GWTC-2:

Are we closer to answering the question of origin?

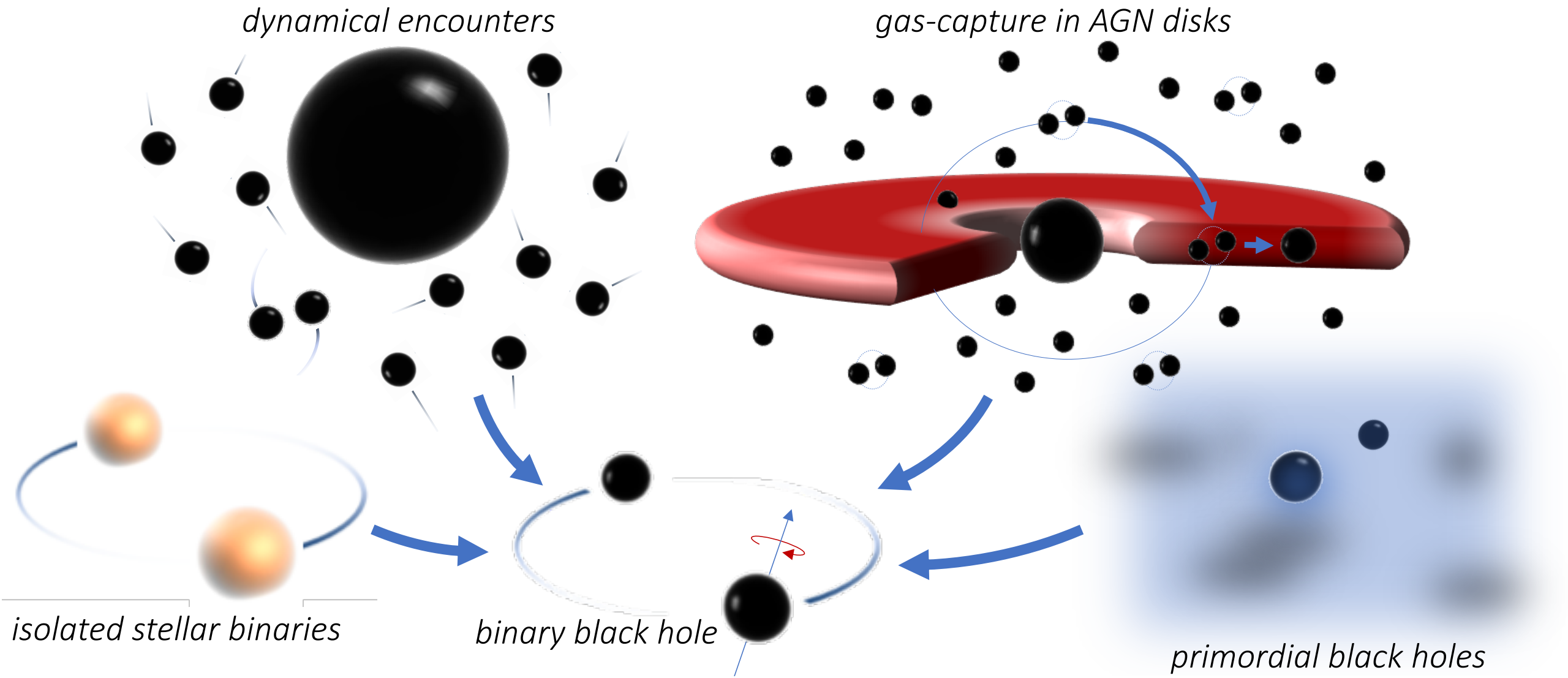
Imre Bartos

University of Florida

