Bayesian Inference of the Anomalous Electron Transport in a Multi-fluid Hall Thruster Model

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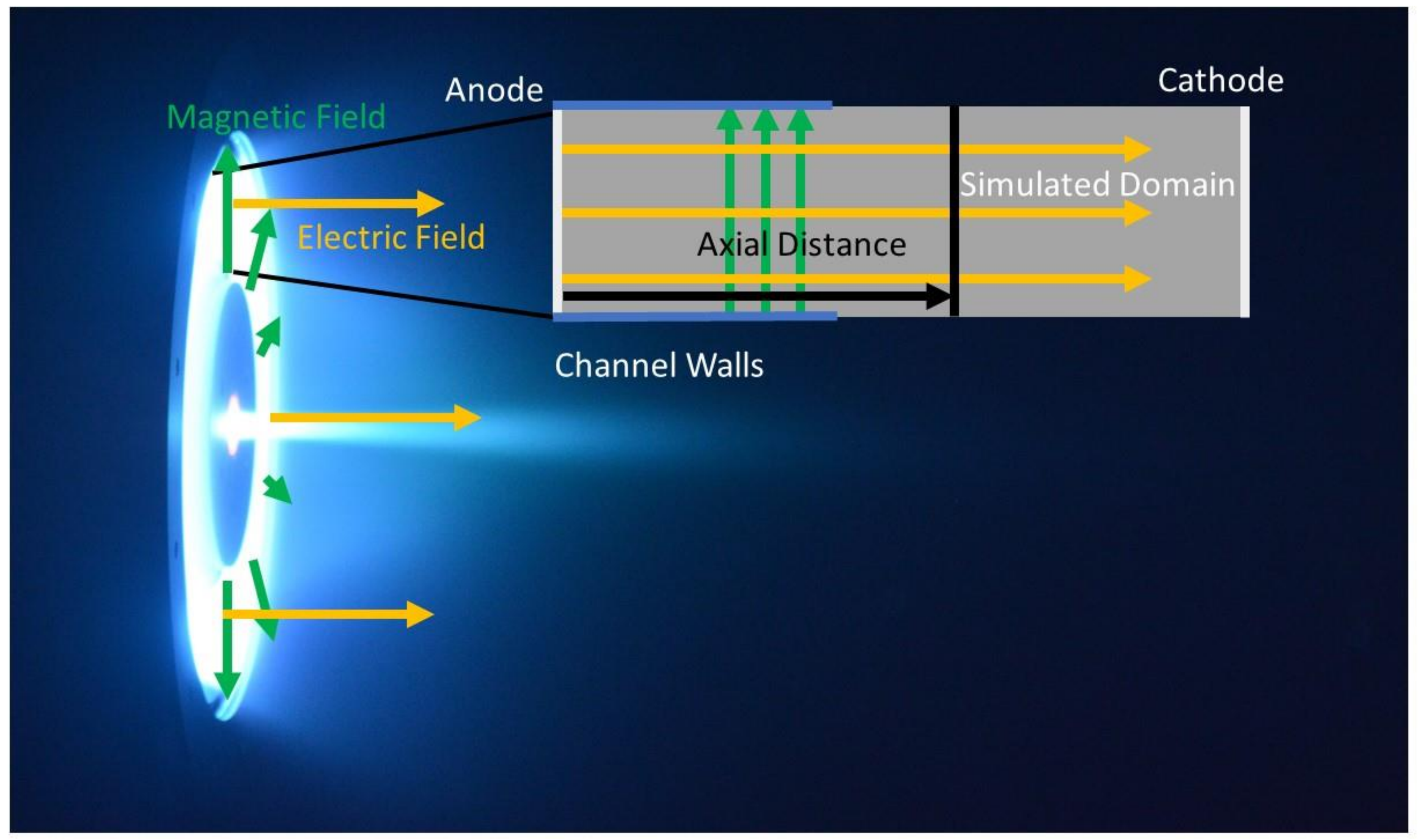
Introduction



Although Hall Thrusters, a type of E × B device, are widely used for spacecraft propulsion, there are aspects of their operation related to cross-field electron transport that remain poorly understood. In an effort approximate this transport, state-of-the-art fluid-based models of Hall thrusters employ an ad hoc "anomalous" electron collision frequency, ν_{an}, to artificially increase the electron cross-field currents. The values of collision frequency are not known from first-principles, however, and must be calibrated by comparing model predictions to experiment. The most common approach to determining the values of ν_{an} is based on an iterative process with a user-in-the-loop (**UIL**) guiding the selection of the collision frequency values. This process has two major drawbacks.

