Rapid response gravitational wave follow-up with the PIRATE robotic telescope

By Dean Roberts

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From Micrometres to Megaparsecs, Southampton University, March 2018

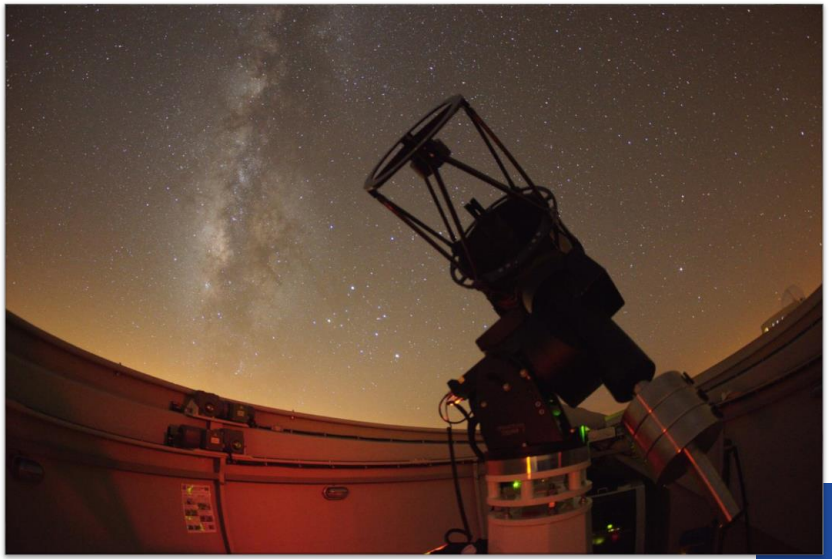
01 Introduction

The PIRATE robotic telescope facility

INTRODUCTION

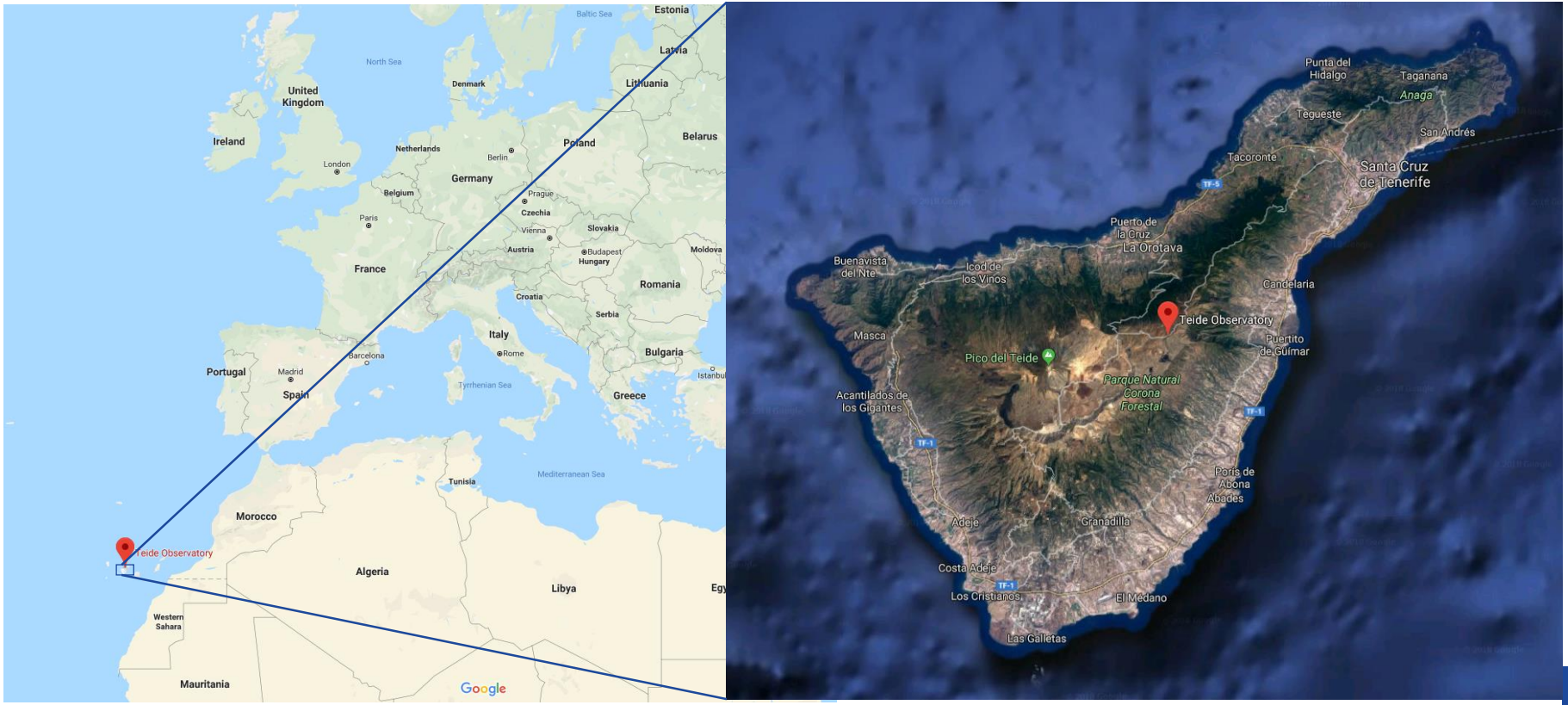
PIRATE

	PIRATE Mark III
Dome	Baader Planetarium All-Sky 4.5m
Mount	10Micron GM4000
OTA	CDK17 corrected Dall-Kirkham
Aperture	17 inch (42 cm)
Focal length	2940 mm (f/6.8)
camera	FLI ProLine KAF-16803
CCD type, size	KAF-16803, 4096x4096
Pixel size	9 microns
Filters	Baader LRGB, Halpha, OIII and SII
Field of view	43 arcmin
Plate scale	0.63 arcsec/px



INTRODUCTION

PIRATE's Location



Credit: Google Maps

INTRODUCTION

Using PIRATE for my research

- My research involves using PIRATE to perform gravitational wave follow-up
- The robotic nature allows me to program automated follow-up observations with rapid response times.
- Ideal for catching rapidly fading transients.
- PIRATE is also used for various other research projects including: exoplanets, variable stars & transients.
- Additionally it is also used by OU undergraduate students & amateur astronomers via telescope.org

02 Gravitational Waves

A new window on the universe

Gravitational Waves

An Introduction

- They are ripples in the fabric of space-time, produced by accelerating masses.
- First predicted by Einstein in his theory of General Relativity (GR).
- They are very weak signals, with fluctuations on the order 10^{-22}
- Laser Interferometers are used to detect them.
- Sources of GWs include: Black Hole (BH) & Neutron Star (NS) mergers and supernovae burst events.

