Wandering through the Virtual MIST: Autumn MIST 2021 Round-up

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Introduction

In the twilight of another unprecedented year, containing many unique challenges both professional and personal, the annual MIST Autumn Meeting was held on the 25th and 26th November 2021. Due to the on-going impacts of the global pandemic, the usual in-person meeting at Burlington House was once again forced to shift into the virtual domain. However, without the logistical constraints of travel and housing, the meeting was once again well attended with more than 80 scientists, and extended from one to two days.

With the majority of attendees now well versed in the realm of virtual conferences the meeting operated smoothly. Iterating on the lessons of the previous year and compounding upon its successes, the meeting took a slightly different format to the usual, with mornings given entirely over to posters. Once again using the gather.town platform, allowing for avatars to wander around a virtual poster hall facilitating all the conversations and collaborations to occur as might be found in a more traditional physical setting. Oral presentations were scheduled in the afternoons using the all too familiar medium of video conferencing.

This year's Autumn MIST meeting gave us a chance to celebrate the exciting science that has recently been carried out, despite the pandemic, and to catch up with colleagues across the UK who we may now see less often and primarily through screens. With many presenters showing promising preliminary results as well as plans for future studies, the meeting also presented a view into an exciting future, full of novel MIST science. Here, we briefly summarise some of the science presented.

Posters

Opening the meeting on both days, attendees had two entire mornings to wander and explore the virtual poster hall, able to interact with the presenters as well as other colleagues. With an impressive array of 34 posters contributed, the task of visiting each was daunting, but the wide range of topics and outstanding quality of the contributions helped propel attendees onwards.

- **Oliver Allanson** (University of Exeter) Quasilinear diffusion for relativistic wave-particle interactions via a Markov approach
- **Martin Archer** (Imperial College London) How a realistic magnetosphere alters the polarizations of surface, fast magnetosonic, and Alfvén waves
- **Aisling Bergin** (University of Warwick) Burst statistics and empirical distribution of AE and SMR geomagnetic indices across solar cycles 21-24
- **Gemma Bower** (University of Leicester) A statistical survey of horse-collar auroras observed by DMSP SSUSI
- **Jesse Coburn** (Queen Mary University of London) Measurement of the effective mean-free-path of the solar wind protons
- **John Coxon** (University of Southampton) The heavy-tailed distributions of Birkeland currents observed by AMPERE
- **Caoimhe Doherty** (University College London) Flux Transfer Events in the Northern Hemisphere Polar Cusp Under Strong IMF Bx
- **Malcolm Dunlop** (Beihang University) Ring current morphology from MMS observations
- **Joseph Eggington** (Imperial College London) Real-Time Simulations of the Magnetosphere-Ionosphere System: Coupling the Gorgon MHD Code at the Virtual Space Weather Modelling Centre
- **Anna Marie Frost** (University of Reading) Estimating the Open Solar Flux from In-Situ Measurements
- **Laura Fryer** (University of Southampton) 3D GUMICS simulations of northward IMF magnetotail structure
- **Joe Kinrade** (Lancaster University) Revisiting seasonal ionospheric conductivities at Saturn as derived from HST auroral imagery between 2004-2017
- **Adrian LaMoury** (Imperial College London) Magnetosheath jets at the magnetopause: reconnection onset conditions

