BOOTES-network and GTC follow-up searches for GWs

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11th Iberian GW
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on behalf of the BOOTES and 10.4m GTC GW optical follow-up team

Outline

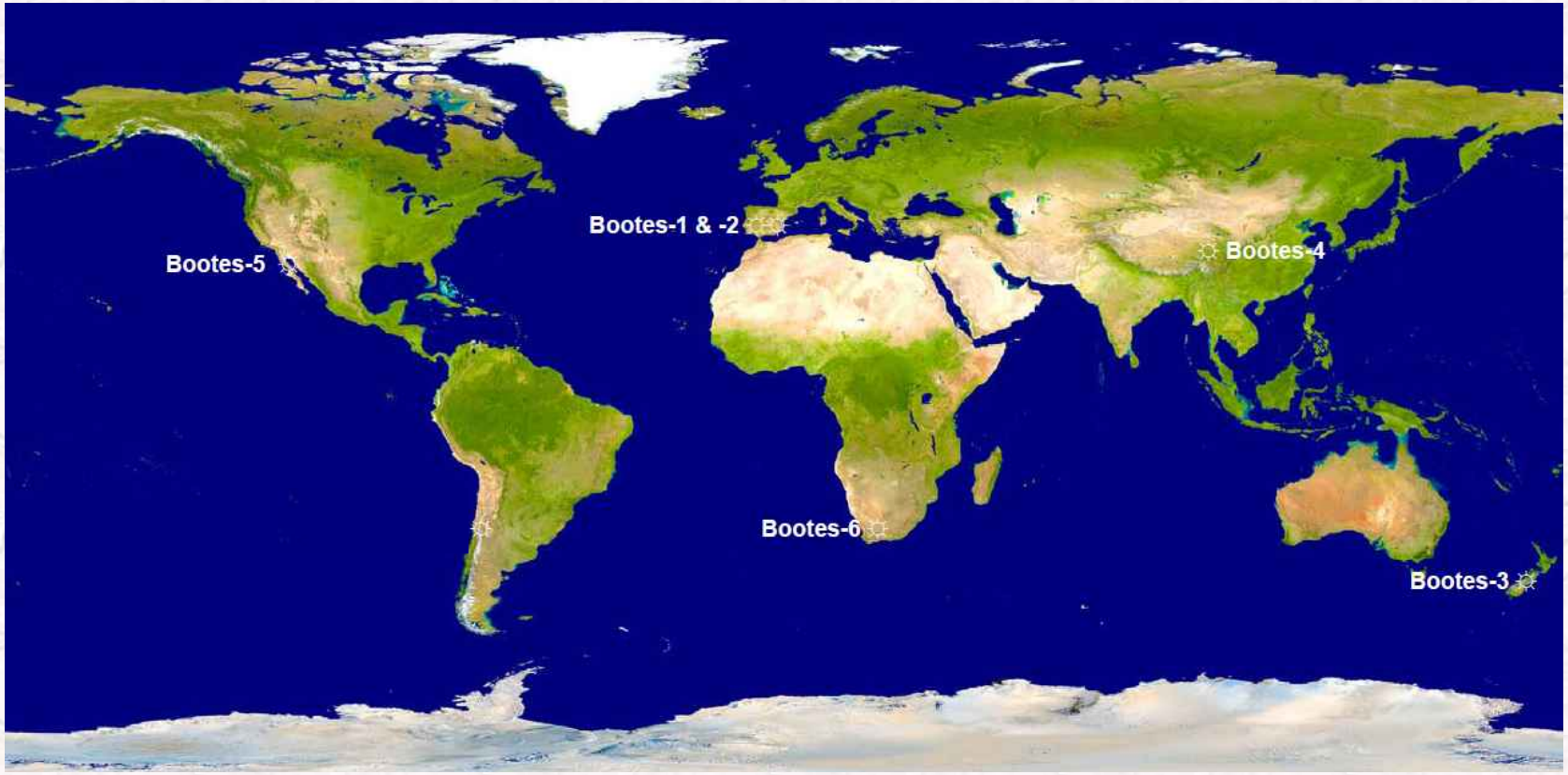
- The statues of BOOTES and the 10.4m GTC
- What we have done before
- Strategy in O3
- Observations in O3

The BOOTES Network

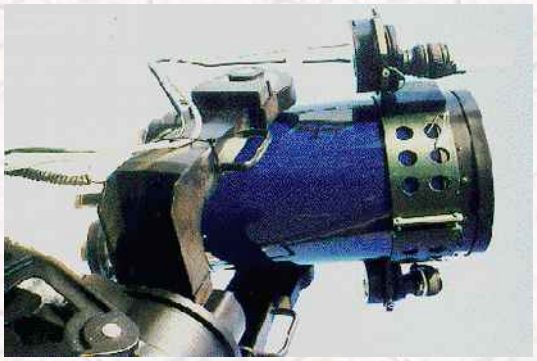
- **BOOTES** (Burst Observer and Optical Transient Exploring System)

Since 1998

The BOOTES Network



The BOOTES-1 station



1998

BOOTES-1 (INTA/CSIC/AUS/CVUT) in El Arenosillo (Huelva) with two domes. *Robotic* 0,3m Ø telescope and wide-field cameras, since June 1998. All-sky camera since Nov 2002. And two wide field camera since 2016.

2000

2006

2009

2016

The BOOTES-2 station

BOOTES-2 (INTA/CSIC/AUS/CVUT), Robotic 0,3m Ø telescope and wide-field cameras in Algarrobo-Costa (Málaga), since November 2001, replaced by a 0,6m Ø telescope in June 2008.

