Astrophysical implications of current O3 results

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Troisième assemblée générale
du GdR Ondes Gravitationnelles
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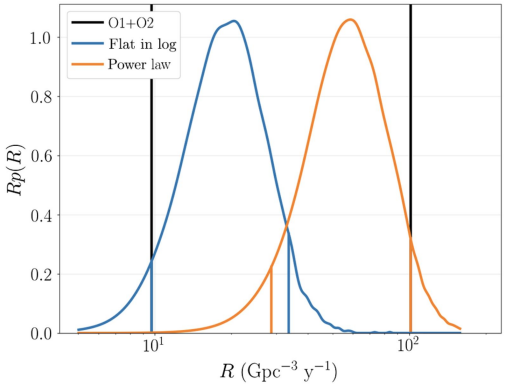
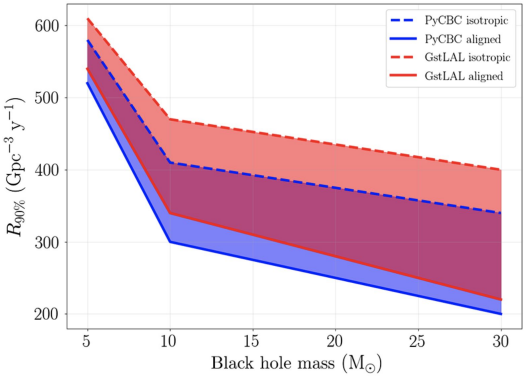
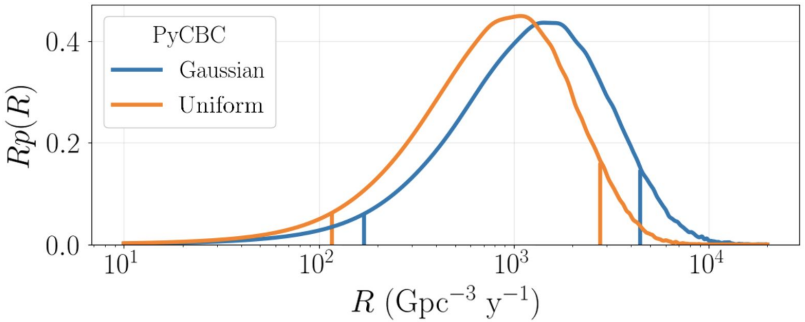
Groupement de recherche
Ondes gravitationnelles

O1-O2 results

- Ten BBH mergers
  - BBH merger rate
- A BNS merger
  - BNS merger rate
  - EoS results
  - Short-GRB engine
  - Kilonova
  - H_0 measurement
- Non-detections: NSBH, IMBH…
  - Limits on merger rate

