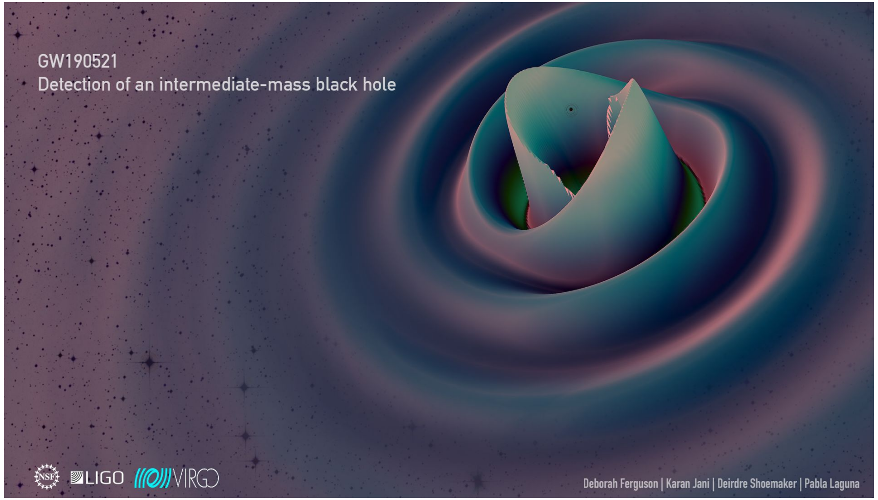
GW190521: A Binary Black Hole Merger with a Total Mass of 150 Solar Masses

LIGO Scientific Collaboration and Virgo Collaboration



Discovery paper -
Phys. Rev. Lett. 125, 101102 (2020)
https://doi.org/10.1103/PhysRevLett.125.101102

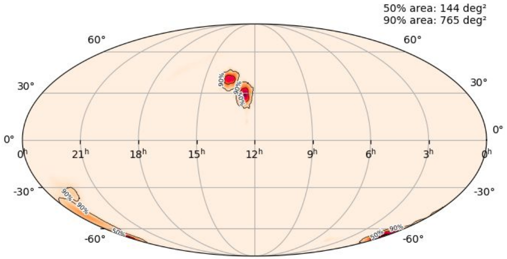
(Astro)physical implications -
Astroph. J. Lett 900 L13 (2020)

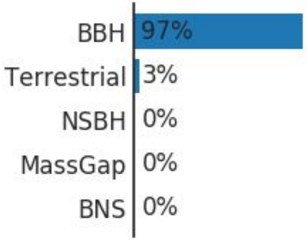
https://doi.org/10.3847/2041-8213/aba493

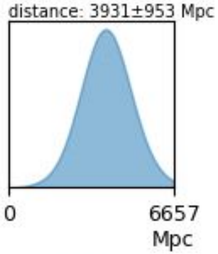
Data release -
https://dcc.ligo.org/LIGO-P2000158/public

Discovery of GW190521

Event was detected May 21, 2019 at 03:02:29 UTC and publicly reported (as S190521g) 6 minutes later.



