APPLIED ARTIFICIAL INTELLIGENCE FOR SCIENCE & EXPLORATION ENABLED BY PUBLIC-PRIVATE PARTNERSHIPS



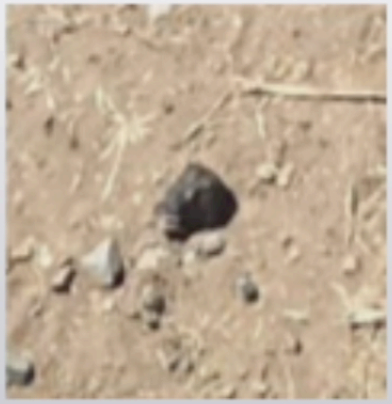


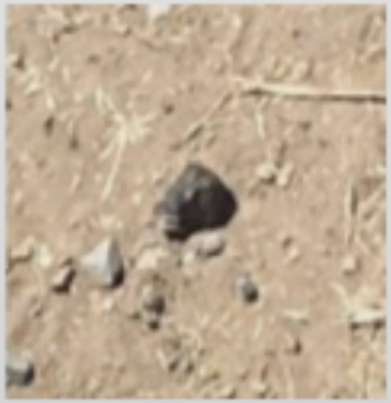
FDL is an **applied artificial intelligence** research accelerator that uses interdisciplinary teams at the PhD and post-doc level to solve challenging problems for **space exploration** and to positively impact **all humankind**.

Lika Guhathakurta & The FDL Team
NASA Ames Research Center (On detail from NASA HQ

“Artificial Intelligence is just fancy statistics”

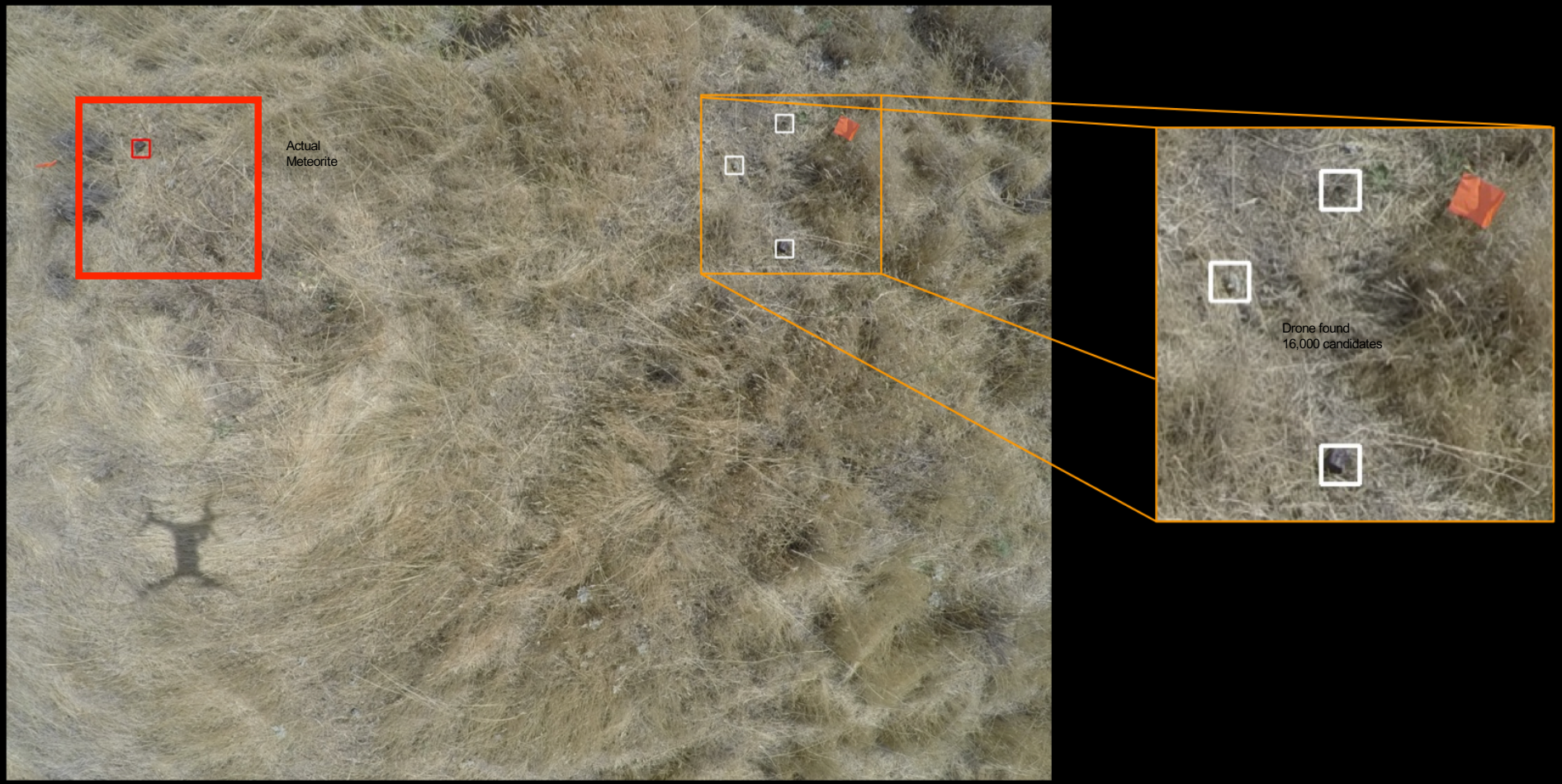
FDL AITC MEMBER






FRONTIER DEVELOPMENT LAB | 2018
CREDIT: FDL
FDL
intel AI
SPACE RESOURCES.LU
XPRIZE
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NVIDIA
LOCKHEED MARTIN
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FRONTIER DEVELOPMENT LAB | 2018



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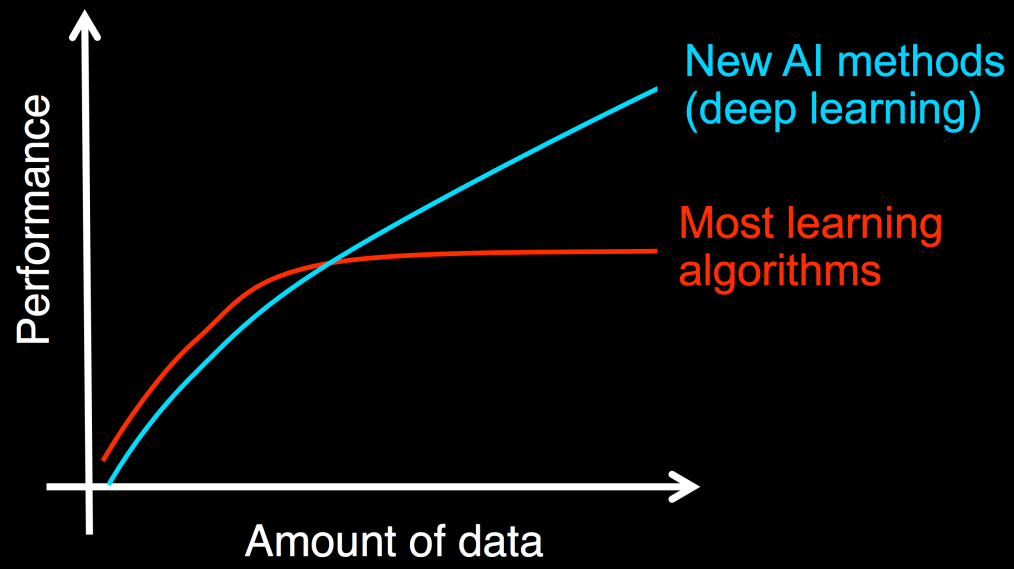
intel AI · SPACE RESOURCES.LU · XPRIZE · Google Cloud · NVIDIA · LOCKHEED MARTIN · kx · IBM · SETI INSTITUTE



CREDIT: A GENIUS

Space Science and Deep Learning

Space Science is Data Heavy

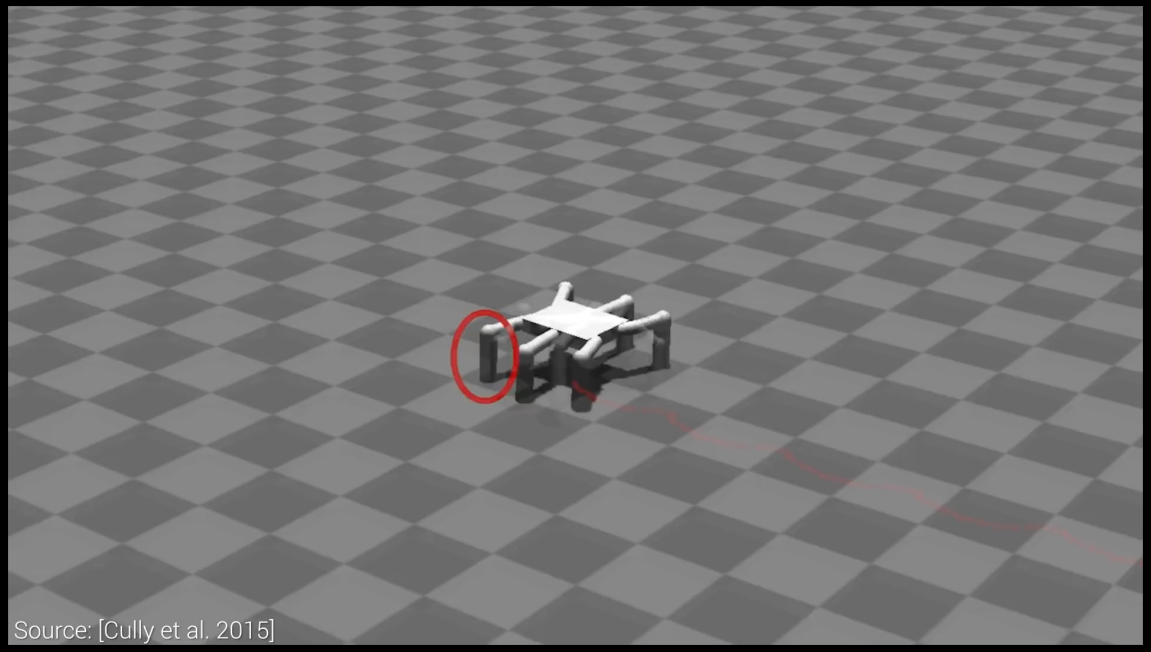


Credits: Andrew Ng

Space Science and Deep Learning

Space Science is Discovery Heavy

Creative AI discovery of features and solutions



Source: [Cully et al. 2015]

2 Gigabytes

Every 15 seconds

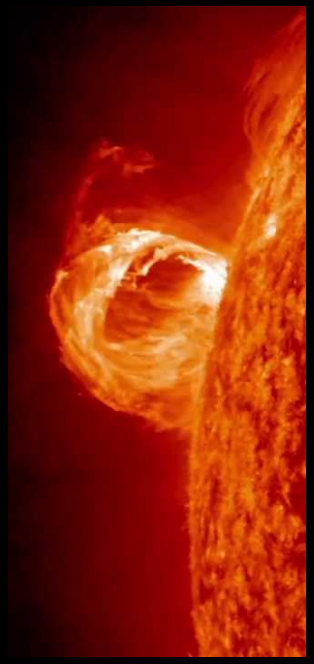
What If…? AI Meets Space Science



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

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)

AI leadership as a U.S. priority:

On February 11, 2019, the White House issued an Executive Order on Maintaining American Leadership in Artificial Intelligence. The order established a policy directive for the federal government to "sustain and enhance the scientific, technological and economic leadership position of the United States in AI R&D and deployment through a coordinated Federal Government Strategy, the American AI Initiative guided by six principles" (in summary):

1. **Promote** sustained investment in AI R&D in collaboration with industry, academia, international partners and allies, and other non-Federal entities to generate technological breakthroughs in AI and related technologies and to rapidly transition those breakthroughs into capabilities that contribute to our economic and national security.
2. **Enhance** access to high-quality and fully traceable Federal data, models, and computing resources to increase the value of such resources for AI R&D, while maintaining safety, security, privacy, and confidentiality protections consistent with applicable laws and policies.
3. **Reduce** barriers to the use of AI technologies to promote their innovative application while protecting American technology, economic and national security, civil liberties, privacy, and values.
4. **Ensure** that technical standards minimize vulnerability to attacks from malicious actors and reflect Federal priorities for innovation, public trust, and public confidence in systems that use AI technologies; and develop international standards to promote and protect those priorities.
5. **Train** the next generation of American AI researchers and users through apprenticeships; skills programs; and education in science, technology, engineering, and mathematics (STEM), with an emphasis on computer science, to ensure that American workers, including Federal workers, are capable of taking full advantage of the opportunities of AI.
6. **Develop and implement** an action plan, in accordance with the National Security Presidential Memorandum of February 11, 2019 (Protecting the United States Advantage in Artificial Intelligence and Related Critical Technologies) (the NSPM) to protect the advantage of the United States in AI and technology critical to United States economic and national security interests against strategic competitors and foreign adversaries.

HISTORY

THE NASA FRONTIER DEVELOPMENT LAB (FDL) IS A PUBLIC / PRIVATE **APPLIED AI RESEARCH PARTNERSHIP** BETWEEN NASA, THE SETI INSTITUTE AND LEADERS IN COMMERCIAL AI, PRIVATE SPACE, ACADEMIA AND PARTNER SPACE AGENCIES.

- NASA FDL is four years old
- FDL has as developed a proven formula for producing excellence in applied AI research over very rapid timescales - with a focus on 'AI explainability' to match the quality expectations of the space industry.
- FDL has produced 15 peer reviewed journal papers and been accepted to 30+ scientific conferences and multiple articles in the science press. FDL results have already been deployed on NASA programs[1].
- NASA FDL is currently based at NASA ARC and hosted and administered by the SETI Institute.
- The formula has attracted the attention of partner space agencies, ESA, CSA, LSA, with more to come.
- Other NASA centers are showing interest too, particularly GSFC, MSFC, JSC and Glenn.



FDL IN NUMBERS

+ **4** years, **6** research sprints (**4** NASA, **2** ESA)
+ **4** Space Agency Partners / **12** Commercial
+ **8** Big Thinks
+ **843** applicants (436 in 2019)
+ **11%** acceptance rate (‘18 / ‘19)
+ **108** Researchers (Phd and Post-Doc)
+ **138** mentors and guest experts
+ **633** Partner reviewer community, **25+** Universities
+ **$1.5m** compute (partner in-kind)
+ **26** Research Projects, **15** Publications* / **30+** Scientific and AI conferences
+ **50/50** US / International split (NASA FDL)

*** As of August 2019**

WHY NASA FDL?

AI is evolving quickly. The revolution was started by the application of neural nets to large quantities of pre-labeled data (known as '**supervised' deep learning**[2]) in 2012. These methods are now mainstream.

The state-of-the-art is now looking towards sparse or unlabeled data (known as **'unsupervised' deep learning**[3] **or machine learning**) and how to explain the uncertainty of the results. This is known as **'explainability'** and a key part of determining the veracity and usefulness of any AI.

Although deep learning is being democratized, **producing excellence** (i.e explainable, bias free and trustworthy results) is increasingly **difficult**, requiring multi-faceted and sophisticated teams and a **deep understanding** of how to use the **newest techniques. This is where FDL provides unique value and opportunity for space science and exploration.**

[2] Supervised methods require tagged data / human in the loop to train the ML

[3] Unsupervised techniques are based on synthetic, physics models or automatic clustering methods to train the ML (e.g. reinforcement learning)

[4] Bayesian and Probabilistic workflows extract uncertainty from Deep Learning models using gaussian methods to determine model confidence.

"Deep Learning Big Bang" 2012

FDL Initiated 2015

NOW

Supervised Pre-labeled data (by humans)
- becoming democratized, simple workflows, clean datasets. ML is 'black box'

FDL FRONTIER DEVELOPMENT LAB

Unsupervised Sparse or unlabeled data

Bayesian and Probabilistic Deep Learning[4]
Quantifying uncertainty - leadership in explainability

Data fusion Rapid increase of data size, compute cost and workflow complexity requires AI management capacity

WHY A DEDICATED AI LAB?

1 ML IS EXPENSIVE

Data scientists at Phd level are difficult to recruit and average salaries are 140K USD/year. Market rate for seniors is 1M USD. Moreover compute costs limit experimentation and ambition.

