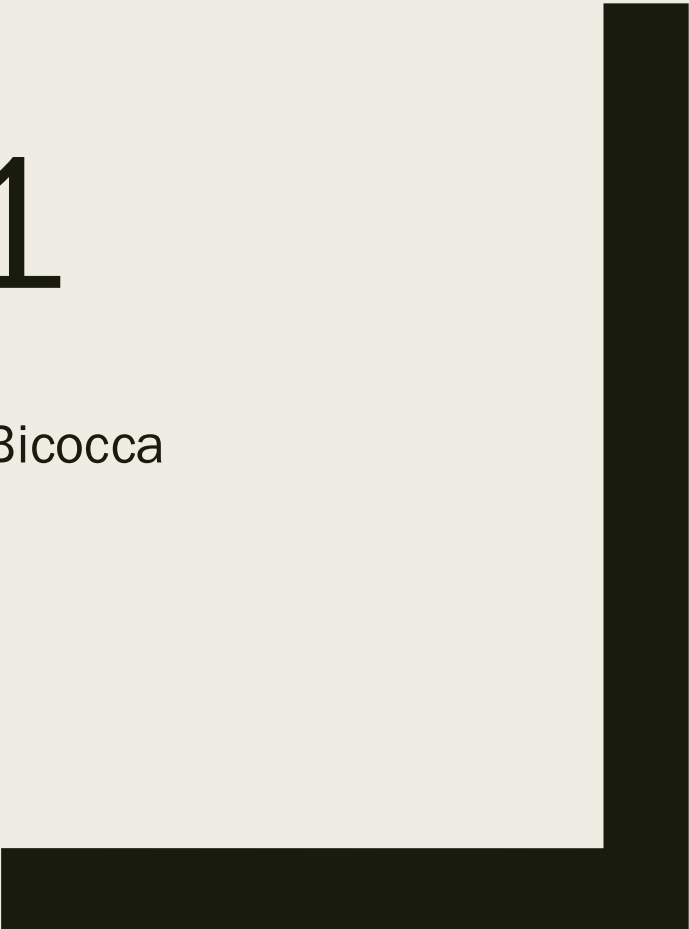




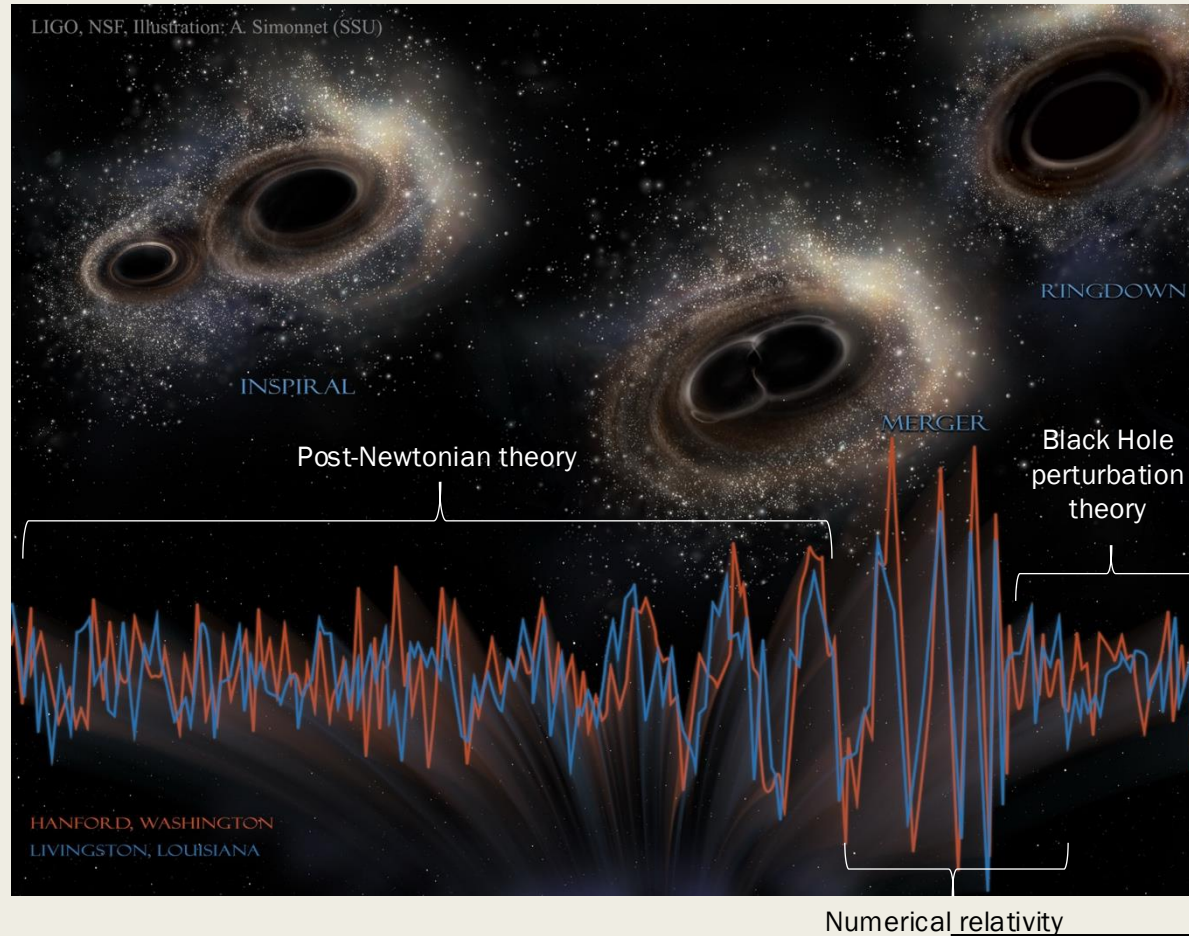
PHD YEAR 1

End of year seminar – University of Milano Bicocca
Matilde Garcia
07/09/2026





INTRODUCTION



MERGING BINARIES OF COMPACT OBJECTS ACROSS THE COSMOS

10 Years of Detections (2015-2024) of Compact Binary Coalescences with Black Holes and Neutron Stars

O1

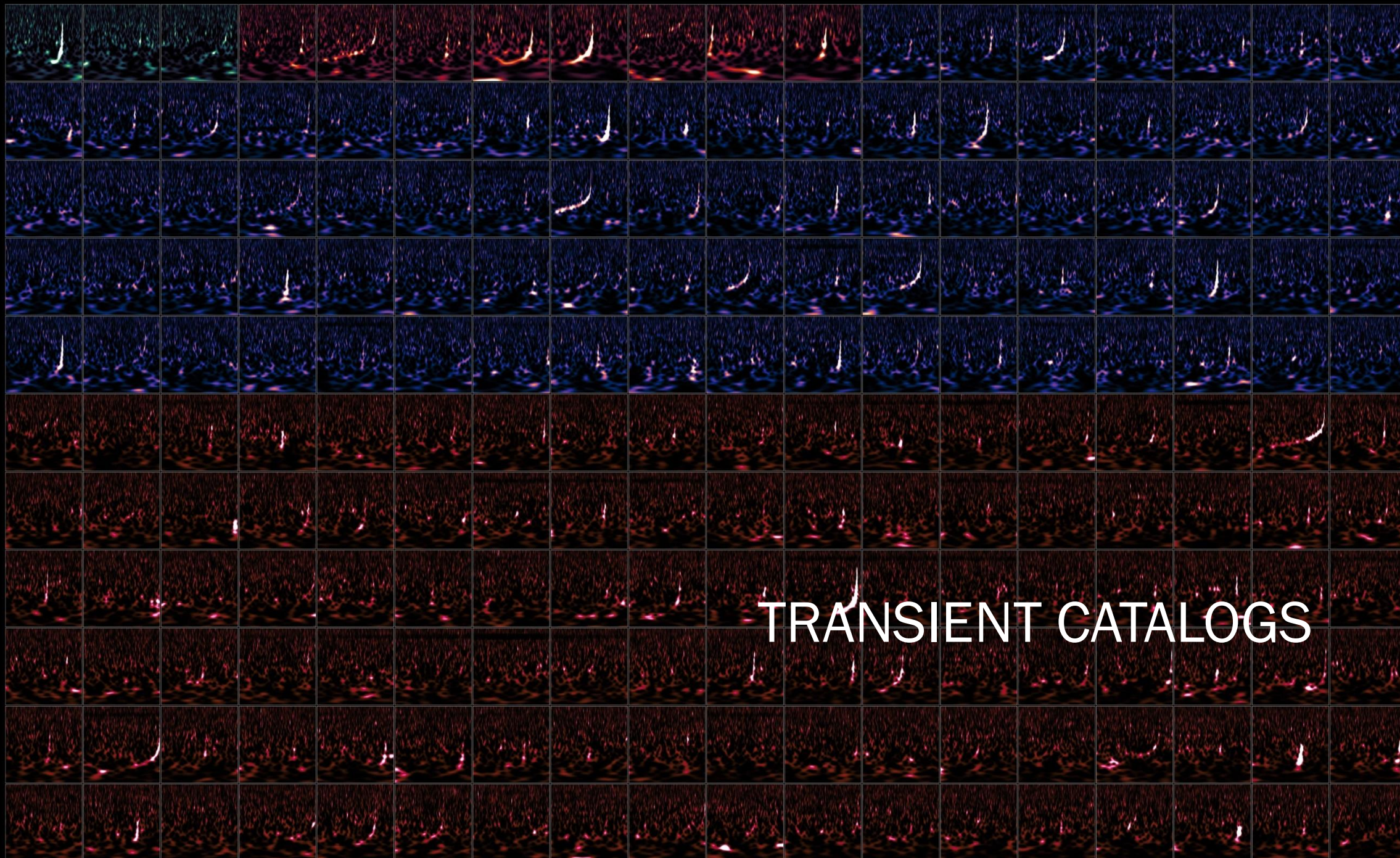
O2

O3

O4a

TRANSIENT CATALOGS

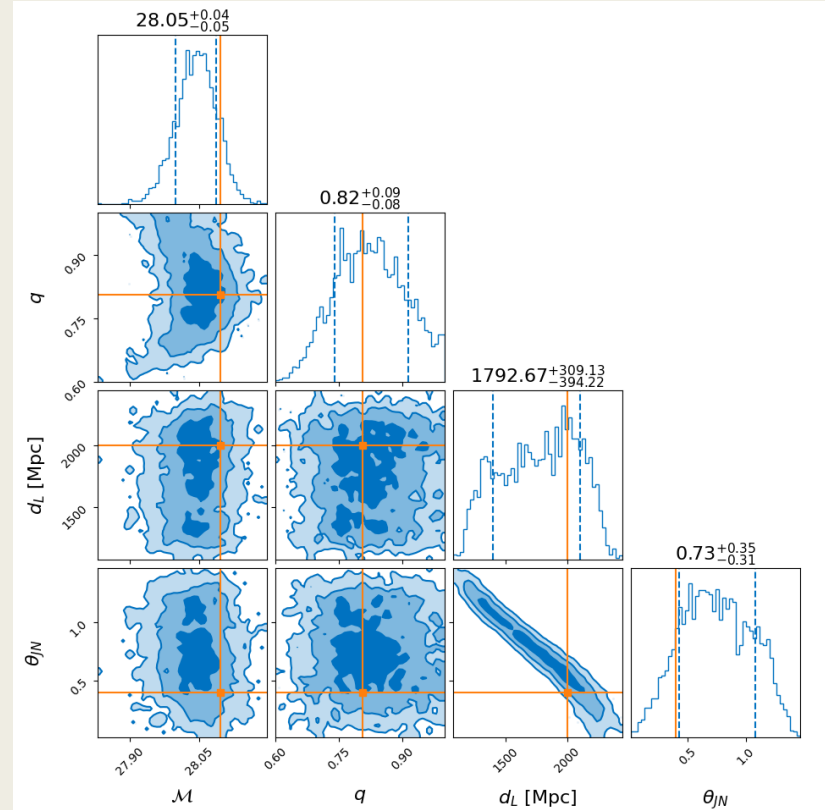
↑



Gravitational wave data analysis

