Enhanced Gravitational Wave Science with LISA and gLISA

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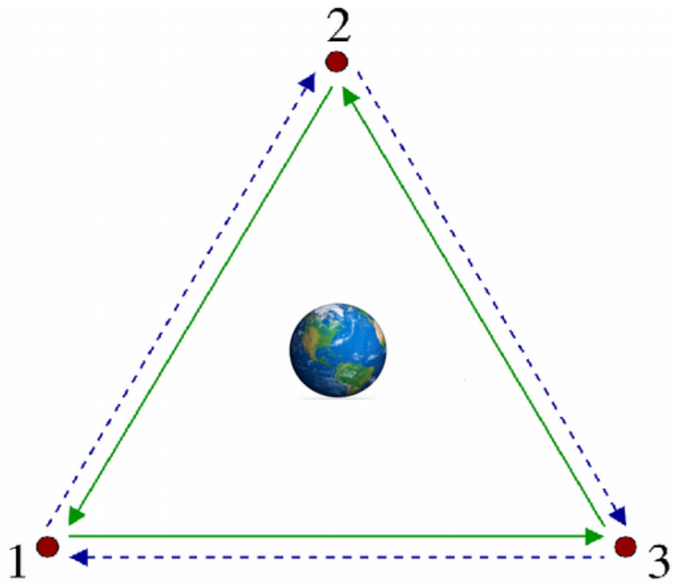

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Historical Perspective

- We are witnessing an historical and pivotal moment in the field of gravitational wave astronomy!
  - aLIGO announced its first detection (02/2016), and the observation of an additional signal (06/2016).
  - LISA Pathfinder was a success (06/2016).
- Given the magnitude and the implications of these extraordinary events, we should seriously consider the possibility of flying two GW missions rather than a single one.

