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Report on the ESO Workshop

Planning ESO Observations of Future Gravitational Wave Events

held at ESO Headquarters, Garching, Germany, 31 January–1 February 2018

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Understanding the nature and results of black hole and neutron star mergers has become a hot topic in astrophysics. The combination of gravitational wave and electromagnetic observations of GW170817/GRB 170817A has triggered new and exciting science projects. The timeline for observations of gravitational wave events lies between seconds and days, and coordinated observations of electromagnetic radiation are critical when probing the nature of these events. The great success of the observations of GW170817/GRB 170817A from more than 50 observatories has highlighted the importance of coordination between different instruments and facilities. This two-day workshop focused on what has been learned from ESO observations of GW170817/GRB 170817A, and discussed strategies for coordinating observations of future events.

Background

The first detection of an electromagnetic counterpart of a gravitational wave event had a historic dimension, as it connected two seemingly separate "universes". Several mergers of black holes had been observed prior to that, indicating black holes of several tens of solar masses; this presented a puzzle, as black holes of these sizes had not previously been anticipated. The detection of gravitational waves — a technical feat requiring measurements of strains of a few times 10^{-20} — in 2015 was epochal, and was recognised with the Nobel Prize in Physics in 2017. While black hole mergers are not expected to carry an electromagnetic signal, theoretical modelling predicted that the merger of two neutron stars would lead to short gamma-ray bursts (GRBs), and would potentially be site of the formation of heavy elements through the *r*-process.

When, on 17 August 2017, an unusal gravitational event (GW170817) was observed that coincided with a short gamma-ray burst (GRB170817A) two seconds later, the search for an optical/infrared counterpart was on. Within a few hours, an optical counterpart was detected in the galaxy NGC 4993. Spectroscopic follow-up observations began immediately, resulting in a detailed record of the evolution of the event over the following two weeks.

ESO and ESA telescopes and instruments participated in this global observing campaign. Parts of the community focused on the search of the optical counterpart with ESO's Visible and Infrared Survey Telescope for Astronomy (VISTA) and the VLT Survey Telescope (VST), but as soon as the GRB detected by the ESA INTErnational Gamma-Ray Astrophysics Laboratory (INTEGRAL) satellite and its optical counterpart had been identified, the event was followed up using several spectrographs and imagers.

Workshop goals

The goal of the workshop was to bring the community together to discuss the best way to obtain ESO observations of future gravitational wave events. Despite the speed with which the workshop was organised — it was announced in the ESO Science Newsletter on 20 December 2017 — 55 participants had registered by the deadline in early January.

The speaker list was partially defined through the Principal Investigators (PIs) of exisiting proposals. Eight of the 26 speakers were female (corresponding to 31%), which reflected the gender distribution amongst the registered participants (29% female). The first day of the programme was dedicated to assessing the status of the gravitational wave detections and their follow-up observations, in particular for GW170817; while the second day focused on the planning and coordination of future observations. Each day finished with an extensive discussion session. On 31 January, the past and current ESO observations of (fast) transients were discussed, and potential lessons for future observations debated. The afternoon of 1 February was entirely devoted to a community discussion of the best strategies for future electromagnetic observations of gravitational wave events. The programmatic aspects of ESO observations were also exhaustively explored.[1]

The first session was focused on GW170817 observations. The gravitational wave signal was presented and compared to that from black hole mergers by Sarah Antier (Laboratoire de l'Accélérateur Linéaire Orsay), followed by a description of the event as seen at optical and near-infrared wavelengths (Stephen Smartt, Queen's University Belfast), in X-rays (Maria Grazia Bernardini, Laboratoire Univers et Particules de Montpellier) and in gamma rays (Roland Diehl, Max Planck Institute for Extraterrestrial Physics [MPE] in Garching).

Marina Rejkuba (ESO) reported on the ESO observations and the activities associated with the release of the data to the community. Optical observations of GW170817 could only be conducted for a couple of hours before the object set each evening in Chile, with several instruments being used simultaneously on the VLT. The ESA satellites INTEGRAL and X-ray Multi-Mirror satellite (XMM-Newton) also participated in the observing campaign, and Peter Kretschmar (European Space Agency, ESA) gave an account of the activities required at the operations centres in order to obtain these data at short notice.

Since it is still very early days for the electromagnetic observation of gravitational wave events, Anders Jerkstrand (Max Planck Institute for Astrophysics, Garching) gave a theorist's view of what we should expect and how to make sense of the observations of GW170817. He gave a comprehensive overview of what the signatures of the *r*-process elements would look like in the optical and near-infrared spectral sequences, and outlined where we still have significant gaps in our interpretation of the spectra. There remains plenty of room for future observations to clarify the many questions and uncertainties we still have in respect of these events. The session ended with a presentation by Nial Tanvir (University of Leicester) on his experience of ESO observations of fast transient phenomena, focusing on gamma-ray bursts. Target of Opportunity observations have been offered at the VLT since the beginning of

operations, with the addition of refinements such as the rapid response mode about 10 years ago. This frank presentation was an excellent basis for a discussion on how ESO operations could help to secure critical data for similar events in the future.

