyager, ET, SKA

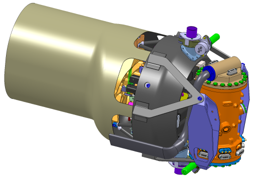


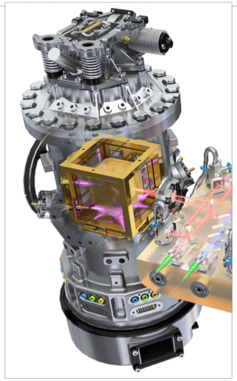
Critical elements of the instrument

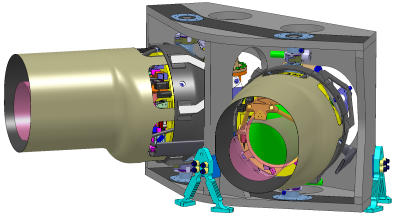
- Continuous laser interferometric ranging with picometer sensitivity
- Arms millions of kilometers long
- Drag-free masses with femto-g disturbances
- Triangular constellation of spacecraft in heliocentric orbits
- Time delay interferometry (TDI)







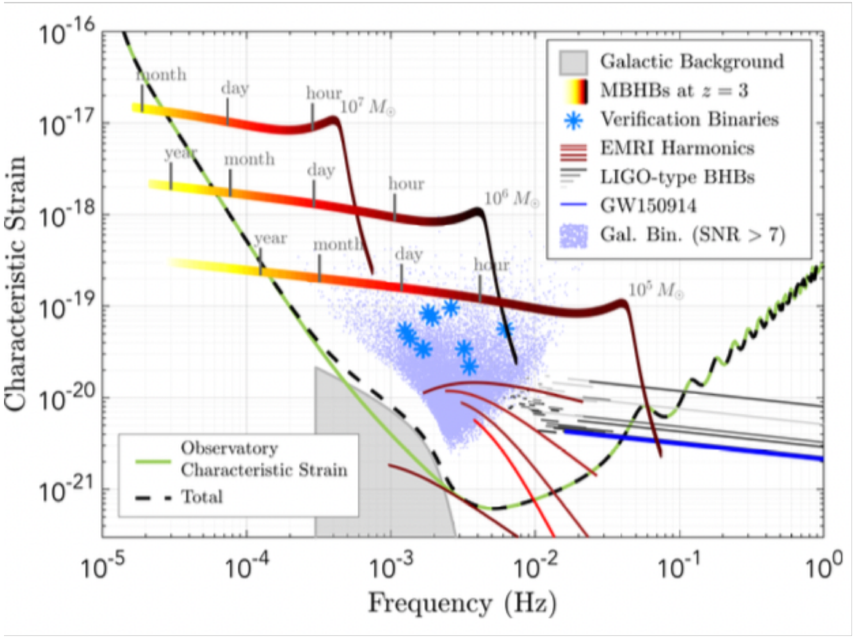


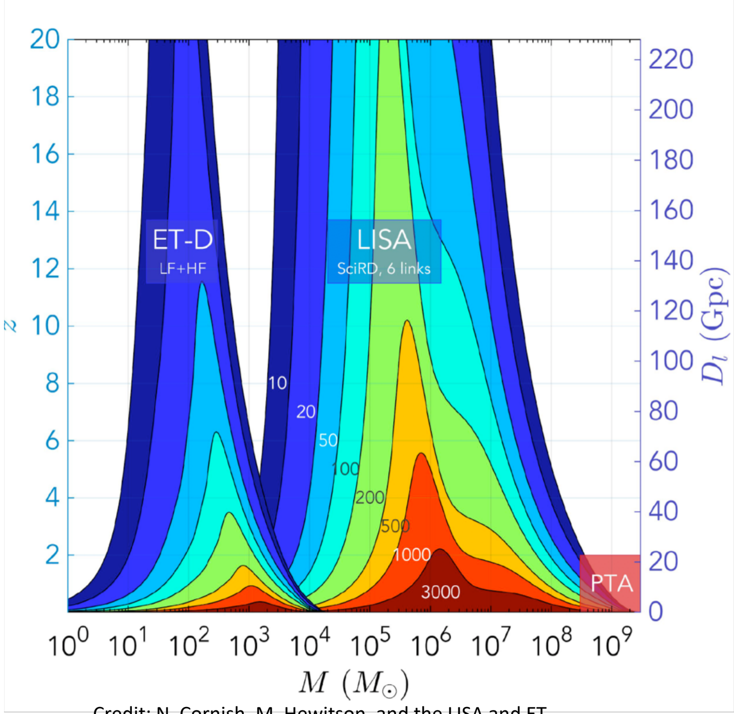


Instrument

Characteristic	Next-Gen Ground-Based Detectors	LISA
Operating band	IFOs: 1-10k Hz. PTAs: 1-10 nHz	0.1mHz – 0.1 Hz
Armlength	IFOs: Few - 40 km, set by real estate and earth's radius. PTAs: N/A	2.5 Mkm, could be 1-10 Mkm, set by orbit choices and evolution, and system design choices.
Limiting noises	IFOs: Thermal noise, quantum effects, gravity-gradient noise, seismic noise. PTAs: pulse noise, timing.	Spurious low-frequency forces: thermal effects, residual gas, stray electrostatics, shot noise, cross-couplings
Directional information	IFOs: Network timing and orientation. PTAs: numerous pulsars.	Orbital motion gives amplitude modulation, frequency modulation and phase modulation
Polarization information	IFOs: Instantaneous from network orientation. PTAs: numerous baselines.	Instantaneous from 2 interferometers, evolves with time.
Detector lifetime	IFOs and PTAs: decades with upgrades, repairs, facility renovations.	Fixed, up to 10 yrs. No repairs. Lifetime limited by consumables and orbital evolution
Outstanding technology challenges	IFOs: Extreme optics, high power lasers, squeezed light, extreme thermal management, isolation/suspension. PTAs: N/A.	Reliability of lasers and microthrusters, system robustness, stray light