2 ML HAS LARGE FAILURE RATE

Data scientists cite the following for project failure:

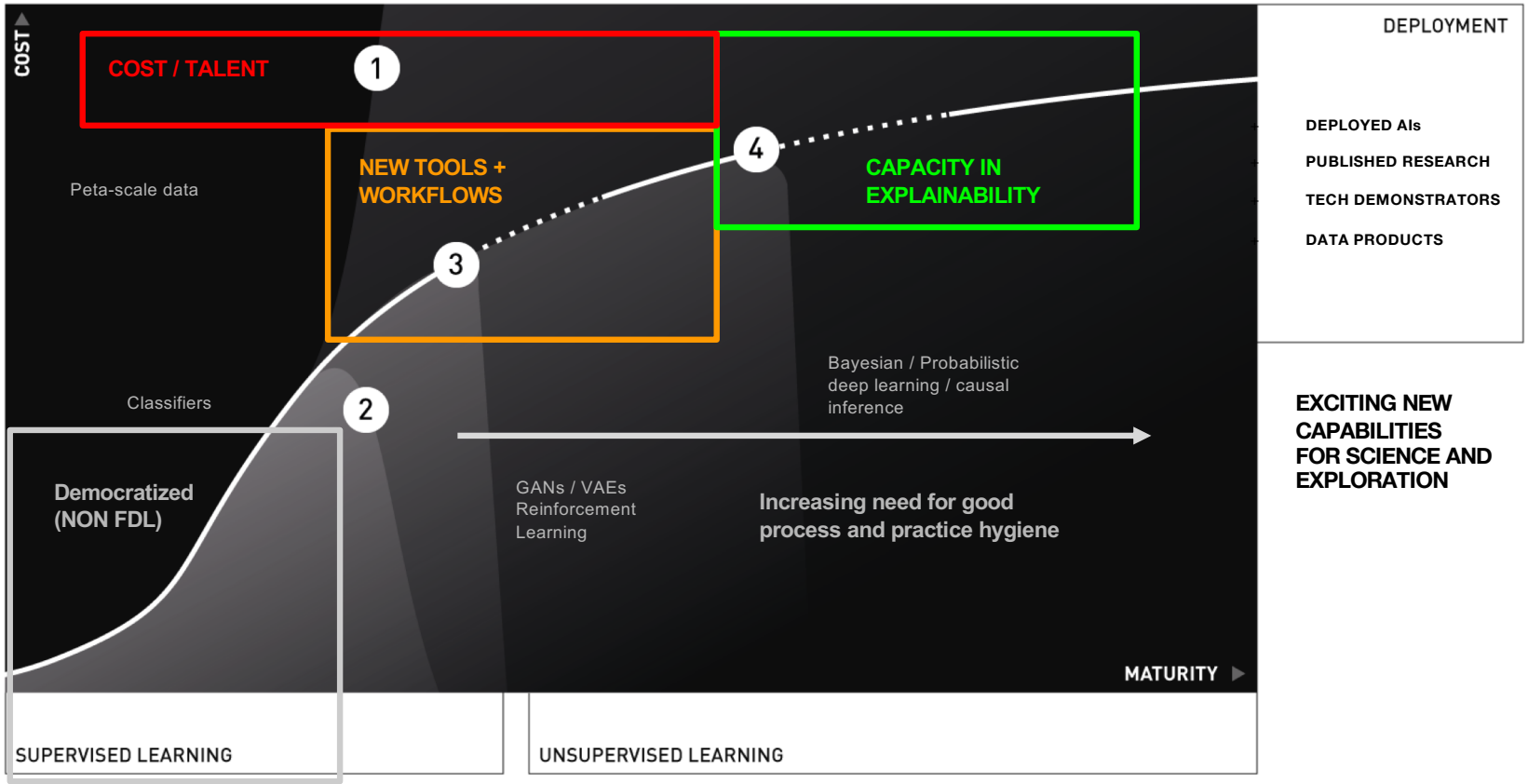
1. Not knowing the data
2. Poor management
3. Lack of good questions

3 THE UNSUPERVISED LEARNING GAP

AI tools have been maturing quickly and most scientists are now familiar with the basics get results with off-the-shelf tools using well tagged data. (Supervised). FDL's team approach allows teams to tackle far more sophisticated AI workflows.

4 THE EXPLAINABILITY GAP

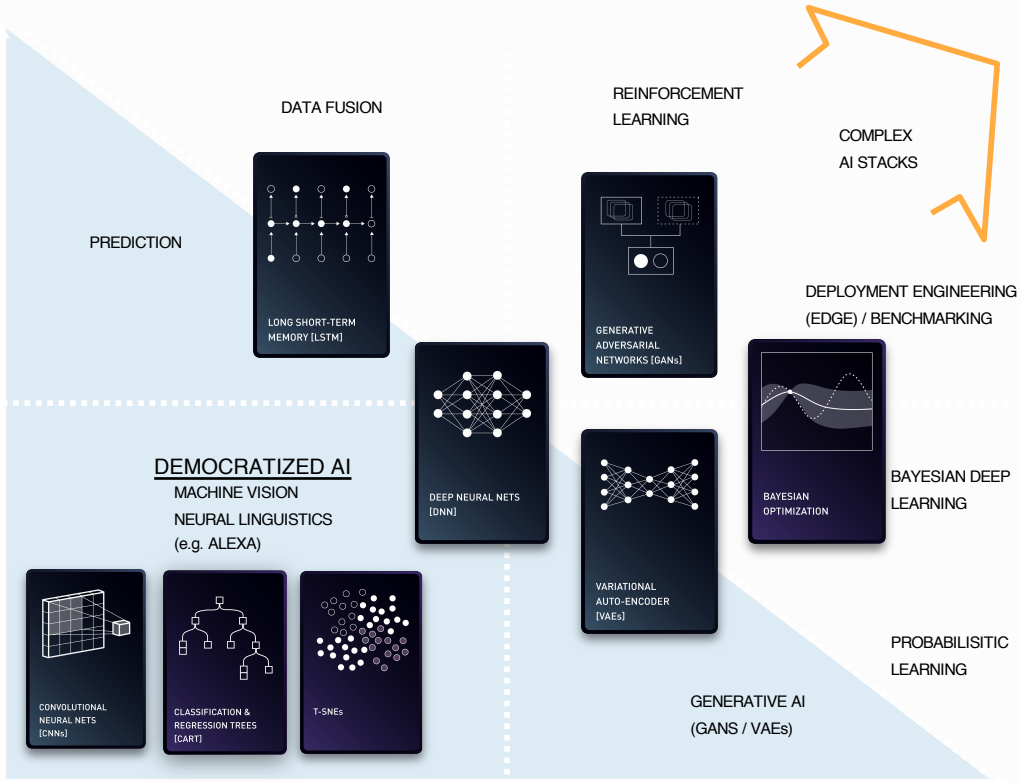
Similarly, while it may be possible to develop a compelling demo, ML often fails in the real world due to procedural errors, unintended variables and biases. Understanding what works and why is key.



EXCITING NEW CAPABILITIES FOR SCIENCE AND EXPLORATION

OVERVIEW:

WHY A DEDICATED AI LAB?



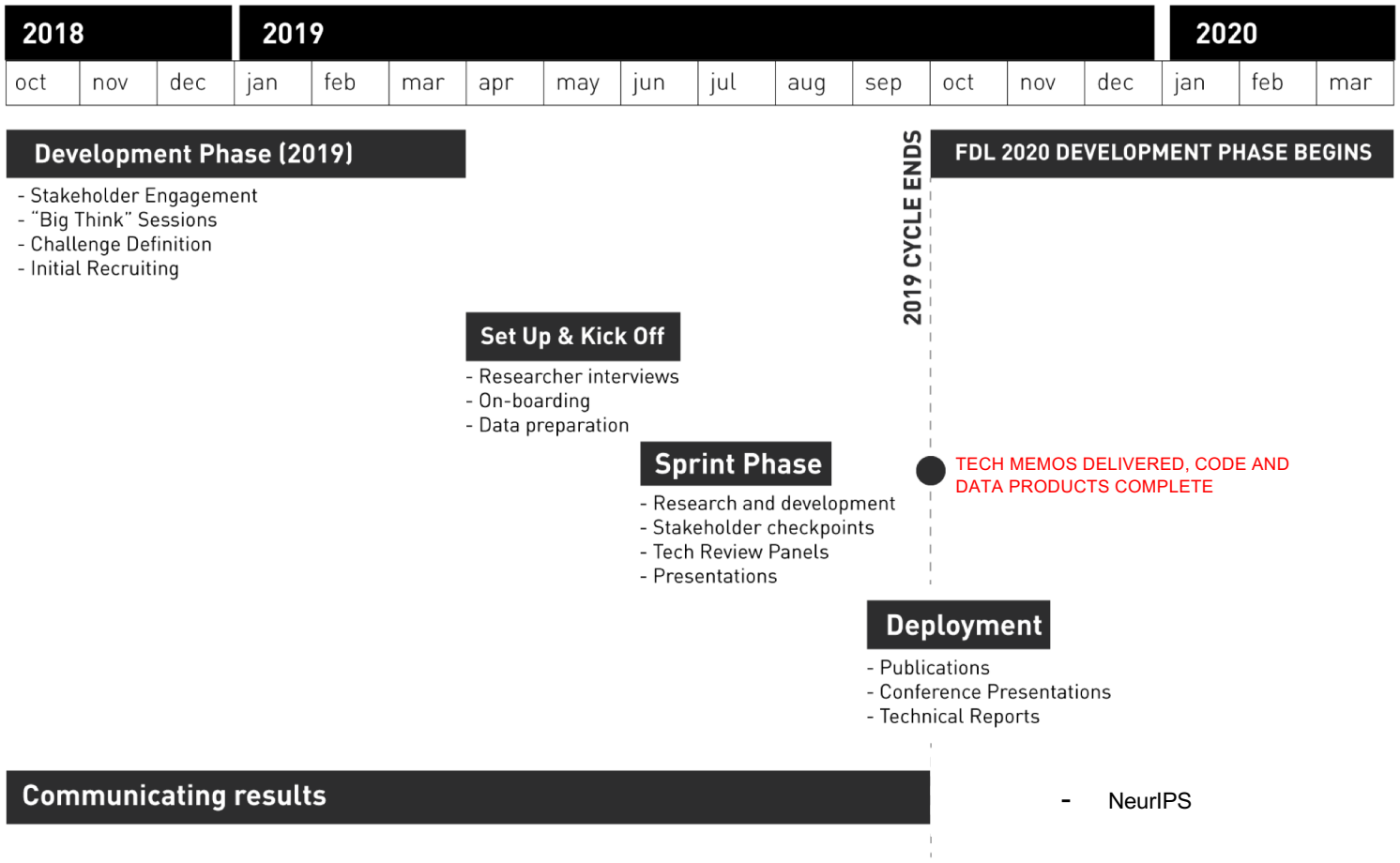
Requires data pipeline innovation or large compute (High cost)

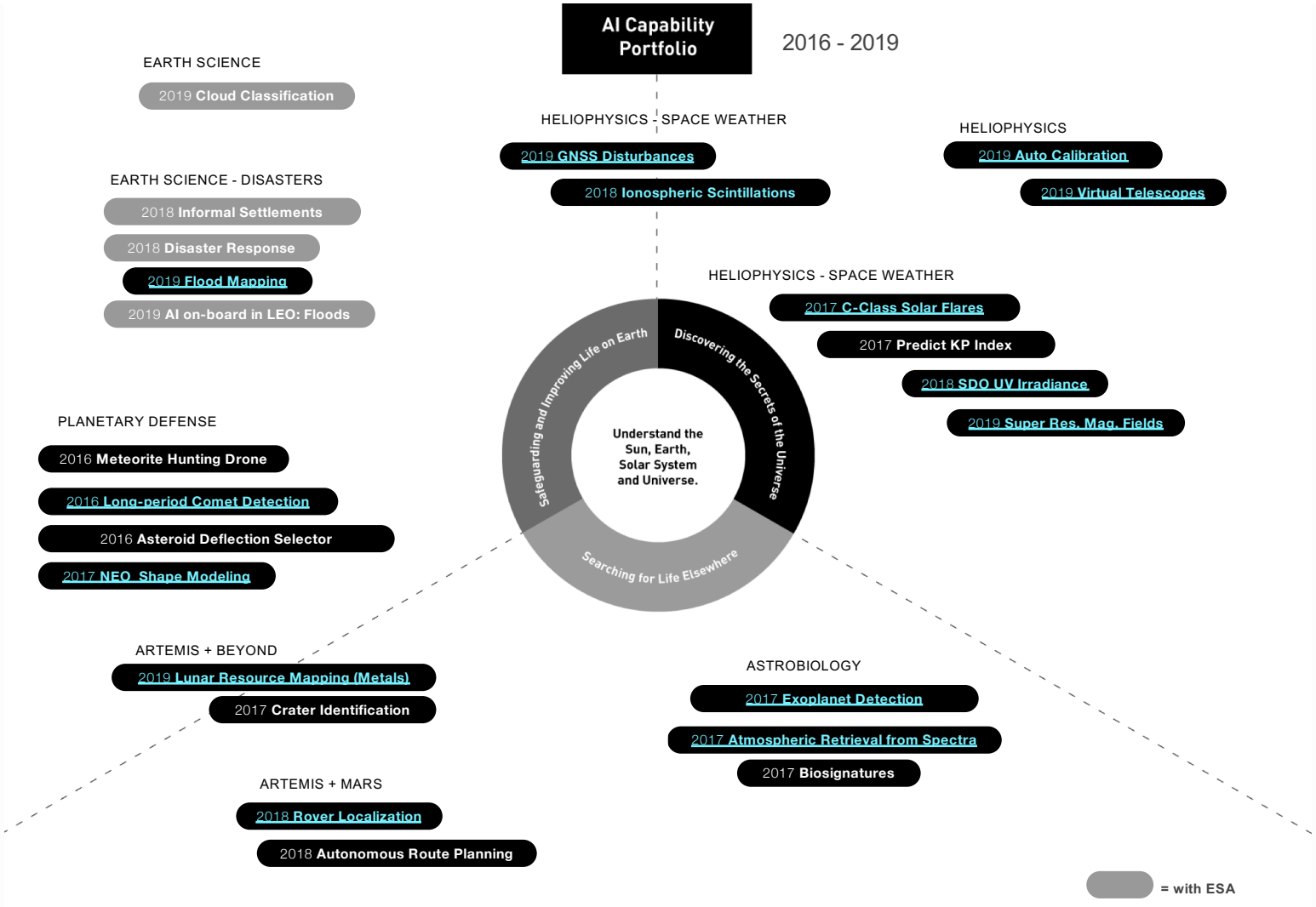
Simple data workflows e.g. static data (low cost)

- PROBLEMS THAT REQUIRE INNOVATION IN DATA PIPELINES / TRAINING
- PROBLEMS THAT USE VERY LARGE DATASETS = SIGNIFICANT TRAINING AND ENGINEERING COSTS (TIME / CAPITAL)
- PROBLEMS THAT REQUIRE INTEGRATION OF NUMEROUS AI TOOLS TO CREATE AI WORKFLOWS.
- PROBLEMS THAT REQUIRE HIGH DEGREE OF CONFIDENCE IN THE OUTCOME.
- PROBLEMS THAT HAVE SPARSE OR DYNAMIC DATA OR REQUIRE TRANSFER LEARNING

"SUPERVISED" | Available AI tools / containers | Emerging AI techniques | "UNSUPERVISED"