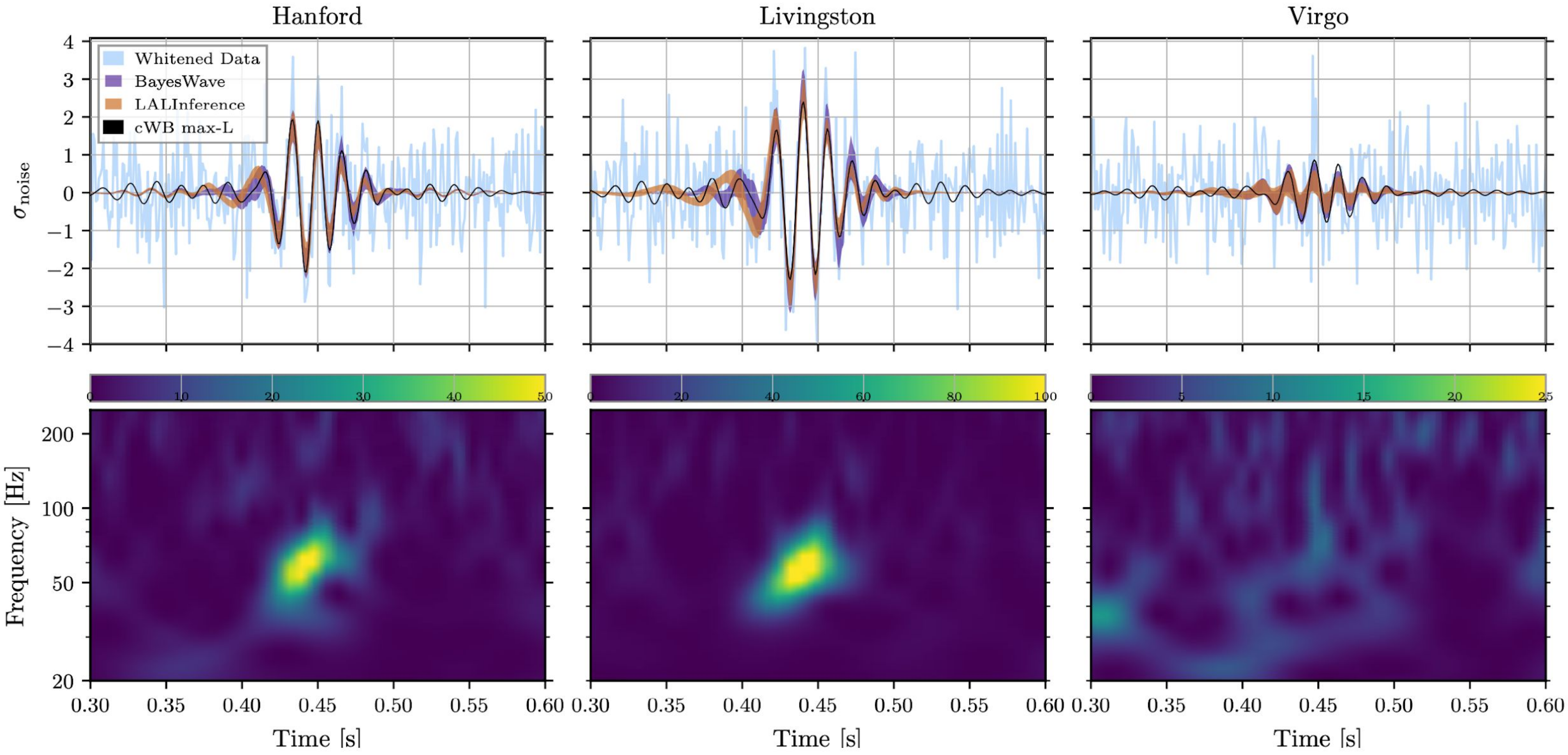




Subsequent offline analysis confirmed that this is a confident gravitational wave detection by LIGO and Virgo.

Parameter estimation routines using more complex general relativistic models for the waveform provide the information about the signal source.

