Virtual Conference on Applications of Statistical Methods and Machine Learning in the Space Sciences

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Applications of Statistical Methods and Machine Learning in the Space Sciences

ABSTRACTS

1. **Yasser Abduallah**, New Jersey Institute of Technology, Newark, New Jersey, USA
   Deep Learning-Based Reconstruction of Solar Irradiance
   Yasser Abduallah, Jason T. L. Wang, Khalid A. Alobaid, Serena Criscuoli, Haimin Wang

   The Earth's primary source of energy is the radiant energy generated by the Sun, which is referred to as solar irradiance, or total solar irradiance (TSI) when all of the radiation is measured. A minor change in the solar irradiance can have a significant impact on the Earth's climate and atmosphere. As a result, studying and measuring solar irradiance is crucial in understanding climate changes and solar variability. Several methods have been developed to reconstruct total solar irradiance for long and short periods of time; however, they are physics-based and rely on the availability of data, which does not go beyond 9,000 years. Here we present a new method, dubbed TSInet, to reconstruct total solar irradiance by deep learning for short and long periods of time that span beyond the physical models' data availability. On the data that are available, our method agrees well with the state-of-the-art physics-based reconstruction models. To our knowledge, this is the first time that deep learning has been used to reconstruct total solar irradiance for more than 9,000 years.

2. **Tommaso Alberti**, INAF-IAPS, Rome, Italy
   Chaos in the solar wind
   T. Alberti, G. Consolini, M. Laurenza, M.F. Marcucci, A. Milillo, S. Benella, V. Quattrociocchi, M. Stumpo

   The solar wind is a natural example of a multiscale chaotic system. Within the usual Richardson picture the solar wind can be considered as a collection of eddies of different size that can break up and merge together via both a direct and an inverse cascade mechanism. Over the 1940-60 period Kolmogorov, Landau, Iroshnikov, and Kraichnan posed and questioned some fundamental points on both fluid and MHD turbulence and intermittency based on the statistics of velocity and magnetic field increments. From 1980s the novel concept of fractal allowed to build up several formalisms and cascade models to deal with fluid and MHD transfer mechanisms. Nevertheless, less attention has been paid to the solar wind turbulence in the framework of chaotic systems being only usually associated with a Kolmogorov-like spectral scaling (i.e., a non-universal concept). This contribution will address solar wind multiscale properties in a different framework based on concepts coming from dynamical systems and chaos theory showing that both marginally-stable and unstable fixed points are observed across both the MHD and the sub-proton regimes. The obtained results seems to suggest the existence of a multi-stability, characterizing a dynamic bifurcation, opening a novel perspective and view of the Richardson cascade over MHD scales, as well as, a stochastic description to successfully reproduce the main statistical features of the sub-proton dynamics.

3. **Inigo Arregui**, Instituto de Astrofisica de Canarias, Spain
   Applications of Bayesian Methods in the Solar Corona
   Inigo Arregui

   Solar coronal seismology is based on the remote diagnostics of physical conditions in the corona of the Sun by comparison between model predictions and observations of magnetohydrodynamic wave activity. Our lack of direct access to the physical system of interest makes information incomplete and uncertain so our conclusions are at best probabilities. Bayesian inference is increasingly being employed in the area, following a general trend in other astrophysical research areas. In this contribution, we first justify the use of a Bayesian probabilistic approach to seismology diagnostics of

Note: Color coding: Magenta – Keynote talks; Contributed orals; Blue – e-posters.

coronal plasmas. Then, we report on recent results that demonstrate its feasibility and advantage in applications to coronal loops, prominences and extended regions of the corona.

4. **Berkay Aydin**, Georgia State University, USA
Building Cyberinfrastructure for Operational Space Weather Analytics
Berkay Aydin

Extreme space weather events are capable of disrupting our societal fabric by causing detrimental effects to the electric grid, satellites, avionics, navigation systems, and more. Building sustainable and reliable cyberinfrastructure services for analyzing and operationally forecasting these events is of utmost importance, especially considering the devastation it can cause to the world economy. Creation and deployment of such a cyberinfrastructure is a challenging and truly interdisciplinary effort. These cyberinfrastructure services have many different aspects requiring expertise from multiple domains, which include but are not limited to feature engineering, data generation and integration services, predictive model generation and persistence, system building and deployment, and software sustainability. This talk aims to explore the issues involved with both establishing robust space weather prediction methods and sustaining them in the face of evolving requirements and data opportunities. An overview of the current challenges will be presented first, followed by a discussion on remedies and how to address these issues.

5. **Abigail Azari**, Space Sciences Lab, UC Berkeley, USA
Interpretable Models for Understanding Planetary Space Environments: Bayesian Views of Mars' Magnetic Environment
Abigail Azari[1], John Biersteker[2], Facundo Sapienza[3], Ellianna Abrahams[3,4], David Mitchell[1], & Fernando Pérez[3,5]
[1] Space Sciences Lab, UC Berkeley
[2] Earth, Atmospheric, and Planetary Sciences, Massachusetts Institute of Technology
[3] Statistics Department, UC Berkeley
[4] Astronomy Department, UC Berkeley
[5] Department of Data Science and Technology at Lawrence Berkeley National Laboratory

Recent planetary science missions are returning increasingly large datasets. The data volumes generated by modern missions have necessitated the use of data science methods, including machine learning to engage in data analysis. It is advantageous to use these data-intensive methods to study planetary systems as they provide new system-wide perspectives. However there are several challenges that create difficulties when engaging in the scientific process with currently available data and methods. First, planetary science data, much like other data from natural systems, is inherently spatio-temporal, of multiple resolutions, and contains uncertainty. This creates a barrier for data processing when using traditional machine learning methods. Second, many planetary science questions require the use of interpretable models to pursue inference. In other words, answering these questions requires models that follow some underlying physical rules or constraints, or otherwise simple functional form that allows for human understanding of the model's form and outputs. This presentation will provide an overview of these challenges before discussing a recent application of Bayesian methods to quantify the spatio-temporal nature of Mars' magnetic field environment. This environment is shaped by the competing influences of spatially variable crustal fields and the temporally variable solar wind. This project aims to provide a quantified understanding of Mars' solar wind interaction.

6. **Hazel M Bain**, CIRES/NOAA, Boulder, Colorado, USA
A Verification Study of NOAA Space Weather Prediction Center's Energetic Proton Event Forecasts during Solar Cycles 23 and 24
Hazel M Bain[1, 2], Robert Steenburgh [2], Terry Onsager [2], Eliza M. Stitely [3], Robert Rutledge [2], Christopher Balch [2]

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[3] Millersville Univeristy

Solar energetic particles (SEPs) are a driver of space weather, the effects of which can impact high-frequency communications systems, satellite systems and pose a radiation hazard for astronauts, as well flight crew and passengers on polar flight routes. The National Oceanic and Atmospheric Administration's Space Weather Prediction Center (NOAA/SWPC) issues space weather forecasts and products for energetic protons at Earth. Specifically, short lead time (minutes to hours), high confidence hazard Warning and Alert products and three day probabilistic proton event forecasts. We present a statistical verification study of SWPC proton event products for Solar Cycles 23 and 24 and discuss the performance and skill with which these events can be forecast. It is hoped that this study will serve as a benchmark for SEP model development and validation.

7. **Georgios Balasis**, National Observatory of Athens, Greece
Dynamical complexity in Swarm Dst-like time series using information theory measures
Georgios Balasis (1), Constantinos Papadimitriou (1,2), Stelios M. Potirakis (3), Adamantia Zoe Boutsi (1,2), Ioannis A. Daglis (2,4,1), and Omiros Giannakis (1)
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For 7 years now, the European Space Agency's Swarm fleet of satellites surveys the Earth's magnetic field, measuring magnetic and electric fields at low-Earth orbit (LEO) with unprecedented detail. We have recently demonstrated the feasibility of Swarm measurements to derive a Swarm Dst-like index for the intense magnetic storms of solar cycle 24. We have shown that the newly proposed Swarm Dst-like index monitors magnetic storm activity at least as good as the standard Dst index. The Swarm derived Dst index can be used to (1) supplement the standard Dst index in near-real-time geomagnetic applications and (2) replace the "prompt" Dst index during periods of unavailability. Herein, we employ a series of information theory methods, namely Hurst exponent and various entropy measures, for analyzing Swarm Dst-like time series. The results show that information theory techniques can effectively detect the dissimilarity of complexity between the pre-storm activity and intense magnetic storms (Dst $<$ 150 nT), which is convenient for space weather applications.

8. **Laura A. Balmaceda**, George Mason University, Fairfax, Virginia, USA
Probabilistic cross-matching of CME catalogs
Laura A. Balmaceda (presenter), Fernando Mut (GMU)

Coronal mass ejections (CMEs) are huge amounts of plasma expelled from the Sun into the interplanetary medium. They play the most important role in Sun-Earth relationship as they cause severe perturbations in the Earth's space environment. These include large solar energetic particle (SEP) events and major geomagnetic storms, both representing hazards to humans and their technology in space and ground. Although they were discovered in the 70's, it was not until 1995 that their systematic observation was possible. The rapid increase of the CME research with the advent of the Solar and Heliospheric Observatory mission in 1995 and Solar TErrestrial RElations Observatory in 2006 enabled the compilation of CME catalogs which present differences in the techniques used for CME detection, the delivered products, and the number of events reported, among other things. In order to advance in the knowledge of CMEs it is crucial to obtain a unified list of CMEs. The cross-identification among the entries of different catalogs is, however, a difficult task scientifically, computationally and statistically.
In this work we explore the applicability of a probabilistic approach that uses Bayesian hypothesis and has already been proven successful in other fields in Astrophysics, to this problem.

9. **Carsten Baumann**, Institute for Solar-Terrestrial Physics - German Aerospace Center, Germany
Propagate L1 solar wind measurements to Earth with the help of machine learning
Carsten Baumann, Aoife E. McCloskey

The propagation of solar wind measurements from L1 to the bow shock nose of Earth is the basis of the frequently used OMNI dataset. Depending on the solar wind speed, the propagation time delay from L1 to Earth lies between 20 and 90 minutes. In this study we present a machine learning algorithm that is suitable to predict the solar wind propagation delay between Lagrangian point L1 and the Earth. This work introduces the proposed algorithm and investigates its applicability to propagate ACE data to Earth.
The propagation delay is measured from interplanetary shocks passing the Advanced Composition Explorer (ACE) first and their sudden commencements within the magnetosphere later, as recorded by ground-based magnetometers. Overall 380 interplanetary shocks with data ranging from 1998 to 2018 builds up the database that is used to train the machine learning model. We investigate two different feature sets. The training of one machine learning model will use all three components of solar wind speed , the other only bulk solar wind speed. Both feature sets also contain the position of the spacecrafts.
The major advantage of the machine learning approach is its simplicity when it comes to its application. After training, values for the different features have to be fed into the algorithms only and the evaluation of the propagation delay can be continuous. Both machine learning models will be used to propagate ACE data to Earth. The propagated ACE measurements are compared to OMNI data during different solar wind conditions. Future assessments will include a comparisons of propagated solar wind data to satellite measurements of the IMF just outside of Earth magnetosphere.

10. **Simone Benella**, INAF - Istituto di Astrofisica e Planetologia Spaziali, Italy
A study on the Markovian character of the AE-index fluctuations
Simone Benella, Mirko Stumpo, Giuseppe Consolini, Tommaso Alberti, Monica Laurenza, Maria Federica Marcucci and Virgilio Quattrociocchi

We present a statistical analysis of the AE-index time series in order to investigate the Markovian character of its fluctuations on different time-scales. More precisely, we analyze the features of the fluctuations of the logarithm of AE, which are quasi-stationary, using a time series of 23-years at 1-minute sampling rate. At first, we compute the conditional probabilities of fluctuations on different time-scales and compare the obtained results with predictions based on the Chapman-Kolmogorov equation, that is a necessary condition for a process to be Markovian. We find that at long time-scales, i.e., where the AE-index spectral density displays a f^{-1} regime, the fluctuation statistics deviates from the Markov condition. On the contrary, at small time-scales, where the spectral density behaves as f^{-2}, a Markovian character of AE fluctuations is observed. This allows to interpret the AE small-scale fluctuations in terms of Langevin process with drift and diffusion terms defined by the first- and second-order Kramers-Moyal coefficients. Finally, we provide a consistency check by comparing the distribution of the AE-index fluctuations with the solution of the related Fokker-Planck equation.

11. **Guillerme Bernoux**, ONERA / DPHY, Universite de Toulouse, F-51005 Toulouse, France
Evaluating a data-driven model to forecast the geomagnetic index Ca from near-Earth solar wind parameters
Guillerme Bernoux[1], Antoine Brunet[1], Angélica Sicard[1], Eric Buchlin[2], Miho Janvier[2]
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We present a data-driven approach to forecast a novel geomagnetic index – the so-called Ca index – that correlates well with the dynamics of the Earth's radiation belts. Using a model build around Long Short Term Memory (LSTM) neural networks and solar wind parameters available in the OMNIweb database we are able to obtain forecasts of the Ca index up to 24 hours in advance. We evaluate our model with novel metrics (such as the Temporal Distortion Mix) that allow for a better characterization of the behavior of our model, especially in periods of strong disturbances. We also select our training and evaluation data-sets carefully, for example by distinguishing between periods under the influence of Stream Interaction Regions (SIRs) or Interplanetary Coronal Mass Ejections (ICMEs). In addition, we discuss how this model would perform to provide risk levels in a more operational context. In particular it is shown that our model loses some of its usefulness in an operational context for time horizons longer than 6 hours, which is not observable when evaluating our model with common metrics such as the Root-Mean-Squared error (RMSE) and the Pearson linear correlation.

12. **Jason Bernstein**, Lawrence Livermore National Laboratory (LLNL), USA
U Statistic Estimation of Space Object Conjunction Probabilities
Jason Bernstein, Michael Schneider, Andrey Filippov (LLNL), Jem Corcoran, Caleb Miller (University of Colorado Boulder)

Accurate estimation of space object conjunction probabilities is essential for efficient space traffic management and predicting collisions between planets and asteroids. Due to the non-linear motion of objects in space, the probabilities are not available in closed-form and must be approximated. Monte Carlo is a popular approach for this approximation, but is difficult because the probabilities are typically small, the state space is high-dimensional, and orbit propagation is expensive. Thus, the problem is essentially to estimate a small probability with a limited number of Monte Carlo samples. In this work, we interpret a previously proposed Monte Carlo estimate of the conjunction probability as a U statistic, which enables construction of an approximate confidence interval for the probability. We further discuss properties of U statistics that make them optimal for conjunction probability estimation, namely unbiasedness and minimal variance, and demonstrate the advantages of the estimator over a binomial probability estimator. Last, we note that the estimator can account for different numbers of Monte Carlo samples for the two objects, which may be needed if the objects have orbit models of different fidelities, for example.
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13. **Shreya Bhattacharya**, Royal Observatory of Belgium, Belgium
Quality Assessment of Sunspot data using various catalogs
Shreya Bhattacharya, Maarten Jansen, Laure Lefèvre, Frédéric Clette

The SN series is one of the longest and most detailed available series in astrophysics. The series was first constructed in 1849 by Prof. Rudolf Wolf and a time series is built in real time since then, involving a lot of observers who differ from each other in terms of their way of counting sunspots, different telescopes and eye sights, which demands proper calibration.
We present a novel time-dependent error determination on the sunspot number (SN) based on nonparametric statistical techniques in smoothing. In particular we propose a generalized linear regression model with overdispersed count data as response variables in the estimation of a time varying calibration of different sunspot time series with overlapping periods. The nonparametric regression takes place through a local polynomial smoothing procedure.
This data assimilation model does not restrict to SN only but is applicable to most sunspots' parameters such as area covered on the Sun, position etc... Many catalogs such as the one from Catania Observatory, the Royal Greenwich Observatory, the US Air Force solar observations and others, include the above mentioned parameters whose overall quality assessment is lacking as of yet. The time dependence criteria of our model allows us to access the quality of daily observations with respect to other catalogs thus adding an error bar. We focus this study on one of the stable stations (Mathieu et al,2019) of the World Data Center SILSO network, the Uccle Solar Equatorial table station in Brussels (USET).

The study we present aims at a further refinement of earlier work in Mandal et al. (2020), adding a realistic statistical model and a time dependent calibration factor. Applying regression before computing the calibration avoids the presence of outliers and biased estimation.

14. **Sylvain Blunier**, Universidad de Chile, Chile
Neural network-based methods to determine the robust SMI couplings
Sylvain Blunier, Jose Rogan, Benjamin Toledo, Pablo Medina, Juan Alejandro Valdivia

Machine Learning (ML) tools are becoming very popular in space physics, as they allow to cope with the inherent complexities that driven dissipative systems display. This is particularly true when we talk about modelling the solar wind-ionosphere-magnetosphere (SMI) system. Many models and methods are being proposed to increase our understanding of the SMI system, to catch the time scales that are at play, or the best variables to be considered when forecasting in space weather applications. The models are being constructed for space or ground based measurements, and even for geomagnetic indices (GI) such as DST or AE.
These methods constantly face common ML issues such as overfitting, insufficient or noisy data, that turns out to be very challenging to work around given the nature of the usual ML techniques. For example, a great number of indices are regularly used to characterize the SMI system, and their interactions are not fully understood. Naively, we could ask the ML technique to sort out these couplings. However, this is normally not viable due to overfitting, and insufficient and noisy data. Therefore, it would be quite useful to have strategies, within the same ML framework used to reconstruct the model, to ascertain what are the relevant and robust variables that should be included in such a model.
In this presentation we will show how these strategies can be implemented. First, we will show how these issues occur in toy models, and propose counter intuitive ways to circumvent them. And second, we will apply such Neural Network (NN) based methods to identify the robust solar wind variables that drive GIs, in an effort to understand some of the robust relevant variables that participate in the SMI coupling [1].
[1] S. Blunier, B. Toledo, J. Rogan, J. A. Valdivia, A Nonlinear System Science Approach to Find the Robust Solar Wind Drivers of the Multivariate Magnetosphere, To be Published in Space Weather, 2021.

