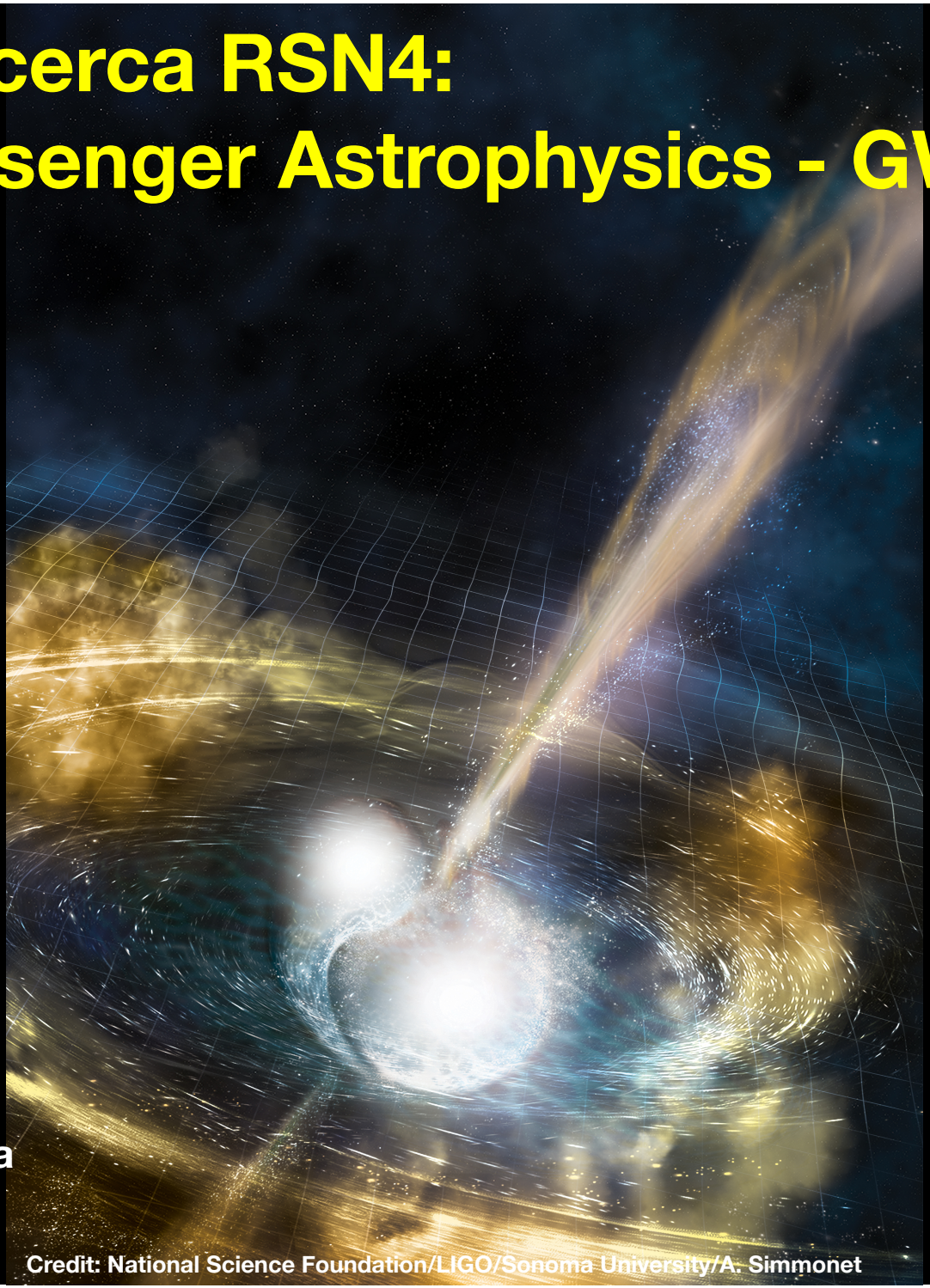
Linee di ricerca RSN4: Multi-Messenger Astrophysics - GW

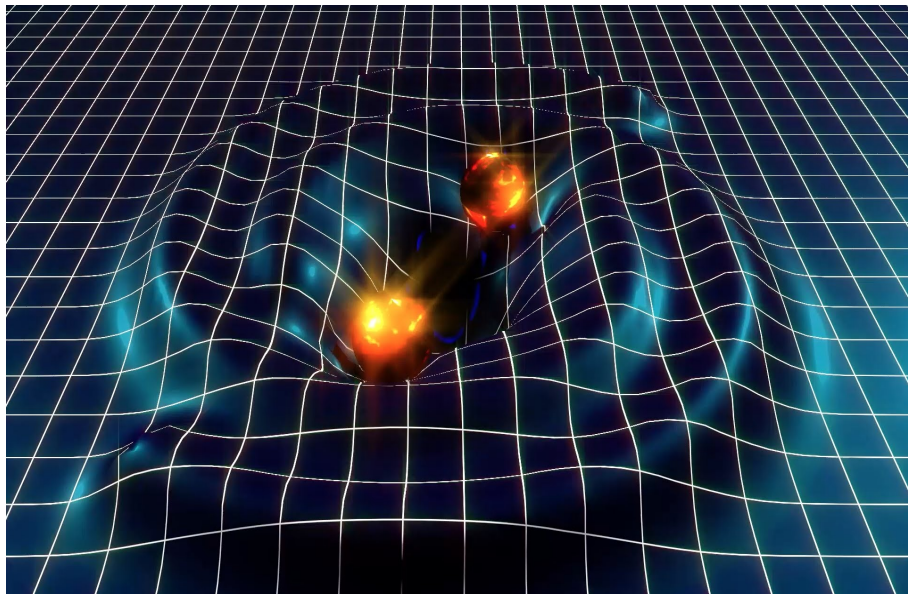


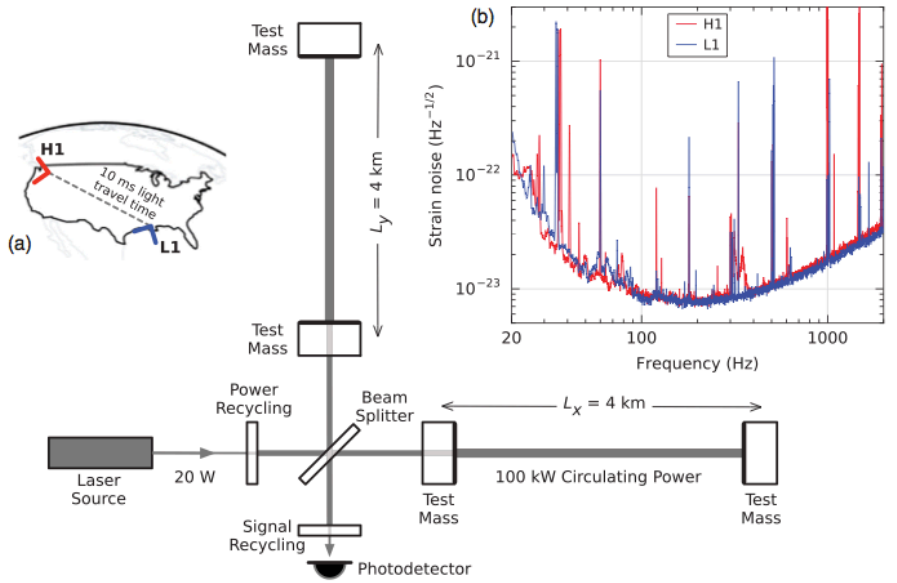
Credit: National Science Foundation/LIGO/Sonoma University/A. Simmonet

Paolo D'Avanzo
INAF – Osservatorio Astronomico di Brera

The GW era


LIGO Hanford
LIGO Livingston
GEO 600
Virgo
KAGRA
LIGO-India




H1
10 ms light travel time
L1
(a)
Test Mass
L_y = 4 km
Test Mass
Power Recycling
Beam Splitter
L_x = 4 km
Laser Source
20 W
100 kW Circulating Power
Test Mass
Test Mass
Signal Recycling
Photodetector
(b)
H1
L1
10^{-21}
10^{-22}
10^{-23}
Strain noise (Hz$^{-1/2}$)
20
100
1000
Frequency (Hz)

The GW era: GW 150914

INAF
ISTITUTO NAZIONALE
DI ASTROFISICA

PRL 116, 061102 (2016)

Selected for a Viewpoint in *Physics*
PHYSICAL REVIEW LETTERS

week ending
12 FEBRUARY 2016

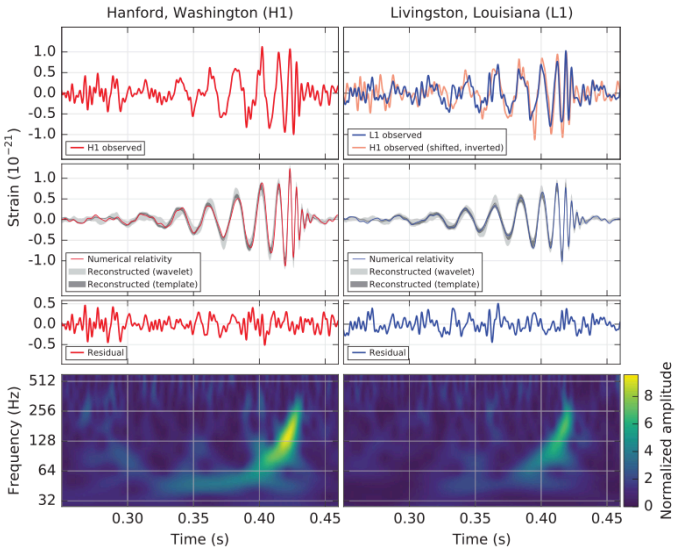
Observation of Gravitational Waves from a Binary Black Hole Merger

B. P. Abbott *et al.*[*]
(LIGO Scientific Collaboration and Virgo Collaboration)
(Received 21 January 2016; published 11 February 2016)

On September 14, 2015 at 09:50:45 UTC the two detectors of the Laser Interferometer Gravitational-Wave Observatory simultaneously observed a transient gravitational-wave signal. The signal sweeps upwards in frequency from 35 to 250 Hz with a peak gravitational-wave strain of 1.0×10^{-21}. It matches the waveform predicted by general relativity for the inspiral and merger of a pair of black holes and the ringdown of the resulting single black hole. The signal was observed with a matched-filter signal-to-noise ratio of 24 and a false alarm rate estimated to be less than 1 event per 203 000 years, equivalent to a significance greater than 5.1σ. The source lies at a luminosity distance of 410^{+160}_{-180} Mpc corresponding to a redshift $z = 0.09^{+0.03}_{-0.04}$. In the source frame, the initial black hole masses are $36^{+5}_{-4}M_\odot$ and $29^{+4}_{-4}M_\odot$, and the final black hole mass is $62^{+4}_{-4}M_\odot$, with $3.0^{+0.5}_{-0.5}M_\odot c^2$ radiated in gravitational waves. All uncertainties define 90% credible intervals. These observations demonstrate the existence of binary stellar-mass black hole systems. This is the first direct detection of gravitational waves and the first observation of a binary black hole merger.

DOI: 10.1103/PhysRevLett.116.061102

Primary black hole mass	$36^{+5}_{-4}M_\odot$
Secondary black hole mass	$29^{+4}_{-4}M_\odot$
Final black hole mass	$62^{+4}_{-4}M_\odot$
Final black hole spin	$0.67^{+0.05}_{-0.07}$
Luminosity distance	410^{+160}_{-180} Mpc
Source redshift z	$0.09^{+0.03}_{-0.04}$



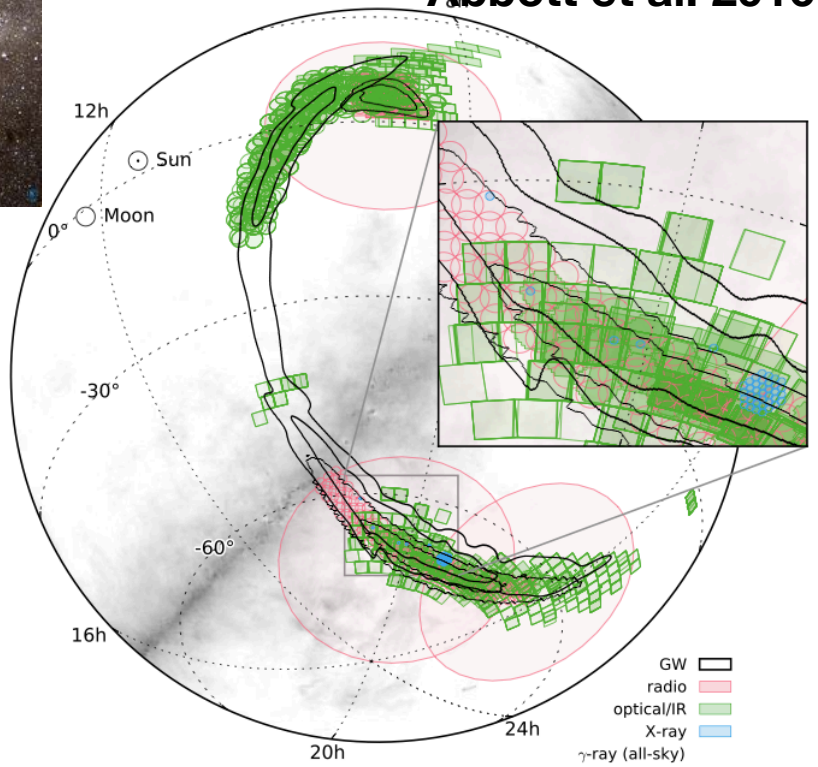
GW 150914 – EM search

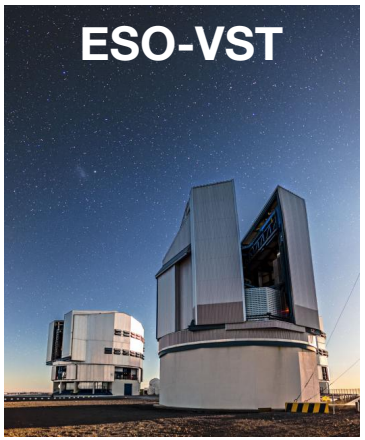
600 deg^2 skymap from LIGO/Virgo
Huge observational effort, mainly with wide-field facilities

No EM counterpart found

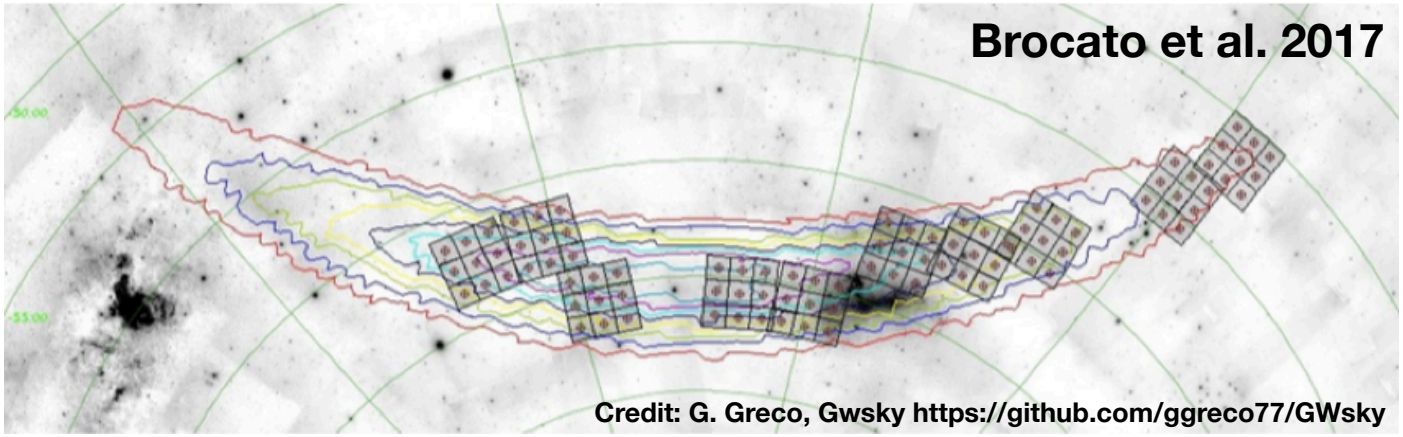
No EM counterpart expected from BHBH merger
Expected EM counterparts for NSNS/NSBH merger:
-Short GRBs (beamed emission)
-Kilonovae (isotropic emission)

Abbott et al. 2016



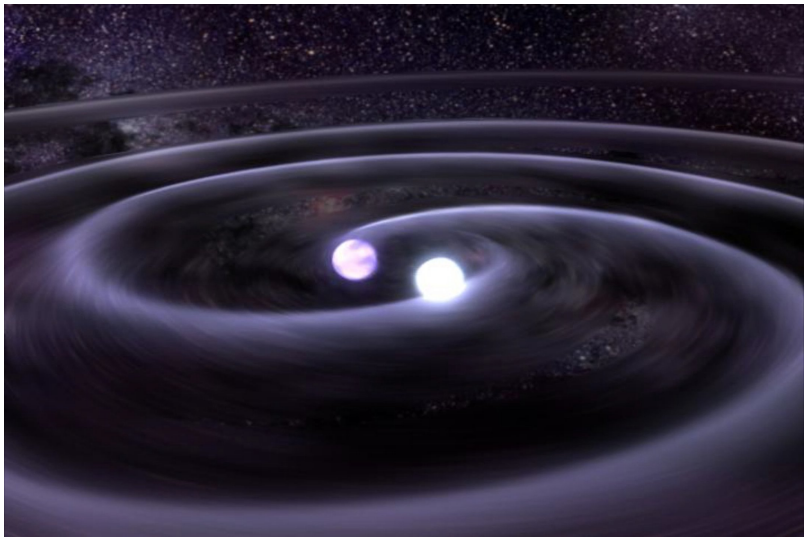


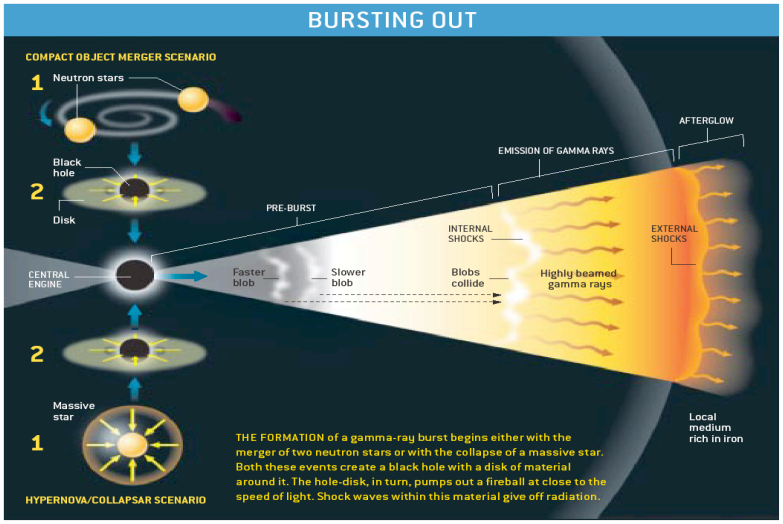
Brocato et al. 2017

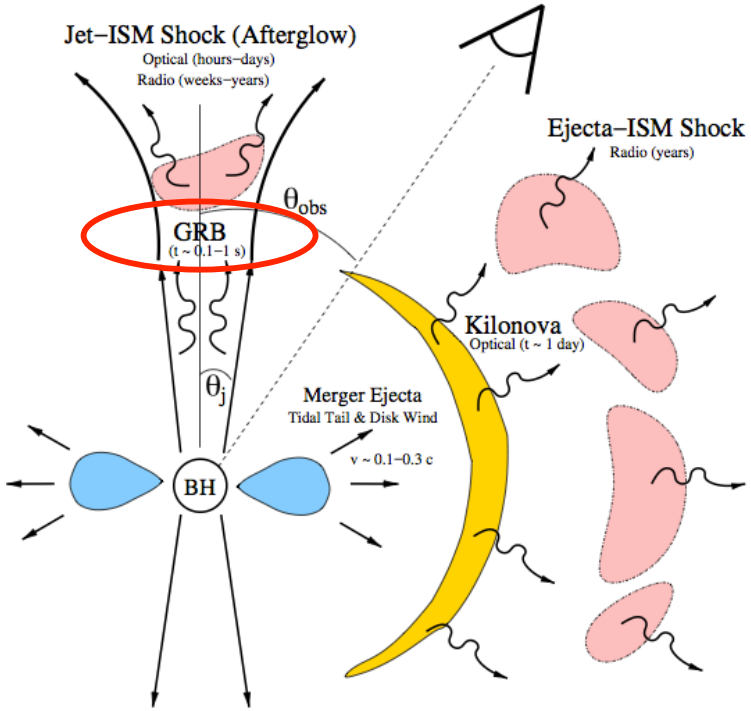


Credit: G. Greco, Gwsky https://github.com/ggreco77/GWsky

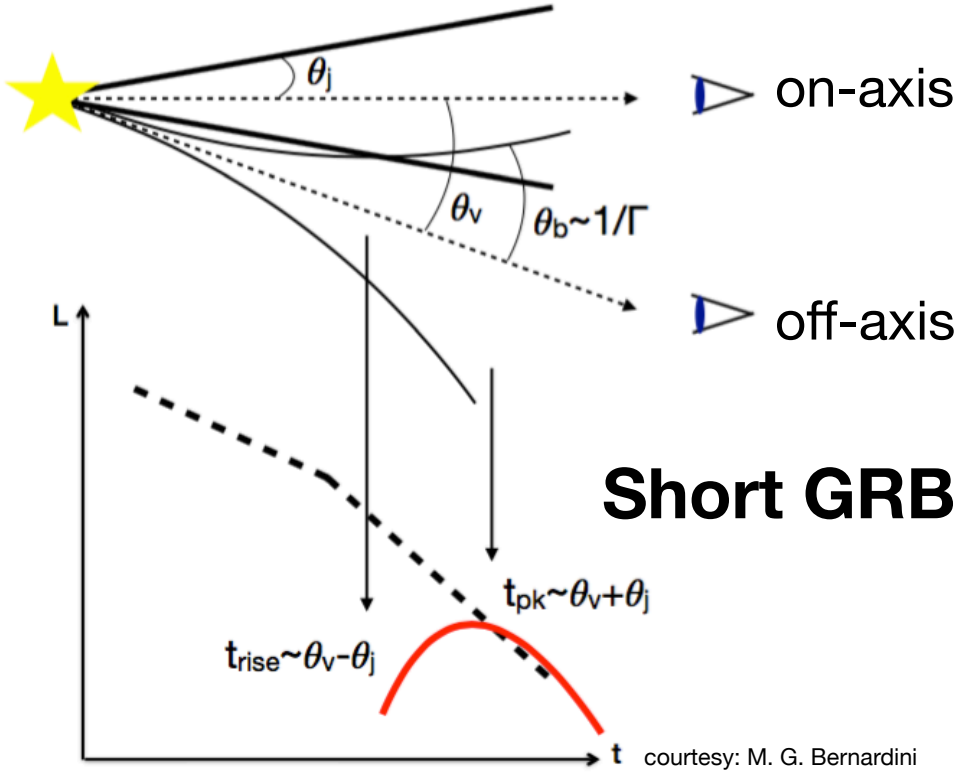
NS-NS / NS-BH electromagnetic counterparts