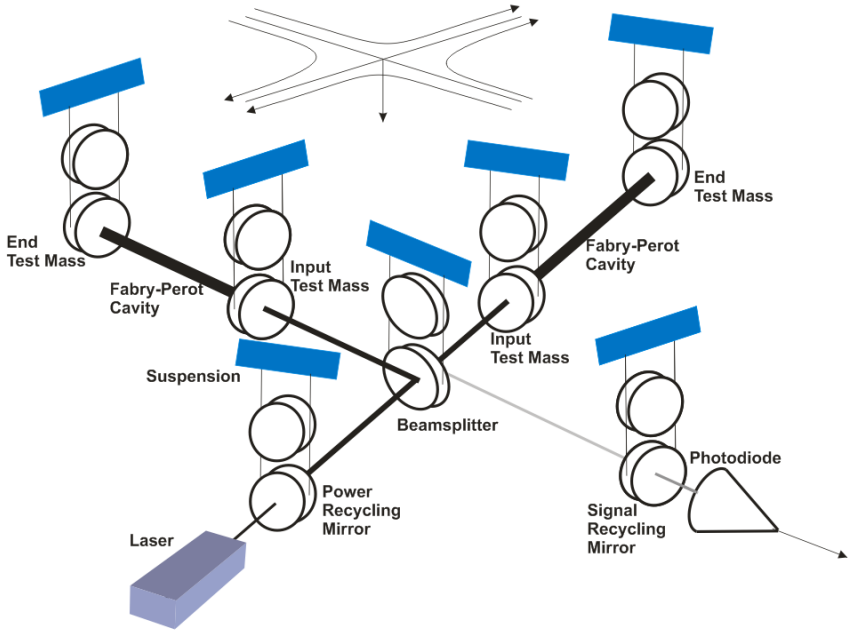


Image Credits: Swinburne Astronomy Productions & LIGO

Gravitational Waves

An Introduction

- First confirmed GW detection from a Binary Black Hole (BBH) merger by LIGO in 2015.
- First Neutron Star merger detected by LIGO & Virgo last summer (more details later).
- Next observing run (O3) scheduled for Autumn this year.
- Still awaiting first GW detection from a supernova.

