

Tuesday, October 1

Long-Term Solar Activity 9:15+0:25

keynote talk

Stellar forcing of exoplanets from the perspective of star-planet interactions

Aline A. Vidotto

Leiden University, the Netherlands

The vast majority of the currently known exoplanets have no counterpart in the solar system. Most of them have significantly closer orbital distances than solar system planets. Additionally, their host stars can be substantially different than the Sun. For these reasons, known exoplanets are often embedded in much harsher particle and radiation environments, leading to stronger interactions between the exoplanet and its surrounding environment. In this talk I will present an overview of how stellar radiative forcing can induce and shape atmospheric escape in exoplanets. I will focus mostly on close-in gas giant planets, whose escaping atmospheres are somewhat easier to observe through spectroscopic transits. I will also present how their escaping atmospheres evolve on billions of years timescales.

Tuesday, October 1

Long-Term Solar Activity 9:40+0:15

contributed talk

Insights into the Solar Dynamo and Activity Cycles from Helioseismology

Alexander Kosovichev (1); Alexander Getling (2); Krishnendu Mandal (1); Valery Pipin (3)

(1) New Jersey Institute of Technology, Newark, U.S.A.; (2) Lomonosov Moscow State University, Moscow, Russia; (3) Institute for Solar-Terrestrial Physics, Irkutsk, Russia

Almost 30 years of uninterrupted helioseismic observations have provided a unique opportunity to investigate long-term variations of the solar interior structure and dynamics associated with the Sun's magnetic activity and get insight into the mechanisms of the solar cycles and formation of active regions. In particular, variations of zonal flows (torsional oscillations) observed from the tachocline to the surface reveal patterns of the dynamo waves responsible for the formation of active regions and polar magnetic field reversals. High-resolution maps of plasma flows in the near-surface shear layer provided detailed measurements of variations in near-surface meridional circulation and convection power coupled to modulations of the convective energy transport by subsurface magnetic fields. We argue that the helioseismology results are consistent with a 3D non-linear MHD dynamo model that includes the formation and emergence of bipolar magnetic regions initiated by the magnetic buoyancy instability in the convection zone. We present a data-driven model of Solar Cycles 23 and 24 based on this dynamo theory, compare the results with the helioseismic, photospheric, and heliospheric observations, and discuss model predictions and future perspectives for helioseismic investigations of the origins of space weather and climate.

Tuesday, October 1

Long-Term Solar Activity 9:55+0:20

solicited talk

**A Window into the Past – Simulating the Sun’ s Historical Photospheric Magnetic Field
using AFT**

Bibhuti Kumar Jha (1), Lisa A. Upton (1)

(1) Southwest Research Institute, Boulder, USA

The Advective Flux Transport (AFT) model is a realistic surface flux transport model that has demonstrated its ability to predict the evolution of the Sun’ s Photospheric Magnetic Field, both on short and timescales. Using the Sunspot Indices and Long-term Solar Observations (SILSO) version 2.0 sunspot-number, we have developed a synthetic active region generator (SARG) catalog based on observed solar active regions. This catalog was then used as the input for magnetic sources in AFT, to create simulations of the evolution of the Sun’ s magnetic field in the past. In order to ensure that the simulations were consistent with solar dynamo mechanisms, the amplitudes of the solar axial dipole moment (i.e., polar fields) at solar-cycle minima were carefully curated by varying the average Joy’ s Law tilt. In this way, we have created a continuous AFT simulation of the evolution of the Sun’s Photospheric Magnetic Field from 1750 to present. The results from this simulation can be used to estimate the solar magnetic open and closed magnetic flux, an crucial ingredient in historical TSI reconstruction.

Tuesday, October 1

Long-Term Solar Activity 10:15+0:15

contributed talk

Solar activity parameters do not follow each other: What is going on in the solar atmosphere?

Kalevi Mursula (1,2); Timo Asikainen (1); Ismo Tähtinen (1); Alexei Pevtsov (2)

”(1) University of Oulu, Space physics and astronomy, Space Climate Group, Oulu, Finland; (2) National Solar Observatory, Boulder, CO 80303, USA ”

”The Sun experienced a period of unprecedented activity during solar cycle 19 in 1950s and 1960s, now called the Modern Maximum (MM). The decay of the MM has changed the Sun, the heliosphere and the planetary environments in many ways. However, this decay may not have proceeded synchronously in all solar parameters. One of the related key issues is if the relation between the two long parameters of solar activity, sunspot number and the solar 10.7cm radio flux, has remained the same during this decay.

Here we use the 10.7cm radio flux, sunspot numbers and several other, independent measures of solar activity in order to study their mutual relations during the decay of MM. We find that, during this overall decay, the 10.7cm radio flux increases relative to sunspot numbers. This is supported by four other radio fluxes measured independently in Japan. All five radio fluxes depict an increasing trend with respect to the sunspot number from 1970s to 2010s. This excludes the possibility for an inhomogeneity in the 10.7cm flux.

Interestingly, the fluxes of longer radio waves increased with respect to the shorter waves, which implies a long-term change in the solar spectrum at radio frequencies. We also find that solar UV irradiance, and the number of active regions also increased with respect to the sunspot number, indicating a difference in the long-term evolution in chromospheric and photospheric parameters.

These results give evidence for important structural changes in solar magnetic fields and solar atmosphere during the decay of the MM when solar activity weakened considerably. We show that these changes are related to the centennial Gleissberg cycle and opposite changes are already ongoing with the increasing solar activity from cycle 25 onwards.”

Tuesday, October 1

Long-Term Solar Activity 10:30+0:20

solicited talk

Sunspot drawings analysis: current status and future trend

Sabrina Bechet

Royal Observatory of Belgium

”Sunspot drawings are a unique source of data to retrieve long-term information on the evolution of the solar cycle.

In this talk we will discuss major challenges concerning the analysis of sunspot drawings, and in particular the need of a general tool available in the solar physics community. Currently there is a lack of homogeneity among the analysed data, and some sunspot drawing collections from all over the world are still not exploited to their full potential, because they are buried in archives, or not in machine readable format. The use of a standard tool for the parameters measurement would make it easier to analyse contemporary sunspot drawings, and especially to fill the inevitable gaps from a single observing station by merging homogeneous data.

We will present our experience at the Royal Observatory of Belgium (ROB), with DigiSun, the in-house software developed for the measurement of sunspot drawings and for the construction of a sunspot catalogue for the local station USET. The software is multi-platform and can handle different drawing formats, which allows its application to collections from other observatories. A first successful international collaboration with the Specola Observatory in Locarno was initiated in 2019. In addition, DigiSun could be used to analyse historical drawings and extend the series of detailed solar parameters further back in the past.”

Tuesday, October 1

Long-Term Solar Activity 10:50+0:15

contributed talk

Long-term variations of solar filaments and active region features detected via machine learning

Qi Hao (1,2); Tianmai Zhang (1); Wutong Lu (1); Ruishuo Chen (3); Yifan Meng (1); Pengfei Chen (1,2)

(1) School of Astronomy and Space Science, Nanjing University, Nanjing, China; (2) Key Laboratory of Modern Astronomy and Astrophysics (Nanjing University), Ministry of Education, Nanjing, China; (3) Department of Mathematics, Nanjing University, Nanjing, China

Solar active regions (ARs) are areas on the Sun with very strong magnetic fields where various activities take place. Filaments (prominences) are one of the typical solar features in the solar atmosphere, whose eruptions often lead to solar flares and CMEs. Therefore, studying their morphological features and their relationship with solar activity is useful in predicting eruptive events and in understanding the long-term evolution of solar activities. A huge amount of data has been collected from various ground-based telescopes and satellites. The massive data make human inspection difficult. For this purpose, we developed automated detection methods for filaments, prominences, and ARs based on machine learning techniques. We applied them to process the data during recent solar cycles. Besides the butterfly diagrams and latitudinal migrations of the filaments, prominences and ARs, the variations of their morphological features and their N-S asymmetries with the calendar years and the latitude bands were analyzed. Most of these statistical results based on our methods are in agreement with previous studies, which also guarantees the validity of our methods. Especially, the tilt angle of dipole in ARs in solar cycle 24 and the rising phase of solar cycle 25 are analyzed and we find that there are 13% and 16% of ARs violate Hale's law, respectively.

Tuesday, October 1

Long-Term Solar Activity 11:25+0:15

contributed talk

Ca II K Polar Network as A Proxy for the Estimation of Historical Polar Magnetic Field of the Sun

Dibya Kirti Mishra (1,2); Bibhuti Kumar Jha (3); Theodosios Chatzistergos (4); Ilaria Ermolli (5); Dipankar Banerjee (1,6,7); Lisa A. Upton (3)

”(1) Aryabhata Research Institute of Observational Sciences, Nainital-263002, Uttarakhand, India; (2) Mahatma Jyotiba Phule Rohilkhand University, Bareilly-243006, Uttar Pradesh, India; (3) Southwest Research Institute, Boulder, CO 80302, USA; (4) Max Planck Institute for Solar System Research, Justus-von-Liebig-Weg 3, D-37077 Göttingen, Germany; (5) INAF Osservatorio Astronomico di Roma, Via Frascati 33, 00078 Monte Porzio Catone, Italy; (6) Indian Institute of Astrophysics, Koramangala, Bangalore 560034, India; (7) Center of Excellence in Space Sciences India, IISER Kolkata, Mohanpur 741246, West Bengal, India”

The polar magnetic field in the Sun is an important aspect of the solar dynamo for predicting future solar cycles. However, systematic measurements of this polar field have only been available since 1976 at the Wilcox Solar Observatory (WSO). Prior to 1976, there is a lack of direct information on polar magnetic fields, leading people to utilize various proxies such as polar faculae to infer polar field data. The use of polar faculae, however, introduced uncertainties due to manual counting methods, impacting the accuracy of polar field information. Recently, the polar network has emerged as a more reliable proxy for polar field information due to its appearance in higher latitudes and automatic detection. In this study, we employed newly calibrated and rotation-corrected Ca II K data from the Kodaikanal Solar Observatory (KoSO; 1907- 2007) and as well the Rome Precision Solar Photometric Telescope(Rome-PSPT; 1996-2022) to detect the polar network automatically and make composite polar network index (PNI) series from these. We found a significant correlation between the WSO polar field and PNI (Pearson correlation coefficient, $CC > 0.91$), allowing us to reconstruct the polar field over a 116-year period (1907-2007) using combined PNI measurements. Furthermore, we observed a strong correspondence between the cycle strength and the reconstructed polar field from PNI at the preceding solar cycle minimum, enabling us to estimate the strength of solar cycle 25.

Tuesday, October 1

Long-Term Solar Activity 11:40+0:15

contributed talk

An independent small-scale dynamo and long-term solar and solar wind activity

Ed Cliver

National Solar Observatory

Based on a comparison of two long-term (1845-present) geomagnetic indices, we recently argued (1) for the existence of a small-scale (SS) turbulent dynamo that is independent of the large-scale cyclic dynamo and (2) that the constant level (or floor) of SS-flux generated by this dynamo is the source of a corresponding magnetic floor in the slow solar wind. In the absence of the large-scale dynamo (a condition most closely approached during the Maunder Minimum), the solar wind would consist entirely of slow wind with a magnetic field strength of 2.8 nT at Earth at all times. Determination of well-defined floors in the magnetism of the Sun and solar wind based on modern instrumentation and modelling can help to constrain the range in TSI variability and specify the state of the solar wind during the Maunder Minimum. Evidence for a SS-dynamo will be reviewed along with rapidly-developing related work on the generation of slow and fast solar wind.

Tuesday, October 1

the May 2024 solar-terrestrial storm

11:55+0:15

contributed talk

Drastic Evolution of Active Region Complex 13664/13668

Shin Toriumi (1); Xudong Sun (2); Aimee Norton (3); Peter Schuck (4); Jie Zhang (5)

(1) Japan Aerospace Exploration Agency; (2) University of Hawai'i at Manoa; (3) Stanford University; (4) NASA Goddard Space Flight Center; (5) George Mason University

The solar active region complex NOAA 13664/13668 (AR 13664/8) appeared in May 2024 and caused numerous massive flares, including the 10 X-class events, disturbing the entire geomagnetic environment. Using the series of SDO/HMI stray-light-removed magnetograms, we made a preliminary study of the evolution of AR 13664/8. This region showed a complex evolution. A pair of newly emerging bipoles (AR 13668) appeared to the east of the existing AR 13664 and caused collisions and shearing, eventually forming a complex, large-scale delta-type sunspots. The magnetic flux started to increase on May 7, about one day before the series of large eruptions, and the emergence rate was found to be the highest in the SDO era. Therefore, this AR complex can be considered a representative flare-producing AR that combines all three key factors, namely, area, complexity, and rapid growth. In this talk, we summarize the important features of the AR evolution, emphasizing the correspondence between its outstanding flux growth rate and the resulting flare eruptions.

Tuesday, October 1

the May 2024 solar-terrestrial storm 12:10+0:15

contributed talk

3D magnetic field analysis and flare predictability of AR NOAA 13664

Kanya Kusano (1); Yumi Bamba (2); Daikou Shiota (2)

(1) Nagoya University, (2) NICT

Solar active regions NOAA 13664 produced many large flares, causing severe space weather events. We systematically analyzed the evolution of the three-dimensional magnetic field of this active region using the nonlinear force-free field extrapolation technique and investigated the relationship between the magnetic field structure and flares. Through the analyses, we clarify the characteristics of this active region by comparing it with several major active regions in solar cycle 24. We also apply the physics-based prediction scheme, the kappa-scheme (Kusano et al. 2020), to this active region and show how the large flares produced in this region can be predicted.

Tuesday, October 1

the May 2024 solar-terrestrial storm

12:25+0:15

contributed talk

Interplanetary scintillation observation of coronal mass ejections in May 2024

Kazumasa Iwai (1); Daikou Shiota (2,1); Ken'ichi Fujiki (1); Hirofumi Isogai (1)

(1) ISEE, Nagoya University, Nagoya, Japan; (2) NICT, Koganei, Japan

Coronal mass ejections (CMEs) cause various disturbances in the solar-terrestrial system. However, their propagation in interplanetary space has not been understood well. In early May 2024, multiple CMEs were generated and some of them arrived at the Earth, that caused severe solar-terrestrial storms. We have investigated these CMEs using the Interplanetary scintillation (IPS) observations. The IPS is a radio scattering phenomenon generated by the disturbances in the solar wind. IPS observation has been one of the most important tools for observing CMEs propagating in interplanetary space. The Institute for Space and Earth Environmental Research (ISEE), Nagoya University has observed IPS at 327 MHz using an observation system consist of three large radio telescopes. We found that an increasing number of large-amplitude IPS responses on 10 May, just before the shock arrival at the Earth. Large-amplitude IPS responses were detected especially in the line of sight in the direction of large solar separation angles, where the ICMEs of interest supposed to be located. Enhancements on IPS responses can be associated with the high-density region where the fast-propagating ICMEs pile up the background solar wind. In addition, several CMEs were generated from the same active region and some of them merged in the interplanetary space. Multiple ICME merging can enhance compression of the solar wind plasma that can produce intense radio scattering. Therefore, the enhanced IPS amplitude can be caused by the CME-CME interaction. The propagation of CMEs observed during this period have been reproduced using the MHD simulations that suggests multiple CMEs were generated in a short period of time, forming a dense region with multiple CME-CME interactions.

Tuesday, October 1

Dynamo 13:45+0:25

keynote talk

Origins of Decadal-scale Variations in Solar Activity

Prantika Bhowmik

Department of Physics, Indian Institute of Science, Bangalore, India

”Solar variability governs the electromagnetic, radiative, and particulate environment in the heliosphere, and it is closely associated with and dominated by the sunspot cycle. The sunspots are one of the primary manifestations of the Sun’s magnetic field. Thus, our understanding of the origin and spatio-temporal evolution of the solar magnetic field through sunspot cycles helps the community to probe and predict solar activity and associated variability.

The sunspot cycles have an average periodicity of 11 years, originating from a magnetic dynamo functioning within the solar convection zone. A continuous interaction and energy exchange between the dynamic plasma and magnetic field result in the decadal-scale sunspot cycles. Despite knowing this, the intrinsic stochastic nature of the solar convection zone limits the deterministic aspect of the dynamo process, thereby adding additional irregularities in cycle amplitude. However, a new methodology has been devised recently, combining an observational data-driven surface flux transport model with an interior dynamo model to understand the decadal scale solar activity. This new methodology has been validated by performing a century-scale data-driven simulation that successfully reproduced the past sunspot cycle observation of 100 years - the first of its kind. Subsequently, this technique was employed to predict sunspot cycle 25 while considering various possible uncertainties. This work and other recent contemporary works have identified the importance of the Babcock-Leighton mechanism manifested through the surface flux transport processes as the primary source inducing the variability in the decadal-scale solar activity. Now, the community is converging towards a common viewpoint, paving the path towards a better understanding of the solar cycle variability and improving its prediction ability.”

Tuesday, October 1

Dynamo 14:10+0:15

contributed talk

Magnetochronology of solar-type star dynamos

Allan Sacha Brun (1), Quentin Noraz (2,1), Antoine Strugarek (1)

(1) CEA Paris-Saclay, Dept. of Astrophysics, (2) RoCS, Oslo University

”We present an extensive study on the dynamo origin of the solar-type star’s magnetism, based on a series of 35 3D MHD numerical simulations. We assess how the combination of rotation and convection via the Rossby number influences the type of magnetism established (short or long cycles, statistically steady activity) and their expected differential rotation (solar-like, anti-solar, cylindrical or almost solid). This large survey allows us to understand further why the Sun possesses a long decadal cycle and a conical differential rotation profile. We also discuss various scaling laws that this study allows to derive by comparing them directly to observations. We find an overall very good agreement between simulations and observations if we use the large scale field computed in the simulation to reproduce observations. Finally, we also show that they may exist a minimum of magnetic activity near the Rossby number 1, which in the context of magneto-/gyro-chronology may help explain a stalling of solar-like star spin down recently proposed by several authors.”