- **Corentin Louis** (Dublin Institute for Advanced Studies) Observing Jupiter's radio emissions using multiple LOFAR stations: a first case study of Io-decametric emission using the Irish IE613, French FR606 and German DE604 stations
- **Seán McEntee** (Dublin Institute for Advanced Studies) Comparing Jupiter's equatorial X-ray emissions with solar X-ray flux over 19 years of the Chandra mission
- **Jack McIntyre** (Queen Mary University of London) The evolution of the magnetic field spectral index with heliocentric distance in the solar wind
- **Tracy Moffat-Griffin** (British Antarctic Survey) MesoS2D: mesospheric sub-seasonal to decadal predictability
- **Elizabeth O'Dwyer** (Dublin Institute of Advanced Studies) Machine Learning for the Classification SKR emission using Cassini data
- **Lauren Orr** (Lancaster University) Quantitative comparison of high latitude ionospheric electric field models
- **Gabrielle Provan** (University of Leicester) Magnetosphere-ionosphere coupling at Jupiter: Comparison of Juno magnetic field observations with expectations from a steady-state axisymmetric physical model
- **Tianshu Qin** (Lancaster University) Transient Flashes in Saturn's UV Aurora
- **Catherine Regan** (University College London) Investigating the influence of the 2007 global Martian dust storm on the bow shock and induced magnetospheric boundary with ASPERA-3 - Mars Express
- **Beatriz Sanchez-Cano** (University of Leicester) Space Weather detections with housekeeping sensors in the ESA's spacecraft flotilla in the Solar System
- **Robert Shore** (British Antarctic Survey) Strong variation in forecast skill for similar empirical models trained on randomised spans of midlatitude geomagnetic data
- **Andy Smith** (University College London) The Correspondence between Sudden Commencement and Induced Currents; Insights from New Zealand
- **Kevin Smith** (Dublin Institute for Advanced Studies) Machine learning classification of Mercury magnetospheric boundary crossings

- **Gabriel Suen** (University College London) The identification of a magnetic reconnection exhaust in the solar wind using early data from Solar Orbiter
- **Maria-Theresia Walach** (Lancaster University) Super Dual Auroral Radar Network Expansion and its Influence on the Derived Ionospheric Convection Pattern
- **Samuel Walton** (University College London) Examining the Statistical Variation of Electron Pitch Angle Distributions in the Heart of the Outer Radiation Belt During Storm Time
- **Xueyi Wang** (University of Warwick) Spectral Characterisation of Turbulent Fluctuations Seen by Parker Solar Probe
- **Ruoyan Wang** (University of Leicester) Measurements of Intensity and Velocity of Jupiter's H2 and H3+ IR Aurora
- **James Waters** (University of Southampton) A statistical exploration of Auroral Kilometric Radiation observations with Wind during the substorm timeline
- **Dale Weigt** (University of Southampton) Identifying jovian X-ray auroral families: tying the morphology of X-ray emission to associated magnetospheric dynamics
- **Josh Wiggs** (Lancaster University) JERICHO: a Kinetic-Ion, Fluid-Electron Hybrid Plasma Model for the Outer Planets

Earth's Magnetosphere from Space

After a morning of greetings and digesting the initial contributions in the virtual poster hall, attendees sat behind screens ready for the oral presentations. Initiating proceedings **Imogen Gingell** (University of Southampton) presented an analysis of thin current sheet prevalence downstream of the terrestrial bow shock, identified using data from the Magnetospheric Multiscale spacecraft (MMS). The data was first reduced to 1-dimension and it was determined that there was a weak correlation between the number of current sheets and proximity to the bow shock, with the number reducing as the spacecraft moved away. Increasing data dimensionality to 3-dimensions further improved the results obtained with the prevalence of thin current sheets now clearly reducing with distance from the bow shock (see Figure 1). Further, there was also some correlation found between the occurrence of current sheets and proximity to the flanks of the magnetosphere. Finally, there was found to be no clear correlation determined between current sheet

