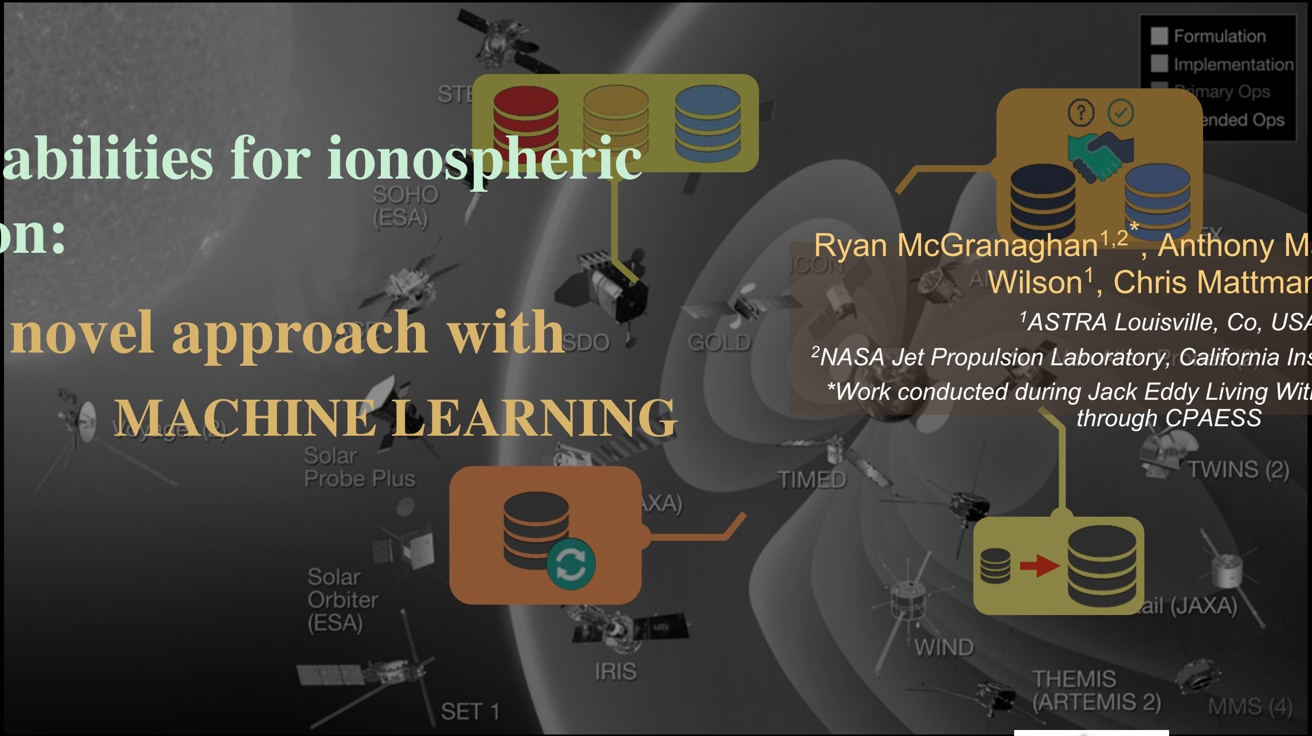
New capabilities for ionospheric prediction:

A novel approach with MACHINE LEARNING



Ryan McGranaghan[1,2*], Anthony Mannucci[1], Brian Wilson[1], Chris Mattmann[1]

[1]ASTRA Louisville, Co, USA

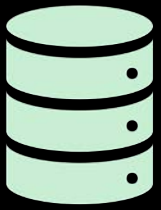
[2]NASA Jet Propulsion Laboratory, California Institute of Technology

*Work conducted during Jack Eddy Living With a Star Fellowship through CPAESS

ASTRA

CPAESS

Agenda

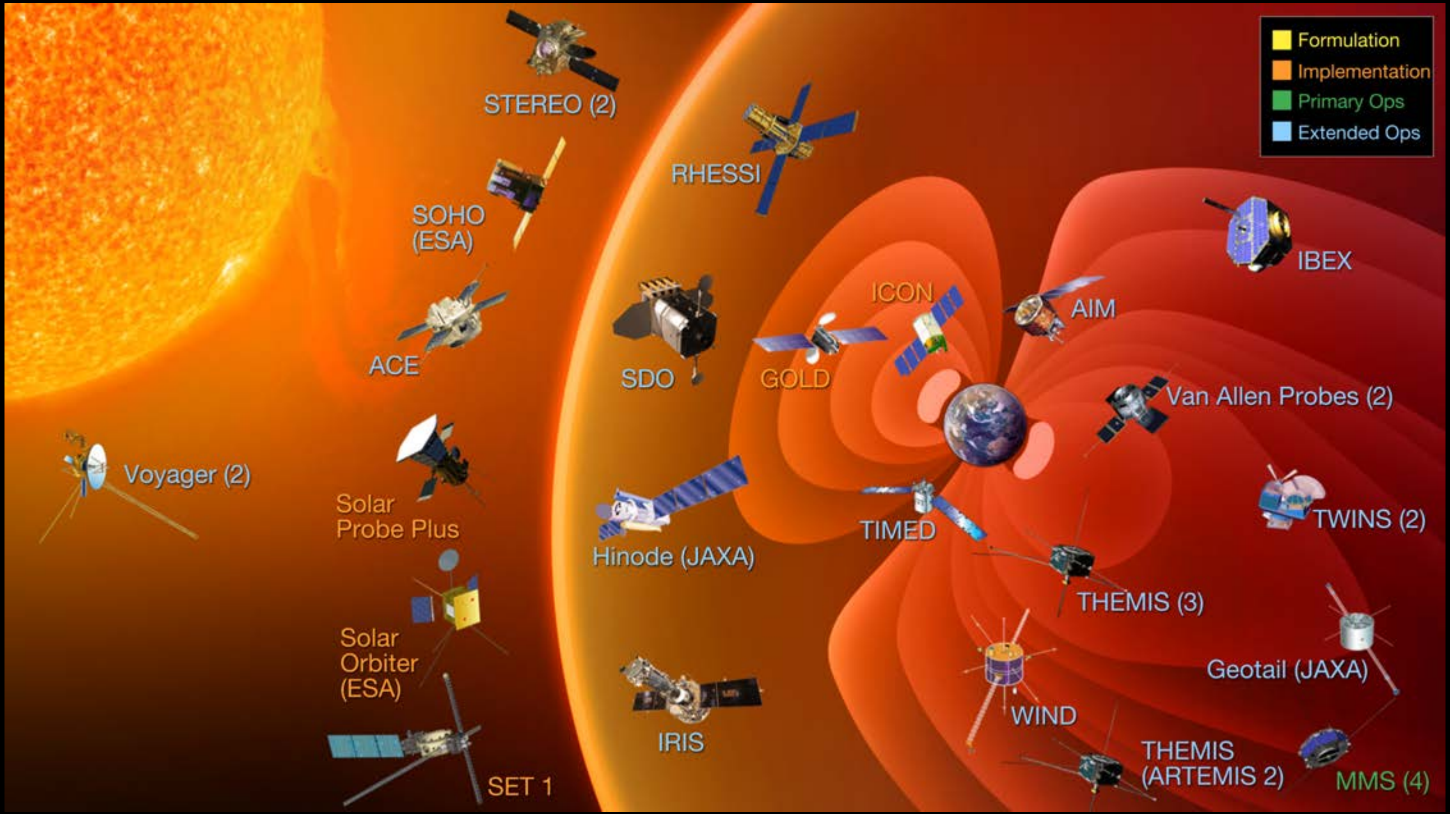


How is CEDAR evolving and why do we need data science?

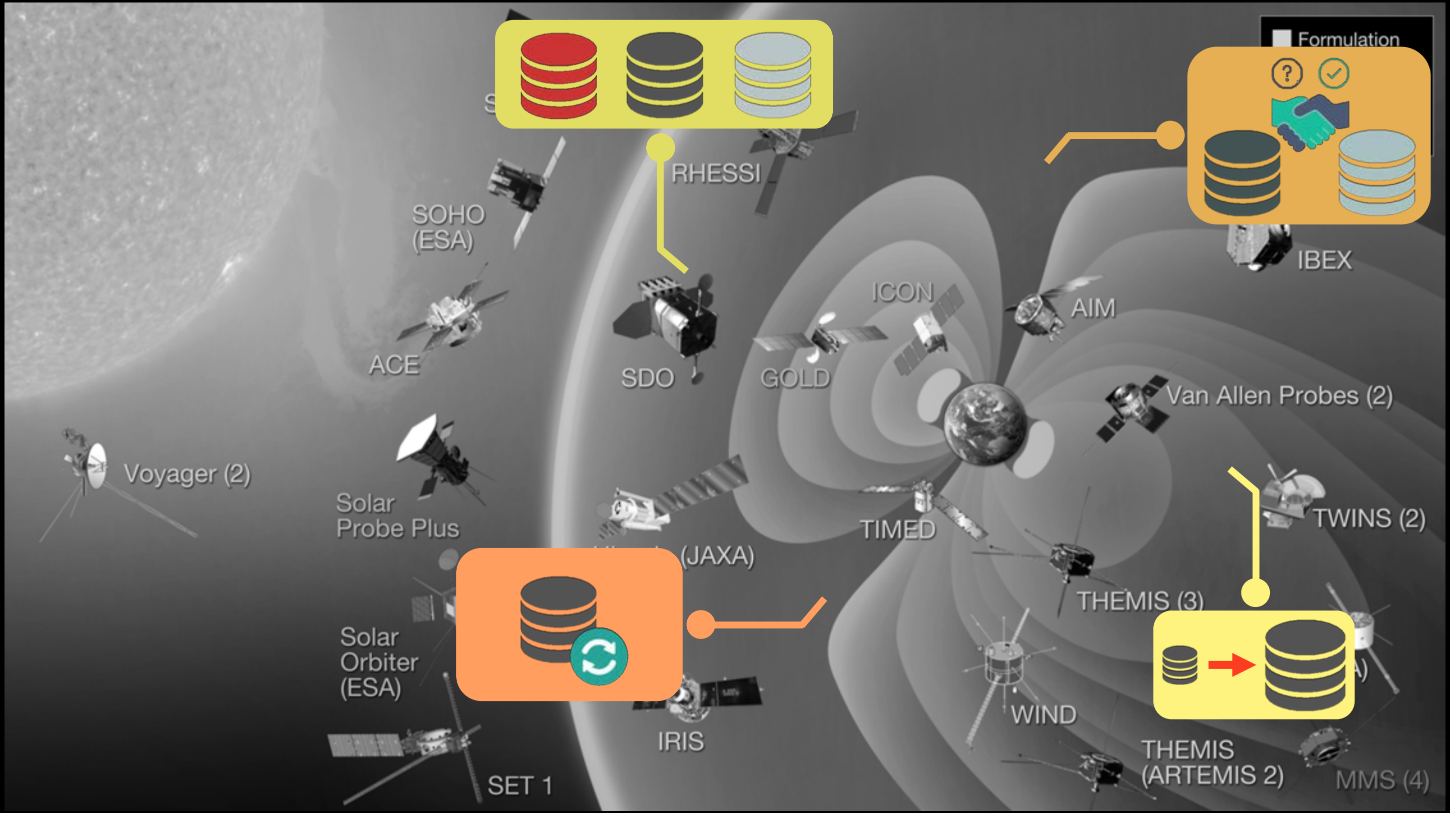
Why is ionospheric scintillation a fantastic use case and what progress have we made?

