Electromagnetic counterparts of GW sources

Eleonora Troja

University of Tor Vergata

erc

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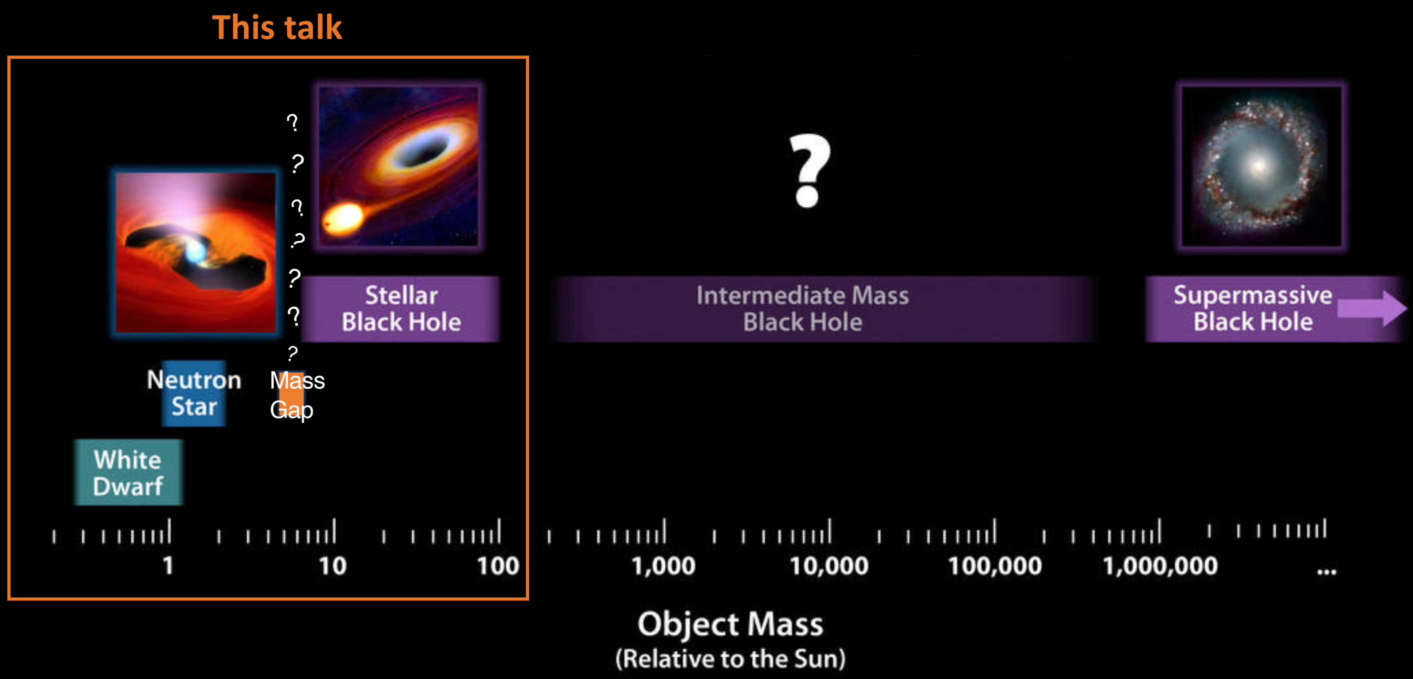
NSF

Observed Mass Ranges of Compact Objects



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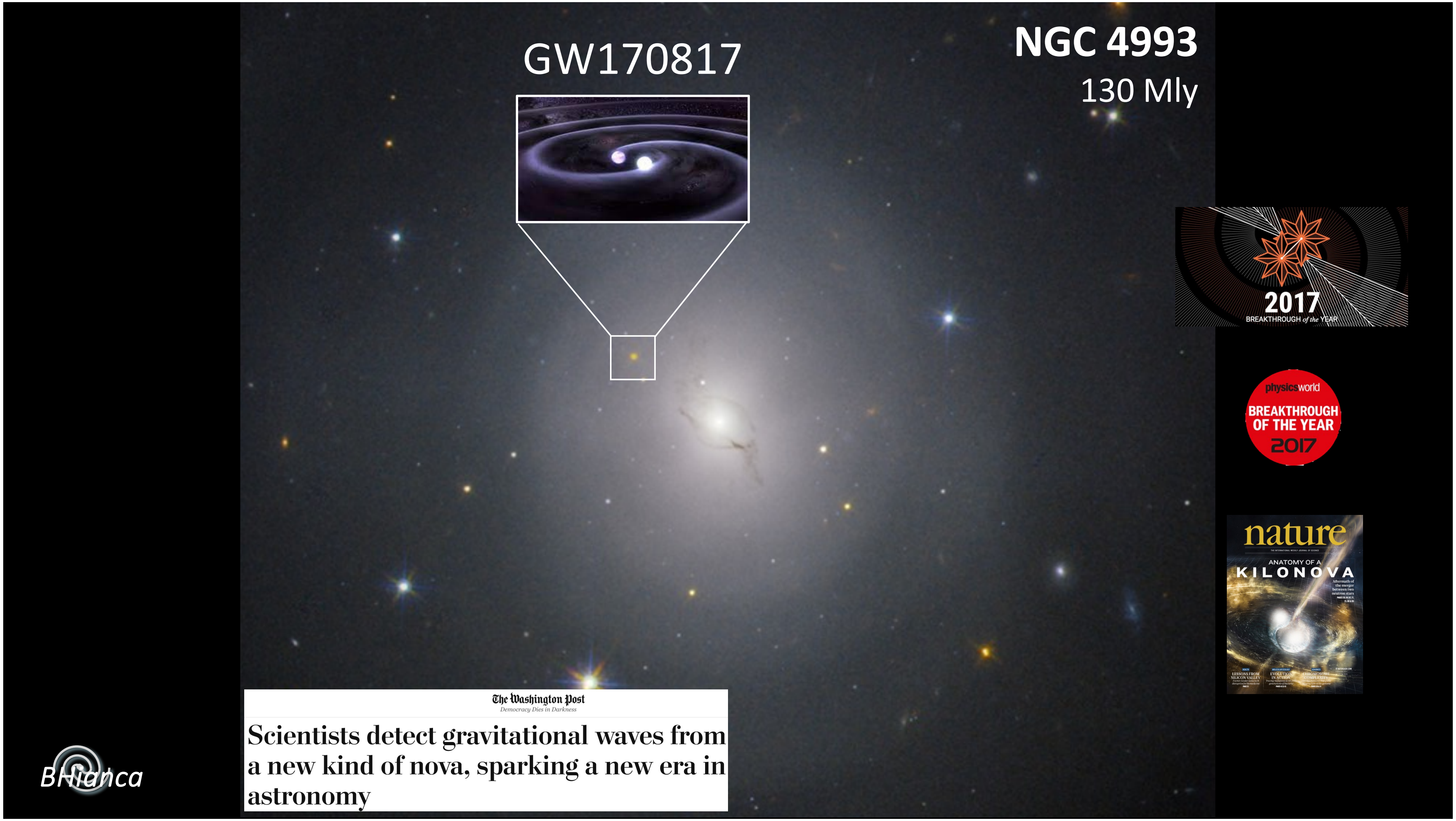
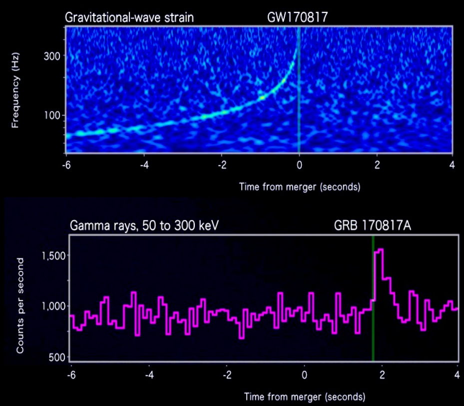
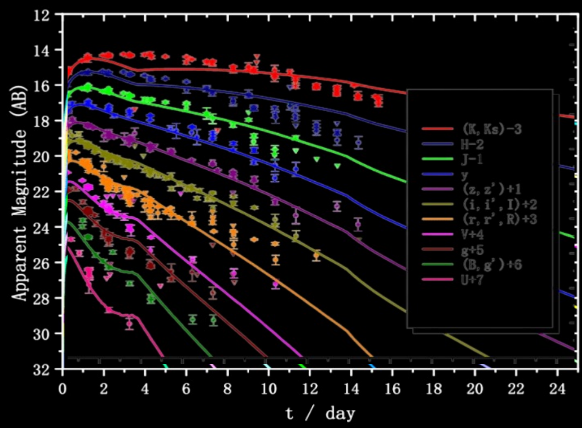