- $\mathcal{L}(d | \theta) = \frac{1}{2\pi\sigma^2} \exp\left(-\frac{1}{2} \frac{|d - \mu(\theta)|^2}{\sigma^2}\right)$ - Likelihood, introduces a noise and waveform model
- $\pi(\theta)$ - Prior probability on the parameters
- $\mathcal{Z} = \int d\theta \mathcal{L}(d | \theta) \pi(\theta)$ - Evidence, normalizing factor / model comparison
- $p(\theta | d)$ - Posterior probability, ultimate goal of bayesian inference

BAYES THEOREM $p(\theta | d) = \frac{\mathcal{L}(d|\theta)\pi(\theta)}{\mathcal{Z}}$





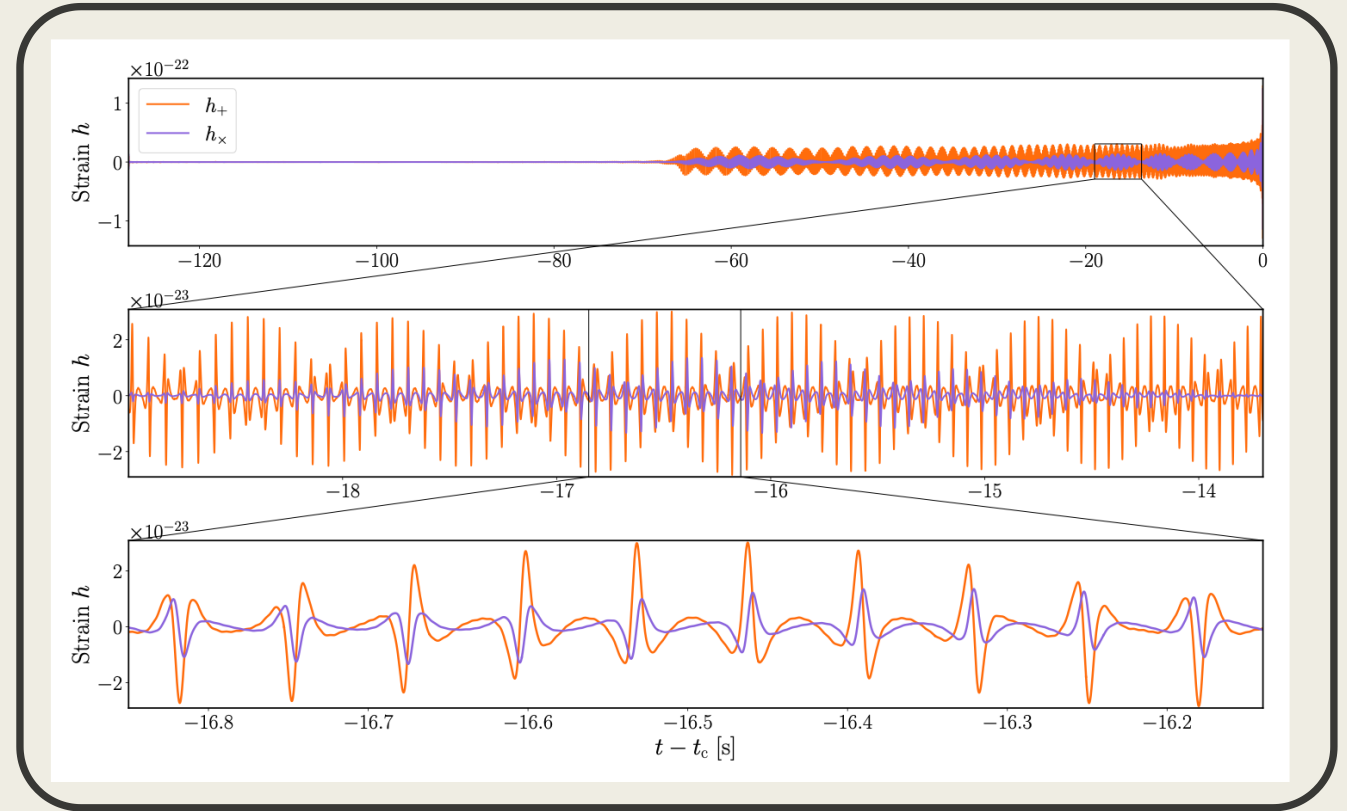
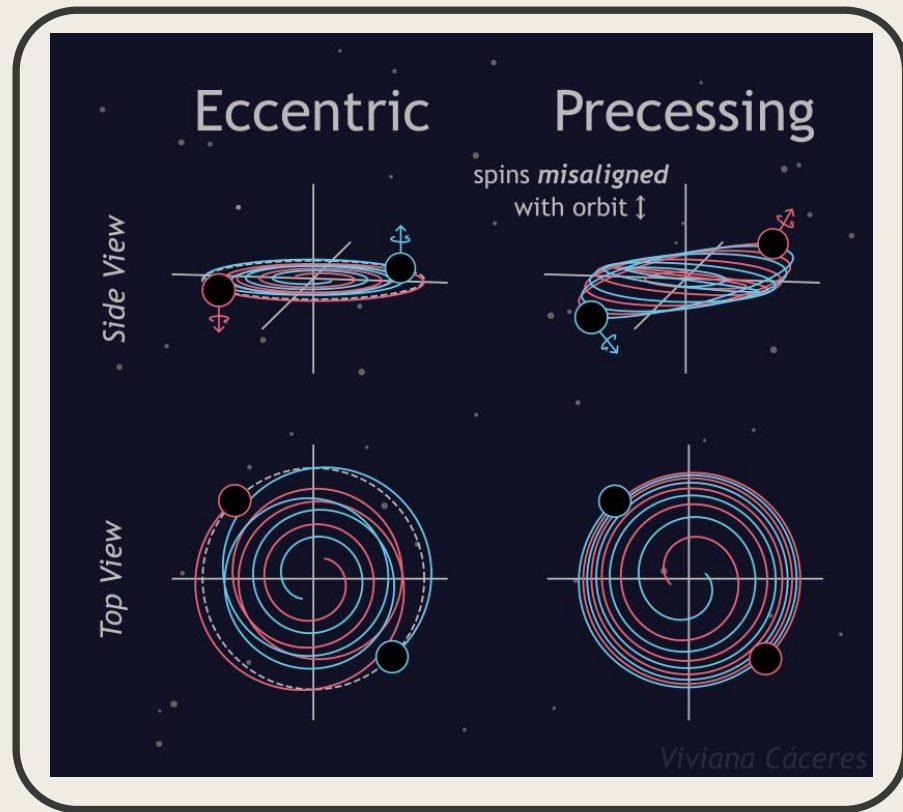
RESEARCH
PROJECT 1