LISA Science





Credit: N. Cornish, M. Hewitson, and the LISA and ET Teams. Created for the Gravitational Wave International Committee (GWIC).

Science

Sources	Next-Gen Ground-Based Detectors	LISA
Stellar-mass compact objects	IFOs: mergers of NS/BH binaries to z~2; non-spherical pulsars	~10^4 quasi-stationary WD/NS/BH binaries in the galaxy, confusion foreground, optical counterparts
Massive stellar BHs (<10^2 M_{sun})	IFOs: mergers/ringdowns, detection to z~10	~100 BH early inspirals out to z~0.1, crossing into the IFO band to merge
IMBHs (10^2 - 10^4 M_{sun})	IFOs: detection of lower masses to high z, rate uncertain	Detection to high z, rate uncertain
EMRIs & IMRIs		~100s/yr EMRIs, rate uncertain, out to z~1
MBHs	PTAs: possibly a few 10^8 - 10^9 M_{sun} quasi-stable inspirals, z<1.	~100 10^4 - 10^7 M_{sun} inspirals/mergers/ringdowns out to z~20
Bursts and backgrounds	PTAs: stochastic background of SMBHBs. IFOs: core collapse Sne.	Possibly cosmic strings.

LISA signals and data analysis

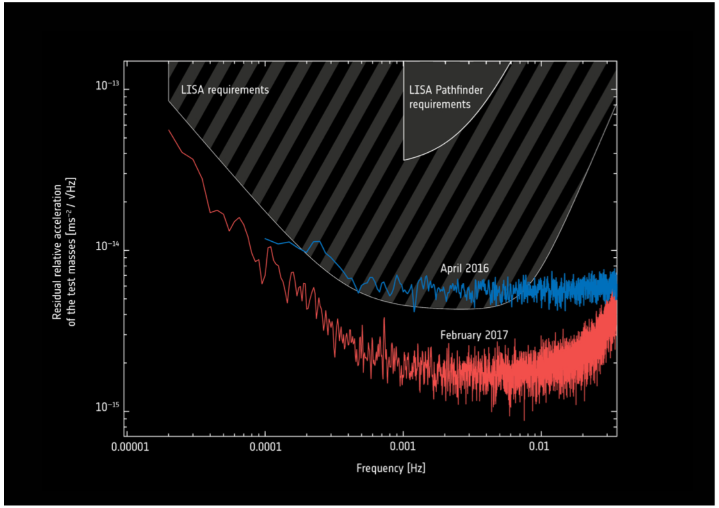
- Tens of thousands of superimposed sources, requiring simultaneous fitting
- SNRs up to 10^4 enable high precision measurement of source parameters, like mass, spin vectors, orbital parameters, distance, sky location
- All sky instrument with sky location encoded in the waveforms through amplitude, frequency and phase modulation
- Merger events weekly, sources emerging and disappearing constantly
- Most galactic binaries and EMRIs are detectable for the duration of the mission
- MBH mergers predicted weeks to months in advance, with progressively improving information. Alerts will be sent out.
- Source information improves with weekly-monthly catalog updates
- Sagnac mode allows monitoring the instrument noise constantly.