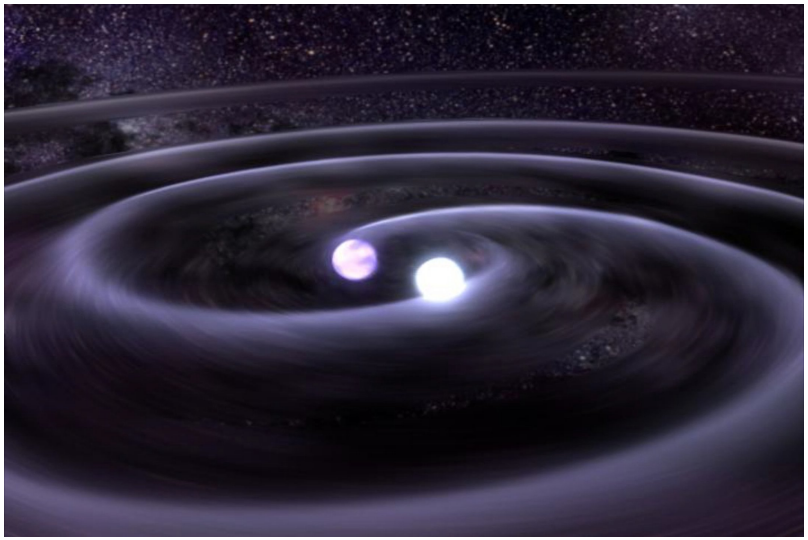


Metzger & Berger 2012

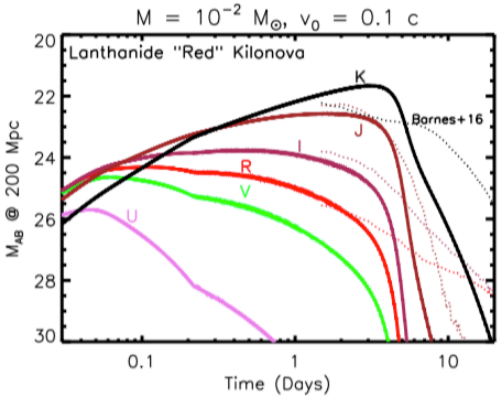


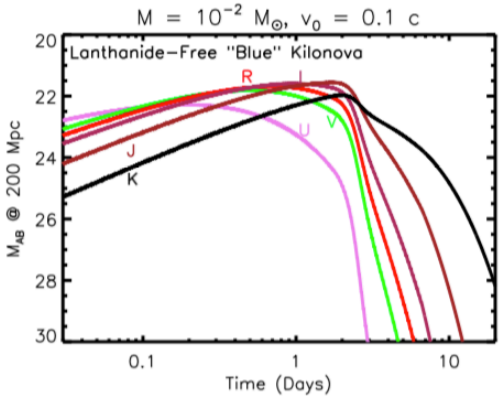
courtesy: M. G. Bernardini

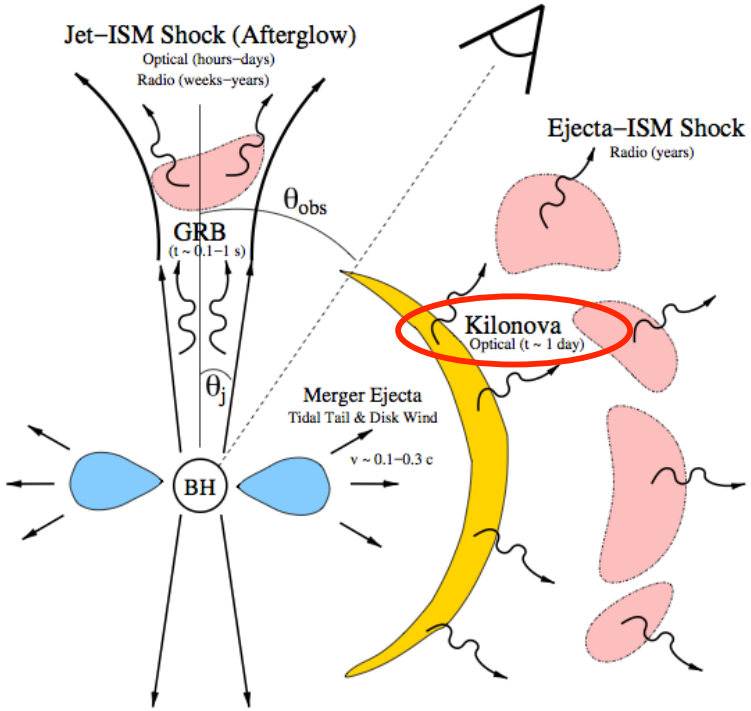
NS-NS / NS-BH electromagnetic counterparts



Kilonova

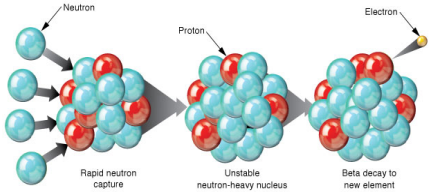


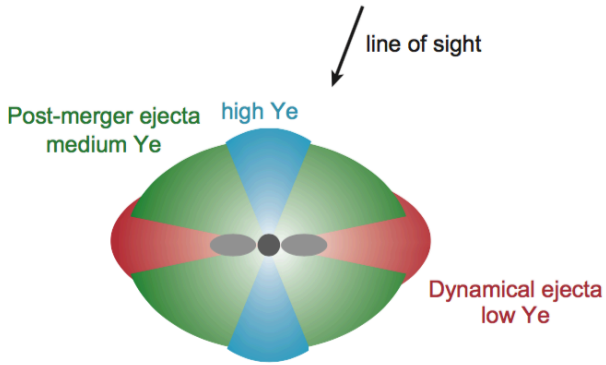




Metzger & Berger 2012

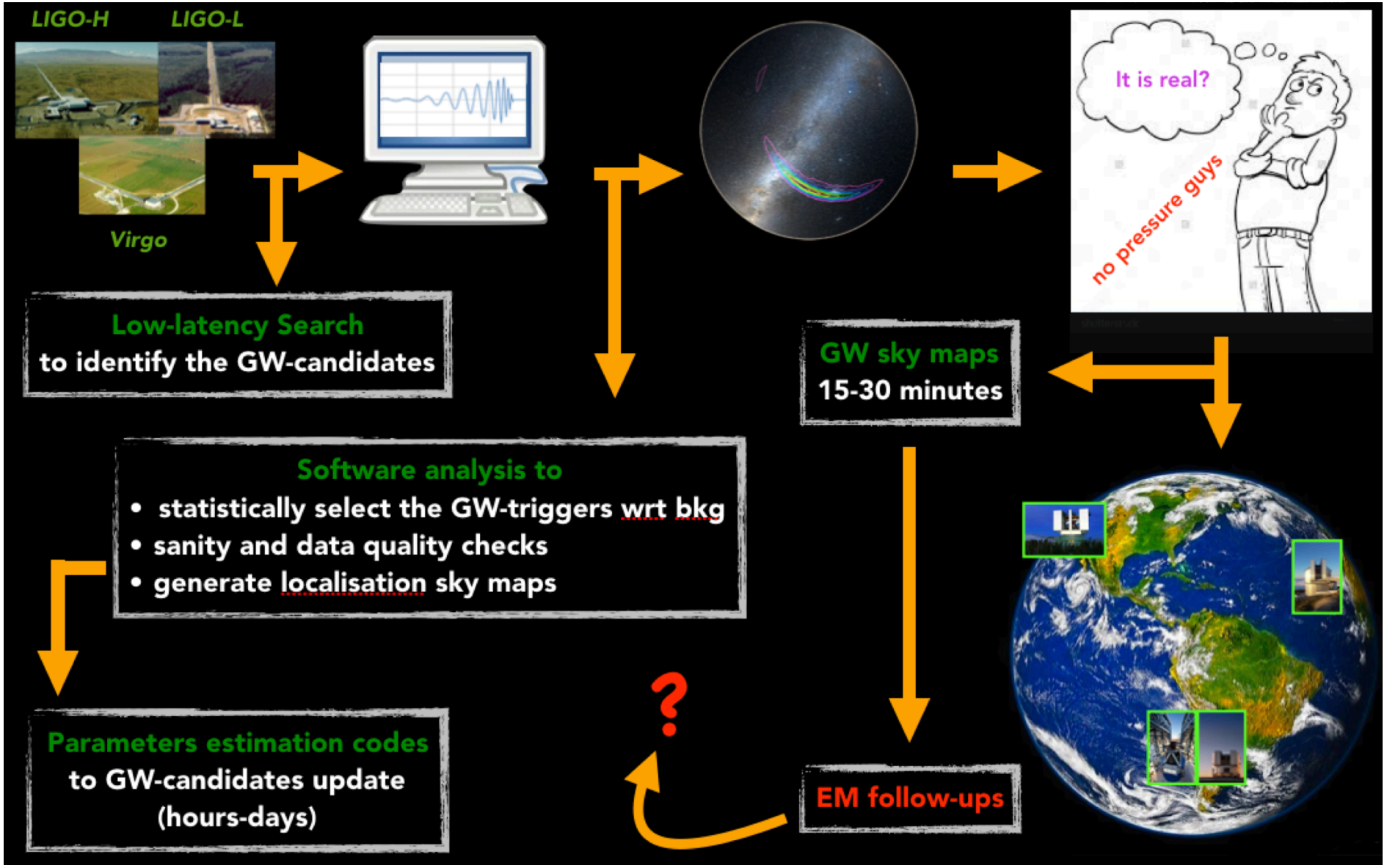
A key signature of an NS–NS/NS–BH binary merger is the production of a so-called "kilonova" (aka "macronova") due to the decay of heavy radioactive species produced by the *r*-process and ejected during the merger that is expected to provide a source of heating and radiation (Li and Paczynski 1998; Rosswog, 2005; Metzger et al., 2010).



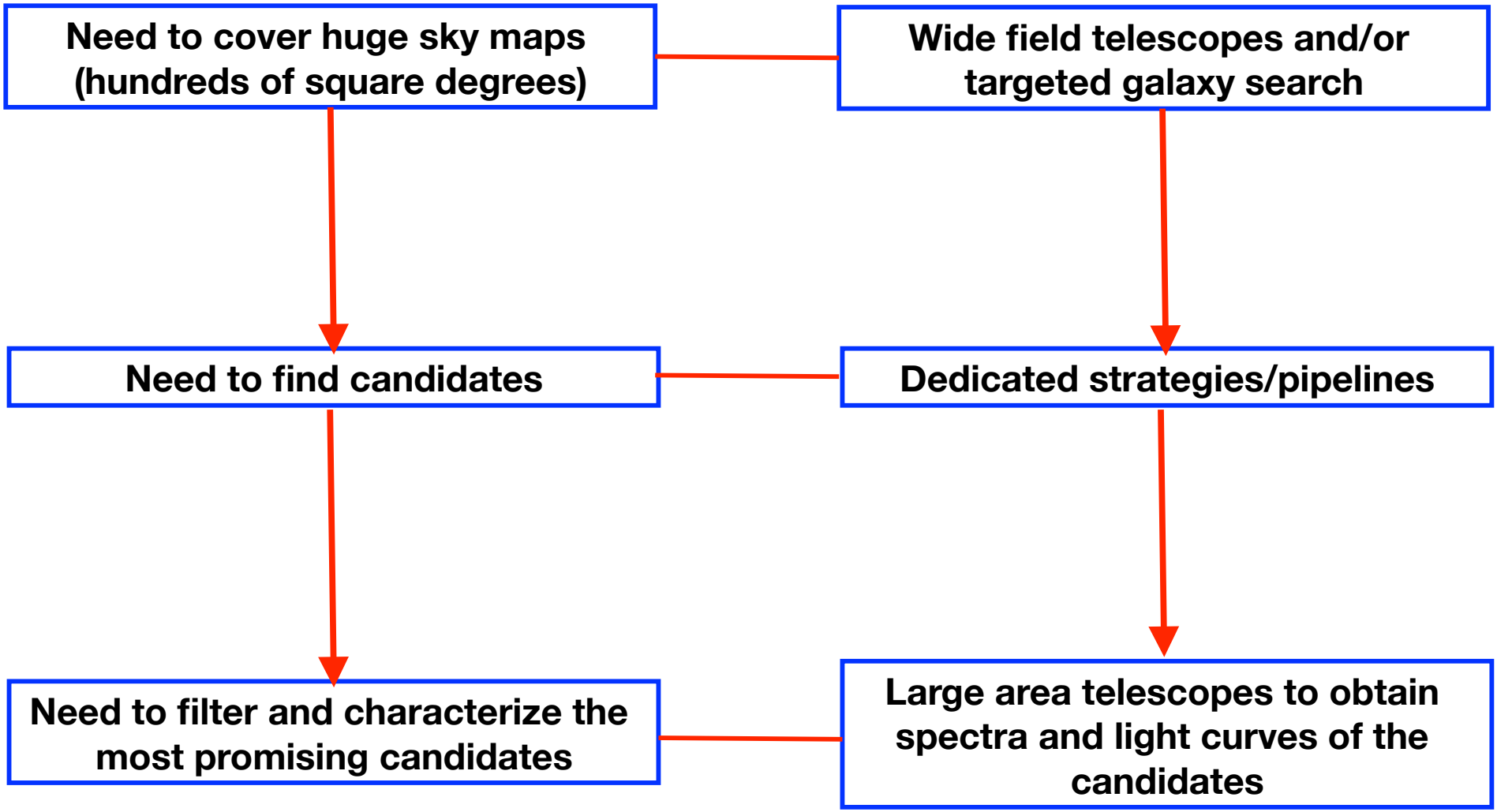


Tanaka et al. (2017)

Follow-up strategy



Follow-up strategy



The GW era – O1 & O2

Sept 2015 – Jan 2016: LVC O1 science run
Nov 2016 – Aug 2017: LVC O2 science run

Event	$m_1/M_\odot$	$m_2/M_\odot$	$\mathcal{M}/M_\odot$	$\chi_{\rm eff}$	$M_{\rm f}/M_\odot$	$a_{\rm f}$	$E_{\rm rad}/(M_\odot c^2)$	$\ell_{\rm peak}/({\rm erg\,s^{-1}})$	$d_L/{\rm Mpc}$	z	$\Delta\Omega/{\rm deg}^2$
GW150914	$35.6^{+4.8}_{-3.0}$	$30.6^{+3.0}_{-4.4}$	$28.6^{+1.6}_{-1.5}$	$-0.01^{+0.12}_{-0.13}$	$63.1^{+3.3}_{-3.0}$	$0.69^{+0.05}_{-0.04}$	$3.1^{+0.4}_{-0.4}$	$3.6^{+0.4}_{-0.4}\times10^{56}$	430^{+150}_{-170}	$0.09^{+0.03}_{-0.03}$	180
GW151012	$23.3^{+14.0}_{-5.5}$	$13.6^{+4.1}_{-4.8}$	$15.2^{+2.0}_{-1.1}$	$0.04^{+0.28}_{-0.19}$	$35.7^{+9.9}_{-3.8}$	$0.67^{+0.13}_{-0.11}$	$1.5^{+0.5}_{-0.5}$	$3.2^{+0.8}_{-1.7}\times10^{56}$	1060^{+540}_{-480}	$0.21^{+0.09}_{-0.09}$	1555
GW151226	$13.7^{+8.8}_{-3.2}$	$7.7^{+2.2}_{-2.6}$	$8.9^{+0.3}_{-0.3}$	$0.18^{+0.20}_{-0.12}$	$20.5^{+6.4}_{-1.5}$	$0.74^{+0.07}_{-0.05}$	$1.0^{+0.1}_{-0.2}$	$3.4^{+0.7}_{-1.7}\times10^{56}$	440^{+180}_{-190}	$0.09^{+0.04}_{-0.04}$	1033
GW170104	$31.0^{+7.2}_{-5.6}$	$20.1^{+4.9}_{-4.5}$	$21.5^{+2.1}_{-1.7}$	$-0.04^{+0.17}_{-0.20}$	$49.1^{+5.2}_{-3.9}$	$0.66^{+0.08}_{-0.10}$	$2.2^{+0.5}_{-0.5}$	$3.3^{+0.6}_{-0.9}\times10^{56}$	960^{+430}_{-410}	$0.19^{+0.07}_{-0.08}$	924
GW170608	$10.9^{+5.3}_{-1.7}$	$7.6^{+1.3}_{-2.1}$	$7.9^{+0.2}_{-0.2}$	$0.03^{+0.19}_{-0.07}$	$17.8^{+3.2}_{-0.7}$	$0.69^{+0.04}_{-0.04}$	$0.9^{+0.05}_{-0.1}$	$3.5^{+0.4}_{-1.3}\times10^{56}$	320^{+120}_{-110}	$0.07^{+0.02}_{-0.02}$	396
GW170729	$50.6^{+16.6}_{-10.2}$	$34.3^{+9.1}_{-10.1}$	$35.7^{+6.5}_{-4.7}$	$0.36^{+0.21}_{-0.25}$	$80.3^{+14.6}_{-10.2}$	$0.81^{+0.07}_{-0.13}$	$4.8^{+1.7}_{-1.7}$	$4.2^{+0.9}_{-1.5}\times10^{56}$	2750^{+1350}_{-1320}	$0.48^{+0.19}_{-0.20}$	1033
GW170809	$35.2^{+8.3}_{-6.0}$	$23.8^{+5.2}_{-5.1}$	$25.0^{+2.1}_{-1.6}$	$0.07^{+0.16}_{-0.16}$	$56.4^{+5.2}_{-3.7}$	$0.70^{+0.08}_{-0.09}$	$2.7^{+0.6}_{-0.6}$	$3.5^{+0.6}_{-0.9}\times10^{56}$	990^{+320}_{-380}	$0.20^{+0.05}_{-0.07}$	340
GW170814	$30.7^{+5.7}_{-3.0}$	$25.3^{+2.9}_{-4.1}$	$24.2^{+1.4}_{-1.1}$	$0.07^{+0.12}_{-0.11}$	$53.4^{+3.2}_{-2.4}$	$0.72^{+0.07}_{-0.05}$	$2.7^{+0.4}_{-0.3}$	$3.7^{+0.4}_{-0.5}\times10^{56}$	580^{+160}_{-210}	$0.12^{+0.03}_{-0.04}$	87
GW170817	$1.46^{+0.12}_{-0.10}$	$1.27^{+0.09}_{-0.09}$	$1.186^{+0.001}_{-0.001}$	$0.00^{+0.02}_{-0.01}$	≤ 2.8	≤ 0.89	≥ 0.04	$\geq 0.1\times10^{56}$	40^{+10}_{-10}	$0.01^{+0.00}_{-0.00}$	16
GW170818	$35.5^{+7.5}_{-4.7}$	$26.8^{+4.3}_{-5.2}$	$26.7^{+2.1}_{-1.7}$	$-0.09^{+0.18}_{-0.21}$	$59.8^{+4.8}_{-3.8}$	$0.67^{+0.07}_{-0.08}$	$2.7^{+0.5}_{-0.5}$	$3.4^{+0.5}_{-0.7}\times10^{56}$	1020^{+430}_{-360}	$0.20^{+0.07}_{-0.07}$	39
GW170823	$39.6^{+10.0}_{-6.6}$	$29.4^{+6.3}_{-7.1}$	$29.3^{+4.2}_{-3.2}$	$0.08^{+0.20}_{-0.22}$	$65.6^{+9.4}_{-6.6}$	$0.71^{+0.08}_{-0.10}$	$3.3^{+0.9}_{-0.8}$	$3.6^{+0.6}_{-0.9}\times10^{56}$	1850^{+840}_{-840}	$0.34^{+0.13}_{-0.14}$	1651

Abbott+19

The GW era – O1 & O2

Sept 2015 – Jan 2016: LVC O1 science run
Nov 2016 – Aug 2017: LVC O2 science run

Event	$m_1/M_\odot$	$m_2/M_\odot$	$\mathcal{M}/M_\odot$	$\chi_{\rm eff}$	$M_{\rm f}/M_\odot$	$a_{\rm f}$	$E_{\rm rad}/(M_\odot c^2)$	$\ell_{\rm peak}/({\rm erg\,s^{-1}})$	d_L/Mpc	z	$\Delta\Omega/{\rm deg}^2$
GW150914	$35.6^{+4.8}_{-3.0}$	$30.6^{+3.0}_{-4.4}$	$28.6^{+1.6}_{-1.5}$	$-0.01^{+0.12}_{-0.13}$	$63.1^{+3.3}_{-3.0}$	$0.69^{+0.05}_{-0.04}$	$3.1^{+0.4}_{-0.4}$	$3.6^{+0.4}_{-0.4}\times10^{56}$	430^{+150}_{-170}	$0.09^{+0.03}_{-0.03}$	180
GW151012	$23.3^{+14.0}_{-5.5}$	$13.6^{+4.1}_{-4.8}$	$15.2^{+2.0}_{-1.1}$	$0.04^{+0.28}_{-0.19}$	$35.7^{+9.9}_{-3.8}$	$0.67^{+0.13}_{-0.11}$	$1.5^{+0.5}_{-0.5}$	$3.2^{+0.8}_{-1.7}\times10^{56}$	1060^{+540}_{-480}	$0.21^{+0.09}_{-0.09}$	1555
GW151226	$13.7^{+8.8}_{-3.2}$	$7.7^{+2.2}_{-2.6}$	$8.9^{+0.3}_{-0.3}$	$0.18^{+0.20}_{-0.12}$	$20.5^{+6.4}_{-1.5}$	$0.74^{+0.07}_{-0.05}$	$1.0^{+0.1}_{-0.2}$	$3.4^{+0.7}_{-1.7}\times10^{56}$	440^{+180}_{-190}	$0.09^{+0.04}_{-0.04}$	1033
GW170104	$31.0^{+7.2}_{-5.6}$	$20.1^{+4.9}_{-4.5}$	$21.5^{+2.1}_{-1.7}$	$-0.04^{+0.17}_{-0.20}$	$49.1^{+5.2}_{-3.9}$	$0.66^{+0.08}_{-0.10}$	$2.2^{+0.5}_{-0.5}$	$3.3^{+0.6}_{-0.9}\times10^{56}$	960^{+430}_{-410}	$0.19^{+0.07}_{-0.08}$	924
GW170608	$10.9^{+5.3}_{-1.7}$	$7.6^{+1.3}_{-2.1}$	$7.9^{+0.2}_{-0.2}$	$0.03^{+0.19}_{-0.07}$	$17.8^{+3.2}_{-0.7}$	$0.69^{+0.04}_{-0.04}$	$0.9^{+0.05}_{-0.1}$	$3.5^{+0.4}_{-1.3}\times10^{56}$	320^{+120}_{-110}	$0.07^{+0.02}_{-0.02}$	396
GW170729	$50.6^{+16.6}_{-10.2}$	$34.3^{+9.1}_{-10.1}$	$35.7^{+6.5}_{-4.7}$	$0.36^{+0.21}_{-0.25}$	$80.3^{+14.6}_{-10.2}$	$0.81^{+0.07}_{-0.13}$	$4.8^{+1.7}_{-1.7}$	$4.2^{+0.9}_{-1.5}\times10^{56}$	2750^{+1350}_{-1320}	$0.48^{+0.19}_{-0.20}$	1033
GW170809	$35.2^{+8.3}_{-6.0}$	$23.8^{+5.2}_{-5.1}$	$25.0^{+2.1}_{-1.6}$	$0.07^{+0.16}_{-0.16}$	$56.4^{+5.2}_{-3.7}$	$0.70^{+0.08}_{-0.09}$	$2.7^{+0.6}_{-0.6}$	$3.5^{+0.6}_{-0.9}\times10^{56}$	990^{+320}_{-380}	$0.20^{+0.05}_{-0.07}$	340
GW170814	$30.7^{+5.7}_{-3.0}$	$25.3^{+2.9}_{-4.1}$	$24.2^{+1.4}_{-1.1}$	$0.07^{+0.12}_{-0.11}$	$53.4^{+3.2}_{-2.4}$	$0.72^{+0.07}_{-0.05}$	$2.7^{+0.4}_{-0.3}$	$3.7^{+0.4}_{-0.5}\times10^{56}$	580^{+160}_{-210}	$0.12^{+0.03}_{-0.04}$	87
GW170817	$1.46^{+0.12}_{-0.10}$	$1.27^{+0.09}_{-0.09}$	$1.186^{+0.001}_{-0.001}$	$0.00^{+0.02}_{-0.01}$	≤ 2.8	≤ 0.89	≥ 0.04	$\geq 0.1\times10^{56}$	40^{+10}_{-10}	$0.01^{+0.00}_{-0.00}$	16
GW170818	$35.5^{+7.5}_{-4.7}$	$26.8^{+4.3}_{-5.2}$	$26.7^{+2.1}_{-1.7}$	$-0.09^{+0.18}_{-0.21}$	$59.8^{+4.8}_{-3.8}$	$0.67^{+0.07}_{-0.08}$	$2.7^{+0.5}_{-0.5}$	$3.4^{+0.5}_{-0.7}\times10^{56}$	1020^{+430}_{-360}	$0.20^{+0.07}_{-0.07}$	39
GW170823	$39.6^{+10.0}_{-6.6}$	$29.4^{+6.3}_{-7.1}$	$29.3^{+4.2}_{-3.2}$	$0.08^{+0.20}_{-0.22}$	$65.6^{+9.4}_{-6.6}$	$0.71^{+0.08}_{-0.10}$	$3.3^{+0.9}_{-0.8}$	$3.6^{+0.6}_{-0.9}\times10^{56}$	1850^{+840}_{-840}	$0.34^{+0.13}_{-0.14}$	1651

