

Deep Learning: Lessons from the Launch of IAI FI

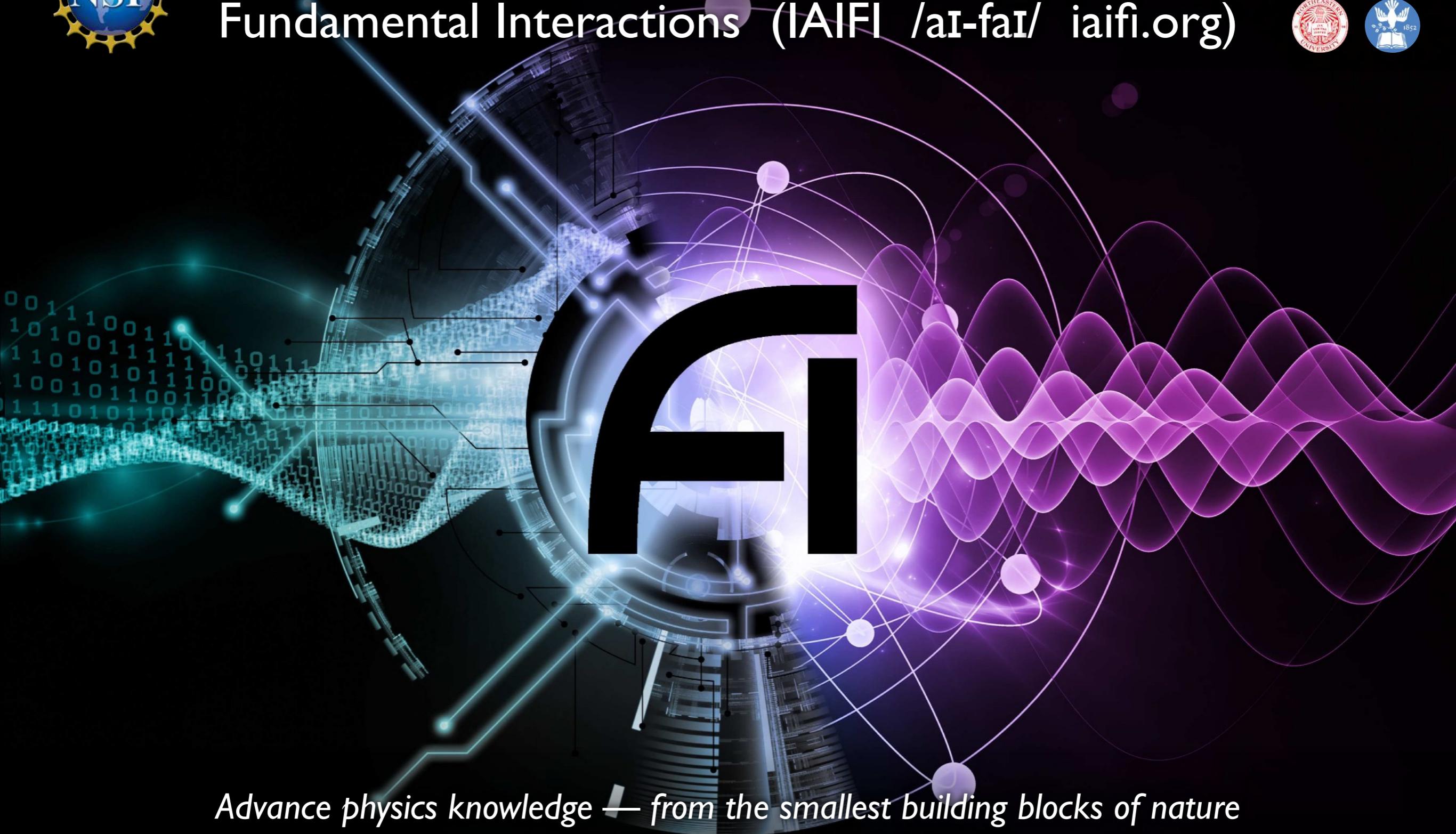
Jesse Thaler



MIT Physics Faculty Lunch — May 5, 2022



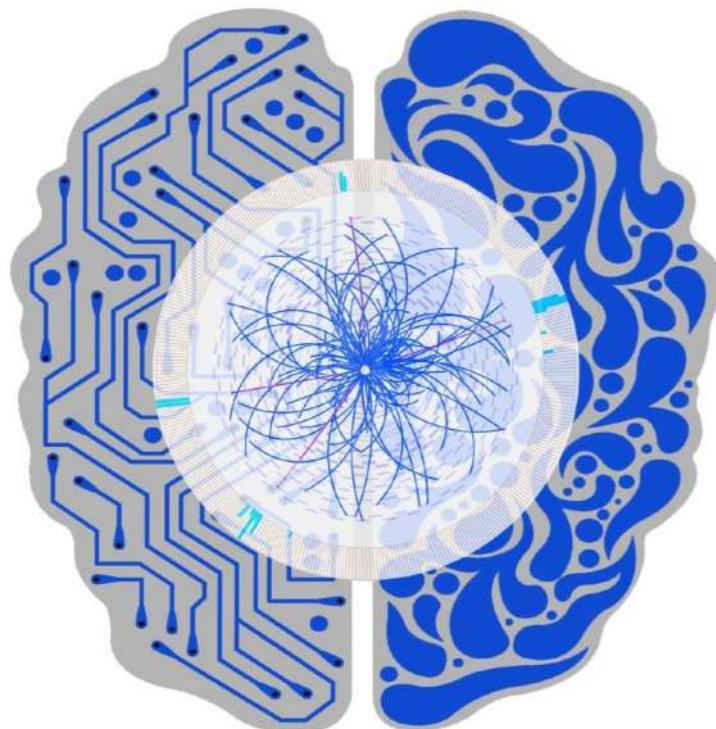
The NSF AI Institute for Artificial Intelligence and Fundamental Interactions (IAIFI /ai-fai/ iaifi.org)



*Advance physics knowledge — from the smallest building blocks of nature
to the largest structures in the universe — and galvanize AI research innovation*



The NSF AI Institute for Artificial Intelligence and Fundamental Interactions (IAIFI /ai-fai/ iaifi.org)



*Infuse physics intelligence
into artificial intelligence*

Symmetries, conservation laws, scaling relations, limiting behaviors, locality, causality, unitarity, gauge invariance, entropy, least action, factorization, unit tests, exactness, systematic uncertainties, reproducibility, verifiability, ...

*Advance physics knowledge — from the smallest building blocks of nature
to the largest structures in the universe — and galvanize AI research innovation*

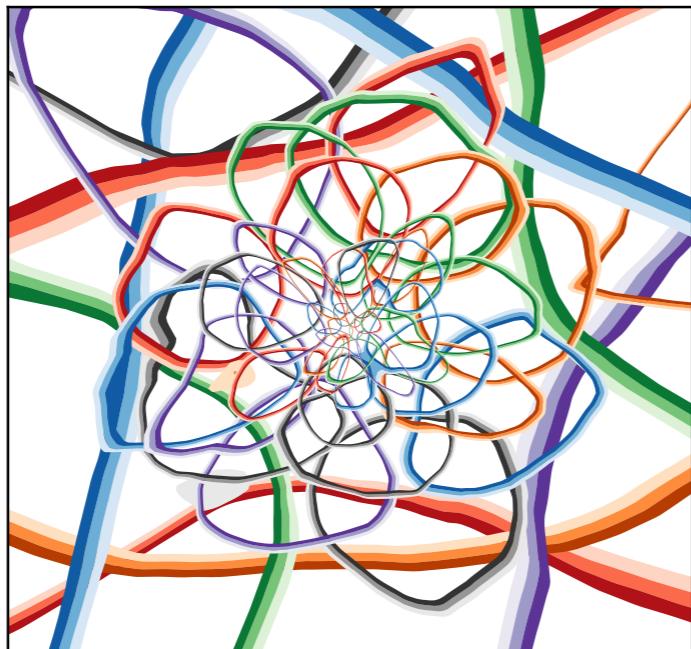
The Before Times

My Faculty Lunch Talk, Sept 2019

Today's Talk: Two Anecdotes

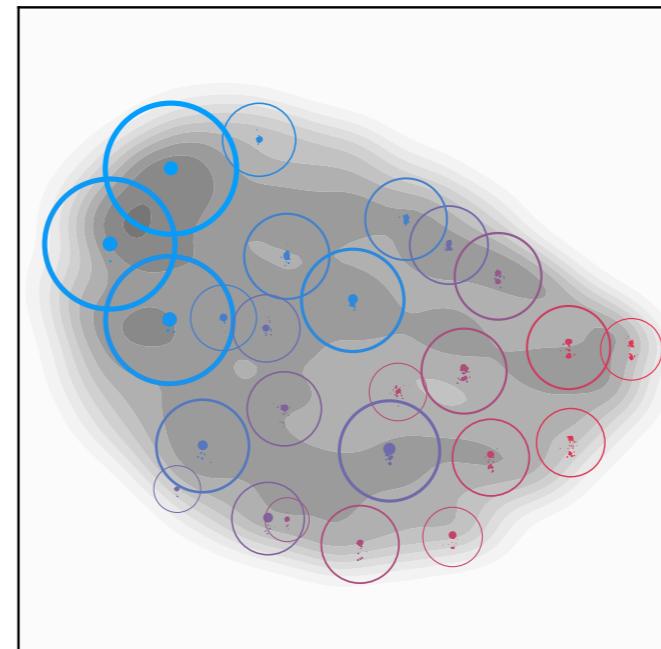


Teaching a Machine to
“Think Like a Physicist”