NBIA hybrid workshop | 11.19.2020

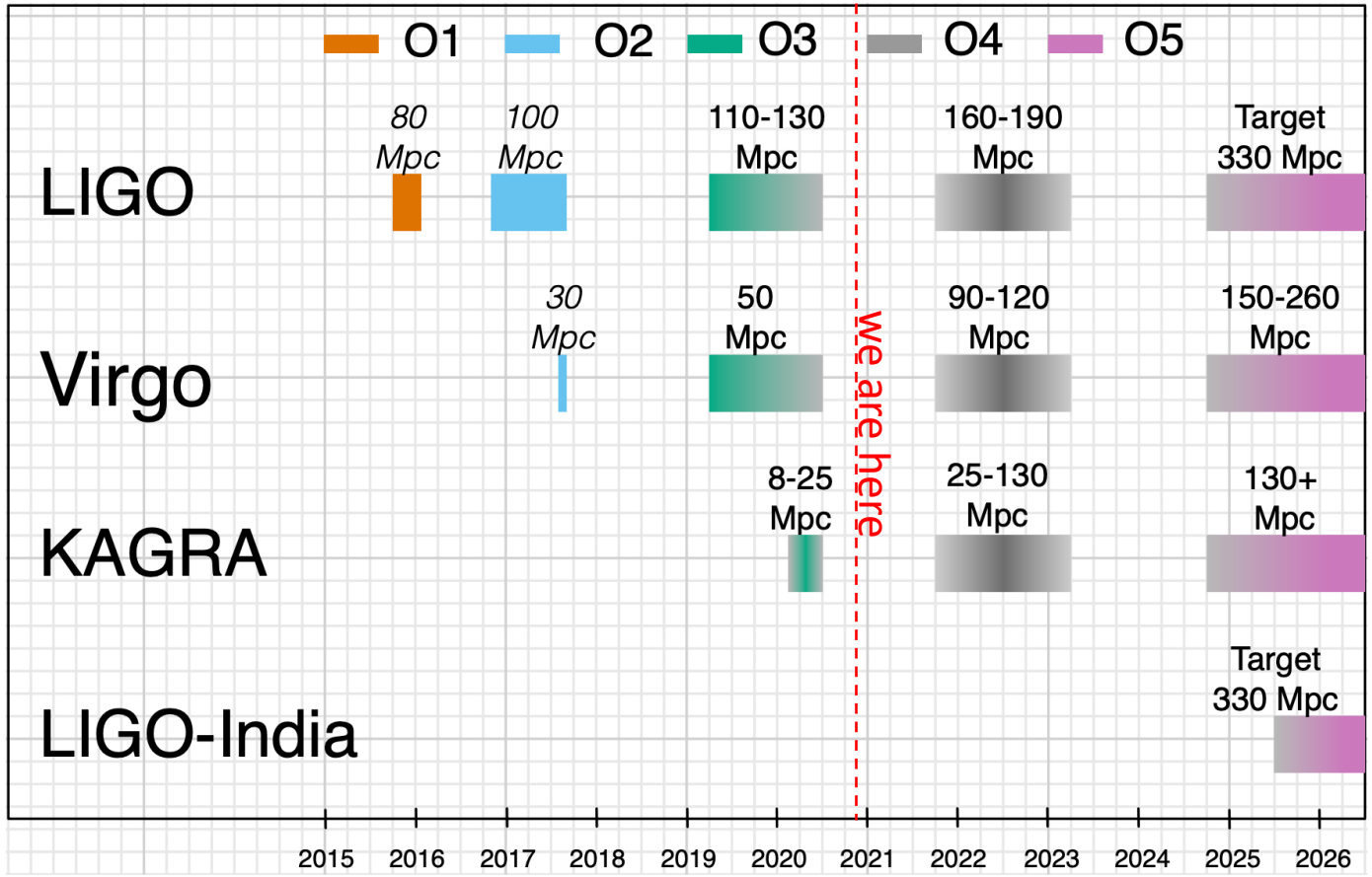
Origin of binary black holes

The central question right now (?)



What are we working with?