Signals and data analysis

Aspects	Next-Gen Ground-Based Detectors	LISA
Noise	IFOs: many types of noise limited by design, and then veto/notch the remainder. PTAs: single pulsar timing noise, number of pulsars, obs time	Cancel dominant noise with TDI, then minor corrections. Non-stationary.
Signals	IFOs: most sources are late-stage mergers, observable for seconds to hours. Continuous sources and bursts possible. PTAs: spectrum of averaged timing correlations from many pulsars. Individual sources possible.	Most sources are observable for weeks to mission lifetime. Bursts possible.
Analysis	IFOs: template fitting one-few sources, other search algorithms. PTAs: compare timing correlations with expected spectrum.	Massive simultaneous fit, requiring high precision waveforms
Extracting source information	IFOs: merger/ringdown templates templates. Need tidal effects and detailed dynamics for NSBs. PTAs: stochastic background prediction from SMBH population/evolutionary models.	Inspiral/merger/ringdown templates with higher precision waveforms, with more astrophysical content (eccentricity, triplets, mass exchange, etc.)

Technologies

- Heritage from LISA Pathfinder and GRACE FO/LRI
- Optical bench fabrication
- GRS refinements
- Ultra-stable telescope, stray light
- Microthrusters
- Space-qualified laser
- Phasemeter



Technologies

Technology	Next-gen Ground Based Detectors	LISA
Heritage	IFOs: operating LIGO, Virgo, GEO, Tama, Advanced LIGO, Advanced Virgo and second generation detectors. PTAs: operating at many radio observatories	LPF demonstrated disturbance budget and optical bench performance. LRI demonstrated phase measurement and acquisition. 20 yrs of technology development.
Lasers	IFOs: higher power, squeezing and possibly a different wavelength	Space-qualified, 2W, high reliability
Optics	IFOs: extraordinary performance in coatings and optics	Ultra-stable telescope, low stray-light optics, optical bench fabrication
Test masses	IFOs: large Si, or other suitable material, test masses	Improved caging and release, charge management based on UV-LEDs
Suspensions and isolation	Improved performance, possibly undergrounding detector	Microthrusters with adequate reliability and lifetime. Discharging.
Thermal management	Materials advances in coatings and suspensions, cooled masses or cryogenic instrument	

LISA Progress and Plans

- ESA: lead agency, Phase A, project staffed, 2 competing prime contractors, Science Study Team in place, technology development in progress
- NASA: junior partner (20% flight system + US science support), study office staffed, NLST in place, technology development in progress
- LISA Consortium: ~1,000 members, ~14 national agencies, management established, contractor selected, working groups in place
- NLST: Preparing for Astro2020, promoting broader US participation, producing studies for HQ
- Schedule: mission selected in 2017, Mission Adoption early-to-mid 2020s, launch early 2030s, operations to 2040+

Summary

- First generation, space-based interferometric GW detector
- Will be contemporaneous with third generation, ground-based interferometric detectors, and SKA, ca 2035.
- LISA is complementary to next-gen detectors in
  - Sources
  - Science
- LISA is different from ground-based detectors in
  - Detector design and technologies
  - Nature of its signals and data analysis
- LISA is progressing through its initial design and engineering phase.