GW170817
NGC 4993
130 Mly
2017
BREAKTHROUGH of the YEAR
physicsworld
BREAKTHROUGH
OF THE YEAR
2017
nature
ANATOMY OF A
KILONOVA
The Washington Post
Democracy Dies in Darkness
Scientists detect gravitational waves from a new kind of nova, sparking a new era in astronomy

A GRB followed by a kilonova



GRB170817A

Abbott et al. 2017
Goldstein et al. 2017
Savchenko et al. 2017
Zhang et al. 2018

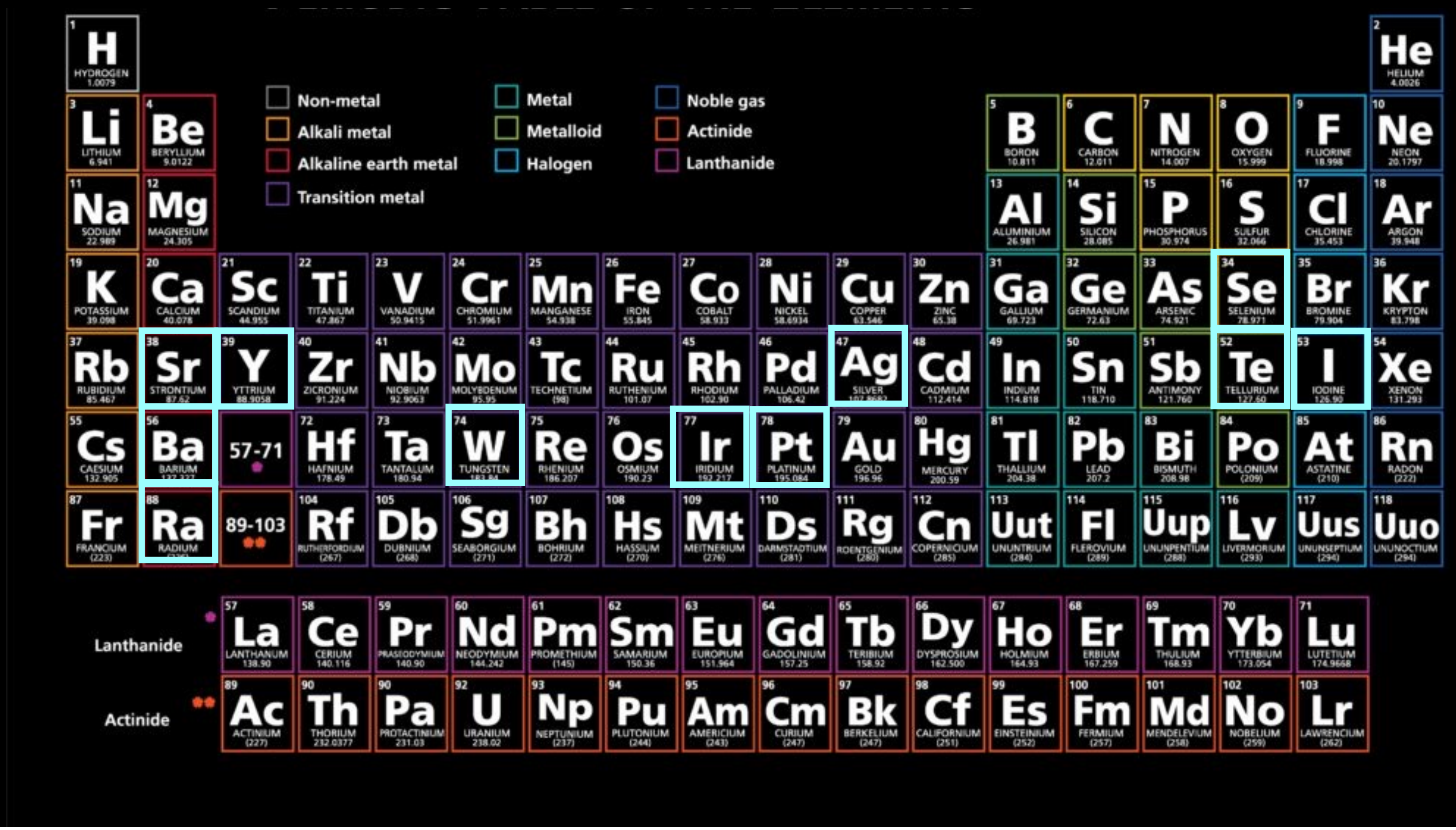


The kilonova AT2017gfo

Coulter et al. 2017, Valenti et al. 2017, Drout et al. 2017, Arcavi et al. 2017, Lipunov et al. 2017, Soares-Santos et al. 2017, Tanvir et al. 2017, Andreoni et al. 2017, Smartt etal. 2017, Chornock et al. 2017, Kasliwal et al. 2017, Pian et al. 2017, Troja et al. 2017, Cowpertwaite et al. 2017,…

BHlanca

Cauldron of heavy elements



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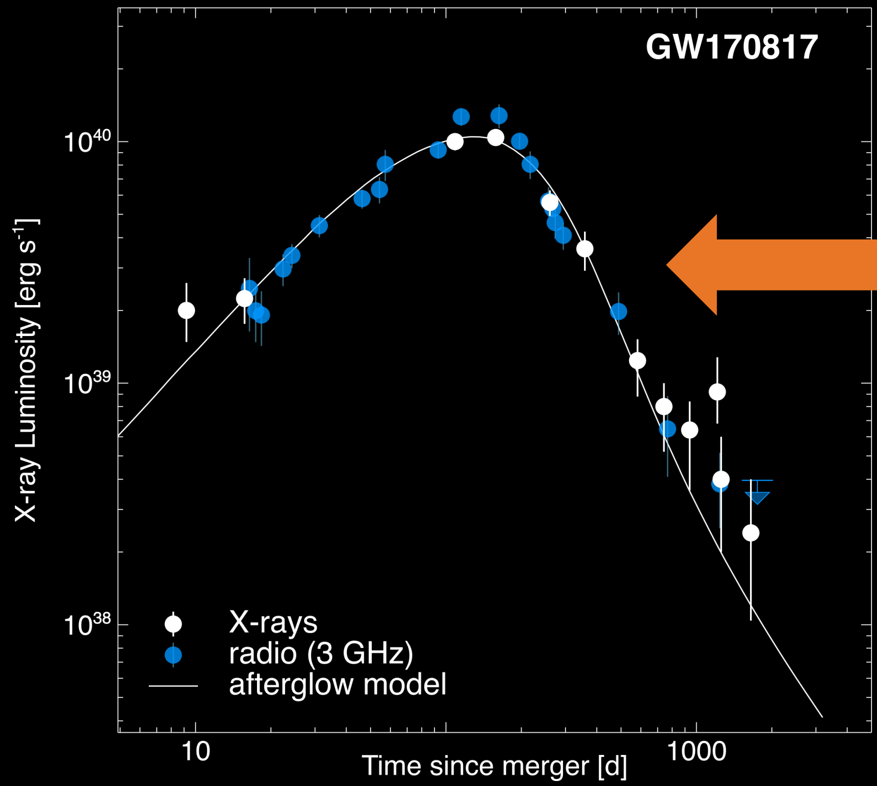
Last but not least, the broadband afterglow

Troja et al. 2017
Troja et al. 2018
Troja et al. 2019
Piro, Troja et al. 2019
Ryan et al. 2020
Troja et al. 2020
Troja et al. 2022
Ryan et al. 2024

Hallinan et al. 2017
Lazzati et al. 2017
Mooley et al. 2017
Mooley et al. 2018
Balasubramanian et al. 2021