Tuesday, October 1

Dynamo 14:25+0:15

contributed talk

Nonlinearities and long timescale modulation of solar and stellar dynamos

Christian Thibeault (1); Alexandre Lemerle (1,2); Paul Charbonneau (1)

(1) Université de Montréal, Canada; (2) Collège de Bois-de-Boulogne, Montréal, Canada

The predominant magnetic backreaction channel through which the Lorentz force stabilizes the growth of solar/stellar dynamos has not yet been identified with confidence. In this work we investigate the types of long timescale modulation behaviors characterizing a flux transport dynamo relying on the Babcock-Leighton mechanism for regeneration of the large-scale dipole. We consider distinct nonlinearities acting at different steps of the dynamo loop, with a focus on the variations of differential rotation directly driven by the Lorentz force associated with the cycling large-scale magnetic field. Acting jointly with the time-delay dynamics characterizing flux transport dynamos operating in or close to the advection-dominated regime, we find a variety of long timescale modulations even in weakly supercritical dynamo solutions, as well as for Prandtl number approaching unity. We offer specific examples showing the degree to which an accurate characterization of long timescale modulations, as obtained from cosmogenic isotopes, can provide (or not) useful constraints on the saturation mechanism(s) of solar and stellar dynamos.

Tuesday, October 1

Dynamo 14:40+0:15

contributed talk

Long-term solar cycle evolution in context of solar dynamos

Dmitry Sokoloff

Moscow State University

Solar dynamo theory was suggested to explain the Schwabe cycle. The basic explanation was that the cycle corresponds to a growing eigensolution of some mean-field dynamo equations. Long-term evolution of the cycle is obviously something more than an eigensolution. Of course, the contemporary dynamo models contain a long-term evolution. The question however do remain – why and how this evolution is compatible with the initial idea of dynamo? The aim of the talk is to present some ways how this long-term evolution could be included in the framework of dynamo theory.

Tuesday, October 1

Dynamo 14:55+0:25

keynote talk

Non-linear and stochastic mechanisms that modulate the solar cycle

Jie Jiang

Beihang University, China

The 11-year solar activity cycles exhibit significant inter-cycle variations that impact both the space environment and climate. Understanding and reproducing these variations require accounting for nonlinear and stochastic mechanisms. In this presentation, I will discuss recent advancements in identifying observable nonlinearity and stochasticity in solar cycle modulation. I will clarify these mechanisms and analyze their distinct effects on solar cycle variability. And I will show that while the variability of solar cycles displays weak nonlinear characteristics, it primarily manifests as stochastic rather than chaotic behavior.

Tuesday, October 1

Dynamo 15:20+0:15

contributed talk

Dynamo modelling for cycle variability and occurrence of grand minima in different solar-type stars

Bidya Binay Karak; Vindya Vashishth (1); Leonid Kitchatinov (2)

(1) Department of Physics, Indian Institute of Technology (Banaras Hindu University), Varanasi 221005, India;

(2) Institute of Solar-Terrestrial Physics SB RAS, Lermontov Str. 126A, Irkutsk 664033, Russia

Like the solar cycle, stellar activity cycles are also irregular. Observations reveal that rapidly rotating (young) Sun-like stars exhibit a high level of activity with no Maunder-like grand minima and rarely display smooth regular activity cycles. On the other hand, slowly rotating old stars like the Sun have low activity levels and smooth cycles with occasional grand minima. We, for the first time, model these observational trends using flux transport dynamo models. We build kinematic dynamo models of one solar mass star with different rotation rates. Differential rotation and meridional circulation are specified by computing them using equivalent mean-field hydrodynamic models of these stars. We include stochastic fluctuations in the Babcock-Leighton source of the poloidal field to capture the inherent fluctuations in the stellar convection. Based on extensive simulations, we find that rapidly rotating stars produce highly irregular cycles with strong magnetic fields and rarely produce Maunder-like grand minima, whereas the slowly-rotating stars (with a rotation period of 10 days and longer) produce smooth cycles of weaker strength, long-term modulation in the amplitude, and occasional extended grand minima. The average duration and the frequency of grand minima increase with decreasing rotation rate. These results can be understood as the tendency of less supercritical dynamo in slower rotating stars to be more prone to produce extended grand minima. We further conclude that even in rapidly rotating stars for which the star spots appear at high latitudes, the Babcock-Leighton dynamo operates.

Tuesday, October 1

Dynamo 15:35+0:25

keynote talk

Predicting solar cycles with a parametric time series model

Kristof Petrovay

ELTE Eötvös Loránd University, Budapest

The series of solar cycle amplitudes is reproduced and predicted by a simple time series model. The Gleissberg oscillation is shown to be quite satisfactorily modelled as a sinusoidal variation of constant amplitude with a period increasing linearly with time. Subtracting this model from the actual cycle amplitudes, a clear even–odd alternating pattern is discerned in the time series of the residuals since SC9. For this period of time, the mean value of the residuals for odd-numbered cycles is shown to exceed the value for even-numbered cycles by more than 4 sigma, providing the clearest evidence yet for a persistent odd–even–odd alternation in cycle amplitudes. Random deviations from these means are less than half the standard deviation of the raw cycle amplitude time series for the same period, which allows to use these regularities for solar cycle prediction with substantially better confidence than the simple climatological average. Predicted cycle amplitudes are found to be robust against the addition or omission of some data points from the input set and the method correctly hindcasts SC23 and SC24. The potential physical background of the regularities is also discussed. Our predictions for the amplitudes of SC25, SC26 and SC27 are 155.8 ± 20.7 , 96.9 ± 25.1 and 140.8 ± 20.7 , respectively. This would suggest that SC26 will be even lower than SC24 was, making it the weakest cycle since the Dalton Minimum.

Tuesday, October 1

Pre-Telescopic Data 16:20+0:20

solicited talk

Reuse of the Babylonian Astronomical Diaries for astronomy and space climatology

Yasuyuki Mitsuma (1); Hisashi Hayakawa (2)

(1) Kwansei Gakuin University; (2) Nagoya University

Systematic daily observational records provide base references for reconstructions of long-term solar-terrestrial environments in the past. This is especially the case with pre-instrumental periods. In this context, Babylonian Astronomical Diaries form a large corpus of daily astronomical observations and weather reports conducted in Mesopotamia between the mid-7th to the mid-1st century BCE. This corpus contains numerous observations for terrestrial climate such as those for daily weather, droughts, floods, and atmospheric optics, and numerous astronomical records such as those for aurora-like phenomena, lunar and solar eclipses, meteors, and comets. From the fourth century, our information from the diaries became dense and detailed and, by the invention of the zodiac signs, astronomical data in the diaries became computable against ecliptic. We review their historical background, possible applications for astronomy, geophysics, and space science, showing actual examples of recent studies on their records for weather records, comets, eclipses, and aurora-like phenomena for reconstructions of historical climate, cometary orbits, variability of Earth's rotation speed, and space-weather condition. This study also compares such results with recent studies on Assyrian Astrological Reports.

Tuesday, October 1

Pre-Telescopic Data 16:40+0:15

contributed talk

Analyses of Byzantine Eclipse Records from the 4th to the 12th Centuries: A Progress Report

Koji Murata (1); Hisashi Hayakawa (2); Mitsuru Sôma (3)

(1) University of Tsukuba; (2) Nagoya University; (3) National Astronomical Observatory of Japan

This presentation documents a progress report for an analysis of Byzantine eclipse records and their utility in reconstructing the Earth's ΔT (delta T) values and the solar coronal structure from the 4th to the 12th centuries. ΔT , the difference between Terrestrial Time (TT) and Universal Time (UT), is a crucial parameter for understanding variations in the Earth's rotation speed. Additionally, descriptions of the solar corona during total eclipses provide insights into historical solar activity. The Byzantine Empire, known for its meticulous historical documentation, provides a wealth of astronomical observations, although they have not been adequately utilized in the modern astronomical discussions. This study develops a detailed examination of Byzantine writings, from chronicles to manuscript colophons, to extract eclipse records and analyze their implications to the modern astronomical discussions, partially based on Hayakawa et al. (2022, PASP, 134, 094401). Our analyses have suggested considerable updates in the ΔT variability in the 4th to 7th centuries. Our findings tighten the variability of ΔT in 346 CE, show a larger range in 418 CE, and give lower ranges in 484, 601, and 693 CE. Additionally, Byzantine records include potential descriptions of the solar corona during total eclipses in the 10th and 12th centuries, which helps to understand the variability of coronal structure around the so-called 'Medieval Grand Maximum'.

Tuesday, October 1

Pre-Telescopic Data 16:55+0:25

keynote talk

Historical Records of Total Solar Eclipses: Their Reuse and Implications for Modern Science

Mitsuru Sôma (1); Hisashi Hayakawa (2)

(1) National Astronomical Observatory of Japan; (2) Nagoya University

As one of the greatest astronomical spectacles, total solar eclipses have left footprints in the human history for millennia from ancient documents to modern scientific observations. These events occur only infrequently in any given single sites. Owing to their rarity, their records have been used to pin down historical chronology in the human history. However, these records are valuable not only for historical chronology but also for scientific discussions. This presentation briefly describes some examples of scientific implications of these eclipse records. Firstly, the eclipse records allow us to constrain the Earth's rotation speed variability with identifications of observational sites. Their case studies are shown with several examples. Secondly, the eclipse records allow us to reconstruct visual structure of the solar coronal streamers. Some case studies are shown for the Dalton Minimum, the Maunder Minimum, and the Medieval Grand Maximum. As such, the modern astrophysics still has a lot to learn from historical records of past total solar eclipses.

Tuesday, October 1

Pre-Telescopic Data 17:20+0:20

solicited talk

Millennial Record of Sun-Earth Connection in Korean Chronicles

Rok-soon Kim; Hong-jin Yang

Korea Astronomy and Space Science Institute

We have examined 38 sunspots and related 25 auroras found in Korean chronicles from the 10C to 18C. The records can be divided into the warm period before and AD1300 including the medieval warming period and the cool period after 1300 including several grand minima. The sunspot observation rates are similar in two periods, while more auroras are observed in the cool period. We also studied notable strong sunspots and associated auroras and found some interesting results. First, the rate of the large sunspot is more than three times higher in the warm period than in the cool period, and the large sunspot is around two times more geoeffective than the small sunspot in the cool period. Second, We confirmed the recursive sunspot in 1185 and it seemed to have similar activity to the Halloween event in 2003 in the size and geoeffectiveness. Last, the size of the sunspot recorded in Korean chronicles can be an index of solar activity such as the sunspot number. From these results, we insist that the historical sunspot records are useful not only to examine long-term solar activity but also to speculate extreme activities of the Sun and the Earth.

Tuesday, October 1

Pre-Telescopic Data 17:40+0:15

contributed talk

The Eight-Year Solar Cycle During the Maunder Minimum

”Limei Yan(1) , Fei He(1), Xinan Yue(1) , Yong Wei(1) , Yuqi Wang(1) , Si Chen(2), Kai Fan(1) , Hui Tian(3), Jiansen He(3) , Qiugang Zong(3) , and Lidong Xia(4)”

”(1) Institute of Geology and Geophysics, Chinese Academy of Sciences, Beijing, China. (2) Aerospace Information Research Institute, Chinese Academy of Sciences, Beijing, China. (3) School of Earth and Space Sciences, Peking University, Beijing, China. (4) School of Space Science and Physics, Shandong University, Weihai, China”

The presence of grand minima, characterized by significantly reduced solar and stellar activity, poses a challenge to our understanding of solar and stellar dynamo. The cyclic variation of solar activity during the Maunder Minimum (1645–1715 AD) is critical to understand the solar and stellar dynamo but remains under-explored. By analyzing variations in solar activity-related red equatorial auroras recorded in Korean historical texts, specifically in the context of the low-intensity paleo-West Pacific geomagnetic anomaly, we find clear evidence of an 8-year solar cycle rather than the typical 11-year cycle during the Maunder Minimum. This result provides a key constraint on solar dynamo models and the generation mechanism of grand solar minima.

Tuesday, October 1

Pre-Telescopic Data 17:55+0:15

contributed talk

Implications of Korean historical astronomical records and climate change

Hong-Jin Yang

Korea Astronomy and Space Science Institute / University of Science and Technology

”The over 2,000 years of historical astronomical records from Korean chronicles are valuable for various aspects of modern research. Historical records of sunspots and auroras are particularly useful for studying climate change, as are historical meteorological observation records. Additionally, historical records of meteors and showers can be useful data for researching the evolution of comets as well as variations in solar activity. In this talk, we will introduce the Korean historical records, particularly focusing on the study of climate change over the past millennium using sunspot and frost records, as well as solar activities embedded in historical meteor shower records.”

Wednesday, October 2

Corona & Heliosphere 9:00+0:25

keynote talk

**On the structure and evolution of the solar corona and inner heliosphere during the
Maunder Minimum**

Pete Riley (1); Ron Caplan (1); Duncan Mackay (2)

(1) Predictive Science Incorporated; (2) University of St Andrews

Observations of the Sun's corona during the space era have led to a well-observed and constrained picture of relatively constant but cyclically varying solar output and structure. In contrast, the "Maunder Minimum" was an albeit poorly documented period between approximately 1645 and 1715 during which time: (1) sunspots effectively disappeared for long intervals; (2) eclipse observations suggested the distinct lack of a visible K-corona but possible appearance of the F-corona; (3) reports of aurora were notably reduced; and (4) cosmic ray intensities at Earth were inferred to be substantially higher. In this talk, we review previous studies and present new results that couple a surface flux transport model with a global thermodynamic MHD model to explore the structure and evolution of the extended solar corona during the Maunder Minimum. We compare their predictions with the available but limited observational constraints and distinguish between the two proposed states of the Maunder-Minimum Sun: (1) a 2009/2019-like minimum or (2) a truly extreme state devoid of any large-scale structure driven by a photospheric field composed of only ephemeral regions, and likely substantially reduced in strength. We also address the interesting question of whether the current Sun is a precursor and that we are living on the cusp of a new grand solar minimum.

Wednesday, October 2

Corona & Heliosphere 9:25+0:20

solicited talk

Interplanetary Scintillation Observations Over 40 Years

Ken'ichi Fujiki; Kazumasa Iwai; Keita Morishima

Institute for Space-Earth Environmental Research, Nagoya University

”The solar wind, a stream of charged particles emanating from the Sun, profoundly influences space weather, space climate, and heliophysics. Despite its significance, the origin and propagation of the solar wind remain incompletely understood. This study employs interplanetary scintillation (IPS) to investigate solar wind variations. Since 1985, the Institute for Space-Earth Environmental Research (ISEE) has conducted IPS observations at 327 MHz. This frequency is ideal for observing solar wind flow through the inner heliosphere, approximately 0.2-1.0 AU from the Sun. Consequently, the IPS data enables long-term reconstruction of solar wind velocity structures. Our research reveals that solar wind structures evolve in concert with the solar cycle. During solar minima, low-speed wind concentrates near the equator, while high-speed solar wind dominates higher latitudes. As solar activity intensifies, high-speed solar wind regions shrink towards the poles. At solar maximum, low-speed solar wind becomes globally dominant throughout the heliosphere. These findings reveal a strong correlation between solar wind structure, its origin at the solar surface, and its acceleration region in the solar corona. While solar cycles 22 and 23 exhibited high activity, cycle 24 experienced a marked decline. This decrease manifested in reduced scintillation levels and significant structural changes in the solar wind, reflecting variations in its sources. These observations provide crucial insights into the long-term evolution of solar wind structure and their relationship to solar activity cycles. This presentation offers a comprehensive review of four decades of IPS observations at ISEE. It details solar wind structural changes, explores its origins, and examines the correlation between solar wind characteristics and solar activity amplitudes. ”

Wednesday, October 2

Corona & Heliosphere 9:45+0:15

contributed talk

Comparison of the 3-D solar wind from solar cycles 22 to 24 within the inner heliosphere

P K Manoharan

Florida Space Institute, University of Central Florida

In this presentation, I will review the evolution and characteristics of the large-scale structure of three-dimensional quasi-steady solar wind in the inner heliosphere, spanning solar cycles 22 to 24. The solar wind datasets used are derived from interplanetary scintillation (IPS) measurements conducted with the Ooty Radio Telescope (operating at 327 MHz) and the Arecibo Radio Telescope (covering frequencies from 300 to 3000 MHz). During solar cycles 22 to 24, there was a general decrease in density turbulence in the solar wind, consistent with the observed decline in the strength of the solar magnetic field. These changes influence the dynamics of the solar wind and contribute to reduced mass and energy supply from the corona into the heliosphere. Notably, solar cycle 24 exhibited the weakest characteristics, with a weak polar field during its minimum phase resulting in asynchronous and weak polar field reversals, along with significant hemispheric asymmetry. Observations of storm intensities suggest that cycle 24 has lower geo-effectiveness compared to previous cycles. Galactic cosmic ray measurements from neutron monitors at the end of cycle 24 were comparable to those observed during similar phases of cycle 23. Additionally, comparisons were made between the latitudinal extents of slow-speed solar wind near low and mid latitudes and the corresponding high-density turbulence regions during the minima of solar cycles 22 to 24.

Wednesday, October 2

Corona & Heliosphere 10:00+0:15

contributed talk

Straight outta photosphere: Open solar flux without coronal modeling

Ismo Tähtinen; Timo Asikainen; Kalevi Mursula

University of Oulu, Oulu, Finland

”Open solar flux, i.e., the total magnetic flux escaping the Sun, is one of the most important parameters connecting solar activity to the Earth. Open solar flux is commonly estimated from photospheric magnetic field measurements by making model assumptions about the solar corona. However, the question how the open solar flux is directly related to the distribution of photospheric magnetic field is still partly unknown.

We reconstruct the open solar flux directly from the photospheric magnetic fields without making any assumptions about the corona, or, e.g., using coronal hole observations. We modify the vector sum method of Vernova et al. (2007) by taking into account magnetic field polarities, and apply the method to the synoptic magnetograms of six instruments so to find the open solar flux from solar cycles 21–24. The modified vector sum method produces a vector of the global solar magnetic field whose magnitude closely matches the open solar flux from the PFSS model both by the absolute scale and the overall time evolution for each of the six magnetograms. The latitude of this vector follows the Hale cycle by always pointing towards the dominantly positive-polarity hemisphere, and its longitude coincides with the location of main coronal holes of the McIntosh Archive. We find multi-year periods during which the longitude of the vector slowly drifts or stays rather stationary in the Carrington frame. These periods are punctuated by times when the longitude moves rapidly in the Carrington frame. By comparing the magnitude of this vector to the open solar flux calculated from the PFSS model with different source surface heights, we find that the best match is produced with source surface height 2.4-2.5 times the solar radius.”

