Optical/NIR GW follow up in P101 (and beyond)

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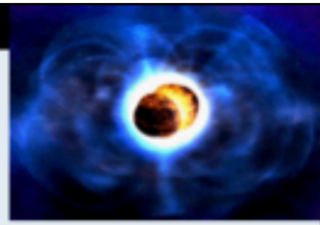
INAF – Osservatorio Astronomico di Brera
On behalf of GRAWITA (GRAvitational Wave Inaf TeAm)

GraWITA The GW era – EM follow-up policies in O1 & O2

VIRGO LSC



In 2012, **LVC agreed policy on releasing GW alerts**

*"Initially, **triggers** (partially-validated event candidates) will be **shared promptly only with astronomy partners who have signed a Memorandum of Understanding** (MoU) with LVC involving an agreement on deliverables, publication policies, confidentiality, and reporting.*

***After four GW events have been published**, further event candidates with high confidence will be **shared immediately with the entire astronomy community**, while lower-significance candidates will continue to be shared promptly only with partners who have signed an MoU."*

courtesy M. Branchesi

INAF MoU with LIGO/Virgo collaboration (LVC) signed in 2014

GraWITA
GRAvitational Waves Inaf TeAm
www.grawita.inaf.it

→

OA Roma (PI: E. Brocato)
OAS Bologna
OA Brera
IASF Milano
OA Padova
OA Napoli
GSSI
SNS Pisa
Urbino University
ASI-SSDC

The GW era – O1 & O2

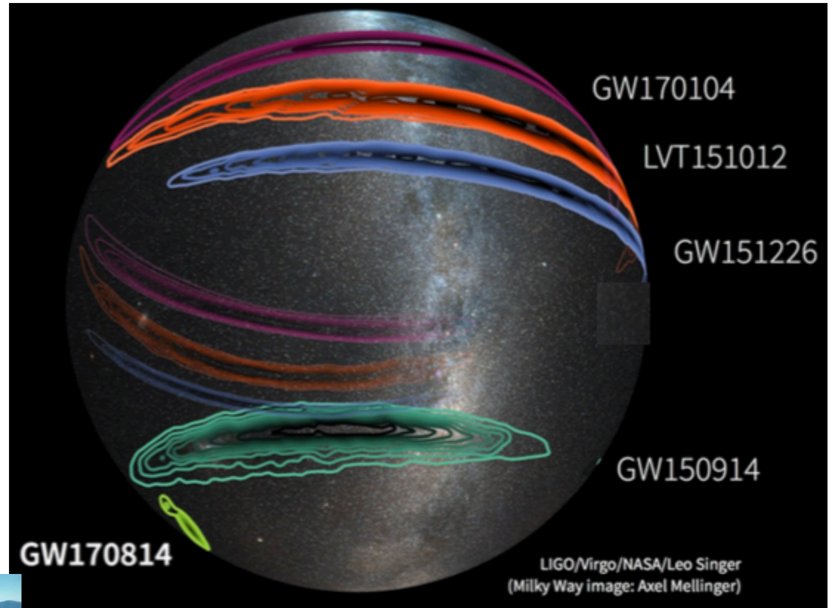
Sept 2015 – Jan 2016: LVC O1 science run

2 high-significance (FAR < 1/century) GW events during O1 (GW 150914, GW 151226) + 1 possible, low-significance event (LVT 151210). All BBH. (Abbott et al. 2016a,b)

Nov 2016 – Aug 2017: LVC O2 science run

Other BBH detected (GW 170104, GW 170608, GW 170814) and one NSNS (GW 170817)
Improved strategies for EM follow-up at all wavelengths.

Sky localizations (90% credible area)
600 deg^2 GW 150914
1600 deg^2 LVT 151012
1000 deg^2 GW 151226
1200 deg^2 GW 170104
520 deg^2 GW 170608
62 deg^2 GW 170814
28 deg^2 GW 170817



No EM counterpart found for BBH (despite huge observational effort)

!!! EM counterpart found for NSNS !!!

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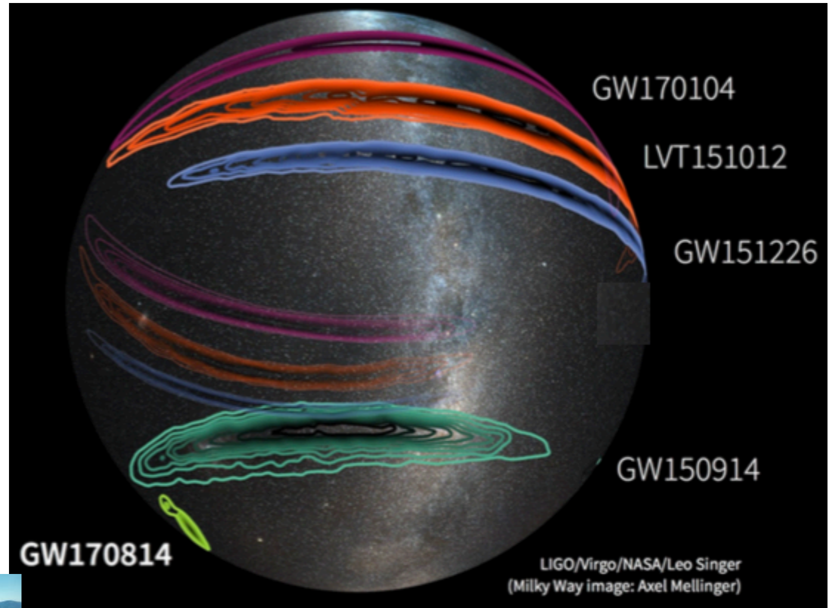

