National Aeronautics and
Space Administration

Heliophysics Division Snapshot

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HELIOPHYSICS SYSTEM OBSERVATORY

- *20 Operating Missions with 27 Spacecraft*
- *1 Missions in Development*
- *11 Missions in Formulation*

OPERATING & FUTURE

Parker Solar Probe

Breaking Records

Parker Solar Probe completed its eighth close approach to the Sun, perihelion, on April 29, 2021, coming within a record of 6.5 million miles of the Sun’s surface at a record speed of over 330,000 miles per hour.

Parker Solar Probe Ushers in New Science on the Sun and Solar Wind

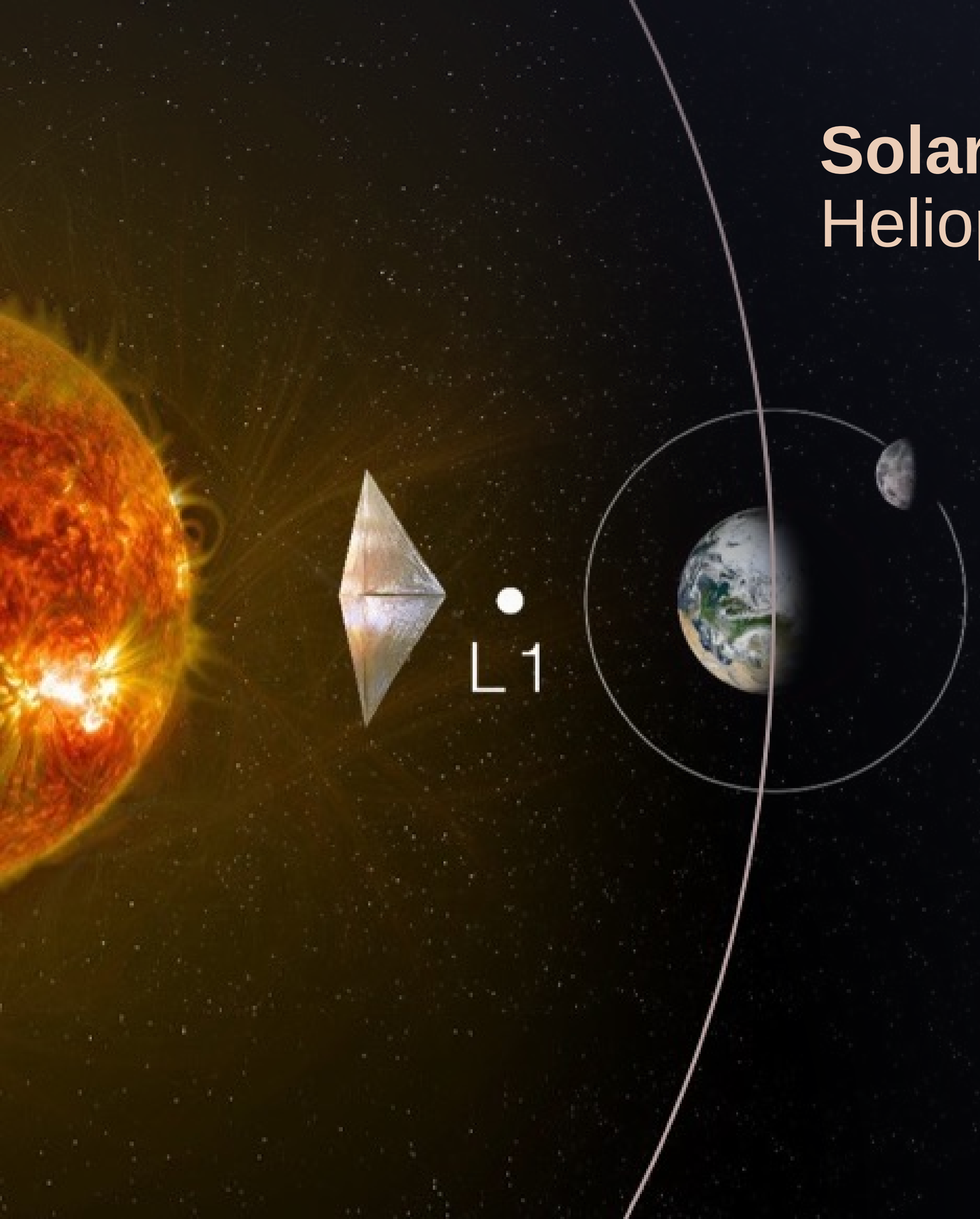
Scientists using data from Parker Solar Probe released a new collection of research papers in a special issue of the journal ***Astronomy & Astrophysics*** on June 2, 2021.

The issue, titled Parker Solar Probe: Ushering a New Frontier in Space Exploration, includes 37 papers on discoveries made during mission’s first four orbits around the Sun. The new research builds upon initial results released in *Nature* in 2019 and a special supplement of The *Astrophysical Journal* in 2020.

SDO Forever Stamps Issued by USPS

Understanding the sun has always been a top priority for space scientists. Studying how the sun affects space and the space environment of planets is a field known as heliophysics: As a source of light and heat for life on Earth, scientists want to understand how our sun works, why it changes, and how these changes influence us here on planet Earth.

As Living with a Star (LWS) program's corner stone mission, NASA's Solar Dynamics Observatory (SDO) has been observing the Sun for one solar cycle (~11 years) in exquisite detail—almost IMAX quality—providing details of the sun and its features that have rarely been seen before. To commemorate this mission the U.S. Postal Service issued a set of stamps highlighting views of the Sun from SDO on June 18th. As the SDO program scientist for the past two decades, I cannot imagine a better outreach platform to reach everyone in the US and globally than these Forever Stamps from the USPS.



Solar Cruiser TechDemo *Enables* Sub-L1 Heliophysics and Solar Storm Monitoring

Address key science questions such as:

- How do Coronal Mass Ejections (CMEs) and shock properties vary on moderate radial distances (~0.1 AU)?
- How do CME and shock properties vary with moderate angular distance?
- What is the structure of interplanetary CMEs, etc.?

