Radio afterglows of Gravitational Waves

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Covid-19 statement

The research project presented in this thesis has been impacted by Covid-19. Because of the pandemic, international and national conferences were not held in person. I was hence not able to expand my network of researchers and build up new collaborations.

Moreover, the Laser Interferometer Gravitational-wave Observatory (LIGO) and Virgo suspended their observations in 2020. As a consequence, the PhD project has been repositioned by modifying the methodology and research topic. The project was originally supposed to be a study on radio transients with a particular focus on gravitational wave events. However, a study of variable galactic nuclei was inserted and the study of gravitational waves was from a more theoretical approach.

During the pandemic, Australian borders were closed and universities in Australia fired part of their staff as the number of international students dramatically decreased in 2020 and 2021. In those uncertain times, my main supervisor, Martin Bell, decided to resign from his position as a researcher at the University of Technology, Sydney. He decided to leave research and start a career as a data scientist at the University of Newcastle. During the year 2022, I never met with my supervisor in person and all our meetings were held online. He did everything possible to give me support and proper supervision. Nevertheless, remote supervision clearly made this PhD project more challenging.

Abstract

This thesis describes a study of the research conducted by myself during these years as a PhD candidate working at the University of Technology, Sydney (UTS) and the Commonwealth Scientific and Industrial Research Organisation (CSIRO). The thesis is divided in two main parts: the first part is comprised of research analysing the radio variable sky with a *classical* approach while the second part proposes the usage of statistical techniques poorly used in Astrophysics at the moment of writing this work.

Firstly, a comprehensive description of the instrumentation which has involved my research work. The instrumentation consists in the Australia Telescope Compact Array (ATCA), The Australian Square Kilometre Pathfinder (ASKAP), the Swift Gamma-ray Burst Explorer (*Swift*), the High Energy Stereoscopic System (HESS) and the two Michelson interferometers the Laser Interferometer Gravitational-Wave Observatory (LIGO) and Virgo. Principles of radio astronomy observations are also reported.

Secondly, a transients follow-up with the Australia Telescope Compact Array is presented. The research project comprised the study of the gamma-ray burst GRB190114c, the two flare stars AT Mic and UV Ceti. The investigation has been carried out by using the Rapid Response Mode. This modality consists in triggering radio telescopes as soon as a transient is detected by X-ray and gamma-ray telescopes. The analysis of the gamma-ray burst revealed possible scintillation while the flare stars activity could be due to gyrosynchrotron radiation, electron cyclotron maser or plasma radiation. Furthermore, campaign for detecting ultra-cool dwarfs (UCDs). These objects are hardly detectable and at the time of writing this work, only 25 sources were detected. The campaign is based on searching for objects with photometric variability and fast rotation. The search allowed to detect at least 3 objects from 11 radio observations.

Moreover, a study of variable active galactic nuclei (AGN) using the Australian Square Kilometre Pathfinder (ASKAP) is outlined. This research has been conducted with a targeted approach by selecting ASKAP sources listed in AGN catalogues. The study showed the detection of 30 variable AGN. The most likely explanation for their radio variability is scintillation because of the brightness temperature values above the Compton catastrophe limit of 10^{12}K.

Finally, the second part of this thesis is an analysis of innovative methods for studying variable and transient sources in Astrophysics. The work involves the study of light curves by using statistical methods named State Space Models. These models can be used for detecting a transient source hosted by a variable active galaxy. In this thesis, a method for detecting a gravitational waves event hosted by a hypothetical active galaxy

is explained. In addition, State Space Models can also encode several properties in light curves, such as slope, rise or decline for a given time t.

The conclusions of this thesis summarise the main results and the possible developments of the research projects described in the other chapters.

The thesis also contains an appendix showing fragments of the code used for testing State Space Models on astronomical time series data.

Author's declaration

I, *Daniele d'Antonio* declare that this thesis, submitted in fulfilment of the requirements for the award of Doctor of Philosophy, in the *School of Mathematical and Physical Sciences*, *Faculty of Science* at the University of Technology Sydney. This thesis is wholly my own work unless otherwise referenced or acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis. This document has not been submitted for qualifications at any other academic institution. This research is supported by the Australian Government Research Training Program and the Australian Research Council.

Production Note:
SIGNATURE: Signature removed prior to publication.

[Daniele d'Antonio]

DATE: 16th December, 2022

PLACE: Sydney, Australia

Dedication

To my parents and my sister
Ai miei genitori e mia sorella

Acknowledgments

I feel like I started this PhD yesterday. I still remember how I was feeling my first day at UTS. How nervous I was! I could not wait to start this journey! The first time I stepped into Martin's office to talk about my project I could not be more excited! However, everything comes to an end and here I am writing this section and having a final look at this thesis after three years and half of being a PhD student in Sydney. Time flies!

During these years, my supervisor Martin Bell, has always been a good fella. He assisted me not just on research but also on life in general. Martin, thank you for all our chats. Thank you for checking on me and for sharing your life experience when I broke up with my ex girlfriend. Besides, I will never forget how you did anything possible to supervise me even when you were no longer in Sydney. You didn't even get paid to supervise me anymore but you kept helping me whenever I needed. Maybe I could go to Newcastle and see you for a beer after submitting this thesis!

I'd like to thank also the great researchers I worked with in Australia such as Gemma Anderson who gave me the opportunity to explore the world of gamma-ray bursts and flare stars. It was great to chat with you in person in Narrabri. What a pity that the pandemic made that to be our first and last meeting in person. Thanks to Vanessa Moss who assisted me when I worked at CSIRO and when I had to deal with ATCA observations. You were so easy going and friendly since our first chat! I will always remember our chat about my future, when we talked about a career in research or industry. I also remember when you introduced me to Matthew Bailes. Thanks for everything you have done!

I want to thank Tara Murphy as well. It's been exciting to work in your research group and learn about radio and variable transients. Thanks for your efforts on granting me a PhD stipend during these years. Without those funds my PhD would not be possible. A thing I always appreciated of you is that you are always clear and direct on giving feedback and comments. This makes you tough sometimes but also honest.

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I can't not mention the people I came across these years at UTS. PhD means years of work but also fun. I shared my office with several people and I can't forget of Aishwarya whose the name still worries me when I have to write it. Now, I hope I wrote it well (damn! why didn't I give her a short easy nickname these years???). Thanks for being my main mate at the office. Thank you Trudy for being there and stand me whenever you came to the office. Natalia, thank you. You did not spend much time with us at UTS but those six months together have been amazing! Virginia, thanks for your company as well. Thanks to Luca who has been one my best friends. I missed you when you left UTS. We had good fun together. Thank you Matias and Tom for the nice time we spent together!

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Thank you Jessie. You just came to my life but you already mean a lot to me. You made this final stage of my PhD life a wonderful time. I feel soooo lucky I met you.

Finally, I really want to thank my parents mamma and papa', my sister and zio Remo for being always supportive and helpful during these four years in Australia. We were far but at the same time close, especially when I had just arrived in this country and I was alone on the other side of the World. My family always supported me in every decision since I was born. They indeed supported me when I decided to become an astrophysicist. I couldn't ask for a better family!

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