The afternoon session was reserved for presentations of ongoing projects dedicated to the follow-up of transient events. ESO is supporting several such programmes, either with its own telescopes or by hosting dedicated experiments at its sites. These include the following projects: the public survey called VIsta Near-infraRed Observations Unveiling Gravitational wave Events (VINROUGE), which uses VISTA to obtain infrared light curves (Andrew Levan, University of Warwick); the extended Public ESO Spectroscopic Survey of Transient Objects (ePESSTO), which uses the ESO Faint Object Spectrograph and Camera 2 (EFOSC2) at the New Technology Telescope (NTT) to provide optical spectroscopy (Maria Teresa Botticella, INAF–Osservatorio di Capodimonte); the Rapid Eye Mount telescope (REM) at La Silla, which is part of a larger collaboration set up to follow the optical counterparts of gravitational wave events (Eliana Palazzi, INAF–IASF Bologna); and the Gamma-Ray burst Optical/Near-infrared Detector (GROND) instrument on the Max-Planck-Gesellschaft/ESO 2.2-metre telescope at La Silla, which obtains photometry in seven filters simultaneously (Janet Chen, MPE Garching).

A new project that is just starting operations is the Gravitational-wave Optical Transient Observer (GOTO), which was described by Danny Steeghs (University of Warwick). In addition, the long-running Télescopes à Action Rapide pour les Objets Transitoires (TAROT) project was presented by Michel Boer (Centre National de la Recherche Scientifique, CNRS). Future facilities to detect and characterise the electromagnetic counterparts of gravitational wave events are: BlackGEM, to be installed at La Silla (Paul Groot, University of Nijmegen); the Son Of X-Shooter (SOXS), to be installed on the NTT in 2020 (Sergio Campana, INAF–Osservatorio Astronomico di Brera); and the Zwicky Transient Facility in California (Ulrich Feindt, Oskar Klein Centre Stockholm).

The discussion session covered past ESO observations, and aimed to identify what worked and where difficulties were encountered. The panel members were Stefano Covino, Marina Rejkuba, Steven Smartt and Nial Tanvir. The open discussion yielded some interesting comments, and comparisons were made with the experience of using ESO telescopes for observations of gamma-ray bursts. It was concluded that overall ESO provided valuable — and sometimes unique — resources that can be essential, providing insights in areas where theoretical predictions are lacking. Recommendations were made to strengthen the communications between various observatories and facilities in order to avoid duplication and to increase synergies.

The second day of the workshop concentrated on the planning of future observations. The schedule of science observations with the Laser Interferometer Gravitational-wave Observatory (LIGO)-Virgo collaboration was presented by Marica Branchesi (Gran Sasso Science Institute). The next science run is planned to start in October 2018 and is scheduled to last for approximately one year. The principal investigators of the current ESO programmes to search for and follow up electromagnetic signals from gravitational wave events then presented their plans for the next semester. Elena Pian (INAF–IASF Bologna) and Paolo D’Avanzo (INAF–Osservatorio Astronomico di Brera) presented their VLT proposals. A proposal to obtain spectropolarimetry of such events was detailed by Stefano Covino (INAF–Osservatorio Astronomico di Brera). Aniello Grado (INAF–Osservatorio Capodimonte) then presented two ongoing programmes with the VST.

A special session on the observing opportunities with ESA satellites followed. The capabilities of INTEGRAL, and in particular its operational constraints, were introduced by Erik Kuulkers (ESA), followed by a presentation on XMM-Newton by Norbert Schartel (ESA). Jan-Uwe Ness (ESA) described some programmatic aspects of the planning and coordination of space-based observations. The INTEGRAL and XMM-Newton schedules are built well in advance of he observations and the rapid observation of an unexpected transient may mean a serious interruption to the uploaded schedule, requiring the corresponding recovery of the schedule timeline afterwards. There may also be pointing constraints for satellites which need to be evaluated before schedule interruptions. Aitor Ibarra (ESA) and Richard Saxton (ESA) set out a new tool for the improved coordination of observations and information sharing.

The afternoon was devoted to a discussion centred on the optimal planning of future observations, including the best possible coordination of ESO telescopes and instruments. Ferdinando Patat, Enzo Brocato, Peter Jonker and Erik Kuulkers were the panel members, and a lively discussion ensued between the panel and the audience. Several important points were raised, among them the wish that ESO accept Large Programmes with Target of Opportunity observations. Additionally ESO was asked to provide rapid delivery of pre-reduced data so that quick assessments and scientific decisions can be made, potentially to then interactively modify observation blocks for follow-up observations. ESO will have to investigate which of these requests can be implemented operationally. As a first step, Target of Opportunity Large Programmes were accepted again for ESO Period 102 (from October 2018 to March 2019). An important discussion point was whether the (European) community could agree to submitting a single ESO proposal for observations of future gravitational wave events. As a result of this discussion one single Period 102 proposal was submitted before the deadline of 28 March 2018. ESO was also invited to attend the LIGO–Virgo town hall meeting in April 2018 in Amsterdam, where these discussions will continue.

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Links

[1] Workshop programme: http://www.eso.org/sci/meetings/2018/gw2018.html