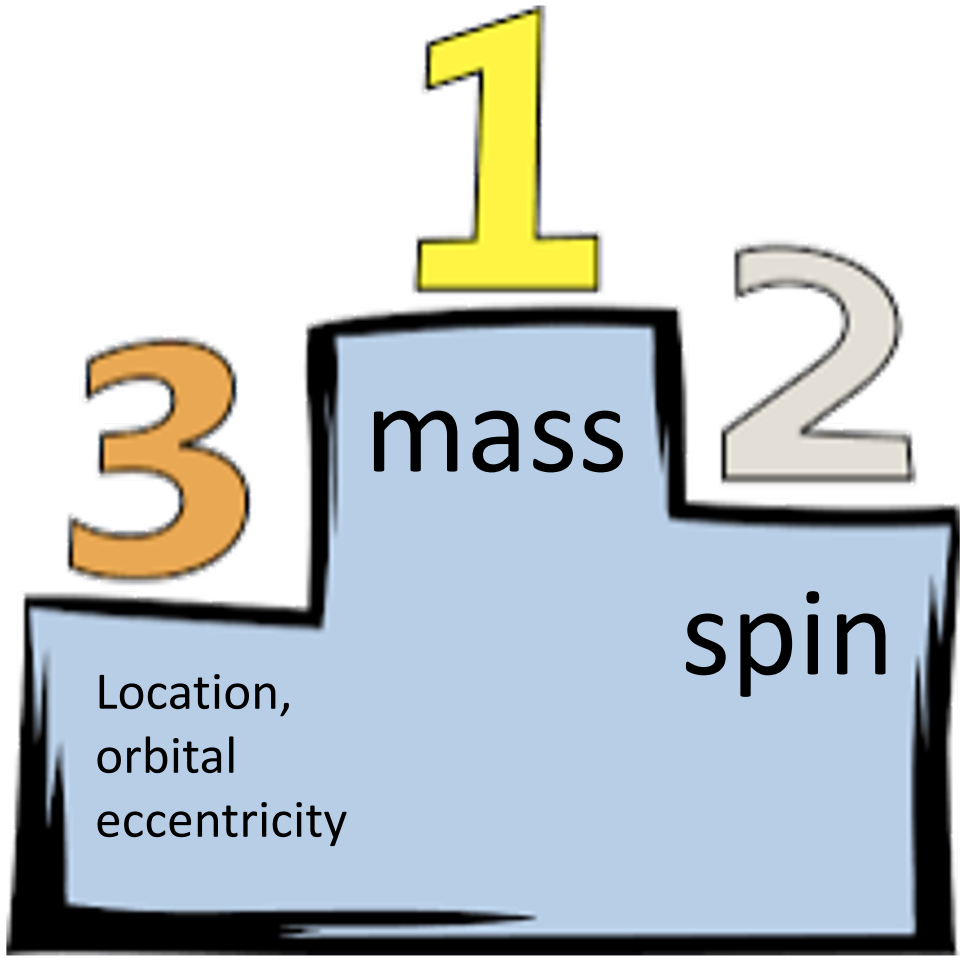
- 39 GWs from O1+O2+O3a (c.f. 11 GWs from O1+O2).
- Most of O3b is still unpublished but coming (special events are looked at first).
- Not just more but also some special binaries (unanticipated based on O1+O2…). (Michela's talk)
- No EM counterpart for binary neutron stars. (Samaya's and Saavik's talks)



LIGO, Virgo, KAGRA (2020)

Information in gravitational wave detections

- The more information we have the better we can establish the origin of binary mergers. Ideally, we should model all these and compare to observations.
- Not all information is equally accessible.
- It is not just reconstruction uncertainties. Some parameters simply make GW emission less detectable:
  - Antialigned spin (weaker GW)
  - Precessing spin (unusual waveform)
  - Orbital eccentricity (unusual waveform)
- Reconstruction uncertainties are somewhat deceiving as they fold in prior assumptions that can dominate recovered distribution. It is important not to overinterpret results.



Ranking of how well these can be extracted from GWs.

