(MIS)INTERPRETING GRAVITATIONAL WAVES
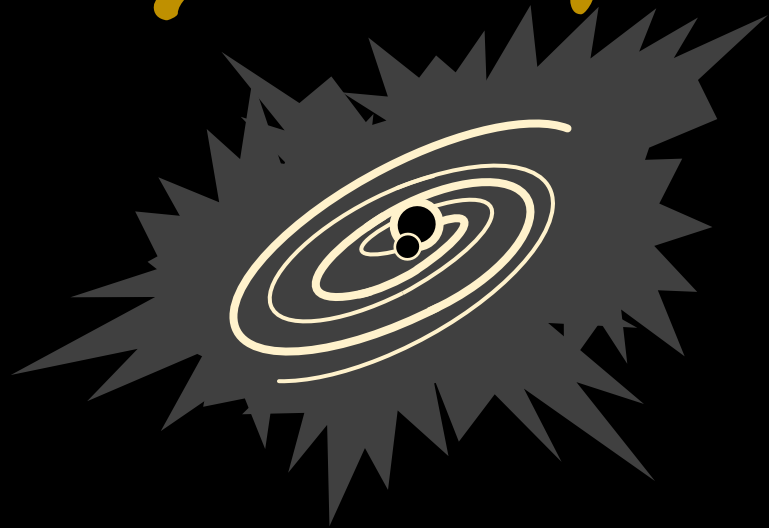## *from binary compact objects*
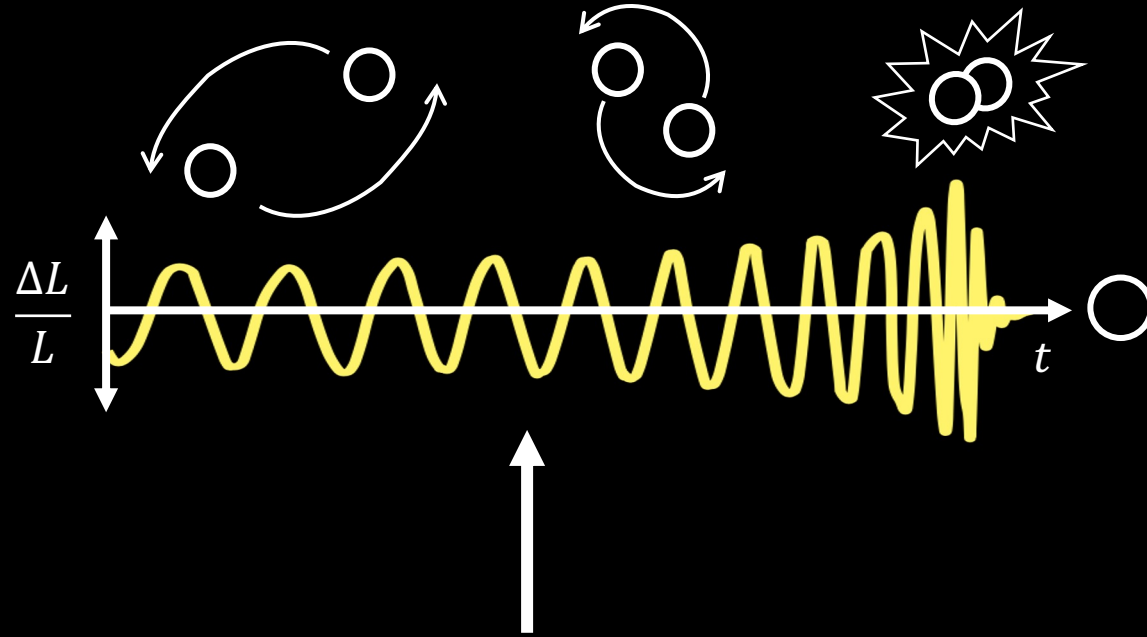
ISOBEL ROMERO-SHAW

HERCHEL SMITH FELLOW | DAMTP | KICC

UNIVERSITY OF CAMBRIDGE
KICC
LIGO
OzGrav
MONASH University

GRAVITATIONAL WAVES FROM BINARY BLACK HOLES
how do we interpret them?

The signal describes its source!
...if you know how to read it...

how do we interpret them?