Wednesday, October 2

Corona & Heliosphere 10:15+0:15

contributed talk

Modeling Solar/Stellar CME-induced Coronal Dimmings and Comparisons with SDO/HST Observations

Meng Jin (1); Parke Loyd (2); Mark Cheung (3); Marc DeRosa (1); Nariaki Nitta (1); Karel Schrijver (1); Kevin France (4); James Paul Mason (5); Allison Youngblood (6); Sudeshna Boro Saikia (7); Theresa Lueftinger (8)

(1)Lockheed Martin Solar and Astrophysics Laboratory, Palo Alto, CA, United States; (2)Eureka Scientific, Oakland, United States; (3)CSIRO, Space & Astronomy, Epping, NSW, Australia;(4)Laboratory for Atmospheric and Space Physics, Astrophysical and Planetary Sciences, Boulder, United States; (5)Johns Hopkins University Applied Physics Laboratory, Laurel, MD, United States; (6)NASA Goddard Space Flight Center, Greenbelt, United States; (7)University of Vienna, Vienna, Austria; (8) European Space Agency, Keplerlaan, Netherlands

In the last two decades, extensive observations of solar coronal dimmings have been made by multiple space missions (e.g., SOHO, STEREO, SDO, etc.). Due to their close association with coronal mass ejections (CMEs), there is a critical need to comprehend the underlying physical processes and intricate relationships between dimmings and CMEs. A growing body of evidence, including observed dimming signals from distant stars, indicates the potential of utilizing coronal dimming as an instrumental tool for diagnosing stellar CMEs. In this study, we first conduct an in-depth comparative analysis of solar coronal dimming, employing MHD simulations in conjunction with SDO observations. A detailed analysis of the simulation and observation data shows that coronal dimmings encode important information about the associated CMEs, which provides a physical basis for detecting stellar CMEs from distant solar-like stars. We then adapt the MHD model to stellar cases. The Zeeman Doppler Imaging surface magnetic map of the star is used to drive the inner boundary condition. Observationally derived Emission Measure distributions are integrated to refine the coronal heating parameters within the model. By modeling the stellar CMEs and synthesizing the FUV line intensities, we present a coronal dimming analysis of modeled Fe XII 1349 Å and Fe XXI 1354 Å emission with archival FUV observations by Hubble Space Telescope’s Cosmic Origins Spectrograph. Our findings unveil both the potential and complexities inherent in using coronal dimming as a proxy for solar and stellar CMEs.

Wednesday, October 2

Corona & Heliosphere 10:30+0:15

contributed talk

Relationship of the plasma upflow and the source region of the slow solar wind from 2007 to 2021

Keita Morishima (1); Kazumasa Iwai (1); Ken'ichi Fujiki (1)

(1) Institute for Space-Earth Environmental research

"Solar wind is a supersonic plasma flow blowing from the Sun and is basically classified into the fast solar wind (> 500 km/s) and the slow solar wind (< 500 km/s). While the main source region of the fast solar wind is relatively well understood to be coronal holes in the polar regions, the source region of the slow solar wind has not been fully understood. Plasma upflows observed at the edge of the active region have been considered as one of the possible candidates of the source region of the slow solar wind. However, there are only a few cases in which upflows have been identified as a source region of the slow solar wind based on in situ observations (e.g., D. Baker et al., 2023). In this study, we have investigated the relationship between coronal plasma upflows and slow solar wind. We analyzed the 48 upflow observations (2007-2021) by Extreme Ultraviolet Imaging Spectrometer (EIS) onboard the Hinode satellite, the Potential Field Source Surface (PFSS) model, and interplanetary scintillation (IPS) observations at 327 MHz by ISEE, Nagoya University. The upflows were extracted using the Doppler velocity derived from the Fe XIII (202.04 \AA) emission lines in the EIS. We also extrapolated coronal magnetic field lines by the PFSS model. The solar wind speed was obtained from the IPS observations. We found that the upflows in 14 observations were connected to the slow solar wind through the coronal magnetic field lines extrapolated by the PFSS model. This result suggests that some of the upflows could be the source region of the slow solar wind as shown in previous studies. The majority of the upflows in this study were found not to be the source region of the slow solar wind. On the other hand, open magnetic footprints were located in the immediate vicinity of the several upflow regions. The magnetic field connectivity could contain ambiguity due to the uncertainty of the PFSS model and the limited observation field of view of the EIS. "

Wednesday, October 2

Corona & Heliosphere 10:45+0:15

contributed talk

Three-Dimensional Simulation of Geo-Effective Small-to-Mesoscale Solar Wind Structures

**W. Manchester IV (1); N. Sachdeva (1); M. Ala-Lahti (1); E. Kilpua (2); S. Lata Soni (1);
Z. Huang (1); H. Chen (1); A. Jivani (1); B. van der Holst (1); A. Szabo (3); M.
Akhavan-Tafti (1)**

(1) University of Michigan; (2) University of Helsinki; (3) NASA GSFC

We investigate the interaction of a coronal mass ejection (CME) with a corotating interaction region (CIR) that results in the intensification of magnetic field and formation of geoeffective meso-scale flux ropes. We simulate the CME-meso-scale system with the Alfvén Wave Solar Atmosphere Model (AWSoM) by first producing the background solar wind condition for solar maximum conditions occurring September 2014. The CME is initiated from the originating active region with a Gibson-Low magnetic flux rope defined to match the observed event. With the use of high-resolution grids, we capture magnetic reconnection within the erupting flux rope as it impacts the CIR leading to the formation of meso-scale flux ropes containing sufficiently strong magnetic fields (40 nT) to be geoeffective. We use these simulation results to demonstrate the capabilities of the proposed Space Weather Investigation Frontier (SWIFT) mission comprising four spacecraft orbiting in tetrahedral orientation with 125 Rs radial separation from L1 to sub-L1 location and 150 Re longitudinal/latitudinal separation at L1 location to observe the magnetic reconnection and evolution of small to-meso scale current sheet structure within the ICME.

Wednesday, October 2

Data Resque 11:25+0:25

keynote talk

**THE IMPORTANCE OF ARCHIVAL DATA FOR UNDERSTANDING
SUPERFLARES ON SUN-LIKE STARS**

Bradley E. Schaefer

Louisiana State University, Baton Rouge, USA

Back in 1989, I defined Superflares to be those with $> 10^{35}$ ergs of energy. For the next decade, I found Superflares to occur on stars of all types, everywhere across the HR diagram, with special interest being that closely sun-like stars (including several of the closest known solar-twins) have observed Superflares up to 10^{39} ergs. I have recently discovered from archival photographs at Harvard, that one star (V2487 Oph, as a G-type main-sequence star of radius $0.96 R_{sun}$) has daily Superflares that average $10^{39.2}$ ergs, and two flares in 1941 and 1942 had energies of $10^{42.5}$ ergs (30-billion ‘Carringtons’). These superflares have deep implications for the origin of life, the habitability of exoplanets, and the possibility of Superflares on our Sun. With archival data for magnetic storms, Miyake events, and global aurora, I can estimate the frequency of solar flares at the Carrington level (10^{32} ergs). This can be extrapolated to higher energies by the universal number-energy distribution of E^{-2} . With this, our Sun would produce a Superflare $> 10^{35}$ ergs only once in three billion years. Our Sun is **not** a Superflare star. It is bad for parts of our community to represent our Sun as a Superflare star, both because such is wrong and because such is scaremongering that detracts from the very real and dire threat to modern civilization from an ordinary top-level Carrington Event.

Wednesday, October 2

Data Resque 11:50+0:20

solicited talk

Changes in the Sun' s diameter over time. Seen from space, would our star be a pulsating star?

Jean-Pierre Rozelot

Université de la Côte d'Azur, Nice (France)

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Since the highest Antiquity – and up-to-now- men have striven to measure the sizes of celestial bodies and among them the solar diameter. An estimate of the latter is of importance, as it serves as an astronomical standard. Changing its absolute measurement can, for example, significantly alter the absolute diameter of stars, since the diameter of all stars is defined in relation to that of the Sun. Considerable efforts have been made during the second half of the XXth century, involving dedicated space instruments. Moreover, modern 3-D solar theories show that the very near sub-solar surface (NSSL, that we have called leptocline) can be modelized and is in rather good agreement with helioseismic observations deduced, for instance, from the HMI experiment on board the Solar Dynamics Observatory (SDO) NASA satellite. Helioseismic data analysis through the accurate determination of the so-called asphericities coefficients, addressed at high degree (i.e. 1 up to 800), lead to solar radius relative variations in depth with the solar cycle. In this lecture, after defining what a solar diameter is, we will give an overview of changes in the Sun' s diameter over time. Then we will address the role of the leptocline in such variations. Finally, how the solar shape can be seen from the far outer space? Building on the progress made to date, can we conclude that our star would appear from the far space as a very slowly pulsating star? In any case, findings can be transposed to exoplanets in their environment vis-a-vis a variable host star, a fact hardly considered up-to-now.

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Wednesday, October 2

Data Resque 12:10+0:15

contributed talk

Long-Term Observations of the Sun at the National Astronomical Observatory of Japan

Takashi Sakurai

National Astronomical Observatory of Japan

The National Astronomical Observatory of Japan (NAOJ, established in 1988) and its predecessor, Tokyo Astronomical Observatory of the University of Tokyo (established in 1878) have conducted observations of the Sun in various optical wavelengths. The oldest ones are full-disk images of the Sun in the calcium K-line (since 1917), white light (since 1918), H-alpha (since 1949), and sunspot drawings (since 1938). They were all digitized and accessible at <https://solarwww.mtk.nao.ac.jp/en/database.html>. Sunspot relative numbers (1929-present), polar faculae counts (1951-1998), and coronal green-line intensities (1951-2009) are provided at the same site. More modern, digital data of solar magnetic fields (since 1982) and helium 10830 spectroheliograms (since 1991) are also available. In this presentation, an overview on these data and research topics based on them will be given. A recent study on the recalibration of Mitaka sunspot relative numbers in terms of the Version-2.0 International Sunspot Numbers will also be presented.

Wednesday, October 2

Data Resque 12:25+0:15

contributed talk

”Exploring the Potential Uses of Digital Archive for the Development of Interdisciplinary Research -Based on Tokai National Higher Education and Research System (THERS) Academic Digital Archive”

”Sachie TANAKA (1), Rui GAKIYA (1), Yoshizumi MIYOSHI (2), Yasunori MORI (2) ”

” (1)Nagoya University Library, (2) Institute for Space and Earth Environmental Research, Nagoya University ”

”The Tokai National Higher Education and Research System has launched the digital archive system to make its digitized academic resources widely available. Nagoya University Library also expects that the system will enhance the development of interdisciplinary research. In this presentation, we will report the recent progress and future plan of this archive system.”

Wednesday, October 2

Data Resque 12:40+0:15

contributed talk

Current Efforts at NSO to Preserve and Digitize Historical Solar Observations

Alexander Pevtsov

US National Solar Observatory

Historical observations go back centuries long before the first permanent solar observatory at Mt Wilson. However, in the current era there is a drive for bigger, better, and newer instruments and observations. This leaves historical data often overlooked. As time progresses there is an ever-increasing risk of these observations being lost or becoming inaccessible. This presentation will focus on current efforts within different frameworks such as COSPARS International Space Weather Action Teams to preserve and make accessible historical solar observations. Along with a discussion on how the community may play a role in helping to identify and facilitate access to at risk historical archives.

Wednesday, October 2

Data Resque 13:55+0:15

contributed talk

Digitization of Toyokawa Radio Polarimeter Data and Estimation of the Size of Past Solar Flares

Satoshi Masuda (1); Keitarou Matsumoto (2); Masumi Shimojo (3); Hisashi Hayakawa (1)

(1) Nagoya University; (2) New Jersey Institute of Technology; (3) The National Astronomical Observatory of Japan

”Toyokawa Radio Polarimeters (ToRP) started operation in 1951 and continuously measured solar radio intensity and polarization at four frequencies (1, 2, 3.75, and 9.4 GHz) from 1957 to 1994. The time series plot data taken in 1958-1978 and before 1958 were stored in photographs (microfilms) and paper records, respectively. In order to preserve them for a long term, we have scanned all of the microfilm records and have made their digital-image database in ISEE, Nagoya University. Estimating the scale of past large flares that occurred before the 1980s, before the GOES solar X-rays measurements, will be important information for understanding past space weather events such as geomagnetic storms and GLEs. Long-term ToRP data can contribute to this purpose. At first, we explored 341 solar flares observed with the Nobeyama Radio Polarimeters (NoRP) and ToRP from 1988–2014 and compared them with the GOES soft X-ray observations. Then, we found a correlation in peak flux between microwave (3.75 and 9.4 GHz) and soft X-ray. This means that the GOES X-ray class can be estimated from the peak flux at 3.75 and 9.4 GHz. Actually, we succeeded to estimate the GOES X-ray class for some past large solar flares observed with ToRP in 1950s.

References: Shimojo, M. and K. Iwai, Over seven decades of solar microwave data obtained with Toyokawa and Nobeyama Radio Polarimeters, *Geoscience Data Journal*, 10, 1, 114-129 (doi: 10.1002/gdj3.165) Matsumoto, K., S. Masuda, K. Shimojo, and H. Hayakawa, Relationship of peak fluxes of solar radio bursts and X-ray class of solar flares: Application to early great solar flares, *PASJ*, 75, 6, 1095-1104, 2023 (doi: 10.1093/pasj/psad058).”

Wednesday, October 2

Data Resque 14:10+0:15

contributed talk

Global Solar Activity Data Portal for Long-Term Forecasts

Irina N. Kitiashvili (1); Vincent Wang (1,2); Matthew Vu (1,3); Arthur Foy (1,4); Zoe Fischer (1,5); Andrew Ngo (1,6); Hannah Suresh (1,7); Valery Pipin (8); Shubha S. Ranjan (1); Ryan C. Spaulding (1); Donald G. Deardorff (1)

(1) NASA Ames Research Center, USA; (2) Purdue University, USA; (3) George Mason University, USA; (4) University of California, USA; (5) University of Minnesota, USA; (6) University of Delaware, USA; (7) University of Maryland, USA, (8) Institute Solar-Terrestrial Physics, Russia

”Building a reliable forecast of global solar activity is crucial for obtaining short-term forecasts of the eruptions and release of high-energy particles and for long-term planning to improve the readiness level for upcoming activity. Modern data analyses, such as machine learning and data assimilation, demonstrated a great capability to develop a technology based on a synergy of advanced MHD modeling and observations, taking into account uncertainties in observations and models. However, uncertainty estimation and calibration of models remain challenging because of the limited availability of long-term observational data that are scattered over numerous data sources and often poorly described. We developed the Global Solar Activity (GSA) Data Portal to resolve these issues, which accumulates diverse data relevant to global solar dynamics and activity. The data portal collects observations from space- and ground-based instruments, including raw observational and processed data and helioseismic inferences. In this presentation, we will discuss the existing capabilities of the GSA Data Portal and ongoing research activities, such as the assimilation of observational data into dynamo models to build a unified platform to explore the global activity of the Sun and develop long-term forecasts of its activity. This work is supported by the NASA Heliophysics Supporting Research, Heliophysics Guest Investigator, and the NASA DRIVE Center Programs (COFFIES project).”

Wednesday, October 2

Sunspot Number Recalibration 14:25+0:15

contributed talk

The Diurnal Variation of the Geomagnetic field 1740-2023 as a Measure of Solar Activity

Leif Svalgaard

Stanford University

Solar Extreme Ultraviolet (EUV) radiation creates the conducting E-layer of the ionosphere, mainly by photo ionization of molecular Oxygen. Solar heating of the ionosphere creates thermal winds which by dynamo action induce an electric field driving an electric current having a magnetic effect observable on the ground, as was discovered and published by G. Graham just 300 years ago [1724]. The current rises and sets with the Sun and thus causes a readily observable diurnal variation of the geomagnetic field, allowing us to deduce the conductivity and thus the EUV flux as far back as reliable magnetic data reach. High-quality data go back to the ‘Magnetic Crusade’ of the 1830s and less reliable, but still usable, data are available for portions of the hundred years before that. Wolf and, independently, Gautier discovered the dependence of the diurnal variation on solar activity, and today we understand and can invert that relationship to construct a reliable record of the EUV flux from the geomagnetic record. Svalgaard [2016] reported the UV-flux for 1740-2015 based on 48 million hourly values of the geomagnetic East-component from 129 magnetic observatories. Here we extend the record until the present using highly accurate 1-minute geomagnetic data from the InterMagnet Network covering 146 participating stations for 1996-2023. The overlap with the previous series allows us to scale the new series to the old, yielding a series with yearly resolution for 1740-2023.

Wednesday, October 2

Sunspot Number Recalibration 14:40+0:15

contributed talk

Cycle variations of number of sunspots per group

Alexei A. Pevtsov (1); Yury A. Nagovitsyn (2,3); Nina Karachik (4); Kalevi Mursula (5)

”(1) National Solar Observatory, Boulder, CO, USA (2) Central Astronomical Observatory at Pulkovo, St.Peterburg, Russia (3) St Petersburg State University of Aerospace Instrumentation, St Petersburg, Russia (4) Ulugh Beg Astronomical Institute, Uzbekistan Academy of Sciences, Tashkent, Uzbekistan (5) University of Oulu, Finland ”

Long-term reconstructions of SSN and GSN often assume that basic characteristics of solar activity are largely unchanged, and so, sunspot “groups” now and 100, 200, 500 years ago should have similar properties. This assumption has been recently challenged (Mursula et al., 2024). We are using a long series of sunspot observations to investigate two simple questions: what is the typical number of sunspots per group, and how does it change on the time scales of solar cycle and longer? We show that the observed average number of spots per group experiences variations with the 11-year cycle. In addition, the group number also shows secular changes, which are close in phase to the SSN variations.