Space Weather Applications:

- Increase the warning times by up to 50% for both “typical” and “fast” CMEs from ~55 min. to 83 min., and 20 min. to 30 min
- Directly benefits human exploration beyond LEO

Research and Analysis Update

Overall

- Maintaining healthy R&A Program
- Maintaining DRIVE initiative and establishment of DRIVE Science Centers (planning for Phase 2 selections)
- ECIP cadence every 2 years
- Engaging in efforts to increase diversity in research
    - Dual anonymous, high risk high reward, diversity and inclusion-specific solicitations
- Cross-Divisional programs – E.3 Exoplanets; E.4 Habitable Worlds (made 2 selections in E.3 for 2020; E.4 upcoming);
- AI/ML – strong emphasis in TMS program in ROSES 2019 (compete again in 2022)

Citizen Science (new NASA HPD strategy)

- **Vision:** Leverage public participation in Heliophysics to help drive innovation and diversity in science, society, and education
- **Mission:** Build a robust, dynamic, and engaging Heliophysics citizen science portfolio that fuses natural phenomena, mission opportunities, and the power of people's diverse viewpoints to fuel collective innovation
- **Planning for Heliophysics Big Year** (2023-2024)
    - Focus on two solar eclipses and solar max
    - POC: Liz MacDonald
- 4 selections in 2021 from Citizen Science Seed Funding Program

2020 Jack Eddy Fellows

Lindsay Goodwin
NJIT

Murong Qin
BU

Camilla Scolini
UNH

Research Opportunities in Heliophysics (cont.)

ROSES-20 (New or restructured elements)

- Parker Solar Probe Guest Investigator
- GIGI (GOLD-ICON Guest Investigators)
- HTIDS: Technology and Instrument Development for Science
- HLCAS: Low-Cost Access to Space
- HFOS: Flight Opportunity Studies
- HFORT: Flight Opportunities for Research and Technology
- HERMES IDS

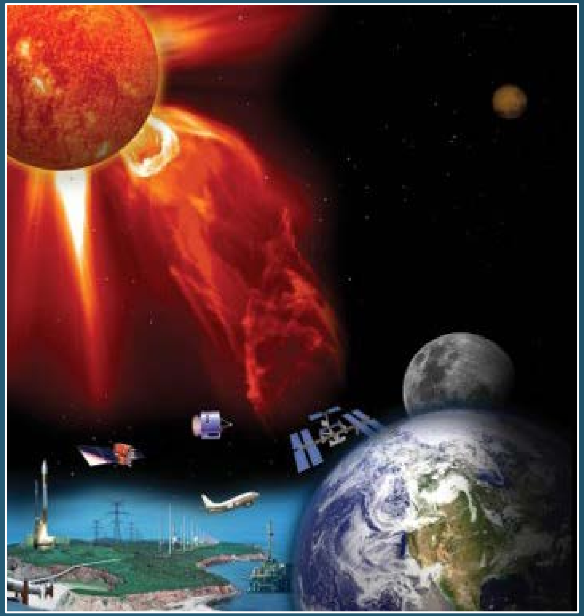
ROSES-21 (New or restructured)

- Living With a Star Tools and Methods
- GDC IDS
- Interdisciplinary Science for Eclipse
- Heliophysics Mission Concept Studies (HMCS)
- Heliophysics Innovations for Technology and Science (HITS)

Low-Cost Access to Space (LCAS)

- **Sounding Rockets:** Launches have resumed after multiple sounding rocket missions in 2020 were delayed or cancelled due to COVID-19.
- **CubeSats:** 3 HPD CubeSats on orbit and 16 in development.

NASA Space Weather



Recent Accomplishments

- NASA space weather strategy and implementation plan
- NOAA and DoD Framework to transition NASA research, techniques and technology relevant to space weather operations
- Joint NSF-NASA Space Weather Quantification of Uncertainty (SWQU) grant solicitation
- Research to Operations to Research (R2O2R) grant solicitation: Includes additional Transition-Step for efforts that show promise to use in an operational space weather environment at NOAA or DoD
- Rapid turnaround HERMES instrument package in support of Gateway and Artemis; HEMRES IDSs selected June 2021

Looking Ahead

- PROSWIFT: continue with actions already underway to support interagency efforts, space weather observations, research, modeling, operational forecasting, and applications (SOHO, SWFO-L1, R2O2R)
- Develop space weather instrument pipeline for future opportunities
- Engage international partners on future collaborations (ESA L5, CSA AOM, Daedalus, SNIPE)
- Continue transitioning Radiation Assessment Detector (RAD) instrument on Curiosity rover on Mars from Planetary Science Division to the Heliophysics Division to engage space weather community supporting forecasting research at Mars

Planning for the next Decadal

- **Heliophysics 2050 Workshop held in early May 2021**
  - NASA- and NSF-enabled, community-led workshop
  - Developed short-, medium-, and long-term science objectives, including capability needs
  - Discipline-specific science, fundamental physics, interdisciplinary and inter-Agency sessions
  - Over 1,150 domestic and international registrants with approximately 425 to 650 engaged each day
  - “Heliophysics as a Community in 2050” considered how to strengthen inclusion, diversity, equity, and access (IDEA) within the community as well as developing and sustaining healthy, multi-generational approaches for teaming
  - Enabled cross- and interdisciplinary connections
    - “Expanding the Frontiers” session brought together different heliophysics disciplines, planetary science, and astrophysics to discuss how and where the scope of heliophysics can grow
- **Mission concept studies for decadal survey white papers**
- **Conversations between NAS, CSSP and Agencies (NASA, NSF, NOAA) ongoing**
  - Decadal preparation, community insight/involvement
  - Defining decadal survey scope, focus
  - NASEM and HPD coordinated community webinars in development

HELIOPHYSICS 2050 WORKSHOP

Inclusion, Diversity, Equity, and Accessibility (IDEA) in Heliophysics

IDEA initiatives in SMD recognized as a long-term effort, but immediate action and problem solving will advance initiatives in parallel with systemic, enduring activity.

Heliophysics Division Goal

- Incorporate IDEA into the Heliophysics Division mission, vision, and strategy, resulting in a Division-wide commitment to lasting and specific IDEA goals and objectives.

Ongoing and Exploratory Efforts

- Members of HPD participating in various trainings and working groups to identify potential near-, mid-, and long-term Division actions .
- Identify Division and SMD leadership opportunities for staff.
- Explore best practices for IDEA recruitment efforts, including hiring panels.
- Adopt inclusive R&A code of conduct.
- Sponsor and incentivize enhanced and innovative mission outreach activities with IDEA as a major focus (e.g., PUNCH, IMAP).
- Establish a community-wide early- and mid-career support network pilot in partnership with other SMD Divisions, professional and scientific societies with a focus on providing mentors and mentees training and resources that consider the “whole” STEM individual.
- Develop targeted and innovative R&A solicitations with an IDEA emphasis.