What *trends* does this reveal?

How is CEDAR evolving and why do we need data science?



Formulation
Implementation
Primary Ops
Extended Ops
STEREO (2)
RHESSI
SOHO (ESA)
ACE
SDO
GOLD
ICON
AIM
IBEX
Van Allen Probes (2)
Voyager (2)
Solar Probe Plus
Hinode (JAXA)
TIMED
TWINS (2)
THEMIS (3)
Solar Orbiter (ESA)
Geotail (JAXA)
IRIS
WIND
SET 1
THEMIS (ARTEMIS 2)
MMS (4)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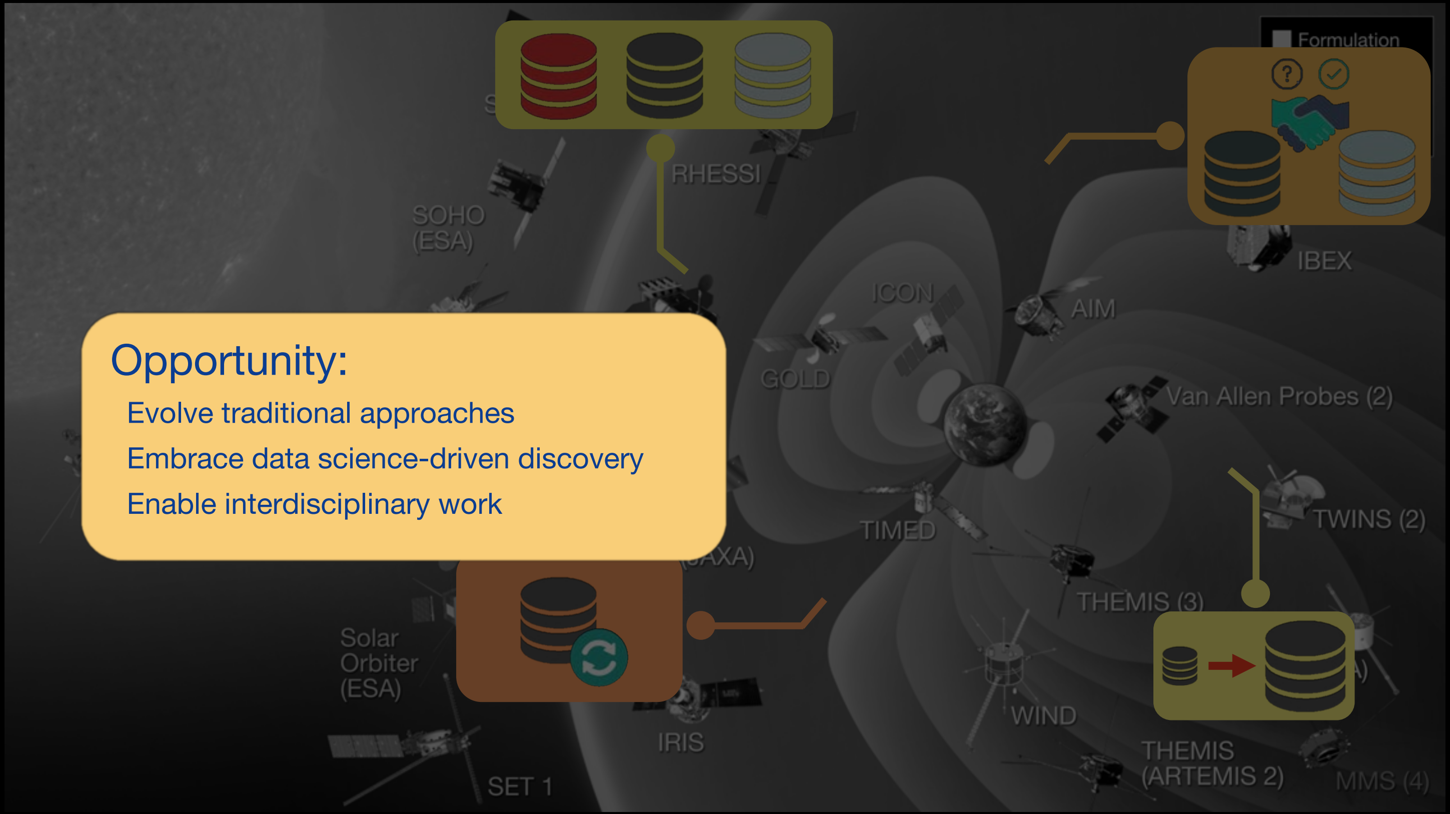


Opportunity:

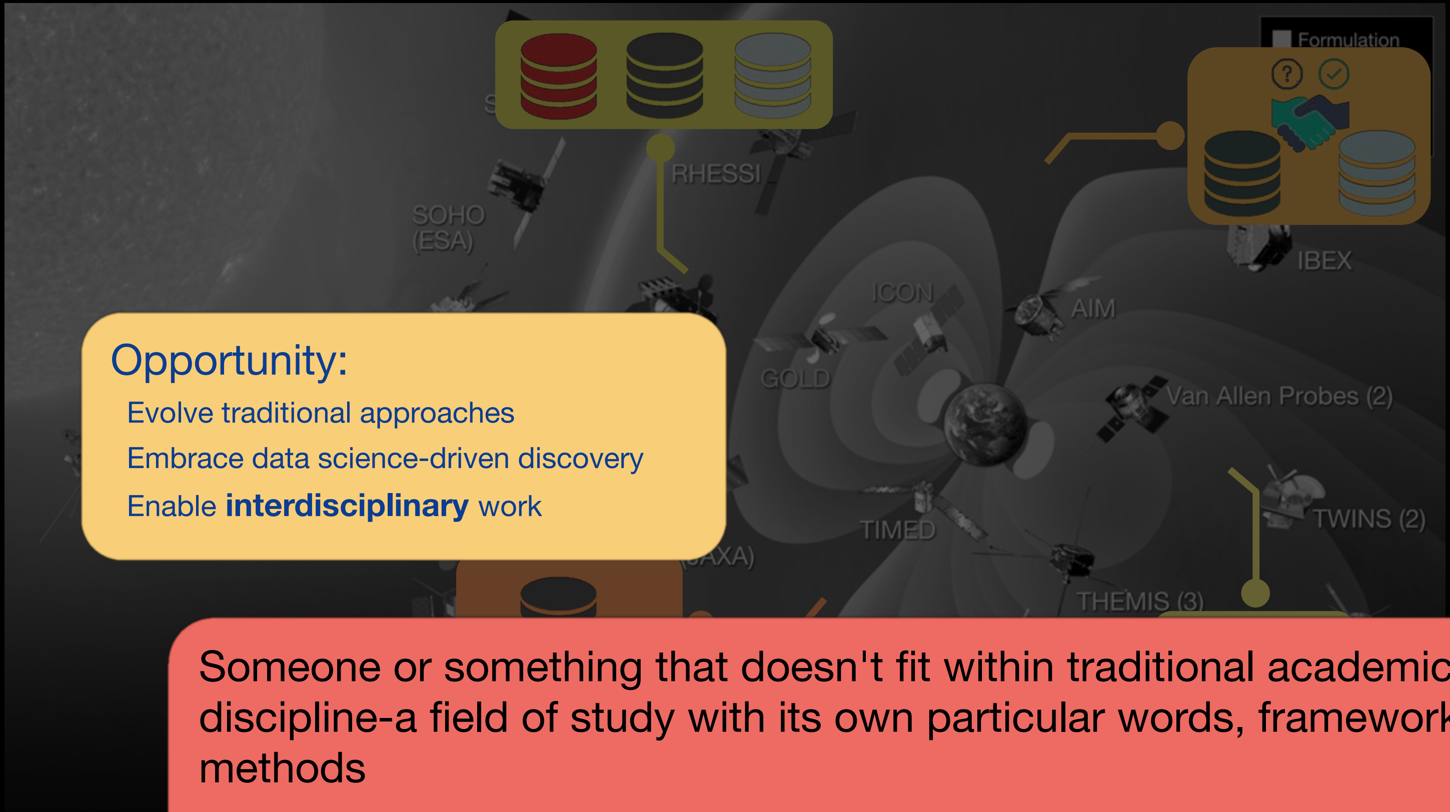
- Evolve traditional approaches
- Embrace data science-driven discovery
- Enable interdisciplinary work

Opportunity:

- Evolve traditional approaches
- Embrace **data science-driven** discovery
- Enable interdisciplinary work

Scalable architectural approaches, techniques, software and algorithms which alter the paradigm by which data are collected, managed and analyzed.

Dan Crichton, JPL

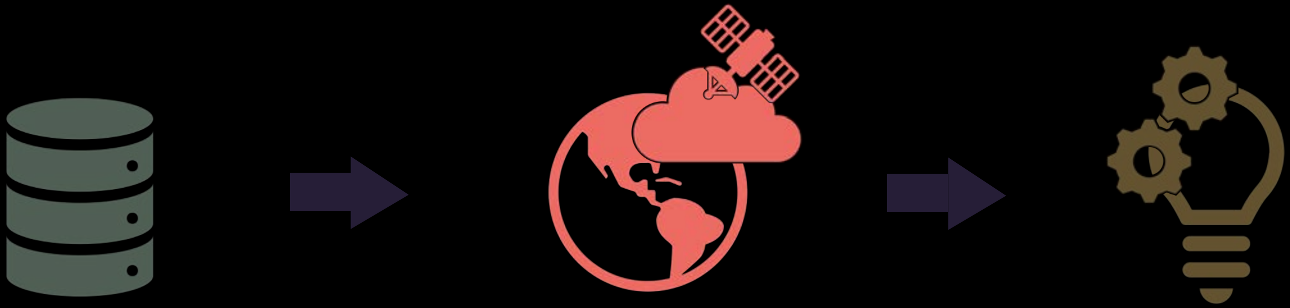


Opportunity:

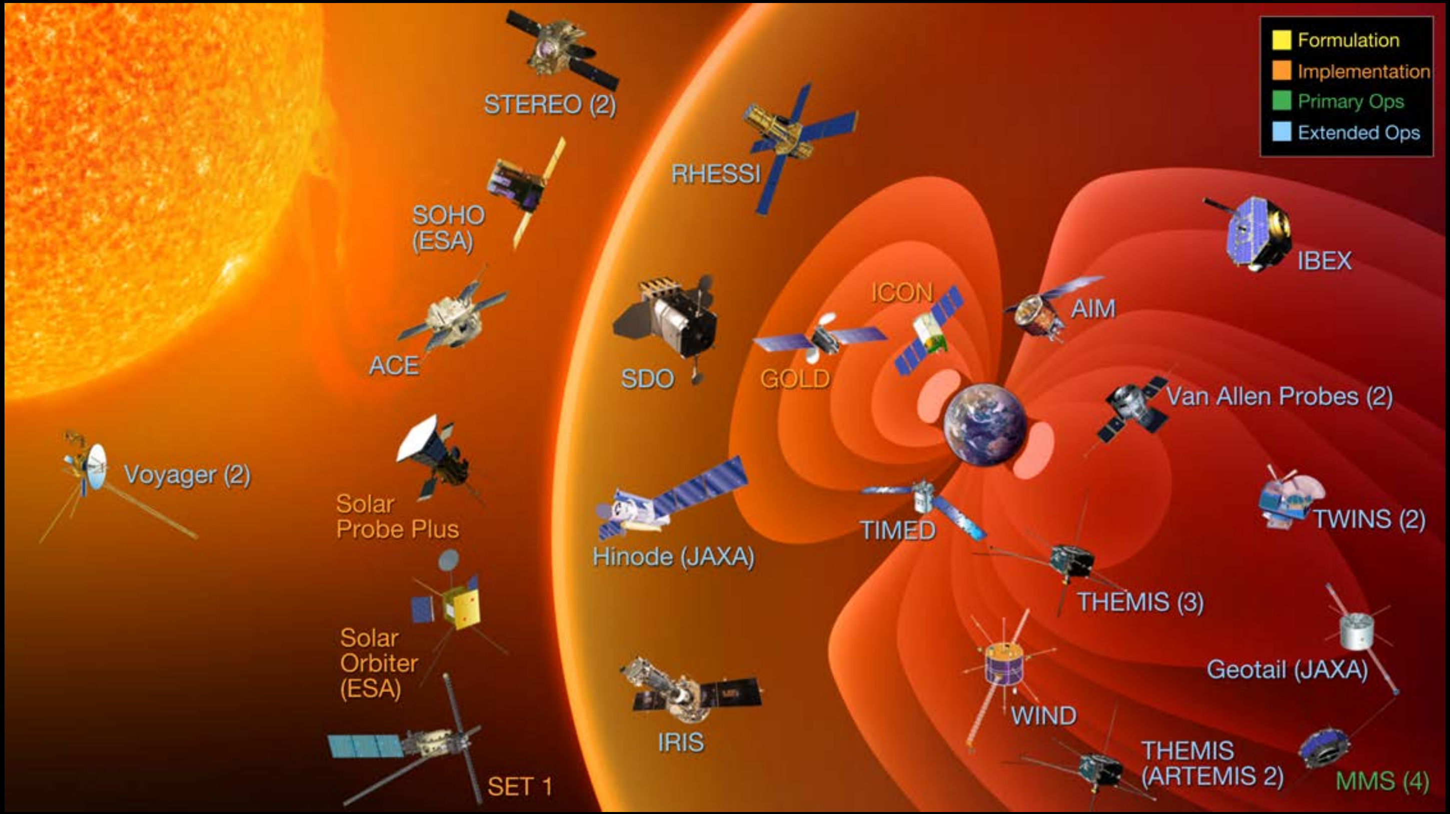
- Evolve traditional approaches
- Embrace data science-driven discovery
- Enable **interdisciplinary** work

Someone or something that doesn't fit within traditional academic discipline-a field of study with its own particular words, frameworks, and methods

Joi Ito, MIT Media Lab, "Antidisciplinary"



Why is ionospheric scintillation a fantastic use case and what progress have we made?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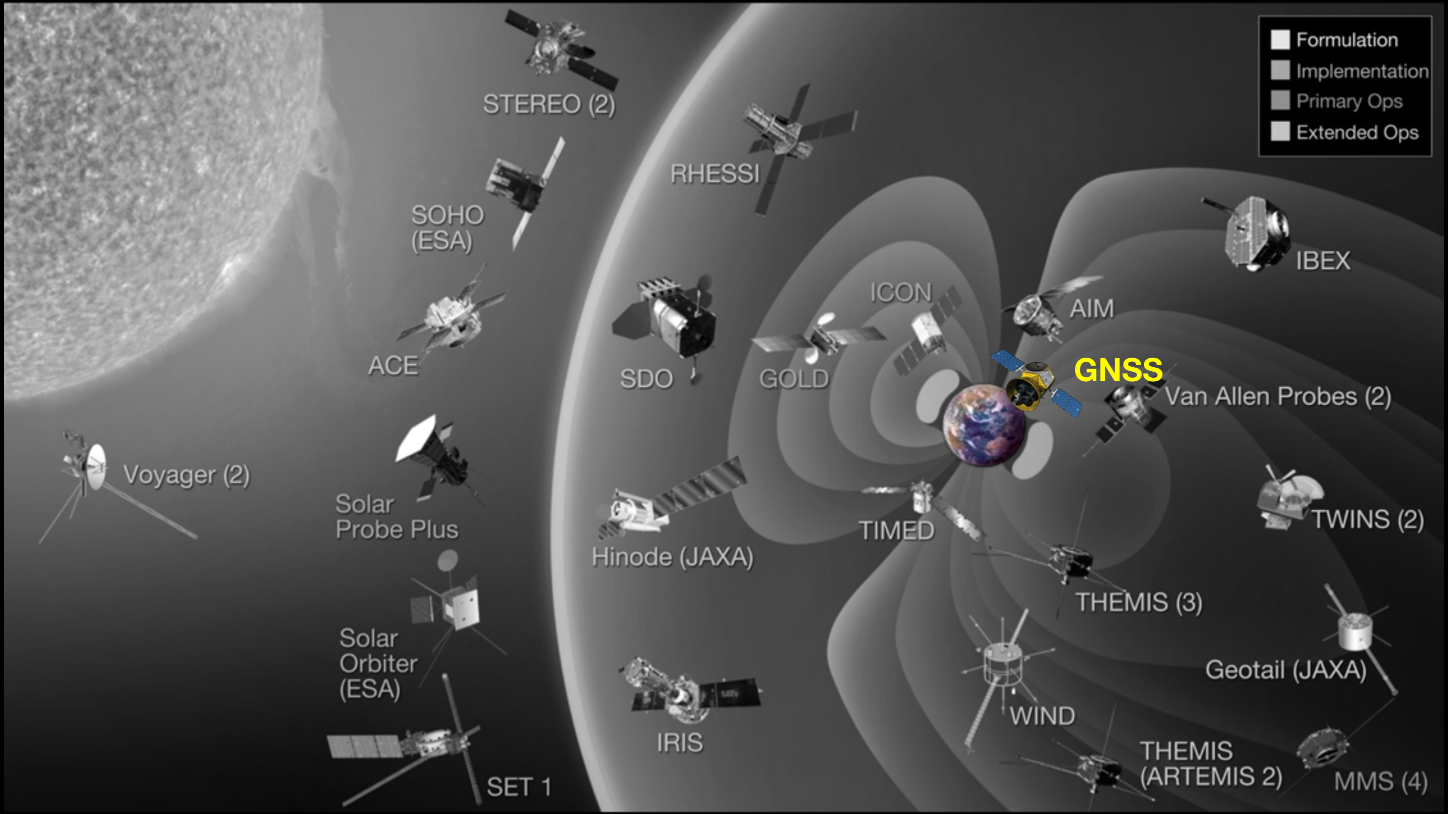

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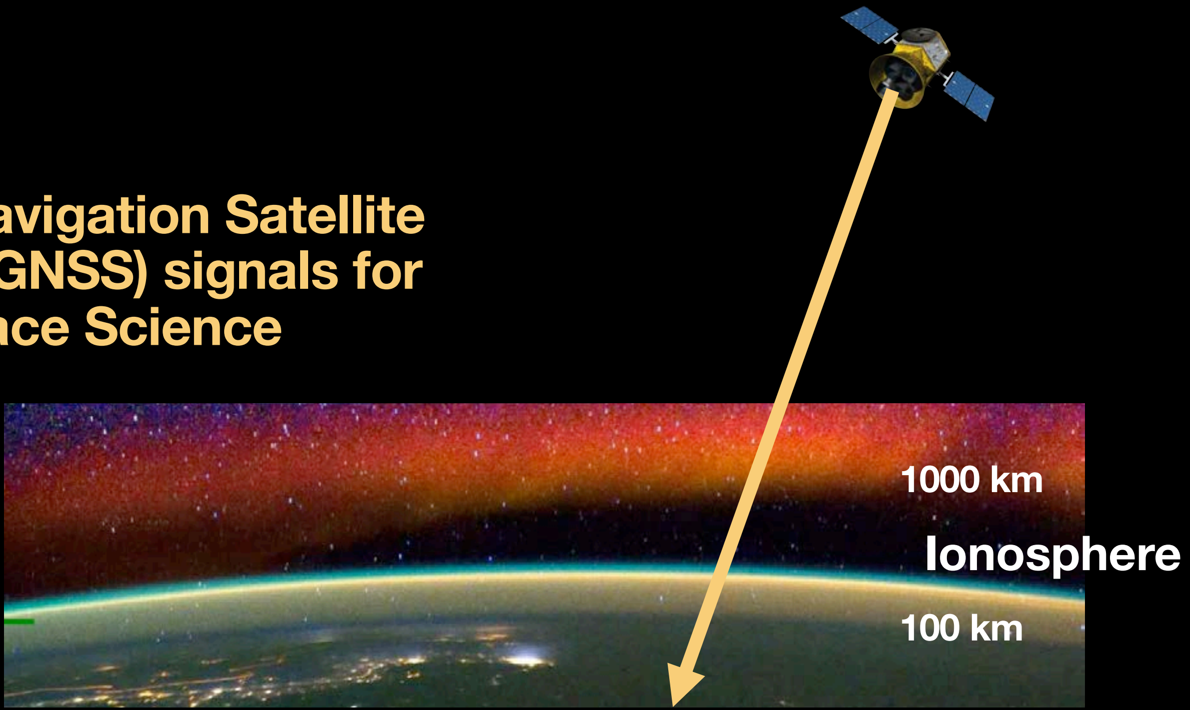
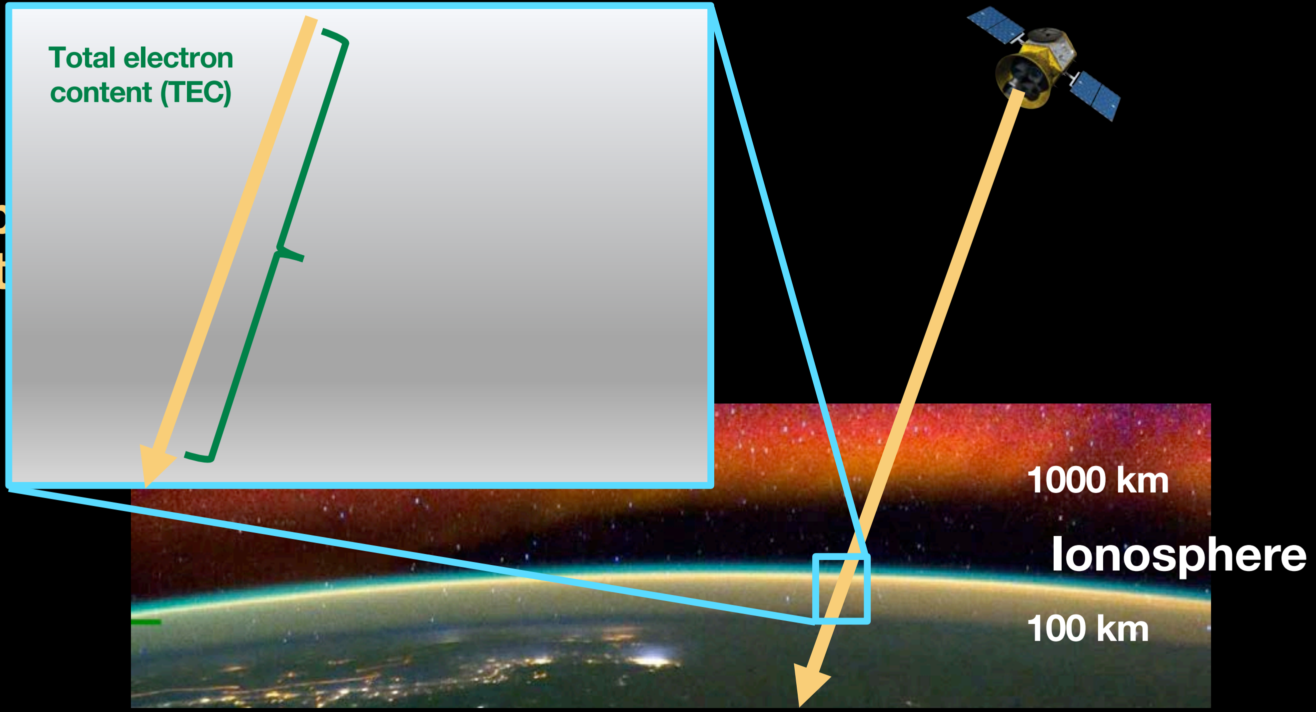
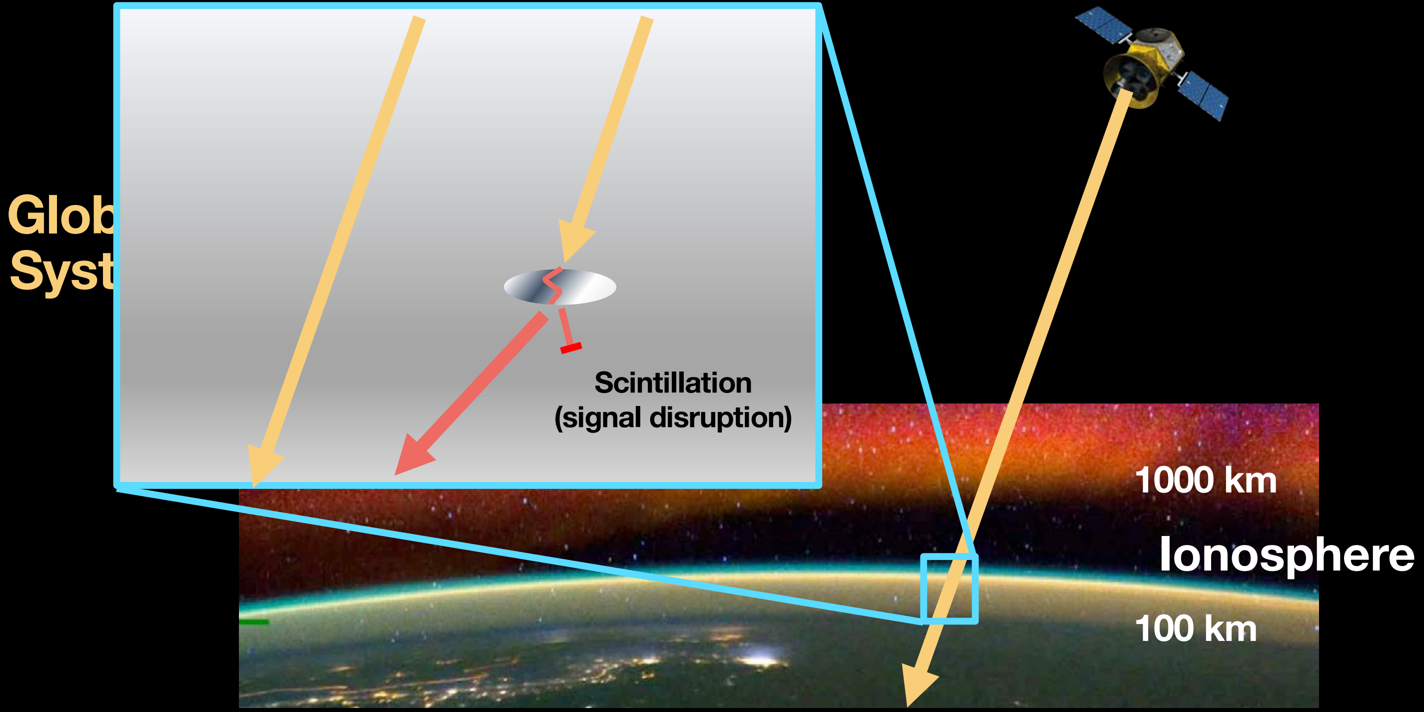
Global Navigation Satellite System (GNSS) signals for Space Science