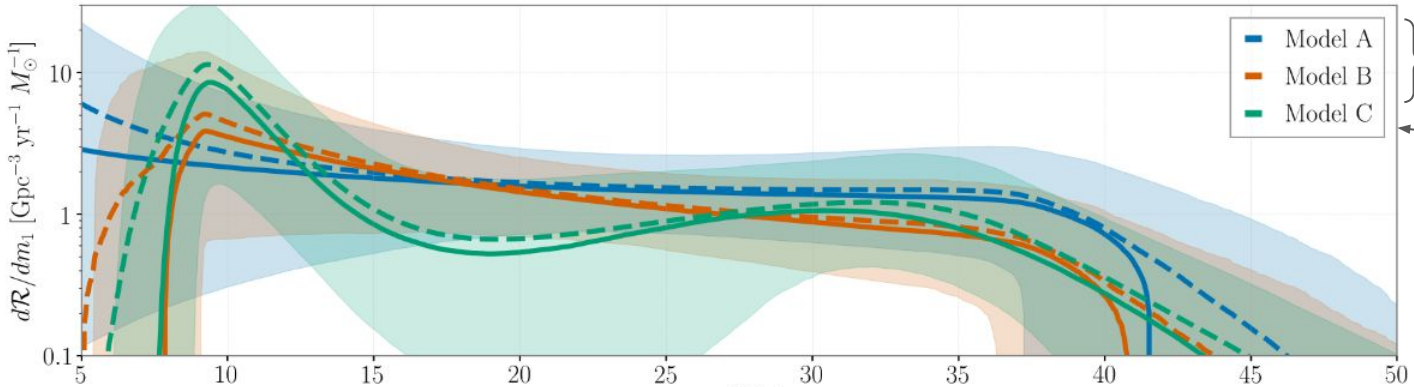






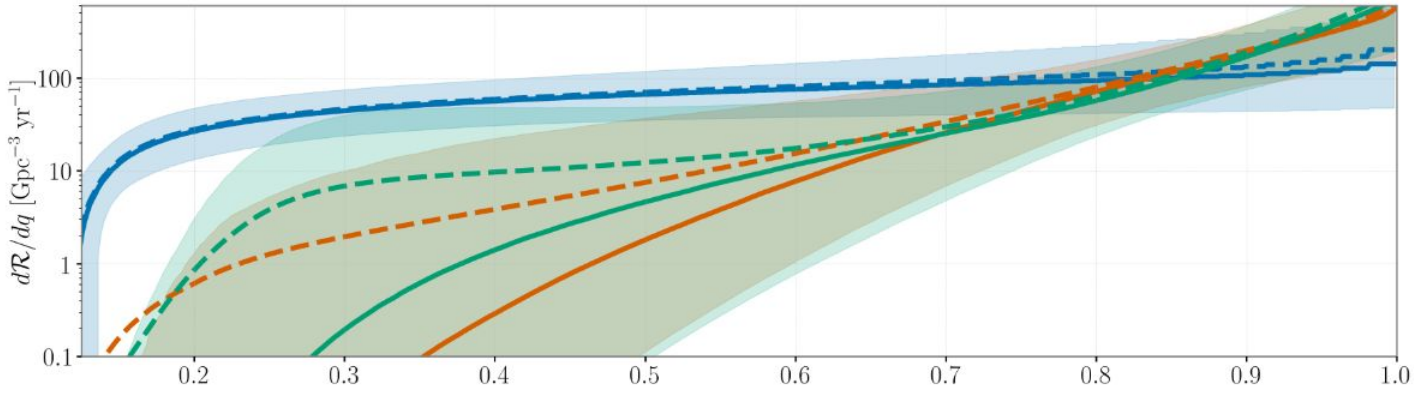
10.1103/PhysRevX.9.031040 (Abbott+ PRX 2019)
10.3847/2041-8213/ab3800 (Abbott+ ApJL 2019)