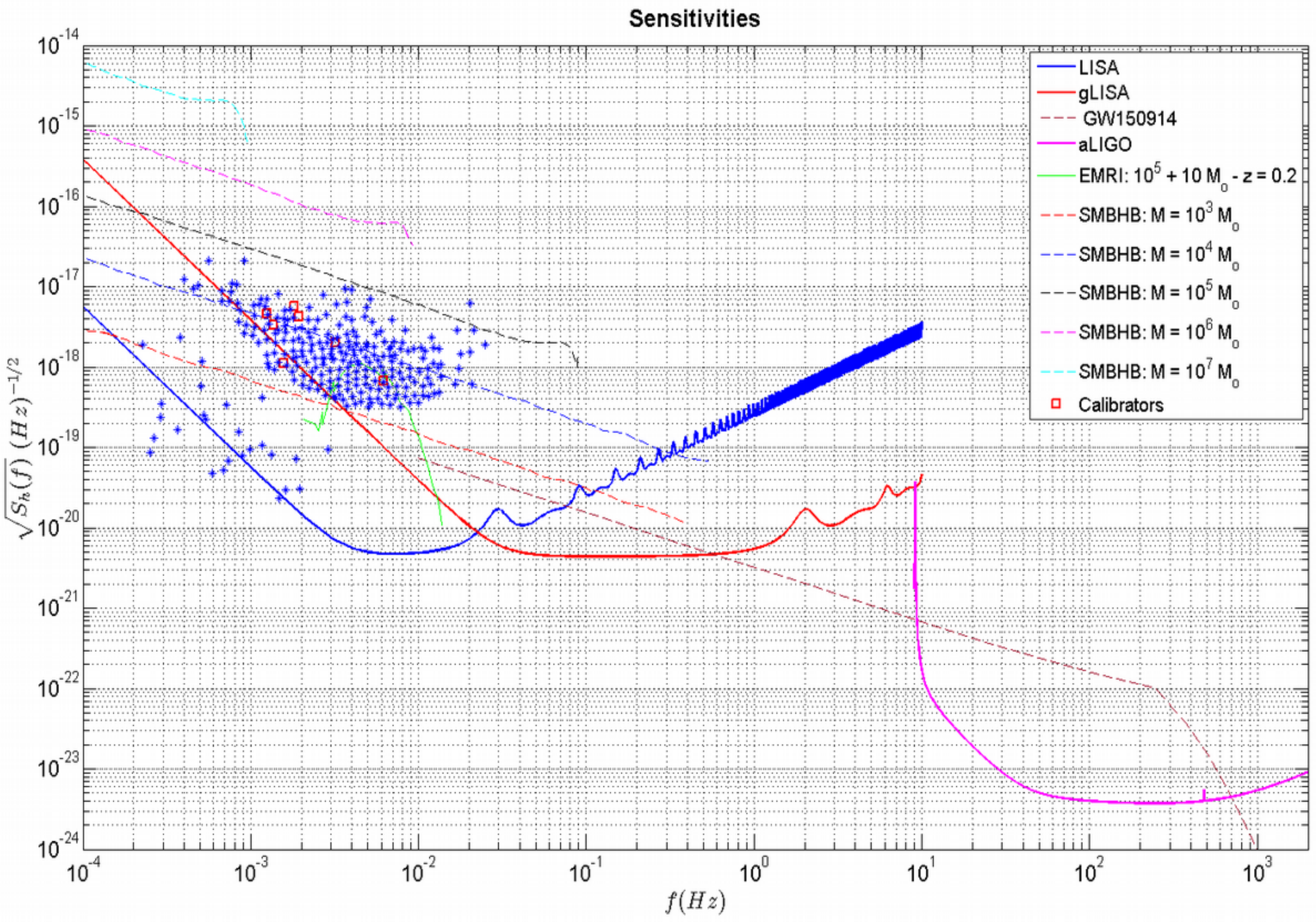
Ground- vs. Space-based

- Ground-based observations inherently require use of multiple detectors widely separated on Earth and operating in coincidence.
- This is because a network of spatially separated GW interferometers operating at the same time can
  - Very effectively discriminate a GW signal from random noise (see how the GW150914 was detected!);
  - Provide enough information for reconstructing the parameters characterizing a wave's astrophysical source (sky-location, luminosity distance, mass(es), dynamical time scale, etc.)
- Space-based interferometers instead, with their six links along their three-arms, have enough data redundancy to validate their TDI measurements and uniquely reconstruct an observed signal.

Why 2 GW Missions?

- Although a single space-based array such as LISA can synthesize the equivalent of four interferometric combinations (the Sagnac TDI combinations (α, β, γ, ζ)), its best sensitivity level is achieved only over a relatively narrow region of the mHz frequency band.
- To cover a broader frequency region of the GW spectrum it is critically important to fly missions of different arm-lengths as they can naturally complement and enhance each other's scientific capabilities.
- This is particularly evident when considering signals sweeping up-wards in frequency such as those emitted by coalescing binary systems containing black-holes.
- It is theoretically expected that an ensemble of coalescing black-hole binary systems with masses comparable to those of GW150914 will be observable over the ~ 10^{-2} - 10^{2} Hz GW band.

Sensitivity



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The geosynchronous Laser Interferometer Space Antenna

- **gLISA** is a space-based gravitational wave (GW) mission concept that, for the past five years, has been studied jointly at the Jet Propulsion Laboratory, Stanford University, the National Institute for Space Research (I.N.P.E., Brazil), and Space Systems Loral.
- It was first proposed during the 2011 NASA RFI exercise; at the same time & independently, Dr. Sean McWilliams also considered a similar mission concept (GADFLI) (see his presentations at the last two LISA symposiums)
- Geosynchronous/geostationary trajectories are easy to reach, providing a triangular array with ~ 73,000 km arm-length.
- An A-TEAM study&cost exercise performed at JPL in February 2016 considered the following two mission architectures
    - ➢ NASA science instrument hosting program onboard comsats: $560 M
    - ➢ Dedicated, off-the-shelf satellites: $710 M