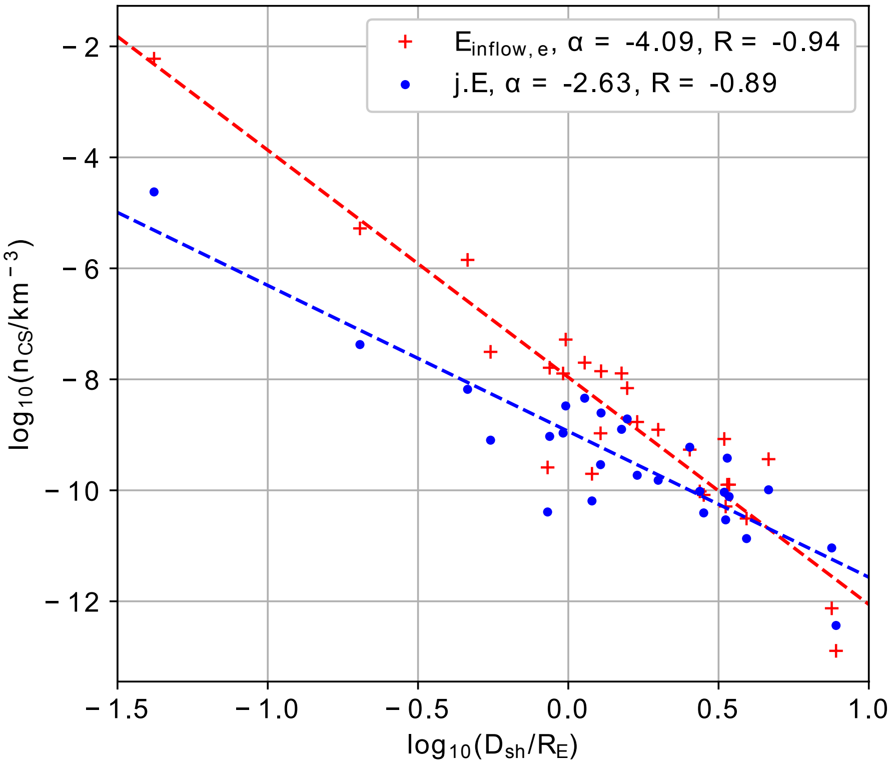

Figure 1: The density of current sheet structures is derived from two measures of energy exchange in the plasma (red and blue). Both methods reveal that the number of current sheets reduces rapidly with distance downstream of Earth's bow shock. *Figure provided by Imogen Gingell* (from Gingell et al. [2021]).

numbers and the orientation of the bow shock and the associated Mach number.

Staying with MMS at the terrestrial bow shock, **James Plank** (University of Southampton) analysed data from the spacecraft, obtaining the magnetic spectrum in order to examine turbulence in the plasma mediums of the solar wind, the bow shock and the magnetosheath. The angle of intersection between MMS and the bow shock effects the length of time it takes to cross it, with shallow angles leading to longer crossing times. It is found for longer, quasi-parallel crossings that the time taken for the turbulent spectrum to transition from an expected configuration found in the solar wind to one in the magnetosheath is also longer. The turbulent spectrum contains additional differences in behaviour depending on the angle of intersection.

Julia Stawarz (Imperial College London) also used MMS to explore turbulence in the terrestrial magnetosheath, specifically looking at instances of magnetic reconnection driven by turbulence. The magnetic topology and conditions found in this region can lead to electron-only reconnection events, which are tied to shorter correlation lengths. Analysing intervals of turbulence, a number of reconnection events were found which can be categorised as electron-only. The electron jet speeds for these events were found to increase as the correlation length decreased and it was determined that heating from the events studied matched previous estimates for the region.

Tom Elsden (University of Glasgow) provided insights on the polarisation properties of 3-dimensional field line resonances (FLR) in the terrestrial magnetosphere, a process in which energy is transferred from the fast magnetohydrodynamic (MHD) to the Aflvénic wave mode. Examining FLR using MHD modelling finds that generalising the process from 2 to 3 dimensions allows resonance paths to break confinement and cross from one L-shell to another. Placing virtual satellites into the modelled space, a range of polarisation signatures were found dependent on the selected location.