data = signal + noise
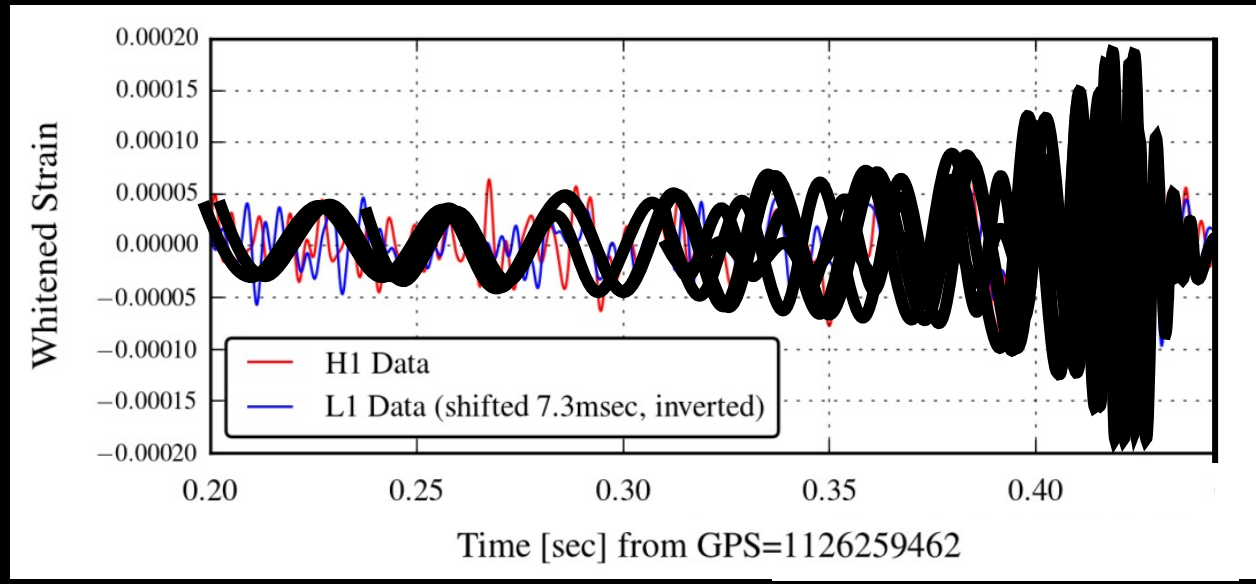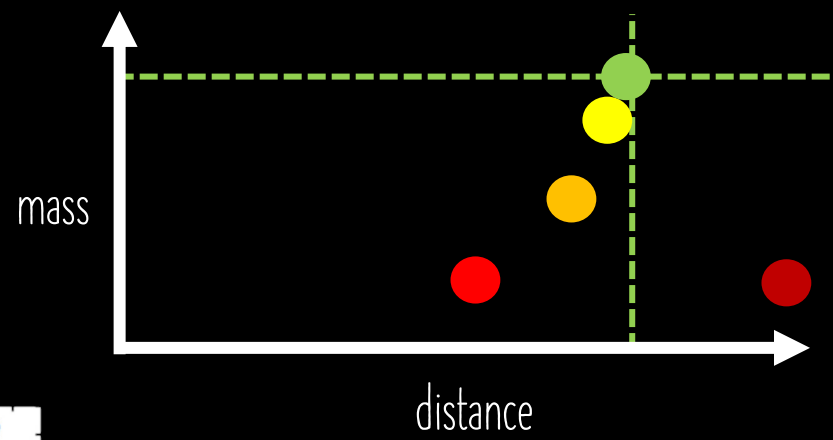
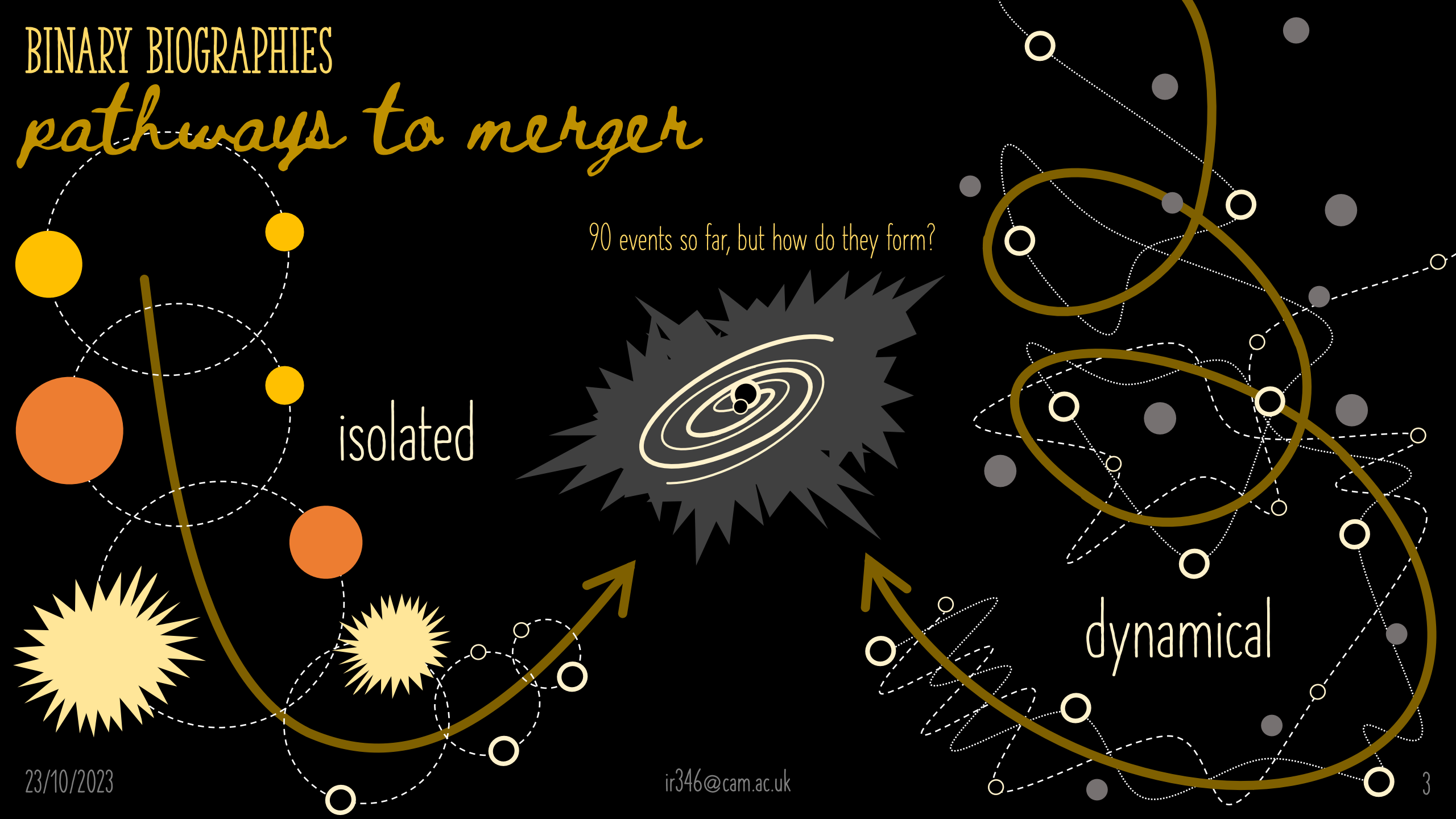With added uncertainties due to: noise, **signal model**, parameter correlations...

