Multimessenger

Barbara Patricelli[1,2,3]

[1] Physics Department - University of Pisa

[2] INFN - Sezione di Pisa

[3] INAF - Osservatorio Astronomico di Roma

Virgo-ET Pisa Internal Workshop

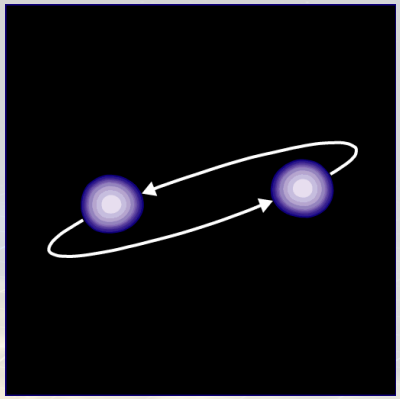
May 22-23, 2024

Pisa, Italy

Outline

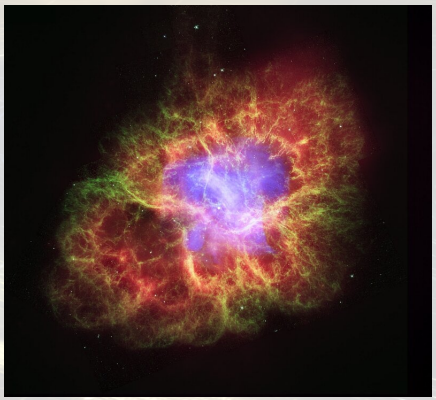
High frequency (10-1000 Hz) GW transient sources

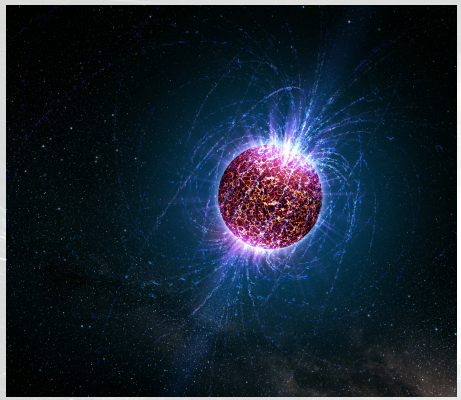
Coalescence of binary systems of NSs and/or BHs



- Accurate modeling of the GW signals
- Matched filter modeled searches (CBC group)

Core collapse of massive stars and Isolated neutron stars





- The modeling of the GW signal is complicated
- Unmodeled searches (Burst group)

Associated multi-wavelength electromagnetic (EM) emission

NS-NS and NS-BH mergers

- Short Gamma-Ray Bursts (GRBs):
  - *Prompt* γ-ray emission (< 2 s).
  - Multiwavelegth *afterglow* emission: X-ray, optical and radio (minutes, hours, days, months).
- Kilonova: optical and NIR (days-weeks).
- Late blast wave emission: radio ($\sim$ months, years).

