SEARCHING FOR ECCENTRICITY

ISOBEL ROMERO-SHAW
PAUL LASKY
ERIC THRANE

METHOD

quasi-circular likelihood
quasi-circular posterior

$$p_\theta(\theta|d) = \frac{\mathcal{L}_\theta(d|\theta)\,\pi(\theta)}{Z_\theta}$$

1. Compute **posteriors** using **quick quasi-circular waveform model**

2. For **every** sample, use **inverse transform sampling** from **1D likelihood over eccentricity** to generate **eccentricity** value

random number
cumulative likelihood
likelihood
chosen eccentricity

3. **Reweight** initial posteriors using **eccentricity-marginalised likelihood**

eccentric posterior
eccentricity-marginalised likelihood

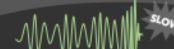$$p(\theta|d) = \frac{L(d|\theta)}{L_\theta(d|\theta)} \times p_\theta(\theta|d)$$

BACKGROUND

★ **Binary black holes** are thought to form primarily via two channels: **isolated** and **dynamical**.

★ The formation channel of a binary can be encoded in its **masses, spins,** and **eccentricity**. These properties are imprinted on its gravitational wave signal.

★ Binary properties are measured by comparing signals to thousands of templates. **Eccentricity is hard to measure**, because eccentric templates are slow to generate.

★ We use **likelihood reweighting** to measure the binary eccentricity of ten events from the first Gravitational Wave Transient Catalogue of LIGO and Virgo.
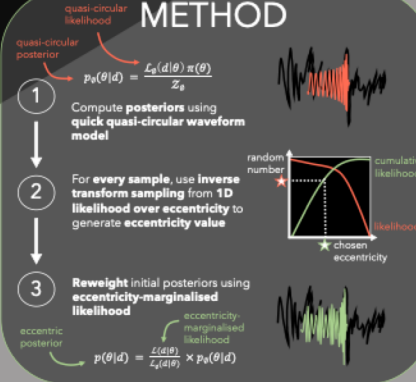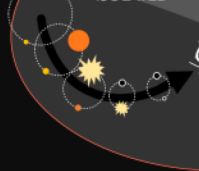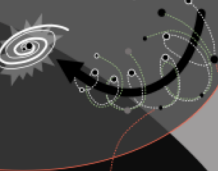
QUASI-CIRCULAR — QUICK!

ECCENTRIC — SLOW!
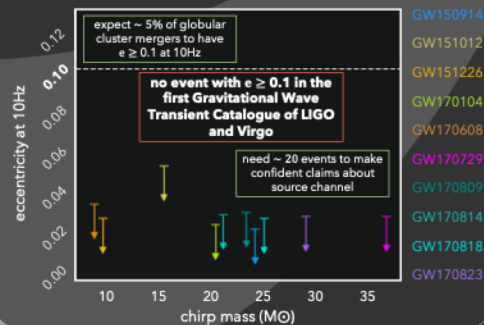
FORMATION CHANNELS

ISOLATED — DYNAMICAL

ISOLATED MERGERS
FORMATION
Stellar binaries evolve into black hole binaries.
MERGE MECHANISM
Binaries tighten & merge due to the emission of gravitational waves.
BINARY PROPERTIES
Total mass below ~ 80 $M_\odot$
Spins aligned with binary angular momentum vector
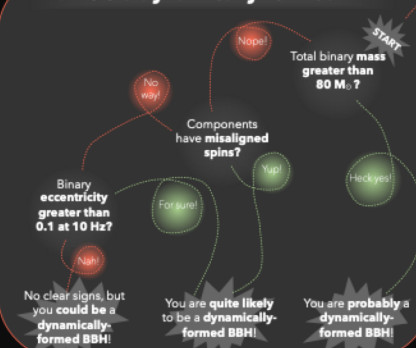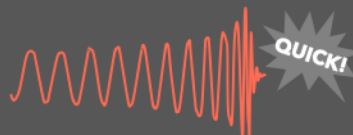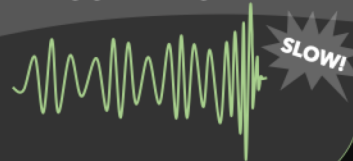**Eccentricity** negligible at 10Hz