Turning our gaze closer to Earth, **Amy Fleetham** (University of Leicester) analysed AMPERE data from 2010 to 2016 in search of current saturation in the polar cap. To investigate this, solar wind parameters were used. These were the solar wind speed, solar wind density, and the southward interplanetary magnetic field (IMF) component, the solar wind electric field and the Milan et al. (2012) coupling parameter. The IMF was also separated out into northwards and southwards components. Interestingly, in the northwards IMF data for the solar wind speed, there appears to be a decrease in the current magnitude. However, there were no signs of the predicted current saturation in the available data. Saturation has been found in previous observations of the cross polar cap potential, but not in the corresponding current magnitudes, this may suggest that ionospheric conductance plays an important part in the strength of the solar wind-magnetosphere-ionosphere coupling.

Earth's Magnetosphere from the Ground

Travelling virtually back onto the Earth, next we heard about ground based instruments being used to probe the terrestrial upper atmosphere into its magnetosphere. Despite many years of MIST science in this area, novel techniques continue to emerge and observing the upper atmosphere remains challenging, with many science questions remaining open.

Shahbaz Chaudhry (University of Warwick) examined Pc waves, ultra-low frequency (ULF) waves measured using ground based magnetometers, during the famous 2015 St. Patrick's day geomagnetic storm using new high resolution data from the SuperMAG network. This was done by constructing a dynamical network of observatories. By constructing a series of nodes and edges across the network, the spatially coherent Pc wave response to the storm can then be characterised. The network coverage during the storm is not homogenous, however it was determined that both long and short ranges respond to storm onset. It was also found that enhancements in the magnetic SME index, which is a proxy for the auroral electrojet, are seen strongly by the network across stations in North America, where no ocean hinders observing magnetic fluctuations.

When trying to understand physical mechanisms often it is convenient to construct physics based models. However, it is also important to ensure that the results from these models reflect measurements and accurately recreate the dynamics that are being studied. **Rosie Hodnett** (University of Leicester) modelled the Ionospheric Alfvén Resonator, a process that occurs when Alfvén waves are reflected at ionospheric boundaries. The model construction was outlined for obtaining harmonic frequency separation. Examining the separation over an entire year, it was determined that the resonance is always greatest in winter months and an interesting double peak is identified in the model. Increasing temporal resolution to hours it can also be determined that at solar maximum harmonic separation is lower throughout a day. Comparing model results to measurements taken by the Eskdalemuir Observatory, some discrepancy is found, which can be attributed to the low resolutions of model inputs.

Elliott Day (Lancaster University) analysed Joule heating at mid-latitudes, comparing estimates from ground-based observations to those obtained using computational models. The estimation process was outlined and the difficulty of obtaining concurrent high quality data from different ground-based instruments was highlighted. However, examining a time when data was available, a turning in the IMF was identified, causing Joule heating. Comparing this data to outputs from the Thermosphere-Ionosphere-Electrodynamics General Circulation Model (TIEGCM), it was found that the model lacks the variability seen in the data and misses some of the heating. It was also determined that the Pederson conductivity model used as an input substantially impacts the results, so care must be taken when selecting this.

Constructing physics based models to improve our understanding of underlying physical mechanisms, and then comparing these to observations is one approach. It is also possible to apply machine learning algorithms directly to datasets and have these classify and identify physical dynamics contained within. **Federico Speranza** (University College London) presented a convolution neural network (CNN) for the classification of auroral images. CNNs try to replicate human pattern recognition, extracting features from input data and in this case identifying 7 different classes of auroral morphology. Testing a range of different CNNs it was decided that the simplest network, ResNet50, would be utilised, although this was better at identifying some classifications than others. Ensemble learning was used to try and improve identification accuracy and the problem of overlapping classes in images was highlighted. It is hoped with continued development that future networks with be able to accurately determine the physical parameters of auroral images.

The Solar-Terrestrial System

Turning our attention next to the larger solar system, we first started by examining our local star and its connection back to the terrestrial magnetospheric system. **Nachiketa Chakraborty** (University of Reading) used casual inference, a technique which identifies unique precursors to particular events and then uses these as a predictive mechanism, to examine the drivers of solar wind and their application to space weather forecasting. The drivers utilised for this study were the sunspot number, the co-rotational lead and latitudinal offset in spacecraft measurements. From these it was determined that using a combination of the co-rotational lead with latitudinal offset yielded the most information with a strong influence on forecasting.

