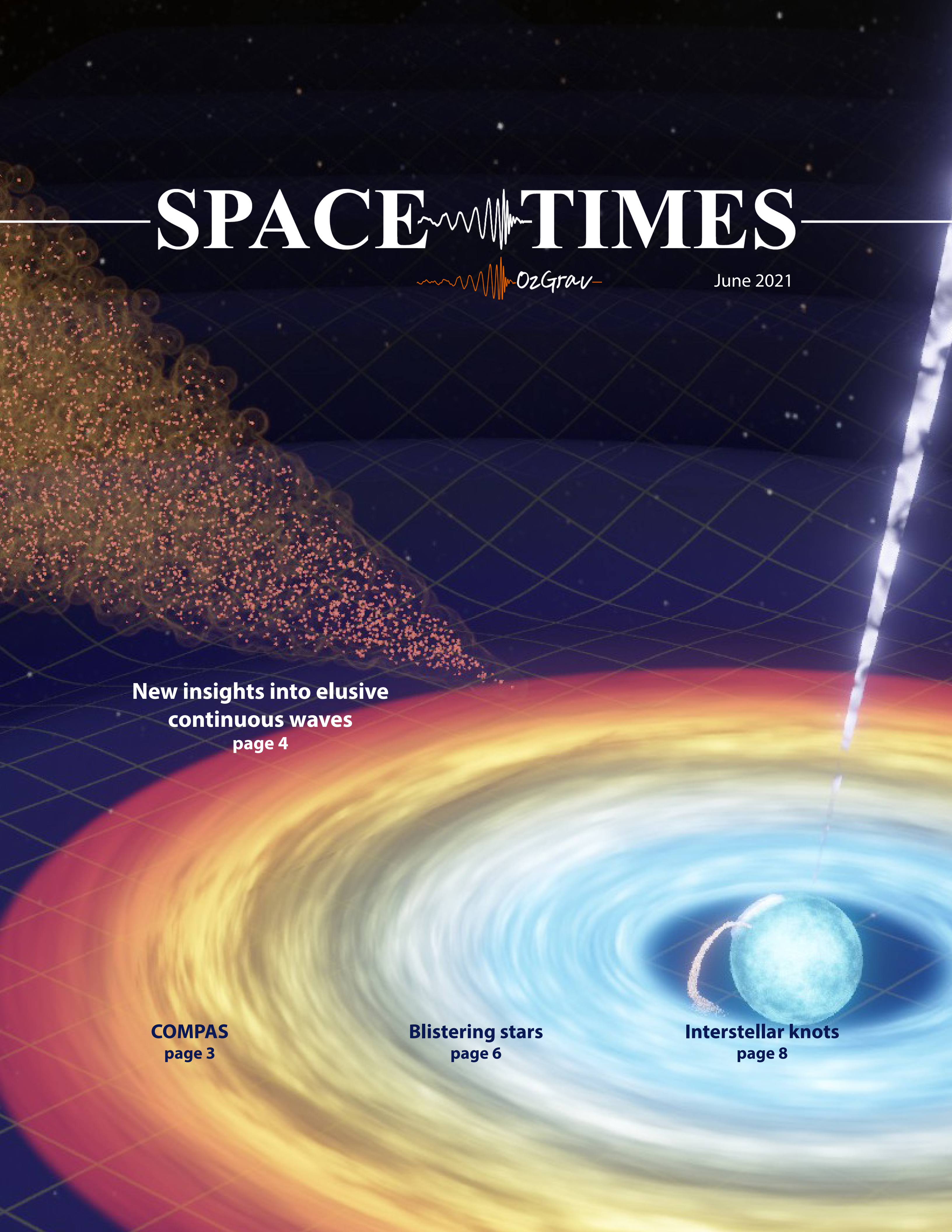
SPACE TIMES

OzGrav

June 2021



Welcome

Dear Colleagues,

Welcome to another edition of Space Times! After some months of comparative normality, Melbourne found itself back in a COVID-19 lockdown, albeit just for two weeks. Our thoughts are with our Melbourne staff and students, and for everyone whose life continues to be affected by the pandemic, no matter where you are in the world.

