Andrew Lundgren

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Overview

I have been a member of the LIGO Scientific Collaboration since 2008. In that time we've made the first detection of a binary black hole merger and a binary neutron star merger, and about 90 total events. My primary goal is to enable the discovery and understanding of new and exotic types of compact binaries with LIGO-Virgo data, like binaries with substantial spin or with very high masses. I do this by inventing new data-analysis algorithms which combine a deep understanding of signal processing and data analysis with detailed physical understanding of all parts of the LIGO detectors and their environment.

Current Position

Reader in Gravitational-wave Physics (Associate Professor with tenure) — 2017-present
Institute of Cosmology and Gravitation — *University of Portsmouth, UK*

Previous Positions

Senior scientist — 2011-2017
Max Planck Institute for Gravitational Physics (Albert Einstein Institute) — *Hannover, DE*

Postdoctoral associate — 2010-2011
Pennsylvania State University — *State College, PA, USA*

Postdoctoral associate — 2008-2010
Syracuse University — *Syracuse, NY, USA*

Education

Cornell University — 2008
PhD in Physics — *Ithaca, NY, USA*

Massachusetts Institute of Technology — 2001
Bachelor of Science in Physics — *Cambridge, MA, USA*

Funding

STFC Gravitational-waves Consolidated Grant 2021-2024, "Gravitational Waves at the University of Portsmouth"
Support for postdoc plus faculty time.

STFC Astronomy Consolidated Grant 2019-2022, "Cosmology, Gravitation and Astrophysics at Portsmouth"
Support for postdoc plus faculty time.

Charity Award (185k total), "GBRow: Race with Purpose"
Support for postdoc to analyze coastal noise pollution, and funding for co-supervised PhDs.

MAVA Foundation, "Assessment of seagrass ecosystem services in West Africa"
Support for PhD placement using Bayesian machine learning on satellite Earth observation data.

Department Leadership and Service

Founder and PI of University of Portsmouth LIGO group

Senior Management Team & Director of Training for Year 2-4, DISCnet Centre for Doctoral Training in Data-Intensive Science
DISCnet is an STFC-funded CDT network of 5 Unis (Sussex, Portsmouth, Southampton, Queen Mary, and Open U.) that provides data science training and industry placements for physics PhD students.

Director of ICG Software Innovation Service
I manage a group of (currently) four Research Software Engineers on long-term contracts, plus secondments of postdocs and PhD students for short-term work. Their current portfolio includes UKSA funding for Euclid and LISA software, STFC funding for LIGO software, developing training for PhD students, and innovation in satellite data, disaster response, machine learning in medicine, etc.

Vice-Chancellor's Award for Excellence, as part of the ICG Covid Response Team, 2021

Member of: Equality, Diversity, and Inclusion Committee; Computing Committee

LIGO Leadership and Activities

Chair of Detector Characterization Working Group, 2015-2019
The DetChar Working Group is the key connection between the four data analysis groups and the operations and commissioning staff at the detectors. We have ultimate responsibility for ensuring that the data is clean and analyzable, and maximiing our ability to make detections.

Data Quality for Compact Binaries Lead, 2009-2015
Liaison between DetChar and Compact Binary working groups

LIGO authorship: I have been on the LIGO author list since 2009, covering the S6, O1, O2, and O3 science runs to date. I am also on the instrumental author list which is a shorter list specifically for detchar and instrumental papers. There are too many papers to list but they include all key results in the enhanced and advanced LIGO era.

Selected LIGO Collaboration Publications

GWTC-3: Compact Binary Coalescences Observed by LIGO and Virgo During the Second Part of the Third Observing Run
Submitted to Phys.Rev.X (2022)

Observation of gravitational waves from two neutron star–black hole coalescences
Astrophys. J. Lett. 915, L5 (2021)

GWTC-2.1: Deep Extended Catalog of Compact Binary Coalescences Observed by LIGO and Virgo During the First Half of the Third Observing Run
Phys. Rev. X 11, 021053 (2021)

GW190521: A Binary Black Hole Merger with a Total Mass of 150 Msolar
Phys. Rev. Lett. 125, 101102 (2020)

GW190814: Gravitational Waves from the Coalescence of a 23 Msun Black Hole with a 2.6 Msun Compact Object
Astrophys. J. Lett. 896, L44 (2020)

GW190412: Observation of a Binary-Black-Hole Coalescence with Asymmetric Masses
Phys. Rev. D 102, 043015 (2020)

GW190425: Observation of a compact binary coalescence with total mass 3.4 Msun
Astrophys. J. Lett. 892, L3 (2020)