Probing the origin of black hole mergers

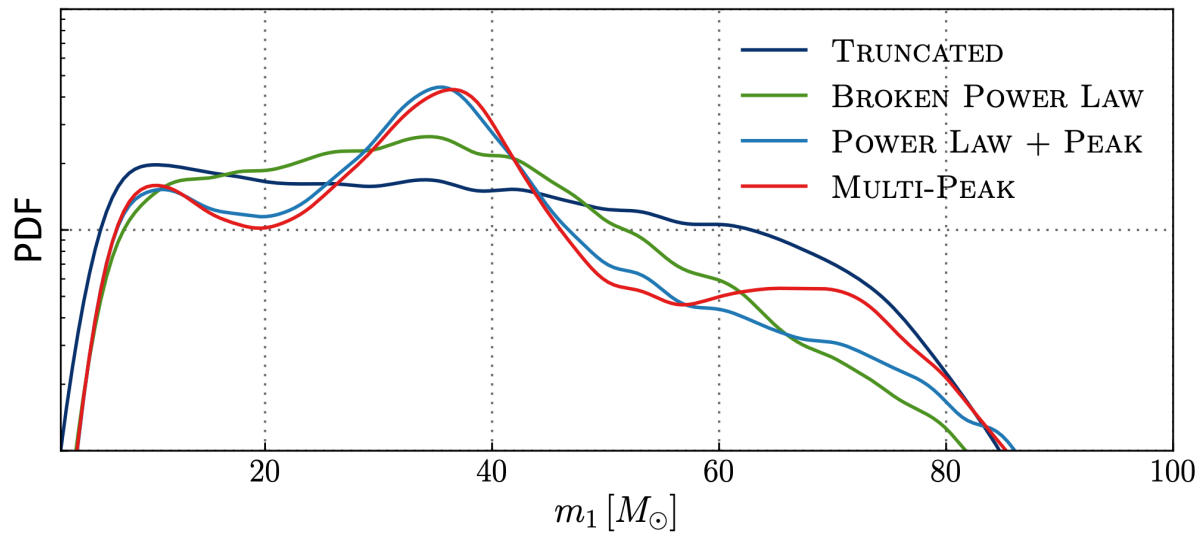
We can look at:

- Populations (where different models make different predictions on distributions)
  - ✓ *e.g. mass, spin distribution*
- Special events (some parameter rules out some of the models)
  - ✓ unusual mass / spin
  - ✓ orbital eccentricity
- Smoking guns (observationally unique even if the event itself is not)
  - host galaxy properties
  - EM counterpart

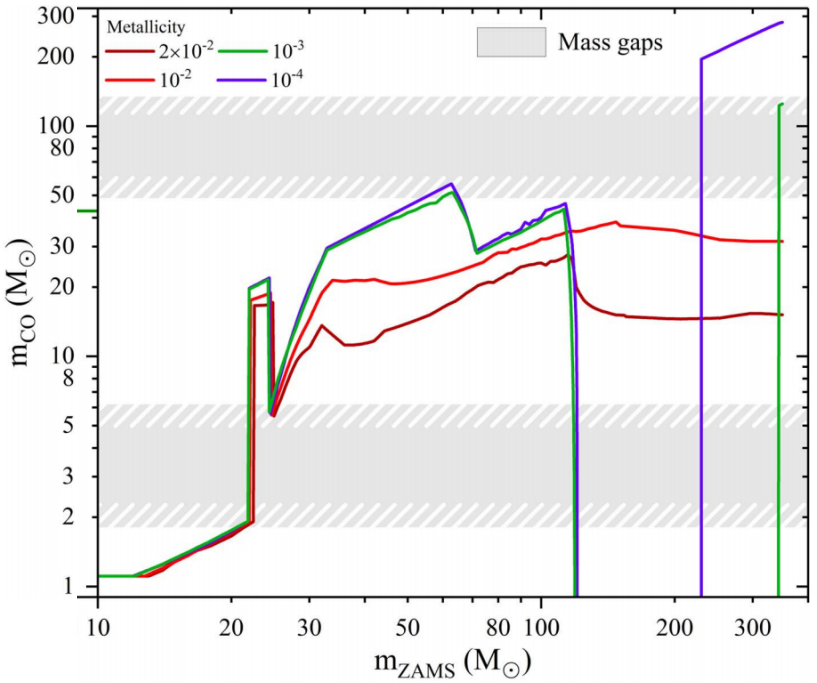
What we learned about binary black hole populations?

