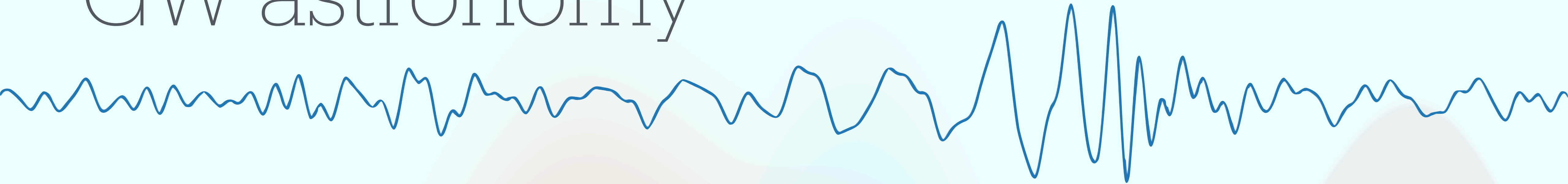


GW astronomy



without waveform approximants

M.B., J. Alvey, D. Gerosa, P. Cole

m.boschini1@campus.unimib.it



GW astronomy



without waveform “approximants”*

M.B., J. Alvey, D. Gerosa, P. Cole

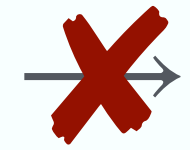
* to be explained

m.boschini1@campus.unimib.it



(*) Waveform approximants

$$R_{\mu\nu} - \frac{1}{2}g_{\mu\nu}R = 8\pi T_{\mu\nu}$$

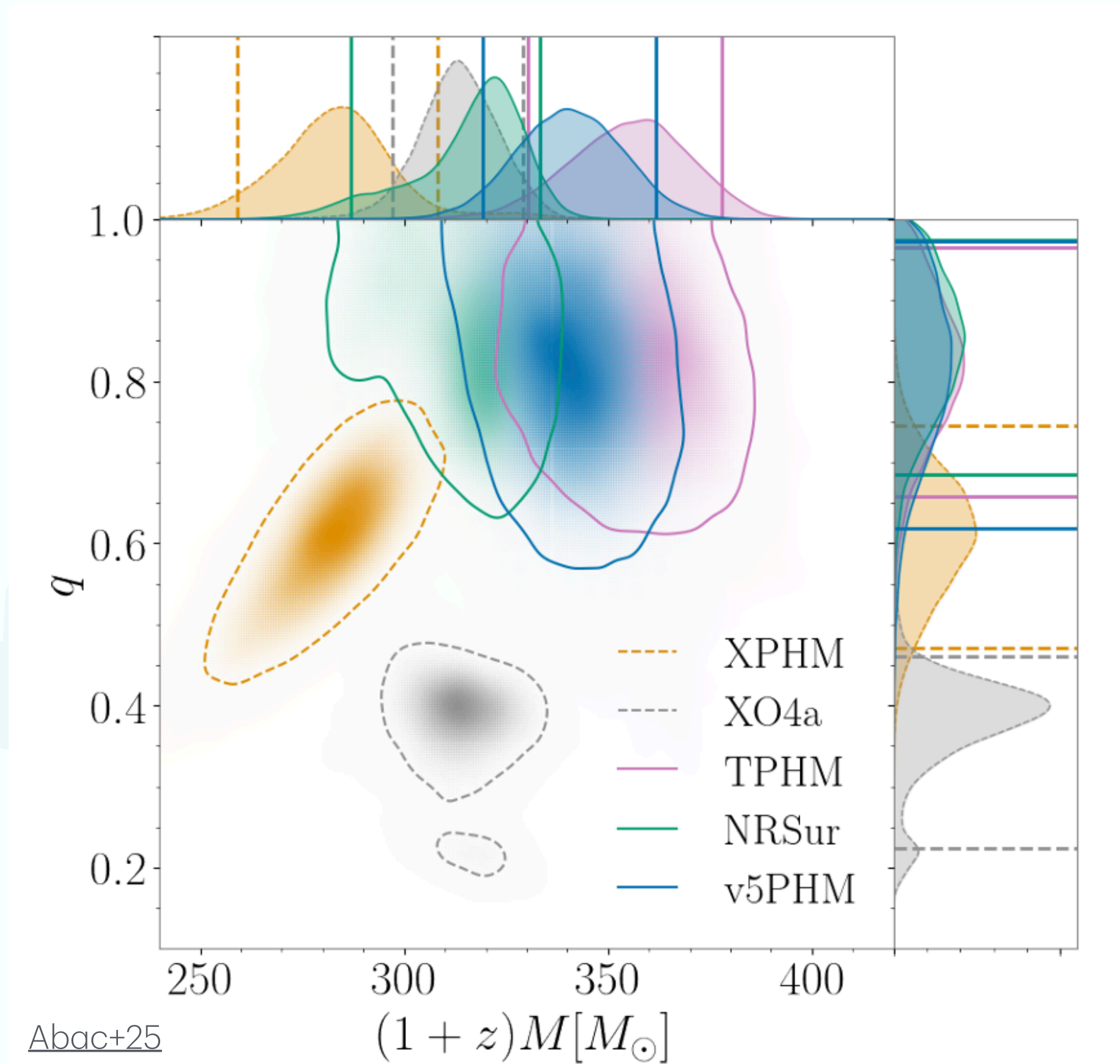


Approximants of approximants

$$R_{\mu\nu} - \frac{1}{2}g_{\mu\nu}R = 8\pi T_{\mu\nu}$$



Waveform systematics



How to deal with wf systematics: [Mezzasoma+25](#), [Pompili+24](#), [Hoy+24](#), [Khan+24](#), ...

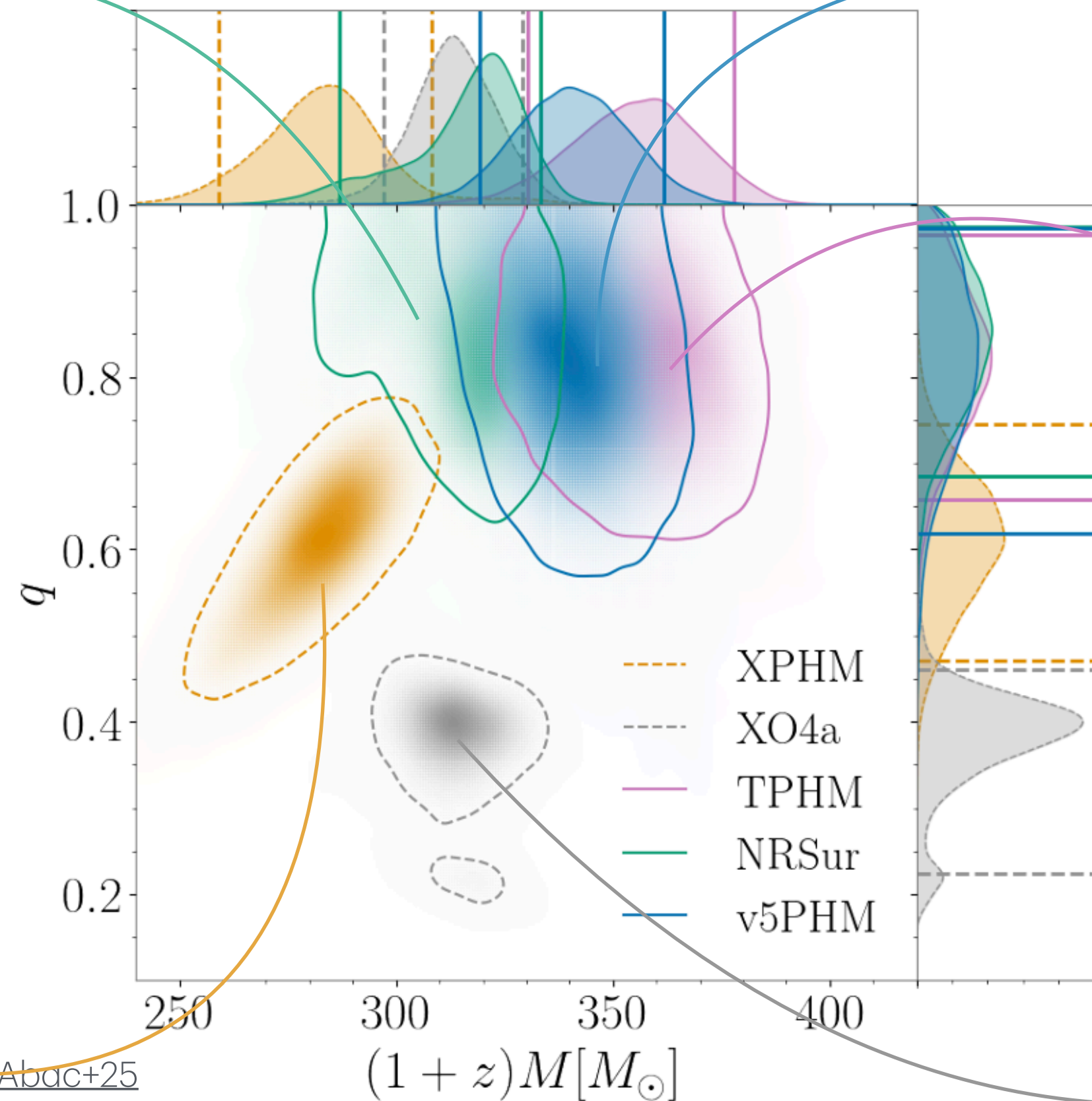
Waveform systematics

NRSur

- Built on NR
- Extrapolation $q < 0.25$, $\chi > 0.8$
- Mode asymmetry and $l \leq 4$
- Time domain

XPHM

- Calibrated to NR for spin-aligned
- Spins evolved numerically
- Waveform twisting for precession
- Higher multipoles
- Frequency domain



v5PHM

- Calibrated to NR for spin-aligned
- Effective-one-body
- Spins evolved numerically
- Higher multipoles
- Time domain

TPHM

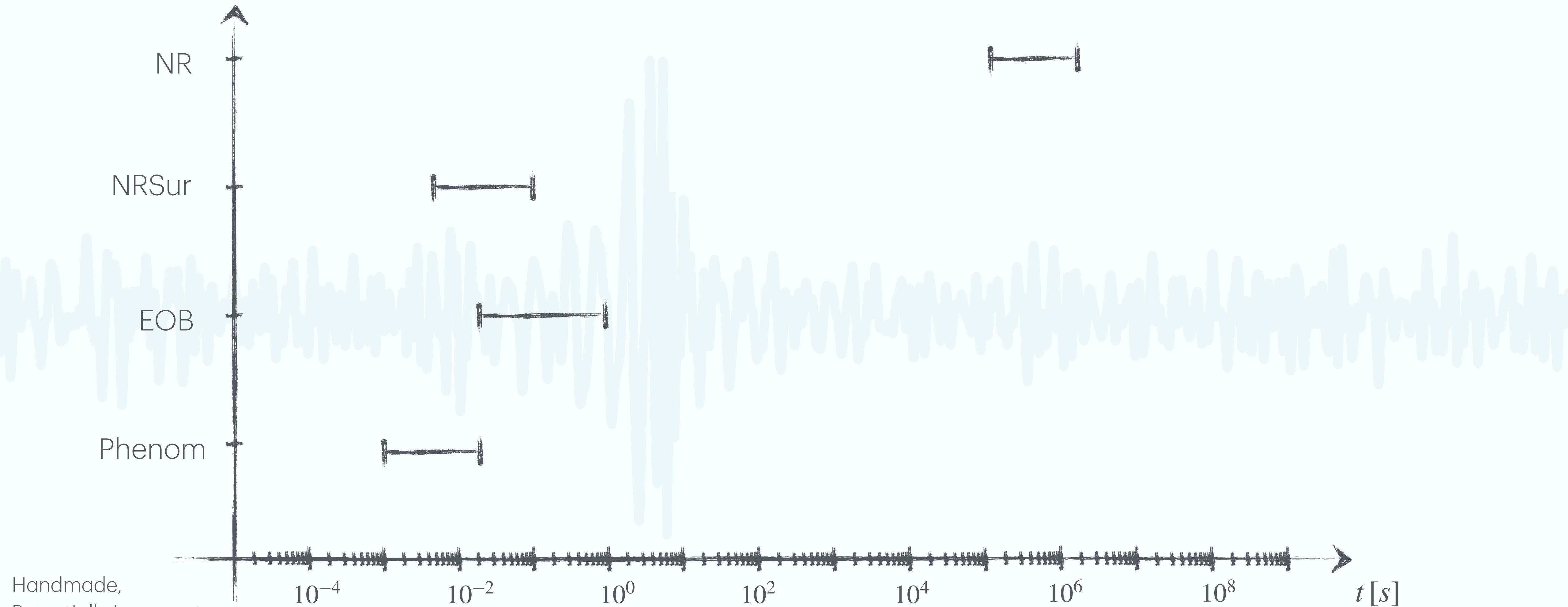
- Calibrated to NR for spin-aligned
- Spins evolved numerically
- Different ringdown prescription
- Time domain