TIMELINE

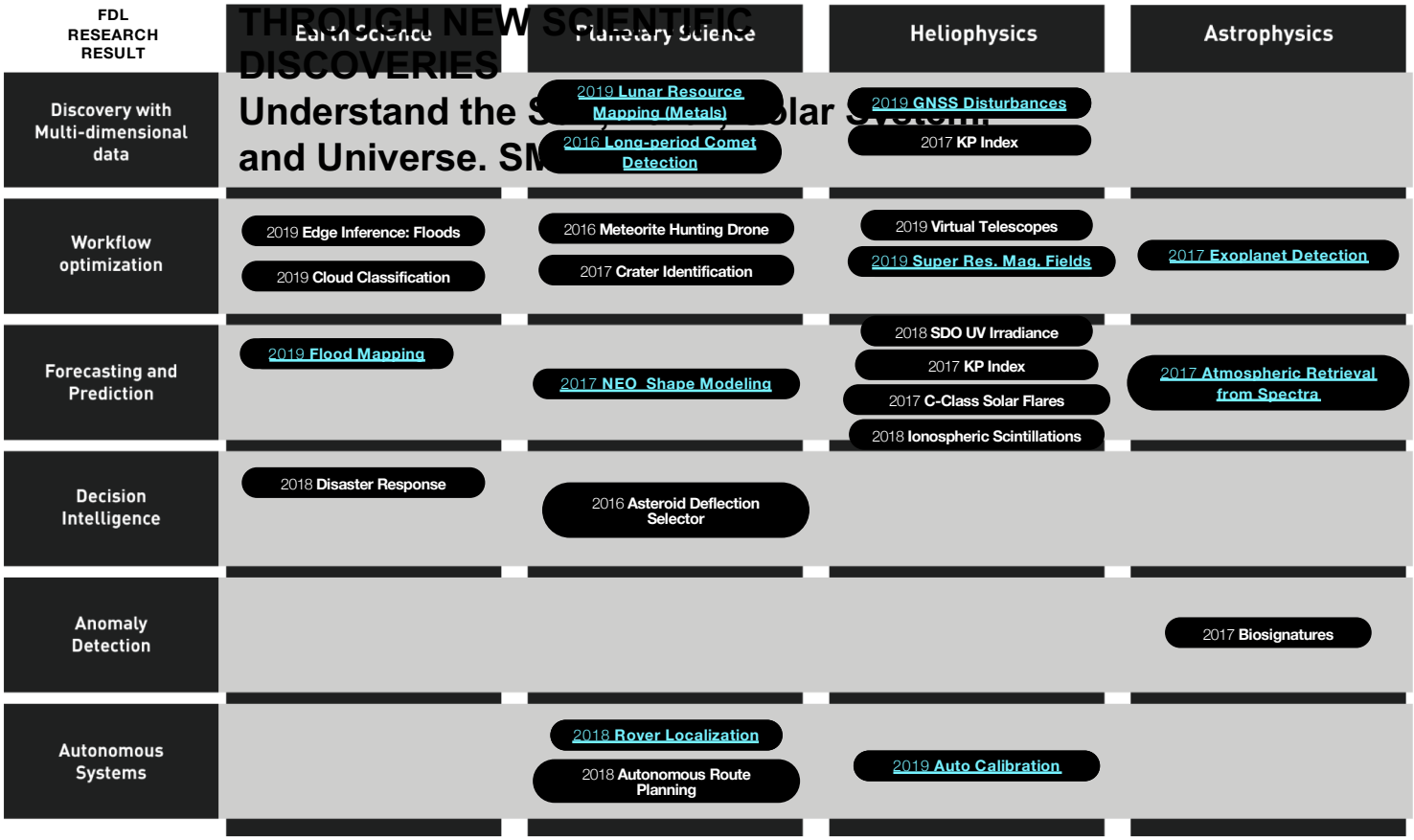

2018
2019
2020
oct
nov
dec
jan
feb
mar
apr
may
jun
jul
aug
sep
oct
nov
dec
jan
feb
mar
Development Phase (2019)
- Stakeholder Engagement
- "Big Think" Sessions
- Challenge Definition
- Initial Recruiting
2019 CYCLE ENDS
FDL 2020 DEVELOPMENT PHASE BEGINS
Set Up & Kick Off
- Researcher interviews
- On-boarding
- Data preparation
Sprint Phase
- Research and development
- Stakeholder checkpoints
- Tech Review Panels
- Presentations
TECH MEMOS DELIVERED, CODE AND DATA PRODUCTS COMPLETE
Deployment
- Publications
- Conference Presentations
- Technical Reports
Communicating results
- NeurIPS


AI Capability Portfolio
2016 - 2019
EARTH SCIENCE
2019 Cloud Classification
EARTH SCIENCE - DISASTERS
2018 Informal Settlements
2018 Disaster Response
2019 Flood Mapping
2019 AI on-board in LEO: Floods
HELIOPHYSICS - SPACE WEATHER
2019 GNSS Disturbances
2018 Ionospheric Scintillations
HELIOPHYSICS
2019 Auto Calibration
2019 Virtual Telescopes
HELIOPHYSICS - SPACE WEATHER
2017 C-Class Solar Flares
2017 Predict KP Index
2018 SDO UV Irradiance
2019 Super Res. Mag. Fields
Safeguarding and Improving Life on Earth
Discovering the Secrets of the Universe
Understand the Sun, Earth, Solar System and Universe.
Searching for Life Elsewhere
PLANETARY DEFENSE
2016 Meteorite Hunting Drone
2016 Long-period Comet Detection
2016 Asteroid Deflection Selector
2017 NEO Shape Modeling
ARTEMIS + BEYOND
2019 Lunar Resource Mapping (Metals)
2017 Crater Identification
ARTEMIS + MARS
2018 Rover Localization
2018 Autonomous Route Planning
ASTROBIOLOGY
2017 Exoplanet Detection
2017 Atmospheric Retrieval from Spectra
2017 Biosignatures
= with ESA

PROGRAM IMPACT: DEMONSTRATED CAPACITY

EXPAND HUMAN KNOWLEDGE THROUGH NEW SCIENTIFIC DISCOVERIES

Understand the S… / …olar System and Universe. SM…



After four years FDL has a proven formula for AI success:

1) FDL is INTERDISCIPLINARY

Tailored teams of Phds and World class ML mentors are curated around a challenge to drive excellence.

= HIGHER QUALITY

2) FDL creates LASER FOCUS

Silicon Valley sprint methods, culture and vast donated compute allow rapid iteration key to ML progress.

= SPEED TO RESULTS

3) FDL is about PARTNER EXPERTISE

Commercial, academic and space agency partners combine to create a unique envelope of expertise that massively increases challenge success, raises quality and lowers cost.

= IMPROVED STRIKE RATE/ LOWER COST

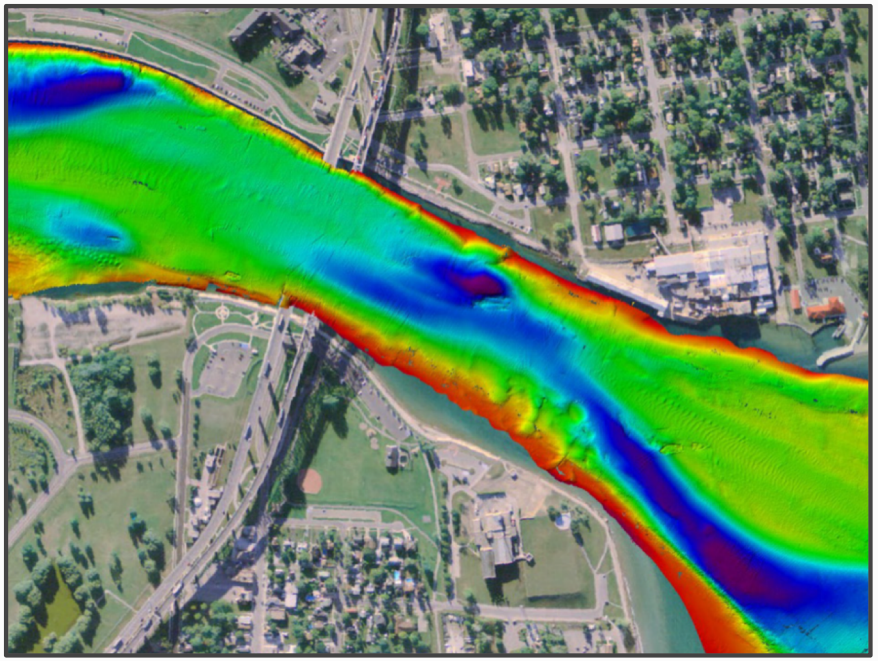

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EUROPE
EARTH OBSERVATION
esa
UNIVERSITY OF
OXFORD
NVIDIA
CATAPULT
Satellite Applications
CREDIT: ESA


FDL
Source: NASA


Kali Harris
CBS NEWS
CBSNEWS.COM

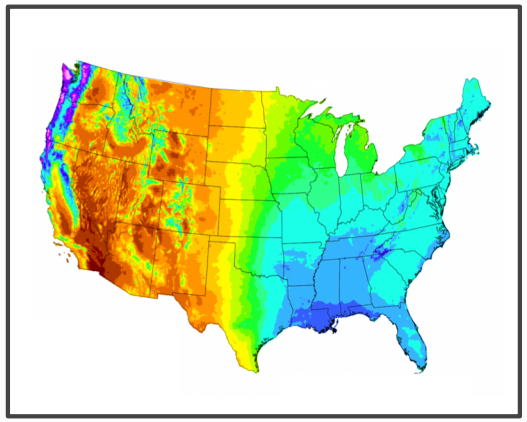
Current Approach: Physics-Based Flood Modeling



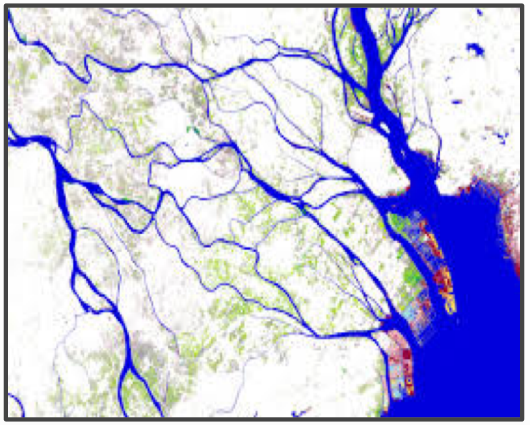


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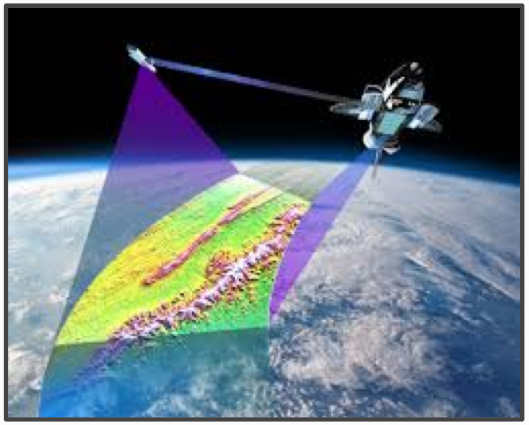
Data Inputs



Accumulated Rainfall

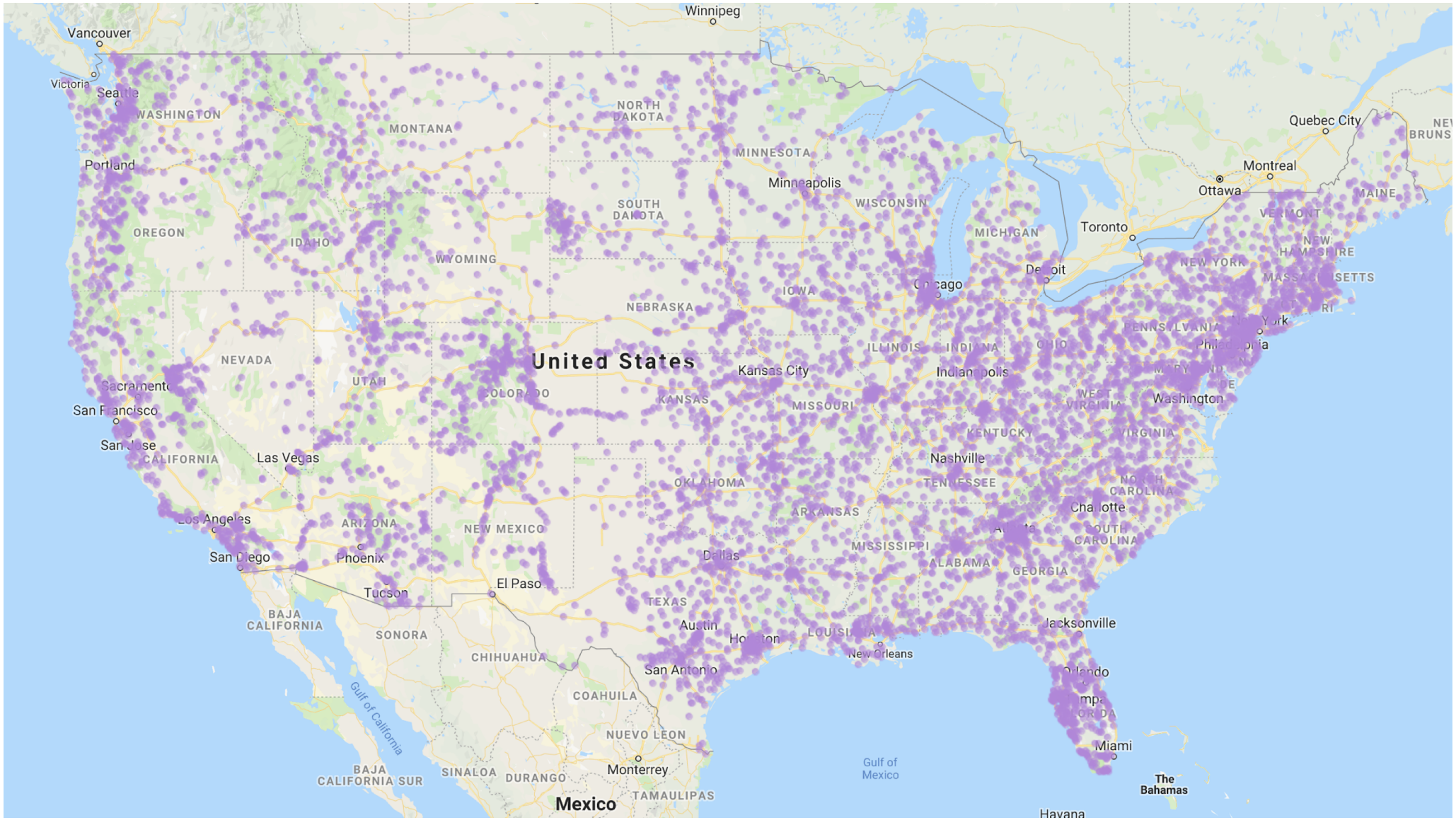


River Basin Characteristics

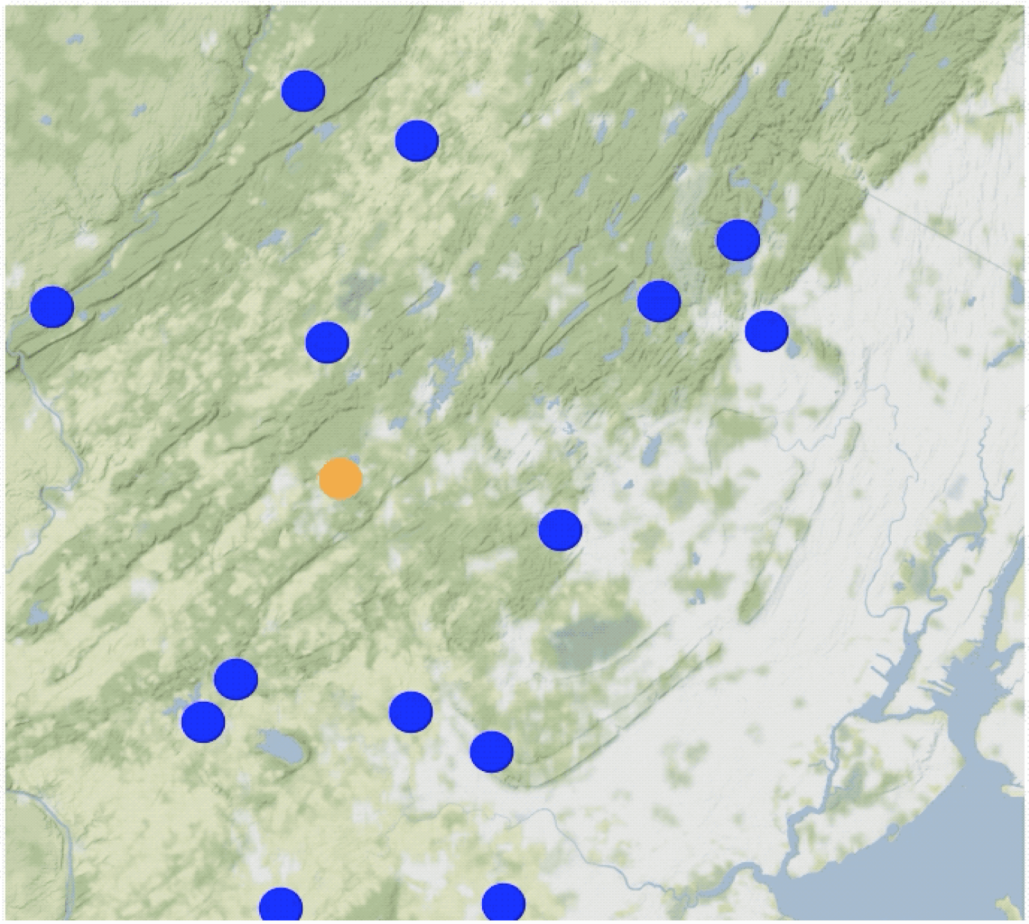


Remotely-Sensed Land Use and Topography

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Winnipeg
Vancouver
Victoria
Seattle
WASHINGTON
MONTANA
NORTH DAKOTA
MINNESOTA
Portland
Minneapolis
SOUTH DAKOTA
WISCONSIN
Quebec City
Montreal
Ottawa
MAINE
OREGON
IDAHO
WYOMING
MICHIGAN
Toronto
Detroit
Chicago
IOWA
NEBRASKA
NEW YORK
NEVADA
United States
ILLINOIS
INDIANA
OHIO
Kansas City
Indianapolis
Sacramento
UTAH
COLORADO
KANSAS
MISSOURI
Washington
San Francisco
CALIFORNIA
Las Vegas
KENTUCKY
VIRGINIA
Nashville
OKLAHOMA
TENNESSEE
Los Angeles
ARIZONA
NEW MEXICO
ARKANSAS
Charlotte
San Diego
Phoenix
Dallas
MISSISSIPPI
ALABAMA
GEORGIA
Tucson
El Paso
TEXAS
BAJA CALIFORNIA
SONORA
Austin
Houston
LOUISIANA
Jacksonville
New Orleans
CHIHUAHUA
San Antonio
Orlando
COAHUILA
Gulf of California
NUEVO LEON
Miami
Gulf of Mexico
BAJA CALIFORNIA SUR
SINALOA
DURANGO
Monterrey
The Bahamas
TAMAULIPAS
Mexico
Havana