O1-O2 results: BH mass distribution

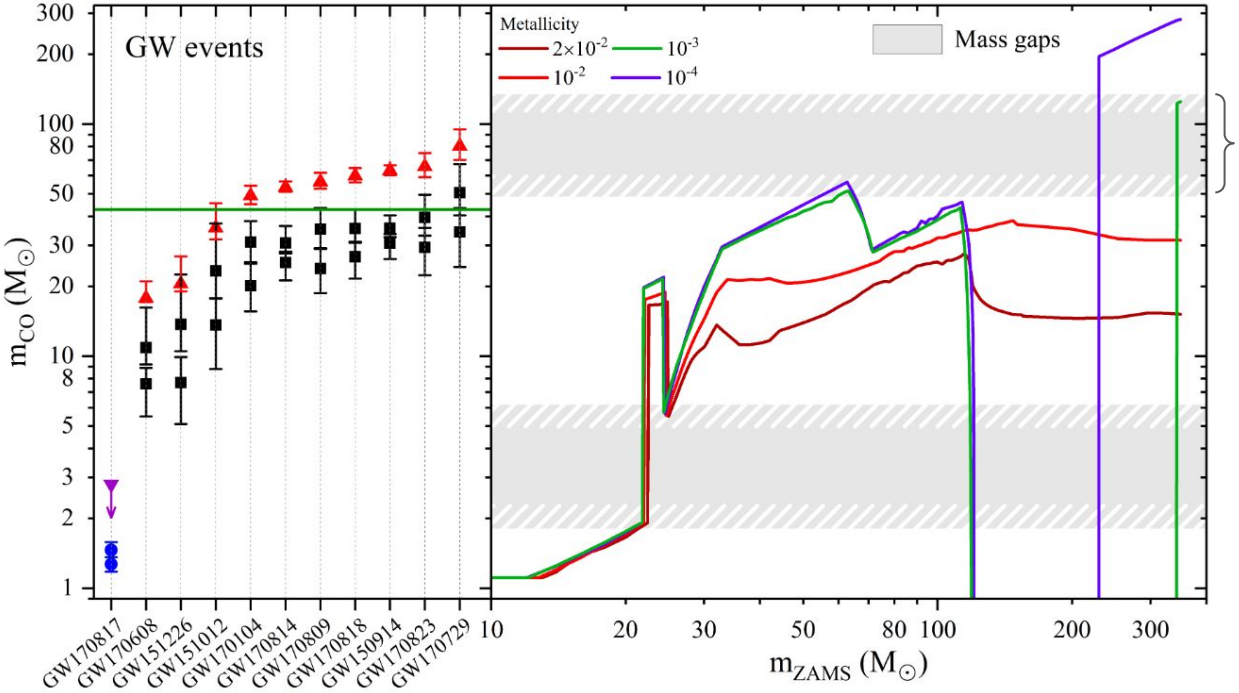


Power laws with hard cutoff

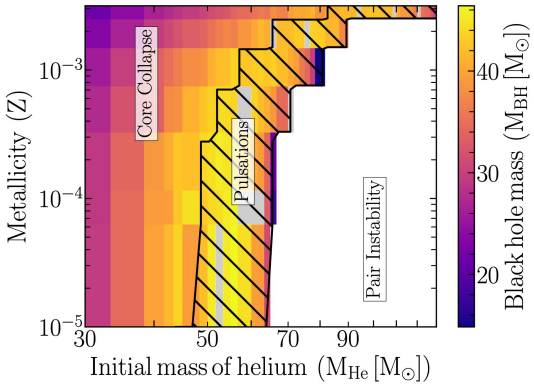
Power laws with smooth cutoff + Gaussian peak



O1-O2 results: BH mass gaps?