Where do compact binaries come from?

Different formation channels are predicted by theorists

- Dynamical formation channels – can leave imprints on gravitational wave signals
- Eccentricity is smoking gun evidence that a binary was externally driven to form
- Isolated binaries – expected to circularize by the time they reach LVK's frequency band





ECCENTRICITY – SPIN PRECESSION DEGENERACY

The two effects, in general, operate on different timescales

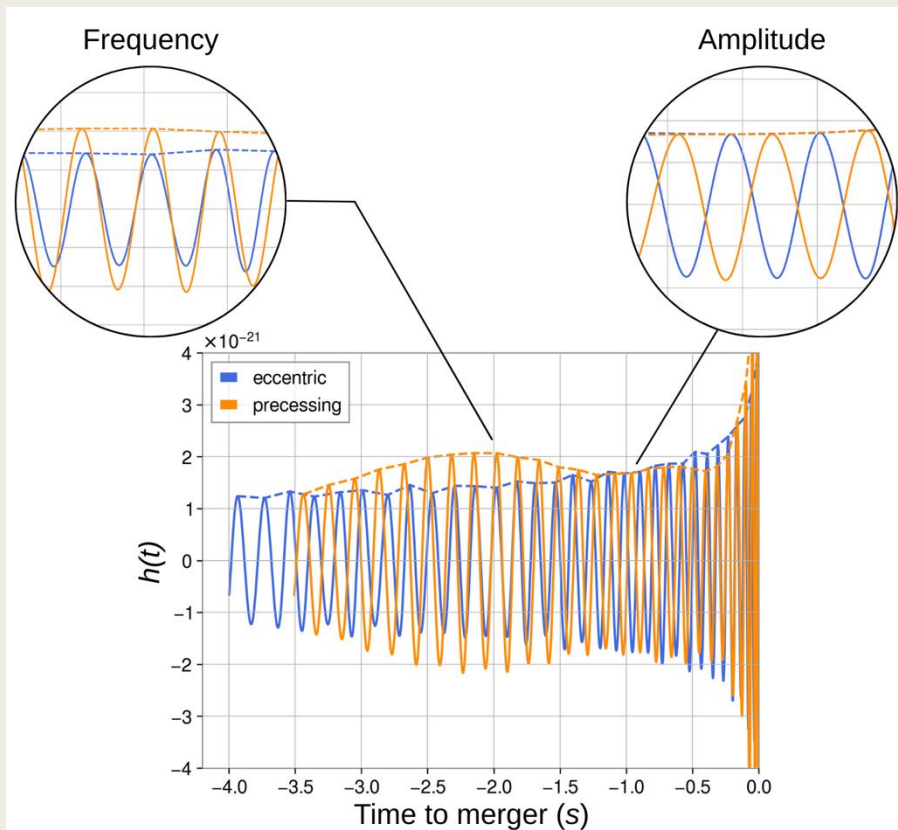
However...

Eccentricity or spin precession? Distinguishing subdominant effects in gravitational-wave data

Isobel M. Romero-Shaw^{*} ^{1,2,3}, Davide Gerosa ^{4,5,6}, Nicholas Loutrel ⁷

Misinterpreting Spin Precession as Orbital Eccentricity in Gravitational-Wave Signals

Snehal Tibrewal,¹ Aaron Zimmerman,¹ Jacob Lange,^{2,1} and Deirdre Shoemaker¹

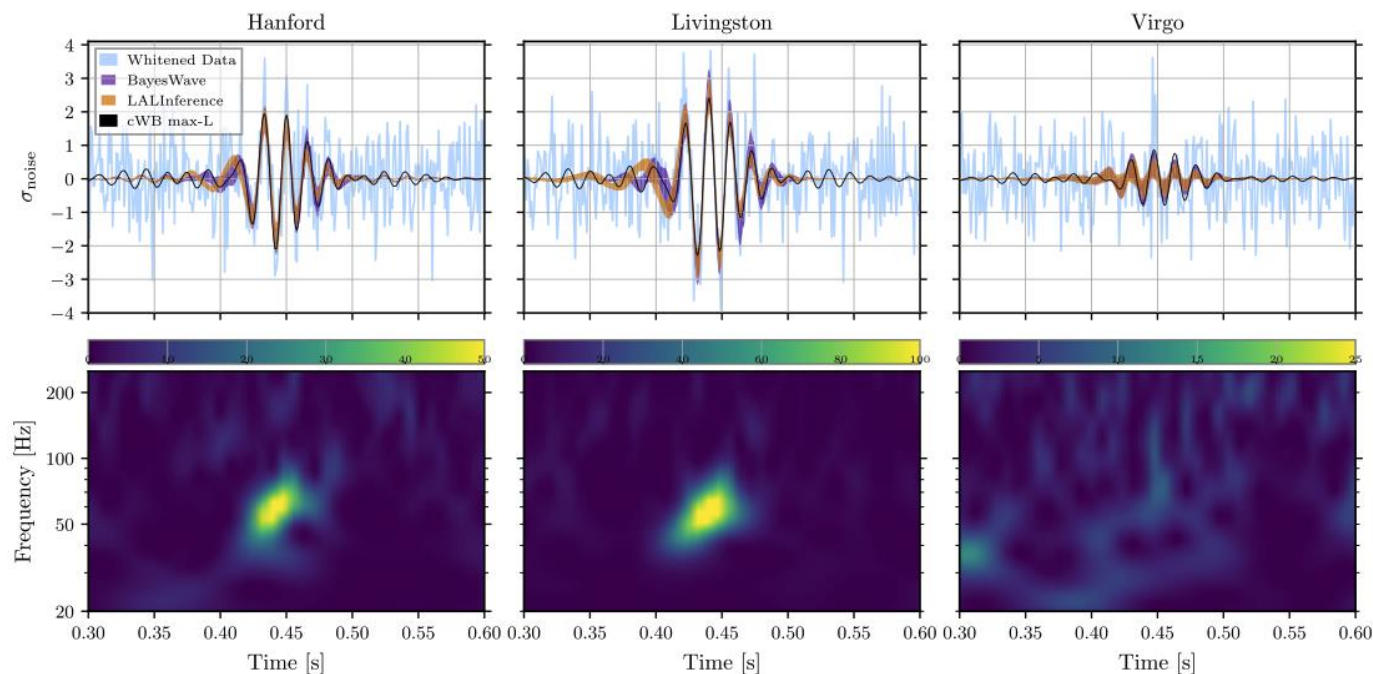


For short signals, with only a few cycles in band, the two effects can become indistinguishable

GW190521: A Binary Black Hole Merger with a Total Mass of $150 M_{\odot}$

R. Abbott *et al.*^{*}

(LIGO Scientific Collaboration and Virgo Collaboration)



Breaking the degeneracy

- In theory:

Long enough signal (many inspiral cycles)



Accurate waveform models $\mu(\theta)$ – both eccentric and spin precessing



Appropriate choice of priors, data glitch mitigation ...