Abbott+19

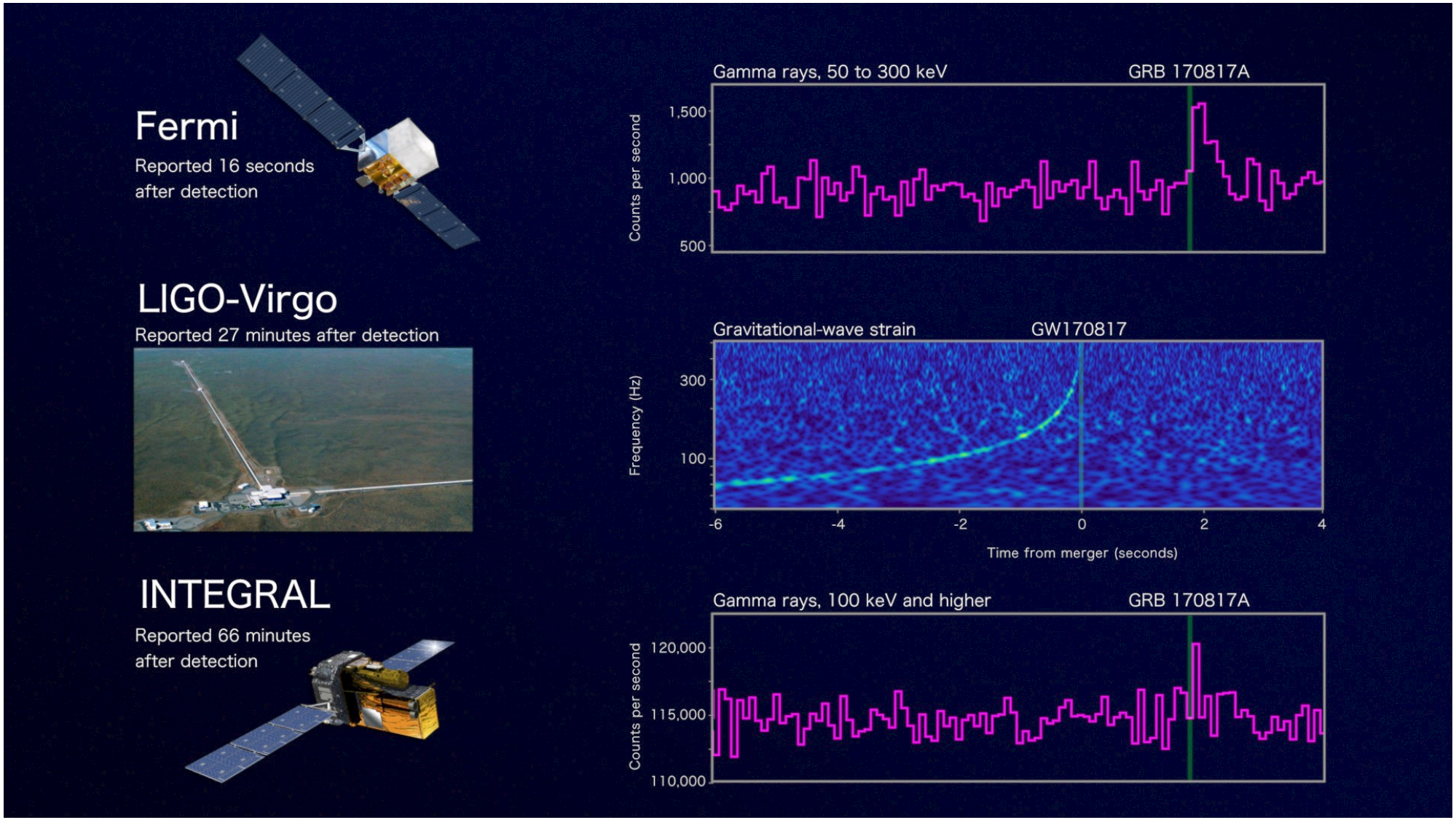
The GW era – O1 & O2

Sept 2015 – Jan 2016: LVC O1 science run
Nov 2016 – Aug 2017: LVC O2 science run

Event	$m_1/M_\odot$	$m_2/M_\odot$	$\mathcal{M}/M_\odot$	$\chi_{\rm eff}$	$M_{\rm f}/M_\odot$	$a_{\rm f}$	$E_{\rm rad}/(M_\odot c^2)$	$\ell_{\rm peak}/({\rm erg\,s^{-1}})$	d_L/Mpc	z	$\Delta\Omega/{\rm deg}^2$
GW150914	$35.6^{+4.8}_{-3.0}$	$30.6^{+3.0}_{-4.4}$	$28.6^{+1.6}_{-1.5}$	$-0.01^{+0.12}_{-0.13}$	$63.1^{+3.3}_{-3.0}$	$0.69^{+0.05}_{-0.04}$	$3.1^{+0.4}_{-0.4}$	$3.6^{+0.4}_{-0.4}\times10^{56}$	430^{+150}_{-170}	$0.09^{+0.03}_{-0.03}$	180
GW151012	$23.3^{+14.0}_{-5.5}$	$13.6^{+4.1}_{-4.8}$	$15.2^{+2.0}_{-1.1}$	$0.04^{+0.28}_{-0.19}$	$35.7^{+9.9}_{-3.8}$	$0.67^{+0.13}_{-0.11}$	$1.5^{+0.5}_{-0.5}$	$3.2^{+0.8}_{-1.7}\times10^{56}$	1060^{+540}_{-480}	$0.21^{+0.09}_{-0.09}$	1555
GW151226	$13.7^{+8.8}_{-3.2}$	$7.7^{+2.2}_{-2.6}$	$8.9^{+0.3}_{-0.3}$	$0.18^{+0.20}_{-0.12}$	$20.5^{+6.4}_{-1.5}$	$0.74^{+0.07}_{-0.05}$	$1.0^{+0.1}_{-0.2}$	$3.4^{+0.7}_{-1.7}\times10^{56}$	440^{+180}_{-190}	$0.09^{+0.04}_{-0.04}$	1033
GW170104	$31.0^{+7.2}_{-5.6}$	$20.1^{+4.9}_{-4.5}$	$21.5^{+2.1}_{-1.7}$	$-0.04^{+0.17}_{-0.20}$	$49.1^{+5.2}_{-3.9}$	$0.66^{+0.08}_{-0.10}$	$2.2^{+0.5}_{-0.5}$	$3.3^{+0.6}_{-0.9}\times10^{56}$	960^{+430}_{-410}	$0.19^{+0.07}_{-0.08}$	924
GW170608	$10.9^{+5.3}_{-1.7}$	$7.6^{+1.3}_{-2.1}$	$7.9^{+0.2}_{-0.2}$	$0.03^{+0.19}_{-0.07}$	$17.8^{+3.2}_{-0.7}$	$0.69^{+0.04}_{-0.04}$	$0.9^{+0.05}_{-0.1}$	$3.5^{+0.4}_{-1.3}\times10^{56}$	320^{+120}_{-110}	$0.07^{+0.02}_{-0.02}$	396
GW170729	$50.6^{+16.6}_{-10.2}$	$34.3^{+9.1}_{-10.1}$	$35.7^{+6.5}_{-4.7}$	$0.36^{+0.21}_{-0.25}$	$80.3^{+14.6}_{-10.2}$	$0.81^{+0.07}_{-0.13}$	$4.8^{+1.7}_{-1.7}$	$4.2^{+0.9}_{-1.5}\times10^{56}$	2750^{+1350}_{-1320}	$0.48^{+0.19}_{-0.20}$	1033
GW170809	$35.2^{+8.3}_{-6.0}$	$23.8^{+5.2}_{-5.1}$	$25.0^{+2.1}_{-1.6}$	$0.07^{+0.16}_{-0.16}$	$56.4^{+5.2}_{-3.7}$	$0.70^{+0.08}_{-0.09}$	$2.7^{+0.6}_{-0.6}$	$3.5^{+0.6}_{-0.9}\times10^{56}$	990^{+320}_{-380}	$0.20^{+0.05}_{-0.07}$	340
GW170814	$30.7^{+5.7}_{-3.0}$	$25.3^{+2.9}_{-4.1}$	$24.2^{+1.4}_{-1.1}$	$0.07^{+0.12}_{-0.11}$	$53.4^{+3.2}_{-2.4}$	$0.72^{+0.07}_{-0.05}$	$2.7^{+0.4}_{-0.3}$	$3.7^{+0.4}_{-0.5}\times10^{56}$	580^{+160}_{-210}	$0.12^{+0.03}_{-0.04}$	87
GW170817	$1.46^{+0.12}_{-0.10}$	$1.27^{+0.09}_{-0.09}$	$1.186^{+0.001}_{-0.001}$	$0.00^{+0.02}_{-0.01}$	≤ 2.8	≤ 0.89	≥ 0.04	$\geq 0.1\times10^{56}$	40^{+10}_{-10}	$0.01^{+0.00}_{-0.00}$	16
GW170818	$35.5^{+7.5}_{-4.7}$	$26.8^{+4.3}_{-5.2}$	$26.7^{+2.1}_{-1.7}$	$-0.09^{+0.18}_{-0.21}$	$59.8^{+4.8}_{-3.8}$	$0.67^{+0.07}_{-0.08}$	$2.7^{+0.5}_{-0.5}$	$3.4^{+0.5}_{-0.7}\times10^{56}$	1020^{+430}_{-360}	$0.20^{+0.07}_{-0.07}$	39
GW170823	$39.6^{+10.0}_{-6.6}$	$29.4^{+6.3}_{-7.1}$	$29.3^{+4.2}_{-3.2}$	$0.08^{+0.20}_{-0.22}$	$65.6^{+9.4}_{-6.6}$	$0.71^{+0.08}_{-0.10}$	$3.3^{+0.9}_{-0.8}$	$3.6^{+0.6}_{-0.9}\times10^{56}$	1850^{+840}_{-840}	$0.34^{+0.13}_{-0.14}$	1651

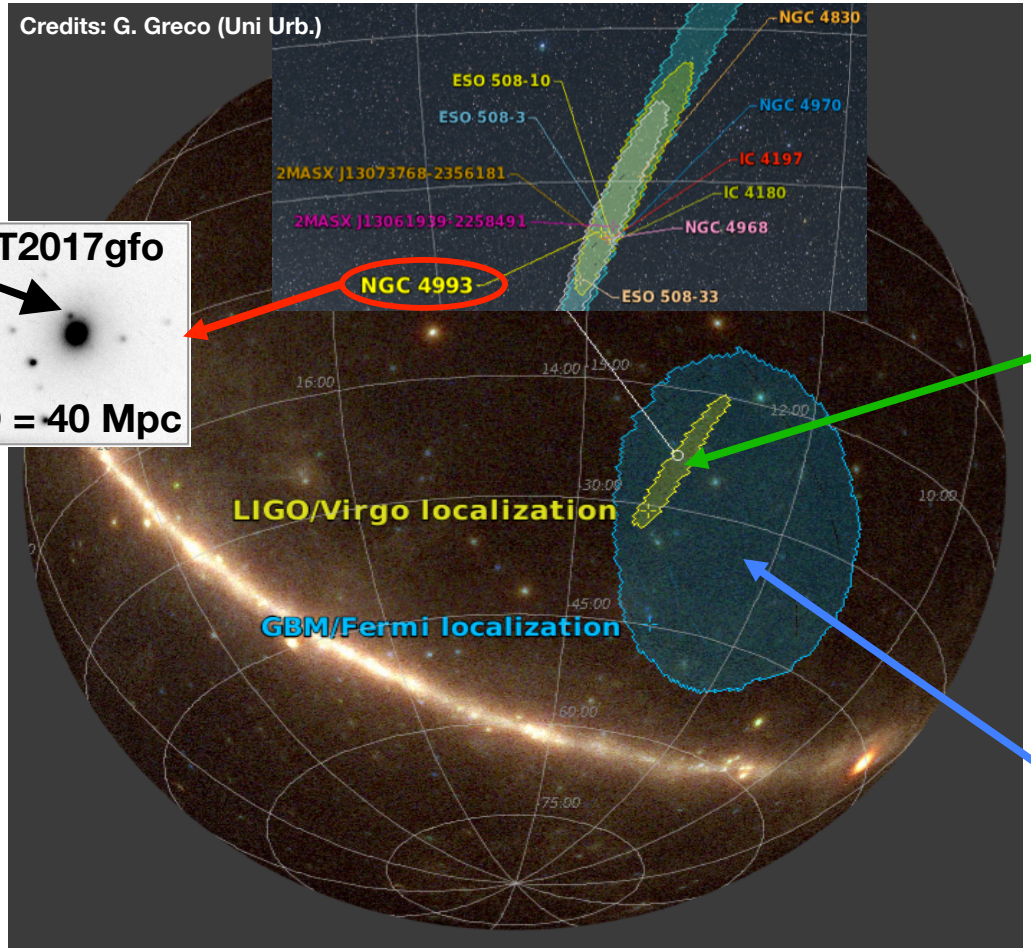
Abbott+19

GW 170817 & GRB 170817A



Abbott+17; Goldstein+17; Savchenko+17

GW 170817 / GRB 170817A / AT2017gfo



PRL 119, 161101 (2017) — Selected for a Viewpoint in *Physics* — PHYSICAL REVIEW LETTERS — week ending 20 OCTOBER 2017

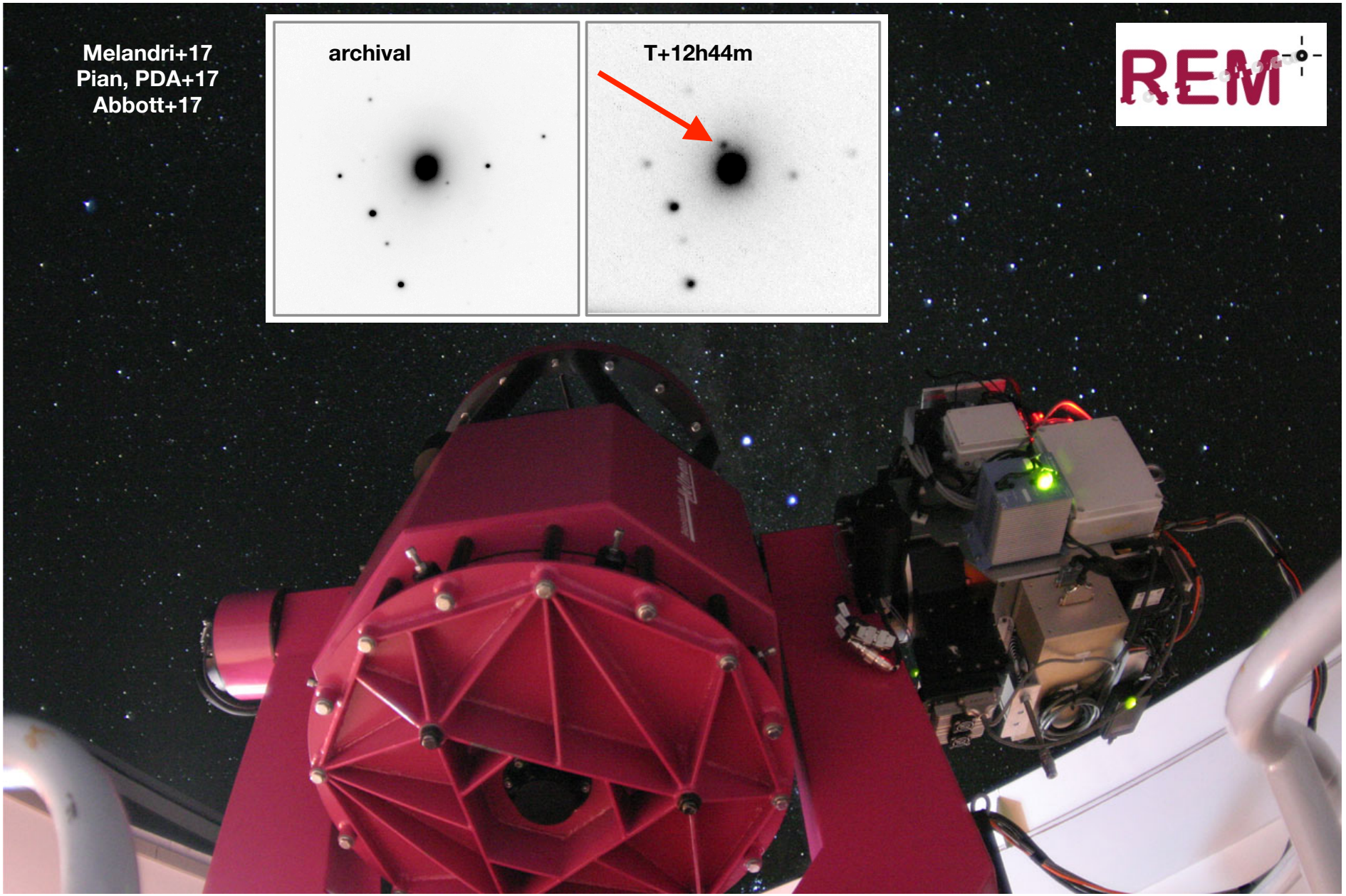
GW170817: Observation of Gravitational Waves from a Binary Neutron Star Inspiral

B. P. Abbott *et al.**
(LIGO Scientific Collaboration and Virgo Collaboration)

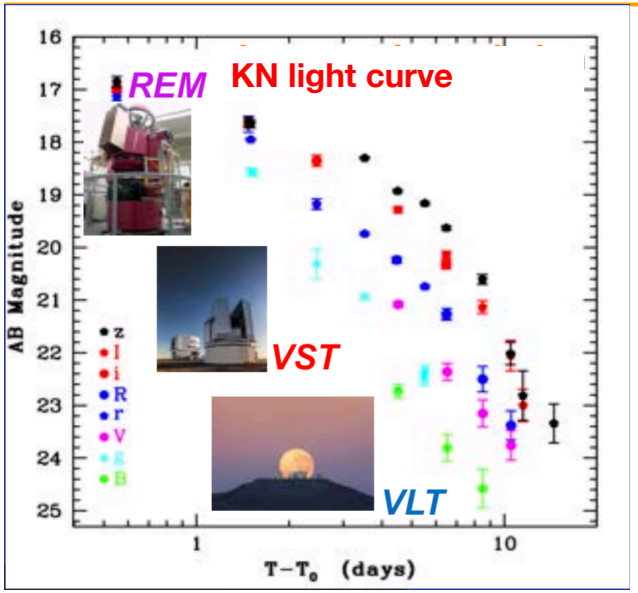
(Received 26 September 2017; revised manuscript received 2 October 2017; published 16 October 2017)

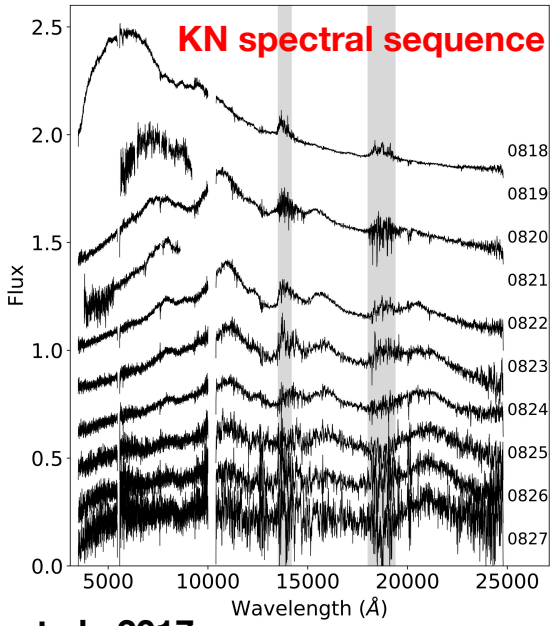
GW 170817 / GRB 170817A / AT2017gfo

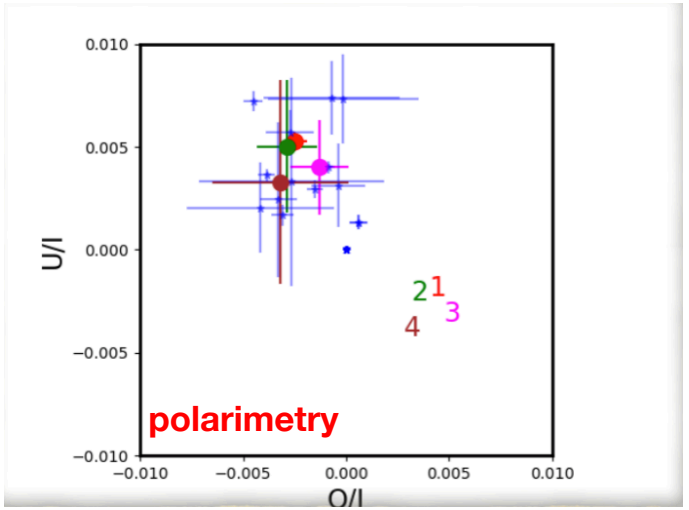
INAF
ISTITUTO NAZIONALE
DI ASTROFISICA



GW 170817 / GRB 170817A / AT2017gfo





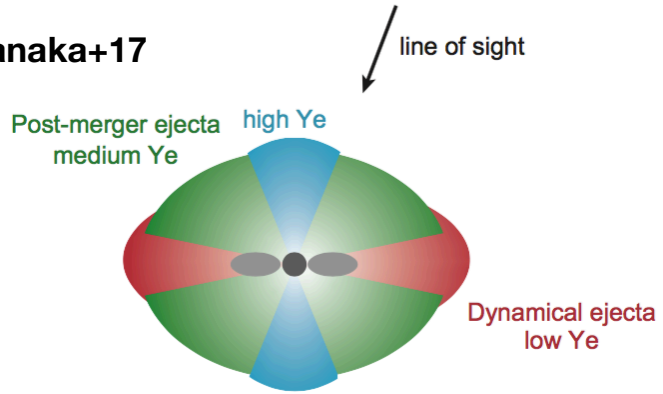


Pian, PDA et al., 2017
(see also Arcavi+17; Coulter+17; Evans+17; Lipunov+17; Smartt+17; Soares-Santos+17; Tanvir+17; Valenti+17 and many others)

Covino et al., 2017

Full characterization of the KN properties

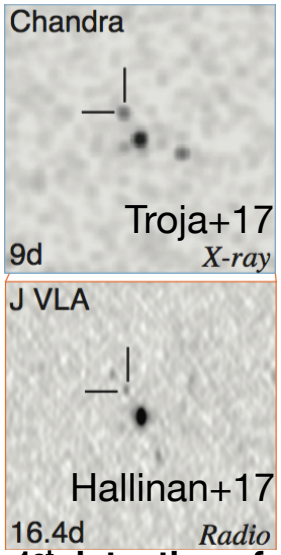
Tanaka+17



Three components Kilonova model with different velocity, composition and electron (proton) fraction (low Ye: lanthanide-rich; high Ye: lanthanide-poor)

