RDP Seventh Autumn PhD School & Workshop

"Frontiers of QCD"

Gravitational Waves from Mirror World

Beradze R. and Gogberashvili M.,
"LIGO signals from the Mirror world",
MNRAS 487 (2019) 650

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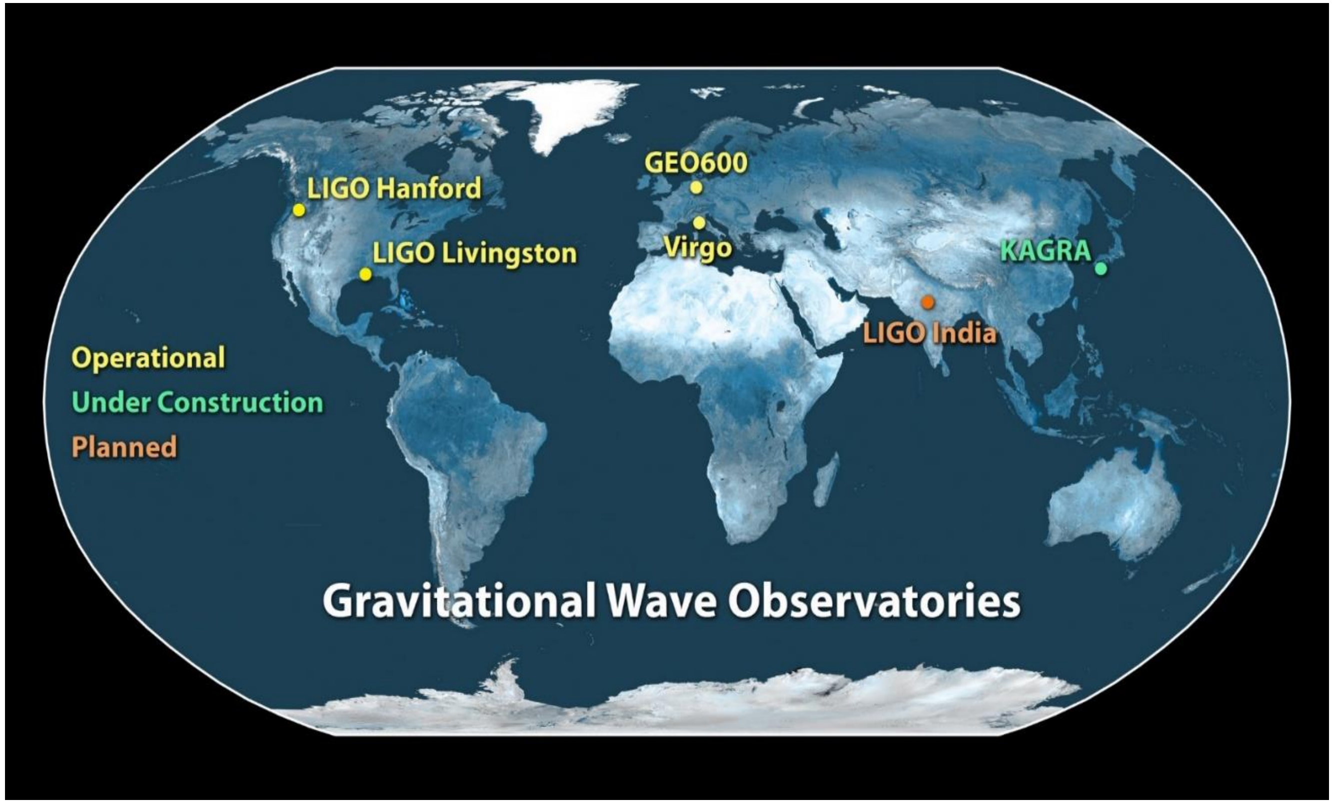
23.09.2019 - 28.09.2019
Tbilisi, Georgia

Laser Interferometer Gravitational-Wave Observatory



LIGO - gravitational wave detectors in **Hanford** and **Livingston**, **4 km** tunnels separated by **3000 km.**

VIRGO - GW detector in **Cascina, Italy** .

