The Gravitational Wave Optical Transient Observer (GOTO)

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MONASH University

Armagh Observatory

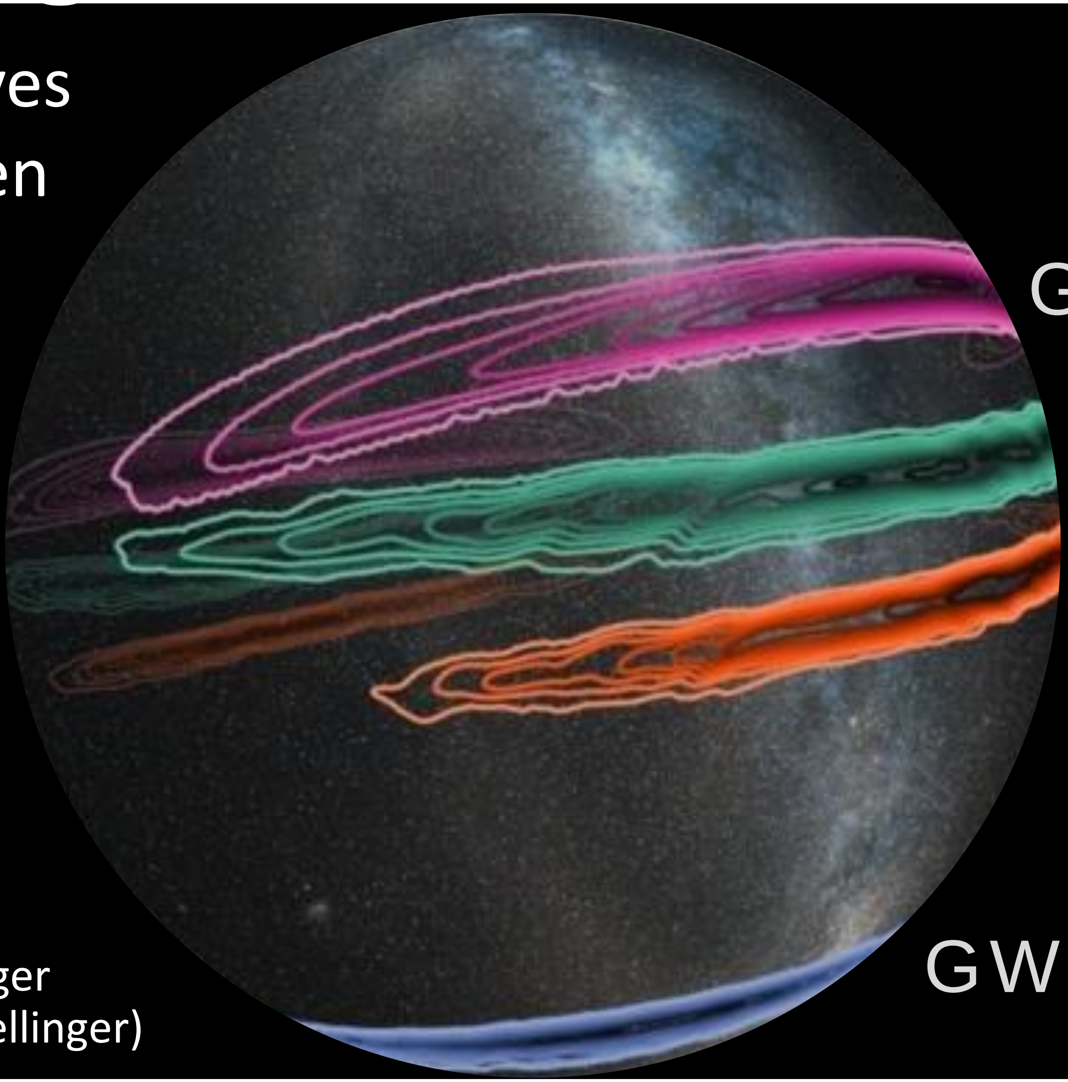
UNIVERSITY OF LEICESTER

Sheffield.