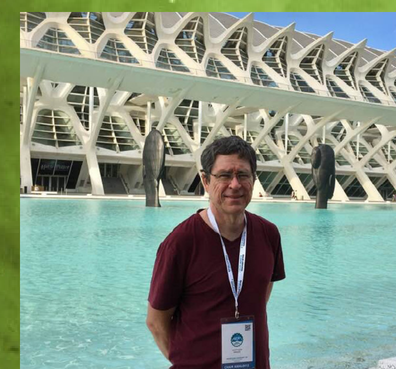
Instead of preparing for the normal northern summer conferences at this time of year, we find ourselves getting ready for "virtual" conferences where we watch zoom presentations and try to reap all the intangible benefits of conferences—the informal discussions over coffee breaks and social events, the sampling of local restaurants, and the forging of lasting collaborations.

This year OzGrav is the lead institution for the 14th Amaldi conference on gravitational waves. We've been busy processing applications, reviewing abstracts with an international scientific organising committee, and trying to ensure the international community stays connected.

We've also just received the welcome news that OzGrav won a Silver Pleiades award for our efforts to improve Equity and Diversity in the Centre. I'm indebted to our very active E&D committee and to everyone in OzGrav for their efforts that led to this success.

I hope you enjoy this edition of Space Times and that the vaccination programs underway allow us to catch up in person again soon.

Regards
Matthew Bailes
OzGrav Director



The Director at the 13th Amaldi Conference in Valencia, Spain.

NEWS IN BRIEF

- OzGrav won a Silver Pleiades Award by the ASA, for our continued commitment to promoting equity and inclusion.
- Congratulations to OzGrav Chief Investigator Prof Susan Scott (ANU) on receiving an Honorable Mention in the international Gravity Research Foundation Essay Awards for 2021. Title of her essay, co-written with Benjamin Whale: What actually happens when you approach a gravitational singularity?
- Congratulations to the following 2021 ASA prize-winning OzGrav members and associates:
  Tamara Davis (UQ) on receiving the Robert Ellery Lectureship for outstanding contributions in astronomy or a related field.
  Colm Talbot (Monash) on receiving the Charlene Heisler Prize for most outstanding PhD thesis in astronomy or a closely related field. Doctoral Thesis: Astrophysics of Binary Black Holes at the Dawn of Gravitational-Wave Astronomy.
  Ethan Payne (Monash) on receiving an honourable mention for the Bok Prize for outstanding research in astronomy or a closely related field.

Editor-in-chief: Luana Spadafora
Subscribe or submit your contributions to lspadafora@swin.edu.au

RESEARCH HIGHLIGHT

Applying machine learning to gravitational-wave source models

Have you heard the joke about how many stars it takes to create a merging binary black hole? Hundreds of thousands in the real world… but only a few, if they're OzStars and you're using the latest COMPAS version with machine learning tools.

COMPAS is a public code for synthesising mock populations of stellar binaries, developed by an international team led by OzGrav researchers. COMPAS is very fast, taking a fraction of a second to evolve a pair of binary stars all the way to their possible collapse into neutron stars or black holes, which then merge due to the emission of gravitational waves. Provided that is the fate of the binary—but it's most likely not. Most binaries merge before forming compact objects, or are disrupted by supernovae, or are too wide to merge. So, if we're interested in modelling the formation of gravitational-wave sources, the vast majority of COMPAS simulations are wasted effort.

A new collaboration between Team COMPAS and statisticians from the Simon Fraser University in Vancouver, Canada, addresses this problem. Luyao Lin, Derek Bingham, Floor Broekgaarden and OzGrav Chief Investigator Ilya Mandel developed a machine learning tool to predict which binaries will go on to form gravitational-wave sources, and which won't. This tool relies on a Gaussian process classifier to predict the outcome of a COMPAS simulation based on an existing database of simulations, saving the cost of having to run more models.

When the outcome of the evolution should be a merging binary black hole, this new tool is also able to predict the chirp mass by using a related machine learning technique called local Gaussian process regression. Of course, the accuracy of machine learning tools depends on a judicious choice of the training data set, and the new set of tools we developed can suggest on the fly where to run additional simulations in order to optimise the ratio of prediction accuracy to computational cost.

As the observed dataset of gravitational-wave events grows, we're increasingly able to learn from the population of observations by comparing them against models built, using a variety of assumptions. This requires developing a large set of models, a computationally costly task. Techniques like the one described in 'Uncertainty quantification of a computer model for binary black hole formation' (Lin et al., accepted to the *Annals of Applied Statistics*) will enable us to meet this challenge and get the most out of the data.

Written by OzGrav Chief Investigator Prof Ilya Mandel, Monash University.

