Memorandum of Understanding (LIGO-M1000080-v1, VIR-0362A-10)

between the

LOFAR Transients Key Science Project

and the

Laser Interferometer Gravitational Wave Observatory (LIGO) Scientific Collaboration

and

VIRGO

June 7, 2010

This Memorandum of Understanding (MOU) establishes collaboration among the Laser Interferometer Gravitational-Wave Observatory Scientific Collaboration (LSC)[1], the European Gravitational Observatory and Virgo Collaboration (EGO/Virgo), and the Transients Key Science Project (Transients KSP) of the LOFAR collaboration, to perform a joint search for gravitational-wave events accompanied by radio transients. The joint detection of such an event would be a landmark occurrence and could provide unique information about the progenitor and astrophysics of the emission. On the other hand, the absence of a radio counterpart to a gravitational-wave event candidate, or conversely the absence of a gravitational-wave signal accompanying certain radio transients, could also provide significant information about the possible source astrophysics.

The purpose of this MOU is to reference the parties involved and their relevant policies; outline the planned work and the general timeline for it; define the appropriate data and its use that is to be shared under this arrangement; and establish how any publications and presentations resulting from of this work will be handled. By signing this MOU, the parties agree that they understand the nature of the collaborative work, consider it to be scientifically worthwhile, and will do their best to bring it to successful completion.

A. Description of Participating Groups

1. LOFAR consists of an array of radio antennae operated by ASTRON in collaboration with researchers from other European countries including France, Germany, Sweden and the United Kingdom. The antennae are arranged in clusters connected together by the Internet, and also connected to a computing cluster that synthesizes images by correlating the signals from the different antennae. The telescope is sensitive between 30 MHz and 240 MHz, a band in which the radio sky is relatively unexplored. The analysis effort is split between six

1 LSC data includes data from the LIGO and GEO detectors.

key projects. The LOFAR Transients KSP is concerned with the identification and study of transient and variable phenomena.

2. The Laser Interferometer Gravitational-Wave Observatory (LIGO) Laboratory is aimed at opening the field of gravitational-wave astrophysics through the direct detection of gravitational waves. LIGO detectors are using laser interferometry to measure the distortions of the space between free masses induced by passing gravitational waves. Scientists, engineers, and staff at the California Institute of Technology (CALTECH) and the Massachusetts Institute of Technology (MIT) are carrying out the operation of LIGO, and are participating in the development of Advanced LIGO and future interferometer enhancements.

   Caltech has prime responsibility for the LIGO Project under the terms of a Cooperative Agreement[2] with the National Science Foundation (NSF). LIGO is a national facility for gravitational-wave research, providing opportunities for the broader scientific community to participate in detector development, observations, and data analysis. LIGO welcomes the participation of outside scientists at any of these levels.

   LIGO includes the LIGO Laboratory and the LIGO Scientific Collaboration (LSC). The Charter of the LIGO Scientific Collaboration establishes the functions, organizational structure and responsibilities of the LSC as well as its role in the research of the LIGO Laboratory, and the release of scientific results. The LIGO Leadership includes the Laboratory Directorship and the LSC Spokesperson. The German/British Collaboration for the Detection of Gravitational Waves (GEO600) is part of the LSC.

   The LSC is composed of approximately 750 individuals from about 61 institutions worldwide, including scientists and engineering personnel from the LIGO Laboratory. It is the policy of the LSC that all LIGO participants who have earned authorship rights be included as authors on any publication reporting on LIGO and GEO observations and astrophysics results. (This does not apply to technical papers.)

3. The German/British Collaboration for the Detection of Gravitational Waves (GEO) has built a detector of arm length 600m (GEO600) near Hannover in Germany, with the purposes of joining in a worldwide search for gravitational radiation from astronomical sources and of developing advanced interferometric and suspension technologies for Advanced LIGO. The design, construction and operation of the GEO600 system is being carried out by scientists and technologists at the University of Hannover, the University of Glasgow, and the Max Planck Institute for Gravitational Physics (Albert Einstein Institute) in Hannover and Golm. Data acquisition and analysis are managed by the Albert Einstein Institute (AEI), Cardiff University, and Birmingham University. The project is funded in Germany by the State Government of Niedersachsen, the Max Planck Gesellschaft (MPG), and the Bundesministerium fuer Bildung und Forschung (BMBF) in Germany, and by the Science and Technology Facilities Council (STFC) in the UK.