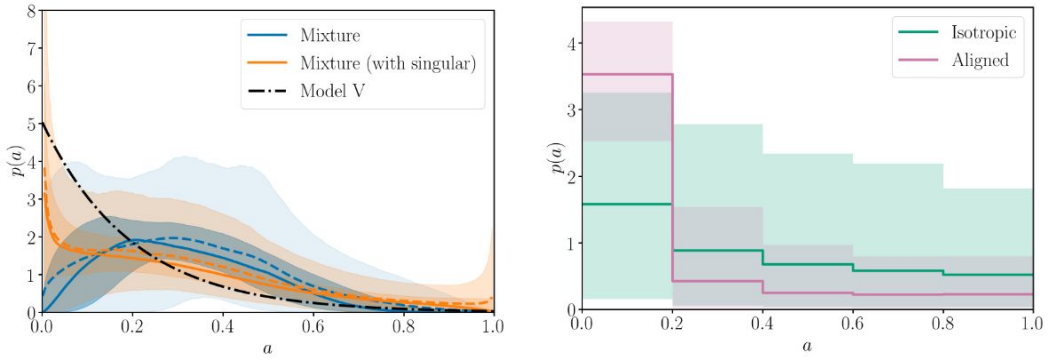
Pair-instability gap



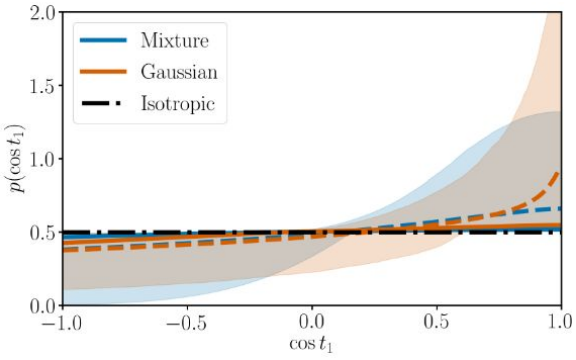
Farmer+ ApJ 2019

O1-O2 results: BH spins

Magnitude



Tilt with respect to orbital angular momentum

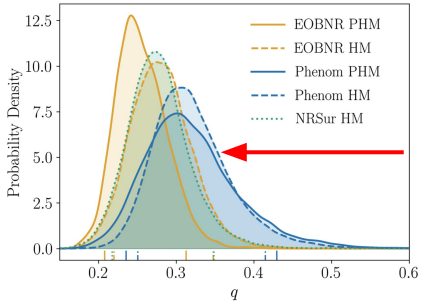


Antiparallel Orthogonal Parallel

GW190412

Abbott+ PRD 2020 - 10.1103/PhysRevD.102.043015

Parameter[a]	EOBNR PHM	Phenom PHM	Combined
$m_1/M_\odot$	$31.7^{+3.6}_{-3.5}$	$28.1^{+4.8}_{-4.3}$	$30.1^{+4.6}_{-5.3}$
$m_2/M_\odot$	$8.0^{+0.9}_{-0.7}$	$8.8^{+1.5}_{-1.1}$	$8.3^{+1.6}_{-0.9}$
$M/M_\odot$	$39.7^{+3.0}_{-2.8}$	$36.9^{+3.7}_{-2.9}$	$38.4^{+3.8}_{-3.9}$

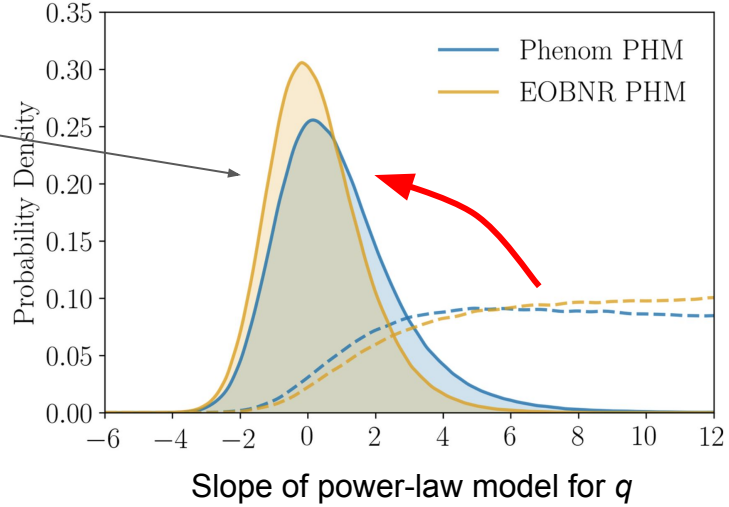


Comparison with O1+O2 population

- Not a strong outlier
- Large effect on the BBH mass-ratio distribution

What formed such a binary?

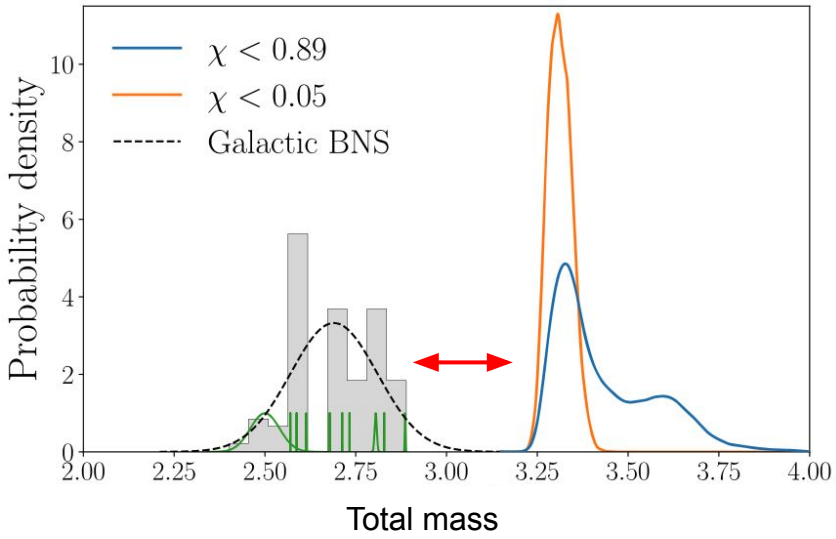
- Many channels predict comparable masses
- Evolution of an isolated binary
  - Maybe in tension with GW190412's spins
- Remnants of previous mergers in clusters
- Galactic triple or quadruple systems
- Evolution in an AGN disk