References

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- M. Tinto, J.C.N. de Araujo, O.D. Aguiar, M.E.S. Alves, “Searching for gravitational waves with a Geostationary Interferometer”, *Astroparticle Physics*, **48**, 50 (2013)
- M. Tinto, D. DeBra, S. Buchman, S. Tilley, “gLISA: geosynchronous Laser Interferometer Space Antenna concepts with off-the-shelf satellites”, *Review of Scientific Instruments*, **86**, 014501 (2015).
- M. Tinto, J.C.N. de Araujo, H.K. Kuga, M.E.S. Alves, O.D. Aguiar, “Orbit analysis of a geostationary gravitational wave interferometer array”, *Class. Quantum Grav.*, **32**,185017 (2015)
- Sean T. McWilliams, *Optimizing LISA for cost and science*, 9th

Joint Sensitivity

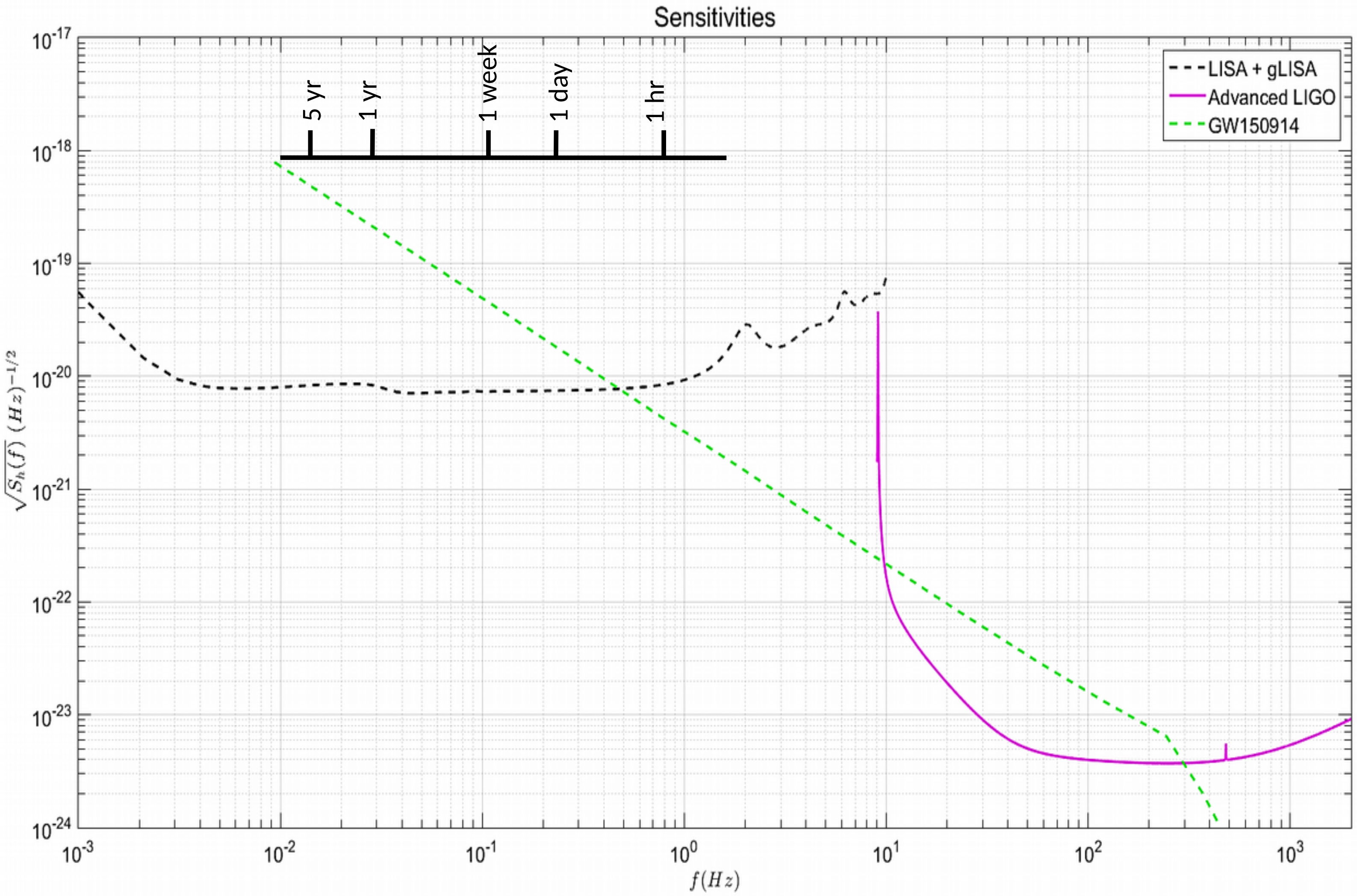
- Since the noises affecting the measurements made by the two arrays are independent, the network signal-to-noise ratio (SNR) squared-averaged is equal to the sum of the squared-averaged SNRs:

$$\langle SNR^2_{eL+gL}\rangle \equiv 4\int_{f_1}^{f_2} \frac{|\widetilde{h}(f)|^2}{S_h^{eL+gL}(f)}\,df = \langle SNR^2_{eL}\rangle + \langle SNR^2_{gL}\rangle$$
$$= 4\int_{f_1}^{f_2} \left\{\frac{1}{S_h^{eL}(f)} + \frac{1}{S_h^{gL}(f)}\right\} |\widetilde{h}(f)|^2\,df\ ,$$

- This implies the following expression of the network squared-averaged sensitivity in terms of the squared-averaged sensitivities of the two arrays:

$$S_h^{eL+gL}(f) = \frac{S_h^{eL}(f)\, S_h^{gL}(f)}{S_h^{eL}(f) + S_h^{gL}(f)}\ .$$

LISA-gLISA Sensitivity



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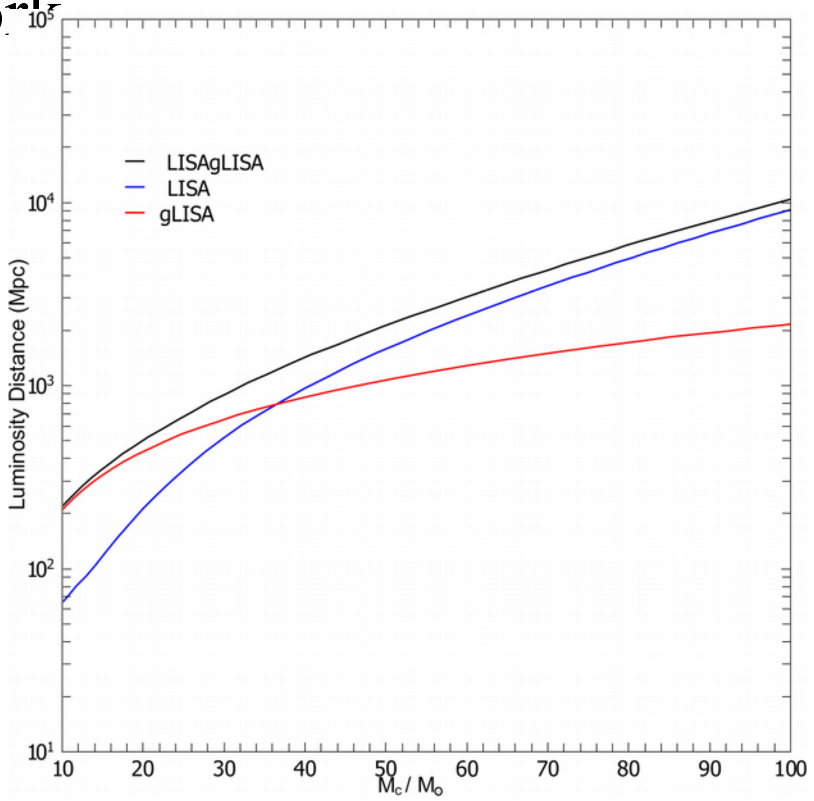
Results

- LISA alone will observe a GW150914-like signal with an SNR ~ 11 after integrating for 5 years; gLISA will reach a slightly higher SNR (~ 14) with the same integration time.
- The LISA-gLISA network can achieve an SNR ~ 18, again with a 5 yr integration time.
- gLISA can achieve an SNR of ~ 11 with an integration time of ~135 days.
- From SNR considerations alone, the LISA-gLISA network will improve the parameter precisions by about a factor of ~1.8 over those estimated by Sesana.
- However, diurnal signal amplitude modulations will