Heliophysics Division Looking Ahead

- Confirmation of the following missions in 2021: HERMES, PUNCH, IMAP, TRACERS, SunRISE, ESCAPADE
- Down-select Medium Class Explorers (MIDEX-19)
- Continue pre-formulation activities ahead of DYNAMIC mission
- Maintain healthy Research and Analysis Program
  - Early Career Investigator Program cadence every 2 years
  - Support robust suborbital program, including CubeSats
  - Maintaining DRIVE initiative
  - Enhance the scientific return by innovatively connecting observations from one or more missions with satellite or ground observations from other Divisions, and/or other agencies within or outside the U.S. (HSO Connect, Daniel K. Inouye Solar Telescope, etc.)
- Continue planning for 2023 Decadal Survey (mission concepts, conversations with NASEM, NSF, and NOAA)
- Implement IDEA actions into the Heliophysics strategy
- Support early and mid-career individuals through roundtables and a robust support network

Get Involved and Stay Informed!

We are continuing to work hard to grow the Heliophysics community. Stay in touch and help us find new ways to highlight your work and keep you in the loop!

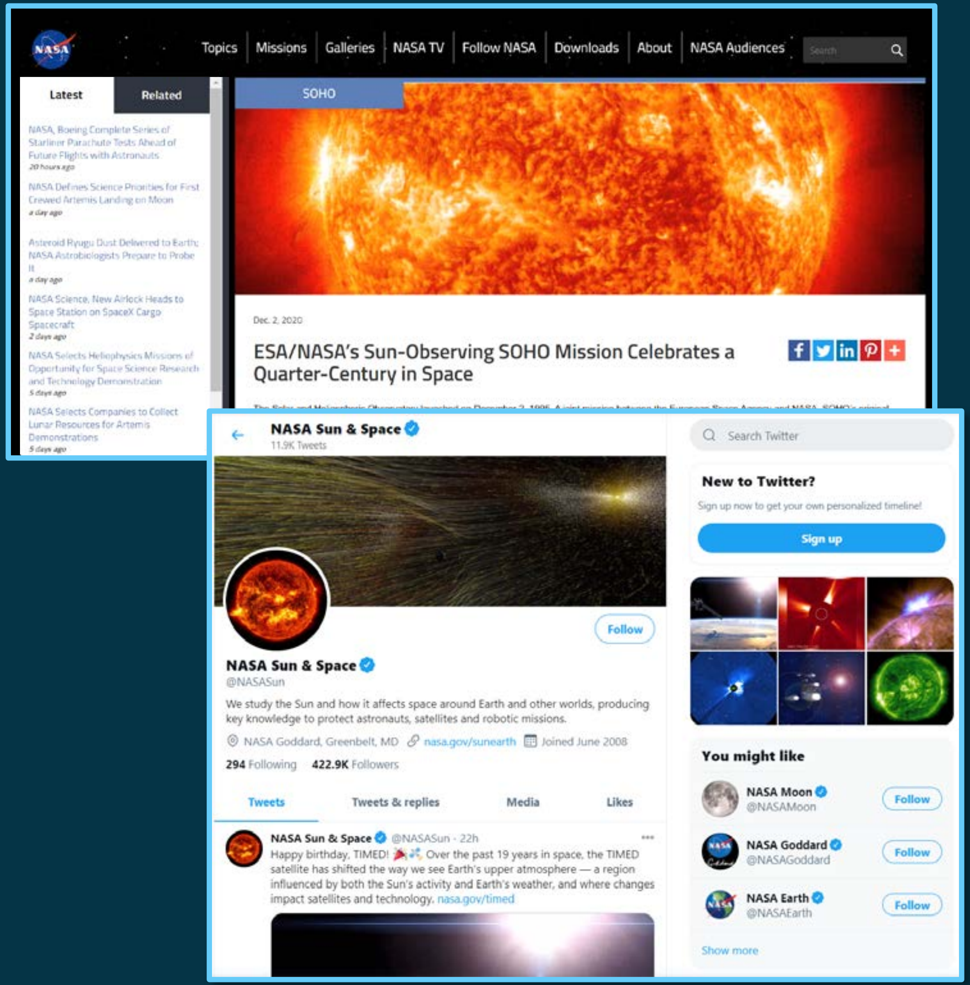
Check out our "Nicky Notes" email!
- Sign up for it: https://bit.ly/2R1w8HT

Stay up to date with what's happening at Headquarters:
- https://science.nasa.gov/researchers/virtual-townhall-2020

Let us know what you've been working on:
- bit.ly/SubmitHelioScience

Web and social media:
- NASA.gov/sunearth
- blogs.nasa.gov/sunspot
- @NASASun
- facebook.com/NASASunScience

Volunteer for a panel:
- https://science.nasa.gov/researchers/volunteer-review-panels



Every Day Space Weather

To bring our focus back to Everyday Space Weather/Ordinary Space Weather, here is a new commentary in Journal of Space Weather & Space Climate
https://www.swsc-journal.org/articles/swsc/full_html/2021/01/swsc210009/swsc210009.html

