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COMMISSION D1 **GRAVITATIONAL WAVE ASTROPHYSICS**

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TRIENNIAL REPORT 2015-2018

1. Introduction

The IAU commission D1 Gravitational Wave Astrophysics was proposed and instituted in July 2015 recognizing the importance of integrating gravitational-wave observations into the mainstream astronomy, and of the great scientific benefit from observing gravitational-wave sources in all bands of the electromagnetic spectrum with ground-based and space-borne telescopes. The commission aims at expanding the knowledge and science impact of gravitational-wave astrophysics to the broader IAU community. It wants to foster open and effective communication among diverse communities, providing the forum to bring together gravitational-wave physicists and astronomers, observers and theorists, to share their expertise and to plan gravitational-wave and electromagnetic observations, joint analysis and interpretation.

The commission represents gravitational-wave searches over 12 orders of magnitude in frequency: going from nanohertz of the Pulsar Timing Array (PTA) to low frequencies between 20 μHz to 0.2 Hz of the LISA space-based planned detector, and the high frequencies from 10 Hz to kHz of ground-based detectors, such as the Advanced LIGO and Virgo interferometers. This large frequency window covers a wide variety of sources and an exceptionally diverse range of instruments.

In 1997, GWIC, the Gravitational Wave International Committee (Working Group 11 of the International Union of Pure and Applied Physics, a fellow organization of IAU under the International Council of Scientific Unions), was formed to facilitate international collaboration and cooperation in the construction, operation and use of the major gravitational-wave detection facilities world-wide. Although the commission D1 emphasis on astrophysics is complimentary to the instrumental project emphasis of GWIC, the development of increasingly capable gravitational-wave detectors requires to be driven by science, and, viceversa, the improved facilities determine the steps forward in the astrophysical knowledge. Recognizing the importance of effective communication with GWIC, the IAU commission D1 and GWIC have cross-representation on each other's leadership committee. David Shoemaker is a member of GWIC which serves on the Commission Organizing Committee, and Neil Gehrels was the IAU commission D1 representative in the GWIC.

During 2017, the astrophysics community lost two prominent inspiring scientists, Neil Gehrels and Pierre Binetruy. Both were key persons, passionate, enthusiastic promoters of gravitational-wave astrophysics and multi-messenger astronomy, mentors for colleagues

and students. Neil drove as chair the proposal for the D1 GW astrophysics commission and was the first president of the IAU D1 commission. Pierre was co-proposer and member of the organizing committee. After Neil's passing, Marica Branchesi was appointed to be president of the commission and IAU representative in the GWIC. Robin Stebbins was appointed to be vice-president.

2. Developments within the past triennium

September 14 2015 marked the beginning of a new era of observations of the Universe through the detections of gravitational waves from binary black-hole mergers by the Advanced LIGO detectors (Abbott et al. 2016a). This detection was followed by other binary black-hole coalescence detections during the first and second observative run of the Advanced detectors (Abbott et al. 2016b, 2017c,d,e). A qualitative step forward, establishing the network of GW detectors, was made with GW170814 with an observation by three detectors: Virgo joined the O2 run and contributed almost immediately to a much more precise localization of the binary black hole signal source (Abbott et al. 2017e). Another epochal discovery happened on August 17, 2017 with the detection of GW170817, the first gravitational wave observation from the inspiral and merger of a binary neutron-star system (Abbott et al. 2017f). This discovery started the era of multi-messenger astronomy including gravitational waves. A weak short GRB 170817A was observed by the Fermi and INTEGRAL satellites 1.7s after the gravitational-wave signal (Abbott et al. 2017g; Goldstein et al. 2017; Savchenko et al. 2017). For GW170817, the event's relatively good localization accuracy (about 30 square degrees) led to the identification of a bright optical counterpart and the host galaxy of the gravitational-wave source (Coulter et al. 2017). An impressive multi-wavelength world-wide campaign, which involved about 100 instruments, has been performed for weeks-months from the radio to very high-energy gamma rays (Abbott et al. 2017). The experiments to develop capable gravitational-wave detectors have rapidly transformed into observatories able to have strong impact on many astrophysical fields, from the physics governing compact object formation and evolution, to the relativistic and nuclear astrophysics, and cosmology.

