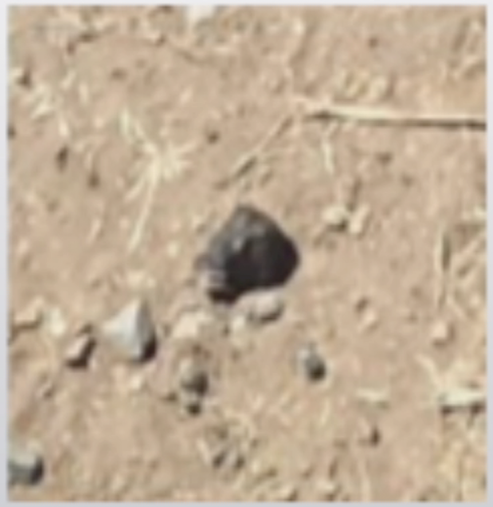
# ARTIFICIAL INTELLIGENCE FOR SPACE EXPLORATION AND ALL HUMANKIND.

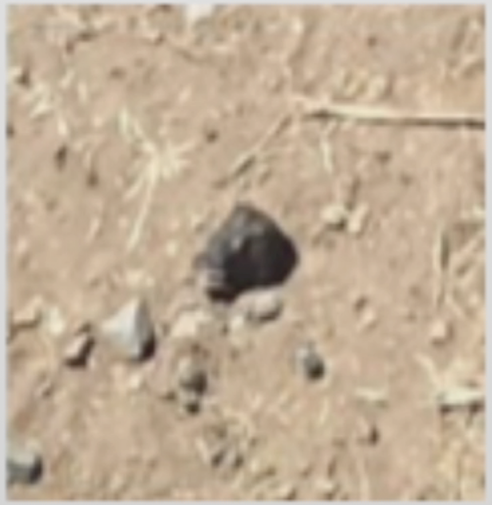
**Dr. Lika Guhathakurta on behalf of the FDL Team**
NASA Ames Research Center/Exploration Technology Directorate

NASA Goddard Workshop on AI 11/28/2018

# “Artificial Intelligence is just fancy statistics”

FDL AITC MEMBER





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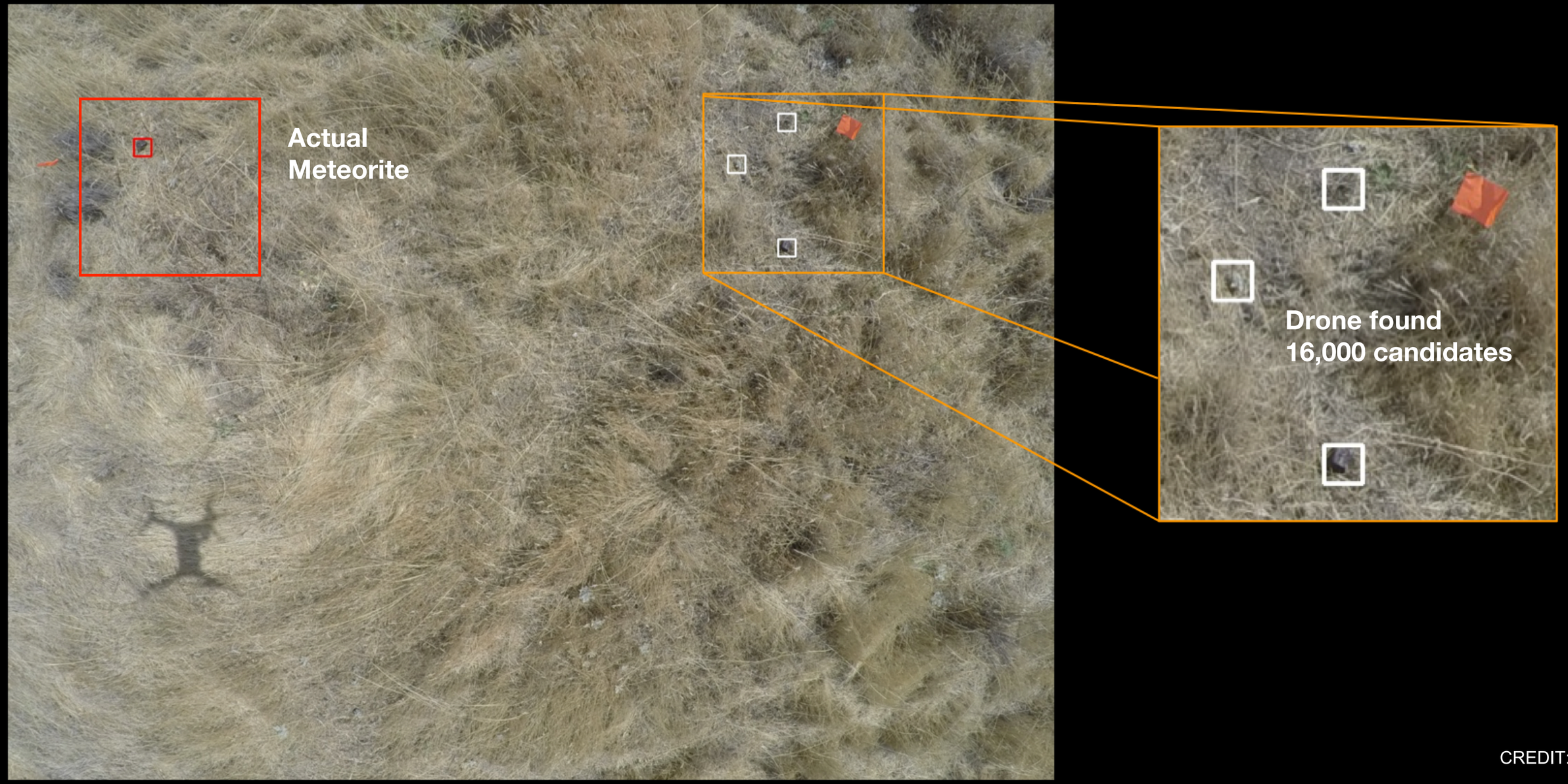


CREDIT: FDL

CREDIT: A GENIUS

# 2 Gigabytes

# Every 15 seconds

# What If…?  AI Meets Space Science

Planetary Defense

Space Resources

Space Weather

Exoplanets

Astrobiology

# Enter – NASA Frontier Development Lab - FDL

Deep Learning meets Deep Science +
Public / Private partnership
= New synergies for NASA research

# FDL is a public / private research partnership between NASA, the SETI Institute and leaders in commercial AI and private space.

Twitter @NASA_FDL

**Over the past four years FDL has demonstrated a model for breakthrough AI application over a highly accelerated time period - and commercial and international partnership.**

Ames Research Center

# 16 AI Case Studies

## DISCOVERY WORKFLOWS → SITUATIONAL AWARENESS → DECISION INTELLIGENCE

### ARE WE ALONE?

INARA
(Atmospheric Retrieval)
ATMOS 2.0
(BioHints)
ExoNET

### PLANETARY DEFENSE

CAMS (long period comets)
NEO SHAPE MODELING
DEFLECTOR SELECTOR
METEORITE DRODNE

### LIVING WITH A STAR

FLARENET
STING (Kp Index)
MEGS-A UV Prediction
GPS Scintillation

### THE MOON FOR GOOD

LUNARUSH
(Lunar Mapping)
MARMOT
(Co-operative Robots)
LOCALIZATION

### MISSION CONTROL EARTH

Multi³Net
(Disaster Response)

Informal Settlements

FDL

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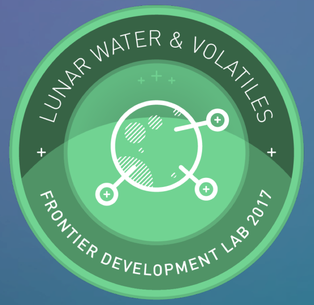
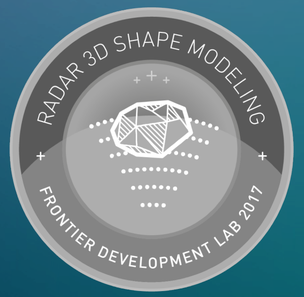
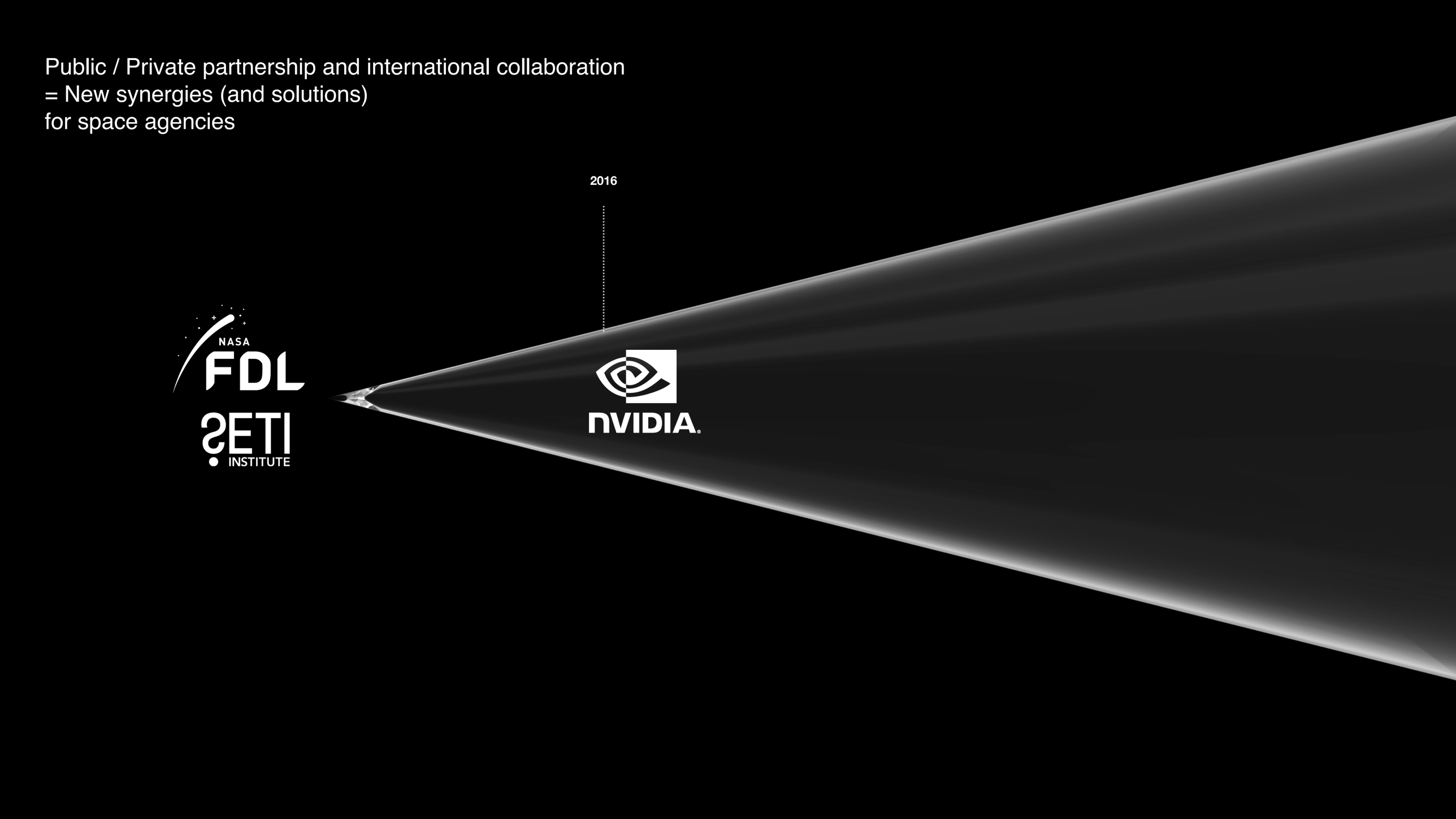
# Artificial Intelligence is already a crucial keystone capability

| | Autonomous systems | Workflow optimization | Forecasting and Prediction | Anomaly Detection | Discovery within multi-dimensional data | Decision Intelligence |
|---|---|---|---|---|---|---|
| FDL PROJECTS | |   | | | | |
| | ISRU / Swarms | Radical cost and time savings | Situational Awareness / Uncertainty reduction | Safer systems | Science breakthroughs | Rapid assessment / improved strategic decisions |