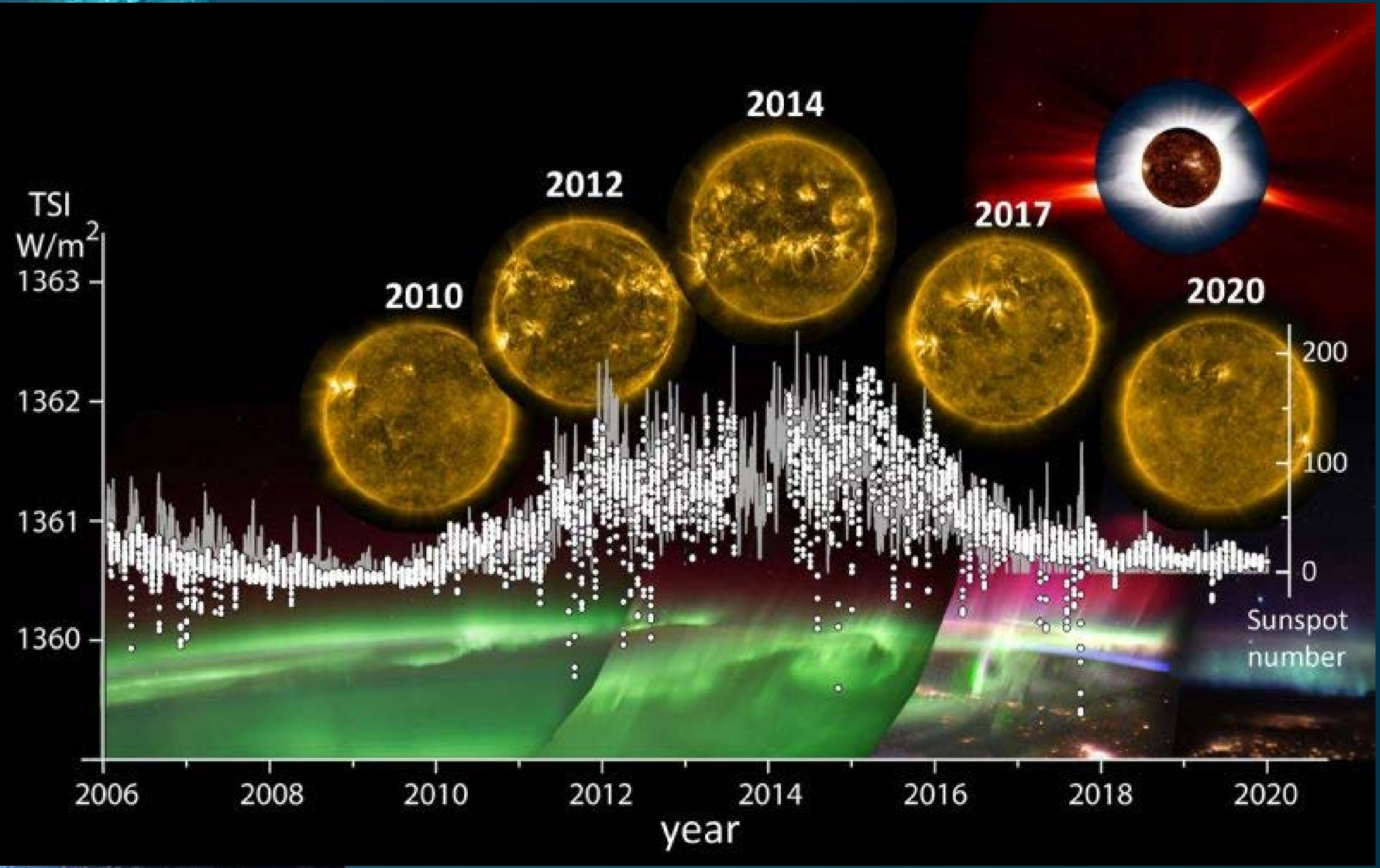


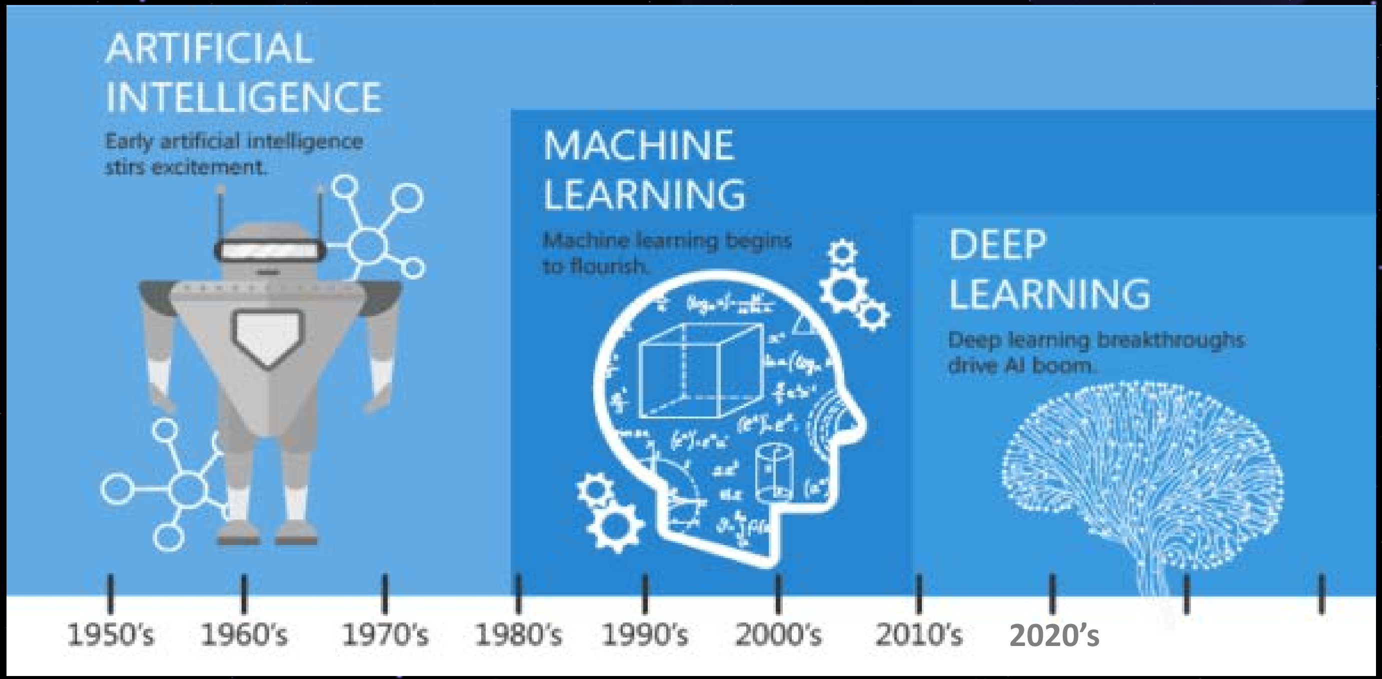
Illustration of solar activity impacts on the Earth's space environment during Solar Cycle 24. The solar activity increased the Total Solar Irradiance (TSI; white dots) during the solar maximum. Whole-disk observations of the solar corona in the extreme ultraviolet light from the Atmospheric Imaging Assembly (AIA) instrument onboard NASA's Solar Dynamics Observatory (SDO) show numerous brightenings caused by magnetic active regions emerging from the solar interior. Aurora images at the bottom are taken from the International Space Station at different solar cycle stages. The upper right corner shows a composite image of the Sun during the total solar eclipse of 2017, at the maximum of solar activity.