Following solar outflows, **Simon Opie** (University College London) has been using the new high-resolution Solar Orbiter data-sets to explore kinetic instabilities and turbulence in the solar wind. Using this data it is possible to construct a series of 'Brazil' plots from data points within the solar wind, categorising the plasma as stable or turbulent as well as identifying the type of instability. An example of these are shown in Figure 2. Analysis of these plots finds that the angle between solar wind propagation and that of the solar magnetic field is strongly correlated with which instability is prevalent in the plasma, along with an additional dependence on the temperature anisotropy. Additionally, for instabilities to reach maximum growth, a spatial scale of around 8 wavelengths is optimal.

Mike Lockwood (University of Reading) gave us 'a good look under the hood' of solar wind- magnetospheric coupling functions, devices for combining interplanetary parameters to predict responses to space weather. This

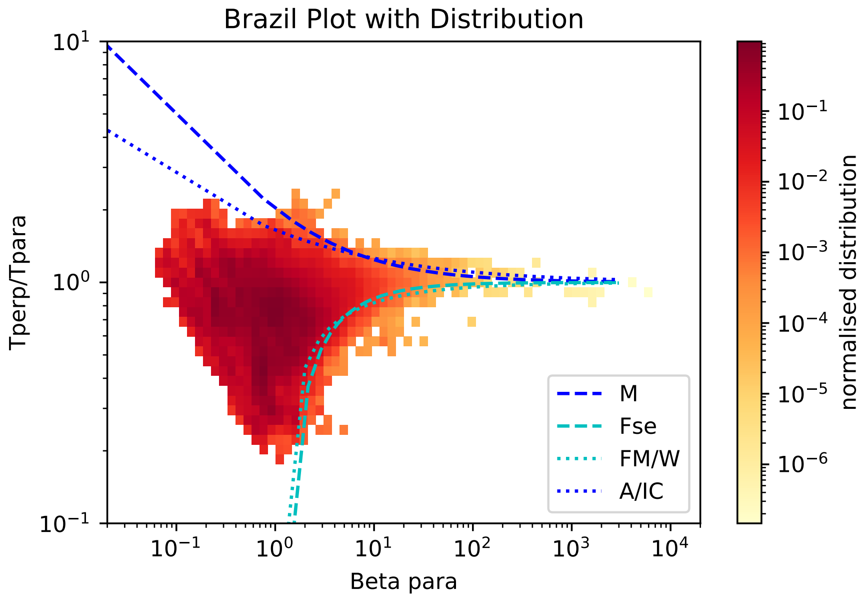

Figure 2: 'Brazil' plot of the solar wind from Solar Orbiter data for 7-12/10/2020 showing distribution of protons in the parameter space defined by plasma beta and temperature anisotropy. Instability thresholds for Mirror (M), Oblique Firehose (Fse), Fast Magnetosonic (FM/W) and Ion-Cyclotron (A/IC) modes are shown. Protons occupying 'unstable' space are revealed at the resolution of this data. *Figure provided by Simon Opie.*

study examines many previously overlooked issues in the employment of these functions. Additionally, it identifies that many different coupling functions developed display similar behaviour and possess the same limitations. Therefore, it is important that these are highlighted to ensure new schemes avoid them.

Extraterrestrial Magnetospheres

After considering the solar-terrestrial system, we shifted our focus once again, this time onto the Sun's connection to other planet's magnetospheric systems. **Sophia Zomerdijk-Russell** (Imperial College London) examined the variability of the IMF at Mercury, using the MESSENGER spacecraft, and how this could be used to better understand the internal composition of the planet. By analysing the data at heliospheric current sheet crossing, it was reported that the orientation of the IMF has an appreciable impact on current densities at Mercury's magnetopause. This results in the significant induction of magnetic field at the planetary surface, having a larger impact than the ram pressure of the solar wind. It is hoped that this work will be assisted by the arrival of the BepiColombo mission in the near future.