BINARY BIOGRAPHIES
pathways to merger

90 events so far, but how do they form?
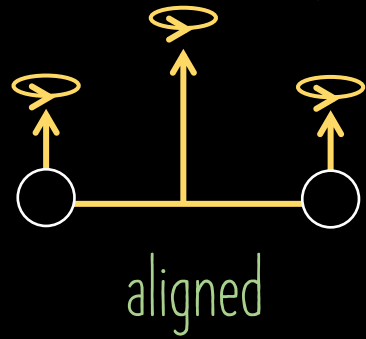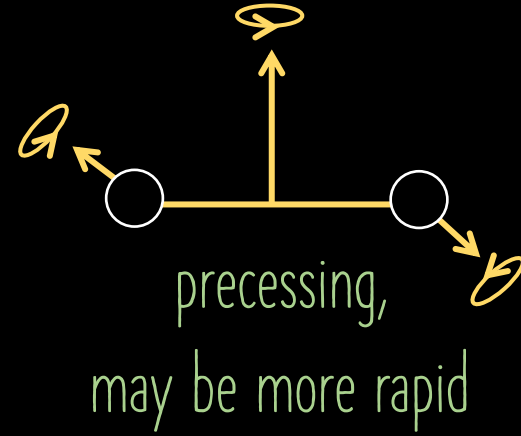
isolated

dynamical

ir346@cam.ac.uk

BINARY BIOGRAPHIES
decoding binary formation

spin

aligned
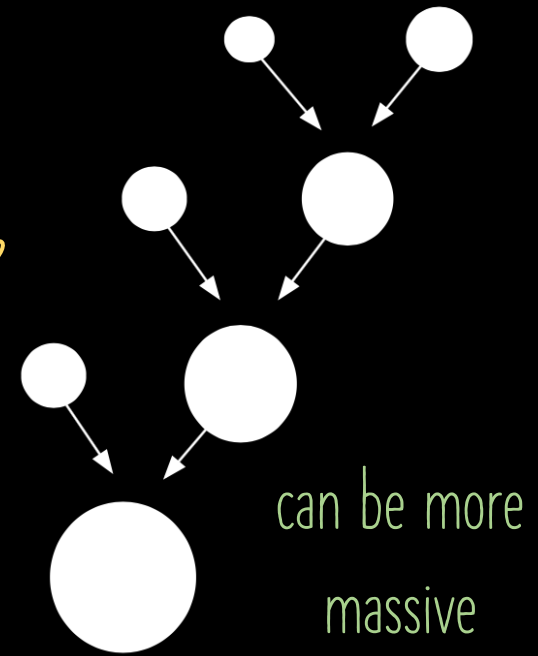
precessing,
may be more rapid
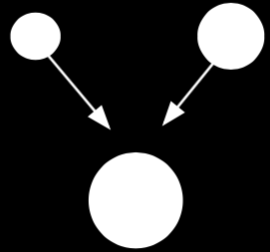
isolated

mass

have upper limit
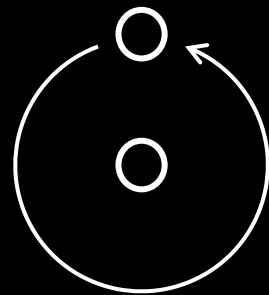
can be more

massive

eccentricity

dynamical

circular
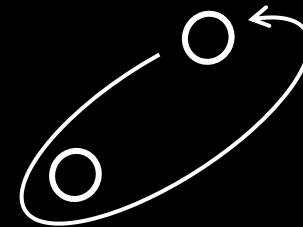
can be eccentric

BINARY BIOGRAPHIES
decoding binary formation

Both eccentricity and spin-induced precession are signatures of dynamical formation...