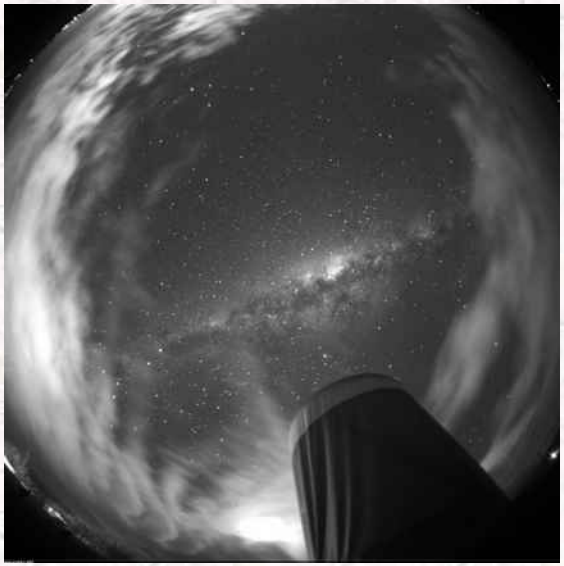
2001

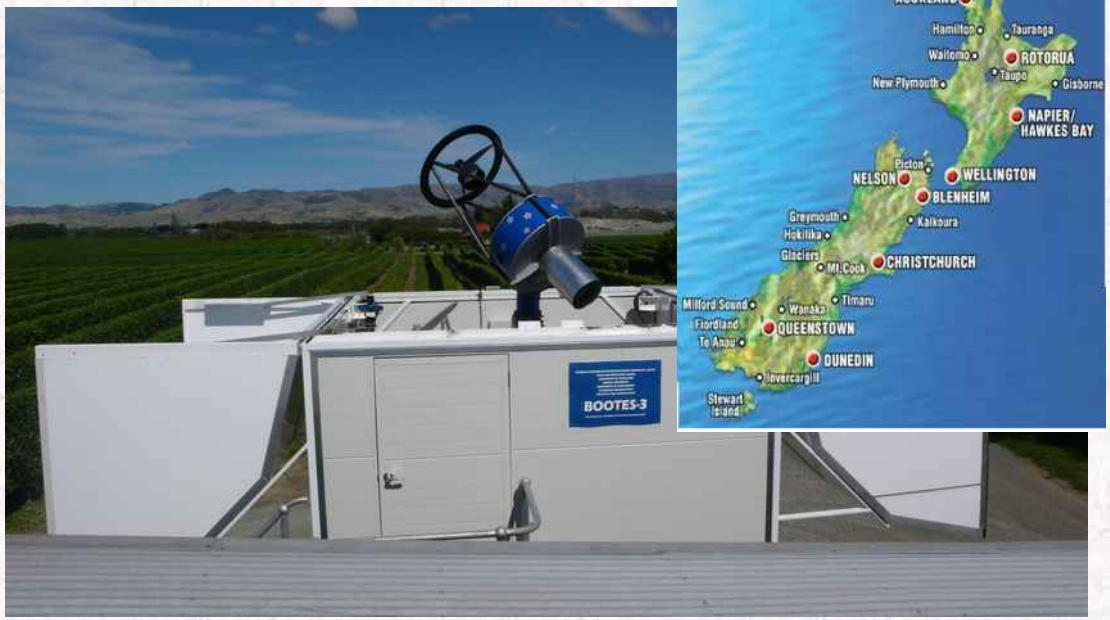
2007

2008

The BOOTES-3 station

BOOTES-3 (CSIC-UoA), robotic 0.6m Ø telescope and wide-field camera in Blenheim (New Zealand), since Feb 2009 (optical). Moved to Lauder (NZ) in .Sep 2014.





The BOOTES-4 station

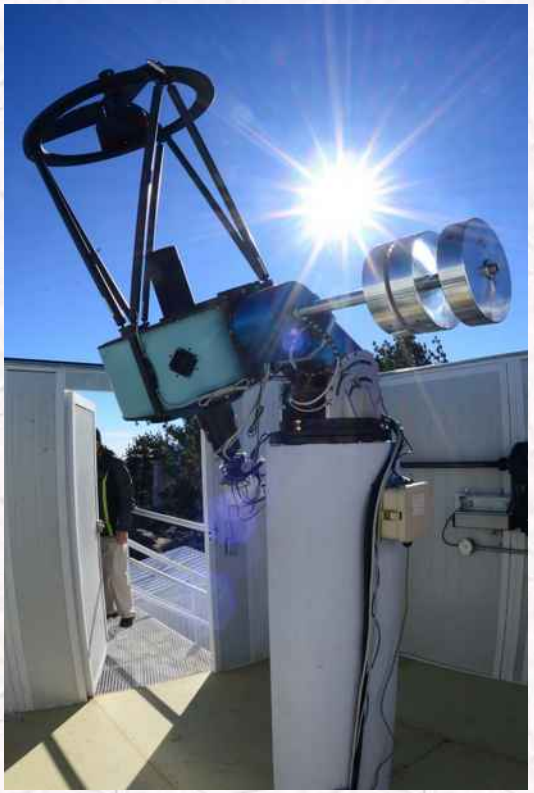
BOOTES-4 (CSIC-CAS), 0.6m Ø Robotic Telescope (ME) at the Lijiang Astronomical Observatory (China), since Mar 2012 (optical).

Coordinates
Lat: 26° 41'43"N
Long: 100° 01'47"E
Elev: 3231m

The BOOTES-5 station

BOOTES-5 (CSIC-UNAM-SKKU), 0.6m Ø Robotic Telescope (JGT) at the San Pedro Mártir Astronomical Observatory (México), since Nov 2015 (optical).

CASANDRA: Compact All-Sky Automated Network
Developed for Research in Astronomy 180 degree



BOOTES pending station

BOOTES-6 @ Boyden Observatory (South Africa) (2021?)

