



# AI and Scientific Judgment

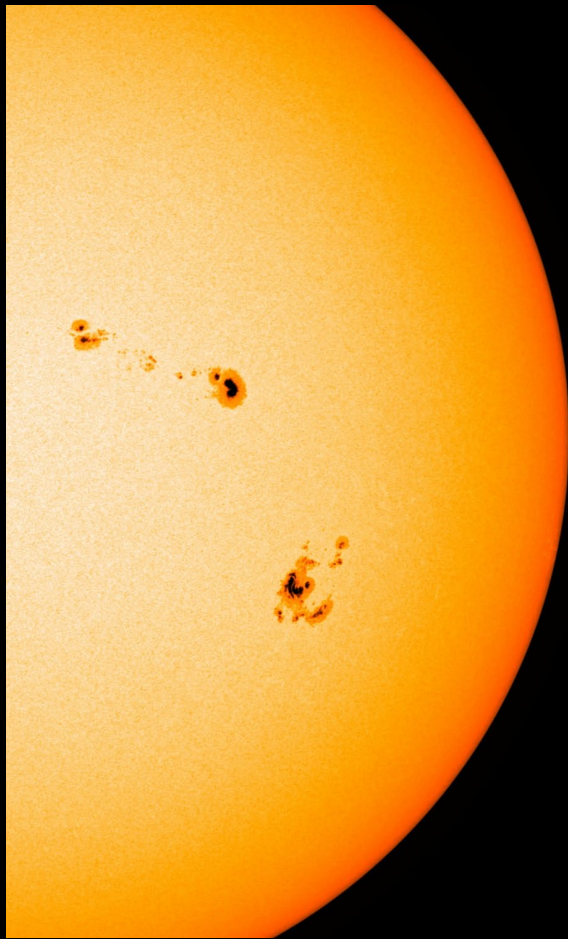
- Beyond analysis
- Shaping scientific judgment

Madhulika Guhathakurta

NASA SMD/Heliophysics Division Program Scientist

NAS Panel Discussion, March 25, 2026

# The Sun



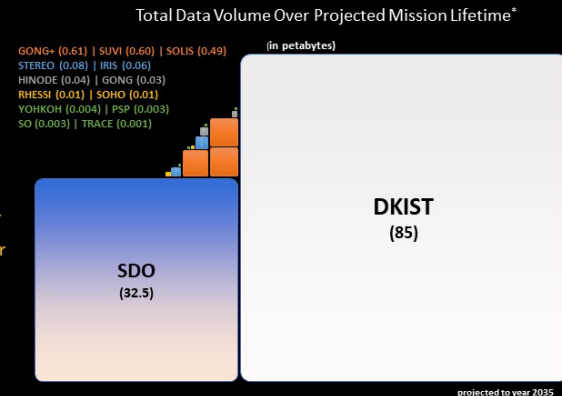
- Solar magnetism is the main driver of solar variability.
- There are three main forms in which the Sun interacts with Earth:
  - **Light.**
  - **Magnetic fields.**
  - **Particles.**
- Light changes the density and conductivity of our upper atmosphere.
- Magnetic fields induce currents in our atmosphere and the ground.
- Particles affect assets in space.

# The Sun Meets the Machine

- Why AI in Heliophysics?
- Why now?
- Terabytes of underused data
- AI as a pattern seeking tool

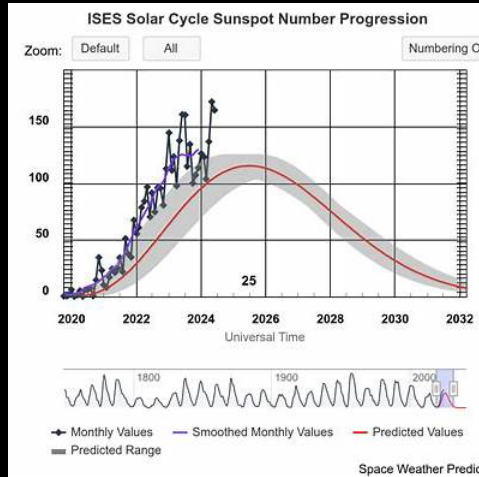
## The Scale of Data

- There is currently over 8.7 PB of compressed AIA images and products.
- Uncompressed this would expand to over 20 PB.
- Optimized SSD reading at 7000MB/s would take over 14 days to read through all AIA files. *Real-world* read/write SSD speeds are closer to 500 MB/s or more than 200 days
- Size isn't the only issue, there are over 230 million AIA images.



