Coherent and Coincident Analyses of LIGO-Virgo Data from the Third Observing Run

Tesi di laurea magistrale in Fisica

SAPIENZA
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GRAVITY: FROM APPLES TO RIPPLES

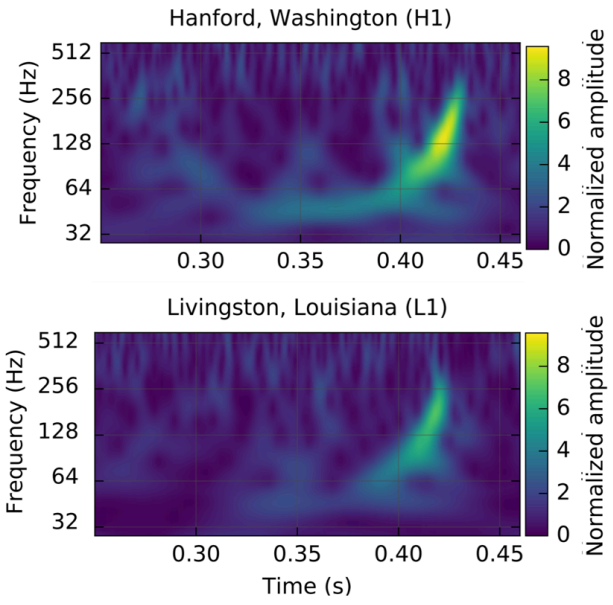
Einstein Field Equations

$$G_{\mu\nu} = \frac{8\pi G_N}{c^4} T_{\mu\nu}$$

Linearised Field Equations

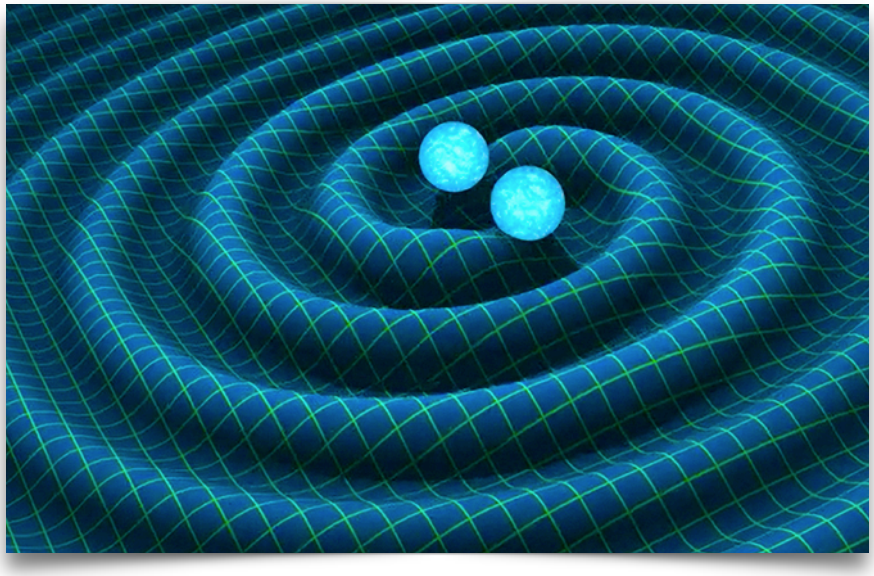
$$\Box \bar{h}_{\mu\nu} = 0$$

GW1590914



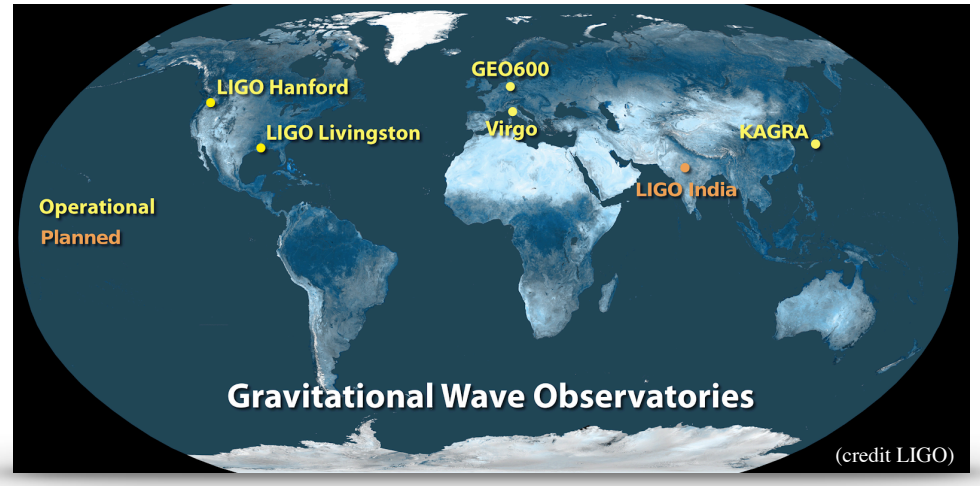
Abbott et al. (2016) Phys. Rev. Lett. 116, 061102

