Data-driven modeling of numerical relativity simulations

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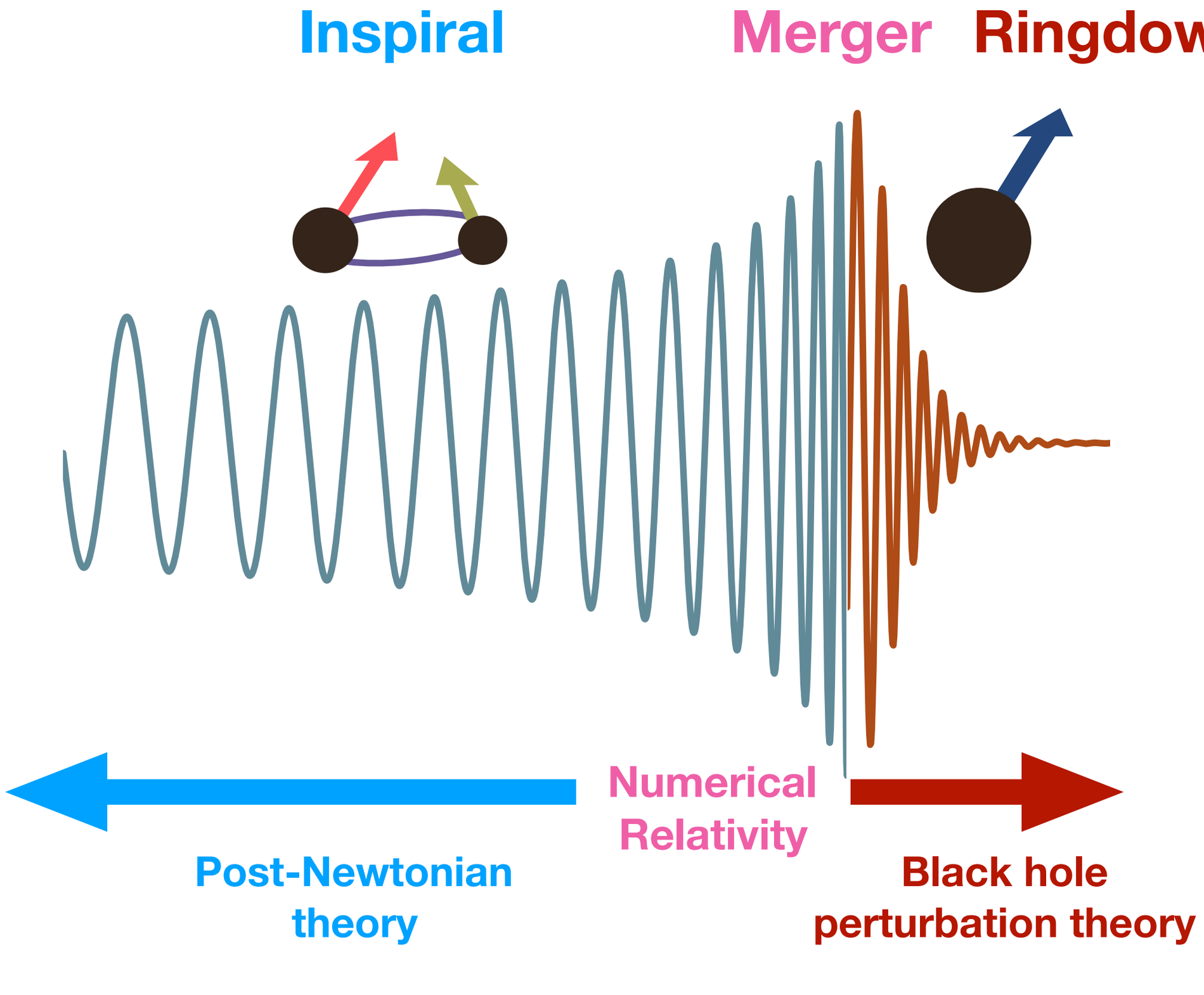
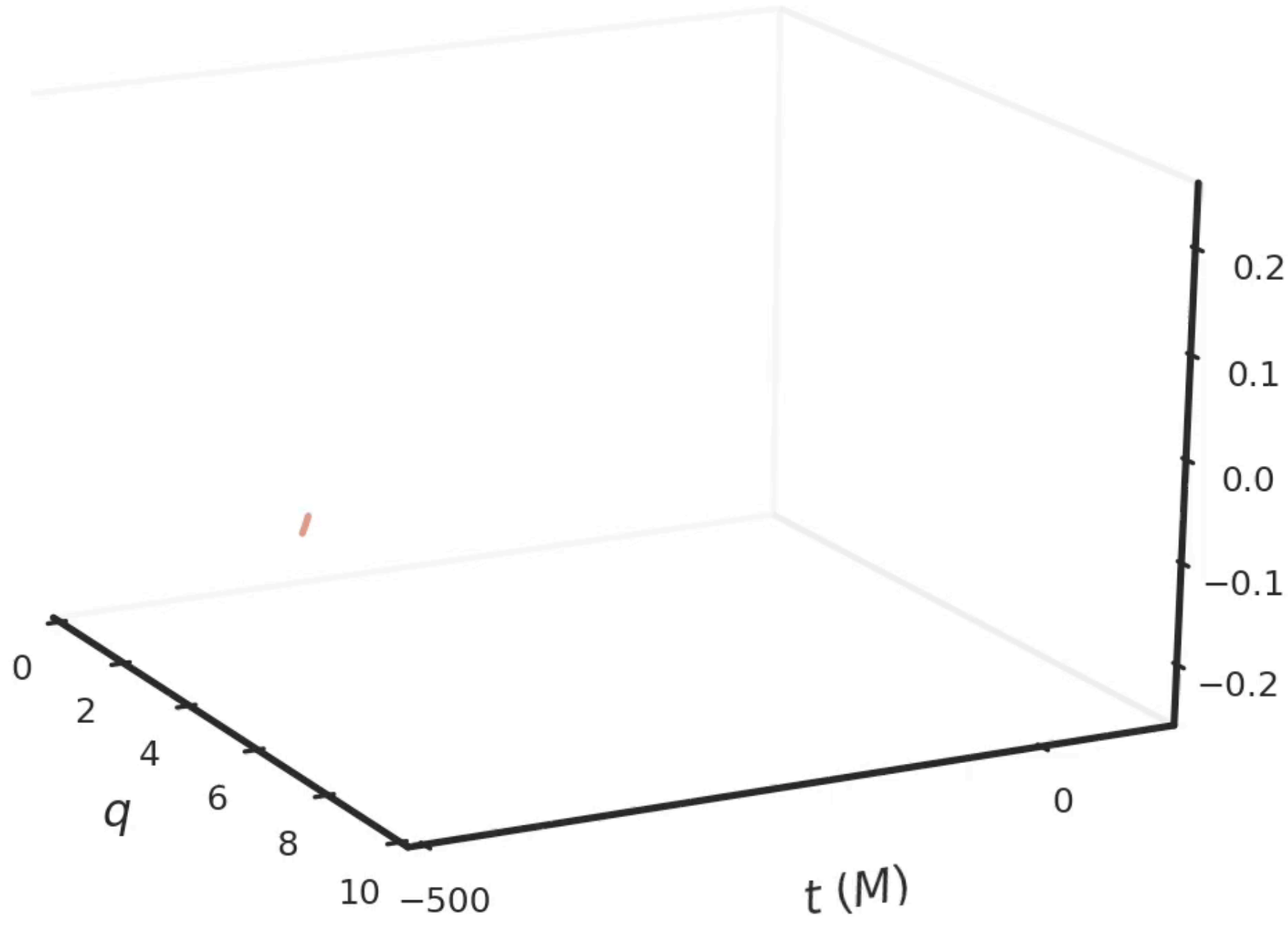
Credit: LIGO/Caltech/MIT/Sonoma State (Aurore Simonnet)