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15. **Téo Bloch**, University of Reading, UK
Deep-Ensemble Modelling of Electron Flux at the Radiation Belt's Outer Boundary With Bayesian Neural Networks
T. Bloch, P. Tigas, C. E. J. Watt, M. J. Owens

As space-based infrastructure (and society's dependence on it) becomes more ubiquitous, it is evermore important to be able to accurately model the environment within which spacecraft will pass their lifetime. For spacecraft in geosynchronous orbits or those which utilise electric orbit raising, specifically, understanding the outer (electron) radiation belt is critical.
There are a variety state-of-the-art radiation belt models each taking different approaches to understanding the radiation belts. One commonality between them is the importance of correctly quantifying the outer boundary – which acts as a time dependent source for the simulations. Previous work (T. Bloch et al., 2021, under review) quantified one aspect of this boundary, it's location – nominally located at 8.25 RE, further out that most models currently use. This leaves the other curial aspect to be characterised - the electron distribution function at the boundary location. Our work addresses this latter aspect.

Given the relatively distant location of the boundary (well beyond geosynchronous orbit, or the apogee of RBSP), we use THEMIS SST data obtained in its vicinity. As the THEMIS spacecraft cannot always be in the correct location, we create a deep-ensemble Bayesian neural network model to map from fluxes measured from geosynchronous orbit by GOES to the boundary location. The model is additionally parameterised using solar wind and geomagnetic index data from OMNI. Our approach not only allows us to predict fluxes for 11 THEMIS SST energy channels simultaneously, but also produces probabilistic outputs with associated uncertainties.
On average, our model predicts the fluxes within a factor of 1.5 for the lower energies and with a factor of 2.5 for the higher energies. The correlation between our predictions and the measured values is 0.5-0.8 across the energy channels.

16. Malgorzata Bogdan, Wroclaw University, Poland
Statistical methods for the analysis of large dimensional data
M. Bogdan

In this talk we will present some modern statistical methods for the analysis of large dimensional data. We will mainly concentrate on different statistical techniques for selecting important variables, building predictive models and identifying relationships in the database when the number of variables is comparable or larger than the sample size.

17. **Joe Borovsky**, Space Science Institute, Boulder, Colorado, USA
Vector-Vector Correlations: Deriving a New Composite Geomagnetic Index
Joe Borovsky and Mick Denton

For analysis of the solar-wind-driven magnetosphere-ionosphere-thermosphere system, we have developed a systems-science methodology to reduce a state-vector description of a time-dependent driven system to a composite scalar picture of the activity in the system. The technique uses canonical correlation analysis (vector-vector correlations) to reduce (1) the multidimensional time-dependent solar-wind state vector and (2) the multidimensional time-dependent magnetospheric-system state vector to (1) a time-dependent driver scalar and (2) a time-dependent system scalar. The system scalar describes the global response of the magnetospheric system to the solar wind. This description that is a reduction from the state vectors has advantages: simplicity, low noise, high prediction efficiency, linearity in the described system response to the driver. The scalar description of the magnetosphere also has robustness with respect to (a) storm-versus-quiet intervals, (b) solar maximum versus solar minimum, and (c) the various types of solar-wind plasma. As an NSF-GEM activity, we are now in the process of developing a single system-wide index to gauge magnetospheric activity.

18. **Laura Boucheron**, Klipsch School of Electrical & Computer Engineering, New Mexico State University, USA
Spatiotemporal Visualization of Solar Energetic Particle Events
Mark Roberts, Kylan Wilson, Laura E. Boucheron, Steven J. Stochaj, (Klipsch School of Electrical & Computer Engineering, New Mexico State University); R. T. James McAteer (Department of Astronomy, New Mexico State University)

We use data from the Combined X-Ray and Dosimeter (CXD) instrument on the Global Positioning System (GPS) satellites to analyze the spatiotemporal nature of solar energetic particle (SEP) events from several large coronal mass ejections (CMEs). While satellites such as the Advanced Composition Explorer (ACE) and the Geostationary Operational Environmental Satellites (GOES) provide measurements of energetic particles at key points between the Earth and Sun, newly released data from the CXD instrument on the GPS constellation now provides the ability to analyze the evolution of SEP events at mid-Earth orbit ($\sim 20,200$ km) with data distributed spatially across the constellation. Here we present results from a spatiotemporal analysis of protons combining data from ACE, GOES, and GPS, as well as WSA-ENLIL models of CME propagation through the solar system.First, we study the propagation of SEPs from GOES to GPS using a cross-correlation of the proton integrated flux fit and compute the average delay between the satellites for four energy bins across several large CME events. Next, we present a spatially interpolated visualization of the proton integrated flux fit across the GPS constellation. Finally, we present an integrated spatiotemporal visualization combining WSA-ENLIL, ACE, GOES, and interpolated GPS data. Information on the spatial distribution of protons provided by the CXD instrument on GPS provides a new visualization of the effects of SEPs around Earth.

19. **Luke Bowden**, Cornell University and the SULI program at SLAC
Cosmological Evolution of the Formation Rate of Short Gamma-ray Bursts With and Without Extended Emission
Dainotti, M. G., Petrosian, V., and Bowden, Luke

Originating from neutron star-neutron star (NS-NS) or neutron star-black hole (NS-BH) mergers,short gamma-ray bursts (SGRBs) are the first electromagnetic emitters associated with gravitationalwaves. This association makes the determination of SGRBs formation rate (FR) a critical issue. Wedetermine the true SGRB FR and its relation to the cosmic star formation rate (SFR). This canhelp in determining the expected GW rate involving small mass mergers. We present nonparametricmethods for the determination of the evolutions of the luminosity function (LF) and the FR usingSGRBs observed bySwift, without any assumptions. These are powerful tools for small samples, suchas our sample of 68 SGRBs. We combine SGRBs with and without extended emission (SEE), assumingthat both descend from the same progenitor. To overcome the incompleteness introduced by redshiftmeasurements we use the Kolmogorov-Smirnov (KS) test to find flux thresholds yielding a sample ofsources with a redshift drawn from the parent sample including all sources. Using two subsamples ofSGRBs with flux limits of 4.57×10^{-7} and 2.15×10^{-7}erg cm^{-2} s^{-1} with respective KSp=(1, 0.9), wefind a 3σevidence for luminosity evolution (LE), a broken power-law LF with significant steepeningatL $\sim$ 1050erg s^{-1}, and a FR evolution that decreases monotonically with redshift (independent ofLE and the thresholds). Thus, SGRBs may have been more luminous in the past with a FR delayedrelative to the SFR as expected in the merger scenario.

20. **Carlos R. Braga**, George Mason University, Fairfax, Virginia, USA
Can machine learning and artificial intelligence improve the compilation of coronal mass ejections event lists?
Carlos R. Braga (1), Angelos Vourlidas (2)
1 - George Mason University, Fairfax, VA, 22030, US. Also at The Johns Hopkins University Applied Physics Laboratory, Laurel, MD 20723, USA
2 - The Johns Hopkins University Applied Physics Laboratory, Laurel, MD 20723, USA

Thousands of coronal mass ejections (CMEs) have been observed over the last decades, particularly from the coronagraphs on the SOHO and STEREO missions. CME lists essential for facilitating scientific discovery and are being used extensively. Manual creation of CME catalogs by visual inspection is both time-consuming and subjective. Many studies have pursued some level of automation for CME detection and characterization of its properties (e.g. speed, size) with varying degrees of success. Overall, most methods detect correctly only some events. Many errors happen in faint CMEs, such as halo CMEs, or when coronagraphs observe multiple adjacent events. A common problem for automated methods is segmenting the CME partially or splitting them into multiple events. Another challenge is distinguishing shocks observed ahead of fast CMEs and streamers adjacent to slow events. Here, we review CME cataloguing methods, highlight their advantages and disadvantages, and pose questions and challenges for potential machine learning developments.

21. **Lorenzo Branca**, Scuola Normale Superiore, Pisa, Italy
Physics Informed Neural Networks to solve non-equilibrium chemistry of Inter Stellar Medium
Lorenzo Branca, Andrea Pallottini

Non-equilibrium chemistry is a fundamental astrophysical process in order to study the Inter Stellar Medium (ISM), the formation of molecular clouds, that eventually leads to the star formation process. However, computationally it is among the most difficult tasks to include in cosmological simulations, because of the typically high (¿40) number of reactions, the short evolutionary timescales (about ¡10^4 times less then the ISM dynamical time) and the characteristic non-linearity and stiffness of the associated Ordinary Differential Equations (ODE) systems. Physics Informed Neural Network (PINN) approach might give an intriguing solution, since – once the models are trained – the PINN should give a full solution of the system with an accuracy comparable to the procedural algorithms, but with potentially a considerable computational speed-up. In this proof of concept work we show that it indeed is possible to solve the time evolution of a complex chemical system in a wide range of thermodynamic variables typical of the ISM, also testing the various cooling and heating processes that govern its evolution. Our PINN results show a good match with the precision of procedural solvers, well reproducing the strong non-linear nature of the solutions. We conclude showing the advantages in terms of computational time and parallelizability, paving the way for AI-driven simulations to be a very palatable addition for cosmological and astrophysical computation.

22. **Amy Braverman**, Jet Propulsion Laboratory, Caltech, USA
Post hoc Uncertainty Quantification for Remote Sensing Observing Systems
Amy Braverman, Jonathan Hobbs, Joaquim Teixeira, and Michael Gunson

The ability of spaceborne remote sensing data to address important Earth and climate science problems rests crucially on how well the underlying geophysical quantities can be inferred from these observations. Remote sensing instruments measure parts of the electromagnetic spectrum and use computational algorithms to infer the unobserved true physical states. However, the accompanying uncertainties, if they are provided at all, are usually incomplete. There are many reasons why including but not limited to unknown physics, computational artifacts and compromises, unknown uncertainties in the inputs, and more.
In this talk I will describe a practical methodology for uncertainty quantification of physical state estimates derived from remote sensing observing systems. The method we propose combines Monte Carlo simulation experiments with statistical modeling to approximate conditional distributions of unknown true states given point estimates produced by imperfect operational algorithms. Our procedure is carried out post hoc; that is, after the operational processing step because it is not feasible to redesign and rerun operational code. I demonstrate the procedure using four months of data from NASA's Orbiting Carbon Observatory-2 mission, and compare our results to those obtained by validation against data from the Total Carbon Column Observing Network where it exists.

23. **Elena Garca Broock**, Instituto Astrofsico de Canarias, La Laguna, Tenerife, Spain
Performance of solar far-side active regions neural detection
Tobas Felipe (1,2) and Andrés Asensio Ramos (1,2)
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Far-side helioseismology is a technique used to detect activity signatures in the far hemisphere of the Sun, based on near-side wave field interpretation. We evaluated the performance of a new neural network approach, developed to improve the sensitivity of the seismic maps to the presence of far-side active regions, and thoroughly compared it with the standard method commonly applied to predict far-side active regions from seismic measurements, using STEREO extreme ultraviolet observations of the far hemisphere as a proxy of activity.
We have confirmed the improved sensitivity of the neural network to the presence of far-side active regions. Approximately 96% of the active regions identified by the standard method with strength above the threshold commonly employed by previous analyses are related to locations with enhanced extreme ultraviolet emission. For the same amount of false positives, the neural network can provide a 28% increase in the number of far-side active region detections confirmed by their extreme ultraviolet

brightness. Weaker active regions can be detected by relaxing the threshold in their seismic signature. For almost all the range of thresholds, the neural network delivers a higher number of confirmed detections and a lower rate of false positives.
The neural network is a promising approach to improve the interpretation of the seismic maps provided by local helioseismic techniques, which can lead to improvements in space weather forecasting.

24. **Giovanni Bruno**, INAF - Catania Astrophysical Observatory, Italy
Filtering stellar activity out from exoplanet observations with Gaussian processe
Giovanni Bruno, Vikash Singh, Luca Malavolta, Isabella Pagano, Gaetano Scandariato, Daniela Sicilia, Flavia Calderone

Dynamo-driven stellar magnetic activity is one of the most problematic sources of contamination on the exoplanet signal, because of the stochastic behaviour of its manifestations, such as starspots and faculae. Photometric and spectroscopic spurious signals with a similar amplitude as the planetary signal hamper the detection and characterization of Earth-like planets.
Machine-learning Gaussian processes (GP) regression algorithms have become a standard approach to tackle at least part of this issue. The flexibility of this method allows the treatment of stellar noise as correlated signal.
Our team is active in the application of this technique to exoplanet detection and characterization.

25. **Andrea Bulgarelli**, INAF/OAS Bologna, Italy
The AGILE on-ground event filtering
A. Bulgarelli, A. Argan, A. Chen, V. Fioretti, A. Giuliani, F. Longo, N. Parmiggiani, A. Pellizzoni, M. Tavani, A. Trois, S. Vercellone, N. Parmiggiani, L. Baroncelli, A. Addis, A. Di Piano

AGILE is an ASI (Italian Space Agency) Small Scientific Mission dedicated to high-energy astrophysics, which was successfully launched on April 23, 2007. The AGILE/GRID instrument is composed of three main detectors: a Tungsten-Silicon Tracker designed to detect and image photons in the 30 MeV - 50 GeV energy band, a Mini-Calorimeter that detects gamma-rays and charged particles energy deposits between 300 keV and 100 MeV, and an anti-coincidence (AC) system that surrounds the two detectors.
This paper presents the AGILE/GRID event filter executed by the on-ground analysis software to discriminate the background events. This background event filter called FM3 is currently used for the scientific analysis of the AGILE/GRID data. It is based on a Boosted Decision Tree (BDT) technique and selects events of interest (signal events) out of numerous background events.
The BDT technique maximizes the signal-to-background ratio, suppressing the background events and keeping a high signal detection efficiency. Each event is described by a set of parameters used as input for the BDT. The FM3 filter is developed by training the BDT with a Monte Carlo training sample of events and then tested with an independent Monte Carlo testing sample. The track reconstruction is performed with a Kalman filtering technique and provides the event incident direction and energy. The track reconstruction and other methods are used to provide input parameters to the Multivariate analysis method.

26. **Saverio Cambioni**, California Institute of Technology, Pasadena, California, USA
Building terrestrial planets using machine learning
Saverio Cambioni[1,2], Erik Asphaug[2], Alexandre Emsenhuber[2], Roberto Furfaro[3], Travis S. J. Gabriel[4], Seth A. Jacobson[5], Rahel Mizrahi[6], David C. Rubie[7], Stephen R. Schwartz[2]
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Arizona; (7) Bayerisches Geoinstitut, University of Bayreuth, D-95440 Bayreuth, Germany

Terrestrial planets are thought to conclude their formation in a series of pairwise collisions (giant impacts). In planet formation studies, collisions are commonly modelled as fully accretionary (perfect merging), but this is a computationally convenient assumption: decades of hydrocode simulations reveal that perfect merging is unlikely, save for a confined subset of impact conditions.
Here we show how machine learning can be used to reproduce giant impact results and thus improve the realism of planet formation studies. Our approach is to streamline a large dataset of high-resolution giant impact simulations [1, 2] into surrogate models [3] and to implement these in planet formation [4] and differentiation studies [5]. We present the advantages and challenges of adopting this approach with respect to physics-based models, and discuss how the erosive nature of giant impacts may explain the spread in planetary densities among the rocky bodies in the solar system and potentially low-mass rocky exoplanets. Finally, we describe our current efforts to explore the high-dimensional parameter space of giant impacts with unsupervised machine learning, and further discuss our extended database of giant impact simulations, now ranging from large asteroids to super-Earth exoplanets.

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[5] Cambioni, S. et al. 2021, in press.

27. **Vincent Caillé**, LATMOS, Sorbonne Université, UVSQ Paris-Saclay, CNRS, Paris, France
Cloud Catalog and Statistics Using Machine Learning Algorithms on Mars Orbiter Laser Altimeter / Mars Global Surveyor Data
Anni Määttänen, LATMOS, Sorbonne Université, UVSQ Paris-Saclay, CNRS, Paris, France Aymeric Spiga, LMD/IPSL, Sorbonne Université, Paris, France - Institut Universitaire de France, France Lola Falletti, LATMOS, Sorbonne Université, UVSQ Paris-Saclay, CNRS, Paris, France Gregory A. Neumann, NASA Goddard Space Flight Center, Greenbelt, Maryland, USA

In modeling Mars' climate, CO2 clouds are challenging due to the complexity of the processes involved in their formation and their evolution. Therefore, having as many observations as possible is crucial and it is important to extract all information we can from the rare available data sets. Mars Orbiter Laser Altimeter was aboard the Mars Global Surveyor mission in the late 90's. Originally designed to characterize Mars' surface topography using laser pulses oriented toward Mars' surface, the altimeter sensitivity was better than expected, allowing the detection of atmospheric features among the received laser returns. Some of them were revealed as clouds by previous studies (Neumann & al. 2003; Ivanov & Muhlemann 2001). These studies used fairly simple detection criteria to deal with the amount of data.

In order to distinguish the different kinds of returns (surface, atmosphere, noise), today clustering algorithms provide an efficient way to do this. We use K-means methods on MOLA data to distinguish atmospheric returns from surface and noise returns. Parametrization of the algorithm has been made by finding the most appropriate observed parameter for this distinction and by determining the optimized number of clusters through three independent otpimization methods. Validation of our results is done comparing the obtained atmospheric returns distribution (spatial and temporal) with previous studies.

Using the product of surface reflectivity and two-way atmosphere transmissivity as our distinction parameter as proposed by Neumann & al. (2003), all three optimization methods converge toward the use of a same number of 6 clusters. After applying the K-means method with 6 clusters to the data, we can clearly identify clusters gathering respectively surface, noise and atmospheric returns. While our distribution is overall in agreement with previous results, we found around 100 times more atmospheric returns thanks to our less stringent detection method. We have regrouped the cloud returns in a global catalog of the whole dataset. We have used the catalog to acquire statistic on the clouds (size, position, etc.). This prepares also the second phase of our work: distinguishing different kinds of atmospheric returns (absorptive and reflective clouds, CO2 / water clouds, dust . . .). We plan to do this with machine learning methods and with the help of the MOLA Mars's surface reflectivity map published by Heavens & al. (2016).

28. **Enrico Camporeale**, CIRES/NOAA, Boulder, Colorado, USA
Solving inverse problems with physics informed neural networks: a radiation belt case study
Enrico Camporeale

In an inverse problem one wants to infer the parameters of a model in such a way that the solution of that model matches observations the best it can. Since all physics models contain some degree of approximation and several assumptions, it is often important to understand whether the inaccuracies of a model are intrinsically due to those approximations, or if the model can be improved with a better choice of free parameters. However, solving inverse problems pose a significant challenge, since they are typically ill-posed and computationally much more costly than solving the associated forward model. Recently, a new framework based on physics-informed neural network has been introduced to solve forward and inverse problems.