Introduction to Machine Learning

Applying Machine Learning to Space Weather

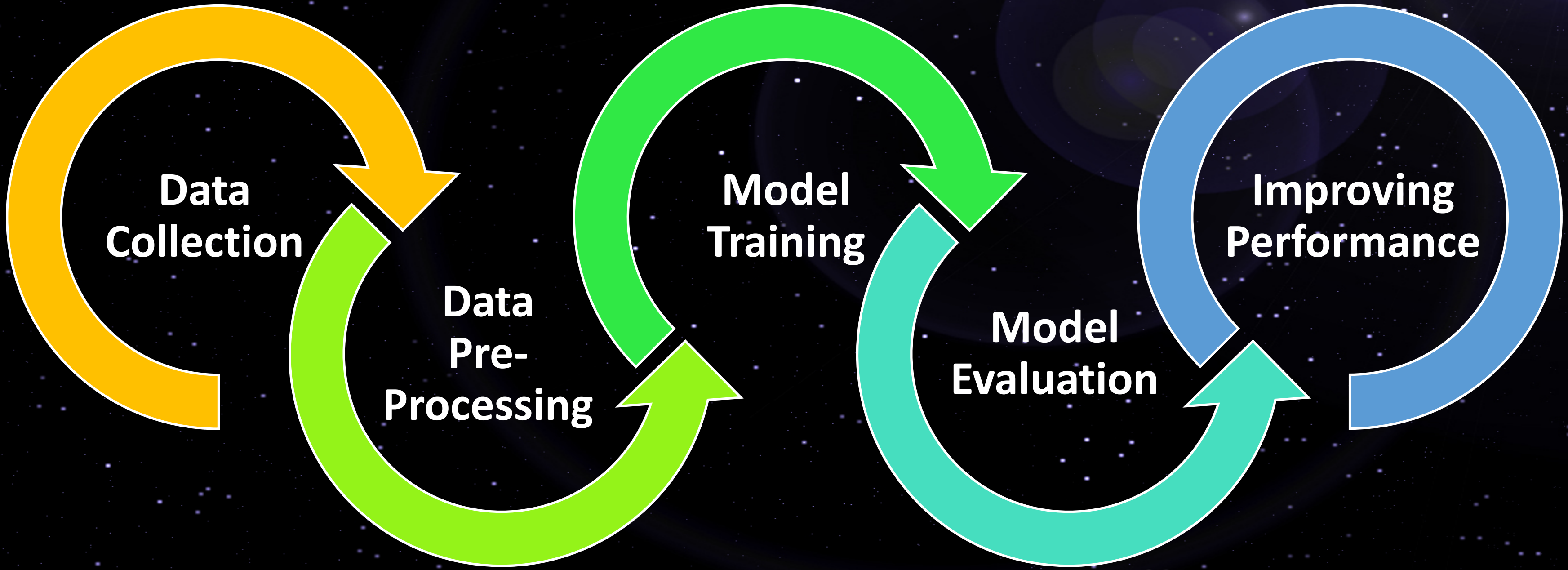
Introduction to Machine Learning

- Machine Learning (ML) evolved from Artificial Intelligence (AI) in the 1980s
- ML is data-based, training machines to recognize human-like connections
- Deep Learning (DL) is simply a "deeper" form of ML
- DL utilizes more intricate algorithms and techniques that allow the ML models to function more naturally without human involvement



http://aimagnifi.com/blog/index.php/2017/10/13/what-is-the-difference-between-machine-learning-and-deep-learning/

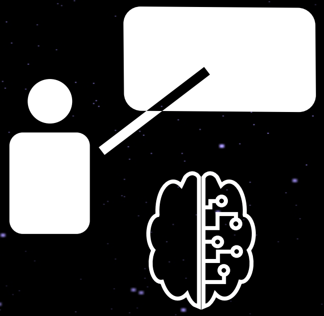
How does Machine Learning actually work?



https://towardsdatascience.com/machine-learning-a-gentle-introduction-17e96d8143fc

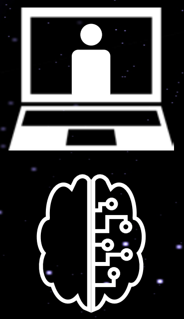
Learning Styles

There are four types of common ML/DL Learning Styles



Supervised

- A pre-labeled dataset
- Human supervision

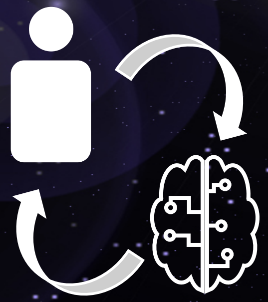


Semi-Supervised

- Supervised, but without pre-labeled data

Unsupervised

- Un-labeled dataset
- No instructions during experiment

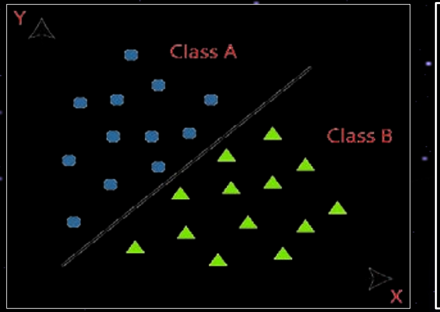


Reinforcement

- The human can change/alter the learning environment to test results

Techniques and Algorithms

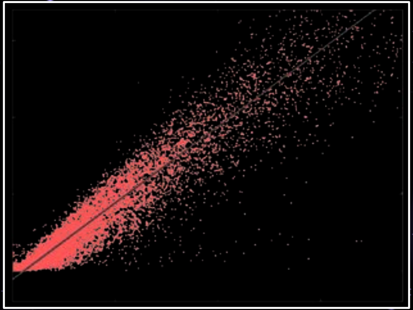
Techniques and Algorithms are methods used to implement, support, and/or otherwise alter a ML/DL model



Regression

Predicting continuous quantities from data. Examples: financial forecasting, click rate prediction.