Wednesday, October 2

Cosmogenic Isotopes 14:55+0:25

keynote talk

Unveiling extreme solar events through cosmogenic isotopes in environmental archives

Florian Mekhaldi (1)

(1) Stockholm University

”Environmental archives, such as tree rings, ice cores, and sediments, hold a wealth of proxy information on past climate changes. Among these archives, cosmogenic isotopes serve as unique recorders of past solar activity, documenting events far more intense than any observed during the Space Age. Cosmogenic radionuclides such as ^{10}Be , ^{14}C , and ^{36}Cl are produced in the lower atmosphere through interactions between cosmic rays and atmospheric gases. Once generated, these isotopes are transported and deposited in ice sheets (^{10}Be , ^{36}Cl), trees (^{14}C), and sediments (^{10}Be), where they remain preserved, allowing us to measure and analyze the signals they carry. Significant discoveries, such as the large ^{14}C peaks identified in Japanese tree rings from the 8th and 10th centuries by Miyake et al., highlight the occurrence of extreme solar particle events. Recent studies have revised the fluence estimates of these events, indicating they were up to two orders of magnitude stronger than modern ground-level enhancements (GLEs). To date, five such events have been confirmed in the past 12,000 years, with several candidates pending verification. Despite ongoing uncertainties, a number of efforts in measurements and modelling have improved our understanding of these phenomena and their frequency. Here, major paleo-events will be reviewed in light of these recent advancements, discussing their implications and the evolving understanding of extreme solar activity phenomena. ”

Wednesday, October 2

Cosmogenic Isotopes 15:20+0:15

contributed talk

Exploring extreme solar events by carbon-14 measurements of tree rings

Fusa Miyake (1); Masataka Hakozaki (2); Rashit Hantemirov (3); Samuli Helama (4); A J Timothy Jull (5); Katsuhiko Kimura (6); Hiroko Miyahara (7); Toru Moriya (8); Markku Oinonen (9); Irina Panyushkina (5); Mirei Takeyama (8); Fuyuki Tokanai (8)

(1) Nagoya University, Nagoya, Japan; (2) National Museum of Japanese History, Sakura, Japan; (3) Ural Federal University, Ekaterinburg, Russia; (4) Natural Resources Institute Finland, Rovaniemi, Finland; (5) University of Arizona, Tucson, USA; (6) Fukushima University, Fukushima, Japan; (7) Musashino Art University, Tokyo, Japan; (8) Yamagata University, Yamagata, Japan; (9) University of Helsinki, Helsinki, Finland

”Cosmogenic nuclides such as ^{14}C in tree rings, and ^{10}Be and ^{36}Cl in ice cores, serve as proxies for past extreme solar energetic particle (SEP) events. Since the initial report of an extreme SEP event signature in 774/775 CE in 2012, several similar events have been identified as spikes in cosmogenic nuclide concentrations over the past decade. The magnitude of these SEP events has been estimated to be several tens to a hundred times larger than the largest SEP events observed in modern era over the past 70 years, potentially significantly impacting modern society. However, many periods in the Holocene remain unexplored using cosmogenic nuclides with high temporal resolution, and the characteristics of extreme SEP events have not been fully investigated. This study aims to detect extreme SEP events of the largest magnitude, similar to the 774 CE event, by analyzing ^{14}C concentrations in tree rings with high temporal resolution spanning approximately the past 8,000 years. In this presentation, we provide an update on the latest status in our exploration of extreme SEP events. ”

Wednesday, October 2

Cosmogenic Isotopes 15:35+0:15

contributed talk

Development and evaluation of new ^{10}Be -anomaly proxy for past solar activity

Naoyuki Kurita(1); Fusa Miyake(1); Stepan Poluianov(2); Sumito Matoba(3); Hiroyuki Matsuzaki(4), Takeyasu Yamagata(4)

(1) Nagoya University; (2) University of Oulu; (3) Hokkaido University; (4) University of Tokyo

Past intense solar eruptions are thought to have been recorded as positive anomalies of cosmogenic isotopes (e.g., ^{10}Be) in paleoarchives, such as ice cores. However, the reconstruction using the cosmogenic isotope method is uncertain because the cosmogenic isotopes archived in the ice cores reflect not only changes in the production of cosmogenic isotopes in the upper atmosphere but also the atmospheric transport and deposition processes at the site. Therefore, to reconstruct the past solar eruptions, it is essential to understand the sensitivity of ice-core records to variations in the production of cosmogenic isotopes in the upper atmosphere. Here, we experimentally examine the sensitivity of cosmogenic isotopes in the ice cores to variation in past solar activities. We collected a snow-pit sample from a depth of 5.4 m Dome Fuji in December 2022. Subsequently, we measured ^{10}Be concentrations at 3-cm intervals and obtained a ^{10}Be profile with high temporal resolution. Additionally, we analyzed several properties of the chemistry, and determined the age of the snow pit from volcanic signals recorded and tritium peaks from past bomb tests. The age of the deepest sample corresponds to the early 1950s. Theoretically, the ^{10}Be time-series shows good agreement with the variations in ^{10}Be production owing to solar cycles. However, ^{10}Be variations related to solar cycles were unclear, although multi-year variations in ^{10}Be were evident. This may be because ^{10}Be is strongly influenced by atmospheric circulation. Therefore, we have developed a new ^{10}Be -anomaly proxy that is less affected by atmospheric circulation. In this presentation, we show how efficiently the new ^{10}Be proxy improve the reproducibility of the past solar cycles.

Wednesday, October 2

Cosmogenic Isotopes 15:50+0:20

solicited talk

Modelling of cosmogenic beryllium: new parametrization

Kseniia Golubenko (1); Eugene Rozanov (2,3); Gennady Kovaltsov (4); Melanie Baroni (5); Ilya Usoskin (1)

(1) University of Oulu, Finland; (2) PMOD/WRC (Switzerland); (3) SPbU (Russia); (4) Ioffe Physical Technical Institute (Russia); (5) Aix Marseille Univ (France)

We introduce a chemistry-climate model (CCM) SOCOL-AERv2-BE, specifically designed to track cosmogenic beryllium in the atmosphere. The model includes the general circulation model (GCM) MA-ECHAM5 for the low and middle atmosphere, the chemistry-transport model MEZON, and the aerosol module AER. SOCOL can operate with various levels of detail in terms of horizontal resolution (spectral truncation T31 or T42) and vertical layers (39 or 90). Model includes the interactive deposition scheme (wet and dry depositions). The modelled concentrations of ^{10}Be in near-ground air have been systematically compared with the measured values at four high-latitude locations. Results agree with the measurements within the uncertainties, suggesting that the model reasonably well reproduces the main processes of the isotopes. Furthermore, the model demonstrating an adequate reproduction of the dominant annual cycle observed in the Northern Hemisphere. For practical applications, we developed a straightforward parameterization of the full-model outcomes, which provides a quick robust estimate of the ^{10}Be in near-surface air in polar regions, which agrees within 20% with the full model. This simplification enables rapid yet robust estimation of near-ground ^{10}Be concentrations, based on production rates in 18 or 96 production zones, without the need for full-model computations. Such practical can be directly used in studies of solar and geomagnetic variability using cosmogenic isotopes.

Wednesday, October 2

Extreme Events 16:35+0:25

keynote talk

Extreme Space Weather Events as Exact Time Markers

Michael Dee

Centre for Isotope Research, University of Groningen

Understanding both natural and cultural processes is dependent upon precise and accurate chronological information. The sequence in which events take place, and their tempo, allow us to then address the fundamental questions of how and why they occur. Important developments in human history have often taken place at the scale of decades, years, or even days. Likewise, some environmental and climatic changes only make sense when supported by annual chronological data. Unfortunately, scientific dating techniques have generally only been able to achieve century-scale resolution, at best. This was certainly true of radiocarbon dating, the most widely used chronometric technique in archaeology and palaeoenvironmental science. However, within the last decade or so, extreme space weather events have shifted this paradigm completely. Individual bursts of cosmic radiation that have resulted in upsurges in the production of cosmogenic isotopes, including radiocarbon, are now allowing annual or even subannual dating to be achieved. This presentation will outline of the mechanism by which this step change in chronology has been realised and discuss some of its most significant achievements so far, including exact-year dating of volcanic eruptions to pinpointing when the Vikings were present in the Americas.

Wednesday, October 2

Extreme Events 17:00+0:25

keynote talk

Extreme geomagnetic storms and their terrestrial effects

Yusuke Ebihara (1)

(1) Kyoto University

Extreme geomagnetic storms are of interest for science, and of importance for space weather application. Magnetic storms are characterized by long-lasting large-amplitude geomagnetic disturbances at low latitudes. The magnetic disturbances are thought to be largely caused by the ring current around the Earth. The major issues are: How the ring current is extremely developed, and what the impacts are. For the first issue, the magnetospheric convection is a key. The convection transports hot plasma from the plasma sheet on the nightside toward the Earth. The accumulation of the hot plasma results in the development of the ring current. The earthward transport of hot plasma also gives rise to equatorward expansion of the auroral oval. The development of the convection under extreme solar wind condition is not well understood. For the second issue, the geomagnetically induced current (GIC) flowing in the power grid is the major concern. In Japan, GIC with amplitude of 129 A was recorded during the October 2003 magnetic storm. If the extremely large magnetic storm of September 1859 (Carrington event) occurs again, large-amplitude electric field of 2.5 V/km is expected to appear on the surface of the ground at Kakioka Magnetic Observatory, Japan. Vulnerability assessment of power transformers against such extreme magnetic storms is a subject to be studied to prevent potential risk. We overview recently achieved advances on the extreme magnetic storms and possible impacts.

Wednesday, October 2

Extreme Events 17:25+0:20

solicited talk

The geomagnetic field during reversals and excursions and implications for shielding

Monika Korte

GFZ German Research Centre for Geosciences

The geomagnetic field creates the magnetosphere that shields our planet from solar wind and galactic cosmic rays. The field varies continuously and has experienced several polarity reversals throughout Earth's history that go along with severe drops in global geomagnetic field intensity. The field loses its dipole dominated structure during these events and displays a complex and multipolar morphology at Earth's surface for several decades to millennia. Moreover, intervals of stable polarity are interrupted by short, sometimes only regionally manifesting geomagnetic excursions. The detailed global processes and field morphology during these extreme events in general are still relatively poorly known as paleomagnetic records provide only a limited global coverage and have intrinsic limitations regarding temporal resolution and accurate dating. However, some of the most recent events such as the Laschamps excursion (41 kyr ago) and the Matuyama-Brunhes reversal (780 kyr ago) are now described by global spherical harmonic reconstructions, that can be used to obtain estimates about the geomagnetic field shielding against solar wind and galactic cosmic rays. I discuss recent findings regarding the global and regional characteristics of geomagnetic reversals and excursions and implications for, e.g. geomagnetic cutoff rigidity and cosmogenic isotope production estimates.

Wednesday, October 2

Extreme Events 17:45+0:20

solicited talk

Solar energetic particle events: bridging direct observations and imprints in cosmogenic isotopes

Sergey Koldobskiy

The University of Oulu

Solar energetic particle events represent one of the types of solar eruptive activity, which is crucially important both for a deeper understanding of solar physics and for a better assessment of related hazards for modern technological society. Today we have a lot of instrumentation, which allows us to directly measure SEP fluxes' characteristics, however, the two last solar cycles did not produce intense SEP events. For greater events, we must consider events registered during the last 80 years using ground-based instrumentation. For the greatest ones, we have to understand how to quantify peaks in cosmogenic-isotope imprints. In our talk, we will cover all these observational data, related inter-calibration challenges, and how they were solved.

Wednesday, October 2

Extreme Events 18:05+0:20

solicited talk

Radiation Impacts of Extreme Space Weather Events on Earth – Observation and Modelling

Fan Lei, Keith Ryden & Clive Dyer

Surrey Space Centre, University of Surrey, Guildford, Surrey GU2 7HX, UK

Extreme space weather events, such as the solar energetic particles and geomagnetic storm, can dramatically change the atmospheric ionization radiation field and have profound impacts to aviation in terms of the enhanced radiation exposure to crew and passengers, and more importantly malfunctions of avionics. Such impacts can be significant even at ground level during a so-called ground level enhancement (GLE) event. In this talk, we assess these impacts in the cases of extreme GLEs, and report on the observational and modelling activities of the Surrey Space Centre team on these subjects over the past decades and the latest developments.

Wednesday, October 2

Extreme Events 18:25+0:15

contributed talk

Is there a relationship between extreme solar particle events and super-flares?

Ilya Usoskin; Sergey Koldobskiy

University of Oulu, Finland

Extreme solar particle events (ESPEs) are known to occur rarely, roughly one event per 1500–2000 years, as detected through cosmogenic-isotope data for the last 12 millennia of the Holocene. During an ESPE, the fluence of solar energetic particles at Earth can exceed that of ‘normal’ SPEs by several orders of magnitude. Although the solar origin of such events is established, the mechanism of particle acceleration is not understood. It is also independently known from precision photometric measurements that sun-like stars can produce super-flares, with the bolometric energy exceeding that of the known solar flares by 2–3 orders of magnitude and the occurrence rate of one such flare per 200–1000 years per star. The question of whether these two types of events are directly inter-related is still open. Here we discuss the updated statistics of these events and try to reconcile their possible relationship using the statistics of major directly observed solar events. It is suggested that different occurrence rates of the two types of events are mutually consistent within the known uncertainties because not each super-flare is expected to produce an ESPE at Earth.

Wednesday, October 2

Extreme Events 18:40+0:15

contributed talk

Solar Origins of Extreme Space Weather Events

Nariaki Nitta (1); Meng Jin (1); Tamitha Mulligan Skov (2); Erika Palmerio (3)

(1) Lockheed Martin Advanced Technology Center; (2) Millersville University; (3) Predictive Science Inc.

On 23 July 2012, we witnessed a very energetic coronal mass ejection (CME) hitting STEREO-A spacecraft, which was then located about 30 degrees behind the west limb from Earth view. Despite occultation by the limb, the eruption was clearly captured by the Atmospheric Imaging Assembly on board the Solar Dynamics Observatory. The solar wind magnetic field and plasma data at STEREO-A showed extremely large enhancements, and the flux of energetic particles was also extreme. This event thus has been conceived as a "Carrington-class event", even though the estimated GOES-equivalent soft X-ray peak flux was not much larger than the X1 level. Much work has been conducted to estimate its space weather impact had the CME been directed to Earth. One of the scenarios that may have been conducive to the extreme space weather event was the double effect of two successive CMEs that launched very close in time and evacuation of the passage of the CME by a previous CME. We revisit this scenario by further data analysis and improved numerical simulations. Moreover, we examine the evolution of NOAA AR 11520 over a solar rotation in relation to near-by coronal structures and discuss possible anomalies of the region that may have produced an extreme event without the preconditioning effects.

Wednesday, October 2

Extreme Events 18:55+0:15

contributed talk

The Extreme Solar-Terrestrial Storm in February 1872: Archival Investigations

Hisashi Hayakawa (1)

(1) Nagoya University

Welcome to Nagoya. It has been already more than 150 years since aurora was last seen in Nagoya by naked eye. This presentation document recent archival investigation for this rare occasion — the February 1872 storm — that extended auroral visibility even down to Nagoya, on the basis of Hayakawa et al. (2023, ApJ, 959, 23). Contemporaneous solar observations allow us to identify the probable source active region as a medium-sized but complex sunspot group near the central meridian. Geomagnetic records allow us to digitize their temporal evolutions and quantify the magnitude as < -834 nT in terms of the min Dst estimate. Auroral reports are found throughout the world, even down to East Asia, India, Arabian Peninsula, Indian Ocean, Sudan, Southern Africa, and the Caribbean Sea. These records allow us to reconstruct the equatorward boundary of the auroral oval down to 24.2° in invariant latitude and auroral visibility 8.3° in magnetic latitude. In magnitude, this storm is twice as intense as the May 2024 storm and comparable with the Carrington storm in 1859 in intensity. Further investigations are needed for extreme space weather events in the past.

Wednesday, October 2

Extreme Events 19:10+0:15

contributed talk

Generation of ionospheric disturbances after the 2022 Tonga volcanic eruption

Atsuki Shinbori (1); Yuichi Otsuka (1); Takuya Sori (9); Michi Nishioka (2); Perwitasari Septi(2); Takuo Tsuda (3); Nozomu Nishitani (1); Atsushi Kumamoto (4); Fuminori Tsuchiya (5); Shoya Matsuda (6); Yoshiya Kasahara (6); Ayako Matsuoka (7); Yoshizumi Miyoshi (1); Iku Shinohara (8)

(1) Institute for Space-Earth Environmental Research (ISEE), Nagoya University; (2) National Institute of Information and Communications Technology (NICT); (3) The University of Electro-Communications; (4) Department of Geophysics, Tohoku University; (5) Planetary Plasma and Atmospheric Research Center, Tohoku University; (6) Graduate School of Natural Science and Technology, Kanazawa University; (7) World Data Center for Geomagnetism, Graduate School of Science, Kyoto University; (8) Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency; (9) Research Institute for Sustainable Humanosphere, Kyoto University

The Earth's ionosphere is formed by a partial ionization of the upper atmosphere due to solar extreme ultraviolet radiation and particle precipitation from the magnetosphere. The electron density variation in the ionosphere is caused by both solar activities and lower atmospheric disturbances. Because the ionosphere influences the propagation of radio signals from global navigation satellite systems (GNSS) with charged particles, it is important to understand the generation processes of the electron density perturbations in the ionosphere associated with solar flares, geomagnetic storms, earthquakes, tsunamis, volcanic eruptions, and meteorological phenomena. The explosive eruption of the undersea volcano near the coast of Tonga occurred at 04:15 UT on 15 January 2022. This eruption is one of the most explosive events in the modern era, and a vertical plume reached approximately 55 km, corresponding to a height of the lower mesosphere. The intense explosion and subsequent plume generated strong atmospheric waves (acoustic and atmospheric gravity waves) detected by ground-based instruments worldwide. Because a global-scale atmospheric and ionospheric response to such the large volcanic eruption has not yet been observed, it provides a unique opportunity to promote interdisciplinary studies of coupling processes in lithosphere-atmosphere-ionosphere-plasmasphere with various kinds of observation techniques (GNSS, SuperDARN, ionosonde, Arase, and Himawari-8). The Tonga volcanic eruption allows us to elucidate the propagation and occurrence features of traveling ionospheric disturbances, the generation of equatorial plasma bubbles, the cause of electron density holes around the volcano, and the magnetic conjugacy of magnetic field perturbations. In this talk, we will introduce an overview of ionospheric disturbances after the Tonga volcanic eruption and summarize what we know from this extreme event analysis.