XO4a

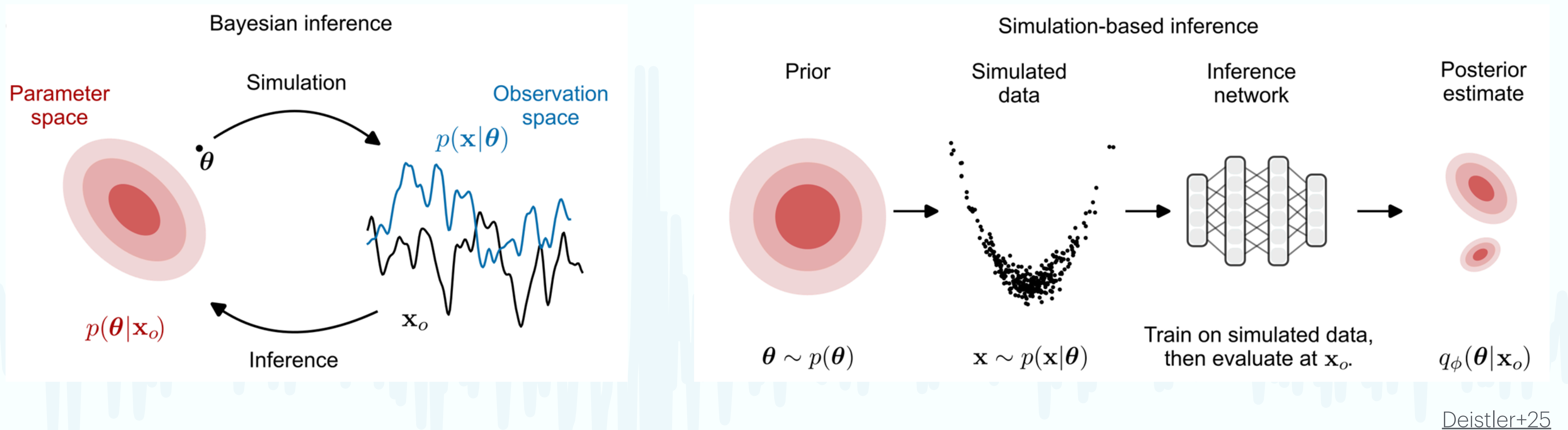
- Closed-form orbit averaged inspiral
- Calibrated to single spin simulation
- Quadrupole mode asymmetry
- Frequency domain

How to deal with wf systematics: [Mezzasoma+25](#), [Pompili+24](#), [Hoy+24](#), [Khan+24](#), ...

PE with NR?

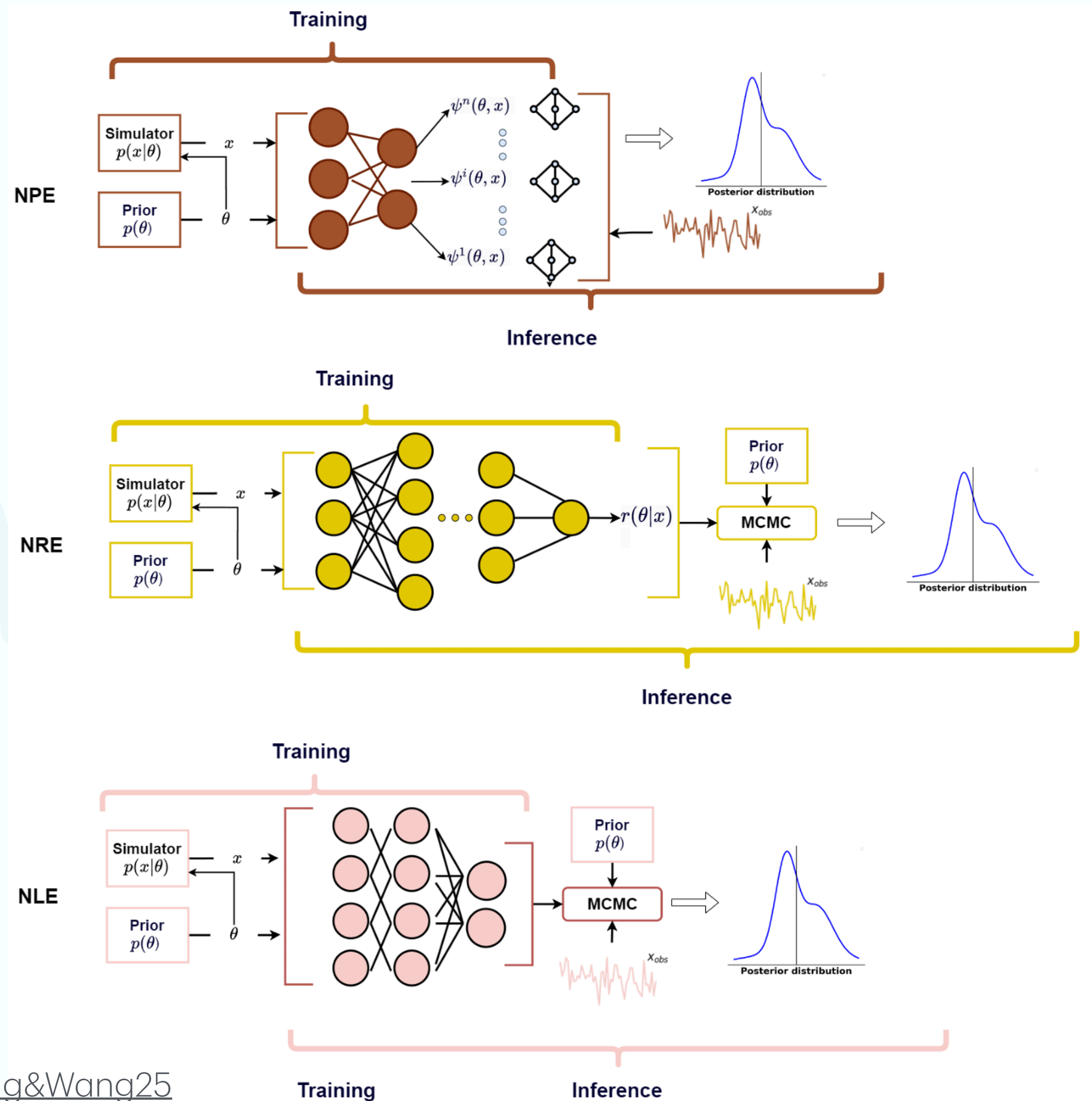


SBI comes in...



Applications: [Dax+21](#), [Dax+23](#), [Wildberger+23](#), [Chatterjee&Wen23](#), [Gupte+24](#), [De Santi+24](#), [Pacilio+24](#), [Dax+25](#), [Anselmo+25](#),...

SBI comes in...



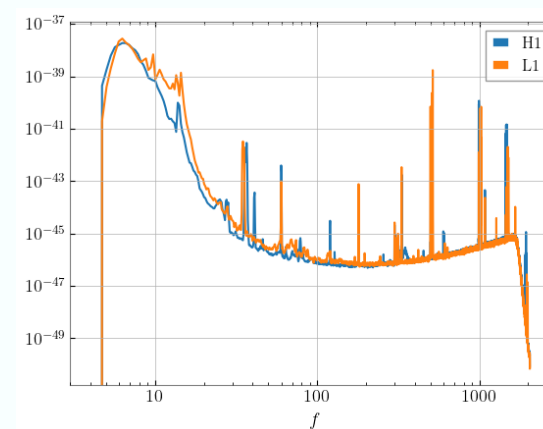
$$q(\theta | x) = q_0(\psi_x^{-1}(\theta)) \left| \det \frac{d\psi_x^{-1}}{d\theta} \right|$$

$$q(\theta | x) \sim p(\theta | x)$$

$$L_{NPE} = - \mathbb{E}_{\theta \sim p(\theta)} \mathbb{E}_{x \sim p(x|\theta)} \log q(\theta | x)$$

...with ideas...