In this talk, I will focus on the problem of solving the one-dimensional Fokker-Planck equation for radiation belt electrons, from a data-driven standpoint.We use aphysics-informed neural networkto discover the optimal diffusion coefficients that, once used in the Fokker-Planck equation, yield the solution with smaller discrepancy with respect to Van Allen Probes observations.Further, we train a machine learning algorithm that generalizes such coefficients for any radiation belt condition (boundary conditions and initial values). Interestingly, a feature selection analysis shows that the drift and diffusion coefficients are weakly dependent on the value of the geomagnetic index Kp, in contrast with all previous parameterizations presented in the literature.This approach, although well rooted in our physical understanding of the process in play, seeks to extract the largest amount of information from the data with minimal assumptions, and we believe it promises to shed light on the physics of resonant and non-resonant wave-particle interactions in the radiation belts.

29. **Madhurjya Changmai**, Centre for mathematical Plasma-Astrophysics, KU Leuven, Belgium
Turbulence Characteristics of Quiescent Solar Prominence due to Rayleigh Taylor Instabilities
Madhurjya Changmai, Rony Keppens

The purpose of our study is to deepen our understanding on the turbulence that arises from Rayleigh Taylor Instabilities in quiescent solar prominences. Quiescent prominences in the solar corona are cool and dense condensates that show internal dynamics over a wide range of spatial and temporal scales. These dynamics are dominated by vertical flows in the prominence body where the mean magnetic field is predominantly in the horizontal direction and the magnetic pressure suspends the dense prominence material. We perform numerical simulations using MPI-AMRVAC (http://amrvac.org) to study the Rayleigh Taylor Instability at the prominence-corona transition region using the Ideal-magnetohydrodyamics approach. High resolution simulations achieve a resolution of $\sim$ 23 km for $\sim$ 21 min transitioning from a multi-mode perturbation instability to the non-linear regime and finally a fully turbulent prominence. We use statistical methods to quantify the rich dynamics in quiescent prominence as being indicative of turbulence.

30. **Carlo Cannarozzo**, Alma Mater Studiorum Universitá di Bologna, Italy
Inferring the Dark Matter halo mass in galaxies from other observables with Machine Learning
Cannarozzo, Carlo, Alexie Leauthaud, Alessandro Sonnenfeld, Carlo Nipoti, et al.

In the context of the galaxy-halo connection, it is widely known that the dark matter (DM) halo of a galaxy exhibits correlations with other physical properties, like the well-studied stellar-to-halo-mass relation. However, given the complexity of the problem and the high number of galaxy properties that might be related to the DM halo in a galaxy, the study of the galaxy-halo connection can be approached relying on machine learning techniques to shed light on this intricate network of relations. Hence, with the aim of inferring the DM halo mass and then finding a unique functional form able to link the halo mass to other observables in real galaxies, in this talk I will present some preliminary results of this project obtained by relying on the state-of-the-art Explainable Boosting Machine (EBM) algorithm, a novel method with a very high accuracy and intelligibility that exploits some machine learning techniques like boosting or bagging in the field of the generalised additive models with pairwise interactions (GA2M). Unlike a simple GAM, EBM is an additive model that makes final predictions as a summation of shape functions of each individual feature, considering also any possible pairwise interaction between two features. I will illustrate an analysis performed on a sample of galaxies at different redshifts extracted from the IllustrisTNG simulation, making use of several galactic properties. This method is proving to be very promising, finding, at all redshifts, a scatter of $\leq 0:06$ dex between the actual value of M_{DM} from the simulation and the value predicted by the model.
This project is supported by the Marie Sklodkowska-Curie grant received in 2019, and financed by the *Horizon2020-MSCA-RISE-2017 Project 777822 GHAIA Geometric and Harmonic Analysis with Interdisciplinary Applications"*.

31. **Luisa Capannolo**, Boston University, USA
Deep Learning Techniques to Identify the Drivers of Relativistic Electron Precipitation
L. Capannolo, W. Li, and S. Huang

Energetic (> 10s keV) electrons that populate the Earth's radiation belts can precipitate into the Earth's atmosphere. Electron precipitation is not only one of the key mechanisms of causing radiation belt electron loss, but also affects the Earth's atmosphere. Thus, identifying the drivers and quantifying this process is important to understand the dynamics of the radiation belts and the impact on the Earth's atmosphere.
Previous studies found that relativistic electron precipitation is typically associated with various plasma waves. However, electron precipitation can also be caused by another process called current sheet scattering (CSS), which occurs when magnetic field lines are stretched away from Earth. These two drivers can be distinguished by the shape of precipitation fluxes observed at Low-Earth-Orbit (LEO).
In this study, we use deep learning techniques to identify the driver of electron precipitation (waves or CSS) by classifying the electron precipitation observed by the NOAA POES satellites at LEO. POES satellites provide measurements of electron fluxes in 4 integral channels, from > 30 keV up to > 700 keV, over several magnetic local time (MLT) sectors and L shells. To train the models, we use a dataset of wave-driven events together with a dataset of CSS-driven events that occur over 22-02 MLT. These events were classified by visual inspection in the two categories depending on their precipitation shape. We use data augmentation techniques to improve the dataset, and we compare the performance of the various deep learning models. Our ultimate goal is to obtain a dataset of events associated either with waves or with CSS at all MLTs, which can be used in future studies to understand how the distribution of wave-driven electron precipitation compares to that driven by CSS, and to quantify their relative contribution to the overall observed electron precipitation.

32. **Saida Milena Díaz Castillo**, Leibniz-Institut fuer Sonnenphysik (KIS), Germany
Identification and classification of solar granulation structures using semantic segmentation
Saida Milena Daz Castillo[1], Catherine E. Fischer[1], Andrés Asensio Ramos[2],
Svetlana Berdyugina[1]

Solar granulation is the result of the emergence of convective cells from the inner layers of the solar atmosphere to its visible surface. This is mainly observed in the continuum emission and is characterized by a recurrent and dynamical cellular pattern. At the solar surface, it is possible to identify specific structures in the granulation pattern, as *individual granules*: bright extended patches of hot rising gas, its borders: *dark intergranular lanes* and bright small spots seen in intergranular lanes: *Bright points*. Moreover, the access to new instrumentation capabilities has given us the possibility to obtain high-resolution images, which have revealed the high complexity of the granulation, evidencing new dynamic phenomena, e.g. *granular lanes* seen as dark lanes travelling into the bright granules (Fischer et al. (2020)). In that sense, any research focused on understand solar small-scale phenomena on the solar surface are sustained on the effective identification and localization of the different resolved structures. In this work, we present the initial results of our classification algorithm of solar granulation structures based on semantic segmentation. We inspect the approach presented in the U-Net architecture, which uses convolutional networks for biomedical image segmentation (Ronneberger et al. (2015)) to adapt a suitable fully convolutional network and training strategy for our science case. As our training set, we use continuum intensity maps of IMaX instrument inside Sunrise balloonborne solar observatory (Martínez Pillet et al. (2010)) and their corresponding segmented maps, initially labelled using the multiple-level technique (MLT) based on a sequence of descending detection thresholds (Bovelet & Wiehr (2007)) and also labelled by hand. We will perform several tests of the performance and precision of this approach in order to evaluate the versatility of the U-Net architecture, which we will present in the meeting.

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33. **Giacomo D'Amico**, University of Bergen, Bergen, Norway

Signal estimation in On/Off measurements including event-by-event variables

G. D'Amico, T. Terzić, J. Strišković, M. Doro, M. Strzys, J. van Scherpenberg

Signal estimation in the presence of background noise is a common problem in several scientific disciplines. An "On/Off" measurement is performed when the background itself is not known, being estimated from a background control sample. The "frequentist" and Bayesian approaches for signal estimation in On/Off measurements are reviewed and compared, focusing on the weakness of the former and on the advantages of the latter in correctly addressing the Poissonian nature of the problem. In this work, we devise a novel reconstruction method, dubbed BASiL (Bayesian Analysis including Single-event Likelihoods), for estimating the signal rate based on the Bayesian formalism. It uses information on event-by-event individual parameters and their distribution for the signal and background population. Events are thereby weighted according to their likelihood of being a signal or a background event and background suppression can be achieved without performing fixed fiducial cuts. Throughout the work, we maintain a general notation, that allows to apply the method generically, and provide a performance test with simulated data from imaging atmospheric Cherenkov telescopes for demonstration purposes. BASiL allows to estimate the signal more precisely, avoiding loss of exposure due to signal extraction cuts. We expect its applicability to be straightforward in similar cases.

34. **Daniel de Andres**, Department of Theoretical Physics Universidad Autónoma de Madrid (Autonomous University of Madrid), Spain

A Deep Learning Approach to Infer Galaxy Cluster Masses in Planck Compton parameter maps

Daniel de Andres[1], Weiguang Cui[2], Florian Ruppin[3], Gustavo yepes[1], Marco de Petris[4].

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In this work, we evaluate for the first time Convolutional Neural Networks(CNNs) to infer the masses of observed galaxy clusters in the Planck Compton parameter maps. We train our network using simulated maps from the THREE HUNDRED SIMULATION project up to redshiftz of order 1 and test our model on real Planck Sunyaev-Zel'dovich (SZ) maps. Our data set consists on 191862 mock maps, which are based on 7106 different clusters from our simulations, and 1094 observed SZ maps. Furthermore, we train 4 separate CNNs for different redshifts intervals between z=0 and z=1. We show that our results are compatible with Planck estimates of the mass and also with weak lensing measurements.

35. **Biagio De Simone**, University of Salerno, Department of Physics "E.R. Caianiello",Via Giovanni Paolo II, 132, 84084 Fisciano SA (Italy)
On the Hubble constant tension in the SNe Ia Pantheon sample
Dainotti Maria Giovanna, De Simone Biagio, Schiavone Tiziano, Montani Giovanni, Rinaldi Enrico, Lambiase Gaetano

The Hubble constant (H0) tension between Type Ia Supernovae (SNe Ia) and Planck measurements ranges from 4 to 6σ. To investigate this tension, we estimate H0 in the ΛCDM and w0waCDM models by dividing the Pantheon sample, a collection of 1048 SNe Ia, into 3, 4, 20, and 40 bins. For the first two divisions, a presence of SNe Ia in the hundreds for each bin is required to effectively account for systematic effects while the last two are required to test for results independence on the bin divisions. A preliminary consistency check is performed, considering the compatibility of contours for 3 and 4 bins with the ones of the total Pantheon sample through a 2-D analysis where the nuisance parameters are H0 and Ω0m. For each bin, a 1-D Monte Carlo Markov-Chain analysis for H0 with the D'Agostini method is performed in order to extract the value of H0, considering a fiducial absolute magnitude of SNe Ia M -19.25. We will show the MCMC application through the Cobaya package for Python. We fit the extracted H0 values with a function describing the redshift evolution: $g(z) = H'0/(1+z)^{\alpha}$, where α is the evolutionary parameter and H'0=H0 at z=0. We find that H0 evolves with redshift, showing a slowly decreasing trend, with α coefficients in the order of 10^{-2}, consistent with zero only from 1.2 to 2.0σ. Interestingly, in the extrapolation of H0 to z=1100, the redshift of the last scattering surface, we obtain values of H0 compatible in 1σ with Planck measurements independently of cosmological models. Thus, we have reduced the H0 tension from 54% to 72% for the ΛCDM and w0waCDM models, respectively. If the decreasing trend of H0 is real, it could be due to astrophysical selection effects, such as the stretch evolution, or to modified gravity, such as the f(R) theories.

36. **Annie Didier**, NASA JPL, USA
Incepting Interplanetary "Google Search" through Machine Learning
Masahiro Ono, Annie Didier, Sami Sahnoune, Chris Mattmann, Bhavin Shah

Spacecraft can produce a far greater volume of data than can be downlinked. Though interplanetary communication rates have grown in orders of magnitude since early missions, they are far surpassed by the growth in data volume produced by on-board instruments. To bypass the communication bottleneck between spacecraft and ground while optimizing scientific yield, we propose the concept of 'Interplanetary Google Search,' a novel approach to spacecraft data retrieval inspired by the Google search engine. We envision a selective downlink capability with on-board indexing and search where scientists can query a spacecraft's on-board database for specific, relevant information. To realize this on-board data storage and indexing vision, we must first introduce the means to extract features

relevant to scientific interest from historic data payloads. The key to our a pproach is utilizing machine learning to extract features and summarize data. We have demonstrated this capability using image segmentation and image captioning models of MSL RGB imagery. Such methods would, for instance, enable scientists to download a full textual summary of the imagery taken by a rover and use this information to downlink data with specific features for further analysis. This concept has even more potential for a wider range of deep-space missions with more data-intensive instruments (e.g. ground-penetrating radar and hyperspectral imagers), and can be realized with the application of data science.

37. **Yaxue Dong**, Laboratory for Atmospheric and Space Physics, University of Colorado, Boulder, Colorado, USA

Identifying Fundamental Drivers of Martian Ion Escape Using an Artificial Neural Network Model

Y. Dong[1], R. Ramstad[1], D. Brain[1], X. Fang[1], S. Ruhunusiri[2], J. McFadden[3], J. Halekas[2], J. Espley[4], F. Eparvier[1], and B. Jakosky[1]

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Understanding the dependence of Martian ion escape with upstream solar radiation and solar wind conditions is crucial for the studies of long-term atmospheric loss and evolution of Mars, and more generally, unmagnetized planets. However, quantifying the dependence of the Martian ion escape rate on multiple upstream drivers (solar Extreme UltraViolet flux, solar wind, and interplanetary magnetic field) from observations can be challenging. With limited data and correlated upstream parameters, it is difficult to distinguish the effect of each individual parameter on the ion escape. Besides, manually constructing any empirical model of the ion escape rate as a function of multiple upstream parameters risks introducing subjective bias. In order to avoid these limitations in traditional data analysis methods, we apply machine learning methods to study the Martian ion escape variation with multiple upstream drivers. We train neural network models using data from the NASA Mars Atmosphere and Volatile EvolutioN mission, with positions and multiple upstream parameters as input and planetary ion densities and velocities as output. The successfully trained model will return spatial distributions of the escaping ion density and velocity with any upstream condition input, and thus can be used to quantify the ion escape rate dependence on multiple upstream drivers and to study the underlying mechanism of these variations. We will also compare the results from machine learning methods with those from traditional data analysis methods to assess the advantages and limitations of both methods in studying Martian ion escape variation.

38. **Luiz Fernando Guedes dos Santos**, NASA GSFC/CUA

How flux rope signatures are impacted by magnetic field fluctuations? A machine learning approach

Luiz F. G. dos Santos, Ayris Narock, Thomas Narock, Teresa Nieves-Chinchilla, Vadim Uritsky

Identifying a coherent magnetic configuration of internal magnetic structures inside Interplanetary CMEs (ICMEs) caused by a spacecraft crossing a large flux rope with helical magnetic field lines topology is critical for predicting these structures' geomagnetic effect reaching Earth. The increased number of space- and ground-based capabilities increased the amount of data available, necessitating more people and methods to analyze this additional data. Dos Santos et al. (2020, Solar Physics) recently conducted a study to implement machine learning (ML) techniques and expand our understanding of the Space Weather hazard's main drivers. This study successfully interpreted the ICME in situ magnetic field observations using ML. It gained a thorough understanding of what to expect from in situ magnetic field observations when a spacecraft crosses flux ropes with different trajectories. We use a pre-existing Deep Neural Network handwriting model that has been trained with synthetic data with high accuracy in well-behaved events and then tested it against observed ICMEs

from WIND from 1995 to 2015.
We correctly identified flux rope signatures in 84 percent of simple real-world cases and had a 76 percent success rate when applied to a more extensive set. Moreover, we use this established model to investigate magnetic field fluctuations in flux rope identification by analyzing observed fluctuations in magnetic components and constructing more realistic synthetic data ones.

39. **James "Andy" Edmond**, graduate student at University of New Hampshire, USA
Magnetospheric Plasma Region Classification From THEMIS Data Using Machine Learning
James Edmond, Joachim Raeder, Banafsheh Ferdousi, Maria Elena Innocenti

The volume of data generated by magnetospheric instruments accelerates with our computational progress, but this data becomes voluminous enough that parsing it is time-consuming for the scientist. Using machine learning to automate the classification of magnetospheric data into different regions would reduce the human time spent. To this end, we have used the KMeans clustering algorithm to classify 2 minute-averaged THEMIS data into different plasma regions of the magnetosphere. Among the regions we can generally identify are, (1) pristine solar wind / magnetosheath plasma, (2) lobe plasma, (3) inner magnetospheric plasma, and (4) the plasma sheet. We also discuss how these algorithmically-determined regions change using different styles of input (e.g. the classifications found when using all components of the magnetic field vector measurements vs simply the vector magnitude).

40. **Haroun El Mir**, Cranfield University, UK
Certification Approach for Physics Informed Machine Learning and its Application in Landing Gear Life Assessment
Suresh Perinpanayagam, Haroun El Mir, Cranfield University

Landing Gear Systems on Aircraft undergo a multitude of forces during their life cycle, leading to the eventual replacement of this system based on a "safe life" approach that majorly underestimates the component's remaining life due to factors such as generalizing the impact cycle to all Landing Gear systems. The efficacy of fatigue life approximation methodologies is studied and compared to the ongoing Structural Health Monitoring techniques being researched, which will forecast failures based on the system's specific life and withstanding abilities, ranging from creating a digital twin to applying neural network technologies, in order to simulate and approximate locations and levels of failure along the structure. Explainable Artificial Intelligence allows for the ease-of-integration of Deep Neural Network data into Predictive Maintenance, which is a procedure focused on the health of a system and its efficient upkeep via the use of sensor-based data. Test data from a flight includes a multitude of conditions and varying parameters such as the surface of the landing strip as well as the aircraft itself, requiring the use of Deep Neural Network models for damage assessment and failure anticipation, where compliance to standards is a major question raised, as the EASA AI roadmap is followed, as well as the ICAO and FAA. This paper additionally discusses the challenges faced with respect to standardizing the Explainable AI methodologies and their parameters specifically for the case of Landing Gear.