Laser Interferometer Gravitational-Wave Observatory

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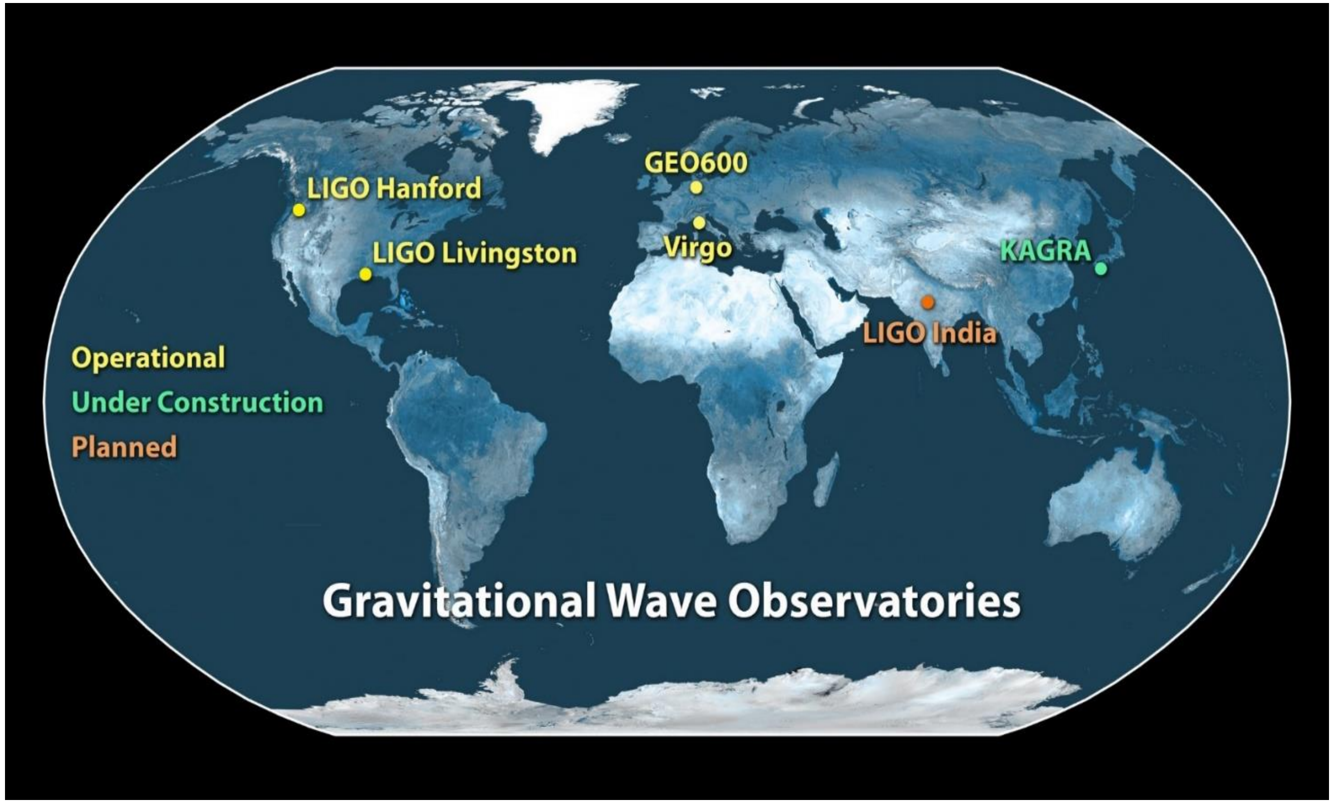

LIGO - gravitational wave detectors in **Hanford** and **Livingston**, **4 km** tunnels separated by **3000 km.**

VIRGO - GW detector in **Cascina, Italy** .

First and second observing runs detected: *(The LIGO Scientific Collaboration-1 2018)*

- **1** event from binary neutron star (BNS) merger.
- **10** events from binary black hole (BBH) mergers.

BNS merger was accompanied by Gamma-Ray Burst.
BBH mergers had no counterpart electromagnetic radiation.