[Komiske, Metodiev, JDT, JHEP 2019]

Letting Collider Data
Speak for Itself



[Komiske, Mastandrea, Metodiev, Naik, JDT, submitted to PRD;
based on Komiske, Metodiev, JDT, PRL 2019]

*Data analysis strategies motivated by the
symmetries and structures of particle physics*

Jesse Thaler — Collision Course: Particle Physics meets Machine Learning

4

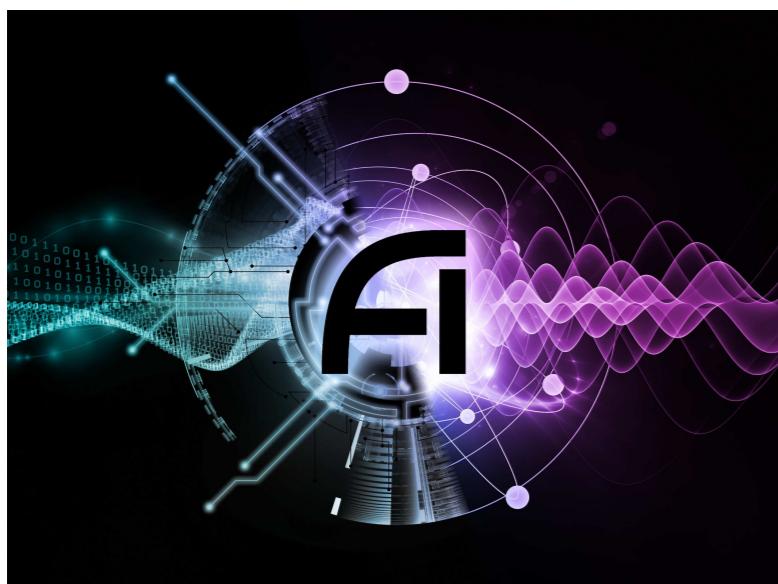
National Science Foundation announces MIT-led Institute for Artificial Intelligence and Fundamental Interactions

IAIFI will advance physics knowledge — from the smallest building blocks of nature to the largest structures in the universe — and galvanize AI research innovation.

Laboratory for Nuclear Science

August 26, 2020

 [PRESS INQUIRIES](#)



The U.S. National Science Foundation (NSF) announced today an investment of more than \$100 million to establish five artificial intelligence (AI) institutes, each receiving roughly [\\$20 million over five years](#). One of these, the NSF AI Institute for Artificial Intelligence and Fundamental Interactions ([IAIFI](#)), will be led by MIT's Laboratory for Nuclear Science (LNS) and become the intellectual home of [more than 25 physics and AI senior researchers](#) at MIT and Harvard, Northeastern, and Tufts universities.

IAIFI Partner Organizations

Senior Investigators: 18 Physicists + 9 AI Experts + 11 IAIFI Affiliates

Junior Investigators: ≈23 FTE PhD Students, ≈7 IAIFI Fellows in steady state



Pulkit Agrawal
Lisa Barsotti
Isaac Chuang
William Detmold
Bill Freeman
Philip Harris
Lina Necib
Kerstin Perez
Alexander Rakhlin
Dan Roberts

Phiala Shanahan
Tracy Slatyer
Tess Smidt
Marin Soljacic
Justin Solomon
Washington Taylor
Max Tegmark
Jesse Thaler
Mike Williams

Carlos Argüelles
Demba Ba
Edo Berger
Mike Douglas
Cora Dvorkin
Daniel Eisenstein
Doug Finkbeiner
Cengiz Pehlevan

Artan Sheshmani
Haim Sompolinsky
Matthew Schwartz
Yaron Singer
Todd Zickler

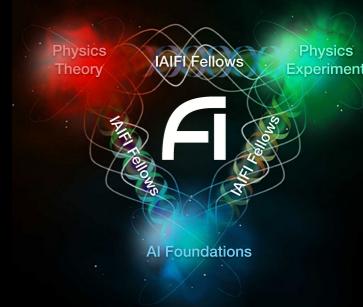
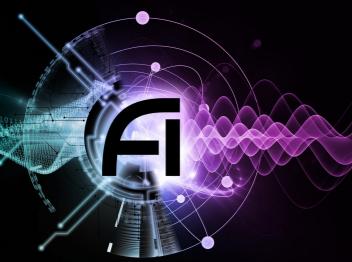
Ning Bao
James Halverson
Brent Nelson
Fabian Ruehle



Shuchin Aeron
Taritree Wongjirad

Inter-institutional, inter-departmental,
cross-disciplinary





IAIFI Activities

IAIFI Research

Theoretical Physics

- Nuclear & Particle Physics
- String Theory/Physical Mathematics
- Astroparticle Physics
- Automated Discovery of Models

Experimental Physics

- Particle Physics Experiments
- Gravitational Wave Interferometry
- (Multi-Messenger) Astrophysics

Foundational AI

- Symmetries & Invariance
- Speeding up Control & Inference
- Physics-Informed Architectures
- Neural Networks Theory

IAIFI Colloquia

- Biweekly talks from leaders in AI and Physics
- Broadcast live on [IAIFI YouTube Channel](#)
- Fall 2021/Spring 2022: every other Friday at 2 pm

IAIFI Fellowship Program

- Three-year postdoctoral appointment
- Freedom in pursuing research and collaborations
- Applications for 2023-2025 open Summer 2022

Interdisciplinary PhD Program at MIT

- Physics, Statistics, and Data Science
- Take 4 classes, 1 each in the areas of Probability, Statistics, Computation & Statistics, and Data Analysis
- Submit and defend a PhD thesis that involves the utilization of statistical methods in a substantial way

IAIFI Affiliate Program

- Senior researchers in the Boston area contributing to IAIFI mission
- Must include nomination from existing IAIFI Senior Investigator

IAIFI Early Career and Equity Committee

- Serves as advisory board to IAIFI Management on aspects related to early career researchers and diversity, equity, and inclusion (DEI)
- Developed a Code of Conduct for IAIFI
- Established and monitors anonymous form for feedback

IAIFI Internal Events

- Includes IAIFI Internal Discussion Seminars, Journal Club, and social/networking events
- Open to IAIFI Investigators and affiliated junior and senior researchers in the Boston area