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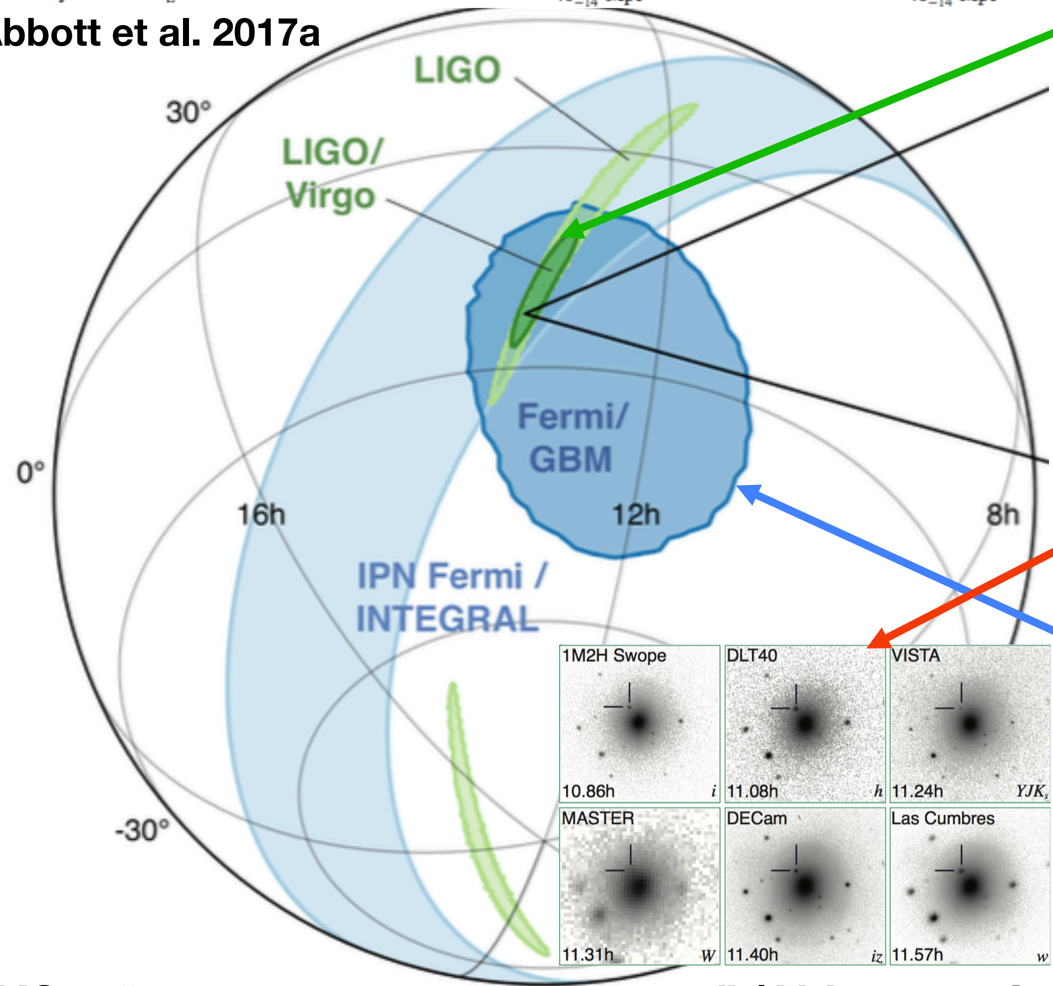
GW 170817 / GRB 170817A

First NS-NS GW event. 90% skymap of ~28 deg^2 (LIGO+VIRGO)

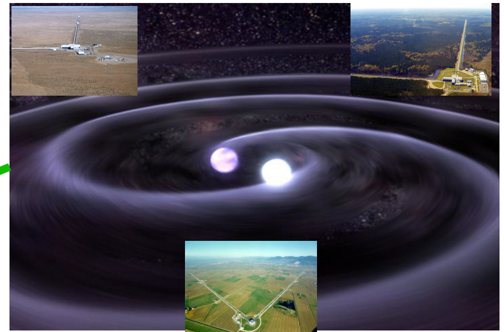
	Low-spin priors ($\|\chi\| \le 0.05$)	High-spin priors ($\|\chi\| \le 0.89$)
Primary mass m_1	1.36–1.60 $M_\odot$	1.36–2.26 $M_\odot$
Secondary mass m_2	1.17–1.36 $M_\odot$	0.86–1.36 $M_\odot$
Chirp mass $\mathcal{M}$	$1.188^{+0.004}_{-0.002} M_\odot$	$1.188^{+0.004}_{-0.002} M_\odot$
Mass ratio m_2/m_1	0.7–1.0	0.4–1.0
Total mass m_{tot}	$2.74^{+0.04}_{-0.01} M_\odot$	$2.82^{+0.47}_{-0.09} M_\odot$
Radiated energy E_{rad}	$> 0.025 M_\odot c^2$	$> 0.025 M_\odot c^2$
Luminosity distance D_L	40^{+8}_{-14} Mpc	40^{+8}_{-14} Mpc