GWTC-1: A Gravitational-Wave Transient Catalog of Compact Binary Mergers Observed by LIGO and Virgo during the First and Second Observing Runs
Published in Phys. Rev. X 9, 031040 (2019)

Binary Black Hole Population Properties Inferred from the First and Second Observing Runs of Advanced LIGO and Advanced Virgo
Astrophys. J. Lett. 882, L24 (2019)

Tests of General Relativity with the Binary Black Hole Signals from the LIGO-Virgo Catalog GWTC-1
Phys. Rev. D 100, 104036 (2019)

A Gravitational-wave Measurement of the Hubble Constant Following the Second Observing Run of Advanced LIGO and Virgo
Astrophys. J. 909, 218 (2021)

GW170817: Observation of Gravitational Waves from a Binary Neutron Star Inspiral
Phys. Rev. Lett. 119, 161101 (2017)
plus 12+ companion papers

GW170814: A Three-detector Observation of Gravitational Waves from a Binary Black Hole Coalescence
Phys. Rev. Lett. 119, 141101 (2017)

Observation of Gravitational Waves from a Binary Black Hole Merger
Phys. Rev. Lett. 116, 061102 (2016)
plus 16 companion papers

Selected Recent Publications

Comparison of breath-guards and face-masks on droplet spread in eye clinics
R. Newsom, C. Pattison, A. Lundgren, et. al., Eye (2022).

Issues of mismodeling gravitational-wave data for parameter estimation
O. Edy, A. Lundgren, et.al., Phys. Rev. D 103, 124061 (2021)

Failure of the Fisher matrix when including tidal terms: considering construction of template banks of tidally deformed binary neutron stars
I. Harry and A. Lundgren, Phys. Rev. D 104, 043008 (2021)

Dynamic normalization for compact binary coalescence searches in non-stationary noise
S Mozzon, L. Nuttall, A. Lundgren, et.al., Class. Quantum Grav. 37 215014 (2020)

Improving the sensitivity of Advanced LIGO using noise subtraction
D. Davis, T.J. Massinger, A. Lundgren, et.al., Class. Quantum Grav. 36 055011 (2019)

2-OGC: Open Gravitational-wave Catalog of binary mergers from analysis of public Advanced LIGO and Virgo data
A. Nitz et.al., ApJ 891 123 (2020)

Omicron: a tool to characterize transient noise in gravitational-wave detectors
F. Robinet, N. Arnaud, N. Leroy, A. Lundgren et.al., SoftwareX 12 100620 (2020)

Blip glitches in Advanced LIGO data
M. Cabero, A. Lundgren, et.al., Class. Quantum Grav. 36, 155010 (2019)

Gravity Spy: Integrating Advanced LIGO Detector Characterization, Machine Learning, and Citizen Science
M. Zevin et.al., Class. Quantum Grav. 34 064003 (2017)

Classifying the unknown: discovering novel gravitational-wave detector glitches using similarity learning
S. Coughlin et.al., Phys. Rev. D 99, 082002 (2019)

A semianalytic Fisher matrix for precessing binaries with a single significant spin
R. O'Shaughnessy, P. Nepal, and A. Lundgren, Class. Quantum Grav. 37 115006 (2020)

A stochastic template bank for gravitational wave searches for precessing neutron-star–black-hole coalescence events
N. Indik et.al., Phys. Rev. D 95, 064056 (2017)

Selected Group Publications

These are publications of groups of more than 10 authors where I have made a substantial contribution.

LIGO detector characterization in the second and third observing runs
D Davis et.al., Class. Quantum Grav. 38 135014 (2021)

Effects of data quality vetoes on a search for compact binary coalescences in Advanced LIGO's first observing run
B P Abbott et.al., Class. Quantum Grav. 35 065010 (2018)

The PyCBC search for gravitational waves from compact binary coalescence
S. Usman et.al., Class. Quantum Grav. 33 215004 (2016)

Improving the data quality of advanced LIGO based on early engineering run results
L. Nuttall et.al., Class. Quantum Grav. 32 245005 (2015)

SkyPy: A package for modelling the Universe
A. Amara et.al., J. Open Source Software 6 65, 3056 (2021)

SDSS-IV MaStar: Theoretical Atmospheric Parameters for the MaNGA Stellar Library
L. Hill et.al., MNRAS 509, 3 (2022)