41. **Manolis K. Georgoulis**, Research Center for Astronomy and Applied Mathematics, Academy of Athens, Greece
Machine Learning Methods for the Forecasting of Solar Eruption Products
Manolis K. Georgoulis

A brief report on recent efforts to forecast solar energetic events is given. We focus on major solar weather agents, such as flares, coronal mass ejections (CMEs) and solar energetic particle (SEP) events. The approach used is scalable and aligns with the notion of positive vs. negative samples, appropriate for supervised machine learning methods. The capability for predictor ranking, offering a possibility to physically interpret the outcome of forecasts is highlighted as the key benefit of supervision in machine learning methodology. Core challenges in training, testing and predictor ranking are also described, keeping in sight the central objective, which is to build a verifiable forecasting infrastructure that can be expanded horizontally and vertically to switch from flare forecasting to eruptive flare forecasting (i.e., forecasting of CME-associated flares) to SEP forecasting, connecting physically and statistically the entire Sun-Earth space and beyond. Results from the European Union FLARECAST project and the NSF Award No. 1931555 on Time Series Data Analysis for the Prediction of Solar Flares and Eruptions are mainly shown.

42. **Divyam Goel**, University of California Berkeley, USA
Exploringthe effectsof geomagnetic storms in the ionosphere using Principal Component Analysis
Divyam Goel,Thomas Immel, Yen-Jung Wu, Brian Harding, Colin Triplett, Chihoko Cullens

Understanding the short term variability of the ionosphere is a key puzzle in our understanding of space physics. The recently launch GOLD satellite provides a consistent view of the Earth due to its Geostationary orbit positioned above the SAA. This view creates geospatial-temporal data which allows us to observe the trends in the ionosphere over the same location. This is especially useful when studying the effects of geomagnetic storms on the ionosphere by allowing us to draw comparisons with quiet days. We perform Principal Component Analysis to GOLD's O/N2 disk data to study the disturbances of the O/N2 ratio due to geomagnetic storms. We plot the eigenvectors from the PCA to study the major modes of variation in O/N2 data in the month of April. We also compare the weights of the principal components for every day of April. We observe that the first principal component in April 2020 shows a significantly large weight on the 20th April storm day. We then verify the influence of the storm on the monthly principal component by comparing the eigenvectors from the PCs with and without the storm day. The weights of the third principal component also hint at a quasi 6-day variation in the month of April. We intend on further investigating the quasi 6-day variation and its relationship with the geomagnetic storm. We also intend on applying more machine learning techniques to try and find daily O/N2 variations in the ionosphere.

43. **Jeremy Grajeda**, Klipsch School of Electrical & Computer Engineering, New Mexico State University, USA
Exploring Stability of Coronal Hole Detection to Intensity, Spatial Resolution, and Short Timescales
Jeremy Grajeda & Laura E. Boucheron (NMSU), Michael Kirk (ASTRA LLC, NASA GSFC)

Accurate detection and segmentation (delineation) of coronal holes is an important input to solar wind models. Many algorithms for automated coronal hole detection, however, rely on intensity thresholds to segment solar images. Relying on intensity thresholds can produce vastly different segmentations between and within datasets as a result of changes in overall image intensity due to intrinsic and extrinsic factors. Rather than relying on intensity thresholds, the Active Contours Without Edges (ACWE) algorithm relies on the relative homogeneity of quiet sun and coronal hole regions. The use of the ACWE algorithm for coronal hole segmentation was validated in Boucheron, Valluri, & McAteer (2016). Here, we quantify the stability of ACWE-based coronal hole segmentation to variation in image intensity and resolution such as those introduced in common image formats. In this work we study 193 A images from SDO for August 1 through September 27, 2010. We use a suite of metrics including Intersection over Union (Jaccard index), Structural Similarity Index Measure, and Global and Local Consistency Error. We find that the ACWE algorithm is stable for aggressive intensity scaling, displays no significant artifacts for spatially scaled images, and is consistent in segmentation across small timescales. Through this study we are able to study the systematic versus physical changes within a coronal hole.

44. **Margherita Grespan**, NCBJ, Warsaw, Poland
Machine Learning for transient selection in wide-field optical surveys

Margherita Grespan, and Enrico Cappellaro, INAF Padova

Modern-time domain astronomical surveys are able to monitor large swaths of sky registering the variability of celestial sources. I will focus on the search of transients possibly related to gravitational waves (GW) events. Until recently astronomers need to visually select promising candidates from surveys containing a large number of false positives, a procedure that is very time consuming. In a wide-field observations the number of detections can easily grow to $10^4 - 10^5$ and their visual inspection would require days of work. In this thesis I will present a transient evaluation thorough a ranking approach used by the INAF Padua GRAWITA group which strongly reduce the need for visual inspection though it is not yet optimal. We then explore an alternative approach using a machine learning algorithm (The Random Forest Classifier) providing an automate probabilistic statement about the nature of an astrophysical source as a real transient or as an artifact.

I will describe how I prepared the training set, the test set and the cross-check of the machine learning detection results. With the internal validation the algorithm secured a missed detection rate of 10% that in the best case of the external validation corresponds to false positives rate of 14%.

45. **Madhulika Guhathakurta**, Senior Advisor for New Initiatives, NASA GSFC Heliophysics Division
Emerging Frontiers in Heliophysics Enabled by AI and Public-Private Partnerships
Madhulika Guhathakurta

The recent advances in Artificial Intelligence (AI) capabilities are particularly relevant to NASA Heliophysics because there is growing evidence that AI techniques can improve our ability to model, understand and predict solar activity using the petabytes of space weather data already within NASA and other agency archives. This represents a strategic opportunity, since the need to improve our understanding of space weather is not only mandated by directives such as the National Space Weather Action Plan and the Presidential Executive Order for Coordinating Efforts to Prepare the Nation for Space Weather Events, but also because space weather is a critical consideration for astronaut safety as NASA moves forward with the Space Policy Directive to leave LEO and return to the Moon.

The Frontier Development Lab (FDL) is an AI research accelerator that was established in 2016 to apply emerging AI technologies to space science challenges which are central to NASA's mission priorities. FDL is a partnership between NASA Ames Research Center and the SETI Institute, with corporate sponsors that include Google, Intel, IBM, NVidia, Lockheed, Autodesk, Xprize, Space Resources Luxembourg, as well as USC and other academic organizations. The goal of FDL is to apply leading edge Artificial Intelligence and Machine Learning (AI/ML) tools to space challenges that impact space exploration and development, and even humanity.

The applied AI projects for space weather that are being undertaken by the Frontier Development Lab (FDL) represent an ideal opportunity for utilization of vast amount of NASA and other data to leverage the public-private partnerships of the FDL program in a manner that is highly complementary to ongoing efforts in space weather research. In this talk I will summarize the findings from two space weather topics, "Solar flare forecasting" and "A tool for exploring variability of Solar-Terrestrial interactions" that were part of FDL 2017 -2020 summer program and also develop concepts for Heliophysics AI Affinity Network.

46. **Michael Himes**, University of Central Florida, USA
Neural Network Surrogate Models for Fast Bayesian Inference: Application to Exoplanet Atmospheric Retrieval
Michael D. Himes, Joseph Harrington, Adam D. Cobb, Frank Soboczenski, Molly D. O'Beirne, Simone Zorzan, David C. Wright, Zacchaeus Scheffer, Shawn D. Domagal-Goldman, Giada N. Arney, Atilim Gunes Baydin

Exoplanet atmospheres are characterized via retrieval, the inverse modeling method where atmospheric properties are determined based on the exoplanet's observed spectrum. To determine the posterior probabilities of model parameters consistent with the data, a Bayesian framework proposes atmospheric models, calculates the theoretical spectra corresponding to the models via radiative transfer (RT), and compares the spectra with the observed spectrum. This typically requires thousands to millions of evaluated models, with each taking 1 second for RT. While recent machine-learning approaches to retrieval reduce the compute cost to minutes or less, they do so at the cost of reduced posterior accuracy. Here we present a novel machine-learning assisted retrieval approach which replaces the RT code with a neural network surrogate model to significantly reduce the compute cost of RT simulations, while retaining the Bayesian framework. Using emission data of HD 189733 b, we demonstrate close agreement between this method and that of the Bayesian Atmospheric Radiative Transfer (BART) code (mean Bhattacharyya coefficient of 0.9925 between 1D marginalized posteriors). This approach is 9x faster per parallel evaluation than BART when using an AMD EPYC 7402P central processing unit (CPU), and it is 90–180x faster per parallel evaluation when using an NVIDIA Titan Xp graphics processing unit than BART on that CPU.

47. **Jonathan Hobbs**, Jet Propulsion Laboratory, California Institute of Technology, USA
Simulation-Based Uncertainty Quantification for Infrared Sounder Atmospheric Retrievals
Jonathan Hobbs[1], Amy Braverman[1], Berlin Chen[2], Eric Fetzer[1], Kyo Lee[1], Hai Nguyen[1], Joaquim Teixeira[1]

1 – Jet Propulsion Laboratory, California Institute of Technology; 2 – University of Cambridge

Space-based remote sensing of the Earth's surface and atmosphere has provided comprehensive spatio-temporal coverage in observing geophysical processes. This capability includes a multi-decade record from hyperspectral infrared sounders, including the Atmospheric Infrared Sounder (AIRS) and Cross-track Infrared Sounder (CrIS). Atmospheric quantities of interest (QOIs) are inferred from the satellite spectra through an inverse method known as a retrieval. In the case of AIRS, the retrieval involves a multi-stage algorithm that combines statistical and physical models with a nonlinear optimization. We carry out comprehensive uncertainty quantification (UQ) for this complex observing system with a Monte Carlo simulation framework that represents key system elements probabilistically. A flexible statistical model extends the simulation results to provide a conditional distribution for retrieved and derived QOIs produced by the operational AIRS retrieval. We illustrate the framework and results for temperature and humidity retrievals over the continental United States.

48. **Andong Hu**, CWI, Amsterdam
Using Least-Squares based Ensemble Re-weighted Convolutional Neural Network to Predict Dst probabilities based on Full-Disk SoHO Images
Andong Hu, Carl Shneider, Jannis Teunissen and Enrico Camporeale

We present a novel algorithm that predicts the probability that the disturbance storm time index (Dst) exceeds a specied threshold in a certain period. This quantity provides essential information about the strength of the ring current around the Earth caused by the protons and electrons from solar winds.

The model follows a "gray-box" approach by combining the output of a customized model with machine learning. Specifically, we combine a re-weighted class-entropy (CE) loss function and least-squares based multi-target modeling trained from SoHO full-disk solar images. We discuss how the model predictions perform in several storm events to see if reliable probabilities can be obtained. This model developed can predict the probabilities of Dst longer than any other current Dst Empirical model.

The performance of the model is evaluated by typical metrics for probabilistic forecasts: Probability of Detection and False Detection, True Skill Statistic, Matthews correlation coefficient, and Receiver Operating Characteristic curve. We show that the proposed algorithm can improves those the metrics considered.

49. **Sheng Huang**, Boston University, USA
Hiss in the Plasmasphere and Plumes: Global Distribution From Machine Learning Technique and Their Effects on Global Loss of Energetic Electrons
Sheng Huang, Boston University; Wen Li, Boston University; Xiaochen Shen, Boston University; Qianli Ma, Boston University; Xiangning Chu, University of California Los Angeles; Luisa Capannolo, Boston University

Whistler mode hiss waves are typically observed inside the plasmasphere and plumes, and are known to play an important role in energetic electron loss processes in the Earth's inner magnetosphere. In particular, hiss in plumes is previously shown to be stronger than the waves inside the plasmasphere; however, it has been challenging to achieve the dynamic evolution of hiss inside the plumes on a global scale. We use machine learning technique, more specifically, artificial neural network (ANN) to construct the global evolution of total electron density and hiss wave amplitude inside the plasmasphere and plume and the associated hiss waves therein. These constructed hiss wave models are used to quantify the effects of hiss on the global electron loss at $L < 6$ using the 3D Fokker Planck simulation. We demonstrate that neural network is able to reconstruct the dynamic evolution of total electron density and hiss inside the plasmasphere and plume. Moreover, the simulation result indicates that plume hiss can cause an efficient loss of energetic electrons in the outer radiation belt.

50. **Egor Illarionov**, Moscow State University, Russia
Deep embeddings learnt from sunspot groups
Illarionov E., Moscow State University, Tlatov A., Kislovodsk Mountain Astronomical Station, Listopad M., Moscow State University

Morphological classification of sunspot groups is, probably, one of the most sensitive parts in sunspot data analysis. Expert conclusions on a particular sunspot group require a stable methodological framework and long-term expertise. In practice, however, the separation between sunspot group classes becomes fuzzy and the overall process becomes subjective. The point is that any attempt to isolate a finite number of classes looks as an oversimplification to the observable variability of sunspot groups. We present a new approach to sunspot group classification based on deep embeddings leant by convolutional autoencoder models. The idea of autoencoder neural networks is to map input data (sunspot group images) into a latent space of usually lower dimension and preserve an inverse mapping. Proper architecture of the neural network and careful training process can provide a reasonable structure of the latent space and reveal many non-trivial relations. In particular, one can trace continuous deformations of the sunspot group triggered by deformations in the latent space. We investigate a structure of the latent space and discuss an interpretation of classes and features leant. Finally, the embeddings obtained can be used as new descriptors or precursors in solar activity models, while the autoencoder based approach can be applied to investigation of other solar activity traces.

51. **Egor Illarionov**, Moscow State University, Russia
Machine-learning framework for synoptic maps construction and coronal holes segmentation
Illarionov E., Moscow State University, Sitdikov D., Moscow State University, Kosovochev A., New Jersey Institute of Technology, Tlatov A., Kislovodsk Mountain Astronomical Station

Fast and reliable automatic pipelines for data processing and interpretation are an essential part in space weather prediction models. We present an open-source framework https://github.com/observethesun/helio for convenient pipelines construction, training and prediction with machine learning models. In particular, we demonstrate a construction of solar synoptic maps from SDO/AIA, SOHO/EIT and GONG/SUVI data, training a coronal holes (CHs) segmentation model from daily solar disk images and model application to CHs identification in synoptic maps. The continuously updated catalogue of solar synoptic maps built from SDO/AIA images is available at https://sun.njit.edu/coronal_holes starting from the very beginning of SDO observations. At the moment

we prepare an extension of the catalogue based of SOHO data archive. In the presentation we also discuss a correlation between SDO and SOHO synoptic maps over a common period of observations as well as physical properties of CHs identified.

52. **Maria Elena Innocenti**, Ruhr-Universitaet Bochum, Germany
Unsupervised classification of simulated magnetospheric regions
Maria Elena Innocenti, Jorge Amaya, Joachim Raeder, Romain Dupuis, Banafsheh Ferdousi, Giovanni Lapenta

In this work, we apply an unsupervised classification method based on Self Organizing Maps (SOMs) to data points from global magnetospheric simulations obtained with the OpenGGCM-CTIM-RCM code, as a first step towards classification of magnetospheric observations.
The classification relies exclusively on local plasma properties at the selected data points, without information on their neighborhood or on their temporal evolution, a characteristic that makes the method particularly appealing for spacecraft on-board data analysis. We classify the SOM nodes into an automatically selected number of classes, and we obtain clusters that map to well defined magnetospheric regions. For the sake of result interpretability, we examine the SOM feature maps, and we use them to unlock information on the clusters. We repeat the classification experiments using different sets of features, and we obtain insights on which magnetospheric variables make more effective features for unsupervised classification.

53. **Robert Jarolim**, University of Graz, Austria
Multi-channel coronal hole detection with convolutional neural networks
R. Jarolim[1], A. Veronig[1,2], S. Hofmeister[3], S. G. Heinemann[4], M. Temmer[1], T. Podladchikova[5], K. Dissauer[1,6]

[1]Institute of Physics, University of Graz, Austria; [2]Kanzelhöhe Observatory for Solar and Environmental Research, University of Graz, Austria; [3]Columbia Astrophysics Laboratory, Columbia University, 550 West 120th Street, New York, NY 10027, USA; [4]Max-Planck-Institut für Sonnensystemforschung, Justus-von-Liebig-Weg 3, 37077 Göttingen, Germany; [5]Skolkovo Institute for Science and Technology, Moscow, Russia; [6]NorthWest Research Associates, 3380 Mitchell Ln, Boulder, CO 80301, USA.

The precise detection of the coronal hole boundary is of primary interest for a better understanding of the physics of coronal holes, their role in the solar cycle evolution and space weather forecasting. We present a reliable, fully automatic method for the detection of coronal holes, that provides consistent full-disk segmentation maps over the full solar cycle and can perform in real-time. We use a convolutional neural network to identify the boundaries of coronal holes from the seven EUV channels of the Atmospheric Imaging Assembly (AIA) as well as from line-of-sight magnetograms from the Helioseismic and Magnetic Imager (HMI) onboard the Solar Dynamics Observatory (SDO). For our primary model (Coronal Hole RecOgnition Neural Network Over multi-Spectral-data; CHRONNOS), we use a progressively growing network approach that allows for efficient training, provides detailed segmentation maps and takes relations across the full solar-disk into account. We provide a thorough evaluation for performance, reliability and consistency by comparing the model results to an independent manually curated test set. The evaluation over almost the full solar cycle no. 24 shows that CHRONNOS provides reliable and consistent detections, independent of the solar activity. In addition, we train our model to identify coronal holes from each channel separately and show that segmentation maps can be also obtained solely from line-of-sight magnetograms.
(article status: submitted to A&A)

54. **Jay Johnson**, Andrew University, USA
Transfer Entropy Approach to Identifying Cross-Scale Coupling in Kelvin-Helmholtz Structures in Hybrid Simulations
Jay Johnson, Wesley Martin, Peter Delamere, Xuanye Ma, Simon Wing

Kelvin-Helmholtz vortices frequently develop at the magnetopause boundary of planetary magnetospheres.The nonlinear development of the vortices involves the process of coalescence where smaller vortices coalesce into larger vortices suggestive of an inverse cascade. Large-scale structures tend to have a slower growth rate, yet saturate at larger amplitude, so it is possible that the shift in scale may simply result from nonlinear saturation of the small-scale structures and the linear growth of the large-scale structures which eventually dominate the power spectrum. On the other hand, nonlinear cross-scale turbulent coupling between the modes on different scales may facilitate transfer of energy from small scale to large scale. We utilize transfer entropy to explore cross-scale coupling in hybrid simulations of Kelvin-Helmholtz instability. The analysis provides evidence that nonlinear coupling across scales is important in the coalescence process and also identifies the temporal and spatial scales over which the coupling occurs.