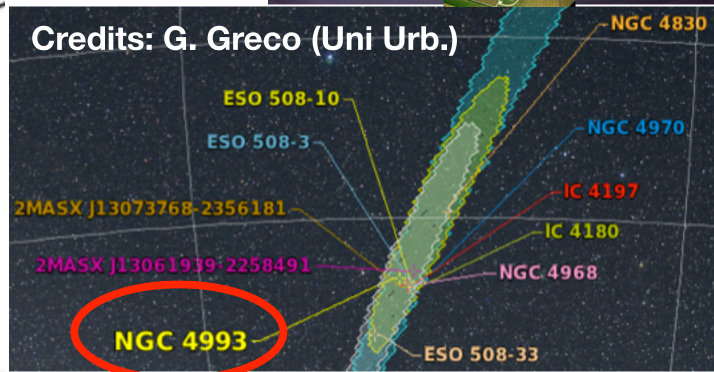
Abbott et al. 2017a



LVC + “partner astronomy groups” (Abbott et al. 2017b)

12:41:04 UTC

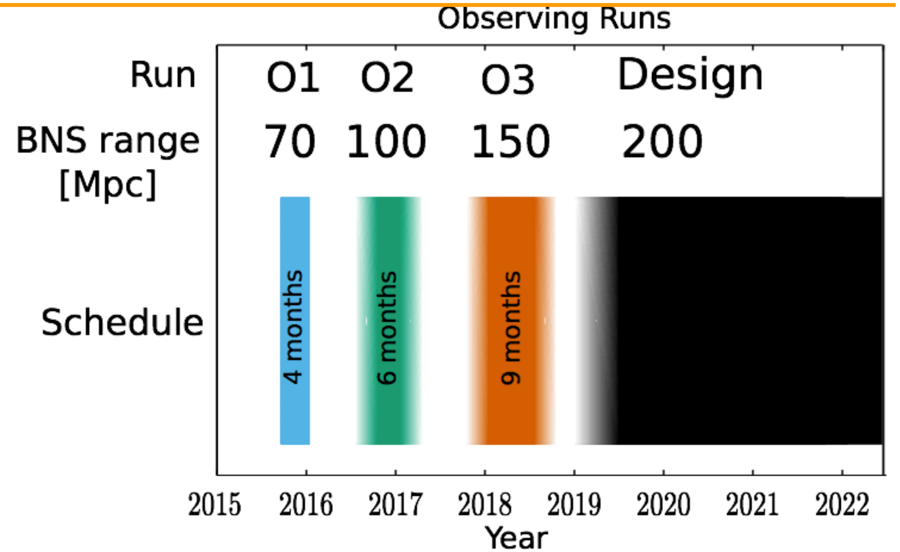




LIGO/Virgo O3 & the ESO-VLT role

The LIGO/Virgo O3 run is expected to start on Oct/Nov 2018. An Engineering Run (ER) with possibility of GW triggers (as it happened with GW 150914 before the official start of O1) is expected for the end of the summer.

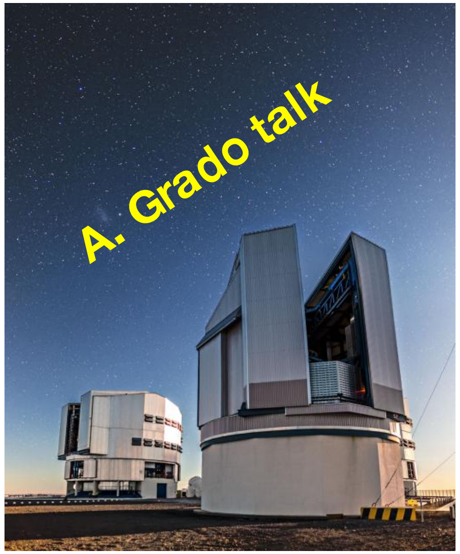
This translates into the possibility of a partial overlap with ESO P101. We expect up to 1-2 high significance GW trigger during the overlap between O3 and P101.



In P101 we will have 20h VLT ToO time (Xshooter, FORS2, HAWKI; ID: 0101.D-0823, PI: P. D'Avanzo). We aim at carrying out VLT imaging and spectroscopic follow-up of any **promising** candidate counterpart. Finding the optical counterpart of GW 170817 was relatively easy (proximity of the event and 'precise' skymap). We can't be sure this will be always the case. A scenario with promising triggers (NS) with large skymaps, large distances -> many candidates, cannot be excluded. To this end, it is important to point to an **optimized use** of different facilities.

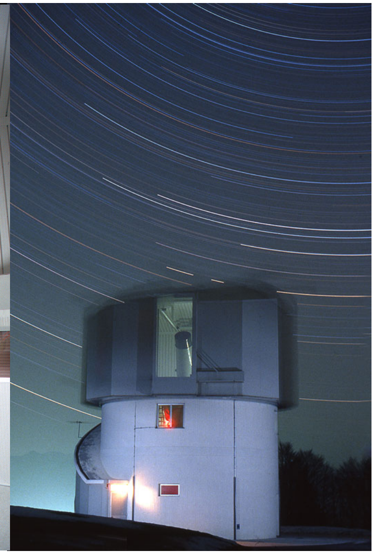
Search for counterparts: wide field

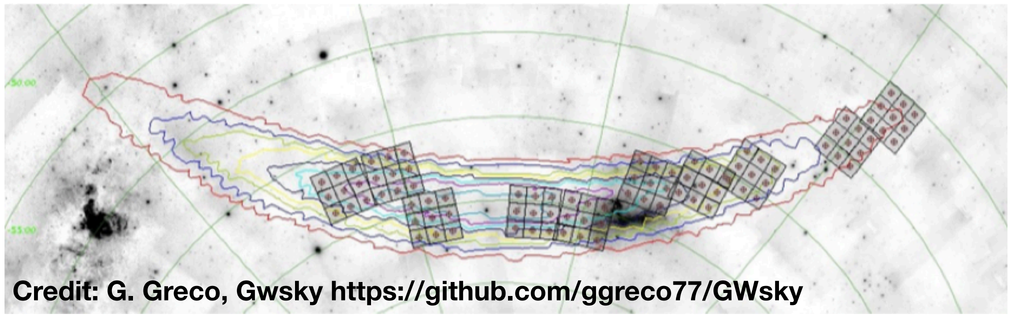
ESO–VST 2.6m
FoV = 1 deg^2 (PI Cappellaro/Grado)