Students

- Nathaniel Indik, completed 2018, 1st supervisor
- Marco Surace, completed Apr 2020, 2nd supervisor
- Oliver Edy, handed in Sep 2022, 1st supervisor
- Simone Mozzon, completed Nov 2022, 2nd supervisor
- Susanna Green, commenced Sep 2021, 1st supervisor
- Sergi Sirera Lahoz, commenced Sep 2021, 2nd supervisor
- Laura Fantuzzi, commencing Apr 2023, 2nd supervisor; joint with Schools of Civil Engineering and Biology, working on GB Row
- Three PhD vivas as internal
- As external, one MPhil viva (Cardiff), one PhD (KCL)

Teaching and Education

- Level 5 Computational Physics, 2017-present, module coordinator 2019-present. 40 students per year. I authored about half the material. Taught as interactive computational labs. Covers intermediate Python and data analysis.
- Level 7 Advanced Computational Techniques, 2018-present, module coordinator 2022-present. 15 students per year. I authored about half the material. Taught as interactive computational labs. Covers C, MCMC, and Machine Learning with Tensorflow.
- Level 6 Introduction to General Relativity, 2019-2021. 40 students per year. I authored 1/3 of the lecture notes and parts of the coursework and exam.
- In past years, I have delivered introductory PhD lectures in gravitational waves. Now we prefer to give our postdocs the experience of delivering these.
- I supervise the RSE group's preparation and delivery of PhD lectures in computing, and material for DISCnet (a 5-university CDT in data science).
- I have mentored PhD and postdoc placements in innovation, on Covid droplets, detection of seagrass, analysis of environment agency datasets, etc.

Dector Characterization

Gravitational wave detectors are dominated by noise, because the signals are so incredibly weak. The sensitivity required is measuring a displacement smaller than a nucleus across a distance of kilometers. Most of the noise is steady and normally-distributed (stationary and Gaussian). For instance thermal noise In the mirrors, and shot noise of the laser beam, have these properties. So does the seismic noise from the motion of the ground, most of the time. These types of noise can only be reduced by improving the instruments - new mirror coatings, more laser power, quantum squeezing. The different observing periods are about these improvements.

My work is concerned with all the additional sources of noise, which are non-stationary and heavy-tailed. They are caused both by environmental effects and internal problems in the instrument. The most problematic type of noise are short detector artefacts called glitches. They are usually less than a second long and range from almost unnoticeable to extremely loud. Many glitches actually look very similar to high-mass binary black holes and make it very difficult to confidently detect these signals. The same is true for searches for unmodeled short signals from unknown sources. This could include interesting detections like cosmic string collapse or boson stars. Loud glitches make it impossible to detect signals nearby in time unless they are carefully removed. Most concerning are quiet glitches which could subtly alter the parameters inferred for the source properties. This must be carefully assessed if we are to make any claims of detections of new physics with gravitational waves.

LIGO and Virgo have important working groups called Detector Characterization (or Detchar). This group interacts with the all of the data analysis groups (compact binaries, unmodeled burst, continuous waves, and stochastic), as well as the operations team running the interferometers and providing public alerts for rapid followup with telescopes and satellites. I was chair of this group from the start of the O1 observing run in September 2015 to the start of the third observing run in April 2019. I was the first to assess the data quality just minutes after the first event GW150914 and to contact the sites to inform them of the possible detection. During the run, the group I led was ultimately responsible for vetting the data quality of every detection, and providing guidance to all four data analysis groups on data quality cuts. I was also one of eight Detchar members on the Rapid Response Team during this period, responsible for vetting alerts to telescopes within 30 minutes after first detection.

The group also monitors, investigates, and documents any and all problematic noise sources and works with the commissioning teams at the detector sites to mitigate them. This is a particular specialty of mine. I have developed a very broad knowledge of all the systems in the instrument, from seismic and environmental sensors to control electronics to optics and feedback loops. When unknown noise sources occur, I am often able to track down the cause and eliminate the problem. I have developed many innovative data analysis methods and pieces of software to assist those investigations as well, many of which are now integrated into the automated detector summary pages.

Current Data Analysis Research Priorities

My main concern in advance of the O4 Observing Run (planned for May 2023) is to integrate a rigorous understanding of the noise sources into our data analysis. I have developed a mathematical model of non-stationary noise which is being integrated into our analysis methods and will prevent subtle biases in our estimation of source properties. I have begun a collaboration with B.S. Sathyaprakash, Alessandra Buonnano, and others to prepare a white paper on “False Causes of Violation of GR” which will set out the requirements to make a solid case for detection of physics beyond general relativity, which requires my extremely detailed understanding of the detector noise and its effect on data analysis.