GTC follow up proposal

The Gran Telescopio CANARIAS

Instrument: OSIRIS spectrogrph

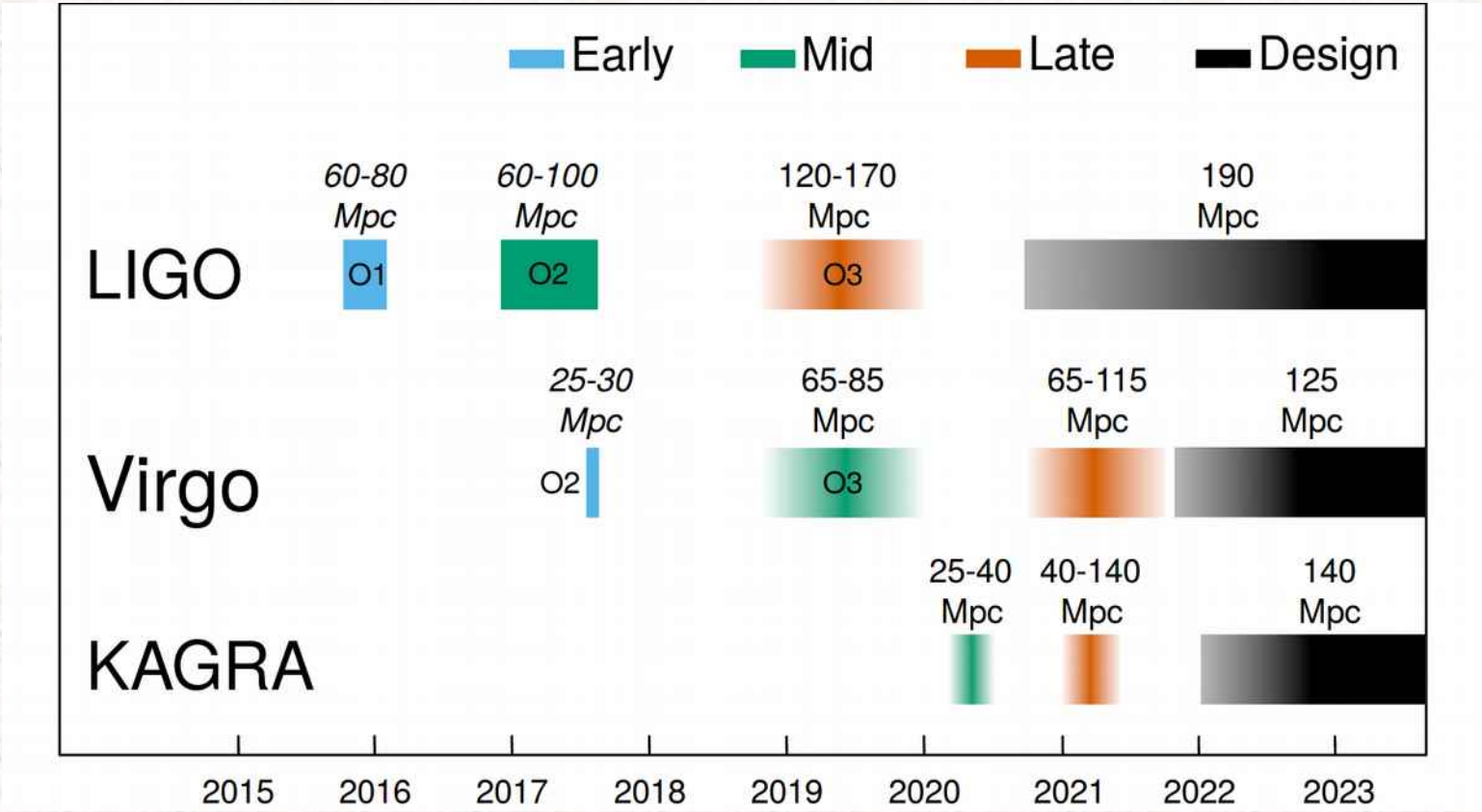
Long Slit Spectroscopy

3700 – 10000 AA (R1000B R1000R grisms)

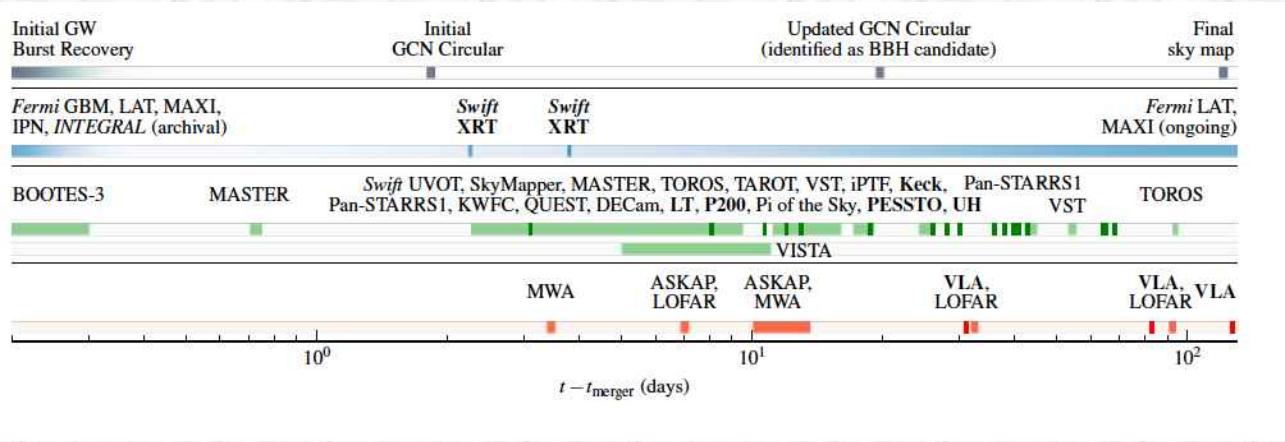
Duration: more than 50 hr of observing time granted

Observation for Ligo/Virgo

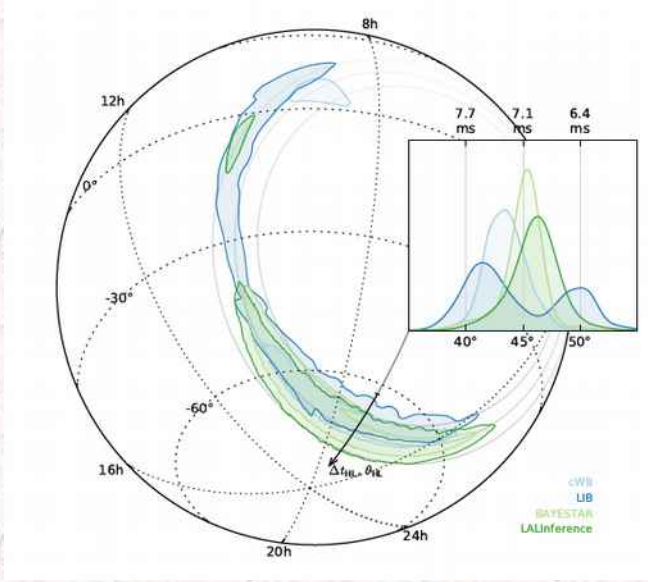
O1: Four-month run (12 Sep 2015-19 Jan 2016)
O2: Nine-month run (30 Nov 2016-25 Aug 2017)
O3: One year run (1 Apri 2019 – 27 Mar 2020)