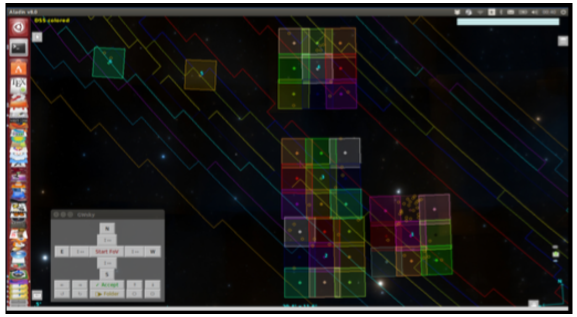
Campo Imperatore Schmidt Telescope
0.61/0.91m FoV=1.3 deg^2 (PI: Brocato)

Asiago Schmidt Telescope
0.67/0.92m FoV=1 deg^2 (PI: Tomasella)





Credit: G. Greco, Gwsky https://github.com/ggreco77/GWsky



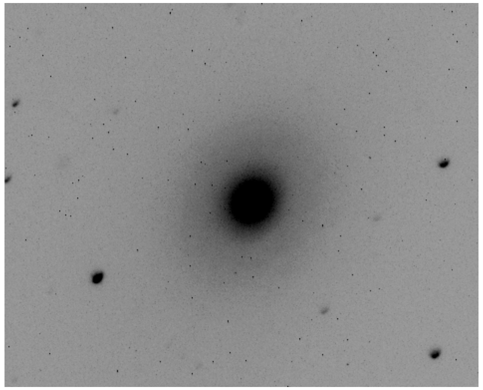
FAST: hours after LVC alert
WIDE: 50 - 90 deg^2 large contained probability
DEEP: r_lim ~ 21 (CI & Asiago) - 22.5 (VST) mag

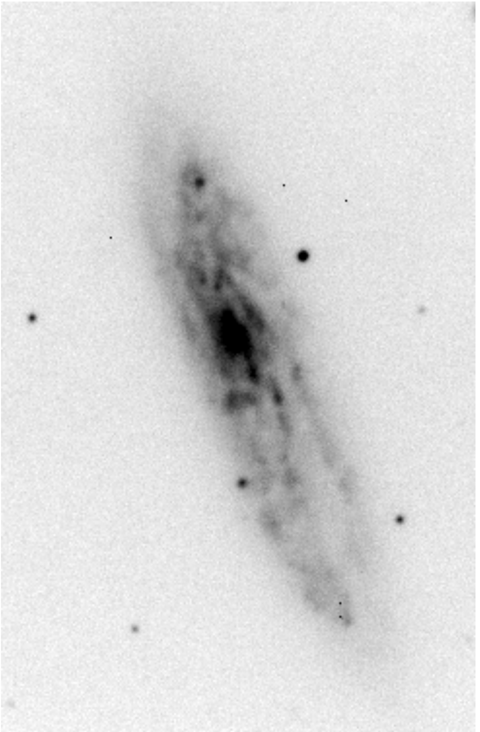
VST & CI successfully operated in O1 & O2, Asiago ready for O3

Brocato et al. 2017

Search for counterparts: target/galaxy

REM 0.6 m telescope
optical/NIR simultaneous imaging
(PI: Campana)





Copernico 1.8 m telescope (Asiago, IT)
optical imaging & spectroscopy
(PI: Tomasella)

Both successfully operated in O1 & O2

Piranomonte et al. in prep.