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2 Cooperative Agreement No. PHY-0107417 between the National Science Foundation, Washington D.C. 20550 and the California Institute of Technology, Pasadena, CA 91125, dated October 2001

4. VIRGO denotes the Virgo Collaboration and the European Gravitational Observatory (EGO) consortium.

   CNRS and INFN signed an agreement on 27 June 1994 concerning the realization of a three kilometer Fabry-Perot interferometric antenna aimed at the detection of gravitational waves in the frequency range 10-10 000 Hz, named Virgo, located at Cascina, Italy. This agreement was superseded by the Agreement between CNRS and INFN, founding the "European Gravitational Observatory" Consortium under Italian law (EGO), signed on 11 December 2000.

   The main purpose of EGO is to ensure the end of the construction of the Virgo antenna, its commissioning, its operation and its upgrade, as well as to promote an open co-operation in R&D. The Consortium is supervised by the EGO Council. The implementation of the above is performed via the involvement of the Virgo collaboration in the framework of the Memorandum of Agreement between the Virgo Collaboration and EGO Consortium, signed on 20 November 2002.

   The Virgo collaboration is composed of over 200 scientists and technicians coming from CNRS and INFN laboratories and from EGO, which have signed an Agreement on 19 December 2001, as well as from the Netherlands, Poland and Hungary. Decisions are taken by its steering committee. The overall scientific exploitation of the Virgo antenna is under the responsibility of the Virgo Collaboration. Publications identified as Virgo publications by their use of Virgo data (and in general according to criteria listed in the Virgo publication rules) have an author list that includes all Virgo members that have earned authorship rights.

   In this MOU the Virgo collaboration is represented by the spokesman appointed by the Virgo steering committee and the EGO Consortium by the director of EGO appointed by the EGO council.

B. General Policies and Provisions

1. In entering into this Memorandum of Understanding, the LIGO Laboratory will carry out its responsibilities following the requirements of the Cooperative Agreement.

2. The LIGO Laboratory is responsible for obtaining NSF approval of all collaborative Memoranda of Understanding with international partners, or involving NSF costs exceeding $100,000. All Memoranda of Understanding will be provided to NSF for their information.

3. Each party to this agreement continues to be responsible for all support of its staff including travel costs associated with the activities under this agreement. Exceptional support of travel may be allowed for travel requested by that institution.

4. This MOU does not prevent the parties from establishing other agreements on data exchange or external collaborations. The existence and general terms of any other agreements that are scientifically related will be freely shared among the parties of this MOU.

5. The Principal Investigator of the LOFAR Transients KSP is responsible for obtaining approval for this memorandum of understanding from the LOFAR executive.

C. Description of Planned Work

The overarching goal of this project is to search for transients that yield signals in gravitational waves in coincidence with a radio signature. In practice, this suggests three different possible searches, listed below. Due to the early phase of LOFAR operations during the LSC/Virgo S6/VSR2/VSR3 run, described in Section D, it is possible that only a fraction of the planned work may be achieved in practice.

(1) A search of the LSC/Virgo gravitational wave data for transient gravitational wave signals consistent with radio transients from the LOFAR radio telescope. The LOFAR Transients KSP will result in a published database of 'prime' transient candidates, together with an unpublished 'sub-prime' candidate list. Under this agreement, both public and 'sub-prime' candidate transient events would be released to collaborating members of the LSC/Virgo collaboration for use in the search for corresponding transients in data from gravitational wave interferometers of the LSC and Virgo collaborations.

(2) Real-time observing using LOFAR in response to LSC/Virgo transients from a network of detectors resulting in an estimate of the sky position consistent with the LSC/Virgo signals. Under this agreement, LSC/Virgo will supply the LOFAR Transients KSP with the parameters of transient events from gravitational wave data analysis, which can then be followed up by the collaborating group of scientists in LOFAR, LSC, and Virgo. Initially, simulated transient data may be supplied to test the pipeline to LOFAR observations, as stated in the LOFAR Transients KSP stage 1 internal proposal

(3) A search of the LSC/Virgo gravitational wave data for transient gravitational wave signals consistent with glitches of known pulsars observed using the LOFAR radio telescope. LOFAR is likely to be an instrument of discovery for young pulsars likely to exhibit discontinuities. As for project (1), this agreement allows pulsar glitch data from LOFAR to be made available to LSC/Virgo scientists so that searches can be made in gravitational wave data for transients consistent with the arrival time of the pulsar glitch.