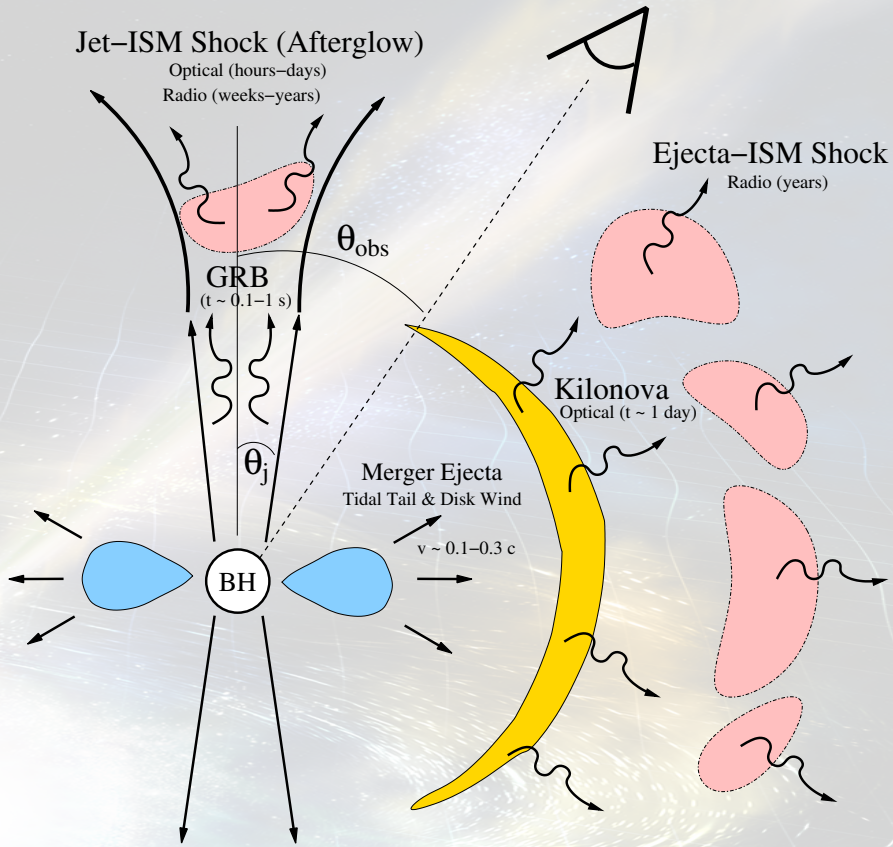


Image credit: Metzger & Berger 2012

Associated multi-wavelength EM emission

- They are typically not expected to produce bright EM signal due to the absence of baryonic matter left outside the merger remnant...
- ... However, some rare scenarios which predict an unusual presence of matter around the BBH have been proposed in the last years, e.g.
  - the matter comes from the remnants of the stellar progenitors (Loeb 2016, Perna et al. 2016, Janiuk et al. 2017)
  - the matter comes from the tidal disruption of a star in triple system with two BHs (Seto & Muto 2011, Murase et al. 2016)
- In addition, **BBH mergers can take place in gas rich environment in the disks of active galactic nuclei** (AGN, Bartos et al. 2017, McKernan et al. 2019)

Associated multi-wavelength EM emission

Core collapse of massive stars

- supernovae (SNe):
  - X-rays, UV
  (minutes, days)
  - optical (week, months)
  - radio (years)

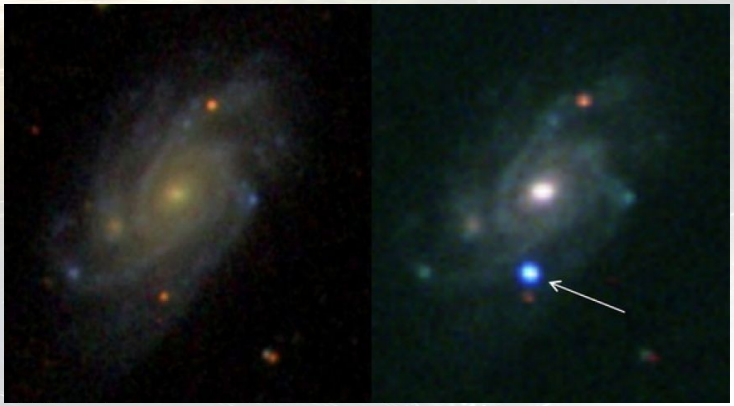


Image Credit: Avishay Gal-Yam

- long GRBs (prompt duration > 2 s)