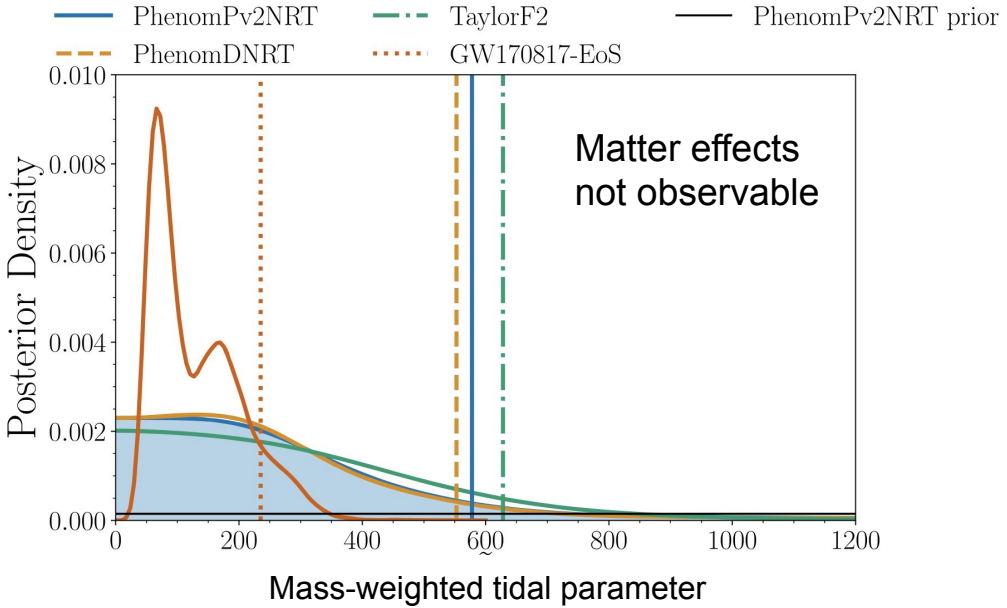


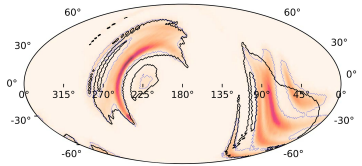
GW190425

Abbott+ ApJ 2020 - 10.3847/2041-8213/ab75f5

Substantially heavier
than galactic systems







No compelling EM counterpart
(but see Pozanenko+ 2019, with caveats)

GW190425

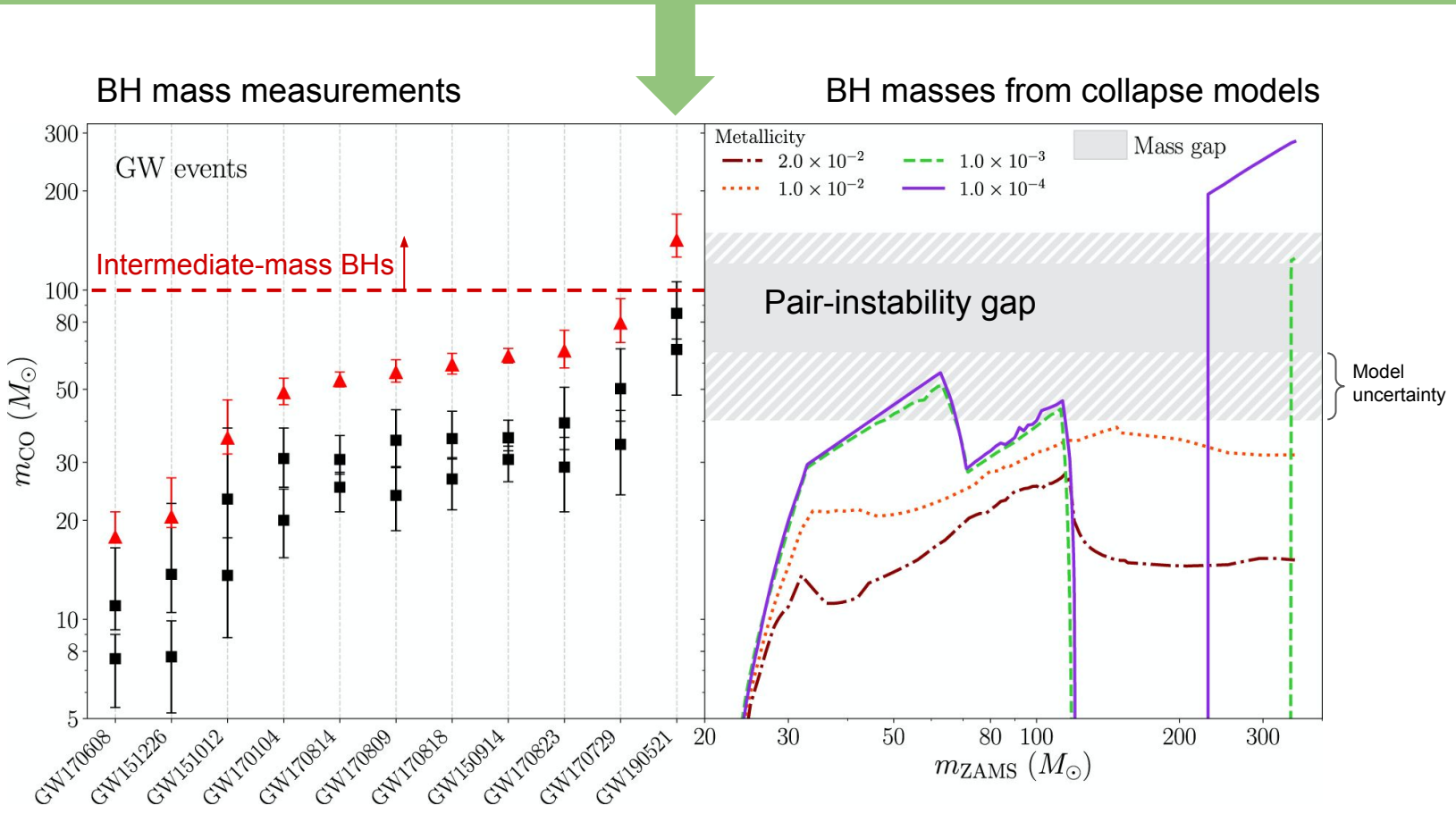
Possible interpretations and formation channels:

- BNS from standard isolated binary evolution
  - Requires ultra-tight orbits or low-metallicity progenitor stars
- BNS from dynamical encounter in a cluster
  - Rate of dynamically-formed BNS is debated
- Gravitationally lensed BNS merger
  - Unlikely based on lensing optical depth
- BBH merger
  - BHs in the NS-BH mass gap?
  - Primordial BHs?

BNS rate updated:
250–2810 Gpc^{-3} yr^{-1}

GW190521

Abbott+ 2020 ApJ - 10.3847/2041-8213/aba493



GW190521

1. Intermediate-mass BHs can form via mergers of smaller BHs
2. Primary mass in tension with the population inferred from O1 and O2
3. BHs with mass in the pair instability gap merge at a non-negligible rate
4. *Maybe* large spins and/or eccentricity
   (e.g. Romero-Shaw+ ApJL 2020)

$$R = 0.13^{+0.30}_{-0.11}\,\mathrm{Gpc}^{-3}\,\mathrm{yr}^{-1}$$

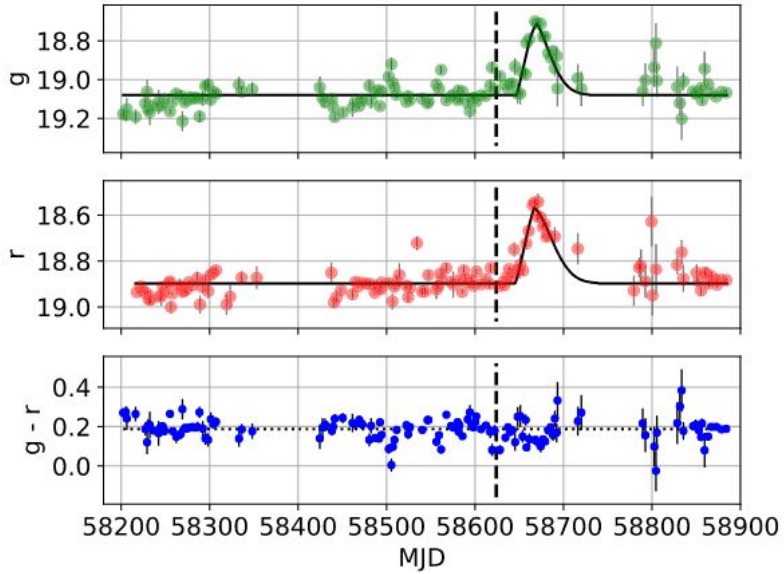
How can such BHs (and GW190521) form?