A relativistic structured jet seen off-axis

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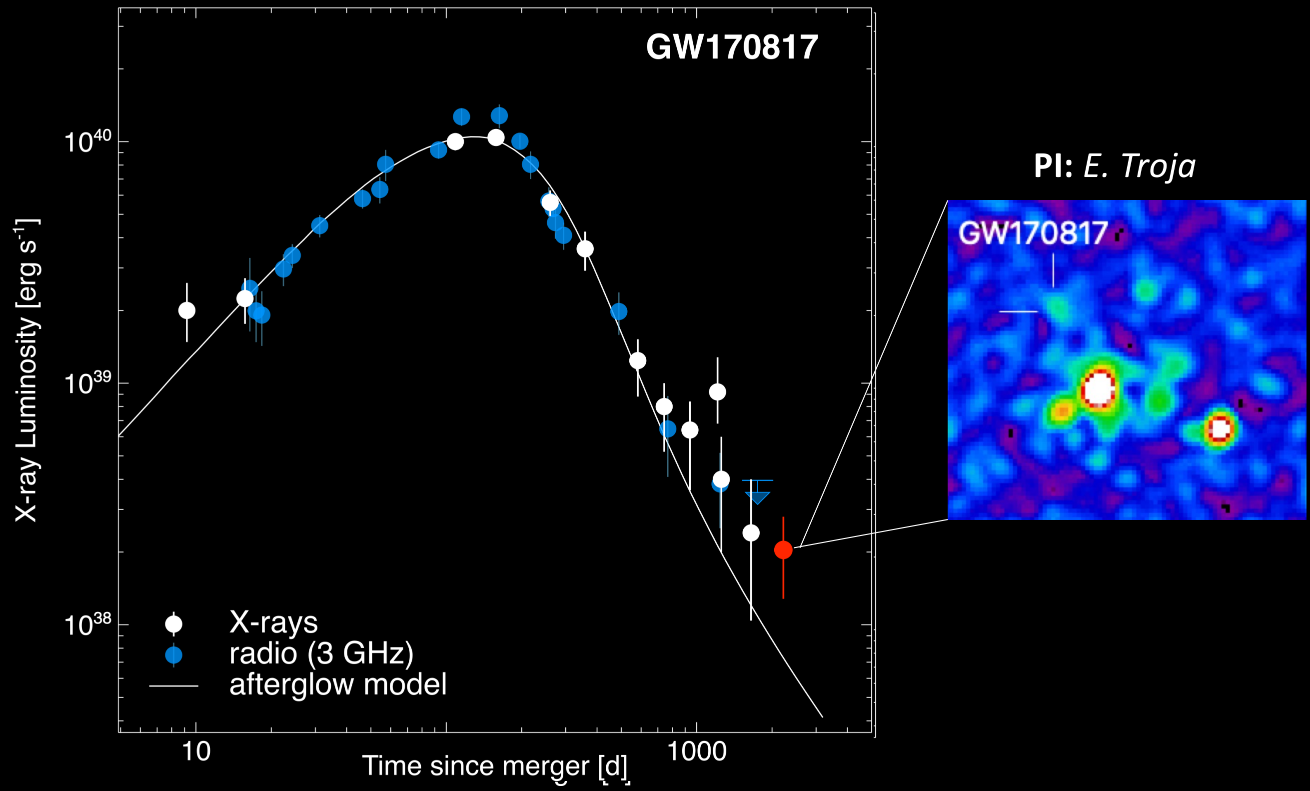
GW170817, lately



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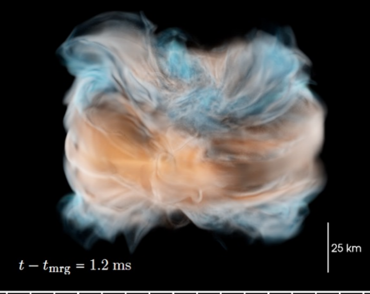
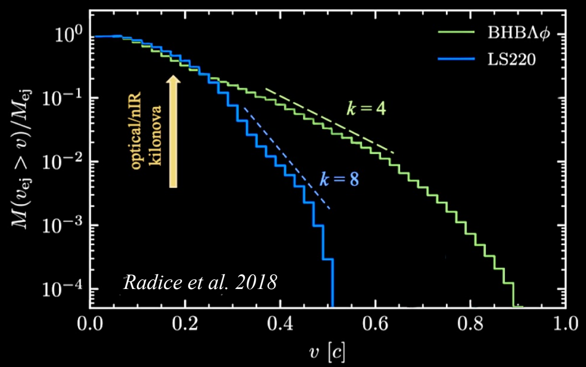
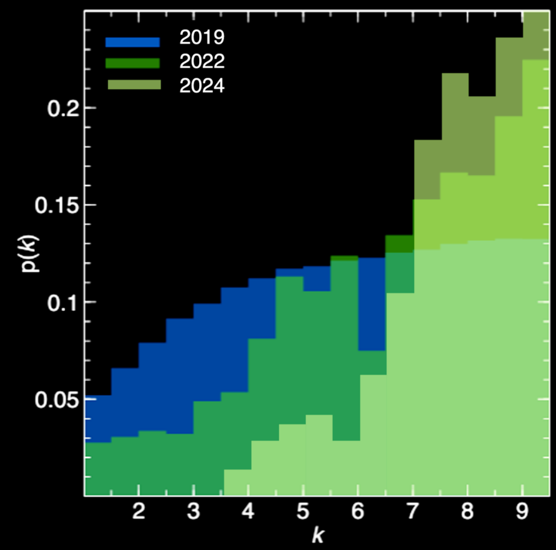
Beyond the GRB jet: novel constraints on the ejecta





Troja et al. 2024 (PRELIMINARY)



Exploring a phase of dense matter otherwise not accessible

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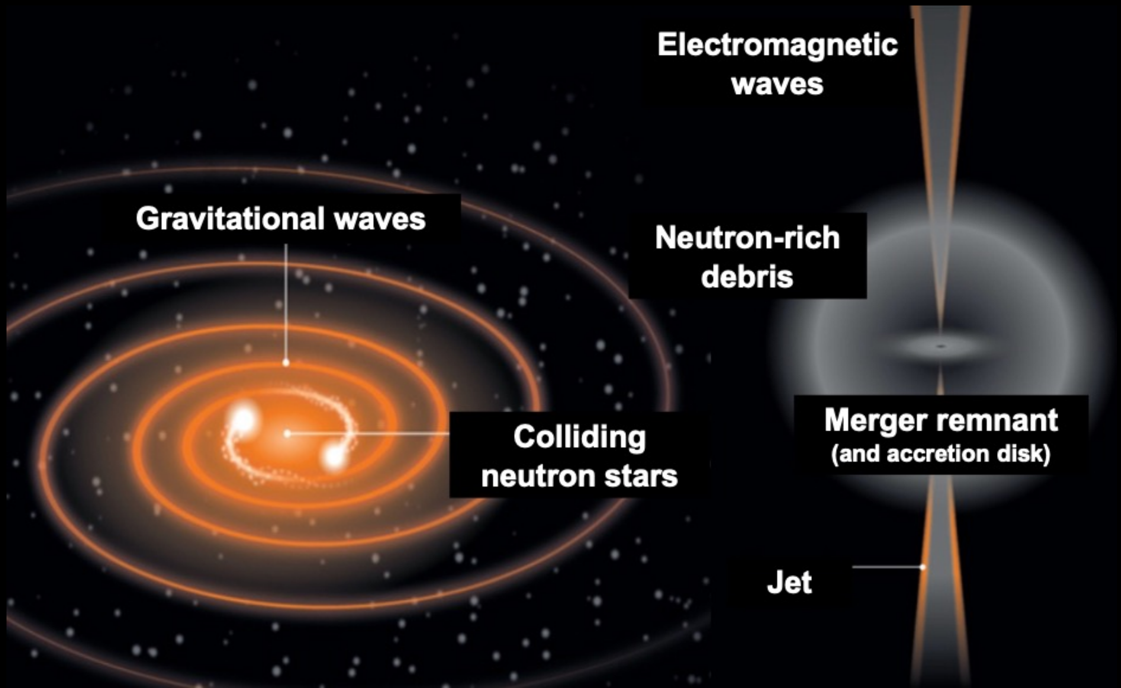
Why multi-messenger astronomy?