55. **Sudha Kapali**, Computational Physics Inc., Massachusetts, USA

Data Validation Framework for Scientific Instruments: A platform for positive feedback between scientific expertise and machine-learning based validation

Sudha Kapali, Jennifer L Gannon, John Noto, Charles Poole, Robert Kerr, Juanita Riccobono, and Michael A. Migliozzi, Computational Physics Inc.

Technological advancements in sensors and instrumentation have made available a large volume of data for space weather analysis, modeling and forecasting. However, the ready availability of validated data sets that can be immediately absorbed for scientific analysis has been unable to keep up with the rapid growth in the volume of data. It requires expert knowledge to tease out true physical events from subtle non-physical artifacts, however, active human involvement in performing the categorization is often not possible when fielding a large array of remote instruments. Further, non-physical artifacts such as system drifts and environmental perturbances are often subtle as data is streamed in from the instrument.

The above characteristics of sensor data from scientific instruments points to the realization that it takes both – domain-specific scientific expertise and the use of advanced statistical, signal processing and machine learning algorithms to produce a solution for the data validation problem.

We present the design of a validation framework and a set of machine-learning based validation tools that are deployed within this framework. The analytics-based framework creates a pathway to capture and utilize domain-specific scientific expertise, provides mechanisms for analyzing science-informed trends in data and takes advantage of co-located sensors and distributed sensor networks to handle complex constraints. Further, incorporating the validation algorithms within a framework rather than implementing them as standalone operations streamlines the process of evaluating new algorithms. Trends and patterns in data validation results provide valuable insights back to the scientific expert thus completing the feedback loop between technology and science.

56. **Hannah Kerner**, University of Maryland, College Park, USA

Novelty-guided onboard targeting and tactical planning for Mars rovers

Hannah Kerner[1], Kiri Wagstaff[2], Steven Lu[2], Raymond Francis[2], Gary Doran[2], Paul Horton[3], Sakshum Kulshrestha[1], Samantha Jacob[3], James F. Bell III[3]

[1]University of Maryland, College Park, USA; [2]Jet Propulsion Laboratory, California Institute of Technology, USA; [3]Arizona State University, USA

For planetary missions like the Mars Curiosity and Perseverance rovers that are exploring new environments, novelty detection systems that use machine learning to identify observations that differ from what previously has been seen may be used to aid scientists and accelerate scientific discovery. This can be achieved through onboard systems that autonomously select targets for follow-up analyses to enable targeted observations beyond ground-in-the-loop commanding opportunities as well as through ground-based systems that prioritize observations in downlinked data to accelerate tactical planning. The design of these novelty detection systems is driven by resource availability

and other constraints that may differ between the onboard and ground-based settings. In this talk, I will describe two novelty detection capabilities developed for onboard targeting and tactical planning and present results that evaluate these systems for use in the Mars Science Laboratory (Curiosity) rover mission.

57. **Irina N. Kitiashvili**, NASA Ames Research Center, USA
Building Physics-Based Solar Cycle Forecasts Using the Ensemble Kalman Filter Method
Irina N. Kitiashvili

The accuracy of a solar cycle forecast is closely related to our understanding of the global dynamics of the Sun. Limited observational capabilities and a shortage of available observations make the description of past and current solar activity challenging and increase the uncertainty in the resulting forecast. Therefore, proper testing of the sensitivity of the underlying dynamo models to limited time-series and the development of criteria to evaluate model predictions are critical for obtaining a reliable prediction. An Ensemble Kalman Filter (EnKF) analysis of dynamo models, using the available observational data, allows us to estimate the prediction uncertainties and obtain a more reliable description of past, current, and future states of solar activity. In this work, the sunspot number series are used to investigate the sensitivity of the Parker-Kleeorin-Ruzmaikin (PKR) dynamo model to data uncertainties and shortage and to develop criteria for evaluating the reliability of the cycle forecasts. It is found that 22-year series of observations can be sufficient to obtain a reasonable forecast of the following solar cycle. The results of the EnKF assimilation of the four-cycle long synoptic magnetograms from SOLIS, SoHO/MDI, and SDO/HMI into a low-order non-linear PKR dynamo model suggest a weak Solar Cycle 25.

58. **Elena Kronberg**, University of Munich, Germany
Prediction and understanding of soft proton contamination in XMM-Newton
Kronberg, E., Gastaldello, F., Haaland, S., Smirnov, A., Berrendorf, M., Ghizzardi, S., Kuntz, K., Sivadas, N., Allen, R., Tiengo, A., llie, R., Huang, Y., and Kistler, L.

One of the major and unfortunately unforeseen sources of background for the current generation of X-ray telescopes flying mainly in the magnetosphere are soft protons with few tens to hundreds of keV concentrated. One such telescope is the X-ray Multi-Mirror Mission (XMM-Newton) by ESA. Its observing time lost due to the contamination is about 40%. This affects all the major broad science goals of XMM, ranging from cosmology to astrophysics of neutron stars and black holes. The soft proton background could dramatically impact future X-ray missions such Athena and SMILE missions. Magnetopsheric processes that trigger this background are still poorly understood. We derived a machine learning model which utilizes an ensemble of the predictors (Extra Trees Regressor) to delineate related important parameters and to develop a model to predict the background contamination using 12 years of XMM observations. As predictors we use the location of XMM, solar and geomagnetic activity parameters. We revealed that the contamination is most strongly related to the distance in southern direction, ZGSE, (XMM observations were in the southern hemisphere), the solar wind velocity and the location on the magnetospheric magnetic field lines. Based on our analysis, future X-Ray missions in the magnetosphere should minimize observations during times associated with high solar wind speed and avoid closed magnetic field lines, especially at the dusk flank region at least in the southern hemisphere.

59. **Otto Lamminpää**, Jet Propulsion Laboratory, California Institute of Technology, USA
Gaussian Process Emulator for Computationally Expensive Physics Models
OttoLamminpää,[1] Jonathan Hobbs[1], Amy Braverman[1], Pulong Ma[2], Anirban Mondal[3]
1 - Jet Propulsion Laboratory, California Institute of Technology; 2 - Duke University; 3 - Case Western Reserve University

In recent years, satellite-based observations of atmospheric carbon dioxide (CO2) concentrations have emerged as a means of providing data with global coverage and high spatial resolution. Inferring CO2 concentrations from measured radiances, known as retrieval, requires iterative solvers and thus repeated evaluations of a computationally expensive atmospheric radiative transfer physics model. This makes it prohibitively expensive to perform rigorous Uncertainty Quantification (UQ) for the retrieval, which is crucial for further science applications of the CO2 data. To remedy this computational problem, we propose and implement a Gaussian Process based statistical emulator for the physics model used in NASA's Orbiting Carbon Observatory 2 (OCO-2) satellite's CO2 retrieval algorithm. Our approach leverages Functional Principal Component Analysis (FPCA) to find a low dimensional basis for the radiance data. The corresponding FPCA scores are then learned from inputs consisting of synthetic atmospheric state vectors after employing a gradient-based Active Subspace dimension reduction scheme.

60. **Giovanni Lapenta**, SSI and KU Leuven, Belgium
Observation, Simulation and Machine Learning: analysing vast particle data sets to extract physics insight into turbulence and reconnection
Giovanni Lapenta, Jorge Amaya, Brecht Laperre, Martin Goldman, David Newman

Particle in cell simulations of 3D reconnection and turbulence can highlight the fundamental physics and lead to true discovery. But they are a virtual experiment. There is a need to understand the information present in the output in terms of fields and particle distributions. Field data is more manageable but particle data currently can easily reach the size of several TB produced by each time step. Similarly, space missions in bursts mode can produce a large number of time series for fields and moments but analysing the particle distribution functions is a tremendous challenge.
We think two new developments can transform the way we analyse the data. The first is ML that provides techniques to treat this large data sets and discover within them features and properties that would escape traditional approaches [1,2]. But the second profoundly transforming development is the rise of heterogeneous computers where GPUs and CPUs have to be used together. These twi developments allow us to design PIC simulations and their methods of analysis using ML that make the best use of these new resources.

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[2] Goldman, M. V., Newman, D. L., Eastwood, J. P., & Lapenta, G. (2020). Multibeam Energy Moments of Multibeam Particle Velocity Distributions. *Journal of Geophysical Research: Space Physics*, 125(12), e2020JA028340.

61. **Thurmon Lockhart** - School of Biological and Health Systems Engineering, Arizona State University, USA
Dynamic Stability of Exoplanetary Systems using the Largest Lyapunov Exponent
Thurmon Lockhart and Douglas Walker

Empirical methods to measure dynamic stability are available from the field of nonlinear dynamics. These have been applied to quantify dynamic stability of exoplanetary systems and to identify chaotic motion (Toth, and Nagy, 2014) as well as musculoskeletal stability during dynamic human locomotion (Lockhart and Liu, 2008). It is reasonable to assume that every walking stride could be similar to every other stride. Similarly, we assume that every orbital rotation of any planetary systems is similar to every other rotation. Natural variance observed in empirical data is therefore attributed to random mechanical disturbances or in humans, neuromuscular control errors. These disturbances are attenuated in time by the gravity (or friction) in order to maintain a stable orbital pattern resembling and exhibiting a fractal and chaotic structure. Disturbance to the orbital trajectory is an ongoing process so the attenuation of these variability is continually manifest in order to remain stable in the planetary system. Thus, stability can be characterized from the time-dependent attenuation or

expansion of variability. This is measured by the Lyapunov exponent, λ. One Lyapunov exponent exists for every rotation or partial rotation and has the dimension, λi. A system is stable when the sum of λi is negative, i.e. the rate of kinematic convergence is greater than the rate of divergence. However, calculation of the full Lyapunov spectrum from experimental data is exceedingly difficult. These calculations may be greatly simplified by realizing that two randomly selected initial trajectories diverge, on average, at a rate determined by the largest Lyapunov exponent, λMax. Presentation will include the demonstration of acquiring λMax from using human gait data. We will also investigate the precision of radial velocity data needed to establish λMax for examples of known exoplanet systems.

Lockhart, T., and Liu, J., Differentiating fall-prone and healthy adults using local dynamic stability. Ergonomics, 51(12), 1860-1872.

Toth, Z. and Nagy, I., 2014. Dynamical stability of the Gliese 581 exoplanetary system. MNRAS 442, 454-461 (2014)

62. **Luning Li**, School of Aerospace Transport and Manufacturing, Cranfield University, UK
Digital Twin in Aerospace Industry: The Concept, Applications and Challenges
Luning Li, Suresh Perinpanayagam, Andrew Wileman

Digital Twin (DT), a virtual replica of any conceivable entity, is a highly transformative technology with implications that are profound in nature. For instance, by leveraging the tetra-drivers of innovation (namely, cloud, internet of things, big data, and artificial intelligence), DT can be made to undertake real-time performance assessments and diagnostics more precisely than presently possible; repairs can be affected instantly; and innovations can be catapulted. This, however, is marred with a number of challenges and uncertainties, such as an unobstructed transfer and assimilation of heterogenous data from various source-streams including design, manufacturing, and operations. This paper highlights such challenges in the adaptation of DTs to an aerospace environment whilst also providing a way ahead and future directions. Besides presenting the concept and the growing significance of Digital Twin across a wider spectrum of industries, the paper puts forth several critical future challenges within the aerospace industry vis--vis key applications, such as for prognostics and health management, manufacturing, data quality and quantification, visualization, cybersecurity, etc. These aspects of DT for aerospace (aero-DT) have not been previously elaborated in the literature, thus leaving a void in DTs' optimal implementation. This paper has filled this void by providing a critical analysis of challenges that pose difficult questions for the aerospace industry and suggesting ways along with a roadmap to steer away from them and multiply their potential for innovation in aircraft design, manufacture, and operation.

63. **Hamlin Liu**, Department of Computer Science at University of California, Los Angeles, USA
Traveling Ionospheric Disturbances detection with Convolutional Neural Networks: a proof-of-concept with the 2012 Hawaii earthquake and tsunami
Valentino Constantinou (Jet Propulsion Lab, California Institute of Technology), Michela Ravanelli (Geodesy and Geomatics Division, Sapienza University of Rome), Dr. Jacob Bortnik (Atmospheric and Oceanic Sciences, UCLA), Hamlin Liu, Department of Computer Science, University of California, Los Angeles

It is well known that tsunamis can trigger internal gravity waves (IGWs) that are able to propagate to the ionosphere, causing a perturbation in the natural Total Electron Content (TEC). These perturbations are often referred to as Traveling Ionospheric Disturbances (TIDs) and are easily detectable through the Global Navigation Satellite System (GNSS) signal. In this context, the VARION (Variometric Approach for Real-Time Ionosphere Observation) algorithm has been successfully applied to TID detection in several real-time scenarios. The large quantity of GNSS data currently available (over 9.8 TB of data from 1992 to present day for UNAVCO GNSS network) allows us to explore the possibility of using deep learning methods for TID detection. As a proof-of-concept, starting from

the core base of the VARION algorithm, i.e the time differences of geometry-free combination, we demonstrate the effectiveness of training a convolutional neural network (CNN) to detect signs of IGWs, achieving a 92.3% F0.5 score on out-of-sample validation data. While we present the work through experiments using the real-time scenario of the 2012 Haida-Gwaii earthquake that induced a tsunami off the coast of the Hawaiian islands, the approach - which overcomes issues related to missing data - is applicable to other time-series anomaly detection problems in geosciences. In this presentation, we discuss our current work and exciting applications of using deep learning in detection and further study of gravity waves and their effect on the ionosphere.

64. **Chris J. Maddison**, University of Toronto, Canada
Lossy Compression for Lossless Prediction
Yann Dubois, Benjamin Bloem-Reddy, Karen Ullrich, Chris J. Maddison

Most data is automatically collected and only ever "seen" by algorithms. For example, thenumber of images in many sky surveys is so large that visual inspection is impractical. Despite this, classicallossy data compression methods are designed to store the information needed to guarantee perceptual fidelity rather than just the informationneeded byalgorithms performing downstream tasks. So, we are likely storing vast amounts of unneeded information. In this talk, we characterize theminimum bit-rates required to ensure high performance on all predictive tasks that are invariant under a set of transformations. Based on our theory,we designunsupervised objectives for designing deep-learning-based compression methods, and we show that it is possible to achieve dramatic rate savingson standard datasets, including Galaxy Zoo, without decreasing predictive performance.

65. **Daniel Magro**, Institute of Space Sciences and Astronomy, University of Malta, Italy
Object Detection with Mask-RCNN
Daniel Magro, Simone Riggi, Andrea DeMarco, Kristian Zarb Adami, Eva Sciacca, C. Bordiu, F. Bufano, A. Ingallinera, R. Sortino, C. Pino, C. Spampinato, T. Cecconello, G. Vizzari, F. Vitello, U. Becciani

Source finding is one of the most challenging tasks in upcoming radio continuum surveys with SKA precursors, such as the Evolutionary Map of the Universe (EMU) survey of the Australian SKA Pathfinder (ASKAP) telescope. The resolution, sensitivity, and field-of-view of such surveys is unprecedented, requiring new features and improvements to be made in existing source finders. Among them, reducing the false detection rate, particularly in the Galactic plane, and the ability to associate multiple detected islands into physical objects.
To bridge this gap, we developed a new source finder, based on the deep learning Mask-RCNN framework, capable of both detecting and classifying compact sources, radio galaxies or imaging sidelobes in radio images. The model was trained using ASKAP data, taken during the Early Science phase, and previous radio survey data.
Typical detection and classification performances, obtained for different model configuration parameters, will be presented at the conference.

66. **Aoife McCloskey**, German Aerospace Center, Germany
Sunspot Classifications & Solar Flare Prediction: A comparative performance analysis of machine learning and Poisson-based prediction models
A. E., McCloskey, P. T., Gallagher, D. S., Bloomfield

Historically, McIntosh classifications of sunspots have been utilised for the prediction of solar flares, with modern day operational flare forecast services still reliant upon these classifications for their predictions. Here, building upon previous Poisson-based flare forecasting models that make use of Mcintosh classifications, machine learning (ML) techniques are applied to construct a set of new models to predict flares within a 24-hr period. These ML algorithms are trained and tested using data from a range of independent solar cycle periods (22, 23 and 24), cross-validation techniques are applied and the relative performance of each algorithm is compared. The implications these results have when compared with the previous Poisson-based approach are discussed as well as the problem of solar cycle dependence. Additionally, an exploration of the importance of the individual features (i.e., McIntosh components) on the performance of each prediction model is presented.

67. **Robert McPherron**, Department of Earth, Planetary, and Space Sciences, University of California Los Angeles, USA
Statistics of Substorm Onset in the SuperMag Lower Index (SML)
Robert L. McPherron

The SuperMag Project has developed a version of the standard AL index that utilizes many more stations than the standard does to monitor the strength of the westward electrojet underneath the expanding auroral bulge. This SML index has been download and processed by a pattern recognition algorithm that detects the start and ending times of the expansion. From 1980 to the current time there are more than 100,000 expansion onsets averaging about five per day. The duration and strength of the decrease in SML are easily calculated parameters that characterize the substorm. These parameters exhibit breaks in their probability distributions that separate the events into six classes: including small, big, narrow, wide, small/narrow, and big/wide. Ensembles of events have been created relative to the expansion onset. Averages of these reveal such properties as concurrence rate and strength as functions of solar cycle, season, storm time, and time relative to passage of a corotating interaction region. It is essential to separate the small/narrow events from the big/wide events as they have very different occurrence statistics. Although duration and strength have broad distributions, ensemble averages of substorms binned by strength of SML decrease have identical shapes in the averages of standardized data indicating the average temporal behavior is independent of strength. A persistent feature in the ensemble averages is a pea in coupling strength, or a minimum in Bz at expansion onset. This has previously been interpreted as triggering by a northward turning of the IMF. This idea has been dismissed as an artifact or chance association, primarily because no one could explain how the onset might happen physically. This feature is present in all our averages, but more accurate onset times enable us to examine the rate of change of coupling relative to onset. We find a substantial fraction of all substorm onsets is preceded by a negative spike in Bz starting 15 minutes before onset that corresponds to a sudden increase in coupling strength followed by the northward turning. This spike could cause a sudden thinning of the current sheet and possible onset of reconnection.

68. **Meg Millhouse**, University of Melbourne, Australia
Bayesian inference in gravitational-wave data analysis
Meg Millhouse

Bayesian inference is used widely in gravitational-wave (GW) astrophysics.Bayesian methods are used for GW signal detection, the characterization of that signal and its parameters, and to make inferences about the population properties of binary black holes and neutron stars.This talk will give an overview of gravitational waves and their sources, and present some of the methods and applications of Bayesian inference in GW data analysis. We will give an overview of how parameters are inferred for systems of binary black holes and neutron stars. We will also discuss methods for detecting GW signals with no a priori assumption on the signal morphology, and distinguishing these signals from instrumental noise.