Public / Private partnership and international collaboration
= New synergies (and solutions)
for space agencies



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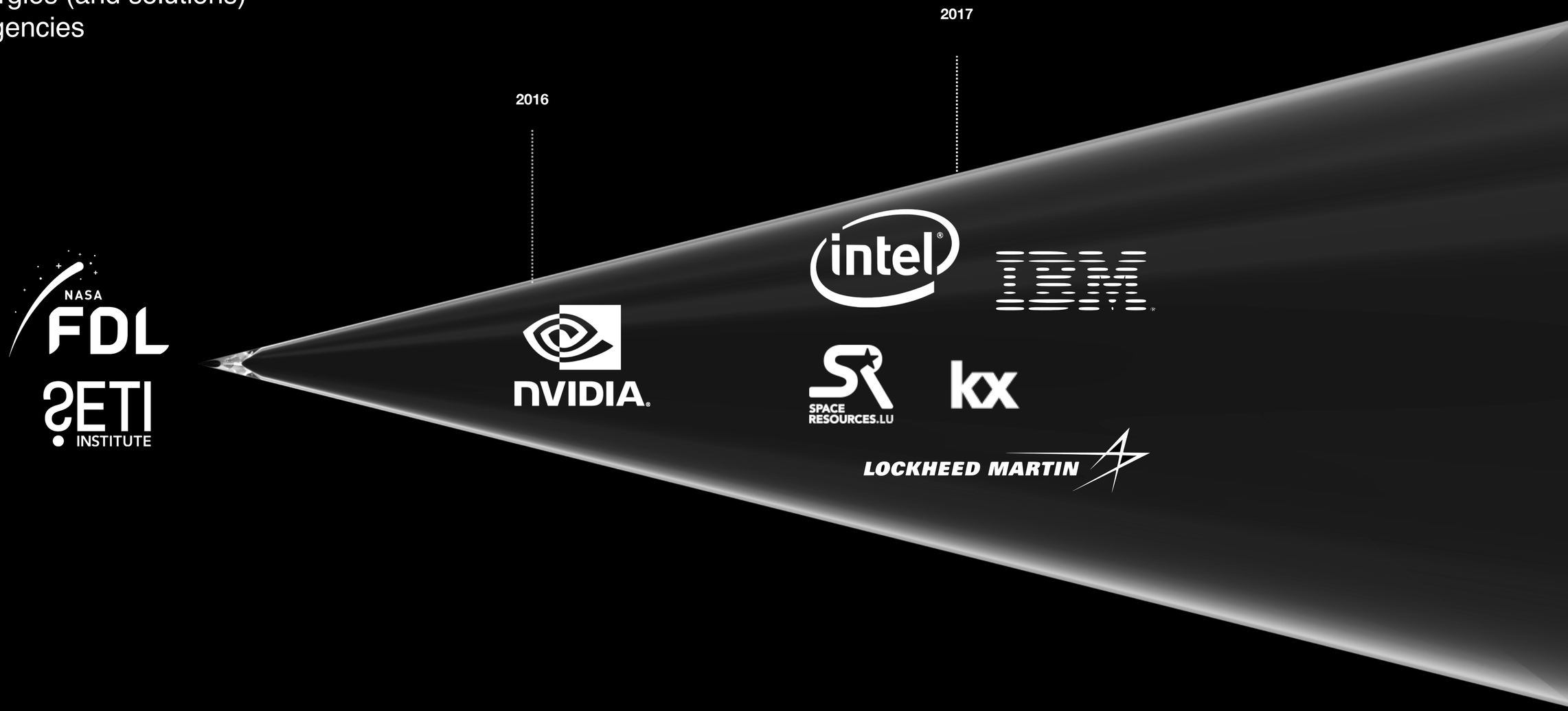

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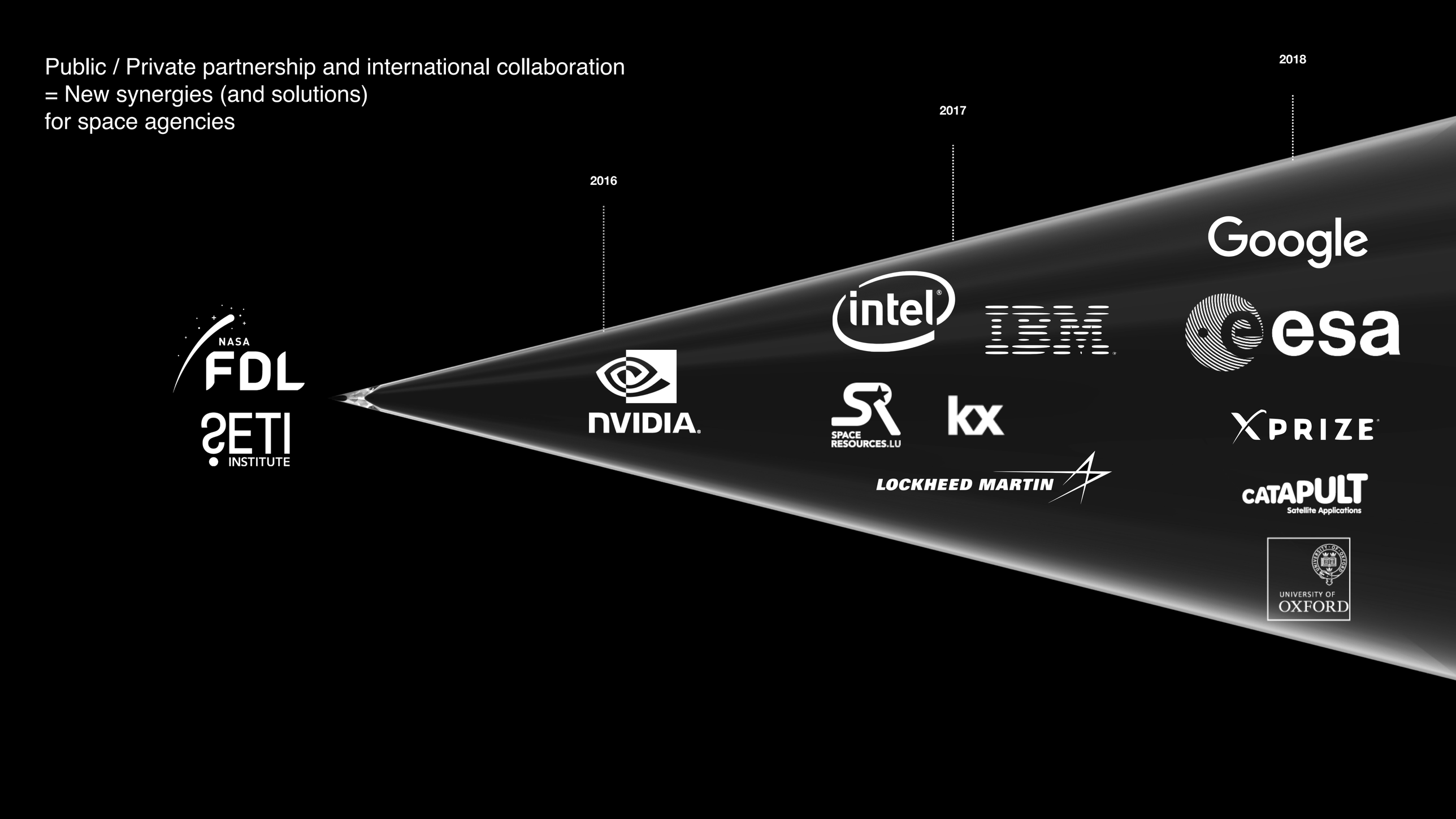


**CUSTOM TAILORED TEAMS PhD / Post Docs = INTERDISCIPLINARY AND INTERNATIONAL REACH**

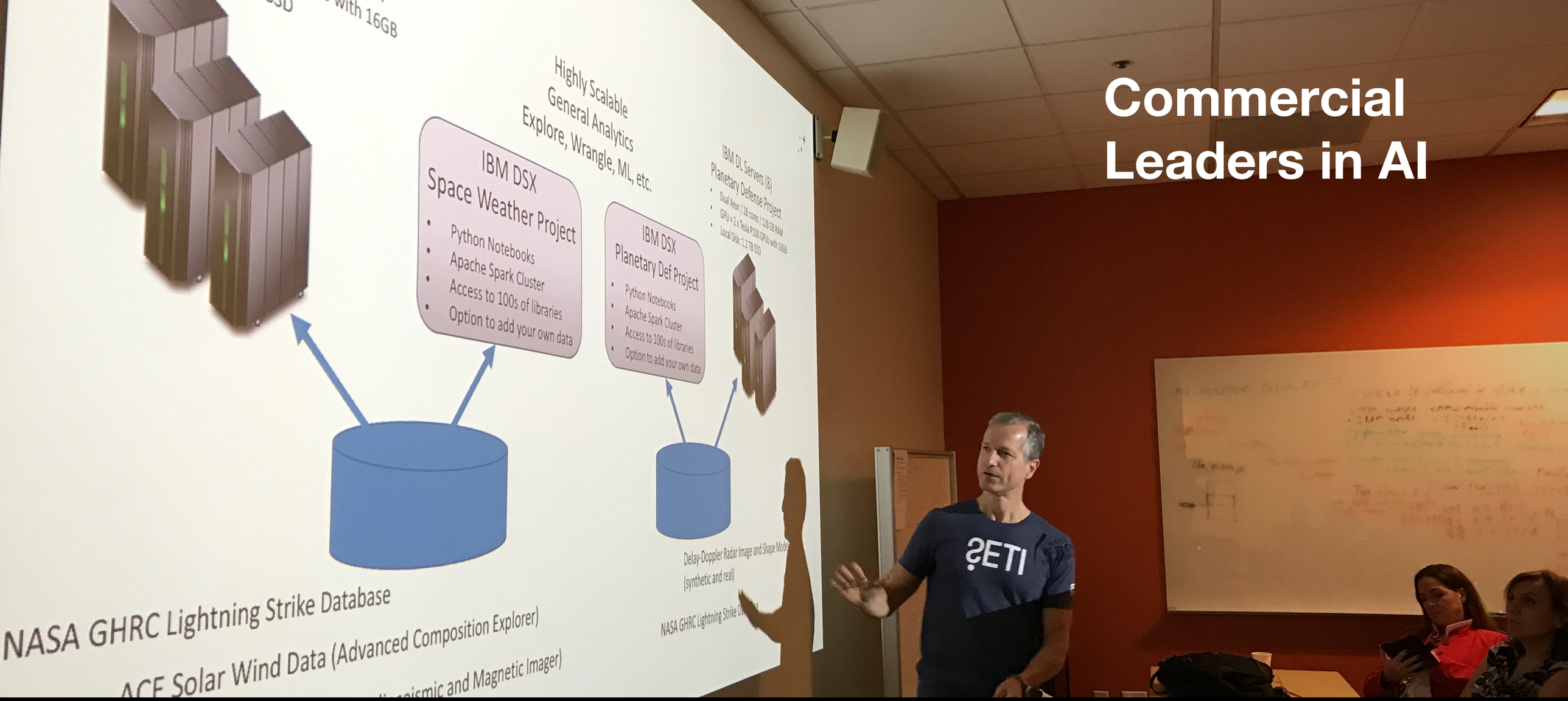
**12% Acceptance rate (parity with MIT)**

# WHY PARTNER WITH SILICON VALLEY?

GPU POWER OUTSTRIPPING MOORE'S LAW

PETA-SCALE ERA OF DATA - ALGORITHM DEV IS 5% OF TASK

DEVELOPING INFERENCE MODELS IS COSTLY (FDL = $1M USD DONATED COMPUTE)




# Commercial Leaders in AI

**MASSIVE GPU / COMPUTE**

+ **1-2 HOUR TURN-AROUND**
+ **MULTIPLE INSTANCES**
+ **DATA HANDLING / PROTOTYPING**
+ **PRIVATE SECTOR EXPERTISE**

NVIDIA intel Google IBM

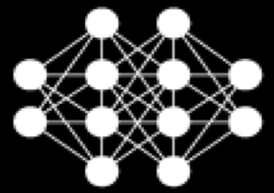
## WHAT'S IN IT FOR SPACE?