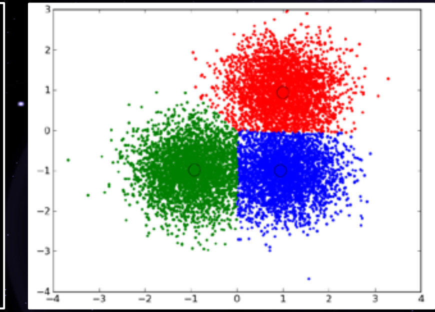
https://www.javatpoint.com/classification-algorithm-in-machine-learning



Classification

Assigning data to one of several categories. Applications include facial recognition, image recognition, medical results.

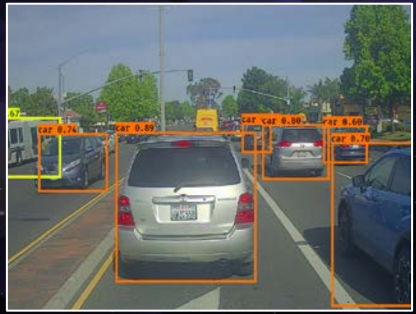
https://elleknowsmachines.com/linear-regression/



Clustering

Creating clusters or groups of “similar” data, usually with large datasets. Examples include gene expression, astronomy, and network modelling.

https://machinelearningmastery.com/get-your-hands-dirty-with-scikit-learn-now/



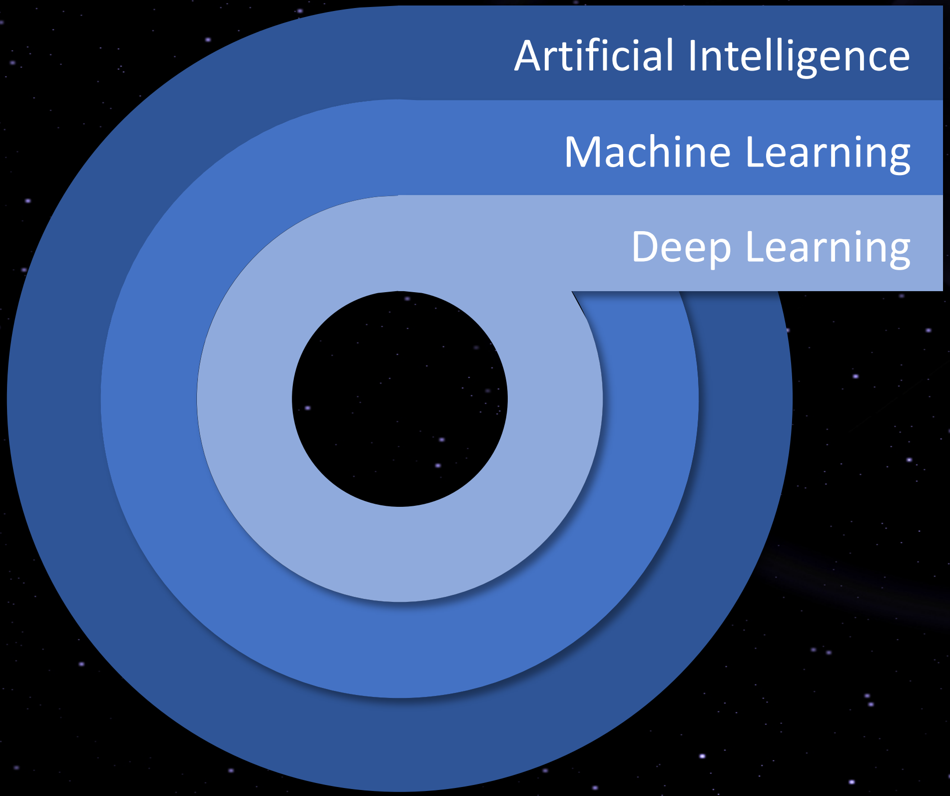
Dimensionality reduction

When data has many dimensions, this maps data onto low dimensions, while preserving relevant information; data mining, scientific analysis, or image recognition are examples.

https://medium.com/analytics-vidhya/a-guide-to-the-object-detection-exercise-using-yolo-model-c551f65df637

Deep Learning

- **Deep Learning** is currently the fastest growing and most promising field of AI/ML



EXAMPLES

Artificial Intelligence

SA – Smart Automation

DA – Discrete Automation (Assembly or factory automation which produces materials or other items)

PA – Process Automation (The continuous production processes that transforms materials into products – such as the oil & gas or chemicals industry)

Machine Learning

ANI – Artificial Narrow Intelligence (ONE functional area)

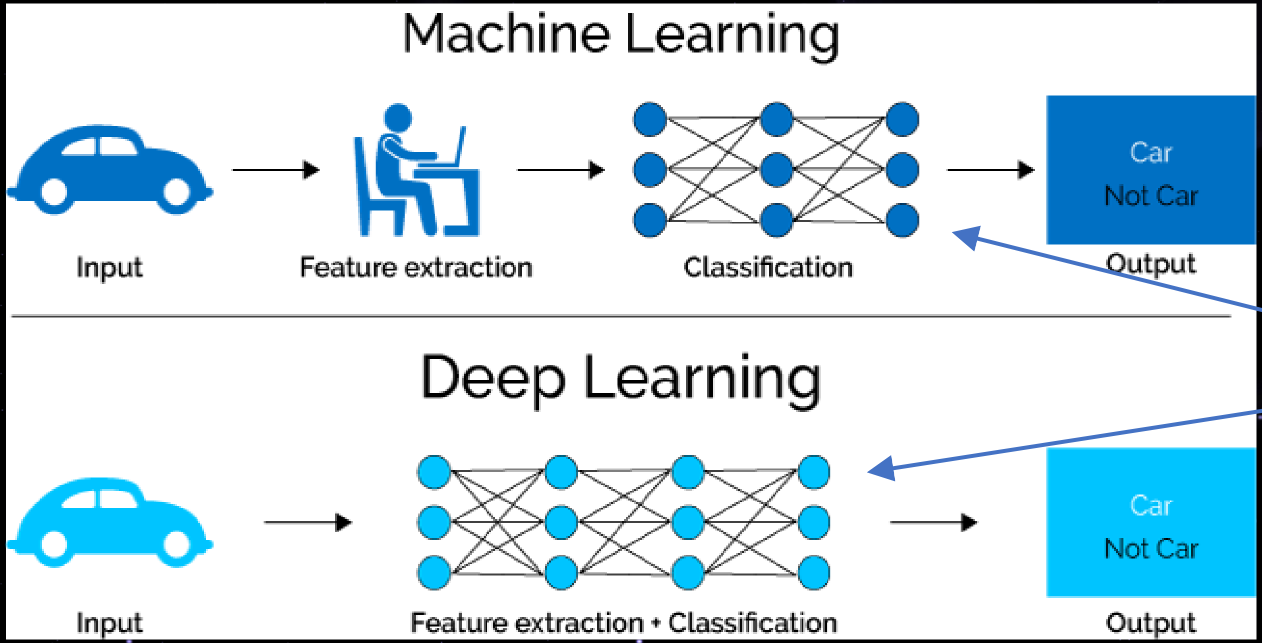
Deep Learning

AGI – Artificial General Intelligence (reasoning capabilities, problem solving)