Somewhat confident eccentricity measurement

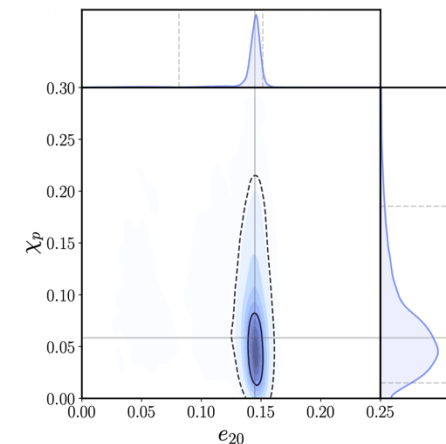
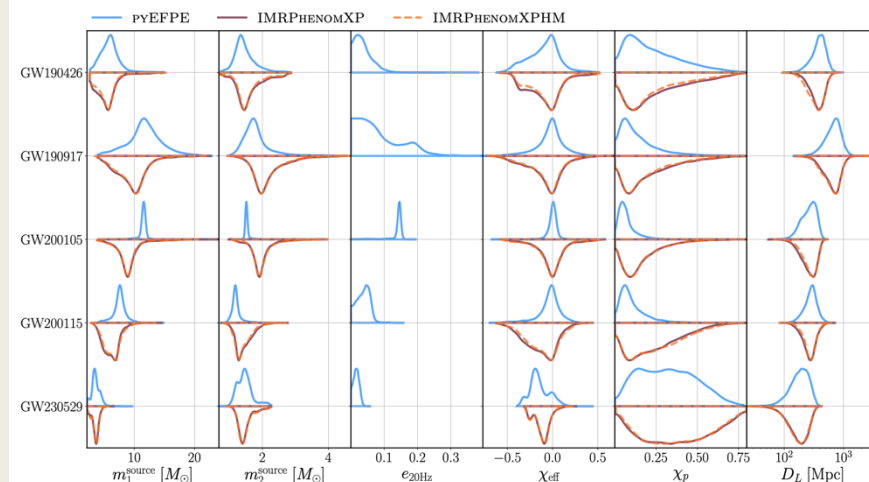
- It has been done!

(For very light systems of BHNS)

Only inspiral is modelled

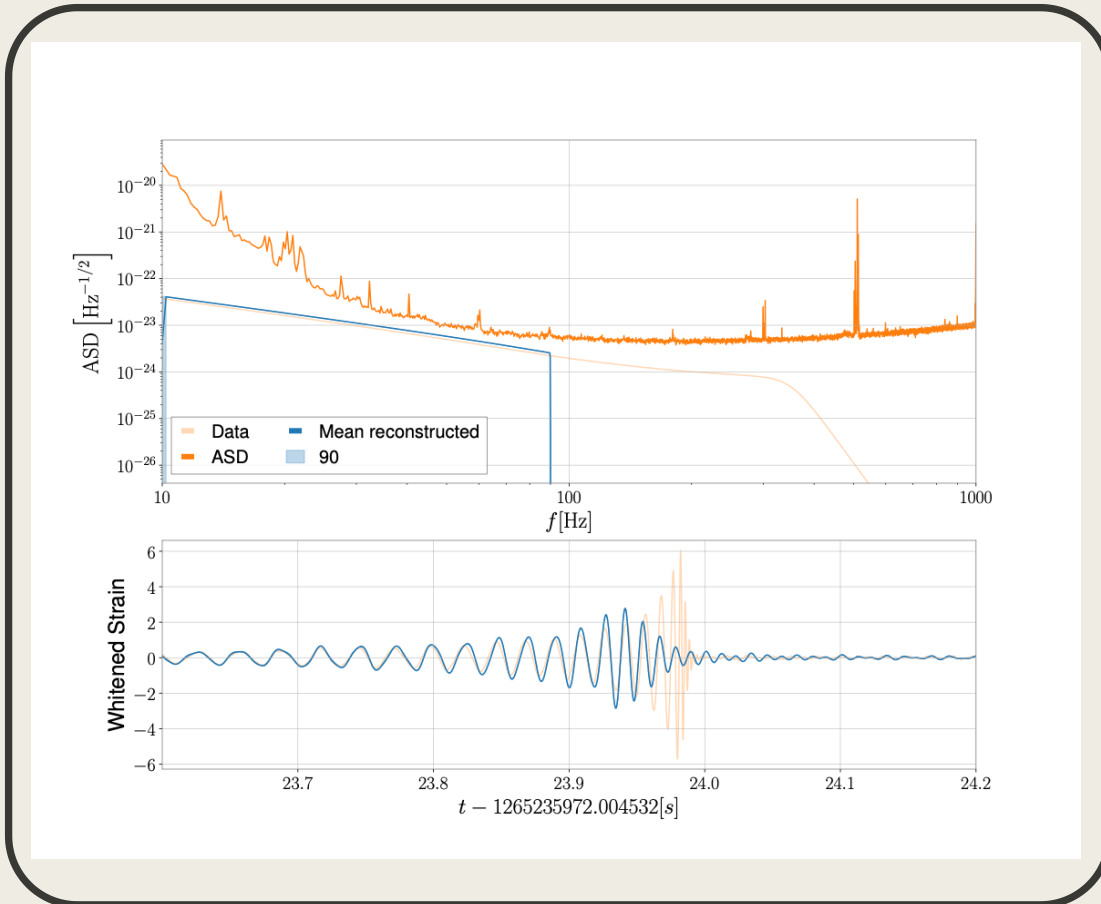
Impact of eccentricity on the population properties of neutron star – black hole mergers