DYNAMICAL MERGERS
FORMATION
Black holes form bound pairs during interactions in star clusters.
MERGE MECHANISM
Binaries driven to merge through dynamical interactions & gravitational wave emission.
BINARY PROPERTIES
Total mass can be > 80 $M_\odot$
Spins isotropically distributed & misaligned
Eccentricity can be ≥ 0.1 at 10Hz

RESULTS

expect ~ 5% of globular cluster mergers to have e ≥ 0.1 at 10Hz

no event with e ≥ 0.1 in the first Gravitational Wave Transient Catalogue of LIGO and Virgo

need ~ 20 events to make confident claims about source channel

eccentricity at 10Hz — 0.12, 0.10, 0.08, 0.06, 0.04, 0.02, 0.00

chirp mass ($M_\odot$) — 10, 15, 20, 25, 30, 35

GW150914
GW151012
GW151226
GW170104
GW170608
GW170729
GW170809
GW170814
GW170818
GW170823

Are YOU a dynamically-formed BBH?

START

Total binary **mass** greater than 80 $M_\odot$?

Nope!

No way!

Components have **misaligned** spins?

Yup!

Heckyes!

Binary **eccentricity** greater than 0.1 at 10 Hz?

For sure!

Nah!

No clear signs, but you **could be** a dynamically-formed BBH!

You are **quite likely** to be a dynamically-formed BBH!

You are **probably** a dynamically-formed BBH!

THIS RESEARCH:
Romero-Shaw, Lasky & Thrane (2019), Searching for Eccentricity: Signatures of Dynamical Formation in the First Gravitational-Wave Transient Catalogue of LIGO and Virgo. Monthly Notices of the Royal Astronomical Society.
FURTHER READING:
Isolated evolution: de Mink+2010, Ivanova+2013, de Mink+2016, Krukow+2016, Tagawa+2018, Celoria+2018
Dynamical formation: Morscher+2015, Gondan+2018, Rodriguez+2018a, Rodriguez+2018b, Rodriguez+2019
Likelihood reweighting: Payne+2019 **Waveform models (quasi-circular, eccentric):** Khan+2015, Cao+2017
Eccentric globular cluster mergers: Wen 2013, Samsing+2014, Samsing 2018, Zevin+2019, Fragione+2019
Distinguishing formation channels: Rodriguez+2016, Vitale+2017, Zevin+2017, Fishbach+2017, Wysocki+2018
Gravitational Wave Transient Catalogue 1: The LIGO Scientific Collaboration 2019

LIGO • OzGrav • MONASH University

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random number — cumulative likelihood — likelihood — chosen eccentricity

(3) **Reweight** initial posteriors using **eccentricity-marginalised likelihood**

eccentric posterior

eccentricity-marginalised likelihood

$$p(\theta|d) = \frac{\mathcal{L}(d|\theta)}{\mathcal{L}_\emptyset(d|\theta)} \times p_\emptyset(\theta|d)$$

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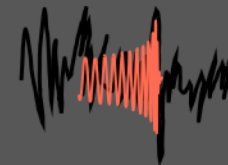
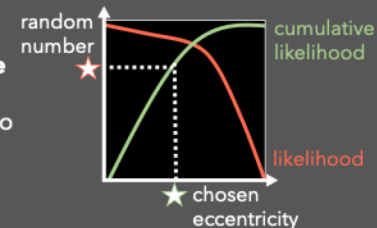QUASI-CIRCULAR