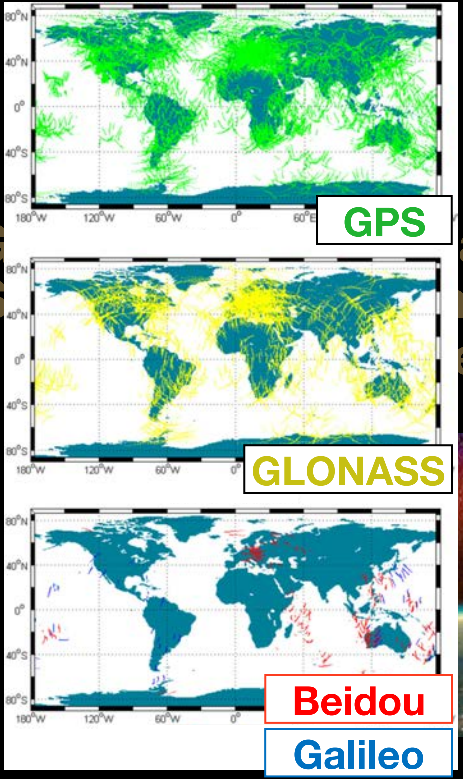


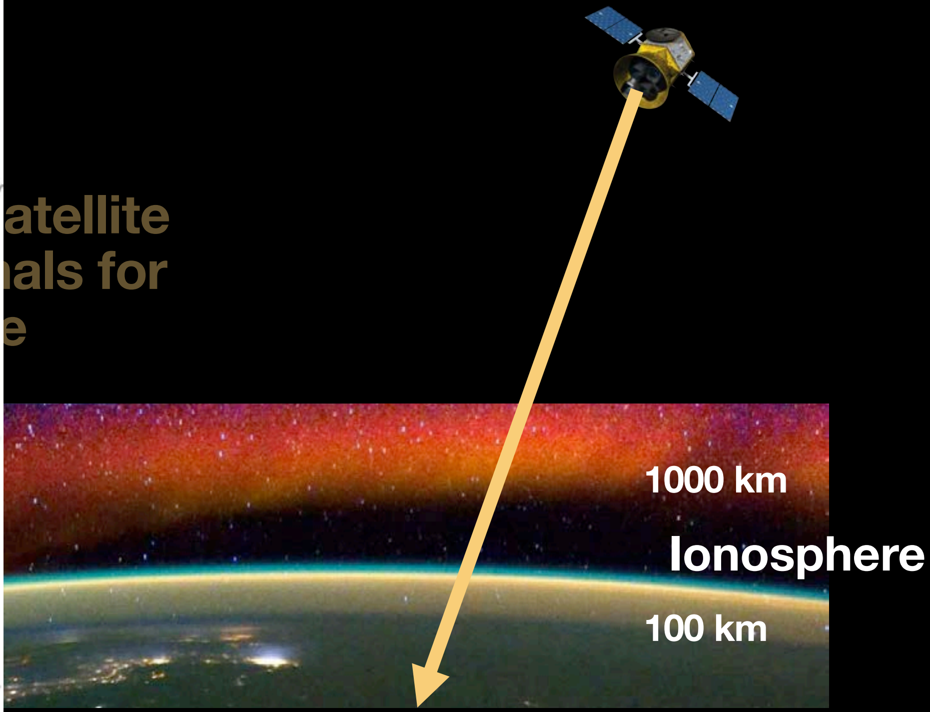
Glob
Syst




Glob
Syst
Scintillation
(signal disruption)
1000 km
Ionosphere
100 km

G atellite
S nals for
e



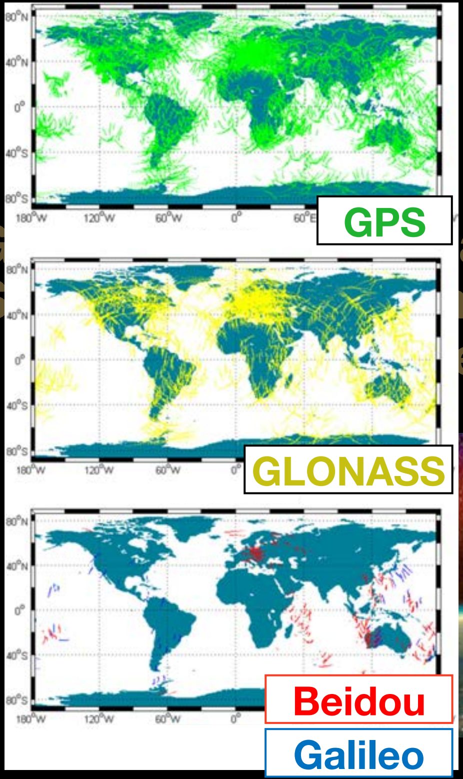


Support Vector Machine (SVM) — **Decision Trees** — **Random Forests** — **Neural Networks**

Easily explainable → *Difficult to explain*

Create a narrative of new scientific understanding across spectrum of machine learning approaches