Background image from Pixabay

OZGRAV IN THE MEDIA

Scientists find new insights into the elusive continuous waves from spinning neutron stars

Five years on from the first discovery of gravitational waves, an international team of scientists, including from the ARC Centre of Excellence for Gravitational Wave Discovery (OzGrav), are continuing the hunt for new discoveries and insights into the Universe. Using the super-sensitive, kilometre-sized LIGO detectors in the United States, and the Virgo detector in Europe, the team have witnessed the explosive collisions of black holes and neutron stars. Recent studies, however, have been looking for something quite different: the elusive signal from a solitary, rapidly-spinning neutron star.

Take a star similar in size to the Sun, squash it down to a ball about twenty kilometres across—roughly the distance from Melbourne airport to the city centre—and you'd get a neutron star: the densest object in the known Universe. Now set your neutron star spinning at hundreds of revolutions per second and listen carefully. If your neutron star isn't perfectly spherical, it will wobble about a bit, and you'll hear a faint "humming" sound. Scientists call this a continuous gravitational wave.

So far, these humming neutron stars have proved elusive. As OzGrav postdoctoral researcher Karl Wette from the Australian National University explains: "Imagine you're out in the Australian bush listening to the wildlife. The gravitational waves from black hole and neutron star collisions we've observed so far are like squawking cockatoos—loud and boisterous, they're pretty easy to spot! A continuous gravitational wave, however, is like the faint, constant buzz of a faraway bee, which is much more difficult to detect. So we've got to use a few different strategies. Sometimes we hone in on a particular direction—for example, a flowering bush where bees are likely to congregate. Other times, we close our eyes and listen keenly to all the sounds we can hear, and try to pick out any buzzing sounds in the background. So far, we haven't had any luck, but we'll keep trying! Once we do hear a continuous gravitational wave, we'll be able to peer deep into the heart of a neutron star and unravel its mysteries, which is an exciting prospect."

A recent collaborative study with OzGrav has taken a closer look at the remnants of exploded stars, called supernovae. OzGrav PhD student Lucy Strang from the University of Melbourne explains: "Our search targets fifteen young supernova remnants containing young neutron stars. We use three different pipelines: one optimized for sensitivity, one that can handle a rapidly evolving signal, and one optimized for one likely astrophysical scenario. This is the first LIGO study covering all three of these scenarios, maximising our chance of a continuous wave detection. Continuous gravitational waves are proving very difficult to detect, but the same properties that make them elusive make them appealing targets. The exact form of the signal (i.e. its frequency, how rapidly the frequency changes, how loud it is, etc.) is dependent on what neutron stars are made of. So far, the structure of neutron stars is an open question that draws in all kinds of physicists. Even without a detection, a search allows us to peek behind the curtain at the unknown physics of neutron stars. When we do detect continuous waves, we'll open the curtain and shine a spotlight on new physics. Until then, we can use the information we do have to refine our understanding and improve our search methods."

OzGrav Associate Investigator Lilli Sun from the Australian National University says: "Young neutron stars in supernova remnants are promising targets to look for those tiny continuous gravitational waves, because they haven't spent a long enough time to relax and smooth out the asymmetries introduced at their birth. In our endeavor to search for continuous waves from these young neutron stars in our third observing run, we take into consideration, for the first time, the possibilities that the interior configuration and structure of the star can result in signals emitted at two different harmonics. Although no signal has been detected in O3, we set interesting constraints on the neutron star properties. If such a signal can be detected in future observations when the detectors are more sensitive, it will shed light on the fascinating structure of a neutron star."

In addition, recent studies announced by the international research team have focussed on pulsars. These are neutron stars which act as cosmic lighthouses, beaming out copious energy in the form of radio waves. Pulsars are like giant spinning magnets, except they're billions of times stronger than the ones stuck to your fridge. So strong, in fact, that the magnetic field distorts the shape of the neutron star, and may lead to a tell-tale hum of continuous gravitational waves. While the recent studies did not pick up anything, they found tight constraints on how loud the "hum" could be, which, in some cases, are starting to challenge theoretical predictions.

OzGrav PhD student Deeksha Beniwal from the University of Adelaide says: "Gravitational-wave observation from O3 run of LIGO and Virgo detectors has allowed us to set realistic constraints on signals expected from young pulsars. O3 observations also provide an opportunity to test out different pipelines—such as different search methods for continuous wave signals—in realistic environments."

Scientists estimate that there are billions of neutron stars in the Milky Way with a faint murmur of continuous gravitational waves. Further studies have therefore taken an "ears wide open" approach, combing through the LIGO and Virgo data for any hint of a signal. The results so far suggest that these murmurings are extremely quiet and out of the detectors' "ear" range. However, as detector technology becomes more advanced and sensitive, the first ever detection of continuous gravitational waves could soon become a reality.