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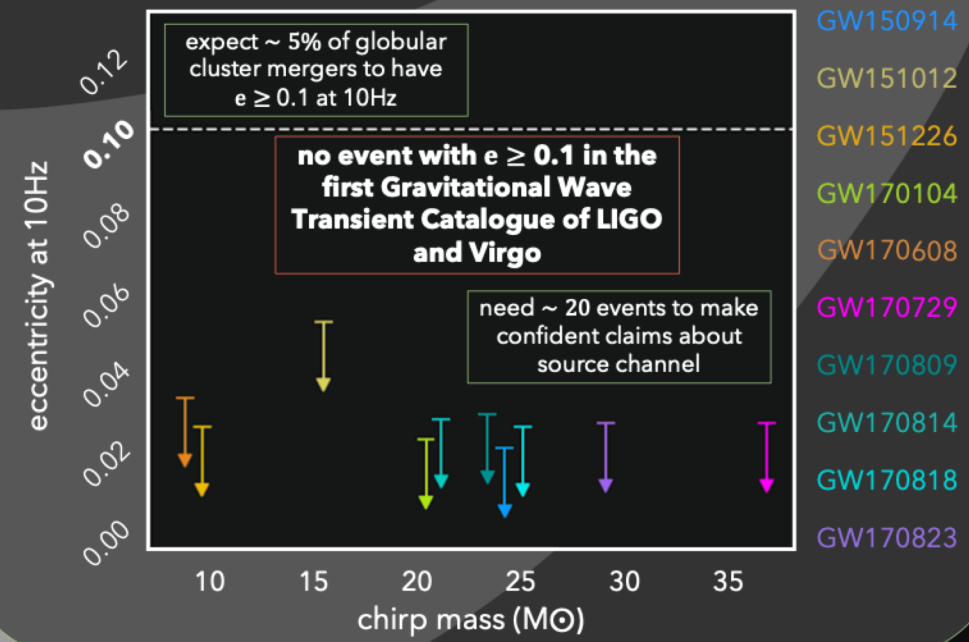
ISOLATED

DYNAMICAL
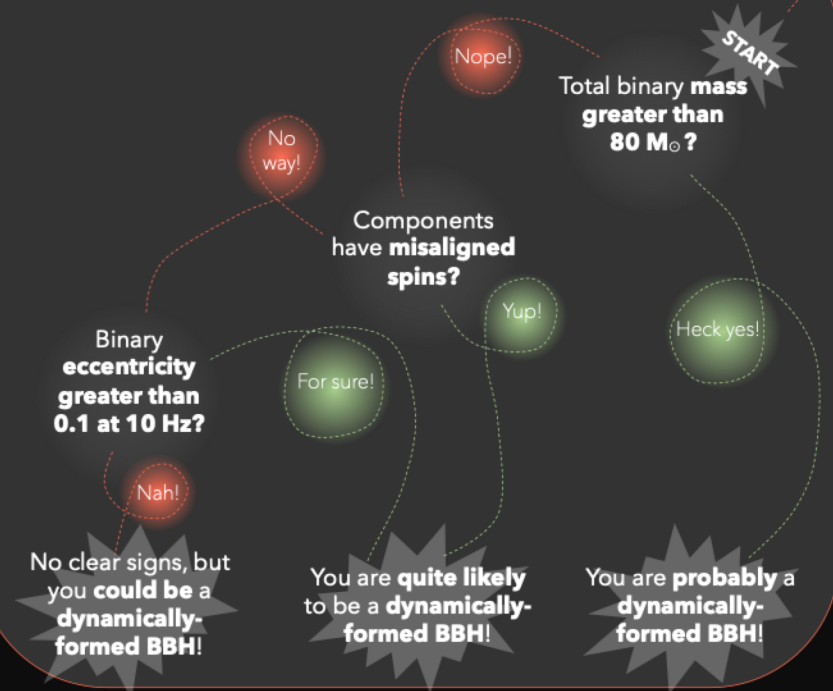
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Total mass can be > 80M$_\odot$
Spins isotropically distributed & misaligned
Eccentricity can be $\geq$ 0.1 at 10Hz

RESULTS

expect ~ 5% of globular cluster mergers to have e $\geq$ 0.1 at 10Hz

no event with e $\geq$ 0.1 in the first Gravitational Wave Transient Catalogue of LIGO and Virgo

need ~ 20 events to make confident claims about source channel

y-axis: eccentricity at 10Hz — 0.00, 0.02, 0.04, 0.06, 0.08, 0.10, 0.12
x-axis: chirp mass (M$_\odot$) — 10, 15, 20, 25, 30, 35

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