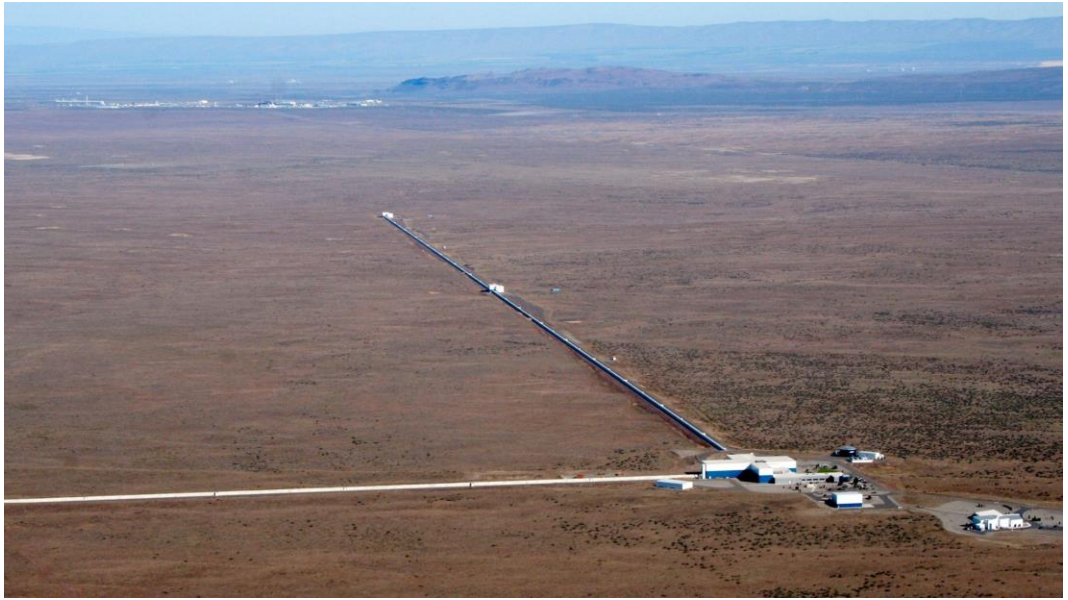


Image Credit: LIGO Laboratory

Gravitational Waves

Skymaps

- My project r
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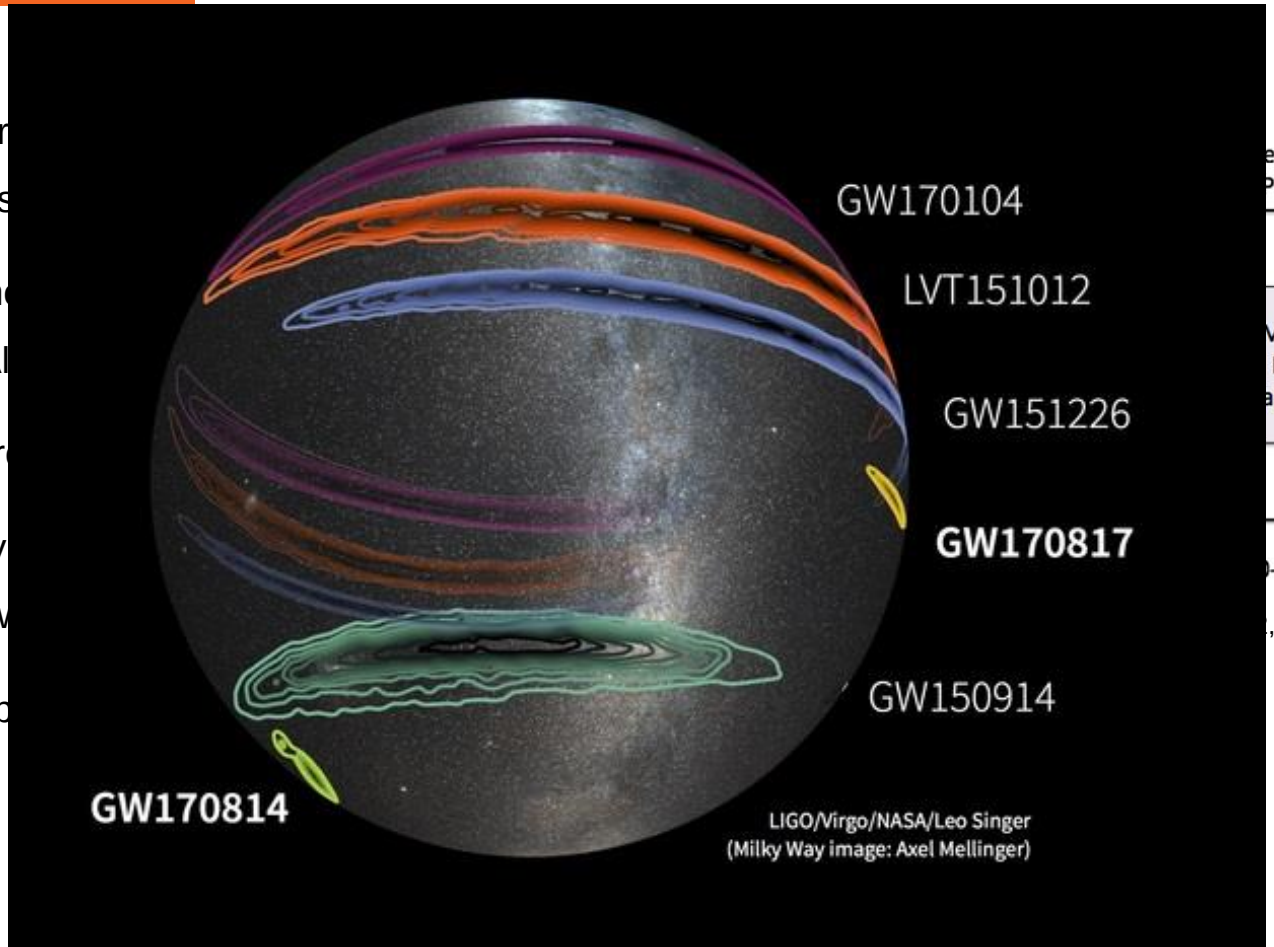