Ongoing Observing run 3

- Began on 1st of April, commissioning break is planed for 1-30 October, 2019 and O3 will end on 31 of April, 2020.
- So far it detected 30 candidate events;
- Among the candidate events are the first ever Black hole - Neutron star binary systems;
- And several other possible Binary Neutron star mergers;

Ongoing Observing run 3

GraceDB — Gravitational-Wave Candidate Event Database

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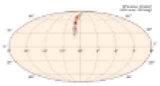
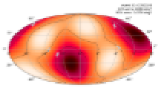
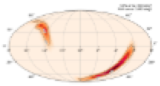
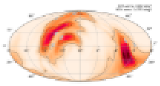
LIGO/Virgo O3 Public Alerts

Detection candidates: 29

SORT: EVENT ID (A-Z)

Event ID	Possible Source (Probability)	UTC	GCN	Location	FAR	Comments
S190915ak	BBH (99%)	Sept. 15, 2019 23:57:02 UTC	GCN Circulars Notices | VOE		1 per 32.55 years	
S190910h	BNS (61%), Terrestrial (39%)	Sept. 10, 2019 08:29:58 UTC	GCN Circulars Notices | VOE		1.1312 per year	
S190910d	NSBH (98%), Terrestrial (2%)	Sept. 10, 2019 01:26:19 UTC	GCN Circulars Notices | VOE		1 per 8.5248 years	
S190901ap	BNS (86%), Terrestrial (14%)	Sept. 1, 2019 23:31:01 UTC	GCN Circulars Notices | VOE		1 per 4.5093 years	

https://gracedb.ligo.org/superevents/public/O3/

Ongoing Observing run 3

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S190503bf	BBH (96%), MassGap (3%)	May 3, 2019 18:54:04 UTC	GCN Circulars Notices | VOE		1 per 19.368 years
S190426c	BNS (49%), MassGap (24%), Terrestrial (14%), NSBH (13%)	April 26, 2019 15:21:55 UTC	GCN Circulars Notices | VOE		1 per 1.6276 years
S190425z	BNS (>99%)	April 25, 2019 08:18:05 UTC	GCN Circulars Notices | VOE		1 per 69834 years
S190421ar	BBH (97%), Terrestrial (3%)	April 21, 2019 21:38:56 UTC	GCN Circulars Notices | VOE		1 per 2.1285 years
S190412m	BBH (>99%)	April 12, 2019 05:30:44 UTC	GCN Circulars Notices | VOE		1 per 1.883e+19 years