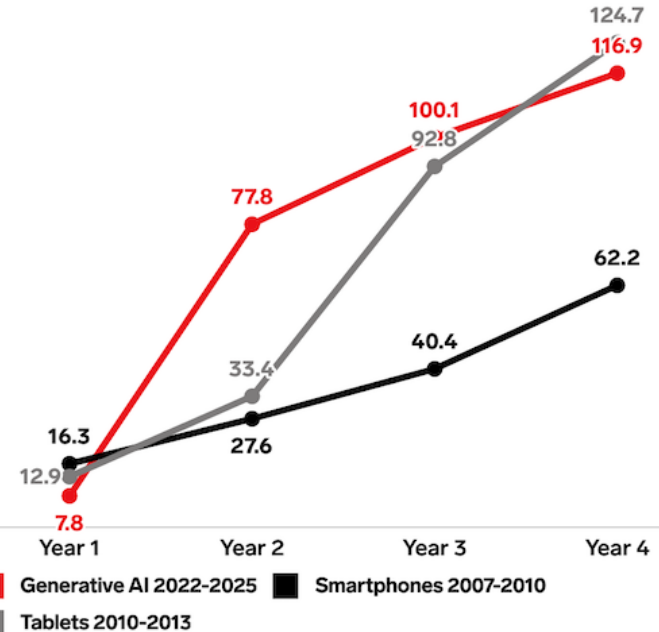
# Why?

- Enable new scientific investigations of physical processes and natural phenomena related to the sun, impacts on earth, other planets, solar system and exploration of space.
- Expand range of researchers; highly interdisciplinary.
- Create sufficient credibility to convince heliophysicists to use AI as a tool and understand its potential.



## Generative AI Has a Steeper Initial Adoption Curve Than Other Recent Technologies

millions of US users



Note: individuals of any age who use each technology at least once per month; Year 1 for smartphones corresponds with the June 2007 release of the iPhone; Year 1 for tablets corresponds with the April 2010 release of the iPad; Year 1 of generative AI corresponds with the November 2022 release of ChatGPT  
Source: Insider Intelligence, June 2023



# From Observation to Prediction: AI as a System Imperative

- Heliophysics studies a **coupled system**: Sun → heliosphere → geospace
- Data is **continuous, multi-modal, and massive** → requires integrated analysis at scale
- Physicsbased models remain essential:  
but are **computationally expensive** and limited in gaps/extremes
- AI augments physics:
  - flare & precursor detection
  - thermospheric drag (surrogates)
  - cross-mission data fusion
- **Foundation models (e.g., Surya)** enable shared representations
- **RADIANT** builds infrastructure and community capability
- Shift: **isolated studies** → **system-level understanding**

# What is a Foundation Model?

Foundation models represent a major shift in how we think about artificial intelligence. Rather than training a separate model for every task, a foundation model is trained on a massive, diverse dataset and then fine-tuned for specific tasks as needed.

These models—often based on transformer architectures—capture broad latent representations that can be adapted quickly. In heliophysics, a foundation model might be trained on years of solar EUV imagery, solar wind time series, and magnetometer data.

Once trained, it could be fine-tuned to detect coronal holes, predict thermospheric density, or synthesize 3D corona reconstructions. Think of it as “pretraining the brain of the Sun.” The key advantage is reusability.

One model can support dozens of downstream applications, reducing duplication and accelerating discovery. In NASA science, this is already happening. Earth science has Prithvi. Weather has WxC. Heliophysics now has HelioFM. This paradigm shift promises not only efficiency, but consistency, and community-wide interoperability.