Stages of a binary black hole

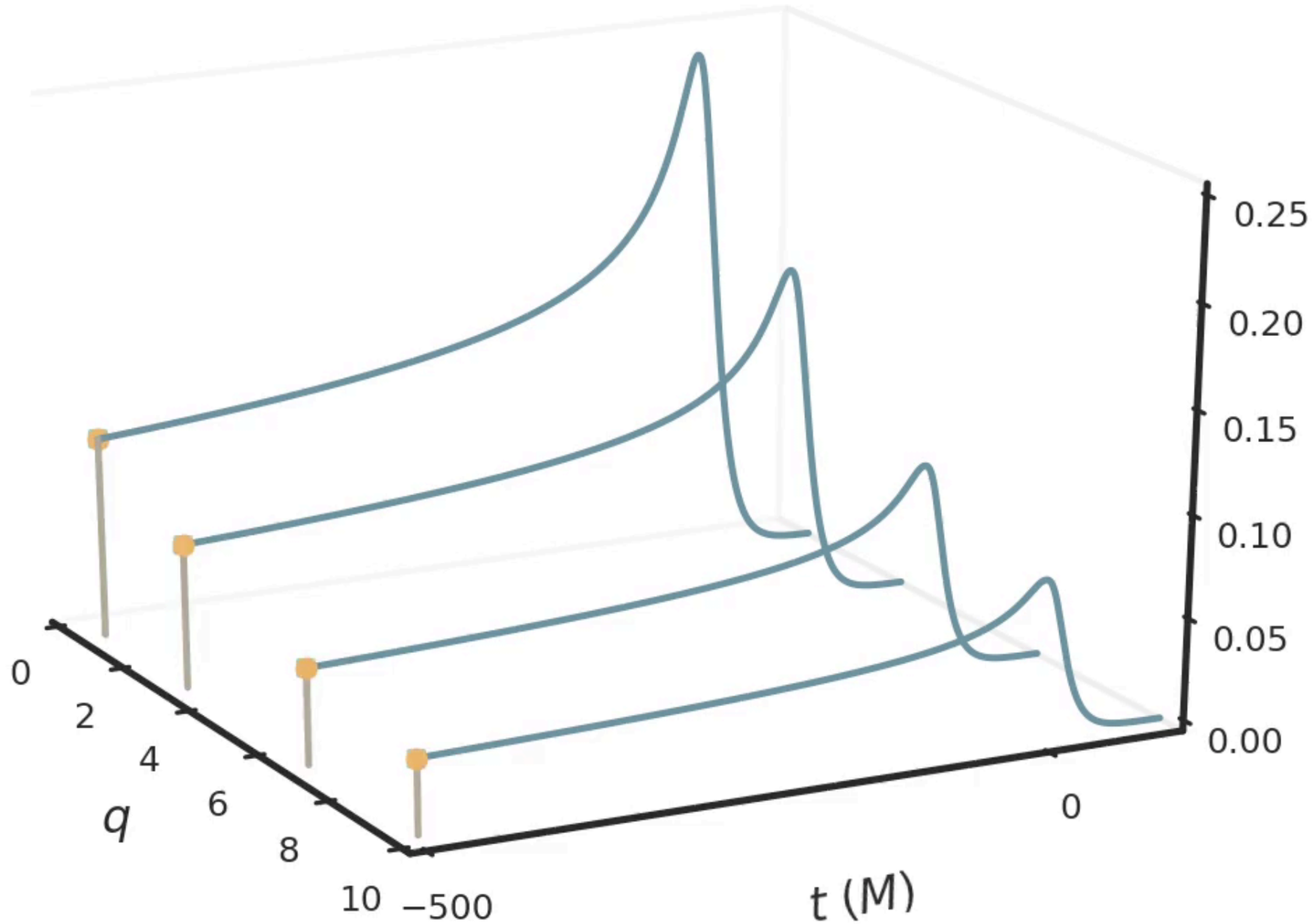


Surrogate modeling 1d example: Reduced basis

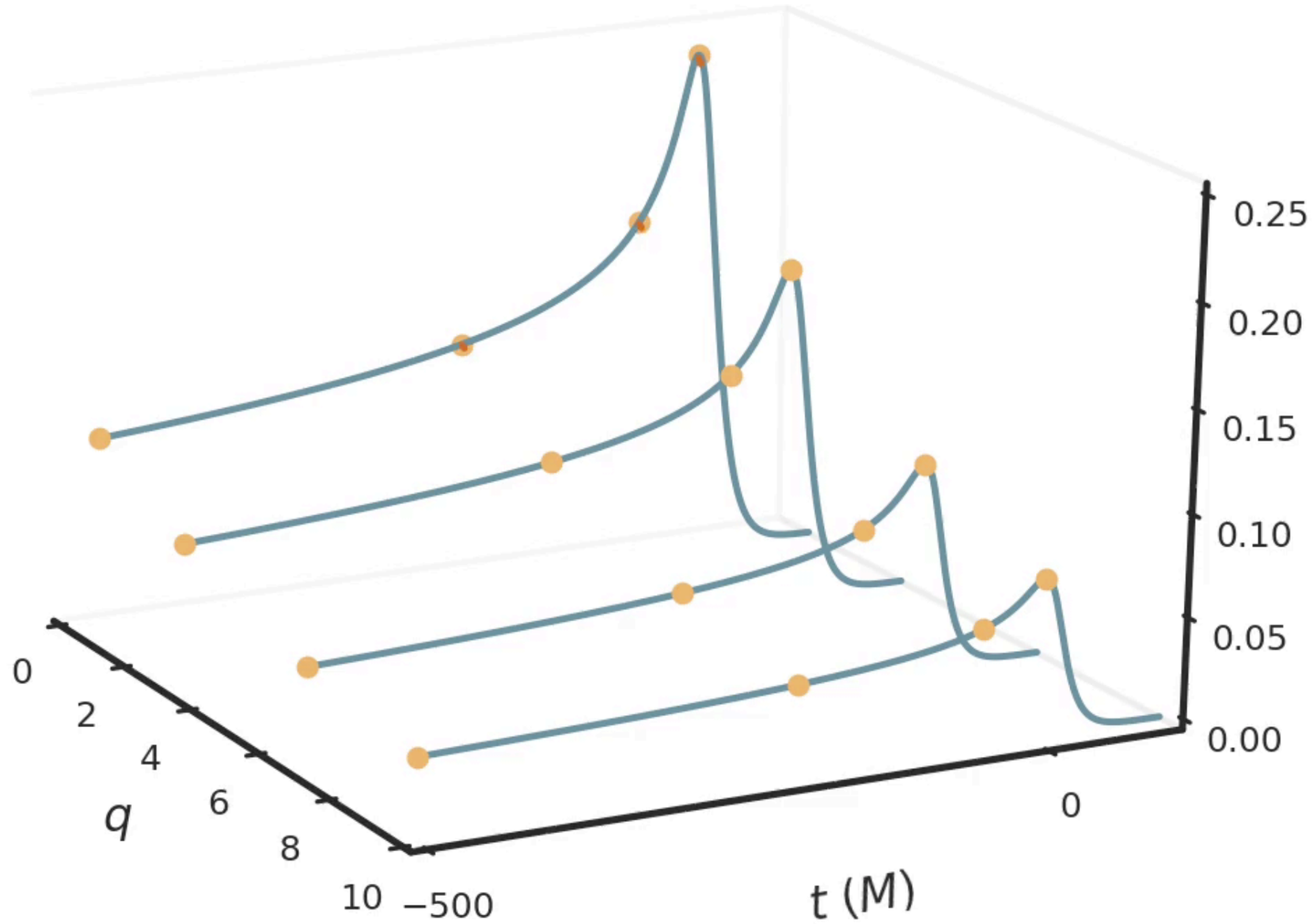


$$h(q,t) = \sum_{i=1}^{n} c_i(q)\ e_i(t)$$