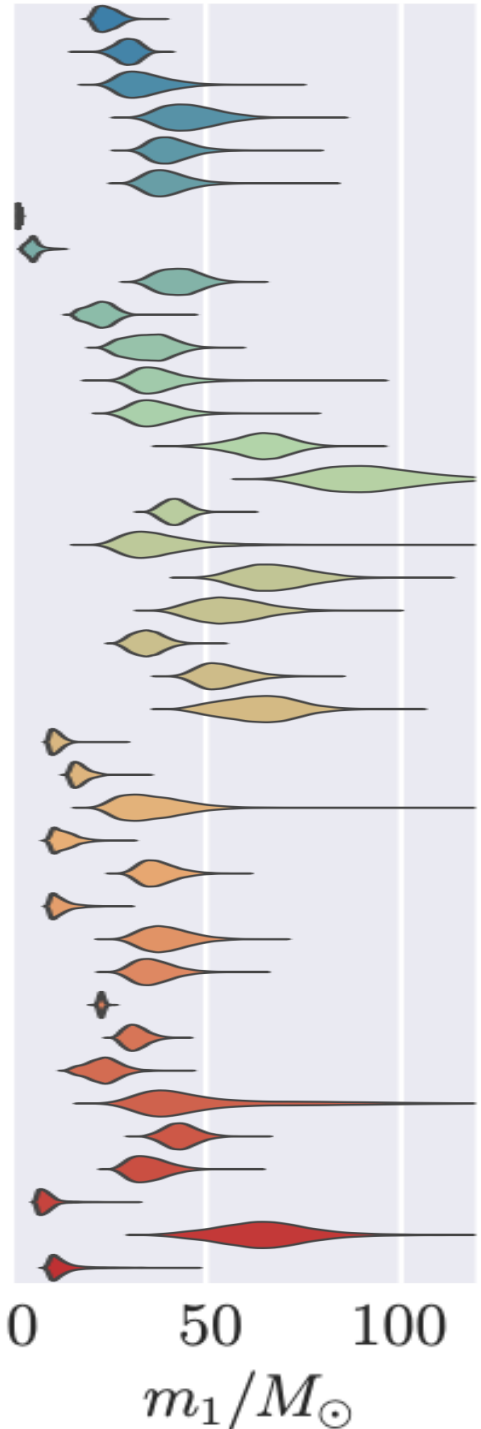
(Maya's talk)

1. Mass distribution:
   - Single power law with max and min cutoff doesn't work.
   - Extends to high masses
   - Possibly overabundance at $\sim 40 M_{\odot}$, or two components (model-based possibilities).
   - Beyond this, we don't really have enough information to tell.
   - General distribution not conclusive regarding origin (other than extreme events).



