Observations and implications of electromagnetic counterparts to gravitational wave sources

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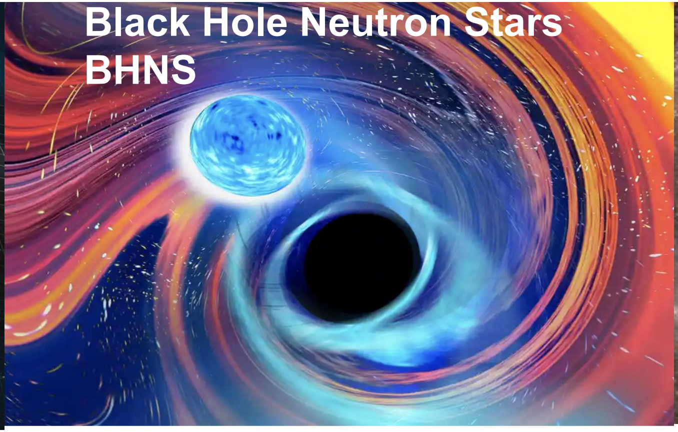
Gravitational Wave (GW) sources

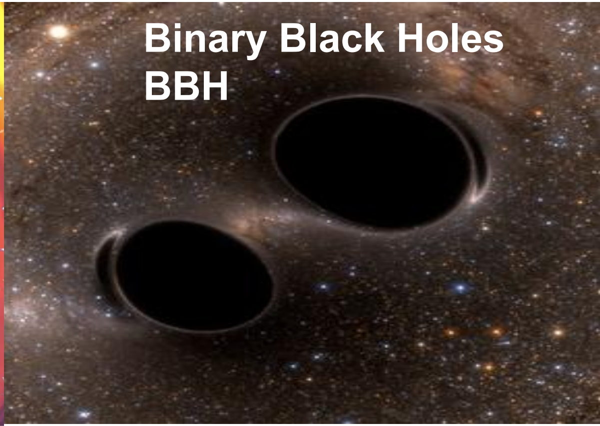
Low frequency range (<10Hz):

- Continuous signal from spinning NS or X-ray binaries
- Stochastic background originated in the early universe (very low frequency)
- Merger of supermassive black holes

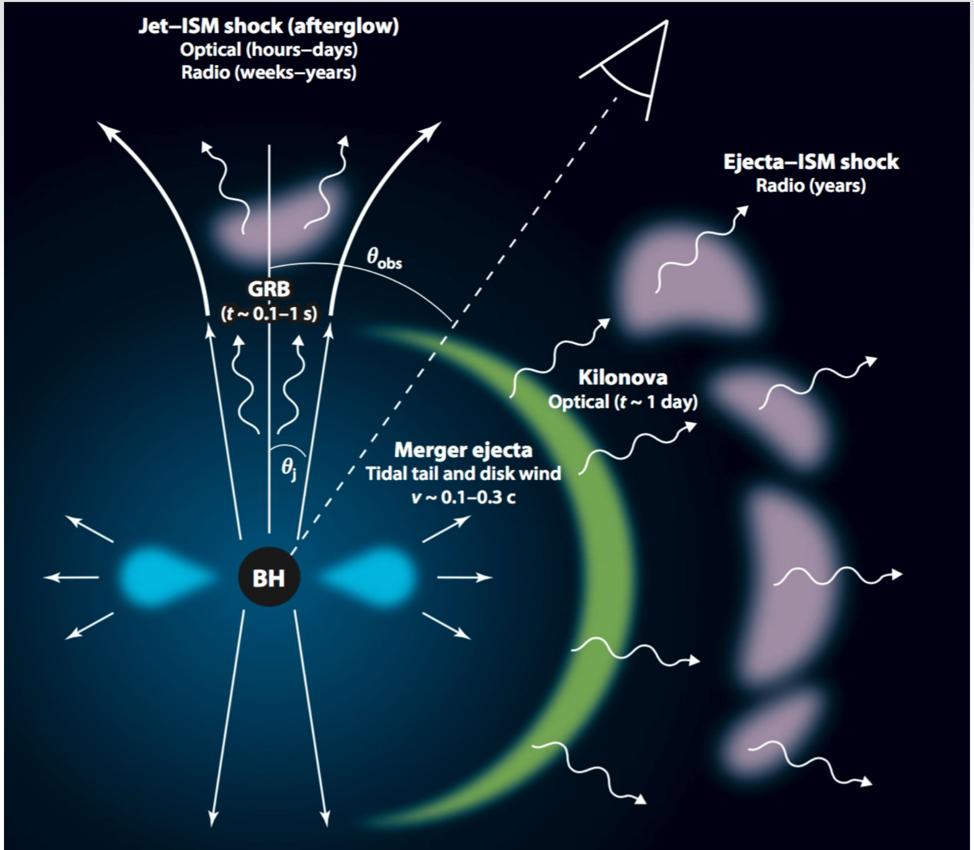
In the frequency range sensitive for laser interferometers:

- Gravitational collapses (e.g. core-collapse SN, hypermassive NS)
- **Compact Binary Mergers**





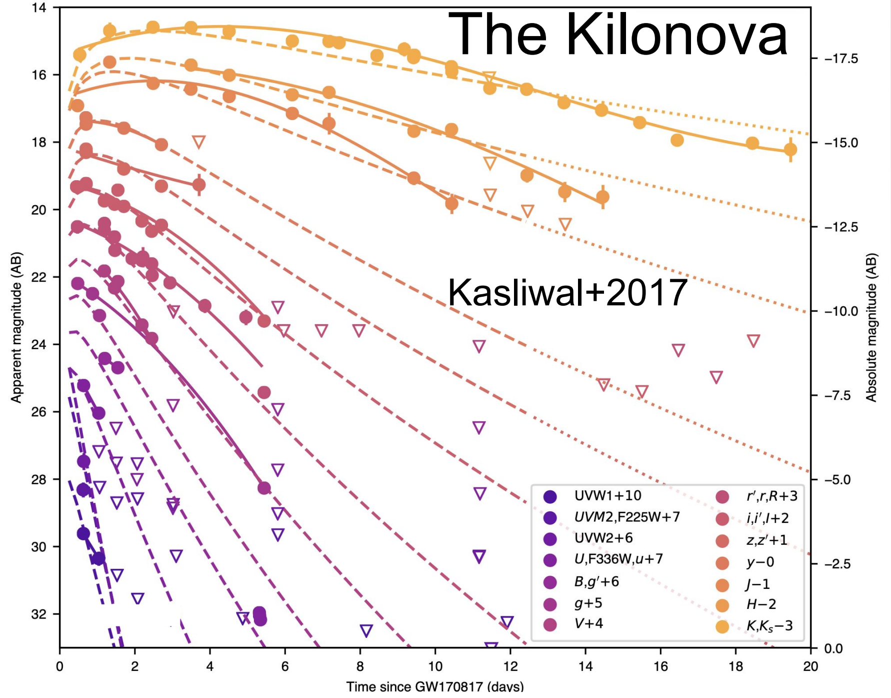
Electromagnetic signals from Compact Binary Coalesciences (CBCs)