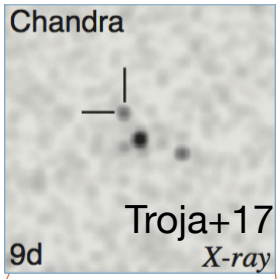
0.03-0.05 M_{Sun} ejected mass
Fast moving dynamical ejecta (0.2c) + slower wind (0.05c)

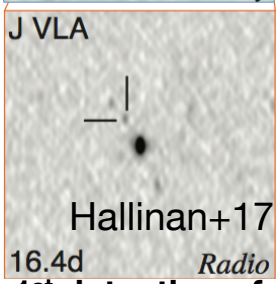
GW 170817 / AT2017gfo / GRB 170817A



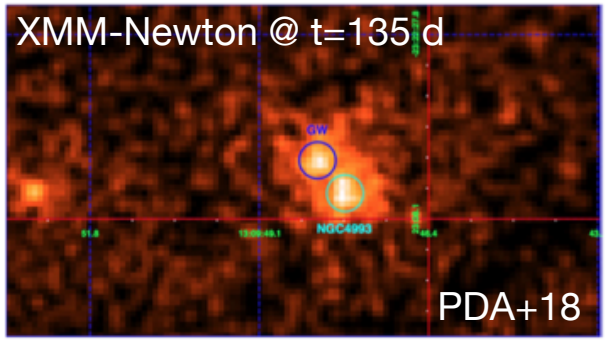
1st detection of the afterglow

GW 170817 / AT2017gfo / GRB 170817A



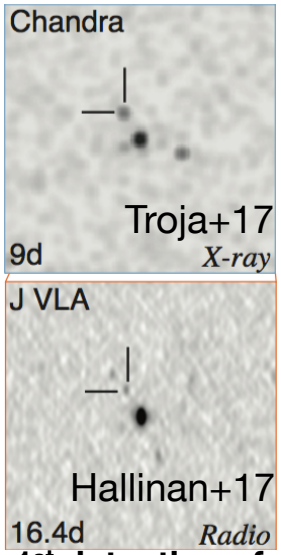


1st detection of the afterglow

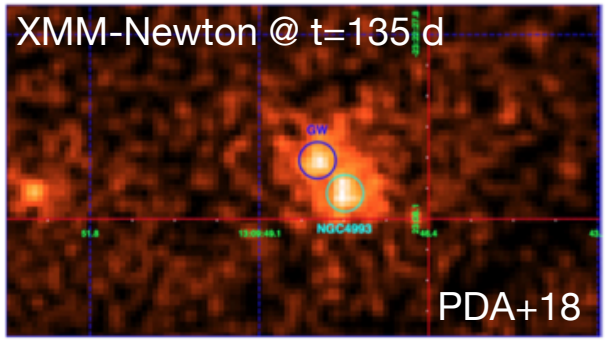


detection of the afterglow at the peak

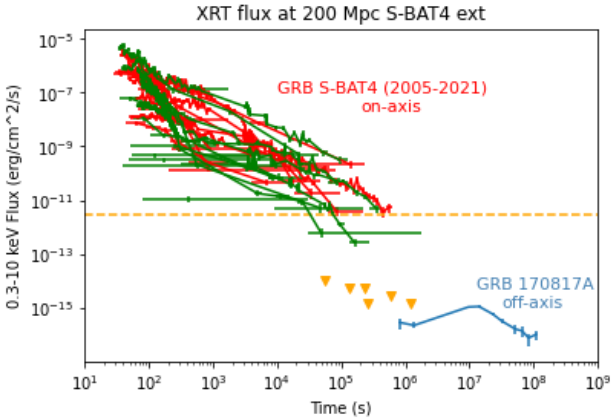
GW 170817 / AT2017gfo / GRB 170817A



1st detection of the afterglow

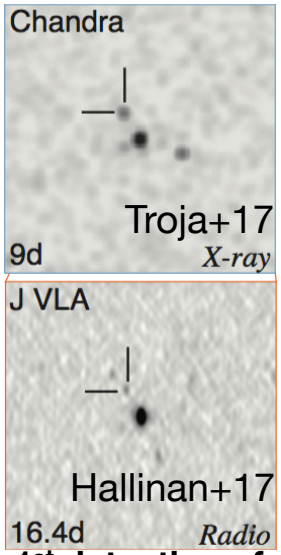


detection of the afterglow at the peak

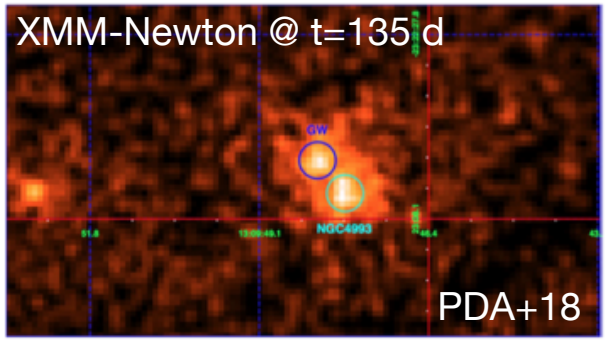


Michela Di Natolo (Bachelor student)
see also Duan+19; Salafia+19

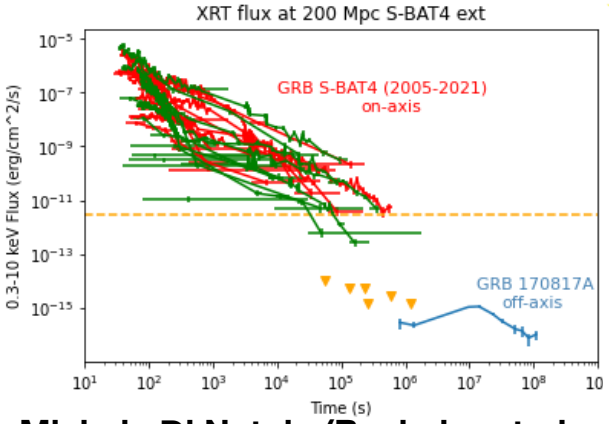
GW 170817 / AT2017gfo / GRB 170817A

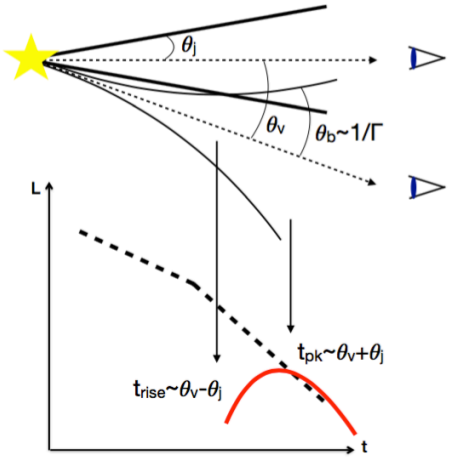


1st detection of the afterglow



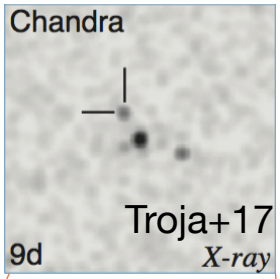
detection of the afterglow at the peak



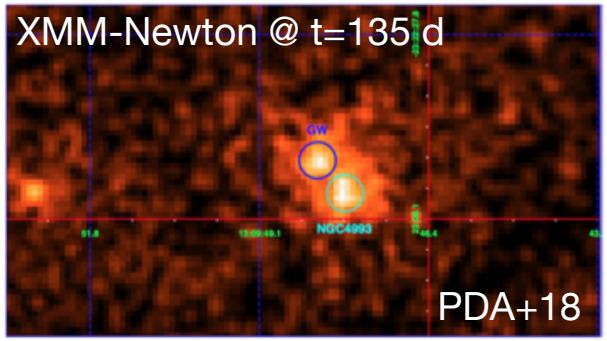


Michela Di Natolo (Bachelor student)
see also Duan+19; Salafia+19

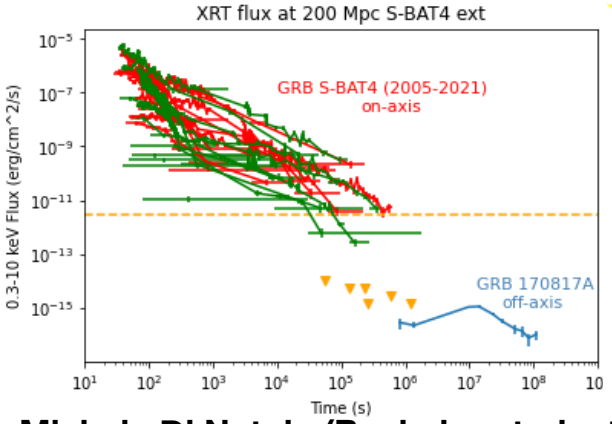
GW 170817 / AT2017gfo / GRB 170817A

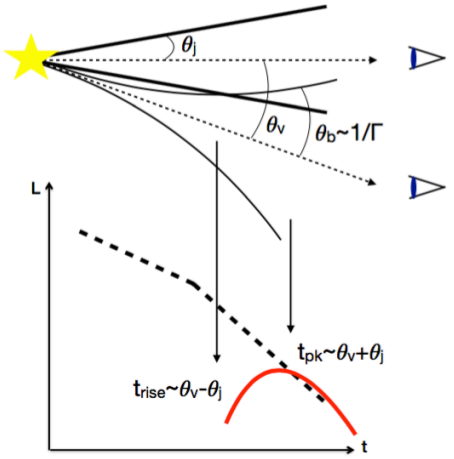


1st detection of the afterglow

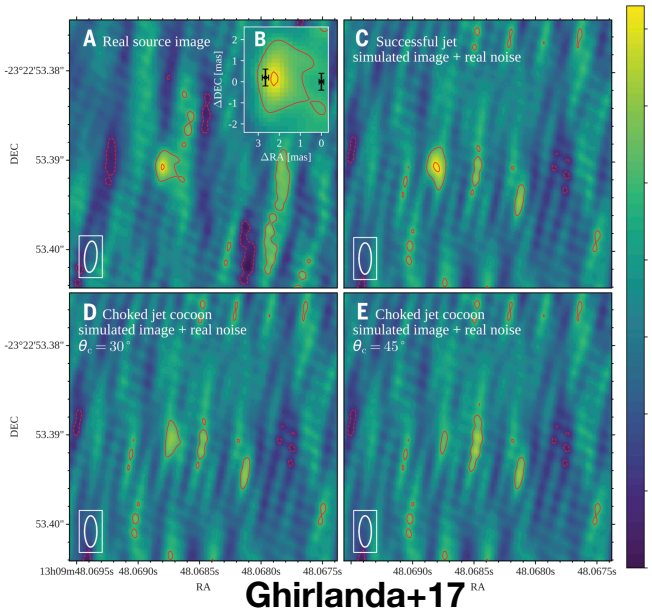


detection of the afterglow at the peak





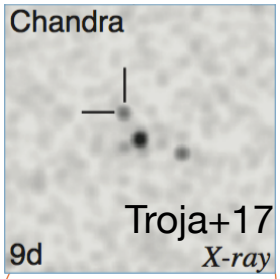
Michela Di Natolo (Bachelor student)
see also Duan+19; Salafia+19



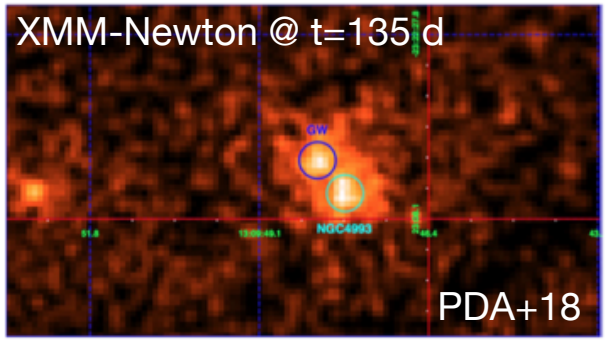
Ghirlanda+17

The radio afterglow is detected with an angular size < 2 mas in VLBI data obtained ~ 207 d after the merger. Evidence for superluminal motion is also found measuring an angular offset between T+75 d and T+235 d.

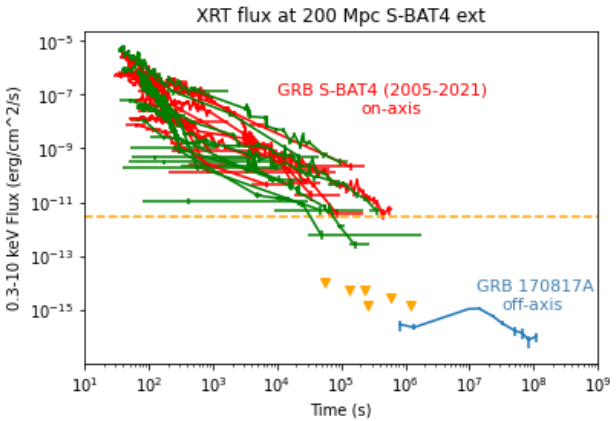
GW 170817 / AT2017gfo / GRB 170817A

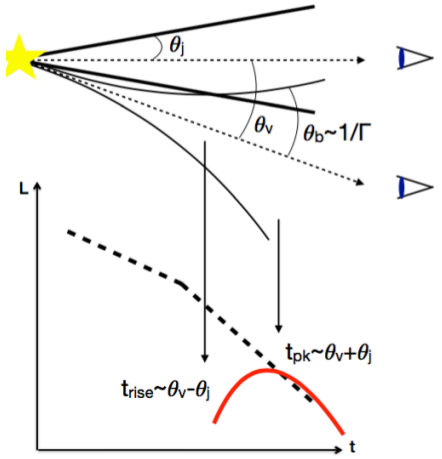


1st detection of the afterglow



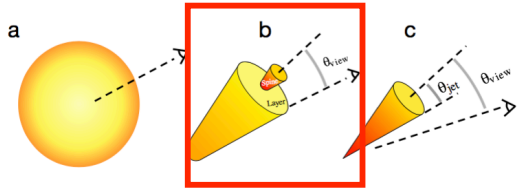
detection of the afterglow at the peak



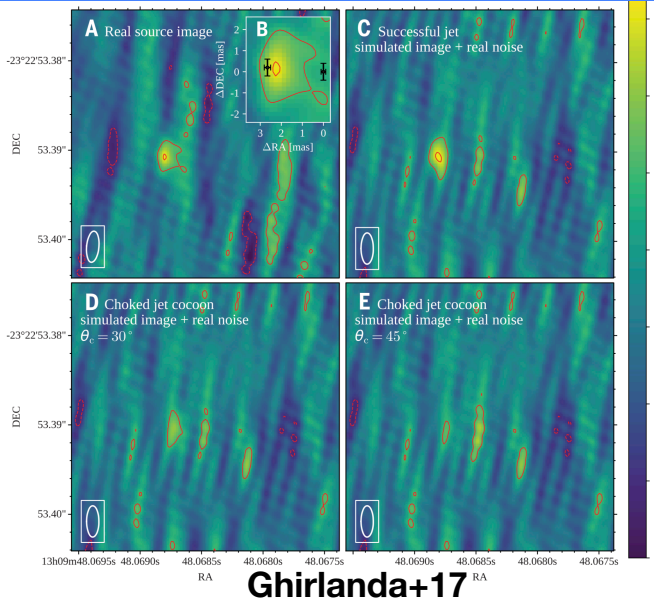


Michela Di Natolo (Bachelor student)
see also Duan+19; Salafia+19

Full characterization of the GRB properties: evidence for a structured jet



Salafia+17



Ghirlanda+17

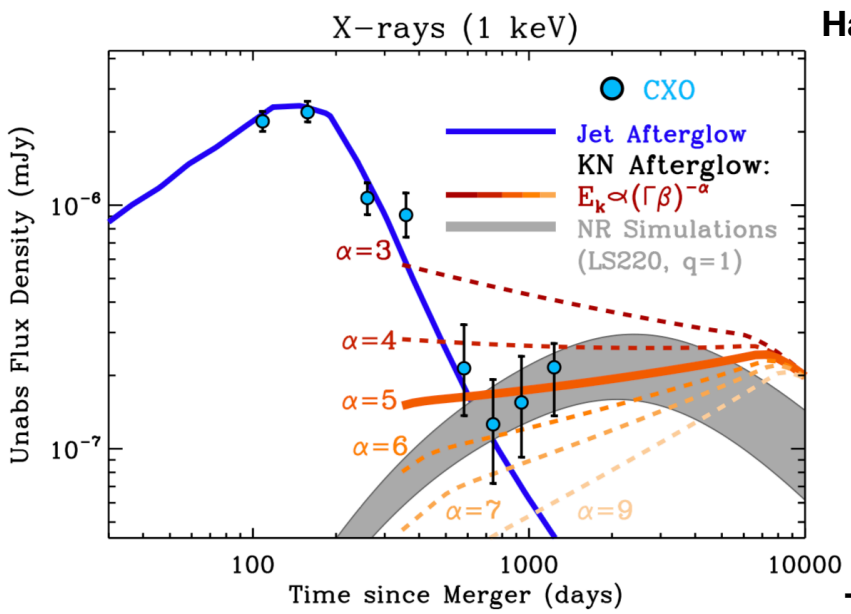
The radio afterglow is detected with an angular size < 2 mas in VLBI data obtained ~ 207 d after the merger. Evidence for superluminal motion is also found measuring an angular offset between T+75 d and T+235 d.

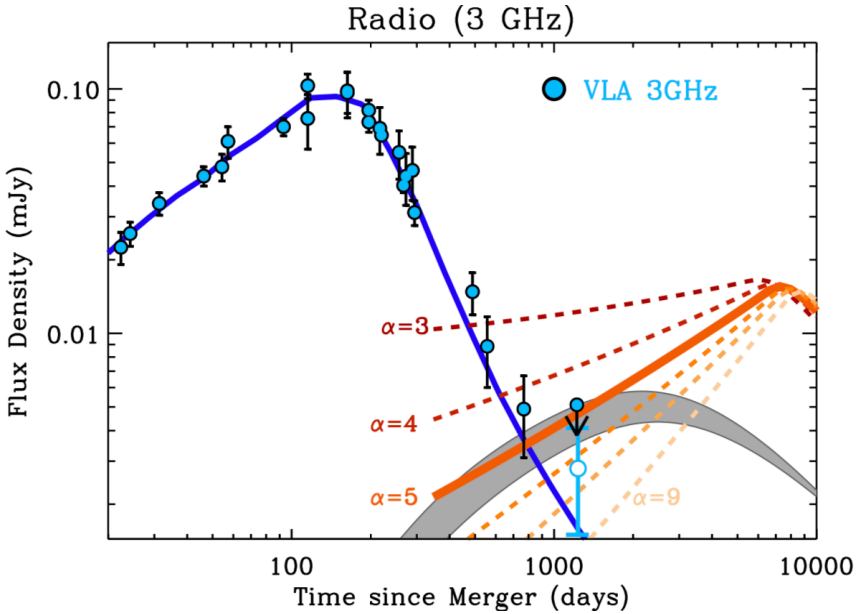
These findings, together with the afterglow light curve modelling, support the structured jet model. Fit to the data and numerical simulations are in agreement with the scenario of a structured jet with a relativistic core with $\theta_{jet} < 5$ deg and $\theta_{view} \sim 20$ deg.

Alexander+17,18; PDA+18; Dobie+18; Fong+19; Haggard+17; Hallinan+17; Hajela+19; Margutti+17,18; Mooley+18a,b; Reasmi+18; Ruan+18; Troja+18a,b, 19,20; Ghirlanda+19; Piro+19; Margutti & Chornock 21 and many others

GRB170817A: still detected after years

Hajela+21



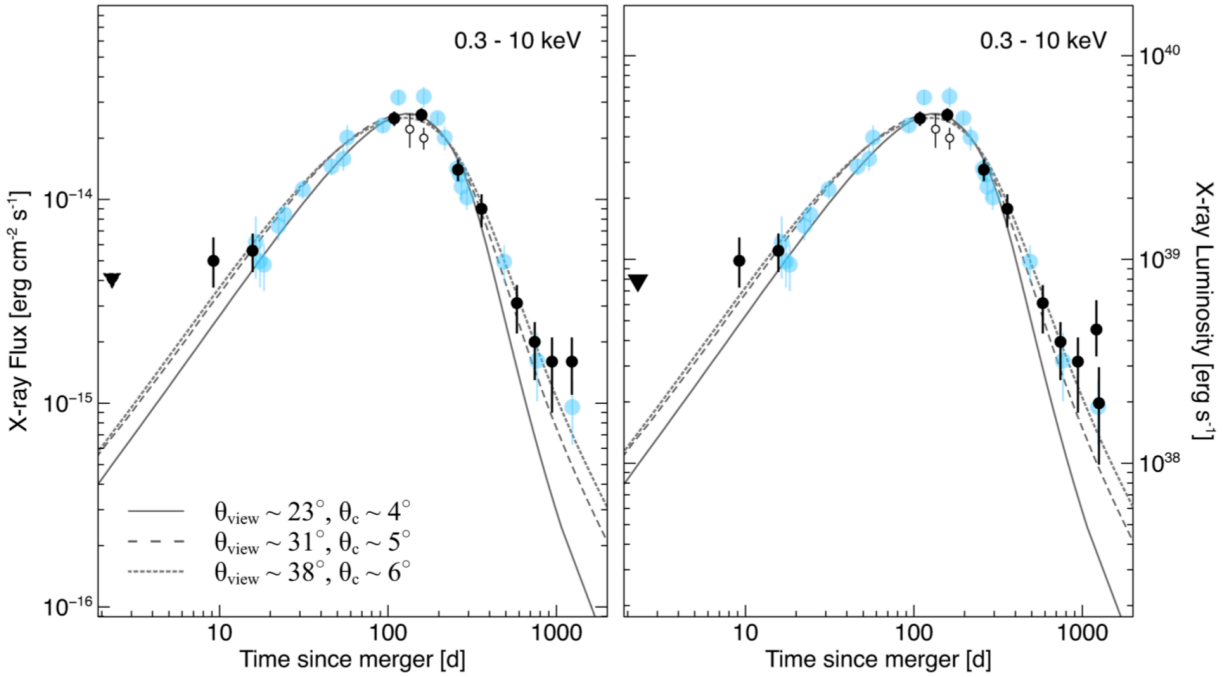


Troja+21

KN afterglow?

Accretion on compact remnant?

Magnetar?