Thursday, October 3

Space Weather 9:00+0:20

solicited talk

Detecting solar flare precursors using DEFT

Larizza Krista (1,2)

(1) University of Colorado; (2) NOAA

”The Detection and EUV Flare Tracking (DEFT) tool automatically identifies flare precursors in EUV observations in a fast and consistent manner, with minimal computational overhead. DEFT currently uses GOES/SUVI 304 A observations to detect, group and flag sudden impulses that could be precursors to flares. In this study we analyzed signatures before 351 flares (150 C, 150 M and 51 X class flares) that occurred between 2017- to date. Across these magnitudes, precursors were detected for 93% of the flares when using a 6 hour window before the flare start times. Using superposed epoch analysis, we found that elevated precursor activity tends to occur across all magnitude flares in the last two hours before the flares. The frequency of precursors gradually increases before M class flares but decreases for C class flares. In the last 20 minutes there is a significantly higher precursor frequency, pixel count and power associated with M class flares than C class flares. We suggest that the observed EUV precursors are signatures of small-scale magnetic reconnection events, and the increasing frequency of precursors could indicate increasing instability and impending flare initiation. Continuing research on EUV precursors is essential to better understand pre-flare processes that influence magnetic instability prior to flares. The consistent and reliable detection and differentiation of EUV precursors could also complement and significantly improve current flare forecasting efforts. ”

Thursday, October 3

Space Weather 9:20+0:20

solicited talk

Long-term variation of space weather effects on the Earth's ionosphere

Ioanna Tsagouri

National Observatory of Athens, Institute for Astronomy, Astrophysics, Space Applications and Remote Sensing, Athens, Greece

Ionospheric variability affects the society's technological infrastructure in many different ways, especially under severe space weather events. Due to the practical needs, ionospheric specification applications have seen enormous progress in the last decades, but certain limitations in our prediction ability indicate that the deeper understanding of the ionospheric response to external forcing remains a high priority task. Key challenges to be addressed are reflected in a set of dependencies that compile a complicated scene for the occurrence of ionospheric disturbances. In this framework, recent results suggest that the ionospheric activity may vary with solar cycle activity, as qualitative and quantitative differences in the peak electron density disturbances for different solar cycle 24 phases were identified. Ionization increases (decreases) tend to dominate and be higher in intensity during solar minimum (maximum), probably as different ionospheric response to different solar wind drivers (e.g., high speed streams or coronal mass ejections). This presentation aims to summarize key results on long-term changes of the ionospheric activity, while expanding relevant analyses to a period longer than two solar cycles (1997 - 2024). To this effect, ionospheric observations of the critical frequency, foF2 and peak electron density, hmF2 obtained in the middle latitude ionosphere are analyzed to reveal the morphology and the intensity of the disturbances, but also key aspects of their triggering mechanisms. The discussion of the ionospheric behavior in a wide range of geophysical conditions facilitates the determination of general trends in the ionospheric response to different faces of the impact from above.

Thursday, October 3

Space Weather 9:40+0:15

contributed talk

Expanding the View of the Great 4-5 February 1872 Geomagnetic Storm

Delores Knipp (1); Kalevi Mursula (2,3); Hisashi Hayakawa (3)

”(1) University of Colorado, Boulder; (2) The University of Oulu; (3) Nagoya University ”

There is strong evidence that the geomagnetic storm of 4-5 February 1872 rivaled the intensity and geo-effectiveness of the great storms of 1859 and 1921 (e.g., Hayakawa et al., 2023, <https://doi.org/10.3847/1538-4357/acc6cc>). Thus far, most of the information presented about the February 1872 storm has focused on sub-auroral to equatorial observations reported after 14 UT on 4 February. We expand the view of this storm to deep inside the polar cap, based on eye witness reports from observers on an ice-bound arctic expedition. There is suggestion that moderate-to-strong magnetic disturbances developed very early on 4 February. Such reports are consistent with telegraph system disturbances reported in the United Kingdom and with magnetometer observations from the Helsinki Observatory. We discuss the implications of this early disturbance and also provide vivid descriptions of the storm time aurora viewed from inside the northern polar cap region. The auroral observations suggest that at times during the peak of the storm the sky was alight with visible disturbances from 10-90 degrees MLAT.

Thursday, October 3

Space Weather 9:55+0:15

contributed talk

Characteristics of white-light flares and their relationship to space weather

Kyoko Watanabe (1); Satoshi Masuda (2)

(1) National Defense Academy of Japan; (2) Nagoya University

”White-light flares were the world’s first solar flare, observed by Carrington in 1859. It has been reported that a large-scale Dellinger phenomenon occurred with this Carrington flare, and that auroras were also observed at low latitudes such as Hawaii and the Caribbean coast (e.g. Tsurutani et al., 2003; Green and Boardsen, 2006). Therefore, it has been suggested that white-light flares are related to space weather phenomena. White-light flares can be observed by ground-based instruments because they are observed in visible continuum, but the number of observations is limited because they are almost always associated with large solar flares such as X-class flares. We therefore used data from the Solar Optical Telescope (SOT) onboard the Hinode satellite, to explore the conditions under which white-light flares occur. And then we found that the precipitation of a large amount of accelerated non-thermal electrons within a short duration is a key factor of generating of white-light flares (Watanabe et al., 2017). This result suggests that the occurrence of white-light flares is related to the intensity of particle acceleration in solar flares, and that the time-integrated values of white-light emission have a similar relationship with soft X-ray and EUV emissions, which cause the occurrence of communication failures, but do not match the conditions for the occurrence of CMEs that have a significant impact on space weather environments. In this talk we will discuss the relationship between white-light flares and space weather phenomena.”

Thursday, October 3

Space Weather 10:10+0:15

contributed talk

Correction for the Missed Important Early Part of the Main Phase of Geomagnetic Storms

Balan Nanan (1)

(1) Shandong University, China

Geomagnetic storms have been studied for over 150 years using data, models and indices like Dst and SymH. Recently, we notice that the important early decreasing part of the main phase (MP) from the positive main phase onset (MPO) to the 0-level of Dst and SymH indices is missed in the treatment of the main phase (MP) in the literature. We correct and explain this inconsistency in over 1000 storms having positive MPO (out of over 1300 storms) in SymH during 1981–2023 by raising the 0-level of SymH to the MPO-level. The correction considers the full range of the main phase, increases the corrected storm intensity (SymHMin*) and impulsive strength (IpsSymH*) by up to -149 nT and -134 nT, respectively, compared to their uncorrected values. The correction seems important for all aspects of global space weather. For example, the corrected SymHMin* largely changes the conventional storm identification and classification and corrected IpsSymH* clearly identifies all 3 severe space weather (SvSW) events from over 1300 normal space weather (NSW) events with a large separation of 52 nT; it also identifies all 8 minor-system-damage space weather (MSW) events from the NSW events. The correction is physical meaningful. The decrease of SymH from MPO to (original) 0-level is found mainly due IMF Bz turning southward (or increase in westward ring current) in majority of the cases. Only in a small number of cases, the decrease is mainly due to the sudden decrease in the solar wind dynamic pressure (or decrease in eastward magnetopause current).

Thursday, October 3

Space Weather 10:25+0:15

contributed talk

Modelling the Impacts of Geomagnetically Induced Currents on Railway Signalling Systems

Cameron Patterson (1); Jim Wild (1); David Boteler (2); Ciaran Beggan (3); Gemma Richardson (3); Juliane Huebert (3)

(1) Lancaster University, Lancaster, United Kingdom; (2) Natural Resources Canada, Ottawa, Canada; (3) British Geological Survey, Edinburgh, United Kingdom

”Track circuit signalling systems are widely utilised across the world, and their ability to accurately detect trains is crucial for the safe and smooth operation of a railway network. These systems use electric circuits to detect the presence or absence of trains in sections along a railway line, and they can be susceptible to interference from geomagnetically induced currents.

The model we have developed to analyse the impacts of space weather on the UK railway network has been expanded to include new arterial routes across Great Britain.

Results from the model will be presented, including for the storm of May 2024.”

Thursday, October 3

Space Weather 10:40+0:15

contributed talk

Aurorasaurus: A citizen science platform for viewing and reporting the aurora

Vincent Ledvina (1,2); Elizabeth MacDonald (3,2); Laura Edson (3,2)

(1) University of Alaska Fairbanks, Fairbanks, AK, USA; (2) Aurorasaurus, New Mexico Consortium, Los Alamos, NM, USA; (3) NASA Goddard Space Flight Center, Greenbelt, MD, USA

Aurorasaurus is an award-winning project that maps auroras via volunteer reports on its website. Each report serves as a valuable data point for scientists to analyze and incorporate into space weather models. In addition, the real-time ability of this platform facilitates the combination of citizen science observations with auroral oval models to improve auroral visibility nowcasting. Aurorasaurus experienced its largest aurora event ever during the May 10-11, 2024 solar storm, receiving more than 5,000 participatory science reports from 55+ countries, all 7 continents, and even ships in the ocean. In operation since 2014, the project's peer-reviewed publications have included a number of discoveries, interdisciplinary research, as well as innovative data-model comparisons. For example, in collaboration with participatory scientists and the scientific community Aurorasaurus published the first modern scientific study of STEVE (Strong Thermal Emission Velocity Enhancement), an aurora-like phenomenon that appears closer to the equator and flows from east to west. Aurorasaurus provides easily understandable aurora information, basic gamification, and real-time location-based notification of verified aurora activity to engage citizen scientists. The project conducts outreach and education across the globe, often through partnerships with local groups of enthusiasts (such as its "Aurorasaurus Ambassadors" group). The project is one of only a handful of space weather citizen science projects and can provide useful results for the space weather and citizen science communities. Aurorasaurus is a research project within the New Mexico Consortium, supported by the National Science Foundation and NASA.

Thursday, October 3

Space Weather 11:25+0:25

keynote talk

Recent Japanese Activities for Operational Space Weather Services

Takuya Tsugawa

National Institute of Information and Communications Technology

”National Institute of Information and Communications Technology (NICT) is responsible for operational space weather forecasting in Japan, and provide nowcast and forecast information twice a day via email and website. Based on the report of “Study group on the advancement of space weather forecasting” published in June 2022 by the Ministry of Internal affairs and Communication, NICT have developed warning operation system for new criteria that takes into account social impacts. Target field is HF Communications and broadcasting, Space system operation, and aviation human exposure for the first step. The new warning system is planned to open for public in 2024. As for research and development on the observation side, we are expanding ground-based observations through international cooperation and developing satellite-based observations using GEO satellite in Japan. We constructed a 7.3m diameter parabolic antenna at Kashima Space Technology Center, NICT in March 2023 for real-time receiving of SWFO-L1 observation data as a member of SWFO Antenna Network. We have been working on Radiation Monitors for Space Weather (RMS) project to develop instruments to measure energetic particles in GEO for safe and stable use of satellite operation, aviation and human activities in space. We have almost finished developing the engineering model. Development of flight model will start in 2024 and RMS on Himawari-10 will be operated in 2029. As for the international activities related with space weather, we joined international space environment services (ISES). ISES is a community of organizations that provide operational space weather forecasting services and has been active since 1962. NICT has been the chair since 2023. We also contribute to hold the international collaborative meetings such as International Space Weather Coordination Forum (ISWCF), Asia-Oceania Space Weather Alliance (AOSWA), etc.

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Thursday, October 3

Atmosphere and Climate 11:50+0:15

contributed talk

Climate of the Maunder Minimum in SOCOLv4 model simulations and reanalysis data

Timofei Sukhodolov (1); Tatiana Egorova (1), Jan Sedlacek (1), Eugene Rozanov (1)

Physikalisch-Meteorologisches Observatorium Davos/World Radiation Center (PMOD/WRC), Davos, Switzerland

Centennial climate evolution correlates with the solar activity proxies. However, this correlation hasn't yet been proven or disproved as a causal relationship because of the large uncertainties in the amplitude of solar forcing reconstructions from these proxies and uncertainties in responses to other forcings like volcanic eruptions. Motivated by recent developments in modeling, which allow direct simulations of volcanic aerosols in the Earth system model (ESM) framework, and the availability of homogenized climate reconstruction data, we focused our study on establishing the approximate amplitude of long-term solar forcing variation exploiting these two components. In other words, we aimed to answer the question of how large the solar forcing must be to reproduce the observations. We focused on the period around the Maunder Minimum (17th–18th centuries), characterized by a substantial decline and recovery in solar activity overlapping with a series of volcanic eruption clusters. We exploited the ESM SOCOLv4 that was explicitly designed for simulating the volcanic- and solar-related processes in the atmosphere, which has been forced by the latest estimates for the volcanic SO₂ emissions and a range of solar scenarios with varying amplitudes. As a reference, we used the Modern Era Reanalysis data and individual regional temperature reconstructions from the proxy data. To better understand regional sensitivities and non-linearities in climatic responses to volcanoes and variations in solar activity, we additionally performed 200-year-long time-sliced simulations with different solar forcing amplitudes ranging from -20 to +10 Wm⁻² and the ensemble Tambora-like simulations.

Thursday, October 3

Atmosphere and Climate 12:05+0:15

contributed talk

Investigating the Impact of Solar Minima on Global and Regional Climate Patterns

**Lorenza Lucaferri (1); Francesco Berrilli (1); Simona Bordoni (2); Valentina Penza (1);
Stephen I. Thomson (3)**

(1) University of Rome Tor Vergata; (2) University of Trento; (3) University of Exeter

”Despite being the primary energy source for Earth’s atmosphere and oceans, the Sun’s variable output, in terms of radiative forcing and particle modulation, remains a topic of debate. The key question lies in the extent to which solar variability can significantly influence climate change and the specific regional and temporal patterns of this influence. Understanding solar variations and their imprint on Earth’ s climate is crucial for interpreting past global and regional changes, and reducing the uncertainty of future projections under anthropogenic global warming . This study investigates the potential influence of long-term solar cycle variations on regional and global climate. More specifically, we investigate the climatic response to a Maunder Minimum-like grand solar minimum using the ISCA intermediate-complexity modeling framework. We perform and employ a range of simulations with total solar irradiance (TSI) reductions from 1.7 Wm⁻² to 2.5 Wm⁻² to explore potential global and regional climate impacts. We are particularly interested in exploring dynamic and thermodynamic mechanisms that might amplify the response to the solar forcing at the regional scale and lead to localised cooling, for instance in the North Atlantic region, similarly to what was observed in the Little Ice Age. A single climate model is chosen to isolate the solar signal from the background noise of internal climate variability, allowing for a clearer understanding of the direct solar influence on climate.”

Thursday, October 3

Atmosphere and Climate 12:20+0:15

contributed talk

Seasonal forecast of the late boreal temperature anomalies based on solar forcing

Mikhail Vokhmianin, Timo Asikainen, Antti Salminen, Kalevi Mursula

University of Oulu, Finland

The polar stratosphere in the Northern Hemisphere significantly influences surface weather patterns across regions such as Northern Eurasia, Eastern Canada, the Middle East, and the Eastern United States. This influence is particularly pronounced following sudden stratospheric warmings (SSWs), during which the polar vortex breaks down. Our analysis reveals a statistically significant pattern: the surface impact of SSWs is observed in late winter, specifically in February and March, especially when the Quasi-Biennial Oscillation (QBO) is in the easterly phase. Conversely, during the westerly QBO phases, the surface impact of SSWs is less systematic. Surface anomalies in winters without SSWs are also more pronounced in the late phase of QBO-E winters. Recently, we have shown that the occurrence of SSW events is modulated by geomagnetic activity (a proxy for the energetic particles precipitation) and solar activity (a proxy for UV radiance). Our study demonstrates that probabilistic seasonal forecasts based on solar forcing could be beneficial for predicting surface winter weather several months in advance.

Thursday, October 3

Atmosphere and Climate 12:35+0:15

contributed talk

Digitalizing Korean Weather Records (1623-1910) via Seungjeongwon Ilgi for Climate Studies

Kohei Ichikawa (1); Zeyu Lyu (2); Yongchao Cheng (2); Hisashi Hayakawa (3); Yukiko Kawamoto (3)

(1) Waseda University; (2) Tohoku University; (3) Nagoya University

Historical weather records from Europe indicate that the Earth experienced substantial climate variability, such as the Little Ice Age between the 14th and 19th centuries and several global crises tentatively associated with these phenomena. However, it remains unclear how global this climate variability was due to the scarcity of meteorological data from other regions, including East Asia, particularly around the 17th century. In this context, the Seungjeongwon Ilgi, a daily record of the Royal Secretariat of the Joseon Dynasty of Korea, serves as a valuable source of historical meteorological records for the Korean Peninsula, covering 288 years of weather observations from 1623 to 1910. We utilized the digital database of Seungjeongwon Ilgi to construct a machine-readable weather condition dataset. To achieve this, we extracted valid weather information from the original text descriptions and categorized them into predefined weather categories. Additionally, we enhanced the usability of the dataset by converting the dates from the traditional Korean calendar to the Gregorian calendar. We also report a few results from this dataset, especially regarding long-term weather trends. Overall, future studies focusing on past climate and weather could use this meteorological database to investigate long-term climate variability in East Asia.

Thursday, October 3

Atmosphere and Climate 13:50+0:25

keynote talk

Can cosmic rays impact Earth' climate?

Irina Mironova

St. Petersburg State University

”The Earth is constantly bombarded by energetic charged particles from space, collectively known as energetic precipitating particles, which enter the Earth’s atmosphere and can be drives of various atmospheric processes. Most energetic particles originate from space and are known as galactic cosmic rays (GCR), consisting primarily of protons.

GCR, compared to other energetic precipitating particles, penetrate most deeply into the Earth’s atmosphere. At altitudes from the troposphere to the stratosphere, the main source of ionization is precisely protons from galactic cosmic rays. An additional contribution to ionization at the same altitudes is made by solar protons that penetrate the atmosphere after solar eruptions and are usually associated as solar proton events (SPE and GLE). The lower and middle atmosphere is essentially neutral and ionization created mainly by galactic and solar protons, is low compared to the higher layers of the atmosphere/ionosphere, but the presence of mobile ions is important for atmospheric chemistry and atmospheric electricity.

Atmospheric ions induced by GCR and SPE/GLE may underlie the processes affecting atmospheric ozone depleting components and ozone; atmospheric electricity; cloud formation due to ion-induced aerosol formation and thus lead to changes in surface temperature.