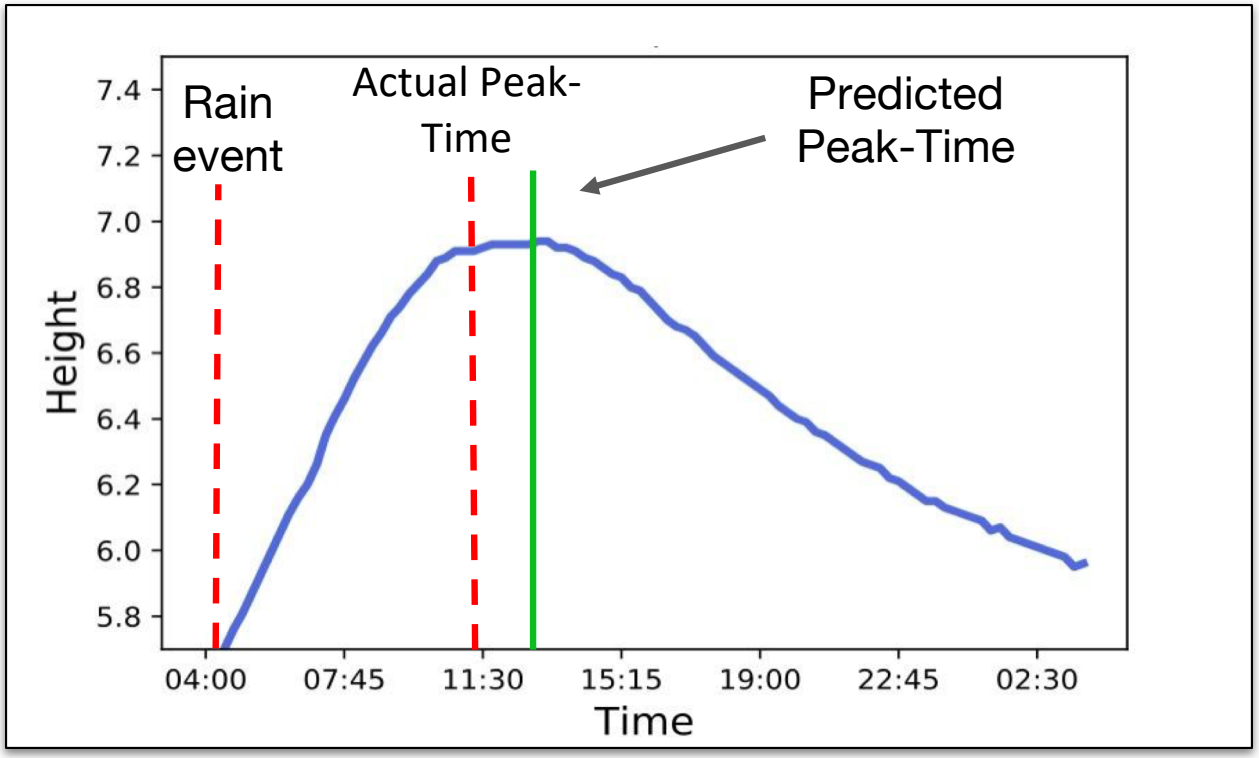
Predicted Floods 2011-02



Improved Accuracy

- Correct Prediction
- Incorrect Prediction

Use Case: Time-to-Peak Prediction



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Ungauged Basin Challenge

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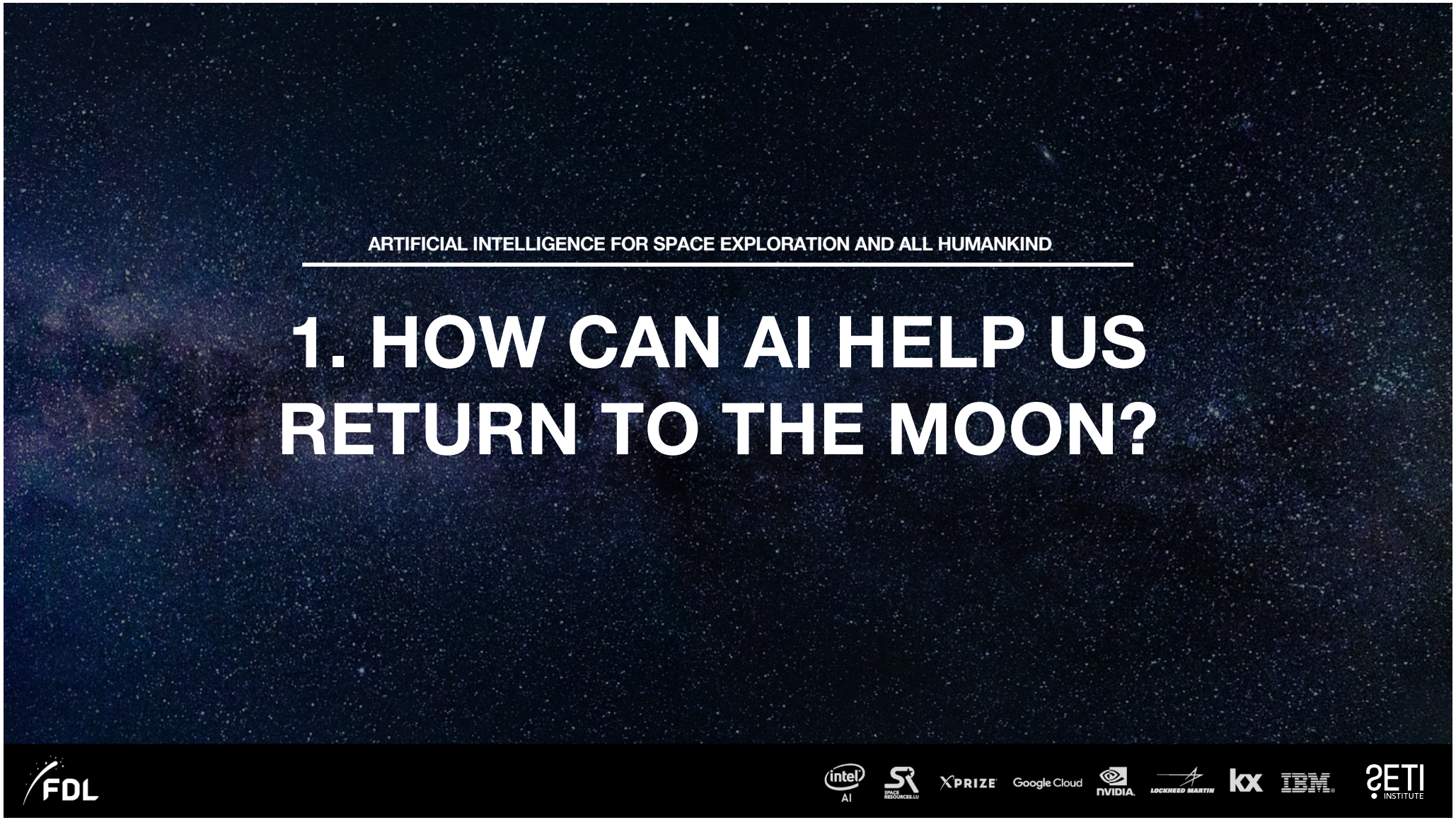
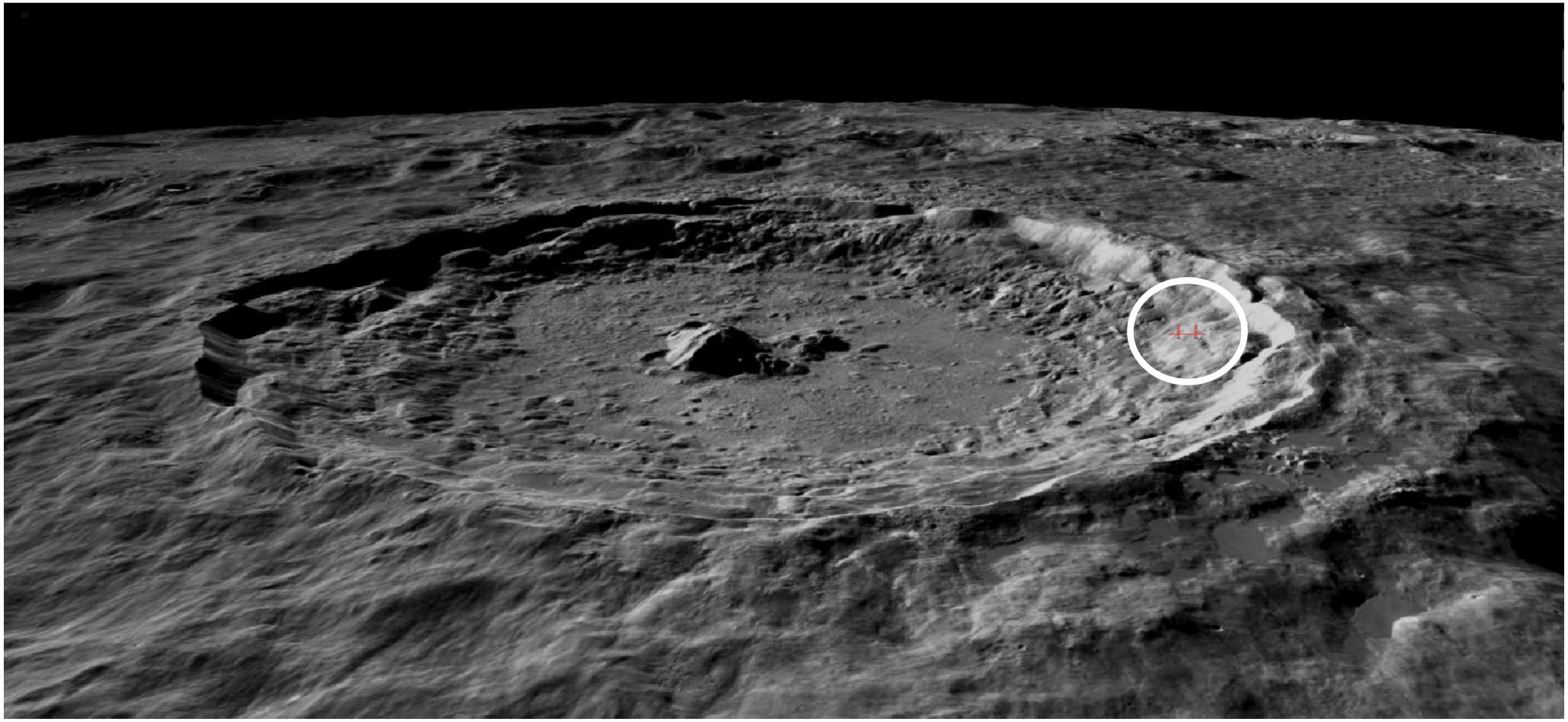

ARTIFICIAL INTELLIGENCE FOR SPACE EXPLORATION AND ALL HUMANKIND
1. HOW CAN AI HELP US RETURN TO THE MOON?
FDL
intel AI
SPACE RESOURCES.LU
XPRIZE
Google Cloud
NVIDIA
LOCKHEED MARTIN
kx
IBM
SETI INSTITUTE

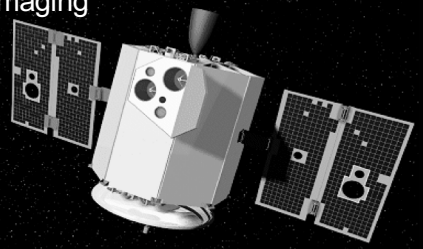


Image Credit: JPL/NASA

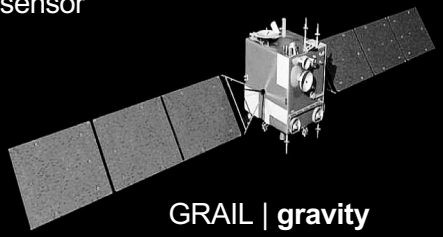


NASA FRONTIER DEVELOPMENT LAB 2019

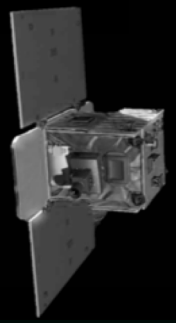
Clementine | **visible & ultraviolet** imaging