IAIFI Computing Resources

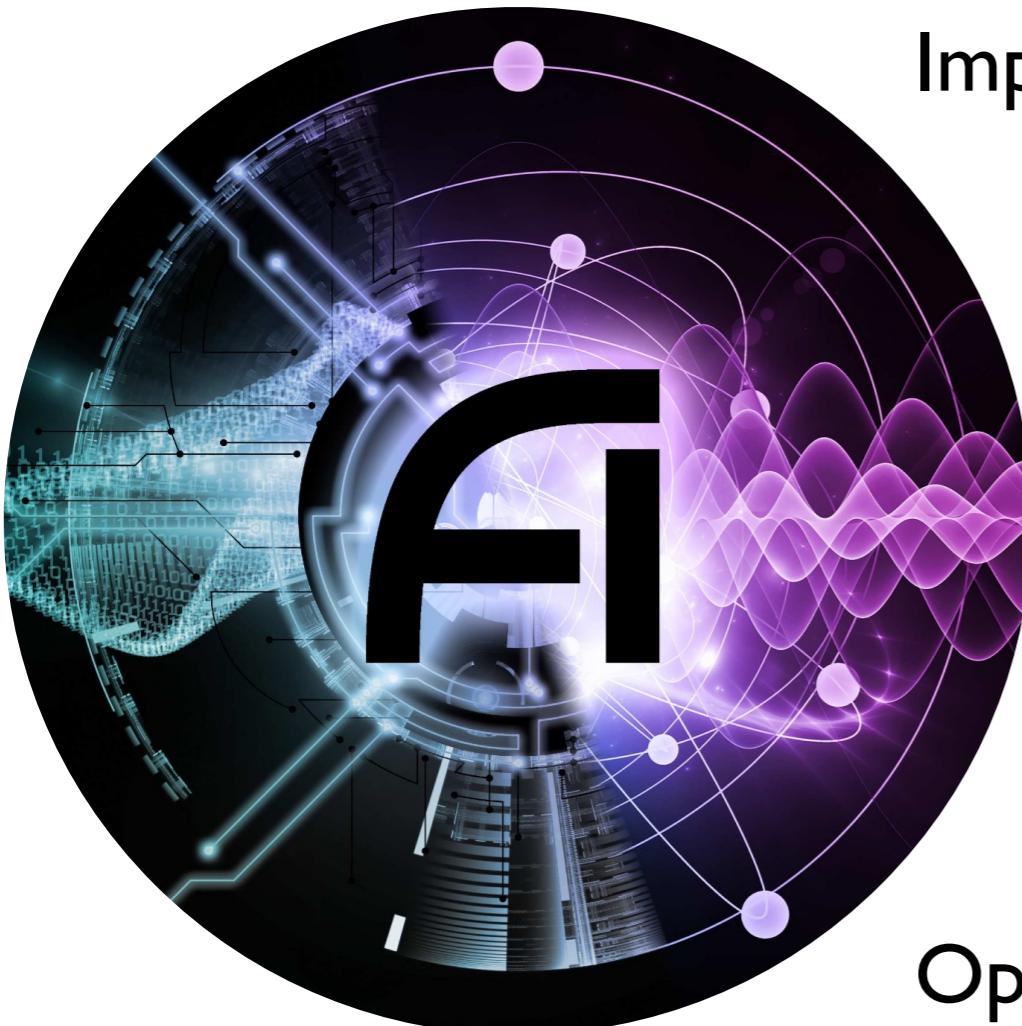
- Conducted a survey of IAIFI members regarding their computing needs
- Plan to purchase 8 Lenovo GPU nodes, each with 4x nVidia A100 GPUs (~\$540k)
- Will be stored and operated through Harvard Cannon

MITx course

- Developing digital course based on IAP course: "Computational Data Science in Physics"
- 12 weeks of content at the undergraduate/graduate level
- Received a \$72,000 grant from MIT for development



Lessons from Launching IAIFI



Importance of Shared Vision

Need for Cross-Disciplinary Education

Enthusiasm of Junior Researchers

Vibrancy from Community Building

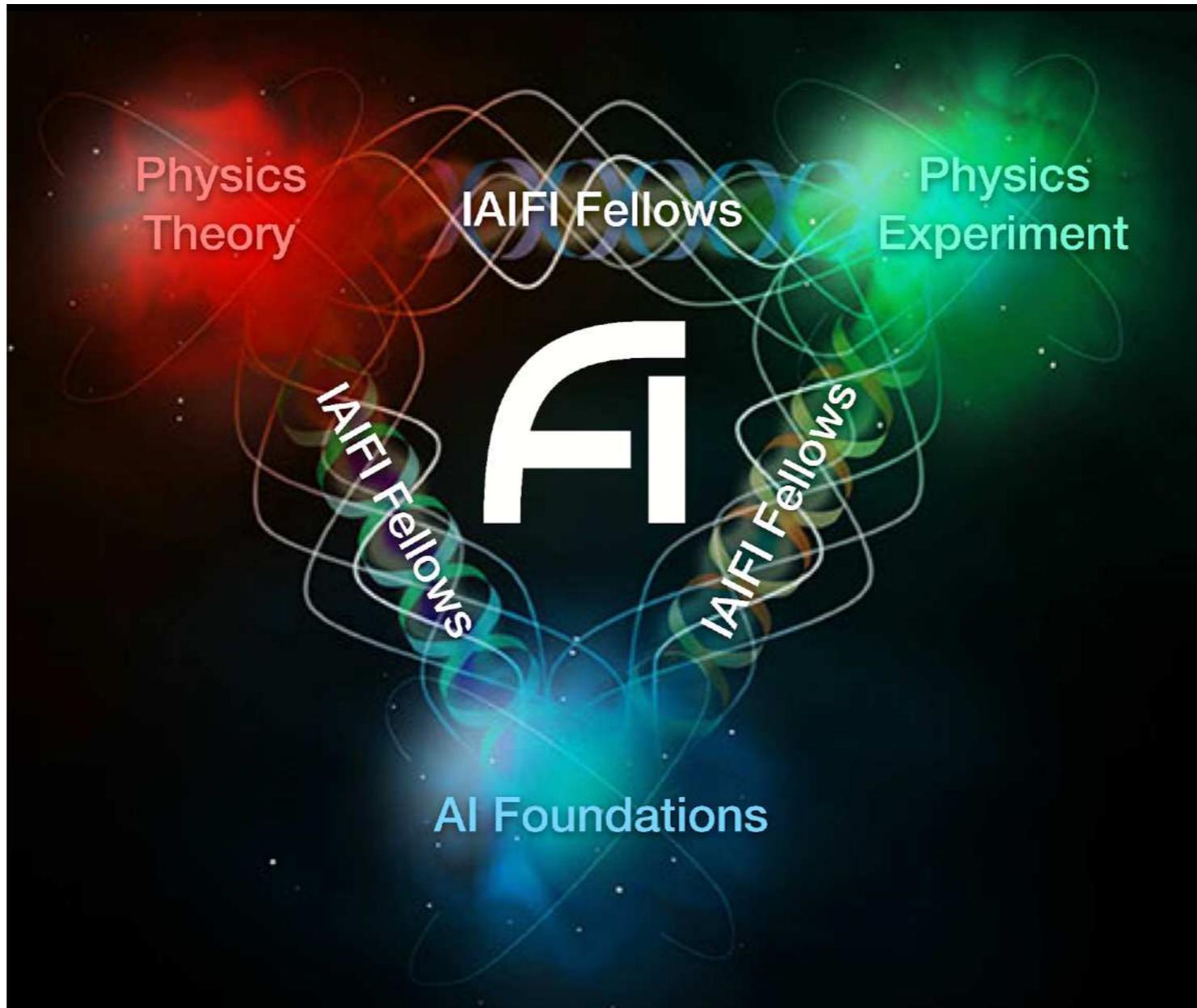
Power of Project Management

Opportunities for Future Growth

<http://iaifi.org/>

iaifi@mit.edu

[@iaifi_news](#)



Importance of Shared Vision



NSF AI Institute for Artificial Intelligence & Fundamental Interactions

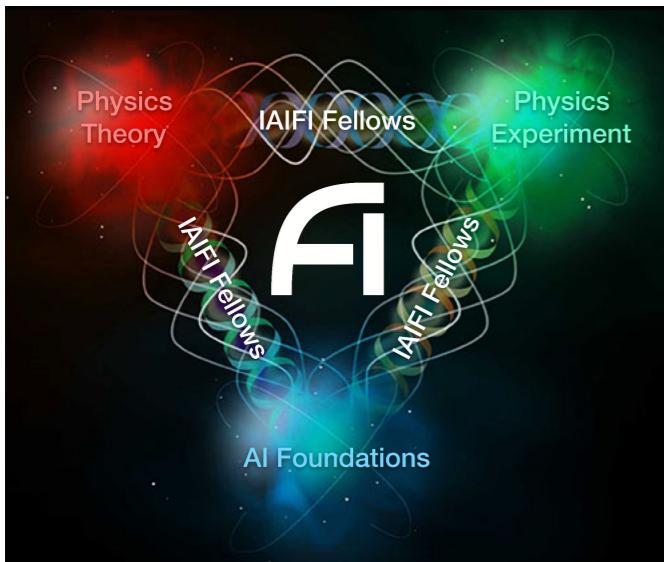


AI Foundations:

Power of machine learning to process large, rich data sets

Physics Theory & Experiment:

First principles and best practices from fundamental interactions

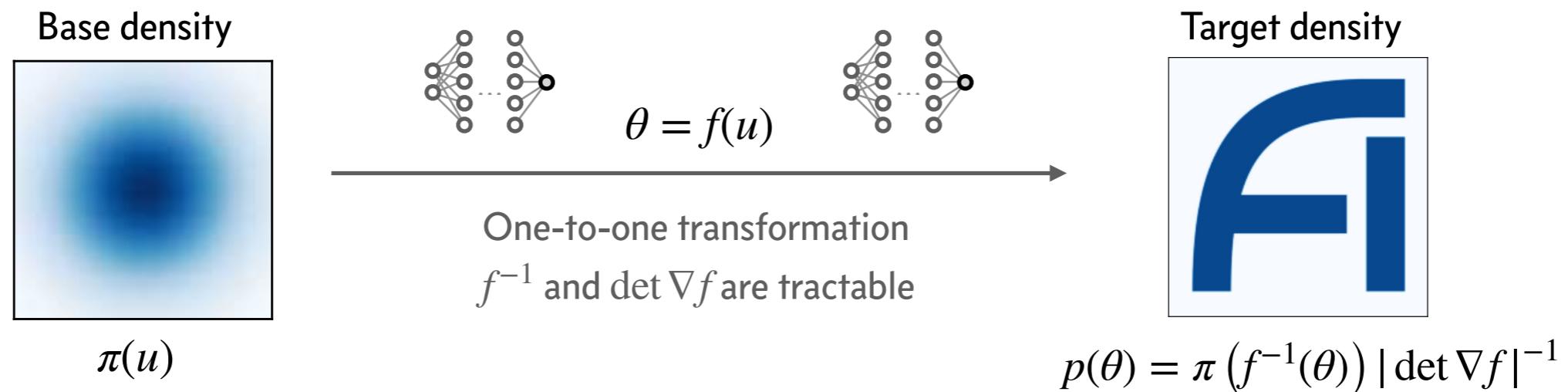


Enable physics discoveries by developing and deploying the next generation of AI technologies ($AI \Rightarrow Physics$)

Galvanize AI innovation by incorporating physics intelligence into artificial intelligence ($Physics \Rightarrow AI$)

E.g. Generative Models

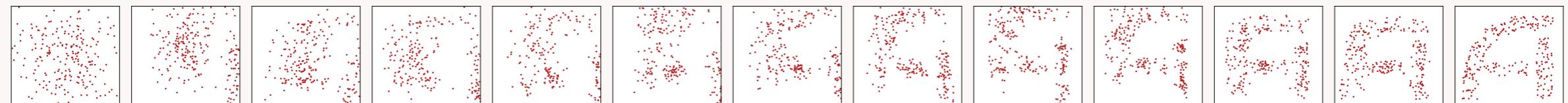
Normalizing flows



Efficient density estimation: $\log \hat{p}(\theta)$



Efficient sampling: $\theta \sim \hat{p}(\theta)$

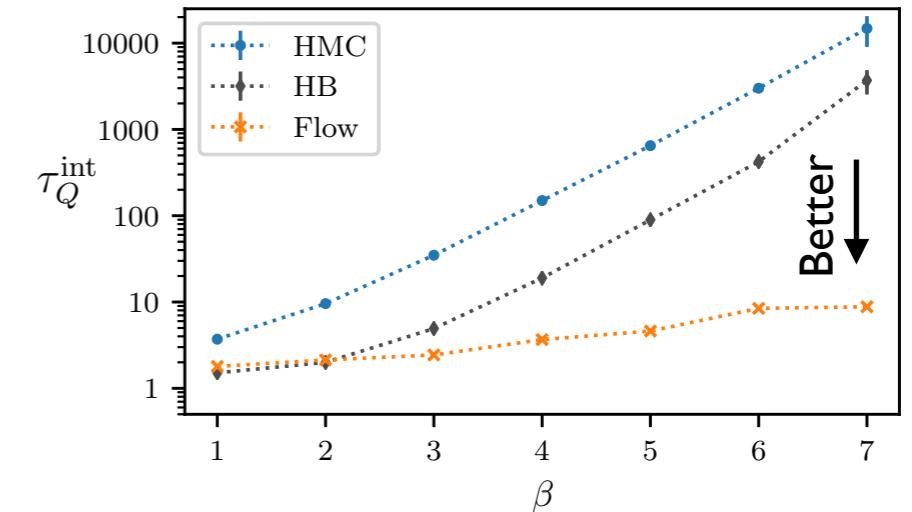
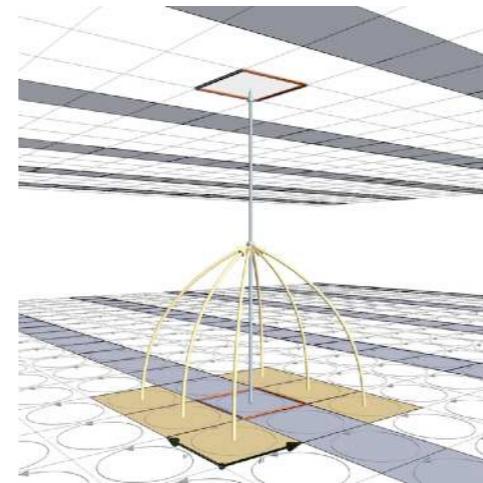


AI \Rightarrow Th/Ex Physics

Normalizing flows as flexible generative model

Theoretical Calculations

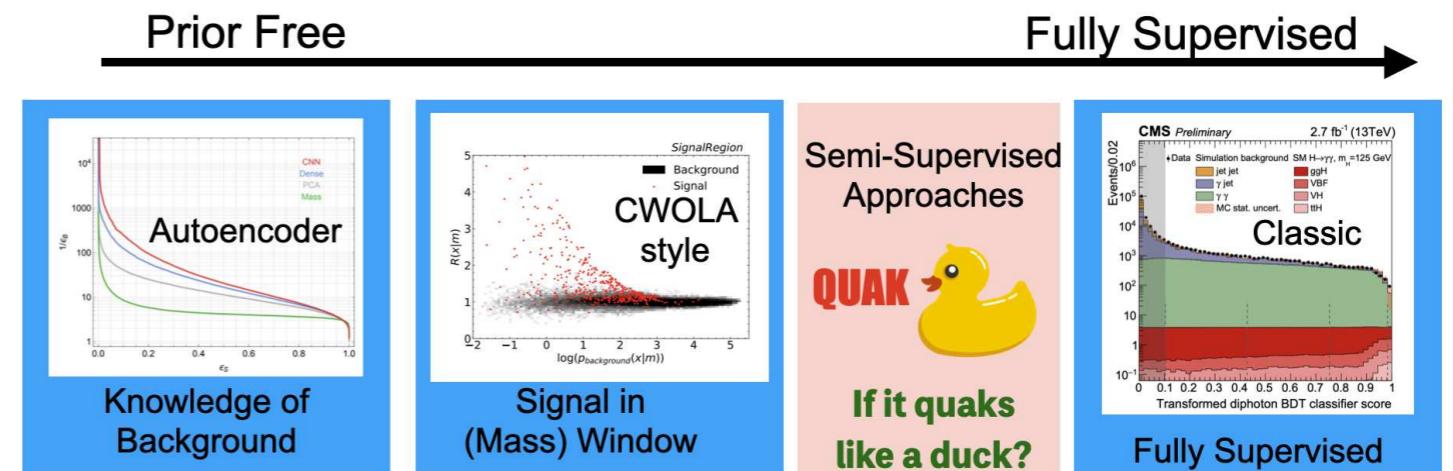
Guarantees of Exactness
Gauge Equivariance
Compact Domains



[Kanwar, Albergo, Boyda, Cranmer, Hackett, Racanière, Rezende, [Shanahan, PRL 2020](#)]

Experimental Searches

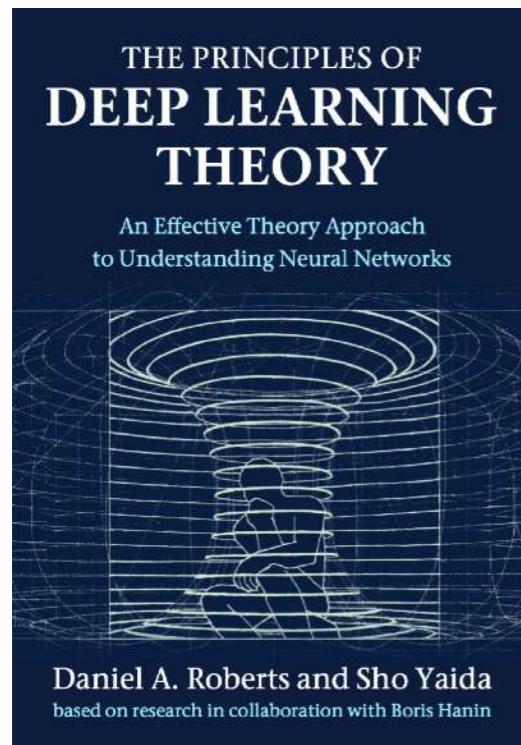
Prior (In)dependence
Dimensionality Reduction



[Park, Rankin, Udrescu, Yunus, [Harris, JHEP 2021](#)]

Th Physics \Rightarrow AI

Quantum field theory for nearly Gaussian processes



NGP / finite NN	Interacting QFT
input x	external space or momentum space point
kernel $K(x_1, x_2)$	free or exact propagator
network output $f(x)$	interacting field
non-Gaussianities	interactions
non-Gaussian coefficients	coupling strengths
log probability	effective action S

[Halverson, Maiti, Stoner, [MLST 2021](#); Roberts, Yaida, Hanin, [CUP 2022](#)]



From Robots...