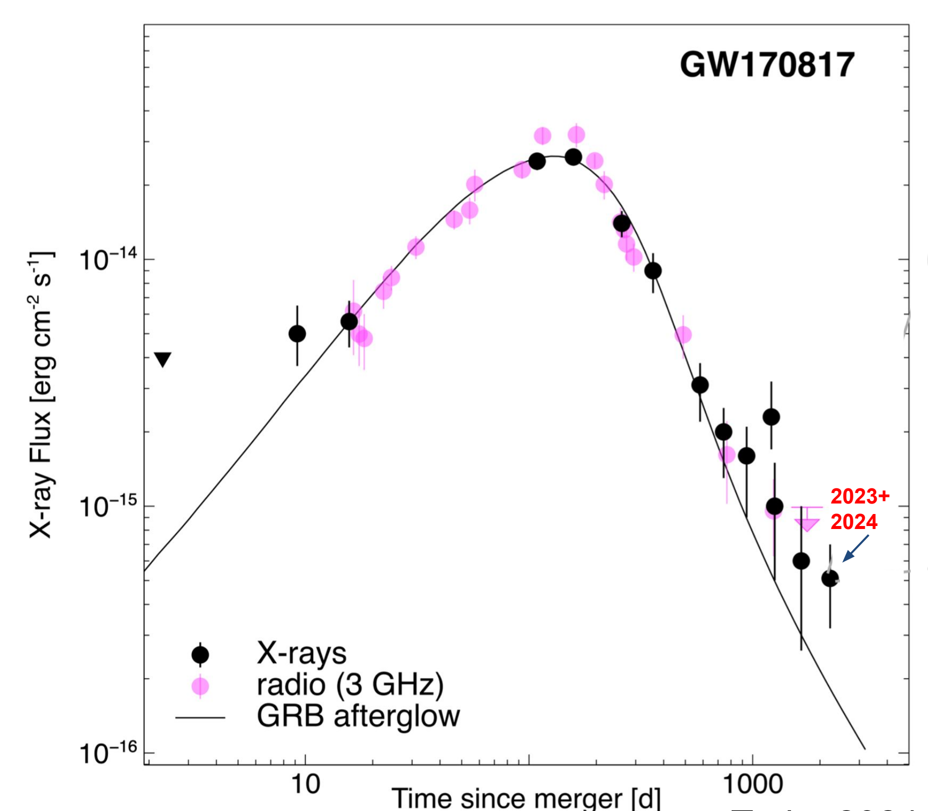
Metzger+2019

Hendrik van Eerten and Chris Fryer's talks

Electromagnetic signals from CBCs GW170817/GRB170817A

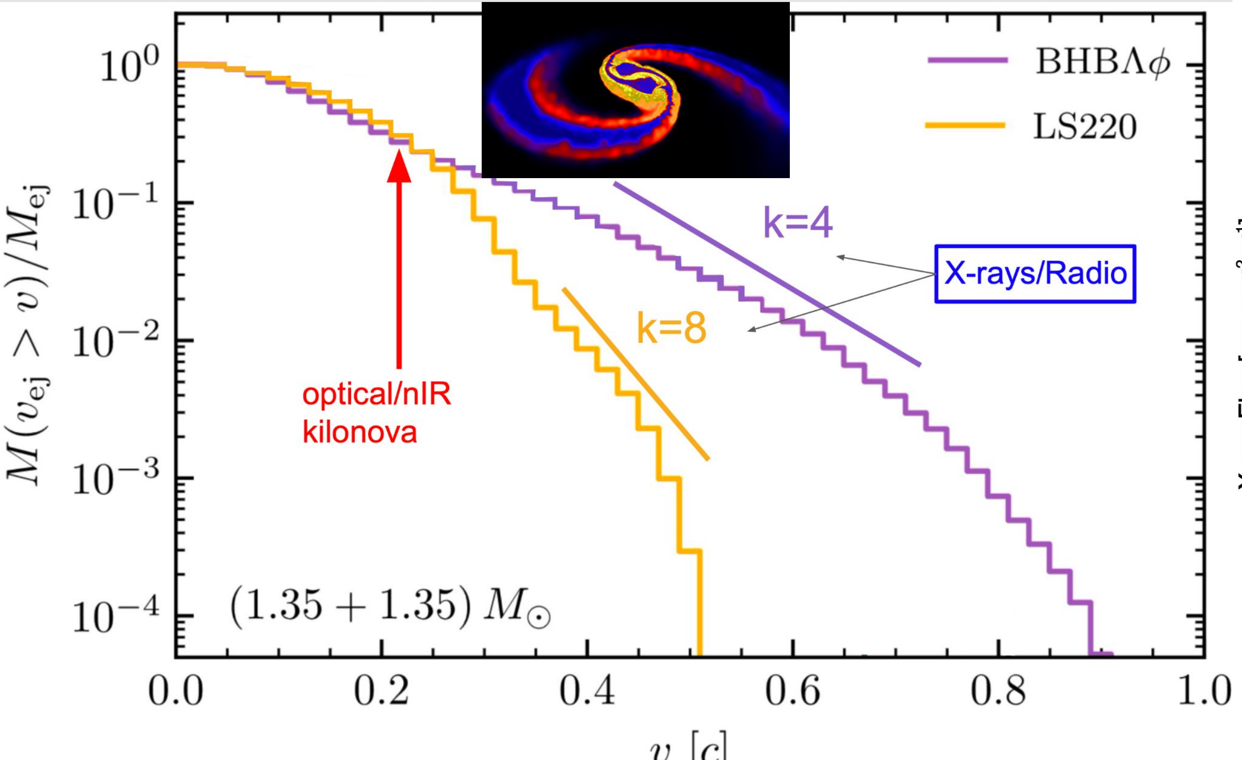


Several other works: e.g. Arcavi+2017; Coulter+2017; Drout+2017; Evans+2017; Pian+2017; Shappee+2017; Smartt+2017; Troja+2017; Utsumi+2017,.....

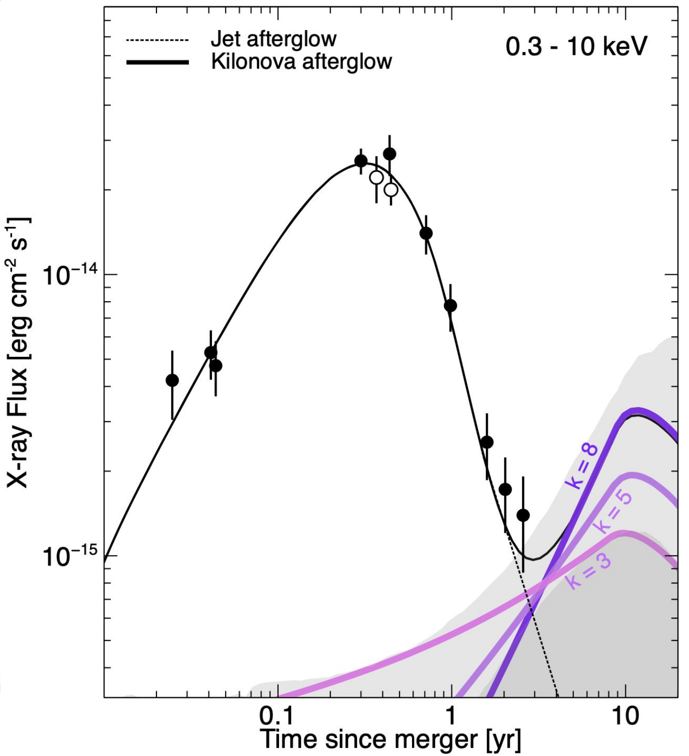


Troja+2024

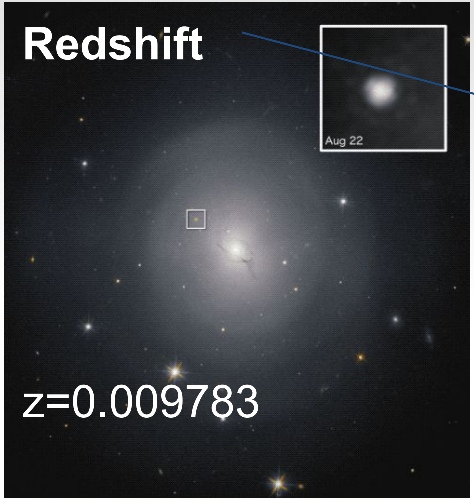
Electromagnetic signals from CBCs
Kilonova afterglow