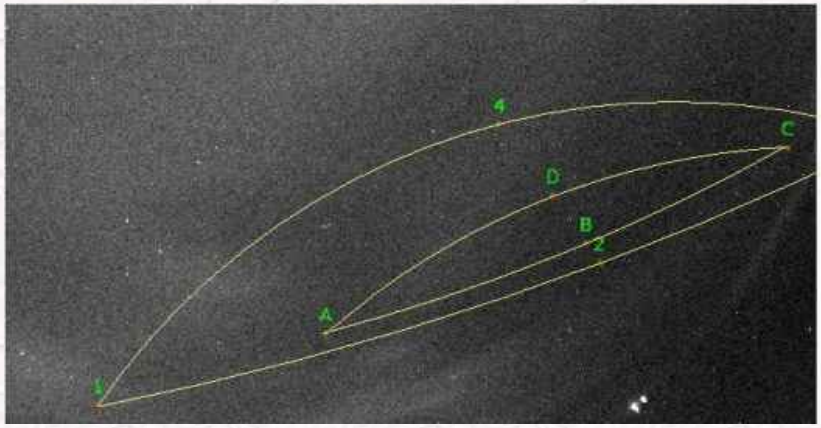


The BOOTES Network: GW150914



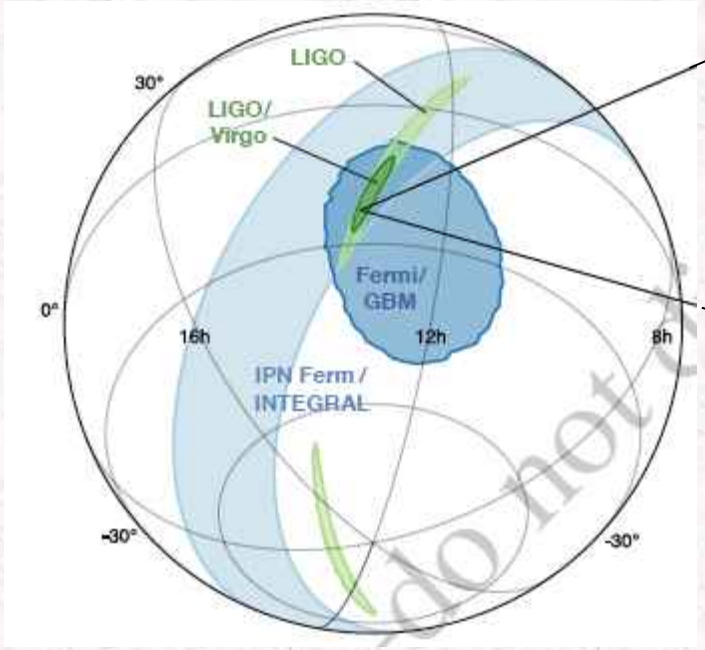
Localization and follow-up efforts (Abbott et al. 2016)

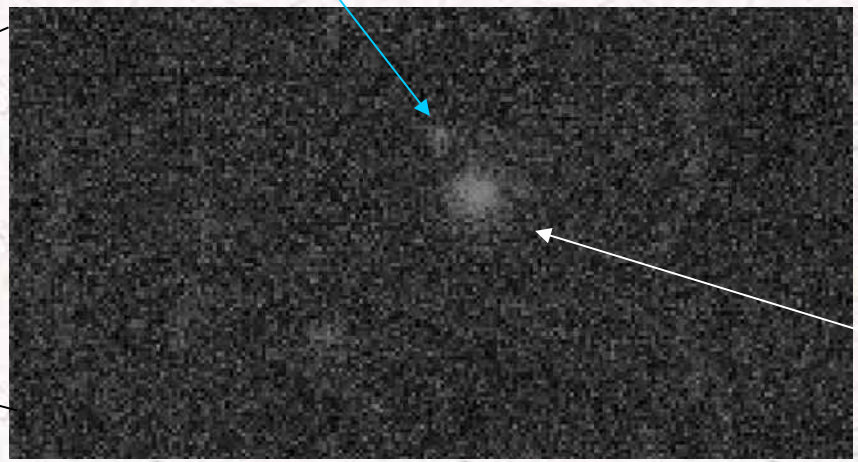




The only simultaneous optical image to GW 150914, taken from New Zealand with the BOOTES-3 allsky camera (CASANDRA-3) . From Castro-Tirado et al. (2008)

The BOOTES Network: GW170817





Localization and follow-up to GW 170817 (Abbott et al. 2017, ApJ 848, L12)