Capital
(50% of FDL's capital requirement*)
Massive GPU compute = **rapid iteration**
Expertise and mentorship
Software services / Hardware
Locations and event hosting
New perspectives and Solutions
Validation as AI leader
Continuity

## WHAT'S IN IT FOR PARTNERS?

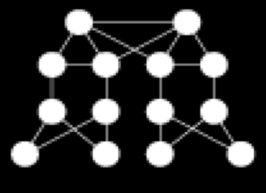
Brand association / Outreach
Inspirational case studies
Access to talent
Critical learning about tools and user feedback
Relations with other partners.

# AI/ML Tools Applied to FDL Challenges



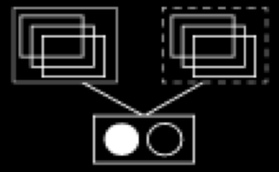
Convolutional Neural Nets (CNNs)

Machine Vision



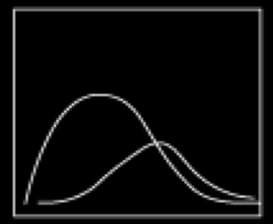
Deconvolutional Neural Nets (DNNs)

Machine Learning



Generative Adversarial Networks (GANS)

"Alpha-Go"

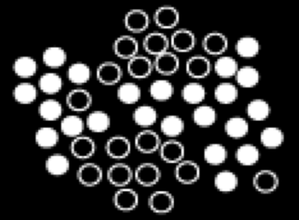


Bayesian Optimasation

Optimising expensive functions

Variational Auto-Encoders (VAEs)

Generated Sample Data

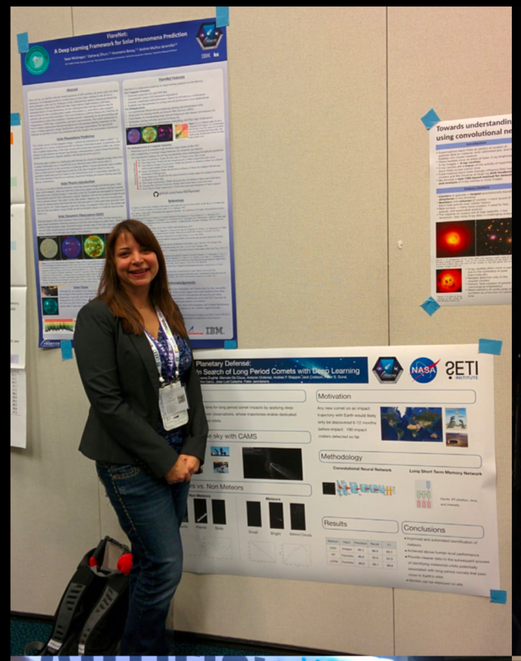


T-SNEs

Multi-dimensional Visualization

DEEP LEARNING

MACHINE INTELLIGENCE



# Impact

**One FDL AI output is already running on a NASA funded program (planetary Defense) with two more going on-line soon.**

FDL has already generated a broad spectrum of peer-reviewed papers, conference posters, and conference appearances in both the AI and Space Sciences - with **presentations at AI and scientific conferences around the world.**

Another has gained follow on funding to get to the next stage.

GPU GTC - Washington DC 2016

IPC's Planetary Defence, Tokyo

AI Futures conference, San Jose

Digital DNA, Belfast

GPU GTC - Munich 2017

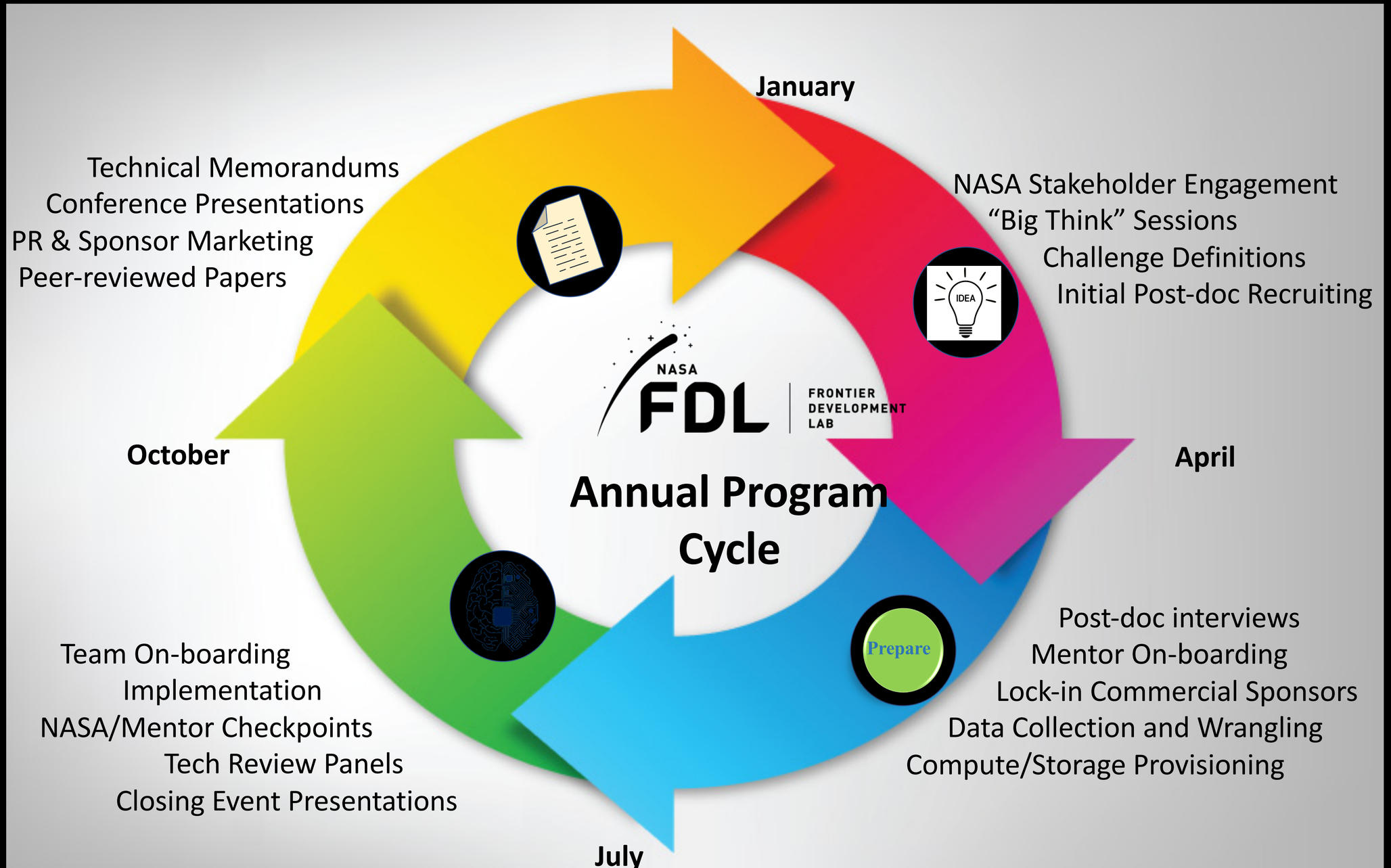
LEAG (Lunar Exploration Analysis Group) 2017

New Space Europe, 2017

NIPS ( Neural Information Processing Systems)

Women in Machine Learning workshop 2017

# Annual Cycle of AI Innovation & Growth



ARTIFICIAL INTELLIGENCE FOR SPACE EXPLORATION AND ALL HUMANKIND

# CAN AI MAKE SCIENTIFIC DISCOVERIES?

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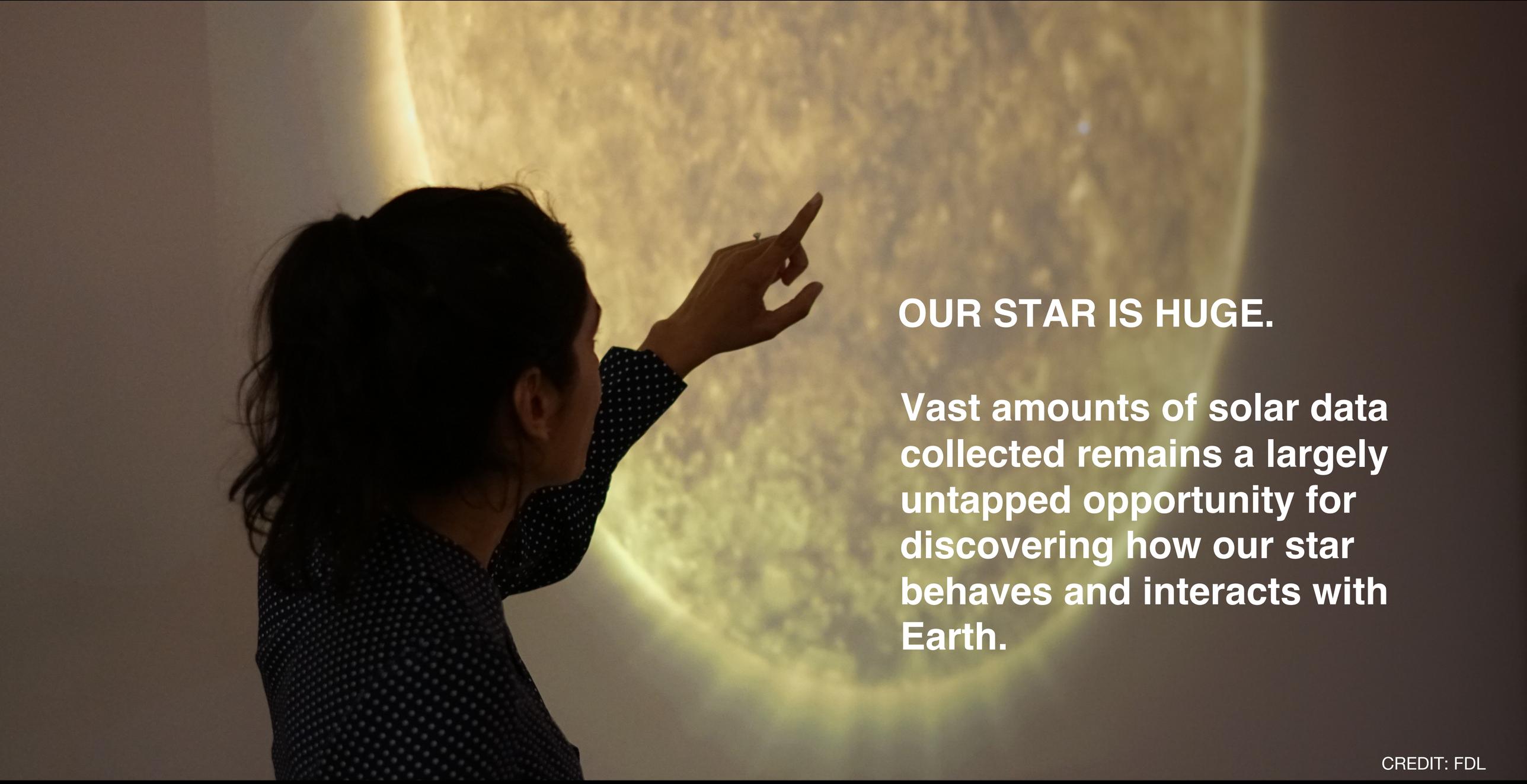
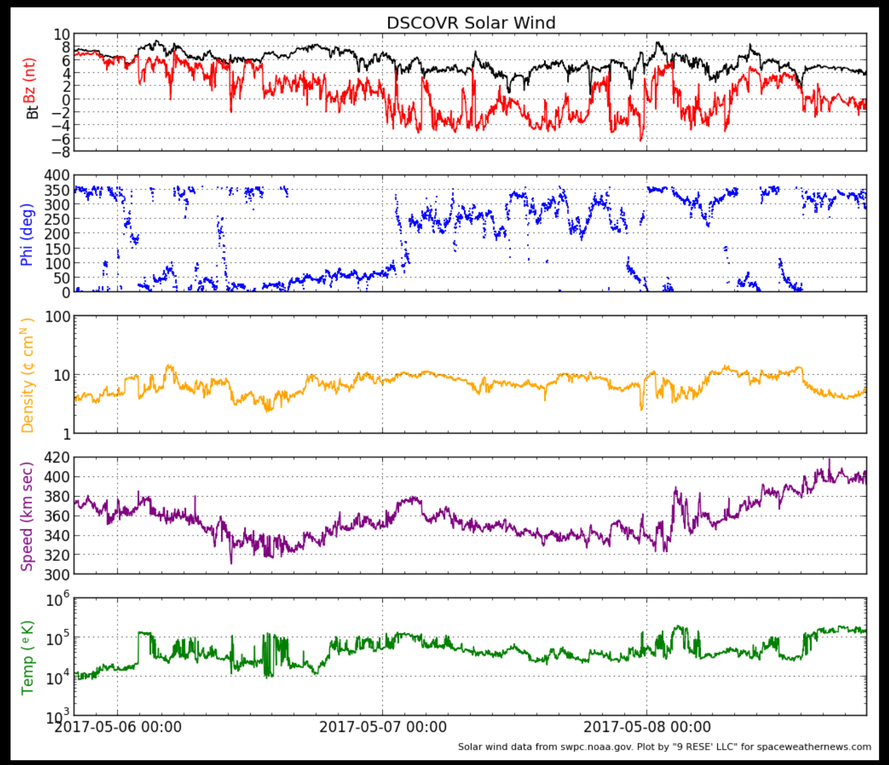


## OUR STAR IS HUGE.

Vast amounts of solar data collected remains a largely untapped opportunity for discovering how our star behaves and interacts with Earth.