O1 & O2: lessons learned

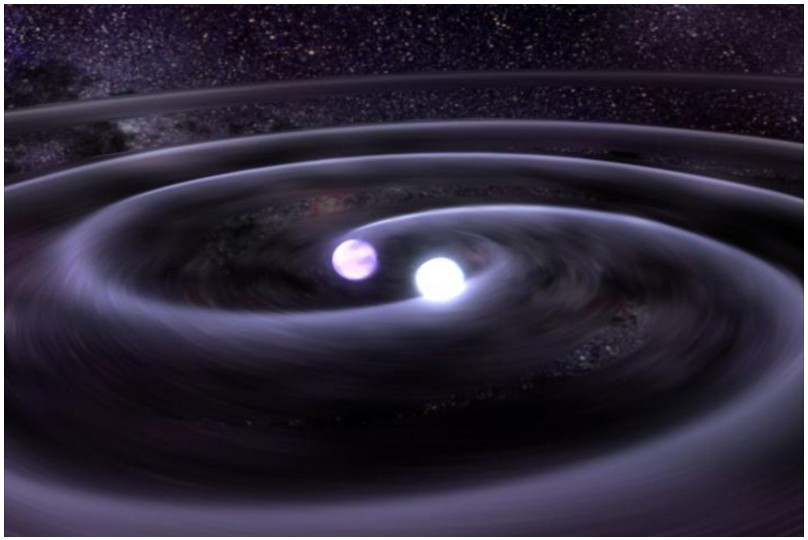
INAF
ISTITUTO NAZIONALE
DI ASTROFISICA

O1 & O2: lessons learned

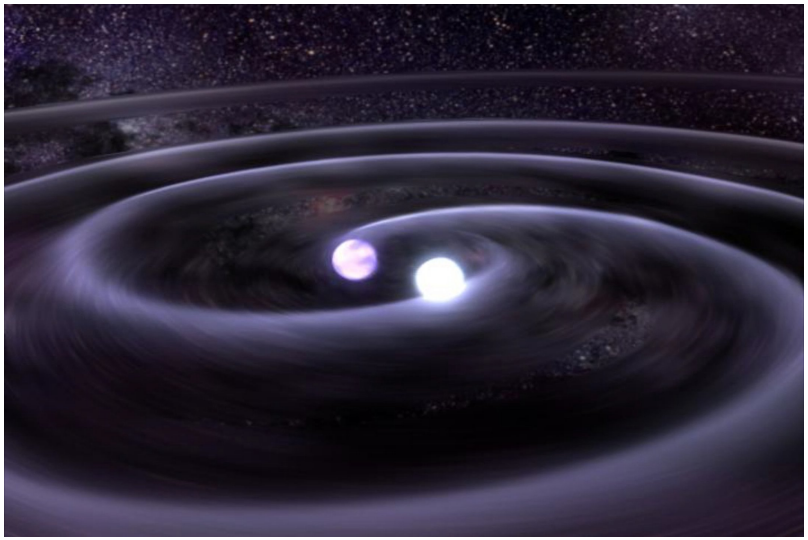
O1 & O2: lessons learned

O1 & O2: lessons learned

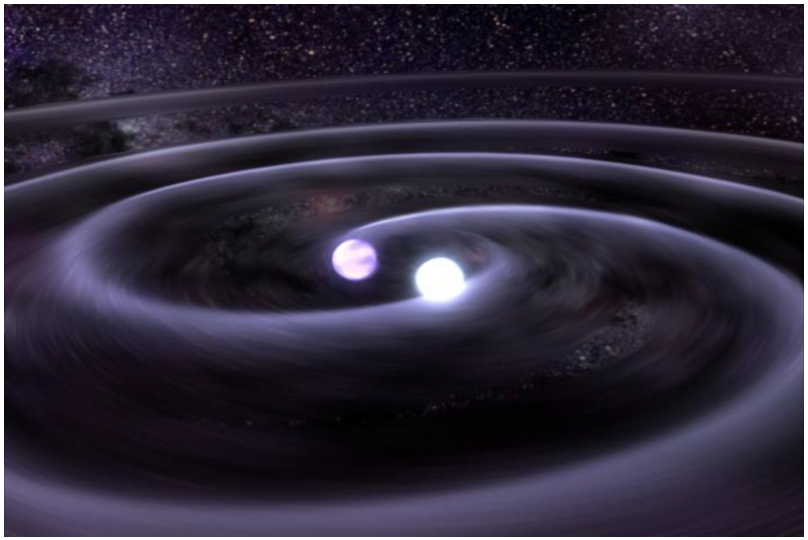
O1 & O2: lessons learned

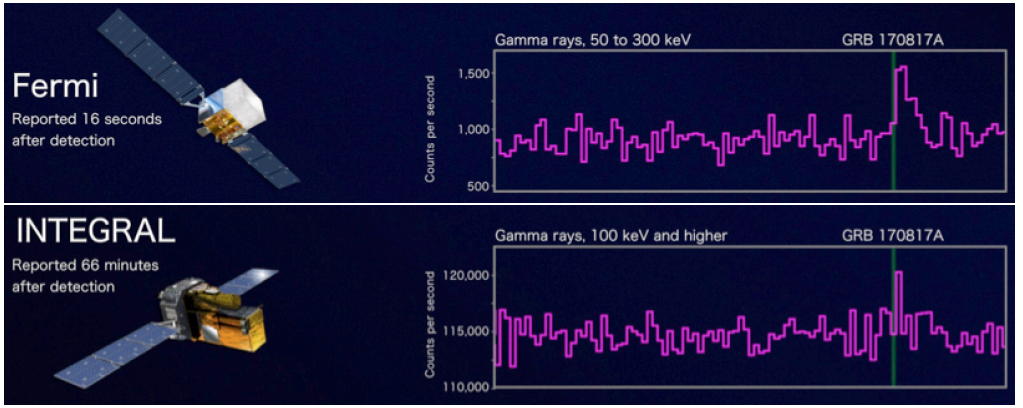


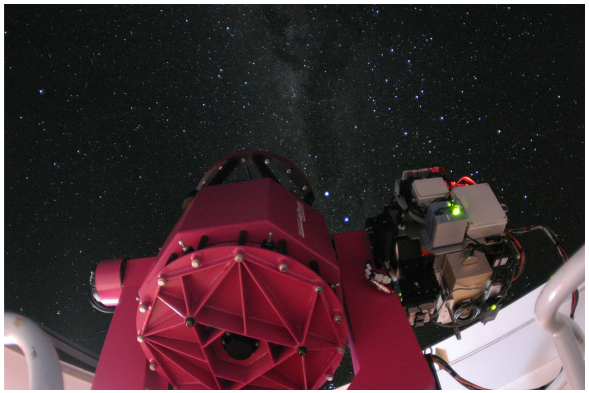
O1 & O2: lessons learned

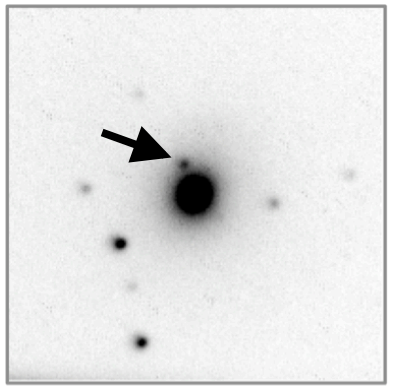


O1 & O2: lessons learned

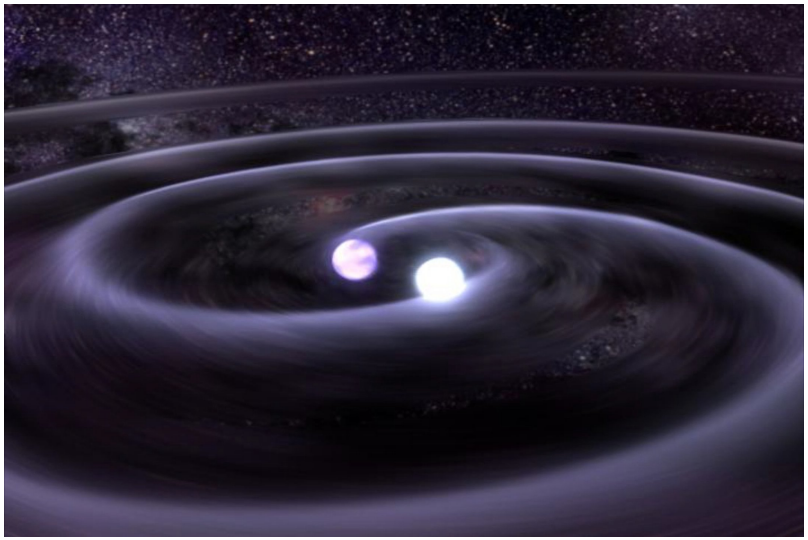


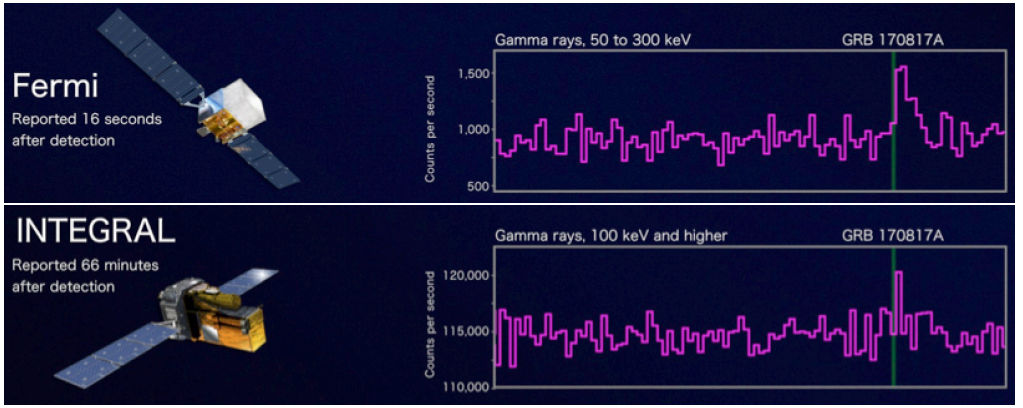


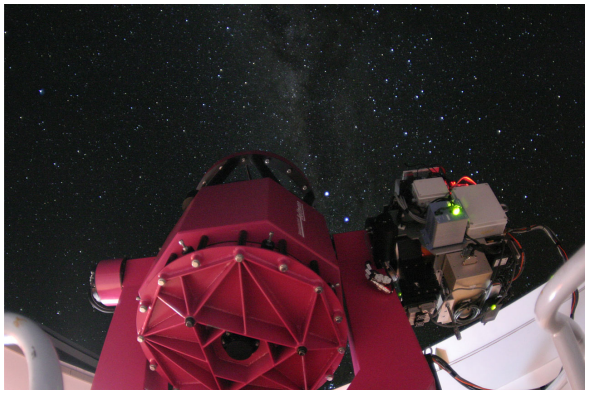


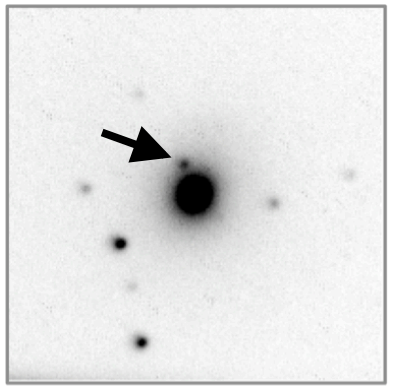


O1 & O2: lessons learned









The Multi-Messenger era

- GW 170717 / GRB 170817A / AT2017gfo results:

- Definition and consolidation of successful follow-up strategies
- First GW EM counterpart (at all wavelengths)
- First unambiguous observational evidence for a kilonova
- Evidence for kilonovae as a heavy elements factory
- `Smoking gun' for short GRB progenitors
- Clues on short GRB outflow geometry and properties: first evidence for a structured jet
- Direct EM distance determination (cosmology)

- Still a number of open issues

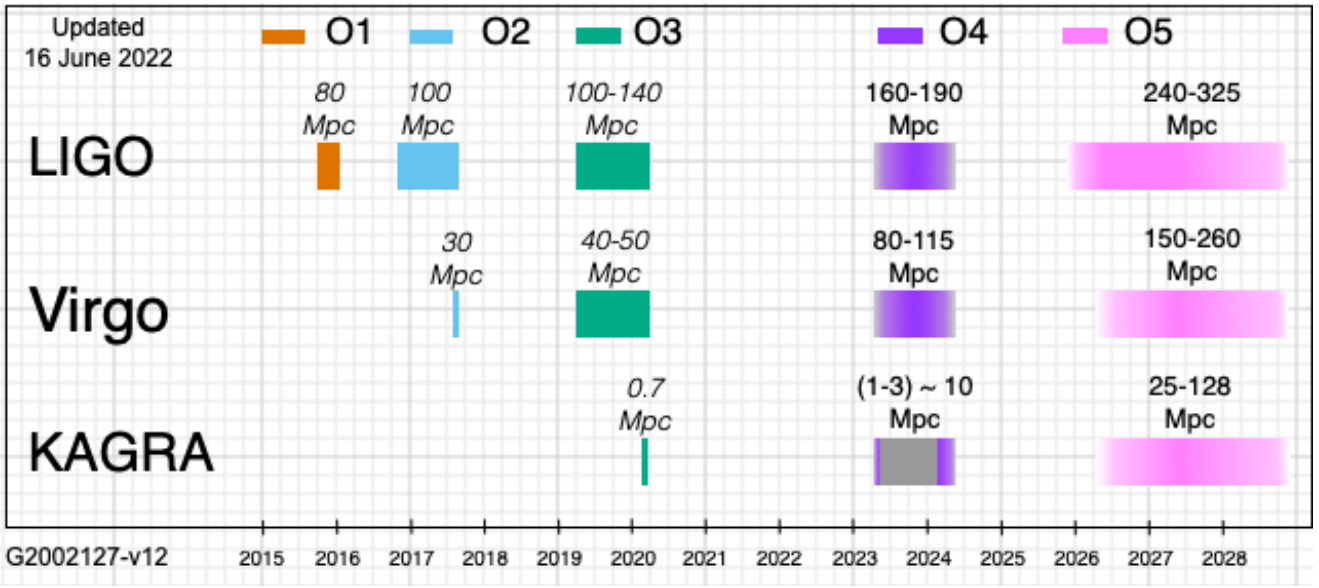
- what about BH-NS EM counterparts?
- what is the origin of the blue KN component?
- are KNe associated to every short GRB?
- how to unveil the nature of the NS-NS remnant?
- (…)

-Scientific perspectives and opportunities:

- Characterize the counterparts of NS-NS / NS-BH mergers
- Determine the yield of heavy elements from KNe
- Study the jet structure, rate and energetics of short GRBs
- Characterize the environment & probe into the binary evolutionary channels
- Direct EM distance determinations on a sample of events
- The unknown

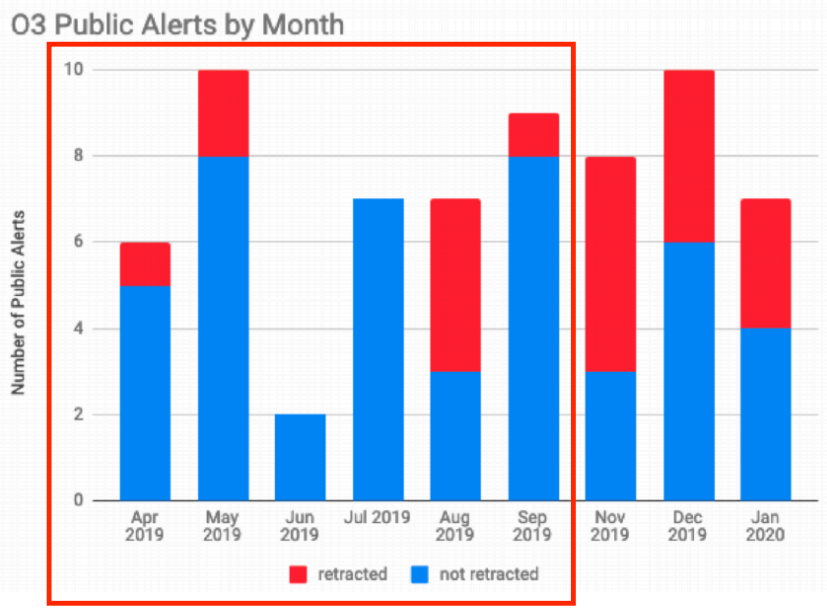
The GW era – O3


LIGO Hanford
LIGO Livingston
GEO 600
Virgo
KAGRA
LIGO-India


Updated
16 June 2022
O1
O2
O3
O4
O5
LIGO
80 Mpc
100 Mpc
100-140 Mpc
160-190 Mpc
240-325 Mpc
Virgo
30 Mpc
40-50 Mpc
80-115 Mpc
150-260 Mpc
KAGRA
0.7 Mpc
(1-3) ~ 10 Mpc
25-128 Mpc
G2002127-v12
2015
2016
2017
2018
2019
2020
2021
2022
2023
2024
2025
2026
2027
2028