G… atellite
S… als for
… e



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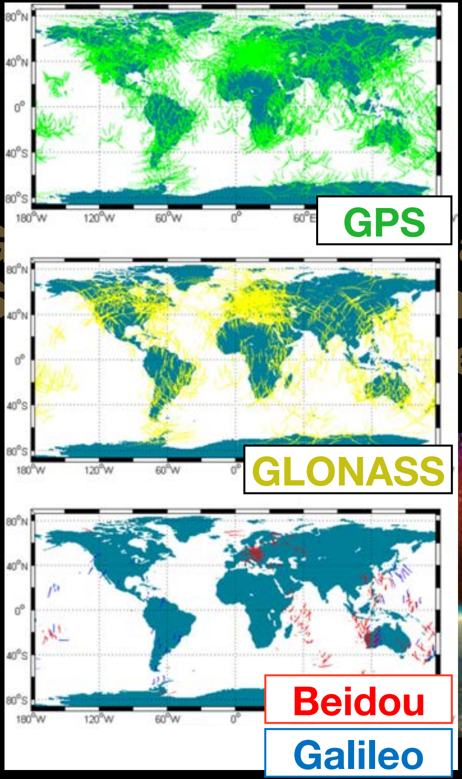
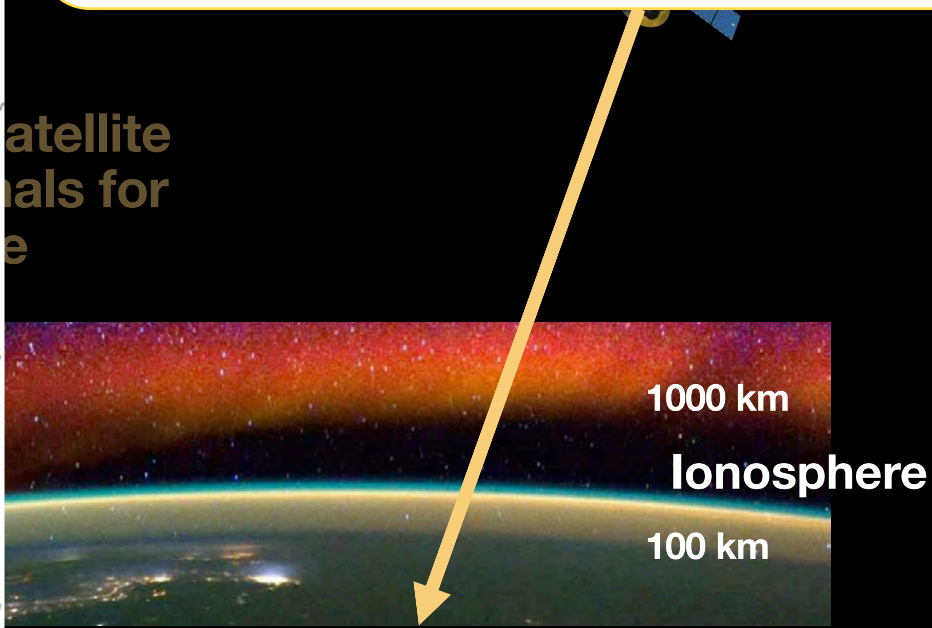
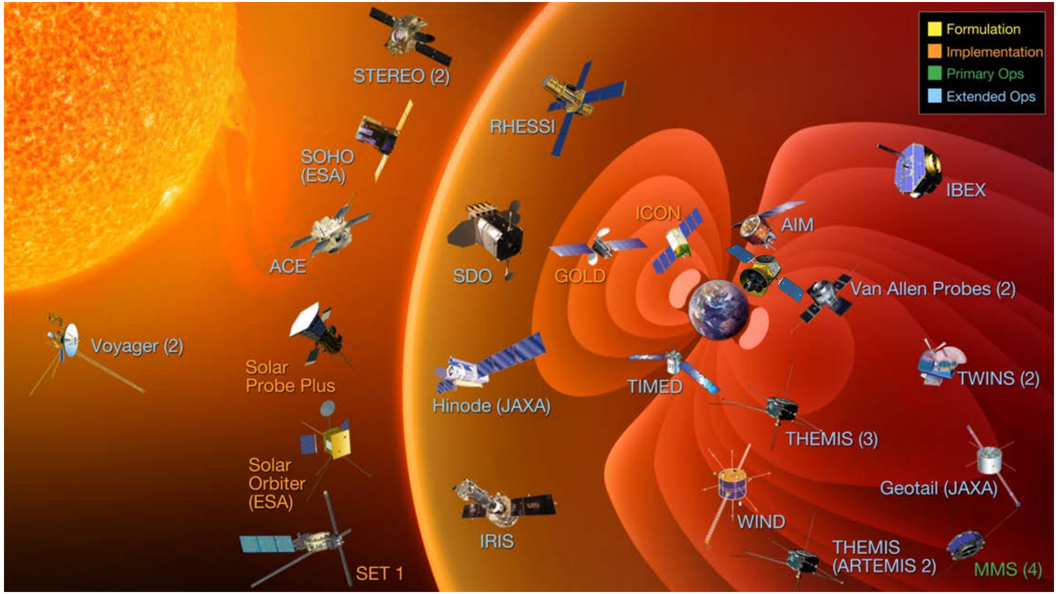




Step 1:

Obtain solar, geomagnetic, and ionospheric data



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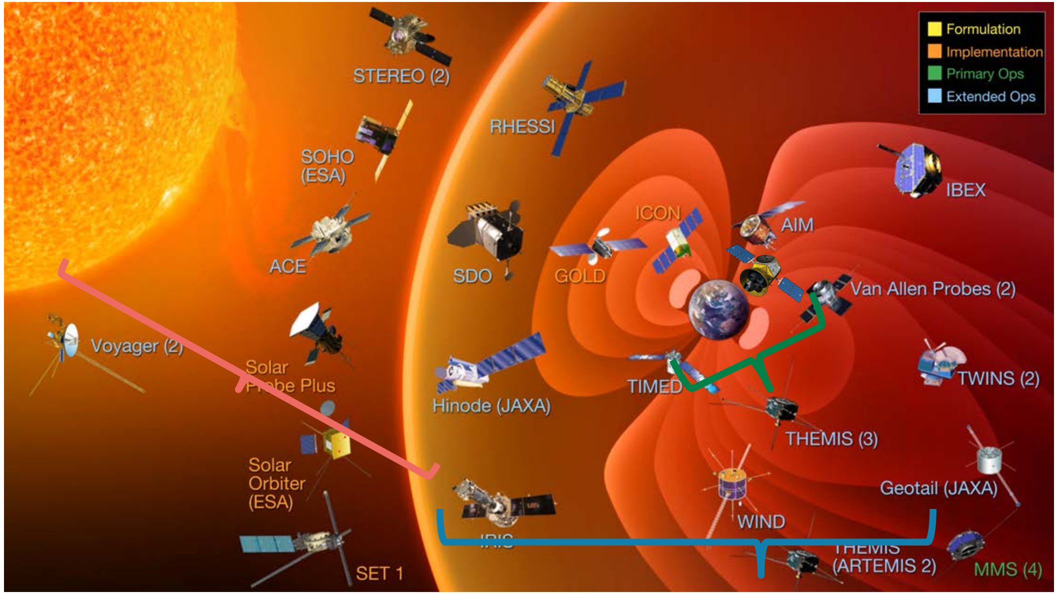

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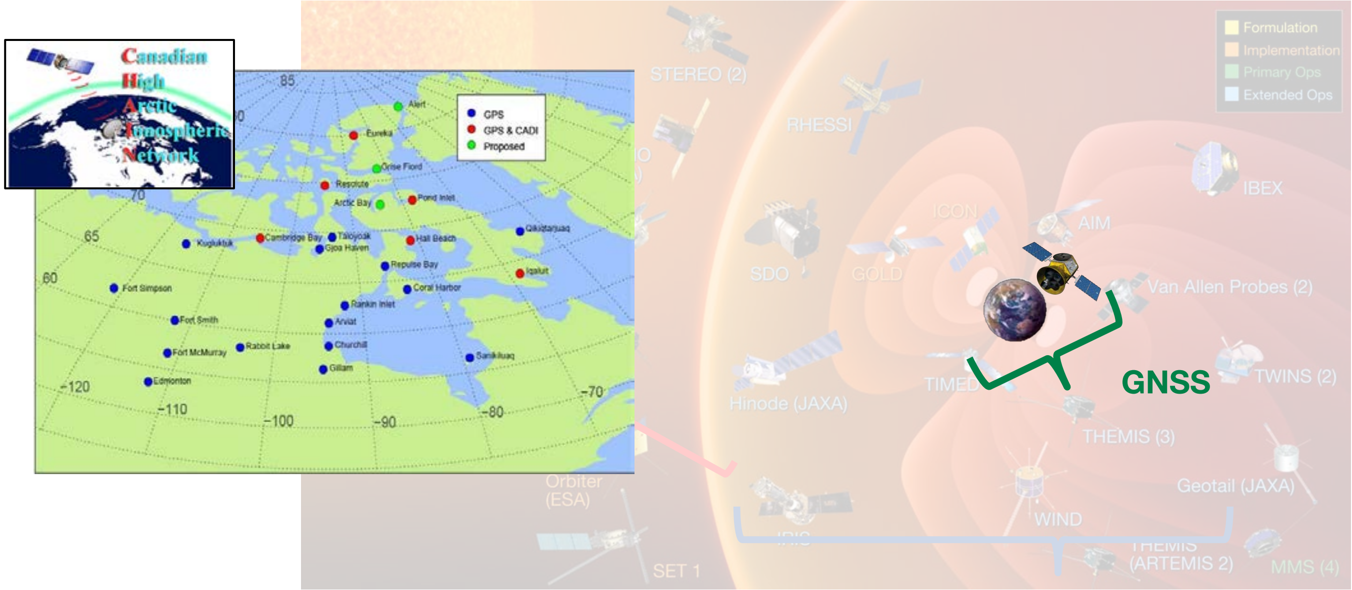
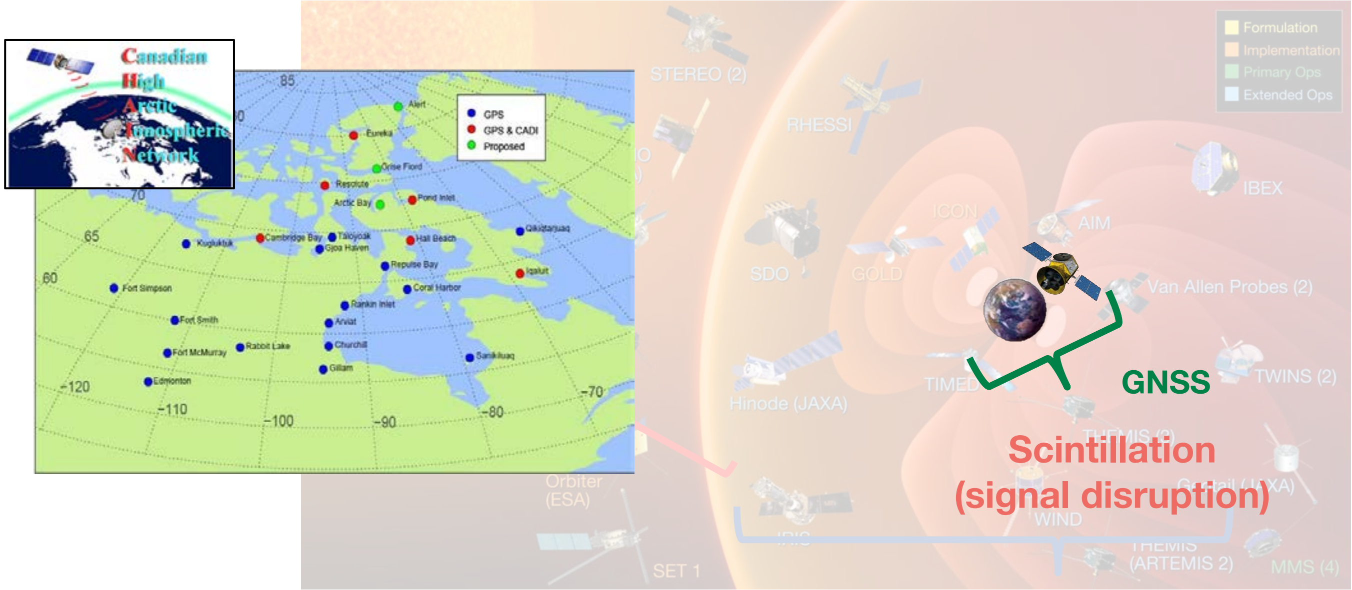


Step 2:

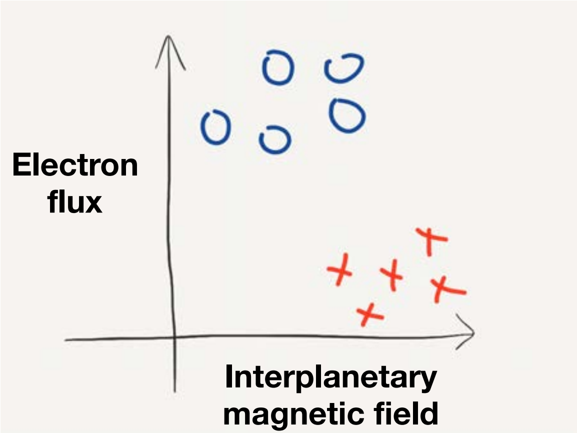
Define the predictive task



Step 3:

Machine learning algorithm for prediction

Support Vector Machine



Cortes and Vapnik (1995)