All messengers are needed to complete **the big picture** of cosmic explosions



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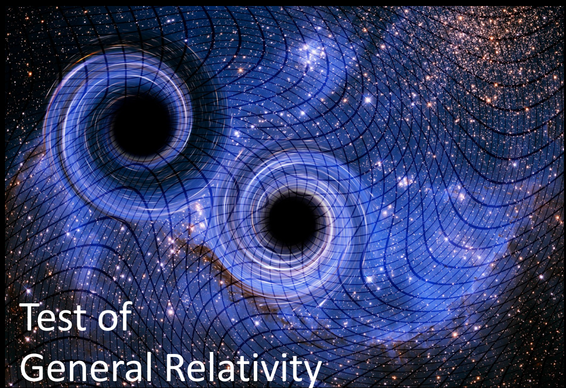
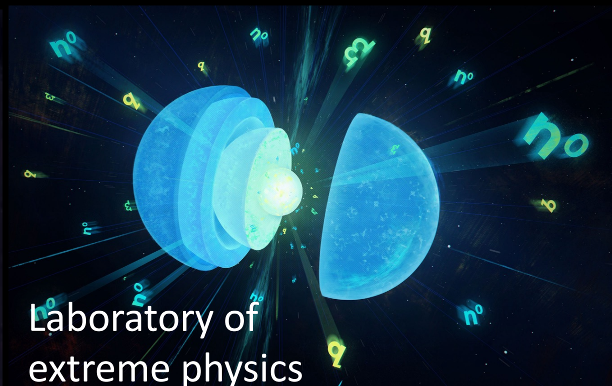
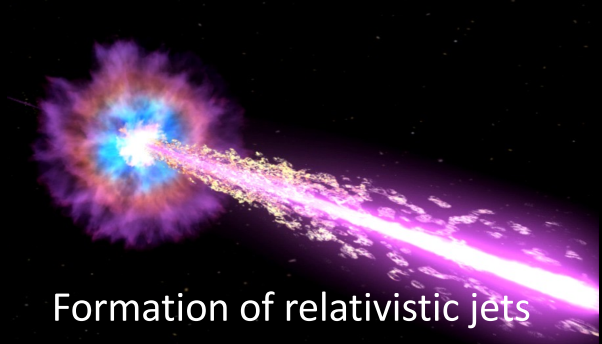
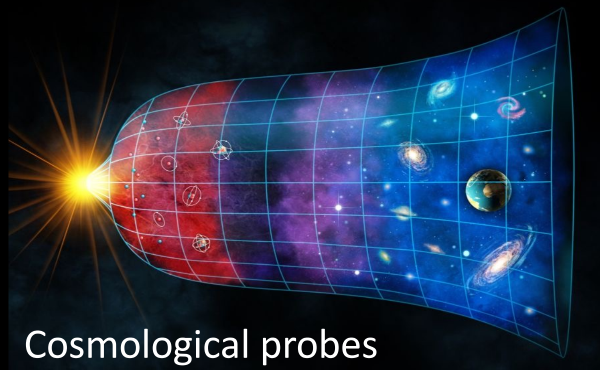
Key questions of modern astrophysics


Test of
General Relativity


Origin of the heavy
r-process elements


Laboratory of
extreme physics


Formation of relativistic jets


Cosmological probes

Expanding our **discovery space**

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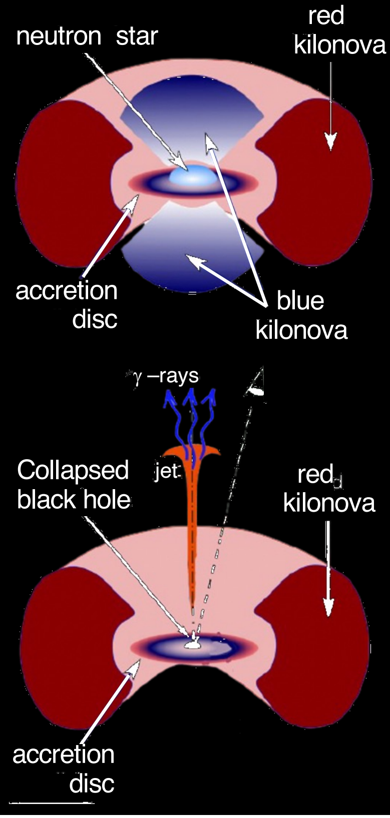
Outstanding questions

- Do all NS mergers produce relativistic jets and GRBs like GRB170817A?
- Do all NS mergers forge large amounts of heavy elements? How robust is the r-process production?
- What is the remnant of a NS merger, a massive NS or a prompt BH? Does it produce FRBs?
- How do NS-BH mergers look like?
- In which conditions binary BHs emit light?

We need MORE EVENTS to map and understand the diversity of initial conditions and outcomes.



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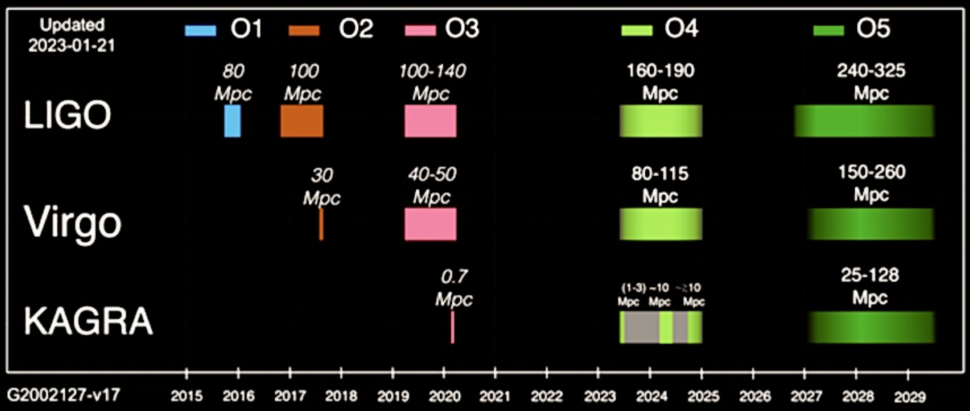
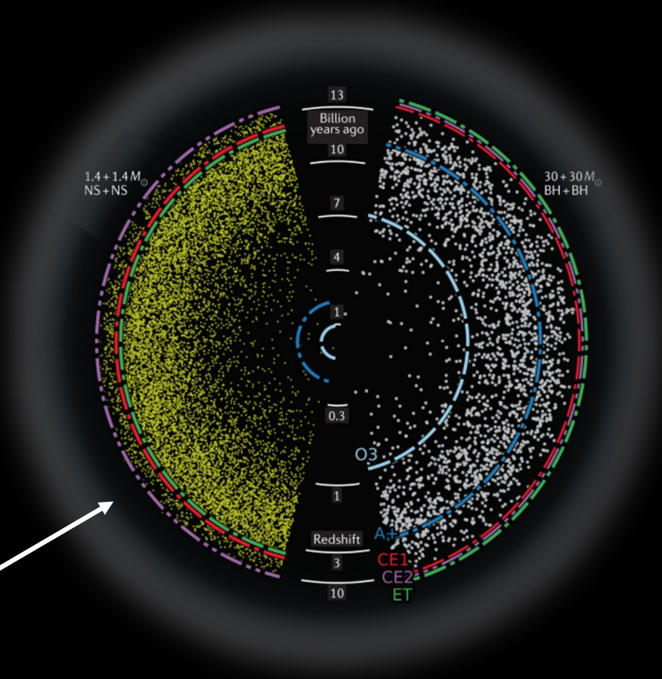
Finding new GW sources





From a trickle … to a flood

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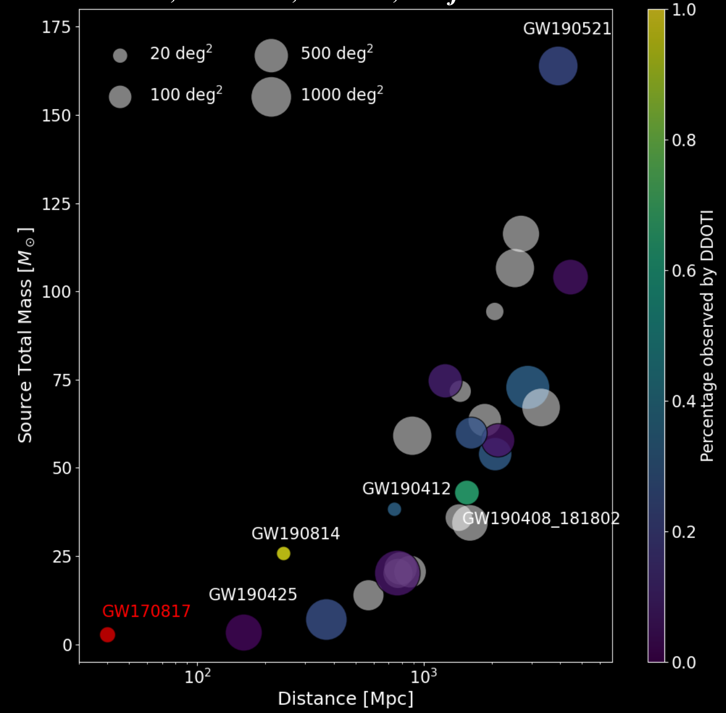
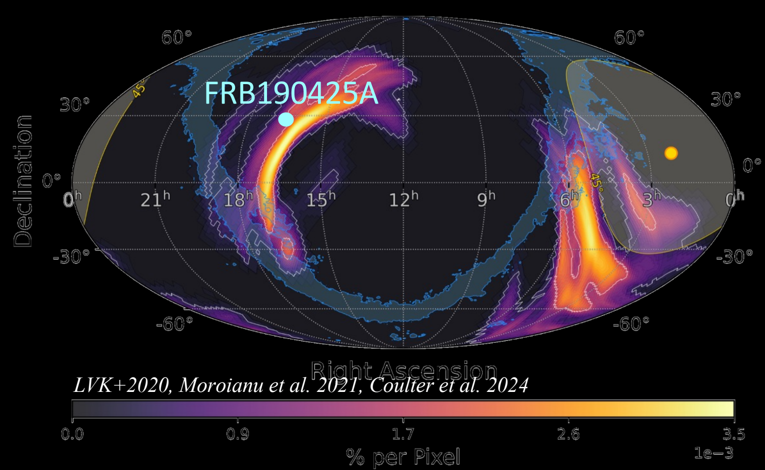
Localizations, localizations, localizations