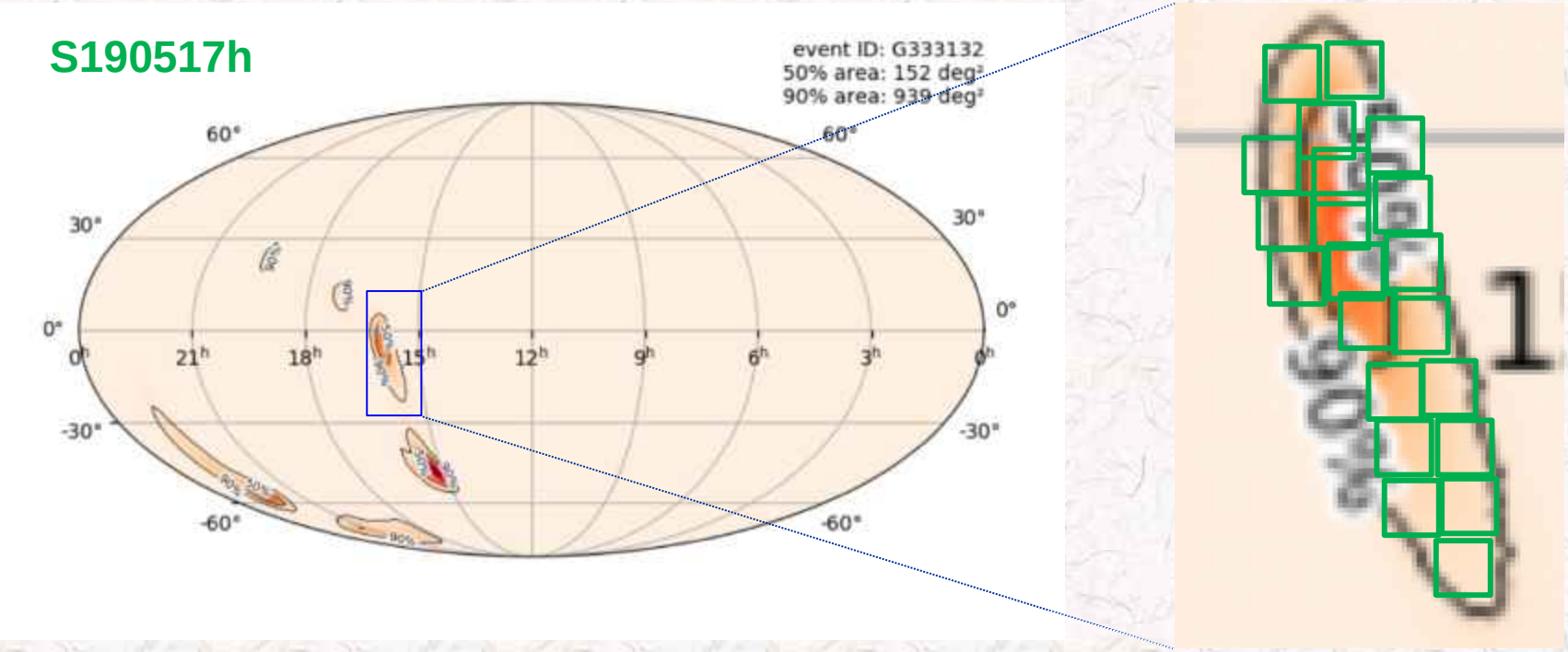
The only optical image obtained by a Spanish facility: the Javier Gorosabel 0,6-m robotic telescope at the BOOTES-5 in Observatorio Astronómico de San Pedro Mártir (MX), 1,6 days after the arrival of the GW wavefront (Castro-Tirado et al. 2017, GCNC, Binbin Zhang et al. 2018, Nat Commun 9, 447)

Observational strategy For GWs in O3

BH-BH mergers

rate ~1/week - average distance ~ 1 Gpc - apparent error boxes $\varnothing_{90\%}$ ~10^3 deg^2

S190517h



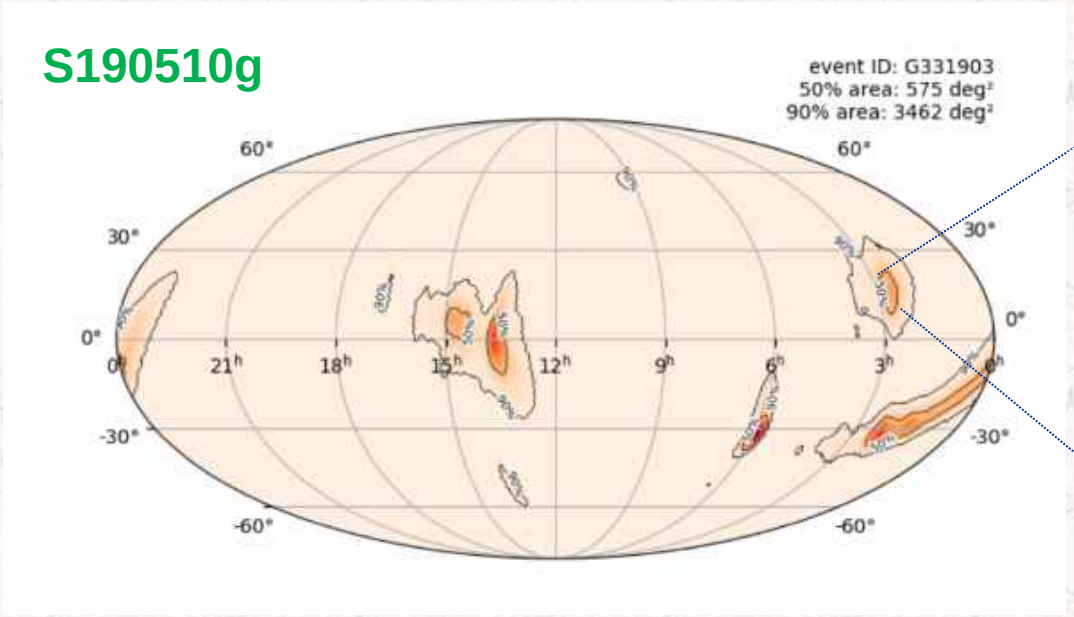
Tiling of fields using devices providing few deg^2 FOV are needed to cover as much as possible the error box. This should be AUTONOMOUSLY scheduled.

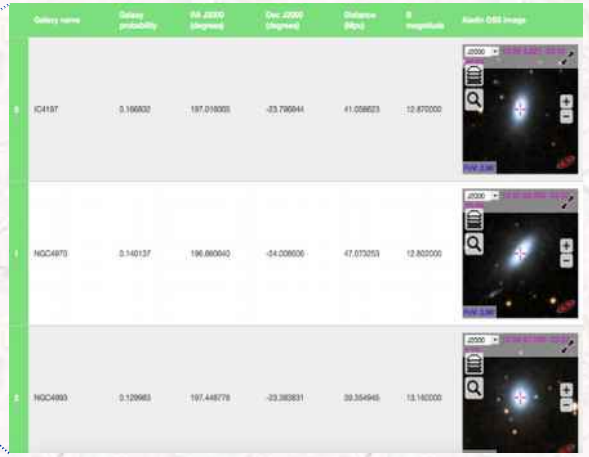
Observational strategy For GWs in O3

NS-NS mergers

rate~1/month - average distance ~ 150 Mpc - apparent error boxes $Ø_{90\%}$ ~10^3 deg^2