Detector PSD

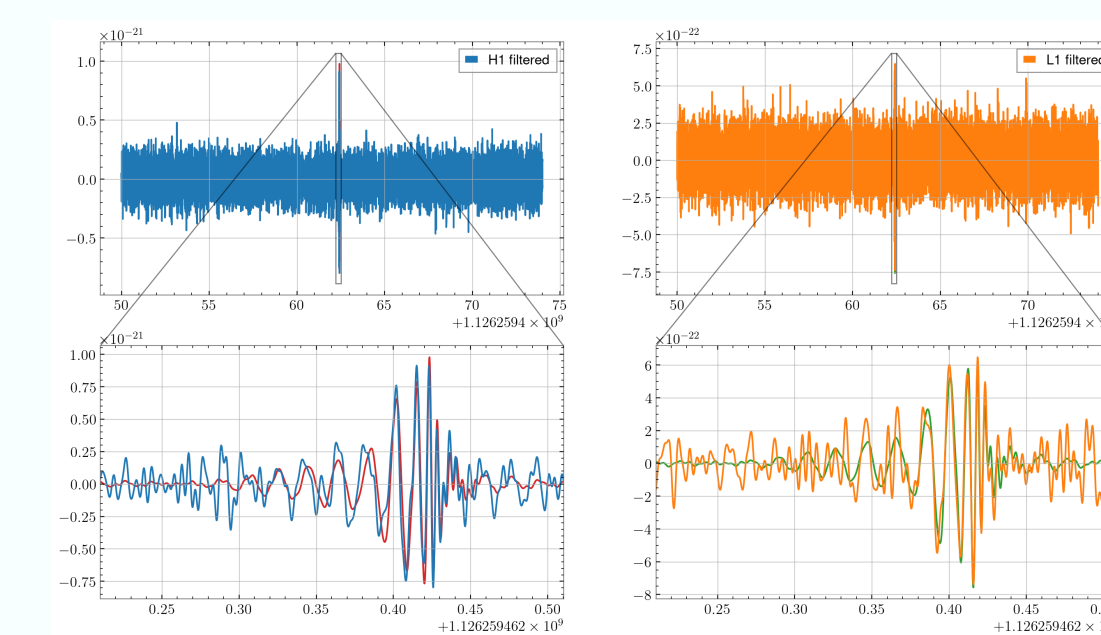


Simulated data



$$\mathbf{x} \sim p(\mathbf{x}|\boldsymbol{\theta})$$

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Posterior estimate



$$q_{\phi}(\boldsymbol{\theta}|\mathbf{x}_o)$$

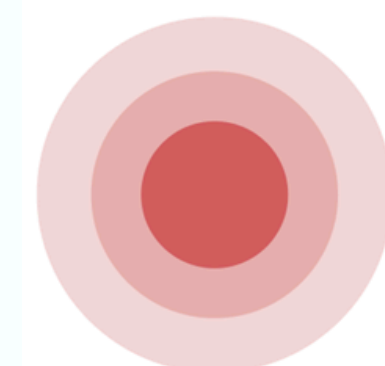
Preprocessing

Simulator

Intrinsic prior

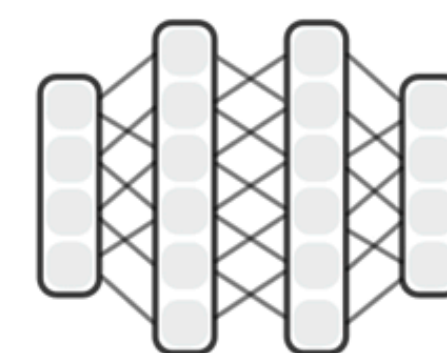
$$q, \chi_1, \chi_2$$

Prior



$$\boldsymbol{\theta} \sim p(\boldsymbol{\theta})$$

Inference network



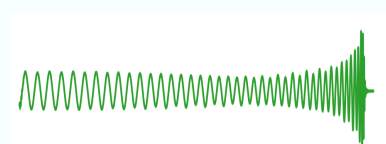
Extrinsic prior

$$M_{\text{tot}}, D_l, \theta, \phi, \text{ra}, \text{dec}, \psi$$

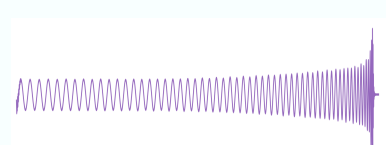
BBH sim 1



BBH sim 2

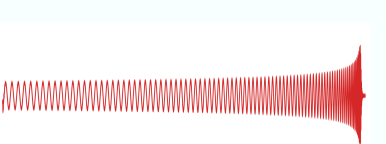


BBH sim 3










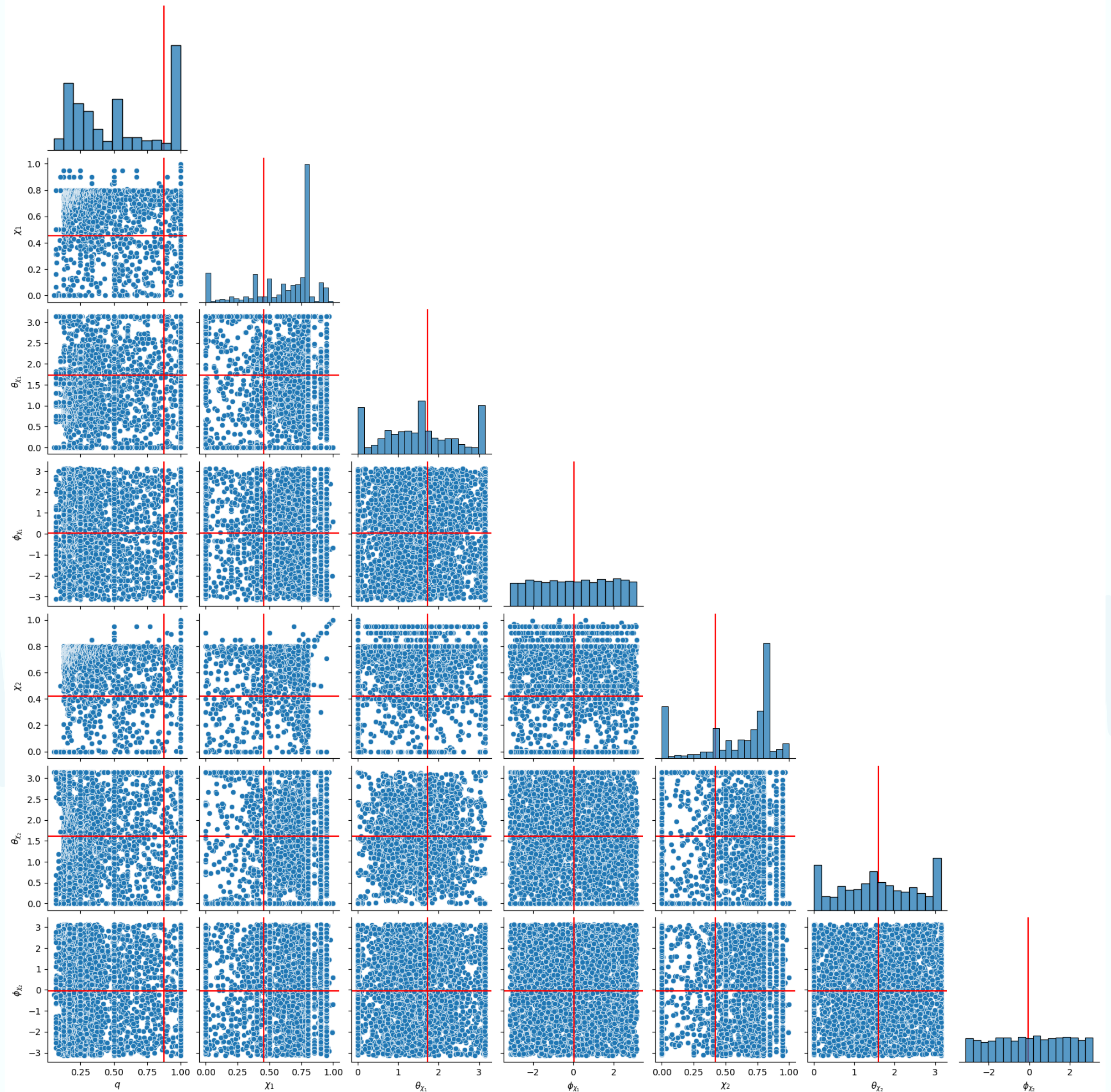
⋮

BBH sim n



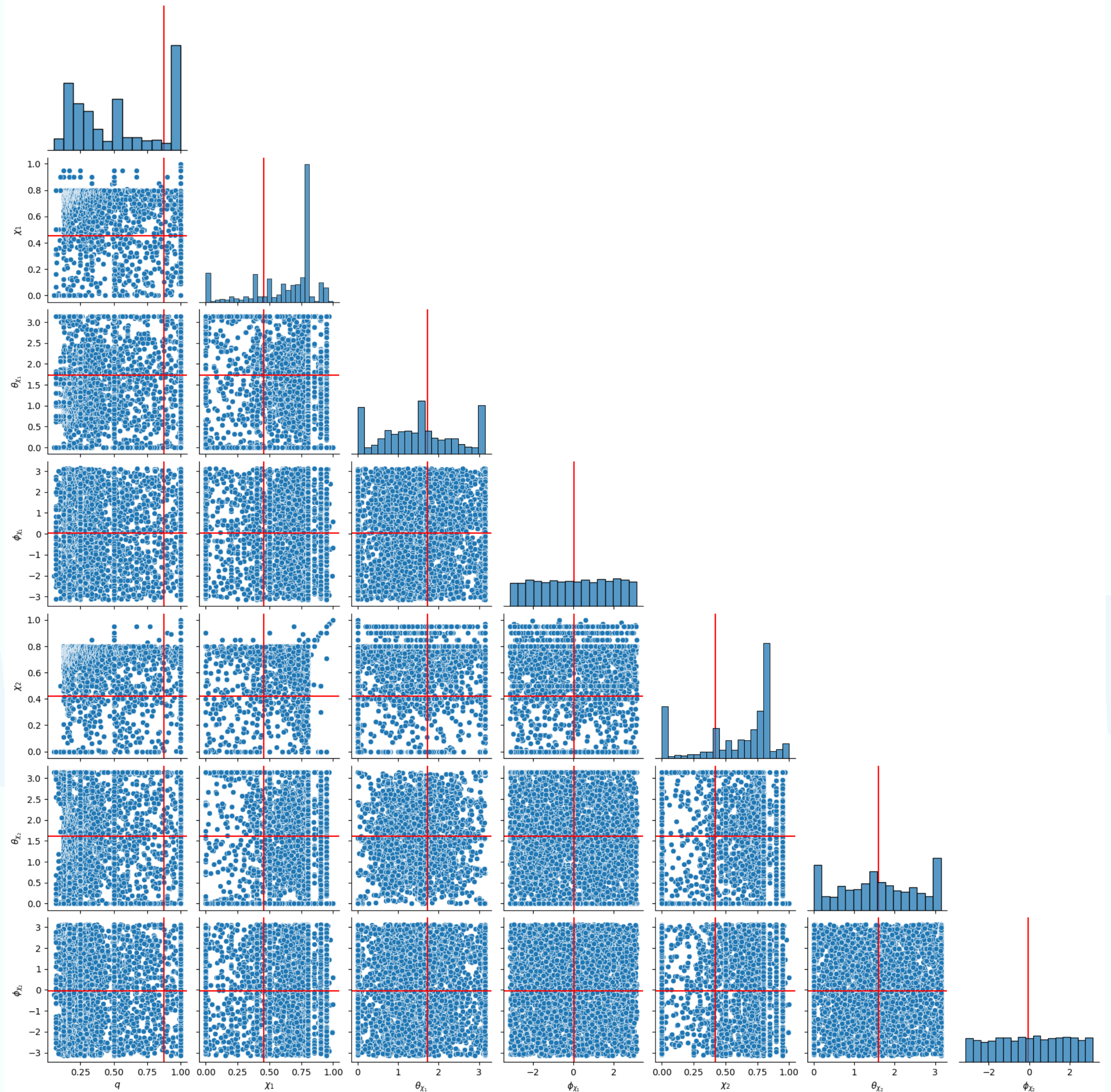
...and challenges

- Simulations are already done   
- “Only” ~4k simulations to train the network  
- Discrete coverage of intrinsic parameter space 
- Sample extrinsic parameters for free 
- Find the optimal architecture ?



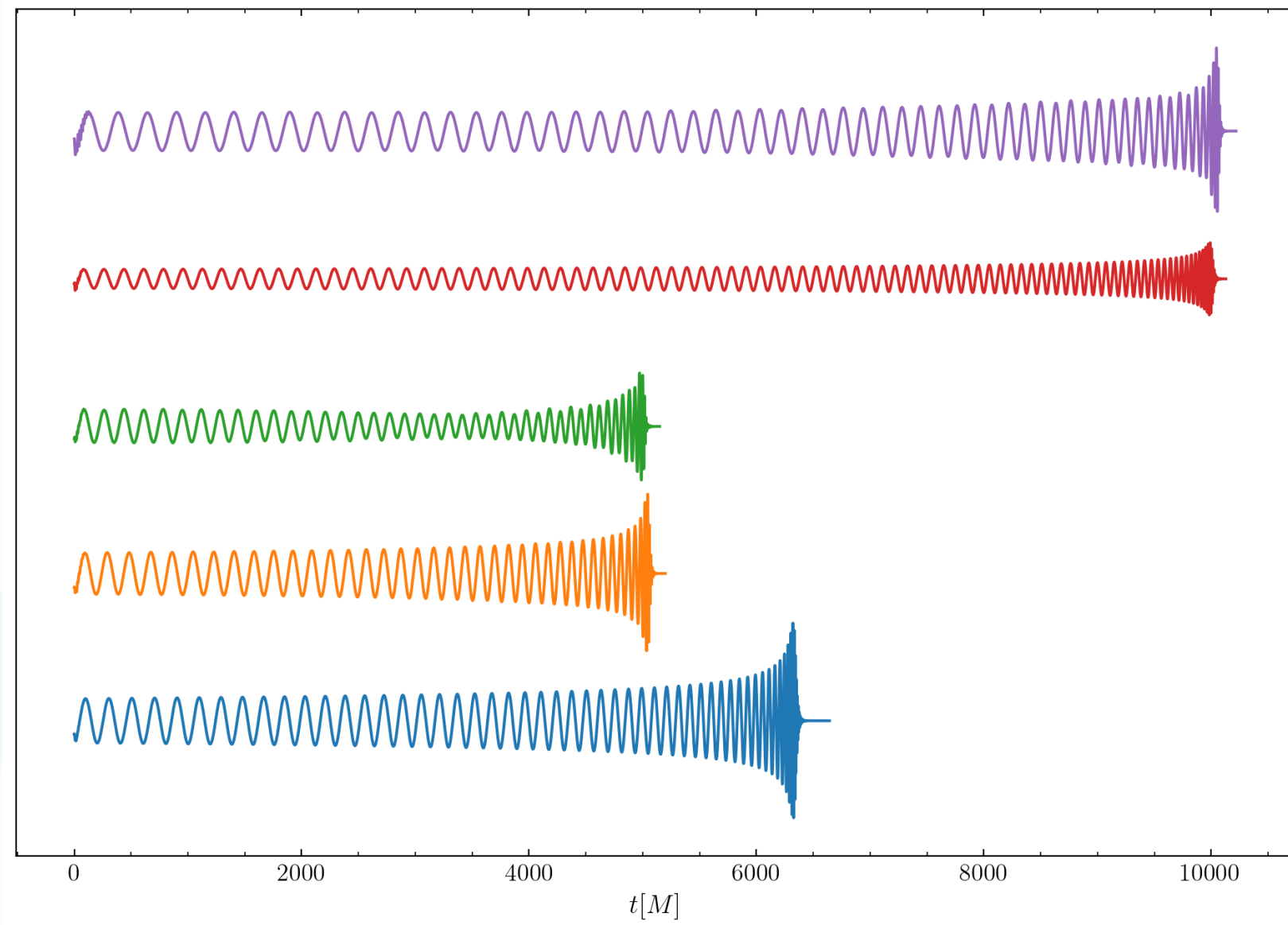
Waveforms database

- 3776 IMR simulations from SXS catalog
[Scheel+25](#), [Boyle+19](#)
- Quasi-circular BBH with $1250M$ -long inspiral
- Preprocessing & standardization
- Frame rotation & spin evolution



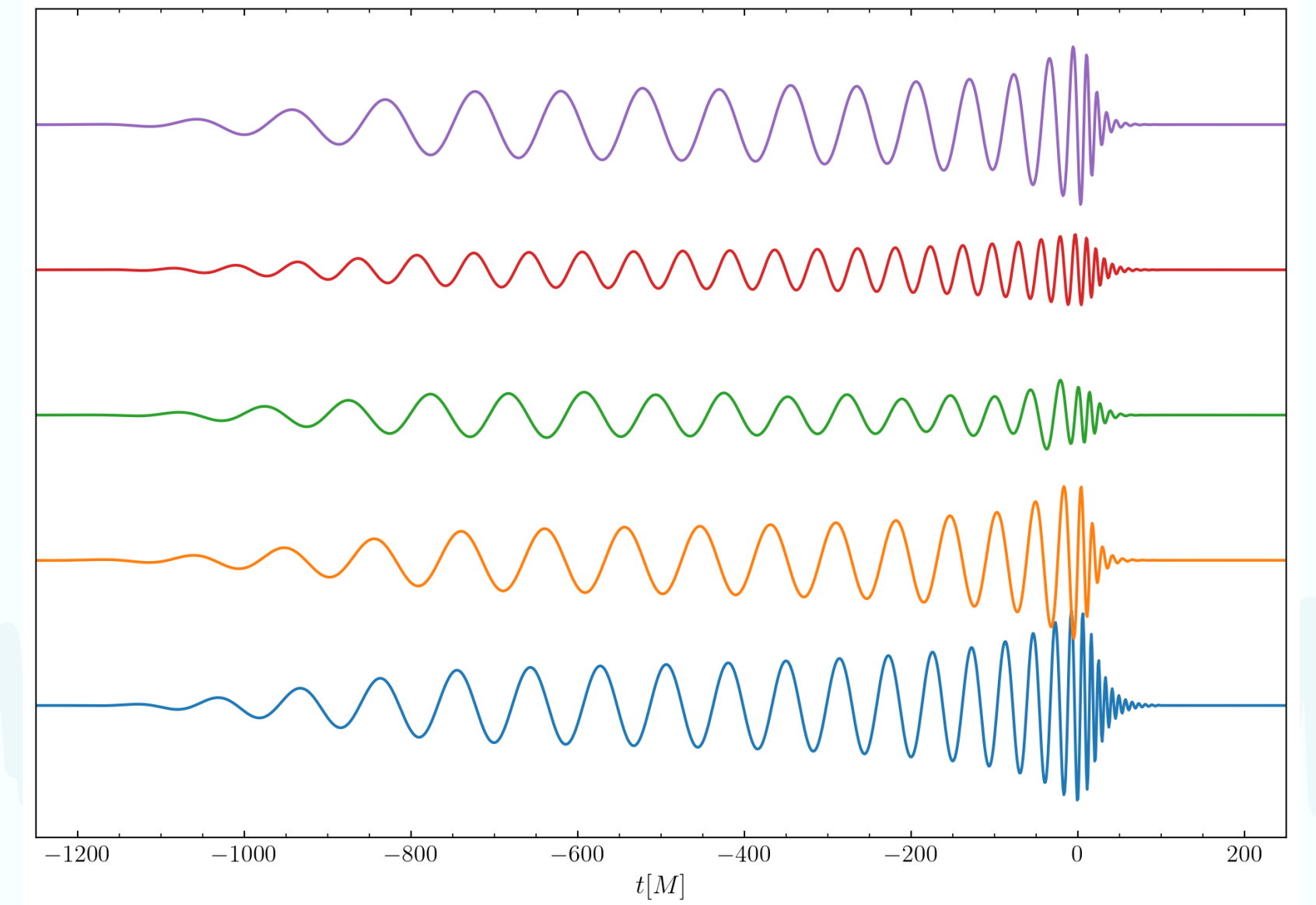
Waveforms database

$$l \leq 4$$



Preprocessing

- Interpolation
- Tapering
- Padding
- (Zeroing memory)