Gabriel Margolis
Ge Yang (IAIFI Fellow)
Pulkit Agrawal

...to LIGO!

+ Lisa Barsotti



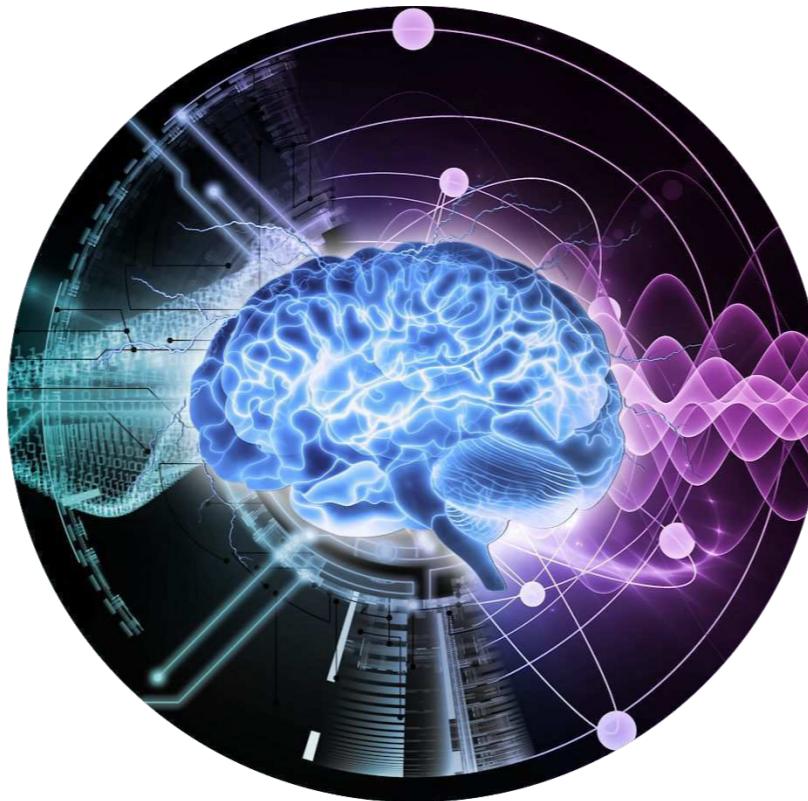


Interested in learning more about IAIFI?

<http://iaifi.org/>

iaifi@mit.edu

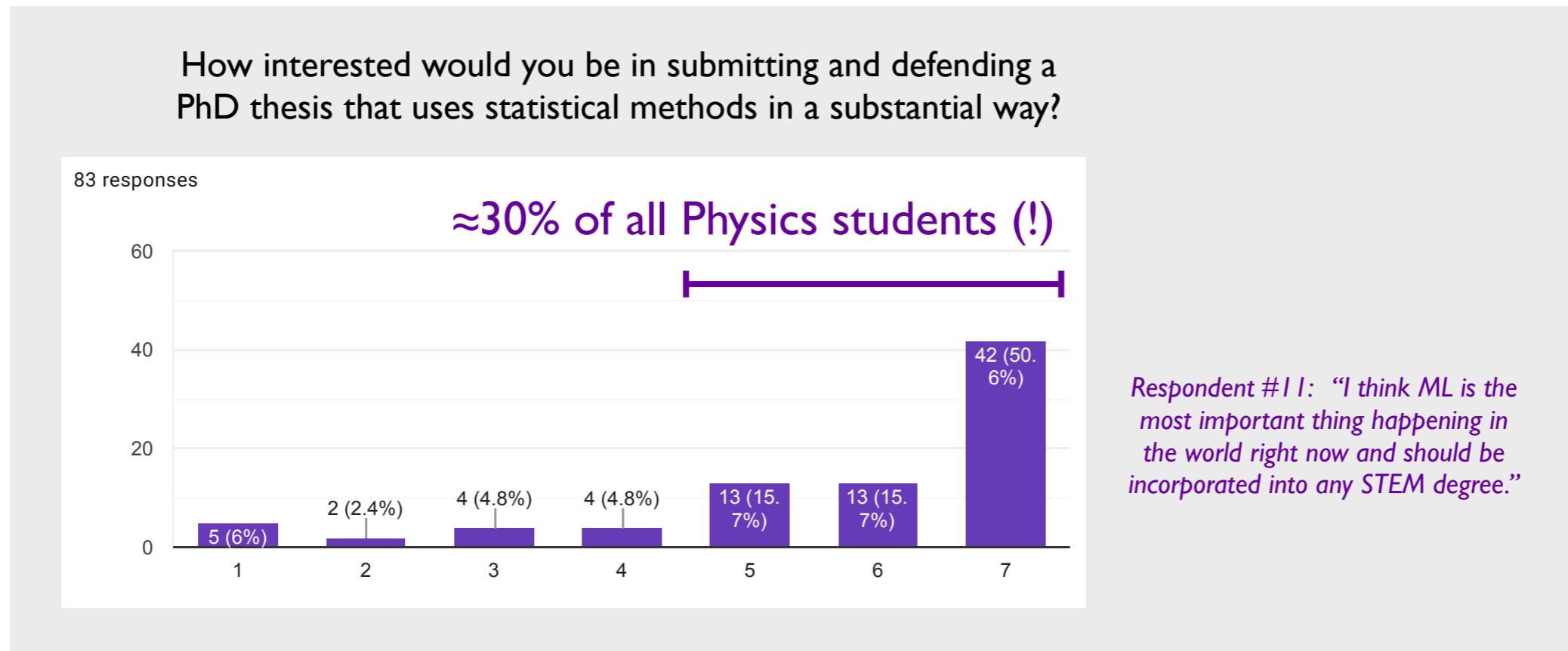
[@iaifi_news](https://twitter.com/@iaifi_news)



Need for Cross-Disciplinary Education

PhD in Physics, Statistics & Data Science

≈ Physics PhD + 4 courses (probability, statistics, computation, data analysis)



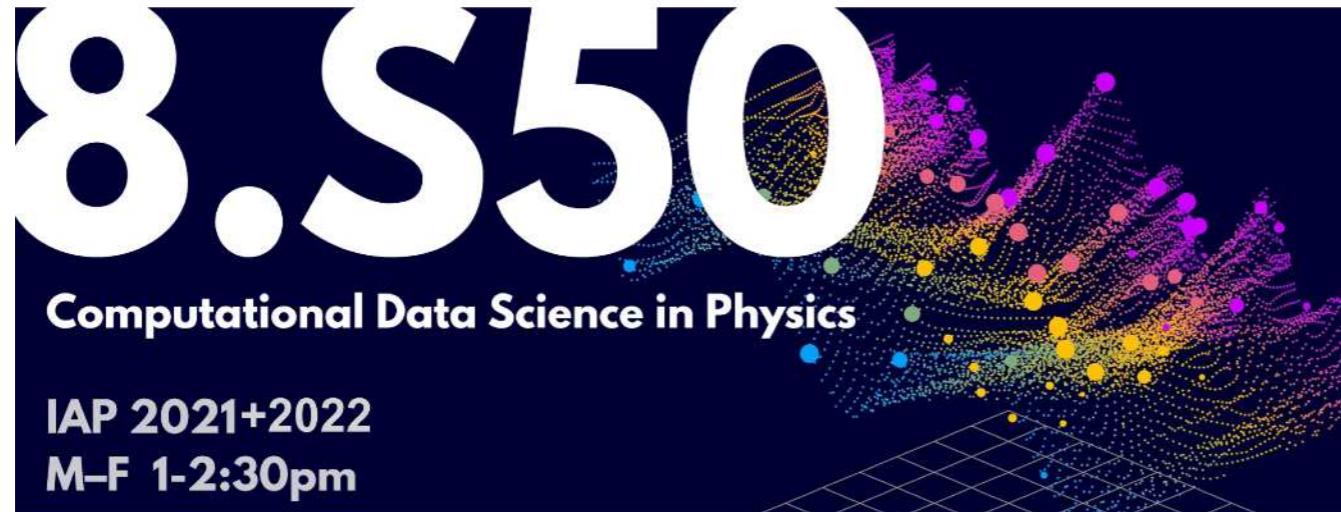
Congratulations,
Dr. Constantin Weisser!
(March 30, 2021)