Isolated neutron stars

- soft γ-ray repeaters
- radio/X-ray pulsar glitches

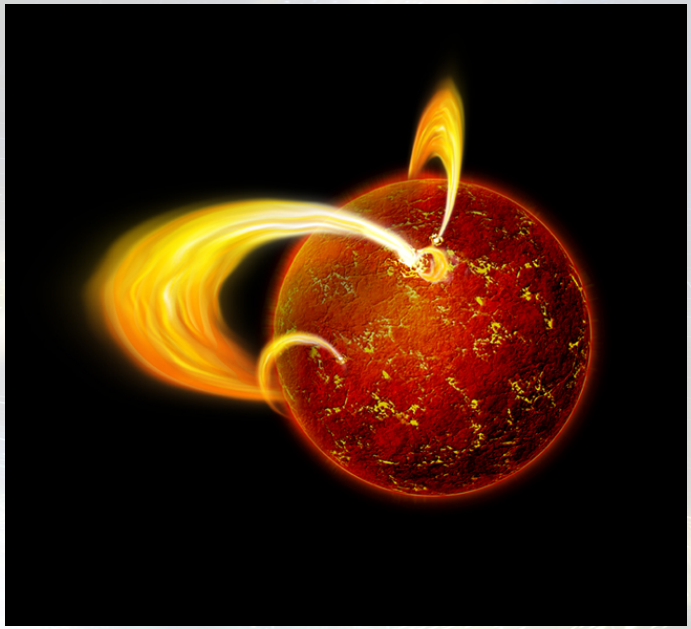


Image Credit: NASA, CXC, M. Weiss

Why multi-messenger astronomy with GWs?

GWs and photons provide complementary information about the physics of the source and its environment

GW

- *mass*
- *spin*
- *system orientation*
- *luminosity distance*
- *compact object binary rate*

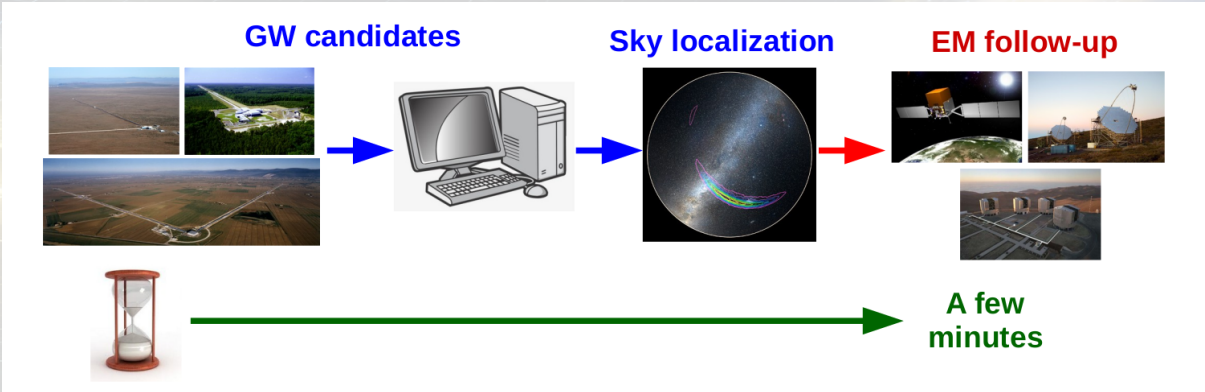
EM

- *precise (arcsec) sky localization*
- *host galaxy*
- *redshift*
- *emission processes*
- *acceleration mechanisms*

Joint GW and EM/neutrino detections

Possible scenarios:

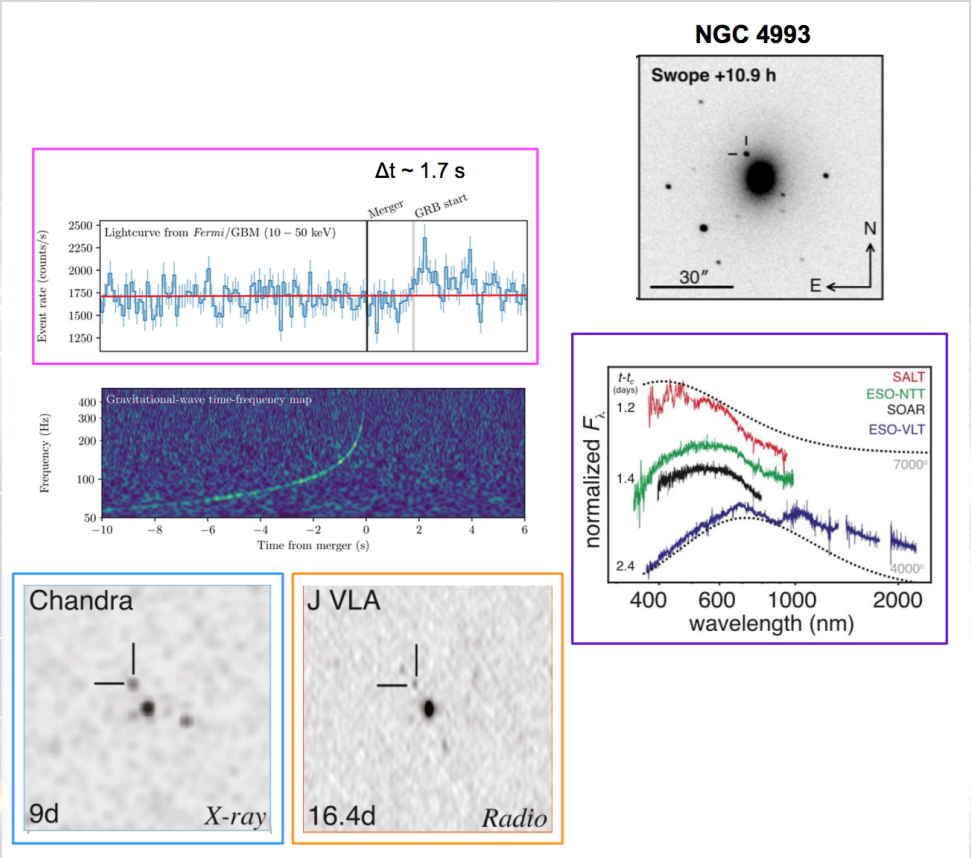
- **EM follow-up:** low-latency GW data analysis pipelines promptly identify GW candidates and send GW alerts to trigger prompt EM observations and start archival searches



- **Externally-triggered GW searches:** an EM transient event is detected and GW data are analyzed to look for possible associated GW events.

GW170817: multi-messenger observation

August 17, 2017: the beginning of multi-messenger astronomy with GWs



- Coincident short GRBs detected in gamma rays ⇒ first direct evidence that at least some **BNS mergers are progenitors of short GRBs**
- An optical/infrared/UV counterpart has been detected ⇒ first spectroscopic **identification of a kilonova**
- An X-ray and a radio counterparts have been identified ⇒ off-axis afterglow from a **structured jet**
- Important implications for fundamental physics and cosmology