CREDIT: FDL

## SOLAR WIND DATA

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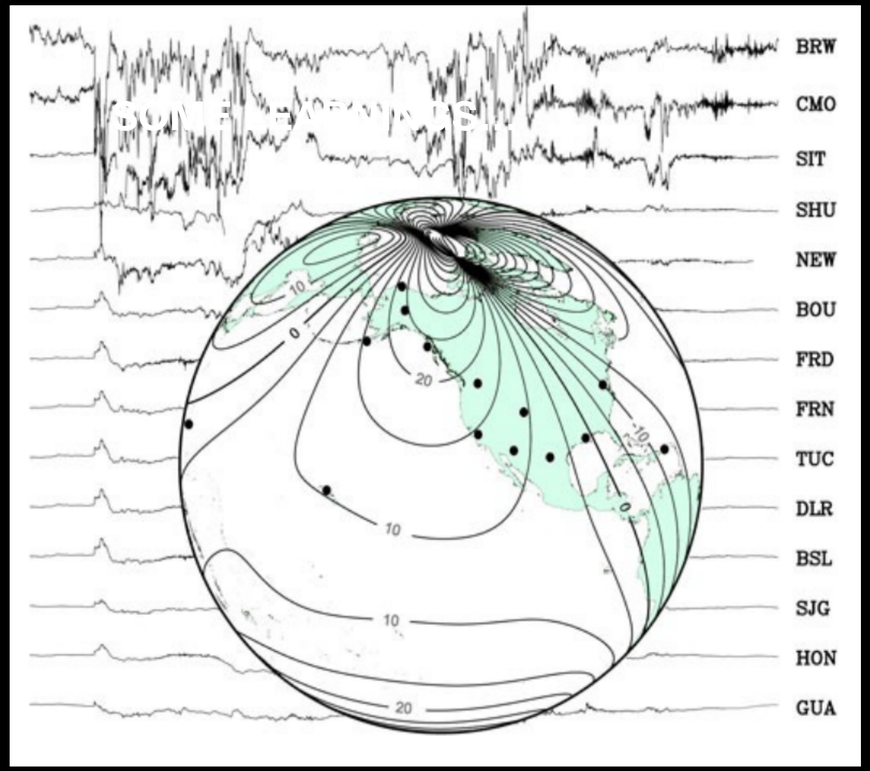
## GEOMAG DATA

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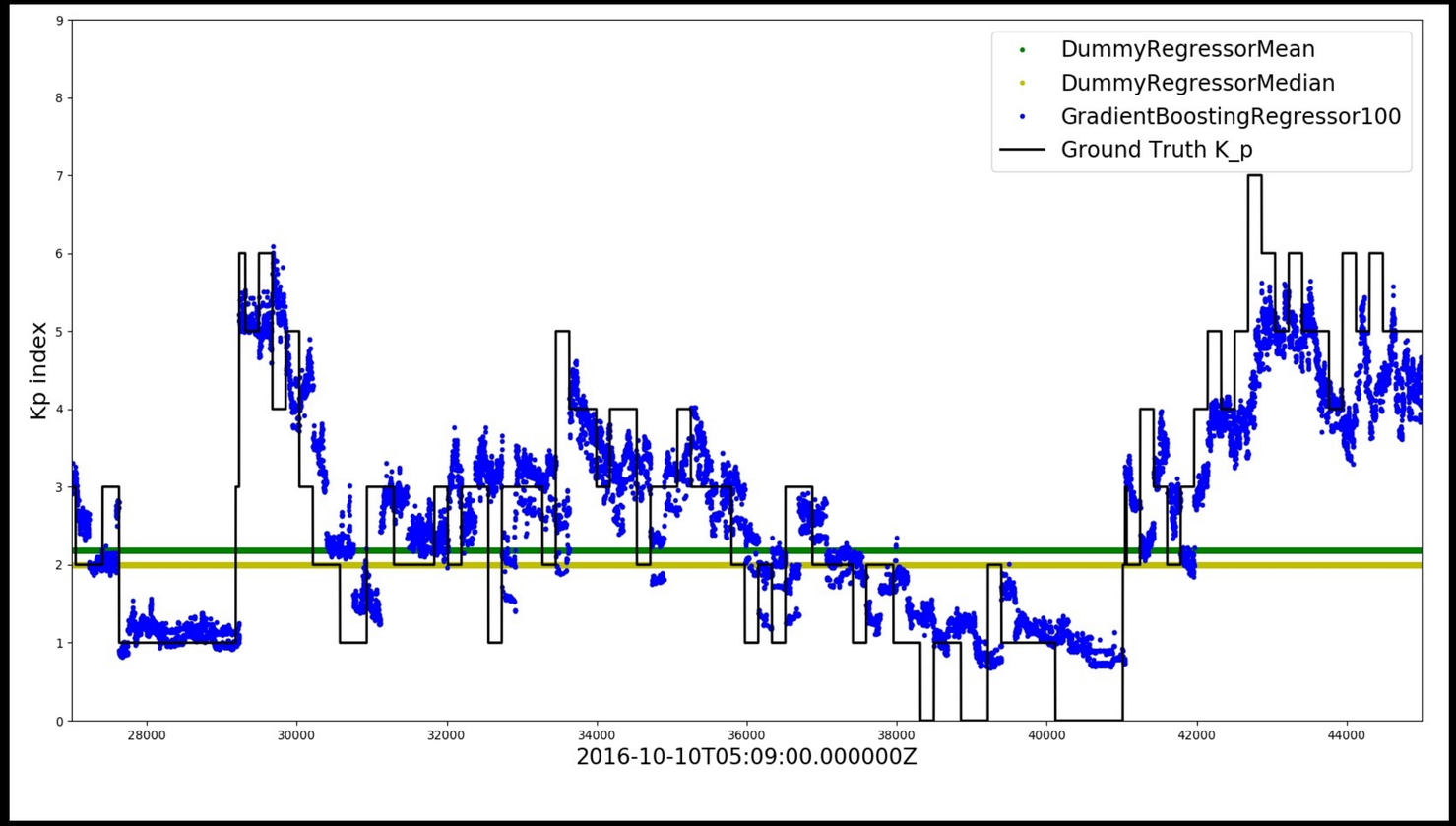
## “STING”

**(Solar Terrestrial Interactions Neural Network Generator)**

# Kp Index

**Refers to a range of geomagnetic activity levels within a 3-hr interval each day.**



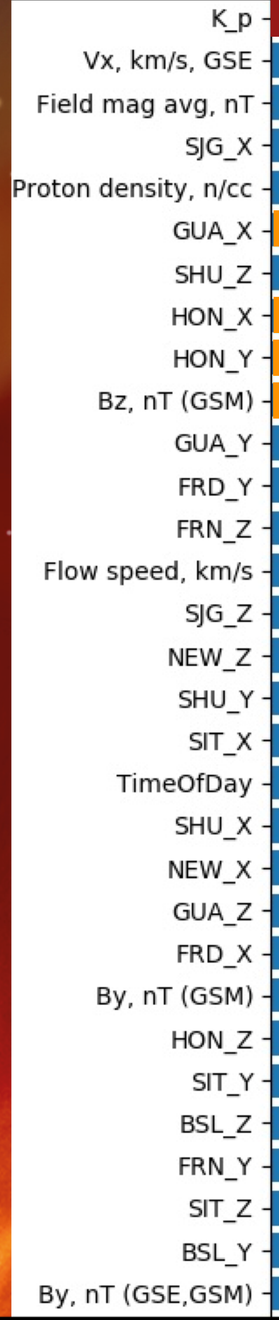

**STING is able to predict Kp 3 hours in advance.**

**Accurately predicting the variability of Earth's geomagnetic fields in response to solar driving.**

SPACE WEATHER
MISSION 01

IBM LOCKHEED MARTIN

# SOLAR-TERRESTRIAL INTERACTIONS




Other important predictors:

- Solar wind magnetic field strength and Bz,
- Solar wind speed and proton density,
- **Unexpected Result:** N-S component of the geomagnetic field at low latitude stations (Guam, Hawaii, Puerto Rico). **This points to the importance of the magnetospheric ring current.**

**Machine learning extracted important physical parameters without prior knowledge of the system.**

- **In the process STING discovered the imprint of the magnetospheric ring current in precursors of geomagnetic storms - an example of an AI derived discovery.**