ers and Pointing | Send Alerts to Telescopes

Manual Event alidation

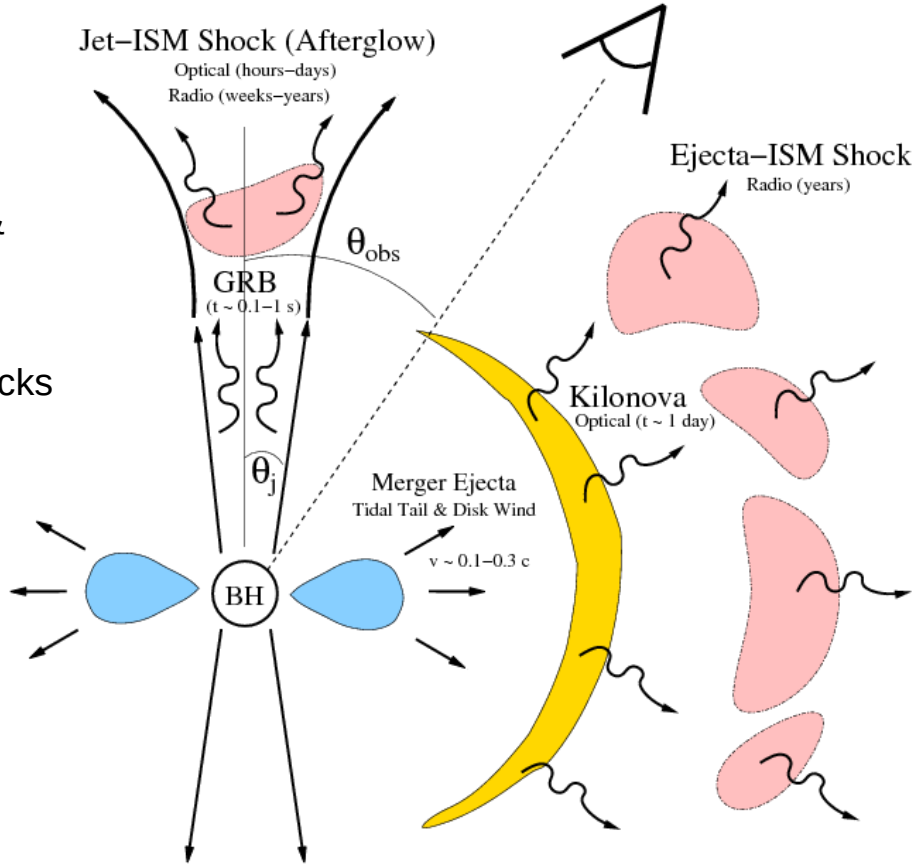
-20 min. | Total Latency: ~30 minutes

, A&A, 539, A124

Gravitational Waves

EM Counterparts

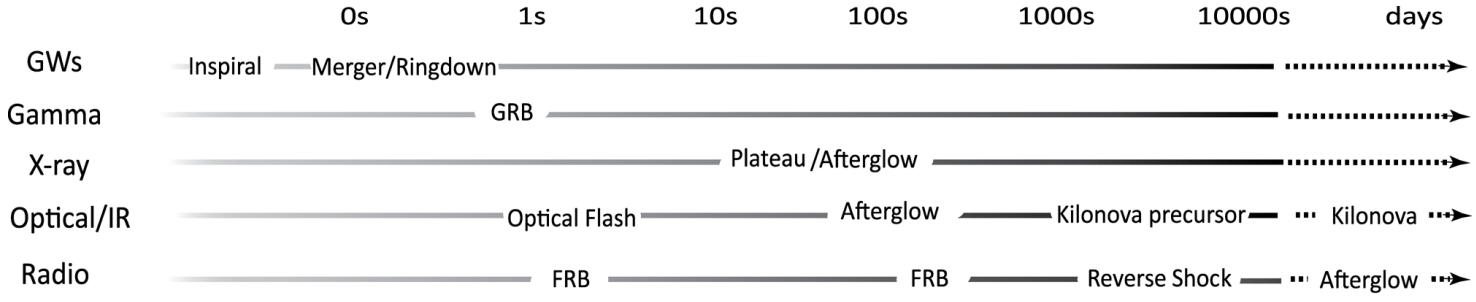
- No EM counterparts predicted in BBH mergers.
- BNS mergers produce Gamma Ray Burst (GRB) & kilonova events.
- GRB is highly beamed, directional dependant, shocks the surrounding ISM.
- GRB afterglow powered by synchrotron radiation.
- Kilonova is both isotropic and independent of the density of the circumburst environment.
- Isotropic thermal emission, powered by the radioactive decay of heavy.