*Becerra, Dichiara, Watson, **Troja** et al. 2021*



GW190425



LVK+2020, Moroianu et al. 2021, Coulter et al. 2024

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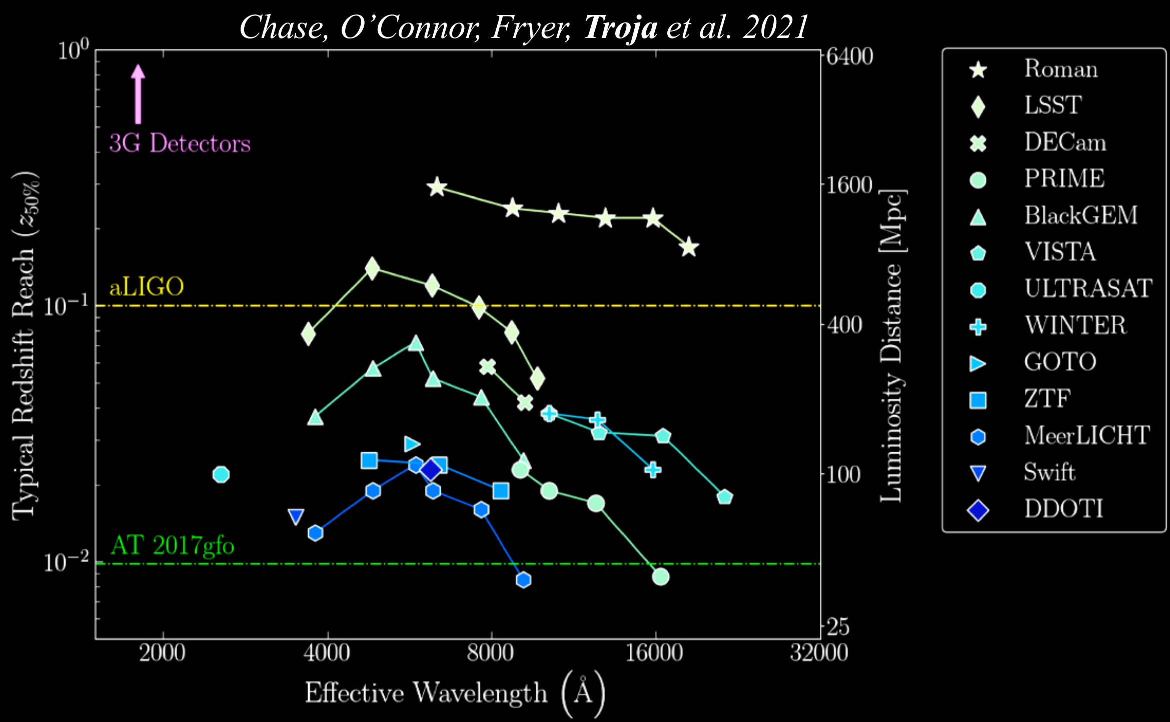
Kilonova detectability



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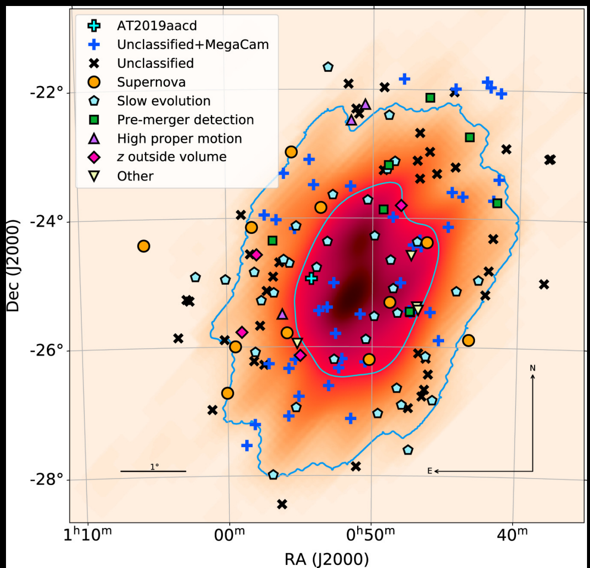
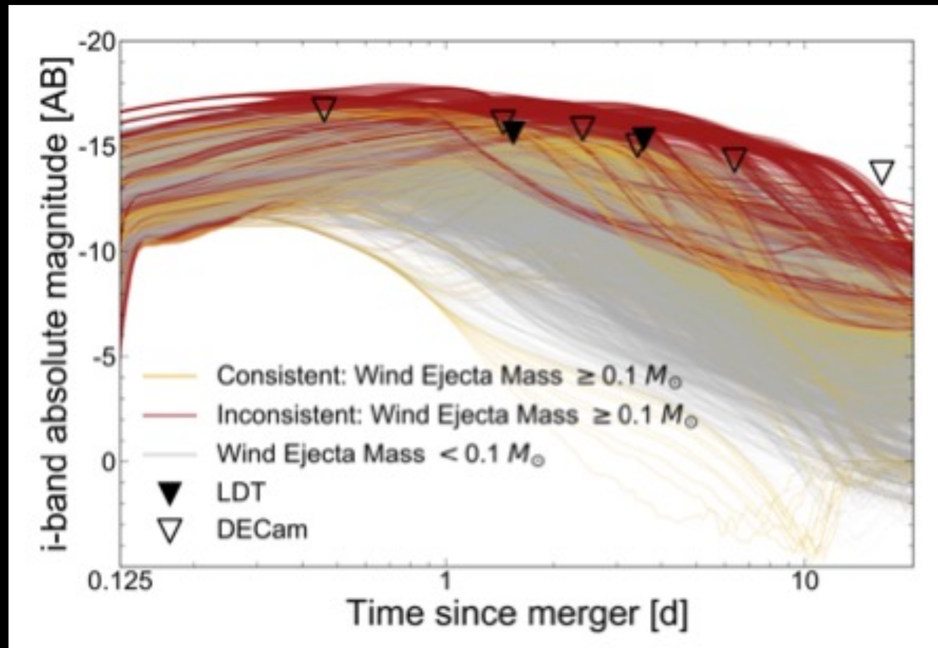
Constraints from GW follow-up: GW190814