The GW era – O3a

Event	M ($M_\odot$)	$\mathcal{M}$ ($M_\odot$)	m_1 ($M_\odot$)	m_2 ($M_\odot$)	$\chi_{\rm eff}$	$D_{\rm L}$ (Gpc)	z	$M_{\rm f}$ ($M_\odot$)	$\chi_{\rm f}$	$\Delta\Omega$ (deg^2)	SNR
GW190408_181802	$43.0^{+4.2}_{-3.0}$	$18.3^{+1.9}_{-1.2}$	$24.6^{+5.1}_{-3.4}$	$18.4^{+3.3}_{-3.6}$	$-0.03^{+0.14}_{-0.19}$	$1.55^{+0.40}_{-0.60}$	$0.29^{+0.06}_{-0.10}$	$41.1^{+3.9}_{-2.8}$	$0.67^{+0.06}_{-0.07}$	150	$15.3^{+0.2}_{-0.3}$
GW190412	$38.4^{+3.8}_{-3.7}$	$13.3^{+0.4}_{-0.3}$	$30.1^{+4.7}_{-5.1}$	$8.3^{+1.6}_{-0.9}$	$0.25^{+0.08}_{-0.11}$	$0.74^{+0.14}_{-0.17}$	$0.15^{+0.03}_{-0.03}$	$37.3^{+3.9}_{-3.8}$	$0.67^{+0.05}_{-0.06}$	21	$18.9^{+0.2}_{-0.3}$
GW190413_052954	$58.6^{+13.3}_{-9.7}$	$24.6^{+5.5}_{-4.1}$	$34.7^{+12.6}_{-8.1}$	$23.7^{+7.3}_{-6.7}$	$-0.01^{+0.29}_{-0.34}$	$3.55^{+2.27}_{-1.66}$	$0.59^{+0.29}_{-0.24}$	$56.0^{+12.5}_{-9.2}$	$0.68^{+0.12}_{-0.13}$	1500	$8.9^{+0.4}_{-0.7}$
GW190413_134308	$78.8^{+17.4}_{-11.9}$	$33.0^{+8.2}_{-5.4}$	$47.5^{+13.5}_{-10.7}$	$31.8^{+11.7}_{-10.8}$	$-0.03^{+0.25}_{-0.29}$	$4.45^{+2.48}_{-2.12}$	$0.71^{+0.31}_{-0.30}$	$75.5^{+16.4}_{-11.4}$	$0.68^{+0.10}_{-0.12}$	730	$10.0^{+0.4}_{-0.5}$
GW190421_213856	$72.9^{+13.4}_{-9.2}$	$31.2^{+5.9}_{-4.2}$	$41.3^{+10.4}_{-6.9}$	$31.9^{+8.0}_{-8.8}$	$-0.06^{+0.22}_{-0.27}$	$2.88^{+1.37}_{-1.38}$	$0.49^{+0.19}_{-0.21}$	$69.7^{+12.5}_{-8.7}$	$0.67^{+0.10}_{-0.11}$	1200	$10.7^{+0.2}_{-0.4}$
GW190424_180648	$72.6^{+13.3}_{-10.7}$	$31.0^{+5.8}_{-4.6}$	$40.5^{+11.1}_{-7.3}$	$31.8^{+7.6}_{-7.7}$	$0.13^{+0.22}_{-0.22}$	$2.20^{+1.58}_{-1.16}$	$0.39^{+0.23}_{-0.19}$	$68.9^{+12.4}_{-10.1}$	$0.74^{+0.09}_{-0.09}$	28000	$10.4^{+0.2}_{-0.4}$
GW190425	$3.4^{+0.3}_{-0.1}$	$1.44^{+0.02}_{-0.02}$	$2.0^{+0.6}_{-0.3}$	$1.4^{+0.3}_{-0.3}$	$0.06^{+0.11}_{-0.05}$	$0.16^{+0.07}_{-0.07}$	$0.03^{+0.01}_{-0.02}$	–	–	10000	$12.4^{+0.3}_{-0.4}$
GW190426_152155	$7.2^{+3.5}_{-1.5}$	$2.41^{+0.08}_{-0.08}$	$5.7^{+3.9}_{-2.3}$	$1.5^{+0.8}_{-0.5}$	$-0.03^{+0.32}_{-0.30}$	$0.37^{+0.18}_{-0.16}$	$0.08^{+0.04}_{-0.03}$	–	–	1300	$8.7^{+0.5}_{-0.6}$
GW190503_185404	$71.7^{+9.4}_{-8.3}$	$30.2^{+4.2}_{-4.2}$	$43.3^{+9.2}_{-8.1}$	$28.4^{+7.7}_{-8.0}$	$-0.03^{+0.20}_{-0.26}$	$1.45^{+0.69}_{-0.63}$	$0.27^{+0.11}_{-0.11}$	$68.6^{+8.8}_{-7.7}$	$0.66^{+0.09}_{-0.12}$	94	$12.4^{+0.2}_{-0.3}$
GW190512_180714	$35.9^{+3.8}_{-3.5}$	$14.6^{+1.3}_{-1.0}$	$23.3^{+5.3}_{-5.8}$	$12.6^{+3.6}_{-2.5}$	$0.03^{+0.12}_{-0.13}$	$1.43^{+0.55}_{-0.55}$	$0.27^{+0.09}_{-0.10}$	$34.5^{+3.8}_{-3.5}$	$0.65^{+0.07}_{-0.07}$	220	$12.2^{+0.2}_{-0.4}$
GW190513_205428	$53.9^{+8.6}_{-5.9}$	$21.6^{+3.8}_{-1.9}$	$35.7^{+9.5}_{-9.2}$	$18.0^{+7.7}_{-4.1}$	$0.11^{+0.28}_{-0.17}$	$2.06^{+0.88}_{-0.80}$	$0.37^{+0.13}_{-0.13}$	$51.6^{+8.2}_{-5.8}$	$0.68^{+0.14}_{-0.12}$	520	$12.9^{+0.3}_{-0.4}$
GW190514_065416	$67.2^{+18.7}_{-10.8}$	$28.5^{+7.9}_{-4.8}$	$39.0^{+14.7}_{-8.2}$	$28.4^{+9.3}_{-8.8}$	$-0.19^{+0.29}_{-0.32}$	$4.13^{+2.65}_{-2.17}$	$0.67^{+0.33}_{-0.31}$	$64.5^{+17.9}_{-10.4}$	$0.63^{+0.11}_{-0.15}$	3000	$8.2^{+0.3}_{-0.6}$
GW190517_055101	$63.5^{+9.6}_{-9.6}$	$26.6^{+4.0}_{-4.0}$	$37.4^{+11.7}_{-7.6}$	$25.3^{+7.0}_{-7.3}$	$0.52^{+0.19}_{-0.19}$	$1.86^{+1.62}_{-0.84}$	$0.34^{+0.24}_{-0.14}$	$59.3^{+9.1}_{-8.9}$	$0.87^{+0.05}_{-0.07}$	470	$10.7^{+0.4}_{-0.6}$
GW190519_153544	$106.6^{+13.5}_{-14.8}$	$44.5^{+6.4}_{-7.1}$	$66.0^{+10.7}_{-12.0}$	$40.5^{+11.0}_{-11.1}$	$0.31^{+0.20}_{-0.22}$	$2.53^{+1.83}_{-0.92}$	$0.44^{+0.25}_{-0.14}$	$101.0^{+12.4}_{-13.8}$	$0.79^{+0.07}_{-0.13}$	860	$15.6^{+0.2}_{-0.3}$
GW190521	$163.9^{+39.2}_{-23.5}$	$69.2^{+17.0}_{-10.6}$	$95.3^{+28.7}_{-18.9}$	$69.0^{+22.7}_{-23.1}$	$0.03^{+0.32}_{-0.39}$	$3.92^{+2.19}_{-1.95}$	$0.64^{+0.28}_{-0.28}$	$156.3^{+36.8}_{-22.4}$	$0.71^{+0.12}_{-0.16}$	1000	$14.2^{+0.3}_{-0.3}$
GW190521_074359	$74.7^{+7.0}_{-4.8}$	$32.1^{+3.2}_{-2.5}$	$42.2^{+5.9}_{-4.8}$	$32.8^{+5.4}_{-6.4}$	$0.09^{+0.10}_{-0.13}$	$1.24^{+0.40}_{-0.57}$	$0.24^{+0.07}_{-0.10}$	$71.0^{+6.5}_{-4.4}$	$0.72^{+0.05}_{-0.07}$	550	$25.8^{+0.1}_{-0.2}$
GW190527_092055	$59.1^{+21.3}_{-9.8}$	$24.3^{+9.1}_{-4.2}$	$36.5^{+16.4}_{-9.0}$	$22.6^{+10.5}_{-8.1}$	$0.11^{+0.28}_{-0.28}$	$2.49^{+2.48}_{-1.24}$	$0.44^{+0.34}_{-0.20}$	$56.4^{+20.2}_{-9.3}$	$0.71^{+0.12}_{-0.16}$	3700	$8.1^{+0.3}_{-0.9}$
GW190602_175927	$116.3^{+19.0}_{-15.6}$	$49.1^{+9.1}_{-8.5}$	$69.1^{+15.7}_{-13.0}$	$47.8^{+14.3}_{-17.4}$	$0.07^{+0.25}_{-0.24}$	$2.69^{+1.79}_{-1.12}$	$0.47^{+0.25}_{-0.17}$	$110.9^{+17.7}_{-14.9}$	$0.70^{+0.10}_{-0.14}$	690	$12.8^{+0.2}_{-0.3}$
GW190620_030421	$92.1^{+18.5}_{-13.1}$	$38.3^{+8.3}_{-6.5}$	$57.1^{+16.0}_{-12.7}$	$35.5^{+12.2}_{-12.3}$	$0.33^{+0.22}_{-0.25}$	$2.81^{+1.68}_{-1.31}$	$0.49^{+0.23}_{-0.20}$	$87.2^{+16.8}_{-12.1}$	$0.79^{+0.08}_{-0.15}$	7200	$12.1^{+0.3}_{-0.4}$
GW190630_185205	$59.1^{+4.6}_{-4.8}$	$24.9^{+2.1}_{-2.1}$	$35.1^{+6.9}_{-5.6}$	$23.7^{+5.2}_{-5.1}$	$0.10^{+0.12}_{-0.13}$	$0.89^{+0.56}_{-0.37}$	$0.18^{+0.10}_{-0.07}$	$56.4^{+4.4}_{-4.6}$	$0.70^{+0.05}_{-0.07}$	1200	$15.6^{+0.2}_{-0.3}$
GW190701_203306	$94.3^{+12.1}_{-9.5}$	$40.3^{+5.4}_{-4.9}$	$53.9^{+11.8}_{-8.0}$	$40.8^{+8.7}_{-12.0}$	$-0.07^{+0.23}_{-0.29}$	$2.06^{+0.76}_{-0.73}$	$0.37^{+0.11}_{-0.12}$	$90.2^{+11.3}_{-8.9}$	$0.66^{+0.09}_{-0.13}$	46	$11.3^{+0.2}_{-0.3}$
GW190706_222641	$104.1^{+20.2}_{-13.9}$	$42.7^{+10.0}_{-7.0}$	$67.0^{+14.6}_{-16.2}$	$38.2^{+14.6}_{-13.3}$	$0.28^{+0.26}_{-0.29}$	$4.42^{+2.59}_{-1.93}$	$0.71^{+0.32}_{-0.27}$	$99.0^{+18.3}_{-13.5}$	$0.78^{+0.09}_{-0.18}$	650	$12.6^{+0.2}_{-0.4}$
GW190707_093326	$20.1^{+1.9}_{-1.3}$	$8.5^{+0.6}_{-0.5}$	$11.6^{+3.3}_{-1.7}$	$8.4^{+1.4}_{-1.7}$	$-0.05^{+0.10}_{-0.08}$	$0.77^{+0.38}_{-0.37}$	$0.16^{+0.07}_{-0.07}$	$19.2^{+1.9}_{-1.3}$	$0.66^{+0.03}_{-0.04}$	1300	$13.3^{+0.2}_{-0.4}$
GW190708_232457	$30.9^{+2.5}_{-1.8}$	$13.2^{+0.9}_{-0.6}$	$17.6^{+4.7}_{-2.3}$	$13.2^{+2.0}_{-2.7}$	$0.02^{+0.10}_{-0.08}$	$0.88^{+0.33}_{-0.39}$	$0.18^{+0.06}_{-0.07}$	$29.5^{+2.5}_{-1.8}$	$0.69^{+0.04}_{-0.04}$	14000	$13.1^{+0.2}_{-0.3}$
GW190719_215514	$57.8^{+18.3}_{-10.7}$	$23.5^{+6.5}_{-4.0}$	$36.5^{+18.0}_{-10.3}$	$20.8^{+9.0}_{-7.2}$	$0.32^{+0.29}_{-0.31}$	$3.94^{+2.59}_{-2.00}$	$0.64^{+0.33}_{-0.29}$	$54.9^{+17.3}_{-10.2}$	$0.78^{+0.11}_{-0.17}$	2900	$8.3^{+0.3}_{-0.8}$
GW190720_000836	$21.5^{+4.3}_{-2.3}$	$8.9^{+0.5}_{-0.8}$	$13.4^{+6.7}_{-3.0}$	$7.8^{+2.3}_{-2.2}$	$0.18^{+0.14}_{-0.12}$	$0.79^{+0.69}_{-0.32}$	$0.16^{+0.12}_{-0.06}$	$20.4^{+4.5}_{-2.2}$	$0.72^{+0.06}_{-0.05}$	460	$11.0^{+0.3}_{-0.7}$
GW190727_060333	$67.1^{+11.7}_{-8.0}$	$28.6^{+5.3}_{-3.7}$	$38.0^{+9.5}_{-6.2}$	$29.4^{+7.1}_{-8.4}$	$0.11^{+0.26}_{-0.25}$	$3.30^{+1.54}_{-1.50}$	$0.55^{+0.21}_{-0.22}$	$63.8^{+10.9}_{-7.5}$	$0.73^{+0.10}_{-0.10}$	830	$11.9^{+0.3}_{-0.5}$
GW190728_064510	$20.6^{+4.5}_{-1.3}$	$8.6^{+0.5}_{-0.3}$	$12.3^{+7.2}_{-2.2}$	$8.1^{+1.7}_{-2.6}$	$0.12^{+0.20}_{-0.07}$	$0.87^{+0.26}_{-0.37}$	$0.18^{+0.05}_{-0.07}$	$19.6^{+4.7}_{-1.3}$	$0.71^{+0.04}_{-0.04}$	400	$13.0^{+0.2}_{-0.4}$
GW190731_140936	$70.1^{+15.8}_{-11.3}$	$29.5^{+7.1}_{-5.2}$	$41.5^{+12.2}_{-9.0}$	$28.8^{+9.7}_{-9.5}$	$0.06^{+0.24}_{-0.24}$	$3.30^{+2.39}_{-1.72}$	$0.55^{+0.31}_{-0.26}$	$67.0^{+14.6}_{-10.8}$	$0.70^{+0.10}_{-0.13}$	3400	$8.7^{+0.2}_{-0.5}$
GW190803_022701	$64.5^{+12.6}_{-9.0}$	$27.3^{+5.7}_{-4.1}$	$37.3^{+10.6}_{-7.0}$	$27.3^{+7.8}_{-8.2}$	$-0.03^{+0.24}_{-0.27}$	$3.27^{+1.95}_{-1.58}$	$0.55^{+0.26}_{-0.24}$	$61.7^{+11.8}_{-8.5}$	$0.68^{+0.10}_{-0.11}$	1500	$8.6^{+0.3}_{-0.5}$
GW190814	$25.8^{+1.0}_{-0.9}$	$6.09^{+0.06}_{-0.06}$	$23.2^{+1.1}_{-1.0}$	$2.59^{+0.08}_{-0.09}$	$0.00^{+0.06}_{-0.06}$	$0.24^{+0.04}_{-0.05}$	$0.05^{+0.009}_{-0.010}$	$25.6^{+1.1}_{-0.9}$	$0.28^{+0.02}_{-0.02}$	19	$24.9^{+0.1}_{-0.2}$
GW190828_063405	$58.0^{+7.7}_{-4.8}$	$25.0^{+3.4}_{-2.1}$	$32.1^{+5.8}_{-4.0}$	$26.2^{+4.6}_{-4.8}$	$0.19^{+0.15}_{-0.16}$	$2.13^{+0.66}_{-0.93}$	$0.38^{+0.10}_{-0.15}$	$54.9^{+7.2}_{-4.3}$	$0.75^{+0.06}_{-0.07}$	520	$16.2^{+0.2}_{-0.3}$
GW190828_065509	$34.4^{+5.4}_{-4.4}$	$13.3^{+1.2}_{-1.0}$	$24.1^{+7.0}_{-7.2}$	$10.2^{+3.6}_{-2.1}$	$0.08^{+0.16}_{-0.16}$	$1.60^{+0.62}_{-0.60}$	$0.30^{+0.10}_{-0.10}$	$33.1^{+5.5}_{-4.5}$	$0.65^{+0.08}_{-0.08}$	660	$10.0^{+0.3}_{-0.5}$
GW190909_114149	$75.0^{+55.9}_{-17.6}$	$30.9^{+17.2}_{-7.5}$	$45.8^{+52.7}_{-13.3}$	$28.3^{+13.4}_{-12.7}$	$-0.06^{+0.37}_{-0.36}$	$3.77^{+3.27}_{-2.22}$	$0.62^{+0.41}_{-0.33}$	$72.0^{+54.9}_{-16.8}$	$0.66^{+0.15}_{-0.20}$	4700	$8.1^{+0.4}_{-0.6}$
GW190910_112807	$79.6^{+9.3}_{-9.1}$	$34.3^{+4.1}_{-4.1}$	$43.9^{+7.6}_{-6.1}$	$35.6^{+6.3}_{-7.2}$	$0.02^{+0.18}_{-0.18}$	$1.46^{+1.03}_{-0.58}$	$0.28^{+0.16}_{-0.10}$	$75.8^{+8.5}_{-8.6}$	$0.70^{+0.08}_{-0.07}$	11000	$14.1^{+0.2}_{-0.3}$
GW190915_235702	$59.9^{+7.5}_{-6.4}$	$25.3^{+3.2}_{-2.7}$	$35.3^{+9.5}_{-6.4}$	$24.4^{+5.6}_{-6.1}$	$0.02^{+0.20}_{-0.25}$	$1.62^{+0.71}_{-0.61}$	$0.30^{+0.11}_{-0.10}$	$57.2^{+7.1}_{-6.0}$	$0.70^{+0.09}_{-0.11}$	400	$13.6^{+0.2}_{-0.3}$
GW190924_021846	$13.9^{+5.1}_{-1.0}$	$5.8^{+0.2}_{-0.2}$	$8.9^{+7.0}_{-2.0}$	$5.0^{+1.4}_{-1.9}$	$0.03^{+0.30}_{-0.09}$	$0.57^{+0.22}_{-0.22}$	$0.12^{+0.04}_{-0.04}$	$13.3^{+5.2}_{-1.0}$	$0.67^{+0.05}_{-0.05}$	360	$11.5^{+0.3}_{-0.4}$
GW190929_012149	$104.3^{+34.9}_{-25.2}$	$35.8^{+14.9}_{-8.2}$	$80.8^{+33.0}_{-33.2}$	$24.1^{+19.3}_{-10.6}$	$0.01^{+0.34}_{-0.33}$	$2.13^{+3.65}_{-1.05}$	$0.38^{+0.49}_{-0.17}$	$101.5^{+33.6}_{-25.3}$	$0.66^{+0.20}_{-0.31}$	2200	$10.1^{+0.6}_{-0.8}$
GW190930_133541	$20.3^{+8.9}_{-1.5}$	$8.5^{+0.5}_{-0.5}$	$12.3^{+12.4}_{-2.3}$	$7.8^{+1.7}_{-3.3}$	$0.14^{+0.31}_{-0.15}$	$0.76^{+0.36}_{-0.32}$	$0.15^{+0.06}_{-0.06}$	$19.4^{+9.2}_{-1.5}$	$0.72^{+0.07}_{-0.06}$	1700	$9.5^{+0.3}_{-0.5}$

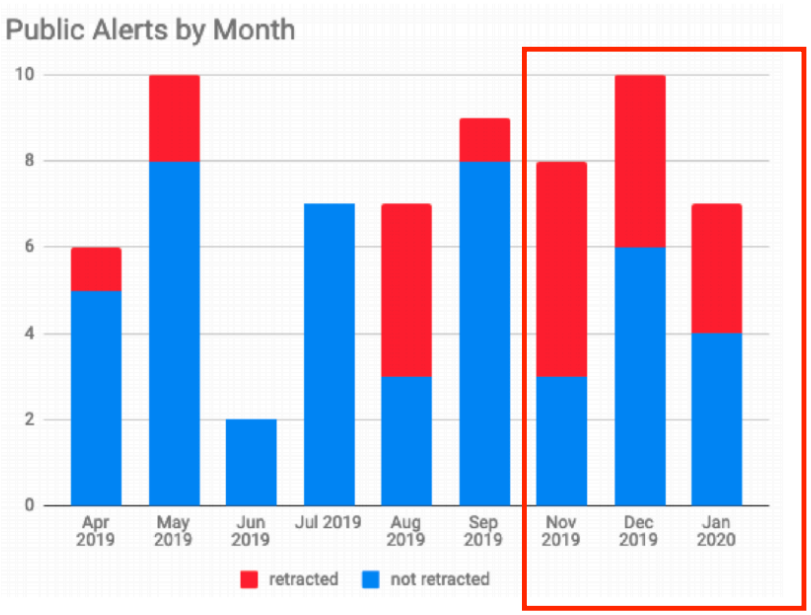


O3a (Apr – Sep 2019)
39 events, 3 with $M < 3\ M_{SUN}$:

GW 190425 -> BNS, 10^4 deg^2 skymap
GW 190426 -> BHNS, 10^3 deg^2 skymap
GW190814 -> (?) BHNS, 19 deg^2 skymap

The GW era – O3b

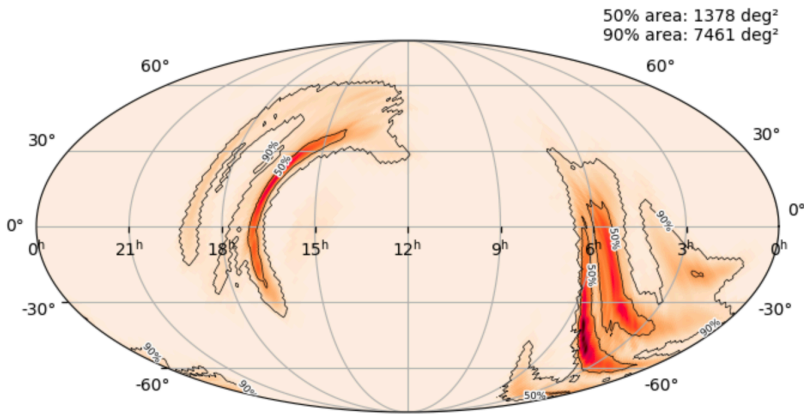
Event	M ($M_\odot$)	$\mathcal{M}$ ($M_\odot$)	m_1 ($M_\odot$)	m_2 ($M_\odot$)	$\chi_{\rm eff}$	$D_{\rm L}$ (Gpc)	z	$M_{\rm f}$ ($M_\odot$)	$\chi_{\rm f}$	$\Delta\Omega$ (deg^2)	SNR
GW191103_012549	$20.0^{+3.7}_{-1.8}$	$8.34^{+0.66}_{-0.57}$	$11.8^{+6.2}_{-2.2}$	$7.9^{+1.7}_{-2.4}$	$0.21^{+0.16}_{-0.10}$	$0.99^{+0.50}_{-0.47}$	$0.20^{+0.09}_{-0.09}$	$19.0^{+3.8}_{-1.7}$	$0.75^{+0.06}_{-0.05}$	2500	$8.9^{+0.3}_{-0.5}$
GW191105_143521	$18.5^{+2.1}_{-1.3}$	$7.82^{+0.61}_{-0.45}$	$10.7^{+3.7}_{-1.6}$	$7.7^{+1.4}_{-1.9}$	$-0.02^{+0.13}_{-0.09}$	$1.15^{+0.43}_{-0.48}$	$0.23^{+0.07}_{-0.09}$	$17.6^{+2.1}_{-1.2}$	$0.67^{+0.04}_{-0.05}$	640	$9.7^{+0.3}_{-0.5}$
GW191109_010717	112^{+20}_{-16}	$47.5^{+9.6}_{-7.5}$	65^{+11}_{-11}	47^{+15}_{-13}	$-0.29^{+0.42}_{-0.31}$	$1.29^{+1.13}_{-0.65}$	$0.25^{+0.18}_{-0.12}$	107^{+18}_{-15}	$0.61^{+0.18}_{-0.19}$	1600	$17.3^{+0.5}_{-0.5}$
GW191113_071753	$34.5^{+10.5}_{-9.8}$	$10.7^{+1.1}_{-1.0}$	29^{+12}_{-14}	$5.9^{+4.4}_{-1.3}$	$0.00^{+0.37}_{-0.29}$	$1.37^{+1.15}_{-0.62}$	$0.26^{+0.18}_{-0.11}$	34^{+11}_{-10}	$0.45^{+0.33}_{-0.11}$	3600	$7.9^{+0.5}_{-1.1}$
GW191126_115259	$20.7^{+3.4}_{-2.0}$	$8.65^{+0.95}_{-0.71}$	$12.1^{+5.5}_{-2.2}$	$8.3^{+1.9}_{-2.4}$	$0.21^{+0.15}_{-0.11}$	$1.62^{+0.74}_{-0.74}$	$0.30^{+0.12}_{-0.13}$	$19.6^{+3.5}_{-2.0}$	$0.75^{+0.06}_{-0.05}$	1400	$8.3^{+0.2}_{-0.5}$
GW191127_050227	80^{+39}_{-22}	$29.9^{+11.7}_{-9.1}$	53^{+47}_{-20}	24^{+17}_{-14}	$0.18^{+0.34}_{-0.36}$	$3.4^{+3.1}_{-1.9}$	$0.57^{+0.40}_{-0.29}$	76^{+39}_{-21}	$0.75^{+0.13}_{-0.29}$	980	$9.2^{+0.7}_{-0.6}$
GW191129_134029	$17.5^{+2.4}_{-1.2}$	$7.31^{+0.43}_{-0.28}$	$10.7^{+4.1}_{-2.1}$	$6.7^{+1.5}_{-1.7}$	$0.06^{+0.16}_{-0.08}$	$0.79^{+0.26}_{-0.33}$	$0.16^{+0.05}_{-0.06}$	$16.8^{+2.5}_{-1.2}$	$0.69^{+0.03}_{-0.05}$	850	$13.1^{+0.2}_{-0.3}$
GW191204_110529	$47.2^{+9.2}_{-8.0}$	$19.8^{+3.6}_{-3.3}$	$27.3^{+11.0}_{-6.0}$	$19.3^{+5.6}_{-6.0}$	$0.05^{+0.26}_{-0.27}$	$1.8^{+1.7}_{-1.1}$	$0.34^{+0.25}_{-0.18}$	$45.0^{+8.6}_{-7.6}$	$0.71^{+0.12}_{-0.11}$	3700	$8.8^{+0.4}_{-0.6}$
GW191204_171526	$20.21^{+1.70}_{-0.96}$	$8.55^{+0.38}_{-0.27}$	$11.9^{+3.3}_{-1.8}$	$8.2^{+1.4}_{-1.6}$	$0.16^{+0.08}_{-0.05}$	$0.65^{+0.19}_{-0.25}$	$0.13^{+0.04}_{-0.05}$	$19.21^{+1.79}_{-0.95}$	$0.73^{+0.03}_{-0.03}$	350	$17.5^{+0.2}_{-0.2}$
GW191215_223052	$43.3^{+5.3}_{-4.3}$	$18.4^{+2.2}_{-1.7}$	$24.9^{+7.1}_{-4.1}$	$18.1^{+3.8}_{-4.1}$	$-0.04^{+0.17}_{-0.21}$	$1.93^{+0.89}_{-0.86}$	$0.35^{+0.13}_{-0.14}$	$41.4^{+5.1}_{-4.1}$	$0.68^{+0.07}_{-0.07}$	530	$11.2^{+0.3}_{-0.4}$
GW191216_213338	$19.81^{+2.69}_{-0.94}$	$8.33^{+0.22}_{-0.19}$	$12.1^{+4.6}_{-2.3}$	$7.7^{+1.6}_{-1.9}$	$0.11^{+0.13}_{-0.06}$	$0.34^{+0.12}_{-0.13}$	$0.07^{+0.02}_{-0.03}$	$18.87^{+2.80}_{-0.94}$	$0.70^{+0.03}_{-0.04}$	490	$18.6^{+0.2}_{-0.2}$
GW191219_163120	$32.3^{+2.2}_{-2.7}$	$4.32^{+0.12}_{-0.17}$	$31.1^{+2.2}_{-2.8}$	$1.17^{+0.07}_{-0.06}$	$0.00^{+0.07}_{-0.09}$	$0.55^{+0.25}_{-0.16}$	$0.11^{+0.05}_{-0.03}$	$32.2^{+2.2}_{-2.7}$	$0.14^{+0.06}_{-0.06}$	1500	$9.1^{+0.5}_{-0.8}$
GW191222_033537	79^{+16}_{-11}	$33.8^{+7.1}_{-5.0}$	$45.1^{+10.9}_{-8.0}$	$34.7^{+9.3}_{-10.5}$	$-0.04^{+0.20}_{-0.25}$	$3.0^{+1.7}_{-1.7}$	$0.51^{+0.23}_{-0.26}$	$75.5^{+15.3}_{-9.9}$	$0.67^{+0.08}_{-0.11}$	2000	$12.5^{+0.2}_{-0.3}$
GW191230_180458	86^{+19}_{-12}	$36.5^{+8.2}_{-5.6}$	$49.4^{+14.0}_{-9.6}$	37^{+11}_{-12}	$-0.05^{+0.26}_{-0.31}$	$4.3^{+2.1}_{-1.9}$	$0.69^{+0.26}_{-0.27}$	82^{+17}_{-11}	$0.68^{+0.11}_{-0.13}$	1100	$10.4^{+0.3}_{-0.4}$
GW200105_162426	$11.0^{+1.5}_{-1.4}$	$3.42^{+0.08}_{-0.08}$	$9.0^{+1.7}_{-1.7}$	$1.91^{+0.33}_{-0.24}$	$0.00^{+0.13}_{-0.18}$	$0.27^{+0.12}_{-0.11}$	$0.06^{+0.02}_{-0.02}$	$10.7^{+1.5}_{-1.4}$	$0.43^{+0.05}_{-0.02}$	7900	$13.7^{+0.2}_{-0.4}$
GW200112_155838	$63.9^{+5.7}_{-4.6}$	$27.4^{+2.6}_{-2.1}$	$35.6^{+6.7}_{-4.5}$	$28.3^{+4.4}_{-5.9}$	$0.06^{+0.15}_{-0.15}$	$1.25^{+0.43}_{-0.46}$	$0.24^{+0.07}_{-0.08}$	$60.8^{+5.3}_{-4.3}$	$0.71^{+0.06}_{-0.06}$	4300	$19.8^{+0.1}_{-0.2}$
GW200115_042309	$7.4^{+1.8}_{-1.7}$	$2.43^{+0.05}_{-0.07}$	$5.9^{+2.0}_{-2.5}$	$1.44^{+0.85}_{-0.29}$	$-0.15^{+0.24}_{-0.42}$	$0.29^{+0.15}_{-0.10}$	$0.06^{+0.03}_{-0.02}$	$7.2^{+1.8}_{-1.7}$	$0.42^{+0.09}_{-0.05}$	370	$11.3^{+0.3}_{-0.5}$
GW200128_022011	75^{+17}_{-12}	$32.0^{+7.5}_{-5.5}$	$42.2^{+11.6}_{-8.1}$	$32.6^{+9.5}_{-9.2}$	$0.12^{+0.24}_{-0.25}$	$3.4^{+2.1}_{-1.8}$	$0.56^{+0.28}_{-0.28}$	71^{+16}_{-11}	$0.74^{+0.10}_{-0.10}$	2600	$10.6^{+0.3}_{-0.4}$
GW200129_065458	$63.4^{+4.3}_{-3.6}$	$27.2^{+2.1}_{-2.3}$	$34.5^{+9.9}_{-3.2}$	$28.9^{+3.4}_{-9.3}$	$0.11^{+0.11}_{-0.16}$	$0.90^{+0.29}_{-0.38}$	$0.18^{+0.05}_{-0.07}$	$60.3^{+4.0}_{-3.3}$	$0.73^{+0.06}_{-0.05}$	130	$26.8^{+0.2}_{-0.2}$
GW200202_154313	$17.58^{+1.78}_{-0.67}$	$7.49^{+0.24}_{-0.20}$	$10.1^{+3.5}_{-1.4}$	$7.3^{+1.1}_{-1.7}$	$0.04^{+0.13}_{-0.06}$	$0.41^{+0.15}_{-0.16}$	$0.09^{+0.03}_{-0.03}$	$16.76^{+1.87}_{-0.66}$	$0.69^{+0.03}_{-0.04}$	170	$10.8^{+0.2}_{-0.4}$
GW200208_130117	$65.4^{+7.8}_{-6.8}$	$27.7^{+3.6}_{-3.1}$	$37.8^{+9.2}_{-6.2}$	$27.4^{+6.1}_{-7.4}$	$-0.07^{+0.22}_{-0.27}$	$2.23^{+1.00}_{-0.85}$	$0.40^{+0.15}_{-0.14}$	$62.5^{+7.3}_{-6.4}$	$0.66^{+0.09}_{-0.13}$	30	$10.8^{+0.3}_{-0.4}$
GW200208_222617	63^{+100}_{-25}	$19.6^{+10.7}_{-5.1}$	51^{+104}_{-30}	$12.3^{+9.0}_{-5.7}$	$0.45^{+0.43}_{-0.44}$	$4.1^{+4.4}_{-1.9}$	$0.66^{+0.54}_{-0.28}$	61^{+100}_{-25}	$0.83^{+0.14}_{-0.27}$	2000	$7.4^{+1.4}_{-1.2}$
GW200209_085452	$62.6^{+13.9}_{-9.4}$	$26.7^{+6.0}_{-4.2}$	$35.6^{+10.5}_{-6.8}$	$27.1^{+7.8}_{-7.8}$	$-0.12^{+0.24}_{-0.30}$	$3.4^{+1.9}_{-1.8}$	$0.57^{+0.25}_{-0.26}$	$59.9^{+13.1}_{-8.9}$	$0.66^{+0.10}_{-0.12}$	730	$9.6^{+0.4}_{-0.5}$
GW200210_092254	$27.0^{+7.1}_{-4.3}$	$6.56^{+0.38}_{-0.40}$	$24.1^{+7.5}_{-4.6}$	$2.83^{+0.47}_{-0.42}$	$0.02^{+0.22}_{-0.21}$	$0.94^{+0.43}_{-0.34}$	$0.19^{+0.08}_{-0.06}$	$26.7^{+7.2}_{-4.3}$	$0.34^{+0.13}_{-0.08}$	1800	$8.4^{+0.5}_{-0.7}$
GW200216_220804	81^{+20}_{-14}	$32.9^{+9.3}_{-8.5}$	51^{+22}_{-13}	30^{+14}_{-16}	$0.10^{+0.34}_{-0.36}$	$3.8^{+3.0}_{-2.0}$	$0.63^{+0.37}_{-0.29}$	78^{+19}_{-13}	$0.70^{+0.14}_{-0.24}$	2900	$8.1^{+0.4}_{-0.5}$
GW200219_094415	$65.0^{+12.6}_{-8.2}$	$27.6^{+5.6}_{-3.8}$	$37.5^{+10.1}_{-6.9}$	$27.9^{+7.4}_{-8.4}$	$-0.08^{+0.23}_{-0.29}$	$3.4^{+1.7}_{-1.5}$	$0.57^{+0.22}_{-0.22}$	$62.2^{+11.7}_{-7.8}$	$0.66^{+0.10}_{-0.13}$	700	$10.7^{+0.3}_{-0.5}$
GW200220_061928	148^{+55}_{-33}	62^{+23}_{-15}	87^{+40}_{-23}	61^{+26}_{-25}	$0.06^{+0.40}_{-0.38}$	$6.0^{+4.8}_{-3.1}$	$0.90^{+0.55}_{-0.40}$	141^{+51}_{-31}	$0.71^{+0.15}_{-0.17}$	3000	$7.2^{+0.4}_{-0.7}$
GW200220_124850	67^{+17}_{-12}	$28.2^{+7.3}_{-5.1}$	$38.9^{+14.1}_{-8.6}$	$27.9^{+9.2}_{-9.0}$	$-0.07^{+0.27}_{-0.33}$	$4.0^{+2.8}_{-2.2}$	$0.66^{+0.36}_{-0.31}$	64^{+16}_{-11}	$0.67^{+0.11}_{-0.14}$	3200	$8.5^{+0.3}_{-0.5}$
GW200224_222234	$72.2^{+7.2}_{-5.1}$	$31.1^{+3.2}_{-2.6}$	$40.0^{+6.9}_{-4.5}$	$32.5^{+5.0}_{-7.2}$	$0.10^{+0.15}_{-0.15}$	$1.71^{+0.49}_{-0.64}$	$0.32^{+0.08}_{-0.11}$	$68.6^{+6.6}_{-4.7}$	$0.73^{+0.07}_{-0.07}$	50	$20.0^{+0.2}_{-0.2}$
GW200225_060421	$33.5^{+3.6}_{-3.0}$	$14.2^{+1.5}_{-1.4}$	$19.3^{+5.0}_{-3.0}$	$14.0^{+2.8}_{-3.5}$	$-0.12^{+0.17}_{-0.28}$	$1.15^{+0.51}_{-0.53}$	$0.22^{+0.09}_{-0.10}$	$32.1^{+3.5}_{-2.8}$	$0.66^{+0.07}_{-0.13}$	370	$12.5^{+0.3}_{-0.4}$
GW200302_015811	$57.8^{+9.6}_{-6.9}$	$23.4^{+4.7}_{-3.0}$	$37.8^{+8.7}_{-8.5}$	$20.0^{+8.1}_{-5.7}$	$0.01^{+0.25}_{-0.26}$	$1.48^{+1.02}_{-0.70}$	$0.28^{+0.16}_{-0.12}$	$55.5^{+8.9}_{-6.6}$	$0.66^{+0.13}_{-0.15}$	6000	$10.8^{+0.3}_{-0.4}$
GW200306_093714	$43.9^{+11.8}_{-7.5}$	$17.5^{+3.5}_{-3.0}$	$28.3^{+17.1}_{-7.7}$	$14.8^{+6.5}_{-6.4}$	$0.32^{+0.28}_{-0.46}$	$2.1^{+1.7}_{-1.1}$	$0.38^{+0.24}_{-0.18}$	$41.7^{+12.3}_{-6.9}$	$0.78^{+0.11}_{-0.26}$	4600	$7.8^{+0.4}_{-0.6}$
GW200308_173609*	$50.6^{+10.9}_{-8.5}$	$19.0^{+4.8}_{-2.8}$	$36.4^{+11.2}_{-9.6}$	$13.8^{+7.2}_{-3.3}$	$0.65^{+0.17}_{-0.21}$	$5.4^{+2.7}_{-2.6}$	$0.83^{+0.32}_{-0.35}$	$47.4^{+11.1}_{-7.7}$	$0.91^{+0.03}_{-0.08}$	2000	$7.1^{+0.5}_{-0.5}$
GW200311_115853	$61.9^{+5.3}_{-4.2}$	$26.6^{+2.4}_{-2.0}$	$34.2^{+6.4}_{-3.8}$	$27.7^{+4.1}_{-5.9}$	$-0.02^{+0.16}_{-0.20}$	$1.17^{+0.28}_{-0.40}$	$0.23^{+0.05}_{-0.07}$	$59.0^{+4.8}_{-3.9}$	$0.69^{+0.07}_{-0.08}$	35	$17.8^{+0.2}_{-0.2}$
GW200316_215756	$21.2^{+7.2}_{-2.0}$	$8.75^{+0.62}_{-0.55}$	$13.1^{+10.2}_{-2.9}$	$7.8^{+1.9}_{-2.9}$	$0.13^{+0.27}_{-0.10}$	$1.12^{+0.47}_{-0.44}$	$0.22^{+0.08}_{-0.08}$	$20.2^{+7.4}_{-1.9}$	$0.70^{+0.04}_{-0.04}$	190	$10.3^{+0.4}_{-0.7}$
GW200322_091133*	55^{+37}_{-27}	$15.5^{+15.7}_{-3.7}$	34^{+48}_{-18}	$14.0^{+16.8}_{-8.7}$	$0.24^{+0.45}_{-0.51}$	$3.6^{+7.0}_{-2.0}$	$0.60^{+0.84}_{-0.30}$	53^{+38}_{-26}	$0.78^{+0.16}_{-0.17}$	6500	$6.0^{+1.7}_{-1.2}$