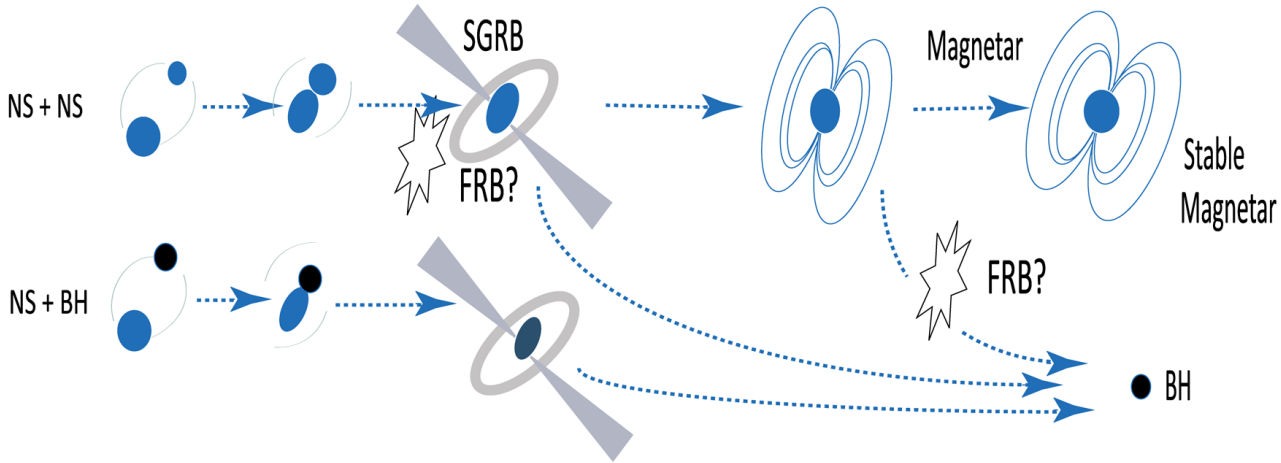


Metzger & Berger (2012)