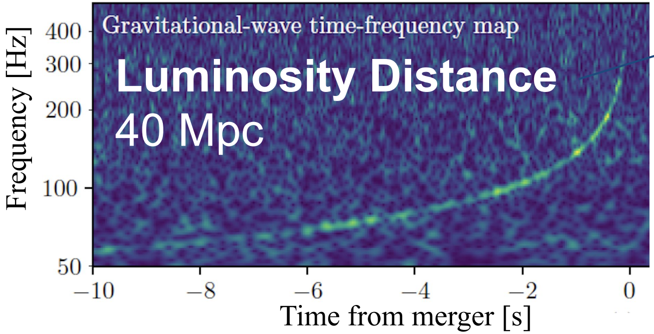


Radice+2018

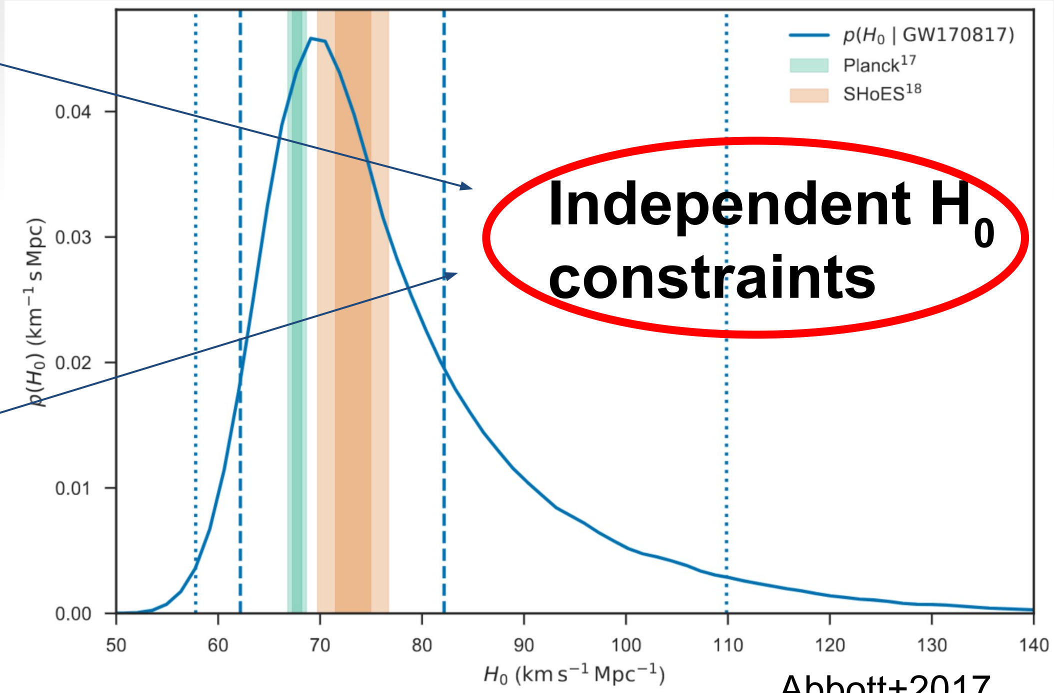


Electromagnetic signals from GWs - Physical implications





Test Cosmology



Abbott+2017

Eleonora Di Valentino and Giulia Gianfagna talks

O3 LIGO/Virgo Observing run

From April 1st, 2019 to March 27th, 2021

75 compact binary coalescence candidates - 39 during O3a (Abbott+2021a) and 36 discovered during O3b (Abbott+2021b)

1 confirmed BNS (GW190425)

3 BHNS candidates (GW190426, GW210105 amd GW210115)

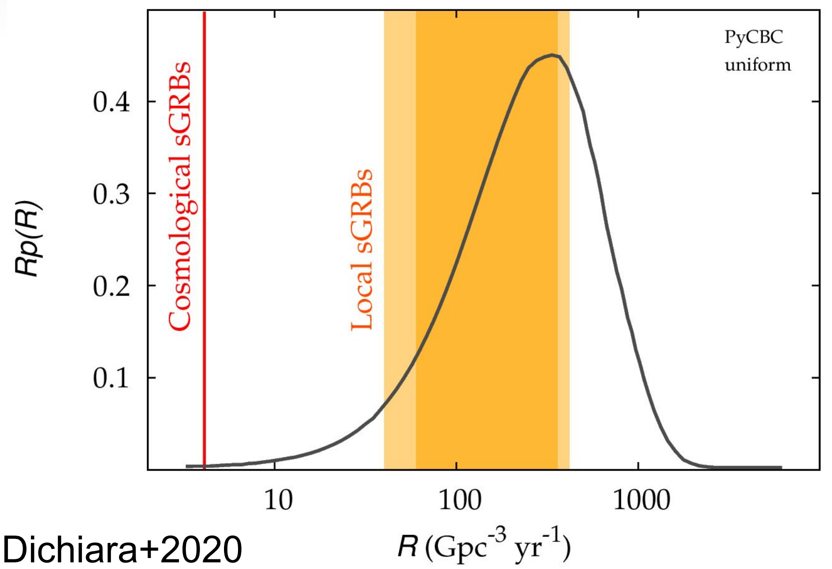
1 candidate merger where one compact object has a mass of 23 $M_{\odot}$ BH and the other 2.6 $M_{\odot}$ (GW190814)

Rates as derived from first runs of observations:

BNS = 320 $^{+490}_{-240}$ Gpc/yr

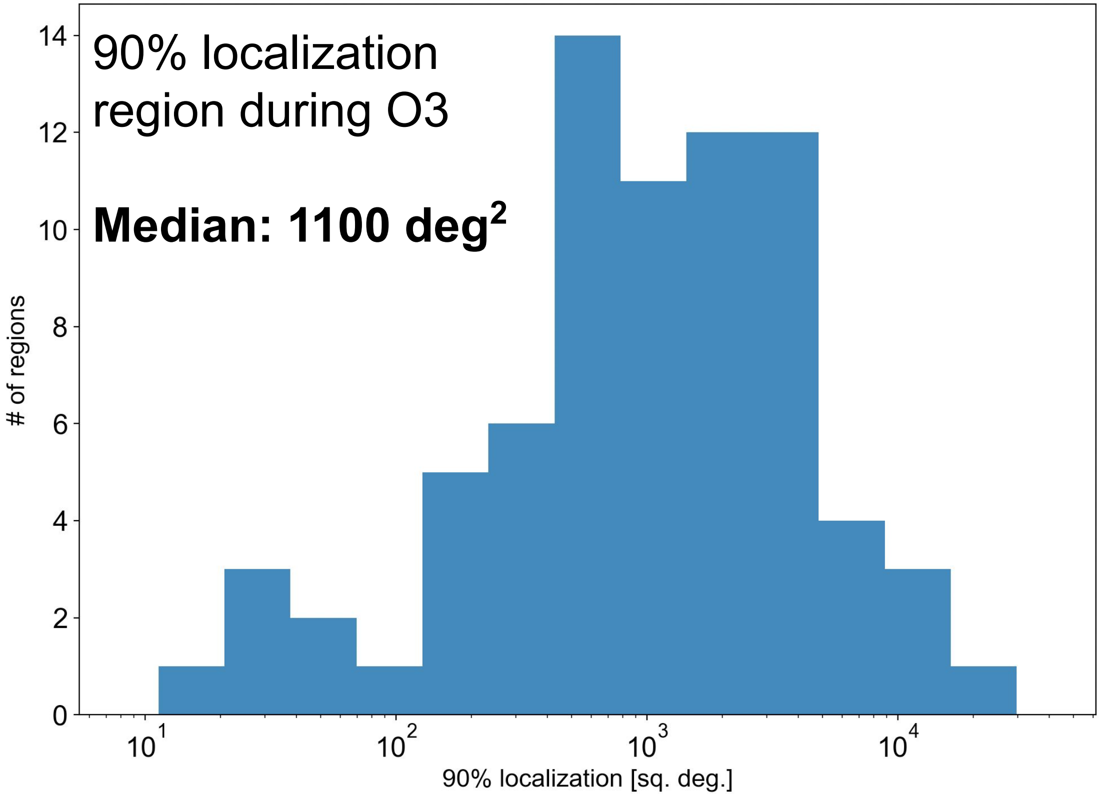
BHNS = 130 $^{+112}_{-69}$ Gpc/yr

BBH = 23.9 $^{+14.9}_{-8.6}$ Gpc/yr

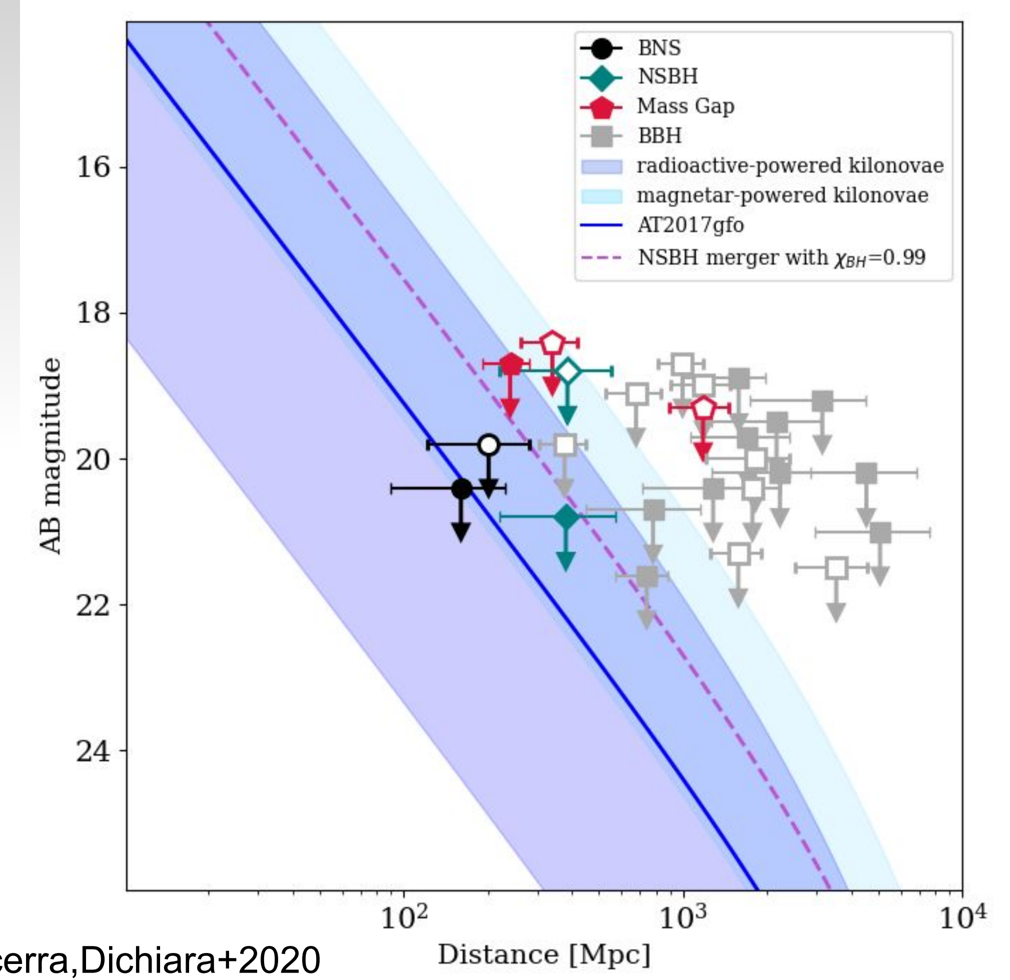


Dichiara+2020

Localization of compact binary mergers during O3

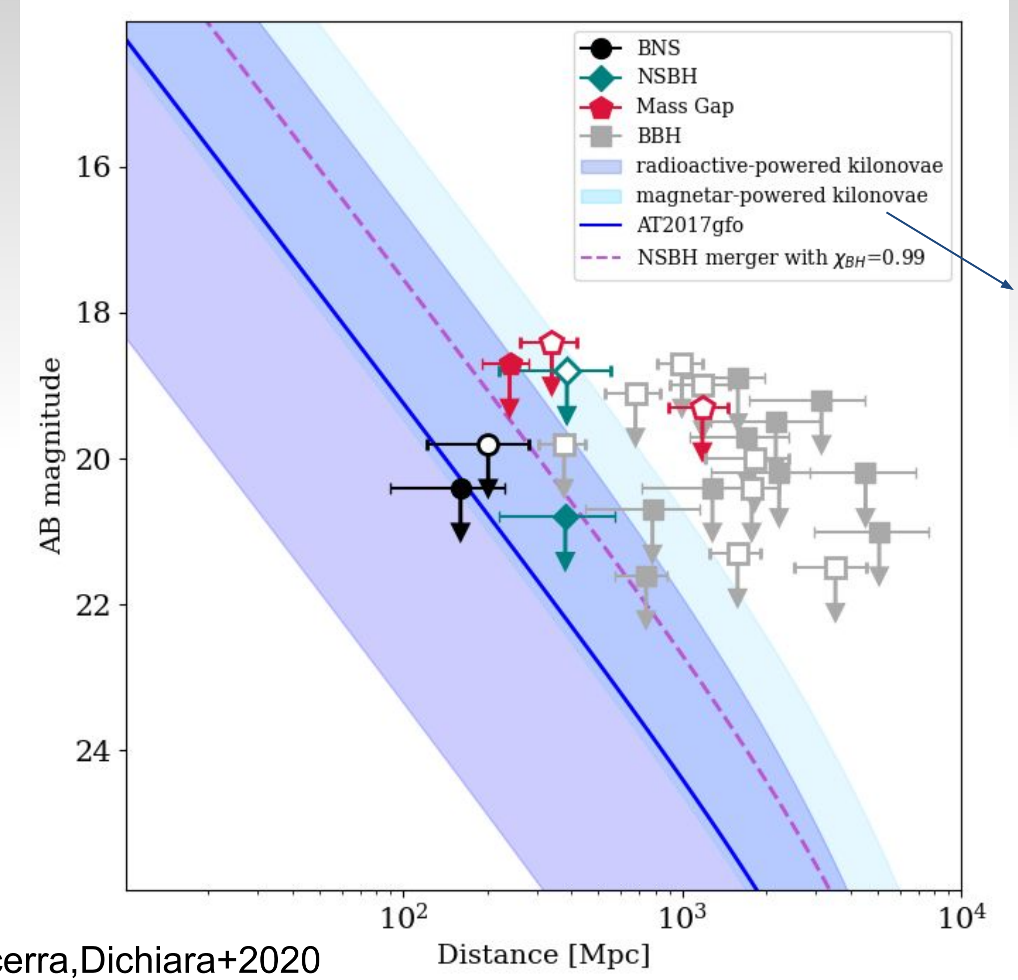


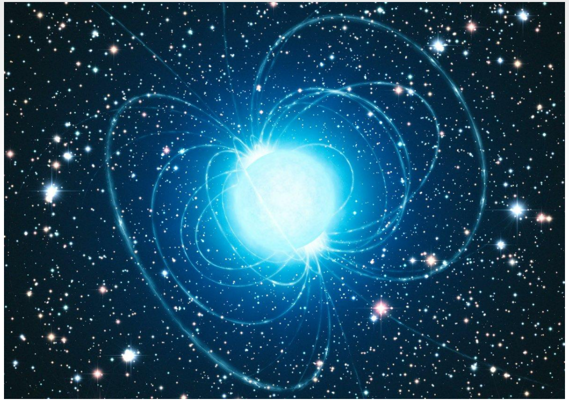
Constraints on kilonova



Becerra,Dichiara+2020

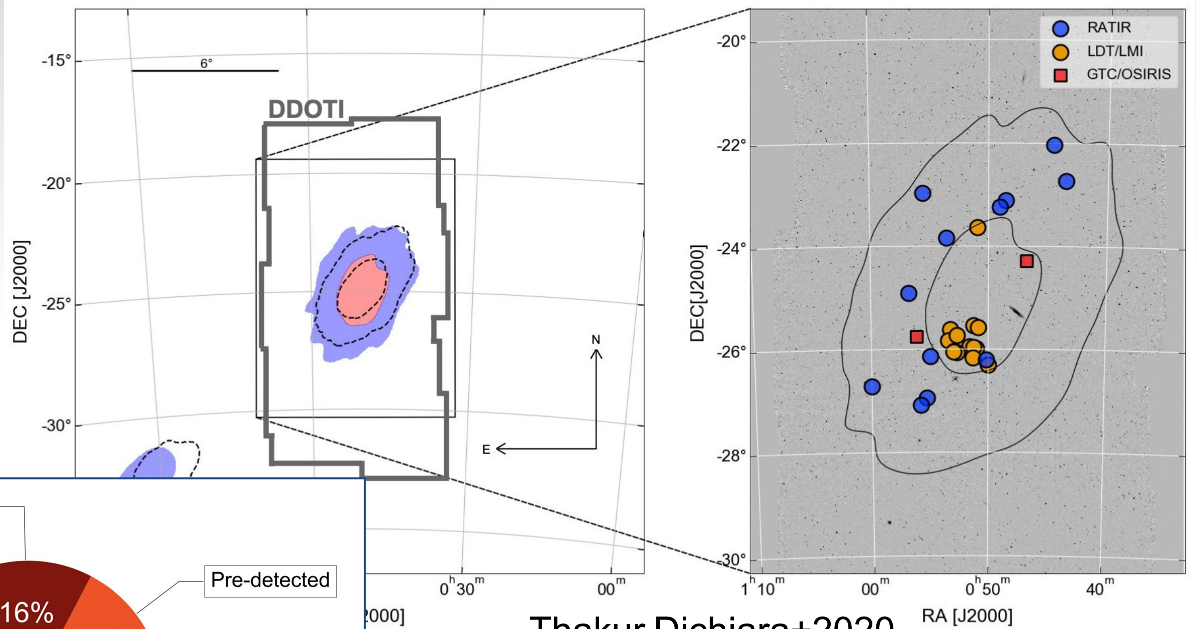
Constraints on kilonova