LIGO+Virgo 2020

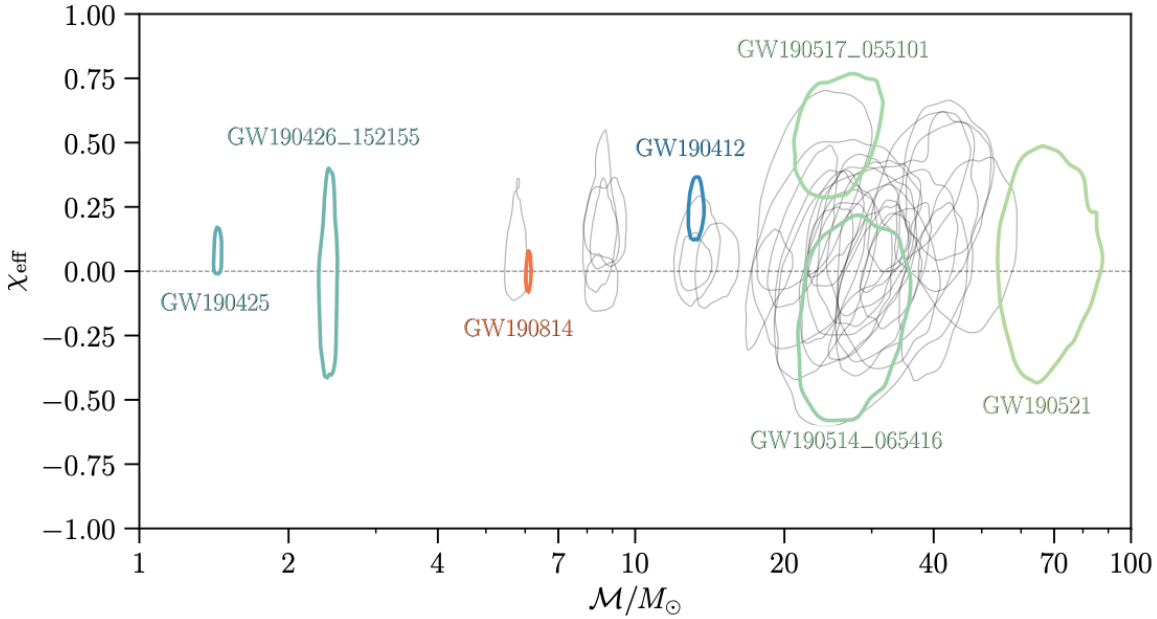


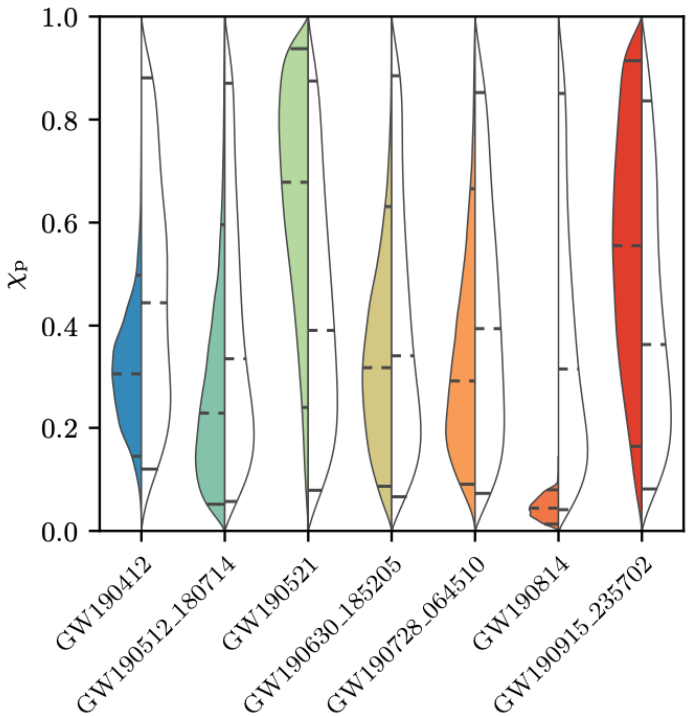


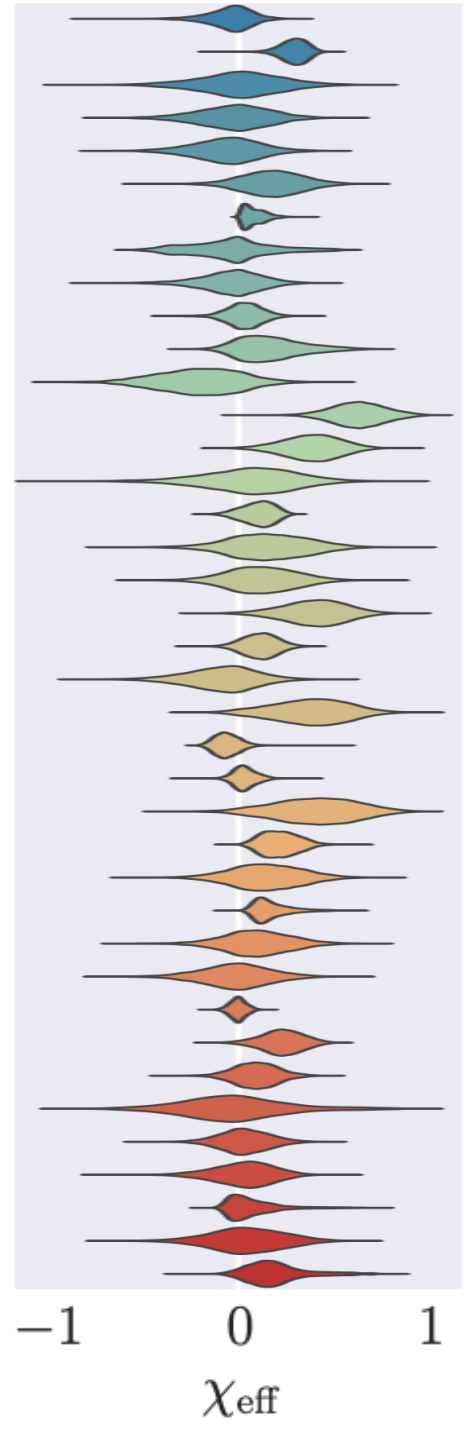
What we learned about binary black hole populations?

(Maya's talk)

1. Spin distribution:
   - Significant χ_{eff} (parallel with orbital axis) for some events.
   - About a third of BBHs have $\chi_{eff} < 0$.
   - Significant χ_p (perpendicular with orbital axis) for some events.
   - Both χ_{eff} and χ_p distributions are difficult to reconcile with isolated stellar binary origin, but are consistent with expectations of dynamical / AGN gas-capture origin.
   - (more spin-modeling needed on isolated binary side).