Vieira et al. 2020



*Thakur, Dichiara, **Troja**, et al. 2020*

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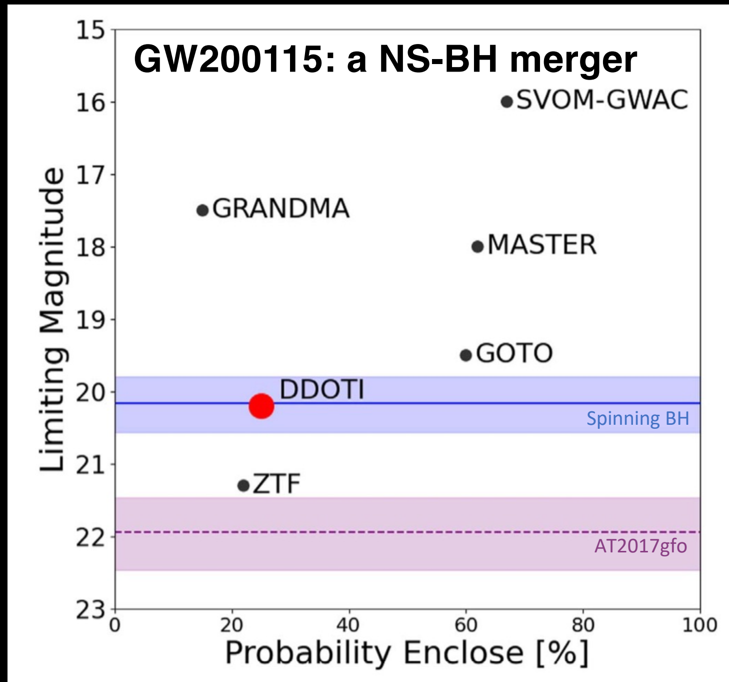
Constraints from GW follow-up: GW200115



*Dichiara, Becerra, Chase, **Troja**, et al. 2021*

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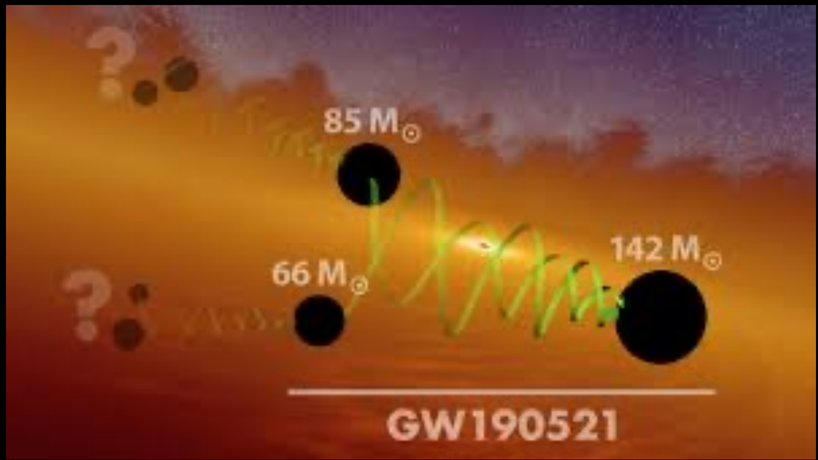
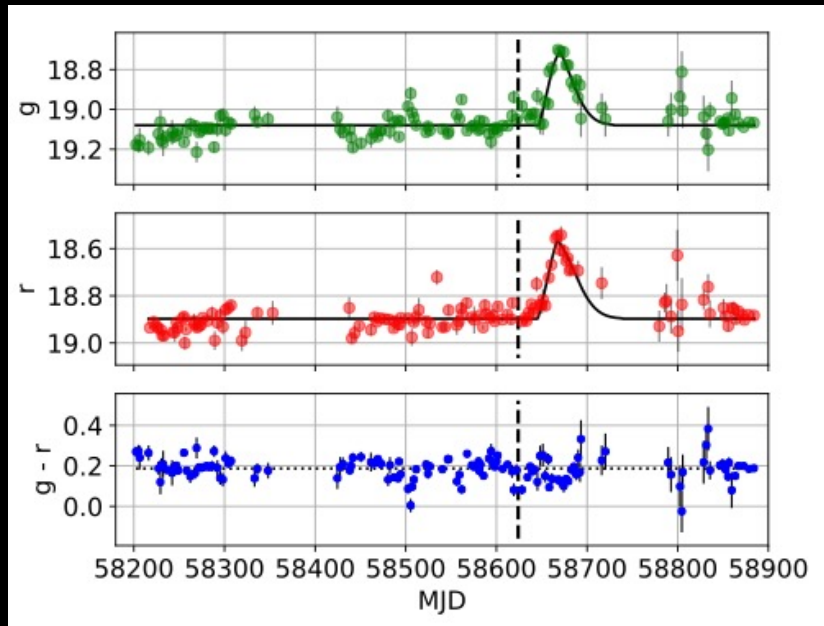
Constraints from GW follow-up: GW190521





Graham et al. 2021

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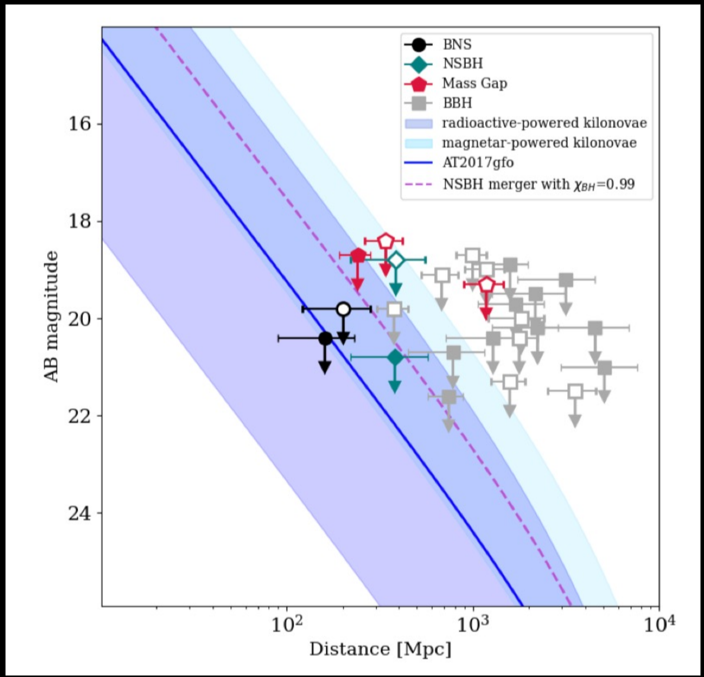
Constraints from GW follow-up: summary



*Becerra, Dichiara, Watson, **Troja**, et al. 2021*

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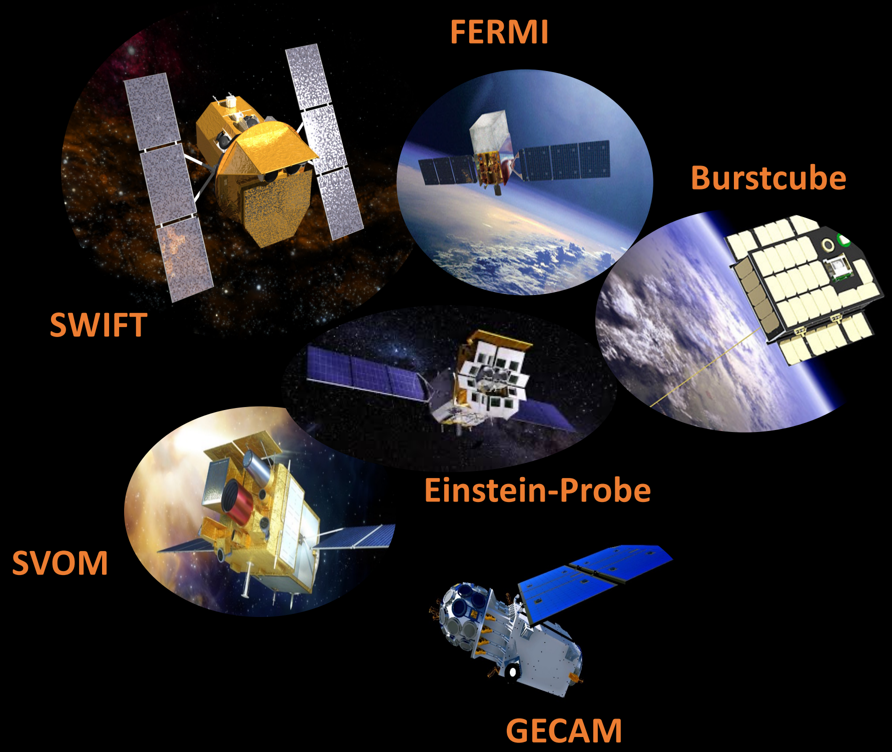
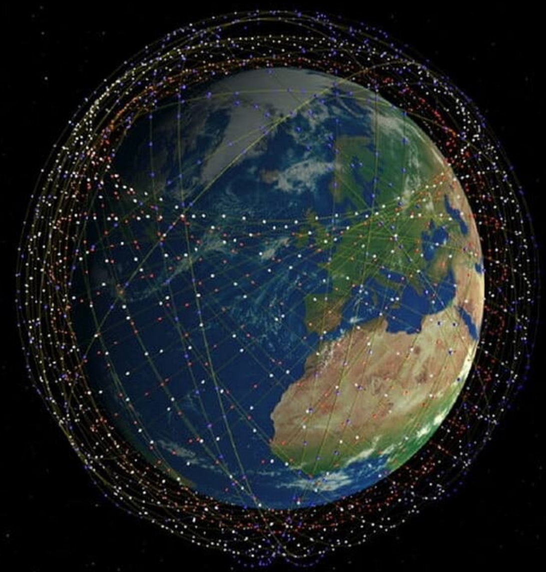
GW sources at high-energies