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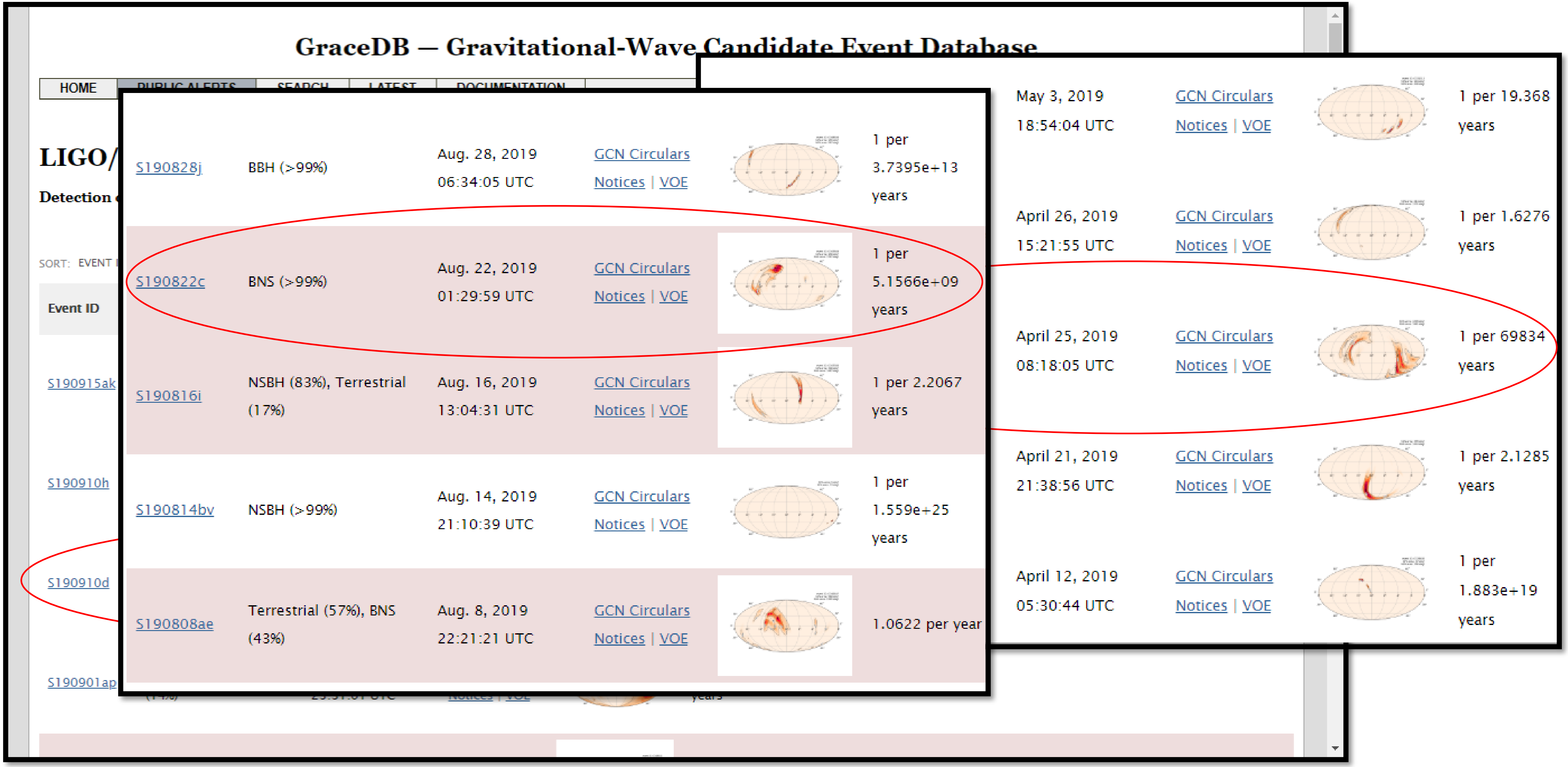
Ongoing Observing run 3



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LIGO/

Detection

SORT: EVENT

Event ID
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S190910h
S190910d
S190901ap

S190828j	BBH (>99%)	Aug. 28, 2019 06:34:05 UTC	GCN Circulars Notices | VOE		1 per 3.7395e+13 years
S190822c	BNS (>99%)	Aug. 22, 2019 01:29:59 UTC	GCN Circulars Notices | VOE		1 per 5.1566e+09 years
S190816i	NSBH (83%), Terrestrial (17%)	Aug. 16, 2019 13:04:31 UTC	GCN Circulars Notices | VOE		1 per 2.2067 years
S190814bv	NSBH (>99%)	Aug. 14, 2019 21:10:39 UTC	GCN Circulars Notices | VOE		1 per 1.559e+25 years
S190808ae	Terrestrial (57%), BNS (43%)	Aug. 8, 2019 22:21:21 UTC	GCN Circulars Notices | VOE		1.0622 per year