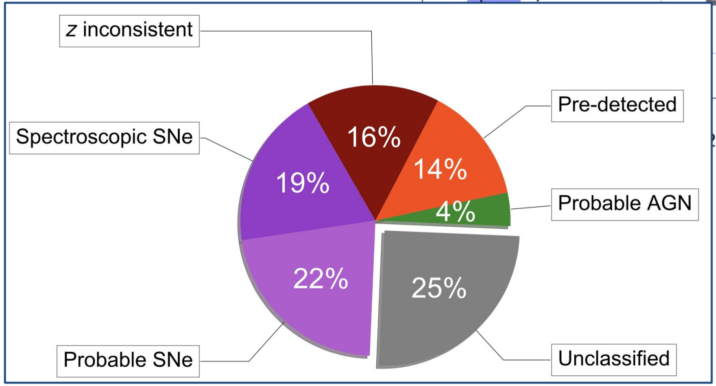


Becerra,Dichiara+2020

Search for EM counterpart GW190814



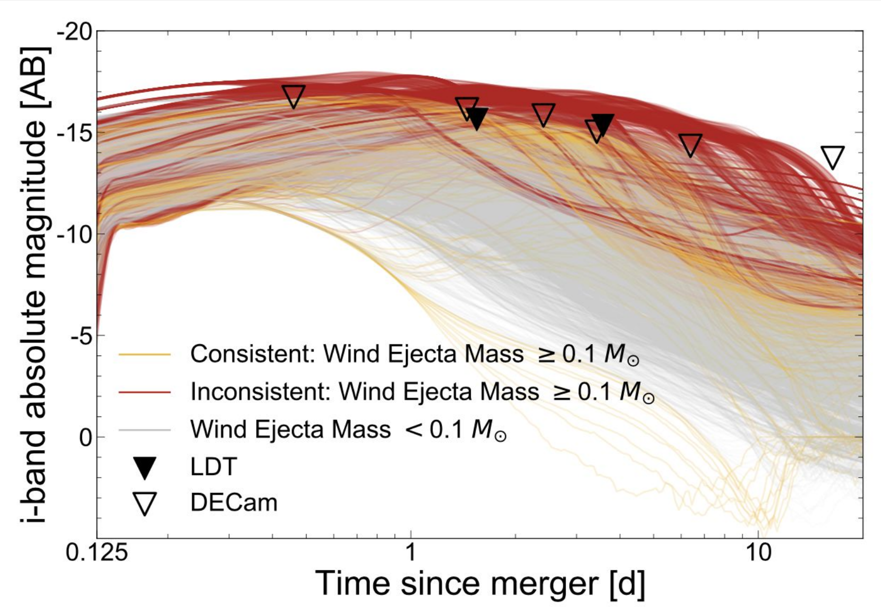
Thakur,Dichiara+2020

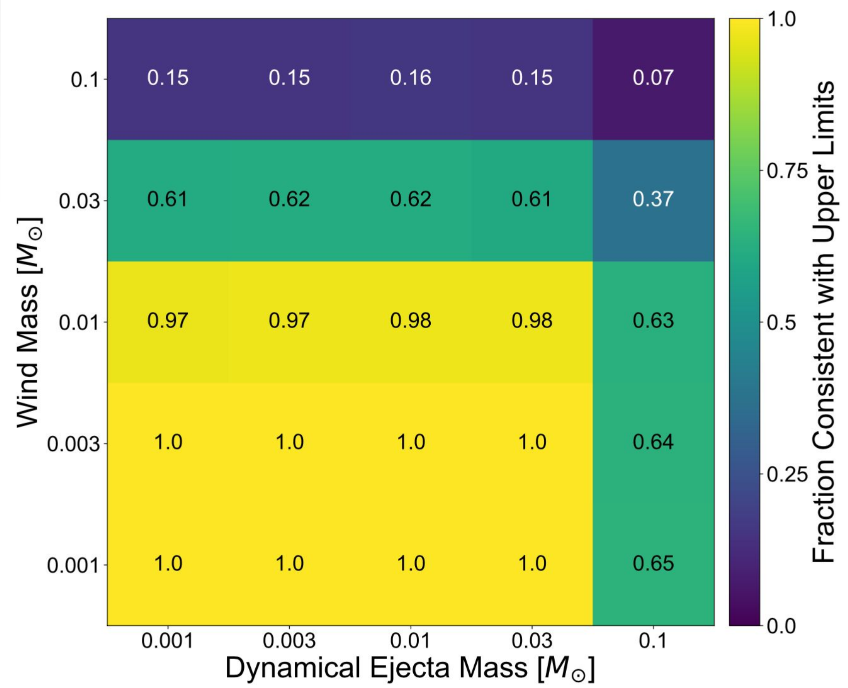


85 candidates discovered by ground based facilities

Search for EM counterpart GW190814

Constraints on the Kilonova

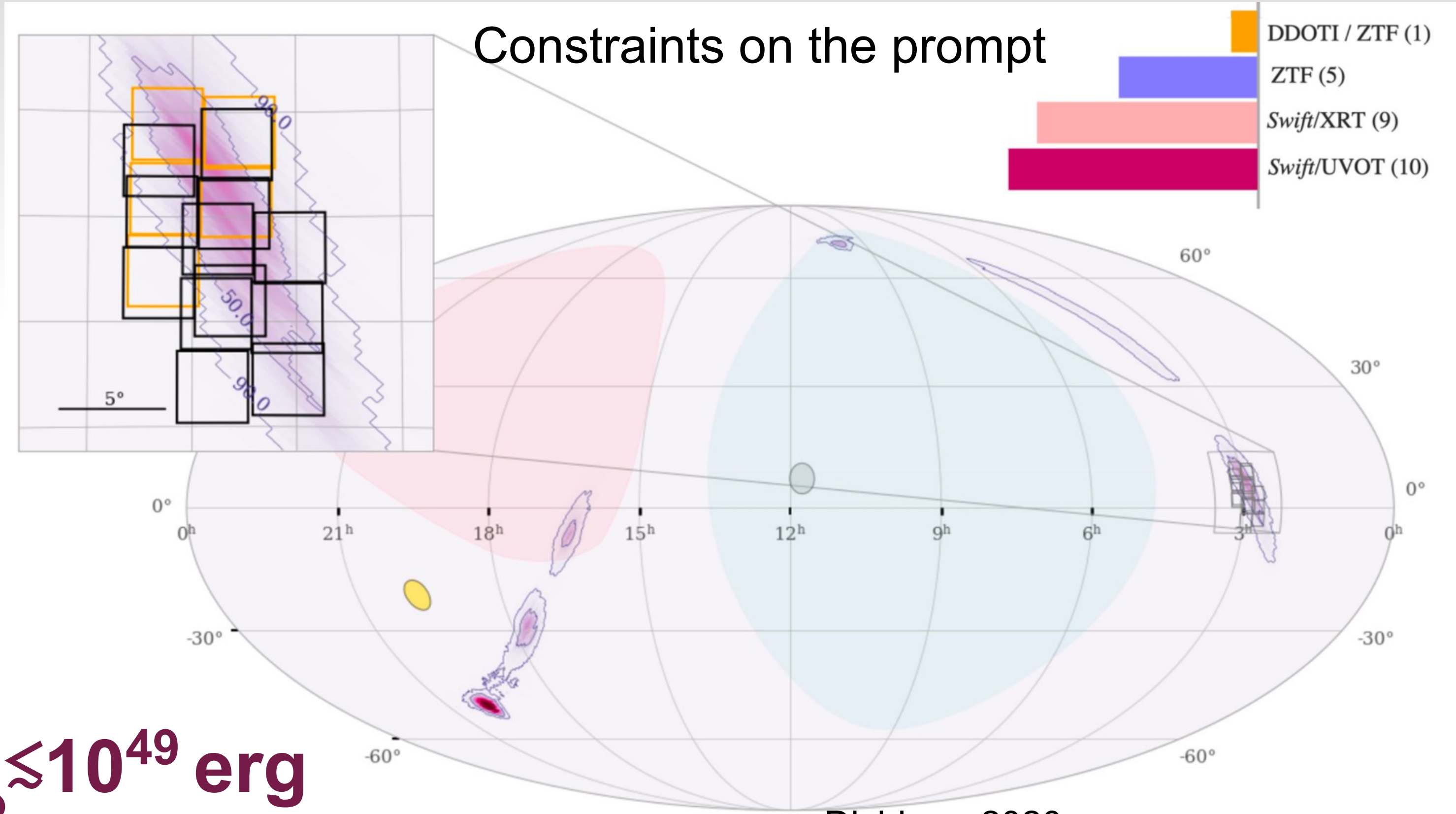




Thakur,Dichiara+2020

Search for EM counterpart GW200115

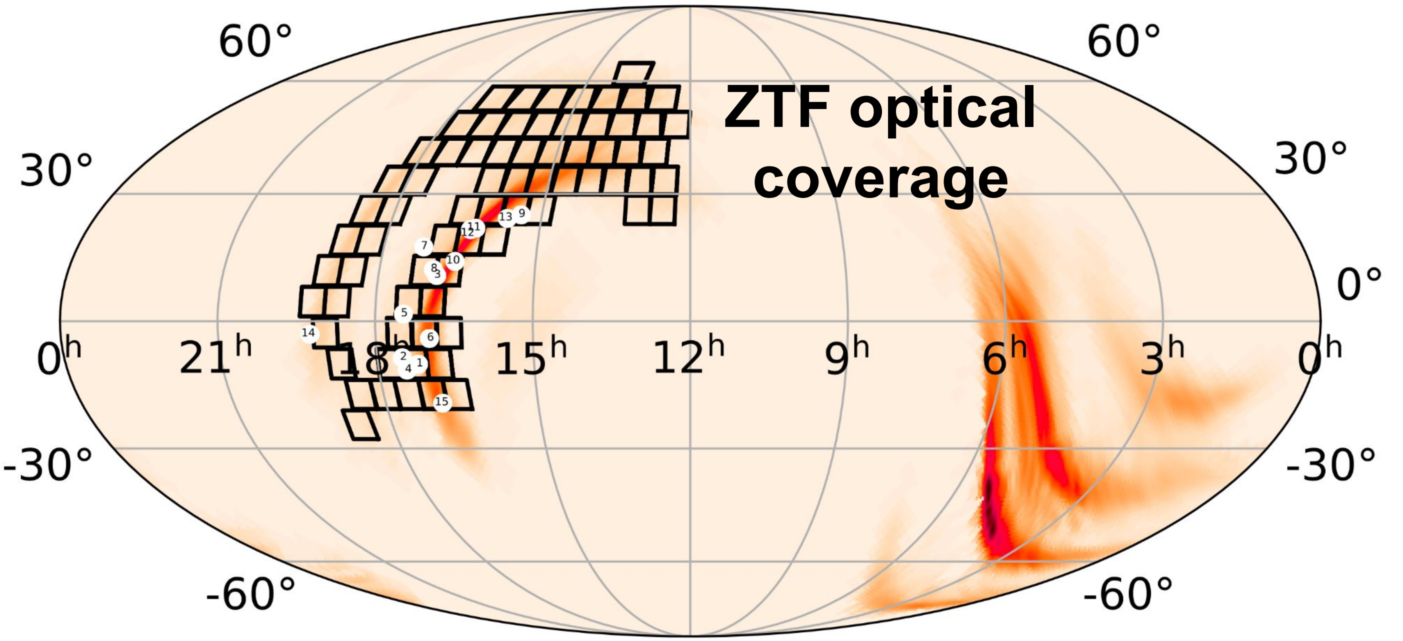