Gravitational Waves

EM Counterparts



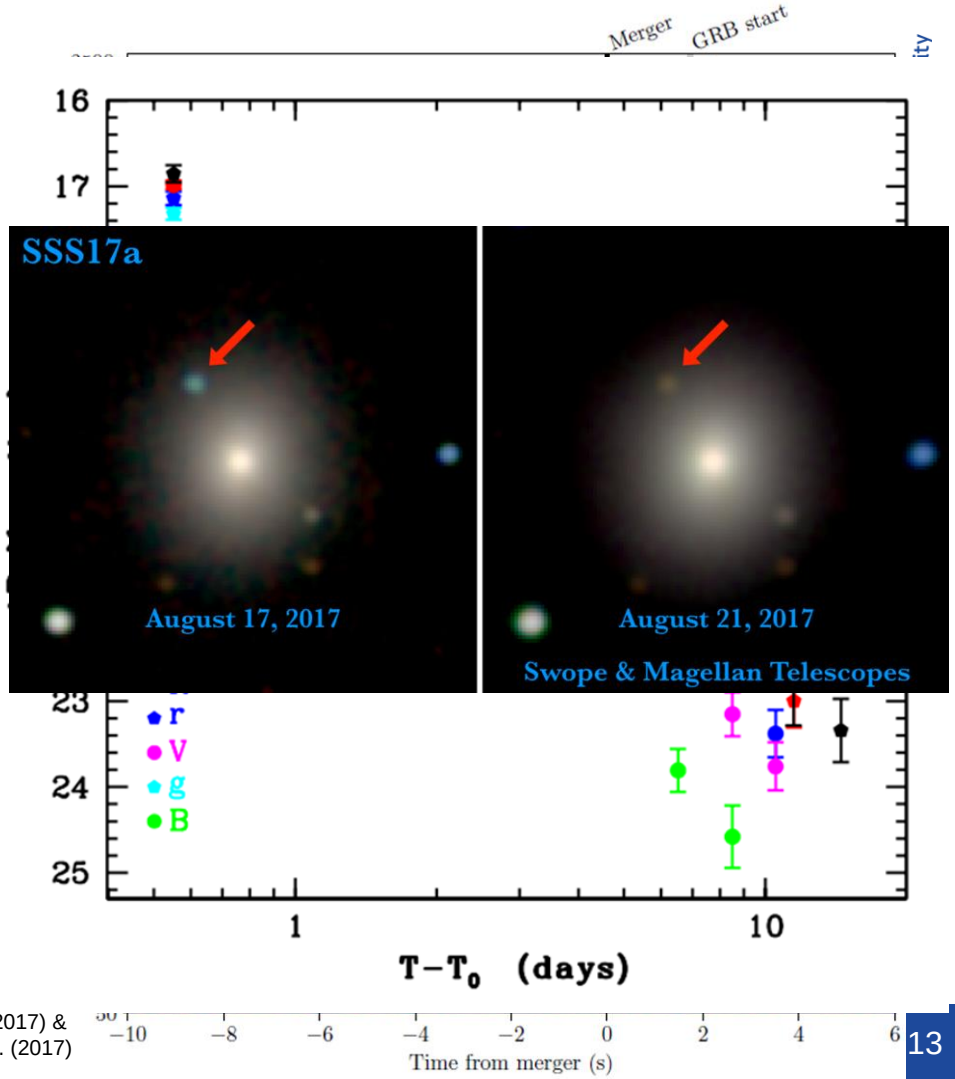


Chu et. al (2016)

Gravitational Waves

GW170817

- Loudest & closest GW signal to date.
- First time GWs have been detected from a BNS merger.
- First joint GW-EM observations of a source.
- First joint GW-GRB detections that demonstrates BNS mergers are progenitors for SGRBs.
- First observed “kilonova” event.
- Most rapidly fading transient ever observed.
- Solves the puzzle of the “missing” heavy elements, heavier than iron.
- Bright enough to have been detected by PIRATE



Pian et al. (2017) &
Coulter et al. (2017)

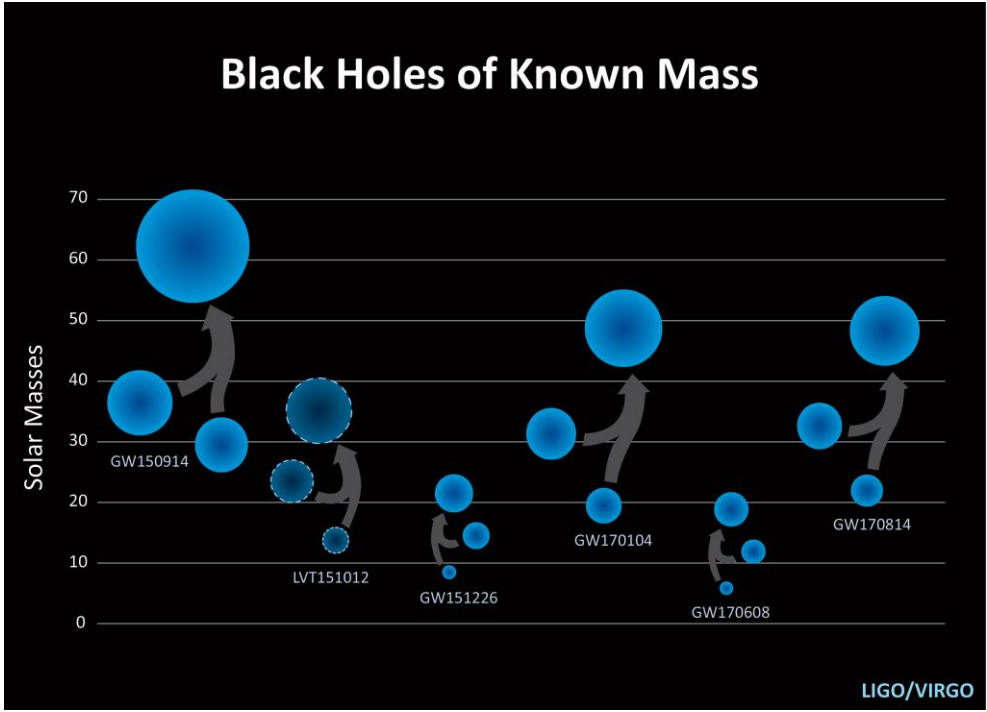
03 EM Follow-up Campaign & Results

The beginning of the multi-messenger astronomy era

EM Follow-up Campaign & Results

O2

- O2 ran from 30th Nov 2016 - 26th Aug 2017.
- LVC released 10+ alerts over 9 months.
- 4 have so far been confirmed as GWs
- This includes 3 black hole mergers and 1 binary neutron star merger.
- PIRATE was able to follow up 70% of these alerts!
- Missed out on GW170817 due to latitude.