This article is an extract from the original media release. Also featured on Cosmos Magazine, IFL Science, Space Australia and Sci Tech Daily.

Blistering stars in the Universe: **Rare insights into the evolution of stars**

What happens if a supernova explosion goes off right beside another star? The star swells up which scientists predict as a frequent occurrence in the Universe. Supernova explosions are the dramatic deaths of massive stars that are about 8 times heavier than our Sun.

Most of these massive stars are found in binary systems, where two stars closely orbit each other, so many supernovae occur in binaries. The presence of a companion star can also greatly influence how stars evolve and explode. For this reason, astronomers have long been searching for companion stars after supernovae-- a handful have been discovered over the past few decades and some were found to have unusually low temperatures.

When a star explodes in a binary system, the debris from the explosion violently strikes the companion star. Usually there's not enough energy to damage the whole star, but it heats up the star's surface instead. The heat then causes the star to swell up, like having a huge burn blister on your skin. This star blister can be 10 to 100 times larger than the star itself.

The swollen star appears very bright and cool, which might explain why some discovered companion stars had low temperatures. Its inflated state only lasts for an 'astronomically' short while--after a few years or decades, the blister can "heal" and the star shrinks back to its original form.

Artist's impression of supernova outflow. Credit: James Josephides, Swinburne University.

In their recently published study by a team of scientists led by OzGrav postdoctoral researcher Dr Ryosuke Hirai (Monash University), the team carried out hundreds of computer simulations to investigate how companion stars inflate, or swell up, depending on its interaction with a nearby supernova. It was found that the luminosity of inflated stars is only correlated to its mass and doesn't depend on the strength of the interaction with supernova. The duration of the swelling is also longer when the two stars are closer in distance.

"We applied our results to a supernova called SN2006jc, which has a companion star with a low-temperature. If this is in fact an inflated star as we believe, we expect it should rapidly shrink in the next few years," explains Hirai

The number of companion stars detected after supernovae are steadily growing over the years. If scientists can observe an inflated companion star and its contraction, these data correlations can measure the properties of the binary system before the explosion—these insights are extremely rare and important for understanding how massive stars evolve.

"We think it's important to not only find companion stars after supernovae, but to monitor them for a few years to decades to see if it shrinks back," says Hirai.

Written by OzGrav Postdoctoral researcher Dr Ryosuke Hirai, Monash University.

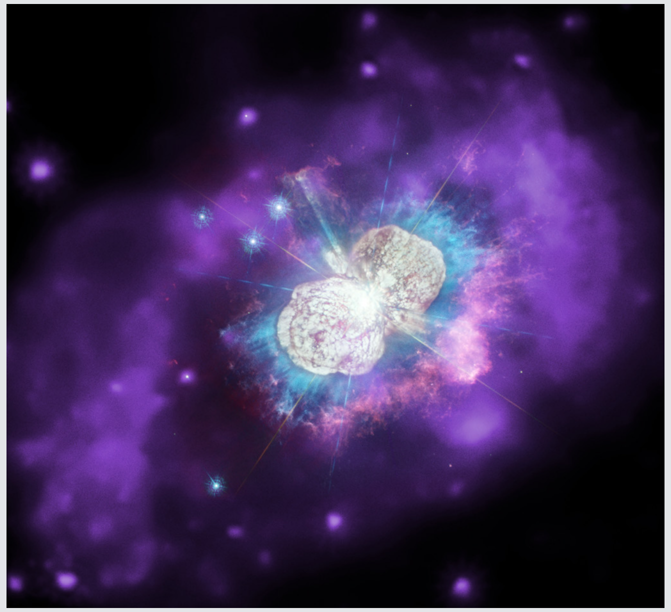
As featured on Phys.org.

UPCOMING VIRTUAL CONFERENCES HOSTED BY OZGRAV

- **International Pulsar Timing Array (IPTA) zoom conference**
  21 - 25 June 2021. Visit ipta4gw.org/meetings/2021/
- **14th Edoardo Amaldi Conference on Gravitational Waves**
  19 - 23 July 2021. Visit amaldi14.org

Bright cosmic explosions could reveal strange interstellar "knots"

Gamma-ray bursts are enormous cosmic explosions and are one of the brightest and most energetic events in the Universe. Their brightness changes over time, illuminating deep space like a flashlight shining into a dark room. Intense radiation emitted from most observed gamma-ray bursts is predicted to be released during a supernova as a star implodes to form a neutron star or a black hole.