Empirical interpolation

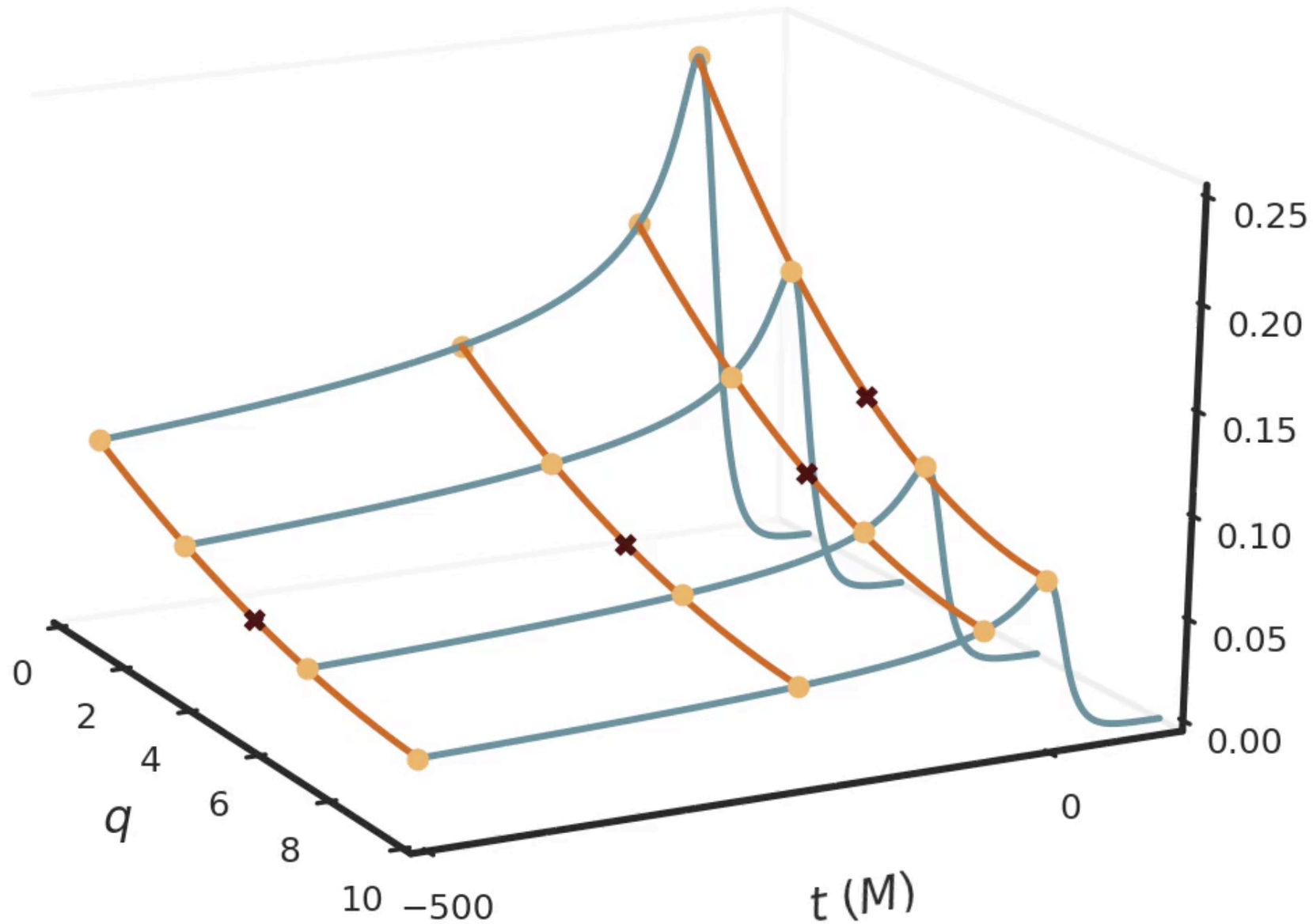


Fit at nodes



$$A(q,t) = \sum_{i=1}^{n} c_i(q)\ e_i(t) \qquad A(q,t_k) \longleftrightarrow c_i(q)$$