I am developing new methods for detecting and removing glitches, with the goal of greatly increasing our sensitivity to high-mass black holes and unknown burst signals. We do not understand the origin of many of these glitches, so a physical model is not possible. I am instead using a quasi-physical model which makes use of the fact that these glitches fall into a few main categories, and there are thousands of glitches in each with similar characteristics. This builds on the classifications made by the GravitySpy project. I am using a Bayesian approach to model these glitches accurately so they can be removed in the data. In addition, I am developing methods to use auxiliary channels (like RF sensors) to remove glitches that are witnessed by other sensors than the gravitational-wave channel. This builds on the noise subtraction methods I have used previously, but now must go beyond simple linear coupling. I am using building machine learning models that can discover and exploit non-linear couplings to remove this noise.

I am also developing methods in anticipation of the increased computational cost of the compact binary searches. I previously developed a geometrical method for placing template banks to efficiently cover the space of compact binaries with spin. However, we now face a greatly expanded search space if we want to measure precession and eccentricity. I am developing neural network mocks of the ambiguity function which determines the template bank shape, which will allow the entire process to run on a graphical processing unit with much less computational time. This will allow template banks to also adapt to different detector configurations rather than being a compromise averaging over the available detectors. I am beginning to investigate as well how known symmetries of signals, such as their transformation under rotation groups, can be used to build better algorithms, similar to the way that the Fast Fourier transform allows for very efficient exploitation of the time symmetry of the data.

Research Software Engineering group

I am the director of the ICG's Software Innovation Service, a team of four research software engineers (RSEs) which was formed in 2020. The RSEs have PhDs in physics but also have substantial expertise in fields like high-performance computing, probabilistic programming, machine learning, databases and big data, citizen science, and project management. They also have expertise in development of clean and reliable software, including packaging and documentation, and collaborative software development in small teams and large collaborations. My role is line manager for the team, interface with external partners, and I also provide the vision for strategic development.

The projects taken on by the RSEs span ICG's core science, wider University collaborations, to innovation projects and industrial collaborations. They currently do software development for UKSA/ESA on the Euclid and LISA projects, LIGO and other astrophysics funded by STFC, and strong lensing on an ERC grant. They have delivered projects in satellite remote sensing, Covid genomics, tracking of disease-spreading droplets, and productizing a lithium battery simulation.

The key characteristic of our RSEs is that their research skills allow them to develop innovative software solutions with only loosely-defined plans and little guidance. They work well with domain experts in many academic fields: from physics and math, to remote sensing and environment, through to medicine. They can train and mentor PhDs and postdocs, and they also develop and maintain software infrastructure that makes the entire department more productive.

Innovation

I have been personally involved in several projects with wider impact outside of physics. These projects are powered by a combination of my data analysis and computing skills and my facility with working with domain experts in applied fields. These projects often use methods and algorithms from my physics and gravitational waves background.

During the Covid pandemic, I collaborated with an ophthalmologist, respiratory therapists, aerosol chemists, and one of the RSEs on a project to track the spread of droplets from coughs. We used fluorescein dye to make the small droplets visible. I developed an array of bright blue LED illuminators from easily available components and powered by lab power supplies for high intensity with zero flicker. We worked with cameras provided by Canon Education UK to image aerosols as small as 30 micron. The images are analyzed with custom software based on astronomical image analysis. We have published this in journals like Nature Eye. We have used the same setup to visualize airborne microplastics with Nile red fluorescent dye. The high-speed videos we produced were featured on Good Morning Britain as part of a feature on microplastics in food.

I developed a model that calculated bathymetry of coastal waters over 100,000 square kilometers in the Fiji, Vanuatu, and Solomon Island archipelagos as part of the CommonSensing project (commonsensing.org.uk) funded by UKSA's International Partnership Programme. My method was an automated machine learning model using Sentinel-2 satellite data. The depth maps that I delivered are used to predict the tsunami hazard due to run-up on long flat underwater shelves. With hundreds of islands, this kind of prediction is otherwise infeasible.

I am also one of three scientists on the GB Row Challenge (gbrowchallenge.com), or "Row with a Purpose". The event is a rowing race around Great Britain where the rowers also collect scientific environmental data during the race. Two of the boats in the 2022 race carried hydrophones which collected a combined 4 terabytes of data over a month. The University of Portsmouth has received charitable funding to analyze this environmental data. I, along with a postdoc, am analyzing this data to build a soundscape of the British coastline, measuring the effect of noise from both large and small boat traffic, as well as detecting the sounds of sea life. We also link this with microplastics and the biodiversity measured by collecting environmental DNA from the water. We will continue this work in future years of the race.