S190510g

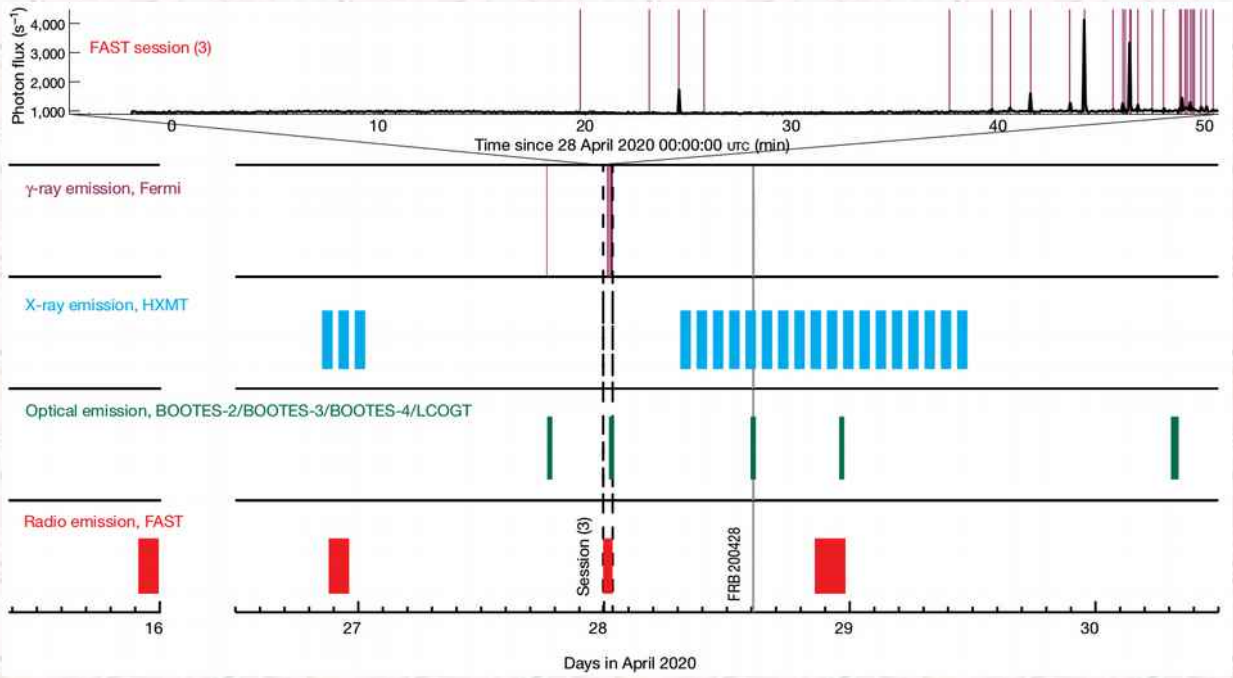




Different strategy: select the galaxies from the GLADES catalogue at the given distance range: ~10^3 - 10^4 and image them with small-medium size robotic telescopes looking for "new" objects on the outskirts of the galaxies.

Observational strategy For GWs in O3

Following compact objects related events



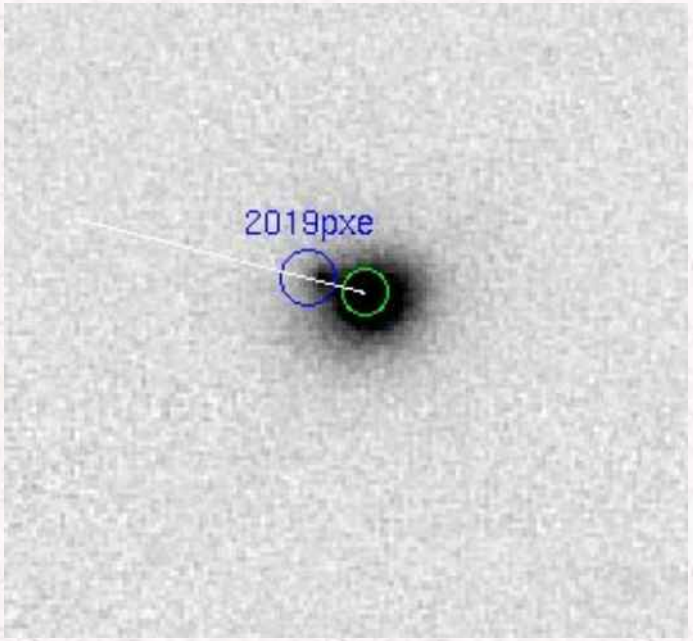
A. de Ugarte Postigo et al. 2005 A&A 443, 841-849

FRB200428 from SGR 1935+2154
L. Lin et al. 2020 Nature 587, 63-65

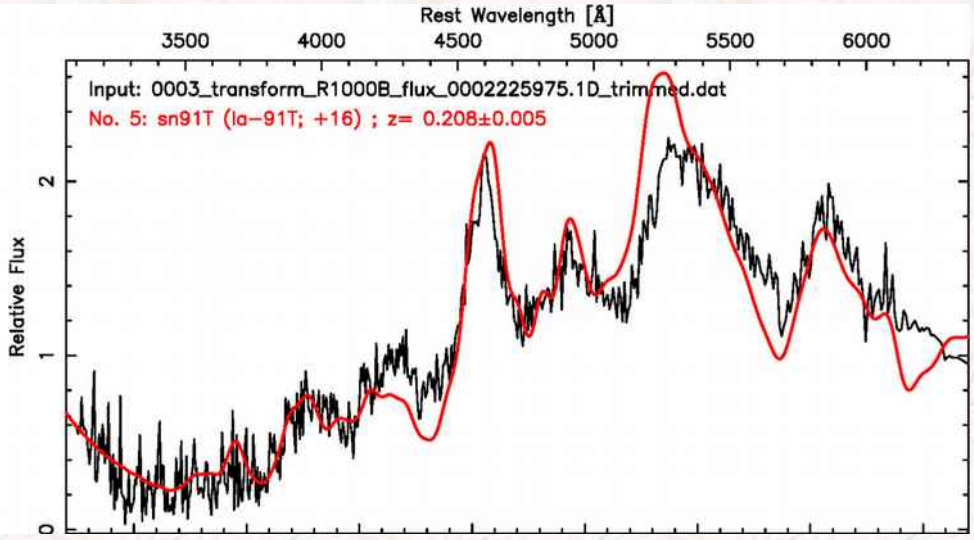
Observational strategy For GWs in O3

10.4m GTC spectrosopic observations:

Slit position to cover the center of the host galaxy



Redshift both from the narrow galactic emission lines and SNID template classification



Observations in O3

Georgescu, I. Nat Rev Phys 2020

Since Mar 2019 there were 72 triggers in O3 which include
4 Mass gap
16 retractions
16 NS-related merger
35 BBH
1 Burst