...but we expect all dynamical BBH to have misaligned spins (if they are spinning), and only about 5% to be eccentric, so the fraction of the population forming dynamically is uncertain if the two effects are confused

most events are vanilla, i.e., circular and non-spinning

high mass ➜ short signal
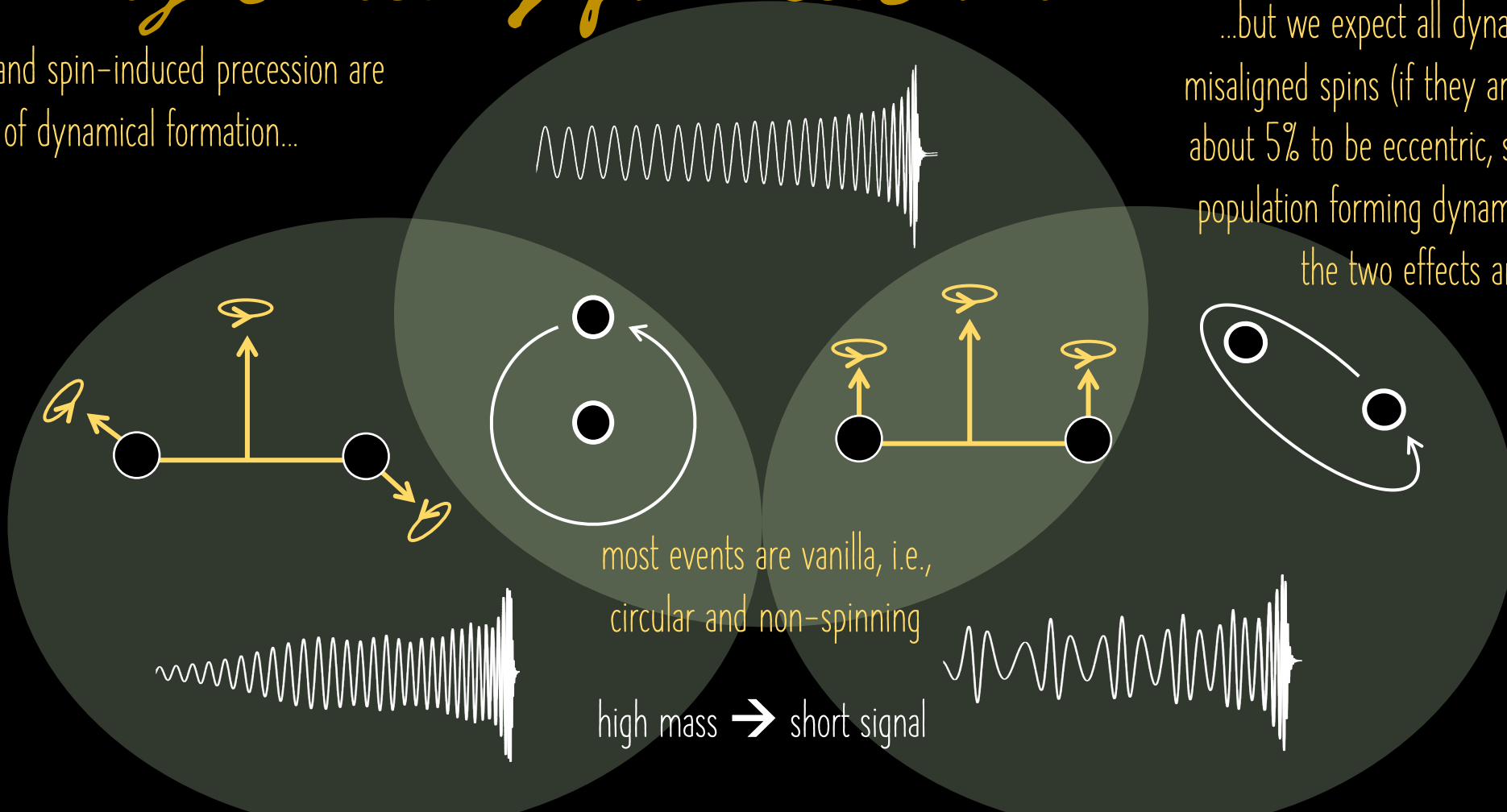
See, e.g., IRS, Lasky, Thrane & Calderon Bustillo 2020; Calderon Bustillo et al 2020, 2021

(MIS)INTERPRETING GRAVITATIONAL WAVES
eccentricity or precession? — gw190521

GW190521

"better described" : ratio of Bayesian evidences = Bayes factor

Log B = 1.8 for eccentricity vs precession
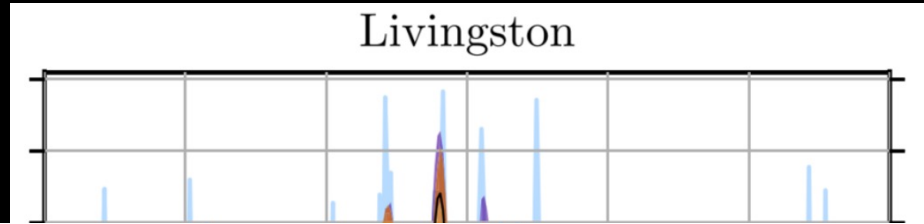
Log B = 8 required for confident statement

Can compare hypotheses, but not analyse simultaneously

Possible eccentricity [edit]