NARIT

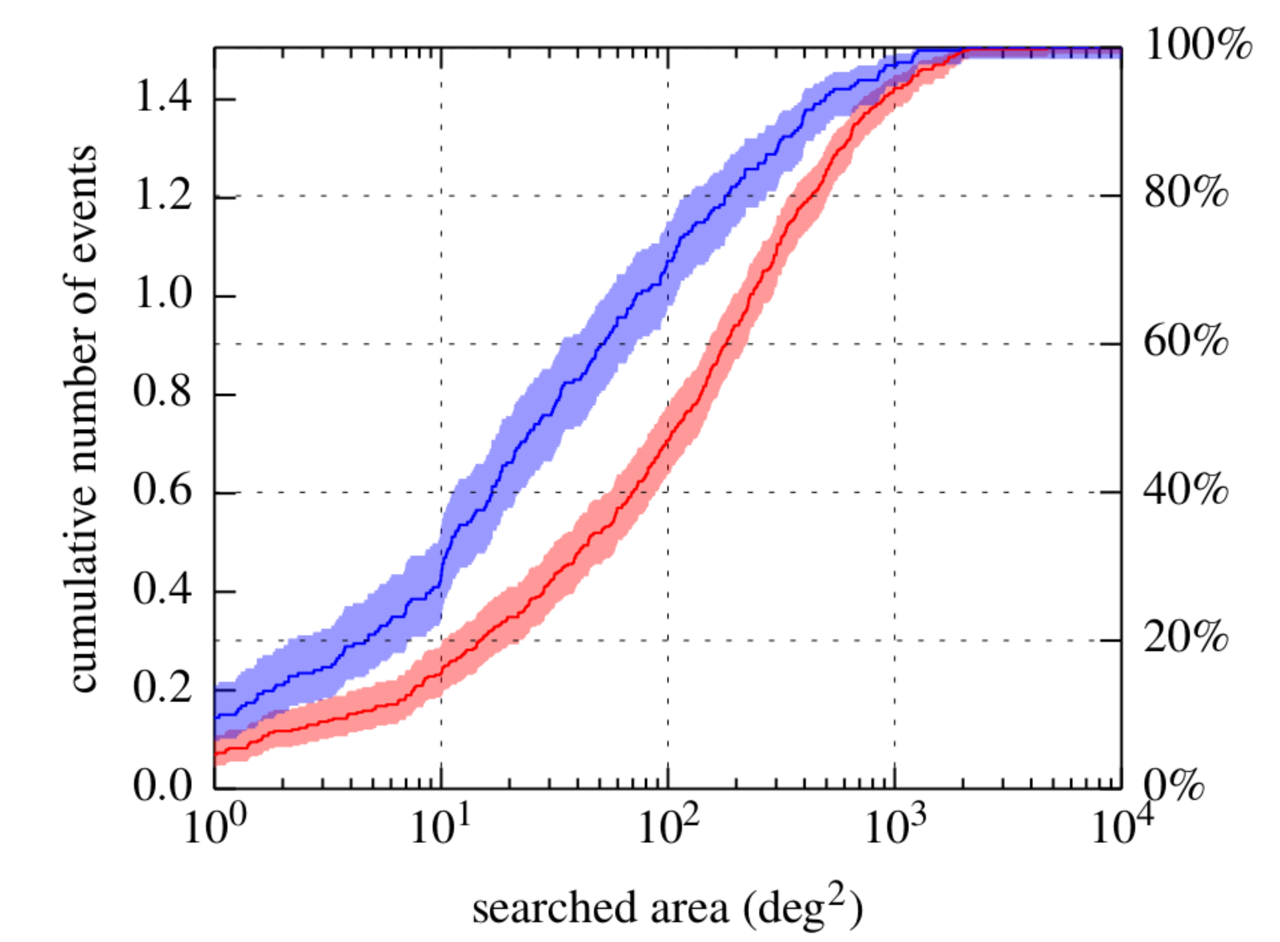
Detecting Gravitational Waves

Gravitational waves are detected when compact objects merge.



LIGO/Caltech/MIT/Leo Singer
(Milky Way image: Axel Mellinger)

