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NASA Astrophysics Program: Present and Future

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Abstract. NASA's astrophysics program includes support of space-based gravitational wave research in the U.S. The future includes plans for NASA's contributions as a minority partner to the ESA-led L3 Gravitational Wave Observatory.

1. Astrophysics at NASA

Astrophysics at NASA encompasses a broad range of topics, from the birth of the universe and its evolution and composition, to the processes leading to the development of planets and stars and galaxies, to the physical conditions of matter in extreme gravitational fields, and to the search for life on planets orbiting other stars. In seeking to understand these phenomena, NASA's astrophysics science embodies some of the most enduring quests of humankind. [1]

The U.S. science community sets the science priorities for astrophysics at NASA through advisory committees and the Decadal Surveys, which occur every ten years and are conducted by the National Academy of Sciences. The 2010 Decadal Survey report, *New Worlds, New Horizons in Astronomy and Astrophysics* [2], recommends as its highest priority the Wide-Field Infrared Survey Telescope (WFIRST) [3], a mission aimed at addressing the origin of dark energy, a search for exoplanets, and an infrared survey of the universe. The second and third priorities of the 2010 Decadal Survey among large missions are the Laser Interferometer Space Antenna (LISA) space-based gravitational wave observatory and the International X-ray Observatory (IXO).

Astrophysics at NASA is managed by the Astrophysics Division in the Science Mission Directorate. [4] Figure 1 shows NASA's current portfolio of astrophysics missions, including operating missions and mission in formulation and development. Among the latter is the James Webb Space Telescope [5], the top priority of the 2000 Decadal Survey [6] and a NASA Agency priority; the Webb Telescope remains on track for a launch in 2018. WFIRST entered the formulation phase in February 2016 and the WFIRST project is working toward a launch in the mid-2020s. As shown in Figure 1, NASA's suite of operating astrophysics missions includes small (Swift, NuSTAR), medium-size (Spitzer, Fermi, Kepler), and large (Hubble, Chandra, SOFIA) missions. An update on current and future NASA astrophysics missions can be found in the *Astrophysics Implementation Plan* and its updates. [7]



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Figure 1: NASA Astrophysics Missions as of December 2016

2. Gravitational Wave Astrophysics at NASA

As part of NASA's objective to understand the scientific principles governing the universe, the new discipline of gravitational wave astrophysics is an important component of astrophysics at NASA. NASA's activities in this field go back to the early 2000s with the support of Gravity Probe B [8], a satellite-based gyroscope aimed at directly measuring space-time curvature near Earth, and even earlier to the 1970s with Gravity Probe A [9], which aimed at testing Einstein's equivalence principle.

NASA has a history of working with ESA on space-based gravitational wave missions. During the 1990s and 2000s, NASA and ESA jointly formulated the LISA mission. Another, most recent example is the successful partnership between NASA and ESA for the LISA Pathfinder mission [10]. NASA provided the Disturbance Reduction System experiment [11], which includes a set of micro-thrusters that control the spacecraft's position to within a millionth of a millimeter. The NASA-provided Disturbance Reduction System successfully met its science requirements, and NASA extended its operations through the extended LISA Pathfinder mission.

Additionally, NASA continues to invest in additional activities in support of gravitational wave (GW) research in the U.S. These include:

- **Searching for the electromagnetic counterparts of LIGO sources.** NASA's *Fermi* and *Swift* observatories, with their large sky coverage, are particularly suited to observe possible electromagnetic counterparts of LIGO sources in gamma-rays and X-ray/optical/UV radiation, respectively, allowing a better understanding of their nature. A recent example is the tentative

Fermi detection of a possible gamma-ray counterpart to GW150914 [12]. Less than half a second after the LIGO detection, the Gamma-ray Burst Monitor on *Fermi* picked up a brief, weak burst of high-energy light consistent with the same part of the sky. Analysis of this burst suggests just a 0.2% chance of simply being random coincidence. Gamma-rays arising from a black hole merger would be a landmark finding because black holes are expected to merge “cleanly,” without producing light.

- **Developing GW technology for a future space-based GW observatory.** Through its Strategic Astrophysics Technology program, NASA is supporting development of four main technologies for GW astrophysics: 1) lasers, developed at NASA’s Goddard Space Flight Center (GSFC); 2) telescope, also developed at GSFC; 3) phasemeters, developed at NASA’s Jet Propulsion Laboratory (JPL); and 4) microthrusters, similar to those flown on LISA Pathfinder, also developed at JPL. In addition, NASA-supported activities for the optical bench are ongoing at the University of Florida. Detailed reports on the state-of-the-art of these technologies can be found in this Volume by J. Livas, J. Camp, W. Klipstein, and I. Thorpe.
- **Supporting theory studies and data analysis,** through grants from NASA’s Astrophysics Theory Program and NASA’s Astrophysics Research and Analysis program.

Looking to the future, and building on the successful LISA Pathfinder collaboration, NASA has started discussions with ESA for a possible role as a minority partner in ESA’s Large 3 (L3) Gravitational Wave Observatory. To this end, NASA has drawn from the U.S. astrophysics community to establish the L3 Study Team (L3ST) [13]. NASA has directed the L3ST to provide an analysis of possible NASA hardware contributions and to collaborate with the European community in responding to the ESA L3 Call for Mission Proposals. Also part of the charge to the L3ST is developing a science case for the 2020 Decadal Survey on behalf of the U.S. astrophysics community, to reinforce the case for NASA’s participation in L3.

The L3ST has recently released an Interim Report [14] with an analysis of possible hardware contributions and a plan for NASA to develop these technologies to a sufficient level of maturation for ESA mission adoption.

The Midterm Assessment of progress in implementing the 2010 Decadal Survey was conducted by the National Academy of Sciences [15]. The Midterm Assessment recommended that NASA seek an increased participation level on the L3 mission, with the goal of enabling the U.S. to be “a strong technical and scientific partner in the ESA-led L3 [gravitational wave] mission.” [16] As a result, NASA is studying an increase in its contribution to L3, within the ESA-set contribution cap of 20% of the mission cost.

3. Summary and Conclusions

Within the broad swath of NASA’s objectives for astrophysics, advancing the new field of gravitational wave astrophysics plays a fundamental role in directly addressing the question of how our universe works. NASA is currently supporting a large variety of GW-related activities, from technology development to modelling and data analysis. Building on the successful LISA Pathfinder partnership, NASA is currently discussing with ESA its role in ESA’s L3 Gravitational Wave Observatory. NASA has established the L3 Study Team to assist NASA in identifying potential hardware contributions and to collaborate with the European community in the development of the L3 mission concept. The future of space-based gravitational wave astrophysics is bright, and NASA looks forward to being a part of it.

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