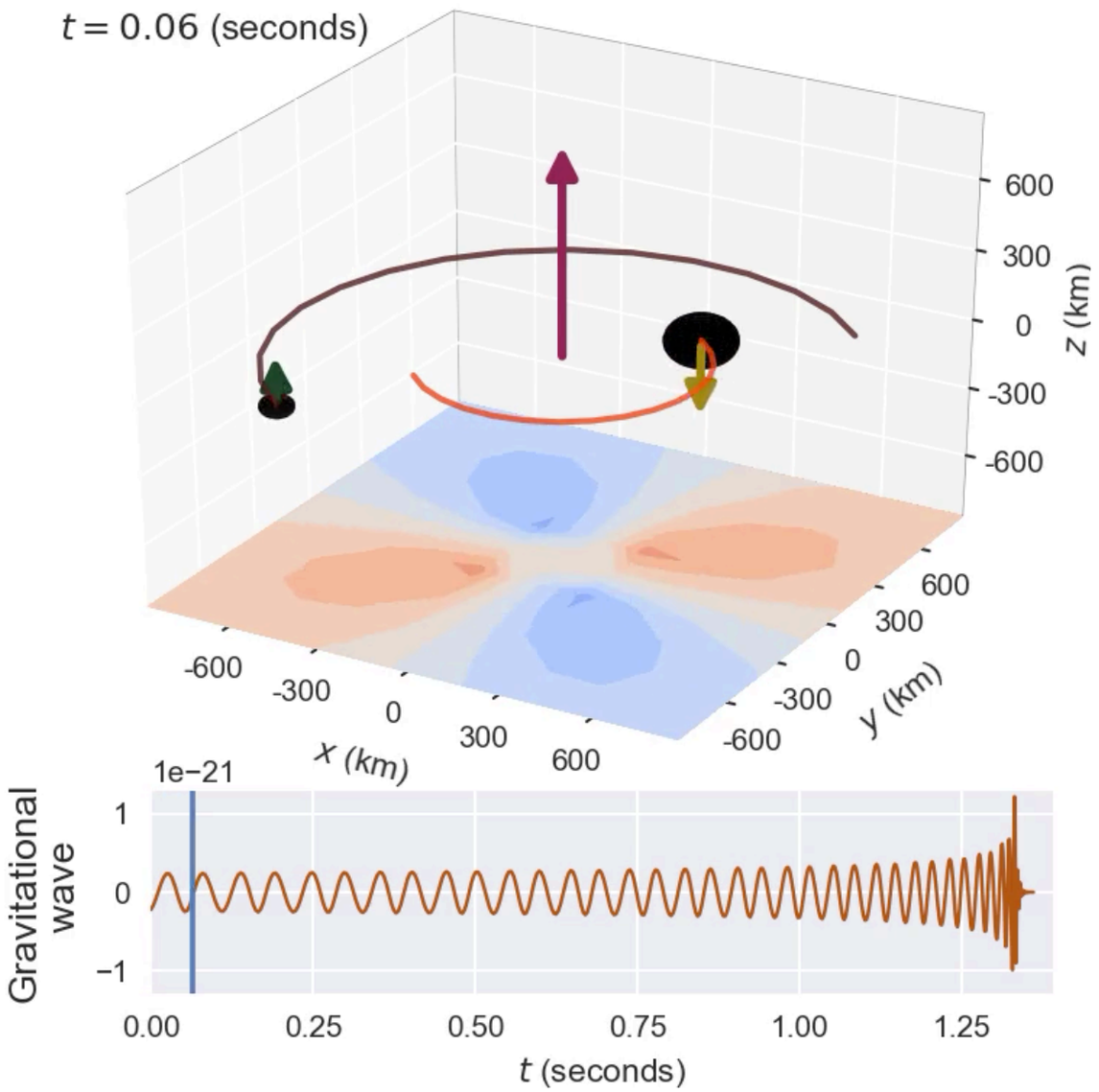
Evaluation



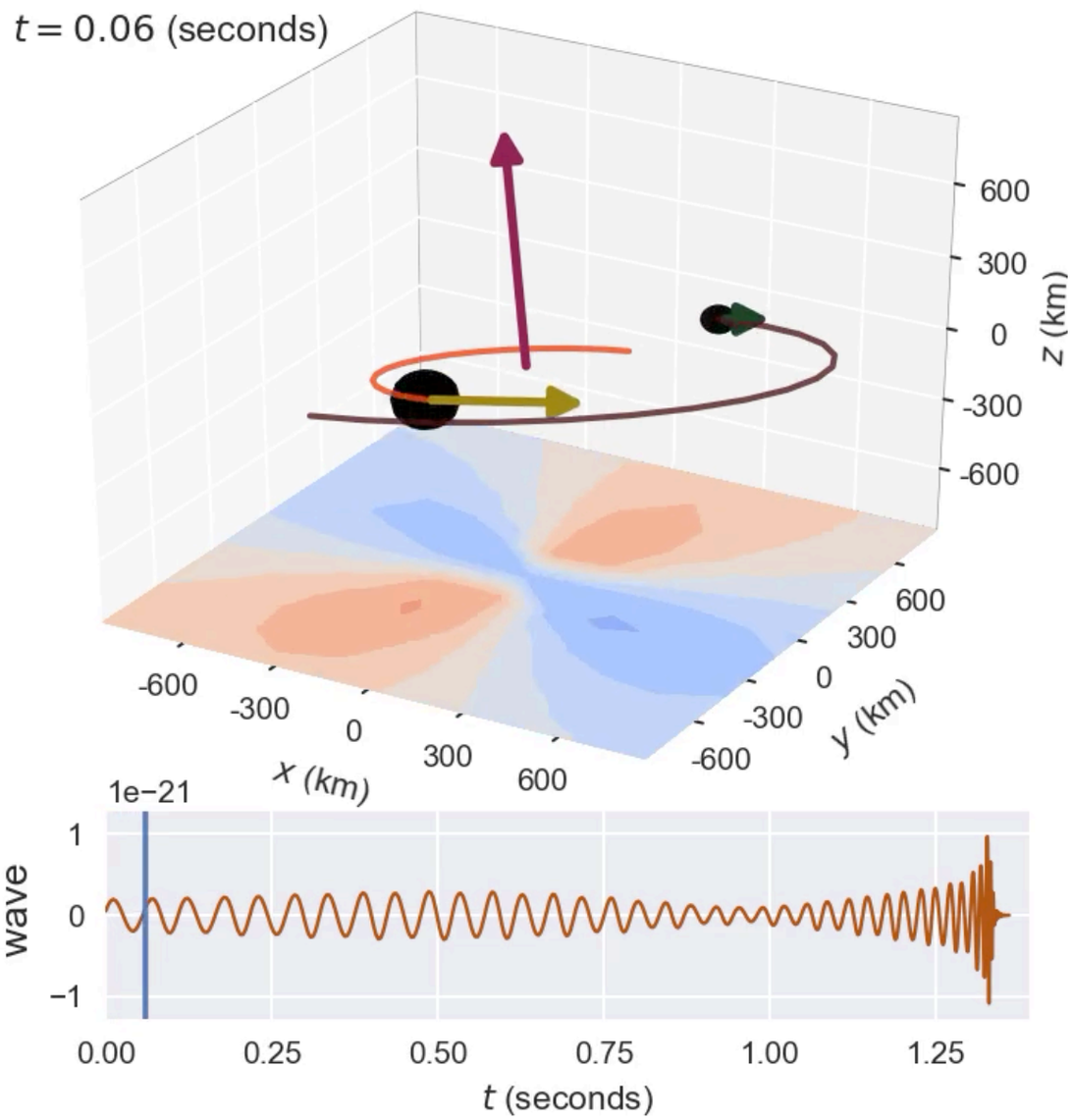
$$A(q, t_k) \quad \Longleftrightarrow \quad c_i(q) \qquad A(q,t) = \sum_{i=1}^{n} c_i(q)\ e_i(t)$$