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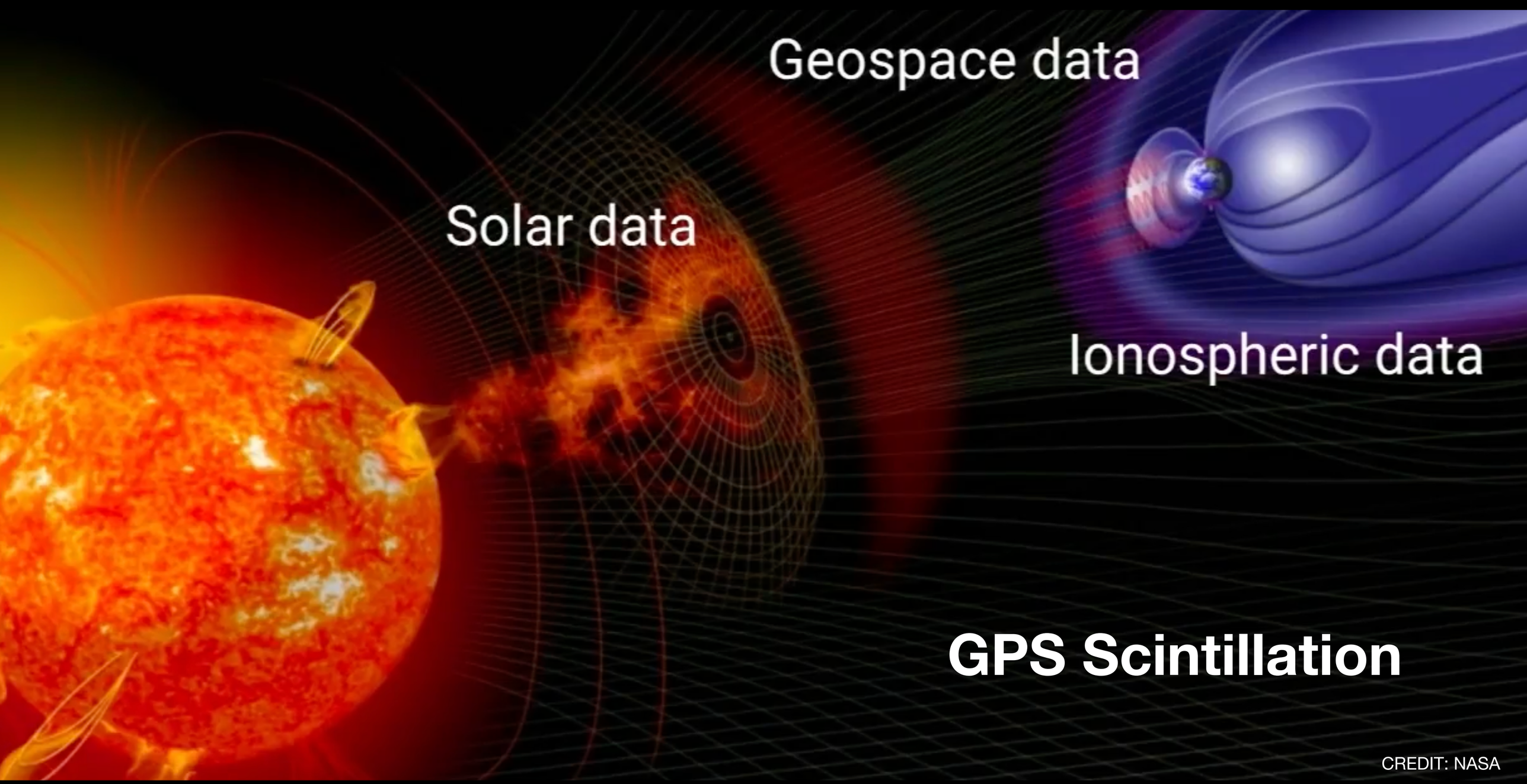
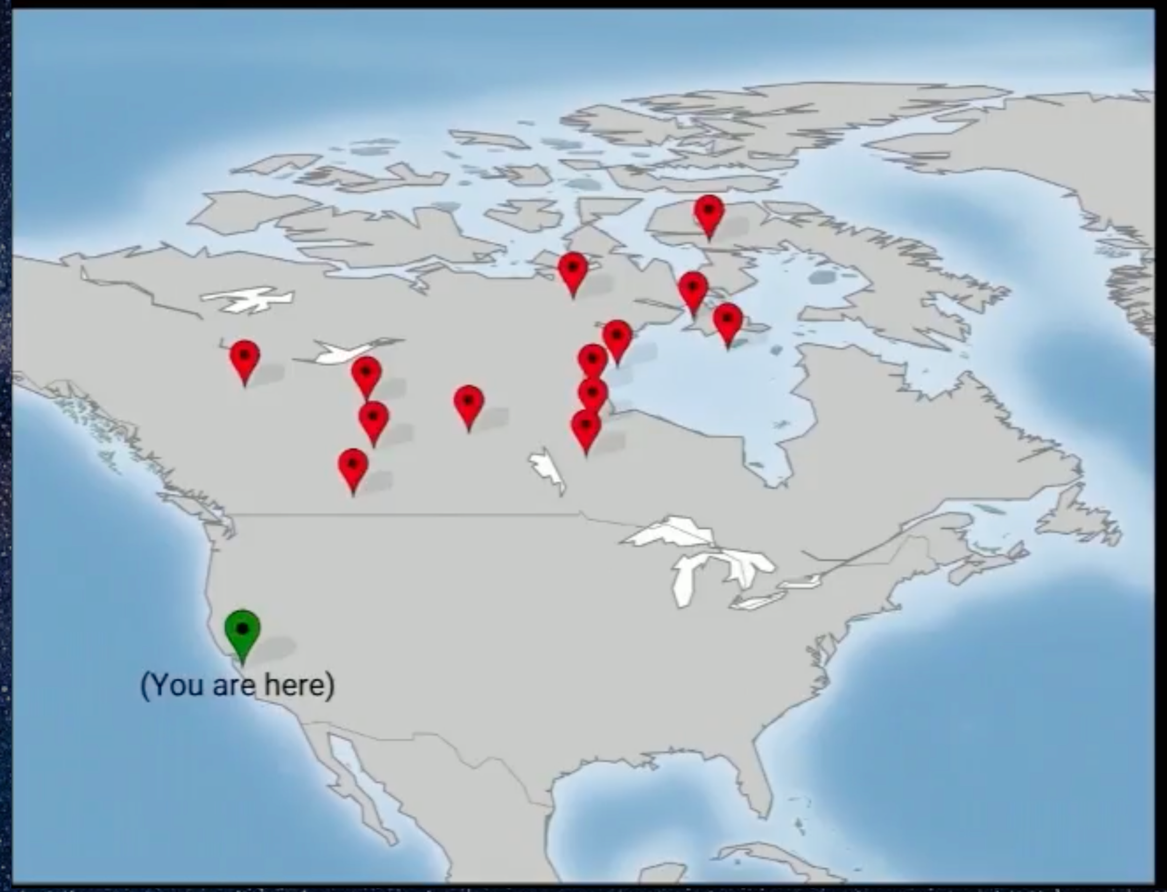

