Gravitational Wave Astrophysics; The Next Frontier in Understanding the Universe *and* LISA-2020; An Intermediate Scale Space Gravitational Wave Observatory for This Decade

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Astrophysics, our present understanding of the Universe, rests primarily on imaging in the electromagnetic spectrum, spanning radio to gamma ray astronomy. 'Visible' matter generating photons represents only about 0.4% of the total mass of the Universe, with dark energy 73%, dark matter 23% and intergalactic gas 3.6% constituting the rest. Of the four fundamental forces two are long range allowing remote observation; electromagnetism, carried by photons, and gravitation, carried by gravitons. Photons are an important but incomplete source of information, as they are generated by 'secondary' forces in 0.4% of matter, are readily absorbed and/or scattered, are only weekly influenced by gravitation and do not interact with dark matter and dark energy - believed to make up 96% of all matter.

Over the last three decades, an exceptionally good science case has been made for pursuing gravitational wave (GW) astronomy. This has engendered a worldwide effort to detect the extremely weak signals generated by expected sources. With the next round of upgrades the ground based instruments are likely to make the first detections of the sources, and a new era of astronomy will begin, possibly as early as 2017. Inconveniently, due to seismic noise and baseline length issues, the low frequency (<10Hz) part of the spectrum, where the most interesting events are expected, will not be accessible. The space-based detector LISA[1] was conceived to fill this gap extending the observational capability to about 10^{-4} Hz. Due to mission cost growth and severe budget constraints, a flight prior to 2030 now seems very unlikely.

However, a 30-year program in low frequency GW astronomy should set as its goal the development and implementation of **three generations of space antennas, one per decade,** with an absolute minimum requirement of two generations. This would allow getting science data early in the next decade, keeping the next observatories open to new technology advances and engaging in a robust parallel technology development program on the ground and on small satellites.

For the **'first' decade observatory** we make the case for a scaled down mission, of the LISA-2020 type, that is comparable in cost and duration to medium scale astrophysics missions such as the 1978 ($630M) Einstein (HEAO 2) x-ray Observatory[2], the 1989 ($680M) COBE Cosmic Background Explorer[3], and the 1999 ($420M) FUSE Far Ultraviolet Spectroscopic Explorer[4]. We find that a mission of this class is possible if the measurement requirements are somewhat relaxed and a baseline smaller than LISA is used. Such a mission could be launched by 2020 using a conventional program development plan, possibly including international collaboration[5]. It would enable the timely development of this game-changing field of astrophysics, complementing the expected ground results with observations of massive black hole binary systems. It would also serve as a stepping stone to the next missions, greatly reducing their risk profile.

LISA-2020 is based on three principles: a) aim for the core science, the merger of supermassive black hole binaries; it has the greatest intellectual return and, fortuitously, requires easier technology b) develop and test critical technologies in parallel, utilize alternative approaches where required and take advantage of the modern capabilities of small and nano-

satellites; each team of your marching army solves its own problem and the overall program starts when all technology is in hand, c) engage the international community in the effort, using both conventional and non-conventional partners; this science program is literally a 'new vision for humanity' and should be approached as such.

A **'second' decade observatory** could be either an enhanced LISA-type technology observatory (the more ambitious and costly eLISA[6], or an upgraded version thereof) or an instrument based on alternative technologies; if available on a timely basis. For the **'third' decade observatory** one would expect new technologies and approaches for very high precision measurements to dominate the design. Technology development for second and third generation low frequency GW antennas would proceed in parallel with the implementation of the previous instruments.

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[1] LISA – *Pre Phase A Report*, December 1995, MPQ 208 (1996)
[2] R. Giacconi et al., *Astrophysical Journal*, **230**, 540 (1979)
[3] J.C. Mather, et al., Adv. Space Res., **11**(2), 181 (1991)
[4] D.A. Content, et al., *Instrumentation in Astronomy VII* **1235,** 943 (1990)
[5] S. Buchman, et al., arXiv:1302.2368 (2013)
[6] P. Amaro-Seoane, et al., Class. Quantum Grav. **29** 124016 (2012)