GW190521 in LIGO Hanford, LIGO Livingston, Virgo



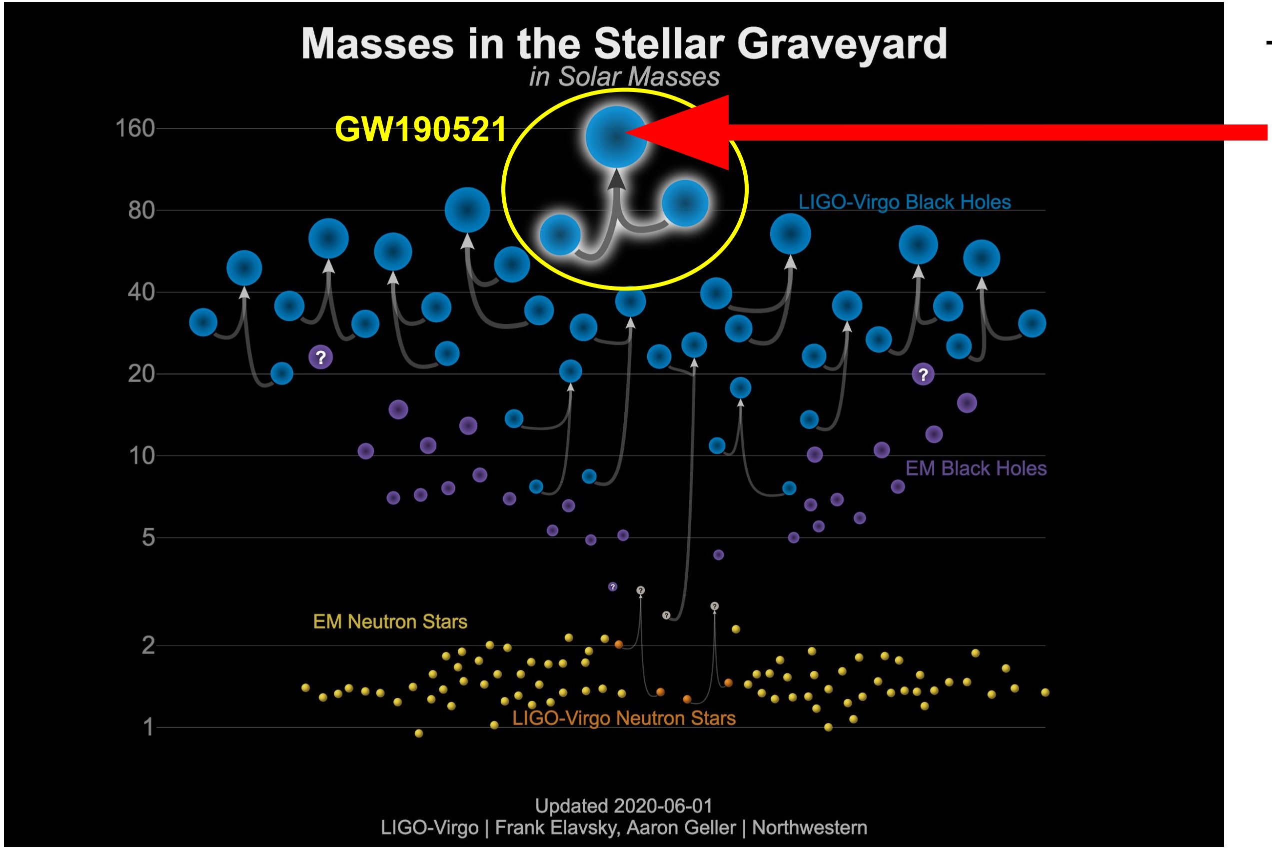
GW190521 Parameters

- Most massive observation to date
- Most distant
- Pair-instability supernova mass gap, 65-120 $M_\odot$
- Intermediate Mass Black Hole
- Important astrophysical implications
- Orbital precession

TABLE I. Parameters of GW190521 according to the NRSur7dq4 waveform model. We quote median values with 90% credible intervals that include statistical errors.

Parameter	
Primary mass	$85^{+21}_{-14}\ M_\odot$
Secondary mass	$66^{+17}_{-18}\ M_\odot$
Primary spin magnitude	$0.69^{+0.27}_{-0.62}$
Secondary spin magnitude	$0.73^{+0.24}_{-0.64}$
Total mass	$150^{+29}_{-17}\ M_\odot$
Mass ratio ($m_2/m_1 \leq 1$)	$0.79^{+0.19}_{-0.29}$
Effective inspiral spin parameter ($\chi_{\rm eff}$)	$0.08^{+0.27}_{-0.36}$
Effective precession spin parameter (χ_p)	$0.68^{+0.25}_{-0.37}$
Luminosity Distance	$5.3^{+2.4}_{-2.6}$ Gpc
Redshift	$0.82^{+0.28}_{-0.34}$
Final mass	$142^{+28}_{-16}\ M_\odot$
Final spin	$0.72^{+0.09}_{-0.12}$
$P\ (m_1 < 65\ M_\odot)$	0.32%
$\log_{10}$ Bayes factor for orbital precession	$1.06^{+0.06}_{-0.06}$
$\log_{10}$ Bayes factor for nonzero spins	$0.92^{+0.06}_{-0.06}$
$\log_{10}$ Bayes factor for higher harmonics	$-0.38^{+0.06}_{-0.06}$