Chang'e 1 & 2 | **microwave** sensor



GRAIL | **gravity** sensor

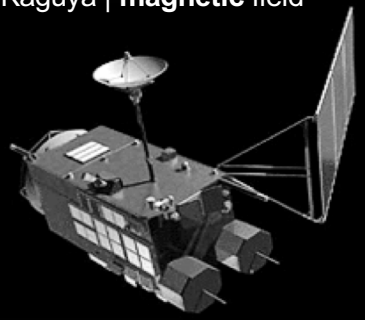




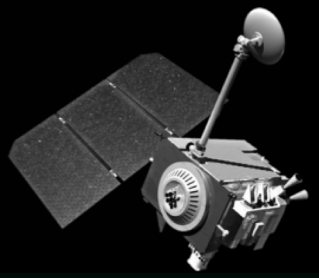
Lunar Prospector | **gamma** rays



Kaguya | **magnetic** field

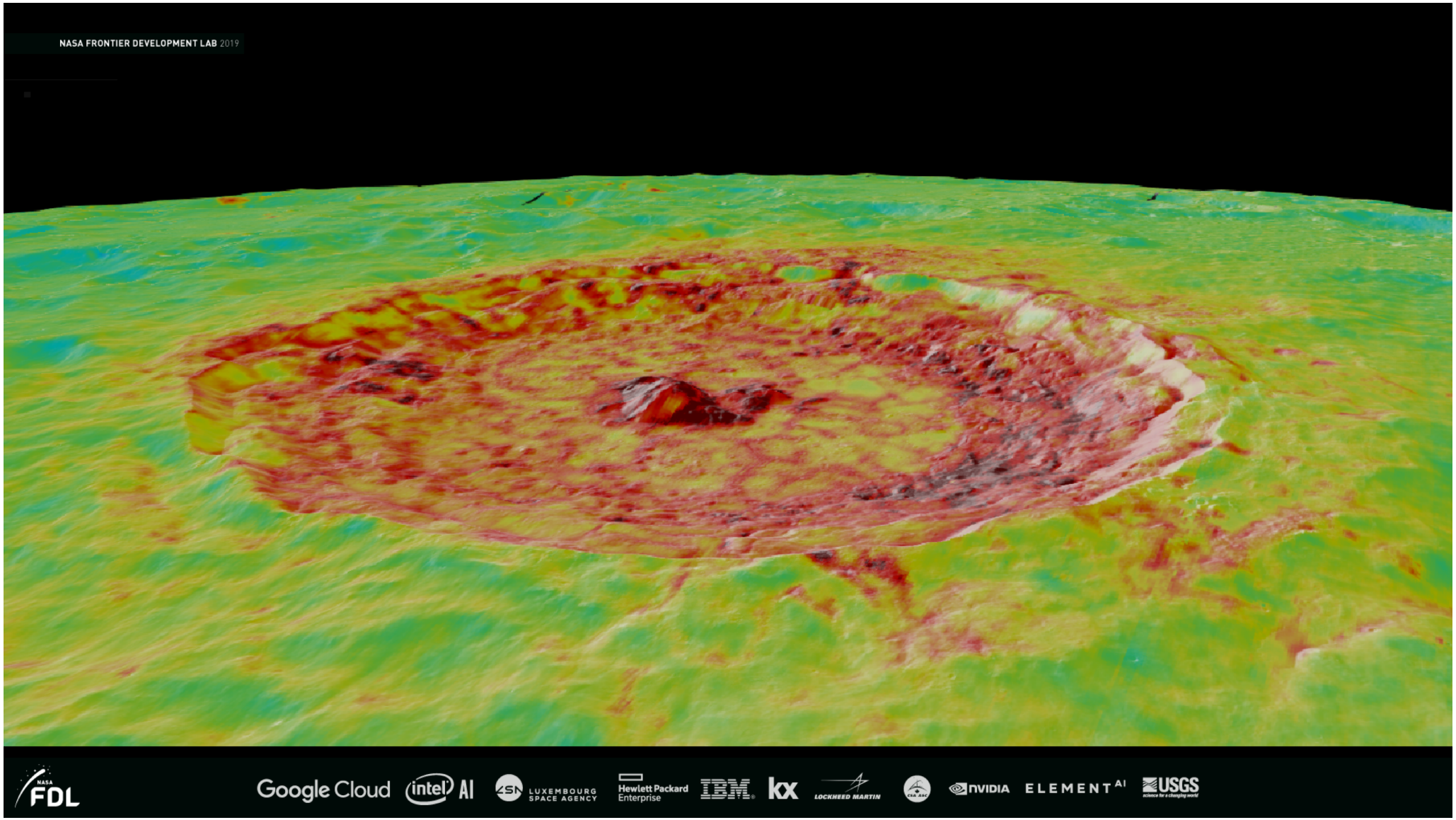


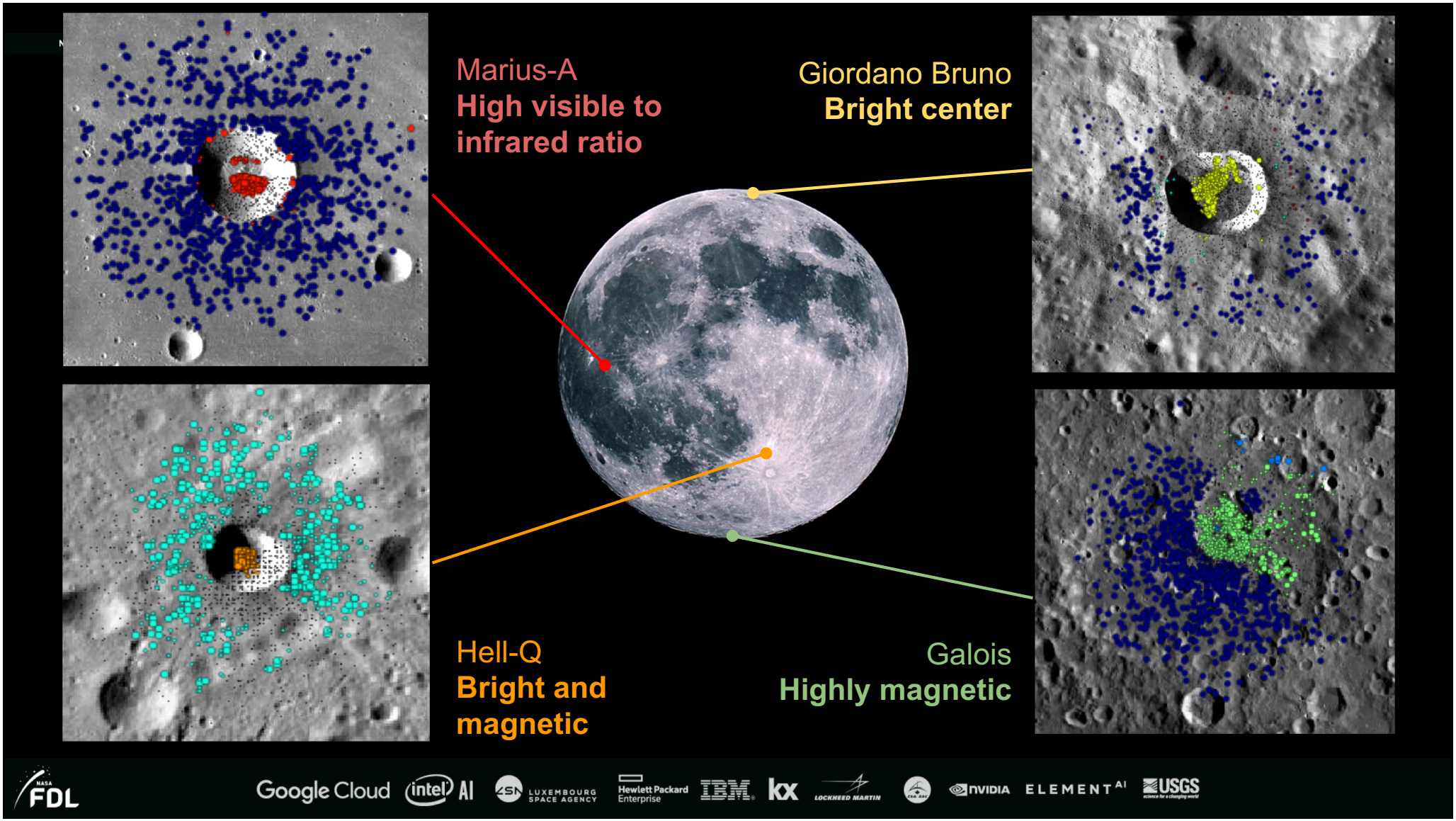
Lunar Reconnaissance Orbiter | **thermal** imaging

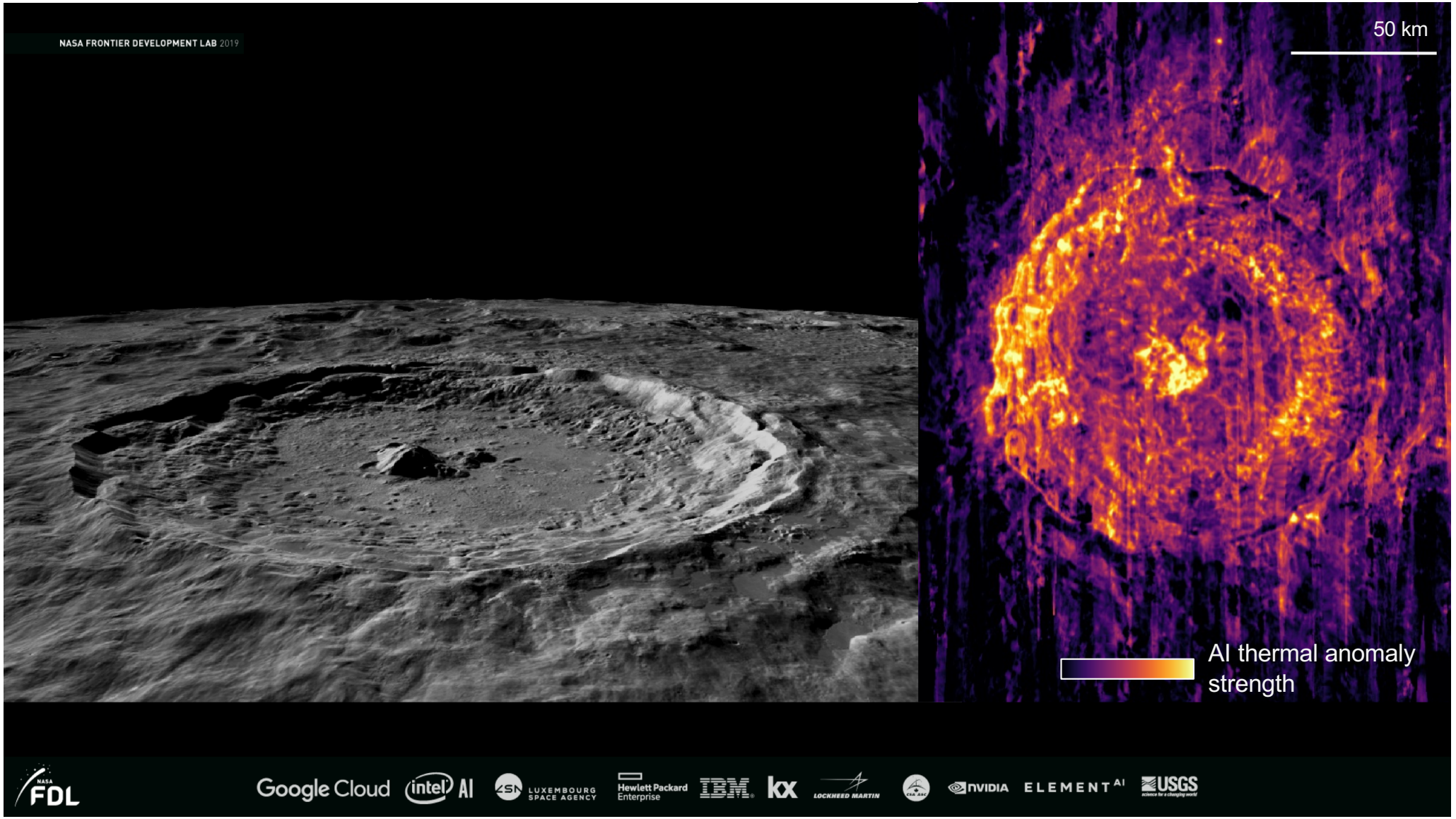


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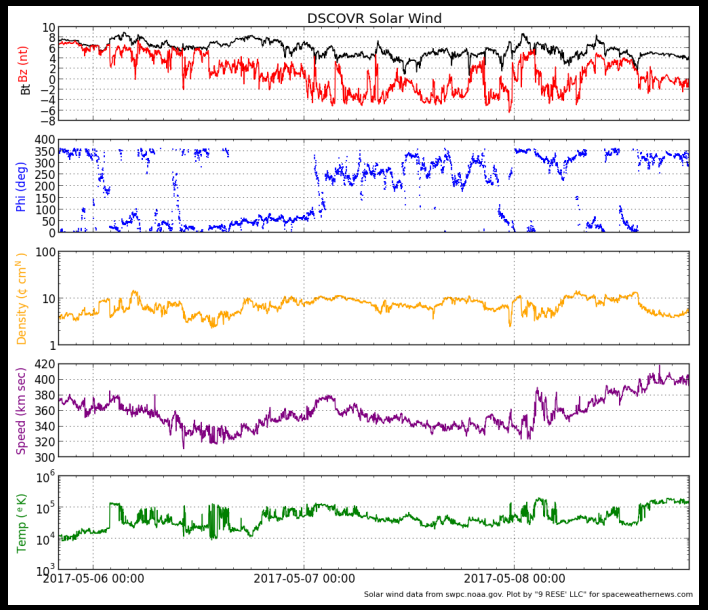

Marius-A
High visible to infrared ratio
Giordano Bruno
Bright center
Hell-Q
Bright and magnetic
Galois
Highly magnetic
NASA FDL
Google Cloud
intel AI
LUXEMBOURG SPACE AGENCY
Hewlett Packard Enterprise
IBM
kx
LOCKHEED MARTIN
NVIDIA
ELEMENT AI
USGS


NASA FRONTIER DEVELOPMENT LAB 2019
50 km
AI thermal anomaly strength
NASA FDL
Google Cloud
intel AI
LUXEMBOURG SPACE AGENCY
Hewlett Packard Enterprise
IBM
kx
LOCKHEED MARTIN
NVIDIA
ELEMENT AI
USGS


ARTIFICIAL INTELLIGENCE FOR SPACE EXPLORATION AND ALL HUMANKIND
5. CAN AI MAKE SCIENTIFIC DISCOVERIES?
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NVIDIA
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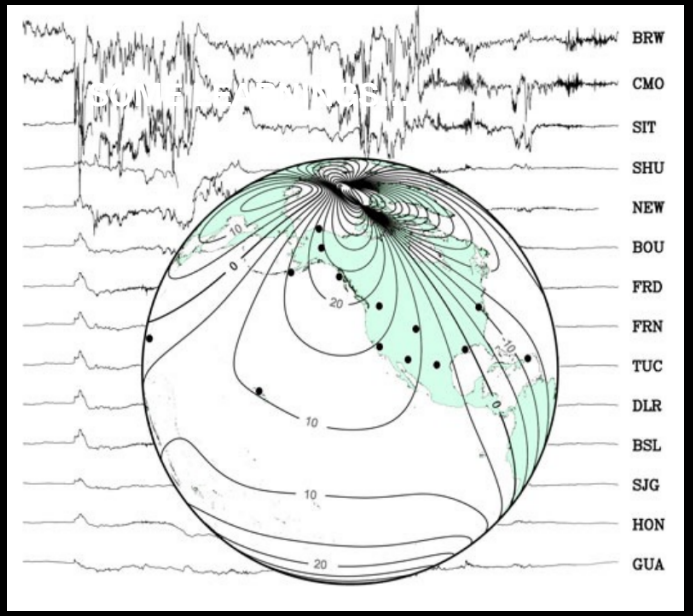

FDL

SOLAR WIND DATA



+

GEOMAG DATA



= **“STING”**

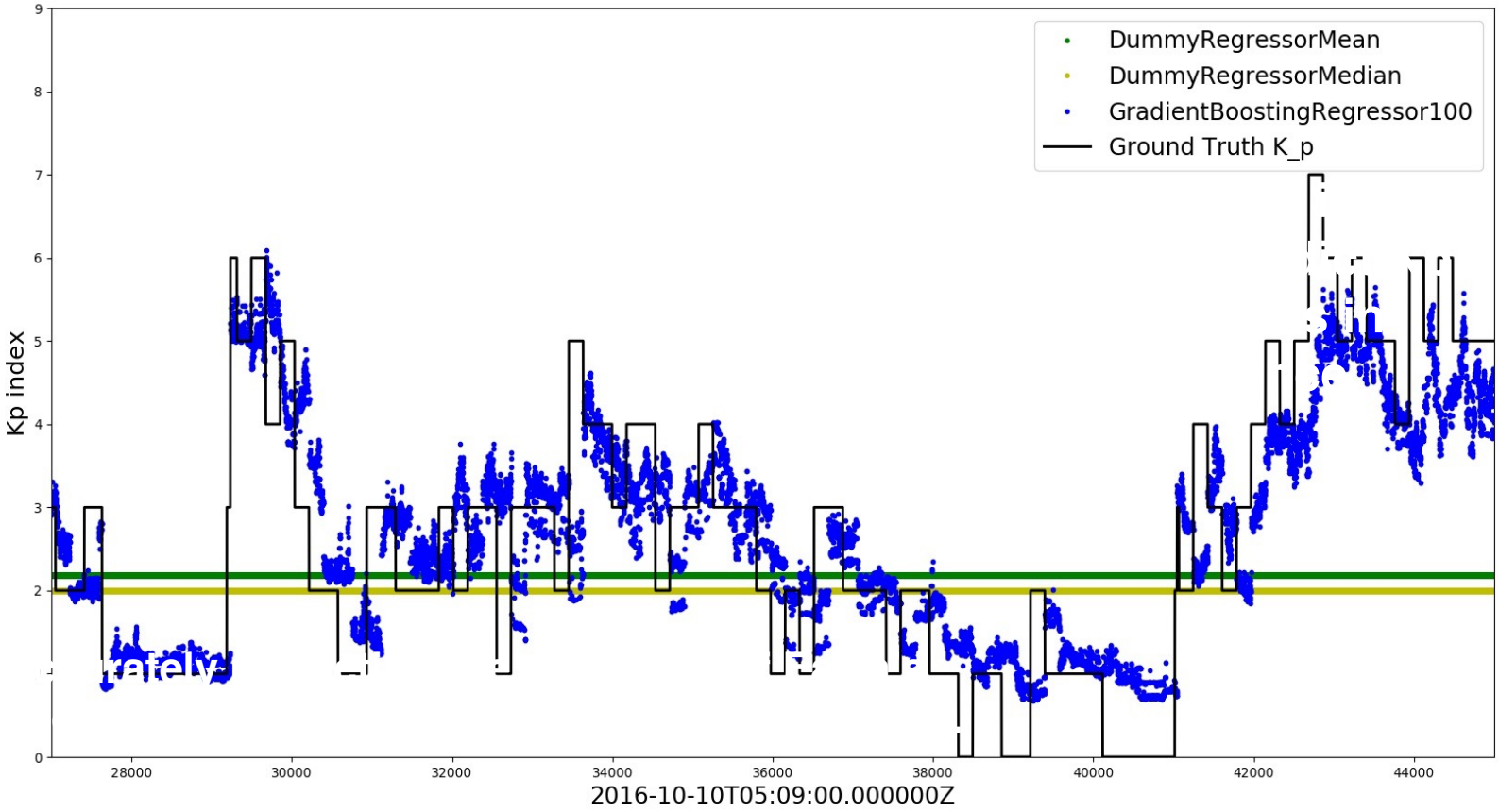
(Solar Terrestrial Interactions Neural Network Generator)