Full view of the sky at any time



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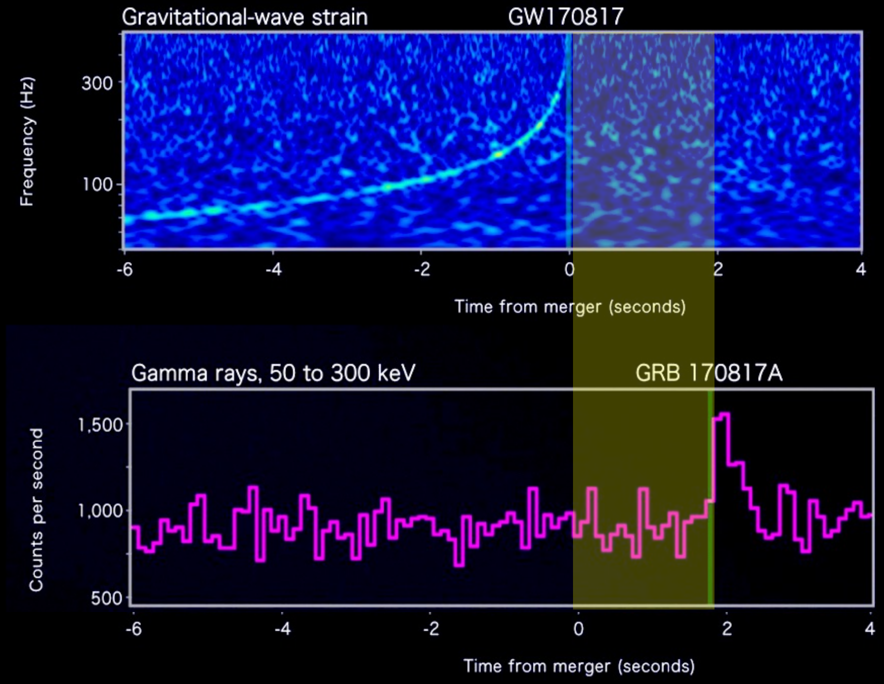
The GRB/GW connection



Why a
1.7 s delay?

- Viewing angle?
- Jet-launching?
- NS collapse?
- Modified gravity?

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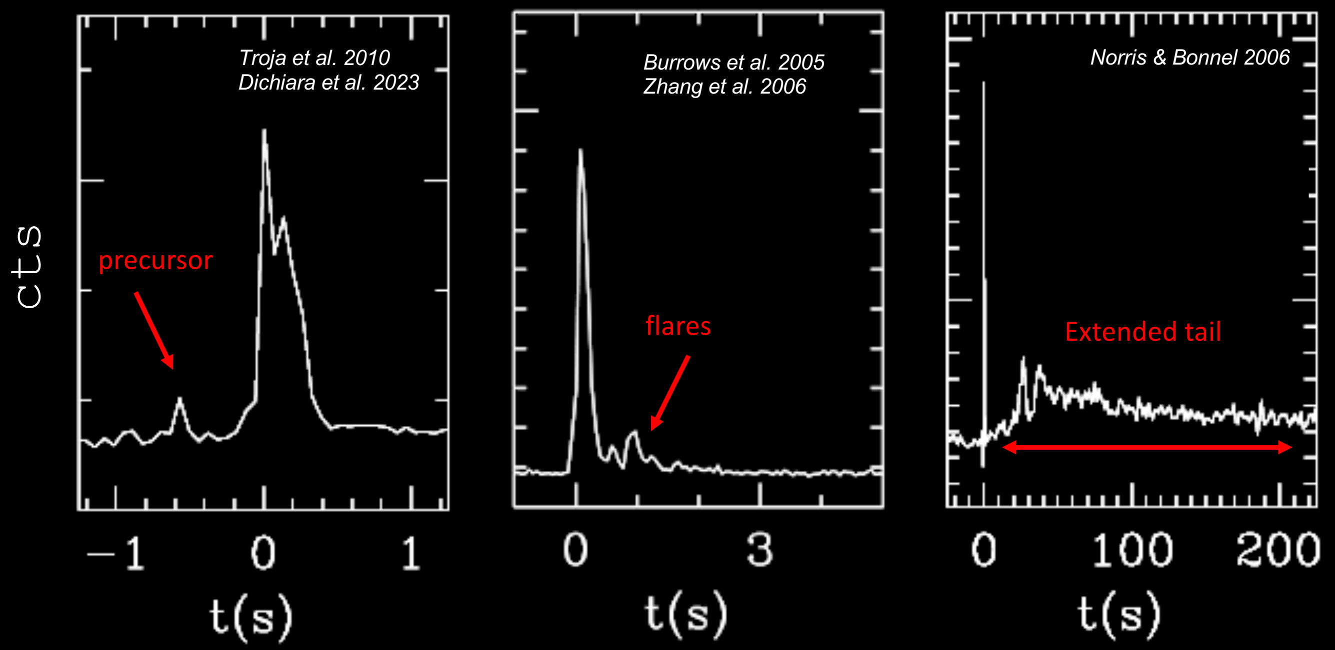
A new look at the gamma-ray emission



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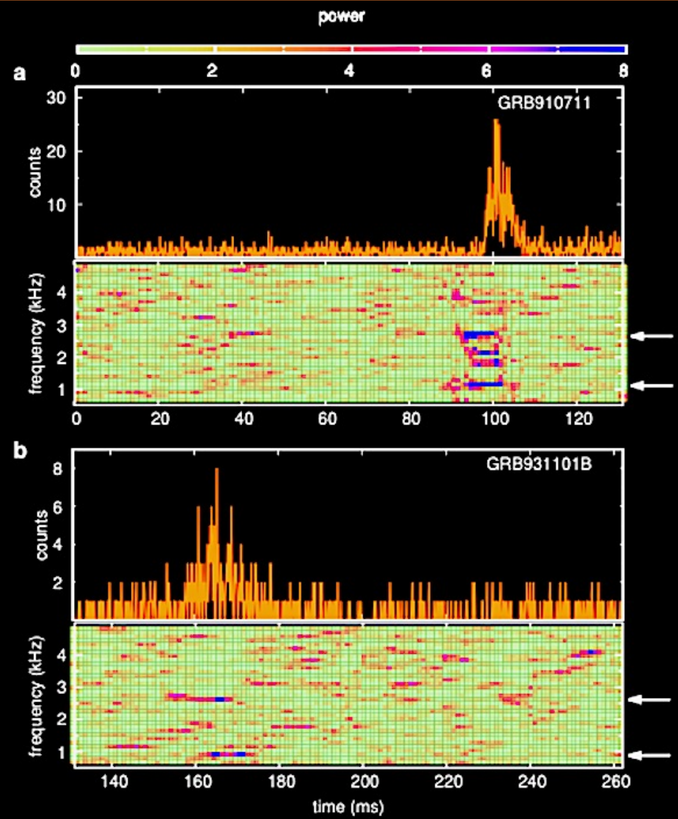
A new look at the gamma-ray emission