# Surya Foundation Model: AI Capability for Predictive Heliophysics

- **What it is**

NASA–IBM open foundation model, trained on ~a decade of SDO data

- **it does**

Learns a **shared representation of solar activity** → reusable across tasks

(flare prediction, feature tracking, multi-modal analysis)

- **What we see**

~15% performance improvement

Forecasts hours in advance

One model → many applications

- **Why it matters**

Enables **predictive space weather** for satellites, GPS, power grids, human spaceflight

- **Momentum**

Surya Workshop: 100+ participants, 13+ applications

RADIANT accelerating adoption and infrastructure

- **What's next**

Open access, validation frameworks, transition to operations (e.g., CCMC)

## What Counts as Successful AI?

- Pattern recognition
- Surrogate models
- Foundation models
- Hybrid physics+ML

## Why Some Problems Yield to AI

- High data volume
- Hidden structure
- Multi-scale coupling
- Incomplete physics

## When NOT to Use AI

- Low data
- Well-understood physics
- Need causal guarantees
- High-risk decisions

## Discovery: What Has Changed?

- New feature classification
- Anomaly detection
- Crossmission patterns

## What Is Exciting

- Physics-ML hybrids
- Visual language (Surya)
- Generative models

## From Models to Systems

- Surya: shared representation
- Heliolab: orchestration
- Fleet-level thinking



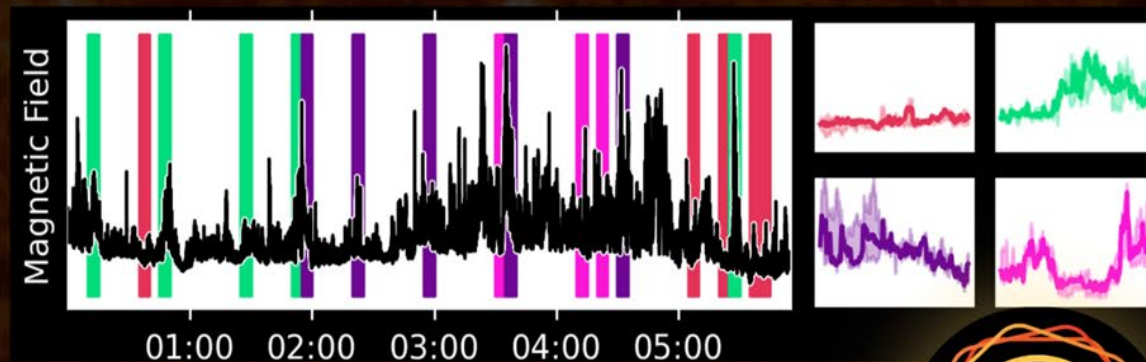
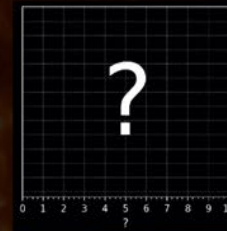
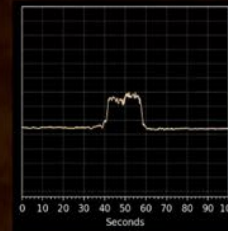
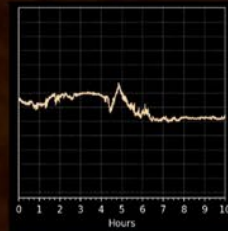
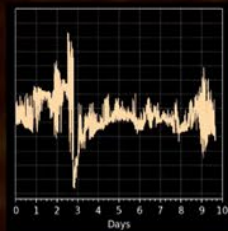
FDL 2021

## UNCOVERING THE ORIGIN OF THE SOLAR WIND

### CAN AI HELP US FIND THE COMPLEX STRUCTURES IN THE SOLAR WIND?

DATA SOURCE

Parker  
Solar  
Probe &  
WIND



Clusters of solar magnetic field structures



OPEN ACCESS

A Machine-learning Data Set Prepared from the NASA *Solar Dynamics Observatory* Mission

Richard Galvez<sup>1</sup>, David F. Fouhey<sup>2</sup>, Meng Jin<sup>3,4</sup>, Alexandre Szenicer<sup>5</sup>,  
 Andrés Muñoz-Jaramillo<sup>6</sup>, Mark C. M. Cheung<sup>3,7</sup>, Paul J. Wright<sup>8</sup>, Monica G. Bobra<sup>7</sup>,  
 Yang Liu<sup>7</sup>, James Mason<sup>9</sup> + Show full author list

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[The Astrophysical Journal Supplement Series, Volume 242, Number 1](#)