GRAVITATIONAL WAVES



GRAVITATIONAL WAVE DETECTION

Network of detector required.



- COINCIDENCE OF DETECTIONS: confidence that signal is from extraterrestrial sources, rather than from noise.

- SKY LOCALISATION: triangulation techniques based on the time delay in more than two detectors.

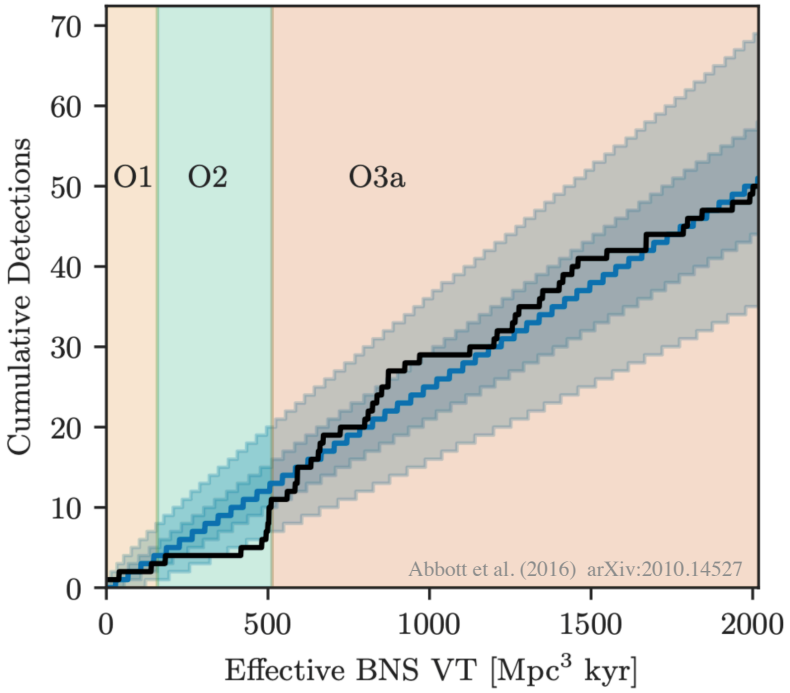
Multi Messenger Astronomy: given an accurate sky location, a corresponding EM transient

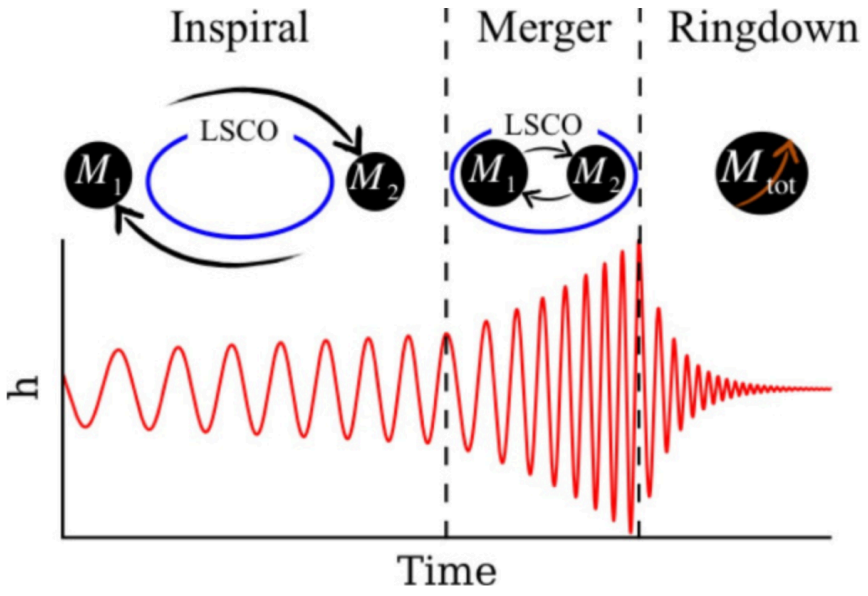
- identified in a list of events obtained with the all-sky telescope surveys,