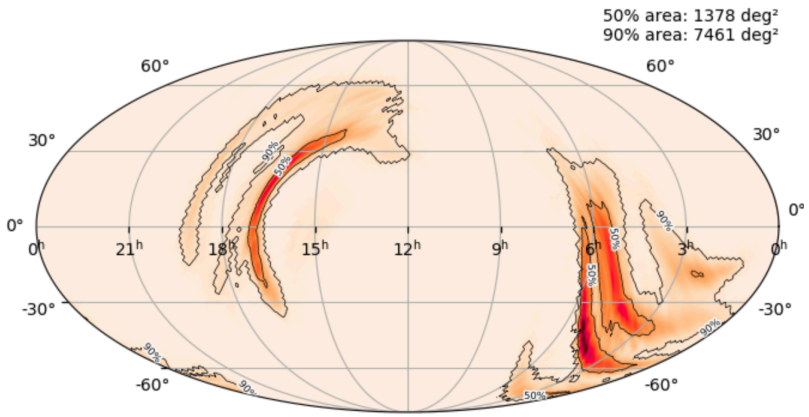
O3b (Nov 2019 – Mar 2020)
35 events, 2 with $M < 3\ M_{SUN}$:

GW 191219 -> BHNS, 10^3 deg^2 skymap
GW 200210 -> BHNS/BBH, 10^3 deg^2 skymap

O3: lessons learned



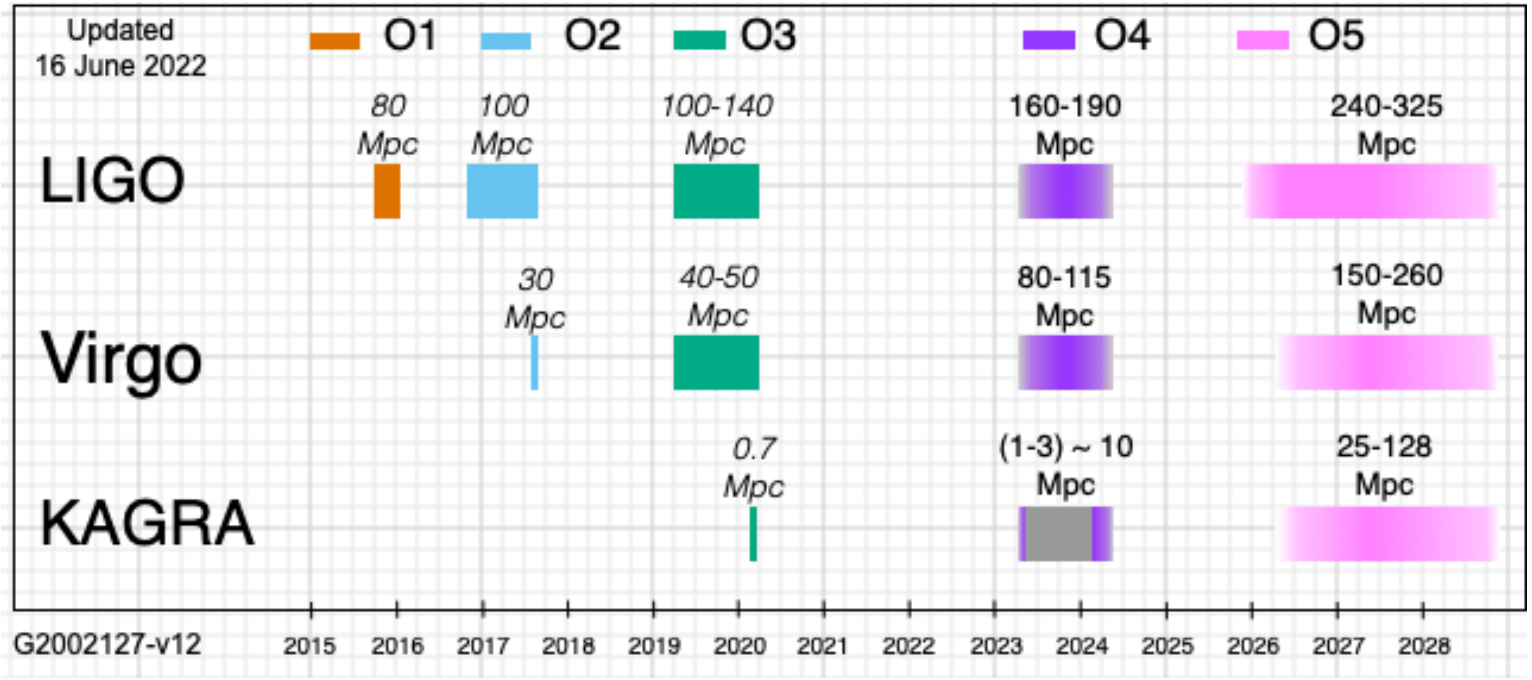
O3: lessons learned



O4 timeline

https://observing.docs.ligo.org/plan/

LIGO, Virgo, and KAGRA continue to work to prepare the detectors for the start of O4. Our ability to start O4 in March 2023 is currently under review. Unanticipated delays in some construction elements of LIGO has delayed remaining detector commissioning (…) we expect to be able to make a more confident plan for starting early in January.



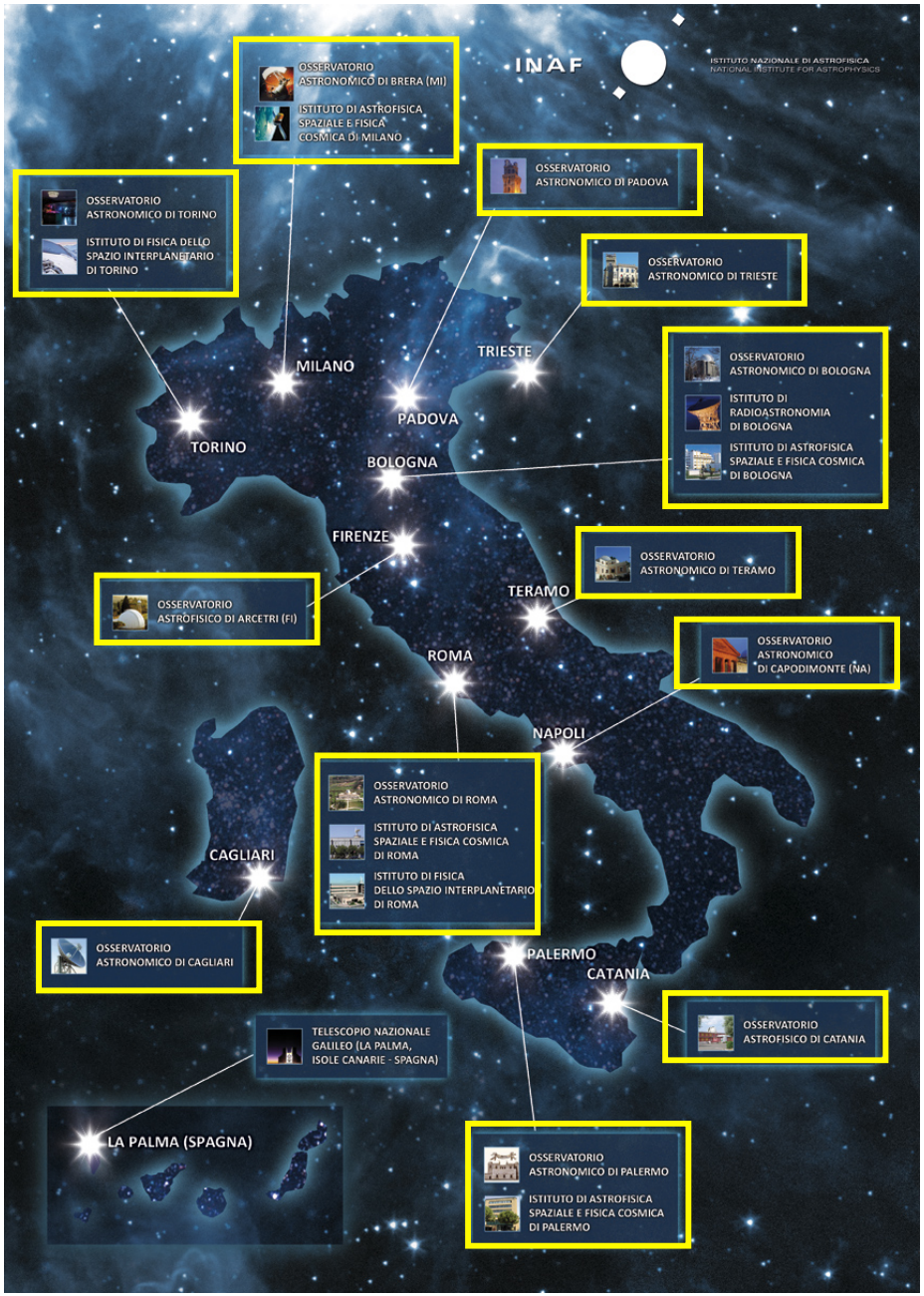
During O4, we expect that four facilities (LIGO Hanford (LHO) and Livingston (LLO), KAGRA and Virgo) will observe for one year with a month break in the middle. KAGRA is expected to start with Virgo and LIGO, and then step away for commissioning and return to observing with a greater sensitivity toward the end of the O4 run.

Rates in O4 are highly uncertain: we may have > 3 GW trigger per week

Multi-Messenger Astrophysics (GW) @ RSN4

INAF
ISTITUTO NAZIONALE
DI ASTROFISICA

Multi-Messenger Astrophysics (GW) @ RSN4



Scheda	Coordinator	# INAF Institutes	# INAF people
AGILE	C. Pittori	8	35
ET	*M. Branchesi*	13	55
Fermi Science	P. Caraveo	4	12
GAME	L. Piro	4	13
GRAWITA	E. Brocato	11	66
GRB@Mi	G. Ghirlanda	3	13
GRB@OAS	E. Pian	4	11
GuRu	S. Piranomonte	6	9
HERMES	F. Fiore	8	30
INTEGRAL	L. Natalucci	3	14
INTEGRAL HEASS	A. Malizia	3	14
LGWA	*J. Harms*	9	27
NuMerJet	R. Ciolfi	9	18
Progress	L. A. Antonelli	15	244
Swift	G. Tagliaferri	4	24

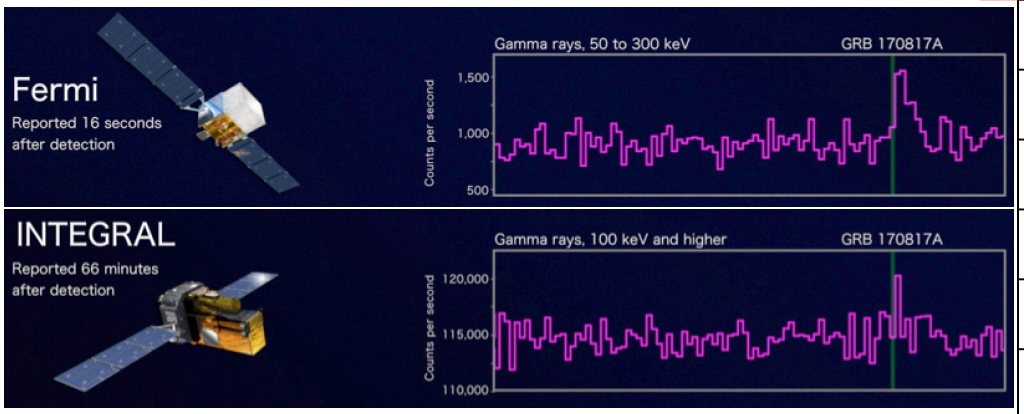
Multi-Messenger Astrophysics (GW) @ RSN4

Search for coincident GW-GRBs since O1

Scheda	Coordinator	# INAF Institutes	# INAF people
AGILE	C. Pittori	8	35
ET	*M. Branchesi*	13	55
Fermi Science	P. Caraveo	4	12
GAME	L. Piro	4	13
GRAWITA	E. Brocato	11	66
GRB@Mi	G. Ghirlanda	3	13
GRB@OAS	E. Pian	4	11
GuRu	S. Piranomonte	6	9
HERMES	F. Fiore	8	30
INTEGRAL	L. Natalucci	3	14
INTEGRAL HEASS	A. Malizia	3	14
LGWA	*J. Harms*	9	27
NuMerJet	R. Ciolfi	9	18
Progress	L. A. Antonelli	15	244
Swift	G. Tagliaferri	4	24

Multi-Messenger Astrophysics (GW) @ RSN4

Detection of the short GRB 170817A, associated to GW 170817

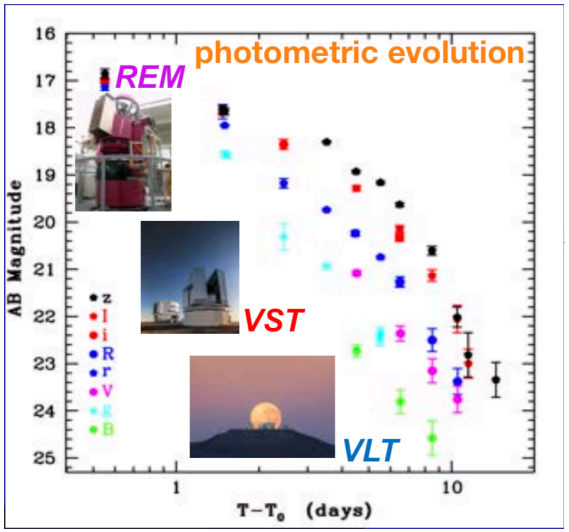


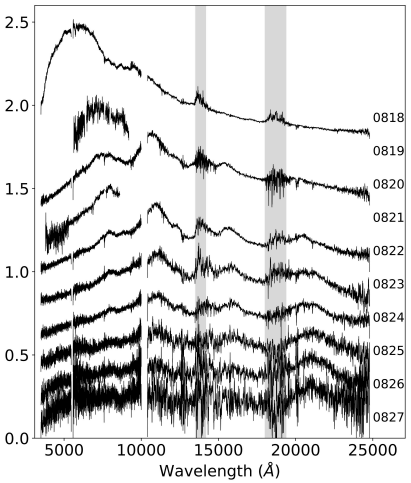
Scheda	Coordinator	# INAF Institutes	# INAF people
AGILE	C. Pittori	8	35
ET	*M. Branchesi*	13	55
Fermi Science	P. Caraveo	4	12
GAME	L. Piro	4	13
GRAWITA	E. Brocato	11	66
GRB@Mi	G. Ghirlanda	3	13
GRB@OAS	E. Pian	4	11
GuRu	S. Piranomonte	6	9
HERMES	F. Fiore	8	30
INTEGRAL	L. Natalucci	3	14
INTEGRAL HEASS	A. Malizia	3	14
LGWA	*J. Harms*	9	27
NuMerJet	R. Ciolfi	9	18
Progress	L. A. Antonelli	15	244
Swift	G. Tagliaferri	4	24