Geospace data
Solar data
Ionospheric data
GPS Scintillation

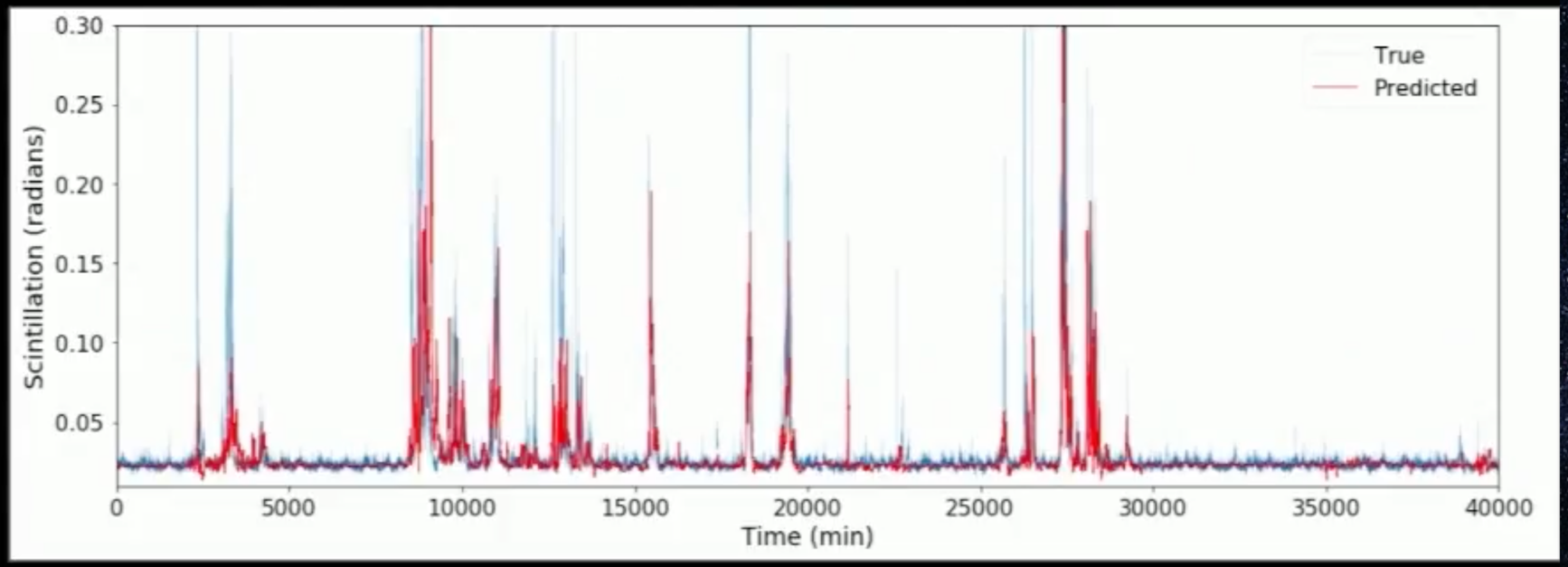
CREDIT: NASA




Build data-driven model to forecast GPS disruptions here

Canadian High Artic Ionospheric Network (CHAIN) GPS Receivers

## GPS Scintillation



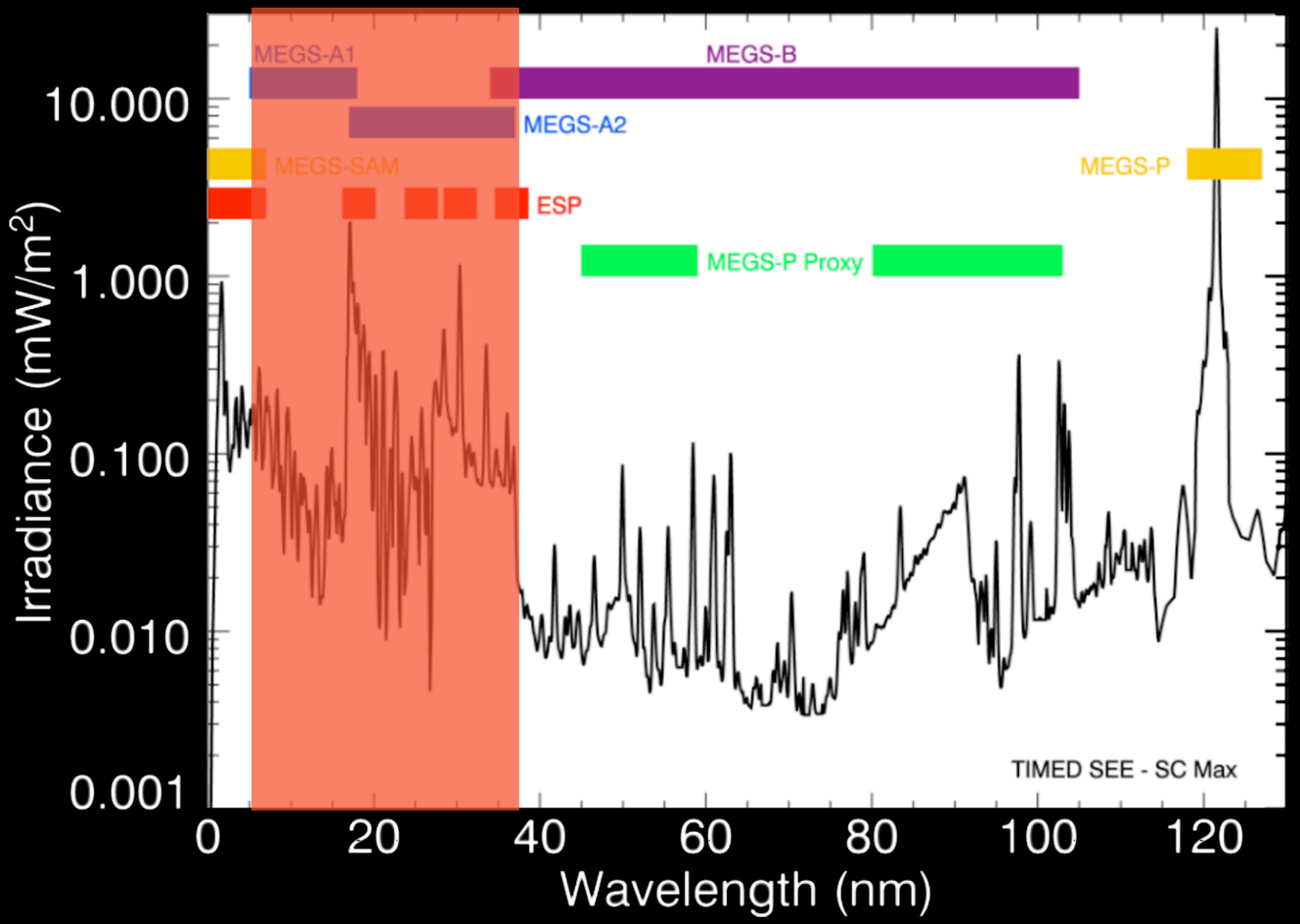

Model : Multilayer Perceptron w/ feature engineered inputs

**Predict GPS disruptions 1 hour in advance**

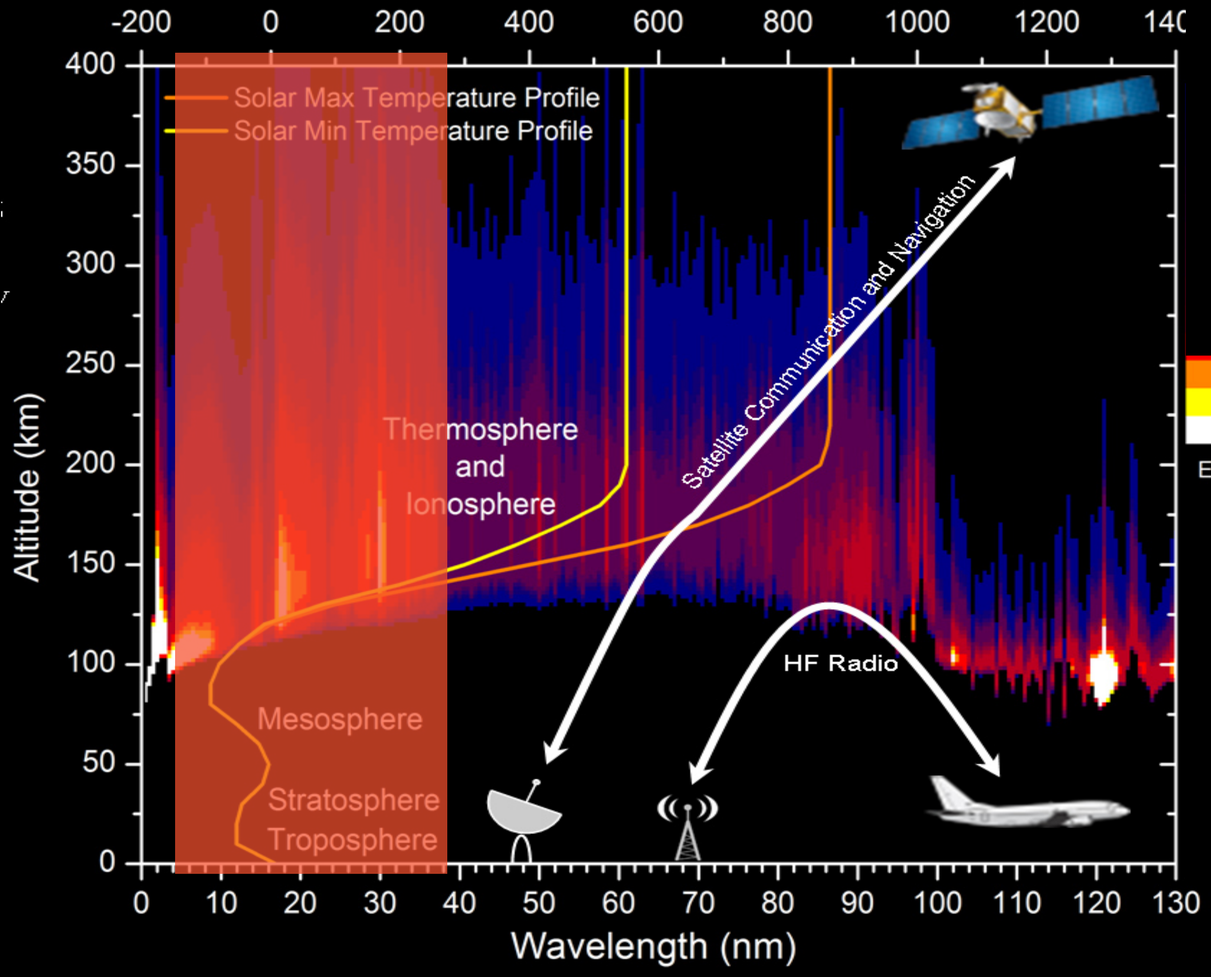
**Improved forecasting metrics by 70%**

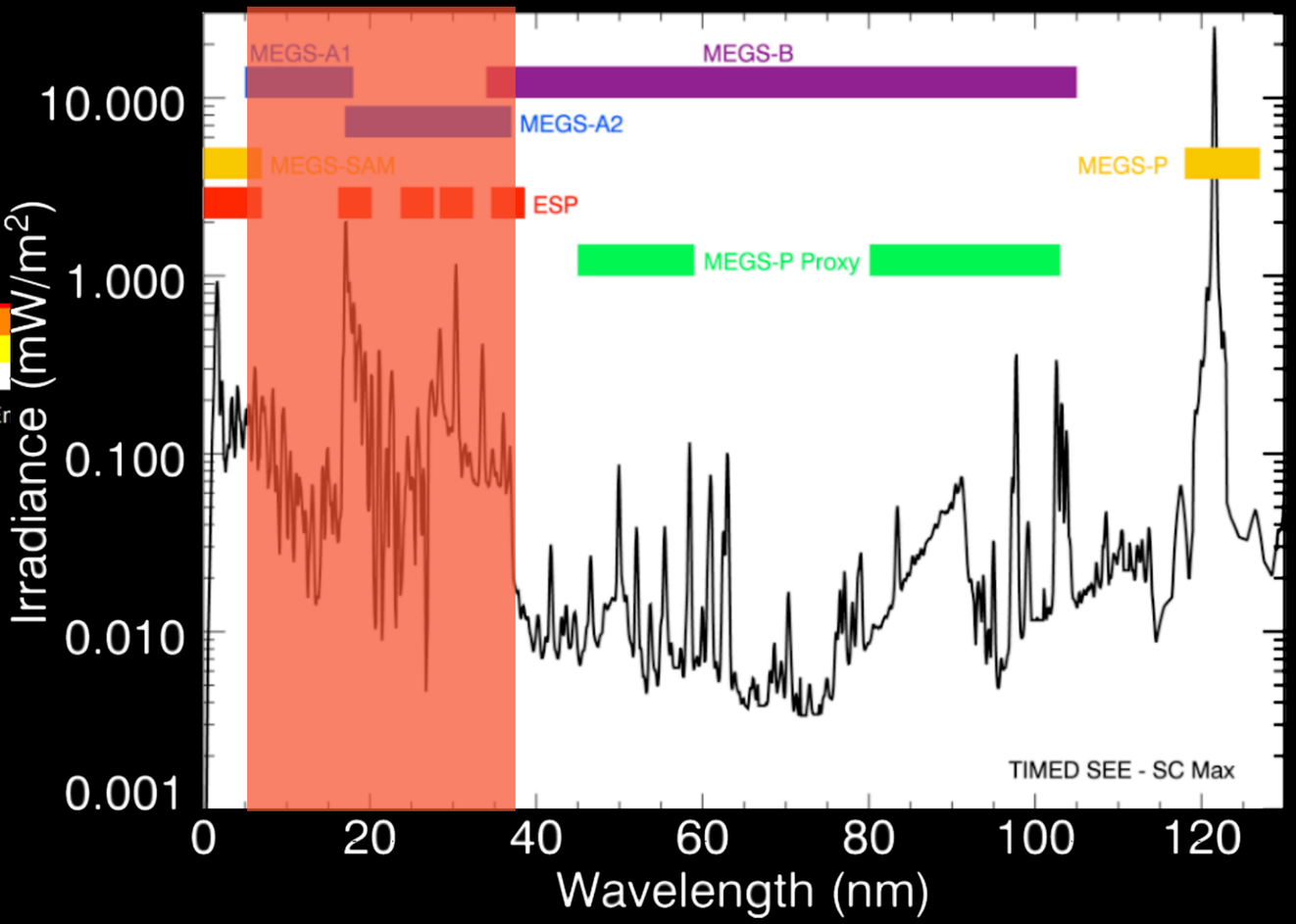
# EUV Variability Experiment (EVE)

- **EUV spectrograph.**
- **EUV spectral irradiance.**
- **MEGS-A suffered electrical fault in 2014 and is no longer operational.**



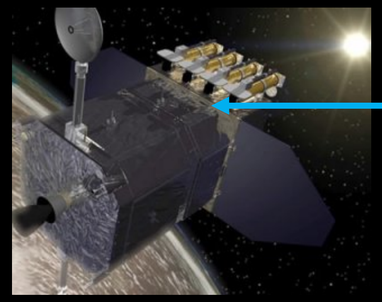
# This left an observational blackout in the most energetic part of the EUV spectrum



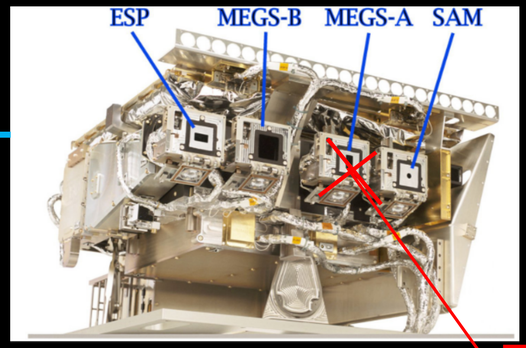



NASA FRONTIER DEVELOPMENT LAB

NASA



**NASA Solar Dynamics Observatory (SDO)**




**Failed in 2014**

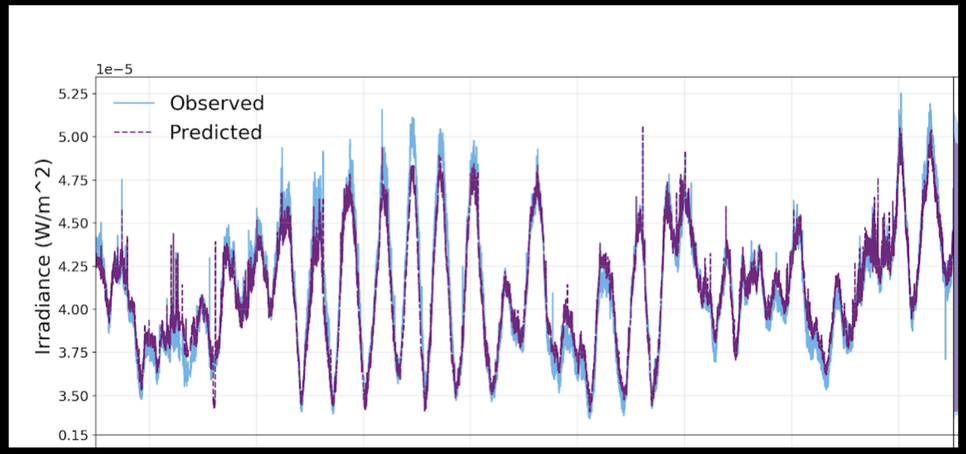
**AI model reduced mean error of spectral irradiance prediction to 2.83%**

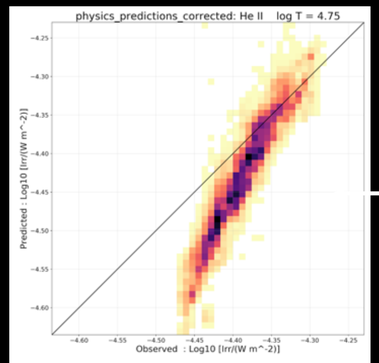
- **Need:** Measurement of solar spectral irradiance is needed for satellite orbit boost planning. Currently, this can be difficult because the MEGS-A module on SDO stopped functioning in 2014.

- **Goal:** The SDO AIA EUV imager co-observed with MEGS-A from 2011 to 2014 -- Can we use this data overlap to train a deep learning model to “virtually resurrect” the MEGS-A instrument and fill the observational gap left by the MEGS-A failure, thereby improving spectral irradiance prediction?

- **Methodology:** Develop a machine learning model using 2011/2014 data, test the accuracy using 2012/2013 data. After training and testing over 1000 machine learning configurations, the best implementation was found to be a Residual neural net model augmented with a Multi-Layer Perceptron.

- **Findings:** The neural net model significantly improved upon physics based models, **reducing mean error from 7.46% to 2.83%.** This improved accuracy may constitute a scientifically useful virtualization of MEGS-A.

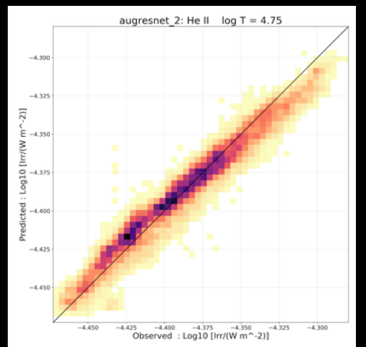



Plot of Predicted v.s Observed

Physics-based model

Improved AI model



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# CAN AI HELP HERE ON EARTH?