May 3, 2019 18:54:04 UTC	GCN Circulars Notices | VOE		1 per 19.368 years
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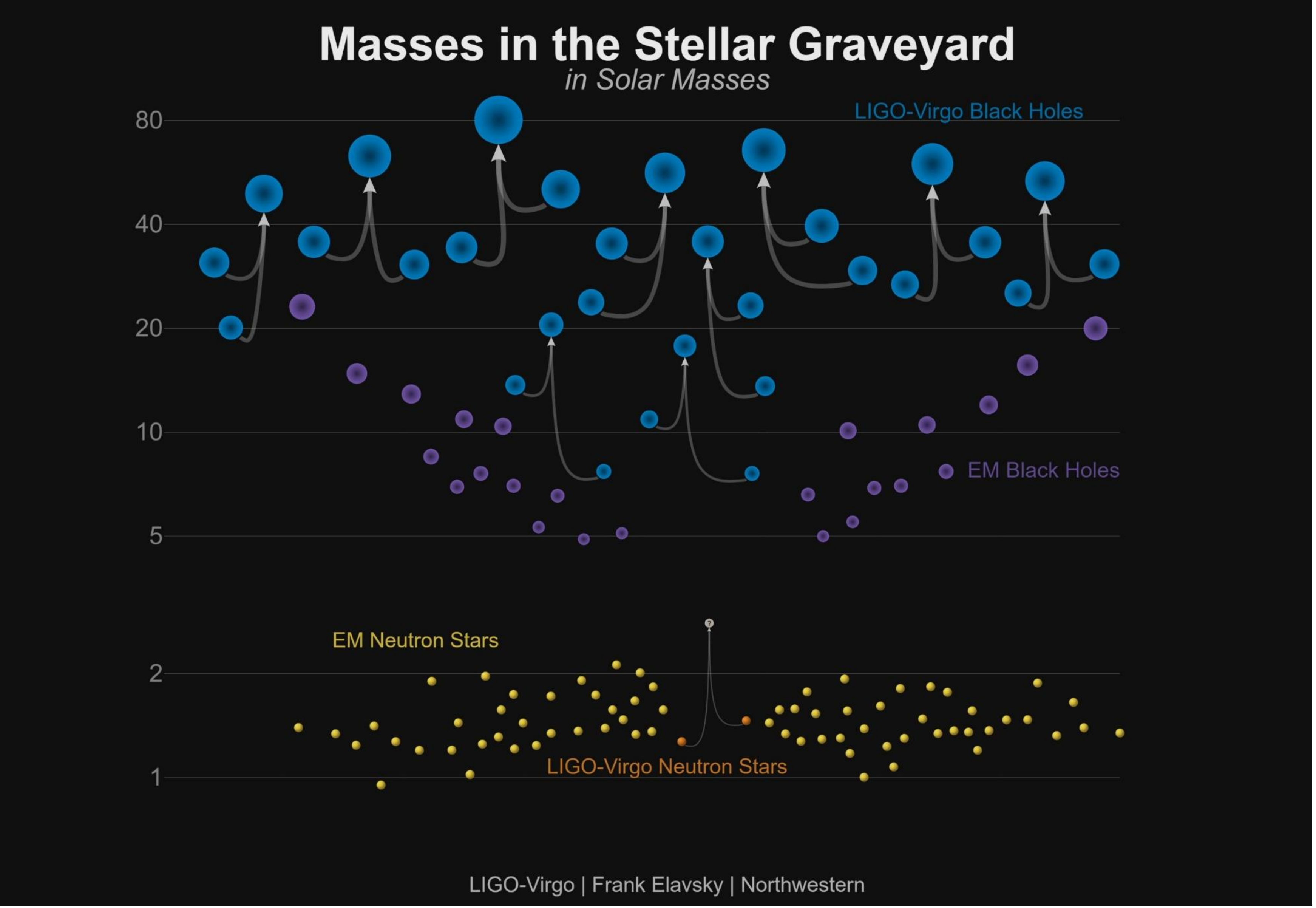
But no sign of electromagnetic radiation have been reported yet!

- BNS merger must always be accompanied by Gamma-Ray Bursts;
- BH-NS mergers in many configurations should emit EM-radiation;



GW170729

Most massive and most distant

$$M_{\rm total} = 85.1^{+15.6}_{-10.9}\ M_\odot$$

$$l_{\rm Lum} = 2750^{+1350}_{-1320}\ {\rm Mpc}$$

These discoveries confirm that:

- „massive“ ($\gtrsim 25 M_\odot$) black holes exist;
- They create binary systems;
- And can merge within Hubble time.

Merger rate: $\mathcal{R}_{\rm LIGO} = 9.7 - 101\ {\rm Gpc}^{-3}{\rm yr}^{-1}$

BBH creation mechanisms

- Primordial Black Holes; *(Sasaki, Suyama, Tanaka & Yokoyama 2018)*

  PBH abundance is constrained by microlensing, CMB spectral distortion and wide binaries.