Precessing binary black holes

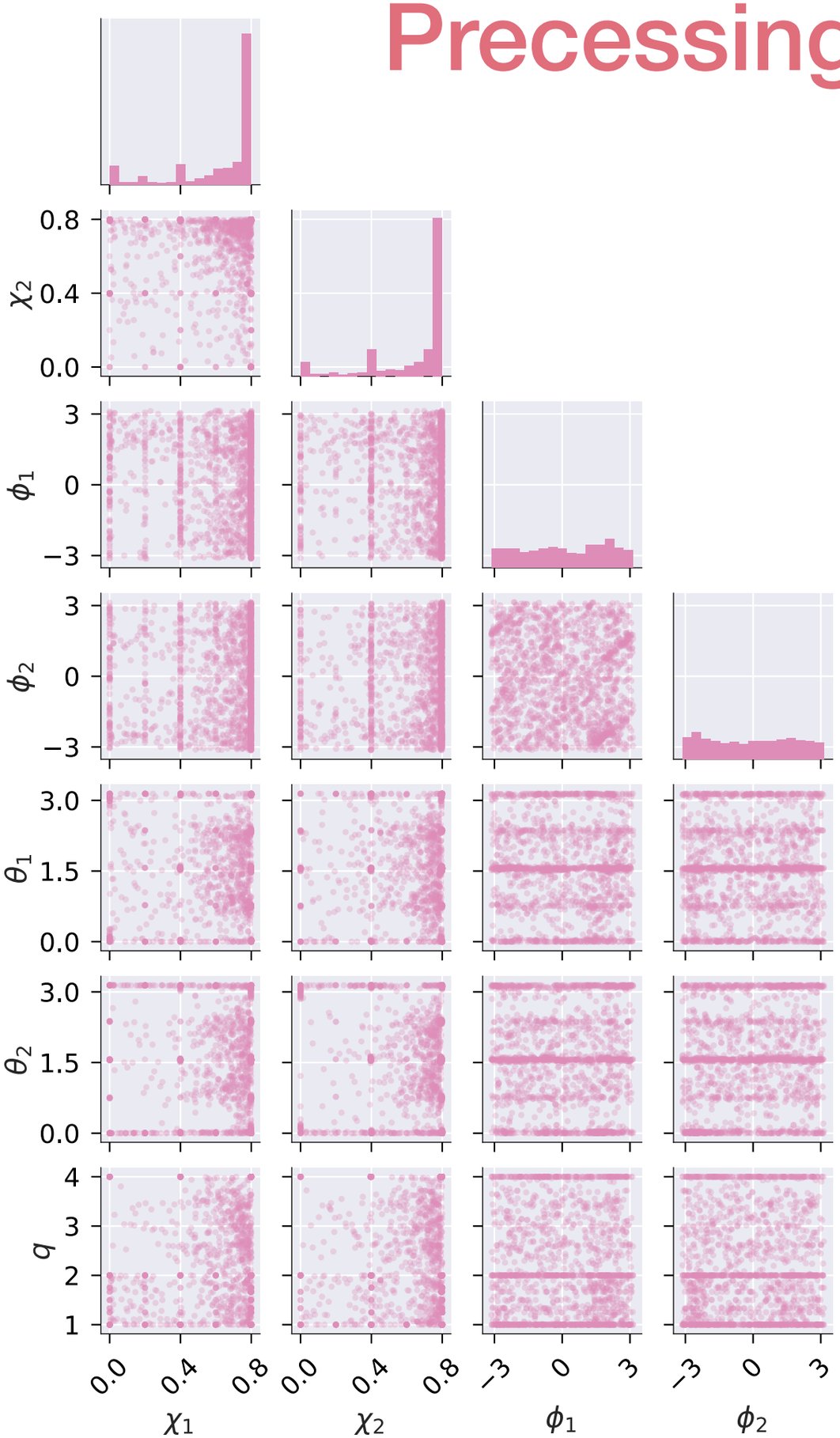
Aligned-spin



Precessing



Precessing NR surrogate model



NRSur7dq2

- Blackman et al. (1705.07089)