1. **An optimal solution for electron transport is not guaranteed**
2. **Difficult to quantify uncertainty due to ν_{an} profile**

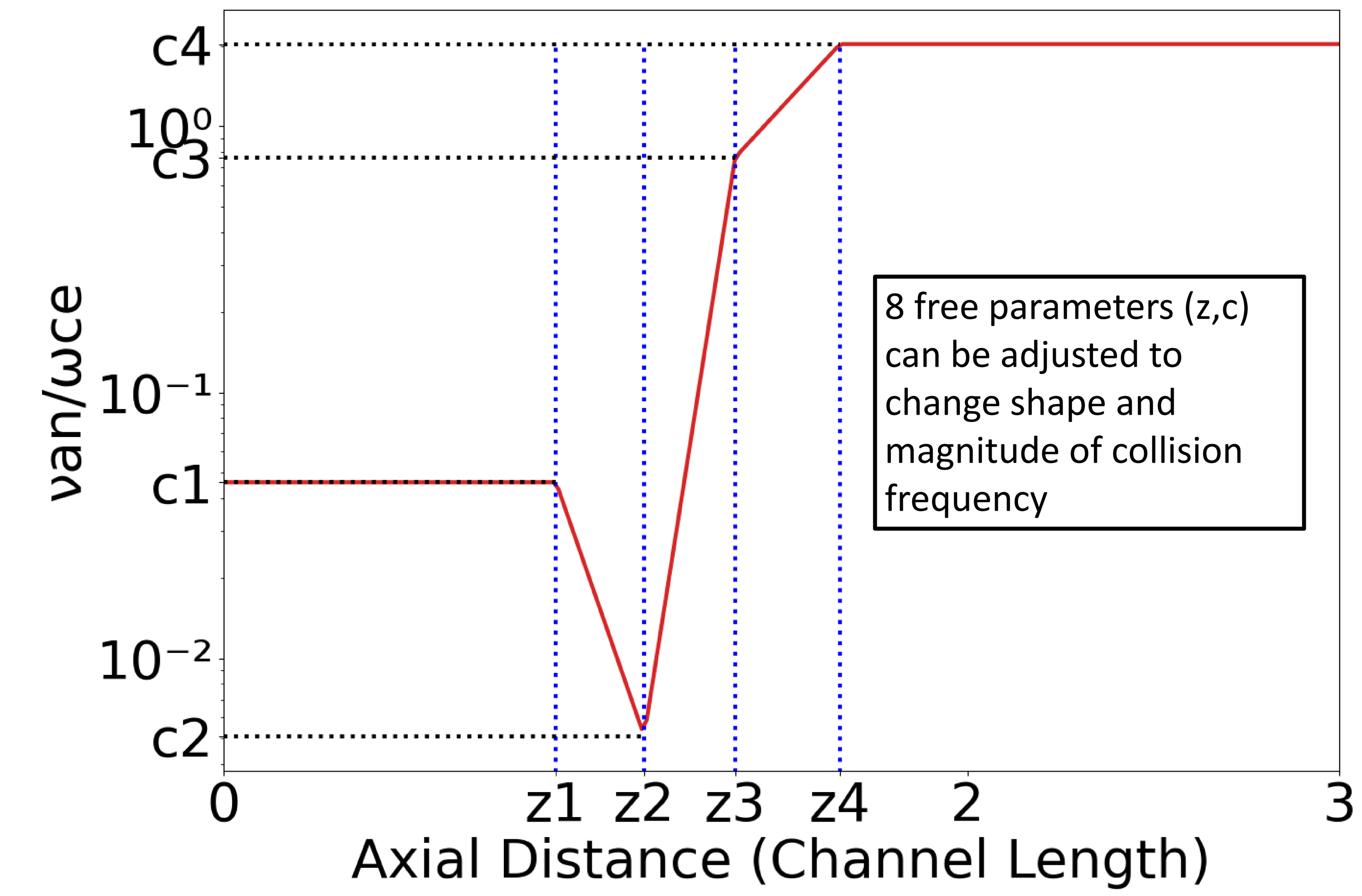
Approach

Bayesian inference to determine optimal values for collision frequency in Hall thruster model subject to uncertainty