GONZALO MORRAS^{1,2}, GERAINT PRATTEN³ AND PATRICIA SCHMIDT^{1,3}



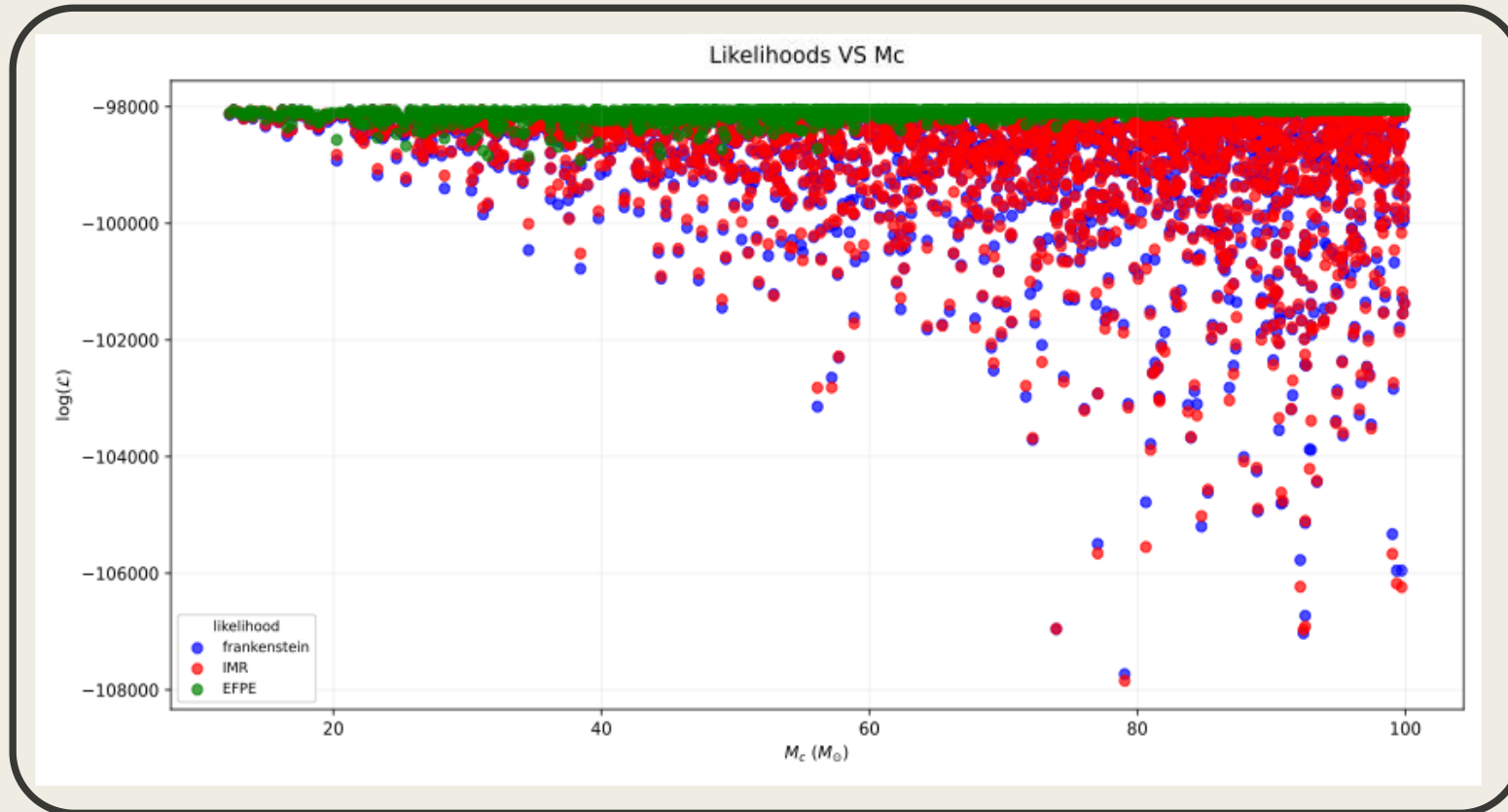
Heavy systems case study – my attempts

- Attempt 1: using an inspiral – only model on a BBH signal



Heavy systems case study – my attempts

- Attempt 1: using an inspiral – only model on a BBH signal



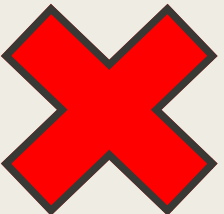
- BBH have short signals

+

merger within band



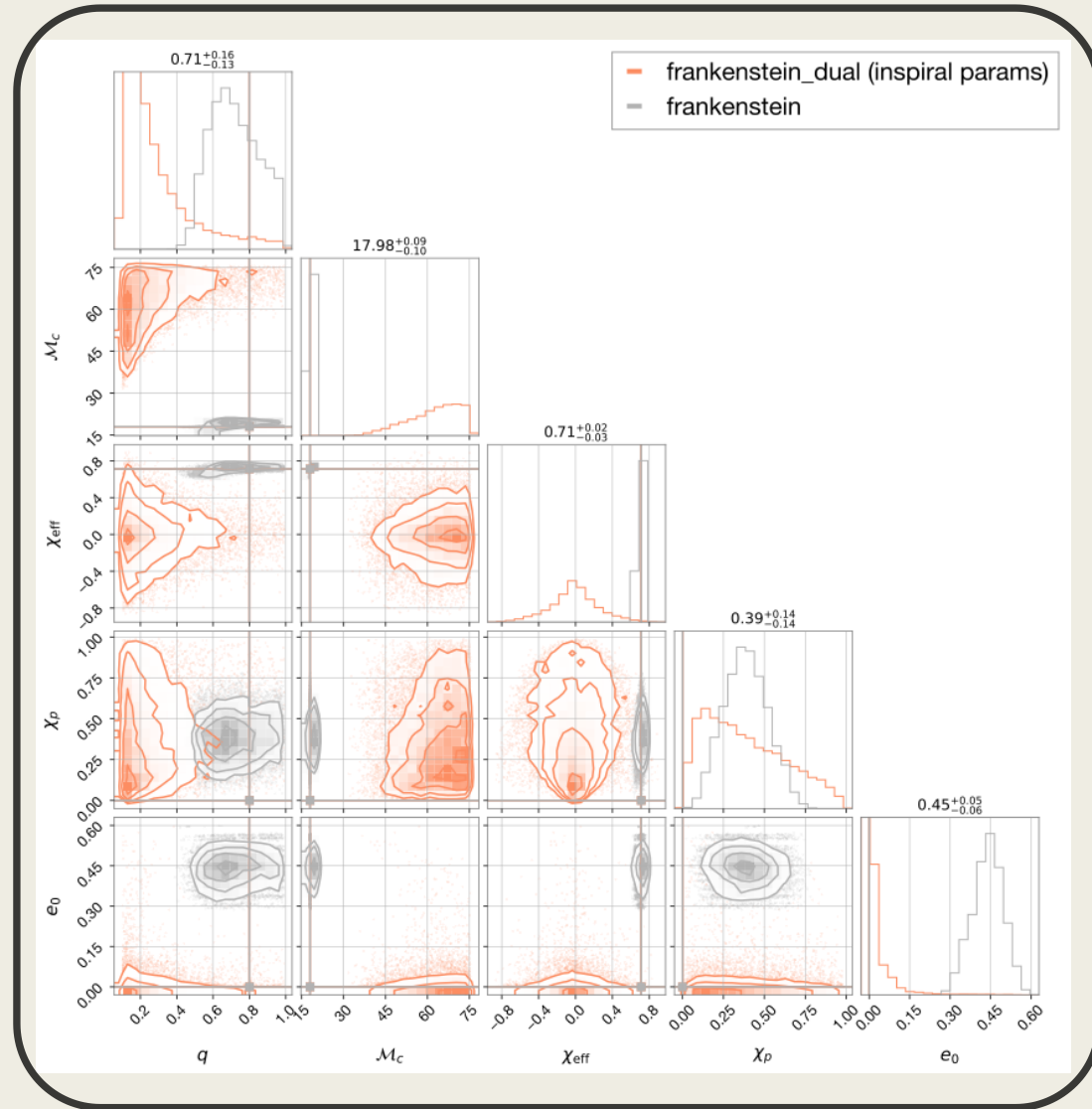
- Modelling inspiral alone is not enough



Heavy systems case study – my attempts

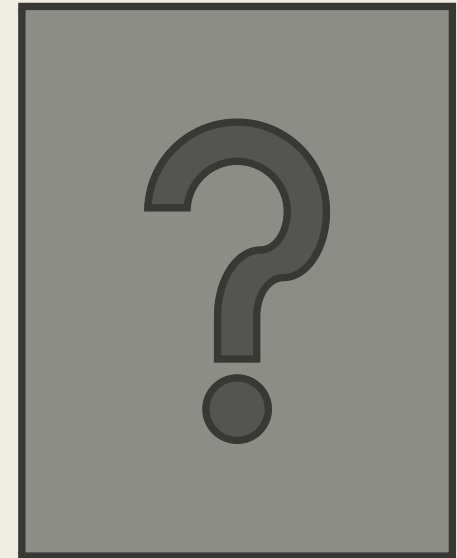
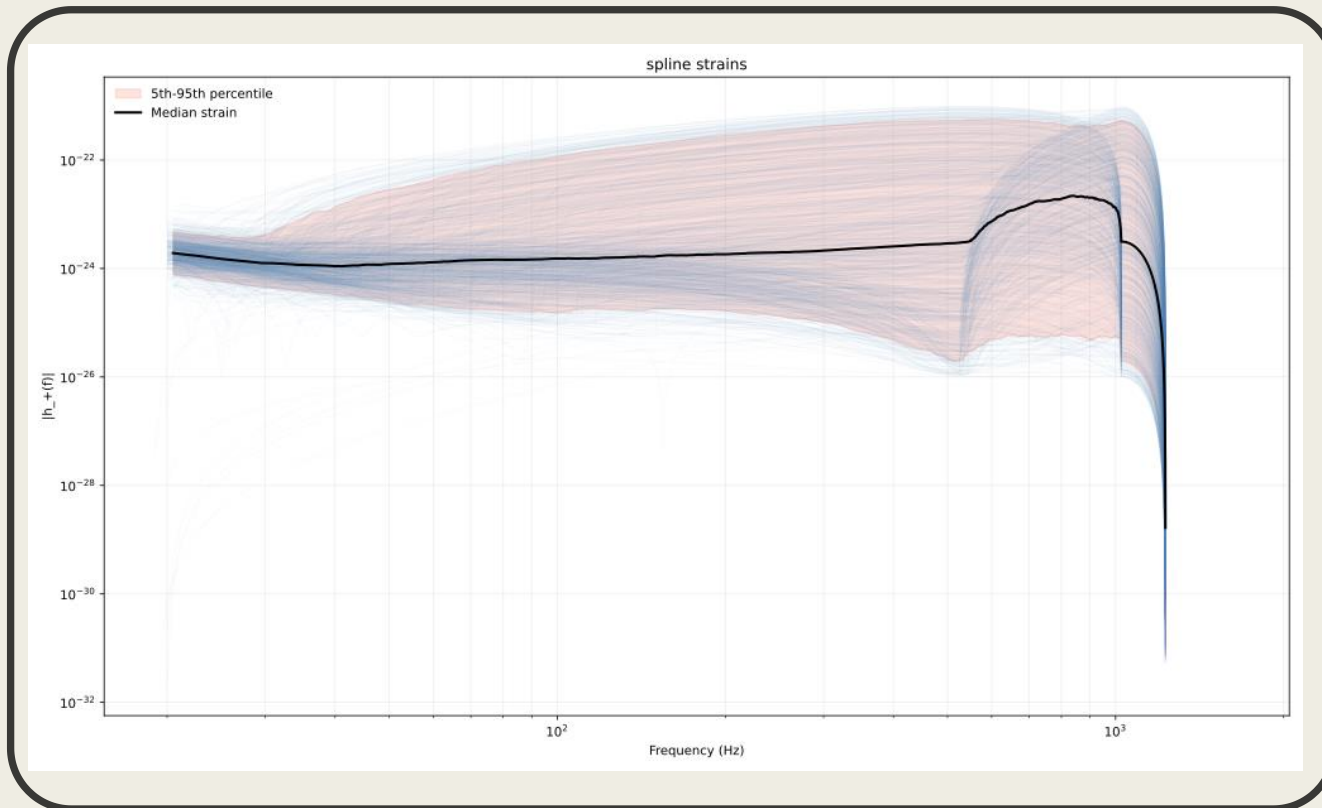
- Attempt 2: What if we patch a different model for the merger-ringdown part?

