# ISNET Introduction

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#### Welcome to ISNET-11



# ISNET-11: Information and Statistics in Nuclear Experiment and Theory

This workshop will gather leading international researchers in nuclear physics, statistics, and applied mathematics to discuss how statistical methods can enable progress on the frontiers of nuclear physics, spawn new directions, and catalyze techniques that ensure best use of data taken in nuclear-physics experiments.

#### Organizers: Andreas Ekström, Amy Lovell, Daniel Phillips







#### Information and Statistics in Nuclear Experiment and Theory

**The mission** of the Information and Statistics in Nuclear Experiment and Theory (ISNET) community is to encourage, facilitate and develop the use of statistical and computational methodologies that maximize the knowledge gained from and quantify uncertainties in nuclear measurements and theoretical calculations.

We do this by combining domain knowledge from the nuclear physics research community with expertise in cognate fields of research and practice, such as statistics, mathematics and computer science.

The main deliverables of ISNET are conferences at which relevant research results & pedagogical materials are discussed and shared with the community.









### Past, present, and future ISNET Workshops

ISNET-1	2012 Krakow, Poland
ISNET-2	2013 Glasgow, UK
ISNET-3	2015 Trento, Italy
ISNET-4	2016 INT, USA
ISNET-5	2017 York, UK
ISNET-6	2018 Darmstadt, Germany
ISNET-7	2019 Gothenburg, Sweden
ISNET-8v	2020 East Lansing, USA (virtual)
ISNET-8	2021 East Lansing, USA
ISNET-9	2023 St. Louis, USA
ISNET-10	2024 Shanghai, China
ISNET-11	2025 Trento, Italy
ISNET-12	2026 Berkeley, USA (Oct 5-9)



Figure 1. Workshop participants.

There were no formal talks; most of the time was devoted to discussion. Based on the exchanges during the meeting, it is clear that the progress in quantification of theoretical uncertainties is badly needed, especially when planning the new experiments and experimental programs. [...] (NPN 23 (2) 2012)

### ISNET-3 was at the ECT\* exactly 10 years ago

Organized by *David Ireland, Witek Nazarewicz, Bartlomiej Szpak* 16 November 2015 — 20 November 2015

Who in the audience was there?

Who is "newer" to the ISNET community?

**Then:** 'How do we quantify and propagate uncertainty in existing models?', 'The early days of EFT truncation errors', 'no emulators, not even gaussian processes, in talk titles'

**Now:** 'How to build and deploy full Bayesian statistical workflows in nuclear physics?',

# Some trends in how ISNET method discussions have evolved over the years

**The same core questions.** We still ask how to quantify uncertainties, validate extrapolations, and identify informative observables — but we have learned more statistics and applied math!

- From error bars to Bayesian workflows: First workshops had a focus on covariance analysis and parameter estimation; recent workshops integrate priors, likelihoods, model discrepancy, posterior predictive distributions, and more connected inference pipelines.
- From single models to ensembles and emulators: The focus has also broadened from tuning specific EDFs/forces to using and developing emulators, model mixing, and machine learning tools
- From analysis to experimental design: there's now a clear push for uncertainty and information to help guide which experiments to perform, where theory needs improvement, and how to prioritize in research programs.
- Went beyond nuclear physics in some meetings (weather forecasting, philosophy, particle physics, astrophysics,...)

#### Nuclear Physics News Vol. 34, No. 4, 2024, feature article

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Some ISNET history, connections, and projects that have come out of ISNET

#### feature article

#### Information and Statistics in Nuclear Experiment and Theory (ISNET)

Andreas Ekström<sup>1</sup>, Dave Ireland<sup>2</sup>, and Daniel R. Phillips<sup>3</sup> Chalmers University of Technology <sup>2</sup>University of Glasgow 3Ohio University

As with all empirical sciences, nuclear physics operates in the virtuous cycle of the scientific method: observations inspire theoretical models: models lead to new predictions: predictions are tested in experiments: experiments lead to new observations; and so on. Evaluating what we are inferring, and how certain we are of it, is key

These requirements and a general interest in applying novel statistical, mathematical, and computational techniques, led to the formation of a dedicated research community entitled "Information and Statistics in Nuclear Experiment and Theory (ISNET)" (https://isnet-series.github.io/), which now includes more than 300 members. While the community's interests lean toward nuclear theory, the unifying theme for this group is the inference of knowledge from data.