- q≤2, χ ≤ 0.8, generically precessing (7d)

NRSur7dq4

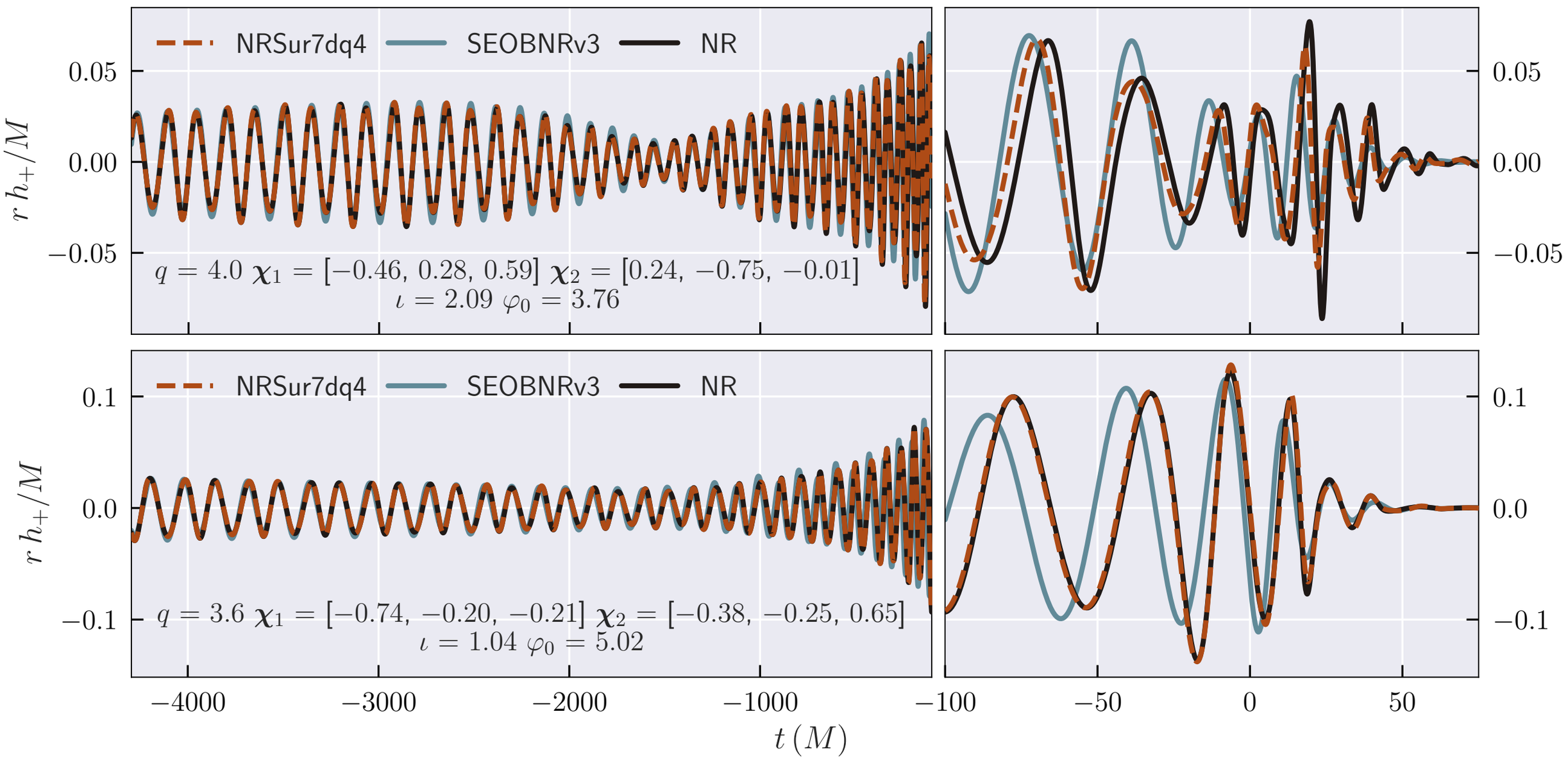
- q≤4 extension of NRSur7dq4
- 1528 waveforms
- Varma et al. (1905.09300)

