Accelerated Bayesian inference of multimessenger astronomy with `jax` and machine learning

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23 – 27 September 2024

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Nuclear Multi-Messenger Astrophysics

- NMMA: Nuclear Multi-Messenger Astrophysics (Peter T.H. Pang)

- A Pythonic library for probing nuclear physics and cosmology with multimessenger analysis

- Used for overview of EOS constraints, with "precomputed" EOS set (arXiv:2402.04172)
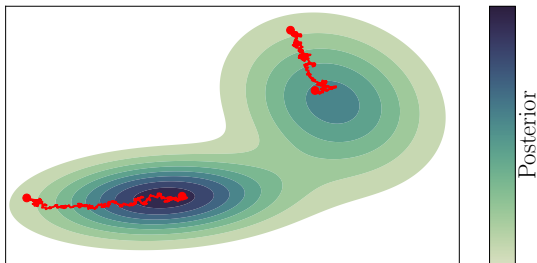 - Metamodel
  - Speed-of-sound extension scheme

Next step: Infer EOS parameters directly from multimessenger data

Bayesian inference

Bayesian inference: get posterior of parameters θ from data d

$$p(\theta|d) = \frac{p(d|\theta)p(\theta)}{p(d)} = \frac{\text{likelihood} \times \text{prior}}{\text{evidence}}$$

Problem: Prohibitively expensive with multimessenger data

JAX and normalizing flows

JAX = NUMPY + composable transformations:

1. Automatic differentiation

2. Just-in-time (JIT) compilation

3. GPU acceleration

4. Parallelization

Normalizing flows: generative deep learning model to approximate target distribution

Accelerating Bayesian inference for MMA: progress

- Gravitational waves:
  - Analyze binary neutron stars in 15 − 30 minutes rather than $\mathcal{O}(\text{hours})$ (arXiv:2404.11397)
  - ⬭ `kazewong/jim`

- TOV solver:
  - 10 − 100 × faster
  - ⬭ `tsunhopang/jose`

- Kilonovae, GRBs: ⬭ `ThibeauWouters/fiesta`

- Ongoing:
  - Next-generation gravitational wave detectors
  - Combine into one multimessenger analysis pipeline