Step 3:

Machine learning algorithm for prediction

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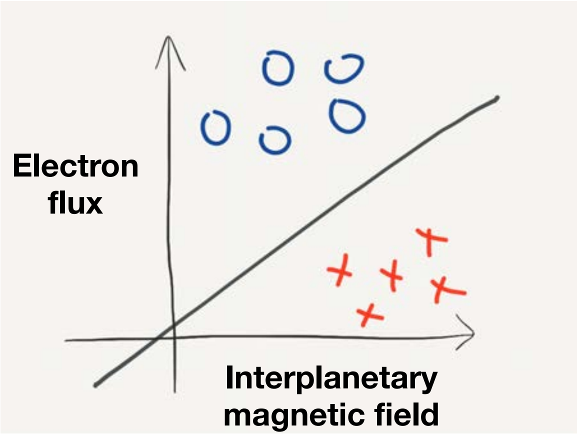

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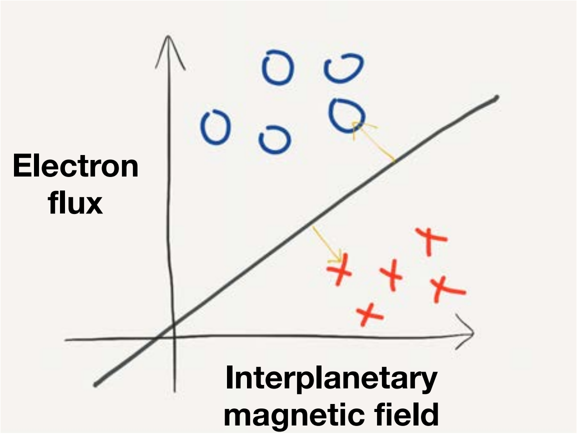

Cortes and Vapnik (1995)

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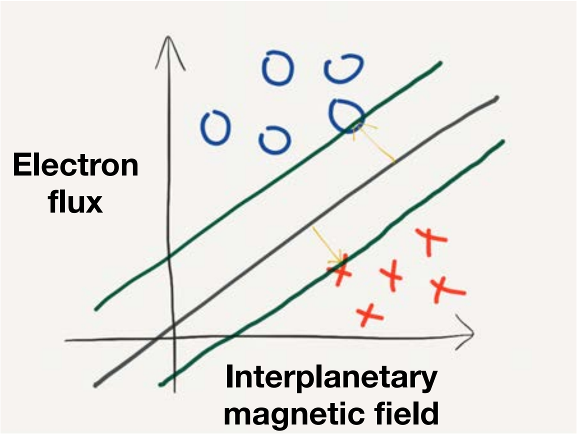


Cortes and Vapnik (1995)

Step 3:

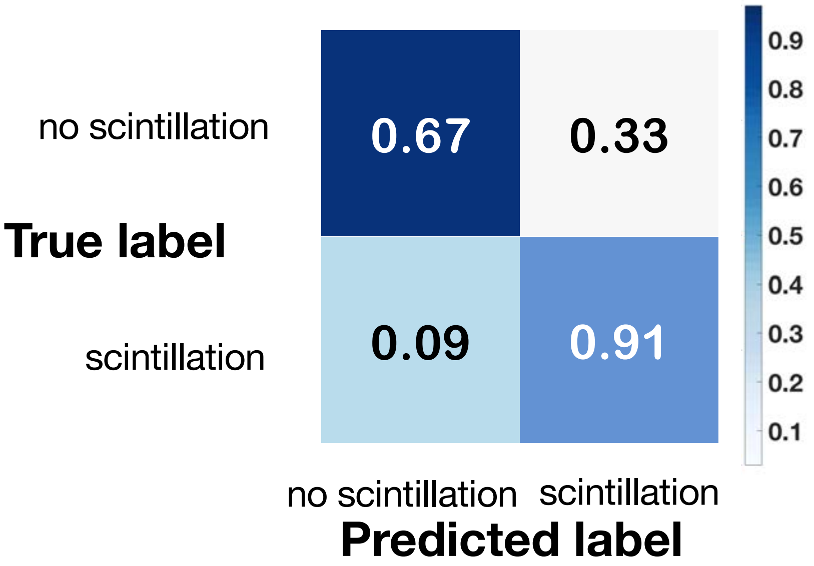
Machine learning algorithm for prediction

True label \ Predicted label	no scintillation	scintillation
no scintillation	True negative	False positive
scintillation	False negative	True positive

McGranaghan et al., (2018)

Step 3:

Machine learning algorithm for prediction



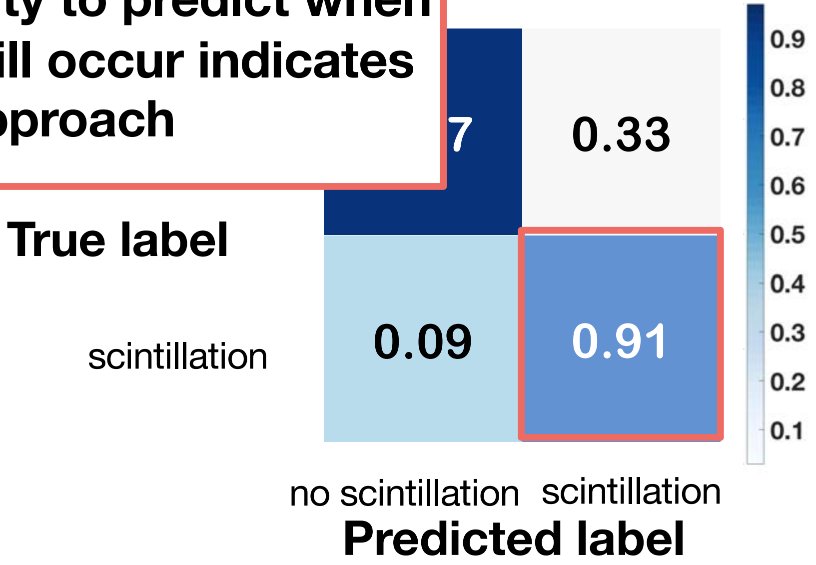
McGranaghan et al., (2018)

Step 3:

Machine learning algorithm for prediction

91%

Improved ability to predict when scintillation will occur indicates potential of approach



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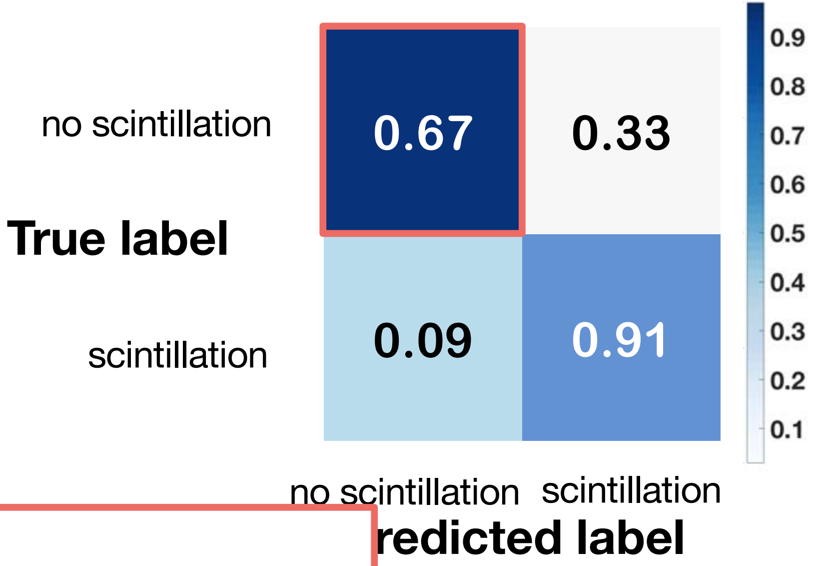

67%

High accuracy predicting when scintillation would not occur

Step 4:

Interrogate the model

Step 4:
Interrogate the model

Evaluation

Step 4:
Interrogate the model

Evaluation

True Skill Statistic (TSS)

$$\mathrm{TSS} = \frac{\mathrm{TP}}{\mathrm{TP} + \mathrm{FN}} - \frac{\mathrm{FP}}{\mathrm{FP} + \mathrm{TN}}$$

True label / **Predicted label**

True label \ Predicted label	no scintillation	scintillation
no scintillation	True negative	False positive
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True Skill Statistic (TSS)

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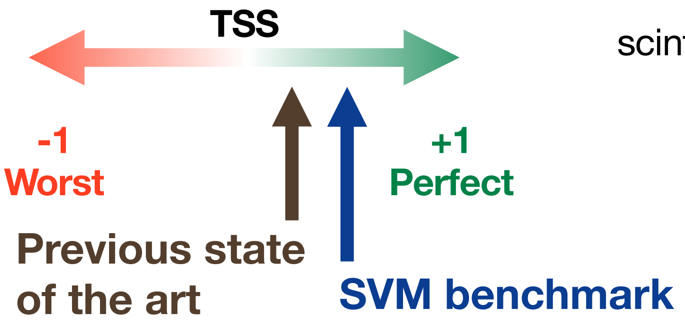

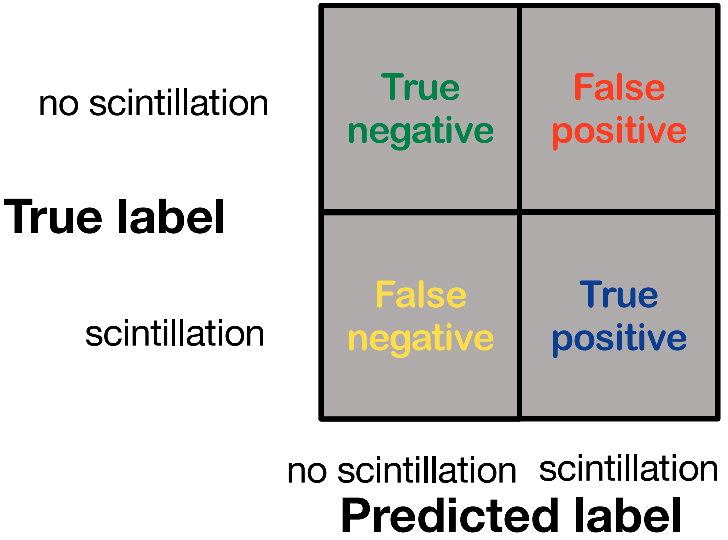

Step 4:
Interrogate the model

Evaluation

Explanation

Step 4:
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Step 4:
Interrogate the mode