BHNS, BNS

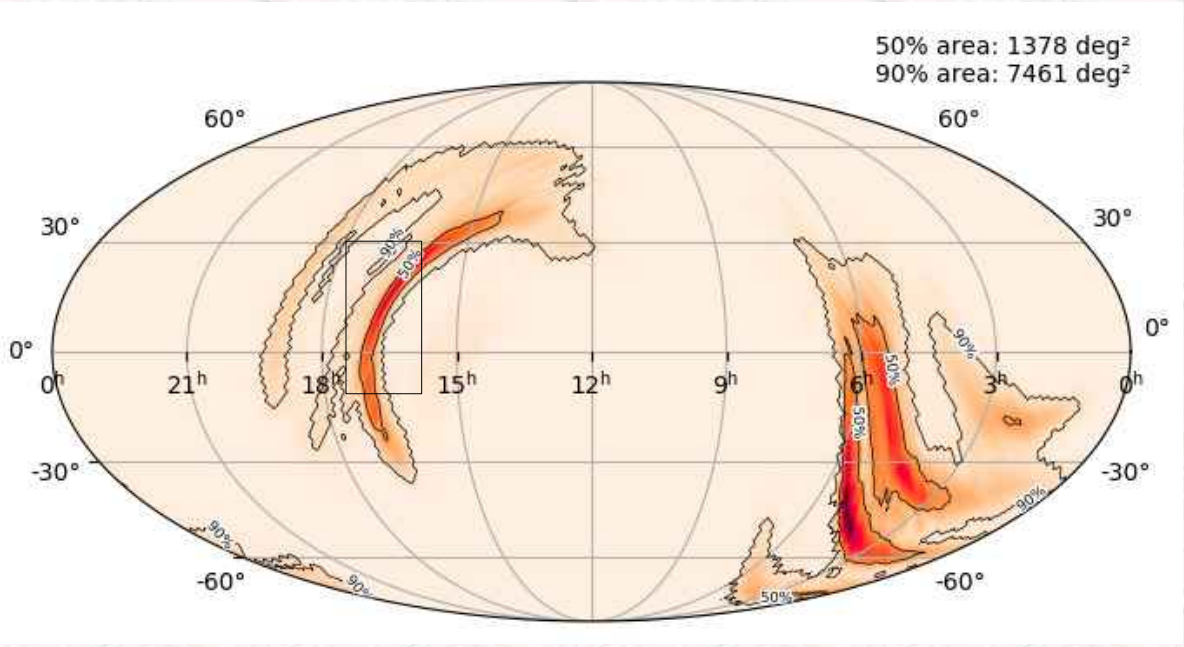
BOOTES followed-up 55 events.
3 Mass gap
7 retractions
13 NS-related merger
31 BBH
1 Burst

The 10.4m GTC followed 116 candidates from 16 events

Observations in O3

For example: S190425z

The first reported BNS event in O3
Distance range (approx): 156 +/- 41 Mpc (z = 0.025-0.047)
ProbContainsNeutronStar: >99%
False alarm rate: 4.5e-13 Hz = 1/(7e4 yr)



A series of images were obtained by Bootes-4 and Bootes-5 Station, which cover 63 galaxies in that distance range. While no source is detected down to 20 mag.