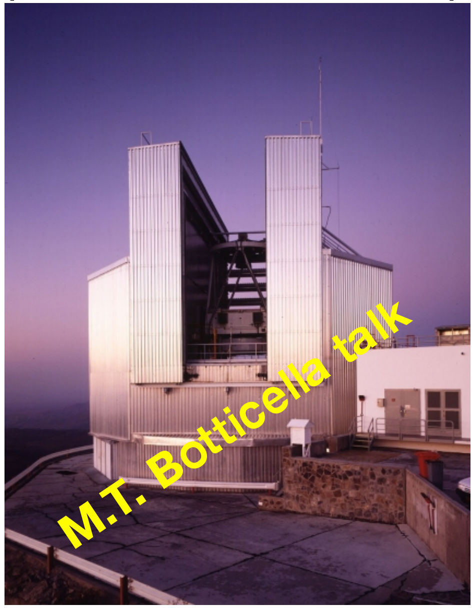
Candidate classification / follow-up

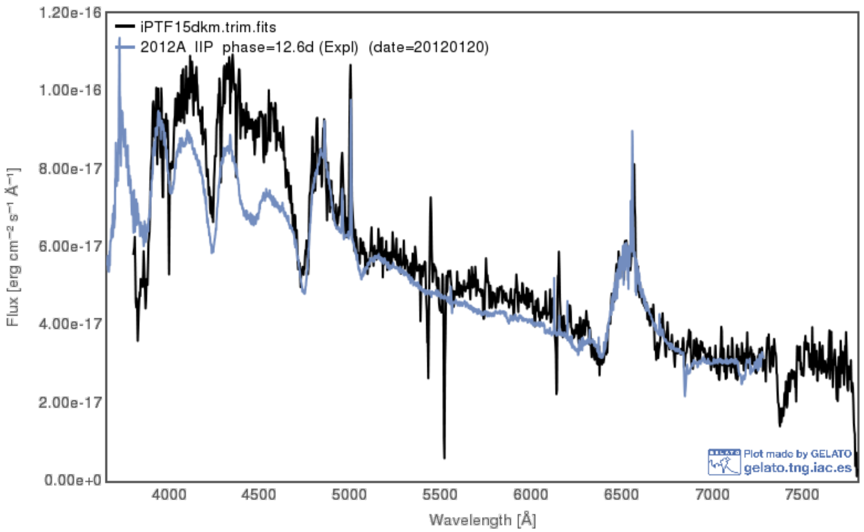
Copernico 1.8 m telescope (Asiago)
optical imaging & spectroscopy
(PI: Tomasella)

TNG 3.6 m
optical/NIR imaging & spectroscopy
(PI: Piranomonte)

LBT (2x)8.2 m
optical/NIR imaging & spectroscopy
(PI: Palazzi)

ESO-NTT 3.6 m
optical/NIR imaging & spectroscopy
(PI: Botticella within **ePESSTO**)





All successfully operated in O1 & O2

Piranomonte et al. in prep.

Multi-wavelength search & follow-up

Swift
- BAT: 15-150 keV, 2 sr FoV
- XRT: 0.2-10 keV, 0.15 deg^2 FoV
- UVOT: UV/opt imaging; 0.08 deg^2 FoV
- ToO program (GRAWITA co-Is)
- Tiling
- Targeted search
- Follow-up

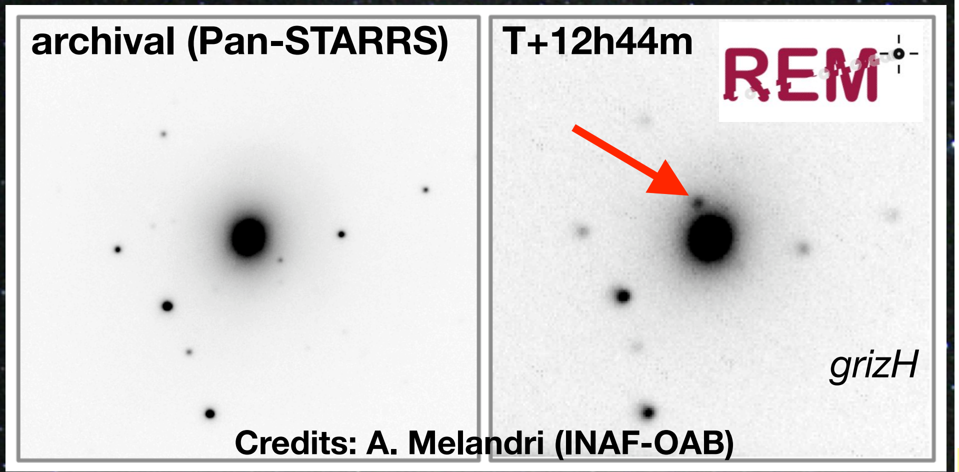
Sardinia Radio Telescope (SRT)
- 64 m antenna
- 300 MHz – 100 GHz
- ToO program (PI: Possenti)
- Targeted search
- Follow-up

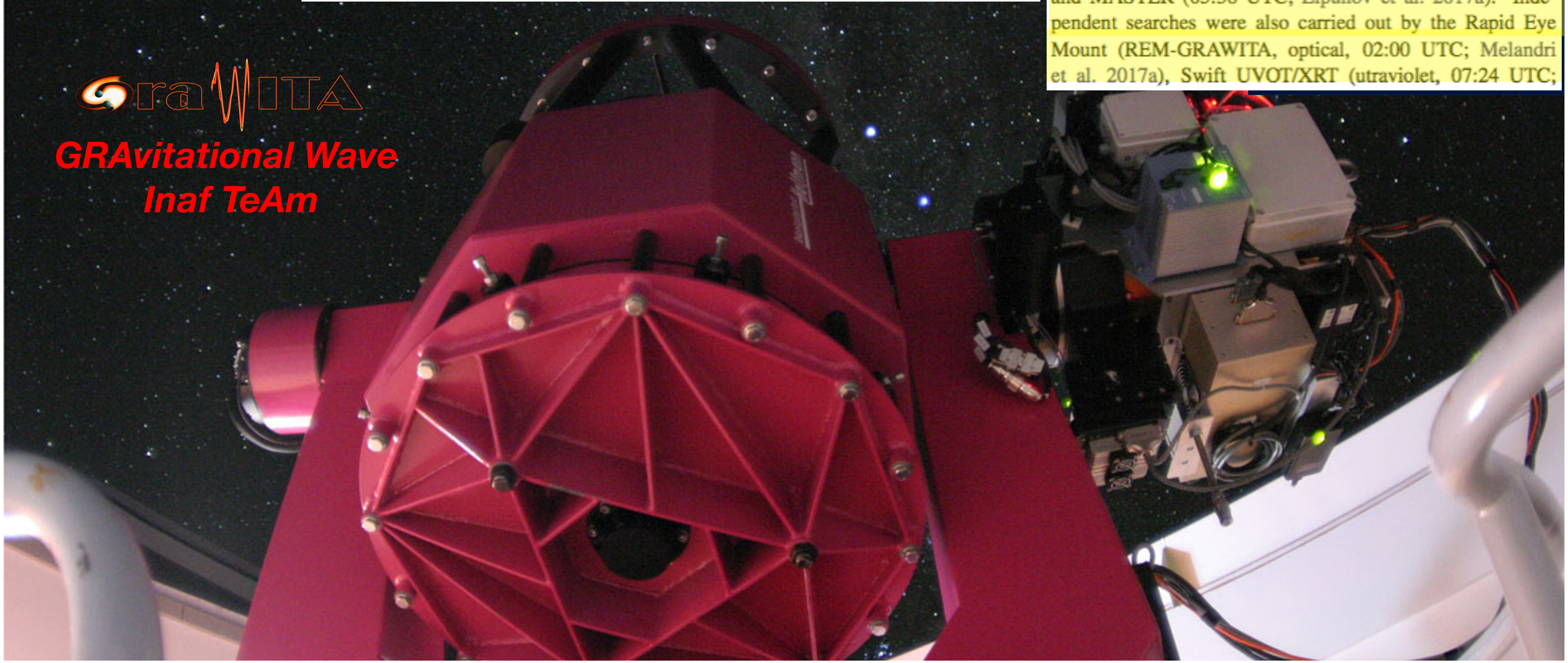
also Medicina & Noto radio telescopes (2x32m)