Citation Richard Galvez et al 2019 ApJS 242 7



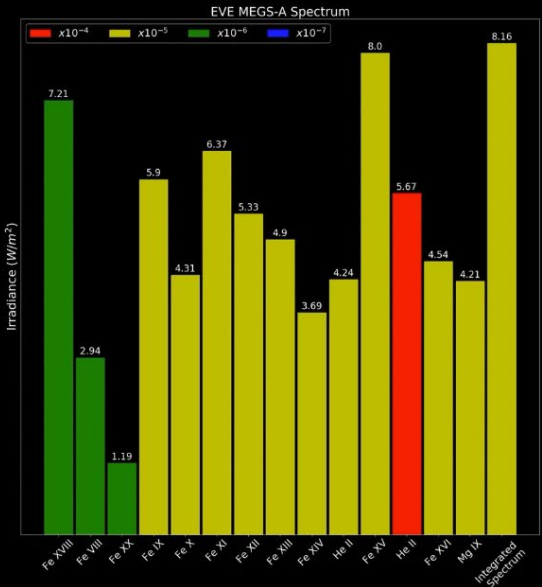
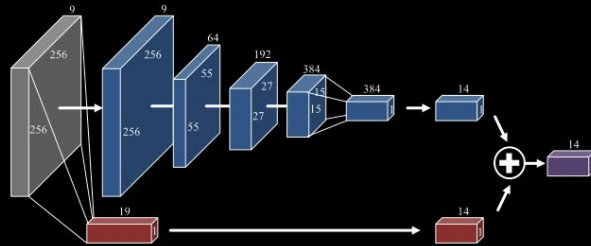
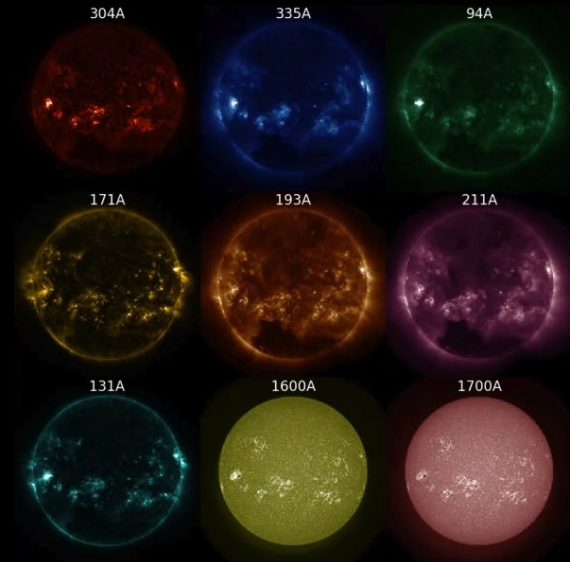
**DATASET**

**SDOML**

A Curated Data Set From The NASA Solar Dynamics Observatory (SDO) Mission In A Format Suitable For Machine-Learning Research.

7TB

<https://doi.org/10.3847/1538-4365/ab1005>  
<https://doi.org/10.1051/0004-6361/202040051>

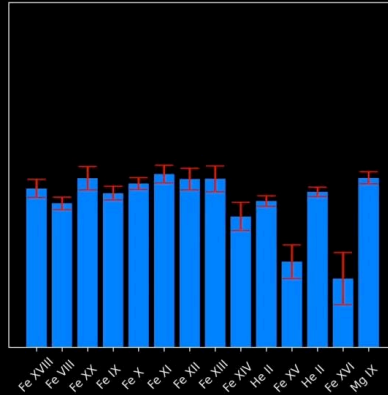


# SUN as a fully resolved star

# Irradiance from different vantage point

## 4π EUV Irradiance

## IRRADIANCE



4π Combines SDO/STEREO A & STEREO B observations into a consistent 4π map of the Sun

It predicts what the Sun's EUV emission images would look like from non-ecliptic viewpoints

**NeRFS (Neural Radiance Fields) AND ITI (Instrument to Instrument translation) ENABLE A 4PI VIEW OF OUR SUN IN EUV**

<https://doi.org/10.3847/2041-8213/ad12d2>

At each viewpoint we can determine the total energy that is emitted from the Sun.