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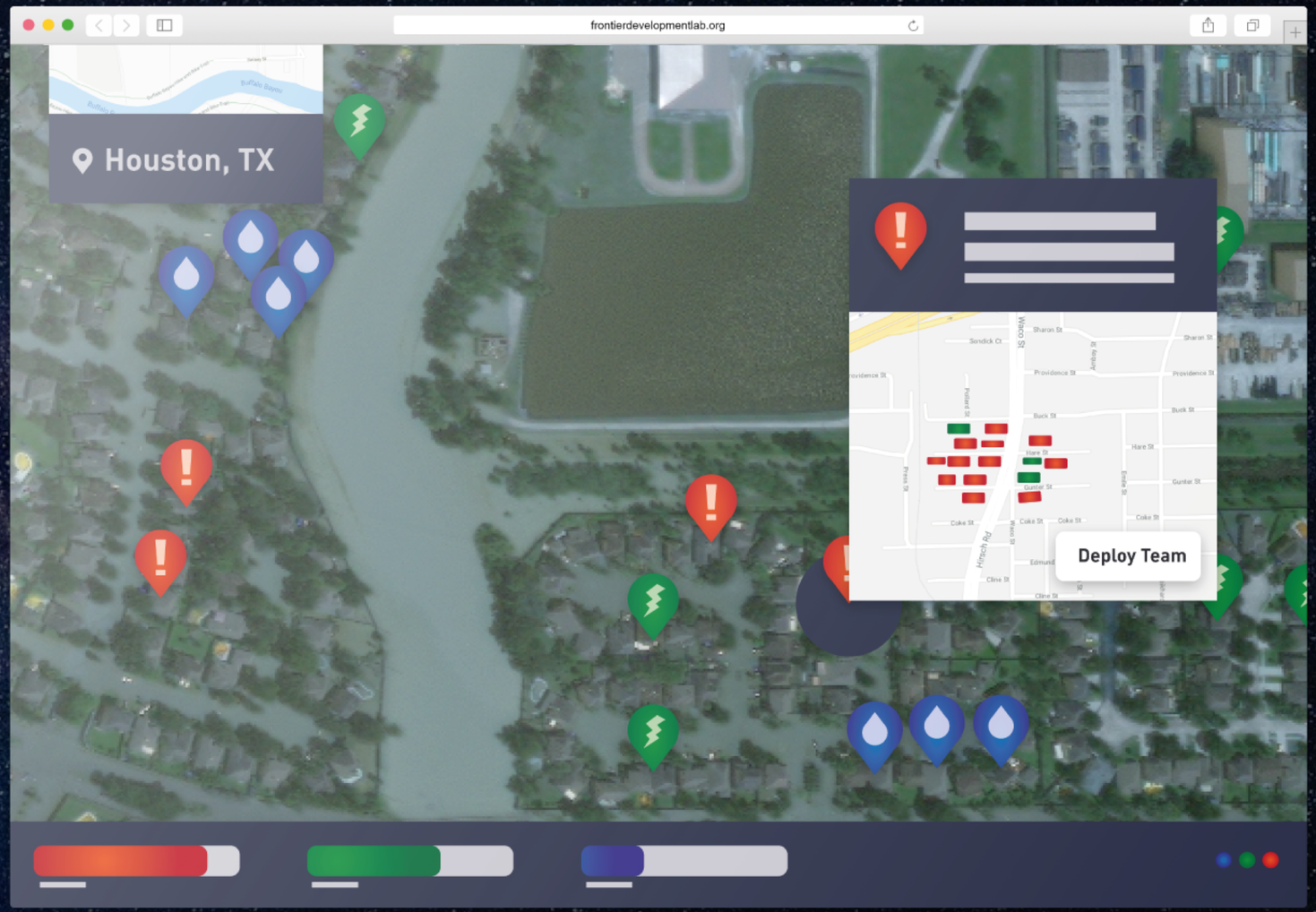
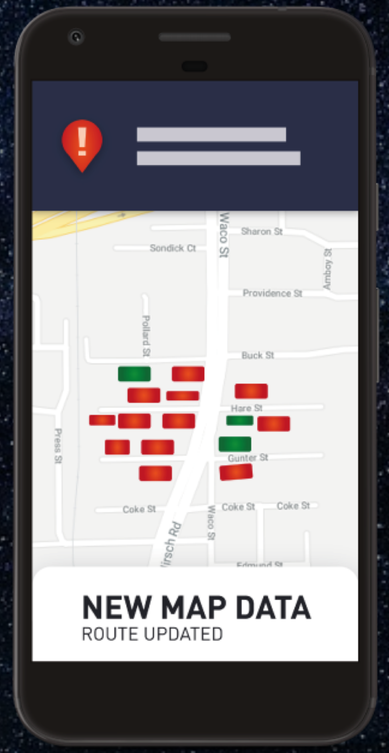
EUROPE
EARTH OBSERVATION
esa
UNIVERSITY OF
OXFORD
NVIDIA
CATAPULT
Satellite Applications
CREDIT: ESA

FDL
Source: NASA

DISASTER RESPONSE DISPATCHER




# Segmenting Flooded Buildings via Fusion of Multiresolution, Multisensor, and Multitemporal Satellite Imagery




"Multi³Net"

esa

NVIDIA

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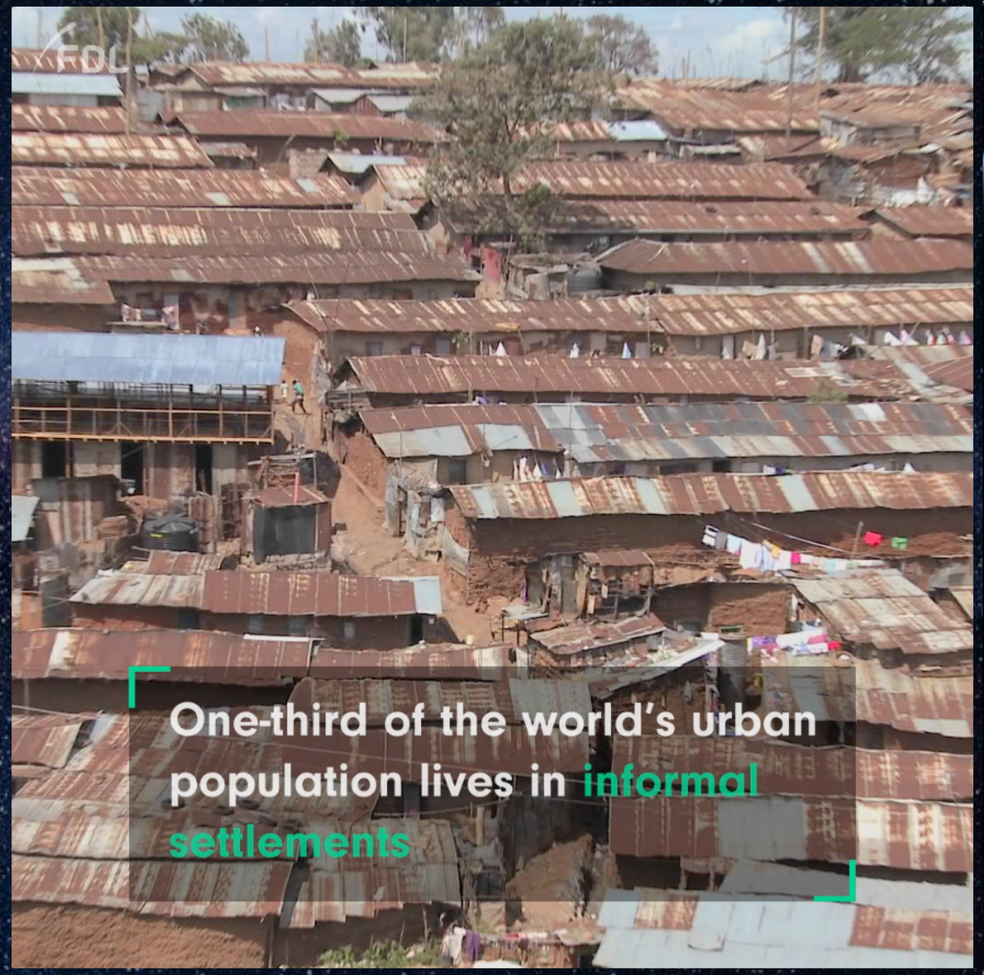