2 students already graduated
7 students currently enrolled
many more students taking the courses

[<https://physics.mit.edu/academic-programs/graduate-students/psds-phd/>]

Data Science in Physics

IAP \Rightarrow MITx: *Phil Harris, Ike Chuang, Alex Shvonski*



https://github.com/violatingcp/MIT_8.S50

Guiding Principles

- Analysis of data as central part of scientific process
- Computation as essential scientific tool
- Open data to make inference on recent physics
- Statistical principles behind computation

Exploring possibility to adapt this for “8.16” and/or “8.316”

The LIGO logo consists of the word "LIGO" in a bold, black, sans-serif font next to a graphic of three concentric grey ellipses representing gravitational waves.	Project 1 : Gravitational Wave Data From LIGO
The CMS logo features the acronym "CMS" in a blue, stylized font above a graphic of a particle collision event with red, yellow, and green tracks.	Project 2 : Collider Physics Data from the Compact Muon Solenoid on the Large Hadron Collider
The chime logo shows the word "chime" in red below a graphic of several black wavy lines representing microwave signals.	Project 3 : Cosmic Microwave Background (simulated) Data

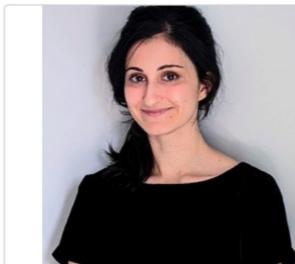


IAIFI

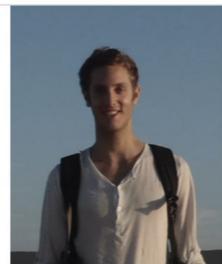
Summer School & Workshop
August 1–9, 2022

≈ 200 applicants \Rightarrow Hybrid sessions

Five Leading AI/Physics Experts



Yasaman Bahri
Research Scientist, Google Research
(Brain Team)



Taco Cohen
Research Scientist, Qualcomm
Research Netherlands



Sven Krippendorff
Senior Researcher, Mathematical
Physics and String Theory, Ludwig-
Maximilians Universität



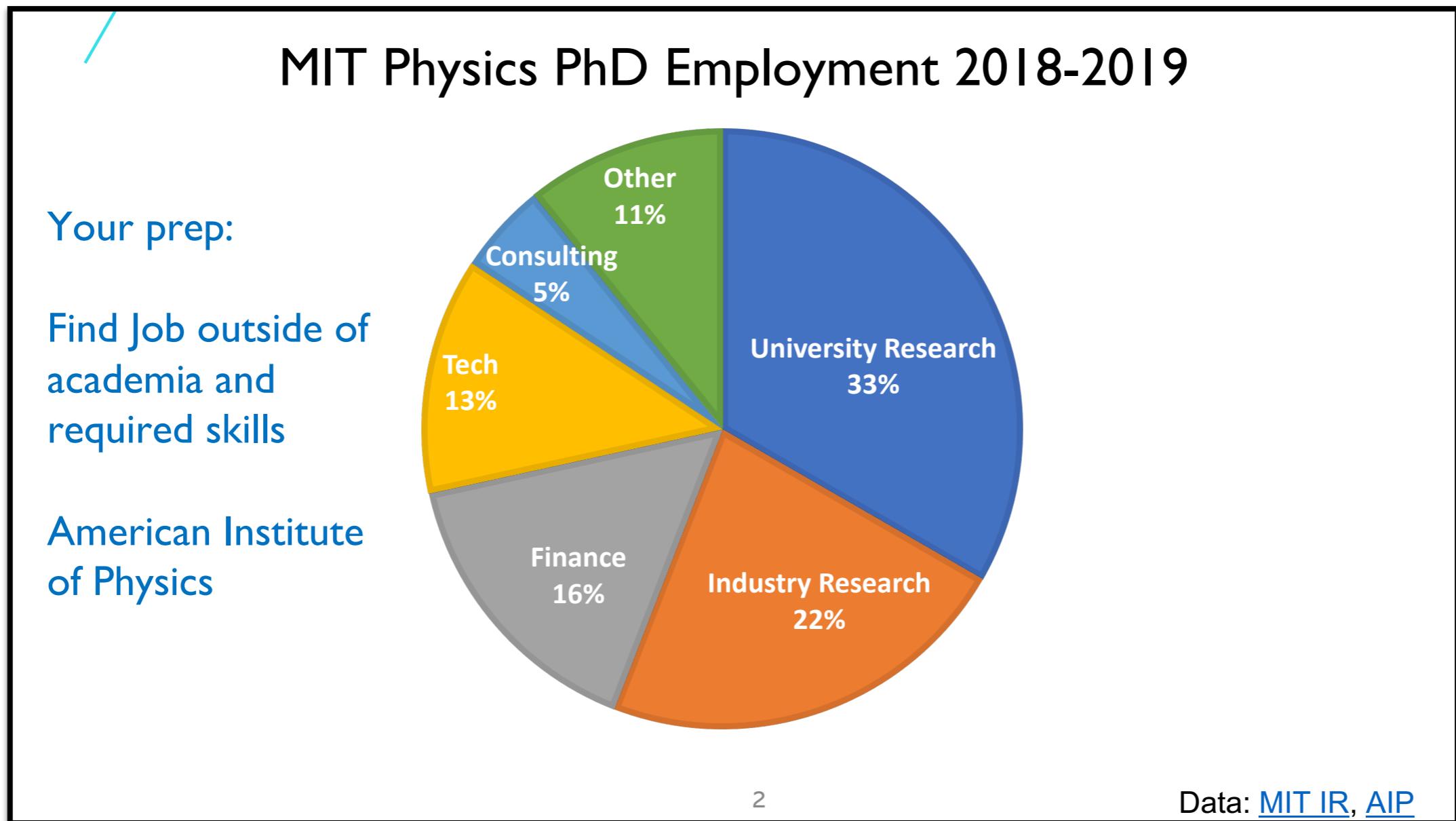
Juan Carrasquilla
Faculty Member, Vector Institute;
Adjunct Assistant Professor,
University of Waterloo



Javier Duarte
Assistant Professor, University of
California, San Diego

Workshop registration now open!
<https://iaifi.org/phd-summer-school.html>

Cross-Disciplinary Training... ...Needs Cross-Disciplinary Career Advice



Constantin Weisser, 8.398 Presentation, March 2022



* sadly, no longer junior

Enthusiasm of Junior Researchers

IAIFI Postdoctoral Fellows

Our flagship program; applications opens this summer!

Class of
2022-25



Denis Boyda

AI for
Lattice Field Theory



Carolina Cuesta

AI for Observational
Cosmology



Jessie Micallef

AI for
Neutrino Physics

Class of
2021-24



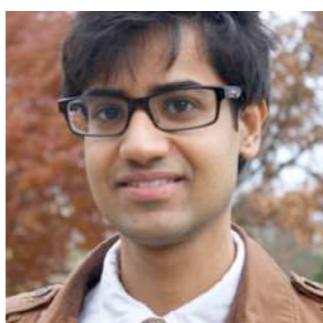
Anna Golubeva

Statistical
Foundations of AI



Di Luo

AI for Quantum
Many-Body Physics



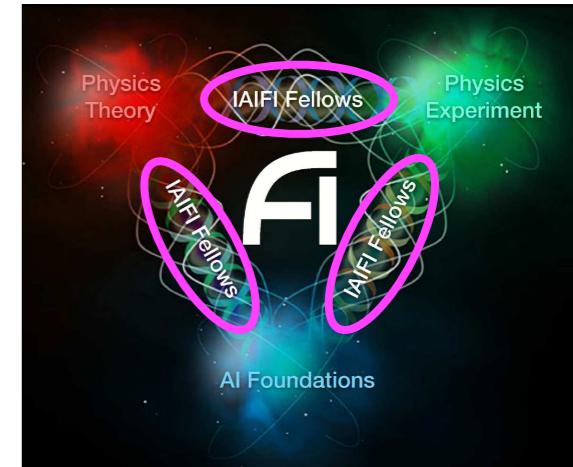
Siddharth Mishra-Sharma

AI for
Astroparticle Physics



Ge Yang

AI Frontiers of
Reinforcement Learning



“Gluons” of IAIFI

Empowering/Entrusting Junior Researchers

E.g. IAIIFI Early Career and Equity Committee

Code of Conduct, Related Policies, Reporting, and Resources

IAIFI Code of Conduct

Regardless of their position or seniority, members of the IAIIFI and participants in IAIIFI activities are expected to:

- Act in an ethical and collaborative manner at all times and abide by the [MIT Physics Community Values](#)
- Work with the utmost scientific integrity and respect the confidentiality of information and work presented at internal IAIIFI meetings
- Treat each other with dignity and respect, support and encourage each other's growth, and step in as needed to maintain an environment free of discrimination, harassment, and bullying

Katie Fraser (Graduate Student)

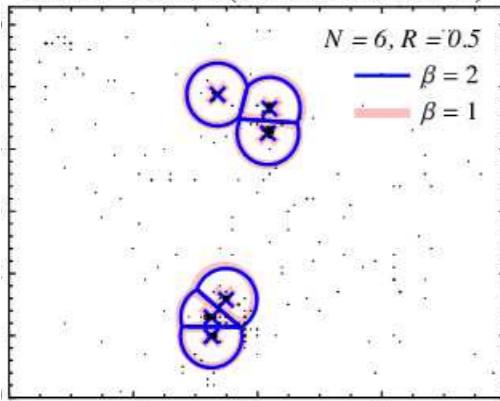
As a junior member of IAIIFI, being on the ECEC has been **rewarding because our suggestions are taken seriously** and often end up **contributing to concrete changes that positively impact DEI**, with only a **limited time commitment**.

Based on ECEC success, we are now engaging grad students and postdocs on most IAIIFI committees

Junior Researchers as Translators

Gambhir, Thaler (MIT, Physics) \leftrightarrow Ba, Dogra (Harvard, AI)

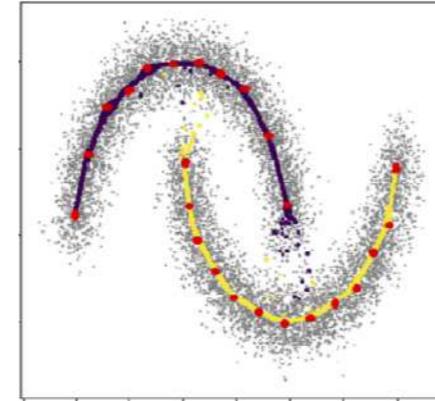
Point-like Jets



XCone

(Stewart, Thaler, Tackmann, Vermilion, Wilkason, 2015)

Learned Manifolds

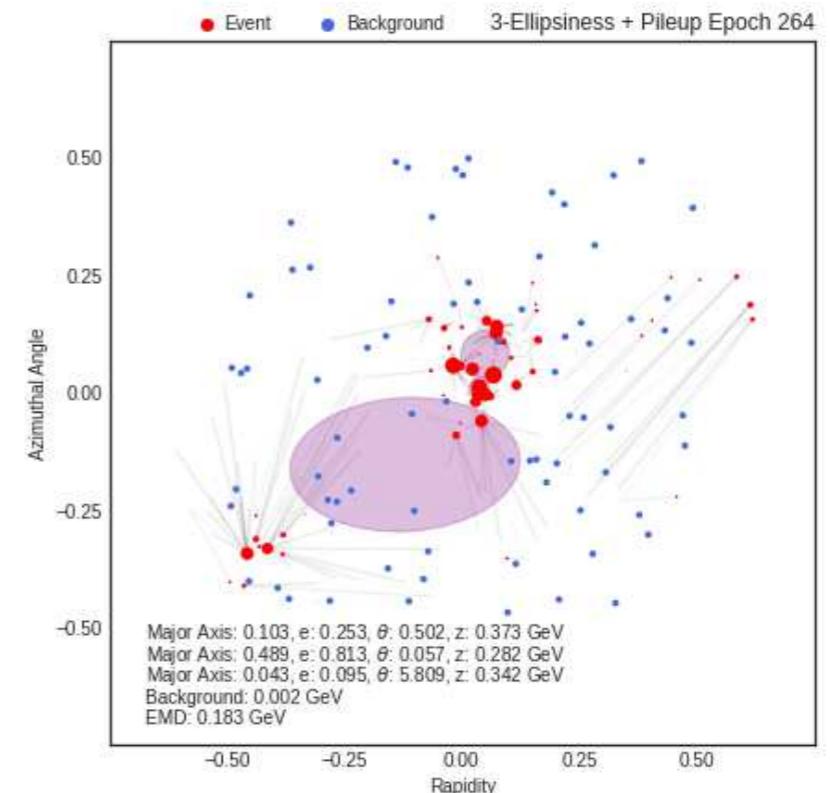


K-Deep Simplex

(Tankala, Tasissa, Murphy, Ba, 2020)



Interpretable Structures!



Preliminary: 3 disks + pileup

Conversations with Kitouni, Nolte, Williams:
Speed this up using LHCb trigger development!

Would we have realized this connection without IAI FI?



Vibrancy from Community Building

Social Events under the Tent



October 2021, MIT



April 2022, Harvard

Scientific connections through pizza & beverages

The IAI FI Penthouse (Building 26)



From Socializing...

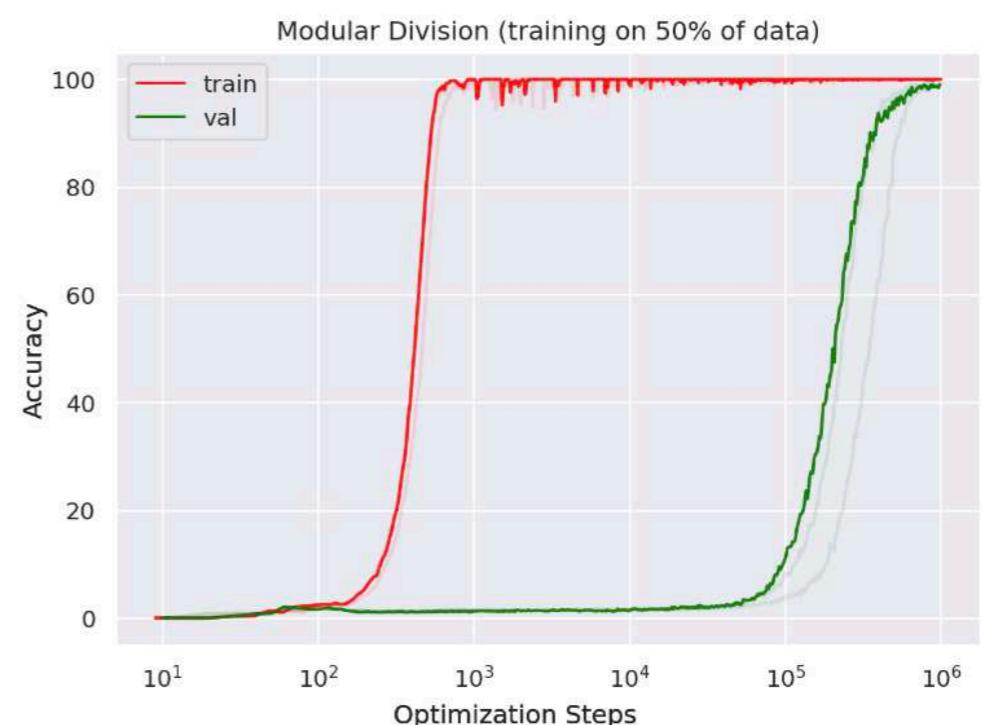
Thanks Peter, Nergis, Bolek!

(And Karen, Caitlin, Jack, Joe, Becca, Marisa, ...)

...to Science!

Memorize, Generalize, or “Grok”?

Journal Club Talk + Penthouse + Physics Insights
= New Understanding of AI Dynamics

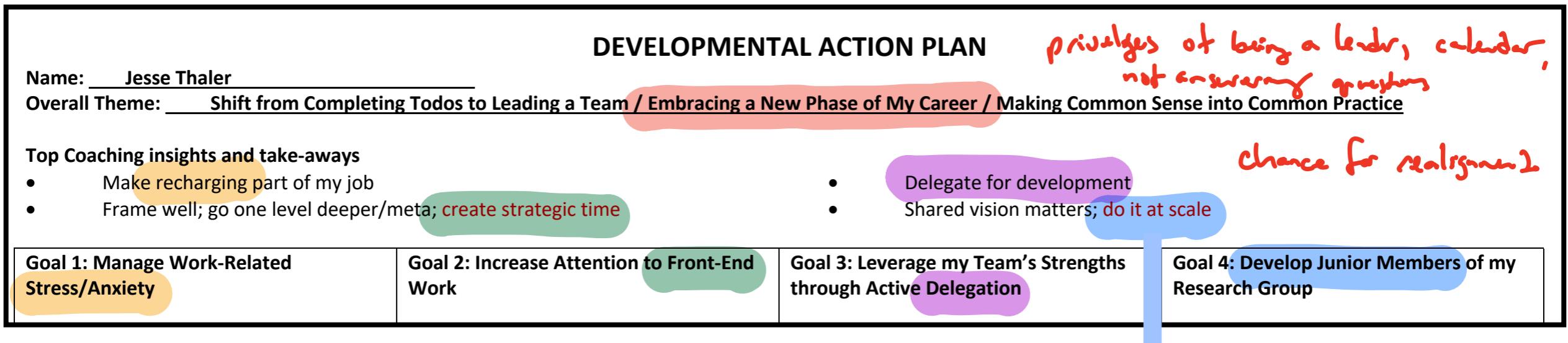




Power of Project Management

Adventures in Professional Coaching

If I seem like a happier person than I was 18 months ago, it's because I am!