Input from beyond nuclear research has been critical to the success of the ISNET workshops. The most important contributions have come from statisticians and applied mathematicians, many of whom hail from the uncertainty quantification (UQ) community.

The series of ISNET meetings can be traced to a small workshop held at the Institute of Nuclear Physics in Krakow in 2012 to review the quantification of uncertainties in theoretical predictions: a response to an editorial in Phys. Rev. A [1] that highlighted "...the importance of including uncertainty estimates in papers involving theoretical calculations of physical quantities

This was followed by an extension to incorporate UO in phenomenology and inference from experimental results, with a small workshop in Glasgow in 2013. The ISNET workshop series developed thereafter including meetings at the European Centre for Theoretical Studies in Nuclear Physics and Related Areas in Trento. Italy: the Institute for Nuclear Theory (INT) in Seattle, USA; and Gothenburg, Sweden (see Figure 1). We are now an-

proaching the 10th edition of ISNET at the Jiangwan Campus of Fudan University in Shanghai China (https:// napp.fudan.edu.cn/event/757/), in November 2024.

The first task was to learn how to speak each other's languages. For example, what statisticians call simulations, physicists call models, and whereas  $\theta$  will trigger a statistician to think about a parameter, physicists imagine an angle. For Bayesians, probability represents un certainty, and in the context of UQ, Bayesian credibility intervals should encompass all of our ignorance. This enables not just UO for model parameters and predictions, but also probabilistic assessment of models themselves. Nuclear physicists were more used to frequentist concluded that the different communities could benefit each other. A result of this was the compilation of IS-NET-themed articles in two Journal of Physics G Focus issues [2, 3].



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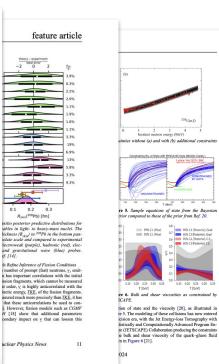
polation. Recently, eigenvector continuation, a ven reduced-basis method [6], emerged in the nuy community as a very useful technique for devis-

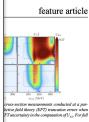
matching [7] is an iterative strategy that uses the emulators to shed light on computationally expenllations that depend on inputs living in highnal parameter spaces. It does this by ruling out f parameter space that do not give acceptable setween the emulator output and observed (i.e., data. It thus identifies a "non-implausible rearameter space. History matching is one example so-called likelihood-free methods that were into nuclear physicists by statisticians at ISNET and have since been successfully imported into ivsics research

an model averaging (BMA) [8] is sometimes sugthe best way to formulate an assessment of model y. However, statisticians at ISNET meetings poilimitations of BMA, and encouraged more gensaches, such as stacking [9], or local Bayesian xing. These strategies generalize the BMA apways that locally leverage the strengths of differ-

an experimental design (BED) [10] explores a ection that encodes the goal of an experimental (e.g., to pin down certain parameters or refine a i). BED differs from optimal experimental design s in that it recognizes that there may be multiple n the utility function, and that it can guide the seesign of multiple, successive, experiments.

est-Fit Values for Mass-Model Parameters functional theory (DFT) requires sophisticated ion methods to be applied to 22-functions involvneous nuclear data if optimal DFT parameters dentified. GP emulators were leveraged, together esian inference and marginalization, to quantify gate parametric uncertainties in DFT predictions masses, the two-neutron drip-line, and fission ee Figure 2 [11]. The ability of Bayesian methods e information from multiple models has been FT to provide a posterior probability for each nustable against neutron emission, enabling probaatements regarding the location of the neutron 12]. Future mass measurements that will yield the reduction in uncertainty as to where the drip-line





of this study are summarized in Figure 7. They best to focus on proton Compton scattering exor just below the pion threshold.

esian Analysis of Nuclear Dynamics (BAND) was funded in 2020 by the National Science s Office of Advanced Cyberinfrastructure to urate software tools that make ISNET-initiated the ones described in this article available to clear physics community. BAND includes nuists, applied mathematicians, and statisticians om are veterans of the ISNET series. Its overall discussed in Ref. [24]. The collaboration is et of software tools that enable emulation, innulation, Bayesian model mixing, and BED. lucts regular "BAND camps" during which who are mainly, but not exclusively, graduate postdocs-go through various examples of and learn how to use the software tools (Figure 8). amples, and BAND camp materials can be found dframework,github.io.