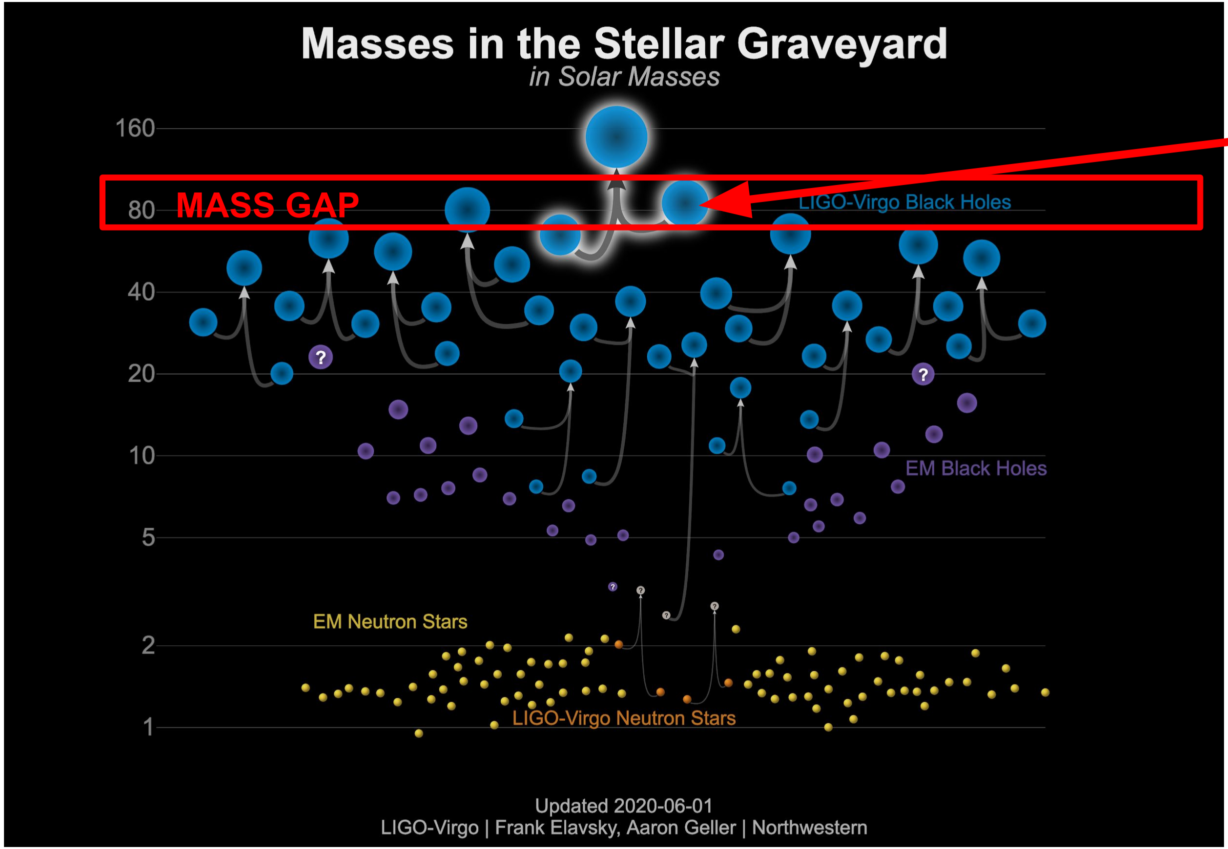
The most massive black hole ever observed with gravitational waves



The final black hole is

- the most massive black hole ever observed with gravitational waves
- the first evidence of a black hole in the 100 - 1000 solar mass range
- an intermediate-mass black hole: the missing link between stellar-mass and supermassive black holes

