Bayesian Inference in Physics-Based Nonlinear Flame Models

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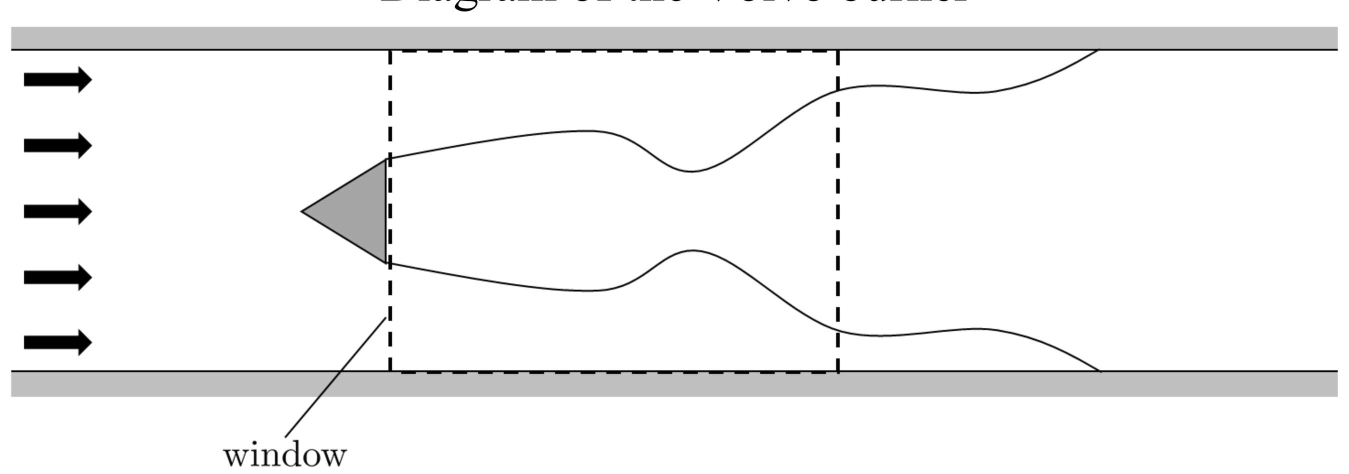
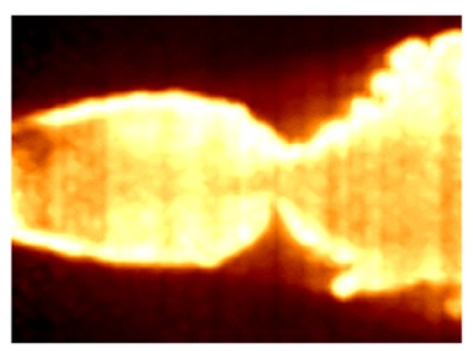
NEURAL INFORMATION PROCESSING SYSTEMS

1. The Volvo Burner Experiment

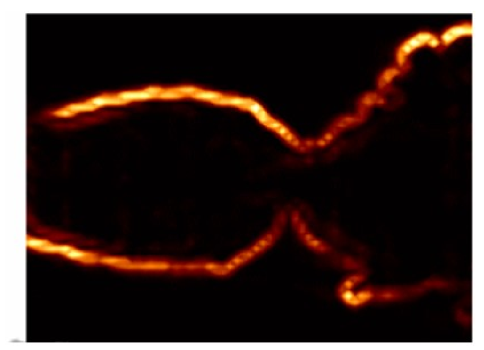
A flame is stabilized on a triangular bluff-body and burns premixed air and propane. Images of the flame are taken through an observation window at high frequency.

