Do Neutron Stars give us Nuclear Matter properties? Machine Learning answers

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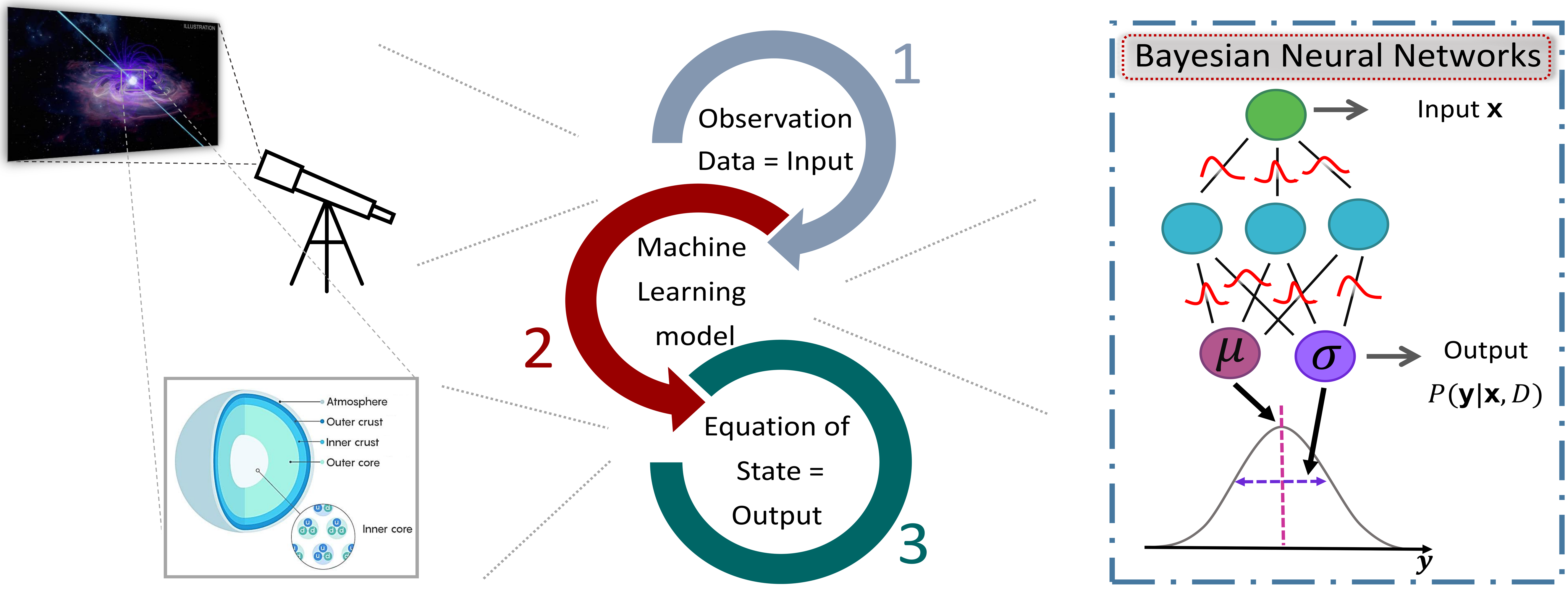
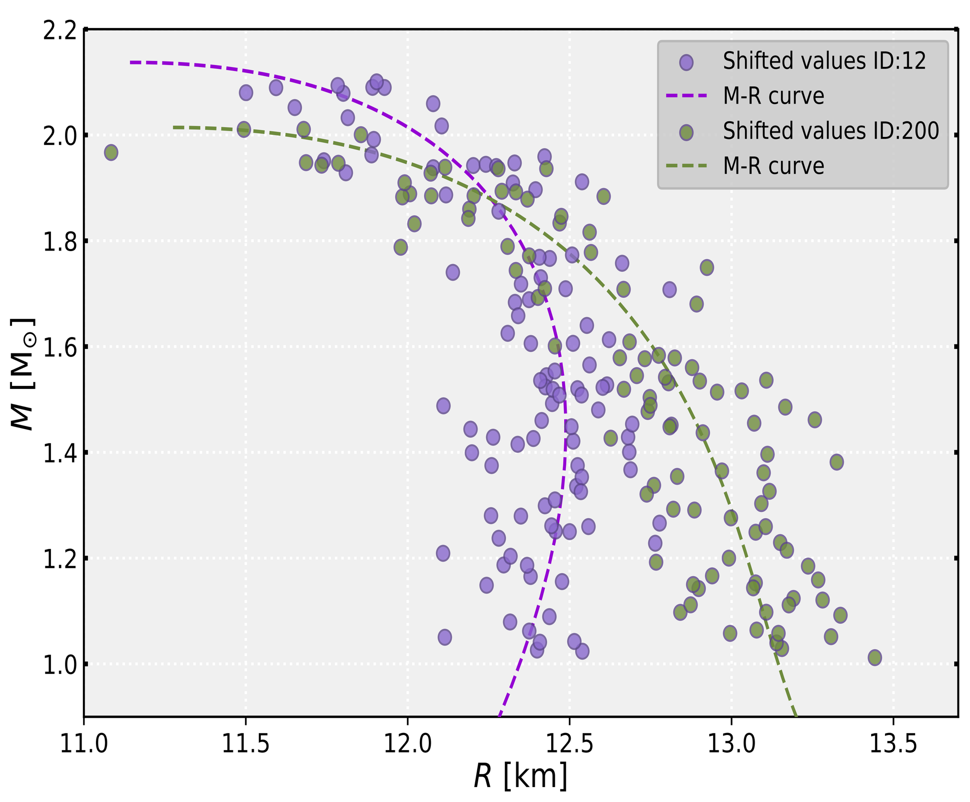
Overview

Neutron stars are a remarkable object towards the study of nuclear matter properties under extreme conditions. In this work we extract some properties contained in the Equation of State (EoS) 3 with the help of Bayesian Neural Networks (BNN) 2 using the mass and the radius from observations 1.