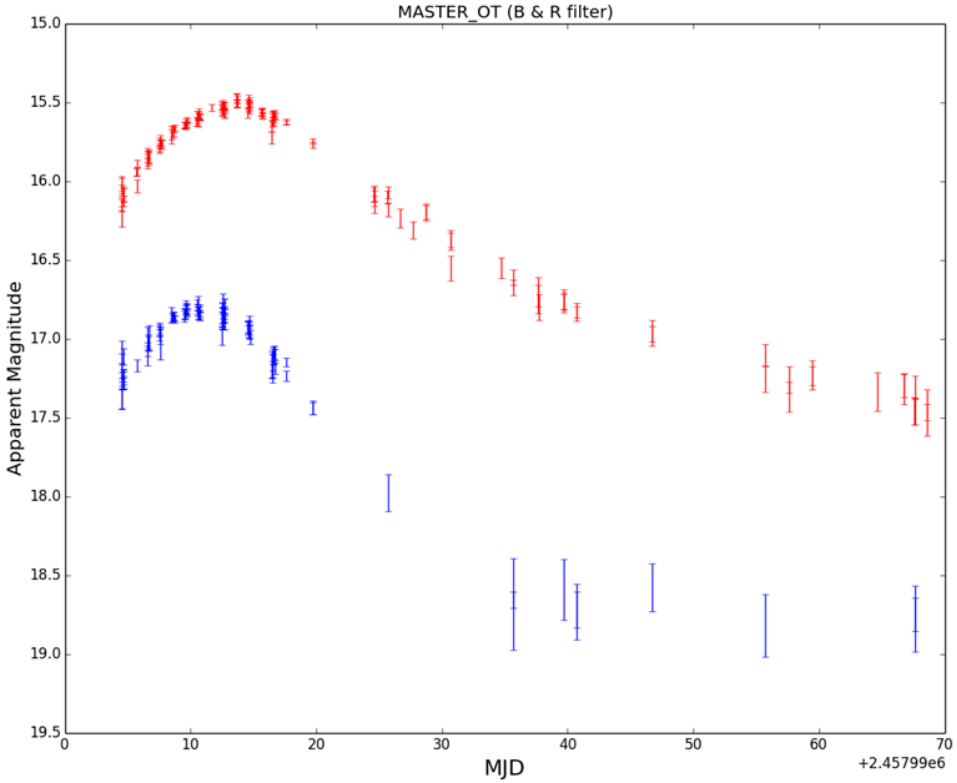
EM Follow-up Campaign & Results

Results

- All LIGO follow-up images were calibrated and processed.
- Main lightcurve plotting tool was called VaST.
- VaST is a variability search tool, useful in searching for transients in large data sets.
- I used the variability index 1/η called the ratio of the variance over the mean square successive difference.

$$\frac{1}{\eta} = \frac{\sigma^2}{\delta^2}$$

- Where $\delta^2 = \frac{1}{n-1}\sum_{\mu=1}^{n-1}\left(x_{\mu+1} - x_{\mu}\right)^2$
- This shows up variables that change brightness over time, rather than large variations night to night.



MASTER OT J033744.97+723159.0 – Type IIb SN

04 Conclusions

The summary at the end.

Conclusions

Summary

- I have given details on the new robotic telescope facility (PIRATE) owned and operated by the OU in Tenerife.
- In addition to this I have given a brief overview of gravitational wave EM counterparts.
- Also, I have shown the methods we used to search for potential EM counterparts in our data.
- Lastly I outlined some of the results we obtained with PIRATE from O2, including the successful follow-up of a supernova.
- However we were unable to observe the historic neutron star merger event. Nevertheless this work proves that had the alert been visible we would have been able to detect it.

THANK YOU

ANY QUESTIONS?

The Open University