Both successfully operated in O1 & O2

Evans et al. 2016, 2017
Aresu et al. GCN 21914

GW 170817: optical counterpart in NGC 4993

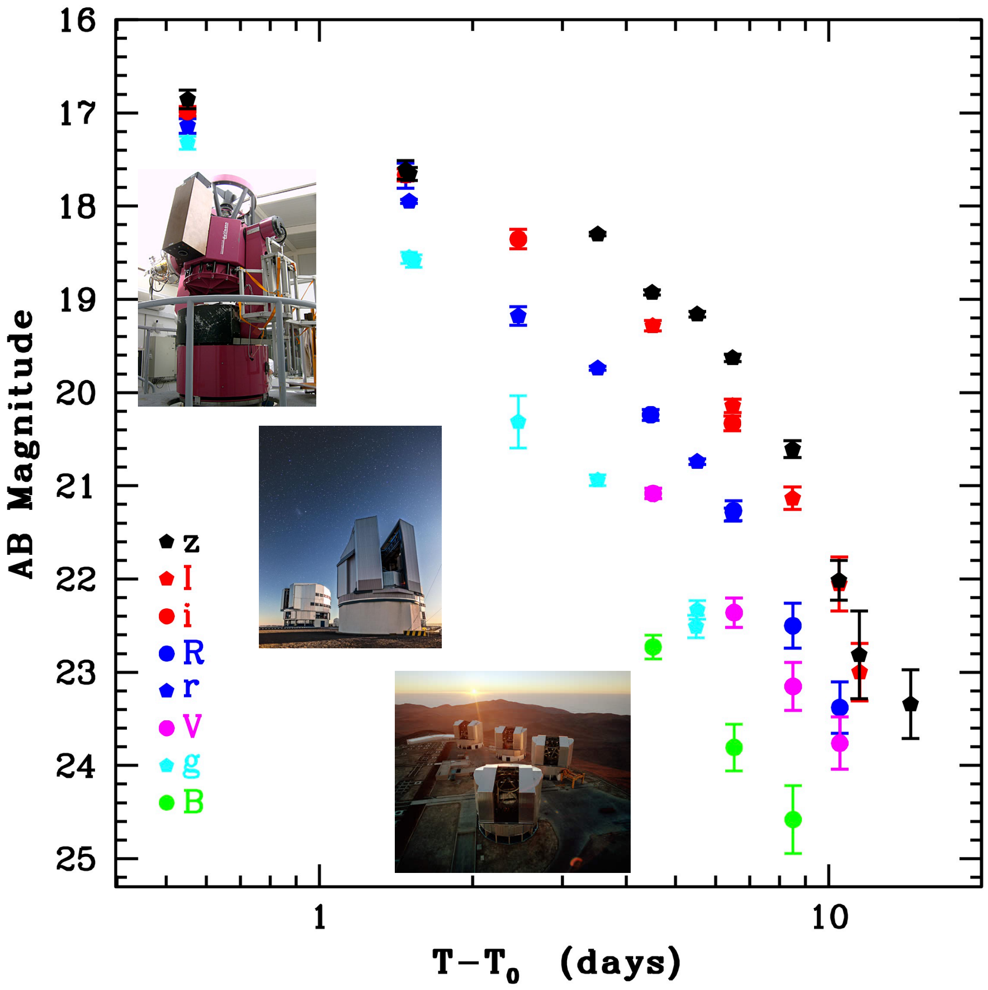


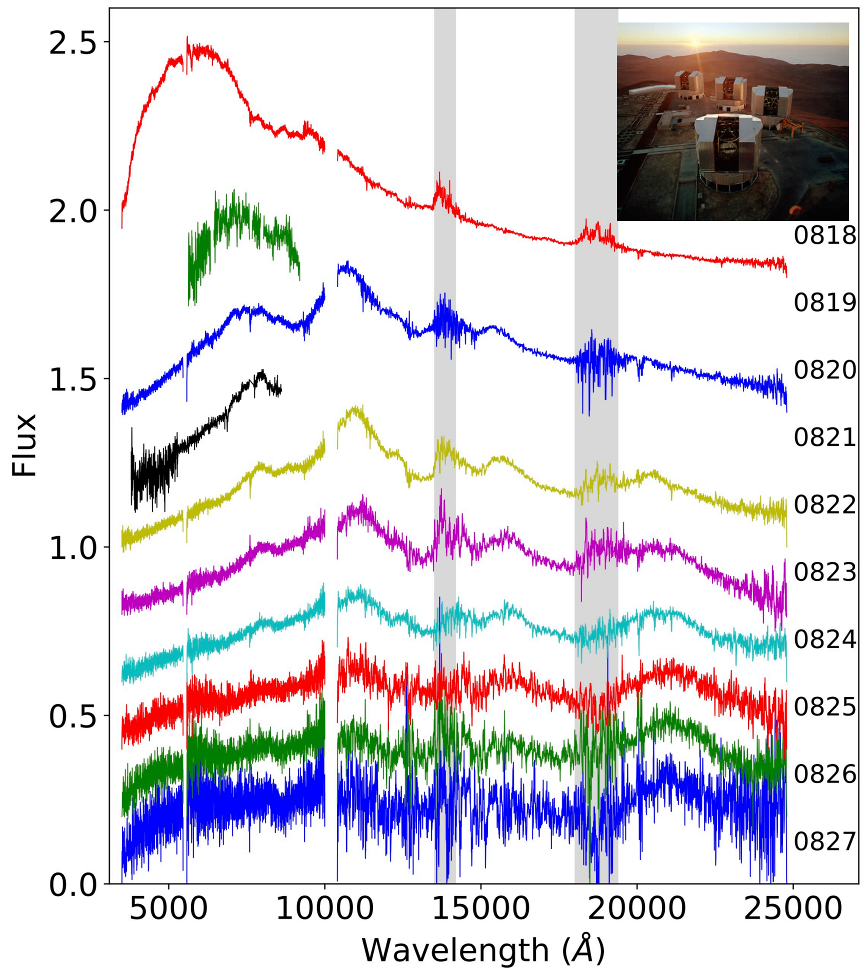


LVC + "partner astronomy groups" (2017)

Five other teams took images of the transient within an hour of the 1M2H image (and before the SSS17a announcement) using different observational strategies to search the LIGO-Virgo sky localization region. They reported their discovery of the same optical transient in a sequence of GCNs: the Dark Energy Camera (01:15 UTC; Allam et al. 