Detecting Gravitational Waves

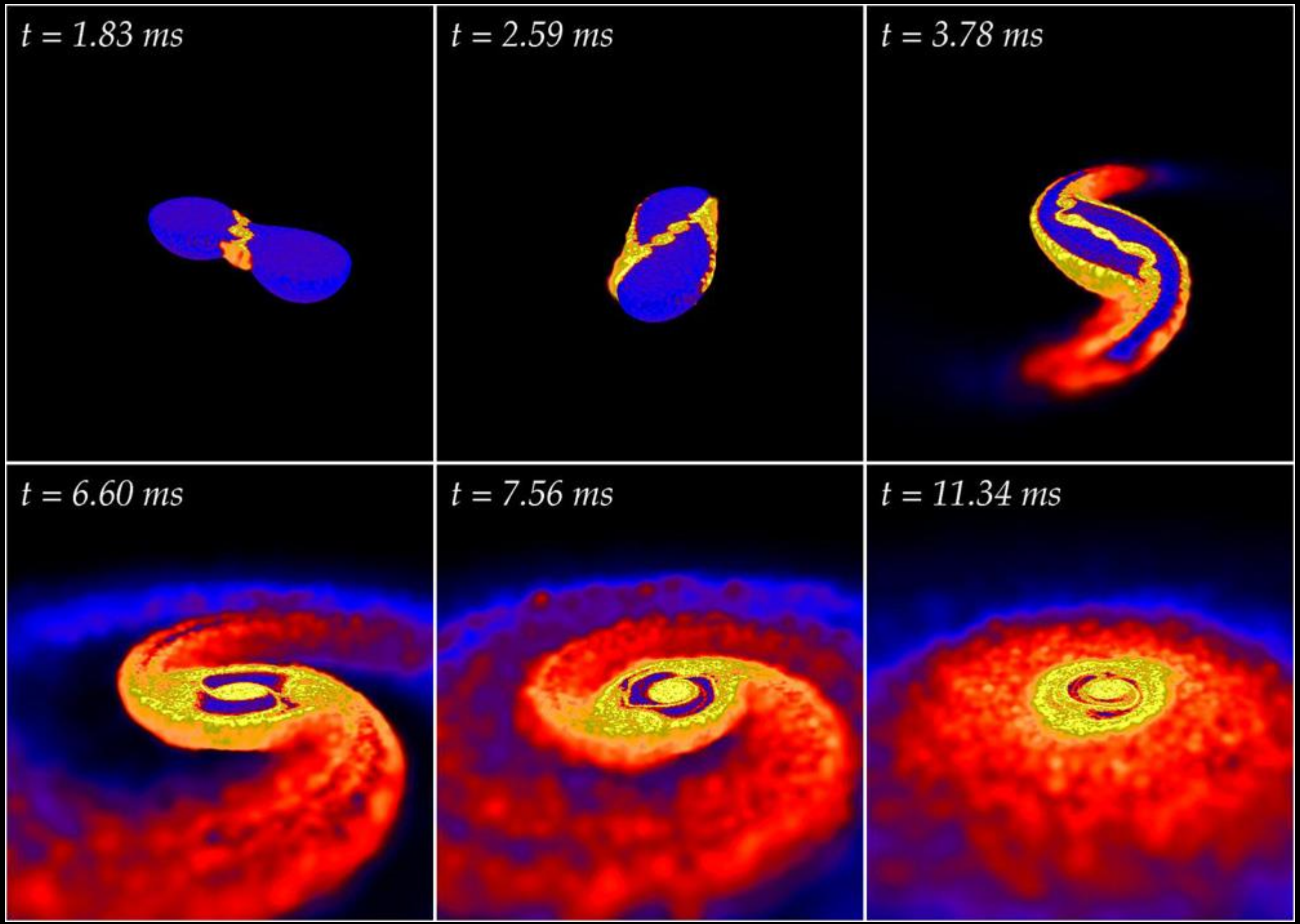


Singer, L.P., et al. (2014)

Sky Localisation simulation:

- Even with 3 gravitational wave observatories there is still a large search area
- Covering on average 500 deg^2 per event

Electromagnetic Signatures



Price, D. P., Rosswog, S. (2006)

Electromagnetic Counterparts:

- Binary Neutron Star mergers
- Black Hole + Neutron Star Mergers