Another epochal achievement was reached by the LISA Pathfinder mission, which has successfully demonstrated that the technology to build ESA's future space observatory of gravitational waves is even better than that required (Armano et al. 2016, 2018).

In these ground-breaking times for gravitational-wave astrophysics, the IAU commission D1 (composed by 166 members) operated following the goals described in the introduction.

• The Commission Organizing Committee supported and participated in the organization of the International Astronomical Union 2017 Symposium, Gravitational Wave Astrophysics: Early Results from GW Searches and Electromagnetic Counterparts, which was held October 16-19, in Baton Rouge, Louisiana (https://tigers.phys.lsu.edu/wordpress/). The symposium brought together astrophysicists and gravitational-wave researchers to compare past, present and future of observations of gravitational-wave sources, and share the excitement of a new field in astronomy. This symposium covered all frequencies of the gravitational-wave spectrum, discussing the latest ground-breaking results in gravitational-wave astronomy and multi-messenger astronomy.

• The commission D1 endorsed with Letter of Support the proposal for the IAU Symposium "High-mass Xray binaries: illuminating the passage from massive binaries to merging compact objects", which will be held during the general assembly in Vienna, August 20-31, 2018. Division D High Energy Phenomena and Fundamental Physics endorsed this symposium as co-sponsor. We endorsed also the proposals for the "Bayesian

Inference in Astronomy" and "The New Era of Multi-Messenger Astrophysics" symposia which (if selected) will be held in 2019.

• The commission circulated through the IAU Div D Bulletin the monthly update on LIGO and Virgo second observing run about sensitivity, the number of alerts (shared with astronomers who have signed memoranda of understanding with LIGO and Virgo for electromagnetic follow-up), and the major achievements. We circulated also information of multi-messenger meetings.

• The commission circulated the announcement of an open call to the astrophysicists interested in joining the effort to develop the Science Case for building the next generation of ground-based gravitational wave detectors. The GWIC formed a subcommittee on third generation ground-based detectors tasked with examining the path to a future network of observatories/facilities. One of the teams of this subcommittee was formed to develop the Science Case with the following charge:
"commission a study of ground-based gravitational wave science from the global scientific community, investigating potential science vs. architecture vs. network configuration vs. cost trade-offs, recognizing and taking into account existing studies for 3G projects (such as ET) as well as science overlap with the larger gravitational-wave spectrum."

3. Closing remarks

The success of the first observing run of the Advanced LIGO and Virgo network and its outstanding discoveries, the promising perspectives for gravitational-wave astrophysics by ground and space for the next decades make the continuation of the IAU D1 commission in this highly active and emerging area of astrophysics a necessity.

The upcoming runs of the Advanced LIGO and Virgo network will see the open release of gravitational-wave transient alerts and data to the astronomical community. The commission wants to stimulate discussions about the development of common infrastructure and software, about standard data format, and naming conventions to improve the cross-correlation of signals discovered at different wavelengths and by different messengers. Other ground-based interferometers (KAGRA and LIGO-India) are expected to join the network in a few years.

During the next decades, the transient sky will be explored by new promising electromagnetic observatories and surveys, which will probe different time scales with better sensitivity than ever reached before. Multi-messenger astronomy is only entering its golden age and will require planning of global networks of gravitational wave, electromagnetic and neutrino observatories, which will allow us to observe new sources, to increase the rate of detections and explore the cosmic evolution of the gravitational-wave sources. It will be crucial to stimulate discussion about joint science cases to drive projects for new facilities and their operation, observational strategies, analysis and interpretation.

The IAU commission D1 will continue to promote a broader participation with attention to initiatives increasing the participation of gender and under-represented minorities in the field of gravitational-wave astronomy, and to support education and development of young researchers interested in gravitational-wave astronomy.

Marica Branchesi
president of the Commission

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