gan 12 years ago. Since then, UQ has gone from istream in nuclear theory, Bayesian methods find plication in both experiment and theory, and MI part of the nuclear physics toolkit. There are now tings every year that seek to leverage these methprogress on particular nuclear physics problems. ape, ISNET continues to play a key role by proena for statisticians and physicists to meet and olinary conversation regarding better ways to

Nuclear Physics News

lou et al., Comput. Phys. Commun. 269 (2021), 108087 ://doi.org/10.1016/j.cpc.2021.108087 Lovell et al., Phys. Rev. C 103 (2021), 014615, https:// vo/10 1103/PhysRevC 103 014615

Lovell et al., LA-UR-22-30006. Los Alamos, NM, Los Alamos National Laboratory (2024). ratt, E. Sangaline, P. Sorensen, and H. Wang, Phys. Rev. 114 (2015). 202301. https://doi.org/10.1103/PhysRev

L. Heffernan, C. Gale, S. Jeon, and J.-F. Paquet (2023). c//arxiv.org/abs/2302.09478. Melendez et al., Eur. Phys. J. A 57 (2021), 81, https://

org/10.1140/epia/s10050-021-00382-2 Melendez et al., Phys. Rev. C 100 (2019). 044001. e//doi.org/10.1103/PhysRevC.100.044001 Phillips et al., J. Phys. G 48 (2021). 072001. https://







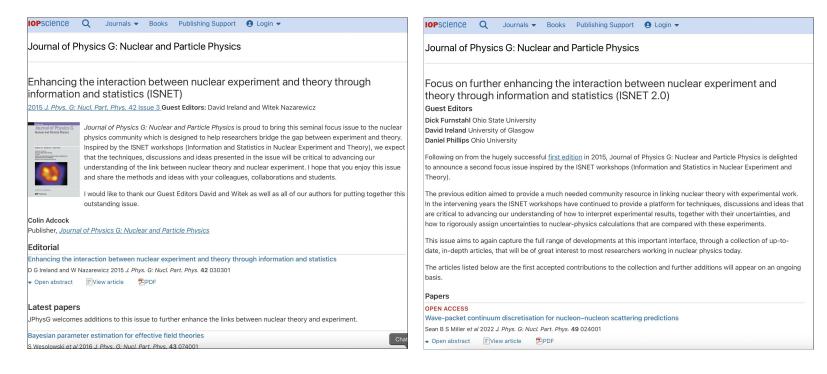
DANIEL R. PHILLIP

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#### More ISNET output!

Two special issues in J Phys. G, interesting to see how the topics and ISNET evolve



### ISNET website <a href="https://isnet-series.github.io/">https://isnet-series.github.io/</a>

#### ISNET Series Website

The online knowledge base of the Information and Statistics in Nuclear Experiment and Theory (ISNET) series

Home		
About ISNET		
Code of conduct		
Charter		
Board		
Publications		
JPhysG Special Issues		
Resources		
Schools		
Collaborations		
ISNET meetings		

#### Welcome #

This site is the online home of the ISNET community. The purpose of this site is to host information about past and future meetings, publications, and to maintain a base of knowledge about statistics and nuclear physics resources such as articles, textbooks, and websites.

#### Become a member by joining our email list #

Send an email with *subscribe* in the body (empty subject) to <u>isnet-request@lists.chalmers.se</u>
Confirm subscription by replying to listserv email

#### Resources

This page links to schools and training courses and their resources.

- Learning from Data: Bayesian Methods and Machine Learning. This links to a course webpage and github repository for a Nuclear TALENT (Training in Low Energy Nuclear Theory) course held at the University of York in York, UK from June 10 to 28, 2019
- Learning from Data: OSU Physics 8820. A course by R. J. Furnstahl on Bayesian statistics for physicists.
   Course material in the form of a Jupyter Book.
- Learning from Data: Chalmers Physics TIF285. A course by C. Forssen on scientific data analysis using Bayesian inference and machine learning. Course material in the form of a Jupyter Book.