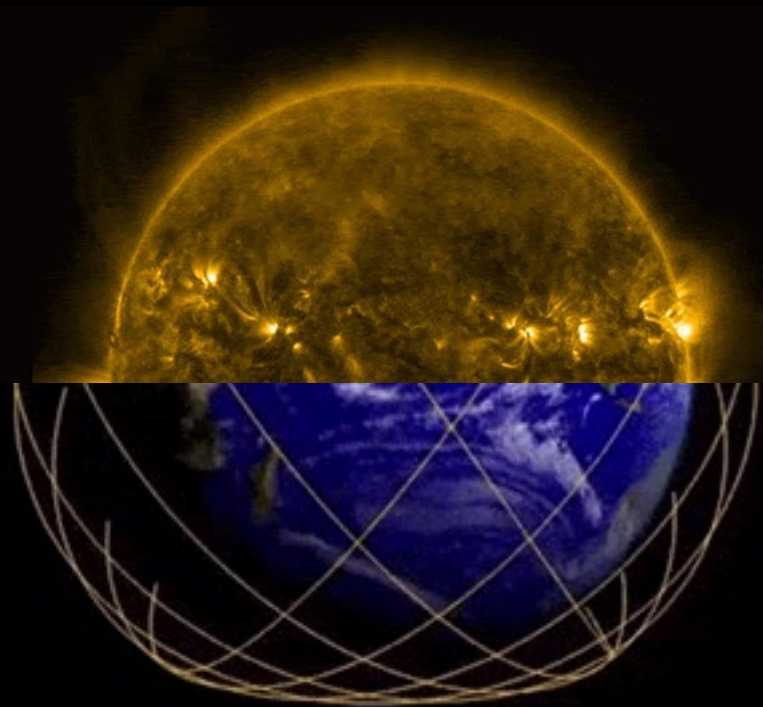
For Earth this provides a new generation of space weather forecasting, where we can already estimate the amount of incoming radiation several days ahead.



**KARMAN**

**Karman** can predict thermospheric changes due to solar EUV, crucial for calculating changes to satellite drag and de-orbiting spacecraft.

<https://doi.org/10.1029/2023SW003652>



# D.A.G.G.E.R

DEEP LEARNING GEOMAGNETIC PERTURBATION

Dagger can predict the effects of solar activity on Earth's geomagnetic field, 30 mins in advance, globally.

<https://doi.org/10.1029/2022SW003045>

**NASA's DAGGER could give advance warning of the next big solar storm**

Devlin Coldeway | [@coldeway](#) / 10:56 PM GMT+1 March 31, 2022

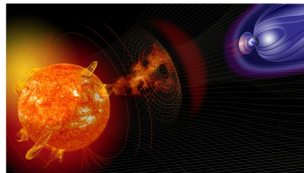
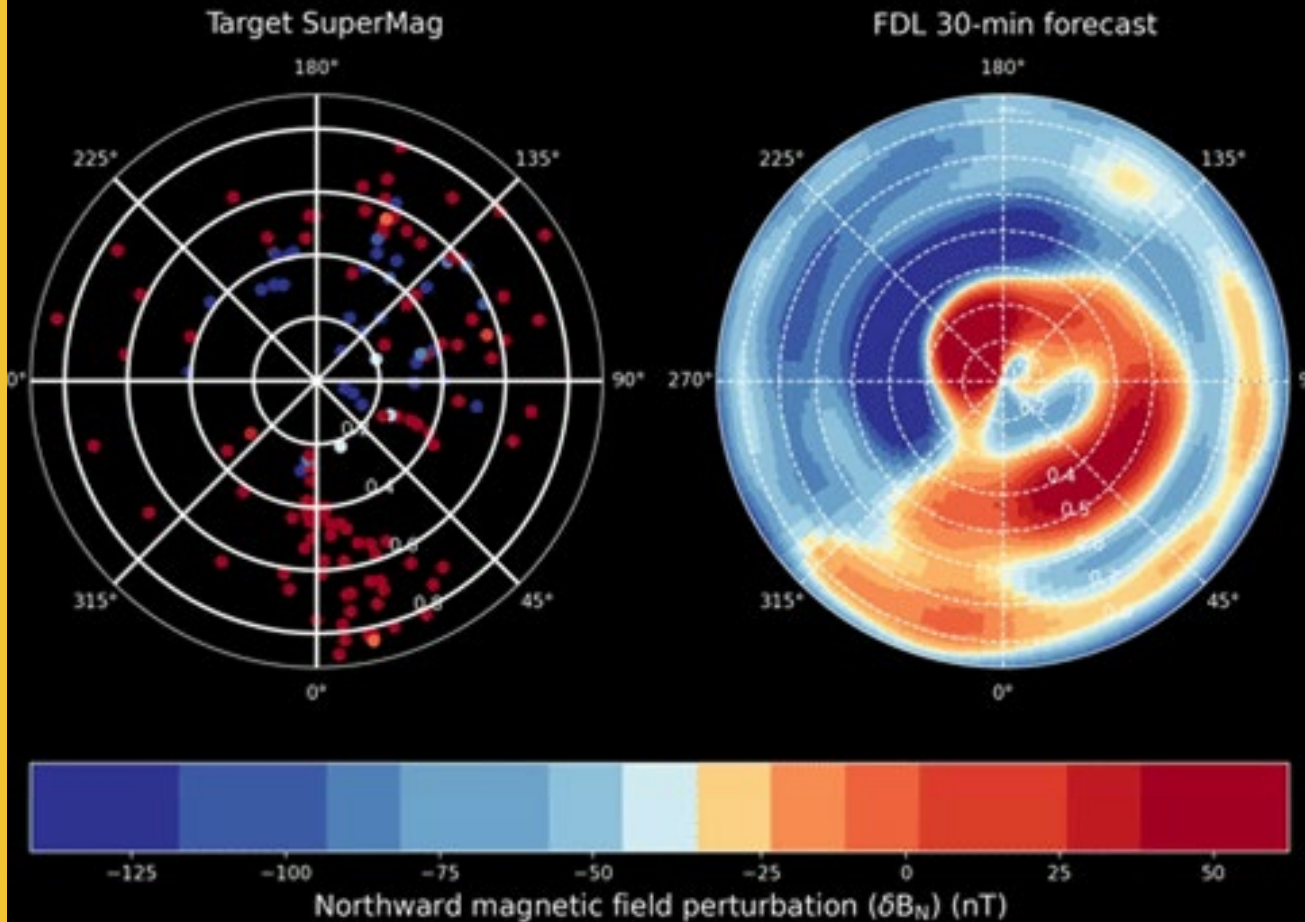