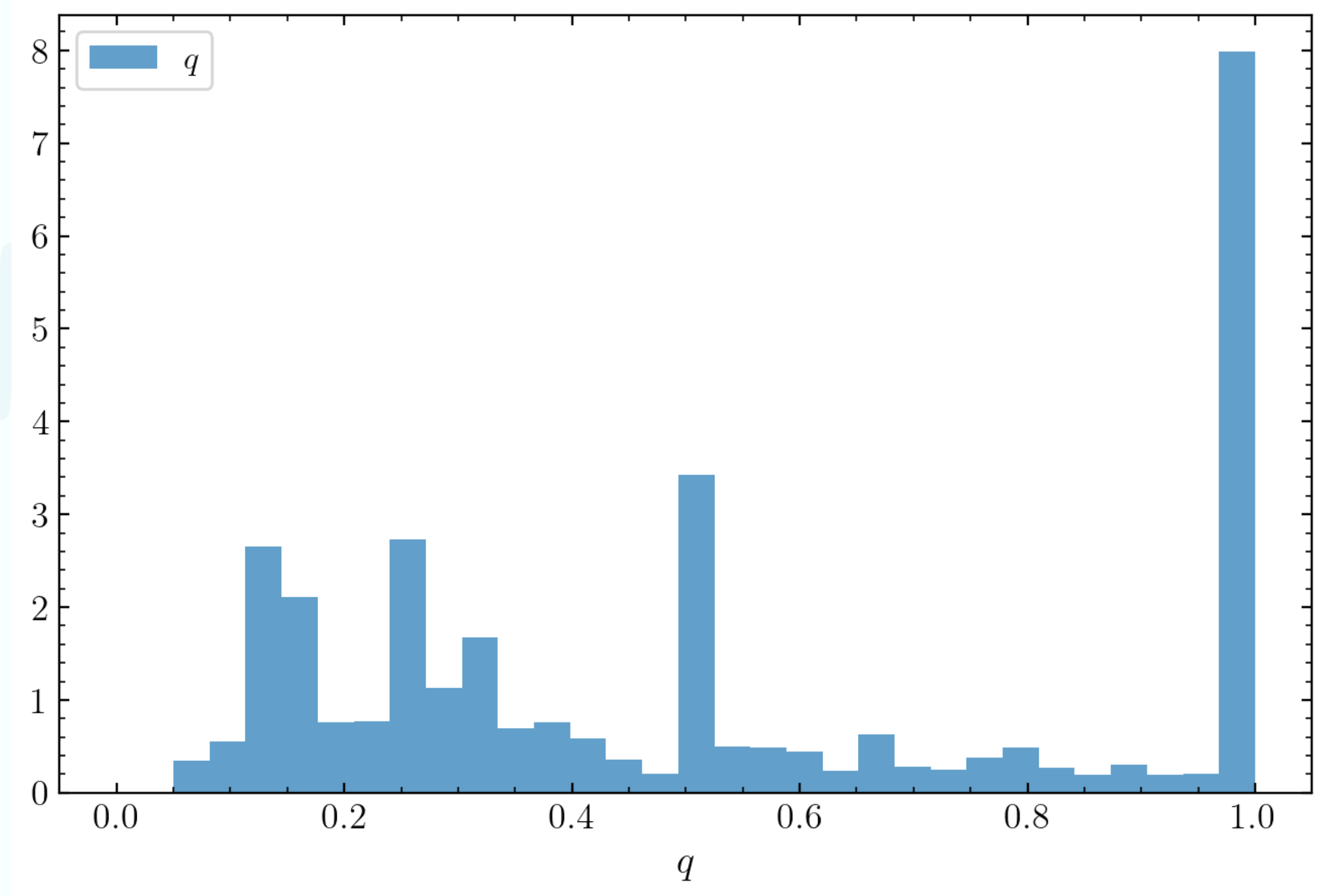


+

Frame rotation to account for spin definition

Intrinsic prior

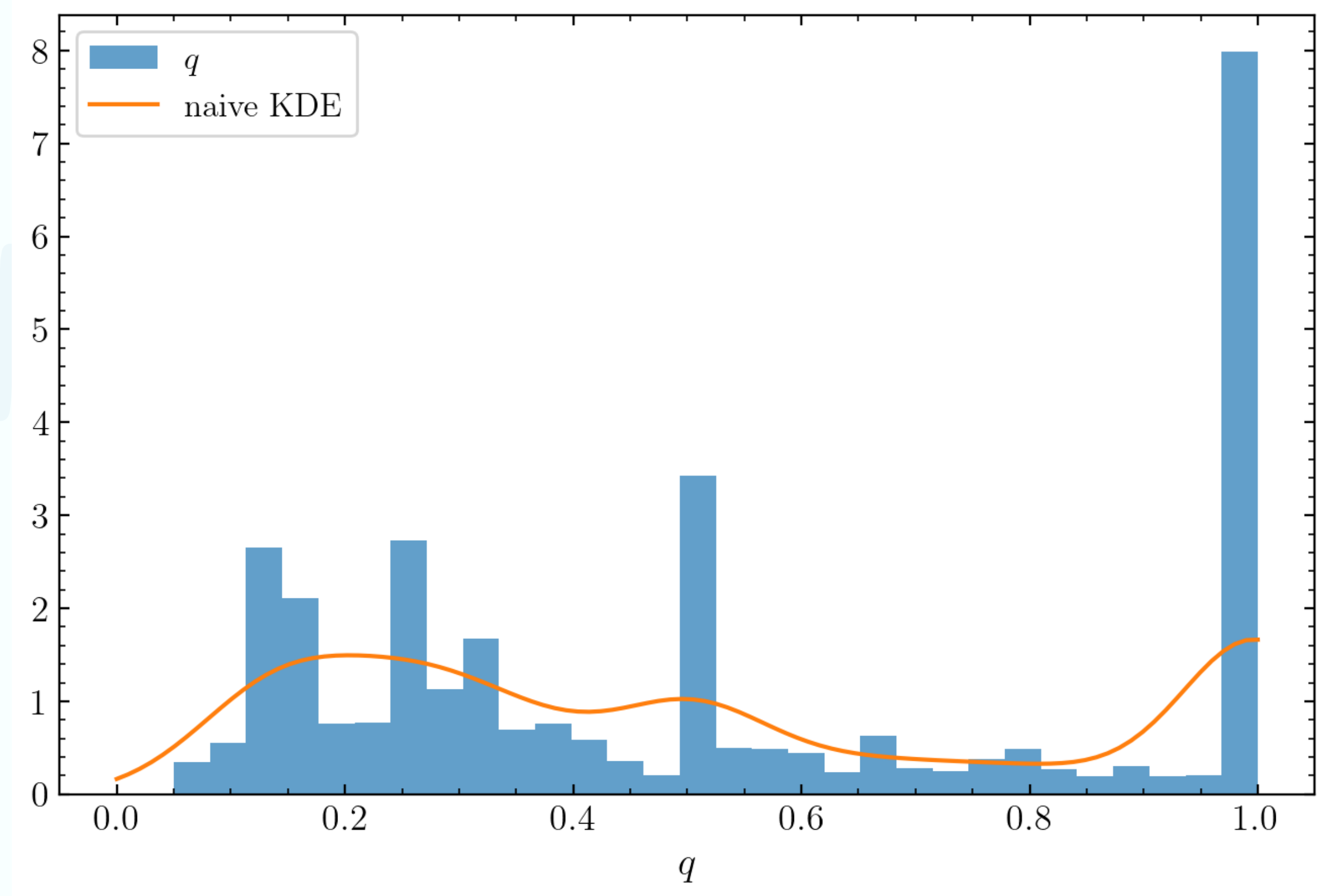
• $m_1, m_2 \sim U[10, 80] M_\odot \longrightarrow q, M_{tot}$



Intrinsic prior

• $m_1, m_2 \sim U[10, 80] M_\odot \longrightarrow q, M_{tot}$ **XX**

• KDE(θ^{intr})



Intrinsic prior

• $m_1, m_2 \sim U[10, 80] M_\odot \longrightarrow q, M_{tot} \quad \times \times$

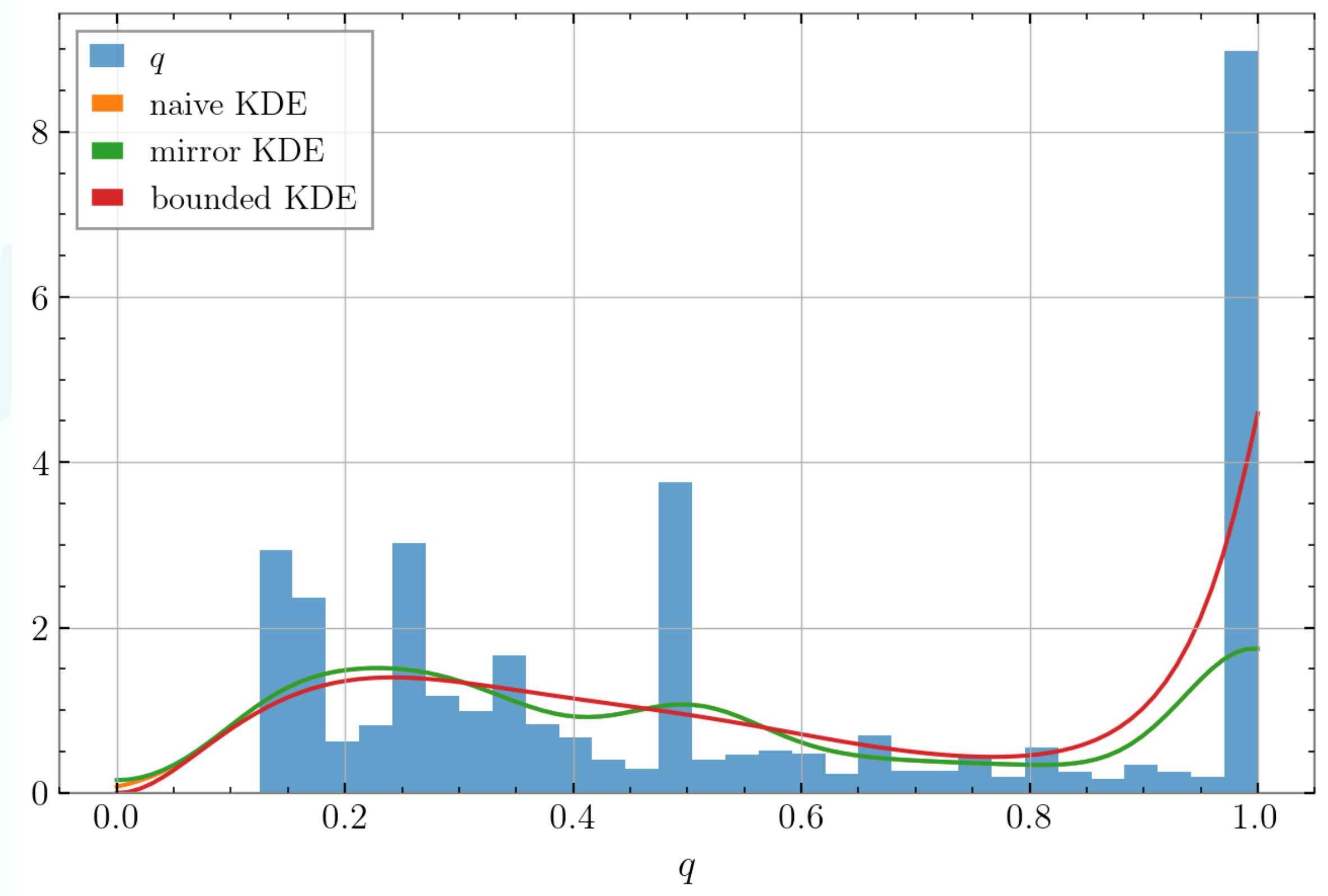
• $\text{KDE}(\theta^{intr}) \quad \times$