- Potentially some Black Hole mergers
  DeMink, S. E., King, A. (2017)

GOTO Mission

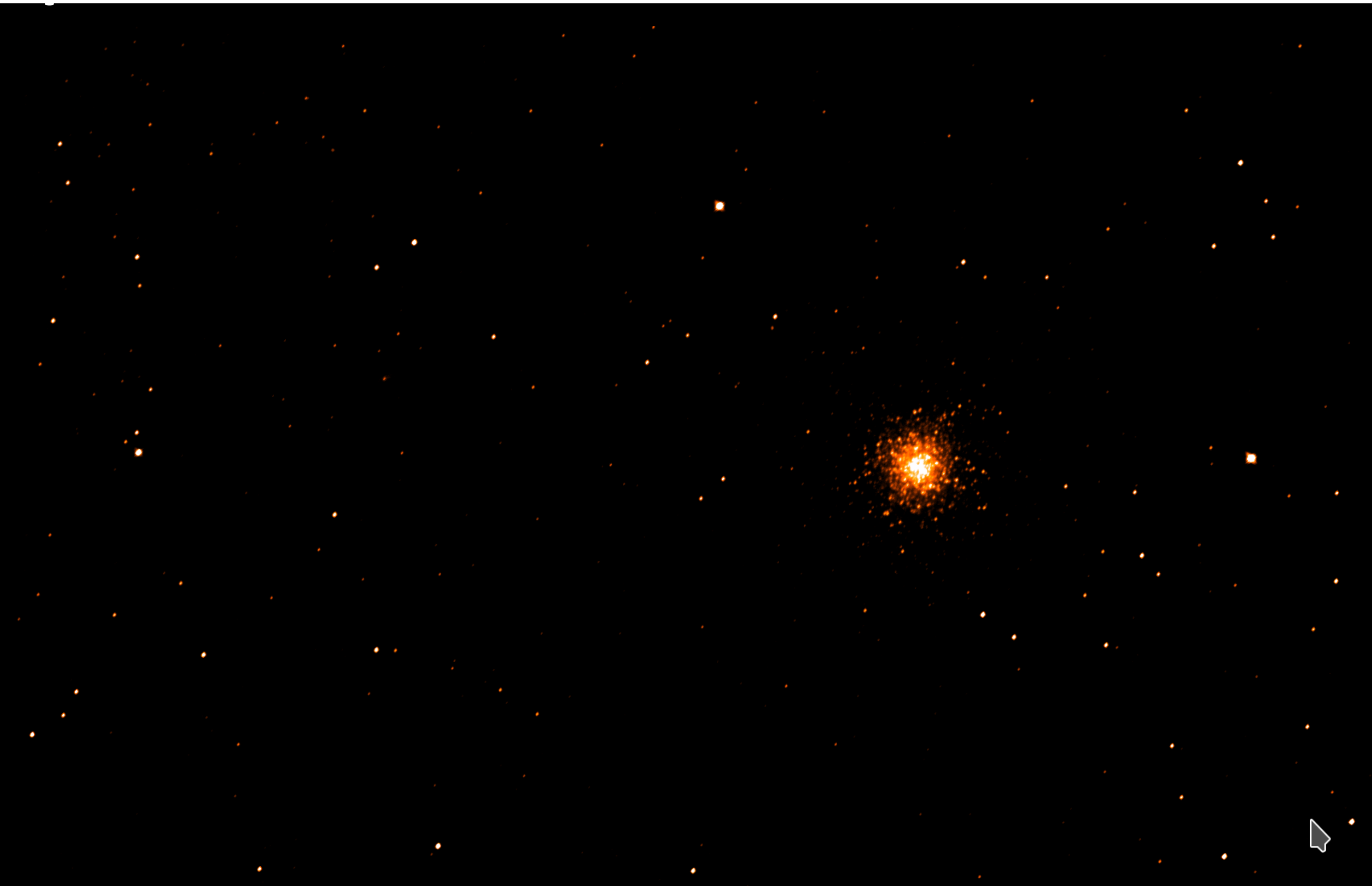
- Wide angle, fast survey allowing high cadence reference. Allowing coverage of GW localisation error boxes.
- Seeing deep enough to probe EM signatures from NS mergers
- Robotic with an automatic response to LIGO alerts
- Optimised pipeline to extract transient sources in real time.