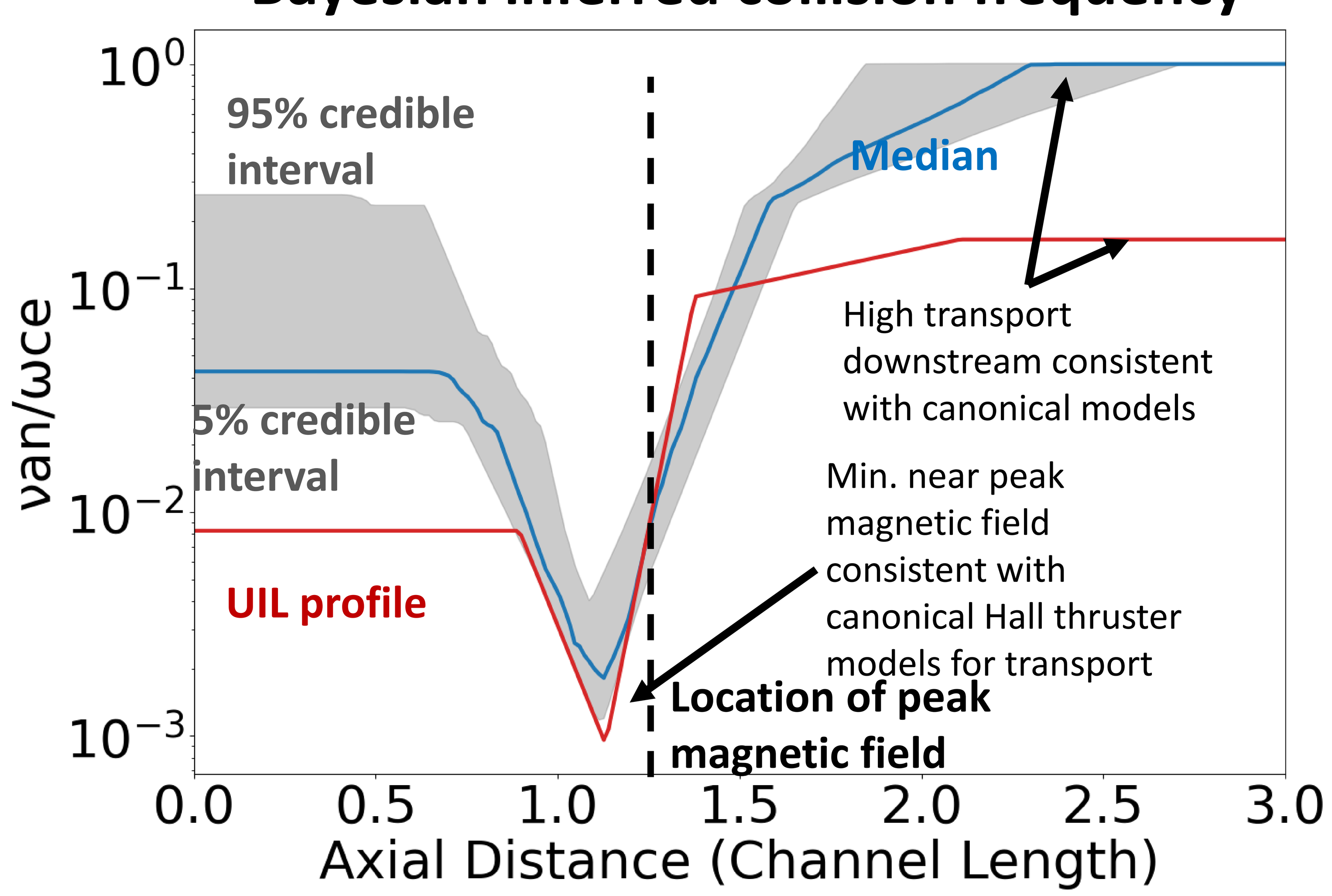
Hall Thruster Model	HallThruster.jl, a 1D multi-fluid code [1]
Parameterization of electron collision	Static, multi-Bohm specified along channel centerline
Source of data for regression	H9 magnetically shielded Hall thruster operating at 300 V and 15 A [2]
Data	Ion velocity along centerline, thrust, anode efficiency, discharge current
Likelihood function	Normal
Priors	Bounded Uniform
Sampling	Delayed rejection adaptive MCMC