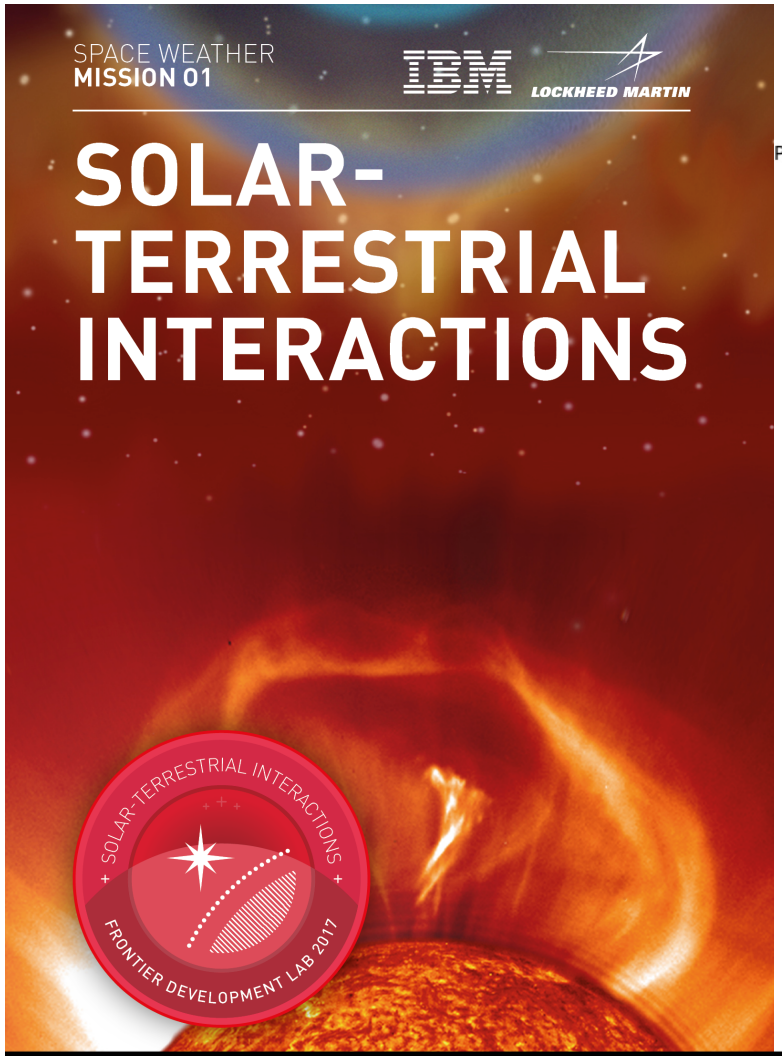
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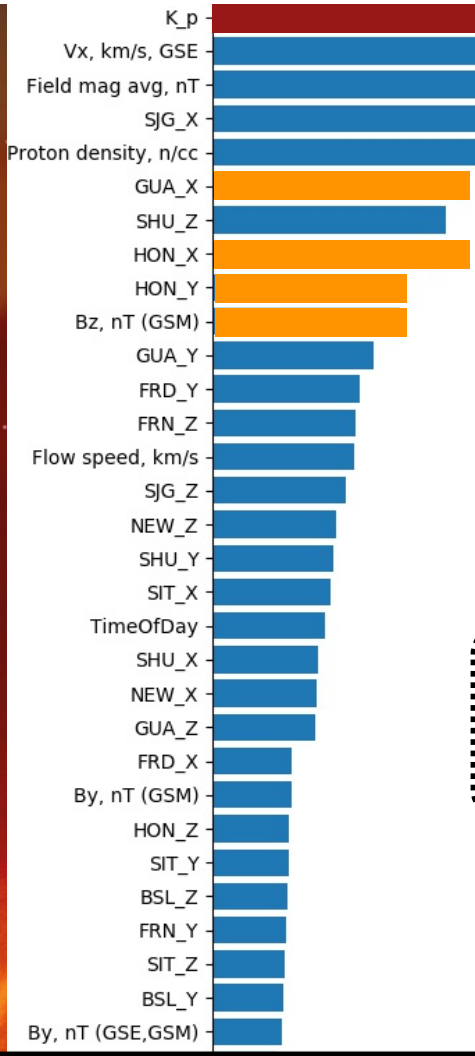
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Kp Index

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







Other important predictors:

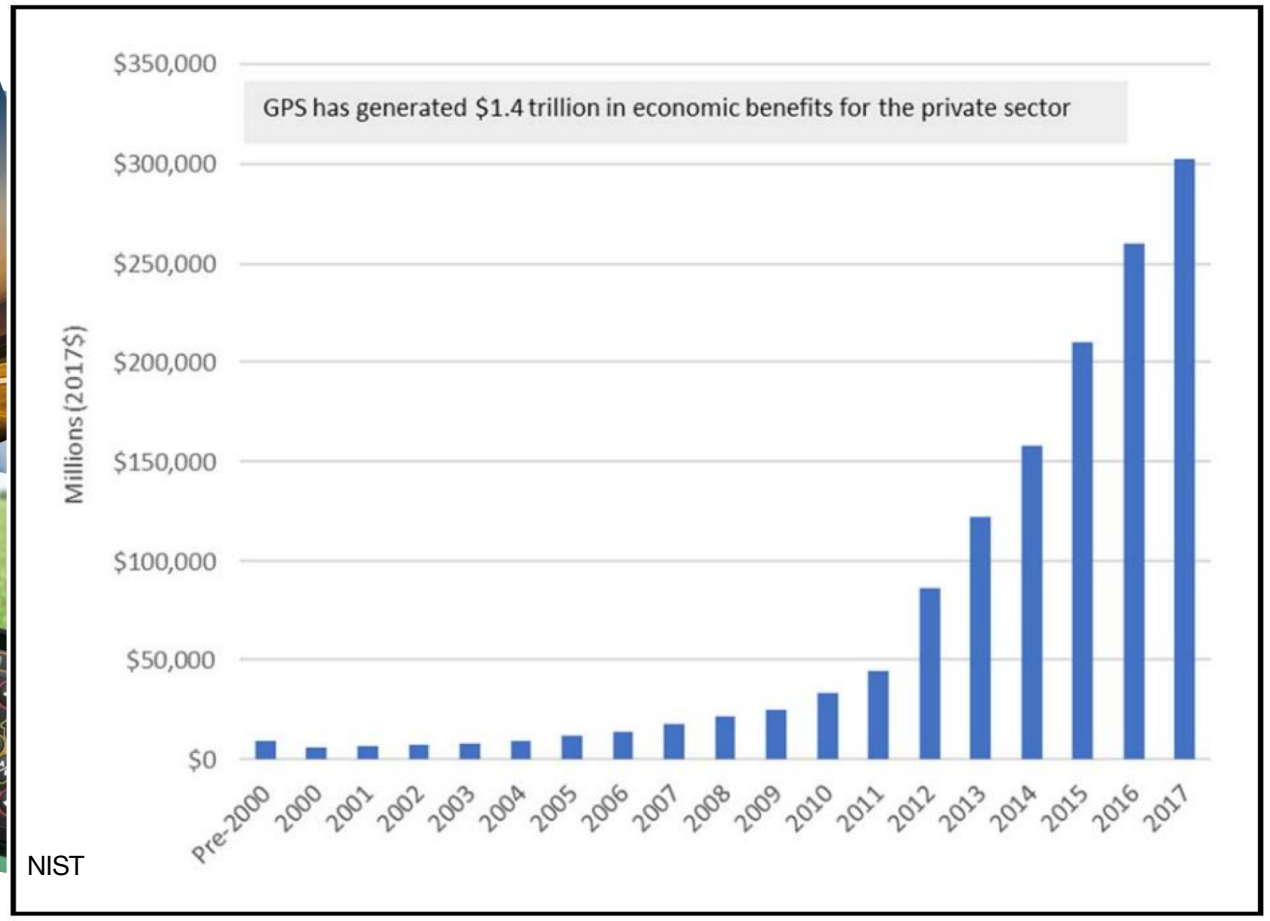
- Solar wind magnetic field strength and Bz,
- Solar wind speed and proton density,
- **Unexpected Result:** N-S component of the geomagnetic field at low latitude stations (Guam, Hawaii, Puerto Rico). **This points to the importance of the magnetospheric ring current.**

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.**

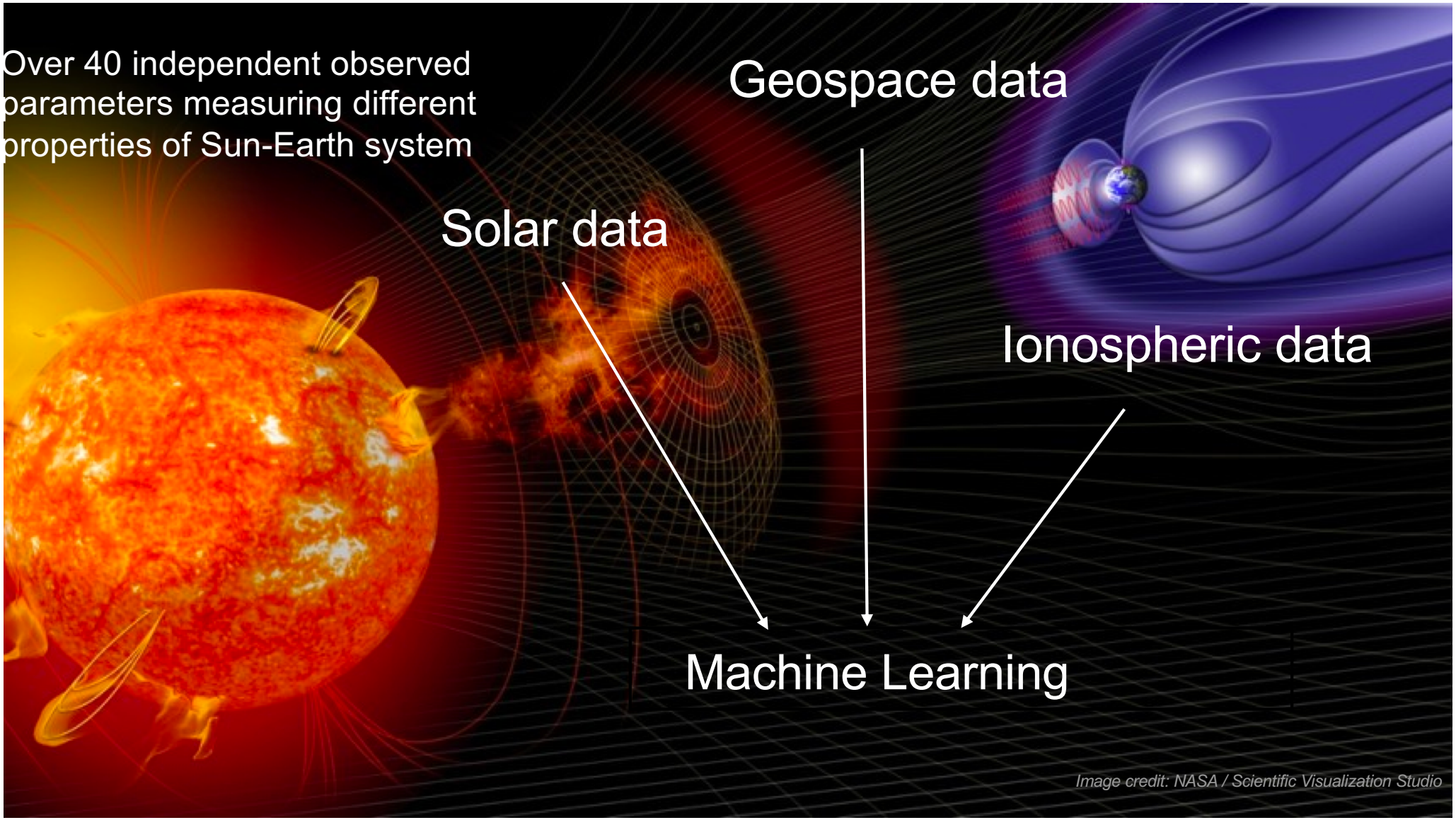
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Teejet
6.9 ft


GPS has generated $1.4 trillion in economic benefits for the private sector
Millions (2017$)
$350,000
$300,000
$250,000
$200,000
$150,000
$100,000
$50,000
$0
Pre-2000
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017

NIST




Over 40 independent observed parameters measuring different properties of Sun-Earth system
Geospace data
Solar data
Ionospheric data
Machine Learning
Image credit: NASA / Scientific Visualization Studio

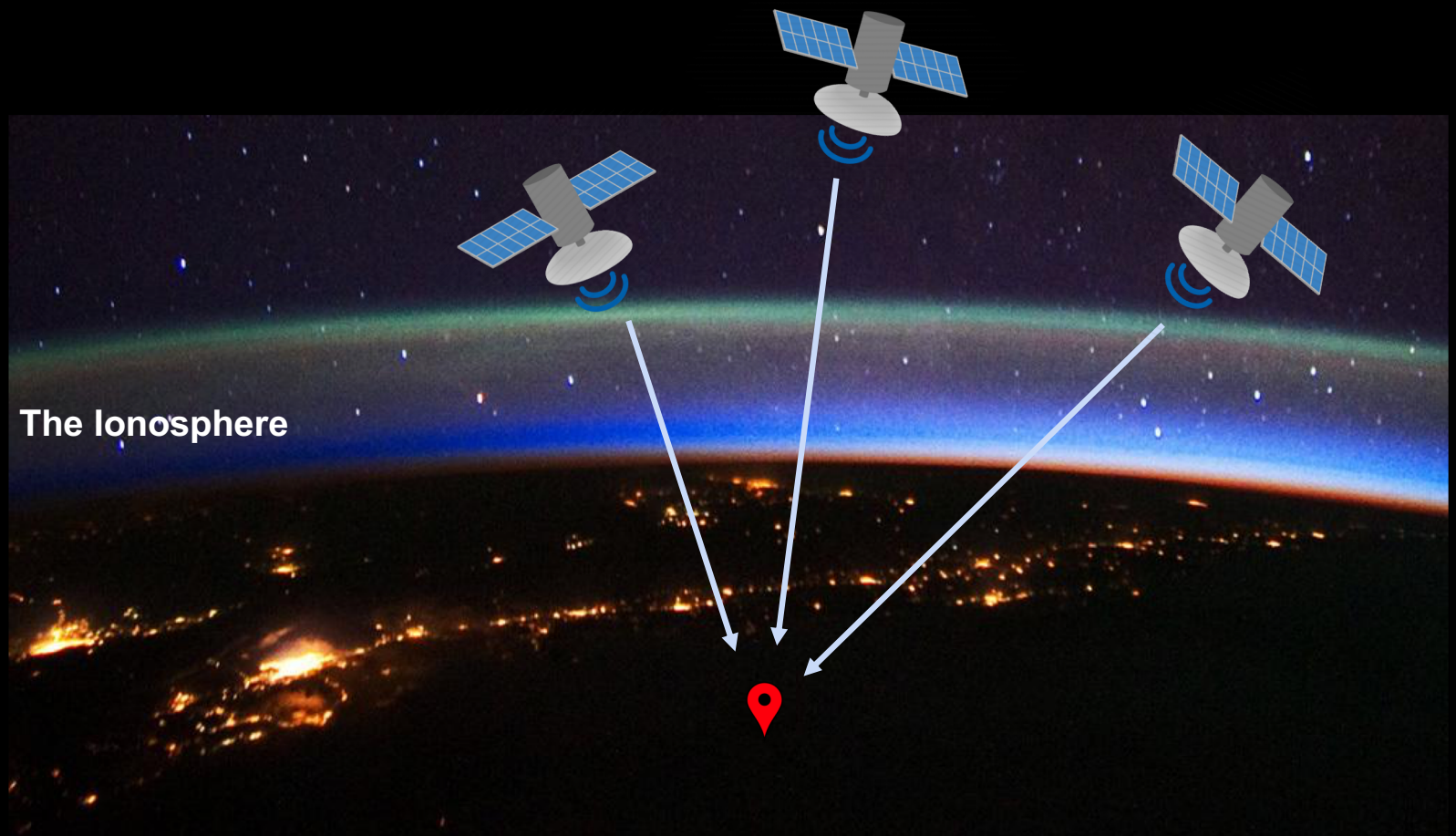


Image credit: NASA / Scientific Visualization Studio

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Ionosphere is Susceptible to Space Weather