Given the different possible emission mechanisms that may be involved, timescales of interest for the difference between arrival times of the gravitational wave and radio signals range from tens of seconds, for strong coherent sources like the Lorimer burst[3], to weeks for incoherent, dispersed signals from sources tens of megaparsecs away. Besides checking for truly coincident events, LOFAR's wide field search capability will provide important information on the false alarm probability as a function of coincidence time window and the size of the sky patch from both foreground and background noise sources.

At the current LSC-VIRGO sensitivity level, it is possible but probably unlikely that a gravitational-wave event will be successfully identified during the S6/VSR2/VSR3 run using the

[3] D. R. Lorimer, M. Bailes, M. A. McLaughlin, D. J. Narkevic, F. Crawford, *Science*, **318** (5851), 777-780, 2007.

gravitational-wave data alone. The opportunity to follow up on many candidates and identify an radio transient counterpart to an event candidate—thus helping to confirm the event—increases, to some extent, the chance of making the first detection of a gravitational-wave signal in this run. Prompt radio image data would also provide extremely valuable additional information about any source observed. Although a successful detection in this run is still far from certain, the huge possible payoff motivates this joint observing project.

Notes:

1. This project is not intended to unduly interfere with the other scientific activities of LOFAR and LSC-VIRGO. In particular, the rate of triggers for imaging requests will be kept at a comfortably low level, currently expected to be about one target per week on average.

2. LIGO and Virgo are carrying out a "blind injection challenge" which allows for up to a few simulated signals to be injected into the interferometers during the science run at times unknown to the data analysis teams, to be revealed after the data is analyzed. Therefore, it is possible that a few of the triggers sent to LOFAR will turn out to be artificial.

3. Because of the extensive time required to fully characterize LSC-VIRGO data, and because of the blind injection challenge, it will probably take several months to arrive at the final verdict on any event candidate. During that time, the existence of a possible event candidate (if any) will be kept strictly confidential by LOFAR, the LSC, and Virgo.

4. LOFAR's automated data processing and transient identification pipeline will provide a prompt first look at the image data to check for any obvious transient. Further analysis, especially in the case of an apparent radio transient, will be a cooperative undertaking, using existing analysis tools and techniques where appropriate, with the exact division of tasks to be determined by mutual agreement.

D. Scope and Timeline

1. This agreement concerns data collected during LIGO's S6 science run and Virgo's VSR2/VSR3 science run, which began July 7, 2009 and are currently expected to continue through the summer or fall of 2010. This project will encompass times when three LSC-VIRGO interferometers are operating simultaneously, providing the best position reconstruction; there will also be periods when one of the interferometers is offline for maintenance or upgrading. Analysis of the data is likely to continue for many months after the end of data collection.

2. Cessation of any data exchange may take place at the request of either the LOFAR Transients KSP, LSC or VIRGO. Data exchanged under the terms of this agreement (prior to its cessation), on-going analyses of them, and any publications and presentations using them are governed by the terms of this MOU and its attachments indefinitely, unless all of the LOFAR Transients KSP, LSC and VIRGO agree to a change. This MOU may be extended by mutual agreement between the LOFAR Transients KSP, LSC and VIRGO.

E. Appropriate Use of Data and Other Information

1. All parties agree that any data or data products received from the other parties shall be used only for the purposes of the collaborative work covered by this agreement, and shall be held confidential (unless already made public). Any public release of data would not affect the goals or terms of this project.

2. Access to collaboration web sites and/or mailing lists may be granted to facilitate working together. Any information exchanged related to this MOU concerning the LOFAR Transients KSP, LIGO, or Virgo should be treated as confidential unless it has already been made public. Senior scientists should ensure that all involved persons, including students and technical staff, understand and respect the sensitive nature of the data and information exchanged.