Installing GOTO on La Palma
Credit: Paul Chote

GOTO Specs

- Currently in phase I
- 4 × 40cm bespoke telescopes
- 50 Megapixel detector per telescope
- 4.5 deg^2 field of view per telescope
- 21^{st} Magnitude in the optical regime, taking 5-10 minutes.
- Filter wheel R,G,B, Optical band, and Clear
- Scalable, flexible design. More telescopes can be added

GOTO Specs



First light! (11/06/2017)
M13 (a giant globular cluster in Hercules)

GOTO Specs

Phase II

Illustration of GOTO’s second phase

- Fully funded
- 4 additional telescopes
- Covering a total area of 36deg^2 per pointing
- 6-7 days to cover the night sky
- To be completed end of 2017

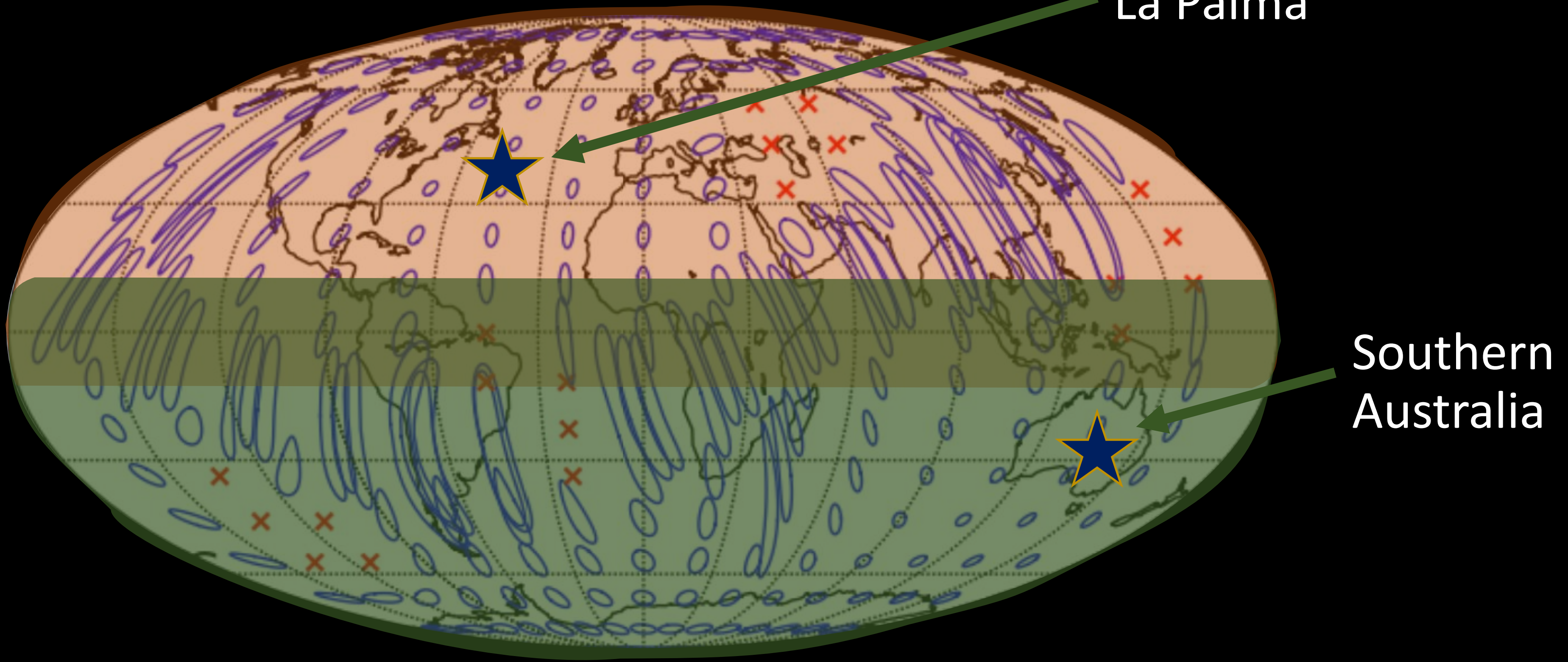
GOTO Specs

Phase III and beyond

Illustration of GOTOs third phase

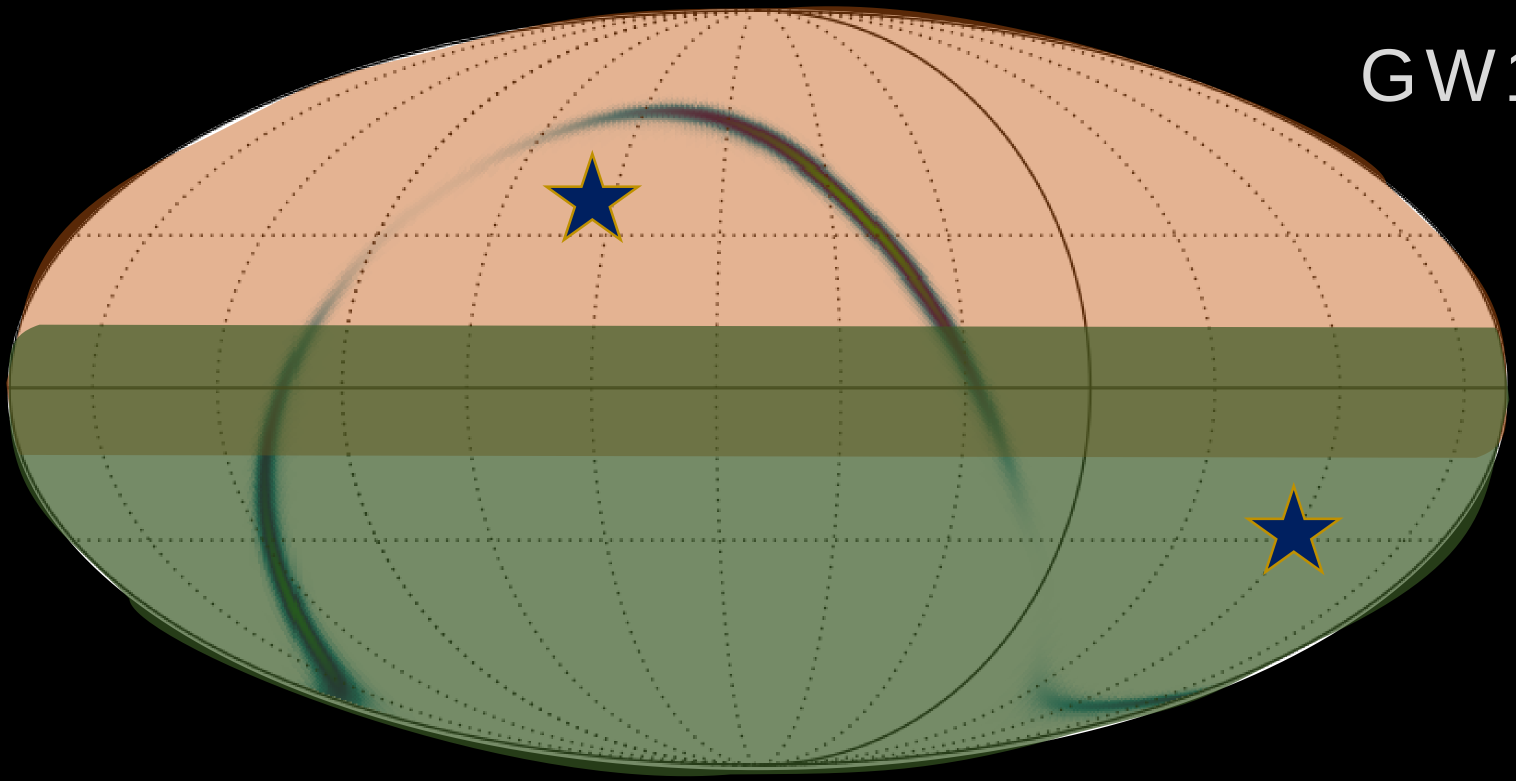
- Add another 8 telescopes on La Palma
- Lowers sky cadence 3-4 days
- Filter flexibility
- Considering a second node in the southern hemisphere.