Diagram of the Volvo burner





Experimental OH PLIF images



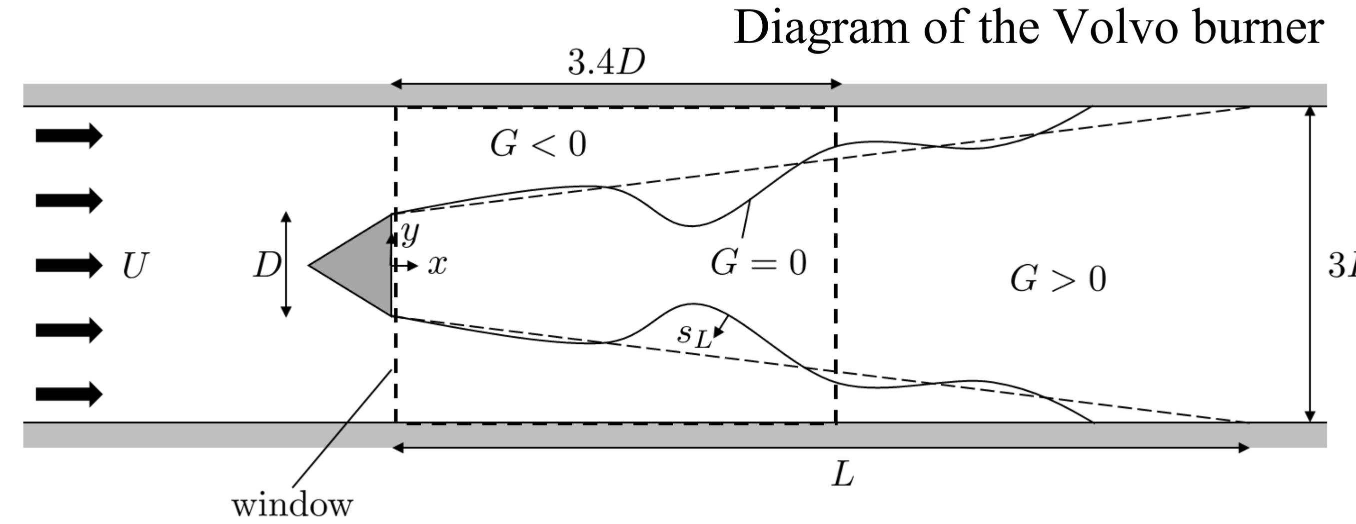
Flame front detection

The flame is only partially observed, so it is not possible to estimate the heat release rate from the images alone.

Task:
How can we assimilate the data into a model, so that key quantities like the heat release rate can be estimated?

2. The G-equation Model

Diagram of the Volvo burner



In the G-equation model (Williams, 1985), the flame is assumed to be a thin boundary between unburnt and burnt gases. This is modelled by the G=0 contour of the G-field.

$$\frac{\partial G}{\partial t} + \mathbf{u} \cdot \nabla G = s_L |\nabla G|$$

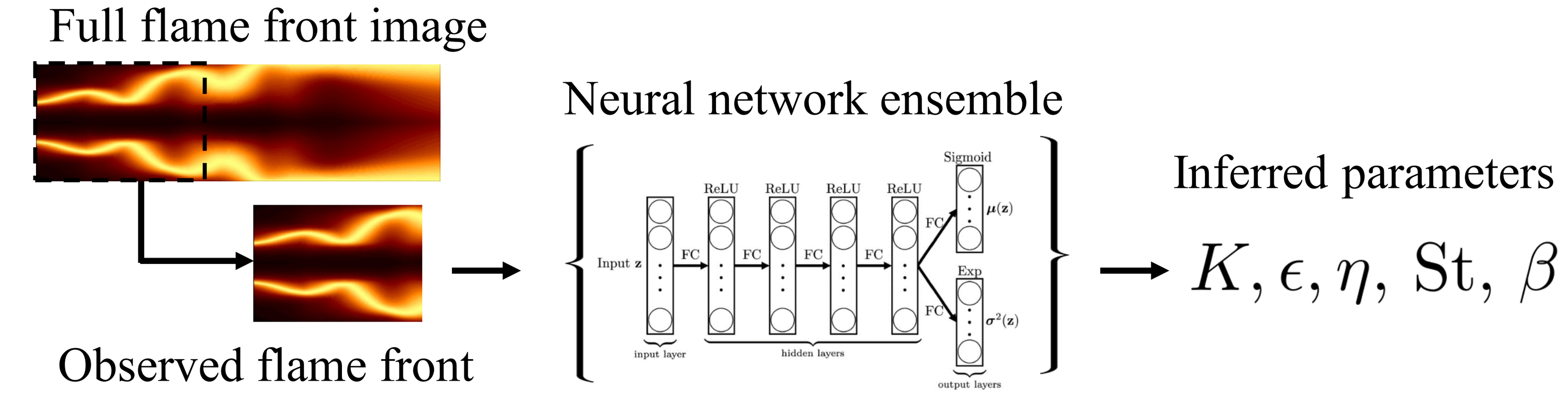
The flame front wrinkles and cusps under a prescribed velocity field **u**.