So You Want To...

...add your name to the author list?
Anyone who is (or was) a member of Jesse Thaler's research group is welcome to contribute!

8 ...Gain Knowledge in Theoretical Physics?	29
8.1 ...Get Exposed to Exciting Physics Ideas?	29
8.2 ...Learn QFT/Particle Physics/Pheno?	S. Alipour-fard, R. Gambhir 30
8.3 ...Learn Machine Learning for Research?	R. Wynne 33
8.4 ...Pass the Oral Qualifying Exam?	P. Komiske 33
8.5 ...Learn Particle Phenomenology for Research with Jesse?	S. Alipour-fard, R. Gambhir 34

Thanks Peter and Coach Bob!

Proactive Project Management

Thanks Marisa!

Leveraging spectrum of talents to enable scientific advances

Transactional

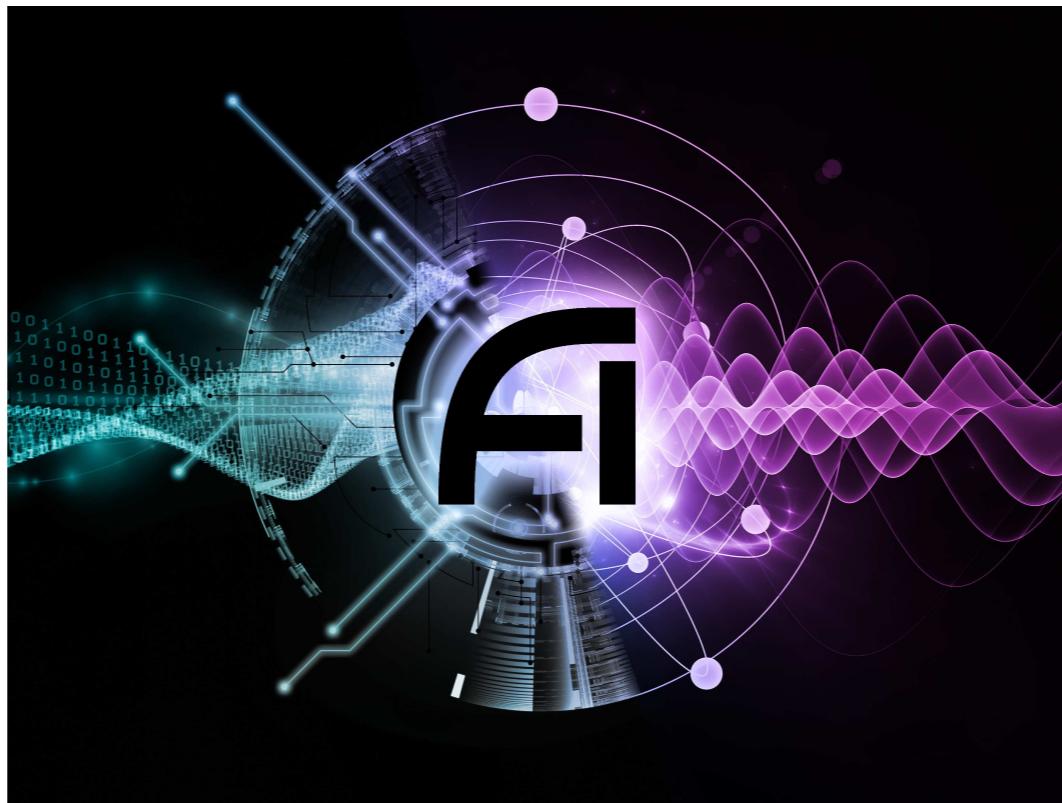
Administrative

Strategic



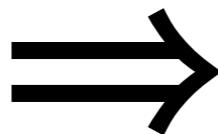
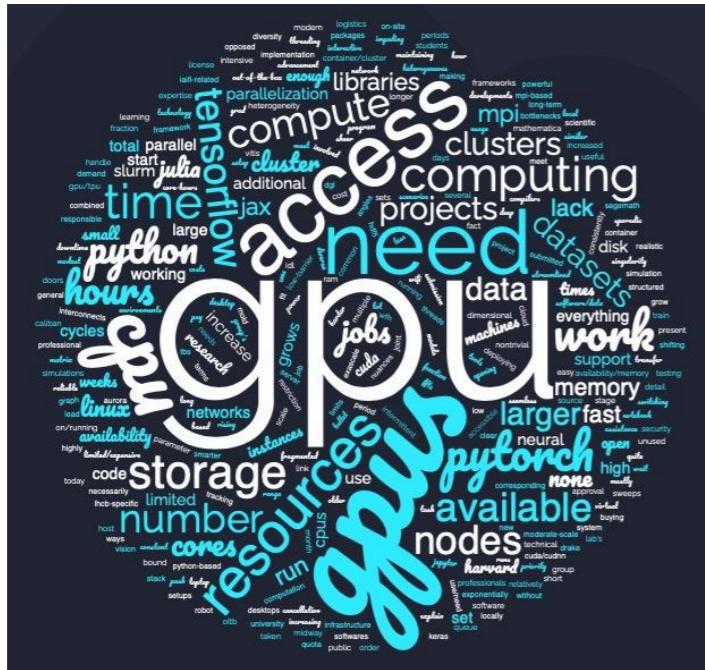
Active Delegation:

Reduce time burden on faculty
Enable staff career development
Create collaborative environment



Opportunities for Future Growth

Towards the Computational Frontier



IAIFI needs circa 2022

32 AI00s @ Harvard Cannon

What science could be unlocked with advanced computing?

Building a bridge from proof-of-concept to leadership class?

Role of MIT Office of Research Computing and Data?

The Future of Physics + AI at MIT

CS Faculty using
Physics Principles



Physics Faculty using
AI/ML Techniques



Tess Smidt, EECS

“Euclidean Neural Networks”

*Watch
this space!*



Lina Necib, Physics

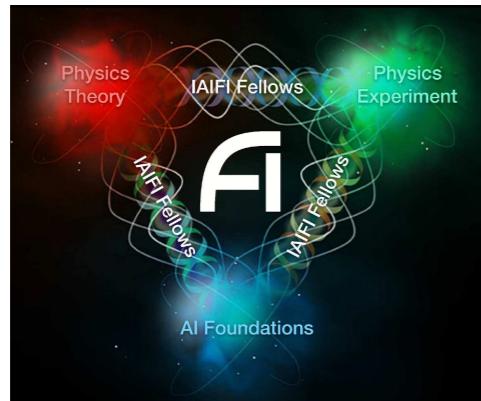
“AI-Assisted Astrometry”

Cultivating talent in this interdisciplinary arena?

Bridge to Schwarzman College of Computing?

Long-term sustainability of IAIPI effort?

Lessons from Launching IAI FI



Shared Vision



Cross-Disciplinary Education



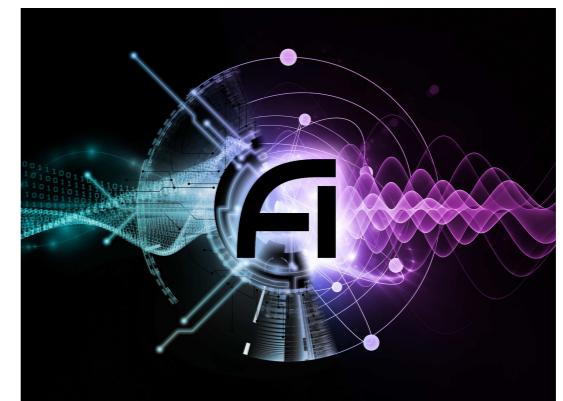
Junior Researchers



Community Building



Project Management



Future Growth

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