ASI – Artificial Super Intelligence (exceeds human intelligence

ML vs. DL

Machine Learning	Deep Learning
▪ ML uses algorithms in order to make predictions or decisions without being explicitly programmed to do so ▪ Often involves a "human in the loop" that influences the model prior to running the actual trial/experiment	▪ DL is a class of ML that uses more network layers to extract higher level features from data. Each layer transforms its data into a more abstract representation ▪ DL models have no human interaction once the data is inputted, and are generally much more able to detect new connections and patterns in the data



Neural Network Layers

https://towardsdatascience.com/deep-learning-101-for-dummies-like-me-a53e3caf31b1

Advantages/Disadvantages of ML

Advantages	Disadvantages
1. Easily identifies trends and patterns 2. No human intervention needed 3. Continuous Improvement 4. Handling multi-dimensional and multi-variety data 5. Wide Applications	1. Needs high volume data 2. Time and Resources ➢ Compute time and expensive hardware 3. Interpretation of Results ➢ Neural Networks are complex to present 4. High error susceptibility ➢ Models are subject to overfitting and may break with small changes

Source: Michael Limotta, Proximai

Key Challenges to Applying ML to Space Weather

As expressed by E. Camporeale[1]

The data problem.

What is the minimal information required to make a forecast? This problem determines the failure or success of any machine learning application.

The uncertainty problem.

Space Weather largely forecasts, in terms of single-point predictions. There is a clear need to understand and assess the uncertainty associated to these predictions.

The Gray-box problem.

Gray boxes are essentially hybrid or mixed AI models. For Space Weather, how can we best understand the large amount of data in the Sun-Earth system?

The too often too quiet problem.

Space weather data is typically imbalanced: many days of quiet conditions and a few hours of storms. This poses a serious problem in any machine learning algorithm that tries to find patterns in the data.

The surrogate problem.

As many ML models are complex and difficult to understand (black box), how can surrogate (or simpler) models help translate difficult Space Weather data?

The knowledge discovery problem.

How do we distill some knowledge from a machine learning model and improve our understanding of a given system?

[1] E. Camporeale, The Challenge of Machine Learning in Space Weather: Nowcasting and Forecasting, 10.1029/2018SW002061

The Current State of Machine Learning in Heliophysics and Space Weather

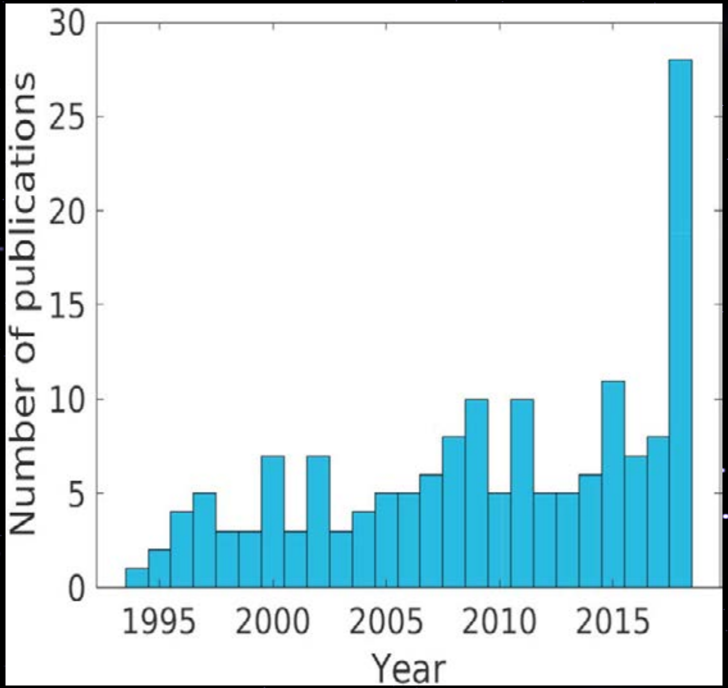
- NASA, NSF, and NOAA opened solicitations for machine learning research
- Conference series called Machine Learning in Heliophysics
- Books
  - Machine Learning Techniques for Space Weather (Camporeale et al., 2018)
  - Statistics, Data Mining, and Machine Learning for Heliophysics (Bobraand Mason, 2020)
- Research accelerator called Frontier Development Laboratory
- Interdisciplinary collaborations with computer scientists and statisticians
- An increased emphasis in the machine learning community on science applications

"Observing the Sun from different perspectives and multiple perspectives is the most meaningful way to improve flare prediction using machine learning models"