The velocity field has **5 tunable parameters** which **must be inferred** to match the experiments:

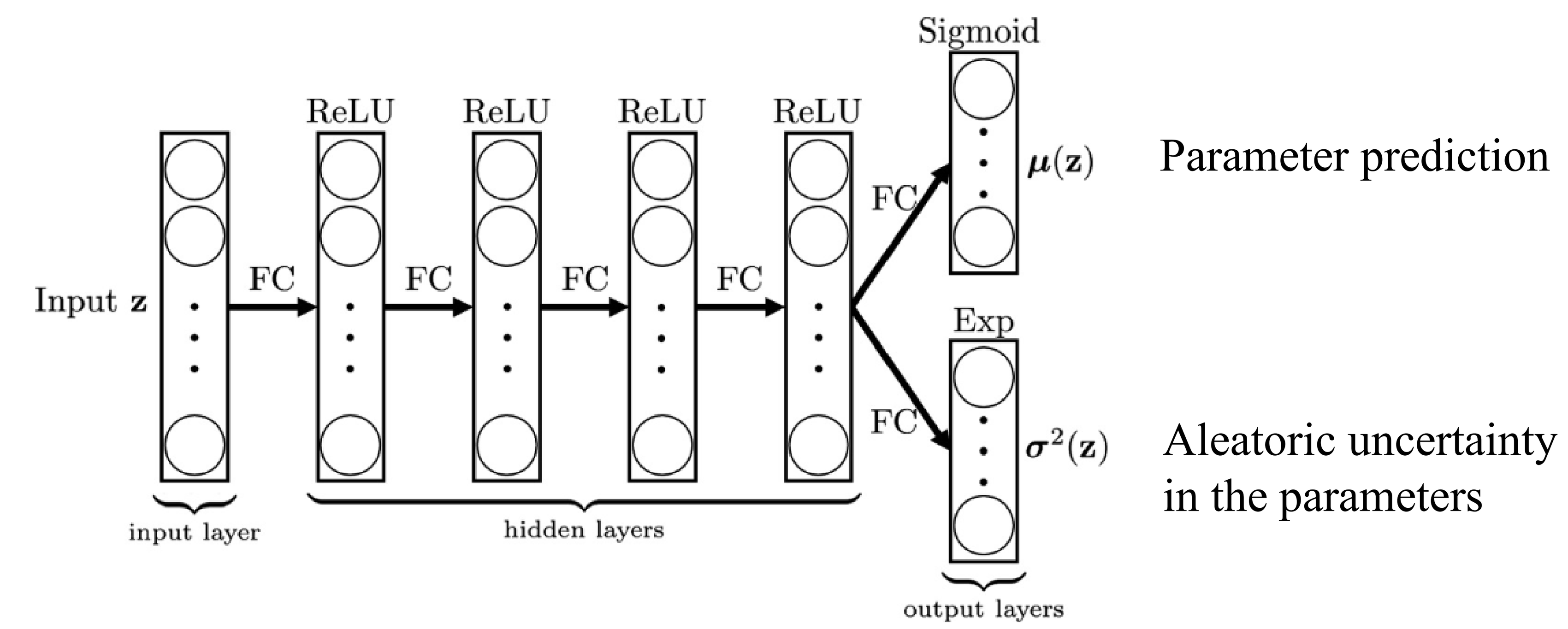
K	Perturbation wavelength
ϵ	Perturbation amplitude
η	Perturbation exponent
St	Strouhal number
β	Steady flame aspect ratio

3. Bayesian Neural Network Ensembles

Bayesian neural network ensembles are used to infer the parameters and their uncertainties from flame front images.



Each neural network is a fully-connected MLP with 2 output layers: one predicts the parameters, the other estimates the aleatoric uncertainty in the parameters