Features

- Waveform modes ℓ≤4, -ℓ≤m≤ℓ
- Spin and precessing frame dynamics

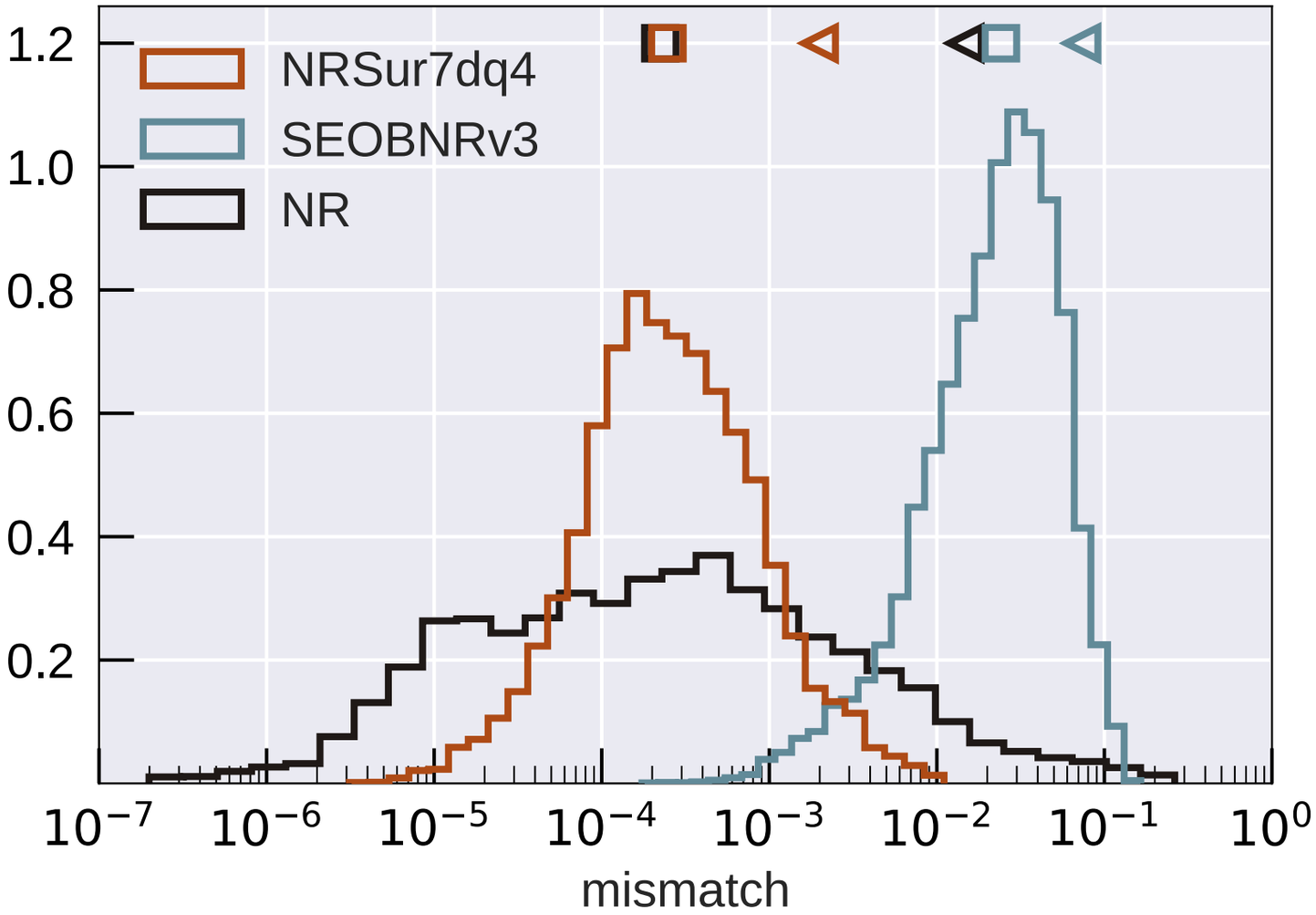
$$h(\theta,\phi,t) = \sum_{\ell,m} {}_{-2}Y_{\ell m}(\theta,\phi)\; h_{\ell m}(t)$$