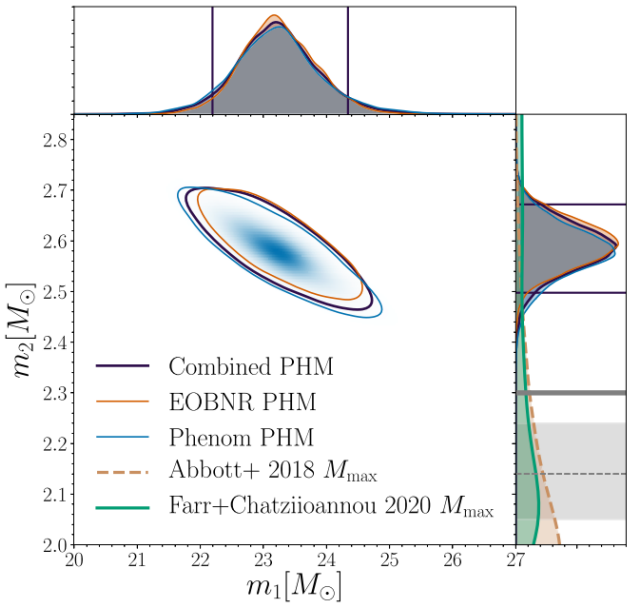


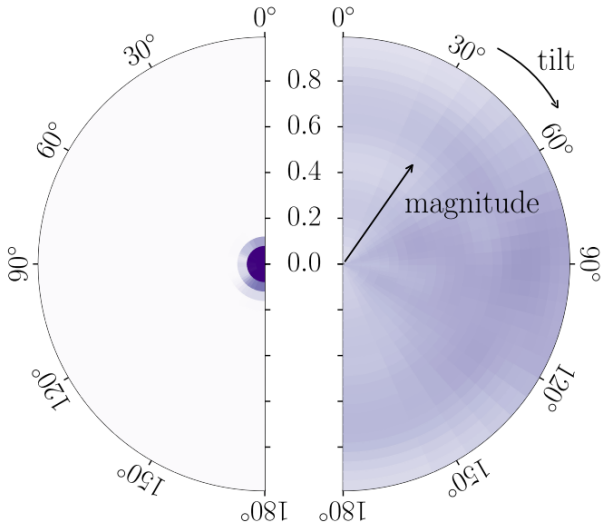
LIGO+Virgo 2020

What we learned from special events?

Lower mass gap (GW190814):

- Stars are not expected die as 2–5$M_\odot$ compact objects.
- So there was either:
  - Accretion (e.g. in AGNs)
  - Previous merger of two neutron stars
- Mass = $\boldsymbol{2.6M_\odot}$ = mass of Galactic BNSs → unlikely accretion.
- BH has 0 spin (most precise spin measurement!)
- Possibilities:
  - Hierarchical merger
    (Yang, Gayathri, Bartos, Haiman, Safarzadeh, Tagawa 2020, Kimball+ 2020)
    (see also Zoltan's talk)
  - Stellar triple system (Lu+ 2020)





LIGO+Virgo 2020

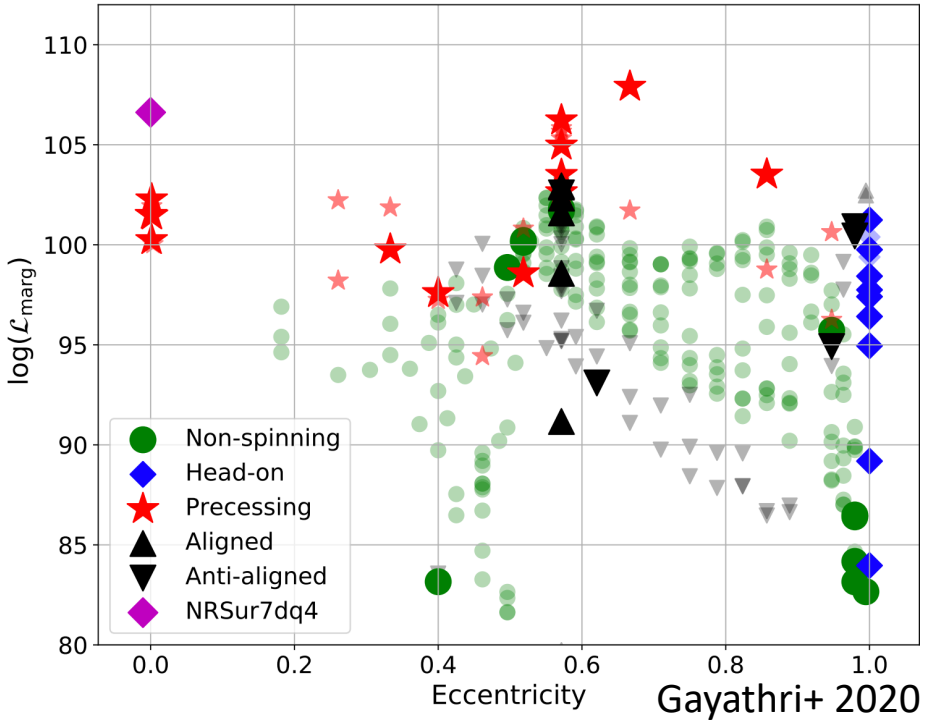
What we learned from special events?