Constraints on the prompt



$L_{\gamma,iso} \lesssim 10^{49}$ erg

Dichiara+2020

Search for EM counterpart GW190425



Coughlin+2019

About **8000 sq. deg.** covered by the wide field facilities for this event (~20% of the updated skymap)

Follow-up photometry and spectral observations ruled out all the possible EM candidate identified

O4 LIGO/Virgo/KAGRA Observing run

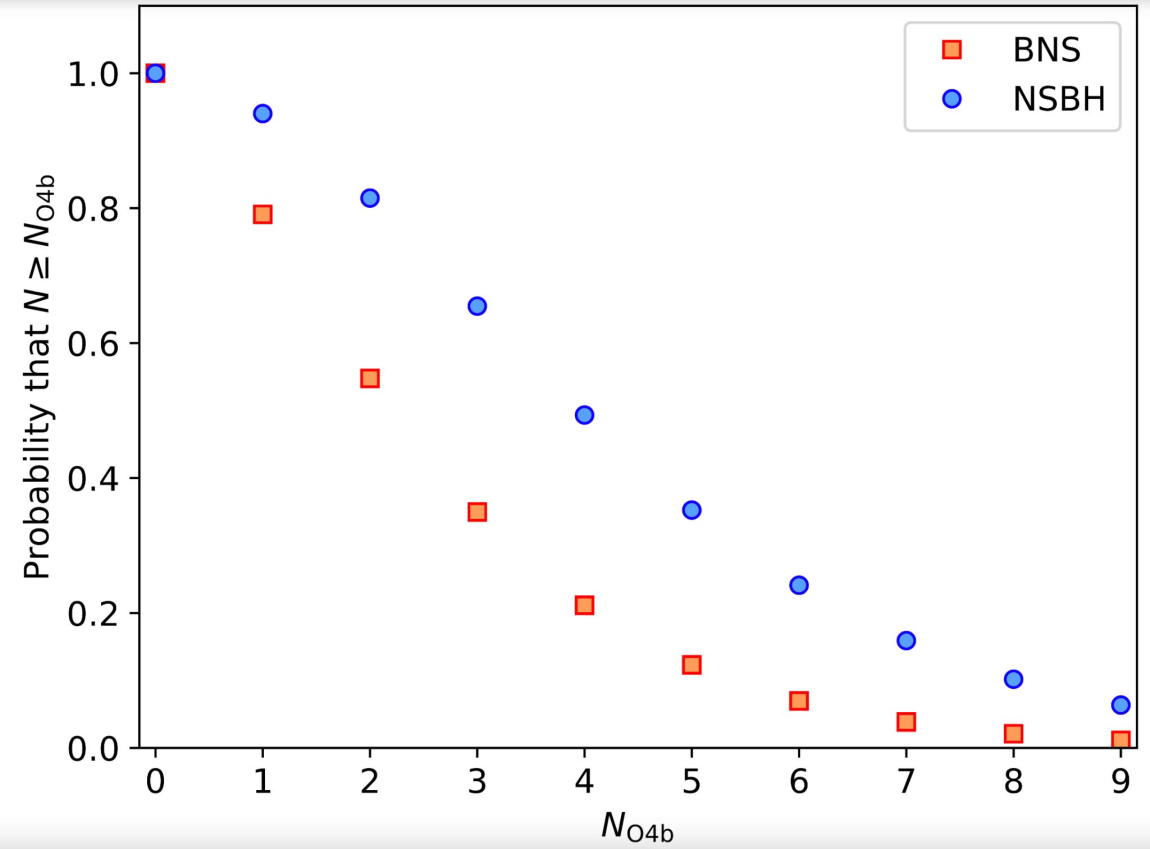
Current status (as today from GraceDB):