### ISNET Board (formed 2022) & rotation of board members

- (Chair) Andreas Ekström, Chalmers University of Technology
- (Co-chair) Amy Lovell, Los Alamos National Laboratory
- Tanja Horn, The Catholic University of America
- David Ireland, University of Glasgow
- Alessandro Lovato, Argonne National Laboratory
- Jean-François Paquet, Vanderbilt University
- Agnieszka Sorensen, Facility for Rare Isotope Beams
- Özge Surer, Miami University
- Ian Vernon, Durham University
- Simin Wang, Fudan University
- Stefan M. Wild, Lawrence Berkeley National Laboratory
- Richard Wilkinson, University of Nottingham

Former members:

Daniel Phillips (chair 2022-2024)

Dick Furnstahl

Paul Stevenson

Matt Plumlee

Scott Pratt

Maria Piarulli

Junchen Pei

4 Board-members rotate out every 2 years. Next rotation summer 2027 Meets quarterly. Issues yearly calls for proposals to host the ISNET workshop.

#### ISNET Code of Conduct

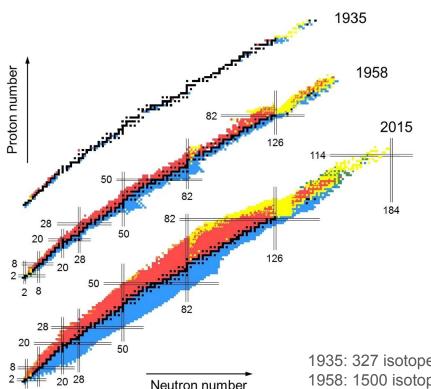
ISNET is committed to fostering a safe, diverse, inclusive, and equitable environment that values mutual respect and personal integrity. Therefore, all participants in ISNET activities will conduct themselves in a welcoming and professional manner, treating one another respectfully and considerately. Participants shall not discriminate against, harass, or bully other meeting attendees. Creating such an ISNET culture — one that is collegial, inclusive, and professional is the responsibility of all meeting participants and ISNET members.

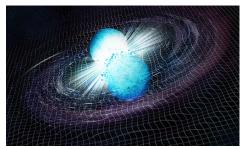
If you observe inappropriate comments or actions and personal intervention seems appropriate and safe, you are encouraged to intervene in ways that are, insofar as it is possible, considerate of all parties involved. ISNET members and meeting participants will not discriminate against, act in an inappropriate way, or make inappropriate statements related to others': age, race, ethnicity, perceived or actual social class, sexual orientation, gender identity, gender expression, marital status, nationality, political affiliation, religion, ability status, educational background, or any other characteristic protected by law. No kind of harassment (including sexual harassment) or bullying will be tolerated.

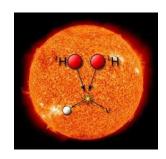
Bullying is unwelcome, aggressive behavior involving the use of influence, threat, intimidation, or coercion to dominate others. Harassment includes but is not limited to: inappropriate or intimidating behavior and language, unwelcome jokes or comments, unwanted touching or attention, offensive images, photography without permission, and stalking. Sexual harassment is unwelcome sexual advances, requests for sexual favors, and other verbal or physical conduct of a sexual nature that creates an intimidating, hostile, or offensive environment.

Violations of this code of conduct policy should be reported to meeting organizers and/or members of the <u>ISNET Board</u>, including the Chair, Andreas Ekström or Co-Chair Amy Lovell. Sanctions may range from verbal warning, to ejection from the meeting, to a suspension from future ISNET activities, to the notification of appropriate local authorities. Retaliation for complaints of inappropriate conduct will not be tolerated and will result in an escalated sanction.

#### Multiple data streams "from the cosmos and the lab"



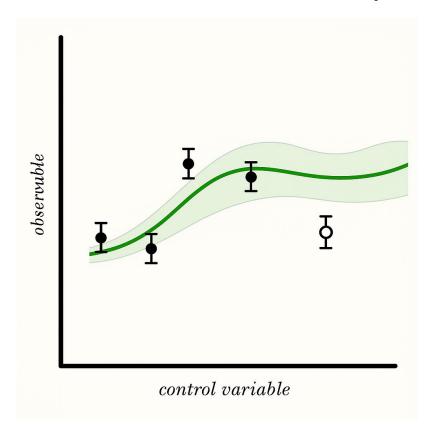




- How do we quantify what we know, and what we don't know?
- How do we connect uncertain models to uncertain data?