• Mirror $\text{KDE}(\theta^{intr}) \quad \checkmark / \triangle!$

• Bounded $\text{KDE}(\theta^{intr}) \quad \checkmark$

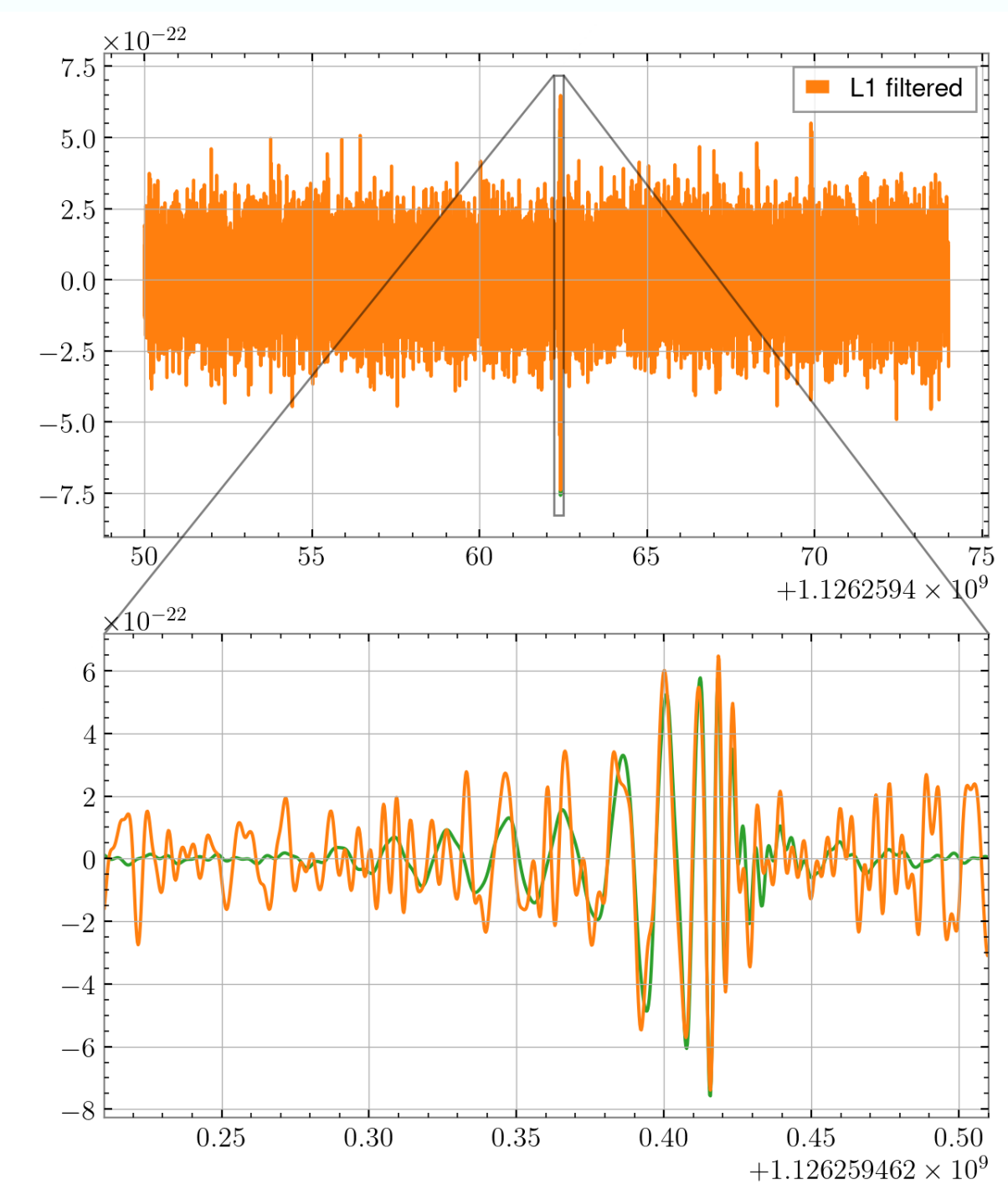
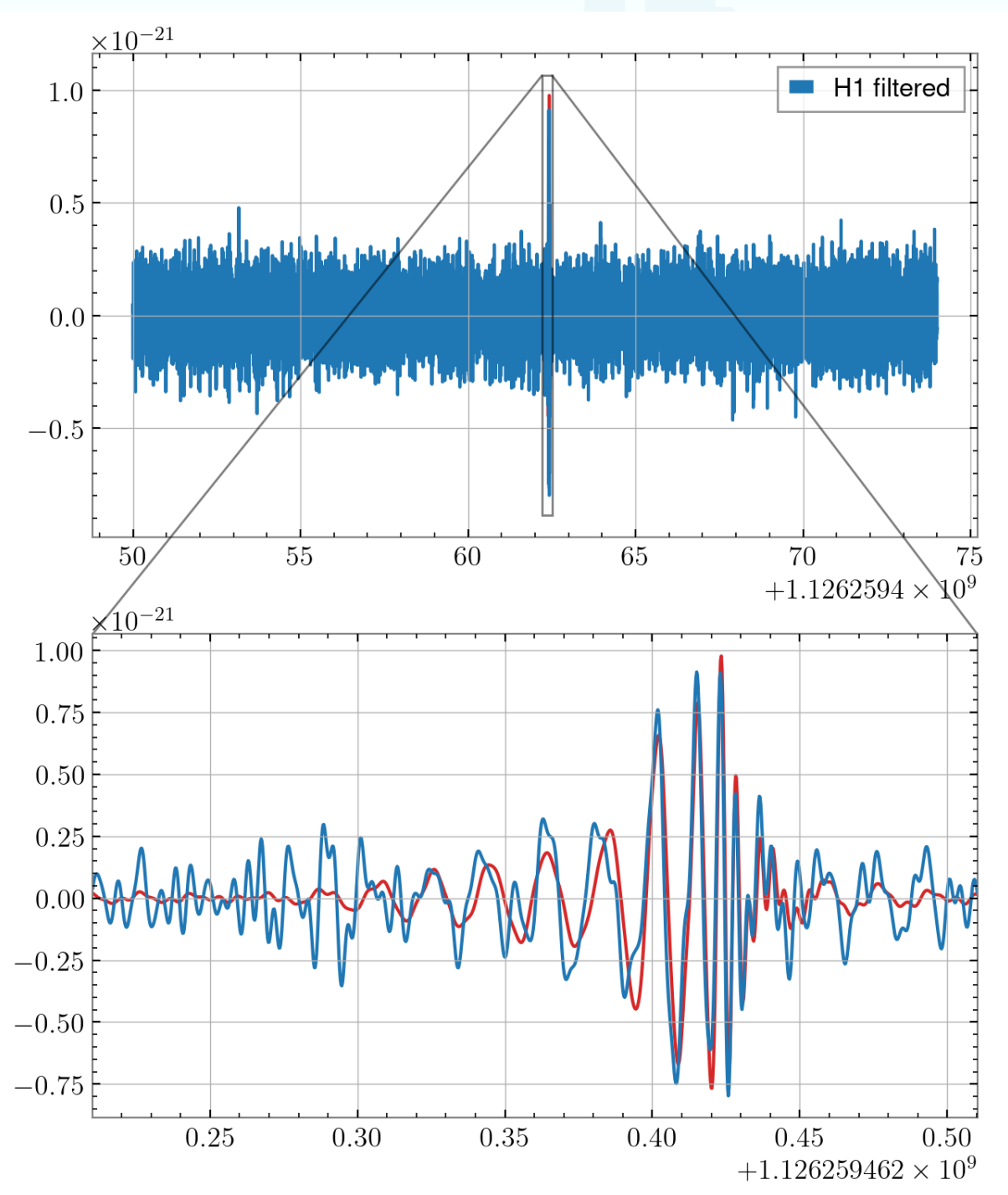
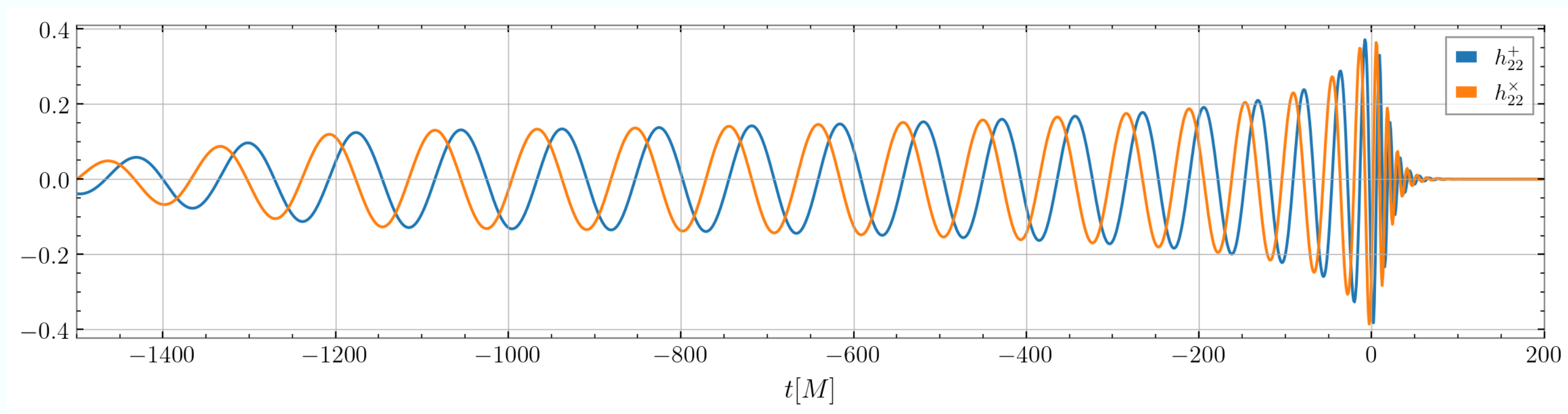
+

uninformative extrinsic priors

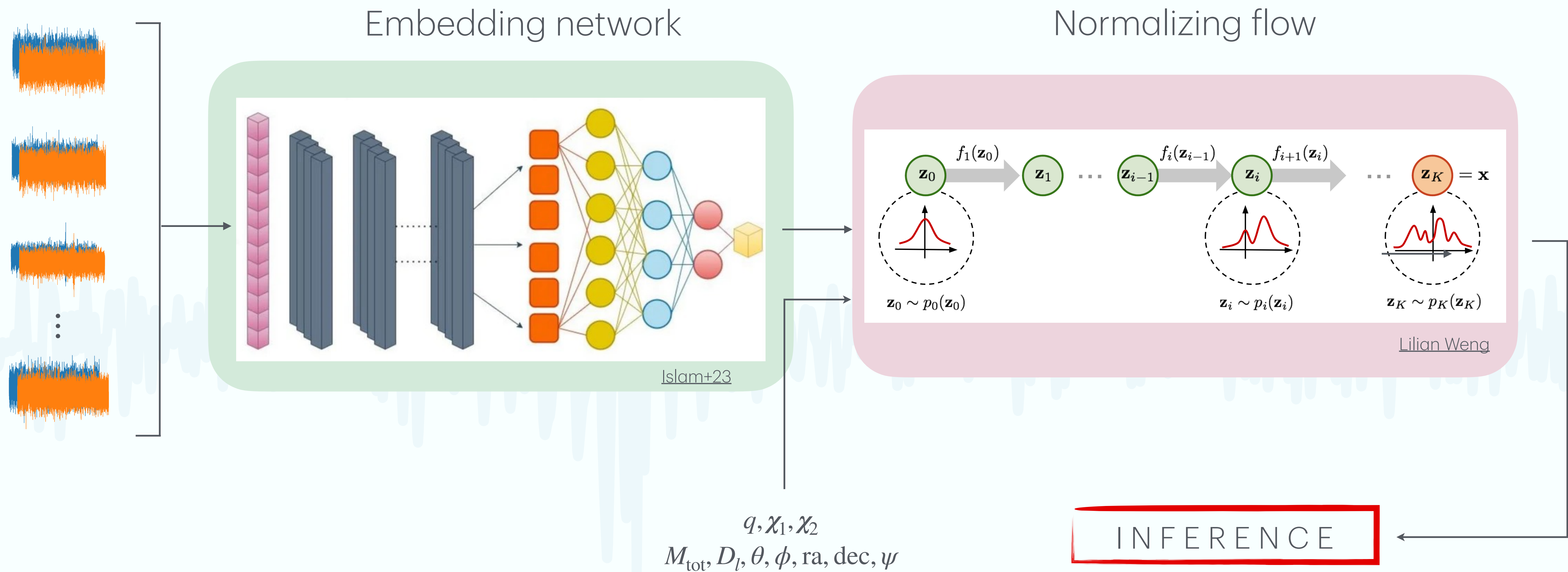


The Beauty...