While the original LIGO/Virgo data analysis assumed a quasi-circular inspiral waveform model, subsequent publications claimed that this source could have been significantly eccentric. Romero-Shaw et al. showed that the data is better described by a non-precessing eccentric waveform with $e_{10Hz} \geq 0.1$ than a spin-precessing quasi-circular model.[16]

eccentricity or precession? - cycles
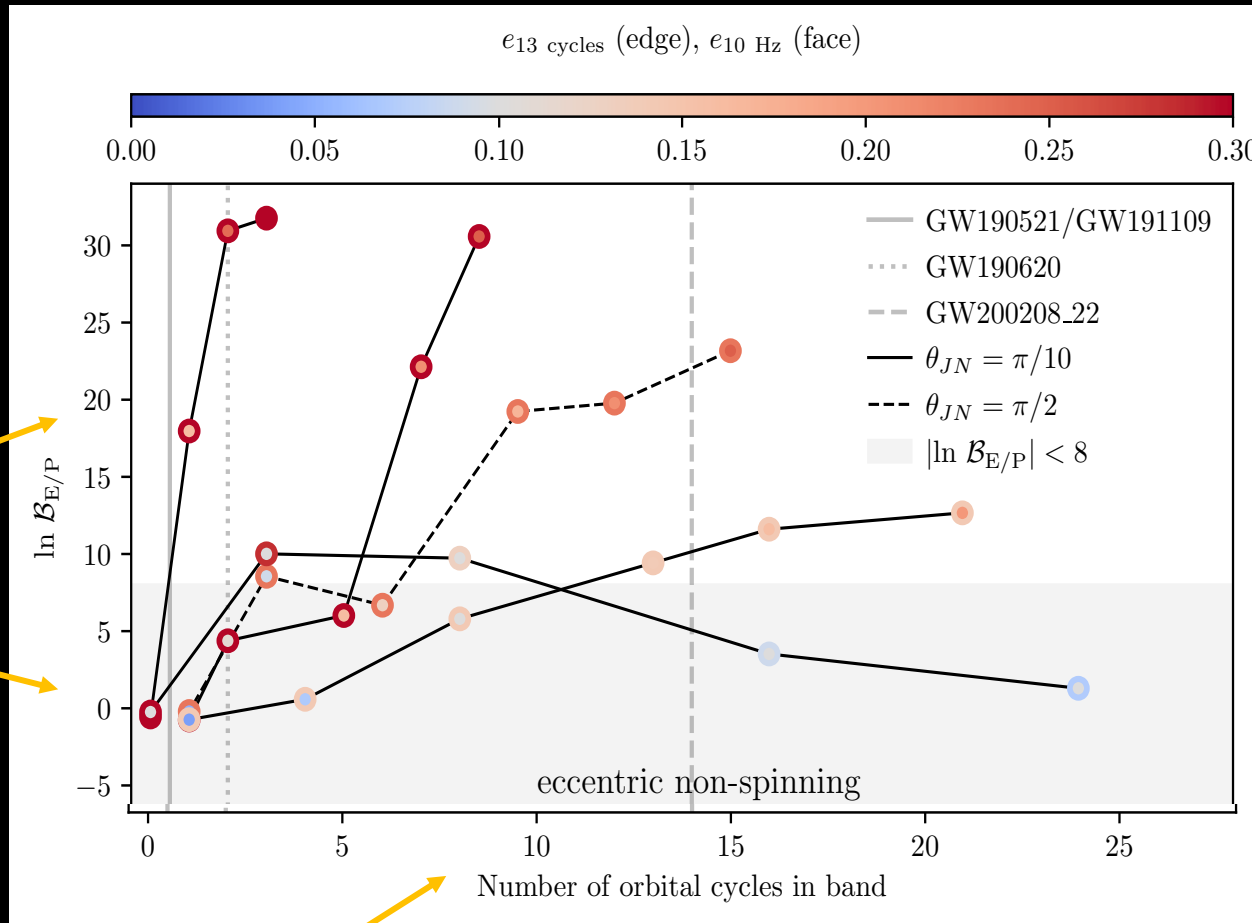

$e_{13 \text{ cycles}}$ (edge), $e_{10 \text{ Hz}}$ (face)

Can distinguish eccentric systems from precessing systems if signal is long enough, i.e., system is low-mass

How much eccentric hypothesis preferred over circular, precessing hypothesis

Need longer signals for lower eccentricity

Grey area shows log B < 8

If highly eccentric, can distinguish eccentric from precessing system with only a few cycles in-band

How many orbital cycles are in the observed signal (higher mass ➔ shorter)

IRS, Gerosa & Loutrel 2023

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eccentric or circular? – biases

Inject circular, recover with different circular models:

Inject eccentric, recover with different circular models:
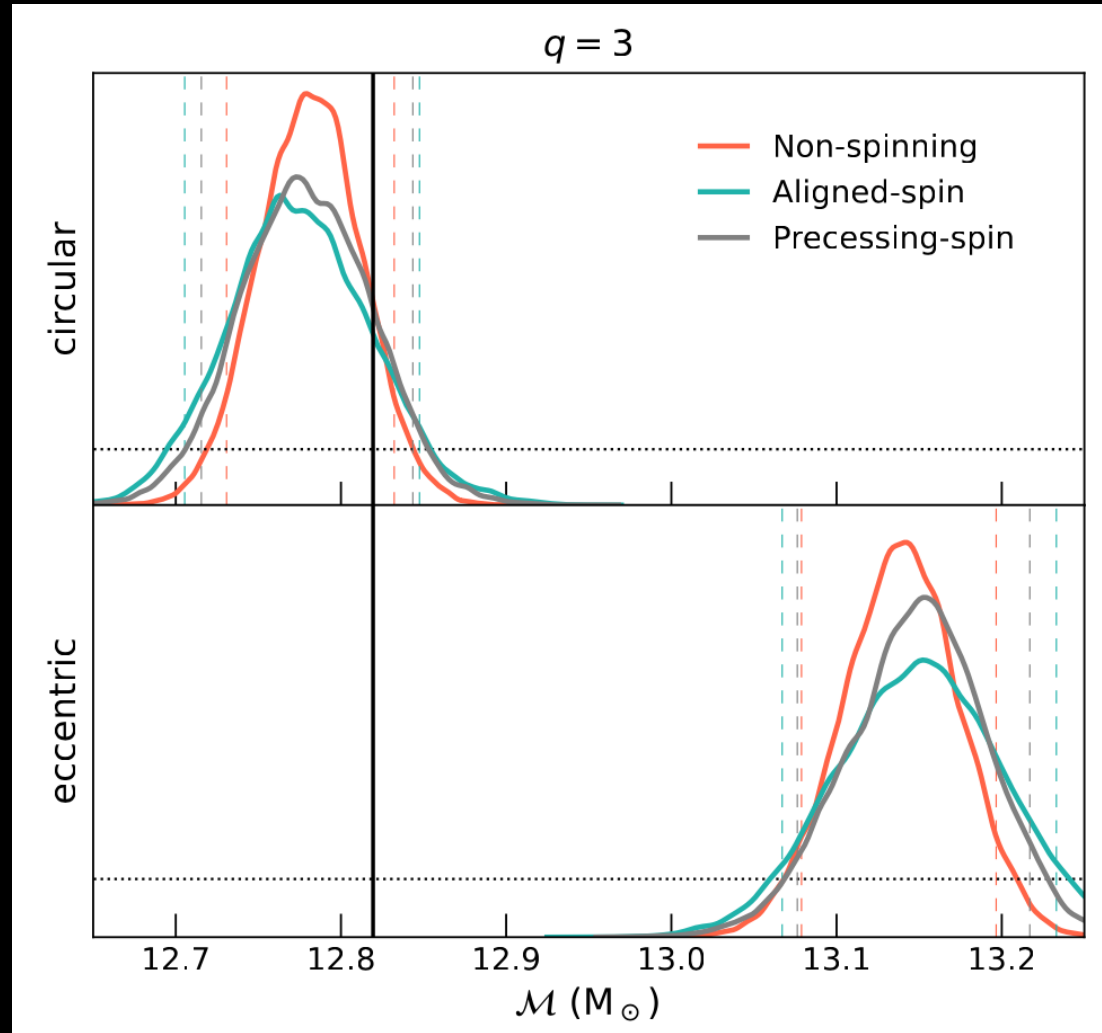
Dangers of ignoring eccentricity illustrated with low-mass injections

Divyajyoti et al. incl. IRS in press. 2023

other exotic physics? – biases

Injected:

Binary boson star merger

Mass 1: 40 Msol

Mass 2: 40 Msol
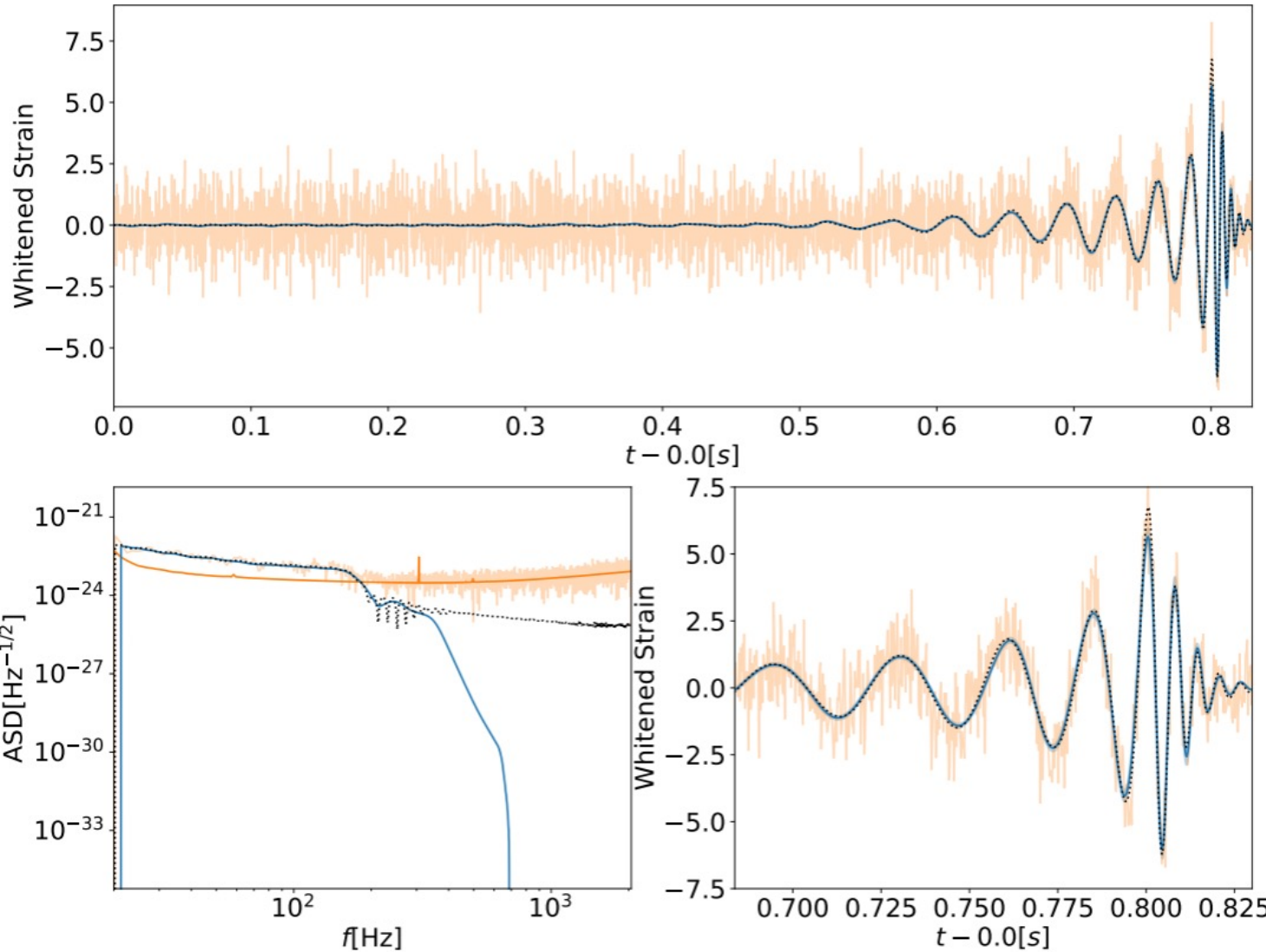
Spin 1: 0.0

Spin 2: 0.0

Recovered:

Binary black hole merger

Mass 1: 56 Msol

Mass 2: 40 Msol

Spin 1: 0.9 (close to max.)

Spin 2: 0.0

Evstafyeva et al. incl. IRS
in prep. 2024

(MIS)INTERPRETING GRAVITATIONAL WAVES
other exotic physics? – biases

Injected:
Binary boson star merger
Mass 1: 40 Msol
Mass 2: 40 Msol
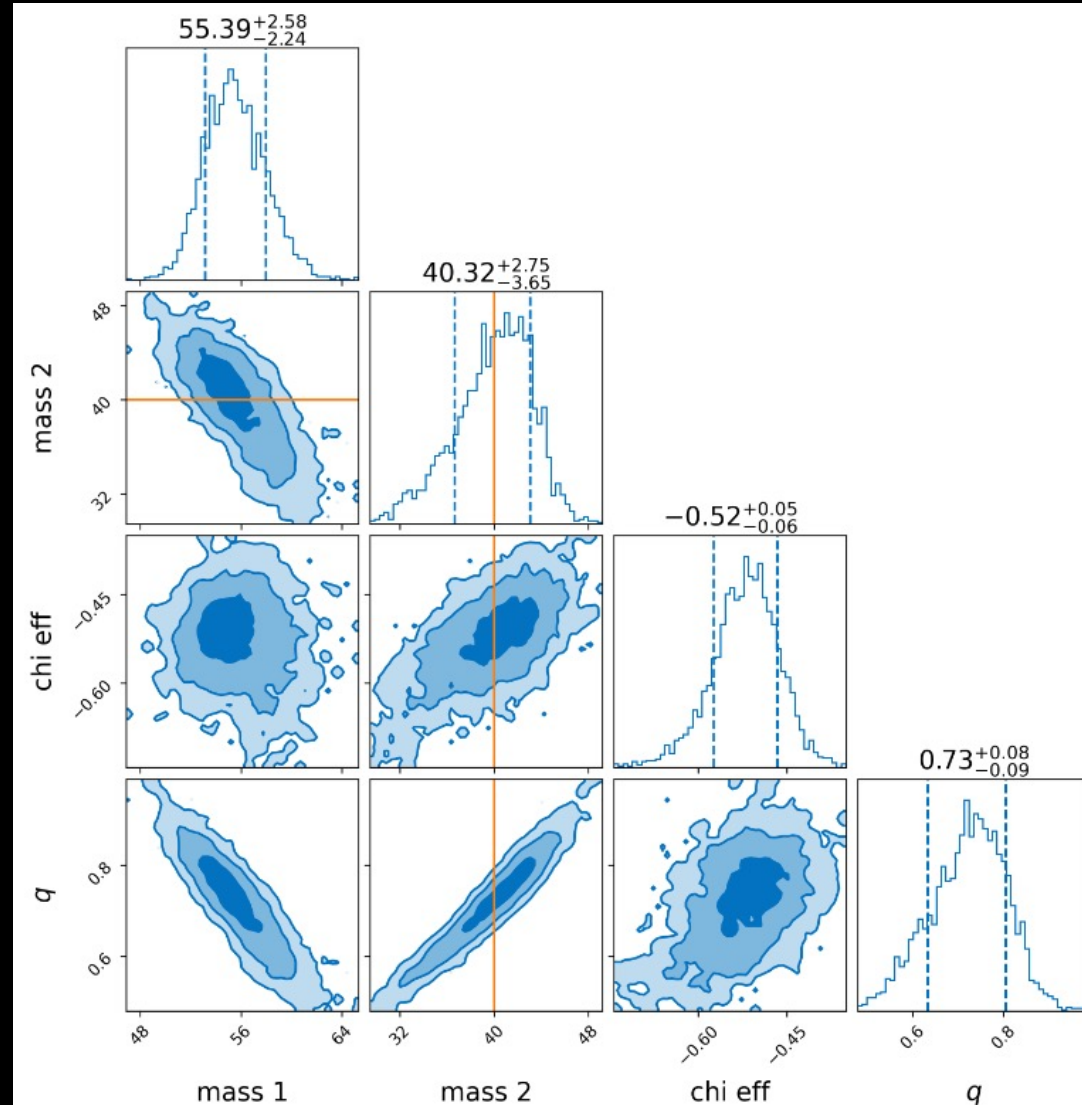Spin 1: 0.0
Spin 2: 0.0

Mergers of exotic objects successfully masquerade as BBH mergers...