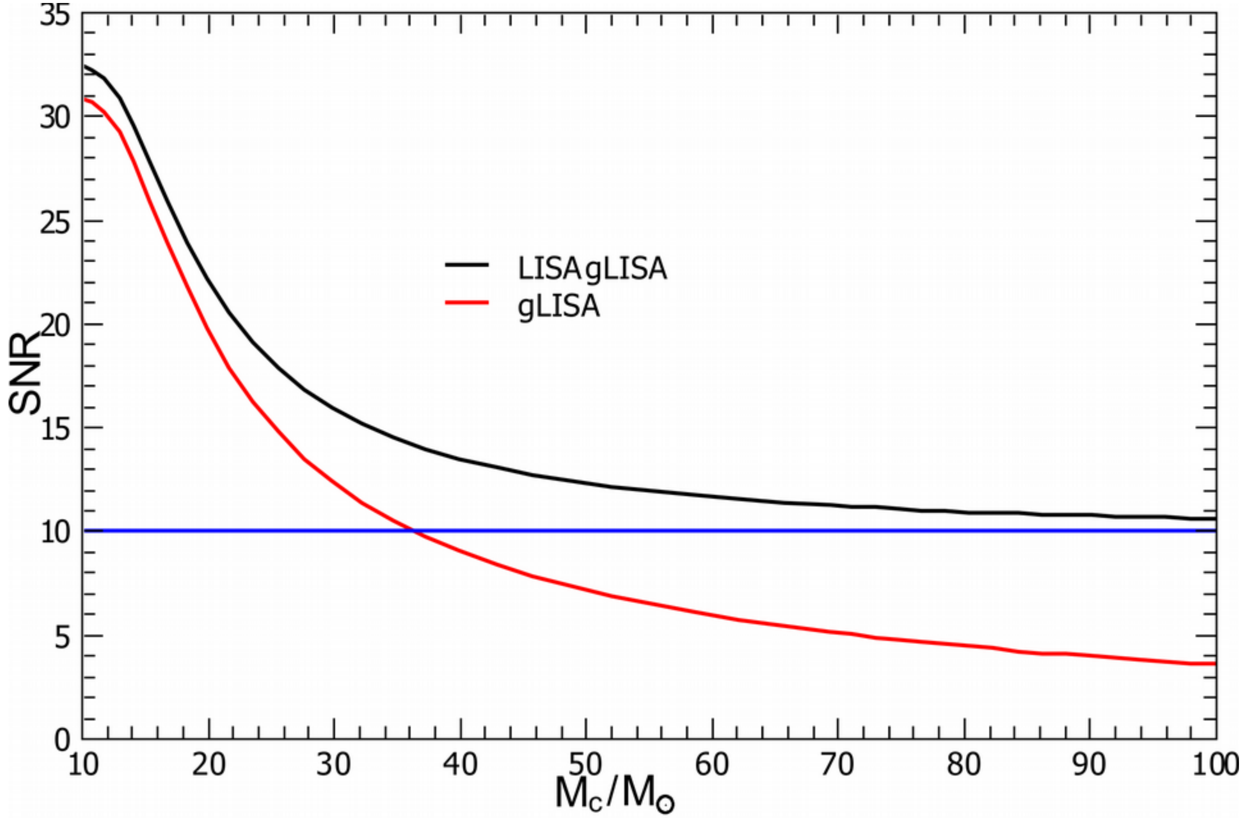
Results (Cont.)

- By assuming a given SNR (10 in the plot below) one can derive (as a function of the chirp mass) the corresponding average luminosity distance at which coalescing black-hole binaries can be detected by LISA, gLISA, and the LISA-gLISA network.



Results (Cont.)

- By assuming the LISA SNR = 10, one can also derive the corresponding average SNR achievable by gLISA and the LISA-gLISA network when observing coalescing binary black-holes with chirp-mass in the range 10 – 100 M_0



Summary

- LISA and gLISA will jointly cover with "white" sensitivity the frequency band from ~ 2 x 10^{-3} Hz to ~ 2 Hz
- LISA, gLISA, and aLIGO will make astronomical observations of highly relativistic objects radiating in the 10^{-4} – 10^{3} Hz GW band!