Observations in O3

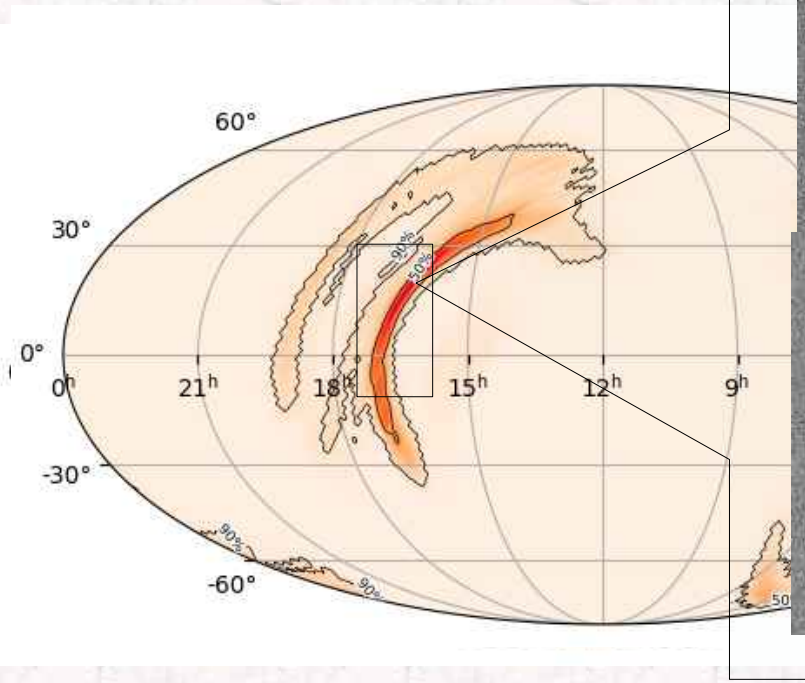
For example: S190425z

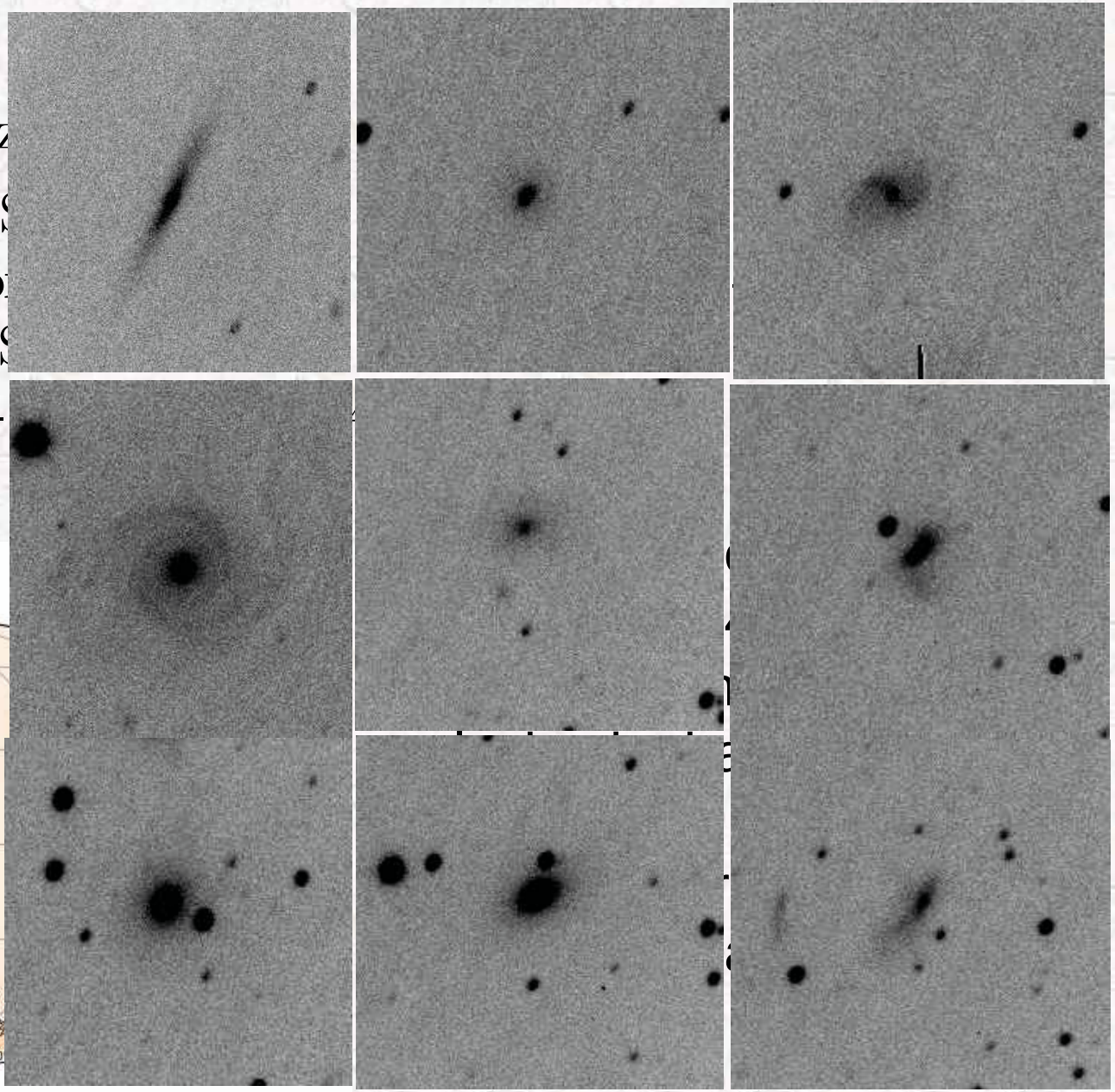
The first reported BNS

Distance range (appro

ProbContainsNeutronS

False alarm rate: 4.5e-





Observations in O3

For example: S190814bv

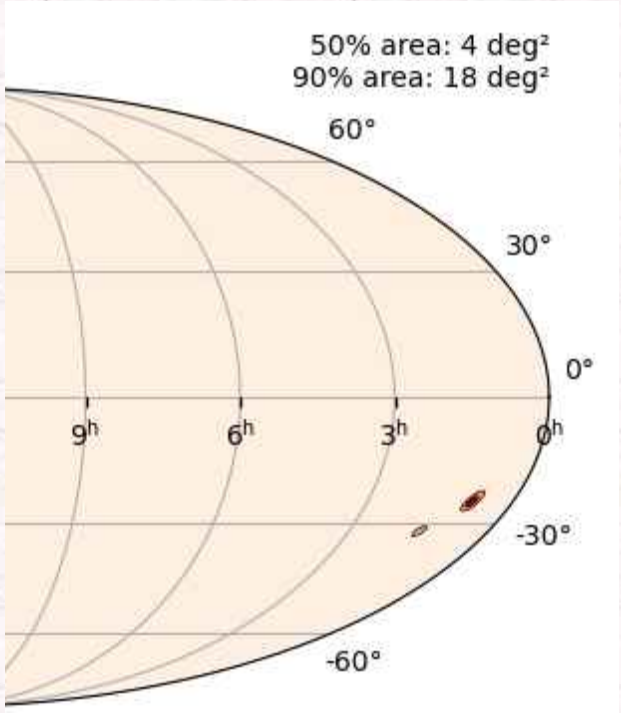
The smallest error region BBH event in O3

Distance range (approx): 236 ± 53 Mpc

False alarm rate: 2.033e-33 Hz $= 1/(1.6\text{e}25\ \text{yr})$

23 Solar Mass Black Holewith a 2.6 Solar Mass Compact Object

R. Abbott, et al. 2020 ApJL. 896, L44



Num	Name	class	redshift	gcn
1	2019nqq	SN IIP	0.071	25419
2	2019nxe	SNIa	0.0777	25543
3	2019obc	SNIa	0.216	25543
4	2019nqc	SNIIP	0.078	25571
5	2019nqz	invisible	0.1076	25571
6	2019odc	invisible	0.0540	25588
7	2019omt	SNIIL	0.1564	25588

Contribution to publications

Anand, S. et al. 2021, Nat Astron, 5, 46–53
Andreoni, I., Goldstein, D. A., et al. 2020, ApJ, 890, 131
K. Ackley et al. 2020, A&A, 643, A113
Mansi M Kasliwal et al. 2020, ApJ, 905, 145
Y. Hu et al. 2021, Rev. Mex. A&A Conf. Ser. vol. 53, in press
A. F. Valeev et al. 2021, Rev. Mex. A&A Conf. Ser. vol. 53, in press

And many GCN Circulars.

Summary

The BOOTES network contain both wide field and narrow field telescope in the Multi-messenger astronomy era.

The BOOTES Network continues expanding worldwide, with forthcoming stations (BOOTES-6) to be deployed in South Africa.

Improvement for the system should be prepared before the next scientific run O4.

The strategy on the observation of gravitational wave is working well since over 80% events can be followed up automatically.

Regarding the 10.4m GTC, spectroscopy classification shows that most of the candidates are SNe, especially type Ia, but also include other types Ic , IIp , dwarf nova ...

Hope we can find more interesting objects especially the NS+NS, BH+NS events with remnants in O4.

Thanks for all your attention!!