2017), the Distance Less Than 40 Mpc survey (01:41 UTC; Yang et al. 2017a), Las Cumbres Observatory (04:07 UTC; Arcavi et al. 2017a), the Visible and Infrared Survey Telescope for Astronomy (05:04 UTC; Tanvir et al. 2017a), and MASTER (05:38 UTC; Lipunov et al. 2017a). Independent searches were also carried out by the Rapid Eye Mount (REM-GRAWITA, optical, 02:00 UTC; Melandri et al. 2017a), Swift UVOT/XRT (utraviolet, 07:24 UTC;

GW 170817: imaging & spectroscopic follow-up

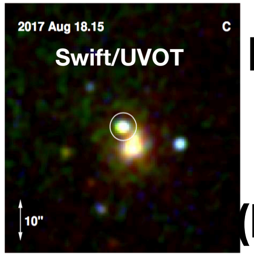




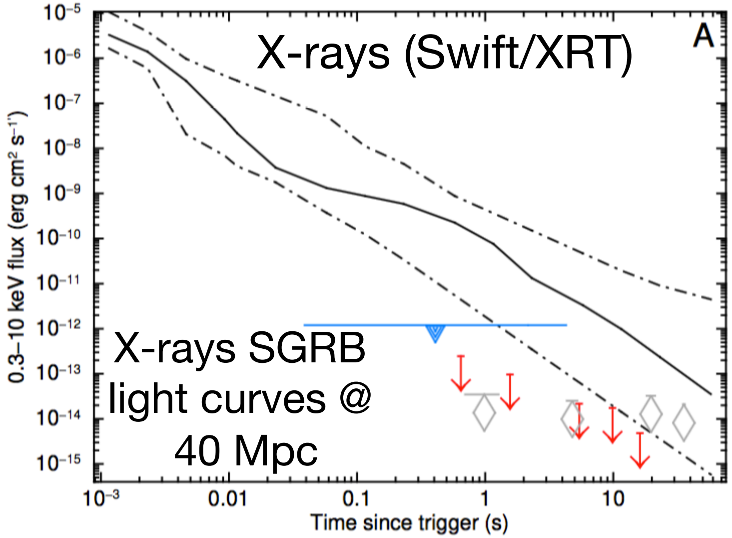
Pian, PDA et al. (2017, Nature)