GOTO Specs



Aasi, J., et al. (2013)

GOTO Specs



Abbott, B. P., et al. (2016)

GW151226

Hunt for the Counterpart

- Survey mode building a high cadence reference of the night sky
- When a gravitational wave event is received GOTO will shift from survey mode to a targeted search mode.
- Optimised pipeline to extract transient sources

Follow-up Astronomy

- Confirmation
- Light curves
- Spectroscopy
- Red shifts
- Host properties

Follow-up Astronomy

Consortium Facilities

- Warwick 1.0 Metre telescope
- PT5M
- NARIT 2.4 Metre telescope
- NARIT 0.7 Metre cluster

Approved Facilities

- William Herschel Telescope
- Isaac Newton Telescope
- Liverpool Telescope
- Hubble Space Telescope
- …

Additional Research Opportunities

- Big data challenges such as storage, machine learning, gaussian processes.
- Real-time processing while searching for a counterpart. Filtering false positives such as supernovae and galactic foreground
- Developing the best search strategy that exploits GOTO's flexibility.
- Large sky survey offering opportunities for other time domain science.

Time Domain Science

Extra-Galactic

- Tidal Disruption Events
- Active Galactic Nuclei
- Fast Radio Bursts
- Gamma Ray Bursts
- Supernovae

Galactic

- Millisecond pulsar companions
- White dwarf binaries
- Pulsating variables
- Luminous Blue Variables
- Symbiotics
- Cataclysmic Variables