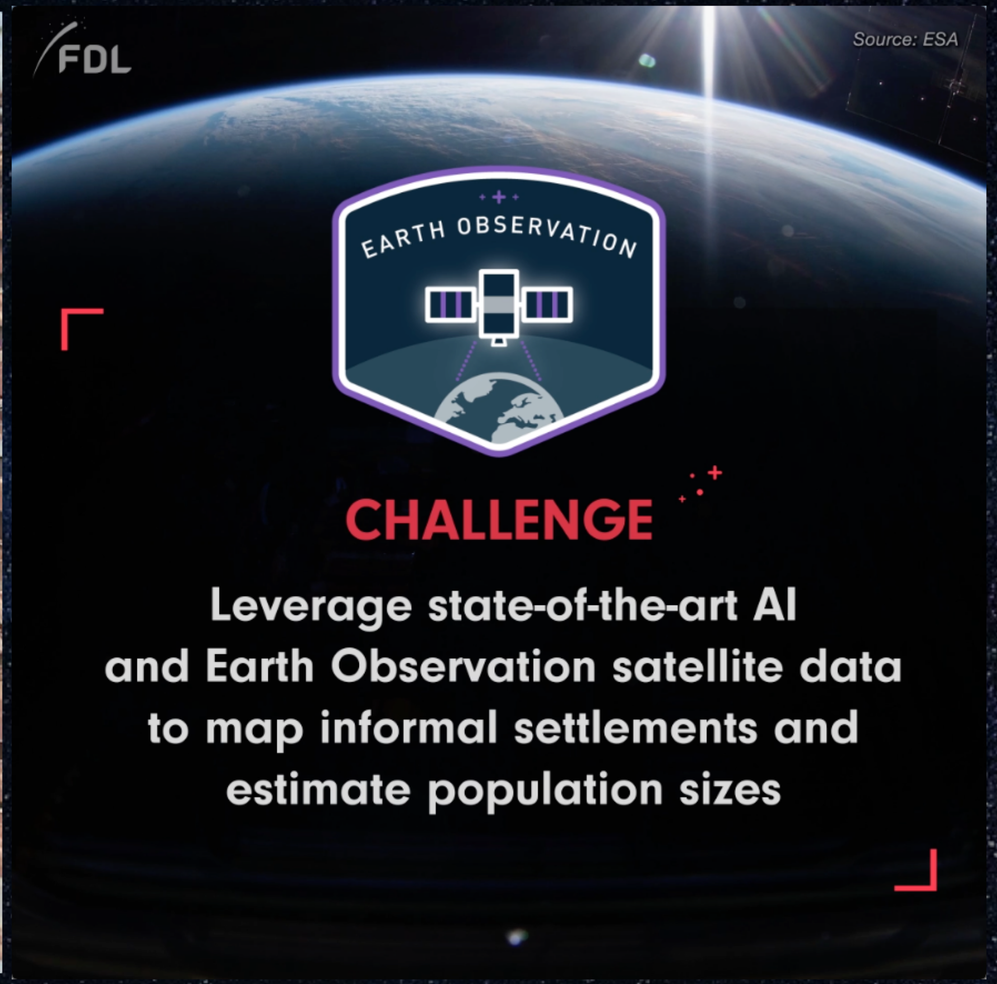


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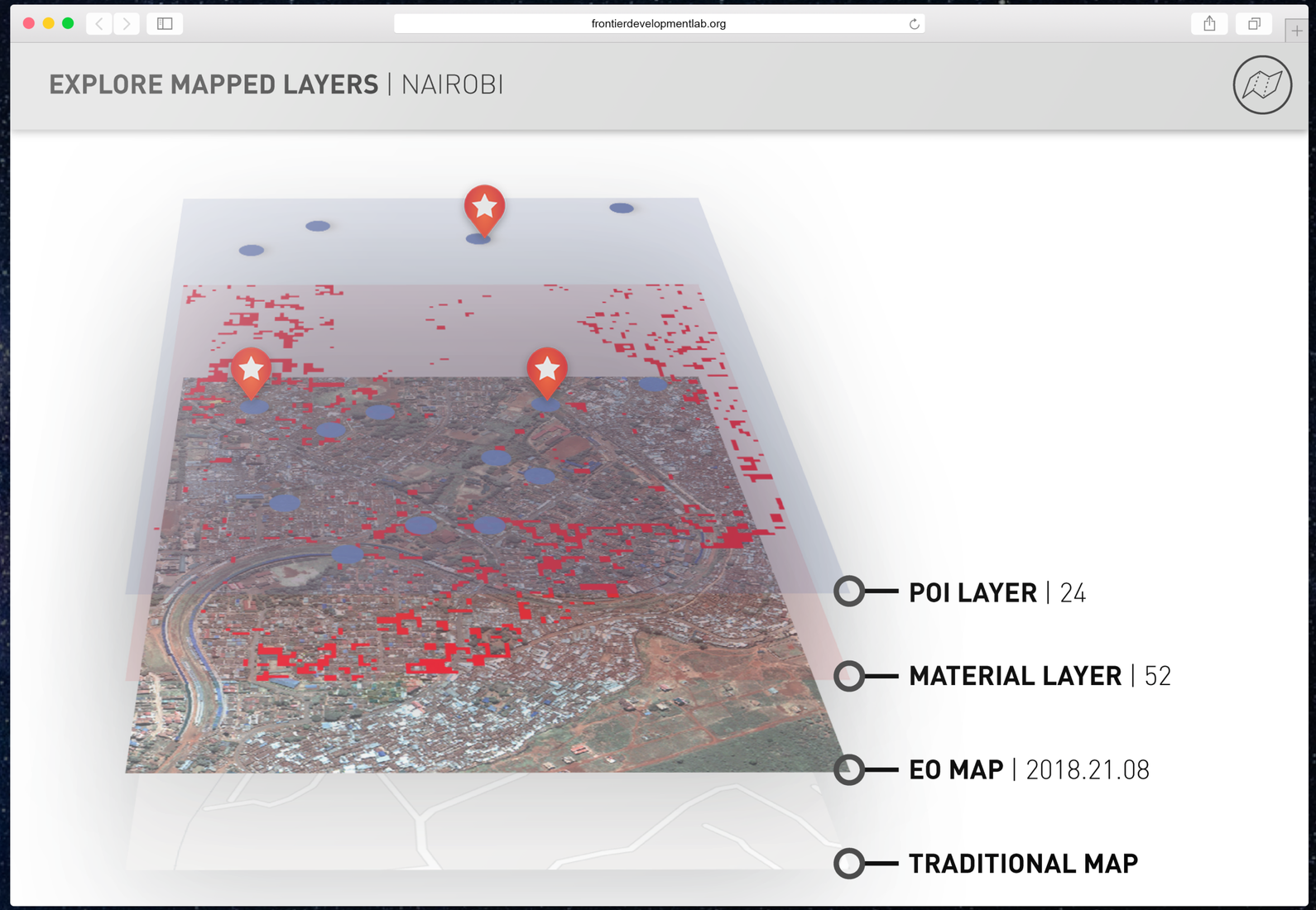


**Fused VHR (Digital Globe) and Hyperspectral (Sentinel) to create a spectral ‘fingerprint’ of informal settlements.**

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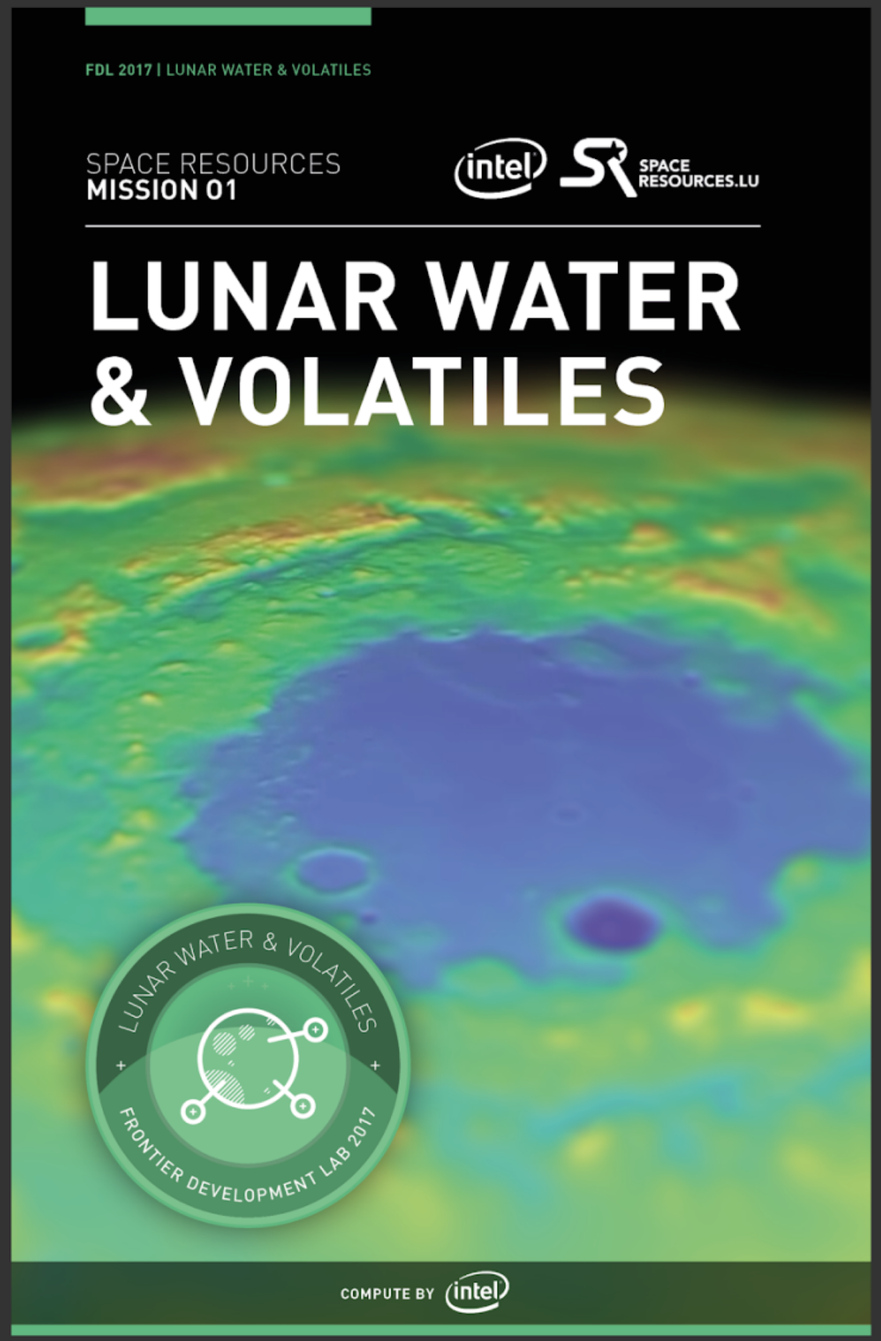
ARTIFICIAL INTELLIGENCE FOR SPACE EXPLORATION AND ALL HUMANKIND

# HOW CAN AI HELP US RETURN TO THE MOON?




# 01 DETERMINE THE LOCATION AND MOST PROMISING ACCESS POINTS FOR VITAL LUNAR H2O, IN TERMS OF COST EFFECTIVENESS AND ENGINEERING CONSTRAINTS.

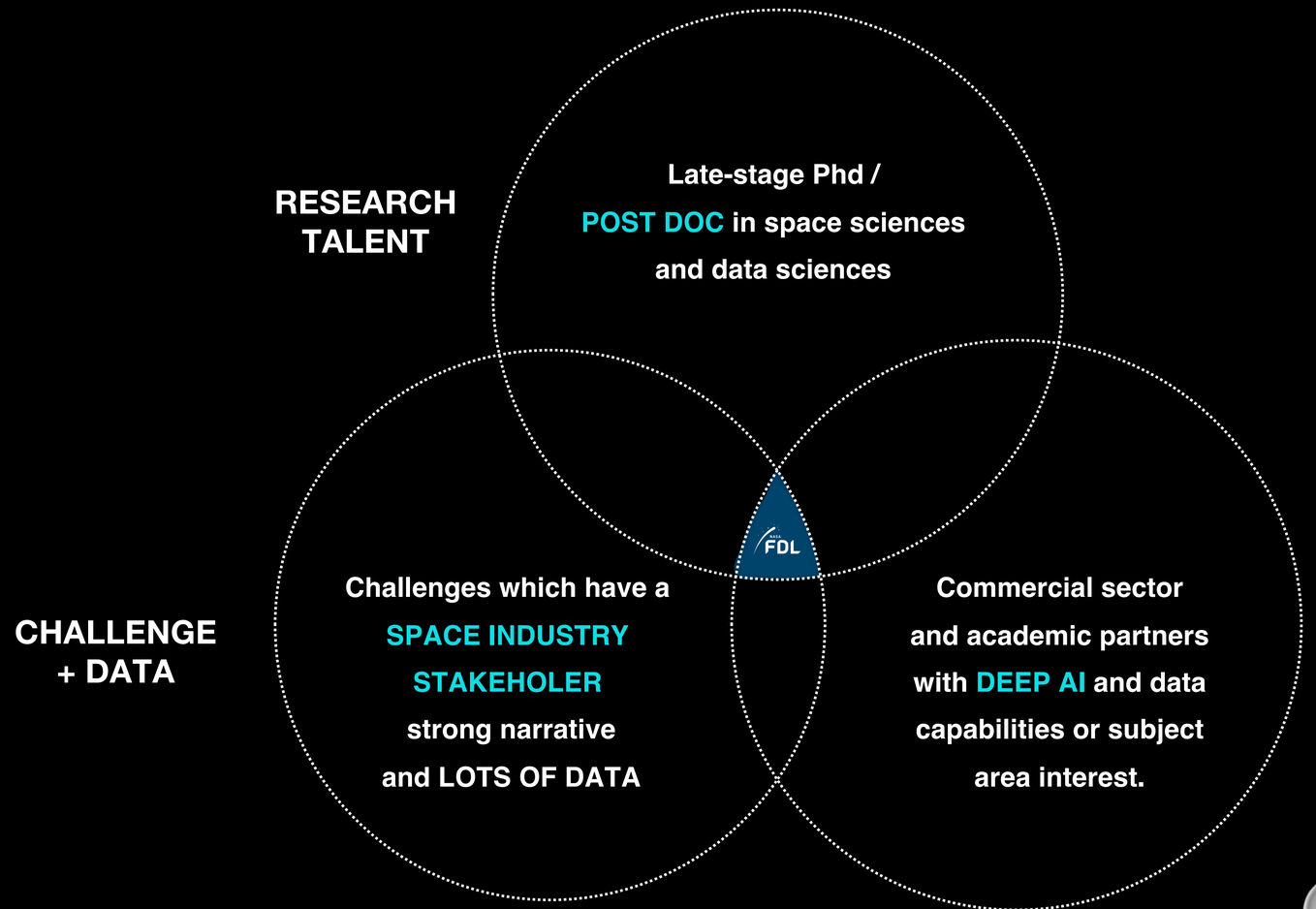
- Maps in the dark polar regions are plagued by artefacts and shadow variability.
- A large dataset was compiled for the south polar region and high-level feature extraction was performed. Results showed an **impressive speed-up of 100x compared to human experts**, with more than 98.4% agreement when approaching a crater labelling.
- This work represents a potential keystone to facilitate accessing water on the Lunar surface and future traverse planning.

Where am I?
Photo: NASA

# 01 AUTONOMOUS ROUTE PLANNING AND COOPERATIVE PLATFORMS

- Mission Planner for Cooperative Multi-Agent Systems.
- Current lunar missions based on **human-teleoperations** of a single robot could be significantly improved and optimized through the use of **multi-agent collaborative systems and assistive AI** for mission control.
- Multi-Agent Resource Operations Tool (MARMOT). **Path planning** for communications relay rover based on shadow time-dependence, communications coverage and lunar environment.

# NASA FRONTIER DEVELOPMENT LAB - FORMULA




A culture of ‘anything is possible ‘