Very messy
+
biased results...



Heavy systems case study – my attempts

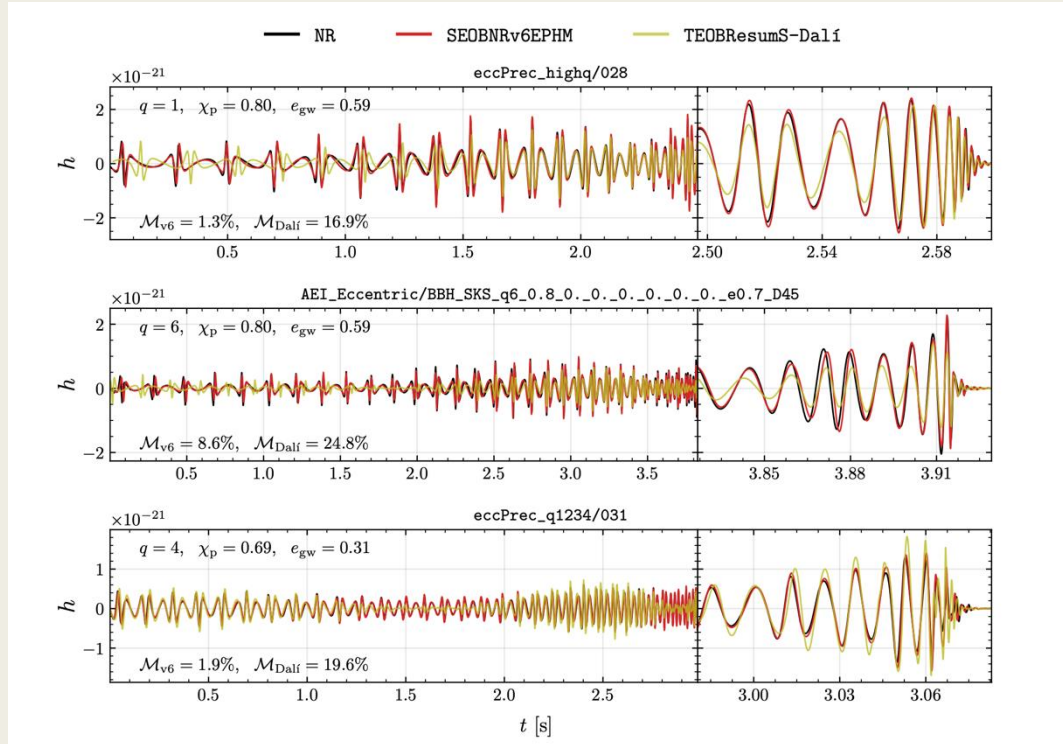
- **Attempt 3:** What if we patch a physically uninformed model? A simple spline, for example



Enabling gravitational-wave astronomy with spin-precessing black holes on generic orbits

Aldo Gamboa,^{1,*} Lorenzo Pompili,^{2,1} Alessandra Buonanno,^{1,3} Luca Sebastiani,¹ Raffi Enficiaud,¹
Michael Boyle,⁴ Lawrence E. Kidder,⁴ Harald P. Pfeiffer,¹ Antoni Ramos-Buades,^{5,1} and Mark A. Scheel⁶
¹Max Planck Institute for Gravitational Physics (Albert Einstein Institute), Am Mühlenberg 1, Potsdam 14476, Germany
²Nottingham Centre of Gravity & School of Mathematical Sciences, University of Nottingham, University Park, Nottingham NG7 2RD, United Kingdom
³Department of Physics, University of Maryland, College Park, MD 20742, USA
⁴Cornell Center for Astrophysics and Planetary Science, Cornell University, Ithaca, New York 14853, USA
⁵Departament de Física, Universitat de les Illes Balears, IAC3 – IEEC, Crta. Valldemossa km 7.5, E-07122 Palma, Spain
⁶Theoretical Astrophysics 350-17, California Institute of Technology, Pasadena, California 91125, USA
(Dated: September 2, 2026)

Eccentric + precessing + inspiral-
merger-ringdown models now exist!



IN THE MEANTIME...

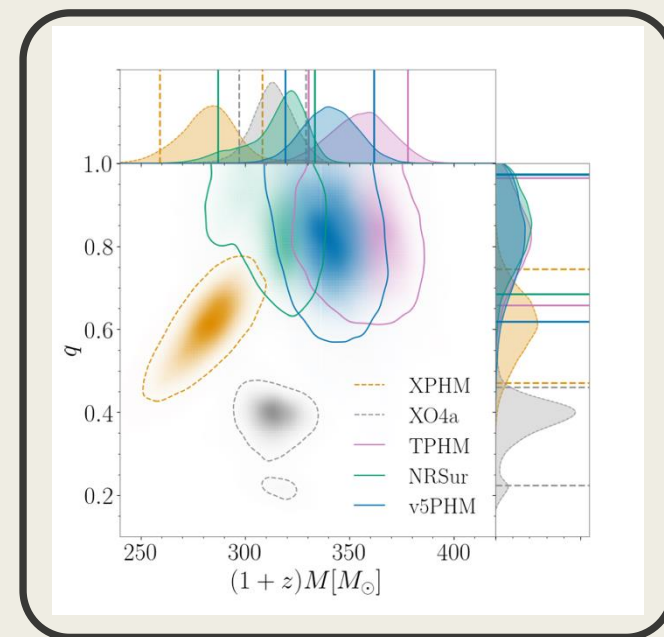
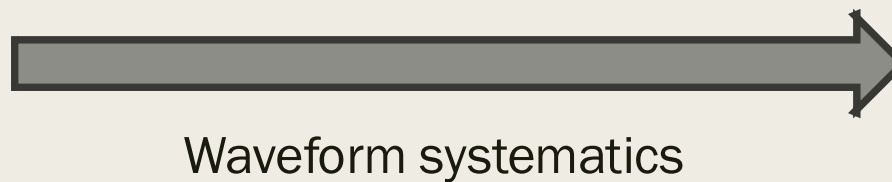
Science is dynamical, the waveform modelling field moves (quickly)



RESEARCH PROJECT 2

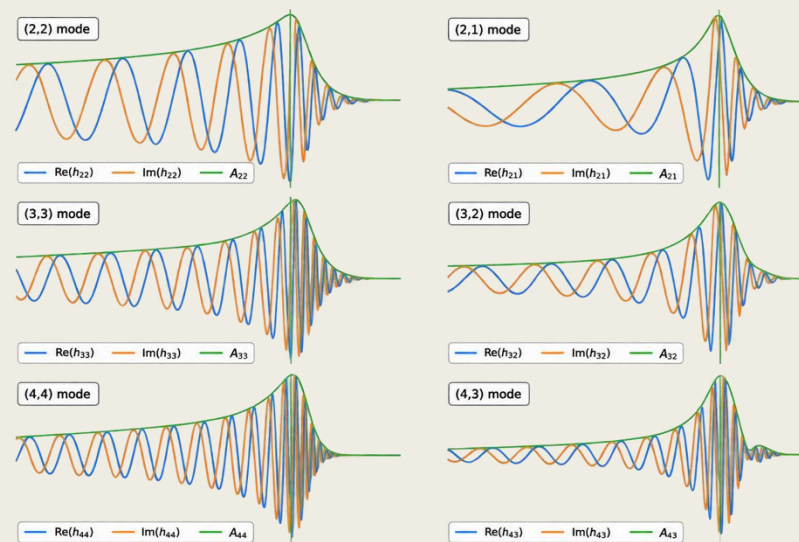
Parameter estimation without approximants

- Waveform approximants
are, after all
approximants!