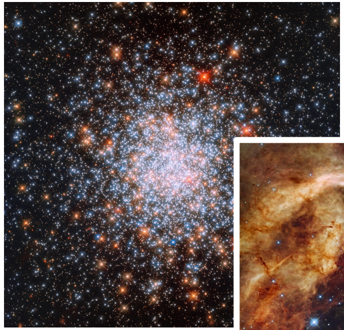
The first black hole in the pair-instability mass gap



- One of the two merging black holes has mass 85 solar masses: it cannot form from stellar collapse
- Very massive stars (He core ~ 30 - 135 solar masses) undergo (PULSATIONAL) PAIR INSTABILITY
- Expected gap in the black hole mass spectrum between ~ 65 and ~120 solar masses

Challenge for the models of black hole formation

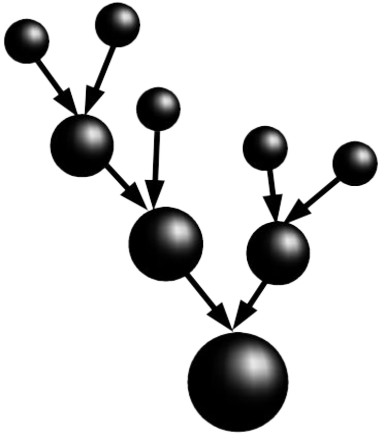
In dense star clusters and galactic nuclei, black holes can have close encounters with other black holes