Abbott et al., ApJ Letters, 848, 2 (2017) and refs. therein

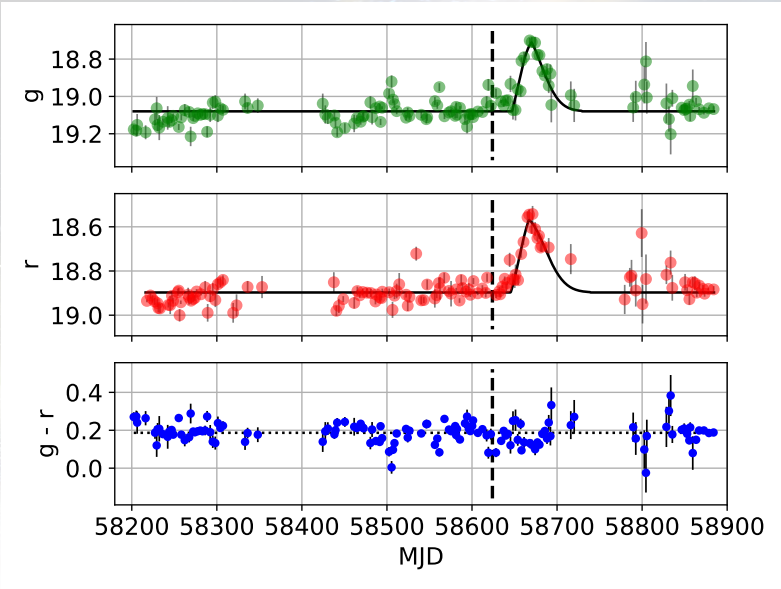
GW190521

BBH event; m_1: 85^{+21}_{-14} $M_\odot$, m_2: 66^{+17}_{-18} $M_\odot$

$\Rightarrow$ Isolated binary evolution is disfavoured

Dynamical scenario? e.g., hierarchical mergers in an AGN disk

- ZTF observed 48% of the 90% C.R. of the GW skymap (765 deg^2)
- An EM flare was observed $\sim$ 34 days after the GW event in a AGN
- It is consistent with expectations for a **BBH merger in the accretion disk of an AGN** (see McKernan et al. 2019, ApJL, 884, 50)



Common origin of the two transients seems to be preferred with respect to random coincidence (Morton et al. 2023; see, however, Ashton et al. 2021, Palmese et al. 2021)

Externally triggered GW searches: GRBs

GRB prompt emission detection $\Rightarrow$ GW triggered search

Known GRB time and sky position:

- reduction in the search parameter space
- gain in sensitivity search

Two kind of searches:

Short/Ambiguous GRBs

- Modeled binary merger search (PyGRB)
- 'On-source' search window: $[-5, +1]$ s from the GRB trigger time

All GRBs

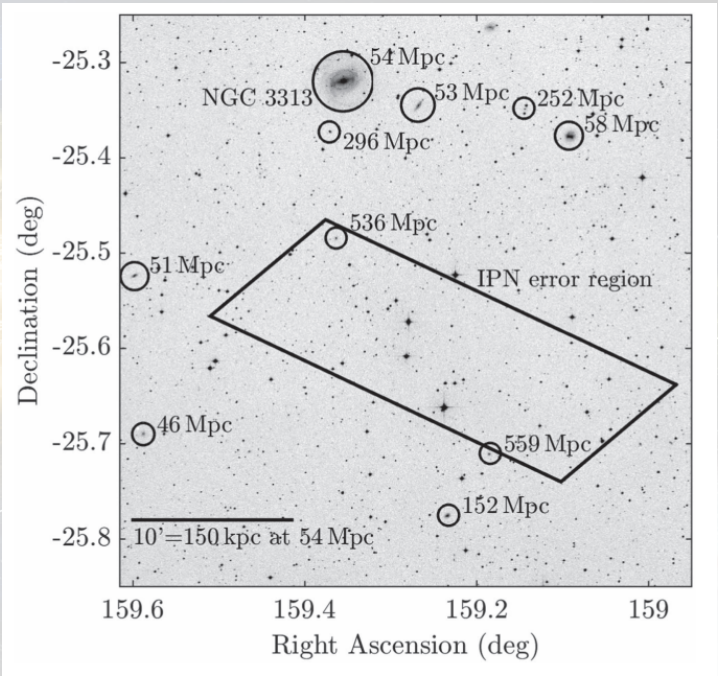
- Unmodeled generic GW transient search (X-pipeline)
- 'On-source' search window: $[-600, +\max(60, \mathrm{T90})]$ s from the GRB trigger time

No evidence for GW counterparts other than GW170817 in the first three observing runs. $\rightarrow$ **Non GW-detection result: lower bound on the progenitor distance**