The talk will examine the basic physical and chemical processes and mechanisms in the Earth atmosphere associated with galactic and solar protons. Particular attention will be paid to the terrestrial climate impacts of GCR during solar cycles and the effects of extreme SPE/GLE. The feasibility of well-known ionization-aerosol-cloud mechanisms such as the Svensmark mechanism and the Tinsley mechanism, as well as the CLOUD and SKY experiments, will be assessed and determined. ”

Thursday, October 3

Atmosphere and Climate 14:15+0:15

contributed talk

Recent Advances in the Cosmic Ray-Climate Connection

Nir J. Shaviv (1); Henrik Svensmark (2); Martin Bødker Enghoff (2); Jacob Svensmark (3); Irina Thaler (3)

”(1) Hebrew University of Jerusalem; (2) Danish Technical University; (3) University of Copenhagen ”

Significant progress has been made in understanding the cosmic ray-climate connection, supported by increasing empirical and experimental evidence and a strengthened theoretical framework. Empirical findings range from responses during multi-day Forbush decreases in cosmic ray flux to variations over geological timescales. Theoretically, three distinct mechanisms have been identified, linking atmospheric ionization to aerosol nucleation and their subsequent growth and survival, as demonstrated in our experiments. Additionally, we quantify the strength of this link using ocean heat content and global aerosol simulations.

Thursday, October 3

Atmosphere and Climate 14:30+0:15

contributed talk

Quantifying the impact of variable solar forcing on sudden stratospheric warmings

Monali Borthakur (1); Miriam Sinnhuber (1)

(1) Karlsruhe Institute of Technology

We investigate the response of coupling processes from the upper atmosphere to the stratosphere. The focus is on the impact of two different solar forcings, variable extreme ultraviolet (EUV) photo-ionisation and solar particle forcings in the middle atmosphere on the sudden stratospheric warmings (SSWs). Sudden stratospheric warmings (SSWs) are events in which polar stratospheric temperatures rise by several tens of kelvins (up to increases of about 50° C (90° F)) over the course of a few days. Model experiments were conducted with the chemistry-climate model EMAC extending from surface to thermosphere first by doubling and halving the EUV photo-ionisation. Stratospheric and mesospheric chemistry with five ions was used, and particle impact ionization was prescribed from the AisStorm ionization model. To assess the impact of variable energetic particle fluxes, ionization rates from a different moderate forcing scenario as well as for an extreme geomagnetic storm were prescribed and synchronised on the day of the warming. In both cases, electron fluxes vary in the keV to 100 keV range that mostly affects the MLT region. The effects on the polar vortex breakdown were studied using temperature, ozone, and NO_y for the two days. Simulations nudged to ERA-5 and free running ensemble simulations were performed and difference in the polar vortex reformation and evolution afterwards was found with variable EUV and particle forcings.

Thursday, October 3

Atmosphere and Climate 14:45+0:20

solicited talk

Global impacts of an extreme solar particle event under different geomagnetic field strengths

Pavle Arsenović (1,2); Eugene Rozanov (3,4); Ilya Usoskin (5); Chris Turney (6); Timofei Sukhodolov (3); Ken McCracken (6); Marina Friedel (2); Julien Anet (7); Stana Simića (1); Ville Maliniemi (8); Tatiana Egorova (3); Monika Korte (9); Harald Rieder (1), Alan Cooper (10), and Thomas Peter (2).

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Solar particle events (SPEs) are short-lived bursts of high-energy particles from the solar atmosphere and are widely recognized as posing significant economic risks to modern society. Most SPEs are relatively weak and have minor impacts on the Earth’ s environment, but historic records contain much stronger SPEs which have the potential to alter atmospheric chemistry, impacting climate and biological life. The impacts of such strong SPEs would be far more severe when the Earth’ s protective geomagnetic field is weak, such as during past geomagnetic excursions or reversals. Here, we model the impacts of an extreme SPE under different geomagnetic field strengths, focusing on changes in atmospheric chemistry and surface radiation using the atmosphere–ocean–chemistry–climate model SOCOL3-MPIOM and the radiation transfer model LibRadtran. Under current geomagnetic conditions, an extreme SPE would increase NO_x concentrations in the polar stratosphere and mesosphere, causing reductions in extratropical stratospheric ozone lasting for about a year. In contrast, with no geomagnetic field, there would be a substantial increase in NO_x throughout the entire atmosphere, resulting in severe stratospheric ozone depletion for several years. The resulting ground-level ultraviolet (UV) radiation would remain elevated for up to 6 y, leading to increases in UV index up to 20 to 25% and solar-induced DNA damage rates by 40 to 50%. The potential evolutionary impacts of past extreme SPEs remain an important question, while the risks they pose to human health in modern conditions continue to be underestimated.

Thursday, October 3

Ionosphere and Magnetsphere 15:05+0:15

contributed talk

Solar flux dependence of electric conductivity in the dayside ionosphere of Earth

”Aki Ieda (1); K. Watanabe (2); S. Kitajima (2); M. Nishioka (3); H. Jin (3); T. Hori (1)

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”(1) Nagoya University; (2) National Defense Academy of Japan; (3) National Institute of Information and Communications Technology ”

”Solar radiation ionizes Earth’ s neutral atmosphere to generate the ionosphere. The ionospheric E-region is characterized by the presence of horizontal electric currents, which cause magnetic variations on the ground. E-region electric conductivity models traditionally assume that the relevant solar flux is proportional to the solar radio flux F10.7 (10.7 cm) index. However, such an assumption may be inappropriate because the E-region peak is not generated by solar radio waves but rather by Lyman β . In this study, we compared the solar fluxes with the maximum electron density in the E-region, which is often assumed to be proportional to the E-region electric conductivity. Electron density data were obtained from ionosonde observations conducted at Yamagawa station in Kagoshima, Japan. Lyman β (103 nm) and Lyman α (122 nm) data were obtained from the thermosphere ionosphere mesosphere energetics and dynamics (TIMED) satellite. Data from 2002 to 2017 were used for least squares analyses.

The fitted straight lines showed qualitative differences regarding the origin. The line fitted to the Lyman β data passed near the origin, suggesting that Lyman β directly generates the E-region density peak. In contrast, the line fitted to the F10.7 index deviated from the origin, implying that the offset of the F10.7 index should be subtracted in models associated with the E-layer. This correction presumably improves models of ionospheric electric conductivity, and thus, horizontal electric currents, geomagnetic variations, and Joule heating. ”

Thursday, October 3

Ionosphere and Magnetsphere 15:20+0:25

keynote talk

Solar activity dependence of medium-scale traveling ionospheric disturbances: GPS observations

Yuichi Otsuka (1); Kazui Watanabe (1); Atsuki Shinbori (1); Veera Kumar Maheswaran (2); Michi Nishioka (3); Septi Perwitasari (3)

(1) Institute for Space-Earth Environmental Research, Nagoya University; (2) SASTRA Deemed University; (3) National Institute of Information and Communications Technology

Medium-scale traveling ionospheric disturbances (MSTIDs) are electron density perturbations in the F-region, and have horizontal wavelengths of approximately hundreds of kilometers and periods ranging from 15 min to 1 h. Global Positioning System (GPS) receiver networks have made it possible to observe two-dimensional horizontal structures of the MSTIDs. Recent studies reveal that MSTIDs are caused by atmospheric gravity waves during daytime and by electro-dynamic forces during nighttime. In this study, we investigate solar activity dependence of MSTIDs by analyzing total electron content (TEC) data obtained from a Global Positioning System (GPS) receiver network in Japan during 22. We have found that the mean horizontal phase velocity of the MSTIDs during daytime showed an anticorrelation with solar activity. This result suggests that gravity waves with low phase velocity could be dissipated by high viscosity in the thermosphere under low solar activity conditions. On the other hand, the nighttime MSTID occurrence rate is found to increase with decreasing solar activity. We also have found that the correlation between the nighttime MSTID and sporadic E increases with solar activity. This finding indicates that in the high solar activity conditions, when the growth rate of Perkins instability is relatively low, generation of the polarization electric fields in the layer could play a more important role to grow MSTIDs than in the low solar activity conditions.

Thursday, October 3

Ionosphere and Magnetsphere 16:15+0:15

contributed talk

ULF wave power spectral density and radial diffusion coefficients from RBSP and THEMIS mission data

Konstantina Thanasoula (1), Christos Katsavrias (1), Ioannis A. Daglis (1,2), Aaron W. Breneman (3), Marina Georgiou (1), Georgios Balasis (4), Theodore Sarris (5)

(1) Department of Physics, National and Kapodistrian University of Athens, Greece; (2) Hellenic Space Center, Greece; (3) Goddard Space Flight Center, NASA, Greenbelt, MD, USA; (4) IAASARS, National Observatory of Athens, Greece; (5) Department of Electrical & Computer Engineering, Democritus University of Thrace, Greece

The outer radiation belt includes a very dynamic charged particle population, primarily composed of high-energy electrons, which are trapped by the Earth's magnetic field. One of the most important mechanisms that causes electron acceleration and losses is radial diffusion, which is caused through the resonant interaction of particles with Ultra Low Frequency (ULF) waves. Many studies have focused on the formalism of radial diffusion and the factors that drive it. A commonly used formalism to calculate radial diffusion coefficients (DLLs) is that of Fei et al. (2006), which assumes a uniform azimuthal power distribution. However, in-situ measurements indicate that the azimuthal wave power distribution is based on the origin and propagation characteristics of the waves. Due to the limited azimuthal and temporal coverage of most spacecraft missions, using data from one mission may lead to the underestimation or overestimation of DLLs. To overcome these limitations, in this study, we use electric and magnetic field data from both the RBSP and THEMIS missions to increase the azimuthal coverage, so as to study the azimuthal power distribution of ULF waves and to subsequently study the radial diffusion coefficients as a function of Magnetic Local Time (MLT). Our results indicate that, when the spacecraft of both the RBSP and THEMIS missions are located at the same L^* and MLT, there is a good correlation between their magnetic field data. This means that, by combining the data from two or more missions, the coverage of MLT, L^* and time increases, which leads to a more detailed calculation of ULF waves power spectral density (PSD) and subsequently to a better estimation of DLLs. A future goal is to extend the existing "SafeSpace" database (<https://synergasia.uoa.gr/modules/document/?course=PHYS120>), which was created using magnetic and electric field measurements by the THEMIS satellites in the 2011-2019 time period, with missions such as RBSP and ARASE.

Thursday, October 3

Ionosphere and Magnetsphere 16:30+0:15

contributed talk

Temporal and spatial evolution of cold ions in the inner magnetosphere during geomagnetic storms

Khan-Hyuk Kim (1); Junhyun Lee (1)

(1) School of Space Research, Kyung Hee University, Republic of Korea

To understand the temporal and spatial evolution of low-energy (< 10 eV) ions within the inner magnetosphere ($L < 6.5$) during geomagnetic storms, we performed superposed epoch analyses of partial ion densities of H⁺ (nH), He⁺ (nHe), and O⁺ (nO) obtained from the Van Allen Probes' flux data in the 1-10 eV energy range. The analyses were carried out for an ensemble of 14 large storms ($Dst < 100$ nT) over a 6-year period from September 2012 to September 2017. We examined the ion density ratios (nH/ne, nHe/ne, and nO/ne) normalized to the electron number density (ne) and found that the nO/ne ratio dramatically increases during the early recovery phase outside the model plasmopause. The enhanced nO/ne ratio persisted for a period exceeding three days subsequent to the Dst minimum. The variation of the nHe/ne ratio observed outside the plasmopause exhibited a trend similar to that of the nO/ne ratio during the recovery phase. However, the nHe/ne ratio is more than an order of magnitude smaller than the nO/ne ratio. In contrast to the nHe/ne and nO/ne ratios, the nH/ne ratio does not exhibit a significant increase during the recovery phase. The values of the nH/ne ratio inside and outside the plasmopause are similar. We also examined the pitch angles of cold ions and found that the enhanced He⁺ and O⁺ ion populations during the recovery phase show field-aligned pitch angle distributions. This indicates that these enhanced cold heavy ions are traveling directly from the ionosphere along the background magnetic field.

Thursday, October 3

Ionosphere and Magnetsphere 16:45+0:20

solicited talk

Energetic Electron Dynamic in the Inner Radiation Belt and SAA Region

Q-G Zong

"SKL Lunar and Planetary Science, MUST ISPAT, PKU"

"Energetic Electron Dynamics are ones of the most dynamic processes in Earth's magnetosphere and have global consequences and broad implications for space weather. They can be monitored using energetic electron detectors on both Macao Science Satellites (MSS-1A/B) and sunsynchronous satellites (Fengyun 3E). There are triple Imaging Electron Spectrometer (IES) instruments to be installed in the Macao Science Satellites and Chinese Sun-synchronous (FY3E) satellites, respectively. The IES instrument on board both Macao Science Satellites and Chinese Meteorology FY-3 (sunsynchronous) satellite, launched on May, 2023, and 4 July, 2021 (FY-3) into a sunsynchronous satellite orbit (LEO), provides the first constellation energetic electron measurements in the inner Radiation Belt and SAA region. The Macau Scientific Satellite - 1 (MSS) comprises two satellites orbiting the Earth at an inclination of 41. MSS1-A follows a circular orbit at an altitude of 450 km, while MSS1-B's orbit is elliptical, ranging between 450 and 500 km in altitude, with its apogee positioned near the South Atlantic Anomaly (SAA). These two satellites share a similar orbit, maintaining a separation of approximately 5-10s minutes, which has varied since their launch. The orbital period for both satellites is approximately 94 minutes.

Such a configuration will provide a unique opportunity to investigate Energetic Electron Dynamics simultaneously at low and high L shells. It will further elucidate potential mechanisms for the particle energization and transport, two of the most important topics in inner radiation belt dynamics. "

Thursday, October 3

Ionosphere and Magnetsphere 17:05+0:15

contributed talk

**Climatology of Nighttime Periodic Ionospheric TEC Disturbances Related to MSTIDs
Over China**

Donghe Zhang (1); Ke Li (1)

(1) Peking University

The climatology of the nighttime periodic disturbances associated with MSTIDs are investigated over the entire China sector from January 2014 to August 2017, using data from global navigation satellite systems (GNSS) receivers. Firstly, a comparative case analysis of propagation characteristics reveals the complexity and day-to-day variations of nighttime MSTIDs. The main statistical findings indicate that these periodic disturbances predominantly occur during the summer months, with a higher occurrence rate during solar minimum. In summer, the disturbances occur more frequently in regions with lower latitudes ($20\text{-}35^\circ$ N) and tend to exhibit an extended duration. In the meantime, some disturbances are also detected at much lower latitudes ($<20^\circ$ N), with noticeable longitudinal differences. Additionally, there are two peaks in the geographic distribution of disturbances, located in the sector of $90\text{-}100^\circ$ E and $105\text{-}125^\circ$ E at lower latitudes, respectively. The distinct spatiotemporal evolution patterns of the two peak disturbance regions suggest that their formation mechanisms should be different. The disturbances in the eastern region exhibit similarities with electrified MSTIDs, which are closely related to Perkins instability, whereas the western disturbance region does not display apparent movement, but exhibits a higher occurrence rate and longer durations, which may be attributed to the frequent upward propagation of GWs in the southeastern region of the Qinghai-Tibet Plateau.

Thursday, October 3

Ionosphere and Magnetsphere 17:20+0:20

solicited talk

Influence of CIRs on relativistic electron enhancements

Ioannis A. Daglis (1,2), Afroditi Nasi (1), Christos Katsavrias (1), Sigiava Aminalragia-Giamini (1,3), Nour Dahmen (4), Antoine Brunet (4), Constantinos Papadimitriou (1,3), Sébastien Bourdarie (4), Ondrej Santolik (5), Ingmar Sandberg (3,6), Fabien Darrouzet (7), Yoshizumi Miyoshi (8), Wen Li (9), Georgios Balasis (10), Hugh Evans (11)

(1) Department of Physics, National and Kapodistrian University of Athens (NKUA), Athens, Greece; (2) Institute of Accelerating Systems and Applications (IASA), Athens, Greece; (3) Space Applications & Research Consultancy (SPARC), Greece; (4) Department of Physics, Instrumentation, Environment, Space (DPHY), Office National d'Etudes et de Recherches Aérospatiales (ONERA), University of Toulouse, Toulouse, France; (5) Institute of Atmospheric Physics (IAP) of the Czech Academy of Sciences, Prague, Czechia; (6) Department of Aerospace Science and Technology, National and Kapodistrian University of Athens (NKUA), Athens, Greece; (7) Royal Belgian Institute for Space Aeronomy (BIRA-IASB), Brussels, Belgium; (8) Institute for Space-Earth Environmental Research (ISEE), Nagoya University, Nagoya, Japan; (9) Center for Space Physics, Boston University, Boston, MA, USA; (10) Institute for Astronomy, Astrophysics, Space Applications and Remote Sensing (IAASARS), National Observatory of Athens, Athens, Greece; (11) European Space Research and Technology Centre (ESTEC), European Space Agency (ESA), Noordwijk, The Netherlands

We investigate the influence of a sequence of Corotating Interaction Regions (CIRs) on relativistic electron enhancements during four consecutive solar rotations in the second half of 2019. Based on solar wind properties, those CIRs can be divided in four groups, with the 3rd group (August-September 2019) resulting in significant multi-MeV electron enhancements, up to ultra-relativistic energies of 9.9 MeV. We investigate the effect of each CIR group by exploiting combined measurements from the Van Allen Probes, THEMIS, and Arase satellites and we pay particular attention to the acceleration efficiency of VLF and ULF waves on various electron populations of the outer Van Allen belt. We produce Phase Space Density (PSD) radial profiles and inspect their dependence on the values of the first and second adiabatic invariants (μ, K), ranging from seed to ultra-relativistic electrons and from near-equatorial to off equatorial mirroring populations, respectively. Focusing on the 3rd CIR group, and in order to assess the relative contribution of radial diffusion and gyro-resonant acceleration, we perform numerical simulations of the radiation belt environment, combining several relevant models: EMERALD (NKUA), GEO model (NKUA), Salammbô (ONERA), VLF model (IAP), Plasmaspheric model (BIRA-IASB), FARWEST (ONERA). We further compare the temporal evolution of the simulated electron PSD with the above observations.