Recovered:
Binary black hole merger
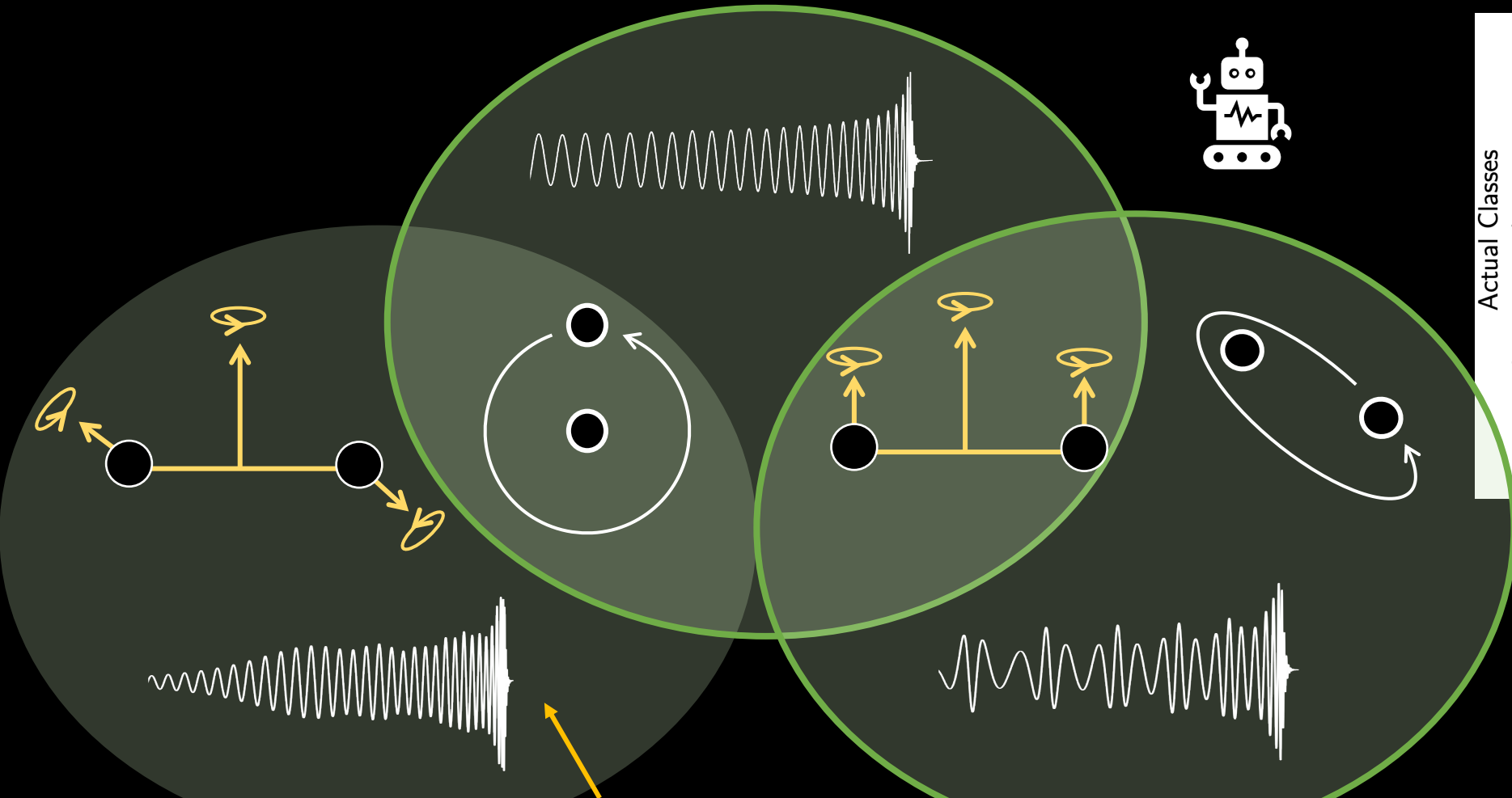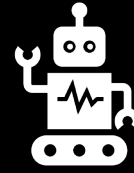Mass 1: 56 Msol
Mass 2: 40 Msol
Spin 1: 0.9 (close to max.)
Spin 2: 0.0

...and PE **confidently** infers incorrect properties (unequal mass, high spin)

Evstafyeva et al. incl. IRS in prep. 2024

23/10/2023

10

machine learning to the rescue?

Ravichandran et al. 2023

Look out for Ravichandran et al. incl. IRS 2024

INTERPRETING GRAVITATIONAL WAVES
outlook

- Gravitational waves must be modelled correctly to be understood.
- Incomplete or incorrect models can lead to confident inferences of incorrect physics...
- ...which can lead to inferences of incorrect merger object identities...
- ...and inferences of incorrect formation channels!
- Machine learning can help us find the right path – Work In Progress.
- Students, postdocs, ECRs at KICC / DAMTP are working hard to deduce BBH origins!

$e_{13\text{ cycles}}$ (edge), $e_{10\text{ Hz}}$ (face)

quasi-circular spin-precessing

- - $\theta_{JN} = \pi/4$
- ◆ maximal spin precession

$\ln \mathcal{B}_{\text{E/P}}$

Number of orbital cycles in band