69. **A. Muñoz-Jaramillo**, Southwest Research Institute, Boulder, CO, USA
Cross-calibration, super-resolution, and uncertainty estimation of the conversion of MDI and GONG to HMI full-disk magnetograms using deep learning
A. Munoz-Jaramillo (1), A. Jungbluth (2), X. Gitiaux (3), P. Wright (4), C. Shneider (5), S. Maloney (6), A. Kalaitzis (2), A. Baydin (2), Y. Gal (2), M. Deudon (7)
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Over the past 50 years, a variety of instruments have obtained images of the Sun's magnetic field (magnetograms) to study its origin and evolution. While improvements in instrumentation have led to breakthroughs in our understanding of physical phenomena, differences between subsequent instruments such as resolution, noise, and saturation levels all introduce inhomogeneities into long-term data sets. This has proven to be an insurmountable obstacle for research applications that require high-resolution and homogeneous data spanning time frames longer than the lifetime of a single instrument.
Here we show that deep-learning-based super-resolution techniques can successfully up-sample and homogenize solar magnetic field images obtained both by space and ground-based instruments. In particular, we show the results of cross-calibrating and super-resolving MDI and GONG magnetograms to the characteristics of HMI.
We also discuss the importance of agreeing on a standardized set of training, validation, and test data, as well as metrics that enable the community to benchmark different approaches to collectively and quantitatively identify the best practices. This includes distributing test data within the broad heliophysics community.
Finally, we discuss our approach for making an empirical estimation of uncertainty and the importance that uncertainty estimation plays in the credibility and usefulness of deep learning applications in heliophysics.

70. **Jorge H. Namour**, Facultad de Ciencias Exactas y Tecnología (FACET), Universidad Nacional de Tucumán (UNT), Argentina
Ionosphere F2 critical frequency forecasting using deep learning
Namour, Jorge H (1); Molina, Mara Graciela (1, 2) ; Ise, Juan (1)
(1) Facultad de Ciencias Exactas y Tecnologa (FACET), Universidad Nacional de Tucumán (UNT);
(2) CONICET

In this work, we present preliminary results obtained for the forecasting of the F2 ionospheric layer using deep learning. The forecasting model has been done using 12 years data set (almost a complete solar cycle) of measurements corresponding to the foF2 parameter (F2 ionospheric layer critical frequency) obtained from the AIS-INGV ionospheric sounder deployed at Tucumán Space Weather Center (https://spaceweather.facet.unt.edu.ar/) in Argentina. The mentioned low latitude ionospheric station ($26°51'$ S, $65°12'$ W) is located near the south crest of the Equatorial Ionization Anomaly posing great interest for the space weather community.
We present the preliminary results of forecasting 3 hours in advance using a Long-Short-Term Memory (LSTM) model. This recurrent neural network model is univariate, multistep, and uses 3 hours backward to perform the forecast. Often, data available is highly unbalanced due to the domain characteristics where few cases of sudden ionospheric irregularities caused by space weather events occur within a certain period (e.g. during a year). Thus the training set has been selected to comply with the following criteria: it has to consider as much as possible the different scenarios of the domain, minimize missing values effects (e.g. due to instrument failure), and cover a great portion of a solar cycle. Then, the more intense work was done in selecting and cleaning the training, validation, and testing sets.
In order to evaluate the performance, we used RMSE. The results for the testing sets showed a good agreement with the actual measurements. We also tested the model using extended data sets to stress the model and test how it behaves against new data. Finally, we discuss the results, the possibility of an operative implementation and we propose further approaches to be implemented in the near future.

71. **Aditya Narendra**, Jagiellonian University, Poland
Redshift estimation of AGNs and GRBs using machine learning

Maria Giovanna Dainotti, Malgorzata Bogdan, Aditya Narendra,Trevor Nelson, Ioannis Liodakis, Johan Larrson, Blazej Miasojedow, Spencer James Gibson, and Zooey Nguyen

Our project is focused on predicting the redshifts of Active Galactic Nuclei (AGNs) and Gamma Ray Bursts (GRBs). Knowing the redshift of AGNs and GRBs allows us to determine their distance from us, and learn about the evolution of the early universe, star formation rate, along with studying the structure of early galaxies. However, measuring the redshift of these objects is a challenging task. In fact, there are few AGN and GRB data with measured redshift. We use data from the fourth catalog of the Fermi Large Area Telescope (Fermi LAT). Out of 2863 AGNs observed by the Fermi Satellite only 1591 (55%) have redshift. It is clearly useful to find an accurate way to obtain the redshift from the features of existing AGNs whose redshift have been observed reliably. Similarly, only 1/3 of GRBs are observed with redshift from the Swift Satellite, the most appropriate tool to determine the GRB redshift. These are measured by localizing the GRBs to their parent galaxy and by spectroscopy. This method has only allowed us to accurately measure the redshifts of only a few hundred GRBs. Indeed, the persistent caveat on the use of GRB and AGN correlations for cosmological studies is the incompleteness of their samples with known redshifts.
Thus, we tackle this problem using machine learning with regression algorithms to infer the redshift of the AGNs and GRBs for which the redshift is unknown. We will implement multiple machine learning algorithms, such as Big Lasso, Support Vector Machine, Random Forest among others. We are primarily use the Superlearner algorithm, which uses cross-validation to estimate the performance of multiple machine learning, and we use the nested 10-fold cross validation method to test the performance of our model in a real-world scenario.

72. **Tom Narock**, Goucher College, Center for Data, Mathematical, and Computational Sciences, USA
Identification of Flux Rope Orientation via Neural Networks
Tom Narock[1], Luiz F. G. dos Santos[2], Ayris Narock[3,4], and Teresa Nieves-Chinchilla[4]
1, Goucher College, Center for Data, Mathematical, and Computational Sciences; 2, Catholic University of America; 3, Adnet Systems Inc.; 4, NASA Goddard Space Flight Center

In situ observations of flux ropes are essential for the prediction of geomagnetic disturbances, yet the identification of a flux rope's orientation and key parameters (e.g. latitude, longitude, chirality, and spacecraft impact parameter) is currently a tedious and manual process. Building on previous work (dos Santos et al, 2020), we explore a neural network's ability to predict a flux rope's orientation once it has been identified from in situ solar wind observations. This ongoing work uses an image recognition neural network trained with magnetic field vectors from analytical flux rope data. The simulated flux ropes span many possible spacecraft trajectories and flux rope orientations. We simulate real-time forecasting by having the neural network continually update the flux rope orientation predictions as the spacecraft traverses the flux rope. The prediction accuracy of the neural network as a function of flux rope observed is discussed as well as the process of casting the physics problems as a machine learning problem. We highlight the impacts on prediction accuracy of trying various neural network topologies and flux rope analytical models (circular vs. elliptical cross-section). Finally, preliminary results from evaluating the trained network against the observed ICMEs from WIND during 1995-2015 are presented.

73. **Hai Nguyen**, Jet Propulsion Laboratory, USA
Spatial Statistical Data Fusion for Remote Sensing Applications
Hai Nguyen, Amy Braverman, Peter Kalmus

A wealth of available remote sensing data promises many new scientific insights about climate and other aspects of our environment, but only if those data can be efficiently exploited. Remote sensing data are often simultaneously massive and sparse: massive because their domains are so large, but sparse relative to geophysical processes of interest. If massiveness can be overcome, combining complementary data from multiple sources can fill in gaps, and lead to more complete and accurate inferences. We describe a data fusion application using data from the Atmospheric Infrared Sounder (AIRS) and Cross-track Infrared Sounder (CrIS) using a linearly scalable, practical data fusion methodology that does not require assumptions of stationary or isotropy, and provides for change of support. Our data fusion methodology relies on a dimension-reduction technique called the Spatial-Random-Effects model, and the advantage of this approach is that we are able to propagate measurement uncertainties into output uncertainties. We will also detail some practical challenges to data fusion, and present validation against Mesonet data.

74. **Adnane Osmane**, Department of Physics, University of Helsinki, Finland
Consequences of ULF fluctuations with finite correlation time on radial diffusion of radiation belts' particles
A. Osmane & Solène Lejosne (Space Science Laboratory, Berkeley, California, USA)

Radial diffusion in planetary radiation belts is a dominant transport mechanism resulting in the energisation and losses of trapped particles by large-scale ULF fluctuations. In this talk we will revisit the radial diffusion formalism of Fälthammer JGR, (1965) by relaxing the assumption of zero correlation time in the spectrum of fluctuations responsible for the diffusion of trapped particles. We will show that a finite autocorrelation time comparable or larger than the azimuthal drift period results in (1) a nonlinear L* dependence of the diffusion coefficient qualitatively consistent with recent statistical studies (Sarma et al. JGR, 2020) and (2) characteristic diffusion time faster than for short correlation time. However, in the absence of sources and sinks, radial diffusion for both short and long autocorrelation times inevitably result in a flattening of the distribution function along L* with differences of less than ten percents across lower drift shells. Thus, the presence of ULF fluctuations with long autocorrelation time leads to faster diffusion during intermediary times and before the flattening of the distribution function across a broad range of magnetic drift shells. We will conclude by using information-theoretic measures to quantify the length of intermediary time periods upon which the inclusion of finite correlation time of fluctuations significantly impacts modelling results.

75. **Yang Pan**, University of Texas at Arlington, Arlington, Texas, USA.
TEC map reconstructions using deep neural networks
Yang Pan, University of Texas at Arlington, Arlington, Texas; Mingwu Jin, University of Texas at Arlington, Arlington, Texas; Shunrong Zhang, Haystack Observatory, Massachusetts Institute of Technology, Westford, Massachusetts; Yue Deng, University of Texas at Arlington, Arlington, Texas

Limited coverage of global receiver stations yields incomplete global total electron content (TEC) maps with large data gaps for Massachusetts Institute of Technology (MIT)-TEC. Although the International Global Navigation Satellite System Service (IGS)-TEC offers completed global TEC data, it tends to ignore those meso-scale structures due to over-smoothness. These drawbacks of existing TEC data and maps curb the ionospheric research about TEC structures. In this work, we adapt the Spectral-Normalized Patch Generative Adversarial Networks (SNP-GAN) trained on large amount of IGS-TEC data. Based on the 10-folder cross-validation experiment of 20-year IGS-TEC data, the root mean squared error (RMSE) is reduced more than 30% by SNP-GAN over our previous model, deep convolutional GAN with Poisson blending (DCGAN-PB). Moreover, we test our model on MIT-TEC data using two case studies for 2013 and 2016 storms. The results show that SNP-GAN is able to not only preserve the large-scale TEC structure shown in IGS-TEC, but also reconstruct the meso-scale TEC structure from MIT-TEC data, which is not presented in IGS-TEC. SNP-GAN could serve as an efficient and automatic TEC map completion tool, and could be further improved by training with high-resolution TEC maps.

76. **Carmelo Pino**, INAF Astrophysical Observatory of Catania, Italy
A deep object segmentation approach on radio-astronomical images
Carmelo Pino*, Renato Sortino*, Daniel Magro*, Eva Sciacca*, Simone Riggi*, Giuseppe Fiameni**
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In the last decade, the use of machine learning and deep learning techniques in object detection and segmentation became crucial in several scientific fields. In radio-astronomical images domain the use of traditional image processing techniques are largely used in order to extract some kind of information.
The use of some deep model for object detection is actually used on radio-astronomical dataset.
In this work we present a method for object segmentation based on the Tiramisu model applied to a dataset of astrophysical images, composed by 16000 samples belonging to three different object classes: galaxy, sidelobe, compact source.
Tests have been performed in order to compare the model performance also with object detection approaches. The experimental results show high values in mean per-pixel accuracy (> 90% over all classes), while per-object precision yields a result of more than 70% over all the three classes.

77. **Victor Pinto**, University of New Hampshire, USA
Forecasting ground magnetic fluctuations using deep learning. Overview of the MAGICIAN team recent results
Victor Pinto, Amy Keesee, Hyunju Connor, Jeremiah Johnson, Md Shaad Mahmud, Dogacan Ozturk,Michael Coughlan, Matthew Blandin

Prediction of ground magnetic fluctuations is a first step towards the risk assessment and forecasting of geomagnetically induced currents (GICs) considering that direct GIC measurements are rarely available, are heavily restricted, and in the best cases are very limited in their spatial distribution. The continuous measurements of solar wind parameters by monitors located at L1 provide a near-real time data stream that anticipates the arrival of solar wind by approximately 20-40 minutes to the Earth, which makes it ideal for the creation of early warning tools. In this talk, we are going to present the recent results and general approach of the MAGICIAN (Machine Learning Algorithms for Geomagnetically Induced Currents in Alaska and New Hampshire) team regarding the prediction of ground magnetic fluctuations at different latitudes using different deep learning algorithms. We will discuss the use of fully connected neural networks and recurrent neural networks when they are restricted to the use of data from the solar wind, and we will present results regarding the best parameters to use when forecasting as a function of the location in the planet, using measurements provided by the SuperMag initiative. Additionally, we will discuss the merits of using additional data from ground or low altitude observatories to improve our current predictions and our recent advances in finding metrics and evaluation tools that are appropriate in the context of GICs.

78. **Andrei Plotnikov**, Crimean Astrophysical Observatory, Russia
Inversion of Stokes profiles in Milne-Eddingtone atmosphere model with deep neural networks
A.Plotnikov, I.Knyazeva, T.Medvedeva

Inversion methods are a powerful instrument for acquisition of stellar atmospheres' parameters from observed spectral profiles. The methods constitute a search of parameters set, that makes the simulated spectral data fits real observation best. The search could be provided with any available optimization method.
Modern instruments for solar observations allow achieving high spectral and spatial resolution. That leads the inversion problem to be more computationally expensive. "Classic" optimization methods, like Levenberg-Marquardt (LM) algorithm, require several hours for calculating atmosphere parameters of a typical active region. At the same time, current researchers in solar physics are interested in high-cadence data. Another goal is using more complicated atmosphere models with a greater number of parameters to derive.
In this work, we tried to use various neural network architectures as a method for the inverse problem solving. To reduce the instrument's effects, only synthetic spectral profiles were used.

The results of parameters reconstruction with the neural networks model have been able to achieve a good agreement with the data, provided by High Altitude Observatory. The neural networks show significant speed gain, compared with the LM algorithm.

79. **Mariano Poisson**, Instituto de Astronoma y Fsica del Espacio (IAFE), Argentina
Modeling the photospheric magnetic field distribution of emerging solar active regions
M. Poisson[1], F. Grings[1], M. López Fuentes[1], C.H. Mandrini[1,2], P. Démoulin[3]
[1] Instituto de Astronoma y Fsica del Espacio (UBA-CONICET), Argentina; [2] Universidad de Buenos Aires, Argentina; [3] Observatoire de Meudon, France.

Active regions (ARs) appear in the solar atmosphere as a consequence of the emergence of magnetic flux tubes. It has been shown that in order to survive their transit through the convective zone, these flux tubes should be twisted, forming so-called magnetic flux-ropes (FR) and transporting with them magnetic helicity from the solar interior. This quantity plays a key role in the production of energetic events such as flares and coronal mass ejections. Photospheric observations of the line-of-sight (LOS) component of the magnetic field reveal that during the emergence of ARs the presence of twisted field lines around the FR axis produces an elongation of the main AR magnetic polarities known as magnetic tongues. In this work we aim to estimate the intrinsic geometrical properties of FRs, by comparing LOS magnetograms of emerging ARs with synthetic magnetograms derived from a toroidal magnetic flux tube model. In particular, we estimate the tilt angle, defined as the inclination of the AR main bipolar axis with respect to the solar equator, which is strongly affected by magnetic tongues. Our method uses a probabilistic scheme based on the Bayes theorem to infer the most probable intrinsic parameters of an emerging flux tube, assuming a normal departure between the model and the observations. Open access python 3 packages, pymc3 and Theano are used to optimize the sampling of the model 8-dimensional parameterco space. Analyzing a sequence of 66 magnetograms, we are able to infer the most probable values of the intrinsic parameters for AR 10268, including its magnetic helicity content and its intrinsic tilt angle.

80. **Artem Poliszczuk**, National Centre for Nuclear Research (NCBJ), Poland
Active Galactic Nuclei Selection in Panchromatic North Ecliptic Pole Data: a Machine Learning Approach
A. Poliszczuk (NCBJ), A. Pollo (NCBJ, AOJU), K. Malek (NCBJ, LAM), A. Durkalec (NCBJ), W.J. Pearson (NCBJ), T. Goto (NTHU), , S.J. Kim (NTHU), M. Malkan (UCLA), N. Oi (TUS), S.C.-C. Ho (NTHU), H. Shim (KNU), C. Pearson (UO) and the North Ecliptic Pole Team
Affiliations of co-authors:
NCBJ - National Centre for Nuclear Research, Poland; AOJU - Astronomical Observatory of the Jagiellonian University, Poland; LAM - Aix Marseille Univ. CNRS, CNES, LAM, Marseille, France; NTHU - Institute of Astronomy, National Tsing Hua University, Taiwan; TUS - Tokyo University of Science, Japan; KNU - Department of Earth Science Education, Kyungpook National University, Korea; UO - Oxford Astrophysics, University of Oxford, UK

Context: The North Ecliptic Pole (NEP) field provides a unique set of panchromatic data, well suited for active galactic nuclei (AGN) studies. Selection of AGN candidates is often based on mid-infrared (MIR) measurements. Such method, despite its effectiveness, strongly reduces a catalog volume due to the MIR detection condition. Modern machine learning techniques can solve this problem by finding similar selection criteria using only optical and near-infrared (NIR) data.

Aims: Aims of our work were to create a reliable AGN candidate catalog from the NEP field using a combination of optical SUBARU/HSC and NIR AKARI/IRC data and, consequently, to create an efficient alternative for the MIR-based selection technique.

Methods: A set of supervised machine learning algorithms was tested in order to perform efficient AGN selection. Best of the models were combined into a majority voting scheme, which produced the final AGN catalog.

Results and conclusions: Our new optical and NIR combined classification shows consistency with the MIR-based selection. Moreover, 76% of the obtained AGN catalog can be found only with the new method, due to the lack of MIR detection for most of the AGN candidates. New selection method presented in this paper proves to be a better alternative for the MIR color AGN selection. Machine learning techniques not only show similar effectiveness, but involve less demanding optical and NIR observations substantially increasing the volume of available data samples.