Image Credits: NASA

There's enough trouble on this planet already that we don't need new problems coming here from the sun. Unfortunately, we can't just destroy this planet like we see in sci-fi movies. But NASA at least



## ITI : Instrument to Instrument Translation Tool

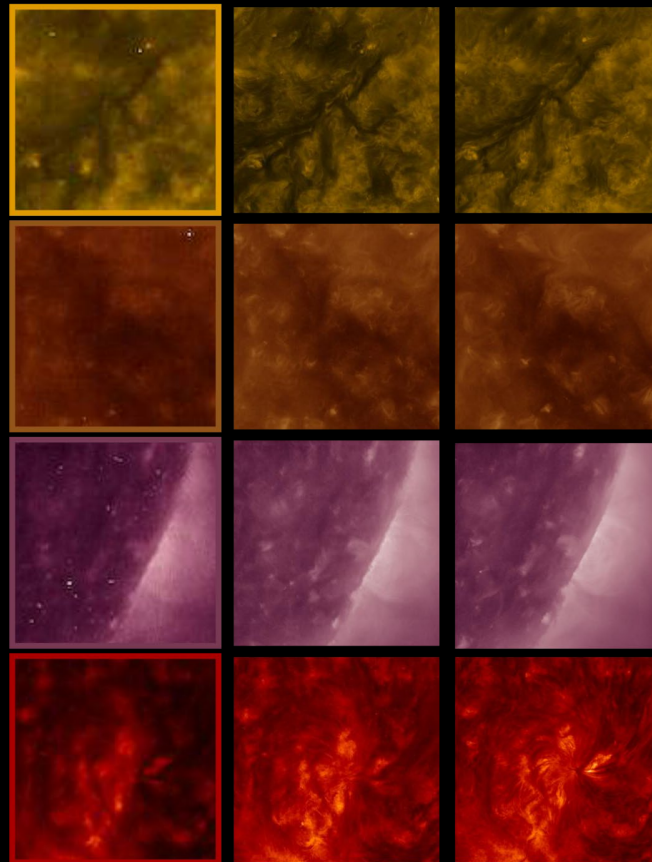
Instrument intercalibration

Image super-resolution

Mitigation of degradations

Channel approximation

**Universal tool** for  
domain translations



# What Has Not Been Done Yet

- Crossmission causality
- AI experiment design
- Realtime science+ops
- Human-AI reasoning

# The Real Question

- Can AI participate responsibly in science?
- Heliophysics as proving ground