- Astrophysical binary systems:
  - Common Envelope Evolution; *(Giacobbo & Mapelli 2018)*
  - Chemically homogenous evolution; *(Mandel & de Mink 2016)*
  - Dynamical processes in dense stellar clusters. *(Askar, et al. 2017)*

$$\mathcal{R}_{\rm theor} \sim 5 - 10 \ {\rm Gpc}^{-3} \ {\rm yr}^{-1} \quad < \ \mathcal{R}_{\rm LIGO}$$

Theoretical BBH merger rate

$$\mathcal{R} = \frac{1}{2}\,\epsilon P(\tau) N_{\rm BH}$$

$\epsilon \simeq 0.01 - 0.001$ - dimensionless efficiency coefficient

$P(\tau)$ - delay time distribution

Number of Black Holes: *(Elbert, Bullock & Kapling-hat 2018)*

$$N_{\rm BH} = {\rm SFR(z)} \times \int \phi(m)\; N(m) \int f(Z,m) \int \xi(M)\; dM\; dZ\; dm$$

$N(m) = \dfrac{m}{\int M\; \xi(M)\; dM}$ - Number of stars in galaxy of m mass;

$\xi(M)$ - Initial mass function (IMF);

$\phi(m)$ - Galactic mass function;

$f(Z,m)$ - Metallicity distribution function;

Star formation rate: *(Madau & Dickinson 2014)*

$$\rm SFR(z) = 0.015 \frac{(1+z)^{2.7}}{1+[(1+z)/2.9]^{5.6}}\; M_\odot\; Mpc^{-3}\; yr^{-1}$$

Peaks at:

$z \sim 2 \;\approx\; t_{\rm lookback} \sim 10.3$ Gyr

LIGO signals from Mirror world

- GW from BBHs has no counterpart EM radiation, that is why these BBHs may have existed in Mirror world.

Mirror World model

- Each Standard Model (SM) particle has its Mirror partner with opposite chirality;
- Ordinary and Mirror particles interact only by gravity;
- Mirror world, along with Ordinary world, was created by Big Bang, but with low reheating temperature;
- Constrain from Big Bang Nucleosynthesis: $x \equiv \frac{T'}{T} < 0.64$
- Certain leptogenesis mechanism gives: $1 \leq \frac{n'_b}{n_b} \lesssim 10$
- Mirror world can explain all Dark Matter: $\frac{\Omega'_b}{\Omega_b} \approx 5$
- Helium abundance in Mirror world is higher: He - 40-80 %
- Stars in Mirror world are more massive and evolve faster.

For the review of mirror world see Berezhiani 2005

LIGO signals from Mirror world

- GW from BBHs has no counterpart EM radiation, that is why these BBHs may have existed in Mirror world.

- In Mirror World:

Star formation peaks at $t_{lookback} \sim 13.3$ Gyr and so: $\mathrm{SFR}'(z) \sim 1.3 \times \mathrm{SFR}(z)$

High He abundance increases initial mass function: $\mathrm{IMF}' \sim 1.5 \times \mathrm{IMF}$

Number of stars: $N'(m) \sim 5 \times N(m)$

Number of black holes: $N'_{\mathrm{BH}} \sim 10 \times N_{\mathrm{BH}}$

$$\mathcal{R}_{\mathrm{mirror}} \sim 10 \times \mathcal{R}_{\mathrm{theor}} \sim 50 - 100\ \mathrm{Gpc}^{-3}\ \mathrm{yr}^{-1}$$

Coincides with LIGO's upper bound

Prediction

Among the O3 candidate events are the first ever Black hole - Neutron star binary systems and several other possible Binary Neutron star mergers;

But none of them was accompanied by EM-radiation!

We predict:

Order of 10 higher merger rates of BNS and BH-NS systems and only 1 of the 10 BNS LIGO/VIRGO event may have EM-counterpart.

New LIGO/VIRGO O3 results expected to be announced at October 1, 2019

Summary

- BBH Merger rate calculated by LIGO/VIRGO exceeds number predicted by majority of models;
- None of the events except one was accompanied by another type of radiation;
- In the Mirror world scenario:
  - Number of binary systems is higher;
  - So merger rate is amplified, coinciding better with LIGO estimations;
  - Non-detection of EM-radiation is natural, since Mirror particles DO NOT interact with Ordinary particles;
  - Majority events with BNS are expected without EM-counterpart.


Thank you for your attention!