More than 1900 triggers in total reported in public notices (including low significance events)
101 Significant triggers (FAR < 1/month for CBC and FAR < 1/year for unmodelled GW bursts) of which:

- 96 BBH candidates (>70% probability)
- 1 possible BHNS merger (86% probability) **S230518h** (460 sq.deg.) - Distance = 204 ± 57 Mpc - discovered during the engineering run
- **1 binary menger including at least 1 NS and a "Mass Gap"** object **S230529ay**- bad localized (25622 sq.deg.) - Distance = 201 ± 63 Mpc
- **1 candidate BHNS merger** (>99% probability) **S240422ed** - relatively well localized (259 sq. deg.), with high probability of having a disrupted NS during the merger - 188± 43 Mpc

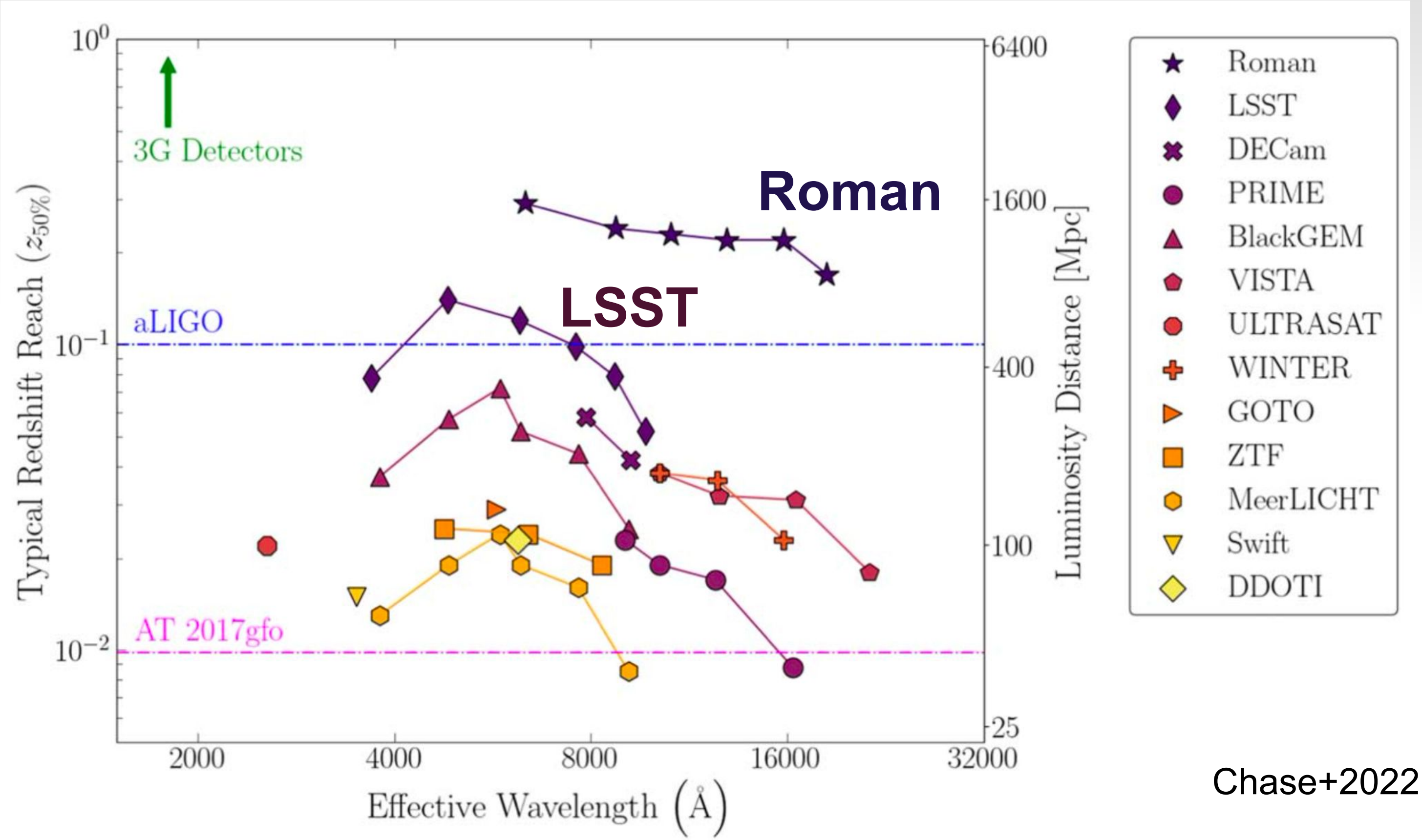
Virgo joined O4b up to February 2025 - Average localization during O4a ≳2000 sq. deg