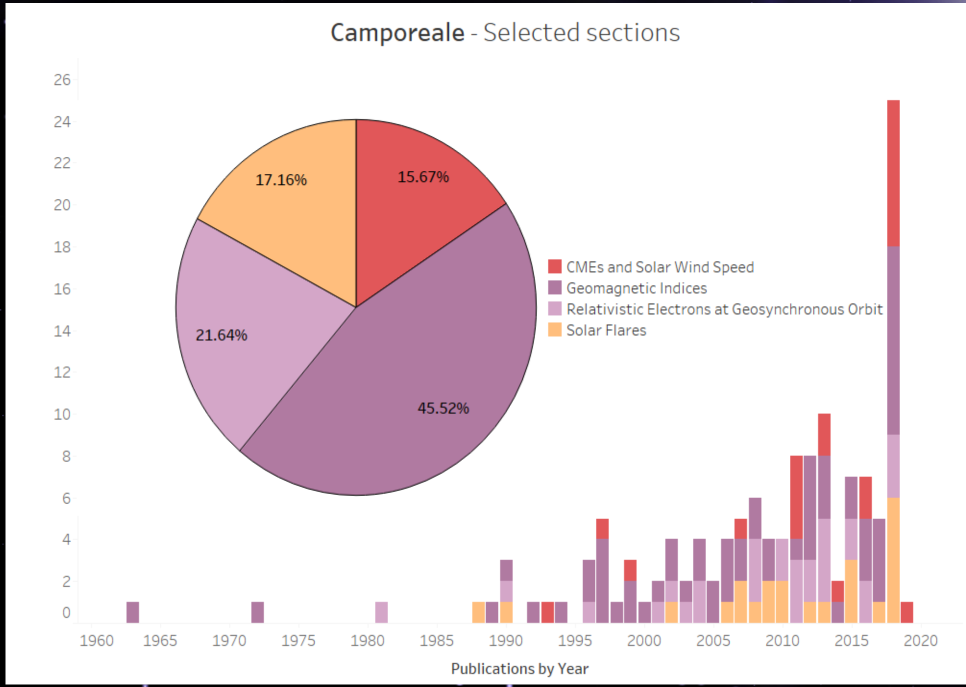
- Monica Bobra

Source – Monica Bobra, presentation

Space Weather ML Publication Growth



Publications between 1993 and 2018 in the area of machine learning applied to Space Weather cited in all sections of Camporeale's article, as presented in the paper (Figure 4)

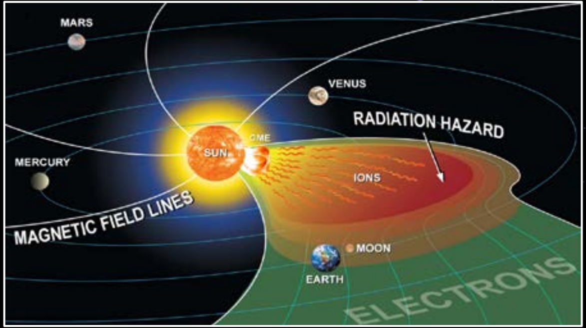


Publications Cited in Camporeale (compiled in this review)
5.1 (Geomagnetic Indices)
5.3 (Relativistic Electrons at Geosynchronous Orbit)
5.5.1 (Solar Flares)
5.5.2 (CMEs and Solar Wind Speed)

[1] E. Camporeale, The Challenge of Machine Learning in Space Weather: Nowcasting and Forecasting, 10.1029/2018SW002061

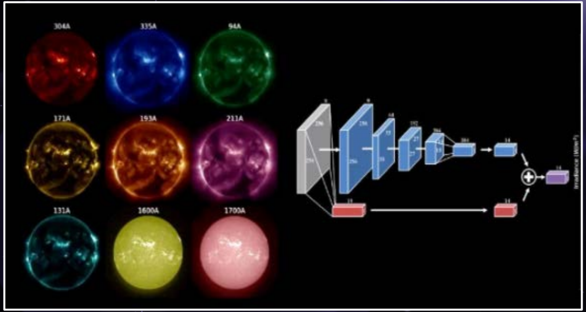
Examples of ML in Space Weather

NASA's ML Threat Assessment Tool (STAT) tracks the severity of CMEs

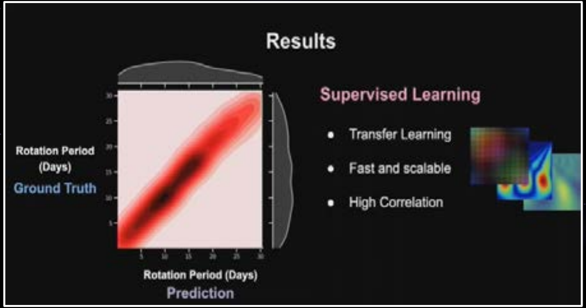


https://www.nas.nasa.gov/SC18/demos/demo21.html#prettyPhoto

NASA's FDL tracking the Sun's EUV irradiance through Deep Learning

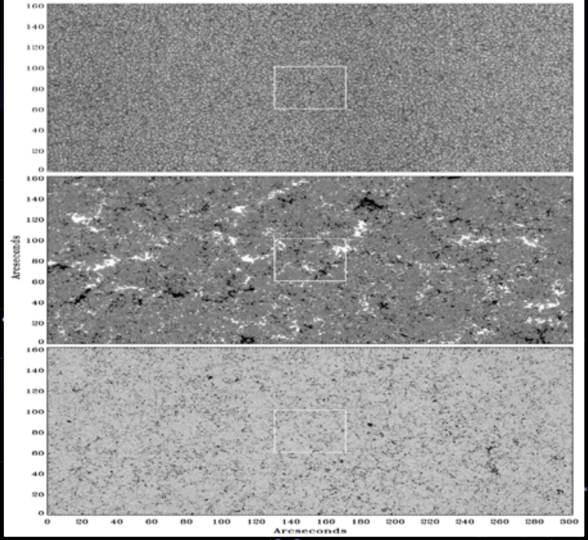


NASA's FDL using a Supervised Probabilistic Model to predict sun spots



https://vimeo.com/452163073/822f09a304

Convolutional Neural Networks studying Solar Magnetic Field images



Space ML

- June 17, 2021, Mountain View, CA - The SETI Institute and Frontier Development Lab announced the launch of SpaceML.org.
- SpaceML is a resource that makes AI-ready datasets available to researchers working in space science and exploration, enabling rapid experimentation and reproducibility.
- The SpaceML Repo is a machine learning toolbox and community managed resource to enable researchers to more effectively engage in AI for space science and exploration. It is designed to help bridge the gap between data storage, code sharing and server-side (cloud) analysis. You should check it out!

Projects hosted on SpaceML.org for the research community include:

A project tackling the problem of how to use ML to auto-calibrate space-based instruments used to observe the Sun. After years of exposure to our star, these instruments degrade over time – a bit like cataracts. Recalibration requires expensive sounding rockets. Using ML, the team has been able to augment the data, in effect “removing” the cataracts.

“The hurdle for many researchers to start using the SDOML dataset, and to begin developing ML solutions, is the friction they experience when first starting,” said Mark Cheung, Sr. Staff Physicist at Lockheed Martin and Principal Investigator for NASA Solar Dynamics Observatory/Atmospheric Imaging Assembly. “SpaceML gives them a jumpstart by reducing the effort needed for exploratory data analysis and model deployment. It also demonstrates reproducibility in action.”