- guide EM instruments to take images of a small area in the sky.

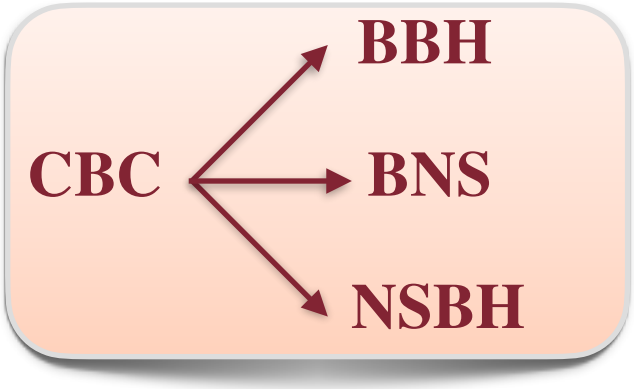
- Smaller sky localisation, larger signal-to-noise ratio.

COMPACT BINARY COALESCENCE (CBC)





O1: September 12, 2015 - January 19, 2016
O2: November 30, 2016 - August 25, 2017
O3a: April 1, 2019 - 30 September, 2019



CBC SEARCHES

- **ONLINE**: detect and report events with sub-minute latencies.
- **OFFLINE**: data calibration and data quality to produce a more sensitive search.

PyGRB

- Targeted coherent search
- Follow-up to EM transient (GRBs)
- Analysis of three GRBs in O3a data published in arXiv:2010.14550

PyCBC

- All-sky coincident search
- Targets all kind of CBC
- Background analysis of a chunk of O3b data (yet to be published by LVC)

GAMMA RAY BURSTS

Farthest and brightest explosions in the Universe (1 keV–10 MeV).

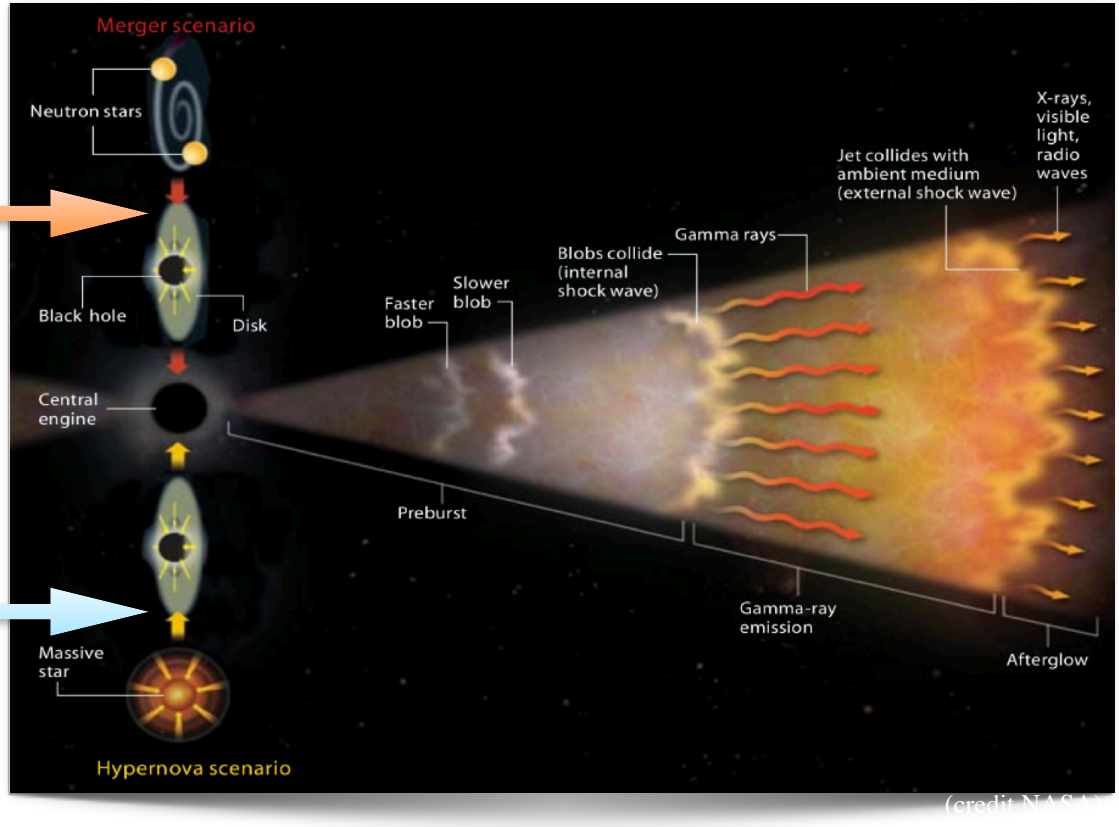
Short Gamma Ray Burst ($T_{90} < 2s$)