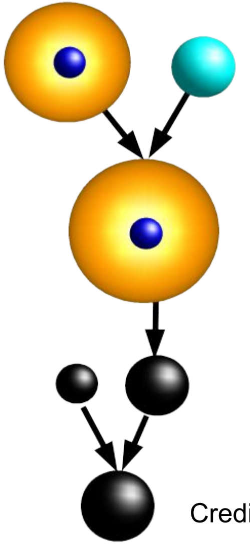
credit: NASA / ESA / Hubble

credit: NASA, ESA, F. Paresce, R. O'Connell

Hierarchical mergers

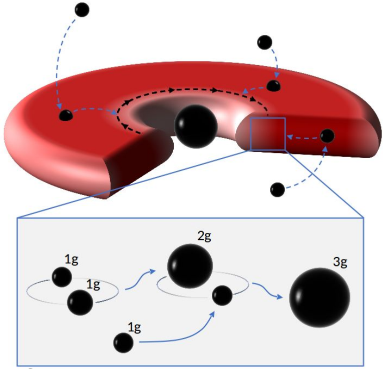


Stellar mergers



Credit: Ugo N. Di Carlo

AGN disks



Credit: Imre Bartos

...or even more exotic scenarios

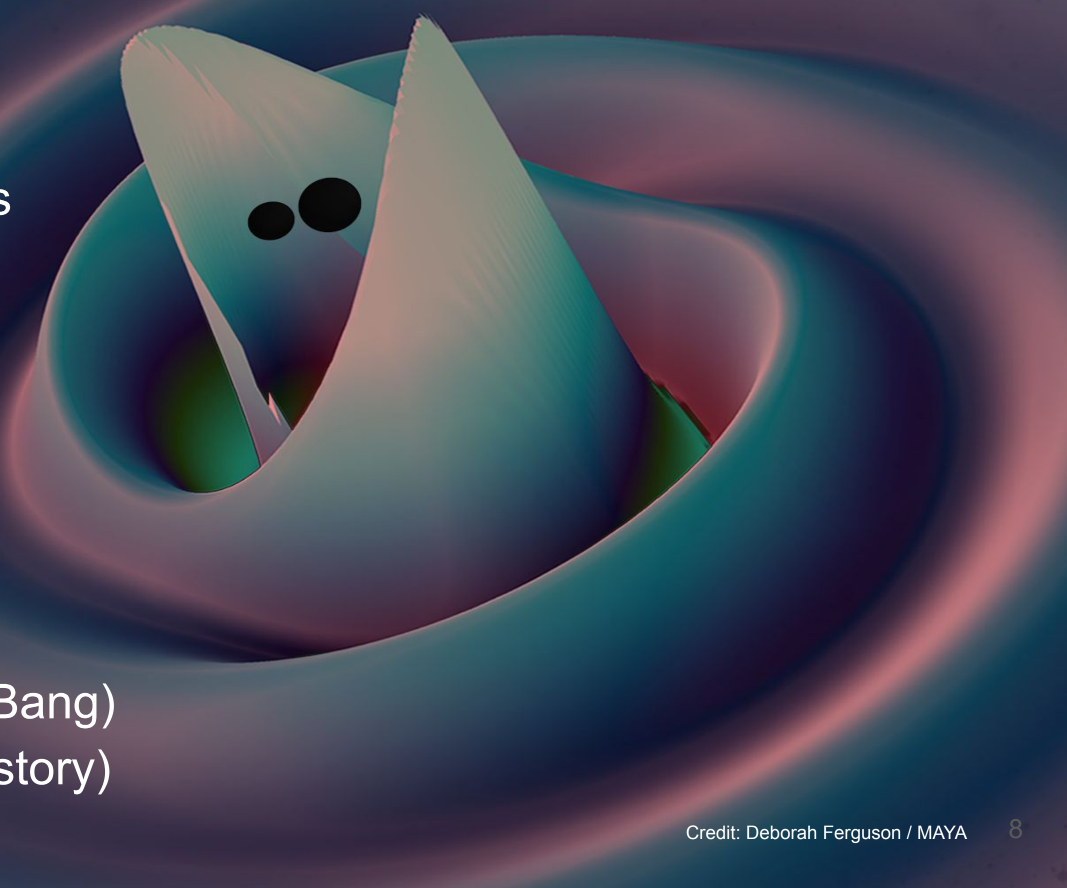
Decoding the black holes

State-of-the-art tools:

- 3 advanced GR models + 3000 supercomputer simulations of black hole collisions from Einstein's GR theory

Records book event!

- Heaviest
- First of its kind
- Most energetic
- Farthest (halfway since the Big Bang)
- Tilted spins (hints of the origins story)



Credit: Deborah Ferguson / MAYA

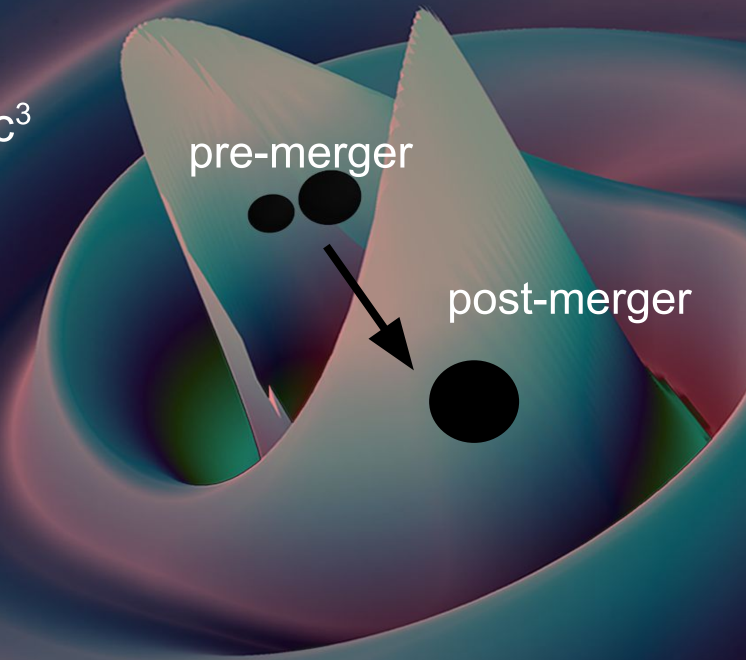
New Tests for Einstein

This event is a rare catch:

- Only once every 10 years in Gpc^3
- 500 times rarer than past LIGO-Virgo events

Full points to Einstein!

- Consistency at extreme gravity regime between pre- and post-merger black holes
- No signs in the data for alternative theories



Credit: Deborah Ferguson / MAYA

Future is bright!

Black hole desert:

- LIGO-Virgo-KAGRA will have large sample of GW190521-like black holes
- Next-generation detectors can find all size of intermediate-mass black holes

Multi-band source:

- Space+ground
- Critical for origin stories