Worst cases


NRSur7dq4
SEOBNRv3
NR
$r\,h_+/M$
$q = 4.0\ \boldsymbol{\chi}_1 = [-0.46, 0.28, 0.59]\ \boldsymbol{\chi}_2 = [0.24, -0.75, -0.01]$
$\iota = 2.09\ \varphi_0 = 3.76$
$q = 3.6\ \boldsymbol{\chi}_1 = [-0.74, -0.20, -0.21]\ \boldsymbol{\chi}_2 = [-0.38, -0.25, 0.65]$
$\iota = 1.04\ \varphi_0 = 5.02$
$t\,(M)$

Results

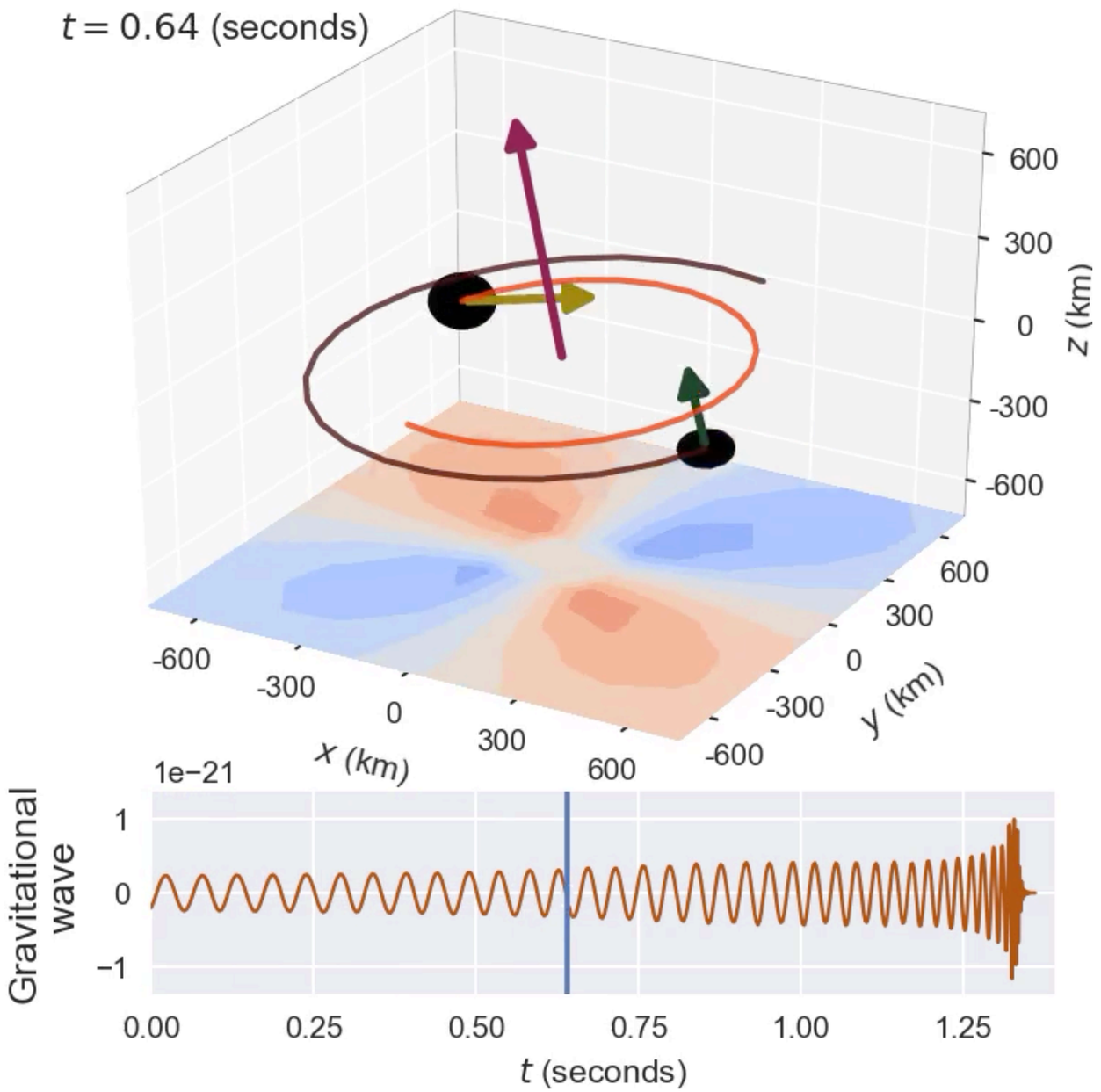
Triangle = 95 percentile, square = median



$$\text{Mismatch} = 1 - \frac{\langle h_1, h_2 \rangle}{\sqrt{\langle h_1, h_1 \rangle \langle h_2, h_2 \rangle}}$$

$$\langle h_1, h_2 \rangle = 4\mathcal{R}\left[\int_{f_{min}}^{f_{max}} \frac{\tilde{h}_1(f)\tilde{h}_2^*(f)}{S_n(f)}\, df\right]$$

Putting it all together: the super kick



- **Numerical relativity (NR) is expensive!**
- **Surrogate models to the rescue:**

Reproduce NR cheaply without a loss of accuracy!

Final velocity = 0.01c

movies at vijayvarma392.github.io/binaryBHexp