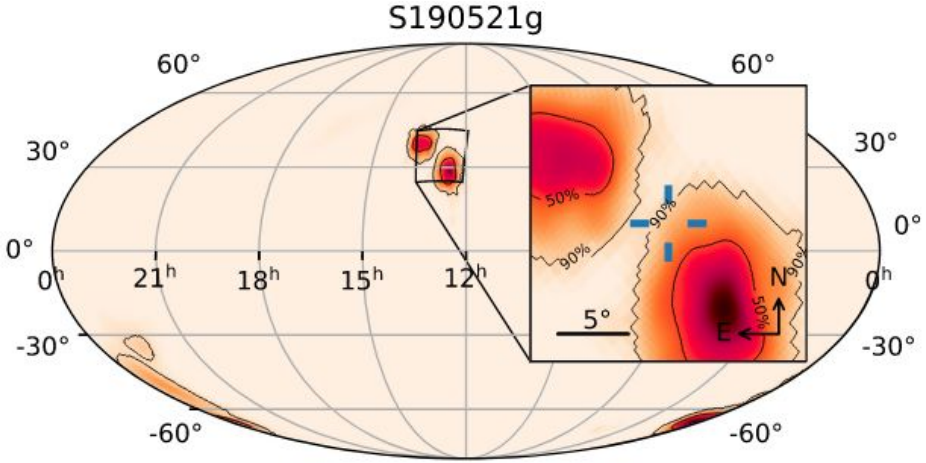
- Previous BH mergers in stellar clusters
  - Depends on 1g BH properties in the cluster
- Stellar mergers (avoids pair instability)
  - More common than hierarchical mergers
  - Assumptions about H envelope, stellar rotation…
- AGN disks (gas accretion, torque, high escape velocity)
  - ZTF optical candidate

- All ~compatible with GW190521
- Large uncertainties

GW190521 and ZTF19abanrhr

Graham+ PRL 2020





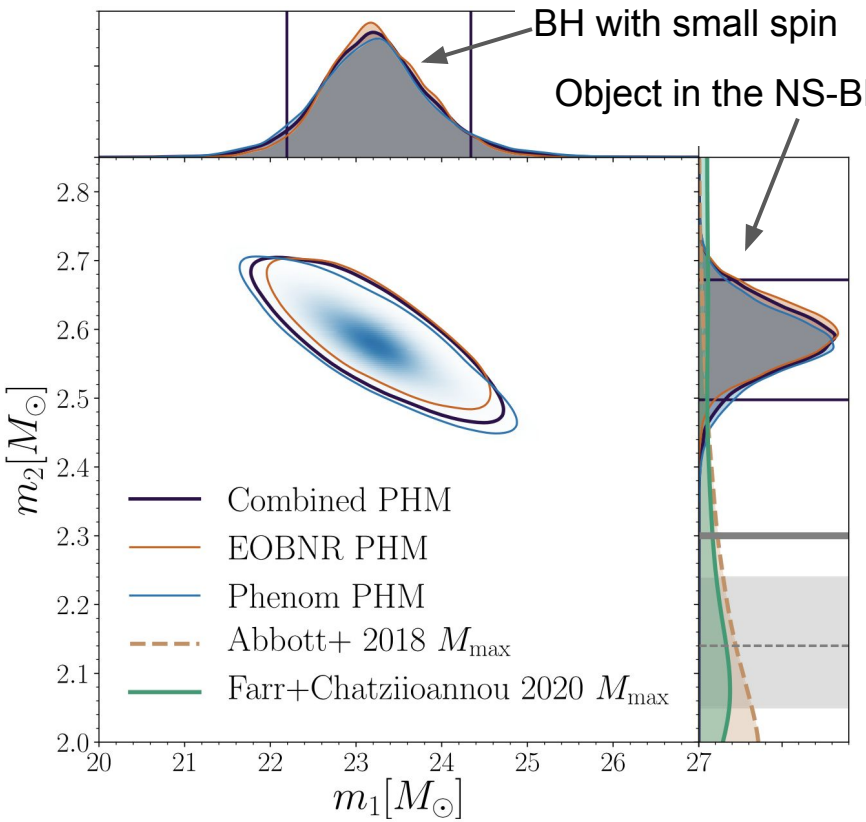
We predict a similar repeat flare in this source when the kicked BBH reencounters the disk on timescale $1.6\ \mathrm{yr}(M_{\mathrm{SMBH}}/10^8\ M_\odot)(a/10^3 r_g)^{3/2}$.