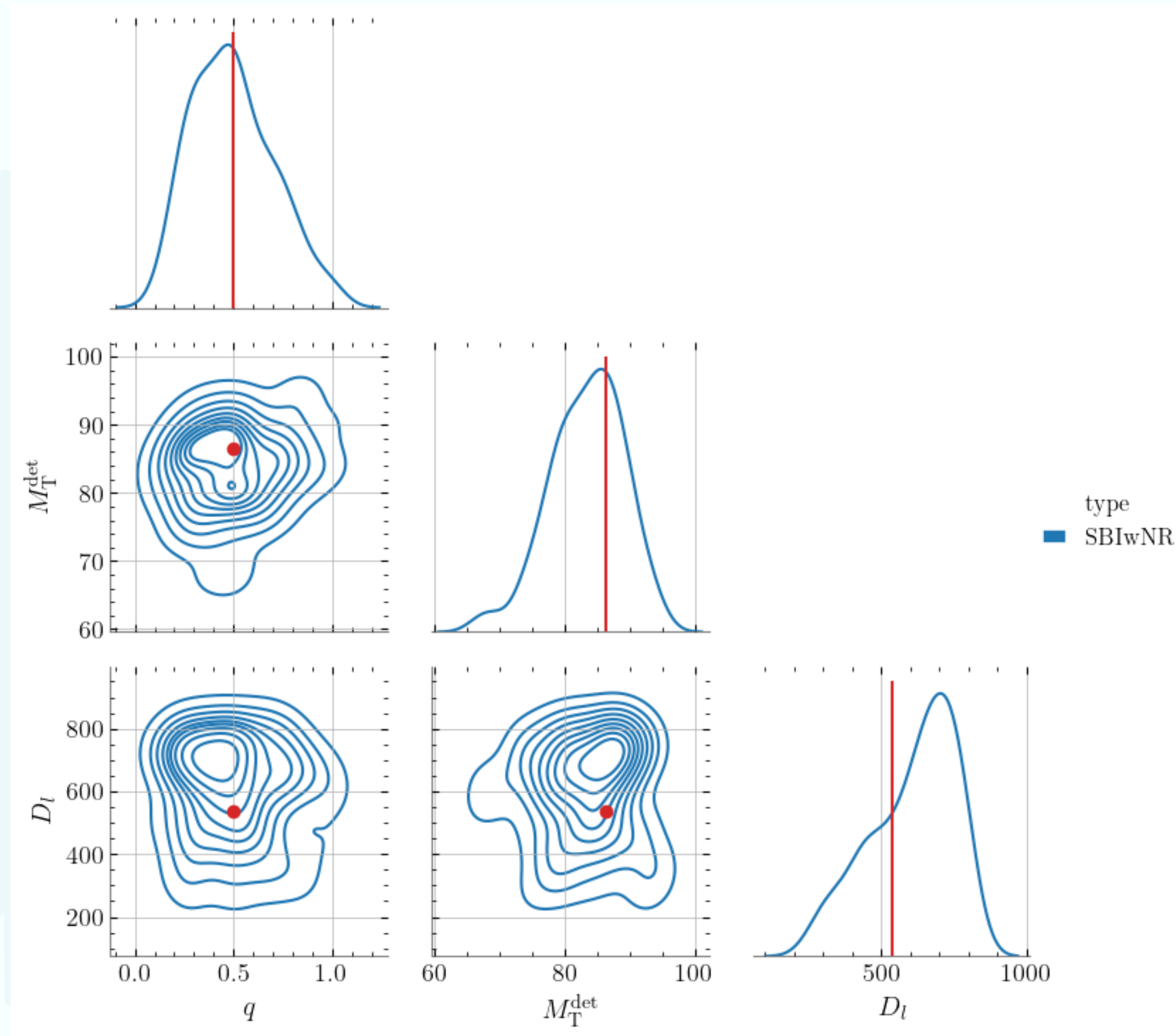
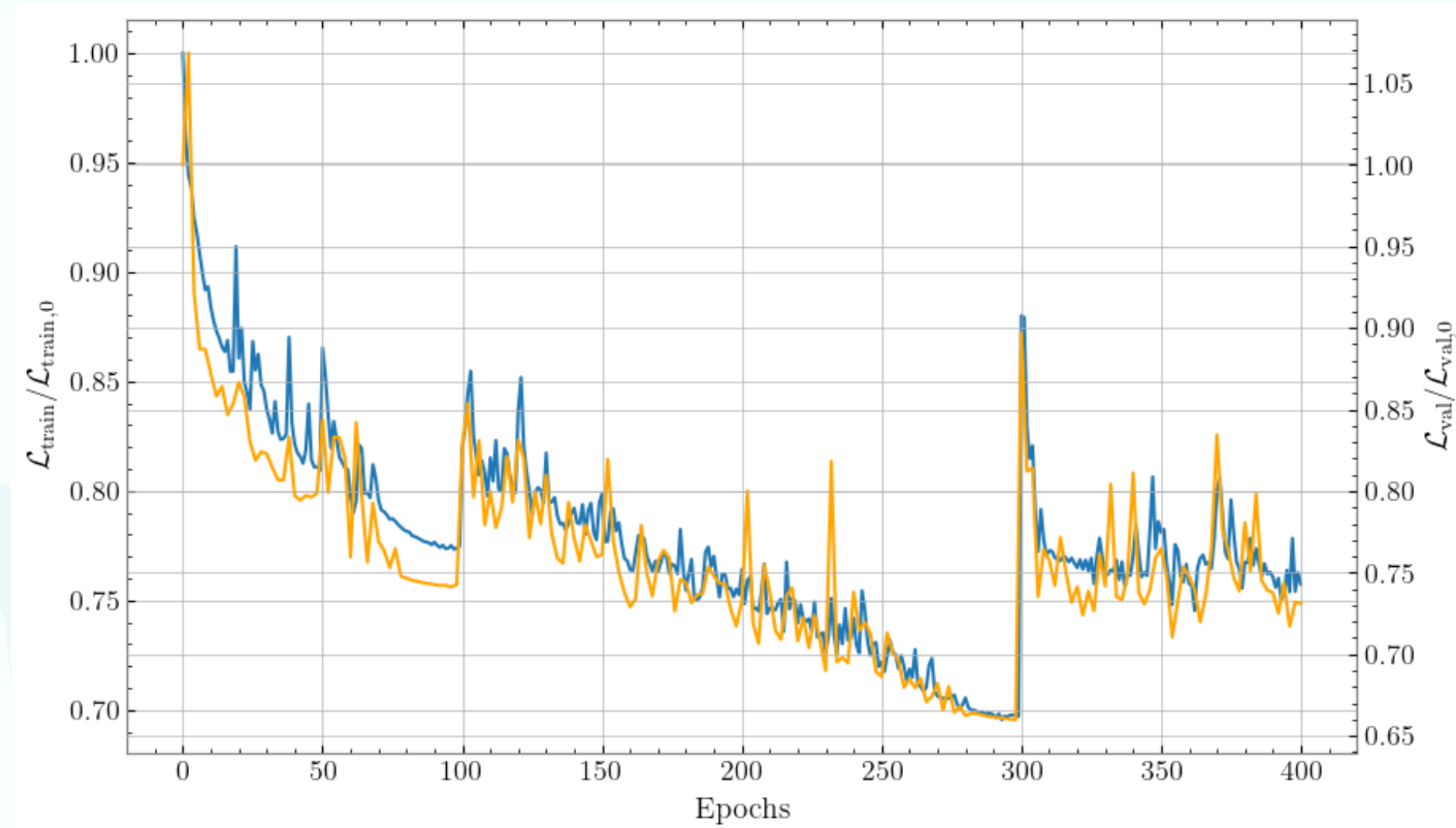
Not inference (yet)!



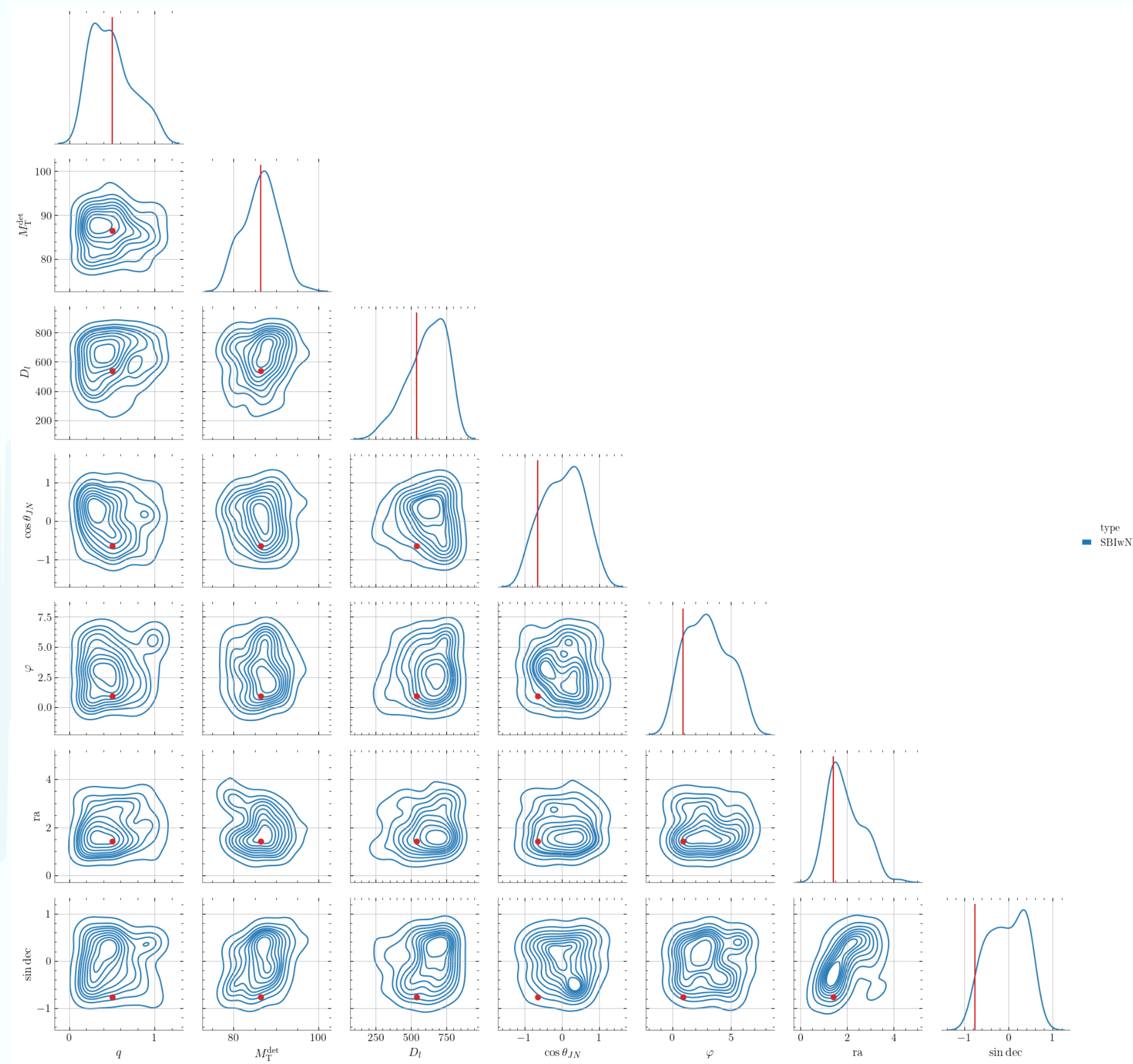
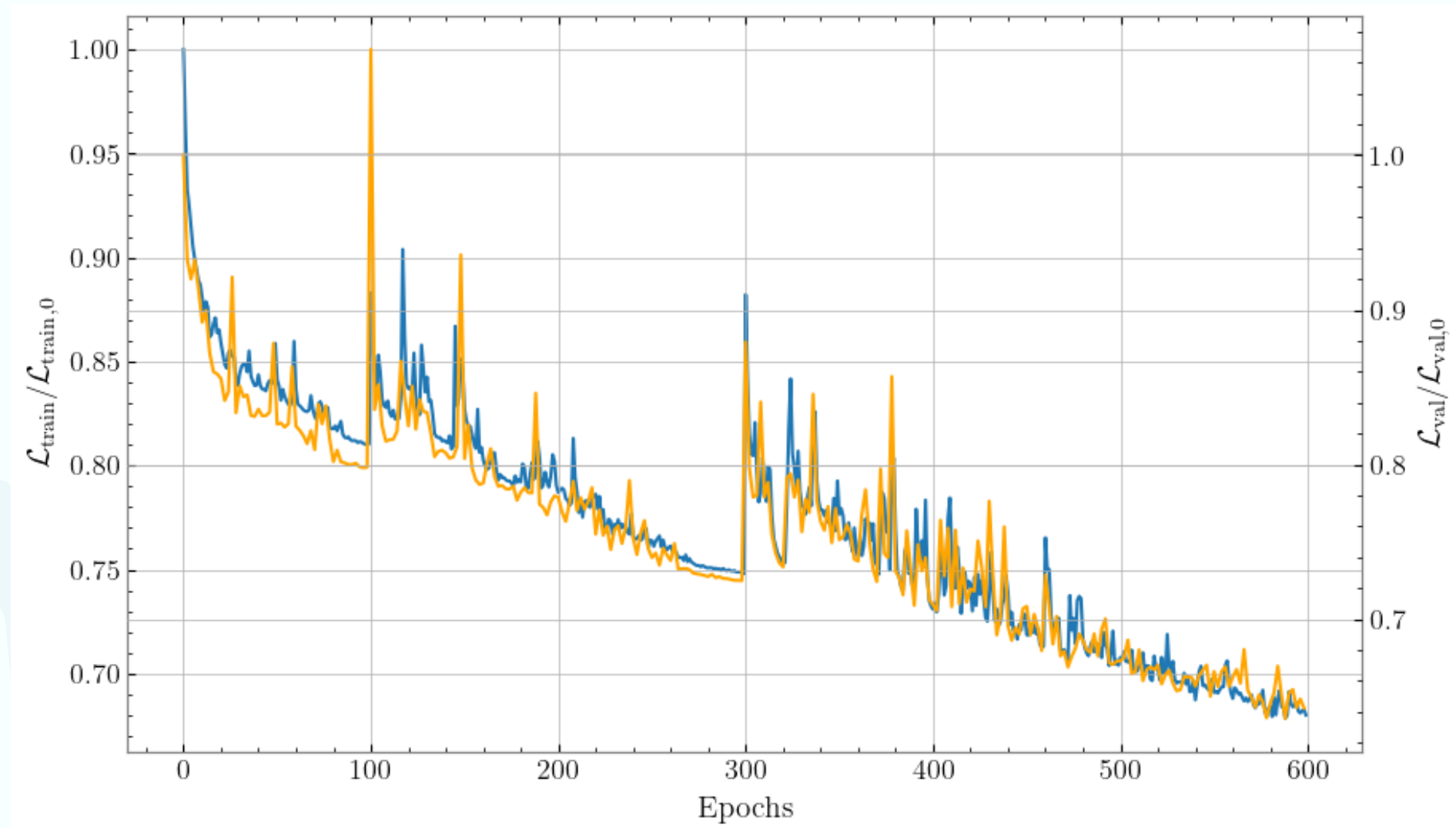
...and the Beast