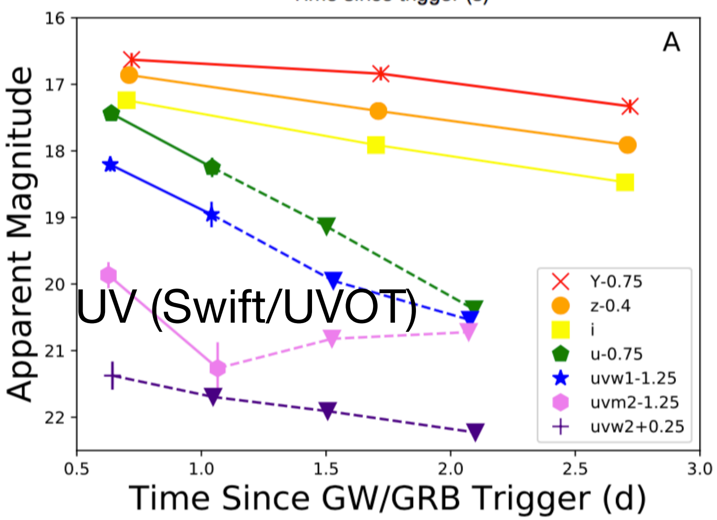
More results from VLT spectroscopic and polarimetric observations of GW 170817: Smartt et al. (2017, Nature); Covino et al. (2017, Nature Astronomy) and Stephen & Stefano's talks

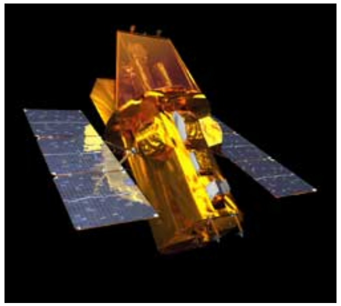
GW 170817: multi-wavelength follow-up



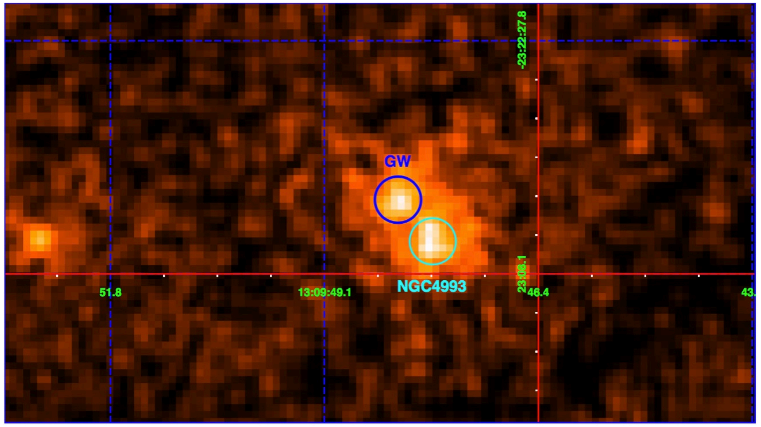
Early-time *Swift* follow-up
UV detection of the KN
X-ray upper-limits
(Evans et al. 2017, Science)

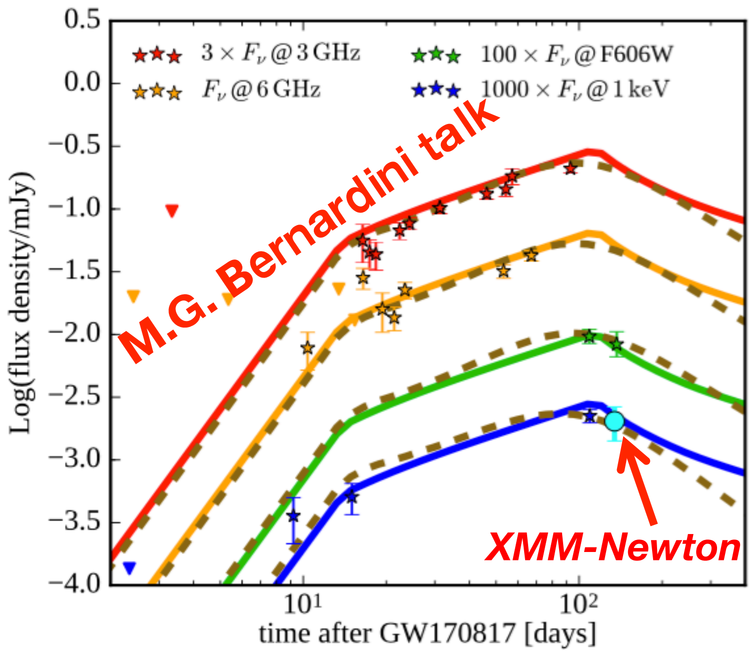






Late-time *XMM-Newton* follow-up
detection of the GRB X-ray afterglow
(D'Avanzo et al. 2018)





Conclusions

The detection of GW 170817/GRB 170817A marked the dawn of multimessenger astronomy. The follow-up campaign carried out with ESO telescopes (VLT in particular) provided an excellent dataset. The ESO ToO organization helped a lot in this respect. The future is very promising. However, we are just at the beginning. Rates for the next LIGO/Virgo run are highly uncertain.

As **GRAWITA** collaboration we have access to a wide range of observing facilities. The use of such facilities, combined with the experience our team gathered during the past LVC runs, will ensure a careful search and selection of the candidate optical/NIR counteparts and an **optimal use of the VLT** to characterize and study them.

As demonstrated by the GW 170817 case, the use of the VLT with its varied instrumentation (X-shooter in particular) will provide an enormous scientific return that will be maximized by coordinated multi-wavelength and multi-facility campaigns.

Basic predictions of the kilonova models are correct, but much has still to be done. While the excellent VLT dataset of GW 170817 is providing a benchmark for any further model development, new events will clearly provide a stress test for these updated models in different conditions.

Coordination/collaboration among different teams will be crucial