O4 LIGO/Virgo/KAGRA Predictions



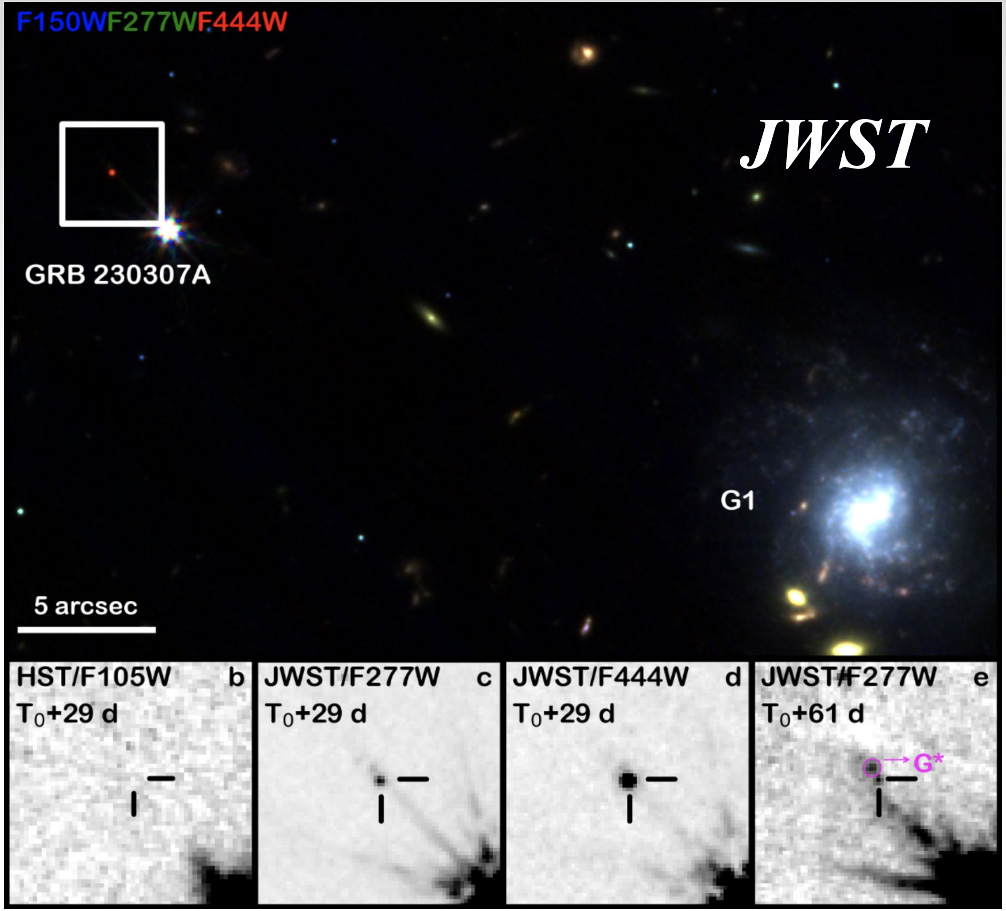
From GraceDB

O4 LIGO/Virgo/KAGRA Prospects



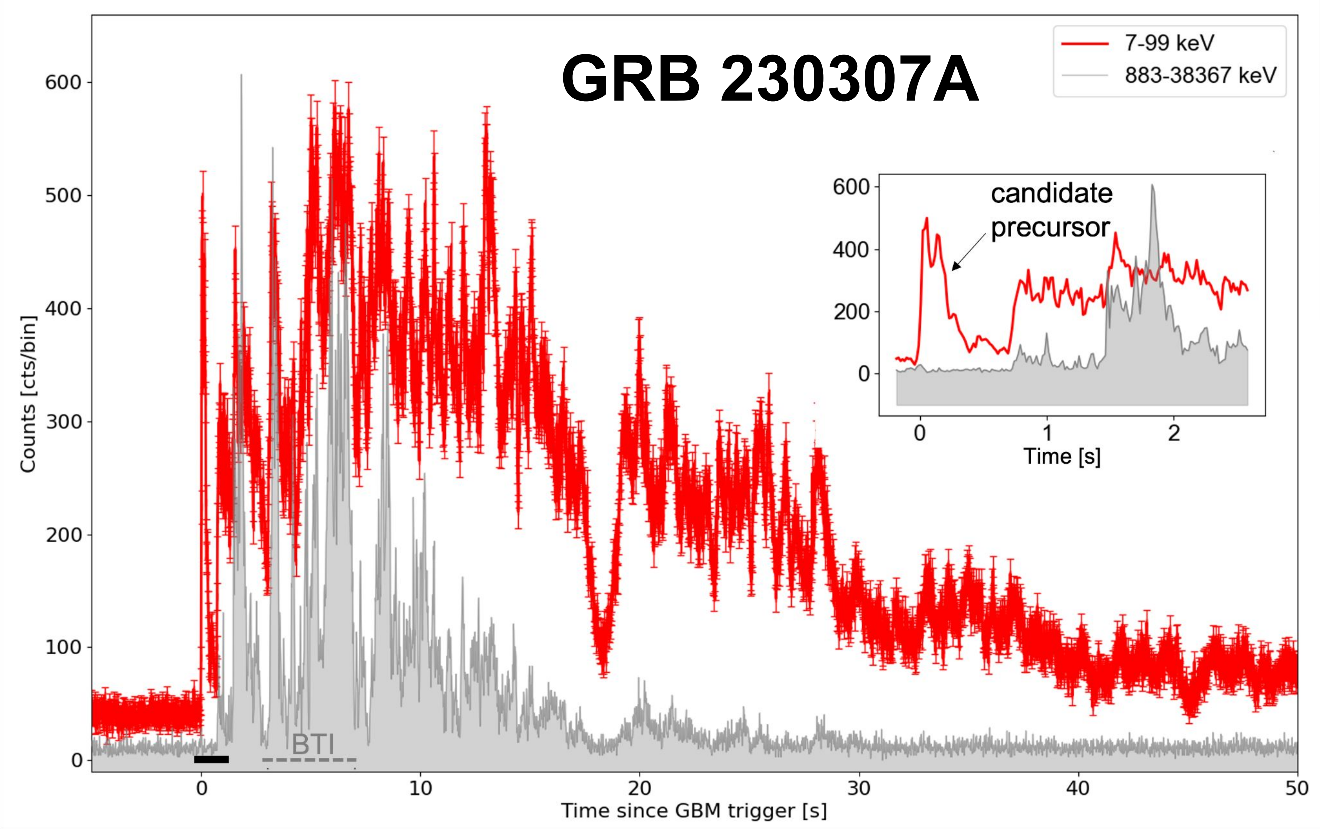
Chase+2022

EM counterpart from BNS mergers



Yang+2024

O4 LIGO/Virgo/KAGRA Prospects

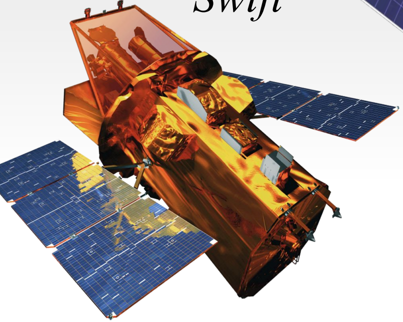


Dichiara+2023

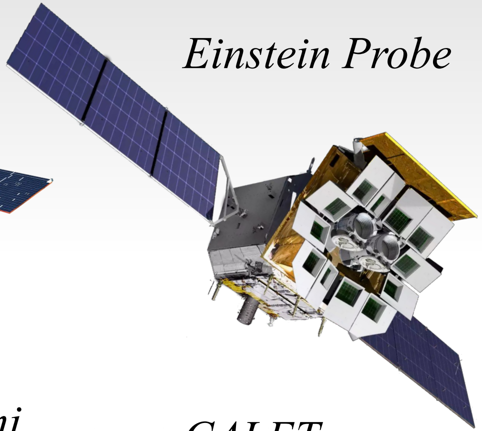
O4 LIGO/Virgo/KAGRA Prospects

Current

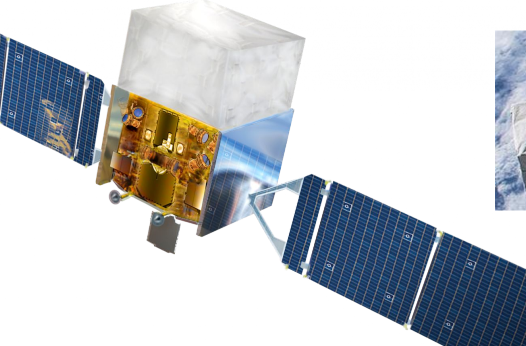
Swift



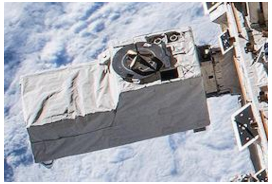
Einstein Probe



Fermi

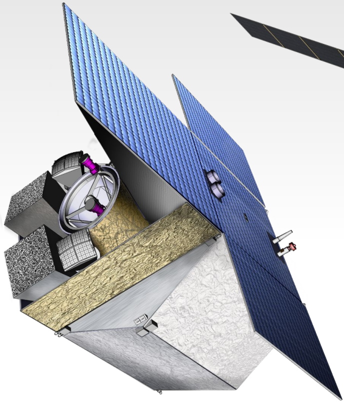


CALET

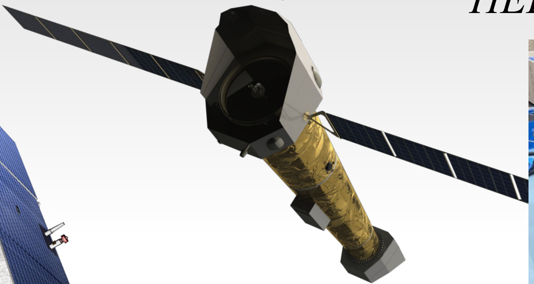


Future Missions

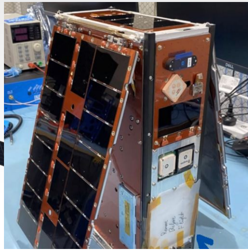
THESEUS



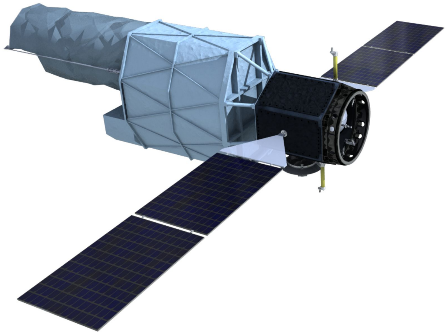
ATHENA



HERMES/SpIRIT



UVEX



Summary

- The study of **electromagnetic counterparts** associated with GW signals is extremely important as it entail major physical implications, including: the study **heavy elements production**, test of **cosmology**, test of **gravity** and the study of the neutron star's **equation of state**
- Current optical wide-field facilities involved in the follow-up of GW signals can detect the electromagnetic counterpart **up to 1 Gpc** in case of magnetar powered kilonovae
- Satellites can detect gamma-ray emission coming from an **on-axis jet up to cosmological distances** and slightly off-axis signals from nearby events (e.g. <200 Mpc). Several new missions will join the efforts in the near future
- **Late time observations** of confirmed BNS mergers (e.g. GW170817) are important **to constrain the kilonova afterglow models and the merger dynamics**
- Only few BNS mergers will have a good localization during O4. **An optimization of the follow-up strategy (e.g. rapid dissemination of candidates and spectroscopic classification) would be the key to increase the effectiveness of the search.**

Thank you!
Grazie mille!

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