- More highly-energetic (hard) gamma rays
- Fainter afterglow
- Offset relative to their host galaxy center
- Baryon-poor environments
- Observation in all type of host galaxies

MERGER PROGENITOR HYPOTHESIS

Long Gamma Ray Burst ($T_{90} > 2s$)

- Observed only in star-forming galaxies
- Direct associations of LGRBs with core-collapse supernovae



SHORT GAMMA RAY BURSTS

Necessary condition for SGRB ignition: presence of NS.

PROGENITOR CANDIDATES

BNS

Confirmed by the joint detection of GW170817 and GRB 170817A.

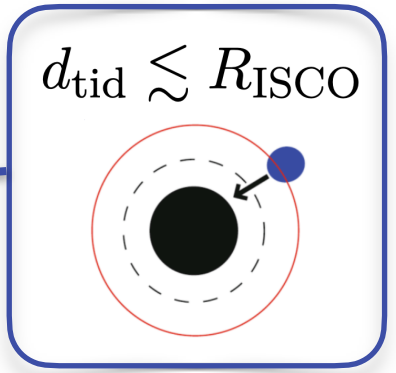
[Abbott *et al* 2017 *ApJL* **848** L13]

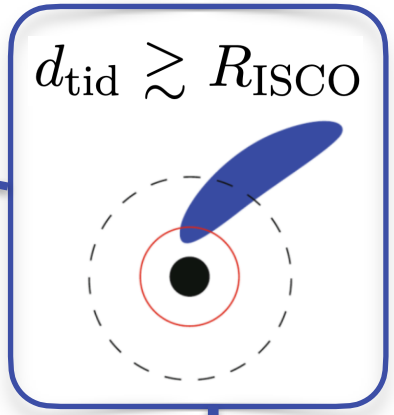
NSBH

- Potential source, no observed NSBH so far
- Not all systems are “bright”

SHORT GAMMA RAY BURSTS

NSBH MERGER SCENARIO





M_{rem}

- **indicator of potential GRB source**
- **estimation through models fitted to numerical simulations**