Finally, **Diego Moral Pombo** (Lancaster University) examined the Jovian ultra-violet (UV) aurorae using images taken by the Hubble Space Telescope and then compared these with images taken in X-ray. Images were identified when both UV and X-ray coverage was present and these then characterised, based on the morphology of the aurorae. This is illustrated in Figure 3. Examining these images in UV it was determined that the external perturbation morphology was the most energetic; injections were clearly recognisable and noon was almost always brighter than dusk. Compared with X-ray emissions, the UV emission was almost always brighter, however the study will need extending to the southern pole in the future. This work provides an excellent example of cross-institutional MIST collaboration as Dale Weigt showed the regions of X-ray activity used by Diego Moral Pombo on his MIST poster. Dale Weigt showed the classifications and analysed the locations of X-ray aurora statistically and with respect to magnetospheric drivers.

References

I. Gingell, S. J. Schwartz, H. Kucharek, C. J. Farrugia, and K. J. Trattner. Observing the prevalence of thin current sheets downstream of earth's bow shock. *Physics of Plasmas*, 28(10):102902, 2021. doi: 10.1063/5.0062520. URL `https://doi.org/10.1063/5.0062520`.

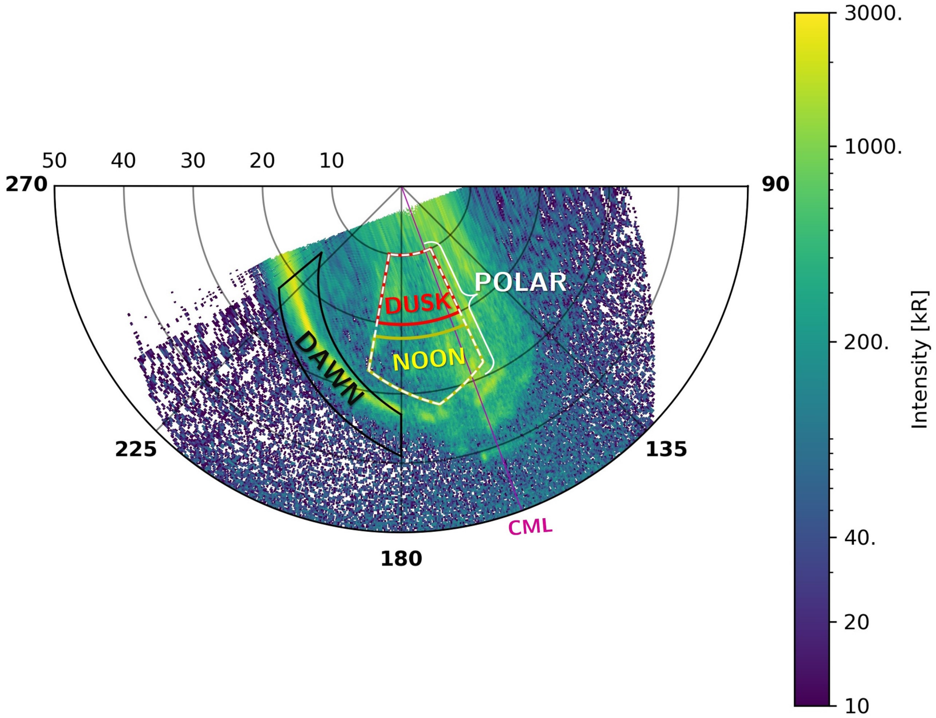

Figure 3: HST image of Jupiter's northern UV aurorae, showing regions of X-ray activity defined by Weigt et al. (in prep.) for comparison. The regions were also shown by the work presented on Dale Weigt's poster. *Figure provided by Diego Moral Pombo.*