F. Publications and Presentations

1. All LOFAR Transients KSP observations that have *not* been triggered by LSC-VIRGO event candidates, and all LOFAR observations not involving the LOFAR Transients KSP, and all LSC-VIRGO analyses that do not make use of LOFAR image data (either for confirmation or non-confirmation of event candidates), are not affected by this agreement.

2. LIGO, Virgo, and the LOFAR Transients KSP will cooperate on any publication of scientific results resulting from the collaborative work described in this agreement. Any intention to publish (in any form, including peer-reviewed articles, conference proceedings, and theses) results or status of the LSC-VIRGO-LOFAR joint analysis must be communicated and approved in advance.

3. Publication or other presentation of results related to the collaborative work, whether they are detection statements or not, will follow the usual principles for scientific credit and authorship. We can anticipate some possible scenarios:

   - If either the LOFAR Transients KSP on the one hand or LSC-VIRGO on the other hand can make a detection/evidence claim based solely on a *separate* analysis of their own data and in the absence of corroborating evidence from the other party, then each party may choose to publish their result separately and independently of the other.

   - An independent or joint follow-up article may complement an independent “discovery” paper.

   - If neither the LOFAR Transients KSP nor LSC-VIRGO can make a claim of a detection/evidence based solely on a separate analysis of their own data, but a joint analysis results in a detection or substantial evidence for a signal, that will be published in a jointly authored article.

   - If there is no discovery, a joint paper may be written to state upper-limits and associated astrophysical interpretations.

- A joint technical paper (without observational results) may be written to describe the project and methods.

4. Any joint paper(s) or presentation(s) will be guided by the publication policies of all the participating collaborations for authorship, internal review, and approvals[4]. In particular, LSC-VIRGO *observational result* papers will include all collaboration members as authors. The list of LOFAR Transients KSP authors will be established according to LOFAR Transients KSP rules and preferences. The author list will have one block for LIGO/Virgo authors and a separate block for LOFAR Transients KSP authors; or, if journal rules allow only a single block, then the collaboration affiliations of all authors will be indicated in a suitable way. Whenever an individual author listing is not allowed (e.g. for conference proceedings), the contributing author will clearly identify the fact that he/she represents all collaborations in presenting the joint work. Technical papers, that is publications that do not present observational results, may have limited author lists. Criteria for precisely identifying technical papers are stated in the collaborations' publications policies.

5. All members of the LOFAR Transients KSP and LSC-VIRGO collaborations will be given the opportunity to read and comment upon any scientific publications resulting from this collaborative work before their submission to any public archive or to a journal.

6. Any press release(s) reporting the observational results of this work must be coordinated and approved by the LIGO Executive Director, LSC Spokesperson, Virgo Spokesperson, and LOFAR Transients KSP Principal Investigator.

7. Any conflicts between the policies of the collaborations will be resolved by mutual agreement. If a conflict cannot be resolved, the joint paper or presentation may be vetoed by the LIGO Executive Director, LSC Spokesperson, Virgo Spokesperson, or the LOFAR Transients KSP principal investigator.

8. After publication of a joint paper, all members of the LOFAR Transients KSP, LIGO and Virgo collaborations will be able to present the results publicly following the prevailing polices of all collaborations. All such presentations of the joint work must give credit to the LOFAR Transients KSP, the LOFAR collaboration, and the LIGO and Virgo collaborations.

Rob Fender Principal Investigator, LOFAR Transients Key Science Project	Jay Marx LIGO Laboratory Executive Director

4 The publication rules are available in the following documents: LSC [http://www.ligo.caltech.edu/docs/T/T010168-03/], VIRGO [VIR-0560A-09 https://tds.ego-gw.it/ql/?c=6872 and VIR-0559A-09 https://tds.ego-gw.it/ql/?c=6871].

_____ Date	_____ Date
_____ David Reitze LSC Spokesperson	_____ Albert Lazzarini LIGO Laboratory Deputy Director
_____ Date	_____ Date
_____ Jacques Colas Director of EGO	_____ Francesco Fidecaro Virgo Spokesperson
_____ Date	_____ Date

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Bernard Schutz
GEO 600 Principal Investigator for Data Analysis

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Date