EM BRIGHT

EM-BRIGHT TEMPLATE BANK

PyGRB template bank targets potentially EM-bright CBC

Point is accepted and added to the bank if conditions are satisfied

- ★ **BNS ($M_1, M_2 < 2.8\ M_\odot$)**

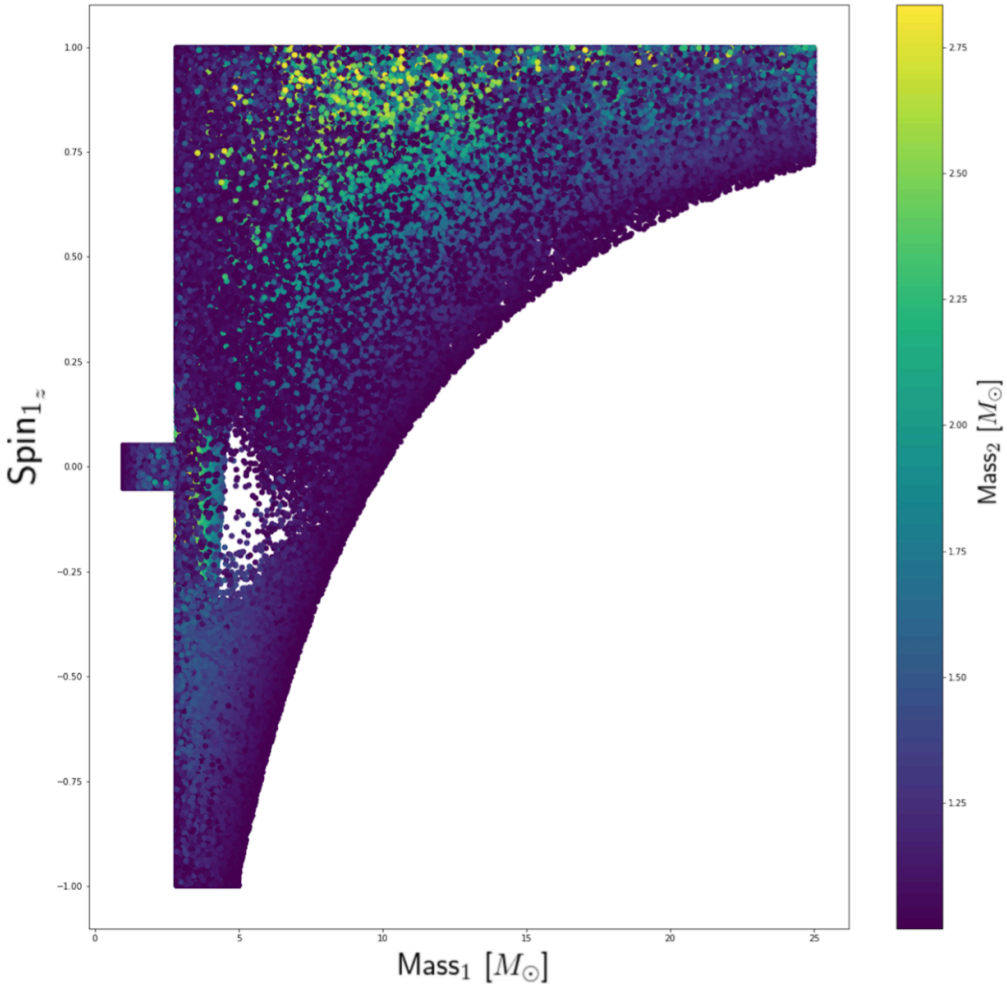
or

- ★ **NSBH with $M_{rem} > 0$**

Minimum Match: 0.97
=
Max Signal loss: 10%

NEW M_{rem} MODEL IMPLEMENTED IN O3a TEMPLATE BANK TO PROCESS ALL GRBs

EM-BRIGHT TEMPLATE BANK



BANK PARAMETER SPACE

M_1 = BH mass

M_2 = NS mass

S_1 = BH spin

BANK EFFECTUALNESS TESTS

Recovery of 10,000 injections for BNS and NSBH sets

EFFECTIVE FITTING FACTOR

FF_{eff} = 99%

(6% signal loss)

THE PyGRB PIPELINE

THE PyGRB PIPELINE

BACK UP SLIDES

Post-merger remnant mass

$$\frac{M_{\rm rem}^{\rm model}}{M_{\rm NS}^{b}} = \alpha(3q)^{1/3}(1-2C_{\rm NS}) - \beta\frac{R_{\rm ISCO}}{R_{\rm NS}}$$

$$\frac{M_{\rm rem}^{\rm model}}{M_{\rm NS}^{b}} = \left[\max\left(\alpha\frac{1-2C_{\rm NS}}{\eta^{1/3}} - \beta\frac{R_{\rm ISCO}C_{\rm NS}}{\eta M_{\rm BH}} + \gamma, 0\right)\right]^{\delta}$$

Bank hole