1935: 327 isotopes of 92 elements 1958: 1500 isotopes of 102 elements 2015: 4000 isotopes of 118 elements

#### Predictions are hard, especially about the future...



"All models are wrong, but some are useful"

Effective field theories introduce truncation errors

Many-body methods are approximative

Data, predictions, and parameters exhibit correlations

We need to assess how reliable our predictions are

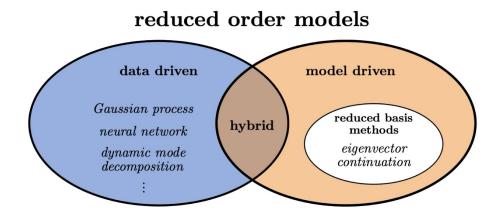
- What limits the predictive power in nuclear physics?
- Where to measure next?

### Computing nuclei typically requires HPC resources

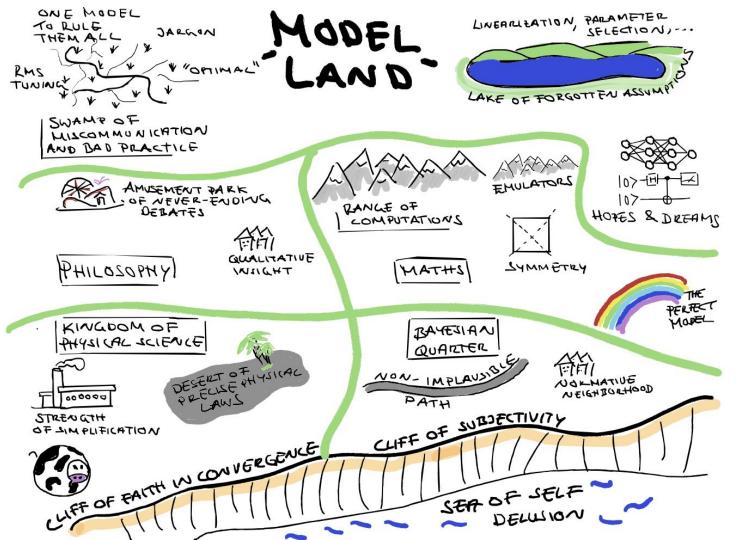
Simulator = numerical solver for the Schrödinger equation

*Emulator* = computationally cheaper surrogate model for the simulator



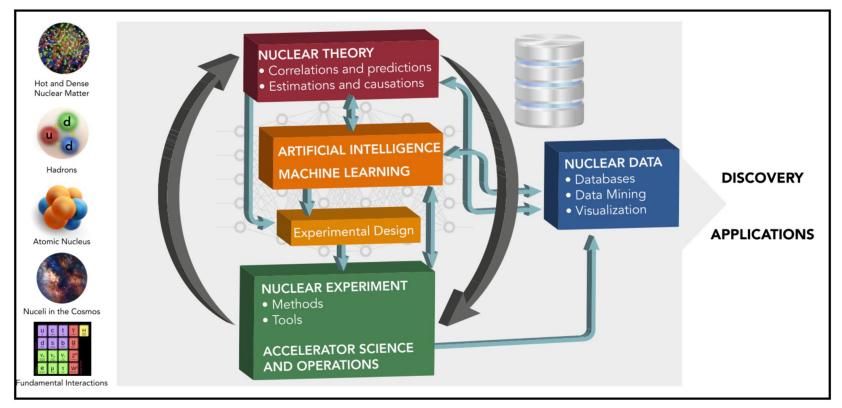


How do we quantify emulation errors?



Inspiration: Thomson & Smith, Economics 13 (2019) Escape from model-land

### Putting it all together: synergy!



#### We look forward to an exciting week full of discussions!

Monday	Tuesday	Wednesday	Thursday	Friday
Emulation	Calibration	Forecasting	Data	Synergy
	9:00-9:45: No stupid questions Christian Forssen, Dick Furnstahl, Daniel Phillips Send topics ideas to phillid1@ohio.edu			

Talks
Schedule at:

https://indico.ectstar.eu/event/247/timetable/#20251117

Discussions (Friday ends with lunch at 12:45pm)

### We look forward to an exciting week full of discussions!

- Things to keep in mind if you are a speaker:
- The audience contains diverse backgrounds, avoid heavy jargon and technical physics details, focus on the connections between the statistics and physics.
- Engage in discussions! There's plenty of time built into the week for this.
- Talks are either 45 minutes (30+15) or 30 minutes (20+10).