Shells of material surround the stars of Eta Carinae. A Gamma-ray burst coming from those stars should release large amounts of light as it collides with the denser medium.

Image credit: X-ray: NASA/CXC; Ultraviolet/Optical: NASA/STScI; Combined Image: NASA/ESA/N. Smith (University of Arizona), J. Morse (BoldlyGo Institute) and A. Pagan

In the recently observed gamma-ray burst event called GRB 160203A, remains of the explosion started glowing much brighter than expected, according to standard scientific models, even several hours after the initial flash. We now believe that this "rebrightening" was caused by the main body of the burst crashing through shells of material ejected by the source star, or interstellar "knots". Both theories suggest that the standard gamma-ray burst model needs to be re-examined, and perhaps the surrounding space isn't as smooth and uniform as originally predicted.

In our study, we began collecting reports from all over the world that observed the gamma-ray burst event, including the archives of the Zadko research telescope. By carefully calibrating the data from different sources and comparing the different brightness over time, we unpacked the surrounding galaxy and defined key characteristics of the burst: the temporal index (how quickly it fades over time), the spectral index (the overall colour of the burst), and the extinction (how much light is absorbed by the matter between here, on Earth, and the burst). One surprising finding was that the density of the burst's host galaxy is unusually dense – about the same as our own galaxy, the Milky Way.

The next step was to see how and when the data moved away from the model. With further calculations, we identified three interesting time periods that indicated significant brightness differences compared to the model's prediction. Although the third period was probably a coincidence, the first and second periods were too large to ignore. Normally, rebrightening is caused by something happening to the host galaxy(?), such as suddenly collapsing into a black hole; however, these kinds of events normally happen within the first few minutes of a gamma-ray burst – in this event, the first rebrightening didn't start until three hours after the initial explosion.

As a result, we decided to expand the conventional model of gamma-ray bursts to explain this unusual event. One of the properties of such events is the relationship between the density of the medium and the intensity of radiation emitted from the explosion. What's particularly convincing about this explanation is its applicability to many contexts. As stars prepare to explode into supernovas and gamma-ray bursts, they eject their outer shells into the surrounding space. For bursts that don't come from supernovas, these changes in brightness could be the result of turbulence in the interstellar medium. In either case, the change in brightness gives us a new tool to probe the structure of distant space, and we are now eagerly anticipating another burst with similar features to put our new model to the test.

Written by OzGrav PhD student Hayden Crisp, University of Western Australia.

About OzGrav

The ARC Centre of Excellence for Gravitational Wave Discovery (OzGrav) is funded by the Australian Government through the Australian Research Council Centres of Excellence funding scheme. OzGrav is a partnership between Swinburne University of Technology (host of OzGrav headquarters), the Australian National University, Monash University, University of Adelaide, University of Melbourne, and University of Western Australia, along with other collaborating organisations in Australia and overseas.

The mission of OzGrav is to capitalise on the historic first detections of gravitational waves to understand the extreme physics of black holes and warped spacetime, and to inspire the next generation of Australian scientists and engineers through this new window on the Universe.

OzGrav is part of the international LIGO-Virgo collaboration. LIGO is funded by NSF and operated by Caltech and MIT, which conceived of LIGO and led the Initial and Advanced LIGO projects. Financial support for the Advanced LIGO project was led by the NSF with Germany (Max Planck Society), the U.K. (Science and Technology Facilities Council) and Australia (Australian Research Council-OzGrav) making significant commitments and contributions to the project. Nearly 1300 scientists from around the world participate in the effort through the LIGO Scientific Collaboration. The Virgo Collaboration is composed of approximately 350 scientists from across Europe. The European Gravitational Observatory (EGO) hosts the Virgo detector near Pisa in Italy, and is funded by Centre National de la Recherche Scientifique (CNRS) in France, the Istituto Nazionale di Fisica Nucleare (INFN) in Italy, and Nikhef in the Netherlands.

The Kamioka Gravitational Wave Detector (KAGRA), formerly the Large Scale Cryogenic Gravitational Wave Telescope (LCGT), is a project of the gravitational wave studies group at the Institute for Cosmic Ray Research (ICRR) of the University of Tokyo. It will be the world's first gravitational wave observatory in Asia, built underground, and whose detector uses cryogenic mirrors. The design calls for an operational sensitivity equal to, or greater, than LIGO. The project is led by Nobelist Takaaki Kajita who had a major role in getting the project funded and constructed.

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