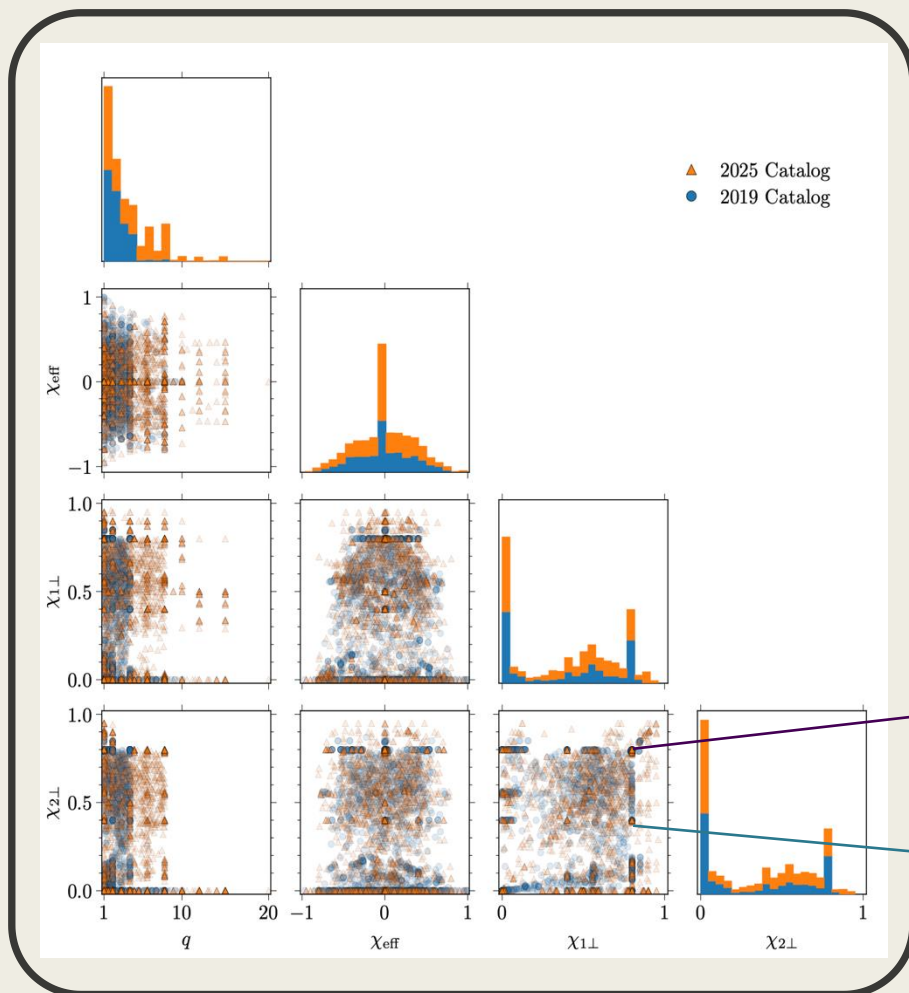
- Numerical relativity:

$$G_{\mu\nu} = 8\pi G T_{\mu\nu} + \text{Computer} = \text{Waveforms}$$

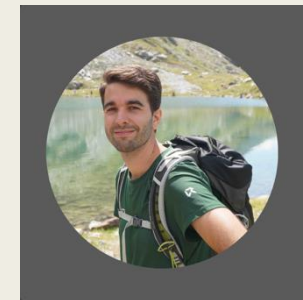


A whole
catalog of
simulations
!!!!!!

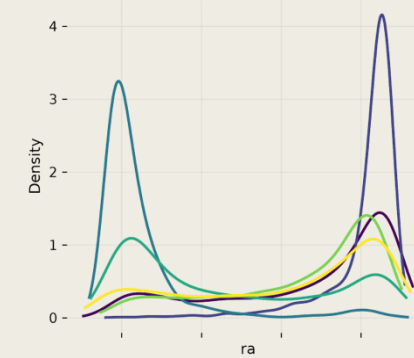
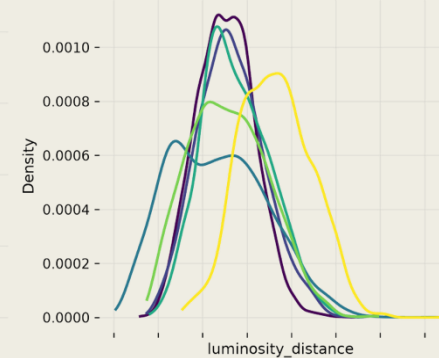
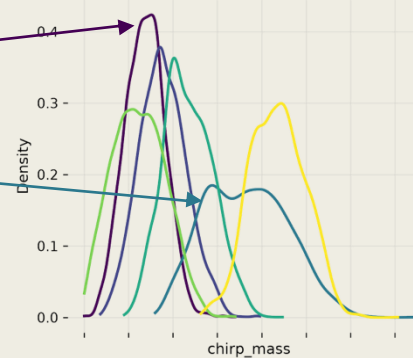
Discrete distributions of parameters



M. Boschini et. al : train a neural network on NR simulations and use it for posterior inference (Simulation Based Inference)



My project: Run inference on extrinsic parameters of GW source at each point of discrete parameter space and then combine posteriors!



Preliminary tests

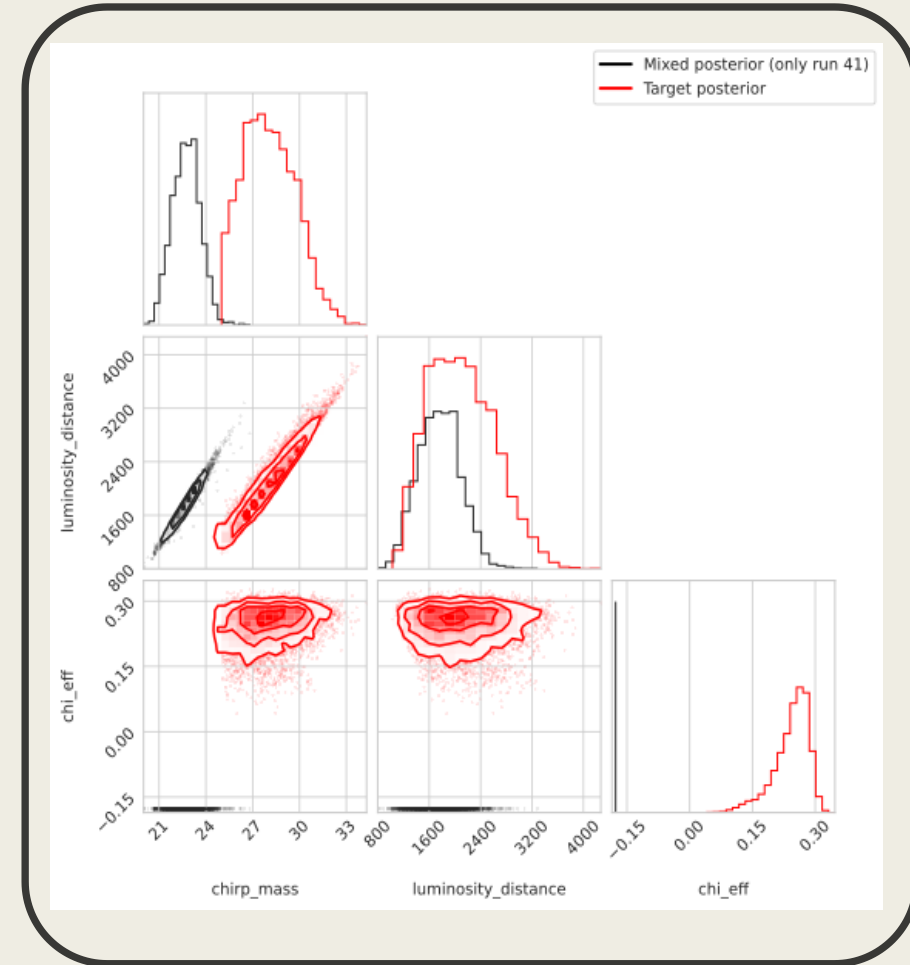
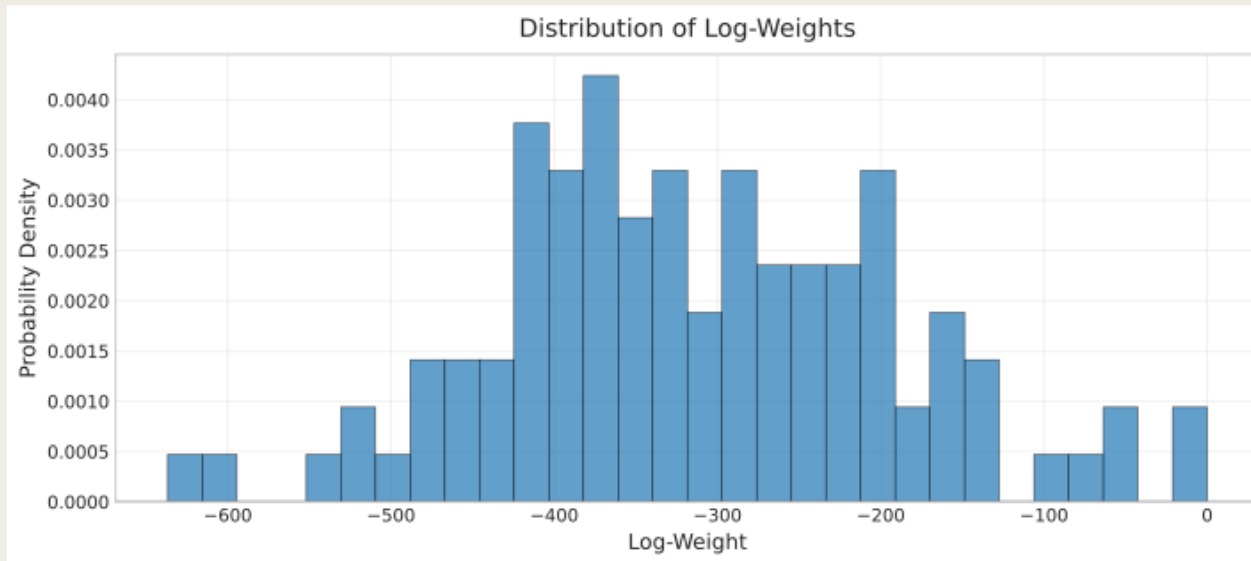
- 100 nested sampling runs