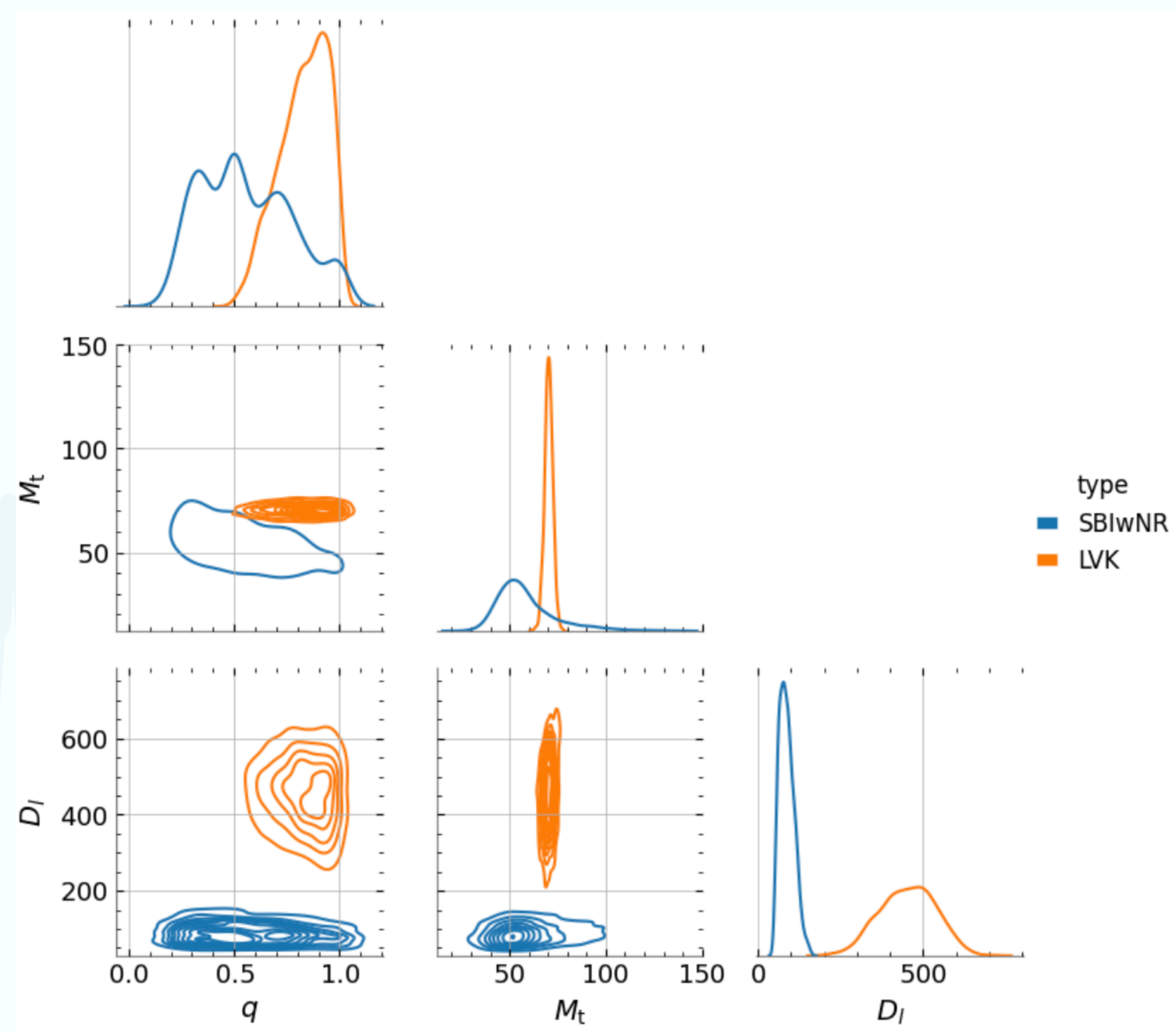
Preliminary results - 3D model



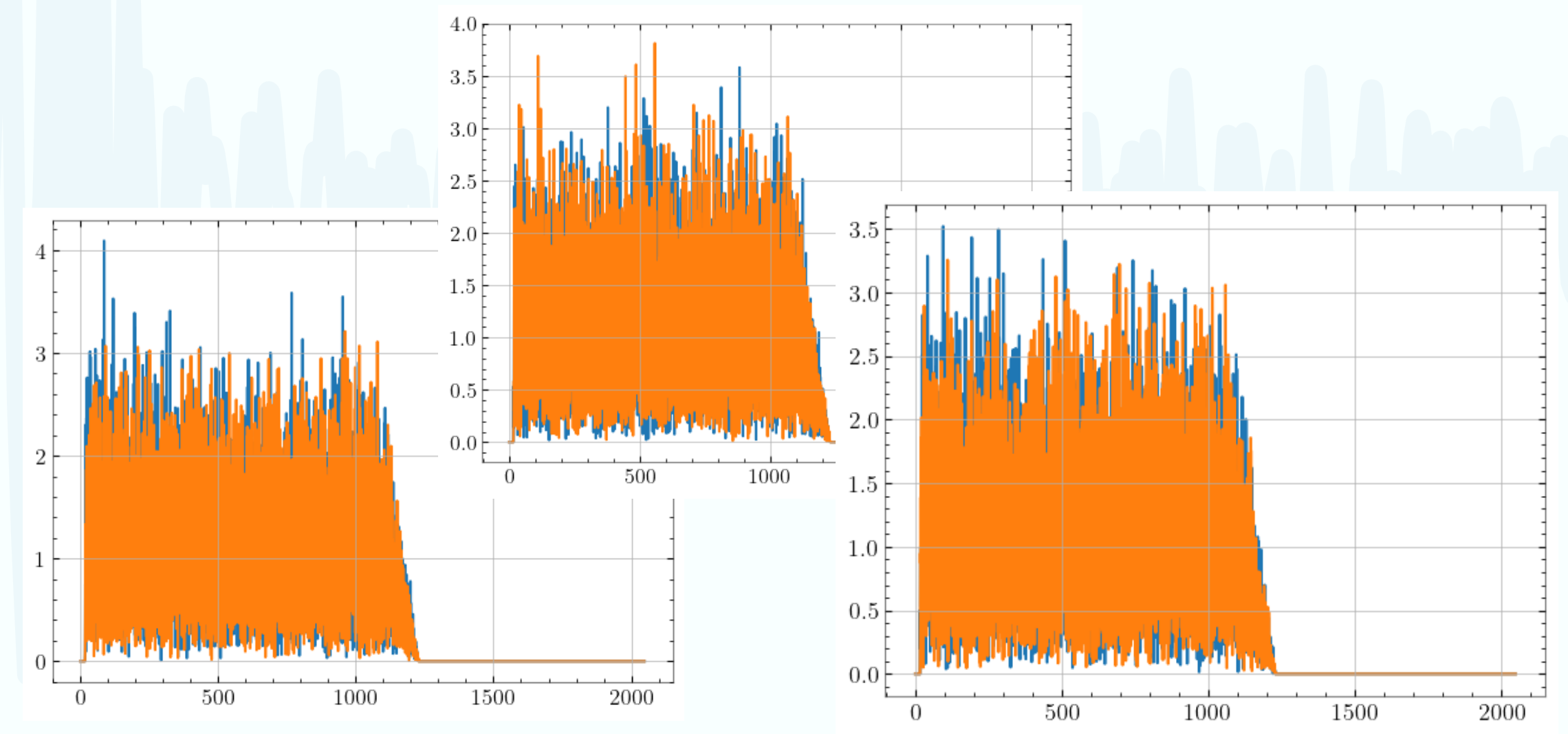
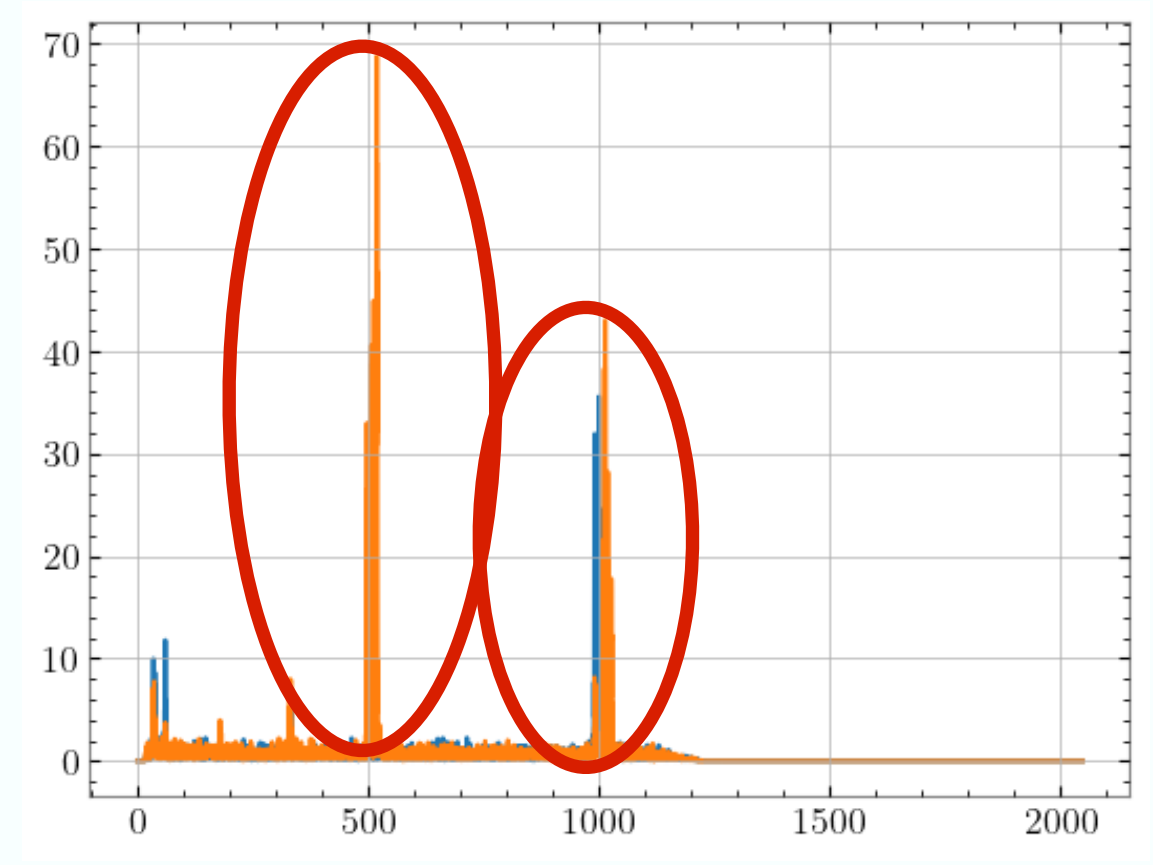
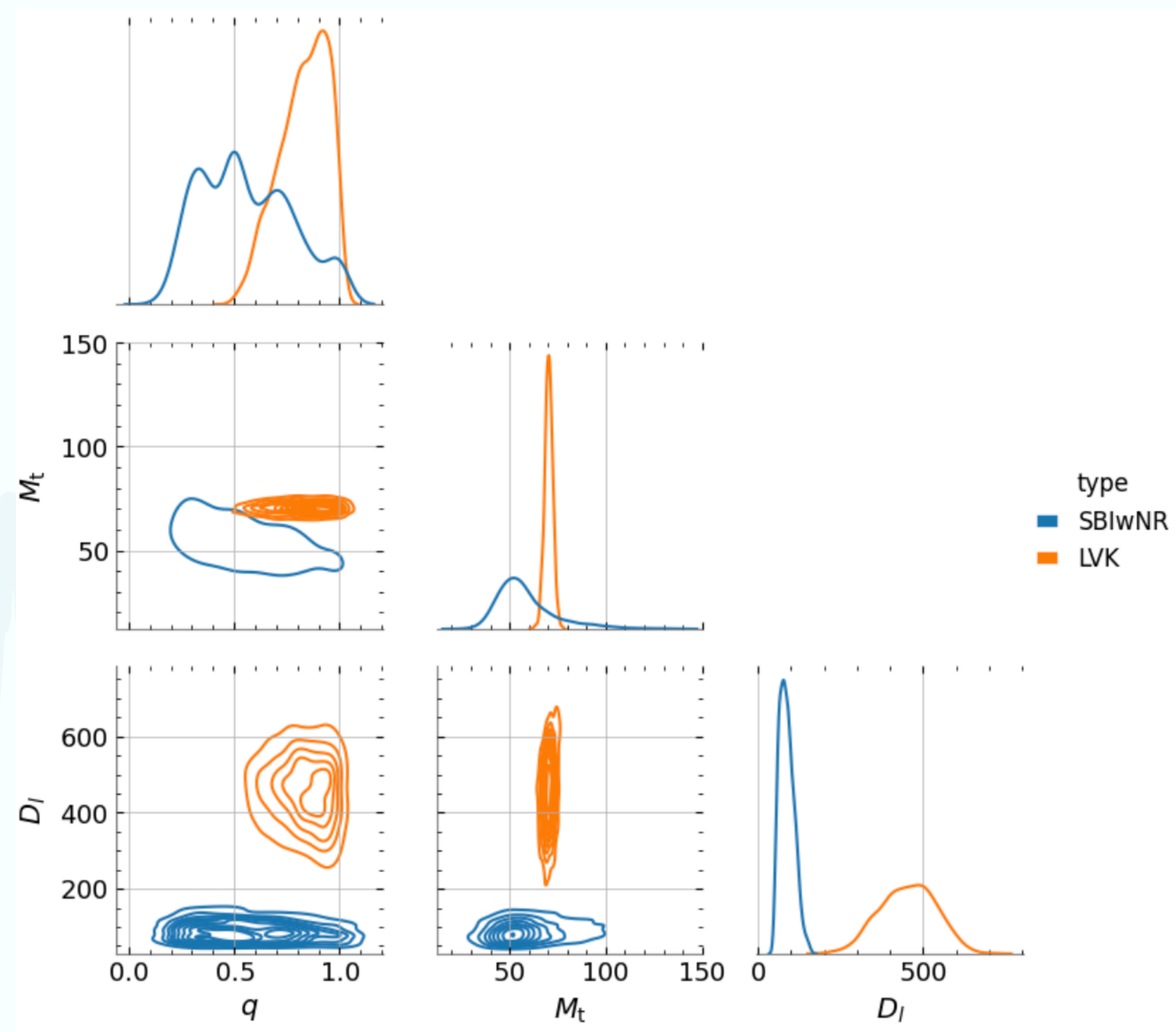
Preliminary results - 7D model