Thursday, October 3

Ionosphere and Magnetsphere 17:40+0:15

contributed talk

Long-term variations of the radiation belt electrons

Y. Miyoshi (1), R. Kataoka (2), S. Kurita (3), S. Kumar (1), I. Shinohara (4), N. Higashi (4), T. Takashima (4), T. Mitani (4), K. Asamura (4), T. Hori(1), and N. Kitamura (1)

(1) Nagoya University, (2) NIPR, (3) Kyoto University, (4) JAXA

During storm periods, the flux of relativistic electrons suddenly decreases and then gradually increases. The precipitation of relativistic electrons has a significant impact on the upper and middle atmospheres through ionization and the resultant ozone depletion. Thus, understanding the variations of relativistic electrons is crucial for space weather and space climate studies. The Japanese Arase satellite has observed the inner magnetosphere and outer belt electrons for over seven years, encompassing the declining phase of the solar cycle 24 and the rising phase of the solar cycle 25. The variations of outer belt electrons during storm periods depend on large-scale solar wind structures, such as CMEs and CIRs. The occurrence of CME-driven and CIR-driven storms changes with the solar cycle phase, which controls the long-term variations of outer belt electrons. In this presentation, we will show the long-term variations of relativistic electrons based on Arase observations and discuss the dependence of energetic electrons on solar wind structures.

Friday, October 4

Solar-Stellar Relations 9:00+0:25

keynote talk

Extremes of Extreme Events: Signatures and Impacts of Superflares, CMEs and SEPs on Environments

Vladimir Airapetian

NASA GSFC and American University

Solar and stellar flares are the most extreme phenomena in solar and stellar atmospheres of the Sun and cool stars. Recent Kepler and TESS observations revealed frequent superflares and megaflares with emission in a wide range of wavelengths (from radio to hard X-ray bands) with energies up to 10³⁷ erg or 100,000 times more powerful than the largest solar flares. They often are associated with ejection of hundreds of billions of tons of magnetized plasma referred to as Coronal Mass Ejections (CMEs) and associated shocks propagating outward into the stellar astrospheres at a few thousand of km/s. CME shocks are the sites of solar/stellar energetic particle (or SEP) events at energies up to a few tens of GeV. In this review, I will describe the basic signatures and mechanisms of solar and stellar extremely powerful events and their impact in circumstellar disks around pre-main sequence stars and exoplanets around zero-age solar-like stars. Also, I will review observational evidence of impact of these extreme events on gas chemistry and describe theoretical models and laboratory experiments that can explain observations. Theoretical models were recently validated with laboratory experiments of proton irradiation of gas mixtures representative of a weakly reducing volcanically driven secondary atmospheres of young rocky exoplanets. I will discuss the implications of our recent theoretical simulations and laboratory experiments for the conditions required to find a prebiotic exoplanet around a solar-like stars and its pre-biosignatures.

Friday, October 4

Solar-Stellar Relations 9:25+0:20

solicited talk

Recent spectroscopic observations of stellar flares and possible stellar mass ejections

**Yuta Notsu (1,2); Adam F. Kowalski (1,2); Kosuke Namekata (3); Hiroyuki Maehara (4);
Shun Inoue (3); Teruaki Enoto (3); Isaiah Trisitan (1,2); Rachel Osten (5); Kazunari
Shibata (3); superflare observation team; Fulcrum flare campaign team**

*(1)University of Colorado Boulder (LASP); (2) National Solar Observatory; (3) Kyoto University; (4) NAOJ;
(5) STScI*

”Large stellar flares (so called “superflares”) generate strong high energy X+UV emissions and coronal mass ejections (CMEs), which can greatly affect the planetary environment and habitability. Recent Kepler/TESS photometric data have revealed the statistical properties of superflares on G, K, M-type stars. Young rapidly-rotating stars (e.g., “Young Suns”) and cooler stars (“M dwarfs”) tend to have frequent flares, which can be more “hazardous” for the habitable planets. However, we still do not know the emission mechanisms of superflares, and how large CMEs are associated with superflares on these active stars. Then recently, these active flare stars have been investigated in more detail through multi-wavelength campaign observations. In particular, we have worked on the observation campaigns of M-dwarfs and young G-dwarfs (young Sun analogs). We have investigated multi-wavelength (NUV-optical-Xray) response of stellar flares to discuss the how flare emission is generated. We also investigate candidates of stellar filament/prominence eruptions, probably leading to CMEs, as a blue-shifted absorption/emission of chromospheric lines associated with stellar flares. Notably, the erupted masses for superflares are larger than those of the largest solar CMEs, indicating severe influence on various planets including exoplanets and young Earth/Mars. In this presentation, I will overview our recent observation results of flares and stellar CME candidates described in the above, and discuss future prospects on further multi-wavelength observations, and the importance of more collaborations with solar-based observation/modeling studies.”

Friday, October 4

Solar-Stellar Relations 9:45+0:15

contributed talk

Rapid, short-duration prominence eruptions in M-dwarf: Insights from solar observations

Yuto Kajikiya (1); Kosuke Namekata (2); Yuta Notsu (3); Hiroyuki Maehara (4); Bunei Sato (1); Daisaku Nogami (2)

(1) Tokyo Institute of Technology; (2) Kyoto University; (3) University of Colorado Boulder; (4) National Astronomical Observatory of Japan

”On the Sun, flares are often accompanied by coronal mass ejections (CMEs), impacting space climates. Recently, the discovery of multiple habitable planets around M-dwarfs has drawn attention to M-dwarf flares/CMEs and their impacts on planets. Previous spectroscopic observations of M-dwarf flares often show asymmetries in the red/blue shifts of H α line profiles, suggesting prominence eruptions (early CME stages). Many of these events show velocities around 100 km/s, slower than typical solar prominence eruptions, and durations exceeding 20 minutes. However, previous studies, with time-cadence over 5 minutes, might have missed rapid velocity changes due to the strong surface gravity of M-dwarfs, potentially missing short-duration prominence eruptions (e.g., Notsu et al. 2024). In this study, we performed spectroscopic observations of the active M-dwarf YZ CMi, with approximately 1-minute time cadence using the Seimei telescope, simultaneously with photometric observations by TESS. We detected 27 H α flares, with 8 showing asymmetry (5 red-shifted, 3 blue-shifted). Particularly, compared to solar flare observations, two events (one blue-shifted, one red-shifted) suggest rapid, short-duration prominence eruptions with durations of approximately 5 minutes and velocities exceeding 300 km/s. This suggests previous studies underestimated the frequency of prominence eruptions due to insufficient time resolution, which is crucial for assessing the impact of flares/CMEs on planets. ”

Friday, October 4

Solar-Stellar Relations 10:00+0:15

contributed talk

Optical and X-ray signature of high-velocity stellar CMEs of the RS CVn- type stars

Shun Inoue (1); Teruaki Enoto (1,2); Yuta Notsu (3,4); Hiroyuki Uchida (1); Kosuke Namekata (1,5); Hiroyuki Maehara (6); Satoshi Honda (7); Wataru Buz Iwakiri (8); Miki Kurihara (9,10); Masahiro Tsujimoto (10); Kenji Hamaguchi (11,12); Keith Gendreau (11); Zaven Arzoumanian (11); Keiichi Namizaki (1); Takeshi Go Tsuru (1); Daisaku Nogami (1); Kazunari Shibata (1,13)

(1) Kyoto University; (2) RIKEN Cluster for Pioneering Research; (3) University of Colorado Boulder (4) National Solar Observatory; (5) National Astronomical Observatory of Japan; (6) National Astronomical Observatory of Japan Okayama Branch Office; (7) University of Hyogo; (8) Chiba University; (9) The University of Tokyo; (10) Japan Aerospace Exploration Agency / Institute of Space and Astronautical Science; (11) NASA' s Goddard Space Flight Center; (12) University of Maryland; (13) Doshisha University;

Stellar superflares and Coronal Mass Ejections (CMEs) are important as proxies of them on the young Sun. One particular observational advance of the study of them over the past decade is the increase of detections of blue wing asymmetries of Balmer lines, which may be attributed to prominence eruptions. As a next step, we need two things to know whether these eruptions are developing into CMEs: detection of fast eruptions that exceed escape velocities and blue-shifted X-ray lines. RS CVn-type stars are active close binary systems and large flares with its energy exceeding 10^{35} erg often occur on them. We conducted simultaneous optical spectroscopic and photometric observations of the RS CVn-type star V1355 Ori with Seimei and TESS in December 2020 and X-ray observations of the RS CVn-type star IM Peg with NICER in July 2023. As a result, we found a blueshifted excess component of H α extending its velocity up to 760 – 1690 km/s during a superflare of V1355 Ori and a blueshift of the line center of the Fe XXV He α line with its maximum Doppler velocity reaching 2200 ± 600 km/s during a superflare of IM Peg. These high-velocity blueshifts, which overwhelmingly exceed the escape velocity of the stars, likely to suggest stellar extreme (fast and massive) CMEs. We will discuss whether such events follow existing theories and scaling laws on solar flares and CMEs even when the energy scale far exceeds current solar cases.

Friday, October 4

Solar-Stellar Relations 10:15+0:15

contributed talk

CME association rates for solar flares and stellar superflares

Kazunari Shibata(1, 2); Akito D. Kawamura(2); Takako T. Ishii(2)

”(1) Doshisha University (2) Kwasan Observatory, Kyoto University ”

We statistically analyze the properties of coronal mass ejections (CMEs) associated with flares during the solar cycle 23. Combining observations of sunspots, flares, and CMEs allows to calculate the probabilities of CME association for flares of different magnitude at sunspots of different area. An interpretation with an empirical model of a flare highlights on scale-free characteristics of flare activities following the nature of magnetohydrodynamics (MHD). Our result shows that a large sunspot (e.g. AR12192) needs a large flare for an eruption and could have a confined X-class flare. We also apply our results to stellar superflares, and derived unified scaling laws of the CME association rates for solar flares and stellar superflares as a function of flare energy and spot area.

Friday, October 4

Solar-Stellar Relations 10:30+0:20

solicited talk

Lessons from Grand Magnetic Minima in Sun-like Stars

Jason Wright(1); Jacob Luhn (2); Gregory Henry (3); Steven Saar (4); Anna Baum (5)

(1) Penn State; (2) University of California, Irvine; (3) Tennessee State; (4) Harvard; (5) Lehigh

Today, the 11-year solar magnetic cycle is well tracked by sunspot number, but shortly after the discovery of sunspots by Galileo, sunspots all but vanished from the surface of the Sun for 80 years during the "Maunder Minimum". This event can presumably teach us much about the nature of the solar dynamo. While we cannot build a time machine to study the sun during the Maunder Minimum, we can study the long-term magnetic behavior of sun-like stars to find analogs of the event. I will discuss astronomers' decades-long hunt for a true Maunder-Minimum analog, and what the discovery of one can tell us about the nature of the solar dynamo.

Friday, October 4

Solar-Stellar Relations 11:15+0:15

contributed talk

Solar-like stars unleash superflares once per century

Valeriy Vasilyev

Max Planck Institute for Solar System Research

Can superflares occur on the Sun, and how frequently do they happen? One possible way to answer this question is to compare solar and stellar flare records. In recent years, stellar flares have been detected through data collected by large photometric surveys. In this study, we applied a new method for identifying the true flare sources in large photometric surveys, using both light curves and CCD images. In addition to the light curves analysis, we accounted for potential sources of contamination, such as background stars or small solar system objects appearing in the same aperture as the primary target. Both scenarios can mimic flares in the light curves and so distort the true flare statistics. We analyzed a new solar-stellar comparison sample of 56450 Sun-like stars observed by the Kepler space telescope, which is much larger than previous samples and more representative of the Sun, and detected 2889 superflares on 2527 stars. Superflares with energies exceeding $1e34$ erg occur approximately once every century on stars that have temperatures and variability similar to the Sun, which is nearly two orders of magnitude higher than previously reported. Our results show that the stellar superflare frequency distribution is consistent with the observed solar flare frequency distribution extrapolated to larger energies, indicating a common mechanism behind the generation of flares.

Friday, October 4

Solar-Stellar Relations 11:30+0:15

contributed talk

**Driving mechanism of wind from solar-type stars: Alfvén wave, interchange reconnection,
or hybrid**

Munehito Shoda

The University of Tokyo

Emerging insights from the recent observations of the inner heliosphere by Parker Solar Probe elucidate that interchange reconnection serves as a crucial mechanism in both the acceleration of solar winds and the formation of magnetic switchbacks. Motivated by these revelations, we develop a novel hybrid model of the stellar wind that incorporates both Alfvén wave dynamics and interchange reconnection (driven by flux emergence). To test the performance of our model, we engage in a parameters survey concerning the (unsigned) surface magnetic flux and the ratio of open-to-surface magnetic flux. This exploration enables us to contrive a scaling law, delineating the mass-loss rate in relation to these dual parameters. Our constructed scaling law exhibits a profound congruity with observations of the solar wind, collated over a span of four decades. Our findings suggest that interchange reconnection may play a significant role in the stellar wind, in particular that originating from magnetically active stars.

Friday, October 4

Cosmic Rays 11:45+0:25

keynote talk

Reconstruction of GLEs using records from ground based detectors

Alexander Mishev

University of Oulu

Systematic studies of relativistic solar energetic particles give the necessary basis to understand and reveal the physics of various processes, such as the acceleration of energetic particles at the Sun, their transport in the Heliosphere as well as the related terrestrial effects due to interactions of energetic particles with atmospheric constituents. According to the current paradigm, solar energetic particles are accelerated following eruptive processes, such as solar flares and/or coronal mass ejections. When the energy of the accelerated solar ion is in the GeV/n range, it is great enough high, so that solar particles generate an atmospheric cascade, that is particle shower in the Earth's atmosphere, whose secondary particles reach the ground, eventually registered by ground-based detectors, such as Geiger tubes, neutron monitors (NMs), ionization chambers (ICs). This particular class of events is known as ground-level enhancements (GLEs). Herein, we demonstrate the capacity of the ground based records from NMs, and ICs to be used for reconstruction of GLEs.

Friday, October 4

Cosmic Rays 12:10+0:15

contributed talk

New revised and standardised data sets for the first GLEs #1-5 observed in 1942-1956

Stepan Poluianov (1,2); Hisashi Hayakawa (3,4,5,6); Sergey Koldobskiy (1,2); Alexander Mishev (1,2); Ilya Usoskin (1,2); Inna Usoskina (1); Agnieszka Gil (7, 8)

(1) Sodankylä Geophysical Observatory, University of Oulu, Finland; (2) Space Physics and Astronomy Research Unit, University of Oulu, Finland; (3) Institute for Space-Earth Environmental Research, Nagoya University, Japan; (4) Institute for Advanced Research, Nagoya University, Japan; (5) Science and Technology Facilities Council, RAL Space, Rutherford Appleton Laboratory, Didcot, UK; (6) Nishina Centre, Riken, Wako, Japan; (7) Institute of Mathematics, University of Siedlce, Poland; (8) Space Research Centre of Polish Academy of Sciences, Warsaw, Poland

”The Sun occasionally produces bursts of solar energetic particles (SEP). Some of such SEP events can be detected by ground-based instruments as a sudden increase in the particle intensity (so-called “Ground-Level Enhancement” (GLE)). Among the 74 GLE events registered since 1942, the first four were poorly studied mainly because there were no calibrated measurements and unified data sets. For GLEs #1-4, most of the original sources provided data only in the graphic format (plots). Although the data set for GLE #5 observed by neutron monitors exists, it was compiled from different, sometimes secondary, sources with mutual contradictions and inconsistencies.

In this work, we reviewed sources describing observations of GLEs #1-5 with different instruments including, in particular neutron monitors, and ionisation chambers. Several inconsistencies in the datasets were identified and resolved. Also, several new, previously forgotten, data series were found in archives and published for the first time. The graphical data were digitised. All records were carefully checked and saved in the standard GLE format in the International GLE Database IGLED (<https://gle oulu.fi>). For the first time, we published a digitised and standardised data set for GLEs #1-4, and a significantly revised and improved dataset for GLE #5. Also, SEP energy spectra and their angular characteristics from a new analysis of GLE #5, based on the revised data, are presented. The new records are available in IGLED. ”

Friday, October 4

Cosmic Rays 12:25+0:20

solicited talk

On modelling the potential impact of galactic cosmic rays on astrospheric habitability

N.E. Engelbrecht (1); J. Light (1); K. Herbst (2); K. Scherer (3)

(1) Centre for Space Research, North-West University; (2) Institute for Experimental and Applied Physics, Kiel University; (3) Institute for Theoretical Physics IV, Ruhr-University Bochum

In recent years it has become clear that a multiplicity of factors influence the potential habitability of an exoplanet beyond its location in the nominal habitable zone of its host star. In particular, a growing number of modulation studies have recently investigated the role of galactic cosmic radiation in particular, drawing often widely-varying conclusions as to the significance of galactic cosmic rays (GCRs) in relation to exoplanetary habitability. After briefly reviewing these existing studies, a framework for a physics-first 3D astrospheric GCR modulation model will be introduced, and the results so computed compared with those reported on by prior studies. Furthermore, a novel constraint on exoplanetary habitability is deduced, and further investigated for several different astrospheres. Finally, the influence of GCR intensity spectra so calculated on potential exoplanetary atmospheres is briefly discussed.

Friday, October 4

Cosmic Rays 14:40+0:15

contributed talk

A Comprehensive Comparison of Galactic Cosmic Ray Models

Jingnan Guo^{1,3}; Weihao Liu^{1,2}; Yubao Wang¹; Tony Slaba⁴

*"1, University of the Science and Technology of China, Hefei, China 2, University of Michigan, Ann Arbor, USA
3, University of Kiel, Kiel, Germany 4, NASA Langley Research Center, USA"*

Galactic Cosmic Rays (GCRs) are the slowly varying background energetic particles that originate outside the solar system. As they propagate into the heliosphere, their intensity and energy are modulated by the varying heliospheric magnetic fields. A handful of GCR models have been developed to predict the GCR flux near Earth based on GCR propagation theories and/or empirical models. It is important to benchmark these models by validating them against the state-of-the-art measurements. Although the energy-integrated GCR fluxes and their variations have been observed for a long time at Earth, both by ground-based neutron monitors and by spaceborne instruments, the energy-resolved GCR spectrum of different particle types and its dependence on the solar cycle evolution are only available by a few instruments. In order to compare various GCR models with the observational data, we use data from the Cosmic Ray Isotope Spectrometer (CRIS) on the Advanced Composition Explorer (ACE) spacecraft at the relatively low-energy part and data from the Payload for Antimatter Matter Exploration and Light-nuclei Astrophysics (PAMELA) and Alpha Magnetic Spectrometer (AMS-02) at the higher energy part. Our work shows that for different particle types and energy ranges, the best model, which has the minimum relative difference or chi-square divergence from the data, can be different. We also apply a silicon phantom to calculate the absorbed dose rates by various GCR models and compare them to the micro-dosimeter on the Cosmic Ray Telescope for the Effects of Radiation (CRaTER). Our results have implications on the advantages and limitations of the individual models.