Space Weather is Extremely Dynamic and Nonlinear

CSA-ASC

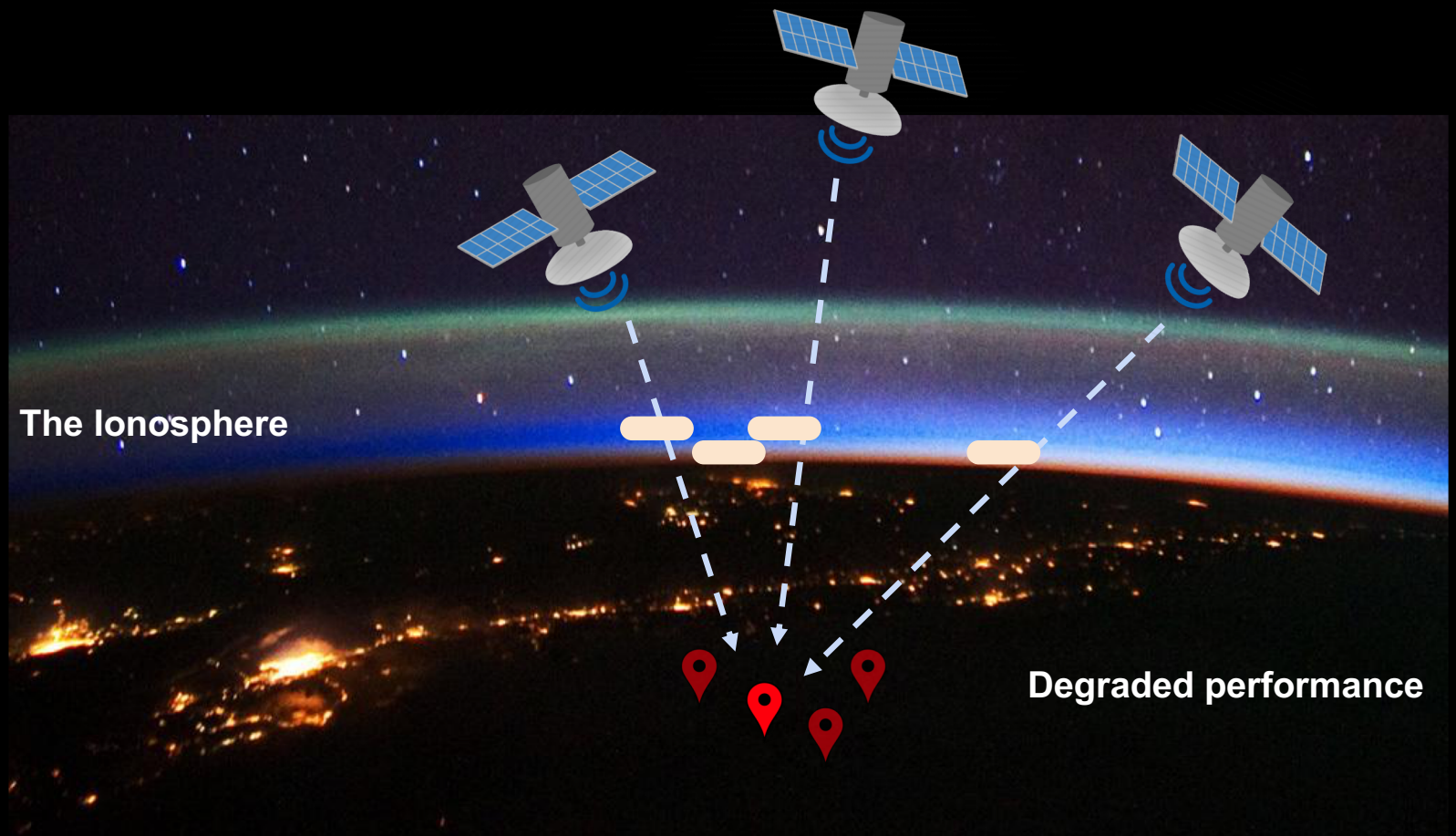


Image credit: NASA / Scientific Visualization Studio

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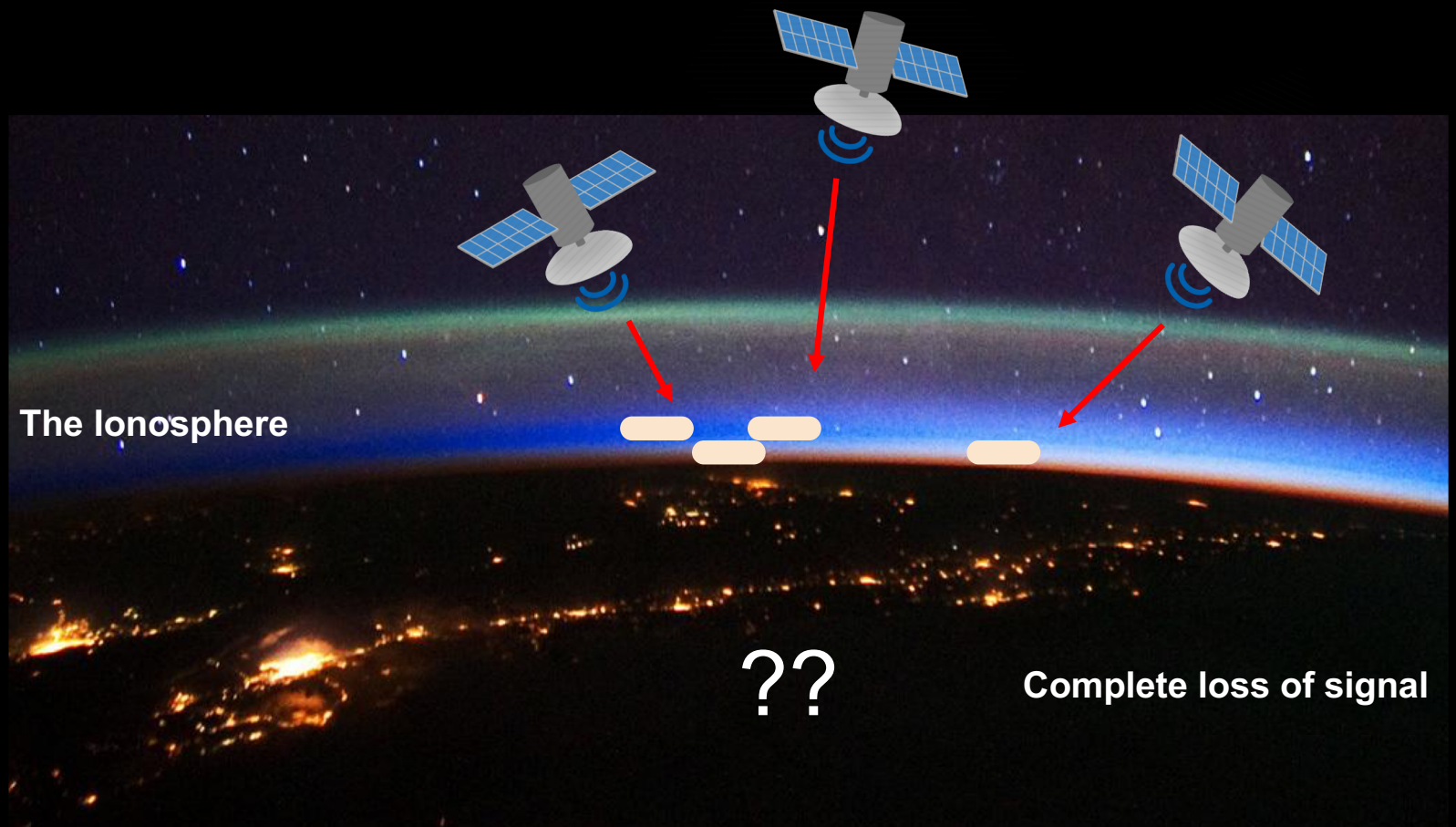
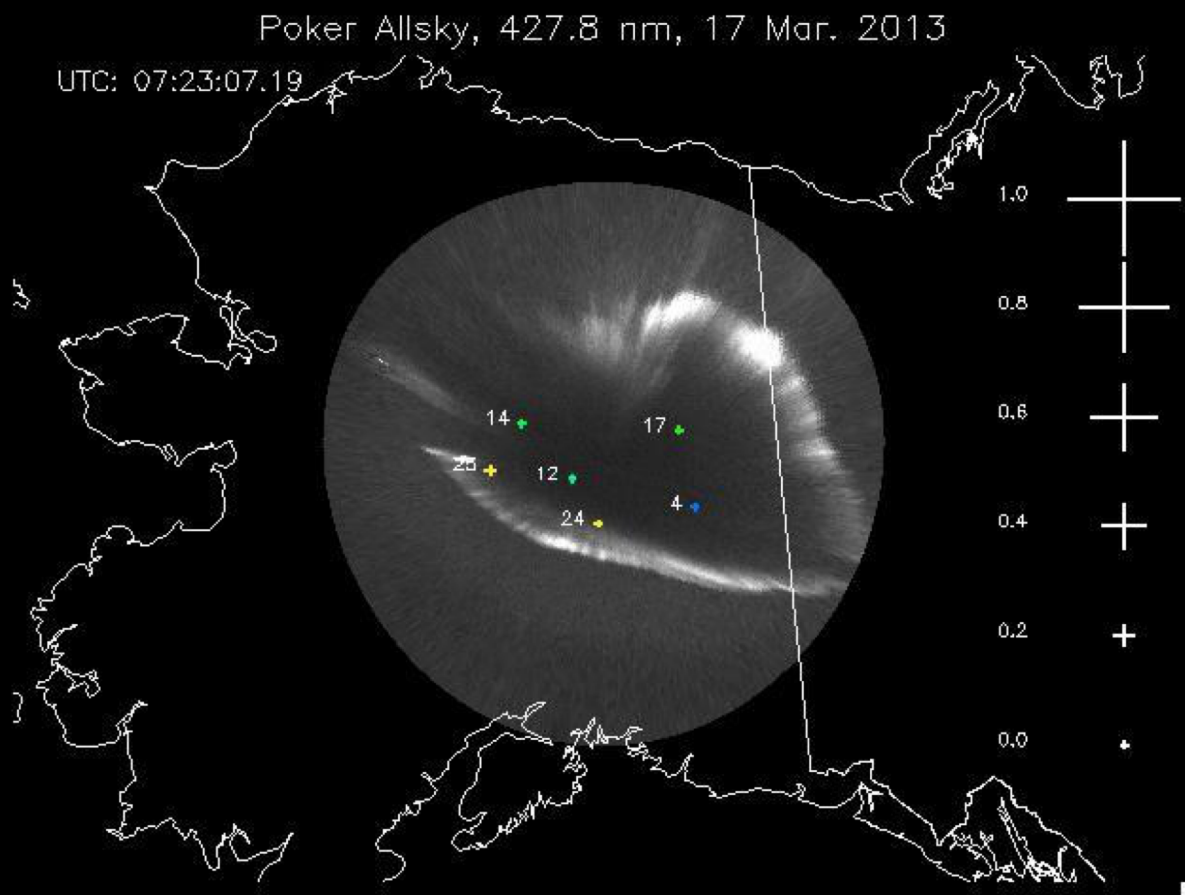


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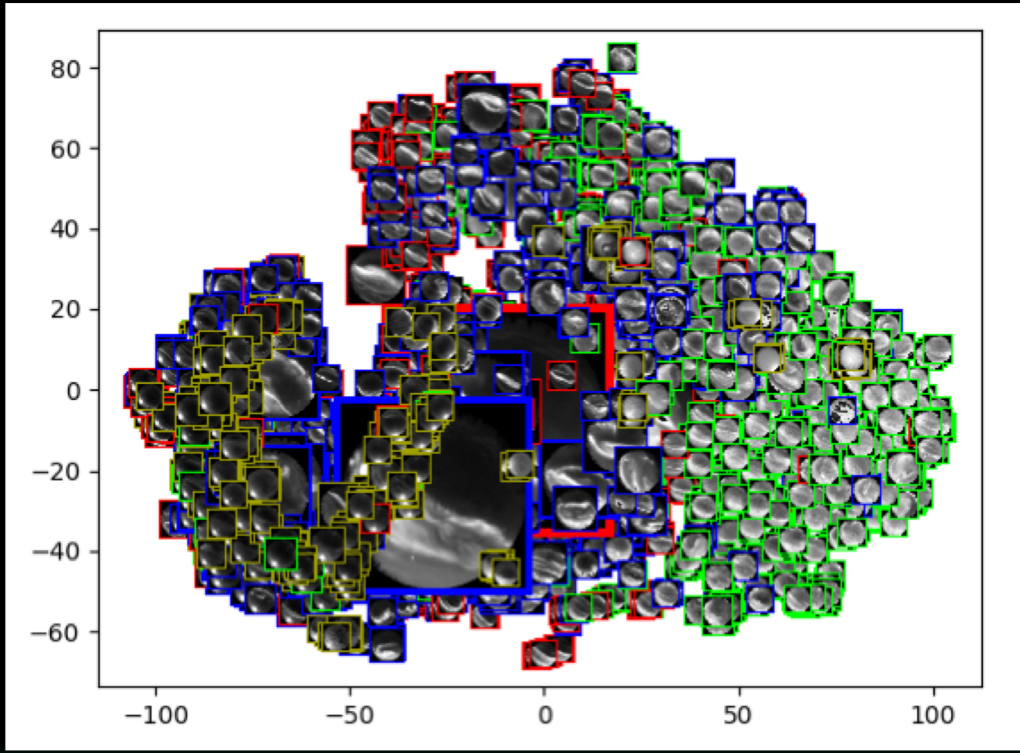
Auroras are correlated with GPS disturbances



Courtesy:
Donald Hampton,
University of
Alaska, Fairbanks

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Discrete structures in aurora are more important for GPS disturbances!

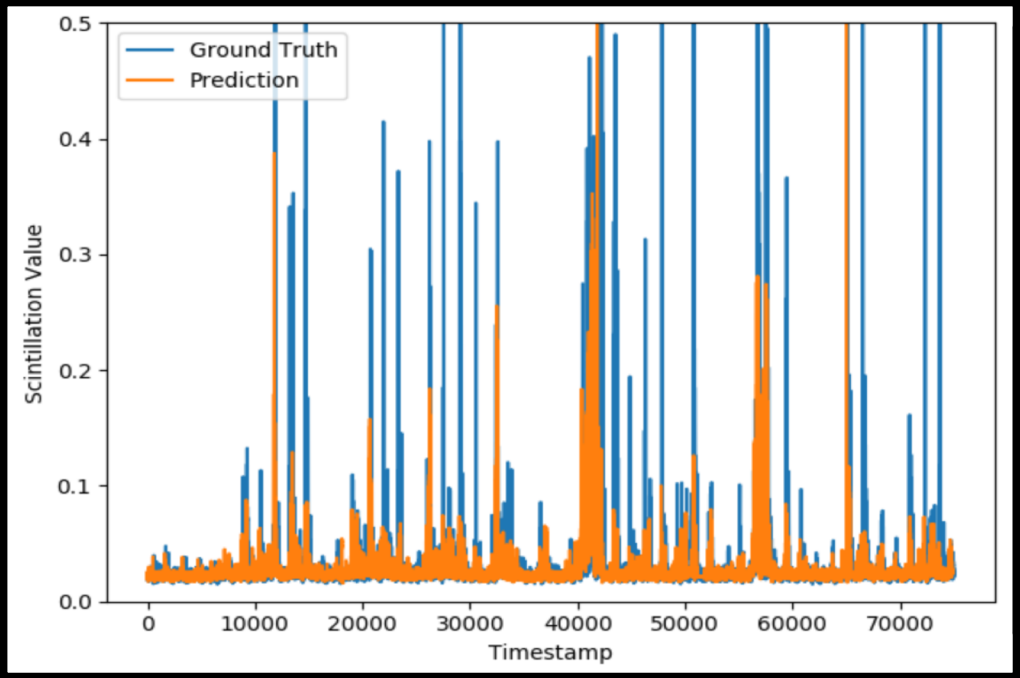


...which agrees with Physics

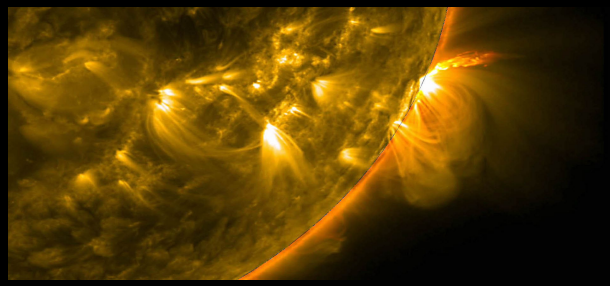
The bigger the image the more significant the GPS disturbances

Disturbances can be forecast 1 hour in advance!