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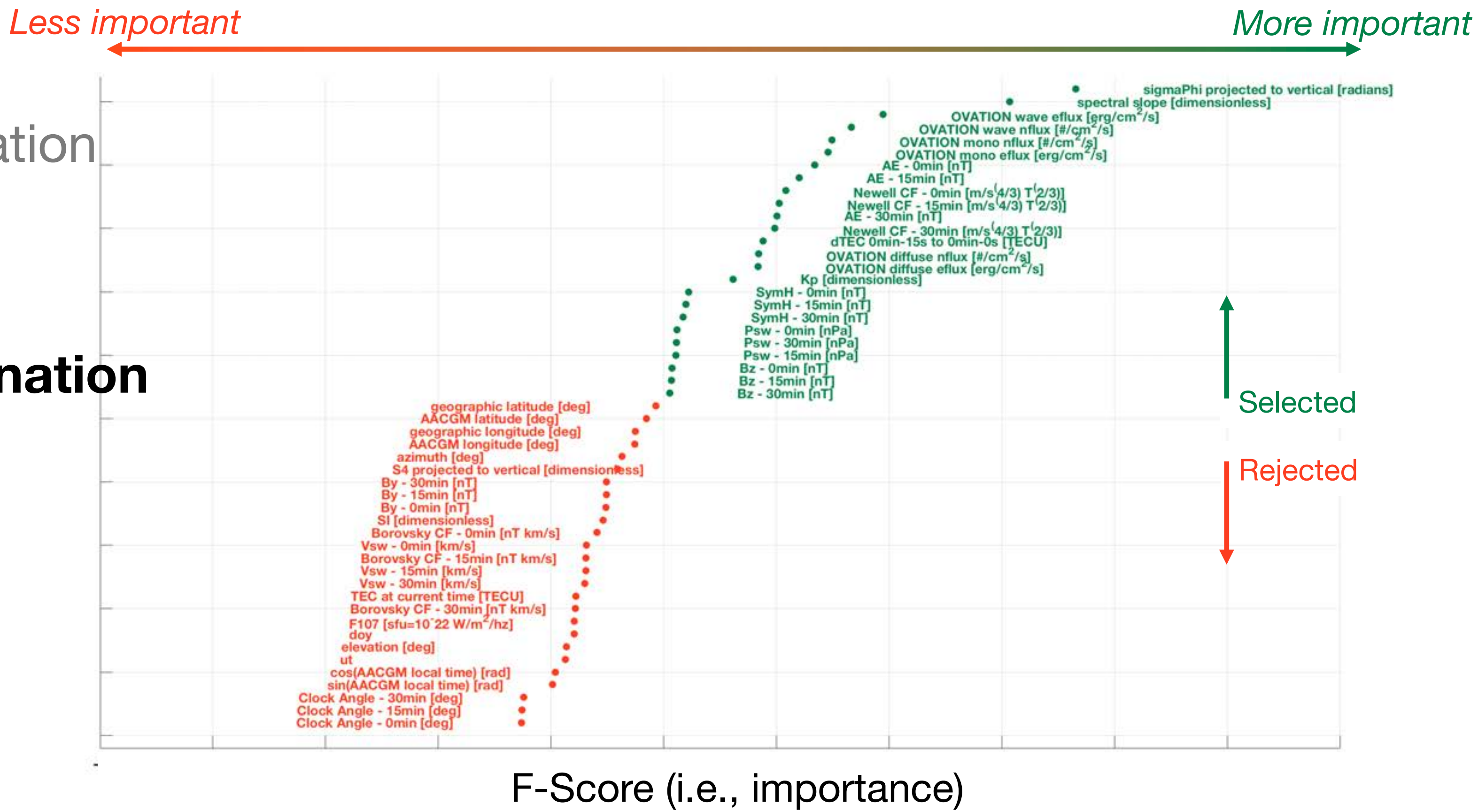

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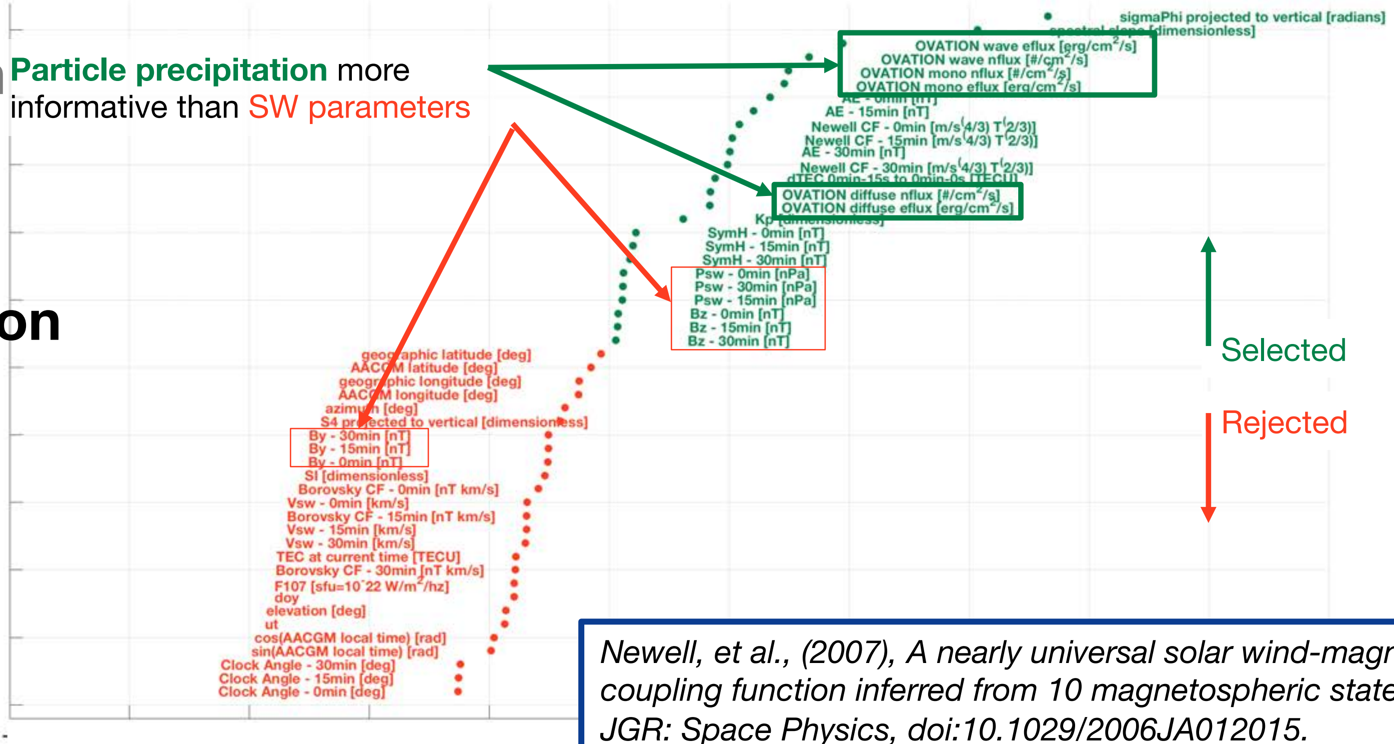


Newell, et al., (2007), A nearly universal solar wind-magnetosphere coupling function inferred from 10 magnetospheric state variables, JGR: Space Physics, doi:10.1029/2006JA012015.

F-Score (i.e., importance)

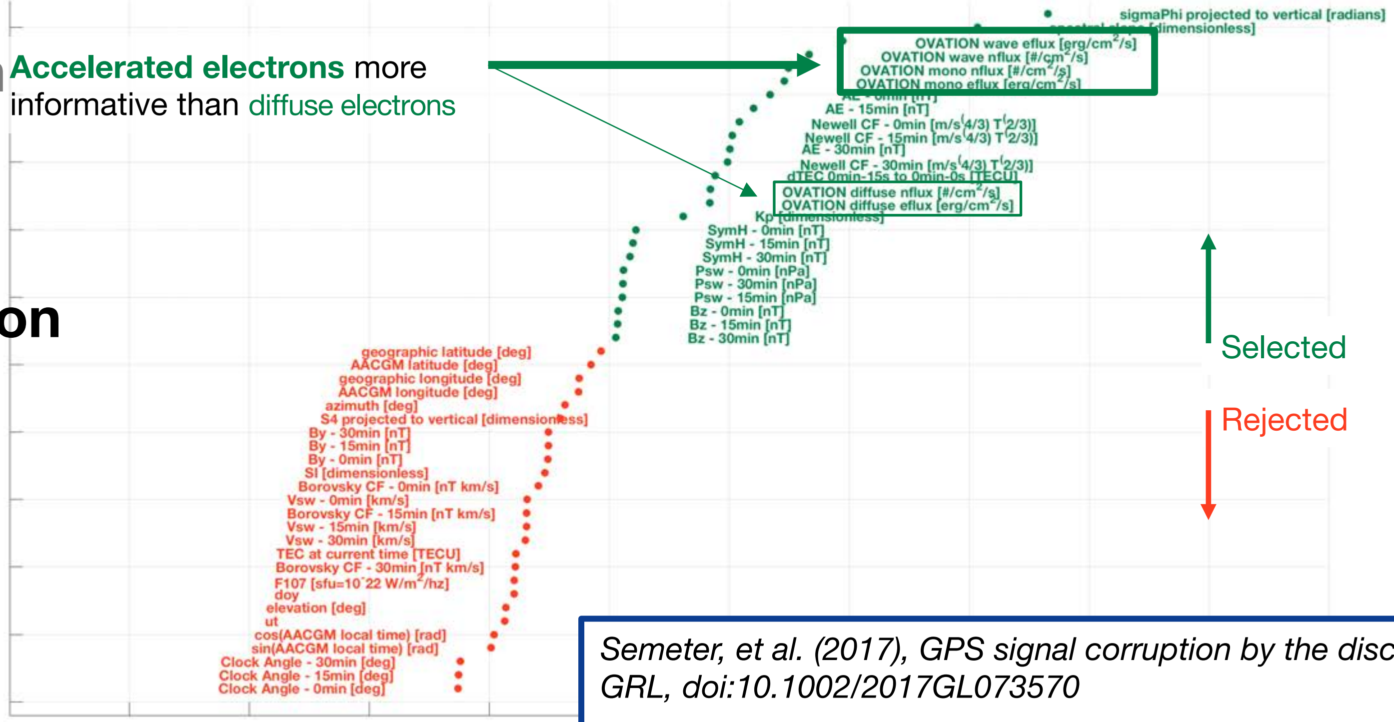
Step 4:

Interrogate the mode

Evaluation

Accelerated electrons more informative than diffuse electrons

Explanation



F-Scor

Semeter, et al. (2017), GPS signal corruption by the discrete aurora. GRL, doi:10.1002/2017GL073570

Mrak, et al., (2017), Field- aligned GPS scintillation: Multisensor data fusion, JGR: Space Physics, doi:10.1002/2017JA024557.