Friday, October 4

TSI/SSI 14:55+0:25

keynote talk

TSI: What, How, and Why

Greg Kopp

Univ. of Colorado / LASP

”What: Our space climate is driven by a relatively benign star. It’ s a star burning 6.2×10^{11} kg of hydrogen per second and producing 3.828×10^{26} W which, radiantly emitted from the 5772 K photosphere, heats the Earth with 1361 W m^{-2} , warming it as a blackbody to 278 K (well, 288 K actually, but that’ s the Earth’ s fault). Net variations in the solar-photospheric temperature are a mere 1.4 K on timescales from minutes to several solar cycles. That stability is fortunate since the Sun’ s radiant output provides the Earth with 99.974% of its total energy, and fluctuations in that energy directly affect the Earth’ s climate.

How: How do we know those quantities to so many decimal places? They can be derived from accurate measurements of the total solar irradiance (TSI), the net radiant energy from the Sun at 1 AU and the best spaceborne radiometric measurements of any natural object made. How are those measurements made? I’ ll present the history and present-day TSI-measurement methods and results.

Why: Why does the Sun vary and why might we care? Stable as the Sun is, we want to know how much it varies on daily, solar-rotational, solar-cycle, multi-decadal, and millennial timescales; the causes of solar variability; and the mechanisms by which that variability affects our local Earth environment. ”

Friday, October 4

TSI/SSI 15:20+0:20

solicited talk

Modelling and Reconstructions of Total and Spectral Irradiance Variations

Natalie Krivova

Max Planck Institute for Solar System Research

Solar irradiance and its spectral distribution vary on time scales from minutes to centuries and probably longer. Variations on time scales longer than roughly a day are driven by the continuously evolving solar surface magnetic field. Thus, to model these variations we need to know how the emerging magnetic field is distributed on the Sun, how it evolves with time and how it affects the radiative properties of the solar surface. I will provide an update on our progress in irradiance modelling and reconstructions with the SATIRE model.

Friday, October 4

TSI/SSI 15:40+0:15

contributed talk

Towards an annual solar irradiance reconstruction over the last millennium

D. Temaj (1); N.A. Krivova (1); S.K. Solanki (1,2); I. G. Usoskin (3); B. Hofer (1)

(1) Max-Planck-Institut für Sonnensystemforschung, Germany; (2) School of Space Research, Kyung Hee University; (3) University of Oulu, Oulu, Finland

The Sun influences climate and life on Earth. Space-based monitoring of solar irradiance revealed variations at all apparent time scales, allowing insights into the mechanisms behind these changes. However, the short duration of this record limits our understanding of the Sun's impact on Earth's climate, necessitating reconstructions of past solar variability. The variability on the climatic time scales is driven by the Sun's surface magnetism. Thus reconstructions of past irradiance require knowledge of the Sun's historical magnetic field evolution. The longest direct proxy of solar magnetic activity is the sunspot number, spanning 400 years. To reconstruct solar activity further back, cosmogenic isotope data can be used. However, sunspot observations do not provide reliable information on bright features, such as faculae and the network, which are primary drivers of irradiance variations over the solar cycle and longer. This leads to high uncertainty in the magnitude of the secular irradiance changes in existing reconstructions. To account for this, we use the recent model of the Sun's magnetic field evolution, linking the emergence rate of small-scale magnetic regions to sunspots through relationships based on modern observations. This allows a more realistic reconstruction. We use the model to first reconstruct solar irradiance from telescopic data back to 1700, then extend it over the past millennium using annual sunspot data derived from cosmogenic isotopes.

Friday, October 4

TSI/SSI 15:55+0:15

contributed talk

Revisiting the Hoyt and Schatten 1993 Total Solar Irradiance Model

Theodosios Chatzistergos

Max Planck Institute for Solar System Research

”The Sun is an important forcer of Earth’s climate, making reliable and long-term data on solar irradiance essential. Unfortunately, direct measurements of Total Solar Irradiance (TSI) have only been available since 1978, while irradiance models show a discrepancy of an order of magnitude in their estimated long-term trends. One such model with a high secular trend is the one by Hoyt and Schatten 1993. This empirical model reconstructs TSI by linearly scaling five solar activity indices. The methodology behind this model was not adequately described, and the limited overlap between the data used by this model and direct TSI measurements has so far hindered its performance evaluation. The short overlap with direct measurements also meant that the magnitude of variations in the reconstructed TSI was imposed arbitrarily based on indirect data.

To address these issues, we reverse-engineered the Hoyt and Schatten 1993 model. Additionally, we use recent data to extend the reconstructed TSI to the present, allowing us to evaluate its performance and better assess the secular trend of TSI returned by this model.”

Friday, October 4

TSI/SSI 16:10+0:20

solicited talk

Modeling of stellar chromospheric emission variations

Sowmya Krishnamurthy

Max Planck Institute for Solar System Research

”Stellar emission variations on timescales longer than a day are attributed to the emergence and evolution of surface magnetic features such as spots and faculae. The chromospheric counterparts of these magnetic features cause variations in strong spectral lines like Ca II H&K: one of the most widely used stellar magnetic activity proxies, and Mg II h&k: a proxy for the solar UV irradiance in Earth’s atmosphere modeling.

Firstly, despite its routine use as a proxy of magnetic activity, many aspects of the connection between Ca II emissions and stellar magnetism remain poorly understood. Secondly, physics-based models to accurately calculate Mg II emission variability on climate-relevant timescales are still lacking, making it challenging to understand solar UV radiation influence on Earth’s climate.

To this end, we developed a physics-based approach to model chromospheric emission variability in strong spectral lines. We validate the model against solar observations and use it to understand the sources of stellar Ca II emissions as well as to identify biases in solar-stellar comparison studies.

Further, we synthesize Mg II emissions and reconstruct the solar Mg II emission variability.”

Friday, October 4

TSI/SSI 16:30+0:15

contributed talk

Once is not enough: Why high-cadence MgII is important

Martin Snow (1,2); Janet Machol (3,4)

(1) South African National Space Agency; (2) University of Colorado Boulder LASP; (3) University of Colorado CIRES, (4) National Centers for Environmental Information NOAA

The magnesium II core-to-wing ratio has been measured on a daily basis since 1978. It is a widely used proxy for solar chromospheric activity, essential for satellite drag calculations as well as the model that is the NOAA Climate Data Record for solar spectral irradiance. In 2017, this measurement became available operationally from GOES-16/EXIS at three-second cadence with high signal-to-noise. While the Earth's atmosphere may not respond to ultraviolet irradiance changes on such short timescales, it does respond to the time-integrated irradiance variation. Using a once-a-day measurement as was available before GOES-16 introduces a systematic bias in the estimated facular brightening that gets worse as solar activity increases. Using data from solar cycle 24, we can estimate a correction factor for the daily magnesium II index for previous solar cycles. In this presentation, we will discuss the magnesium II index and provide details of the instrumentation as well as how to retrieve the data from the NOAA web page.

Friday, October 4

Dynamo 17:05+0:15

contributed talk

A look on the solar leptocline, its role and the underlying physics

Jean-Pierre Rozelot (1); Ali Kilcik (2)

(1) Université de la Côte d'Azur, Nice, France; (2) Akdeniz University Faculty of Science, Department of Space Science and Technologies, 07058, Antalya, Turkey

Studies of solar (as well as stellar) dynamos face a problem of utter complexity, i.e., the interaction of a turbulent plasma in the convection zone, associated with latitudinal rotation together with magnetic field acting in a highly stratified medium, moreover covering wide ranges of spatial and temporal scales. Recent theoretical models for the solar dynamo in complex 3D simulations highlighted changes of the Sun's stratification, mainly in the upper zones, pointing the role of the leptocline, a shallow and sharp shear layer in the top 8 Mm. We will give here a brief history of the circumstances that led to the discovery of this layer, characterized by a strong radial rotational gradient at mid latitudes and self-organized meridional flows. We give an overview of the physical solar parameters that originate in this layer: opacity, superadiabicity and turbulent pressure changes; the hydrogen and helium ionization processes; sharp decrease in the sound speed; probably an oscillation phase of the seismic radius associated with a non-monotonic expansion with depth; probably temporal changes in photospheric zonal and sectorial modes and their associated gravitational moments. Likely also the initial place of the solar wind escape. In addition, the leptocline may play a key role in the formation of the magnetic butterfly diagram. Such results should be the starting point of systematic further investigations of structure and dynamics in this layer, leading to a better understanding of the solar cycle.

Friday, October 4

Sunspot Number calibration 17:20+0:15

contributed talk

**CORRECTING THE ZURICH AND AAVSO SUNSPOT COUNTS, AND A
VALIDATION OF THE GROUP-COUNT**

Bradley E. Schaefer

Louisiana State University

I have identified two systematic errors in the Zurich and the AAVSO sunspot counts, and the means to correct for these errors. (1) For the Zurich count, the problem was that the final published counts were slaved to the Standard Observer (Wolf, Wolfer,...), while these observers are known to have variations in their K-coefficient ($R_Z = K * (10 * G + F)$) by factors of up to 2 on all timescales. For solutions: (1A) I have pulled up extensive archival records of the daily 'corrected' sunspot counts for 100 observers, each with > 20 years of measures. When all the overlapping measures increase, we can quantify the decrease in the K-coefficient for the Standard Observer, so I have measured the monthly corrections to the Zurich Count. (1B) In a theory study of visual sunspot detection thresholds, the K-coefficient is a function of $\sqrt{F/G}$, which is derived from the data itself. It turns out that R_Z just equals $14.0 * G$. That is, a simple group count avoids all the problems with K-coefficient variations. This validates the Sunspot Group Count of Hoyt & Schatten as correcting the systematic errors introduced by the Wolf Number use of 'F' in the definition of R_Z . (2) The AAVSO Sunspot Count has a mathematical mistake in the derivation that produces an automatic 0.3% rise in the Count everytime the K-coefficients are recalculated (usually yearly). This spurious exponential rise can be easily corrected by simply using logarithmic averages (instead of linear averages) when calculating the new K-coefficients.

Friday, October 4

Sunspot Number calibration 17:35+0:25

keynote talk

The sunspot number recalibration : an on-going effort

Laure Lefevre (1); Shreya Bhattacharya (1)

(1) WDC SILSO - Royal Observatory of Belgium

”We discuss the problems presented in the historical Sunspot Number (SN) and Group Number (GN) series and the recalibration effort that started almost 15 years ago with the sunspot workshops. Since 2010, a wealth of historical sunspot data has been recovered, corrected, and partly digitized. We present surveys of the data that are or will be available for going one step further, reconstructing the sunspot number (?) series.

We then introduce our current work we to digitize, extract, and homogenize the available data, e.g. the Belgian FARSUN project.

Finally, we present the reconstruction problems in two contexts: the Sunspot Number and the Group Number. On one hand, the reconstruction of SN depends on the availability of the counts of single sunspots over time, and this quantity is harder to access than the group number. On the other hand, the GN database from Hoyt and Schatten (1998), updated by Vaquero et al. (2016) has been readily available for a long time and gave birth to several new GN reconstructions that all suffer from various problems, the biggest being that the end user (e.g. for climate simulations) has to make an informed choice without enough information available from the scientific community. We propose and present an endeavor that aims at solving these issues.”

Friday, October 4

Sunspot Number calibration 18:00+0:20

solicited talk

Sunspot records in Locarno and the comparison of the weighted and unweighted counting method

”Renzo Ramelli(1,2); Marco Cagnotti(2); Andrea Manna(2); Michele Bianda(1); Mario Gatti

”

”(1) Istituto ricerche solari Aldo e Cele Daccò (IRSOL), Faculty of Informatics, Università della Svizzera italiana, CH-6605 Locarno, Switzerland; (2) Specola Solare Ticinese, CH-6605 Locarno, Switzerland

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”Specola Solare in Locarno, Switzerland, was built in 1957 as an external observing station of the Swiss Federal Observatory in Zurich. Under the guidance of Max Waldmeier, the two observer assistants Cortesi and Pittini were instructed on how to count the sunspots for the determination of the Sunspot Number (SSN), based on the weighted counting method used in Zurich, where the sunspots get a different weight depending on their size. When in 1980, after the retirement of Waldmeier, the international data center for the determination of the SSN was transferred from Zurich to the Royal Observatory of Belgium (ROB) in Brussels, Specola Solare got the role of pilot station. Before being replaced by Cagnotti, Cortesi acted as main observer until 2010 and still continued to regularly observe until 2021. Thus, his long-lasting observing career has been 65 years long, contributing to the stability of the counting method.

Since 2014 the unweighted counting method, which became the standard reference for the revised SSN v2 officially adopted at ROB in 2015, is routinely applied on the Specola observations and has also been applied to the archived and digitized past sunspot drawings. Recently, all the data obtained from the sunspot records in Locarno, have been collected in a sunspot group database which has been published online and allows for further analysis. In particular, we intend to present a comparison between the two counting methods applied in Locarno.”

Friday, October 4

Sunspot Number calibration 18:20+0:15

contributed talk

Towards SN V3 : data and techniques

Shreya Bhattacharya

Royal Observatory of Belgium

”The Sunspot Number series is one of the longest and most detailed available series in astrophysics, now produced and maintained at SILSO (<https://sidc.be/SILSO/home>). The series was first constructed in 1849 by Prof. Rudolf Wolf, and a time series has been 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 eyesight. After the recalibration from 2015 (Clette et al., 2016), the series still suffers from various scale discrepancies which would benefit from a complete reconstruction (for example because of a persistent jump in 1849). Here, we will present the exploitation of all the available databases of sunspots along with other available recounts of various observers to identify scale discrepancies or inhomogeneities that occurred during the Sunspot Number series over time. We also introduce statistical techniques to stitch together all these recovered data and implement confidence bands or errors on daily Sunspot Numbers, information that existing versions lack. The long-term aim is a complete reconstruction of the Sunspot Number series from the available raw data instead of a recalibration. Hence, gathering and exploitation of all the available data sources is extremely important which is the goal of our new project, FARSuN: to improve access to the historical data that form the sunspot record, the primary index for understanding solar variability over the last 400 years. ”

Friday, October 4

Sunspot Number calibration 18:35+0:15

contributed talk

Reanalysing English Sunspot Observations during the Maunder Minimum

Thomas Teague (1); Hisashi Hayakawa (2);

(1) WDC-SILSO observer; (2) Nagoya University;

Instrumental sunspot observations since 1607 have provided a basis for measuring solar cycles and long-term solar activity. Within this period, solar cycles from the Maunder Minimum in 1645 – 1715 have been considered exceptional, owing to their extremely small amplitude, anomalous hemispheric asymmetry, and the apparent loss of significant coronal streamers. However, poor documentation of sunspot data from that era, relying mainly on observational records from Paris and Nürnberg, necessitates further independent assessment. In this presentation, therefore, we reanalyse contemporaneous records of English sunspot observations. Our analysis has entirely revised the sunspot group number and removed many contaminations from solar-altitude measurements and general descriptions. It has also reduced the maximum sunspot group number and requires significant modification to the existing estimate with the brightest star method. Our analysis has also derived sunspot positions from these observations and confirmed considerable hemispheric asymmetry of the reported sunspot groups and their concentration in the southern solar hemisphere. Overall, our presentation independently confirms the uniqueness of the Maunder Minimum in comparison with other solar cycles, including the Dalton Minimum.

Friday, October 4

Sunspot Number calibration 18:50+0:15

contributed talk

Assessing the performance of cross-calibration methods for group sunspot numbers

Theodosios Chatzistergos (1); Natalie A Krivova (1); Hannah Sundermann (2); Ilya G. Usoskin (3)

(1) Max Planck Institute for Solar System Research, Göttingen Germany; (2) Institut für Astrophysik und Geophysik, Georg-August-Universität Göttingen, Germany; (3) University of Oulu, Finland

”The group sunspot number forms one of the longest records providing direct information on solar activity and variability. However, these records derive from different observers, telescopes, and locations, which leads to significant variability in their quality. To ensure consistency and bring all sunspot data onto a common scale, careful cross-calibration is necessary. Traditionally, this cross-calibration has been performed with simple linear scaling, while more recently non-linear and non-parametric approaches have also been developed. Several compilations, using different methodologies, of the group number data exist, which significantly disagree before the 1900s. Biases in the calibration methods may contribute to this issue, but a comprehensive sensitivity study of these methods is still lacking. Here, we use synthetic observers to evaluate the majority of existing sunspot cross-calibration approaches. Our findings indicate that calibration methods based on the observer’s acuity threshold perform better than the linear scaling ones. Methods based on direct comparison of daily observations yield more precise results than those based on statistical properties but may diverge over long-term timescales, where a multi-step daisy-chain (backbone) calibration is needed. We recommend using direct calibration based on the observer’s acuity threshold when data coverage is sufficient and a statistical method, such as the active-day fraction, to bridge extensive data gaps.”

Friday, October 4

Long-Term Solar Activity 19:05+0:15

contributed talk

The Polar Magnetic Field revealed by Polar Faculae

W. Dean Pesnell(1), Julia Clark(1,2), and Matt Barzal(1,3)

(1) NASA Goddard Space Flight Center, Greenbelt, MD, USA; (2) George Mason University, Fairfax, VA, USA; (3) University of Maryland, College Park, MD, USA

Polar Faculae (PFe) are bright points at the edges of granules that illuminate where magnetic field lines intersect the solar surface near the Sun's poles. We previously reported the average PF lifetime determined from the Helioseismic and Magnetic Imager (HMI) on Solar Dynamics Observatory (SDO) is 6.0 +/- 2.7 hours. We also showed that the number of PFe in Solar Cycle 24 is correlated with the strength of the polar magnetic field and anti-correlated with the sunspot number. Those correlations had been known before but, as with any solar activity variable, the time dependence is more complicated than a linear correlation. We will describe our continuing analysis of HMI PF data, increasing the time resolution of the number of PFe and measuring the magnetic field associated with a sample of those PFe. We will show the variation of the magnetic field within PFe between Sep 2010 and Dec 2022. The field shows a more complicated behavior in this analysis than from observations that average over the poles. The ridgeplots show the polar field is typically dominated by field of one polarity or another but close to solar maximum a mix of polarities is often seen. The ratios of the radial and latitudinal fields are consistent with a radially dominated field orientation. These observations will help design space missions to observe the solar polar regions.