- Accurate within ± 5 min
  - +15% better than previous methods
  - Magnitude prediction with 17% error - new benchmark.
- Realtime Performance



A deep learning virtual instrument for monitoring extreme UV solar spectral irradiance

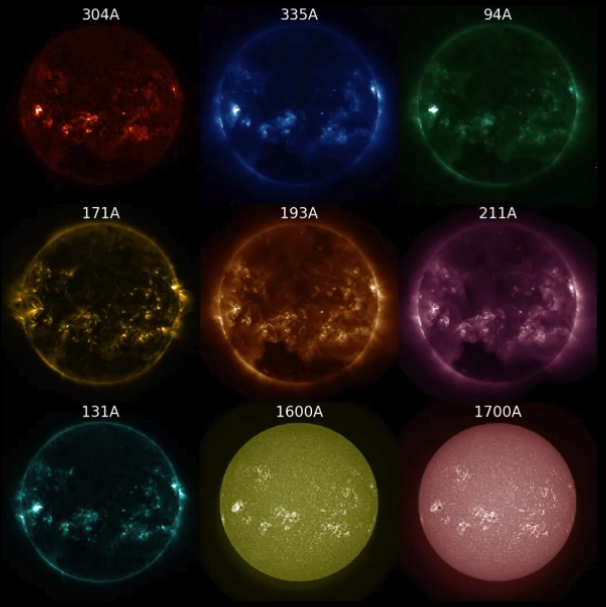


NASA could soon use an artificial intelligence-fueled fix for a malfunctioning instrument sensor on its Solar Dynamics Observatory, which observes solar activity in extraordinary detail.

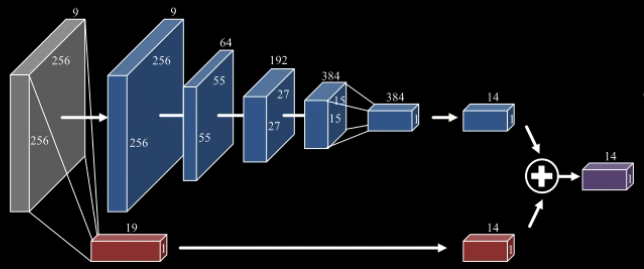
- **Why it matters:** Powerful solar storms, bursts of solar plasma and charged particles can harm satellites in orbit and even cause major problems for power grids on Earth. NASA's Solar Dynamics Observatory (SDO), which can spot solar storms in near real-time, is a key part of that. One of the SDO instrument sensor MEGS-A was designed to keep an eye on extreme ultraviolet (EUV) radiation levels, which correlate with a ballooning of the Earth's outer atmosphere that control the longevity of satellites in near-Earth orbit. This instrument stopped working in 2014

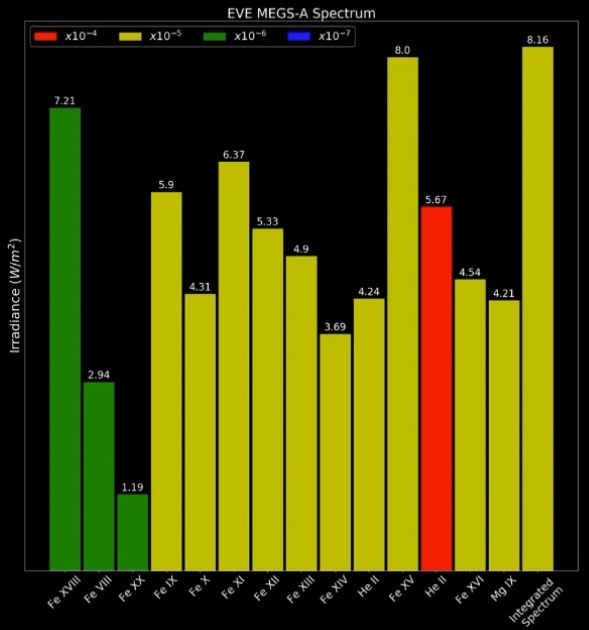
- **What the team did:** A deep-learning network created in 2018 can now be used to replace the data from the non-working sensor by inferring what ultraviolet radiation levels that sensor would have detected based on what the other instruments on SDO are observing at any given time. Using deep learning, this work demonstrates a way of virtually monitoring the Sun's extreme ultraviolet emission, which is an important driver of space weather.

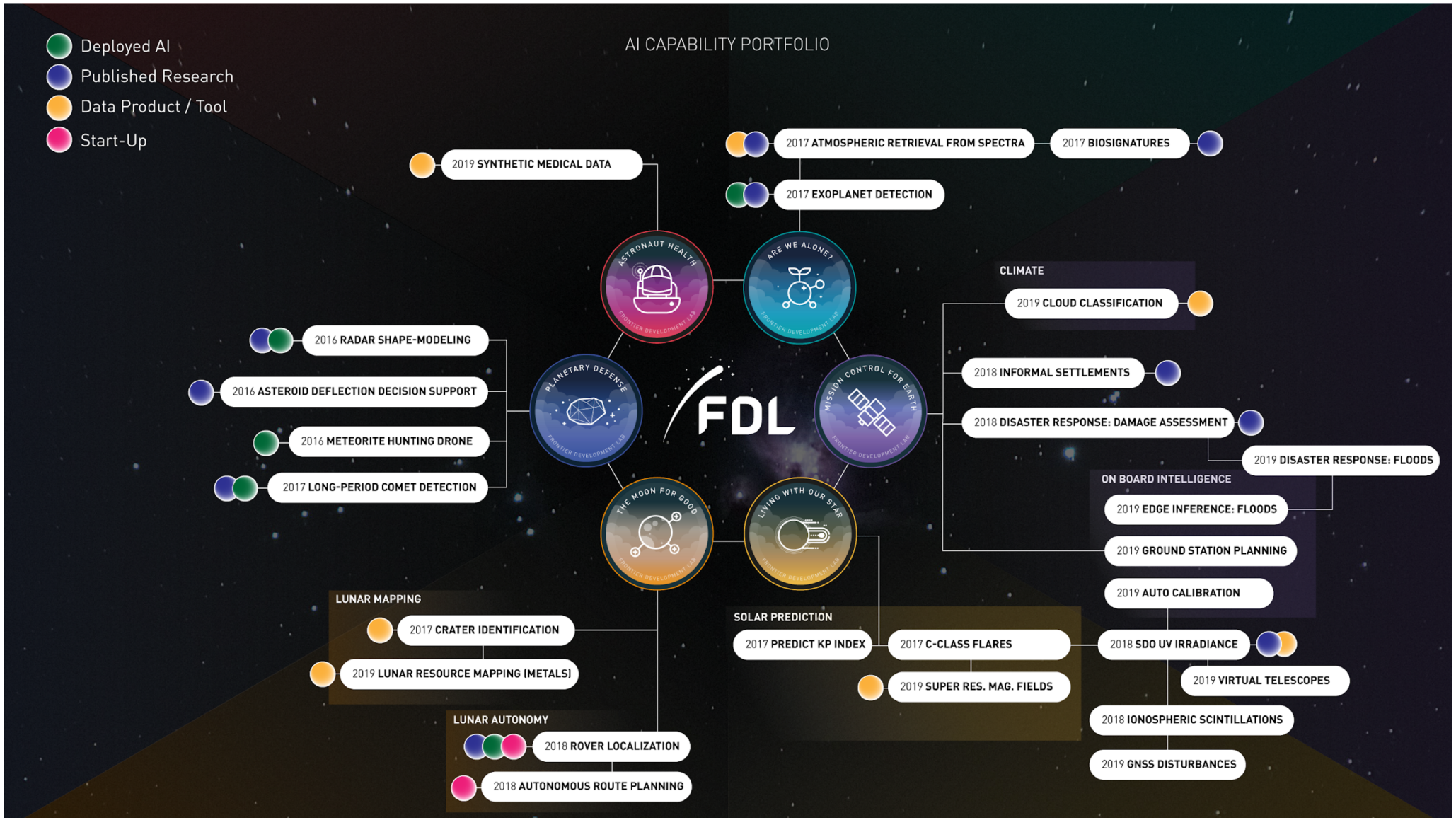
- **What is the benefit:** Deep learning can help us get more value out of our current ability to monitor the Sun by providing virtual instruments that can supplement our physical instruments.AI models like this could also be used for other future missions. Instead of putting say three instruments on a satellite to measure different aspects of the space environment, you could potentially launch two and use the data collected to infer the information that would have been measured by a third.


304A
335A
94A
171A
193A
211A
131A
1600A
1700A




9
256
256
9
256
256
64
55
55
192
27
27
384
14
15
384
14
19
14


EVE MEGS-A Spectrum
x10⁻⁴
x10⁻⁵
x10⁻⁶
x10⁻⁷
Irradiance (W/m²)
7.21
2.94
1.19
5.9
4.31
6.37
5.33
4.9
3.69
4.24
8.0
5.67
4.54
4.21
8.16
Fe XVIII
Fe VIII
Fe XX
Fe IX
Fe X
Fe XI
Fe XII
Fe XIII
Fe XIV
He II
Fe XV
He II
Fe XVI
Mg IX
Integrated Spectrum


Deployed AI
Published Research
Data Product / Tool
Start-Up
AI CAPABILITY PORTFOLIO
FDL
ASTRONAUT HEALTH
ARE WE ALONE?
PLANETARY DEFENSE
MISSION CONTROL FOR EARTH
THE MOON FOR GOOD
LIVING WITH OUR STAR
2019 SYNTHETIC MEDICAL DATA
2017 ATMOSPHERIC RETRIEVAL FROM SPECTRA
2017 BIOSIGNATURES
2017 EXOPLANET DETECTION
2016 RADAR SHAPE-MODELING
2016 ASTEROID DEFLECTION DECISION SUPPORT
2016 METEORITE HUNTING DRONE
2017 LONG-PERIOD COMET DETECTION
CLIMATE
2019 CLOUD CLASSIFICATION
2018 INFORMAL SETTLEMENTS
2018 DISASTER RESPONSE: DAMAGE ASSESSMENT
2019 DISASTER RESPONSE: FLOODS
ON BOARD INTELLIGENCE
2019 EDGE INFERENCE: FLOODS
2019 GROUND STATION PLANNING
2019 AUTO CALIBRATION
LUNAR MAPPING
2017 CRATER IDENTIFICATION
2019 LUNAR RESOURCE MAPPING (METALS)
LUNAR AUTONOMY
2018 ROVER LOCALIZATION
2018 AUTONOMOUS ROUTE PLANNING
SOLAR PREDICTION
2017 PREDICT KP INDEX
2017 C-CLASS FLARES
2019 SUPER RES. MAG. FIELDS
2018 SDO UV IRRADIANCE
2019 VIRTUAL TELESCOPES
2018 IONOSPHERIC SCINTILLATIONS
2019 GNSS DISTURBANCES

THE POWER OF PARTNERSHIP

"AI is changing the way we think about problems."

MASSIMO MASCARO,
TECHNICAL DIRECTOR OF APPLIED AI.

Google Cloud

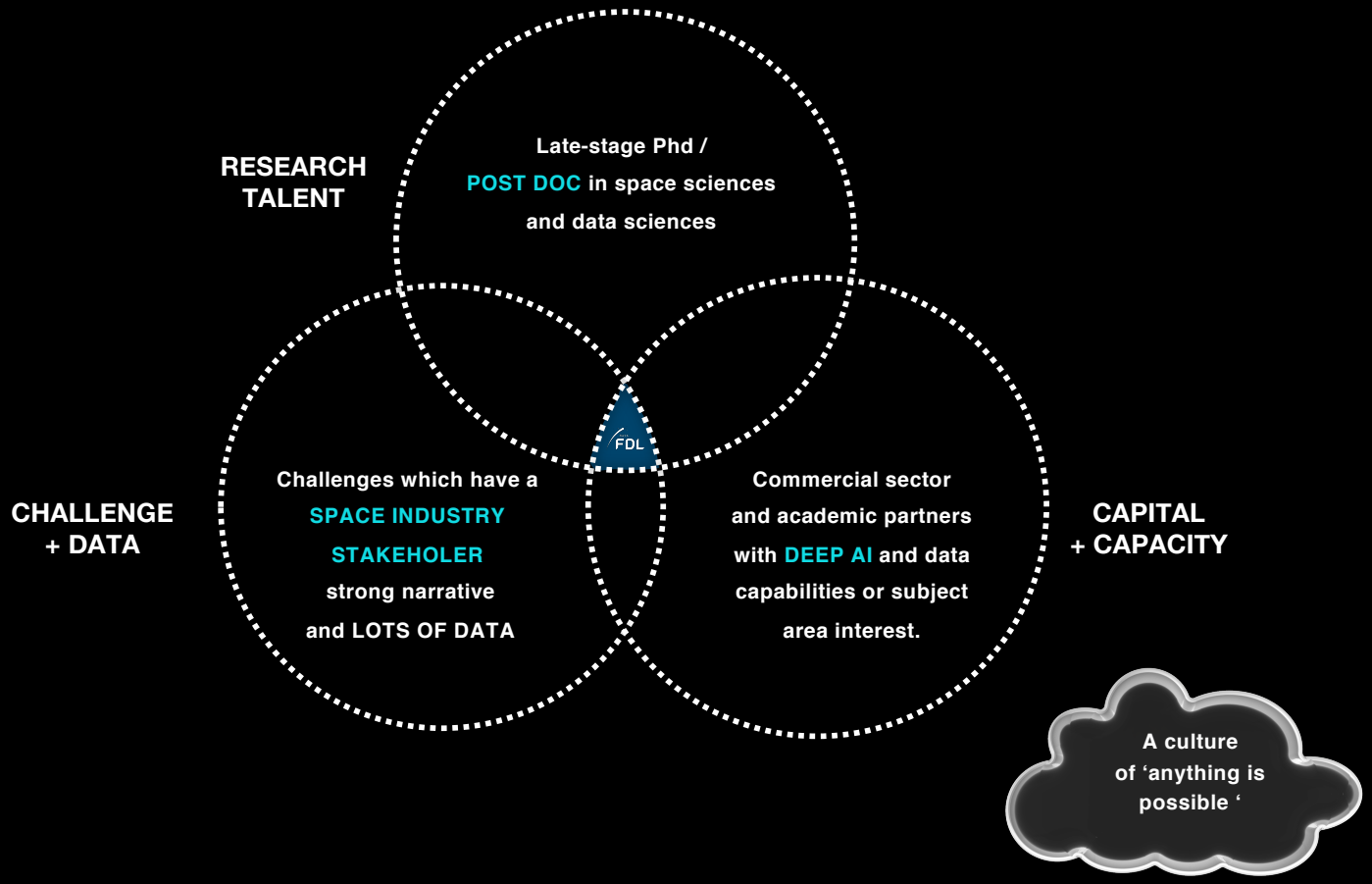
"NVIDIA is proud to have been one of 'the Mavericks', at the inception of the Frontier Development Laboratory. Our headquarter is named Endeavor and its companion will be Voyager - mighty ships for our journey to the stars. We are delighted to support the FDL as we push the frontiers for the human race."

JEN-HSUN HUANG, PRESIDENT & CEO,
NVIDIA CORPORATION

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NASA FRONTIER DEVELOPMENT LAB - FORMULA



Grand Challenge : Integration of the knowledge provided by the vast amount of data collected by NASA for the Earth System, the Heliophysics System, the Solar System and the Universe beyond, coupled with theoretical and computational models to understand and predict the behavior of the world we live in

"I think the…21st century will be the century of complexity. We have already discovered the basic laws that govern matter and understand all the normal situations. We don't know how the laws fit together, and what happens under extreme conditions….There is no limit to the complexity we can build using those basic laws."----Stephen Hawking



1942-2018