Upper mass gap (GW190521):

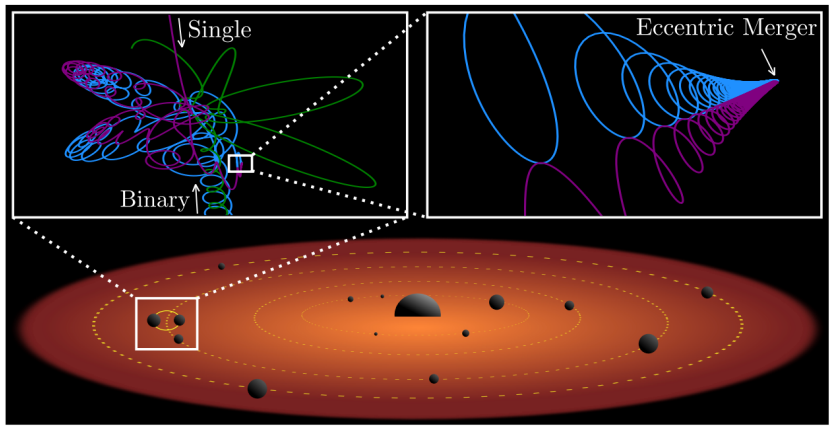
- Mass of heavier black hole ($\sim 85M_{\odot}$) difficult to explain with stellar evolution, although uncertainties remain (Michela's talk)
  - Could be that it is actually above the mass gap ($\sim 160M_{\odot}$) but this was not found due to limited resolution at highly asymmetric binaries?! (Nitz & Capano 2020)

- Spin: likely high and ~perpendicular to orbital angular momentum.
  - This is difficult to explain with isolated stellar binary.

- Indication of highly eccentric orbit (Gayathri+ 2020)
  - ~proof of dynamical / AGN origin
  - AGNs may be optimal sites for high eccentricity (Samsing+ 2020, Tagawa+ 2020)
  - Lower-mass highly-eccentric mergers are difficult to detect --- no templates for search, lower model-agnostic search sensitivity, weaker GW signal.



Gayathri+ 2020



Samsing+ 2020

Takeaway

- We have a lot more information now than after O1+O2.

- It is becoming difficult to explain observations with the standard isolated binary paradigm:
  - ✓ $\sim 1/3$ of events have negative χ_{eff}.
  - ✓ Many binaries with nonzero χ_p.
  - ✓ Objects in lower and upper mass gap.
  - ✓ Event with mass ratio $q \ll 1$.
  - ✓ Highly eccentric merger.
  - ✓ EM counterpart of a BBH?

- Differentiating between dynamical / AGN channels is more difficult:
  - ✓ Large model uncertainties remain making population comparisons hard.
  - ✓ How much are hierarchical mergers in globular clusters limited by small escape velocities?
  - ✓ High eccentricity favors AGN origin?
  - ✓ EM counterpart if true would be smoking gun.

- I am looking forward to:
  - ✓ Are there even more massive BHs than GW190521?
  - ✓ Are there more eccentric binaries?
  - ✓ Are there mass-gap events with masses different from 2 x NS?
  - ✓ Can we localize the host galaxy of some BBHs?