Closer still

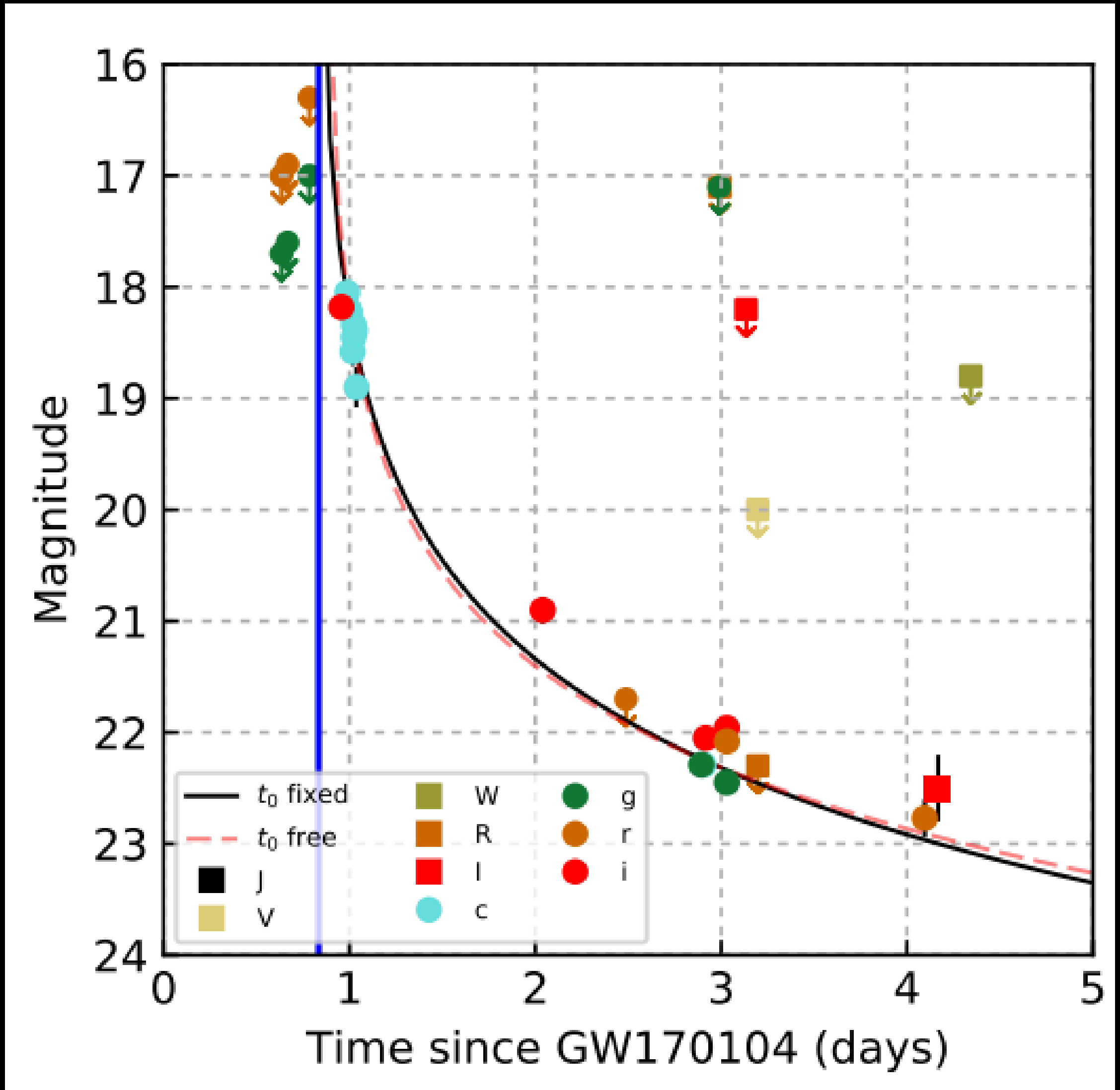
- Asteroids
- Comets

Summary

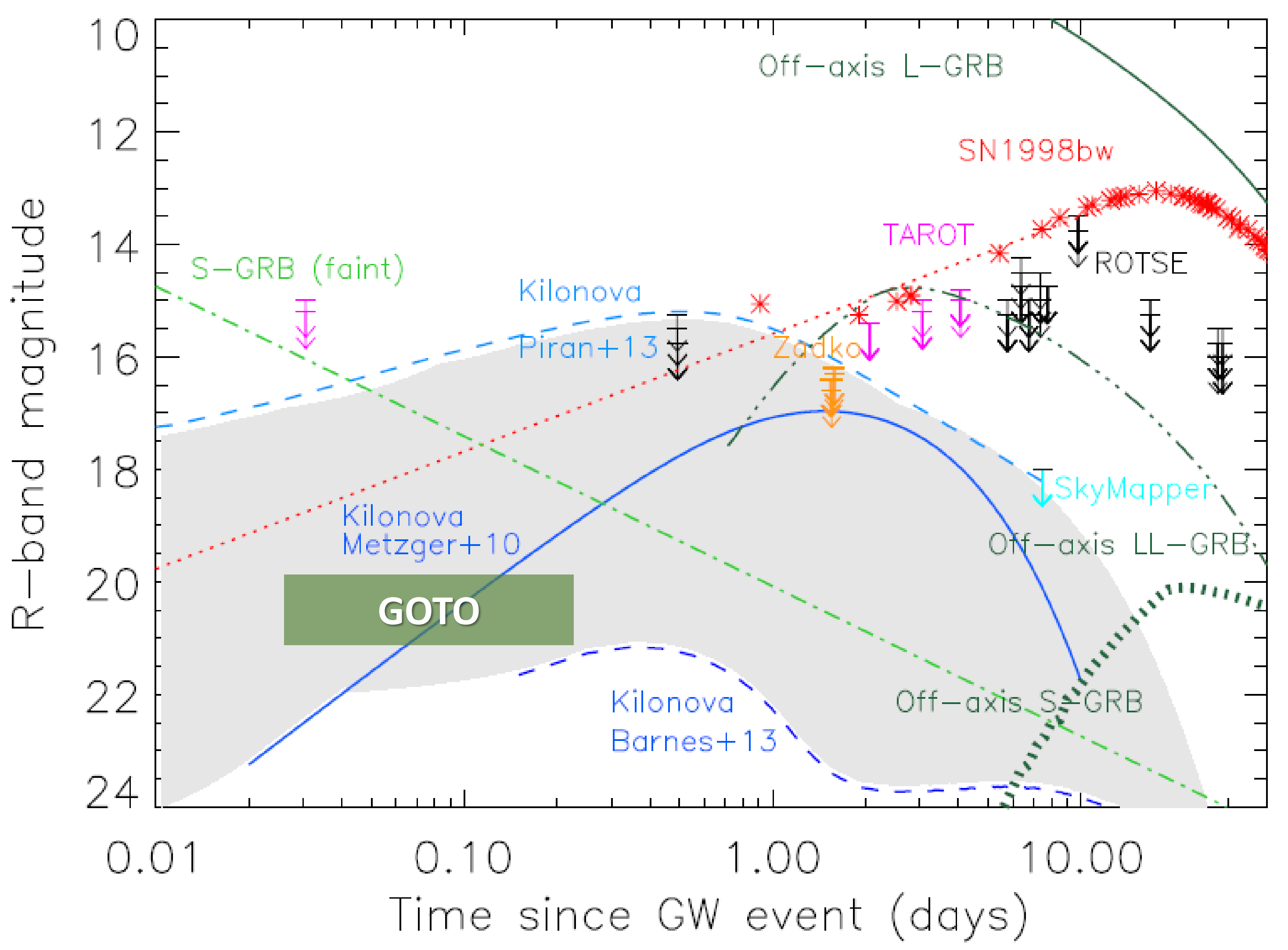
- Entering the era of Multi-Messenger Astronomy and a dedicated fast wide field of view survey telescope would be optimal when searching for the counterpart to a Gravitational Wave trigger.
- The GOTO prototype has just been deployed in La Palma with plans in place to upgrade it into its second phase.
- A vast array of secondary time domain astronomy can be completed using the wide field survey.
- Opportunities for research in big data Astronomy