1 Input features

Input vector is: $\mathbf{x}_i = [M_1, M_2, M_3, M_4, M_5, R_1, R_2, R_3, R_4, R_5]$



How we do data augmentation in the input:

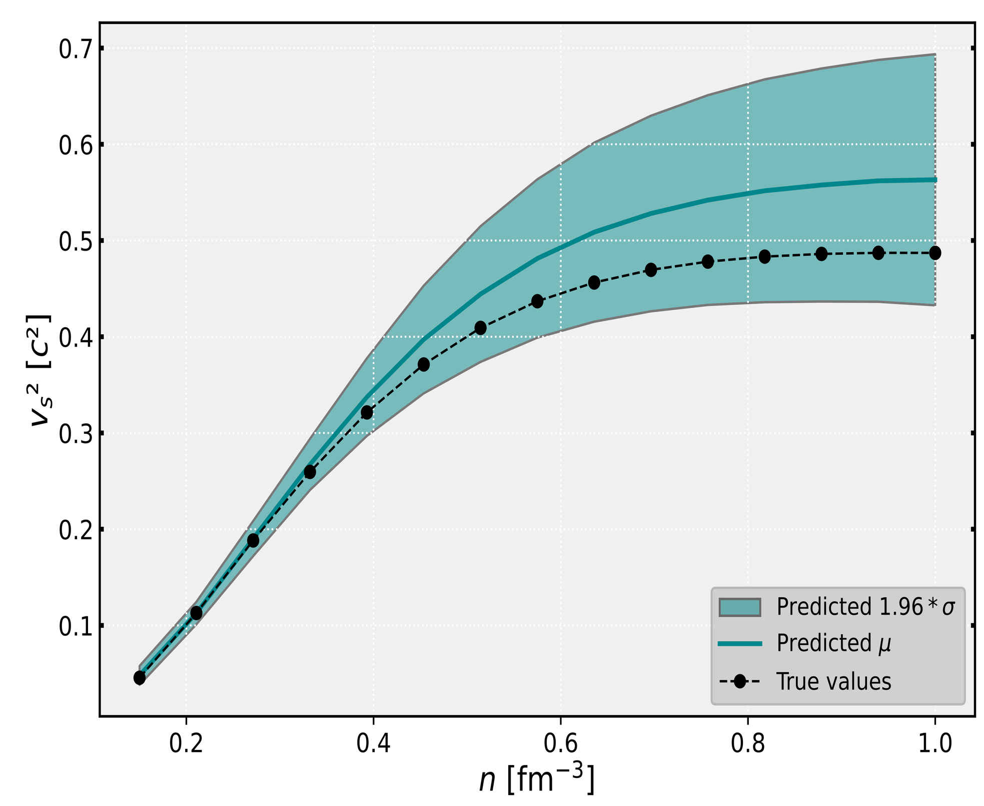
$$M_i^{(0)} = \mathcal{U}[M_\odot, M_{Max}],$$
$$M_i = \mathcal{N}\left(M_i^{(0)}, \sigma_M I\right),$$
$$R_i = \mathcal{N}\left(\mathbf{R}\left(M_i^{(0)}\right), \sigma_R I\right)$$
$$(i = 1, .., 5)$$

The process is repeated n_s times for the same EoS.

3 Output predictions

Output vector is: $\mathbf{y}_i = [v_s^2(n_1), ..., v_s^2(n_{15})]$, n_i = baryonic density.

Our 15 true values for one EoS of the test set are all contained in the 95% Confidence Interval predicted by the model.



2 What is a Bayesian Neural Network?

Is the combination between Neural Networks (NN) and Bayesian Inference (BI).

NN: Mapping of Input space **x** onto the output space **y** by several successive layers of linear transformations (given by the weights **w**) interleaved with element-wise non-linear transforms. The probabilistic view is $P(\mathbf{y}|\mathbf{x}, \mathbf{w})$.

BI: The calculus of the posterior distribution of the weights, given the training data, $D = (\mathbf{x}, \mathbf{y})$:

$$P(\mathbf{w}|D) = \frac{\overbrace{P(\mathbf{w})}^{\text{Prior}}\ \overbrace{P(D|\mathbf{w})}^{\text{Likelihood}}}{\underbrace{P(D)}_{\text{Evidence}}}$$

The prediction distribution of a BNN is then for an unknown $\hat{\mathbf{y}}$ of a test data item $\hat{\mathbf{x}}$:

$$P(\hat{\mathbf{y}}|\hat{\mathbf{x}}, D) = \int P(\hat{\mathbf{y}}|\hat{\mathbf{x}}, \mathbf{w}) P(\mathbf{w}|D) d\mathbf{w}$$

Ongoing work

- Working with other outputs, such as pressure and proton fraction;
- Using tidal deformability in the input;
- Testing how data augmentation affects our results;
- And so on ...

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