81. **Agnieszka Pollo**, National Centre for Nuclear Research and Jagiellonian University, Poland
Extragalactic Big Data: promises and challenges
Agnieszka Pollo (and the team)

Present-day astronomical catalogues already very often fall into the Big Data category, listing millions or even billions of sources. Near-future projects like LSST conducted at the Vera Rubin Observatory will raise these numbers by orders of magnitude. The rize is not only in numbers: newly observed objects are fainter, more distant or otherwise different from the ones which are already well studied. In the same time, the amount of information available for each source is usually very limted. On one hand, this creates a perfect area for application of statistical and machine-learning based methods. On the other hand, we need to face a number of challenges: small training sets, limitations of the feature space(s), extrapolation ability and interpretability of the results.
In my talk I plan to review some results of the methods applied by our team to classify and effectively extract information on different types of astrophysical sources from large astronomical surveys, including (but not limited to) VIPERS, AKARI and WISE. (TBC)

82. **Gouri Ramesh**; Cranfield University, UK
Digital Fault Simulation and Identification in an Electric Braking System
Gouri Ramesh, Pablo Eduardo Garza, Suresh Perinpanayagam

In recent years, the aerospace industry has tried to introduce technologies such as More Electric Aircraft (MEA) and Integrated Vehicle Health Management (IVHM) to achieve various benefits such as weight reduction and lesser fuel consumption and a decrease in unexpected failures and in turn unavailability of the aircraft. In this paper, data from digital model of an electric braking system of an aircraft is used to identify faults that are critical in nature, namely Open Circuit fault, Intermittent Open Circuit, and Jamming. The variation of characteristic parameters during normal working conditions, and when faults are encountered are analysed qualitatively, and training features for the reasoner are selected. A data-driven approach is adopted for the development of the reasoner due to the availability of clean data. The paper discusses the performance of univariate and multivariate models of Long Short - Term Memory Neural Network time series classifier. Its performance is also studied w.r.t two other models - K Nearest Neighbour time series and Time Series Forest classifiers. The comparison of the reasoners is then carried out in terms of accuracy, precision, recall and F1-score and the relevancy of choosing the correct metrics for evaluation is also discussed.

83. **Viacheslav Sadykov**, Georgia State University, USA
"All-Clear" Prediction of Solar Proton Events using Machine Learning and Comparison with Operational Forecasts
Viacheslav Sadykov (GSU), Alexander Kosovichev (NJIT), Irina Kitiashvili (NASA ARC), Vincent Oria (NJIT), Gelu Nita (NJIT), Egor Illarionov (Moscow SU), Yucheng Jiang (NJIT), Patrick O'Keefe (NJIT), Sheldon Fereira (NJIT)

Solar Energetic Particles (SEPs) are among the most dangerous transient effects of solar activity. Representing hazardous radiation, SEPs may adversely affect the health of astronauts in outer space and therefore can endanger current and future space exploration. In this work, we consider the important problem of developing "all-clear" forecasts of Solar Proton Events (SPEs). First, we highlight our progress in developing an online-accessible database that integrates a variety of solar and heliospheric data, metadata, and descriptors related to SPEs. Second, we construct daily forecasts of

Solar Proton Events based on the properties of magnetic fields in Active Regions (ARs), preceding soft X-ray and proton fluxes, and statistics of solar radio bursts. Machine learning (ML) is applied as an artificial neural network of custom architecture designed for whole-Sun input. The predictions of the ML model are compared with the SWPC NOAA operational forecasts of SPEs. Our preliminary results indicate that 1) for AR-based predictions, it is necessary to take into account ARs at the western limb and on the far side of the Sun, 2) characteristics of the preceding proton flux are the most important for prediction, 3) daily median properties of ARs may be excluded from the forecast without significant performance loss, and 4) ML-based forecasts outperform SWPC NOAA forecasts in situations in which failing to predict an SPE event is very undesirable.

84. **Viacheslav Sadykov**, Georgia State University, USA
Compression of Solar Spectroscopic Observations: Case Study of Mg II k Spectral Line Profiles Observed by NASA's IRIS Satellite
Viacheslav Sadykov (GSU), Irina Kitiashvili (NASA ARC), Alberto Sainz Dalda (LMSAL), Vincent Oria (NJIT), Alexander Kosovichev (NJIT), Egor Illarionov (Moscow SU)

In this study, we investigate the compression of the Mg II k spectral line profiles observed in quiet Sun regions by NASA's IRIS satellite by extracting deep features. For the analysis, we use a data set obtained on April 20th, 2020, at the solar disc center, which contains $\sim 300,000$ individual Mg II k line profiles. For the compression, we use an autoencoder of the varying embedding layer size. An early stopping criterion was implemented to prevent the model from overfitting. Our results indicate that it is possible to compress the spectral data by a factor of 27 and reduce the data dimensionality from 110 to 4, while an average reconstruction error comparable to the variations in the line continuum. The mean square error and the reconstruction error of even statistical moments sharply decrease when the dimensionality of the embedding layer increases from 1 to 4 and almost stop decreasing for higher numbers. The observed occasional improvements in training for values higher than 4 indicate that a better compact embedding may potentially be obtained if other training strategies and longer training times are used. The features learned for the critical four-dimensional case can be interpreted in terms of the line physical characteristics. In particular, three of these four features mainly control the line width, line asymmetry, and line dip formation, respectively. The results confirm the value of this approach for feature extraction, data compression, and denoising.

85. **Lána Salmon**, School of Physics and Centre for Space Research, University College Dublin, Ireland
Wavelet-based feature extraction from gamma-ray burst light curves
Lána Salmon, Lorraine Hanlon, Antonio Martin-Carrillo, Michael Fop,Brendan Murphy

Gamma-Ray Bursts (GRBs) are the most luminous electromagnetic explosions in the Universe and many thousands have been detected by numerous spacecraft since their discovery in the late 1960's.

GRBs are traditionally classified as long (durations longer than 2s) or short (durations less than 2s). Short GRBs have harder spectra and are linked to the merger of compact objects such as neutron stars, while the long GRBs are spectrally softer and associated with the collapse of massive stars. Some previous analyses, based on summary GRB data (e.g. spectral fit parameters, peak energies and durations), have identified the presence of more than two groups. In particular, an 'intermediate' group, which may be associated with a different formation channel, has been tentatively identified in several studies. An alternative approach is to attempt to classify GRBs based on their complex, highly variable, gamma-ray time profiles in different energy bands. In this work, wavelet-based feature extraction has been applied to GRB time-series data. Principal Component Analysis is used to reduce the dimensionality of the returned wavelet coefficients, and t-distributed Stochastic Neighbourhood Embedding is used to visualise the transformed dataset. Clusters are identified using Gaussian Mixture model-based clustering, and the optimal number of groups is chosen using the Bayesian Information Criterion. I will present the results of this analysis applied to several large GRB data-sets.

86. **Francesco Schillirò**, Istituto Nazionale Astrofisica, Osservatorio astrofisico di Catania, Italy
Segmentation of spectroscopic images of the low solar atmosphere by the self-organizing map technique
Francesco Schillirò; Paolo Romano

We describe the application of semantic segmentation by using a self-organizing map (SOM) technique to a high spatial and spectral resolution dataset acquired along the Hα line at 656.28 nm by the Interferometric Bi-dimensional Spectrometer, installed at the focus plane of the Dunn Solar Telescope.The dataset consists of a datacube of 750x350 pixel images taken in 17 spectral points along the Hα 656.28 nm line. We used the images to extract some physical parameters by the Gaussian fit of the line profile.
From these parameters and the datacube itself, with a 'non supervised' approach, using Cluster Analysis we derived a method of calculating an 'optimal' number of independent features.
The SOM technique is able to perform a perfectly suitable segmentation of the multispectral datacube: differently from other skeletonization methods, SOM segmentation is able to identify many structures at the same time, without using the simple selection of several thresholds, achieving a good correspondence between the features and the physical properties of the identified structures.
Moreover the algorithm described in this presentation shows a computational efficiency, can be parallelized and exported on heterogeneous calculation platforms, having a computational speed-up (e.g. GPU, FPGA). The work is in progress in order to implement a front-end framework allowing a complete automatic analysis in almost real-time regime.

87. **Carl Schneider**, Dutch National Center for Mathematics and Computer Science (CWI), The Netherlands
A Machine-Learning-Ready Software Framework Prepared for the SoHO and SDO Missions for Space Weather Readiness
Carl Shneider, Andong Hu, Ajay K. Tiwari, Monica G. Bobra, Karl Battams, Jannis Teunissen, Enrico Camporeale.

We present a software framework that allows for user-defined selection criteria and a range of preprocessing steps to generate a standard data set from solar images. Our software framework works with all image products from both the Solar and Heliospheric Observatory (SoHO) mission as well as the Solar Dynamics Observatory (SDO) mission. We discuss a data set produced from SoHO mission's multi-spectral images which is both free of missing or corrupt data and is temporally synced making it ready for input to a machine learning system. Machine-learning-ready images are a valuable resource for the community because they can be used, for example, for forecasting space weather parameters. We illustrate the use of this data with an application of a deep convolutional neural network (CNN) to a subset of the full SoHO data set in an effort to provide a 3-5 day-ahead forecast of the north-south component of the of the interplanetary magnetic field (IMF) observed at L1. We present baselines from applying a Gaussian Naive Bayes classifier and CNN methodology.

88. **Anastasia Marie Seifert**, Institute of Space Sciences and Astronomy, Malta
Mask R-CNN based FRB Detection in Noisy Environments
Anastasia Marie Seifert, Andrea De Marco, and Kristian Zarb Adami

The automatic detection and segmentation of fast radio bursts (FRBs) from radio telescopes is extremely useful for instruments with high data throughput such as the Square Kilometre Array. In this paper, we apply a recent deep learning technique to scan channelised spectra for the detection and segmentation of FRBs in simulated highly noisy backgrounds, as well as with injected RFI contamination. Our dataset consists of simulated dispersed FRBs and Green Bank Telescope (GBT) telescope observations were used for backgrounds including RFI, with the simulated events injected at different Signal-to-Noise ratios. This work evaluates the use of Mask R-CNN to be able to detect FRBs in harsh conditions whilst avoiding the need to correct for dispersion before running a more standard FRB detection pipeline. We evaluate our model using the Average Precision (AP) metric at select Intersection of Union (IoU) for object detection and instance segmentation tasks. This paper will also describe the optimal parameters for the task of FRB detection for a Mask R-CNN implementation. The implementation is publicly available at https://github.com/radastro/FRBMaskRCNN/.

89. **Federico Siciliano**, Sapienza University of Rome, Rome
Forecasting SYM-H Index: A Comparison Between Long Short-Term Memory and Convolutional Neural Networks
F. Siciliano, G. Consolini, R. Tozzi, M. Gentili, F. Giannattasio, P. De Michelis

Forecasting geomagnetic indices represents a key point to develop warning systems for the mitigation of possible effects of severe geomagnetic storms on critical ground infrastructures. Here we focus on SYM-H index, a proxy of the axially symmetric magnetic field disturbance at low and middle latitudes on the Earth's surface. To forecast SYM-H, we built two artificial neural network (ANN) models and trained both of them on two different sets of input parameters including interplanetary magnetic field components and magnitude and differing for the presence or not of previous SYM-H values. These ANN models differ in architecture being based on two conceptually different neural networks: the long short-term memory (LSTM) and the convolutional neural network (CNN). Both networks are trained, validated, and tested on a total of 42 geomagnetic storms among the most intense that occurred between 1998 and 2018. Performance comparison of the two ANN models shows that (1) both are able to well forecast SYM-H index 1h in advance, with an accuracy of more than 95% in terms of the coefficient of determination R2; (2) the model based on LSTM is slightly more accurate than that based on CNN when including SYM-H index at previous steps among the inputs; and (3) the model based on CNN has interesting potentialities being more accurate than that based on LSTM when not including SYM-H index among the inputs. Predictions made including SYM-H index among the inputs provide a root mean squared error on average 42% lower than that of predictions made without SYM-H.

90. **Andy Smith**, Mullard Space Science Laboratory, University College London, UK
Forecasting the Probability of Large Rates of Change of the Surface Magnetic Field in the UK
A. W. Smith, C. Forsyth, I. J. Rae, T. M. Garton, M. R. Bakrania, T. Bloch, C. M. Jackman

Rapid changes in the surface geomagnetic field can induce potentially damaging currents in conductors on the ground; this is a critical consideration for the operation of power networks and pipelines. Forecasting intervals when there may be a risk of large induced currents would enable mitigating action to be taken. Several physical drivers of such field variability exist, including solar wind pressure pulses, geomagnetic storms and substorms. These phenomena are complex, but are ultimately driven by the coupling and interaction of the magnetosphere with the solar wind.
We assess the ability of three distinct machine learning model architectures to skilfully process the time history of the solar wind and provide a probabilistic forecast as to whether the rate of change of the ground magnetic field will exceed specific, high thresholds in the UK. The three models tested are a feed forward neural network, a convolutional network and a recurrent network.
We benchmark the performance of the models using several metrics, and use several example magnetospheric storms to highlight the conditions and processes during which the models perform best, as well as areas of improvement. Finally, we assess how increasing the input time history of the solar wind provided to the models, as well as changing the horizon with which the forecast is required, impact the skill and reliability of the model predictions.

91. **Grant Stephens**, The Johns Hopkins University Applied Physics Laboratory, USA
Empirically picturing the global magnetosphere during storms and substorms by data mining spaceborne magnetometer measurements
Grant Stephens, Mikhail Sitnov, Eric Winter

Geomagnetic storms and substorms are two of the most prominent space weather phenomena. Recently, the synthesis of data-mining algorithms along with flexible empirical magnetic field models have allowed for unprecedented reconstructions of the morphology and evolution the magnetospheric magnetic and electric fields during these dynamic events. In this approach, the combined magnetosphere storm-substorm state is characterized by the Sym-H and AL indices, their time derivatives, and the solar wind electric field vBz. The k-Nearest Neighbors algorithm is used to mine a historical database of spaceborne magnetometer missions to form a constellation of observations from times when the magnetosphere was in a similar configuration as the event of interest. The constellation of data is then used to fit empirical models utilizing general expansions to describe the equatorial and field-aligned current systems. The models capture the primary features of storms, including the formation of the westward and eastward ring current and pressure distributions, and substorms, such as the thinning and rapid dipolarization of the magnetotail during the growth and expansion phases respectively.This class of models is currently being rewritten in the Python programming language, and will eventually be incorporated into the 'Python in Heliophysics Community' (PyHC). This will enable the models to integrate with other PyHC projects while also leveraging the powerful mathematical libraries that exist in Python.

92. **Zena Stevenson**, Klipsch School of Electrical & Computer Engineering, New Mexico State University, USA
Using Fully Convolutional Neural Networks to Infer Solar Magnetic Structure from Extreme Ultraviolet Image
Zena Stevenson, Laura E. Boucheron

Recent applications for fully convolutional neural networks (FCNNs) have included the prediction of an image. This has been used extensively for image segmentation, style transfer, and translation between image modalities. Here we study the use of a UNet-based FCNN originally proposed to predict fluorescence microscopy images from transmitted light images of cells. Using data from NASA's Solar Dynamics Observatory, we train a similar FCNN to translate extreme ultraviolet (304 A) images of active regions on the Sun into predicted unsigned line-of-sight solar magnetograms. These SDO data comprise a larger volume and variety than used in the cellular microscopy application. We first present small-scale experiments with similar training data volume to the cellular microscopy images, using 30 training pairs from a single active region at a time. Using normalized mean-squared error and structural similarity index to compare predictions, we find these small scale experiments demonstrate similar success to the cellular microscopy experiments. We next present preliminary results from larger scale experiments using several thousand image pairs for training, first drawn from 10 active regions and then from 52 active regions. We find that this is a promising application for this type of neural network and expect that future work will be able to train a model that can produce quality predictions when working with even higher volumes of data.

93. **Mirko Stumpo**, INAF-Istituto di Astrofisica e Planetologia Spaziali, Italy
Machine learning approach for the ESPERTA forecasting tool of solar proton events
M. Stumpo, S. Benella, M. Laurenza, T. Alberti, G. Consolini, M.F. Marcucci and V. Quattrociocchi

Several techniques have been developed in the last two decades to forecast the occurrence of Solar Proton Events (SPEs), which are mainly based on the statistical association between the > 10 MeV proton flux and precursor parameters. We reinterpret the ESPERTA model (Laurenza et al., 2009) in the framework of machine learning. ESPERTA is a model providing a prediction of SPEs after the occurrence of $>$ M2 X-ray bursts that takes as input parameters the flare heliolongitude, the soft X-ray fluence and the 1 MHz radio fluence. We find that by applying a cut-off on the heliolongitude of the $>$M2 flares, we are able to reduce the False Alarm Rate (FAR) of the model. The cut-off is set to E20 where the cumulative distribution of $>$M2 SPE-associated flares shows a break, which reflects the poor magnetic connection between the Earth and the Sun eastern locations. The best performances are obtained by using the SMOTE algorithm, leading to probability of detection (POD) of 0.85 and a FAR of 0.38. Nevertheless, we demonstrate that a relevant FAR on the predictions is a natural consequence of the sample base rates. From a Bayesian point of view, we found that the FAR contains explicitly the prior knowledge about the class distributions. This is a critical issue of any statistical approach, thus we discuss the importance of performing the model validation by preserving the class distributions within the training and test datasets.

94. **Hu Sun**, University of Michigan, Ann Arbor, USA
Improved and Interpretable Solar Flare Predictions with Spatial and Topological Features of the Polarity-Inversion-Line Masked Magnetograms
Hu Sun, Ward Manchester, Yang Chen

Many recent efforts undertake solar flare prediction and classification using the Space-weather HMI Active Region Patch (SHARP) parameters as the predictors. The SHARP parameters are scalar quantities calculated from spatial averaging or integrating physical values defined over the two-dimensional image plane of the vector magnetic field. The SHARP parameters are representative of the average structure and total free energy of the magnetic field, but possess no detailed information of the spatial distribution of the physical quantities. In our project, we construct two new sets of features to expand flare classification. The first set uses the idea of topological data analysis to summarize the geometric information of the distributions of various SHARP parameters. The second set is derived from the tools of spatial statistics used here to summarize the spatial variations of the vertical magnetic field component Br, and find the clustering pattern of pixels with high flux values. To isolate data most relevant to the flare, all the features are constructed within the regions near the polarity inversion line (PIL). The classification performances obtained using the new features are compared against those from SHARP parameters (also along PIL), revealing that the new features can improve the skill of the flare classification model and that the new features tend to have higher feature importance, especially the spatial statistics features over the SHARP parameters. These results show that by using the Br channel alone, one can still derive predictive features for flare classification that are of comparable or superior value to the SHARP parameters derived from the full vector field.