Results

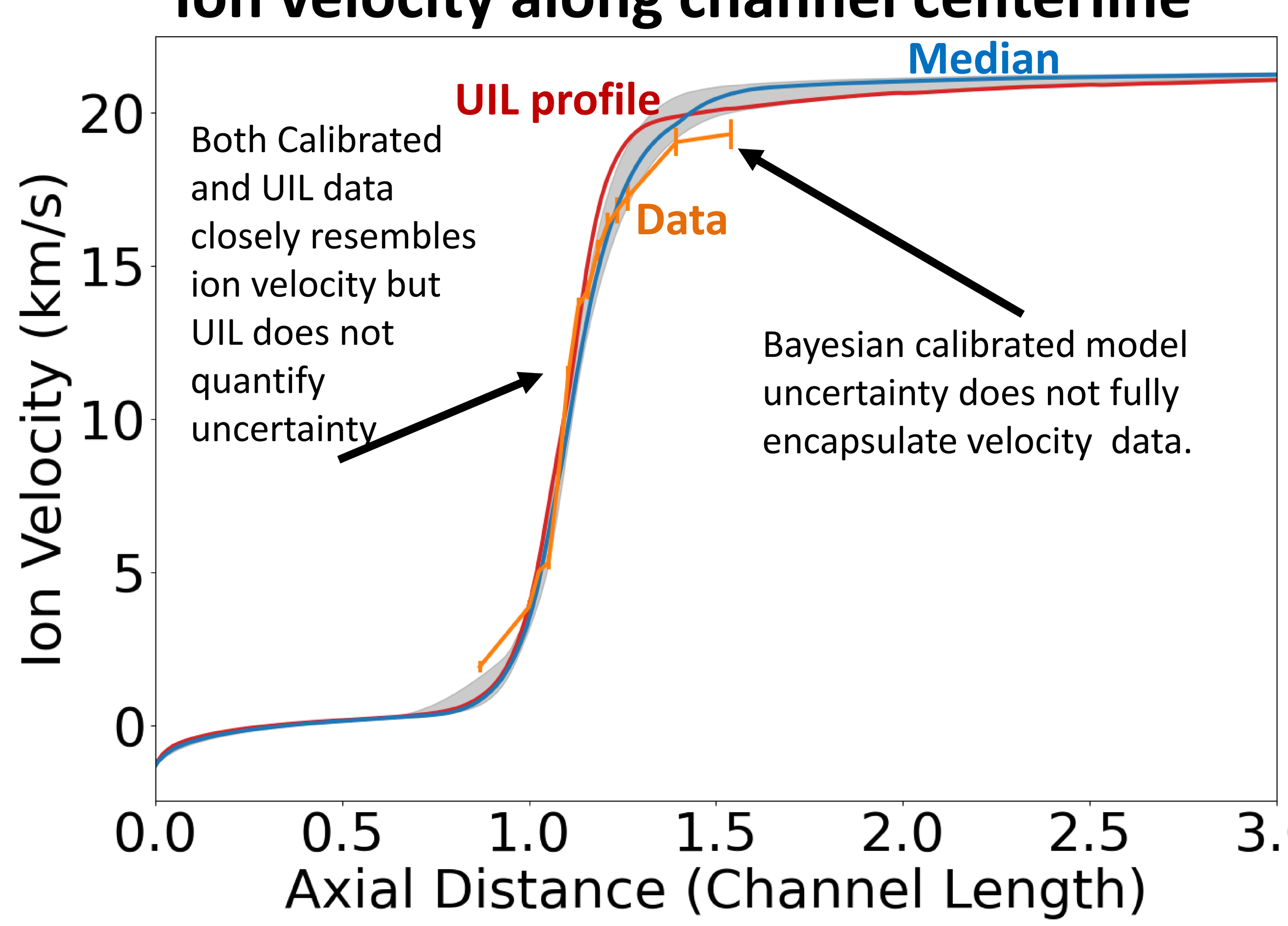
Multi-Bohm parameterization of collision frequency