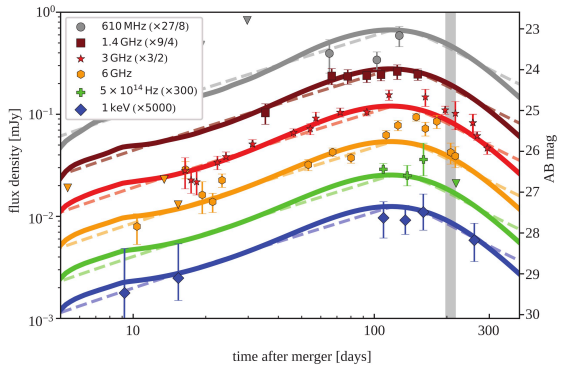
Multi-Messenger Astrophysics (GW) @ RSN4

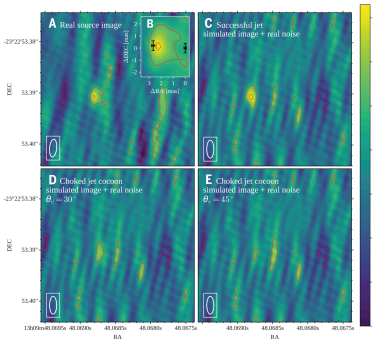
INAF ISTITUTO NAZIONALE DI ASTROFISICA

Full characterisation of the GW 170817 KN







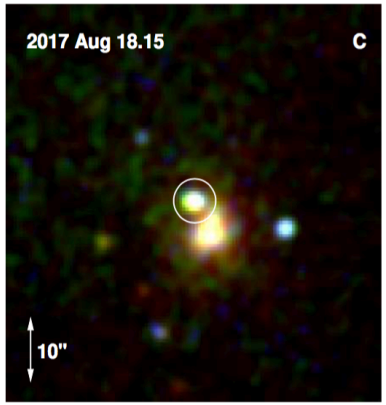


Study of the off-axis GRB afterglow emission
-> evidence for structured jet

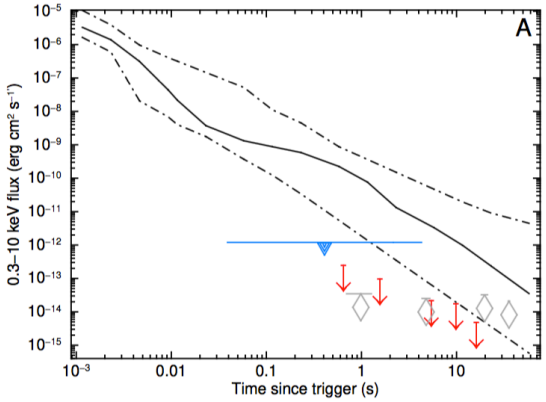
Scheda	Coordinator	# INAF Institutes	# INAF people
AGILE	C. Pittori	8	35
ET	*M. Branchesi*	13	55
Fermi Science	P. Caraveo	4	12
GAME	L. Piro	4	13
GRAWITA	E. Brocato	11	66
GRB@Mi	G. Ghirlanda	3	13
GRB@OAS	E. Pian	4	11
GuRu	S. Piranomonte	6	9
HERMES	F. Fiore	8	30
INTEGRAL	L. Natalucci	3	14
INTEGRAL HEASS	A. Malizia	3	14
LGWA	*J. Harms*	9	27
NuMerJet	R. Ciolfi	9	18
Progress	L. A. Antonelli	15	244
Swift	G. Tagliaferri	4	24

Multi-Messenger Astrophysics (GW) @ RSN4

1st (unique) UV KN detection (blue KN)



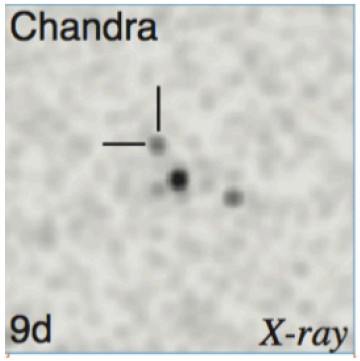
Early-time X-ray limits (1st hint for GRB off-axis emission)

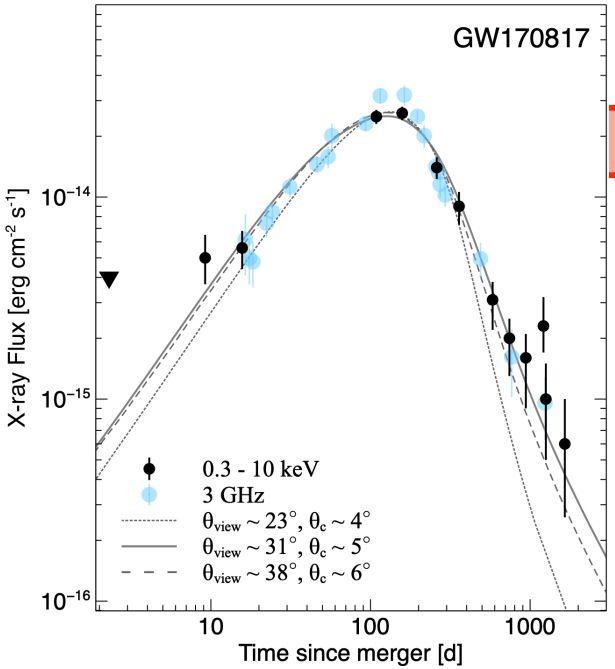


Scheda	Coordinator	# INAF Institutes	# INAF people
AGILE	C. Pittori	8	35
ET	*M. Branchesi*	13	55
Fermi Science	P. Caraveo	4	12
GAME	L. Piro	4	13
GRAWITA	E. Brocato	11	66
GRB@Mi	G. Ghirlanda	3	13
GRB@OAS	E. Pian	4	11
GuRu	S. Piranomonte	6	9
HERMES	F. Fiore	8	30
INTEGRAL	L. Natalucci	3	14
INTEGRAL HEASS	A. Malizia	3	14
LGWA	*J. Harms*	9	27
NuMerJet	R. Ciolfi	9	18
Progress	L. A. Antonelli	15	244
Swift	G. Tagliaferri	4	24

Multi-Messenger Astrophysics (GW) @ RSN4

Discovery of the X-ray afterglow

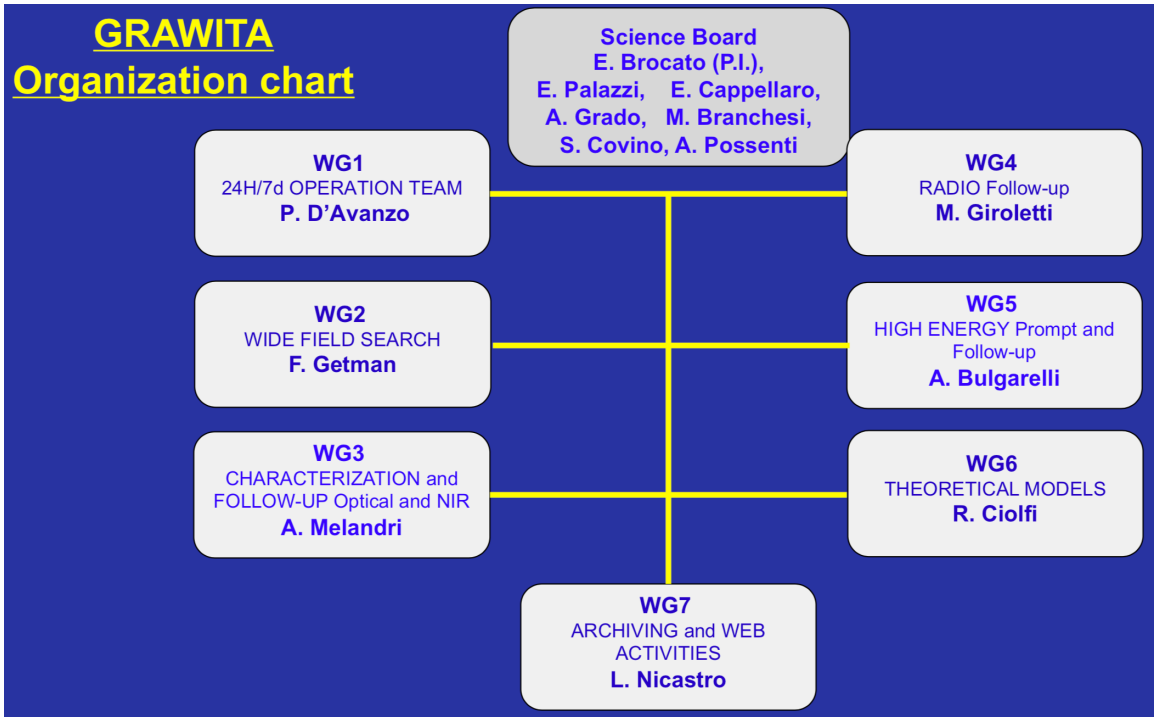




Long-term monitoring of the off-axis GRB afterglow emission -> evidence for structured jet

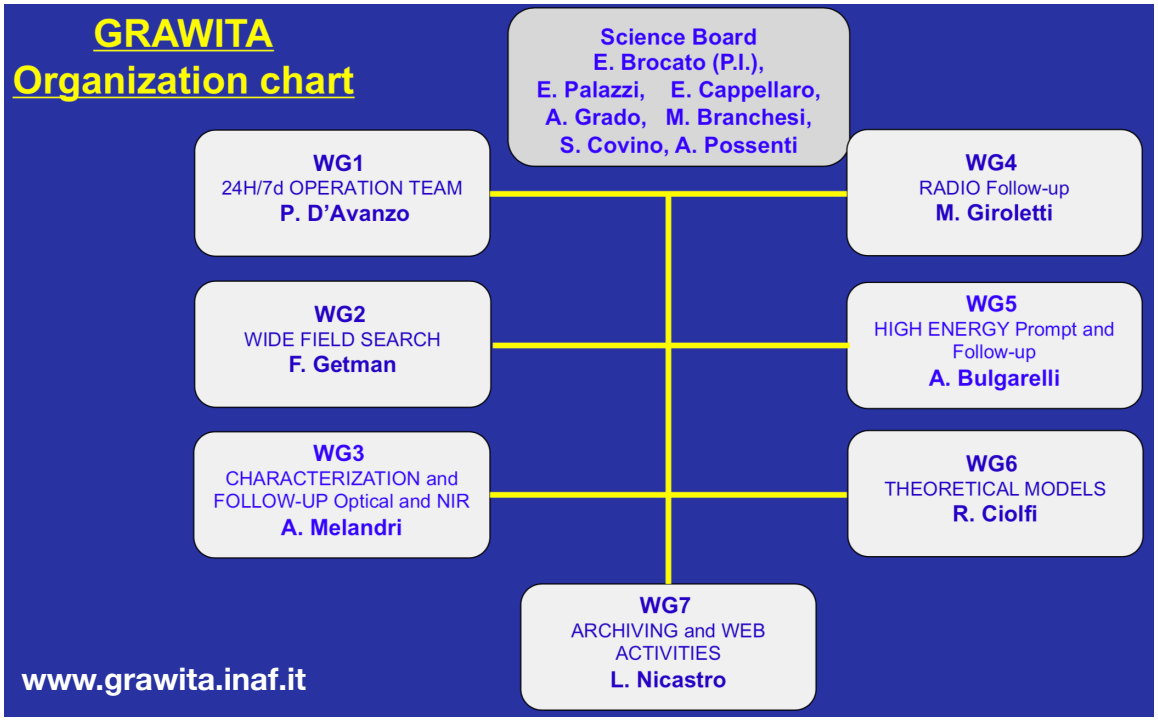
Scheda	Coordinator	# INAF Institutes	# INAF people
AGILE	C. Pittori	8	35
ET	*M. Branchesi*	13	55
Fermi Science	P. Caraveo	4	12
GAME	L. Piro	4	13
GRAWITA	E. Brocato	11	66
GRB@Mi	G. Ghirlanda	3	13
GRB@OAS	E. Pian	4	11
GuRu	S. Piranomonte	6	9
HERMES	F. Fiore	8	30
INTEGRAL	L. Natalucci	3	14
INTEGRAL HEASS	A. Malizia	3	14
LGWA	*J. Harms*	9	27
NuMerJet	R. Ciolfi	9	18
Progress	L. A. Antonelli	15	244
Swift	G. Tagliaferri	4	24

GRAvitational Wave Inaf TeAm



~ 100 scientists
from 21 Institutes
(INAF + Universities)
Active since O1

(Super-)GRAWITA & ENGRAVE



~ 100 scientists
from 21 Institutes
(INAF + Universities)
Active since O1

+

Coordination with AGILE, Fermi, INTEGRAL & Swift INAF research teams
(Super-GRAWITA, since O3)

www.engrave-eso.org

Governing Council: *M. Branchesi*, **E. Brocato**, **P. D'Avanzo**, J. Hjorth, P. Jonker, E. Pian, S. Smartt (Chair), J. Sollerman, D. Steeghs, N. Tanvir.
Executive Committee: A. Levan (Chair), M. Fraser, K. Maguire, *D. Malesani*, *O. S. Salafia*, *S. Vergani*.

A collaboration of ~ 200 ESO scientists (since O3)
Approved program during Oct 2018 – Mar 2020 fully covering O3. Time for EM counterparts **follow-up** on every useful **VLT** instrument + **ALMA** **HST** and **JWST**.

Follow-up strategy

Need to cover huge sky maps (hundreds of square degrees)

Wide field telescopes and/or targeted galaxy search

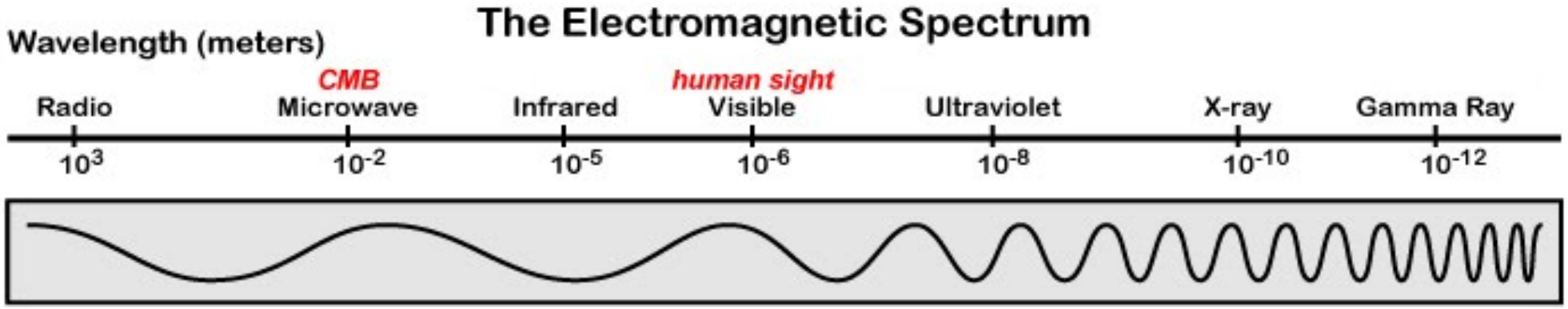
Need to find candidates

Dedicated strategies/pipelines

Need to filter and characterize the most promising candidates

Large area telescopes to obtain spectra and light curves of the candidates

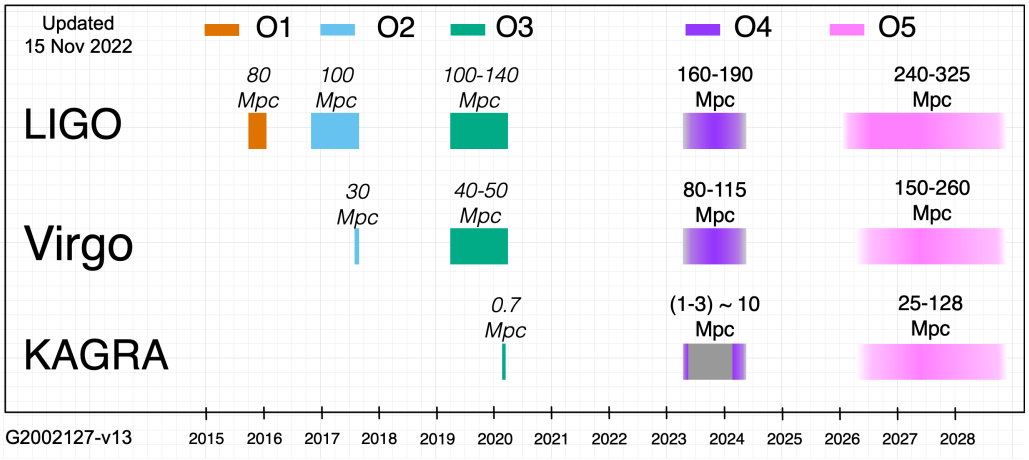
Facilities in O4

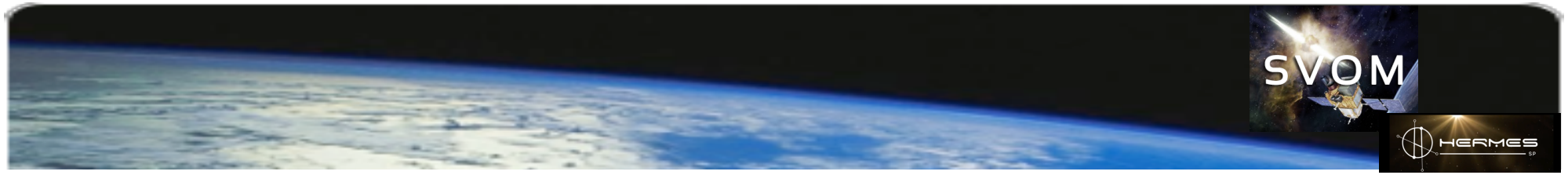


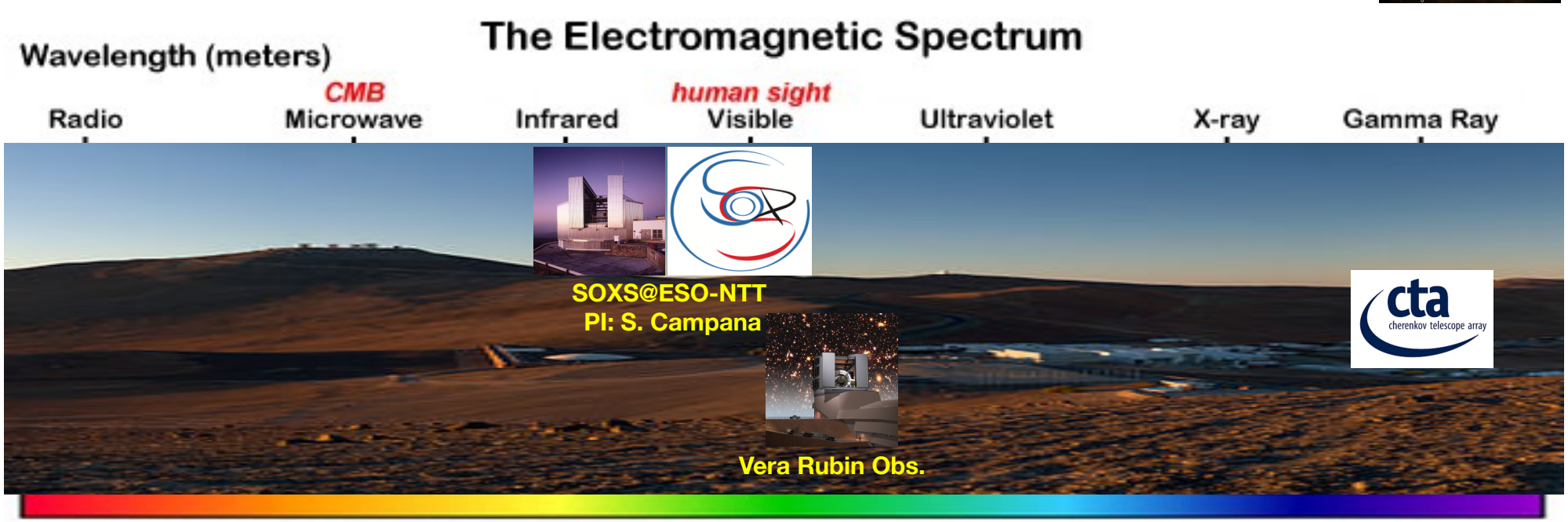
INAF
ISTITUTO NAZIONALE
DI ASTROFISICA

Beyond O4

Future Facilities







Future Facilities

INAF
ISTITUTO NAZIONALE
DI ASTROFISICA

ET EINSTEIN TELESCOPE

LGWA
LUNAR GRAVITATIONAL
WAVE ANTENNA

Lisa

esa athena

theseus

The Electromagnetic Spectrum

Wavelength (meters)

CMB

human sight

Radio | Microwave | Infrared | Visible | Ultraviolet | X-ray | Gamma Ray

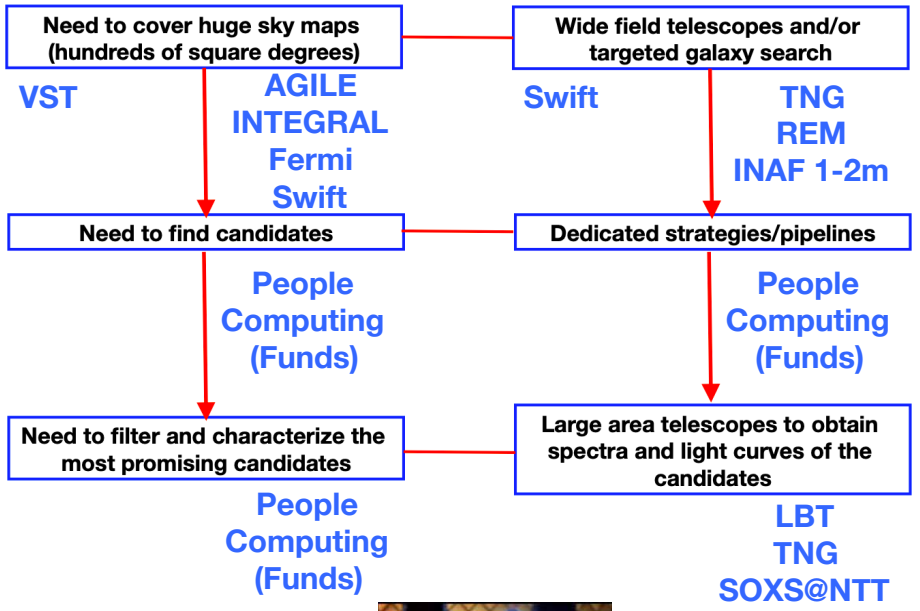
SKA
SQUARE KILOMETRE ARRAY

ELT

cta
cherenkov telescope array

Final Thoughts

- A new era for astrophysics, great discovery space, opportunities for early career astronomers
- INAF at the forefront (worldwide) since the dawn of this era
- Leadership gained (also) thanks to the GRB (BeppoSAX & Swift) and SNe heritage
- Future can be (very) bright, but also hard (see O3)
- Importance of multi-wavelength and theoretical expertises -> importance of collaborations (also international)
- Importance of flexible facilities, ToO, possibly dedicated
- ESO has (and will have) a very good ToO policy
- National facilities (at all scales) should be kept in operations, with a ToO policy (LBT and TNG have ToO, REM is robotic – great! - very good that VST will have -> to be improved!)
- Vital to keep as long as possible high-energy satellites
- Great SVOM will arrive soon, it would be fantastic to have THESEUS and Athena in the ’30s



A new era just begun, great opportunities for breakthrough discoveries,
INAF should keep sustaining at all levels (funds, facilities, recruitment, collaborations) this field, to keep leadership (worldwide) role.
GRAWITA will benefit from a Large Grant-> vital to reach the O4 horizon