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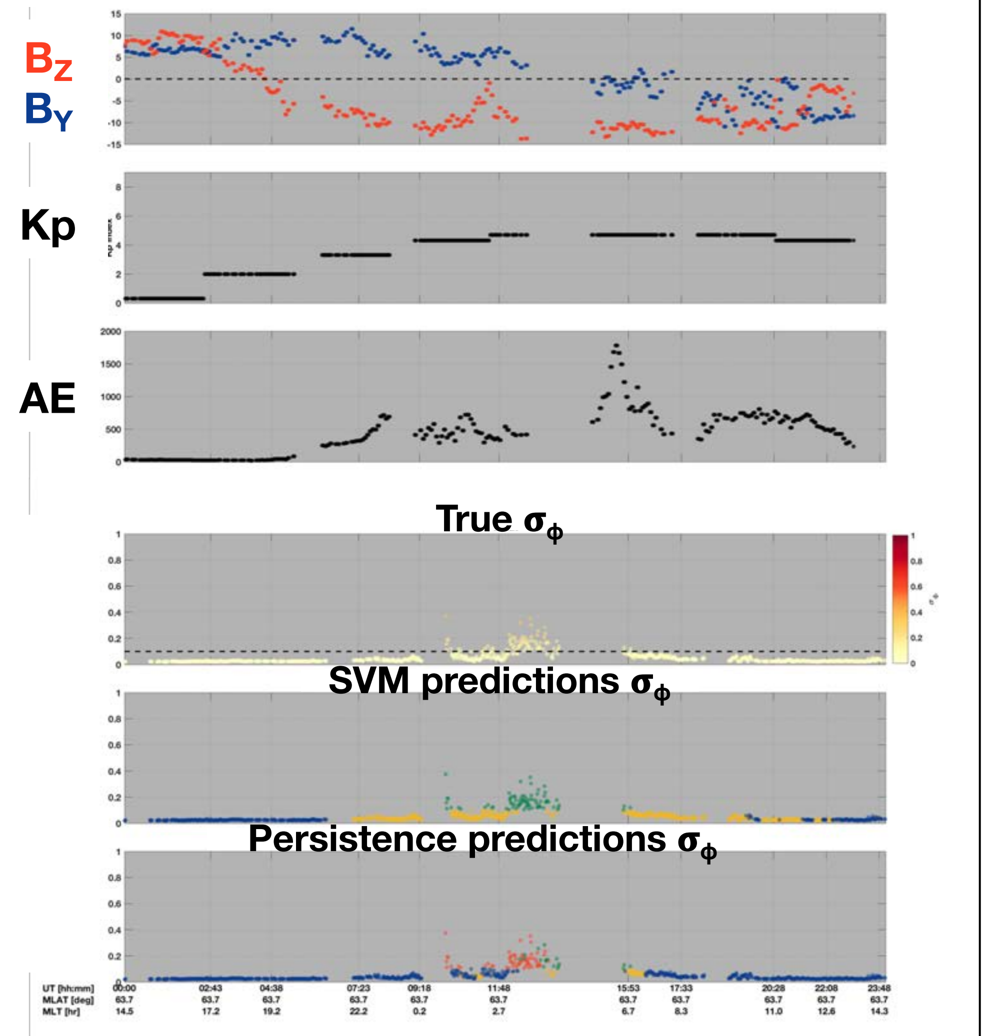
January 20, 2016



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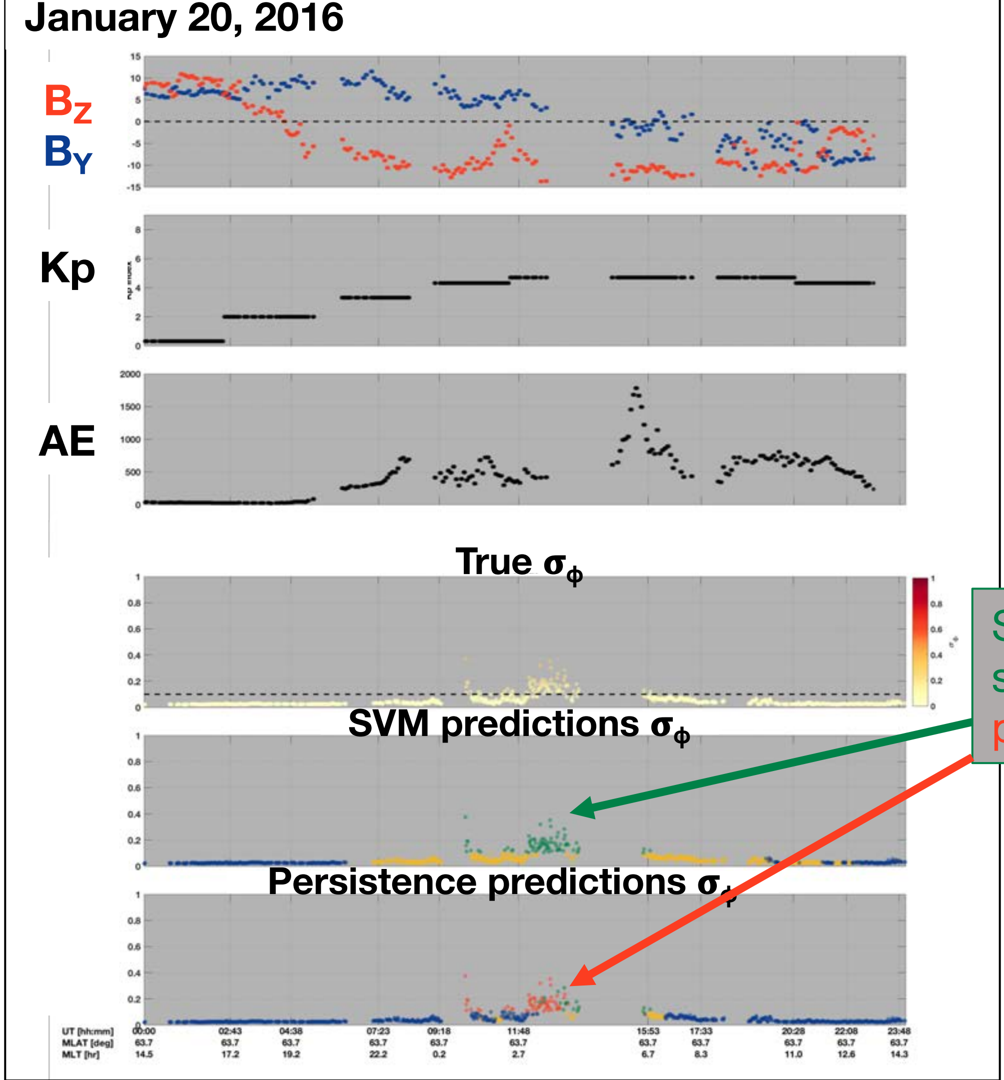
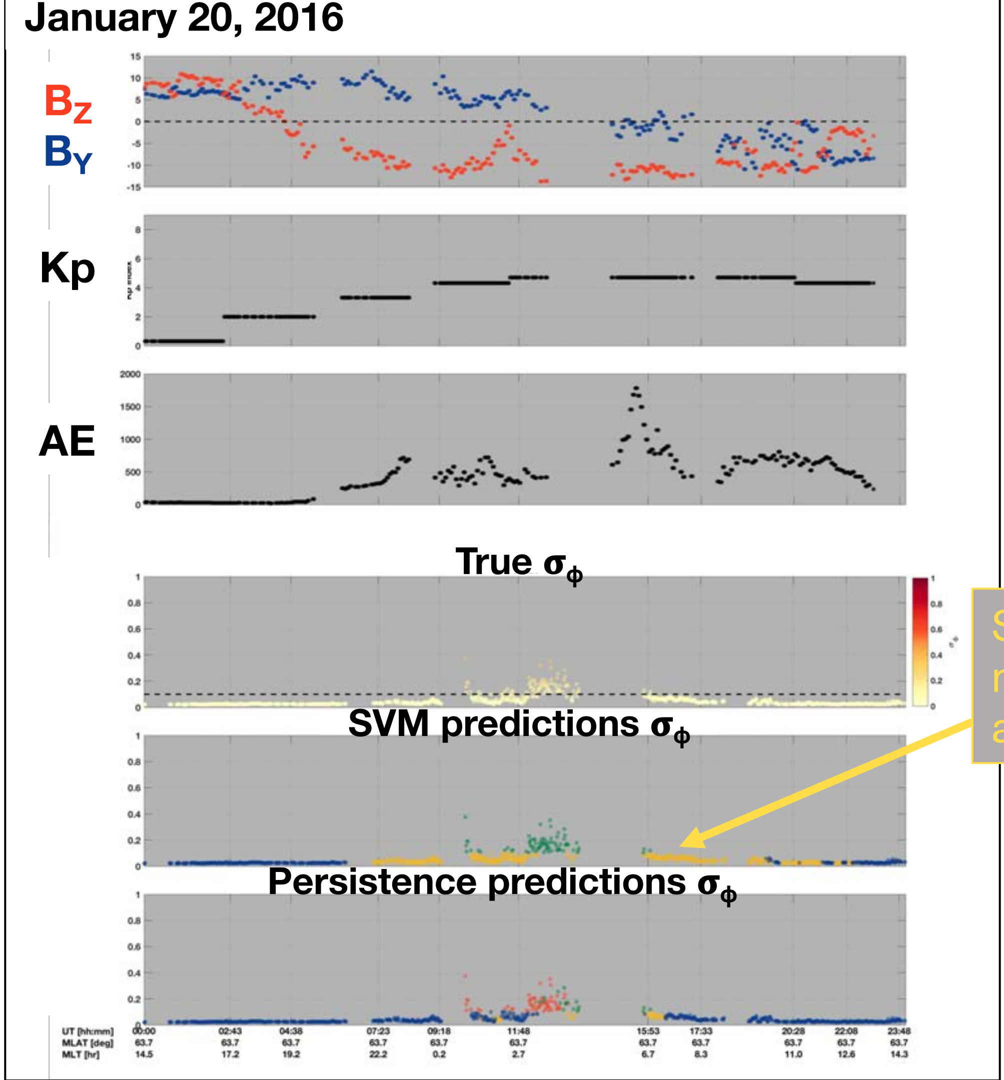


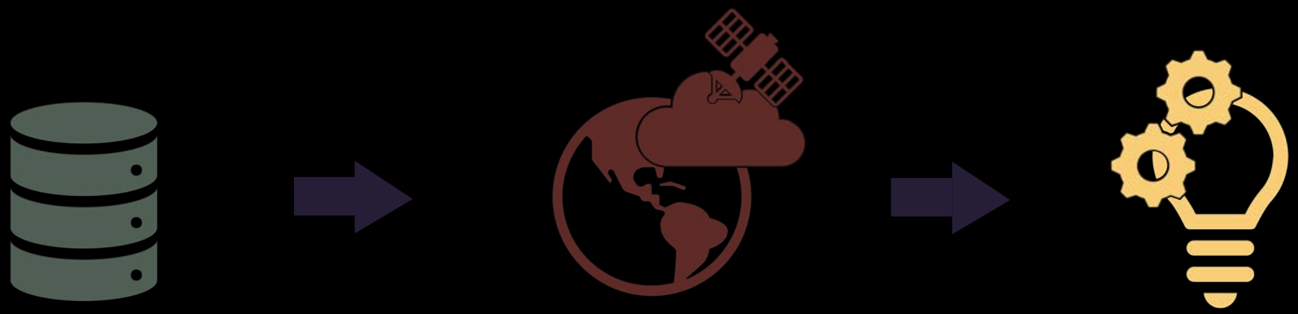
SVM identifies strong scintillation,
persistence does not

Evaluation

Explanation



SVM contains high number of ‘false alarms’



What *trends* does this reveal?

Be antidisciplinary

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Be open by default

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Understand the models

What *trends* does this reveal?

Trends

Be *antidisciplinary*

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Understand the models

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McGranaghan, R. M., Bhatt, A., Matsuo, T., Mannucci, A. J., Semeter, J. L., & Datta-Barua, S. (2017). Ushering in a new frontier in geospace through data science. Journal of Geophysical Research: Space Physics, 122, 12,586–12,590. https://doi.org/10.1002/2017JA024835

McGranaghan, R. M., A.J. Mannucci, B.D Wilson, C.A. Mattmann, and R. Chadwick. (2018), New capabilities for prediction of high-latitude ionospheric scintillation: A novel approach with machine learning, Space Weather, 16. https://doi.org/10.1029/2018SW002018

Curated Sources of Data Science Learning Resources

Ryan McGranaghan running list of resources (Github repository)

- https://github.com/rmcgranaghan/data_science_tools_and_resources

HelioAnalytics website and list of resources

- https://sites.google.com/view/heliodata/resources?authuser=0