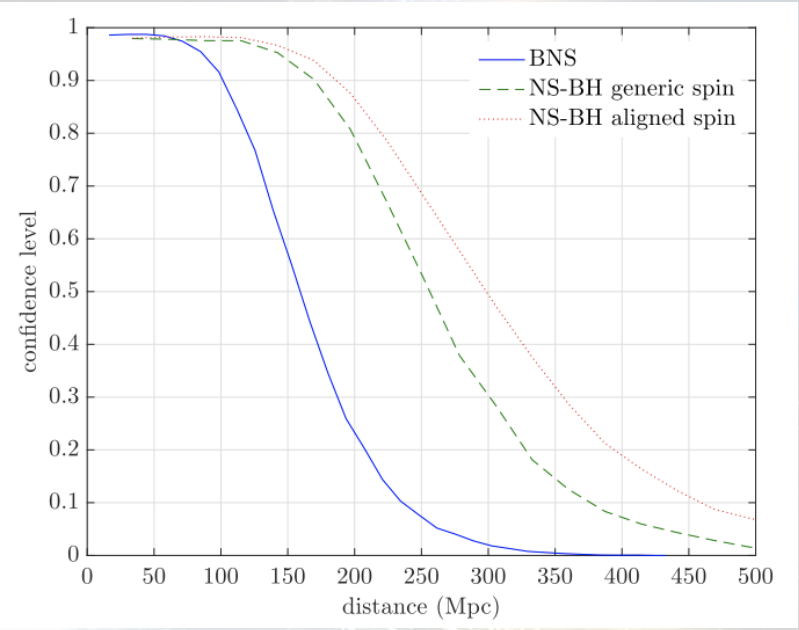
Abbott et al. 2017, ApJ 841 89 (O1), Abbott et al. 2019, ApJ, 886, 75 (O2), Abbott et al 2021 ApJ 915 86 (O3a),Abbott et al. 2022, ApJ, 928, 186 (O3b)

Externally triggered GW searches: the case of GRB 150906B

- Short duration/hard spectrum GRB close to the galaxy NGC 3313 (D=54 Mpc)



- No evidence for NS-NS or NS-BH GW signals up to 102/170/186 Mpc



Abbott et al. 2017, ApJ, 841, 89

How to contribute to multi-messenger searches within LVK?

- Multi-messenger Transient Searches Working Group
- Rapid Response Team
- CBC EM Counterpart Task Force

Multimessenger Transient (MMT) Searches Working Group

- Joint Burst and CBC working group (Wiki)
- Co-chairs: **Barbara Patricelli** and Ryan Fisher (CBC) + Ray Frey (Burst)
- Main projects of the group:
  - Offline/medium latency modeled and unmodeled GW searches triggered by:

    GRB, Fast Radio Bursts (FRBs), Magnetar flares, High Energy Neutrinos (HEN)
  - Low-latency searches for coincident GW and EM/HEN (RAVEN)
  - Offline joint, multi-messenger analysis of LVK, Fermi and Swift data to search for sub-threshold coincident GRBs and GWs
- O4: 1 active paper (O4a-GRB) and many papers under development (see the LVK Publication Plan)

Do you want to be involved in MMT activities? Please contact me and:

- Subscribe to the MMT mailing lists: cbc+grb@ligo.org, burst+grb@ligo.org
- Attend the MMT weekly telecons (Thursdays at 17:00 CEST on Zoom)

Rapid Response Team (RRT) activities

- **GW alerts**: they are public; there are currently two classes of GW alerts, depending on the False Alarm Rate of the GW candidate:
  - Low Significant GW alerts → Only automated data quality checks
  - Significant GW alerts → Automated data quality checks and human vetting → Rapid Response Team (RRT)
- **Organization of the RRT**:

  Level-0 (24/7 shifts): these are "non-specialists" who will respond to public alerts in real time, following a prescribed procedure (guide)

  Level-1 (on-call) are experts of pipelines, data quality and detectors

  Level-2 = Level-0 + Level-1 + RRT co-chairs. Semi-regular calls
- **Useful material:** Alfresco

Do you want to contribute to Level-0 shifts? Add your name here: shifter roaster

CBC EM Counterpart Task Force

Purpose:

> Combination of experts within the LVK and tools to evaluate any external claim of a significant coincidence, **to decide whether greater resources should be allocated for low significant events**

- Example: to launch more detailed PE or trigger new analyses (see also, e.g., G2202124)
- Presentation of the task force: CBC Call April 11, 2023; September 2023 LVK meeting
- Wide range of expertise within the group, from GW pipelines to multi-wavelength EM follow-up
- Do you want to help? Join the dedicated Mattermost Channel!