Possible
Quasi-Periodic Oscillations

Chirenti et al. 2023
Chirenti et al. 2024



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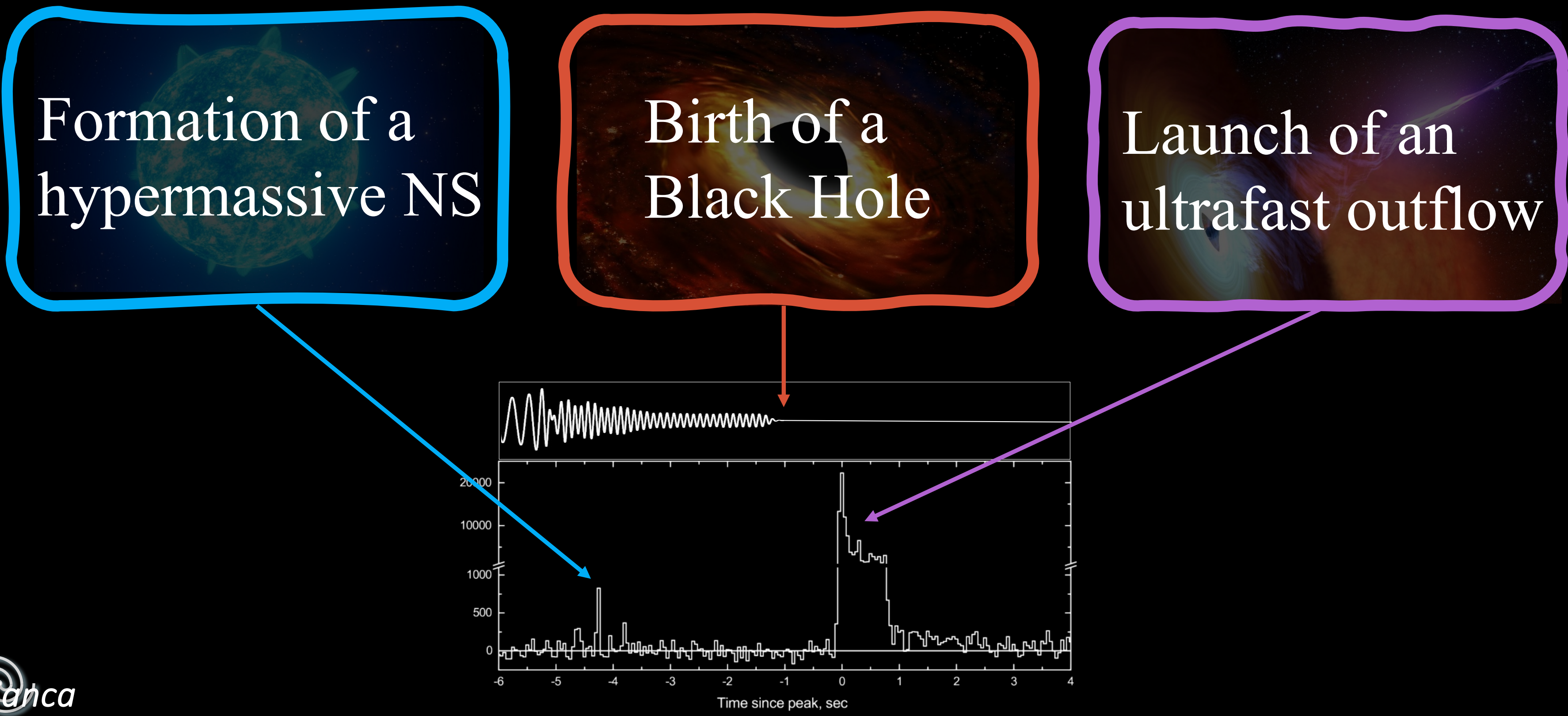
Stellar forensics: a multi-messenger approach



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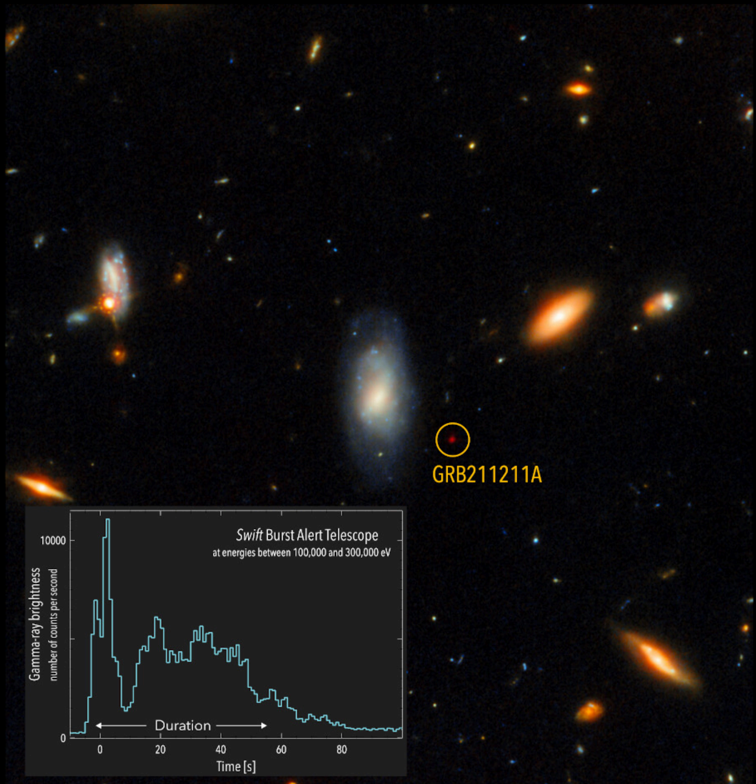
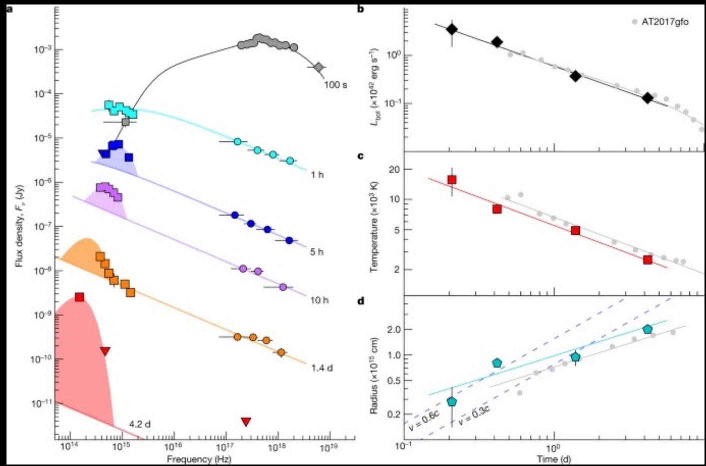
New Enigma: Long GRBs from NS mergers



Troja et al., Nature, 2022



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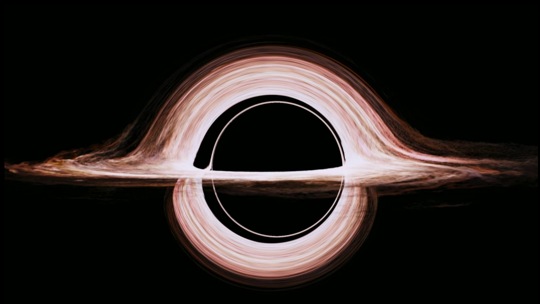
See also Yang et al. 2022, Rastinejad et al. 2022, Yang et al. 2024, Levan et al. 2024

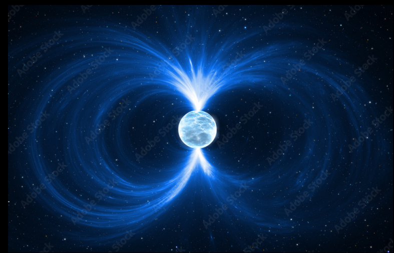
Who will solve the enigma?

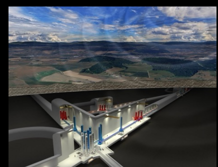
LIGO and Virgo



Neutron Star - Black Hole merger?

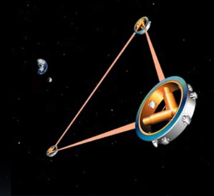
A long lived Magnetar?

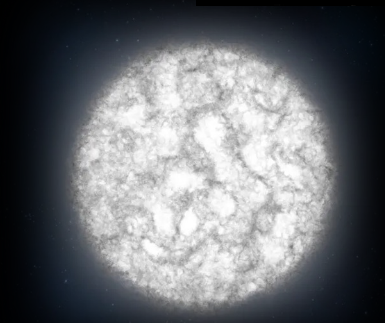




Einstein Telescope

LISA





White Dwarf – Neutron Star merger?

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Summary and final thoughts

The combination of multiple messengers is the **most powerful tool** to explore our Universe. EM observations can break the degeneracy of some GW parameters (distance, inclination, merger remnant).
To fully realize the promise of multi-messenger astronomy, electromagnetic facilities must keep up with the advancement of GW detectors

Our knowledge will be built upon a few key events in the next few years, but the **rate of events** might drammatically increase in the next decade

Expect the unexpected: GW170817 was one NS-NS merger, a wide range of diverse outcomes is likely

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Thanks!