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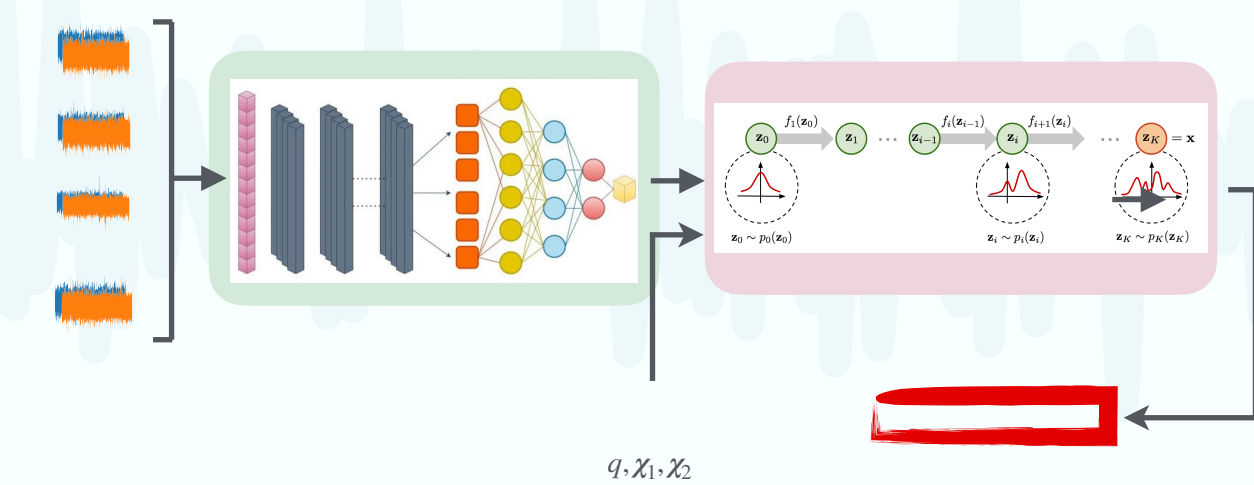
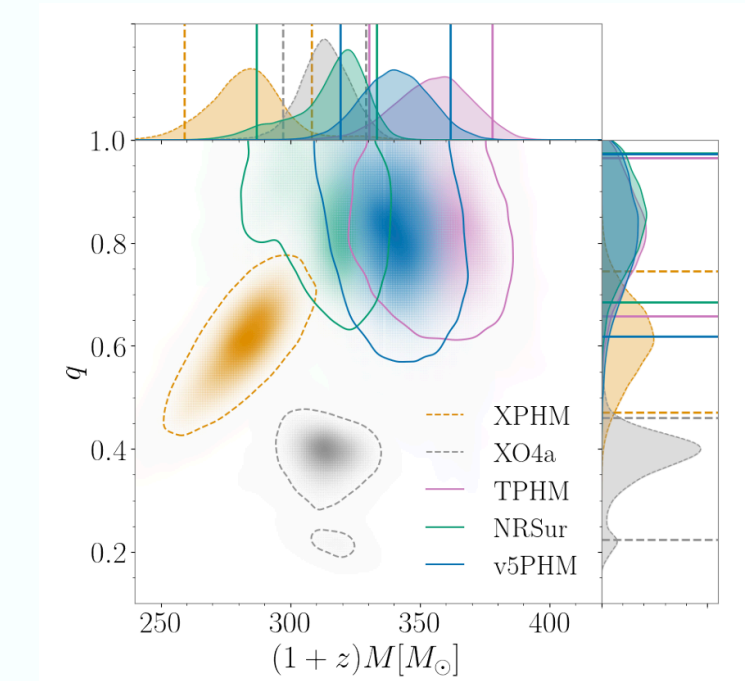
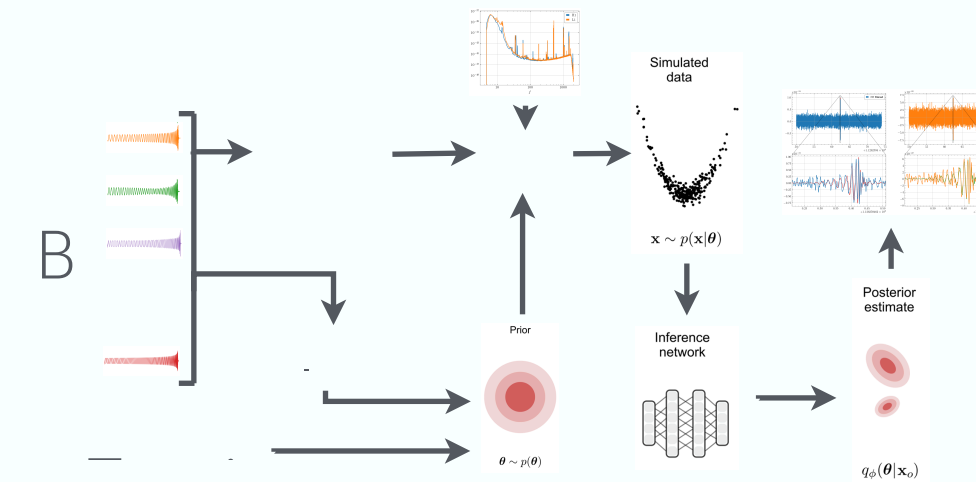


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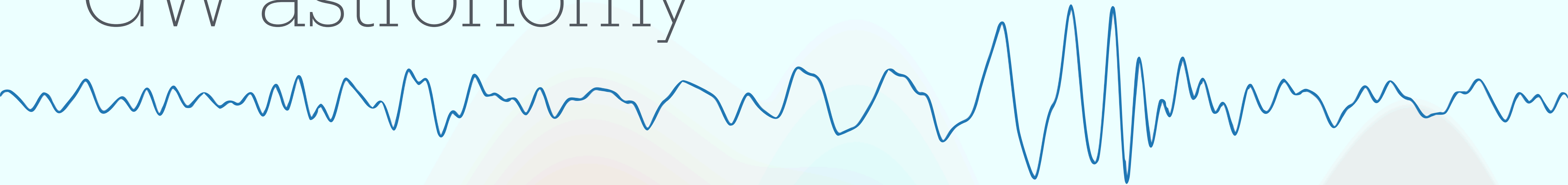


Summary

- Waveform systematics can impact PE (and science)
- SBI with NR simulations
- Easy to span extrinsic parameters space
- The net requires fine-tuning of hyperparameters
- Real signal requires more detailed preprocessing
- Alternative to standard technique, can help leveraging or understanding systematics



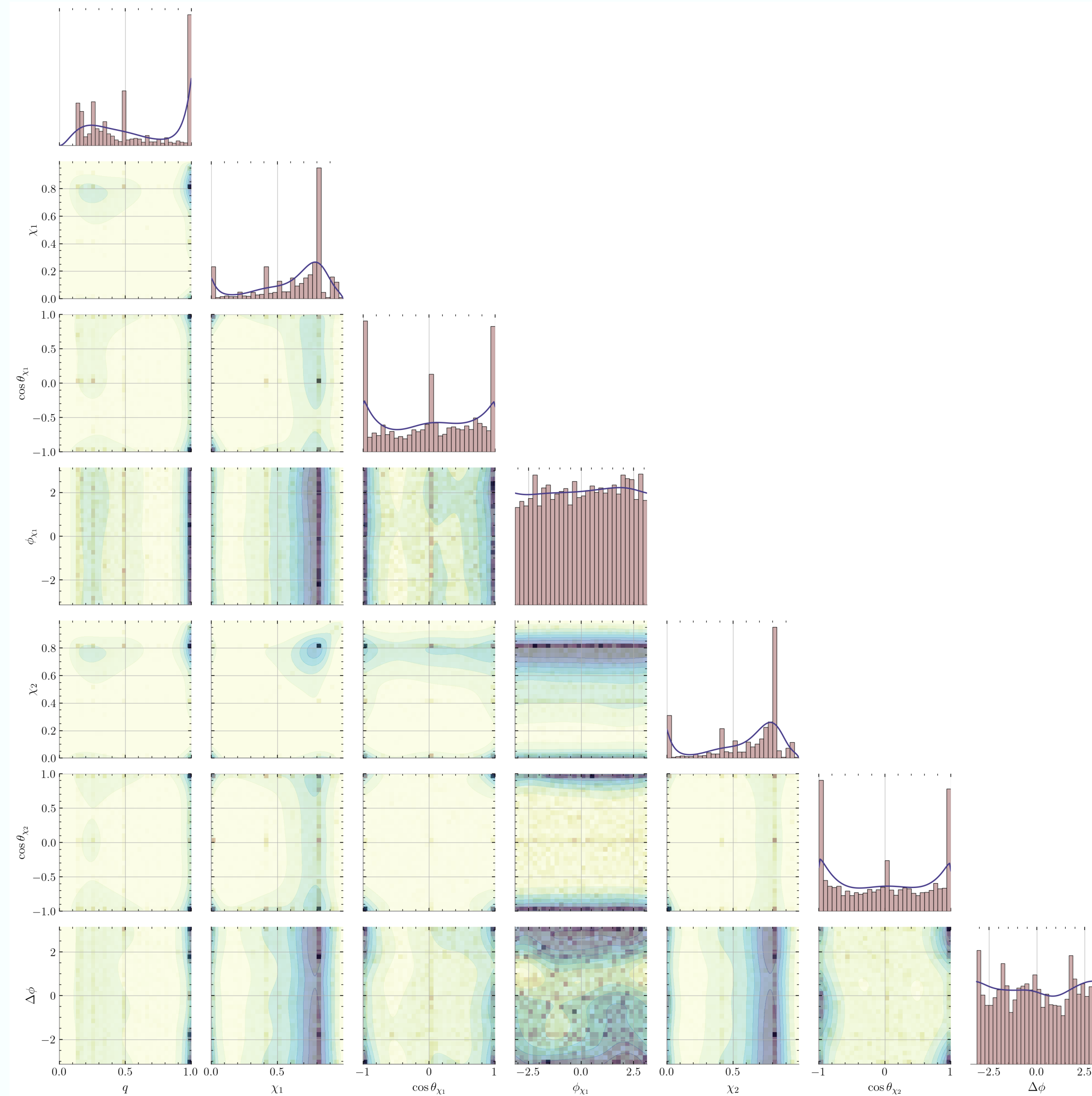
GW astronomy



without waveform “approximants”

Stay tuned for results!

Intrinsic prior



NR coverage