95. **Sujitra Sutthithatip**, Cranfield University, UK
The current stage of AI in aerospace applications
Sujitra Sutthithatip, Suresh Perinpanayagam, Sohaib Aslam

In this era, Artificial Intelligence (AI) has been well-known as a machine that is capable of doing things like humans. The growth of AI technology can benefit humans in unsafe and time-cost situations such as aerospace tasks. This technology advancement facilitates human decision-making in crisis events like flight control operation, and with the pros of dealing with massive data, it helps to predict subsequent events in aircraft maintenance. Likewise, AI is also used as a tool to increase passenger satisfaction. The exploiting AI in aerospace arises in a state of applying machine learning models as a simple classifier, and neural network models in sophisticated problems. Whilst the current AI development state carries out the ability of self-driving, motion recognition, and ethical and privacy issues. These technologies come to be a key role to improve in autonomous scenarios like autonomous navigation, real-time vehicle health monitoring, flight prediction, diagnostic and prognostic. However, At the data level, other learnings are recommended to present better performance; for example, Distributed and parallel learning are selected to reduce the suffering of the data volume of learning models in either large or tiny scales of data which might cost infinite computing time. Also, representation learning is chosen when the variety of different types of data such as structured, semi-structured, and unstructured sources manipulate non-linearity, high-dimensionality, and heterogeneous characteristics for the dataset. When the occurrence of a feature changes over time, the feature selection which relies on time range should be considered. Moreover, in case of uncertainty and incompleteness data where the feature is controlled by various values, deep learning is preferably exploited.

96. **Brian Swiger**, University of Michigan, Climate and Space Sciences and Engineering, USA
Connecting the solar wind to the near-Earth magnetospheric plasma sheet through deep learning
Brian Swiger, Michael Liemohn, Natalia Ganushkina

Suprathermal (1-100keV) electron flux in the near-Earth plasma sheet varies with solar wind and interplanetary magnetic field (IMF) conditions. Ionospheric outflow, which is influenced by solar extreme ultraviolet (EUV) photons, also plays a role in regulating the near-Earth plasma sheet. Understanding how the plasma sheet behaves in relation to solar EUV flux, solar wind, and IMF variations is crucial for inner magnetosphere dynamics prediction. We developed a machine-learned, neural network model with inputs of upstream solar wind, IMF, and solar EUV flux to predict plasma sheet electron flux. The target data for our model comes from THEMIS mission samples of the plasma sheet from 2008-2020. The full feature set includes individual solar wind/IMF parameters (sourced from OMNI), solar wind-magnetosphere coupling functions (calculated from OMNI), solar EUV flux (FISM-2 model output) and plasma sheet sampling location (extracted from THEMIS data). We discuss hyper-parameter tuning using Bayesian optimization. We rank feature importance, extracted by calculating and interpreting Shapley values using the DeepSHAP method. Initial results indicate that the most important features for model prediction are sampling location, solar wind speed, and IMF Bz. In contrast, coupling functions had very little impact on model output. We show how the model performs very well with the overall trend of plasma sheet suprathermal electron flux, yet does not fully capture transient events.

97. **Daniele Telloni**, National Institute for Astrophysics, Astrophysical Observatory of Torino, Italy
Statistical Methods Applied to Space Weather Science
D. Telloni

All forecasting models of solar phenomena causing geomagnetic storms are based on remote-sensing observations of the Sun and their direct identification in satellite's coronagraphic images. They provide warnings 1 to 4 days in advance of the geomagnetic storm, even if predictions (often significantly different depending on the model) suffer from large uncertainties. Prediction methods based on in-situ measurements acquired at L1 are nowadays not available, even if this complementaryapproach to forecasting space weather phenomena would allow much more accurate (though shorter) alerts. Statistical studies based on Wind in-situ survey data allowed (1) the development of the first in-situ data-based tool for detecting Coronal Mass Ejections at the Lagrangian point L1 and for forecasting their geo-effectiveness. This provides an alert lying, with a 98% confidence level, between 2 and 8 hours before a geomagnetic storm. In-situ statistical investigation of solar-terrestrial relationship has led also to two other important results: (2) the derivation of an empirical law for a proper forecasting ofthe upper limit of the intensity of any geomagnetic disturbance based on the solar wind energy derived at L1 and(3) thecorrelation between long recovery phases of geomagnetic storms and the presence of Alfvénic turbulent plasma flows following the geomagnetic driver. This talk summarizes all the recent results achieved by applying statistical methods to space weather science.

98. **Ajay K Tiwari**, Centrum Wiskunde and Informatica, Amsterdam
Predicting arrival time for CMEs: Machine learning and ensemble methods
Ajay K Tiwari, Enrico Camporeale, Jannis Teunissen, Raffaello Foldes, Gianluca Napoletano, and Dario Del Moro

Coronal mass ejections (CMEs) are arguably one of the most violent explosions in our solar system. CMEs are also one of the most important drivers for space weather. CMEs can have direct adverse effects on several human activities. Reliable and fast prediction of the CMEs arrival time is crucial to minimize such damage from a CME. We present a new pipeline combining machine learning (ML) with a physical drag-based model of CME propagation to predict the arrival time of the CME. We evaluate both standard ML approaches and a combination of ML + probabilistic drag based model (PDBM, Napoletano et al. 2018) on the database of more than 200 CMEs. We analyzed and compared various machine learning algorithms to identify the best performing algorithm for this database of the CMEs. We also examine the relative importance of various features such as mass, CME propagation speed, and height above the solar limb of the observed CMEs in the prediction of the arrival time. The model is able to accurately predict the arrival times of the CMEs with a mean square error of 8.8 hours. We also explore the differences in prediction from ML models and ensemble predictions method namely P-DBM model. We also present a way to predict the distribution of the parameters of the PDBM model just using the physical properties of the CMEs.

99. **Alessio Troiani**, Department of Mathematics, University of Padova, Italy
Lonely planets and light belts: the Statistical Mechanics of Gravitational Systems
G. Pinzari, B. Scoppola, A. Troiani Dipartimento di Matematica "Tullio Levi-Civita" Universitá di Padova Via Trieste, 63 – 35121 Padova (Italy)

We propose a notion of stability, that we call "-stability, for systems of particles interacting via Newton's gravitational potential, and orbiting a much bigger object. For these systems the usual thermodynamical stability condition, ensuring the possibility to perform the thermodynamical limit, fails, but one can use as relevant parameter the maximum number of particles that guarantees the "-stability. With some judicious but not particularly optimized estimates, borrowed from the classical theory of equilibrium statistical mechanics, we show that our model has a good fit with the data observed in the Solar System, and it gives a reasonable interpretation of some of its global properties. In particular, we show that this notion of stability is consistent with the observed power law distribution of the masses of the asteroids in the main belt and provides a "thermodynamical" justification to the "Titius-Bode" law for the distances of planets from the Sun. Moreover we show that to have "-stability the total mass of the objects orbiting the star must go to zero as their number grows to infinity.

References

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100. **Thorold Tronrud**, Universidad Andres Bello, in Santiago, Chile
Machine Learning for Galactic Archaeology
Patricia Tissera (Pontificia Universidad Catlica), and Facundo Gomez (Universidad de La Serena)

Present-day surveys are providing exquisite information about stellar population distributions in the MW, allowing us to reconstruct its formation history, however it can be difficult to separate stars formed in-situ from those that have been accreted over the course of our galaxy's evolution. We introduce a probability-based binary classification method to identify accreted stars in galactic discs using a neural network trained on the age and chemical properties of disc and halo stars. We implement this method across multiple suites of simulations, and quantify the performance of the model in both the recovery of accreted stars, and rates of false positives to build a robust understanding of the model's strengths and weaknesses.

This method is designed to be applied to data collected from observational surveys to both eliminate spurious stellar data from the disc for modelling of galactic chemical evolution. More importantly, it can be applied to flag and isolate accreted stars in the Galactic disc in order to elucidate the accretion history of the Milky Way.

101. **Juan Alejandro Valdivia**, Departamento de Fisica, Facultad de Ciencias, Universidad de Chile, Chile
Neural network-based method to characterize the robust interactions between geomagnetic storms and substorms

Sylvain Blunier[1], Jose Rogan[1,2], Benjamin Toledo[1,2], Pablo Medina[1], Juan Alejandro Valdivia[1,2]
[1]Departamento de Fsica, Facultad de Ciencias, Universidad de Chile; [2] Center for the Development of Nanoscience and Nanotechnology

The Earth magnetic field is constantly whipped by the solar wind, a plasma of ions and electrons that permeates the whole Solar System. Understanding the dynamic between the magnetosphere and the outer space medium is essential since our modern society relies more and more on technology that can be affected by these phenomena.
4pt] In order to characterize the interaction of the solar wind - magnetosphere - ionosphere system, many geomagnetic indices (GI) have been introduced. Among them, SYM-H has been implemented to measure its eastern component in equatorial regions in order to capture the effects of the ring current at ground level with minute time resolutions. In the polar region the Auroral Electrojet index measures the amplitude of the envelope of the perturbations to the magnetic field.

The time-series generated by these GIs reveal that the response of the magnetosphere to solar wind varies significantly with latitude and longitude. In addition, complementary observations such as the high concentration of oxygen ions in the ring current during active periods, suggest that the magnetosphere is also a dynamic driven mutliscale system with coupled subsystems. Thus, in order to model it accurately, a correct understanding of the coupling of its subsystems is also necessary. And here Machine learning approaches that are particularly designed as a system science discovery technique [1], can be quite useful.

We propose, following the strategy described in [1], a system science discovery method, based on neural networks (NN) trained to forecast GIs, that are capable of highlighting some properties of storm-substorms interactions, such as the most predictable variable, or the most significant inputs and time delay that should be considered in the forecast. Also we present considerations on the efficiency of the prediction depending on different NN architectures. Our method gives considerations that should be taken into account to construct forecasting models of coupled subsystems, such as storms - substorms subsystems. In addition, it provides a new interdisciplinary method that can give clues on how NNs are working.

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102. **Olga Verkhoglyadova**, Jet Propulsion Laboratory, Caltech, USA

Approaches to identification of high-density TEC regions in ionospheric global maps

Olga Verkhoglyadova (1), Jacob Kosberg (1), Natalie Maus (2) and Xing Meng (1)
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2) Colby College, Waterville, ME

Global ionospheric state is frequently characterized by the total electron content (TEC) that is vertically integrated electron density. Global ionospheric maps (GIMs) are gridded 2D data products for global TEC binned in latitude, longitude, and time steps. High density regions (HDRs) of TEC are the characteristic feature of a GIM, but their occurrences are not well understood nor their correlation with ionosphere drivers sufficiently studied. Additionally, forecasting of intense TEC regions is important for space weather, and the inclusion of ionosphere driver datasets in such prediction models must be physically and statistically justified. Therefore, a database of HDRs spanning many years and their statistical analysis are needed to clarify physics behind their formation and explore their forecasting.

We based our research on GIMs from 2000 through 2017 produced by JPL. We apply computer vision and statistical analysis methods for GIM characterization to explore occurrences and locations of HDRs in connection with multiple external drivers. The study is aimed to understand causal connections and evaluate relative importance of the major ionosphere drivers with robust significance tests toward the inclusion of ionosphere driver datasets in experimental forecasting models. We present our approaches to identification of HDRs based on different algorithms and the first results of a statistical analysis of the HDR occurrence timeseries in correlation to ionosphere drivers.

103. **Giuseppe Vizzari**, University of Milano-Bicocca, Italy
Presented jointly by: Thomas Cecconello, University of Milano-Bicocca and Cristobal Bordiu, INAF, Italy
Towards a Modern Unsupervised Machine Learning Approach to the Analysis of Astrophysics Images
Giuseppe Vizzari, Thomas Cecconello (University of Milano-Bicocca), Cristobal Bordiu, Filomena Bufano, Eugenio Schisano, Eva Sciacca (INAF)
Next generation astronomical facilities such as the Square Kilometre Array will generate an overwhelming volume of data at a rate that cannot be matched by our ability to make sense out of them.

Sometimes it is *impossible* to use supervised techniques: the studied phenomena are object of intense study, *classification schemes are still to be defined*. Automated/semi-automated tools are needed to support this kind of research: machine learning can be an instrument in an overall flow including domain experts and computer scientists. Adopted machine learning approaches need to be unsupervised, employing just the input data as a teacher. The workflow provides two steps: (i) achieving a compact representation of images by means of autoencoders, shifting the analysis from cumbersome representations to compact vectors in a latent space, and (ii) clustering points associated to images of the starting dataset to suggest patterns to the domain experts that will evaluate their potential physical meaning. We will report on ongoing experience in which this workflow is being applied within the H2020 NEANIAS project.

The first application concerns the analysis of infrared and radio images of Supernova Remnants (SNRs), whose study is fundamental to understand the galactic structure and composition.

The second application is aimed at the analysis of images associated to compact sources (clumps) that could lead to interesting innovative insights on star formation.

104. **Simon Wing**, The Johns Hopkins University Applied Physics Lab, Laurel, MD, USA
Modeling radiation belt electrons with information theory and neural networks
Simon Wing[1], Sasha Ukhorskiy[1], Drew Turner[1], Jay Johnson[2], Tom Sotirelis[1], Romina Nikoukar[1], Giuseppe Romeo[1], Alex Boyd[3], and Kiley Yeakel[1]
[1]The Johns Hopkins University Applied Physics Lab; [2]Andrews University;
[3]The Aerospace Corporation

An empirical model of radiation belt electrons is developed using RBSP data 2013-2018. The model inputs the solar wind and magnetospheric parameters and outputs radiation belt electron phase space density (psd). The process of selecting input parameters is complex. Many solar wind and magnetospheric parameters are correlated or anticorrelated with one another, making it difficult to determine which parameters would carry relevant and which would carry redundant information. Information theory is used to determine the relevant input parameters and their response lag times. It is also used to determine the effect of solar wind parameters as a function of L^*. The input parameters are ranked based on their information transfer to the radiation belt electrons. Using this ranking as a guide for selecting input parameters, the radiation belt electron model based on neural networks is developed. The preliminary result shows that the model predictive efficiency (PE) is ~ 0.66, which is comparable to those obtained in some previous models.

105. **Yen-Jung Wu**, Space Sciences Lab, UC Berkeley, USA
Application of deep learning on integrating cross-satellite and multi-field measurements in Earth's upper atmosphere
Yen-Jung Wu and ICON team

The Ionospheric CONnection Explorer (ICON) and Global-scale Observations of the Limb and Disk (GOLD) are two of the latest NASA missions monitoring Earth's upper atmosphere. ICON is on a low-inclination angle orbit and equipped with instruments that measure the neutral drivers of the ionosphere and at the same time the response of the ionosphere to those drivers. A limitation of single-spacecraft missions in low-earth orbit including ICON is that only one measurement at one location is made at each time. GOLD, on the other hand, is on a geostationary orbit above the Americas and the Atlantic Ocean, which allows a continuous but spatially limited view of the globe. Due to the spatial and temporal entanglement and limited coverage of data, monitoring the day-to-day variation of the upper atmosphere from space-borne observations is a challenging task and requires support from whole atmospheric modeling. Since the upper atmosphere is a continuous medium in both time and space, it is reasonable to assume that the upper atmosphere at the current time is highly correlated to the upper atmosphere within a few days in the past. We make use of deep learning architectures such as recurrent neural network (RNN) algorithms to provide computational grids with a memory in space and time, and then train the machine learning model by data from ICON and GOLD without any human bias. In this presentation, we will report the result and challenge of integrating ICON and GOLD observations from a deep learning perspective.

106. **Shasha Zou**, University of Michigan, USA
Specification and Forecast of Ionospheric Total Electron Content Using VISTA and Machine Learning
Shasha Zou, Yang Chen, Hu Sun, Jiaen Ren, Zhijun Hua

In the current era, the ionospheric total electron content (TEC) derived from multi-frequency Global Navigation Satellite System (GNSS) receiver is arguably the most utilized dataset in the ionospheric research area, and also has essential practical importance, as it is the largest naturally occurring error source for GNSS positioning, navigation, and timing (PNT) accuracy. The potential of using the GNSS data as a backbone of the space weather observational system has been demonstrated in the last decade with the GPS system, and as we are moving into the multi-GNSS era, we are at the forefront of a new chapter by combining the traditional space science and the modern optimization and machine learning (ML) algorithms to make a leap forward in the specification and forecasting of ionosphere state and variability. We proposed a new video completion method called the VISTA (Video Imputation with SoftImpute, Temporal smoothing and Auxiliary data), which can be implemented via an optimization algorithm, to specify the global ionosphere TEC maps. The VISTA model is able to capture multi-scale ionospheric TEC structures, such as large-scale storm-enhanced density (SED) and meso-scale equatorial plasma bubbles (EPBs). After constructing the database using VISTA, we apply advanced machine learning tool to forecast the TEC maps. Performance of the new forecasting model is then compared with the forecasting model previously developed using traditional IGS maps and validated against real TEC observations.

107. **Jack Ziegler**, ASTRA Louisville Colorado, USA
New ML Approaches for Nowcasting of Global Auroral Particle Precipitation
Dr. Jack Ziegler, Dr. Ryan Mcgranaghan
We have developed multiple Deep Learning models to predict the global auroral particle precipitation, using the solar wind, geomagnetic indices, and their time histories as input to predict the total electron energy flux, total number flux, and auroral boundaries globally. We show results for nowcasts (prediction at the time of observation). More than 40 satellite years of Defense Meteorological Satellite Program (DMSP) precipitation data provide the observations, which are split into training

and validation sets. DMSP data provide local information along the orbital paths of the spacecraft, and require intensive data treatment. We detail the data preparation process as well as the model development that will be illustrative for many similar time series global regression problems in space weather. We highlight our design of a new pipeline for higher time and spatial resolutions in training, as well as new loss functions and an exploration of a novel grid based approach using transposed convolutional neuralnetworks (inverse CNN) that directly trains with spatial variations from simultaneous satellites.

END ABSTRACTS