"Current observations are insufficient to confidently associate the binary black hole merger GW190521 with AGN J124942.3+344929"

Ashton+ 2020

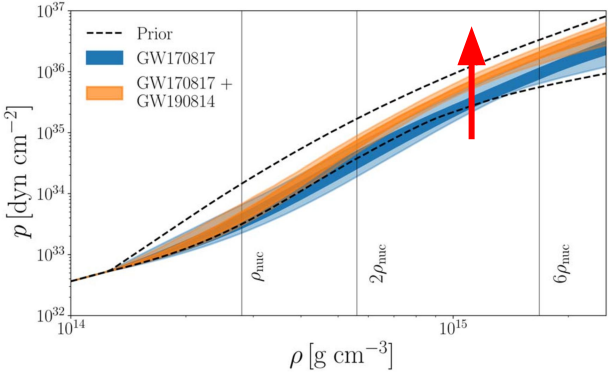
GW190814

Abbott+ 2020 ApJ - 10.3847/2041-8213/ab960f



What is it?

1. The lightest BH in a CB yet
   - Most plausible scenario considering max NS mass estimates
2. The heaviest NS in a CB yet
   - Could imply rapid rotation
   - Leads to a “stiffer” EoS (bigger NSs)



   - Constraints from EM nondetection (using preliminary estimates)
3. A more exotic object

GW190814

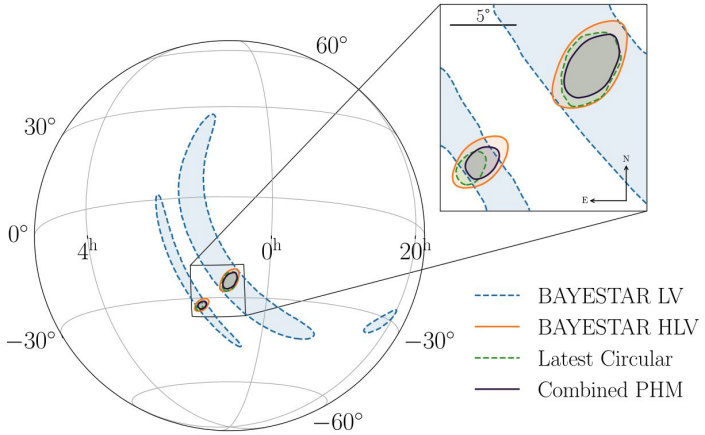
Challenge to all formation channels

- Isolated binary evolution
  - Models may require revisions
- Dynamical origin
  - Globular cluster models may require revisions
  - Young star cluster more likely
- Hierarchical triple or quadruple systems
- AGN disks

Rate density of similar systems

$7^{+16}_{-6}\ \mathrm{Gpc^{-3}\ yr^{-1}}$

Best localized dark siren → H_0 estimate



$75^{+59}_{-13}\ \mathrm{km\ s^{-1}\ Mpc^{-1}}$ GW190814 alone

$70^{+17}_{-8}\ \mathrm{km\ s^{-1}\ Mpc^{-1}}$ GW170817+GW190814

Not yet enough to resolve the tension

Conclusion

- Four interesting events from O3
  - Formation models must deal with unequal-mass mergers
  - Intermediate-mass BHs as merger remnants
  - High-mass NSs and/or low-mass BHs
  - Possibly the first NSBH merger
- How deep are the NS-BH and PI mass gaps?
- Do NS and BH masses overlap?

Merger type	Rate (Gpc^{-3} yr^{-1})
BNS	~1000
BBH	~50
GW190814 (NSBH?)	~7
GW190521	~0.13

- 56 public alerts during O3
- 📣 Half-O3 results to appear soon, then full-O3
  - Catalog of compact binary mergers
  - Updated inferences on merger rates, mass spectrum, spin distribution, cosmology…

~ Thank you! ~