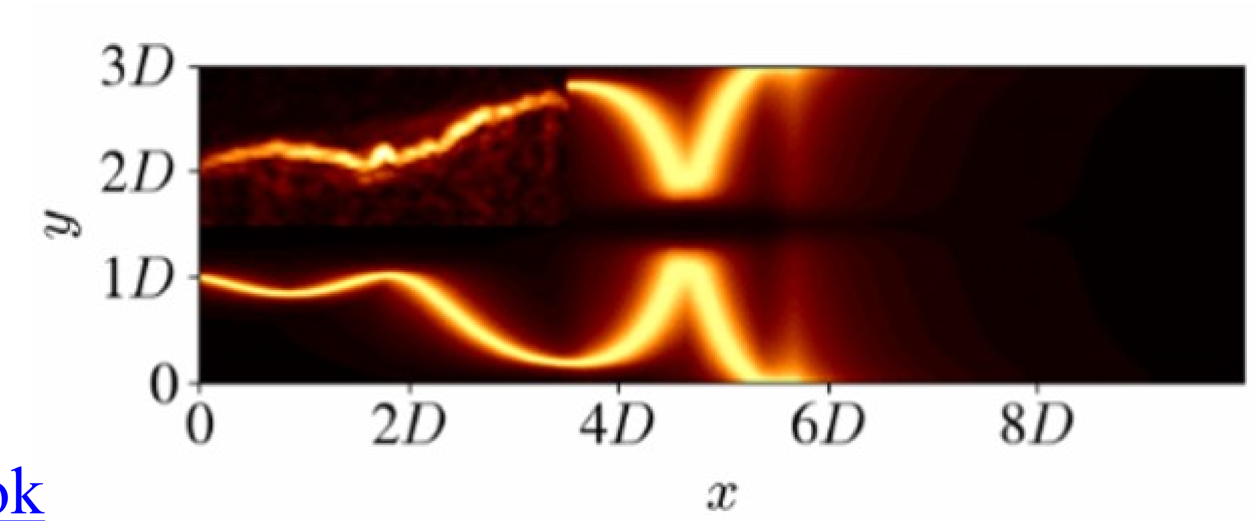
The ensemble is trained on a library of synthetic flame data, comprising 4.8M pairs of images with known parameters. The flame shapes are generated using LSGEN2D, a level-set solver (Hemchandra, 2009).

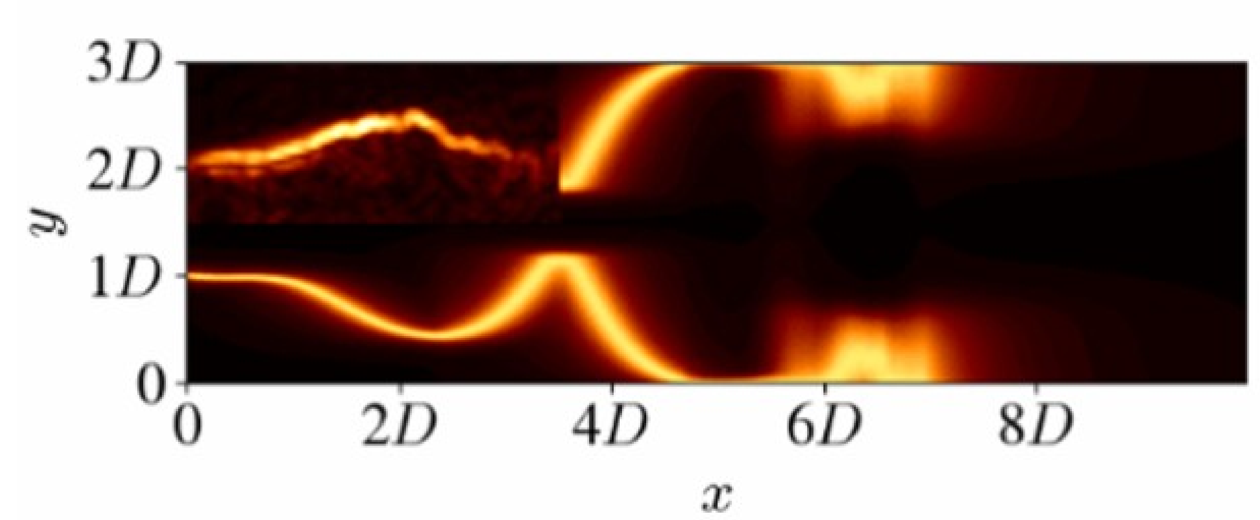
4. Results

Watch the results here!

https://youtu.be/Uov0poQy1ok

Flame fronts generated using the inferred parameters predicted by the neural networks





5. Summary

Bayesian neural network ensembles can be used to **infer the parameters of the model and their uncertainties**. In this way, the heat release rate can be calculated.

The method is general: once trained, the neural network ensemble can estimate parameters and uncertainties for any flame front data (so long as the parameters are within the training library ranges).