Time (MJD)	dt1 (days)	dt2 (days)	Filter	Mag	Telescope	Flux[a] (μJy)	Reference
57758.0595	0.6345	−0.2003	g	> 17.7	SWASP/GOTO	< 340	Steeghs et al. (2017)
57758.0595	0.6345	−0.2003	r	> 17.0	SWASP/GOTO	< 580	"
57758.0920	0.6670	−0.1678	g	> 17.6	SWASP/GOTO	< 370	"
57758.0920	0.6670	−0.1678	r	> 16.9	SWASP/GOTO	< 640	"
57758.2100	0.7850	−0.0498	g	> 17.0	SWASP/GOTO	< 650	"
57758.2100	0.7850	−0.0498	r	> 16.3	SWASP/GOTO	< 1120	"

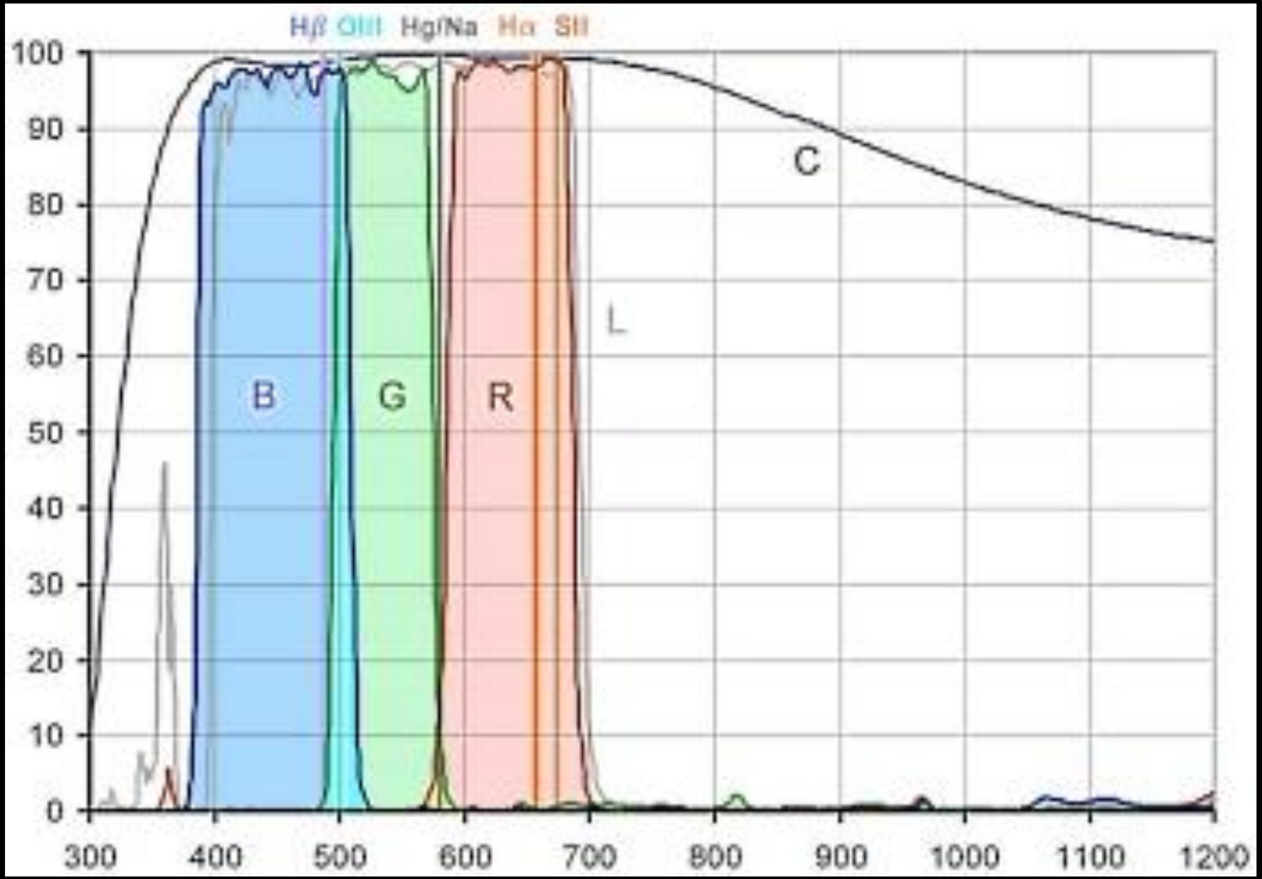
Bhalerao, V., et.al (2017)



Bhalerao, V., et.al (2017)



Aasi, J., et al. (2014)



Hβ OIII Hg/Na Hα SII
100
90
80
70
60
50
40
30
20
10
0
300
400
500
600
700
800
900
1000
1100
1200
C
L
B
G
R