Bayesian inferred collision frequency

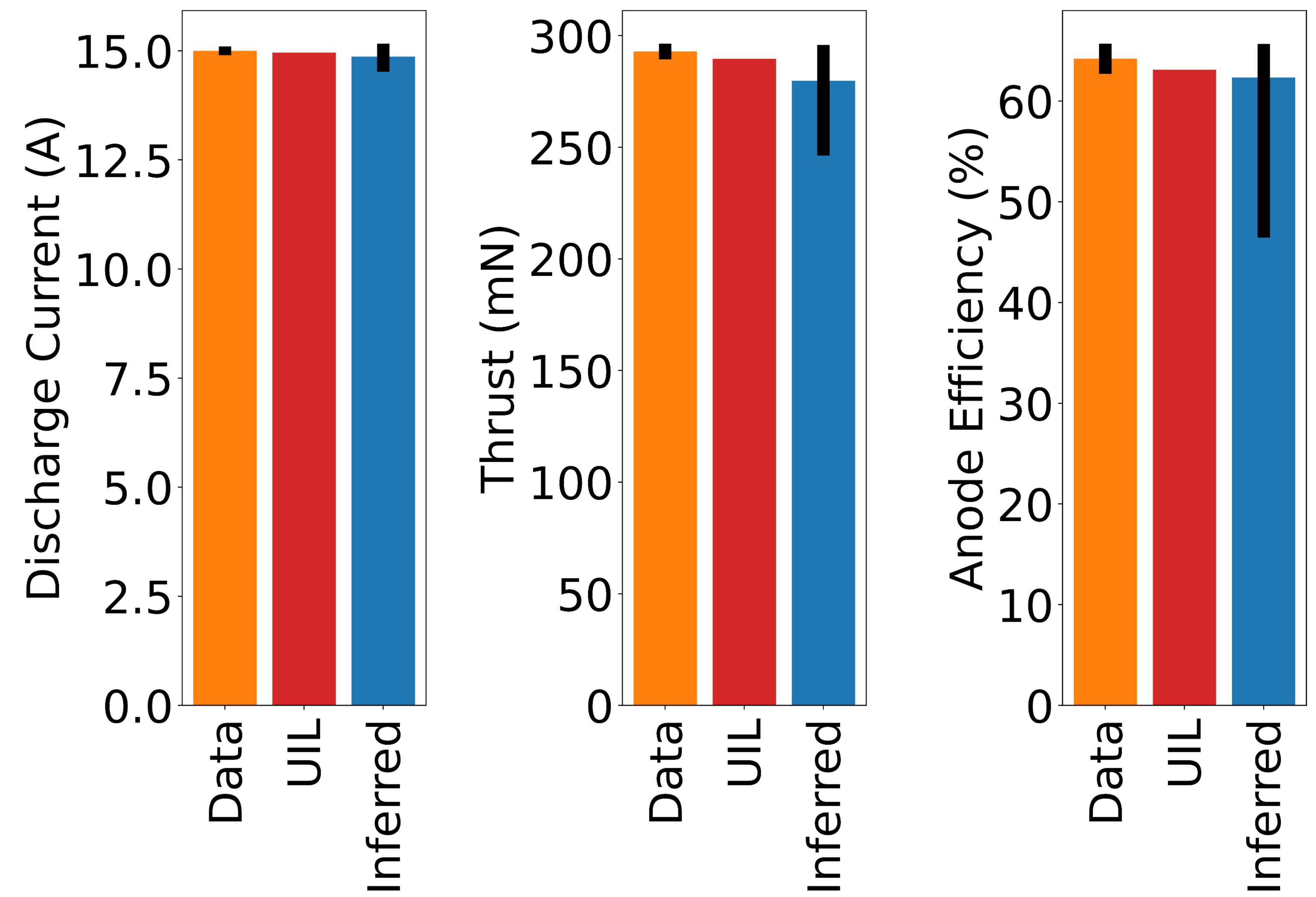


Ion velocity along channel centerline



Results Continued

Global performance metrics



- Bayesian calibrated profile agrees within uncertainty with measurement

Conclusions

1 .Demonstrated ability to apply rigorous inference to determine model for anomalous collision frequency

- Median result "optimal" as it corresponds approximately to maximum of likelihood (minimum of sum of residuals)
- Inferred coefficients correctly capture both the ion velocity profile and global metrics
- Application of UQ reveals large uncertainty. May be related to poor sampling or highly nonlinear model. May also indicate collision frequency profiles non-unique

2. Proof of concept for algorithm provides path forward for exploring additional parameterization or applying inference to more sophisticated, multi-dimensional models

Acknowledgements

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References

1. Marks, T. A., Schedler P., Jorns, B.A., JOSS, 2023, doi:10.21105/joss.04672
2. Su L.L. and Jorns B.A., J. of App. Phys., 130:163306, 2021 doi: 10.1063/5.0066849