- 100 posteriors

- 100 evidences
 $\int d\theta \mathcal{L}(d | \theta) \pi(\theta)$

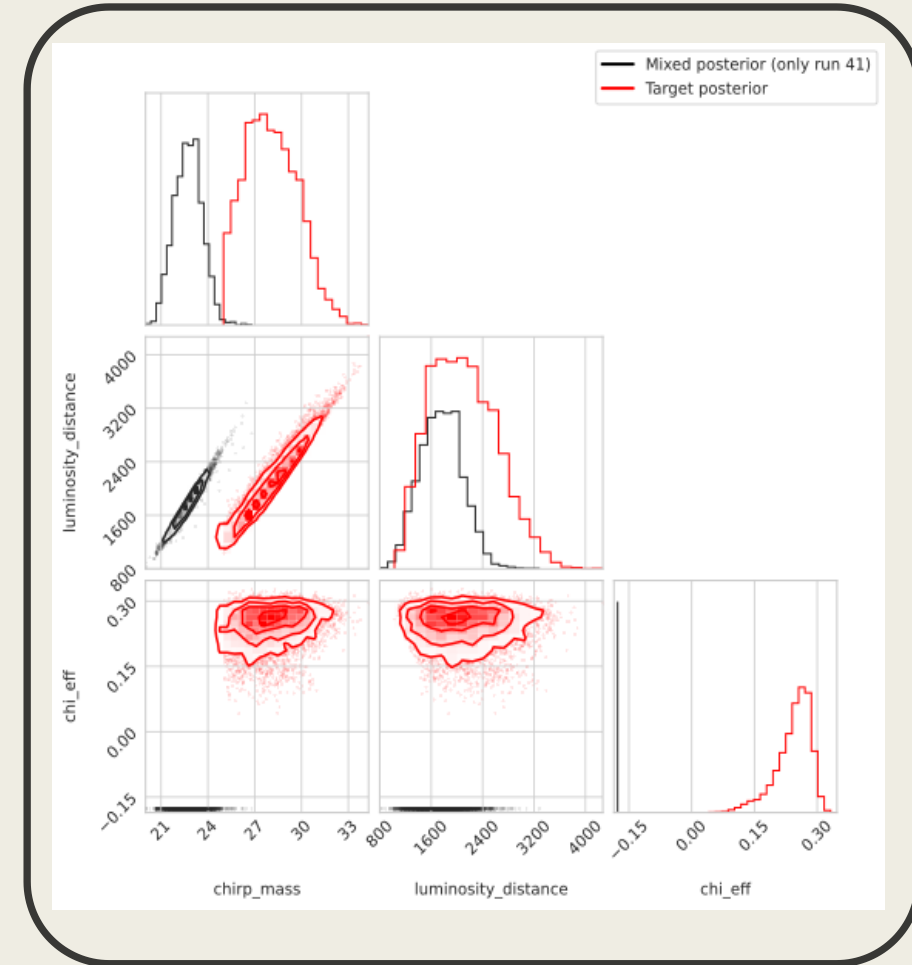
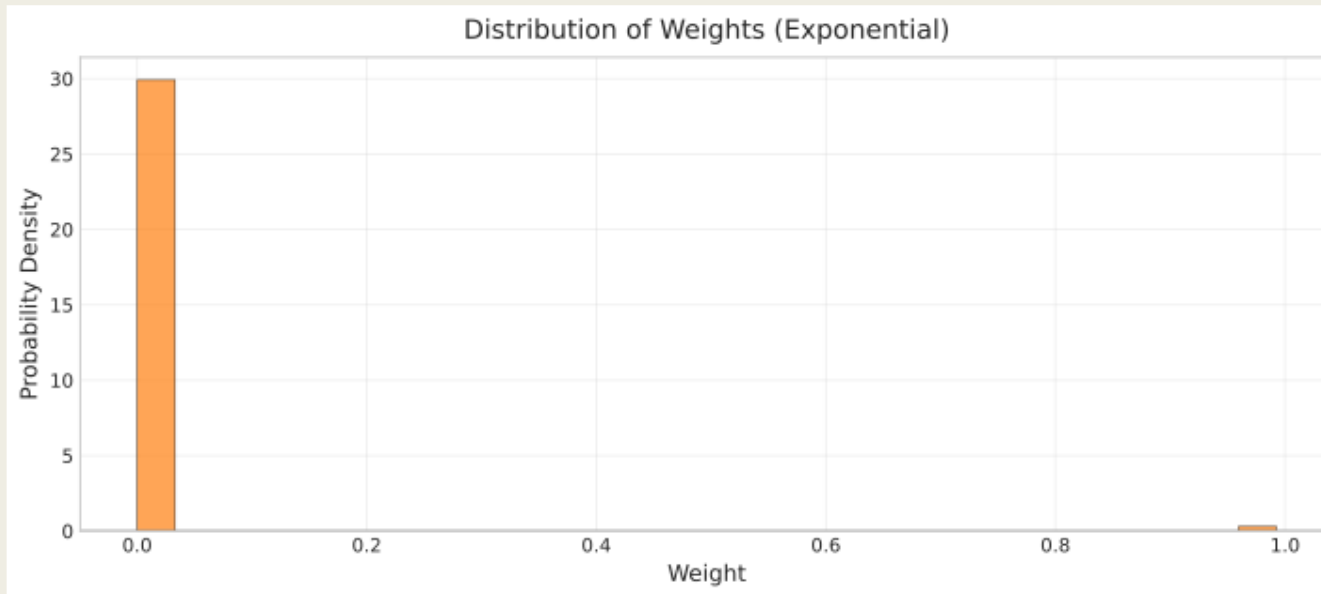
$Z =$

MIX



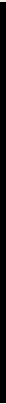
Preliminary tests

- 100 nested sampling runs
 - 100 posteriors
 - 100 evidences
- $Z = \int d\theta \mathcal{L}(d | \theta) \pi(\theta)$
- MIX**





OTHER PHD ACTIVITIES



Courses

■ Interdisciplinary courses:

- *Writing of scientific papers*
- *Topics in contemporary public philosophy*
- *Philosophy of artificial intelligence and robotics*



=

3 CFU

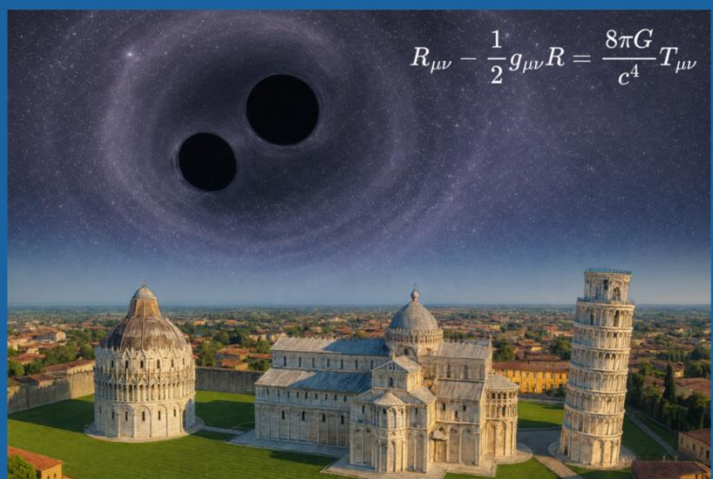
■ Physics courses:

- *Scientific computing with python*
- *Current and future challenges in gravitational wave astronomy*
- *Detection of gravitational waves (soon)*



=

4 CFU
(hopefully 6 soon)



TEONGRAV workshop 2026



BINARY COMPACT OBJECTS ON ECCENTRIC ORBITS AND THEIR GRAVITATIONAL-WAVE SIGNATURES

CORFU SUMMER INSTITUTE (GREECE) - SEPTEMBER 1ST-6TH, 2026



THE SCHOOL ON
GRAVITY
FROM MOTION TO COMMOTION

AUDITORIUM A
NIELS BOHR INSTITUTE
22-26 JUNE 2026

(1 CFU)

CONFERENCES/SCHOOLS

THANK YOU
FOR YOUR
ATTENTION

